

The Generic Mapping Tools

GMT

Version 4.5.0

Technical Reference and Cookbook

by

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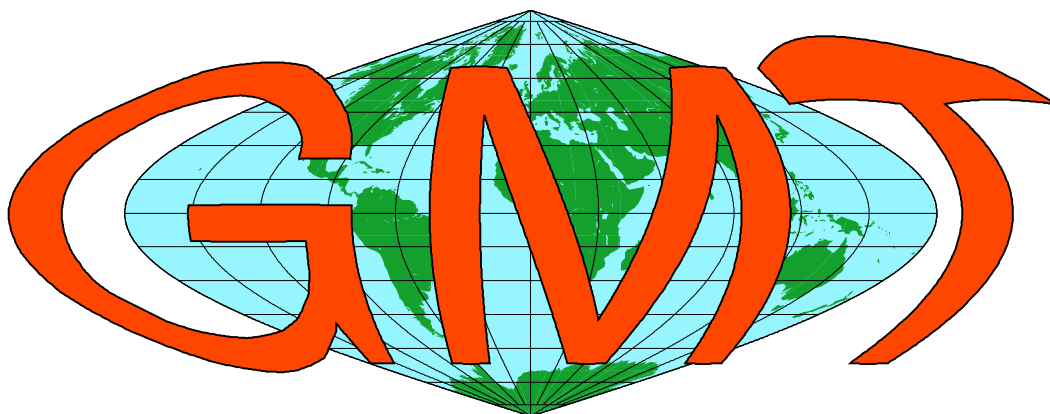
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Generic Mapping Tools Graphics

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The GMT Documentation Project

Starting with *GMT* version 3.2, all *GMT* documentation was converted from Microsoft **Word** to \LaTeX files. This step was taken for a number of reasons:

1. Having all the documentation source available in ASCII format makes it easier to access by several *GMT* developers working on different platforms in different countries.
2. *GMT* scripts can now be included directly into the text so that the documentation is automatically up-to-date when scripts are modified.
3. All figures are generated on the fly and included as *GMT* EPS files which thus are always up-to-date.
4. It is easy to convert the \LaTeX files to other formats, such as HTML, SGML, *PostScript*, and PDF.
5. The whole task of assembling the pieces, be it generating figures or extracting text portions from the master archive under CVS control, is automated by a makefile.
6. Only free software are used to maintain the *GMT* Documentation.

Please send email to the GMT help list if you find errors or inconsistencies in the documentation.

A Reminder

If you feel it is appropriate, you may consider paying us back by citing our *EOS* articles on *GMT* (and perhaps also our Geophysics article on the *GMT* program **surface**) when you publish papers containing results or illustrations obtained using *GMT*. The *EOS* articles on *GMT* are

- Wessel, P., and W. H. F. Smith, New, improved version of Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U.*, vol. 79 (47), pp. 579, 1998.
- Wessel, P., and W. H. F. Smith, New version of the Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U.*, vol. 76 (33), pp. 329, 1995.
- Wessel, P., and W. H. F. Smith, New version of the Generic Mapping Tools released, *EOS Trans. Amer. Geophys. U. electronic supplement*, http://www.agu.org/eos_elec/95154e.html, 1995.
- Wessel, P., and W. H. F. Smith, Free software helps map and display data, *EOS Trans. Amer. Geophys. U.*, vol. 72 (41), pp. 441, 445-446, 1991.

The article in *Geophysics* on surface is

- Smith, W. H. F., and P. Wessel, Gridding with continuous curvature splines in tension, *Geophysics*, vol. 55 (3), pp. 293-305, 1990.

GMT includes some code supplied by others, in particular the Triangle code used for Delaunay triangulation. Its author, Jonathan Shewchuk, says

“If you use Triangle, and especially if you use it to accomplish real work, I would like very much to hear from you. A short letter or email (to jrs@cs.cmu.edu) describing how you use Triangle will mean a lot to me. The more people I know are using this program, the more easily I can justify spending time on improvements and on the three-dimensional successor to Triangle, which in turn will benefit you.”

A few *GMT* users take the time to write us letters, telling us of the difference *GMT* is making in their work. We appreciate receiving these letters. On days when we wonder why we ever released *GMT* we pull these letters out and read them. Seriously, as financial support for *GMT* depends on how well we can “sell” the idea to funding agencies and our superiors, letter-writing is one area where *GMT* users can affect such decisions by supporting the *GMT* project.

Copyright and Caveat Emptor!

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¹<http://www.gnu.org/copyleft/gpl.html>

Typographic conventions

In reading this documentation, the following provides a summary of the typographic conventions used in this document.

1. User input and *GMT* or *UNIX* commands are indicated by using the `typewriter` type style, e.g.,
`chmod +x job03.sh`.
2. The names of *GMT* programs are indicated by the **bold, sans serif** type style, e.g., we plot text with **pstext**.
3. The names of other programs are indicated by the **bold, slanted** type style, e.g., ***grep***.
4. File names are indicated by the underline type style, e.g., gmt.h.

1. Preface

While *GMT* has served the map-making and data processing needs of scientists since 1988¹, the current global use was heralded by the first official release in *EOS Trans. AGU* in the fall of 1991. Since then, *GMT* has grown to become a standard tool for many users, particularly in the Earth and Ocean Sciences. Development has at times been rapid, and numerous releases have seen the light of day since the early versions. For a detailed history of the changes from release to release, see file [ChangeLog](#) in the main *GMT* directory. For a nightly snapshot of ongoing activity, see the online [ChangeLog](#) page.

The success of *GMT* is to a large degree due to the input of the user community. In fact, most of the capabilities and options in *GMT* programs originated as user requests. We would like to hear from you should you have any suggestions for future enhancements and modification. Please send your comments to the *GMT* help list.

1.1 What is new in GMT 4.x?

GMT 4.x continues to see both development of new features as well as corrections of legacy bugs and problems. It is likely we will continue to do so for a while until we reach a stable point from which we can initiate the *GMT* 5 development branch. *GMT* 5 will be distinguished by being completely restructured so as to allow developers to call high-level *GMT* processes from a variety of programming environments. Below is a brief history of the development milestones in the 4.x series.

1.1.1 Overview of GMT 4.5.0 [July-15, 2009]

This is another significant update of the official distribution and hence it has a mix of bug fixes and program enhancements. We have added a new supplement (**sph**) which offers interpolation, triangulation (Delaunay and Voronoi), and distance calculations on a spherical surface. The hard work is done by the original effort of Robert Renka who developed the Fortran-77 SSRFPACK and STRIPACK libraries; these are here supplied via a **f2c**-assisted translation. The **imgsrc** supplement has a new Bourne script **img2google**, which simplifies making Google Earth tiles from Sandwell and Smith bathymetry. The **mgd77** supplement has a new program **mgd77magref**, which is used to evaluate either the CM4 comprehensive geomagnetic model, a more sophisticated alternative to IGRF, or the IGRF. The **misc** supplement has received two new tools (**gmt2kml** and **kml2gmt**) that simplify the presentation of *GMT* data in Google Earth, and one (**dimfilter**) that offers directional spatial filtering of grids. The **x2sys** supplement has a new tool (**x2sys_merge**) to merge updated COEs table into a main COE table database. Finally, **ps2raster.c** has evolved further and can now be used to create simple KML files for Google Earth.

A major new enhancement is the global option **-g**, which is used to determine if excessive spacing between data points (“gaps”, to be defined in a variety of ways) should be used to segment an otherwise continuous line. We expect to enable **-g** in several programs during the next revision; at the moment it is available in **gmtconvert**, **mapproject**, **psxy** and **psxyz**. Given that all the lower-case *GMT* options deal with low-level data i/o settings we have decided to rename the **-M** option (which controls the presence of multiple segment headers) to **-m**; this allows us to promote this ubiquitous option to global status (*i.e.*, has the same meaning in all *GMT* programs). Use of **-M** will remain valid for the rest of *GMT* 4.x but results in a warning about the new usage. Related to this is the introduction of a new parameter (**NAN_RECORDS**) that determines if NaNs in key columns (such as longitude, latitude) should constitute a line break or bad data to be skipped.

We have revised how ellipsoids are specified. When importing an ellipsoid file, we allow a,b,f as ellipsoid parameters, where b or f could both be zero. If file does not exist, attempt to read name as a/[b=f]/f, meaning *semi-major axis*, *b=semi-minor axis*, *f = flattening*, or *inverse flattening*. We have also added parameters for the TOPEX ellipsoid and for the Moon and planets (IAU2000).

This release of *GMT* coincides with the release 2.0 of GSHHS, the coastline data used by *GMT*. In addition to general improvements to the data, we have expanded the **-A** option that controls the limits on

¹Version 1.0 was then informally released at the Lamont-Doherty Earth Observatory.

what features to extract. New modifiers allow users to exclude “river-lakes” and any feature whose area is less than a fraction of the original full resolution feature.

Finally, our configure script continues to evolve and now better supports installation on 64-bit systems and can automatically detect if and where netCDF exists on your system.

Here is the list of bug corrections:

gmt.customio.c : In `GMT_ras_read_grd_info`, wrong size was passed to `fread`.

gmt.grdio.c : Fixed bug in `GMT_grd_setregion`: longitudes were limited inward instead of outward. Caused white-space left and right in **grdimage**.

gmt.init.c : No longer remove supposedly empty `.gmtcommands4` file. Could have been written to by piped `GMT` command. Now create/write only when new matter is to be written.

gmt.io.c : When only `-mi` is set there should be no multisegment headers on output. yet there was no if-test to check for that.

gmt.map.c : Fixed serious bug in `GMT_az_backaz_flatearth`: incorrectly converted degrees to radians. Fixed bug in `GMT_get_rotate_pole`: called `GMT_rotate_pole_forward` with radians instead of degrees. Incorrectly attempted to free array only used when `antialias` is on. Fixed inability to determine projection pole when central meridian and western boundary are the same (Albers, Conic equidistant). Incorrectly used central longitude to set default midpoint for 3-D maps using the `-E...+` mechanism when data were not geographic. Numerous bug fixes related to UTM: Did not report bad zone for `< A` or `> Z`; Zones `A+B` reached till 84S instead of 80S; Zone `J` wrongly produced value for Zone `K`; Zones `U+W` were not recognized; Now also equates Zone `O` to Zone `P` (already equated Zone `I` to `J`).

gmt.mgg_header2.c : There was no support for (a) floating point grids and (b) swapping happened based on machine byte order and not based on actual file byte order.

gmt.nc.c : Argument `[layer]` was not stripped from varname and would end up in output grid. Set `zmin/zmax` to NaN when info not in header.

gmt.plot.c : Crashed when using time labels in 3D plot.

gmt.proj.c : Fixed bug in longitude computation when standard parallel is on Southern Hemisphere.

gmt.support.c : Exceeded array bounds in `GMT_read_cpt` for hsv conversion. The 3-D view `-E` option used in many programs (such as **psxyz**) could not handle exponential notations. Determining of a color scale is continuous should be based on HSV (not RGB) values when read as HSV. The modifier `:radius[unit]` to the `-G` option in **grdcontour** for the placement of contour labels is now `+rradius[unit]` since the colon interfered with `ddd:mm:ss` coordinates. Given `-I601+/601+` the y-increment was not processed correctly. Fixed bug when `x.inc` in km, m, etc, the value was ignored (always 1).

blockmean.c : Gave bogus usage about number of input columns when `-E` is set but `-E` only affects output. Same for **blockmedian.c** and **blockmode.c**.

gmtconvert.c : With `-S`, did not report the number of output segments.

gmtmath.c : Tried to free memory that was not allocated.

grdfilter.c : Toggle `-T` was not processed correctly if `-Rgridfile` was given.

grdgradient.c : For geographic grids, make sure N and S pole only has a single value on output.

greenspline.c : Calculation of nz layers was off by one, leaving out the penultimate layer.

grdimage.c : We now make sure the NaN color is unique when `-Q` is used.

grdmath.c : The **PDIST** operator did not handle binary input files (as **LDIST** does).

ps2raster.c : Exceeded memory allocation for out_file. Now in static memory.

psclip.c : Produce at least “S V” when the clippath is empty.

pscoast.c : Produce at least “S V” when the clippath is empty.

psscale.c : When using **-A** with a vertical color bar, the annotations were left- instead of right-aligned.
When using **-A** on horizontal bar, the last tick mark would not appear.

gshhs/gshhs.c : Checked wrong variable to test if a file was given on the command line.

meca/util_meca.c : Needed to convert the output from `datan2` to degrees.

mgd77/mgd77.c : Was failing to read Windows terminated ASCII files. Fixed bug in `MGD77_igrf10syn` routine (mistake done while cleaning the **f2c** version) that resulted in altitude always being on Earth surface when geocentric coordinates were used. Do not use any *GMT* i/o-functions to access ascii files on creation/writing so that it can work under Windows as well. Converting files from netCDF to MGD77 where time = NaN gave junk records.

mgd77/mgd77list.c : Used `GMT_LONG` in `memset` for an array allocated as `int`. Used wrong time for IGRF calculation; worst case situation was off by 1 year.

mgd77/mgd77manage.c : The **-D** option would remove original attributes. Now both original and revised attributes are carried in memory. This problem also affected **mgd77convert -FC** if used on a file after **mgd77manage -D** had been run. Used wrong time for IGRF calculation; worst case situation was off by 1 year. Now uses `GMT_readimg` to handle *.img files; earlier the inline code would fail on the new extended img files.

mgd77/mgd77sniffer.c : Did not reset the E77 structure between cruises.

misc/gmtstitch.c : Did not read standard input if no files were given. Now honors **-V** properly.

x2sys/x2sys.c : Wrong array argument passed for correction aux values.

x2sys/x2sys.cross.c : Removed the **-F** option which was not honored anyway.

x2sys/x2sys.init.c : Now properly copies the *.def file to the TAG dir.

x2sys/x2sys.datalist.c : Only ASCII output had corrections (**-L**) applied.

x2sys/x2sys.put.c : Fixed **-D** option (was falling in a endless loop).

Here is a list of the recent enhancement to various programs:

1. **gmt_init.c** has added support for enhanced **-E** option for 3-D perspective views which allows the specification of a fixed point (needed for new Default setting **NAN_RECORDS** = skip/pass [skip]. If “pass” we treat let the programs handle the NaNs; for some programs the NaNs in input record will act as indicators of data gaps for continuous lines. If “skip” we report them as bad records. In both cases the records are skipped. Allow negative integer interval (-n) for annotating log axis; this means annotate every nth power of 10.
2. **gmt_nc.c** will properly handle netCDF that have LatLon = 0, 1: flip x and y.
3. **gmt_shore.c** Added support for the **+pppercent** modifier to limit features whose area is less *percent* of the corresponding full-resolution polygon.
4. **gmt_support.c** enables `GMT_intpol` to handle NaNs by treating them as segment boundaries. Rely on Shewchuk’s triangle function to get Voronoi output.
5. **blockmedian.c** now returns the quantile(x), quantile(y) location when **-T** is used. Added **-Eb** to get box-and-whisker output (0, 25, 50, 75, and 100% quantiles).

6. **gmtconvert.c** now allows **-S~pattern** which reports segments whose header does NOT contain pattern. Should pattern actually start with ~ we escape it with \ ~pattern.
7. **gmtselect.c** can now handle dateTclock strings in **-Z** when used with data whose 3rd column contains time.
8. **gmtmath.c** added **MOD** function (remainder after floored division, Knuth style). This is in contrast to **FMOD** which gives the remainder after (horror) truncated division.
9. **gmtselect.c** Same upgrade to **-A** option as **pscoast**.
10. **grdcut.c** has new option **-Z** which is used to determine a rectangular subregion so that the rejected area have values entirely outside the given z-range.
11. **grdfft.c** now also has a Butterworth band-pass filter.
12. **grdinfo.c** will now use plain text (and not code) to report the file format used. Add option **-L0** to actually scan data to determine *zmin* and *zmax*.
13. **grdlandmask.c** Same upgrade to **-A** option as **pscoast**.
14. **grdmath.c** added **MOD** function (remainder after floored division).
15. **ps2raster.c** takes **-W+k** to create a simple KML file for Google Earth. Several other modifiers help to populate the KML file.
16. **psclip.c** has a new option **-T** that turns on map region clipping without any input data files; it is a shorthand for **-N /dev/null**.
17. **pscoast.c** has enhanced **-C[l|r]** fill offers to paint river-lakes separately from lakes. The **-A** option can be used to exclude river-lakes or lakes for level 2. **-W** now allows different pens for the 4 levels of shorelines.
18. **pglegend.c** allows **S** record not to have *text*. Until now, when left empty would use whatever *text* was set to in previous record. The **>** record no longer needed before **T**; **T**, **L**, **S**, **H** alignment harmonized; **I**, **M**, **B** spacing improved; **-B** option added.
19. **psxy.c** added **-g** to break lines into segments based on gap criteria; added **-T** to be a shorthand for reading no input, where we used **/dev/null** before.
20. **psxyz.c** added **-g** to break lines into segments based on gap criteria.
21. **triangulate.c** has new option **-Q** to generate Voronoi polygon edges.
22. **mgd77/mgd77convert.c** allows users to give file.ext on command line.
23. **mgd77/mgd77list.c** can now take **-DA** and **-DB** which, in the presence of time = NaN, will not output such records [**-Da|b** will]. Also clarified the ranges implied by **-D** and **-S**. Added **-Fytime** which gives decimal absolute year for time output. Modifier **-At** added which attempts to create fake cruise times based on header information and distance along track.
24. **mgd77/mgd77manage.c** added **-AE** to ignore the verification status and process *e77* anyway.
25. **mgd77/mgd77path.c** added **-P-** to just list the IDs and not the full paths.
26. **mgd77/mgd77track.c** added **-Gt|dgap** to recognize gaps in tracks based on distance or time between successive points.
27. **mgg/mgd77togmt.c** added new **-T** and **-W** options to store total field and account for the magnetometer tow distance. Also tries to get info from header file.

28. **misc/gmtstitch.c** has enhanced **-T** option to eliminate connections when the 2nd closest pair is too close. Also added **-C** option to simply separate the open from the closed polygons (no stitching). Added **-L** option to write out segment-link information.
29. **x2sys/x2sys_list.c** can now accept list of weights for each track and output the composite weight for each crossover.
30. **x2sys/x2sys_solve.c** has option **-W** means an extra column with crossover weight.

1.1.2 Overview of GMT 4.4.0 [Feb-15, 2009]

This is a significant update of the official distribution and hence has a mix of bug fixes and program enhancements. We have added a new program (**greenspline.c**) which offers interpolation and grid-ding in 1–3 dimensions using Green’s functions of various splines. Also, the **misc** supplement has a new tool (**gmtdp.c**) which offers line-reduction using the Douglas-Peucker algorithm we used for the various shoreline resolutions. The **mex** supplement has a new Matlab/Octave function (**imgread.m**) to directly read Sandwell/Smith *.img files. The **x2sys** supplement has three new programs: **x2sys_list.c** can extract a subset of crossovers from the list produced by **x2sys_cross.c**, **x2sys_report.c** reports statistics of crossovers, whereas **x2sys_solve.c** will determine systematic trends from a set of crossover errors. These programs are intended to replace the old **x_system** tools **x_list.c**, **x_report.c** and **x_solve_dc_drift.c**. We have also temporarily added **GMT_qsort** which is a 64-bit compliant version of **qsort**. The latter is broken under OS X 64-bit and is thus substituted on that platform only for 64-bit compilations until Apple fixes the problem. Finally **ps2raster.c** can now be used to create geotiff images if **gdal** is installed on your system. Here is the list of bug corrections:

gmt_customio.c : Fixed sub-region access in Surfer format. This bug would manifest itself mainly when doing a **grdcut** with a N-S sub-region.

gmt_init.c : Modified special checks for FreeBSD by also considering **_AMD64_**. **-JXh** was misinterpreted whereas **-JXv** was OK.

gmt_io.c : Did not properly apply **PLOT_DEGREE_FORMAT=ddd.x** for decimal degrees.

gmt_map.c : Determining where parallels and meridians intersected the map boundary was susceptible to roundoff for very small regions. Added improved clipping for geographic polygons using the Sutherland and Hodgman algorithm when there are no map jumps in longitude. Fixes problem with tiny strips of “land” along map perimeter for some projections.

gmt_math.h : Check for macro definitions for system math functions.

gmt_plot.c : Wrongly checked for map jumps for non-periodic map boundaries. Bug in **GMT_fill_polygon** that affected polygon outline. 3D text box was computed incorrectly. Could exceeded array size in **GMTlepsinfo**.

gmt_proj.c : Fixed bug in Lambert conformal conic projection for southern hemisphere.

gmt_support.c : Function **GMT_get_arc** did not check for division by zero. The **-Gxfile:radius[unit]** option in **grdcontour.c** passed the entire argument as the file name. Function **GMT_polygon_is_open** did not test for empty polygons ($n = 0$). Avoid interpolating hue (converted from RGB) over more than 180 degrees. Changed **GMT_rgb_to_hsv** to integer logic to avoid errors on some compilers. As a result: much shorter code as well.

gmt_vector.c : Function **GMT_resample_path** would add 360 to points along meridians.

pslib.c : **ps_polygon** can only split line when **rgb[0] == -1** not < 0 since **-3** now means to use a fill pattern. Redefined **PostScriptcode** for circle which needed a stroke (**S**) first, otherwise a line would be drawn from the previous symbol. Updated **PSL_prologue.ps** version. Image placement now in integers. Ensures that placement is consistent with e.g. box drawn with the same coordinates. Does not produce colormap with number of pixels and colors is the same.

gmtmath.c : The **D2DT2** operator whose boundary condition yields 0 should yield NaN if one or more of the nearby nodes are NaN.

grdblend.c : A side-effect of the 2007-02-01 fix was that when the file is re-opened the row range is reset. Now the possible offset is computed during initialization but applied when the file is finally opened for reading. Better treatment of longitude periodicity if **-fg** is selected. E.g., if **-Rg** is used and a grid is -30/30 in longitude the output grid will consider 0-30 and 330-360 correctly

grdfilter.c : **-D5** did not initialize *xscale* so filter search box was set to region width which typically is much larger. The bug did not affect the results but unnecessarily increased runtime. Complained if **-R** was used and *xmin* was less than grid *xmin* for a full 360-range grid.

grdimage.c : Failed to determine boundary of projected grid with enough precision.

grdmath.c : Some 2nd-order derivatives whose boundary condition yields 0 should yield NaN if one or more of the nearby nodes are NaN.

grdreformat.c : Since there is no longer a `share/conf/gmt_formats.conf` the usage message crashed. Did not initialize grid header structure and could get netCDF error "Named variable does not exist in file". This could also occur in **grd2cpt.c**, **grdedit.c**, **grdtrack.c**, **grdvector.c**, **grdview.c**, and **grdvolume.c**.

psbasemap.c : The syntax for the **-L** option had to change since one could not easily use the `:label:` specification if the coordinates were given in `dd:mm[:ss]` format. A new syntax has been implemented where one or more `+?[args]` strings are appended after the required parameters (see man page). Erroneously suggested that 3-D base was plotted at $z=0$, instead of at the bottom end of the z -axis.

pscoast.c : The **-Q** option incorrectly required **-J**. Also, see revised **-L** as for **psbasemap.c**.

pslegend.c : Now use Unix `remove` function to delete script after completion; this avoids a Windows problem.

psmask.c : Fixed a bug for **-D-file** which did not write multi-segment headers.

psscale.c : Logarithmic scale did not function properly when scale bar was vertical. When **-I** and **-Li** was used we did not draw box outlines. Did not check if **-D** was not given, and had wrong test for **-E**. Added **-Aa** and **-Al** options to move only the annotations or label to the other side of the color bar. Now requires **-Ac** to keep writing the vertical labels as columns.

pstext.c : We incorrectly removed blank lines but those mark new paragraphs when in **-M** mode.

psxyz.c : Did not pick up y -size for column from input data file.

xyz2grd.c : For **-E** under Windows we used `fscanf` with a pointer from GMT DLL which would fail for mysterious reasons.

meca/psmeca.c : Fixed bugs that would give strange beach balls for some input.

meca/pscoupe.c : Fixed bugs that would give strange beach balls for some input.

misc/gmtstitch.c : Check to see if format was set was wrong.

mgd77/mgd77.c : Index array error resulting in wrong IGRF start and stop years was fixed. Now applies recalculation of fields requested by E77 flags as part of reading netcdf `mgd77+` files. However, if the original anomaly was NaN then we leave it as is.

mgd77/mgd77sniffer.c : Bitwise assignment error was deactivating other fields when depth field was missing from a cruise. Another bitwise error was overwriting E77 nav flags when navigation was found on land Updated sample grid function to handle longitudes for `img` files.

mgd77/mgd77track.c : Missing newline after last source line.

spotter/backtracker.c : The **-W** option always assumed the reverse rotation, *i.e.* from hotspot to seamount. Now obeys the **-D** option.

x2sys/x2sys.get.c : Now handles **-R** with longitude periodicity correctly.

xgrid/xGridEdit.c : Needed `GMTlio_init` to get all pieces needed to read grids.

Here is a list of the recent enhancement to various programs:

1. **gmt.init.c** has added support for enhanced **-E** option for 3-D perspective views which allows the specification of a fixed point (needed for creating animations). Updated all programs to use the new option and added updated man page and synopsis to all programs. Now, **-R** may take the name of an existing grid file. Then, the grid domain is used to set **-R** as well as the grid increment (and registration) for those programs that have such options.
2. **gmt.map.c** also has added support for enhanced **-E** option for 3-D perspective views.
3. **gmtmath.c** has added new operators **NOT** and **INRANGE**.
4. **grd2cpt.c** can now accept multiple grid files at once.
5. **grdfilter.c** has new options **-Np** to honor any NaNs found so output can be NaN, **-Nr** to replace output node with NaN if input node is NaN, and **-Ni** to ignore NaNs [Default].
6. **mapproject.c** has extended the **-A** option by making the fixed point optional; if not given we compute azimuths between successive data points.
7. **minmax.c** has optional */col* that may be added to **-Tdz** to select another column [third]. Added **-S** to leave space for error bars. Useful with **-I** and subsequent **psxy -E**.
8. **pscoast.c** has a new modifier **+** to the **-D** option, which determines the next lower resolution should the selected one not be available. This enhancement also affects both **gmtselect.c** and **grdland-mask.c**.
9. **psimage.c** has new **-Gt** option, with assignment of color to be made transparent.
10. **pslegend.c** lets **N** (number of columns) also affect the printing of labels. Can now use rectangle among the symbols.
11. **psmask.c** now has modifiers **+nn_points** and **+q** to the **-D** option to limit the minimum number of points a polygon must have and, to suppress *PostScript* output, respectively.
12. **pstext.c** has enhanced **-Z+** option expects z-level values in 3rd column.
13. **pslib.c** internals now measure paper size in double precision points instead of truncating to nearest integer. To remain backwards compatible for **pslib.c** users we now initialize all plotting in GMT with `ps_plotinit_hires` instead of `ps_plotinit`. Allow transparency when plotting 8-bit images (as well as 24-bit). We now use a new implementation of `ps_textdim` to ensure proper alignment of texts and the optional surrounding boxes. Finally, we have simplified the *PostScript* code for symbols and removed some limitations on plotting by officially moving to *PostScript* language level 2.
14. **ps2raster.c** now will scan for the optional comment `%%HiResBoundingBox` which takes precedence over the values in `%%BoundingBox`. New format **-TG** turns on transparency for PNG output, and **-Tb** selects Microsoft BMP output. Formats **b**, **g**, **j**, and **t** accept modifier **"-"** to produce grayscale images. Added **-Cgs-command** to pass one or more custom switches directly to **ghostscript**, and **-Q[g|t]bits** to set the level of anti-aliasing for graphics and text, respectively. We also added a new option **-F** to force a specified output file name. Finally, added **-W** to help create world files and geotiff output. To simplify boundary annotations for such plots (which must be inside the map region) we added the new choice *inside* for the **BASEMAP_TYPE** default parameter.

15. **psxy.c** has new option **-Iintens** to modulate fill color via a fixed illumination value.
16. **psxyz.c** has the same new option **-Iintens**.
17. **xyz2grd.c** has new format (A) for **-Z** which allows more than one floating point value per input record. Cannot be used if the z-values are in dateTclock or ddd:mm:ss format.
18. **mgd77/mgd77track.c** has enhanced **-A** option to place cruise ID equidistantly (distance or time) along the track.
19. **spotter/backtracker.c** has new option **-e** to specify a single fixed total reconstruction rotation that will be applied to all input points.
20. **x2sys/x2sys.c** internals now has automatic swabbing of index files, if required. Can now handle netCDF 1-D COARDS files.
21. **x2sys/x2sys_init.c** Now, the distance and speed unit settings (**-C**, **-N**) are set here and kept with the TAG for use in other **x2sys** programs.
22. **x2sys/x2sys_datalist.c** now has [experimental] support for using a correction table and can compute auxiliary data such as distance and azimuth.

Finally, we have added three new examples to demonstrate plotting of *.img grids, mixing UTM grids and geographic projections, and using **greenspline.c** for gridding on a spherical surface.

1.1.3 Overview of GMT 4.3.1 [May-15, 2008]

This quick update only 2 weeks after the release of version 4.3.0 was prompted by the discovery of three serious bugs; two of which were quite old but had caused no harm until tested under Fedora 9. The third critical bug prevented the wholesale reading and writing of GRD98 format grids. In addition a few minor bugs were discovered; this is the list of all corrections:

gmt.io.c : GMT_nc_input would not read all data columns when no variable names were given.

gmt.mgg_header2.c : Passed two of the arguments to *fread* in the wrong order. Prior to version 4.2.0 the return code (which indicated an error) was not checked yet the read did return the correct data. With better error checking this latent bug now caused a refusal to read any GRD98 grid.

gmt.support.c : Allow a little more slop in determining whether primary tick is at same location as secondary tick.

gmtselect.c : Did not like a variable number of input columns. Now OK if both input and output is ASCII and there are at least 2 (3 with **-Z**) input columns present.

grd2xyz.c : For option **-E**, the test for *xinc* == *yinc* was susceptible to round-off.

project.c : Now explicitly initializes the pointers in the data structure to NULL since *realloc* does not initialize new memory (yet almost all implementations of *realloc* appear to have done so anyway, masking the memory bug).

psxy.c : The **-D** option erroneously gave an error despite being used properly.

psxyz.c : Similar problem as described for **project**.

xyz2grd.c : The **-S** option incorrectly insisted that **-G** must be used.

In addition, many of the supplements did not work properly under Windows due to internal problems with the DLL. Finally, one enhancement snuck in before the decision to issue this update was made:

1. **gmt_init.c** was enhanced so that the media size **Custom.WxH** can use W and H in inch, cm, or m by appending **i**, **c**, or **m** to each dimension [Default remains points].

1.1.4 Overview of GMT 4.3.0 [May-1, 2008]

Changes are once again a mix of structural improvements, bug fixes, and a few enhancements. The coast-line files (now GSHHS 1.10) have seen minor modifications, the mex supplement now offers support for *Octave*², all source code is now fully 64-bit compliant, we have added an isolation mode option (if `GMT_TMPDIR` is defined, write temporary and hidden files to that directory), and the configure/make setup has been further improved (such as honoring CFLAGS and LDFLAGS set by user). Colors may now be specified as hexadecimal codes (e.g., #ff0000 for red), and projections can be specified by name (similar to *Proj*³). Finally, binary table data can now be COARDS-compliant netCDF files. As for documentation, we have now switched from C shell to Bourne shell (although the *cs*h examples are still distributed).

The following lists specific enhancements or new program options:

1. **gmt_grdio.c** is modified so the grid i/o supports the `GMT_[DATA|IMG|GRID]DIR` environment settings.
2. **gmt_init.c** was enhanced so `-U` can now interpret a justification (e.g., *just/dx/dy* on the command line or by setting `UNIX_TIME_POS`) and we introduced a new default parameter `UNIX_TIME_FORMAT` which controls the formatting of the timestamp.
3. **gmt_io.c** now implements `-b[i|o]c[var1/...]` option to indicate input is netCDF.
4. **gmtmath** recognizes new constants `TMIN`, `TMAX`, `TINC`, and `N`.
5. **grdimage** uses `-N` to not clip image at map boundary.
6. **grdview** now uses `-Wf` to change the facade pen from its default value.
7. **grdmath** recognizes new constants `XMIN`, `XMAX`, `XINC`, `NX`, and similarly `YMIN`, `YMAX`, `YINC`, `NY`.
8. **mapproject -G+** will compute distances between coordinates in first 4 columns.
9. **ps2raster** has new option `-D` to specify alternative output directory and `-V` to report progress.
10. **psrose** has new option `-F` to disable the plotting of the scale bar.
11. **psxyz** has new option `-D` to match option set in **psxy**.
12. **mgd77/mgd77list** added `-Ga|brec` to limit output to a certain record range.
13. **spotter/hotspotter** added `-S` to normalize output to percent of CVA maximum.
14. **spotter/grdspotter** is a new program, like **hotspotter**, but using gridded data as input.

A long list of bugs has been squashed since the last release, the most important are listed below:

gmt_grdio.c : Fixed 3 bugs in `GMT_decode_grd_h_info` that caused problems parsing `-D` option. Explicitly exclude = sign from becoming separator.

gmt_io.c : Now skips blank lines that has leading whitespace.

gmt_init.c : `c` for seconds was not recognized as `TIME_UNIT` (expected `s`, which is kept for backwards compatibility). `-B` processing of labels used an internal string that was too short, which could lead to label truncation. Fixed “Holiday-bug” in `GMT_parse_Joption` introduced 2007-12-21. `GMT_str_tolower` could run out of bounds. Probably only affected 32-bit compilers. `GMT_is_a_blank_line` is now used wherever ascii input is processed.

²<http://www.octave.org>

³<http://proj.maptools.org>

gmt_map.c : Fixed bug in radial clipping. The radial clipping would sometimes add arcs using the arc that exceeds 180 degrees. Added new rectangular clip function using Sutherland/Hodgman algorithm in order to fix incorrect results in **grdlandmask**. Minor bug in 4th term in conformal to geodetic lat. Round-off could mess mapping of west/east to xmin/xmax. Now has a safety valve for checking that this does not occur.

gmt_plot.c : 3-D basemap axis did not use **LABEL_OFFSET**.

gmt_proj.c : Fixed bug in azimuthal equal area projection that had the horizon shifted from where it ought to be. Avoid error in `GMT_lamb_sph` when lat is 90 degrees. Clip path for general perspective projection was not closed. For **-JS**: Would set slice to NaN if central meridian was not Greenwich. For **-JR**: Longitudes beyond 180 were set to 180.

gmt_stat.c : Bug in `GMT_median` would sometime give subtle mistakes, most noticeable when only a few values were passed to the function. Traced to the use of *size_t* variables in expressions that could yield a negative value. Fixed minor issues in `GMT_PvQv` function.

gmt_support.c : Made `GMT_polygon_is_open` tolerant of round-off and if polygon is not open set last to exactly equal first point. `GMT_get_annot_label` did not properly honor the *ddd.xx* setting. Now implements annotation for Gnomonic maps. In `GMT_contour`, would occasionally not check internal crossings for some interior contours.

pslib.c : Bug in `ps_shorten_path` lead to SEGV when path resulted in a single point. Fixed error in applying **pstext**'s **-Djdx/dy** shift in paragraph mode (**-M**). Redefine rect symbol to be less prone to round-off. Used internal *point_code* before it was initialized. This caused **PAGE.COLOR** not to work (wrote <NUL> rather than C).

gmtmath.c : Implemented Welford (1962) algorithm in **KURT**, **SKEW** and **STD** operators for more precise one-pass computation of mean and sum of squares.

gmtselect.c : The **-:o** option failed to reverse output order.

grd2xyz.c : Do not abort when **-R** exceeds grid; simply output common region. For gridline oriented grids: **-E** returned xll and yll one cell too large. Now writing [xy]llcenter properly.

grdblend.c : Did not pick up node registration before calculating output grid size.

grdedit.c : Adjust z_min and z_max when changing add_offset or scale_factor.

grdgradient.c : With **-D** and **-S** the slopes were not set to NaN if data were NaN.

grdinfo.c : Implemented Welford (1962) algorithm for more precise one-pass computation of mean and sum of squares. `zmin==zmax` no longer forces **-M** option.

grdmask.c : Tiny bug for determining which hemisphere (N/S) unlikely to have had any effect. Needed to allow for some slop when comparing shrink to 0.0 since sometimes the result of *acos* is 1e-14 or thereabouts.

grdmath.c : Implemented Welford (1962) algorithm in **KURT**, **SKEW** and **STD** operators for more precise one-pass computation of mean and sum of squares.

grdview.c : The facade (**-N**) outline was drawn with contour pen. The **-Qc** option failed to set the "build image" flag and produced garbage surface tiles. Also, **-T[s]** produced polygons that were not checked for wrapping at a periodic map boundary. Clarified that **-T** cannot take **-JZ|z**.

minmax.c : Could get confused when longitudes crossed dateline or Greenwich, and **OUTPUT_DEGREE_FORMAT** could interfere with result.

pscontour.c : **-T** option was susceptible to infinite loop if bad record was found.

psistogram.c : The **-R** option was processed separately and did not understand time coordinates. Bug in **-F** option failed to center bins.

psmask.c : The **-D** option used the wrong output file name.

psscale.c : Inverted vertical scale, when using filled rectangles: Colors remained in the original order. Inverted vertical or horizontal scale, when using rectangles with gradients: Size of rectangles followed original order, not inverted. In reverse mode, **-Eb** was plotting foreground triangle, **-Ef** background triangle.

pstext.c : Parsing of **-C** complained about % sign.

psxy.c : If first symbol in list with size was not circle, it got rejected. When sizes of **-Sr** or **-Sj** were read from list, they were always assumed to be in inches. Drawing arrows with **-SvS** and time-coordinates did not work as 2nd time coordinate did not get processed properly.

psxyz.c : If first symbol in list with size was not circle, it got rejected. When sizes of **-Sr** or **-Sj** were read from list, they were always assumed to be in inches.

sample1d.c : Calendar time knots did not get properly interpreted with **-N**.

mgg/mgd77togmt.c : Did not initialize the MGG_SHARED_DIR path.

mgd77/mgd77.c : Wrong header order written if **mgd77convert ... -Tt** was used.

mgd77/mgd77info.c : Could get confused when longitudes crossed dateline or Greenwich, and **OUTPUT_DEGREE_FORMAT** could interfere with result.

mgd77/mgd77sniffer.c : Numerous fixes and enhancements; see ChangeLog.

x2sys/x2sys.c : Error in determining which columns had been requested.

x2sys/x2sys.binlist.c : Could create bad bins because of incorrect reallocation of memory.

x2sys/x2sys.get.c : The **-L** option did not honor any **-F** or **-N** settings.

x2sys/x2sys.put.c : Wrong test when replacing older track info lead to data base loss.

x2sys/x2sys.cross.c : Used wrong data column order and computed speed when there is no time.

1.1.5 Overview of GMT 4.2.1 [October-10, 2007]

Changes in *GMT* 4.2.1 once again address many structural issues as well as numerous bug fixes. System-wide changes include a revamping of the entire configure/make setup for both regular installations and CVS users, an improvement to how the BCR 2-D interpolations for images and grids are done by adding B-spline and nearest neighbor as optional interpolants, introduction of a new *PostScript* Level 2 pattern machinery in **pslib.c**, an updated GSHHS coastline version (which also includes Australia internal state boundaries, fixes to the Yemeni and Lebanese borders, and more river lines), and general improvements and corrections to the documentation, such as placing all man pages in section 1 (except **pslib** which goes in section 3). Starting with *GMT* 4.2.1 we will also begin naming the coastline-related archives by the GSHHS prefix and use the actual GSHHS version number (now 1.9).

Individual programs have also seen some new options or enhancements:

1. **gmtselect** has enhancement **-Lp** to limit points beyond a line's endpoints.
2. **grdfilter** has new option **-D5** to allow direct filtering of Mercator grids (img).
3. **grdmask** has an enhanced **-A** option; append **m** or **p** to design a mask polygon by first following a meridian, then a parallel, or vice versa.

4. **gmtmath** has several new operators, such as **PLMg** (geophysical normalization and suitable for high degree and order), **FACT**, **SKEW**, **KURT**, **PQUANT**, **EULER**, **PSI**, **PV**, **QV**, **COT**, **COTD**, **ACOT**, **SEC**, **SECD**, **ASEC**, **CSC**, **CSCD**, and **ACSC**.
5. **grdmath** has the same new operator as **gmtmath**, plus **YLMg** and **CBAZ**.
6. **grdproject** now considers **-R** an optional setting.
7. **mapproject** has an enhanced **-G**- option where increments rather than cumulative distances are returned. Also, for UTM projections with **-C**, the **-R** option is now optional provided the UTM zone is properly specified.
8. **ps2raster** has now a new **-P** option for forcing portrait orientation.
9. **pshistogram** has now a new **-C** option for using a cpt file to paint the bars.
10. **pstext** will now accept the @_, @: and @; escape sequences for underline, font size change, and font color change regardless of mode.
11. **psrose** has a new option **-L** to control the labels.
12. **psxy** has an enhanced **-A** option; append **m** or **p** to draw a line by first following a meridian, then a parallel, or vice versa. Can now plot a notched box-and-whisker symbol, and we added **+ndx/dy** to nudge placement of quoted line labels. Enhanced **-E.../[-|+]pen** where + means apply cpt color (**-C**) to symbol and bar - means apply to bar only (no fill). Likewise, **-W[+|-]pen** controls if **-C** sets outline (-) or both fill and outline (+).
13. **psxyz** has enhanced **-W[+|-]pen** that controls if **-C** sets outline (-) or both fill and outline (+).
14. **sample1d** now accepts **-Fn** for no interpolation (returns nearest value).
15. Two additional color maps have been added: **panoply** mimics the default colormap in the netCDF viewing program **Panoply**; **cyclic** provides a full spectrum of 360 degrees in hue.
16. **originator** (*spotter* supplement) has new option **-Q** to specify constant r/t for (x,y,z) data only.

Below is a list of previous problems that we have identified and corrected in the current release:

gmt_agc.io.c : Failed when nx and/or ny was multiple of 40 + 1.

gmt_custom.io.c : Surfer grid start at lower, not upper left.

gmt.io.c : Combinations of **OUTPUT_DEGREE_FORMAT=ddd:mm:ss.xxxF** and **-:** would add W|E to lat and S|N to lon for formatted output. Blank lines were not recognized under cygwin/SFU. When no delimiters are used for input date format (e.g., yyyyymmdd) then yyyy *must be* 4 characters and we must use %4d. Leading zeros are required if year < 1000.

gmt.init.c : For quoted lines, the :Lh modifier did not reset label if a segment header had no label specified. Also, label would include the leading in a multi-word label. Now, UTM zones may be A,B,Y,Z or 1-60 with modifiers C-X (except I and O). Parsing of psxy's **-Sf** incorrectly scaled a count to inches. Suffices **h|+|-** in **-J** were mistaken for units.

gmt.map.c : **KM_PER_DEG** was not reset in **GMT_set_spherical**. This may have caused errors in scaling when **ELLIPSOID** was not set to Sphere. **GMT_distances** function did not work with correct pointer. Great circle intersection did not select correct vector sign so points 180 degrees from a line could pass as close in **gmtselect**. Removed restriction that east and west limits can not be both negative. This fixed the remaining Hexagone problem.

gmt.nc.c : The attribute **actual_range** was erroneously stored in grid units in stead of actual units. The difference is only relevant when storing scaled integers. A backward compatibility for grids written with previous versions is built in. Also the **GMT** version number is added to the global attributes and text attributes are truncated to their proper length.

gmt_plot.c : Failed to activate ddd.mm.xxx format for maps. Oblique tickmarks sometimes were missing for latitudes.

gmt_proj.c : **-JS** inverse did not apply quadrant check.

gmt_support.c : ddd:mm.xx (2 or more x) failed to format properly. Needed to reverse z_low and z_high values as well as rgb values when reversing color maps.

gmt_vector.c : Function `GMT_fix_up_path`: Intermediate longitudes now wrapped based on segment, not on map extent. “greenwich” argument became superfluous and was removed. Argument “step” was found to be in degrees, not in inches as some calling programs assumed.

filter1d.c : For **-Ffile**, set filter width to `DBL_MAX` until filter is read.

grd2cpt.c : **-E** flag did not work unless **-T** was used.

grd2xyz.c : Did not switch to binary i/o mode when **-Z** specified binary output (Windows bug only).

grdblend.c : Now works with Windows DLL by using the GMT i/o functions.

grdcontour.c : **-Avalue** would turn off the expected default transparency.

grdcut.c : Domain check failed for geographic 360-degree grid with **-fg**.

grdedit.c : Disallow **-T** for Surfer grids since they don’t support both kinds of node registration. **-N** did not take into account if **-fg** was given.

grdfilter.c : **-Inx+/ny+** was not propagated to the output grid setup.

grdimage.c : Removed **-T** option; no more polygon drawing (use **grdview**). **-Smax_radius** changed to **-S[-]b|c|l|n[/threshold]** to take advantage of new and improved projection function `GMT_grd_project`.

grdlandmask.c : Failed to set rightmost, empty bin if 360-periodicity in effect; also needed to set repeating right column to left column.

grdmask.c : For **-S..k**, did not properly account for latitude effect on dx. SEGV error when `GMT_fix_up_path` returned fewer points than originally allocated and the `n_alloc` variable was not reduced accordingly.

grdmath.c : When $M=0$, set Imaginary component of **YLM** to 0 (was same as real).

grdproject.c : **-Smax_radius** changed to **-S[-]b|c|l|n[/threshold]** to take advantage of new and improved projection function `GMT_grd_project`.

grdreformat.c : Could not determine format of output file automatically since file does not yet exist (must append file-type code).

grdsample.c : **-Qvalue** changed to **-Q[-]b|c|l|n[/threshold]** to take advantage of new BCR code.

makecpt.c : Colormaps with non-equidistant intervals can now be reversed properly.

project.c : Wrong azimuth for **-N** and **-G** generating lines.

pslegend.c : Usage message did not explain the **-L** option. Added `@ECHO OFF` to avoid commands being echoed into the *PostScript* output under Windows. The color change (C) macro messed up **-Xa** and **-Ya** absolute settings.

psbasemap.c : Check that **-L** is used with geographic coordinates only.

psimage.c : The **-I** option had become always active.

pslib.c : Now no text is written if font size equals 0.

psscale.c : Annotations did not work properly if **-Q** and **-B1p** were used together.

psxyz.c : Fixed bug in painting outline of text symbols.

xyz2grd.c : **-E** did not process pixel grids properly.

A few bug-fixes applies to the supplements as well:

gshhstograss.c : Removed use of `getopt` so even the lamest systems can compile it (including Windows).

img2mercgrd.c : Fixed AND vs OR logic in lat bounds check when **-D** was set. Used wrong origin when **-C** was used. Now relative to lon = lat = 0.

DLL : The *meca* supplements now work with Windows DLL by using the GMT i/o functions.

utilmeca.c : Make sure that checks on floating point numbers work well, even in case of small round off errors. Thanks to Peter Lombard.

mgd77manage.c : **-Qvalue** changed to **-Q[-]b|c|l|n[/threshold]** to take advantage of new BCR code. Added E77 status attribute to MGD77+ files.

mgd77sniffer.c : Same. Adjusted anomaly recalculation code so that cruises with m=1 and b=0 are reported to be same as expected. Repaired 8 memory leaks. Fixed two regression bugs, one in grid comparisons in which not all data were copied into the regression arrays and the other in faa recomputation regression where eot was being applied twice. Added code to check if regression is outside a specified percent (**-P**). Updated e77 messages and moved along-track grid offset errors to e77 header rather than having its own error class.

gmtdigitize.c : Must use separate x and y-scales if **-Jx** is specified. Wrong coordinates used to calculate rms misfit.

originator.c Now lists option **-L** in both usage and man page.

x2sys.c `x2sys_set_system` did not initialize structures properly.

x2sys_cross.c Skip duplicate files with a warning. Distance calculations were bogus (see **gmt_map.c**), and wrong number of arguments passed to `readfile` function pointer.

Finally, as far as CVS users are concerned, the old "gurumake" system has gone. To compile from CVS, users need to use a GNU compatible make program. A combination of GNUmakefile and makefile files make sure that those components not in the tarballs are created from scratch. Type **make** in the GMT directory to get a list of targets.

1.1.6 Overview of GMT 4.2.0 [April-1, 2007]

Changes in *GMT* 4.2.0 address many structural issues as well as many bug fixes. We have consolidated user initialization files in the `./gmt` directory, continued to replace tiling with bitmaps, and have performed a myriad of under-the-hood changes. One important and more visible new feature is the fact that **grdimage** and **pscoast** now can use the general perspective projection with arbitrary elevation (**-JG** has been enhanced to handle the extra arguments required – see the new example 26 for details). Also, the coastline files have been updated to use GSHHS version 1.5 which fixes minor inconsistencies in the coastline database. We have also corrected issues that made the Windows DLL explode in 4.1.4. Finally, a few enhancements have been made to these programs:

1. NGDC's GRD98 format has been updated to handle both gridline and pixel node registrations.

2. We have relaxed the restriction on latitude for **-JA**, **-JS** for polar aspects; now more than one hemisphere may be displayed. Better warning/error messages.
3. **gmtconvert** has an enhanced **-E** option; append **f** or **l** to only get first or last record per segment.
4. **gmtmath -T** can now have **+** appended to indicate number of points instead of increment.
5. **grdcontour** has a new option **-F** to orient dumped contours. Can now append *:radius* to the **-G** option in order to specify a minimum spacing (measured in the x/y plane) between contour labels.
6. **grdinfo** has an enhanced **-I** option. With no arguments we return the grid's **-Idx/dy** string whereas **-I** will return the grid's **-Rw/e/s/n** string.
7. **grdmath** has new option **-M** for using map units in gradients and new **D2DXY** operator. Also added **SBAZ** for back-azimuths and now allow **ELLIPSOID** to control if great circles or geodesics should be used (Sphere selects great circles)
8. **psrose** has new **-D** option to center the sector bins (like **pshistogram -C**).
9. **psxy** understand **-W-** and **-W+** in multisegment headers which will turn off outline or reset to default, respectively. Similarly, **-G-** and **-G+** will turn off fill or reset to default (with **-M**). Also added new option **-SB** for horizontal bar (**-Sb** is vertical).
10. **psxyz** also has **-SB** for horizontal bar (**-Sb** is vertical).
11. **sample1d** now allows absolute time in **-S** option.
12. **imgsrc/img2mercgrd** can take **-C** to let the Mercator x/y use the global origin of img file.
13. Because of its popularity, ease of use, and importance to many user how otherwise would not know about its existence, **ps2raster** is moved from the supplementary *misc* directory to the main set of *GMT* programs.

Below is a list of previous problems that we have identified and corrected in the current release:

gmt_init.c : Fixed unit problem with **-Jx1:xxxxx**. Erroneously added degree symbol to both coordinates in case of **-JX.d/.** (single d). Now properly adds only degree symbol on specified axis. Did not change time-system when only **TIME_UNIT** was specified. Failed to properly parse a single **PAR=ARG** (one word) argument given to **gmtset**.

gmt.io.c : Did not terminate a calendar string after copying it.

gmt_plot.c : The logic to check for seconds annotations failed if **inc < 1** arc second. Did not set the contour annotation font before writing labels.

gmt_support.c : Parsing old-style pens did not set offset to 0 when no texture was given. Fixed **IFACT** size in the old Brenner FORTRAN FFT – bug undetected since GMT 1! Contouring of grids with NaNs need to check both vertical AND horizontal interior gridcell boundaries for possible crossings. The label machinery for **ddd:mm:ss.xx** used the wrong parameter to check for fractional seconds annotation (the .xxx part).

gmt.time_systems.h : J2000 epoch was 1.0 Jan 2000, instead of 1.5 Jan 2000.

filter1d : The **-T** option can now parse datestrings for the min/max fields.

gmtmath : Fixed memory allocation bug for files with more than **BUFSIZ** records. Now works correctly with multisegment headers. Multisegment headers now written to the output file and not always to stdout. Option **-C** now works (used to deselect all columns). Fixed **LSQFIT** (used wrong columns when some were skipped).

grdcontour : Interior contours were not smoothed unless NaNs were involved. Also the labeling of closed highs/lows were insensitive to pixel versus gridline grids and could get the wrong result. **-C** need to check for “.cpt” at END of file name. Fixed contour label angle specifications were always ignored.

grdfft : **-D** and **-I** options could have junk in the parameter arrays if given more than once.

grdimage : **-JX** with a negative scale/length and **-Edpi** failed to flip the image.

grdinfo : Would not take both **-L1** and **-L2**.

grdview : Plot no mesh when **-T** is used.

mapproject : **-L** option did not allocate enough output memory for extra columns.

pscoast : Did not list **-Z** in synopsis/usage.

pscontour : For 3-D views, **-E** projected contours (**-W**) twice and mesh lines (**-L**) not at all. Fixed contour label angles were always ignored.

pslib.c : Only issue setdash *PostScript* commands if texture has changed. `ps_clipoff` needed to reset memory of last pen width/color/pattern. `ps_color_tiles` used wrong node registration.

psrose : Failed to skip pie-slice filling when no fill was selected. **-C** lead to SEGV as it tried to read from a non-existent file.

psxy : When used with **-S** but no **-W** or **-G** given, only set default **-W** if **-M** not used. Erroneously turned symbol outlines on if just **-C** was given. Incorrectly suggested that **-Svs** needs 5 instead of 4 columns. **-Sf** option was parsed to require 3 instead of 2 coordinates.

psxyz : **-Svs** could fail to plot by confusing y-coordinate and y-size. Also need 6 rather than 5 input columns. Bar width has only half of what was requested

splitxyz : Reported headings in radians instead of degrees.

trend2d : Failed to pass the new variable with column choices. Also did not accept **z** as an output choice.

A few bug-fixes applies to the supplements as well:

gshhs.c : Had **&&** instead of **&** in bit-arithmetic that reported level.

mgd77manage : Failed to enforce that a new column abbreviation must be in lower case.

x2sys.cross : Failed to check for crossovers falling exactly on data nodes.

1.1.7 Overview of GMT 4.1.4 [Nov-1, 2006]

Changes in *GMT* 4.1.4 are again relatively minor and predominantly bug fixes. One important new feature is that *GMT* can now automatically recognize the format of the grid file given to a program. The use of the “=id” mechanism is now only needed when writing an output file in a grid format other than the netCDF default or when reading using custom scaline and translation is required. We have also added a new user directory pointed to by **GMT_USERDIR** (default directory is `~/gmt`) where items such as `.gmtdefaults4` will be looked for. Additionally, a few enhancements have been made to overcome limitations in the previous versions:

1. **grd2cpt** has a new option **-T** for the creation of tables symmetric about zero.
2. **grdblend** will accept negative weights which are taken to mean that the sense of tapering should be reversed.
3. **grdedit** has a new option **-E** to transpose the entire grid.

4. **grdmath** has a new option **-N** to turn off strict domain match checking when multiple grid files are involved.
5. **grdreformat** now supports the **-f** option.
6. **nearneighbor** will now optionally accept a *min_sectors* argument appended to the **-N** option.
7. **pshistogram**'s option **-I** can now accept a modifier **O** to output all bin data even if $y = 0$.
8. **psscale** will now invert the color scale if a negative length is provided, and **-I** will now work with colormaps with non-constant interval and with gaps (**-L**).
9. **psxy** and **psxyz** have a new option **-Sj|J** that plots a rotatable rectangle but otherwise behaves similarly to **-Se|E**.
10. **ps2raster** has many improvements; added EPS output; high-quality PDF output. Also removed **-dDOINTERPOLATE** option which caused inversion of colour map and had no benefits.

Below is a list of previous problems (a few accidentally introduced in **GMT 4.1.3**) that we have identified and corrected in the current release:

gmt_agc.c : AGC grids use 0 to represent NaNs – this was not implemented yet.

gmt_calclock.c : Proper rounding of time when converting to dates.

gmt_support.c : Fixed bug in **-I** when modifier **=** was used.

gmt_init.c : Fixed bug not recognizing **PAGE_ORIENTATION** as well as a bug that prevented proper writing of **PAGE_ORIENTATION** in defaults. Added a check so **gmtset** will not crash if **VALUE** is not given. Finally, let **GMT_HOMEDIR** default to **C:** under Windows if **HOME** is not set.

gmt_io.c : **GMT_scanf_argtime** now returns **RELTIME** (not **ABSTIME**) when relative time is found.

gmt_grdio.c : Set **[xy].units** also in **GMT_update_grd_info**. Fixed time-scaling bug on input (was always seconds). Make units check case-insensitive. Check for toggled lat/lon coordinates.

gmt_nc.c : Made sure no garbage remains under Cygwin when using **strncpy**. Check if x- and y-coordinates have constant step sizes; issue warning if not.

gmt_plot.c : Bugs related to annotations with **-JPa** and its **z** modifier fixed. Log gridlines did not work for 3-D view. 3-D axis label would sometimes get misplaced due to round-off. 3-D map scale did not project correctly. Duplicate title could appear if **-JX** was used and one axis was geographic (d). Needed to add secondary font to list to be encoded.

pslib.c : Fixed memory management in LZW compression (memory leak). Improved EPS conformance.

filter1d : Robust option used extreme rather than median to determine the outliers.

gmtconvert : Did not have **-L** listed in synopsis.

grdblend : Now skip grids that are entirely outside the region of interest.

grdcontour : Crashed if **-M** and **-D** were used with no file name specified. The **-W[+][c|a]** option was susceptible to misinterpreting things like **-Wcyan** as contour pen with color **yan**.

grdcut : Require geographical instead of global in order to shift by 360 degrees.

grdfilter : Should not wrap over pole unless grid extends all the way to the pole.

grdinfo : When **-C** was used there was no linefeed at the end.

grdsample : **-T** did not ignore **-R** (as per manual), resulting in changed cell size. **-F** did not use gridline node registration as default, rather that of the input grid. When using pixel node registration, number of cells would be one too large. **-L** worked only in very limited case: going from $x=[-180;180]$ to $x=[0;360]$. Now supports any periodicity in X and Y (as per manual). **-F** again forces pixel node registration. Default is same as input. More consistency with manual.

grdtrack : The **-Z** option failed to be set for some input configurations.

grdvector : Added **-f** option.

grdview : The **-W[c|m]** option was susceptible to misinterpreting things like **-Wcyan** as contour pen with color yan.

grdvolume : Three bugs squashed: gridcell oriented grids now get proper area and volume, including edges; only one cell per NaN is excluded; when **-C** and **-L** are combined, the volume is properly corrected for the baseline height.

pscoast : **-N** and **-I** reset pens to default settings after initially changing them. Did not change output mode to binary (Windows only) if **-M** and **-b** were set. Both **-Gc** and **-Sc** needed to check that no letter is following the **c** modifier.

pscontour : The **-D** dump option wrote projected instead of original coordinates.

psimage : **-Gcolorname** (e.g., **-Gblack**) will now be interpreted as foreground color, e.g. **-Gfblack**.

pslegend : Did not replace octagons with polygon form when pattern was requested. Did not consider if absolute coordinates were given in **-X** and **-Y**. Passed the wrong character code when **M** was chosen with a plain scale modifier.

psscale : A vertical bar with a label placed along it was mis-justified.

pstext : Default for **-G** is now **BASEMAP_FRAME_RGB** as for other map annotations. The box option **-W[fill][o|O|c|C][pen]** is now **-W[fill,][o|O|c|C][pen]**, i.e., we now use a comma to separate the fill and pen (done since fill may be a name containing o|c); parsing is backwards compatible.

psxyz : **-C** for symbols did not pick up color fill.

trend2d : Processing of **-F** happened after checking.

xyz2grd : Had **-Az** as default rather than no **-A**. Fixed bad header parsing when **-E** was selected.

A few bug-fixes applies to the supplements as well:

grdraster : Only do 360-degree wrapping if working on a geographic grid.

mgd77list : Did not process time when **-Am2|4** was set and time was not requested as output. Also, did not process time when **-Am2|4** was set and time was not requested as output.

x2sys.c : Did not look in current dir for *.def files.

1.1.8 Overview of GMT 4.1.3 [June-1, 2006]

Changes in *GMT* 4.1.3 are relatively minor and predominantly bug fixes. However, a few enhancements have been made to overcome limitations in the previous versions:

1. Added the Hughes 1980 ellipsoid for projection support for DMSP SSM/I grid products.
2. **grdfft** has an extended **-F** option to allow for either Gaussian- or cosine-tapered filtering.
3. **psscale** now has a **-Q** option so that logarithmic color scales and annotations can be handled properly.

4. **makecpt** and **grd2cpt** have a new **-M** option to allow the background, foreground, and NaN-colors to be assigned using the *GMT* defaults instead of the settings in the master CPT file.
5. **mgd77list** in the **mgd77** supplement has new option **-Q** to specify limits on speed and azimuths for output records.

Below is a list of previous problems (some accidentally introduced in **GMT 4.1.2**) that we have identified and corrected in the current release:

gmt_grdio.c : Bug in `GMT_grd_shift` for gridline-registered grids; this function is used in **grdedit** to rotate grids of 360-degree longitudinal extent. Also added better testing for subsets of global (0-360) grids.

gmt_init.c : `GMT_PS_init` was called after `-PAR=val` had been decoded, resetting the *PostScript*-related parameters to their default settings.

gmt_support.c : `GMT_set_xy_domain` padded region for pixel instead of gridline node registration, which could cause SEGV in **xyz2grd** if (x,y) was less than half the grid-spacing outside region.

blockmean : The **-C** option got reversed in 4.1.2 - now fixed.

blockmedian : The **-C** option got reversed in 4.1.2 - now fixed.

grdcontour : The **-C** option with a non-cpt file failed to read due to lack of proper if-test.

grdedit : The **-S** option was backwards and tested $w-e=360$; should be $e-w=360$.

grdimage : Fixed bug introduced by `GMT_get_inc` in 4.1.2. Internal projected grid never took `node.offset` from input grid.

grdmask : Polygons with zig-zag shape would sometimes cause a node exactly on a polygon vertex to be considered inside. Radius was reset to 0 after **-Sradius** was assigned.

grdvector : The **-A** option was not properly initiated.

psbasemap : The **-L** option did not properly parse the optional `:label:just` part.

pslegend : If the **M** (for map scale) was used, the **-R** and **-J** options would be reset. Also prevented the undoing of **-X** and **-Y** at the end of the program.

1.1.9 Overview of GMT 4.1.2 [May-15, 2006]

On the surface, changes in *GMT 4.1.2* are relatively minor. Most of the work has involved realignment of code and parsing of arguments to simplify the upcoming port to *GMT 5*; a brief listing of more visible changes include

1. Coastline files have been updated to use GSHHS version 1.4 which fixes minor inconsistencies in the coastline database.
2. All coastline files are now stored in a new subdirectory `coast` under the `share` directory, and the tar archives for coastlines now have their own version numbers as they do not change as frequently as the source code. Current coastline version number is 4.1.
3. The archives have been reorganized so that `GMT_share.*` contains all files needed at runtime whereas the standard coastline files are in the new `GMT_coast.*` archive. The `GMT_progs.*` archive has been renamed `GMT_src.*`.
4. CPT files can now have z -values that are date-time strings.
5. Optionally append **z** to the **-Jp** projection to annotate depths (*i.e.*, “north-y”) rather than radius.

6. Two new tools added to the *misc* supplement for digitizing lines (**gmtdigitize**) and to stitch digitized lines into continuous lines or polygons (**gmtstitch**).
7. Extended **-M** option to take optional modifiers **i** or **o** for input or output.
8. Added support for custom grd format AGC from Atlantic Geoscience Center, assigned the code **af** [21].

A few programs or options have received minor updates and new features, such as

blockmean : Added **-E** for reporting standard deviation, min, and max values per block.

blockmedian : Added **-E** for reporting L1 scale, min, and max values per block. Also added **-T** to specify a particular quartile [Default $q = 0.5 = \text{median}$].

blockmode : Added **-E** for reporting LMS scale, min, and max values per block.

configure : Added explicit options to bypass the installation of supplements that require Matlab (**-disable-mex**) and X11 (**-disable-xgrid**).

gmtconvert : Added **-D** option to write segments to individual output files.

gmtdefaults : Support for new default **PS_VERBOSE** which controls the writing of comments to *PostScript* files. **COLOR_MODEL** can now accept a prefix “+” which forces color interpolation in the selected system (RGB or HSV only). Default remains RGB. **PS_COLOR** has been extended to accept HSV as well (only applies to polygon, symbol, pen, and text colors, not images.). New parameter **POLAR_CAP** which controls the number of gridlines that converge on the poles for azimuthal and some other projections. Added new default **HISTORY** [TRUE] which controls whether or not we maintain a common command option history via `.gmtcommands4` files.

gmtmath : Added option **-M** to indicate the program can now handle multisegment files. Added **CPOISS** for cumulative Poisson distribution.

grdmath : Added **CPOISS** for cumulative Poisson distribution.

minmax : **-D** made obsolete by improved range checking for longitudes (but available for backwards compatibility).

psscale : Enhanced **-I** option for asymmetrical intensity ranges from *low* to *high*.

psxy : Added **-SW** for wedges defined by azimuths rather than directions. Polygons of large longitudinal extent now clip correctly.

splitxyz : New option **-Q** to specify the output columns and their order.

Below is a list of previous problems that we have identified and corrected in the current release:

gmt_plot.c : The 3-D perspective plotting of text was not scaled correctly.

gmt_support.c : Parsing of **-L** option used in **psbasemap** and **pscoast** failed to get correct unit when `ddd:mm:ss` syntax was used for the position. Corner boundary conditions for grids (needed by **grdtrack**, **grdsample**, **grdview**, and **grdgradient**) had the wrong sign.

gmt2rgb : Did not check name template properly, and did not initialize region.

gmtselect : Option **-F** insisted on using spherical testing for Cartesian x,y data.

grd2xyz : The **-E** option had the y -direction reversed.

grdfilter : Needed the **-f** option to process **-Rddd:mm** syntax.

grdimage : Would hang in *stdin* if **-C** not given when one grid is plotted.

grdmask : Did not explicitly close polygons before using them. Test for polar caps applied to the opposite pole.

grdmath : Command **INSIDE** for Cartesian data had bug (passed y where x was expected).

grdsample : Failed when **-I** was specified.

grdview : Bug in plotting north facade (**-N**). Also tried to free unallocated memory if **-G** was used.

project : Cartesian projections gave incorrect results for p, w, t, s . Removed 0–360 restriction on azimuth. Option **-G** was susceptible to round-off and thus sometimes reissued the final point.

psxy : **-SV** and **-SE** for **-JX** did not convert azimuths to directions. The **-Sq** option would get confused when distances between successive labels were smaller than the line's point spacing.

mgd77/mgd77manage : Did not properly close the file after ingesting E77 information.

pslib.c : `ps_load_raster` did not use open mode **rb** and hence failed under Windows.

xyz2grd : The **-E** option had the y -direction reversed.

A few bug-fixes applies to the supplements as well:

x2sys_get : **-N** did not work properly (now fixed and tested).

1.1.10 Overview of GMT 4.1.1 [Mar-1, 2006]

Changes in *GMT* 4.1.1 are mostly minor; a brief listing include

1. **gmt.nc.c**: Introduced handling of 4-D COARDS compliant grids (See Chapter 4 for details).
2. **mgd77/mngd77sniffer**: New tool for along-track quality control checking of MGD77 files.
3. **spotter/grdrotater**: New tool that rotates grids given a specified finite rotation.
4. Jonathan Shewchuk's triangulation routines are now stored with the rest of the source in the `GMT_progs.tar|zip` archives. (However, because his copyright is not GPL, installing it is still an option).

A few programs or options have received minor updates and new features, such as

grdedit : Added option **-T** to toggle between gridline and pixel node registrations (header only).

grdgradient : Implemented variation on Lambertian illumination.

grdmask : Now takes **-Sradius[c|m|k|K]** as is done in **nearneighbor**.

gmtmath : If file is STDIN we read data from *stdin* and put the contents on the stack. Also added **-F** to select which columns to use for output [all].

grdtrack : Can now sample Sandwell/Smith IMG grids directly.

psmask : -Now takes **-Sradius[c|m|k|K]** as is done in **nearneighbor**. Can now plot tiles regardless of projection and use patterns.

pstext : **-D[...]*vpen*** can now be used with or without **-M**.

psxyz : **-SO|U** imitate **-So|u** but without the 3-D color shading.

mgd77.c : Added mechanism to search directories for files (*mgd77* supplement).

mgd77list : Activated **-X** option and associated machinery for applying data corrections (*mgd77* supplement).

Inevitably, when new features are added, new bugs come along with them. Below is a list of problems that we have identified and corrected in the current release:.

configure.in : Extracting VERSION from **gmt.version.h**, not **gmt.h**.

gmt_init.c : BASEMAP_FRAME_RGB overrode any changes to grid pens etc. Now only does so if prefixed by '+'.
gmt_calclock.c : Did not allow **-B0** for time-axis.

gmt_map.c : **-JX...d** now plots with WESN or degrees:minutes as per PLOT_DEGREE_FORMAT. Map clip paths for **-JElon/±90** were no good. Under certain circumstances, GMT_non_zero_winding might be passed a polygon that was not closed, resulting in an error. **-JQ** would give garbage if central lon was way outside **-R**.

gmt_plot.c : **-JX...d** now plots with WESN or degrees:minutes as per PLOT_DEGREE_FORMAT.

gmt_grdio.c : Changed logic to avoid false "scale==0" warning on Windows. GMT_open_grd (used in **grdblend**) reset scale to NaN. Initialize header information at start of GMT_read_grd.info.

gmt_support.c : Initialize [xyz]_unit with more appropriate values. Got wrong conversion for dx in meters to degrees.

gmt_grd.h : Improved definition of GMT_x_to_i macro should reduce bugs

pslib.c : ps_polygon: if outline == -9 just fill and no clip. Fixed two bugs concerning the /MaskColor operator.

ISO-8859-9.ps : Added /dotlessi per Onur Tan.

blockm* : Now correctly deals with periodic longitude data.

grdcontour : Fixed several issues at grid limits and inappropriate scaling of grid dimensions..

grdfilter : Used -1 as index flag instead of INT_MIN.

grdimage : Fixed several issues at grid limits and inappropriate scaling of grid dimensions.

grdmask : Only let you change the value for outside nodes.

grdmath.man : Did not list **-f** option. Operators **LT**, **LE**, **EQ**, **GE**, **GT** returned TRUE if NaNs were involved Now NaN is returned if any of the two operands is a NaN.

grdreformat : Update grd.command before writing grid

grdvector : Did not place vectors correctly for pixel-registered grids.

grdview : Skipped nodes outside boundary but they might be needed to draw a tile.

pscoast : With **-JE** and **-Gr/g/b**, the painting of the antipodal bin would incorrectly turn off clipping, messing up the rest of the plot. Now pass -9 to GMT_fill which means just fill and no end of clipping.

xyz2grd : For geographic grids with 360° range and gridline node registration, the west and east bin did not get replicated properly. Now considers data inside the first and last tiles which might stick outside w/e/s/n.

A few bug-fixes applies to the supplements as well:

x2sys.cross : Several problems fixed.

1.1.11 Overview of GMT 4.1 [Jan-7, 2006]

Most changes in *GMT* 4.1 are improvements “under the hood”. The most significant of these are

1. Addition of ability to both read and write netCDF files that are COARDS compliant. This means that *GMT*, for the first time, is able to read netCDF files created by applications other than itself, and that other applications capable of reading COARDS-compliant netCDF grids can directly import data from *GMT*. We have added the new parameter **GRID_FORMAT** to the *GMT* defaults with “nf” as default. Users who, against our recommendation, prefer to maintain the old non-COARDS compliant format as their default grid format can instead select “cf”. Support for extracting 2-D slices from 3-D netCDF grids has also been added.
2. An overhaul of how the **pslib** library encodes *PostScript* images, resulting in vastly smaller files when certain conditions are met, and general shrinking overall by enabling RLE or LZW compression. We have also added hooks for setting three new *PostScript* parameters via **gmtdefaults** settings: **PS_LINE_CAP**, **PS_LINE_JOIN**, and **PS_MITER_LIMIT**. See **gmtdefaults** for details.
3. Improved alignment of strings ending in “l” in the *PostScript* output.
4. Adjustments to how native *GMT* grid headers are read and written in order to be fully 64-bit safe. *GMT* now runs in full 64-bit mode on platforms that supports it (e.g., Mac OS X G5).
5. Making *GMT* tread-safe by replacing *strtok* with our own *GMT_strtok* function.
6. Implemented full inverse Winkel map projection based on a new algorithm by Ipbuker, 2002, *Cartography & Geographical Information Science*, 29, 37-42.
7. Extended the options that is used to specify grid spacing (usually **-Ixinc/yinc**) to allow for specifying *nx/ny* instead (by appending +). Also, append ! to adjust the range so it fits exactly the given increment [by default the range is kept fixed and sloppy increments are adjusted accordingly]. Append **e|k|i|n** for increments in meter, km, miles or nautical miles, respectively. These increments are converted to degrees longitude (at the middle latitude) and degrees latitude.
8. The polar r, θ projection **-Jp** now takes an optional suffix **r** that reverses the radial coordinates (useful when r is elevation as used by sky plots.)
9. The **misc** supplement has two new items: **ps2raster** uses *ghostscript* to facilitate the rasterization of *PostScript* files, while **nc2xy** allows extraction of data columns from COARDS-compliant netCDF files.
10. The **mgd77** supplement has two new items: **mgd77convert** translates between different MGD77 formats (including a new netCDF-based format), while **mgd77manage** assists in the management of trackline data sets.
11. We now have improved PDF layout and navigation (thanks to Misha Tchernychev).
12. The HTML versions of all manual pages are now generated with **groff**, and has active links for *GMT* Default parameters as they are references in the documentation.

Many programs or options have received minor updates and new features, such as

-b : Ability to specify byte-swapping for native binary input and output tables by using upper case **S|D**. This is useful if you have binary tables created on a little-endian machine (e.g., Linux PC) and need to read them on a big-endian machine (e.g., most RISC-chip machines from Sun, HP, Apple).

filter1d : Allow NaNs in all but the “independent data” column.

grdcontour : Label option **+ap[u|d]** for always having labels be readable up or down hills.

gmtconvert : New **-N** option suppresses output records when all fields are NaNs.

gmtmath : Added **TN** function for evaluating Chebyshev polynomials; new constant **Tn** was added to easily select normalized **T** (gives coordinates from -1 to + 1 suitable for evaluating Legendre and Chebyshev polynomials). Finally, we added **CORRCOEFF** for calculation of correlation coefficients, and **-I** to reverse the output by printing the last row first.

grd2cpt : New option **-D** sets the back- and foreground colors to the colors at the limits of the cpt file.

grd2xyz : Added **-E** for ESRI interchange ASCII grid dump.

grdfilter : Geographic boundary conditions are now in effect if **-D4** is selected.

grdgradient : Added option **-E** for Lambertian or Peuckee illumination.

grdmath : Allow **-bi** to be used with input files for commands **PDIST**, **LDIST**, and **INSIDE**. When spherical calculations are selected we now use the **ELLIPSOID** setting to determine if distance calculations should be along geodesics or great circles. Also added **TN** function for evaluating Chebyshev polynomials; new constants **Xn** and **Yn** was added to easily select normalized **X** and **Y**. Finally, we added **CORRCOEFF** for calculation of correlation coefficients.

grdraster : Optionally select a data set by giving a text pattern instead of data ID number. This makes it easier to specify a certain data set (*i.e.*, “ETOPO2”) than having to remember its arbitrary numerical ID. Also, native grids with *GMT* headers can also be placed in the database by appending **Hnbytes** to the corresponding `grdraster.info` entry, where *nbytes* is the size of the header that should be skipped (use 892 for *GMT* headers).

makecpt : New option **-D** sets the back- and foreground colors to the colors at the limits of the cpt file.

mapproject : **-L** now outputs both the minimum distance and the coordinates of the nearest point on the line.

pscoast : Added **-Z** for 3-D map z-level (as in **psbasemap** and others).

pshistogram : New option **-Tcol** lets user select any column to be used, starting with 0 (first). The old **-2** option is retired (but remains accessible for backwards compatibility).

psimage : Now support inclusion of EPS images.

pslegend : Added layout option **B** for inserting color bars via **psscale**.

psscale : Now supports an optional *;label* at end of each line in cpt files. If present this label will replace the default annotations when option **-L** is used.

psxyz : Added **-Q** to disable sorting of points based on distance.

sample1d : Allow NaNs in all but the “independent data” column.

xyz2grd : Added **-E** for ESRI interchange ASCII grid digest.

Inevitably, when new features are added, new bugs come along with them. Below is a list of problems that we have identified and corrected in the current release:

install_gmt : No longer test netcdf installation since that can fail even when install was successful [e.g., under Mac OS X Tiger].

gmt.h : `GMT_swab4` used `unsigned long` instead of `unsigned int` which could cause 64-bit problems.

gmt.time.system.h : Fixed MJD offsets by subtracting 10 days.

gmt.calclock.c : time to hr,min,sec was vulnerable to round-off when optimized. Also, *hh:mm* data (without trailing *:ss*) would lose the minutes (*hh:mm:ss* was OK).

gmt_grdio.c : Bug in scale/offset for **grdblend**'s row-by-row i/o.

gmt_init.c : Would eat number with leading plus sign without checking if it actually was a `+gmtdefaults` file instruction; thus **gmtmath** could not see numbers such as +13.5. Command line argument `-BASEMAP_FRAME_RGB=color` was not passed through to tick-, grid- and annotation-properties. `GMT_end` now frees memory used for hashing. Did not use custom ellipsoid to set DEG2M parameter so we got large errors for planets with significantly different radii.

gmt_io.c : Bug in reading `yyyy[/ljjj]` data fixed. `GMT_lines_init` had trouble if 2000 segments had no data at all. It also allocated 2000 points for each segment but never deallocated the unused portions, thus running up memory fast. `GMT_write_segmentheader` wrote nothing if input was binary and output is ASCII. Fixed a few memory leaks.

gmt_map.c : Azimuth to angle calculation for linear projections now properly handle different scales in *x* and *y*. The calculation was also vulnerable to bad wrap-around, giving strange directions for vectors in **psxy**. Geodesic distance calculation could get wrong quadrant.

gmt_plot.c : 360° polar basemaps could lack outline. Direction for map roses were inaccurate. Circle and θ -*r* boundaries did not allocate enough memory for arrays. Would plot both -180 and +180 annotations for periodic maps.

gmt_shore.c : Must explicitly close polygons since inside/outside test in other programs expects it.

gmt_support.c : Trouble extracting subregions of grid with *east* = 0. Cartesian **LDIST** failed when minimum distance was requested (only done via **grdmath**). Color names got truncated to 16 characters. Improved workings of `GMT_sample_cpt` in support of **makecpt**. Fixed more memory leaks. Bad LF/CR removal for `coastline.conf` dir.

filter1d : `-Ff` with even number of coefficients sometimes skip a coefficient.

gmtconvert : Missed first multisegment output header if input file was ASCII.

gmtmath : No longer have to say `-Ca` if there is only one input column. Did not understand `dateTclock` as command line data.

gmtselect : If `-M` is on and a portion of a segment is skipped, we must reissue the multisegment header when segment resumes. Now handles both Cartesian and spherical polygons correctly.

grd2xyz : Sloppy `-R` resulted in bad *x,y* values and sometimes allocation error.

grdfilter : Convolution filters now use correct area normalization.

grdgradient : If `-M` is used with grids that include poles, ignore the poles when normalizing the slopes.

grdimage : Cannot use `-R` to extract subset when `-J` is oblique. Reverse log-axes did not work.

grdmask : Now handles both Cartesian and spherical correctly.

grdmath : Wrong sign in **D2DY2**, and bogus value at *y* = *ymin*. Now handles both Cartesian and spherical polygons correctly. Constants given on command line can now be absolute time, geographic coordinates, or regular floating-point numbers.

grdtrack : Would fail to skip first two columns for ASCII input if `dd:mm:ss` format was used.

grdview : Cannot use `-R` to extract subset when `-J` is oblique.

grdvolume : `-Clow/high/delta` did not check for *low* | *high*, etc.

pscoast : Recursive painting could get tricked when boundaries were curved.

pslegend : Did not pass `+gmtdefaults` and `-PAR=val` onto system calls.

psscale : Vertical annotations w/custom **D.FORMAT** were not aligned. Now uses more optimal means to display the color bar, leading to smaller *PostScript* files. **-E** did not flip sides when a negative width was used.

psxy : **-Sp** is now a true point, but can also take an optional size. Pentagon symbol had wrong normalization scale. If a fixed symbol size was given in **-S**, with the symbol type supplied from file, we would not scale symbols correctly if upper case symbols were given.

psxyz : Wrong index used in assigning color from cpt and in updating vector lengths. If a fixed symbol size was given in **-S**, with the symbol type supplied from file, we would not scale symbols correctly if upper case symbols were given

spectrum1d : Bugs in error expressions for admittance, gain, and phase have been corrected.

x2sys & mgd77 supplements : Made DOS-format (CR/LF) tolerant. Both supplements are now undergoing rapid development.

1.1.12 Overview of GMT 4.0 [Oct-10, 2004]

GMT 4 represents a major overhaul of the package, hence the major version number increment. There are four categories of changes that have been implemented:

Time-series support. *GMT* can now read and write time-series data where the time coordinates are of the form *dateTclock*⁴. The formats used for *date* and *clock* are under the user's control. Both Gregorian and ISO calendars are supported. Frame annotation for time-series are now supported via the **-B** option; there are many new modifiers reflecting the vast number of ways one may want to annotate time axes, including support for primary and secondary annotation levels and the day- and month-names in numerous languages (send us the information we need if your language is not supported). The capability to handle time (in **-R**, **-J**, **-B**, i/o, and plotting) required considerable changes "under the hood", including the introduction of numerous new **gmtdefaults** parameters to make the time series support as "generic" as we need it to be.

New Tools. Three new tools have been added:

1. **gmt2rgb**: Makes red, green, and blue component grid files from an image (to be used with new options for false color imaging or image draping by **grdimage** or **grdview**).
2. **grdblend**: Blends several partially over-lapping grid files into one combined grid. Output grid is written one row at the time so truly enormous grids can be created.
3. **pslegend**: Designs and plots elaborate legends on maps.

New Program Options. Many programs have received additional options or features that enhances their usefulness:

- **blockmean**: New option **-Sw** will return weight sum while **-Sz** returns the data sums (*i.e.*, it duplicates the previous **-S** option).
- **filter1d**: New filters **-Fl|L|u|U** that return extreme (min, max) values.
- **gmtconvert**: Added new options **-F**, **-A**, and **-I** that simulate *UNIX* **cut**, **paste**, and **tail -r** (or **tac**) capabilities. Option **-E** reports first and last point per segment only, **-L** lists the segment headers only, while **-S** lists records from segments whose header matches a given text pattern.
- **gmtmath**: Added new operators for solving least squares problems (**COL**, **LSQFIT**), finding function roots (**ROOTS**), and evaluating critical values (**CHICRIT**, **FCRIT**, **TCRIT**, **ZCRIT**). We also added some general functions (**SINC**, **LOG2**, **LRAND**) and miscellaneous operations (**FLIPUD**, **NEQ**). The **-S** option may now take a modifier to select first or last record only.
- **gmtselect**: New option **-Z** to pass or skip based on input *z*-range.

⁴Use standard *UNIX* tools such as **awk** or **perl** to reformat files should your *date* and *clock* components reside in separate columns.

- **grd2cpt**: New options **-Q** for logarithmic scales, **-E** for equidistant color intervals, **-R** for selecting a grid sub-region, and **-N** to suppress output of B, F, N colors⁵.
- **grd2xyz**: New option **-W** to write a constant weight factor as a 4th output column, and ability to process several grid files at the same time.
- **grdcontour**: Expanded the **-G** option to handle 5 algorithms (4 new) for the placement of contour labels.
- **grdedit**: New option **-N** to replace selected node values given *x, y, z* data in table form (options **-H**, **-b**, **-f**, and **-:** added for file support).
- **grdfilter**: New geospatial filters **-Fl|L|u|U** that return extreme (min, max) values.
- **grdimage**: New option for colormasking (**-Q**; *PostScript* Level 3 only), *PostScript* image interpolation (**-E-dpi**), and false RGB color image (when given three grids), as well as a modifier to **-T** to draw tile outlines.
- **grdinfo**: New option to create argument for **makecpt** (**-T**) and to round-off region boundary coordinates (**-I**).
- **grdmath**: Added new operators for critical values (**CHICRIT**, **FCRIT**, **TCRIT**, **ZCRIT**), geospatial analysis (**LDIST**, **PDIST**, **INSIDE**) and for calculating azimuths (**CAS**, **SAZ**). We have also added some general functions (**SINC**, **LOG2**, **LRAND**) and a few grid operations (**FLIPLR**, **FLIPUD**, **ROTX**, **ROTY**, **NEQ**, **INRANGE**). We may now create multiple output grids from a single command.
- **grdproject**: Option to supply false easting/northing or other offsets from the origin(**-C**).
- **grdreformat**: Option to suppress header in raw output (**-N**).
- **grdsample**: Option to push the bilinear interpolation closer to nodes that are NaN (**-Q**).
- **grdtrack**: Options to retrieve nearest node value (**-N**, no interpolation) and to push the bilinear interpolation closer to nodes that are NaN (**-Q**).
- **grdview**: Colormasking (**-Qc**, PS Level 3 only), draping of images via red, green, and blue component grids (**-G**). Also, drapegrids can have higher resolution than the relief grid, and we added a modifier to **-T** to draw tile outlines.
- **makecpt**: New options **-Q** for logarithmic scales and **-N** to suppress output of B, F, N colors.
- **mapproject**: New options for datum conversions (**-T**, **-E**, and **-Q**), azimuth and back-azimuth (**-A**), distance to point (**-G**) and line (**-L**) calculations, and optional false easting/northing (**-C**).
- **minmax**: Added **-Tdz** option to produce **-T** string for **makecpt**, **-E** for returning extreme records, and the **-I** option was extended to handle any number of columns when **-C** is used.
- **psbasemap**: Extended **-L** to allow alternate label and justification, and added **-T** for directional rose ornament or magnetic compass directions.
- **pscoast**: Extended **-L** to allow alternate label and justification, and added **-T** for directional rose ornament or magnetic compass directions.
- **pscontour**: Expanded the **-G** option to handle 5 algorithms (4 new) for the placement of contour labels.
- **psimage**: *PostScript* image interpolation (**-W-xlength**), and justification option in **-C**.
- **psscale**: Options to annotate on opposite side (**-A**) and to plot back or foreground triangle only (**-E[b|f]**). Also, draw discrete color-key table with centered annotations by appending an optional *gap* to the **-L** option.
- **pstext**: New option **-A** should azimuths rather than angles be given,
- **psxy**: Line color control (via **-C**), symbol position offset (with **-D**), custom symbols access (with **-Sk**; use any of the 35 (Appendix N) that come with *GMT* or design your own), many new symbols (horizontal and vertical dashes, pentagon, octagon, rectangle, double-headed and centered vectors), and annotated (“quoted”) lines with **-Sq**.

⁵Used to color the background, foreground, and Not-a-Number areas.

- **psxyz**: Same, plus a vertical dash symbol.
- **xyz2grd**: Added **-Au|l** for upper/lower value at each node.

General enhancements. These affect most of the programs:

- The coastline data have been updated to GSHHS version 1.3. About 50 or so polygons had lingering crossovers and some had duplicate points or failed to close; these have now been fixed. Major errors in the Puget Sound coastline have also been corrected.
- New shorthand to repeat the most recently used projection (**-J**).
- Options for phase-shifting the stride and supplying a prefix for frame annotations (**-B**).
- Override *GMT* defaults directly on the command line with any number of **—PAR=value** options.
- Now choose from 63 ellipsoids and 223 datums, or use your own values.
- Numerous new *GMT* defaults parameters, mostly in support of time-series functionality.
- Shorthand for global regions (**-Rg** for **-R0/360/-90/90** and **-Rd** for **-R-180/180/-90/90**).
- Full support for either RGB, HSV, or CMYK in pen/fill command-line options or in cpt files.
- Support for English color names (e.g., red, lightbrown).
- Choice of unit when specifying pen thickness (cm, inch, point).
- Easier pen specification mechanism, with predefined names for certain pen thicknesses.
- Centering of plots on current page with **-Xc**, **-Yc**.
- More control over input/output table formats (**-f**, **-:[i|o]**).
- Ability to read and write NOAA/NGDC GRD98 grid format.
- Ability to add additional fonts.
- Custom paper media size (useful for posters and large maps).
- All text are now justified by the *PostScript* interpreter, as is the clipping of contours and “quoted lines” to make space for annotation labels.
- Better support for various international character encodings.
- New Appendices M (color tables), N (custom symbols), O (contours and “quoted lines”), and P (using both *GMT* 3 and 4).
- New hidden files .gmtdefaults4 and .gmtcommands4 to ensure peaceful coexistence with *GMT* 3-series.
- Data files in directories pointed to by the three environmental parameters **\$GMT_DATADIR**, **\$GMT_GRIDDIR**, and **\$GMT_IMGDIR** can be specified without their full path names when used as input files.
- We have added five new examples for a total of 25.
- Bourne shell utility **gmtswitch** simplifies switching between installed *GMT* versions.

2. Introduction

Most scientists are familiar with the sequence: *raw data* \rightarrow *processing* \rightarrow *final illustration*. In order to finalize papers for submission to scientific journals, prepare proposals, and create overheads and slides for various presentations, many scientists spend large amounts of time and money to create camera-ready figures. This process can be tedious and is often done manually, since available commercial or in-house software usually can do only part of the job. To expedite this process we introduce the Generic Mapping Tools (*GMT* for short), which is a free¹, software package that can be used to manipulate columns of tabular data, time-series, and gridded data sets, and display these data in a variety of forms ranging from simple x - y plots to maps and color, perspective, and shaded-relief illustrations. *GMT* uses the *PostScript* page description language [Adobe Systems Inc., 1990]. With *PostScript*, multiple plot files can easily be superimposed to create arbitrarily complex images in gray tones or 24-bit true color. Line drawings, bitmapped images, and text can be easily combined in one illustration. *PostScript* plot files are device-independent: The same file can be printed at 300 dots per inch (dpi) on an ordinary laserwriter or at 2470 dpi on a phototypesetter when ultimate quality is needed. *GMT* software is written as a set of *UNIX* tools² and is totally self-contained and fully documented. The system is offered free of charge and is distributed over the computer network (Internet) [Wessel and Smith, 1991; 1995a,b; 1998].

The original version 1.0 of *GMT* was released in the summer of 1988 when the authors were graduate students at Lamont-Doherty Earth Observatory of Columbia University. During our tenure as graduate students, L-DEO changed its computing environment to a distributed network of *UNIX* workstations, and we wrote *GMT* to run in this environment. It became a success at L-DEO, and soon spread to numerous other institutions in the US, Canada, Europe, and Japan. The current version benefits from the many suggestions contributed by users of the earlier versions, and now includes more than 50 tools, more than 30 projections, and many other new, more flexible features. *GMT* provides scientists with a variety of tools for data manipulation and display, including routines to sample, filter, compute spectral estimates, and determine trends in time series, grid or triangulate arbitrarily spaced data, perform mathematical operations (including filtering) on 2-D data sets both in the space and frequency domain, sample surfaces along arbitrary tracks or onto a new grid, calculate volumes, and find trend surfaces. The plotting programs will let the user make linear, \log_{10} , and x^a - y^b diagrams, polar and rectangular histograms, maps with filled continents and coastlines choosing from many common map projections, contour plots, mesh plots, monochrome or color images, and artificially illuminated shaded-relief and 3-D perspective illustrations.

GMT is written in the highly portable ANSI C programming language [Kernighan and Ritchie, 1988], is fully POSIX compliant [Lewine, 1991], has no Year 2000 problems, and may be used with any hardware running some flavor of *UNIX*, possibly with minor modifications. In writing *GMT*, we have followed the modular design philosophy of *UNIX*: The *raw data* \rightarrow *processing* \rightarrow *final illustration* flow is broken down to a series of elementary steps; each step is accomplished by a separate *GMT* or *UNIX* tool. This modular approach brings several benefits: (1) only a few programs are needed, (2) each program is small and easy to update and maintain, (3) each step is independent of the previous step and the data type and can therefore be used in a variety of applications, and (4) the programs can be chained together in shell scripts or with pipes, thereby creating a process tailored to do a user-specific task. The decoupling of the data retrieval step from the subsequent massage and plotting is particularly important, since each institution will typically have its own data base formats. To use *GMT* with custom data bases, one has only to write a data extraction tool which will put out data in a form readable by *GMT* (discussed below). After writing the extractor, all other *GMT* modules will work as they are.

GMT makes full use of the *PostScript* page description language, and can produce color illustrations if a color *PostScript* device is available. One does not necessarily have to have access to a top-of-the-line color printer to take advantage of the color capabilities offered by *GMT*: Several companies offer imaging services where the customer provides a *PostScript* plot file and gets color slides or hardcopies in return. Furthermore, general-purpose *PostScript* raster image processors (RIPs) are now becoming available, letting the user create raster images from *PostScript* and plot these bitmaps on raster devices like computer

¹ See GNU General Public License (www.gnu.org/copyleft/gpl.html) for terms on redistribution and modifications.

² The tools can also be installed on other platforms (see Appendix L).

screens, dot-matrix printers, large format raster plotters, and film writers³. Because the publication costs of color illustrations are high, *GMT* offers 90 common bit and hatchure patterns, including many geologic map symbol types, as well as complete graytone shading operations. Additional bit and hatchure patterns may also be designed by the user. With these tools, it is possible to generate publication-ready monochrome originals on a common laserwriter.

GMT is thoroughly documented and comes with a technical reference and cookbook which explains the purpose of the package and its many features, and provides numerous examples to help new users quickly become familiar with the operation and philosophy of the system. The cookbook contains the shell scripts that were used for each example; *PostScript* files of each illustration are also provided. All programs have individual manual pages which can be installed as part of the on-line documentation under the *UNIX man* utility or as web pages. In addition, the programs offer friendly help messages which make them essentially self-teaching – if a user enters invalid or ambiguous command arguments, the program will print a warning to the screen with a synopsis of the valid arguments. All the documentation is available for web browsing and may be installed at the user's site.

The processing and display routines within *GMT* are completely general and will handle any (x,y) or (x,y,z) data as input. For many purposes the (x,y) coordinates will be (longitude, latitude) but in most cases they could equally well be any other variables (e.g., wavelength, power spectral density). Since the *GMT* plot tools will map these (x,y) coordinates to positions on a plot or map using a variety of transformations (linear, log-log, and several map projections), they can be used with any data that are given by two or three coordinates. In order to simplify and standardize input and output, *GMT* uses two file formats only. Arbitrary sequences of (x,y) or (x,y,z) data are read from multi-column ASCII tables, i.e., each file consists of several records, in which each coordinate is confined to a separate column⁴. This format is straightforward and allows the user to perform almost any simple (or complicated) reformatting or processing task using standard *UNIX* utilities such as **cut**, **paste**, **grep**, **sed** and **awk**. Two-dimensional data that have been sampled on an equidistant grid are read and written by *GMT* in a binary grid file using the functions provided with the netCDF library (a free, public-domain software library available separately from UCAR, the University Corporation of Atmospheric Research [Treinish and Gough, 1987]). This XDR (External Data Representation) based format is architecture independent, which allows the user to transfer the binary data files from one computer system to another⁵. *GMT* contains programs that will read ASCII (x,y,z) files and produce grid files. One such program, **surface**, includes new modifications to the gridding algorithm developed by Smith and Wessel [1990] using continuous splines in tension.

Most of the programs will produce some form of output, which falls into four categories. Several of the programs may produce more than one of these types of output:

1. 1-D ASCII Tables — For example, a (x,y) series may be filtered and the filtered values output. ASCII output is written to the standard output stream.
2. 2-D binary (netCDF or user-defined) grid files – Programs that grid ASCII (x,y,z) data or operate on existing grid files produce this type of output.
3. *PostScript* – The plotting programs all use the *PostScript* page description language to define plots. These commands are stored as ASCII text and can be edited should you want to customize the plot beyond the options available in the programs themselves.
4. Reports – Several *GMT* programs read input files and report statistics and other information. Nearly all programs have an optional “verbose” operation, which reports on the progress of computation. All programs feature usage messages, which prompt the user if incorrect commands have been given. Such text is written to the standard error stream and can therefore be separated from ASCII table output.

GMT is available over the Internet at no charge. To obtain a copy, read the relevant information on the *GMT* home page gmt.soest.hawaii.edu, or email listserv@hawaii.edu a note containing the single message

³One public-domain RIP is **ghostscript**, available from www.gnu.org.

⁴Programs now also allow for fast, binary multicolumn file i/o.

⁵While the netCDF format is the default, other formats are also possible, including user-defined formats.

information gmt-group

The listserver will mail you back a shell-script that you may run to obtain all necessary programs, libraries, and support data. After you obtain the *GMT* archive, you will find that it contains information on how to install *GMT* on your hardware platform and how to obtain additional files that you may need or want. The archive also contains a license agreement and registration file. We also maintain two electronic mailing lists you may subscribe to in order to stay informed about bug fixes and upgrades (See Chapter 7).

For those without net-access that need to obtain *GMT*: Geoware (<http://www.geoware-online.com>) makes and distributes CD-R and DVD-R media with the *GMT* package, compatible supplements, and several Gb of useful Earth and ocean science data sets. For more information send e-mail to geoware@geoware-online.com.

GMT has served a multitude of scientists very well, and their responses have prompted us to develop these programs even further. It is our hope that the new version will satisfy these users and attract new users as well. We present this system to the community in order to promote sharing of research software among investigators in the US and abroad.

References

1. Kernighan, B. W., and D. M. Ritchie, *The C programming language*, 2nd edition, p. 272, Prentice-Hall, Englewood Cliffs, New Jersey, 1988.
2. Adobe Systems Inc., *PostScript Language Reference Manual*, 2nd edition, p. 764, Addison-Wesley, Reading, Massachusetts, 1990.
3. Lewine, D., *POSIX programmer's guide*, 1st edition, p. 607, O'Reilly & Associates, Sebastopol, California, 1991.
4. Treinish, L. A., and M. L. Gough, A software package for the data-independent management of multi-dimensional data, *EOS trans. AGU*, 68, 633–635, 1987.
5. Smith, W. H. F., and P. Wessel, Gridding with continuous curvature splines in tension, *Geophysics*, 55, 293–305, 1990.
6. Wessel, P., and W. H. F. Smith, New, improved version of Generic Mapping Tools released, *EOS trans. AGU*, 79, 579, 1998.
7. Wessel, P., and W. H. F. Smith, New version of the Generic Mapping Tools released, *EOS trans. AGU*, 76, 329, 1995a.
8. Wessel, P., and W. H. F. Smith, New version of the Generic Mapping Tools released, *EOS electronic supplement*, http://www.agu.org/eos_elec/95154e.html, 1995b.
9. Wessel, P., and W. H. F. Smith, Free software helps map and display data, *EOS trans. AGU*, 72, 441 & 445–446, 1991.

3. GMT overview and quick reference

3.1 GMT summary

The following is a summary of all the programs supplied with *GMT* and a very short description of their purpose. For more details, see the individual *UNIX* manual pages or the online web documentation. For a listing sorted by program purpose, see Section 3.2.

blockmean	L_2 (x,y,z) table data filter/decimator
blockmedian	L_1 (x,y,z) table data filter/decimator
blockmode	Mode estimate (x,y,z) table data filter/decimator
filter1d	Filter 1-D table data sets (time series)
fitcircle	Finds the best-fitting great or small circle for a set of points
gmt2rgb	Convert Sun raster or grid file to red, green, blue component grids
gmtconvert	Convert data tables from one format to another
gmtdefaults	List the current default settings
gmtmath	Mathematical operations on table data
gmtselect	Select subsets of table data based on multiple spatial criteria
gmtset	Change selected parameters in current <code>.gmtdefaults4</code> file
grd2cpt	Make color palette table from a grid files
grd2xyz	Conversion from 2-D grid file to table data
grdblend	Blend several partially over-lapping grid files onto one grid
grdclip	Limit the z-range in gridded data sets
grdcontour	Contouring of 2-D gridded data sets
grdcut	Cut a sub-region from a grid file
grdedit	Modify header information in a 2-D grid file
grdfft	Perform operations on grid files in the frequency domain
grdfilter	Filter 2-D gridded data sets in the space domain
grdgradient	Compute directional gradient from grid files
grdhisteq	Histogram equalization for grid files
grdimage	Produce images from 2-D gridded data sets
grdinfo	Get information about grid files
grdlandmask	Create masking grid files from shoreline data base
grdmask	Reset grid nodes in/outside a clip path to constants
grdmath	Mathematical operations on grid files
grdpaste	Paste together grid files along a common edge
grdproject	Project gridded data sets onto a new coordinate system
grdreformat	Converts grid files into other grid formats
grdsample	Resample a 2-D gridded data set onto a new grid
grdtrack	Sampling of 2-D gridded data set along 1-D track
grdtrend	Fits polynomial trends to grid files
grdvector	Plotting of 2-D gridded vector fields
grdview	3-D perspective imaging of 2-D gridded data sets
grdvolume	Calculate volumes under a surface within specified contour
greenspline	Interpolation using Green's functions for splines in 1–3 dimensions
makecpt	Make color palette tables
mapproject	Transformation of coordinate systems for table data
minmax	Report extreme values in table data files
nearestneighbor	Nearest-neighbor gridding scheme
project	Project table data onto lines or great circles
ps2raster	Crop and convert PostScript files to raster images, EPS, and PDF
psbasemap	Create a basemap plot
psclip	Use polygon files to define clipping paths

pscoast	Plot (and fill) coastlines, borders, and rivers on maps
pscontour	Contour or image raw table data by triangulation
pshistogram	Plot a histogram
psimage	Plot Sun raster files on a map
pslegend	Plot a legend on a map
psmask	Create overlay to mask out regions on maps
psrose	Plot sector or rose diagrams
psscale	Plot gray scale or color scale on maps
pstext	Plot text strings on maps
pswiggle	Draw table data time-series along track on maps
psxy	Plot symbols, polygons, and lines on maps
psxyz	Plot symbols, polygons, and lines in 3-D
sample1d	Resampling of 1-D table data sets
spectrum1d	Compute various spectral estimates from time-series
splitxyz	Split <i>xyz</i> files into several segments
surface	A continuous curvature gridding algorithm
trend1d	Fits polynomial or Fourier trends to $y = f(x)$ series
trend2d	Fits polynomial trends to $z = f(x, y)$ series
triangulate	Perform optimal Delauney triangulation and gridding
xyz2grd	Convert an equidistant table <i>xyz</i> file to a 2-D grid file

3.2 GMT quick reference

Instead of an alphabetical listing, this section contains a summary sorted by program purpose. Also included is a quick summary of the standard command line options and a breakdown of the **-J** option for each of the over 30 projections available in *GMT*.

FILTERING OF 1-D AND 2-D DATA

blockmean	L_2 estimate (x, y, z) data filters/decimators
blockmedian	L_1 estimate (x, y, z) data filters/decimators
blockmode	Mode estimate (x, y, z) data filters/decimators
filter1d	Filter 1-D data (time series)
grdfilter	Filter 2-D data in space domain

PLOTTING OF 1-D and 2-D DATA

grdcontour	Contouring of 2-D gridded data
grdimage	Produce images from 2-D gridded data
grdvector	Plot vector fields from 2-D gridded data
grdview	3-D perspective imaging of 2-D gridded data
psbasemap	Create a basemap frame
psclip	Use polygon files as clipping paths
pscoast	Plot coastlines, filled continents, rivers, and political borders
pscontour	Direct contouring or imaging of <i>xyz</i> data by triangulation
pshistogram	Plot a histogram
psimage	Plot Sun raster files on a map
pslegend	Plot a legend on a map
psmask	Create overlay to mask specified regions of a map
psrose	Plot sector or rose diagrams
psscale	Plot gray scale or color scale
pstext	Plot text strings
pswiggle	Draw anomalies along track
psxy	Plot symbols, polygons, and lines in 2-D
psxyz	Plot symbols, polygons, and lines in 3-D

GRIDDING OF (X,Y,Z) TABLE DATA

greenspline	Interpolation using Green's functions for splines in 1–3 dimensions
nearneighbor	Nearest-neighbor gridding scheme
surface	Continuous curvature gridding algorithm
triangulate	Perform optimal Delauney triangulation on xyz data

SAMPLING OF 1-D AND 2-D DATA

grdsample	Resample a 2-D gridded data onto new grid
grdtrack	Sampling of 2-D data along 1-D track
sample1d	Resampling of 1-D data

PROJECTION AND MAP-TRANSFORMATION

grdproject	Transform gridded data to a new coordinate system
mapproject	Transform table data to a new coordinate system
project	Project data onto lines or great circles

INFORMATION

gmtdefaults	List the current default settings
gmtset	Command-line editing of parameters in the .gmtdefaults4 file
grdinfo	Get information about the content of grid files
minmax	Report extreme values in table data files

MISCELLANEOUS

gmtmath	Reverse Polish Notation (RPN) calculator for table data
makecpt	Create GMT color palette tables
spectrum1d	Compute spectral estimates from time-series
triangulate	Perform optimal Delauney triangulation on xyz data

CONVERT OR EXTRACT SUBSETS OF DATA

gmt2rgb	Convert Sun raster or grid file to red, green, blue component grids
gmtconvert	Convert table data from one format to another
gmtselect	Select table data subsets based on multiple spatial criteria
grd2xyz	Convert 2-D gridded data to table data
grdcut	Cut a sub-region from a grid file
grdblend	Blend several partially over-lapping grid files onto one grid
grdpaste	Paste together grid files along common edge
grdreformat	Convert from one grid format to another
splitxyz	Split (x,y,z) table data into several segments
xyz2grd	Convert table data to 2-D grid file

DETERMINE TRENDS IN 1-D AND 2-D DATA

fitcircle	Finds best-fitting great or small circles
grdtrend	Fits polynomial trends to grid files ($z = f(x,y)$)
trend1d	Fits polynomial or Fourier trends to $y = f(x)$ series
trend2d	Fits polynomial trends to $z = f(x,y)$ series

OTHER OPERATIONS ON 2-D GRIDS

grd2cpt	Make color palette table from grid file
grdclip	Limit the z-range in gridded data sets
grdedit	Modify grid header information
grdfft	Operate on grid files in frequency domain
grdgradient	Compute directional gradients from grid files
grdhisteq	Histogram equalization for grid files
grdlandmask	Creates mask grid file from coastline database
grdmask	Set grid nodes in/outside a clip path to constants
grdmath	Reverse Polish Notation (RPN) calculator for grid files
grdvolume	Calculate volume under a surface within a contour

MANIPULATING GMT POSTSCRIPT FILES

ps2raster	Crop and convert PostScript files to raster images, EPS and PDF
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STANDARDIZED COMMAND LINE OPTIONS WITH OLD PROJECTION CODES

-B [p s]xinfo[/yinfo[/zinfo]][WESNZwesnz+][.title:]	Tickmarks. Each <i>info</i> is [t]stride[±phase][u][l p][:."label":][:="prefix":][:,"unit":], where l and p apply to log ₁₀ axes only, and type t = { a , A , f , g , i , I }; unit u = { c , C , d , D , h , H , K , k , m , M , o , O , r , R , u , U , y , Y } The leading p s selects primary [Default] or secondary axis items
-H [i][n_headers]	ASCII [input] tables have header record[s]
-J (upper case for <i>width</i> , lower case for <i>scale</i>)	Map projection
-JA lon ₀ /lat ₀ /[/horizon]/width	Lambert azimuthal equal area
-JB lon ₀ /lat ₀ /lat ₁ /lat ₂ /width	Albers conic equal area
-JC lon ₀ /lat ₀ /width	Cassini cylindrical
-JCyl_stere [lon ₀ /[/lat ₀ /]]width	Cylindrical stereographic
-JD lon ₀ /lat ₀ /lat ₁ /lat ₂ /width	Equidistant conic
-JE lon ₀ /lat ₀ /[/horizon]/width	Azimuthal equidistant
-JF lon ₀ /lat ₀ /[/horizon]/width	Azimuthal gnomonic
-JG lon ₀ /lat ₀ /[/horizon]/width	Azimuthal orthographic
-JG lon ₀ /lat ₀ /alt/lazim/tilt/twist/W/H/width	General perspective
-JH [lon ₀ /width	Hammer equal area
-JI [lon ₀ /width	Sinusoidal equal area
-JJ [lon ₀ /width	Miller cylindrical
-JKf [lon ₀ /width	Eckert IV equal area
-JKs [lon ₀ /width	Eckert VI equal area
-JL lon ₀ /lat ₀ /lat ₁ /lat ₂ /width	Lambert conic conformal
-JM [lon ₀ /[/lat ₀ /]]width	Mercator cylindrical
-JN [lon ₀ /width	Robinson
-JOa lon ₀ /lat ₀ /azim/width	Oblique Mercator, 1: origin and azimuth
-JOB lon ₀ /lat ₀ /lon ₁ /lat ₁ /width	Oblique Mercator, 2: two points
-JOc lon ₀ /lat ₀ /lon _p /lat _p /width	Oblique Mercator, 3: origin and pole
-JP [a]width[/origin]	Polar [azimuthal] (θ, r) (or cylindrical)
-JQ [lon ₀ /[/lat ₀ /]]width	Equidistant cylindrical
-JR [lon ₀ /width	Winkel Tripel
-JS lon ₀ /lat ₀ /[/horizon]/width	General stereographic
-JT lon ₀ /[/lat ₀ /width	Transverse Mercator
-JU zone/width	Universal Transverse Mercator (UTM)
-JV [lon ₀ /width	Van der Grinten
-JW [lon ₀ /width	Mollweide
-JX width[l pexp T t [/height[l pexp T t][d]	Linear, log ₁₀ , $x^a - y^b$, and time
-JY lon ₀ /lat ₀ /width	Cylindrical equal area
-K	Append more PS later
-O	This is an overlay plot
-P	Select Portrait orientation
-R west/east/south/north[/zmin/zmax][r]	Specify Region of interest
-U [[/just]/dx/dy/][label]	Plot time-stamp on plot
-V	Run in verbose mode
-X [a c r]off[u]	Shift plot origin in x-direction
-Y [a c r]off[u]	Shift plot origin in y-direction
-b [i o][c s S d D][ncol]	Select binary input or output
-ccopies	Set number of plot copies [1]
-f [i o]colinfo	Set formatting of ASCII input or output
-g [+ x X y Y d D]gap[u]	Segment data by detecting gaps
-m [i o]flag	Set multi-segment data mode
-: [i o]	Expect y/x input rather than x/y

STANDARDIZED COMMAND LINE OPTIONS (WITH *Proj4* PROJECTION CODES)

-B [p s]xinfo[/yinfo[/zinfo]][WESNZwesnz+][.title:]	Tickmarks. Each <i>info</i> is [t]stride[±phase][u][l p][:label:][:prefix:][:unit:], where l and p apply to \log_{10} axes only, and type t = { a , A , f , g , i , I }; unit u = { c , C , d , D , h , H , K , k , m , M , o , O , r , R , u , U , y , Y } The leading p s selects primary [Default] or secondary axis items
-H [i][n_headers]	ASCII [input] tables have header record[s]
-J (upper case for <i>width</i> , lower case for <i>scale</i>)	Map projection
-Jaea /lon ₀ /lat ₀ /lat ₁ /lat ₂ /scale	Albers conic equal area
-Jaeqd /lon ₀ /lat ₀ /[horizon]/scale	Azimuthal equidistant
-Jcass /lon ₀ /lat ₀ /scale	Cassini cylindrical
-Jcea /lon ₀ /lat ₀ /scale	Cylindrical equal area
-Jcyl.stere /[lon ₀ /[lat ₀]]/scale	Cylindrical stereographic
-Jeqc /[lon ₀ /[lat ₀]]/scale	Equidistant cylindrical
-Jeqdc /lon ₀ /lat ₀ /lat ₁ /lat ₂ /scale	Equidistant conic
-Jgnom /lon ₀ /lat ₀ /[horizon]/scale	Azimuthal gnomonic
-Jhammer /[lon ₀]/scale	Hammer equal area
-Jeck4 /[lon ₀]/scale	Eckert IV equal area
-Jeck6 /[lon ₀]/scale	Eckert VI equal area
-Jlaea /lon ₀ /lat ₀ /[horizon]/scale	Lambert azimuthal equal area
-Jlcc /lon ₀ /lat ₀ /lat ₁ /lat ₂ /scale	Lambert conic conformal
-Jmerc /[lon ₀ /[lat ₀]]/scale	Mercator cylindrical
-Jmill /[lon ₀]/scale	Miller cylindrical
-Jmoll /[lon ₀]/scale	Mollweide
-Jnsper /lon ₀ /lat ₀ /alt/azim/tilt/twist/W/H/scale	General perspective
-Jomerc /lon ₀ /lat ₀ /azim/scale	Oblique Mercator, 1: origin and azimuth
-Jomerc /lon ₀ /lat ₀ /lon ₁ /lat ₁ /scale	Oblique Mercator, 2: two points
-Jomercp /lon ₀ /lat ₀ /lon _p /lat _p /scale	Oblique Mercator, 3: origin and pole
-Jortho /lon ₀ /lat ₀ /[horizon]/scale	Azimuthal orthographic
-Jpolar /[a]scale/[origin]	Polar [azimuthal] (θ, r) (or cylindrical)
-Jrobin /[lon ₀]/scale	Robinson
-Jsinu /[lon ₀]/scale	Sinusoidal equal area
-Jstere /lon ₀ /lat ₀ /[horizon]/scale	General stereographic
-Jtmerc /lon ₀ /[lat ₀]/scale	Transverse Mercator
-Jutm /zone/scale	Universal Transverse Mercator (UTM)
-Jvandg /[lon ₀]/scale	Van der Grinten
-Jwintri /[lon ₀]/scale	Winkel Tripel
-Jxy /xscale[l pexp T t]/yscale[l pexp T t][d]	Linear, \log_{10} , $x^a - y^b$, and time
-K	Append more PS later
-O	This is an overlay plot
-P	Select Portrait orientation
-R west/east/south/north[/zmin/zmax][r]	Specify Region of interest
-U [[just]/dx/dy][label]	Plot time-stamp on plot
-V	Run in verbose mode
-X [a c r]off[u]	Shift plot origin in x-direction
-Y [a c r]off[u]	Shift plot origin in y-direction
-b [i o][c s S d D][ncol]	Select binary input or output
-ccopies	Set number of plot copies [1]
-f [i o]colinfo	Set formatting of ASCII input or output
-g [+ x X y Y d D]gap[u]	Segment data by detecting gaps
-m [i o]flag	Set multi-segment data mode
-: [i o]	Expect y/x input rather than x/y

4. General features

This section explains features common to all the programs in *GMT* and summarizes the philosophy behind the system. Some of the features described here may make more sense once you reach the cook-book section where we present actual examples of their use.

4.1 GMT units

GMT programs can accept dimensional quantities in **cm**, **inch**, **meter**, or **point** (1/72 of an inch)¹. There are two ways to ensure that *GMT* understands which unit you intend to use.

1. Append the desired unit to the dimension you supply. This way is explicit and clearly communicates what you intend, e.g., **-X4c** means the length being passed to the **-X** switch is 4 cm.
2. Set the parameter **MEASURE_UNIT** to the desired unit. Then, all dimensions without explicit unit will be interpreted accordingly.

The latter method is less secure as other users may have a different unit set and your script may not work as intended. We therefore recommend you always supply the desired unit explicitly.

4.2 GMT defaults

4.2.1 Overview and the `.gmtdefaults4` file

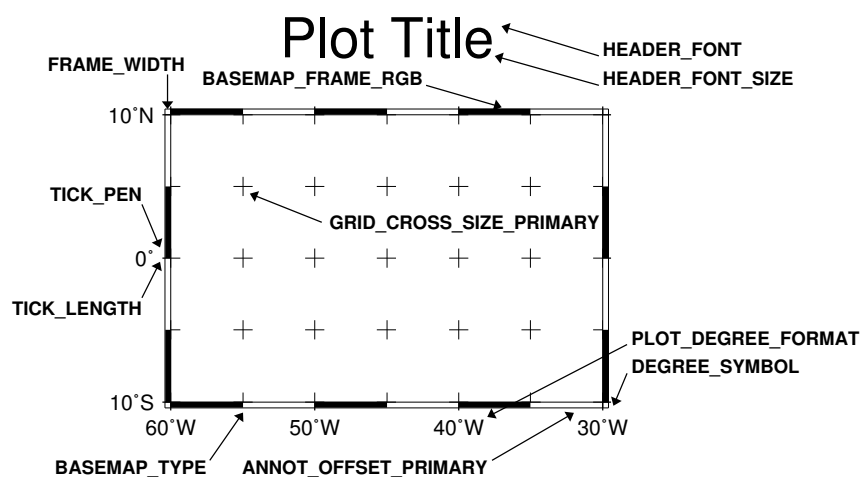


Figure 4.1: Some **GMT** parameters that affect plot appearance.

There are about 100 parameters which can be adjusted individually to modify the appearance of plots or affect the manipulation of data. When a program is run, it initializes all parameters to the *GMT* defaults², then tries to open the file `.gmtdefaults4` in the current directory³. If not found, it will look for that file in a sub-directory `~/.gmt` of your home directory, and finally in your home directory itself. If successful, the program will read the contents and set the default values to those provided in the file. By editing this file you can affect features such as pen thicknesses used for maps, fonts and font sizes used for annotations and labels, color of the pens, dots-per-inch resolution of the hardcopy device, what type of spline interpolant

¹ *PostScript* definition. In the typesetting industry a slightly different definition of point (1/72.27 inch) is used.

² Choose between SI and US default units by modifying `gmt.conf` in the *GMT* share directory.

³ To remain backwards compatible with *GMT* 3.4.x we will also look for `.gmtdefaults` but only if `.gmtdefaults4` cannot be found.

to use, and many other choices (A complete list of all the parameters and their default values can be found in the **gmtdefaults** manual pages). Figures 4.1, 4.2, and 4.3 show the parameters that affect plots). You may create your own `.gmtdefaults4` files by running **gmtdefaults** and then modify those parameters you want to change. If you want to use the parameter settings in another file you can do so by specifying `+<defaultfile>` on the command line. This makes it easy to maintain several distinct parameter settings, corresponding perhaps to the unique styles required by different journals or simply reflecting font changes necessary to make readable overheads and slides. Note that any arguments given on the command line (see below) will take precedent over the default values. E.g., if your `.gmtdefaults4` file has `x offset = 1i` as default, the `-X1.5i` option will override the default and set the offset to 1.5 inches.

There are at least two good reasons why the *GMT* default options are placed in a separate parameter file:

1. It would not be practical to allow for command-line syntax covering so many options, many of which are rarely or never changed (such as the ellipsoid used for map projections).
2. It is convenient to keep separate `.gmtdefaults4` files for specific projects, so that one may achieve a special effect simply by running *GMT* commands in the directory whose `.gmtdefaults4` file has the desired settings. For example, when making final illustrations for a journal article one must often standardize on font sizes and font types, etc. Keeping all those settings in a separate `.gmtdefaults4` file simplifies this process and will allow you to generate those illustrations with the same settings later on. Likewise, *GMT* scripts that make figures for PowerPoint presentations often use a different color scheme and font size than output intended for laser printers. Organizing these various scenarios into separate `.gmtdefaults4` files will minimize headaches associated with micro-editing of illustrations.

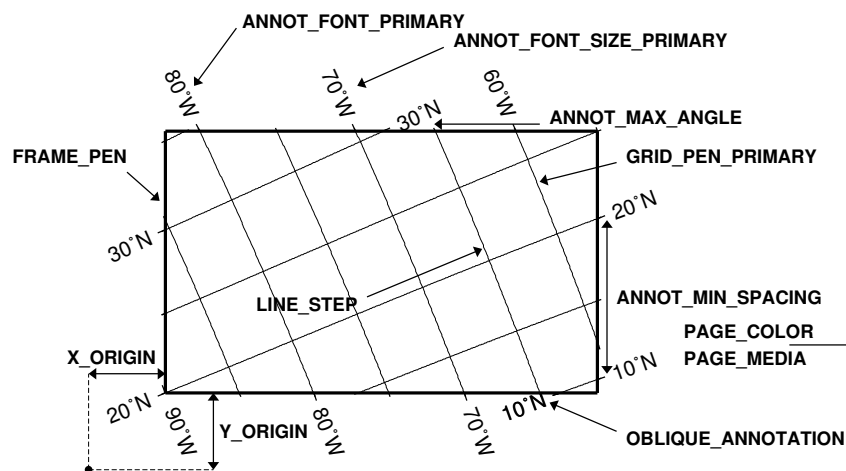


Figure 4.2: More **GMT** parameters that affect plot appearance.

4.2.2 Changing GMT defaults

As mentioned, *GMT* programs will attempt to open a file named `.gmtdefaults4`. At times it may be desirable to override that default. There are several ways in which this can be accomplished.

1. Supply another filename using the `+filename` syntax, i.e., on the same command line as the *GMT* command we append the name of the alternate `.gmtdefaults4` file with the plus sign as a prefix. Because any changes only apply to that one command you would have to append the alternate file to every command in your script. This is tedious but may be an option for situations when you cannot write in the current directory (e.g., some CGI scripts).
2. A perhaps less tedious method is to start each script by making a copy of the current `.gmtdefaults4`, then copy the desired `.gmtdefaults4` file to the current directory, and finally undo the changes at the end of

the script. Possible side effects include premature ending of the script due to user error or bugs which means the final resetting does not take place (unless you write your script very carefully.)

3. To permanently change some of the *GMT* parameters on the fly inside a script the **gmtset** utility can be used. E.g., to change the primary annotation font to 12 point Times-Bold we run

```
gmtset ANNOT_FONT_PRIMARY Times-Bold ANNOT_FONT_SIZE_PRIMARY 12
```

These changes will remain in effect until they are overridden.

4. If all you want to achieve is to change a few parameters during the execution of a single command but otherwise leave the environment intact, consider passing the parameter changes on the command line via the `—PAR=value` mechanism. For instance, to temporarily set the output format for floating points to have lots of decimals, say, for map projection coordinate output, append `—D_FORMAT=% .12lg` to the command in question.
5. Finally, since version 4.2.2 *GMT* provides to possibility to override the settings only during the running of a single script, reverting to the original settings after the script is run, as if the script was run in “isolation”. The isolation mode is discussed in Section P.1.

In addition to those parameters that directly affect the plot there are numerous parameters than modify units, scales, etc. For a complete listing, see the **gmtdefaults** man pages. We suggest that you go through all the available parameters at least once so that you know what is available to change via one of the described mechanisms.

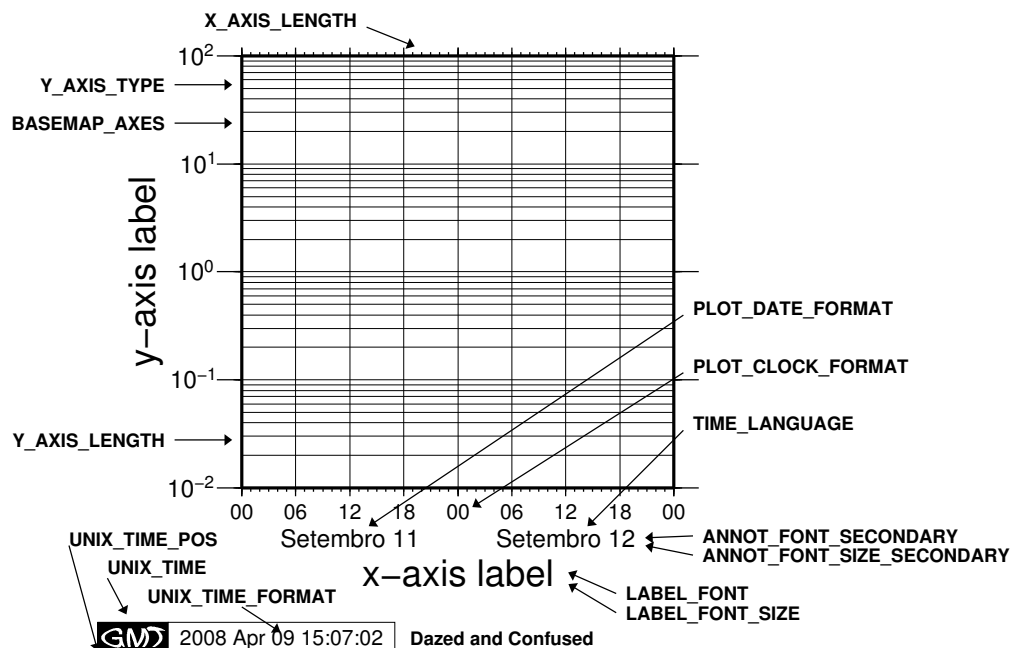


Figure 4.3: Even more **GMT** parameters that affect plot appearance.

Note: All examples presented in this document started by copying the file `.gmtdefaults4.doc` from the directory `doc/scripts` to `.gmtdefaults4`. As a result the commands **gmtset** of other scripts were overall, reverting to a “virgin” of parameters set in `.gmtdefaults4.doc`. The graphs in Chapter 7 were created using `.gmtdefaults4.doc` from the directory `examples` after which the graphs were scaled down by 50%.

<i>Option</i>	<i>Meaning</i>
-B	Defines tickmarks, annotations, and labels for basemaps and axes
-H	Specifies that input/output tables have header record(s)
-J	Selects a map projection or coordinate transformation
-K	Allows more plot code to be appended to this plot later
-O	Allows this plot code to be appended to an existing plot
-P	Selects Portrait plot orientation [Default is landscape]
-R	Defines the extent of the map/plot region
-U	Plots a time-stamp, by default in the lower left corner of page
-V	Selects verbose operation; reporting on progress
-X	Sets the <i>x</i> -coordinate for the plot origin on the page
-Y	Sets the <i>y</i> -coordinate for the plot origin on the page
-b	Selects binary input and/or output
-c	Specifies the number of plot copies
-f	Specifies the data format on a per column basis
-g	Identify data gaps based on supplied criteria
-m	Specifies data in multiple segment format
-:	Assumes input geographic data are (<i>lat,lon</i>) and not (<i>lon,lat</i>)

Table 4.1: The 17 standardized **GMT** command line switches.

4.3 Command line arguments

Each program requires certain arguments specific to its operation. These are explained in the manual pages and in the usage messages. Most programs are “case-sensitive”; almost all options must start with an upper-case letter. We have tried to choose letters of the alphabet which stand for the argument so that they will be easy to remember. Each argument specification begins with a hyphen (except input file names; see below), followed by a letter, and sometimes a number or character string immediately after the letter. *Do not* space between the hyphen, letter, and number or string. *Do* space between options. Example:

```
pscoast -R0/20/0/20 -Ggray -JM6i -Wthin -B5 -V -P > map.ps
```

4.4 Standardized command line options

Most of the programs take many of the same arguments like those related to setting the data region, the map projection, etc. The 17 switches in Table 4.1 have the same meaning in all the programs (although some programs may not use all of them). These options will be described here as well as in the manual pages, as is vital that you understand how to use these options. We will present these options in order of importance (some are use a lot more than others).

4.4.1 Data domain or map region: The **-R** option

The **-R** option defines the map region or data domain of interest. It may be specified in one of three ways (Figure 4.4):

1. **-Rxmin/xmax/ymin/ymax**. This is the standard way to specify Cartesian data domains and geographical regions when using map projections where meridians and parallels are rectilinear.
2. **-Rxlleft/ylleft/xuright/yurightr**. This form is used with map projections that are oblique, making meridians and parallels poor choices for map boundaries. Here, we instead specify the lower left corner and upper right corner geographic coordinates, followed by the suffix **r**.

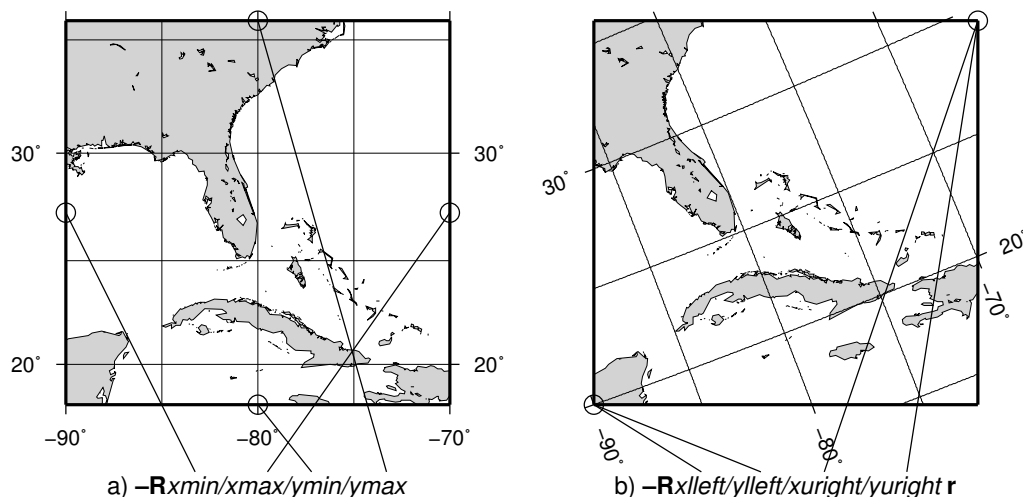


Figure 4.4: The plot region can be specified in two different ways. (a) Extreme values for each dimension, or (b) coordinates of lower left and upper right corners.

3. **$-R_{gridfile}$.** This will copy the domain settings found for the grid in specified file. Note that depending on the nature of the calling program, this mechanism will also set grid spacing and possibly the grid registration (see Appendix B.2.2).

For rectilinear projections the first two forms give identical results. Depending on the selected map projection (or the kind of expected input data), the boundary coordinates may take on three different formats:

Geographic coordinates: These are longitudes and latitudes and may be given in decimal degrees (e.g., -123.45417) or in the $[\pm]ddd[:mm[:ss[:.xxx]]][W|E|S|N]$ format (e.g., 123:27:15W). Note that **$-R_g$** and **$-R_d$** are shorthands for “global domain” **$-R_0/360/-90/90$** and **$-R_{-180/180/-90/90}$** , respectively.

When used in conjunction with the Cartesian Linear Transformation (**$-J_x$** or **$-J_X$**)—which can be used to map floating point data, geographical coordinates, as well as time coordinates—it is prudent to indicate that you are using geographical coordinates in one of the following ways:

- Use **$-R_g$** or **$-R_d$** to indicate the global domain.
- Use **$-R_{gxmin/xmax/ymin/ymax}$** to indicate a limited geographic domain.
- Add **W**, **E**, **S**, or **N** to the coordinate limits or add the generic **D** or **G**. Example: **$-R_0/360G/-90/90N$** .

Calendar time coordinates: These are absolute time coordinates referring to a Gregorian or ISO calendar. The general format is $[date]T[clock]$, where *date* must be in the $yyyy[-mm[-dd]]$ (year, month, day-of-month) or $yyyy[-jjj]$ (year and day-of-year) for Gregorian calendars and $yyyy[-Www[-d]]$ (year, week, and day-of-week) for the ISO calendar. If no *date* is given we assume the present day. Following the [optional] *date* string we require the **T** flag.

The optional *clock* string is a 24-hour clock in $hh[:mm[:ss[:.xxx]]]$ format. If no *clock* is given it implies 00:00:00, i.e., the start of the specified day. Note that not all of the specified entities need be present in the data. All calendar date-clock strings are internally represented as double precision seconds since proleptic Gregorian date Mon Jan 1 00:00:00 0001. Proleptic means we assume that the modern calendar can be extrapolated forward and backward; a year zero is used, and Gregory’s reforms⁴ are

⁴The Gregorian Calendar is a revision of the Julian Calendar which was instituted in a papal bull by Pope Gregory XIII in 1582. The reason for the calendar change was to correct for drift in the dates of significant religious observations (primarily Easter) and to prevent further drift in the dates. The important effects of the change were (a) Drop 10 days from October 1582 to realign the Vernal Equinox with 21 March, (b) change leap year selection so that not all years ending in “00” are leap years, and (c) change the beginning of the year to 1 January from 25 March. Adoption of the new calendar was essentially immediate within Catholic countries. In the Protestant countries, where papal authority was neither recognized nor appreciated, adoption came more slowly. England finally adopted the new calendar in 1752, with eleven days removed from September. The additional day came because the old and new calendars disagreed on whether 1700 was a leap year, so the Julian calendar had to be adjusted by one more day.

extrapolated backward. Note that this is not historical.

Relative time coordinates: These are coordinates which count seconds, hours, days or years relative to a given epoch. A combination of the parameters **TIME.EPOCH** and **TIME.UNIT** define the epoch and time unit. The parameter **TIME.SYSTEM** provides a few shorthands for common combinations of epoch and unit, like **j2000** for days since noon of 1 Jan 2000. Denote relative time coordinates by appending the optional lower case **t** after the value. When it is otherwise apparent that the coordinate is relative time (for example by using the **-f** switch), the **t** can be omitted.

Other coordinates: These are simply any coordinates that are not related to geographic or calendar time or relative time and are expected to be simple floating point values such as $[\pm].xxx.xxx[E|e|D|d][\pm]xx$, i.e., regular or exponential notations, with the enhancement to understand FORTRAN double precision output which may use D instead of E for exponents. These values are simply converted as they are to internal representation.⁵

4.4.2 Coordinate transformations and map projections: The **-J** option

This option selects the coordinate transformation or map projection. The general format is

- **-J δ [parameters]/scale**. Here, δ is a *lower-case* letter of the alphabet that selects a particular map projection, the *parameters* is zero or more slash-delimited projection parameter, and *scale* is map scale given in distance units per degree or as 1:xxxxx.
- **-J Δ [parameters]/width**. Here, Δ is an *upper-case* letter of the alphabet that selects a particular map projection, the *parameters* is zero or more slash-delimited projection parameter, and *width* is map width (map height is automatically computed from the implied map scale and region).

Since *GMT* version 4.3.0, there is an alternative way to specify the projections: use the same abbreviation as in the mapping package **Proj4**. The options thus either look like:

- **-Jabbrev/[parameters]/scale**. Here, **abbrev** is a *lower-case* abbreviation that selects a particular map projection, the *parameters* is zero or more slash-delimited projection parameter, and *scale* is map scale given in distance units per degree or as 1:xxxxx.
- **-JAbbrev/[parameters]/width**. Here, **Abbrev** is an *capitalized* abbreviation that selects a particular map projection, the *parameters* is zero or more slash-delimited projection parameter, and *width* is map width (map height is automatically computed from the implied map scale and region).

The projections available in *GMT* are presented in Figure 4.5. For details on all *GMT* projections and the required parameters, see the **psbasemap** man page. We will also show examples of every projection in the next Chapters, and a quick summary of projection syntax was given in Chapter 3.

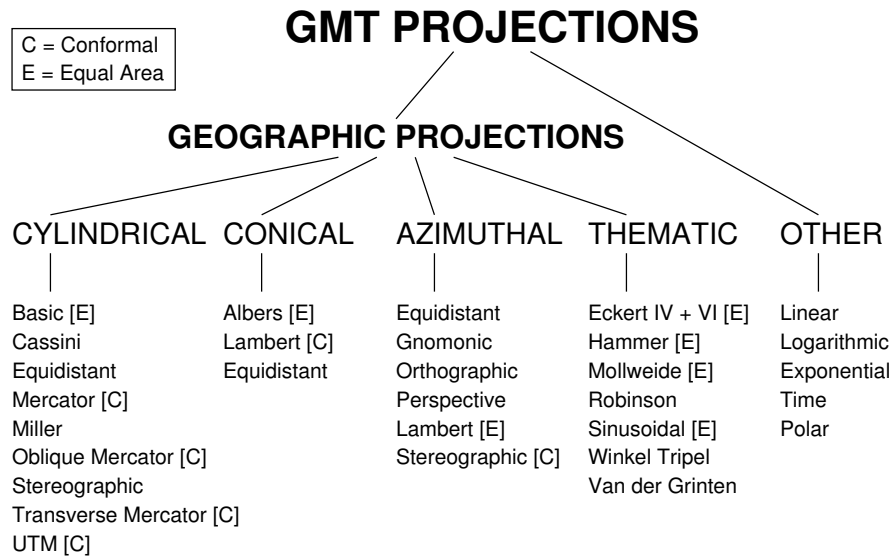
4.4.3 Map frame and axes annotations: The **-B** option

This is by far the most complicated option in *GMT*, but most examples of its usage are actually quite simple. Given as **-B[p|s]xinfo[/yinfo[/zinfo]][:"title string":][W|w][E|e][S|s][N|n][Z|z[+]]**, this switch specifies map boundaries (or plot axes) to be plotted by using the selected information. The optional flag following **-B** selects **p**(rimary) [Default] or **s**(econdary) axes information (mostly used for time axes annotations; see examples below). The components *xinfo*, *yinfo* and *zinfo* are of the form

info[:"axis label":][:="prefix":][:,"unit label":]

where *info* is one or more concatenated substrings of the form **[t]stride[\pm phase][u]**. The **t** flag sets the axis item of interest; the available items are listed in Table 4.2. By default, all 4 map boundaries (or plot

⁵While UTM coordinates clearly refer to points on the Earth, in this context they are considered “other”. Thus, when we refer to “geographical” coordinates herein we imply longitude, latitude.

Figure 4.5: The 30+ map projections and coordinate transformations available in **GMT**.

axes) are plotted (denoted **W**, **E**, **S**, **N**). To change this selection, append the codes for those you want (e.g., **WSn**). Upper case (e.g., **W**) will annotate in addition to draw axis/tick-marks. The title, if given, will appear centered above the plot⁶. Unit label or prefix may start with a leading – to suppress the space between it and the annotation. Normally, equidistant annotations occur at multiples of *stride*; you can phase-shift this by appending $\pm phase$.

<i>Flag</i>	<i>Description</i>
a	Annotation tick spacing
f	Frame tick spacing
g	Grid tick spacing

Table 4.2: Interval type codes.

Note that the appearance of certain time annotations (month-, week-, and day-names) may be affected by the **TIME_LANGUAGE**, **TIME_FORMAT_PRIMARY**, and **TIME_FORMAT_SECONDARY** settings.

The unit flag **u** can take on one of 18 codes; these are listed in Table 4.3. Almost all of these units are time-axis specific. However, the **m** and **c** units will be interpreted as arc minutes and arc seconds, respectively, when a map projection is in effect.

There may be two levels of annotations. Here, “primary” refers to the annotation that is closest to the axis (this is the primary annotation), while “secondary” refers to the secondary annotation that is plotted further from the axis. The examples below will clarify what is meant. Note that the terms “primary” and “secondary” do not reflect any hierarchical order of units: The “primary” annotation interval is usually smaller (e.g., days) while the “secondary” annotation interval typically is larger (e.g., months).

Geographic basemaps

Geographic basemaps may differ from regular plot axis in that some projections support a “fancy” form of axis and is selected by the **BASEMAP_TYPE** setting. The annotations will be formatted according to the **PLOT_DEGREE_FORMAT** template and **DEGREE_SYMBOL** setting. A simple example of part of a basemap is shown in Figure 4.6.

⁶However, it is suppressed when a 3-D view is selected.

<i>Flag</i>	<i>Unit</i>	<i>Description</i>
Y	year	Plot using all 4 digits
y	year	Plot using last 2 digits
O	month	Format annotation using PLOT_DATE_FORMAT
o	month	Plot as 2-digit integer (1–12)
U	ISO week	Format annotation using PLOT_DATE_FORMAT
u	ISO week	Plot as 2-digit integer (1–53)
r	Gregorian week	7-day stride from start of week (see TIME_WEEK_START)
K	ISO weekday	Plot name of weekday in selected language
k	weekday	Plot number of day in the week (1–7) (see TIME_WEEK_START)
D	date	Format annotation using PLOT_DATE_FORMAT
d	day	Plot day of month (1–31) or day of year (1–366) (see PLOT_DATE_FORMAT)
R	day	Same as d ; annotations aligned with week (see TIME_WEEK_START)
H	hour	Format annotation using PLOT_CLOCK_FORMAT
h	hour	Plot as 2-digit integer (0–24)
M	minute	Format annotation using PLOT_CLOCK_FORMAT
m	minute	Plot as 2-digit integer (0–60)
C	seconds	Format annotation using PLOT_CLOCK_FORMAT
c	seconds	Plot as 2-digit integer (0–60)

Table 4.3: Interval unit codes.

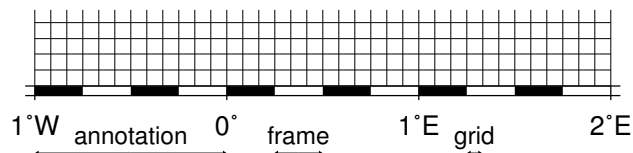


Figure 4.6: Geographic map border using separate selections for annotation, frame, and grid intervals. Formatting of the annotation is controlled by the parameter **PLOT_DEGREE_FORMAT** in your `.gmtdefaults4` file.

The machinery for primary and secondary annotations introduced for time-series axes can also be utilized for geographic basemaps. This may be used to separate degree annotations from minutes- and seconds-annotations. For a more complicated basemap example using several sets of intervals, including different intervals and pen attributes for grid lines and grid crosses, see Figure 4.7.

Cartesian linear axes

For non-geographic axes, the **BASEMAP_TYPE** setting is implicitly set to plain. Other than that, cartesian linear axes are very similar to geographic axes. The annotation format may be controlled with the **D_FORMAT** parameter. By default, it is set to “%g”, which is a C language format statement for floating point numbers⁷, and with this setting the various axis routines will automatically determine how many decimal points should be used by inspecting the *stride* settings. If **D_FORMAT** is set to another format it will be used directly (e.g., “%.2f” for a fixed, two decimals format). Note that for these axes you may use the *unit* setting to add a unit string to each annotation (see Figure 4.8).

⁷Please consult the man page for *printf* or any book on C.

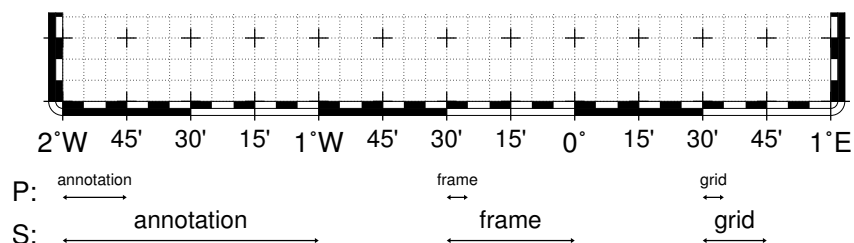
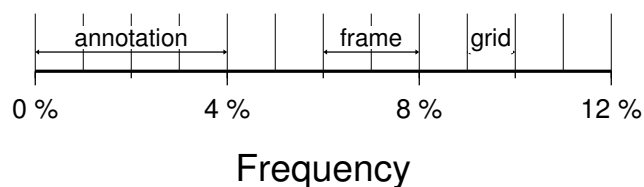


Figure 4.7: Geographic map border with both primary (P) and secondary (S) components.

Figure 4.8: Linear Cartesian projection axis. Long tickmarks accompany annotations, shorter ticks indicate frame interval. The axis label is optional. We used `-R0/12/0/1 -JX3/0.4 -Ba4f2g1:Frequency::,%.`

Cartesian \log_{10} axes

Due to the logarithmic nature of annotation spacings, the *stride* parameter takes on specific meanings. The following concerns are specific to log axes:

1. *stride* must be 1, 2, 3, or a negative integer $-n$. Annotations/ticks will then occur at 1, 1–2–5, or 1,2,3,4,...,9, respectively, for each magnitude range. For $-n$ the annotations will take place every n 'th magnitude.
2. Append **l** to *stride*. Then, \log_{10} of the annotation is plotted at every integer \log_{10} value (e.g., $x = 100$ will be annotated as “2”) [Default annotates x as is].
3. Append **p** to *stride*. Then, annotations appear as 10 raised to \log_{10} of the value (e.g., 10^{-5}).

Cartesian exponential axes

Normally, *stride* will be used to create equidistant (in the user's unit) annotations or ticks, but because of the exponential nature of the axis, such annotations may converge on each other at one end of the axis. To avoid this problem, you can append **p** to *stride*, and the annotation interval is expected to be in transformed units, yet the annotation itself will be plotted as un-transformed units. E.g., if *stride* = 1 and power = 0.5 (i.e., sqrt), then equidistant annotations labeled 1, 4, 9, ... will appear.

Cartesian time axes

What sets time axis apart from the other kinds of plot axes is the numerous ways in which we may want to tick and annotate the axis. Not only do we have both primary and secondary annotation items but we also have interval annotations versus tickmark annotations, numerous time units, and several ways in which to modify the plot. We will demonstrate this flexibility with a series of examples. While all our examples will only show a single x -axis, time-axis is supported for all axes.

Our first example shows a time period of almost two months in Spring 2000. We want to annotate the month intervals as well as the date at the start of each week:

```
gmtset PLOT_DATE_FORMAT -o ANNOT_FONT_SIZE_PRIMARY +9p
psbasemap -R2000-4-1T/2000-5-25T/0/1 -JX5/0.2 -Bpa7Rf1d -Bsa10S -P > GMT_-B_time1.ps
```

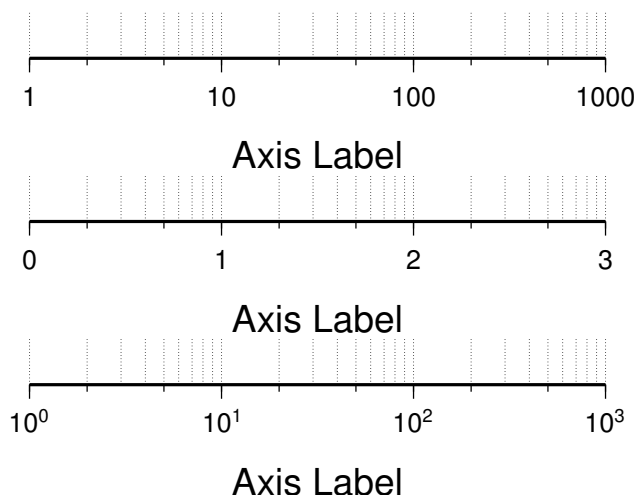


Figure 4.9: Logarithmic projection axis using separate values for annotation, frame, and grid intervals. (top) Here, we have chosen to annotate the actual values. Interval = 1 means every whole power of 10, 2 means 1, 2, 5 times powers of 10, and 3 means every 0.1 times powers of 10. We used `-R1/1000/0/1 -JX3l/0.4 -Ba1f2g3l`. (middle) Here, we have chosen to annotate \log_{10} of the actual values, with `-Ba1f2g3l`. (bottom) We annotate every power of 10 using \log_{10} of the actual values as exponents, with `-Ba1f2g3p`.

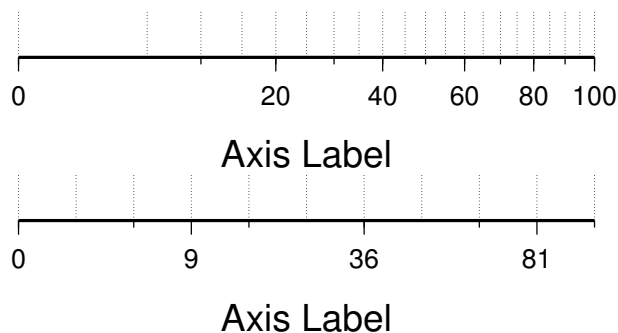


Figure 4.10: Exponential or power projection axis. (top) Using an exponent of 0.5 yields a \sqrt{x} axis. Here, intervals refer to actual data values, in `-R0/100/0/1 -JX3p0.5/0.4 -Ba20f10g5`. (bottom) Here, intervals refer to projected values, although the annotation uses the corresponding unprojected values, as in `-Ba3f2g1p`.

These commands result in Figure 4.11. Note the leading hyphen in the `PLOT_DATE_FORMAT` removes leading zeros from calendar items (e.g., 02 becomes 2).

The next example shows two different ways to annotate an axis portraying 2 days in July 1969:

```
gmtset PLOT_DATE_FORMAT "o dd" PLOT_CLOCK_FORMAT hh:mm ANNOT_FONT_SIZE_PRIMARY +9p
psbasemap -R1969-7-21T/1969-7-23T/0/1 -JX5/0.2 -Bpa6Hf1h -Bsa1KS -P -K > GMT_-B_time2.ps
psbasemap -R -J -Bpa6Hf1h -Bsa1DS -O -Y0.65i >> GMT_-B_time2.ps
```

The lower example (Figure 4.12) chooses to annotate the weekdays (by specifying `a1K`) while the upper example chooses dates (by specifying `a1D`). Note how the clock format only selects hours and minutes (no seconds) and the date format selects a month name, followed by one space and a two-digit day-of-month number.

The third example presents two years, annotating both the years and every 3rd month.

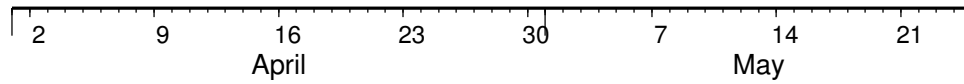


Figure 4.11: Cartesian time axis, example 1.

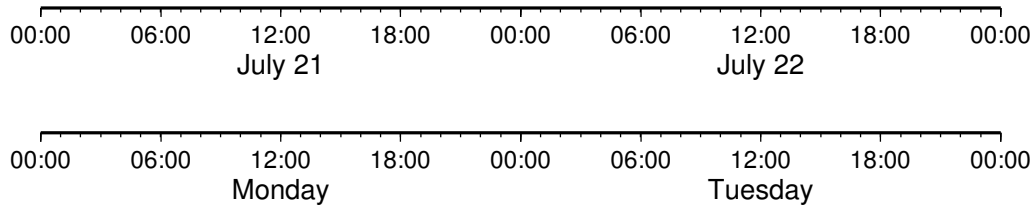


Figure 4.12: Cartesian time axis, example 2.

```
gmtset PLOT_DATE_FORMAT o TIME_FORMAT_PRIMARY Character ANNOT_FONT_SIZE_PRIMARY +9p
psbasemap -R1997T/1999T/0/1 -JX5/0.2 -Bpa3Oflo -BsalYS -P > GMT_-B_time3.ps
```

Note that while the year annotation is centered on the 1-year interval, the month annotations must be centered on the corresponding month and *not* the 3-month interval. The **PLOT_DATE_FORMAT** selects month name only and **TIME_FORMAT_PRIMARY** selects the 1-character, upper case abbreviation of month names using the current language (selected by **TIME_LANGUAGE**).

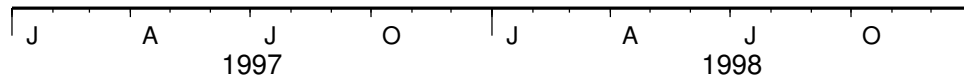


Figure 4.13: Cartesian time axis, example 3.

The fourth example (Figure 4.14) only shows a few hours of a day, using relative time by specifying **t** in the **-R** option while the **TIME_UNIT** is **d** (for days). We select both primary and secondary annotations, ask for a 12-hour clock, and let time go from right to left:

```
gmtset PLOT_CLOCK_FORMAT -hham ANNOT_FONT_SIZE_PRIMARY +9p
psbasemap -R0.2t/0.35t/0/1 -JX-5/0.2 -Bpa15mf5m -BsalHS -P > GMT_-B_time4.ps
```

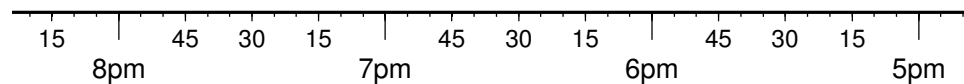


Figure 4.14: Cartesian time axis, example 4.

The fifth example shows a few weeks of time (Figure 4.15). The lower axis shows ISO weeks with week numbers and abbreviated names of the weekdays. The upper uses Gregorian weeks (which start at the day chosen by **TIME_WEEK_START**); they do not have numbers.

```
gmtset PLOT_DATE_FORMAT u TIME_FORMAT_PRIMARY Character TIME_FORMAT_SECONDARY full \
      ANNOT_FONT_SIZE_PRIMARY +9p
psbasemap -R1969-7-21T/1969-8-9T/0/1 -JX5/0.2 -Bpa1K -BsalUS -P -K > GMT_-B_time5.ps
gmtset PLOT_DATE_FORMAT o TIME_WEEK_START Sunday TIME_FORMAT_SECONDARY Character
psbasemap -R -J -Bpa3Kf1k -BsalrS -O -Y0.65i >> GMT_-B_time5.ps
```

Our sixth example shows the first five months of 1996, and we have annotated each month with an abbreviated, upper case name and 2-digit year. Only the primary axes information is specified.

```
gmtset PLOT_DATE_FORMAT "o yy" TIME_FORMAT_PRIMARY Abbreviated
psbasemap -R1996T/1996-6T/0/1 -JX5/0.2 -BaOf1dS -P > GMT_-B_time6.ps
```

Our seventh and final example illustrates annotation of year-days. Unless we specify the formatting with a leading hyphen in **PLOT_DATE_FORMAT** we get 3-digit integer days. Note that in order to have the two years annotated we need to allow for the annotation of small fractional intervals; normally such truncated interval must be at least half of a full interval.

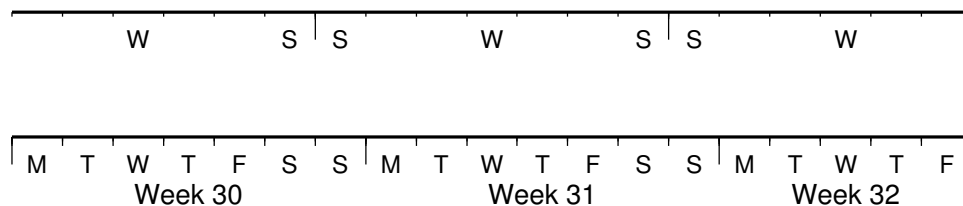


Figure 4.15: Cartesian time axis, example 5.

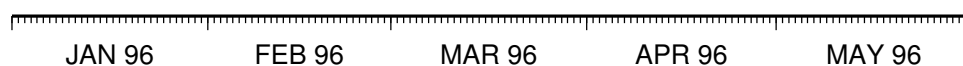


Figure 4.16: Cartesian time axis, example 6.

```
gmtset PLOT_DATE_FORMAT jjj TIME_INTERVAL_FRACTION 0.05 ANNOT_FONT_SIZE_PRIMARY +9p
psbasemap -R2000-12-15T/2001-1-15T/0/1 -JX5/0.2 -Bpa5Df1d -Bsa1YS -P > GMT_-B_time7.ps
```

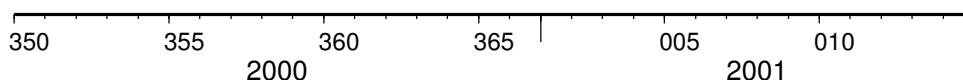


Figure 4.17: Cartesian time axis, example 7.

4.4.4 Header data records: The **-H** option

The **-H**[i][*n_recs*] option lets *GMT* know that input file(s) have one [Default] or more header records. If there are more than one header record you must specify the number after the **-H** option, e.g., **-H4**. The default number of header records if **-H** is used is one of the many parameters in the `.gmtdefaults4` file (**N_HEADER_RECS**), but can be overridden by **-Hn_header_recs**. Note that blank lines and records that be start with the character **#** are automatically skipped. Normally, programs that both read and write tables will output the header records that are found on input. Use **-Hi** to suppress the writing of header records.

4.4.5 Portrait plot orientation: The **-P** option

-P selects Portrait plotting mode⁸. In general, a plot has an *x*-axis increasing from left to right and a *y*-axis increasing from bottom to top. If the paper is turned so that the long dimension of the paper is parallel to the *x*-axis then the plot is said to have *Landscape* orientation. If the long dimension of the paper parallels the *y*-axis the orientation is called *Portrait* (think of taking pictures with a camera and these words make sense). The default Landscape orientation is obtained by translating the origin in the *x*-direction (by the width of the chosen paper **PAPER_MEDIA**) and then rotating the coordinate system counterclockwise by 90°. By default the **PAPER_MEDIA** is set to Letter (or A4 if SI is chosen); this value must be changed when using different media, such as 11" x 17" or large format plotters (Figure 4.18).

4.4.6 Plot overlays: The **-K -O** options

The **-K** and **-O** options control the generation of *PostScript* code for multiple overlay plots. All *PostScript* files must have a header (for initializations), a body (drawing the figure), and a trailer (printing it out) (see Figure 4.19). Thus, when overlaying several *GMT* plots we must make sure that the first plot call omits the trailer, that all intermediate calls omit both header and trailer, and that the final overlay omits the header. **-K** omits the trailer which implies that more *PostScript* code will be appended later [Default terminates the plot system]. **-O** selects Overlay plot mode and omits the header information [Default initializes a new

⁸For historical reasons, the *GMT* Default is Landscape, see **gmtdefaults** to change this.

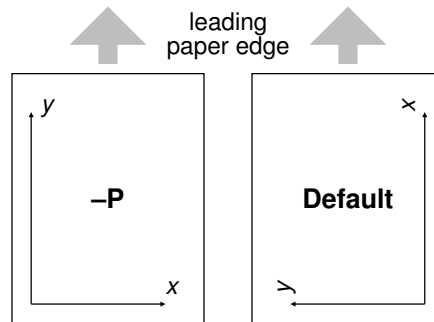


Figure 4.18: Users can specify Landscape [Default] or Portrait (**-P**) orientation.

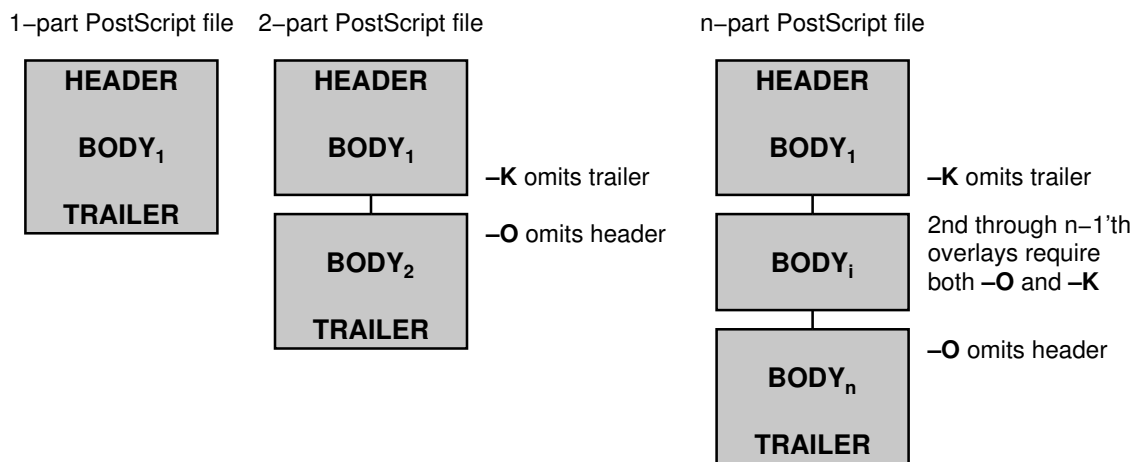


Figure 4.19: A final *PostScript* file consists of any number of individual pieces.

plot system]. Most unexpected results for multiple overlay plots can be traced to the incorrect use of these options. If you run only one plot program, ignore both the **-O** and **-K** options; they are only used when stacking plots.

4.4.7 Timestamps on plots: The **-U** option

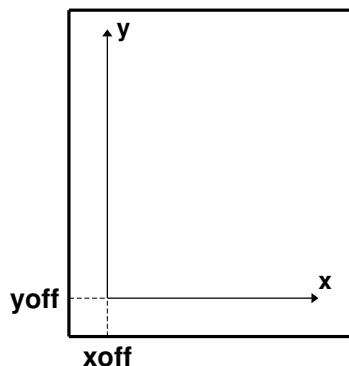
-U draws *UNIX* System time stamp. Optionally, append an arbitrary text string (surrounded by double quotes), or the code **c**, which will plot the current command string (Figure 4.20).



Figure 4.20: The **-U** option makes it easy to “date” a plot.

4.4.8 Verbose feedback: The **-V** option

-V selects verbose mode, which will send progress reports to *stderr* [Default runs “silently”]. The interpretation of this option can be toggled by changing the default **VERBOSE**.

Figure 4.21: Plot origin can be translated freely with **-X -Y**.

4.4.9 Plot positioning and layout: The **-X -Y** options

-X and **-Y** shift origin of plot by $(xoff, yoff)$ inches (Default is **(X_ORIGIN, Y_ORIGIN)** for new plots⁹ and **(0,0)** for overlays (**-O**)). By default, all translations are relative to the previous origin (see Figure 4.21). Supply offset as **c** to center the plot in that direction relative to the page margin. Absolute translations (i.e., relative to a fixed point **(0,0)** at the lower left corner of the paper) can be achieved by prepending “a” to the offsets. Subsequent overlays will be co-registered with the previous plot unless the origin is shifted using these options. The offsets are measured in the current coordinates system (which can be rotated using the initial **-P** option; subsequent **-P** options for overlays are ignored).

4.4.10 Binary table i/o: The **-b** option

All *GMT* programs that accept table data input may read ASCII, native binary, or netCDF data. When using native binary data the user must be aware of the fact that *GMT* has no way of determining the actual number of columns in the file. You must therefore pass that information to *GMT* via the binary **-bi[s]*n*** option, where *n* is the actual number of data columns (**s** indicates single (4 bytes) rather than double (8 bytes) precision). If uppercase **S** (or **D**) are used it implies that byte-swapping should be performed just prior to writing (for output) or immediately after reading (for input). Note that *n* may be larger than *m*, the number of columns that the *GMT* program requires to do its task. If *n* is not given then it defaults to *m*. If *n* < *m* an error is generated.

Because of its meta data, reading netCDF tables (i.e. netCDF files containing 1-dimensional arrays) is quite a bit less complex than reading native binary files. When feeding netCDF tables to programs like **psxy**, the program will automatically recognize the format and read whatever amount of columns are needed for that program. To steer which columns are to be read, the user can either append the suffix **?var1/var2/...** to the netCDF file name or add the option **-bicvar1/var2/...**, where *var1*, *var2*, etc. are the names of the variables to be processed. The latter option is particularly practical when more than one file is read: the **-bic** option will apply to all files.

Currently, netCDF tables can only be input, not output. For more information, see Appendix B.

4.4.11 Number of Copies: The **-c** option

The **-c** option specifies the number of plot copies [Default is 1]. This value is embedded in the *PostScript* file and will make a printer issue the chosen number of copies without respooling.

4.4.12 Data type selection: The **-f** option

When map projections are not required we must explicitly state what kind of data each input or output column contains. This is accomplished with the **-f** option. Following an optional **i** (for input only) or

⁹Ensures that boundary annotations do not fall off the page.

o (for output only), we append a text string with information about each column (or range of columns) separated by commas. Each string starts with the column number (0 is first column) followed by either **x** (longitude), **y** (latitude), **T** (absolute calendar time) or **t** (relative time). If several consecutive columns have the same format you may specify a range of columns rather than a single column, i.e., 0-4 for the first 5 columns. For example, if our input file has geographic coordinates (latitude, longitude) with absolute calendar coordinates in the columns 3 and 4, we would specify **fi0y,1x,3-4T**. All other columns are assumed to have the default, floating point format and need not be set individually. The shorthand **-f[i|o]g** means **-f[i|o]0x,1y** (geographic coordinates). For more information, see Sections 4.10 and 4.11.

4.4.13 Data gap detection: The **-g** option

GMT has several mechanisms that can determine line segmentation. Typically, data segments are separated by multiple segment header records (see section 4.4.14 on **-m** below). However, if key data columns contain a NaN we may also use that information to break lines into multiple segments. This behavior is modified by the parameter **NAN_RECORDS** which by default is set to *skip*, meaning such records are considered bad and simply skipped. If you wish such records to indicate a segment boundary then set this parameter to *pass*. Finally, you may wish to indicate gaps based on the data values themselves. The **-g** option is used to detect gaps based on one or more criteria (use **-g+** if *all* the criteria must be met; otherwise only one of the specified criteria needs to be met to signify a data gap). Gaps can be based on excessive jumps in the *x*- or *y*-coordinates (**-gx** or **-gy**), or on the distance between points (**-gd**). Append the *gap* distance and optionally a unit for actual distances. For geographic data the optional unit may be **meter** [Default], **kilometer**, **miles**, or **nautical miles**. For programs that maps data to map coordinates you can optionally specify these criteria to apply to the projected coordinates (by using upper-case **-gX**, **-gY** or **-gD**). In that case, choose from **inch**, **centimeter**, **meter**, or **points**. [Default unit is controlled by **MEASURE_UNIT**]. Note: For **-gx** or **-gy** with time data the unit is instead controlled by **TIME_UNIT**.

4.4.14 Multiple segment data: The **-m** option

The **-m** option states that the input and output table data will contain special records that marks the start of new line segments. These records are identified by their first character, which can be specified as an argument to **-m** [The default is **>**]. Append the modifiers **i** or **o** if the option should only apply to input or output, respectively. For binary data a multiple segment header is identified as a data record where all fields equal NaN. See section 4.4.14 and Appendix B for more details.

4.4.15 Lat/Lon or Lon/Lat?: The **-:** option

For geographical data, the first column is expected to contain longitudes and the second to contain latitudes. To reverse this expectation you must apply the **-:** option. Optionally, append **i** or **o** to restrict the effect to input or output only. Note that command line arguments that may take geographic coordinates (e.g., **-R**) *always* expect longitude before latitude. Also, geographical grids are expected to have the longitude as first (minor) dimension.

4.5 Command line history

GMT programs “remember” the standardized command line options (See Section 4.4) given during their previous invocations and this provides a shorthand notation for complex options. For example, if a basemap was created with an oblique Mercator projection, specified as

```
-Joc170W/25:30S/33W/56:20N/1:500000
```

then a subsequent **psxy** command to plot symbols only needs to state **-Jo** in order to activate the same projection. In contrast, note that **-J** by itself will pick the most recently used projection. Previous com-

mands are maintained in the file `.gmtcommands4`, of which there will be one in each directory you run the programs from. This is handy if you create separate directories for separate projects since chances are that data manipulations and plotting for each project will share many of the same options. Note that an option spelled out on the command line will always override the last entry in the `.gmtcommands4` file and, if execution is successful, will replace this entry as the previous option argument in the `.gmtcommands4` file. If you call several *GMT* modules piped together then *GMT* cannot guarantee that the `.gmtcommands4` file is processed in the intended order from left to right. The only guarantee is that the file will not be clobbered since *GMT* uses advisory file locking. The uncertainty in processing order makes the use of shorthands in pipes unreliable. We therefore recommend that you only use shorthands in single process command lines, and spell out the full command option when using chains of commands connected with pipes.

4.6 Usage messages, syntax- and general error messages

Each program carries a usage message. If you enter the program name without any arguments, the program will write the complete usage message to standard error (your screen, unless you redirect it). This message explains in detail what all the valid arguments are. If you enter the program name followed by a *hyphen* (`-`) only you will get a shorter version which only shows the command line syntax and no detailed explanations. If you incorrectly specify an option or omit a required option, the program will produce syntax errors and explain what the correct syntax for these options should be. If an error occurs during the running of a program, the program will in some cases recognize this and give you an error message. Usually this will also terminate the run. The error messages generally begin with the name of the program in which the error occurred; if you have several programs piped together this tells you where the trouble is.

4.7 Standard input or file, header records

Most of the programs which expect table data input can read either standard input or input in one or several files. These programs will try to read *stdin* unless you type the filename(s) on the command line without the above hyphens. (If the program sees a hyphen, it reads the next character as an instruction; if an argument begins without a hyphen, it tries to open this argument as a filename). This feature allows you to connect programs with pipes if you like. If your input is ASCII and has one or more header records, you must use the `-H` option (see Section 4.4.4). For binary table data no headers are allowed. ASCII files may in many cases also contain sub-headers separating data segments. These are called “multi-segment files” and requires a special option (typically `-m`); see Appendix B for complete documentation.

If filenames are given for reading, *GMT* programs will first look for them in the current directory. If the file is not found, the programs will look in two other directories pointed to by environmental parameters (if set). These are `GMT_DATADIR` and `GMT_USERDIR`, and they may be set by the user to point to directories that contain data sets of general use. Normally, the first directory (or directories: add multiple paths by separating them with colons (semi-colons under Windows)) will hold data sets of a general nature (tables, grids), although a particular use is to make available large grids accessible via the supplemental programs `grdraster` or `img2grd`; see Appendix A for information about these supplemental programs. The second directory may hold miscellaneous data sets more specific to the user; this directory also stores *GMT* defaults and other configuration files. Data sets that the user finds are often needed may be placed in these directories, thus eliminating the need to specify a full path to the file. Program output is always written to the current directory unless a full path has been specified.

4.8 Verbose operation

Most of the programs take an optional `-V` argument which will run the program in the “verbose” mode (see Section 4.4.8). Verbose will write to standard error information about the progress of the operation you are running. Verbose reports things such as counts of points read, names of data files processed, convergence of iterative solutions, and the like. Since these messages are written to *stderr*, the verbose talk remains separate from your data output.

4.9 Program output

Most programs write their results, including *PostScript* plots, to standard output. The exceptions are those which may create binary netCDF grid files such as **surface** (due to the design of netCDF a filename must be provided; however, alternative binary output formats allowing piping are available; see Section 4.17). With *UNIX* you can redirect standard output to a file or pipe it into another process. Error messages, usage messages, and verbose comments are written to standard error in all cases. You can use *UNIX* to redirect standard error as well, if you want to create a log file of what you are doing.

4.10 Input data formats

Most of the time, *GMT* will know what kind of x and y coordinates it is reading because you have selected a particular coordinate transformation or map projection. However, there may be times when you must explicitly specify what you are providing as input using the **-f** switch. When binary input data are expected (**-bi**) they must all be floating point numbers, however for ASCII input there are numerous ways to encode data coordinates (which may be separated by white-space or commas). Valid input data are generally of the same form as the arguments to the **-R** option (see Section 4.4.1), with additional flexibility for calendar data. Geographical coordinates, for example, can be given in decimal degrees (e.g., -123.45417) or in the $[\pm]ddd[:mm[:ss[:xxx]]][W|E|S|N]$ format (e.g., 123:27:15W).

Because of the widespread use of incompatible and ambiguous formats, the processing of input date components is guided by the template **INPUT_DATE_FORMAT** in your `.gmtdefaults4` file; it is by default set to `yyyy-mm-dd`. Y2K-challenged input data such as 29/05/89 can be processed by setting **INPUT_DATE_FORMAT** to `dd/mm/yy`. A complete description of possible formats is given in the **gmtdefaults** man page. The *clock* string is more standardized but issues like 12- or 24-hour clocks complicate matters as well as the presence or absence of delimiters between fields. Thus, the processing of input clock coordinates is guided by the template **INPUT_CLOCK_FORMAT** which defaults to `hh:mm:ss.xxx`.

GMT programs that require a map projection argument will implicitly know what kind of data to expect, and the input processing is done accordingly. However, some programs that simply report on minimum and maximum values or just do a reformatting of the data will in general not know what to expect, and furthermore there is no way for the programs to know what kind of data other columns (beyond the leading x and y columns) contain. In such instances we must explicitly tell *GMT* that we are feeding it data in the specific geographic or calendar formats (floating point data are assumed by default). We specify the data type via the **-f** option (which sets both input and output formats; use **-fi** and **-fo** to set input and output separately). For instance, to specify that the first two columns are longitude and latitude, and that the third column (e.g., z) is absolute calendar time, we add **-fi0x,1y,2T** to the command line. For more details, see the man page for the program you need to use.

4.11 Output data formats

The numerical output from *GMT* programs can be binary (when **-bo** is used) or ASCII [Default]. In the latter case the issue of formatting becomes important. *GMT* provides extensive machinery for allowing just about any imaginable format to be used on output. Analogous to the processing of input data, several templates guide the formatting process. These are **OUTPUT_DATE_FORMAT** and **OUTPUT_CLOCK_FORMAT** for calendar-time coordinates, **OUTPUT_DEGREE_FORMAT** for geographical coordinates, and **D.FORMAT** for generic floating point data. In addition, the user has control over how columns are separated via the **FIELD_SEPARATOR** parameter. Thus, as an example, it is possible to create limited FORTRAN-style card records by setting **D.FORMAT** to `%7.3lf` and **FIELD_SEPARATOR** to `none` [Default is `tab`].

4.12 *PostScript* features

PostScript is a command language for driving graphics devices such as laser printers. It is ASCII text which you can read and edit as you wish (assuming you have some knowledge of the syntax). We prefer this to binary metafile plot systems since such files cannot easily be modified after they have been created. *GMT* programs also write many comments to the plot file which make it easier for users to orient themselves should they need to edit the file (e.g., % Start of x-axis). All *GMT* programs create *PostScript* code by calling the **pslib** plot library (The user may call these functions from his/her own C or FORTRAN plot programs. See the manual pages for **pslib** syntax). Although *GMT* programs can create very individualized plot code, there will always be cases not covered by these programs. Some knowledge of *PostScript* will enable the user to add such features directly into the plot file. By default, *GMT* will produce freeform *PostScript* output with embedded printer directives. To produce Encapsulated *PostScript* (EPS) that can be imported into graphics programs such as **IslandDraw**, **CorelDraw**, **Illustrator** or **Freehand** for further embellishment, change the **PAPER_MEDIA** setting in the `.gmtdefaults4` file. See Appendix C and the **gmtdefaults** man page for more details.

4.13 Specifying pen attributes

A pen in *GMT* has three attributes: *width*, *color*, and *texture*. Most programs will accept pen attributes in the form of an option argument, with commas separating the given attributes, e.g.,

`-W[width[c|i|p|m]],[color],[texture[c|i|p|m]]`

→ *Width* is by default measured in units of the current device resolution (i.e., the value assigned to the parameter **DOTS_PR_INCH** in your `.gmtdefaults4` file). Thus, if the dpi is set to 300 this unit is 1/300th of an inch. Append **c**, **i**, **p**, or **m** to specify pen width in cm, inch, points (1/72 of an inch), or meters, respectively. Note that a pen thickness of 5 will be of different physical width depending on your dpi setting, whereas a thickness of 5p will always be 5/72 of an inch. Minimum-thickness pens can be achieved by giving zero width, but the result is device-dependent. Finally, a few predefined pen names can be used: default, faint, and {thin, thick, fat}[er|est], and obese. Table 4.4 shows this list and the corresponding pen widths.

<i>Pen name</i>	<i>Width</i>	<i>Pen name</i>	<i>Width</i>
faint	0	thicker	1.5p
default	0.25p	thickest	2p
thinnest	0.25p	fat	3p
thinner	0.50p	fatter	6p
thin	0.75p	fattest	12p
thick	1.0p	obese	18p

Table 4.4: **GMT** predefined pen widths.

→ The *color* can be specified in five different ways:

1. Gray. Specify a *gray* shade in the range 0–255 (linearly going from black [0] to white [255]).
2. RGB. Specify *r/g/b*, each ranging from 0–255. Here 0/0/0 is black, 255/255/255 is white, 255/0/0 is red, etc.
3. HSV. Specify *hue-saturation-value*, with the former in the 0–360 degree range while the latter two take on the range 0–1¹⁰.
4. CMYK. Specify *cyan/magenta/yellow/black*, each ranging from 0–100%.

¹⁰For an overview of color systems such as HSV, see Appendix I.

5. Name. Specify one of 663 valid color names. Use **man gmtcolors** to list all valid names. A very small yet versatile subset consists of the 29 choices *white, black*, and *[light|dark]{red, orange, yellow, green, cyan, blue, magenta, gray|grey, brown}*. The color names are case-insensitive, so mixed upper and lower case can be used (like *DarkGreen*).
- The *texture* attribute controls the appearance of the line. A “.” yields a dotted line, whereas a dashed pen is requested with “-”. Also combinations of dots and dashes, like “.-” for a dot-dashed line, are allowed. The lengths of dots and dashes are scaled relative to the pen width (dots has a length that equals the pen width while dashes are 8 times as long; gaps between segments are 4 times the pen width). For more detailed attributes including exact dimensions you may specify *string:offset*, where *string* is a series of numbers separated by underscores. These numbers represent a pattern by indicating the length of line segments and the gap between segments. The *offset* phase-shifts the pattern from the beginning the line. For example, if you want a yellow line of width 0.1 cm that alternates between long dashes (4 points), an 8 point gap, then a 5 point dash, then another 8 point gap, with pattern offset by 2 points from the origin, specify **-W0.1c,yellow,4_8_5_8:2p**. In general, the texture units can be specified in dpi units, cm, inch, points, or meters (see *width* discussion above).

Table 4.5 contains additional examples of pen specifications suitable for, say, **psxy**.

<i>Pen example</i>	<i>Comment</i>
-W0.5p	Solid black line, 0.5 point thick
-Wgreen	Solid green line with default width
-Wthin,red,-	Dashed, thin red line
-Wfat,.	Fat dotted line [black]
-W0.1c,120-1-1	Green (in h-s-v) pen, 1 mm thick
-Wfaint,100/0/0/0,...-	Very thin, cyan (in c/m/y/k), dot-dot-dashed line

Table 4.5: A few examples of pen specifications.

4.14 Specifying area fill attributes

Many plotting programs will allow the user to draw filled polygons or symbols. The fill specification may take two forms:

```
-Gfill
-Gdpi/pattern[:Bcolor[Fcolor]]
```

fill: In the first case we may specify a *gray* shade (0–255), RGB color (*r/g/b* all in the 0–255 range or in hexadecimal *#rrggbb*), HSV color (*hue-saturation-value* in the 0–360, 0–1, 0–1 range), CMYK color (*cyan/magenta/yellow/black*, each ranging from 0–100%), or a valid color *name*; in that respect it is similar to specifying the pen color settings (see pen color discussion under Section 4.13).

pattern: The second form allows us to use a predefined bit-image pattern. *pattern* can either be a number in the range 1–90 or the name of a 1-, 8-, or 24-bit Sun raster file. The former will result in one of the 90 predefined 64 x 64 bit-patterns provided with *GMT* and reproduced in Appendix E. The latter allows the user to create customized, repeating images using standard Sun raster files¹¹. The *dpi* parameter sets the resolution of this image on the page; the area fill is thus made up of a series of these “tiles”. Specifying *dpi* as 0 will result in highest resolution obtainable given the present dpi setting in *.gmtdefaults4*. By specifying upper case **-GP** instead of **-Gp** the image will be bit-reversed, i.e., white and black areas will be interchanged (only applies to 1-bit images or predefined bit-image patterns). For these patterns and other 1-bit images one may specify alternative background and foreground colors (by appending

¹¹ Convert other graphics formats to Sun ras format using ImageMagick’s **convert** program.

:**Bcolor**[**Fcolor**]) that will replace the default white and black pixels, respectively. Setting one of the fore- or background colors to – yields a *transparent* image where only the back- or foreground pixels will be painted.

Due to *PostScript* implementation limitations the raster images used with **–G** must be less than 146 x 146 pixels in size; for larger images see **psimage**. The format of Sun raster files is outlined in Appendix B. Note that under *PostScript* Level 1 the patterns are filled by using the polygon as a *clip path*. Complex clip paths may require more memory than the *PostScript* interpreter has been assigned. There is therefore the possibility that some *PostScript* interpreters (especially those supplied with older laserwriters) will run out of memory and abort. Should that occur we recommend that you use a regular grayshade fill instead of the patterns. Installing more memory in your printer *may or may not* solve the problem!

Table 4.6 contains a few examples of fill specifications.

<i>Fill example</i>	<i>Comment</i>
–G128	Solid grey
–G127/255/0	Chartreuse, R/G/B-style
–G#00ff00	Green, hexadecimal RGB code
–G25-0.86-0.82	Chocolate, h-s-v – style
–GDarkOliveGreen1	One of the named colors
–Gp300/7	Simple diagonal hachure pattern in b/w at 300 dpi
–Gp300/7:Bred	Same, but with red lines on white
–Gp300/7:BredF-	Now the gaps between red lines are transparent
–Gp100/marble.ras	Using user image of marble as the fill at 100 dpi

Table 4.6: A few examples of fill specifications.

4.15 Color palette tables

Several programs, such as those which read 2-D gridded data sets and create colored images or shaded reliefs, need to be told what colors to use and over what z-range each color applies. This is the purpose of the color palette table (cpt-file). These files may also be used by **psxy** and **psxyz** to plot color-filled symbols. For most applications, you will simply create a cpt-file using the tool **makecpt** which will take an existing color table and resample it to fit your chosen data range, or use **grd2cpt** to build a cpt-file based on the data distribution in one or more given grid files. However, in some situations you will need to make a cpt-file by hand or using text tools like **awk** or **perl**.

Color palette tables (CPT) comes in two flavors: (1) Those designed to work with categorical data (e.g., data where interpolation of values is undefined) and (2) those designed for regular, continuously-varying data.

4.15.1 Categorical CPT files

Categorical data are information on which normal numerical operations are not defined. As an example, consider various land classifications (desert, forest, glacier, etc.) and it is clear that even if we assigned a numerical value to these categories (e.g., desert = 1, forest = 2, etc) it would be meaningless to compute average values (what would 1.5 mean?). For such data a special format of the CPT files are provided. Here, each category is assigned a unique key, a color or pattern, and an optional label (usually the category name). Keys must be monotonically increasing but do not need to be consecutive. The format is

```
key1  fill  label
...
keyn  fill  label
```

The *fill* information follows the format given in Section 4.14. While not always applicable to categorical data, the background color (for *key*-values $< key_1$), foreground color (for *key*-values $> key_n$), and not-a-number (NaN) color (for *key*-values = NaN) are all defined in the `.gmtdefaults4` file, but can be overridden by the statements

```
B  Rback  Gback  Bback
F  Rfore  Gfore  Bfore
N  Rnan  Gnan  Bnan
```

4.15.2 Regular CPT files

Here, the colors may be specified either in the RGB- (red, green, blue), CMYK- (cyan, magenta, yellow, black), or in the HSV-system (hue, saturation, value, and here the comment `# COLOR_MODEL = HSV` must be present in the cpt file since there are no other way to distinguish between HSV and RGB). Color names can also be used. Using the RGB system¹², the format of the cpt-file is:

```
z0    Rmin  Gmin  Bmin  z1    Rmax  Gmax  Bmax  [A]  [;label]
...
zn-2  Rmin  Gmin  Bmin  zn-1  Rmax  Gmax  Bmax  [A]  [;label]
```

Thus, for each “z-slice”, defined as the interval between two boundaries (e.g., z_0 to z_1), the color can be constant (by letting $R_{min} = R_{max}$, $G_{min} = G_{max}$, and $B_{min} = B_{max}$) or a continuous, linear function of z . The optional flag **A** is used to indicate annotation of the color scale when plotted using **psscale**. The optional code **A** may be **L**, **U**, or **B** to select annotation of the lower, upper, or both limits of the particular z-slice. However, the standard **-B** option can be used by **psscale** to affect annotation and ticking of color scales. The optional semicolon followed by a text label will make **psscale**, when used with the **-L** option, place the supplied label instead of formatted z -values.

As for categorical tables, the background color (for z -values $< z_0$), foreground color (for z -values $> z_{n-1}$), and not-a-number (NaN) color (for z -values = NaN) are all defined in the `.gmtdefaults4` file, but can be overridden by the statements

```
B  Rback  Gback  Bback
F  Rfore  Gfore  Bfore
N  Rnan  Gnan  Bnan
```

which can be inserted into the beginning or end of the cpt-file. If you prefer the HSV system, set the `.gmtdefaults4` parameter accordingly and replace red, green, blue with hue, saturation, value. Color palette tables that contain grayshades only may replace the *r/g/b* triplets with a single grayshade in the 0–255 range. For CMYK, give four values in the 0–100 range. Both the min and max color specifications in one z -slice must use the same color system, i.e., you cannot mix “red” and 0/255/100 on the same line.

A few programs (i.e., those that plot polygons such as **grdview**, **psscale**, and **psxy**) can accept pattern fills instead of grayshades. You must specify the pattern as in Section 4.14 (no leading **-G** of course), and only the first (low z) is used (we cannot interpolate between patterns). Finally, some programs let you skip features whose z -slice in the cptfile has grayshades set to $-$. As an example, consider

```
30    p200/16    80    -
80    -          100   -
100   200        0     0     200   255   255   0
200   yellow     300   green
```

where slice $30 < z < 80$ is painted with pattern # 16 at 200 dpi, slice $80 < z < 100$ is skipped, slice $100 < z < 200$ is painted in a range of dark red to yellow, whereas the slice $200 < z < 300$ will linearly yield colors from yellow to green, depending on the actual value of z .

¹²For CMYK the format obviously involves two extra columns.

Some programs like **grdimage** and **grdview** apply artificial illumination to achieve shaded relief maps. This is typically done by finding the directional gradient in the direction of the artificial light source and scaling the gradients to have approximately a normal distribution on the interval $[-1,+1]$. These intensities are used to add “white” or “black” to the color as defined by the z -values and the *cpt*-file. An intensity of zero leaves the color unchanged. Higher values will brighten the color, lower values will darken it, all without changing the original hue of the color (see Appendix I for more details). The illumination is decoupled from the data grid file in that a separate grid file holding intensities in the $[-1,+1]$ range must be provided. Such intensity files can be derived from the data grid using **grdgradient** and modified with **grdhisteq**, but could equally well be a separate data set. E.g., some side-scan sonar systems collect both bathymetry and backscatter intensities, and one may want to use the latter information to specify the illumination of the colors defined by the former. Similarly, one could portray magnetic anomalies superimposed on topography by using the former for colors and the latter for shading.

4.16 Character escape sequences

For annotation labels or text strings plotted with **pstext**, *GMT* provides several escape sequences that allow the user to temporarily switch to the symbol font, turn on sub- or superscript, etc., within words. These conditions are toggled on/off by the escape sequence **@x**, where **x** can be one of several types. The escape sequences recognized in *GMT* are listed in Table 4.7. Note that under Windows the percent symbol indicates a batch variable, hence you must use two percent-signs for each one required in the escape sequence for font switching.

<i>Code</i>	<i>Effect</i>
@~	Turns symbol font on or off
@+	Turns superscript on or off
@-	Turns subscript on or off
@#	Turns small caps on or off
@_	Turns underline on or off
@%fontno%	Switches to another font; @%% resets to previous font
@:size:	Switches to another font size; @:: resets to previous size
@;color;	Switches to another font color; @;; resets to previous color
@!	Creates one composite character of the next two characters
@@	Prints the @ sign itself

Table 4.7: **GMT** text escape sequences.

Shorthand notation for a few special European characters has also been added (Table 4.8):

<i>Code</i>	<i>Effect</i>	<i>Code</i>	<i>Effect</i>
@E	Æ	@e	æ
@O	Ø	@o	ø
@A	Å	@a	å
@C	Ç	@c	ç
@N	Ñ	@n	ñ
@U	Ü	@u	ü
@s	ß		

Table 4.8: Shortcuts for some European characters.

PostScript fonts used in *GMT* may be re-encoded to include several accented characters used in many European languages. To access these, you must specify the full octal code `\xxx` allowed for your choice of character encodings determined by the **CHAR_ENCODING** setting described in the **gmtdefaults** man page. Only the special characters belonging to a particular encoding will be available. Many characters not

directly available by using single octal codes may be constructed with the composite character mechanism @!.

Some examples of escape sequences and embedded octal codes in *GMT* strings using the Standard+encoding:

2@~p@~r@+2@+h@-0@- E\363tv\363s	=	$2\pi r^2 h_0$ Eötvös
10@+-3 @Angstr@om	=	10^{-3} Ångström
Se@nor Gar@con	=	Señor Garçon
M@!\305anoa stra@se	=	Manoa straße
A@ \#cceleration@\# (ms@+-2@+)	=	ACCELERATION (MS ⁻²)

The option in **pstext** to draw a rectangle surrounding the text will not work for strings with escape sequences. A chart of characters and their octal codes is given in Appendix F.

4.17 Grid file format specifications

GMT has the ability to read and write grids using more than one grid file format (see Table 4.9 for supported format and their IDs). For reading, *GMT* will automatically determine the format of grid files, while for writing you will normally have to append `=ID` to the filename if you want *GMT* to use a different format than the default.

By default, *GMT* will create new grid files using the **nf** format; however, this behavior can be overridden by setting the **GRID_FORMAT** defaults parameter to any of the other recognized values (or by appending `=ID`).

GMT can also read netCDF grid files produced by other software packages, provided the grid files satisfy the COARDS and Hadley Centre conventions for netCDF grids. Thus, products created under those conventions (provided the grid is 2-, 3-, 4-, or 5-dimensional) can be read directly by *GMT* and the netCDF grids written by *GMT* can be read by other programs that conform to those conventions. Three such programs are **ncview**, **Panoply** and **ncBrowse**; others can be found on the netCDF website.

In addition, users with some C-programming experience may add their own read/write functions and link them with the *GMT* library to extend the number of predefined formats. Technical information on this topic can be found in the source file [gmt_customio.c](#).

<i>ID</i>	<i>GMT 4 netCDF standard formats</i>
nb	GMT netCDF format (byte) (COARDS-compliant)
ns	GMT netCDF format (short) (COARDS-compliant)
ni	GMT netCDF format (int) (COARDS-compliant)
nf	GMT netCDF format (float) (COARDS-compliant)
nd	GMT netCDF format (double) (COARDS-compliant)
<i>ID</i>	<i>GMT 3 netCDF legacy formats</i>
cb	GMT netCDF format (byte) (deprecated)
cs	GMT netCDF format (short) (deprecated)
ci	GMT netCDF format (int) (deprecated)
cf	GMT netCDF format (float) (deprecated)
cd	GMT netCDF format (double) (deprecated)
<i>ID</i>	<i>GMT native binary formats</i>
bm	GMT native, C-binary format (bit-mask)
bb	GMT native, C-binary format (byte)
bs	GMT native, C-binary format (short)
bi	GMT native, C-binary format (int)
bf	GMT native, C-binary format (float)
bd	GMT native, C-binary format (double)
<i>ID</i>	<i>Miscellaneous grid formats</i>
rb	SUN raster file format (8-bit standard)
rf	GEODAS grid format GRD98 (NGDC)
sf	Golden Software Surfer format 6 (float)
sd	Golden Software Surfer format 7 (double)
af	Atlantic Geoscience Center AGC (float)

Table 4.9: **GMT** grid file formats.

Because some formats have limitations on the range of values they can store it is sometimes necessary to provide more than simply the name of the file and its ID on the command line. For instance, a native short integer file may use a unique value to signify an empty node or NaN, and the data may need translation and scaling prior to use. Therefore, all *GMT* programs that read or write grid files will decode the given filename as follows:

`name[=ID[/scale/offset[/nan]]]`

where everything in brackets is optional. If you are reading a grid then no options are needed: just continue to pass the name of the grid file. However, if you write another format you must append the `=ID` string, where *ID* is the format code listed above. In addition, should you want to (1) multiply the data by a scale factor, and (2) add a constant offset you must append the `/scale/offset` modifier. Finally, if you need to indicate that a certain data value should be interpreted as a NaN (not-a-number) you must append the `/nan` suffix to the scaling string (it cannot go by itself; note the nesting of the brackets!).

Some of the grid formats allow writing to standard output and reading from standard input which means you can connect *GMT* programs that operate on grid files with pipes, thereby speeding up execution and eliminating the need for large, intermediate grid files. You specify standard input/output by leaving out the filename entirely. That means the “filename” will begin with “=*ID*” since no *GMT* netCDF format allow piping (due to the design of netCDF).

Everything looks more obvious after a few examples:

1. To write a native binary float grid file, specify the name as `my_file.grd=bf`.
2. To read a native short integer grid file, multiply the data by 10 and then add 32000, but first let values that equal 32767 be set to NaN, use the filename `my_file.grd=bs/10/32000/32767`.

3. To read a Golden Software “surfer” format 6 grid file, just pass the file name, e.g., my_surferfile.grd.
4. To read a 8-bit standard Sun raster file (with values in the 0–255 range) and convert it to a ± 1 range, give the name as rasterfile=rb/7.84313725e-3/-1 (i.e., 1/127.5).
5. To write a native binary short integer grid file to standard output after subtracting 32000 and dividing its values by 10, give filename as =bs/0.1/-3200.

Programs that both read and/or write more than one grid file may specify different formats and/or scaling for the files involved. The only restriction with the embedded grid specification mechanism is that no grid files may actually use the “=” character as part of their name (presumably, a small sacrifice).

One can also define special file suffixes to imply a specific file format; this approach represents a more intuitive and user-friendly way to specify the various file formats. The user may create a file called .gmt_io in the current directory, home directory or in the directory /.gmt and define any number of custom formats. The following is an example of a .gmt_io file:

```
# GMT i/o shorthand file
# It can have any number of comment lines like this one anywhere
# suffix format_id scale offset NaN    Comments
grd      nf          -   -   -        Default format
b        bf          -   -   -        Native binary floats
i2       bs          -   -   32767    2-byte integers with NaN value
ras      rb          -   -   -        Sun raster files
byte     bb          -   -   255      Native binary 1-byte grids
bit      bm          -   -   -        Native binary 0 or 1 grids
mask     bm          -   -   0        Native binary 1 or NaN masks
faa      bs          0.1 -   32767    Native binary gravity in 0.1 mGal
```

These suffices can be anything that makes sense to the user. To activate this mechanism, set parameter **GRIDFILE_SHORTHAND** to TRUE in your .gmtdefaults4 file. Then, using the filename stuff.i2 is equivalent to saying stuff.i2=bs/1/0/32767, and the filename wet.mask means wet.mask=bm/1/0/0. For a file intended for masking, i.e., the nodes are either 1 or NaN, the bit or mask format file may be as small as 1/32 the size of the corresponding grid float format file.

4.18 Options for COARDS-compliant netCDF files

When the netCDF file contains more than one 2-dimensional variable, *GMT* programs will load the first such variable in the file and ignore all others. Alternatively, the user can select the required variable by adding the suffix “*?varname*” to the file name. For example, to get information on the variable “slp” in file file.nc, use:

```
grdinfo "file.nc?slp"
```

Since COARDS-compliant netCDF files are the default, the additional suffix “=nf” can be omitted.

In case the named variable is 3-dimensional, *GMT* will load first (bottom) layer. If another layer is required, either add “[*index*]” or “(*level*)”, where *index* is the index of the third (depth) variable (starting at 0 for the first layer) and *level* is the numerical value of the third (depth) variable associated with the requested layer. To indicate the second layer of the 3-D variable “slp” use as file name: file.nc?slp[1].

When you supply the numerical value for the third variable using “(*level*)”, *GMT* will pick the layer closest to that value. No interpolation is performed.

Note that the question mark, brackets and parentheses have special meanings on Unix-based platforms. Therefore, you will need to either *escape* these characters, by placing a backslash in front of them, or place the whole file name plus modifiers between single quotes or double quotes.

A similar approach is followed for loading 4-dimensional grids. Consider a 4-dimensional grid with the following variables:

```

lat(lat): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
lon(lon): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
depth(depth): 0, 10, 20, 30, 40, 50, 60, 70, 80, 90
time(time): 0, 12, 24, 36, 48
pressure(time,depth,lat,lon): (5000 values)

```

To get information on the 10×10 grid of pressure at depth 10 and at time 24, one would use:

```
grdinfo "file.nc?pressure[2,1]"
```

or (only in case the coordinates increase linearly):

```
grdinfo "file.nc?pressure(24,10)"
```

The COARDS conventions set restrictions on the names that can be used for the units of the variables and coordinates. For example, the units of longitude and latitude are “degrees_east” and “degrees_north”, respectively. Here is an example of the header of a COARDS compliant netCDF file (to be obtained using **ncdump**):

```

netcdf M2_fes2004 {
  dimensions:
    lon = 2881 ;
    lat = 1441 ;
  variables:
    float lon(lon) ;
        lon:long_name = "longitude" ;
        lon:units = "degrees_east" ;
        lon:actual_range = 0., 360. ;
    float lat(lat) ;
        lat:long_name = "latitude" ;
        lat:units = "degrees_north" ;
        lat:actual_range = -90., 90. ;
    short amp(lat, lon) ;
        amp:long_name = "amplitude" ;
        amp:unit = "m" ;
        amp:scale_factor = 0.0001 ;
        amp:add_offset = 3. ;
        amp:_FillValue = -32768s ;
    short pha(lat, lon) ;
        pha:long_name = "phase" ;
        pha:unit = "degrees" ;
        pha:scale_factor = 0.01 ;
        pha:_FillValue = -32768s ;
}

```

This file contains two grids, which can be plotted separately using the names M2_fes2004.nc?amp and M2_fes2004.nc?pha. The attributes `long_name` and `unit` for each variable are combined in *GMT* to a single unit string. For example, after reading the grid `y_unit` equals `latitude [degrees_north]`. The same method can be used in reverse to set the proper variable names and units when writing a grid. However, when the coordinates are set properly as geographical or time axes, *GMT* will take care of this. The user is, however, still responsible for setting the variable name and unit of the z-coordinate. The default is simply “z”.

4.19 The NaN data value

For a variety of data processing and plotting tasks there is a need to acknowledge that a data point is missing or unassigned. In the “old days” such information was passed by letting a value like -9999.99 take on the

special meaning of “this is not really a value, it is missing”. The problem with this scheme is that -9999.99 (or any other floating point value) may be a perfectly reasonable data value and in such a scenario would be skipped. The solution adopted in *GMT* is to use the IEEE concept Not-a-Number (NaN) for this purpose. Mathematically, a NaN is what you get if you do an undefined mathematical operation like 0/0; in ASCII data files they appear as the textstring NaN. This value is internally stored with a particular bit pattern defined by IEEE so that special action can be taken when it is encountered by programs. In particular, a library function called `isnan` is used to test if a floating point is a NaN. *GMT* uses these tests extensively to determine if a value is suitable for plotting or processing (if a NaN is used in a calculation the result would become NaN as well). Data points whose value is NaN are not normally plotted (or plotted with the special NaN color given in `.gmtdefaults4`). Several tools such as **xyz2grd**, **gmtmath**, and **grdmath** can convert user data to NaN and vice versa, thus facilitating arbitrary masking and clipping of data sets. Note that a few computers do not have native IEEE hardware support. At this point, this applies to some of the Cray super-computers. Users on such machines may have to adopt the old ‘-9999.99’ scheme to achieve the desired results.

Data records that contain NaN values for the *x* or *y* columns (or the *z* column for cases when 3-D Cartesian data are expected) are always skipped during reading. However, the presence of these bad records can be interpreted in two different ways, and this behavior is controlled by the **NAN_RECORDS** defaults parameter. The default setting (*gap*) considers such records to indicate a gap in an otherwise continuous series of points (e.g., a line), and programs can act upon this information, e.g., not to draw a line across the gap or to break the line into separate segments. The alternative setting (*bad*) makes no such interpretation and simply reports back how many bad records were skipped during reading.

4.20 GMT environment parameters

GMT relies on several environment parameters, in particular to find data files and program settings.

\$GMT.SHAREDIR points to the *GMT* share directory where all run-time support files such as coastlines, custom symbols, *PostScript* macros, color tables, and much more reside. If this parameter is not set it defaults to the share sub-directory selected during the *GMT* install process (e.g., your answer to question C.9 on the web install form). If no selection was made the ultimate default is the share directory under the *GMT* installation directory.

\$GMT.DATADIR points to one or more directory where large and/or widely used data files can be placed. All *GMT* programs look in this directories when a file is specified on the command line and it is not present in the current directory. This allows maintainers to consolidate large data files and to simplify scripting that use these files since the absolute path need not be specified. Separate multiple directories with colons; under Windows you use semi-colons.

\$GMT.USERDIR points to a directory where the user may place custom configuration files (e.g., an alternate `coastline.conf` file, preferred default settings in `.gmtdefaults4`, custom symbols and color palettes, and shorthands for gridfile extensions via `.gmt.io`). Users may also place their own data files in this directory as *GMT* programs will search for files given on the command line in both **\$GMT.DATADIR** and **\$GMT.USERDIR**.

\$GMT.TMPDIR is where *GMT* will write its state parameters via the three files `.gmtcommands4`, `.gmtdefaults4` and `.gmt_bb_info`. If not set then these files are written to the current directory. See Appendix P for more on the use of **\$GMT.TMPDIR**.

5. GMT Coordinate Transformations

GMT programs read real-world coordinates and convert them to positions on a plot. This is achieved by selecting one of several coordinate transformations or projections. We distinguish between three sets of such conversions:

- Cartesian coordinate transformations
- Polar coordinate transformations
- Map coordinate transformations

The next chapter will be dedicated to *GMT* map projections in its entirety. Meanwhile, the present chapter will summarize the properties of the Cartesian and Polar coordinate transformations available in *GMT*, list which parameters define them, and demonstrate how they are used to create simple plot axes. We will mostly be using **psbasemap** (and occasionally **psxy**) to demonstrate the various transformations. Our illustrations may differ from those you reproduce with the same commands because of different settings in our `.gmtdefaults4` file.) Finally, note that while we will specify dimensions in inches (by appending **i**), you may want to use cm (**c**), meters (**m**), or points (**p**) as unit instead (see the **gmtdefaults** man page).

5.1 Cartesian transformations

GMT Cartesian coordinate transformations come in three flavors:

- Linear coordinate transformation
- \log_{10} coordinate transformation
- Power (exponential) coordinate transformation

These transformations convert input coordinates (x, y) to locations (x', y') on a plot. There is no coupling between x and y (i.e., $x' = f(x)$ and $y' = f(y)$); it is a **one-dimensional** projection. Hence, we may use separate transformations for the x - and y -axes (and z -axes for 3-D plots). Below, we will use the expression $u' = f(u)$, where u is either x or y (or z for 3-D plots). The coefficients in $f(u)$ depend on the desired plot size (or scale), the chosen (x, y) domain, and the nature of f itself.

Two subsets of linear will be discussed separately; these are a polar (cylindrical) projection and a linear projection applied to geographic coordinates (with a 360° periodicity in the x -coordinate). We will show examples of all of these projections using dummy data sets created with **gmtmath**, a “Reverse Polish Notation” (RPN) calculator that operates on or creates table data:

```
gmtmath -T0/100/1 T SQRT = sqrt.d
gmtmath -T0/100/10 T SQRT = sqrt.d10
```

5.1.1 Cartesian linear transformation (–Jx –JX)

There are in fact three different uses of the Cartesian linear transformation, each associated with specific command line options. The different manifestations result from specific properties of three kinds of data:

1. Regular floating point coordinates
2. Geographic coordinates
3. Calendar time coordinates

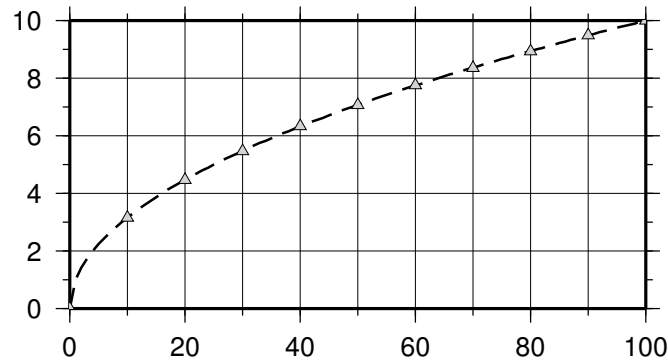


Figure 5.1: Linear transformation of Cartesian coordinates.

Regular floating point coordinates

Selection of the Cartesian linear transformation with regular floating point coordinates will result in a simple linear scaling $u' = au + b$ of the input coordinates. The projection is defined by stating

- scale in inches/unit (**-Jx**) or axis length in inches (**-JX**)

If the y-scale or y-axis length is different from that of the x-axis (which is most often the case), separate the two scales (or lengths) by a slash, e.g., **-Jx0.1i/0.5i** or **-JX8i/5i**. Thus, our $y = \sqrt{x}$ data sets will plot as shown in Figure 5.1.

The complete commands given to produce this plot were

```
psxy -R0/100/0/10 -JX3i/1.5i -Ba20f10g10/a2flg2WSne -Wthick,- -P -K sqrt.d > GMT_linear.ps
psxy -R -J -St0.075i -Glightgray -W -O sqrt.d10 >> GMT_linear.ps
```

Normally, the user's x -values will increase to the right and the y -values will increase upwards. It should be noted that in many situations it is desirable to have the direction of positive coordinates be reversed. For example, when plotting depth on the y -axis it makes more sense to have the positive direction downwards. All that is required to reverse the sense of positive direction is to supply a negative scale (or axis length).

Geographic coordinates

While the Cartesian linear projection is primarily designed for regular floating point x,y data, it is sometimes necessary to plot geographical data in a linear projection. This poses a problem since longitudes have a 360° periodicity. *GMT* therefore needs to be informed that it has been given geographical coordinates even though a linear transformation has been chosen. We do so by adding a **g** (for geographical) or **d** (for degrees) directly after **-R** or by appending a **g** or **d** to the end of the **-Jx** (or **-JX**) option. As an example, we want to plot a crude world map centered on 125°E . Our command will be

```
gmtset GRID_CROSS_SIZE_PRIMARY 0.1i BASEMAP_TYPE FANCY PLOT_DEGREE_FORMAT ddd:mm:ssF
pscoast -Rg-55/305/-90/90 -Jx0.014i -B60g30f15/30g30f15WSen -Dc -A1000 -Glightgray -Wthinnest -P \
> GMT_linear_d.ps
```

with the result reproduced in Figure 5.2.

Calendar time coordinates

Several particular issues arise when we seek to make linear plots using calendar date/time as the input coordinates. As far as setting up the coordinate transformation we must indicate whether our input data have absolute time coordinates or relative time coordinates. For the former we append **T** after the axis scale (or width), while for the latter we append **t** at the end of the **-Jx** (or **-JX**) option. However, other command line arguments (like the **-R** option) may already specify whether the time coordinate is absolute or relative.

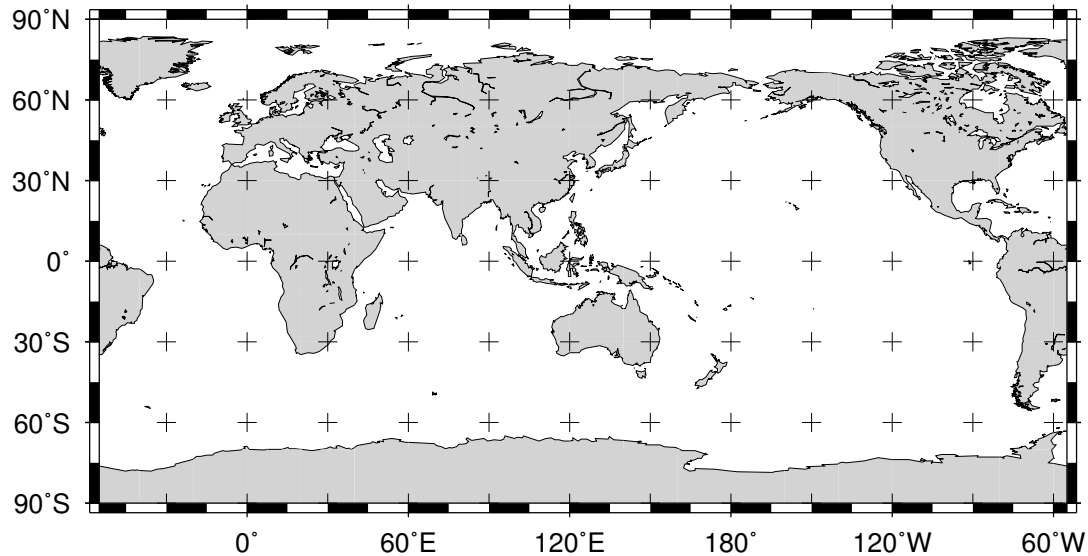


Figure 5.2: Linear transformation of map coordinates.



Figure 5.3: Linear transformation of calendar coordinates.

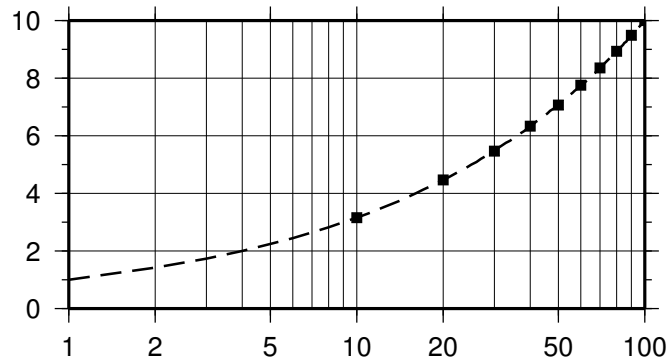
An absolute time entry must be given as `[date]T[clock]` (with *date* given as `yyyy[-mm[-dd]]`, `yyyy[-jjj]`, or `yyyy[-Www[-d]]`, and *clock* using the `hh[:mm[:ss[.xxx]]]` 24-hour clock format) whereas the relative time is simply given as the units of time since the epoch followed by **t** (see **TIME_UNIT** and **TIME_EPOCH** for information on specifying the time unit and the epoch). As a simple example, we will make a plot of a school week calendar (Figure 5.3).

```
gmtset PLOT_DATE_FORMAT o TIME_WEEK_START Sunday PLOT_CLOCK_FORMAT -hham TIME_FORMAT_PRIMARY full
psbasemap -R2001-9-24T/2001-9-29T/T07:0/T15:0 -JX4i/-2i -Ba1Kf1kg1d/a1Hg1hWsNe -P > GMT_linear_cal.ps
```

When the coordinate ranges provided by the **-R** option and the projection type given by **-JX** (including the optional **d**, **g**, **t** or **T**) conflict, *GMT* will warn the users about it. In general, the options provided with **-JX** will prevail.

5.1.2 Cartesian logarithmic projection

The \log_{10} transformation is simply $u' = a \log_{10}(u) + b$ and is selected by appending an **l** (lower case L) immediately following the scale (or axis length) value. Hence, to produce a plot in which the *x*-axis is

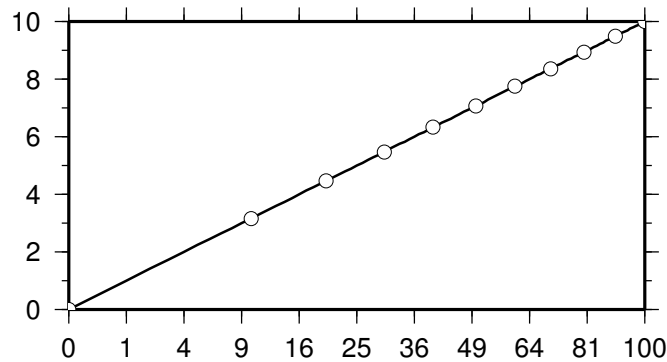
Figure 5.4: Logarithmic transformation of x -coordinates.

logarithmic (the y -axis remains linear, i.e., a semi-log plot), try

```
psxy -R1/100/0/10 -Jx1.5i1/0.15i -B2g3/a2f1g2WSne -Wthick,- -P -K -H sqrt.d > GMT_log.ps
psxy -R -J -Ss0.075i -Gblack -W -O -H sqrt.d10 >> GMT_log.ps
```

Note that if x - and y -scaling are different and a \log_{10} - \log_{10} plot is desired, the **I** must be appended twice: Once after the x -scale (before the $/$) and once after the y -scale.

5.1.3 Cartesian power projection

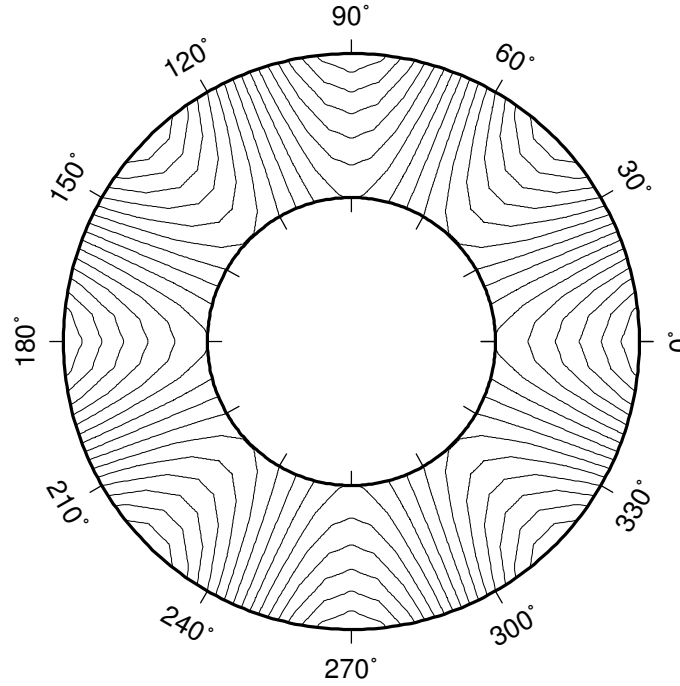
Figure 5.5: Exponential or power transformation of x -coordinates.

This projection uses $u' = au^b + c$ and allows us to explore exponential relationships like x^p versus y^q . While p and q can be any values, we will select $p = 0.5$ and $q = 1$ which means we will plot x versus \sqrt{x} . We indicate this scaling by appending a **p** (lower case P) followed by the desired exponent, in our case 0.5. Since $q = 1$ we do not need to specify **p1** since it is identical to the linear transformation. Thus our command becomes

```
psxy -R0/100/0/10 -Jx0.3ip0.5/0.15i -Ba1p/a2f1WSne -Wthick -P -K sqrt.d > GMT_pow.ps
psxy -R -J -Sc0.075i -Gwhite -W -O sqrt.d10 >> GMT_pow.ps
```

5.2 Linear projection with polar (θ, r) coordinates (-Jp -JP)

This transformation converts polar coordinates (angle θ and radius r) to positions on a plot. Now $x' = f(\theta, r)$ and $y' = g(\theta, r)$, hence it is similar to a regular map projection because x and y are coupled and x (i.e., θ) has a 360° periodicity. With input and output points both in the plane it is a **two-dimensional** projection. The transformation comes in two flavors:

Figure 5.6: Polar (Cylindrical) transformation of (θ, r) coordinates.

1. Normally, θ is understood to be directions counter-clockwise from the horizontal axis, but we may choose to specify an angular offset [whose default value is zero]. We will call this offset θ_0 . Then, $x' = f(\theta, r) = \arccos(\theta - \theta_0) + b$ and $y' = g(\theta, r) = \arcsin(\theta - \theta_0) + c$.
2. Alternatively, θ can be interpreted to be azimuths clockwise from the vertical axis, yet we may again choose to specify the angular offset [whose default value is zero]. Then, $x' = f(\theta, r) = \arccos(90 - (\theta - \theta_0)) + b$ and $y' = g(\theta, r) = \arcsin(90 - (\theta - \theta_0)) + c$.

Consequently, the polar transformation is defined by providing

- scale in inches/unit (**-Jp**) or full width of plot in inches (**-JP**)
- Optionally, insert **a** after **p|P** to indicate CW azimuths rather than CCW directions
- Optionally, append */origin* in degrees to indicate an angular offset [0]
- Optionally, append **r** to reverse the radial direction (here, *south* and *north* must be elevations in 0–90° range).
- Optionally, append **z** to annotate depths rather than radius.

As an example of this projection we will create a gridded data set in polar coordinates $z(\theta, r) = r^2 \cdot \cos 4\theta$ using **grdmath**, a RPN calculator that operates on or creates grid files.

```
grdmath -R0/360/2/4 -I6/0.1 X 4 MUL PI MUL 180 DIV COS Y 2 POW MUL = $$$.grd
grdcontour $$$.grd -JP3i -B30Ns -P -C2 -S4 --PLOT_DEGREE_FORMAT=+ddd > GMT_polar.ps
rm -f $$$.grd
```

We used **grdcontour** to make a contour map of this data. Because the data file only contains values with $2 \leq r \leq 4$, a donut shaped plot appears in Figure 5.6.

6. GMT Map Projections

GMT implements more than 30 different projections. They all project the input coordinates longitude and latitude to positions on a map. In general, $x' = f(x, y, z)$ and $y' = g(x, y, z)$, where z is implicitly given as the radial vector length to the (x, y) point on the chosen ellipsoid. The functions f and g can be quite nasty and we will refrain from presenting details in this document. The interested read is referred to *Snyder* [1987]¹. We will mostly be using the **pscoast** command to demonstrate each of the projections. *GMT* map projections are grouped into four categories depending on the nature of the projection. The groups are

1. Conic map projections
2. Azimuthal map projections
3. Cylindrical map projections
4. Miscellaneous projections

Because x and y are coupled we can only specify one plot-dimensional scale, typically a map *scale* (for lower-case map projection code) or a map *width* (for upper-case map projection code). However, in some cases it would be more practical to specify map *height* instead of *width*, while in other situations it would be nice to set either the *shortest* or *longest* map dimension. Users may select these alternatives by appending a character code to their map dimension. To specify map *height*, append **h** to the given dimension; to select the minimum map dimension, append **-**, whereas you may append **+** to select the maximum map dimension. Without the modifier the map width is selected by default.

In *GMT* version 4.3.0 we noticed we ran out of the alphabet for 1-letter (and sometimes 2-letter) projection codes. To allow more flexibility, and to make it easier to remember the codes, we implemented the option to use the abbreviations used by the **Proj4** mapping package. Since some of the *GMT* projections are not in **Proj4**, we invented some of our own as well. For a full list of both the old 1- and 2-letter codes, as well as the **Proj4**-equivalents see the quick reference cards in Section 3.2. For example, **-JM15c** and **-JMerc/15c** have the same meaning.

6.1 Conic projections

6.1.1 Albers conic equal-area projection (**-Jb -JB**)

This projection, developed by Albers in 1805, is predominantly used to map regions of large east-west extent, in particular the United States. It is a conic, equal-area projection, in which parallels are unequally spaced arcs of concentric circles, more closely spaced at the north and south edges of the map. Meridians, on the other hand, are equally spaced radii about a common center, and cut the parallels at right angles. Distortion in scale and shape vanishes along the two standard parallels. Between them, the scale along parallels is too small; beyond them it is too large. The opposite is true for the scale along meridians. To define the projection in *GMT* you need to provide the following information:

- Longitude and latitude of the projection center.
- Two standard parallels.
- Map scale in inch/degree or 1:xxxxx notation (**-Jb**), or map width (**-JB**).

Note that you must include the “1:” if you choose to specify the scale that way. E.g., you can say 0.5 which means 0.5 inch/degree or 1:200000 which means 1 inch on the map equals 200,000 inches along the standard parallels. The projection center defines the origin of the rectangular map coordinates. As an example we will make a map of the region near Taiwan. We choose the center of the projection to be at 125 °E/20 °N and 25 °N and 45 °N as our two standard parallels. We desire a map that is 5 inches wide. The complete command needed to generate the map below is therefore given by:

¹ Snyder, J. P., 1987, Map Projections A Working Manual, U.S. Geological Survey Prof. Paper 1395.

```
gmtset GRID_CROSS_SIZE_PRIMARY 0
pscoast -R110/140/20/35 -JB125/20/25/45/5i -B10g5 -Dl -Glightgray -Wthinnest -A250 -P > GMT_albers.ps
```

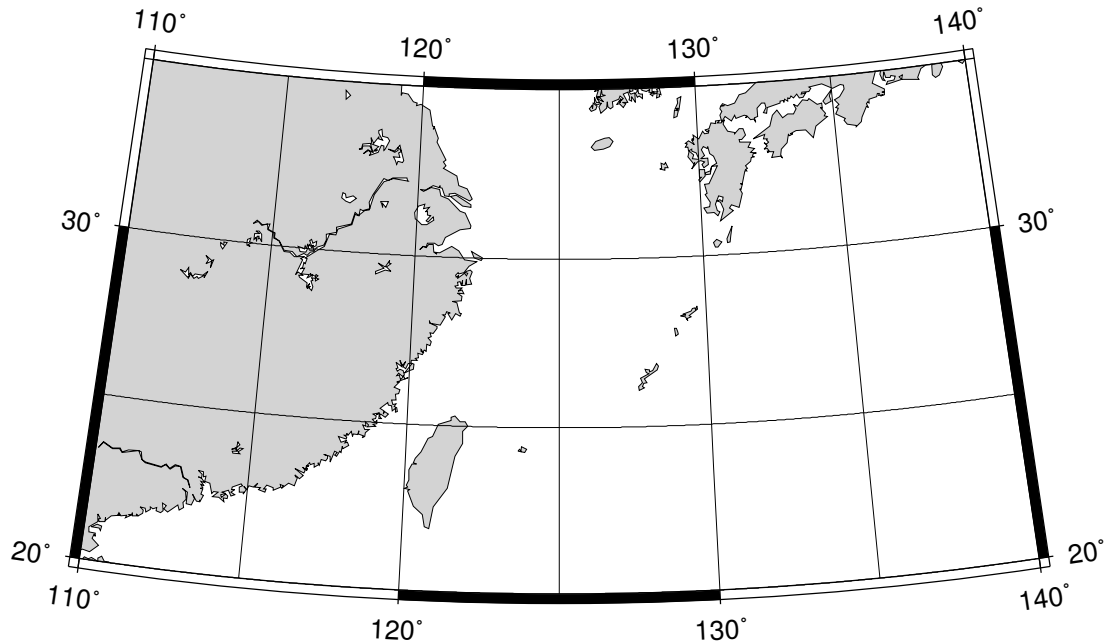


Figure 6.1: Albers equal-area conic map projection

6.1.2 Equidistant conic projection (–Jd –JD)

The equidistant conic projection was described by the Greek philosopher Claudius Ptolemy about A.D. 150. It is neither conformal or equal-area, but serves as a compromise between them. The scale is true along all meridians and the standard parallels. To select this projection in *GMT* you must provide the same information as for the other conic projection, i.e.

- Longitude and latitude of the projection center.
- Two standard parallels.
- Map scale in inch/degree or 1:xxxxx notation (–Jd), or map width (–JD).

The equidistant conic projection is often used for atlases with maps of small countries. As an example, we generate a map of Cuba:

```
gmtset PLOT_DEGREE_FORMAT ddd:mm:ssF GRID_CROSS_SIZE_PRIMARY 0.05i
pscoast -R-88/-70/18/24 -JD-79/21/19/23/4.5i -B5g1 -Di -Nl/thick -Glightgray \
-Wthinnest -P > GMT_equidistant_conic.ps
```

6.1.3 Lambert conic conformal projection (–Jl –JL)

This conic projection was designed by the Alsatian mathematician Johann Heinrich Lambert (1772) and has been used extensively for mapping of regions with predominantly east-west orientation, just like the Albers projection. Unlike the Albers projection, Lambert's conformal projection is not equal-area. The parallels are arcs of circles with a common origin, and meridians are the equally spaced radii of these circles. As with Albers projection, it is only the two standard parallels that are distortion-free. To select this projection in *GMT* you must provide the same information as for the Albers projection, i.e.

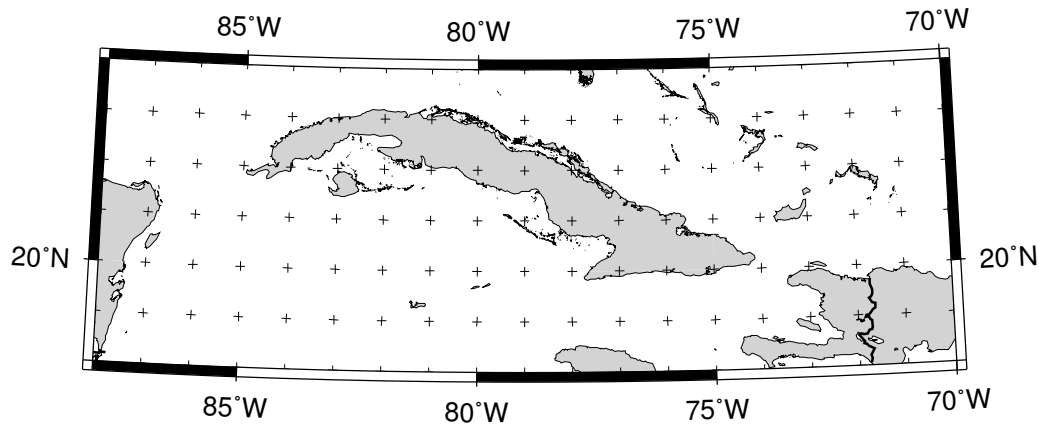


Figure 6.2: Equidistant conic map projection

- Longitude and latitude of the projection center.
- Two standard parallels.
- Map scale in inch/degree or 1:xxxxx notation (**-JI**), or map width (**-JL**).

The Lambert conformal projection has been used for basemaps for all the 48 contiguous States with the two fixed standard parallels 33°N and 45°N. We will generate a map of the continental USA using these parameters. Note that with all the projections you have the option of selecting a rectangular border rather than one defined by meridians and parallels. Here, we choose the regular WESN region, a “fancy” basemap frame, and use degrees west for longitudes. The generating commands used were

```
gmtset BASEMAP_TYPE FANCY PLOT_DEGREE_FORMAT ddd:mm:ssF GRID_CROSS_SIZE_PRIMARY 0.05i
pscoast -R-130/-70/24/52 -Jl-100/35/33/45/1:50000000 -B10g5 -D1 -N1/thick -N2/thinner -A500 \
  -Glightgray -Wthinnest -P > GMT_lambert_conic.ps
```

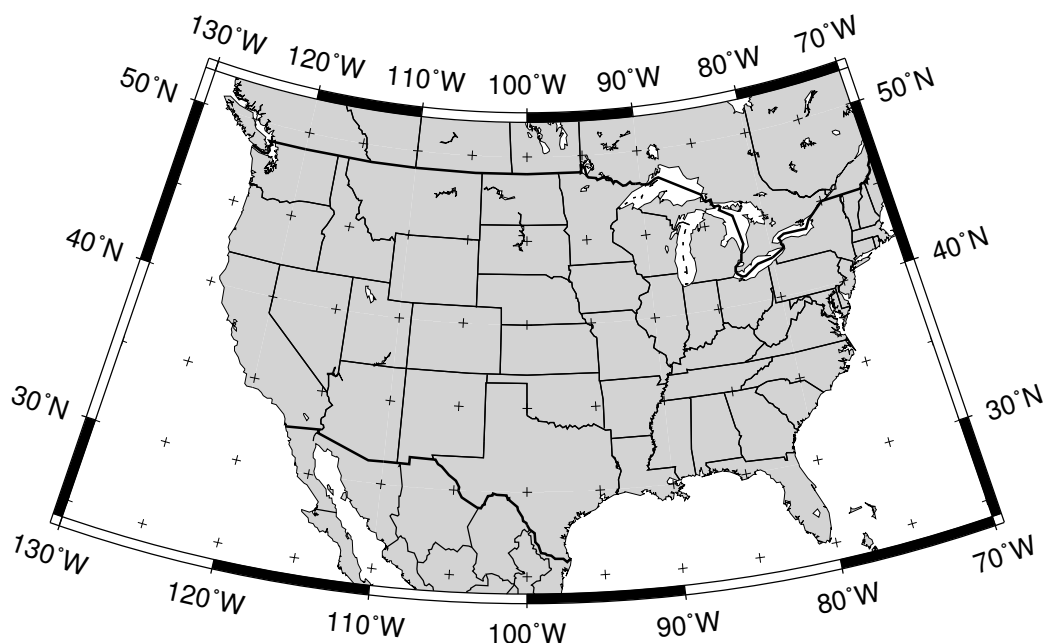


Figure 6.3: Lambert conformal conic map projection

The choice for projection center does not affect the projection but it indicates which meridian (here 100°W) will be vertical on the map. The standard parallels were originally selected by Adams to provide a maximum scale error between latitudes 30.5°N and 47.5°N of 0.5–1%. Some areas, like Florida, experience scale errors of up to 2.5%.

6.2 Azimuthal projections

6.2.1 Lambert Azimuthal Equal-Area (-Ja -JA)

This projection was developed by Lambert in 1772 and is typically used for mapping large regions like continents and hemispheres. It is an azimuthal, equal-area projection, but is not perspective. Distortion is zero at the center of the projection, and increases radially away from this point. To define this projection in *GMT* you must provide the following information:

- Longitude and latitude of the projection center.
- Optionally, the horizon, i.e., the number of degrees from the center to the edge ($\leq 180^\circ$, default is 90°).
- Scale as 1:xxxxx or as radius/latitude where radius is the projected distance on the map from projection center to an oblique latitude (**-Ja**), or map width (**-JA**).

Two different types of maps can be made with this projection depending on how the region is specified. We will give examples of both types.

Rectangular map

In this mode we define our region by specifying the longitude/latitude of the lower left and upper right corners instead of the usual *west*, *east*, *south*, *north* boundaries. The reason for specifying our area this way is that for this and many other projections, lines of equal longitude and latitude are not straight lines and are thus poor choices for map boundaries. Instead we require that the map boundaries be rectangular by defining the corners of a rectangular map boundary. Using $0^\circ\text{E}/40^\circ\text{S}$ (lower left) and $60^\circ\text{E}/10^\circ\text{S}$ (upper right) as our corners we try

```
gmtset PLOT_DEGREE_FORMAT ddd:mm:ssF GRID_CROSS_SIZE_PRIMARY 0
pscoast -R0/-40/60/-10r -JA30/-30/4.5i -B30g30/15g15 -D1 -A500 -Glightgray -Wthinnest -P \
> GMT_lambert_az_rect.ps
```

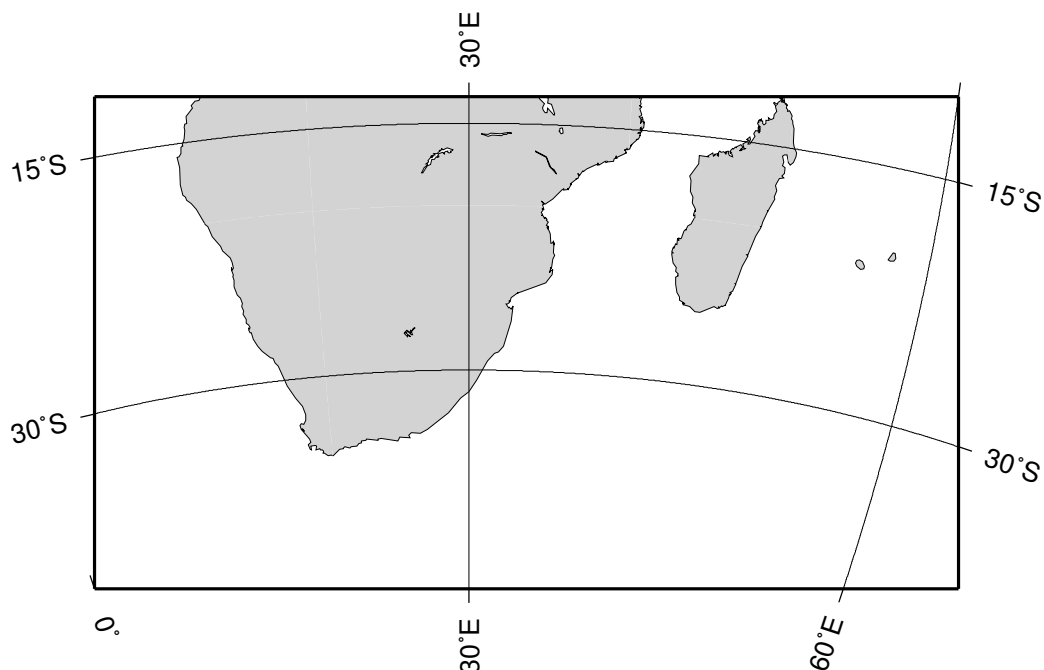


Figure 6.4: Rectangular map using the Lambert azimuthal equal-area projection.

Note that an “r” is appended to the **-R** option to inform *GMT* that the region has been selected using the rectangle technique, otherwise it would try to decode the values as *west*, *east*, *south*, *north* and report an error since *'east' < 'west'*.

Hemisphere map

Here, you must specify the world as your region (**-Rg** or **-Rd**). E.g., to obtain a hemisphere view that shows the Americas, try

```
pscoast -Rg -JA280/30/3.5i -B30g30/15g15 -Dc -A1000 -Gblack -P > GMT_lambert_az_hemi.ps
```



Figure 6.5: Hemisphere map using the Lambert azimuthal equal-area projection.

To geologists, the Lambert azimuthal equal-area projection (with origin at $0^\circ/0^\circ$) is known as the *equal-area* (Schmidt) stereonet and used for plotting fold axes, fault planes, and the like. An *equal-angle* (Wulff) stereonet can be obtained by using the stereographic projection (discussed later). The stereonets produced by these two projections appear below.

6.2.2 Stereographic Equal-Angle projection (**-Js -JS**)

This is a conformal, azimuthal projection that dates back to the Greeks. Its main use is for mapping the polar regions. In the polar aspect all meridians are straight lines and parallels are arcs of circles. While this is the most common use it is possible to select any point as the center of projection. The requirements are

- Longitude and latitude of the projection center.
- Optionally, the horizon, i.e., the number of degrees from the center to the edge ($<180^\circ$, default is 90°).
- Scale as 1:xxxxx (true scale at pole), slat/1:xxxxx (true scale at standard parallel slat), or radius/latitude where radius is distance on map in inches from projection center to a particular [possibly oblique] latitude (**-Js**), or simply map width (**-JS**).

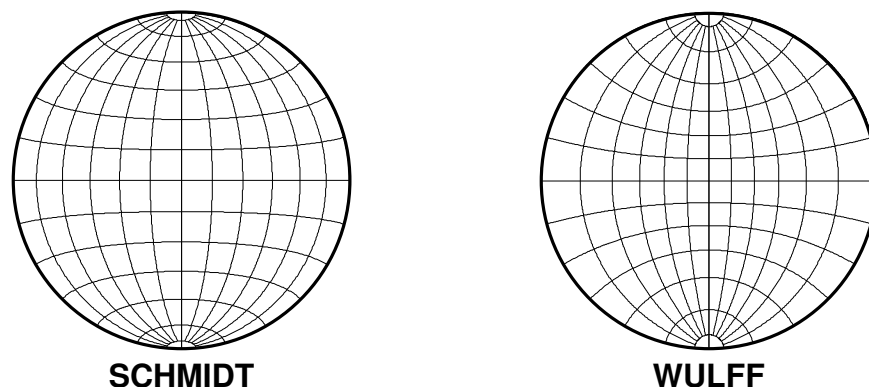


Figure 6.6: Equal-Area (Schmidt) and Equal-Angle (Wulff) stereo nets.

A default map scale factor of 0.9996 will be applied by default (although you may change this with **MAP_SCALE_FACTOR**). However, the setting is ignored when a standard parallel has been specified since the scale is then implicitly given. We will look at two different types of maps.

Polar Stereographic Map

In our first example we will let the projection center be at the north pole. This means we have a polar stereographic projection and the map boundaries will coincide with lines of constant longitude and latitude. An example is given by

```
pscoast -R-30/30/60/72 -Js0/90/4.5i/60 -Ba10g5/5g5 -Dl -A250 -Gblack -P > GMT_stereographic_polar.ps
```

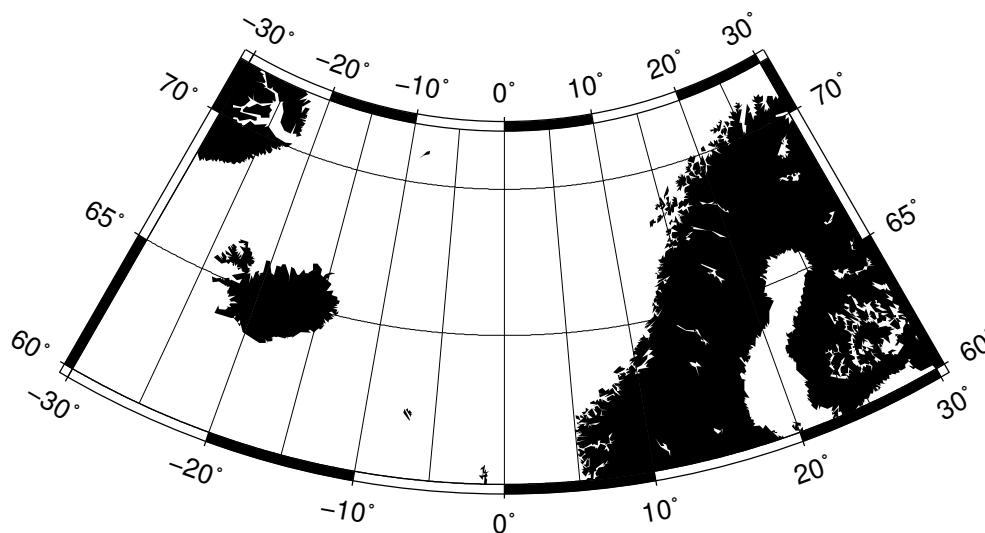


Figure 6.7: Polar stereographic conformal projection.

Rectangular stereographic map

As with Lambert's azimuthal equal-area projection we have the option to use rectangular boundaries rather than the wedge-shape typically associated with polar projections. This choice is defined by selecting two points as corners in the rectangle and appending an "r" to the **-R** option. This command produces a map as presented in Figure 6.8:

```
gmtset OBLIQUE_ANNOTATION 30
pscoast -R-25/59/70/72r -JS10/90/11c -B30g10/5g5 -Dl -A250 -Glightgray -Wthinnest -P \
> GMT_stereographic_rect.ps
```

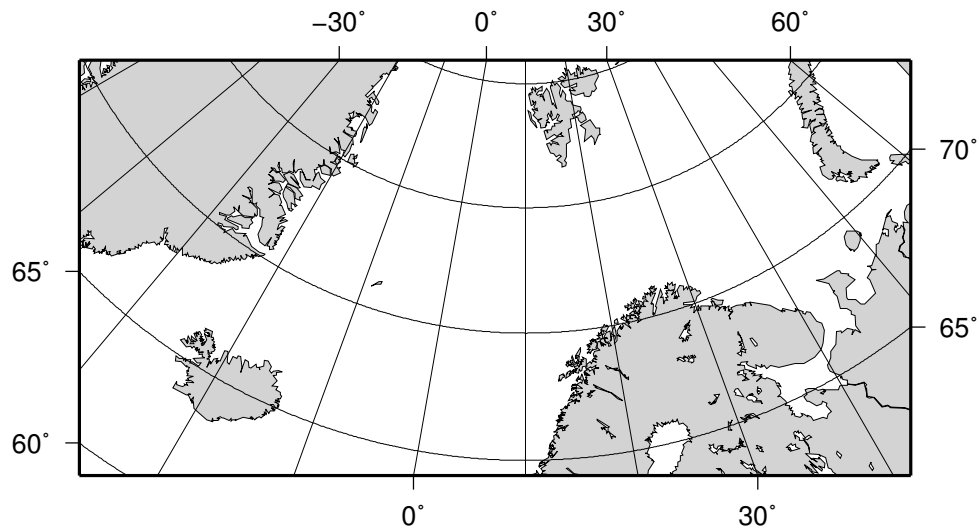


Figure 6.8: Polar stereographic conformal projection with rectangular borders.

General stereographic map

In terms of usage this projection is identical to the Lambert azimuthal equal-area projection. Thus, one can make both rectangular and hemispheric maps. Our example shows Australia using a projection pole at 130E/30°S. The command used was

```
gmtset OBLIQUE_ANNOTATION 0
pscoast -R100/-40/160/-10r -JS130/-30/4i -B30g10/15g15 -Dl -A500 -Gblack -P \
> GMT_stereographic_general.ps
```

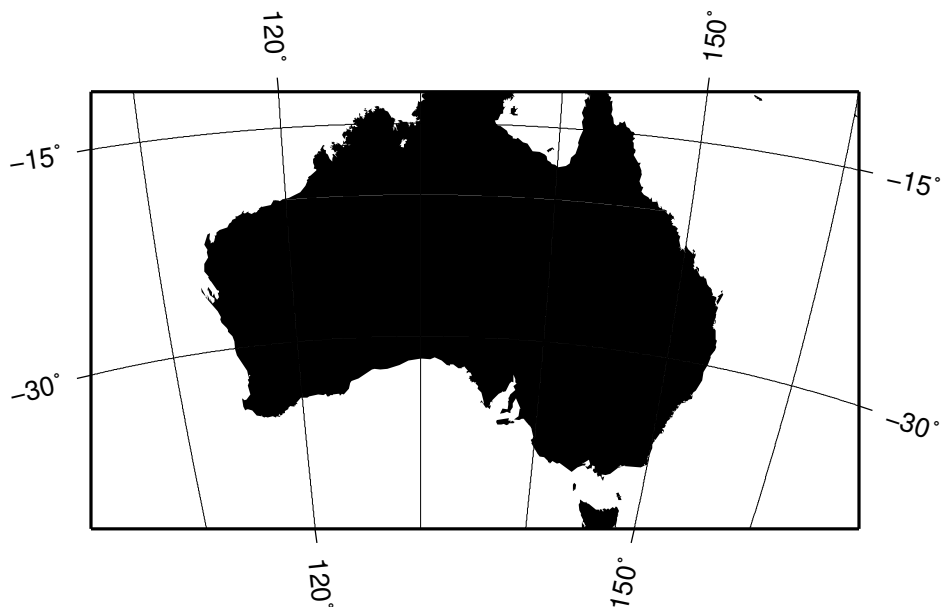


Figure 6.9: General stereographic conformal projection with rectangular borders.

By choosing $0^\circ/0^\circ$ as the pole, we obtain the conformal stereonet presented next to its equal-area cousin in the Section 6.2.1 on the Lambert azimuthal equal-area projection (Figure 6.6).

6.2.3 Perspective projection (**-Jg -JG**)

The perspective projection imitates in 2 dimensions the 3-dimensional view of the earth from space. The implementation in *GMT* is very flexible, and thus requires many input variables. Those are listed and explained below, with the values used in Figure 6.10 between brackets.

- Longitude and latitude of the projection center ($4^\circ\text{E}/52^\circ\text{N}$).
- Altitude of the viewer above sea level in kilometers (230 km). If this value is less than 10, it is assumed to be the distance of the viewer from the center of the earth in earth radii. If an “r” is appended, it is the distance from the center of the earth in kilometers.
- Azimuth in degrees (90° , due east). This is the direction in which you are looking, measured clockwise from north.
- Tilt in degrees (60°). This is the viewing angle relative to zenith. So a tilt of 0° is looking straight down, 60° is looking from 30° above the horizon.
- Twist in degrees (180°). This is the boresight rotation (clockwise) of the image. The twist of 180° in the example mimics the fact that the Space Shuttle flies upside down.
- Width and height of the viewpoint in degrees (60°). This number depends on whether you are looking with the naked eye (in which case you view is about 60° wide), or with binoculars, for example.
- Scale as 1:xxxxx or as radius/latitude where radius is distance on map in inches from projection center to a particular [possibly oblique] latitude (**-Jg**), or map width (**-JG**) (5 inches).

The imagined view of northwest Europe from a Space Shuttle at 230 km looking due east is thus accomplished by the following **pscoast** command:

```
pscoast -Rg -JG4/52/230/90/60/180/60/60/5i -B2g2/1g1 -Ia -Di -Glightgray -Wthinnest -P \
--ANNOT_MIN_SPACING=0.25i > GMT_perspective.ps
```

6.2.4 Orthographic projection (**-Jg -JG**)

The orthographic azimuthal projection is a perspective projection from infinite distance. It is therefore often used to give the appearance of a globe viewed from outer space. As with Lambert’s equal-area and the stereographic projection, only one hemisphere can be viewed at any time. The projection is neither equal-area nor conformal, and much distortion is introduced near the edge of the hemisphere. The directions from the center of projection are true. The projection was known to the Egyptians and Greeks more than 2,000 years ago. Because it is mainly used for pictorial views at a small scale, only the spherical form is necessary.

To specify the orthographic projection the same options **-Jg** or **-JG** as the perspective projection are used, but with fewer variables to supply:

- Longitude and latitude of the projection center.
- Optionally, the horizon, i.e., the number of degrees from the center to the edge ($\leq 90^\circ$, default is 90°).
- Scale as 1:xxxxx or as radius/latitude where radius is distance on map in inches from projection center to a particular [possibly oblique] latitude (**-Jg**), or map width (**-JG**).

Our example of a perspective view centered on $75^\circ\text{W}/40^\circ\text{N}$ can therefore be generated by the following **pscoast** command:

```
pscoast -Rg -JG-75/41/4.5i -B15g15 -Dc -A5000 -Gblack -P > GMT_orthographic.ps
```

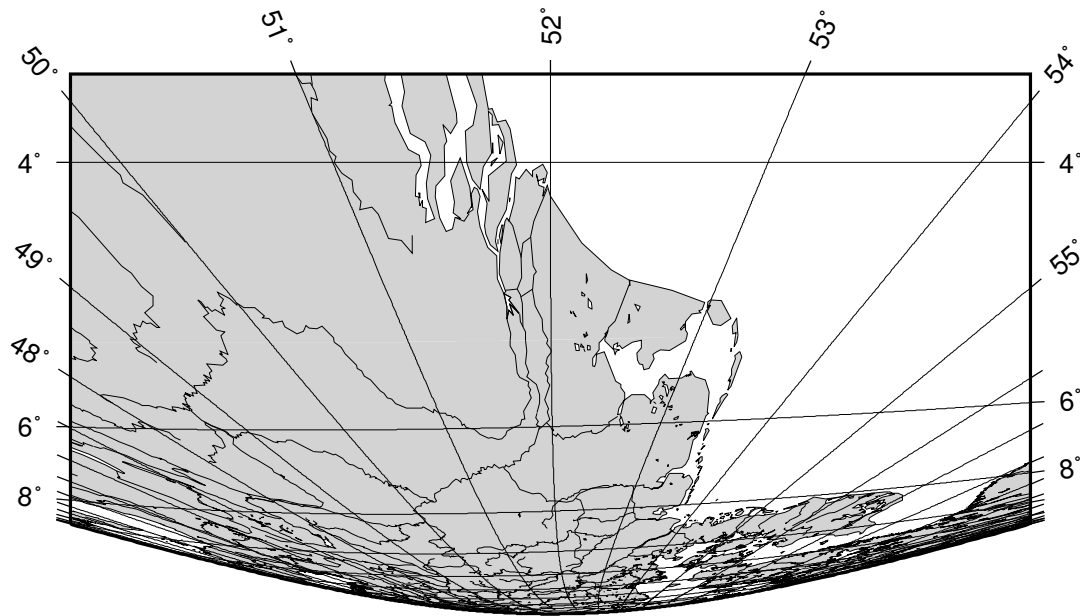


Figure 6.10: View from the Space Shuttle in Perspective projection.

6.2.5 Azimuthal Equidistant projection (**-Je -JE**)

The most noticeable feature of this azimuthal projection is the fact that distances measured from the center are true. Therefore, a circle about the projection center defines the locus of points that are equally far away from the plot origin. Furthermore, directions from the center are also true. The projection, in the polar aspect, is at least several centuries old. It is a useful projection for a global view of locations at various or identical distance from a given point (the map center).

To specify the azimuthal equidistant projection you must supply:

- Longitude and latitude of the projection center.
- Optionally, the horizon, i.e., the number of degrees from the center to the edge ($\leq 180^\circ$, default is 180°).
- Scale as 1:xxxxx or as radius/latitude where radius is distance on map in inches from projection center to a particular [possibly oblique] latitude (**-Je**), or map width (**-JE**).

Our example of a global view centered on $100^\circ\text{W}/40^\circ\text{N}$ can therefore be generated by the following **pscoast** command. Note that the antipodal point is 180° away from the center, but in this projection this point plots as the entire map perimeter:

```
pscoast -Rg -JE-100/40/4.5i -B15g15 -Dc -A10000 -Glightgray -Wthinnest -P > GMT_az_equidistant.ps
```

6.2.6 Gnomonic projection (**-Jf -JF**)

The Gnomonic azimuthal projection is a perspective projection from the center onto a plane tangent to the surface. Its origin goes back to the old Greeks who used it for star maps almost 2500 years ago. The projection is neither equal-area nor conformal, and much distortion is introduced near the edge of the hemisphere; in fact, less than a hemisphere may be shown around a given center. The directions from the center of projection are true. Great circles project onto straight lines. Because it is mainly used for pictorial views at a small scale, only the spherical form is necessary.

To specify the Gnomonic projection you must supply:

- Longitude and latitude of the projection center.



Figure 6.11: Hemisphere map using the Orthographic projection.

- Optionally, the horizon, i.e., the number of degrees from the center to the edge ($<90^\circ$, default is 60°).
- Scale as 1:xxxxx or as radius/latitude where radius is distance on map in inches from projection center to a particular [possibly oblique] latitude (**-Jf**), or map width (**-JF**).

Using a horizon of 60° , our example of this projection centered on $120^\circ\text{W}/35^\circ\text{N}$ can therefore be generated by the following **pscoast** command:

```
pscoast -Rg -JF-120/35/60/4.5i -B30g15 -Dc -A10000 -Glightgray -Wthinest -P > GMT_gnomonic.ps
```

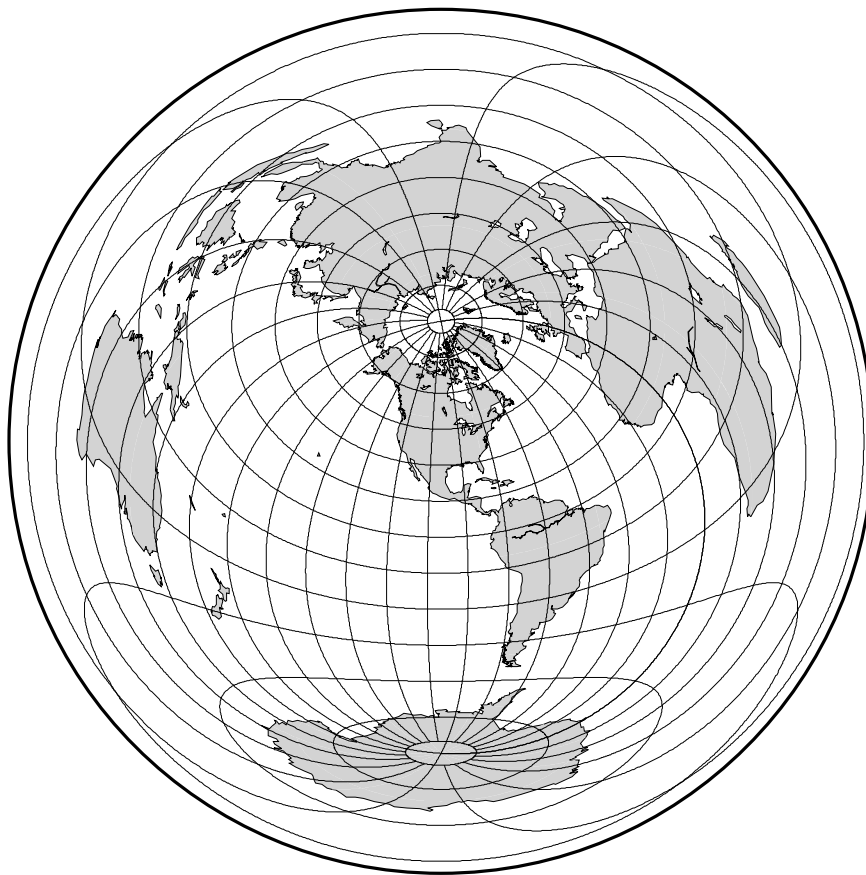


Figure 6.12: World map using the equidistant azimuthal projection.

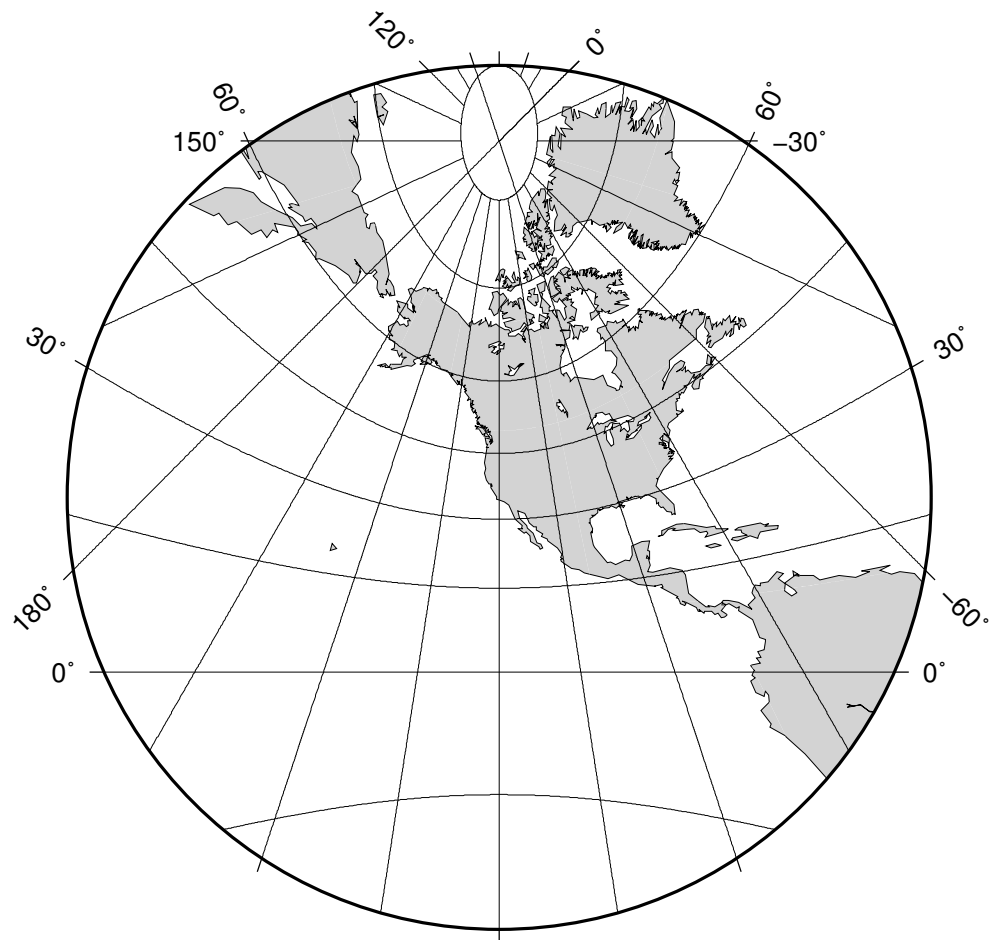


Figure 6.13: Gnomonic azimuthal projection.

6.3 Cylindrical projections

Cylindrical projections are easily recognized for its shape: maps are rectangular and meridians and parallels are straight lines crossing at right angles. But that is where similarities between the cylindrical projections supported by *GMT* (Mercator, transverse Mercator, universal transverse Mercator, oblique Mercator, Cassini, cylindrical equidistant, cylindrical equal-area, Miller, and cylindrical stereographic projections) stops. Each have a different way of spacing the meridians and parallels to obtain certain desirable cartographic properties.

6.3.1 Mercator projection (**-Jm -JM**)

Probably the most famous of the various map projections, the Mercator projection takes its name from the Flemish cartographer Gheert Cremer, better known as Gerardus Mercator, who presented it in 1569. The projection is a cylindrical and conformal, with no distortion along the equator. A major navigational feature of the projection is that a line of constant azimuth is straight. Such a line is called a rhumb line or *loxodrome*. Thus, to sail from one point to another one only had to connect the points with a straight line, determine the azimuth of the line, and keep this constant course for the entire voyage². The Mercator projection has been used extensively for world maps in which the distortion towards the polar regions grows rather large, thus incorrectly giving the impression that, for example, Greenland is larger than South America. In reality, the latter is about eight times the size of Greenland. Also, the Former Soviet Union looks much bigger than Africa or South America. One may wonder whether this illusion has had any influence on U.S. foreign policy.

In the regular Mercator projection, the cylinder touches the globe along the equator. Other orientations like vertical and oblique give rise to the Transverse and Oblique Mercator projections, respectively. We will discuss these generalizations following the regular Mercator projection.

The regular Mercator projection requires a minimum of parameters. To use it in *GMT* programs you supply this information (the first two items are optional and have defaults):

- Central meridian [Middle of your map].
- Standard parallel for true scale [Equator]. When supplied, central meridian must be supplied as well.
- Scale along the equator in inch/degree or 1:xxxxx (**-Jm**), or map width (**-JM**).

Our example presents a world map at a scale of 0.012 inch pr degree which will give a map 4.32 inch wide. It was created with the command:

```
gmtset BASEMAP_TYPE fancy
pscoast -R0/360/-70/70 -Jm1.2e-2i -Ba60f30/a30f15 -Dc -A5000 -Gblack -P > GMT_mercator.ps
```

²This is, however, not the shortest distance. It is given by the great circle connecting the two points.

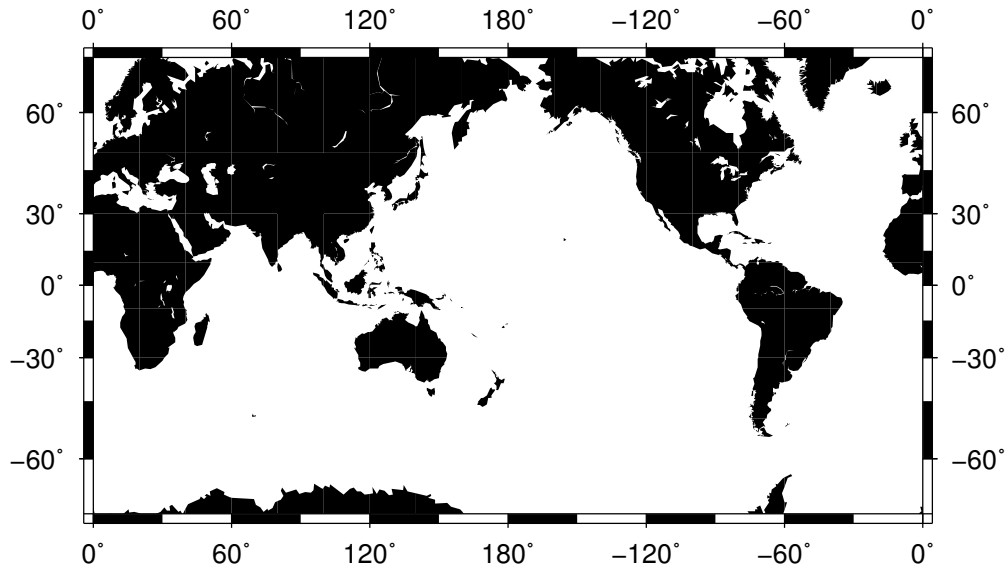


Figure 6.14: Simple Mercator map.

While this example is centered on the Dateline, one can easily choose another configuration with the **-R** option. A map centered on Greenwich would specify the region with **-R-180/180/-70/70**.

6.3.2 Transverse Mercator projection (**-Jt -JT**)

The transverse Mercator was invented by Lambert in 1772. In this projection the cylinder touches a meridian along which there is no distortion. The distortion increases away from the central meridian and goes to infinity at 90° from center. The central meridian, each meridian 90° away from the center, and equator are straight lines; other parallels and meridians are complex curves. The projection is defined by specifying:

- The central meridian.
- Optionally, the latitude of origin (default is the equator).
- Scale along the equator in inch/degree or 1:xxxxx (**-Jt**), or map width (**-JT**).

The optional latitude of origin defaults to Equator if not specified. Although defaulting to 1, you can change the map scale factor via the **MAP_SCALE_FACTOR** parameter. Our example shows a transverse Mercator map of south-east Europe and the Middle East with 35°E as the central meridian:

```
pscoast -R20/30/50/45r -Jt35/0.18i -B10g5 -D1 -A250 -Glightgray -Wthinest -P \
> GMT_transverse_merc.ps
```

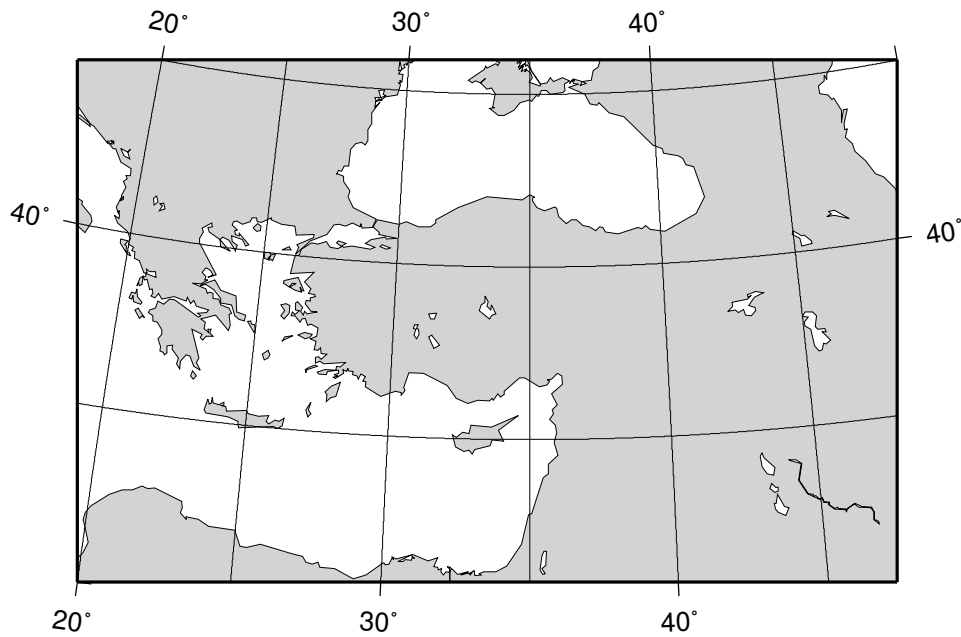


Figure 6.15: Rectangular Transverse Mercator map.

The transverse Mercator can also be used to generate a global map—the equivalent of the 360° Mercator map. Using the command

```
pscoast -R0/360/-80/80 -JT330/-45/3.5i -B30g15/15g15WSne -Dc -A2000 -Gblack -P > GMT_TM.ps
```

we made the map illustrated in Figure 6.16. Note that when a world map is given (indicated by **-R0/360/s/n**), the arguments are interpreted to mean oblique degrees, i.e., the 360° range is understood to mean the extent of the plot along the central meridian, while the “south” and “north” values represent how far from the central longitude we want the plot to extend. These values correspond to latitudes in the regular Mercator projection and must therefore be less than 90°.

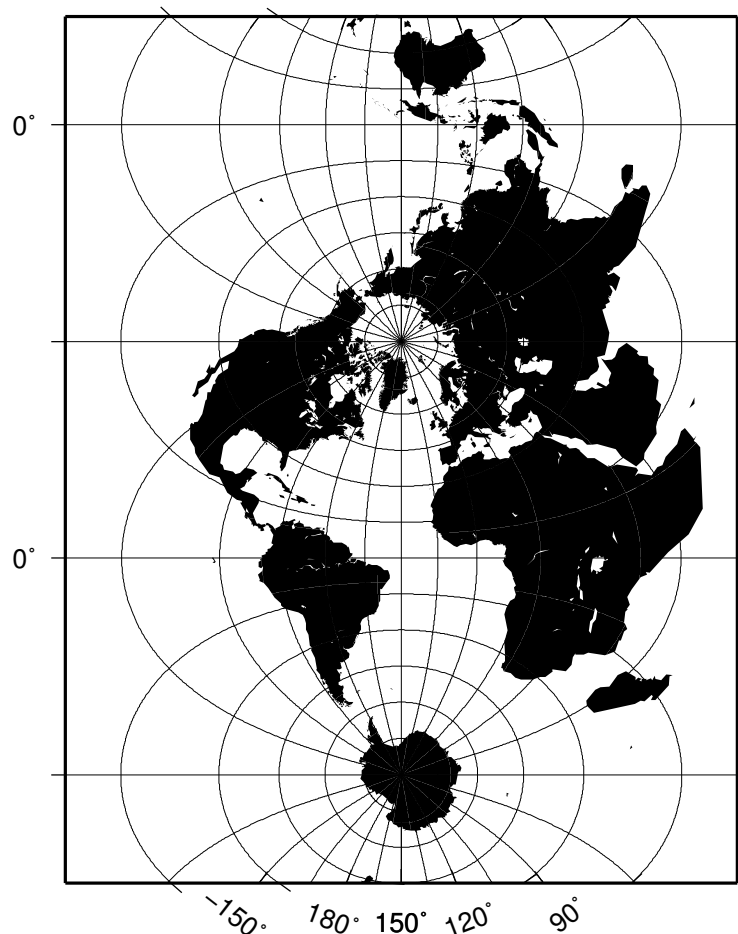


Figure 6.16: A global transverse Mercator map.

6.3.3 Universal Transverse Mercator (UTM) projection (**-Ju -JU**)

A particular subset of the transverse Mercator is the Universal Transverse Mercator (UTM) which was adopted by the US Army for large-scale military maps. Here, the globe is divided into 60 zones between 84°S and 84°N, most of which are 6° wide. Each of these UTM zones have their unique central meridian. Furthermore, each zone is divided into latitude bands but these are not needed to specify the projection for most cases. See Figure 6.17 for all zone designations.

GMT implements both the transverse Mercator and the UTM projection. When selecting UTM you must specify:

- UTM zone (A, B, 1–60, Y, Z). Use negative values for numerical zones in the southern hemisphere or append the latitude modifiers C–H, J–N, P–X) to specify an exact UTM grid zone.
- Scale along the equator in inch/degree or 1:xxxxx (**-Ju**), or map width (**-JU**).

In order to minimize the distortion in any given zone, a scale factor of 0.9996 has been factored into the formulae. (although a standard, you can change this with **MAP_SCALE_FACTOR**). This makes the UTM projection a *secant* projection and not a *tangent* projection like the transverse Mercator above. The scale only varies by 1 part in 1,000 from true scale at equator. The ellipsoidal projection expressions are accurate for map areas that extend less than 10° away from the central meridian. For larger regions we use the conformal latitude in the general spherical formulae instead.

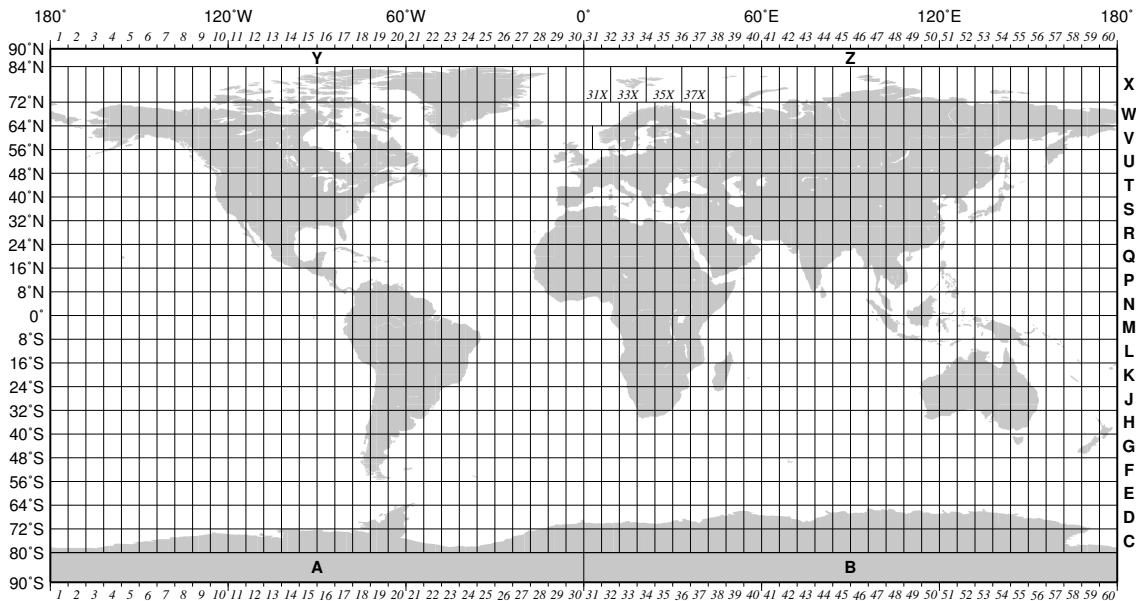


Figure 6.17: Universal Transverse Mercator zone layout.

6.3.4 Oblique Mercator projection (**-Jo -JO**)

Oblique configurations of the cylinder give rise to the oblique Mercator projection. It is particularly useful when mapping regions of large lateral extent in an oblique direction. Both parallels and meridians are complex curves. The projection was developed in the early 1900s by several workers. Several parameters must be provided to define the projection. *GMT* offers three different definitions:

1. Option **-Joa** or **-JOa**:
 - Longitude and latitude of projection center.
 - Azimuth of the oblique equator.
 - Scale in inch/degree or 1:xxxxx along oblique equator (**-Joa**), or map width (**-JOa**).
2. Option **-Job** or **-JOB**:
 - Longitude and latitude of projection center.
 - Longitude and latitude of second point on oblique equator.
 - Scale in inch/degree or 1:xxxxx along oblique equator (**-Job**), or map width (**-JOB**).
3. Option **-Joc** or **-JOc**:
 - Longitude and latitude of projection center.
 - Longitude and latitude of projection pole.
 - Scale in inch/degree or 1:xxxxx along oblique equator (**-Joc**), or map width (**-JOc**).

Our example was produced by the command

```
pscoast -R270/20/305/25r -JOc280/25.5/22/69/4.8i -B10g5 -Di -A250 -Glightgray -Wthinest -P \
-Tf301.5/23/0.4i/2 --HEADER_FONT_SIZE=8p --HEADER_OFFSET=0.05i > GMT_obl_merc.ps
```

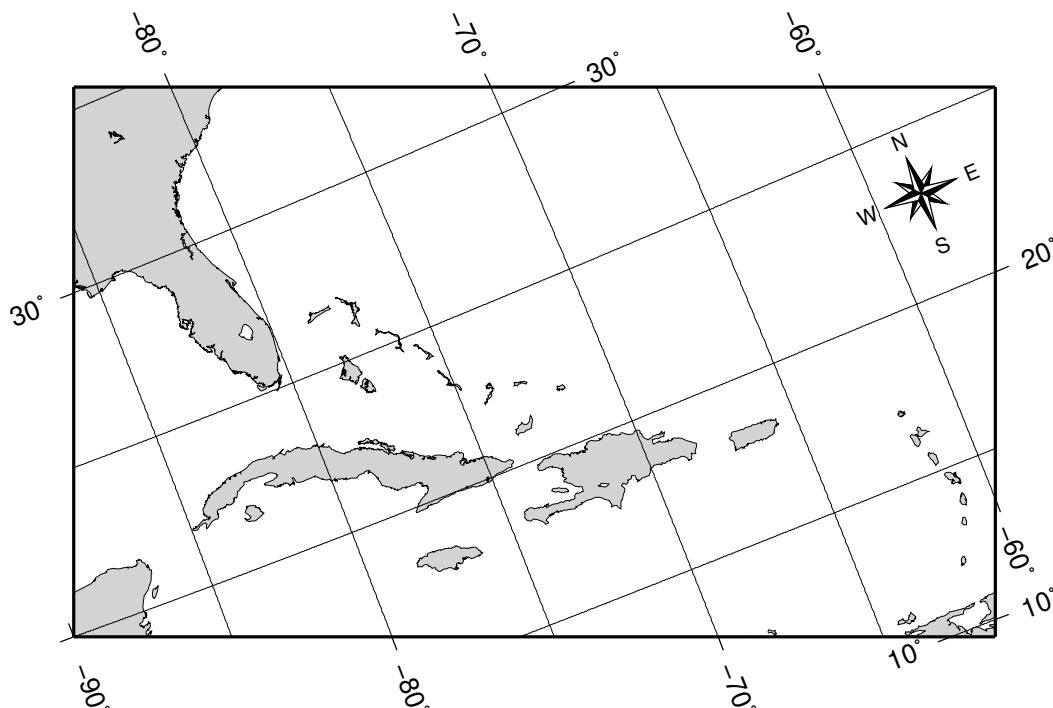


Figure 6.18: Oblique Mercator map using `-Joc`. We make it clear which direction is North by adding a star rose with the `-T` option.

It uses definition 3 for an oblique view of some Caribbean islands. Note that we define our region using the rectangular system described earlier. If we do not append an “r” to the `-R` string then the information provided with the `-R` option is assumed to be oblique degrees about the projection center rather than the usual geographic coordinates. This interpretation is chosen since in general the parallels and meridians are not very suitable as map boundaries.

6.3.5 Cassini cylindrical projection (`-Jc`–`JC`)

This cylindrical projection was developed in 1745 by César-François Cassini de Thury for the survey of France. It is occasionally called Cassini-Soldner since the latter provided the more accurate mathematical analysis that led to the development of the ellipsoidal formulae. The projection is neither conformal nor equal-area, and behaves as a compromise between the two end-members. The distortion is zero along the central meridian. It is best suited for mapping regions of north-south extent. The central meridian, each meridian 90° away, and equator are straight lines; all other meridians and parallels are complex curves. The requirements to define this projection are:

- Longitude and latitude of central point.
- Scale in inch/degree or as 1:xxxxx (`-Jc`), or map width (`-JC`).

A detailed map of the island of Sardinia centered on the $8^\circ 45'$ E meridian using the Cassini projection can be obtained by running the command:

```
pscoast -R7:30/38:30/10:30/41:30r -JC8.75/40/2.5i -Blglf30m -Lf9.5/38.8/40/60 -Dh -Glightgray \
-Wthinest -Ia/thinner -P --LABEL_FONT_SIZE=12 > GMT_cassini.ps
```

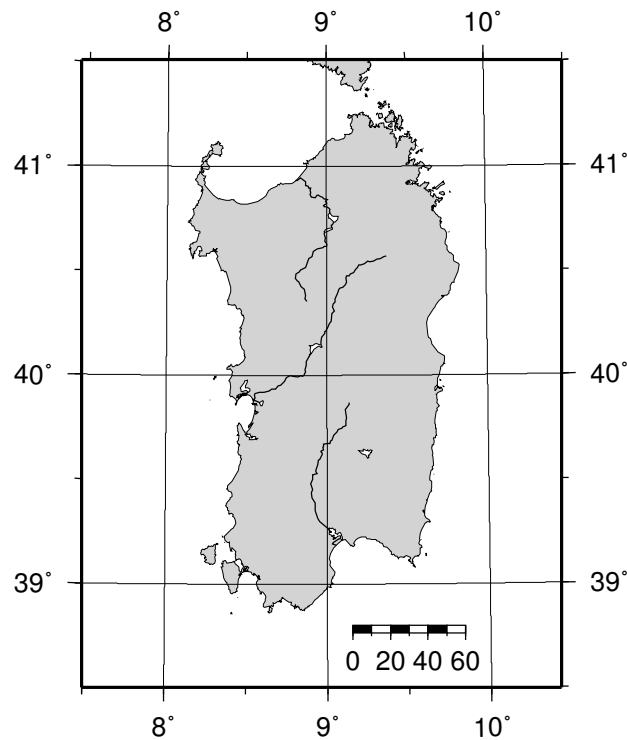


Figure 6.19: Cassini map over Sardinia.

As with the previous projections, the user can choose between a rectangular boundary (used here) or a geographical (WESN) boundary.

6.3.6 Cylindrical equidistant projection (**-Jq -JQ**)

This simple cylindrical projection is really a linear scaling of longitudes and latitudes. The most common form is the Plate Carrée projection, where the scaling of longitudes and latitudes is the same. All meridians and parallels are straight lines. The projection can be defined by:

- The central meridian [Middle of your map].
- Standard parallel [Equator].
- Scale in inch/degree or as 1:xxxxx (**-Jq**), or map width (**-JQ**).

The first two of these are optional and have defaults. When the standard parallel is defined, the central meridian must be supplied as well.

A world map centered on the dateline using this projection can be obtained by running the command:

```
pscoast -Rg -JQ4.5i -B60f30g30 -Dc -A5000 -Gblack -P > GMT_equi_cyl.ps
```

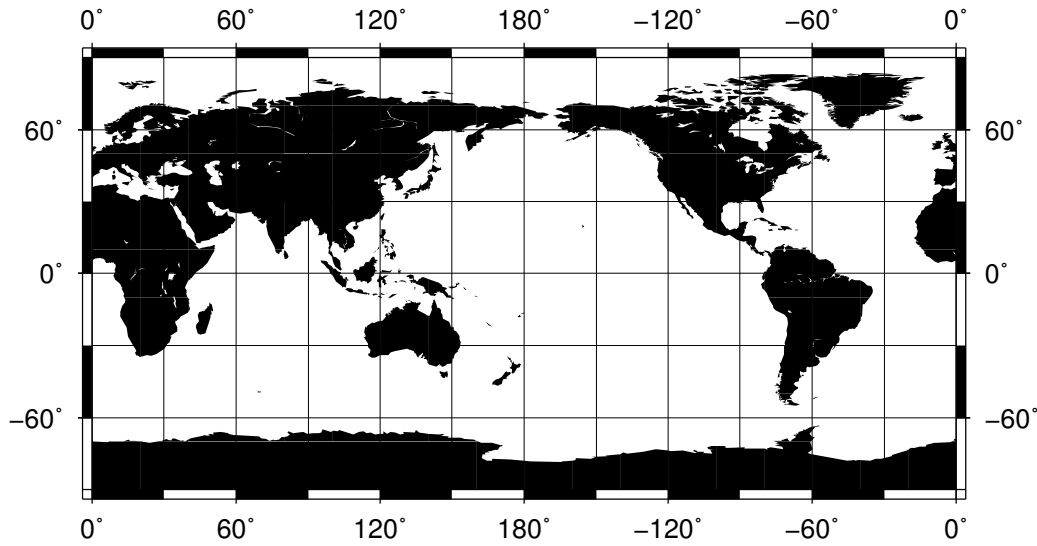


Figure 6.20: World map using the Plate Carrée projection.

Different relative scalings of longitudes and latitudes can be obtained by selecting a standard parallel different from the equator. Some selections for standard parallels have practical properties as shown in Table 6.1.

<i>Projection</i>	<i>Standard parallel</i>
Grafarend and Niermann, minimum linear distortion	61.7°
Ronald Miller Equirectangular	50.5°
Ronald Miller, minimum continental distortion	43.5°
Grafarend and Niermann	42°
Ronald Miller, minimum overall distortion	37.5°
Plate Carrée, Simple Cylindrical, Plain/Plane	0°

Table 6.1: Standard parallels for some cylindrical equidistant projections.

6.3.7 Cylindrical equal-area projections (-Jy -JY)

This cylindrical projection is actually several projections, depending on what latitude is selected as the standard parallel. However, they are all equal area and hence non-conformal. All meridians and parallels are straight lines. The requirements to define this projection are:

- The central meridian.
- The standard parallel.
- Scale in inch/degree or as 1:xxxxx (-Jy), or map width (-JY)

While you may choose any value for the standard parallel and obtain your own personal projection, there are seven choices of standard parallels that result in known (or named) projections. These are listed in Table 6.2.

For instance, a world map centered on the 35°E meridian using the Behrman projection (Figure 6.21) can be obtained by running the command:

```
pscoast -R-145/215/-90/90 -JY35/30/4.5i -B45g45 -Dc -A10000 -Slightgray -Wthinest -P > \
GMT_general_cyl.ps
```

<i>Projection</i>	<i>Standard parallel</i>
Balthasart	50°
Gall-Peters	45°
Hobo-Dyer	37°30' (= 37.5°)
Trystan Edwards	37°24' (= 37.4°)
Caster	37°04' (= 37.0666°)
Behrman	30°
Lambert	0°

Table 6.2: Standard parallels for some cylindrical equal-area projections.

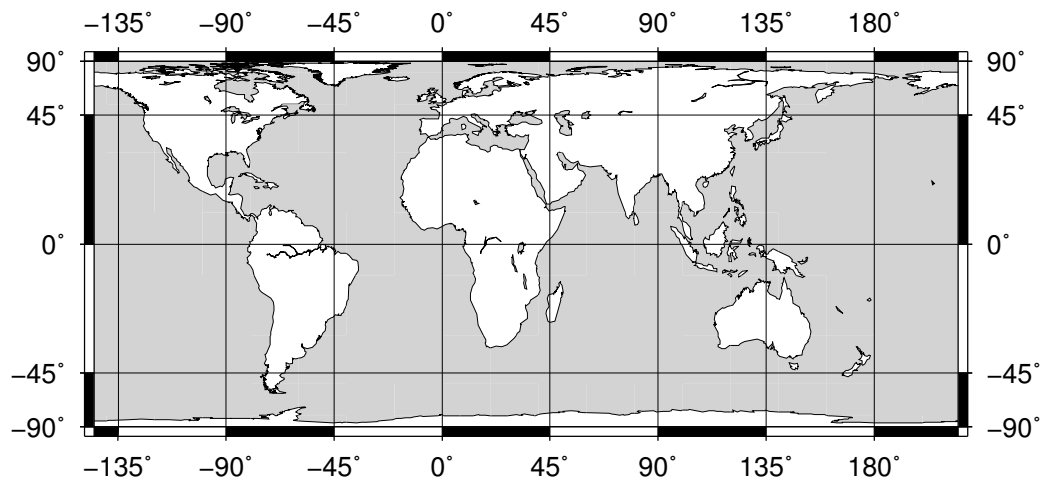


Figure 6.21: World map using the Behrman cylindrical equal-area projection.

As one can see there is considerable distortion at high latitudes since the poles map into lines.

6.3.8 Miller Cylindrical projection (-Jj -JJ)

This cylindrical projection, presented by Osborn Maitland Miller of the American Geographic Society in 1942, is neither equal nor conformal. All meridians and parallels are straight lines. The projection was designed to be a compromise between Mercator and other cylindrical projections. Specifically, Miller spaced the parallels by using Mercator's formula with 0.8 times the actual latitude, thus avoiding the singular poles; the result was then divided by 0.8. There is only a spherical form for this projection. Specify the projection by:

- Optionally, the central meridian (default is the middle of your map).
- Scale in inch/degree or as 1:xxxxx (-Jj), or map width (-JJ).

For instance, a world map centered on the 90°E meridian at a map scale of 1:400,000,000 (Figure 6.22) can be obtained as follows:

```
pscoast -R-90/270/-80/90 -Jj1:400000000 -B45g45/30g30 -Dc -A10000 -Glightgray -Wthinnest -P \
> GMT_miller.ps
```

6.3.9 Cylindrical stereographic projections (`-Jcyl_stere` `-JCyl_stere`)

The cylindrical stereographic projections are certainly not as notable as other cylindrical projections, but are still used because of their relative simplicity and their ability to overcome some of the downsides of other cylindrical projections, like extreme distortions of the higher latitudes. The stereographic projections are perspective projections, projecting the sphere onto a cylinder in the direction of the antipodal point on the equator. The cylinder crosses the sphere at two standard parallels, equidistant from the equator. The projections are defined by:

- The central meridian (uses the middle of the map when omitted).
- The standard parallel (default is the Equator). When used, central meridian needs to be given as well.
- Scale in inch/degree or as 1:xxxxx (`-Jcyl_stere`), or map width (`-JCyl_stere`)

Some of the selections of the standard parallel are named for the cartographer or publication that popularized the projection (Table 6.3).

<i>Projection</i>	<i>Standard parallel</i>
Miller's modified Gall	66.159467°
Kamenetskiy's First	55°
Gall's stereographic	45°
Bolshoi Sovietskii Atlas Mira or Kamenetskiy's Second	30°
Braun's cylindrical	0°

Table 6.3: Standard parallels for some cylindrical equal-area projections.

A map of the world, centered on the Greenwich meridian, using the Gall's stereographic projection (standard parallel is 45°, Figure 6.23), is obtained as follows:

```
gmtset PLOT_DEGREE_FORMAT dddA
pscoast -R-180/180/-60/80 -JCyl_stere/0/45/4.5i -Ba60f30g30/a30g30 -Dc -A5000 -Wblack -Ggrey -P \
> GMT_gall_stereo.ps
```

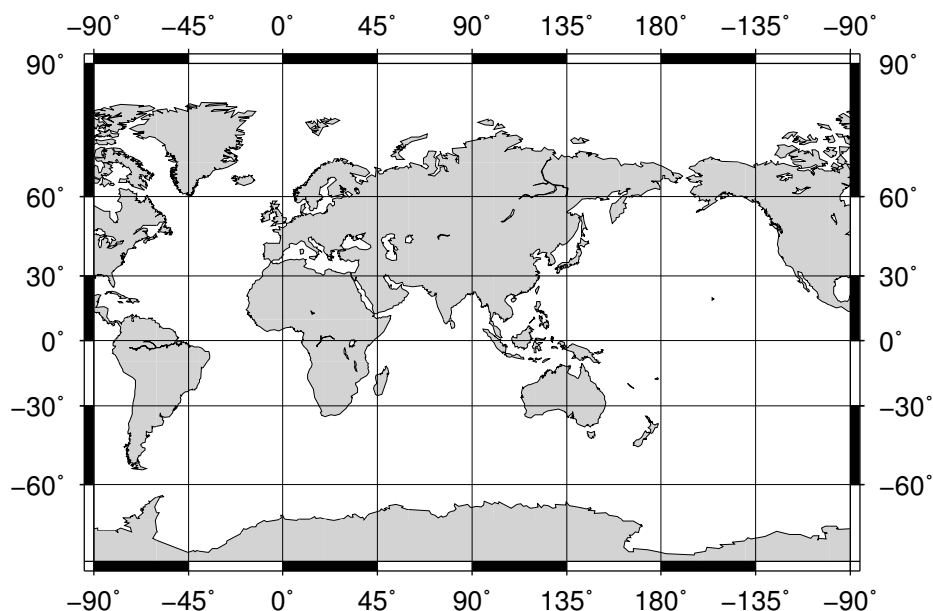


Figure 6.22: World map using the Miller cylindrical projection.

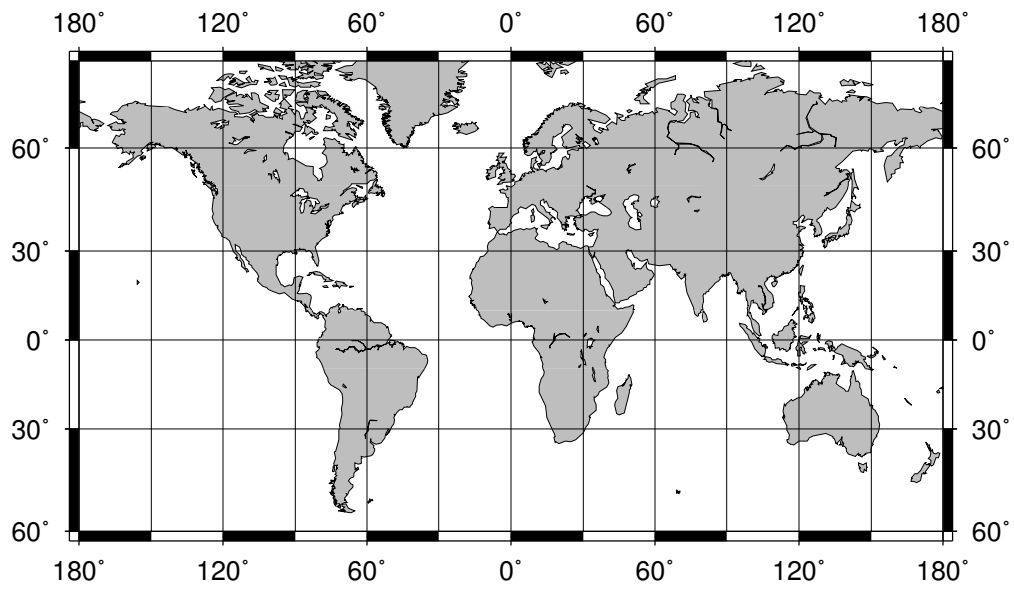


Figure 6.23: World map using Gall's stereographic projection.

6.4 Miscellaneous projections

GMT supports 8 common projections for global presentation of data or models. These are the Hammer, Mollweide, Winkel Tripel, Robinson, Eckert IV and VI, Sinusoidal, and Van der Grinten projections. Due to the small scale used for global maps these projections all use the spherical approximation rather than more elaborate elliptical formulae.

In all cases, the specification of the central meridian can be skipped. The default is the middle of the longitude range of the plot, specified by the `-(R)` option.

6.4.1 Hammer projection (`-Jh -JH`)

The equal-area Hammer projection, first presented by the German mathematician Ernst von Hammer in 1892, is also known as Hammer-Aitoff (the Aitoff projection looks similar, but is not equal-area). The border is an ellipse, equator and central meridian are straight lines, while other parallels and meridians are complex curves. The projection is defined by selecting:

- The central meridian [Middle of your map].
- Scale along equator in inch/degree or 1:xxxxx (`-Jh`), or map width (`-JH`).

A view of the Pacific ocean using the Dateline as central meridian is accomplished thus

```
pscoast -Rg -JH4.5i -Bg30/g15 -Dc -A10000 -Gblack -P > GMT_hammer.ps
```

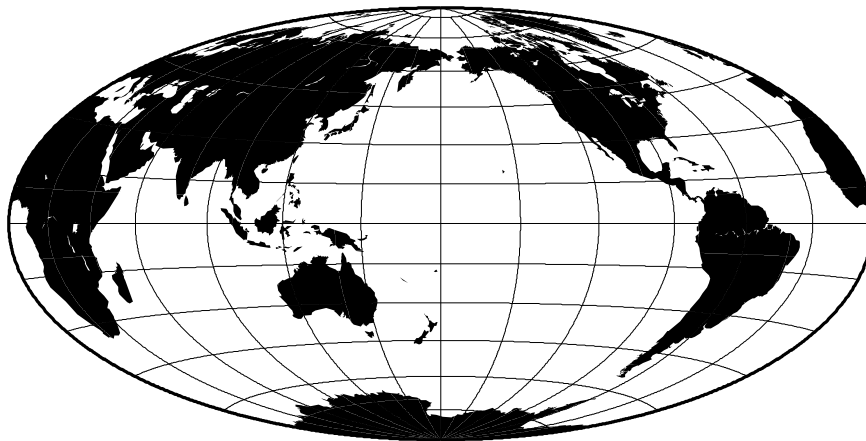


Figure 6.24: World map using the Hammer projection.

6.4.2 Mollweide projection (`-Jw -JW`)

This pseudo-cylindrical, equal-area projection was developed by the German mathematician and astronomer Karl Brandan Mollweide in 1805. Parallels are unequally spaced straight lines with the meridians being equally spaced elliptical arcs. The scale is only true along latitudes $40^{\circ}44'$ north and south. The projection is used mainly for global maps showing data distributions. It is occasionally referenced under the name homalographic projection. Like the Hammer projection, outlined above, we need to specify only two parameters to completely define the mapping of longitudes and latitudes into rectangular x/y coordinates:

- The central meridian [Middle of your map].
- Scale along equator in inch/degree or 1:xxxxx (`-Jw`), or map width (`-JW`).

An example centered on Greenwich can be generated thus:

```
pscoast -Rd -JW4.5i -Bg30/g15 -Dc -A10000 -Gblack -P > GMT_mollweide.ps
```

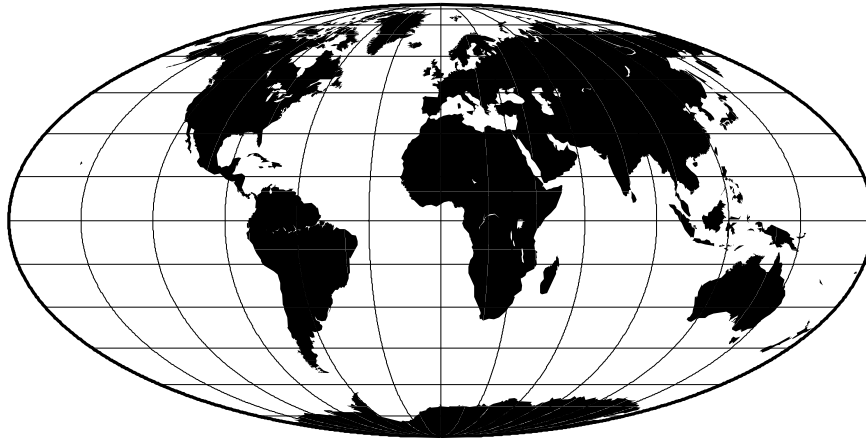


Figure 6.25: World map using the Mollweide projection.

6.4.3 Winkel Tripel projection (**-Jr -JR**)

In 1921, the German mathematician Oswald Winkel a projection that was to strike a compromise between the properties of three elements (area, angle and distance). The German word “tripel” refers to this junction of where each of these elements are least distorted when plotting global maps. The projection was popularized when Bartholomew and Son started to use it in its world-renowned “The Times Atlas of the World” in the mid 20th century. In 1998, the National Geographic Society made the Winkel Tripel as its map projection of choice for global maps.

Naturally, this projection is neither conformal, nor equal-area. Central meridian and equator are straight lines; other parallels and meridians are curved. The projection is obtained by averaging the coordinates of the Equidistant Cylindrical and Aitoff (not Hammer-Aitoff) projections. The poles map into straight lines 0.4 times the length of equator. To use it you must enter

- The central meridian [Middle of your map].
- Scale along equator in inch/degree or 1:xxxxx (**-Jr**), or map width (**-JR**).

Centered on Greenwich, the example in Figure 6.26 was created by this command:

```
pscoast -Rd -JR4.5i -Bg30/g15 -Dc -A10000 -Ggray -P > GMT_winkel.ps
```

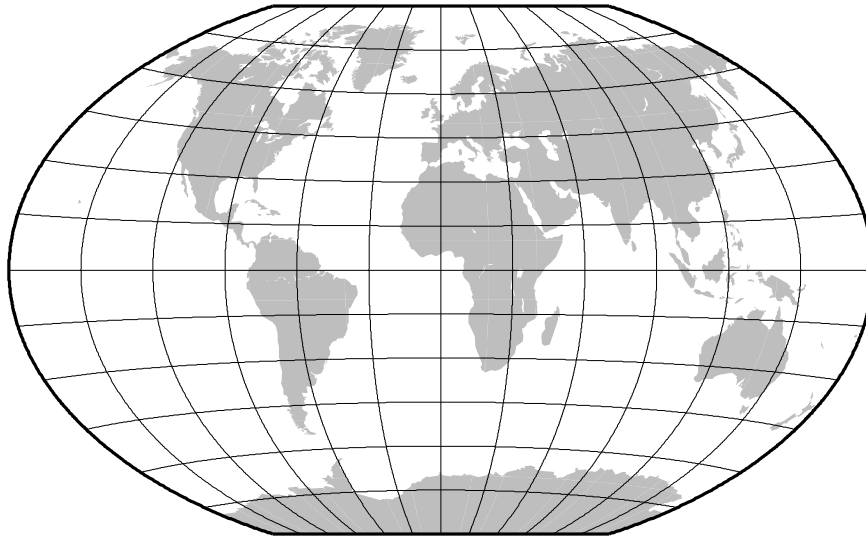


Figure 6.26: World map using the Winkel Tripel projection.

6.4.4 Robinson projection (**-Jn -JN**)

The Robinson projection, presented by the American geographer and cartographer Arthur H. Robinson in 1963, is a modified cylindrical projection that is neither conformal nor equal-area. Central meridian and all parallels are straight lines; other meridians are curved. It uses lookup tables rather than analytic expressions to make the world map “look” right³. The scale is true along latitudes $\pm 38^\circ$. The projection was originally developed for use by Rand McNally and is currently used by the National Geographic Society. To use it you must enter

- The central meridian [Middle of your map].
- Scale along equator in inch/degree or 1:xxxxx (**-Jn**), or map width (**-JN**).

Again centered on Greenwich, the example below was created by this command:

```
pscoast -Rd -JN4.5i -Bg30/g15 -Dc -A10000 -Ggray -P > GMT_robinson.ps
```

³Robinson provided a table of y-coordinates for latitudes every 5° . To project values for intermediate latitudes one must interpolate the table. Different interpolants may result in slightly different maps. **GMT** uses the interpolant selected by the parameter **INTERPOLANT** in the `.gmtdefaults4` file.

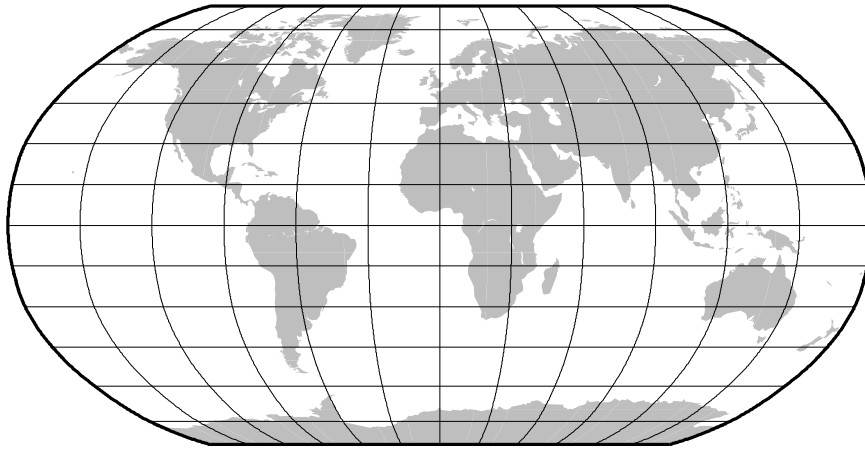


Figure 6.27: World map using the Robinson projection.

6.4.5 Eckert IV and VI projection (**-Jk -JK**)

The Eckert IV and VI projections, presented by the German cartographer Max Eckert-Greifendorff in 1906, are pseudocylindrical equal-area projections. Central meridian and all parallels are straight lines; other meridians are equally spaced elliptical arcs (IV) or sinusoids (VI). The scale is true along latitudes $\pm 40^\circ 30'$ (IV) and $\pm 49^\circ 16'$ (VI). Their main use is in thematic world maps. To select Eckert IV you must use **-JKf** (f for “four”) while Eckert VI is selected with **-JKs** (s for “six”). If no modifier is given it defaults to Eckert VI. In addition, you must enter

- The central meridian [Middle of your map].
- Scale along equator in inch/degree or 1:xxxxx (**-Jk**), or map width (**-JK**).

Centered on the Dateline, the Eckert IV example below was created by this command:

```
pscoast -Rg -JKf4.5i -Bg30/g15 -Dc -A10000 -Wthinnest -Gwhite -Slightgray -P > GMT_eckert4.ps
```

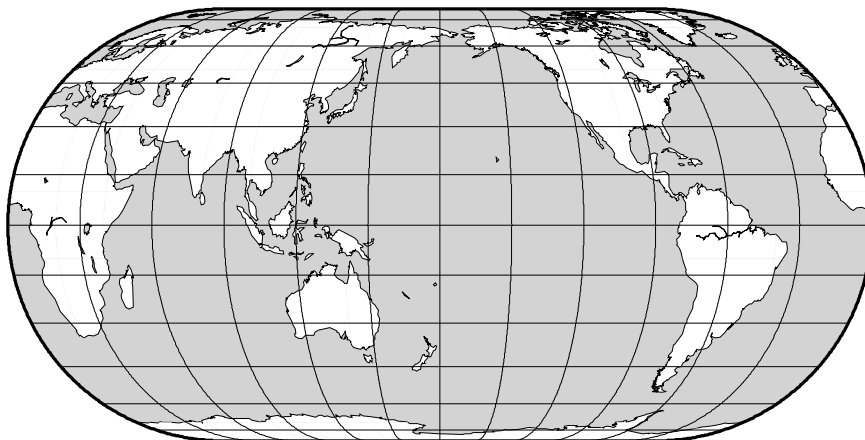


Figure 6.28: World map using the Eckert IV projection.

The same script, with **s** instead of **f**, yields the Eckert VI map:

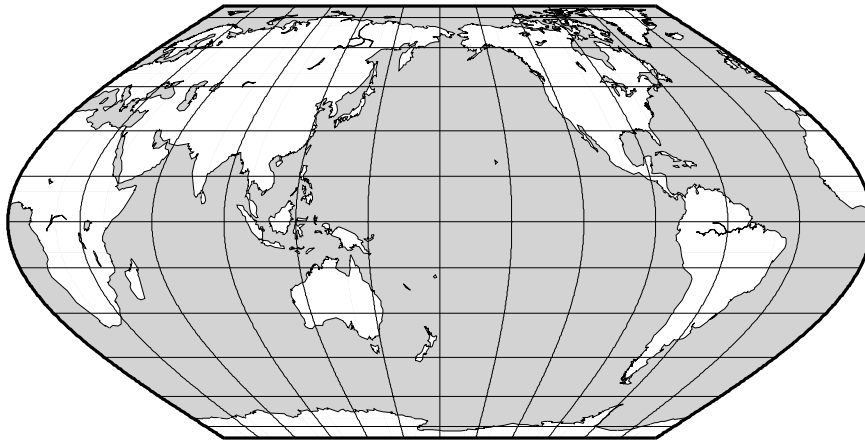


Figure 6.29: World map using the Eckert VI projection.

6.4.6 Sinusoidal projection (**-Ji -Jl**)

The sinusoidal projection is one of the oldest known projections, is equal-area, and has been used since the mid-16th century. It has also been called the “Equal-area Mercator” projection. The central meridian is a straight line; all other meridians are sinusoidal curves. Parallels are all equally spaced straight lines, with scale being true along all parallels (and central meridian). To use it, you need to select:

- The central meridian [Middle of your map].
- Scale along equator in inch/degree or 1:xxxxx (**-Ji**), or map width (**-Jl**).

A simple world map using the sinusoidal projection is therefore obtained by

```
pscoast -Rd -Ji4.5i -Bg30/g15 -Dc -A10000 -Ggray -P > GMT_sinusoidal.ps
```

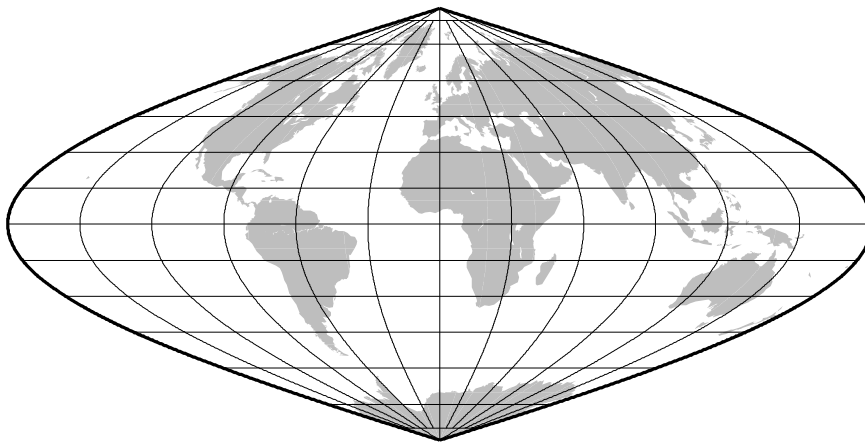


Figure 6.30: World map using the Sinusoidal projection.

To reduce distortion of shape the interrupted sinusoidal projection was introduced in 1927. Here, three symmetrical segments are used to cover the entire world. Traditionally, the interruptions are at 160°W, 20°W, and 60°E. To make the interrupted map we must call **pscoast** for each segment and superpose the results. To produce an interrupted world map (with the traditional boundaries just mentioned) that is 5.04 inches wide we use the scale $5.04/360^\circ = 0.014$ and offset the subsequent plots horizontally by their widths ($140^\circ \cdot 0.014$ and $80^\circ \cdot 0.014$):

```

pscoast -R200/340/-90/90 -Ji0.014i -Bg30/g15 -A10000 -Dc -Gblack -K -P > GMT_sinus_int.ps
pscoast -R-20/60/-90/90 -Ji0.014i -Bg30/g15 -Dc -A10000 -Gblack -X1.96i -O -K >> GMT_sinus_int.ps
pscoast -R60/200/-90/90 -Ji0.014i -Bg30/g15 -Dc -A10000 -Gblack -X1.12i -O >> GMT_sinus_int.ps

```

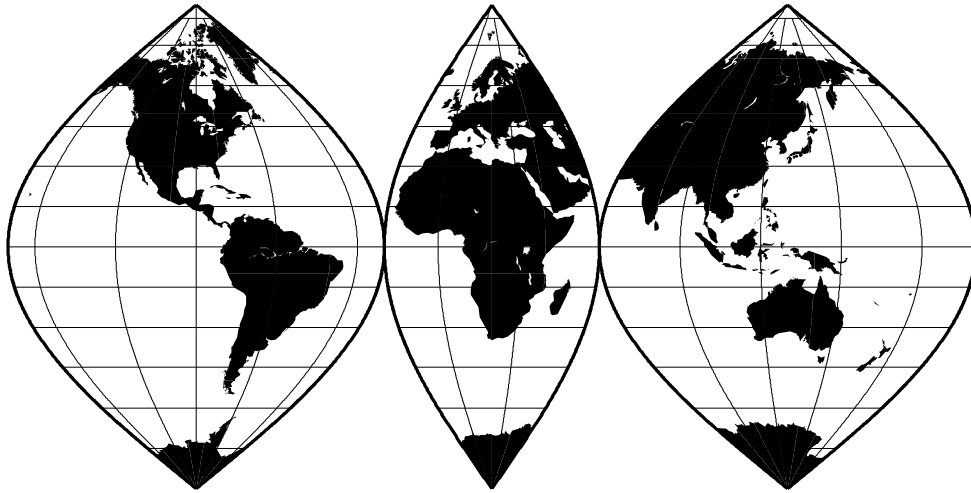


Figure 6.31: World map using the Interrupted Sinusoidal projection.

The usefulness of the interrupted sinusoidal projection is basically limited to display of global, discontinuous data distributions like hydrocarbon and mineral resources, etc.

6.4.7 Van der Grinten projection (**-Jv -JV**)

The Van der Grinten projection, presented by Alphons J. van der Grinten in 1904, is neither equal-area nor conformal. Central meridian and Equator are straight lines; other meridians are arcs of circles. The scale is true along the Equator only. Its main use is to show the entire world enclosed in a circle. To use it you must enter

- The central meridian [Middle of your map].
- Scale along equator in inch/degree or 1:xxxxx (**-Jv**), or map width (**-JV**).

Centered on the Dateline, the example below was created by this command:

```

pscoast -Rg -JV4i -Bg30/g15 -Dc -Glightgray -A10000 -Wthinnest -P > GMT_grinten.ps

```



Figure 6.32: World map using the Van der Grinten projection.

7. Creating GMT Graphics

In this section we will be giving several examples of typical usage of *GMT* programs. In general, we will start with a raw data set, manipulate the numbers in various ways, then display the results in diagram or map view. The resulting plots will have in common that they are all made up of simpler plots that have been overlaid to create a complex illustration. We will mostly follow the following format:

1. We explain what we want to achieve in plain language.
2. We present an annotated Bourne shell script that contains all commands used to generate the illustration.
3. We explain the rationale behind the commands.
4. We present the illustration, 50% reduced in size, and without the timestamp (**-U**).

A detailed discussion of each command is not given; we refer you to the manual pages for command line syntax, etc. We encourage you to run these scripts for yourself. See Appendix D if you would like an electronic version of all the shell-scripts (both **sh** and **csh** scripts are available; only the **sh**-scripts are discussed here) and support data used below. Note that all examples explicitly specifies the measurement units, so although we use inches you should be able to run these scripts and get the same plots even if you have cm as the default measure unit. The examples are all written to be “quiet”, that is no information is echoed to the screen. Thus, these scripts are well suited for background execution.

Note that we also end each script by cleaning up after ourselves. Because **awk** is broken as designed on some systems, and **nawk** is not available on others we refer to **\$AWK** in the scripts below; the **do.examples.sh** scripts will set this when running all examples.

Finally, be aware that for practical purposes the output *PostScript* file name is stored as the variable `ps`.

7.1 The making of contour maps

We want to create two contour maps of the low order geoid using the Hammer equal area projection. Our gridded data file is called `osu91a1f_16.grd` and contains a global 1° by 1° gridded geoid (we will see how to make gridded files later). We would like to show one map centered on Greenwich and one centered on the dateline. Positive contours should be drawn with a solid pen and negative contours with a dashed pen. Annotations should occur for every 50 m contour level, and both contour maps should show the continents in light gray in the background. Finally, we want a rectangular frame surrounding the two maps. This is how it is done:

```
#!/bin/sh
#
#           GMT EXAMPLE 01
#
# Purpose:   Make two contour maps based on the data in the file osu91a1f_16.nc
# GMT progs: gmtset, grdcontour, psbasemap, pscoast
# Unix progs: rm
#
ps=example_01.ps
gmtset GRID_CROSS_SIZE 0 ANNOT_FONT_SIZE_PRIMARY 10
psbasemap -R0/6.5/0/9 -Jx1i -B0 -P -K -U"Example 1 in Cookbook" > $ps
pscoast -Rg -JH6i -Y4i -O -K -Bg30 -Dc -Glightgray >> $ps
grdcontour osu91a1f_16.nc -J -C10 -A50+s7 -Gd4i -L-1000/-1 -Wcthinest,- -Wathin,- -O -K \
-T0.1i/0.02i >> $ps
grdcontour osu91a1f_16.nc -J -C10 -A50+s7 -Gd4i -L-1/1000 -O -K -T0.1i/0.02i >> $ps
pscoast -Rg -JH6i -Y4i -O -K -Bg30:."Low Order Geoid": -Dc -Glightgray >> $ps
grdcontour osu91a1f_16.nc -J -C10 -A50+s7 -Gd4i -L-1000/-1 -Wcthinest,- -Wathin,- -O -K \
-T0.1i/0.02i:-+ >> $ps
grdcontour osu91a1f_16.nc -J -C10 -A50+s7 -Gd4i -L-1/1000 -O -T0.1i/0.02i:-+ >> $ps
rm -f .gmt*
```

The first command draws a box surrounding the maps. This is followed by two sequences of **pscoast**, **grdcontour**, **grdcontour**. They differ in that the first is centered on Greenwich; the second on the dateline. We use the limit option (**-L**) in **grdcontour** to select negative contours only and plot those

with a dashed pen, then positive contours only and draw with a solid pen [Default]. The `-T` option causes tickmarks pointing in the downhill direction to be drawn on the innermost, closed contours. For the upper panel we also added `-` and `+` to the local lows and highs. You can find this illustration as Figure 7.1.

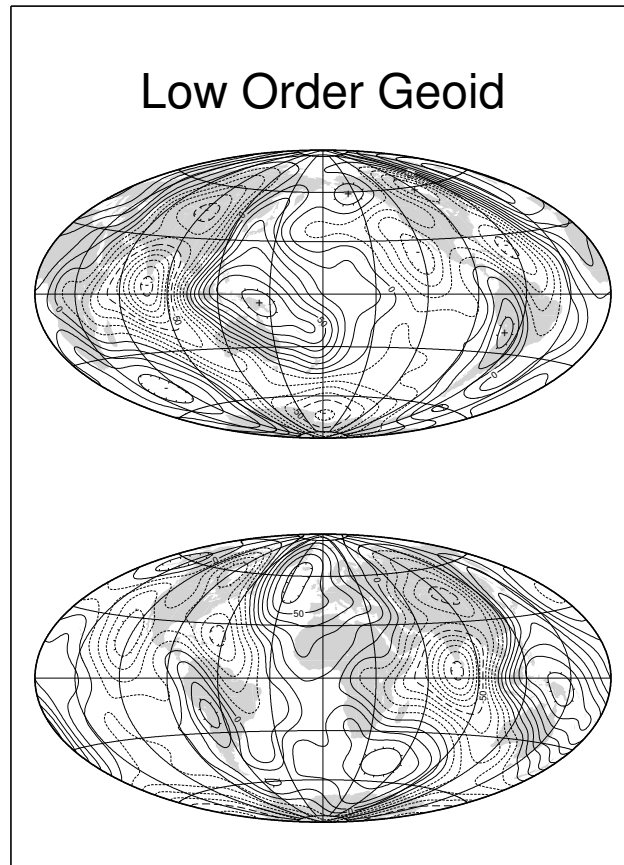


Figure 7.1: Contour maps of gridded data.

7.2 Image presentations

As our second example we will demonstrate how to make color images from gridded data sets (again, we will defer the actual making of grid files to later examples). We will use the supplemental program **grdraster** to extract 2-D grid files of bathymetry and Geosat geoid heights and put the two images on the same page. The region of interest is the Hawaiian islands, and due to the oblique trend of the island chain we prefer to rotate our geographical data sets using an oblique Mercator projection defined by the hotspot pole at (68°W, 69°N). We choose the point (190°, 25.5°) to be the center of our projection (e.g., the local origin), and we want to image a rectangular region defined by the longitudes and latitudes of the lower left and upper right corner of region. In our case we choose (160°, 20°) and (220°, 30°) as the corners. We use **grdimage** to make the illustration:

```
#!/bin/sh
#
#           GMT EXAMPLE 02
#
# Purpose:   Make two color images based gridded data
# GMT progs: gmtset, grd2cpt, grdgradient, grdimage, makecpt, psscale, pstext
# Unix progs: rm
#
ps=example_02.ps
gmtset HEADER_FONT_SIZE 30 OBLIQUE_ANNOTATION 0
```

```

makecpt -Crainbow -T-2/14/2 > g.cpt
grdimage HI_geoid2.nc -R160/20/220/30r -JOC190/25.5/292/69/4.5i -E50 -K -P \
-U/-1.25i/-1i/"Example 2 in Cookbook" -B10 -Cg.cpt -X1.5i -Y1.25i > $ps
psscale -Cg.cpt -D5.1i/1.35i/2.88i/0.4i -O -K -Ac -B2:GEOID/:m: -E >> $ps
grd2cpt HI_topo2.nc -Crelief -Z > t.cpt
grdgradient HI_topo2.nc -A0 -Nt -GHI_topo2_int.grd
grdimage HI_topo2.nc -IHI_topo2_int.grd -R -J -E50 -B10:."H@#awaiian@# T@#opo and @#G@#eoid:" -O -K \
-Ct.cpt -Y4.5i --HEADER_OFFSET=0.5i >> $ps
psscale -Ct.cpt -D5.1i/1.35i/2.88i/0.4i -O -K -I0.3 -Ac -B2:TOPO/:km: >> $ps
pstext -R0/8.5/0/11 -Jxli -O -N -Y-4.5i >> $ps << END
-0.4 7.5 30 0.0 1 CB a)
-0.4 3.0 30 0.0 1 CB b)
END
rm -f HI_topo2_int.grd ?.cpt .gmt*

```

The first step extracts the 2-D data sets from the local data base using **grdraster**, which is a supplemental utility program (see Appendix A) that may be adapted to reflect the nature of your data base format. It automatically figures out the required extent of the region given the two corners points and the projection. The extreme meridians and parallels enclosing the oblique region is **-R159:50/220:10/3:10/47:35**. This is the area extracted by **grdraster**. For your convenience we have commented out those lines and provided the two extracted files so you do not need **grdraster** to try this example. By using the embedded grid file format mechanism we saved the topography using kilometers as the data unit. We now have two grid files with bathymetry and geoid heights, respectively. We use **makecpt** to generate a linear color palette file geoid.cpt for the geoid and use **grd2cpt** to get a histogram-equalized cpt file topo.cpt for the topography data. To emphasize the structures in the data we calculate the slopes in the north-south direction using **grdgradient**; these will be used to modulate the color image. Next we run **grdimage** to create a color-code image of the Geosat geoid heights, and draw a color legend to the right of the image with **psscale**. Similarly, we run **grdimage** but specify **-Y4.5i** to plot above the previous image. Adding scale and label the two plots a) and b) completes the illustration (Figure 7.2).

7.3 Spectral estimation and xy-plots

In this example we will show how to use the *GMT* programs **fitcircle**, **project**, **sample1d**, **spectrum1d**, **psxy**, and **pstext**. Suppose you have (lon, lat, gravity) along a satellite track in a file called sat.xy, and (lon, lat, gravity) along a ship track in a file called ship.xy. You want to make a cross-spectral analysis of these data. First, you will have to get the two data sets into equidistantly sampled time-series form. To do this, it will be convenient to project these along the great circle that best fits the sat track. We must use **fitcircle** to find this great circle and choose the L_2 estimates of best pole. We project the data using **project** to find out what their ranges are in the projected coordinate. The **minmax** utility will report the minimum and maximum values for multi-column ASCII tables. Use this information to select the range of the projected distance coordinate they have in common. The script prompts you for that information after reporting the values. We decide to make a file of equidistant sampling points spaced 1 km apart from -1167 to +1169, and use the *UNIX* utility **\$AWK** to accomplish this step. We can then resample the projected data, and carry out the cross-spectral calculations, assuming that the ship is the input and the satellite is the output data. There are several intermediate steps that produce helpful plots showing the effect of the various processing steps (example_03[a-f].ps), while the final plot example_03.ps shows the ship and sat power in one diagram and the coherency on another diagram, both on the same page. Note the extended use of **pstext** and **psxy** to put labels and legends directly on the plots. For that purpose we often use **-Jxli** and specify positions in inches directly. Thus, the complete automated script reads:

```

#!/bin/sh
#
#           GMT EXAMPLE 03
#
# Purpose:   Resample track data, do spectral analysis, and plot
# GMT progs: filter1d, fitcircle, minmax, project, sample1d
# GMT progs: spectrum1d, trend1d, pshistogram, psxy, pstext
# Unix progs: $AWK, cat, echo, head, paste, rm, tail
#
# This example begins with data files "ship.xy" and "sat.xy" which
# are measurements of a quantity "g" (a "gravity anomaly" which is an
# anomalous increase or decrease in the magnitude of the acceleration

```

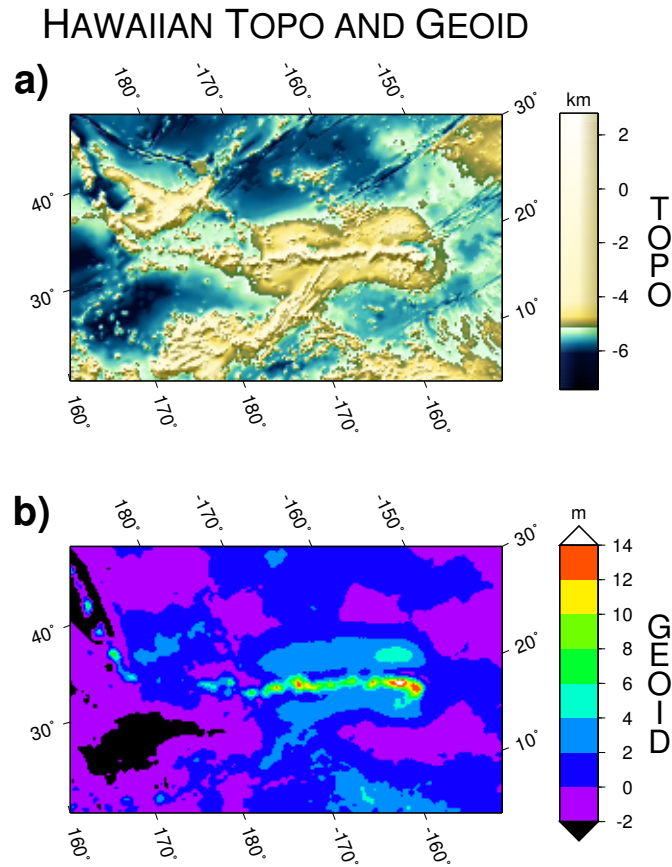


Figure 7.2: Color images from gridded data.

```
# of gravity at sea level). g is measured at a sequence of points "x,y"
# which in this case are "longitude,latitude". The "sat.xyg" data were
# obtained by a satellite and the sequence of points lies almost along
# a great circle. The "ship.xyg" data were obtained by a ship which
# tried to follow the satellite's path but deviated from it in places.
# Thus the two data sets are not measured at the same of points,
# and we use various GMT tools to facilitate their comparison.
# The main illustration (example_03.ps) are accompanied with 5 support
# plots (03a-f) showing data distributions and various intermediate steps.
#
# First, we use "fitcircle" to find the parameters of a great circle
# most closely fitting the x,y points in "sat.xyg":
#
ps=example_03.ps
fitcircle sat.xyg -L2 > report
cposx=`grep "L2 Average Position" report | cut -f1`
cposy=`grep "L2 Average Position" report | cut -f2`
pposx=`grep "L2 N Hemisphere" report | cut -f1`
pposy=`grep "L2 N Hemisphere" report | cut -f2`
#
# Now we use "project" to project the data in both sat.xyg and ship.xyg
# into data.pg, where g is the same and p is the oblique longitude around
# the great circle. We use -Q to get the p distance in kilometers, and -S
# to sort the output into increasing p values.
#
project sat.xyg -C$cposx/$cposy -T$pposx/$pposy -S -Fpz -Q > sat.pg
project ship.xyg -C$cposx/$cposy -T$pposx/$pposy -S -Fpz -Q > ship.pg
#
# The minmax utility will report the minimum and maximum values for all columns.
# We use this information first with a large -I value to find the appropriate -R
# to use to plot the .pg data.
#
plotr=`cat sat.pg ship.pg | minmax -I100/25`
psxy $plotr -U/-1.75i/-1.25i/"Example 3a in Cookbook" \
```

```

-Ba500f100:"Distance along great circle":/a100f25:"Gravity anomaly (mGal)":WeSn \
-JX8i/5i -X2i -Y1.5i -K -Wthick sat.pg > example_03a.ps
psxy -R -JX -O -Sp0.03i ship.pg >> example_03a.ps
#
# From this plot we see that the ship data have some "spikes" and also greatly
# differ from the satellite data at a point about p ~+250 km, where both of
# them show a very large anomaly.
#
# To facilitate comparison of the two with a cross-spectral analysis using "spectrum1d",
# we resample both data sets at intervals of 1 km. First we find out how the data are
# typically spaced using $AWK to get the delta-p between points and view it with
# "pshistogram".
#
$AWK '{ if (NR > 1) print $1 - last1; last1=$1; }' ship.pg | pshistogram -W0.1 -Gblack -JX3i -K \
-X2i -Y1.5i -B:."Ship": -U/-1.75i/-1.25i/"Example 3b in Cookbook" > example_03b.ps
$AWK '{ if (NR > 1) print $1 - last1; last1=$1; }' sat.pg | pshistogram -W0.1 -Gblack -JX3i -O \
-X5i -B:."Sat": >> example_03b.ps
#
# This experience shows that the satellite values are spaced fairly evenly, with
# delta-p between 3.222 and 3.418. The ship values are spaced quite unevenly, with
# delta-p between 0.095 and 9.017. This means that when we want 1 km even sampling,
# we can use "sample1d" to interpolate the sat data, but the same procedure applied
# to the ship data could alias information at shorter wavelengths. So we have to use
# "filter1d" to resample the ship data. Also, since we observed spikes in the ship
# data, we use a median filter to clean up the ship values. We will want to use "paste"
# to put the two sampled data sets together, so they must start and end at the same
# point, without NaNs. So we want to get a starting and ending point which works for
# both of them. Thus we need to start at max( min(ship.p), min(sat.p) ) and end
# conversely. "minmax" can't do this easily since it will return min( min(), min() ),
# so we do a little head, paste $AWK to get what we want.
#
head -1 ship.pg > ship.pg.extr
head -1 sat.pg > sat.pg.extr
paste ship.pg.extr sat.pg.extr | $AWK '{ if ($1 > $3) print int($1); else print int($3); }' > sampr1
tail -1 ship.pg > ship.pg.extr
tail -1 sat.pg > sat.pg.extr
paste ship.pg.extr sat.pg.extr | $AWK '{ if ($1 < $3) print int($1); else print int($3); }' > sampr2
sampr1='cat sampr1'
sampr2='cat sampr2'
#
# Now we can use sampr in $AWK to make a sampling points file for sample1d:
$AWK 'BEGIN { for (i=$sampr1; i <= $sampr2; i++) print i }' /dev/null > samp.x
#
# Now we can resample the projected satellite data:
#
sample1d sat.pg -Nsamp.x > samp_sat.pg
#
# For reasons above, we use filter1d to pre-treat the ship data. We also need to sample it
# because of the gaps > 1 km we found. So we use filter1d | sample1d. We also use the -E
# on filter1d to use the data all the way out to sampr1/sampr2 :
#
filter1d ship.pg -Fm1 -T$sampr1/$sampr2/1 -E | sample1d -Nsamp.x > samp_ship.pg
#
# Now we plot them again to see if we have done the right thing:
#
psxy $plotr -JX8i/5i -X2i -Y1.5i -K -Wthick samp_sat.pg \
-Ba500f100:"Distance along great circle":/a100f25:"Gravity anomaly (mGal)":WeSn \
-U/-1.75i/-1.25i/"Example 3c in Cookbook" > example_03c.ps
psxy -R -JX -O -Sp0.03i samp_ship.pg >> example_03c.ps
#
# Now to do the cross-spectra, assuming that the ship is the input and the sat is the output
# data, we do this:
#
paste samp_ship.pg samp_sat.pg | cut -f2,4 | spectrum1d -S256 -D1 -W -C > /dev/null
#
# Now we want to plot the spectra. The following commands will plot the ship and sat
# power in one diagram and the coherency on another diagram, both on the same page.
# Note the extended use of ptext and psxy to put labels and legends directly on the plots.
# For that purpose we often use -Jxli and specify positions in inches directly:
#
psxy spectrum.coh -Balf3p:"Wavelength (km)":/a0.25f0.05:"Coherency@+2@+":WeSn -JX-4il/3.75i \
-R1/1000/0/1 -U/-2.25i/-1.25i/"Example 3 in Cookbook" -P -K -X2.5i -Sc0.07i -Gblack \
-Ey/0.5p -Y1.5i > $ps
echo "3.85 3.6 18 0.0 1 TR Coherency@+2@+" | ptext -R0/4/0/3.75 -Jxli -O -K >> $ps
cat > box.d << END
2.375 3.75
2.375 3.25
4 3.25
END
psxy -R -Jx -O -K -Wthicker box.d >> $ps

```

```

psxy -Balf3p/alf3p:"Power (mGal@+2@+km)":::."Ship and Satellite Gravity":WeSn spectrum.xpower \
    -Gblack -ST0.07i -O -R1/1000/0.1/10000 -JX-4il/3.75il -Y4.2i -K -Ey/0.5p >> $ps
psxy spectrum.ypower -R -JX -O -K -Gblack -Sc0.07i -Ey/0.5p >> $ps
echo "3.9 3.6 18 0.0 1 TR Input Power" | pstext -R0/4/0/3.75 -Jx -O -K >> $ps
psxy -R -Jx -O -K -Wthicker box.d >> $ps
psxy -R -Jx -O -K -Glightgray -L -Wthicker >> $ps << END
0.25 0.25
1.4 0.25
1.4 0.9
0.25 0.9
END
echo "0.4 0.7" | psxy -R -Jx -O -K -ST0.07i -Gblack >> $ps
echo "0.5 0.7 14 0.0 1 ML Ship" | pstext -R -Jx -O -K >> $ps
echo "0.4 0.4" | psxy -R -Jx -O -K -Sc0.07i -Gblack >> $ps
echo "0.5 0.4 14 0.0 1 ML Satellite" | pstext -R -Jx -O >> $ps
#
# Now we wonder if removing that large feature at 250 km would make any difference.
# We could throw away a section of data with $AWK or sed or head and tail, but we
# demonstrate the use of "trendld" to identify outliers instead. We will fit a
# straight line to the samp_ship.pg data by an iteratively-reweighted method and
# save the weights on output. Then we will plot the weights and see how things
# look:
#
trendld -Fwx -N2r samp_ship.pg > samp_ship.xw
psxy $plotr -JX8i/4i -X2i -Y1.5i -K -Sp0.03i \
    -Ba500f100:"Distance along great circle":/a100f25:"Gravity anomaly (mGal)":WeSn \
    -U/-1.75i/-1.25i/"Example 3d in Cookbook" samp_ship.pg > example_03d.ps
plotr='minmax samp_ship.xw -I100/1.1'
psxy $plotr -JX8i/1.1i -O -Y4.25i -Bf100/a0.5f0.1:"Weight":Wesn -Sp0.03i samp_ship.xw \
    >> example_03d.ps
#
# From this we see that we might want to throw away values where w < 0.6. So we try that,
# and this time we also use trendld to return the residual from the model fit (the
# de-trended data):
trendld -Fxr -N2r samp_ship.pg | $AWK '{ if ($3 > 0.6) print $1, $2 }' \
    | sampleld -Nsamp.x > samp2_ship.pg
trendld -Fxr -N2r samp_sat.pg | $AWK '{ if ($3 > 0.6) print $1, $2 }' \
    | sampleld -Nsamp.x > samp2_sat.pg
#
# We plot these to see how they look:
#
plotr='cat samp2_sat.pg samp2_ship.pg | minmax -I100/25'
psxy $plotr -JX8i/5i -X2i -Y1.5i -K -Wthick \
    -Ba500f100:"Distance along great circle":/a50f25:"Gravity anomaly (mGal)":WeSn \
    -U/-1.75i/-1.25i/"Example 3e in Cookbook" samp2_sat.pg > example_03e.ps
psxy -R -JX -O -Sp0.03i samp2_ship.pg >> example_03e.ps
#
# Now we do the cross-spectral analysis again. Comparing this plot (example_03e.ps) with
# the previous one (example_03d.ps) we see that throwing out the large feature has reduced
# the power in both data sets and reduced the coherency at wavelengths between 20--60 km.
#
paste samp2_ship.pg samp2_sat.pg | cut -f2,4 | spectrumld -S256 -D1 -W -C > /dev/null
#
psxy spectrum.coh -Balf3p:"Wavelength (km)":/a0.25f0.05:"Coherency@+2@+":WeSn -JX-4il/3.75i \
    -R1/1000/0.1 -U/-2.25i/-1.25i/"Example 3f in Cookbook" -P -K -X2.5i -Sc0.07i -Gblack \
    -Ey/0.5p -Y1.5i > example_03f.ps
echo "3.85 3.6 18 0.0 1 TR Coherency@+2@+" | pstext -R0/4/0/3.75 -Jx -O -K >> example_03f.ps
cat > box.d << END
2.375 3.75
2.375 3.25
4 3.25
END
psxy -R -Jx -O -K -Wthicker box.d >> example_03f.ps
psxy -Balf3p/alf3p:"Power (mGal@+2@+km)":::."Ship and Satellite Gravity":WeSn spectrum.xpower \
    -ST0.07i -O -R1/1000/0.1/10000 -JX-4il/3.75il -Y4.2i -K -Ey/0.5p >> example_03f.ps
psxy spectrum.ypower -R -JX -O -K -Gblack -Sc0.07i -Ey/0.5p >> example_03f.ps
echo "3.9 3.6 18 0.0 1 TR Input Power" | pstext -R0/4/0/3.75 -Jx -O -K >> example_03f.ps
psxy -R -Jx -O -K -Wthicker box.d >> example_03f.ps
psxy -R -Jx -O -K -Glightgray -L -Wthicker >> example_03f.ps << END
0.25 0.25
1.4 0.25
1.4 0.9
0.25 0.9
END
echo "0.4 0.7" | psxy -R -Jx -O -K -ST0.07i -Gblack >> example_03f.ps
echo "0.5 0.7 14 0.0 1 ML Ship" | pstext -R -Jx -O -K >> example_03f.ps
echo "0.4 0.4" | psxy -R -Jx -O -K -Sc0.07i -Gblack >> example_03f.ps
echo "0.5 0.4 14 0.0 1 ML Satellite" | pstext -R -Jx -O >> example_03f.ps
#
rm -f box.d report samp* *.pg *.extr spectrum.* .gmt*

```

The final illustration (Figure 7.3) shows that the ship gravity anomalies have more power than altimetry derived gravity for short wavelengths and that the coherency between the two signals improves dramatically for wavelengths > 20 km.

Ship and Satellite Gravity

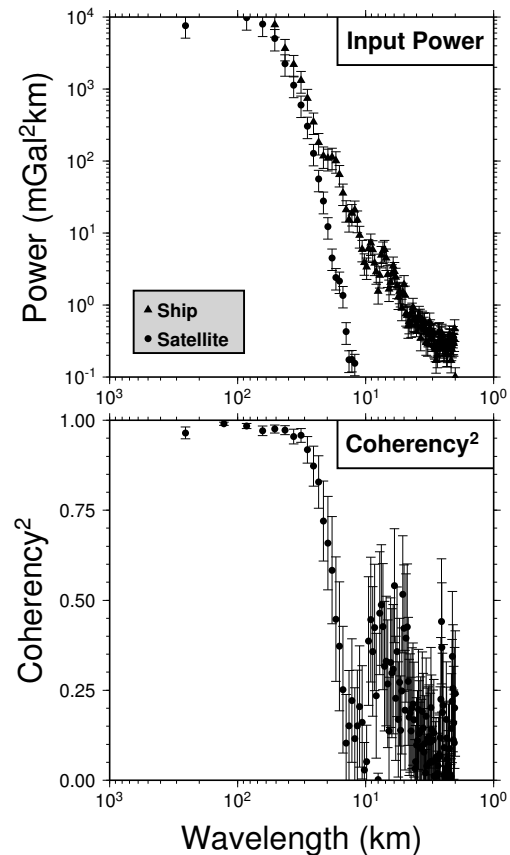


Figure 7.3: Spectral estimation and x/y -plots.

7.4 A 3-D perspective mesh plot

This example will illustrate how to make a fairly complicated composite figure. We need a subset of the ETOPO5 bathymetry¹ and Geosat geoid data sets which we will extract from the local data bases using **grd raster**. We would like to show a 2-layer perspective plot where layer one shows a contour map of the marine geoid with the location of the Hawaiian islands superposed, and a second layer showing the 3-D mesh plot of the topography. We also add an arrow pointing north and some text. This is how to do it:

```
#!/bin/sh
#
#
# Purpose:      3-D mesh plot of Hawaiian topography and geoid
# GMT progs:    grdcontour, grdview, pscoast, pstext
# Unix progs:   echo, rm
#
ps=example_04.ps
```

¹ These data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).

```

echo '-10 255 0 255' > zero.cpt
echo ' 0 100 10 100' >> zero.cpt
grdcontour HI_geoid4.nc -Jm0.45i -E60/30 -R195/210/18/25 -C1 -A5+o -Gd4i -K -P -X1.5i -Y1.5i \
-U/-1.25i/-1.25i/"Example 4 in Cookbook" > $ps
pscoast -J -E60/30 -R -B2/2NEsw -Gblack -O -K -T209/19.5/1i >> $ps
grdview HI_topo4.nc -J -Jz0.34i -Czero.cpt -E60/30 -R195/210/18/25/-6/4 -N-6/lightgray -Qsm -O -K \
-B2/2/2:"Topo (km)":neswZ -Y2.2i >> $ps
echo '3.25 5.75 60 0.0 33 BC H@#awaiian@# R@#ridge' | pstext -R0/10/0/10 -Jx1i -O >> $ps
rm -f zero.cpt .gmt*

```

The purpose of the color palette file `zero.cpt` is to have the positive topography mesh painted light gray (the remainder is white). The left side of Figure 7.4 shows the complete illustration.

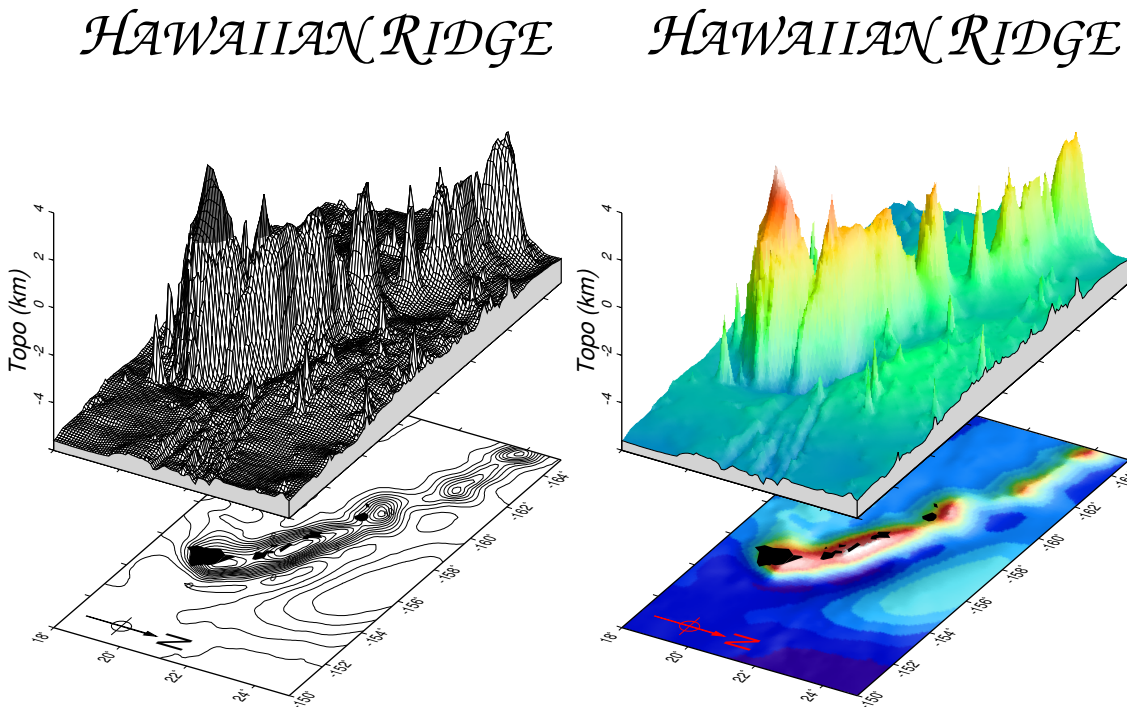


Figure 7.4: 3-D perspective mesh plot (left) and colored version (right).

A color version of this figure was used in our first article in *EOS Trans. AGU* (Oct. 8th, 1991). It was created along similar lines, but instead of a mesh plot we chose a color-coded surface with artificial illumination from a light-source due north. We choose to use the `-Qi` option in `grdview` to achieve a high degree of smoothness. Here, we select 100 dpi since that will be the resolution of our final raster (The EOS raster was 300 dpi). We used `grdgradient` to provide the intensity files. The following script creates the color *PostScript* file. Note that the size of the resulting output file is directly dependent on the square of the dpi chosen for the scanline conversion. A higher value for dpi in `-Qi` would have resulted in a much larger output file. The cpt files were taken from Section 7.2.

```

#!/bin/sh
#
# GMT EXAMPLE 04c
#
# 3-D perspective color plot of Hawaiian topography and geoid
# GMT progs:  grdcontour, grdview, pscoast, pstext
# Unix progs:  echo, rm
#
ps=example_04c.ps
grdgradient HI_geoid4.nc -A0 -Gg_intens.grd -Nt0.75 -M
grdgradient HI_topo4.nc -A0 -Gt_intens.grd -Nt0.75 -M
grdview HI_geoid4.nc -Ig_intens.grd -JM6.75i -E60/30 -R195/210/18/25 -Cgeoid.cpt -Qi100 -K \
-X1.5i -Y1.25i -P -U/-1.25i/-1i/"Example 04c in Cookbook" > $ps
pscoast -J -E60/30 -R -B2/2NEsw -Gblack -O -K >> $ps
psbasemap -R -J -E60/30 -O -K -T209/19.5/1i --COLOR_BACKGROUND=red --TICK_PEN=thinner,red >> $ps
grdview HI_topo4.nc -It_intens.grd -J -JZ3.4i -Ctopo.cpt -E60/30 -R195/210/18/25/-6/4 \

```

```

-N-6/lightgray -Qi100 -O -K -Y2.2i >> $ps
psbasemap -J -JZ3.4i -E60/30 -R -Z-6 -O -K -B2/2/2:"Topo (km)":neZ >> $ps
echo '3.25 5.75 60 0.0 33 BC H@#awaiian@# R@#idge' | pstext -R0/10/0/10 -Jxli -O >> $ps
rm -f *_intens.grd .gmt*

```

7.5 A 3-D illuminated surface in black and white

Instead of a mesh plot we may choose to show 3-D surfaces using artificial illumination. For this example we will use **grdmath** to make a grid file that contains the surface given by the function $z(x,y) = \cos(2\pi r/8) \cdot e^{-r/10}$, where $r^2 = (x^2 + y^2)$. The illumination is obtained by passing two grid files to **grdview**: One with the z -values (the surface) and another with intensity values (which should be in the ± 1 range). We use **grdgradient** to compute the horizontal gradients in the direction of the artificial light source. The **gray.cpt** file only has one line that states that all z values should have the gray level 128. Thus, variations in shade are entirely due to variations in gradients, or illuminations. We choose to illuminate from the SW and view the surface from SE:

```

#!/bin/sh
#
#           GMT EXAMPLE 05
#
# Purpose:   Generate grid and show monochrome 3-D perspective
# GMT progs: grdgradient, grdmath, grdview, pstext
# Unix progs: echo, rm
#
ps=example_05.ps
grdmath -R-15/15/-15/15 -I0.3 X Y HYPOT DUP 2 MUL PI MUL 8 DIV COS EXCH NEG 10 DIV EXP MUL = \
  sombrero.grd
echo '-5 128 5 128' > gray.cpt
grdgradient sombrero.grd -A225 -Gintensify.grd -Nt0.75
grdview sombrero.grd -JX6i -JZ2i -B5/5/0.5SEwnZ -N-l/white -Qs -Iintensify.grd -X1.5i -Cgray.cpt \
  -R-15/15/-15/15/-1/1 -K -E120/30 -U/-1.25i/-0.75i/"Example 5 in Cookbook" > $ps
echo "4.1 5.5 50 0 33 BC z(r) = cos (2\pi r/8) * e@+/-r/10@+" | pstext -R0/11/0/8.5 -Jxli -O >> $ps
rm -f gray.cpt sombrero.grd intensify.grd .gmt*

```

The variations in intensity could be made more dramatic by using **grdmath** to scale the intensity file before running **grdview**. For very rough data sets one may improve the smoothness of the intensities by passing the output of **grdgradient** to **grdhisteq**. The shell-script above will result in a plot like the one in Figure 7.5.

7.6 Plotting of histograms

GMT provides two tools to render histograms: **pshistogram** and **psrose**. The former takes care of regular histograms whereas the latter deals with polar histograms (rose diagrams, sector diagrams, and wind rose diagrams). We will show an example that involves both programs. The file **fractures.yx** contains a compilation of fracture lengths and directions as digitized from geological maps. The file **v3206.t** contains all the bathymetry measurements from *Vema* cruise 3206. Our complete figure (Figure 7.6) was made running this script:

```

#!/bin/sh
#
#           GMT EXAMPLE 06
#
# Purpose:   Make standard and polar histograms
# GMT progs: pshistogram, psrose
# Unix progs: rm
#
ps=example_06.ps
psrose fractures.d -i -A10r -S1.8in -U/-2.25i/-0.75i/"Example 6 in Cookbook" -P -Gblack -R0/1/0/360 \
  -X2.5i -K -B0.2g0.2/30g30 > $ps
pshistogram -Ba2000f1000:"Topography (m)":a10f5:"Frequency"::,"Two types of histograms":WSne \
  v3206.t -R-6000/0/0/30 -JX4.8i/2.4i -Ggray -O -Y5.5i -X-0.5i -Lthinner -Z1 -W250 >> $ps
rm -f .gmt*

```

$$z(r) = \cos(2\pi r/8) * e^{-r/10}$$

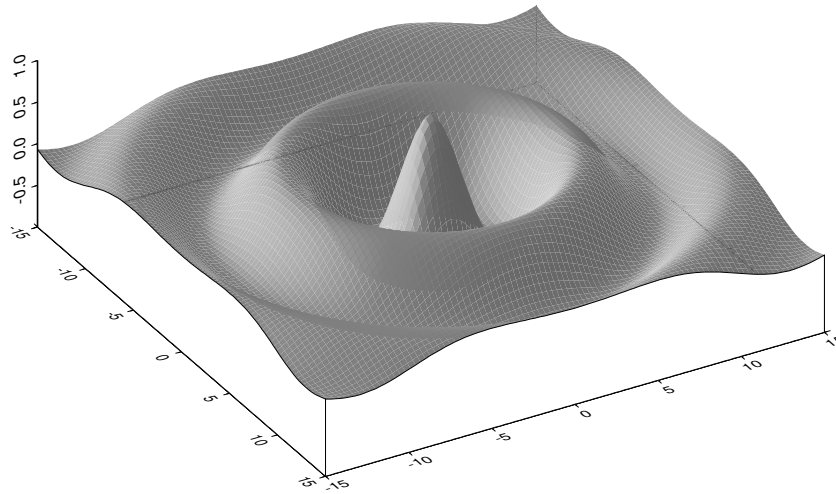


Figure 7.5: 3-D illuminated surface.

Two types of histograms

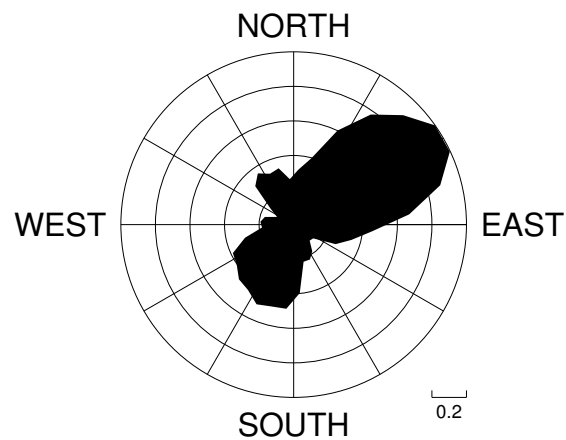
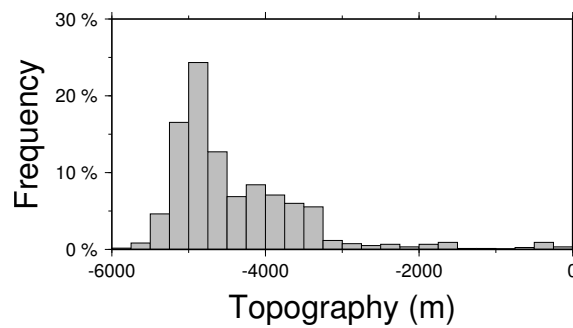


Figure 7.6: Two kinds of histograms.

7.7 A simple location map

Many scientific papers start out by showing a location map of the region of interest. This map will typically also contain certain features and labels. This example will present a location map for the equatorial Atlantic ocean, where fracture zones and mid-ocean ridge segments have been plotted. We also would like to plot earthquake locations and available isochrons. We have obtained one file, `quakes.xym`, which contains the position and magnitude of available earthquakes in the region. We choose to use `magnitude/100` for the symbol-size in inches. The digital fracture zone traces (`fz.xy`) and isochrons (0 isochron as `ridge.xy`, the rest as `isochrons.xy`) were digitized from available maps². We create the final location map (Figure 7.7) with the following script:

```
#!/bin/sh
#
#           GMT EXAMPLE 07
#
# Purpose:   Make a basemap with earthquakes and isochrons etc
# GMT progs: pscoast, pstext, psxy
# Unix progs: $AWK, echo, rm
#
ps=example_07.ps
pscoast -R-50/0/-10/20 -JM9i -K -GP300/26 -Dl -Wthinest -B10 -U"Example 7 in Cookbook" > $ps
psxy -R -J -O -K -m fz.xy -Wthinner,- >> $ps
$AWK '{print $1-360.0, $2, $3*0.01}' quakes.xym | psxy -R -J -O -K -Hl -Sci -Gwhite -Wthinest >> $ps
psxy -R -J -O -K -m isochron.xy -Wthin >> $ps
psxy -R -J -O -K -m ridge.xy -Wthicker >> $ps
psxy -R -J -O -K -Gwhite -Wthick -A >> $ps << END
-14.5 15.2
-2 15.2
-2 17.8
-14.5 17.8
END
psxy -R -J -O -K -Gwhite -Wthinner -A >> $ps << END
-14.35 15.35
-2.15 15.35
-2.15 17.65
-14.35 17.65
END
echo "-13.5 16.5" | psxy -R -J -O -K -Sc0.08i -Gwhite -Wthinner >> $ps
echo "-12.5 16.5 18 0 6 LM ISC Earthquakes" | pstext -R -J -O -K >> $ps
pstext -R -J -O -Sthin -Gwhite >> $ps << END
-43 -5 30 0 1 CM SOUTH
-43 -8 30 0 1 CM AMERICA
-7 11 30 0 1 CM AFRICA
END
rm -f .gmt*
```

The same figure could equally well be made in color, which could be rasterized and made into a slide for a meeting presentation. The script is similar to the one outlined above, except we would choose a color for land and oceans, and select colored symbols and pens rather than black and white.

7.8 A 3-D histogram

The program **psxyz** allows us to plot three-dimensional symbols, including columnar plots. As a simple demonstration, we will convert a gridded netCDF of bathymetry into an ASCII `xyz` table and use the height information to draw a 2-D histogram in a 3-D perspective view. Our gridded bathymetry file is called `topo.grd` and covers the region from 0 to 5 °E and 0 to 5 °N. Depth ranges from -5000 meter to sea-level. We produce the Figure 7.8 by running this script:

```
#!/bin/sh
#
#           GMT EXAMPLE 08
#
# Purpose:   Make a 3-D bar plot
# GMT progs: grd2xyz, pstext, psxyz
# Unix progs: echo, rm
#
ps=example_08.ps
grd2xyz guinea_bay.nc | psxyz -B1/1/1000:"Topography (m)":::ETOP05:WSneZ+ \
```

²These data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).

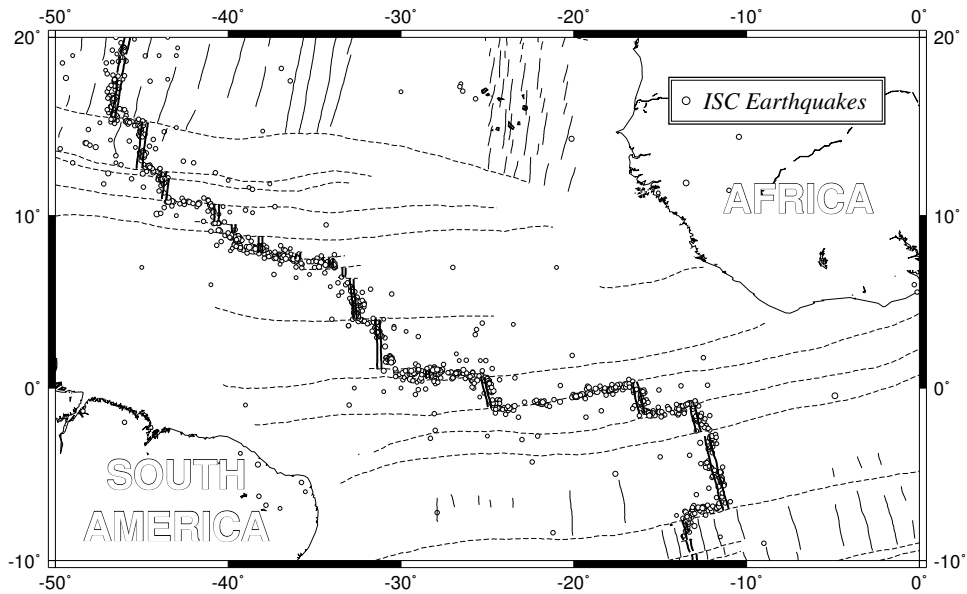


Figure 7.7: A typical location map.

```
-R-0.1/5.1/-0.1/5.1/-5000/0 -JM5i -JZ6i -E200/30 -So0.083333ub-5000 -P \
-U"Example 8 in Cookbook" -Wthinest -Glightgray -K > $ps
echo '0.1 4.9 24 0 1 TL This is the surface of cube' | pstext -R -J -JZ -Z0 -E200/30 -O >> $ps
rm -f .gmt*
```

7.9 Plotting time-series along tracks

A common application in many scientific disciplines involves plotting one or several time-series as “wiggles” along tracks. Marine geophysicists often display magnetic anomalies in this manner, and seismologists use the technique when plotting individual seismic traces. In our example we will show how a set of Geosat sea surface slope profiles from the south Pacific can be plotted as “wiggles” using the **pswiggle** program. We will embellish the plot with track numbers, the location of the Pacific-Antarctic Ridge, recognized fracture zones in the area, and a “wiggle” scale. The Geosat tracks are stored in the files **.xys*, the ridge in *ridge.xy*, and all the fracture zones are stored in the multiple segment file *fz.xy*. We extract the profile id (which is the first part of the file name for each profile) and the last point in each of the track files to construct an input file for **ps**text that will label each profile with the track number. We know the profiles trend approximately N40°E so we want the labels to have that same orientation (i.e., the angle with the baseline must be 50°). We do this by extracting the last record from each track, paste this file with the *tracks.lis* file, and use **\$AWK** to create the format needed for **ps**text. Note we offset the positions by -0.05 inch with **-D** in order to have a small gap between the profile and the label:

```
#!/bin/sh
#
#           GMT EXAMPLE 09
#
# Purpose:   Make wiggle plot along track from geoid deflections
# GMT progs: pswiggle, pstext, psxy
# Unix progs: $AWK, ls, paste, tail, rm
#
ps=example_09.ps
pswiggle track_*.xys -R185/250/-68/-42 -U"Example 9 in Cookbook" -K -Jm0.13i -Ba10f5 -Gblack \
-Z2000 -Wthinest -S240/-67/500/@°m@°rad > $ps
psxy -R -J -O -K ridge.xy -Wthicker >> $ps
psxy -R -J -O -K -m fz.xy -Wthinner,- >> $ps
rm -f tmp
# Make label file
for file in track_*.xys; do
```

ETOPO5

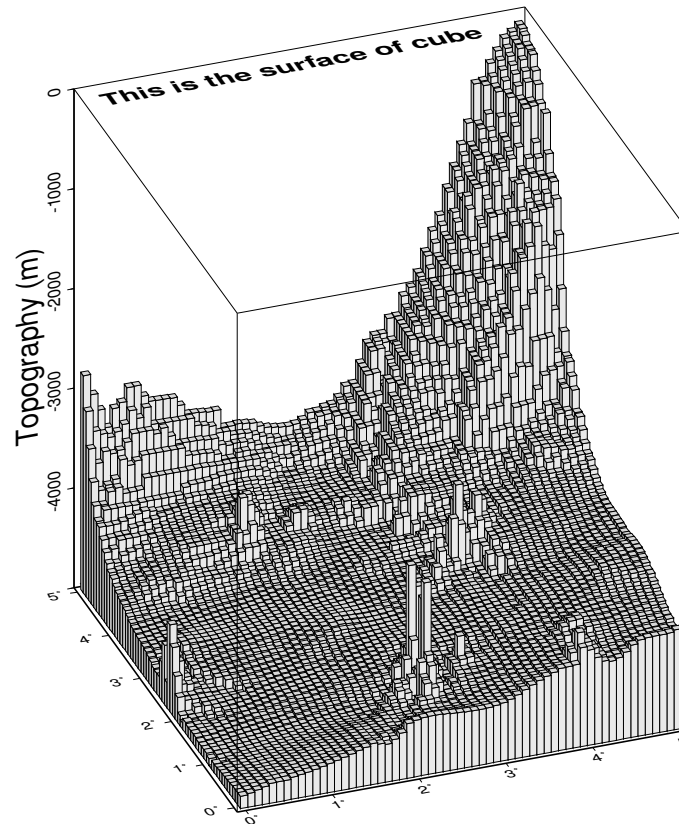


Figure 7.8: A 3-D histogram.

```

tail -1 $file >> tmp
done
ls -l track_*.xys | $AWK -F. '{print $2}' > tracks.lis
paste tmp tracks.lis | $AWK '{print $1, $2, 10, 50, 1, "RM", $4}' \
    | pstext -R -J -D-0.05i/-0.05i -O >> $ps
rm -f tmp tracks.lis .gmt*
```

The output shows the sea-surface slopes along 42 descending Geosat tracks in the Eltanin and Udintsev fracture zone region in a Mercator projection (Figure 7.9).

7.10 A geographical bar graph plot

Our next and perhaps most business-like example presents a three-dimensional bar graph plot showing the geographic distribution of the membership in the American Geophysical Union (AGU). The input data was taken from the January 2008 AGU member directory and added up to give total members per continent. We decide to plot a 3-D column centered on each continent with a height that is proportional to the logarithm of the membership. A \log_{10} -scale is used since the memberships vary by almost 3 orders of magnitude. We choose a plain linear projection for the basemap and add the columns and text on top. Our script that produces Figure 7.10 reads:

```

#!/bin/sh
#
#
# Purpose:      Make 3-D bar graph on top of perspective map
```

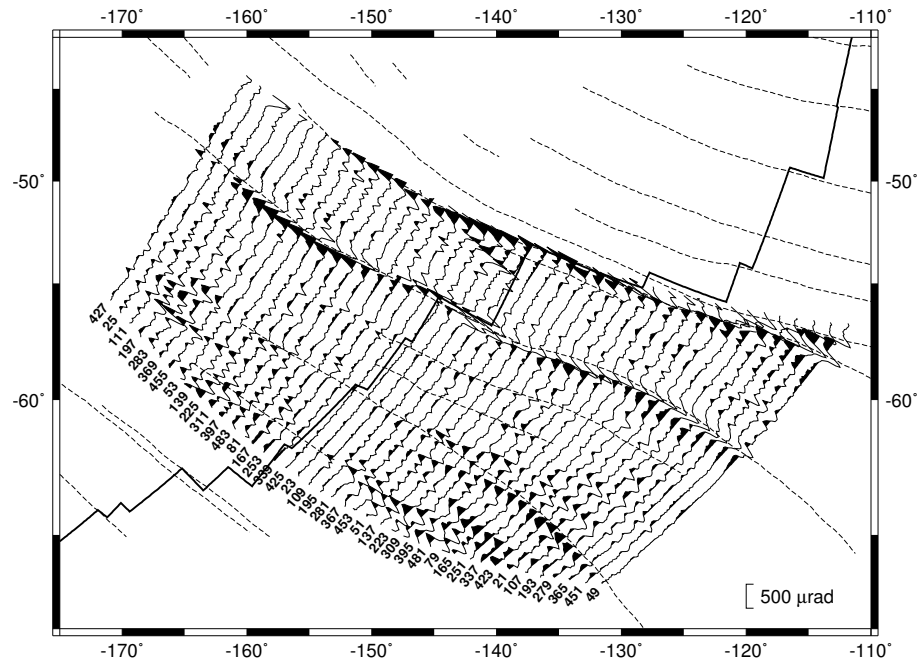


Figure 7.9: Time-series as “wiggles” along a track.

```
# GMT progs:    pscoast, pstext, psxyz
# Unix progs:   $AWK, rm
#
ps=example_10.ps
pscoast -Rd -JX8id/5id -Dc -Gblack -E200/40 -K -U"Example 10 in Cookbook" > $ps
psxyz agu2008.d -R-180/180/-90/90/1/100000 -J -JZ2.5il -So0.3ib1 -Ggray -Wthinner \
-B60g60/30g30/alp:Memberships:WSneZ -O -K -E200/40 >> $ps
$AWK '{print $1, $2, 20, 0, 0, "RM", $3}' agu2008.d \
| pstext -Rd -J -O -K -E200/40 -Gwhite -Sthinner -D-0.2i/0 >> $ps
echo "4.5 6 30 0 5 BC AGU 2008 Membership Distribution" | pstext -R0/11/0/8.5 -Jxli -O >> $ps
rm -f .gmt*
```

7.11 Making a 3-D RGB color cube

In this example we generate a series of 6 color images, arranged so that they can be cut out and assembled into a 3-D color cube. The six faces of the cube represent the outside of the R-G-B color space. On each face one of the color components is fixed at either 0 or 255 and the other two components vary smoothly across the face from 0 to 255. The cube is configured as a right-handed coordinate system with x - y - z mapping R-G-B. Hence, the 8 corners of the cube represent the primaries red, green, and blue, plus the secondaries cyan, magenta and yellow, plus black and white.

The 6 color faces are generated by feeding **grdimage** three grids, one for each color component (R, G, and B). In some cases the X or Y axes of a face are reversed by specifying a negative width or height in order to change the variation of the color value in that direction from ascending to descending, or vice versa.

A number of rays emanating from the white and black corners indicate the Hue value (ranging from 0 to 360°). The dashed and dotted lines near the white corner reflect saturation levels, running from 0 to 1 (in black font). On these 3 faces the brightness is a constant value of 1. On the other 3 faces of the cube, around the black corner, the white decimal numbers indicate brightnesses between 0 and 1, with saturation fixed at 1.

Here is the shell script to generate the RGB cube in Figure 7.11:

```
#!/bin/sh
```

AGU 2008 Membership Distribution

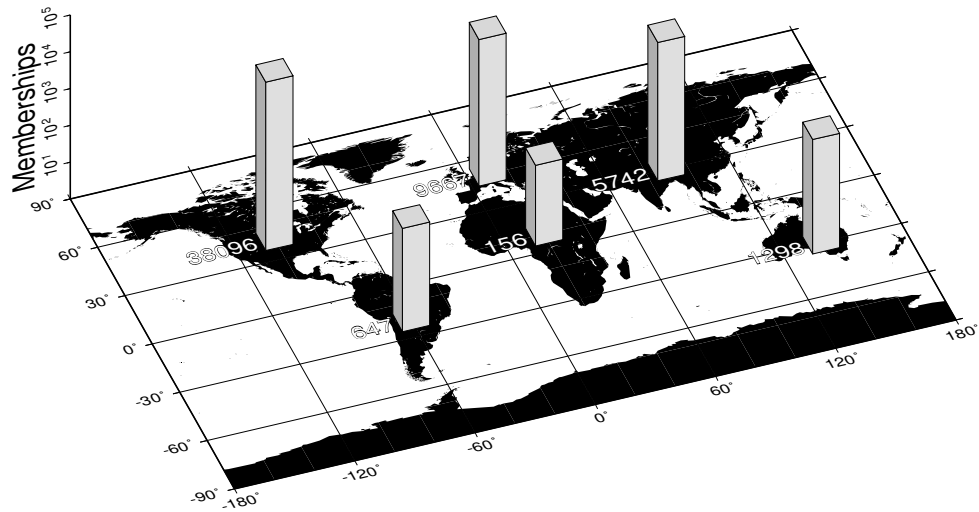


Figure 7.10: Geographical bar graph.

```
#
#           GMT EXAMPLE 11
#
# Purpose:      Create a 3-D RGB Cube
# GMT progs:    gmtset, grdimage, grdmath, pstext, psxy
# Unix progs:   rm
ps=example_11.ps

# Use psxy to plot "cut-along-the-dotted" lines.

gmtset TICK_LENGTH 0 COLOR_MODEL rgb CHAR_ENCODING Standard+

psxy cut-here.dat -Wthinest,. -m -R-51/306/0/1071 -JX3.5i/10.5i -X2.5i -Y0.5i \
-P -U/-2.0i/-0.2i/"Example 11 in Cookbook" -K > $ps

# First, create grids of ascending X and Y and constant 0.
# These are to be used to represent R, G and B values of the darker 3 faces of the cube.

grdmath -I1 -R0/255/0/255 X = x.grd
grdmath -I1 -R Y = y.grd
grdmath -I1 -R 0 = c.grd

grdimage x.grd y.grd c.grd -JX2.5i/-2.5i -R -K -O -X0.5i >> $ps
psxy -m -Wthinner,white,- rays.dat -J -R -K -O -Bwesn >> $ps
echo 128 128 12 -45 1 MC "60\217" | pstext -Gwhite -J -R -K -O >> $ps
echo 102 26 12 -90 1 MC 0.4 | pstext -Gwhite -J -R -K -O >> $ps
echo 204 26 12 -90 1 MC 0.8 | pstext -Gwhite -J -R -K -O >> $ps
echo 10 140 16 180 1 MC G | pstext -Gwhite -J -R -K -O >> $ps
echo 0 0 0 128 | psxy -N -Svs -Gwhite -J -R -K -O >> $ps

grdimage x.grd c.grd y.grd -JX2.5i/2.5i -R -K -O -Y2.5i >> $ps
psxy -m -Wthinner,white,- rays.dat -J -R -K -O -Bwesn >> $ps
echo 128 128 12 45 1 MC "300\217" | pstext -Gwhite -J -R -K -O >> $ps
echo 26 102 12 0 1 MC 0.4 | pstext -Gwhite -J -R -K -O >> $ps
echo 26 204 12 0 1 MC 0.8 | pstext -Gwhite -J -R -K -O >> $ps
echo 140 10 16 -90 1 MC R | pstext -Gwhite -J -R -K -O >> $ps
echo 100 100 16 -45 1 MC V | pstext -Gwhite -J -R -K -O >> $ps
echo 0 0 128 0 | psxy -N -Svs -Gwhite -J -R -K -O >> $ps
echo 0 0 90 90 | psxy -N -Svs -Gwhite -J -R -K -O >> $ps

grdimage c.grd x.grd y.grd -JX-2.5i/2.5i -R -K -O -X-2.5i >> $ps
psxy -m -Wthinner,white,- rays.dat -J -R -K -O -Bwesn >> $ps
echo 128 128 12 135 1 MC "180\217" | pstext -Gwhite -J -R -K -O >> $ps
echo 102 26 12 90 1 MC 0.4 | pstext -Gwhite -J -R -K -O >> $ps
echo 204 26 12 90 1 MC 0.8 | pstext -Gwhite -J -R -K -O >> $ps
echo 10 140 16 0 1 MC B | pstext -Gwhite -J -R -K -O >> $ps
```

```

echo 0 0 0 128 | psxy -N -Svs -Gwhite -J -R -K -O >> $ps
echo 0 0 128 0 | psxy -N -Svs -Gwhite -J -R -K -O >> $ps

# Second, create grids of descending X and Y and constant 255.
# These are to be used to represent R, G and B values of the lighter 3 faces of the cube.

grdmath -I1 -R 255 X SUB = x.grd
grdmath -I1 -R 255 Y SUB = y.grd
grdmath -I1 -R 255      = c.grd

grdimage x.grd y.grd c.grd -JX-2.5i/-2.5i -R -K -O -X2.5i -Y2.5i >> $ps
psxy -m -Wthinner,black,- rays.dat -J -R -K -O -Bwesn >> $ps
echo 128 128 12 -45 1 MC "240\217" | pstext -J -R -K -O >> $ps
echo 102 26 12 270 1 MC 0.4 | pstext -J -R -K -O >> $ps
echo 204 26 12 270 1 MC 0.8 | pstext -J -R -K -O >> $ps

grdimage c.grd y.grd x.grd -JX2.5i/-2.5i -R -K -O -X2.5i >> $ps
psxy -m -Wthinner,black,- rays.dat -J -R -K -O -Bwesn >> $ps
echo 128 128 12 -45 1 MC "0\217" | pstext -J -R -K -O >> $ps
echo 26 102 12 0 1 MC 0.4 | pstext -J -R -K -O >> $ps
echo 26 204 12 0 1 MC 0.8 | pstext -J -R -K -O >> $ps
echo 100 100 16 45 1 MC S | pstext -Gblack -J -R -K -O >> $ps
echo 204 66 16 90 1 MC H | pstext -Gblack -J -R -K -O >> $ps
echo 0 0 90 90 | psxy -N -Svs -Gblack -J -R -K -O >> $ps
echo 204 204 204 76 | psxy -N -Svs -Gblack -J -R -K -O >> $ps

grdimage x.grd c.grd y.grd -JX-2.5i/2.5i -R -K -O -X-2.5i -Y2.5i >> $ps
psxy -m -Wthinner,black,- rays.dat -J -R -K -O -Bwesn >> $ps
echo 128 128 12 135 1 MC "120\217" | pstext -J -R -K -O >> $ps
echo 26 102 12 180 1 MC 0.4 | pstext -J -R -K -O >> $ps
echo 26 204 12 180 1 MC 0.8 | pstext -J -R -K -O >> $ps
echo 200 200 16 225 1 MC GMT 4 | pstext -J -R -O >> $ps

rm -f *.grd *.gmt*

```

7.12 Optimal triangulation of data

Our next example (Figure 7.12) operates on a data set of topographic readings non-uniformly distributed in the plane (Table 5.11 in Davis: *Statistics and Data Analysis in Geology*, J. Wiley). We use **triangulate** to perform the optimal Delaunay triangulation, then use the output to draw the resulting network. We label the node numbers as well as the node values, and call **pscontour** to make a contour map and image directly from the raw data. Thus, in this example we do not actually make grid files but still are able to contour and image the data. We use a color palette table topo.cpt (created via **minmax** and **makecpt**). The script becomes:

```

#!/bin/sh
#                               GMT EXAMPLE 12
#
# Purpose:      Illustrates Delaunay triangulation of points, and contouring
# GMT progs:    makecpt, minmax, pscontour, pstext, psxy, triangulate
# Unix progs:   $AWK, echo, rm
#
# First draw network and label the nodes
#
ps=example_12.ps
triangulate table_5.11 -m > net.xy
psxy -R0/6.5/-0.2/6.5 -JX3.06i/3.15i -B2f1WSNe -m net.xy -Wthinner -P -K -X0.9i -Y4.65i > $ps
psxy table_5.11 -R -J -O -K -Sc0.12i -Gwhite -Wthinest >> $ps
$AWK '{print $1, $2, 6, 0, 0, "CM", NR-1}' table_5.11 | pstext -R -J -O -K >> $ps
#
# Then draw network and print the node values
#
psxy -R -J -B2f1SNw -m net.xy -Wthinner -O -K -X3.25i >> $ps
psxy -R -J -O -K table_5.11 -Sc0.03i -Gblack >> $ps
$AWK '{printf "%g %s 6 0 0 LM %g\n", $1, $2, $3}' table_5.11 | pstext -R -J -O -K -Wwhite,o \
-C0.01i/0.01i -D0.08i/0i -N >> $ps
#
# Then contour the data and draw triangles using dashed pen; use "minmax" and "makecpt" to make a
# color palette (.cpt) file
#
T='minmax -T25/2 table_5.11'
makecpt -Cjet $T > topo.cpt

```

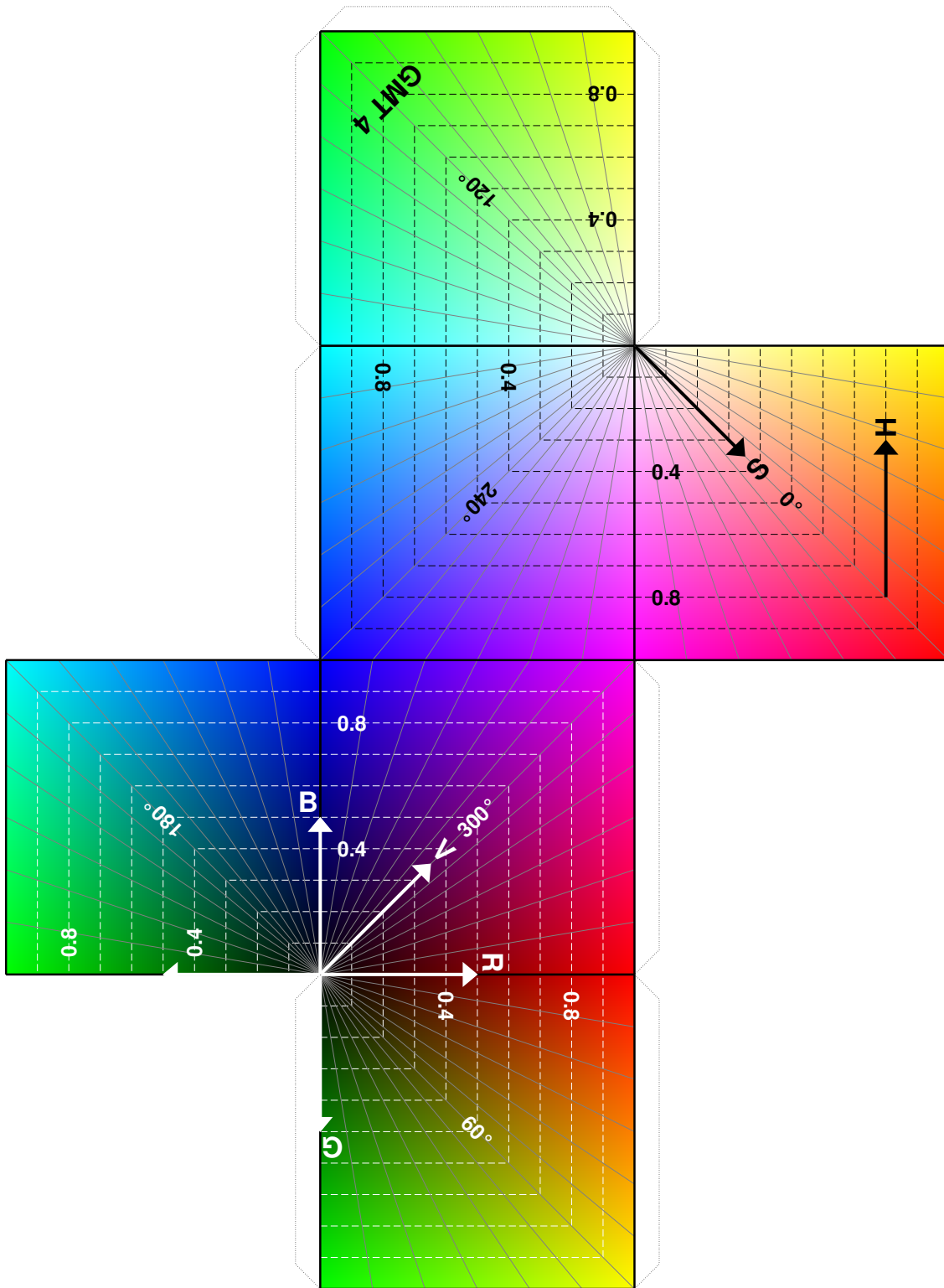



Figure 7.11: The RGB color cube.

```

pscontour -R -J table_5.11 -B2f1WSne -Wthin -Ctopo.cpt -Lthinnest,- -Gli/0 -X-3.25i -Y-3.65i -O -K \
-U"Example 12 in Cookbook" >> $ps
#
# Finally color the topography
#
pscontour -R -J table_5.11 -B2f1eSnw -Ctopo.cpt -I -X3.25i -O -K >> $ps
echo "3.16 8 30 0 1 BC Delaunay Triangulation" | \
    pstext -R0/8/0/11 -Jx1i -O -X-3.25i >> $ps
#
rm -f net.xy topo.cpt .gmt*

```

Delaunay Triangulation

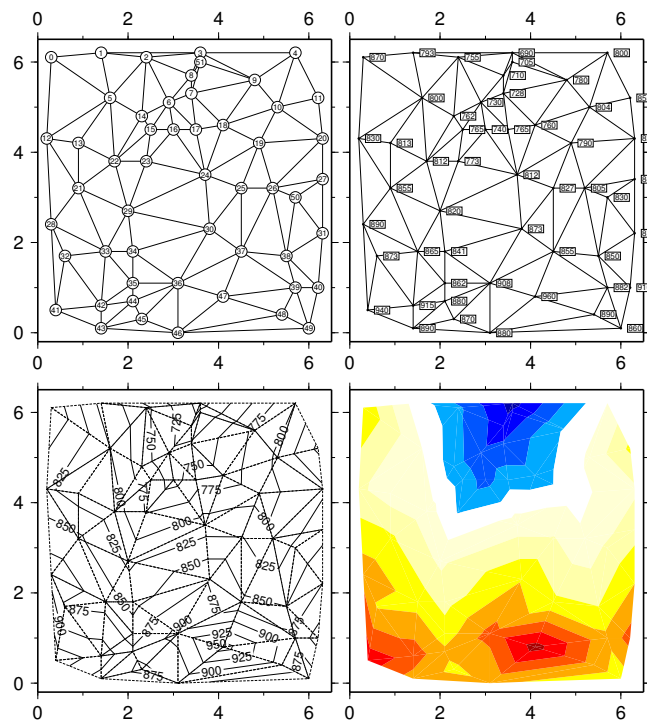


Figure 7.12: Optimal triangulation of data.

7.13 Plotting of vector fields

In many areas, such as fluid dynamics and elasticity, it is desirable to plot vector fields of various kinds. *GMT* provides a way to illustrate 2-component vector fields using the **grdvector** utility. The two components of the field (Cartesian or polar components) are stored in separate grid files. In this example we use **grdmath** to generate a surface $z(x,y) = x \cdot \exp(-x^2 - y^2)$ and to calculate ∇z by returning the x - and y -derivatives separately. We superpose the gradient vector field and the surface z and also plot the components of the gradient in separate windows. A **pstext** call to place a header finishes the plot (Figure 7.13:

```

#!/bin/sh
#
# GMT EXAMPLE 13
#
# Purpose:      Illustrate vectors and contouring
# GMT progs:    grdmath, grdcontour, grdvector, pstext
# Unix progs:   echo, rm
#
ps=example_13.ps

```

```

grdmath -R-2/2/-2/2 -I0.1 X Y R2 NEG EXP X MUL = z.grd
grdmath z.grd DDX = dzdx.grd
grdmath z.grd DDY = dzdy.grd
grdcontour dzdx.grd -JX3i -B1/1WSne -C0.1 -A0.5 -K -P -G2i/10 -S4 -T0.1i/0.03i \
-U"Example 13 in Cookbook" > $ps
grdcontour dzdy.grd -J -B1/1WSne -C0.05 -A0.2 -O -K -G2i/10 -S4 -T0.1i/0.03i -X3.45i >> $ps
grdcontour z.grd -J -B1/1WSne -C0.05 -A0.1 -O -K -G2i/10 -S4 -T0.1i/0.03i -X-3.45i -Y3.45i >> $ps
grdcontour z.grd -J -B1/1WSne -C0.05 -O -K -G2i/10 -S4 -X3.45i >> $ps
grdvector dzdx.grd dzdy.grd -I0.2 -J -O -K -Q0.03i/0.1i/0.09in0.25i -G0 -S5i >> $ps
echo "3.2 3.6 40 0 6 BC z(x,y) = x * exp(-x^2-y^2) " \
| pstext -R0/6/0/4.5 -Jx1i -O -X-3.45i >> $ps
rm -f z.grd dzdx.grd dzdy.grd .gmt*

```

$$z(x,y) = x * \exp(-x^2 - y^2)$$

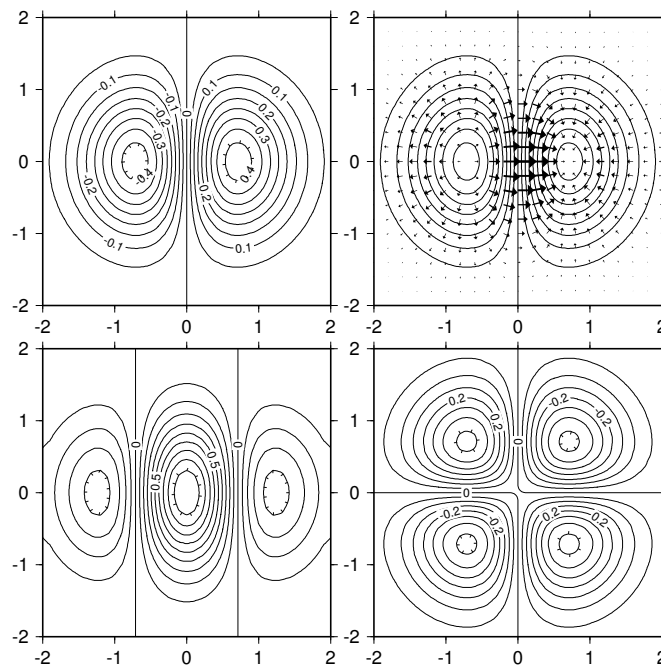


Figure 7.13: Display of vector fields in GMT.

7.14 Gridding of data and trend surfaces

This example shows how one goes from randomly spaced data points to an evenly sampled surface. First we plot the distribution and values of our raw data set (same as in Section 7.12). We choose an equidistant grid and run **blockmean** which preprocesses the data to avoid aliasing. The dashed lines indicate the logical blocks used by **blockmean**; all points inside a given bin will be averaged. The logical blocks are drawn from a temporary file we make on the fly within the shell script. The processed data is then gridded with the **surface** program and contoured every 25 units. A most important point here is that **blockmean**, **blockmedian**, or **blockmode** should always be run prior to running **surface**, and both of these steps must use the same grid interval. We use **grdtrend** to fit a bicubic trend surface to the gridded data, contour it as well, and sample both grid files along a diagonal transect using **grdtrack**. The bottom panel compares the gridded (solid line) and bicubic trend (dashed line) along the transect using **psxy** (Figure 7.14):

```

#!/bin/sh
#
#
# Purpose:      Showing simple gridding, contouring, and resampling along tracks

```

```

# GMT progs:    blockmean, grdcontour, grdtrack, grdtrend, minmax, project
# GMT progs:    gmtset, pstext, psbasemap, psxy, surface
# Unix progs:   $AWK, rm
#
ps=example_14.ps

# First draw network and label the nodes

gmtset GRID_PEN_PRIMARY thinnest,-
psxy table_5.11 -R0/7/0/7 -JX3.06i/3.15i -B2f1WSne -Sc0.05i -Gblack -P -K -Y6.45i > $ps
$AWK '{printf "%g %s 6 0 0 LM %g\n", $1+0.08, $2, $3}' table_5.11 | pstext -R -J -O -K -N >> $ps
blockmean table_5.11 -R0/7/0/7 -I1 > mean.xyz

# Then draw blockmean cells

psbasemap -R0.5/7.5/0.5/7.5 -J -O -K -B0g1 -X3.25i >> $ps
psxy -R0/7/0/7 -J -B2f1eSNw mean.xyz -Ss0.05i -Gblack -O -K >> $ps
$AWK '{printf "%g %s 6 0 0 LM %g\n", $1+0.1, $2, $3}' mean.xyz \
| pstext -R -J -O -K -Wwhite,o -C0.01i/0.01i -N >> $ps

# Then surface and contour the data

surface mean.xyz -R -I1 -Gdata.grd
grdcontour data.grd -J -B2f1WSne -C25 -A50 -G3i/10 -S4 -O -K -X-3.25i -Y-3.55i >> $ps
psxy -R -J mean.xyz -Ss0.05i -Gblack -O -K >> $ps

# Fit bicubic trend to data and compare to gridded surface

grdtrend data.grd -N10 -Ttrend.grd
project -C0/0 -E7/7 -G0.1 > track
grdcontour trend.grd -J -B2f1WSne -C25 -A50 -G1ct/cb -S4 -O -K -X3.25i >> $ps
psxy -R -J track -Wthick,. -O -K >> $ps

# Sample along diagonal

grdtrack track -Gdata.grd | cut -f3,4 > data.d
grdtrack track -Gtrend.grd | cut -f3,4 > trend.d
psxy 'minmax data.d trend.d -I0.5/25' -JX6.3i/1.4i data.d -Wthick -O -K -X-3.25i -Y-1.9i \
-B1/50WSne >> $ps
psxy -R -J trend.d -Wthinner,- -O -U"Example 14 in Cookbook" >> $ps

rm -f mean.xyz track *.grd *.d .gmt*

```

7.15 Gridding, contouring, and masking of unconstrained areas

This example (Figure 7.15) demonstrates some of the different ways one can use to grid data in *GMT*, and how to deal with unconstrained areas. We first convert a large ASCII file to binary with **gmtconvert** since the binary file will read and process much faster. Our lower left plot illustrates the results of gridding using a nearest neighbor technique (**nearneighbor**) which is a local method: No output is given where there are no data. Next (lower right), we use a minimum curvature technique (**surface**) which is a global method. Hence, the contours cover the entire map although the data are only available for portions of the area (indicated by the gray areas plotted using **psmask**). The top left scenario illustrates how we can create a clip path (using **psmask**) based on the data coverage to eliminate contours outside the constrained area. Finally (top right) we simply employ **pscoast** to overlay gray land masses to cover up the unwanted contours, and end by plotting a star at the deepest point on the map with **psxy**. This point was extracted from the grid files using **grdinfo**.

```

#!/bin/sh
#
#
# Purpose:    Gridding and clipping when data are missing
# GMT progs:  blockmedian, gmtconvert, grdclip, grdcontour, grdinfo, minmax
# GMT progs:  nearneighbor, pscoast, psmask, pstext, surface
# Unix progs:  awk, echo, rm
#
ps=example_15.ps
gmtconvert ship.xyz -bo > ship.b
#
region='minmax ship.b -I1 -bi3'
nearneighbor $region -I10m -S40k -Gship.grd ship.b -bi3

```

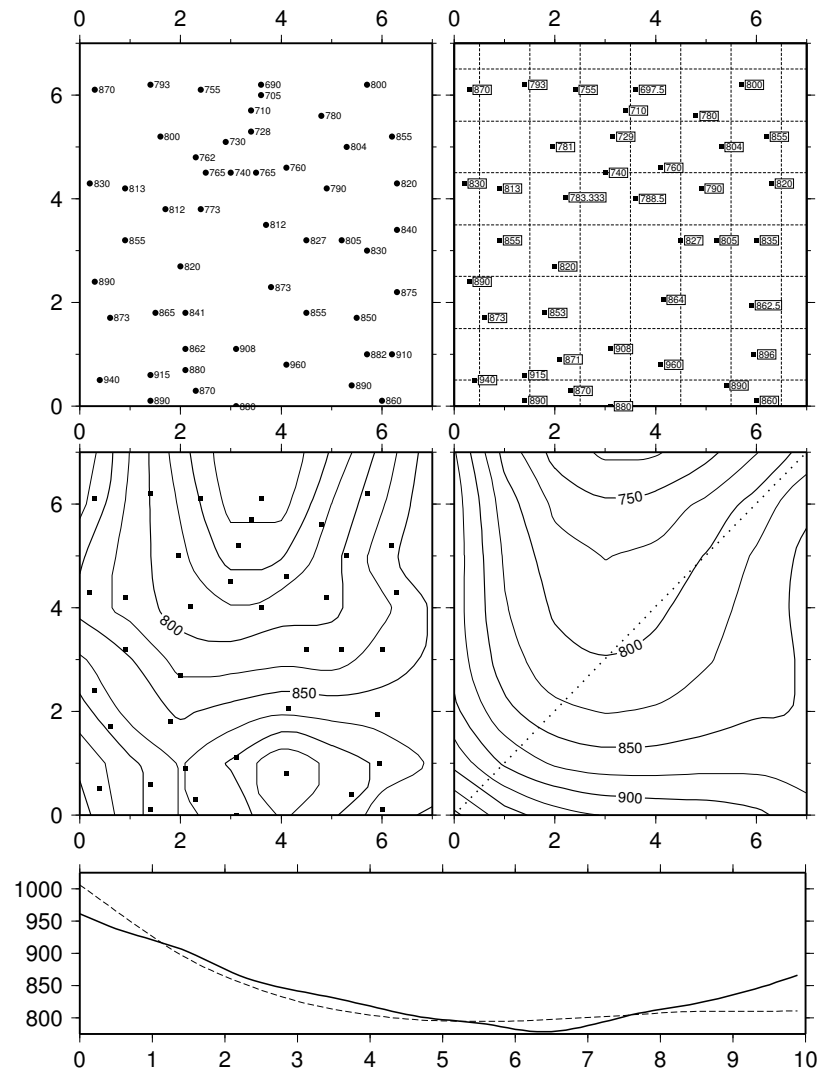


Figure 7.14: Gridding of data and trend surfaces.

```

info='grdinfo -C -M ship.grd'
grdcontour ship.grd -JM3i -P -B2WSne -C250 -A1000 -G2i -K -U"Example 15 in Cookbook" > $ps
#
blockmedian $region -I10m ship.b -bi3 -bo > ship_10m.b
surface $region -I10m ship_10m.b -Gship.grd -bi3
psmask $region -I10m ship.b -J -O -K -T -Glightgray -bi3 -X3.6i >> $ps
grdcontour ship.grd -J -B2WSne -C250 -L-8000/0 -A1000 -G2i -O -K >> $ps
#
psmask $region -I10m ship_10m.b -bi3 -J -B2WSne -O -K -X-3.6i -Y3.75i >> $ps
grdcontour ship.grd -J -C250 -A1000 -L-8000/0 -G2i -O -K >> $ps
psmask -C -O -K >> $ps
#
grdclip ship.grd -Sa-1/NaN -Gship_clipped.grd
grdcontour ship_clipped.grd -J -B2WSne -C250 -A1000 -L-8000/0 -G2i -O -K -X3.6i >> $ps
pscoast $region -J -O -K -Ggray -Wthinnest >> $ps
echo $info | awk '{print $12,$13}' | psxy -R -J -O -K -Sa0.15i -Wthick >> $ps
echo "-0.3 3.6 24 0 1 CB Gridding with missing data" | pstext -R0/3/0/4 -Jxli -O -N >> $ps
rm -f ship.b ship_10m.b ship.grd ship_clipped.grd .gmt*

```

Gridding with missing data

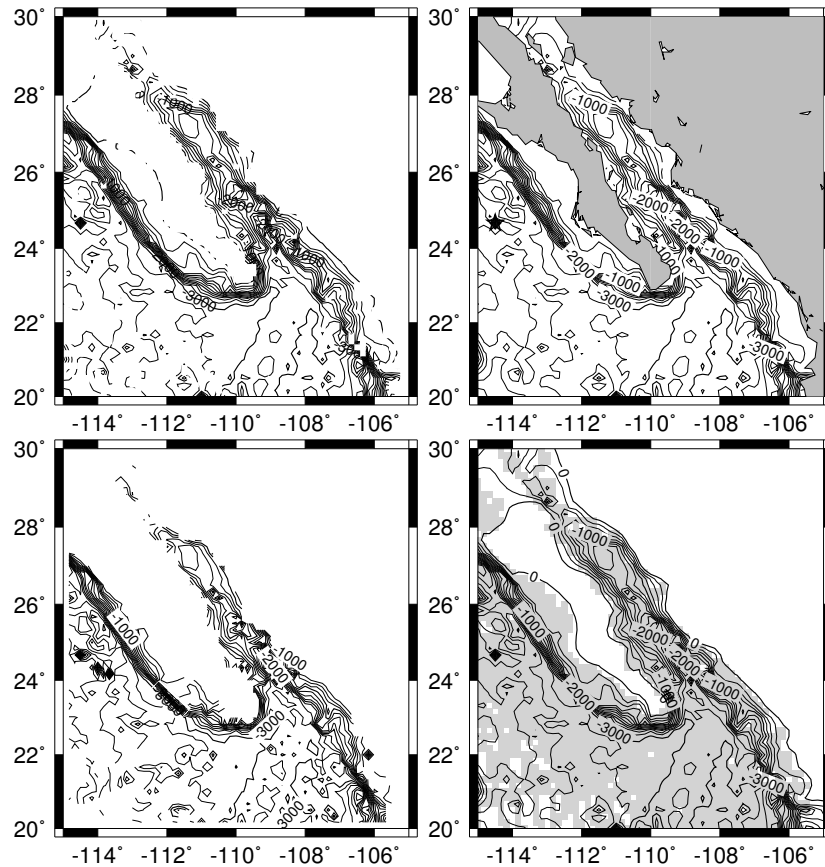


Figure 7.15: Gridding, contouring, and masking of data.

7.16 Gridding of data, continued

pscontour (for contouring) and **triangulate** (for gridding) use the simplest method of interpolating data: a Delaunay triangulation (see Section 7.12) which forms $z(x,y)$ as a union of planar triangular facets. One advantage of this method is that it will not extrapolate $z(x,y)$ beyond the convex hull of the input (x,y) data. Another is that it will not estimate a z value above or below the local bounds on any triangle. A disadvantage is that the $z(x,y)$ surface is not differentiable, but has sharp kinks at triangle edges and thus also along contours. This may not look physically reasonable, but it can be filtered later (last panel below). **surface** can be used to generate a higher-order (smooth and differentiable) interpolation of $z(x,y)$ onto a grid, after which the grid may be illustrated (**grdcontour**, **grdimage**, **grdview**). **surface** will interpolate to all (x,y) points in a rectangular region, and thus will extrapolate beyond the convex hull of the data. However, this can be masked out in various ways (see Section 7.15).

A more serious objection is that **surface** may estimate z values outside the local range of the data (note area near $x = 0.8$, $y = 5.3$). This commonly happens when the default tension value of zero is used to create a “minimum curvature” (most smooth) interpolant. **surface** can be used with non-zero tension to partially overcome this problem. The limiting value $tension = 1$ should approximate the triangulation, while a value between 0 and 1 may yield a good compromise between the above two cases. A value of 0.5 is shown here (Figure 7.16). A side effect of the tension is that it tends to make the contours turn near the edges of the domain so that they approach the edge from a perpendicular direction. A solution is to use **surface** in a larger area and then use **grdcut** to cut out the desired smaller area. Another way to achieve a compromise is to interpolate the data to a grid and then filter the grid using **grdfit** or **grdfilter**. The latter can handle

grids containing “NaN” values and it can do median and mode filters as well as convolutions. Shown here is **triangulate** followed by **grdfilter**. Note that the filter has done some extrapolation beyond the convex hull of the original x, y values. The “best” smooth approximation of $z(x, y)$ depends on the errors in the data and the physical laws obeyed by z . *GMT* cannot always do the “best” thing but it offers great flexibility through its combinations of tools. We illustrate all four solutions using a `cpt` file that contains color fills, predefined patterns for interval (900,925) and NaN, an image pattern for interval (875,900), and a “skip slice” request for interval (700,725).

```
#!/bin/sh
#
#           GMT EXAMPLE 16
#
# Purpose:   Illustrates interpolation methods using same data as Example 12.
# GMT progs: gmtset, grdview, grdfilter, pscontour, psscale, pstext, surface, triangulate
# Unix progs: echo, rm
#
# Illustrate various means of contouring, using triangulate and surface.
#
ps=example_16.ps
gmtset ANNOT_FONT_SIZE_PRIMARY 9
#
pscontour -R0/6.5/-0.2/6.5 -Jx0.45i -P -K -Y5.5i -Ba2f1WSne table_5.11 -Cex16.cpt -I > $ps
echo "3.25 7 18 0 4 CB pscontour (triangulate)" | pstext -R -J -O -K -N >> $ps
#
surface table_5.11 -R -I0.2 -Graws0.grd
grdview raws0.grd -R -J -Ba2f1WSne -Cex16.cpt -Qs -O -K -X3.5i >> $ps
echo "3.25 7 18 0 4 CB surface (tension = 0)" | pstext -R -J -O -K -N >> $ps
#
surface table_5.11 -R -I0.2 -Graws5.grd -T0.5
grdview raws5.grd -R -J -Ba2f1WSne -Cex16.cpt -Qs -O -K -Y-3.75i -X-3.5i >> $ps
echo "3.25 7 18 0 4 CB surface (tension = 0.5)" | pstext -R -J -O -K -N >> $ps
#
triangulate table_5.11 -Grawt.grd -R -I0.2 > /dev/null
grdfilter rawt.grd -Gfiltered.grd -D0 -Fc1
grdview filtered.grd -R -J -Ba2f1WSne -Cex16.cpt -Qs -O -K -X3.5i >> $ps
echo "3.25 7 18 0 4 CB triangulate @`256` grdfilter" | pstext -R -J -O -K -N >> $ps
echo "3.2125 7.5 32 0 4 CB Gridding of Data" | pstext -R0/10/0/10 -Jx1i -O -K -N -X-3.5i >> $ps
psscale -D3.25i/0.35i/5i/0.25ih -Cex16.cpt -O -U"Example 16 in Cookbook" -Y-0.75i >> $ps
#
rm -f *.grd .gmt*
```

7.17 Images clipped by coastlines

This example demonstrates how **pscoast** can be used to set up clip paths based on coastlines. This approach is well suited when different gridded data sets are to be merged on a plot using different color palette files. Merging the files themselves may not be doable since they may represent different data sets, as we show in this example. Here, we lay down a color map of the geoid field near India with **grdimage**, use **pscoast** to set up land clip paths, and then overlay topography from the ETOPO5 data set with another call to **grdimage**. We finally undo the clippath with a second call to **pscoast** with the option **-Q** (Figure 7.17):

```
#!/bin/sh
#
#           GMT EXAMPLE 17
#
# Purpose:   Illustrates clipping of images using coastlines
# GMT progs: grd2cpt, grdgradient, grdimage, pscoast, pstext
# Unix progs: rm
#
ps=example_17.ps

# First generate geoid image w/ shading

grd2cpt india_geoid.nc -Crainbow > geoid.cpt
grdgradient india_geoid.nc -Nt1 -A45 -Gindia_geoid_i.grd
grdimage india_geoid.nc -Iindia_geoid_i.grd -JM6.5i -Cgeoid.cpt -P -K \
    -U"Example 17 in Cookbook" > $ps

# Then use pscoast to initiate clip path for land

pscoast -Rindia_geoid.nc -J -O -K -D1 -Gc >> $ps
```

Gridding of Data

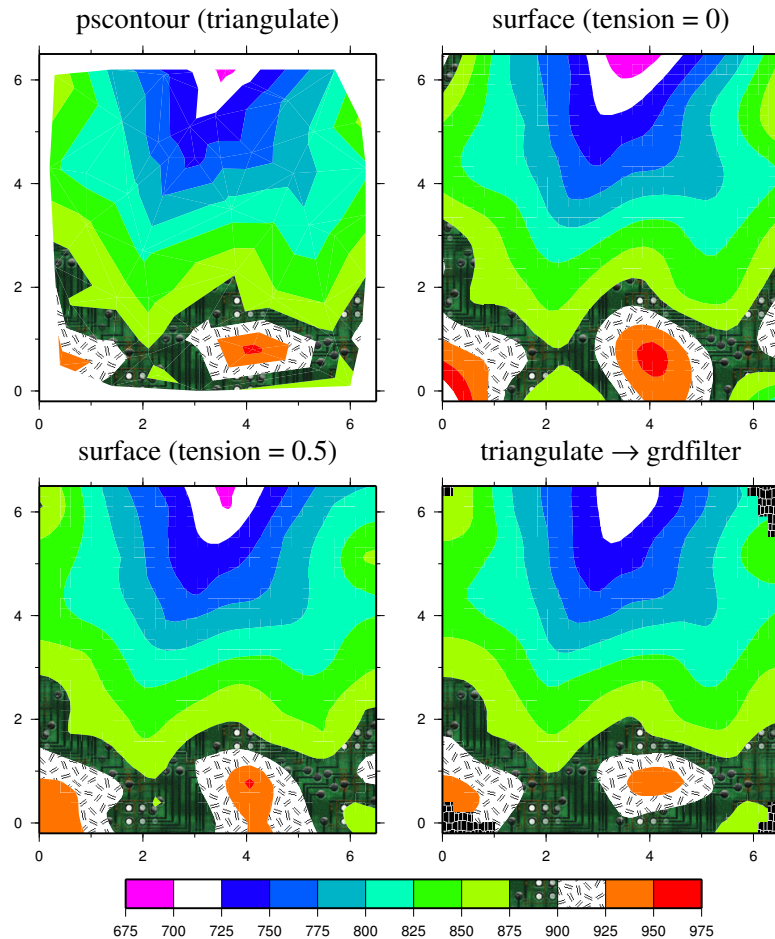


Figure 7.16: More ways to grid data.

```
# Now generate topography image w/shading
echo "-10000 150 10000 150" > gray.cpt
grdgradient india_topo.nc -Nt1 -A45 -Gindia_topo_i.grd
grdimage india_topo.nc -Iindia_topo_i.grd -J -Cgray.cpt -O -K >> $ps

# Finally undo clipping and overlay basemap
pscoast -R -J -O -K -Q -B10f5:."Clipping of Images": >> $ps

# Put a color legend on top of the land mask
psscale -D4i/7.6i/4i/0.2ih -Cgeoid.cpt -B5f1/:m: -I -O -K >> $ps

# Add a text paragraph
pstext -R -J -O -m -Wwhite,Othinner -D-0.1i/0.1i >> $ps << END
> 90 -10 12 0 4 RB 12p 3i j
@_@%5%Example 17.@%@@_ We first plot the color geoid image
for the entire region, followed by a gray-shaded @#etopo5@#
image that is clipped so it is only visible inside the coastlines.
END

# Clean up
rm -f geoid.cpt gray.cpt *_i.grd .gmt*
```

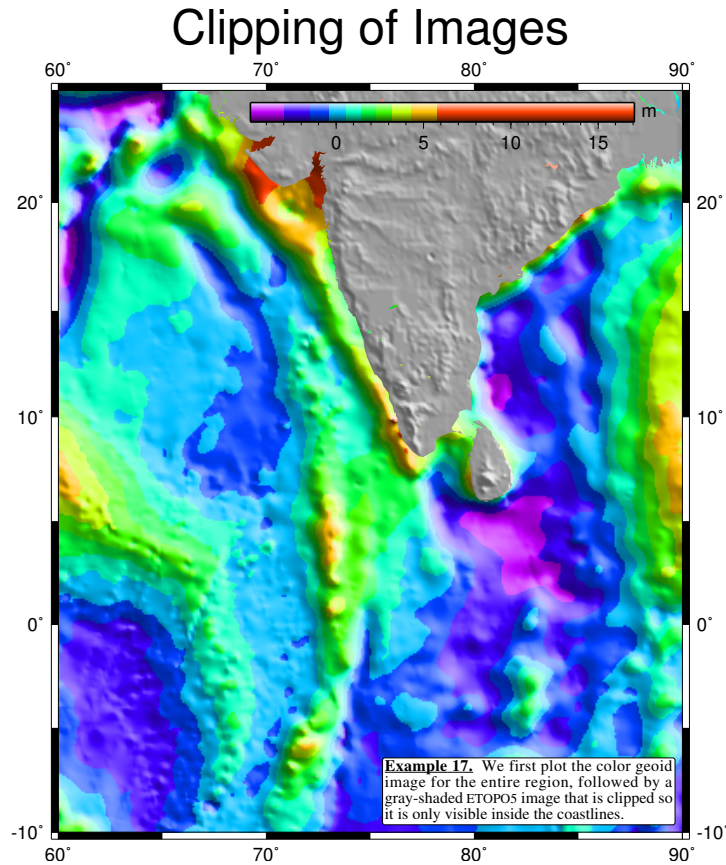



Figure 7.17: Clipping of images using coastlines.

We also plot a color legend on top of the land. So here we basically have three layers of “paint” stacked on top of each other: the underlying geoid map, the land mask, and finally the color legend. This legend makes clear how **grd2cpt** distributed the colors over the range: they are not of equal length but are associated with equal amounts of area in the plot. Since the high amounts (in red) are not very prevalent, that color spans a long range.

For this image it is appropriate to use the **-I** option in **psscale** so the legend gets shaded, similar to the geoid grid. See Appendix M to learn more about color palettes and ways to draw color legends.

7.18 Volumes and Spatial Selections

To demonstrate potential usage of the new programs **grdvolume** and **gmtselect** we extract a subset of the Sandwell & Smith altimetric gravity field³ for the northern Pacific and decide to isolate all seamounts that (1) exceed 50 mGal in amplitude and (2) are within 200 km of the Pratt seamount. We do this by dumping the 50 mGal contours to disk, then making a simple **\$AWK** script `center.awk` that returns the mean location of the points making up each closed polygon, and then pass these locations to **gmtselect** which retains only the points within 200 km of Pratt. We then mask out all the data outside this radius and use **grdvolume** to determine the combined area and volumes of the chosen seamounts. Our illustration is presented in Figure 7.18.

```
#!/bin/sh
#           GMT EXAMPLE 18
#
# Purpose:   Illustrates volumes of grids inside contours and spatial
```

³ See http://topex.ucsd.edu/marine_grav/mar_grav.html.

```

# selection of data
# GMT progs: gmtset, gmtselect, grdclip, grdcontour, grdgradient, grdimage
# GMT progs: grdmath, grdvolume, makecpt, pscoast, psscale, pstext, psxy
# Unix progs: $AWK, cat, rm
#
ps=example_18.ps

# Use spherical projection since SS data define on sphere
gmtset ELLIPSOID Sphere D_FORMAT %lg

# Define location of Pratt seamount
echo "-142.65 56.25" > pratt.d

# First generate gravity image w/ shading, label Pratt, and draw a circle
# of radius = 200 km centered on Pratt.

makecpt -Crainbow -T-60/60/10 -Z > grav.cpt
grdgradient AK_gulf_grav.nc -Nt1 -A45 -GAK_gulf_grav_i.grd
grdimage AK_gulf_grav.nc -IAK_gulf_grav_i.grd -JM5.5i -Cgrav.cpt -B2f1 -P -K -X1.5i -Y5.85i > $ps
pscoast -RAK_gulf_grav.nc -J -O -K -Di -Ggray -Wthinnest >> $ps
psscale -D2.75i/-0.4i/4i/0.15ih -Cgrav.cpt -B20f10:mGal: -O -K >> $ps
$AWK '{print $1, $2, 12, 0, 1, "LB", "Pratt"}' pratt.d | pstext -R -J -O -K -D0.1i/0.1i >> $ps
$AWK '{print $1, $2, 0, 200, 200}' pratt.d | psxy -R -J -O -K -SE -Wthinnest >> $ps

# Then draw 10 mGal contours and overlay 50 mGal contour in green

grdcontour AK_gulf_grav.nc -J -C20 -B2f1WSEn -O -K -Y-4.85i \
-U/-1.25i/-0.75i/"Example 18 in Cookbook" >> $ps
grdcontour AK_gulf_grav.nc -J -C10 -L49/51 -O -K -Dsm -Wcthin,green >> $ps
pscoast -R -J -O -K -Di -Ggray -Wthinnest >> $ps
$AWK '{print $1, $2, 0, 200, 200}' pratt.d | psxy -R -J -O -K -SE -Wthinnest >> $ps
\rm -f sm_*[0-9].xyz # Only consider closed contours

# Now determine centers of each enclosed seamount > 50 mGal but only plot
# the ones within 200 km of Pratt seamount.

# First determine mean location of each closed contour and
# add it to the file centers.d

\rm -f centers.d
for file in sm_*.xyz; do
    $AWK 'BEGIN{x=0;y=0;n=0};{x+=$1;y+=$2;n++};END{print x/n,y/n}' $file >> centers.d
done

# Only plot the ones within 200 km

gmtselect -C200/pratt.d centers.d -fg | psxy -R -J -O -K -SC0.04i -Gred -Wthinnest >> $ps
psxy -R -J -O -K -ST0.1i -Gyellow -Wthinnest pratt.d >> $ps

# Then report the volume and area of these seamounts only
# by masking out data outside the 200 km-radius circle
# and then evaluate area/volume for the 50 mGal contour

grdmath -R `cat pratt.d` GDIST = mask.grd
grdclip mask.grd -Sa200/NaN -Sb200/1 -Gmask.grd
grdmath AK_gulf_grav.nc mask.grd MUL = tmp.grd
area=`grdvolume tmp.grd -C50 -Sk | cut -f2`
volume=`grdvolume tmp.grd -C50 -Sk | cut -f3`

psxy -R -J -A -O -K -L -Wthin -Gwhite >> $ps << END
-148.5 52.75
-140.5 52.75
-140.5 53.75
-148.5 53.75
END
pstext -R -J -O >> $ps << END
-148 53.08 14 0 1 LM Areas: $area km@+2@+
-148 53.42 14 0 1 LM Volumes: $volume mGal\264km@+2@+
END

# Clean up

rm -f grav.cpt sm_*.xyz *_i.grd tmp.grd mask.grd pratt.d center*.gmt*
```

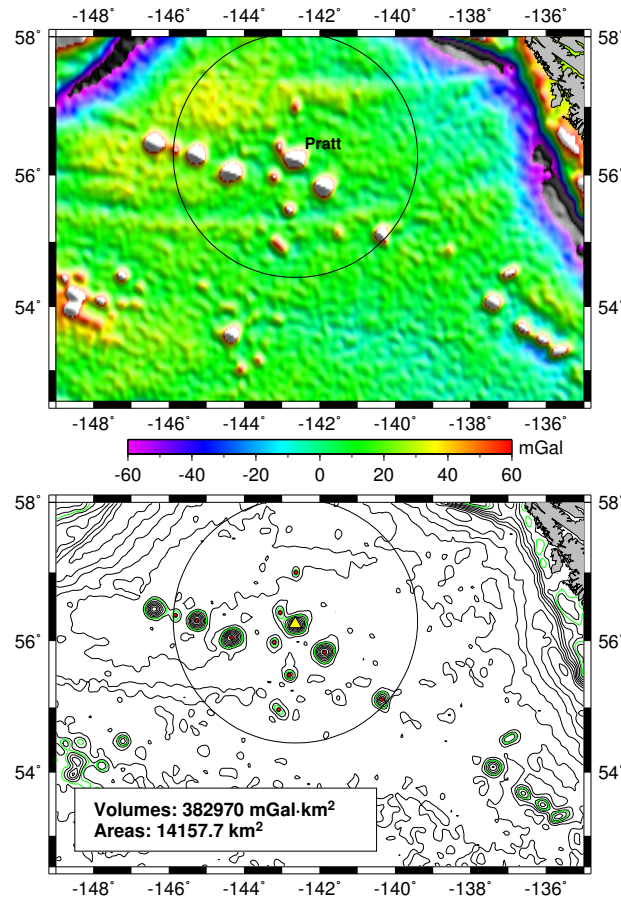


Figure 7.18: Volumes and geo-spatial selections.

7.19 Color patterns on maps

GMT 3.1 introduced color patterns and this examples give a few cases of how to use this new feature. We make a phony poster that advertises an international conference on *GMT* in Honolulu. We use **grdmath**, **makecpt**, and **grdimage** to draw pleasing color backgrounds on maps, and overlay **pscoast** clip paths to have the patterns change at the coastlines. The middle panel demonstrates a simple **pscoast** call where the built-in pattern # 86 is drawn at 100 dpi but with the black and white pixels replaced with color combinations. At the same time the ocean is filled with a repeating image of a circuit board (provides in Sun raster format). The text *GMT* in the center is an off-line *PostScript* file that was overlaid using **psimage**. The final panel repeats the top panel except that the land and sea images have changed places (Figure 7.19).

```
#!/bin/sh
#
#           GMT EXAMPLE 19
#
# Purpose:   Illustrates various color pattern effects for maps
# GMT progs:  gmtset, grdimage, grdmath, makecpt, pscoast, pstext, psimage
# Unix progs:  rm
#
ps=example_19.ps

# First make a worldmap with graded blue oceans and rainbow continents

gmtset COLOR_MODEL rgb
grdmath -Rd -I1 Y COSD 2 POW = lat.grd
grdmath -Rd -I1 X Y ABS 90 NEQ MUL = lon.grd
echo "0 white 1 blue" > lat.cpt
makecpt -Crainbow -T-180/180/60 -Z > lon.cpt
```

```

grdimage lat.grd -S1 -JI0/6.5i -Clat.cpt -P -K -Y7.5i -B0 > $ps
pscoast -R -J -O -K -Dc -A5000 -Gc >> $ps
grdimage lon.grd -S1 -J -Clon.cpt -O -K >> $ps
pscoast -R -J -O -K -Q >> $ps
pscoast -R -J -O -K -Dc -A5000 -Wthinest >> $ps
echo "0 20 32 0 1 CM 8TH INTERNATIONAL" | pstext -R -J -O -K -Gred -Sthinner >> $ps
echo "0 -10 32 0 1 CM GMT CONFERENCE" | pstext -R -J -O -K -Gred -Sthinner >> $ps
echo "0 -30 18 0 1 CM Honolulu, Hawaii, April 1, 2010" | pstext -R -J -O -K -Ggreen -Sthinest >> $ps

# Then show example of color patterns and placing a PostScript image

pscoast -R -J -O -K -Dc -A5000 -Gp100/86:FredByYellow -Sp100/circuit.ras -B0 -Y-3.25i >> $ps
echo "0 30 32 0 1 CM SILLY USES OF" | pstext -R -J -O -K -Glightgreen -Sthinner >> $ps
echo "0 -30 32 0 1 CM COLOR PATTERNS" | pstext -R -J -O -K -Gmagenta -Sthinner >> $ps
psimage -C3.25i/1.625i/CM -W3i GMT_coverttext.eps -O -K >> $ps

# Finally repeat 1st plot but exchange the patterns

grdimage lon.grd -S1 -J -Clon.cpt -O -K -Y-3.25i -B0 -U"Example 19 in Cookbook" >> $ps
pscoast -R -J -O -K -Dc -A5000 -Gc >> $ps
grdimage lat.grd -S1 -J -Clat.cpt -O -K >> $ps
pscoast -R -J -O -K -Q >> $ps
pscoast -R -J -O -K -Dc -A5000 -Wthinest >> $ps
echo "0 20 32 0 1 CM 8TH INTERNATIONAL" | pstext -R -J -O -K -Gred -Sthinner >> $ps
echo "0 -10 32 0 1 CM GMT CONFERENCE" | pstext -R -J -O -K -Gred -Sthinner >> $ps
echo "0 -30 18 0 1 CM Honolulu, Hawaii, April 1, 2010" | pstext -R -J -O -Ggreen -Sthinest >> $ps

rm -f l*.grd l*.cpt .gmt*
```

7.20 Custom plot symbols

One is often required to make special maps that shows the distribution of certain features but one would prefer to use a custom symbol instead of the built-in circles, squares, triangles, etc. in the *GMT* plotting programs **psxy** and **psxyz**. Here we demonstrate one approach that allows for a fair bit of flexibility in designing ones own symbols. The following recipe is used when designing a new symbol.

1. Use **psbasemap** (or engineering paper!) to set up an empty grid that goes from -0.5 to +0.5 in both x and y . Use ruler and compass to draw your new symbol using straight lines, arcs of circles, and stand-alone geometrical objects (see **psxy** man page for a full description of symbol design). In this Section we will create two new symbols: a volcano and a bulls eye.
2. After designing the symbol we will encode it using a simple set of rules. In our case we describe our volcano and bulls eye using these three freeform polygon generators:

$x_0 y_0$ M [-Gfill] [-Wpen]	Start new element at x_0, y_0
$x_1 y_1$ D	Draw straight line from current point to x_1, y_1 around (x_0, y_0)
$x_0 y_0 r \alpha_1 \alpha_2$ A	Draw arc segment of radius r from angle α_1 to α_2

We also add a few stand-alone circles (for other symbols, see **psxy** man page):

$x_0 y_0 r$ c [-Gfill] [-Wpen]	Draw single circle of radius r around x_0, y_0
---	--

The optional **-G** and **-W** can be used to hardwire the color fill and pen for segments (use **-** to disallow fill or line for any specific feature). By default the segments are painted based on the values of the command line settings.

Manually applying these rules to our volcano symbol results in a definition file [volcano.def](#):

```

#
# Definition file for a volcano symbol
# To be used with psxy as -Skvolcano/<size>.
# The symbol will be painted and drawn given the
```

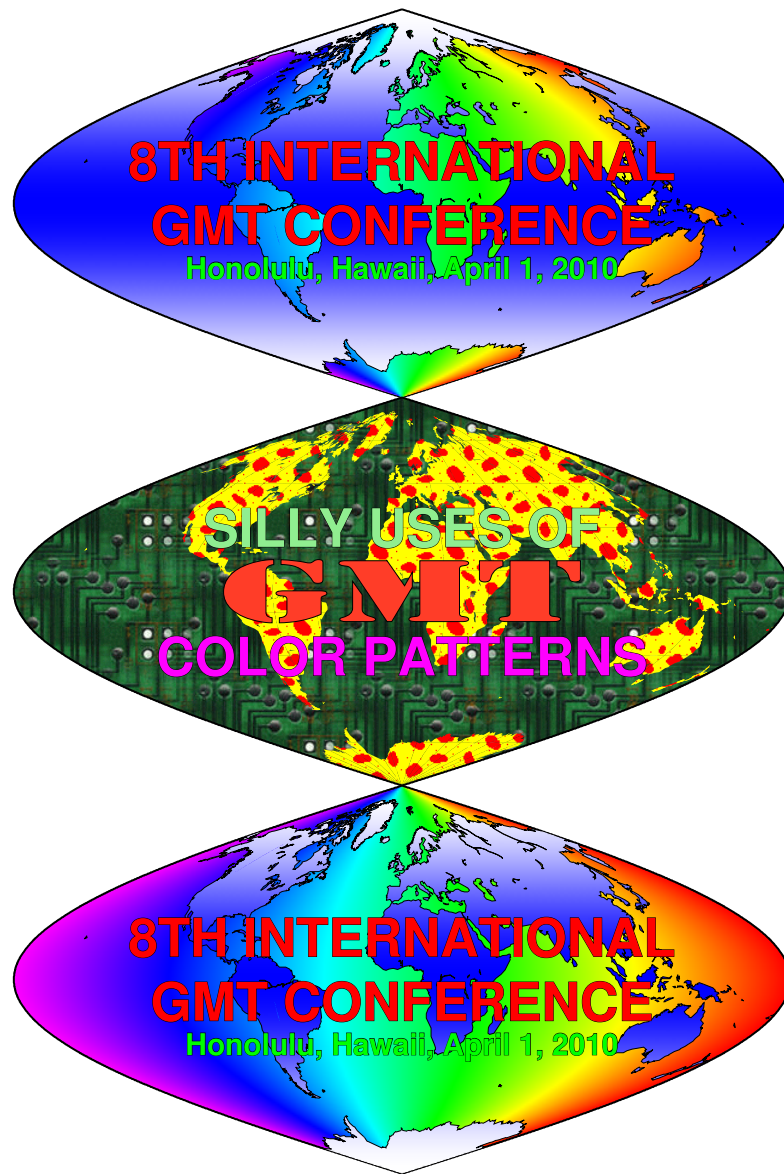
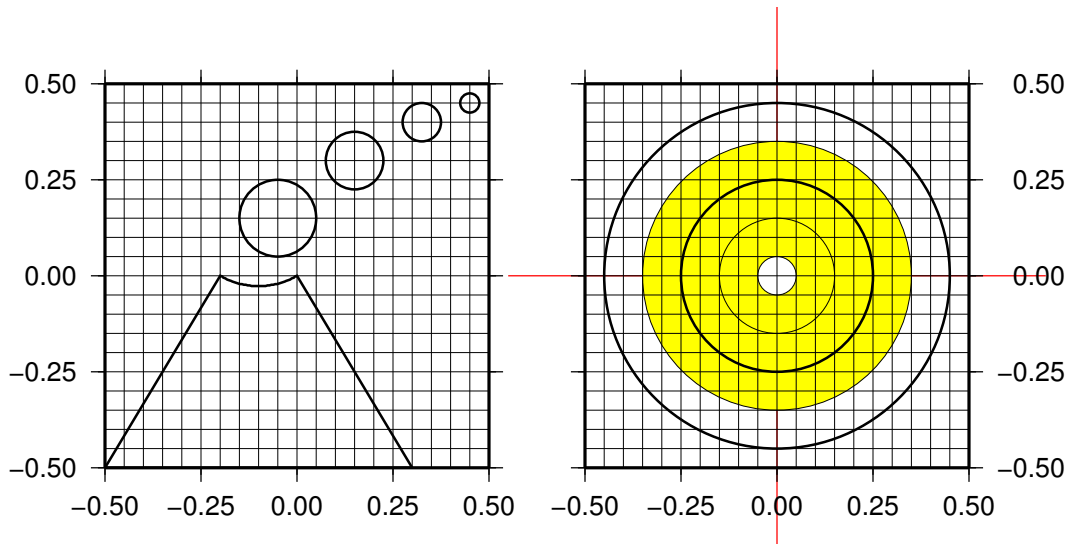


Figure 7.19: Using color patterns and additional PostScript material in illustrations.



```
#      -G -L -W options on the psxy command line.
#
-0.5   -0.5   M
-0.2   0       D
-0.1   0.173205081   0.4   240   300   A
0.3    -0.5   D
-0.5   -0.5   D
-0.05  0.15   0.2   c
0.15   0.3    0.15  c
0.325  0.4    0.1   c
0.45   0.45   0.05  c
```

Without much further discussion we also make a definition file `bullseye.def` for a multi-colored bulls eye symbol. Note that the symbol can be created beyond the -0.5 to $+0.5$ range, as shown by the red lines. There is no limit in *GMT* to the size of the symbols. The center, however, will always be at $(0,0)$. This is the point to which the coordinates in **psxy** refers.

```
#
#      Segment info file for bullseye symbol
#      These instructions are intended for make_symbol
#      which will generate an awk-script that creates
#      multiple-segment output describing the desired
#      symbol at the chosen size. The symbol will be
#      painted drawn given the -G -W options for each
#      segment.
#
0      -0.7    M      -W0.5p,red
0      0.7     D
-0.7   0       M      -W0.5p,red
0.7    0       D
0      0       0.9    c      -Gp0/12
0      0       0.9    c      -W0.25p
0      0       0.7    c      -Gyellow -W0.25p
0      0       0.5    c      -Gp0/9
0      0       0.5    c      -W0.25p
0      0       0.3    c      -Gyellow -W0.25p
0      0       0.1    c      -Gwhite -W0.25p
```

The values refer to positions and dimensions illustrated in the Figure above.

- Given proper definition files we may now use them with **psxy** or **psxyz**.

We are now ready to give it a try. Based on the hotspot locations in the file `hotspots.d` (with a 3rd column giving the desired symbol sizes in inches) we lay down a world map and overlay red volcano symbols using

our custom-built volcano symbol and **psxy**. We do something similar with the bulls eye symbols. Without the **-G** option, however, they get the colors defined in `bullseye.def`.

Here is our final map script that produces Figure 7.20:

```
#!/bin/sh
#
#           GMT EXAMPLE 20
#
# Purpose:   Extend GMT to plot custom symbols
# GMT progs: pscoast, psxy
# Unix progs: rm
#
# Plot a world-map with volcano symbols of different sizes
# on top given locations and sizes in hotspots.d
ps=example_20.ps

cat > hotspots.d << END
55.5    -21.0    0.25
63.0    -49.0    0.25
-12.0    -37.0    0.25
-28.5    29.34    0.25
48.4    -53.4    0.25
155.5    -40.4    0.25
-155.5    19.6    0.5
-138.1    -50.9    0.25
-153.5    -21.0    0.25
-116.7    -26.3    0.25
-16.5    64.4    0.25
END

pscoast -Rg -JR9i -B60/30:."Hotspot Islands and Cities": -Gdarkgreen -Slightblue -Dc -A5000 -K \
-U"Example 20 in Cookbook" > $ps

psxy -R -J hotspots.d -Skvolcano -O -K -Wthinnest -Gred >> $ps

# Overlay a few bullseyes at NY, Cairo, and Perth

cat > cities.d << END
286     40.45    0.8
31.15    30.03    0.8
115.49   -31.58    0.8
END

psxy -R -J cities.d -Skbullseye -O >> $ps

rm -f hotspots.d cities.d .gmt*
```

Given these guidelines you can easily make your own symbols. Symbols with more than one color can be obtained by making several symbol components. E.g., to have yellow smoke coming out of red volcanoes we would make two symbols: one with just the cone and caldera and the other with the bubbles. These would be plotted consecutively using the desired colors. Alternatively, like in `bullseye.def`, we may specify colors directly for the various segments. Note that the custom symbols (Appendix N), unlike the built-in symbols in *GMT*, can be used with the built-in patterns (Appendix E). Other approaches are also possible, of course.

7.21 Time-series of RedHat stock price

As discussed in Section 4.4.3, the annotation of time-series is generally more complicated due to the extra degrees of freedom afforded by the dual annotation system. In this example we will display the trend of the stock price of RedHat (RHAT) from their initial public offering until late 2006. The data file is a comma-separated table and the records look like this:

```
Date,Open,High,Low,Close,Volume,Adj.Close*
12-Mar-04,17.74,18.49,17.67,18.02,4827500,18.02
11-Mar-04,17.60,18.90,17.37,18.09,7700400,18.09
```

Hence, we have a single header record and various prices in USD for each day of business. We will plot the trend of the opening price as a red line superimposed on a yellow envelope representing the low-to-high fluctuation during each day. We also indicate when and at what cost Paul Wessel bought a few shares,

Hotspot Islands and Cities

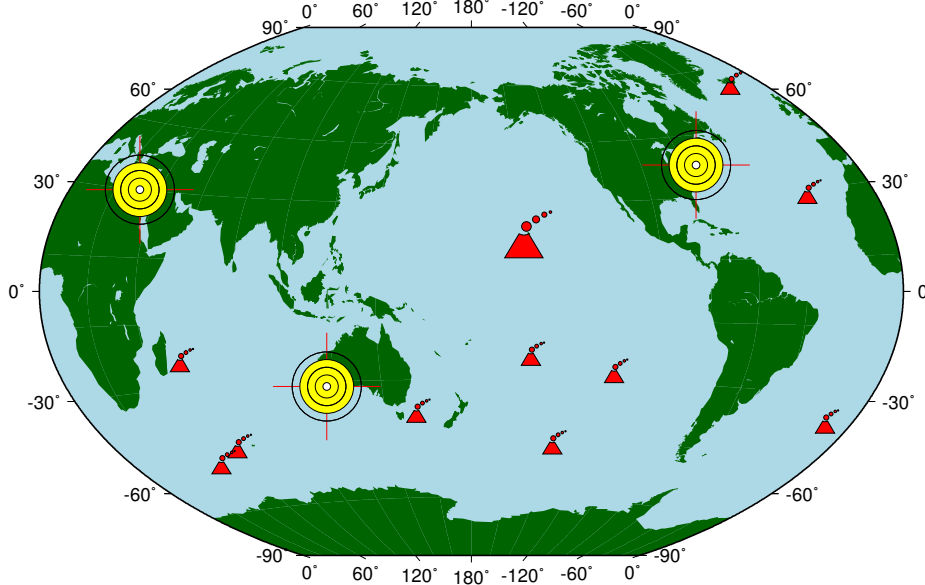


Figure 7.20: Using custom symbols in GMT.

and zoom in on the developments since 2004; in the inset we label the time-axis in Finnish in honor of Linus Thorvalds. Because the time coordinates are Y2K-challenged and the order is backwards (big units of years come *after* smaller units like days) we must change the default input/output formats used by *GMT*. Finally, we want to prefix prices with the \$ symbol to indicate the currency. Here is how it all comes out:

```
#!/bin/sh
#
#
# Purpose:      Plot a time-series
# GMT progs:    gmtset, gmtconvert, minmax, psbasemap, psxy
# Unix progs:   cut, echo
#
ps=example_21.ps

# File has time stored as dd-Mon-yy so set input format to match it

gmtset INPUT_DATE_FORMAT dd-o-yy PLOT_DATE_FORMAT o ANNOT_FONT_SIZE_PRIMARY +10p
gmtset TIME_FORMAT_PRIMARY abbreviated CHAR_ENCODING ISOLatin1+

# Pull out a suitable region string in yyy-mm-dd format

minmax -fT -I50 -C -H RHAT_price.csv > RHAT.info
w='cut -f1 RHAT.info\'
e='cut -f2 RHAT.info\'
s='cut -f3 RHAT.info\'
n='cut -f4 RHAT.info\'
R="-R$w/$e/$s/$n"

# Lay down the basemap:

psbasemap $R -JX9i/6i -Glightgreen -K -U"Example 21 in Cookbook" -BslY/WSen \
-Bpa30f1o/50WSen:=\${:}."RedHat (RHAT) Stock Price Trend since IPO": > $ps

# Plot main window with open price as red line over yellow envelope of low/highs

gmtset OUTPUT_DATE_FORMAT dd-o-yy
gmtconvert -F0,2 -f0T -Hi RHAT_price.csv > RHAT.env
gmtconvert -F0,3 -f0T -I -Hi RHAT_price.csv >> RHAT.env
psxy -R -J -Gyellow -O -K RHAT.env >> $ps
psxy -R -J RHAT_price.csv -H -Wthin,red -O -K >> $ps

# Draw P Wessel's purchase price as line and label it. Note we temporary switch
# back to default yyyy-mm-dd format since that is what minmax gave us.
```



```

echo "05-May-00 0" > RHAT.pw
echo "05-May-00 300" >> RHAT.pw
psxy -R -J RHAT.pw -Wthinner,- -O -K >> $ps
echo "01-Jan-99 25" > RHAT.pw
echo "01-Jan-07 25" >> RHAT.pw
psxy -R -J RHAT.pw -Wthick,- -O -K >> $ps
gmtset INPUT_DATE_FORMAT yyyy-mm-dd
echo "$w 25 12 0 17 LB Wessel purchase price" | pstext -R -J -O -K -D2i/0.05i -N >> $ps
gmtset INPUT_DATE_FORMAT dd-o-yy

# Get smaller region for insert for trend since 2004

R="-R2004T/$e/$s/40"

# Lay down the basemap, using Finnish annotations and place the insert in the upper right:

gmtset TIME_LANGUAGE fi
psbasemap $R -JX6i/3i -Bpa3Of3o/10:=$:ESw -Bs1Y/ -Glightblue -O -K -X3i -Y3i >> $ps
gmtset TIME_LANGUAGE us

# Again, plot close price as red line over yellow envelope of low/highs

psxy -R -J -Gyellow -O -K RHAT.env >> $ps
psxy -R -J RHAT_price.csv -H -Wthin/red -O -K >> $ps

# Draw P Wessel's purchase price as dashed line

psxy -R -J RHAT.pw -Wthick,- -O >> $ps

# Clean up after ourselves:

rm -f RHAT.*.gmt*
```

which produces the plot in Figure 7.21, suggesting Wessel has missed a few trains if he had hoped to cash in on the Internet bubble...

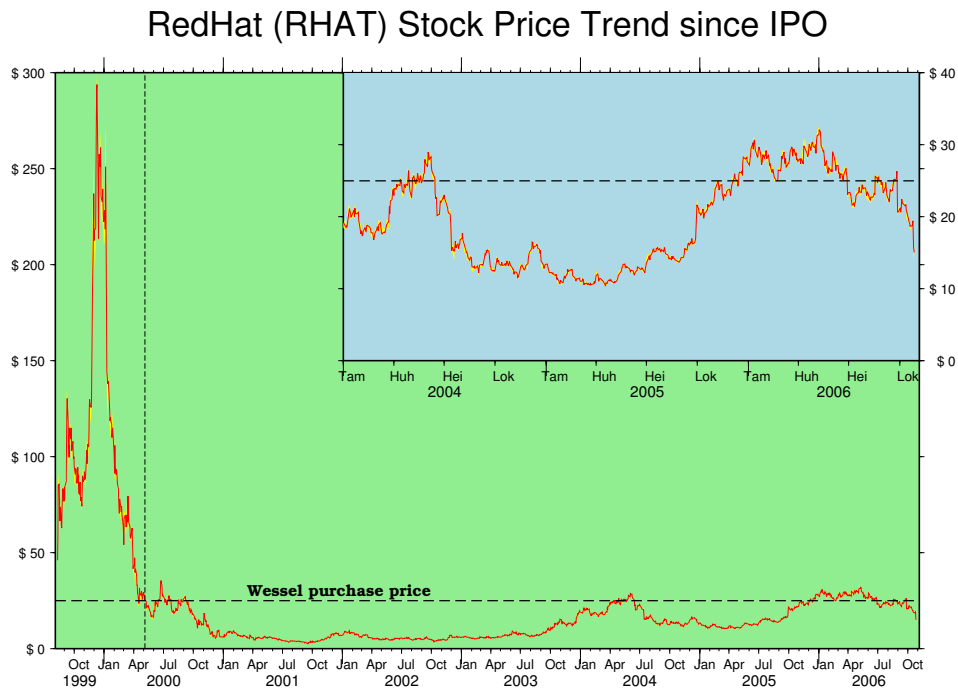


Figure 7.21: Time-series of RedHat stock price since IPO.

7.22 World-wide seismicity the last 7 days

The next example uses the command-line tool **wget** to obtain a data file from a specified URL⁴. In the example script this line is commented out so the example will run even if you do not have **wget** (we use the supplied `neic_quakes.d` which normally would be created by **wget**); remove the comment to get the actual current seismicity plot using the live data. The main purpose of this script is not to show how to plot a map background and a few circles, but rather demonstrate how a map legend may be composed using the new tool **pslegend**. Some scripting is used to pull out information from the data file that is later used in the legend. The legend will normally have the email address of the script owner; here that command is commented out and the user is hardwired to “GMT guru”. The USGS logo, taken from their web page and converted to a Sun raster file, is used to spice up the legend.

```
#!/bin/sh
#
#           GMT EXAMPLE 22
#
# Purpose:   Automatic map of last 7 days of world-wide seismicity
# GMT progs: gmtset, pscoast, psxy, pslegend
# Unix progs: cat, sed, awk, wget|curl
#
ps=example_22.ps
gmtset ANNOT_FONT_SIZE_PRIMARY 10p HEADER_FONT_SIZE 18p PLOT_DEGREE_FORMAT ddd:mm:ssF

# Get the data (-q quietly) from USGS using the wget (comment out in case
# your system does not have wget or curl)

#wget http://neic.usgs.gov/neis/gis/bulletin.asc -q -O neic_quakes.d
#curl http://neic.usgs.gov/neis/gis/bulletin.asc -s > neic_quakes.d

# Count the number of events (to be used in title later. one less due to header)

n=`cat neic_quakes.d | wc -l`
n=`expr $n - 1`

# Pull out the first and last timestamp to use in legend title

first=`sed -n 2p neic_quakes.d | awk -F, '{printf "%s %s\n", $1, $2}'`
last=`sed -n '$p' neic_quakes.d | awk -F, '{printf "%s %s\n", $1, $2}'`

# Assign a string that contains the current user @ the current computer node.
# Note that two @@ is needed to print a single @ in pstext:

#set me = "$user@@hostname"
me="GMT guru @@ GMTbox"

# Create standard seismicity color table

cat > neis.cpt << END
0      red      100      red
100    green    300      green
300    blue     10000    blue
END

# Start plotting. First lay down map, then plot quakes with size = magintude/50":

pscoast -Rg -JK180/9i -B45g30:."World-wide earthquake activity": -Gbrown -Slightblue \
-Dc -A1000 -K -U/-0.75i/-2.5i/"Example 22 in Cookbook" -Y2.75i > $ps
awk -F, '{ print $4, $3, $6, $5*0.02}' neic_quakes.d \
| psxy -R -JK -O -K -Cneis.cpt -Sci -Wthin -H >> $ps
# Create legend input file for NEIS quake plot

cat > neis.legend << END
H 16 1 $n events during $first to $last
D 0 1p
N 3
V 0 1p
S 0.1i c 0.1i red 0.25p 0.2i Shallow depth (0-100 km)
S 0.1i c 0.1i green 0.25p 0.2i Intermediate depth (100-300 km)
S 0.1i c 0.1i blue 0.25p 0.2i Very deep (> 300 km)
V 0 1p
D 0 1p
N 7
V 0 1p
S 0.1i c 0.06i - 0.25p 0.3i M 3
```

⁴You can also use the utility **curl**

```

S 0.1i c 0.08i - 0.25p 0.3i M 4
S 0.1i c 0.10i - 0.25p 0.3i M 5
S 0.1i c 0.12i - 0.25p 0.3i M 6
S 0.1i c 0.14i - 0.25p 0.3i M 7
S 0.1i c 0.16i - 0.25p 0.3i M 8
S 0.1i c 0.18i - 0.25p 0.3i M 9
V 0 1p
D 0 1p
N 1
>
END

# Put together a reasonable legend text, and add logo and user's name:

cat << END >> neis.legend
>
T USGS/NEIS most recent earthquakes for the last seven days. The data were
T obtained automatically from the USGS Earthquake Hazards Program page at
T @_http://neic/usgs.gov @_. Interested users may also receive email alerts
T from the USGS.
T This script can be called daily to update the latest information.
G 0.4i
# Add USGS logo
I USGS.ras 1i RT
G -0.3i
L 12 6 LB $me
END

# OK, now we can actually run pslegend. We center the legend below the map.
# Trial and error shows that 1.7i is a good legend height:

pslegend -Dx4.5i/-0.4i/7i/1.7i/TC -J -R -O -F neis.legend -Glightyellow >> $ps

# Clean up after ourselves:

rm -f neis.* .gmt*

```

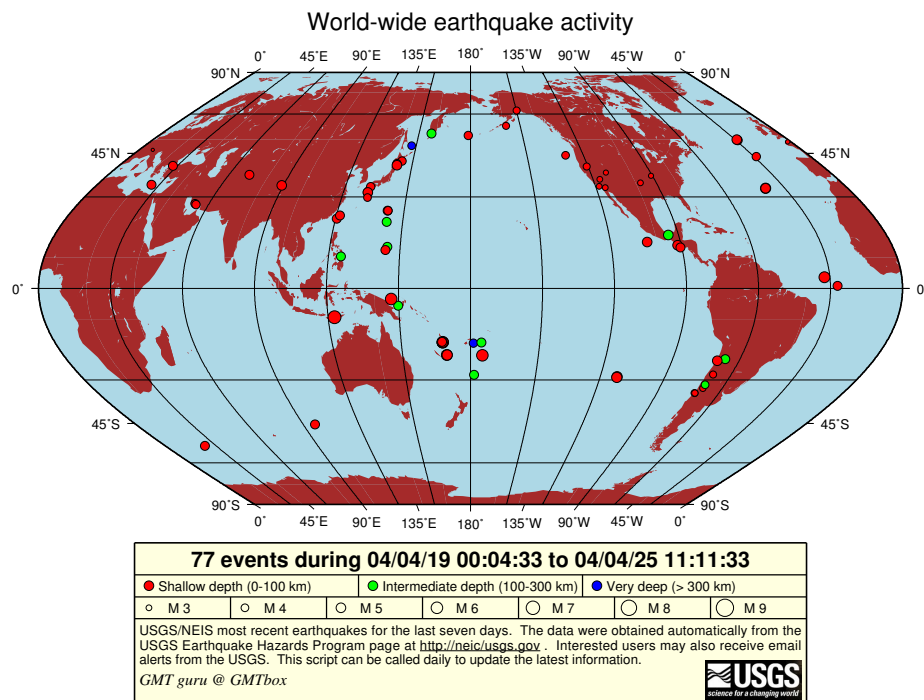


Figure 7.22: World-wide seismicity the last 7 days.

The script produces the plot in Figure 7.22, giving the URL where these and similar data can be obtained.

7.23 All great-circle paths lead to Rome

While motorists recently have started to question the old saying “all roads lead to Rome”, aircraft pilots have known from the start that only one great-circle path connects the points of departure and arrival⁵. This provides the inspiration for our next example which uses **grdmath** to calculate distances from Rome to anywhere on Earth and **grdcontour** to contour these distances. We pick five cities that we connect to Rome with great circle arcs, and label these cities with their names and distances (in km) from Rome, all laid down on top of a beautiful world map. Note that we specify that contour labels only be placed along the straight map-line connecting Rome to its antipode, and request curved labels that follows the shape of the contours.

```
#!/bin/sh
#
#           GMT EXAMPLE 23
#
# Purpose:   Plot distances from Rome and draw shortest paths
# GMT progs: grdmath, grdcontour, pscoast, psxy, pstext, grdtrack
# Unix progs: echo, cat, awk
#
ps=example_23.ps

# Position and name of central point:

lon=12.50
lat=41.99
name="Rome"

# Calculate distances (km) to all points on a global 1x1 grid

grdmath -Rg -I1 $lon $lat SDIST 111.13 MUL = dist.grd

# Location info for 5 other cities + label justification

cat << END > cities.d
105.87 21.02 HANOI          LM
282.95 -12.1  LIMA          LM
178.42 -18.13 SUVA          LM
237.67 47.58 SEATTLE       RM
28.20  -25.75 PRETORIA      LM
END

pscoast -Rg -JH90/9i -Glightgreen -Sblue -U"Example 23 in Cookbook" -A1000 \
-B0g30:.."Distances from $name to the World": -K -Dc -Wthinnest > $ps

grdcontour dist.grd -A1000+v+ukm+kwhite -Glz-/z+ -S8 -C500 -O -K -J \
-Wathin,white -Wcthinest,white,- >> $ps

# For each of the cities, plot great circle arc to Rome with psxy

while read clon clat city; do
    (echo $lon $lat; echo $clon $clat) | psxy -R -J -O -K -Wthickest/red >> $ps
done < cities.d

# Plot red squares at cities and plot names:
psxy -R -J -O -K -Ss0.2 -Gred -Wthinnest cities.d >> $ps
awk '{print $1, $2, 12, 1, 9, $4, $3}' cities.d | pstext -R -J -O -K -Dj0.15/0 -Gred -N >> $ps
# Place a yellow star at Rome
echo "$lon $lat" | psxy -R -J -O -K -Sa0.2i -Gyellow -Wthin >> $ps

# Sample the distance grid at the cities and use the distance in km for labels

grdtrack -Gdist.grd cities.d \
| awk '{printf "%s %s 12 0 1 CT %d\n", $1, $2, int($NF+0.5)}' \
| pstext -R -J -O -D0/-0.2i -N -Wwhite,o -C0.02i/0.02i >> $ps

# Clean up after ourselves:

rm -f cities.d dist.grd .gmt*
```

The script produces the plot in Figure 7.23; note how interesting the path to Seattle appears in this particular projection (Hammer). We also note that Rome’s antipode lies somewhere near the Chatham plateau (antipodes will be revisited in Section 7.25).

⁵Pedants who wish to argue about the “other” arc going the long way should consider using it.

Distances from Rome to the World

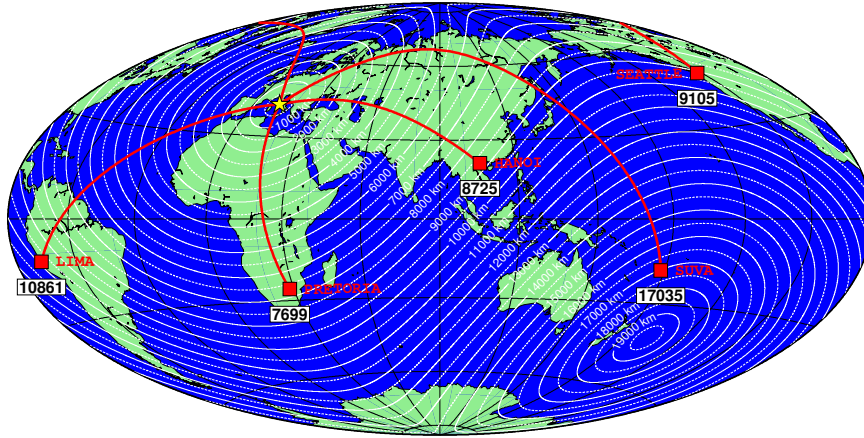


Figure 7.23: All great-circle paths lead to Rome.

7.24 Data selection based on geospatial criteria

Although we are not seismologists, we have yet another example involving seismicity. We use seismicity data for the Australia/New Zealand region to demonstrate how we can extract subsets of data using geospatial criteria. In particular, we wish to plot the epicenters given in the file `oz_quakes.d` as red or green circles. Green circles should only be used for epicenters that satisfy the following three criteria:

1. They are located in the ocean and not on land
2. They are within 3000 km of Hobart
3. They are more than 1000 km away from the International Dateline

All remaining earthquakes should be plotted in red. Rather than doing the selection process twice we simply plot all quakes as red circles and then replot those that pass our criteria. Most of the work here is done by **gmtselect**; the rest is carried out by the usual **pscoast** and **psxy** workhorses. Note for our purposes the Dateline is just a line along the 180° meridian.

```
#!/bin/sh
#
#           GMT EXAMPLE 24
#
# Purpose:   Extract subsets of data based on geospatial criteria
# GMT progs: gmtselect, pscoast, psxy, minmax
# Unix progs: echo, cat, awk
#
# Highlight oceanic earthquakes within 3000 km of Hobart and > 1000 km from dateline
ps=example_24.ps
echo "147:13 -42:48 3000 Hobart" > point.d
cat << END > dateline.d
> Our proxy for the dateline
180      0
180     -90
END
R='minmax -I10 oz_quakes.d'
pscoast $R -JM9i -K -Gtan -Sdarkblue -Wthin,white -Dl -A500 -Ba20f10g10WeSn \
-U"Example 24 in Cookbook" > $ps
psxy -R -J -O -K oz_quakes.d -Sc0.05i -Gred >> $ps
gmtselect oz_quakes.d -L1000/dateline.d -Nk/s -C3000/point.d -fg -R -I1 \
| psxy -R -JM -O -K -Sc0.05i -Ggreen >> $ps
awk '{print $1, $2, 0, $3, $3}' point.d | psxy -R -J -O -K -SE -Wfat,white >> $ps
awk '{print $1, $2, 14, 0, 1, "LT", $4}' point.d | pstext -R -J -O -K -Gwhite -D0.1i/-0.1i >> $ps
psxy -R -J -O -K point.d -Wfat,white -S+0.2i >> $ps
psxy -R -J -O -m dateline.d -Wfat,white -A >> $ps
rm -f point.d dateline.d .gmt*
```

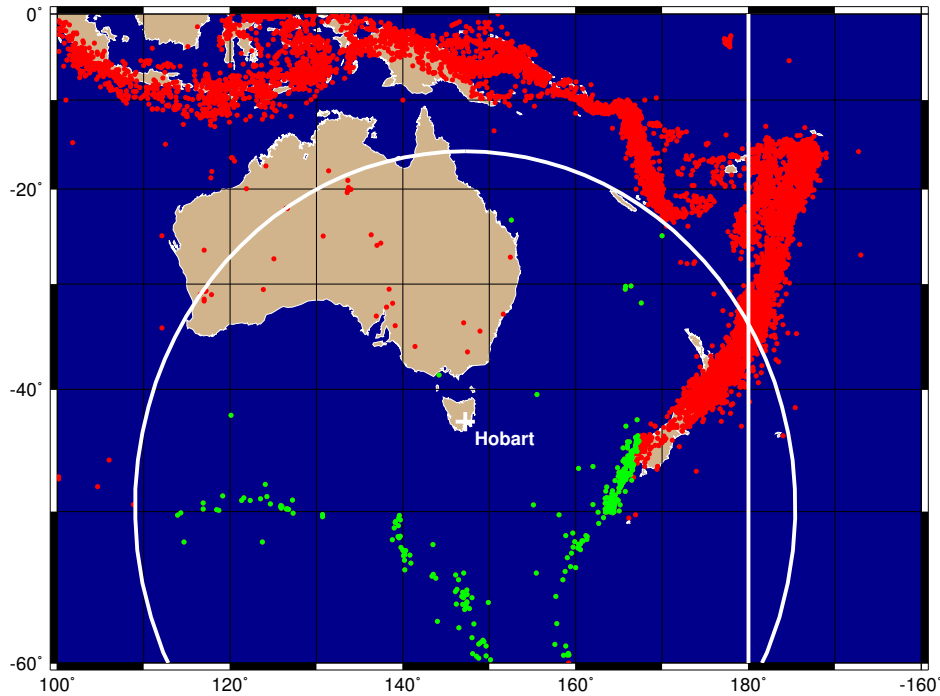


Figure 7.24: Data selection based on geospatial criteria.

The script produces the plot in Figure 7.24. Note that the horizontal distance from the dateline seems to increase as we go south; however that is just the projected distance (Mercator distortion) and not the actual distance which remains constant at 1000 km.

7.25 Global distribution of antipodes

As promised in Section 7.23, we will study antipodes. The antipode of a point at (ϕ, λ) is the point at $(-\phi, \lambda + 180)$. We seek an answer to the question that has plagued so many for so long: Given the distribution of land and ocean, how often is the antipode of a point on land also on land? And what about marine antipodes? We use **grdlandmask** and **grdmath** to map these distributions and calculate the area of the Earth (in percent) that goes with each of the three possibilities. To make sense of our **grdmath** equations below, note that we first calculate a grid that is +1 when a point and its antipode is on land, -1 if both are in the ocean, and 0 elsewhere. We then seek to calculate the area distribution of dry antipodes by only pulling out the nodes that equal +1. As each point represent an area approximated by $\Delta\phi \times \Delta\lambda$ where the $\Delta\lambda$ term's actual dimension depends on $\cos(\phi)$, we need to allow for that shrinkage, normalize our sum to that of the whole area of the Earth, and finally convert that ratio to percent. Since the $\Delta\lambda$, $\Delta\phi$ terms appear twice in these expressions they cancel out, leaving the somewhat intractable expressions below where the sum of $\cos(\phi)$ for all ϕ is known to equal $2N_y/\pi$:

```
#!/bin/sh
#
#           GMT EXAMPLE 25
#
# Purpose:   Display distribution of antipode types
# GMT progs: gmtset, grdlandmask, grdmath, grd2xyz, gmtmath, grdimage, pscoast, pslegend
# Unix progs: cat
#
# Create D minutes global grid with -1 over oceans and +1 over land
ps=example_25.ps
D=30
grdlandmask -Rg -I${D}m -Dc -A500 -N-1/1/1/1 -F -Gwetdry.grd
# Manipulate so -1 means ocean/ocean antipode, +1 = land/land, and 0 elsewhere
```

```

grdmath wetdry.grd DUP 180 ROTX FLIPUD ADD 2 DIV = key.grd
# Calculate percentage area of each type of antipode match.
grdmath -Rg -I${D}m -F Y COSD 60 $D DIV 360 MUL DUP MUL PI DIV DIV 100 MUL = scale.grd
grdmath key.grd -l EQ 0 NAN scale.grd MUL = tmp.grd
grd2xyz tmp.grd -S -ZTLf > key.b
ocean=`gmtmath -bils -Ca -S key.b SUM UPPER RINT =`
grdmath key.grd 1 EQ 0 NAN scale.grd MUL = tmp.grd
grd2xyz tmp.grd -S -ZTLf > key.b
land=`gmtmath -bils -Ca -S key.b SUM UPPER RINT =`
grdmath key.grd 0 EQ 0 NAN scale.grd MUL = tmp.grd
grd2xyz tmp.grd -S -ZTLf > key.b
mixed=`gmtmath -bils -Ca -S key.b SUM UPPER RINT =`
# Generate corresponding color table
cat << END > key.cpt
-1.5    blue    -0.5    blue
-0.5    gray    0.5     gray
0.5     red     1.5     red
END
# Create the final plot and overlay coastlines
gmtset ANNOT_FONT_SIZE_PRIMARY +10p PLOT_DEGREE_FORMAT dddF
grdimage key.grd -Sn -JKs180/9i -B60/30:."Antipodal comparisons":WsNE -K -Ckey.cpt -Y1.2i \
-U/-0.75i/-0.95i/"Example 25 in Cookbook" > $ps
pscoast -R -J -O -K -Wthinnest -Dc -A500 >> $ps
# Place an explanatory legend below
pslegend -R0/9/0/0.5 -Jxli/-li -O -Dx4.5/0/6i/0.3i/TC -Y-0.2i -Fthick >> $ps << END
N 3
S 0.15i s 0.2i red 0.25p 0.3i Terrestrial Antipodes [$land %]
S 0.15i s 0.2i blue 0.25p 0.3i Oceanic Antipodes [$ocean %]
S 0.15i s 0.2i gray 0.25p 0.3i Mixed Antipodes [$mixed %]
END
rm -f *.grd key.* .gmt*

```

In the end we obtain a funny-looking map depicting the antipodal distribution as well as displaying in legend form the requested percentages (Figure 7.25). Note that the script is set to evaluate a global 30 minute grid for expediency ($D = 30$), hence several smaller land masses that do have terrestrial antipodes do not show up. If you want a more accurate map you can set the parameter D to a smaller increment (try 5 and wait a few minutes).

The call to **grdimage** includes the **—Sn** to suspend interpolation and only return the value of the nearest neighbor. This option is particularly practical for plotting categorical data, like these, that should not be interpolated.

7.26 General vertical perspective projection

Next, we present a recent extension to the **—JG** projection option which allows the user to specify a particular altitude (this was always at infinity before), as well as several further parameters to limit the view from the chosen vantage point. In this example we show a view of the eastern continental US from a height of 160 km. Below we add a view with a specific tilt of 55° and azimuth 210° ; here we have chosen a boresight twist of 45° . We view the land from New York towards Washington, D.C.

```

#!/bin/sh
#                               GMT EXAMPLE 26
#
# Purpose:      Demonstrate general vertical perspective projection
# GMT progs:    pscoast
# Unix progs:   rm
#
ps=example_26.ps

# first do an overhead of the east coast from 160 km altitude point straight down

latitude=41.5
longitude=-74.0
altitude=160.0
tilt=0
azimuth=0
twist=0
Width=0.0
Height=0.0

PROJ=-JG${longitude}/${latitude}/${altitude}/${azimuth}/${tilt}/${twist}/${Width}/${Height}/4i

```

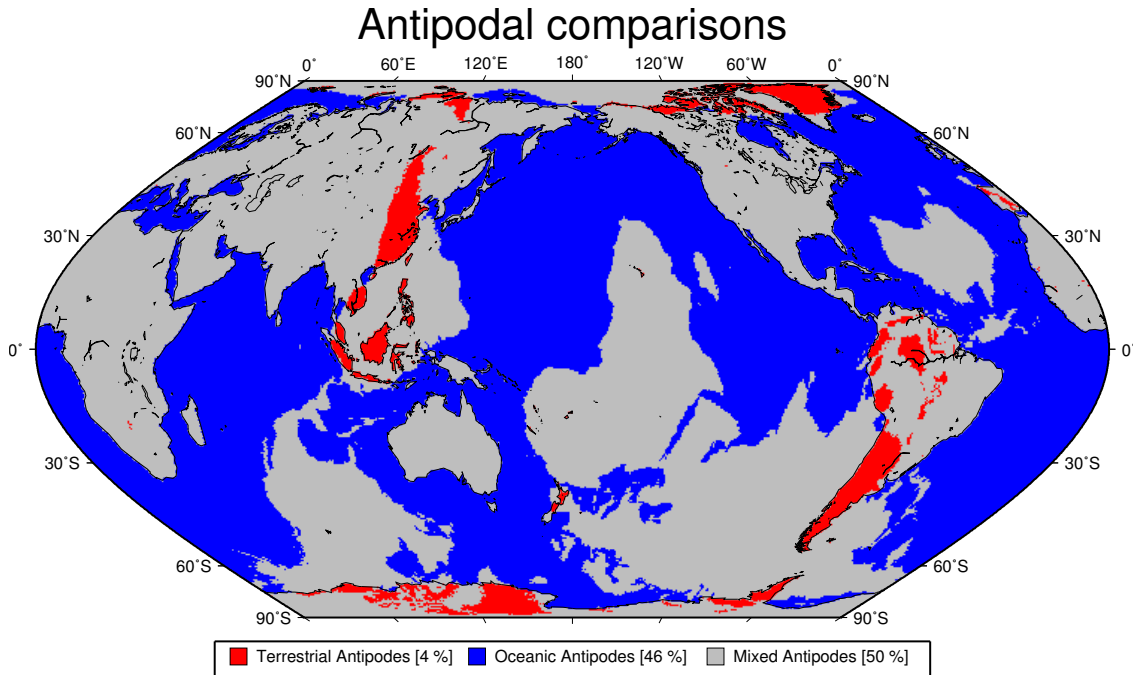


Figure 7.25: Global distribution of antipodes.

```

pscoast -Rg $PROJ -Xli -B5g5/5g5 -Glightbrown -Slightblue -W0.25p -Dl -N1/1p,red -N2,0.5p -P -K \
-Y5i > $ps

# now point from an altitude of 160 km with a specific tilt and azimuth and with a wider restricted
# view and a boresight twist of 45 degrees

tilt=55
azimuth=210
twist=45
Width=30.0
Height=30.0

PROJ=-JG${longitude}/${latitude}/${altitude}/${azimuth}/${tilt}/${twist}/${Width}/${Height}/5i

pscoast -R $PROJ -B5g5/5g5 -Glightbrown -Slightblue -W0.25p -Ia/blue -Di -Na -O -Xli -Y-4i \
-U/-1.75i/-0.75i/"Example 26 in Cookbook" >> $ps
rm -f .gmt*

```

At this point the full projection has not been properly optimized and the map annotations will need additional work. Also, note that the projection is only implemented in **pscoast** and **grdimage**. We hope to refine this further and extend the availability of the full projection to all of the *GMT* mapping programs.

7.27 Plotting Sandwell/Smith Mercator img grids

Next, we show how to plot a data grid that is distributed in projected form. The gravity and predicted bathymetry grids produced by David Sandwell and Walter H. F. Smith are not geographical grids but instead given on a spherical Mercator grid. The *GMT* supplement **imgsrc** has tools to extract subsets of these large grids. If you need to make a non-Mercator map then you must extract a geographic grid using **img2grd** and then plot it using your desired map projection. However, if you want to make a Mercator map then you can save time and preserve data quality by avoiding to re-project the data set twice since it is already in a Mercator projection. This example shows how this is accomplished. We use the **-M** option in **img2grd**⁶ to pull out the grid in Mercator units (i.e., do *not* invert the Mercator projection) and then simply

⁶You could also use **img2mercgrd** directly – your only option under DOS

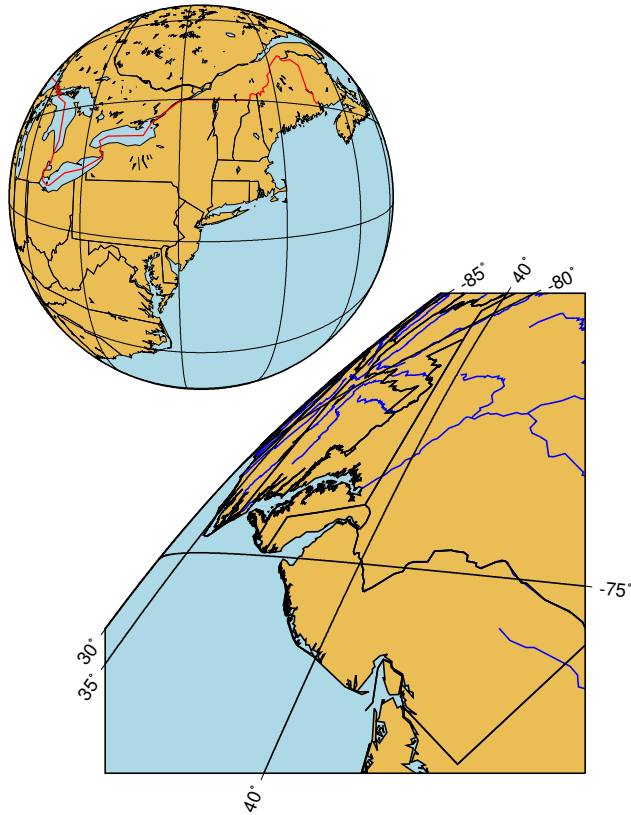


Figure 7.26: General vertical perspective projection.

plot the grid using a linear projection with a suitable scale (here 0.25 inches per degrees of longitude). To overlay basemaps and features that has geographic longitude/latitude coordinates we must remember two key issues:

1. This is a *spherical* Mercator grid so we must use **-ELLIPSOID=Sphere** with all commands that involve projections (or use **gmtset** to change the setting).
2. Select Mercator projection and use the same scale that was used with the linear projection.

```
#!/bin/sh
#
#           GMT EXAMPLE 27
#
# Purpose:   Illustrates how to plot Mercator img grids
# GMT progs: makecpt, grdgradient, grdimage, grdinfo, pscoast
# GMT supplement: img2grd (to read Sandwell/Smith img files)
# Unix progs: rm, grep, $AWK
#
ps=example_27.ps

# First extract a chunk of faa and retain short int precision to
# save disk space. Gravity is thus in 0.1 mGal increments.
# Next get gradients. The grid's region is in Mercator x/y units

#img2grd grav.15.2.img -R145/170/-50/-25 -M -C -T1 -Gtasman_grav.nc=ns
grdgradient tasman_grav.nc -Nt1 -A45 -Gtasman_grav_i.nc

# Make a suitable cpt file for mGal

makecpt -T-120/120/10 -Z -Crainbow > grav.cpt

# Since this is a Mercator grid we use a linear projection

grdimage tasman_grav.nc=ns/0.1 -Itasman_grav_i.nc -Jx0.25i -Cgrav.cpt -P -K \
```

```

-U"Example 27 in Cookbook" > $ps

# Then use pscoast to plot land; get original -R from grid remark
# and use Mercator projection with same scale as above on a spherical Earth

R=`grdinfo tasman_grav.nc | grep Remark | awk '{print $NF}'`

pscoast $R -Jm0.25i -Ba10f5WSne -O -K -Gblack --ELLIPSOID=Sphere \
-Cwhite -Dh+ --PLOT_DEGREE_FORMAT=dddF >> $ps

# Put a color legend on top of the land mask justified with 147E,31S

echo 147E 31S | mapproject -R -J --ELLIPSOID=Sphere > tmp
echo 147E 31S 1 2.5 | psxy -R -J -O -K -Sr -D0.25i/0.05i -Gwhite -Wlp --ELLIPSOID=Sphere >> $ps
pos=`$AWK '{printf "%si/%si\n", $1, $2}' tmp`
psscale -D$pos/2i/0.15i -Cgrav.cpt -B50f10/:mGal: -I -O >> $ps

# Clean up
rm -f grav.cpt *_i.nc .gmt* tmp

```

This map of the Tasman Sea shows the marine gravity anomalies with land painted black. A color scale bar was then added to complete the illustration.

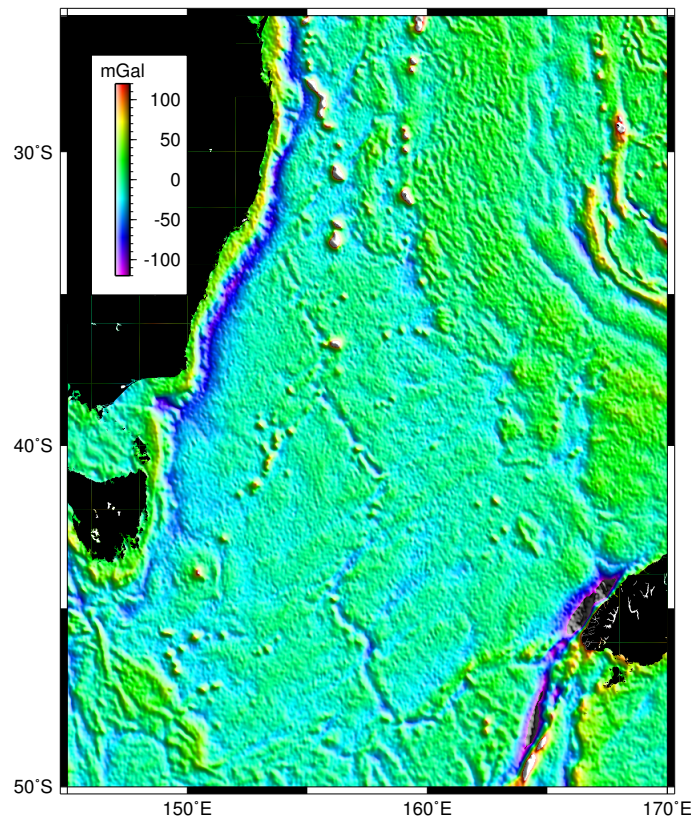


Figure 7.27: Plotting Sandwell/Smith Mercator img grids.

7.28 Mixing UTM and geographic data sets

Next, we present a similar case: We wish to plot a data set given in UTM coordinates and want it to be properly registered with overlying geographic data, such as coastlines or data points. The mistake many *GMT* rookies make is to specify the UTM projection with their UTM data. However, that data have already been projected and is now in linear meters. The only sensible way to plot such data is with a linear

projection, yielding a UTM map. In this step one can choose to annotate or tick the map in UTM meters as well. To plot geographic (lon/lat) data on the same map there are a few things you must consider:

1. You need to know the lower left and upper right UTM coordinates of your map. Given the UTM zone you can use **mapproject** to recover the lon/lat of those two points. Conversely, if you instead know the lon/lat corners then you need to convert those to UTM coordinates. You now have the ability to specify two domains with the **-R** setting: The linear UTM meter domain when plotting UTM data and the geographic domain (remember to use the rectangular variant of **-R** that ends with the modifier **r**) when plotting lon/lat data.
2. Make sure you use the same scale (and not width) with both the linear and UTM projection.

```
#!/bin/sh
#
#           GMT EXAMPLE 28
#
# Purpose:   Illustrates how to mix UTM data and UTM projection
# GMT progs: makecpt, grdgradient, grdimage, grdinfo, pscoast, pstext, mapproject
# Unix progs: rm, cut, grep, $AWK
#
ps=example_28.ps

# Get intensity grid and set up a color table
grdgradient Kilauea.utm.nc -Nt1 -A45 -GKilauea.utm_i.nc
makecpt -Ccopper -T0/1500/100 -Z > Kilauea.cpt
# Save min/max UTM coordinates with enough precision
grdinfo Kilauea.utm.nc --D_FORMAT=%.10g -C > tmp.txt
# Use inverse UTM projection to determine the lon/lat of the lower left and upper right corners
LL='cut -f2,4 tmp.txt | mapproject -Ju5Q/1:1 -F -C -I --OUTPUT_DEGREE_FORMAT=ddd:mm:ss.x | \
    awk '{printf "%s/%s\n", $1, $2}'`
UR='cut -f3,5 tmp.txt | mapproject -Ju5Q/1:1 -F -C -I --OUTPUT_DEGREE_FORMAT=ddd:mm:ss.x | \
    awk '{printf "%s/%s\n", $1, $2}'`
# Lay down the UTM topo grid using a 1:17,000 scale
grdimage Kilauea.utm.nc -IKilauea.utm_i.nc -CKilauea.cpt -Jx1:170000 -P -K -B5000g5000WSne \
    -U"Example 28 in Cookbook" --D_FORMAT=%.10g --ANNOT_FONT_SIZE=9 --GRID_CROSS_SIZE=0.1i > $ps
# Overlay geographic data and coregister by using correct region and projection with the same scale
pscoast -R$LL/$UR -Ju5Q/1:170000 -O -K -Df+ -Slightblue -W0.5p -B5mg5mNE --ANNOT_FONT_SIZE=12 \
    --PLOT_DEGREE_FORMAT=ddd:mmF >> $ps
psbasemap -R -J -O -K --ANNOT_FONT_SIZE=9 -Lf155:07:30W/19:15:40N/19:23N/5k+11:17,000+u \
    --LABEL_FONT_SIZE=10 >> $ps
echo 155:16:20W 19:26:20N 12 0 1 CB KILAUEA | pstext -R -J -O >> $ps
# Clean up

rm -f Kilauea.utm_i.nc Kilauea.cpt tmp.txt .gmt*
```

Our script illustrates how we would plot a UTM grid of elevations near Kilauea volcano on the Big Island of Hawaii. Given we are in UTM zone 5Q, the script determines the geographic coordinates of the lower left and upper right corner of the UTM grid, then uses that region when overlaying the coastline and light blue ocean. We place a scale bar and label Kilauea crater to complete the figure.

7.29 Gridding spherical surface data using splines

Finally, we demonstrate how gridding on a spherical surface can be accomplished using Green's functions of surface splines, with or without tension. Global gridding does not work particularly well in Cartesian coordinates hence the chosen approach. We use **greenspline** to produce a crude topography grid for Mars based on radii estimates from the Mariner 9 and Viking Orbiter spacecrafts. This data comes from *Smith and Zuber* [Science, 1996] and is used here as a small ($N = 370$) data set we can use to demonstrate spherical surface gridding. Since **greenspline** must solve a N by N matrix system your system memory may impose limits on how large data sets you can handle; also note that the spherical surface spline in tension is particularly slow to compute.

```
#!/bin/sh
#
#           GMT EXAMPLE 29
#
# Purpose:   Illustrates spherical surface gridding with Green's function of splines
# GMT progs: makecpt, grdcontour, grdgradient, grdimage, grdmath greenspline, psscale, pstext
```

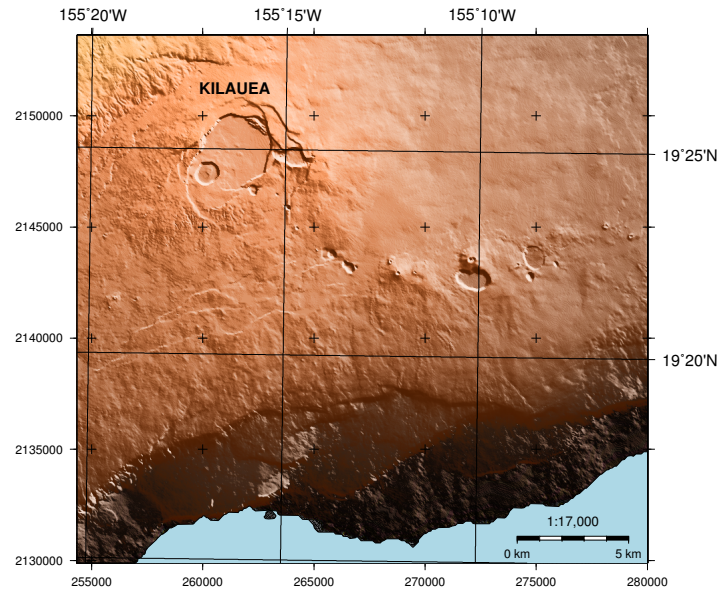


Figure 7.28: Mixing UTM and geographic data sets requires knowledge of the map region domain in both UTM and lon/lat coordinates and consistent use of the same map scale.

```
# Unix progs:  rm, echo
#
ps=example_29.ps

# This example uses 370 radio occultation data for Mars to grid the topography.
# Data and information from Smith, D. E., and M. T. Zuber (1996), The shape of
# Mars and the topographic signature of the hemispheric dichotomy, Science, 271, 184187.

# Make Mars ellipsoid given their three best-fitting axes:
a=3399.472
b=3394.329
c=3376.502
grdmath -Rg -I4 -F X COSD $a DIV DUP MUL X SIND $b DIV DUP MUL ADD Y COSD DUP MUL MUL Y SIND $c DIV \
    DUP MUL ADD SQRT INV = ellipsoid.nc

# Do both Parker and Wessel/Becker solutions (tension = 0.9975)
greenspline -Rellipsoid.nc mars370.in -D4 -Sp -Gmars.nc
greenspline -Rellipsoid.nc mars370.in -D4 -SQ0.9975/5001 -Gmars2.nc
# Scale to km and remove ellipsoid
grdmath mars.nc 1000 DIV ellipsoid.nc SUB = mars.nc
grdmath mars2.nc 1000 DIV ellipsoid.nc SUB = mars2.nc
makecpt -Crainbow -T-7/15/1 -Z > mars.cpt
grdgradient mars2.nc -M -Ne0.75 -A45 -Gmars2_i.nc
grdimage mars2.nc -Imars2_i.nc -Cmars.cpt -B30g30Wsne -JH0/6i -P -K -Ei \
-U"Example 29 in Cookbook" --ANNOT_FONT_SIZE=12 > $ps
grdcontour mars2.nc -J -O -K -C1 -A5 -Glz+/z- >> $ps
psxy -Rg -J -O -K -Sc0.045i -Gblack mars370.in >> $ps
echo "0 90 14 0 1 LB b)" | pstext -R -J -O -K -N -D-3i/-0.2i >> $ps
grdgradient mars.nc -M -Ne0.75 -A45 -Gmars_i.nc
grdimage mars.nc -Imars_i.nc -Cmars.cpt -B30g30Wsne -J -O -K -Y3.6i -Ei --ANNOT_FONT_SIZE=12 >> $ps
grdcontour mars.nc -J -O -K -C1 -A5 -Glz+/z- >> $ps
psxy -Rg -J -O -K -Sc0.045i -Gblack mars370.in >> $ps
psscale -Cmars.cpt -O -K -D3i/-0.1i/5i/0.1ih -I --ANNOT_FONT_SIZE=12 -B2f1/:km: >> $ps
echo "0 90 14 0 1 LB a)" | pstext -R -J -O -N -D-3i/-0.2i >> $ps
# Clean up
rm -f *.nc mars.cpt .gmt*
```

Our script must first estimate the ellipsoidal shape of Mars from the parameters given by *Smith and Zuber* so that we can remove this reference surface from the gridded radii. We run the gridding twice: First with no tension using *Parker's* [1990] method and then with tension using the *Wessel and Becker* [2008] method. The grids are then imaged with **grdimage** and **grdcontour** and a color scale is placed between them.

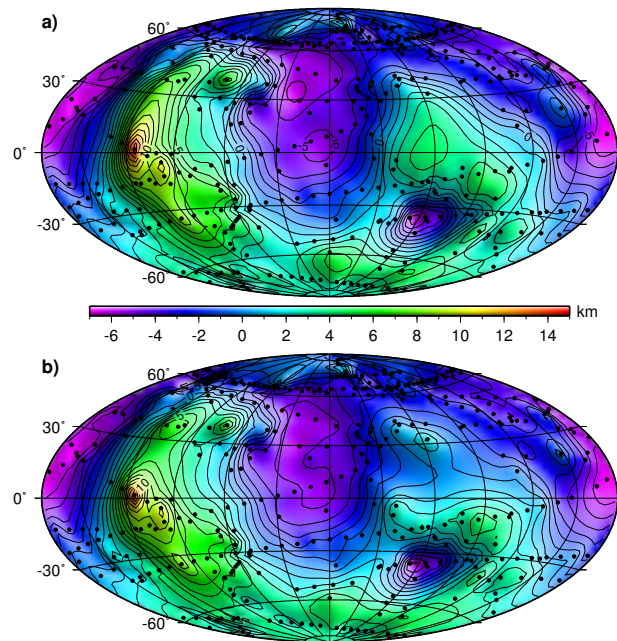


Figure 7.29: Gridding of spherical surface data using Green's function splines.

8. Creating GMT Animations

Unlike the previous chapter, in this chapter we will explore what is involved in creating animations (i.e., movies). Of course, an animation is nothing more than a series of individual images played back in an orderly fashion. Here, these images will have been created with *GMT*. To ensure a smooth transition from frame to frame we will be following some general guidelines when writing our scripts. Since there is no “movie” mode in *GMT* we must take care of all the book-keeping in our script. Thus, animations may require a bit of planning and may use more advanced scripting than the previous static examples. Note: This is a new chapter introduced with the 4.4.0 version and should be considered work in progress.

Most, if not all, animation scripts must deal with several specific phases of movie making:

1. Define parameters that determine the dimension of the final movie.
2. Pre-calculate all variables, data tables, grids, or background map layers that are *independent* of your time variable.
3. Have a frame-number loop where each frame is created as a *PostScript* plot, then rasterized to a TIFF file of chosen dimension.
4. Convert the individual frames to a single movie of suitable format.
5. Clean up temporary files and eventually the individual frames.

We will discuss these phases in more detail before showing our first example.

1. There are several coordinates that you need to consider when planning your movie. The first is the coordinates of your data, i.e., the *user coordinates*. As with all *GMT* plots you will transform those to the second set of *plot coordinates* in inches (or cm) by applying a suitable region and map projection. As before, you normally do this with a particular paper size in mind. When printed you get a high-resolution plot in monochrome or color. However, movies are not device-independent and you must finally consider the third set of *pixel coordinates* which specifies the resolution of the final movie. We control the frame size by selecting a suitable *dpi* setting that will scale your physical dimensions to the desired frame size in pixels. If you decide up front on a particular resolution (e.g., 480 by 320 pixels) then you should specify a paper size and *dpi* so that their product yields the desired pixel dimensions. For instance, here it might make sense to plan your plotting on a 4.8 by 3.2 inch “paper” and use 100 *dpi* to convert it to pixels, but you are free to use any combination that multiplies to the desired dimensions. After deciding on frame size you need to consider how many frames your movie should have. This depends on lots of things such as how patient you are, how many frames per second you need and the time range of your animation. We recommend you use variables to specify the items that go into computing the number of frames so that you can easily test your script with a few frames before changing settings and running the full Hollywood production overnight.
2. Depending on what you want to display, there are usually many elements that do not change between frames. Examples include a coastline base map for background, an overlay of text legends, perhaps some variables that hold information that will be used during the movie, and possibly subsets of larger data sets. Since movie-making can take a long time if you are ambitious, it is best to compute or plot all the elements that can be done outside your main frame-loop rather than waste time doing the same thing over and over again. You are then ready for the main loop.
3. Initialize a frame counter to 0 and have a loop that continues until your frame counter equals the desired number of frames. You must use your frame counter to create a unique file name for each frame image so that the series of images can be lexically arranged. We recommend using the *GMT* shell function ***gmt_set_filename*** to format the frame counter with an adequate number of leading zeros; see our examples for details. The bulk of your main loop involves create the single *PostScript* plot for this particular frame (time). This can be trivial or a serious scripting exercise depending on what you want to show. We will give a few examples with increasing complexity. Once the *PostScript* plot is created

you need to rasterize it; we recommend you use **ps2raster** to generate a TIFF image at the agreed-upon resolution. We also recommend that you place all frame images in a sub-directory. You may increment your frame counter using *gmt.set_framenext*.

4. Once you have all your frames you are ready to combine them into an animation. There are two general approaches. (a) If your image sequence is not too long then you can convert the images into a single animated GIF file. This file can be included in PowerPoint presentations or placed on a web page and will play back as a movie by pausing the specified amount between frames, optionally repeating the entire sequence one or more times. (b) For more elaborate projects you will need to convert the frames into a proper movie format such as Quicktime, AVI, MPEG-2, MPEG-4, etc., etc. There are both free and commercial tools that can help with this conversion and they tend to be platform-specific. Most movie tools such as iMovie or MovieMaker can ingest still images and let you specify the frame duration. Under OS X we prefer to use Quicktime.¹ Free tools exist to call the Quicktime library functions from the command line as we prefer to do in our scripts. You will find yourself experimenting with compression settings and movie formats so that the final movie has the resolution and portability you require.
5. Finally, when all is done you should delete any temporary files created. However, since creating the frames may take a lot of time it is best to not automatically delete the frame sub directory. That way you can redo the frames-to-movie conversion with different settings until you are satisfied.

8.1 Animation of the sine function

Our first animation is not very ambitious: We wish to plot the sine function from 0–360° and take snap shots every 20°. To get a smooth curve we must sample the function much more frequently; we settle on 10 times more frequently than the frame spacing. We place a bright red circle at the leading edge of the curve, and as we move forward in time (here, angles) we dim the older circles to a dark red color. We add a label that indicates the current angle value. Once the 18 frames are completed we convert them to a single animated GIF file and write a plain HTML wrapper with a simple legend. Opening the HTML page [anim01.html](#) in the browser will display the animation.

```
#!/bin/sh
#
#           GMT ANIMATION 01
#
# Purpose:   Make web page with simple animated GIF of sine function
# GMT progs: gmtset, gmtmath, psbasemap, pstext, psxy, ps2raster
# Unix progs: awk, mkdir, rm, mv, echo, convert, cat
#
# 1. Initialization
# 1a) Assign movie parameters
. gmt_shell_functions.sh
width=4i
height=2i
dpi=125
n_frames=18
name='basename $0 '.sh'
# 1b) Do frame-independent calculations and setup
angle_step='gmtmath -Q 360 $n_frames DIV ='
angle_inc='gmtmath -Q $angle_step 10 DIV ='
gmtset DOTS_PR_INCH $dpi
psbasemap -R0/360/-1.2/1.6 -JX3.5i/1.65i -P -K -X0.35i -Y0.25i \
-Ba90g90f30:-,\312:/a0.5f0.1glWSne -Glightgreen \
--PAPER_MEDIA=Custom_${width}x${height} --ANNOT_FONT_SIZE=+9p > $$map.ps
# 2. Main frame loop
mkdir -p $$
frame=0
while [ $frame -le $n_frames ]; do
# Create file name using a name_#.tif format
file='gmt_set_framename $name $frame'
cp -f $$map.ps $$ps
angle='gmtmath -Q $frame $angle_step MUL ='
if [ $frame -gt 0 ]; then
# First plot has no curves
Plot smooth blue curve and dark red dots at all angle steps so far
```

¹While Quicktime is free you must upgrade to QuickTime Pro (USD 30) to use the authoring functions.


```

gmtmath -T0/$angle/$angle_inc T SIND = $$sin.d
psxy -R -J -O -K -Wlp,blue $$sin.d >> $$ps
gmtmath -T0/$angle/$angle_step T SIND = $$sin.d
psxy -R -J -O -K -Sc0.1i -Gdarkred $$sin.d >> $$ps
fi
#      Plot red dot at current angle and annotate
sin=`gmtmath -Q $angle SIND =`
echo $angle $sin | psxy -R -J -O -K -Sc0.1i -Gred >> $$ps
echo $angle | awk '{printf "0 1.6 14 0 1 LT a = %3.3d\n", $1}' \
| pstext -R -J -O -K -N -Dj0.1i/0.05i >> $$ps
psxy -R -J -O -T >> $$ps
if [ $# -eq 0 ]; then
    mv $$ps $name.ps
    gmt_cleanup .gmt
    gmt_abort "$0: First frame plotted to $name.ps"
fi
#      RIP to TIFF at specified dpi
ps2raster -E$dpi -Tt $$ps
mv -f $$tif $$/$file.tif
echo "Frame $file completed"
frame=`gmt_set_framenext $frame`
done
# 3. Create animated GIF file and HTML for web page
convert -delay 20 -loop 0 $$/*.tif $name.gif
cat << END > $name.html
<HTML>
<TITLE>GMT Trigonometry: The sine movie</TITLE>
<BODY bgcolor="#ffffff">
<CENTER>
<H1>GMT Trigonometry: The sine movie</H1>
<IMG src="$name.gif">
</CENTER>
<HR>
We demonstrate how the sine function  $y = \sin(a)$  varies with  $a$  over
the full 360-degree interval. We plot a bright red circle at each
new angle, letting previous circles turn dark red. The underlying
sine curve is sampled at 10 times the frame sampling rate in order to reproduce
a smooth curve. Our animation uses Imagemagick's convert tool to make an animated GIF file
with a 0.2 second pause between frames, set to repeat forever.
<HR>
<I>$name.sh: Created by $USER on `date`</I>
</BODY>
</HTML>
END
# 4. Clean up temporary files
gmtset DOTS_PR_INCH 300
gmt_cleanup .gmt

```

Make sure you understand the purpose of all the steps in our script. In this case we did some trial-and-error to determine the exact values to use for the map projection, the region, the spacing around the frame, etc. so that the final result gave a reasonable layout. Do this planning on a single *PostScript* plot before running a lengthy animation script.

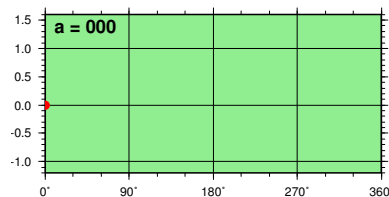


Figure 8.1: Animation of a simple sine function.

8.2 Examining DEMs using variable illumination

Our next animation uses a gridded topography for parts of Colorado (US); the file is distributed with the tutorial examples. Here, we want to use **grdimage** to generate a shaded-relief image sequence in which we sweep the illumination azimuth around the entire horizon. The resulting animation illustrates how

changing the illumination azimuth can bring out subtle features (or artifacts) in the gridded data. The red arrow points in the direction of the illumination.

```
#!/bin/sh
#
#           GMT ANIMATION 02
#
# Purpose:    Make web page with simple animated GIF of a DEM grid
# GMT progs:  gmtset, gmtmath, grdgradient, makecpt, grdimage psxy, ps2raster
# Unix progs: awk, mkdir, rm, mv, echo, convert, cat
#
# 1. Initialization
# 1a) Assign movie parameters
. gmt_shell_functions.sh
width=3.5i
height=4.15i
dpi=72
n_frames=36
TDIR=../../tutorial
name='basename $0 '.sh'
# 1b) setup
del_angle='gmtmath -Q 360 $n_frames DIV ='
makecpt -Crainbow -T500/4500/500 -Z > $$cpt
gmtset DOTS_PR_INCH $dpi
R='gmt_get_gridregion $TDIR/us.nc'
# 2. Main loop
mkdir -p $$
frame=0
while [ $frame -lt $n_frames ]; do
    # Create file name using a name_###.tif format
    file='gmt_set_framename $name $frame'
    angle='gmtmath -Q $frame $del_angle MUL ='
    dir='gmtmath -Q $angle 180 ADD ='
    grdgradient $TDIR/us.nc -A$angle -Nt2 -M -G$$us_int.nc
    grdimage $TDIR/us.nc -I$$us_int.nc -JM3i -P -K -C$$cpt -B1WSne -X0.35i -Y0.3i \
    --PAPER_MEDIA=Custom_${width}x${height} --ANNOT_FONT_SIZE=+9p > $$ps
    echo 256.25 35.6 | psxy -R$R -J -O -K -Sc0.8i -Gwhite -Wthin >> $$ps
    echo 256.25 35.6 $dir 0.37 | psxy -R$R -J -O -Sv0.02i/0.05i/0.05i -Gred -Wthin >> $$ps
    if [ $# -eq 0 ]; then
        mv $$ps $name.ps
        gmt_cleanup .gmt
        gmt_abort "$0: First frame plotted to $name.ps"
    fi
    #
    RIP to TIFF at specified dpi
    ps2raster -E$dpi -Tt $$ps
    mv -f $$tif $$file.tif
    echo "Frame $file completed"
    frame='gmt_set_framenext $frame'
done
# 3. Create animated GIF file and HTML for web page
convert -delay 10 -loop 0 $$/*.tif $name.gif
cat << END > $name.html
<HTML>
<TITLE>GMT shading: A tool for feature detection</TITLE>
<BODY bgcolor="#ffffff">
<CENTER>
<H1>GMT shading: A tool for feature detection</H1>
<IMG src="$name.gif">
</CENTER>
<HR>
We make illuminated images of topography from a section of Colorado and
vary the azimuth of the illumination (see arrow). As the light-source sweeps around
the area over 360 degrees we notice that different features in the data
become highlighted. This is because the illumination is based on data
gradients and such derivatives will high-light short-wavelength signal.
Again, our animation uses Imagemagick's convert tool to make an animated GIF file
with a 0.1 second pause between the 36 frames.
<HR>
<I>$name.sh: Created by $USER on `date`</I>
</BODY>
</HTML>
END
# 4. Clean up temporary files
gmtset DOTS_PR_INCH 300
gmt_cleanup .gmt
```

As you can see, these sorts of animations are not terribly difficult to put together, especially since our vantage point is fixed. In the next example we will move the “camera” around and must therefore deal with how to frame perspective views.

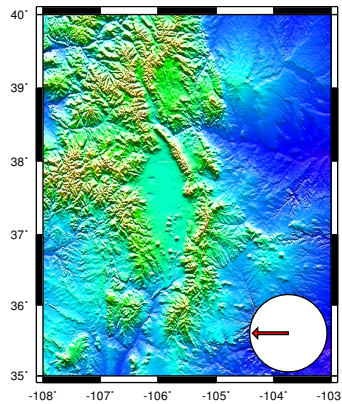


Figure 8.2: Animation of a DEM using variable illumination.

8.3 Orbiting a static map

Our third animation keeps a fixed gridded data set but moves the camera angle around the full 360°. We use **grdview** to generate a shaded-relief image sequence using the new enhanced **-E** option. No additional information is plotted on the image. As before we produce an animated GIF image and a simple HTML wrapper for it.

```
#!/bin/sh
#
#           GMT ANIMATION 03
#
# Purpose:    Make web page with simple animated GIF of Iceland topo
# GMT progs:  gmtset, gmtmath, psbasemap, pstext, psxy, ps2raster
# Unix progs: awk, mkdir, rm, mv, echo, convert, cat
#
# 1. Initialization
# 1a) Assign movie parameters
. gmt_shell_functions.sh
lon=-20
lat=65
dpi=100
x0=1.5
y0=0.75
px=4
py=2.5
el=35
az=0
name=`basename $0 '.sh'`
mkdir -p $$
gmtset DOTS_PR_INCH $dpi
frame=0
grdclip -Sb0/-1 -G$$_above.nc Iceland.nc
grdgradient -M -A45 -Nt1 $$_above.nc -G$$$.nc
makecpt -Crelief -Z > $$$.cpt
while [ $az -lt 360 ]; do
    file=`gmt_set_framename $name $frame`
    if [ $# -eq 0 ]; then # If a single frame is requested we pick this view
        az=135
    fi
    grdview $$_above.nc -JM2.5 -C$$$.cpt -Qi$dpi -B5g10/5g5 -E$az/${el}+w$lon/${lat}+v$x0/$y0 -P -X0.5i -Y0.5i --PAPER_MED
    if [ $# -eq 0 ]; then
        mv $$$.ps $name.ps
        gmt_cleanup .gmt
        gmt_abort "$0: First frame plotted to $name.ps"
    fi
    ps2raster $$$.ps -Tt -E$dpi
    mv $$$.tif $$file.tif
    az=`expr $az + 5`
    echo "Frame $file completed"
    frame=`gmt_set_framenext $frame`
done
convert -delay 10 -loop 0 $$/*.tif $name.gif
cat << END > $name.html
<HTML>
<TITLE>GMT 3-D perspective of Iceland</TITLE>
```

```

<BODY bgcolor="#ffffff">
<CENTER>
<H1>GMT 3-D perspective of Iceland</H1>
<IMG src="$name.gif" border=1>
</CENTER>
<HR>
Here we show ETOPO2 topography of Iceland as we move the view
point around the island.
<I>$name.sh: Created by $USER on `date`</I>
</BODY>
</HTML>
END
# 4. Clean up temporary files
gmtset DOTS_PR_INCH 300
gmt_cleanup .gmt

```

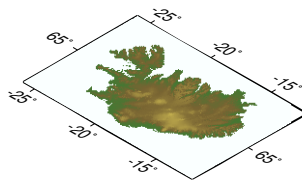


Figure 8.3: Orbiting a static map.

8.4 Flying over topography

Our next animation simulates what an imaginary satellite might see as it passes in a great circle from New York to Miami at an altitude of 160 km. We use the general perspective view projection with **grdimage** and use **project** to create a great circle path between the two cities, sampled every 5 km. The main part of the script will make the DVD-quality frames from different view points, draw the path on the ground, and add frame numbers to each frame. As this animation generates 355 frames we can use 3rd party tools to turn the image sequence into a MPEG-4 movie². Note: At the moment, **grdview** cannot use general perspective view projection to allow “fly-through” animations like Fledermaus; we expect to add this functionality in a future version.

```

#!/bin/sh
#
#           GMT ANIMATION 04
#
# Purpose:   Make DVD-res Quicktime movie of NY to Miami flight
# GMT progs: gmtset, gmtmath, psbasemap, pstext, psxy, ps2raster
# Unix progs: awk, mkdir, rm, mv, echo, qt_export, cat
#
# 1. Initialization
# 1a) Assign movie parameters
. gmt_shell_functions.sh
REGION=-Rg
altitude=160.0
tilt=55
azimuth=210
twist=0
Width=36.0
Height=34.0
px=7.2
py=4.8
dpi=100
name='basename $0 '.sh'

# Set up flight path
project -C-73.8333/40.75 -E-80.133/25.75 -G5 -Q > $.path.d
frame=0
mkdir -p frames
grdgradient USEast_Coast.nc -A90 -Nt1 -G$.int.nc
makecpt -Cglobe -Z > $.cpt
while read lon lat dist; do

```

²QuickTime Pro can do this, as can most video-editing programs.

```

file='gmt_set_framename $name $frame'
ID='echo $frame | awk '{printf "%4.4d\n", $1}'`
grdimage -JG${lon}/${lat}/${altitude}/${azimuth}/${tilt}/${twist}/${Width}/${Height}/7i+ \
    $REGION -P -Y0.1i -X0.1i USEast_Coast.nc -I${int}.nc -C${cpt} \
    --PAPER_MEDIA=Custom_${px}ix${py}i -K > $$ps
psxy -R -J -O -K -Wlp $$path.d >> $$ps
echo 0 4.6 14 0 1 TL $ID | pstext -R0/$px/0/$py -Jxli -O >> $$ps
if [ $# -eq 0 ]; then
    mv $$ps $name.ps
    gmt_cleanup .gmt
    gmt_abort "$0: First frame plotted to $name.ps"
fi
ps2raster $$ps -Tt -E$dpi
mv $.tif frames/$file.tif
echo "Frame $file completed"
frame='gmt_set_framenext $frame'
done < $$path.d
if [ $# -eq 1 ]; then
    echo "anim_04.sh: Made $frame frames at 480x720 pixels placed in subdirectory frames"
    # qt_export $$/anim_0_123456.tiff --video=h263,24,100, ${name}_movie.m4v
fi
# 4. Clean up temporary files
gmtset DOTS_PR_INCH 300
gmt_cleanup .gmt

```

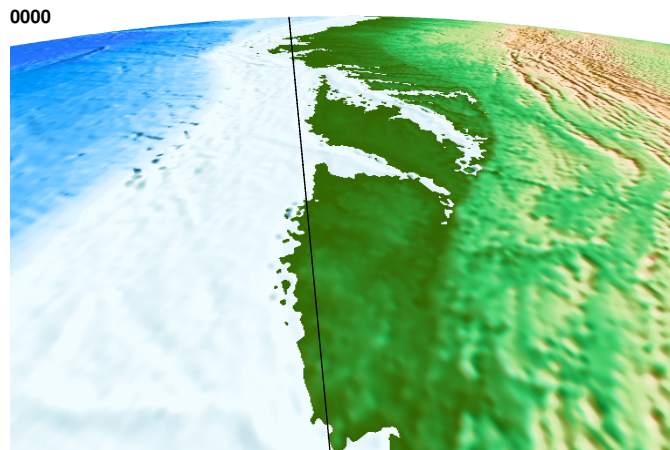


Figure 8.4: Flying over topography.

9. Mailing lists, updates, and bug reports

Most public-domain (and even commercial) software comes with bugs, and the speed with which such bugs are detected and removed depends to a large degree on the willingness of the user community to report these to us in a useful manner. When your car breaks down, simply telling the mechanic that it doesn't work will hardly speed up the repair or cut back costs! Therefore, we ask that if you detect a bug, first make sure that it in fact is a bug and not a user error. Then, send us email about the problem. Be sure to include all the information necessary for us to recreate the situation in which the bug occurred. This will include the full command line used and, if possible, the data file used by the program. Send the bug-reports to `gmt-bugs@hawaii.edu`. We will try to fix bugs as soon as our schedules permit and inform users about the bug and availability of updated code (See Appendix D).

Two electronic mailing lists are available to which users may subscribe. `gmt-group@hawaii.edu` and is primarily a way for us to notify the users when bugs have been fixed or when new updates have been installed in the ftp directory (See Appendix D). We also maintain another list (`gmt-help@hawaii.edu`) which interested users may subscribe to. It basically provides a forum for *GMT* users to exchange ideas and ask questions about *GMT* usage, installation and portability, etc. Please use this utility rather than sending questions directly to us personally. We hope you appreciate that we simply do not have time to be everybody's personal *GMT* tutor.

The electronic mailing lists are maintained automatically by a program. To subscribe to one or both of the lists, send a message to `listserv@hawaii.edu` containing the command(s):

```
subscribe gmt-group <your full name, not email address>
```

```
subscribe gmt-help <your full name, not email address>
```

(Do not type the angular brackets `<>`). You may also register electronically via the *GMT* home web page (`gmt.soest.hawaii.edu`). For information on what commands you may send, send a message containing the word `help`. You must interact with the listserver to be added to or removed from the mailing lists! We strongly recommend that you at least subscribe to `gmt-group` since this is how we can notify you of future updates and bug-fixes. Most new users will also benefit from having the other forum (`gmt-help`) as they struggle to realign their sense of logic with that of *GMT*. While anybody may post messages to `gmt-help`, access to `gmt-group` is restricted to minimize net traffic. Any message sent to `gmt-group` will be intercepted by the *GMT* manager who will determine if the message is important enough to cause thousands of mailtools to go BEEP. Communication with other *GMT* users should go via `gmt-help`. Finally, all *GMT* information is provided online at the main *GMT* home page in Hawaii, i.e., `gmt.soest.hawaii.edu`. Changes to *GMT* will also be posted on this page. The main *GMT* page has links to the official *GMT* ftp sites around the world.

A. GMT supplemental packages

These packages are for the most part written and supported by us, but there are some exceptions. They provide extensions of *GMT* that are needed for particular rather than general applications. The software is provided in a separate, supplemental archive (`GMT_suppl.tar.gz` (or `.bz2`); see Appendix D). Questions or bug reports for this software should be addressed to the person(s) listed in the `README` file associated with the particular program. It is not guaranteed that these programs are fully ANSI-C, Y2K, or POSIX compliant, or that they necessarily will install smoothly on all platforms, but most do. Note that the data sets some of these programs work on are not distributed with these packages; they must be obtained separately. The contents of the supplemental archive may change without notice; at this writing it contains these directories:

A.1 dbase: gridded data extractor

This package contains **grdraster** which you can use to extract data from global gridded data sets such as those available from NGDC. We have used it to prepare some of the grids in the examples (Chapter 6). You can also customize it to read your own data sets. The package is maintained by the *GMT* developers.

A.2 gshhs: GSHHS data extractor

This package contains **gshhs** which you can use to extract shoreline polygons from the Global Self-consistent Hierarchical High-resolution Shorelines (GSHHS) available separately from NGDC¹ or the GSHHS home page² (GSHHS is the polygon data base from which the *GMT* coastlines derive). It also contains **gshhs_dp** for cleverly decimating a shoreline, and **gshhstograss** to convert shoreline segments to the GRASS database format; the latter program is maintained by Simon Cox³. The package is maintained by Paul Wessel.

A.3 imgsrc: gridded altimetry extractor

This package consists of the program **img2mercgrd** to extract subsets of the global gravity and predicted topography solutions derived from satellite altimetry⁴. The package is maintained by Walter Smith⁵.

A.4 meca: seismology and geodesy symbols

This package contains the programs **pscoupe**, **psmeca**, **pspolar**, and **psvelo** which are used by seismologists and geodesists for plotting focal mechanisms (including cross-sections and polarities), error ellipses, velocity arrows, rotational wedges, and more. The package is maintained by Kurt Feigl⁶ and Genevieve Patau⁷.

A.5 mex: Matlab/Octave–GMT interface

Here you will find the mex files **grdinfo**, **grdread**, and **grdwrite**, which can be used in Matlab or Octave to read and write grid files. The package originated with David Sandwell, UCSD, and was subsequently

¹<http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html>

²<http://www.soest.hawaii.edu/wessel/gshhs/gshhs.html>

³Simon.Cox@csiro.au

⁴For data bases, see http://topex.ucsd.edu/marine_grav/mar_grav.html.

⁵walter@raptor.grdl.noaa.gov

⁶Kurt.Feigl@cnes.fr

⁷patau@ipgp.jussieu.fr

modified by Paul Wessel and Phil Sharfstein, UCSB. It is now maintained by Paul Wessel.

A.6 mgd77: MGD77 extractor and plotting tools

This package currently holds the programs **mgd77convert**, **mgd77info**, **mgd77list**, **mgd77magref**, **mgd77manage**, **mgd77path**, **mgd77sniffer**, and **mgd77track** which can be used to extract information or data values from or plot marine geophysical data files in the ASCII MGD77 or netCDF MGD77+ formats⁸). We expect this package eventually to replace the **mgg** package. The package is maintained by Paul Wessel.

A.7 mgg: GMT-MGD77 extractor and plotting tools

This package holds the legacy programs **binlegs**, **dat2gmt**, **gmt2dat**, **gmtinfo**, **gmtlegs**, **gmtlist**, **gmtpath**, **gmttrack**, and **mgd77togmt**, which can be used to maintain, access, extract data from, and plot marine geophysical data files converted from the MGD77 format to the .gmt format⁹). The package is maintained by the *GMT* developers.

A.8 misc: Miscellaneous tools

At the moment, this package contains the programs **dimfilter**, which is an extension of **grdfilter** in that it allows for spatial directional filtering, **psmegaplot** which you can use to make large posters using a simple laserwriter, **makepattern** which generates raster patterns from *GMT* 3.0 icon files, **gmt2kml** which converts *GMT* table data to Google Earth's KML format, **gmtdigitize** which provides a GMT interface to a digitizing tablet via a serial port, **gmtstitch** which can be used to assemble pieces digitized lines into complete lines or polygons, **gmtdp** which performs line reduction using the Douglas-Peucker algorithm, **kml2gmt** which extracts *GMT* table data from Google Earth KML files, and **nc2xy** which can extract data from column-oriented netCDF files. The package is maintained by Paul Wessel. The increasingly popular utility **ps2raster**, which simplifies the rasterization of *GMT PostScript* to raster formats (see Appendix C), was moved to the general tools starting with *GMT* 4.2.0.

A.9 segyprogs: plotting SEGY seismic data

This package contains programs to plot SEGY seismic data files using the *GMT* mapping transformations and postscript library. **pssegy** generates a 2-D plot (x:location and y:time/depth) while **pssegyz** generates a 3-D plot (x and y: location coordinates, z: time/depth). Locations may be read from predefined or arbitrary portions of each trace header. Finally, **segy2grd** can convert SEGY data to a *GMT* grid file. The package is maintained by Tim Henstock¹⁰.

A.10 sph: spherical triangulation and gridding

This package contains the main programs **sphtriangulate**, which you can use to generate data for Delaunay or Voronoi diagrams, **sphdistance** which calculates distances from lines to grid nodes using Voronoi decomposition of the data, and **sphinterpolate** which performs gridding under tension on a sphere. These programs pass the heavy work onto the two Fortran-77 packages SSRFPACK and STRIPACK by Robert Renka; here they have been translated to C with assistance from **f2c**. The package is maintained by Paul Wessel.

⁸The ASCII MGD77 data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).

⁹These data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).

¹⁰Timothy.J.Henstock@soc.soton.ac.uk

A.11 spotter: backtracking and hotspotting

This package contains the plate tectonic programs **backtracker**, which you can use to move geologic markers forward or backward in time, **grdrotater** which rotates entire grids using a finite rotation, **hotspotter** which generates CVA grids based on seamount locations and a set of absolute plate motion stage poles (**grdspotter** does the same using a bathymetry grid instead of seamount locations), **originator**, which associates seamounts with the most likely hotspot origins, and **rotconverter** which does various operations involving finite rotations on a sphere. The package is maintained by Paul Wessel.

A.12 x2sys: track crossover error estimation

This package contains the tools **x2sys_datalist**, which allows you to extract data from almost any binary or ASCII data file, and **x2sys_cross** which determines crossover locations and errors generated by one or several geospatial tracks. Newly added are the tools **x2sys_init**, **x2sys_binlist**, **x2sys_get**, **x2sys_list**, **x2sys_put**, **x2sys_report**, **x2sys_solve** and **x2sys_merge** which extends the track-management system employed by the *mgg* supplement to generic track data of any format. This package represents a new generation of tools intended to replace the old “X-SYSTEM” crossover tools (below). The package is maintained by Paul Wessel.

A.13 x_system: track crossover error estimation

This package contains the tools **x_edit**, **x_init**, **x_list**, **x_over**, **x_remove**, **x_report**, **x_setup**, **x_solve_dc_drift**, and **x_update**. Collectively, they make up the old “XSYSTEM” crossover tools. This package will remain in the *GMT* supplemental archive until **x2sys** is complete. The package is maintained by Paul Wessel.

A.14 xgrid: visual editor for grid files

The package contains an X11 editor (**xgridedit**) for visual editing of grid files. It was originally developed by Hugh Fisher, CRES, in March 1992 but is now maintained by Lloyd Parkes¹¹.

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B. GMT file formats

B.1 Table data

These files have N records which have M fields each. Most programs can read multicolumn files, but require that the x [and y] variable(s) be stored in the 1st [and 2nd] column (There are, however, some exceptions to this rule, such as **filter1d** and **sample1d**). *GMT* can read both ASCII and binary table data.

B.1.1 ASCII tables

Optional file header records

The first data record may be preceded by 1 or more header records. When using such files, make sure to use the **-H** option and set the parameter **N HEADER.RECS** in the `.gmtdefaults4` file (System default is 1 header record if **-H** is set; you may also use **-Hnrecs** directly). Fields within a record must be separated by spaces, tabs, or commas. Each field can be an integer or floating-point number or a geographic coordinate string using the `[+|-]dd[:mm[:ss]][W|S|N|E]w|s|n|e` format. Thus, 12:30:44.5W, 17.5S, 1:00:05, and 200:45E are all valid input strings.

Optional segment header records

When dealing with time- or (x,y) -series it is usually convenient to have each profile in separate files. However, this may sometimes prove impractical due to large numbers of profiles. An example is files of digitized lineations where the number of individual features may range into the thousands. One file per feature would in this case be unreasonable and furthermore clog up the directory. *GMT* provides a mechanism for keeping more than one profile in a file. Such files are called *multiple segment files* and are identical to the ones just outlined except that they have subheaders interspersed with data records that signal the start of a segment. The subheaders may be of any format, but all must have the same character in the first column. When using such files, you must specify the **-m** option. The unique character is by default '>', but you can override that by appending your chosen character to the **M** option. E.g., **-mH** will look for subheaders starting with H, whereas **-m'*'** will check for asterisks (The quotes are necessary since * has special meaning to *UNIX*). Some programs such as **psxy** will examine the subheaders to see if they contain **-W** and **-G** options for specifying pen and fill attributes for individual segments, **-Z** to change color via a cpt-file, or **-L** for label specifications. These settings (and occasionally others) will override the corresponding command line options.

B.1.2 Binary tables

GMT programs also support native binary tables to speed up input-output for i/o-intensive tasks like gridding and preprocessing. Files may have no header (hence the **-H** option cannot be used) and all data must either be single or double precision (no mixing allowed). Multiple segment files are allowed (**-m**) and the segment headers are assumed to be records where all the fields equal NaN. Flags appended to **-m** are ignored. The format and number of fields are specified with the **-b** option. Thus, for input you may set **-bi[s][n]**, where **s** designates single precision (default is **d** for double) and **n** is the number of fields. For output, use **-bo[s]** (the programs know how many columns to write, unless you use **-m** in which case we need to know the number of output columns up front). If you need to swap the byte-order on either input or output you must use upper case **S** or **D** instead.

B.1.3 NetCDF tables

More and more programs are now producing binary data in the netCDF format, and so *GMT* programs started to support tabular netCDF data (files containing one or more 1-dimensional arrays) starting with

<i>Attribute</i>	<i>Description</i>
<i>Global attributes</i>	
Conventions	COARDS, CF-1.0 (optional)
title	Title (optional)
source	How file was created (optional)
node_offset	0 for gridline node registration (default), 1 for pixel registration
<i>x- and y-variable attributes</i>	
long_name	Coordinate name (default: “Longitude” and “Latitude”)
units	Unit of the coordinate (default: “degrees_east” and “degrees_north”)
actual_range (or valid_range)	Minimum and maximum x and y of region; if absent the first and last x - and y -values are queried
<i>z-variable attributes</i>	
long_name	Name of the variable (default: “z”)
units	Unit of the variable (no default)
scale_factor	Factor to multiply z with (default: 1)
add_offset	Offset to add to scaled z (default: 0)
actual_range	Minimum and maximum z (optional)
_FillValue (or missing_value)	Value associated with missing data points; if absent an appropriate default value is assumed, depending on data type.

Table B.1: Attributes of default **GMT** grid file in COARDS-compliant netCDF format.

GMT version 4.3.0. Because of the meta data contained in those files, reading them is much less complex than reading native binary tables, and even than ASCII tables. *GMT* programs will read as many 1-dimensional columns as are needed by the program, starting with the first 1-dimensional it can find in the file. To specifically specify which variables are to be read, append the suffix `?var1/var2/...` to the netCDF file name or add the option `-bicvar1/var2/...`, where `var1`, `var2`, etc. are the names of the variables to be processed. The latter option is particularly practical when more than one file is read: the `-bic` option will apply to all files. Currently, *GMT* only reads, but does not write, netCDF tabular data.

B.2 Grid files

B.2.1 NetCDF files

By default, *GMT* stores 2-D grids as COARDS-compliant netCDF files. COARDS (which stands for Cooperative Ocean/Atmosphere Research Data Service) is a convention used by many agencies distributing gridded data for ocean and atmosphere research. Sticking to this convention allows *GMT* to read gridded data provided by other institutes and other programs. Conversely, other general domain programs will be able to read grids created by *GMT*. COARDS is a subset of a more extensive convention for netCDF data called CF-1.0 (Climate and Forecast, version 1.0). Hence, *GMT* grids are also automatically CF-1.0-compliant. However, since CF-1.0 has more general application than COARDS, not all CF-1.0 compliant netCDF files can be read by *GMT*.

The netCDF grid file in *GMT* has several attributes (See Table B.1) to describe the content. The routine that deals with netCDF grid files is sufficiently flexible so that grid files slightly deviating from the standards used by *GMT* can also be read.

By default, the first 2-dimensional variable in a netCDF file will be read as the z variable and the coordinate axes x and y will be determined from the dimensions of the z variable. *GMT* will recognize whether the y (latitude) variable increases or decreases. Both forms of data storage are handled appropriately.

For more information on the use of COARDS-compliant netCDF files, and on how to load multi-dimensional grids, read Section 4.18.

GMT also allows other formats to be read. In addition to the default netCDF format it can use binary floating points, short integers, bytes, and bits, as well as 8-bit Sun raster files (colormap ignored). Addi-

tional formats may be used by supplying read/write functions and linking these with the *GMT* libraries. The source file `gmt_customio.c` has the information that programmers will need to augment *GMT* to read custom grid files. We anticipate that the number of pre-programmed formats will increase as enterprising users implement what they need. See Section 4.17 for more information.

B.2.2 Gridline and Pixel node registration

Scanline format means that the data are stored in rows ($y = \text{constant}$) going from the “top” ($y = y_{\max}$ (north)) to the “bottom” ($y = y_{\min}$ (south)). Data within each row are ordered from “left” ($x = x_{\min}$ (west)) to “right” ($x = x_{\max}$ (east)). The *node_offset* signals how the nodes are laid out. The grid is always defined as the intersections of all x ($x = x_{\min}, x_{\min} + x_{\text{inc}}, x_{\min} + 2 \cdot x_{\text{inc}}, \dots, x_{\max}$) and y ($y = y_{\min}, y_{\min} + y_{\text{inc}}, y_{\min} + 2 \cdot y_{\text{inc}}, \dots, y_{\max}$) lines. The two scenarios differ in which area each data point represents. The default node registration in *GMT* is gridline node registration. Most programs can handle both types, and for some programs like **grdimage** a pixel registered file makes more sense. Utility programs like **grdsample** and **grdproject** will allow you to convert from one format to the other; **grdedit** can make changes to the grid header and convert a pixel- to a gridline-registered grid, or *vice versa*.

Gridline registration

In this registration, the nodes are centered on the grid line intersections and the data points represent the average value in a cell of dimensions $(x_{\text{inc}} \cdot y_{\text{inc}})$ centered on the nodes (Figure B.1). In the case of grid line registration the number of nodes are related to region and grid spacing by

$$\begin{aligned} nx &= (x_{\max} - x_{\min})/x_{\text{inc}} + 1 \\ ny &= (y_{\max} - y_{\min})/y_{\text{inc}} + 1 \end{aligned}$$

which for the example in Figure B.1 yields $nx = ny = 4$.

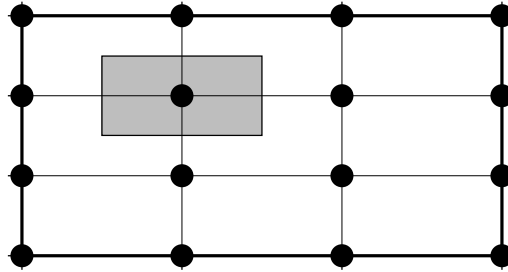


Figure B.1: Gridline registration of data nodes.

Pixel registration

Here, the nodes are centered in the grid cells, i.e., the areas between grid lines, and the data points represent the average values within each cell (Figure B.2). In the case of pixel registration the number of nodes are related to region and grid spacing by

$$\begin{aligned} nx &= (x_{\max} - x_{\min})/x_{\text{inc}} \\ ny &= (y_{\max} - y_{\min})/y_{\text{inc}} \end{aligned}$$

Thus, given the same region (**-R**), the pixel node registered grids have one less column and one less row than the grid line registered grids; here we find $nx = ny = 3$.

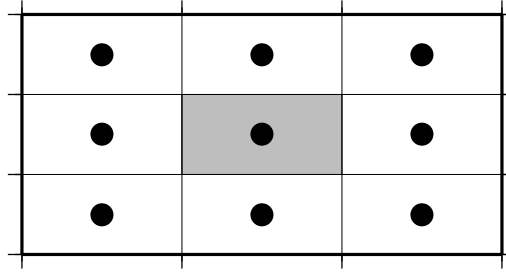


Figure B.2: Pixel registration of data nodes.

B.2.3 Boundary Conditions for operations on grids

GMT has the option to specify boundary conditions in some programs that operate on grids (**grdsample -L**; **grdgradient -L**; **grdtrack -L**; **nearneighbor -L**; **grdview -L**). The boundary conditions come into play when interpolating or computing derivatives near the limits of the region covered by the grid. The *default* boundary conditions used are those which are “natural” for the boundary of a minimum curvature interpolating surface. If the user knows that the data are periodic in x (and/or y), or that the data cover a sphere with x, y representing *longitude, latitude*, then there are better choices for the boundary conditions. Periodic conditions on x (and/or y) are chosen by specifying x (and/or y) as the boundary condition flags; global spherical cases are specified using the g (geographical) flag. Behavior of these conditions is as follows:

Periodic conditions on x indicate that the data are periodic in the distance $(x_{max} - x_{min})$ and thus repeat values after every $N = (x_{max} - x_{min})/x_{inc}$. Note that this implies that in a grid-registered file the values in the first and last columns are equal, since these are located at $x = x_{min}$ and $x = x_{max}$, and there are $N + 1$ columns in the file. This is not the case in a pixel-registered file, where there are only N and the first and last columns are located at $x_{min} + x_{inc}/2$ and $x_{max} - x_{inc}/2$. If y is periodic all the same holds for y .

Geographical conditions indicate the following:

1. If $(x_{max} - x_{min}) \geq 360$ and also $180 \bmod x_{inc} = 0$ then a periodic condition is used on x with a period of 360; else a default condition is used on the x boundaries.
2. If condition 1 is true and also $y_{max} = 90$ then a “north pole condition” is used at y_{max} , else a default condition is used there.
3. If condition 1 is true and also $y_{min} = -90$ then a “south pole condition” is used at y_{min} , else a default condition is used there.

“Pole conditions” use a 180° phase-shift of the data, requiring $180 \bmod x_{inc} = 0$.

Default boundary conditions are

$$\nabla^2 f = \frac{\partial}{\partial n} \nabla^2 f = 0$$

on the boundary, where $f(x, y)$ is represented by the values in the grid file, and $\partial/\partial n$ is the derivative in the direction normal to a boundary, and

$$\nabla^2 = \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right)$$

is the two-dimensional Laplacian operator.

<i>Parameter</i>	<i>Description</i>
int <i>nx</i>	Number of nodes in the <i>x</i> -dimension
int <i>ny</i>	Number of nodes in the <i>y</i> -dimension
int <i>node_offset</i>	0 for grid line registration, 1 for pixel registration
double <i>x_min</i>	Minimum <i>x</i> -value of region
double <i>x_max</i>	Maximum <i>x</i> -value of region
double <i>y_min</i>	Minimum <i>y</i> -value of region
double <i>y_max</i>	Maximum <i>y</i> -value of region
double <i>z_min</i>	Minimum <i>z</i> -value in data set
double <i>z_max</i>	Maximum <i>z</i> -value in data set
double <i>x_inc</i>	Node spacing in <i>x</i> -dimension
double <i>y_inc</i>	Node spacing in <i>y</i> -dimension
double <i>z_scale_factor</i>	Factor to multiply <i>z</i> -values after read
double <i>z_add_offset</i>	Offset to add to scaled <i>z</i> -values
char <i>x_units</i> [80]	Units of the <i>x</i> -dimension
char <i>y_units</i> [80]	Units of the <i>y</i> -dimension
char <i>z_units</i> [80]	Units of the <i>z</i> -dimension
char <i>title</i> [80]	Descriptive title of the data set
char <i>command</i> [320]	Command line that produced the grid file
char <i>remark</i> [160]	Any additional comments
TYPE <i>z</i> [<i>nx</i> * <i>ny</i>]	1-D array with <i>z</i> -values in scanline format

Table B.2: GMT grid file header record. **TYPE** can be **char**, **short**, **int**, **float**, or **double**.

B.2.4 Native binary grid files

The old style native grid file format that was common in earlier version of *GMT* is still supported, although the use of netCDF files is strongly recommended. The file starts with a header containing a number of attributes defining the content. The **grdedit** utility program will allow you to edit parts of the header of an existing grid file. The attributes listed in Table B.2 are contained within the header record in the order given (except the *z*-array which is not part of the header structure, but makes up the rest of the file).

B.3 Sun raster files

The Sun raster file format consists of a header followed by a series of unsigned 1-byte integers that represents the bit-pattern. Bits are scanline oriented, and each row must contain an even number of bytes. The predefined 1-bit patterns in *GMT* have dimensions of 64 by 64, but other sizes will be accepted when using the **-Gp|P** option. The Sun header structure is outline in Table B.3.

<i>Parameter</i>	<i>Description</i>
int <i>ras_magic</i>	Magic number
int <i>ras_width</i>	Width (pixels) of image
int <i>ras_height</i>	Height (pixels) of image
int <i>ras_depth</i>	Depth (1, 8, 24, 32 bits) of pixel
int <i>ras_length</i>	Length (bytes) of image
int <i>ras_type</i>	Type of file; see RT_* below
int <i>ras_maptype</i>	Type of colormap; see RMT_* below
int <i>ras_maplength</i>	Length (bytes) of following map

Table B.3: Structure of a Sun raster file.

After the header, the color map (if *ras_maptype* is not RMT_NONE) follows for *ras_maplength* bytes,

followed by an image of *ras_length* bytes. Some related definitions are given in Table B.4.

<i>Macro name</i>	<i>Description</i>
RAS_MAGIC	0x59a66a95
RT_STANDARD	1 (Raw pixrect image in 68000 byte order)
RT_BYTE_ENCODED	2 (Run-length compression of bytes)
RT_FORMAT_RGB	3 ([X]RGB instead of [X]BGR)
RMT_NONE	0 (ras_maplength is expected to be 0)
RMT_EQUAL_RGB	1 (red[ras_maplength/3],green[],blue[])

Table B.4: Sun macro definitions relevant to raster files.

Numerous public-domain programs exist, such as **xv** and **convert** (in the ImageMagick package), that will translate between various raster file formats such as tiff, gif, jpeg, and Sun raster. Raster patterns may be created with *GMT* plotting tools by generating *PostScript* plots that can be rasterized by **ghostscript** and translated into the right raster format.

C. Including GMT graphics into your documents

Now that you made some nice graphics with *GMT*, it is time to add them to a document, an article, a report, your dissertation, a poster, a web page, or a presentation. Of course, you could try the old-fashioned scissors and glue stick. More likely, you want to incorporate your graphics electronically into the document. Depending on the application, the *GMT PostScript* file will need to be converted to Encapsulated *PostScript* (EPS), Portable Document Format (PDF), or some raster format (e.g., JPEG, PNG, or TIFF) in order to incorporate them into the document.

- When creating a document intended for printing (article, dissertation, or poster) it is best to preserve the scalable vector characteristics of the *PostScript* file. Many applications can directly incorporate *PostScript* in the form of EPS files. Modern programs will often allow the inclusion of PDF files. Either way, the sharpness of lines and fonts will be preserved and can be scaled up or down as required.
- When the aim is to display the graphics on a computer screen or present it using a projector, it is wise to convert the *PostScript* into a raster format. Although applications like **PowerPoint** can do this for you, you can best take the conversion into your own hands for the best results.

A large number of questions to the GMT-Help mailing list are related to these rendering issues, showing that something as seemingly straightforward as incorporating a *PostScript* file into a document is a far from trivial exercise. This Chapter will show how to include *GMT* graphics into documents and how to achieve the best quality results.

C.1 Making GMT Encapsulated *PostScript* Files

GMT can produce both freeform *PostScript* files and the more restricted Encapsulated *PostScript* files (EPS). The former is intended to be sent to a printer or *PostScript* previewer, while the latter is intended to be included in another document (but should also be able to print and preview). You control what kind of *PostScript* that *GMT* produces by manipulating the **PAPER_MEDIA** parameter (see the **gmtdefaults** man page for how this is accomplished). Note that a freeform *PostScript* file may contain special operators (such as `Setpagedevice`) that is specific to printers (e.g., selection of paper tray). Some previewers (among them, Sun's **pageview**) do not understand these valid instructions and may fail to image the file. Also, embedding freeform *PostScript* with such instructions in it into a larger document can create printing to fail. While you could choose another viewer (we recommend **ghostview**) to view single plots prepared by *GMT*, it is generally wiser anyhow to select EPS output when you are creating a plot intended for inclusion into a larger document. Some programs (and some publishers as well) do not allow the use of instructions like `Setpagedevice` as part of embedded graphics.

An EPS file that is to be placed into another document needs to have correct bounding box parameters. These are found in the *PostScript* Document Comment `%%BoundingBox`. Applications that generate EPS files should set these parameters correctly. Because *GMT* makes the *PostScript* files on the fly, often with several overlays, it is not possible to do so accurately. However, *GMT* does make an effort to ensure that the `BoundingBox` is large enough to contain the entire composite plot¹. Therefore, if you need a “tight” `BoundingBox` you need to post-process your *PostScript* file. There are several ways in which this can be accomplished.

- Programs such as Adobe **Illustrator**, Aldus **Freehand**, and Corel **Draw** will allow you to edit the `BoundingBox` graphically.
- A command-line alternative is to use freely-available program **epstool** from the makers of Aladdin **ghostscript**. Running

```
epstool -c -b myplot.ps
```

¹In contrast, regular *GMT PostScript* files simply have a `%%BoundingBox` that equal the size of the chosen paper.

should give a tight BoundingBox; **epstool** assumes the plot is page size and not a huge poster.

- Another option is to use **ps2epsi** which also comes with the **ghostscript** package. Running

```
ps2epsi myplot.ps myplot.eps
```

should also do the trick. The downside is that this program adds an “image” of the plot in the preamble of the EPS file, thus increasing the file size significantly. This image is a rough rendering of your *PostScript* graphics that some programs will show on screen while you are editing your document. This image is basically a placeholder for the *PostScript* graphics that will actually be printed.

- The preferred option is to use the *GMT* utility **ps2raster**. Its **-A** option will figure out the tightest BoundingBox, again using **ghostscript** in the background. For example, running

```
ps2raster -A -Te myplot.ps
```

will convert the *PostScript* file `myplot.ps` into an encapsulated *PostScript* file `myplot.eps` which is exactly cropped to the tightest possible BoundingBox.

If you do not want to modify your illustration but just include it in a text document: many word processors (such as Microsoft **Word**, Corel **WordPerfect**, and Apple **Pages**) will let you include a *PostScript* file that you may place but not edit. Newer versions of those programs also allow you to include PDF versions of your graphics. Except for **Pages**, you will not be able to view the figure on-screen, but it will print correctly.

C.2 Converting GMT *PostScript* to PDF or raster images

Since Adobe’s PDF (Portable Document Format) seems to become the *de facto* standard for vector graphics, you are often well off converting *GMT* produced *PostScript* files to PDF. Being both vector formats (i.e., they basically describe all objects, text and graphics as lines and curves), such conversion sounds awfully straightforward and not worth a full section in this document. But experience has shown differently, since most converters cut corners by using the same tool (Aladdin’s **ghostscript**) with basic default options that are not devised to produce the best quality PDF files.

For some applications it is practical or even essential that you convert your *PostScript* file into a raster format, such as GIF (Graphics Interchange Format), TIFF (Tagged Image File Format), PNG (Portable Network Graphics), or JPEG (Joint Photographic Experts Group). A web page is better served with a raster image that will immediately show on a web browser, than with a *PostScript* file that needs to be downloaded to view, despite the better printing quality of the *PostScript* image. A less obvious reason to convert your image to a raster format is to by-pass **PowerPoint**’s rendering engine in case you want to embed the image into a presentation.

There are a number of programs that will convert *PostScript* files to PDF or raster formats, like Aladdin’s **pstopdf**, pbmplus’ **pstoimg**, or ImageMagick’s **convert**, most of which run **ghostscript** behind the scenes. The same is true for viewers like **ghostview** and Apple’s **Preview**. So a lot of the times when people report that their *PostScript* plot does not look right but prints fine, it is the way **ghostscript** is used with its most basic settings that is to blame.

C.2.1 When converting or viewing *PostScript* goes awry

Here are some notorious pitfalls with **ghostscript** (and other rendering programs for that matter).

Rendering. When you are converting to a raster format, make sure you use a high enough resolution so that the pixels do not show when it is enlarged onto a screen or using a projector. The right choice of resolution depends on the application, but do not feel limited to the default 72 dpi (dots-per-inch) that is offered by most converters.

Image compression. There are *lossy* and *non-lossy* compressions. A compression algorithm is called “lossy” when information is lost in the conversion: there is no way back to get the full original. The effect can be seen when there are sharp color transitions in your image: the edges will get blurry in order to allow a more efficient compression. JPEG uses a lossy compression, PNG is non-lossy, and TIFF generally does not use compression at all. We therefore recommend you convert to PNG if you need to rasterize your plot, and leave JPEG to photographs.

Embedded image compression. When your *GMT* plot includes objects produced by **grdimage**, **psimage** or **pslegend**, they are seen as “images”. The default options of **ghostscript** will use a *lossy* compression (similar to JPEG) on those images when converting them to PDF objects. This can be avoided, however, by inhibiting the compression altogether, or using the non-lossy *flate* compression, similar to the one used in the old **compress** program. This compression is fully reversible, so that your image does not suffer any loss.

Auto-rotation. The **ghostscript** engine has the annoying habit to automatically rotate an image produced with portrait orientation (using the **-P** option) so that the height is always larger than the width. So if you have an image that was printed in portrait mode but happens to have a width larger than height (for example a global map), it would suddenly get rotated. Again, this function needs to be switched off. Apple’s **Preview** uses the **ghostscript** engine and suffers from the same annoying habit. Oddly enough, **ghostscript** does not force landscape plots to be “horizontal”.

Anti-aliasing. This is not something to worry about when converting to PDF, but certainly when producing raster images (discussed below). *Anti-aliasing* in this context means that the rendering tries to avoid *aliasing*, for example, sampling only the blacks in a black-and-white hachure. It does so by first oversampling the image and then using “gray-shades” when a target pixel is only partially white or black.

Clearly, this can lead to some unwanted results. First, all edges and lines get blurry and second, the assumption of a white background causes the gray shades to stand out when transferring the image to background with a different color (like the popular sleep-inducing blue in **PowerPoint** presentations). A more surprising effect of anti-aliasing is that the seams between tiles that make up the land mask when using **pscoast** will become visible. The anti-aliasing somehow decides to blur the edges of all polygons, even when they are seamlessly connected to other polygons.

It is therefore wise to overrule the default anti-aliasing option and over-sample the image yourself by choosing a higher resolution.

Including fonts. When you are producing print-ready copy to publishers, they will often (and justifiably) ask that you include all fonts in your PDF document. Again, **ghostscript** (and all converters relying on that engine) will not do so by default.

C.2.2 Using **ps2raster**

The remedy to all the problems mentioned in the previous section is readily available to you in the form of the *GMT* utility **ps2raster**. It is designed to provide the best quality PDF and raster files using **ghostscript** as a rendering engine. The program **ps2raster** avoids anti-aliasing and lossy compression techniques that are default to **ghostscript** and includes the fonts into the resulting PDF file to ensure portability. By default the fonts are rendered at 720 dots-per-inch in a PDF file and images are sampled to 300 dpi, but that can be changed with the **-E** option. Simply run

```
ps2raster -A -P -Tf *.ps
```

to convert all *PostScript* files to PDF while cropping it to the smallest possible BoundingBox. Or use the **-Tg** option to convert your files to PNG.

The **-P** option of **ps2raster** may also come in handy. When you have *not* supplied the **-P** option in your first *GMT* plot command, your plot will be in Landscape mode. That means that the plot will be rotated 90 degrees (anti-clockwise) to fit on a Portrait mode page when coming out of the printer. The **-P** option of **ps2raster** will undo that rotation, so that you do not have to do so within your document. This will only affect Landscape plots; Portrait plots will not be rotated.

C.3 Examples

C.3.1 GMT graphics in L^AT_EX

Nearly all illustrations in this *GMT* documentation were *GMT*-produced *PostScript* files. They were converted to PDF files using **ps2raster** and then included into a L^AT_EX document that was processed with **pdflatex** to create the PDF document you are reading.

To add the graphics into the L^AT_EX document we use the `\includegraphics` command supplied by the **graphicx** package. In the preamble of your L^AT_EX document you will need to include the line

```
\usepackage{graphicx}
```

The inclusion of the graphics will probably be inside a floating figure environment; something like this

```
\begin{figure}
  \includegraphics{myplot}
  \caption{This is my first plot in \LaTeX.}
  \label{fig:myplot}
\end{figure}
```

Note that the `\includegraphics` command does not require you to add the suffix `.pdf` to the file name. If you run **pdflatex**, it will look automatically for `myplot.pdf`. If you run **latex**, it will use `myplot.eps` instead.

You can scale your plot using the options `width=`, `height=`, or `scale=`. In addition, if your original graphics was produced in Landscape mode (i.e., you did *not* use *GMT*'s **-P** option: not while plotting, nor in **ps2raster**), you will need to rotate the plot as well. For example,

```
\includegraphics[angle=-90,width=0.8\textwidth]{myplot}
```

will rotate the image 90° clockwise and scale it such that its width (after rotation) will be 80% of the width of the text column.

C.3.2 GMT graphics in PowerPoint

In Figure C.1 we have attempted to include Figure 7.20 into a **PowerPoint** presentation. First the *PostScript* file was converted to PDF (using **ps2raster**), then loaded into **PowerPoint** and the white background color was made transparent using the formatting toolbar (shown on the left side of Figure C.1). Clearly, when we let **PowerPoint** do the rendering, we do not get the best result:

1. The anti-aliasing causes the tiles that make up the land to stand out. This is because the anti-aliasing algorithm blurs all edges, even when the tiles join seamlessly.
2. The background color was assumed to be white, hence the text is “smoothed” using gray shades. Instead, shades of blue which would be appropriate for the background we are using.

On the central column of Figure C.1 we have included PNG versions of a portion of the same example. This shows the workings of anti-aliasing and different resolutions. All samples were obtained with **convert**. The one on the top uses all default settings, resulting in an anti-aliased image at 72 dpi resolution (very much like the PDF included directly into **PowerPoint**).

Just switching anti-aliasing off (middle) is clearly not an option either. It is true that we got rid of the gray blurring and the seams between the tiles, but without anti-aliasing the image becomes very blocky. The solution is to render the image at a higher resolution (e.g., 300 dpi) without anti-aliasing and then shrink the image to the appropriate size (bottom of the central column in Figure C.1). The scaling, rotation as well as the selection of the transparent color can be accomplished through the “Formatting” tool bar and the “Format Picture” dialogue box of **PowerPoint** (Figure C.2), which can be found by double clicking the included image (or selecting and right-clicking or control-clicking on a one-button mouse).

C.4 Concluding remarks

These examples do not constitute endorsements of the products mentioned above; they only represent our limited experience with adding *PostScript* to various types of documents. For other solutions and further help, please post messages to gmt-help@hawaii.edu.

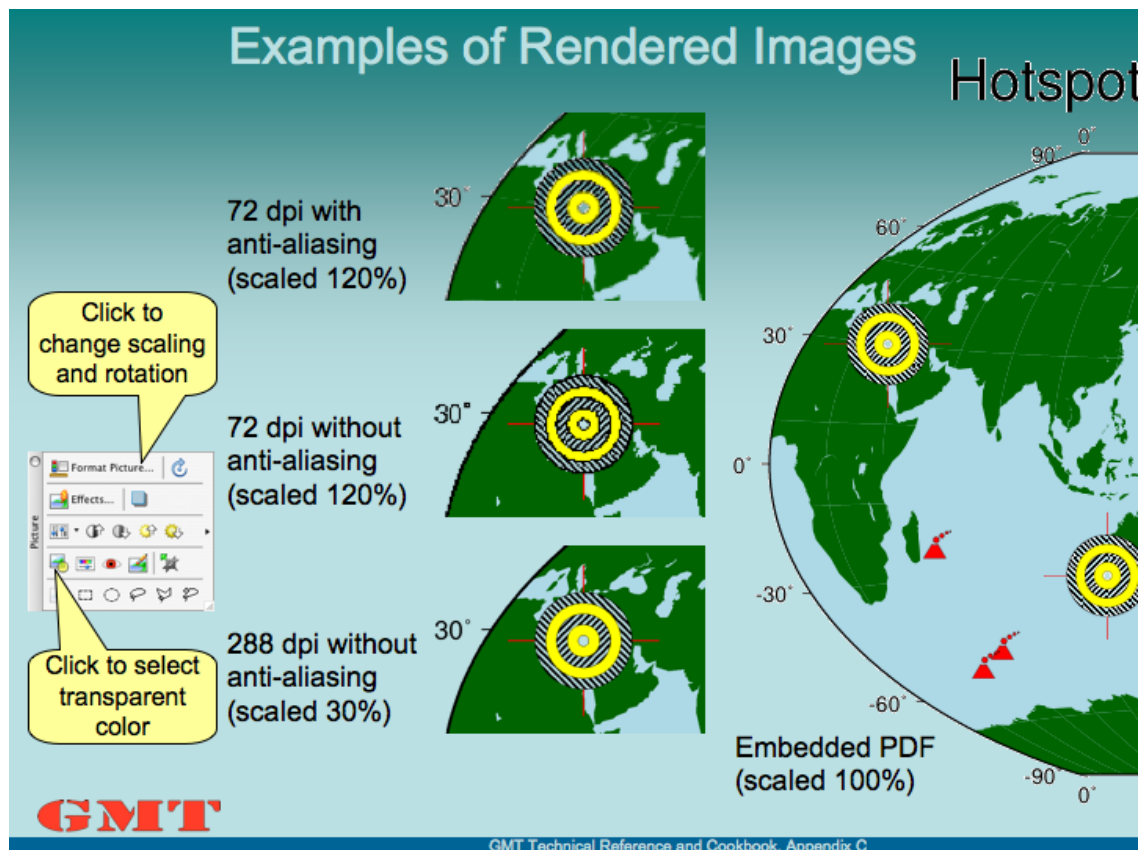


Figure C.1: Examples of rendered images in a *PowerPoint* presentation.

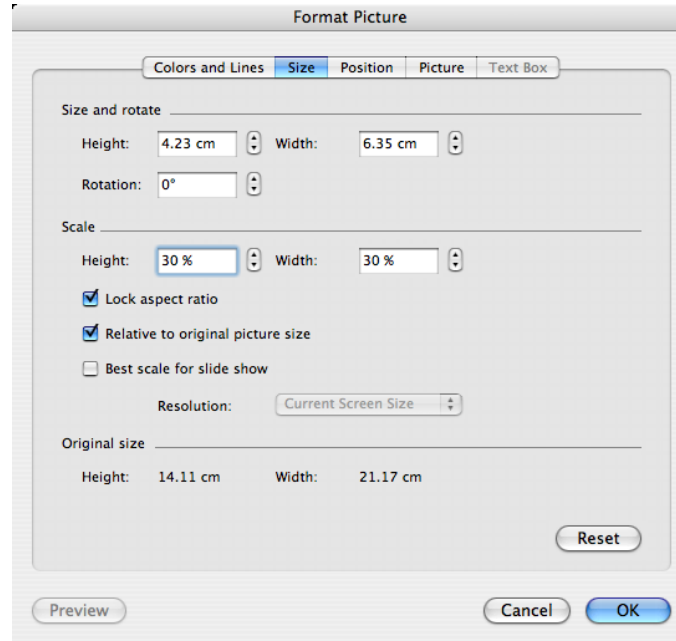


Figure C.2: *PowerPoint*'s "Format Picture" dialogue to set scale and rotation.

D. Availability of GMT and related code

D.1 Source distribution

All the source code, support data, PDF and HTML versions of all documentation (including *UNIX* manual pages) can be obtained by anonymous ftp from several mirror sites. We also maintain a *GMT* page on the World Wide Web (<http://gmt.soest.hawaii.edu>); see this page for installation directions which allow for a simplified, automatic install procedure (for CD-D and DVD-R solutions, see <http://www.geoware-online.com>.)

The *GMT* compressed tar archives requires **bzip2** to expand. If this utility is not installed on your system, you must obtain it by your system's package manager or install it separately¹. The *GMT* archives are as follows:

GMT_src.tar.bz2 Contains all *GMT* source code needed for compilation.

GMT_share.tar.bz2 Contains support files needed at run-time (cpt files, symbols and *PostScript* patterns).

GSHHS_coast.tar.bz2 Contains the intermediate, low, and crude resolutions of the GSHHS coastline database. Required with *GMT_src.tar* and *GMT_share.tar* for minimal setup needed to run *GMT*.

GMT_doc.tar.bz2 Contains HTML and PDF versions all *GMT* documentation (man pages, Cookbook and Technical Reference, and the tutorial), the data files used in the tutorial, and all the shell scripts and support data used in the Cookbook section.

GMT_triangle.tar.bz2 Contains the optional triangulation routine of Shewchuk.

GMT_suppl.tar.bz2 Contains several programs written by us and *GMT* users elsewhere. (See Appendix A for more details).

GSHHS_full.tar.bz2 Contains the optional GSHHS full-resolution coastline database.

GSHHS_high.tar.bz2 Contains the optional GSHHS high-resolution coastline database.

The netCDF library that makes up the backbone of the grid file i/o operations can be obtained from Unidata by downloading the file [netcdf.tar.Z](#) from the anonymous FTP directory of unidata.ucar.edu.

D.2 Pre-compiled Executables

For Windows users who just want executables we have three Windows installers available:

GMT_basic_install.exe The basic install with all *GMT* executables (including supplements), the netCDF DLL, the crude, low, and intermediate GSHHS coastlines, the example batch scripts and data, and all documentation in HTML format.

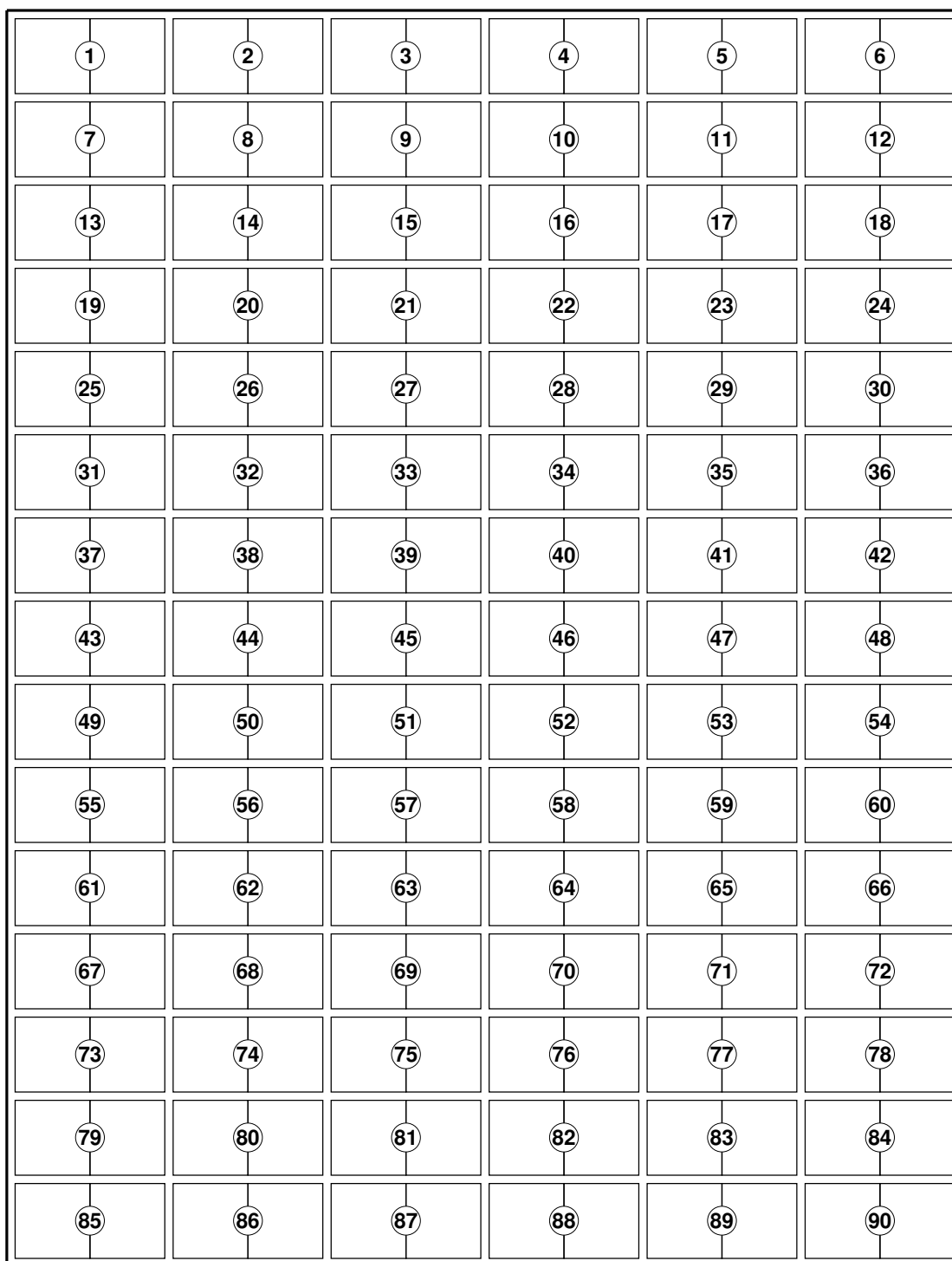
GMT_PDF_install.exe Installer for the optional *GMT* documentation in PDF format.

GSHHS_fullhigh_install.exe Installer for the optional full- and high-resolution GSHHS coastlines.

¹<http://www.bzip.org>

E. Predefined bit and hachure patterns in GMT

GMT provides 90 different bit and hachure patterns that can be selected with the **-Gp** or **-GP** option in most plotting programs. The left side of each image was created using **-Gp**, the right side shows the inverted version using **-GP**. These patterns are reproduced below at 300 dpi.



F. Chart of octal codes for characters

The characters and their octal codes in the Standard and ISOLatin1 encoded fonts are shown in Figure F.1. Dark gray areas signify codes reserved for control characters. In order to use all the extended characters (shown in the light gray boxes) you need to set **CHAR_ENCODING** to Standard+ or ISOLatin1+ in your `.gmtdefaults4` file¹.

Standard+									ISOLatin+								
octal	0	1	2	3	4	5	6	7	octal	0	1	2	3	4	5	6	7
\03x		¾	³	™	²	ý	ÿ	ž	\03x		•	…	™	—	–	fi	ž
\04x		!	"	#	\$	%	&	'	\04x		!	"	#	\$	%	&	'
\05x	()	*	+	,	-	·	/	\05x	()	*	+	,	-	·	/
\06x	0	1	2	3	4	5	6	7	\06x	0	1	2	3	4	5	6	7
\07x	8	9	:	;	<	=	>	?	\07x	8	9	:	;	<	=	>	?
\10x	@	A	B	C	D	E	F	G	\10x	@	A	B	C	D	E	F	G
\11x	H	I	J	K	L	M	N	O	\11x	H	I	J	K	L	M	N	O
\12x	P	Q	R	S	T	U	V	W	\12x	P	Q	R	S	T	U	V	W
\13x	X	Y	Z	[\]	^	–	\13x	X	Y	Z	[\]	^	–
\14x	‘	a	b	c	d	e	f	g	\14x	‘	a	b	c	d	e	f	g
\15x	h	i	j	k	l	m	n	o	\15x	h	i	j	k	l	m	n	o
\16x	p	q	r	s	t	u	v	w	\16x	p	q	r	s	t	u	v	w
\17x	x	y	z	{		}	~	f	\17x	x	y	z	{		}	~	š
\20x	Ã	Ç	Ð	Ł	Ñ	Õ	Š	Þ	\20x	Œ	†	‡	Ł	/	<	Š	>
\21x	Ý	ÿ	Ž	ã	ı	ç	©	°	\21x	œ	ÿ	Ž	ı	‰	”	“	”
\22x	÷	ð	ı	ı	–	μ	×	ñ	\22x	ı	`	´	^	~	-	˘	˙
\23x	½	¼	ı	õ	±	®	š	þ	\23x	”	,	°	˘	’	˘	˙	˚
\24x		ı	¢	£	/	¥	f	\$	\24x		ı	¢	£	¤	¥	ı	\$
\25x	¤	’	“	«	<	>	fi	fl	\25x	”	©	ª	«	¬	-	®	–
\26x	Á	–	‡	‡	·	Â	¶	•	\26x	°	±	²	³	´	μ	¶	·
\27x	,	”	”	»	…	‰	Ä	ı	\27x	˘	ı	°	»	¼	½	¾	ı
\30x	À	˘	˘	˘	˘	˘	˘	˘	\30x	À	Á	Â	Ã	Ä	Å	Æ	Ç
\31x	”	É	°	˘	Ê	˘	˘	˘	\31x	È	É	Ê	Ë	Ì	Í	Î	Ï
\32x	—	Ë	È	Í	Î	Ï	Ì	Ó	\32x	Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×
\33x	Ô	Ö	Ò	Ú	Û	Ü	Ù	á	\33x	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß
\34x	â	Æ	ä	ª	à	é	ê	ë	\34x	à	á	â	ã	ä	å	æ	ç
\35x	è	Ø	Œ	°	í	î	ï	ì	\35x	è	é	ê	ë	ì	í	î	ï
\36x	ó	æ	ô	õ	ò	ı	ú	û	\36x	ð	ñ	ò	ó	ô	õ	ö	÷
\37x	ü	ø	œ	ß	ù	À	á	ÿ	\37x	ø	ù	ú	û	ü	ý	þ	ÿ

Figure F.1: Octal codes and corresponding symbols for StandardEncoding (left) and ISOLatin1Encoding (right) fonts.

¹ If you chose SI units during the installation then the default encoding is ISOLatin1+, otherwise it is Standard+.

The chart for the Symbol character set (*GMT* font number 12) and Pifont ZapfDingbats character set (font number 34) are presented in Figure F.2 below. The octal code is obtained by appending the column value to the \?? value, e.g., ∂ is \266 in the Symbol font. The euro currency symbol is \240 in the Symbol font and will print if your printer supports it (older printer's firmware will not know about the euro).

Symbol

octal	0	1	2	3	4	5	6	7
\04x		!	∀	#	∃	%	&	∞
\05x	()	*	+	,	-	.	/
\06x	0	1	2	3	4	5	6	7
\07x	8	9	:	;	<	=	>	?
\10x	≡	A	B	X	Δ	E	Φ	Γ
\11x	H	I	∅	K	Λ	M	N	O
\12x	Π	Θ	P	Σ	T	Y	ζ	Ω
\13x	Ξ	Ψ	Z	[∴]	⊥	-
\14x	—	α	β	χ	δ	ε	φ	γ
\15x	η	ι	φ	κ	λ	μ	ν	ο
\16x	π	θ	ρ	σ	τ	υ	ϖ	ω
\17x	ξ	ψ	ζ	{		}	~	
\24x	€	Υ	'	≤	/	∞	f	♣
\25x	♦	♥	♠	↔	←	↑	→	↓
\26x	°	±	″	≥	×	∞	∂	•
\27x	÷	≠	≡	≈	...		—	⌋
\30x	ℵ	ℑ	℔	℘	⊗	⊕	∅	∩
\31x	∪	⊃	⊇	⊄	⊂	⊆	∈	∉
\32x	∠	∇	®	©	™	Π	√	·
\33x	¬	^	∨	↔	⇐	↑	⇒	↓
\34x	∅	⟨	®	©	™	Σ	(
\35x	(⌈		⌊	⌈	{	⌋	
\36x		⟩	⌋	⌈		⌋	⌋	
\37x	⌋	⌋		⌋	⌋	⌋	⌋	

ZapfDingbats

octal	0	1	2	3	4	5	6	7
\04x		✂	✂	✂	✂	✂	✂	✂
\05x	✂	✂	✂	✂	✂	✂	✂	✂
\06x	✂	✂	✂	✓	✓	✗	✗	✗
\07x	✗	✗	✗	✗	✗	✗	✗	✗
\10x	✗	✗	✗	✗	✗	✗	✗	✗
\11x	★	☆	☼	☆	★	★	★	★
\12x	☆	✱	✱	✱	✱	✱	✱	✱
\13x	✱	✱	✱	✱	✱	✱	✱	✱
\14x	✱	✱	✱	✱	✱	✱	✱	✱
\15x	✱	✱	✱	✱	●	○	■	□
\16x	□	□	□	▲	▼	◆	◇	◐
\17x				‘	’	“	”	
\24x		♠	♠	♠	♥	♥	♥	♥
\25x	♣	♦	♥	♠	①	②	③	④
\26x	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫
\27x	⑬	⑭	⑮	⑯	⑰	⑱	⑲	⑳
\30x	①	②	③	④	⑤	⑥	⑦	⑧
\31x	⑨	⑩	⑪	⑫	⑬	⑭	⑮	⑯
\32x	⑰	⑱	⑲	⑳	→	→	↔	↕
\33x	↖	→	↗	→	→	→	→	→
\34x	→	→	→	→	→	→	→	→
\35x	→	→	→	→	→	→	→	→
\36x		→	→	→	→	→	→	→
\37x	→	→	→	→	→	→	→	

Figure F.2: Octal codes and corresponding symbols for Symbol (left) and ZapfDingbats (right) fonts.

***G. PostScript* fonts used by GMT**

GMT uses the standard 35 fonts that come with most *PostScript* laserwriters. If your printer does not support some of these fonts, it will automatically substitute the default font (which is usually Courier). The following is a list of the *GMT* fonts:

#	Font Name	#	Font Name
0	Helvetica	17	Bookman-Demi
1	Helvetica-Bold	18	Bookman-DemiItalic
2	<i>Helvetica-Oblique</i>	19	Bookman-Light
3	Helvetica-BoldOblique	20	<i>Bookman-LightItalic</i>
4	Times-Roman	21	Helvetica-Narrow
5	Times-Bold	22	Helvetica-Narrow-Bold
6	<i>Times-Italic</i>	23	<i>Helvetica-Narrow-Oblique</i>
7	Times-BoldItalic	24	Helvetica-Narrow-BoldOblique
8	Courier	25	NewCenturySchlbk-Roman
9	Courier-Bold	26	<i>NewCenturySchlbk-Italic</i>
10	<i>Courier-Oblique</i>	27	NewCenturySchlbk-Bold
11	Courier-BoldOblique	28	NewCenturySchlbk-BoldItalic
12	Σμβολ (Symbol)	29	Palatino-Roman
13	AvantGarde-Book	30	<i>Palatino-Italic</i>
14	<i>AvantGarde-BookOblique</i>	31	Palatino-Bold
15	AvantGarde-Demi	32	Palatino-BoldItalic
16	AvantGarde-DemiOblique	33	<i>ZapfChancery-MediumItalic</i>
		34	⌘ ☐ ☒ ☓ ☔ ☕ ☖ ☗ ☘ ☙ ☚ ☛ ☜ ☝ ☞ ☟ ☠ ☡ ☢ ☣ ☤ ☥ ☦ ☧ ☨ ☩ ☪ ☫ ☬ ☭ ☮ ☯ ☰ ☱ ☲ ☳ ☴ ☵ ☶ ☷ ☸ ☹ ☺ ☻ ☼ ☽ ☿ ♀ ♂ ♁ ♃ ♄ ♅ ♆ ♇ ♈ ♉ ♊ ♋ ♌ ♍ ♎ ♏ ♐ ♑ ♒ ♓ ♀ ♂ ♁ ♃ ♄ ♅ ♆ ♇ ♈ ♉ ♊ ♋ ♌ ♍ ♎ ♏ ♐ ♑ ♒ ♓ (ZapfDingbats)

Figure G.1: The standard 35 *PostScript* fonts recognized by **GMT**.

For the special fonts Symbol (12) and ZapfDingbats (34), see the octal charts in Appendix F. When specifying fonts in *GMT*, you can either give the entire font name *or* just the font number listed in this table. To change the fonts used in plotting basemap frames, see the man page for **gmtdefaults**. For direct plotting of text-strings, see the man page for **pstext**. To add additional fonts that you may have purchased or that are available at your institution, see instructions in the CUSTOM_font_info.d under the share/pslib directory.

H. Problems with display of GMT *PostScript*

GMT creates valid (so far as we know) Adobe *PostScript* Level 1. It does not use operators specific to Level 2 and should therefore produce output that will print on old as well as new *PostScript* printers¹. Sometimes unexpected things happen when *GMT* output is sent to certain printers or displays. This section lists some things we have learned from experience, and some work-arounds. Note that many of these lessons are now rather old so hopefully these workarounds no longer apply to anybody...

H.1 *PostScript* driver bugs

When you try to display a *PostScript* file on a device, such as a printer or your screen, then a program called a *PostScript* device driver has to compute which device pixels should receive which colors (black or white in the case of a simple laser printer) in order to display the file. At this stage, certain device-dependent things may happen. These are not limitations of *GMT* or *PostScript*, but of the particular display device. The following bugs are known to us based on our experiences:

1. Early versions of the Sun SPARCprinter software caused linewidth-dependent path displacement. We reported this bug and it has been fixed in newer versions of the software. Try using **psxy** to draw $y = f(x)$ twice, once with a thin pen (**-W1**) and once with a fat pen (**-W10**); if they do not plot on top of each other, you have this kind of bug and need new software. The problem may also show up when you plot a mixture of solid and dashed (or dotted) lines of various pen thickness
2. The first version of the HP Laserjet 4M (prior to Aug-93) had bugs in the driver program. The old one was *PostScript* SIMM, part number C2080-60001; the new one is called *PostScript* SIMM, part number C2080-60002. You need to get this one plugged into your printer if you have an HP LaserJet 4M.
3. Apple Laserwriters with the older versions of Apple's *PostScript* driver will give the error "limitcheck" and fail to plot when they encounter a path exceeding about 1000–1500 points. Try to get a newer driver from Apple, but if you can't do that, set the parameter `MAX_L1_PATH` to 1000–1500 or even smaller in the file `src/pslib_inc.h` and recompile *GMT*. The number of points in a *PostScript* path can be arbitrarily large, in principle; *GMT* will only create paths longer than `MAX_L1_PATH` if the path represents a filled polygon or clipping path. Line-drawings (no fill) will be split so that no segment exceeds `MAX_L1_PATH`. This means **psxy -G** will issue a warning when you plot a polygon with more than `MAX_L1_PATH` points in it. It is then your responsibility to split the large polygon into several smaller segments. If **pscoast** gives such warnings and the file fails to plot you may have to select one of the lower resolution databases. The path limitation exemplified by these Apple printers is what makes the higher-resolution coastlines for **pscoast** non-trivial: such coastlines have to be organized so that fill operations do not generate excessively large paths. Some HP *PostScript* cartridges for the Laserjet III also have trouble with paths exceeding 1500 points; they may successfully print the file, but it can take all night!
4. 8-bit color screen displays (and programs which use only 8-bits, even on 24-bit monitors, such as Sun's **pageview** under OpenWindows) may not dither cleverly, and so the color they show you may not resemble the color your *PostScript* file is asking for. Therefore, if you choose colors you like on the screen, you may be surprised to find that your plot looks different on the hardcopy printer or film writer. The only thing you can do is be aware of this, and make some test cases on your hardcopy devices and compare them with the screen, until you get used to this effect. (Each hardcopy device is also a little different, and so you will eventually find that you want to tune your color choices for each device.) The rgb color cube in example 11 may help.
5. Some versions of Sun's OpenWindows program **pageview** have only a limited number of colors available; the number can be increased somewhat by starting **openwin** with the option "`openwin -cubsize large`".

¹ Note, however, that the **-Q** option in **grdimage** will exercise a *PostScript* Level 3 feature called colormasking.

6. Finally, **pageview** seem to have problems understanding the `setpagedevice` operator. We recommend you only use **pageview** on EPS files or use **ghostview** instead.
7. Many color hardcopy devices use CMYK color systems. *GMT PostScript* uses RGB (even if your cpt files are using HSV). The three coordinates of RGB space can be mapped into three coordinates in CMY space, and in theory K (black) is superfluous. But it is hard to get CMY inks to mix into a good black or gray, so these printers supply a black ink as well, hence CMYK. The *PostScript* driver for a CMYK printer should be smart enough to compute what portion of CMY can be drawn in K, and use K for this and remove it from CMY; however, some of them aren't.
8. In early releases of *GMT* we always used the *PostScript* command `r g b setrgbcolor` to specify colors, even if the color happened to be a shade of gray ($r = g = b$) or black ($r = g = b = 0$). One of our users found that black came out muddy brown when he used **FreedomOfPress** to make a Versatec plot of a *GMT* map. He found that if he used the *PostScript* command `g setgray` (where g is a graylevel) then the problem went away. Apparently, his installation of **FreedomOfPress** uses only CMY with the command `setrgbcolor`, and so `0 0 0 setrgbcolor` tries to make black out of CMY instead of K. To fix this, in release 2.1 of *GMT* we changed some routines in `pslib.c` to check if ($r = g$ and $r = b$), in which case `g setgray` is used instead of `r g b setrgbcolor`.
9. Recent experience with some Tektronix Phaser printers and with commercial printing shops has shown that this substitution creates problems precisely opposite of the problems our Versatec user has. The Tektronix and commercial (we think it was a Scitex) machines do not use K when you say `0 setgray` but they do when you say `0 0 0 setrgbcolor`. We believe that these problems are likely to disappear as the various software developers make their codes more robust. Note that this is not a fault with *GMT*: $r = g = b = 0$ means black and should plot that way. Thus, the *GMT* source code as shipped to you checks whether $r = g$ and $r = b$, in which case it uses `setgray`, else `setrgbcolor`. If your gray tones are not being drawn with K, you have two work-around options: (1) edit the source for `pslib.c` or (2) edit your *PostScript* file and try using `setrgbcolor` in all cases. The simplest way to do so is to redefine the `setgray` operator to use `setrgbcolor`. Insert the line

`/setgray {dup dup setrgbcolor} def`

immediately following the first line in the file (starts with `%!PS.`)
10. Some color film writers are very sensitive to the brand of film. If black doesn't look black on your color slides, try a different film.

H.2 Resolution and dots per inch

The parameter **DOTS_PR_INCH** can be set by the user through the `.gmtdefaults4` file or **gmtset**. By default it is equal to the value in the `gmt.defaults.h` file, which is supplied with 300 when you get *GMT* from us. This seems a good size for most applications, but should ideally reflect the resolution of your hardcopy device (most laserwriters have at least 300 dpi, hence our default value). *GMT* computes what the plot should look like in double precision floating point coordinates, and then converts these to integer coordinates at **DOTS_PR_INCH** resolution. This helps us find out that certain points in a path lie on top of other points, and we can remove these, making smaller paths. Small paths are important for the laserwriter bugs above, and also to make fill operations compute faster. Some users have set their **DOTS_PR_INCH** to very large numbers. This only makes the *PostScript* output bigger without affecting the appearance of the plot. However, if you want to make a plot which fits on a page at first, and then later magnify this same *PostScript* file to a huge size, the higher DPI is important. Your data may not have the higher resolution but on certain devices the edges of fonts will not look crisp if they are not drawn with an effective resolution of 300 dpi or so. Beware of making an excessively large path. Note that if you change dpi the linewidths produced by your **-W** options will change, unless you have appended **p** for linewidth in points.

H.3 European characters

Note for users of **pageview** in Sun OpenWindows: *GMT* now offers some octal escape sequences to load European alphabet characters in text strings (see Section 4.16). When this feature is enabled, the header on *GMT PostScript* output includes a section defining special fonts. The definition is added to the header whether or not your plot actually uses the fonts.

Users who view their *GMT PostScript* output using **pageview** in OpenWindows on Sun computers or user older laserwriters may have difficulties with the European font definition. If your installation of OpenWindows followed a space-saving suggestion of Sun, you may have excluded the European fonts, in which case **pageview** will fail to render your plot.

Ask your system administrator about this, or run this simple test: (1) View a *GMT PostScript* file with **pageview**. If it comes up OK, you will be fine. If it comes up blank, open the “Edit PostScript” button and examine the lower window for error messages. (The European font problem generates lots of error messages in this window). (2) Verify that the *PostScript* file is OK, by sending it to a laserwriter and making sure it comes out. (3) If the *PostScript* file is OK but it chokes **pageview**, then edit the *PostScript* file, cutting out everything between the lines:

```
%%%%%%%% START OF EUROPEAN FONT DEFINITION %%%%%%%%%
<bunch of definitions>
%%%%%%%% END OF EUROPEAN FONT DEFINITION %%%%%%%%%
```

Now try **pageview** on the edited version. If it now comes up, you have a limited subset of OpenWindows installed. If you discover that these fonts cause you trouble, then you can edit your `.gmtdefaults4` file to set **CHAR_ENCODING** = Standard, which will suppress the printing of this definition in the *GMT PostScript* header. You can make output which will be viewable in **pageview** without any editing. However, you would have to reset this to TRUE before attempting to use European fonts, and then the output will become un-**pageview**-able again. If you try to concatenate segments of *GMT PostScript* made with and without the European fonts enabled, then you may find that you have problems, either with the definition, or because you ask for something not defined.

H.4 Hints

When making images and perspective views of large amounts of data, the *GMT* programs can take some time to run, the resulting *PostScript* files can be very large, and the time to display the plot can be long. Fine tuning a plot script can take lots of trial and error. We recommend using **grdsample** to make a low resolution version of the data files you are plotting, and practice with that, so it is faster; when the script is perfect, use the full-resolution data files. We often begin building a script using only **psbasemap** or **pscoast** to get the various plots oriented correctly on the page; once this works we replace the **psbasemap** calls with the actually desired *GMT* programs.

If you want to make color shaded relief images and you haven’t had much experience with it, here is a good first cut at the problem: Set your **COLOR_MODEL** to HSV using **gmtset**. Use **makecpt** or **grd2cpt** to make a continuous color palette spanning the range of your data. Use the **-Nt** option on **grdgradient**. Try the result, and then play with the tuning of the `.gmtdefaults4`, the `cpt` file, and the gradient file.

I. Color Space: The final frontier

In this Appendix, we are going to try to explain the relationship between the RGB, CMYK, and HSV color systems so as to (hopefully) make them more intuitive. *GMT* allows users to specify colors in cpt files in either of these three systems. Interpolation between colors is performed in either RGB or HSV, depending on the specification in the cpt file. Below, we will explain why this all matters.

I.1 RGB color system

Remember your (parents') first color television set? Likely it had three little bright colored squares on it: red, green, and blue. And that is exactly what each color on the tube is made of: varying levels of red, green and blue light. Switch all of them off, $r = g = b = 0$, then you have black. All of them at maximum, $r = g = b = 255$, creates white. Your computer screen works the same way.

A mix of levels of red, green, and blue creates basically any color imaginable. In *GMT* each color can be represented by the triplet $r/g/b$. For example, 127/255/0 (half red, full green, and no blue) creates a color called chartreuse. The color sliders in the graphics program **GIMP** are an excellent way to experiment with colors, since they show you in advance how moving one of the color sliders will change the color. As Figure I.1a shows: increase the red and you will get a more yellow color, while lowering the blue level will turn it into brown.

Is chocolate your favorite color, but you do not know the RGB equivalent values? Then look them up in Figure I.2 or type **man gmtcolors** for a full list. It's 210/105/30. But *GMT* makes it easy on you: you can specify pen, fill, and palette colors by any of the more than 500 unique colors found in that file.

Are you very web-savvy and work best with hexadecimal color codes as they are used in HTML? Even that is allowed in *GMT*. Just start with a hash mark (#) and follow with the 2 hexadecimal characters for red, green, and blue. For example, you can use #79ff00 for chartreuse, #D2691E for chocolate.

I.2 HSV color system

If you have played around with RGB color sliders, you will have noticed that it is not intuitive to make a chosen color lighter or darker, more saturated or more gray. It would involve changing three sliders. To make it easier to manipulate colors in terms of lightness and saturation, another coordinate system was invented: HSV (hue, saturation, value). Those terms can be made clear best by looking at the color sliders in Figure I.1a. Hue (running from 0° to 360°) gives you the full spectrum of saturated colors. Saturation (from 0 to 1, or 100%) tells you how 'full' your color is: reduce it to zero and you only have gray scales. Value (from 0 to 1, or 100%) will bring you from black to a fully saturated color. Note that "value" is not the same as "intensity", or "lightness", used in other color geometries. "Brilliance" may be the best

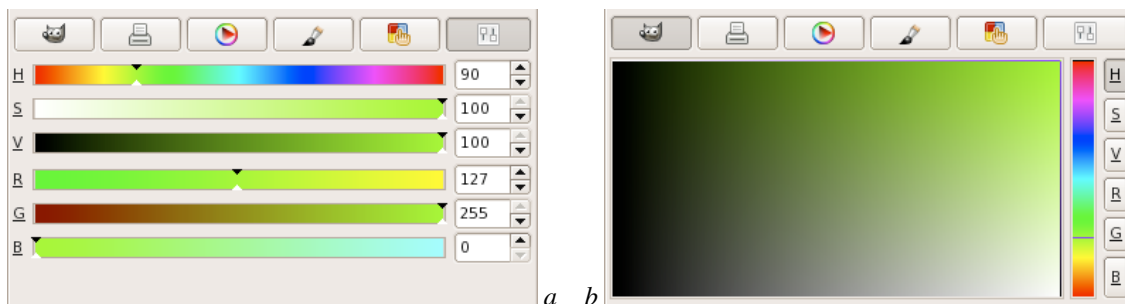


Figure I.1: Chartreuse in **GIMP**. (a) Sliders indicate how the color is altered when changing the H, S, V, R, G, or B levels. (b) For a constant hue (here 90°) value increases to the right and saturation increases up, so the "pure" color is on the top right.

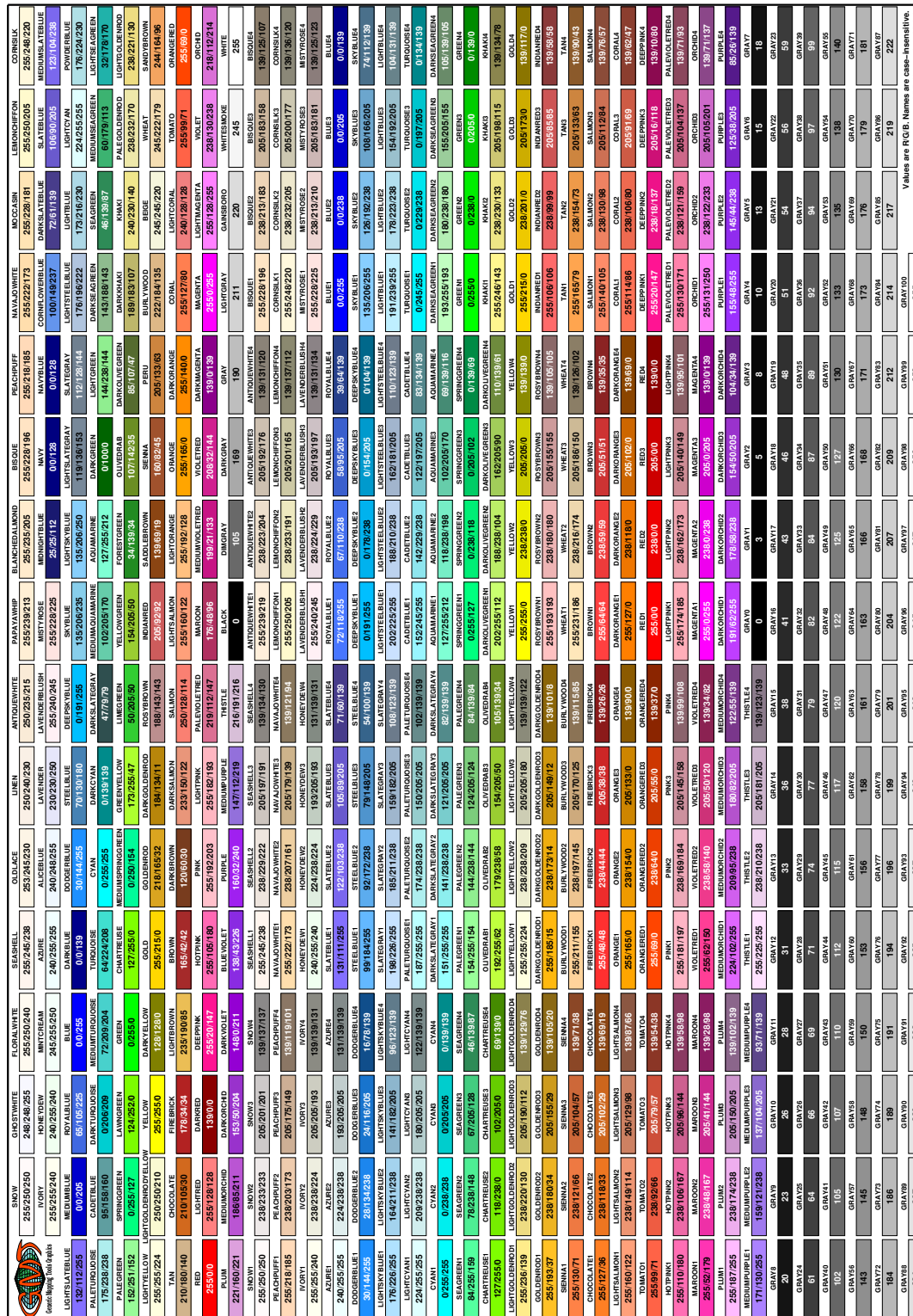


Figure I.2: The 555 unique color names that can be used in GMT. Lower, upper, or mixed case, as well as the british spelling of “grey” are allowed. A4, Letter, and Tabloid sized versions of this RGB chart can be found in the GMT documentation directory.

alternative word to describe “value”. Apple calls it as “brightness”, and hence refers to HSB for this color space.

Want more chartreuse or chocolate? You can specify them in *GMT* as 90-1-1 and 25-0.86-0.82, respectively.

I.3 The color cube

We are going to try to give you a geometric picture of color mixing in RGB and HSV by means of a tour of the RGB cube depicted in Figure 7.11. The geometric picture is most helpful, we think, since HSV are not orthogonal coordinates and not found from RGB by a simple algebraic transformation. So here goes: Look at the cube face with black, red, magenta, and blue corners. This is the $g = 0$ face. Orient the cube so that you are looking at this face with black in the lower left corner. Now imagine a right-handed cartesian (r, g, b) coordinate system with origin at the black point; you are looking at the $g = 0$ plane with r increasing to your right, g increasing away from you, and b increasing up. Keep this sense of (r, g, b) as you look at the cube.

Now tip the cube such that the black corner faces down and the white corner up. When looking from the top, you can see the hue, contoured in gray solid lines, running around in 360° counter-clockwise. It starts with shades of red (0°), then goes through green (120°) and blue (240°), back to red.

On the three faces that are now on the lower side (with the white print) one of (r, g, b) is equal to 0. These three faces meet at the black corner, where $r = g = b = 0$. On these three faces the colors are fully saturated: $s = 1$. The dashed white lines indicate different levels of v , ranging from 0 to 1 with contours every 0.1.

On the upper three faces (with the black print), one of (r, g, b) is equal to the maximum value. These three faces meet at the white corner, where $r = g = b = 255$. On these three faces value is at its maximum: $v = 1$ (or 100%). The dashed black lines indicate varying levels of saturation: s ranges from 0 to 1 with contours every 0.1.

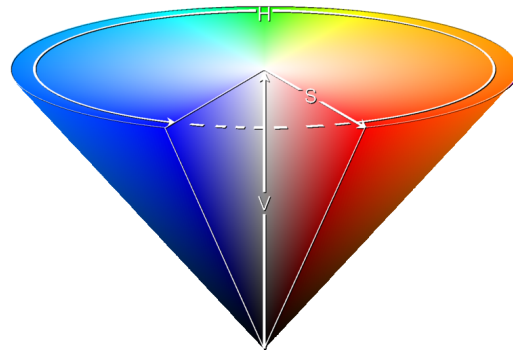
Now turn the cube around on its vertical axis (running from the black to the white corner). Along the six edges that zigzag around the “equator”, both saturation and value are maximum, so $s = v = 1$. Twirling the cube around and tracing the zigzag, you will visit six of the eight corners of the cube, with changing hue (h): red (0°), yellow (60°), green (120°), cyan (180°), blue (240°), and magenta (300°). Three of these are the RGB colors; the other three are the CMY colors which are the complement of RGB and are used in many color hardcopy devices (see below). The only cube corners you did not visit on this path are the black and white corners. They lie on the vertical axis where hue is undefined and $r = g = b$. Any point on this axis is a shade of gray.

Let us call the points where $s = v = 1$ (points along the RYGBM path described above) the “pure” colors. If we start at a pure color and we want to whiten it, we can keep h constant and $v = 1$ while decreasing s ; this will move us along one of the cube faces toward the white point. If we start at a pure color and we want to blacken it, we can keep h constant and $s = 1$ while decreasing v ; this will move us along one of the cube faces toward the black point. Any point in (r, g, b) space which can be thought of as a mixture of pure color + white, or pure color + black, is on a face of the cube.

The points in the interior of the cube are a little harder to describe. The definition for h above works at all points in (non-gray) (r, g, b) space, but so far we have only looked at (s, v) on the cube faces, not inside it. At interior points, none of (r, g, b) is equal to either 0 or 255. Choose such a point, not on the gray axis. Now draw a line through your point so that the line intersects the gray axis and also intersects the RYGBM path of edges somewhere. It is always possible to construct this line, and all points on this line have the same hue. This construction shows that any point in RGB space can be thought of as a mixture of a pure color plus a shade of gray. If we move along this line away from the gray axis toward the pure color, we are “purifying” the color by “removing gray”; this move increases the color’s saturation. When we get to the point where we cannot remove any more gray, at least one of (r, g, b) will have become zero and the color is now fully saturated; $s = 1$. Conversely, any point on the gray axis is completely undersaturated, so that $s = 0$ there. Now we see that the black point is special, s is both 0 and 1 at the same time. In other words, at the black point saturation is undefined (and so is hue). The convention is to use $h = s = v = 0$ at this point.

It remains to define value. To do so, try this: Take your point in RGB space and construct a line through it so that this line goes through the black point; produce this line from black past your point until it hits a face on which $v = 1$. All points on this line have the same hue. Note that this line and the line we made in the previous paragraph are both contained in the plane whose hue is constant. These two lines meet at some arbitrary angle which varies depending on which point you chose. Thus HSV is not an orthogonal coordinate system. If the line you made in the previous paragraph happened to touch the gray axis at the black point, then these two lines are the same line, which is why the black point is special. Now, the line we made in this paragraph illustrates the following: If your chosen point is not already at the end of the line, where $v = 1$, then it is possible to move along the line in that direction so as to increase (r, g, b) while keeping the same hue. The effect this has on a color monitor is to make the color more “brilliant”, your hue will become “stronger”; if you are already on a plane where at least one of $(r, g, b) = 255$, then you cannot get a stronger version of the same hue. Thus, v measures brilliance or strength. Note that it is not quite true to say that v measures distance away from the black point, because v is not equal to $\sqrt{r^2 + g^2 + b^2}/255$.

Another representation of the HSV space is the color cone illustrated in Figure I.3.



“Pure” colors are around the edge of the circular surface at the top. Hue runs counter-clockwise. Saturation decreases to the center. Value increases from zero (black) at the bottom to 1 at the top. Gray shades are along the vertical axis.

Figure I.3: The HSV color space.

I.4 Color interpolation

From studying the RGB cube, we hope you will have understood that there are different routes to follow between two colors, depending whether you are in the RGB or HSV system. Suppose you would make an interpolation between blue and red. In the RGB system you would follow a path diagonally across a face of the cube, from 0/0/255 (blue) via 127/0/127 (purple) to 255/0/0 (red). In the HSV system, you would trace two edges, from 240-1-1 (blue) via 300-1-1 (magenta) to 360-1-1 (red). That is even assuming software would be smart enough to go the shorter route. More likely, red will be recorded as 0-1-1, so hue will be interpolated the other way around, reducing hue from 240° to 0°, via cyan, green, and yellow.

Depending on the design of your color palette, you may want to have it either way. By default, *GMT* interpolates in RGB space, even when the original color palette is in the HSV system. However, when you add the line `#COLOR_MODEL=+HSV` (with the leading ‘+’ sign) in the header of the color palette file, *GMT* will not only read the color representation as HSV values, but also interpolate colors in the HSV system. That means that H, S, and V values are interpolated linearly between two colors, instead of their respective R, G, and B values.

The top row in Figure I.4 illustrates two examples: a blue-white-red scale (the polar palette in Appendix M) interpolated in RGB and the rainbow palette interpolated in HSV. The bottom row of the Figure demonstrates how things can go terribly wrong when you do the interpolation in the other system.

I.5 Artificial illumination

GMT uses the HSV system to achieve artificial illumination of colored images (e.g. `-I` option in **grdimage**) by changing the saturation s and value v coordinates of the color. When the intensity is zero (flat

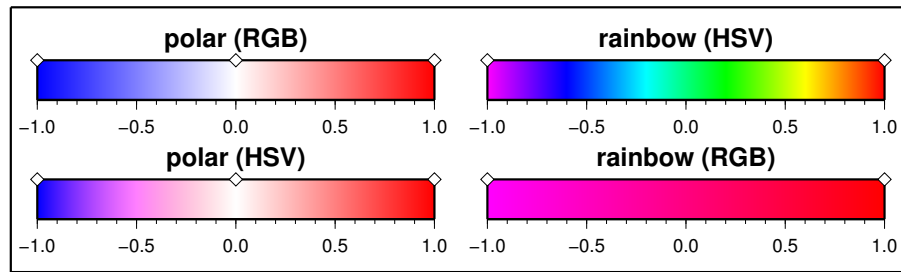


Figure I.4: When interpolating colors, the color system matters. The polar palette on the left needs to be interpolated in RGB, otherwise hue will change between blue (240°) and white (0°). The rainbow palette should be interpolated in HSV, since only hue should change between magenta (300°) and red (0°). Diamonds indicate which colors are defined in the palettes; they are fixed, the rest is interpolated.

illumination), the data are colored according to the cpt file. If the intensity is non-zero, the color is either lightened or darkened depending on the illumination. The color is first converted to HSV (if necessary) and then darkened by moving (s,v) toward **(HSV_MIN_SATURATION, HSV_MIN_VALUE)** if the intensity is negative, or lightened by sliding (s,v) toward **(HSV_MAX_SATURATION, HSV_MAX_VALUE)** if the illumination is positive. The extremes of the s and v are defined in the .gmtdefaults4 file and are usually chosen so the corresponding points are nearly black ($s = 1, v = 0$) and white ($s = 0, v = 1$). The reason this works is that the HSV system allows movements in color space which correspond more closely to what we mean by “tint” and “shade”; an instruction like “add white” is easy in HSV and not so obvious in RGB.

I.6 Thinking in RGB or HSV

The RGB system is understandable because it is cartesian, and we all learned cartesian coordinates in school. But it doesn’t help us create a tint or shade of a color; we cannot say, “We want orange, and a lighter shade of orange, or a less vivid orange”. With HSV we can do this, by saying, “Orange must be between red and yellow, so its hue is about $h = 30^\circ$; a less vivid orange has a lesser s , a darker orange has a lesser v ”. On the other hand, the HSV system is a peculiar geometric construction, more like a cone (Figure I.3). It is not an orthogonal coordinate system, and it is not found by a matrix transformation of RGB; these make it difficult in some cases too. Note that a move toward black or a move toward white will change both s and v , in the general case of an interior point in the cube. The HSV system also doesn’t behave well for very dark colors, where the gray point is near black and the two lines we constructed above are almost parallel. If you are trying to create nice colors for drawing chocolates, for example, you may be better off guessing in RGB coordinates.

I.7 CMYK color system

Finally, you can imagine that printers work in a different way: they mix different paints to make a color. The more paint, the darker the color, which is the reverse of adding more light. Also, mixing more colored paints does not give you true black, so that means that you really need four colors to do it right. Open up your color printer and you’ll probably find four cartridges: cyan, magenta, yellow (often these are combined into one), and black. They form the CMYK system of colors, each value running from 0 to 1 (or 100%). In GMT CMYK color coding can be achieved using *c/m/y/k* quadruplets.

Obviously, there is no unique way to go from the 3-dimensional RGB system to the 4-dimensional CMYK system. So, again, there is a lot of hand waving applied in the transformation. Strikingly, CMYK actually covers a smaller color space than RGB. We will not try to explain you the details behind it, just know that there is a transformation needed to go from the colors on your screen to the colors on your printer. It might explain why what you see is not necessarily what you get. If you are really concerned about how your color plots will show up in your PhD thesis, for example, it might be worth trying to save

and print all your color plots using the CMYK system. Letting *GMT* do the conversion to CMYK may avoid some nasty surprises when it comes down to printing. To specify the color space of your *PostScript* file, set **PS_COLOR** in the .gmtdefaults4 file to RGB, HSV, or CMYK.

J. Filtering of data in GMT

The *GMT* programs **filter1d** (for tables of data indexed to one independent variable) and **grdfilter** (for data given as 2-dimensional grids) allow filtering of data by a moving-window process. (To filter a grid by Fourier transform use **grdfft**.) Both programs use an argument **-F<type><width>** to specify the type of process and the window's width (in 1-d) or diameter (in 2-d). (In **filter1d** the width is a length of the time or space ordinate axis, while in **grdfilter** it is the diameter of a circular area whose distance unit is related to the grid mesh via the **-D** option). If the process is a median, mode, or extreme value estimator then the window output cannot be written as a convolution and the filtering operation is not a linear operator. If the process is a weighted average, as in the boxcar, cosine, and gaussian filter types, then linear operator theory applies to the filtering process. These three filters can be described as convolutions with an impulse response function, and their transfer functions can be used to describe how they alter components in the input as a function of wavelength.

Impulse responses are shown here for the boxcar, cosine, and gaussian filters. Only the relative amplitudes of the filter weights shown; the values in the center of the window have been fixed equal to 1 for ease of plotting. In this way the same graph can serve to illustrate both the 1-d and 2-d impulse responses; in the 2-d case this plot is a diametrical cross-section through the filter weights (Figure J.1).

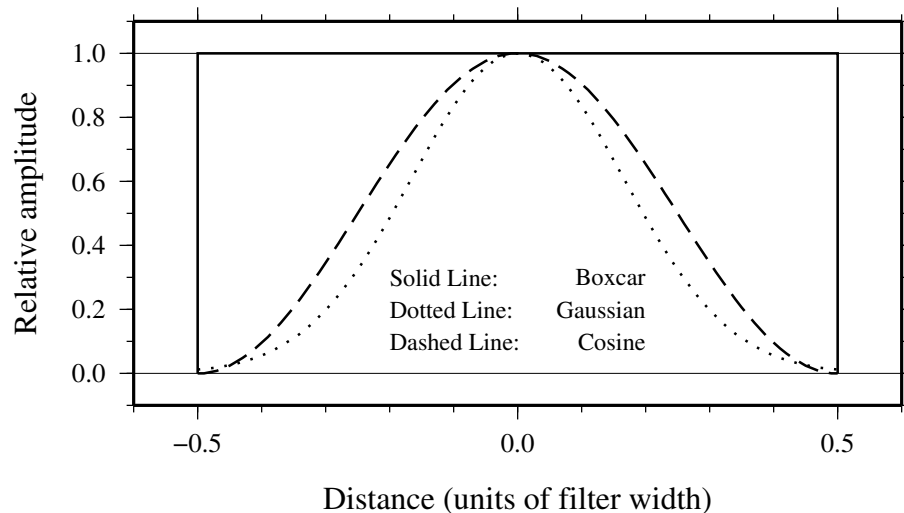
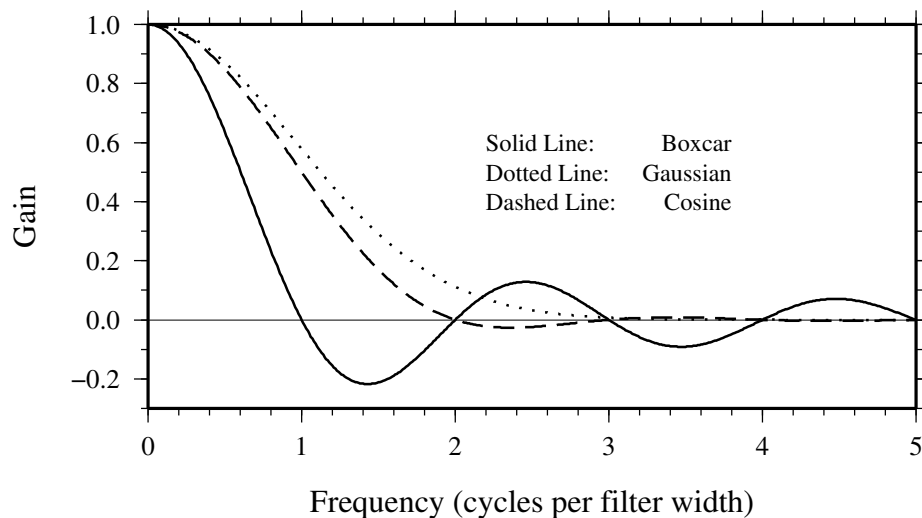
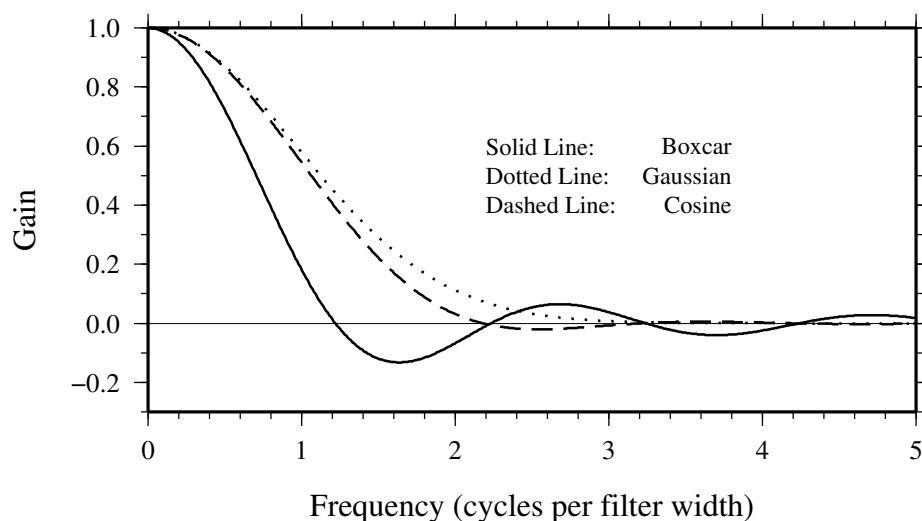


Figure J.1: Impulse responses for **GMT** filters.

Although the impulse responses look the same in 1-d and 2-d, this is not true of the transfer functions; in 1-d the transfer function is the Fourier transform of the impulse response, while in 2-d it is the Hankel transform of the impulse response. These are shown in Figures J.2 and J.3, respectively. Note that in 1-d the boxcar transfer function has its first zero crossing at $f = 1$, while in 2-d it is around $f \sim 1.2$. The 1-d cosine transfer function has its first zero crossing at $f = 2$; so a cosine filter needs to be twice as wide as a boxcar filter in order to zero the same lowest frequency. As a general rule, the cosine and gaussian filters are “better” in the sense that they do not have the “side lobes” (large-amplitude oscillations in the transfer function) that the boxcar filter has. However, they are correspondingly “worse” in the sense that they require more work (doubling the width to achieve the same cut-off wavelength).

Figure J.2: Transfer functions for 1-D **GMT** filters.

One of the nice things about the gaussian filter is that its transfer functions are the same in 1-d and 2-d. Another nice property is that it has no negative side lobes. There are many definitions of the gaussian filter in the literature (see page 7 of Bracewell¹). We define σ equal to 1/6 of the filter width, and the impulse response proportional to $\exp[-0.5(t/\sigma)^2]$. With this definition, the transfer function is $\exp[-2(\pi\sigma f)^2]$ and the wavelength at which the transfer function equals 0.5 is about 5.34σ , or about 0.89 of the filter width.

Figure J.3: Transfer functions for 2-D (radial) **GMT** filters.

¹R. Bracewell, *The Fourier Transform and its Applications*, McGraw-Hill, London, 444p., 1965.

K. The GMT High-Resolution Coastline Data

Starting with version 3.0, *GMT* use a completely new coastline database and the **pscoast** utility was been completely rewritten to handle the new file format. Many users have asked us why it has taken so long for *GMT* to use a high-resolution coastline database; after all, such data have been available in the public domain for years. To answer such questions we will take you along the road that starts with these public domain data sets and ends up with the database used by *GMT*.

K.1 Selecting the right data

There are two well-known public-domain data sets that could be used for this purpose. One is known as the World Data Bank II or CIA Data Bank (WDB) and contains coastlines, lakes, political boundaries, and rivers. The other, the World Vector Shoreline (WVS) only contains shorelines between saltwater and land (i.e., no lakes). It turns out that the WVS data is far superior to the WDB data as far as data quality goes, but as noted it lacks lakes, not to mention rivers and borders. We decided to use the WVS whenever possible and supplement it with WDB data. We got these data over the Internet; they are also available on CD-ROM from the National Geophysical Data Center in Boulder, Colorado¹.

K.2 Format required by GMT

In order to paint continents or oceans it is necessary that the coastline data be organized in polygons that may be filled. Simple line segments can be used to draw the coastline, but for painting polygons are required. Both the WVS and WDB data consists of unsorted line segments: there is no information included that tells you which segments belong to the same polygon (e.g., Australia should be one large polygon). In addition, polygons enclosing land must be differentiated from polygons enclosing lakes since they will need different paint. Finally, we want **pscoast** to be flexible enough that it can paint the land *or* the oceans *or* both. If just land (or oceans) is selected we do not want to paint those areas that are not land (or oceans) since previous plot programs may have drawn in those areas. Thus, we will need to combine polygons into new polygons that lend themselves to fill land (or oceans) only (Note that older versions of **pscoast** always painted lakes and wiped out whatever was plotted beneath).

K.3 The long and winding road

The WVS and WDB together represent more than 100 Mb of binary data and something like 20 million data points. Hence, it becomes obvious that any manipulation of these data must be automated. For instance, the reasonable requirement that no coastline should cross another coastline becomes a complicated processing step.

1. To begin, we first made sure that all data were “clean”, i.e. that there were no outliers and bad points. We had to write several programs to ensure data consistency and remove “spikes” and bad points from the raw data. Also, crossing segments were automatically “trimmed” provided only a few points had to be deleted. A few hundred more complicated cases had to be examined semi-manually.
2. Programs were written to examine all the loose segments and determine which segments should be joined to produce polygons. Because not all segments joined exactly (there were non-zero gaps between some segments) we had to find all possible combinations and choose the simplest combinations. The WVS segments joined to produce more than 200,000 polygons, the largest being the Africa-Eurasia polygon which has 1.4 million points. The WDB data resulted in a smaller data base (~25% of WVS).

¹ www.ngdc.noaa.gov

3. We now needed to combine the WVS and WDB data bases. The main problem here is that we have duplicates of polygons: most of the features in WVS are also in WDB. However, because the resolution of the data differ it is nontrivial to figure out which polygons in WDB to include and which ones to ignore. We used two techniques to address this problem. First, we looked for crossovers between all possible pairs of polygons. Because of the crossover processing in step 1 above we know that there are no remaining crossovers within WVS and WDB; thus any crossovers would be between WVS and WDB polygons. Crossovers could mean two things: (1) A slightly misplaced WDB polygon crosses a more accurate WVS polygon, both representing the same geographic feature, or (2) a misplaced WDB polygon (e.g. a small coastal lake) crosses the accurate WVS shoreline. We distinguished between these cases by comparing the area and centroid of the two polygons. In almost all cases it was obvious when we had duplicates; a few cases had to be checked manually. Second, on many occasions the WDB duplicate polygon did not cross its WVS counterpart but was either entirely inside or outside the WVS polygon. In those cases we relied on the area-centroid tests.
4. While the largest polygons were easy to identify by visual inspection, the majority remain unidentified. Since it is important to know whether a polygon is a continent or a small pond inside an island inside a lake we wrote programs that would determine the hierarchical level of each polygon. Here, level = 1 represents ocean/land boundaries, 2 is land/lakes borders, 3 is lakes/islands-in-lakes, and 4 is islands-in-lakes/ponds-in-islands-in-lakes. Level 4 was the highest level encountered in the data. To automatically determine the hierarchical levels we wrote programs that would compare all possible pairs of polygons and find how many polygons a given polygon was inside. Because of the size and number of the polygons such programs would typically run for 3 days on a Sparc-2 workstation.
5. Once we know what type a polygon is we can enforce a common “orientation” for all polygons. We arranged them so that when you move along a polygon from beginning to end, your left hand is pointing toward “land”. At this step we also computed the area of all polygons since we would like the option to plot only features that are bigger than a minimum area to be specified by the user.
6. Obviously, if you need to make a map of Denmark then you do not want to read the entire 1.4 million points making up the Africa-Eurasia polygon. Furthermore, most plotting devices will not let you paint and fill a polygon of that size due to memory restrictions. Hence, we need to partition the polygons so that smaller subsets can be accessed rapidly. Likewise, if you want to plot a world map on a letter-size paper there is no need to plot 10 million data points as most of them will plot several times on the same pixel and the operation would take a very long time to complete. We chose to make 5 versions on the database, corresponding to different resolutions. The decimation was carried out using the Douglas-Peucker (DP) line-reduction algorithm². We chose the cutoffs so that each subset was approximately 20% the size of the next higher resolution. The five resolutions are called **full**, **high**, **intermediate**, **low**, and **crude**; they are accessed in **pscoast**, **gmtselect**, and **grdlandmask** with the **-D** option³. For each of these 5 data sets (**f**, **h**, **i**, **l**, **c**) we specified an equidistant grid (1°, 2°, 5°, 10°, 20°) and split all polygons into line-segments that each fit inside one of the many boxes defined by these grid lines. Thus, to paint the entire continent of Australia we instead paint many smaller polygons made up of these line segments and gridlines. Some book-keeping has to be done since we need to know which parent polygon these smaller pieces came from in order to prescribe the correct paint or ignore if the feature is smaller than the cutoff specified by the user. The resulting segment coordinates were then scaled to fit in short integer format to preserve precision and written in netCDF format for ultimate portability across hardware platforms⁴.
7. While we are now back to a file of line-segments we are in a much better position to create smaller polygons for painting. Two problems must be overcome to correctly paint an area:

²Douglas, D.H., and T. K. Peucker, 1973, Algorithms for the reduction of the number of points required to represent a digitized line or its caricature, *Canadian Cartographer*, 10, 112–122.

³ The full and high resolution files are in separate archives because of their size. Not all users may need these files as the intermediate data set is better than the data provided with version 2.1.4.

⁴ If you need complete polygons in a simpler format, see the article on GSHHS (Wessel, P., and W. H. F. Smith, 1996, A Global, self-consistent, hierarchical, high-resolution shoreline database, *J. Geophys. Res.* 101, 8741–8743).

- We must be able to join line segments and grid cell borders into meaningful polygons; how we do this will depend on whether we want to paint the land or the oceans.
- We want to nest the polygons so that no paint falls on areas that are “wet” (or “dry”); e.g., if a grid cell completely on land contains a lake with a small island, we do not want to paint the lake and then draw the island, but paint the annulus or “donut” that is represented by the land and lake, and then plot the island.

GMT uses a polygon-assembly routine that carries out these tasks on the fly.

K.4 The Five Resolutions

We will demonstrate the power of the new database by starting with a regional hemisphere map centered near Papua New Guinea and zoom in on a specified point. The map regions will be specified in projected km from the projection center, e.g., we may want the map to go from -2000 km to +2000 km in the longitudinal and the latitudinal direction. However, *GMT* programs expects degrees in the **-R** option that specifies the desired region. Given the chosen map projection we can automate this process by using a simple shell script that we call **getbox.sh**:

```
range=`(echo -$2 -$2; echo $2 $2) | mapproject $1 -R0/360/-90/90 -I -Fk -C`
echo $range | awk '{printf "-R%f/%f/%f/%f\n", $1, $2, $3, $4}'
```

Also, as we zoom in on the projection center we want to draw the outline of the next map region on the plot. To do that we need the geographical coordinates of the four corners of the region rectangle. Again, we automate this task by adding the simple script **getrect.sh**:

```
(echo -$1 -$1; echo -$1 $1; echo $1 $1; echo $1 -$1) | mapproject -R -J -I -Fk -C
```

K.4.1 The crude resolution (-Dc)

We begin with an azimuthal equidistant map of the hemisphere centered on 130°21'E, 0°12'S, which is slightly west of New Guinea, near the Strait of Dampier. The edges of the map are all 9000 km true distance from the projection center. At this scale (and for global maps) the crude resolution data will usually be adequate to capture the main geographic features. To avoid cluttering the map with insignificant detail we only plot features (i.e., polygons) that exceed 500 km² in area. Smaller features would only occupy a few pixels on the plot and make the map look “dirty”. We also add national borders to the plot. The crude database is heavily decimated and simplified by the DP-routine: The total file size of the coastlines, rivers, and borders database is only 283 kbytes. The plot is produced by the script:

```
gmtset GRID_CROSS_SIZE_PRIMARY 0 OBLIQUE_ANNOTATION 22 ANNOT_MIN_SPACING 0.3
pscoast `./getbox.sh -JEl30.35/-0.2/3.5i 9000` -J -P -Dc \
-A500 -Glightgray -Wthinnest -N1/thinnest, -B20g20WSne -K > GMT_App_K_1.ps
./getrect.sh 2000 | psxy -R -J -O -Wthicker -L -A >> GMT_App_K_1.ps
```

Here, we use the **OBLIQUE_ANNOTATION** bit flags to achieve horizontal annotations and set **ANNOT_MIN_SPACING** to suppress some longitudinal annotations near the S pole that otherwise would overprint. The box indicates the outline of the next map.

K.4.2 The low resolution (-Dl)

We have now reduced the map area by zooming in on the map center. Now, the edges of the map are all 2000 km true distance from the projection center. At this scale we choose the low resolution data that faithfully reproduce the dominant geographic features in the region. We cut back on minor features less than 100 km² in area. We still add national borders to the plot. The low database is less decimated and simplified by the DP-routine: The total file size of the coastlines, rivers, and borders combined grows to 907 kbytes; it is the default resolution in *GMT*. The plot is generated by the script:

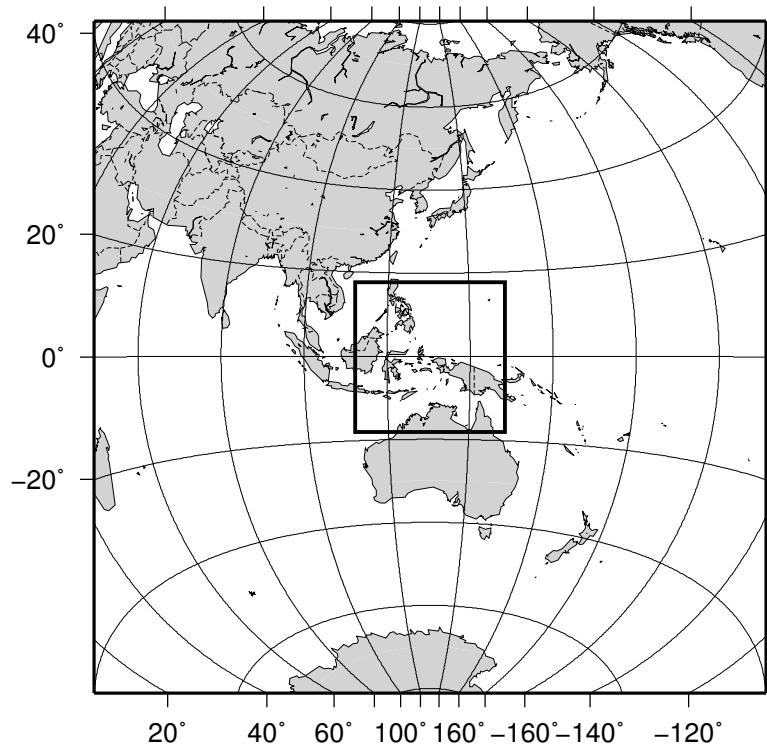


Figure K.1: Map using the crude resolution coastline data.

```
pscoast `./getbox.sh -JE130.35/-0.2/3.5i 2000` -J -P -Dl -A100 \
    -Glightgray -Wthinnest -N1/thinnest,- -B10g5WSne -K > GMT_App_K_2.ps
./getrect.sh 500 | psxy -R -J -O -Wthicker -L -A >> GMT_App_K_2.ps
```

K.4.3 The intermediate resolution (-Di)

We continue to zoom in on the map center. In this map, the edges of the map are all 500 km true distance from the projection center. We abandon the low resolution data set as it would look too jagged at this scale and instead employ the intermediate resolution data that faithfully reproduce the dominant geographic features in the region. This time, we ignore features less than 20 km² in area. Although the script still asks for national borders none exist within our region. The intermediate database is moderately decimated and simplified by the DP-routine: The combined file size of the coastlines, rivers, and borders now exceeds 3.35 Mbytes. The plot is generated by the script:

```
pscoast `./getbox.sh -JE130.35/-0.2/3.5i 500` -J -P -Di -A20 \
    -Glightgray -Wthinnest -N1/thinnest,- -B2glWSne -K > GMT_App_K_3.ps
echo 133 2 | psxy -R -J -O -K -Sc1.4i -Gwhite >> GMT_App_K_3.ps
psbasemap -R -J -O -K -Tm133/2/1i::+45/10/5 --HEADER_FONT_SIZE=12p --TICK_LENGTH=0.05i \
    --ANNOT_FONT_SIZE_SECONDARY=8p >> GMT_App_K_3.ps
./getrect.sh 100 | psxy -R -J -O -Wthicker -L -A >> GMT_App_K_3.ps
```

K.4.4 The high resolution (-Dh)

The relentless zooming continues! Now, the edges of the map are all 100 km true distance from the projection center. We step up to the high resolution data set as it is needed to accurately portray the detailed geographic features within the region. Because of the small scale we only ignore features less than 1 km² in area. The high resolution database has undergone minor decimation and simplification by the

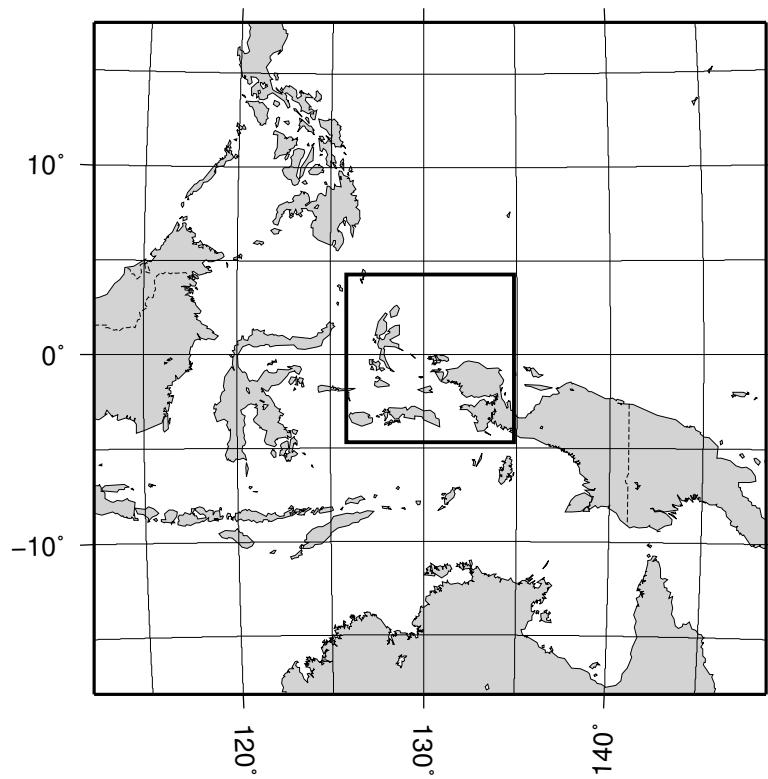


Figure K.2: Map using the low resolution coastline data.

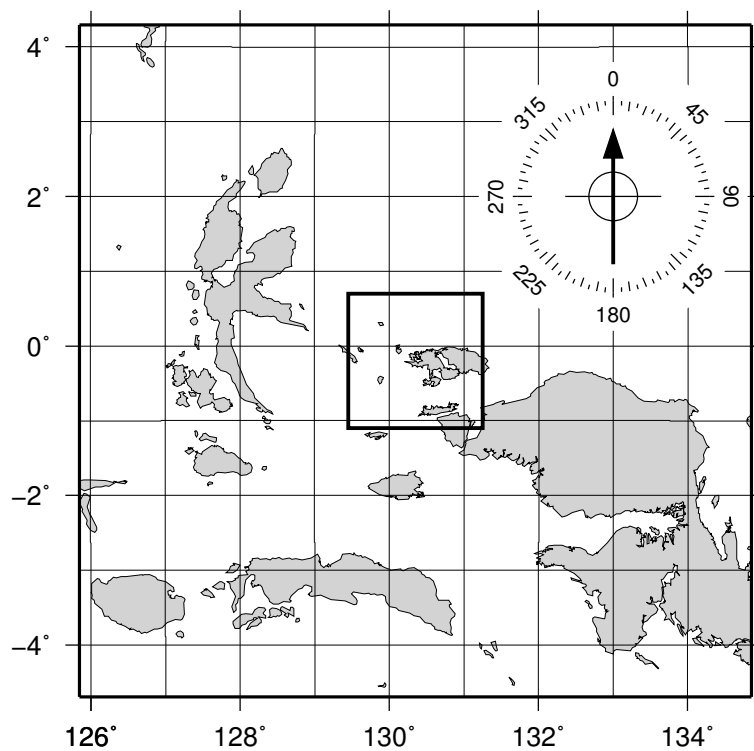


Figure K.3: Map using the intermediate resolution coastline data. We have added a compass rose just because we have the power to do so.

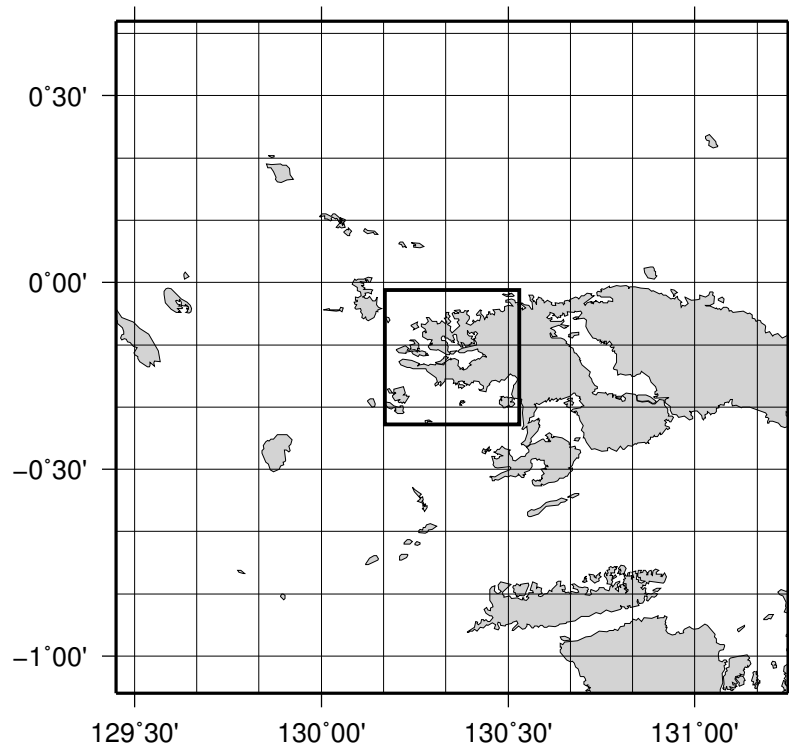


Figure K.4: Map using the high resolution coastline data.

DP-routine: The combined file size of the coastlines, rivers, and borders now swells to 12.3 Mbytes. The map and the final outline box are generated by these commands:

```
pscoast `./getbox.sh -JE130.35/-0.2/3.5i 100` -J -P -Dh -A1 \
  -Glightgray -Wthinnest -N1/thinnest,- -B30mg10mWSne -K > GMT_App_K_4.ps
./getrect.sh 20 | psxy -R -J -O -Wthicker -L -A >> GMT_App_K_4.ps
```

K.4.5 The full resolution (-Df)

We now arrive at our final plot, which shows a detailed view of the western side of the small island of Waigeo. The map area is approximately 40 by 40 km. We call upon the full resolution data set to portray the richness of geographic detail within this region; no features are ignored. The full resolution has undergone no decimation and it shows: The combined file size of the coastlines, rivers, and borders totals a (once considered hefty) 55.9 Mbytes. Our final map is reproduced by the single command:

```
pscoast `./getbox.sh -JE130.35/-0.2/3.5i 20` -J -P -Df \
  -Glightgray -Wthinnest -N1/thinnest,- -B10mg2mWSne > GMT_App_K_5.ps
```

We hope you will study these examples to enable you to make efficient and wise use of this vast data set.

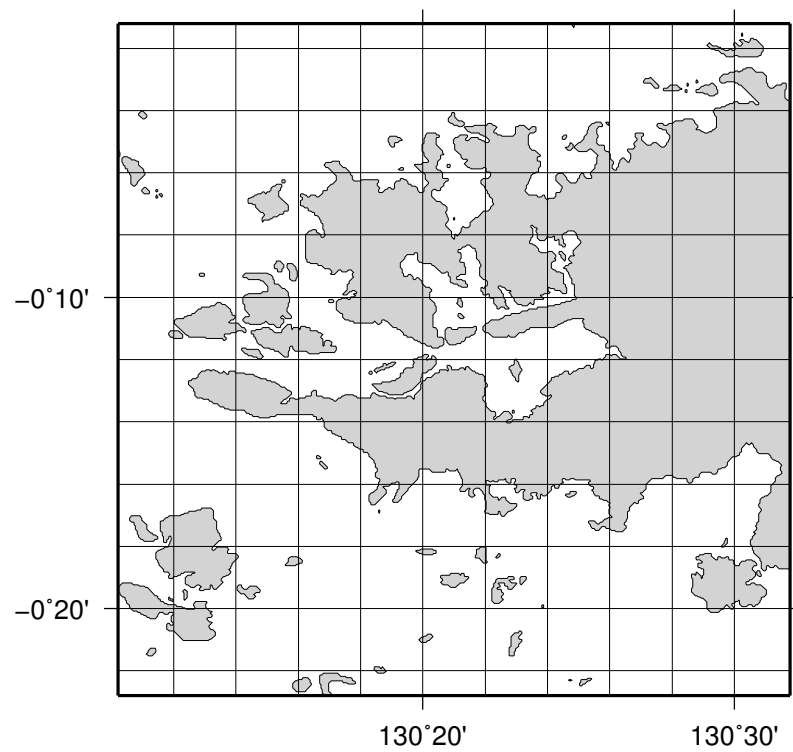


Figure K.5: Map using the full resolution coastline data.

L. GMT on non-UNIX platforms

L.1 Introduction

While *GMT* can be ported to non-UNIX systems such as Windows, it is also true that one of the strengths of *GMT* lies its symbiotic relationship with *UNIX*. We therefore recommend that *GMT* be installed in a POSIX-compliant *UNIX* environment such as traditional *UNIX*-systems, Linux, or Mac OS X. If abandoning your non-UNIX operating system is not an option, consider one of these solutions:

WINDOWS: Choose among these four possibilities:

1. Install *GMT* under Cygwin (A GNU port to Windows).
2. Install *GMT* under SFU (Windows Services for *UNIX*); a free download from Microsoft¹.
3. Install *GMT* under DJGPP (another GNU port to Windows/DOS).
4. Install *GMT* in Windows using Microsoft C/C++ or other compilers. Unlike the first three, this option will not provide you with any *UNIX* tools so you will be limited to what you can do with DOS batch files.

MAC OS9: Here your choice is a commercial offering called MachTen².

L.2 Cygwin and GMT

Because *GMT* works best in conjugation with *UNIX* tools we suggest you install *GMT* using the Cygwin product from Cygnus (now assimilated by Redhat, Inc.). This free version works on any Windows version and it comes with both the Bourne Again shell *bash* and the *tcsh*. You also have access to most standard GNU development tools such as compilers and text processing tools (*awk*, *grep*, *sed*, etc.). Note that executables prepared for Windows will also run under Cygwin.

Follow the instructions on the Cygwin page³ on how to install the package; note you must explicitly add all the development tool packages (e.g., *gcc* etc) as the basic installation does not include them by default. Once you are up and running under Cygwin, you may install *GMT* the same way you do under any other *UNIX* platform by either running the automated install via *install-gmt* or manually running configure first, then type make all. If you install via the web form, make sure you save the parameter file without DOS CR/LF endings. Use *dos2unix* to get rid of those if need be.

Finally, from Cygwin's User Guide: By default, no Cygwin program can allocate more than 384 MB of memory (program and data). You should not need to change this default in most circumstances. However, if you need to use more real or virtual memory in your machine you may add an entry in either the **HKEY_LOCAL_MACHINE** (to change the limit for all users) or **HKEY_CURRENT_USER** (for just the current user) section of the registry. Add the DWORD value **heap_chunk_in_mb** and set it to the desired memory limit in decimal Mb. It is preferred to do this in Cygwin using the *regtool* program included in the Cygwin package. (For more information about *regtool* or the other Cygwin utilities, see the Section called Cygwin Utilities in Chapter 3 of the Cygwin's User Guide or use the help option of each utility.) You should always be careful when using *regtool* since damaging your system registry can result in an unusable system. This example sets the local machine memory limit to 1024 Mb:

```
regtool -i set /HKLM/Software/Cygnus\ Solutions/Cygwin/heap_chunk_in_mb 1024
regtool -v list /HKLM/Software/Cygnus\ Solutions/Cygwin
```

For more installation details see the general README file.

¹Microsoft Services for *UNIX* is formerly known as Interix, in the distant past known as OpenNT.

²www.tenon.com

³cygwin.com

L.3 SFU and GMT

SFU⁴ is also similar to Cygwin in that it provides precompiled *UNIX* tools for DOS/WIN32, including the **sh** and **cs** shells.

L.4 DJGPP and GMT

DJGPP⁵ is similar to Cygwin in that it provides precompiled *UNIX* tools for DOS/WIN32, including the **bash** shell. At the time of this writing we have not been successful in compiling netCDF in this environment. This is fully due to our limited understanding of the innards of the netCDF installation whose configure script did not work for us. As soon as this problem is overcome we expect a smooth install similar to that of Cygwin.

L.5 WIN32 and GMT

GMT will compile and install using the Microsoft Visual C/C++ compiler. We expect other WIN32 C compilers to give similar results. Since **configure** cannot be run you must manually rename gmt_notposix.h.in to gmt_notposix.h. The netCDF home page gives full information on how to compile and install netCDF; precompiled libraries are also available. At present we simply have a lame gmtinstall.bat file that compiles the entire *GMT* package, and gmtsuppl.bat which compiles most of the supplemental programs. If you just need to run *GMT* and do not want to mess with compilations, get the precompiled binaries from the *GMT* ftp sites.

L.6 OS/2 and GMT

GMT has been ported to OS/2 by Allen Cogbill⁶, Los Alamos National Laboratory. One must have EMX⁷ installed in order to use the executables. All features that are present in the *UNIX* version of *GMT* are available in the OS/2 version. All executables may be obtained using links in the following document⁸, which provides more detail on the port.

L.7 Mac OS and GMT

GMT has not been ported to the classical Macintosh platform (i.e. Mac OS 9.x or earlier). For that OS your only option is MachTen. However, *GMT* will install directly under Mac OS X.

⁴See www.microsoft.com/technet/interopmigration/unix/sfu for details.

⁵See www.gnu.org for details.

⁶<mailto:ahc@lanl.gov>

⁷[ftp://ftp.geophysics.lanl.gov/pub/EES3/pub/gmt/emxrt.zip](http://ftp.geophysics.lanl.gov/pub/EES3/pub/gmt/emxrt.zip)

⁸[ftp://ees.lanl.gov/pub/EES3/pub/gmt/gmt4os2.html](http://ees.lanl.gov/pub/EES3/pub/gmt/gmt4os2.html)

M. Of colors and color legends

M.1 Built-in color palette tables

Figure M.1 shows each of the 22 built-in color palettes, stored in so-called cpt tables. The programs **makecpt** and **grd2cpt** are used to access these master cpt tables and translate/scale them to fit the user's range of *z*-values. The top half of the color bars in the Figure shows the original color scale, which can be either discrete or continuous, though some (like **globe**) are a mix of the two. The bottom half the color bar is an example of a discrete color scale build by using **makecpt -T-1/1/0.25**.

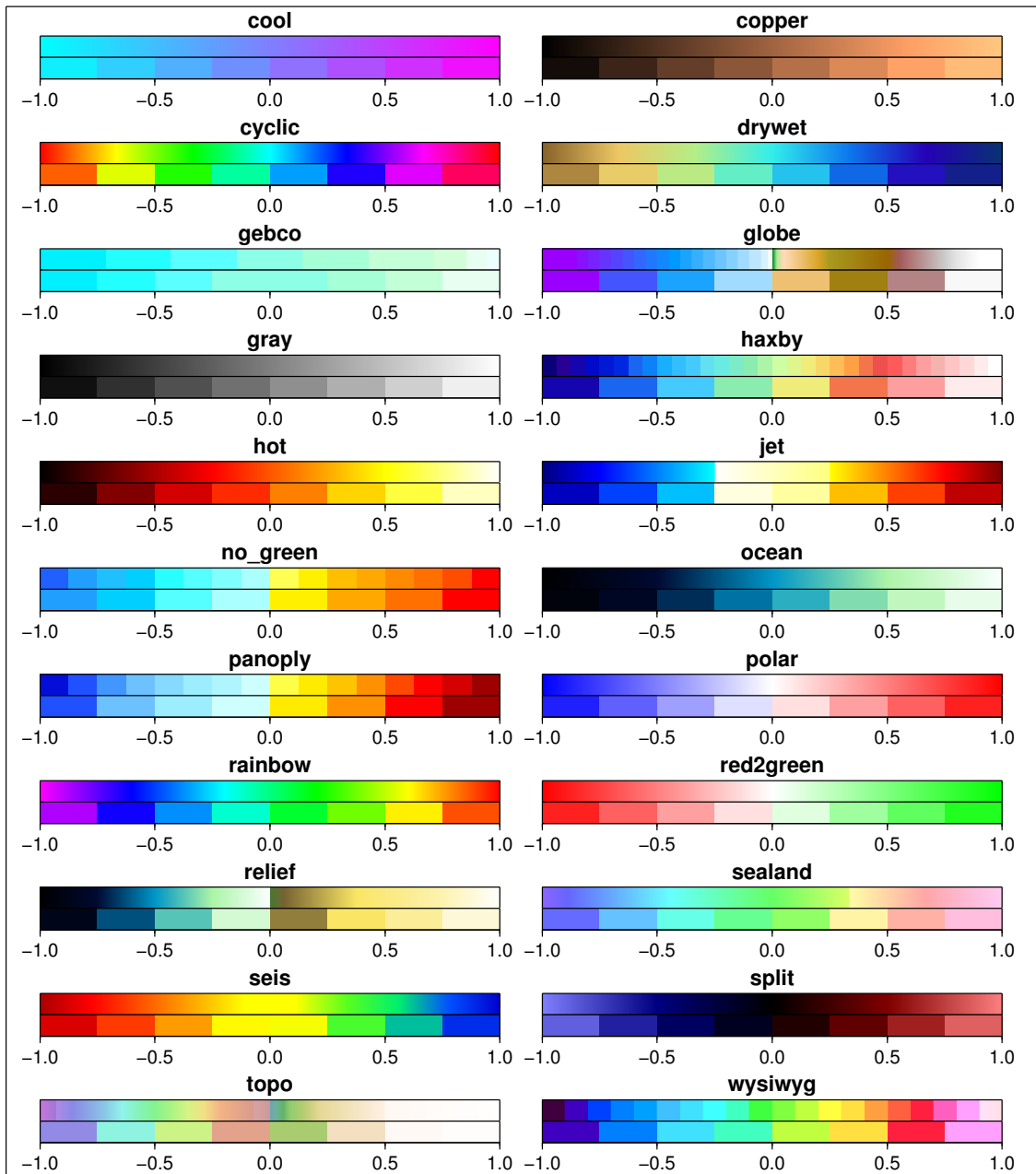


Figure M.1: The standard 22 cpt files supported by GMT.

M.2 Labeled and non-equidistant color legends

The use of color legends has already been introduced in Chapter 7 (examples 2, 16, and 17). Things become a bit more complicated when you want to label the legend with names for certain intervals (like geological time periods in the example below). To accomplish that, one should add a semi-colon and the label name at the end of a line in the cpt table and add the **-L** option to the **psscale** command that draws the color legend. This option also makes all intervals in the legend of equal length, even if the numerical values are not equally spaced.

Normally, the name labels are plotted at the lower end of the intervals. But by adding a *gap* amount (even when zero) to the **-L** option, they are centered. The example below also shows how to annotate ranges using **-Li** (in which case no name labels should appear in the cpt file), and how to switch the color bar around (by using a negative length).

```
#!/bin/sh
#
ps=GMT_App_M_2.ps

gmtset ANNOT_FONT_SIZE 10p MEASURE_UNIT cm

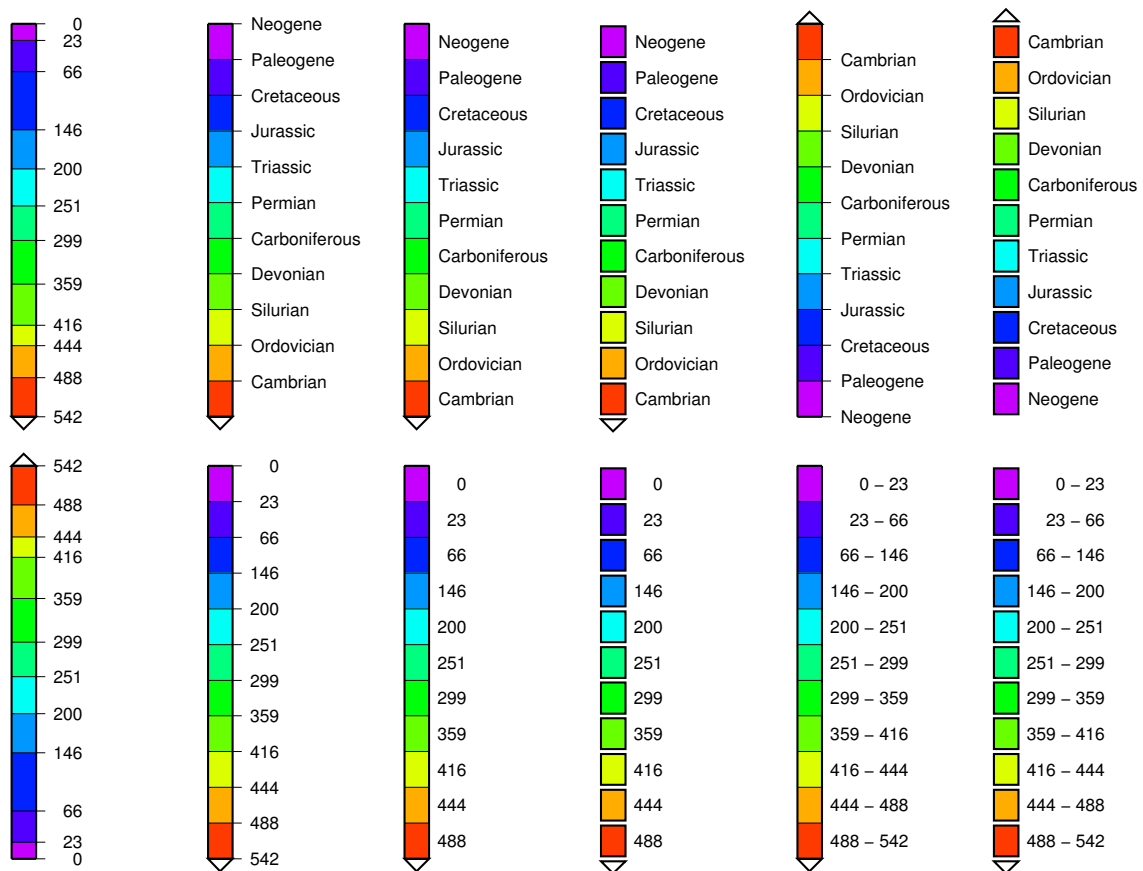
# Set up color palette with named annotations

cat > ages.cpt <<END
#COLOR_MODEL = RGB
#
0      197      0      255      23      197      0      255      ;Neogene
23     81       0      255      66     81       0      255      ;Paleogene
66     0        35     255      146     0        35     255      ;Cretaceous
146    0        151    255      200     0        151    255      ;Jurassic
200    0        255    244      251     0        255    244      ;Triassic
251    0        255    127      299     0        255    127      ;Permian
299    0        255    11       359     0        255    11       ;Carboniferous
359    104      255     0        416     104      255     0        ;Devonian
416    220      255     0        444     220      255     0        ;Silurian
444    255      174     0        488     255      174     0        ;Ordovician
488    255      58      0        542     255      58      0        ;Cambrian
B      black
F      white
END

# Top row, left to right. Using names.
psscale -Ef -Cages.cpt -D00/13/-8/0.5 -K > $ps
psscale -Ef -Cages.cpt -D04/13/-8/0.5 -O -K -L >> $ps
psscale -Ef -Cages.cpt -D08/13/-8/0.5 -O -K -L0.0 >> $ps
psscale -Ef -Cages.cpt -D12/13/-8/0.5 -O -K -L0.1 >> $ps
psscale -Ef -Cages.cpt -D16/13/+8/0.5 -O -K -L >> $ps
psscale -Ef -Cages.cpt -D20/13/+8/0.5 -O -K -L0.1 >> $ps

# Bottom row, left to right. Using numbers.
sed 's/;.*$//' ages.cpt > years.cpt
psscale -Ef -Cyears.cpt -D00/04/+8/0.5 -O -K >> $ps
psscale -Ef -Cyears.cpt -D04/04/-8/0.5 -O -K -L >> $ps
psscale -Ef -Cyears.cpt -D08/04/-8/0.5 -O -K -L0.0 >> $ps
psscale -Ef -Cyears.cpt -D12/04/-8/0.5 -O -K -L0.1 >> $ps
psscale -Ef -Cyears.cpt -D16/04/-8/0.5 -O -K -Li >> $ps
psscale -Ef -Cyears.cpt -D20/04/-8/0.5 -O -Li0.1 >> $ps

rm -f ages.cpt years.cpt
```

Figure M.2: The many forms of color legends created by **psscale**.

N. Custom Plot Symbols

GMT comes with several custom plot symbols ready to go. They are used in **psxy** and **psxyz** using the **-Sk** option. To make your own custom plot symbol, please follow the instructions given in the man pages of those two programs. The following is a plot of each symbol. Note that we only show the symbol outline and not any fill. Be aware that some symbols may have a hardwired fill or no-fill component. Also note that some symbols, in particular the geometric ones, duplicate what is already available as standard built-in symbols.

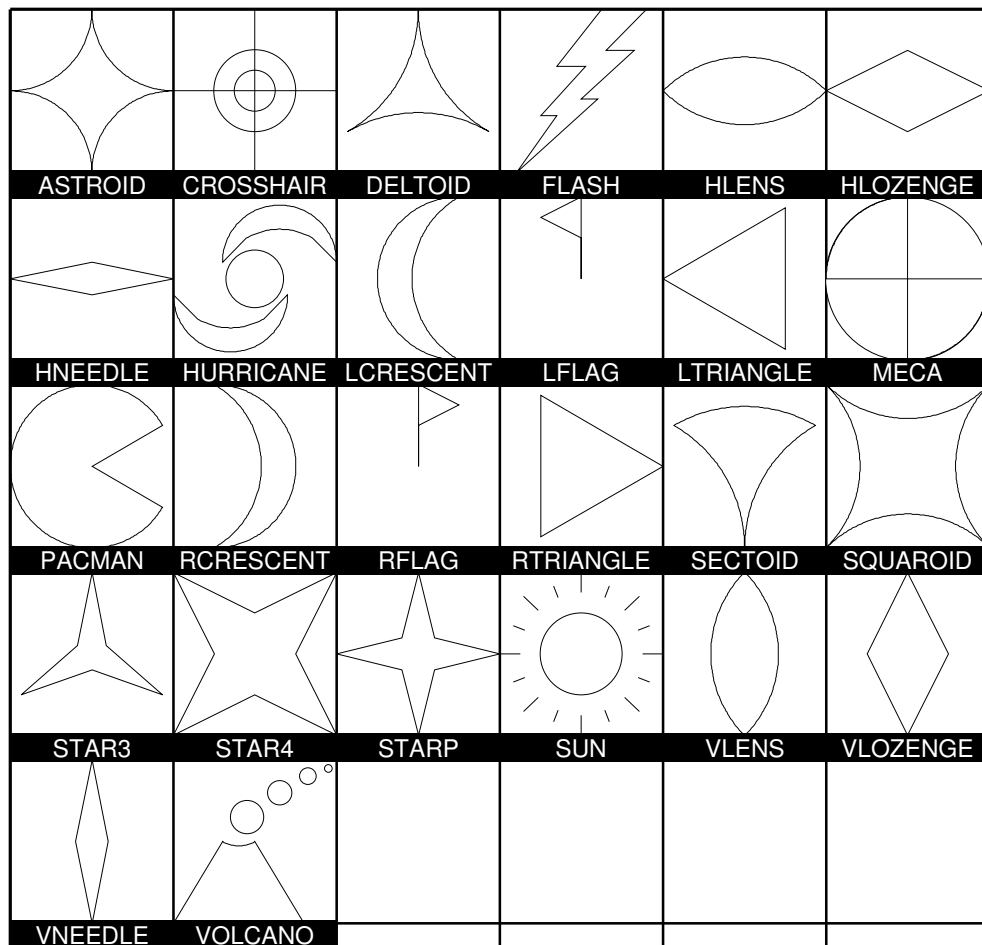


Figure N.1: Custom plot symbols supported by **GMT**.

O. Annotation of Contours and “Quoted Lines”

The *GMT* programs **grdcontour** (for data given as 2-dimensional grids) and **pscontour** (for x,y,z tables) allow for contouring of data sets, while **psxy** and **psxyz** can plot lines based on x,y - and x,y,z -tables, respectively. In both cases it may be necessary to attach labels to these lines. Clever or optimal placements of labels is a very difficult topic, and *GMT* provides several algorithms for this placement as well as complete freedom in specifying the attributes of the labels. Because of the richness of these choices we present this Appendix which summarizes the various options and gives several examples of their use.

O.1 Label Placement

While the previous *GMT* versions 1–3 allowed for a single algorithm that determined where labels would be placed, *GMT* 4 allows for five different algorithms. Furthermore, a new “symbol” option (**-Sq** for “quoted line”) has been added to **psxy** and **psxyz** and hence the new label placement mechanisms apply to those programs as well. The contouring programs expect the algorithm to be specified as arguments to **-G** while the line plotting programs expect the same arguments to follow **-Sq**. The information appended to these options is the same in both cases and is of the form **[code]info**. The five algorithms correspond to the five codes below (some codes will appear in both upper and lower case; they share the same algorithm but differ in some other ways). In what follows, the phrase “line segment” is taken to mean either a contour or a line to be labeled. The codes are:

- d**: Full syntax is **ddist[c|i|m|p][/frac]**. Place labels according to the distance measured along the projected line on the map. Append the unit you want to measure distances in [Default is taken from **MEASURE_UNIT**]. Starting at the beginning of a line, place labels every *dist* increment of distance along the line. To ensure that closed lines whose total length is less than *dist* get annotated, we may append *frac* which will place the first label at the distance $d = dist \times frac$ from the start of a closed line (and every *dist* thereafter). If not given, *frac* defaults to 0.25.
- D**: Full syntax is **Ddist[d|e|k|m|n][/frac]**. This option is similar to **d** except the original data must be referred to geographic coordinates (and a map projection must have been chosen) and actual Earth¹ surface distances along the lines are considered. Append the unit you want to measure distances in; choose among **degree**, **meter** [Default], **kilometer**, **statute miles**, or **nautical miles**. Other aspects are similar to code **d**.
- f**: Full syntax is **ffix.d[/slop[c|i|m|p]]**. Here, an ASCII file *fix.d* is given which must contain records whose first two columns hold the coordinates of points along the lines at which locations the labels should be placed. Labels will only be placed if the coordinates match the line coordinates to within a distance of *slop* (append unit or we use **MEASURE_UNIT**). The default *slop* is zero, meaning only exact coordinate matches will do.
- l**: Full syntax is **lline1[,line2[, ...]]**. One or more straight line segments are specified separated by commas, and labels will be placed at the intersections between these lines and our line segments. Each *line* specification implies a *start* and *stop* point, each corresponding to a coordinate pair. These pairs can be regular coordinate pairs (i.e., longitude/latitude separated by a slash), or they can be two-character codes that refer to predetermined points relative to the map region. These codes are taken from the **pstext** justification keys **[L|C|R][B|M|T]** so that the first character determines the *x*-coordinate and the second determines the *y*-coordinate. In **grdcontour**, you can also use the two codes **Z+** and **Z-** as shorthands for the location of the grid’s global maximum and minimum, respectively. For example, the line **LT/RB** is a diagonal from the upper left to the lower right map corner, while **Z-/135W/15S** is a line from the grid minimum to the point (135°W, 15°S).
- L**: Same as **l** except we will treat the lines given as great circle start/stop coordinates and fill in the points between before looking for intersections.

¹ or whatever planet we are dealing with.

- n:** Full syntax is `nnumber[/minlength[c|i|m|p]]`. Place *number* of labels along each line regardless of total line length. The line is divided into *number* segments and the labels are placed at the centers of these segments. Optionally, you may give a *minlength* distance to ensure that no labels are placed closer than this distance to its neighbors.
- N:** Full syntax is `Nnumber[/minlength[c|i|m|p]]`. Similar to code **n** but here labels are placed at the ends of each segment (for *number* ≥ 2). A special case arises for *number* = 1 when a single label will be placed according to the sign of *number*: -1 places one label justified at the start of the line, while $+1$ places one label justified at the end of the line.
- x:** Full syntax is `xcross.d`. Here, an ASCII file *cross.d* is a multi-segment file whose lines will intersect our segment lines; labels will be placed at these intersections.
- X:** Same as **x** except we treat the lines given as great circle start/stop coordinates and fill in the points between before looking for intersections.

Only one algorithm can be specified at any given time.

O.2 Label Attributes

Determining where to place labels is half the battle. The other half is to specify exactly what are the attributes of the labels. It turns out that there are quite a few possible attributes that we may want to control, hence understanding how to specify these attributes becomes important. In the contouring programs, one or more attributes may be appended to the **-A** option using the format `+code[args]` for each attribute, whereas for the line plotting programs these attributes are appended to the **-Sq** option following a colon (:) that separates the label codes from the placement algorithm. Several of the attributes do not apply to contours so we start off with listing those that apply universally. These codes are:

- +a:** Controls the angle of the label relative to the angle of the line. Append **n** for normal to the line, give a fixed *angle* measured counter-clockwise relative to the horizontal. or append **p** for parallel to the line [Default]. If using **grdcontour** the latter option you may further append **u** or **d** to get annotations whose upper edge always face the next higher or lower contour line.
- +c:** Surrounding each label is an imaginary label “textbox” which defines a region in which no segment lines should be visible. The initial box provides an exact fit to the enclosed text but clearance may be extended in both the horizontal and vertical directions (relative to the label baseline) by the given amounts. If these should be different amounts please separate them by a slash; otherwise the single value applies to both directions. Append the distance units of your choice (**c|i|m|p**), or give % to indicate that the clearance should be this fixed percentage of the label font size in use. The default is 15%.
- +d:** Debug mode. This is useful when testing contour placement as it will draw the normally invisible helper lines and points in the label placement algorithms above.
- +f:** Specifies the desired label font. See **pstext** for font names or numbers. The default font is given by **ANNOT_FONT_PRIMARY**.
- +g:** Selects opaque rather than the default transparent textboxes. You may optionally append the color you want to fill the label boxes; the default is the same as **PAGE_COLOR**.
- +j:** Selects the justification of the label relative to the placement points determined above. Normally this is center/mid justified (**CM** in **pstext** justification parlance) and this is indeed the default setting. Override by using this option and append another justification key code from **[L|C|R][B|M|T]**. Note for curved text (**+v**) only vertical justification will be affected.
- +k:** Sets the color of the text labels, which otherwise defaults to that given by **COLOR_BACKGROUND**.

- +o:** Request a rounded, rectangular label box shape; the default is rectangular. This is only manifested if the box is filled or outlined, neither of which is implied by this option alone (see **+g** and **+p**). As this option only applies to straight text, it is ignored if **+v** is given.
- +p:** Selects the drawing of the label box outline; append your preferred *pen* unless you want the default *GMT* pen [0.25p,black].
- +r:** Do not place labels at points along the line whose local radius of curvature falls below the given threshold value. Append the radius unit of your choice (**c|i|m|p**) [Default is 0].
- +s:** Change the font size of the labels, which by default is 9 points.
- +u:** Append the chosen *unit* to the label. Normally a space will separate the label and the unit. If you want to close this gap, append a *unit* that begins with a hyphen (-). If you are contouring with **grdcontour** and you specify this option without appending a unit, the unit will be taken from the *z*-unit attribute of the grid header.
- +v:** Place curved labels that follow the wiggles of the line segments. This is especially useful if the labels are long relative to the length-scale of the wiggles. The default places labels on an invisible straight line at the angle determined.
- +w:** The angle of the line at the point of straight label placement is calculated by a least-squares fit to the *width* closest points. If not specified, *width* defaults to 10.
- +=:** Similar in most regards to **+u** but applies instead to a label *prefix* which you must append.

For contours, the label will be the value of the contour (possibly modified by **+u** or **+=:**). However, for quoted lines other options apply:

- +l:** Append a fixed *label* that will be placed at all label locations. If the label contains spaces you must place it inside matching quotes.
- +L:** Append a code *flag* that will determine the label. Available codes are:
 - +Lh:** Take the label from the current multi-segment header (hence it is assumed that the input line segments are given in the multi-segment file format; if not we pick the single label from the file's header record). We first scan the header for an embedded **-Llabel** option; if none is found we instead use the first word following the segment marker [**>**].
 - +Ld:** Take the Cartesian plot distances along the line as the label; append **c|i|m|p** as the unit [Default is **MEASURE_UNIT**]. The label will be formatted according to the **D_FORMAT** string, *unless* label placement was determined from map distances along the segment lines, in which case we determine the appropriate format from the distance value itself.
 - +LD:** Calculate actual Earth surface distances and use the distance at the label placement point as the label; append **d|e|k|m|n** to specify the unit [If not given we default to **degrees**, *unless* label placement was determined from map distances along the segment lines, in which case we use the same unit specified for that algorithm]. Requires a map projection to be used.
 - +Lf:** Use all text after the 2nd column in the fixed label location file *fix.d* as labels. This choice obviously requires the fixed label location algorithm (code **f**) to be in effect.
 - +Ln:** Use the running number of the current multi-segment as label.
 - +LN:** Use a slash-separated combination of the current file number and the current multi-segment number as label.
 - +Lx:** As **h** but use the multi-segment headers in the *cross.d* file instead. This choice obviously requires the crossing segments location algorithm (code **x|X**) to be in effect.

O.3 Examples of Contour Label Placement

We will demonstrate the use of these options with a few simple examples. First, we will contour a subset of the global geoid data used in *GMT Example 01*; the region selected encompasses the world’s strongest “geoid dipole”: the Indian Low and the New Guinea High.

O.3.1 Equidistant labels

Our first example uses the default placement algorithm. Because of the size of the map we request contour labels every 1.5 inches along the lines:

```
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_1.ps
grdcontour geoid.grd -J -O -B20f10WSne -C10 -A20+s8 -Gd1.5i -S10 -T:LH >> GMT_App_O_1.ps
```

As seen in Figure O.1, the contours are placed rather arbitrary. The string of contours for -40 to 60 align well but that is a fortuitous consequence of reaching the 1.5 inch distance from the start at the bottom of the map.

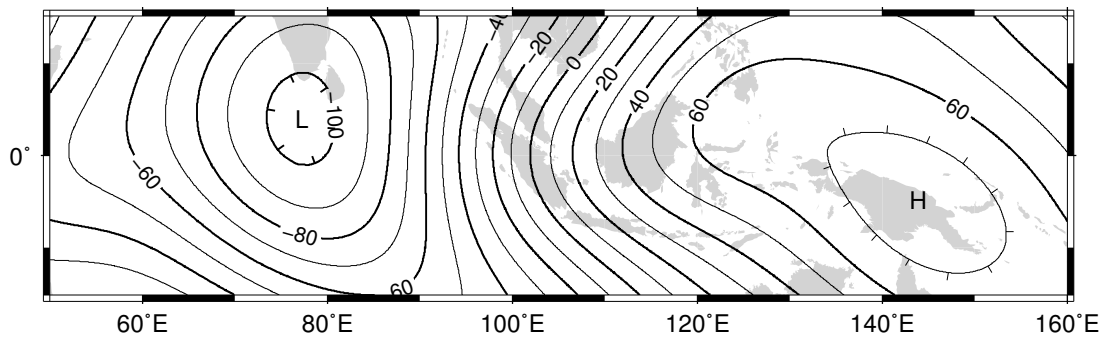


Figure O.1: Equidistant contour label placement with **-Gd**, the only algorithm available in previous **GMT** versions.

O.3.2 Fixed number of labels

We now exercise the option for specifying exactly how many labels each contour line should have:

```
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_2.ps
grdcontour geoid.grd -J -O -B20f10WSne -C10 -A20+s8 -Gn1/1i -S10 -T:LH >> GMT_App_O_2.ps
```

By selecting only one label per contour and requiring that labels only be placed on contour lines whose length exceed 1 inch, we achieve the effect shown in Figure O.2.

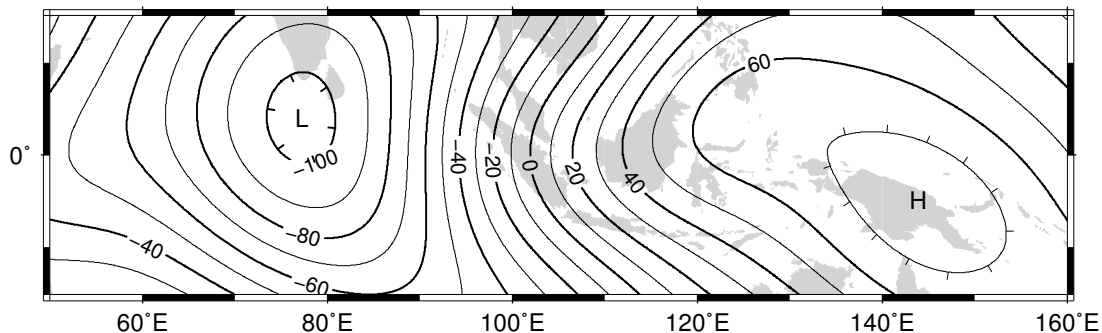


Figure O.2: Placing one label per contour that exceed 1 inch in length, centered on the segment with **-Gn**.

O.3.3 Prescribed label placements

Here, we specify four points where we would like contour labels to be placed. Our points are not exactly on the contour lines so we give a nonzero “slop” to be used in the distance calculations: The point on the contour closest to our fixed points and within the given maximum distance will host the label.

```
cat << EOF > fix.d
80      -8.5
55      -7.5
102     0
130     10.5
EOF
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_3.ps
grdcontour geoid.grd -J -O -B20f10WSne -C10 -A20+d+s8 -Gffix.d/0.1i -S10 -T:LH >> GMT_App_O_3.ps
```

The angle of the label is evaluated from the contour line geometry, and the final result is shown in Figure O.3.

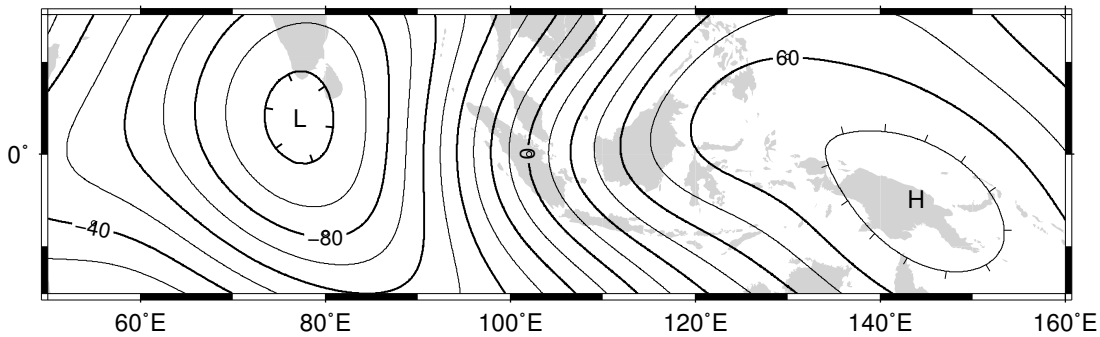


Figure O.3: Four labels are positioned on the points along the contours that are closest to the locations given in the file `fix.d` in the `-Gf` option.

To aid in understanding the algorithm we chose to specify “debug” mode (`+d`) which placed a small circle at each of the fixed points.

O.3.4 Label placement at simple line intersections

Often, it will suffice to place contours at the imaginary intersections between the contour lines and a well-placed straight line segment. The `-GI` or `-GL` algorithms work well in those cases:

```
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_4.ps
grdcontour geoid.grd -J -O -B20f10WSne -C10 -A20+d+s8 -GLZ-/Z+ -S10 -T:LH >> GMT_App_O_4.ps
```

The obvious choice in this example is to specify a great circle between the high and the low, thus placing all labels between these extrema.

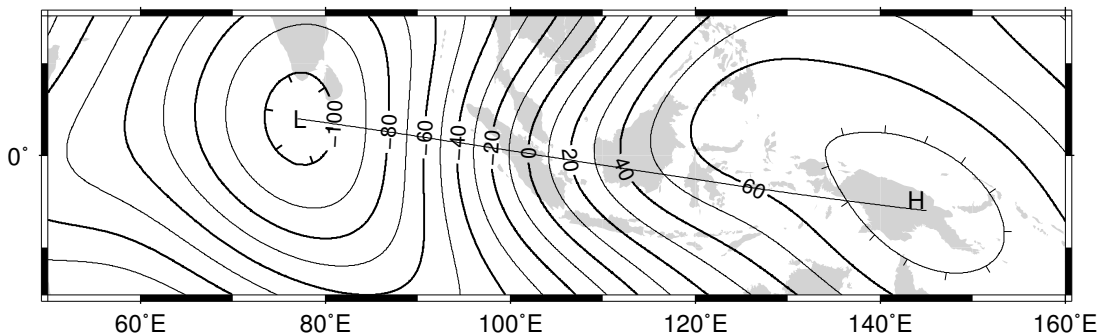


Figure O.4: Labels are placed at the intersections between contours and the great circle specified in the `-GL` option.

The thin debug line in Figure O.4 shows the great circle and the intersections where labels are plotted. Note that any number of such lines could be specified; here we are content with just one.

O.3.5 Label placement at general line intersections

If (1) the number of intersecting straight line segments needed to pick the desired label positions becomes too large to be given conveniently on the command line, or (2) we have another data set or lines whose intersections we wish to use, the general crossing algorithm makes more sense:

```
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_5.ps
grdcontour geoid.grd -J -O -B20f10WSne -C10 -A20+d+s8 -GXcross.d -S10 -T:LH >> GMT_App_O_5.ps
```

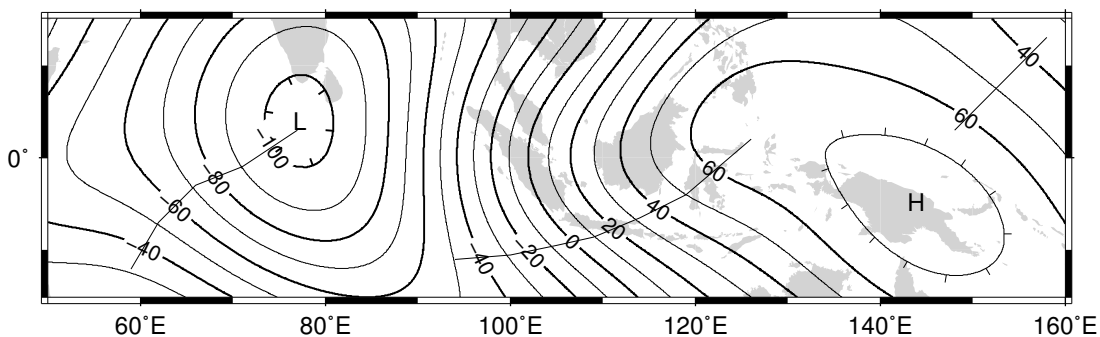


Figure O.5: Labels are placed at the intersections between contours and the multi-segment lines specified in the `-GX` option.

In this case, we have created three strands of lines whose intersections with the contours define the label placements, presented in Figure O.5.

O.4 Examples of Label Attributes

We will now demonstrate some of the ways to play with the label attributes. To do so we will use **psxy** on a great-circle line connecting the geoid extrema, along which we have sampled the ETOPO5 relief data set. The file `transect.d` thus contains *lon*, *lat*, *dist*, *geoid*, *relief*, with distances in km.

O.4.1 Label placement by along-track distances, 1

This example will change the orientation of labels from along-track to across-track, and surrounds the labels with an opaque, outlined textbox so that the label is more readable. We choose the place the labels every 1000 km along the line and use that distance as the label. The labels are placed normal to the line:

```
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_6.ps
grdcontour geoid.grd -J -O -K -B20f10WSne -C10 -A20+d+s8 -G150/10S/160/10S -S10 \
-T:'-+' >> GMT_App_O_6.ps
psxy -R -J -O -SqD1000k:+g+LD+an+p -Wthick transect.d >> GMT_App_O_6.ps
```

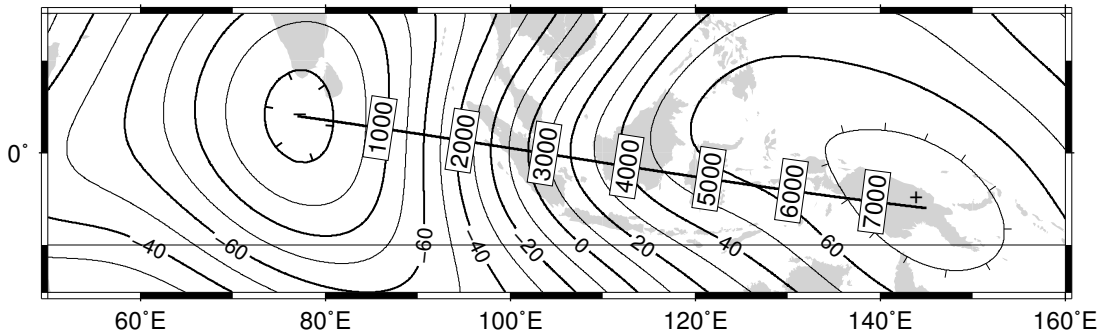


Figure O.6: Labels attributes are controlled with the arguments to the **-Sq** option.

The composite illustration in Figure O.6 shows the new effects. Note that the line connecting the extrema does not end exactly at the ‘-’ and ‘+’ symbols. This is because the placements of those symbols are based on the mean coordinates of the contour and not the locations of the (local or global) extrema.

O.4.2 Label placement by along-track distances, 2

A small variation on this theme is to place the labels parallel to the line, use spherical degrees for placement, append the degree symbol as a unit for the labels, choose a rounded rectangular textbox, and inverse-video the label:

```
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_7.ps
grdcontour geoid.grd -J -O -K -B20f10WSne -C10 -A20+d+um+s8 -G150/10S/160/10S -S10 \
-T:-+ >> GMT_App_O_7.ps
psxy -R -J -O -SqD15d:+gblack+kwhite+Ld+o+u-\\260 -Wthick transect.d >> GMT_App_O_7.ps
```

The output is presented as Figure O.7.

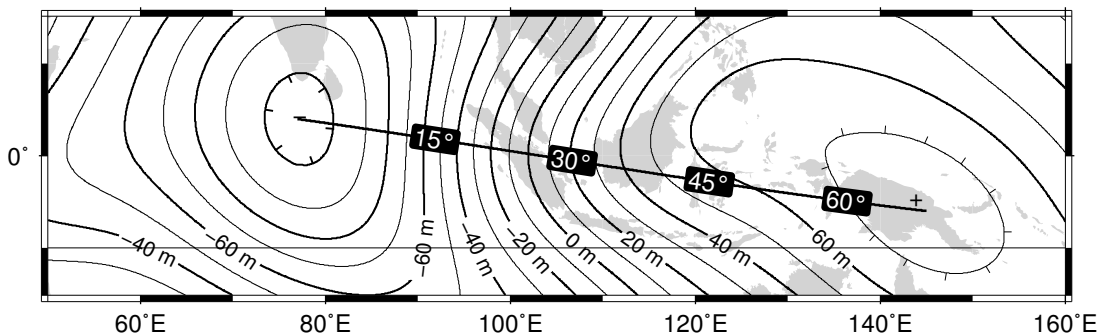


Figure O.7: Another label attribute example.

O.4.3 Using a different data set for labels

In the next example we will use the bathymetry values along the transect as our label, with placement determined by the distance along track. We choose to place labels every 1500 km. To do this we need to pull out those records whose distances are multiples of 1500 km and create a “fixed points” file that can be used to place labels and specify the labels. This is done with **awk**.

```
awk '{if (NR > 1 && ($3 % 1500) == 0) print $1, $2, int($5)}' transect.d > fix2.d
pscoast -R50/160/-15/15 -JM5.3i -Glightgray -A500 -K -P > GMT_App_O_8.ps
grdcontour geoid.grd -J -O -K -B20f10WSne -C10 -A20+d+um+s8 -G150/10S/160/10S -S10 \
-T:-+ >> GMT_App_O_8.ps
psxy -R -J -O -Sqffix2.d:+g+an+p+Lf+um+s8 -Wthick transect.d >> GMT_App_O_8.ps
```

The output is presented as Figure O.8.

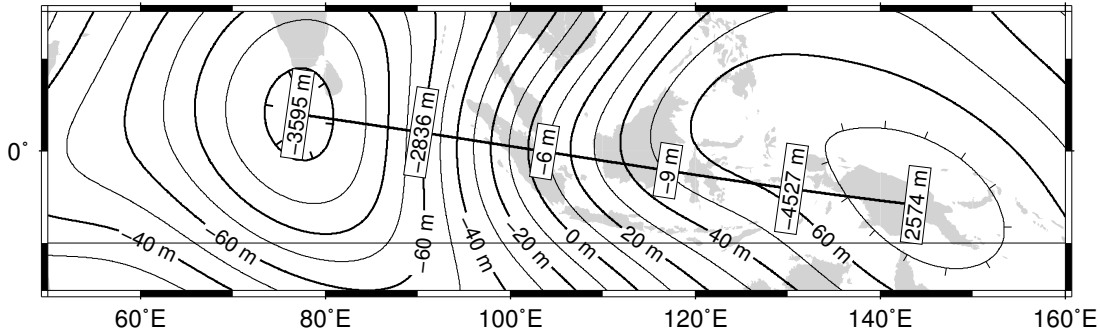


Figure O.8: Labels based on another data set (here bathymetry) while the placement is based on distances.

O.5 Putting it all together

Finally, we will make a more complex composite illustration that uses several of the label placement and label attribute settings discussed in the previous sections. We make a map showing the tsunami travel times (in hours) from a hypothetical catastrophic landslide in the Canary Islands². We lay down a color map based on the travel times and the shape of the seafloor, and travel time contours with curved labels as well as a few quoted lines. The final script is

```
R=-R-85/5/10/55
gdgradient topo5.nc -Nt1 -A45 -Gtopo5_int.nc
gmtset PLOT_DEGREE_FORMAT ddd:mm:ssF ANNOT_FONT_SIZE_PRIMARY +9p
project -E74W/41N -C17W/28N -G10 -Q > great_NY_Canaries.d
project -E74W/41N -C2.33/48.87N -G100 -Q > great_NY_Paris.d
km='echo 17W 28N | mapproject -G74W/41N/k -fg --D_FORMAT=%.0f | cut -f3'
cat << EOF > ttt.cpt
0      lightred      3      lightred
3      lightyellow   6      lightyellow
6      lightgreen    100     lightgreen
EOF
grdimage -Sc/1 ttt_atl.nc -Itopo5_int.nc -Cttt.cpt $R -JM5.3i -P -K > GMT_App_O_9.ps
grdcontour ttt_atl.nc -R -J -O -K -C0.5 -Al+u"hour"+v+s8+f17 -GL80W/31N/17W/26N,17W/28N/17W/50N \
-S2 >> GMT_App_O_9.ps
psxy -R -J -Wfatter,white great_NY_Canaries.d -O -K >> GMT_App_O_9.ps
pscoast -R -J -B20f5:."Tsunami travel times from the Canary Islands":WSne -N1/thick -O -K -Glightgray \
-Wfaint -A500 >> GMT_App_O_9.ps
gmtconvert great_NY*.d -E | psxy -R -J -O -K -Sa0.15i -Gred -Wthin >> GMT_App_O_9.ps
psxy -R -J -Wthick great_NY_Canaries.d -O -K \
-Sqnl:+f6+s8+l"Distance Canary Islands to New York = $km km"+ap+v >> GMT_App_O_9.ps
psxy -R -J great_NY_Paris.d -O -K -Sc0.08c -Gblack >> GMT_App_O_9.ps
psxy -R -J -Wthinner great_NY_Paris.d -O -K -SqD1000k:+an+o+gblue+kwhite+LDk+s7+f1 >> GMT_App_O_9.ps
cat << EOF | pstext -R -J -O -K -Wwhite,Othin -Dj0.1i/0.1i >> GMT_App_O_9.ps
74W      41N      8      0      17      RT      New York
2.33E    48.87N   8      0      17      CT      Paris
17W      28N      8      0      17      CT      Canaries
EOF
psxy -R -J -O /dev/null >> GMT_App_O_9.ps
```

with the complete illustration presented as Figure O.9.

²Travel times were calculated using Geoware's travel time calculator, *ttt*; see (<http://www.geoware-online.com>)

Tsunami travel times from the Canaries

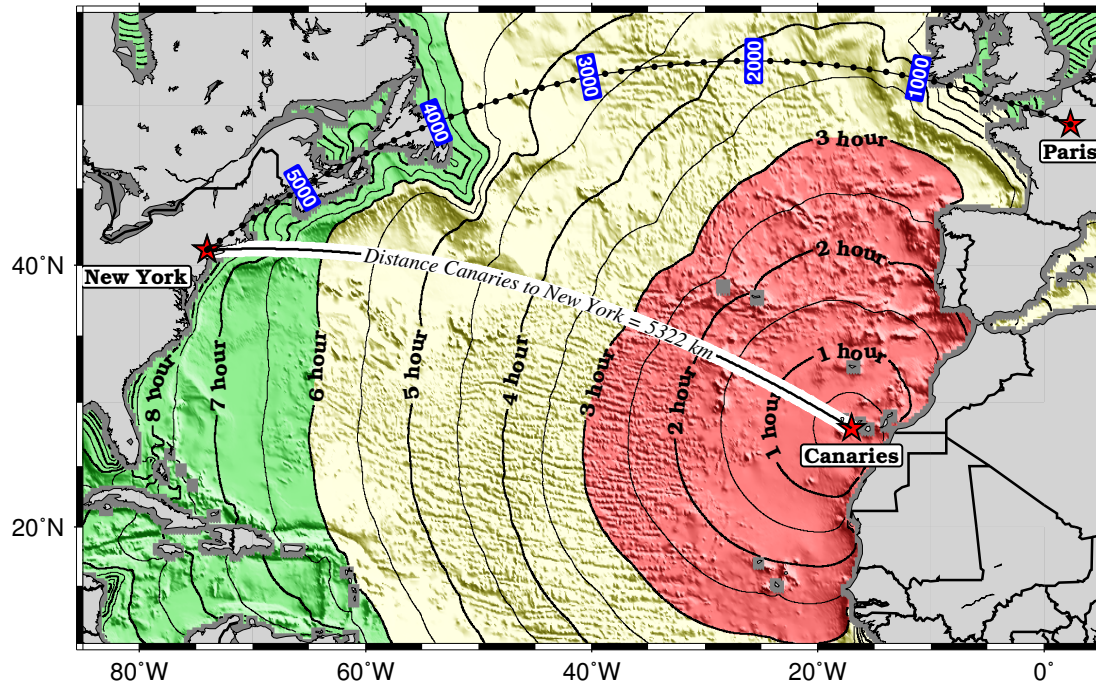


Figure O.9: Tsunami travel times from the Canary Islands to places in the Atlantic, in particular New York. Should a catastrophic landslide occur it is possible that New York will experience a large tsunami about 8 hours after the event.

P. Special Operations

P.1 Running GMT in *isolation mode*

In Chapter 4 it is described how *GMT* creates several (temporary) files to communicate between the different commands that make up the script that finally creates a plot. Among those files are:

.gmtdefaults4. This file covers about 100 different settings that influence the layout of your plot, from font sizes to tick lengths and date formats (See Section 4.2). Those settings can be altered by editing the file, or by running the **gmtset** command. A problem may arise when those settings are changed half-way through the script: the next time you run the script it will start with the modified settings and hence might alter your scripts results. It is therefore often necessary to revert to the original .gmtdefaults4 file. *Isolation mode* avoids that issue.

.gmtcommands4. This file is created to communicate the command line history from one command to the next (Section 4.5) so that shorthands like **-R** or **-J** can be used once it has been set in a previous *GMT* command. The existence of this file makes it impossible to run two *GMT* scripts simultaneously in the same directory, since those .gmtcommand4 files may clash (contain different histories) and adversely affect the results of both scripts.

.gmt_bb.info. This file contains the information about the BoundingBox (Section C.1) of the *PostScript* output. This information too has to be transferred from one *GMT* command to the next in a script. Again, running two commands simultaneously in the same directory may have disastrous effects on that file.

A cure to all these woes is the *isolation mode* introduced in *GMT* version 4.2.2. This mode allows you to run a *GMT* script without leaving any traces other than the resulting *PostScript* or data files, and not altering the .gmtdefaults4 or .gmtcommands4 files. Those files will be placed in a temporary directory instead. And if properly set up, this temporary directory will only be used by a single script, even if another *GMT* script is running simultaneously. This also provides the opportunity to create any other temporary files that the script might create in the same directory.

The example below shows how *isolation mode* works.

```
#!/bin/sh
#
#           GMT Appendix P, example 1
#
# Purpose:   Illustrates the use of isolation mode
# GMT progs: gmtset, grdimage, grdmath, makecpt, pscoast
# Unix progs: mktemp, rm
#
ps=GMT_App_P_1.ps

# Create a temporary directory. $GMT_TMPDIR will be set to its pathname.
# XXXXXX is replaced by a unique random combination of characters.
export GMT_TMPDIR='mktemp -d /tmp/gmt.XXXXXX'

# These settings will be local to this script only since it writes to
# $GMT_TMPDIR/.gmtdefaults4
gmtset COLOR_MODEL rgb ANNOT_FONT_SIZE_PRIMARY 14p

# Make grid file and color map in temporary directory
grdmath -Rd -I1 Y = $GMT_TMPDIR/lat.grd
makecpt -Crainbow -T-90/90/60 -Z > $GMT_TMPDIR/lat.cpt

# The grdimage command creates the history file $GMT_TMPDIR/.gmtcommands4
grdimage $GMT_TMPDIR/lat.grd -S1 -JK6.5i -C$GMT_TMPDIR/lat.cpt -P -K > $ps
pscoast -R -J -O -Dc -A5000 -Gwhite -B60g30/30g30 >> $ps

# Clean up all temporary files and the temporary directory
rm -rf $GMT_TMPDIR
```

The files .gmtdefaults4 and .gmtcommands4 are automatically created in the temporary directory \$GMT_TMPDIR. The script is also adjusted such that the temporary grid file lat.grd and colormap lat.cpt

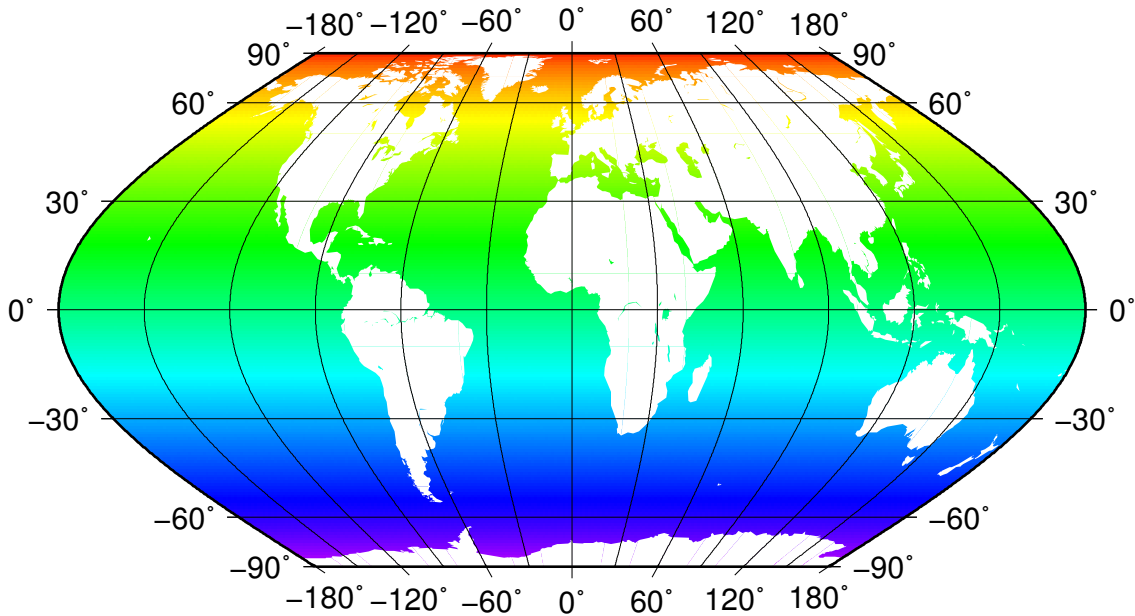


Figure P.1: Example created in isolation mode

are created in that directory as well. To make things even more easy, *GMT* now provides a set of handy shell functions in **gmt.shell.functions.sh**: simply include that file in the script and the creation and the removal of the temporary directory is reduced to a single command.

```
#!/bin/sh
#                               GMT Appendix P, example 2
#
# Purpose:      Illustrates the use of isolation mode
# GMT progs:    gmtset, grdimage, grdmath, makecpt, pscoast
# GMT funcs:    gmt_init_tmpdir, gmt_remove_tmpdir
#
ps=GMT_App_P_2.ps

# Make GMT shell functions accessible the the script
. gmt_shell_functions.sh

# Create a temporary directory. $GMT_TMPDIR will be set to its pathname.
gmt_init_tmpdir

# These settings will be local to this script only since it writes to
# $GMT_TMPDIR/.gmtdefaults4
gmtset COLOR_MODEL rgb ANNOT_FONT_SIZE_PRIMARY 14p

# Make grid file and color map in temporary directory
grdmath -Rd -I1 Y = $GMT_TMPDIR/lat.grd
makecpt -Crainbow -T-90/90/60 -Z > $GMT_TMPDIR/lat.cpt

# The grdimage command creates the history file $GMT_TMPDIR/.gmtcommands4
grdimage $GMT_TMPDIR/lat.grd -S1 -JK6.5i -C$GMT_TMPDIR/lat.cpt -P -K > $ps
pscoast -R -J -O -Dc -A5000 -Gwhite -B60g30/30g30 >> $ps

# Clean up all temporary files and the temporary directory
gmt_remove_tmpdir
```

P.2 Using both GMT 3 and 4

We encourage all *GMT* users to start using version 4 immediately; it has been tested extensively by the *GMT* team and has benefitted from bug reports for the 3.4.x versions. Users who still worry about the new version breaking things may install *GMT* 3.4.x versions and 4.x and use our utility **gmtswitch** to select

their current version should the need to switch arises. You will find **gmtswitch** in the top-level *GMT*4.x directory; install as explained below.

Because *GMT* 4.x is backwards compatible with the 3.4.x series yet maintains its parameters and history in separate hidden files (e.g., `.gmtdefaults4` versus `.gmtdefaults`) it is possible to install and use both versions on the same workstation. To simplify such setups we supply the utility **gmtswitch** which simplifies switching back and forth between any number of installed *GMT* 3-versions and *GMT* 4.x. Place the **gmtswitch** Bourne shell script in your general executable path (not in one of the *GMT* bin directories) and run it after you have finished installing all *GMT* versions of interest. The first time you run **gmtswitch** it will try to find all the available versions installed on your file system. The versions found will be listed in the file `.gmtversions` in your home directory; each line is the full path to a *GMT* root directory (e.g., `/usr/local/GMT3.4.2`). You may manually add or remove entries there at any time. You are then instructed to make two changes to your environment (the details are shell-dependent but explained by **gmtswitch**):

1. **gmtswitch** creates and maintains a symbolic link `this_gmt` in your home directory that will point to a directory with one of the installed *GMT* versions.
2. Make sure `$HOME/this_gmt/bin` is in your executable **PATH**.

Make those edits, logout, and log and back in again. The next time you run **gmtswitch** you will be able to switch between versions. Typing **gmtswitch** with no argument will list the available versions in a numerical menu and prompt you to choose one, whereas **gmtswitch** *version* will immediately switch to that version (*version* must be a piece of unique text making up the full path to a version, e.g., 3.4.2). If you use **tcsh** or **csh** you may have to type “rehash” to initiate the path changes.

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