The Generic Mapping Tools

GMT

Version 4

Technical Reference and Cookbook

by

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Generic Mapping Tools Graphics

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We would also like to acknowledge the feedback we have received from many of the users of earlier versions. Many of these suggestions have been implemented, and the bug reports have been useful in providing more robust programs. Specifically, we would like to thank Michael Barck, Manfred Brands, Stephan Eickschen, Ben Horner-Johnson, John Kuhn, Angel Li, John Lillibridge, Joaquim Luis, Andrew Macrae, Alex Madon, Greg Neumann, Lloyd Parkes, Ameet Raval, Remko Scharroo, Georg Schwarz, Richard Signell, Dirk Stoecker, Malte Thoma, David Townsend, William Weibel, and many others for advice on how to make GMT portable to DEC, SGI, HP, IBM, Apple, and NEXT workstations. John Lillibridge provided example 11. William Yip helped translate GMT to POSIX ANSI C and incorporate netCDF 3, Allen Cogbill provided OS/2 patches for EMX, and Hanno von Lom helped resolve problems with DLL libraries for Win32. The SOEST RCF staff (Ross Ishida, Pat Townsend, and Sharon Stahl) provided valuable help on Linux, web, and CGI script issues.

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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 simple cshell script.
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 documention.

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!

[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.csh`.
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 <u>underline</u> type style, e.g., <u>gmt.h</u>.

1. Preface

While GMT has served the map-making and data processing needs of scientists since 1988[1], 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 history of the changes from release to release, see the online Release Announcements and the file CHANGES in the main GMT directory.

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?

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 *date***T***clock*[2]. 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 gridfiles 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 grdfiles 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.

[1] Version 1.0 was then informally released at the Lamont-Doherty Earth Observatory.
[2] Use standard *UNIX* tools such as ***awk*** or ***perl*** to reformat files should your *date* and *clock* components reside in separate columns.

- **gmtselect**: New option **–Z** to pass or skip based on input *z*-range.
- **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 colors[3].
- **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 **–T***dz* 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,

[3] Used to color the background, foreground, and Not-a-Number areas.

- **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**.
- **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 **–R**0/360/-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 → processing → 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 free[1], 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* tools[2] 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, 25 map 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 25 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 → processing → 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 Licence (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 writers[3]. Because the publication costs of color illustrations are high, GMT offers 90 common bit and hachure patterns, including many geologic map symbol types, as well as complete graytone shading operations. Additional bit and hachure 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 avaliable 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 column[4]. 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 "grdfile" 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 another[5]. GMT contains programs that will read ASCII (*x,y,z*) files and produce gridded 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) "grdfiles" – Programs that grid ASCII (x,y,z) data or operate on existing grdfiles 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 listproc@hawaii.edu a note containing the single message

[3] One public-domain RIP is ***ghostscript***, available from www.gnu.org.
[4] Programs now also allow for fast, binary multicolumn file i/o.
[5] While 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-Rs with the GMT package, compatible supplements, and several Gb of useful 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.

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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 grd 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 .gmtdefaults4 file
grd2cpt	Generate a color palette table from a gridded file
grd2xyz	Conversion from 2-D gridded file to table data
grdblend	Blend several partially over-lapping grdfiles 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 gridded file
grdedit	Modify header information in a 2-D gridded file
grdfft	Perform operations on gridded files in the frequency domain
grdfilter	Filter 2-D gridded data sets in the space domain
grdgradient	Compute directional gradient from gridded files
grdhisteq	Histogram equalization for gridded files
grdimage	Produce images from 2-D gridded data sets
grdinfo	Get information about gridded files
grdlandmask	Create masking gridded files from shoreline data base
grdmask	Reset grid nodes in/outside a clip path to constants
grdmath	Mathematical operations on gridded files
grdpaste	Paste together gridded files along a common edge
grdproject	Project gridded data sets onto a new coordinate system
grdreformat	Converts gridded 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 gridded 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
makecpt	Make color palette tables
mapproject	Transformation of coordinate systems for table data
minmax	Report extreme values in table data files
nearneighbor	Nearest-neighbor gridding scheme
project	Project table data onto lines or great circles
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 rasterfiles 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 grayscale or colorscale on maps
pstext	Plot textstrings 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 *xyz* 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 *xyz* file to a 2-D gridded 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 29 map 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 *xyz* data by triangulation
pshistogram	Plot a histogram
psimage	Plot Sun rasterfiles 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 grayscale or colorscale
pstext	Plot textstrings
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	
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 gridded 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 grd 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 gridded file
grdblend	Blend several partially over-lapping grdfiles onto one grid
grdpaste	Paste together gridded 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 gridded file
DETERMINE TRENDS IN 1-D AND 2-D DATA	
fitcircle	Finds best-fitting great or small circles
grdtrend	Fits polynomial trends to gridded 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 gridded file
grdclip	Limit the z–range in gridded data sets
grdedit	Modify grid header information
grdfft	Operate on gridded files in frequency domain
grdgradient	Compute directional gradients from gridded files
grdhisteq	Histogram equalization for gridded files
grdlandmask	Creates mask gridded file from coastline database
grdmask	Set grid nodes in/outside a clip path to constants
grdmath	Reverse Polish Notation (RPN) calculator for gridded files
grdvolume	Calculate volume under a surface within a contour

<table>
<tr><th colspan="2">STANDARDIZED COMMAND LINE OPTIONS</th></tr>
<tr><td colspan="2">–B[p|s]xinfo[/yinfo[/zinfo]][WESNZwesnz+][:.title:] Tickmarks. Each info 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</td></tr>
<tr><td>–H[bf i][n_headers]</td><td>ASCII [input] tables have header record[s]</td></tr>
<tr><td>–J (upper case for width, lower case for scale)</td><td>Map projection (see below)</td></tr>
<tr><td>–JA$lon_0/lat_0/width$</td><td>Lambert azimuthal equal area</td></tr>
<tr><td>–JB$lon_0/lat_0/lat_1/lat_2/width$</td><td>Albers conic equal area</td></tr>
<tr><td>–JC$lon_0/lat_0/width$</td><td>Cassini cylindrical</td></tr>
<tr><td>–JD$lon_0/lat_0/lat_1/lat_2/width$</td><td>Equidistant conic</td></tr>
<tr><td>–JE$lon_0/lat_0/width$</td><td>Azimuthal equidistant</td></tr>
<tr><td>–JF$lon_0/lat_0/horizon/width$</td><td>Azimuthal Gnomonic</td></tr>
<tr><td>–JG$lon_0/lat_0/width$</td><td>Azimuthal orthographic</td></tr>
<tr><td>–JH$lon_0/width$</td><td>Hammer equal area</td></tr>
<tr><td>–JI$lon_0/width$</td><td>Sinusoidal equal area</td></tr>
<tr><td>–JJ$lon_0/width$</td><td>Miller cylindrical</td></tr>
<tr><td>–JKf$lon_0/width$</td><td>Eckert IV equal area</td></tr>
<tr><td>–JKs$lon_0/width$</td><td>Eckert VI equal area</td></tr>
<tr><td>–JL$lon_0/lat_0/lat_1/lat_2/width$</td><td>Lambert conic conformal</td></tr>
<tr><td>–JM$width$ or –JM$lon_0/lat_0/width$</td><td>Mercator cylindrical</td></tr>
<tr><td>–JN$lon_0/width$</td><td>Robinson</td></tr>
<tr><td>–JOa$lon_0/lat_0/az/width$</td><td>Oblique Mercator, 1: origin and azimuth</td></tr>
<tr><td>–JOb$lon_0/lat_0/lon_1/lat_1/width$</td><td>Oblique Mercator, 2: two points</td></tr>
<tr><td>–JOc$lon_0/lat_0/lon_p/lat_p/width$</td><td>Oblique Mercator, 3: origin and pole</td></tr>
<tr><td>–JP[a]$width$[$/origin$]</td><td>Polar [azimuthal] (θ, r) (or cylindrical)</td></tr>
<tr><td>–JQ$lon_0/width$</td><td>Equidistant cylindrical (Plate Carrée)</td></tr>
<tr><td>–JR$lon_0/width$</td><td>Winkel Tripel</td></tr>
<tr><td>–JS$lon_0/lat_0/width$</td><td>General stereographic</td></tr>
<tr><td>–JT$lon_0/width$</td><td>Transverse Mercator</td></tr>
<tr><td>–JU$zone/width$</td><td>Universal Transverse Mercator (UTM)</td></tr>
<tr><td>–JV$lon_0/width$</td><td>Van der Grinten</td></tr>
<tr><td>–JW$lon_0/width$</td><td>Mollweide</td></tr>
<tr><td>–JXwidth[l|pexp|T|t][/height[l|pexp|T|t]][d]</td><td>Linear, $\log_{10}$, x^a–y^b, and time</td></tr>
<tr><td>–JY$lon_0/lat_s/width$</td><td>General cylindrical equal area</td></tr>
<tr><td>–K</td><td>Append more PS later</td></tr>
<tr><td>–O</td><td>This is an overlay plot</td></tr>
<tr><td>–P</td><td>Select Portrait orientation</td></tr>
<tr><td>–Rwest/east/south/north[/zmin/zmax][r]</td><td>Specify Region of interest</td></tr>
<tr><td>–U[/dx/dy/][label]</td><td>Plot time-stamp on plot</td></tr>
<tr><td>–V</td><td>Run in verbose mode</td></tr>
<tr><td>–X[a]off</td><td>Shift plot origin in x-direction</td></tr>
<tr><td>–Y[a]off</td><td>Shift plot origin in y-direction</td></tr>
<tr><td>–b[i|o][s][ncol]</td><td>Select binary input or output</td></tr>
<tr><td>–ccopies</td><td>Set number of plot copies [1]</td></tr>
<tr><td>–f[i|o]colinfo</td><td>Set formatting of ASCII input or output</td></tr>
<tr><td>–:</td><td>Expect y/x input rather than x/y</td></tr>
</table>

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 **c**m, **i**nch, **m**eter, or **p**oint (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., **–X**4**c** means 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

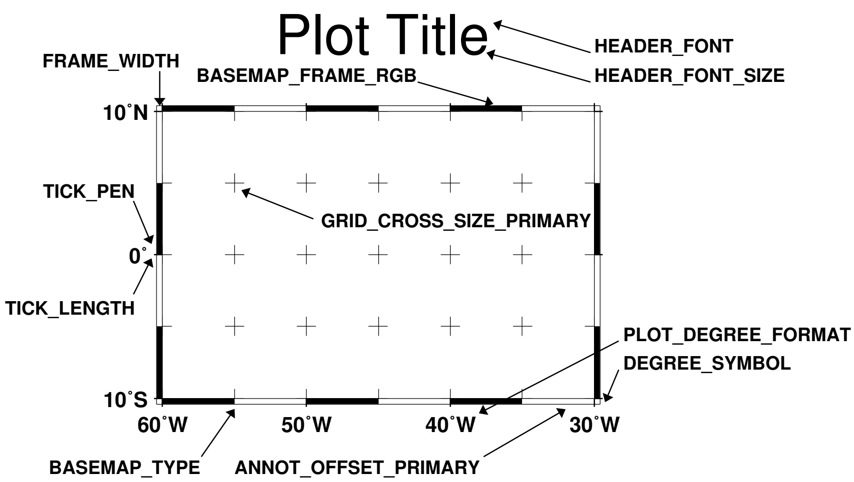


Figure 4.1: Some **GMT** parameters that affect plot appearance.

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 defaults[2], then tries to open the file .gmtdefaults4 in the current directory[3]. If not found, it will look for that file in your home directory. 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 to use, and many other choices (A complete list of all

[1] *PostScript* definition. In the typesetting industry a slighly 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.

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 = 1**i** as default, the **–X**1.5**i** 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 a sub-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. 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.

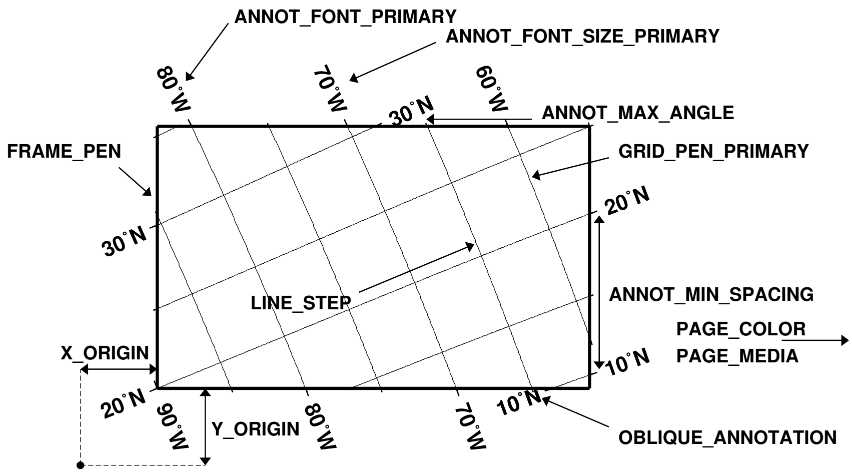


Figure 4.2: More **GMT** parameters that affect plot appearance.

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.

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. Finally, 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.

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.

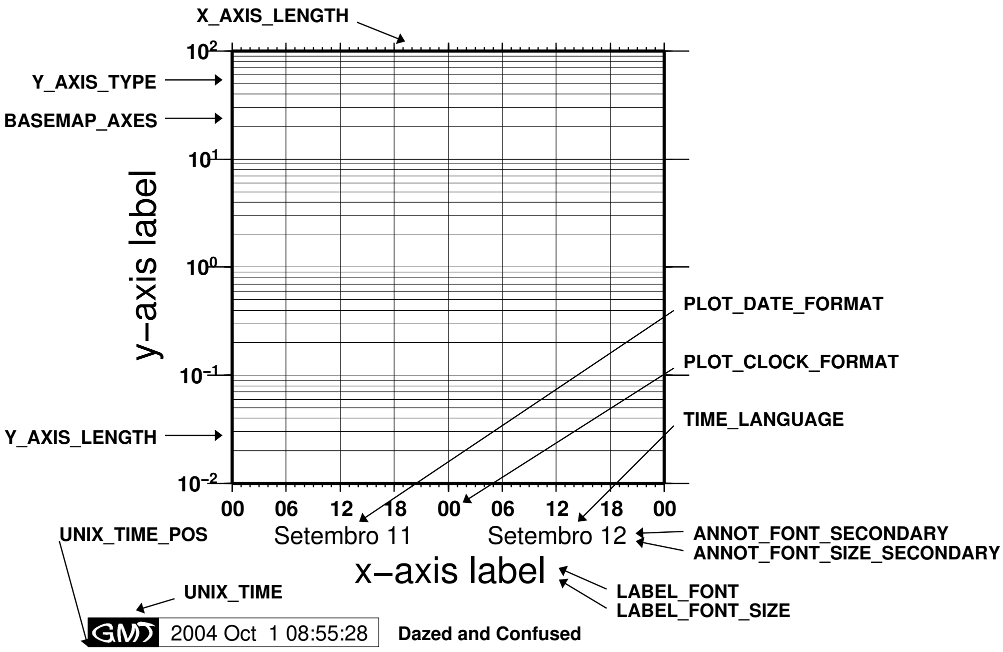


Figure 4.3: Even more **GMT** parameters that affect plot appearance.

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:

Option	*Meaning*
–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 *x*-coordinate for the plot origin on the page
–Y	Sets the *y*-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
–:	Assumes input geographic data are (*lat,lon*) and not (*lon,lat*)

Table 4.1: The 15 standardized **GMT** command line switches.

```
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 15 switches in Table 4.1 have the same meaning in all the programs (allthough 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

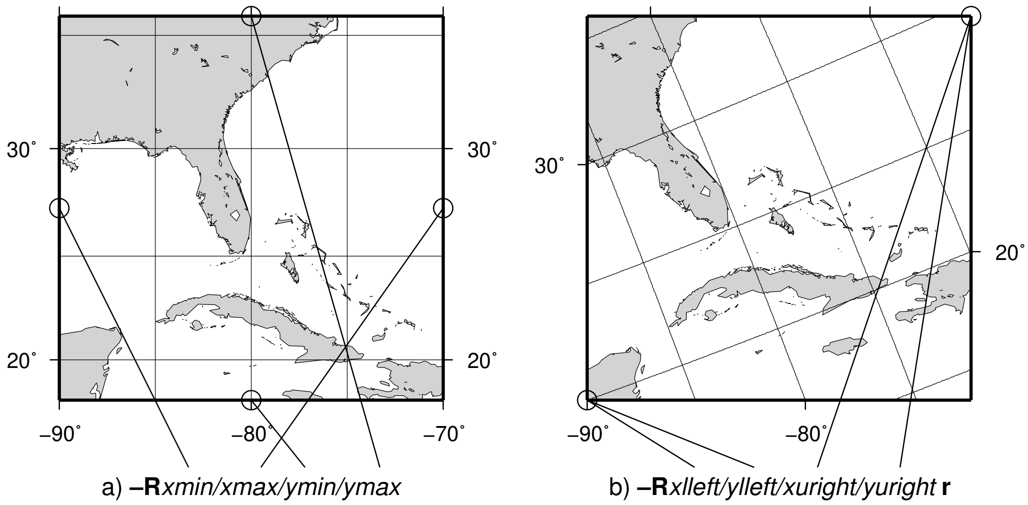


Figure 4.4: The plot region can be specified in two different ways. (a) Extreme values for each dimension, or (b) coordinates of lower left and upper right corners.

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

1. **–R***xmin*/*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. **–R***xlleft*/*ylleft*/*xuright*/*yuright***r**. 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**.

For rectilinear projections the 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 [±]*ddd*[:*mm*[:*ss*[.*xxx*]]][**W**|**E**|**S**|**N**] format (e.g., 123:27:15W). Note that **–Rg** and **–Rd** are shorthands for "global domain" **–R***0*/*360*/*-90*/*90* and **–R***-180*/*180*/*-90*/*90*, respectively.

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*[-**W***ww*[*-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 enteties 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 reforms[4] are extrapolated backward. Note that this is not historical.

Other coordinates: These are simply anything that is neither geographic nor calendar time related and are expected to be simple floating point values such as [±]*xxx.xxx*[E|e|D|d[±][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. One exception is the concept of relative time which is read as a floating point offset from an absolute time reference point (epoch). The unit and the epoch are specified with the **TIME_SYSTEM** parameter. Relative time coordinates are expected when a coordinate transformation involving relative time has been selected or when the **–f** switch has been used to indicate relative time coordinates.[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.

[4]The 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 signifigant 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 not 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.

[5]While 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.

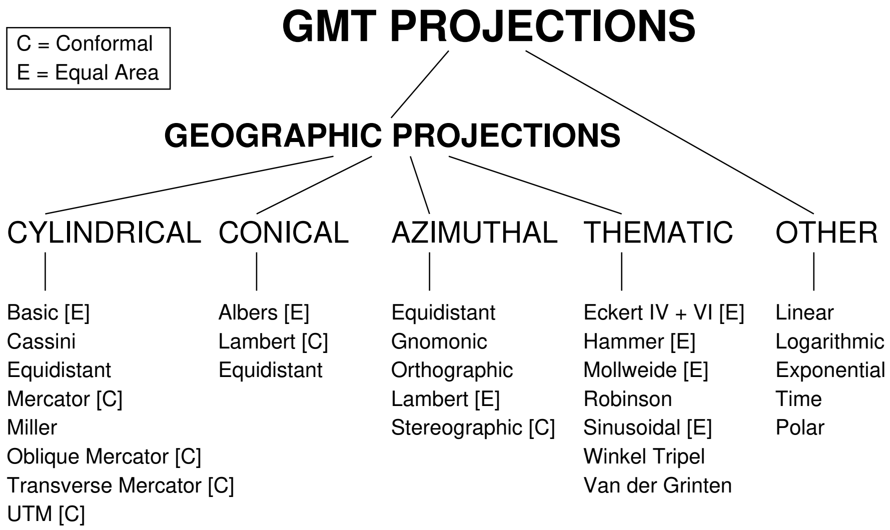


Figure 4.5: The 29 map projections and coordinate transformations available in **GMT**.

- **–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).

The projections avaiable 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 chapter, 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*[±*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 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 plot[6]. 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 ±*phase*.

Flag	*Description*
a	Annotation tick spacing
f	Frame tick spacing
g	Grid tick spacing

Table 4.2: Interval type codes.

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

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.

Flag	*Unit*	*Description*
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 (**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 (**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.

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 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.

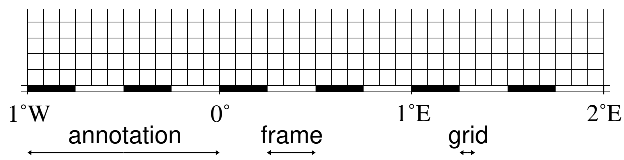


Figure 4.6: Geographic map border using separate selections for annotation, frame, and grid intervals. Formatting of the annotation is controlled by the parameter **PLOT_DEGREE_FORMAT** in your .gmtdefaults4 file.

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.

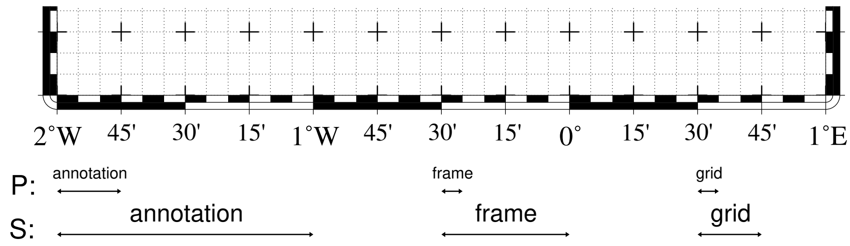


Figure 4.7: Geographic map border with both primary (P) and secondary (S) components.

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 "%lg", which is a C language format statement for floating point numbers[7], 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, "%.2lf" 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).

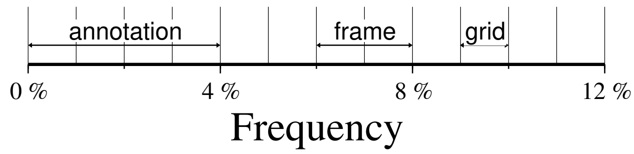


Figure 4.8: Linear Cartesian projection axis. Long tickmarks accompany annotations, shorter ticks indicate frame interval. The axis label is optional. We used **–R**0/12/0/1 **–JX**3/0.4 **–Ba**4**f**2**g**1:Frequency::,%:.

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, or 3. Annotations/ticks will then occur at 1, 1–2–5, or 1,2,3,4,...,9, respectively, for each magnitude range.

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.

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

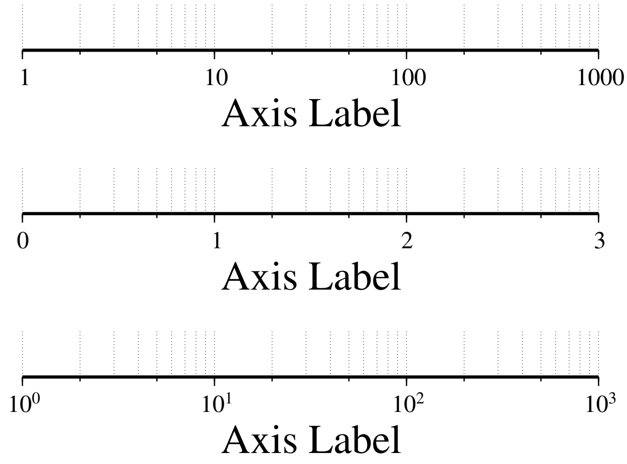


Figure 4.9: Logarithmic projection axis using separate values for annotation, frame, and grid intervals. (top) Here, we have chosen to annotate the actual values. Interval = 1 means every whole power of 10, 2 means 1, 2, 5 times powers of 10, and 3 means every 0.1 times powers of 10. We used **–R**1/1000/0/1 **–JX**3l/0.4 **–Ba**1**f**2**g**3. (middle) Here, we have chosen to annotate $\log_{10}$ of the actual values, with **–Ba**1**f**2**g**3**l**. (bottom) We annotate every power of 10 using $\log_{10}$ of the actual values as exponents, with **–Ba**1**f**2**g**3**p**.

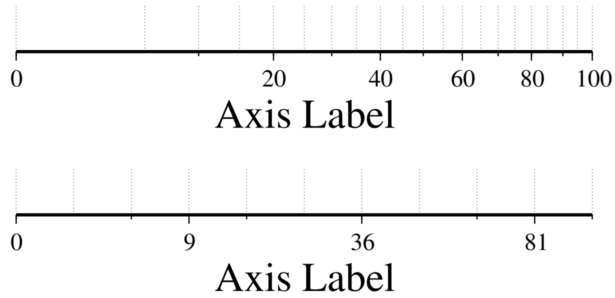


Figure 4.10: Exponential or power projection axis. (top) Using an exponent of 0.5 yields a $\sqrt{x}$ axis. Here, intervals refer to actual data values, in **–R**0/100/0/1 **–JX**3**p**0.5/0.4 **–Ba**20**f**10**g**5. (bottom) Here, intervals refer to projected values, although the annotation uses the corresponding unprojected values, as in **–Ba**3**f**2**g**1**p**.

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 -JX6T/0.2 -Bpa7Rf1d -Bsa1OS -P > GMT_-B_time1.ps
```

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

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

```
gmtset PLOT_CLOCK_FORMAT hh:mm
psbasemap -R2001-9-11T/2001-9-13T/0/1 -JX6t/0.2 -Bpa6Hf1h -Bsa1KS -P -K > GMT_-B_time2.ps
```

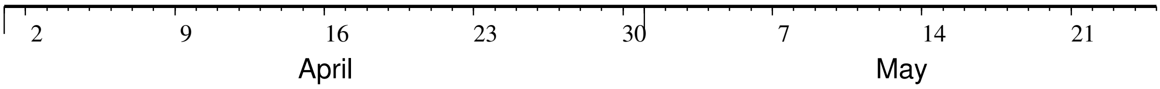


Figure 4.11: Cartesian time axis, example 1.

```
gmtset PLOT_DATE_FORMAT "o dd"
psbasemap -R -JX -Bpa6Hf1h -Bsa1DS -O -Y0.65i >> GMT_-B_time2.ps
```

The lower example (Figure 4.12) chooses to annotate the weekdays (by specifying **a**1**K**) while the upper example choses dates (by specifying **a**1**D**). 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.

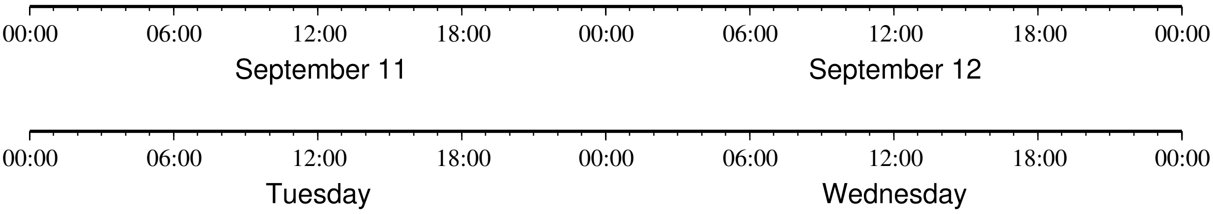


Figure 4.12: Cartesian time axis, example 2.

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

```
gmtset PLOT_DATE_FORMAT o TIME_FORMAT_PRIMARY Character
psbasemap -R1997T/1999T/0/1 -JX6T/0.2 -Bpa3Of1o -Bsa1YS -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 **PLOT_FORMAT_PRIMARY** selects the 1-character, upper case abbreviation of month names using the current language (selected by **TIME_LANGUAGE**).

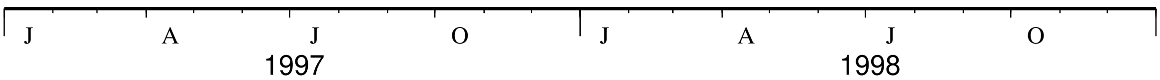


Figure 4.13: Cartesian time axis, example 3.

The fourth example (Figure 4.14) only shows a few hours of a day. 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
psbasemap -R0.2/0.35/0/1 -JX-6t/0.2 -Bpa15mf5m -Bsa1HS -P > GMT_-B_time4.ps
```

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_SECONDARY full
psbasemap -R2001-9-11T/2001-9-29T/0/1 -JX6t/0.2 -Bpa1K -Bsa1US -P -K > GMT_-B_time5.ps
gmtset PLOT_DATE_FORMAT o TIME_WEEK_START Sunday TIME_FORMAT_PRIMARY Char
psbasemap -R2001-9-8T/2001-9-29T/0/1 -JX6t/0.2 -Bpa3Kf1k -Bsa1rS -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.

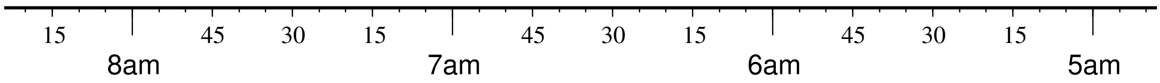


Figure 4.14: Cartesian time axis, example 4.

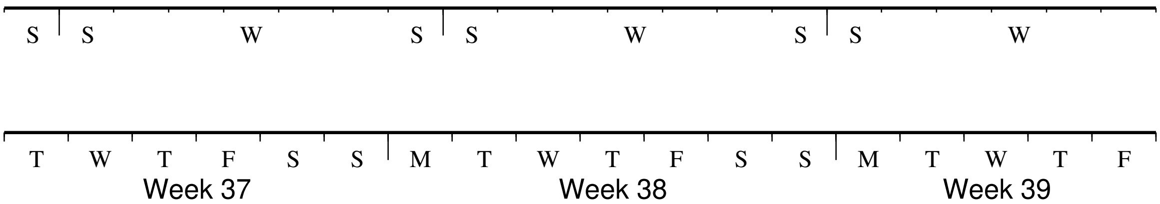


Figure 4.15: Cartesian time axis, example 5.

```
gmtset PLOT_DATE_FORMAT "o yy" TIME_FORMAT_PRIMARY Abbreviated
psbasemap -R1996T/1996-6T/0/1 -JX6T/0.2 -Ba1Of1dS -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.

```
gmtset PLOT_DATE_FORMAT jjj TIME_INTERVAL_FRACTION 0.05
psbasemap -R2000-12-15T/2001-1-15T/0/1 -JX6T/0.2 -Bpa5Df1d -Bsa1YS -P > GMT_-B_time7.ps
```

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., **–H**4. 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 **–H***n_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 mode[8]. 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 ommits the trailer, that all intermediate calls omit both header and trailer, and that the final overlay omits the header.

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

Figure 4.16: Cartesian time axis, example 6.

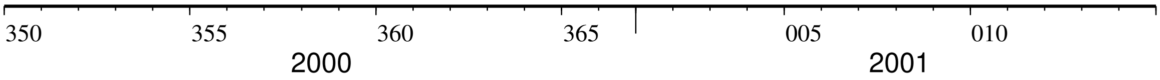


Figure 4.17: Cartesian time axis, example 7.

–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 ommits the header information [Default initializes a new 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).

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**.

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 plots[9] 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 achieve 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 or binary data. When using 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 rather than double precision). 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. For more information, see Appendix B.

4.4.11 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 **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

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

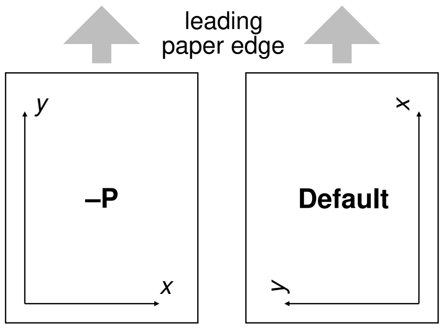


Figure 4.18: Users can specify Landscape [Default] or Portrait (**–P**) orientation.

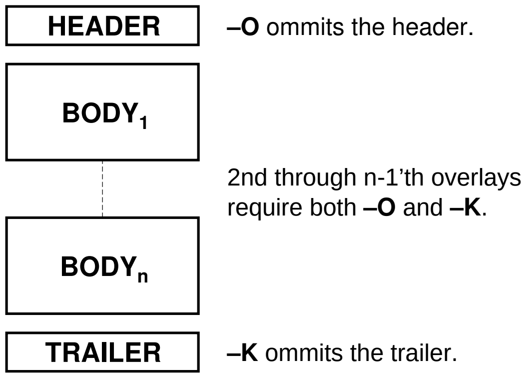


Figure 4.19: A final *PostScript* file consists of a stack of individual pieces.

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 **fi**0y,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 Section 4.10.

4.4.12 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.

4.4.13 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.

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

Figure 4.20: The **–U** option makes it easy to "date" a plot.

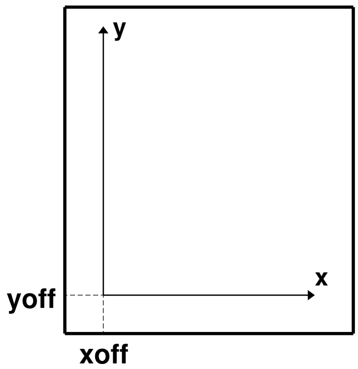


Figure 4.21: Plot origin can be translated freely with **–X –Y**.

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

then a subsequent **psxy** command to plot symbols only needs to state **–J**o in order to activate the same projection. In contrast, note that **–J** by itself will pick the most recently used projection. Previous commands 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 three other directories pointed to by environmental parameters (if set). These are **GMT_GRIDDIR**, **GMT_IMGDIR**, and **GMT_DATADIR**, and they may be set by the user to point to directories that contain data sets of general use. Normally, the first directory will hold gridded data sets accessible via the supplemental program **grdraster** whereas the second will hold the binary Mercator data images accessible via the supplemental program **img2grd**; see Appendix A for information about these supplemental programs. The third directory may hold miscellaneous data sets such as lines, points, and text plottable directly with **psxy** or **pstext**. 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 Output

Most programs write their results, including *PostScript* plots, to standard output. The exceptions are those which may create binary netCDF grd-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 data are expected (**–b**) 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.

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 discription 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 the first two columns are longitude and latitude, and that the third column (e.g., *z*) is absolute calendar time, we add **–fi**0x,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 have 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 5**p** 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]. Table 4.4 shows this list and the corresponding pen widths.

Pen name	*Width*
faint	0
default	0.25p
thinnest	0.25p
thinner	0.50p
thin	0.75p
thick	1.0p
thicker	1.5p
thickest	2p
fat	3p
fatter	6p
fattest	12p

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 0–1[10].
4. CMYK. Specify *cyan*/*magenta*/*yellow*/*black*, each ranging from 0–100%.
5. Name. Specify one of 663 valid color names as defined in the X11 color table[11]. 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 *texture* attribute controls the appearance of the line. "." yieds a dotted line, while a dashed pen is requested with "-". 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 **–W**0.1c,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**.

Pen example	*Comment*
–W0.5p	Solid black line, 0.5 point thick
–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.

[10]For an overview of color systems such as HSV, see Appendix I.
[11]On most *UNIX*-type systems you can find the file rgb.txt in /usr/X11R6/lib/X11 or thereabouts, or use the command ***showrgb***.

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:

–G*fill*
–Gp*dpi/pattern*[:**B***color*[**F***color*]]

fill: In the first case we may specify a *gray* shade (0–255), RGB color (*r*/*g*/*b* all in the 0–255 range), 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 rasterfiles[12]. 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 :**B***color*[**F***color*]) 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 rasterimages 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.

Fill example	*Comment*
–Gblue	Solid blue
–G120/80/35	Kind of brown, R/G/B-style
–G290-0.25-1	Digging pink, h-s-v – style
–GDarkOliveGreen1	One of those X11 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

[12]Convert other graphics formats to Sun ras format using ImageMagick's ***convert*** program.

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 a given grid file. However, in some situations you will need to make a cpt-file by hand or using text tools like ***awk*** or ***perl***.

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 system[13], the format of the cpt-file is:

z_0	R_{min}	G_{min}	B_{min}	z_1	R_{max}	G_{max}	B_{max}	[**A**]
...								
z_{n-2}	R_{min}	G_{min}	B_{min}	z_{n-1}	R_{max}	G_{max}	B_{max}	[**A**]

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 colorscale when plotted using **psscale**. The optional **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 colorscales. 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	R_{back}	G_{back}	B_{back}
F	R_{fore}	G_{fore}	B_{fore}
N	R_{nan}	G_{nan}	B_{nan}

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.

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 grd-file in that a separate grdfile holding intensities in the [-1,+1] range must be provided. Such intensity files can be derived from the data grdfile 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.

[13] For CMYK the format obviously involves two extra columns.

4.16 Character escape sequences

For annotation labels or textstrings 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.

Code	*Effect*
@~	Turns symbol font on or off
@%*fontno*%	Switches to another font; @%% resets to previous font
@+	Turns superscript on or off
@-	Turns subscript on or off
@#	Turns small caps on or off
@!	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):

Code	*Effect*	*Code*	*Effect*
@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} Ångstrøm
`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 Embedded grdfile format specifications

GMT has the ability to read more than one grdfile format. As distributed, GMT now recognizes 13 predefined file formats. These are

0. GMT netCDF 4-byte float format [Default]

1. Native binary single precision floats in scanlines with leading grd header

2. Native binary short integers in scanlines with leading grd header

3. 8-bit standard Sun rasterfile (colormap ignored)

4. Native binary unsigned char in scanlines with leading grd header

5. Native binary bits in scanlines with leading grd header

6. Native binary "surfer" grid files

7. netCDF 1-byte byte format

8. netCDF 1-byte char format

9. netCDF 2-byte int format

10. netCDF 4-byte int format

11. netCDF 8-byte double format

12. NOAA/NGDC MGG grid format

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.

Because of these new formats it is sometimes necessary to provide more than simply the name of the file on the command line. For instance, a 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 grdfiles will decode the given filename as follows:

name[=*id*[/*scale*/*offset*[/*nan*]]]

where everything in brackets is optional. If you only use the default netCDF file format then no options are needed: just continue to pass the name of the grdfile. However, if you use another format you must append the =*id* string, where *id* is the format id number listed above. In addition, should you want to multiply the data by a scale factor, then add a constant offset you may 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 may append the /*nan* suffix to the scaling string (it cannot go by itself; note the nesting of the brackets!).

Some of the grd formats allow writing to standard output and reading from standard input which means you can connect GMT programs that operate on grdfiles with pipes, thereby speeding up execution and eliminating the need for large, intermediate grdfiles. You specify standard input/output by leaving out the filename entirely. That means the "filename" will begin with "=*id*" since the GMT default netCDF format does not allow piping (due to the design of netCDF).

Everything looks more obvious after a few examples:

1. To write a binary float grd file, specify the name as my_file.grd=1.

2. To read a short integer grd 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=2/10/32000/32767.

3. To read a 8-bit standard Sun rasterfile (with values in the 0–255 range) and convert it to a ±1 range, give the name as rasterfile=3/7.84313725e-3/-1 (i.e., 1/127.5).

4. To write a short integer grd file to standard output after subtracting 32000 and dividing its values by 10, give filename as =2/0.1/-3200.

Programs that both read and/or write more than one grdfile may specify different formats and/or scaling for the files involved. The only restriction with the embedded grd specification mechanism is that no grdfiles 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 home directory 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    0          -     -      -      Default format
b      1          -     -      -      Native binary floats
i2     2          -     -      32767  2-byte integers
ras    3          -     -      -      Sun rasterfiles
byte   4          -     -      255    1-byte grids
bit    5          -     -      -      0 or 1 grids
mask   5          -     -      0      1 or NaN masks
faa    2          0.1   -      32767  Gravity in 0.1 mGal
```

These suffices can be anything that make 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=2/1/0/32767, and the filename wet.mask means wet.mask=5/1/0/0. For a file intended for masking, i.e., the nodes are either 1 or NaN, the bit or mask format file may as small as 1/32 the size of the corresponding grd format file.

4.18 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 $0/0$. This value is 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.

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 demostrate 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} coordinatetransformation
- 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-, y-, and z-axes. 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 degree 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

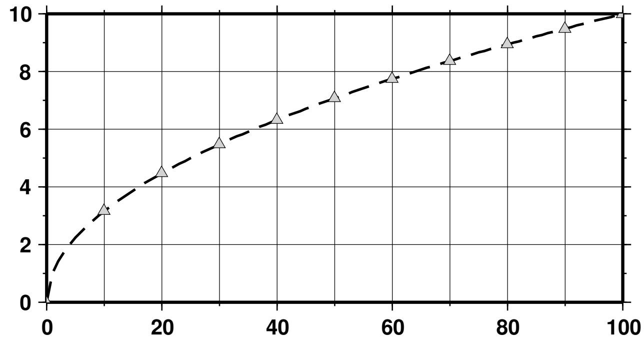


Figure 5.1: Linear transformation of Cartesian coordinates.

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., **–Jx**0.1i/0.5i or **–JX**8i/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/a2f1g2WSne -W1p,- -P -K sqrt.d > GMT_linear.ps
psxy -R -JX -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 data although a linear transformation has been chosen. We do so by appending a **d** (for degrees) 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 -R-55/305/-90/90 -Jx0.014id -B60g30f15/30g30f15WSen -Dc -A1000 -Glightgray -W0.25p -P \
    > GMT_linear_d.ps
gmtset GRID_CROSS_SIZE_PRIMARY 0
```

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**. However, for command line arguments we may specify time using either absolute or relative time. An absolute time entry must be given as [*date*]**T**[*clock*] (with

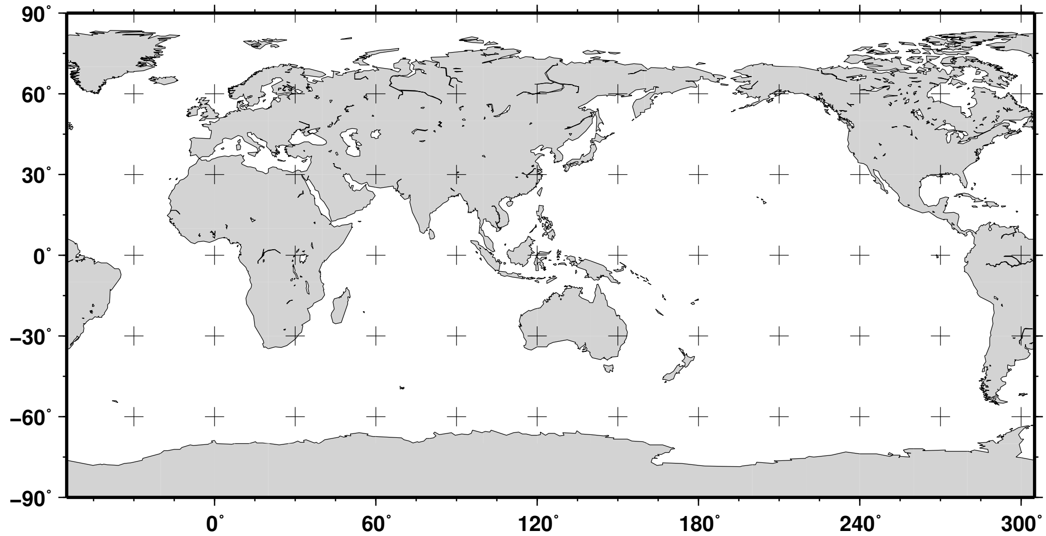


Figure 5.2: Linear transformation of map coordinates.

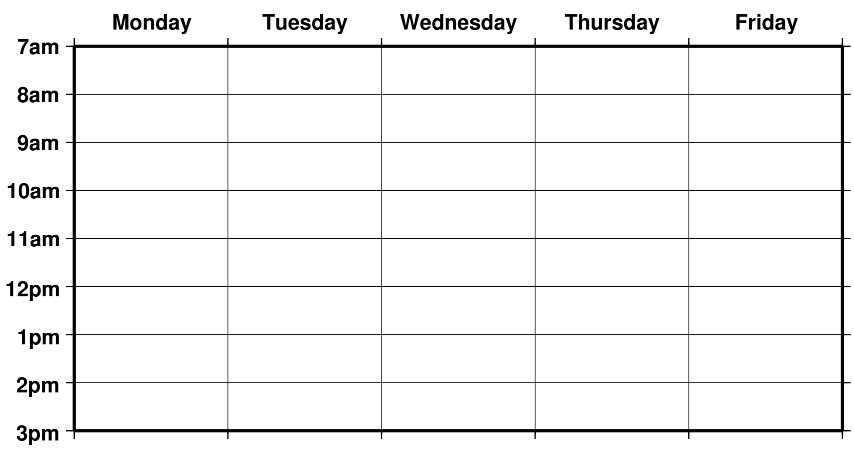


Figure 5.3: Linear transformation of calendar coordinates.

date given as *yyyy*[-*mm*[-*dd*]], *yyyy*[-*jjj*], or *yyyy*[-**W***ww*[-*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 (see **TIME_SYSTEM** 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 -JX4T/-2T -Ba1Kf1kg1d/a1Hg1hWsNe -P > GMT_linear_cal.ps
```

5.1.2 Cartesian Logarithmic projection

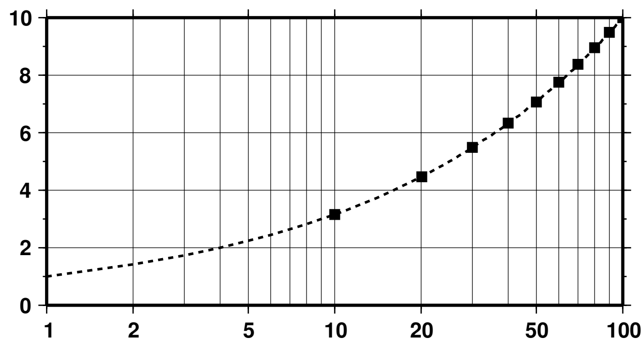


Figure 5.4: Logarithmic transformation of *x*-coordinates.

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

```
psxy -R1/100/0/10 -Jx1.5il/0.15i -B2g3/a2f1g2WSne -W1t2_2:0p -P -K -H sqrt.d > GMT_log.ps
psxy -R -Jx -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 **l** must be appended twice: Once after the *x*-scale (before the /) and once after the *y*-scale.

5.1.3 Cartesian Power projection

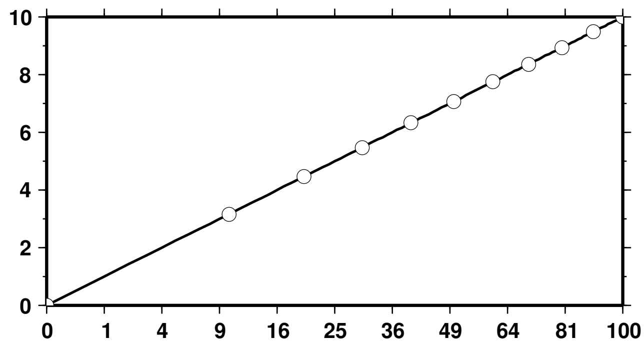


Figure 5.5: Exponential or power transformation of *x*-coordinates.

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 **p**1 since it is identical to the linear transformation. Thus our command becomes

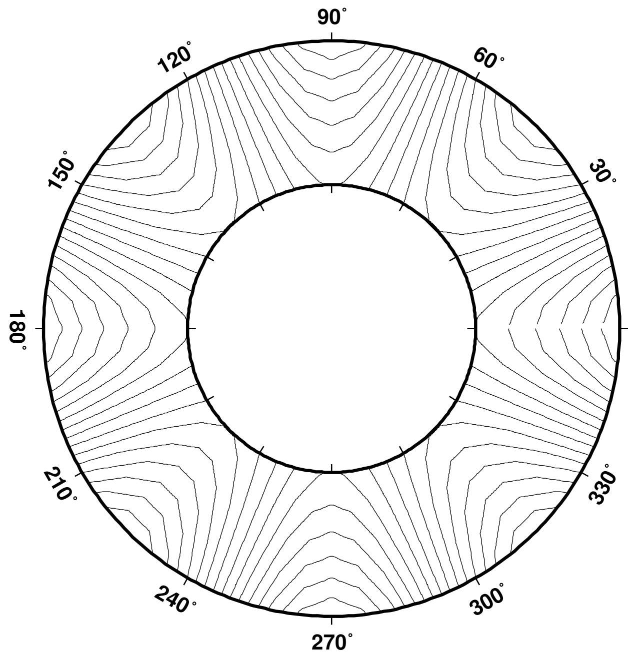


Figure 5.6: Polar (Cylindrical) transformation of (θ, r) coordinates.

```
psxy -R0/100/0/10 -Jx0.3ip0.5/0.15i -Ba1p/a2f1WSne -W1p -P -K sqrt.d > GMT_pow.ps
psxy -R -Jx -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:

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, $x' = f(\theta, r) = ar\cos(\theta - \theta_0) + b$ and $y' = g(\theta, r) = ar\sin(\theta - \theta_0) + c$.
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, $x' = f(\theta, r) = ar\cos(90 - (\theta - \theta_0)) + b$ and $y' = g(\theta, r) = ar\sin(90 - (\theta - \theta_0)) + c$.

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]

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 grdfiles.

```
grdmath -R0/360/2/4 -I6/0.1 X 4 MUL PI MUL 180 DIV COS Y 2 POW MUL = test.grd
grdcontour test.grd -JP3i -B30Ns -P -C2 -S4 --PLOT_DEGREE_FORMAT=+ddd > GMT_polar.ps
rm -f test.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 25 different map 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.

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:

```
gmtset GRID_CROSS_SIZE_PRIMARY 0
pscoast -R110/140/20/35 -JB125/20/25/45/5i -B10g5 -Dl -Glightgray -W0.25p -A250 -P > GMT_albers.ps
```

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

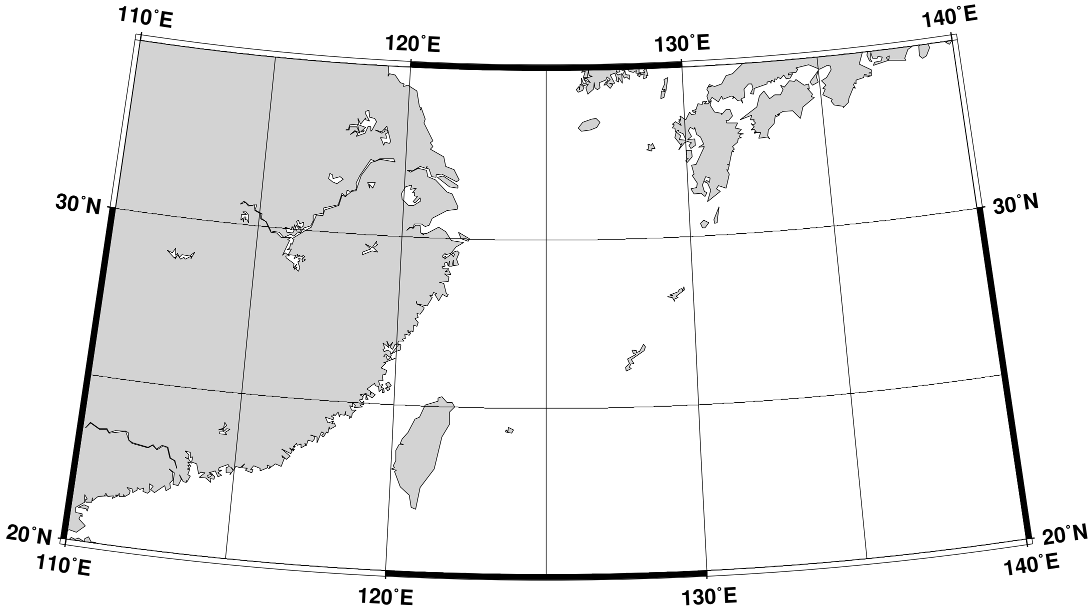


Figure 6.1: Albers equal-area conic map projection

6.1.2 Lambert Conic Conformal Projection (–Jl –JL)

This conic projection was designed by 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.

- Longitude and latitude of the projection center
- Two standard parallels
- Map scale in inch/degree or 1:xxxxx notation (**–Jl**), 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 -Dl -N1/1p -N2/0.5p -A500 -Glightgray \
    -W0.25p -P > GMT_lambert_conic.ps
gmtset GRID_CROSS_SIZE_PRIMARY 0
```

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%.

6.1.3 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

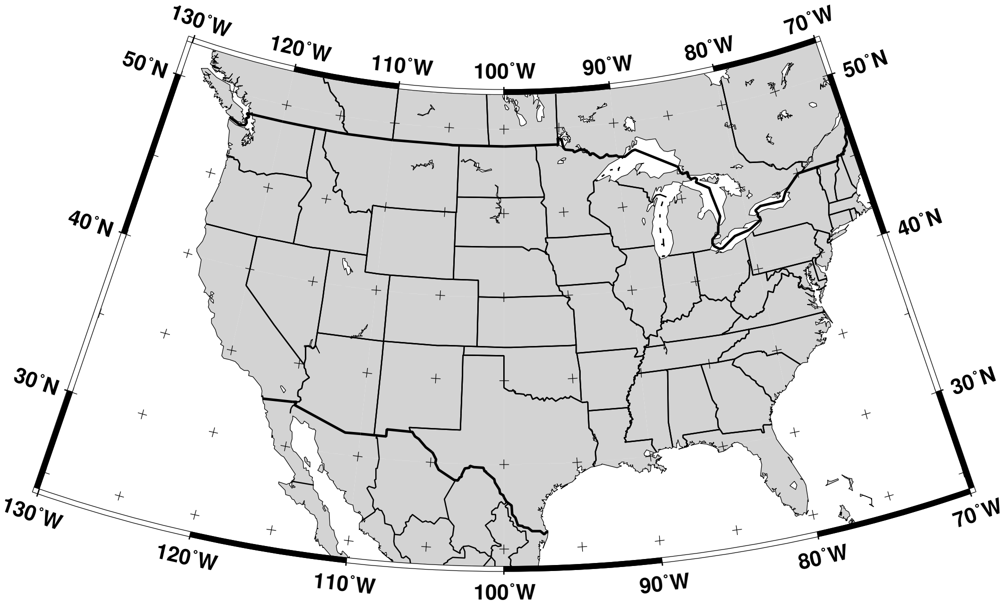


Figure 6.2: Lambert conformal conic map projection

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 -N1/1p -Glightgray \
   -W0.25p -P > GMT_equidistant_conic.ps
gmtset GRID_CROSS_SIZE_PRIMARY 0
```

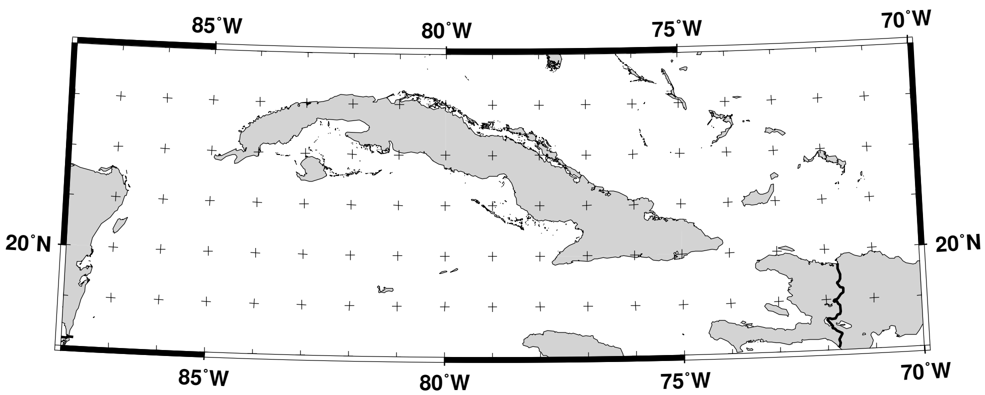


Figure 6.3: Equidistant conic map projection

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
- Scale as 1:xxxxx or as radius/latitude where radius is distance on map in inches from projection center to an oblique latitude (**–Ja**), or map width in inches (**–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°E/40°S (lower left) and 60°E/10°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 -Dl -A500 -Glightgray -W0.25p -P > \
    GMT_lambert_az_rect.ps
```

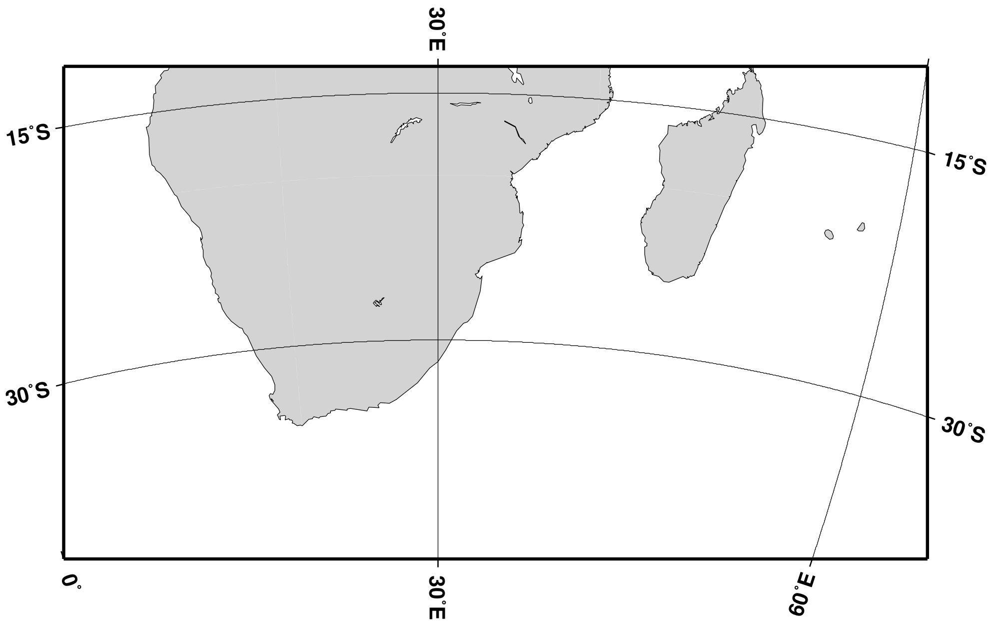


Figure 6.4: Rectangular map using the Lambert azimuthal equal-area projection.

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 (**–R**0/360/-90/90). 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°/0°) 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.

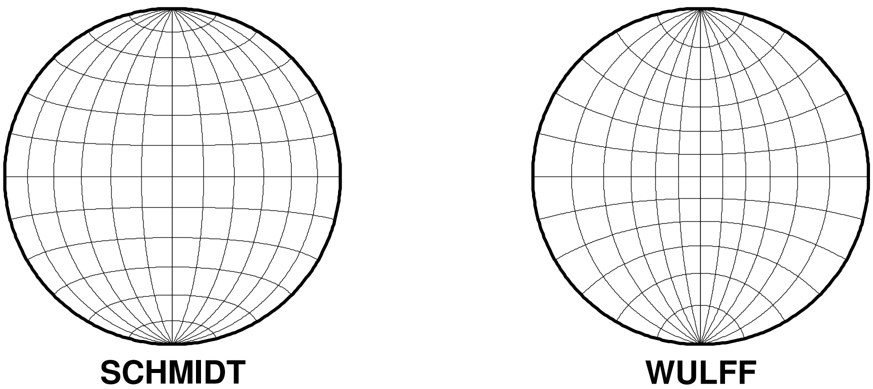


Figure 6.6: Equal-Area (Schmidt) and Equal-Angle (Wulff) stereo nets.

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.
- 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**).

A default map scale factor of 0.9996 will be applied by default (allthough 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

```
gmtset PLOT_DEGREE_FORMAT ddd:mm:ss
pscoast -R-30/30/60/72 -Js0/90/4.5i/60 -Ba10g5/5g5 -Dl -A250 -Gblack -P > GMT_stereographic_polar.ps
```

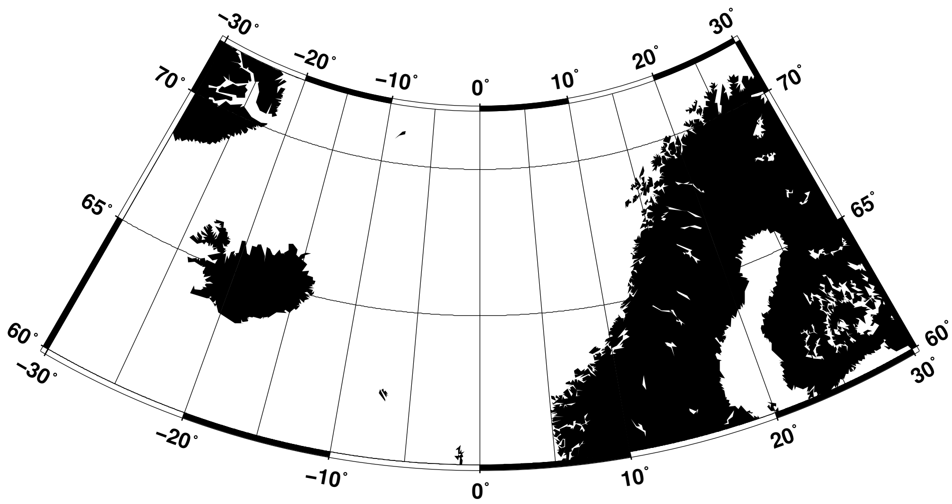


Figure 6.7: Polar stereographic conformal projection.

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 PLOT_DEGREE_FORMAT ddd:mm:ss OBLIQUE_ANNOTATION 30
pscoast -R-25/59/70/72r -JS10/90/11c -B30g10/5g5 -Dl -A250 -Glightgray -W.25p -P > \
    GMT_stereographic_rect.ps
```

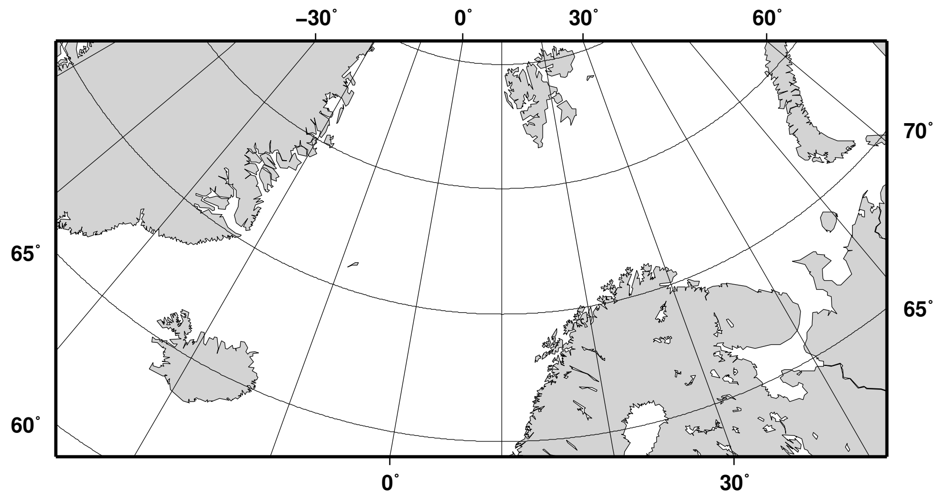


Figure 6.8: Polar stereographic conformal projection with rectangular borders.

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

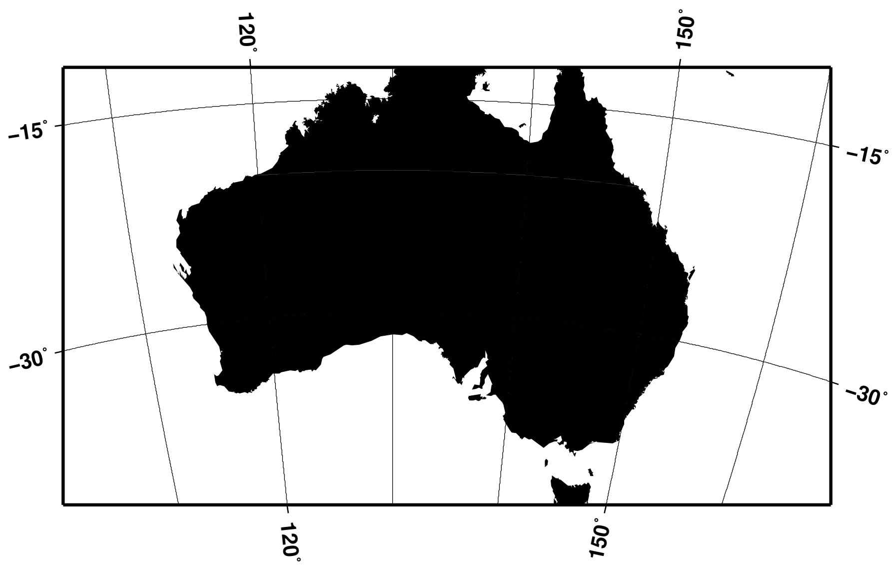


Figure 6.9: General stereographic conformal projection with rectangular borders.

By choosing 0°/0°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 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 space. As with Lambert's equal-areal 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 introducted 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 pictoral views at a small scale, only the spherical form is necessary.

To specify the orthographic projection you must supply

- Longitude and latitude of the projection center.
- 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°W/40°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: Hemisphere map using the Orthographic projection.

6.2.4 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.
- 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°W/40°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 -W0.25p -P > GMT_az_equidistant.ps
```

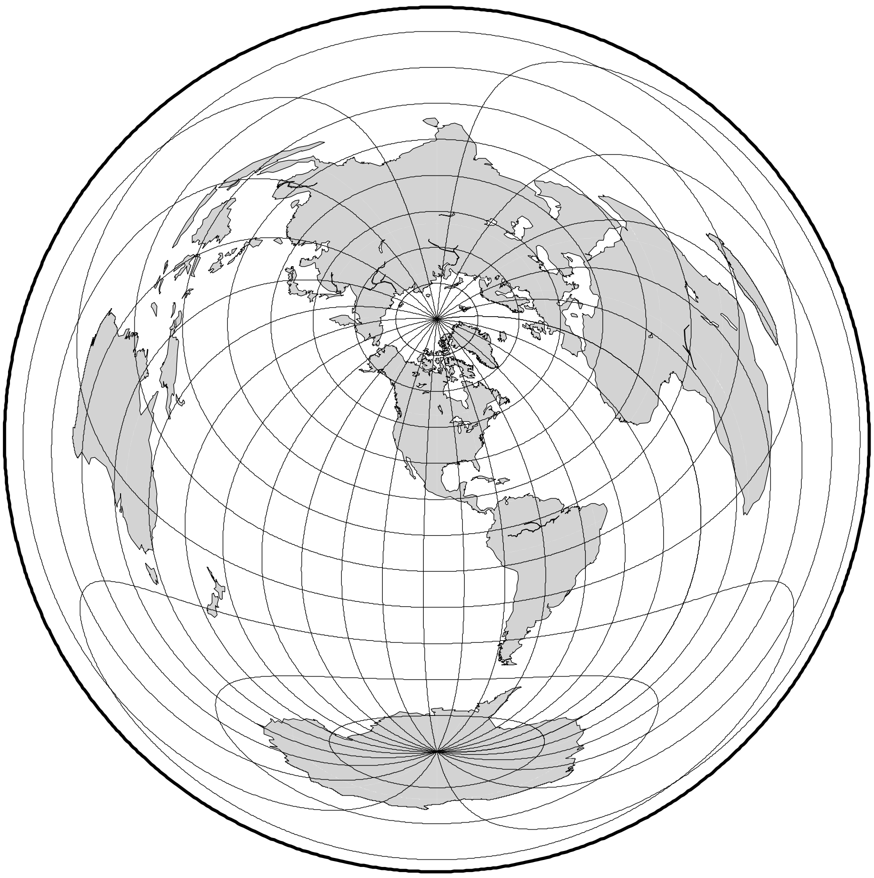


Figure 6.11: World map using the equidistant azimuthal projection.

6.2.5 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 introducted 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 pictoral 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.
- The horizon, i.e., the number of degrees from the center to the edge. This must be $< 90°$.
- 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 (**–Jf**), or map width (**–JF**).

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

```
pscoast -Rg -JF-120/35/60/4.5i -Bg15 -Dc -A10000 -Glightgray -W0.25p -P > GMT_gnomonic.ps
```

Figure 6.12: Gnomonic azimuthal projection.

TM

6.3 Cylindrical Projections

6.3.1 Mercator Projection (–Jm –JM)

Probably the most famous of the various map projections, the Mercator projection takes its name from Mercator who presented it in 1569. It is a cylindrical, conformal projection 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 voyage[2]. 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]
- 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 PLOT_DEGREE_FORMAT ddd:mm:ss BASEMAP_TYPE fancy
pscoast -R0/360/-70/70 -Jm1.2e-2i -Ba60f30/a30f15 -Dc -A5000 -Gblack -P > GMT_mercator.ps
```

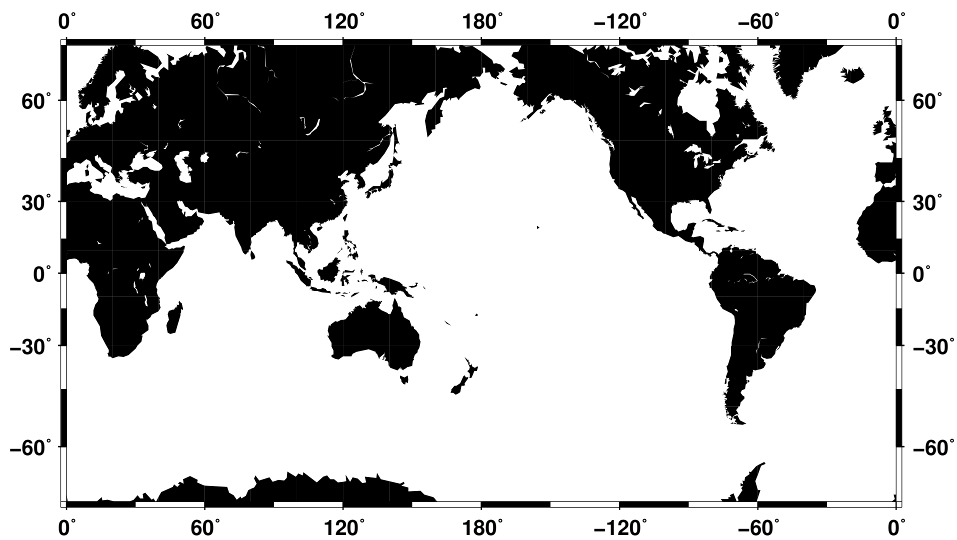


Figure 6.13: Simple Mercator map.

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.

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

6.3.2 Transverse Mercator (–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
- The latitude of origin
- 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 -Dl -A250 -Glightgray -W0.25p -P > GMT_transverse_merc.ps
```

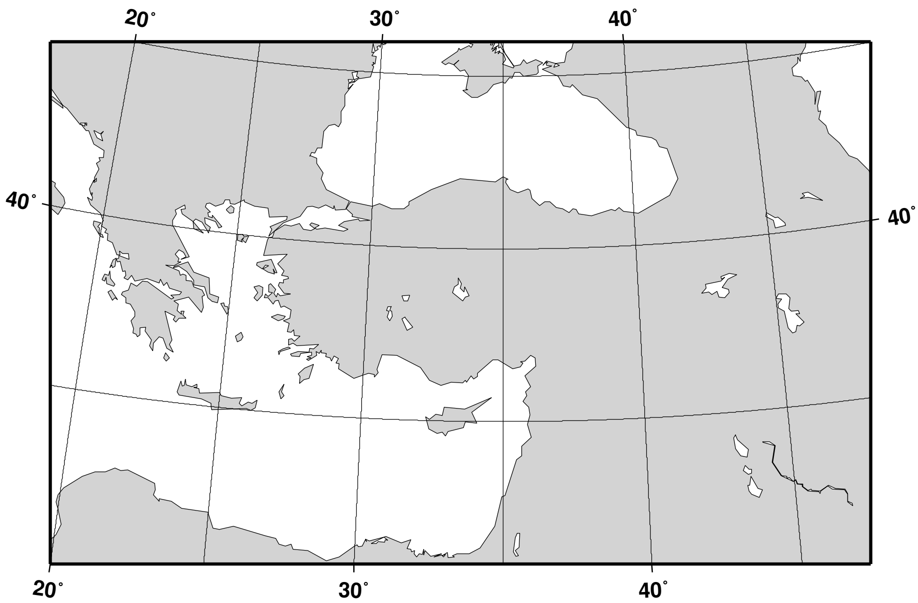


Figure 6.14: Rectangular Transverse Mercator map.

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 6.15. Note that when a world map is given (indicated by **–R***0/360/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 degrees.

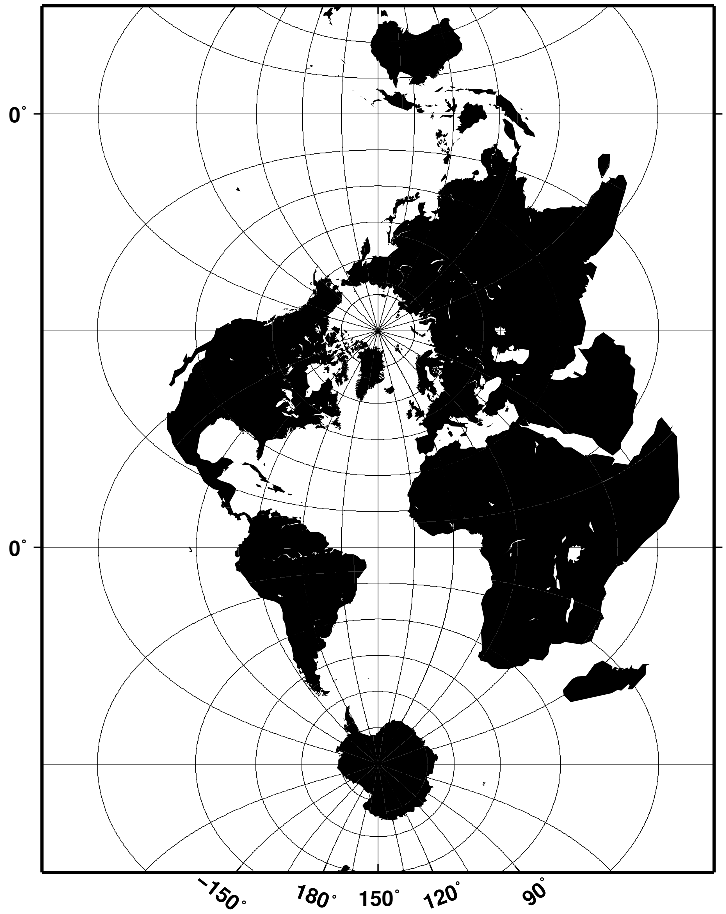


Figure 6.15: A global Transverse Mercator map.

6.3.3 Universal Transverse Mercator UTM (–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. GMT implements both the transverse Mercator and the UTM projection. When selecting UTM you must specify:

- UTM zone (1–60). Use negative value for zones in the southern hemisphere
- 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. (allthough 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.

6.3.4 Oblique Mercator (–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 -Dl -A250 -Glightgray -W0.25p -P \
    -Tf301.5/23/0.4i/2 --HEADER_FONT_SIZE=8p --LABEL_OFFSET=0.05i > GMT_obl_merc.ps
```

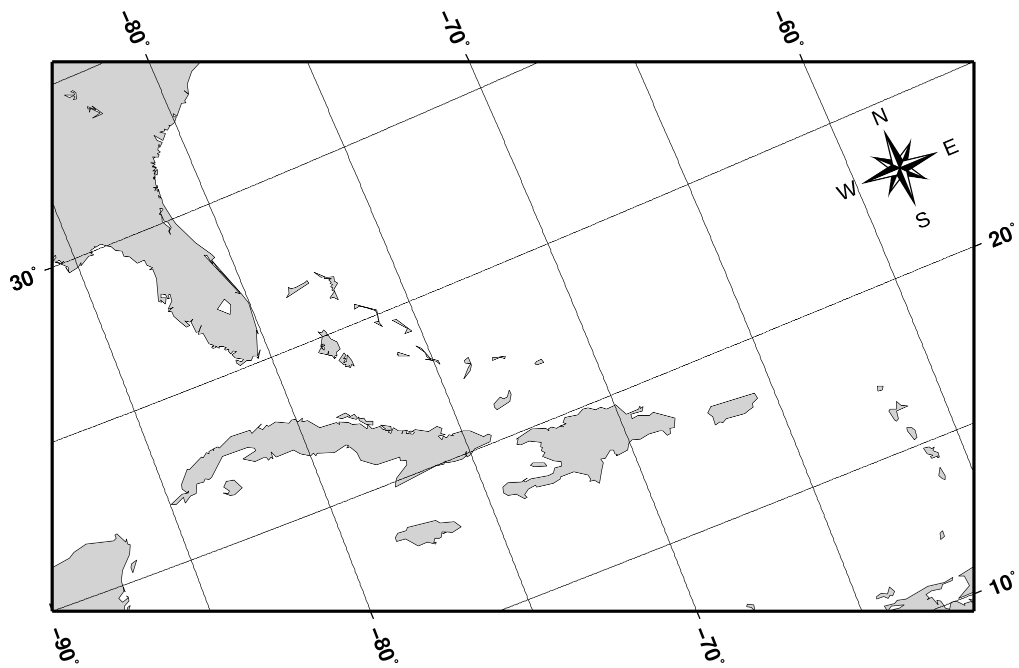


Figure 6.16: Oblique Mercator map using **–Joc**. We make it clear which direction is North by adding a star rose with the **–T** option.

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 C. F. Cassini 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°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 -B1g1f30m -Lf9.5/38.8/40/60 -Dh -Glightgray \
   -W0.25p -Ia/0.5p -P --LABEL_FONT_SIZE=12 > GMT_cassini.ps
```

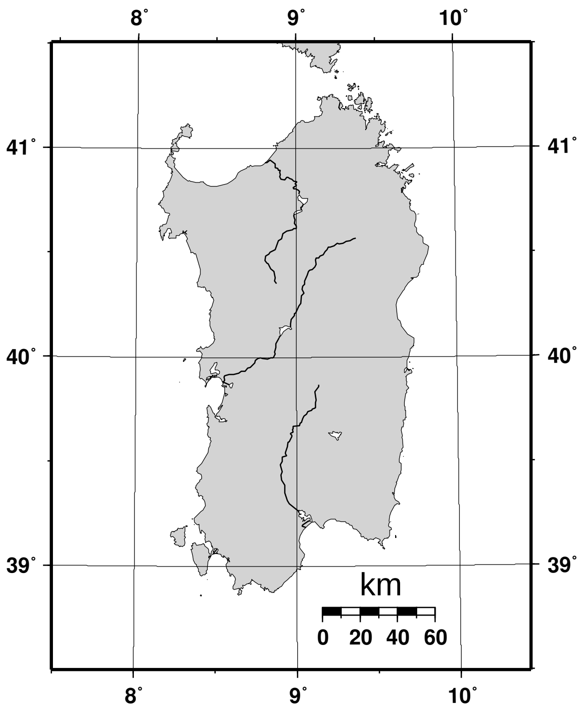


Figure 6.17: Cassini map over Sardinia.

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 (if you desire a different scaling for one of the axes you must choose the linear projection **–Jx** and append **d** for degrees; see Section 5.1.1.) It is also known as the Plate Carrée projection. All meridians and parallels are straight lines. The requirements to define this projection are:

- The central meridian
- Scale in inch/degree or as 1:xxxxx (**–Jq**), or map width (**–JQ**)

A world map centered on the dateline using this projection can be obtained by running the command:

```
pscoast -Rg -JQ180/4.5i -B60f30g30 -Dc -A5000 -Gblack -P > GMT_equi_cyl.ps
```

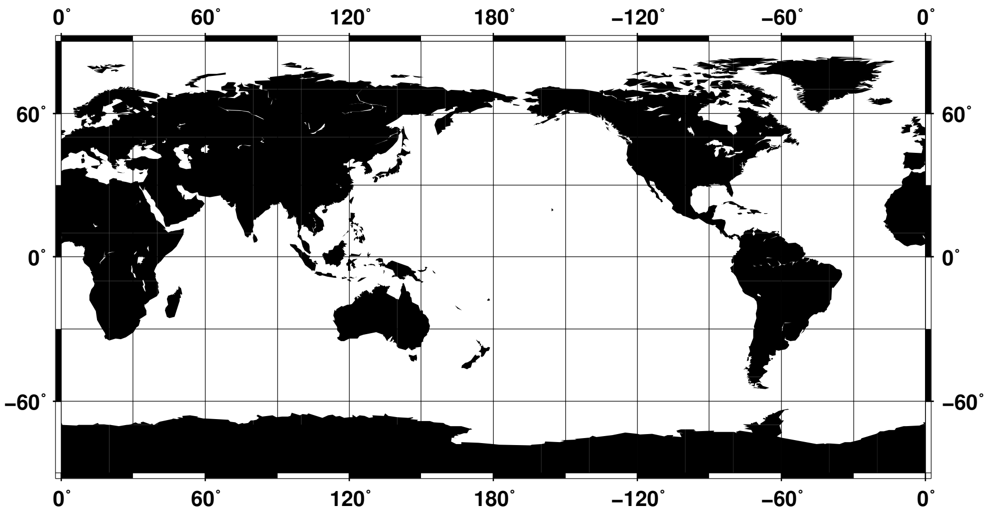


Figure 6.18: World map using the equidistant cylindrical projection.

6.3.7 General Cylindrical 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 four choices of standard parallels that result in known (or named) projections. These are listed in Table 6.1.

For instance, a world map centered on the 35°E meridian using the Behrman projection can be obtained by running the command:

```
pscoast -R-145/215/-90/90 -JY35/30/4.5i -B45g45 -Dc -A10000 -Slightgray -W0.25p -P > \
    GMT_general_cyl.ps
```

Projection name	*Standard parallel*
Lambert	0°
Behrman	30°
Trystan-Edwards	37°24' (= 37.4°)
Peters (Gall)	45°

Table 6.1: Standard parallels for some cylindrical projections.

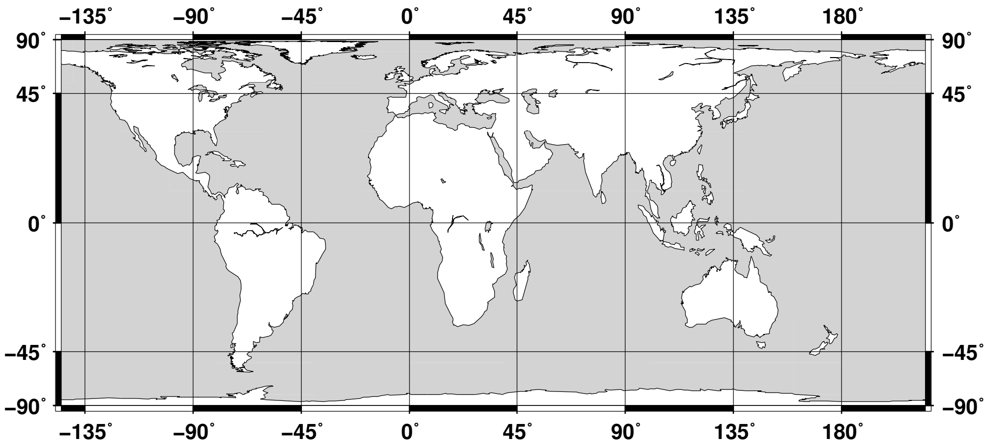


Figure 6.19: World map using the Behrman cylindrical projection.

As one can see there is considerable distortion at high latitudes since the poles map into lines.

6.3.8 Miller Cylindrical Projections (–Jj –JJ)

This cylindrical projection, presented by O. M. 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. The requirements to define this projection are:

- The central meridian
- The standard parallel
- 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 can be obtained as follows:

```
pscoast -R-90/270/-80/90 -Jj90/1:400000000 -B45g45/30g30 -Dc -A10000 -Glightgray -W0.25p -P \
    > GMT_miller.ps
```

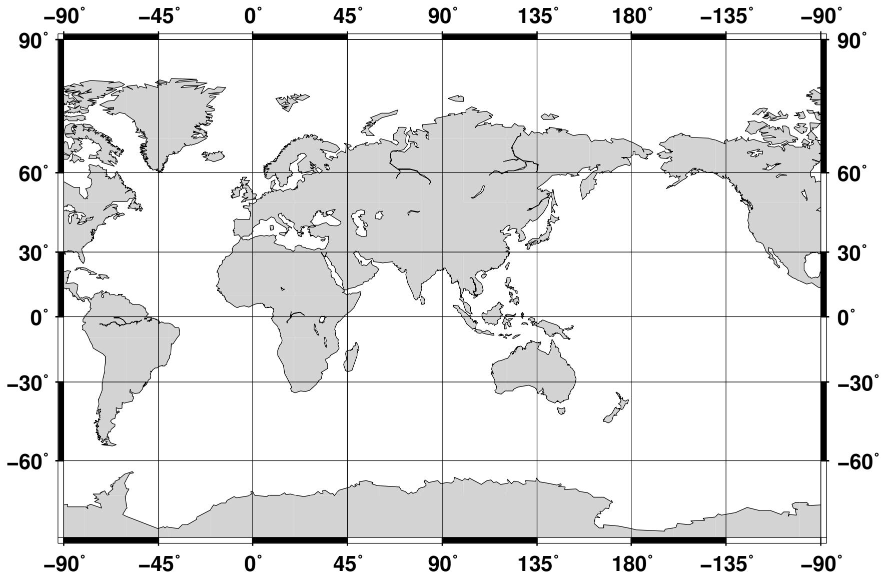


Figure 6.20: World map using the Miller cylindrical projection.

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.

6.4.1 Hammer Projection (–Jh –JH)

The equal-area Hammer projection, first presented by 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
- 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 -JH180/4.5i -Bg30/g15 -Dc -A10000 -Gblack -P > GMT_hammer.ps
```

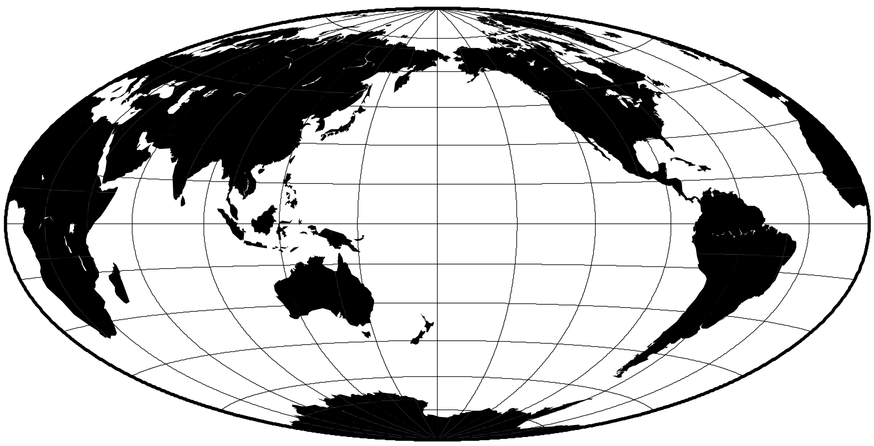


Figure 6.21: World map using the Hammer projection.

6.4.2 Mollweide Projection (–Jw –JW)

This pseudo-cylindrical, equal-area projection was developed by 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°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
- 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 -JW0/4.5i -Bg30/g15 -Dc -A10000 -Gblack -P > GMT_mollweide.ps
```

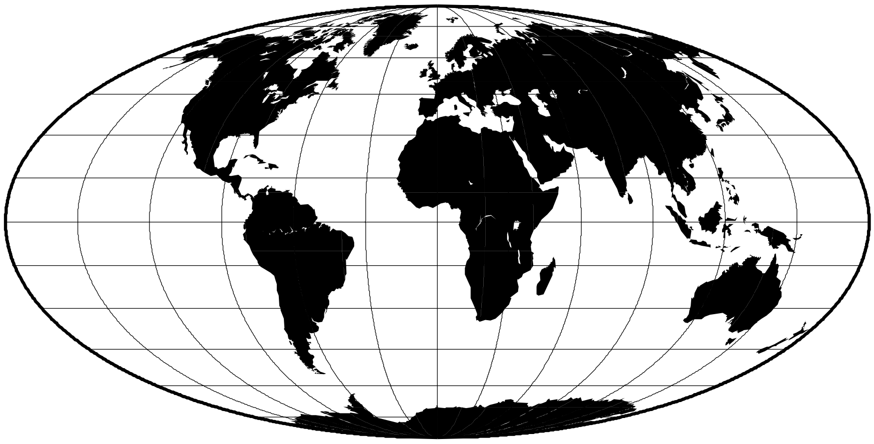


Figure 6.22: World map using the Mollweide projection.

6.4.3 Winkel Tripel Projection (–Jr –JR)

The Winkel Tripel projection, presented by Oswald Winkel in 1921, is a modified azimuthal projection that 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
- Scale along equator in inch/degree or 1:xxxxx (**–Jr**), or map width (**–JR**)

Centered on Greenwich, the example in Figure 6.23 was created by this command:

```
pscoast -Rd -JR0/4.5i -Bg30/g15 -Dc -A10000 -Ggray -P > GMT_winkel.ps
```

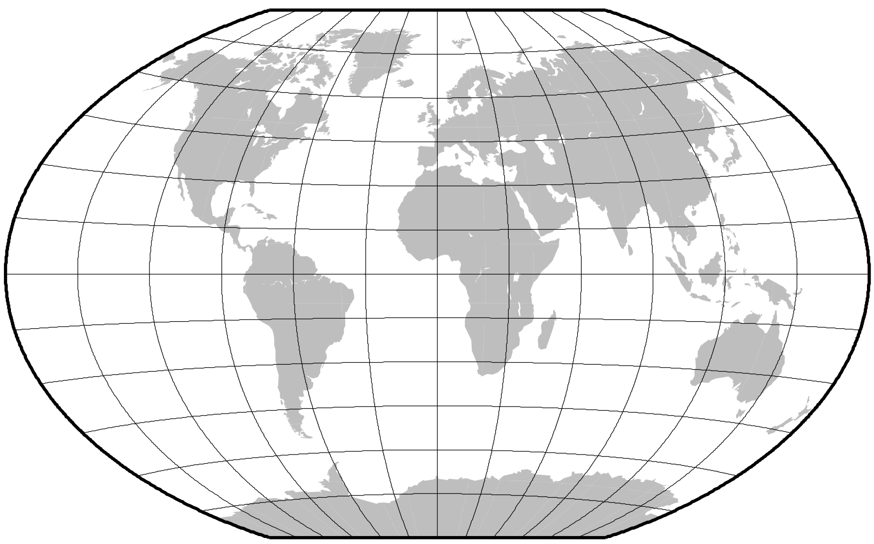


Figure 6.23: World map using the Winkel Tripel projection.

6.4.4 Robinson Projection (–Jn –JN)

The Robinson projection, presented by 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" right[3]. The scale is true along latitudes $\pm$ 38°. 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
- 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 -JN0/4.5i -Bg30/g15 -Dc -A10000 -Ggray -P > GMT_robinson.ps
```

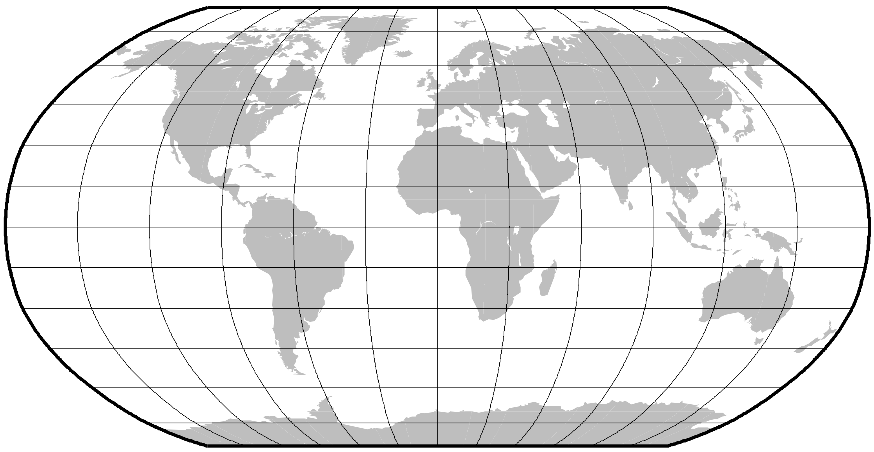


Figure 6.24: World map using the Robinson projection.

6.4.5 Eckert IV and VI Projection (–Jk –JK)

The Eckert IV and VI projections, presented by Max Eckert 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°30' (IV) and $\pm$ 49°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
- 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 -JKf180/4.5i -Bg30/g15 -Dc -A10000 -W0.25p -Gwhite -Slightgray -P > GMT_eckert4.ps
```

The same script, with **s** instead of **f**, yields the Eckert VI map:

[3] Robinson 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.

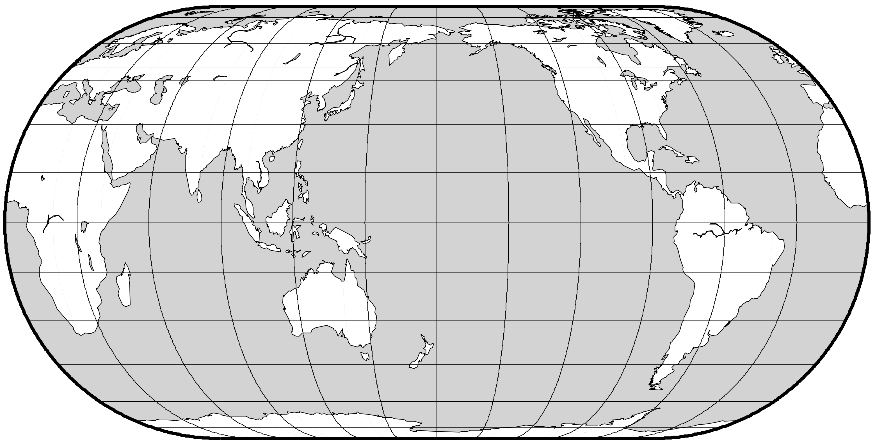


Figure 6.25: World map using the Eckert IV projection.

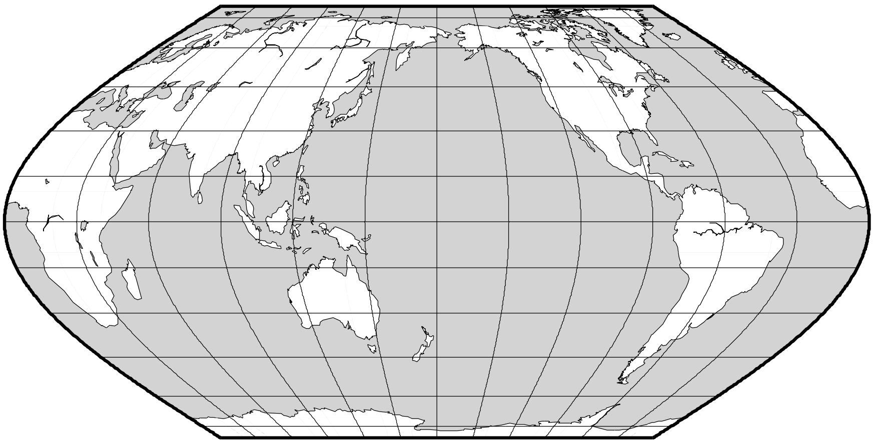


Figure 6.26: World map using the Eckert VI projection.

6.4.6 Sinusoidal Projection (**–Ji –JI**)

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
- Scale along equator in inch/degree or 1:xxxxx (**–Ji**), or map width (**–JI**)

A simple world map using the sinusoidal projection is therefore obtained by

```
pscoast -Rd -JI0/4.5i -Bg30/g15 -Dc -A10000 -Ggray -P > GMT_sinusoidal.ps
```

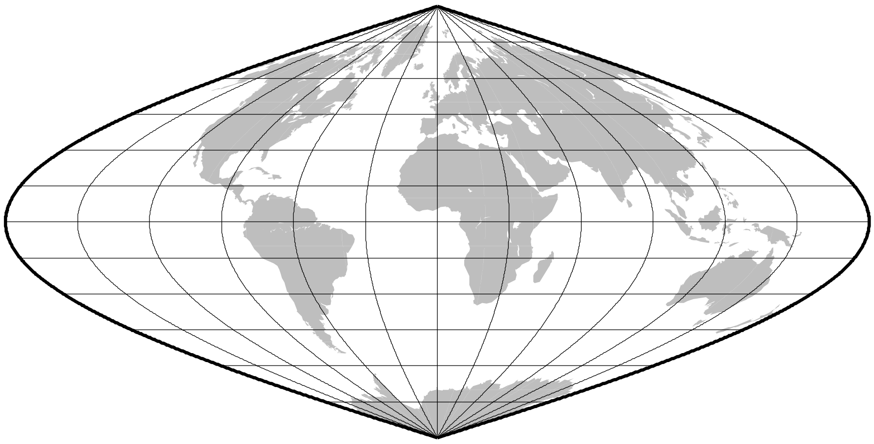


Figure 6.27: World map using the Sinusoidal projection.

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° = 0.014 and offset the subsequent plots horizontally by their widths (140°·0.014 and 80°·0.014):

```
pscoast -R200/340/-90/90 -Ji270/0.014i -Bg30/g15 -A10000 -Dc -Gblack -K -P > GMT_sinus_int.ps
pscoast -R-20/60/-90/90 -Ji20/0.014i -Bg30/g15 -Dc -A10000 -Gblack -X1.96i -O -K >> GMT_sinus_int.ps
pscoast -R60/200/-90/90 -Ji130/0.014i -Bg30/g15 -Dc -A10000 -Gblack -X1.12i -O >> GMT_sinus_int.ps
```

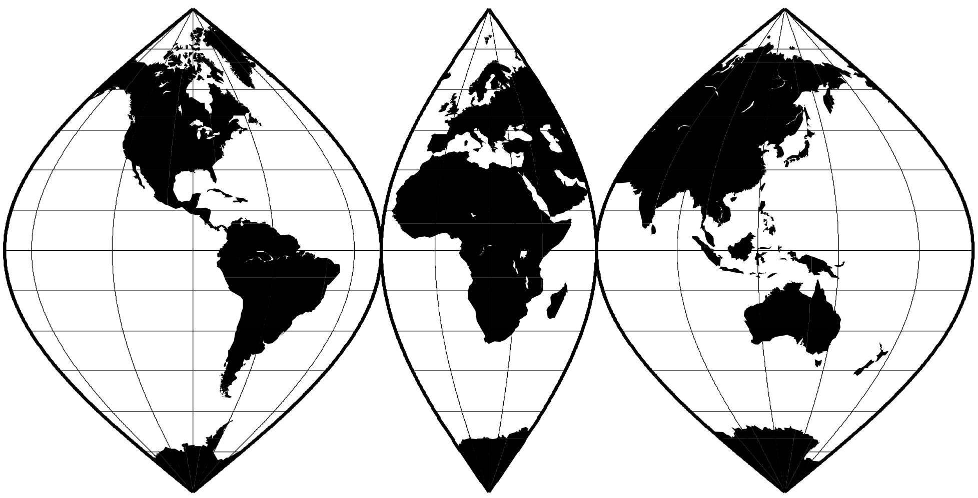


Figure 6.28: World map using the Interrupted Sinusoidal projection.

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
- 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 -JV180/4i -Bg30/g15 -Dc -Glightgray -A10000 -W0.25p -P > GMT_grinten.ps
```

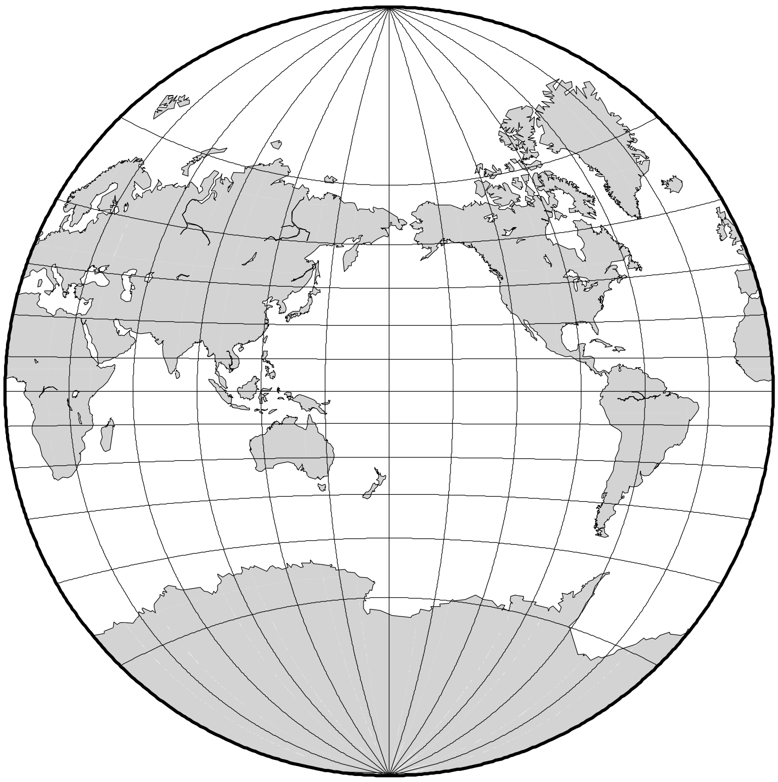


Figure 6.29: World map using the Van der Grinten projection.

7. Cook-book

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 cshell 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 ***csh*** and ***sh*** scripts are available; only the ***csh***-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*** scripts will set this when running all examples.

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/csh
#        GMT EXAMPLE 01
#
#        $Id: job01.csh,v 1.9 2004/05/26 03:25:22 pwessel Exp $
#
# Purpose:    Make two contour maps based on the data in the file osu91a1f_16.grd
# GMT progs:    gmtset grdcontour psbasemap pscoast
# Unix progs:    rm
#
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" >! example_01.ps
pscoast -Rg -JH0/6i -X0.25i -Y0.5i -O -K -Bg30 -Dc -Glightgray >> example_01.ps
grdcontour -R osu91a1f_16.grd -J -C10 -A50+s7 -Gd4i -L-1000/-1 -Wc0.25p,- -Wa0.75p,- -O -K \
   -T0.1i/0.02i >> example_01.ps
grdcontour -R osu91a1f_16.grd -J -C10 -A50+s7 -Gd4i -L-1/1000 -O -K -T0.1i/0.02i >> example_01.ps
pscoast -Rg -JH180/6i -Y4i -O -K -Bg30:."Low Order Geoid": -Dc -Glightgray >> example_01.ps
grdcontour osu91a1f_16.grd -J -C10 -A50+s7 -Gd4i -L-1000/-1 -Wc0.25p,- -Wa0.75p,- -O -K \
   -T0.1i/0.02i:-+ >> example_01.ps
grdcontour osu91a1f_16.grd -J -C10 -A50+s7 -Gd4i -L-1/1000 -O -T0.1i/0.02i:-+ >> example_01.ps
\rm -f .gmtcommands4 .gmtdefaults4
```

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.

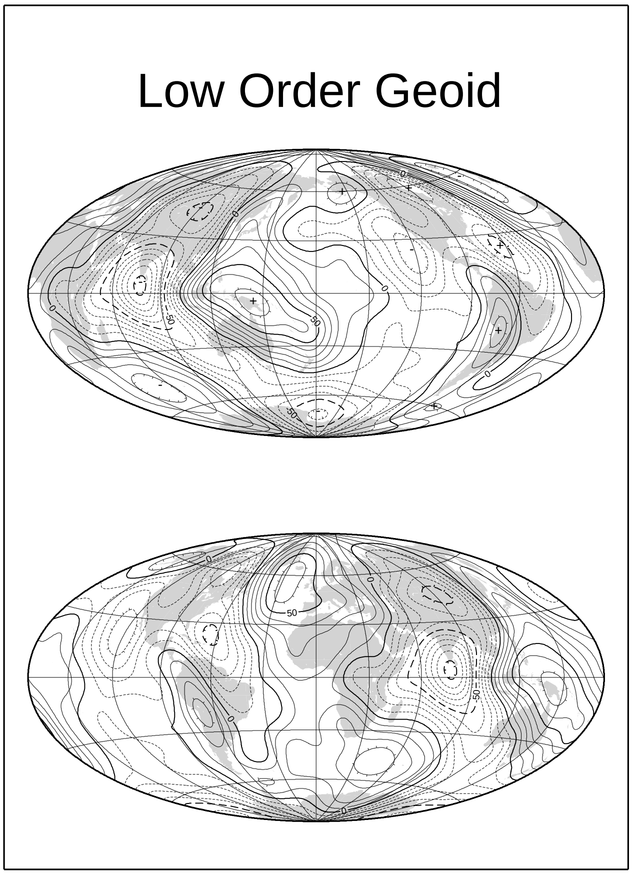


Figure 7.1: Contour maps of gridded data.

7.2 Image presentations

As our second example we will demonstrate how to make color images from gridded data sets (again, we will deferr the actual making of gridded files to later examples). We will use the supplemental program **grdraster** to extract 2-D grdfiles 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/csh
#        GMT EXAMPLE 02
#
#        $Id: job02.csh,v 1.8 2004/04/13 21:32:27 pwessel Exp $
#
# Purpose:    Make two color images based gridded data
# GMT progs:    gmtset grd2cpt grdgradient grdimage makecpt psscale pstext
# Unix progs:    cat rm
#
```

```
gmtset HEADER_FONT_SIZE 30 OBLIQUE_ANNOTATION 0
#get gridded data using GMT supplemental program grdraster
#grdraster 1 -R160/20/220/30r -JOc190/25.5/292/69/4.5i -GHI_topo2.grd=0/0.001/0
#grdraster 4 -R -JO -GHI_geoid2.grd
makecpt -Crainbow -T-2/14/2 >! g.cpt
grdimage HI_geoid2.grd -R160/20/220/30r -JOc190/25.5/292/69/4.5i -E50 -K -P -B10 -Cg.cpt \
   -U/-1.25i/-1i/"Example 2 in Cookbook" -X1.5i -Y1.25i >! example_02.ps
psscale -Cg.cpt -D5.1i/1.35i/2.88i/0.4i -O -K -L -B2:GEOID:/:m: -E >> example_02.ps
grd2cpt HI_topo2.grd -Crelief -Z >! t.cpt
grdgradient HI_topo2.grd -A0 -Nt -GHI_topo2_int.grd
grdimage HI_topo2.grd -IHI_topo2_int.grd -R -J -E50 -B10:."H@#awaiian@# T@#opo and @#G@#eoid:" \
   -O -K -Ct.cpt -Y4.5i >> example_02.ps
psscale -Ct.cpt -D5.1i/1.35i/2.88i/0.4i -O -K -I0.3 -B2:TOPO:/:km: >> example_02.ps
cat << EOF | pstext -R0/8.5/0/11 -Jx1i -O -N -Y-4.5i >> example_02.ps
-0.4 7.5 30 0.0 1 CB a)
-0.4 3.0 30 0.0 1 CB b)
EOF
\rm -f .gmtcommands4 .gmtdefaults4 HI_topo2_int.grd ?.cpt
```

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 **–R**159:50/220:10/3:10/47:35. 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 grdfile format mechanism we saved the topography using kilometers as the data unit. We now have two grdfiles 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 scale to the right of the image with **psscale**. We also annotate the color scales with **psscale**. Similarly, we run **grdimage** but specify **–Y**4.5i 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.xyg, and (lon, lat, gravity) along a ship track in a file called ship.xyg. 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_3[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 **–Jx**1i and specify positions in inches directly. Thus, the complete automated script reads:

```
#!/bin/csh
#        GMT EXAMPLE 03
#
#        $Id: job03.csh,v 1.6 2004/04/10 17:19:14 pwessel Exp $
#
# Purpose:    Resample track data, do spectral analysis, and plot
# GMT progs:    filter1d, fitcircle, gmtset, minmax, project, sample1d,
```

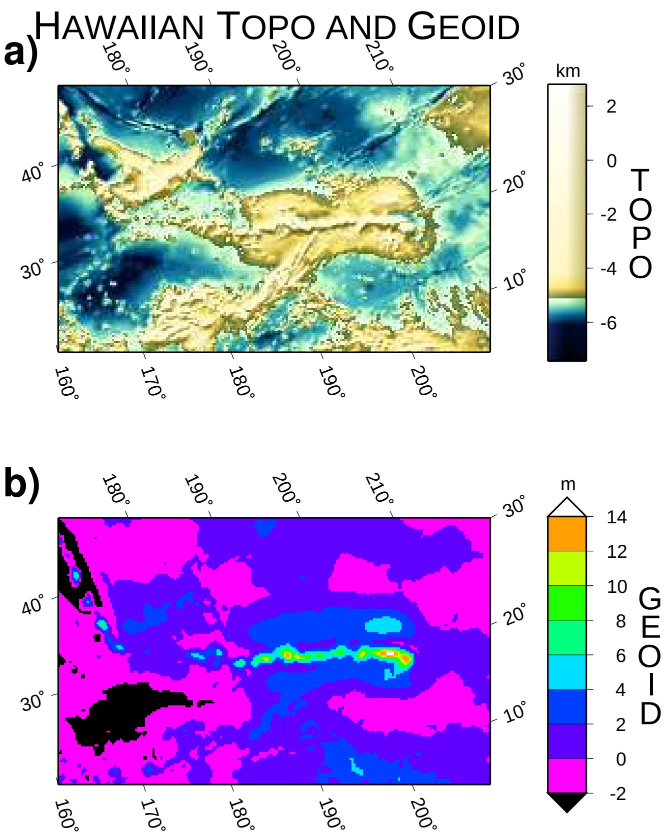


Figure 7.2: Color images from gridded data.

```
#          spectrum1d, trend1d, pshistogram, psxy, pstext
# Unix progs:     $AWK, cat, echo, head, paste, rm, tail
#
# This example begins with data files "ship.xyg" and "sat.xyg" which
# are measurements of a quantity "g" (a "gravity anomaly" which is an
# anomalous increase or decrease in the magnitude of the acceleration
# of gravity at sea level).  g is measured at a sequence of points "x,y"
# which in this case are "longitude,latitude".  The "sat.xyg" data were
# obtained by a satellite and the sequence of points lies almost along
# a great circle.  The "ship.xyg" data were obtained by a ship which
# tried to follow the satellite's path but deviated from it in places.
# Thus the two data sets are not measured at the same set of points,
# and we use various GMT tools to facilitate their comparison.
# The main illustration (example_03.ps) are accompanied with 5 support
# plots (03a-f) showing data distributions and various intermediate steps.
#
# First, we use "fitcircle" to find the parameters of a great circle
# most closely fitting the x,y points in "sat.xyg":
#
fitcircle sat.xyg -L2 >! report
set cpos = `grep "L2 Average Position" report`
set ppos = `grep "L2 N Hemisphere" report`
#
# Now we use "project" to project the data in both sat.xyg and ship.xyg
# into data.pg, where g is the same and p is the oblique longitude around
# the great circle.  We use -Q to get the p distance in kilometers, and -S
# to sort the output into increasing p values.
#
project  sat.xyg -C$cpos[1]/$cpos[2] -T$ppos[1]/$ppos[2] -S -Fpz -Q >! sat.pg
project ship.xyg -C$cpos[1]/$cpos[2] -T$ppos[1]/$ppos[2] -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.
#
set plotr = `cat sat.pg ship.pg | minmax -I100/25 -C`
```

```
gmtset MEASURE_UNIT INCH
psxy -R$plotr[1]/$plotr[2]/$plotr[3]/$plotr[4] -U/-1.75i/-1.25i/"Example 3a in Cookbook" \
   -JX8i/5i -X2i -Y1.5i -K -W1p sat.pg \
   -Ba500f100:"Distance along great circle":/a100f25:"Gravity anomaly (mGal)":WeSn >! 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 AKW 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 unevelnly, 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
set sampr = `paste sampr1 sampr2`
#
# Now we can use sampr in $AWK to make a sampling points file for sample1d:
$AWK 'BEGIN { for (i = '$sampr[1]'; i <= '$sampr[2]'; i++) print i }' /dev/null >! samp.x
#
# Now we can resample the projected satellite data:
#
sample1d sat.pg -Nsamp.x >! samp_sat.pg
#
# For reasons above, we use filter1d to pre-treat the ship data.  We also need to sample it
# because of the gaps > 1 km we found.  So we use filter1d | sample1d.  We also use the -E
# on filter1d to use the data all the way out to sampr[1]/sampr[2] :
#
filter1d ship.pg -Fm1 -T$sampr[1]/$sampr[2]/1 -E | sample1d -Nsamp.x >! samp_ship.pg
#
# Now we plot them again to see if we have done the right thing:
#
psxy -R$plotr[1]/$plotr[2]/$plotr[3]/$plotr[4] -JX8i/5i -X2i -Y1.5i -K -W1p 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 pstext and psxy to put labels and legends directly on the plots.
# For that purpose we often use -Jx1i and specify positions in inches directly:
#
psxy spectrum.coh -Ba1f3p:"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/2 -Y1.5i >! example_03.ps
echo "3.85 3.6 18 0.0 1 TR Coherency@+2@+" | pstext -R0/4/0/3.75 -Jx1i -O -K >> example_03.ps
cat << END >! box.d
2.375    3.75
2.375    3.25
```

```
4    3.25
END
psxy -R -Jx -O -K -W1.5p box.d >> example_03.ps
psxy -Ba1f3p/a1f3p:"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/2 >> example_03.ps
psxy spectrum.ypower -R -JX -O -K -Gblack -Sc0.07i -Ey/2 >> example_03.ps
echo "3.9 3.6 18 0.0 1 TR Input Power" | pstext -R0/4/0/3.75 -Jx -O -K >> example_03.ps
psxy -R -Jx -O -K -W1.5p box.d >> example_03.ps
psxy -R -Jx -O -K -Glightgray -L -W1.5p << END >> example_03.ps
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_03.ps
echo "0.5 0.7 14 0.0 1 ML Ship" | pstext -R -Jx -O -K >> example_03.ps
echo "0.4 0.4" | psxy -R -Jx -O -K -Sc0.07i -Gblack >> example_03.ps
echo "0.5 0.4 14 0.0 1 ML Satellite" | pstext -R -Jx -O >> example_03.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 $AWK or sed or head and tail, but weW
# demonstrate the use of "trend1d" to identify outliers instead.  We will fit a
# straight line to the samp_ship.pg data by an iteratively-reweighted method and
# save the weights on output.  Then we will plot the weights and see how things
# look:
#
trend1d -Fxw -N2r samp_ship.pg >! samp_ship.xw
psxy -R$plotr[1]/$plotr[2]/$plotr[3]/$plotr[4] -JX8i/4i -X2i -Y1.5i -K -Sp0.03i \
   -Ba500f100:"Distance along great circle":/a100f25:"Gravity anomaly (mGal)":WeSn \
   -U/-1.75i/-1.25i/"Example 3d in Cookbook" samp_ship.pg >! example_03d.ps
psxy -R$plotr[1]/$plotr[2]/0/1.1 -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 trend1d to return the residual from the model fit (the
# de-trended data):
trend1d -Fxrw -N2r samp_ship.pg | $AWK '{ if ($3 > 0.6) print $1, $2 }' | sample1d -Nsamp.x >! \
   samp2_ship.pg
trend1d -Fxrw -N2r samp_sat.pg  | $AWK '{ if ($3 > 0.6) print $1, $2 }' | sample1d -Nsamp.x >! \
   samp2_sat.pg
#
# We plot these to see how they look:
#
set plotr = `cat samp2_sat.pg samp2_ship.pg | minmax -I100/25 -C`
psxy -R$plotr[1]/$plotr[2]/$plotr[3]/$plotr[4] -JX8i/5i -X2i -Y1.5i -K -W1p \
   -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_03f.ps) with
# the previous one (example_03.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 | spectrum1d -S256 -D1 -W -C >& /dev/null
#
psxy spectrum.coh -Ba1f3p:"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/2 -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 << END >! box.d
2.375    3.75
2.375    3.25
4    3.25
END
psxy -R -Jx -O -K -W1.5p box.d >> example_03f.ps
psxy -Ba1f3p/a1f3p:"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/2 >> example_03f.ps
psxy spectrum.ypower -R -JX -O -K -Gblack -Sc0.07i -Ey/2 >> 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 -W1.5p box.d >> example_03f.ps
psxy -R -Jx -O -K -Glightgray -L -W1.5p << END >> example_03f.ps
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.* .gmtcommands4 .gmtdefaults4
```

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.

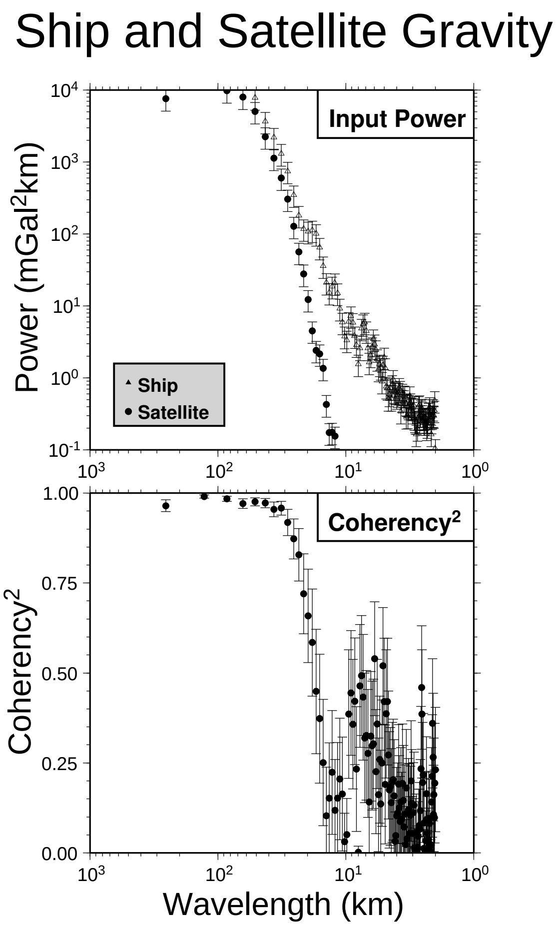


Figure 7.3: Spectral estimation and x/y-plots.

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 bathymetry[1] and Geosat geoid data sets which we will extract from the local data bases using **grdraster**. 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/csh
#       GMT EXAMPLE 04
#
#       $Id: job04.csh,v 1.8 2004/06/01 02:28:31 pwessel Exp $
#
# Purpose:    3-D mesh plot of Hawaiian topography and geoid
```

[1] These data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).

```
# GMT progs:    grdcontour, grdview, pscoast, pstext, psxyz
# Unix progs:    echo, rm
#
echo '-10     255     0       255' >! zero.cpt
echo '0       100     10      100' >> zero.cpt
grdcontour HI_geoid4.grd -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" >! example_04.ps
pscoast -J -E60/30 -R -B2/2NEsw -Gblack -O -K -T209/19.5/1i >> example_04.ps
grdview HI_topo4.grd -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 >> example_04.ps
echo '3.25 5.75 60 0.0 33 BC H@#awaiian@# R@#idge' | pstext -R0/10/0/10 -Jx1i -O >> example_04.ps
\rm -f zero.cpt .gmt*
csh -f job4c.csh
```

The purpose of the color palette file zero.cpt is to have the positive topography mesh painted light gray (the remainder is white). Figure 7.4 shows the complete illustration.

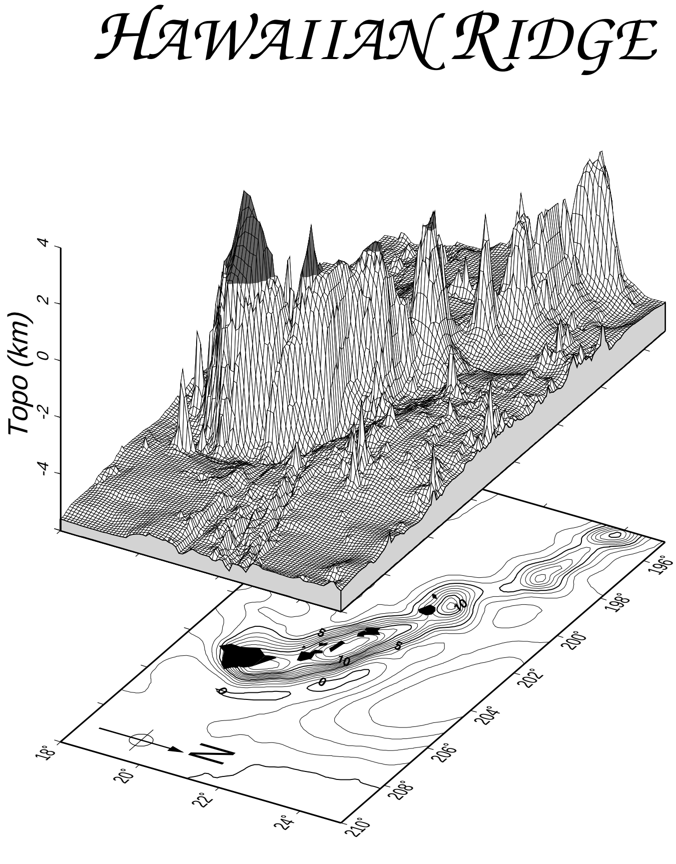


Figure 7.4: 3-D perspective mesh plot.

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 Example 2.

```
#!/bin/csh
#       GMT EXAMPLE 4c
#
#       $Id: job4c.csh,v 1.7 2004/05/11 19:44:44 pwessel Exp $
```

```
#
# 3-D perspective color plot of Hawaiian topography and geoid
# GMT progs:    grdcontour, grdview, pscoast, pstext, psxyz
# Unix progs:    echo, rm
#
grdgradient HI_geoid4.grd -A0 -Gg_intens.grd -Nt0.75 -M
grdgradient HI_topo4.grd -A0 -Gt_intens.grd -Nt0.75 -M
#
grdview HI_geoid4.grd -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 4c in Cookbook" >! example_4c.ps
pscoast -J -E60/30 -R -B2/2NEsw -Gblack -O -K >> example_4c.ps
psbasemap -R -J -E60/30 -O -K -T209/19.5/1i --COLOR_BACKGROUND=red --TICK_PEN=0.5p,red >> example_4c.ps
grdview HI_topo4.grd -It_intens.grd -J -JZ3.4i -Ctopo.cpt -E60/30 -R195/210/18/25/-6/4 \
   -N-6/lightgray -Qi100 -O -K -Y2.2i >> example_4c.ps
psbasemap -J -JZ3.4i -E60/30 -R -Z-6 -O -K -B2/2/2:"Topo (km)":neZ >> example_4c.ps
echo '3.25 5.75 60 0.0 33 BC H@#awaiian@# R@#idge' | pstext -R0/10/0/10 -Jx1i -O >> example_4c.ps
\rm -f *_intens.grd .gmtcommands4
```

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 grdfile 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 grdfiles 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/csh
#        GMT EXAMPLE 05
#
#        $Id: job05.csh,v 1.4 2004/04/10 17:19:14 pwessel Exp $
#
# Purpose:    Generate grid and show monochrome 3-D perspective
# GMT progs:    grdgradient, grdmath, grdview, pstext
# Unix progs:    echo, rm
#
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 -Gintensity.grd -Nt0.75
grdview sombrero.grd -JX6i -JZ2i -B5/5/0.5SEwnZ -N-1/white -Qs -Iintensity.grd -X1.5i -K \
   -Cgray.cpt -R-15/15/-15/15/-1/1 -E120/30 -U/-1.25i/-0.75i/"Example 5 in Cookbook" >! example_05.ps
echo "4.1 5.5 50 0 33 BC z(r) = cos (2@~p@~r/8) * e@+-r/10@+" | pstext -R0/11/0/8.5 -Jx1i -O \
   >> example_05.ps
\rm -f gray.cpt sombrero.grd intensity.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 windrose 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:

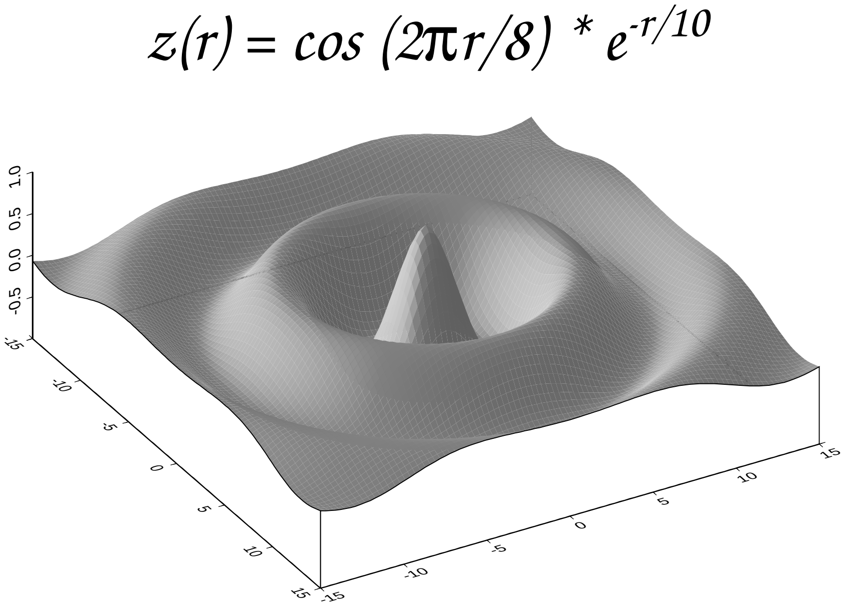


Figure 7.5: 3-D illuminated surface.

```
#!/bin/csh
#        GMT EXAMPLE 06
#
#        $Id: job06.csh,v 1.4 2004/04/13 21:32:27 pwessel Exp $
#
# Purpose:    Make standard and polar histograms
# GMT progs:    pshistogram, psrose
# Unix progs:    rm
#
psrose fractures.d -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 >! example_06.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 -L0.5p -Z1 -W250 >> example_06.ps
\rm -f .gmt*
```

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 maps[2]. We create the final location map (Figure 7.7) with the following script:

```
#!/bin/csh
#        GMT EXAMPLE 07
#
#        $Id: job07.csh,v 1.6 2004/04/10 17:19:14 pwessel Exp $
#
# Purpose:    Make a basemap with earthquakes and isochrons etc
# GMT progs:    pscoast, pstext, psxy
# Unix progs:    $AWK, echo, rm
#
pscoast -R-50/0/-10/20 -JM9i -K -GP300/26 -Dl -W0.25p -B10 -U"Example 7 in Cookbook" >! example_07.ps
```

[2]These data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).

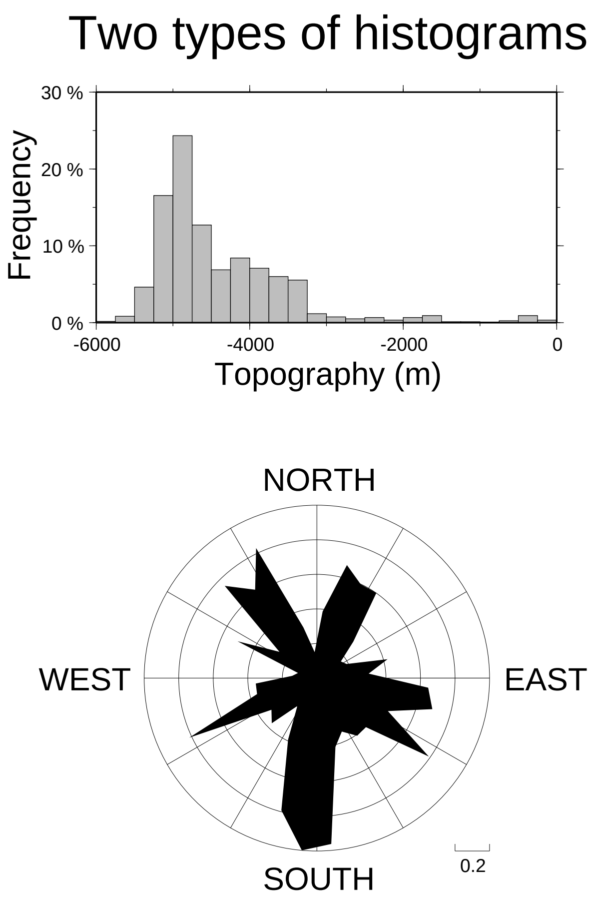


Figure 7.6: Two kinds of histograms.

```
psxy -R -J -O -K -M fz.xy -W0.5pta >> example_07.ps
$AWK '{print $1-360.0, $2, $3*0.01}' quakes.xym | psxy -R -J -O -K -H1 -Sci -Gwhite -W0.25p \
   >> example_07.ps
psxy -R -J -O -K -M isochron.xy -W0.75p >> example_07.ps
psxy -R -J -O -K -M ridge.xy -W1.75p >> example_07.ps
psxy -R -J -O -K -Gwhite -W1p -A << END >> example_07.ps
-14.5    15.2
 -2    15.2
 -2    17.8
-14.5    17.8
END
psxy -R -J -O -K -Gwhite -W0.5p -A << END >> example_07.ps
-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 -W0.5p >> example_07.ps
echo "-12.5 16.5 18 0 6 LM ISC Earthquakes" | pstext -R -J -O -K >> example_07.ps
pstext -R -J -O -S0.75p -Gwhite << END >> example_07.ps
-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.

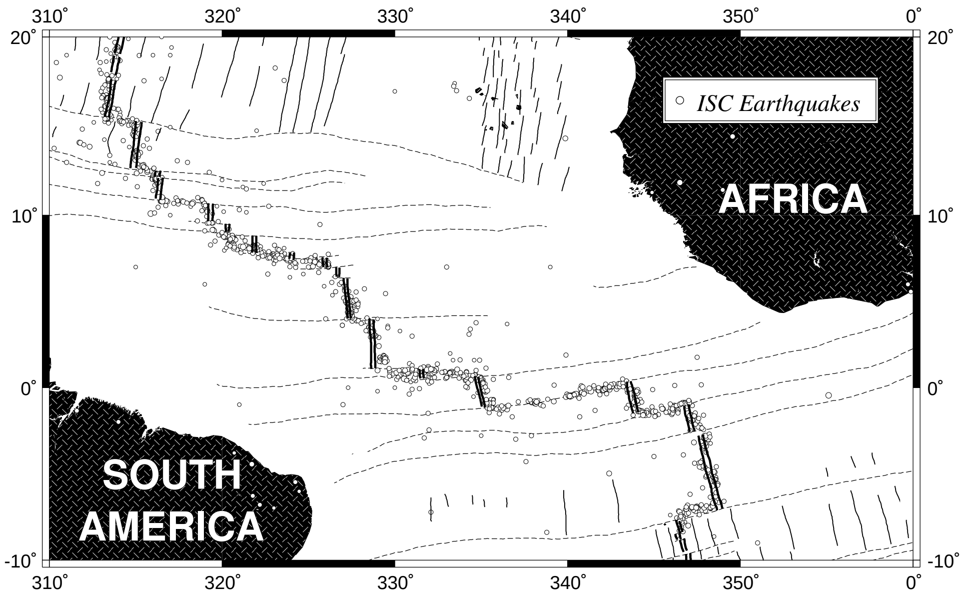


Figure 7.7: A typical location map.

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 illustration by running this command:

```
#!/bin/csh
#        GMT EXAMPLE 08
#
#        $Id: job08.csh,v 1.5 2004/04/10 17:19:14 pwessel Exp $
#
# Purpose:    Make a 3-D bar plot
# GMT progs:    grd2xyz, pstext, psxyz
# Unix progs:    echo, rm
#
grd2xyz guinea_bay.grd >! $$
psxyz $$ -B1/1/1000:"Topography (m)"::.ETOPO5:WSneZ+ -R-0.1/5.1/-0.1/5.1/-5000/0 \
   -P -JM5i -JZ6i -E200/30 -So0.0833333ub-5000 -U"Example 8 in Cookbook" -W0.25p -Glightgray -K >! \
   example_08.ps
echo '0.1 4.9 24 0 1 TL This is the surface of cube' | pstext -R -J -JZ -Z0 -E200/30 -O \
   >> example_08.ps
\rm -f $$ .gmt*
```

The output can be viewed in Figure 7.8.

7.9 Plotting time-series along tracks

A common application in many scientific disciplines involves plotting one or several time-series as 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

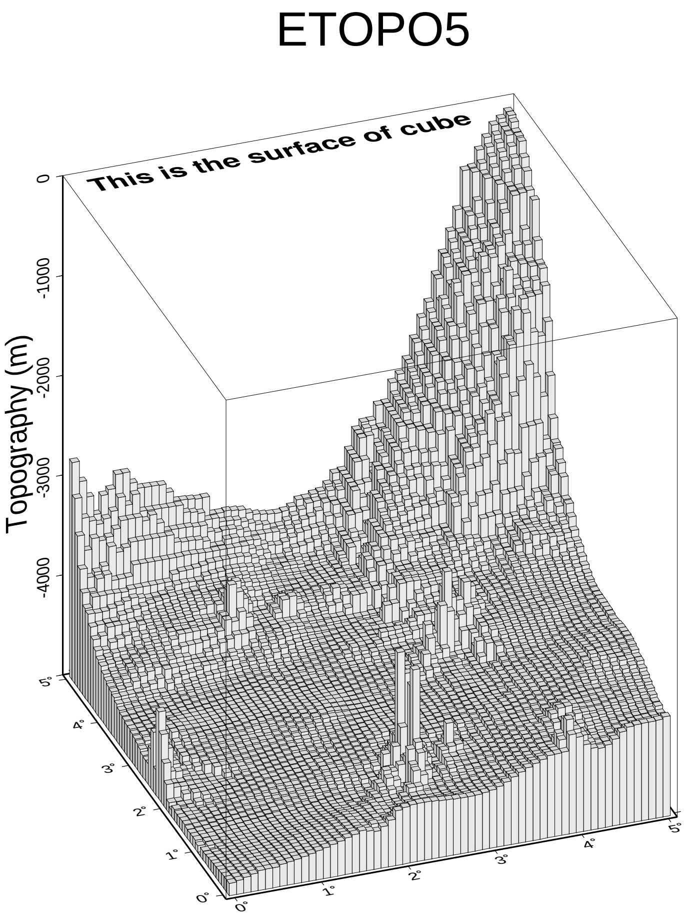


Figure 7.8: A 3-D histogram.

files to construct an input file for **pstext** 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 **pstext**. 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/csh
#        GMT EXAMPLE 09
#
#        $Id: job09.csh,v 1.5 2004/04/10 17:19:14 pwessel Exp $
#
# Purpose:    Make wiggle plot along track from geoid deflections
# GMT progs:    pswiggle, pstext, psxy
# Unix progs:    $AWK, ls, paste, tail, rm
#
pswiggle track_*.xys -R185/250/-68/-42 -U"Example 9 in Cookbook" -K -Jm0.13i -Ba10f5 -Gblack -Z2000 \
   -W0.25p -S240/-67/500/@~m@~rad >! example_09.ps
psxy -R -J -O -K ridge.xy -W1.25p >> example_09.ps
psxy -R -J -O -K -M fz.xy -W0.5pta >> example_09.ps
if (-e tmp) then
    \rm -f tmp
endif
foreach file (track_*.xys)    # Make label file
    tail -1 $file >> tmp
end
ls -1 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 \
   >> example_09.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).

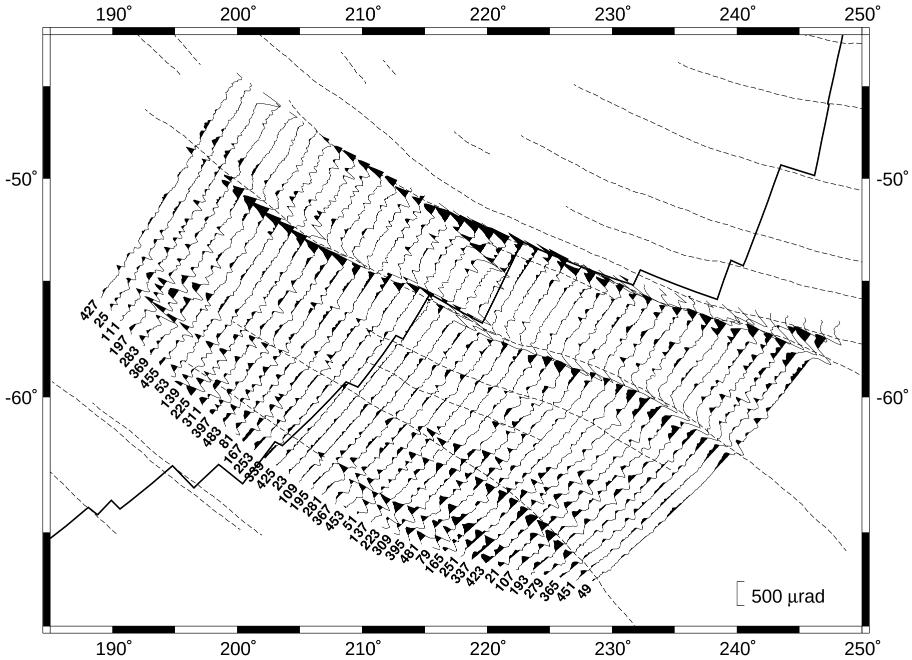


Figure 7.9: Time-series as "wiggles" along a track.

7.10 A geographical bar graph plot

Our next and perhaps silliest example presents a three-dimensional bargraph plot showing the geographic distribution of the membership in the American Geophysical Union (AGU). The input data was taken from the 1991 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 reads:

```
#!/bin/csh
#        GMT EXAMPLE 10
#
#        $Id: job10.csh,v 1.8 2004/08/17 02:30:32 pwessel Exp $
#
# Purpose:    Make 3-D bar graph on top of perspective map
# GMT progs:    pscoast, pstext, psxyz
# Unix progs:    $AWK, rm
#
pscoast -Rd -JX8id/5id -Dc -Gblack -E200/40 -K -U"Example 10 in Cookbook" \
   >! example_10.ps
psxyz agu.d -R-180/180/-90/90/1/100000 -J -JZ2.5il -So0.3ib1 -Ggray -W0.5p -O -K -E200/40 \
   -B60g60/30g30/a1p:Memberships:WSneZ >> example_10.ps
$AWK '{print $1-10, $2, 20, 0, 0, "RM", $3}' agu.d | pstext -Rd -J -O -K -E200/40 \
   -Gwhite -S0.5p >> example_10.ps
echo "4.5 6 30 0 5 BC AGU 1991 Membership Distribution" | pstext -R0/11/0/8.5 -Jx1i -O \
   >> example_10.ps
\rm -f .gmt*
```

The result is presented in Figure 7.10.

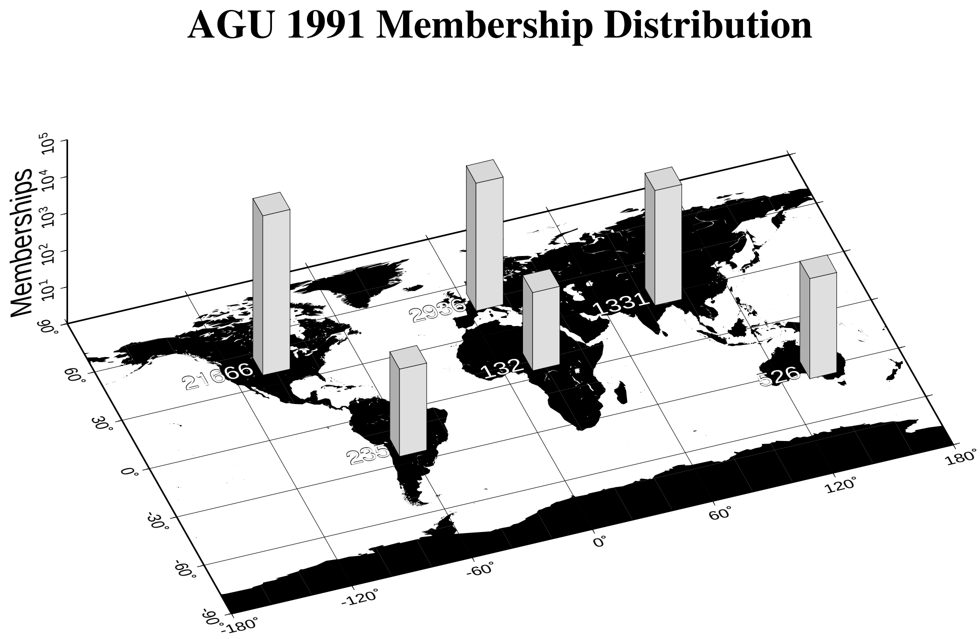


Figure 7.10: Geographical bar graph.

7.11 Making a 3-D RGB color cube

In this example we generate a series of 6 color images, arranged in the shape of a cross, that 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 method for generating the 6 color faces utilizes ***$AWK*** in two steps. First, a *z*-grid is composed which is 256 by 256 with *z*-values increasing in a planar fashion from 0 to 65535. This *z*-grid is common to all six faces. The color variations are generated by creating a different color palette for each face using the supplied ***$AWK*** script rgb_cube.awk. This script generates a “cpt” file appropriate for each face using arguments for each of the three color components. The arguments specify if that component (r,g,b) is to be held fixed at 0 or 255, is to vary in *x*, or is to vary in *y*. If the color is to increase in *x* or *y*, a lower case *x* or *y* is specified; if the color is to decrease in *x* or *y*, an upper case *X* or *Y* is used. Here is the shell script and accompanying ***$AWK*** script to generate the RGB cube:

```
#!/bin/csh
#        GMT EXAMPLE 11
#
#        $Id: job11.csh,v 1.7 2004/04/10 17:19:14 pwessel Exp $
#
# Purpose:    Create a 3-D RGB Cube
# GMT progs:    gmtset, grdimage, grdmath, pstext, psxy
# Unix progs:    $AWK, rm
#
# First create a Plane from (0,0,0) to (255,255,255).
# Only needs to be done once, and is used on each of the 6 faces of the cube.
#

grdmath -I1 -R0/255/0/255 Y 256 MUL X ADD = rgb_cube.grd

#
# For each of the 6 faces, create a color palette with one color (r,g,b) fixed
# at either the min. of 0 or max. of 255, and the other two components
# varying smoothly across the face from 0 to 255.
#
```

```
# This uses $AWK script "rgb_cube.awk", with arguments specifying which color
# (r,g,b) is held constant at 0 or 255, which color varies in the x-direction
# of the face, and which color varies in the y-direction.  If the color is to
# increase in x (y), a lower case x (y) is indicated; if the color is to
# decrease in the x (y) direction, an upper case X (Y) is used.
#
# Use grdimage to paint the faces and psxy to add "cut-along-the-dotted" lines.
#

gmtset TICK_LENGTH 0 COLOR_MODEL rgb

pstext -R0/8/0/11 -Jx1i < /dev/null -P -U"Example 11 in Cookbook" -K >! example_11.ps
$AWK -f rgb_cube.awk r=x g=y b=255 < /dev/null >! rgb_cube.cpt
grdimage rgb_cube.grd -Crgb_cube.cpt -JX2.5i/2.5i -R0/255/0/255 -K -O -X2i -Y4.5i -B256wesn \
   >> example_11.ps

$AWK -f rgb_cube.awk r=255 g=y b=X < /dev/null >! rgb_cube.cpt
grdimage rgb_cube.grd -Crgb_cube.cpt -J -K -O -X2.5i -B256wesn >> example_11.ps

$AWK -f rgb_cube.awk r=x g=255 b=Y < /dev/null >! rgb_cube.cpt
grdimage rgb_cube.grd -Crgb_cube.cpt -J -K -O -X-2.5i -Y2.5i -B256wesn >> example_11.ps

psxy -W0.25pto -J -R -K -O -X2.5i << END >> example_11.ps
0 0
20 20
20 235
0 255
END

psxy -W0.25pto -J -R -K -O -X-2.5i -Y2.5i << END >> example_11.ps
0 0
20 20
235 20
255 0
END

psxy -W0.25pto -J -R -K -O -X-2.5i -Y-2.5i << END >> example_11.ps
255 0
235 20
235 235
255 255
END

$AWK -f rgb_cube.awk r=0 g=y b=x < /dev/null >! rgb_cube.cpt
grdimage rgb_cube.grd -Crgb_cube.cpt -J -K -O -Y-2.5i -B256wesn >> example_11.ps

$AWK -f rgb_cube.awk r=x g=0 b=y < /dev/null >! rgb_cube.cpt
grdimage rgb_cube.grd -Crgb_cube.cpt -J -K -O -X2.5i -Y-2.5i -B256wesn >> example_11.ps

echo "10 10 14 0 Times-BoldItalic BL GMT 4" | pstext -J -R -Gwhite -K -O >> example_11.ps

psxy -W0.25pto -J -R -K -O -X2.5i << END >> example_11.ps
0 0
20 20
20 235
0 255
END

psxy -W0.25pto -J -R -K -O -X-5i << END >> example_11.ps
255 0
235 20
235 235
255 255
END

$AWK -f rgb_cube.awk r=x g=Y b=0 < /dev/null >! rgb_cube.cpt
grdimage rgb_cube.grd -Crgb_cube.cpt -J -K -O -X2.5i -Y-2.5i -B256wesn >> example_11.ps

psxy -W0.25pto -J -R -K -O -X2.5i << END >> example_11.ps
0 0
20 20
20 235
0 255
END

psxy -W0.25pto -J -R -O -X-5i << END >> example_11.ps
255 0
235 20
235 235
255 255
```

```
END

\rm -f rgb_cube.cpt rgb_cube.grd .gmtcommands4 .gmtdefaults4
```

The ***$AWK*** script rgb_cube.awk is as follows:

```
#    $Id: rgb_cube.awk,v 1.1.1.1 2000/12/28 01:23:45 gmt Exp $
END{
  z=-.5;

  if(r=="X" || g=="X" || b=="X"){
    xl=255; xr=0; xd=-255;
  }else{
    xl=0; xr=255; xd=255;
  }

  if(r=="Y" || g=="Y" || b=="Y"){
    yb=255; yt=-1; yd=-1;
  }else{
    yb=0; yt=256; yd=1;
  }

  for(y=yb; y!=yt; y+=yd){

    x=xl;

    if(r=="x" || r=="X"){
      if(g=="y" || g=="Y"){
    printf("%7.1f %3d %3d %3d " ,z,x,y,b);
    x+=xd; z+=256;
    printf("%7.1f %3d %3d %3d\n",z,x,y,b);
      }else{
    printf("%7.1f %3d %3d %3d " ,z,x,g,y);
    x+=xd; z+=256;
    printf("%7.1f %3d %3d %3d\n",z,x,g,y);
      }

    }else if(g=="x" || g=="X"){
      if(r=="y" || r=="Y"){
    printf("%7.1f %3d %3d %3d " ,z,y,x,b);
    x+=xd; z+=256;
    printf("%7.1f %3d %3d %3d\n",z,y,x,b);
      }else{
    printf("%7.1f %3d %3d %3d " ,z,r,x,y);
    x+=xd; z+=256;
    printf("%7.1f %3d %3d %3d\n",z,r,x,y);
      }

    }else{
      if(r=="y" || r=="Y"){
    printf("%7.1f %3d %3d %3d " ,z,y,g,x);
    x+=xd; z+=256;
    printf("%7.1f %3d %3d %3d\n",z,y,g,x);
      }else{
    printf("%7.1f %3d %3d %3d " ,z,r,y,x);
    x+=xd; z+=256;
    printf("%7.1f %3d %3d %3d\n",z,r,y,x);
      }
    }
  }
  exit;
}
```

The cube can be viewed in Figure 7.11.

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 gridded files but still are able to contour

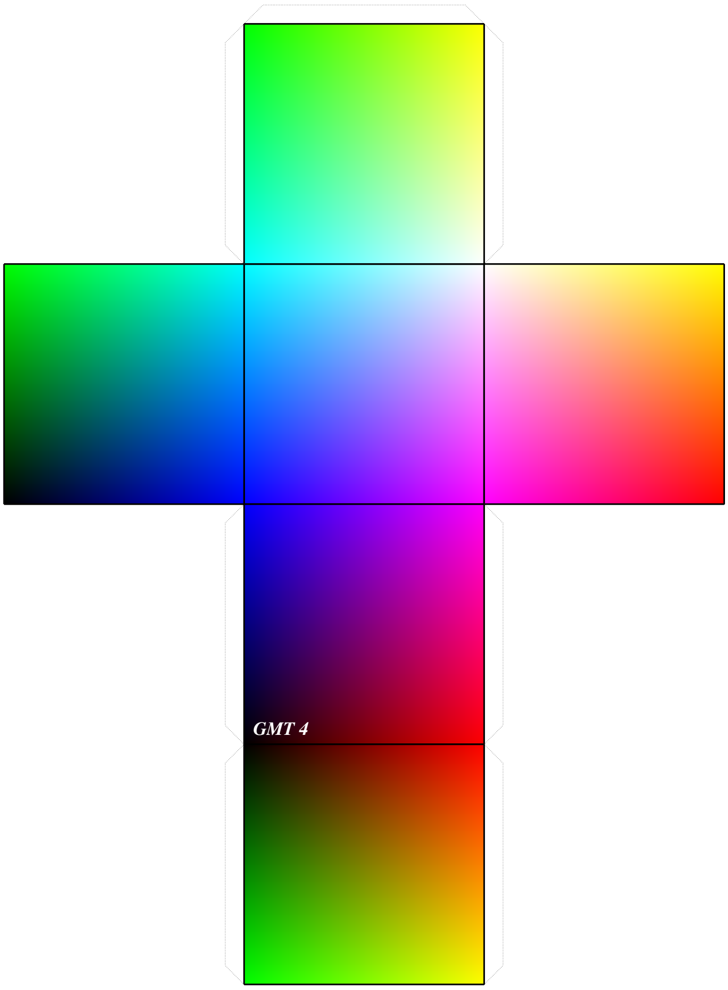


Figure 7.11: The RGB color cube.

and image the data. We use a color palette table topo.cpt (supplied with the script data separately). The script becomes:

```
#!/bin/csh
#        GMT EXAMPLE 12
#
#        $Id: job12.csh,v 1.7 2004/07/14 00:46:17 pwessel Exp $
#
# 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
triangulate table_5.11 -M >! net.xy
psxy -R0/6.5/-0.2/6.5 -JX3.06i/3.15i -B2f1WSNe -M net.xy -W0.5p -P -K -Y4.65i >! example_12.ps
psxy table_5.11 -R -J -O -K -Sc0.12i -Gwhite -W0.25p >> example_12.ps
$AWK '{print $1, $2, 6, 0, 0, "CM", NR-1}' table_5.11 | \
   pstext -R -J -O -K >> example_12.ps
# Then draw network and print the node values
psxy -R -J -B2f1eSNw -M net.xy -W0.5p -O -K -X3.25i >> example_12.ps
psxy -R -J -O -K table_5.11 -Sc0.03i -Gblack >> example_12.ps
$AWK '{printf "%g %s 6 0 0 LM %g\n", $1, $2, $3}' table_5.11 | pstext -R -J -O -K -W255o \
   -C0.01i/0.01i -D0.08i/0i -N >> example_12.ps
# Then contour the data and draw triangles using dashed pen
# Use "minmax" and "makecpt" to make a color palette (.cpt) file
set z = `minmax table_5.11 -C -I25`
makecpt -Cjet -T$z[5]/$z[6]/25 >! topo.cpt
```

```
pscontour -R -J table_5.11 -B2f1WSne -W0.75p -Ctopo.cpt -L0.25pta -G1i/0 -X-3.25i -Y-3.65i -O -K \
   -U"Example 12 in Cookbook" >> example_12.ps
# Finally color the topography
pscontour -R -J table_5.11 -B2f1eSnw -Ctopo.cpt -I -X3.25i -O -K >> example_12.ps
echo "3.16 8 30 0 1 BC Delaunay Triangulation" | pstext -R0/8/0/11 -Jx1i -O -X-3.25i >> example_12.ps
#
\rm -f net.xy topo.cpt .gmt*
```

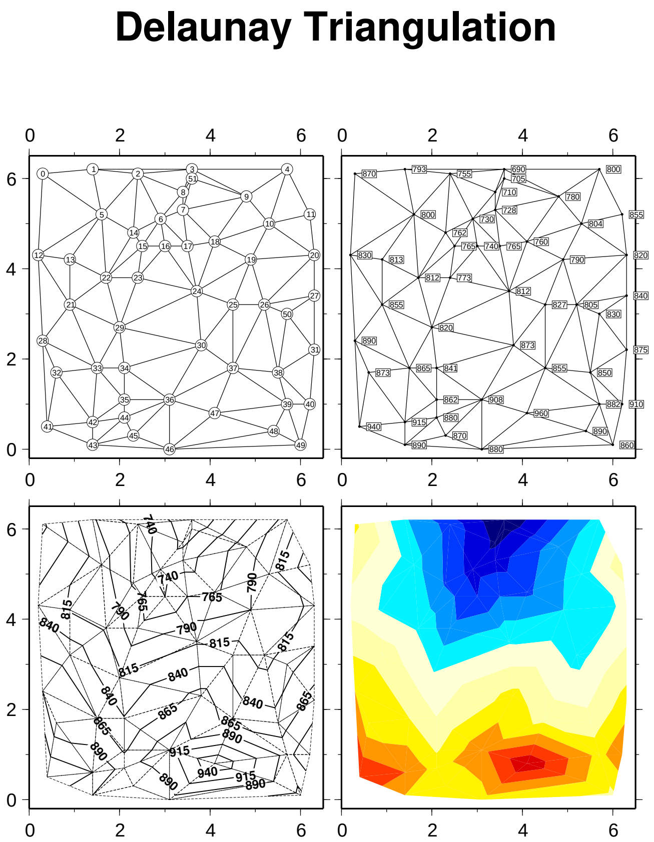


Figure 7.12: Optimal triangulation of data.

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 grdfiles. 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:

```
#!/bin/csh
#        GMT EXAMPLE 13
#
#        $Id: job13.csh,v 1.4 2003/12/18 02:27:21 pwessel Exp $
#
# Purpose:    Illustrate vectors and contouring
# GMT progs:     grdmath, grdcontour, pstext
# Unix progs:     echo, rm
#
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" >! example_13.ps
grdcontour dzdy.grd -J -B1/1WSne -C0.05 -A0.2 -O -K -G2i/10 -S4 -T0.1i/0.03i -X3.45i >> example_13.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 \
   >> example_13.ps
grdcontour z.grd -J -B1/1WSne -C0.05 -O -K -G2i/10 -S4 -X3.45i >> example_13.ps
grdvector dzdx.grd dzdy.grd -I0.2 -J -O -K -Q0.03i/0.1i/0.09in0.25i -G0 -S5i >> example_13.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 \
   >> example_13.ps
\rm -f z.grd dzdx.grd dzdy.grd .gmt*
```

A **pstext** call to place a header finishes the plot (Figure 7.13.

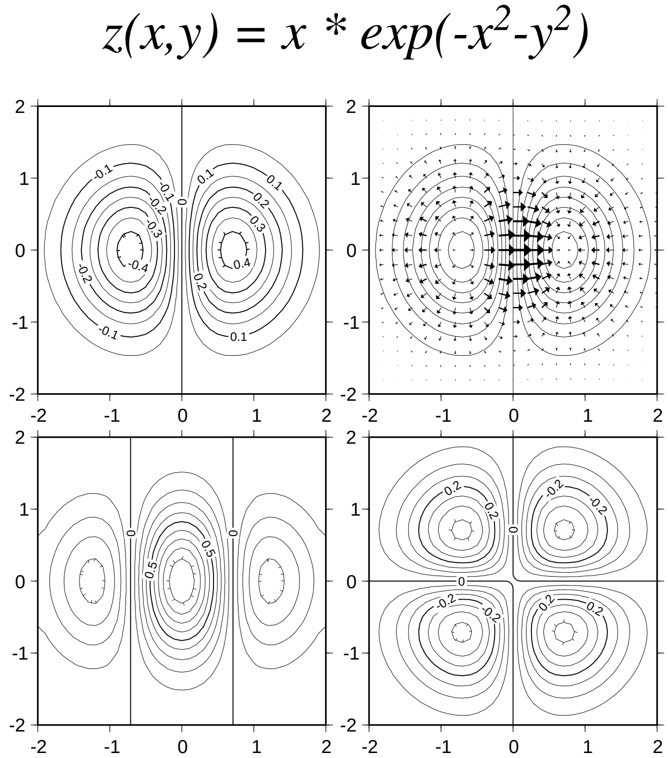


Figure 7.13: Display of vector fields in **GMT**.

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 (table 5.11 from example 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 gridded 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/csh
#       GMT EXAMPLE 14
```

```
#
#       $Id: job14.csh,v 1.8 2004/06/02 22:52:32 pwessel Exp $
#
# Purpose:    Showing simple gridding, contouring, and resampling along tracks
# GMT progs:    blockmean, grdcontour, grdtrack, grdtrend, minmax, project
#       pstext, psbasemap, psxy, surface
# Unix progs:    $AWK, rm
#
# First draw network and label the nodes
gmtset GRID_PEN_PRIMARY 0.25p,-
psxy table_5.11 -R0/7/0/7 -JX3.06i/3.15i -B2f1WSNe -Sc0.05i -Gblack -P -K -Y6.45i >! example_14.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 \
   >> example_14.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 >> example_14.ps
psxy -R0/7/0/7 -J -B2f1eSNw mean.xyz -Ss0.05i -Gblack -O -K >> example_14.ps
$AWK '{printf "%g %s 6 0 0 LM %g\n", $1+0.1, $2, $3}' mean.xyz | pstext -R -J -O -K -W255o \
   -C0.01i/0.01i -N >> example_14.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 >> example_14.ps
psxy -R -J mean.xyz -Ss0.05i -Gblack -O -K >> example_14.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 -Glct/cb -S4 -O -K -X3.25i >> example_14.ps
psxy -R -J track -W1pto -O -K >> example_14.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 -W1p -O -K -X-3.25i -Y-1.9i -B1/50WSne \
   >> example_14.ps
psxy -R -J trend.d -W0.5pta -O -U"Example 14 in Cookbook" >> example_14.ps
\rm mean.xyz track *.grd *.d .gmt*
```

7.15 Gridding, contouring, and masking of unconstrained areas

This example (Figure 7.15) demonstrates some off 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 allthough 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 landmasses 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 gridded files using **grdinfo**.

```
#!/bin/csh
#       GMT EXAMPLE 15
#
#       $Id: job15.csh,v 1.4 2004/04/10 17:19:14 pwessel Exp $
#
# Purpose:    Gridding and clipping when data are missing
# GMT progs:    blockmedian, gmtconvert, grdclip, grdcontour, grdinfo, minmax,
#       nearneighbor, pscoast, psmask, pstext, surface
# Unix progs:    awk, echo, rm
#
gmtconvert ship.xyz -bo >! ship.b
set region = `minmax ship.b -I1 -bi3`
nearneighbor $region -I10m -S40k -Gship.grd ship.b -bi3
set info = `grdinfo -C -M ship.grd`
grdcontour ship.grd -JM3i -P -B2WSne -C250 -A1000 -G2i -K -U"Example 15 in Cookbook" >! example_15.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 >> example_15.ps
grdcontour ship.grd -J -B2WSne -C250 -L-8000/0 -A1000 -G2i -O -K >> example_15.ps
```

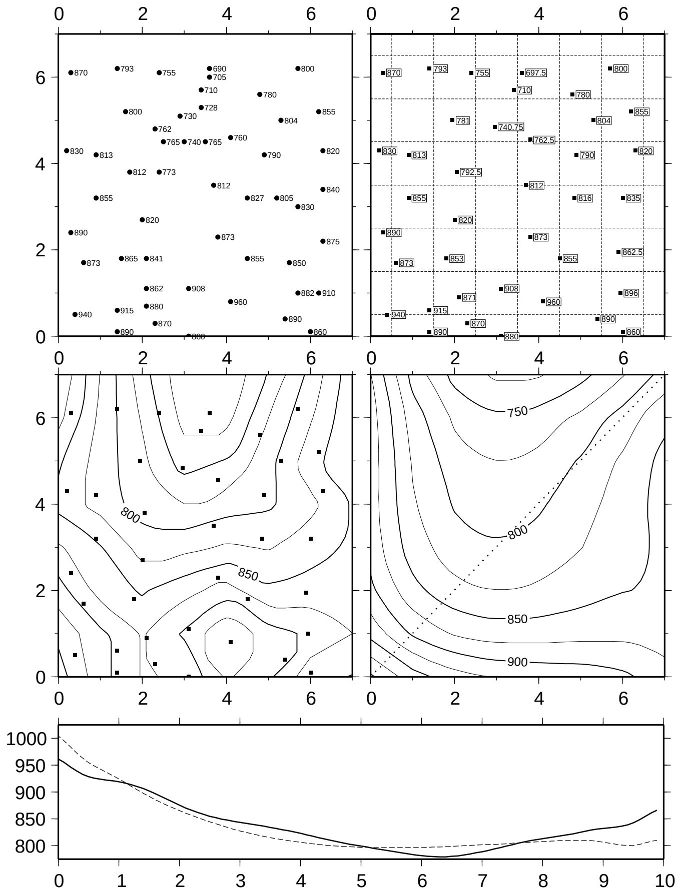


Figure 7.14: Gridding of data and trend surfaces.

```
#
psmask $region -I10m ship_10m.b -bi3 -J -B2WSne -O -K -X-3.6i -Y3.75i >> example_15.ps
grdcontour ship.grd -J -C250 -A1000 -L-8000/0 -G2i -O -K >> example_15.ps
psmask -C -O -K >> example_15.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 >> example_15.ps
pscoast $region -J -O -K -Ggray -W0.25p >> example_15.ps
echo $info[12] $info[13] | psxy -R -J -O -K -Sa0.15i -W1p >> example_15.ps
echo "-0.3 3.6 24 0 1 CB Gridding with missing data" | pstext -R0/3/0/4 -Jx1i -O -N >> example_15.ps
\rm -f ship.b ship_10m.b ship.grd ship_clipped.grd .gmt*
```

7.16 Gridding of data, continued

pscontour (for contouring) and **triangulate** (for gridding) use the simplest method of interpolating data: a Delaunay triangulation (see Example 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 Example 15).

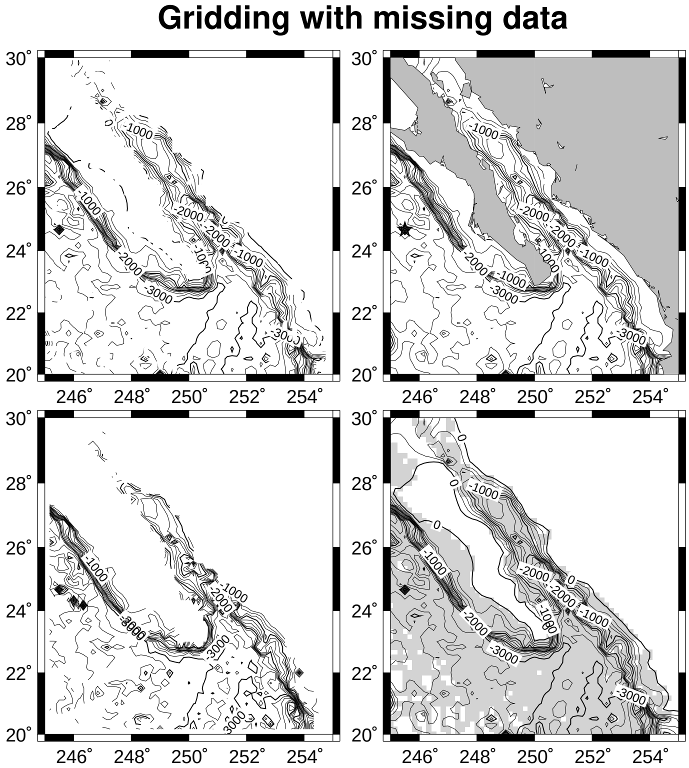


Figure 7.15: Gridding, contouring, and masking of data.

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 **grdfft** 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, patterns, and a "skip slice" request for $700 < z < 725$.

```
#!/bin/csh
#        GMT EXAMPLE 16
#
#        $Id: job16.csh,v 1.7 2004/04/13 21:32:27 pwessel Exp $
#
# Purpose:    Illustrates interpolation methods using same data as Example 12.
# GMT progs:    gmtset, grdview, grdfilter, pscontour, psscale, pstext, surface, triangulate
# Unix progs:    echo, rm
#
# First make a cpt file as in example 12:
#
#set z = `minmax table_5.11 -C -I25`
#makecpt -Crainbow -T$z[5]/$z[6]/25 >! ex16.cpt
#Hand edit to add patterns and skips
#
```

```
# Now illustrate various means of contouring, using triangulate and surface.
#
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 \
   >! example_16.ps
echo "3.25 7 18 0 4 CB pscontour (triangulate)" | pstext -R -J -O -K -N >> example_16.ps
#
surface table_5.11 -R -I0.1 -Graws0.grd
grdview raws0.grd -R -J -Ba2f1WSne -Cex16.cpt -Qs -O -K -X3.5i >> example_16.ps
echo "3.25 7 18 0 4 CB surface (tension = 0)" | pstext -R -J -O -K -N >> example_16.ps
#
surface table_5.11 -R -I0.1 -Graws5.grd -T0.5
grdview raws5.grd -R -J -Ba2f1WSne -Cex16.cpt -Qs -O -K -Y-3.75i -X-3.5i >> example_16.ps
echo "3.25 7 18 0 4 CB surface (tension = 0.5)" | pstext -R -J -O -K -N >> example_16.ps
#
triangulate table_5.11 -Grawt.grd -R -I0.1 > /dev/null
grdfilter rawt.grd -Gfiltered.grd -D0 -Fc1
grdview filtered.grd -R -J -Ba2f1WSne -Cex16.cpt -Qs -O -K -X3.5i >> example_16.ps
echo "3.25 7 18 0 4 CB triangulate @~\256@~ grdfilter" | pstext -R -J -O -K -N >> example_16.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 \
   >> example_16.ps
psscale -D3.25i/0.35i/5i/0.25ih -Cex16.cpt -O -U"Example 16 in Cookbook" -Y-0.75i >> example_16.ps
#
\rm -f *.grd .gmt*
```

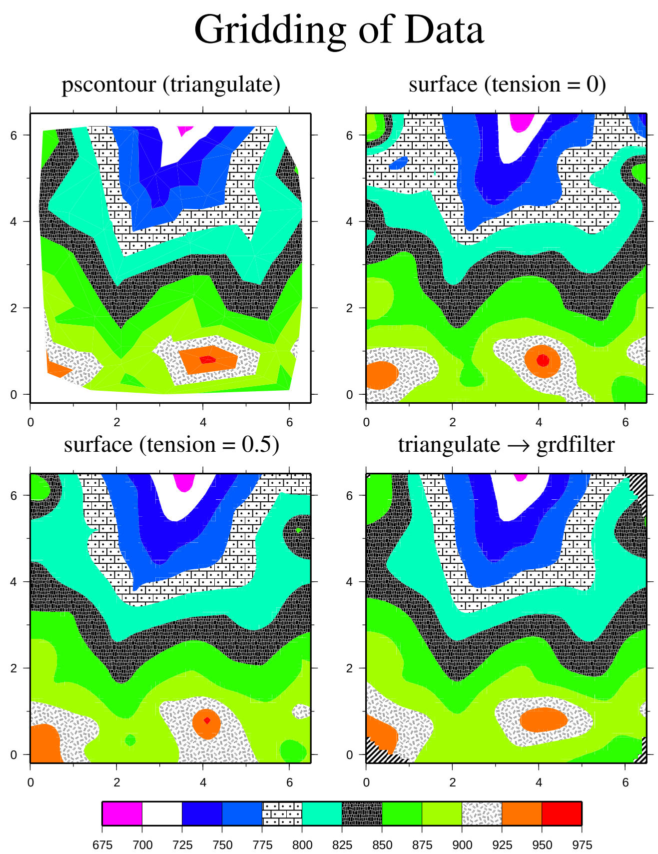


Figure 7.16: More ways to grid data.

7.17 Images clipped by coastlines

This example demonstrates how **pscoast** can be used to set up clippaths 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 clippaths, 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/csh
#        GMT EXAMPLE 17
#
#        $Id: job17.csh,v 1.2 2003/12/18 02:27:21 pwessel Exp $
#
# Purpose:    Illustrates clipping of images using coastlines
# GMT progs:    grd2cpt, grdgradient, grdimage, pscoast, pstext
# Unix progs:    rm
#
# Get Geoid and Topography for the region
#grdraster 1 -R60/90/-10/25 -Gindia_topo.grd
#grdraster 4 -R60/90/-10/25 -Gindia_geoid.grd

# First generate geoid image w/ shading

grd2cpt india_geoid.grd -Crainbow >! geoid.cpt
grdgradient india_geoid.grd -Nt1 -A45 -Gindia_geoid_i.grd
grdimage india_geoid.grd -Iindia_geoid_i.grd -JM6.5i -Cgeoid.cpt -P -K -U"Example 17 in Cookbook" \
   >! example_17.ps

# Then use pscoast to initiate clip path for land

pscoast -R60/90/-10/25 -J -O -K -Dl -Gc >> example_17.ps

# Now generate topography image w/shading

echo "-10000 150 10000 150" >! gray.cpt
grdgradient india_topo.grd -Nt1 -A45 -Gindia_topo_i.grd
grdimage india_topo.grd -Iindia_topo_i.grd -J -Cgray.cpt -O -K >> example_17.ps

# Finally undo clipping and overlay basemap

pscoast -R -J -O -K -Q -B10f5:."Clipping of Images": >> example_17.ps

# Add a text paragraph

pstext -R -J -O -M -W255O0.5p -D-0.1i/0.1i << EOF >> example_17.ps
> 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.
EOF

# Clean up

\rm -f geoid.cpt gray.cpt *_i.grd .gmt*
```

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 field[3] 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.

```
#!/bin/csh
#        GMT EXAMPLE 18
#
#        $Id: job18.csh,v 1.4 2004/04/13 21:32:27 pwessel Exp $
```

[3] See http://topex.ucsd.edu/marine_grav/mar_grav.html.

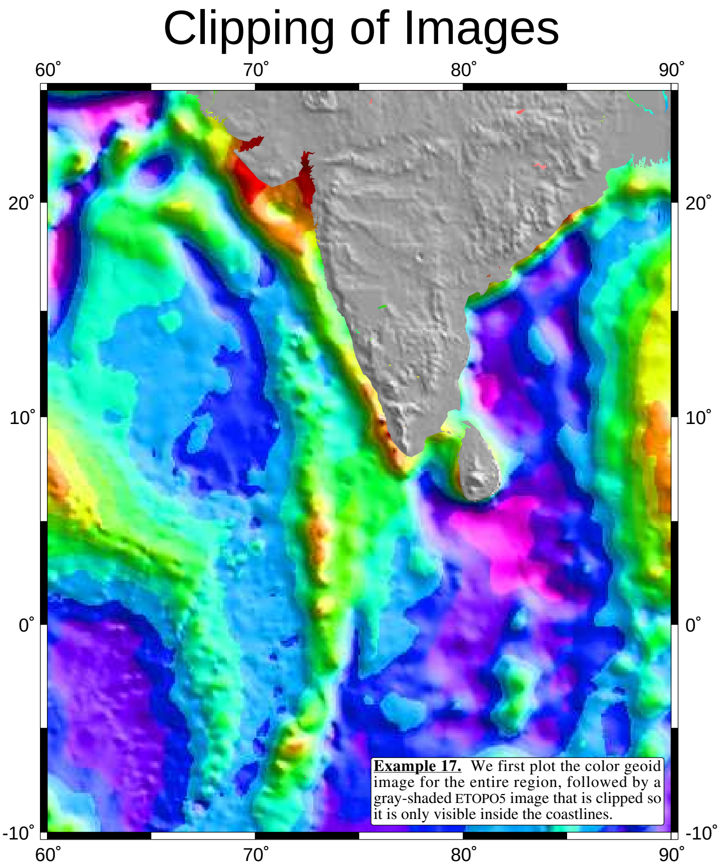


Figure 7.17: Clipping of images using coastlines.

```
#
# Purpose:    Illustrates volumes of grids inside contours and spatial
#        selection of data
# GMT progs:    gmtset, gmtselect, grdclip, grdcontour, grdgradient, grdimage,
#        grdmath, grdvolume, makecpt, pscoast, psscale, pstext, psxy
# Unix progs:    $AWK, cat, rm
#
# Get Sandwell/Smith gravity for the region
#img2latlongrd world_grav.img.7.2 -R-149/-135/52.5/58 -GAK_gulf_grav.grd -T1

# Use spherical projection since SS data define on sphere
gmtset ELLIPSOID Sphere

# 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.grd -Nt1 -A45 -GAK_gulf_grav_i.grd
grdimage AK_gulf_grav.grd -IAK_gulf_grav_i.grd -JM5.5i -Cgrav.cpt -B2f1 -P -K -X1.5i -Y5.85i \
   >! example_18.ps
pscoast -R-149/-135/52.5/58 -J -O -K -Di -Ggray -W0.25p >> example_18.ps
psscale -D2.75i/-0.4i/4i/0.15ih -Cgrav.cpt -B20f10/:mGal: -O -K >> example_18.ps
$AWK '{print $1, $2, 12, 0, 1, "LB", "Pratt"}' pratt.d | pstext -R -J -O -K -D0.1i/0.1i \
   >> example_18.ps
$AWK '{print $1, $2, 0, 200, 200}' pratt.d | psxy -R -J -O -K -SE -W0.25p >> example_18.ps

# Then draw 10 mGal contours and overlay 50 mGal contour in green

grdcontour AK_gulf_grav.grd -J -C20 -B2f1WSEn -O -K -U/-1.25i/-0.75i/"Example 18 in Cookbook" \
   -Y-4.85i >> example_18.ps
grdcontour AK_gulf_grav.grd -J -C10 -L49/51 -O -K -Dsm -Wc0.75p/0/255/0 >> example_18.ps
```

```
pscoast -R -J -O -K -Di -Ggray -W0.25p >> example_18.ps
$AWK '{print $1, $2, 0, 200, 200}' pratt.d | psxy -R -J -O -K -SE -W0.25p >> example_18.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 make a simple $AWK script that returns the average position
# of a file with coordinates x, y (remember to escape the $ sign)

cat << EOF >! center.awk
BEGIN {
    x = 0
    y = 0
    n = 0
}
{
    x += \$1
    y += \$2
    n++
}
END {
    print x/n, y/n
}
EOF

# Now determine mean location of each closed contour and
# add it to the file centers.d

\rm -f centers.d
foreach file (sm_*.xyz)
    $AWK -f center.awk $file >>! centers.d
end

# Only plot the ones within 200 km

gmtselect -R -J -C200/pratt.d centers.d >! $$
psxy $$ -R -J -O -K -SC0.04i -Gred -W0.25p >> example_18.ps
psxy -R -J -O -K -ST0.1i -Gyellow -W0.25p pratt.d >> example_18.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 -I2m -F -142.65 56.25 GDIST = mask.grd
grdclip mask.grd -Sa200/NaN -Sb200/1 -Gmask.grd
grdmath AK_gulf_grav.grd mask.grd MUL = tmp.grd
set info = `grdvolume tmp.grd -C50 -Sk`

psxy -R -J -A -O -K -L -W0.75p -Gwhite << EOF >> example_18.ps
-148.5 52.75
-140.5    52.75
-140.5    53.75
-148.5    53.75
EOF
pstext -R -J -O << EOF >> example_18.ps
-148 53.08 14 0 1 LM Areas: $info[2] km@+2@+
-148 53.42 14 0 1 LM Volumes: $info[3] mGal\264km@+2@+
EOF

# Clean up

\rm -f $$ grav.cpt sm_*.xyz *_i.grd tmp.grd mask.grd pratt.d center* .gmt*
```

Our illustration is presented in Figure 7.18.

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** clippaths 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

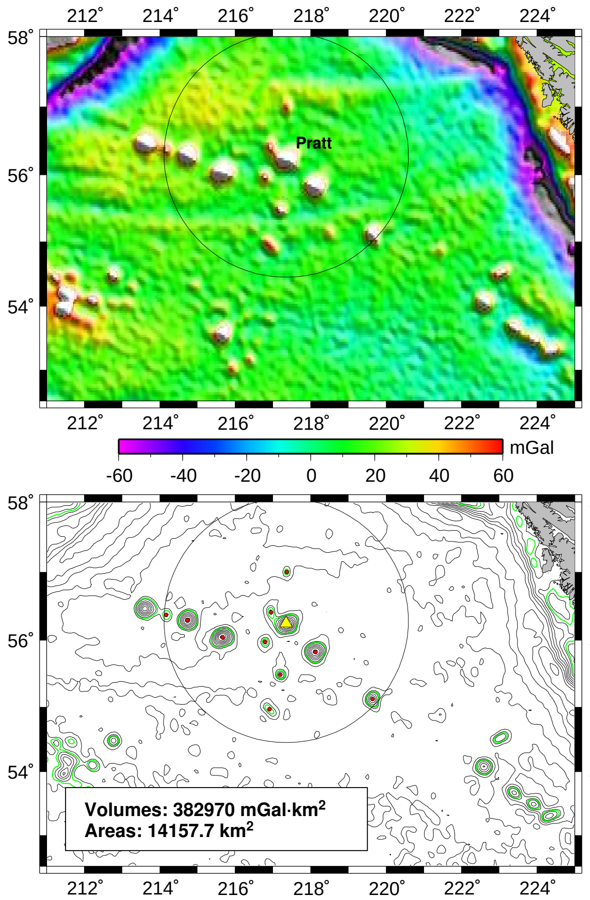


Figure 7.18: Volumes and geo-spatial selections.

color combinations. The final panel repeats the top panel except that the land and sea images have changed places (Figure 7.19).

```
#!/bin/csh
#         GMT EXAMPLE 19
#
#         $Id: job19.csh,v 1.7 2004/06/10 17:45:32 pwessel Exp $
#
# Purpose:    Illustrates various color pattern effects for maps
# GMT progs:    gmtset, grdimage, grdmath, makecpt, pscoast, pstext
# Unix progs:    rm
#
# First make a worldmap with graded blue oceans and rainbow continents

gmtset COLOR_MODEL rgb
grdmath -Rd -I1 -F Y COSD 2 POW = lat.grd
grdmath -Rd -I1 -F X = lon.grd
echo "0 255 255 255 1 0 0 255" >! lat.cpt
makecpt -Crainbow -T-180/180/60 -Z >! lon.cpt
grdimage lat.grd -JI0/6.5i -Clat.cpt -P -K -Y7.5i -B0 >! example_19.ps
pscoast -R -J -O -K -Dc -A5000 -Gc >> example_19.ps
grdimage lon.grd -J -Clon.cpt -O -K >> example_19.ps
pscoast -R -J -O -K -Q >> example_19.ps
pscoast -R -J -O -K -Dc -A5000 -W0.25p >> example_19.ps
echo "0 20 32 0 1 CM 3RD INTERNATIONAL" | pstext -R -J -O -K -Gred -S0.5p >> example_19.ps
echo "0 -10 32 0 1 CM GMT CONFERENCE" | pstext -R -J -O -K -Gred -S0.5p >> example_19.ps
echo "0 -30 18 0 1 CM Honolulu, Hawaii, April 1, 2005" | pstext -R -J -O -K -Ggreen -S0.25p \
   >> example_19.ps

# Then show example of color patterns

pscoast -R -J -O -K -Dc -A5000 -Gp100/86:FredByellow -Sp100/7:FredBblack -B0 -Y-3.25i \
```

```
   >> example_19.ps
echo "0 15 32 0 1 CM SILLY USES OF" | pstext -R -J -O -K -Glightgreen -S0.5p >> example_19.ps
echo "0 -15 32 0 1 CM GMT COLOR PATTERNS" | pstext -R -J -O -K -Gmagenta -S0.5p >> example_19.ps

# Finally repeat 1st plot but exchange the patterns

grdimage lon.grd -J -Clon.cpt -O -K -Y-3.25i -B0 -U"Example 19 in Cookbook" >> example_19.ps
pscoast -R -J -O -K -Dc -A5000 -Gc >> example_19.ps
grdimage lat.grd -J -Clat.cpt -O -K >> example_19.ps
pscoast -R -J -O -K -Q >> example_19.ps
pscoast -R -J -O -K -Dc -A5000 -W0.25p >> example_19.ps
echo "0 20 32 0 1 CM 3RD INTERNATIONAL" | pstext -R -J -O -K -Gred -S0.5p >> example_19.ps
echo "0 -10 32 0 1 CM GMT CONFERENCE" | pstext -R -J -O -K -Gred -S0.5p >> example_19.ps
echo "0 -30 18 0 1 CM Honolulu, Hawaii, April 1, 2005" | pstext -R -J -O -Ggreen -S0.25p \
   >> example_19.ps

\rm -f l*.grd l*.cpt .gmt*
```

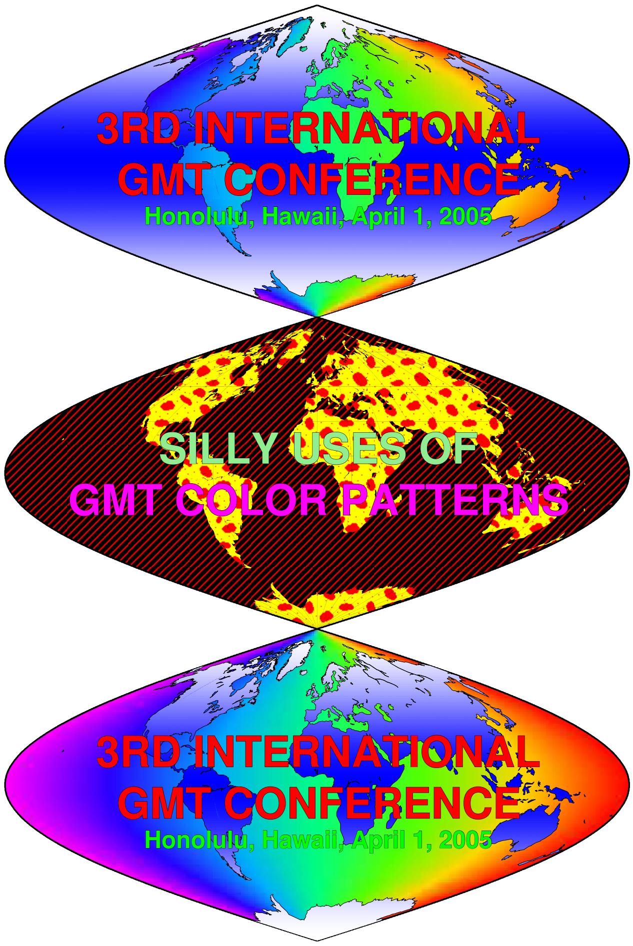


Figure 7.19: Using color patterns in illustrations.

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 decription of symbol design). This is how your symbol will look when a size of 1 inch is chosen. Figure 7.20 illustrates a new symbol we will call volcano.

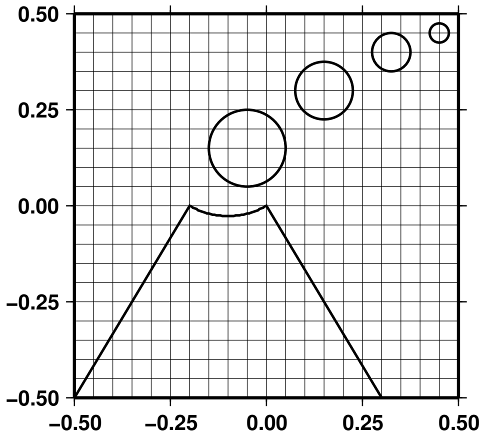


Figure 7.20: Making a new volcano symbol for **GMT**.

2. After designing the symbol we will encode it using a simple set of rules. In our case we describe our volcano using these three freeform polygon generators:

x_0 y_0 **M** [**–G***fill*] [**–W***pen*]	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 α_1 α_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** [**–G***fill*] [**–W***pen*] 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 symbol results in a definition file volcano.def:

```
#	$Id: volcano.def,v 1.5 2004/04/13 21:32:27 pwessel Exp $
#
#	Definition file for a volcano symbol
#	To be used with psxy as -Skvolcano/<size>.
#	The symbol will be painted and drawn given the
#	-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
```

The values refer to positions and dimensions illustrated in Figure 7.20 above.

3. Given a proper definition file we may now use it 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**. Without further discussion we also make a definition for a multi- colored bulls-eye symbol:

```
#    $Id: bullseye.def,v 1.4 2004/04/13 21:32:27 pwessel Exp $
#
#    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
```

Here is our final map script:

```
#!/bin/csh
#        GMT EXAMPLE 20
#
#        $Id: job20.csh,v 1.6 2004/04/13 21:39:49 pwessel Exp $
#
# 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

cat << EOF >! hotspots.d
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
EOF

pscoast -Rg -JR180/9i -B60/30:."Hotspot Islands and Cities": -Gdarkgreen -Slightblue \
   -Dc -A5000 -K -U"Example 20 in Cookbook" >! example_20.ps

psxy -R -J hotspots.d -Skvolcano -O -K -W0.25p -Gred >> example_20.ps

# Overlay a few bullseyes at NY, Cairo, and Perth

cat << EOF >! cities.d
286    40.45    0.8
31.15    30.03    0.8
115.49    -31.58    0.8
EOF

psxy -R -J cities.d -Skbullseye -O >> example_20.ps

\rm -f hotspots.d cities.d .gmt*
```

which produces the plot in Figure 7.21.

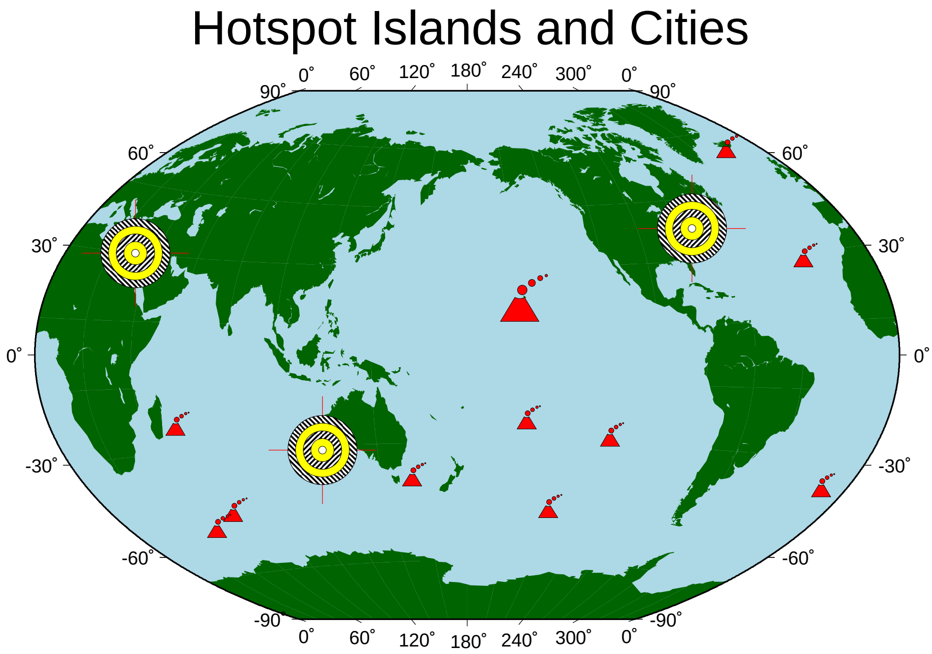


Figure 7.21: Using custom symbols in **GMT**.

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 early 2004. The datafile is a comma-separated table and the first few 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, and zoom in on the developments since 2003; 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/csh
#
#    GMT Example 21  $Id: job21.csh,v 1.13 2004/06/25 22:39:01 pwessel Exp $
#
# Purpose:    Plot a time-series
```

```
# GMT progs:    gmtset, gmtconvert, minmax, psbasemap, psxy
# Unix progs:    echo
#

# File has time stored as dd-Mon-yy so set input format to match it
# Make sure language is us since monthnames are in US english.

gmtset INPUT_DATE_FORMAT dd-o-yy PLOT_DATE_FORMAT o ANNOT_FONT_SIZE_PRIMARY +10p
gmtset TIME_FORMAT_PRIMARY abbreviated CHAR_ENCODING ISOLatin1+
gmtset TIME_LANGUAGE us

# Pull out a suitable region string in default  yyyy-mm-dd format

set info = `minmax -f0T -I50 -C -H RHAT_price.csv`
set R = "-R$info[1]/$info[2]/$info[3]/$info[4]"

# Lay down the basemap:

psbasemap $R -JX9iT/6i -Glightgreen -K -U"Example 21 in Cookbook" -Bs1Y/0WSen \
    -Bpa3Of1o/50WSen:=\$::."RedHat (RHAT) Stock Price Trend since IPO": >! example_21.ps

# Plot main window with open price as red line over yellow envelope of low/highs
# use gmtconvert to stitch the envelope together (-I reverses outout) and
# set output date format to match the input date format.

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 >> example_21.ps
psxy -R -J RHAT_price.csv -H -Wthin,red -O -K >> example_21.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 >> example_21.ps
echo "01-Jan-99    25" >! RHAT.pw
echo "01-Jan-05    25" >> RHAT.pw
psxy -R -J RHAT.pw -Wthick,- -O -K >> example_21.ps
gmtset INPUT_DATE_FORMAT yyyy-mm-dd
echo "$info[2] 25 12 0 17 RB Wessel purchase price" \
    | pstext -R -J -O -K -D-0.1i/0.05i -N >> example_21.ps
gmtset INPUT_DATE_FORMAT dd-o-yy

# Get smaller region for insert for trend since 2003

set R = "-R2003T/$info[2]/$info[3]/30"

# Lay down the basemap, using Finnish annotations and place the insert in the upper right:

gmtset TIME_LANGUAGE fi
psbasemap $R -JX6iT/3i -Bpa1Of3o/10:=\$:ESw -Bs1Y/ -Glightblue -O -K -X3i -Y3i >> example_21.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 >> example_21.ps
psxy -R -J RHAT_price.csv -H -Wthin/red -O -K >> example_21.ps

# Draw P Wessel's purchase price as dashed line

psxy -R -J RHAT.pw -Wthick,- -O >> example_21.ps

# Clean up after ourselves:

\rm -f RHAT.* .gmtcommands4 .gmtdefaults4
```

which produces the plot in Figure 7.22, suggesting Wessel better hold on to those stocks for a while longer...

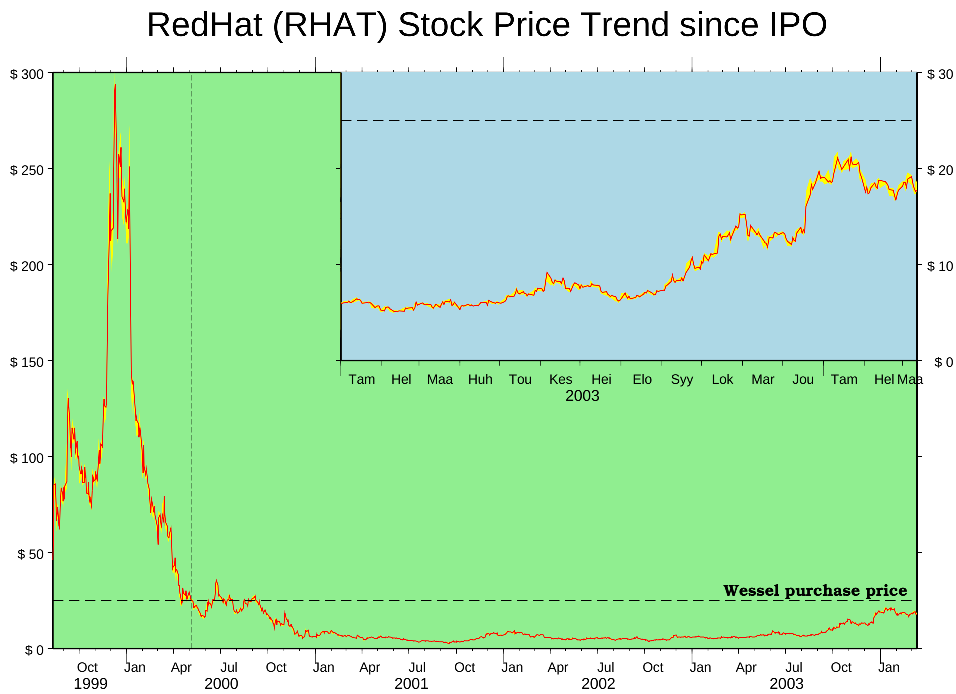


Figure 7.22: Time-series of RedHat stock price since IPO.

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 URL[4]. 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 rasterfile, is used to spice up the legend.

```
#!/bin/csh
#
#    GMT Example 22  $Id: job22.csh,v 1.8 2004/09/29 05:29:16 pwessel Exp $
#
# Purpose:    Automatic map of last 7 days of world-wide seismicity
# GMT progs:    gmtset, pscoast, psxy, pslegend
# Unix progs:    cat, sed, awk, wget|cur
#
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)

set n = `cat neic_quakes.d | wc -l`
@ n--

# Pull out the first and last timestamp to use in legend title
```

[4]You can also use the utility ***curl***

```
set first = `sed -n 2p neic_quakes.d | awk -F, '{printf "%s %s\n", $1, $2}'`
set last  = `sed -n '$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`"
set me = "GMT guru @@ GMTbox"

# Create standard seismicity color table

cat << EOF >! neis.cpt
0    red    100    red
100    green    300    green
300    blue    10000    blue
EOF

# 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 >! example_22.ps
awk -F, '{ print $4, $3, $6, $5*0.02}' neic_quakes.d \
    | psxy -R -JK -O -K -Cneis.cpt -Sci -Wthin -H >> example_22.ps

# Create legend input file for NEIS quake plot

cat << EOF >! neis.legend
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
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
>
EOF

# Put together a reasonable legend text, and add logo and user's name:

cat << EOF >> 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
EOF

# 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 -Jx1i -R0/8/0/8 -O -F neis.legend -Glightyellow >> example_22.ps

# Clean up after ourselves:

\rm -f neis.* .gmtcommands4 .gmtdefaults4
```

The script produces the plot in Figure 7.23, giving the URL where these and similar data can be obtained.

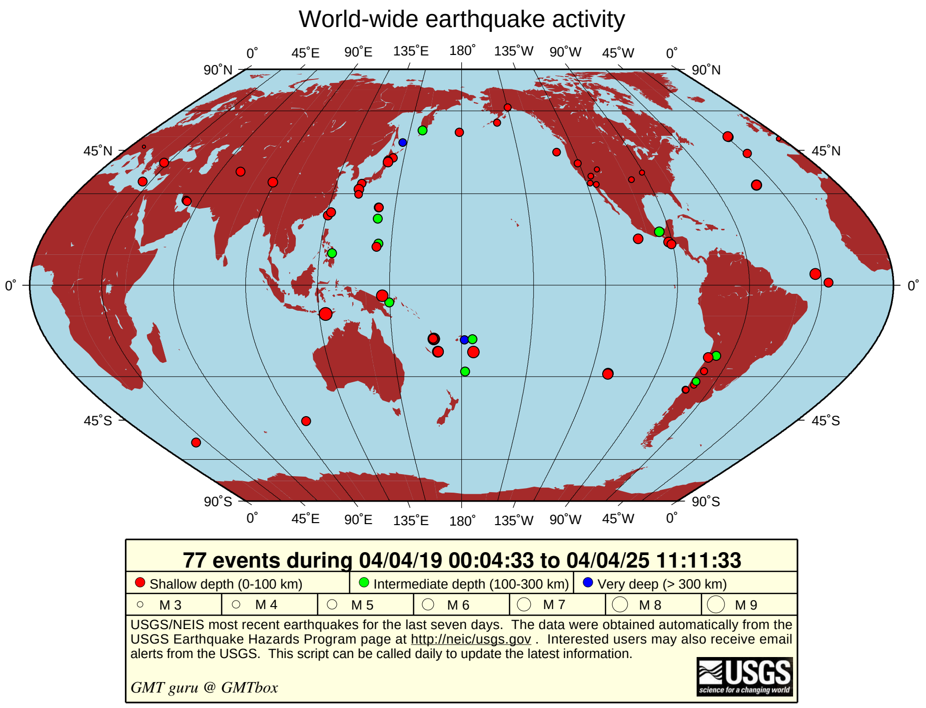


Figure 7.23: World-wide seismicity the last 7 days.

7.23 All great-circle paths lead to Rome

While motorists recenty 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 arrival[5]. 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/csh
#
#    GMT Example 23  $Id: job23.csh,v 1.10 2004/07/13 18:47:09 pwessel Exp $
#
# Purpose:    Plot distances from Rome and draw shortest paths
# GMT progs:    gmtset, grdmath, grdcontour, psxy, pstext, grdtrack
# Unix progs:    echo, cat, awk

# Position and name of central point:

set lon = 12.50
set lat = 41.99
set 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 << EOF >! cities.d
105.87     21.02     HANOI         LM
282.95     -12.1     LIMA         LM
178.42     -18.13     SUVA          LM
```

[5]Pedants who wish to argue about the "other" arc going the long way should consider using it.

```
237.67    47.58    SEATTLE         RM
28.20    -25.75    PRETORIA    LM
EOF

pscoast -Rg -JH90/9i -Glightgreen -Sblue -U"Example 23 in Cookbook" -A1000 \
  -B0g30:."Distances from $name to the World": -K -Dc -Wthinnest >! example_23.ps

grdcontour dist.grd -A1000+v+ukm+kwhite -Glz-/z+ -S8 -C500 -O -K -J -Wathin,white \
  -Wcthinnest,white,- >> example_23.ps

# Find the number of cities:

set n = `cat cities.d | wc -l`

# For each of these cities, plot great circle arc with psxy

set i = 1
while ($i <= $n)
    set record = `awk '{ if (NR == '$i') print $0}' cities.d`
    (echo $lon $lat; echo $record[1] $record[2]) | psxy -R -J -O -K -W2p/red >> example_23.ps
    @ i++
end

# Plot red squares at cities and plot names:
psxy -R -J -O -K -Ss0.2 -Gred -W0.25p cities.d >> example_23.ps
awk '{print $1, $2, 12, 1, 9, $4, $3}' cities.d \
    | pstext -R -J -O -K -Dj0.15/0 -Gred -N >> example_23.ps
# Place a yellow star at Rome
echo "$lon $lat" | psxy -R -J -O -K -Sa0.2i -Gyellow -Wthin >> example_23.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 CB %d\n", $1, $2, int($NF+0.5)}' \
    | pstext -R -J -O -D0/0.2i -N -Wwhiteo -C0.02i/0.02i >> example_23.ps

# Clean up after ourselves:

\rm -f cities.d dist.grd .gmt*
```

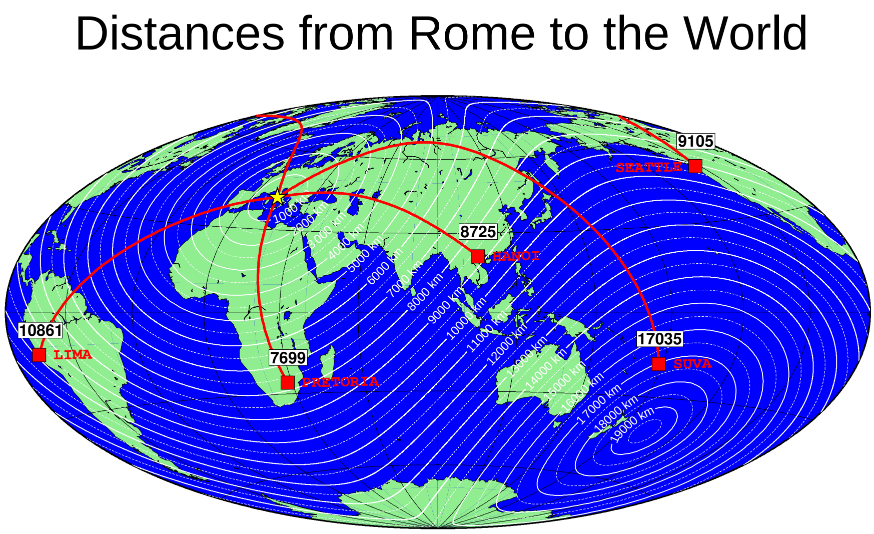


Figure 7.24: All great-circle paths lead to Rome.

The script produces the plot in Figure 7.24; 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 Example 25).

7.24 Data selection based on geospatial criteria

Allthough 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

1. Lie in the ocean and not on land
2. Are within 3000 km of Hobart
3. Are more than 1000 km away from the International Dateline

All remaining earthquakes should be plotted in red. Rather that 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/csh
#
#    GMT Example 24  $Id: job24.csh,v 1.4 2004/04/27 23:24:00 pwessel Exp $
#
# 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
echo "147:13 -42:48 3000 Hobart" >! point.d
cat << EOF >! dateline.d
> Our proxy for the dateline
180    0
180    -90
EOF
set R = `minmax -I10 oz_quakes.d`
pscoast $R -JM9i -K -Gtan -Sdarkblue -Wthin,white -Dl -A500 -Ba20f10g10WeSn \
    -U"Example 24 in Cookbook" >! example_24.ps
psxy -R -J -O -K oz_quakes.d -Sc0.05i -Gred >> example_24.ps
gmtselect oz_quakes.d -L1000/dateline.d -Nk/s -C3000/point.d -fg -R -J -Il \
    | psxy -R -JM -O -K -Sc0.05i -Ggreen >> example_24.ps
awk '{print $1, $2, 0, $3, $3}' point.d | psxy -R -J -O -K -SE -Wfat,white >> example_24.ps
awk '{print $1, $2, 14, 0, 1, "LT", $4}' point.d \
    | pstext -R -J -O -K -Gwhite -D0.1i/-0.1i >> example_24.ps
psxy -R -J -O -K point.d -Wfat,white -Sx0.2i >> example_24.ps
psxy -R -J -O -M dateline.d -Wfat,white -A >> example_24.ps
\rm -f point.d dateline.d .gmt*
```

The script produces the plot in Figure 7.25. 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 Example 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 $2N_y/\pi$:

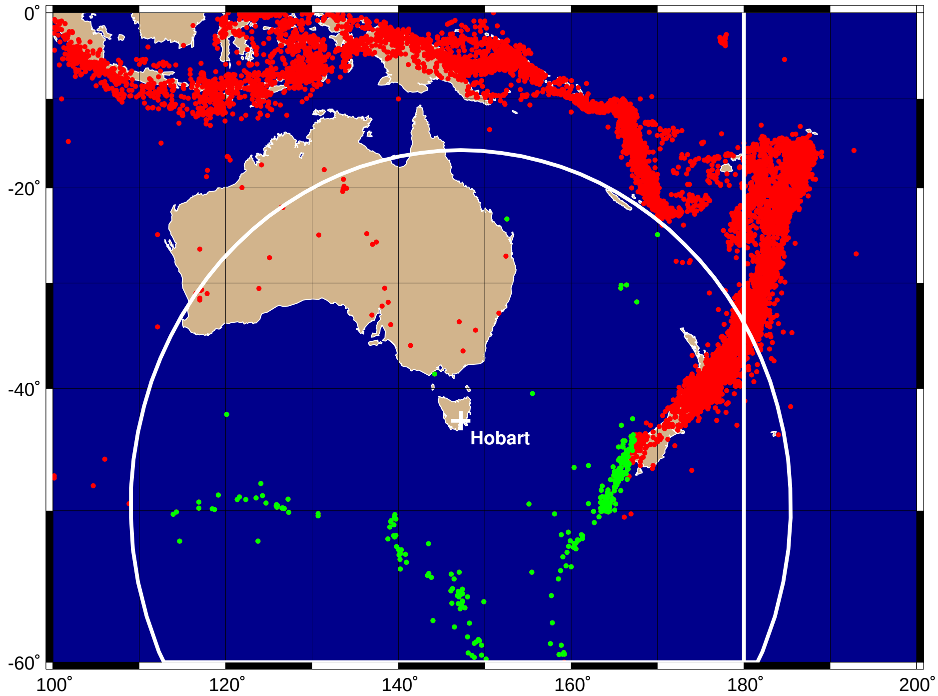


Figure 7.25: Data selection based on geospatial criteria.

```
#!/bin/csh
#
#    GMT Example 25  $Id: job25.csh,v 1.5 2004/07/01 17:57:13 pwessel Exp $
#
# Purpose:    Display distribution of antipode types
# GMT progs:    grdlandmask, grdmath, grd2xyz, gmtmath, grdimage, pscoast, pslegend
# Unix progs:    cat
#
# Create D minutes global grid with -1 over oceans and +1 over land
set D = 30
grdlandmask -Rg -I${D}m -Dc -A500 -N-1/1/1/1/1 -F -Gwetdry.grd
# Manipulate so -1 means ocean/ocean antipode, +1 = land/land, and 0 elsewhere
grdmath wetdry.grd DUP 180 ROTX FLIPUD ADD 2 DIV = key.grd
# Calculate percentage area of each type of antipode match.
grdmath -Rg -I${D}m -F Y COSD 60 $D DIV 360 MUL DUP MUL PI DIV DIV 100 MUL = scale.grd
grdmath key.grd -1 EQ 0 NAN scale.grd MUL = tmp.grd
grd2xyz tmp.grd -S -ZTLf >! key.b
set ocean = `gmtmath -bi1s -Ca -S key.b SUM UPPER RINT =`
grdmath key.grd 1 EQ 0 NAN scale.grd MUL = tmp.grd
grd2xyz tmp.grd -S -ZTLf >! key.b
set land = `gmtmath -bi1s -Ca -S key.b SUM UPPER RINT =`
grdmath key.grd 0 EQ 0 NAN scale.grd MUL = tmp.grd
grd2xyz tmp.grd -S -ZTLf >! key.b
set mixed = `gmtmath -bi1s -Ca -S key.b SUM UPPER RINT =`
# Generate corresponding color table
cat << EOF >! key.cpt
-1    blue     0    blue
0    gray    1    gray
1    red    2    red
EOF
# Create the final plot and overlay coastlines
gmtset ANNOT_FONT_SIZE_PRIMARY +10p PLOT_DEGREE_FORMAT dddF
grdimage key.grd -JKs180/9i -B60/30:."Antipodal comparisons":WsNE -K -Ckey.cpt -Y1.2i \
    -U/-0.75i/-0.95i/"Example 25 in Cookbook" >! example_25.ps
pscoast -R -J -O -K -Wthinnest -Dc -A500 >> example_25.ps
# Place an explanatory legend below
pslegend -R0/9/0/0.5 -Jx1i/-1i -O -Dx4.5/0/6i/0.3i/TC -Y-0.2i -Fthick << EOF >> example_25.ps
N 3
S 0.15i s 0.2i red  0.25p 0.3i Terrestrial Antipodes [$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 %]
EOF
```

```
\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 7.26). Note that the script is set to evaluate a global 30 minute grid for expediency ($D = 30$), hence several smaller landmasses 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).

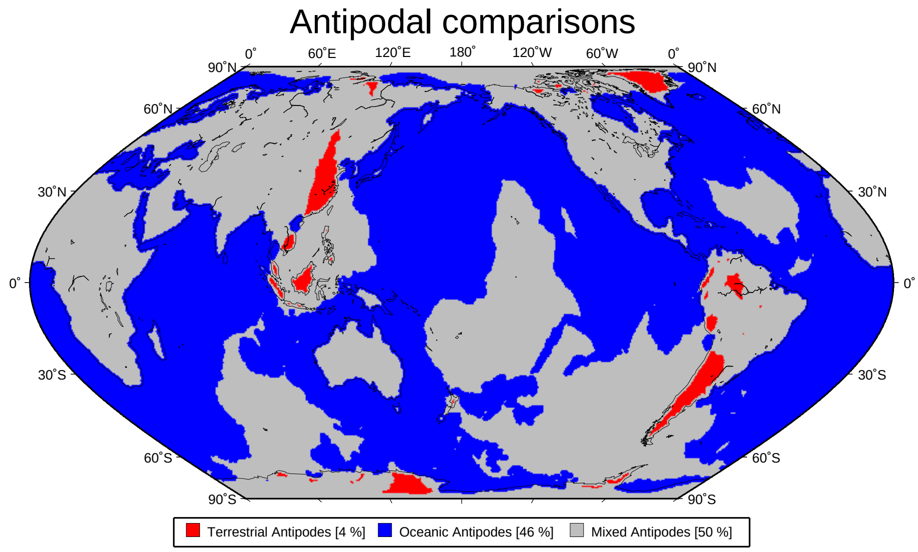


Figure 7.26: Global distribution of antipodes.

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 necessarilly 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 NGDC[1] or the GSHHS home page[2] (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 Cox[3]. 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 altimetry[4]. The package is maintained by Walter Smith[5].

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 Feigl[6] and Genevieve Patau[7].

A.5 mex: Matlab–GMT interface

Here you will find the mex files ***grdinfo***, ***grdread***, and ***grdwrite***, which can be used in Matlab to read and write GMT grdfiles. The package originated with David Sandwell, UCSD, and was subsequently modified

[1] http://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html
[2] http://www.soest.hawaii.edu/wessel/gshhs/gshhs.html
[3] Simon.Cox@csiro.au
[4] For data bases, see http://topex.ucsd.edu/marine_grav/mar_grav.html.
[5] walter@raptor.grdl.noaa.gov
[6] Kurt.Feigl@cnes.fr
[7] patau@ipgp.jussieu.fr

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 **mgd77info**, **mgd77list**, **mgd77path**, and **mgd77track** which can be used to extract information or data values from or plot marine geophysical data files in the MGD-77 format[8]). 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 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 MGD-77 format to the .gmt format[9]). The package is maintained by the GMT developers.

A.8 misc: posters, patterns, and digitizing

At the moment, this package contains the programs **psmegaplot** which you can use to make large posters using a simple laserwriter, **makepattern** which generates raster patterns from GMT 3.0 icon files, and **gmtdigitize** which provides a GMT interface to a digitizing tablet via a serial port. The package is maintained by Paul Wessel.

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. The package is maintained by Tim Henstock[10].

A.10 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, **hotspotter** which generates CVA grids based on seamount locations and a set of absolute plate motion stage poles, **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.11 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_binlist**, **x2sys_put**, and **x2sys_get** 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.

[8]These data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).
[9]These data are available on CD-ROM from NGDC (www.ngdc.noaa.gov).
[10]Timothy.J.Henstock@soc.soton.ac.uk

A.12 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 with remain in the GMT supplemental archive until ***x2sys*** is complete. The package is maintained by Paul Wessel.

A.13 xgrid: visual editor for grdfiles

The package contains an X11 editor (***xgridedit***) for visual editing of grdfiles. It was originally developed by Hugh Fisher, CRES, in March 1992 but is now maintained by Lloyd Parkes[11].

[11] lloyd@must-have-coffee.gen.nz

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 **–H***nrecs* 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 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 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).

B.2 2-D grdfiles

B.2.1 File contents

The default 2-D binary netCDF grdfile in GMT has several attributes. The **grdedit** utility program will allow you to edit parts of the header of an existing grdfile. The attributes listed in Table B.1 are contained

Parameter	*Description*
int *nx*	Number of nodes in the *x*-dimension
int *ny*	Number of nodes in the y-dimension
int *node_offset*	0 for grid line registration, 1 for pixel registration
double *x_min*	Minimum *x*-value of region
double *x_max*	Maximum *x*-value of region
double *y_min*	Minimum *y*-value of region
double *y_max*	Maximum *y*-value of region
double *z_min*	Minimum *z*-value in data set
double *z_max*	Maximum *z*-value in data set
double *x_inc*	Node spacing in *x*-dimension
double *y_inc*	Node spacing in *y*-dimension
double *z_scale_factor*	Factor to multiply *z*-values after read
double *z_add_offset*	Offset to add to scaled *z*-values
char *x_units*[80]	Units of the *x*-dimension
char *y_units*[80]	Units of the *y*-dimension
char *z_units*[80]	Units of the *z*-dimension
char *title*[80]	Descriptive title of the data set
char *command*[320]	Command line that produced the grdfile
char *remark*[160]	Any additional comments
float *z*[nx*ny]	1-D array with *z*-values in scanline format

Table B.1: **GMT** gridded file header record.

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).

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 rasterfiles (colormap ignored). Additional 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 grdfiles. We anticipate that the number of pre-programmed formats will increase as enterprising users implement what they need.

B.2.2 Grid line and Pixel registration

Scanline format means that the data are stored in rows (y = 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 ($x = x_{min}, x_{min} + x_{inc}, x_{min} + 2 \cdot x_{inc}, \ldots, x_{max}$) and y ($y = y_{min}, y_{min} + y_{inc}, y_{min} + 2 \cdot y_{inc}, \ldots, y_{max}$) lines. The two scenarios differ in which area each data point represents. The default registration in GMT is grid line 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.

Grid line 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 ($x_{inc} \cdot y_{inc}$) 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

$$
\begin{aligned}
nx &= (x_{max} - x_{min})/x_{inc} + 1 \\
ny &= (y_{max} - y_{min})/y_{inc} + 1
\end{aligned}
$$

which for the example in Figure B.1 yields $nx = ny = 4$.

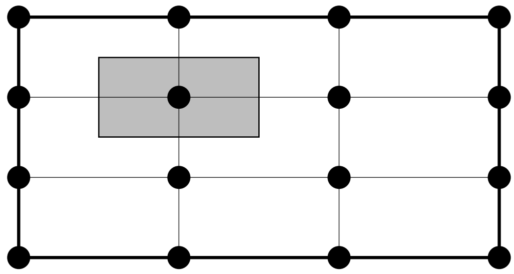


Figure B.1: Grid line registration of data nodes.

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

$$
\begin{aligned}
nx &= (x_{max} - x_{min})/x_{inc} \\
ny &= (y_{max} - y_{min})/y_{inc}
\end{aligned}
$$

Thus, given the same region (**–R**), the pixel registered grids have one less column and one less row than the grid line registered grids; here we find $nx = ny = 3$.

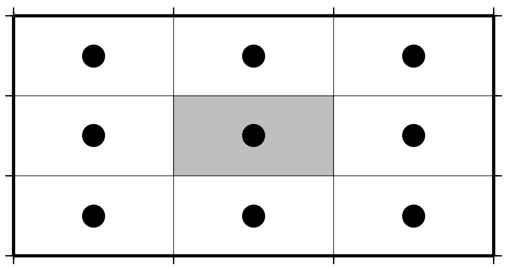


Figure B.2: Pixel registration of data nodes.

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 modulo $x_{inc}=0$ 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 modulo $x_{inc}=0$.

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.

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.2.

Parameter	*Description*
int *ras_magic*	Magic number
int *ras_width*	Width (pixels) of image
int *ras_height*	Height (pixels) of image
int *ras_depth*	Depth (1, 8, 24, 32 bits) of pixel
int *ras_length*	Length (bytes) of image
int *ras_type*	Type of file; see RT_* below
int *ras_maptype*	Type of colormap; see RMT_* below
int *ras_maplength*	Length (bytes) of following map

Table B.2: Structure of a Sun rasterfile.

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.3.

Macro name	*Description*
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.3: Sun macro definitions relevant to rasterfiles.

Numerous public-domain programs exist, such as ***xv*** and ***convert*** (in the ImageMagick package), that will translate between various rasterfile 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. 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 indended 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. If this is your situation you should choose another viewer (we recommend ***ghostview***) or select EPS output instead.

However, there is much confusion over what an EPS file is and if other programs can read it. Much of this has to do with the claim by some software manufacturers that their programs can read and edit EPS files. We used to get much mail from people asking us to let GMT produce EPS files that can be read, e.g., by Adobe ***Illustrator***. This was a limitation of early versions of Adobe ***Illustrator*** and similar programs, not GMT! Since then, Adobe ***Illustrator*** and other programs have improved their abilities to parse freeform *PostScript* such as that produced by GMT, but problems seem to occasionally reappear.

An EPS file that is to be placed into another application (such as a text document) need 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 plot[1]. 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 yourplot.ps
  ```

  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.

If you do not want to modify the illustration but just include it in a text document: Many word processors (such as Microsoft ***Word*** and Corel ***WordPerfect***) will let you include a *PostScript* file that you may place but not edit. You will not be able to view the figure on-screen, but it will print correctly. All illustrations in this GMT documentation were GMT-produced *PostScript* files that were converted to EPS files using ***ps2epsi*** and then included into a LaTeX document.

These examples do not constitute endorsements of the products mentioned above; they only represent our limited experience with the problem. For other solutions and further help, please post messages to gmt-help@hawaii.edu.

[1] In contrast, regular GMT *PostScript* files simply have a %%BoundingBox that equal the size of the chosen paper.

D. Availability of GMT and related code

All the source code, support data, *PostScript* and HTML versions of all documentation, and *UNIX* (including HTML) 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 a CD-R solution, see http://www.geoware-online.com.)

The GMT tar archives are available both in ***gzip*** and ***bzip2*** format. If neither of these utilities are installed on your system, you should know that the former program is available from GNU[1] while the latter can be obtained from Redat[2]. ***bzip2*** compresses much better than ***gzip***: for example, the full resolution coastline database is only ~29 Mb in ***bzip2*** format compared to a hefty ~44 Mb in ***gzip***. These files have the .bz2 suffix.

The GMT archives are as follows:

GMT_progs.tar.{gz,bz2} Contains all GMT source code, cpt files, and *PostScript* patterns.

GMT_share.tar.{gz,bz2} Contains the intermediate, low, and crude resolutions of the coastline database. Required with _progs.tar for minimal setup needed to run GMT.

GMT_doc.tar.{gz,bz2} Contains all GMT documentation (man pages, PostScript versions of both the Cookbook and Technical Reference and the tutorial, and the short course material).

GMT_web.tar.{gz,bz2} Contains all HTML versions of all GMT documentation (man pages, Cookbook and Technical Reference, and tutorial).

GMT_full.tar.{gz,bz2} Contains the optional full-resolution coastline database.

GMT_high.tar.{gz,bz2} Contains the optional high-resolution coastline database.

GMT_scripts.tar.{gz,bz2} Contains all the shellscripts and support data used in the Cookbook section.

GMT_suppl.tar.{gz,bz2} Contains several programs written by us and GMT users elsewhere. (See Appendix A for more details).

triangle.tar.{gz,bz2} Contains John Shewchuk's fast Delaunay triangulation routine which may be installed with GMT. (See the copyright information first if you are a commercial user).

All of the above archives are also available as Windows ZIP archives, e.g., **GMT_progs.zip**. For Windows users who do not want to compile themselves, there are two zip files with Win32 executables:

GMT_exe.zip ZIP archive with all main GMT executables.

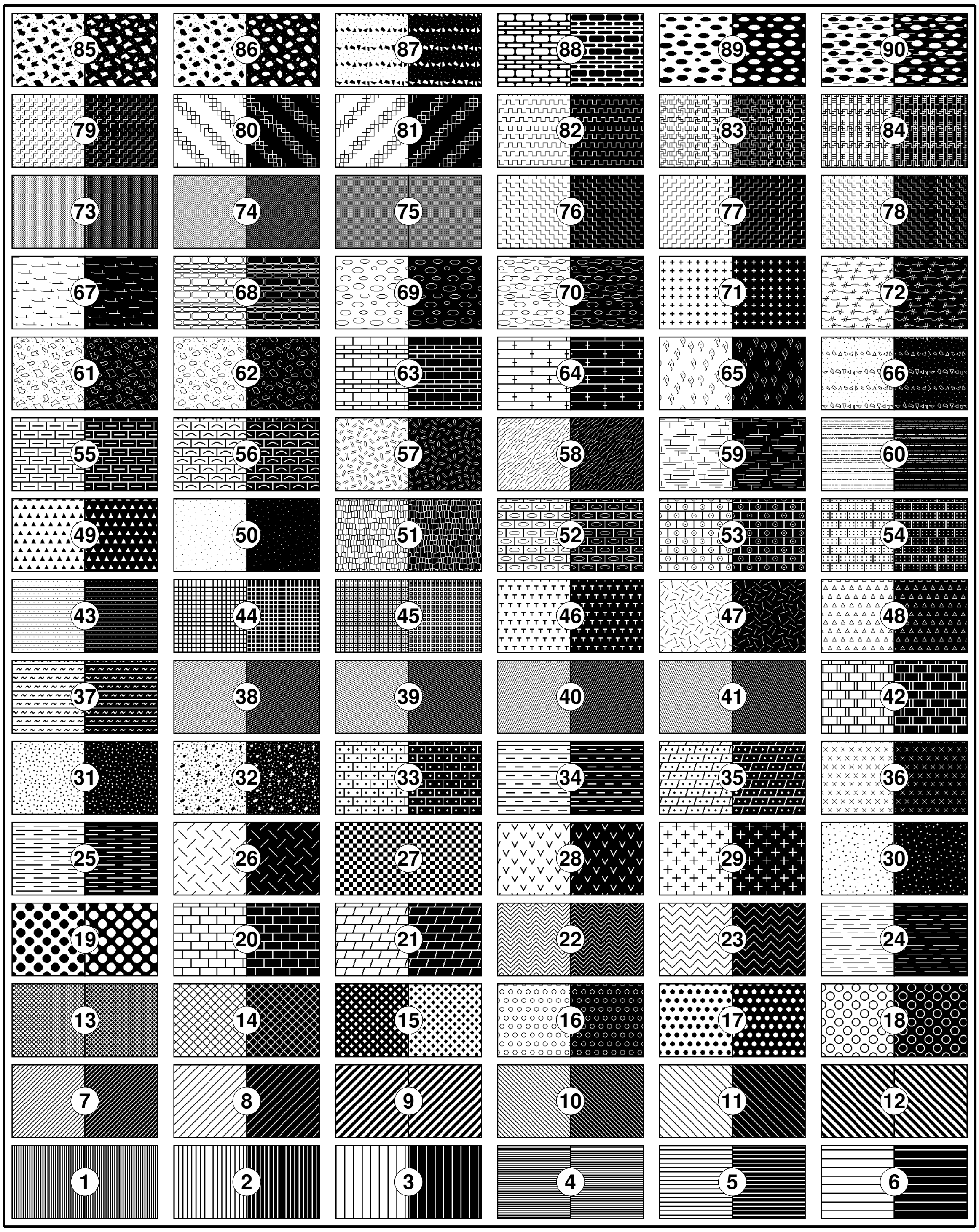
GMT_suppl_exe.zip ZIP archive with all supplemental GMT executables.

The netCDF library that makes up the backbone of the grdfile I/O operations can be obtained from Unidata. A compressed tar file can be accessed (in binary mode) from the file netcdf.tar.Z in the anonymous FTP directory of unidata.ucar.edu. The software distribution includes a *PostScript* file of the netCDF User's Guide, and there is also online documentation from their web site. [netcdfgroup@unidata.ucar.edu is available for discussion of the netCDF interface and announcements about netCDF bugs, fixes, and enhancements. To subscribe, send a request to netcdfgroup-adm@unidata.ucar.edu]. Precompiled libraries for WIN32 are also available[3].

[1] www.gnu.org
[2] http://sources.redhat.com/bzip2/index.html
[3] Required with GMT_exe.zip

E. Predefined bit and hachure patterns in GMT

GMT provides 90 different bit and hachure patterns that can be selected with the **–Gp** option in most plotting programs. These patterns are reproduced below at 300 dpi.



F. Chart of octal codes for characters

octal	0	1	2	3	4	5	6	7
\03x		¾	³	™	²	ý	ÿ	ž
\04x		!	"	#	$	%	&	’
\05x	(	)	*	+	,	-	.	/
\06x	0	1	2	3	4	5	6	7
\07x	8	9	:	;	<	=	>	?
\10x	@	A	B	C	D	E	F	G
\11x	H	I	J	K	L	M	N	O
\12x	P	Q	R	S	T	U	V	W
\13x	X	Y	Z	[	\	]	^	_
\14x	‘	a	b	c	d	e	f	g
\15x	h	i	j	k	l	m	n	o
\16x	p	q	r	s	t	u	v	w
\17x	x	y	z	{	|	}	~	ƒ
\20x	Ã	Ç	Ð	Ł	Ñ	Õ	Š	Þ
\21x	Ý	Ÿ	Ž	ã	¦	ç	©	°
\22x	÷	ð	¬	ł	¯	µ	×	ñ
\23x	½	¼	¹	õ	±	®	š	þ
\24x		¡	¢	£	⁄	¥	ƒ	§
\25x	¤	'	“	«	‹	›	ﬁ	ﬂ
\26x	Á	–	†	‡	·	Â	¶	•
\27x	‚	„	”	»	…	‰	Ä	¿
\30x	À	`	´	ˆ	˜	¯	˘	˙
\31x	¨	É	˚	¸	Ê	˝	˛	ˇ
\32x	—	Ë	È	Í	Î	Ï	Ì	Ó
\33x	Ô	Ö	Ò	Ú	Û	Ü	Ù	á
\34x	â	Æ	ä	ª	à	é	ê	ë
\35x	è	Ø	Œ	º	í	î	ï	ì
\36x	ó	æ	ô	ö	ò	ı	ú	û
\37x	ü	ø	œ	ß	ù	Å	å	ÿ

Figure F.1: Octal codes and corresponding symbols for StandardEncoding fonts.

The characters and their octal codes in the Standard encoded fonts are shown in Figure F.1, while the characters and their octal codes in the ISOLatin1 encoded fonts are shown in Figure F.2. 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 file[1]. The chart for the Symbol (GMT font number 12) character sets are presented in Figure F.3 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

[1]If you chose SI units during the installation then the default encoding is ISOLatin1+, otherwise it is Standard+.

firmware will not know about the euro).

octal	0	1	2	3	4	5	6	7
\03x		•	…	™	—	–	ﬁ	ž
\04x		!	"	#	$	%	&	’
\05x	(	)	*	+	,	−	.	/
\06x	0	1	2	3	4	5	6	7
\07x	8	9	:	;	<	=	>	?
\10x	@	A	B	C	D	E	F	G
\11x	H	I	J	K	L	M	N	O
\12x	P	Q	R	S	T	U	V	W
\13x	X	Y	Z	[	\	]	^	_
\14x	‘	a	b	c	d	e	f	g
\15x	h	i	j	k	l	m	n	o
\16x	p	q	r	s	t	u	v	w
\17x	x	y	z	{	|	}	~	š
\20x	Œ	†	‡	Ł	⁄	‹	Š	›
\21x	œ	Ÿ	Ž	ł	‰	„	“	”
\22x	ı	`	´	ˆ	˜	¯	˘	˙
\23x	¨	,	˚	¸	'	˝	˛	ˇ
\24x		¡	¢	£	¤	¥	¦	§
\25x	¨	©	ª	«	¬	-	®	¯
\26x	°	±	²	³	´	µ	¶	·
\27x	¸	¹	º	»	¼	½	¾	¿
\30x	À	Á	Â	Ã	Ä	Å	Æ	Ç
\31x	È	É	Ê	Ë	Ì	Í	Î	Ï
\32x	Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×
\33x	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß
\34x	à	á	â	ã	ä	å	æ	ç
\35x	è	é	ê	ë	ì	í	î	ï
\36x	ð	ñ	ò	ó	ô	õ	ö	÷
\37x	ø	ù	ú	û	ü	ý	þ	ÿ

Figure F.2: Octal codes and corresponding symbols for ISOLatin1Encoding fonts.

The Pifont ZapfDingbats is available as GMT font number 34 and can be used for special symbols not listed above. The various symbols are illustrated in Figure F.4.

octal	0	1	2	3	4	5	6	7
\04x		!	∀	#	∃	%	&	∍
\05x	(	)	*	+	,	−	.	/
\06x	0	1	2	3	4	5	6	7
\07x	8	9	:	;	<	=	>	?
\10x	≅	Α	Β	Χ	Δ	Ε	Φ	Γ
\11x	Η	Ι	ϑ	Κ	Λ	Μ	Ν	Ο
\12x	Π	Θ	Ρ	Σ	Τ	Υ	ς	Ω
\13x	Ξ_	Ψ	Ζ	[	∴	]	⊥	_
\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	{	|	}	~	

octal	0	1	2	3	4	5	6	7
\24x	€	ϒ	′	≤	⁄	∞	ƒ	♣
\25x	♦	♥	♠	↔	←	↑	→	↓
\26x	°	±	″	≥	×	∝	∂	•
\27x	÷	≠	≡	≈	…	⏐	⎯	↵
\30x	ℵ	ℑ	ℜ	℘	⊗	⊕	∅	∩
\31x	∪	⊃	⊇	⊄	⊂	⊆	∈	∉
\32x	∠	∇	®	©	™	∏	√	⋅
\33x	¬	∧	∨	⇔	⇐	⇑	⇒	⇓
\34x	◊	〈	®	©	™	∑	⎛	⎜
\35x	⎝	⎡	⎢	⎣	⎧	⎨	⎩	⎪
\36x		〉	∫	⌠	⎮	⌡	⎞	⎟
\37x	⎠	⎤	⎥	⎦	⎫	⎬	⎭	

Figure F.3: Octal codes and corresponding symbols for the Symbol font.

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	❶	❷
\27x	❸	❹	❺	❻	❼	❽	❾	❿
\30x	➀	➁	➂	➃	➄	➅	➆	➇
\31x	➈	➉	➊	➋	➌	➍	➎	➏
\32x	➐	➑	➒	➓	➔	→	↔	↕
\33x	➘	➙	➚	➛	➜	➝	➞	➟
\34x	➠	➡	➢	➣	➤	➥	➦	➧
\35x	➨	➩	➪	➫	➬	➭	➮	➯
\36x		➱	➲	➳	➴	➵	➶	➷
\37x	➸	➹	➺	➻	➼	➽	➾	

Figure F.4: Octal codes and corresponding symbols for ZapfDingbats font.

G. *PostScript* fonts used by GMT

GMT uses the standard 35 fonts that come with most *PostScript* laserwriters, as well as 4 Japanese fonts, for a total of 39. 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	*Helvetica–Oblique*	19	Bookman–Light
3	***Helvetica–BoldOblique***	*20*	*Bookman–LightItalic*
4	Times–Roman	21	Helvetica–Narrow
5	**Times–Bold**	**22**	**Helvetica–Narrow–Bold**
6	*Times–Italic*	*23*	*Helvetica–Narrow–Oblique*
7	***Times–BoldItalic***	***24***	***Helvetica–Narrow–BoldOblique***
8	Courier	25	NewCenturySchlbk–Roman
9	**Courier–Bold**	*26*	*NewCenturySchlbk–Italic*
10	*Courier–Oblique*	**27**	**NewCenturySchlbk–Bold**
11	***Courier–BoldOblique***	***28***	***NewCenturySchlbk–BoldItalic***
12	Σψμβολ (Symbol)	29	Palatino–Roman
13	AvantGarde–Book	*30*	*Palatino–Italic*
14	*AvantGarde–BookOblique*	**31**	**Palatino–Bold**
15	**AvantGarde–Demi**	***32***	***Palatino–BoldItalic***
16	***AvantGarde–DemiOblique***	*33*	*ZapfChancery–MediumItalic*
		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 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* printers[1]. 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 (**–W**1) and once with a fat pen (**–W**10); 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.

[1] Note, however, that the **–Q** option in **grdimage** will exercise a *PostScript* Level 3 feature called colormasking.

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 -cubesize large`".

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 appearence 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

Beginning with GMT version 2.1.4, “Example 11” was included in the cookbook. The example makes an RGB color cube by a simple ***awk*** script. We wrote a program to compute HSV grids for each face of this cube, and include a version of the cube with HSV contours on it as file contoured_cube.ps in /share.

In this appendix, we are going to try to explain the relationship between the RGB and HSV color systems so as to (hopefully) make them more intuitive. GMT allows users to specify colors in cpt files in either system (colors on command lines, such as pen colors in **–W** option, are always in RGB). GMT uses the HSV system to achieve artificial illumination of colored images (e.g. **–I** option in **grdimage**) by changing the s and v coordinates of the color. When the intensity is zero, the data are colored according to the cpt file. If the intensity is non-zero, the data are given a starting color from the cptfile but this color (after conversion to HSV if necessary) is then changed by moving (s,v) toward **HSV_MIN_SATURATION**, **HSV_MIN_VALUE** if the intensity is negative, or toward **HSV_MAX_SATURATION**, **HSV_MAX_VALUE** if positive. These 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.

We are going to try to give you a geometric picture of color mixing in HSV from a tour of the RGB cube. The geometric picture is helpful, we think, since HSV are not orthogonal coordinates and not found from RGB by an algebraic transformation. But before we begin traveling on the RGB cube, let us give two formulae, since an equation is often worth a thousand words.

$$
\begin{aligned}
v &= max(r,g,b) \\
s &= (max(r,g,b) - min(r,g,b))/max(r,g,b)
\end{aligned}
$$

Note that when $r = g = b = 0$ (black), the expression for s gives 0/0; black is a singular point for s. The expression for h is not easily given without lots of “if” tests, but has a simple geometric explanation. 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.

The RGB color cube has six faces. On three of these 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 saturation, the S in HSV, has its maximum value; s = 1 on these faces. (Accept this definition and ignore the s singularity at black for now). Therefore h and v are contoured on these faces; h in gray solid lines and v in white dashed lines (v ranges from 0 to 1 and is contoured in steps of 0.1).

On the other three faces 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, the V in HSV, has its maximum value; v = 1 on these faces. Therefore h and s are contoured on these faces; h in gray solid lines and s in black dashed lines (s ranges from 0 to 1 with contours every 0.1).

The three faces where v = 1 meet the three faces where $s = 1$ in six edges where both $s = v = 1$ (and at least one of *(r, g, b)* = 0 and at least one of *(r, g, b)* = 255). Trace your finger around these edges, starting at the red point and moving to the yellow point, then on around. You will visit six of the eight corners of the cube, in this order: red ($h = 0$); yellow ($h = 60$); green ($h = 120$); cyan ($h = 180$); blue ($h = 240$); magenta ($h = 300$). 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 (color monitors usually use RGB). The only cube corners you did not visit on this path are the black and white corners. Imagine an axis running through the black and white corners. If you project the RYGCBM edge path onto a plane perpendicular to the black-white axis, the path will look like a hexagon, with RYGCBM at the vertices, every 60° apart. Now we can make a geometric definition of hue: Take a vector from the origin (black point) to any point in the cube; project this vector onto the plane with the RYGCBM hexagon; then hue is the angle this projected vector makes with the R direction on the hexagon. Thus hue is an angle describing rotation around the black-white axis. Note that by this definition, if a point is on the black-white axis, its *(r, g, b)* vector will project as a point at the center of the hexagon, so its hue is undefined. Points on the black-white axis have $r = g = b$, and they are shades of gray; we will call the black-white axis the gray axis.

Let us call the points where $s = v = 1$ (the points on the RYGCBM path of cube edges) 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 RYGCBM 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, because it is the intersection of three planes on which $s = 1$, but it is on a line where $s = 0$; it is a singular point, and we get "0/0" in the above formula. We see also that saturation is a measure of "purity" or "vividness" of the color.

It remains to define value, and the formula above is really the best definition. But if you like our geometric constructions, 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 equation is hue = 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 shine more brightly, but "brightness" has other meanings in color geometry, so let us say that if you can move in this way, you can make your hue "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 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 $\sqrt{r^2 + g^2 + b^2}/255$.

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; 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, 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.

Well, there you have it, folks. We've been doing GMT for 10 years and all we know about color can be written in about 2 pages. We hope we haven't told you any lies. For more details, you should consult a book about color systems. But as example 11 shows, a lot can be learned by experimenting with GMT tools. Our thanks to John Lillibridge for Example 11.

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 or mode 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).

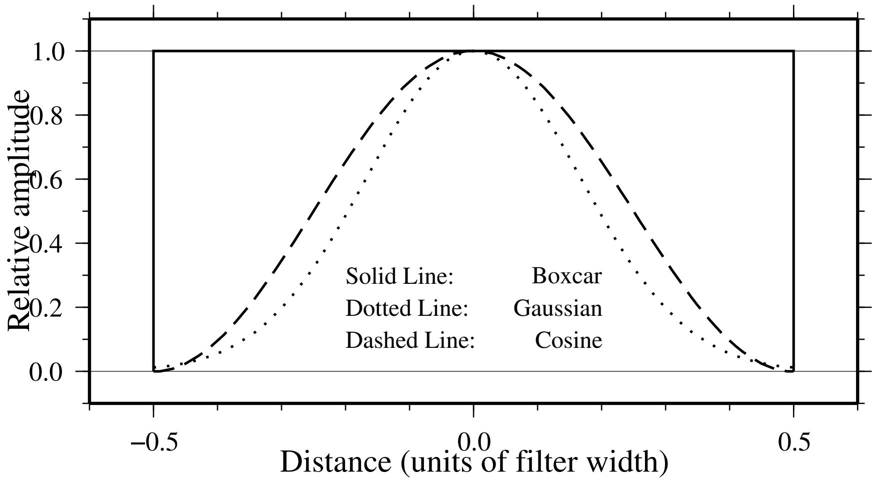


Figure J.1: Impulse responses for **GMT** filters.

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).

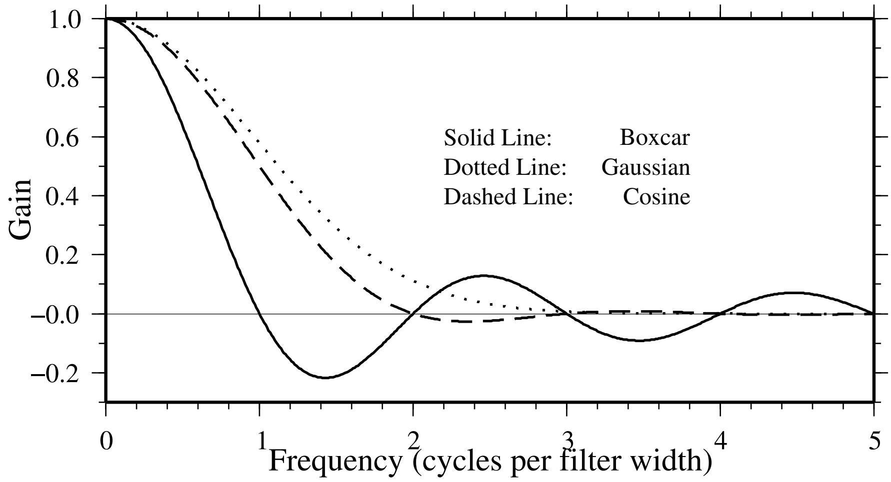


Figure J.2: Transfer functions for 1-D **GMT** filters.

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 Bracewell[1]). 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 5.34 σ, or about 0.89 of the filter width.

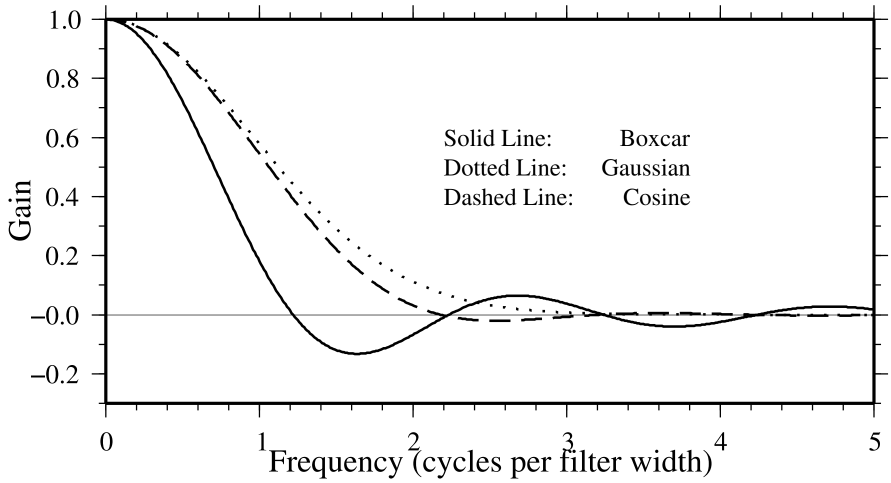


Figure J.3: Transfer functions for 2-D (radial) **GMT** filters.

[1]R. 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. Once 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, Colorado[1].

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 ($\sim$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 algorithm[2]. We chose the cutoffs so that each subset was approximately 20% the size of the next higher resolution. The five resolutions are called **f**ull, **h**igh, **i**ntermediate, **l**ow, and **c**rude; they are accessed in **pscoast**, **gmtselect**, and **grdlandmask** with the **–D** option[3]. 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 platforms[4].

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:

[2] Dougles, 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 direction and -1500 km to +1500 km in 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 cshell script that we call ***getbox***:

```
range=`(echo $2 $4; echo $3 $5) | mapproject $1 -R0/360/-90/90 -I -Fk -C`
echo $range | awk '{printf "-R%f/%f/%f/%fr\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***:

```
(echo $2 $4; echo $3 $4; echo $3 $5; echo $2 $5) | mapproject $1 -R0/360/-90/90 -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 km^2 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 is only 286 Kbytes. The plot is produced by the command (the box indicates the outline of the next map):

```
gmtset GRID_CROSS_SIZE_PRIMARY 0 OBLIQUE_ANNOTATION 22 ANNOT_MIN_SPACING 0.3
pscoast `./getbox -JE130.35/-0.2/1i -9000 9000 -9000 9000` -JE130.35/-0.2/3.5i -P -Dc \
   -A500 -Glightgray -W0.25p -N1/0.25tap -B20g20WSne -K > GMT_App_K_1.ps
./getrect -JE130.35/-0.2/1i -2000 2000 -2000 2000 | psxy -R -JE130.35/-0.2/3.5i -O -W1.5p -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.

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 km^2 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 876 Kbytes; it is the default resolution in GMT. The plot is generated by the command:

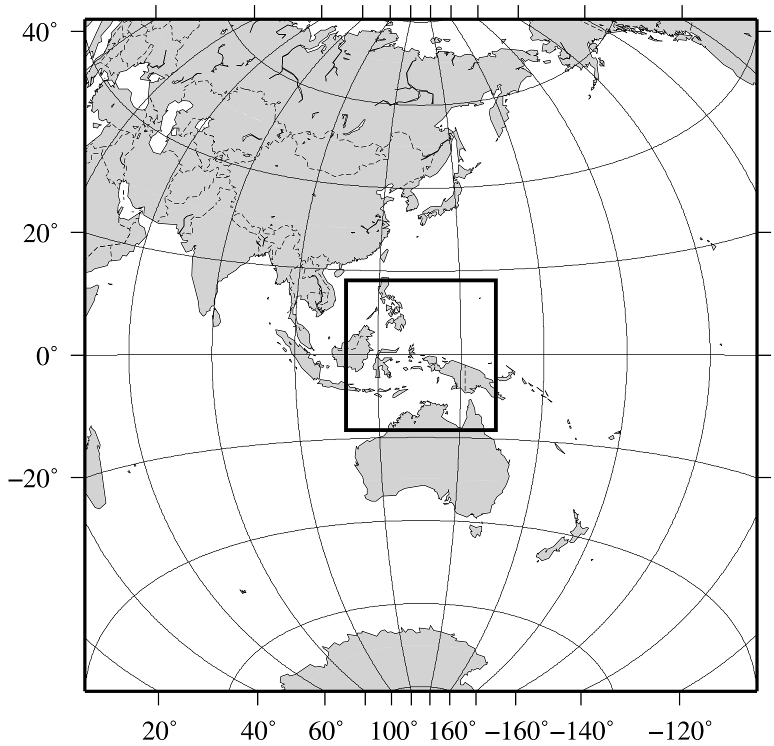


Figure K.1: Map using the crude resolution coastline data.

```
pscoast `./getbox -JE130.35/-0.2/1i -2000 2000 -2000 2000` -JE130.35/-0.2/3.5i -P -Dl -A100 \
   -Glightgray -W0.25p -N1/0.25tap -B10g5WSne -K > GMT_App_K_2.ps
./getrect -JE130.35/-0.2/1i -500 500 -500 500 | psxy -R -JE130.35/-0.2/3.5i -O -W1.5p -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 km^2 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 3.28 Mbytes. The plot is generated by the commands:

```
pscoast `./getbox -JE130.35/-0.2/1i -500 500 -500 500` -JE130.35/-0.2/3.5i -P -Di -A20 -Glightgray \
   -W0.25p -N1/0.25tap -B2g1WSne -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 -JE130.35/-0.2/1i -100 100 -100 100 | psxy -R -JE130.35/-0.2/3.5i -O -W1.5p -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 km^2 in area. The high resolution database has undergone minor decimation and simplification by the

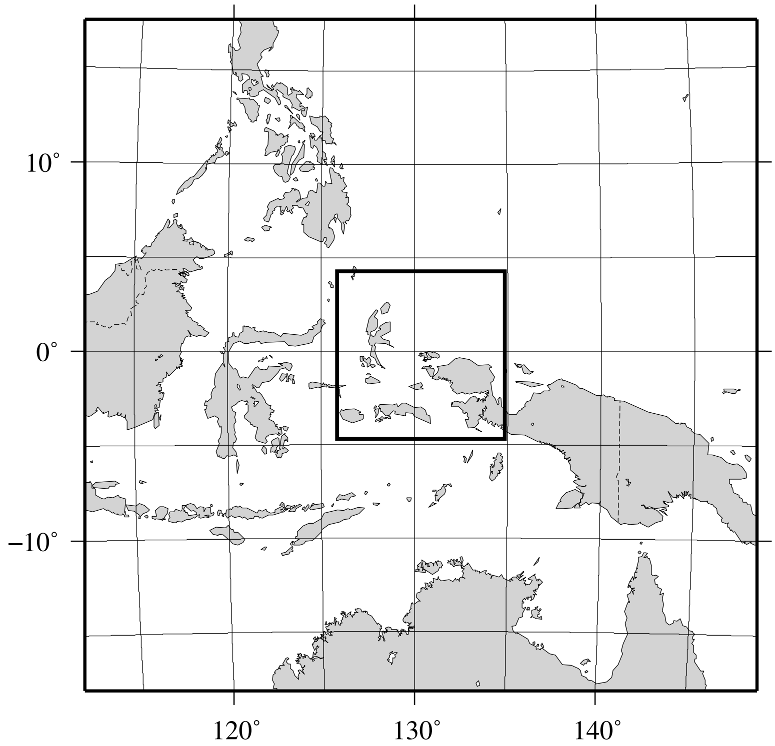


Figure K.2: Map using the low resolution coastline data.

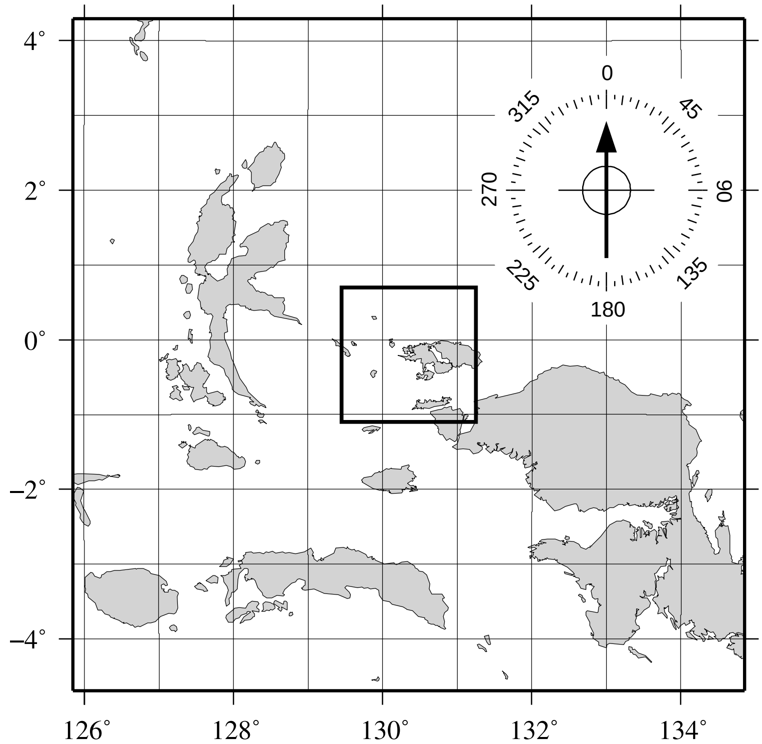


Figure K.3: Map using the intermediate resolution coastline data. We have added a compass rose just because we have the power to do so.

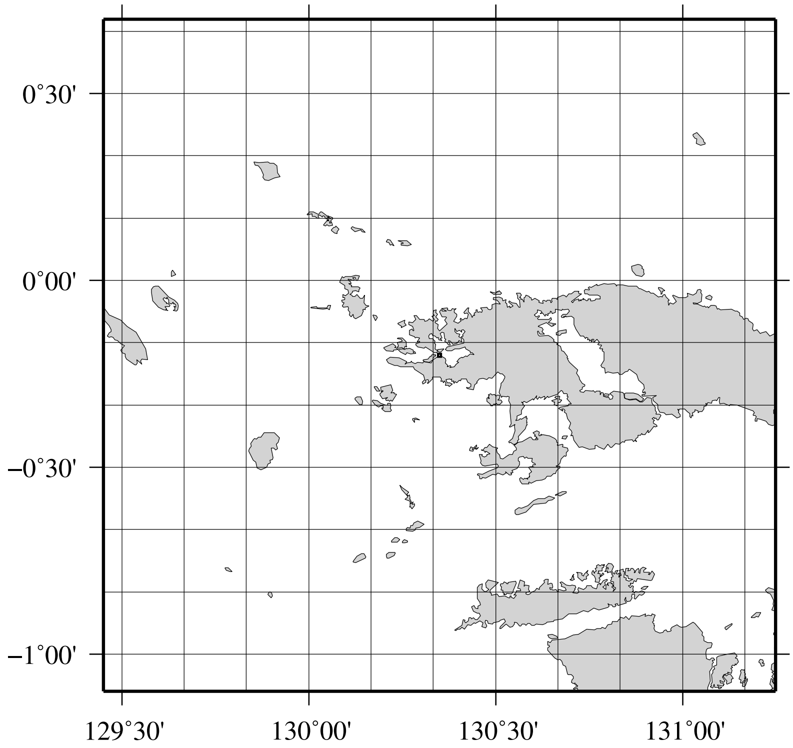


Figure K.4: Map using the high resolution coastline data.

DP-routine: The combined file size of the coastlines, rivers, and borders now swells to 12.2 Mbytes. The map and the final outline box are generated by these commands:

```
pscoast `./getbox -JE130.35/-0.2/1i -100 100 -100 100` -JE130.35/-0.2/3.5i -P -Dh -A1 -Glightgray \
   -W0.25p -N1/0.25tap -B30mg10mWSne -K > GMT_App_K_4.ps
./getrect -JE130.35/-0.2/1i -20 20 -20 20 | psxy -R -JE130.35/-0.2/3.5i -O -W1.5p -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 hefty 55.7 Mbytes. Our final map is reproduced by the single command:

```
pscoast `./getbox -JE130.35/-0.2/1i -20 20 -20 20` -JE130.35/-0.2/3.5i -P -Df -Glightgray -W0.25p \
   -N1/0.25tap -B10mg2mWSne > GMT_App_K_5.ps
```

We hope you will study these examples to enable you to make efficent and wise use of this vast data set.

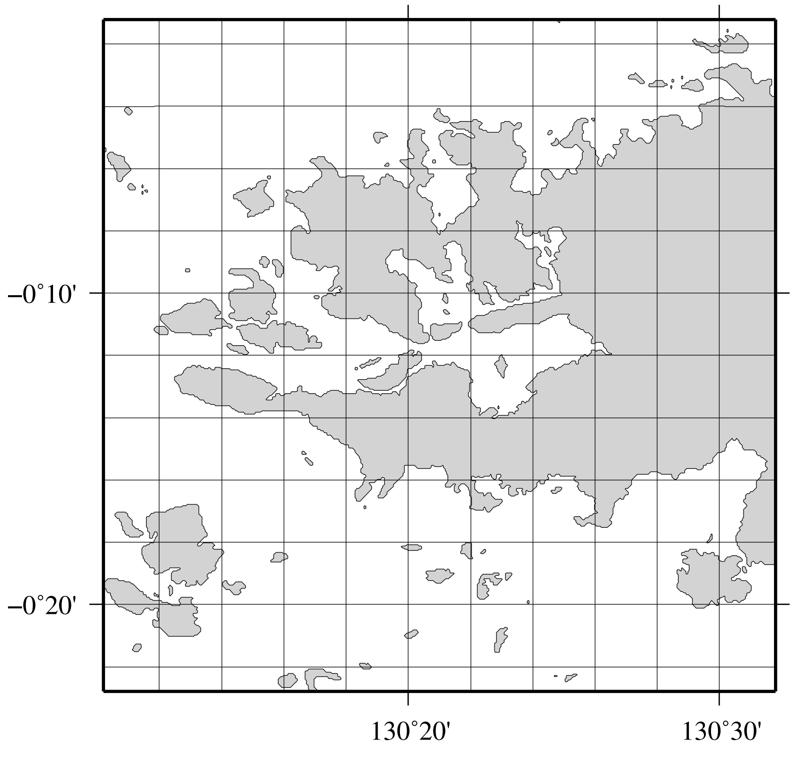


Figure K.5: Map using the full resolution coastline data.

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 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 Microsoft[1].
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 MachTen[2].

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.).

Follow the instructions on the Cygwin page[3] 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. For details see the general README file.

L.3 SFU and GMT

SFU[4] is also similar to Cygwin in that it provides precompiled *UNIX* tools for DOS/WIN32, including the ***csh*** shell.

L.4 DJGPP and GMT

DJGPP[5] 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.

[1] Microsoft Services for *UNIX* is formerly known as Interix, in the distant past known as OpenNT.
[2] www.tenon.com
[3] sources.redhat.com/cygwin
[4] See www.microsoft.com/Windows/sfu for details.
[5] See www.gnu.org for details.

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 Cogbill[6], Los Alamos National Laboratory. One must have EMX[7] 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 document[8], 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.

[6]mailto:ahc@lanl.gov
[7]ftp://ftp.geophysics.lanl.gov/pub/EES3/pub/gmt/emxrt.zip
[8]ftp://ees.lanl.gov/pub/EES3/pub/gmt/gmt4os2.html

M. Built-in color palette tables

GMT has 20 built-in color palette tables (master cpt files). The following is a plot of each one:

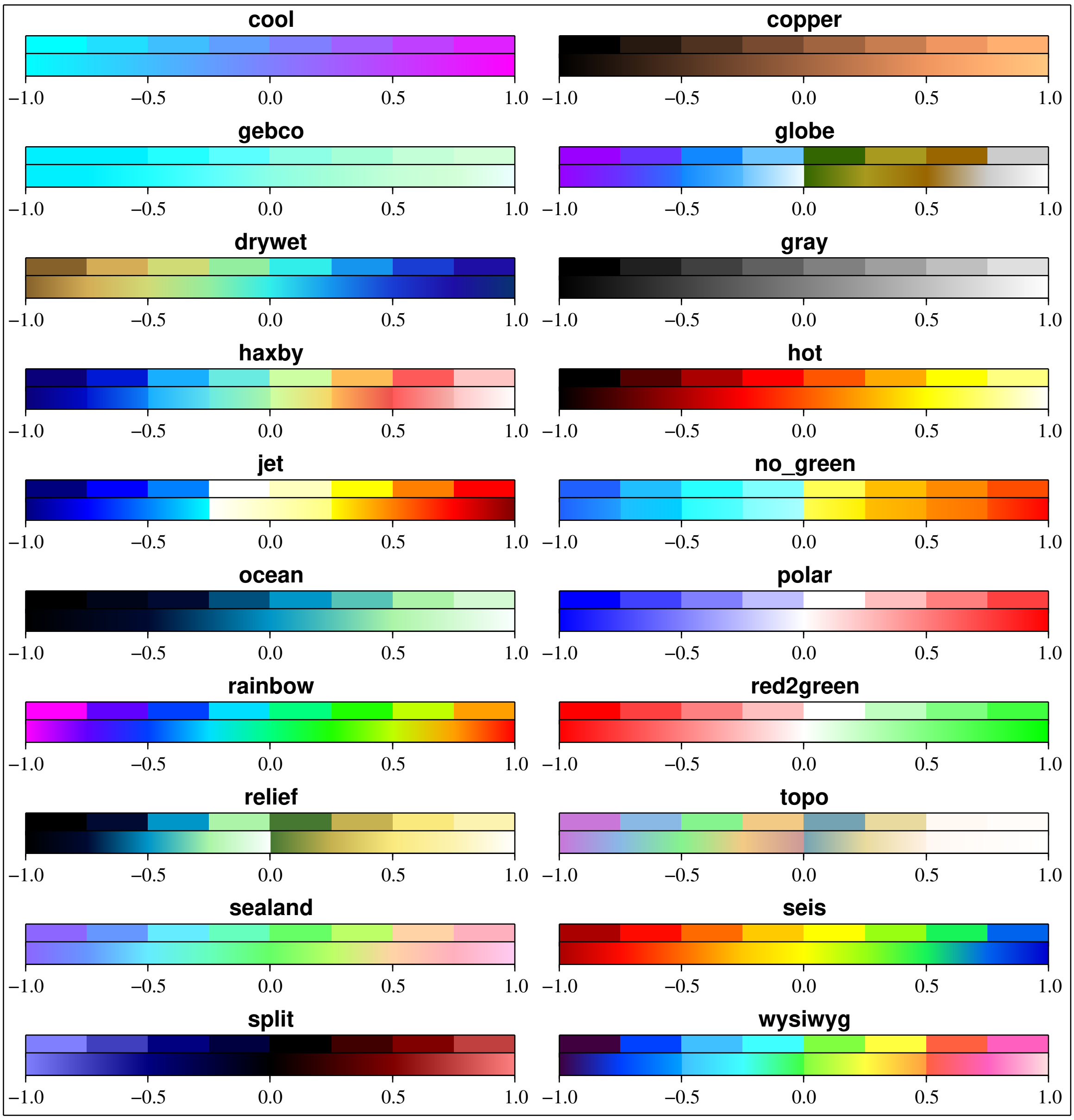


Figure M.1: The standard 20 cpt files supported by **GMT**.

The programs **makecpt** and **grd2cpt** are used to access these master tables and translate/scale them to fit the user's range of *z*-values. The final cpt tables can be discrete (top half of each scale) or continuous (bottom half).

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, appears to duplicate what is already available as built-in symbols. However, the custom symbols differ in that they may be filled with patterns.

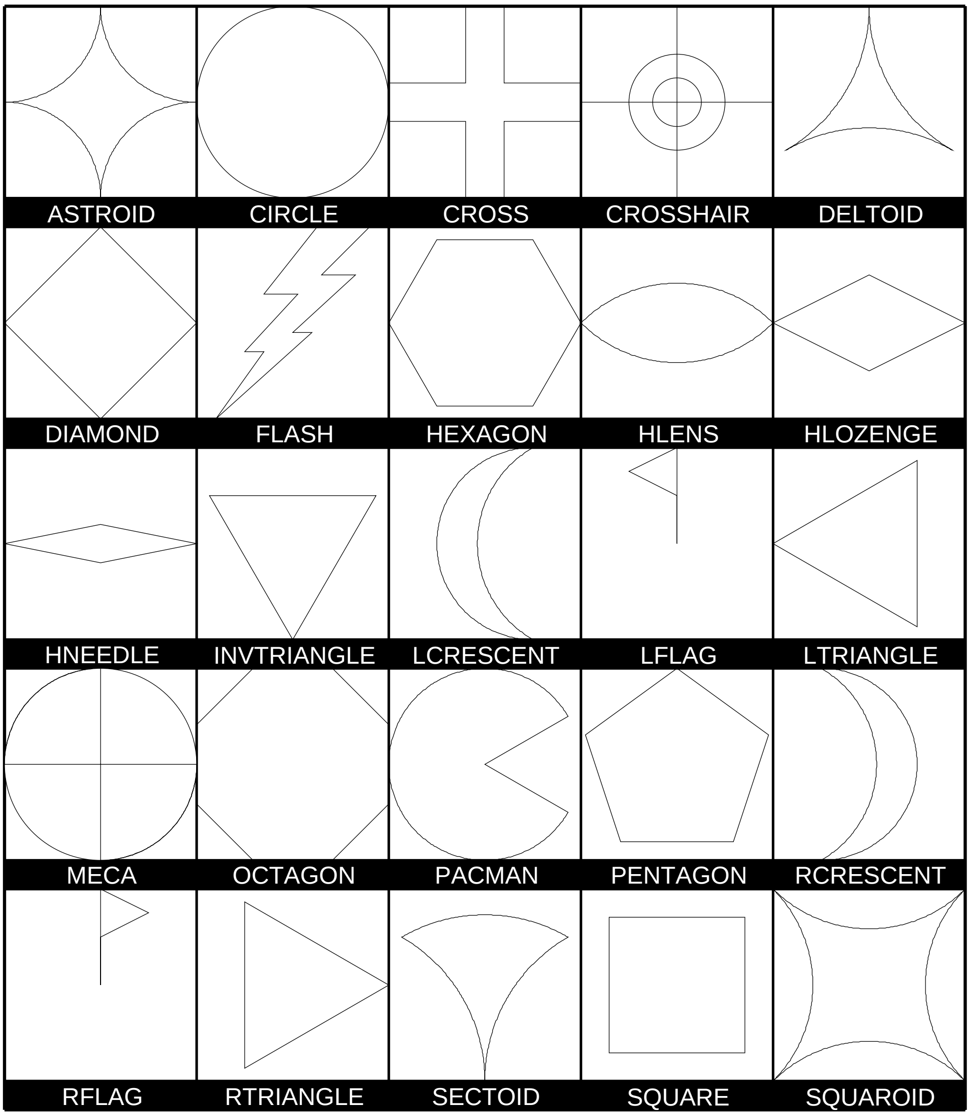


Figure N.1: Custom plot symbols supported by **GMT**.

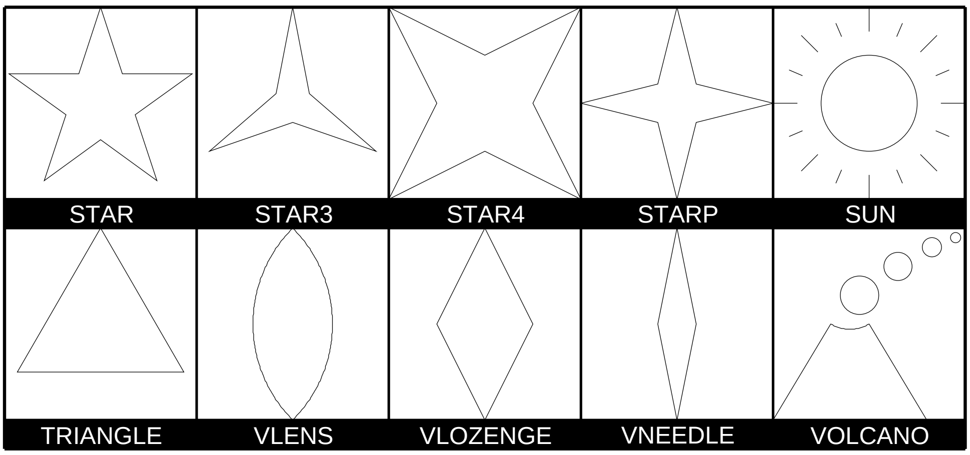


Figure N.2: Additional custom plot symbols

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 verions 1–3 allowed for a single algorithm that determined where labels would be placed, GMT 4 allows for five different algorithms. Futhermore, 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 labelled. The codes are:

d: Full syntax is **d***dist*[**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 **D***dist*[**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 Earth[1] surface distances along the lines are considered. Append the unit you want to measure distances in; choose among **d**egree, m**e**ter [Default], **k**ilometer, statute **m**iles, or **n**autical miles. Other aspects are similar to code **d**.

f: Full syntax is **f***fix.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 **l***line1*[,*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 **n***number*[/*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 **N***number*[/*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 **x***cross.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 universially. These codes are:

+a: Controls the angle of the label relative to the angle of the line. Append **p** for parallel [Default], **n** for normal, or a fixed *angle* measured counter-clockwise relative to the horizontal.

+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 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 **–L***label* 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 **d**egrees, *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 -JM5.5i -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 countours 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.

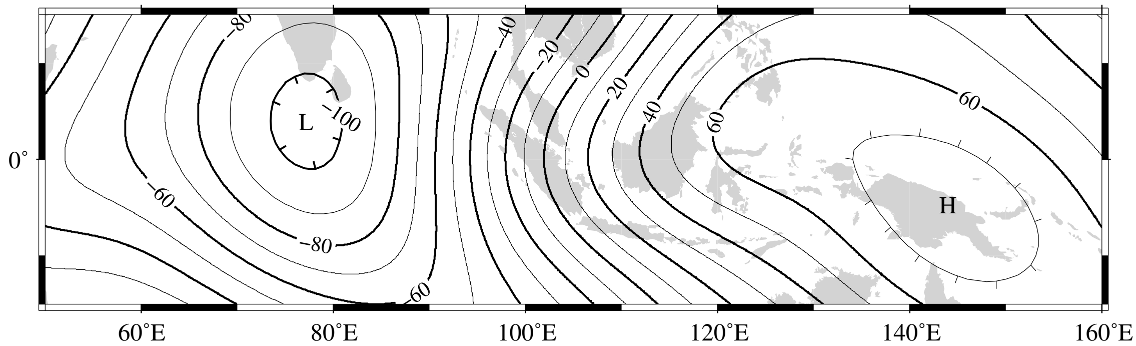


Figure O.1: Equidistant contour label placement with **–Gd**, the only algorithm available in previous **GMT** versions.

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 -JM5.5i -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.

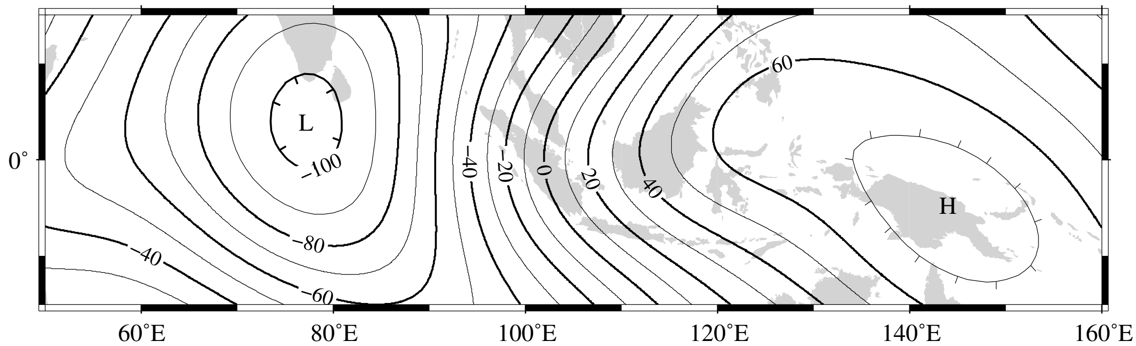


Figure O.2: Placing one label per contour that exceed 1 inch in length, centered on the segment with **–Gn**.

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 -JM5.5i -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.

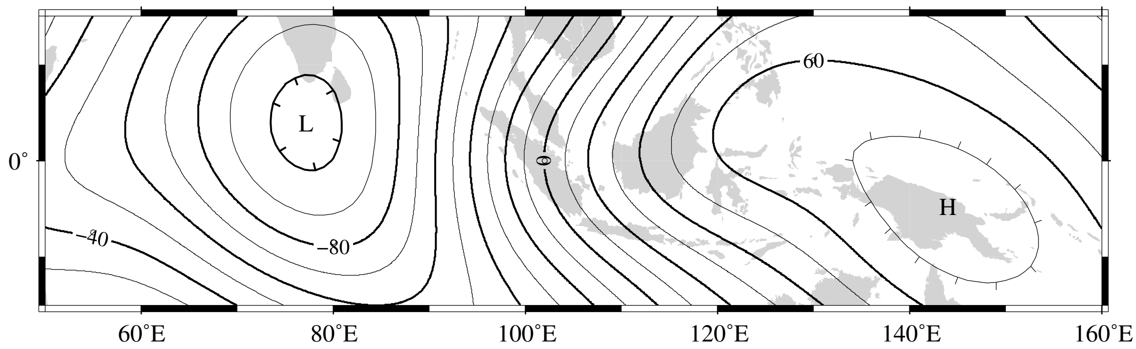


Figure O.3: Four labels are positioned on the points along the contours that are closest to the locations given in the file fix.d in the **–Gf** option.

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 **–Gl** or **–GL** algorithms work well in those cases:

```
pscoast -R50/160/-15/15 -JM5.5i -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.

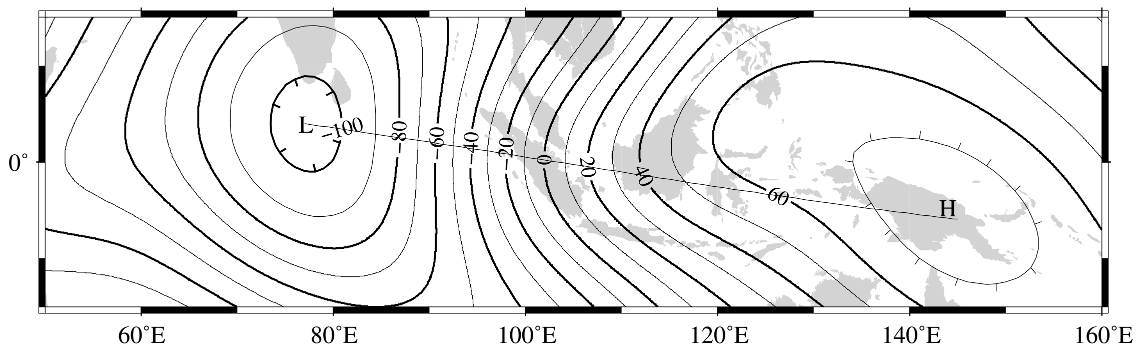


Figure O.4: Labels are placed at the intersections between contours and the great circle specified in the **–GL** option.

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 -JM5.5i -Glightgray -A500 -K -P > GMT_App_O_5.ps
grdcontour geoid.grd -JM -O -B20f10WSne -C10 -A20+d+s8 -GXcross.d -S10 -T:LH >> GMT_App_O_5.ps
```

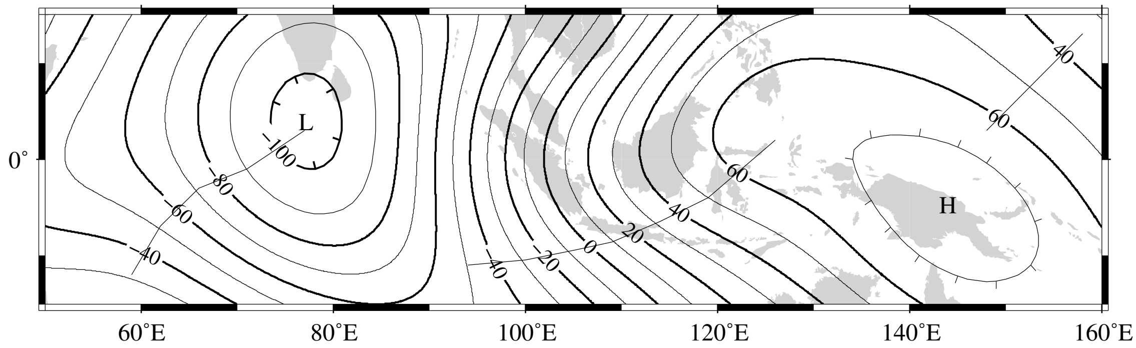


Figure O.5: Labels are placed at the intersections between contours and the multi-segment lines specified in the **–GX** option.

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 -JM5.5i -Glightgray -A500 -K -P > GMT_App_O_6.ps
grdcontour geoid.grd -J -O -K -B20f10WSne -C10 -A20+d+s8 -Gl50/10S/160/10S -S10 \
    -T:'-+' >> GMT_App_O_6.ps
psxy -R -J -O -SqD1000k:+g+LD+an+p -W1p transect.d >> GMT_App_O_6.ps
```

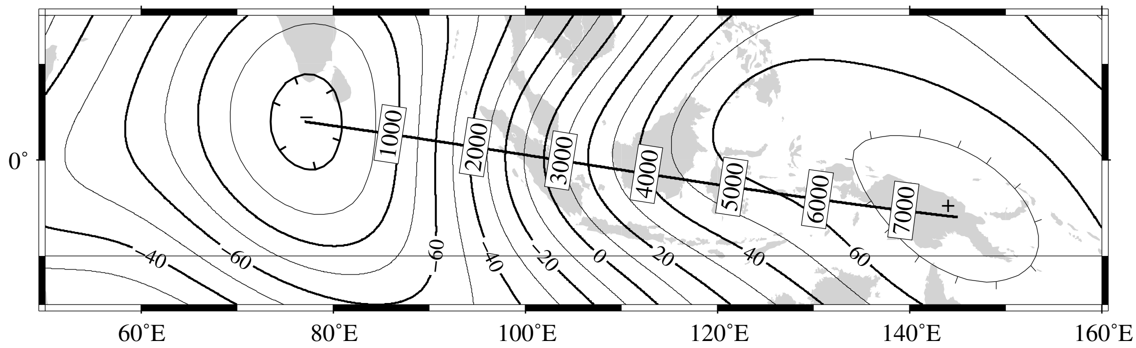


Figure O.6: Labels attributes are controlled with the arguments to the **–Sq** option.

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 -JM5.5i -Glightgray -A500 -K -P > GMT_App_O_7.ps
grdcontour geoid.grd -J -O -K -B20f10WSne -C10 -A20+d+um+s8 -Gl50/10S/160/10S -S10 \
    -T:-+ >> GMT_App_O_7.ps
psxy -R -J -O -SqD15d:+gblack+kwhite+Ld+o+u-\\260 -W1p transect.d >> GMT_App_O_7.ps
```

The output is presented as Figure O.7.

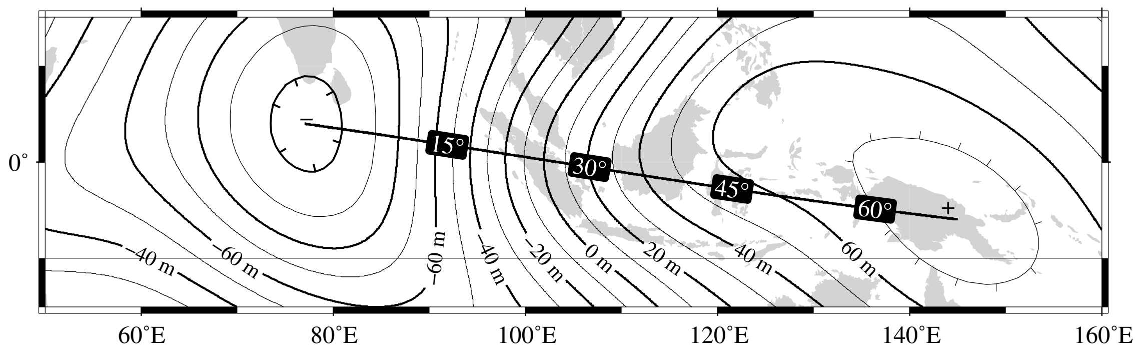


Figure O.7: Another label attribute example.

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 -JM5.5i -Glightgray -A500 -K -P > GMT_App_O_8.ps
grdcontour geoid.grd -J -O -K -B20f10WSne -C10 -A20+d+um+s8 -Gl50/10S/160/10S -S10 \
    -T:-+ >> GMT_App_O_8.ps
psxy -R -J -O -Sqffix2.d:+g+an+p+Lf+um+s8 -W1p transect.d >> GMT_App_O_8.ps
```

The output is presented as Figure O.8.

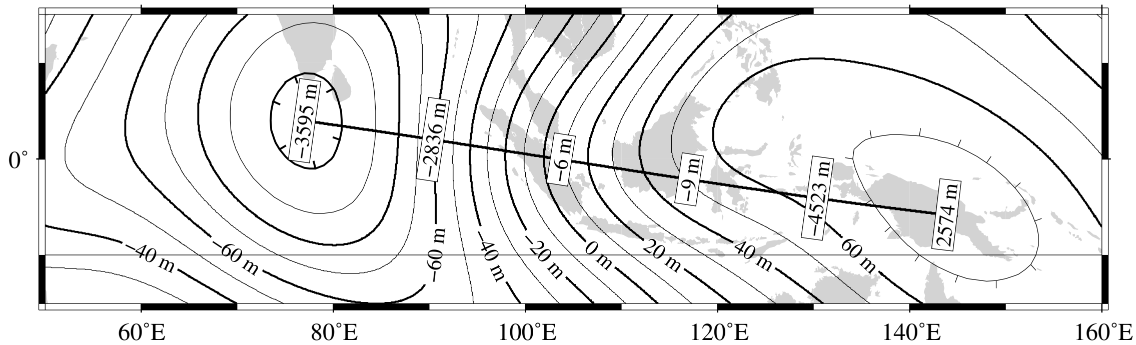


Figure O.8: Labels based on another data set (here bathymetry) while the placement is based on distances.

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 Islands[2]. 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
grdgradient topo5.grd -Nt1 -A45 -Gtopo5_int.grd
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 ttt_atl.grd -Itopo5_int.grd -Cttt.cpt $R -JM5.5i -P -K > GMT_App_O_9.ps
grdcontour ttt_atl.grd -R -J -O -K -C0.5 -A1+u"hour"+v+s8+f17 -GL80W/31N/17W/26N,17W/28N/17W/50N \
    -S2 >> GMT_App_O_9.ps
psxy -R -J -W7p,white great_NY_Canaries.d -O -K  >> GMT_App_O_9.ps
pscoast -R -J -B20f5:."Tsunami Travel Times from the Canaries":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 -W1p great_NY_Canaries.d -O -K -W1p \
    -Sqn1:+f6+s8+l"Distance Canaries 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 -W0.5p 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 -WwhiteOthin -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
rm -f great_NY_Canaries.d great_NY_Paris.d ttt.cpt
```

with the complete illustration presented as Figure O.9.

[2]Travel times were calculated using Geoware's travel time calculator, ***ttt***.

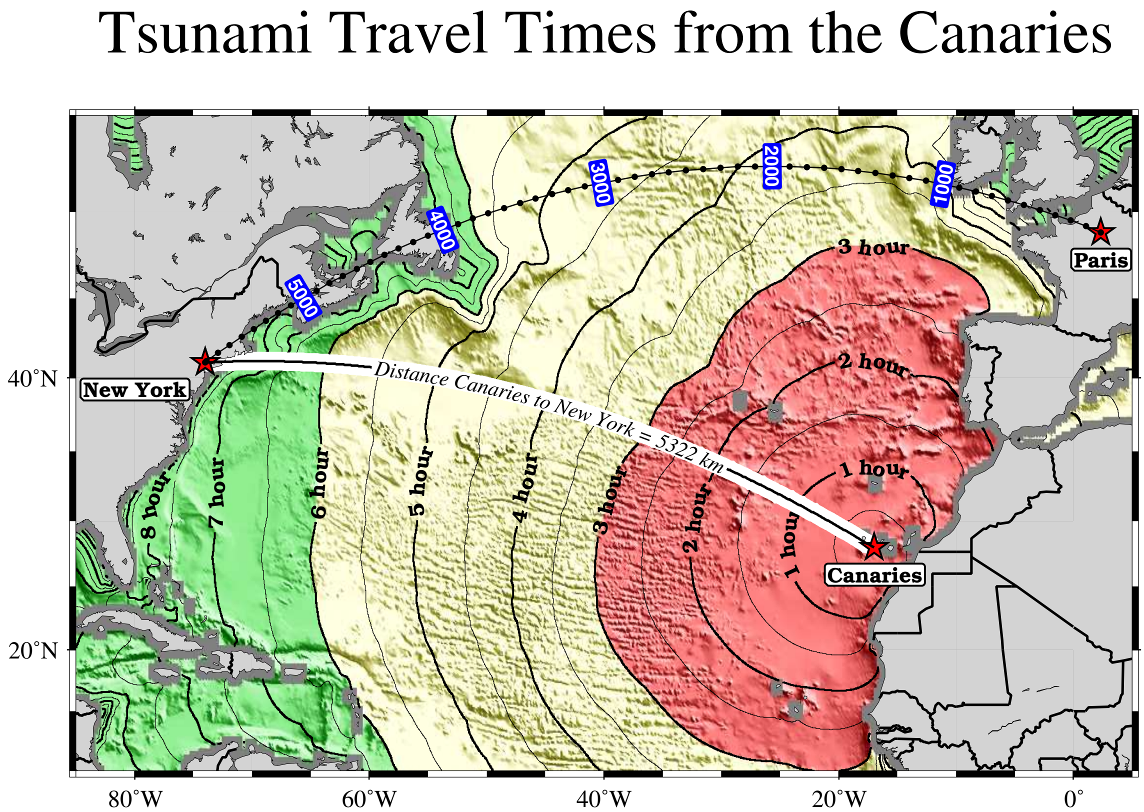


Figure O.9: Tsunami travel times from the Canary Islands to places in the Atlantic, in particular New York. Should a catastrophic landslide occur it is possible that New York will experience a large tsunami about 8 hours after the event.

P. 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 both GMT 3.4.5 and 4 and use our utility ***gmtswitch*** to select their current version should the need to switch arises. You will find ***gmtswitch*** in the top-level GMT4 directory; install as explained below.

Because GMT 4 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. 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. Define the environmental variable **GMTHOME** to point to **$HOME**/this_gmt, where **$HOME** is the full path to your home directory. Here, this_gmt is a symbolic link that will be created and maintained by ***gmtswitch*** to point to a directory with one of the installed versions.

2. Make sure **$GMTHOME**/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 verson, 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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