GMT examples:

Plotting focal mechanisms (beach balls) of global seismicity on equidistant map

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General information

If you make use of the content described in this manual please give reference to my dissertation in whose framework the presented map was developed:

> **Grund, M. (2019)**, *Exploring geodynamics at different depths with shear wave splitting*, Karlsruhe Institute of Technology (KIT), `http://doi.org/10.5445/IR/1000091425`.

Contents

1 Plotting the map

In this manual I provide GMT (Generic Mapping Tools, e.g. Wessel et al., 2013) instructions to go from a raw map in equidistant projection to a publication-ready figure that displays the focal mechanisms (beach balls) of the global seismicity between 28/01/1964 and 31/01/2019 (with $M_W > 6$, only GCMT data) scaled by the magnitude and color-coded by the earthquake hypocenter depth.

All content shown in the following is based on the bash-script GMT_EQglob_BFO_GCMT.gmt that can be downloaded together with all required files (colormaps etc.) from https://github.com/michaelgrund/GMT-plotting. The used earthquake data was downloaded from the International Seismological Centre (ICS, http://www.isc.ac.uk) via wget (for details see the code snippet in section 1.2) and includes only GCMT solutions.
Scientific colormaps are provided by Fabio Crameri (Crameri, 2018a,b) and were downloaded from http://www.fabiocrameri.ch/colourmaps.php. Matplotlib colormaps (originally developed by Nathaniel J. Smith, Stefan van der Walt, and (in the case of viridis) Eric Firing) converted to GMT's cpt format were downloaded from http://soliton.vm.bytemark.co.uk/pub/cpt-city/mpl/index.html. Further information about these colormaps can be found at https://bids.github.io/colormap/.

If GMT 5.2.1 (or higher, Wessel et al., 2013) is installed on your (Linux) system you can directly reproduce the whole content shown in this manual by running GMT_EQglob_BFO_GCMT.gmt via command line. In the following the individual steps to get the final figure are lined out. Detailed comments on each step are included in the code blocks (gray boxes). Since the final GMT output is stored in a postscript file (*.ps), a pdf converter such as ps2pdf (see bottom of the last code block) should be installed on your system. Furthermore, to get a figure without white spaces around the plot, I recommend to install pdfcrop from Heiko Oberdiek (can be downloaded from https://ctan.org/pkg/pdfcrop?lang=de).

1.1 Basic settings

```
#!/bin/bash

gmtset  MAP_GRID_PEN_PRIMARY 0.3p,dimgrey \
        PROJ_LENGTH_UNIT c \
        MAP_ANNOT_OBLIQUE 30 \
        MAP_ANNOT_OFFSET 5p \
        MAP_ANNOT_OFFSET_PRIMARY 5p \
        MAP_ANNOT_OFFSET_SECONDARY 5p \
        COLOR_MODEL rgb \
        FONT_ANNOT_PRIMARY 10p,Helvetica \
        FONT_LABEL 10p \
        MAP_FRAME_WIDTH 2p \
        MAP_FRAME_PEN 1.2p \
        COLOR_BACKGROUND white \
        COLOR_FOREGROUND red3 \
        PS_CHAR_ENCODING Standard+

###########################################################################################
# GMT (5.2.1) script to plot focal mechanisms (beach balls) of global seismicity in an
# equidistant map view (only GCMT data)
############################################################################################

# 2019, Michael Grund (KIT Karlsruhe, Geophysical Institute)

# Required files to run this script are included in the download directory.

###########################################################################################
# If you use the content of this script or the accompanying files please acknowledge GMT
# and my PhD thesis (DOI: 10.5445/IR/1000091425).
###########################################################################################
```

```
###########################################################################################
# define output file name
outps=EQglob_BFO_GCMT.ps

# map is centered on the coordinates centerE/centerN
# given coordinates correspond to station BFO in the Black Forest, Germany (one of the most
# quiet stations around the globe ;), however, you can modify the coordinates to any place
# and plot the corresponding map content related to this location
centerN=48.332 # latitude in degrees
centerE=8.331 # longitude in degrees

# viridis colormap file that is used to color-code the depths of the individual events
# (downloaded from http://soliton.vm.bytemark.co.uk/pub/cpt-city/mpl/tn/viridis.png.index.html)
cmap2use=viridis.cpt

# if you want to apply another colormap you can directly use the following ones
# which are included in the download package (just uncomment the corresponding line):

#cmap2use=batlow.cpt
#cmap2use=bamako.cpt
#cmap2use=nuuk.cpt
#cmap2use=imola.cpt
#cmap2use=devon.cpt
#cmap2use=inferno_mod.cpt
#cmap2use=magma_mod.cpt
#cmap2use=plasma_mod.cpt

# batlow.cpt, bamako.cpt, nuuk.cpt, imola.cpt and devon.cpt are provided by
# Fabio Crameri, further colormaps can be downloaded from:
#                   http://www.fabiocrameri.ch/colourmaps.php
#
# Furthermore, please acknowledge their use by citing:
#   Crameri, F. (2018a), Scientific colour-maps. Zenodo. http://doi.org/10.5281/zenodo.1243862


# inferno_mod.cpt, magma_mod.cpt and plasma_mod.cpt are slightly modified versions of
# inferno.cpt, magma.cpt and plasma.cpt that can be also downloaded from:
#
#            http://soliton.vm.bytemark.co.uk/pub/cpt-city/mpl/

###########################################################################################
```

1.2 Data preparation/download (optional)

```
# get the data between 28/01/1964 to 31/01/2019 (magnitude Mw > 6, only GCMT data)
# from ISC using wget

OUTFILE=ICS_EQs.dat

# The file <<< ICS_EQs.dat >>> is alread available in the download package. If you want to
# modify the event dates or criteria just uncomment the following lines:

#SITE="http://www.isc.ac.uk/cgi-bin/web-db-v4"
#TIME="start_year=1964&start_month=01&start_day=01&start_time=00:00:00&end_year=2019
        &end_month=01&end_day=31&end_time=23:59:59"
#MAG="min_mag=6"
#AGENC="req_mag_agcy=GCMT&req_mag_type=Any&req_fm_agcy=GCMT"
#FORM="out_format=FMCSV&request=COMPREHENSIVE"
#SEARCH="searchshape=GLOBAL"
#URL="${SITE}?${TIME}&${MAG}&${AGENC}&${FORM}&${SEARCH}"

#wget --output-document=$OUTFILE $URL

###########################################################################################
```

1.3 Plot continents and plate boundaries

```
##########
# Fig. 1 # plot continents and plate boundaries after Bird (2003)
##########

# map is centered on the coordinates centerE/centerN
centerN=48.332 # latitude in degrees
centerE=8.331 # longitude in degrees

# define the size of the map
map_radi=2.8i

# define the horizon of the map (which is the maximum distance in degrees displayed from
# the center)
map_horz=160

# map region is global (-Rg), map projection is azimuthal equidistant (-JE), plot continents,
# lakes and rivers in gray (-G and -C), oceans in white with crude resolution (-Dc)
col_cont=217.6/217.6/217.6
pscoast -Rg -JE$centerE/$centerN/$map_horz/$map_radi -Dc -G$col_cont -Swhite \
    -C$col_cont -K -P -Baf > $outps

# plot plate boundaries after Bird (2003) in light red that are stored
# in file <<< PB2002_boundaries_GMTready.txt >>>
col_plb=245.7600/204.8000/204.8000
psxy -J -R PB2002_boundaries_GMTready.txt -W0.5p,$col_plb -O -K >> $outps

###############################################################################################
```

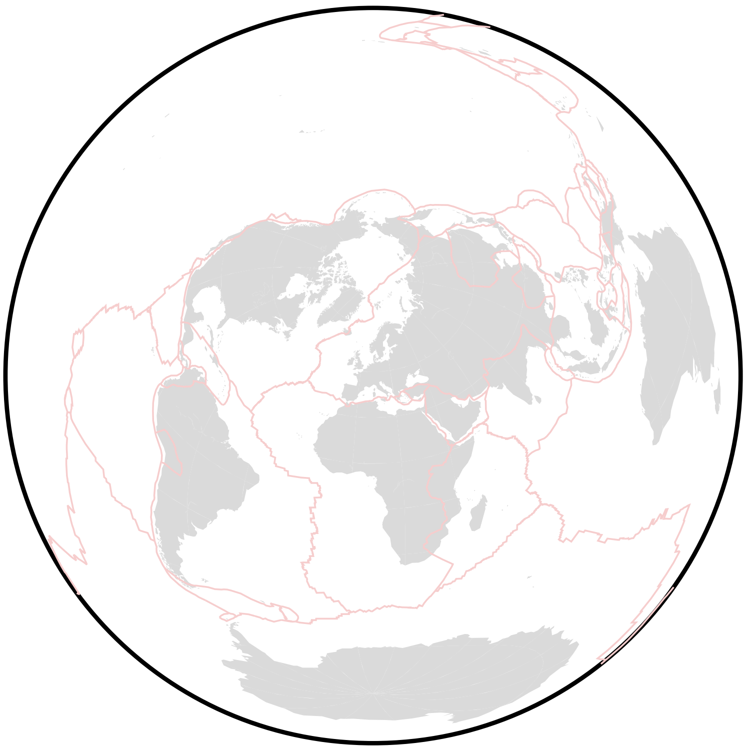

Figure 1: Plot continents (gray) and plate boundaries (light red lines) after Bird (2003).

1.4 Plot dashed circles at 50° and 140° distance from center

```
##########
# Fig. 2 # plot dashed circles at 50 and 140 degrees distance from center
##########

# radius is estimated via XX degrees * 111km <=> 1 degree = 111km,
# here 2*radius is used
psxy -R -J -SE- -Wblack,- -Wthin -O -K << EOF >> $outps
$centerE  $centerN  11100
$centerE  $centerN  31080
EOF

############################################################################################
```

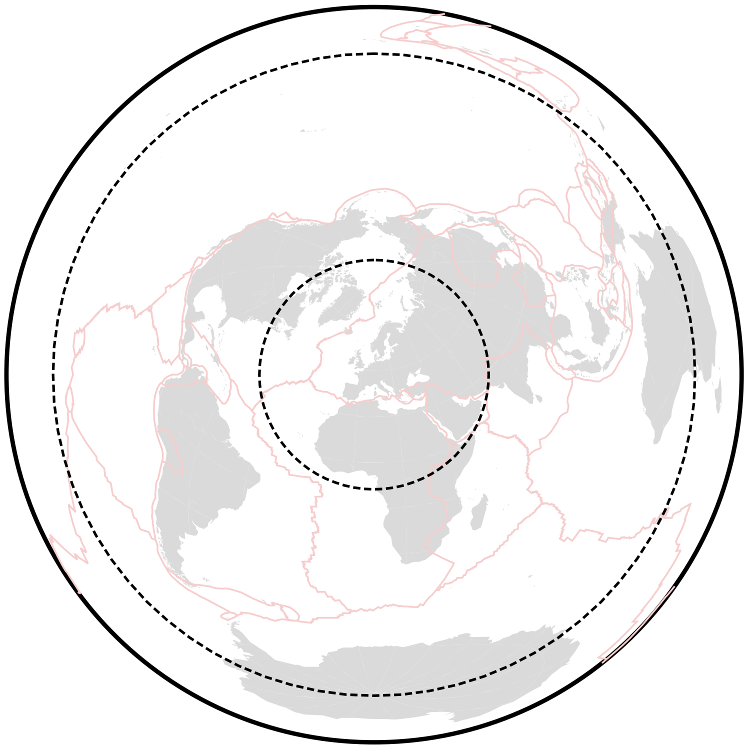

Figure 2: Plot dashed circles at 50° and 140° distance from center.

1.5 Plot "beach balls" at earthquake event locations

```
##########
# Fig. 3 # plot "beach balls" at event locations
##########

# PREPARE DATA
# (A) only use lon lat depth str dip slip str dip slip mant exp plon plat and agency from the
# download data
awk -F',' 'NR > 29 {print $6,$5,$7,$20,$21,$22,$23,$24,$25,exp($12/1.7)*0.047,0,0,0,$9}' \
    $OUTFILE > datextr_gcmt_tmp.dat

# (B) calculate the distance for each point to map center (given in km)
mapproject datextr_gcmt_tmp.dat -R -J -G$centerE/$centerN  > datproj_gcmt_tmp.dat

# (C) recalculate distance as epicentral distance in degrees (from km) and write it in 15th
```

```
# column of file <<< epidistDEG_gcmt.dat >>>
awk '{print($1,$2,$3,$4,$5,$6,$7,$8,$9,$10,$11,$12,$13,$15/1000/111)}' datproj_gcmt_tmp.dat \
    > epidistDEG_gcmt.dat

# (D) define a continous (-Z) colormap based on the viridis.cpt given above (-C) for depths
# between 0 and 600 km with steps of 100 km, -M affects that the defined colors for fore
# and background are used (see gmtset settings in the beginning of the file COLOR_BACKGROUND
# and COLOR_FOREGROUND), thus event locations deeper 600 km are plotted in dark red.
makecpt -C$cmap2use -T0/600/100 -M -Z > EQdepths.cpt

# PLOT DATA
# (E) plot beach balls only between 50 and 140 distance ($14), scaled by magnitude and
# color-coded by event depths, size of the beach balls was calculated by
# <<< exp(x/1.7)*0.0037 >>> with x (magnitude) as input (see A above), adjust <<< $3 > 0 >>>
# to plot only events with depths > the given value, here all events are plotted (> 0)
awk '{if ($14 > 50 && $14 < 140 && $3 >0) print($1,$2,$3,$4,$5,$6,$7,$8,$9,$10,$11,$12,$13)}' \
    epidistDEG_gcmt.dat | psmeca -R -J -Sc0.5 -W.5 -h1 -O -K -ZEQdepths.cpt >>$outps

##########################################################################################
```

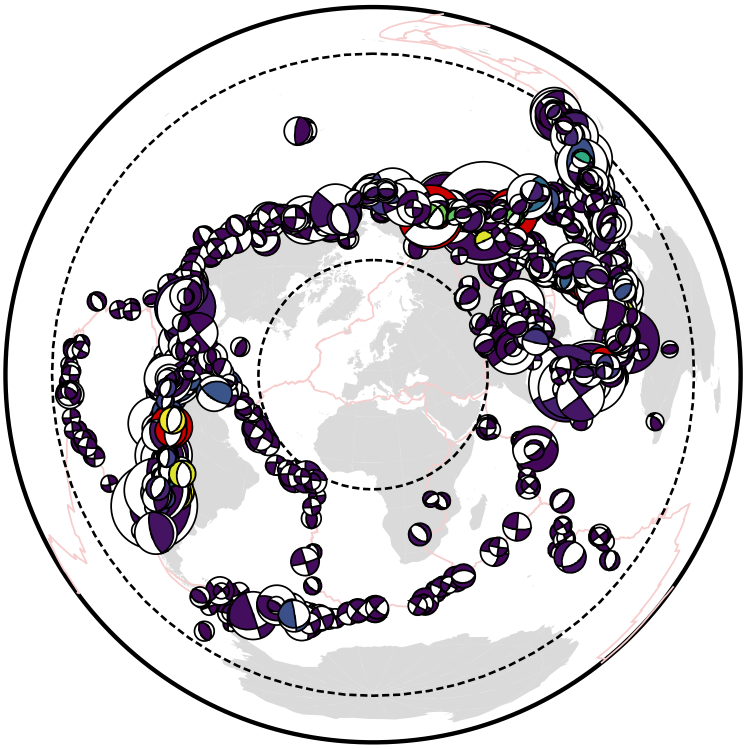

Figure 3: Plot "beach balls" at earthquake event locations. Color-coding displays the event depths in km (here colormap `viridis` is used) and the size of the circles scales with the event moment magnitude M_W.

1.6 Plot station, distance circles (again) and add annotations

```
##########
# Fig. 4 # plot station, distance circles (again) and add annotations
##########

# plot a gray filled triangle (-St) with size of 0.45c as marker at station BFO (Black Forest
# Observatory)
psxy -R -J -St0.45c -G105/105/105 -Wblack -W0.5p -O -K << EOF >> $outps
$centerE  $centerN
```

```
EOF

# plot the distance circles at 50 and 140 degrees again on top in white with slight
# transparency (-t60) this small trick ensures that the circles are also visible when
# the "event circles" overlap
psxy -R -J -SE- -Wwhite,- -Wthin -O -K -t60 << EOF >> $outps
$centerE  $centerN  11100
$centerE  $centerN  31080
EOF

# annotation at 50 and 140 degrees (\217 gives the degree symbol, see PS_CHAR_ENCODING in
# gmtset in the beginning of the file)
pstext -R -J -F+f7p -O -K <<EOF >>$outps
9 5.5 50\217
9 -84 140\217
EOF

##########################################################################################
```

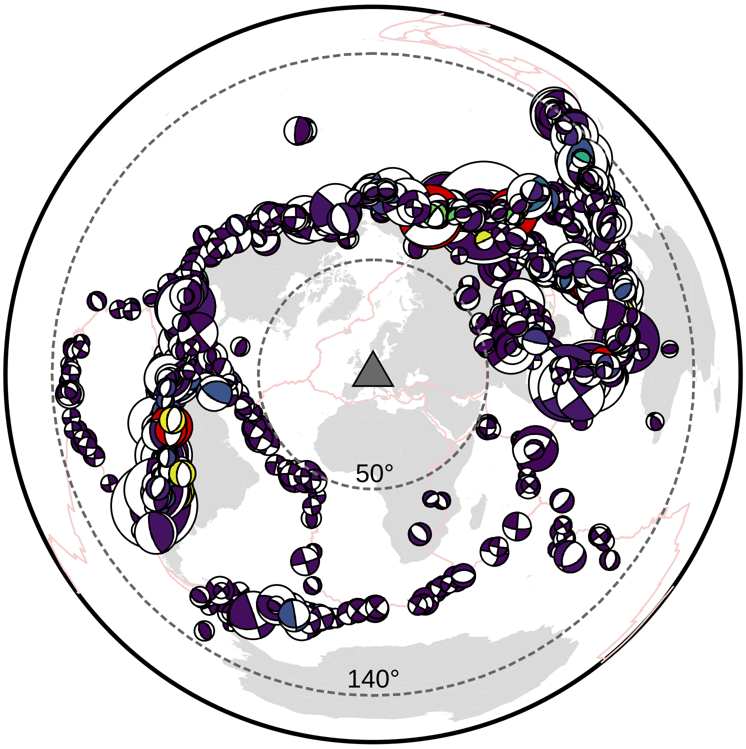

Figure 4: Plot station location (gray triangle) and the distance circles (again) in transparent white. Furthermore, add some annotations.

1.7 Plot the colorbar

```
##########
# Fig. 5 # plot the colorbar
##########

# adjust some settings for plotting
gmtset FONT_ANNOT_PRIMARY 6p,Helvetica  # set fontsize smaller for colorbar
gmtset FONT_LABEL 6p
gmtset MAP_ANNOT_OFFSET 0.14i
gmtset MAP_TICK_LENGTH_PRIMARY -0.1i
gmtset MAP_FRAME_PEN 1p
```

```
# plot the bar with annotation, foreground sidebar angle is added in darkred and specified
# in size (+ef0.06i), location and size of the bar is defined via -Dx, +h gives a horizontal
# bar
psscale -CEQdepths.cpt -Dx0.7/7.7+w1i/0.1i+ef0.06i+ml+h -Bxa+l"depth in km" -O -K >> $outps

# set parameters back to defaults
gmtset FONT_ANNOT_PRIMARY 8p,Helvetica
gmtset FONT_LABEL 8
gmtset MAP_ANNOT_OFFSET 5p
gmtset MAP_TICK_LENGTH_PRIMARY 5p
gmtset MAP_FRAME_PEN 1.5p

###############################################################################################
```

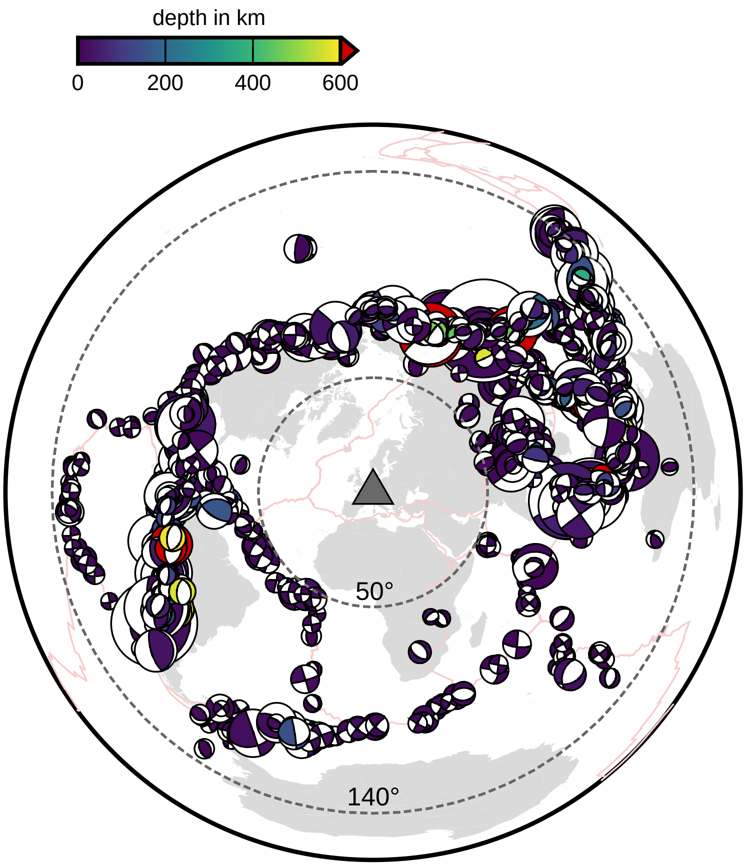

Figure 5: Plot the colorbar in upper left corner.

1.8 Add legend for the beach balls scaled by the event magnitudes

```
##########
# Fig. 6 # add legend for the beach balls scaled by event magnitudes
##########

# size is calculated based on formula given above (see E) for Mw 6 to 9
M6=$(echo "e(6/1.7)*0.047" | bc -l)
M7=$(echo "e(7/1.7)*0.047" | bc -l)
M8=$(echo "e(8/1.7)*0.047" | bc -l)
M9=$(echo "e(9/1.7)*0.047" | bc -l)


# make legend
# plot beach balls with areas in gray, use other projection (-J4),
```

```
# -N allows to plot outside of the map frame
yval=36.6 # shift in y-direction

str1=180
dip1=80
slip1=-90
str2=90
dip2=80
slip2=-90

psmeca -R0/20/0/20 -JM4 -Sc0.5 -h1 -W.5 -O -Glightgray -N -K<< END >>$outps
lon lat depth str1 dip1 slip1 str2 dip2 slip2 mant exp plon plat
23 $yval 10 $str1 $dip1 $slip1 $str2 $dip2 $slip2 $M6 0 0 0
25 $yval 10 $str1 $dip1 $slip1 $str2 $dip2 $slip2 $M7 0 0 0
27.75 $yval 10 $str1 $dip1 $slip1 $str2 $dip2 $slip2 $M8 0 0 0
32.2 $yval 10 $str1 $dip1 $slip1 $str2 $dip2 $slip2 $M9 0 0 0
END

# add annotations
yval2=34
pstext -R -JM4 -F+f6p -N -O -K <<EOF >>$outps
23 35.65 6
25 35.4 7
27.75 34.9 8
32.2 34 9
21 $yval Mw
EOF

##########
rm *tmp.dat # clean up, remove temporary files
ps2pdf $outps $outps.pdf
pdfcrop $outps.pdf $outps.pdf
```

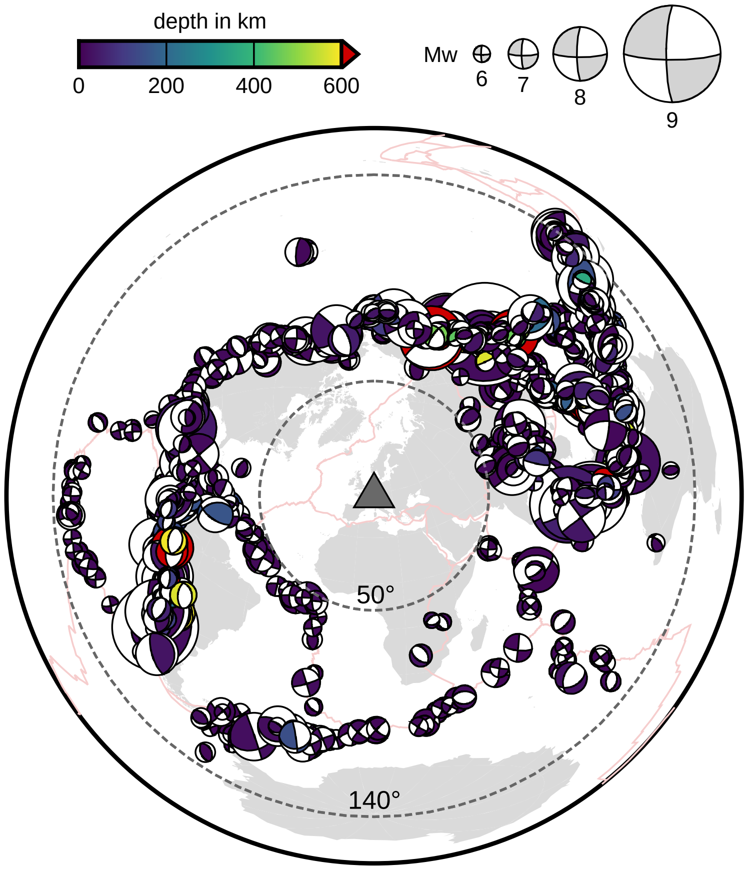

Figure 6: Add legend for the event magnitudes in upper right corner.

2 Using other colormaps

As mentioned in the beginning of this manual, of course you can also use other colormaps to plot the data. In principle each colormap available in (or converted to) GMT's cpt format can be used here. By changing variable `cmap2use` (see first code box, default is `viridis.cpt`) you can generate figures with a few other colormaps included in the download package (`batlow.cpt`, `bamako.cpt`, `nuuk.cpt`, `imola.cpt`, `devon.cpt`, `inferno_mod.cpt`, `magma_mod.cpt` and `plasma_mod.cpt`).

References

Bird, P., 2003. An updated digital model of plate boundaries, *Geochem. Geophys. Geosyst.*, **4**, 1027.

Crameri, F., 2018a. Scientific colour-maps, http://doi.org/10.5281/zenodo.1243862.

Crameri, F., 2018b. Geodynamic diagnostics, scientific visualisation and StagLab 3.0, *Geosci. Model Dev.*, **11**, 2541–2562, doi:10.5194/gmd–11–2541–2018.

Wessel, P., Smith, W. H. F., Scharroo, R., Luis, J., & Wobbe, F., 2013. Generic Mapping Tools: Improved version released, *Eos Trans. AGU*, **94(45)**, 409–420.