GMT examples:

Plotting splitting parameters with color wheel

Michael Grund
(Email: michael.grund@kit.edu)

Karlsruhe Institute of Technology (KIT), Geophysical Institute, Karlsruhe, Germany

General information

Individual single splitting measurements (only *good/fair* quality) used in this example are freely available as download package via the **KITopendata** repository: https://publikationen.bibliothek.kit.edu/1000091427. If you make use of the data please give reference to:

> Grund, M. (2019), *Dissertation electronic appendix*, KITopendata, doi:10.5445/IR/1000091427.

and my disseration in which a slightly modified version of the presented map is included:

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

1 Plotting the map (backazimuth 0° – 360°)

All content shown in the following is based on the bash-script `SWS_MAP_Fenno.gmt` that can be downloaded from https://github.com/michaelgrund/GMT-plotting. 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 `SWS_MAP_Fenno.gmt` via command line. In the following the individual steps to get the final figure are lined out. Some aspects of this figure are build on specific work-arounds to finally receive the results I wanted to get ☺.

1.1 Basic settings and map parameters

```
#!/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        \
        MAP_LABEL_OFFSET  5.5p \
        COLOR_MODEL       rgb        \
        FONT_ANNOT_PRIMARY  8p,Helvetica \
```

```
        FONT_LABEL 8 \
        MAP_FRAME_TYPE fancy \
        MAP_FRAME_WIDTH 2p \
        MAP_TICK_LENGTH_PRIMARY 5p \
        MAP_FRAME_PEN 1.1p  \
        PS_CHAR_ENCODING Standard+

##############################################################################################
# GMT (5.2.1) script to plot color-coded splitting parameters across Fennoscandia
##############################################################################################

# 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) in which a modified version of the generated
# map is included.
##############################################################################################

##############################################################################################

# define considered backazimuth range
BAZstart=0
BAZend=360
scale_down=0.0032  # for 0:360, controls radial axis limits for roseplot, manually set!

##############################################################################################

# input grid containing the area of Fennoscandia
# (other grids can be downloaded from e.g.: https://www.ngdc.noaa.gov/mgg/global/)

grd=etopo1_bedrock.grd

# initial map parameters
projJ="l20/60/16/80/1:10000000"
projR=3.5/36.5/54/71.5

# define output name
ps="SWS_MAP_Fenno_"$BAZstart"_"$BAZend

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

1.2 Plot raw map with shaded topography

```
##########
# Fig. 1 # plot simple map with shaded topography
##########

# generate gradient file from grid file
grdgradient $grd -G$grd.grad -Nt0.8 -A180 -A0/180 -V

grdimage $grd -R$projR -J$projJ -I$grd.grad -Ctopo_whigra.cpt -P -K > $ps

# plot map frame, water areas on top in white, coastlines in black and add scale
pscoast -J -R -Bx5 -By5 -Wthinnest -Swhite -Dh -P -K -O -A20/0/1 >> $ps
pscoast -J -R -BSNEW -Dh -Wthinnest -A20/0/1 -Swhite -Lf31.5/55.5/56/200+lkm+jt -O -K >> $ps
 # plot again to avoid visible "grid lines" in water areas
pscoast -J -R -Dh -Wthinnest -A20/0/1 -Swhite -O -K >> $ps

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

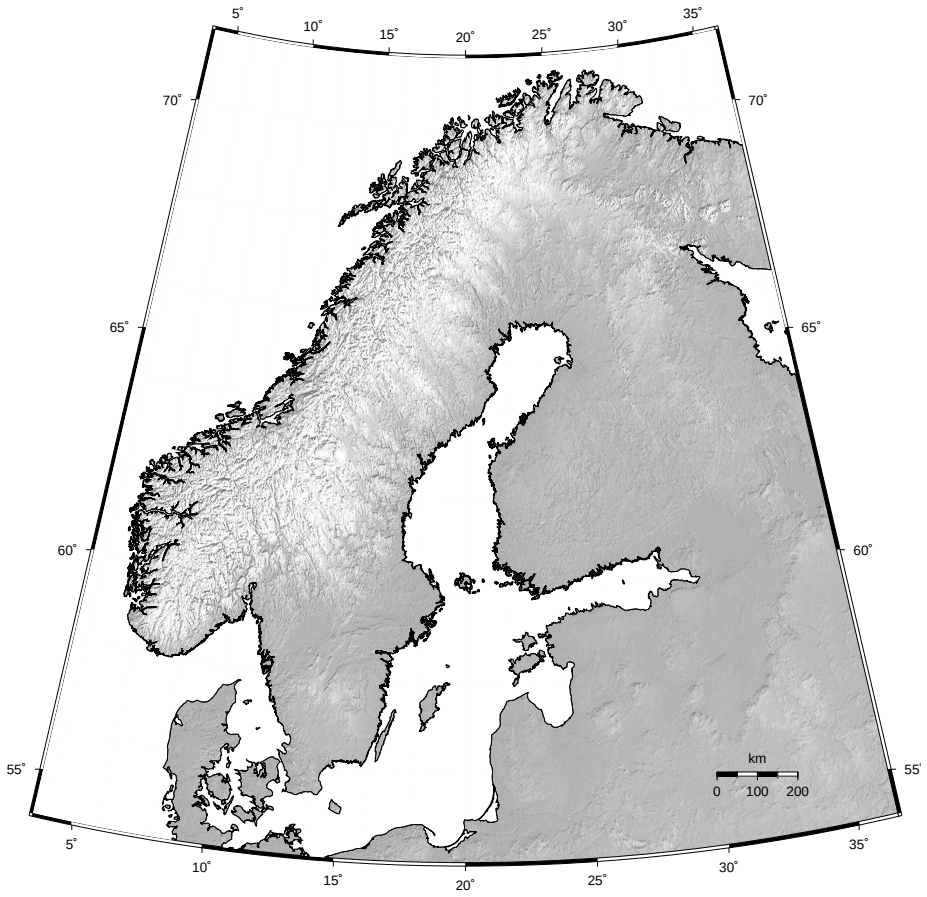

Figure 1: Plot a raw map of Fennoscandia with gray-shaded topography (ETOPO1).

1.3 Add an equidistant map

```
##########
# Fig. 2 # plot an equidistant map in upper left corner
##########

# center of map
centerN=65
centerE=20

# radius of map
map_radi=2.1i

# shift equidistant map in x and y direction
equiX=0.29i
equiY=5i

# plot map
colland=217.6/217.6/217.6 # landmasses are colored in gray (RGB: 217.6/217.6/217.6)
pscoast -Rg -JE$centerE/$centerN/160/$map_radi -Dc -C$colland -Swhite \
    -G$colland -X$equiX -Y$equiY -K -O -P -Baf >> $ps

# plot plate boundaries after Bird (2003)
colbounds=245.7600/204.8000/204.8000 # color of boundaries
psxy -J -R PB2002_boundaries_GMTready.txt -W0.5p,$colbounds -O -K >> $ps

# plot black dashed circles at 80deg and 140deg distance from center, radius estimated
# via XXdeg * 111km  <=> 1deg = 111km
psxy -R -J -SE- -Wblack,- -Wthin -O -K << EOF >> $ps
```

```
$centerE   $centerN   17760
$centerE   $centerN   31080
EOF

# annotation at 80 deg and 140 deg
pstext -R -J -F+f6p -O -K << EOF >>$ps
$centerE  -4.5  80\217
$centerE  -64  140\217
EOF

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

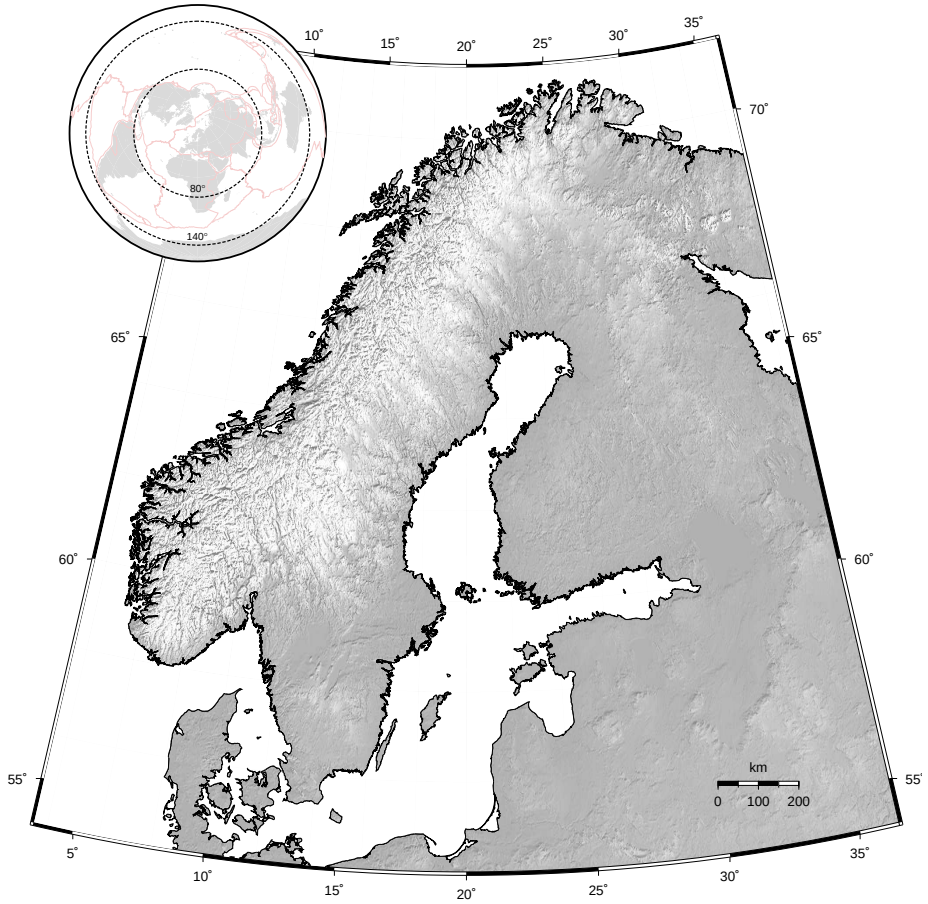

Figure 2: Add equidistant worldmap in upper left corner with plate boundaries after Bird (2003).

1.4 Plot color wheel

```
##########
# Fig. 3 # add color wheel to equidistant map between 80 deg and 140 deg circles
##########

# eps file containing the circular color wheel with transparent background, prepared
# in Inkscape (thanks to Caroline Eakin for the original version and the idea how to
# prepare that wheel!!!)
filename=EPScolorwheel.eps

# center of color wheel (slightly different from center of equidistant map, since
# prepared eps file is not fully circular after Inkscape export)
lon=21.02
```

```
lat=62.85

# size of the eps image in map
sizeIMAGE=1.83i

# import and place color wheel
gmt psimage $filename -R -J -Dg$lon/$lat+w$sizeIMAGE+jCM -K -O >> $ps

# plot 80 deg and 140 deg circle, for basis first in white
psxy -R -J -SE- -Wwhite -Wthin -O -K << EOF >> $ps
$centerE  $centerN 17760
$centerE  $centerN 31080
EOF

# plot annotation at 140 deg again on top of color wheel
pstext -R -J -F+f6p -O -K <<EOF >> $ps
$centerE -64 140\217
EOF

# plot plate boundaries again on top of color wheel
psxy -J -R PB2002_boundaries_GMTready.txt -W0.5p,245.7600/204.8000/204.8000 -O -K  >> $ps

# plot 80 deg and 140 deg circles, now on top in black dahsed again
psxy -R -J -SE- -Wblack,- -Wthin -O -K << EOF >> $ps
$centerE  $centerN 17760
$centerE  $centerN 31080
EOF

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

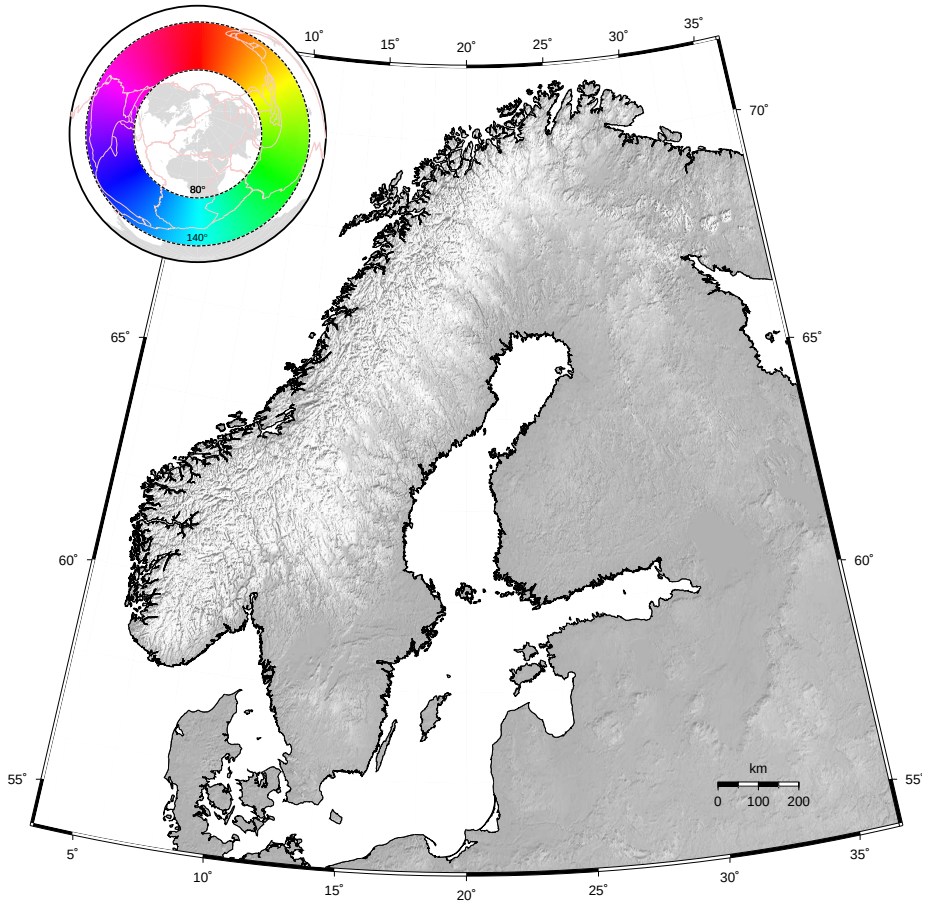

Figure 3: Add a color wheel to the equidistant map by loading and plotting an external eps-file (`EPScolorwheel.eps`) previously prepared in Inkscape.

1.5 Plot event locations

```
##########
# Fig. 4 # plot locations of events used for the splitting analysis
##########

evcircs=0.06i
evcircew=0.45
evcirccecol=44/44/44
col_reg_all=white

### SPLITS
awk '{print($8,$7)}' 00_RESULTS_ALL_MERGED.geo | psxy -R -J -O -K  -G$col_reg_all \
     -W$evcircew,$evcirccecol -Sc$evcircs >> $ps
### NULLS
awk '{print($8,$7)}' 00_RESULTS_nulls_ALL_MERGED.geo | psxy -R -J -O -K  -G$col_reg_all \
     -W$evcircew,$evcirccecol -Sc$evcircs >> $ps

#=========================================================
# highlight events of selected region
# (at this point the plotted content depends on the values for BAZstart and BAZend defined in
# the beginning, in the defaul example shown here all event between 0 deg and 360 deg BAZ are
# used)

col_reg_sel=darkgray
scale_barl=60
bar_thick=12.6

### SPLITS
# prepare data for linking event locations with splitting bars that are plotted later
awk -v x=$scale_barl -v y=$bar_thick -v z=$BAZstart -v c=$BAZend \
     '{if (($6 == "good" || $6 == "fair") && ( $9 > z ) && ( $9 < c )) print $1, $2, $3, \
     y, $4*x, $9, $7, $8}' 00_RESULTS_ALL_MERGED.geo > split_gf.tmp

# plot first great circle paths of corresponding events to network center
awk '{print $8,$7, "\n" ,20, 65}' split_gf.tmp | psxy -R -J -O -K  -Wblack \
     -t60 >> $ps # -t60 sets transperancy of circles

# now plot the event circles
awk '{print($8,$7)}' split_gf.tmp | psxy -R -J -O -K  -G$col_reg_sel \
     -W$evcircew,$evcirccecol -Sc$evcircs >> $ps

### NULLS
# prepare data for linking event locations with Null bars that are plotted later
awk -v x=$scale_barl -v y=$bar_thick -v z=$BAZstart -v c=$BAZend \
'{if (($6 == "good" || $6 == "fair") && ( $9 > z ) && ( $9 < c )) print $1, $2, $3, \
     y, $4*x, $9, $7, $8}' 00_RESULTS_nulls_ALL_MERGED.geo > null_gf.tmp

# plot first great circle paths of corresponding events to network center
awk '{print $8,$7, "\n" ,20, 65}' null_gf.tmp | psxy -R -J -O -K  -Wblack \
     -t60 >> $ps # -t60 sets transperancy of circles

# now plot the event circles
awk '{print($8,$7)}' null_gf.tmp | psxy -R -J -O -K  -G$col_reg_sel \
     -W$evcircew,$evcirccecol -Sc$evcircs >> $ps

#=========================================================

# plot a triangle as marker in center of network
psxy -R -J -St0.25c -G205/0/0 -Wblack -O -K << EOF >> $ps
$centerE  $centerN
EOF

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

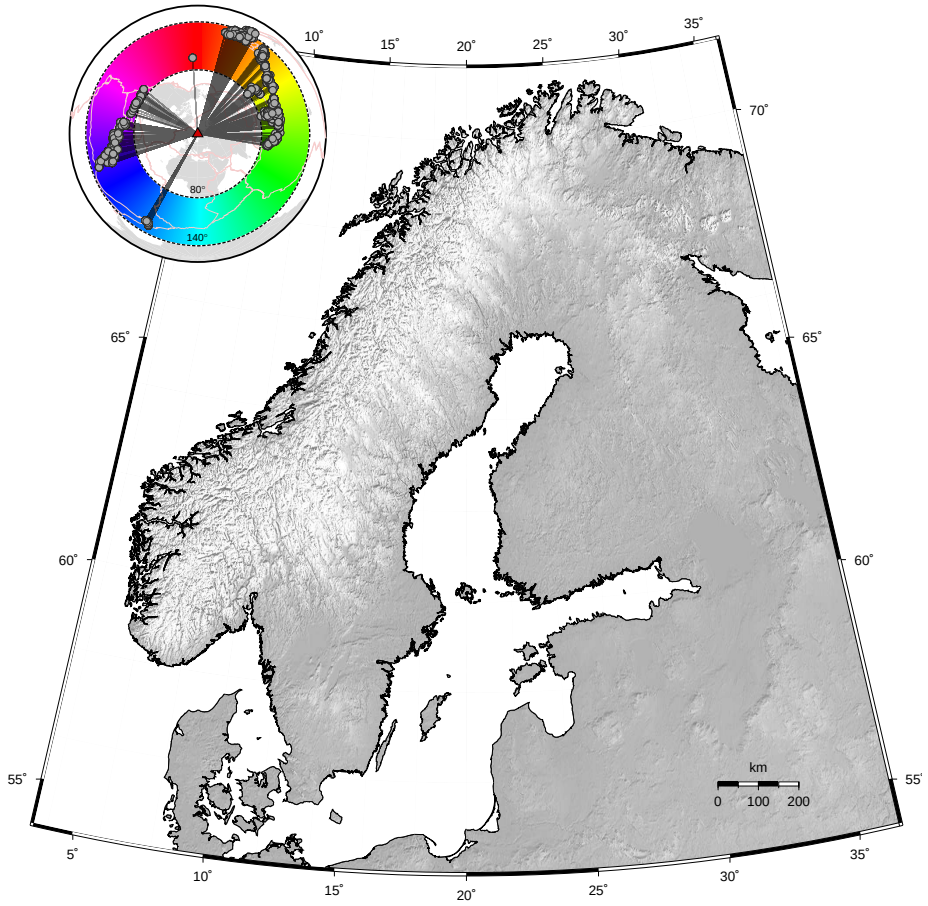

Figure 4: Add event locations (gray circles), a marker in the network center (red triangle) and great circle connections between event locations and network center (thin black lines).

1.6 Plot tectonic content

```
##########
# Fig. 5 # plot tectonic content
##########

# Content was partly digitised using Didger (R) (Golden Software, LLC) based on the
# following references:

# Geological units are modified after Fig. 1 of:
#       >> Hoegdahl et al., 2004, Geological Survey of Finland, Special Paper 37 <<
#       >> The Transscandinavian Igneous Belt (TIB) in Sweden: a review of its character and
#          evolution <<
# Tornquist zone is modified from paper:
#       >> Wylegalla et al.,1999, Tectonophysics 314, <<
#       >> Anisotropy across the Sorgenfrei-Tornquist Zone from shear wave splitting <<
# Major shear zones, faults and inferred paleo-subduction zones are modified after Figs. 1 & 2
#        of:
#       >> Korja & Heikkinen, Precambrian Research 136 (2005) 241-268 <<
#       >> The accretionary Svecofennian orogen-insight from the BABEL profiles <<

# plot shear zones and paleo-subduction zones, go back to original settings -R$projR -J$projJ
infilefaults=scan_shear_zones.dat

awk 'NR > 4 {print $0}' $infilefaults | psxy -R$projR -J$projJ -K -O -W1.1p,black \
     -X-$equiX -Y-$equiY >> $ps
awk 'NR > 4 {if ($3 == "subductionzone" && $4 == "1" ) print $0}' $infilefaults \
```

```
      | psxy -R -J -K -O -Sf0.2/0.09+t+r -Wthinnest -Gblack >> $ps
awk 'NR > 4 {if ($3 == "subductionzone" && $4 == "2" ) print $0}' $infilefaults \
      | psxy -R -J -K -O  -Sf0.2/0.09+t+l -Wthinnest -Gblack>> $ps
awk 'NR > 4 {if ($3 == "subductionzone" && $4 == "3" ) print $0}' $infilefaults \
      | psxy -R -J -K -O -Sf0.2/0.09+t+r -Wthinnest -Gblack >> $ps
awk 'NR > 4 {if ($3 == "subductionzone" && $4 == "4" ) print $0}' $infilefaults \
      | psxy -R -J -K -O -Sf0.2/0.09+t+r -Wthinnest -Gblack >> $ps
awk 'NR > 4 {if ($3 == "subductionzone" && $4 == "5" ) print $0}' $infilefaults \
      | psxy -R -J -K -O -Sf0.2/0.09+t+l -Wthinnest -Gblack >> $ps

# plot Tornquist zone
awk 'NR > 4 {print $0}' scan_STZ.dat | psxy -R -J -K -O -W1.1p,black >> $ps

# annotation Tornquist zone
pstext -R -J -F+10p -O -K -Gwhite@30 -TO <<EOF >>$ps
7.9 57.4 STZ
14.5 54.3 TTZ
EOF

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

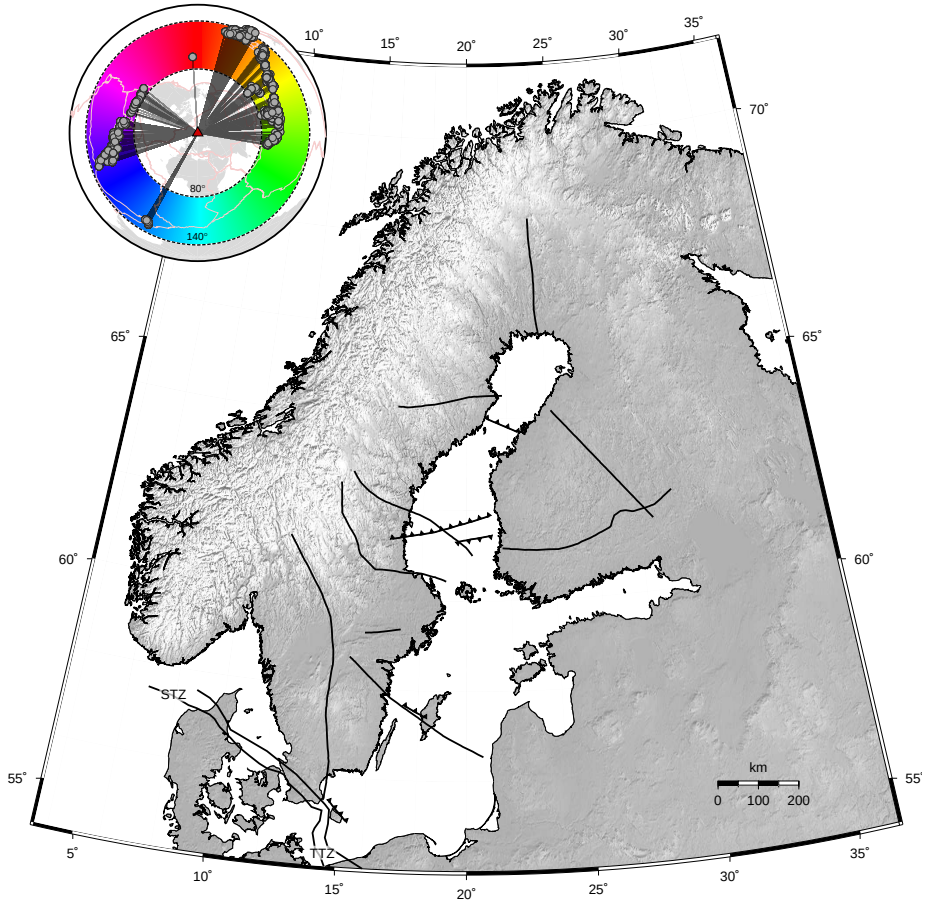

Figure 5: Add tectonic contents (black lines and sawtooth lines) that were previously digitized from different publications (for details see file headers of `scan_shear_zones.dat` and `scan_STZ.dat`).

1.7 Plot Nulls

```
##########
# Fig. 6 # plot Null measurements
##########

# plot nulls with bars parallel to the BAZ and perpendicular to it

barew=0.35p

# $6 is BAZ, barlenght is 80
awk '{print $1, $2, $6, 80, 8.6}' null_gf.tmp | psxy -R -J -SJ -W$barew,white -Gblack \
     -O -K >> $ps

# add +90 deg to BAZ to represent the fast and slow axis as perpendicular bars
awk '{print $1, $2, $6+90, 80, 8.6}' null_gf.tmp | psxy -R -J -SJ -W$barew,white -Gblack \
     -O -K >> $ps

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

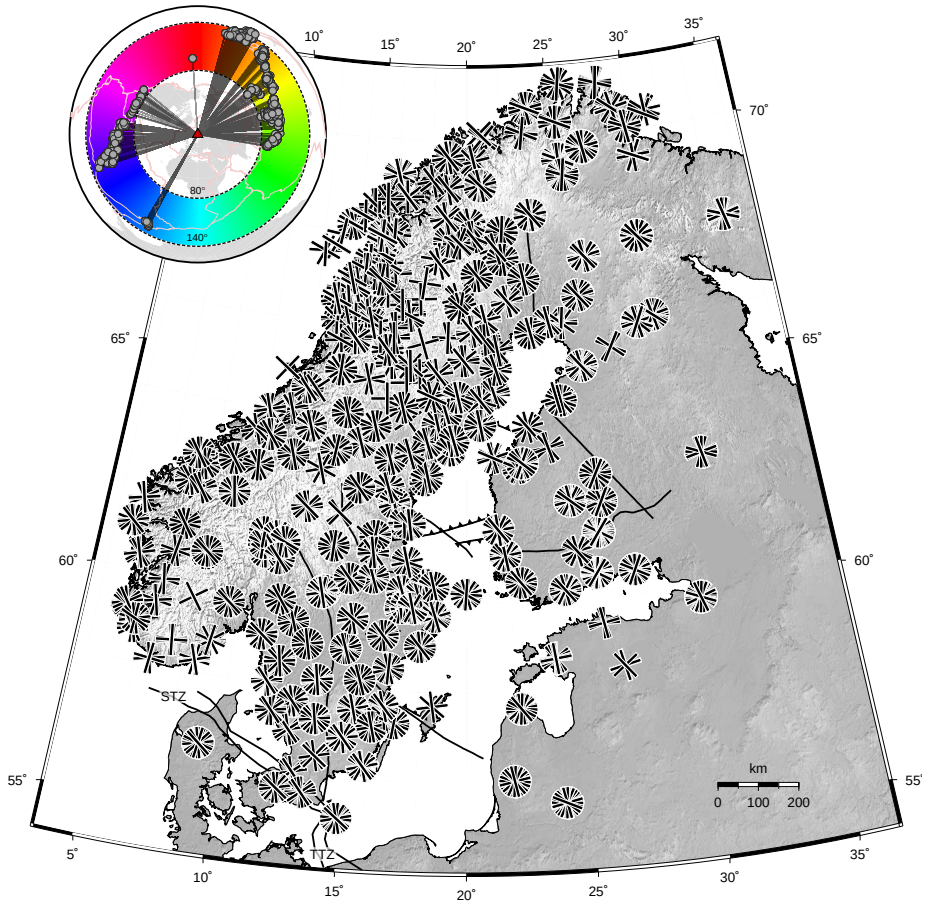

Figure 6: Plot all null measurements presented in Grund (2019). Black bars are plotted parallel and perpendicular to the backazimuth of the corresponding seismic event.

1.8 Plot splits

```
##########
# Fig. 7 # plot split phases in BAZ-dependent color
##########

barew=0.55p
baredcol=black

# cyclic colormap based on GMT's hsv cpt, equivalent to colors shown in the colorwheel
useCPT=cyclicBAZ.cpt

awk '{print $1, $2, $6, $3, $5, $4}' split_gf.tmp | psxy -R -J -SJ -W$barew,$baredcol \
     -C$useCPT -O -K >> $ps

# add station markers on top
stam=c
stamsize=0.08c
stamwie=thinner
stamcolf=black
stamcole=$baredcol

awk '{print $1, $2}' 00_RESULTS_ALL_MERGED.geo | psxy -R -J -S$stam$stamsize -G$stamcolf \
     -W$stamwie,$stamcole  -O -K >> $ps
awk '{print $1, $2}' 00_RESULTS_nulls_ALL_MERGED.geo | psxy -R -J -S$stam$stamsize \
     -G$stamcolf -W$stamwie,$stamcole  -O -K >> $ps

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

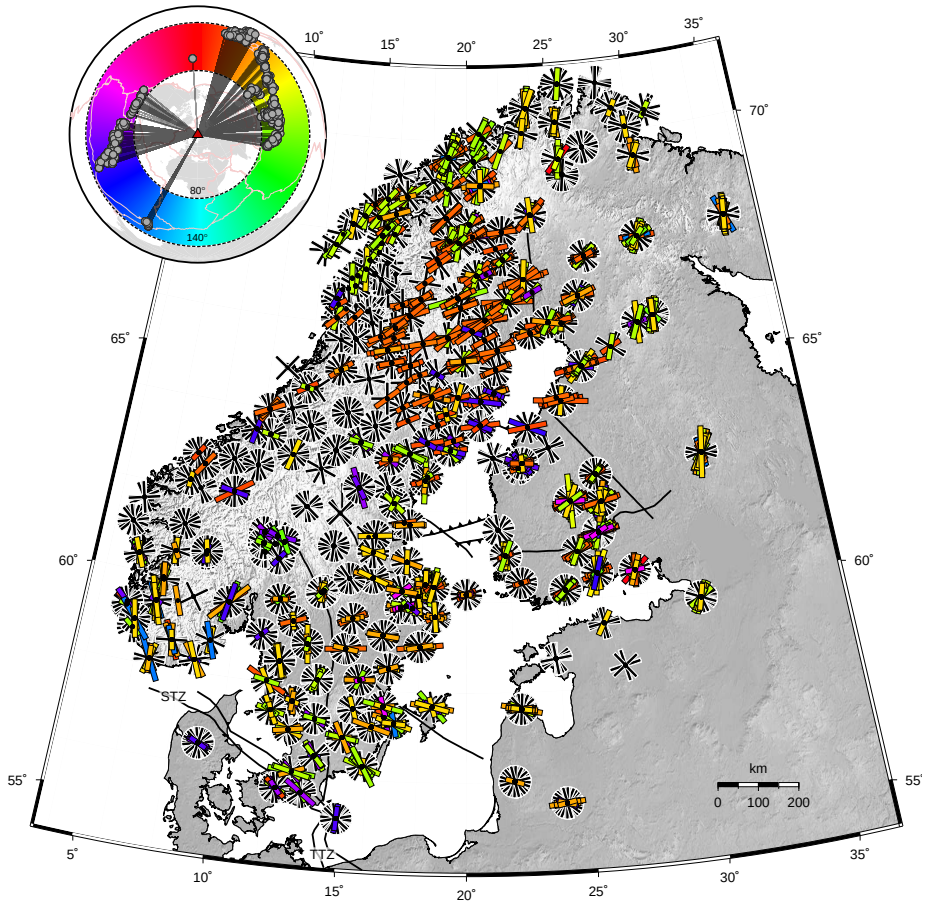

Figure 7: Plot all splitting measurements presented in Grund (2019).

1.9 Plot legend and roseplot

```
##########
# Fig. 8 # add (customized) legend and roseplot
##########

#=========================================================
# LEGEND

dt_1s=1
dt_2s=2

dt_1s_scaled=$(echo "scale=4 ; $dt_1s * $scale_barl" | bc)
dt_2s_scaled=$(echo "scale=4 ; $dt_2s * $scale_barl" | bc)

dotloc=0.12c

pslegend -R -J -Dx12/1/1.6c/2.5c/BL -F+r2p+pblack+gwhite+p0.8p -O -K << EOF >> $ps
G 0.09i
N 3
G -0.25c
H 8 Helvetica  1 s
G -0.03c
S 0.65c j 90,3p,0.5c darkgray 0.55p,$baredcol
S $dotloc c  0.08c black 0.5p,$baredcol -1.3c
H 8 Helvetica 2 s
G -0.03c
S 0.65c j 90,3p,1c darkgray 0.55p,$baredcol
S $dotloc c  0.08c black 0.5p,$baredcol -1.3c
H 8 Helvetica Null
G 0.19c
S 0.65c j 45,2p,0.7c black 0.35p,white
S 0.12c j 135,2p,0.7c black 0.35p,white
S -0.415 c 0.08c black 0.5p,$baredcol -2.6c
G 0.15c
G 0.02i
EOF

#=========================================================
# ROSEPLOT

MAX_radial=1        # plot radius within roseplot
radi_rose=1.1c      # radius roseplot on map

# shift roseplot in x and y directions
x0=2.5
y0=10

infile=split_gf.tmp
color=darkgray # color fill of rose content

# plot individual SWS fast directions on top layer
awk '{print 1.2, $3}' $infile | psrose -F -L -R0/$MAX_radial/0/360 -S$radi_rose \
     -Z$scale_down -A15  -Bx25 -By90g90 -B+gwhite -X$x0 -Y$y0 -T -Gdarkgray \
     -W0.75p,black -O -K >> $ps
#plot again but without cross in center to overlay
awk '{print 1.2, $3}' $infile | psrose -F -L -R0/$MAX_radial/0/360 -S$radi_rose \
     -Z$scale_down -A15 -T -G$color -W0.75p,black -O -K >> $ps


# write splittin results to tmpfile for displaying right number of total measurements
awk '{print $3}' $infile > 00_results_tmp_good_fair

# switch back to original coordinate system
x0=-4
y0=-13.75

#display number of total measurements as value in roseplot (69/9.6 is lat/lon where total
# number is plotted)
```

```
awk 'BEGIN{i=0}{i++;}END{print 69.1, 9.6, i}' 00_results_tmp_good_fair > coord_totval.tmp

pstext coord_totval.tmp -: -R$projR -J$projJ -F+f10p,Helvetica -D0.25/-0.25  -Gwhite@40 \
    -X$x0 -Y$y0 -O -K >> $ps

#=======================================================

##############################################################################################################

########################
#gv $ps &
ps2pdf $ps $ps.pdf
pdfcrop $ps.pdf $ps.pdf
rm $ps
rm *tmp* # delete temporary files
########################
```

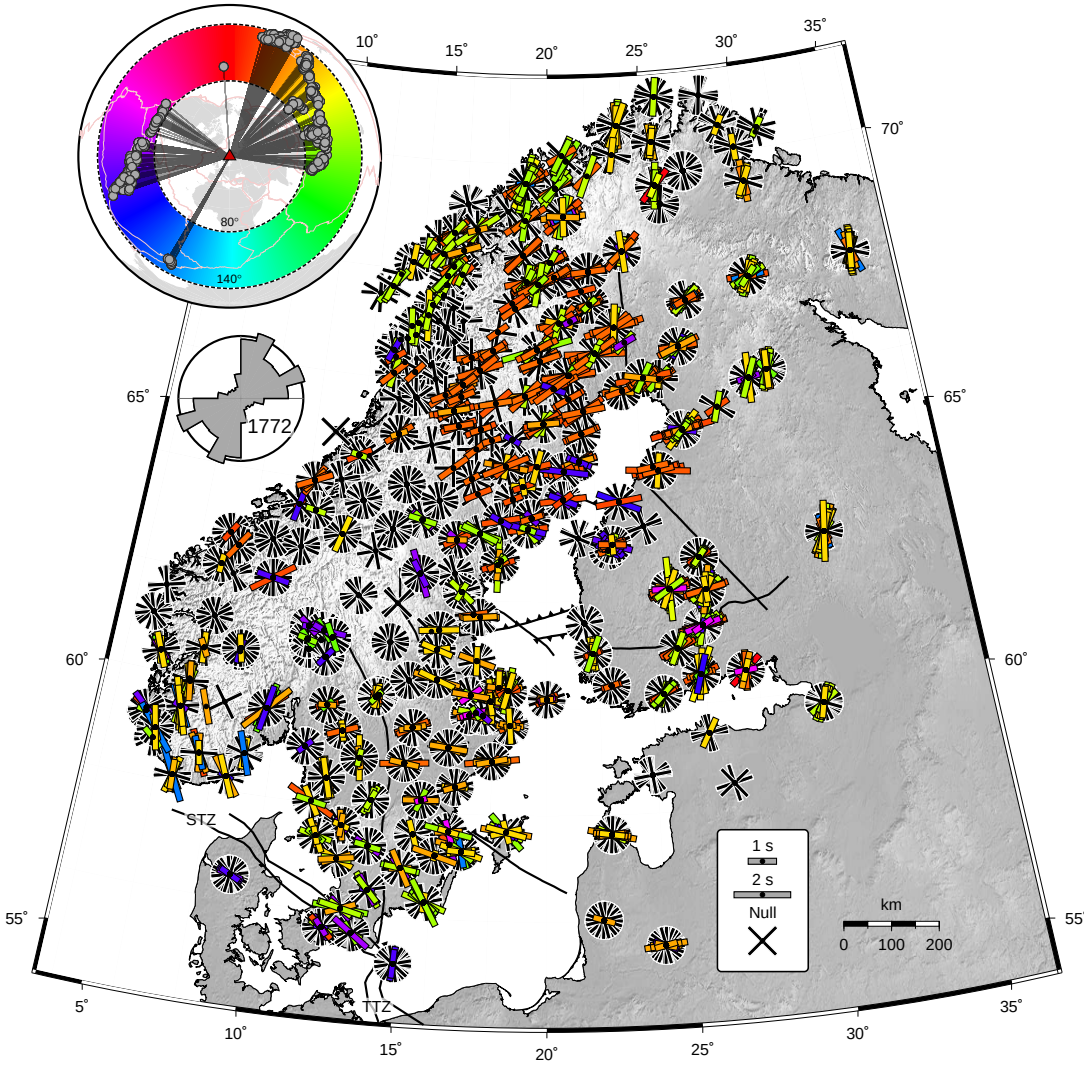

Figure 8: Finally add a legend and a rose plot that shows the overall distribution of the measured fast axis directions of the split phases.

2 Plotting limited backazimuth intervals

If only results corresponding to events of a specific backazimuthal range should be plotted, the parameters `BAZstart`, `BAZend` and `scale_down` (defined in the first code block above) can be adjusted. For instance, see Fig. 9 (left and right) for the following two settings:

- `BAZstart` = 30
- `BAZend` = 90
- `scale_down` = 0.0034

- `BAZstart` = 230
- `BAZend` = 320
- `scale_down` = 0.0364

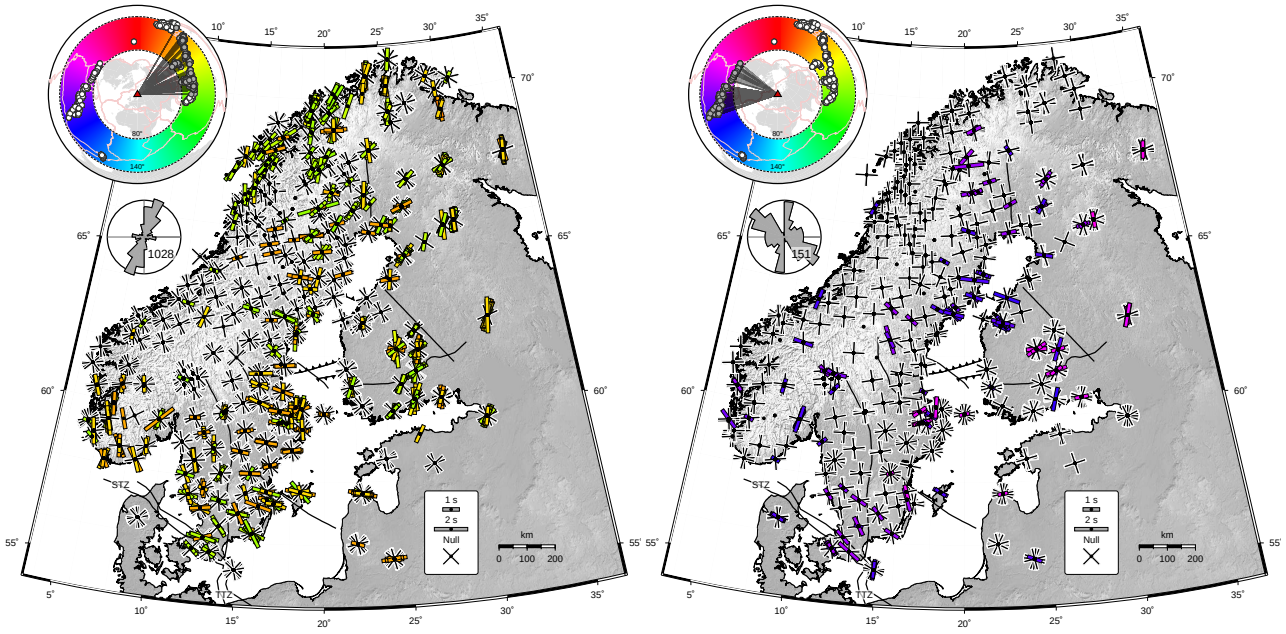

Figure 9: Resulting figures for two other backazimuth settings.

References

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

Grund, M., 2019. *Exploring geodynamics at different depths with shear wave splitting*, Ph.D. thesis, Karlsruhe Institute of Technology (KIT).

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.