Displacement Modeling Recap

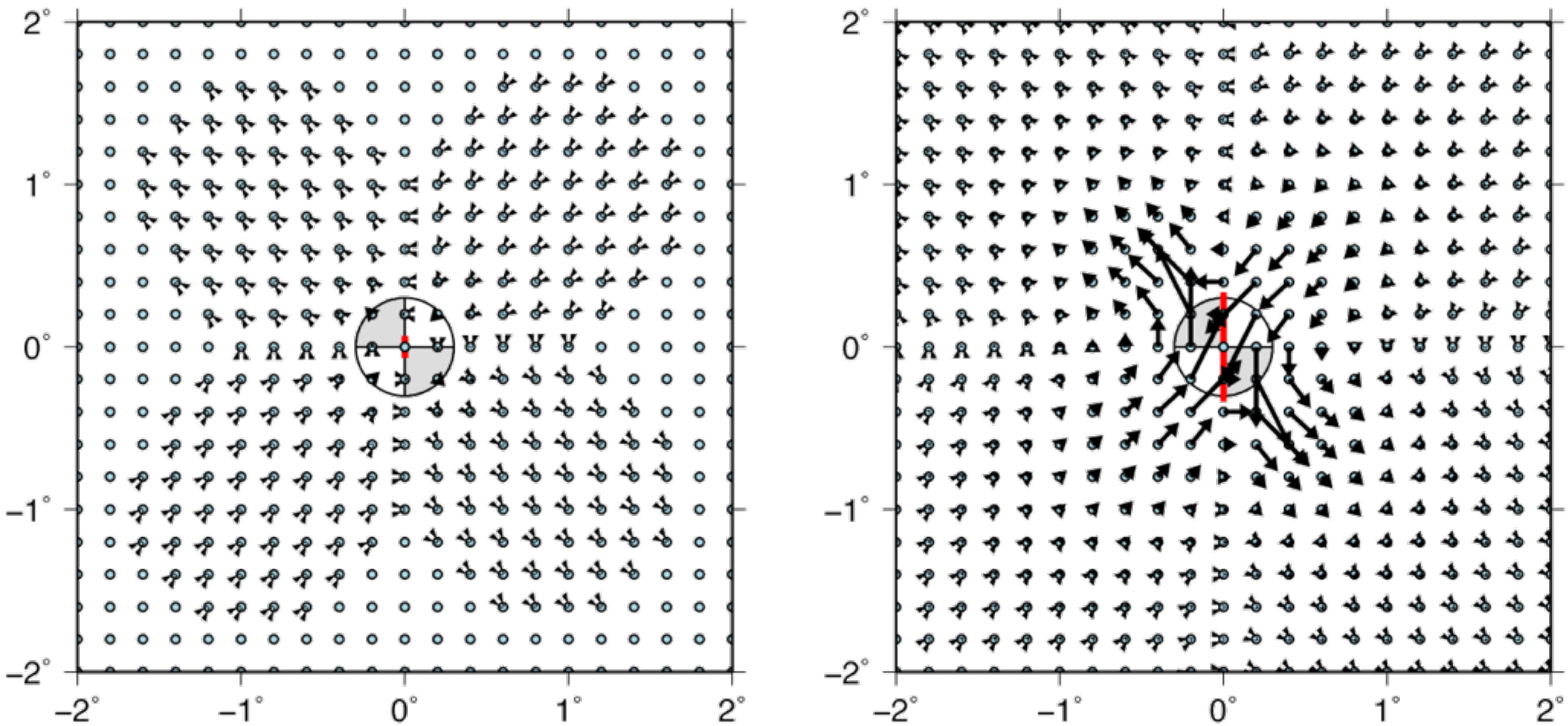
- Earthquake slip on a rectangular fault in an elastic half-space generates systematic surface displacements
- Strike-slip, thrust, normal earthquake deformation patterns
- Displacements of small and large events
- Multiple fault segments

Last updated:
4 February 2020

Activity 3: Common Patterns

- *Exercise 3b: compare the surface displacement fields for hypothetical moderate (Mw 7.0) and large (Mw 7.8) earthquakes, of each common earthquake type (strike-slip, normal, thrust)*
- *Mw 7.8:*
  - *8 m of slip*
  - *25 km wide x 75 km long*

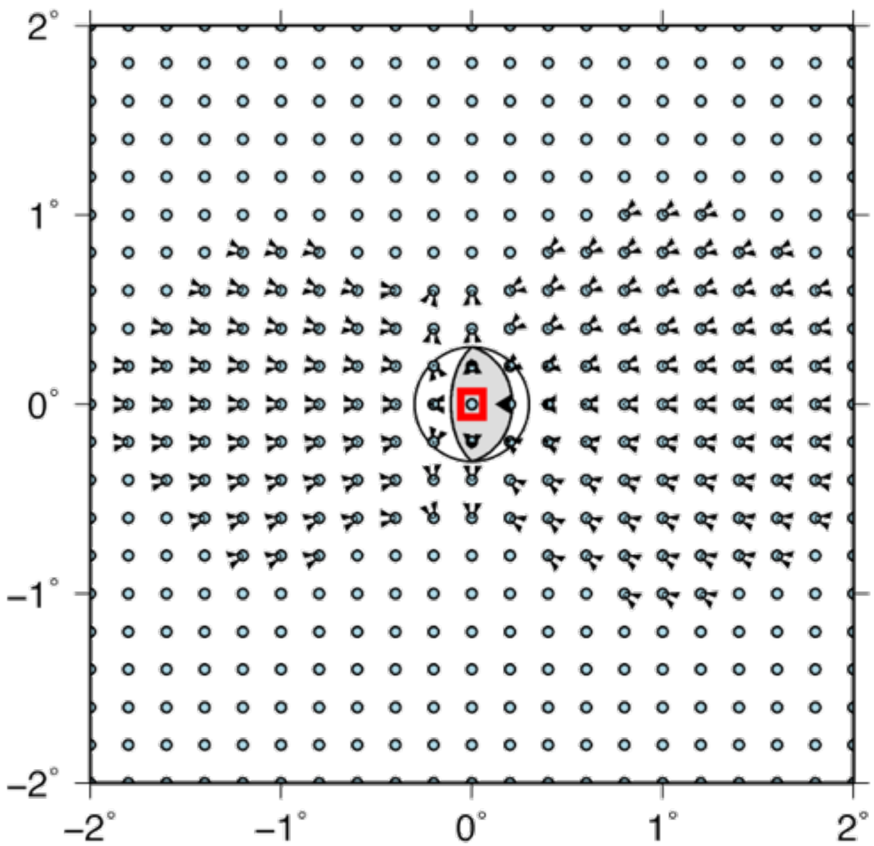
Activity 3: Common Patterns

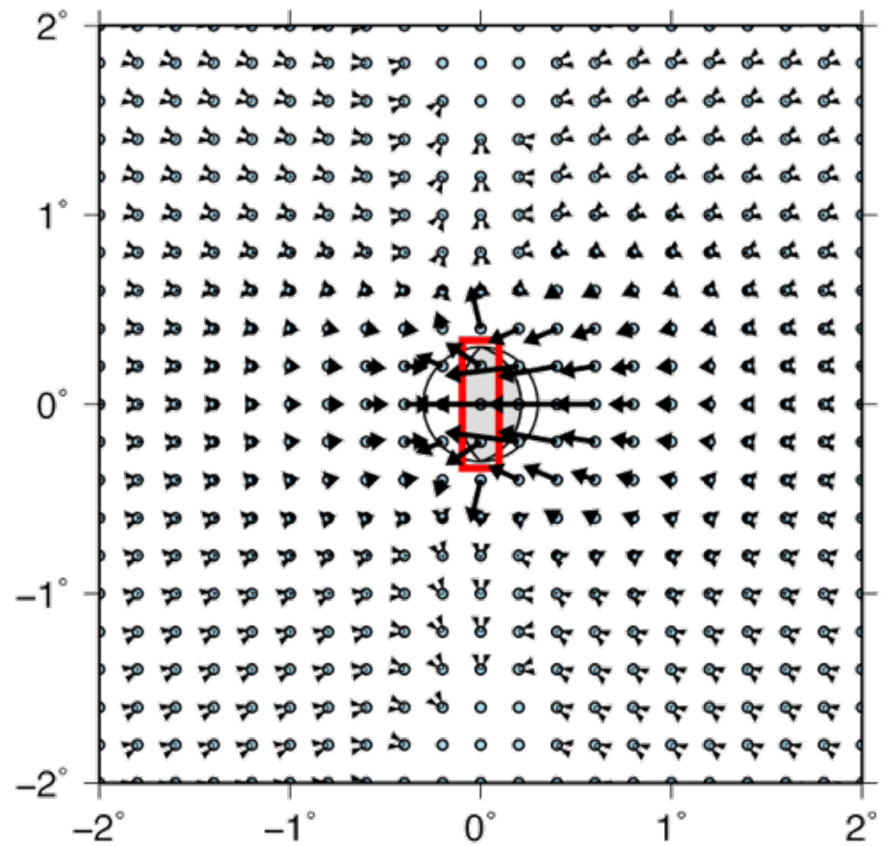


Mw 7.0 Mw 7.8

(Plotted on the same scale)

Activity 3: Common Patterns



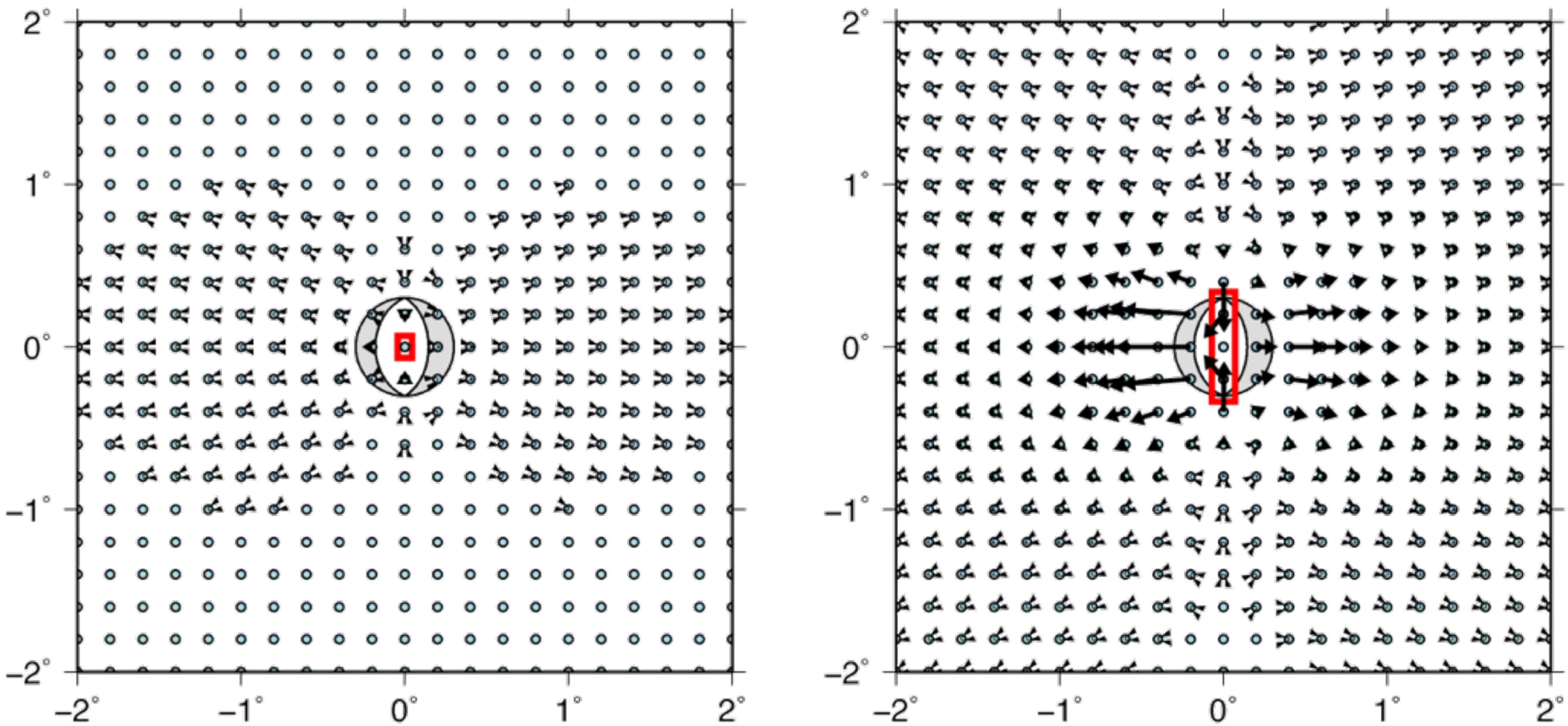


Mw 7.0

Mw 7.8

(Plotted on the same scale)

Activity 3: Common Patterns



Mw 7.0 Mw 7.8

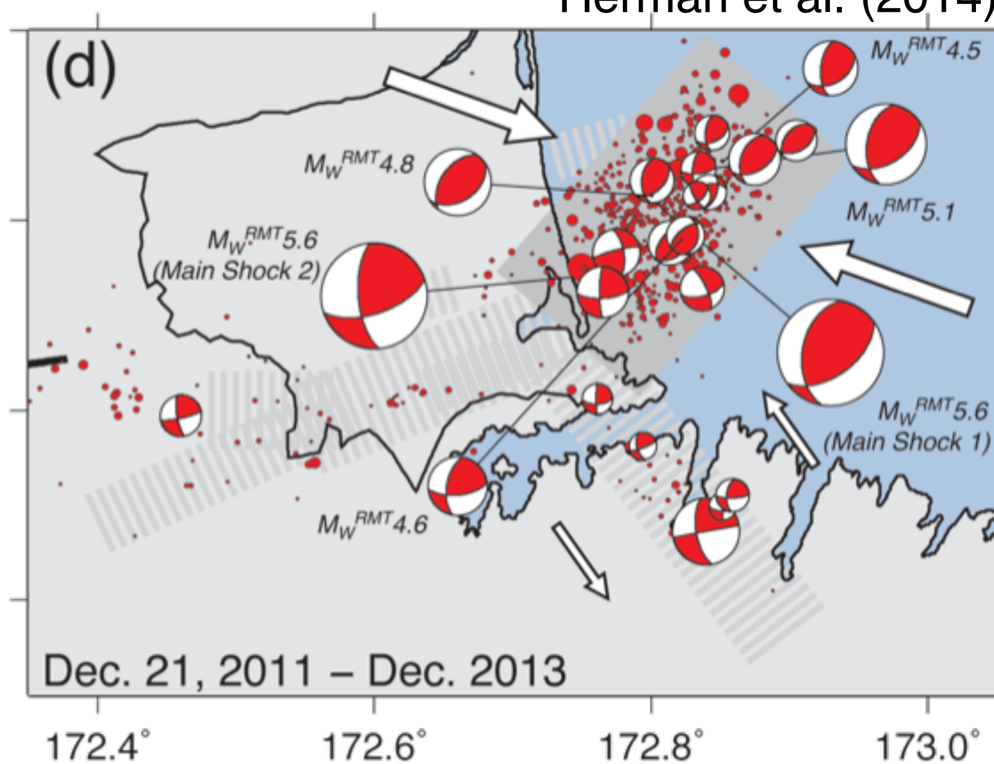
(Plotted on the same scale)

Review Activity: Oblique Slip

- Many earthquakes are not purely strike-slip, reverse, or normal, but a combination of these slip types

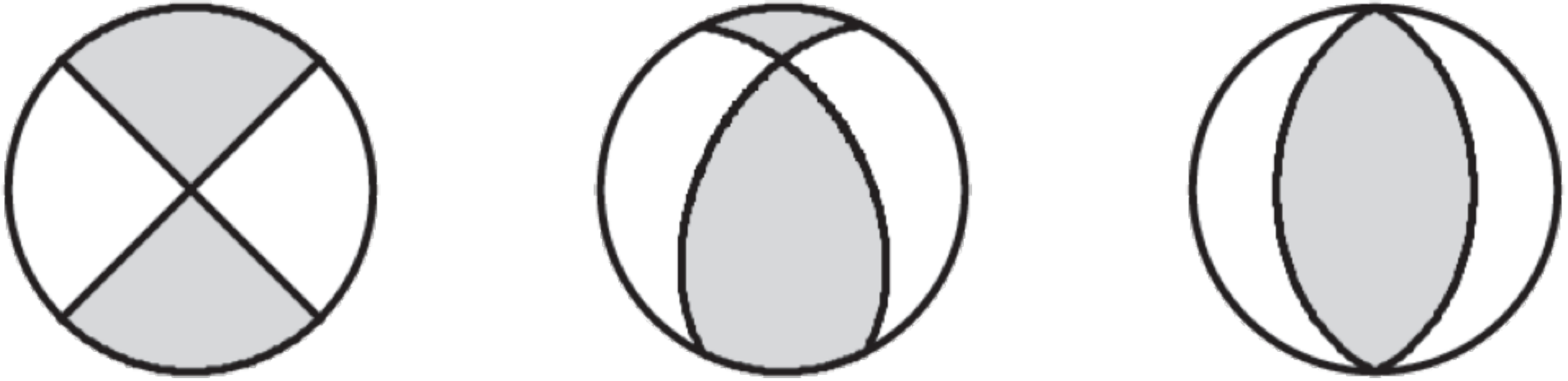
Example: The Dec. 2011 and following sequence of earthquakes immediately offshore of Christchurch, New Zealand, had focal mechanisms from pure strike-slip to oblique to pure reverse.

Herman et al. (2014)



Review Activity: Oblique Slip

- Many earthquakes are not purely strike-slip, reverse, or normal, but a combination of these slip types
- *Exercise: compare the displacements from three earthquakes with the same horizontal, east-west oriented P-axes (strike-slip, oblique, reverse)*



Review Activity: Oblique Slip

Receiver file (station.dat) using GRID

x-limits and spacing, y-limits and spacing,

z-value, output file

```
grid -x -1 1 -dx 0.2 -y -1 1 -dy 0.2
    -z 0.0 -o station.dat
```

Review Activity: Oblique Slip

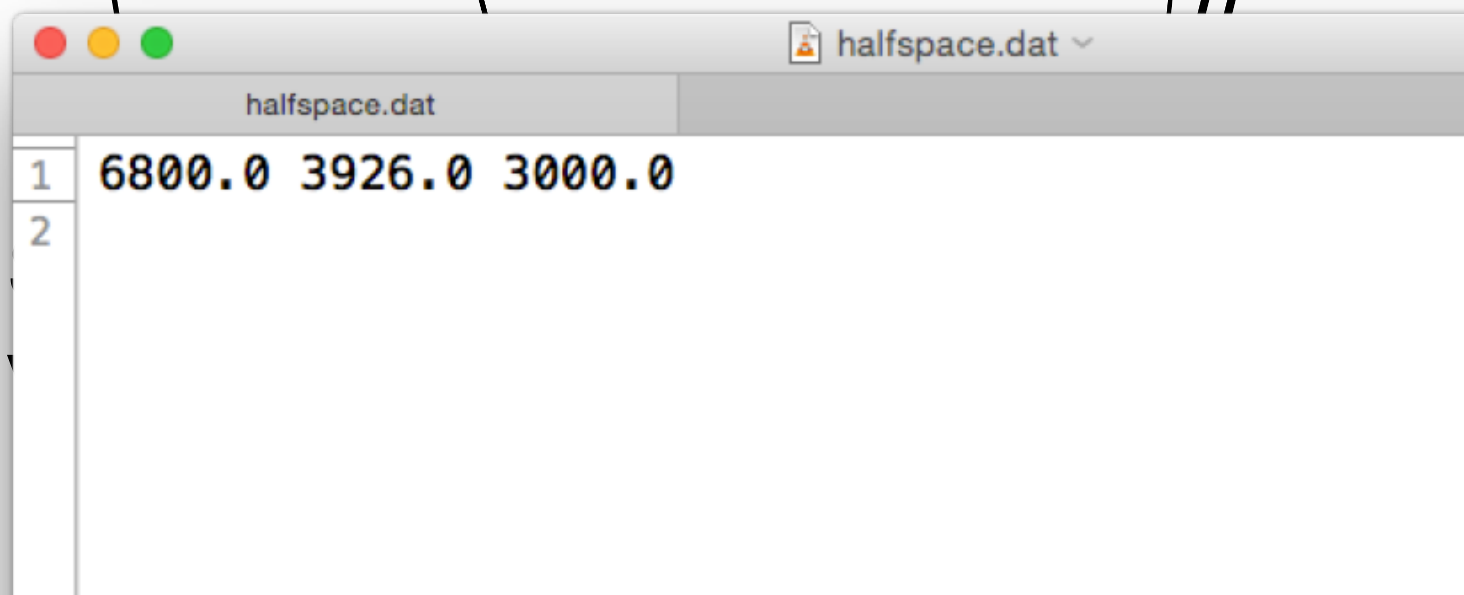
Elastic half-space file (halfspace.dat)

seismic velocities, density

$$v_p = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

6800.0 3926.0 3000.0

P-wave velocity (m/s)



Review Activity: Oblique Slip

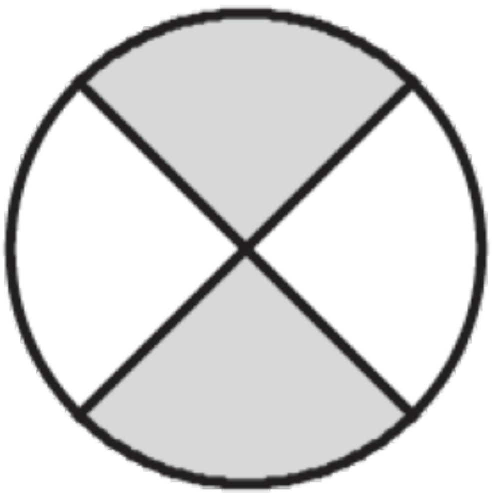
Remember! This input format is deprecated. It still works (for now), but the program will warn you that it is a legacy format and prompt you to use the current format.

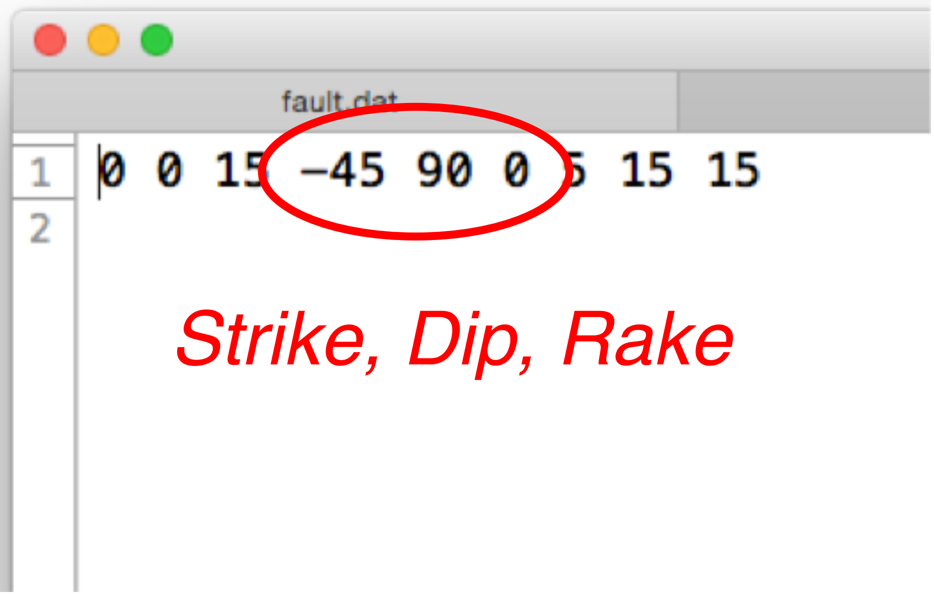
The current format is:
vp 6800 vs 3926 dens 3000

Review Activity: Oblique Slip

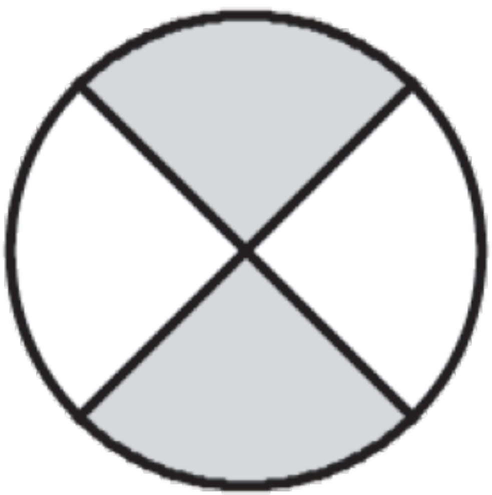
Input fault file (fault.dat) with strike-slip event

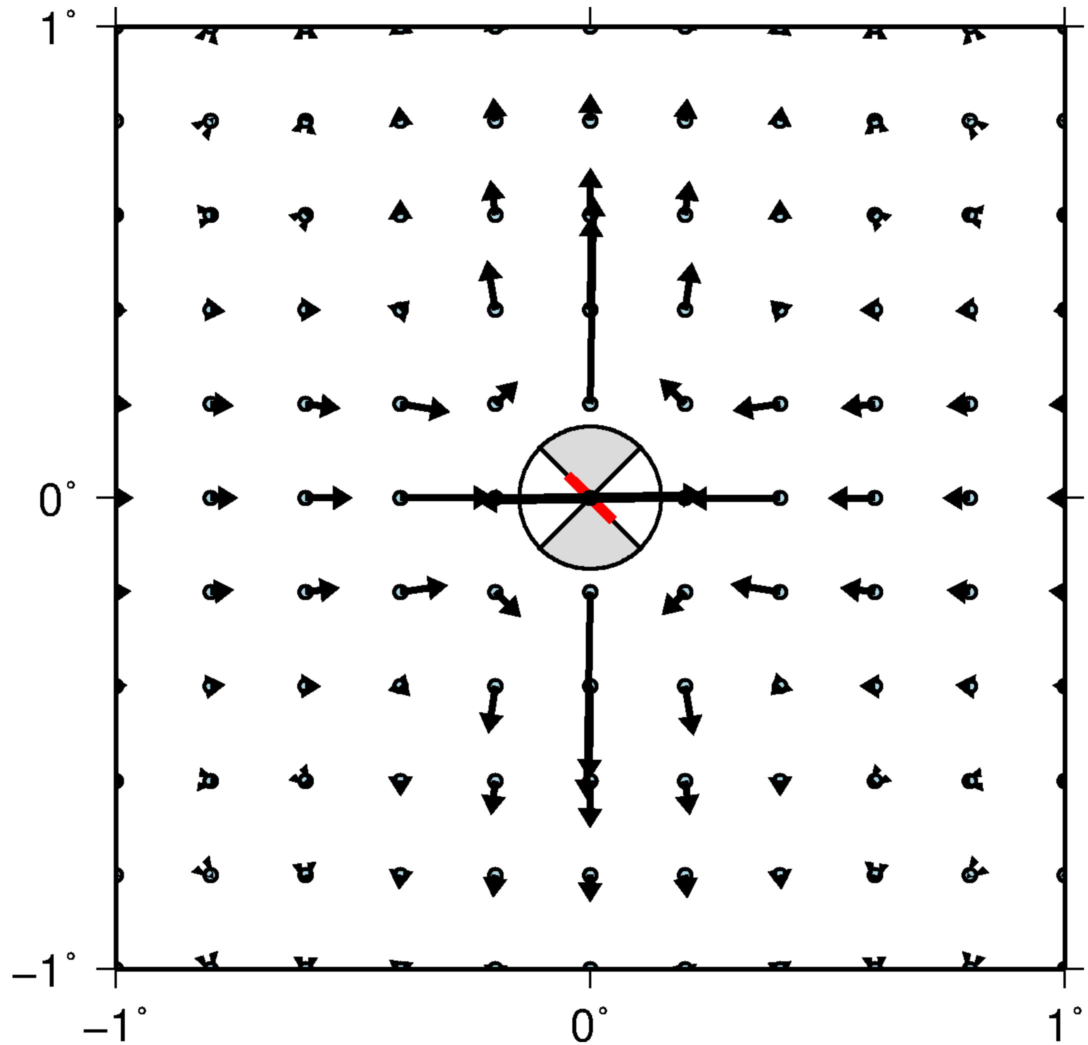
location of center, kinematics, slip, dimensions





Review Activity: Oblique Slip

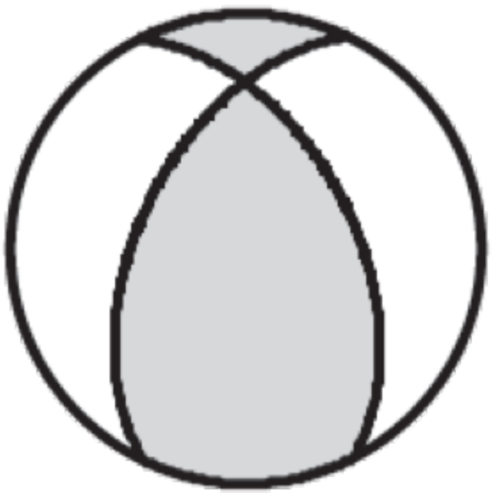


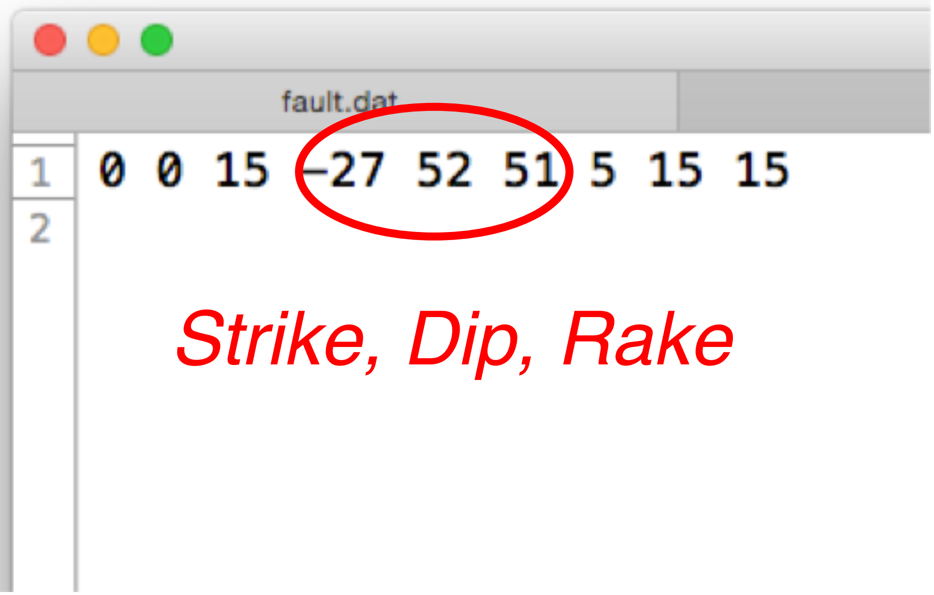


Review Activity: Oblique Slip

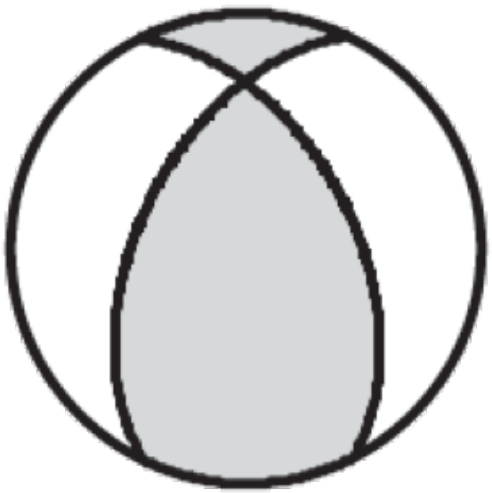
<u>Input fault file (fault.dat) with oblique event</u>

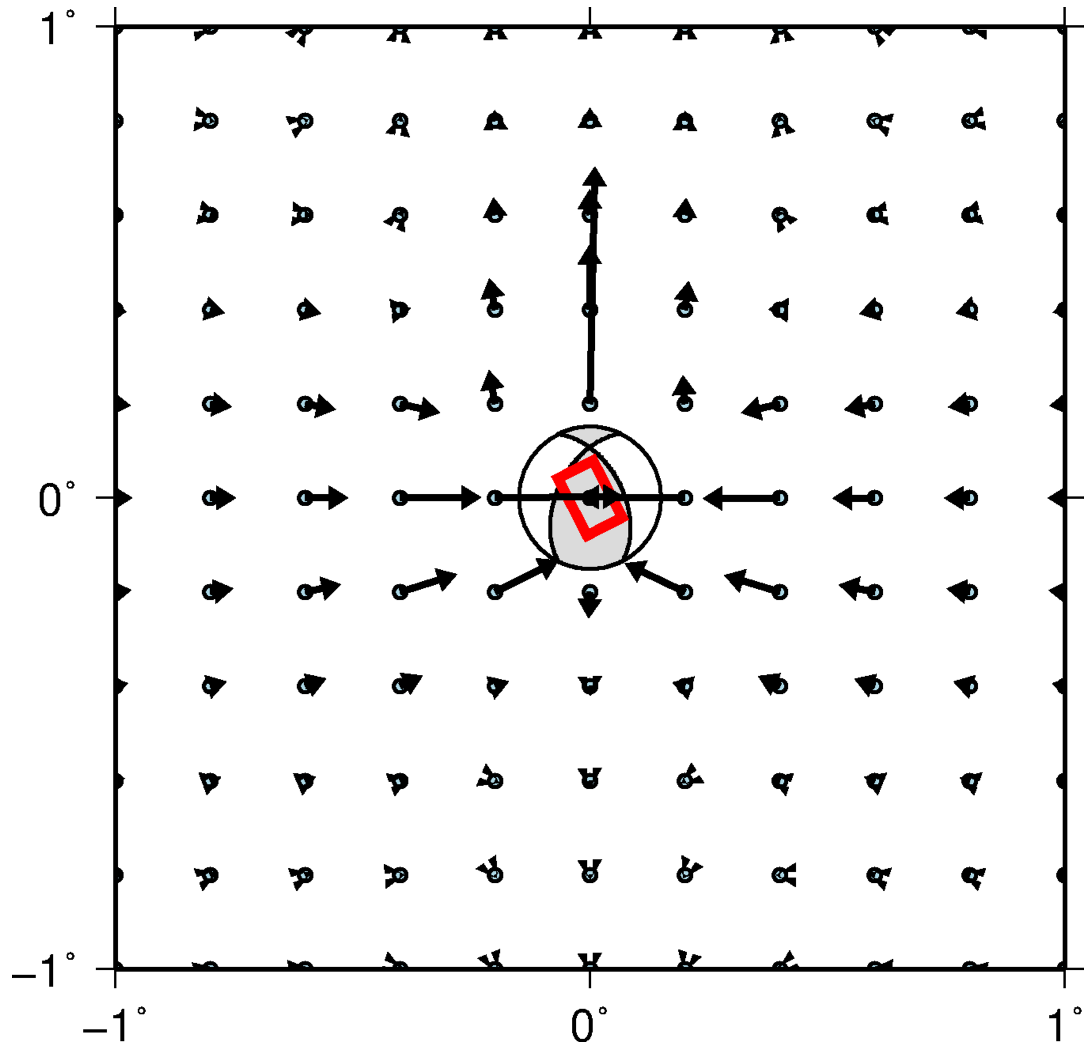
location of center, kinematics, slip, dimensions





Review Activity: Oblique Slip

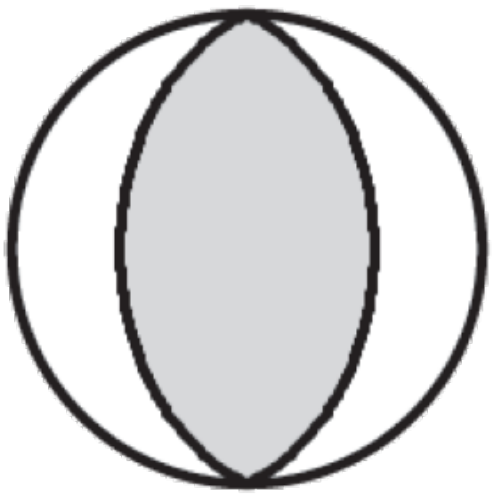


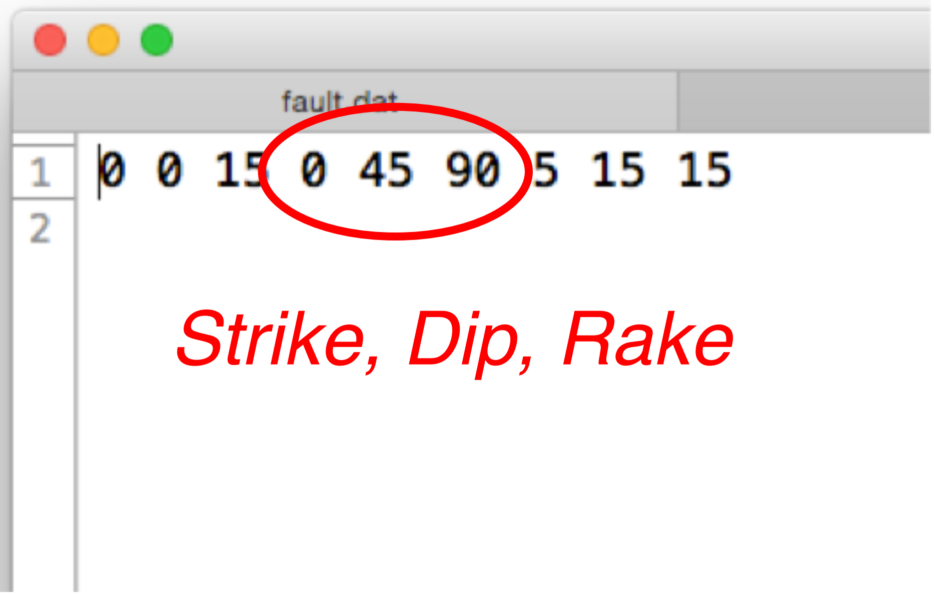


Review Activity: Oblique Slip

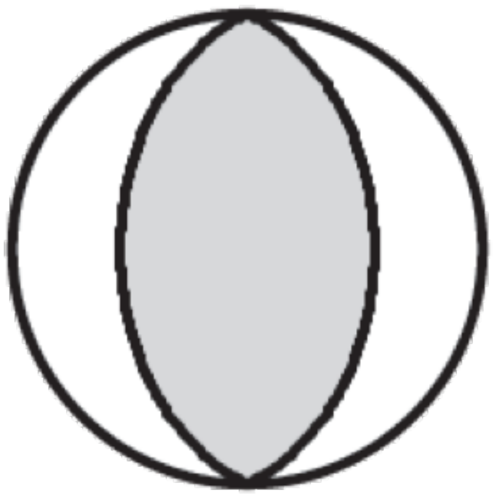
<u>Input fault file (fault.dat) with reverse event</u>

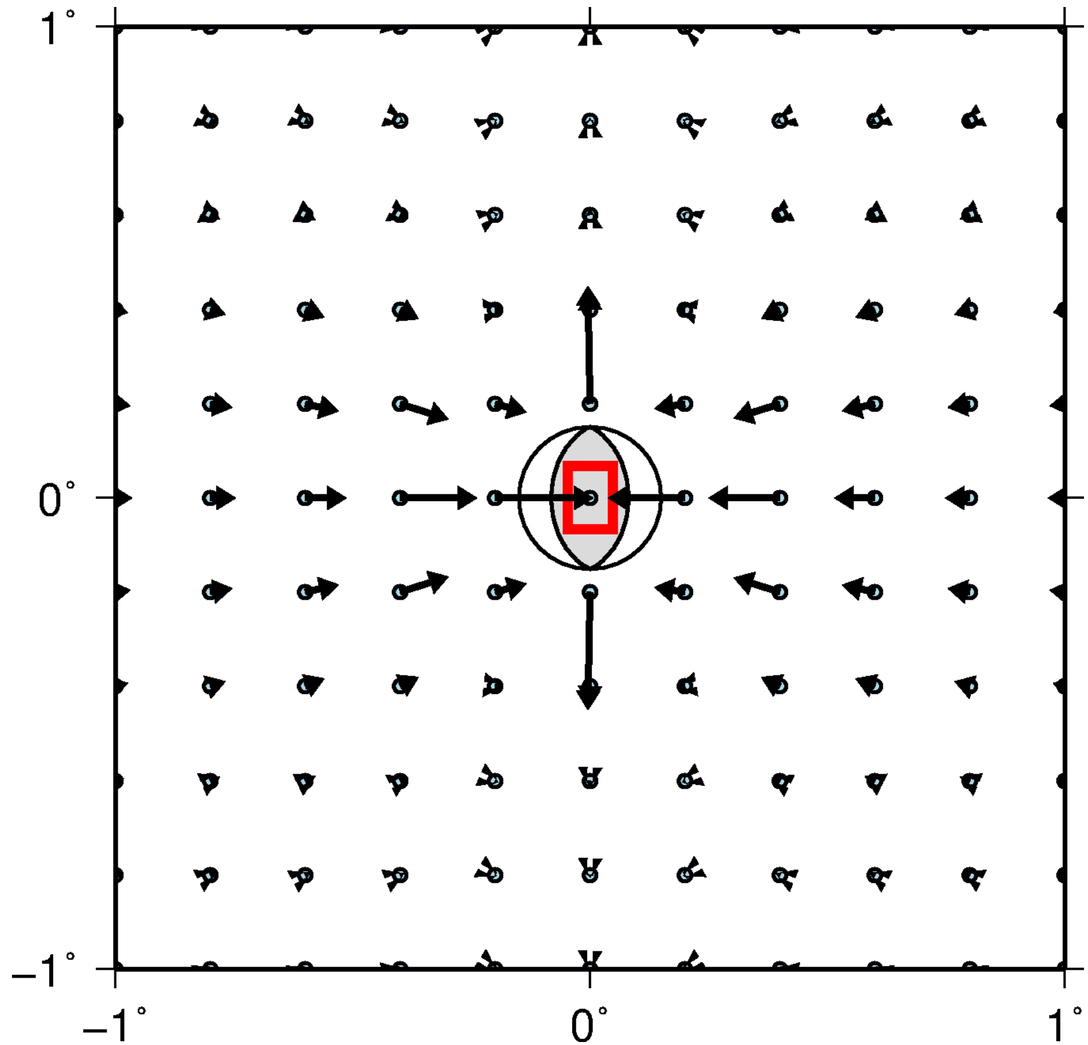
location of center, kinematics, slip, dimensions



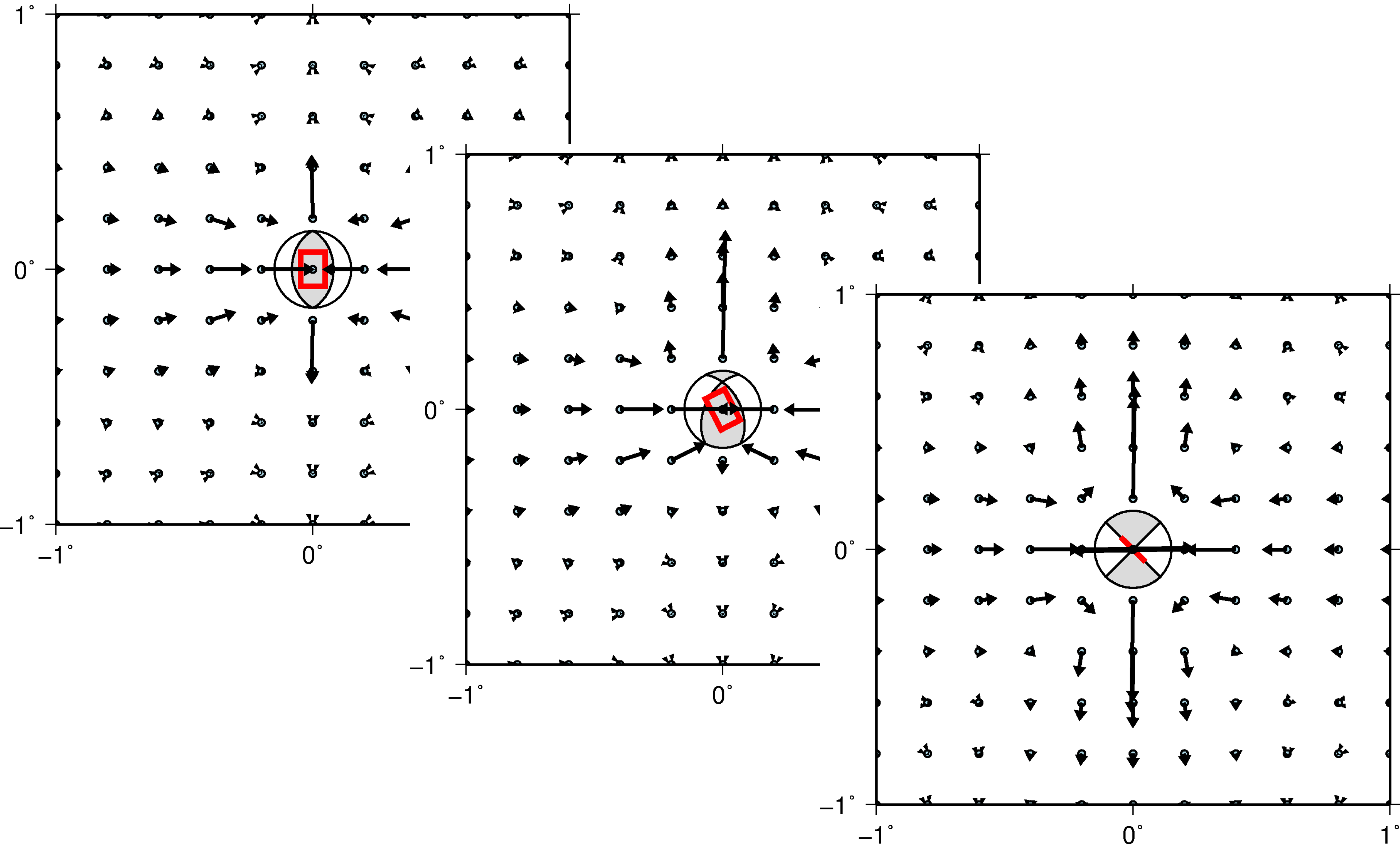


Review Activity: Oblique Slip





Review Activity: Oblique Slip



Introduction to Stress Modeling

Stress Review

Derivatives *Hooke's law*

- Displacement → Strain → Stress
- Stress is a symmetric tensor, (3x3) in 3-D

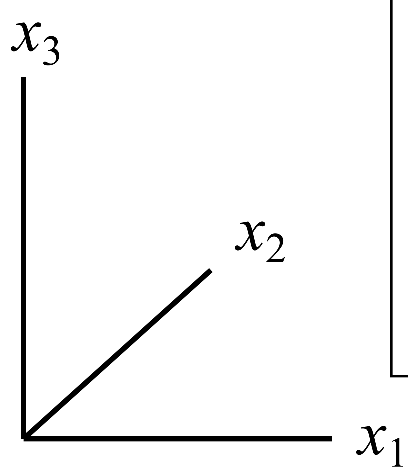
$$\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}$$

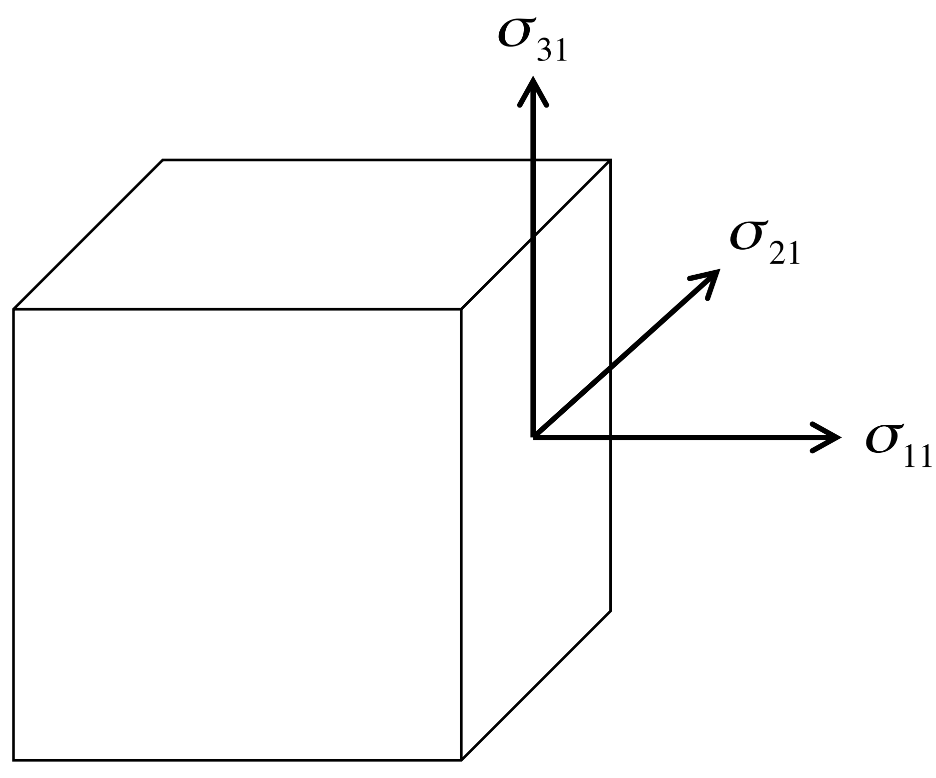
- Units of Pascals (Pa), N/m^2

Stress Review

- Can think of stress tensor as representing tractions on faces of an infinitesimal cube

$$\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}$$





Stress Review

- Eigenanalysis of stress tensor yields:
  - Stress invariants
  - Principal stress values and orientations

$$\sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{bmatrix}$$

$$I_1 = \sigma_{11} + \sigma_{22} + \sigma_{33}$$

$$\boxed{I_2 = \sigma_{11}\sigma_{22} + \sigma_{11}\sigma_{33} + \sigma_{22}\sigma_{33} - \left(\sigma_{12}^2 + \sigma_{13}^2 + \sigma_{23}^2\right)}$$

$$I_3 = \det\left(\sigma\right)$$

$$\sigma' = \begin{bmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{bmatrix}$$

Second invariant of <u>deviatoric</u> stress tensor is also referred to as "effective shear stress." For us, a good measure of the deformation.

Modeling Overview

INPUTS
- Faults
- Receivers
- Elastic properties
- Target faults*

OUTPUTS
- Displacement
- Strain tensor
- Stress tensor
- Normal stress*
- Shear stress*
- Coulomb stress*

**

**To resolve stresses on planes in the subsurface, must define target fault orientations*

Modeling Overview

INPUTS

Faults

Receivers

Elastic properties

Target faults*

OUTPUTS

Displacement

Strain tensor

Stress tensor

stress*

stress*

Coulomb stress*

This morning, focus on stress

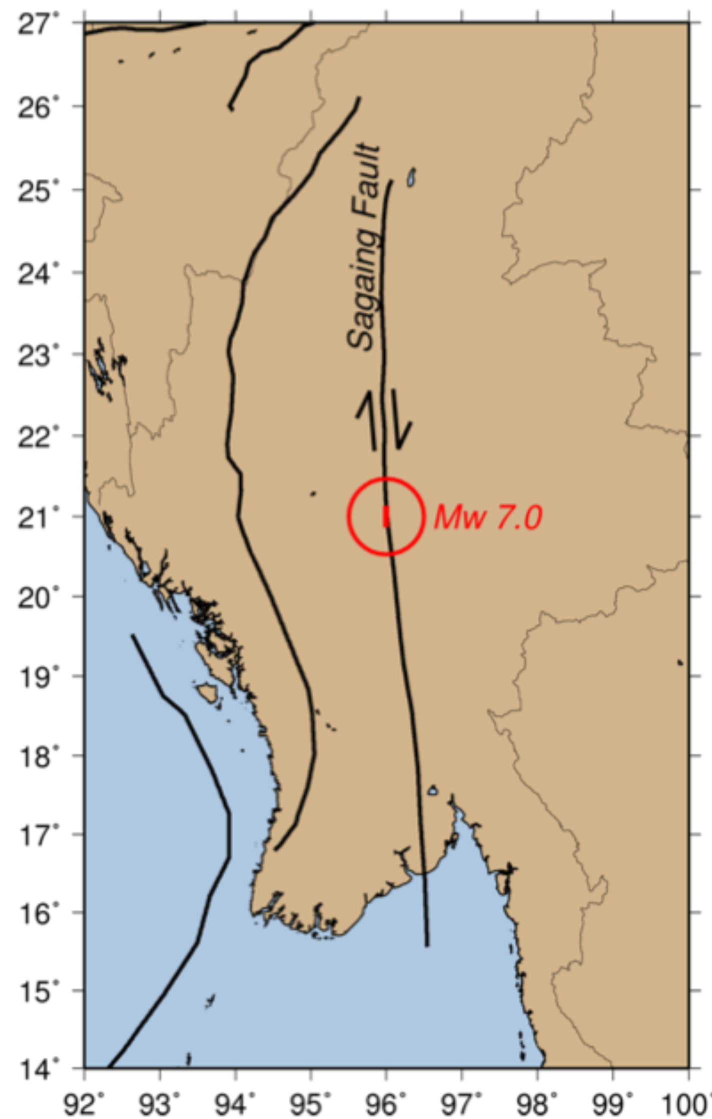
**To resolve stresses on planes in the subsurface, must define target fault orientations*

Modeling Overview

- Using the same cases as yesterday, we will assess the stress responses to simple earthquake sources

Activity 1: Strike-Slip EQ

- Stress change around a <u>hypothetical</u> Mw 7.0 right lateral strike-slip earthquake (e.g. an event on the Sagaing Fault)



Activity 1: Strike-Slip EQ

Input fault file (fault.dat)

location of center, kinematics, slip, dimensions

fault.dat

```
96 21 15 0 90 180 2 15 30
```

Activity 1: Strike-Slip EQ

<u>Receiver file (station.dat) using GRID</u>

x-limits and spacing, y-limits and spacing, z-value

```
grid -x 94 98 -dx 0.2 -y 19 23 -dy 0.2
    -z 15.0 -o station.dat
```

We are especially interested in resolving stresses at the depth of seismogenic faults. In this activity, we will compute stresses at the same depth as the source fault.

Activity 1: Strike-Slip EQ

<u>Receiver file (station.dat) using GRID</u>

x-limits and spacing, y-limits and spacing, z-value, output file

mherman — bash — 96×40

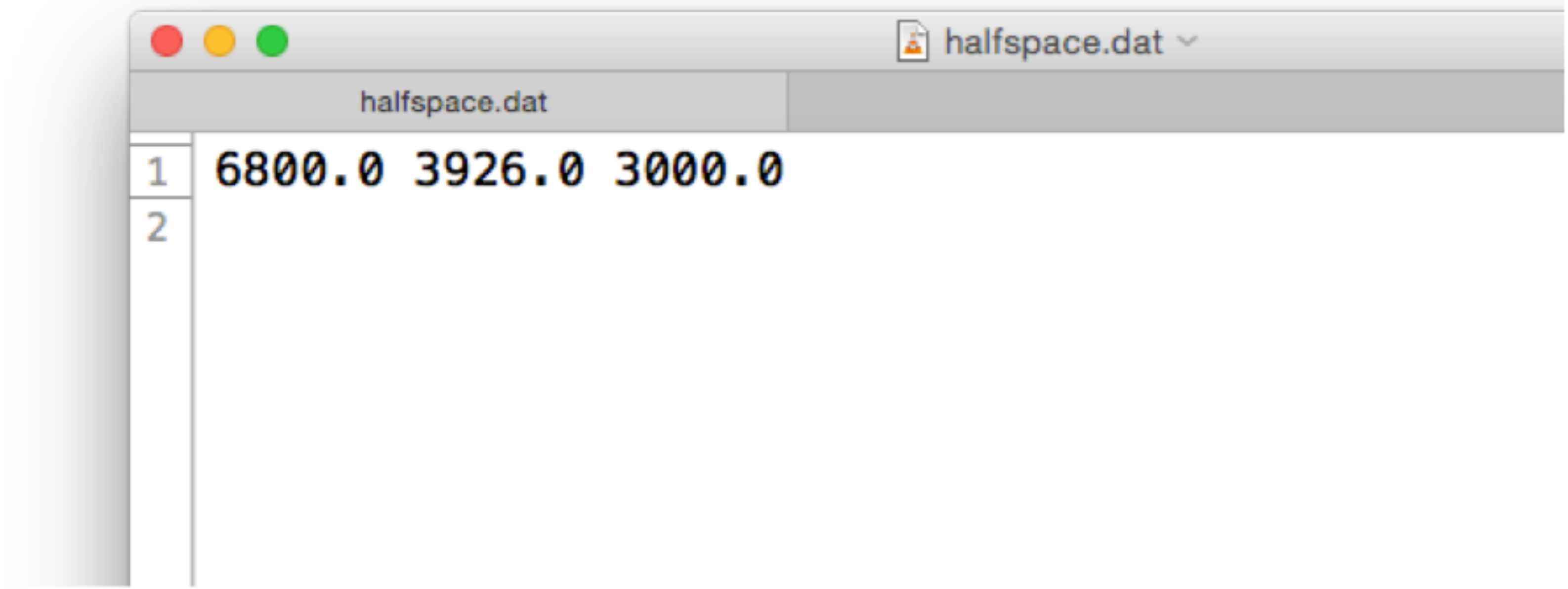
bash

```
mherman: ~ $ grid -x 94 98 -dx 0.2 -y 19 23 -dy 0.2 -z 15 -o station.dat
```

Activity 1: Strike-Slip EQ

Elastic half-space file (halfspace.dat)

seismic velocities, density



Activity 1: Strike-Slip EQ

Compute stresses

input fault

```
o92util -flt fault.dat
```

Activity 1: Strike-Slip EQ

Compute stresses

input fault, input receivers

```
o92util -flt fault.dat -sta station.dat
```

Activity 1: Strike-Slip EQ

<u>Compute stresses</u>

input fault, input receivers,

half-space

```
o92util -flt fault.dat -sta station.dat
    -haf halfspace.dat
```

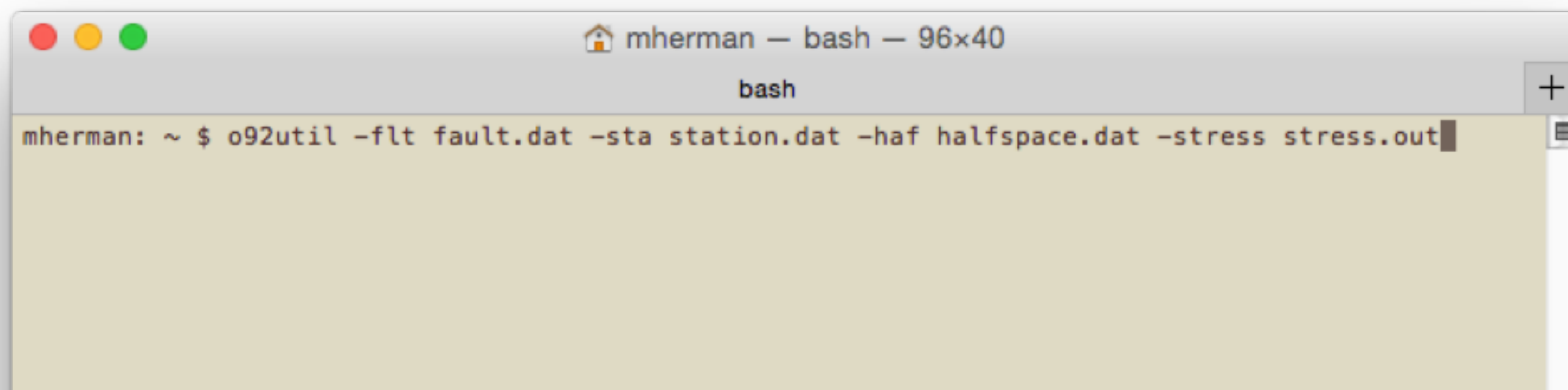
Activity 1: Strike-Slip EQ

<u>Compute stresses</u>

input fault, input receivers,

half-space, output stress tensor components

```
o92util -flt fault.dat -sta station.dat
    -haf halfspace.dat -stress stress.out
```



Activity 1: Strike-Slip EQ

Output stresses (stress.out)

stress.out

94.0000	19.0000	15.0000	0.795191E+03	0.888387E+03	0.774473E+01	0.726675E+03	0.885421E+02	0.948881E+02
94.0000	19.2000	15.0000	0.105551E+04	0.911230E+03	0.100056E+02	0.849311E+03	0.117679E+03	0.107706E+03
94.0000	19.4000	15.0000	0.138457E+04	0.880411E+03	0.127273E+02	0.955354E+03	0.153557E+03	0.117511E+03
94.0000	19.6000	15.0000	0.176138E+04	0.791346E+03	0.157990E+02	0.101250E+04	0.195016E+03	0.120679E+03
94.0000	19.8000	15.0000	0.218516E+04	0.602178E+03	0.189103E+02	0.990061E+03	0.238180E+03	0.112522E+03
94.0000	20.0000	15.0000	0.253712E+04	0.370364E+03	0.214694E+02	0.812223E+03	0.275200E+03	0.883546E+02
94.0000	20.2000	15.0000	0.274735E+04	0.912239E+02	0.225927E+02	0.479347E+03	0.293902E+03	0.458302E+02
94.0000	20.4000	15.0000	0.263013E+04	-0.120032E+03	0.212660E+02	-0.879255E+01	0.279906E+03	-0.117864E+02
94.0000	20.6000	15.0000	0.209949E+04	-0.214337E+03	0.167448E+02	-0.542101E+03	0.222247E+03	-0.732777E+02
94.0000	20.8000	15.0000	0.114633E+04	-0.154406E+03	0.907790E+01	-0.963972E+03	0.121048E+03	-0.121078E+03
94.0000	21.0000	15.0000	-0.815923E+02	0.182660E+02	-0.585930E+00	-0.111658E+04	-0.781817E+01	-0.138306E+03
94.0000	21.2000	15.0000	-0.128740E+04	0.168231E+03	-0.102668E+02	-0.933597E+03	-0.136521E+03	-0.117925E+03
94.0000	21.4000	15.0000	-0.222304E+04	0.210124E+03	-0.179624E+02	-0.484703E+03	-0.237066E+03	-0.671283E+02
94.0000	21.6000	15.0000	-0.272995E+04	0.944814E+02	-0.224766E+02	0.674121E+02	-0.293300E+03	-0.311813E+01
94.0000	21.8000	15.0000	-0.280688E+04	-0.149646E+03	-0.237279E+02	0.560571E+03	-0.305053E+03	0.561431E+02

Station Longitude

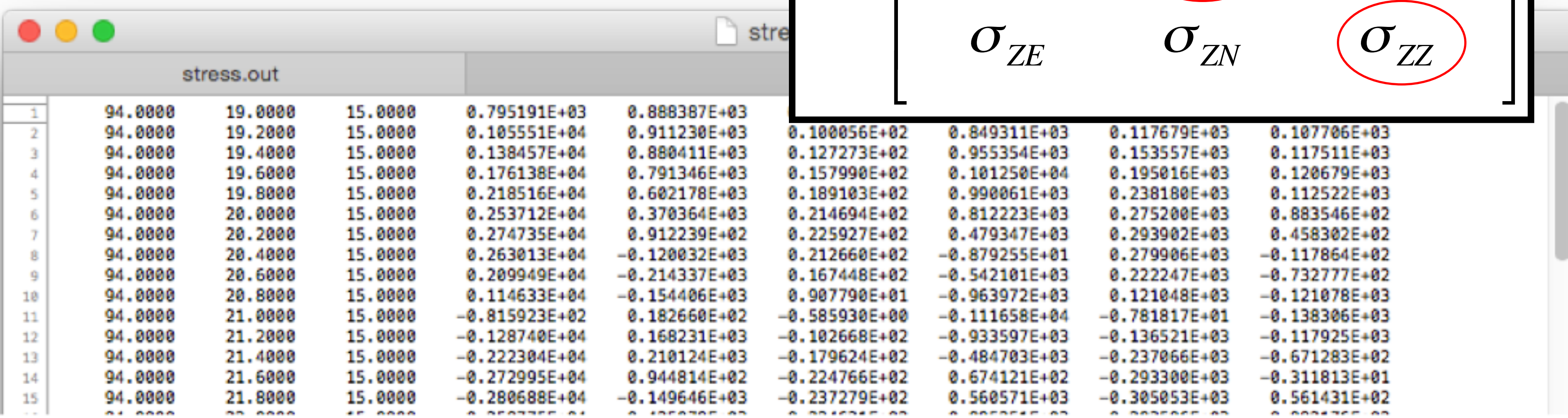
Station Latitude

Station Depth (km)

Activity 1: Strike-Slip EQ

Output stresses (stress

$$\sigma = \begin{bmatrix} \sigma_{EE} & \sigma_{EN} & \sigma_{EZ} \\ \sigma_{NE} & \sigma_{NN} & \sigma_{NZ} \\ \sigma_{ZE} & \sigma_{ZN} & \sigma_{ZZ} \end{bmatrix}$$



94.0000	19.0000	15.0000	0.795191E+03	0.888387E+03					
94.0000	19.2000	15.0000	0.105551E+04	0.911230E+03	0.100056E+02	0.849311E+03	0.117679E+03	0.107706E+03
94.0000	19.4000	15.0000	0.138457E+04	0.880411E+03	0.127273E+02	0.955354E+03	0.153557E+03	0.117511E+03
94.0000	19.6000	15.0000	0.176138E+04	0.791346E+03	0.157990E+02	0.101250E+04	0.195016E+03	0.120679E+03
94.0000	19.8000	15.0000	0.218516E+04	0.602178E+03	0.189103E+02	0.990061E+03	0.238180E+03	0.112522E+03
94.0000	20.0000	15.0000	0.253712E+04	0.370364E+03	0.214694E+02	0.812223E+03	0.275200E+03	0.883546E+02
94.0000	20.2000	15.0000	0.274735E+04	0.912239E+02	0.225927E+02	0.479347E+03	0.293902E+03	0.458302E+02
94.0000	20.4000	15.0000	0.263013E+04	-0.120032E+03	0.212660E+02	-0.879255E+01	0.279906E+03	-0.117864E+02
94.0000	20.6000	15.0000	0.209949E+04	-0.214337E+03	0.167448E+02	-0.542101E+03	0.222247E+03	-0.732777E+02
94.0000	20.8000	15.0000	0.114633E+04	-0.154406E+03	0.907790E+01	-0.963972E+03	0.121048E+03	-0.121078E+03
94.0000	21.0000	15.0000	-0.815923E+02	0.182660E+02	-0.585930E+00	-0.111658E+04	-0.781817E+01	-0.138306E+03
94.0000	21.2000	15.0000	-0.128740E+04	0.168231E+03	-0.102668E+02	-0.933597E+03	-0.136521E+03	-0.117925E+03
94.0000	21.4000	15.0000	-0.222304E+04	0.210124E+03	-0.179624E+02	-0.484703E+03	-0.237066E+03	-0.671283E+02
94.0000	21.6000	15.0000	-0.272995E+04	0.944814E+02	-0.224766E+02	0.674121E+02	-0.293300E+03	-0.311813E+01
94.0000	21.8000	15.0000	-0.280688E+04	-0.149646E+03	-0.237279E+02	0.560571E+03	-0.305053E+03	0.561431E+02

σ_{EE} (Pa) σ_{NN} (Pa) σ_{ZZ} (Pa)

Activity 1: Strike-Slip EQ

Output stresses (stress

$$\sigma = \begin{bmatrix} \sigma_{EE} & \sigma_{EN} & \sigma_{EZ} \\ \sigma_{NE} & \sigma_{NN} & \sigma_{NZ} \\ \sigma_{ZE} & \sigma_{ZN} & \sigma_{ZZ} \end{bmatrix}$$

stress.out

94.0000	19.0000	15.0000	0.795191E+03	0.888387E+03				
94.0000	19.2000	15.0000	0.105551E+04	0.911230E+03	0.100056E+02	0.849311E+03	0.117679E+03	0.107706E+03
94.0000	19.4000	15.0000	0.138457E+04	0.880411E+03	0.127273E+02	0.955354E+03	0.153557E+03	0.117511E+03
94.0000	19.6000	15.0000	0.176138E+04	0.791346E+03	0.157990E+02	0.101250E+04	0.195016E+03	0.120679E+03
94.0000	19.8000	15.0000	0.218516E+04	0.602178E+03	0.189103E+02	0.990061E+03	0.238180E+03	0.112522E+03
94.0000	20.0000	15.0000	0.253712E+04	0.370364E+03	0.214694E+02	0.812223E+03	0.275200E+03	0.883546E+02
94.0000	20.2000	15.0000	0.274735E+04	0.912239E+02	0.225927E+02	0.479347E+03	0.293902E+03	0.458302E+02
94.0000	20.4000	15.0000	0.263013E+04	-0.120032E+03	0.212660E+02	-0.879255E+01	0.279906E+03	-0.117864E+02
94.0000	20.6000	15.0000	0.209949E+04	-0.214337E+03	0.167448E+02	-0.542101E+03	0.222247E+03	-0.732777E+02
94.0000	20.8000	15.0000	0.114633E+04	-0.154406E+03	0.907790E+01	-0.963972E+03	0.121048E+03	-0.121078E+03
94.0000	21.0000	15.0000	-0.815923E+02	0.182660E+02	-0.585930E+00	-0.111658E+04	-0.781817E+01	-0.138306E+03
94.0000	21.2000	15.0000	-0.128740E+04	0.168231E+03	-0.102668E+02	-0.933597E+03	-0.136521E+03	-0.117925E+03
94.0000	21.4000	15.0000	-0.222304E+04	0.210124E+03	-0.179624E+02	-0.484703E+03	-0.237066E+03	-0.671283E+02
94.0000	21.6000	15.0000	-0.272995E+04	0.944814E+02	-0.224766E+02	0.674121E+02	-0.293300E+03	-0.311813E+01
94.0000	21.8000	15.0000	-0.280688E+04	-0.149646E+03	-0.237279E+02	0.560571E+03	-0.305053E+03	0.561431E+02

σ_{EN} (Pa)

σ_{EZ} (Pa)

σ_{NZ} (Pa)

Activity 1: Strike-Slip EQ

<u>Output stresses (stress.out)</u>

stress.out

stress.out

94.0000	19.0000	15.0000	0.795191E+03	0.888387E+03	0.774473E+01	0.726675E+03	0.885421E+02	0.948881E+02
94.0000	19.2000	15.0000	0.105551E+04	0.911230E+03	0.100056E+02	0.849311E+03	0.117679E+03	0.107706E+03
94.0000	19.4000	15.0000	0.138457E+04	0.880411E+03	0.127273E+02	0.955354E+03	0.153557E+03	0.117511E+03
94.0000	19.6000	15.0000	0.176138E+04	0.791346E+03	0.157990E+02	0.101250E+04	0.195016E+03	0.120679E+03
94.0000	19.8000	15.0000	0.218516E+04	0.602178E+03	0.189103E+02	0.990061E+03	0.238180E+03	0.112522E+03
94.0000	20.0000	15.0000	0.253712E+04	0.370364E+03	0.214694E+02	0.812223E+03	0.275200E+03	0.883546E+02
94.0000	20.2000	15.0000	0.274735E+04	0.912239E+02	0.225927E+02	0.479347E+03	0.293902E+03	0.458302E+02
94.0000	20.4000	15.0000	0.263013E+04	-0.120032E+03	0.212660E+02	-0.879255E+01	0.279906E+03	-0.117864E+02
94.0000	20.6000	15.0000	0.209949E+04	-0.214337E+03	0.167448E+02	-0.542101E+03	0.222247E+03	-0.732777E+02
94.0000	20.8000	15.0000	0.114633E+04	-0.154406E+03	0.907790E+01	-0.963972E+03	0.121048E+03	-0.121078E+03
94.0000	21.0000	15.0000	-0.815923E+02	0.182660E+02	-0.585930E+00	-0.111658E+04	-0.781817E+01	-0.138306E+03
94.0000	21.2000	15.0000	-0.128740E+04	0.168231E+03	-0.102668E+02	-0.933597E+03	-0.136521E+03	-0.117925E+03
94.0000	21.4000	15.0000	-0.222304E+04	0.210124E+03	-0.179624E+02	-0.484703E+03	-0.237066E+03	-0.671283E+02
94.0000	21.6000	15.0000	-0.272995E+04	0.944814E+02	-0.224766E+02	0.674121E+02	-0.293300E+03	-0.311813E+01
94.0000	21.8000	15.0000	-0.280688E+04	-0.149646E+03	-0.237279E+02	0.560571E+03	-0.305053E+03	0.561431E+02

Stress tensor components can be very useful for calculations, but they are not a very intuitive output

Activity 1: Strike-Slip EQ

<u>Compute stresses</u>

input fault, input receivers,

half-space, output effective shear stress

```
o92util -flt fault.dat -sta station.dat
    -haf halfspace.dat -estress estress.out
```

$$I_2 = \frac{1}{6}\left[\left(\sigma_{11} - \sigma_{22}\right)^2 + \left(\sigma_{11} - \sigma_{33}\right)^2 + \left(\sigma_{22} - \sigma_{33}\right)^2\right] + \sigma_{12}^2 + \sigma_{13}^2 + \sigma_{23}^2$$

(Second invariant of deviatoric stress tensor)

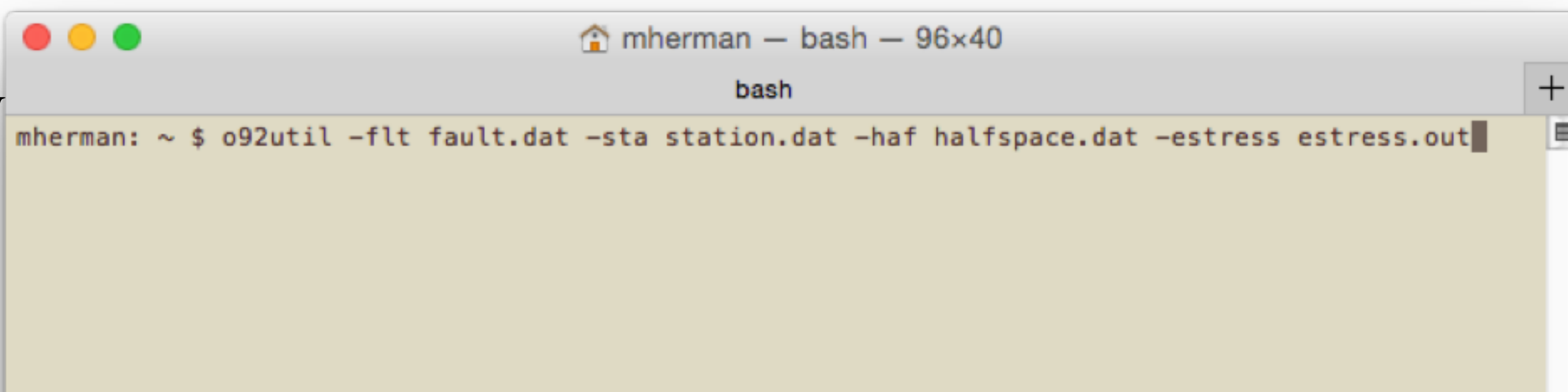
Activity 1: Strike-Slip EQ

<u>Compute stresses</u>

input fault, input receivers,

half-space, output effective shear stress

```
o92util -flt fault.dat -sta station.dat
    -haf halfspace.dat -estress estress.out
```



Activity 1: Strike-Slip EQ

Output stresses (estress.out)

estress.out

94.0000	19.0000	15.0000	0.778948E+06
94.0000	19.2000	15.0000	0.106780E+07
94.0000	19.4000	15.0000	0.143159E+07
94.0000	19.6000	15.0000	0.184266E+07
94.0000	19.8000	15.0000	0.230606E+07
94.0000	20.0000	15.0000	0.260076E+07
94.0000	20.2000	15.0000	0.273225E+07
94.0000	20.4000	15.0000	0.247682E+07

σ_{eff}

(Pa^2)

Activity 1: Strike-Slip EQ

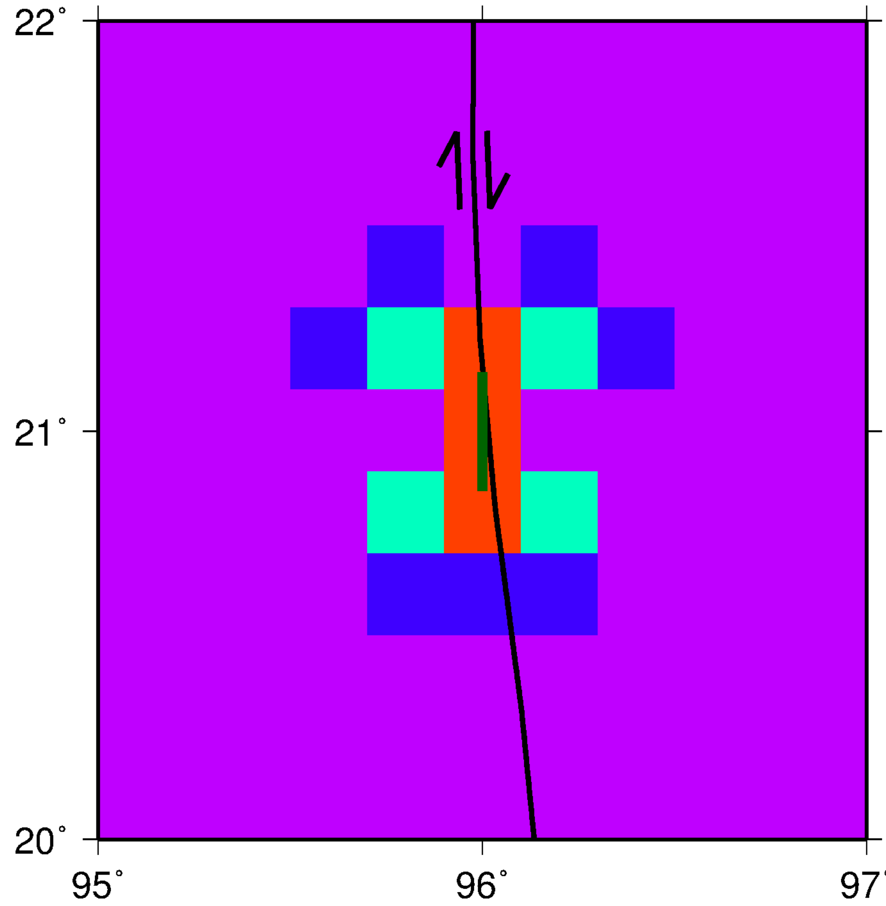
<u>Plot results (basic plotting script provided)</u>

plot_ests.sh

```sh
#!/bin/sh

#####
#	BOURNE SHELL SCRIPT FOR PLOTTING EFFECTIVE STRESS
#####

#####
#	INPUT/OUTPUT FILES FROM O92UTIL
#####
# Input source fault file
FLT_FILE="fault.dat" # EVLO EVLA EVDP STR DIP RAK SLIP WID LEN
# Output effective stress file
DISP_FILE="estress.out" # STLO STLA STDP ESTRS

#####
#	GMT PLOTTING VARIABLES
#####
# Map projection (use 'man psbasemap' to see options)
PROJ="-JM4i -P"
# Map limits (-RXMIN/XMAX/YMIN/YMAX)
LIMS="-R95/97/20/22"
# Output PostScript file name
PSFILE="estress.ps"

#####
#	GMT PLOTTING COMMANDS
#####
# Generate color palette for plotting effective stresses
makecpt -Crainbow -T0/1e6/1e5 -D > estress.cpt

# Convert stress output to NetCDF grid file
# -Ixincr/yincr specifies the grid increments, and should be the same
# as the increment used in the grid command
awk '{print $1,$2,sqrt($4)}' estress.out |\
    xyz2grd -Gestress.grd $LIMS -I0.2/0.2
# Plot effective stress grid, using color palette generated above
grdimage estress.grd $PROJ $LIMS -Cestress.cpt -K > $PSFILE

# Plot focal mechanisms of input faults
awk '{print $1,$2,$3,$4,$5,$6,5}' $FLT_FILE |\
    psmeca $PROJ $LIMS -Sa0.5i -W1p -L1p -Ggrey -K -O >> $PSFILE
# Plot horizontal projection of rectangular input faults
# To convert degrees to radians, multiply by pi/180 = 0.01745
awk '{print $1,$2,$4,$9,$8*cos($5*0.017)}' $FLT_FILE |\
    psxy $PROJ $LIMS -SJ -W3p,darkgreen -K -O >> $PSFILE

# Draw map outline and label axes
psbasemap $PROJ $LIMS -Ba1WeSn -O >> $PSFILE
```

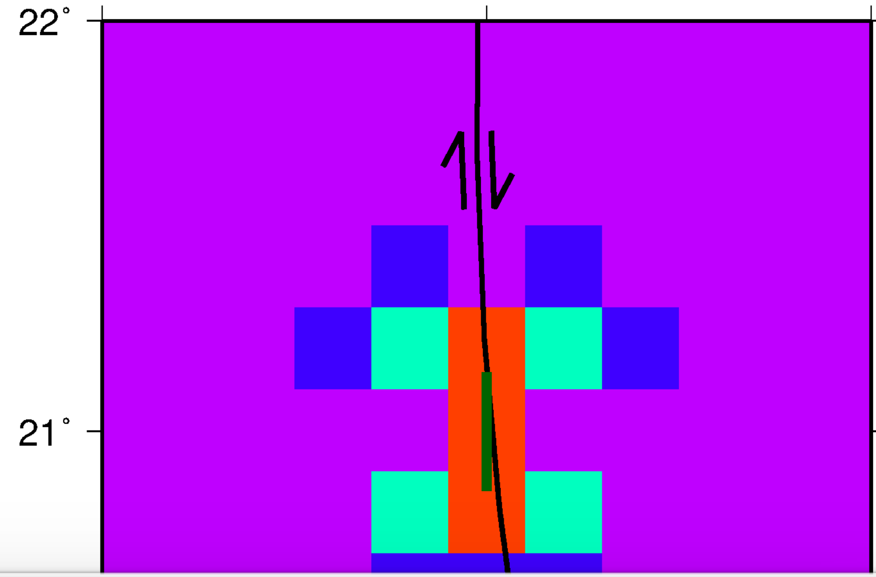
Activity 1: Strike-Slip EQ

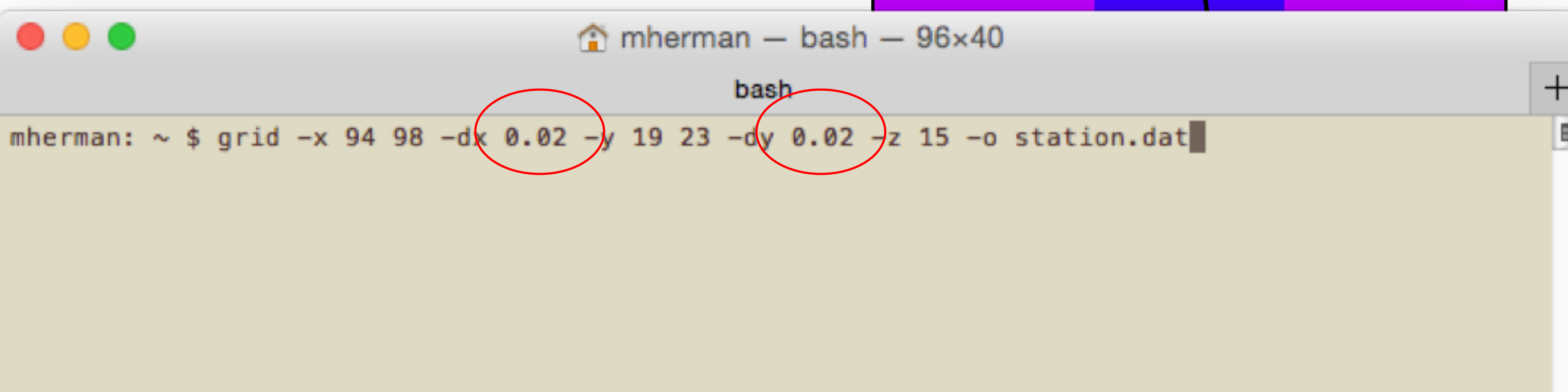
- Resolution not very high...
- Increase resolution by decreasing grid increment by 10x



Activity 1: Strike-Slip EQ

- Resolution not very high...
- Increase resolution by decreasing grid increment by 10x





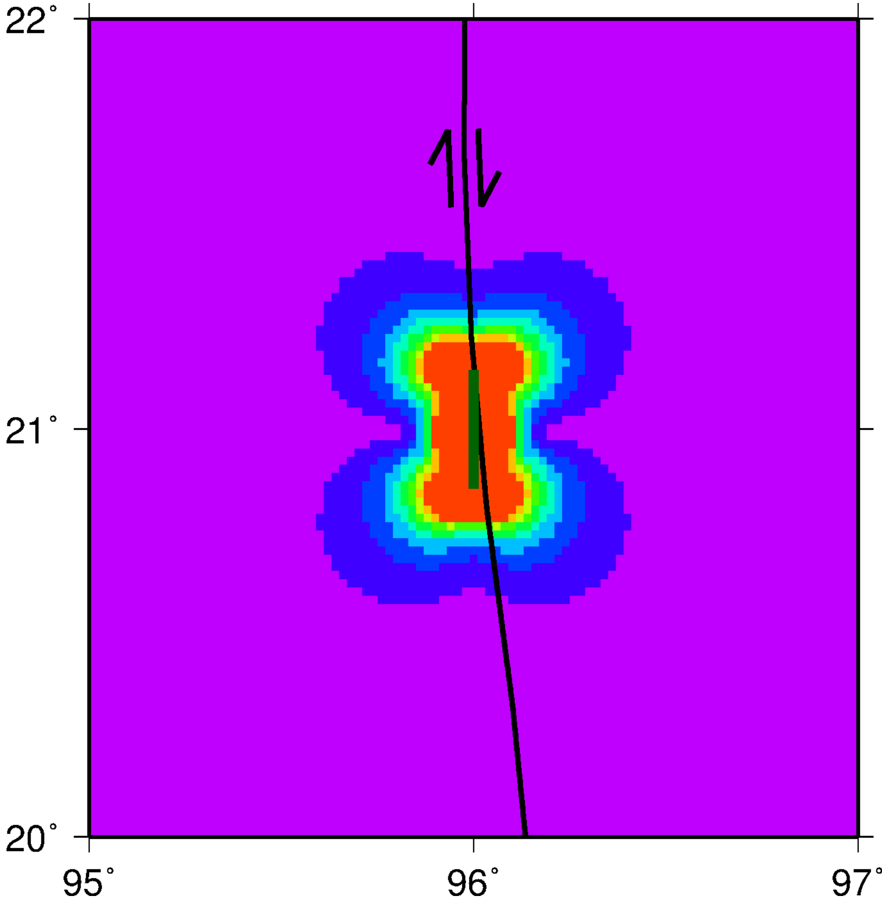
plot_ests.sh

```
#!/bin/sh

#####
#       BOURNE SHELL SCRIPT FOR PLOTTING EFFECTIVE STRESS
#####

#####
#       INPUT/OUTPUT FILES FROM O92UTIL
#####
# Input source fault file
FLT_FILE="fault.dat" # EVLO EVLA EVDP STR DIP RAK SLIP WID LEN
# Output effective stress file
DISP_FILE="estress.out" # STLO STLA STDP ESTRS

#####
#       GMT PLOTTING VARIABLES
#####
# Map projection (use 'man psbasemap' to see options)
PROJ="-JM4i -P"
# Map limits (-RXMIN/XMAX/YMIN/YMAX)
LIMS="-R95/97/20/22"
# Output PostScript file name
PSFILE="estress.ps"

#####
#       GMT PLOTTING COMMANDS
#####
# Generate color palette for plotting effective stresses
makecpt -Crainbow -T0/1e6/1e5 -D > estress.cpt

# Convert stress output to NetCDF grid file
# -Ixincr/yincr specifies the grid increments, and should be the same
# as the increment used in the grid command
awk '{print $1,$2,sqrt($4)}' estress.out |\
    xyz2grd -Gestress.grd $LIMS -I0.02/0.02
# Plot effective stress grid, using color palette generated above
grdimage estress.grd $PROJ $LIMS -Cestress.cpt -K > $PSFILE

# Plot focal mechanisms of input faults
awk '{print $1,$2,$3,$4,$5,$6,5}' $FLT_FILE |\
    psmeca $PROJ $LIMS -Sa0.5i -W1p -L1p -Ggrey -K -O >> $PSFILE
# Plot horizontal projection of rectangular input faults
# To convert degrees to radians, multiply by pi/180 = 0.01745
awk '{print $1,$2,$4,$9,$8*cos($5*0.017)}' $FLT_FILE |\
    psxy $PROJ $LIMS -SJ -W3p,darkgreen -K -O >> $PSFILE

# Draw map outline and label axes
psbasemap $PROJ $LIMS -Ba1WeSn -O >> $PSFILE
```

Decrease grid increment in plotting script

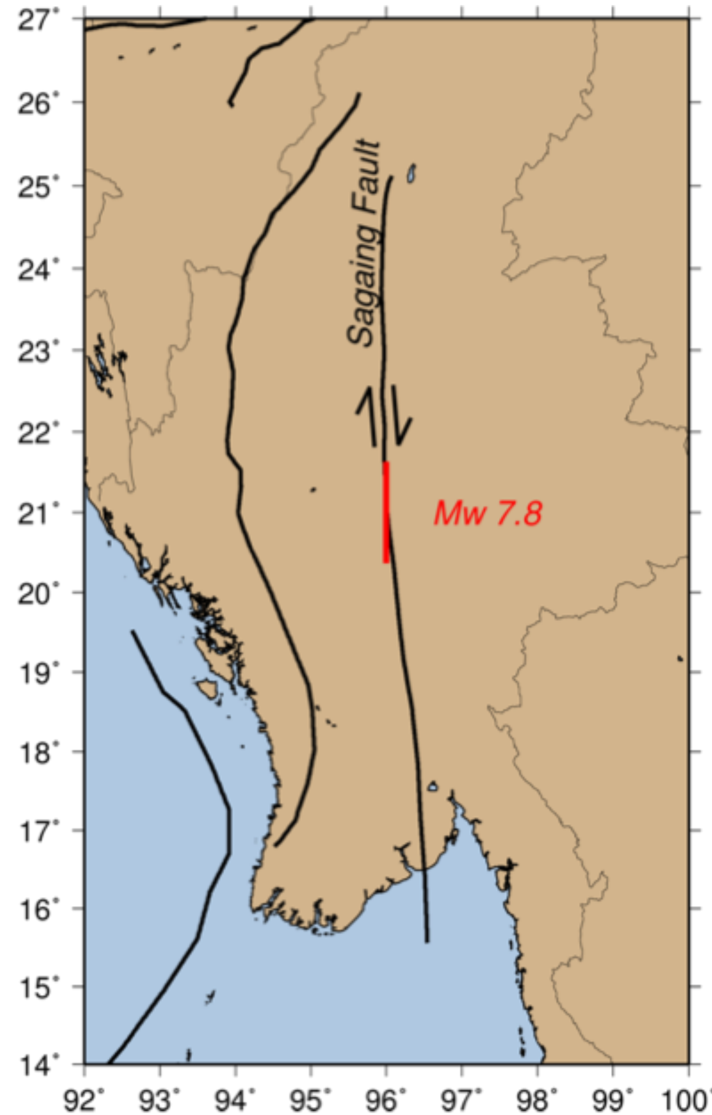
Activity 1: Strike-Slip EQ

- Resolution not very high...
- Increase resolution by decreasing grid increment by 10x
- Much better sense of stress footprint
- *Where is stress concentrated?*



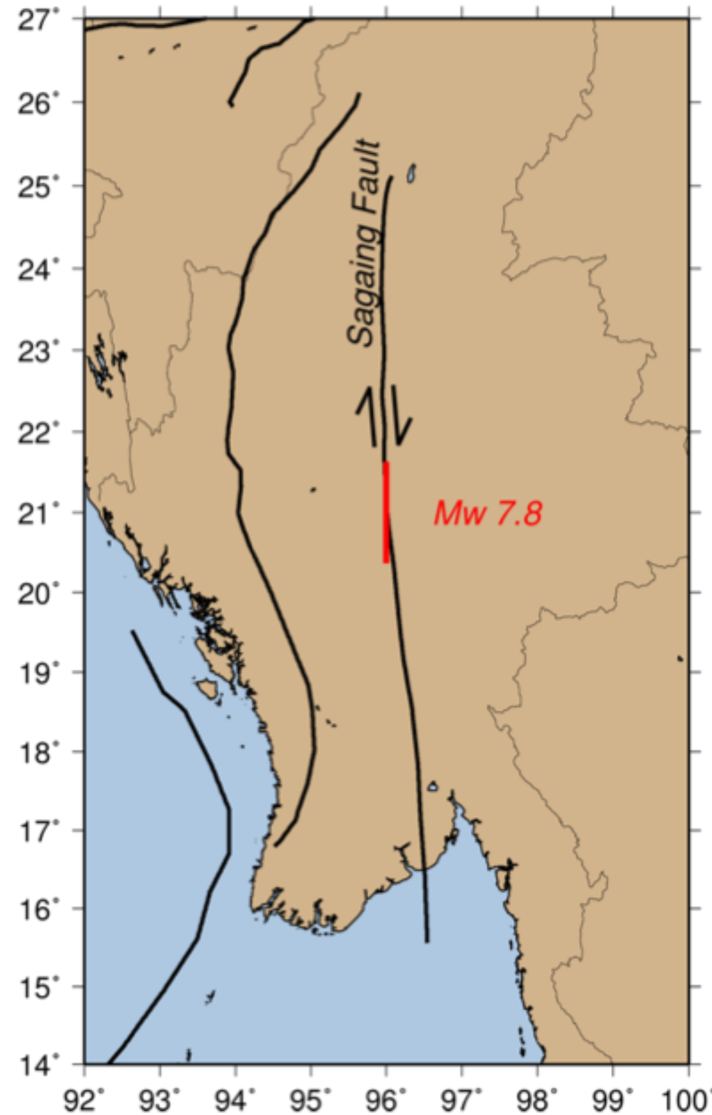
Activity 2: Strike-Slip EQ

- What is the stress footprint from a larger earthquake?



Activity 2: Strike-Slip EQ

- What is the stress footprint from a larger earthquake?
- *Exercise: model a <u>hypothetical</u> Mw 7.8 earthquake on the Sagaing fault and compare results to Mw 7.0*



Activity 2: Strike-Slip EQ

Input fault file (fault.dat)

location of center, kinematics, slip, dimensions

```
96      21      15      0      90   180      5    20   140
```

Slip (m) Width (km) Length (km)

Change the slip and size of the fault. Check that this is equal to Mw 7.8.

Activity 2: Strike-Slip EQ

<u>Compute displacements</u>

input fault, input receivers,

half-space, output displacements

```
o92util -flt fault.dat -sta station.dat
    -haf halfspace.dat -estress estress.out
```

Keep everything else the same.

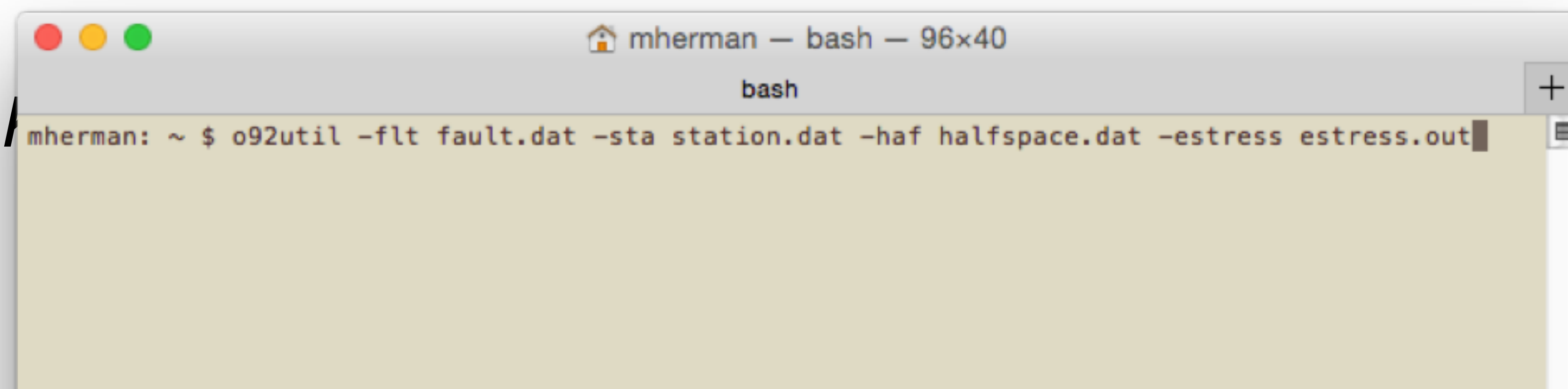
Activity 2: Strike-Slip EQ

<u>Compute displacements</u>

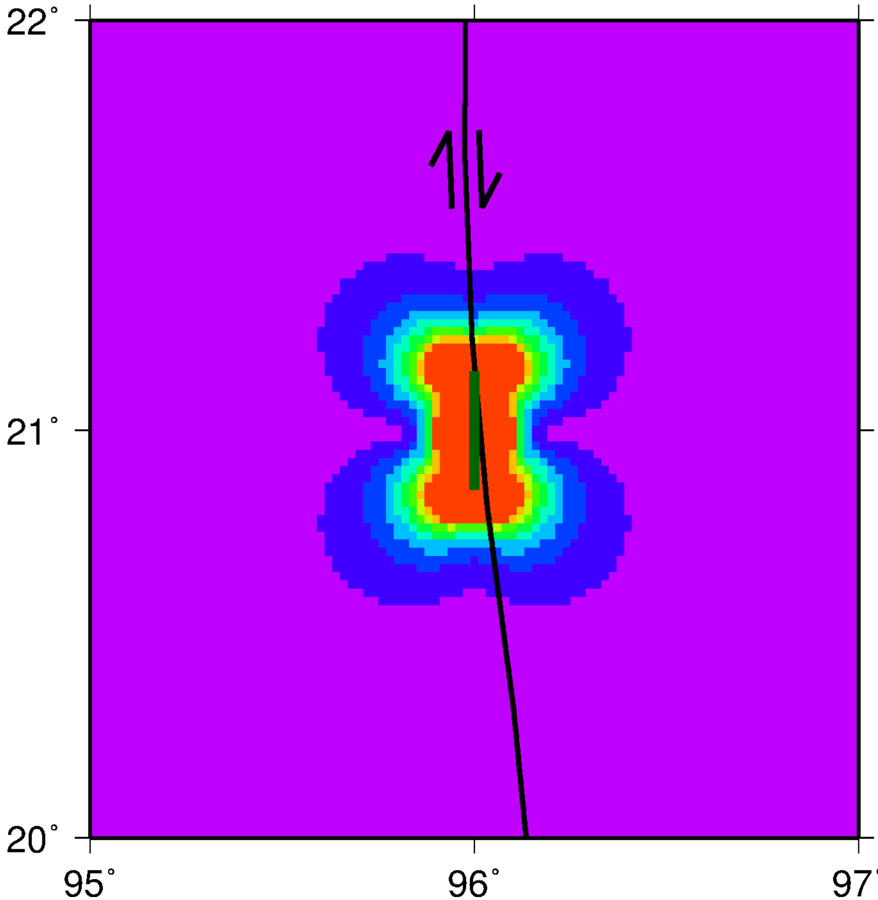
input fault, input receivers,

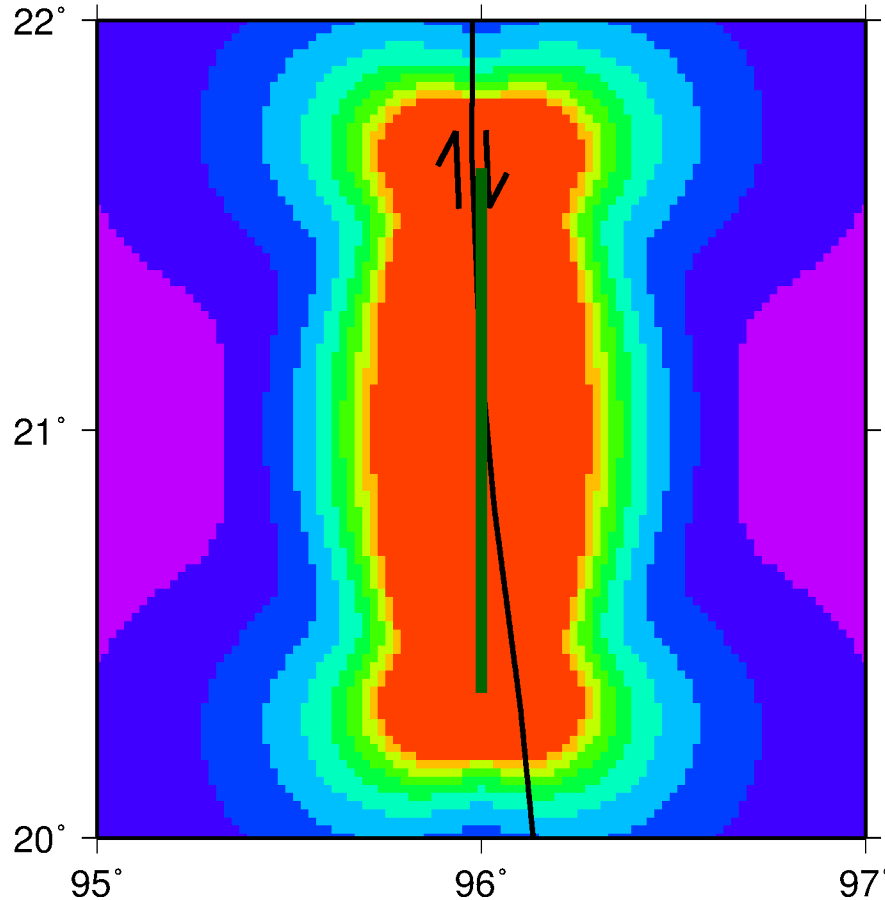
half-space, output displacements

```
o92util -flt fault.dat -sta station.dat
    -haf halfspace.dat -estress estress.out
```



Activity 2: Strike-Slip EQ





Mw 7.0

Mw 7.8

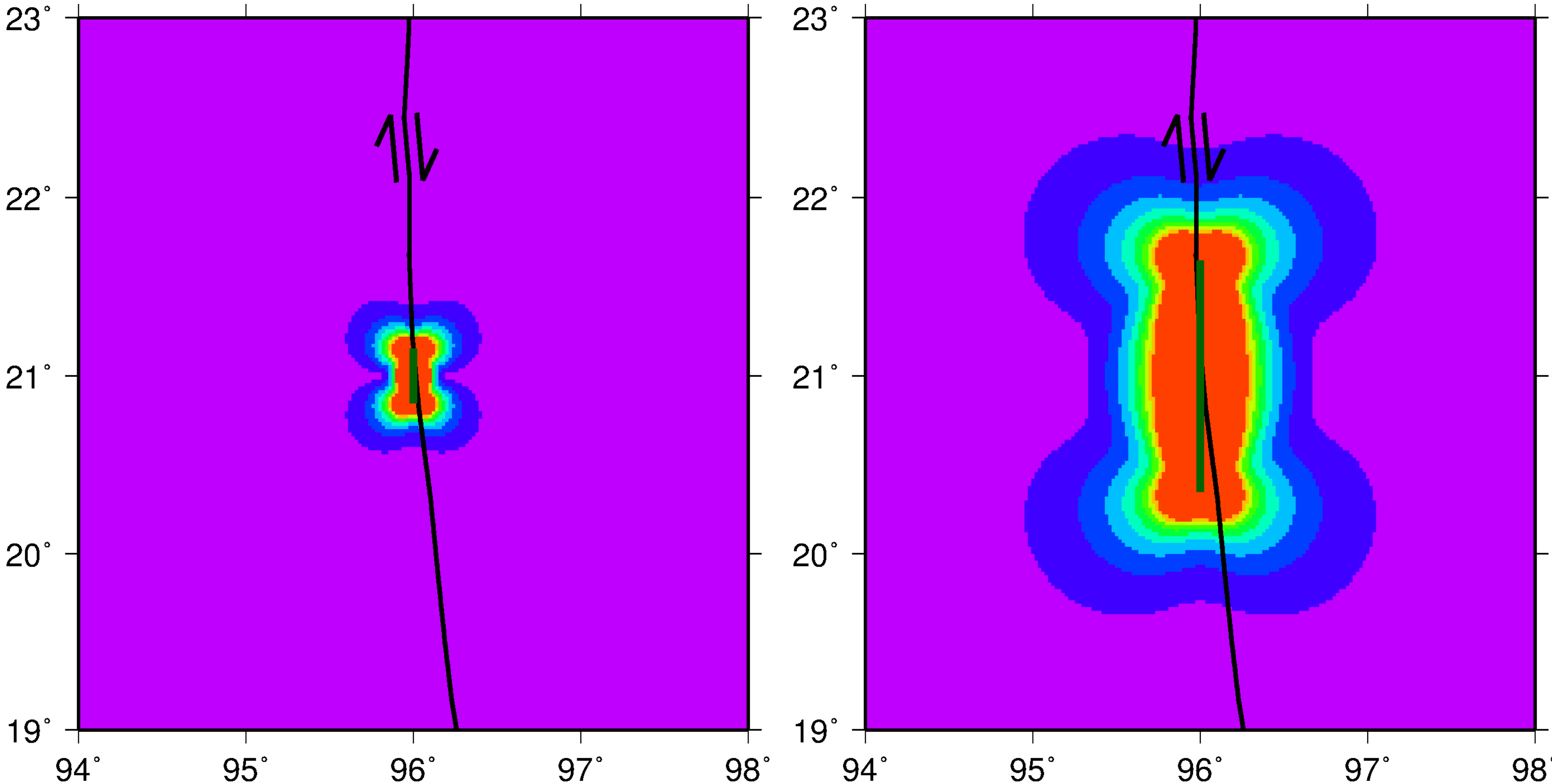
(Plotted on the same scale)

plot_ests.sh

```sh
#!/bin/sh

#####
#       BOURNE SHELL SCRIPT FOR PLOTTING EFFECTIVE STRESS
#####

#####
#       INPUT/OUTPUT FILES FROM O92UTIL
#####
# Input source fault file
FLT_FILE="fault.dat" # EVLO EVLA EVDP STR DIP RAK SLIP WID LEN
# Output effective stress file
DISP_FILE="estress.out" # STLO STLA STDP ESTRS

#####
#       GMT PLOTTING VARIABLES
#####
# Map projection (use 'man psbasemap' to see options)
PROJ="-JM4i -P"
# Map limits (-RXMIN/XMAX/YMIN/YMAX)
LIMS="-R94/98/19/23"
# Output PostScript file name
PSFILE="estress.ps"

#####
#       GMT PLOTTING COMMANDS
#####
# Generate color palette for plotting effective stresses
makecpt -Crainbow -T0/1e6/1e5 -D > estress.cpt

# Convert stress output to NetCDF grid file
# -Ixincr/yincr specifies the grid increments, and should be the same
# as the increment used in the grid command
awk '{print $1,$2,sqrt($4)}' estress.out |\
    xyz2grd -Gestress.grd $LIMS -I0.02/0.02
# Plot effective stress grid, using color palette generated above
grdimage estress.grd $PROJ $LIMS -Cestress.cpt -K > $PSFILE

# Plot focal mechanisms of input faults
awk '{print $1,$2,$3,$4,$5,$6,5}' $FLT_FILE |\
    psmeca $PROJ $LIMS -Sa0.5i -W1p -L1p -Ggrey -K -O >> $PSFILE
# Plot horizontal projection of rectangular input faults
# To convert degrees to radians, multiply by pi/180 = 0.01745
awk '{print $1,$2,$4,$9,$8*cos($5*0.017)}' $FLT_FILE |\
    psxy $PROJ $LIMS -SJ -W3p,darkgreen -K -O >> $PSFILE

# Draw map outline and label axes
psbasemap $PROJ $LIMS -Ba1WeSn -O >> $PSFILE
```

Increase area of map region.

Activity 2: Strike-Slip EQ

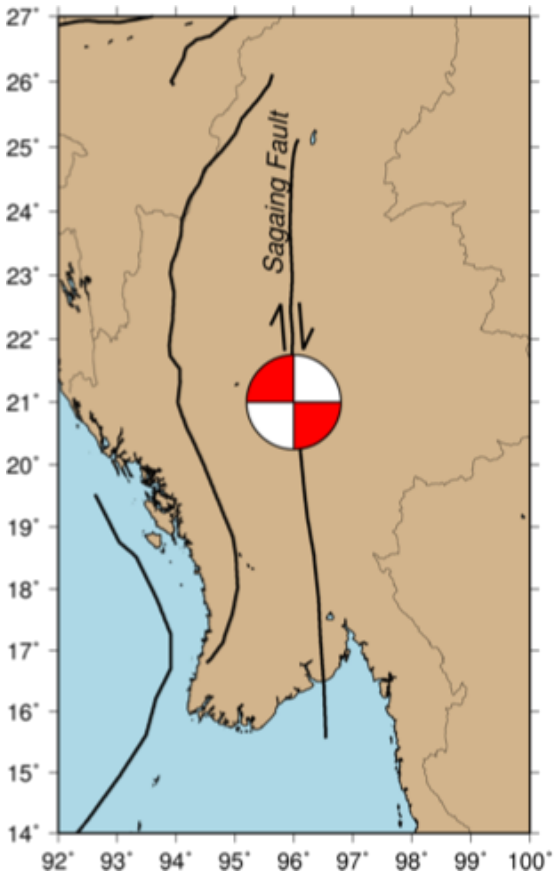


Mw 7.0

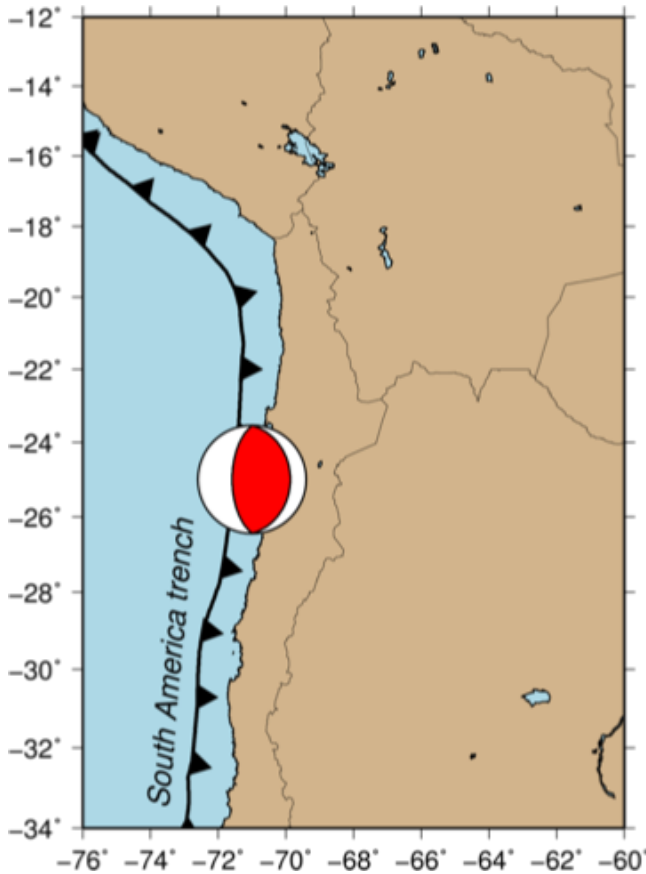
Mw 7.8

(Plotted on the same scale)

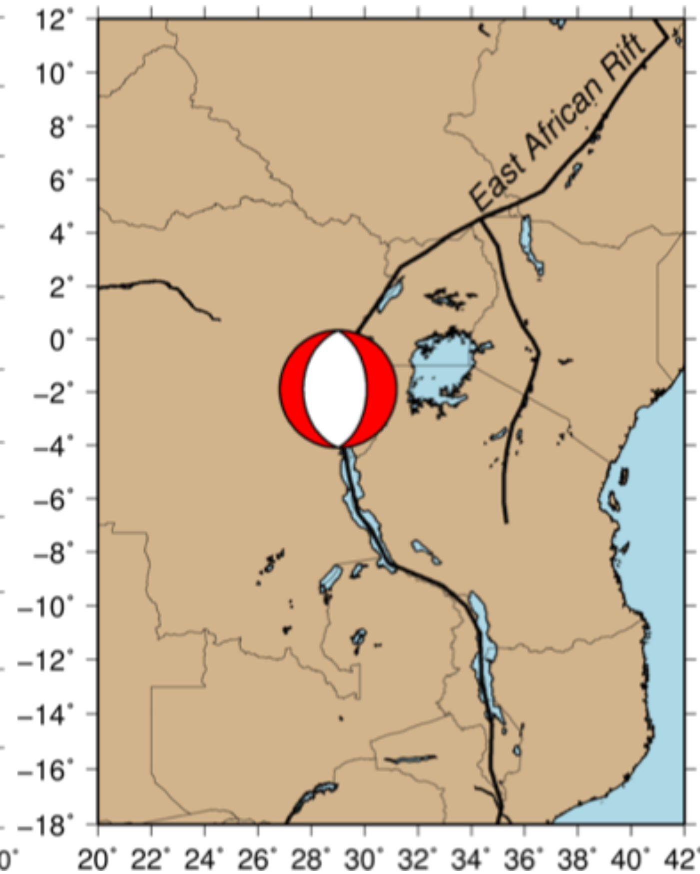
Activity 3: Common Patterns



Strike-slip



Thrust



Normal

Activity 3: Common Patterns

- *Exercise: compute and compare the effective shear stress distributions for hypothetical moderate (Mw 7.0) and large (Mw 7.8) earthquakes, for each common earthquake type (strike-slip, normal, thrust)*
- *Just like exercise yesterday, but computing stress instead of displacement*

Activity 3: Common Patterns

- To systematically compare these fault types:
  - Place each source at the same location

Activity 3: Common Patterns

- To systematically compare these fault types:
  - Place each source at the same location
  - Give sources same slip and dimensions

Activity 3: Common Patterns

- To systematically compare these fault types:
  - Place each source at the same location
  - Give sources same slip and dimensions
  - Use the same receiver grid

Activity 3: Common Patterns

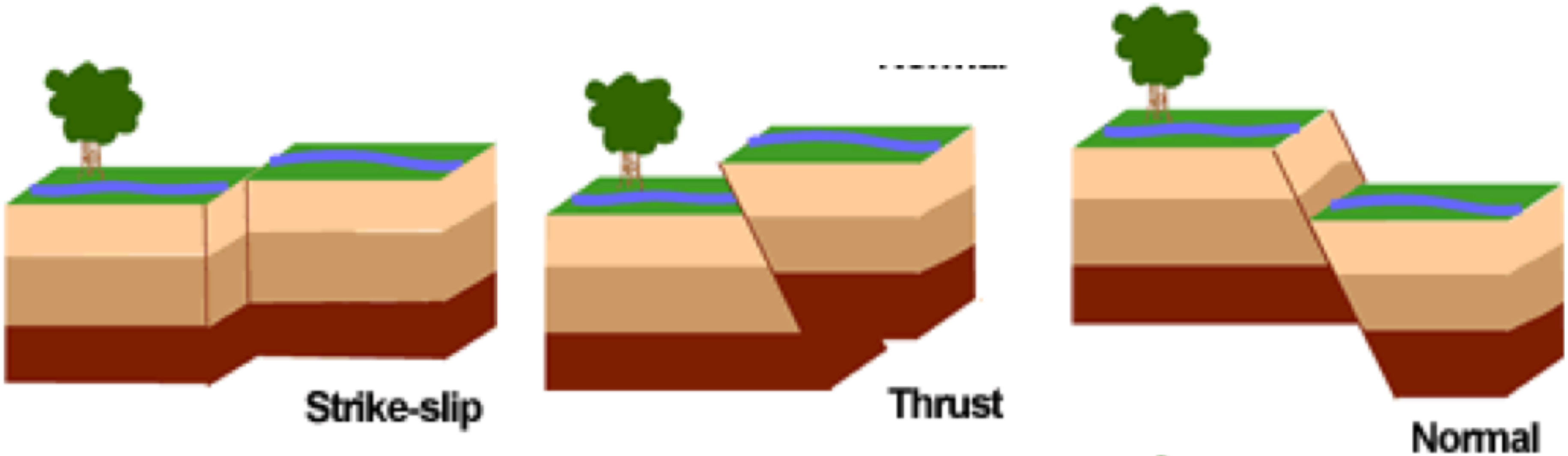
- To systematically compare these fault types:
  - Place each source at the same location
  - Give sources same slip and dimensions
  - Use the same receiver grid

Reminder: use the finer grid increments like in Activities 1 and 2.

Activity 3: Common Patterns

- To systematically compare these fault types:
  – Place each source at the same location
  – Give sources same slip and dimensions
  – Use the same receiver grid
  – Only difference should be fault kinematics

Activity 3: Common Patterns



Dip = 90º
Rake = 0º (left lat)
OR
Rake = 180º (right lat)

Dip = 30º
Rake = 90º

Dip = 50º
Rake = -90º

All have strike = 0º

Activity 3: Common Patterns

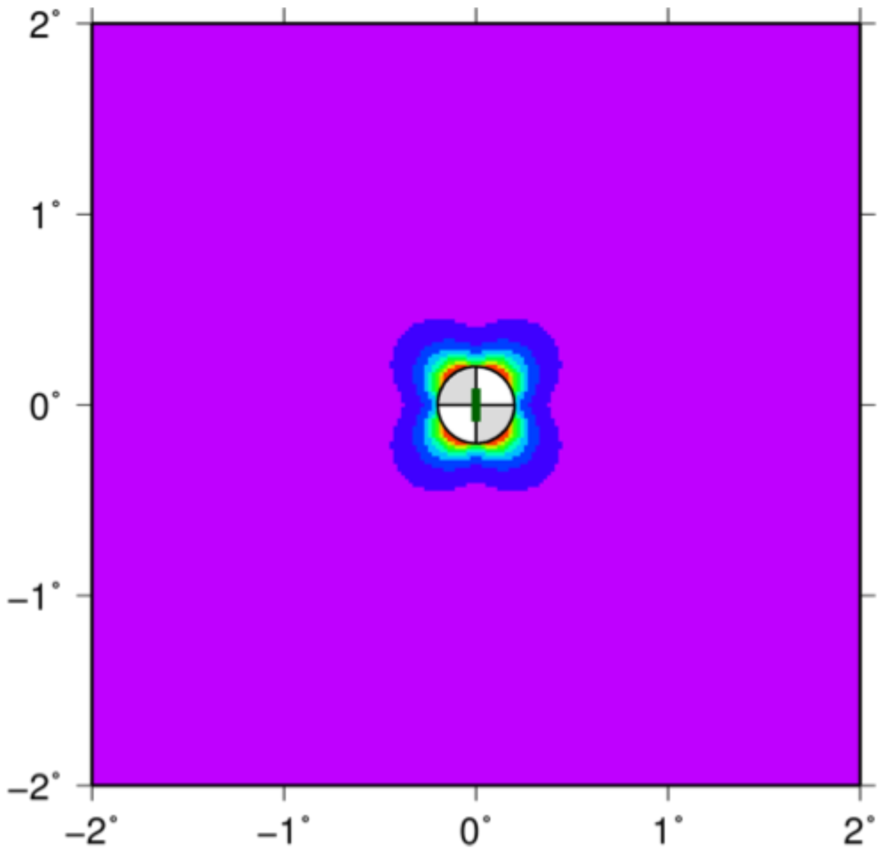
<u>Receiver file (station.dat) using GRID</u>

x-limits and spacing, y-limits and spacing, z-value, output file

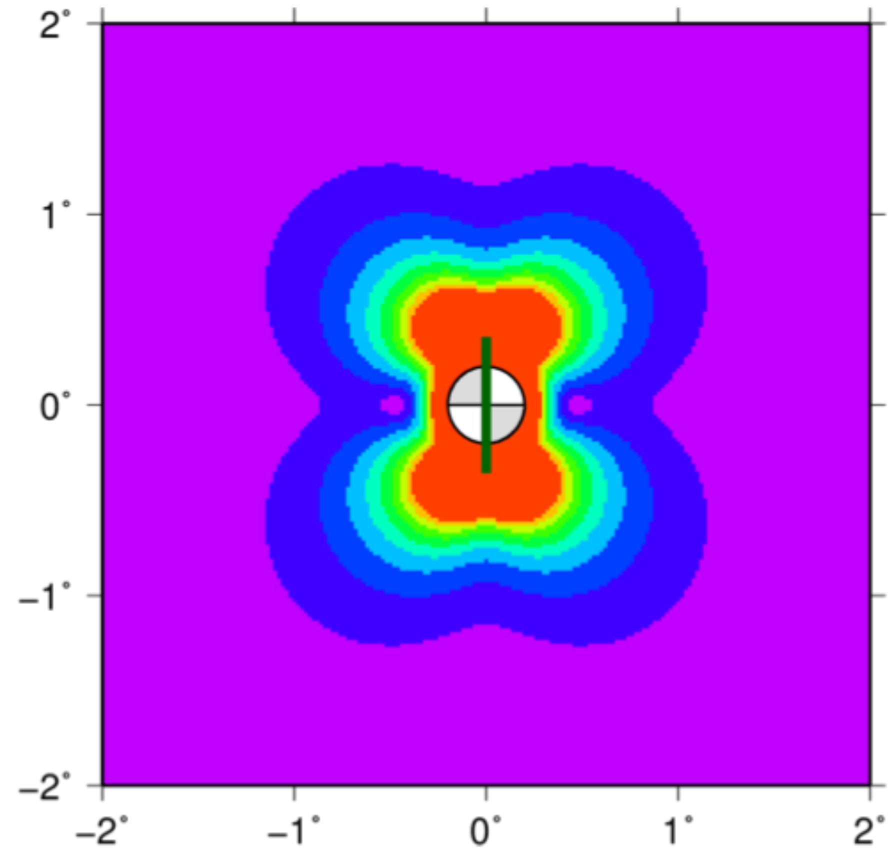
```
grid -x -2 2 -dx 0.02 -y -2 2 -dy 0.02
    -z 15.0 -o station.dat
```

Use the finer grid increments like in Activities 1 and 2.

Activity 3: Common Patterns



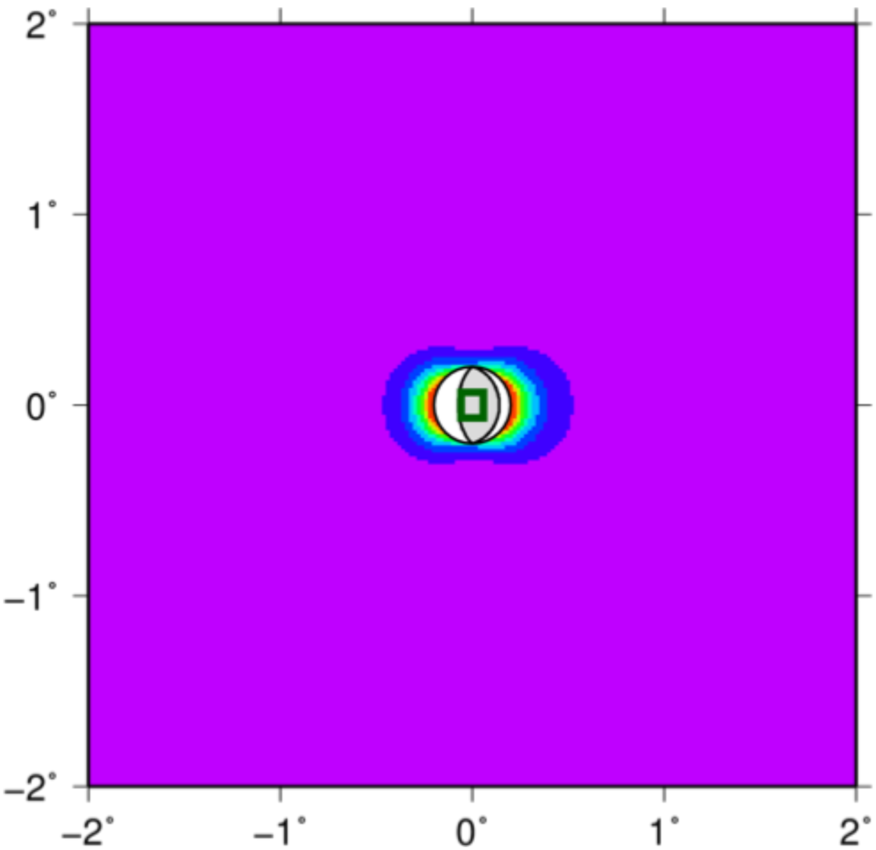
Mw 7.0



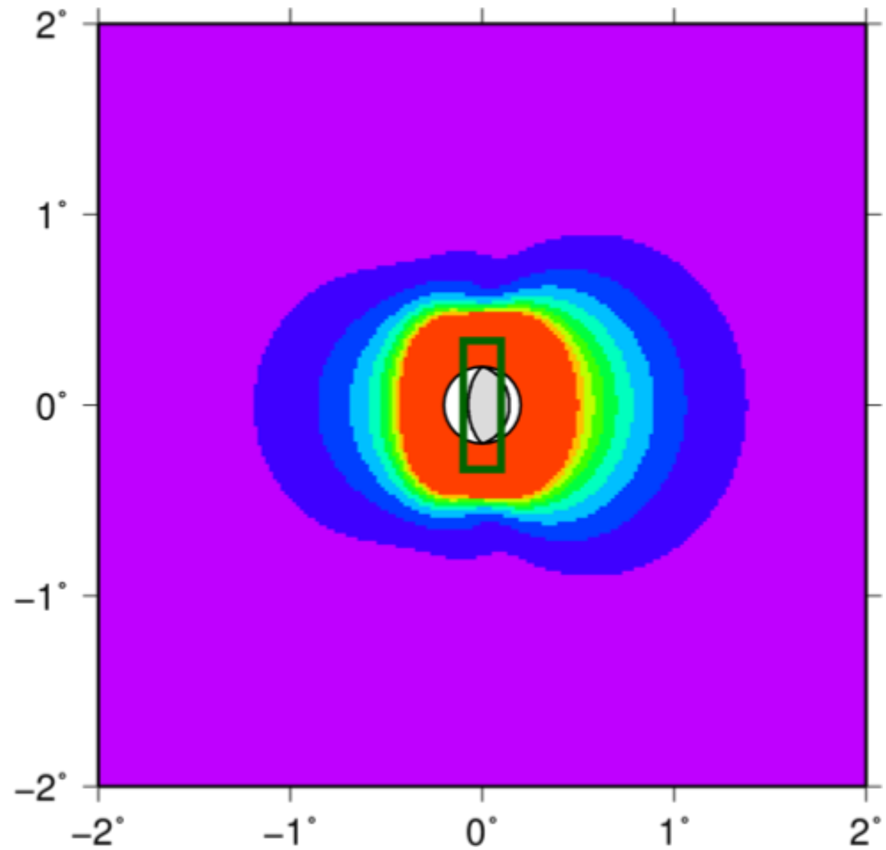
Mw 7.8

(Plotted on the same scale)

Activity 3: Common Patterns



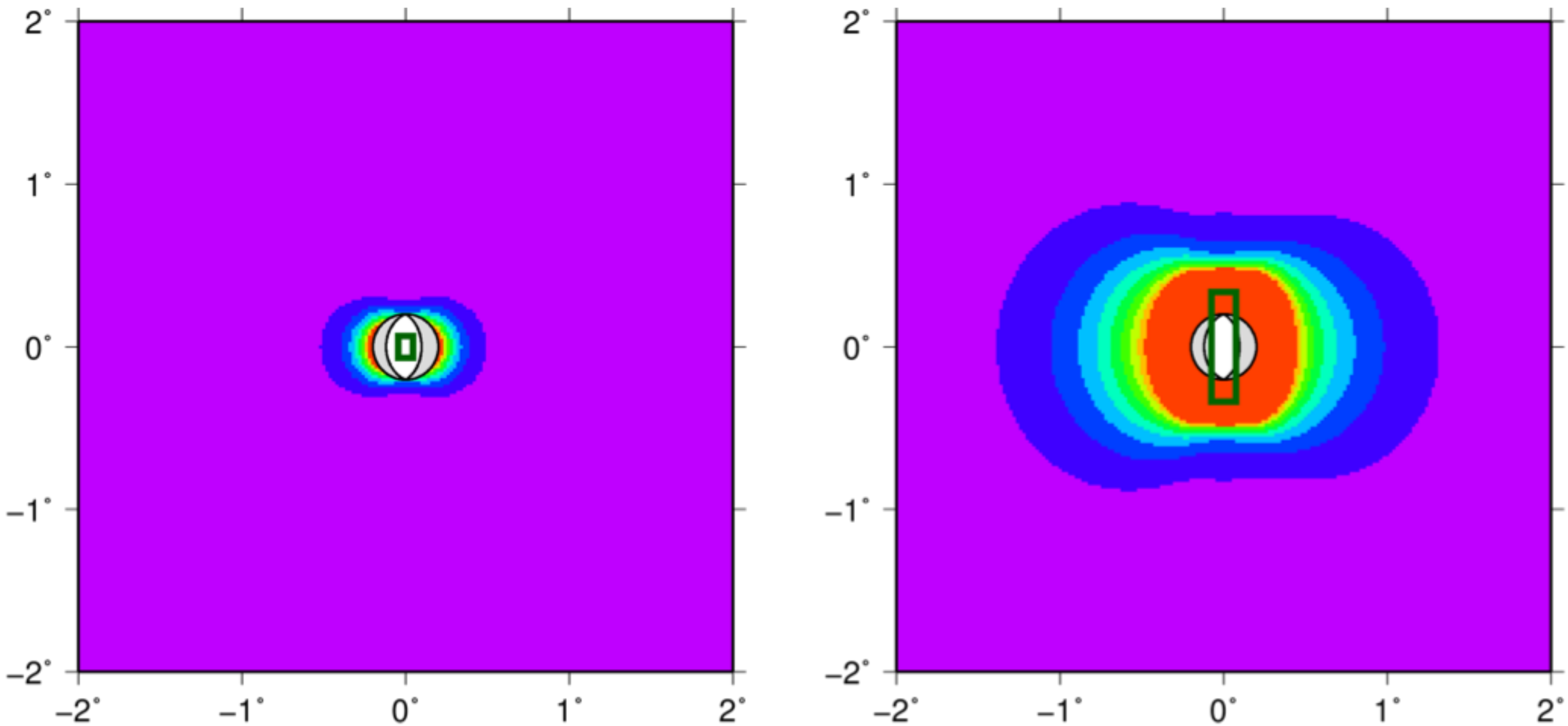
Mw 7.0



Mw 7.8

(Plotted on the same scale)

Activity 3: Common Patterns

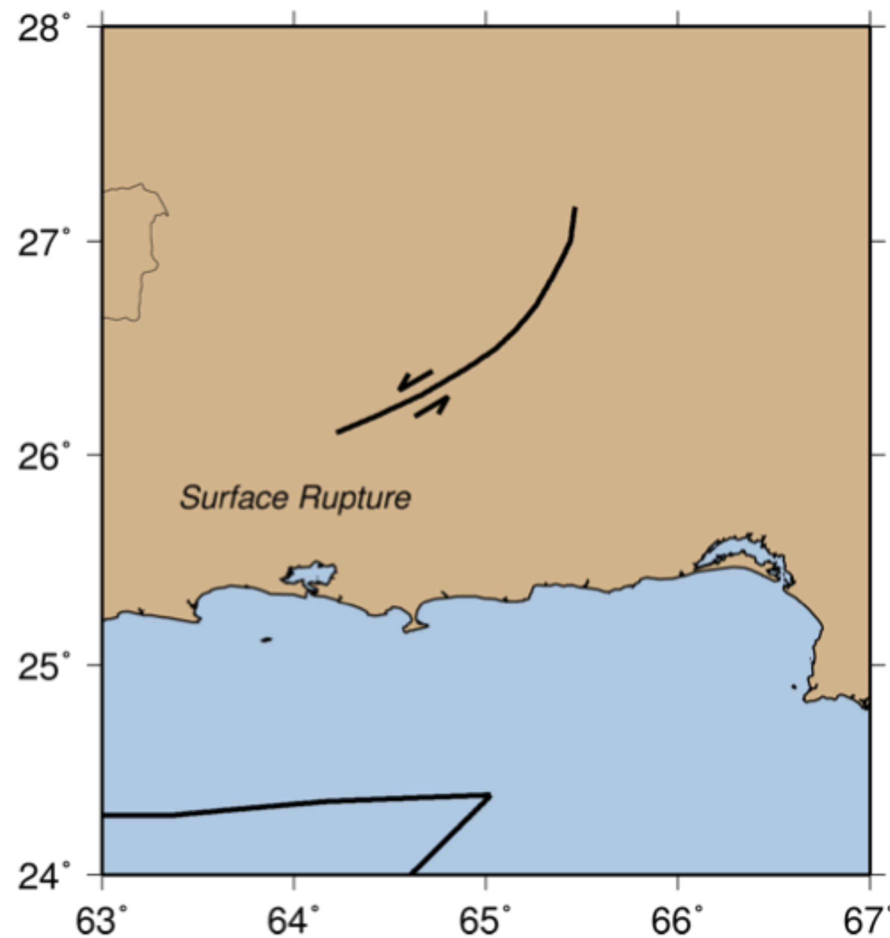


Mw 7.0 Mw 7.8

(Plotted on the same scale)

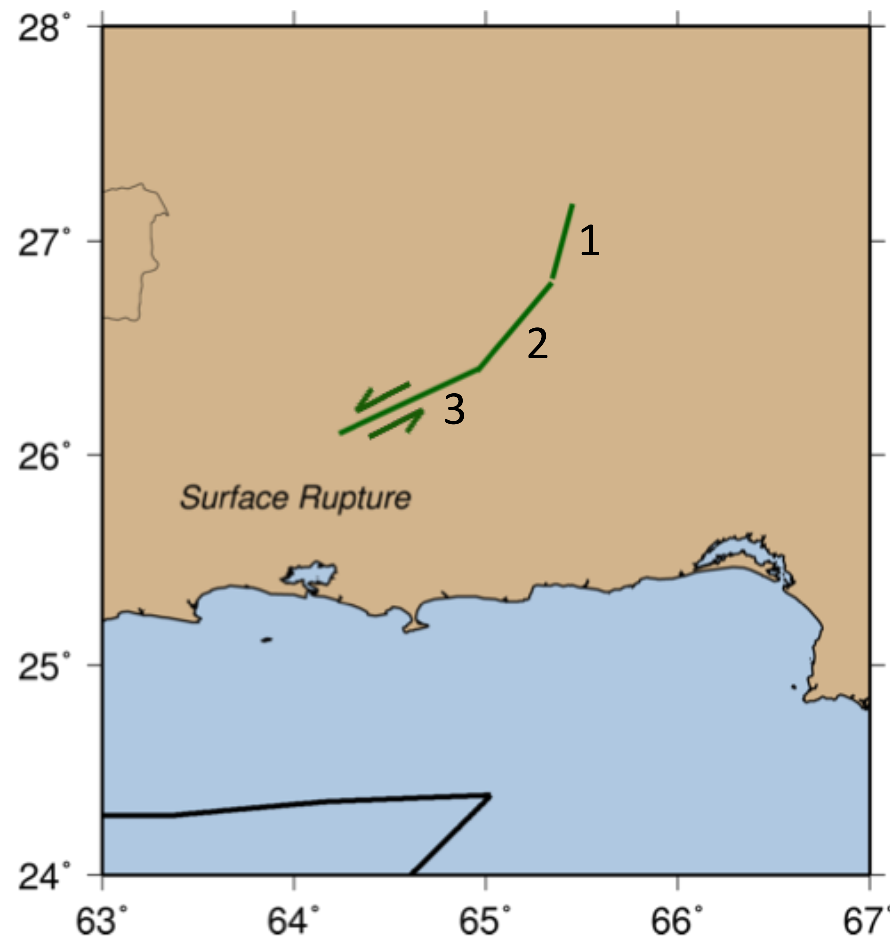
Activity 4: Multiple Faults

- Rupture on fault that changes strike direction along length



Activity 4: Multiple Faults

- Rupture on fault that changes strike direction along length
- Divide into three rectangular segments



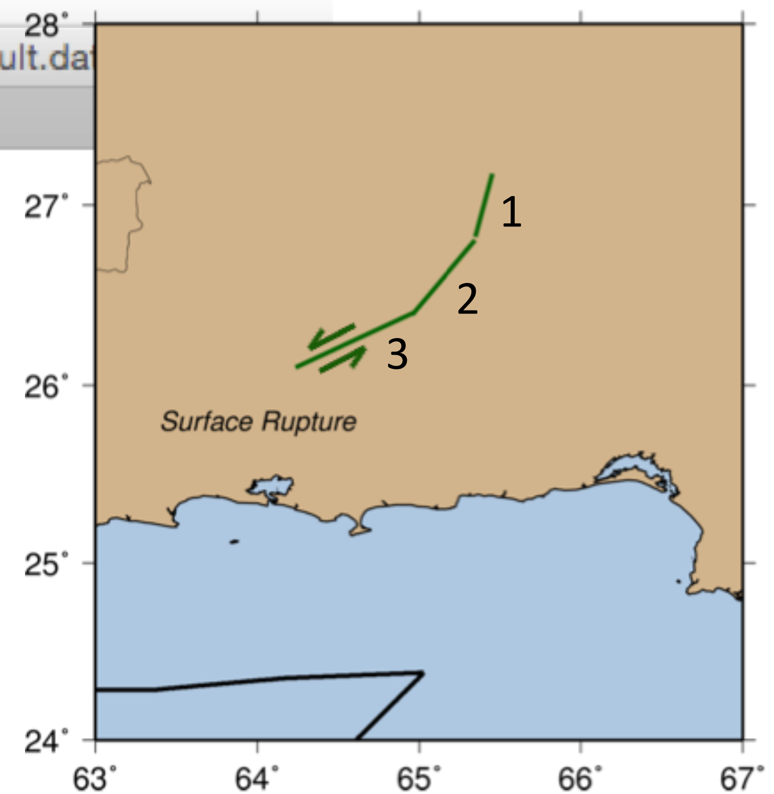
Activity 4: Multiple Faults

<u>Input faults file (fault.dat)</u>

location of center, kinematics, slip, dimensions

fault.dat

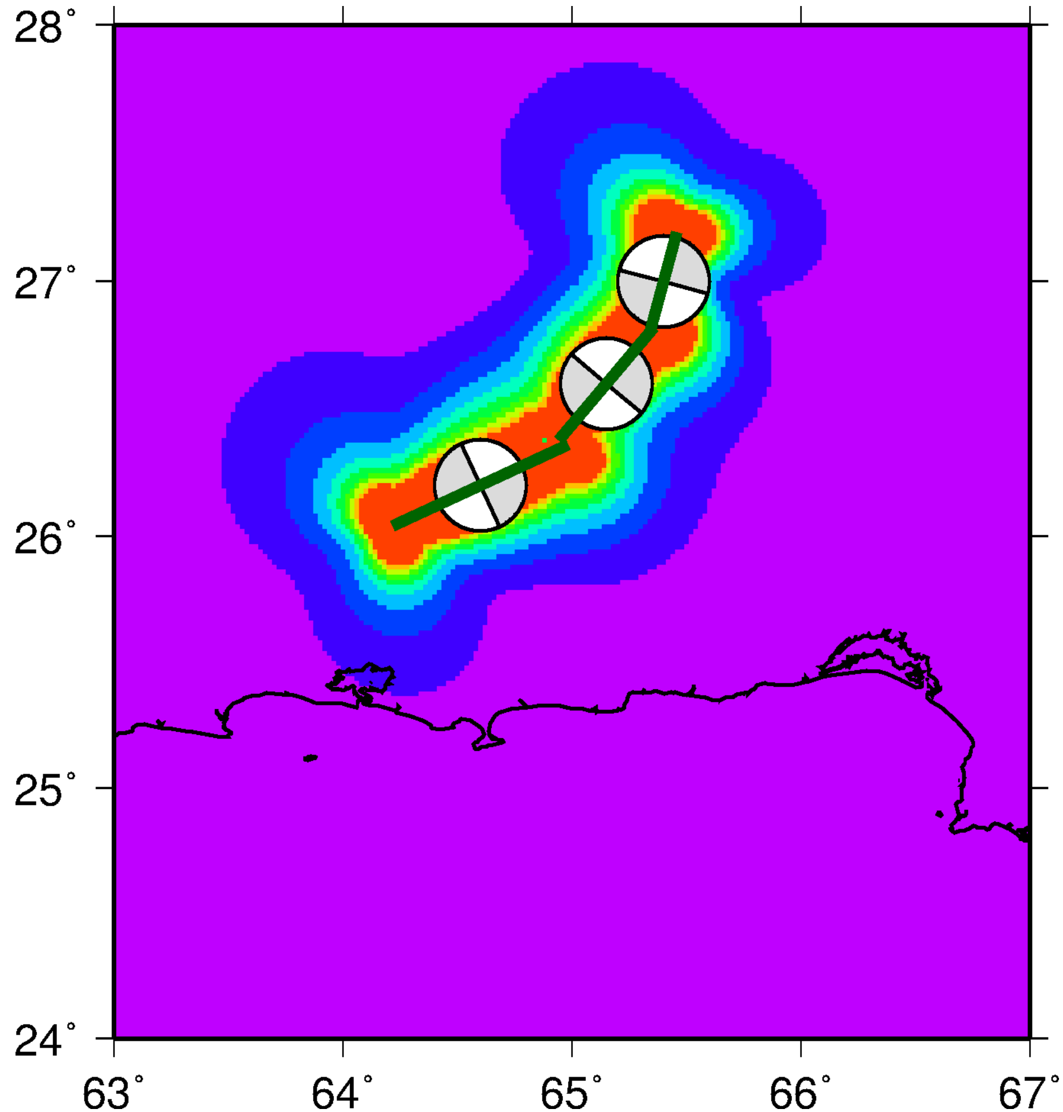
```
65.40 27.00 15 15 90 0 2.75 20 40
65.15 26.60 15 40 90 0 2.75 20 60
64.60 26.20 15 65 90 0 2.75 20 80
```



Deformation from each fault in input file is added together at each receiver. Maximum of 150,000 fault segments.

Activity 4: Multiple Faults

- *How does this stress field differ from the single fault segment results?*

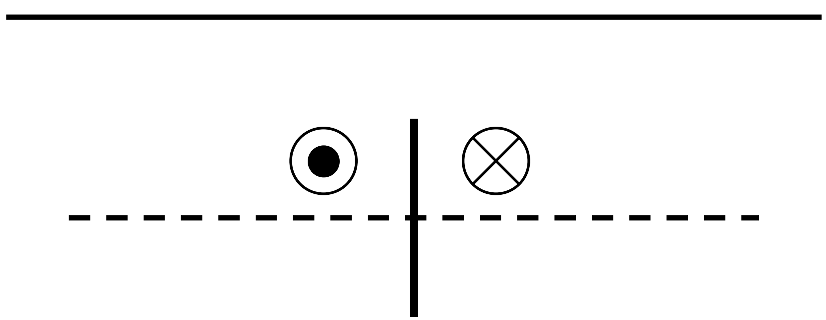


Displacements and Stresses

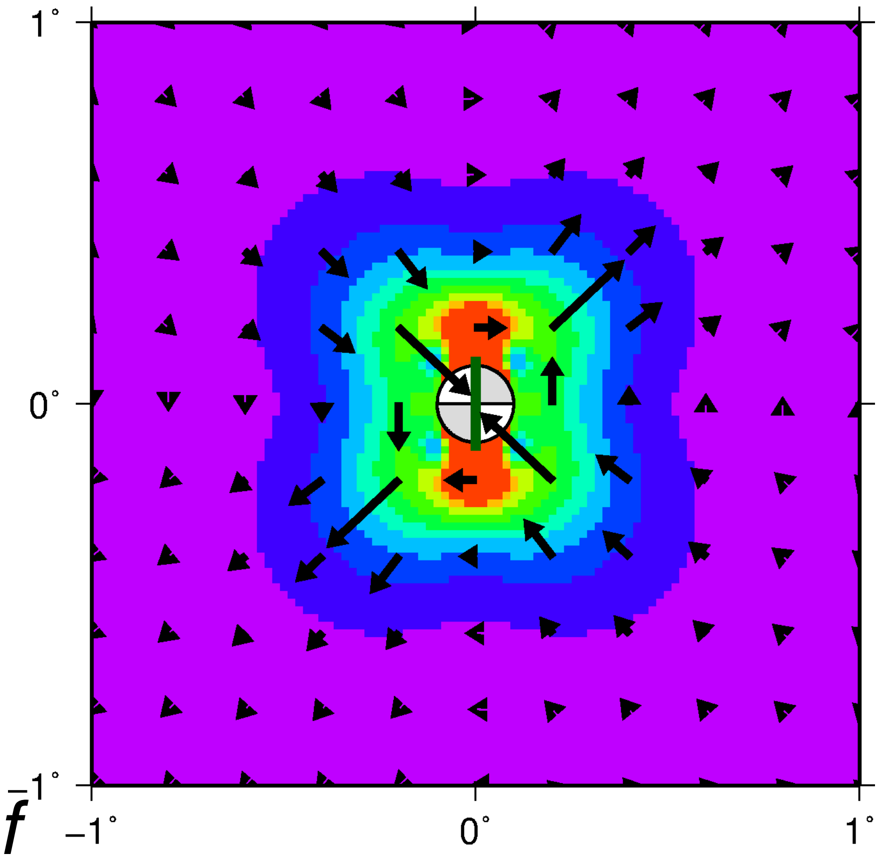
- How does the distribution of stress compare to displacement?
- Recall:
  - Strain is proportional to the partial derivatives of displacement
  - In an elastic body, stress is proportional to strain through the elastic moduli
  - Therefore, stress and strain are largest where the displacements are changing most

Displacements and Stresses

- Strike-slip earthquake

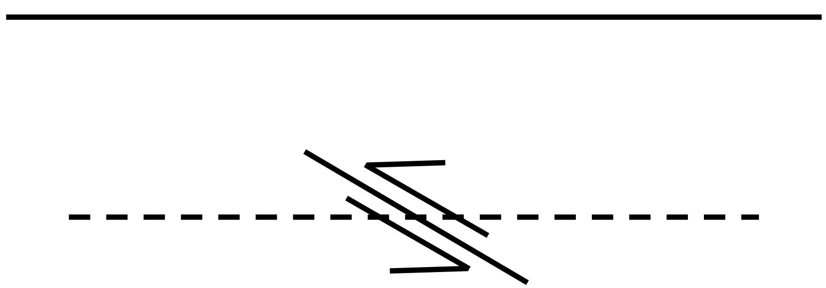


Schematic cross-section of fault; dashed line is depth of stress computation

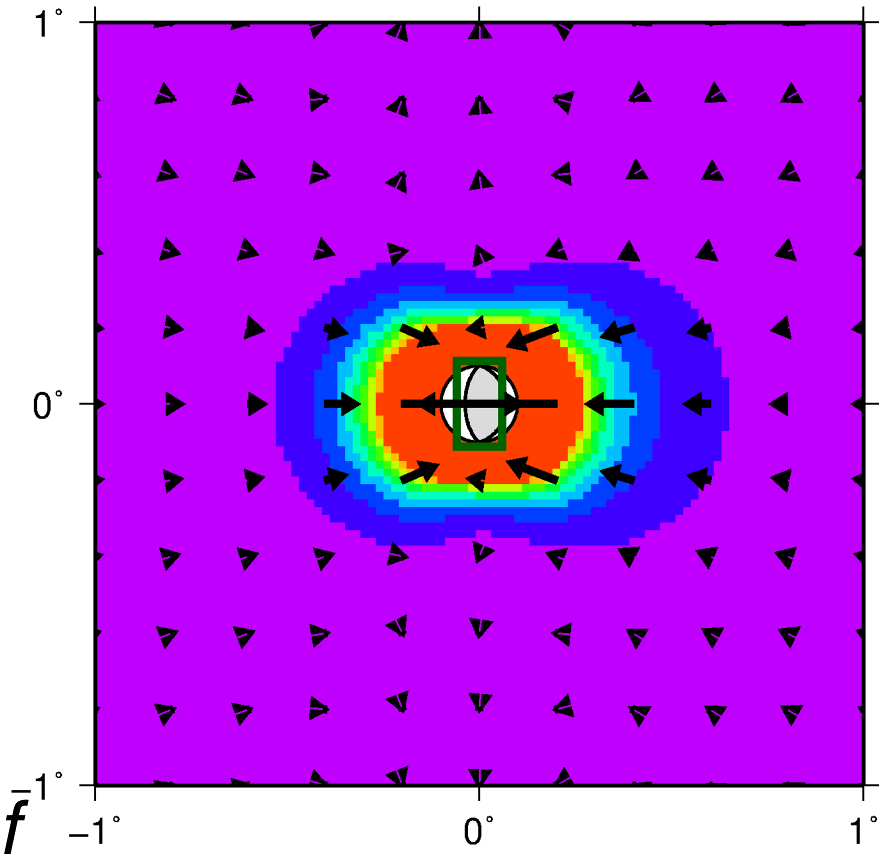


Displacements and Stresses

- Thrust earthquake

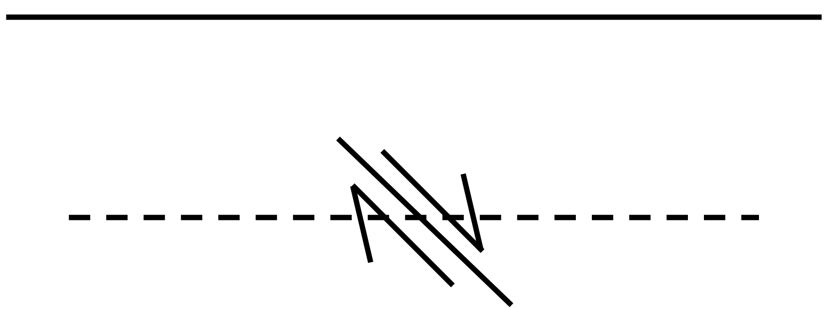


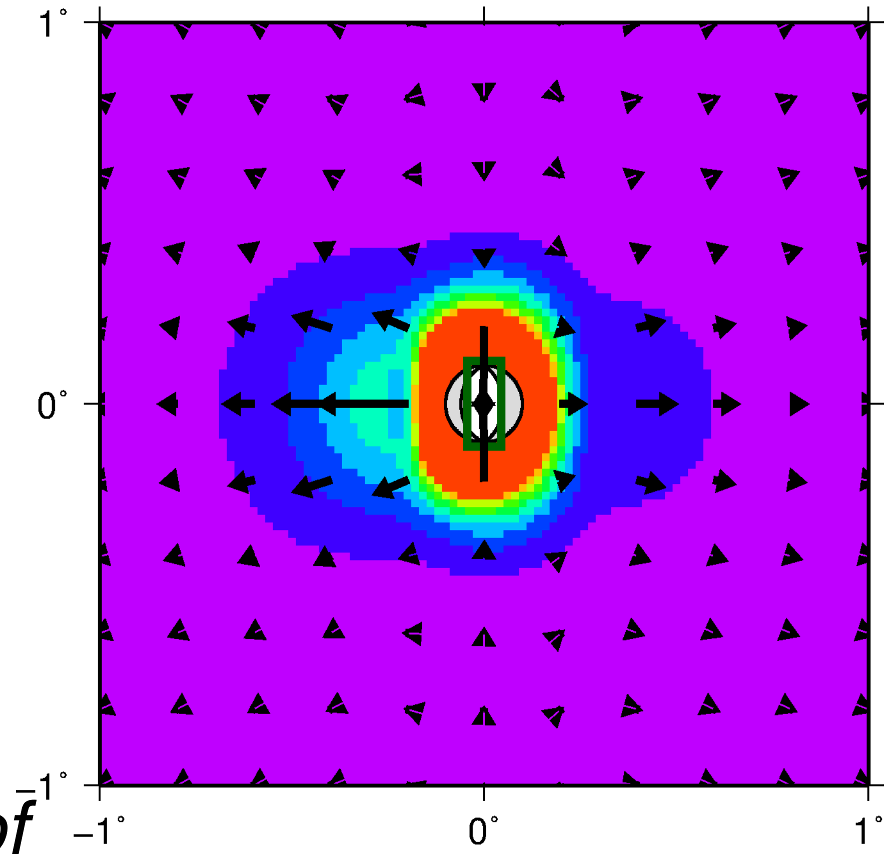
Schematic cross-section of fault; dashed line is depth of stress computation



Displacements and Stresses

- Normal earthquake





Schematic cross-section of fault; dashed line is depth of stress computation

Introduction to Stress Modeling Completed