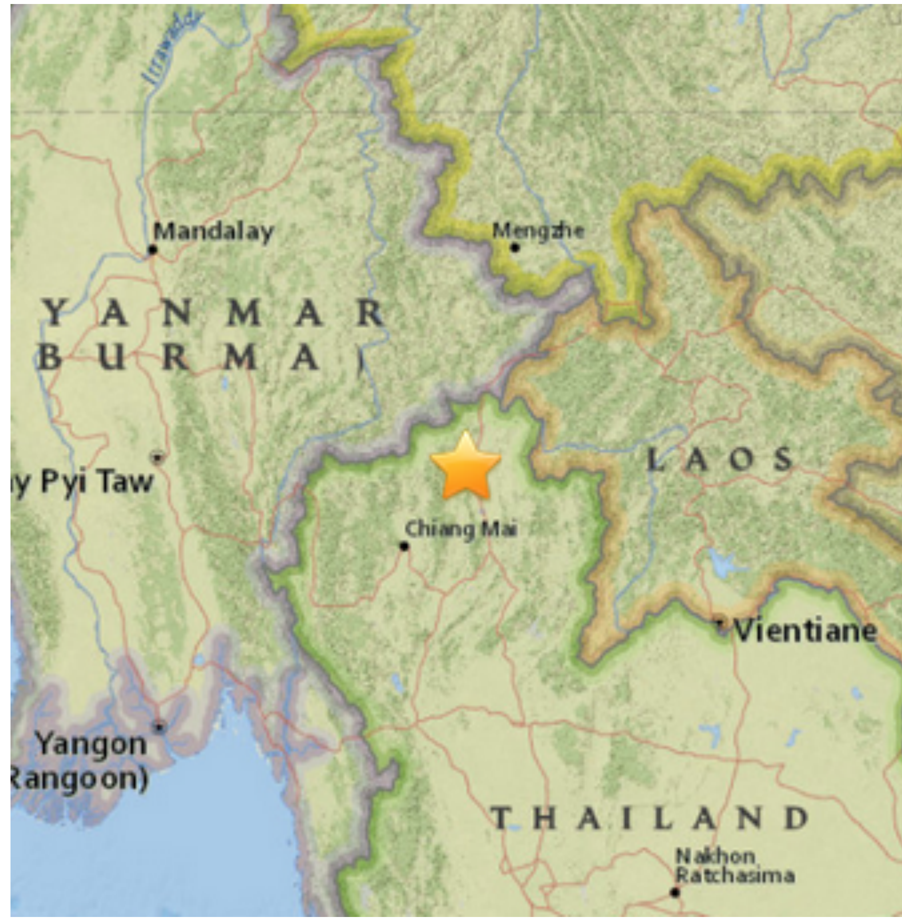
Case Study 1:
2014 Chiang Rai Sequence

Overview

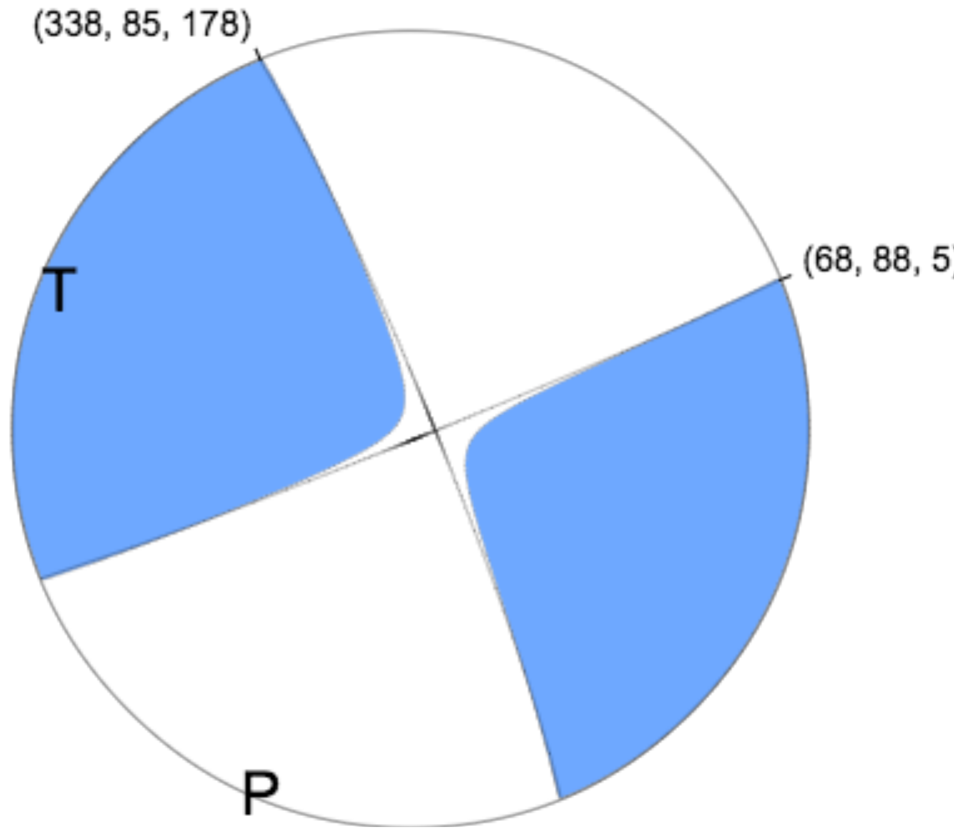
- Mw 6.1 earthquake on 5 May 2014 at 11:08:43 UTC
- Largest recorded earthquake in Thailand



Fault Orientation

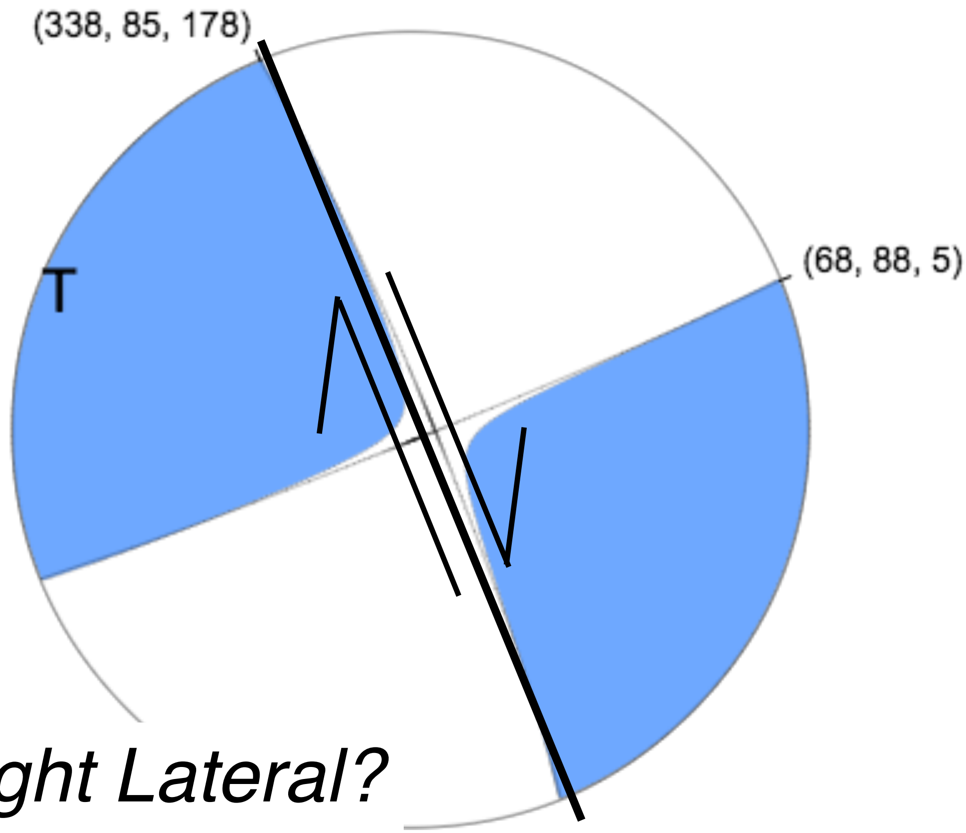
- How does the orientation of the fault affect the displacements and stresses?
- First-order problem is constraining fault orientation

Fault Orientation



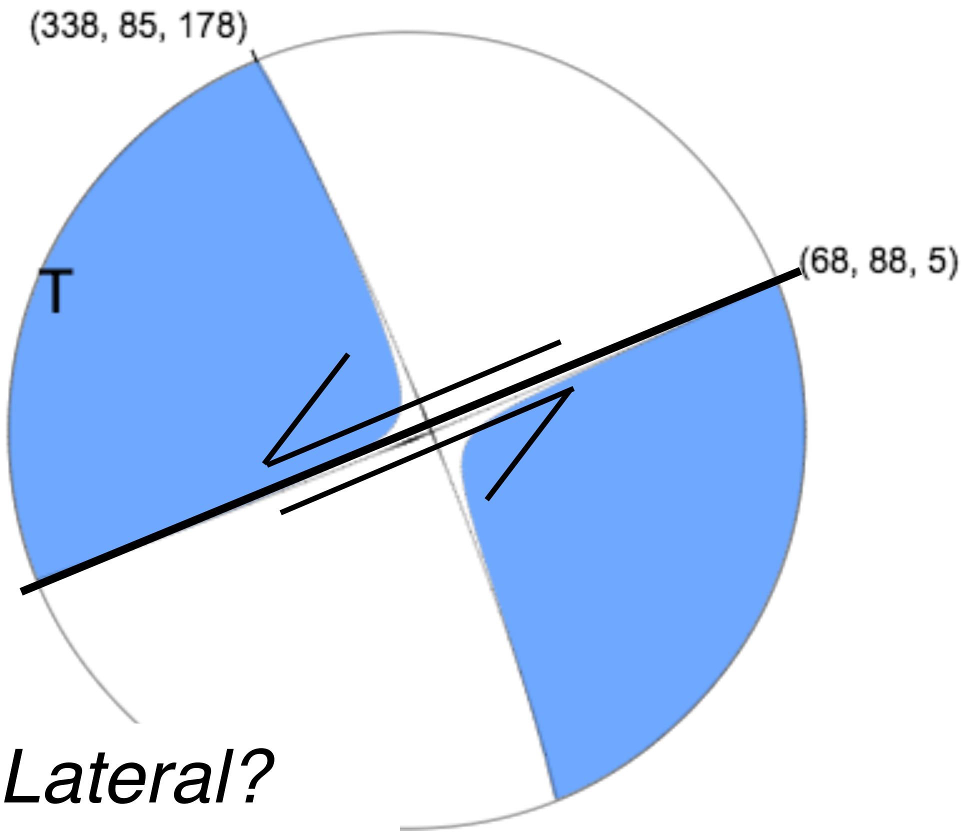
Standard seismological analysis assumes a point source: inherent fault plane ambiguity

Fault Orientation



North-South Right Lateral?

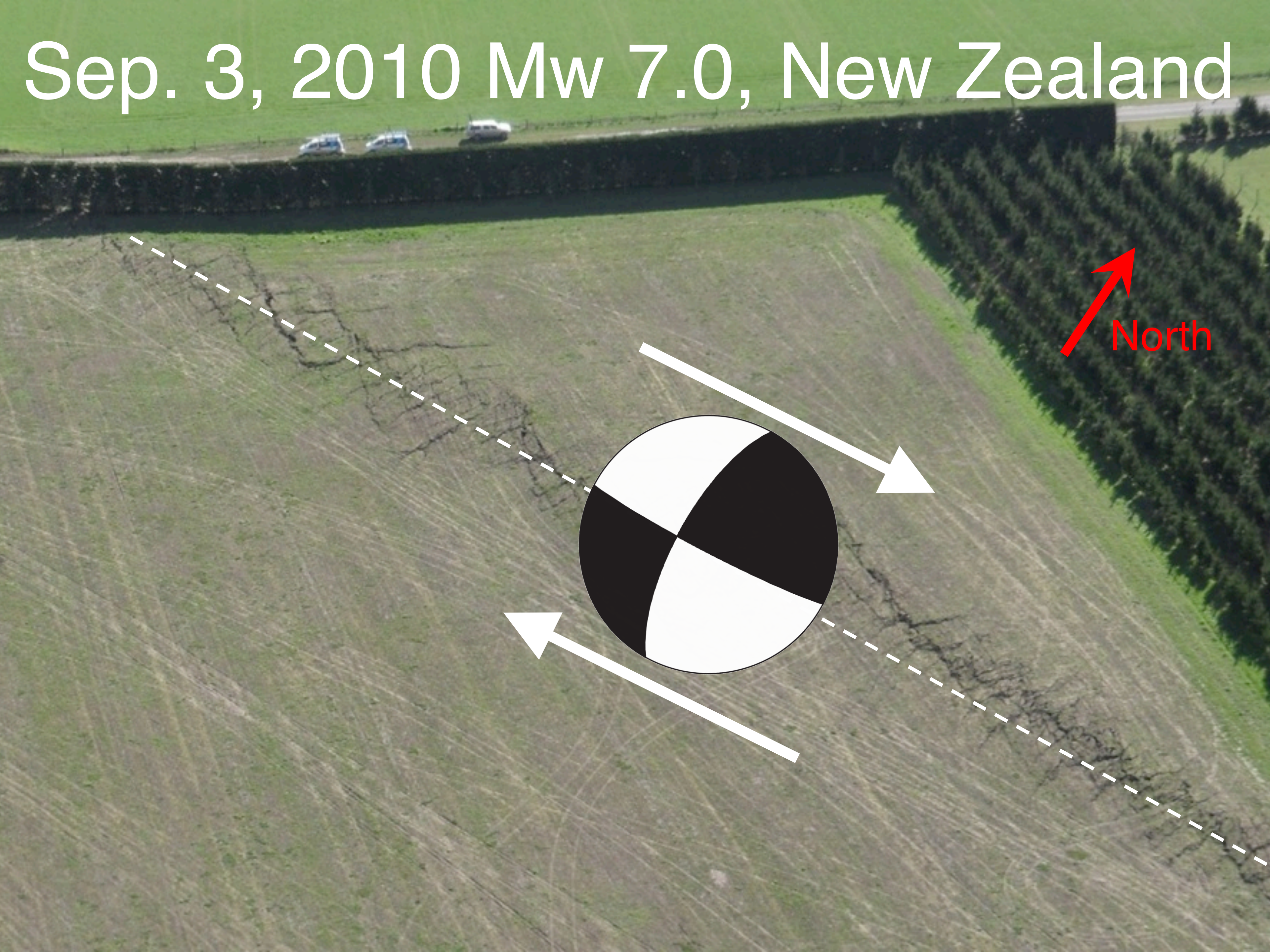
Fault Orientation



East-West Left Lateral?

Fault Orientation

- Preferred constraint: surface rupture


Sep. 3, 2010 Mw 7.0, New Zealand
North

Fault Orientation

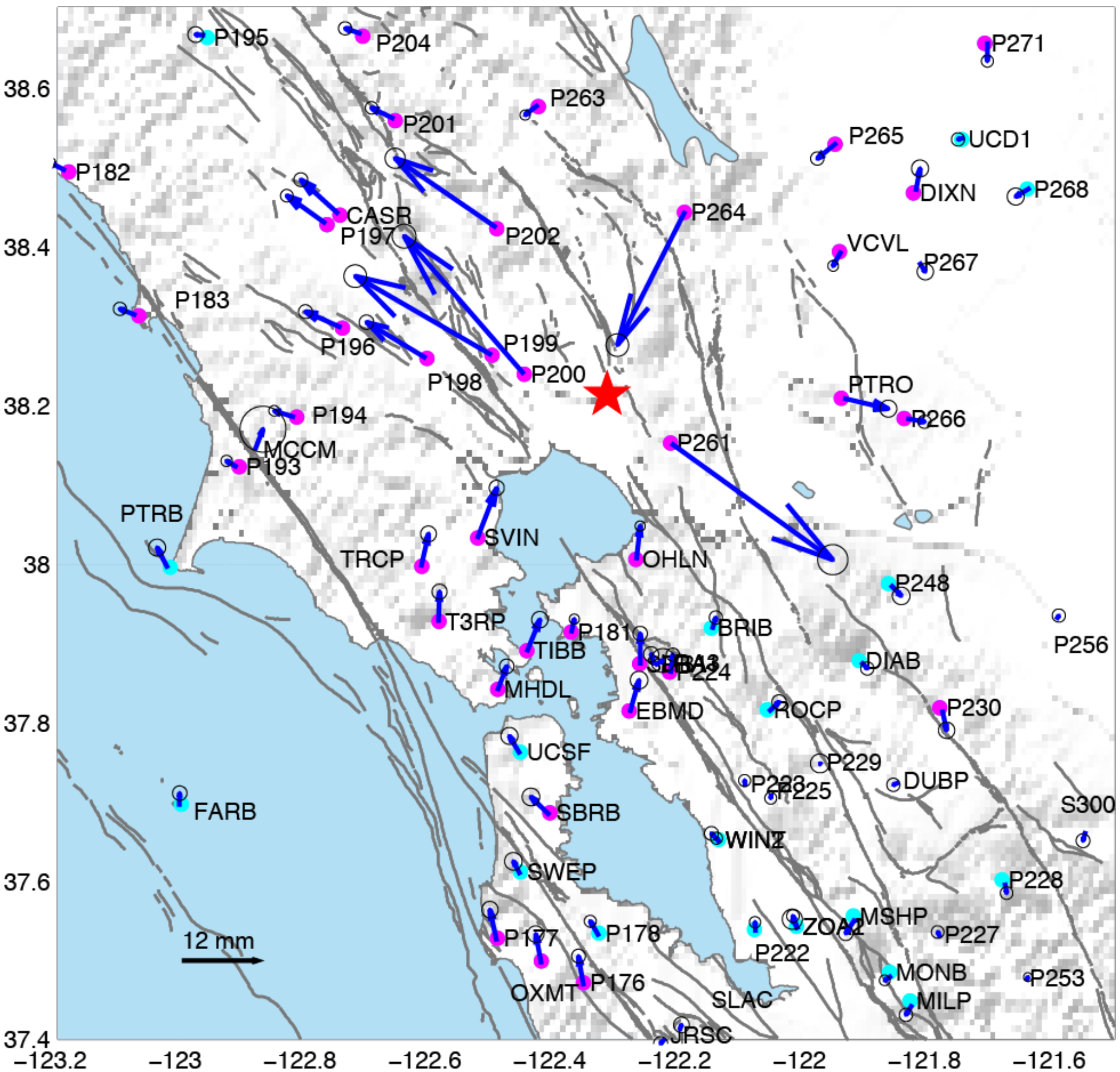
- Preferred constraint: surface rupture

Most earthquakes Mw 6.5 and smaller do not generate surface ruptures.

Fault Orientation

- Preferred constraint: surface rupture
- Geodetic observations

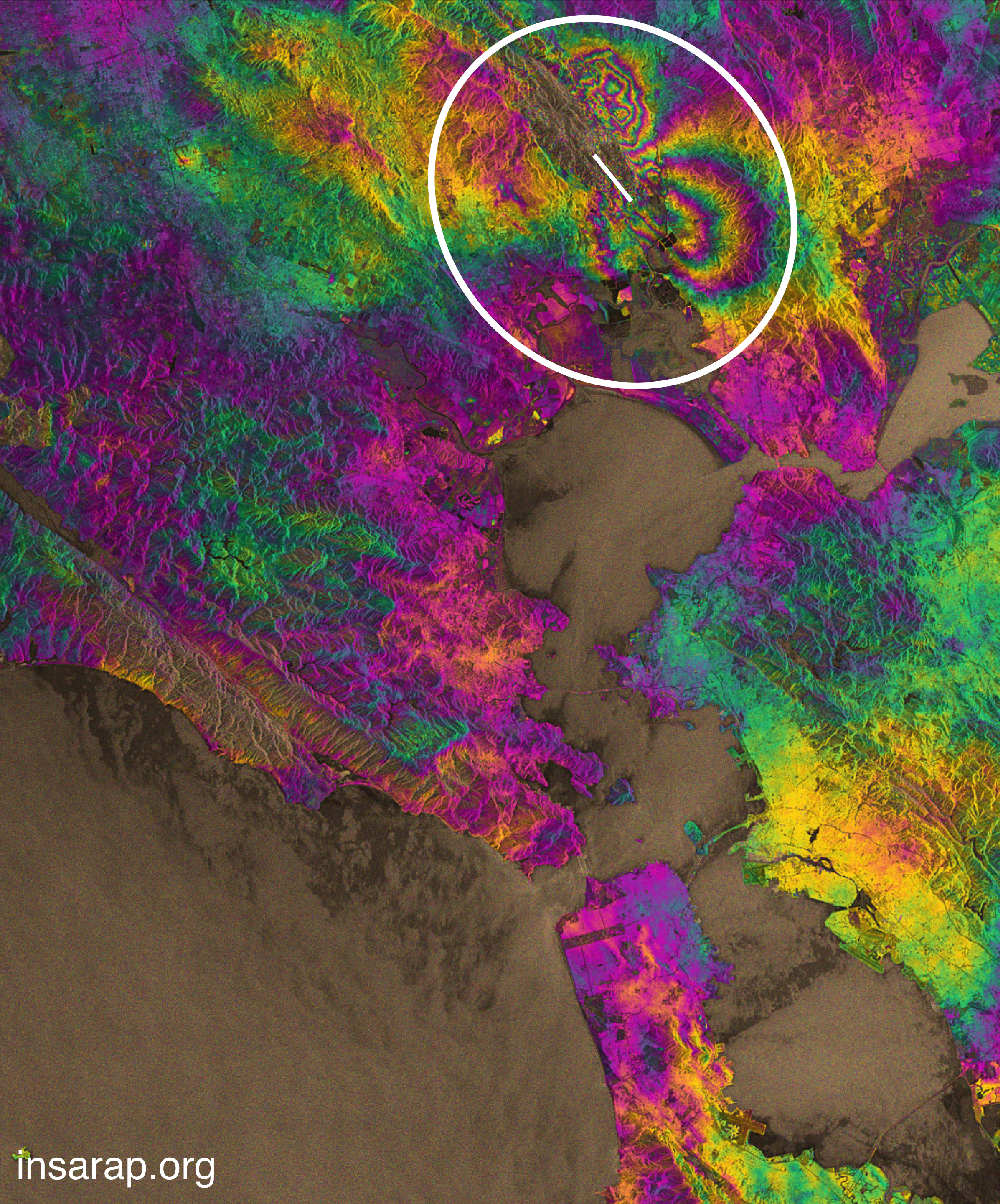
Fault Orientations



Cyan = over 1 sigma, Magenta = over 2 sigma

- 2014 Mw 6.0 Napa, CA earthquake
- Point GPS data not close enough to source to resolve fault plane

Nevada Geodetic Laboratory



- 2014 Mw 6.0 Napa, CA earthquake
- InSAR image can help constrain fault plane
- Swath data instead of point data

Fault Orientation

- *Exercise: compare the expected surface deformation field for both possible fault planes of the 2014 Mw 6.1 Chiang Rai earthquake.*
- *Where would we need geodetic observations to distinguish the fault planes?*

Fault Orientation

- Regional moment tensor solution

Location: 99.683ºE, 19.703ºN, 7.5 km deep
Magnitude: 6.1

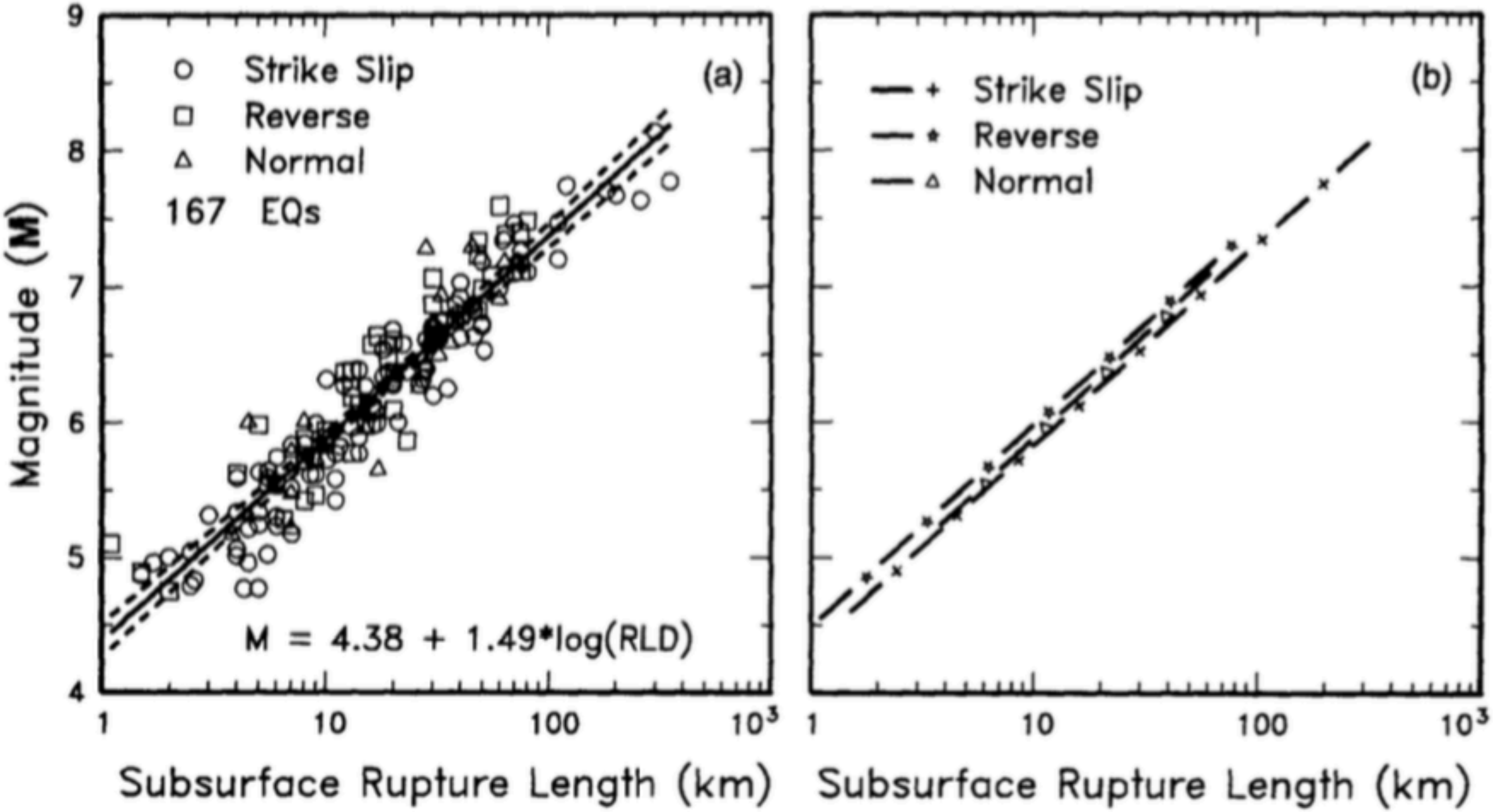
Right lateral kinematics: strike=157, dip=88, rake=177

Left lateral kinematics: strike=247, dip=87, rake=2

Magnitude to Fault Size

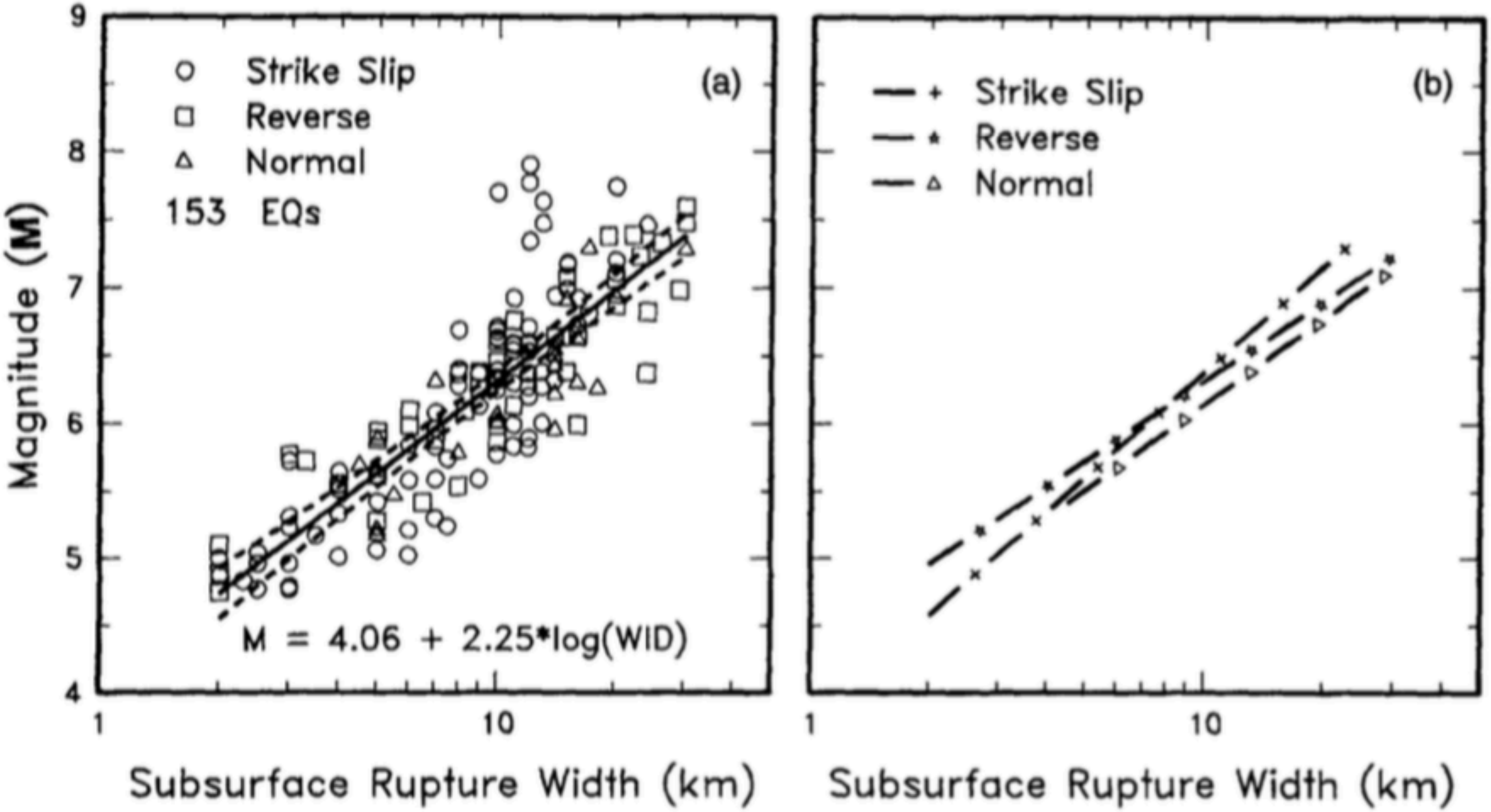
- We usually know the *magnitude* of the earthquake, and have to estimate the *slip and dimensions* of the earthquake for use with O92UTIL
- Typically, both slip and fault area increase systematically with magnitude

Magnitude to Fault Size



Wells and Coppersmith (1994)

Magnitude to Fault Size



Wells and Coppersmith (1994)

Magnitude to Fault Size

- O92UTIL implements several different empirical relations, allowing the user to put magnitude in the input fault file instead of fault slip and dimensions

Magnitude to Fault Size

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

Note: this is not the Chiang Rai earthquake!

```
-70.92 -19.94 12 284 26 54 6.7
```

Lon Lat Dep Strike Dip Rake Mag

Same as previous input format

Magnitude to Fault Size

- Input fault file (fault.dat)

Note: this is not the Chiang Rai earthquake!

```
-70.92 -19.94 12 284 26 54 6.7
```

Lon Lat Dep Strike Dip Rake Mag

Event magnitude is converted to dimensions using empirical relations, and slip is computed using the shear modulus defined in the half-space file.

Magnitude to Fault Size

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

(instead of `o92util -flt fault.dat...`)

Empirical relations can be defined using command line option -empirical

Fault Orientation

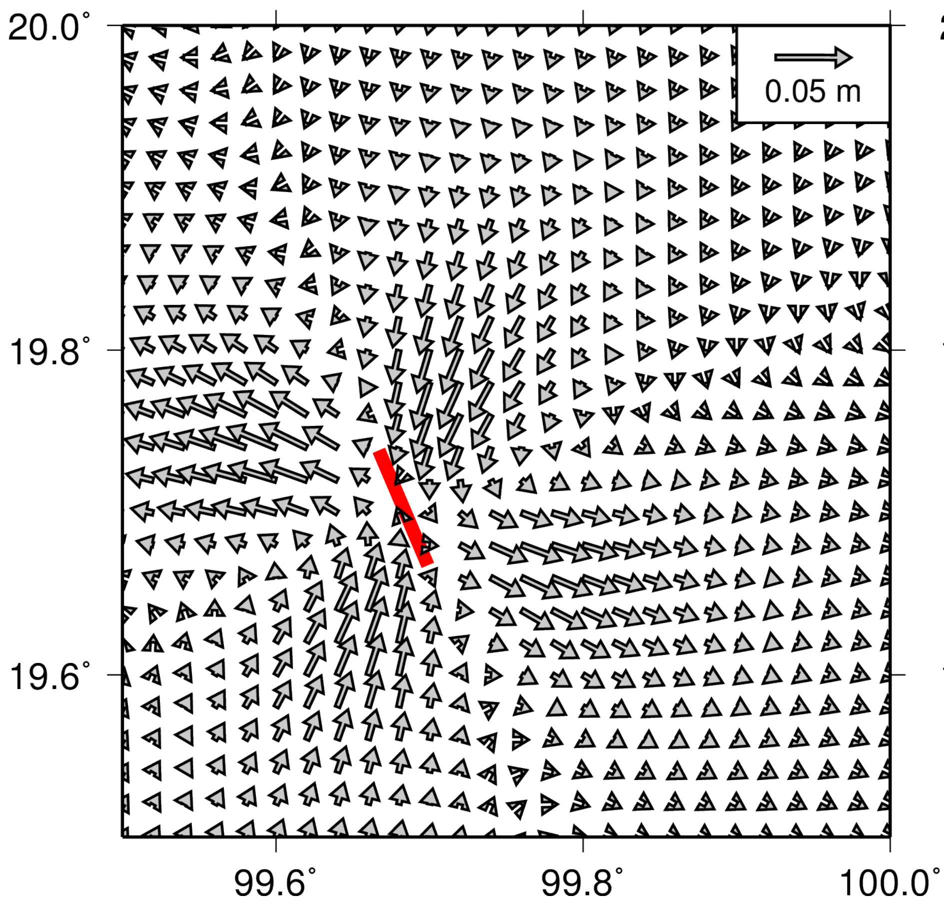
- Regional moment tensor solution

Location: 99.683ºE, 19.703ºN, 7.5 km deep
Magnitude: 6.1

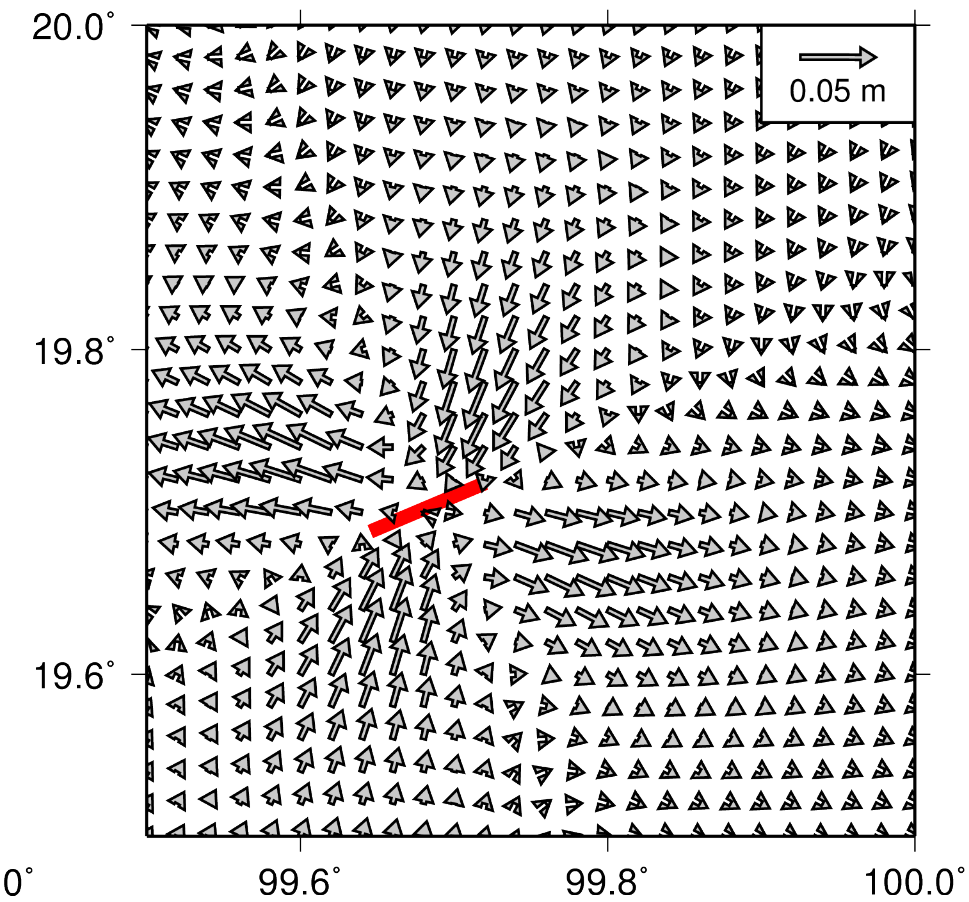
Right lateral kinematics: strike=157, dip=88, rake=177

Left lateral kinematics: strike=247, dip=87, rake=2

Fault Orientation

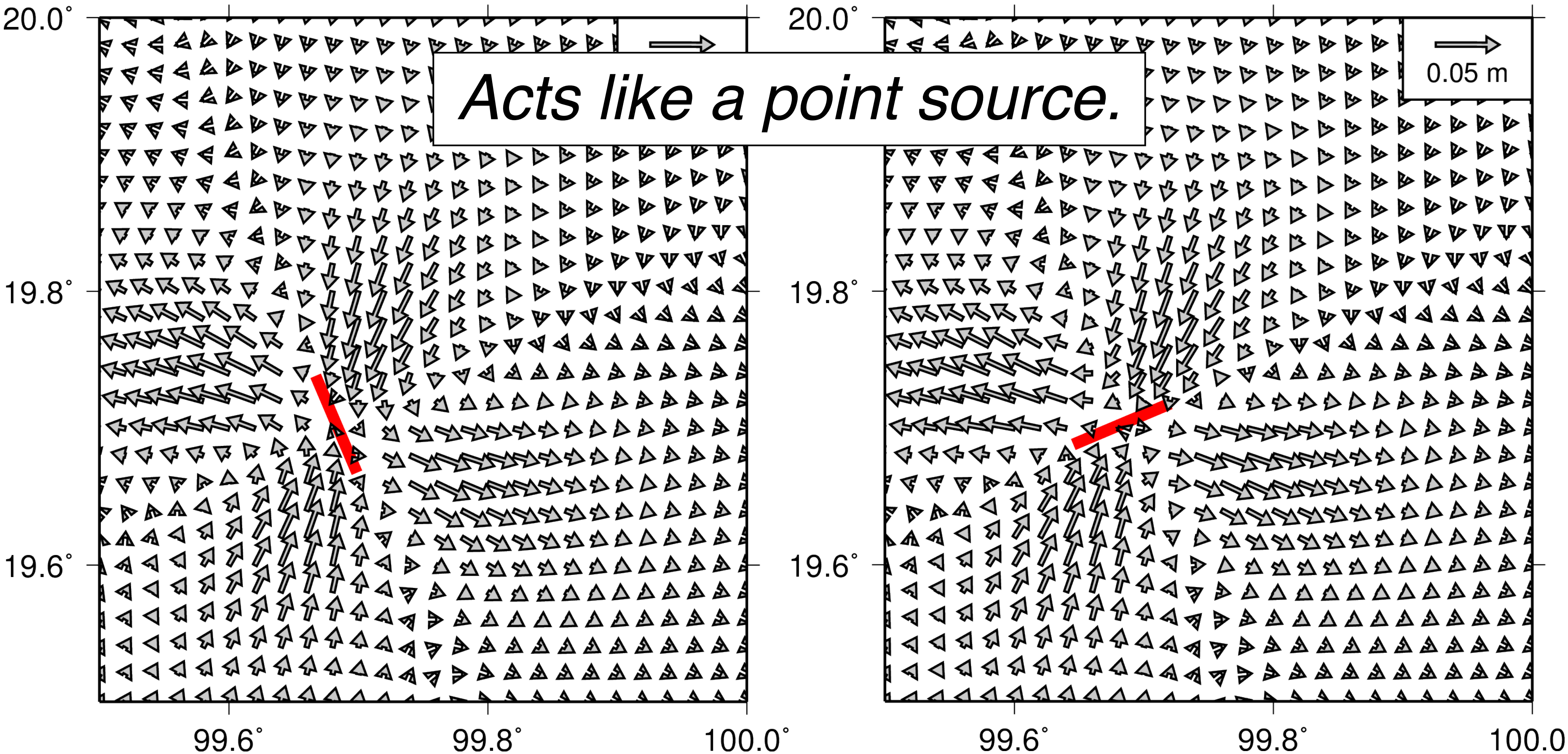


North-South Right Lateral



East-West Left Lateral

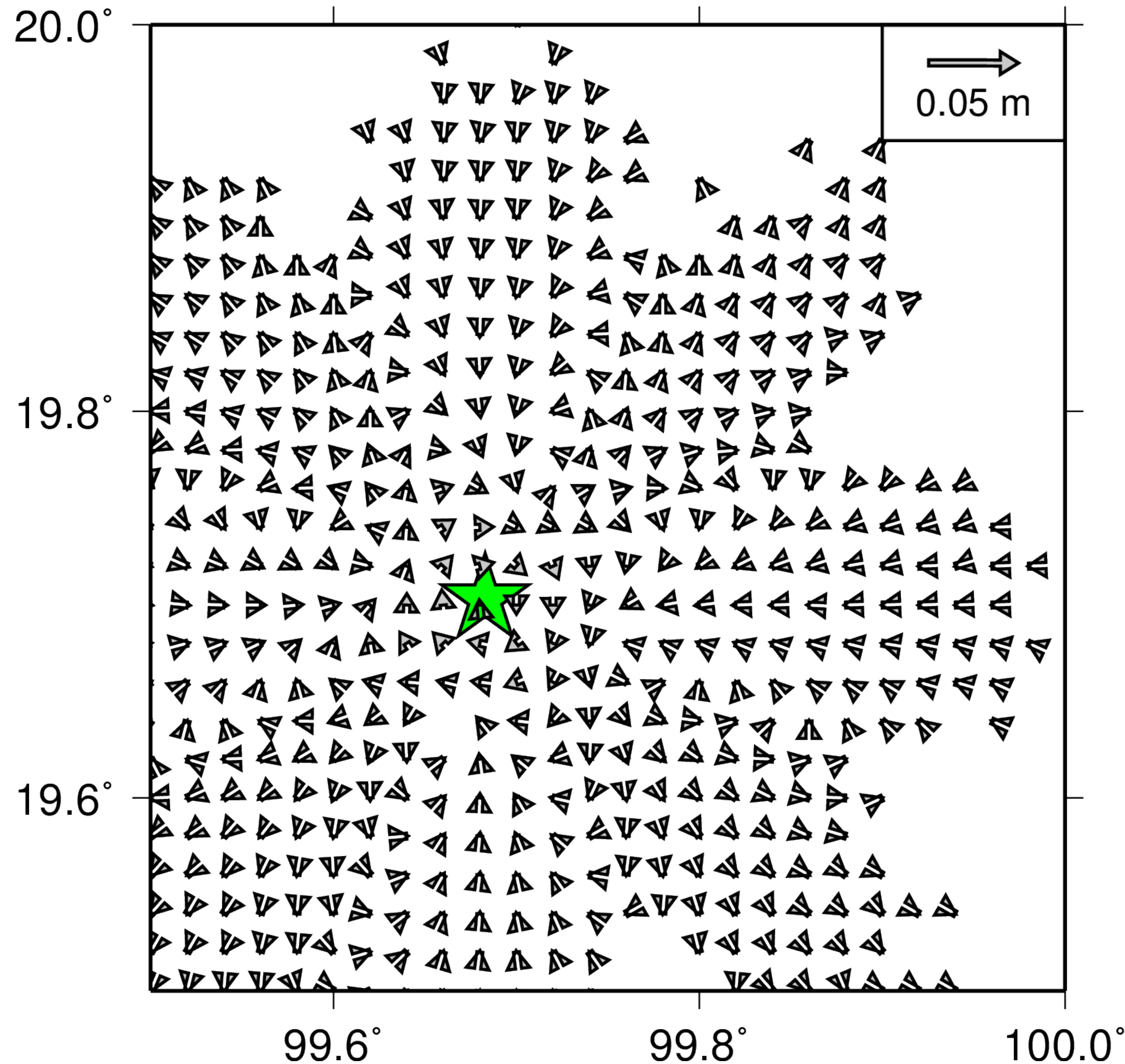
Fault Orientation



North-South Right Lateral *East-West Left Lateral*

Fault Orientation

- Difference between output results
- Greater than ~1 fault length, there is no detectable difference



Fault Orientation

- Input fault file

Right lateral:

```
99.683 19.703 7.5 157 88 177 6.1
```

Left lateral:

```
99.683 19.703 7.5 247 87   2 6.1
```

Fault Orientation

- Input receiver file

```
grid -x 99.5 100 -dx 0.02 -y 19.5 20
    -dy 0.02 -z 0.0 -o station.dat
```

Fault Orientation

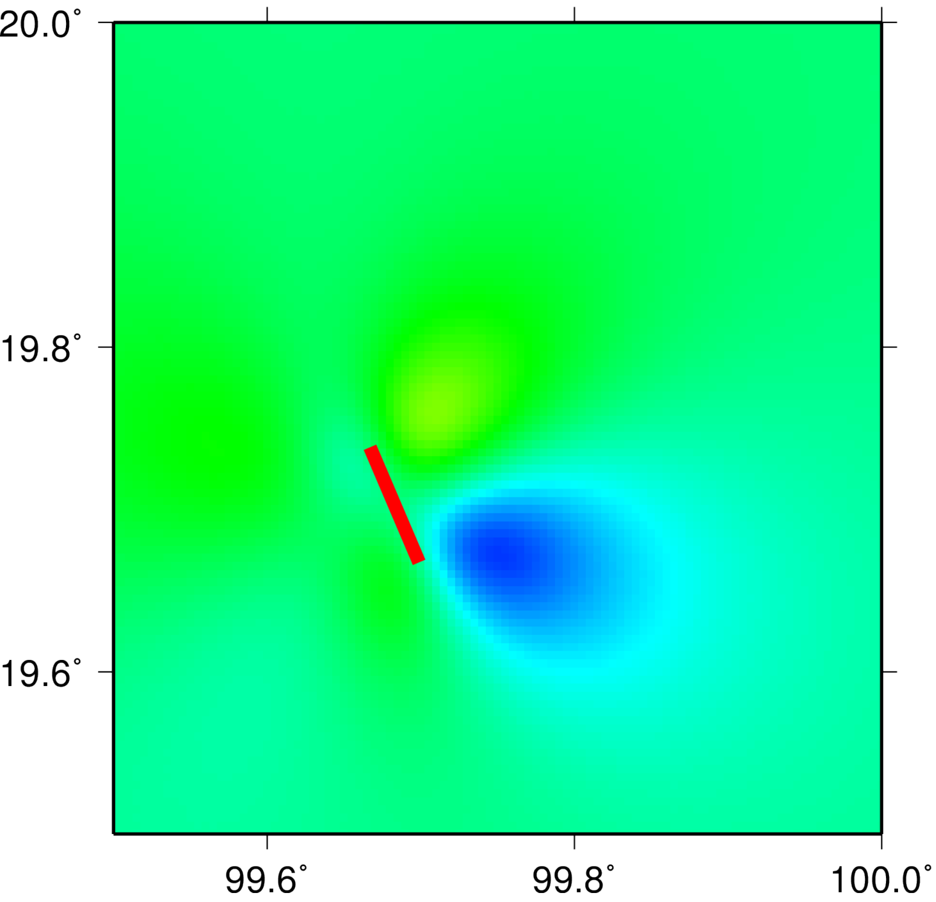
- Input half-space file

```
Lame 3.5e10 3.5e10
```

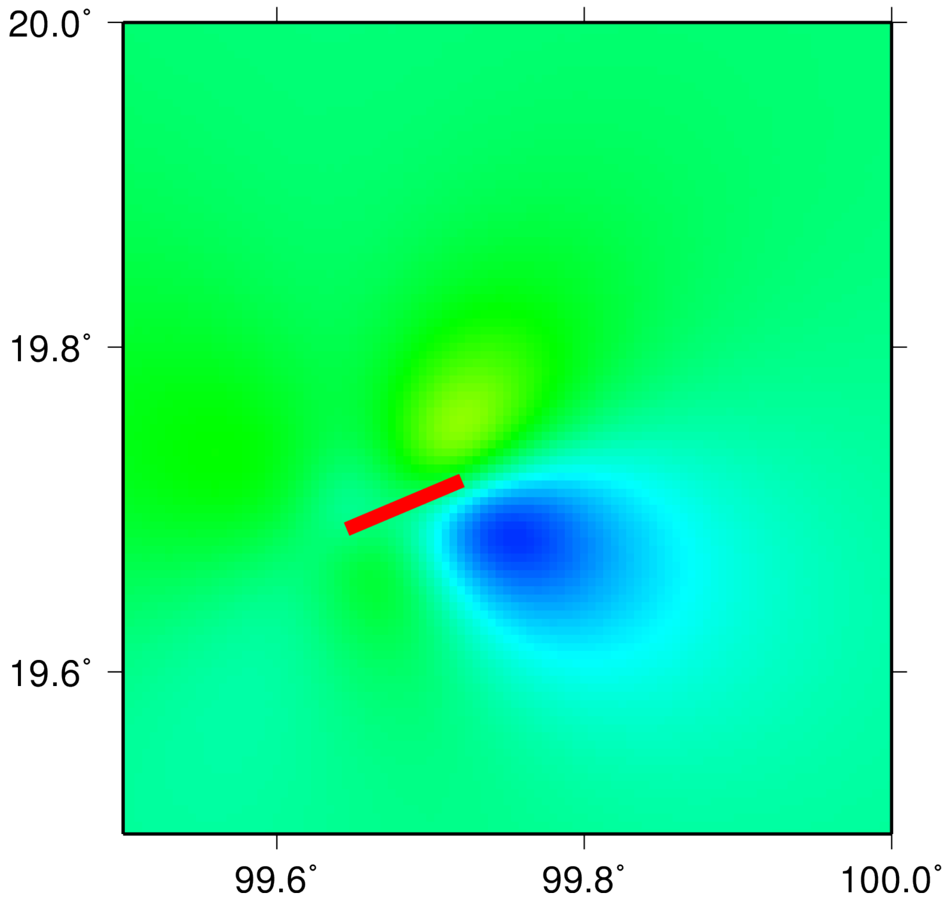
Fault Orientation

- *Bonus exercise: model the expected InSAR deformation for the possible fault planes.*
- *How would we model the InSAR? We need a satellite look azimuth (degrees CW from N) and inclination (degrees from horizontal)*

Fault Orientation



North-South Right Lateral



East-West Left Lateral

Fault Orientation

- VEC2LOS
  - Takes (ENZ) output file from O92UTIL and converts to a line-of-sight displacement

```
vec2los -a AZ -i INC -f disp.out -o los.out
```

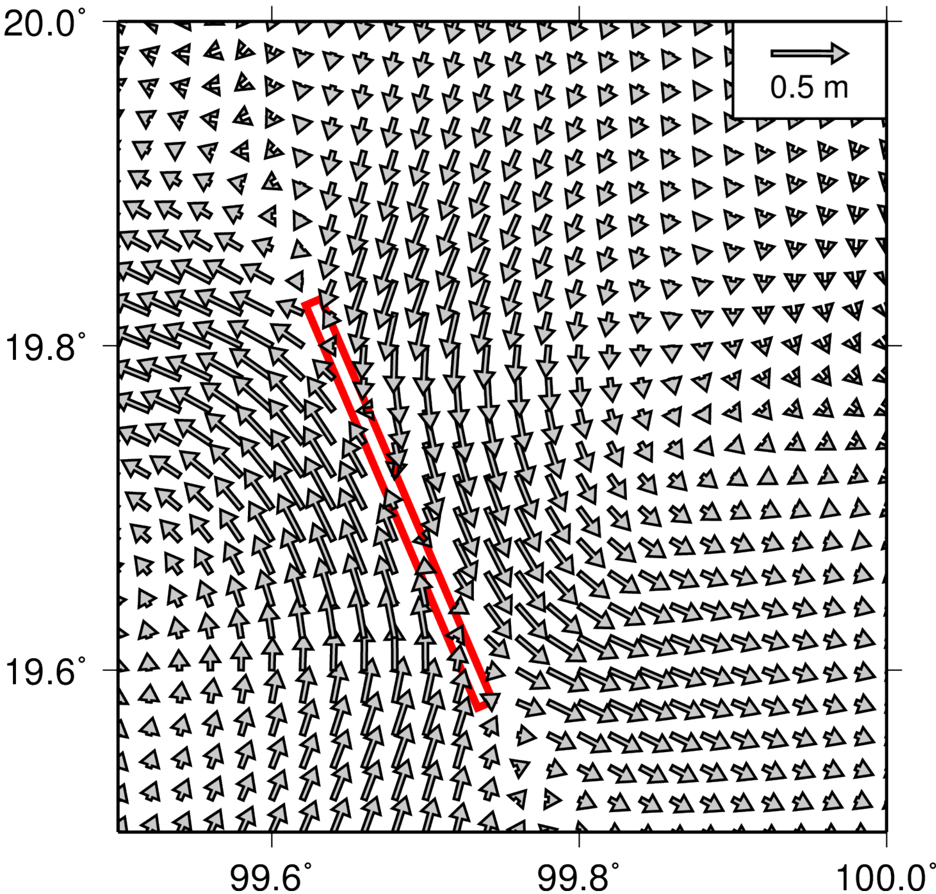
- WRAPLOS
  - Takes output file from VEC2LOS and converts to predicted phase change

```
wraplos -w WVLNTH -f los.out -o phase.out
```

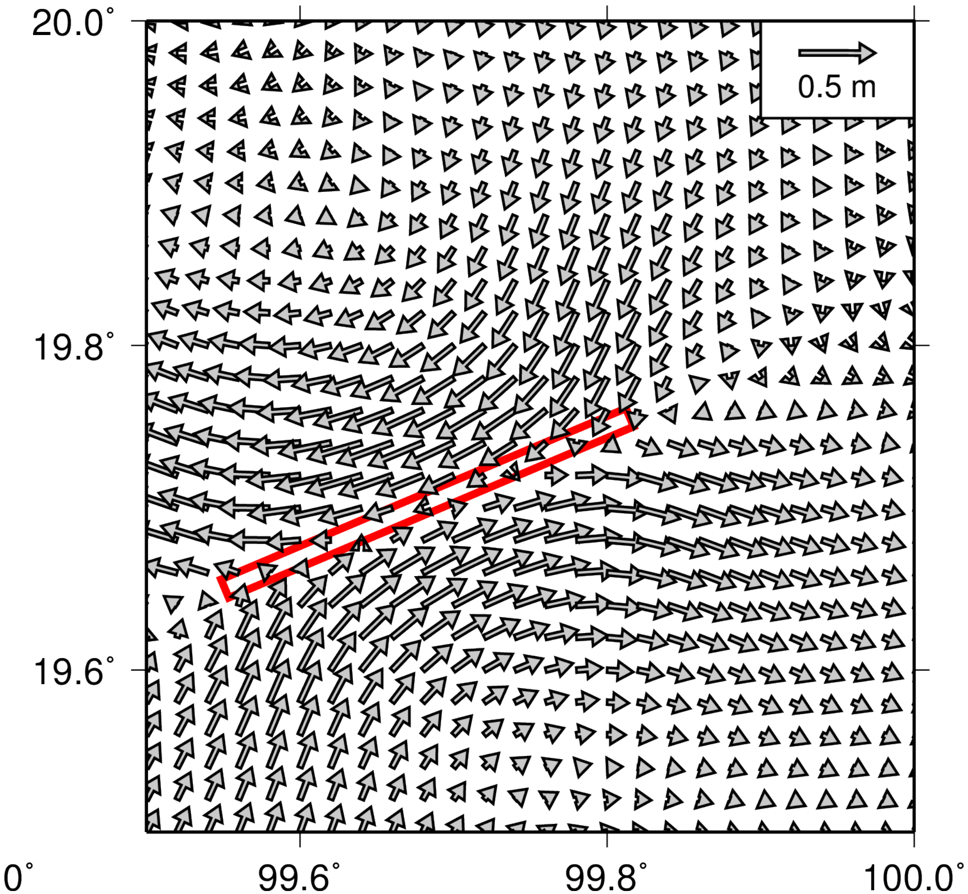
Fault Orientation

- *What if the earthquake had been larger? Could you then use GPS to distinguish between the fault planes? Compare your previous modeled displacements to those from a hypothetical Mw 7.0 earthquake.*

Fault Orientation



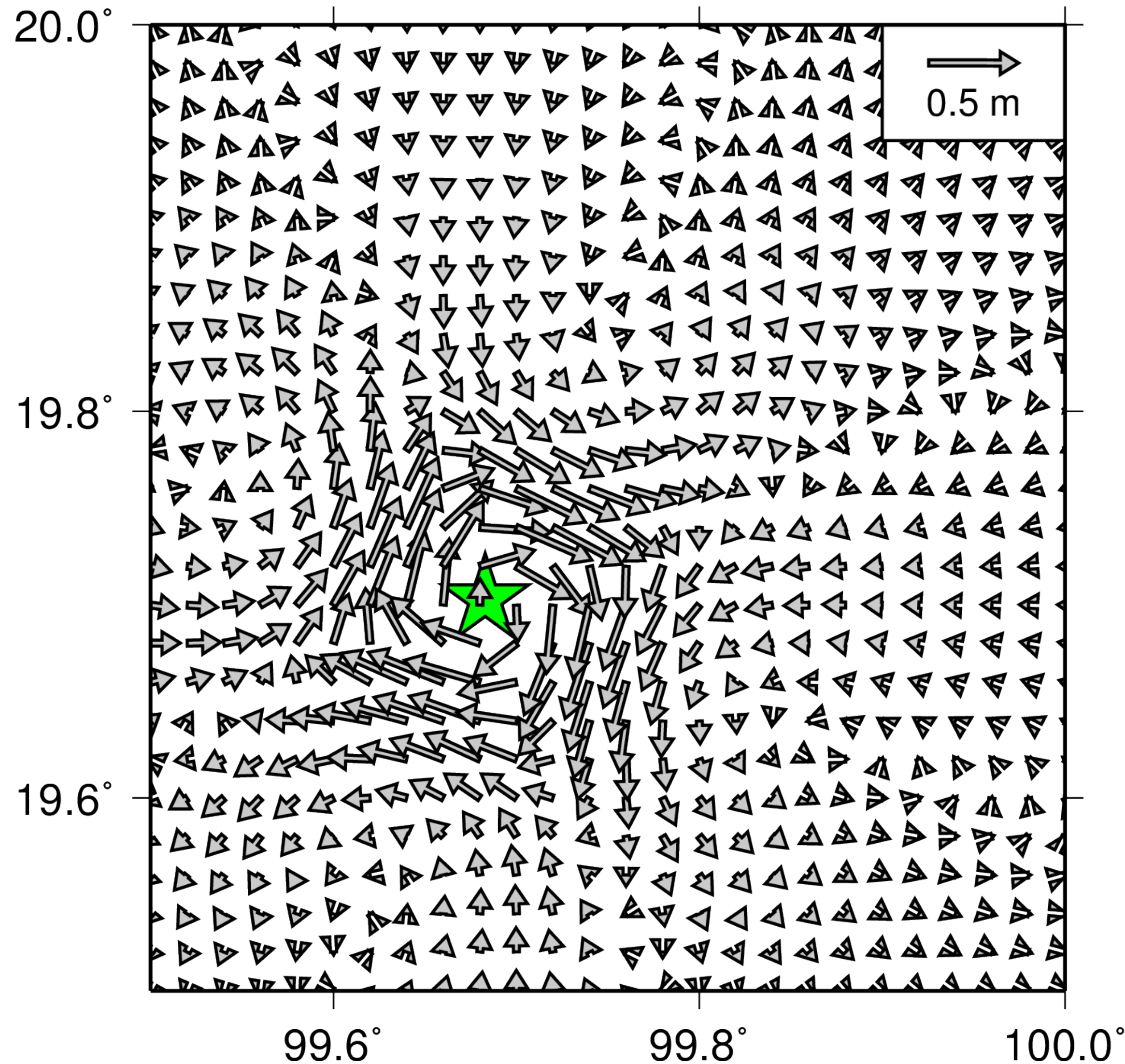
North-South Right Lateral



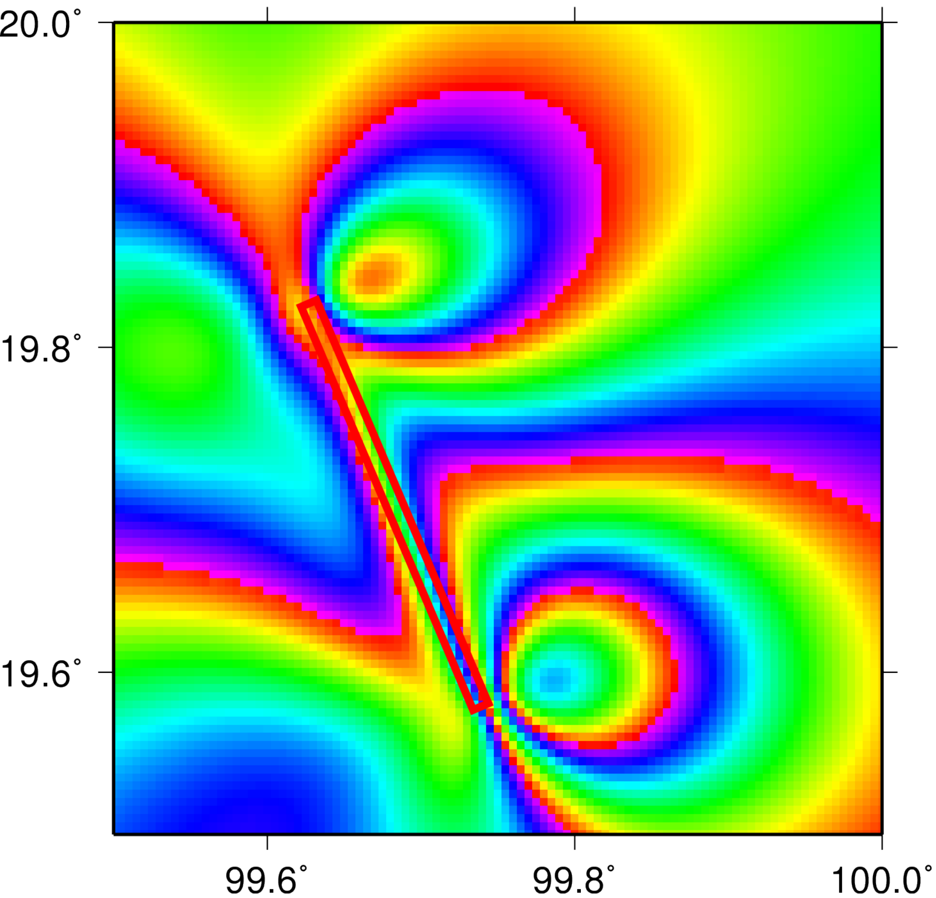
East-West Left Lateral

Fault Orientation

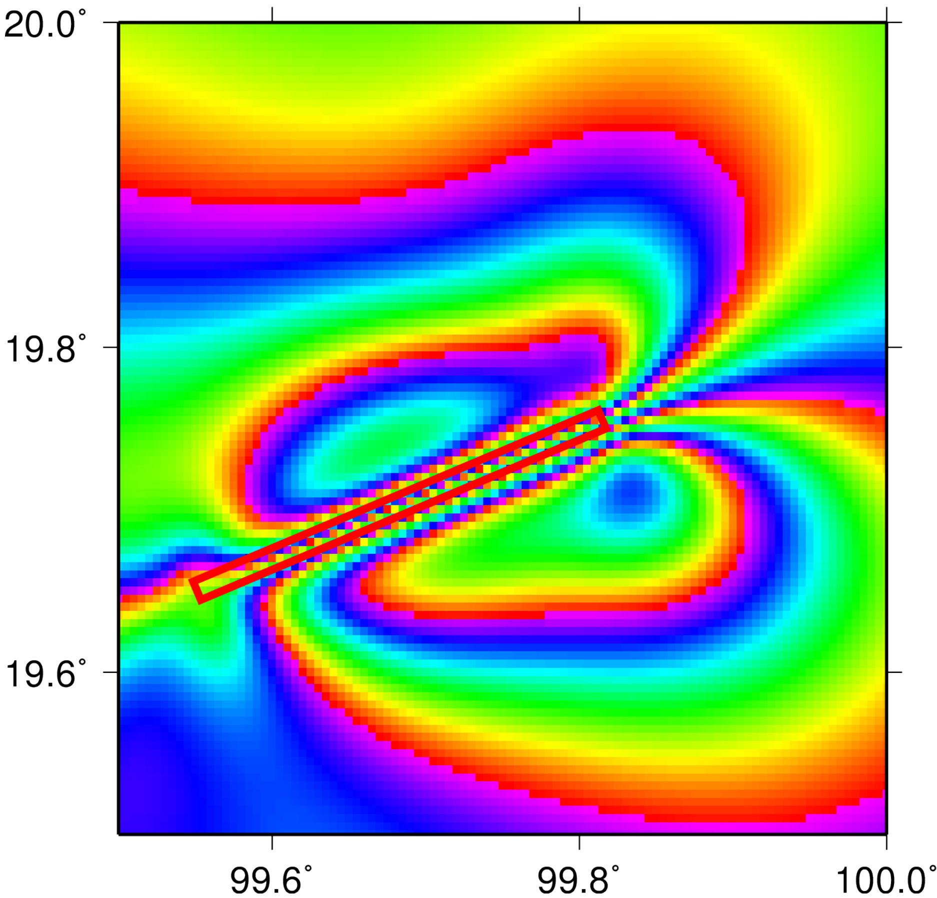
- Difference between output results
- Greater than ~1 fault length, there is no detectable difference
- Now fault length is 30 km



Fault Orientation



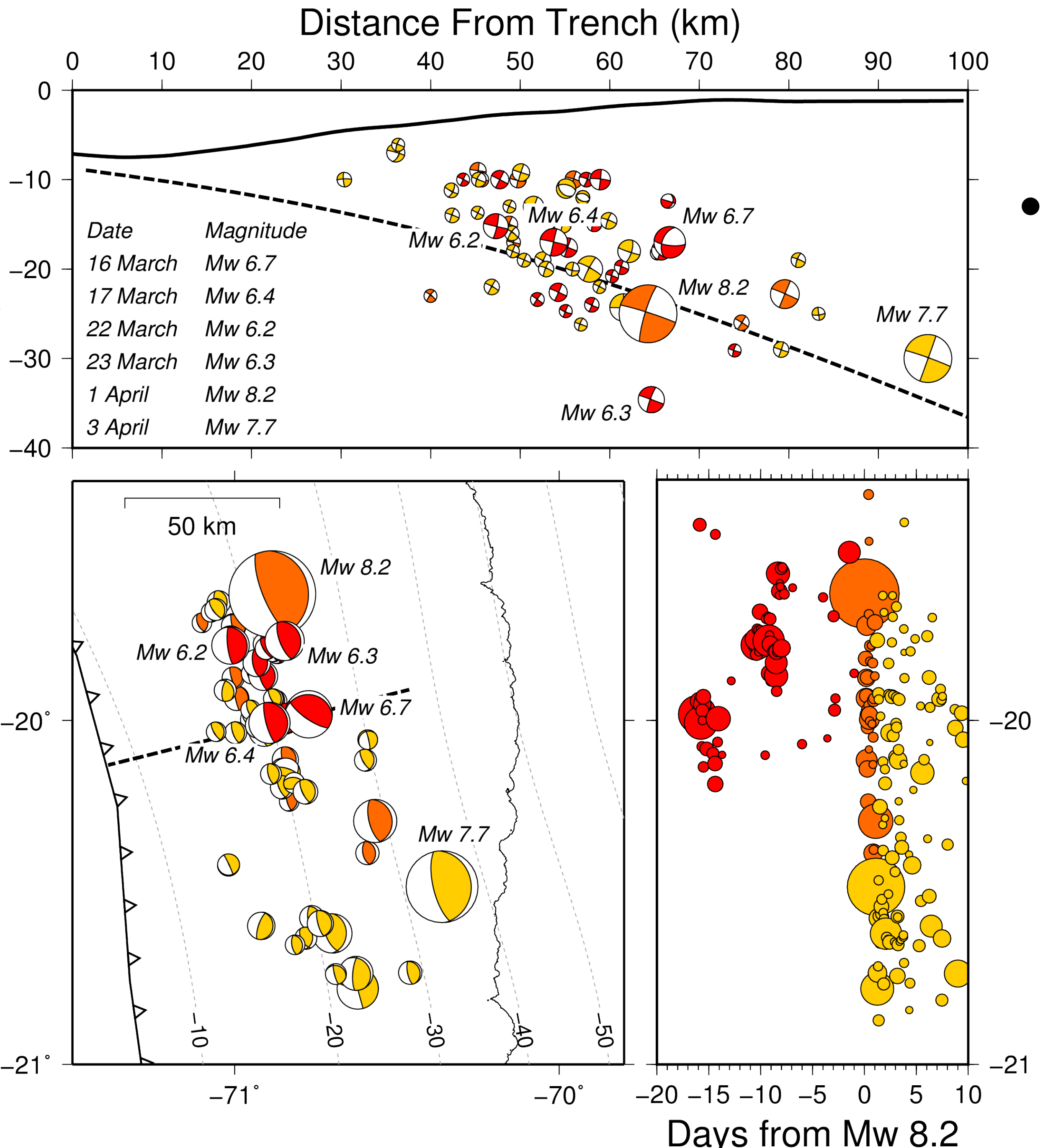
North-South Right Lateral



East-West Left Lateral

Fault Orientation

- Preferred constraint: surface rupture
- Geodetic observations
- Aftershocks aligned along fault plane



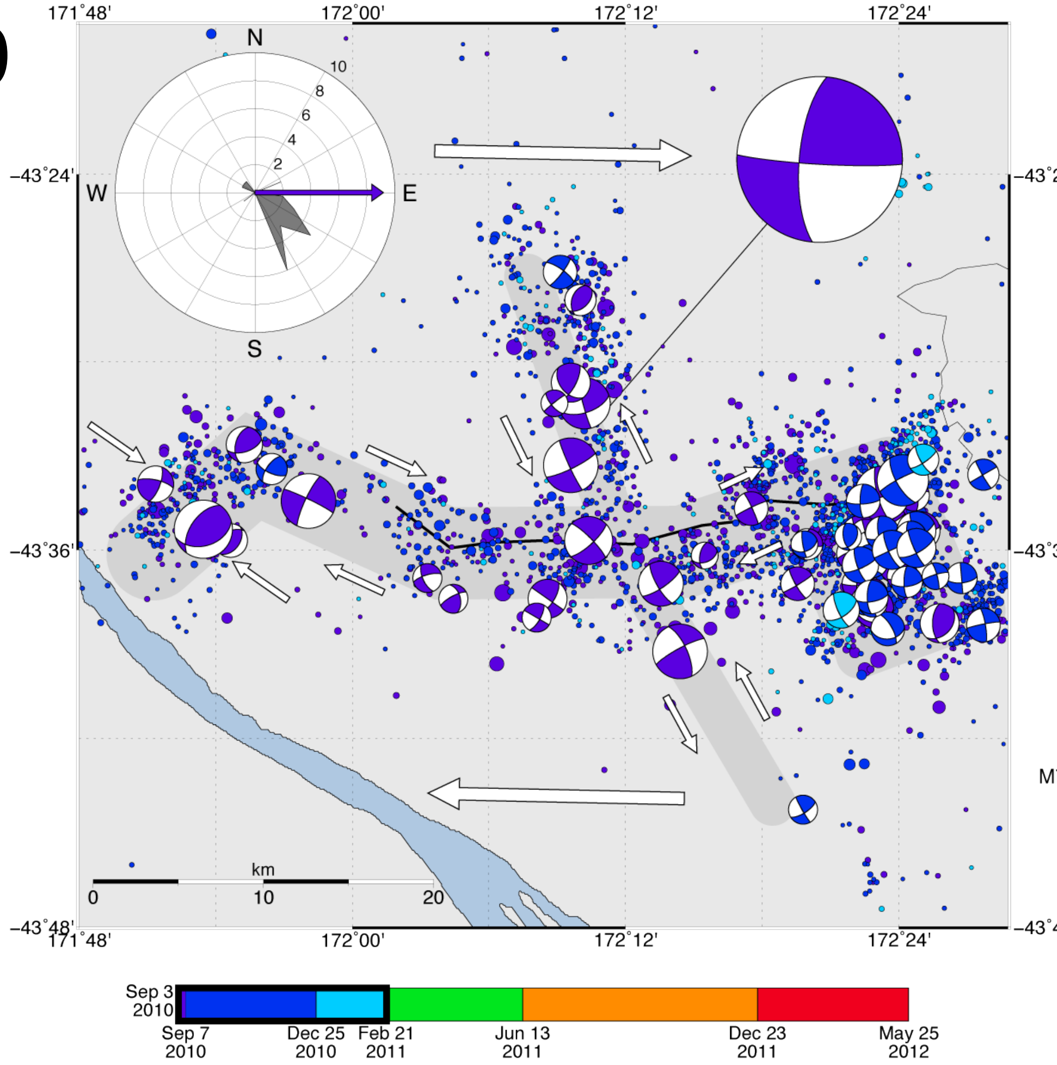
- 2014 Mw 8.2 Iquique earthquake aftershocks lie on plate boundary

Fault Orientation

- Preferred constraint: surface rupture
- Geodetic observations
- Aftershocks aligned along fault plane
- In Thailand, aftershocks on both planes, immediately after main shock rupture, similar to 2010-2011 New Zealand events

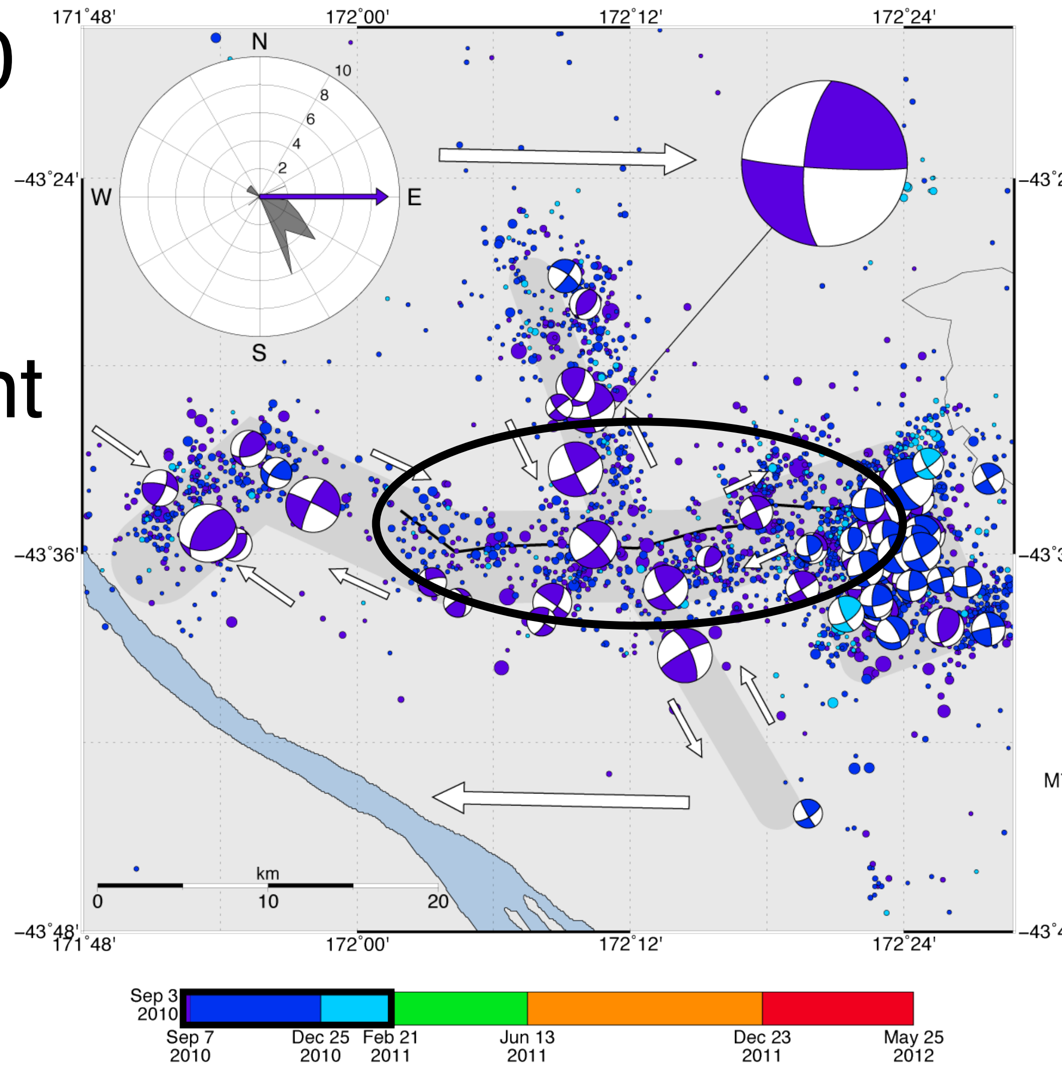
Fault Orientation

- Sep. 2010 Mw 7.0 earthquake



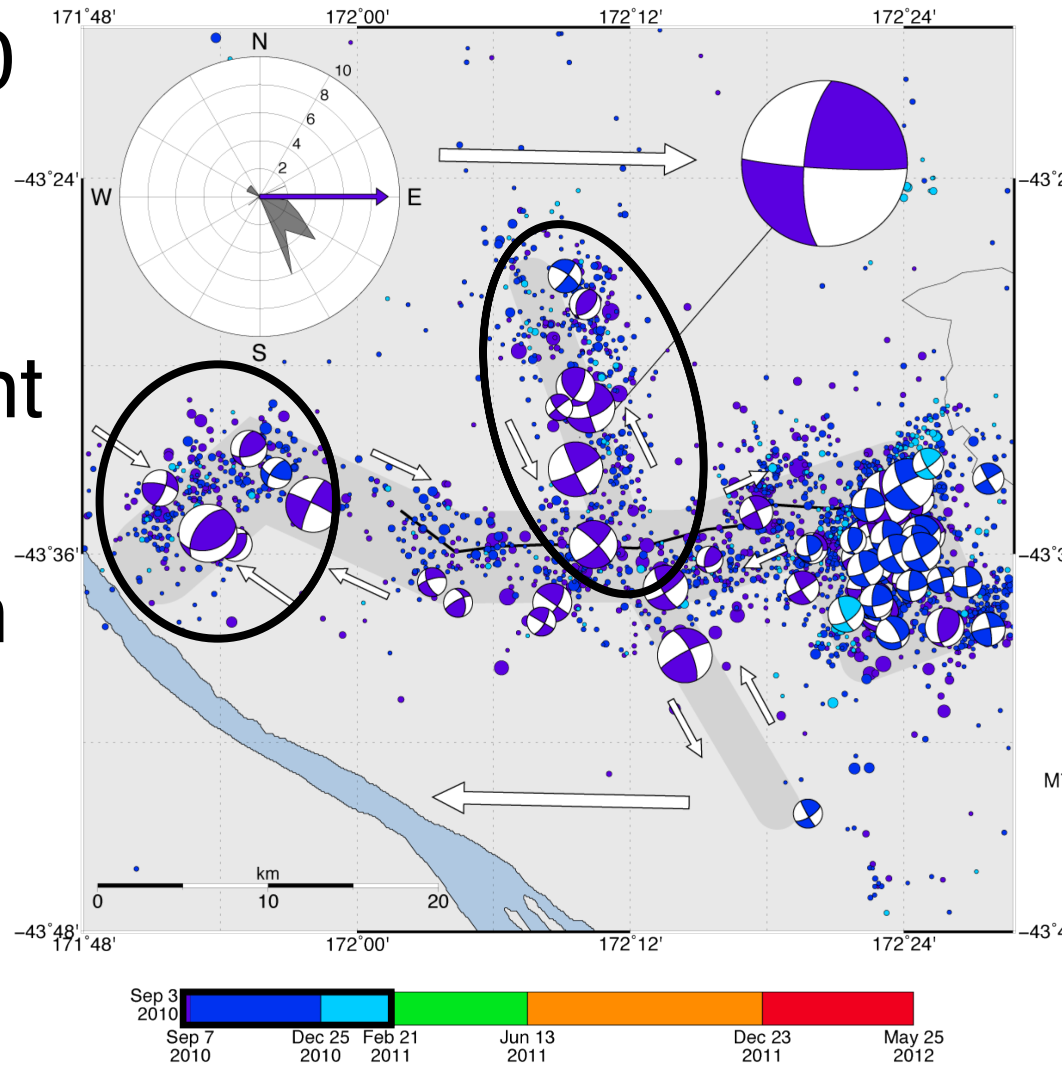
Fault Orientation

- Sep. 2010 Mw 7.0 earthquake
- Dominant slip on east-west segment (surface rupture)



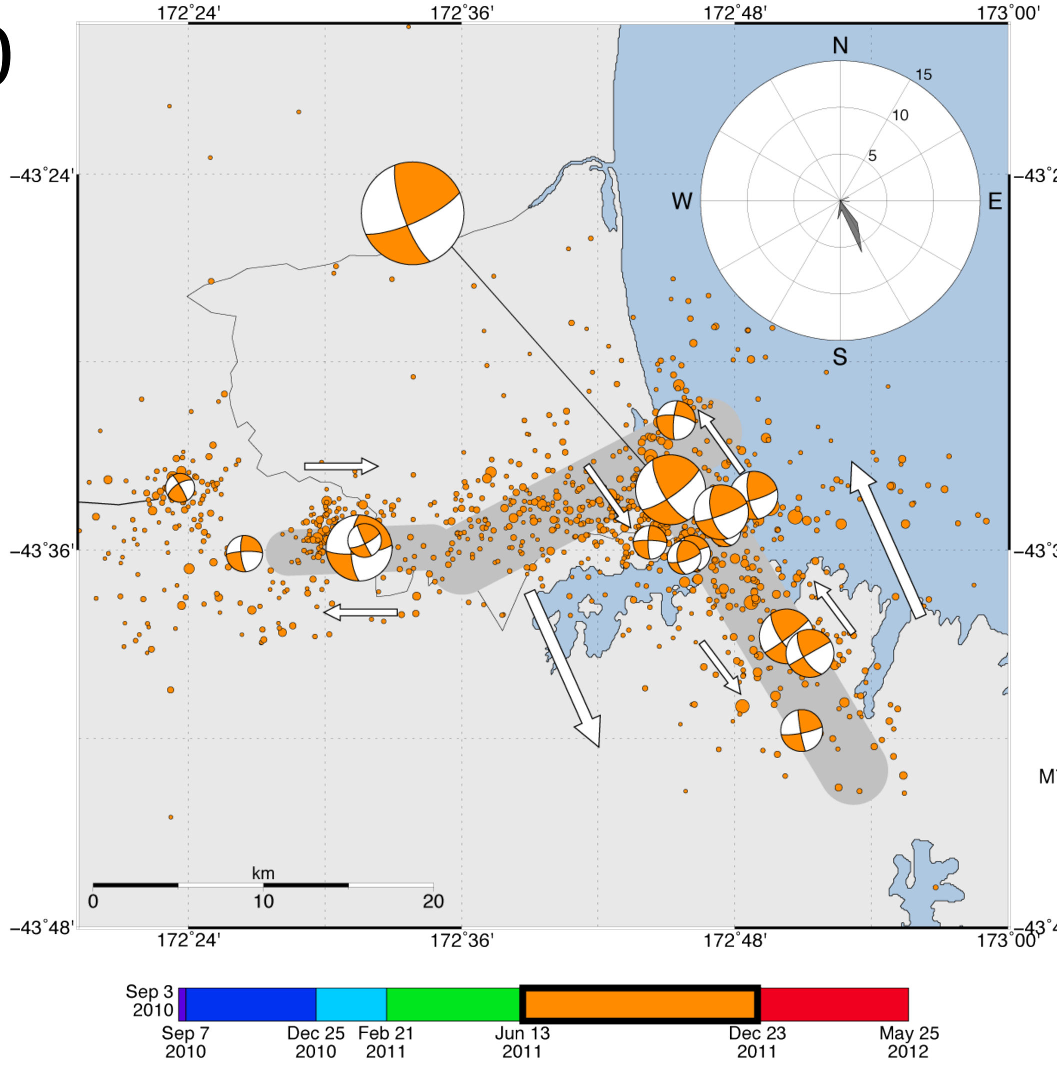
Fault Orientation

- Sep. 2010 Mw 7.0 earthquake
- Dominant slip on east-west segment (surface rupture)
- Western, northern segments



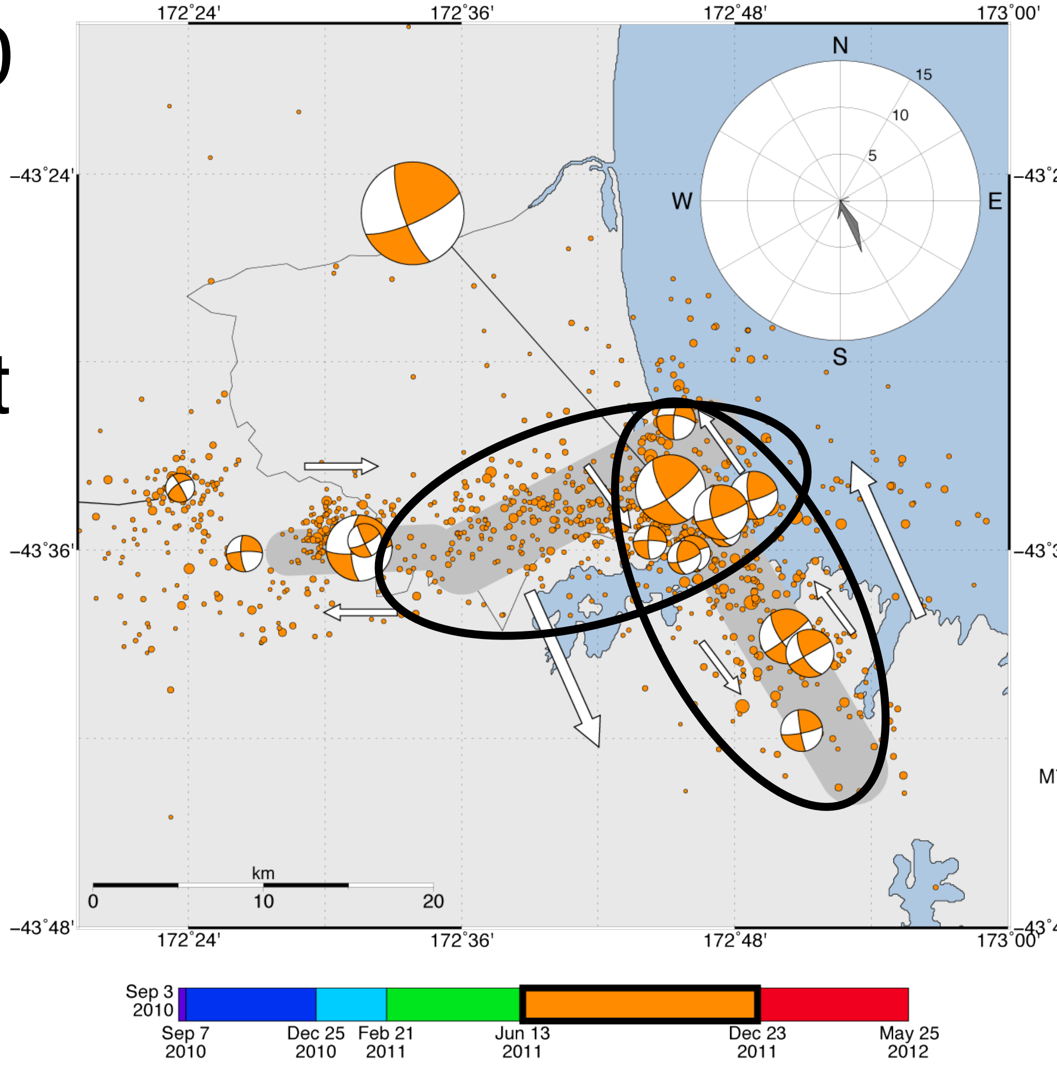
Fault Orientation

- June 2011 Mw 6.0 earthquake



Fault Orientation

- June 2011 Mw 6.0 earthquake
- Aftershocks along both possible fault planes

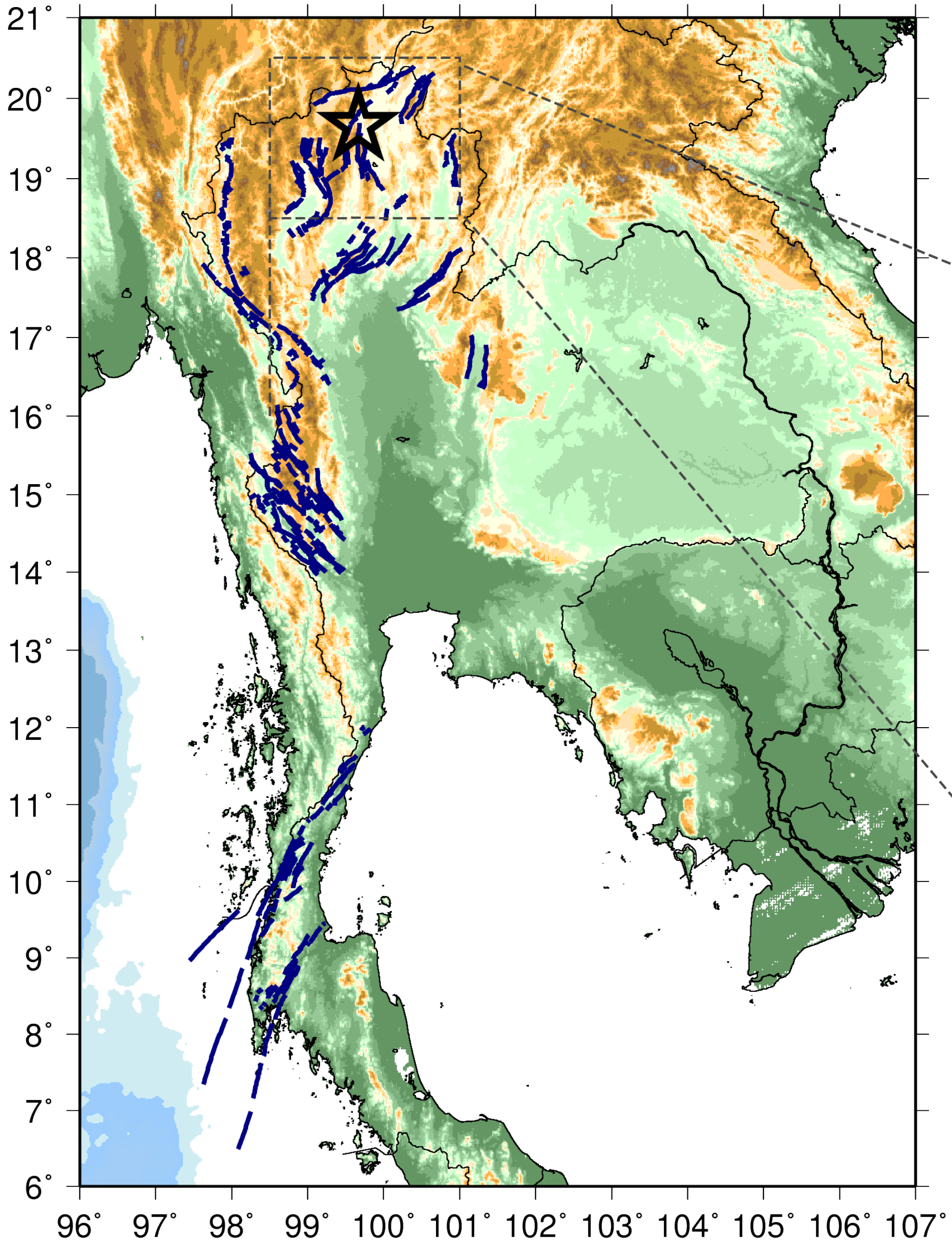


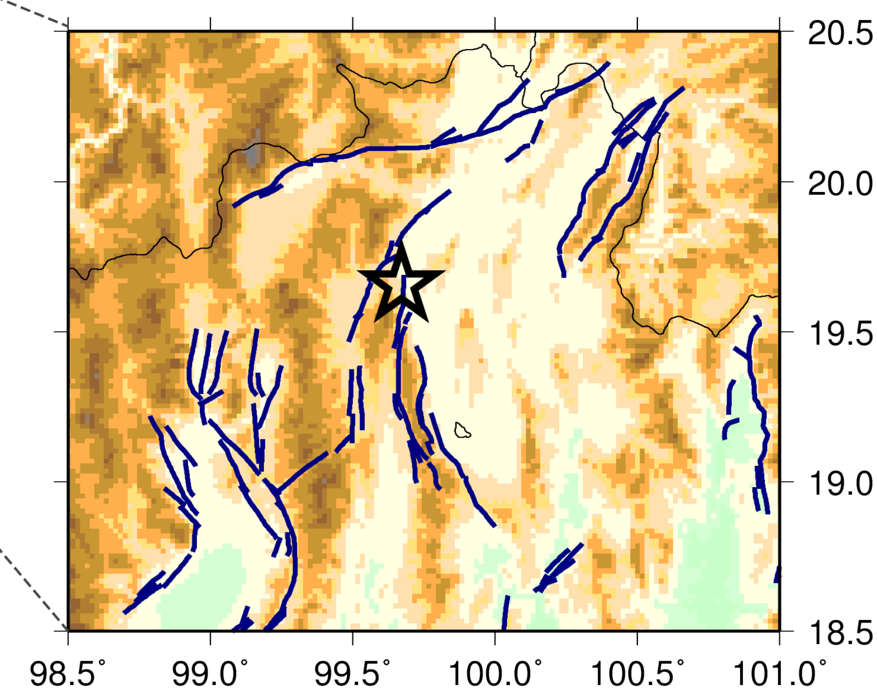
Fault Orientation

- Take-home message: can be difficult to constrain fault plane for:
  - Earthquakes smaller than Mw ~7.0
  - Events occurring under water
  - Deep earthquakes

Fault Loading in N. Thailand

- How did the 5 May 2014 main shock (and largest aftershocks) load the surrounding region?
- Did these earthquakes make a future event more likely?





Active faults in Thailand. The earthquake occurred in a region with many known faults.

Fault Loading in N. Thailand

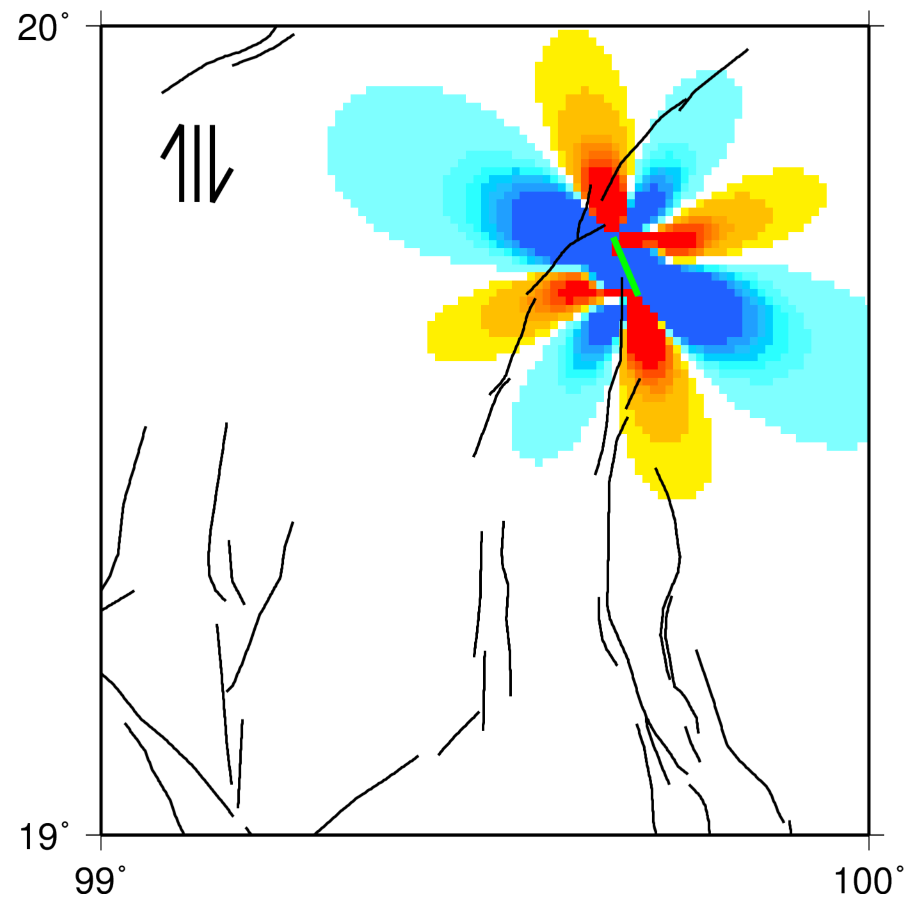
- We can use the tools practiced over the last two days to address these issues
- To do this, we need the earthquake parameters from earlier, and possible target fault orientations
- We will test the effects of both possible fault planes, as well as variations in target fault kinematics

Fault Loading in N. Thailand

- *Exercise 2a: assume the 5 May Mw 6.1 earthquake occurred on the north-south plane, and is right lateral strike-slip. Compute the Coulomb stress change surrounding the event and identify the most positively loaded known faults.*
- We will supply a file to plot the active faults in the region

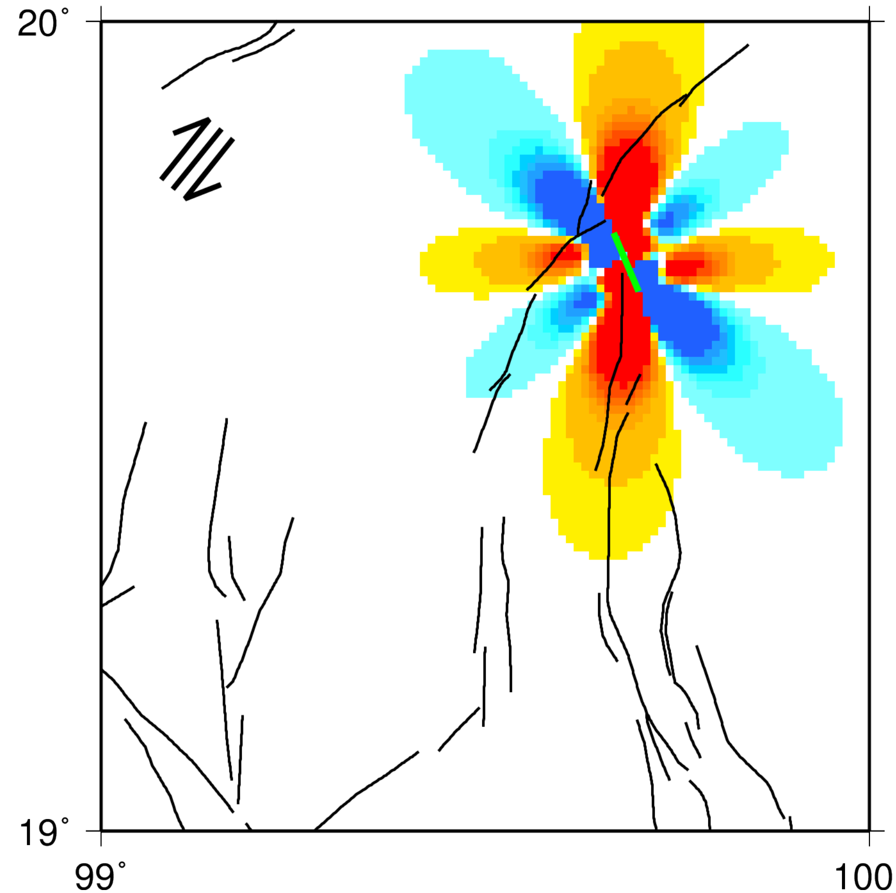
Fault Loading in N. Thailand

- N-S right lateral earthquake
- Resolved on N-S right lateral target faults



Fault Loading in N. Thailand

- N-S right lateral earthquake
- Resolved on NE-SW right lateral target faults

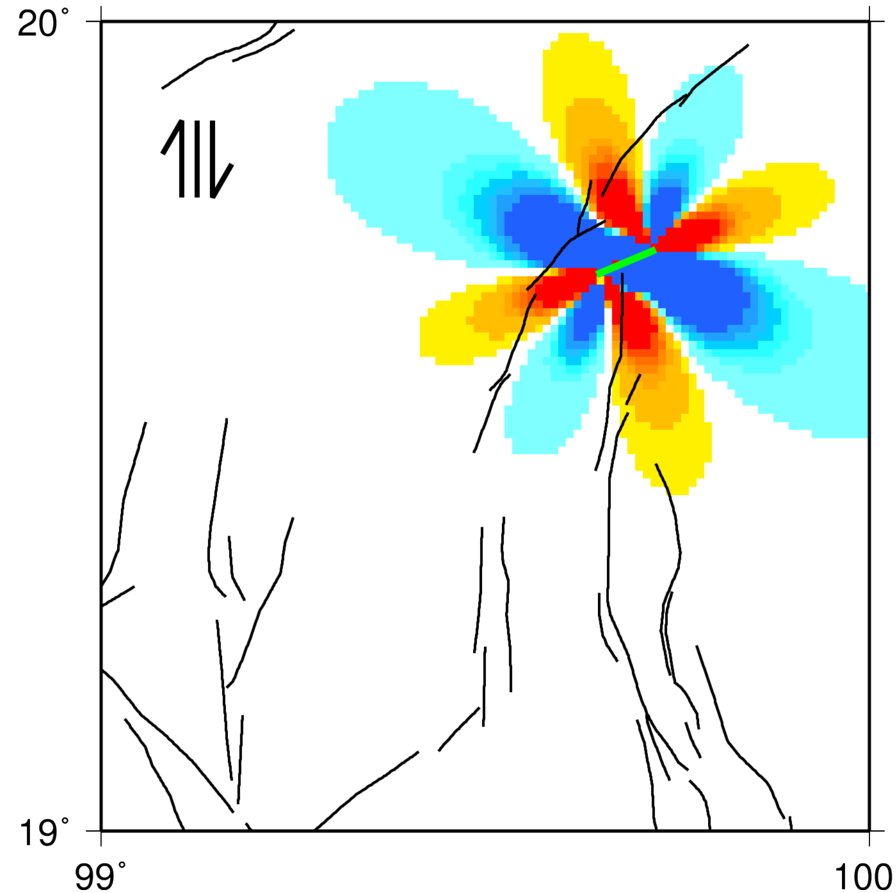


Fault Loading in N. Thailand

- *Exercise 2b: now assume the 5 May Mw 6.1 earthquake occurred on the east-west plane, and is left lateral strike-slip. Compute the Coulomb stress change surrounding the event and identify the most positively loaded known faults. Does the choice of fault plane modify your interpretation of loaded faults?*

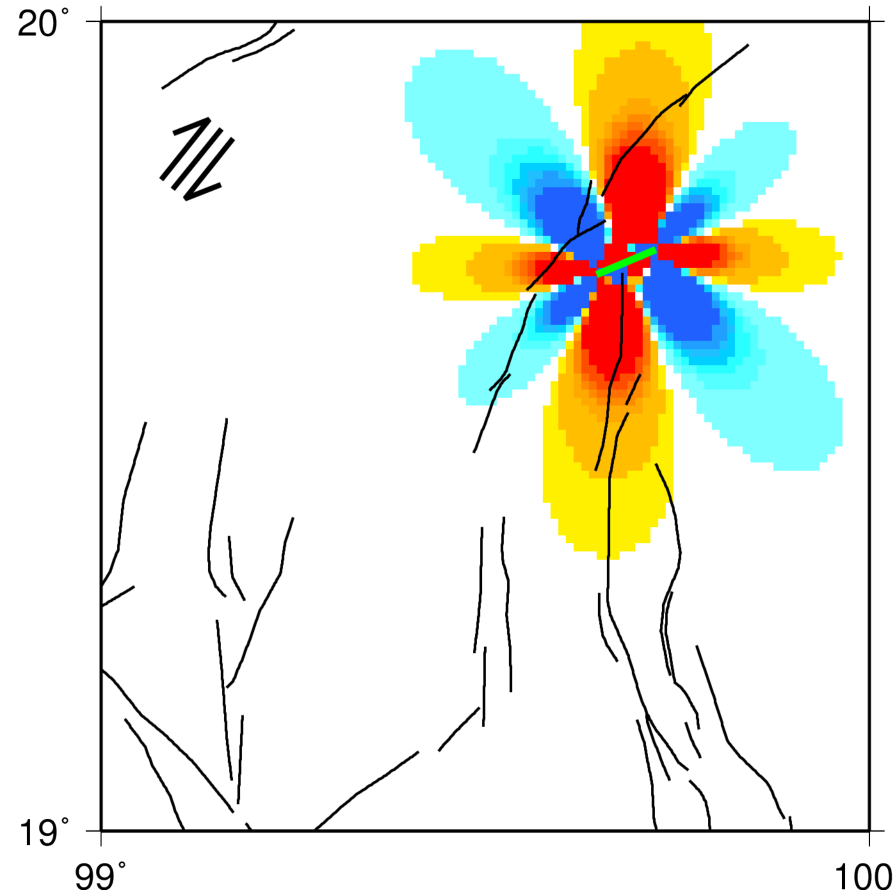
Fault Loading in N. Thailand

- E-W left lateral earthquake
- Resolved on N-S right lateral target faults

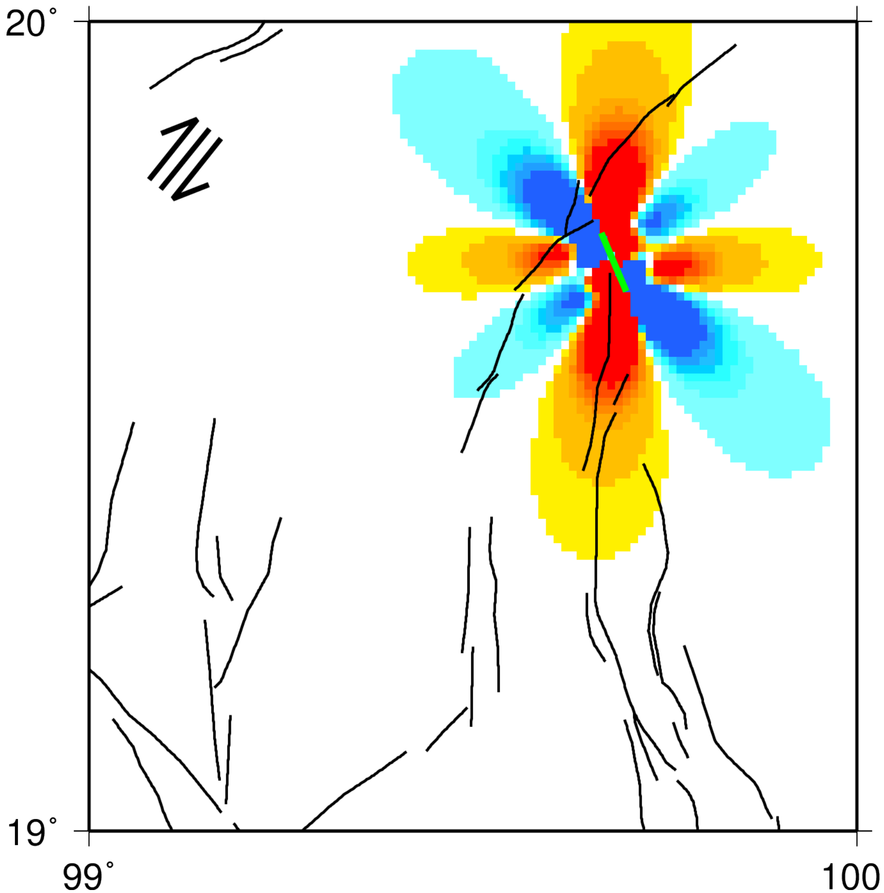


Fault Loading in N. Thailand

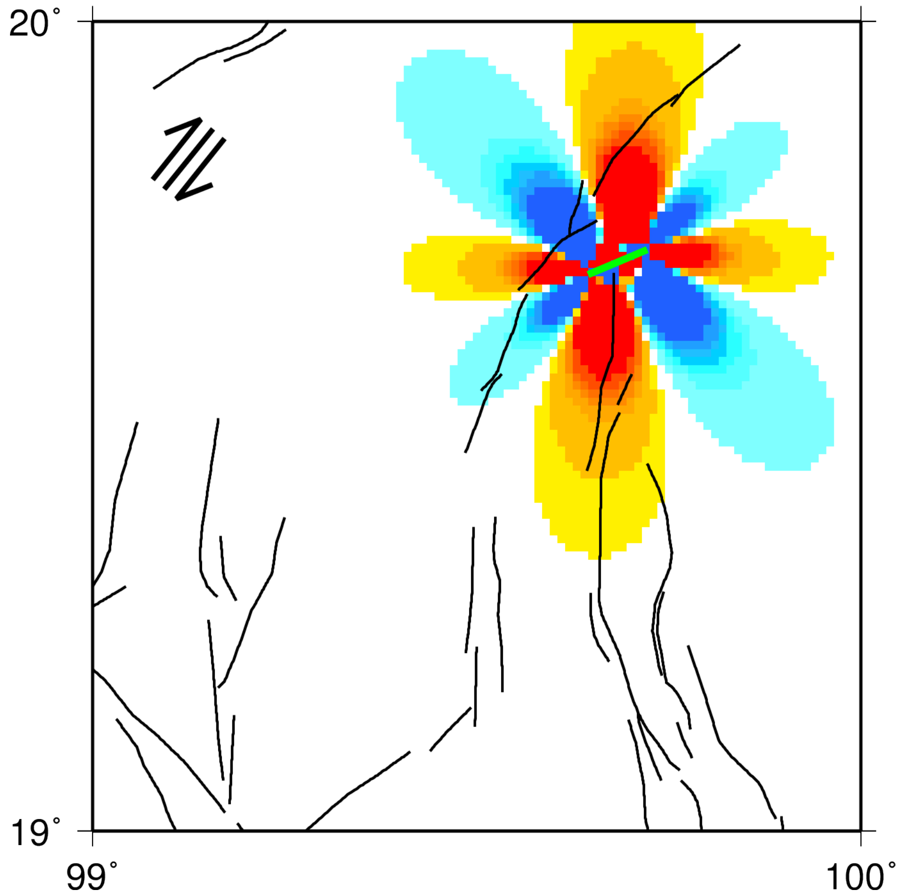
- E-W left lateral earthquake
- Resolved on NE-SW right lateral target faults



Fault Loading in N. Thailand



Right Lateral



Left Lateral

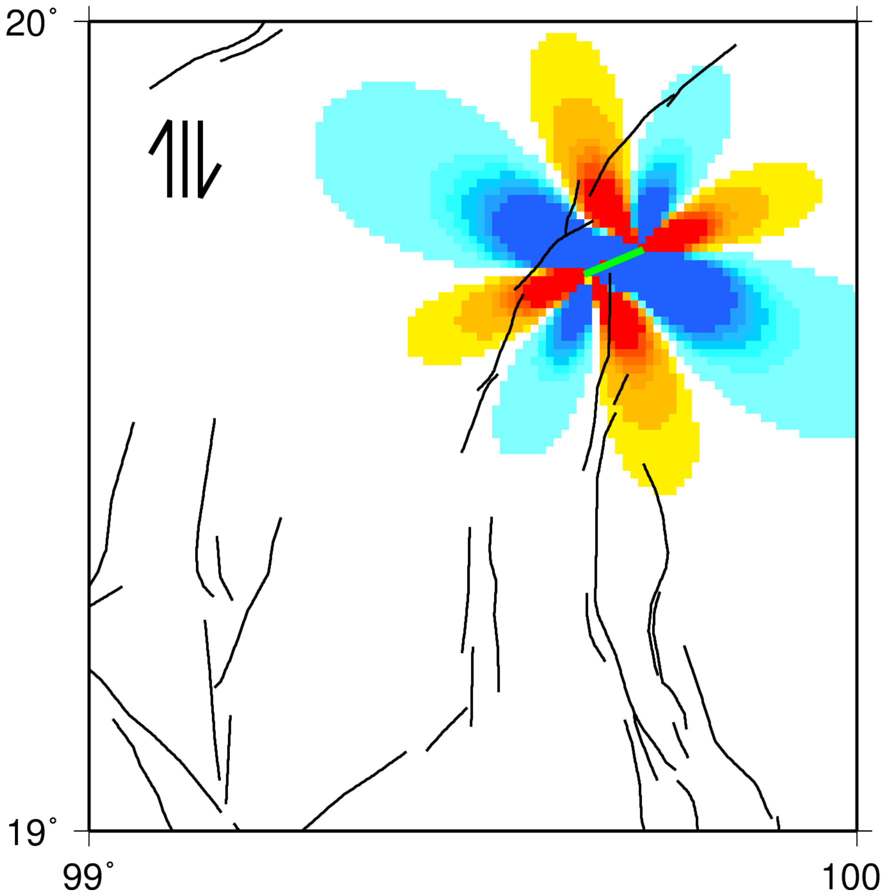
Fault Loading in N. Thailand

- *Exercise 2c: The next two largest earthquakes in the sequence were Mw 5.3. How do these events contribute to the ΔCS and loading of nearby faults?*

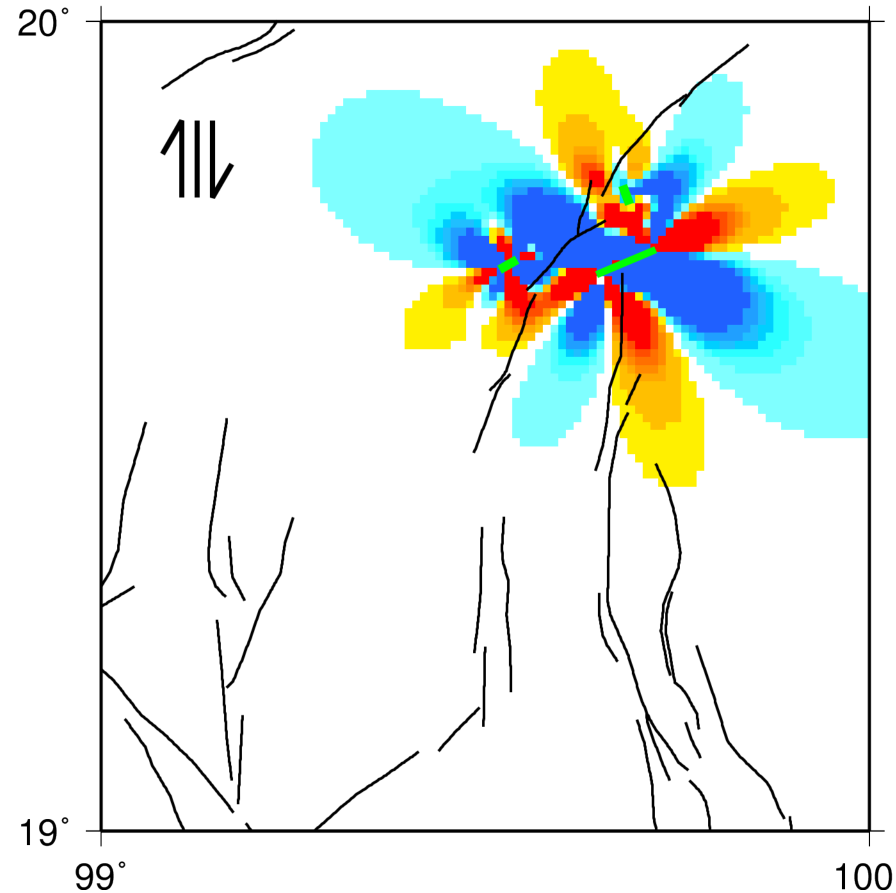
2014/05/06T00:50:16 (99.683ºE,19.786ºN,13km)
Mw 5.3 NP1: 240/75/-10 NP2: 333/80/-165

2014/05/06T00:58:19 (99.530ºE,19.700ºN,10km)
Mw 5.3 NP1: 240/75/-10 NP2: 333/80/-165

Fault Loading in N. Thailand



Mw 6.1 Only



Mw 6.1 + Two
Mw 5.3 events