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



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



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





• Preferred constraint: surface rupture

Sep. 3, 2010 Mw 7.0, New Zealand

• Preferred constraint: surface rupture

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

- Preferred constraint: surface rupture
- Geodetic observations



- 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

- 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?

Regional moment tensor solution

Location: 99.683°E, 19.703°N, 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

- 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 Strike Slip 0 (a) (b) Strike Slip Reverse Reverse Normal Δ Normal 167 EQs Magnitude (**M**) M = 4.38 + 1.49 * log(RLD)103 10 100 10 100 103 Subsurface Rupture Length (km) Subsurface Rupture Length (km)

Wells and Coppersmith (1994)

Magnitude to Fault Size Strike Slip 0 (a) (b) Strike Slip Reverse Reverse 8 Normal Δ Normal 153 EQs Magnitude (**M**) 5 $= 4.06 + 2.25 * \log(WID)$ 10 10 Subsurface Rupture Width (km) Subsurface Rupture Width (km)

Wells and Coppersmith (1994)

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

• Input fault file (fault.dat)

Note: this is not the Chiang Rai earthquake!



Same as previous input format

• Input fault file (fault.dat)

Note: this is not the Chiang Rai earthquake!



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

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

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

Empirical relations can be defined using command line option -empirical

Regional moment tensor solution

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North-South Right Lateral

East-West Left Lateral

- Difference between output results
- Greater than ~1 ¹⁹
 fault length, there is no detectable difference ¹⁹

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• Input fault file

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• Input receiver file

• Input half-space file

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- 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)



North-South Right Lateral

East-West Left Lateral

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

• 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 <u>hypothetical</u> Mw 7.0 earthquake.

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North-South Right Lateral

East-West Left Lateral

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- Difference between output results
- Greater than ~1 fault length, there is no detectable 19.6° difference
- Now fault length is 30 km

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North-South Right Lateral

East-West Left Lateral

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



 2014 Mw 8.2 Iquique earthquake aftershocks lie on plate boundary

- 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



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



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



• June 2011 Mw 6.0 earthquake



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



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

- 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.

- 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

- Exercise 2a: assume the 5 May Mw 6.1 earthquake occurred on the <u>north-south</u> <u>plane</u>, and is <u>right lateral</u> 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

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



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



• 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?

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



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





- 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 (99.683°E,19.786°N,13km) Mw 5.3 NP1: 240/75/-10 NP2: 333/80/-165

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

