Seismotectonic framework of the Feb 27, 2010 Mw 8.8 Maule, Chile earthquake sequence

mainshock slip distribution, aftershock relocations, and regional moment tensors

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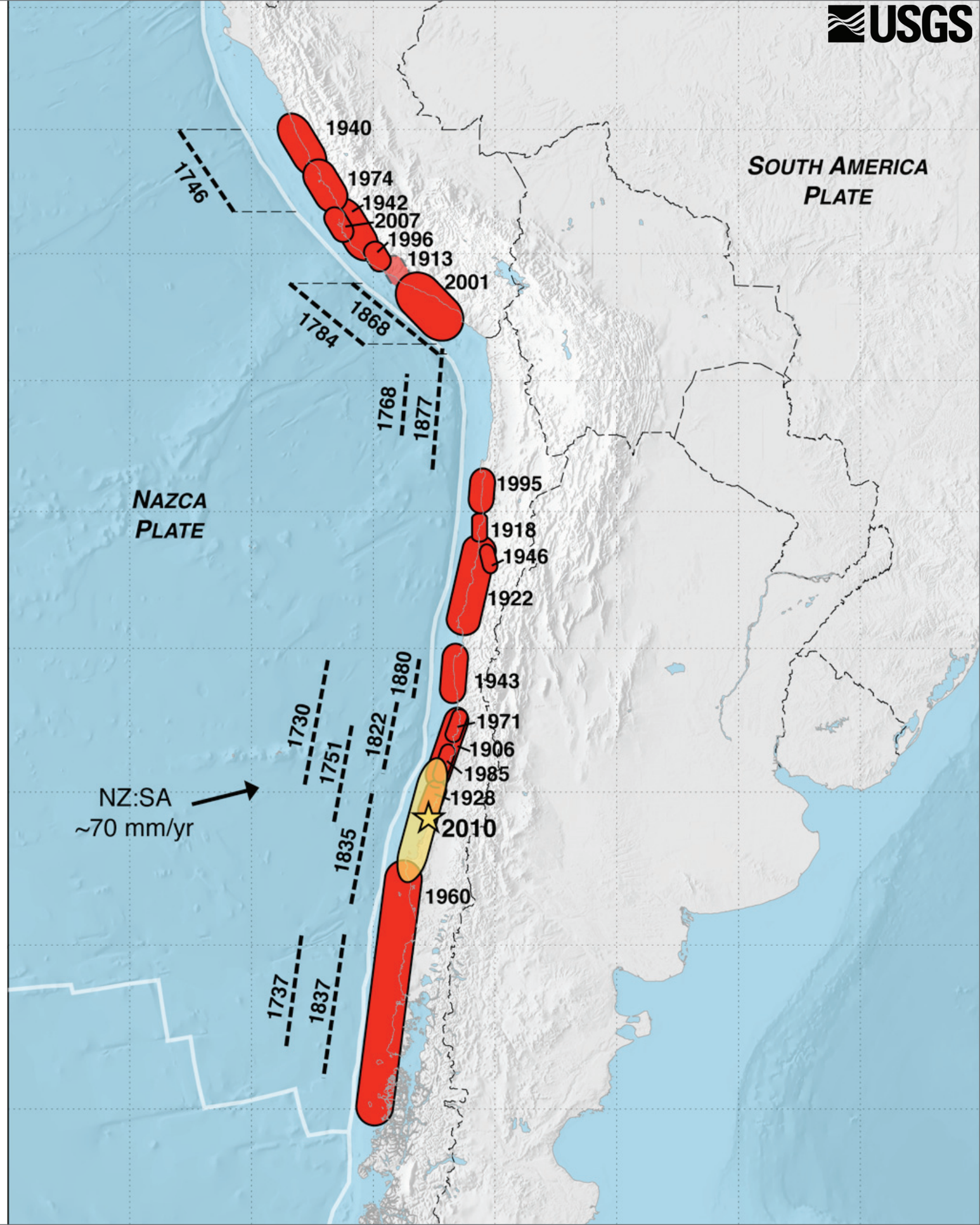
Tectonic Setting

Long, well-documented history of large/great EQs.

The South America subduction zone has both the shallow dip and deep coupled-uncoupled transition (~50 km) capable of producing very large EQs.

Compiled from Beck et al, 1998; Lay & Kanamori, 1981; Chlieh et al., 2004; Dorbath et al., 1990; Biggs et al., 2009.

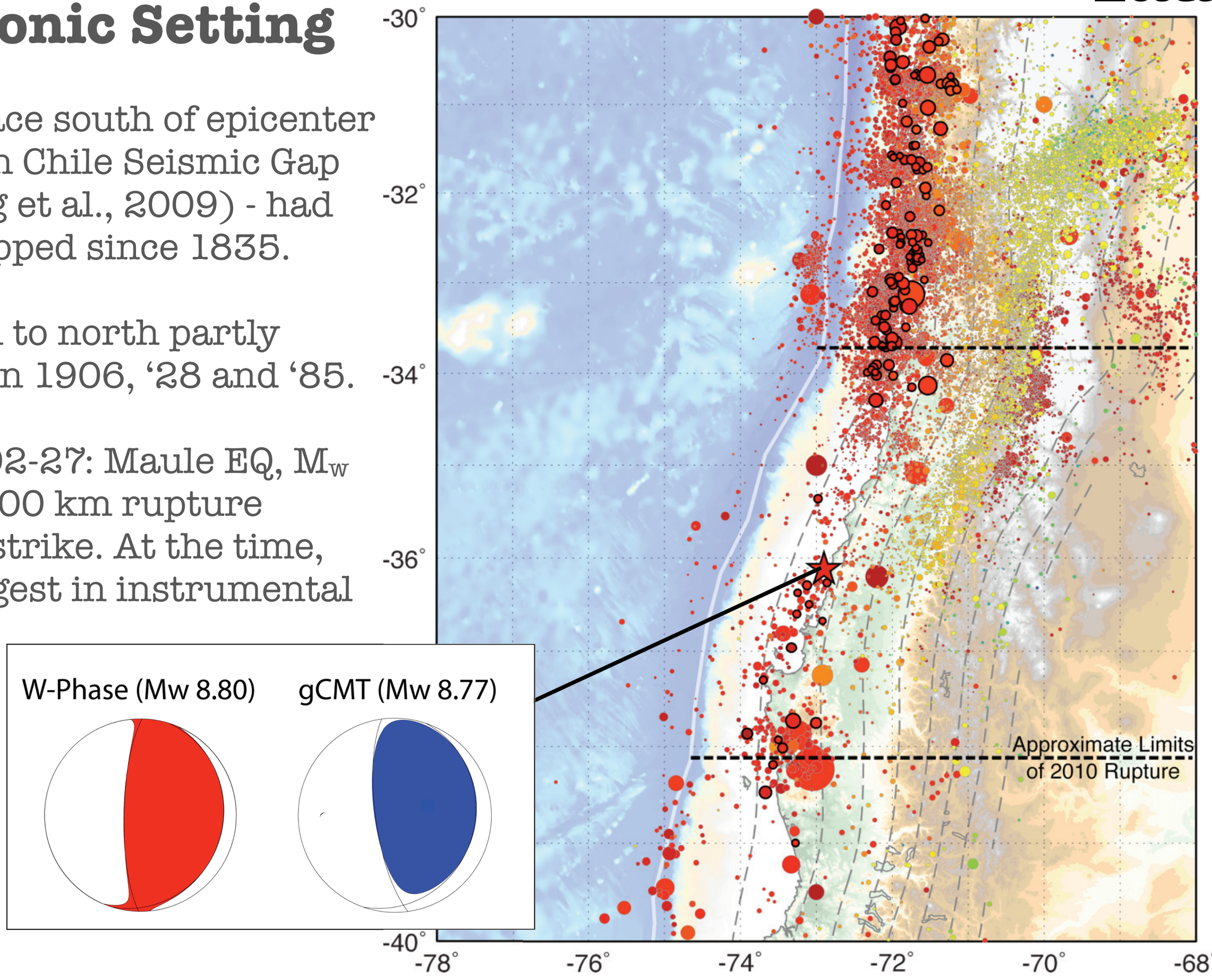


Tectonic Setting

Interface south of epicenter = South Chile Seismic Gap (Ruegg et al., 2009) - had not slipped since 1835.

Region to north partly failed in 1906, '28 and '85.

2010-02-27: Maule EQ, M_W 8.8, ~400 km rupture along-strike. At the time, 5th largest in instrumental era.

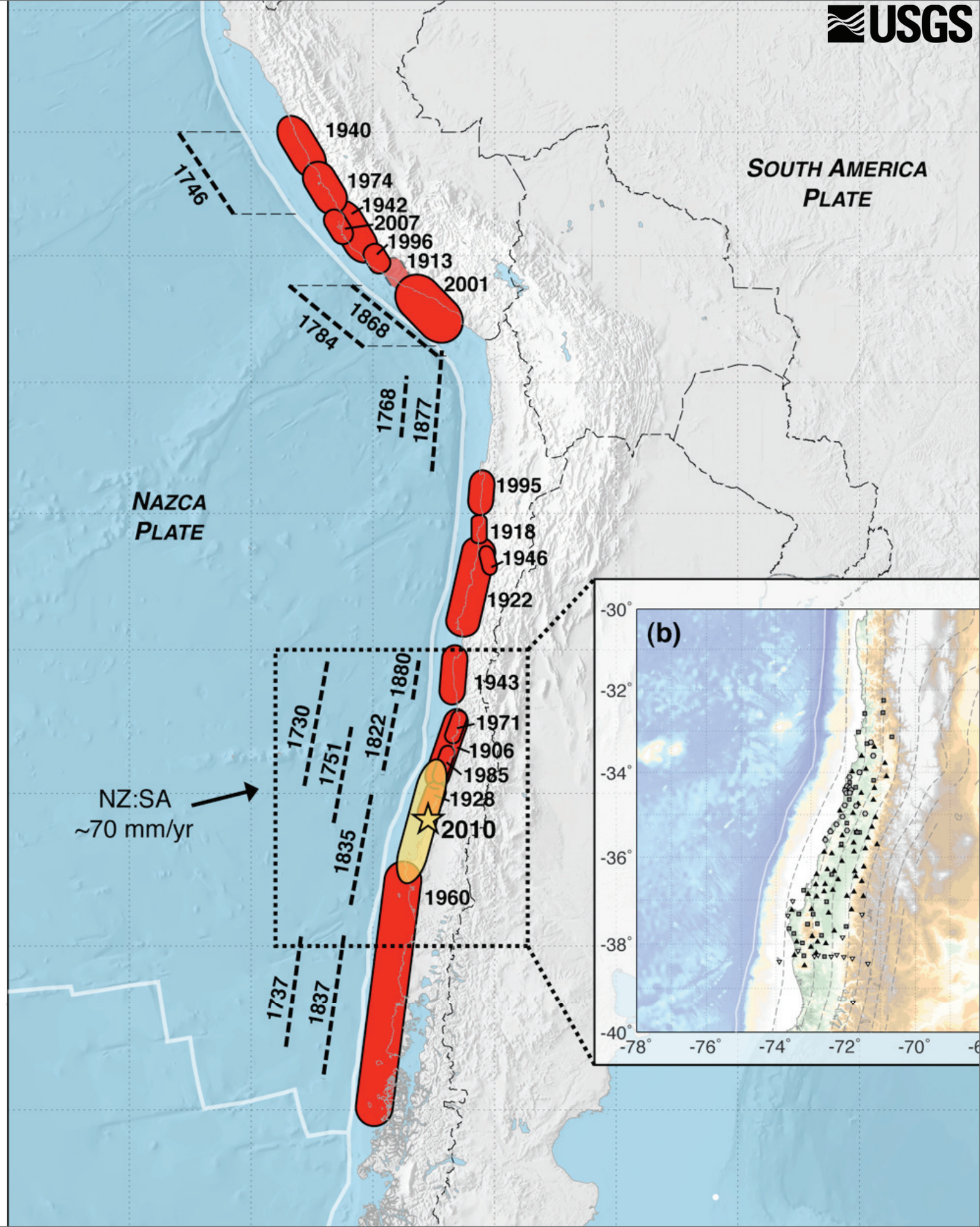


Maule Response

160 mostly broadband sensors deployed as the International Maule Aftershock Deployment (IMAD) temporary network; an international collaboration involving:

- Chilean Universities
- IRIS, USA
- INSU, CNRS, France
- GFZ, Germany
- U. of Liverpool, UK

Data open-access following their collection (most stations operated for ~9 months).



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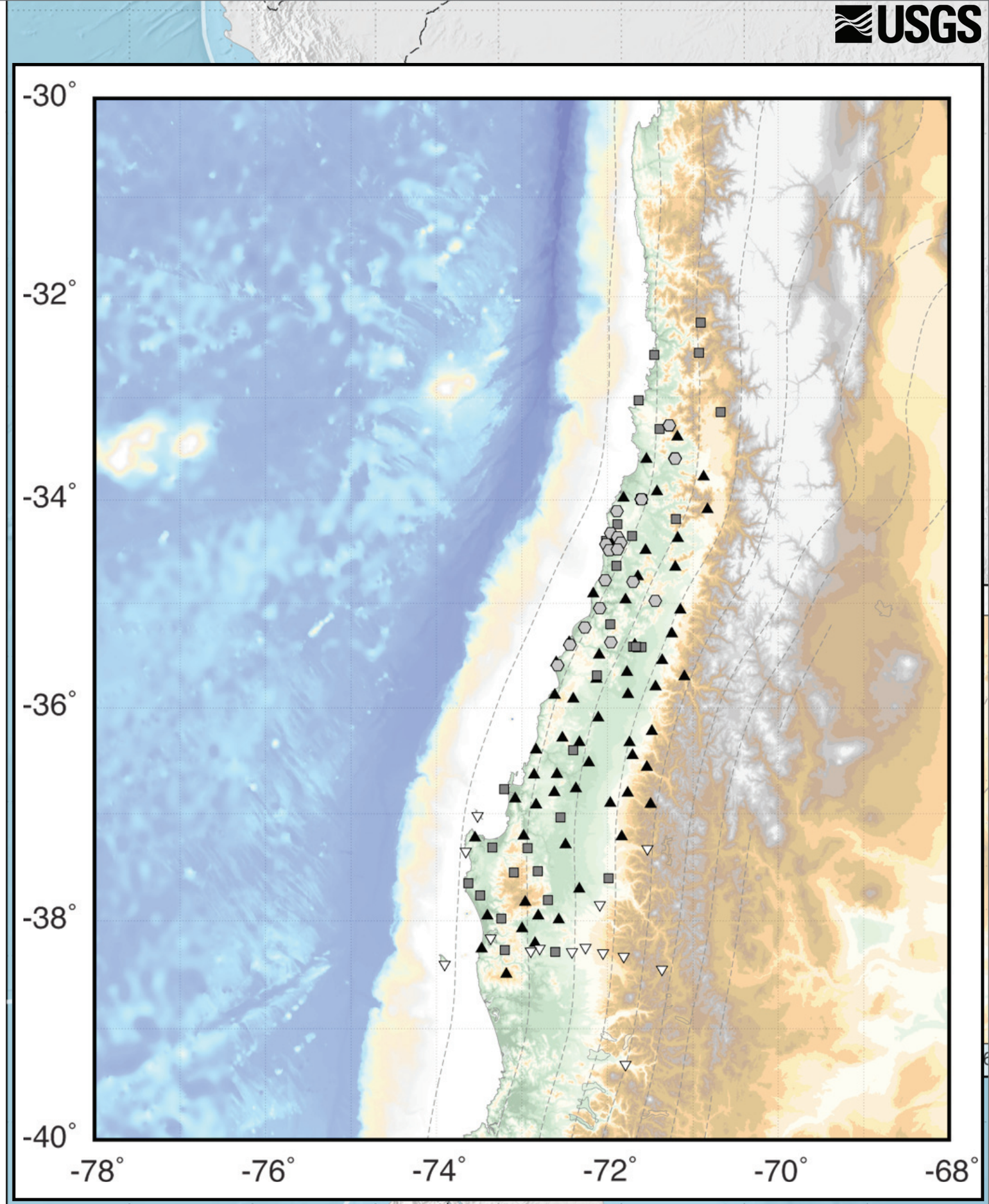
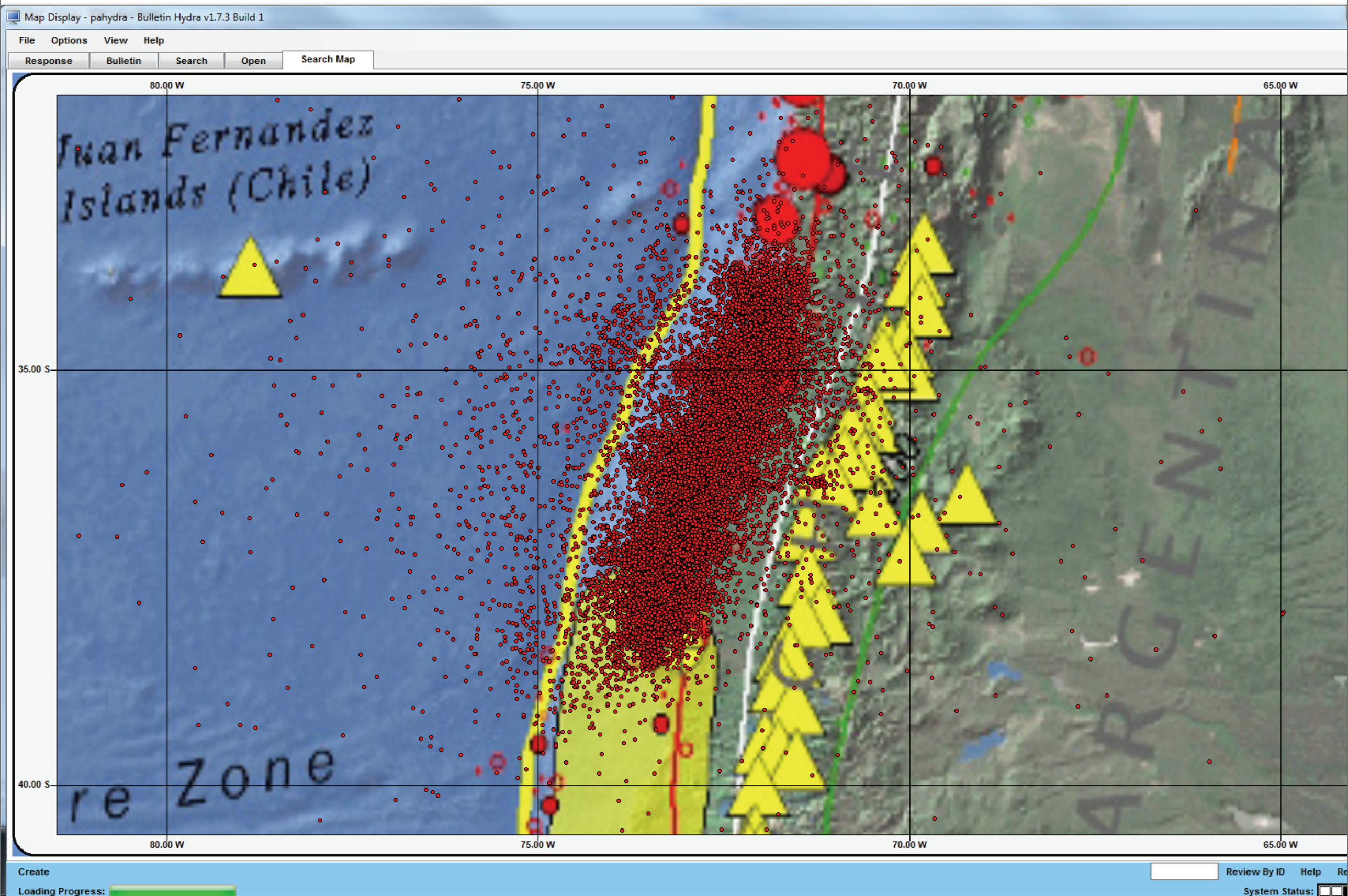


Maule Aftershock Data



Maule Aftershock Data

30,000 events automatically located with PA-HYDRA, an offline module mimicking NEIC's realtime data processing system.

We have relocated the highest quality ~10% of these events, and performed moment tensor analyses on the largest ~500.

Other analyses of the IMAD data include:

- Lange et al. (2012): automatically picked, 6 month catalog, 20,000+ aftershocks.

- Rietbrock et al. (2012): automatically picked, 2 month catalog, 30,000+ aftershocks. ~100 regional moment tensors.

- Agurto et al. (2012): MT catalog of 125 RMTs, 150 gCMTs.

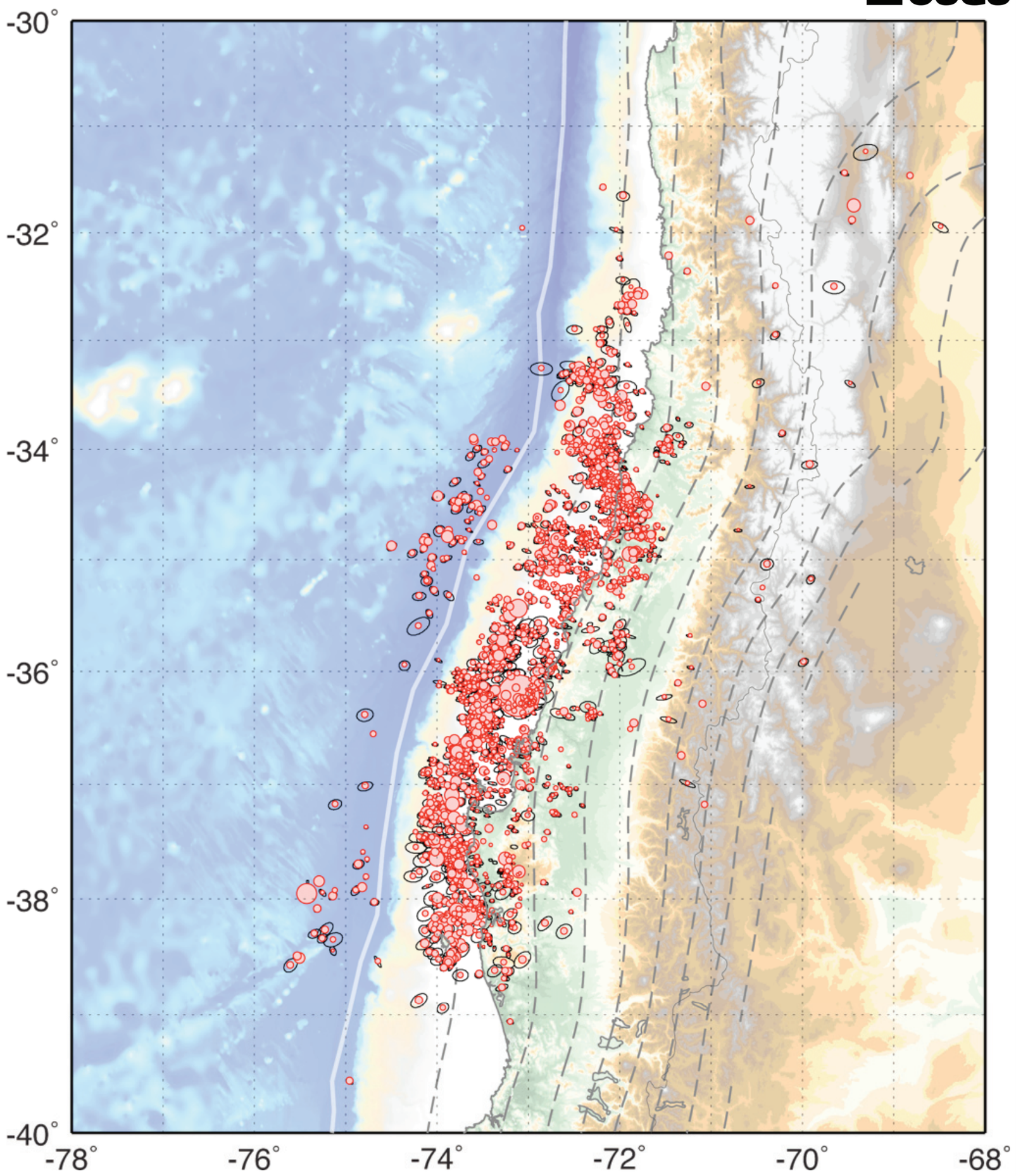
Relocated Aftershocks

2,500 events, relocated using a multiple event location approach (Hypocentral Decomposition).

==> High-precision relative and absolute locations.

Horizontal uncertainty averages ± 2.8 km.

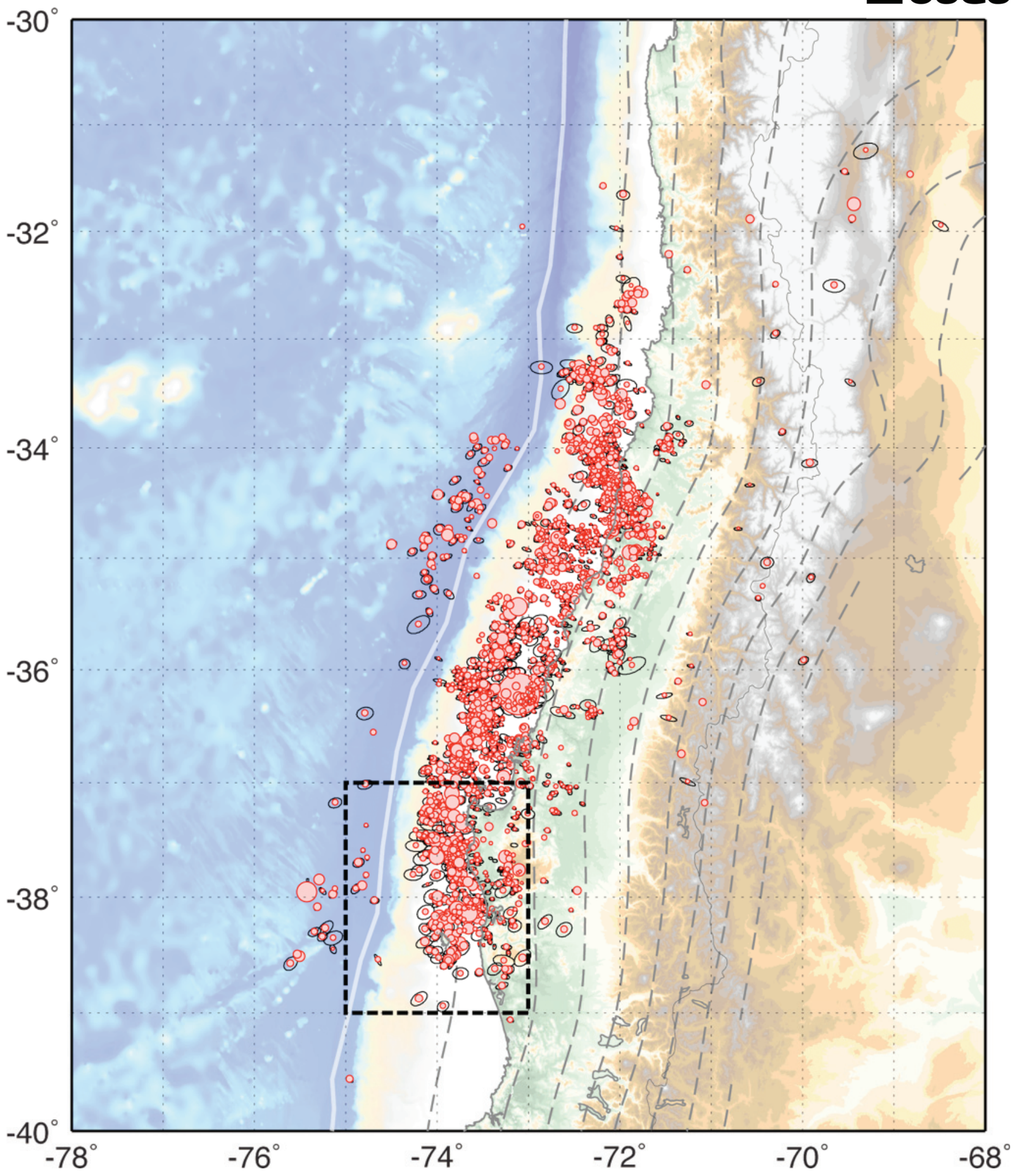
Vertical uncertainty averages ± 3-4 km.



Relocated Aftershocks

Events relocated using both local/regional, and teleseismic phases (linkage provides higher accuracy for offshore events).

Uncertainties demonstrate dominant SW-NE/W-E orientation - i.e., bias in direction of network.



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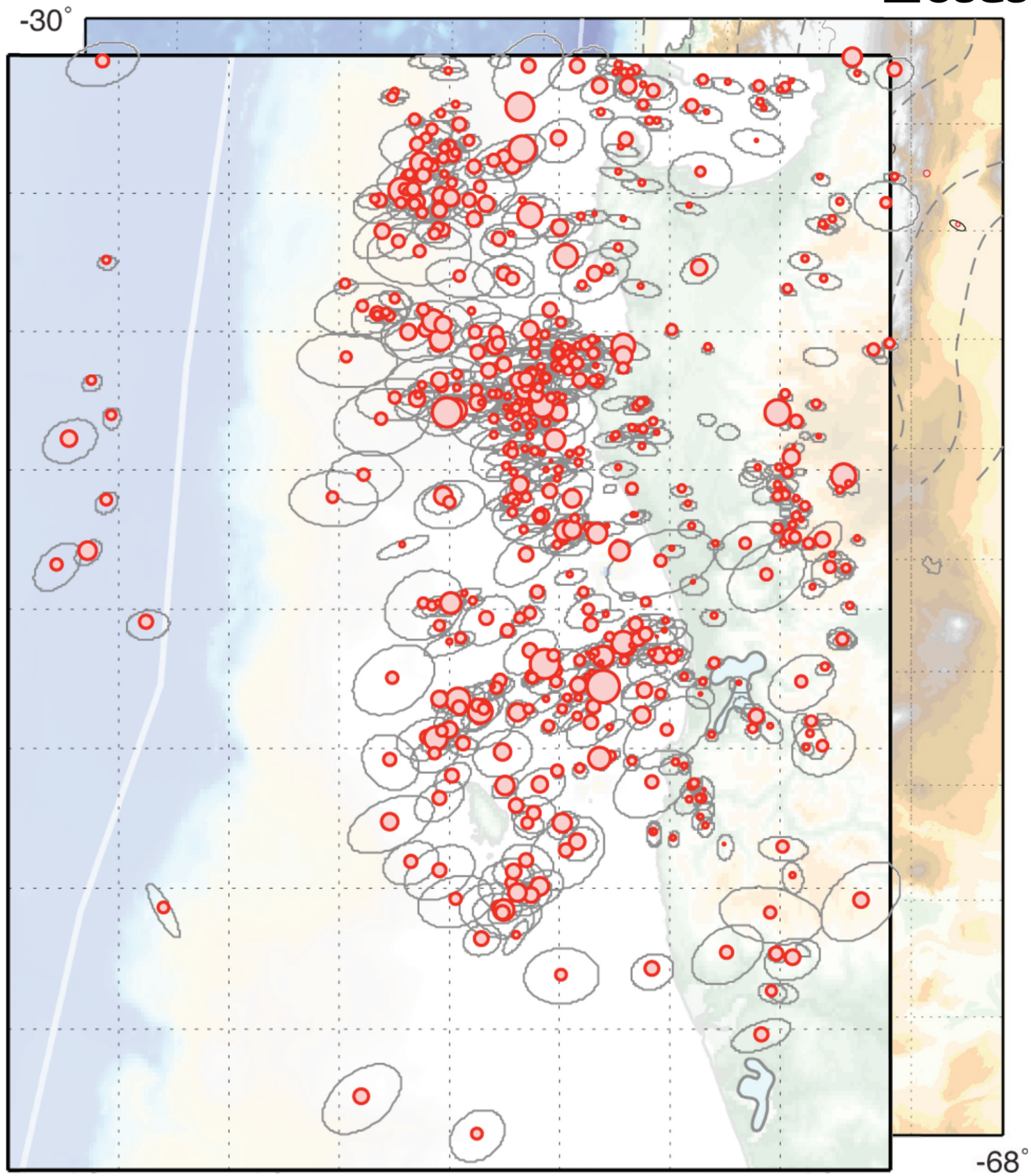
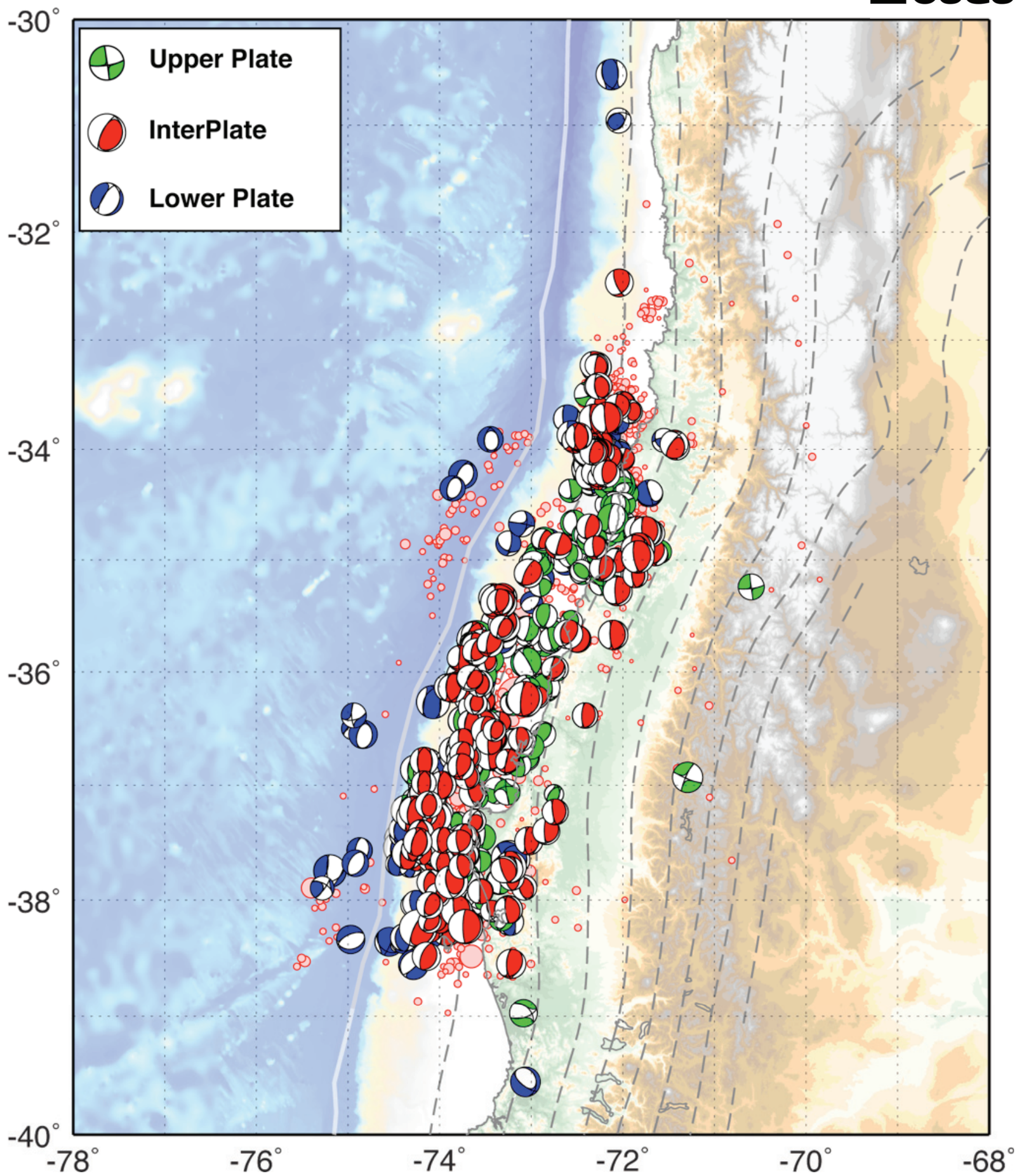


Maule RMTs

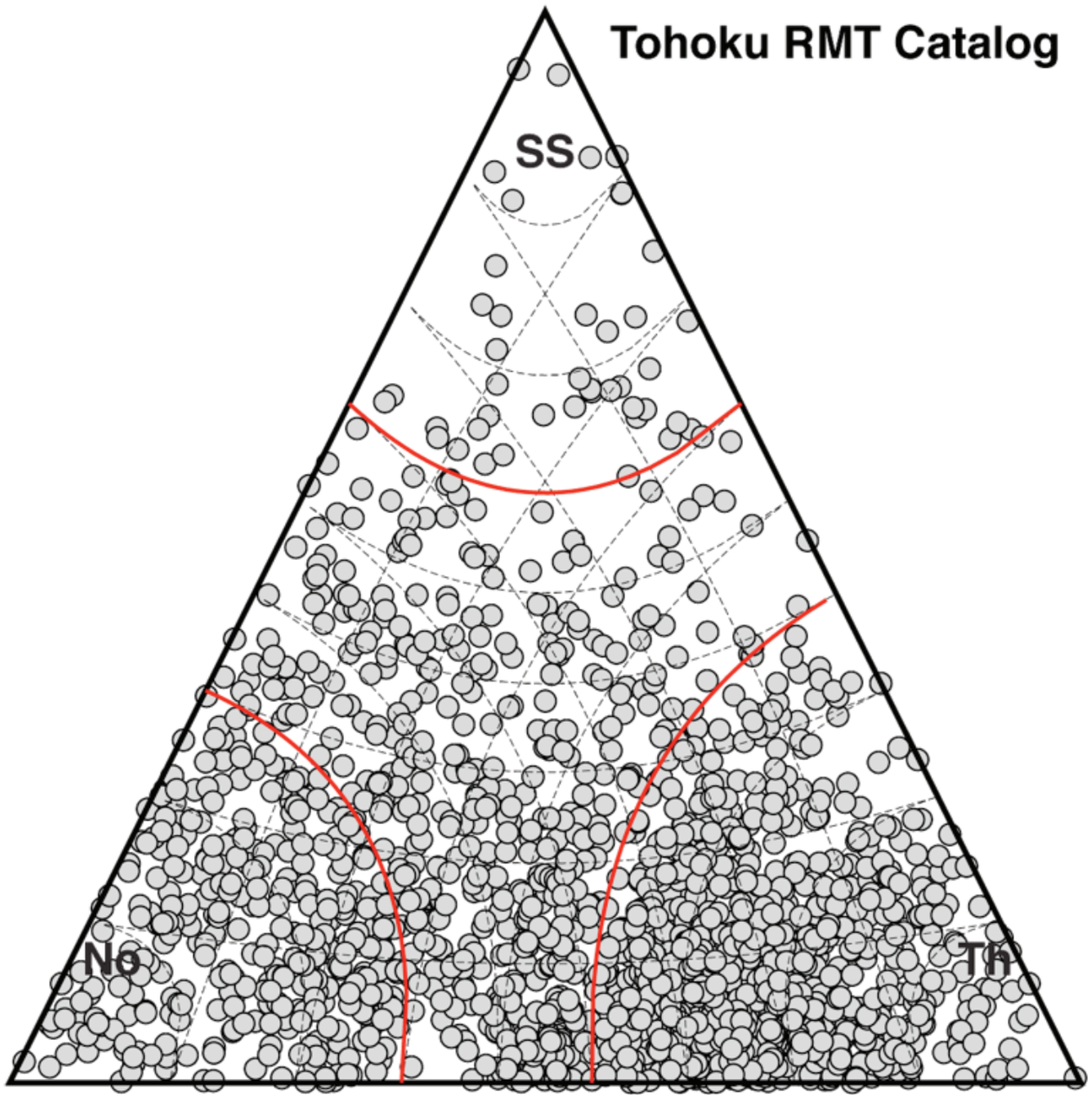
We have also used the PA Hydra system to produce regional moment tensors (RMT) for these earthquakes.

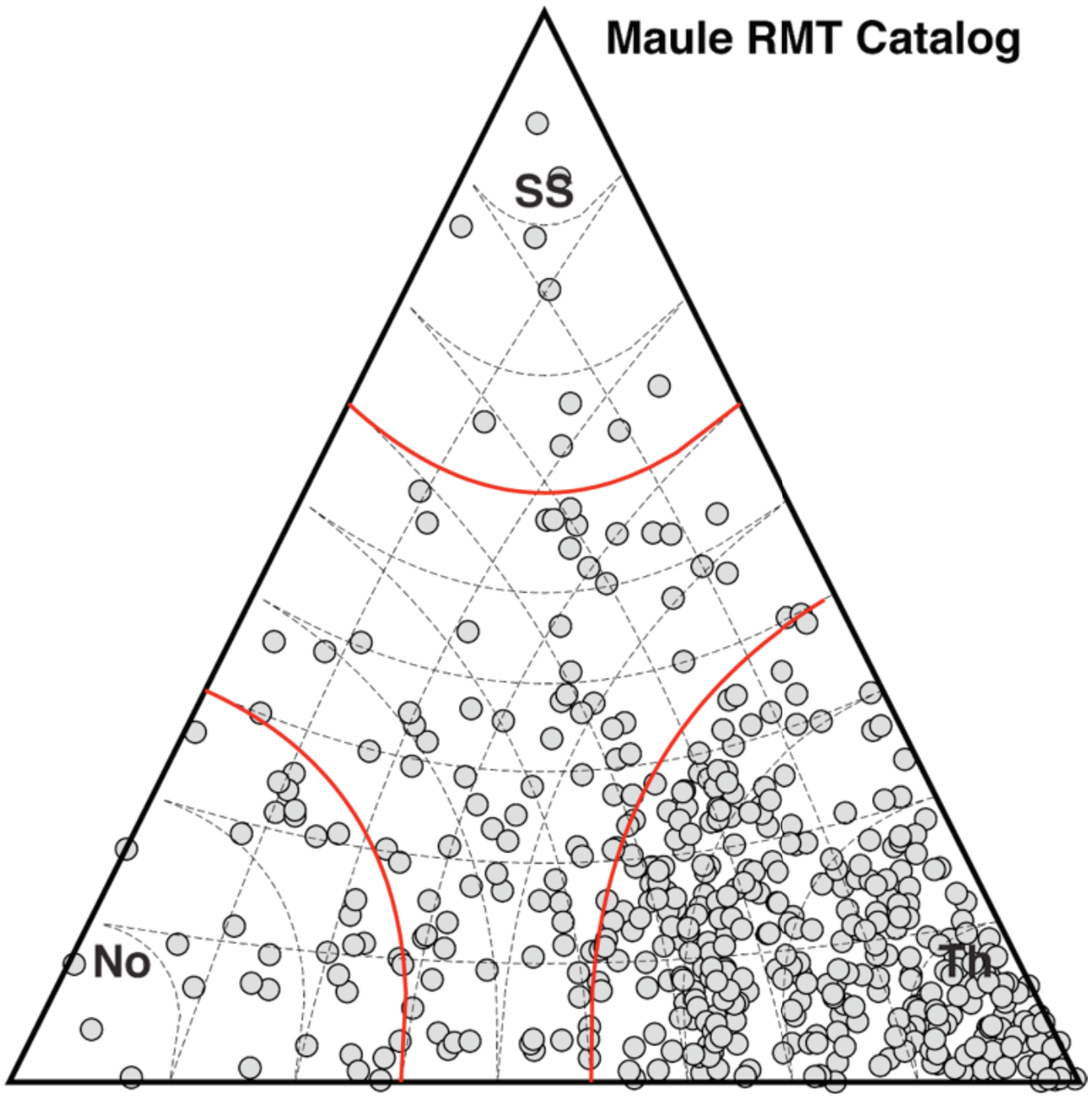
==> RMT catalog of 450 earthquakes, M3.5 and above.

Using these mechanisms and our slab models for the region, we can begin to analyze the tectonics of the sequence, dividing the catalog into upper, lower and interplate EQs.



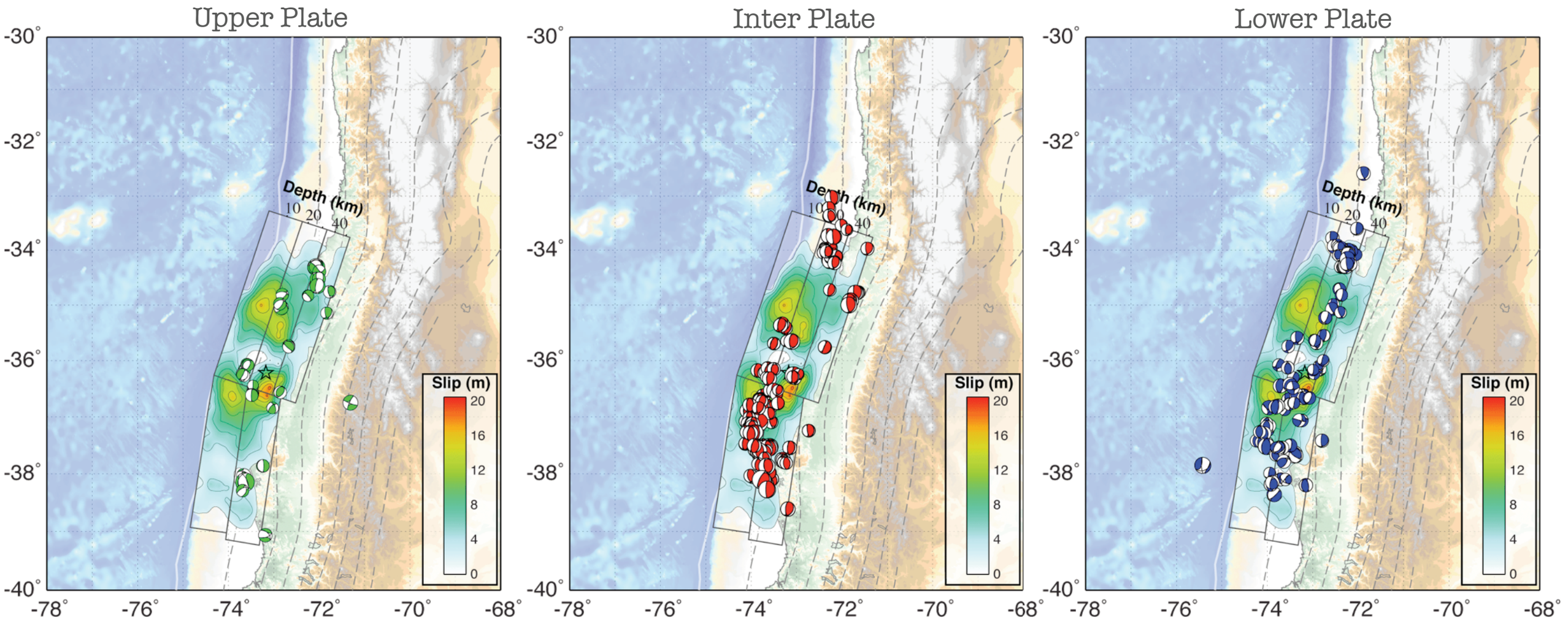
Maule RMTs





Maule moment tensors predominantly thrust, with some distributed normal and oblique faulting events.

Maule RMTs: Well-Constrained

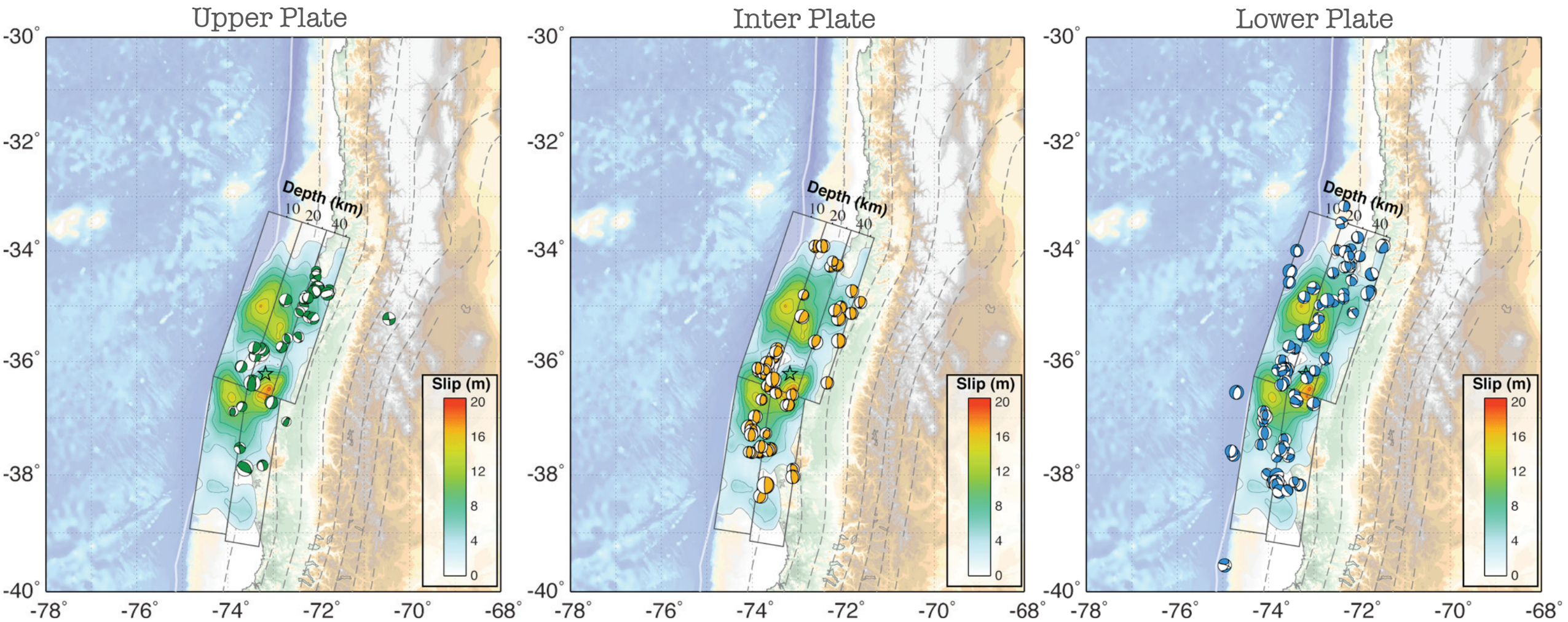


Majority of aftershocks interplate (~55-70%, depending on how data are filtered for tectonic regime).

Large cluster of normal faulting earthquakes in north, near Pichilemu (two M6.9-7.0 EQs on 2010/03/11).

Lower plate faulting on steep reverse structures in the offshore regions north & south of the mainshock slip.

Maule RMTs: Poorly-Constrained



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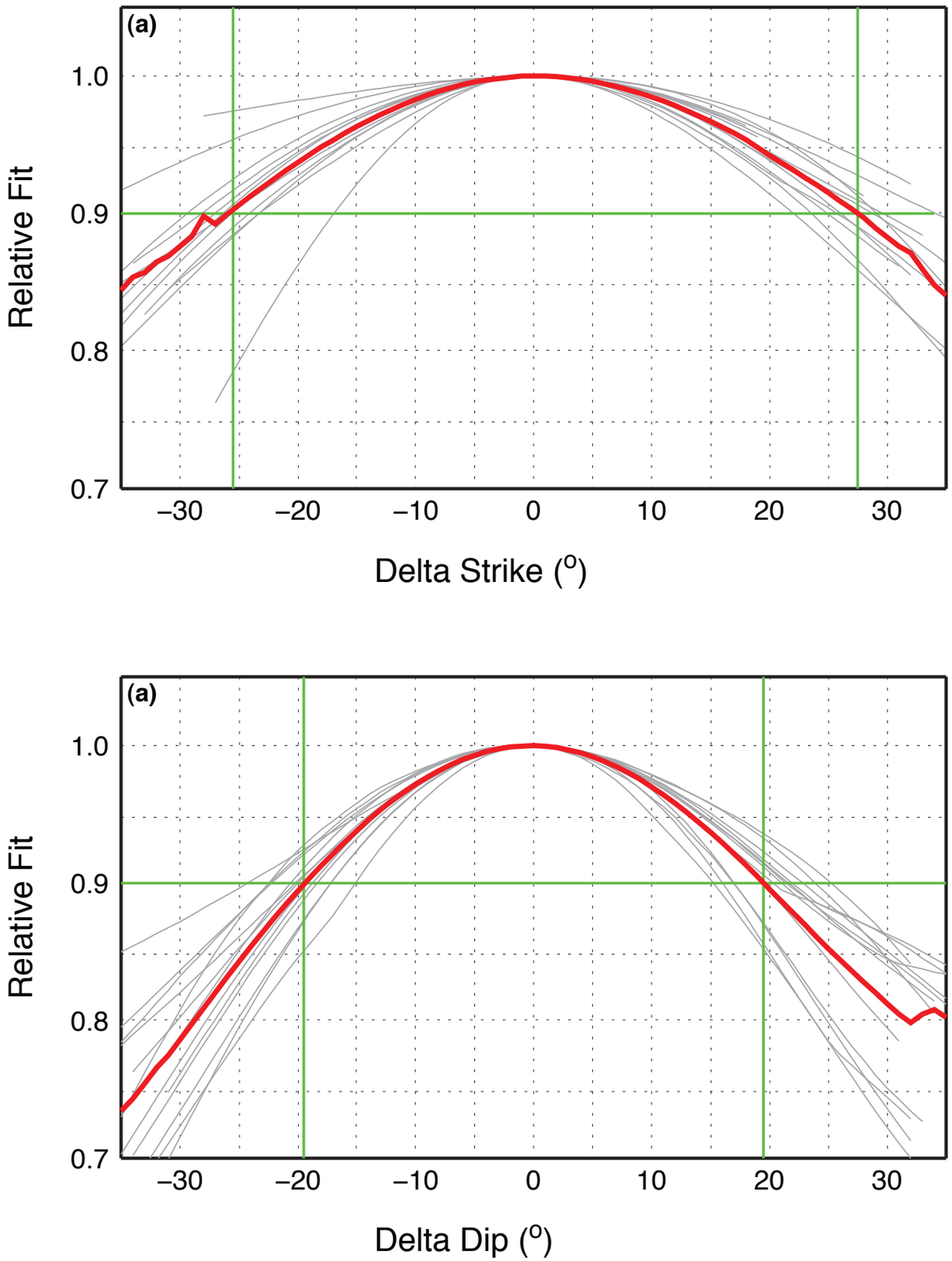
RMT Goodness of Fit Variations

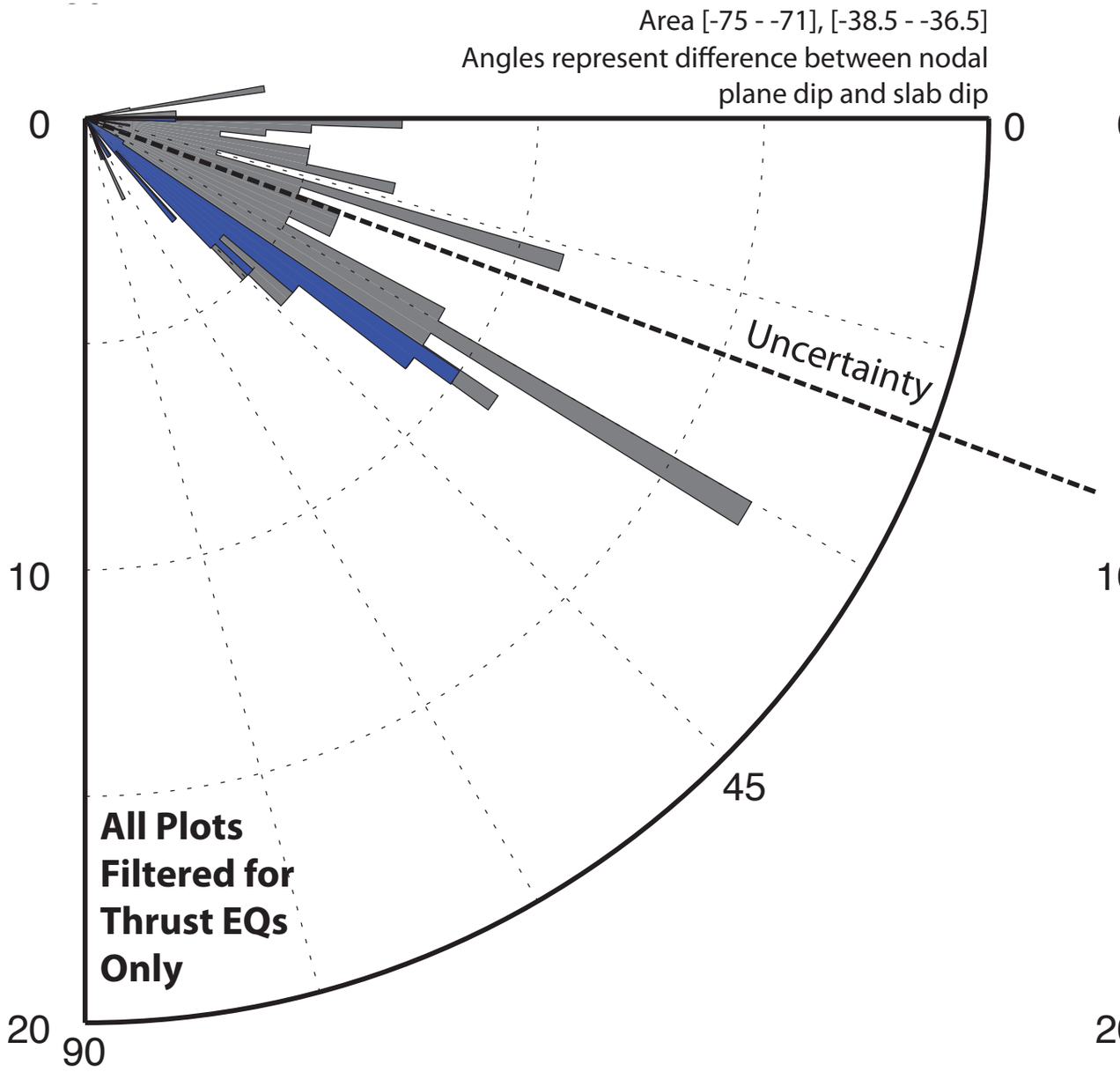


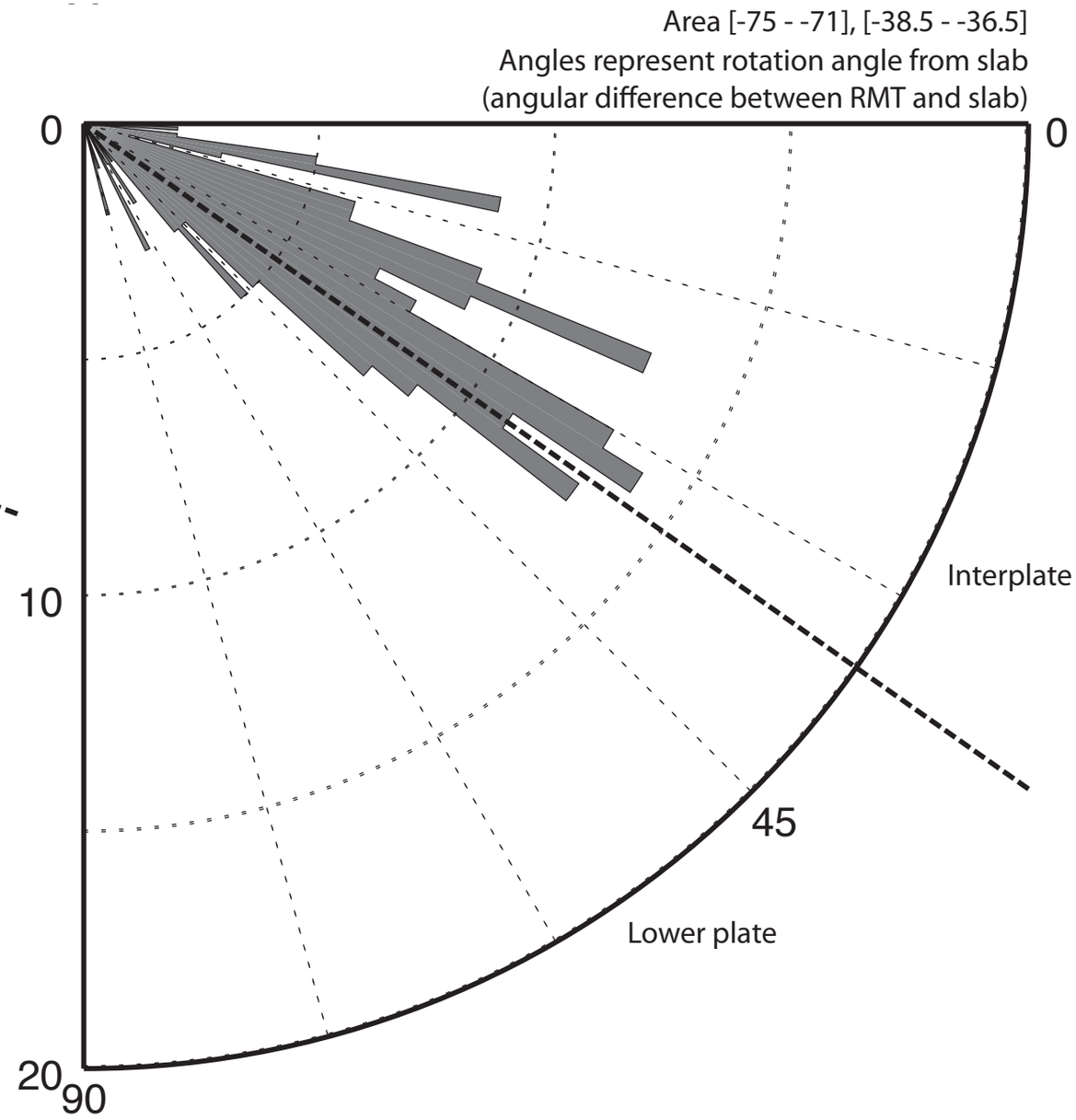
Forward modeling fault plane solutions in Regional Moment Tensor inversions allows us to assess how well-constrained strike and dip are in RMT solutions.

'Good' solutions span +/- 25 deg in strike, +/- 20 deg in dip?

See **Kendra Johnson's** poster at this workshop.

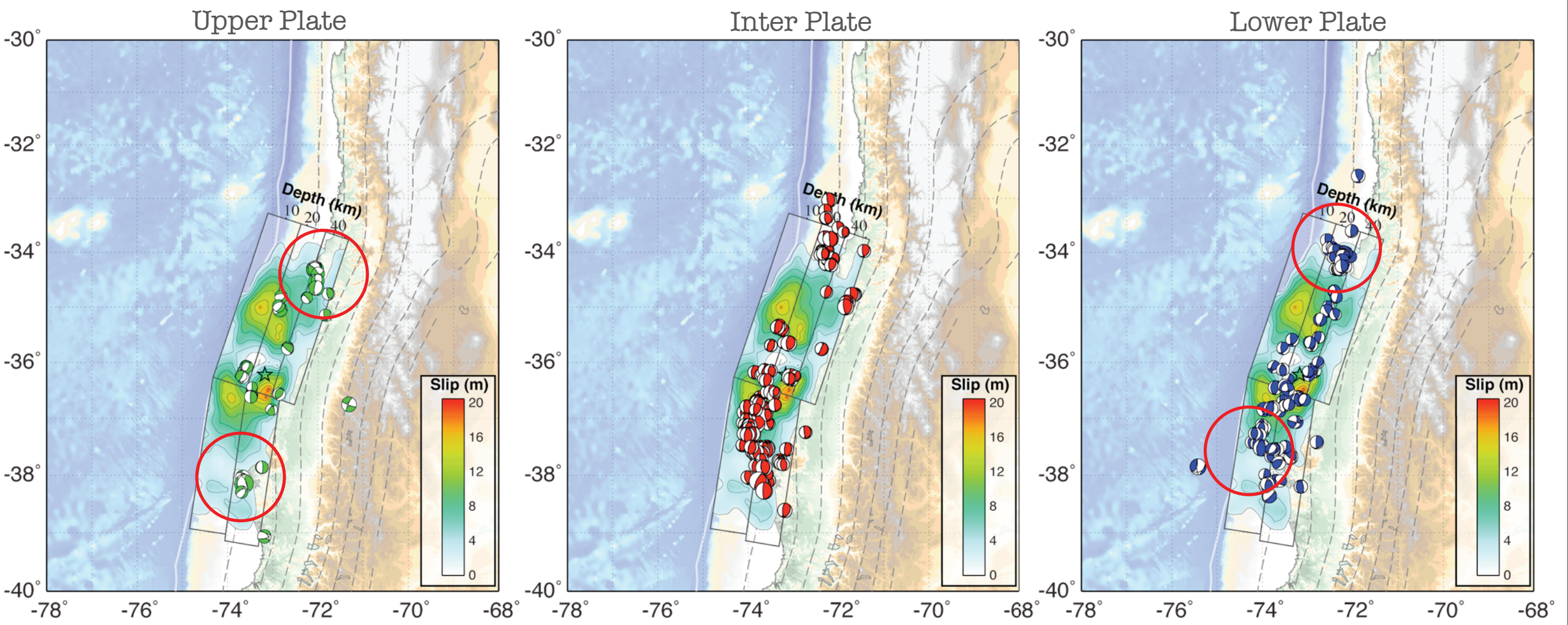
RMT Uncertainty





Even when considering RMT uncertainties, thrust faulting solutions to the south & north of major coseismic slip are still confidently lower plate events.

Maule RMTs: Well-Constrained



Even given the uncertainties of RMT solutions, these clusters of aftershocks near the limits of co-seismic slip cannot be interplate.

==> Upper and lower plates respond to co-seismic slip at ends of rupture.

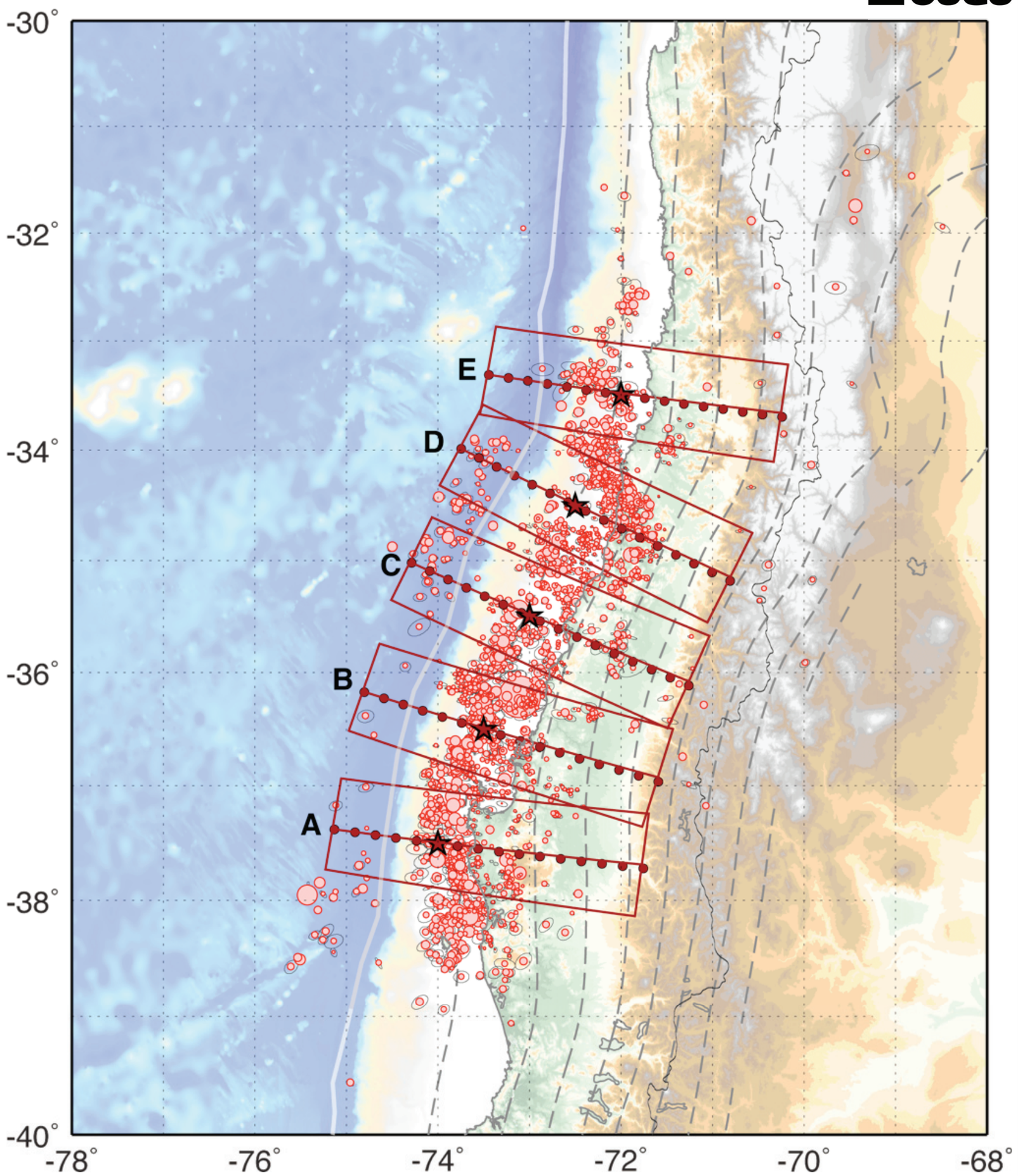
Relocated Aftershocks

Cross-sections show structure of aftershock sequence with depth. Four dominant regions of activity:

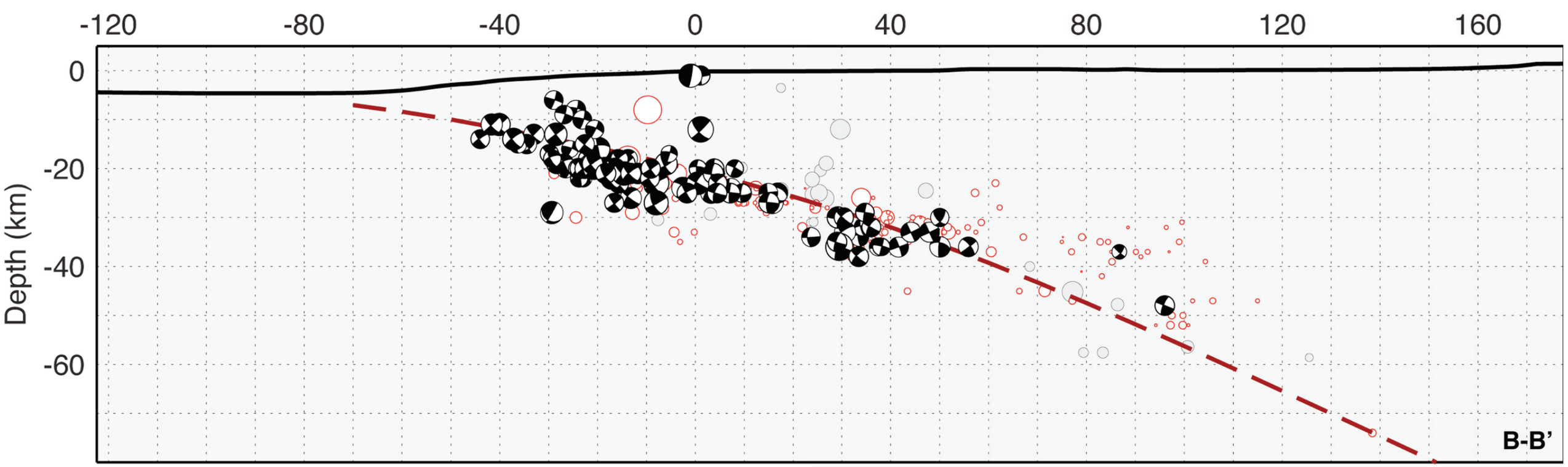
1) Two clusters along interplate thrust (shallow & deep)

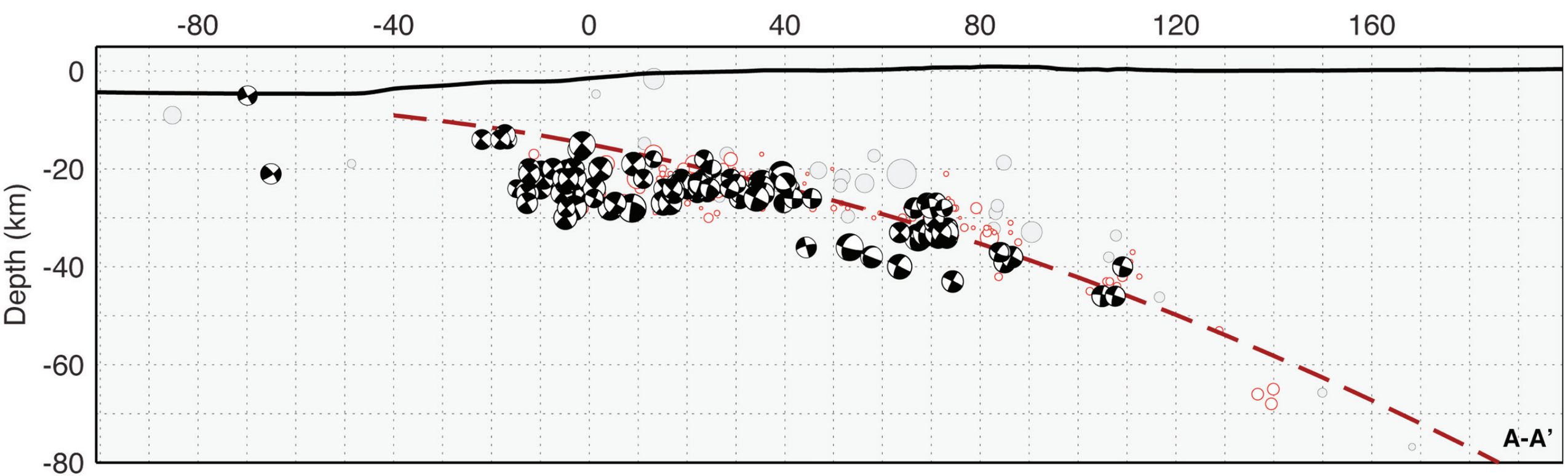
2) Upper plate, near Pichilemu

3) Outboard of SZ



Cross-Sections





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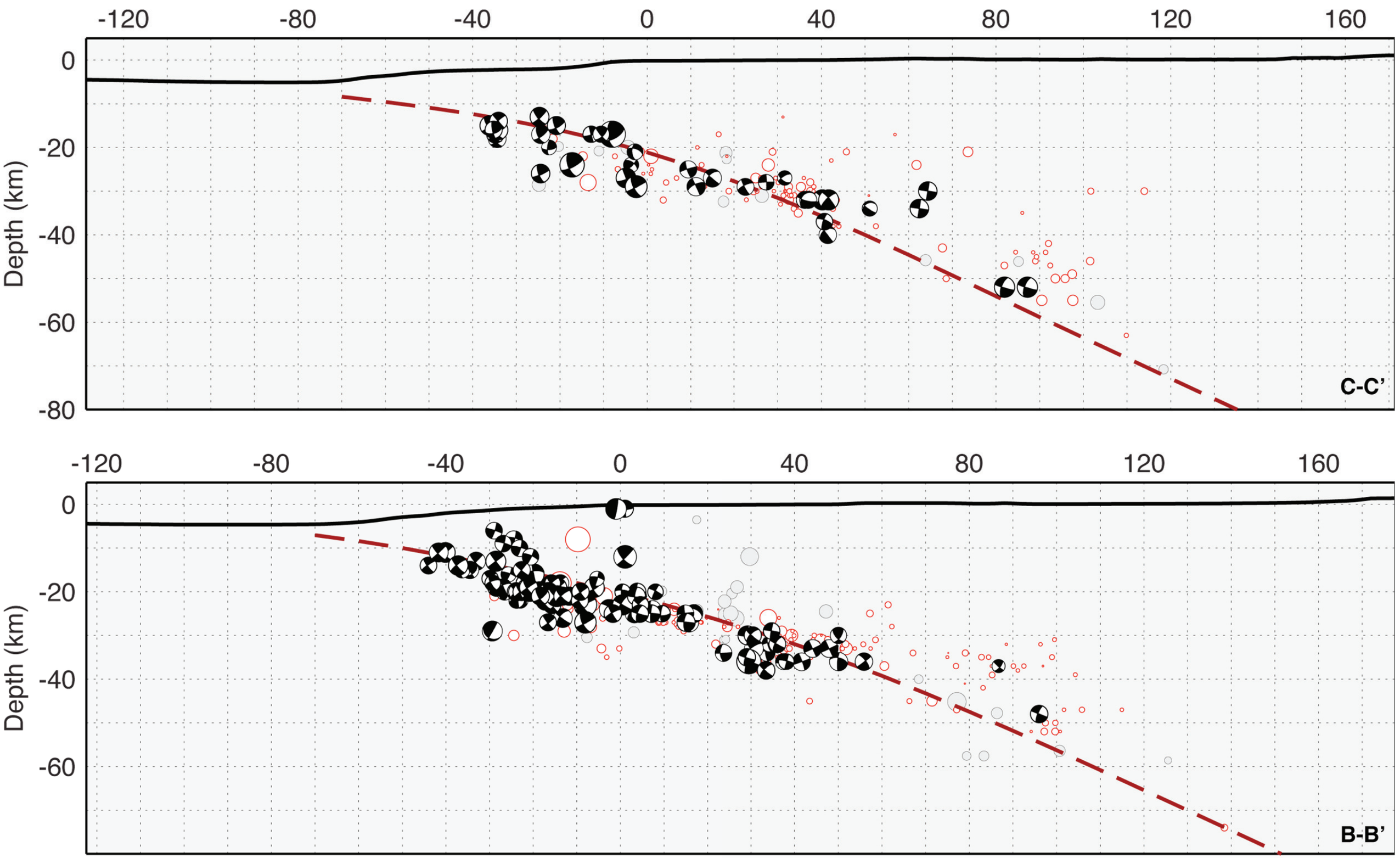

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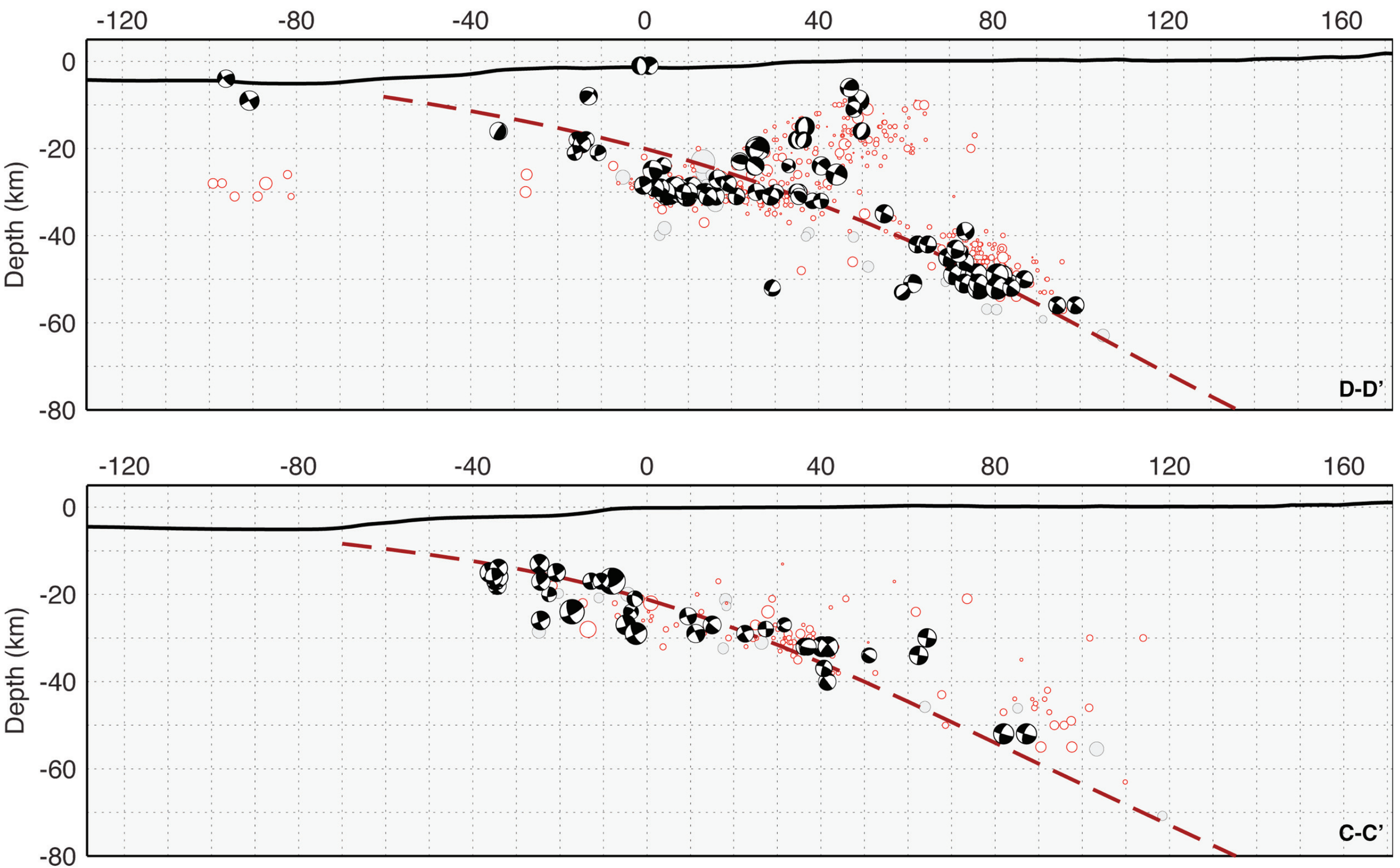

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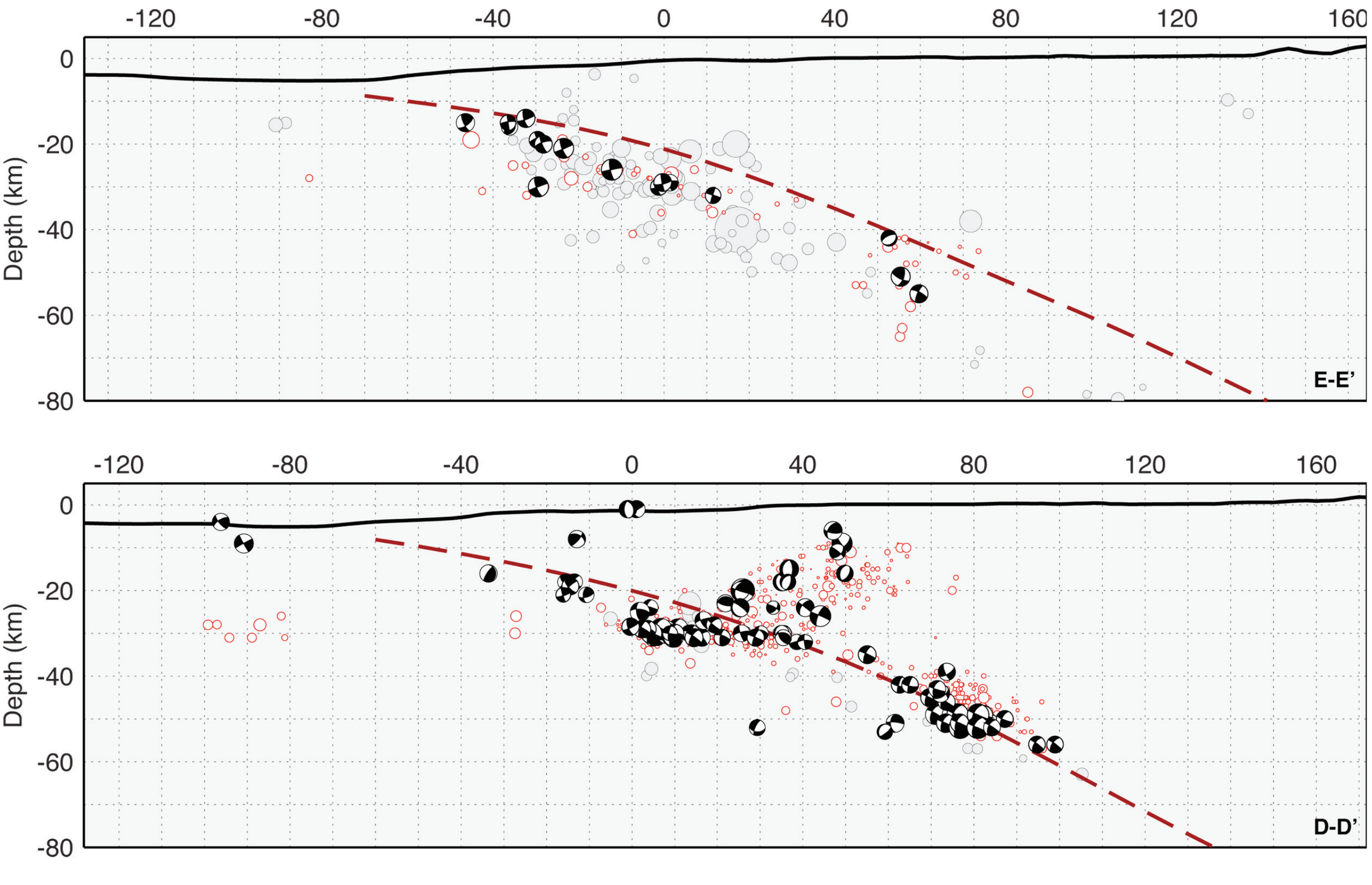


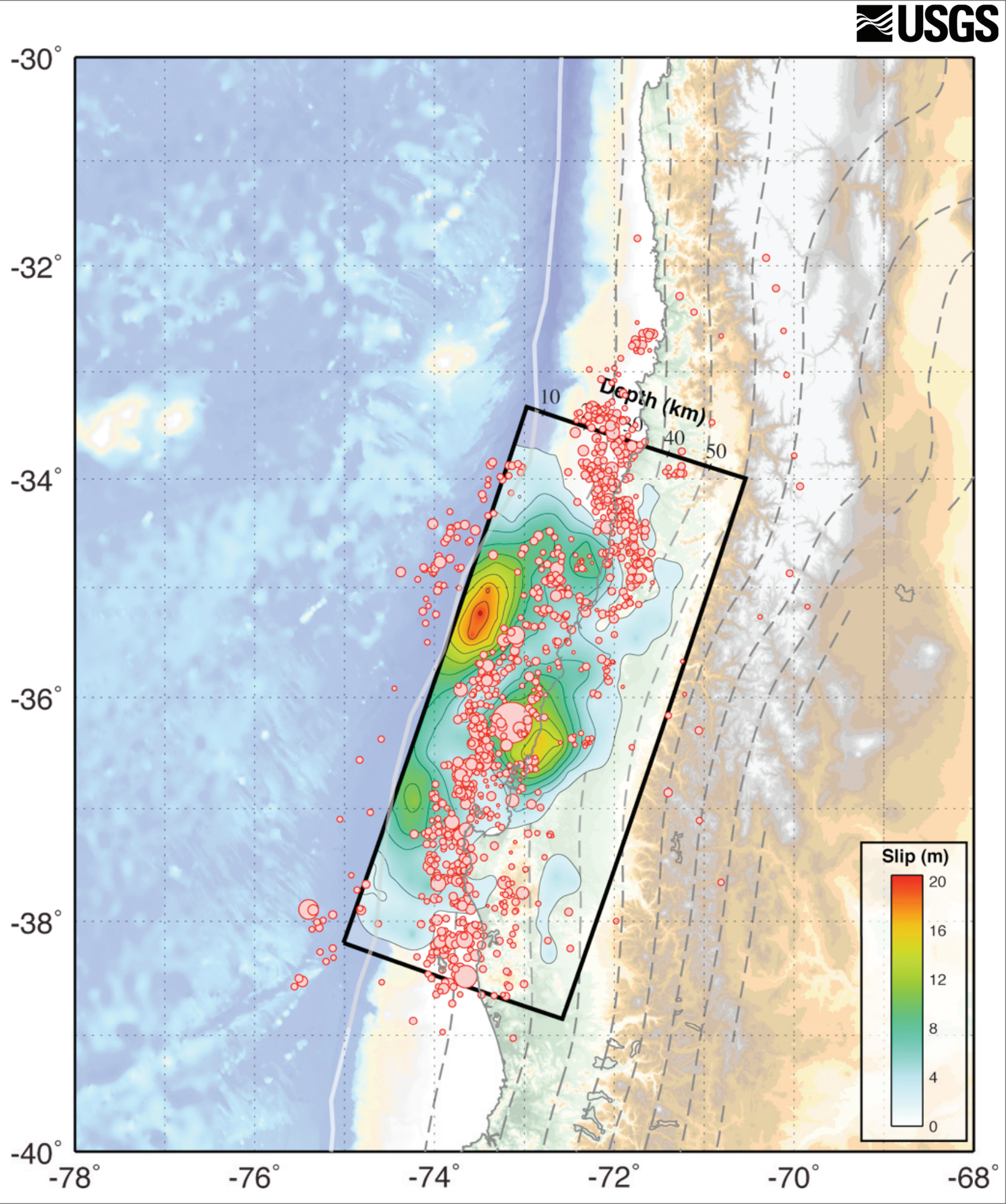
Maule FFM

Single-plane teleseismic FFM.

Fits seismic data extremely well (explains 88% of waveform data).

Aftershocks dominantly cluster in regions of lower or transitional slip.

Reasonable fits to horizontal & vertical GPS data.



Maule FFM

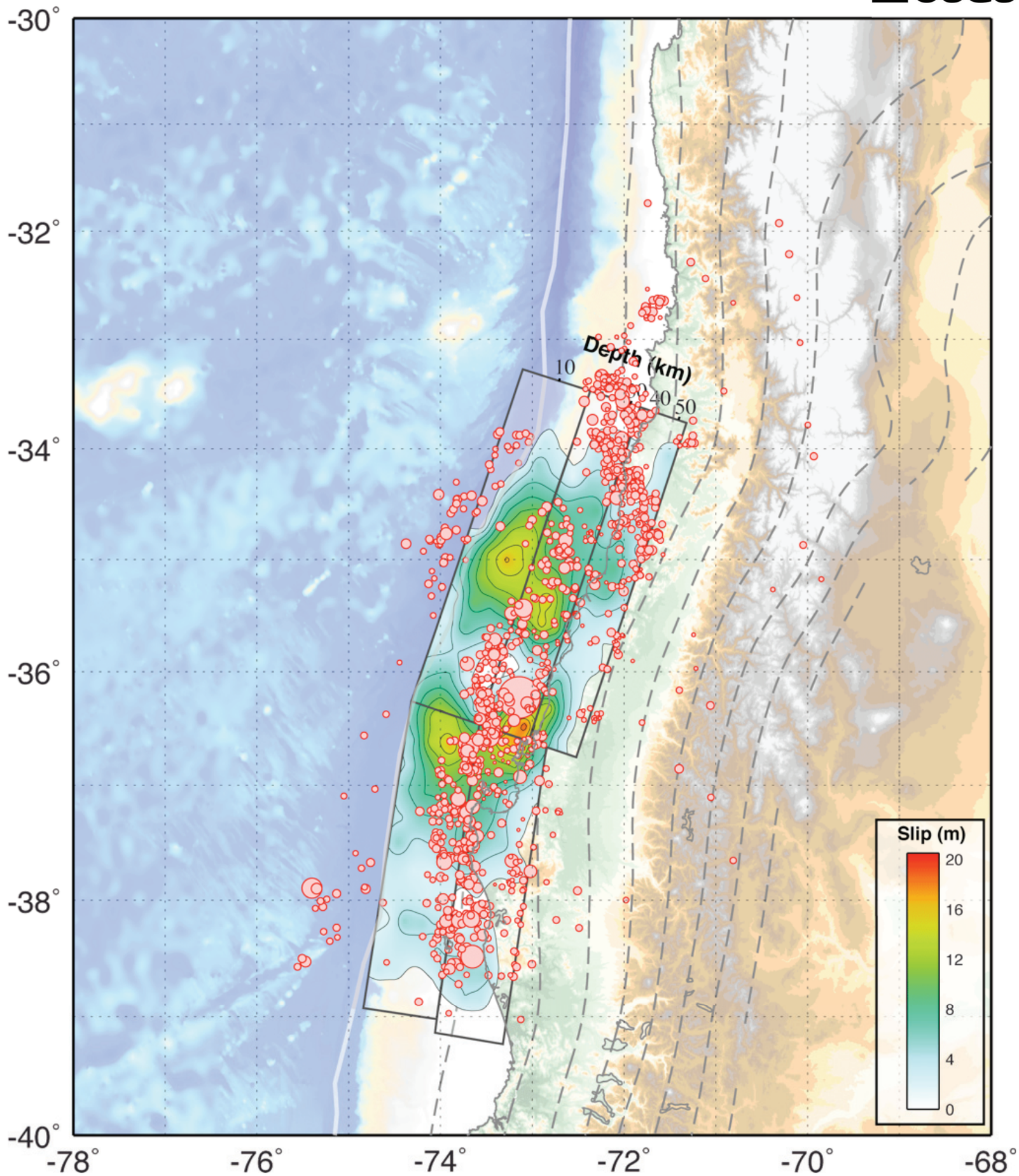
Five-plane teleseismic FFM.

Better accounts for down-dip and along-strike changes in slab geometry.

Still fits seismic data extremely well (explains 90% of waveform data).

Much better fits to horizontal & vertical GPS data.

==> Rapid seismic FFMs still useful!

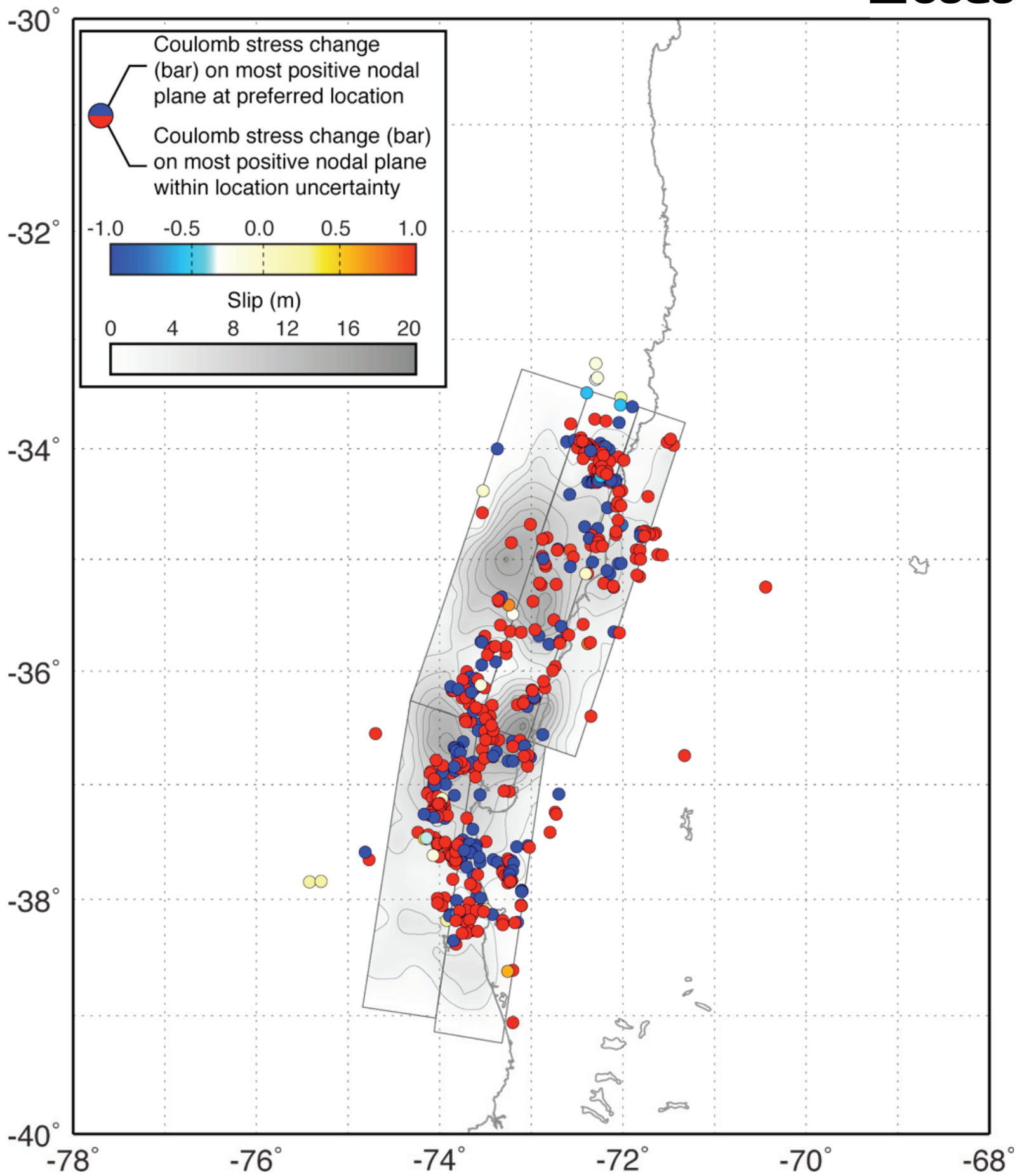


Coulomb Stress Transfer

ΔCFS calculations - comparing favored slip model and aftershock relocations - very sensitive to uncertainties in both.

Preferred locations vs. slip model ==> 55% aftershock nodal planes show +ΔCFS (~5-10% gain over background seismicity).

Within AS uncertainties (a few km), 90% aftershock nodal planes show +ΔCFS (~55% gain over background).



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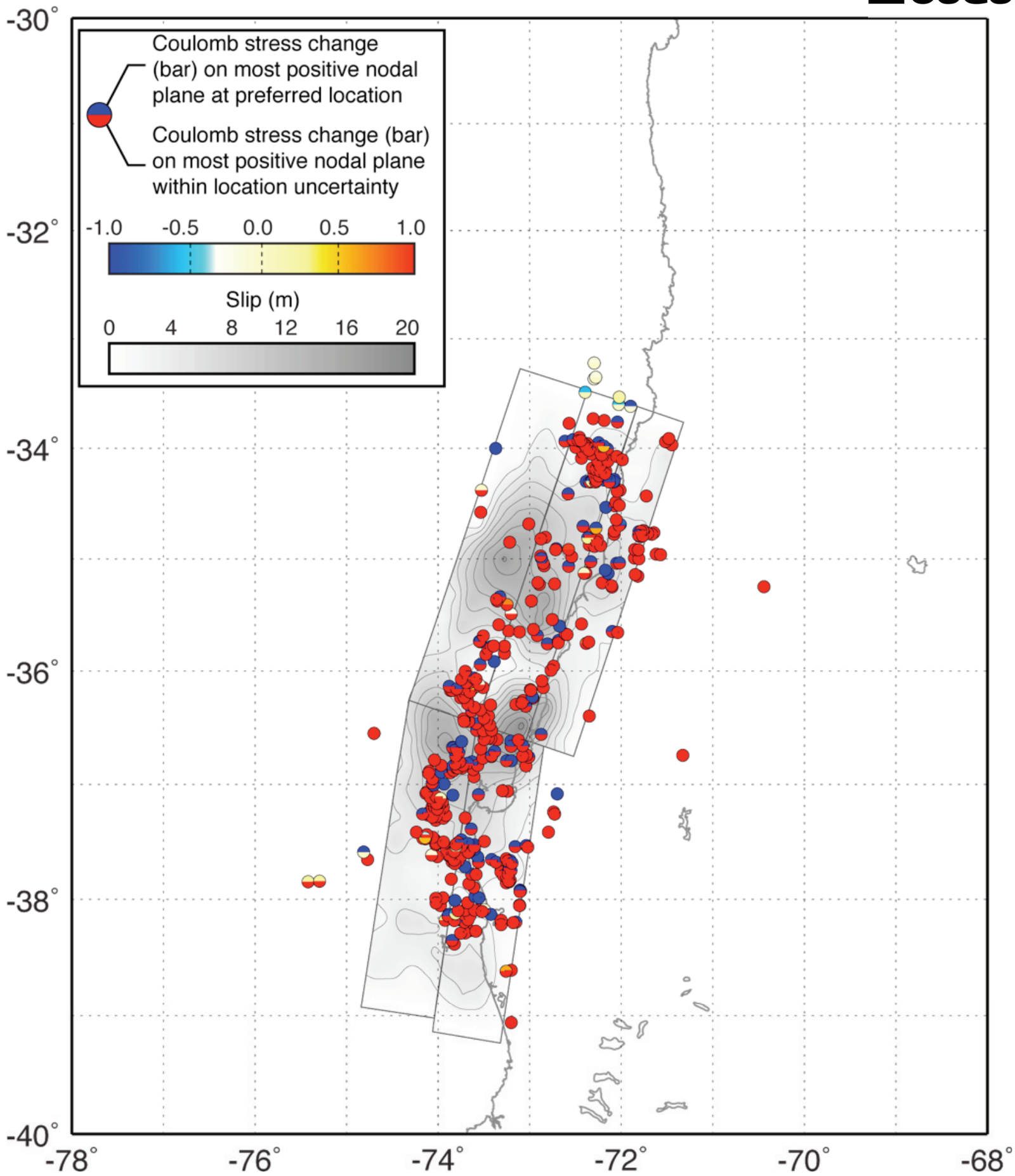


Summary

30,000 aftershocks of the Febrary 2010 Maule earthquake (Mw 8.8) automatically located with an offline module mimicking NEIC's realtime data processing system.

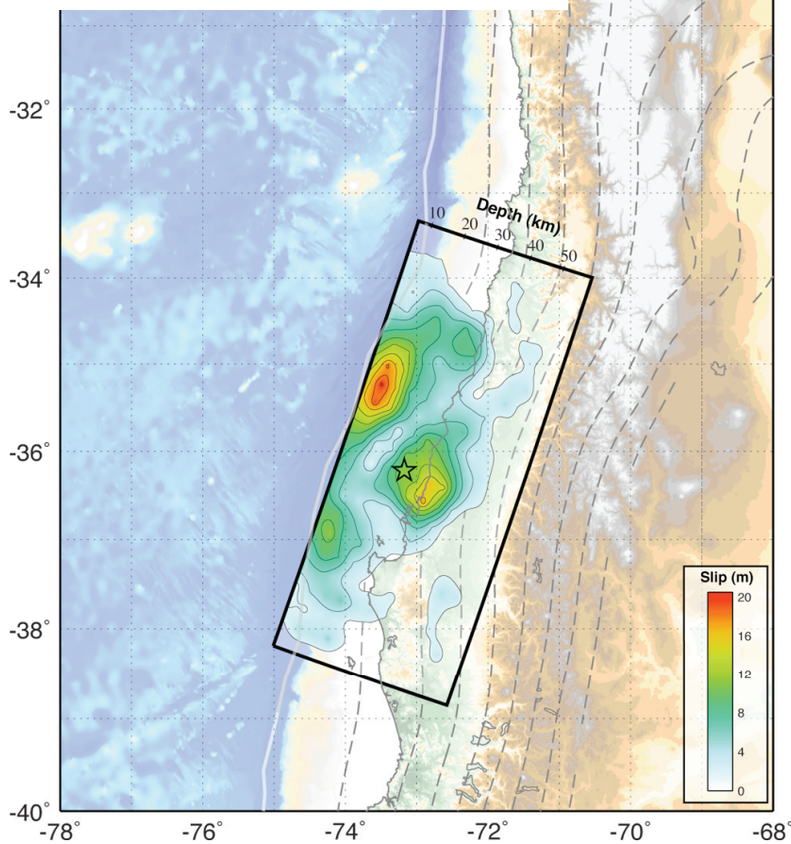
2,500 events relocated to derive a high-precision catalog of the largest aftershocks (uncertainties < 3 km).

500 Regional Moment Tensors allow analysis of tectonics of sequence - EQs divided into upper, lower, interplate. 55% of RMTs are interplate; 35% lower plate. Upper plate aftershocks dominant in north, near Pichilemu, where two large normal faulting aftershocks occurred on 03-11-10.

Coulomb stress transfer calculations demonstrate importance of considering uncertainties - in both aftershock locations and slip distribution. Small uncertainties of relocated aftershocks in this study cause the percentage of events occurring on positively stressed faults to increase from 55% (at preferred locations) to 90% (within location uncertainties).

Geodetic Data Residuals

Maule GPS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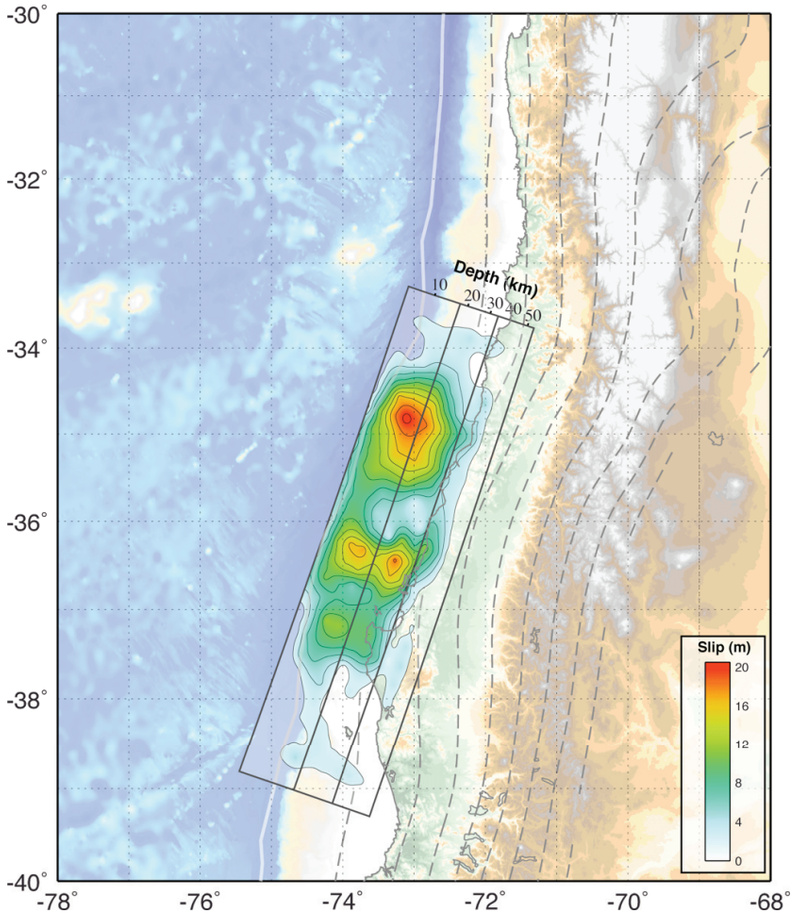
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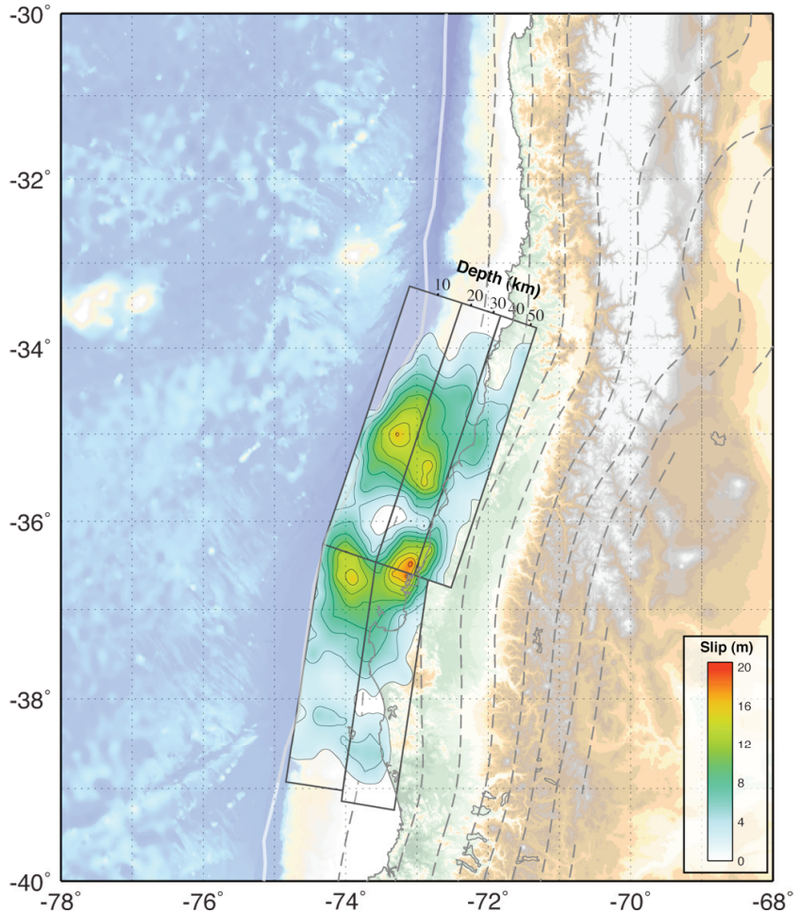
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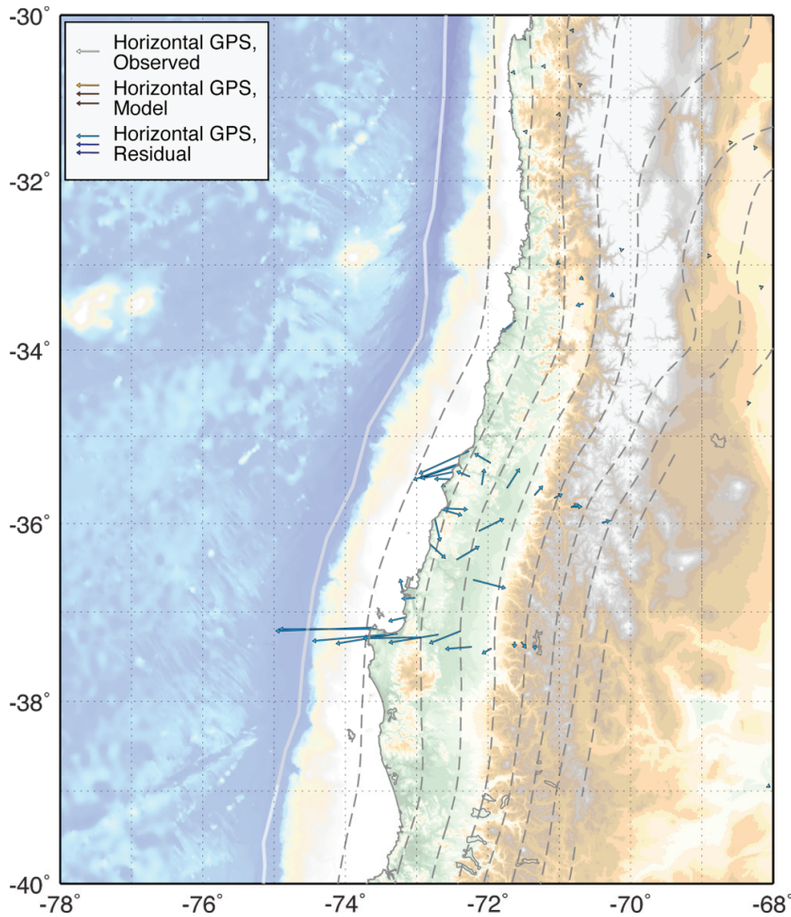
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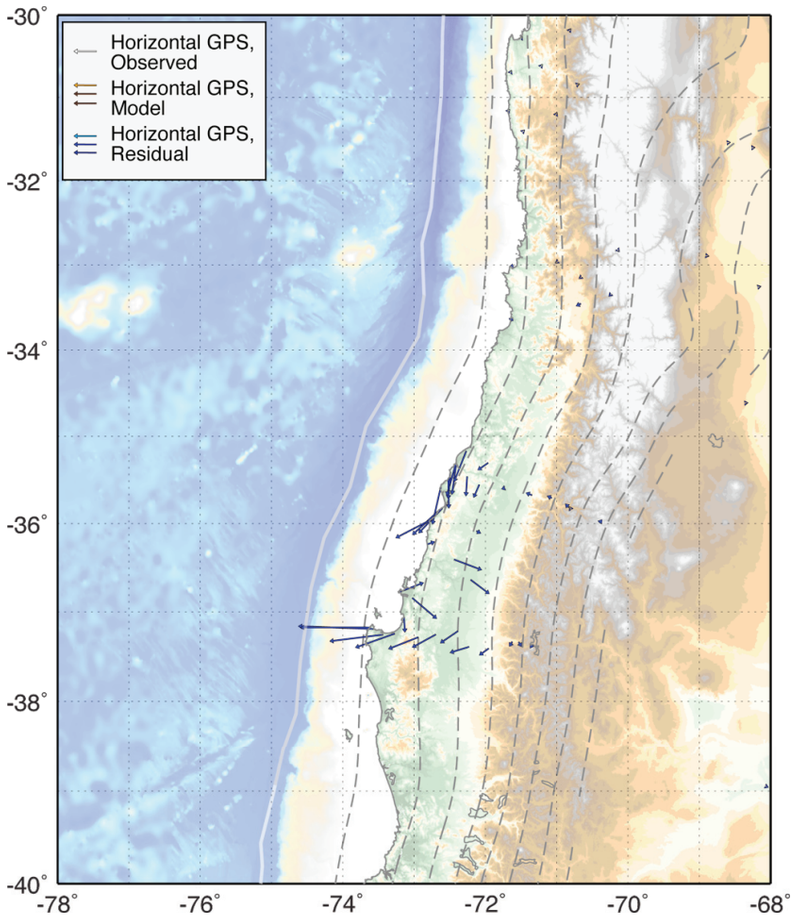
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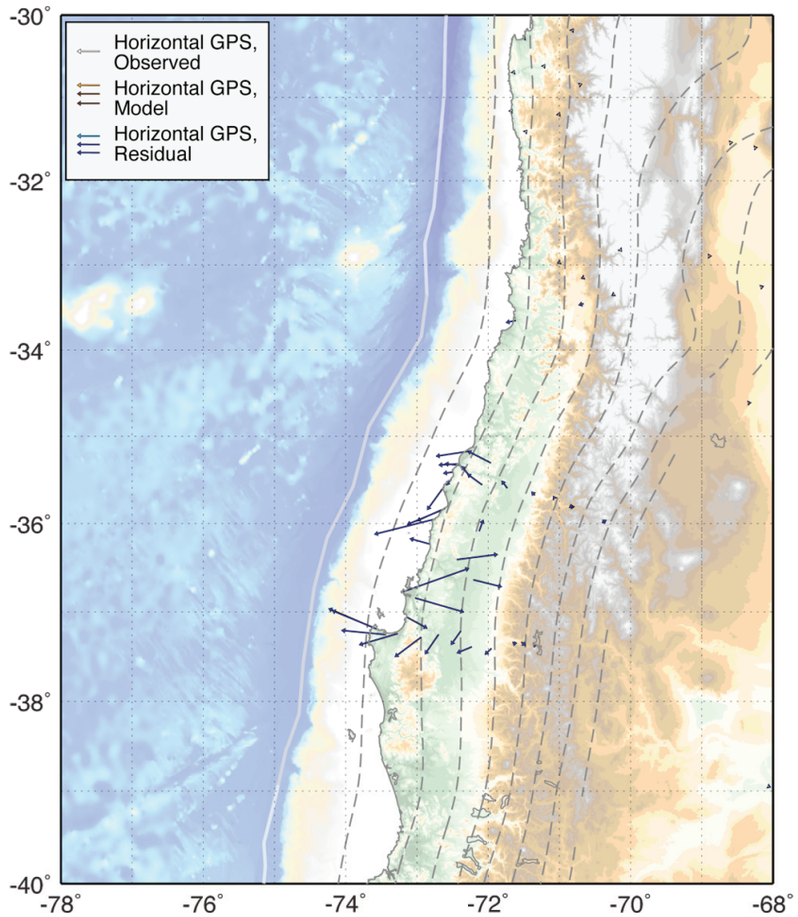
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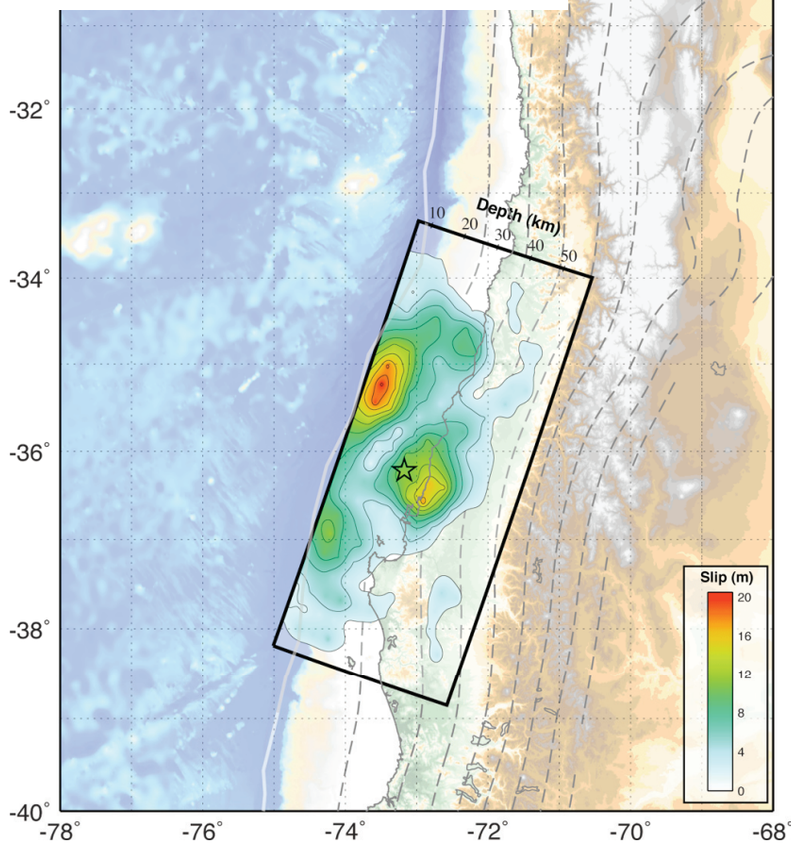
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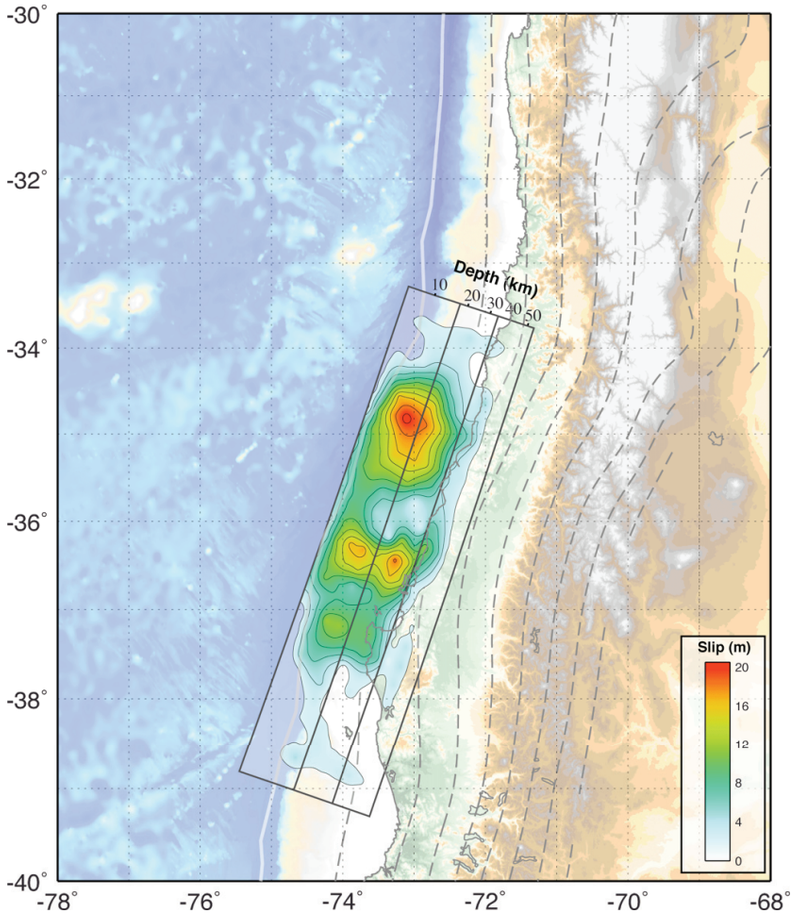
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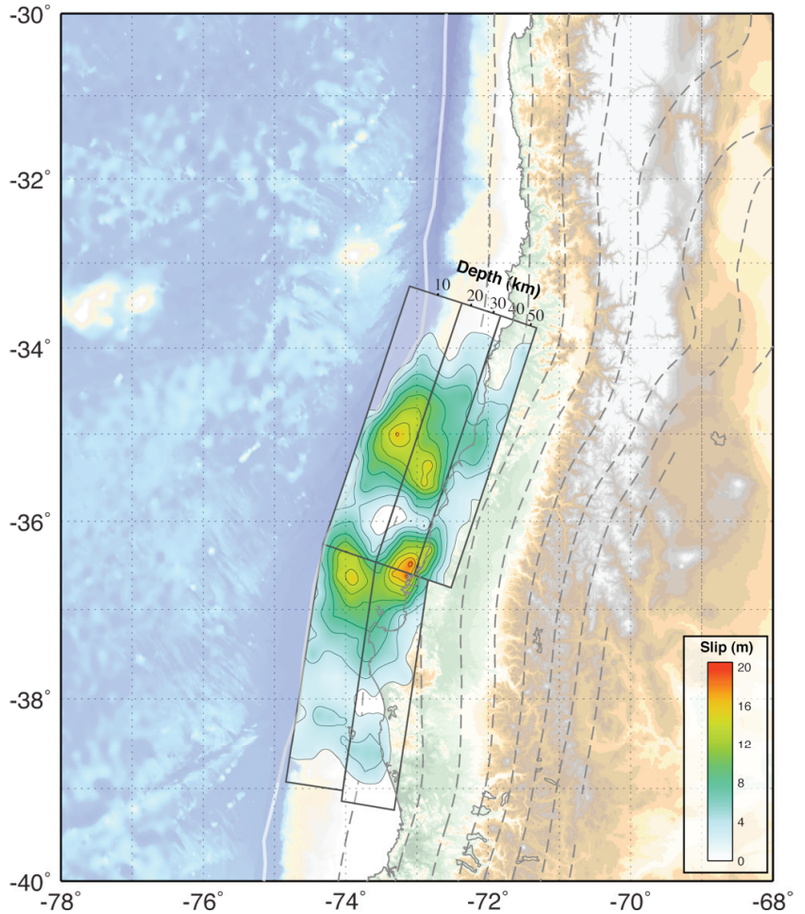
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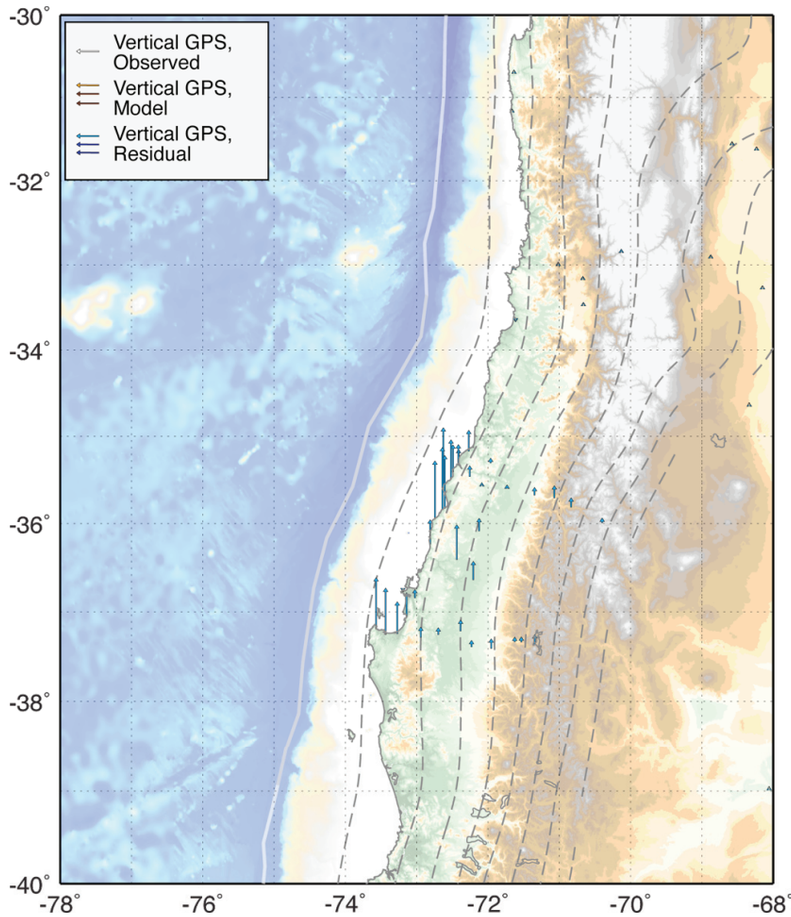
Vertical GPS, Observed
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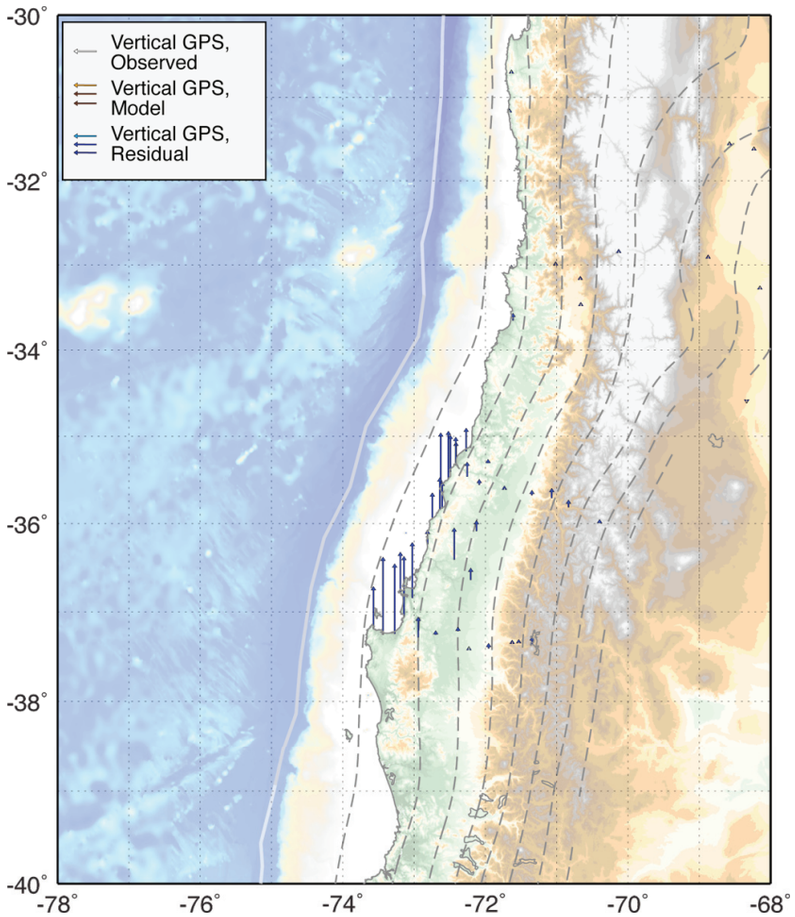
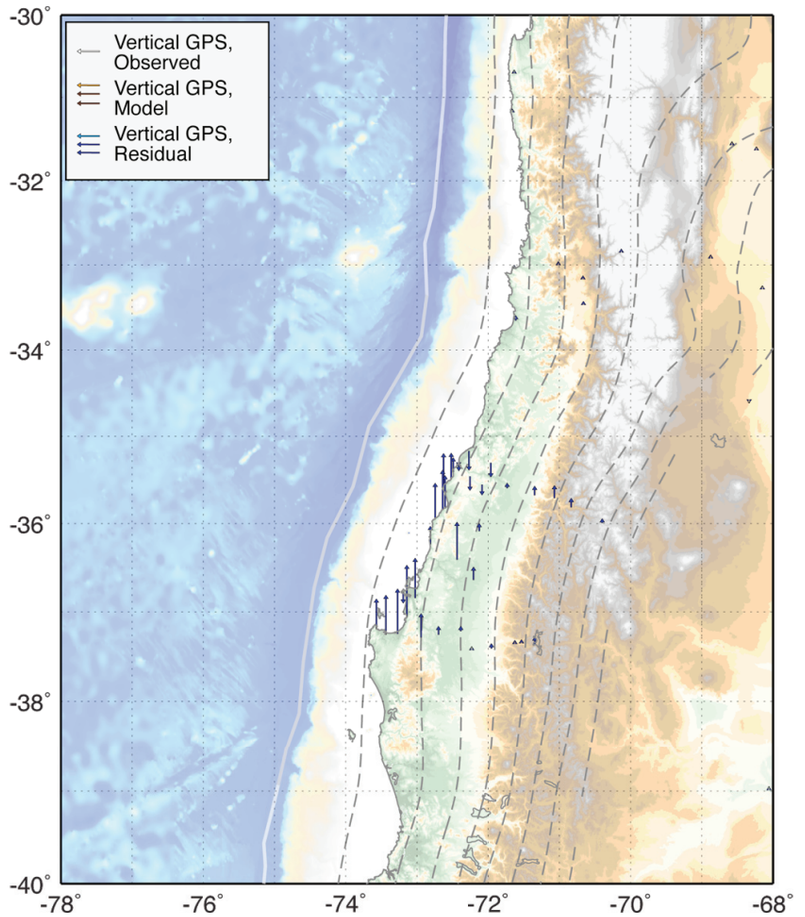
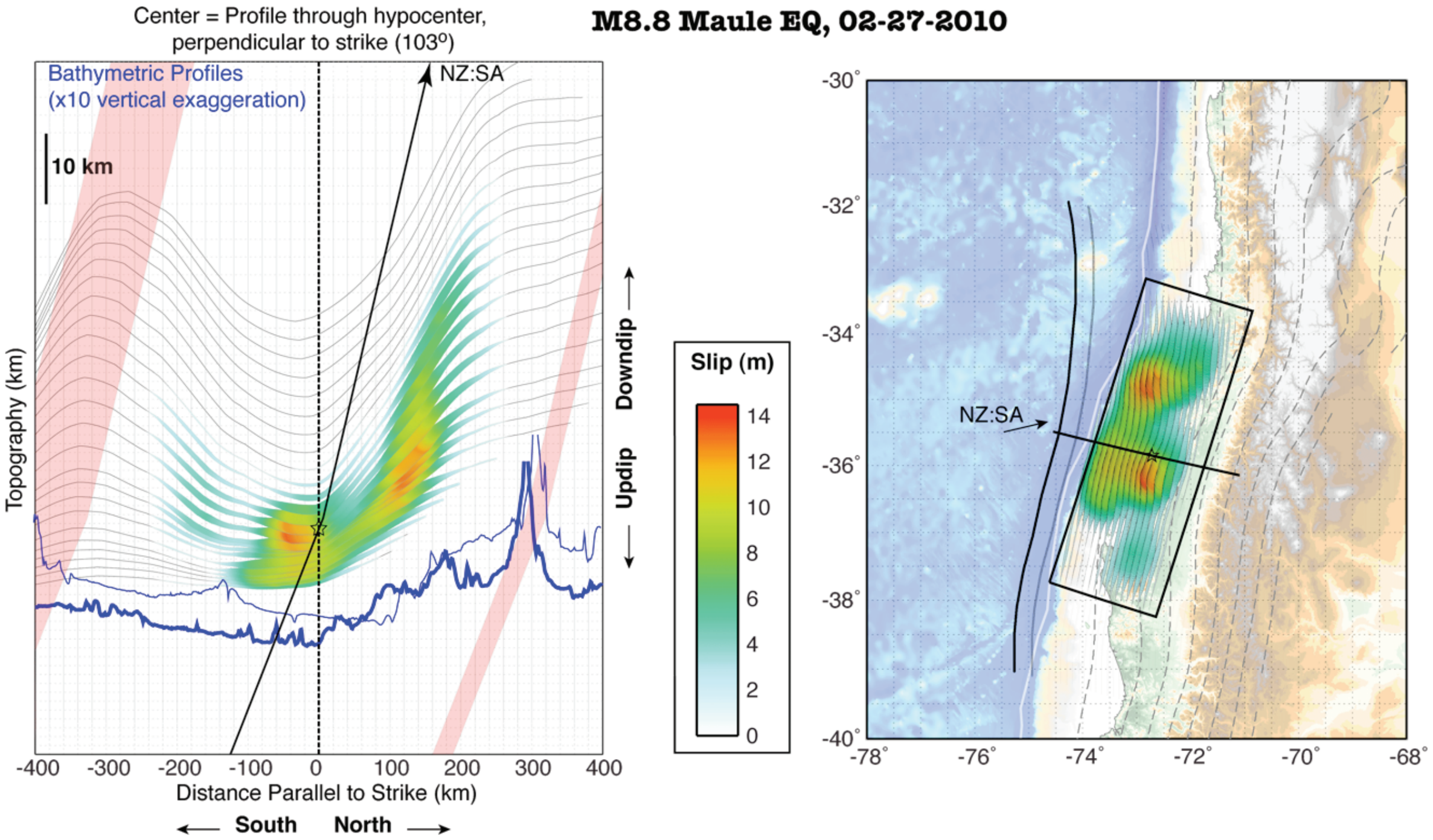
-70°
-68°


Vertical GPS, Observed
Vertical GPS, Model
Vertical GPS, Residual
-30°
-32°
-34°
-36°
-38°
-40°
-78°
-76°
-74°
-72°
-70°
-68°


Vertical GPS, Observed
Vertical GPS, Model
Vertical GPS, Residual
-30°
-32°
-34°
-36°
-38°
-40°
-78°
-76°
-74°
-72°
-70°
-68°

Megathrust Slip VS Slab1.0

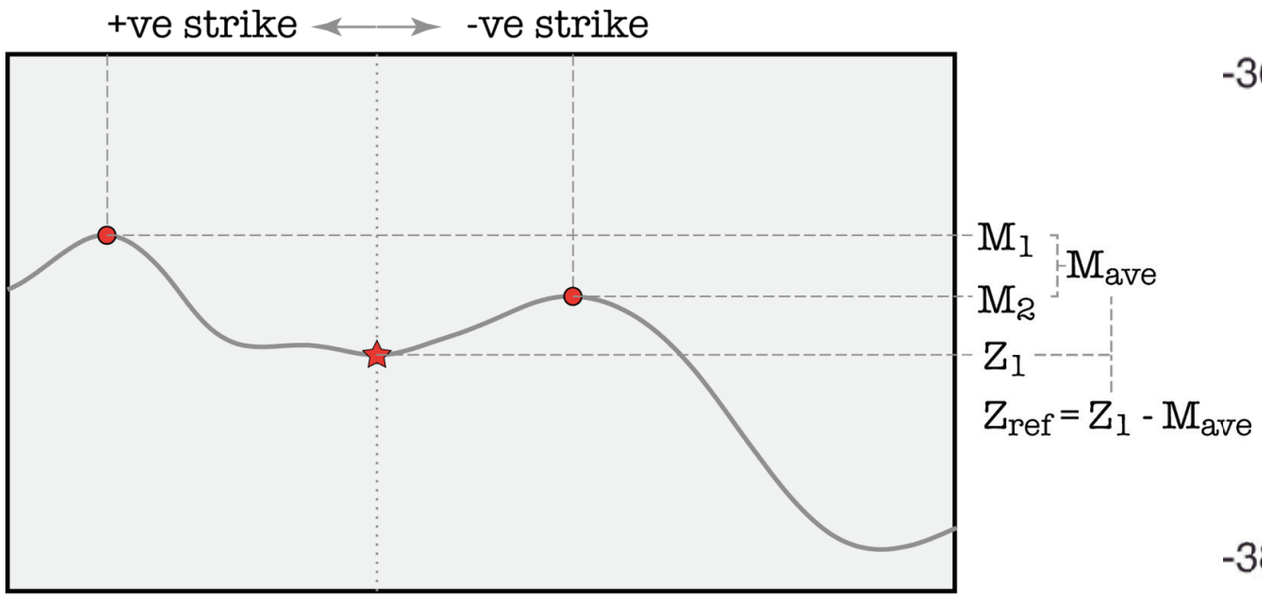
FFMs & Slab1.0 - Slip vs Structure

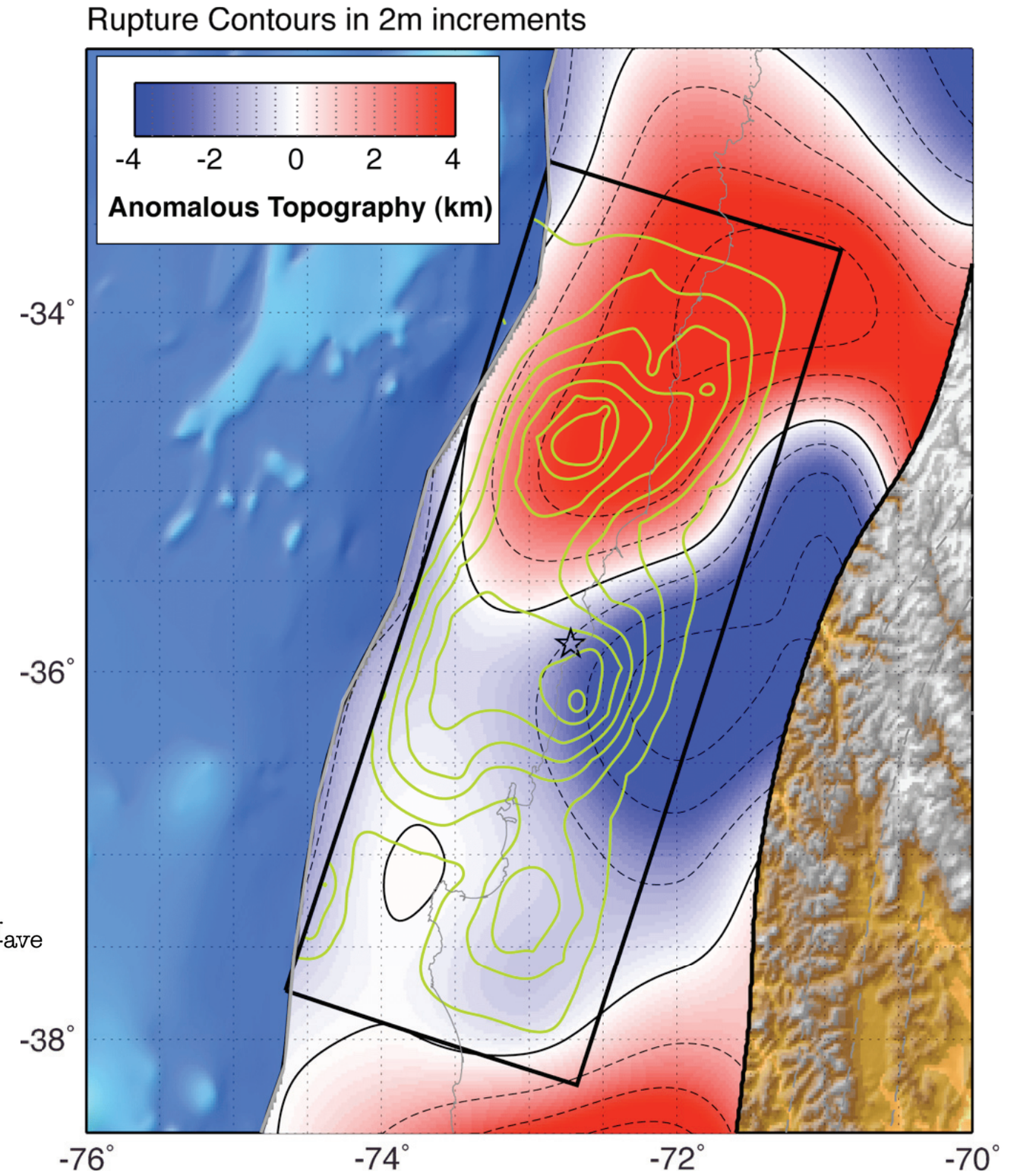


Comparisons of fault models with subduction zone geometry show coseismic slip was confined to a local minima in the subducting plate.

FFMs & Slab1.0 - Slip vs Structure

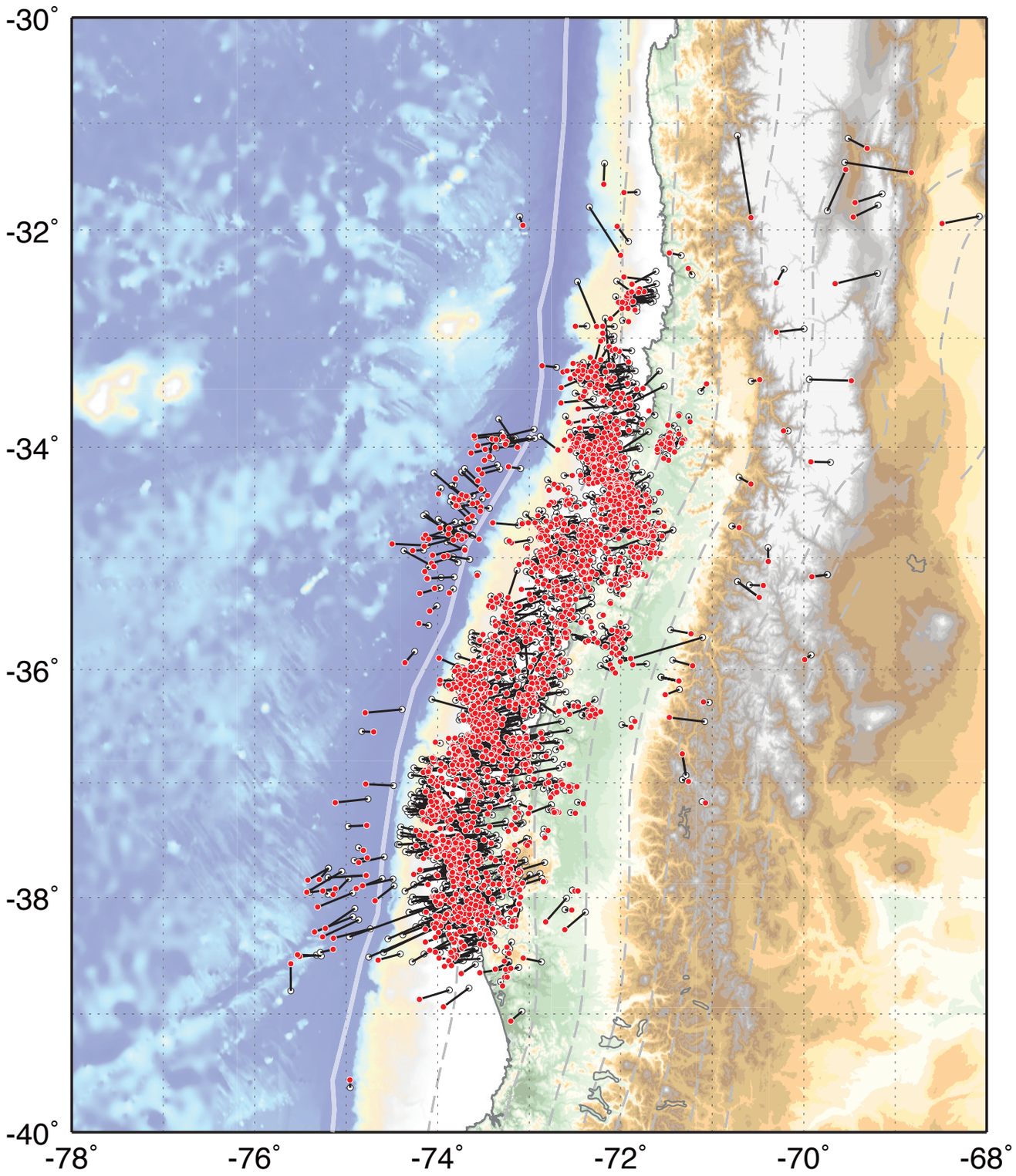
Major northern asterity was located on the south side of a local high in subduction zone topography. Hypocenter and southern asperity was within the local minima.

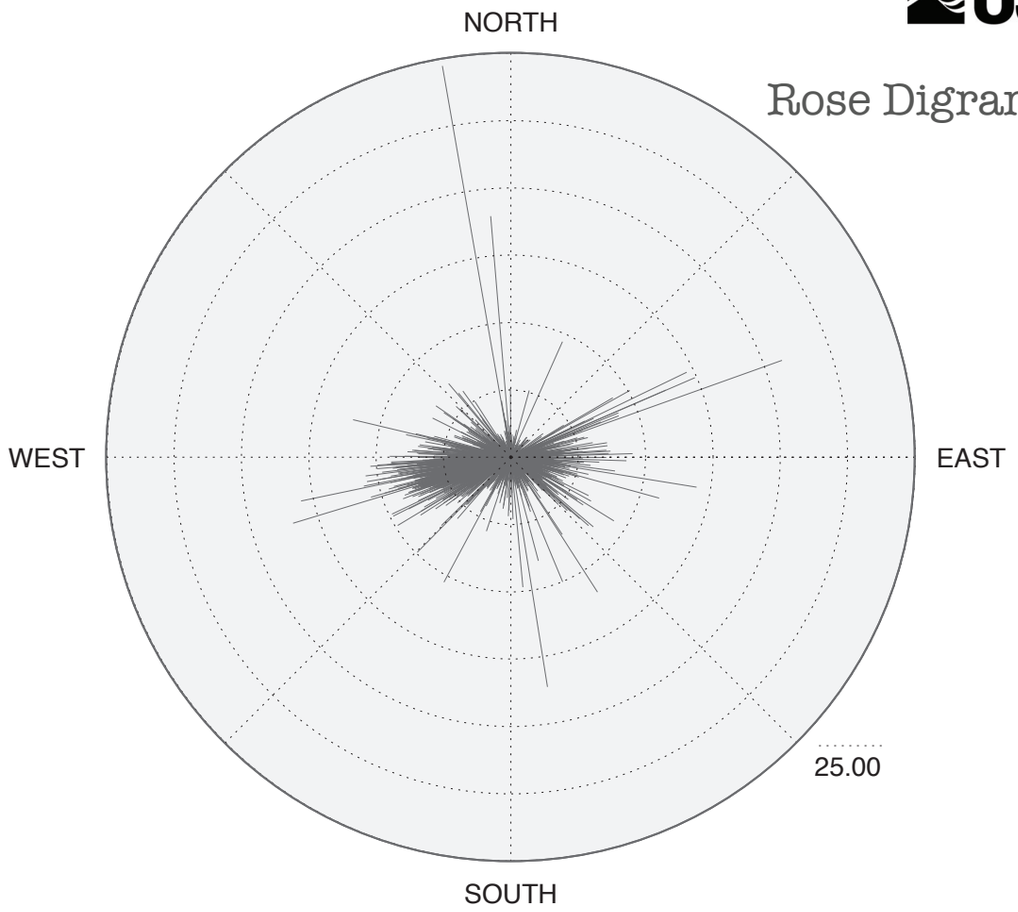




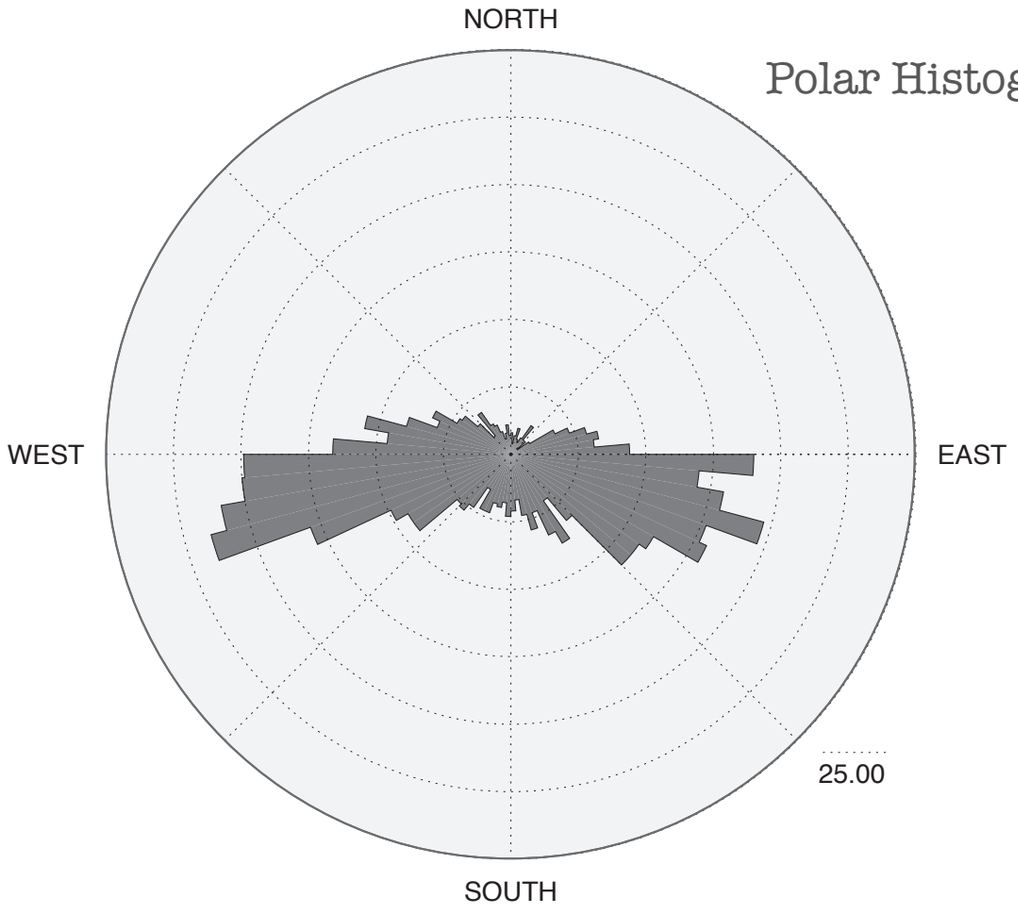
Extra Slides

Relocation Vectors



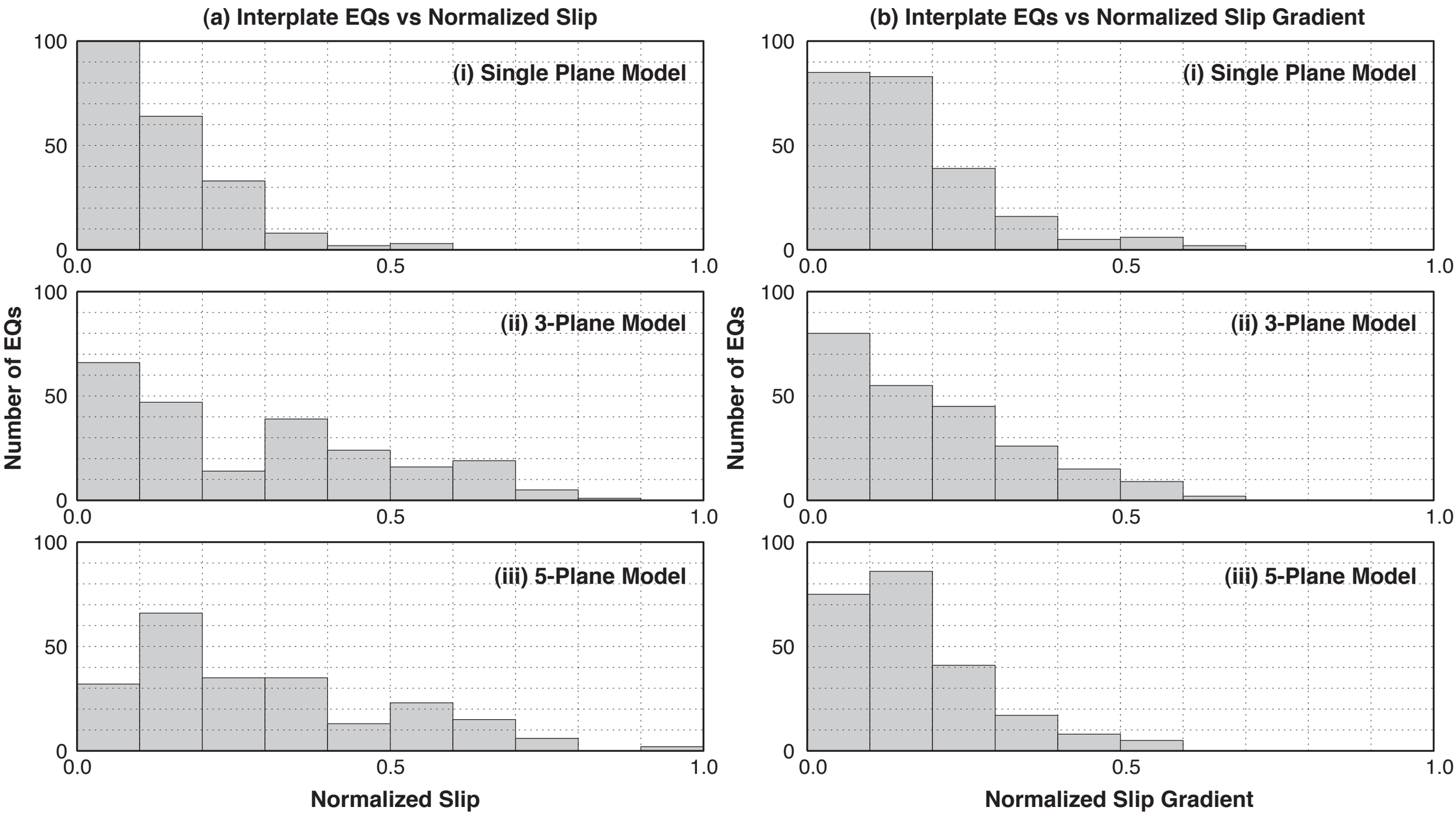


Rose Digram



Polar Histogram

Aftershocks VS Coseismic Slip



Comparisons of aftershock locations and coseismic slip show most events occur away from peak slip, but also where slip gradients are low.