Geodesy (InSAR, GPS, Gravity) and Big Earthquakes

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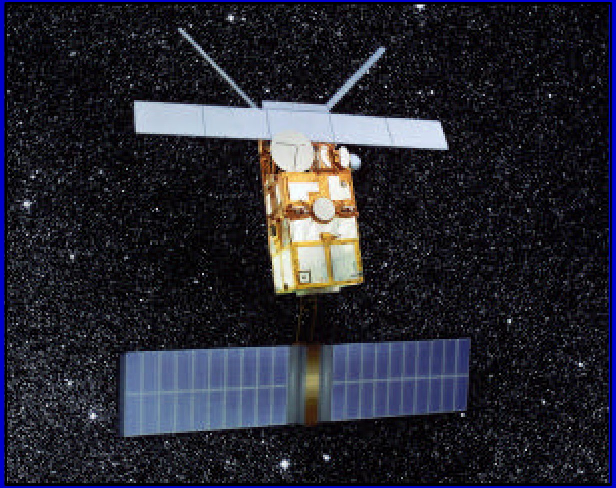
Goals

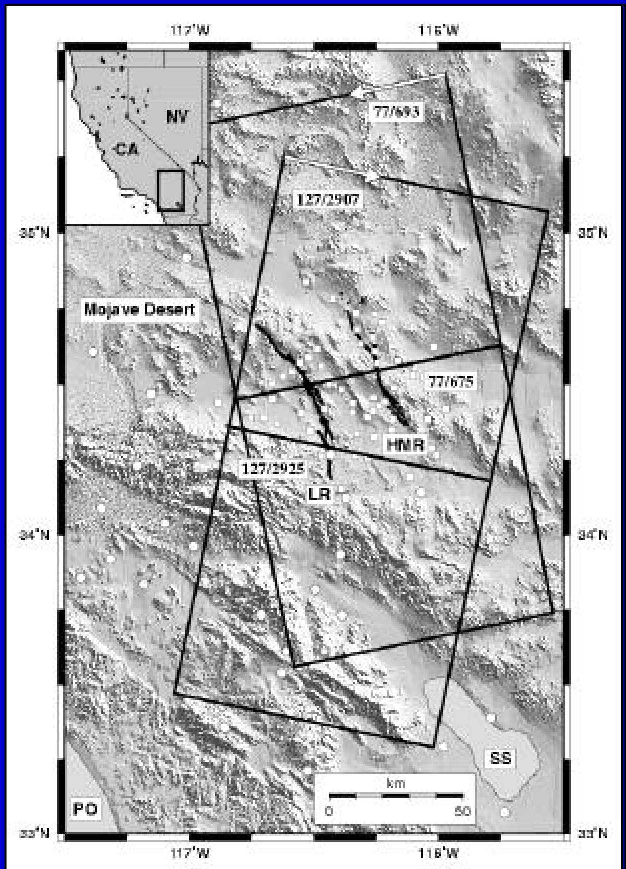
- Accurate and high resolution fault slip models for big EQs
- Why?
  - Moment release budget as a function of position
  - Co-seismic rheology
  - Earthquake interaction
  - Input into post-seismic models
  - Relationship to tectonic geomorphology

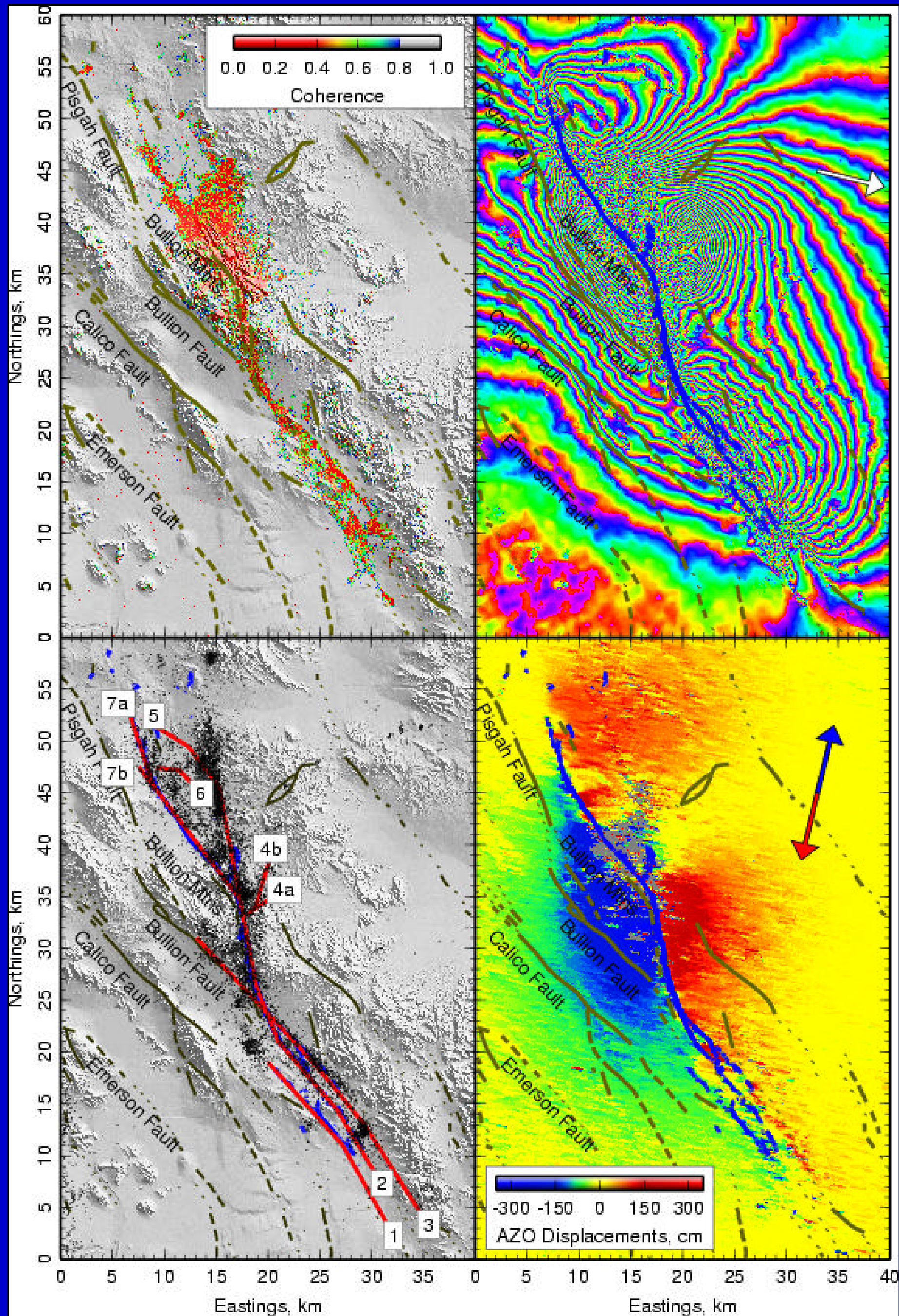


- Issues/difficulties
  - Observational: dataset limitations
  - Mathematical: Choice of inversion technique
  - Earth Structure: Spatial variations of rheology

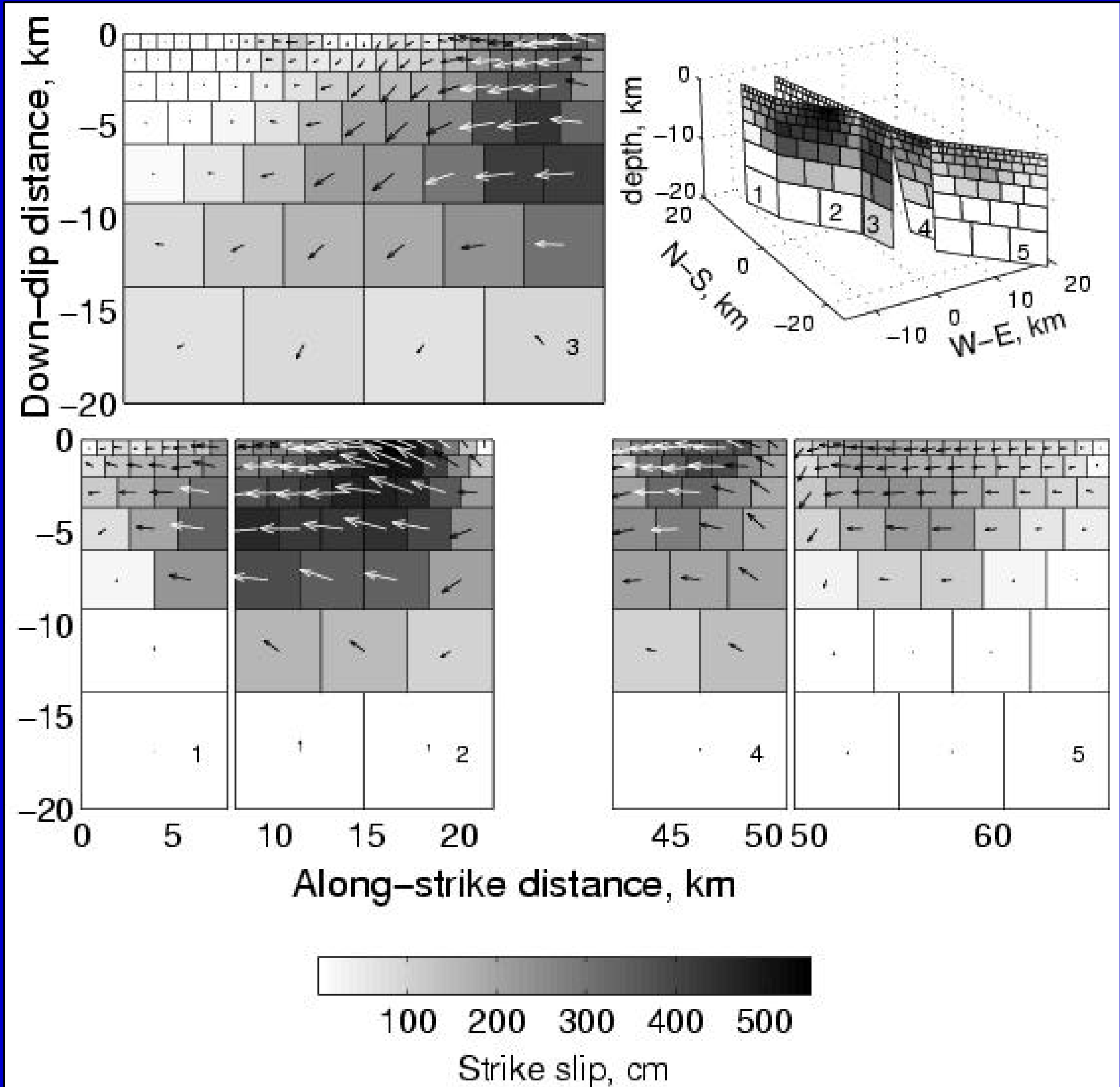
1999 Mw 7.1 Hector Mine EQ

Decorrelation
Phase (multiple LOS)
Seismicity
Azimuth Offsets



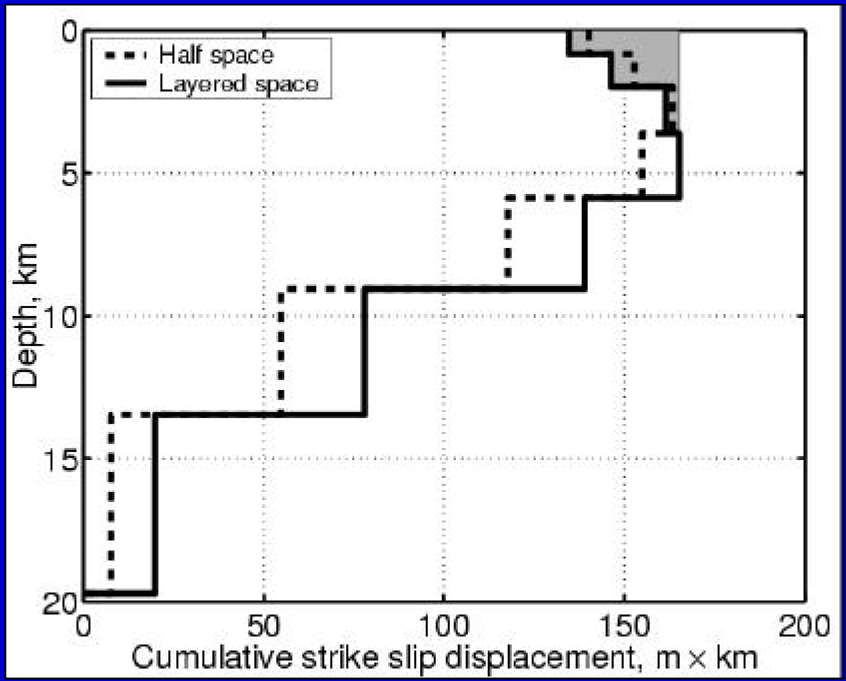


A coseismic distributed slip model



Implications for post-seismic and interseismic models:

- Significant vertical fault slip
- Fault slip concentrated at shallow depth
- Most slip in the northern half
- Apparent slip deficit…



The apparent slip deficit

Integrate slip along strike:

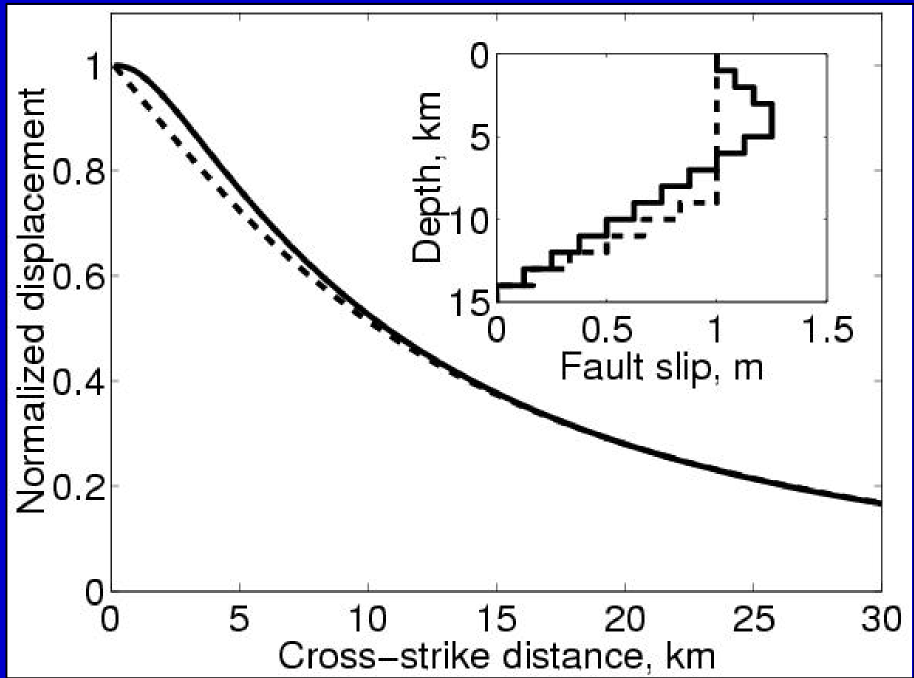
- ➢Half-space vs. layered elastic structure
- ➢Shallow moment deficit required by inversion (Mw 6.1)

Cartoon models:

- ➢Difference in models controlled by near field inflection of displacement profile

Conjecture:

- ➢Inelastic process causes inflection
- ➢Needs improved modeling



1999 Mw 7.1 Hector Mine EQ

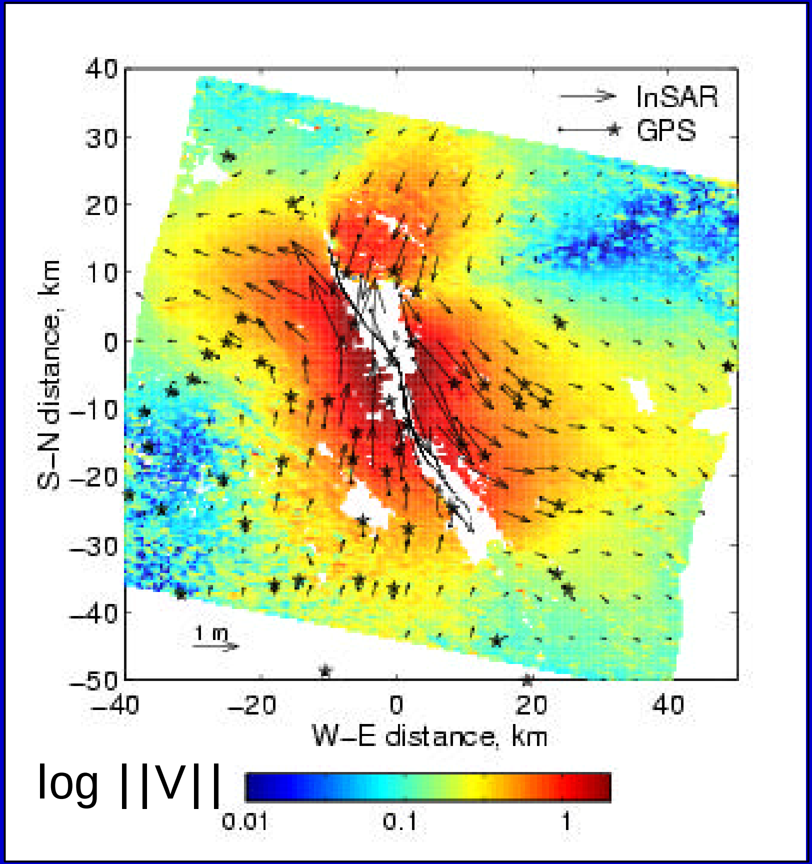
Practical/geophysical lessons:

- Rapid response possible
- 3 components (phase/offsets)
- Decorrelation
  - -> reveals complex faulting
- Permit high spatial resolution models
- Shallow slip deficit
  - -> inelastic processes?

Still to be done...

- Use refined coseismic model for postseismic studies (important for periods immediately following EQ).
- Data/model comparison tricky

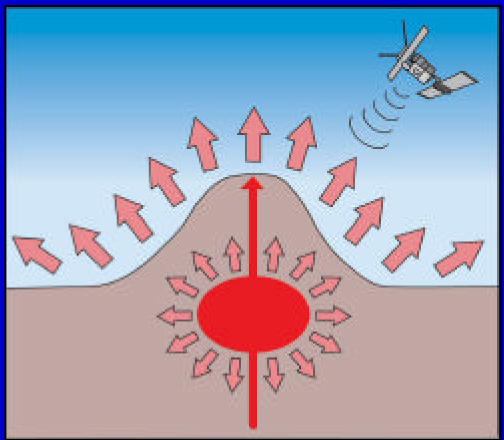
Horizontal Displacements Field

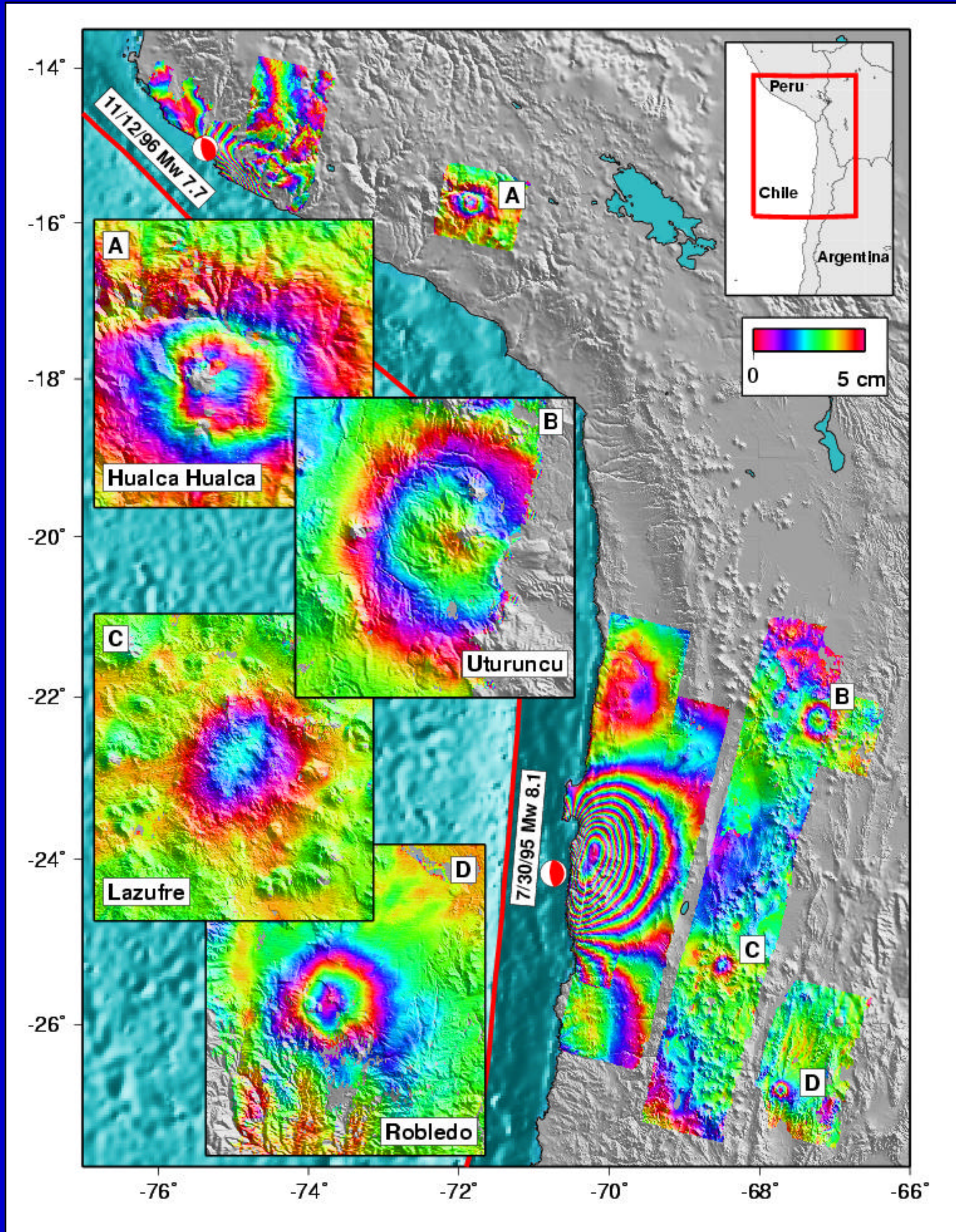


The deforming continent 1992-2000:

Subduction earthquakes
•1995 Mw 8.1 Antofagasta
•1996 Mw 7.7 Peru
•1998 Mw 7.0 Antofagasta
•2001 Mw 8.4 Peru ????

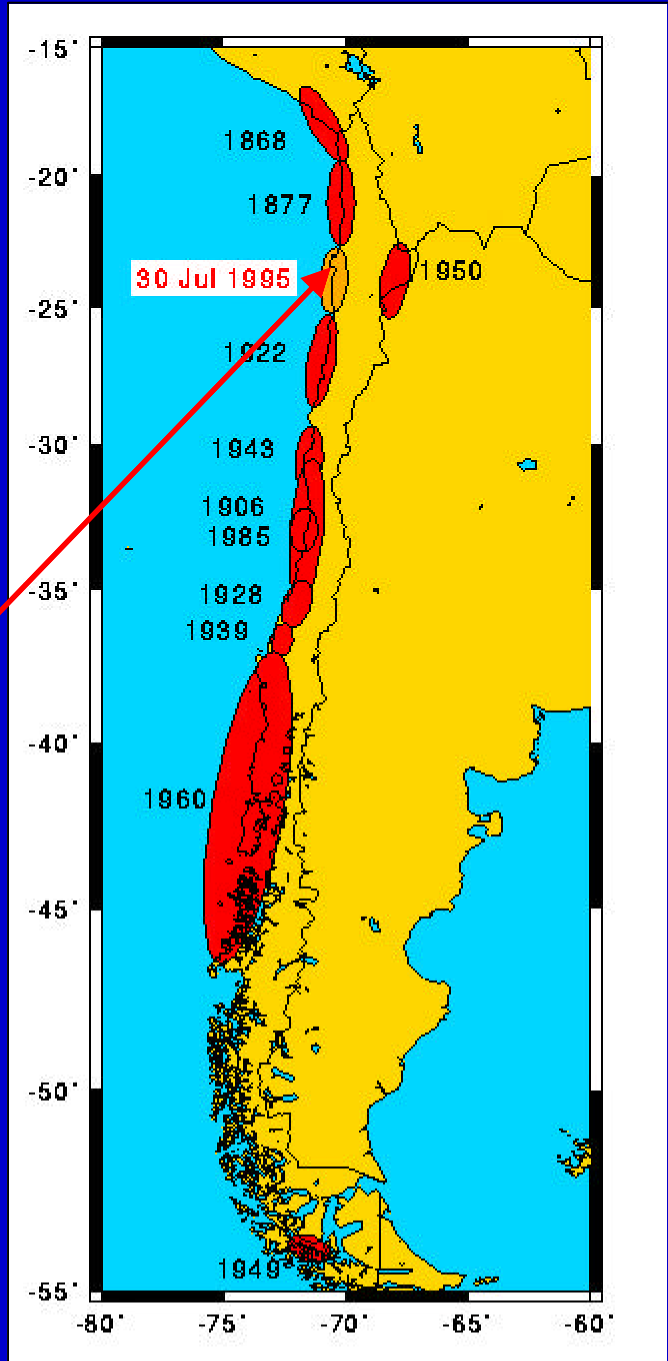
Survey of > 900 volcanoes
•4 undocumented sources
•1 incipient caldera?



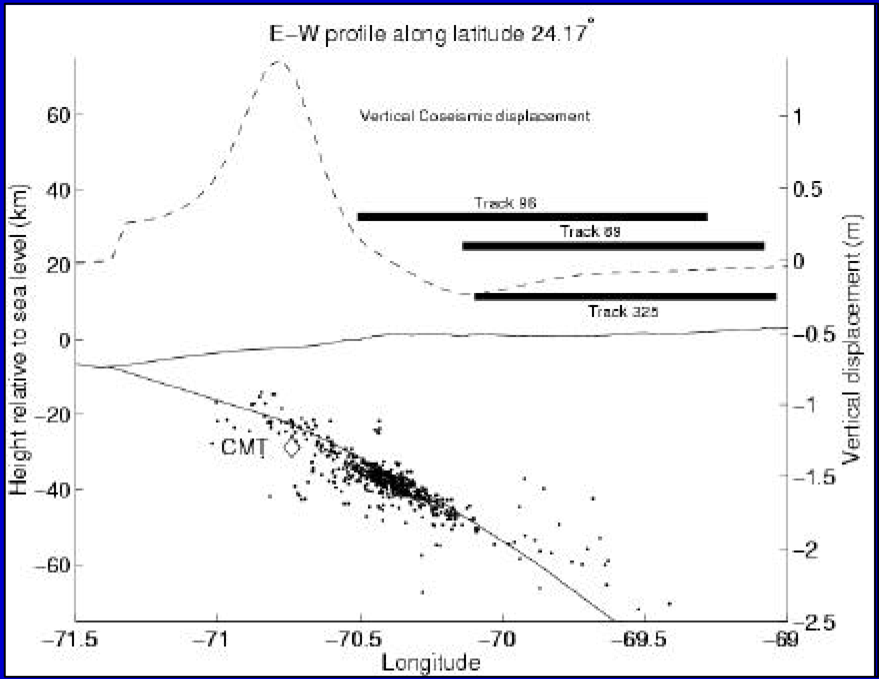


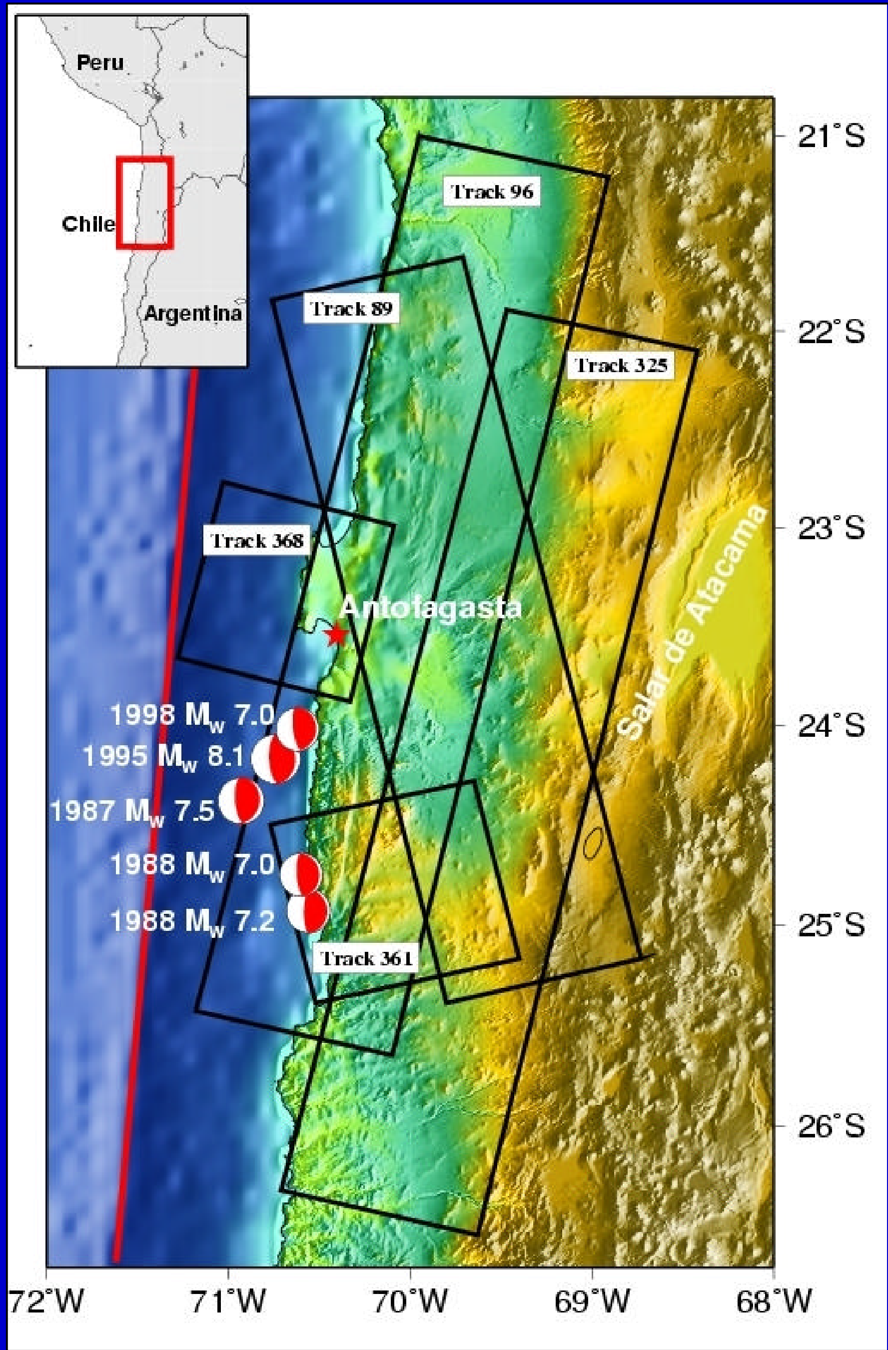
South America:
A Land of Big Earthquakes

The Mejillones Peninsula and Atacama viewed from Apollo

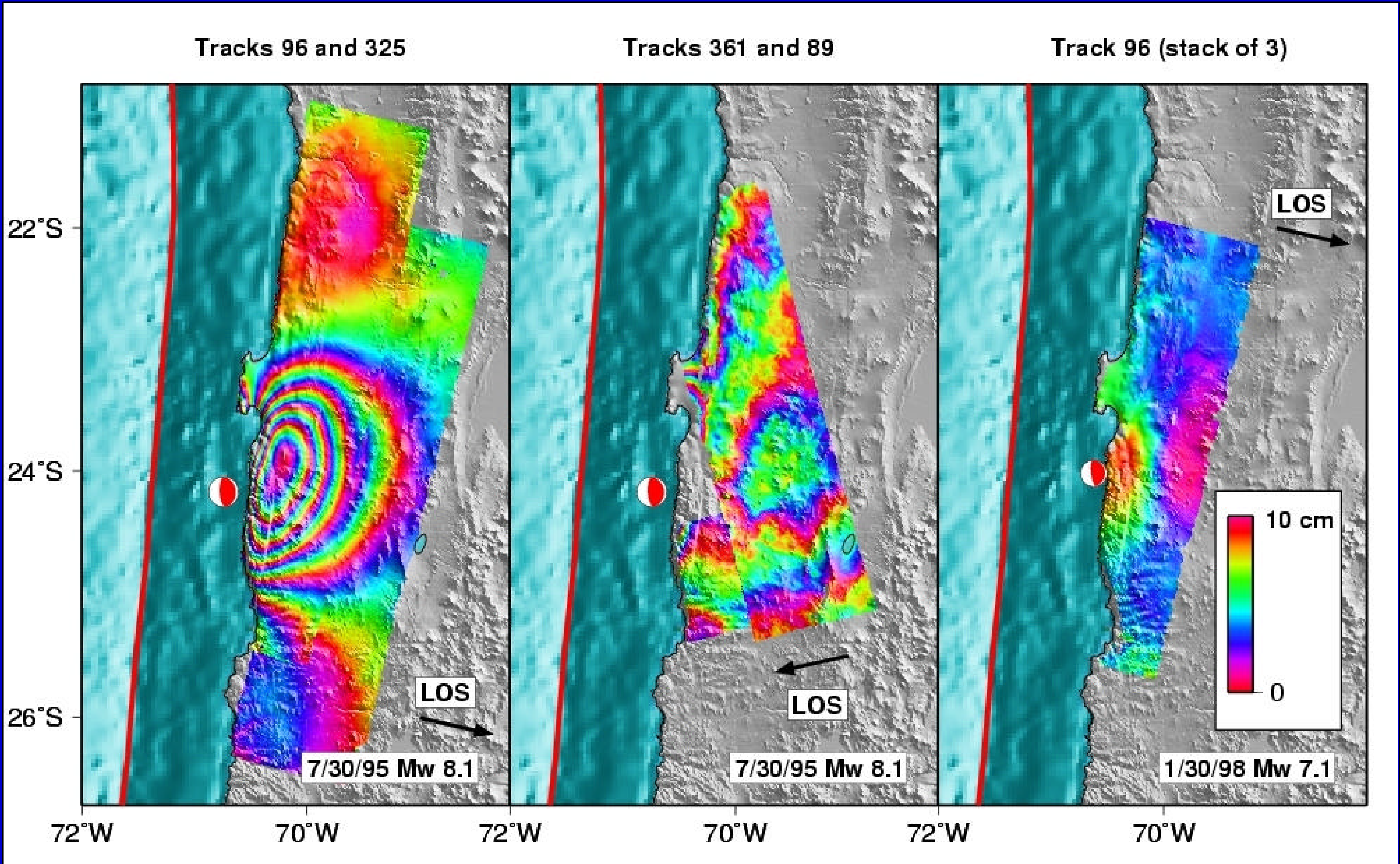


The temporal and spatial pattern of big earthquakes

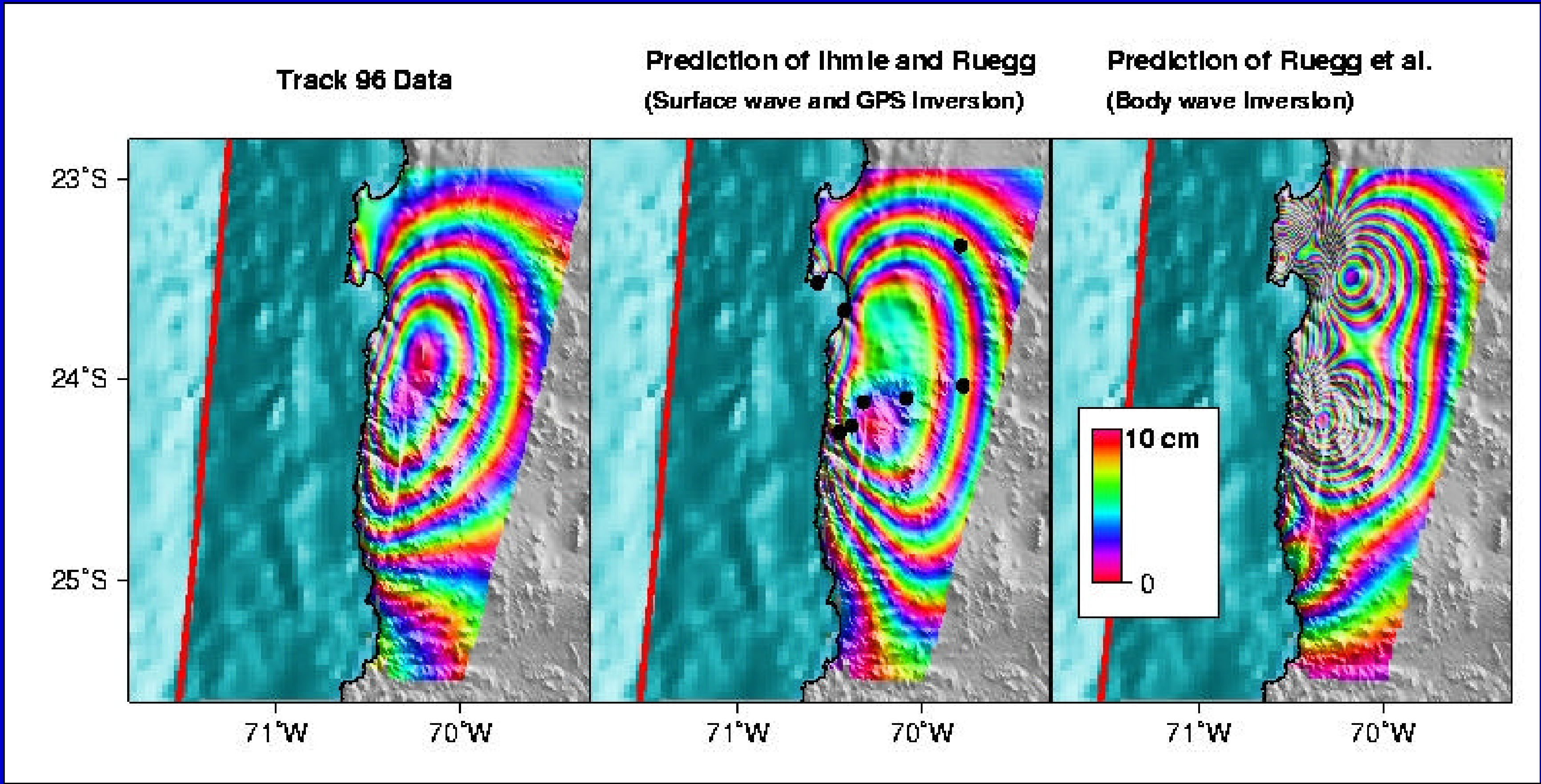




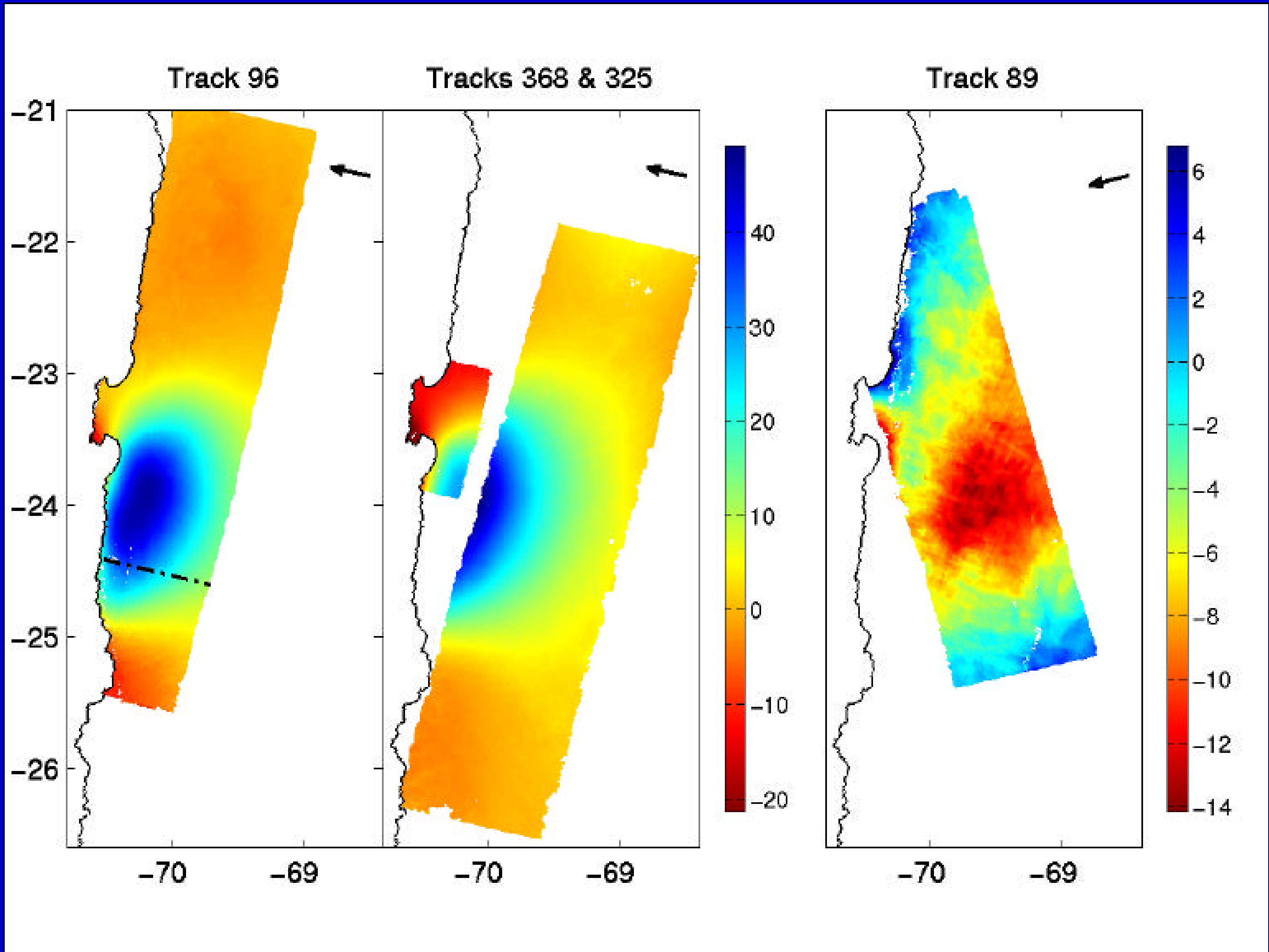
The available data:
Mw 8.1 1995 and Mw 7.1 1998



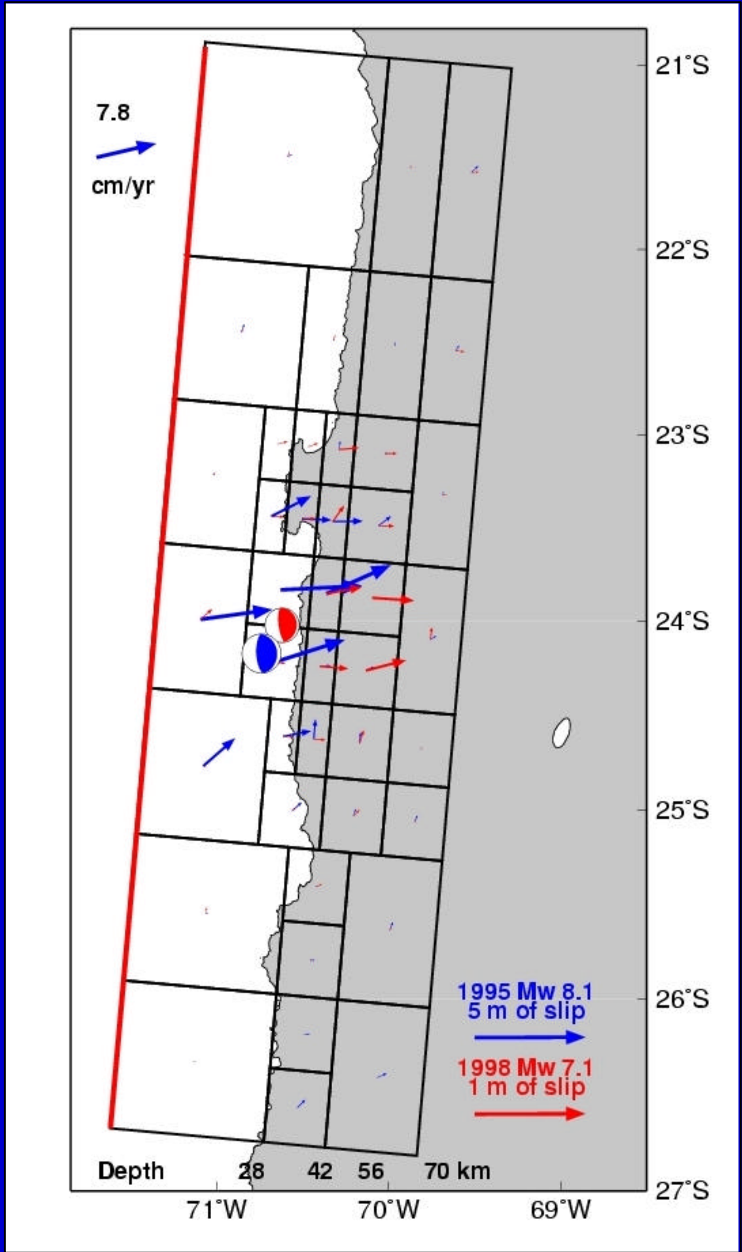
Compare previous models to InSAR

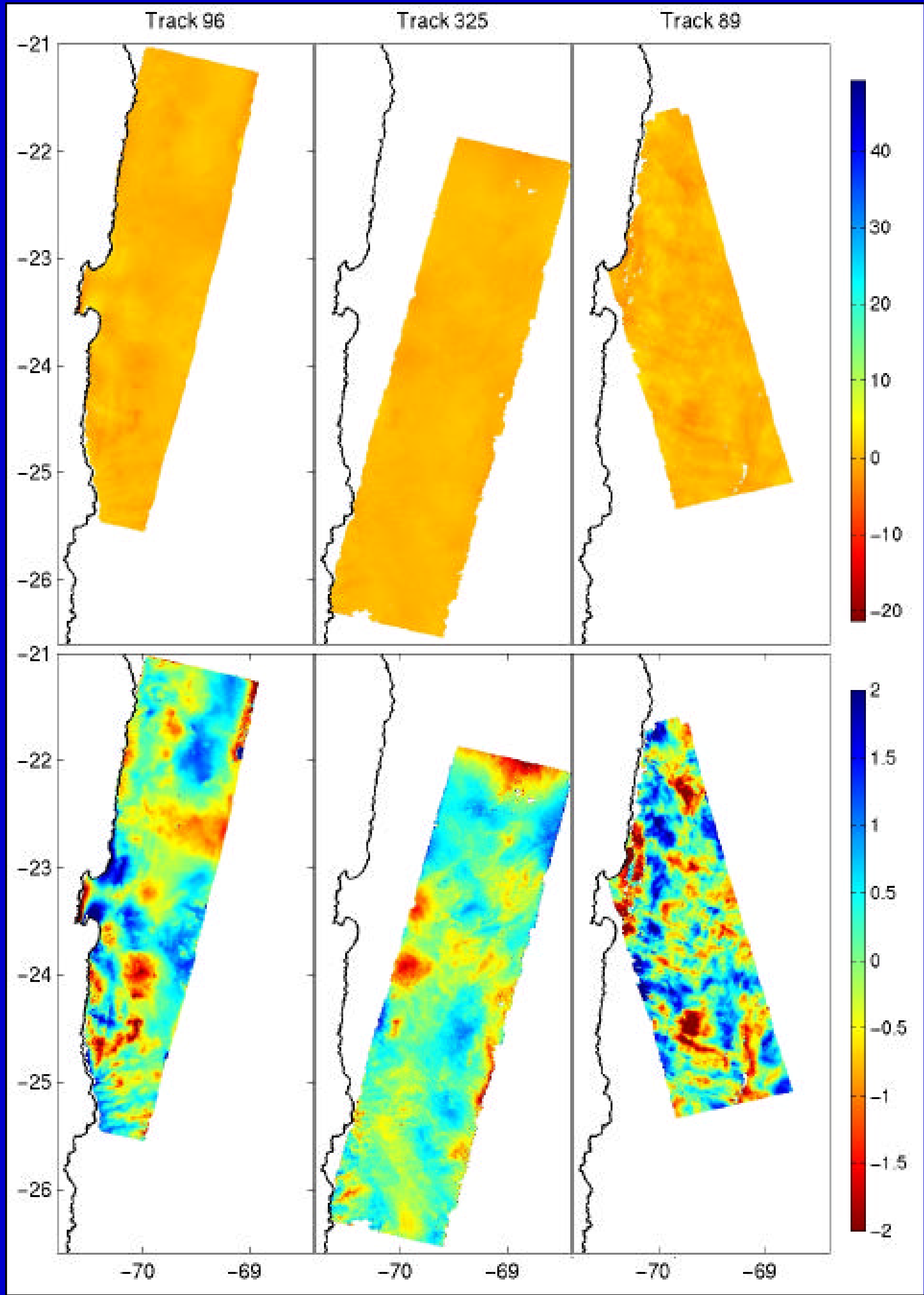


1995 Mw 8.1: Phase unwrapped



1995 Mw 8.1: The model





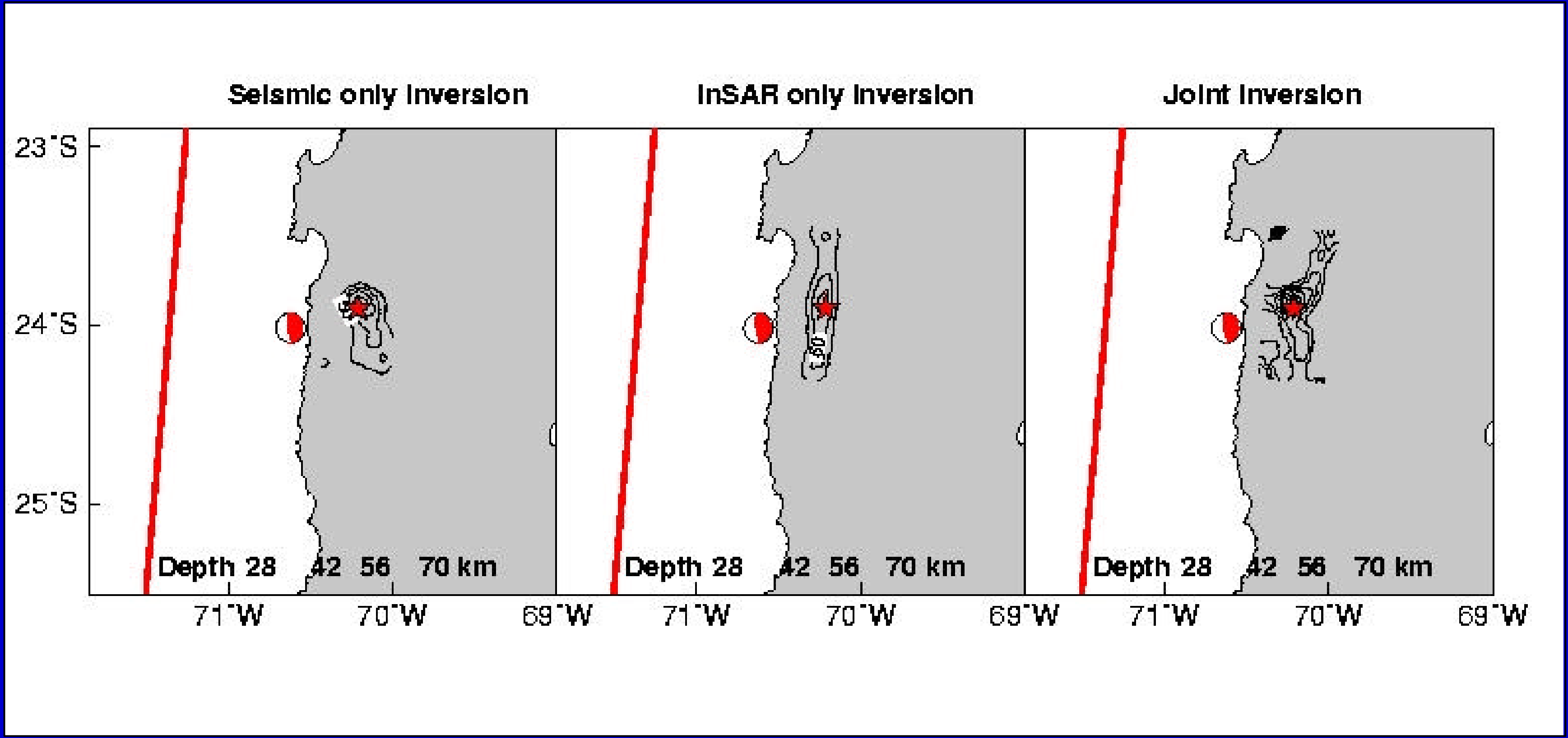
Methods

- Seismic data:
  - Teleseismic displacement data ($30^o<\Delta<90^o$)
    - 1995 Mw 8.1: 125 seconds, 19 P; 16 SH records
    - 1998 Mw 7.1: 60 seconds, 18 P; 15 SH records
  - Station response, attenuation
  - Wavelet transform records to optimize spatial and temporal resolution (Ji et al., 2002)

- InSAR data:
  - 1995: 5 orbital tracks of data, 12 interferograms (ASC/DSC)
  - 1998: 2 orbital tracks of data, 5 interferograms (DSC)

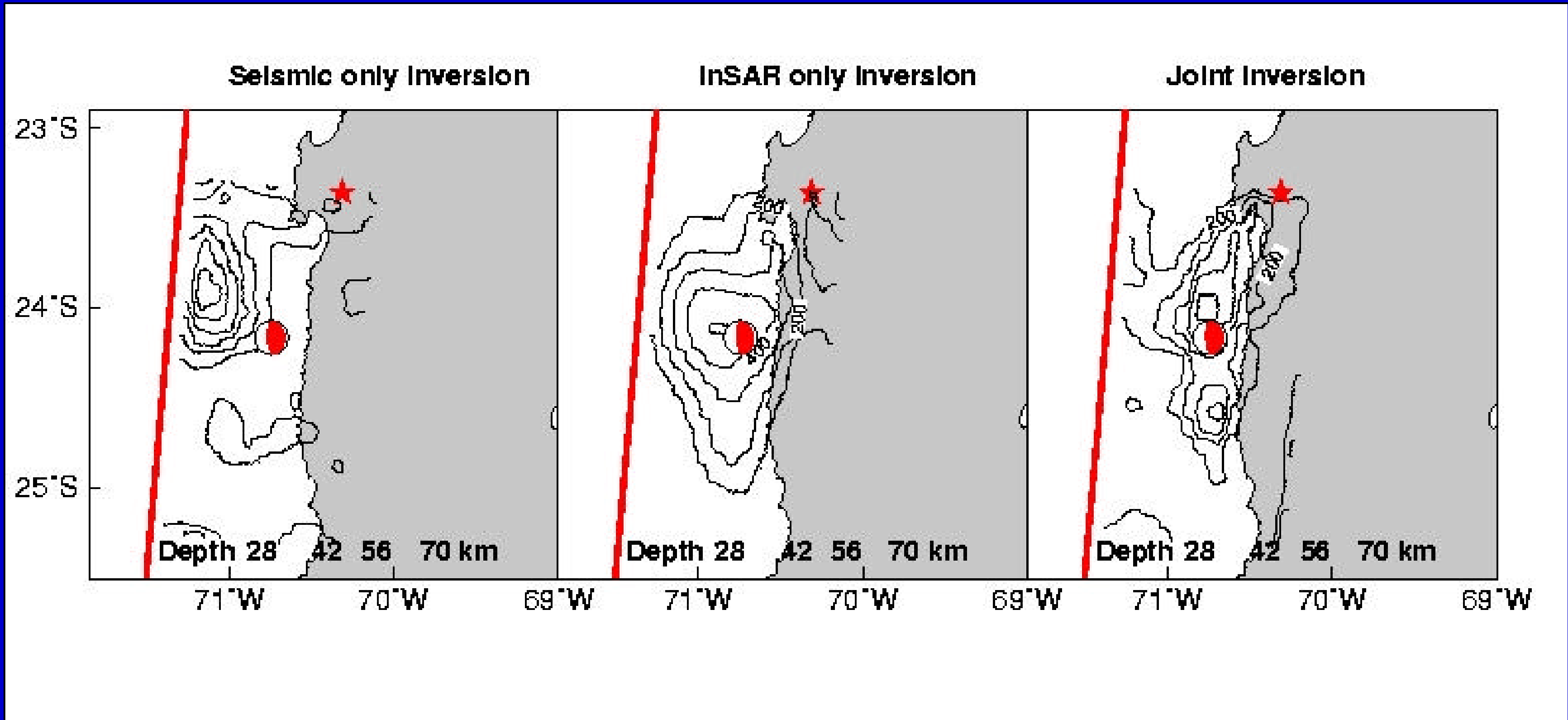
- Inversion
  - 1D layered space model at source (Husen et al., 1999)
  - Minimize misfit, moment, roughness
  - Solve for slip amplitude and direction, rise time, and rupture velocity
  - Simulated annealing algorithm (Rothman, 1986)

Compare slip inferred from different datasets



⇒For 1998 Mw 7.1 earthquake: seismic and geodetic results similar (CMT epicenter off by 40 km)

Compare slip inferred from different datasets



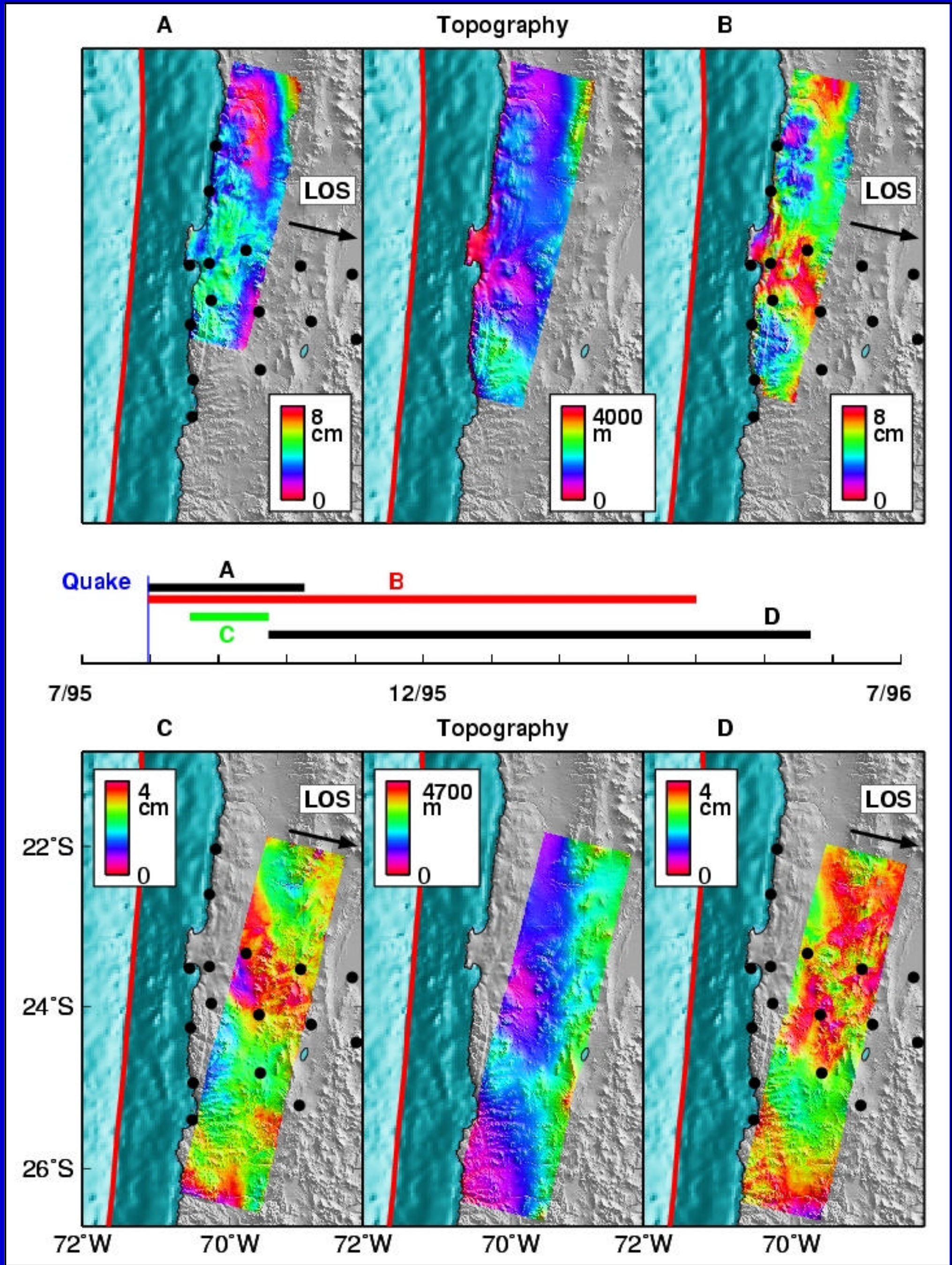
⇒For 1995 Mw 8.1 earthquake: seismic and geodetic results differ

Post Seismic?

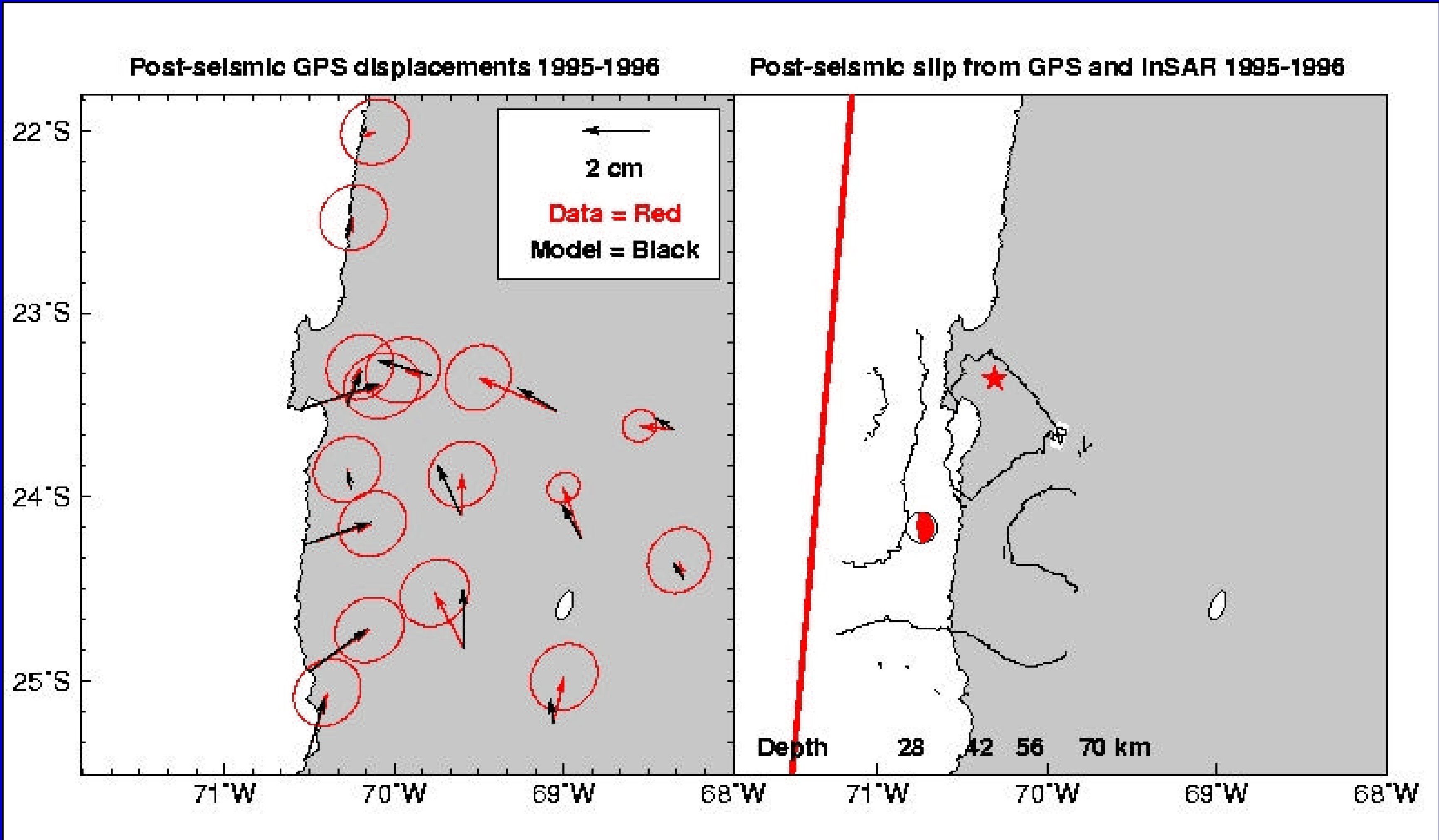
- Little seen with InSAR

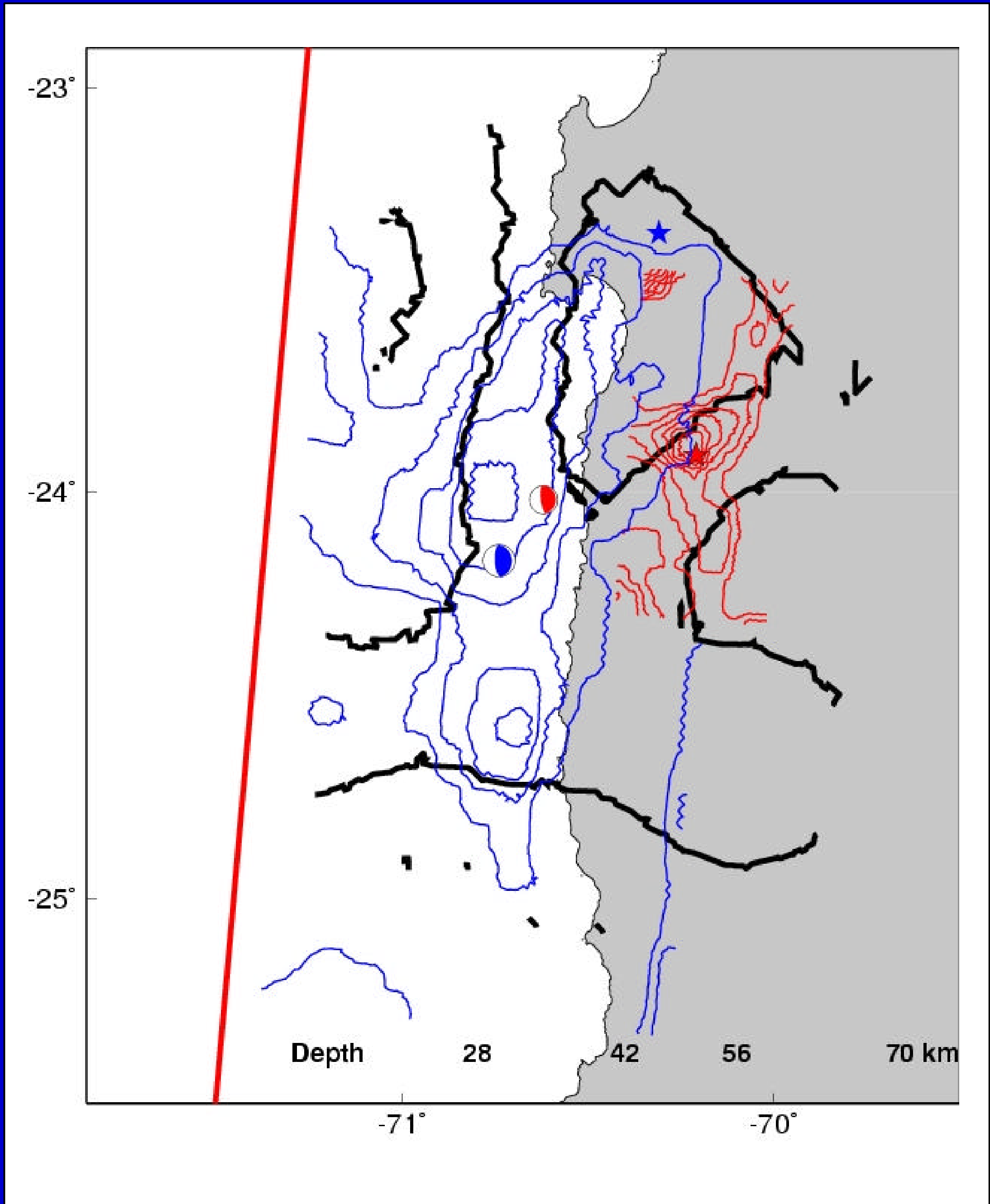
- Signal mostly due to tropospheric contamination

- InSAR constrains where slip did not happen



Post-seismic deformation visible in GPS data





Co-seismic and Post-seismic slip

Max slip:

1995 Mw 8.1: 5m

1998 Mw 7.1: 1 m

1 yr Post: 20 cm

Chile Conclusions

- Seismic and geodetic slip inversions:
  - CMT discrepancy for small, simple event (Mw 7.1, 1998)
- Earthquakes appear to mosaic fault plane
- Little post-seismic deformation from Mw 8.1 compared to earthquakes of similar size
- Future work:
  - 3 Mw 7's from the 1980's
  - Can tsunami waveforms help constrain shallow slip?
  - Are there only smaller earthquakes at the bottom of the seismogenic zone?
  - Why so little post-seismic slip?
  - Role of peninsulas?

Earthquakes, gravity, and the seismogenic behavior of subduction zones

Use precise slip models and earthquake catalogs

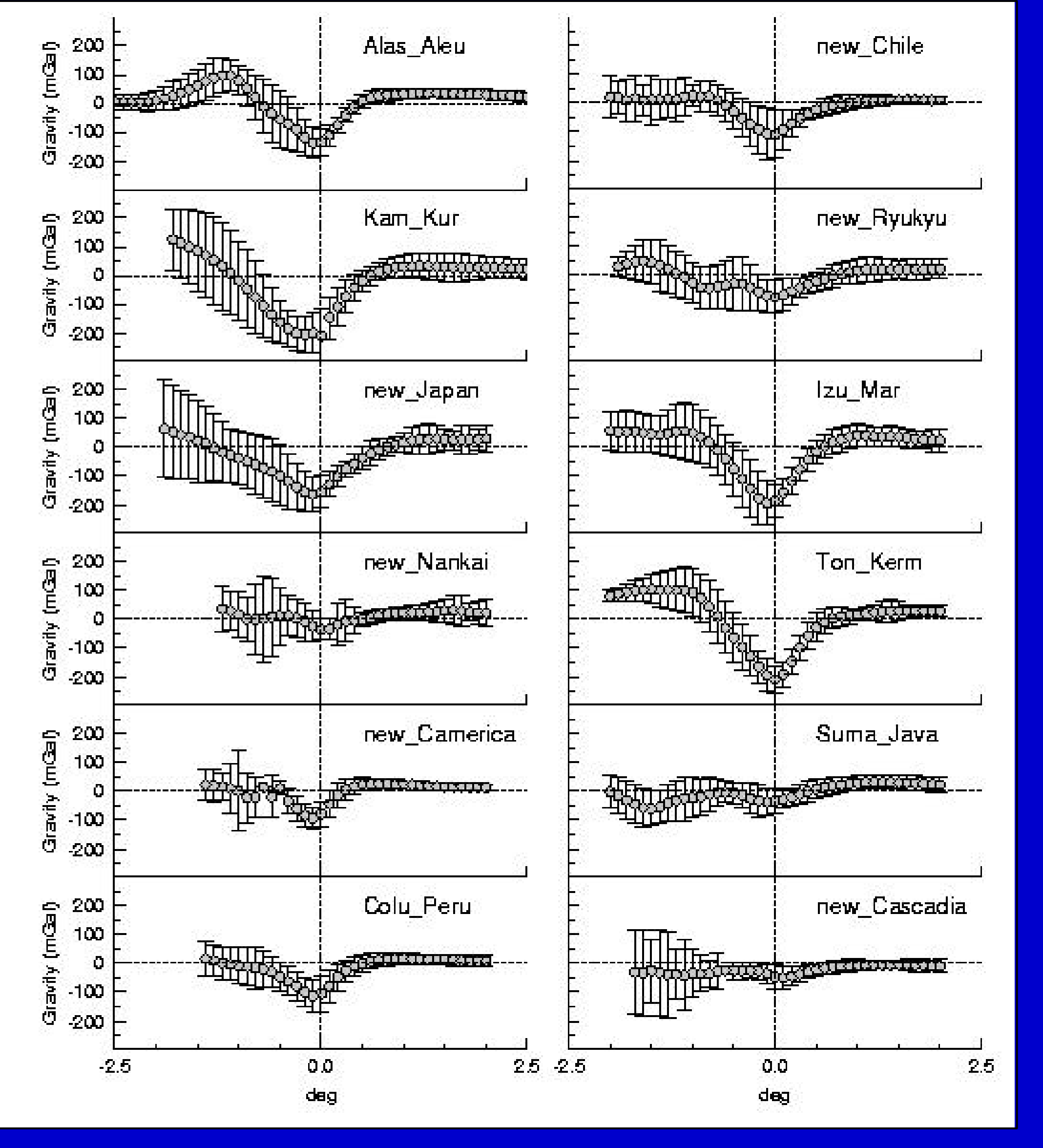
Use sea surface altimetry (Sandwell & Smith)

———————————

Averaged subduction zone gravity profiles

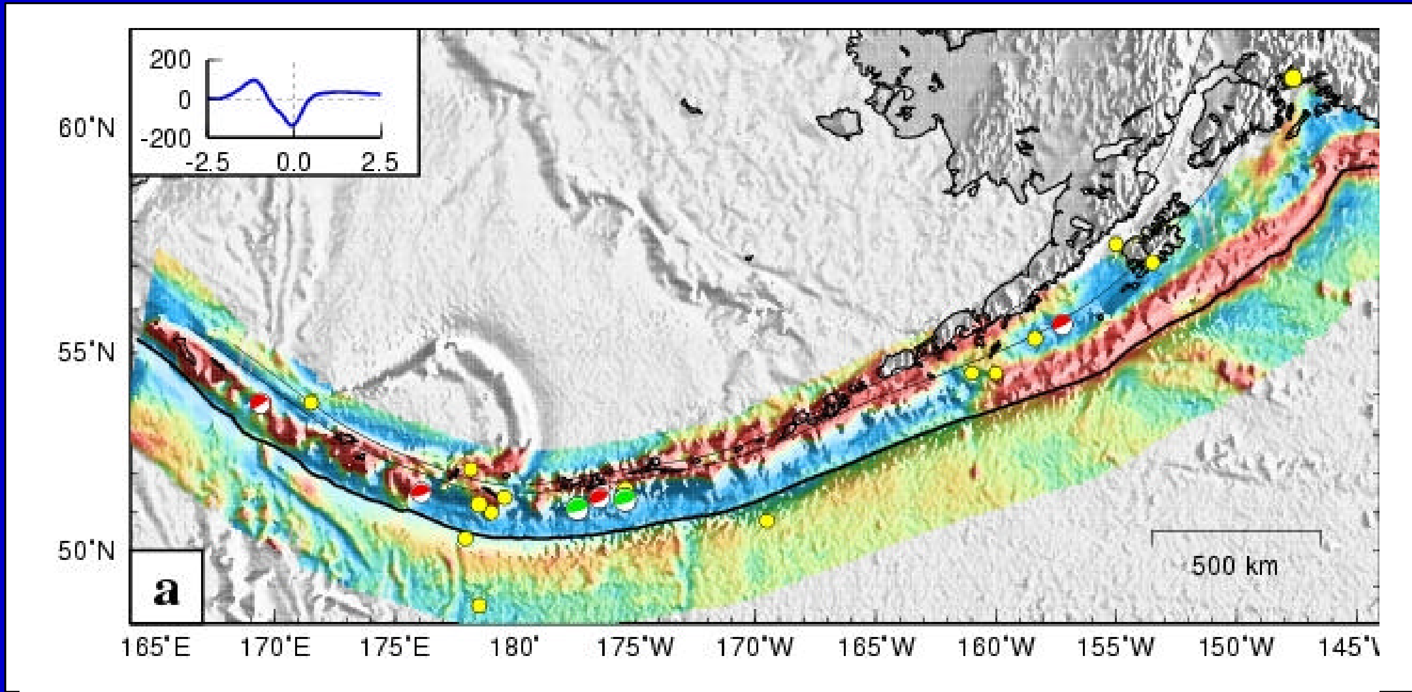
- ➢Variations
  - •Age
  - •Convergence rate
- ➢No strong correlation with seismogenic behavior

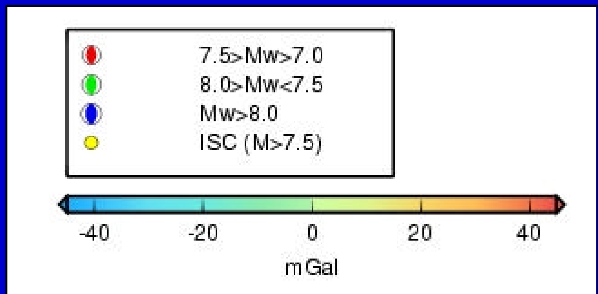
Concentrate on trench parallel gravity anomaly (TPGA)

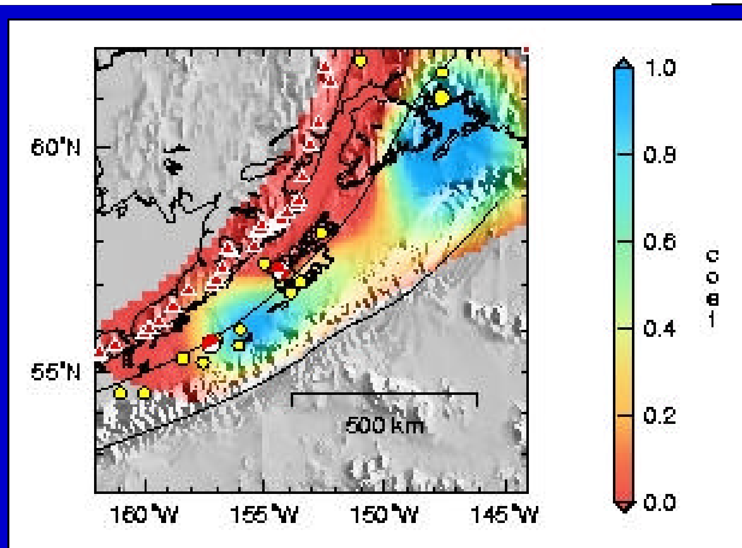


Trench Parallel Gravity Anomaly (TPGA)

Alaska



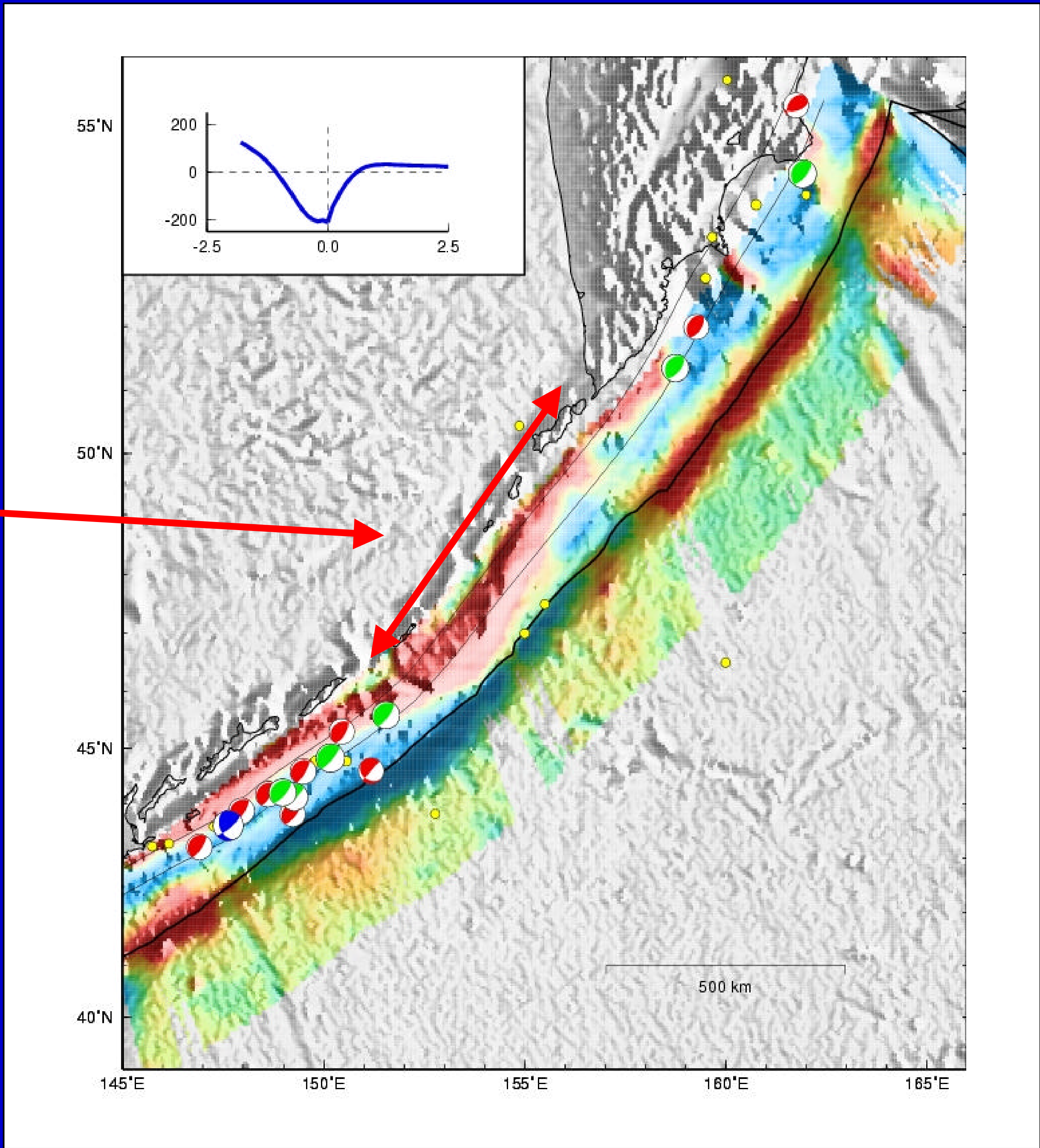


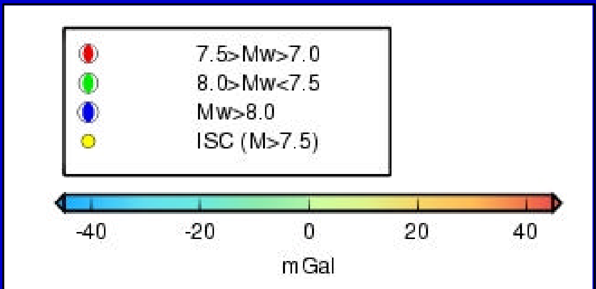


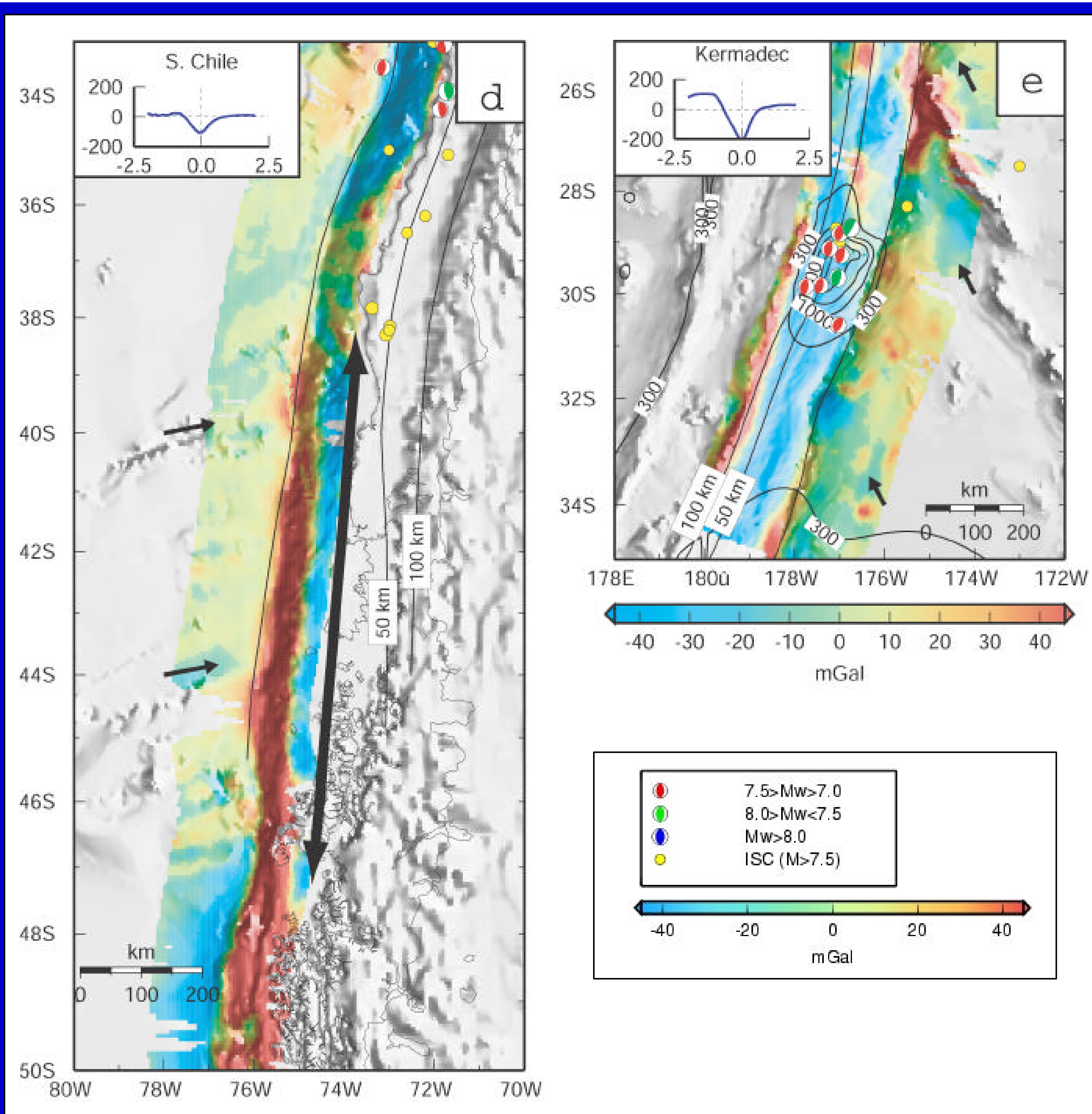
Post 1964 Interseismic
Zweck et al

TPGA for Kamchatka/Kurile

Known seismic gap






S. Chile
200
0
-200
-2.5
0.0
2.5
d
34S
36S
38S
40S
42S
44S
46S
48S
50S
80W
78W
76W
74W
72W
70W
50 km
100 km
km
0
100
200
Kermadec
200
0
-200
-2.5
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e
26S
28S
30S
32S
34S
178E
180û
178W
176W
174W
172W
300
1000
100 km
50 km
km
0
100
200
-40
-30
-20
-10
0
10
20
30
40
mGal
7.5>Mw>7.0
8.0>Mw<7.5
Mw>8.0
ISC (M>7.5)
-40
-20
0
20
40
mGal

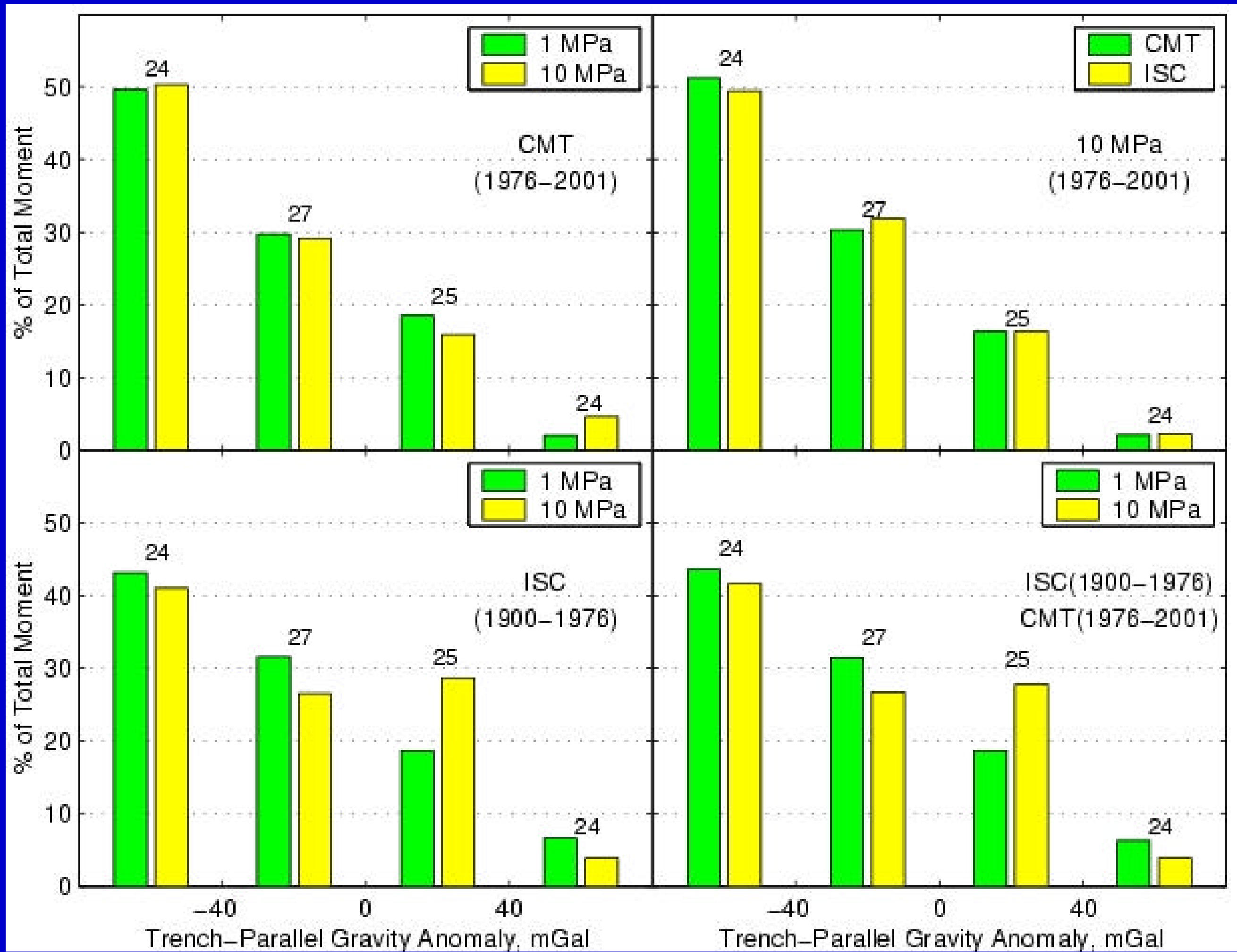
Histograms

Seismic moment release in equal area TPGA bins

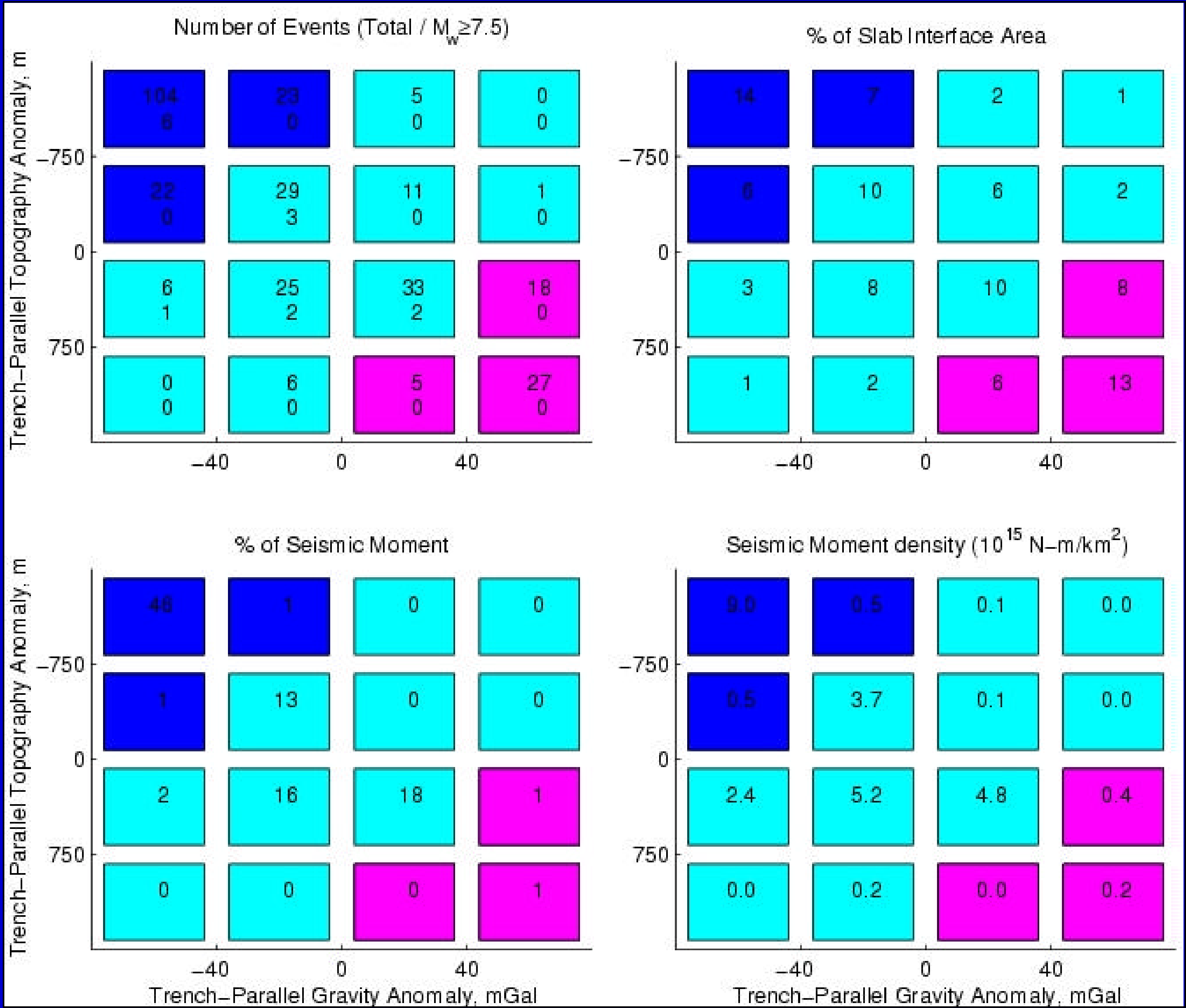
Consider EQ catalogs

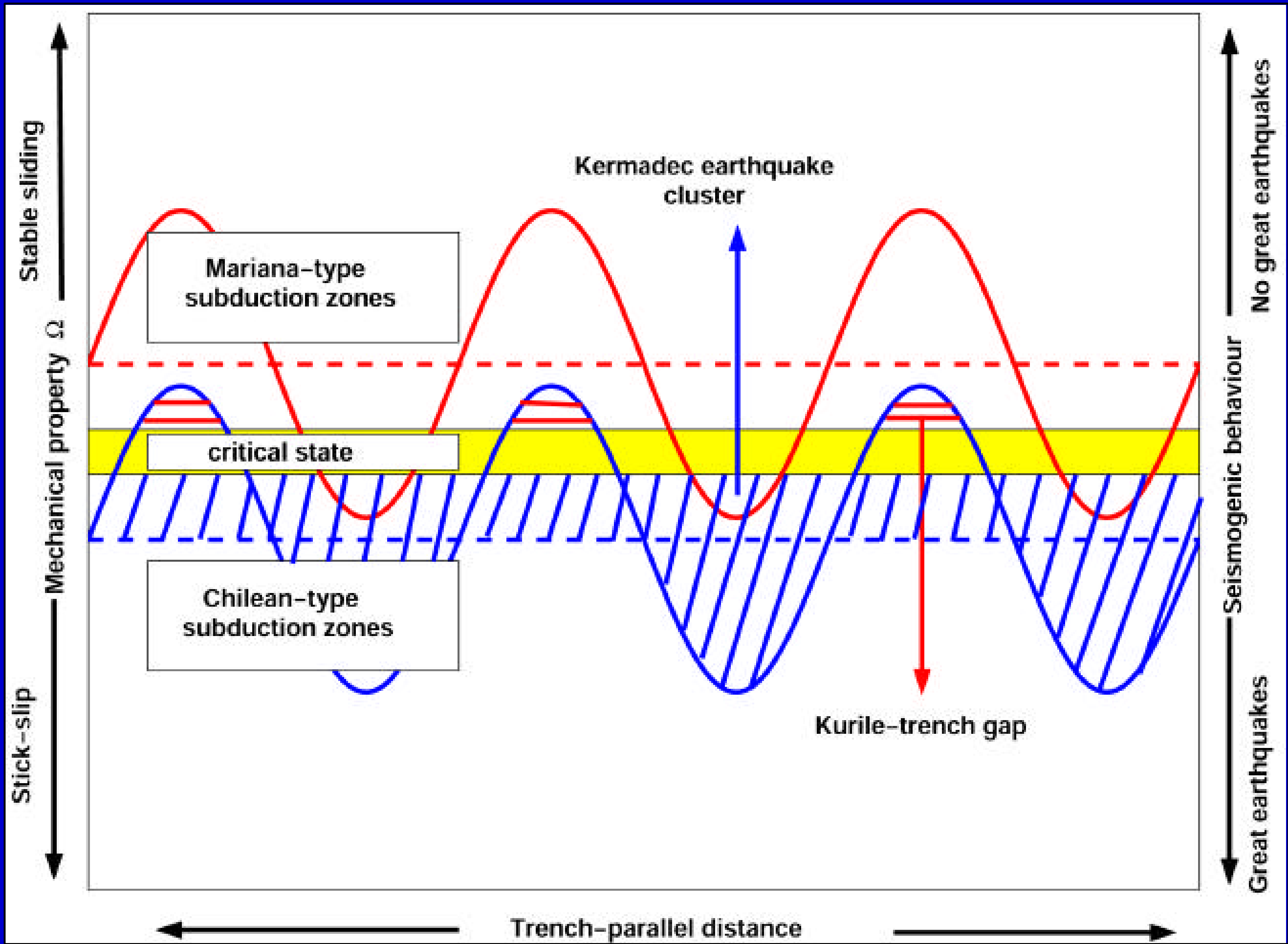
Caveats:
- ➢Location
- ➢Location
- ➢Location

Implications:
- ➢Spatial fixity
- ➢Predictive
- ➢Tsunami potential



Joint TPGA and TPTA Histograms





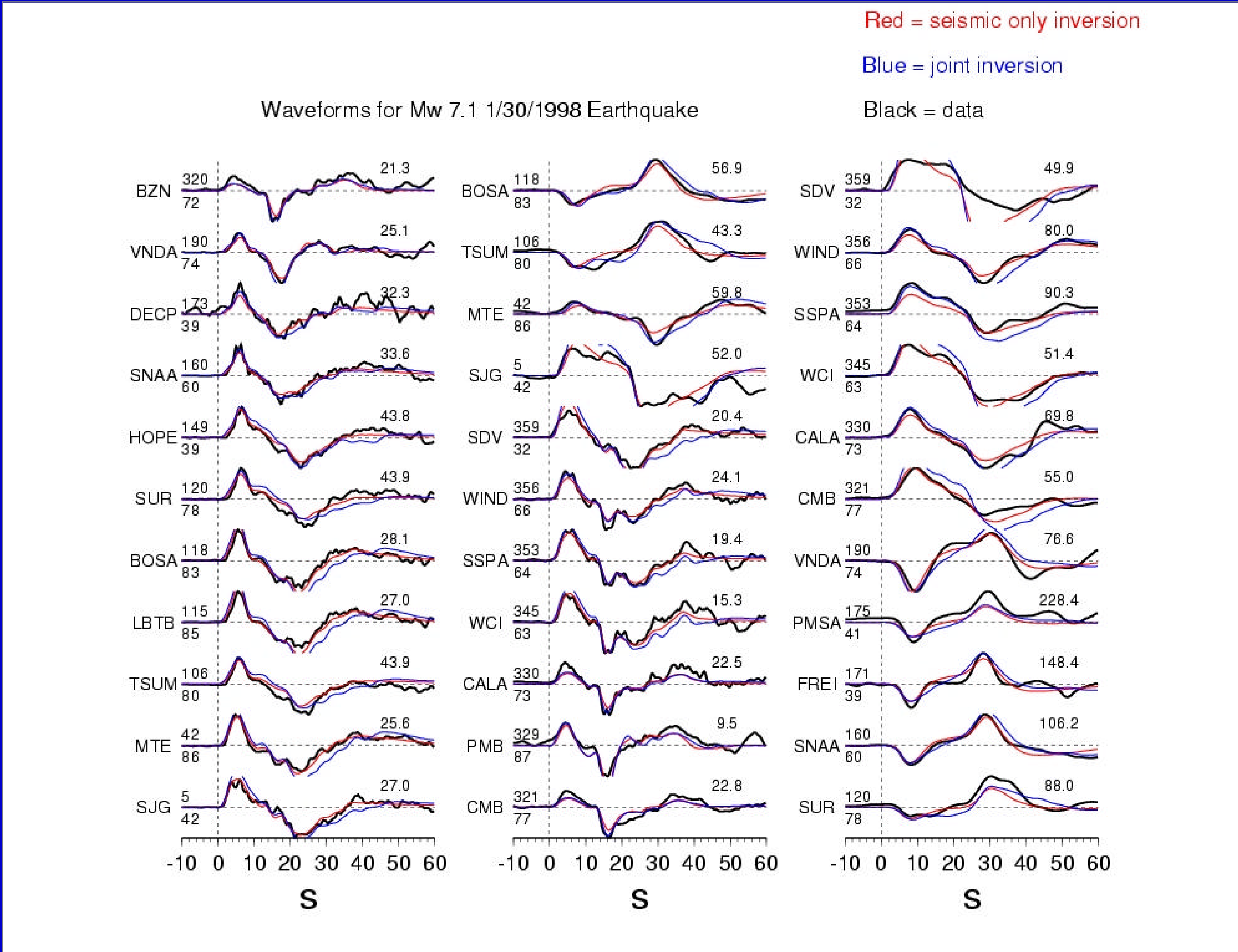
1. Mean level controlled by age, velocity, T…
2. Coupling of long term tectonics and seismogenic behavior
3. Spatial predictivity
4. Tsunamogenic predictivity
5. Eventually model-derived bounds on stress variations
6. Need better source models for historic EQs

The future of InSAR?

- Wide swath
- L Band (25cm wavelength)
- Short revisit times Tight orbital control
- Small pixels for high strain zones and decorrelation
- Reduce troposphere/ionosphere artifacts
- Frequent multiple components (asc/dsc/left/right)
- Global access
- Constellation -> science and robustness
- Rapid delivery
- Free/Cheap data

- ALOS
    - L Band, 45 day repeat, asc only, no US data agreement
- ENVISAT
    - C Band, 35 day repeat, no US data agreement (not free)

END


Red = seismic only inversion
Blue = joint inversion
Black = data
Waveforms for Mw 7.1 1/30/1998 Earthquake
BZN 320 72 21.3
VNDA 190 74 25.1
DECP 173 39 32.3
SNAA 160 60 33.6
HOPE 149 39 43.8
SUR 120 78 43.9
BOSA 118 83 28.1
LBTB 115 85 27.0
TSUM 106 80 43.9
MTE 42 86 25.6
SJG 5 42 27.0
BOSA 118 83 56.9
TSUM 106 80 43.3
MTE 42 86 59.8
SJG 5 42 52.0
SDV 359 32 20.4
WIND 356 66 24.1
SSPA 353 64 19.4
WCI 345 63 15.3
CALA 330 73 22.5
PMB 329 87 9.5
CMB 321 77 22.8
SDV 359 32 49.9
WIND 356 66 80.0
SSPA 353 64 90.3
WCI 345 63 51.4
CALA 330 73 69.8
CMB 321 77 55.0
VNDA 190 74 76.6
PMSA 175 41 228.4
FREI 171 39 148.4
SNAA 160 60 106.2
SUR 120 78 88.0
-10 0 10 20 30 40 50 60
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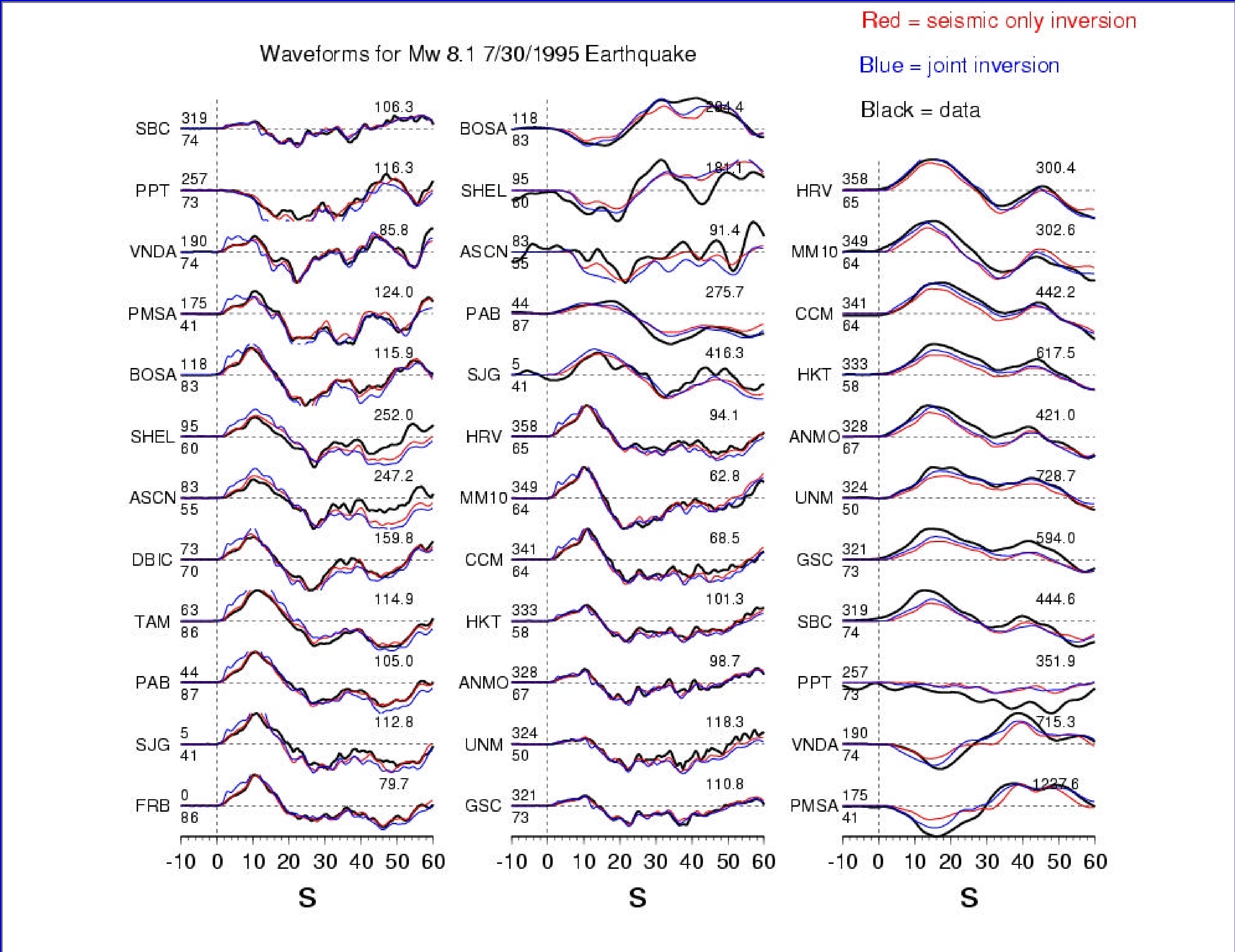
Waveforms for Mw 8.1 7/30/1995 Earthquake
Red = seismic only inversion
Blue = joint inversion
Black = data
SBC 319 74 106.3
PPT 257 73 116.3
VNDA 190 74 85.8
PMSA 175 41 124.0
BOSA 118 83 115.9
SHEL 95 60 252.0
ASCN 83 55 247.2
DBIC 73 70 159.8
TAM 63 86 114.9
PAB 44 87 105.0
SJG 5 41 112.8
FRB 0 86 79.7
BOSA 118 83 294.4
SHEL 95 60 181.1
ASCN 83 55 91.4
PAB 44 87 275.7
SJG 5 41 416.3
HRV 358 65 94.1
MM10 349 64 62.8
CCM 341 64 68.5
HKT 333 58 101.3
ANMO 328 67 98.7
UNM 324 50 118.3
GSC 321 73 110.8
HRV 358 65 300.4
MM10 349 64 302.6
CCM 341 64 442.2
HKT 333 58 617.5
ANMO 328 67 421.0
UNM 324 50 728.7
GSC 321 73 594.0
SBC 319 74 444.6
PPT 257 73 351.9
VNDA 190 74 715.3
PMSA 175 41 1237.6
-10 0 10 20 30 40 50 60
S