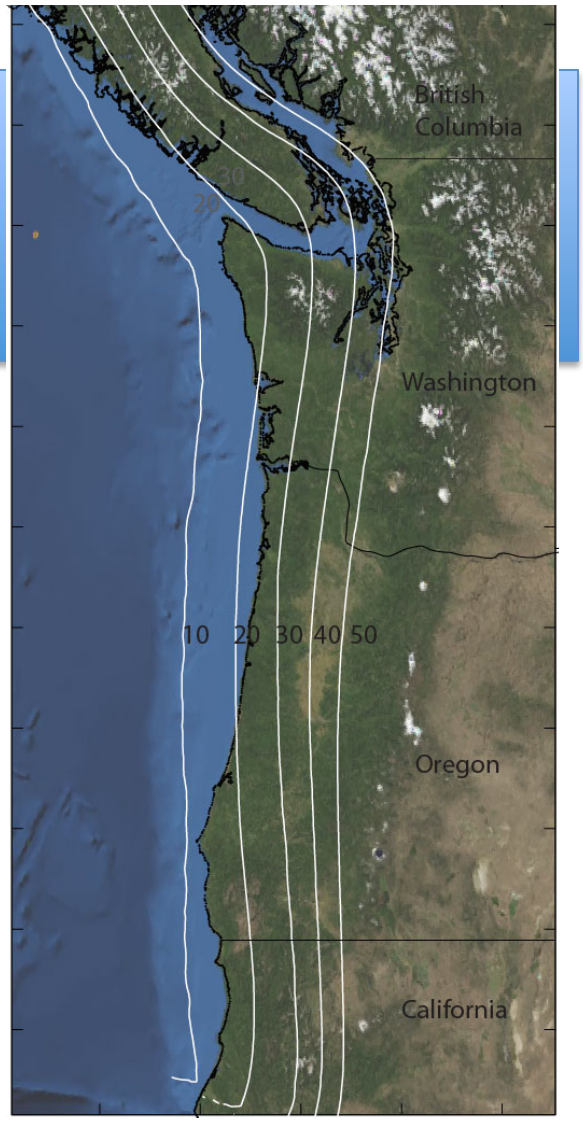
The distribution of interseismic locking on the Cascadia Subduction Zone constrained by leveling, tide gauge, and GPS data

David Schmidt (das@uoregon.edu)
Ray Weldon (ray@uoregon.edu)
Reed Burgette (Reed.Burgette@utas.edu.au)
Randy Krogstad (krogstad@uoregon.edu)

Department of Geological Sciences
University of Oregon



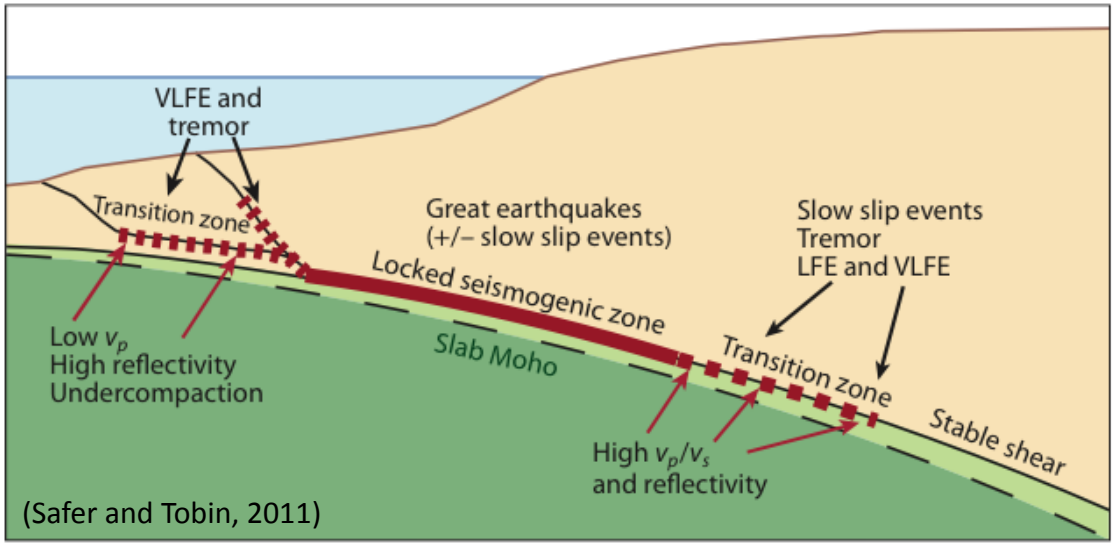
Funding provided by USGS NEHRP

Objectives

• Infer the kinematic locking on the subduction interface from geodetic observations.

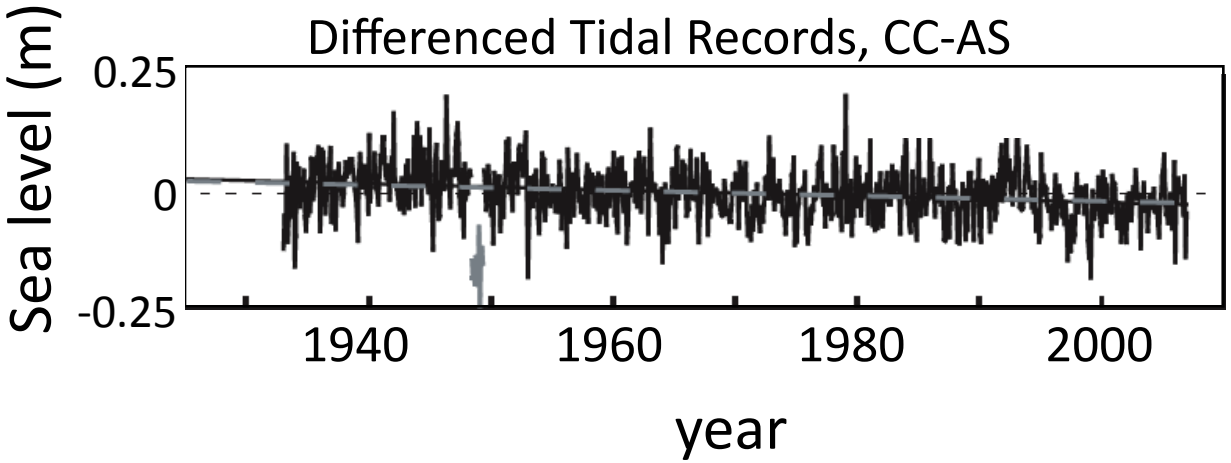
• Constrain the seismic hazard
  - Quantify the seismic moment accumulation rate
  - Identify the distribution and eastward limit of the locked zone

• Resolve along-strike variations in locking that might be tied to variations in frictional properties of the plate interface.

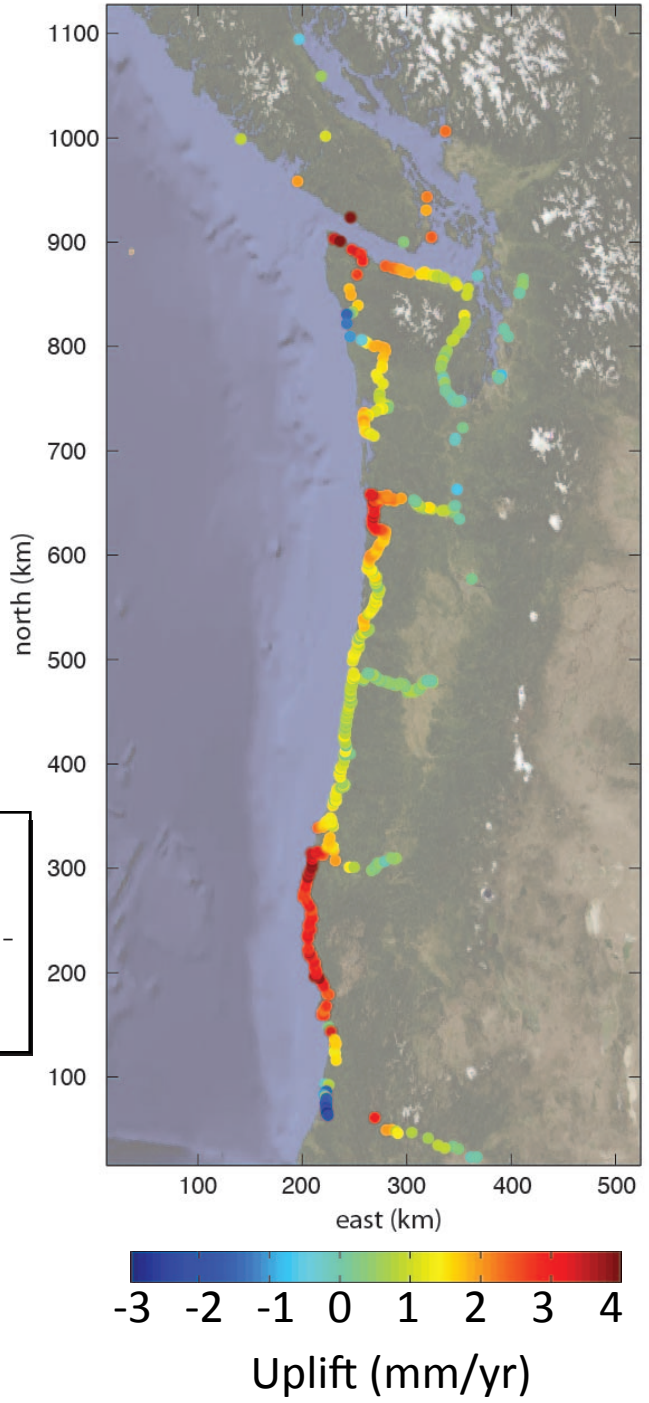


Observations of Interseismic Deformation

- Uplift rates from spirit leveling
  - Observations span 1930-present.
  - Uplift referenced to eustatic sea level.
  - 1-σ uncertainties ~0.5 mm/yr.

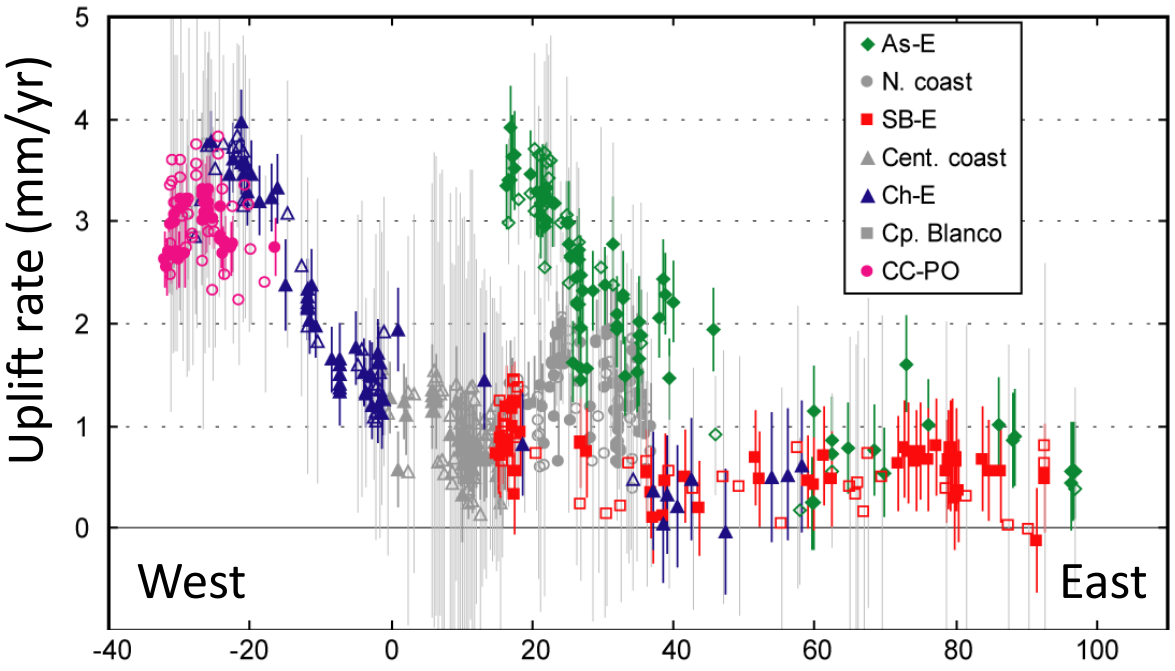


(Burgette et al., JGR, 2009)

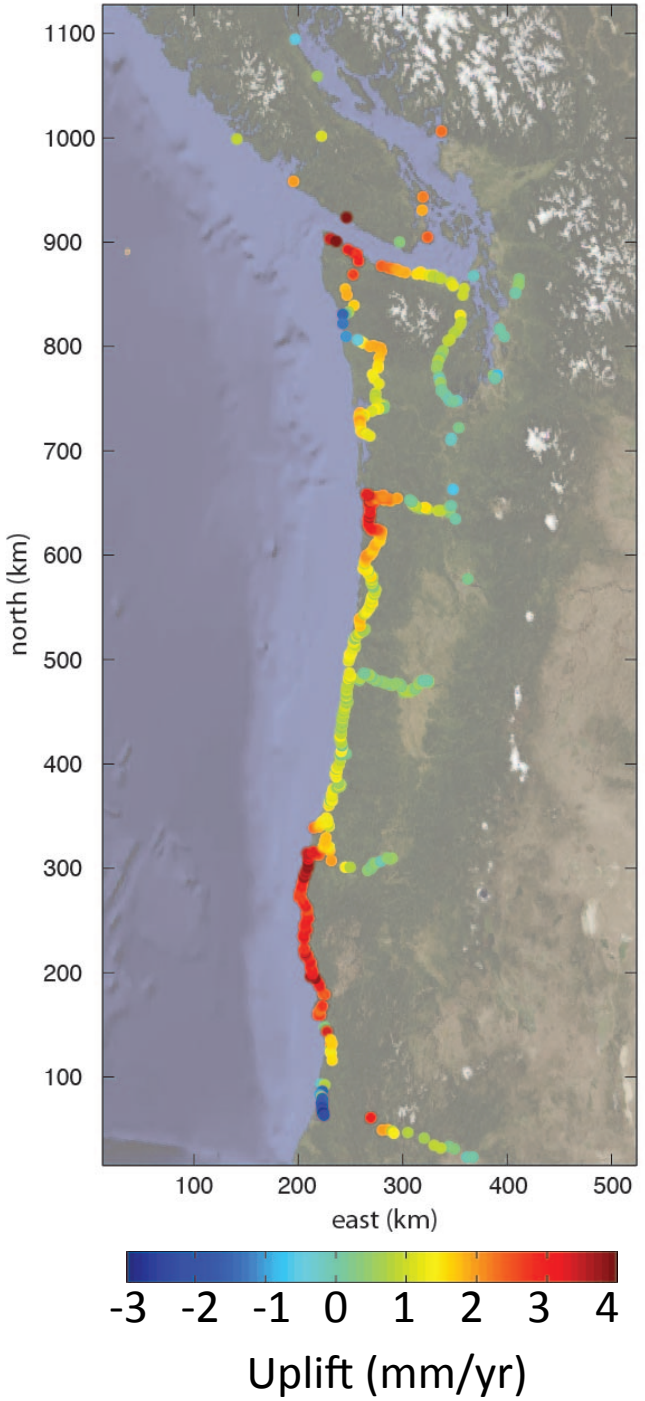


Observations of Interseismic Deformation

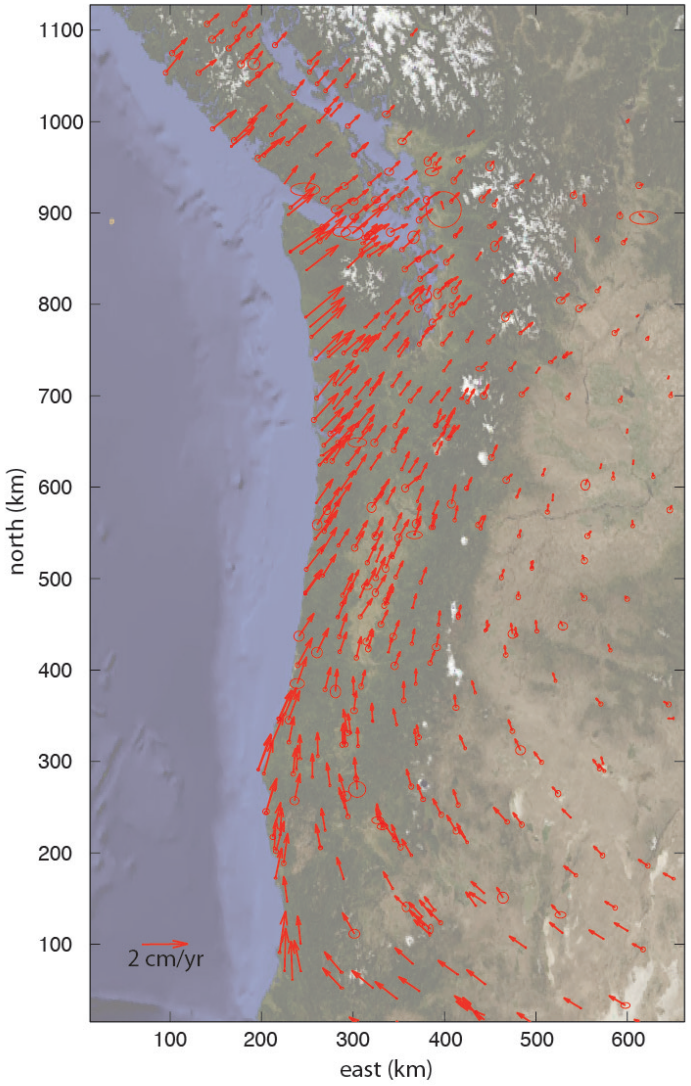
- Uplift rates from spirit leveling
  - Observations span 1930-present.
  - Uplift referenced to eustatic sea level.
  - 1-σ uncertainties ~0.5 mm/yr.



East from 20-km-depth slab contour (km)
(Burgette et al., JGR, 2009)



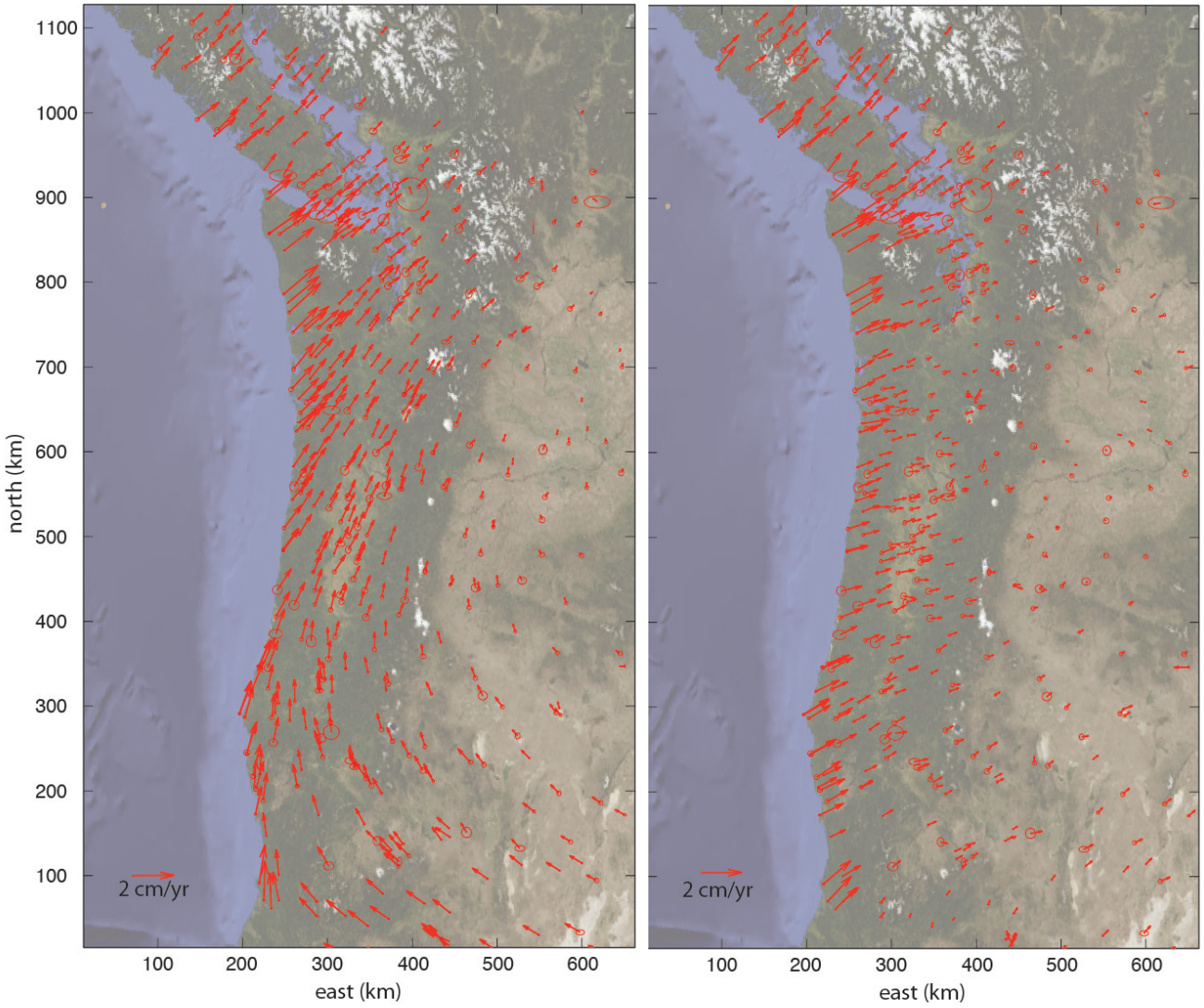
Horizontal Observations of Interseismic Deformation



- Horizontal GPS Velocities from PBO data products and McCaffrey et al. (2007).

- Limited to stations with data for > 2 years

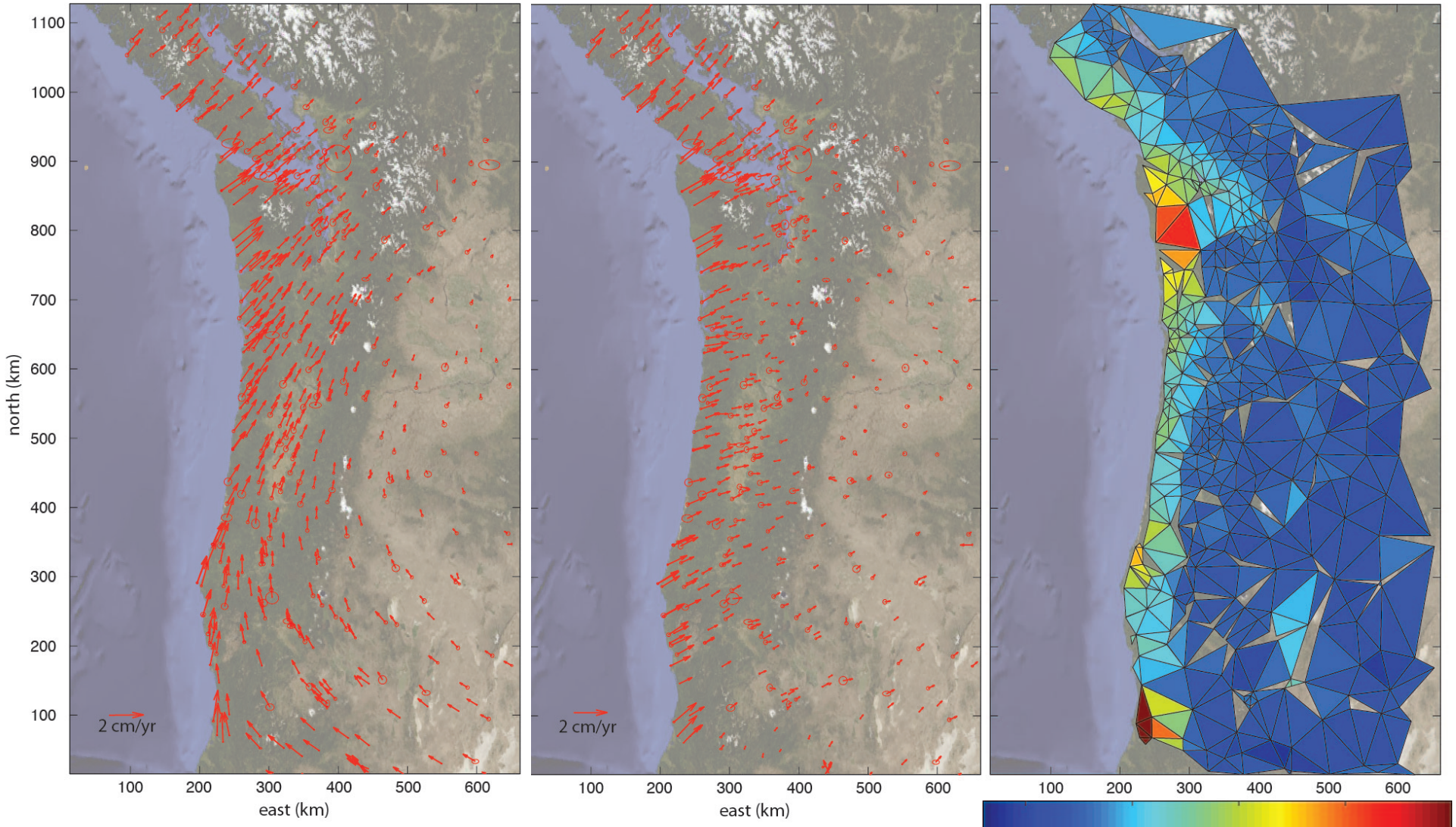
Horizontal Observations of Interseismic Deformation



Original Velocity Field

Rotation of Oregon Removed
(pole of McCaffrey et al., 2007)

Horizontal Observations of Interseismic Deformation



Original Velocity Field

Rotation of Oregon Removed
(pole of McCaffrey et al., 2007)

Compressional Strain Rate
(nanostrain/yr)

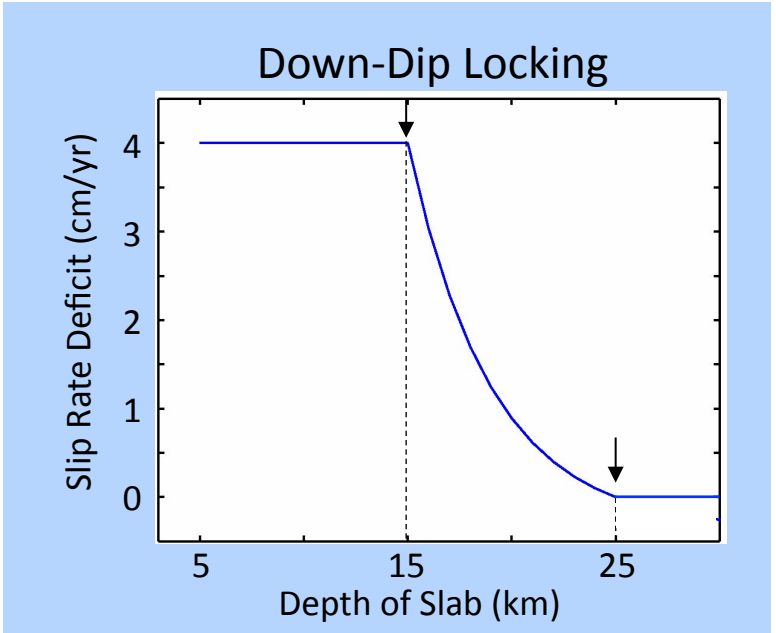
Modeling Methodology

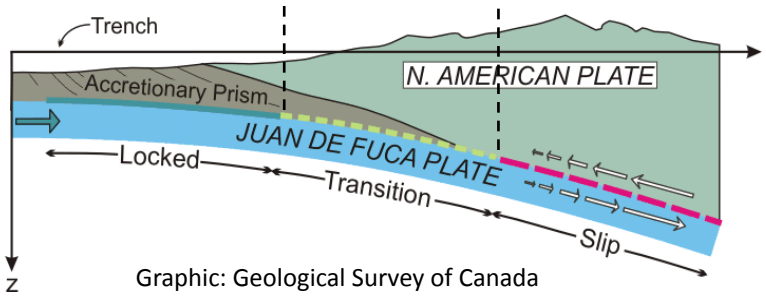
- Fixed parameters
  - Defined Convergence rate
    - JDF-OCR Euler pole for the southern end (Wells & Simpson, 2001).
    - JDF-NA Euler pole for the northern end (Mazzotti et al., 2003)
  - Plate geometry of McCrory et al. (2006).
  - Upper edge of locked zone begins at trench.

Modeling Methodology

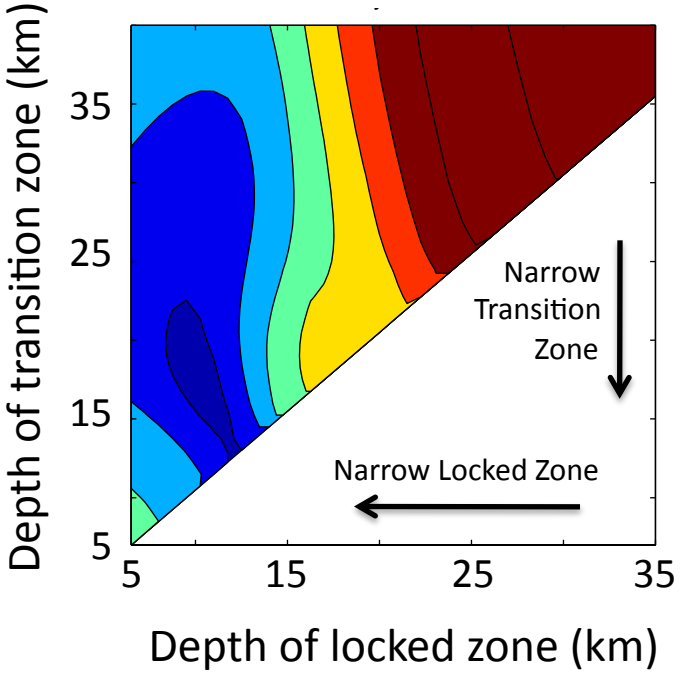
- Fixed parameters
  - Defined Convergence rate
    - JDF-OCR Euler pole for the southern end (Wells & Simpson, 2001).
    - JDF-NA Euler pole for the northern end (Mazzotti et al., 2003)
  - Plate geometry of McCrory et al. (2006).
  - Upper edge of locked zone begins at trench.

- Backslip calculation (Savage, 1983).
- Free parameters
  - Depth of locking; Depth of transition zone.
- Optimization by grid search of parameter space
  - Step 1: Depths constrained along west-east leveling profiles (fit both uplift and strain).
  - Step 2: Optimize along-strike locking with entire dataset.

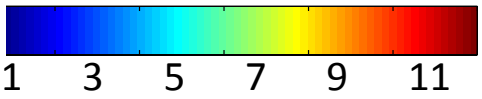




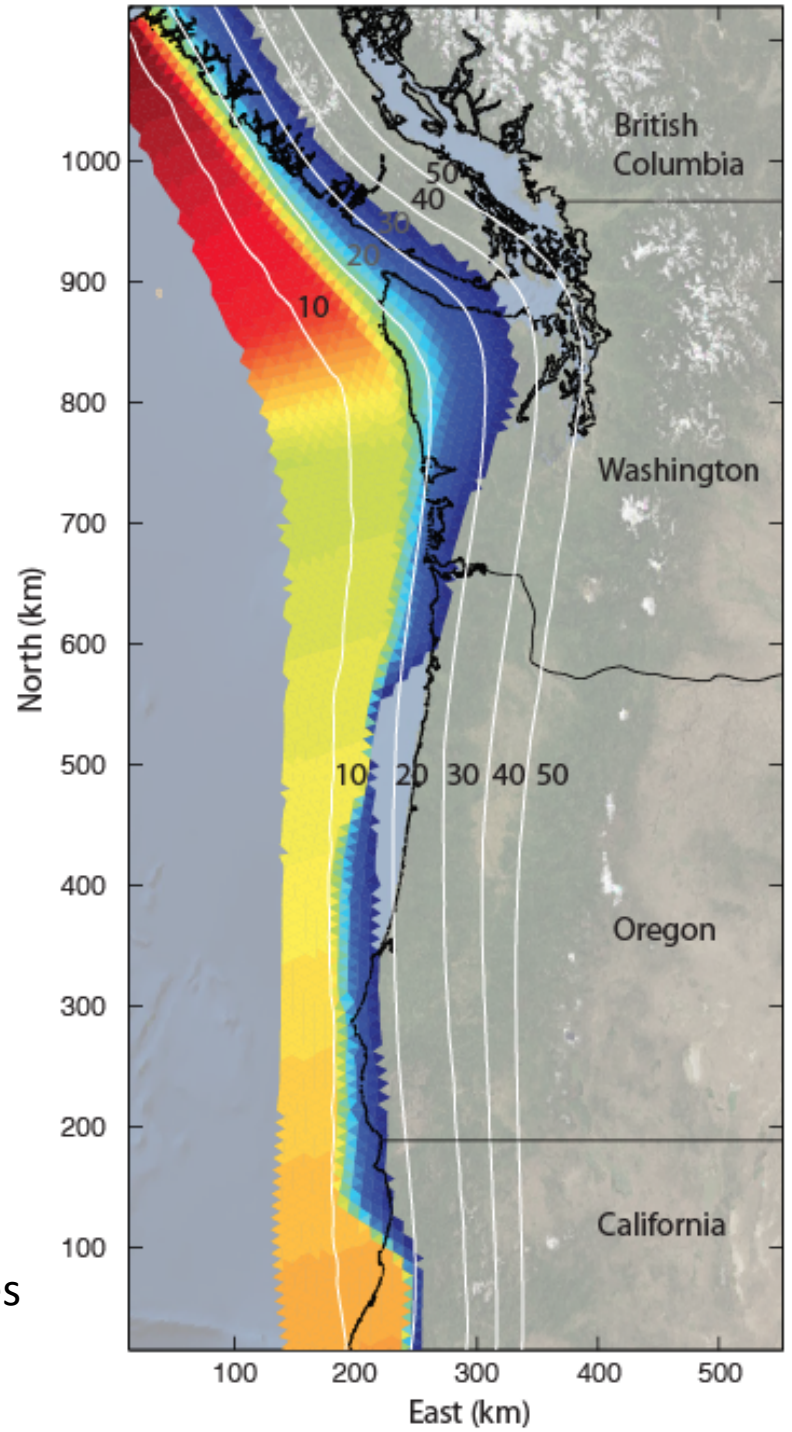
Graphic: Geological Survey of Canada



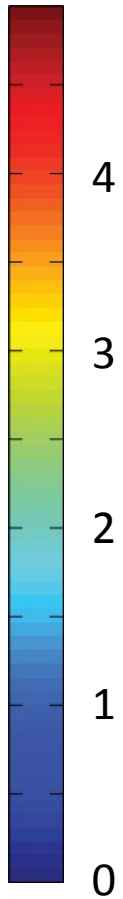
Misfit (χ^2)

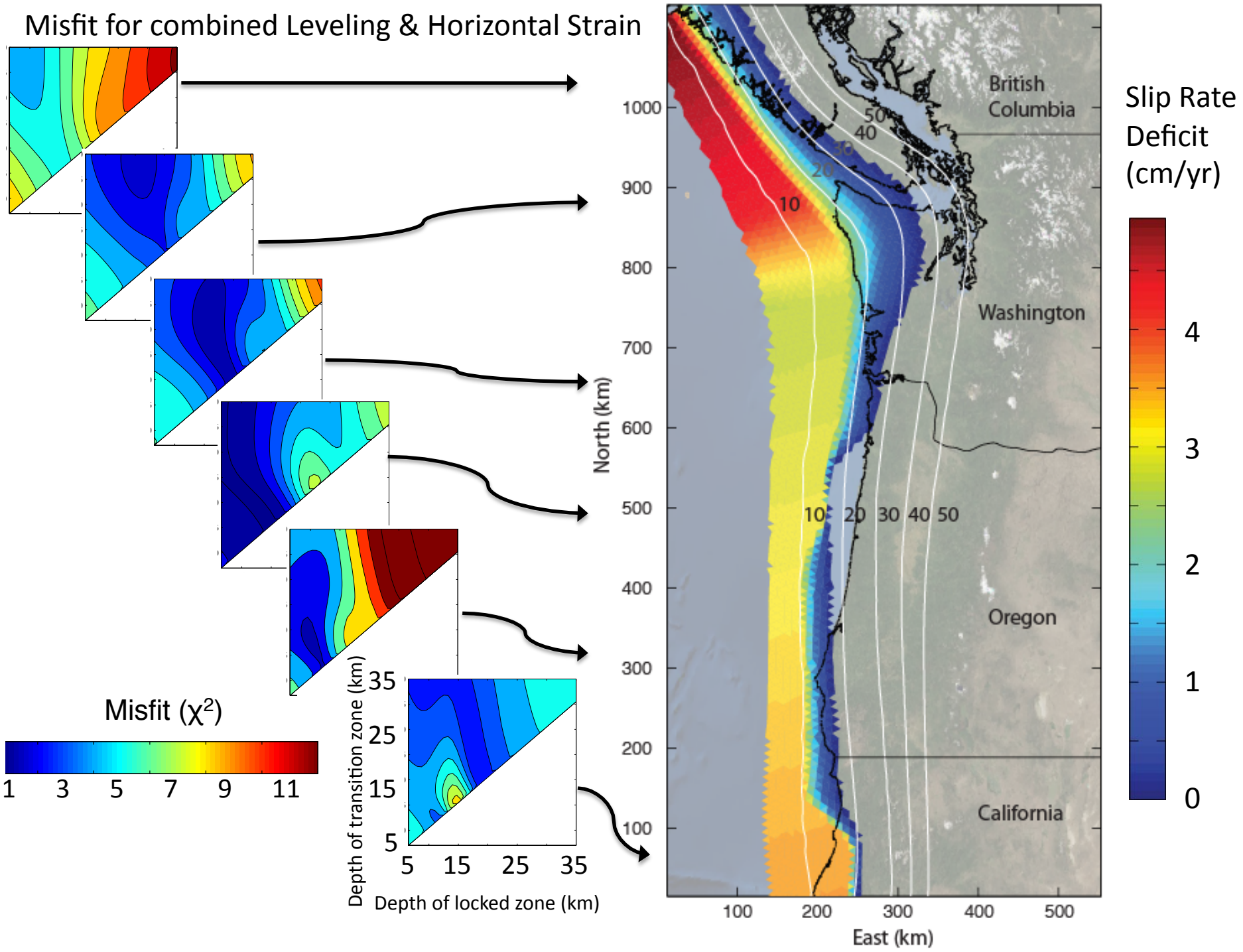


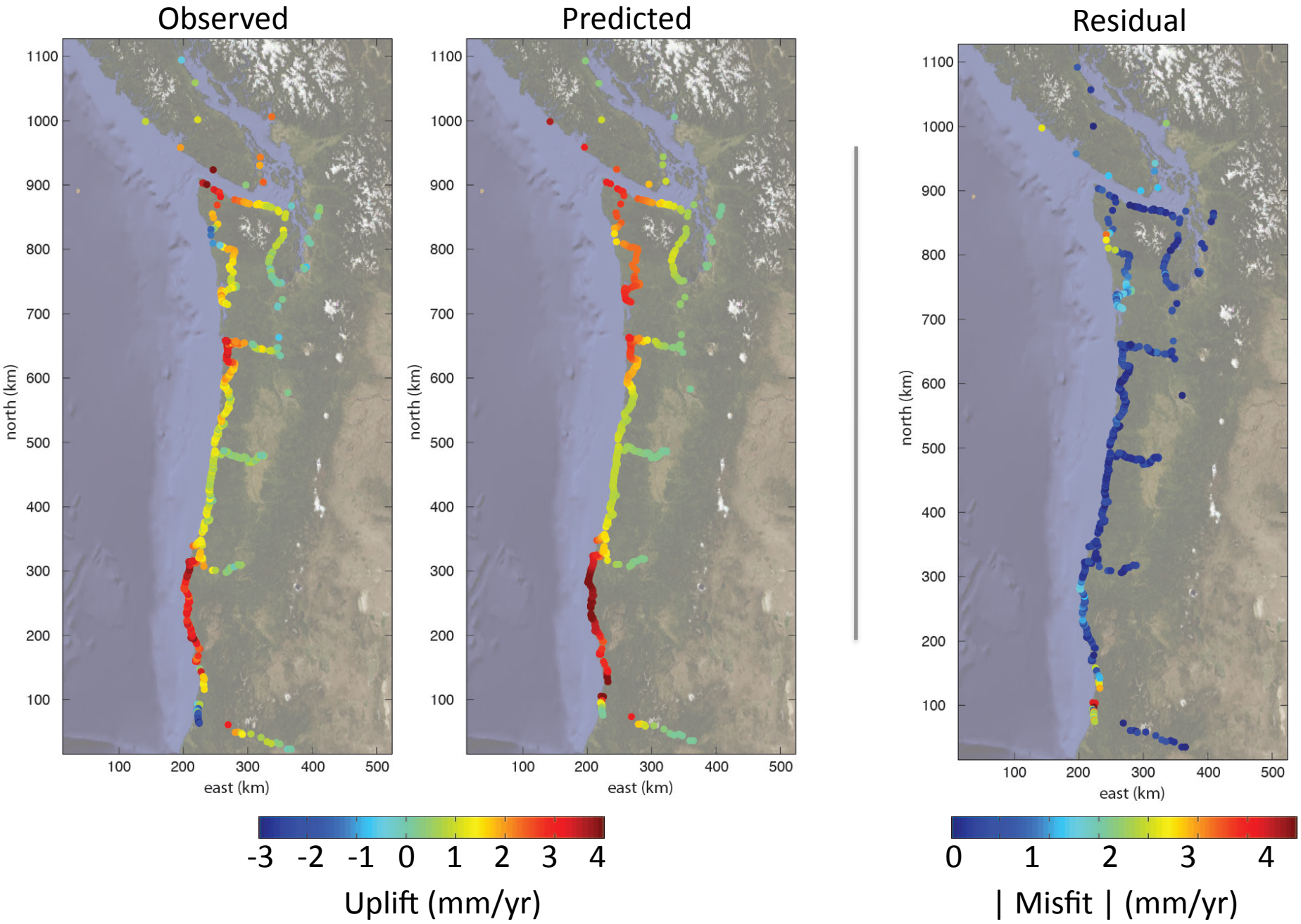
- Combined inversion (uplift and strain)
- Data misfit weighted by data uncertainties

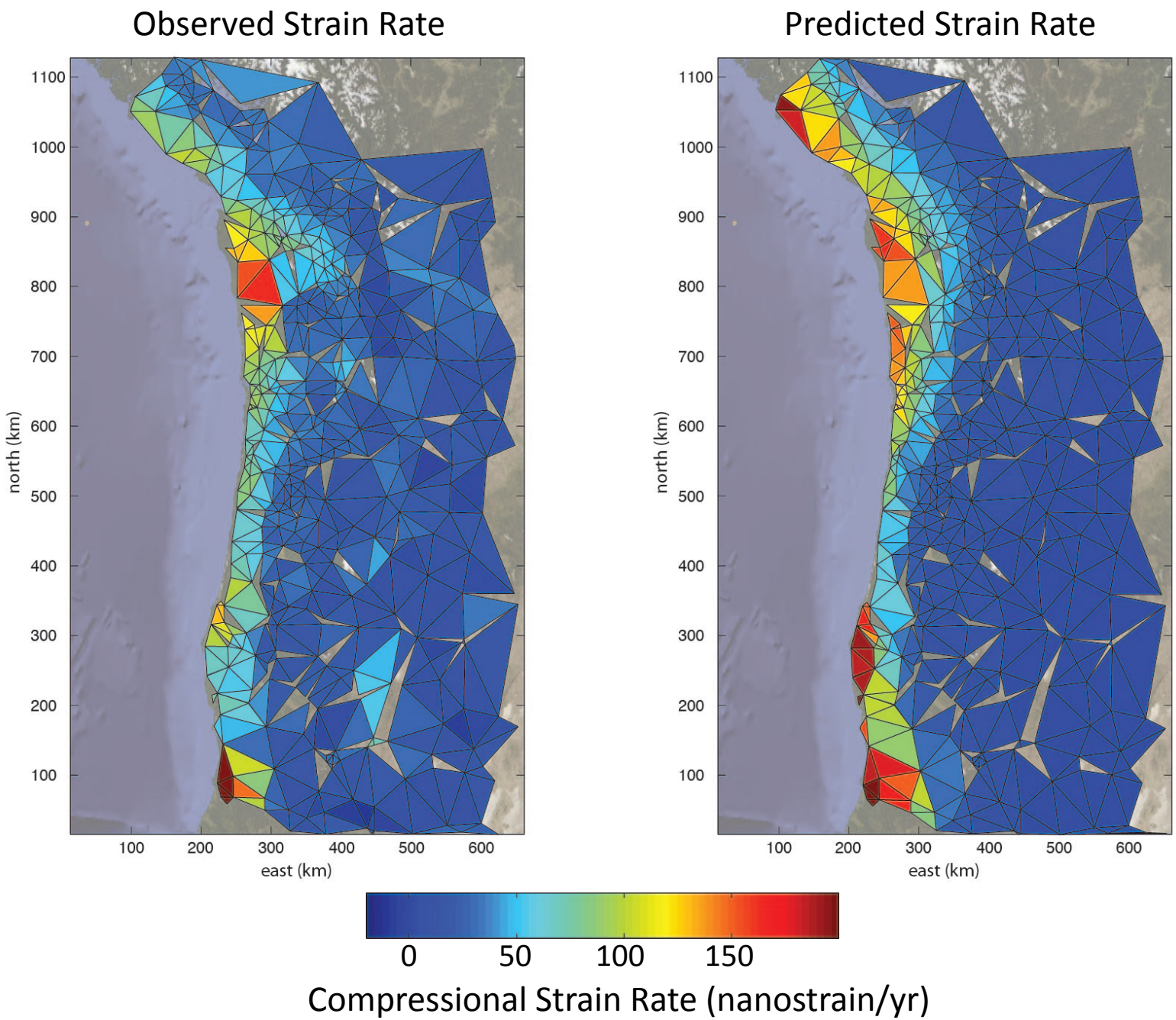


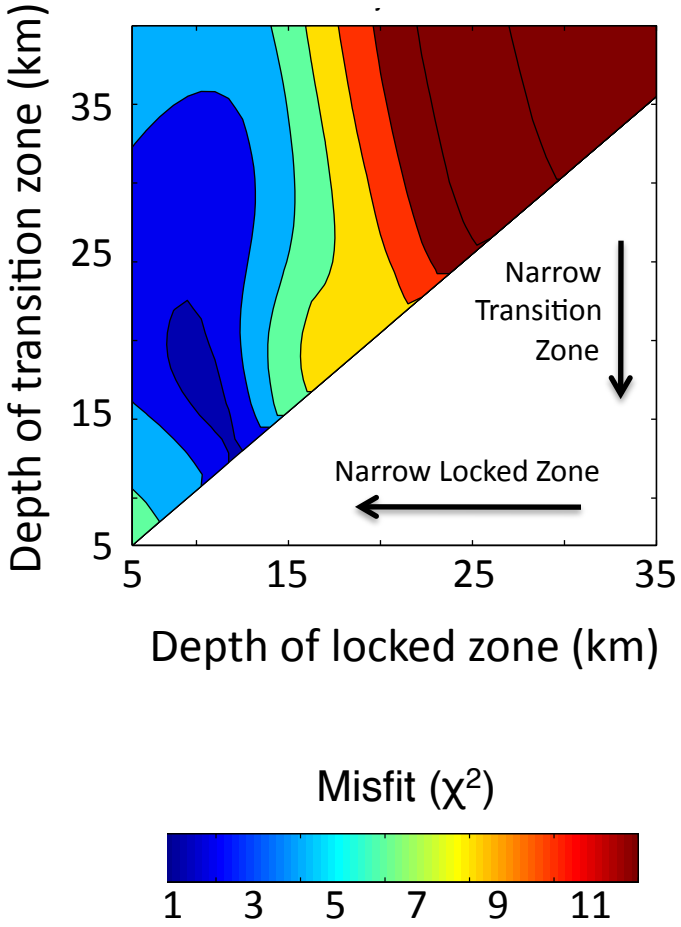
Slip Rate Deficit (cm/yr)

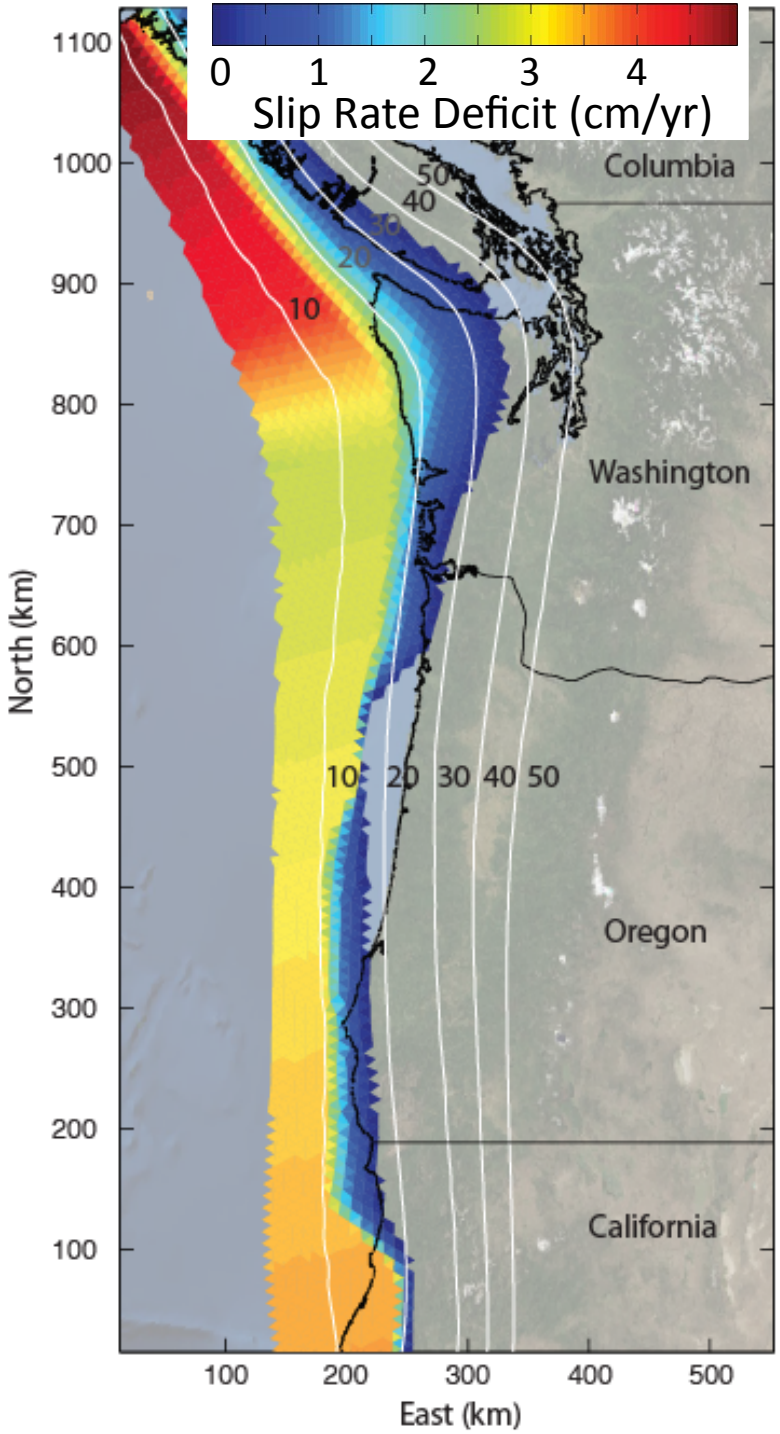


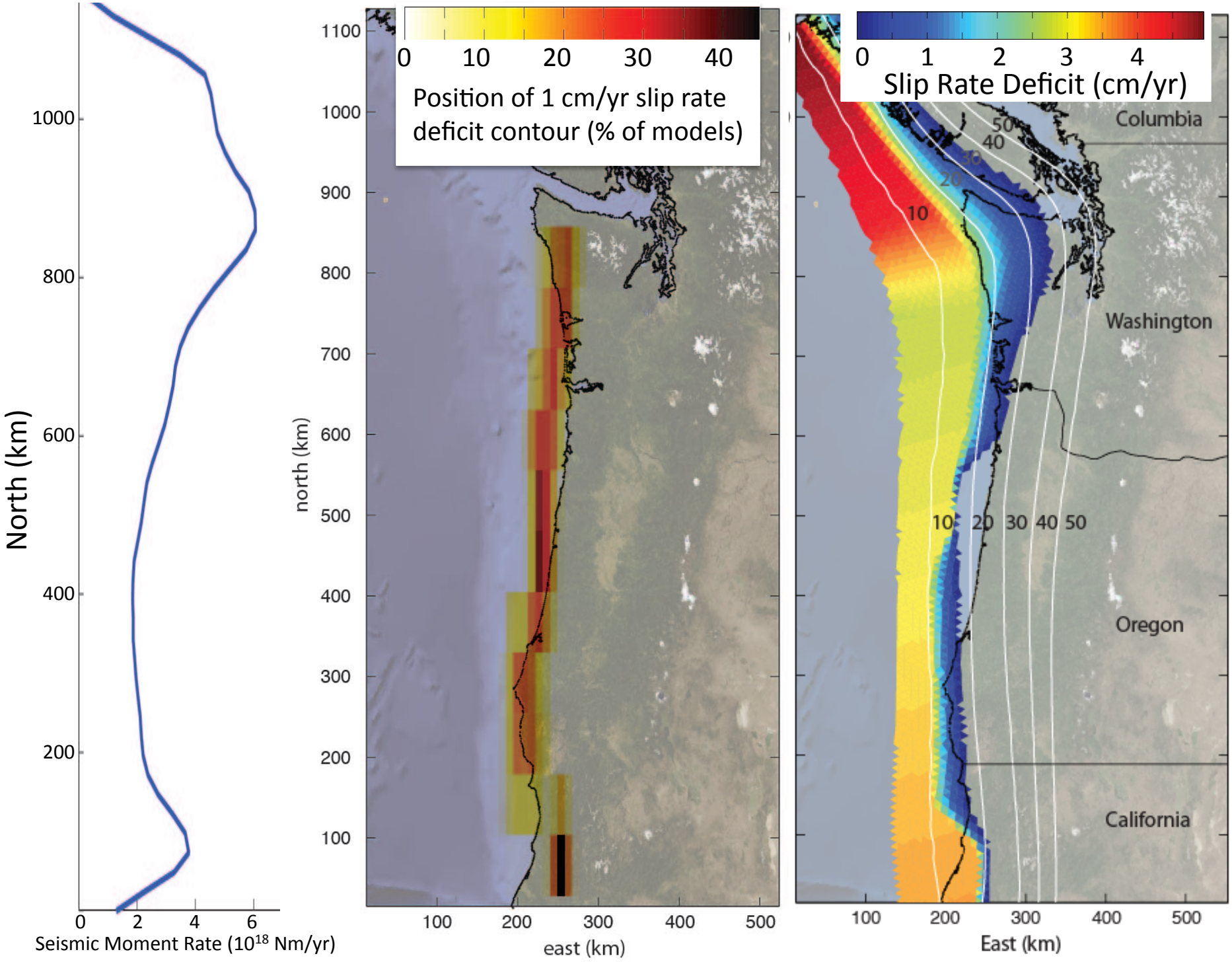

Misfit for combined Leveling & Horizontal Strain
Misfit (χ^2)
1 3 5 7 9 11
Depth of transition zone (km)
5 15 25 35
Depth of locked zone (km)
British Columbia
Washington
Oregon
California
10 20 30 40 50
North (km)
1000 900 800 700 600 500 400 300 200 100
East (km)
100 200 300 400 500
Slip Rate Deficit (cm/yr)
4 3 2 1 0


Observed
Predicted
Residual
north (km)
east (km)
1100
1000
900
800
700
600
500
400
300
200
100
100
200
300
400
500
-3 -2 -1 0 1 2 3 4
Uplift (mm/yr)
0 1 2 3 4
| Misfit | (mm/yr)


Observed Strain Rate
Predicted Strain Rate
north (km)
east (km)
1100
1000
900
800
700
600
500
400
300
200
100
100
200
300
400
500
600
0
50
100
150
Compressional Strain Rate (nanostrain/yr)


Depth of transition zone (km)
35
25
15
5
5
15
25
35
Depth of locked zone (km)
Narrow
Transition
Zone
Narrow Locked Zone
Misfit (χ^2)
1
3
5
7
9
11


0
1
2
3
4
Slip Rate Deficit (cm/yr)
Columbia
Washington
Oregon
California
10
20
30
40
50
North (km)
East (km)
1100
1000
900
800
700
600
500
400
300
200
100
100
200
300
400
500


North (km)
1000
800
600
400
200
0
2
4
6
Seismic Moment Rate (10^{18} Nm/yr)
north (km)
1100
1000
900
800
700
600
500
400
300
200
100
0
10
20
30
40
Position of 1 cm/yr slip rate deficit contour (% of models)
100
200
300
400
500
east (km)
0
1
2
3
4
Slip Rate Deficit (cm/yr)
Columbia
Washington
Oregon
California
10
20
30
40
50
East (km)

Summary

- A Cascadia locking model constrained by leveling and horizontal strain rates from GPS.
- Wide locked zone in WA and CA; Narrow in OR.
- M_o Accumulation Rate: 0.9-1.4 x10^{22} Nm/century
- M_w Accumulation Rate: 8.5-8.7 per century
- Leveling data consistent with segment boundary offshore OR, although not uniquely resolved.