Using Deep Slow Slip in New Zealand to Constrain Slip Partitioning

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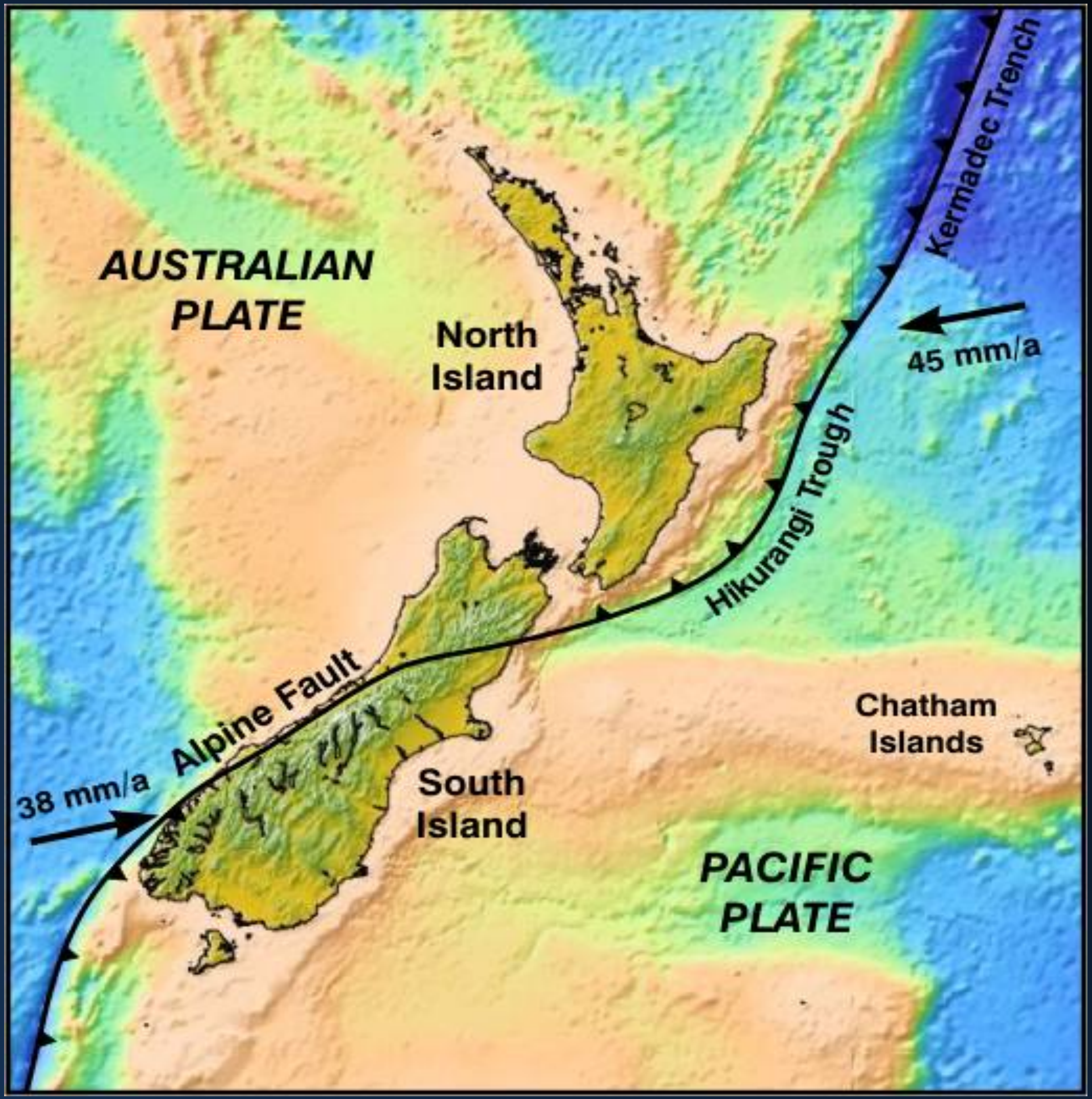
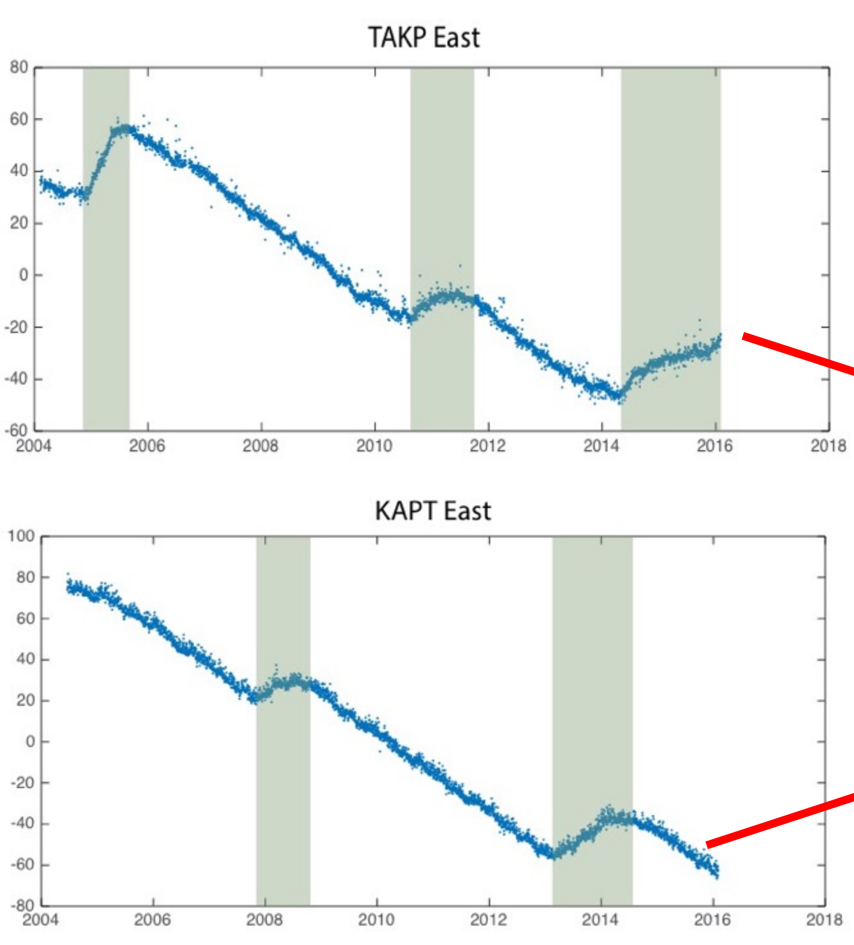
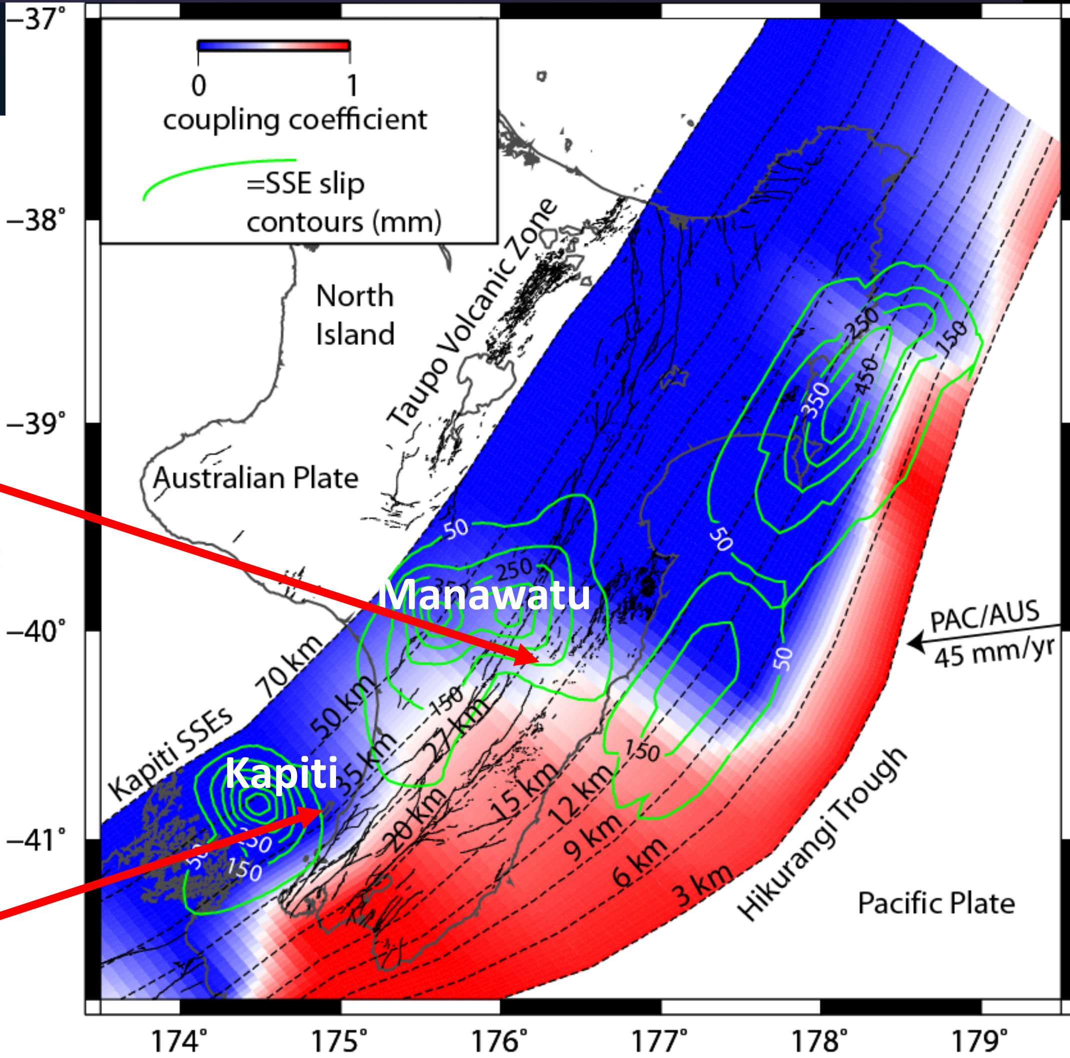
Hikurangi subduction zone



Slow slip in Hikurangi





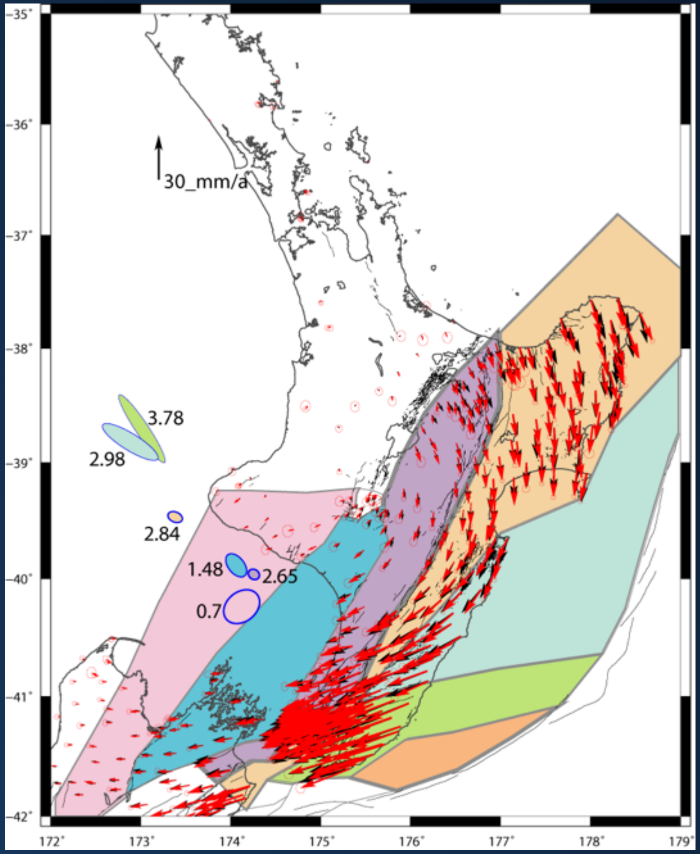
Large cGPS displacements of up to 3-4 cm

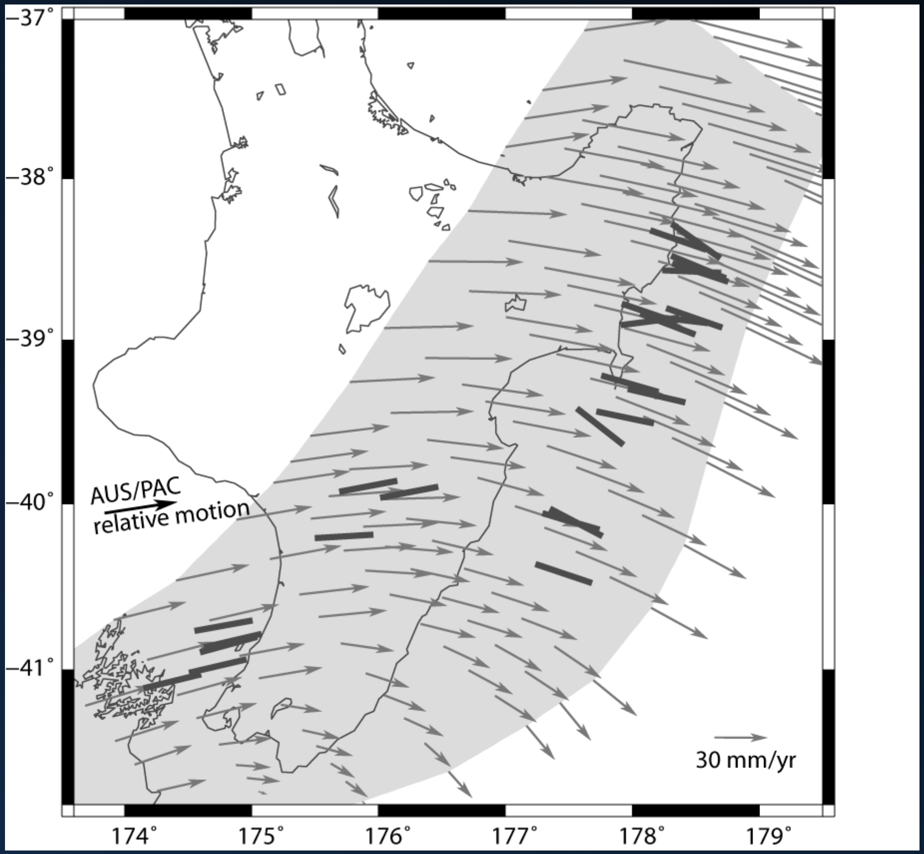
Green contours show cumulative slow slip between 2002 and 2012

Wallace, L. M., and D. Eberhart-Phillips, GRL, 2013

Slip Partitioning in Hikurangi

- Block model used to determine how slip is partitioned between plate interface and upper plate faults
  - Important for hazard assessment
- Many boundaries to constrain at once
  - What if we could isolate slip on just the interface?

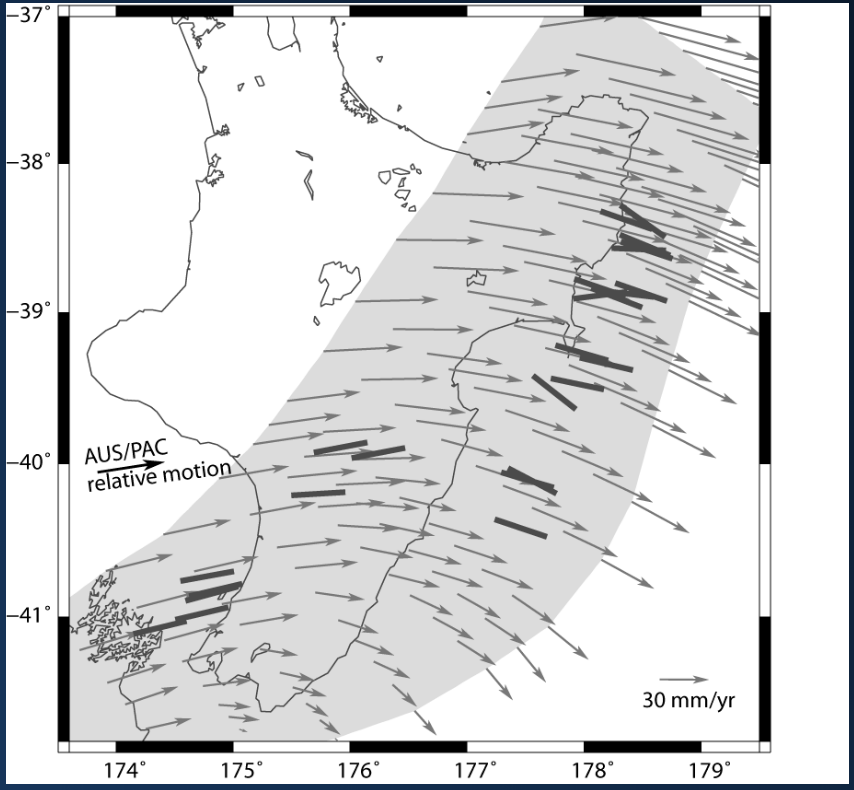


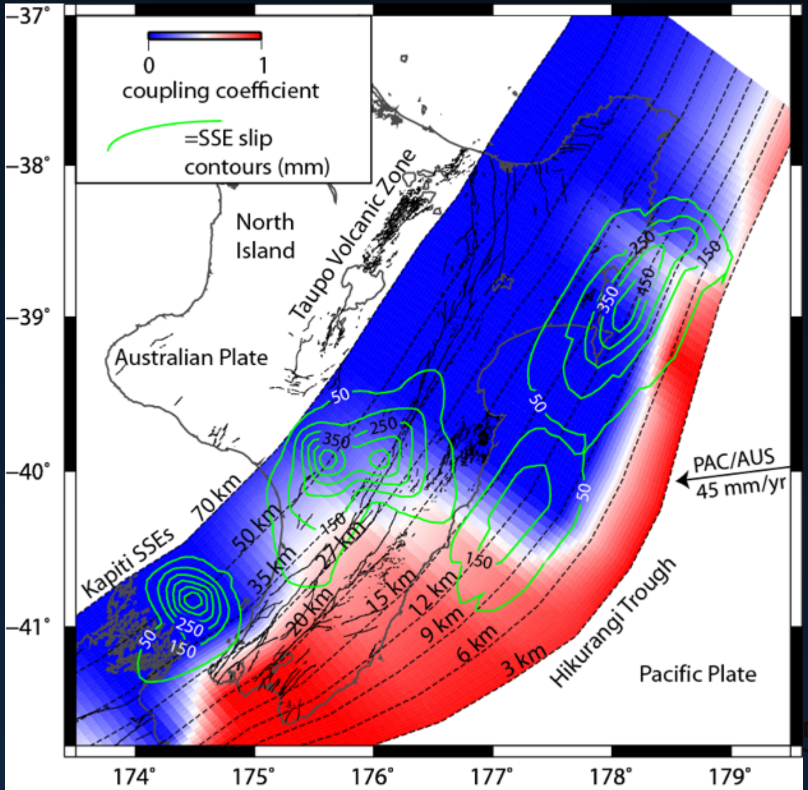


Wallace et al., JGR, 2004 & 2012

Using Slow slip to study slip partitioning

- From early 2013 to late 2015, large slow slip events occurred on the Kapiti and Manawatu patches of the interface
- Fit and remove an inter-SSE velocity at each station, isolating the plate interface slow slip signal
- Invert GPS data to solve for the slip direction on the interface





The Network Inversion Filter

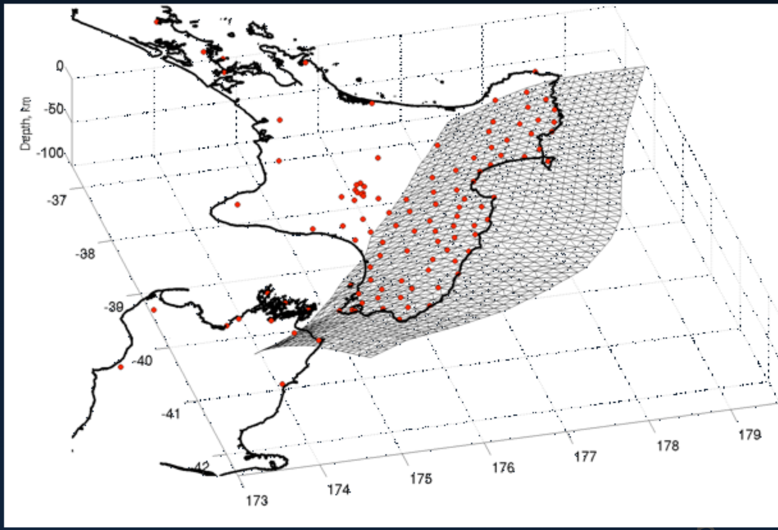
- Fits GPS data as:

$$\boldsymbol{X}(t) = \boldsymbol{X}(t_0) + G\boldsymbol{s}(t - t_0) + Ff(t) + L(\boldsymbol{x}, t - t_0) + \epsilon$$

- Estimates space-time evolution of fault slip.
  - Two “tunable” parameters: spatial smoothing, temporal smoothing

- Based on Kalman Filter
  - Balances noisy data with imprecise physical model

- At each time step, the filter predicts slip and slip rate, then updates with data



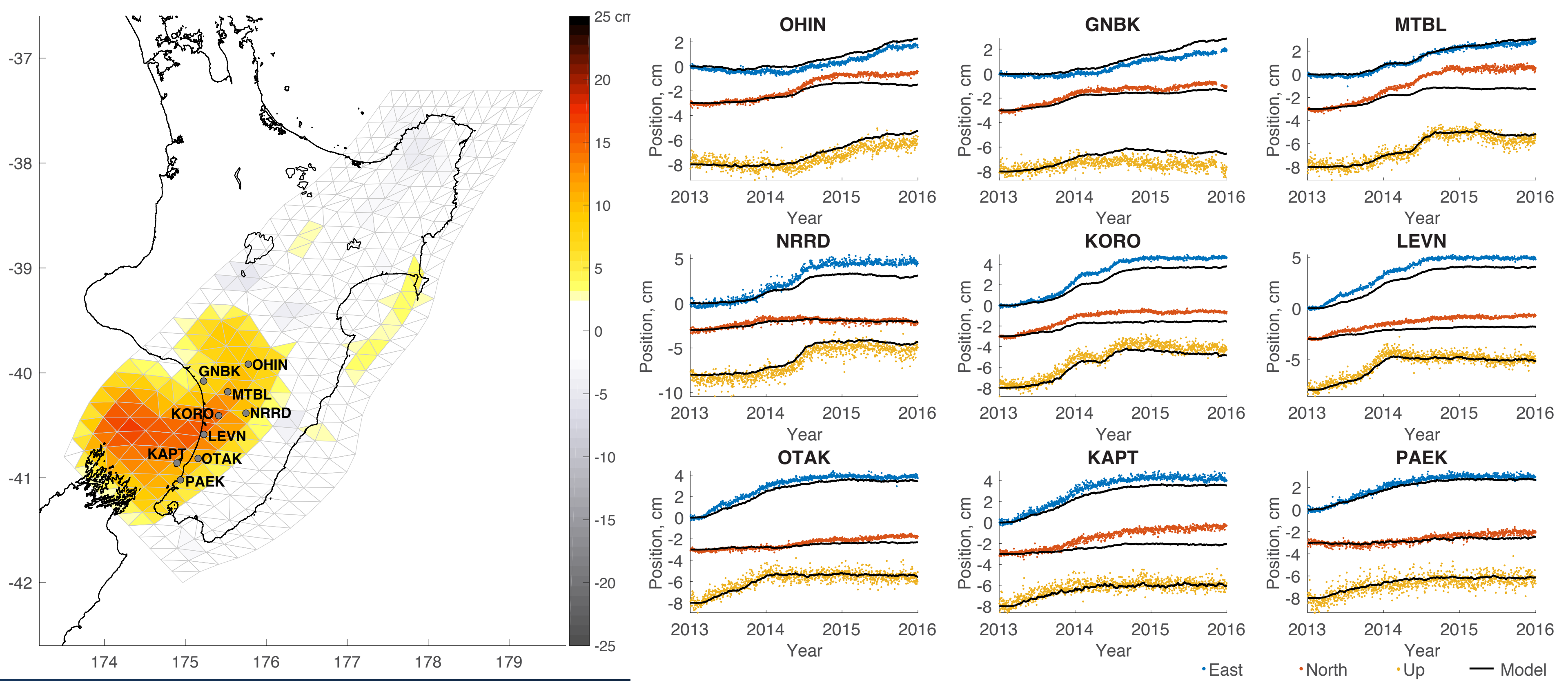
- NIF code (MATLAB) available from:

http://faculty.missouri.edu/~bartlowno/software.html

Also see Segall and Matthews, *J. Geophys. Res.*, 1997.

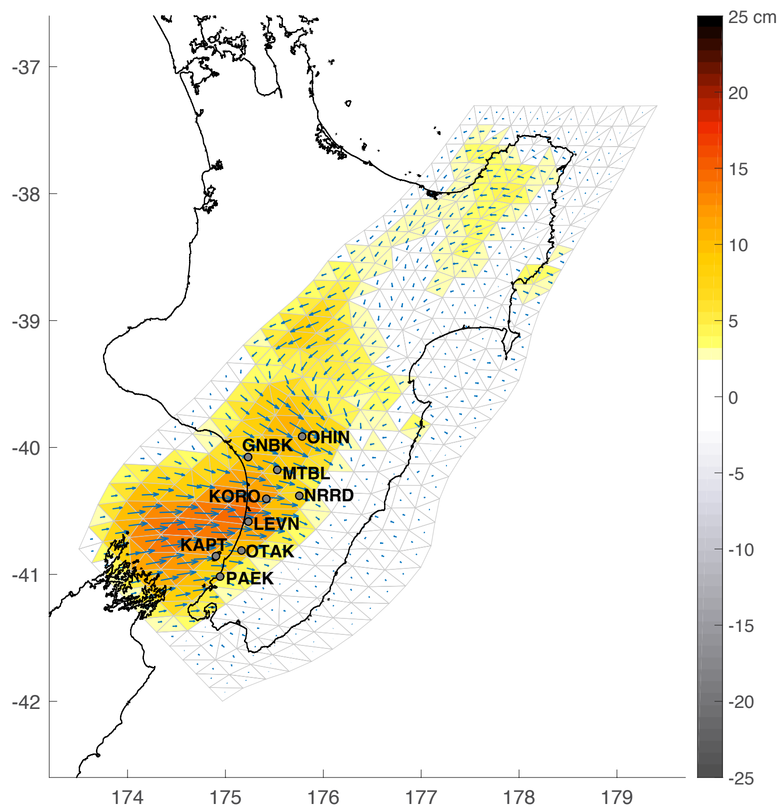
Results

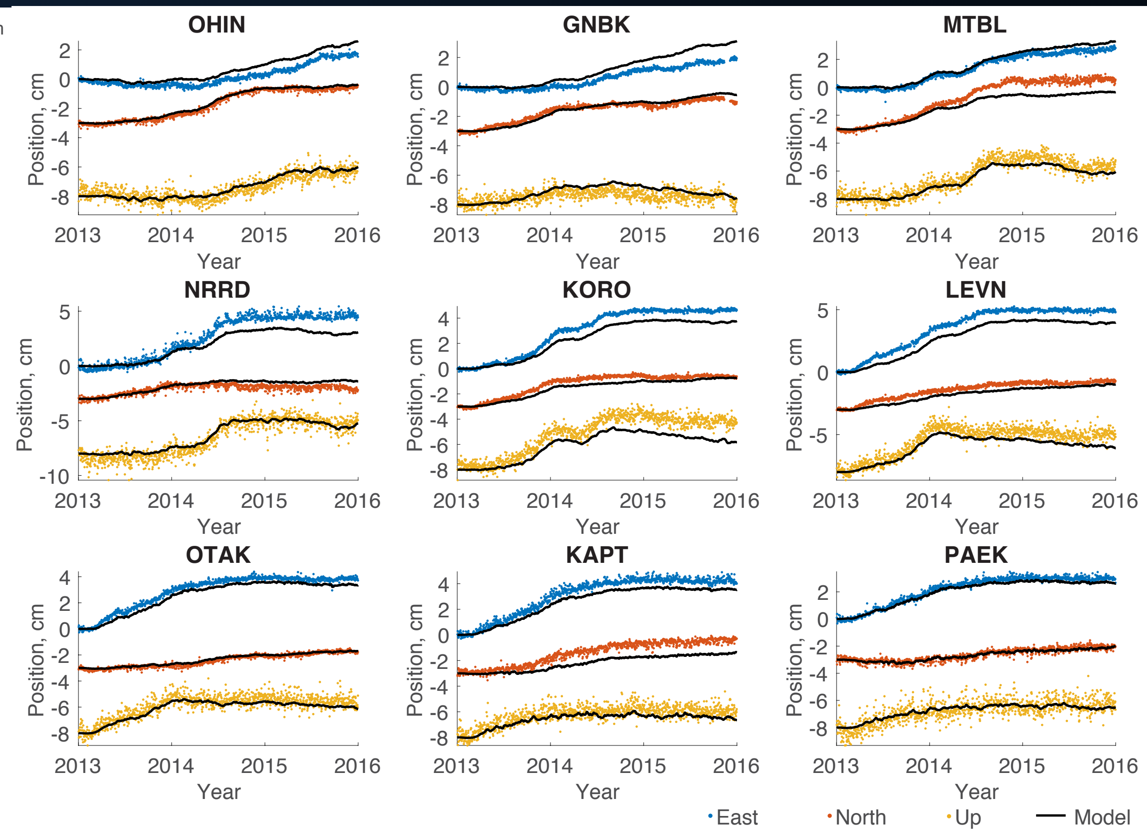
- With slip direction fixed to the block model results, we cannot fit the data from the 2013-2014 SSEs at some stations



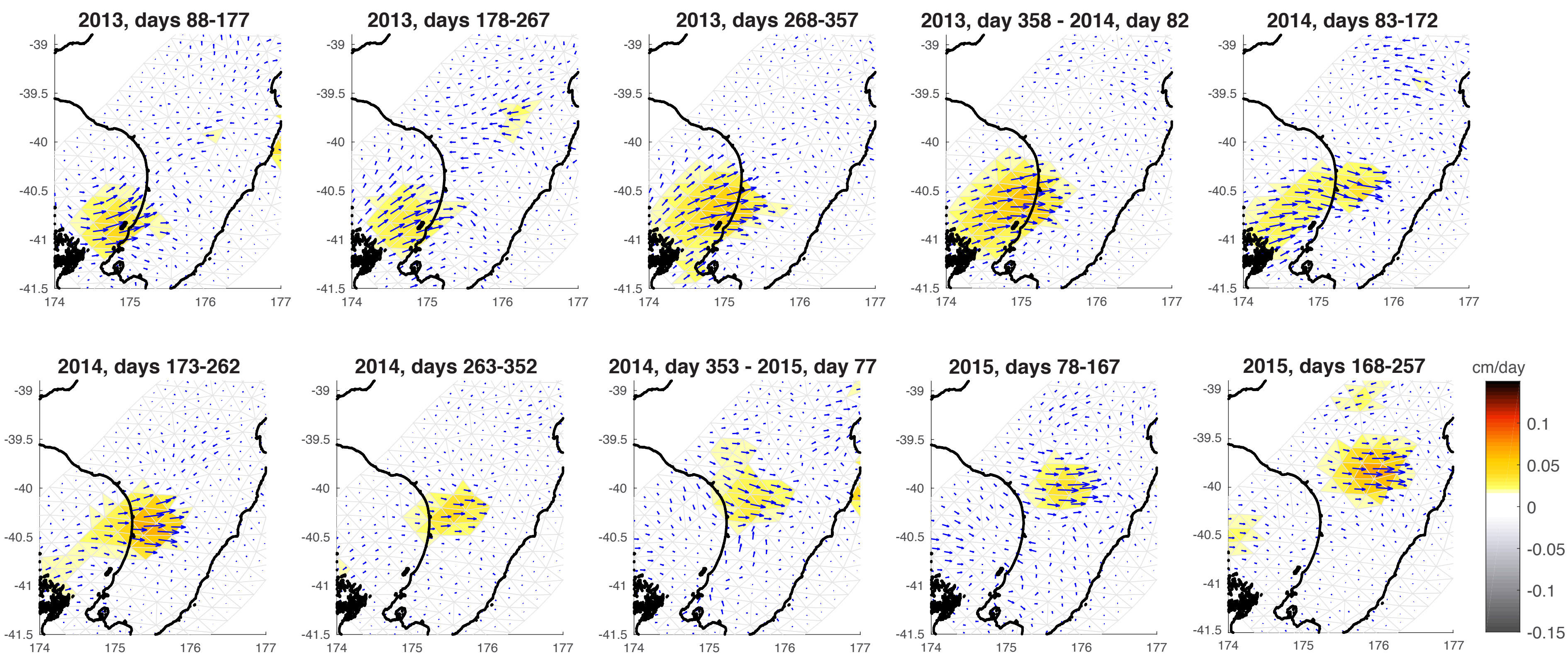
Results – variable slip directions

- Allowing the slip direction to vary does a better job of fitting the data
- We invert for strike- and dip-slip components and calculate rake angles
- Data fit isn't perfect – inter-SSE velocity correction?





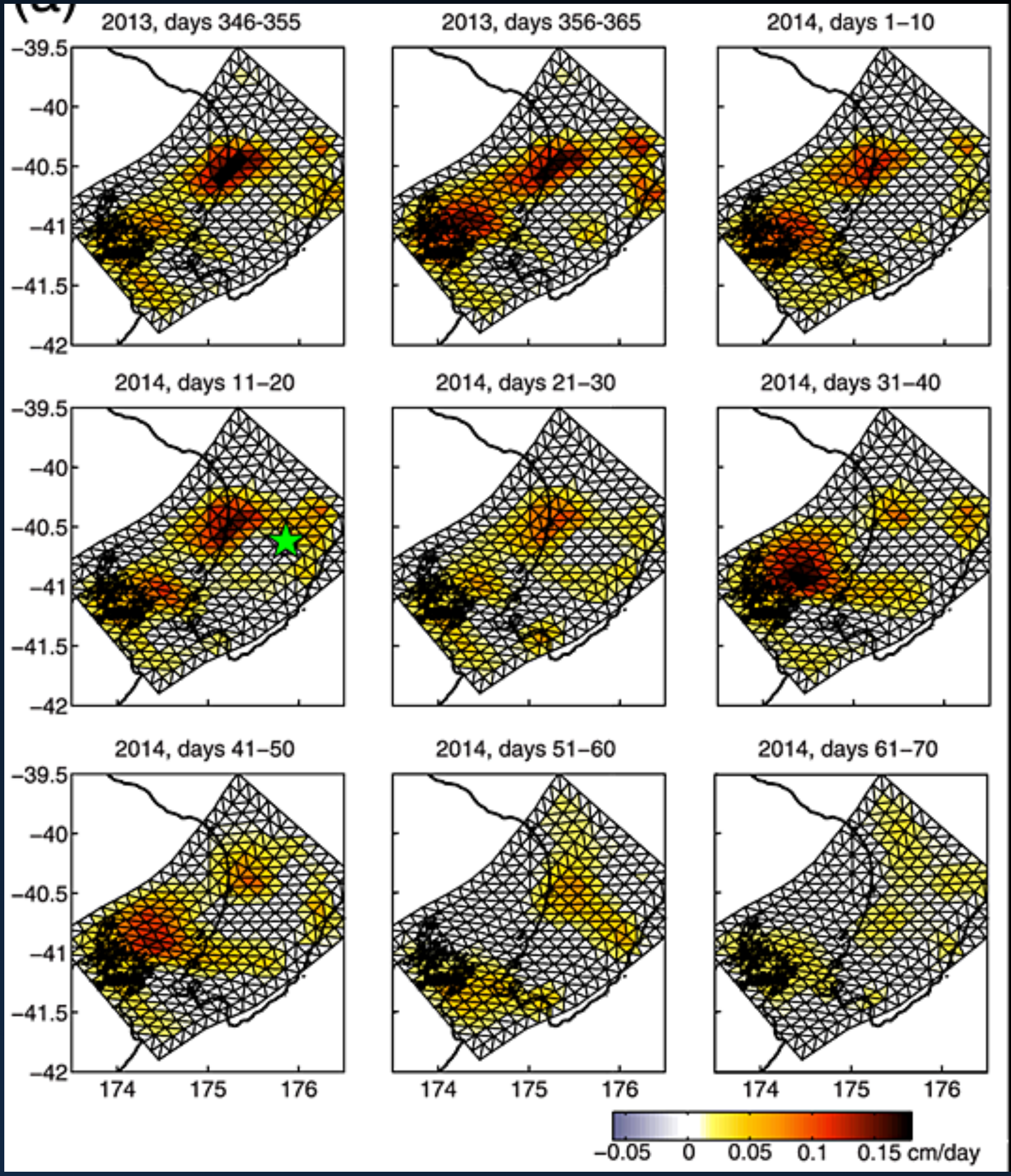
Slip-rate over time



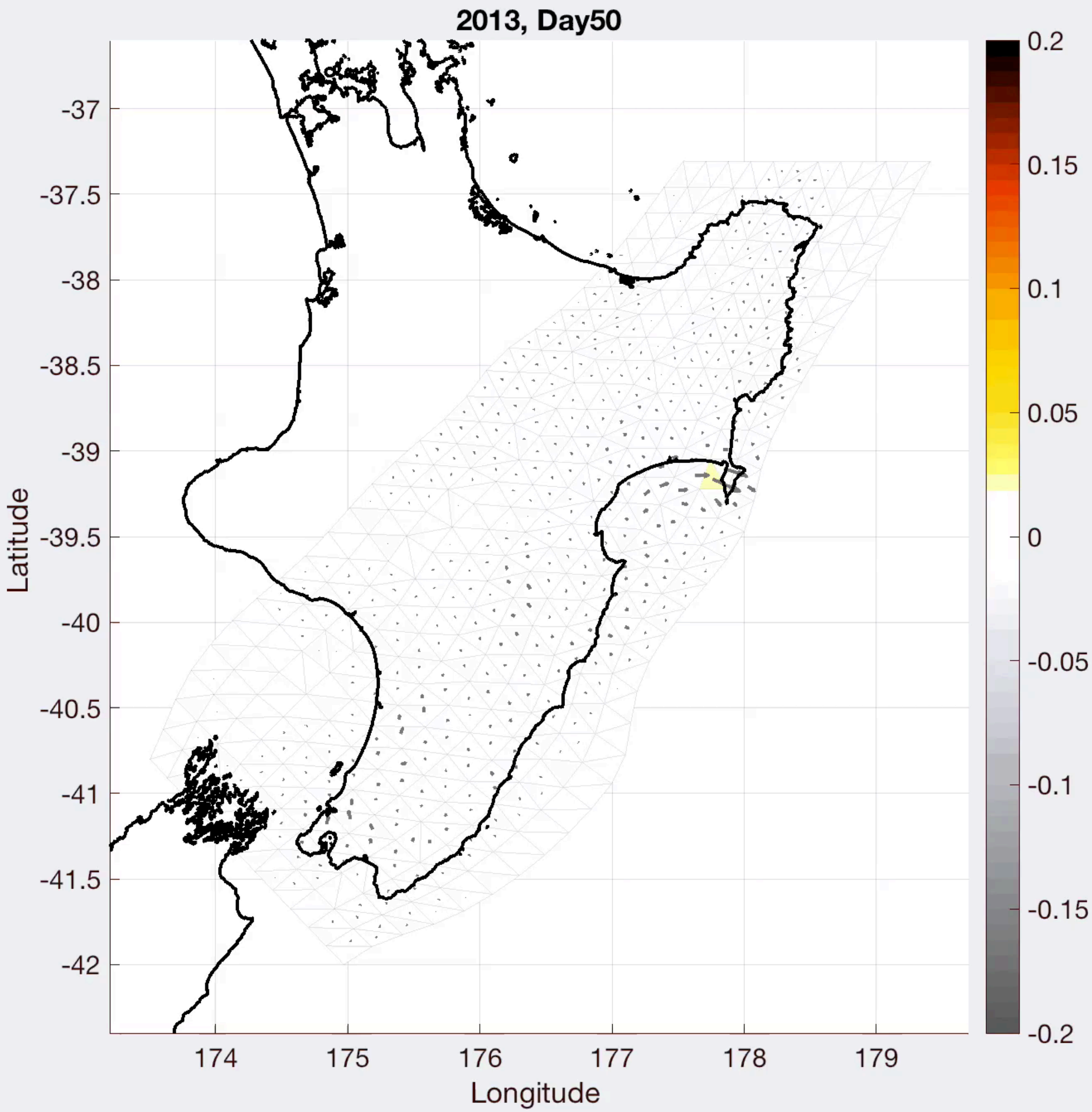
Eketahuna earthquake and Kapiti SSE

- M 6.2 earthquake put a clamping stress of ~100 kPa on the Kapiti SSE, decelerating it

citation: Wallace, L. M., N. Bartlow, I. Hamling, and B. Fry (2014), Quake clamps down on slow slip, Geophys. Res. Lett.

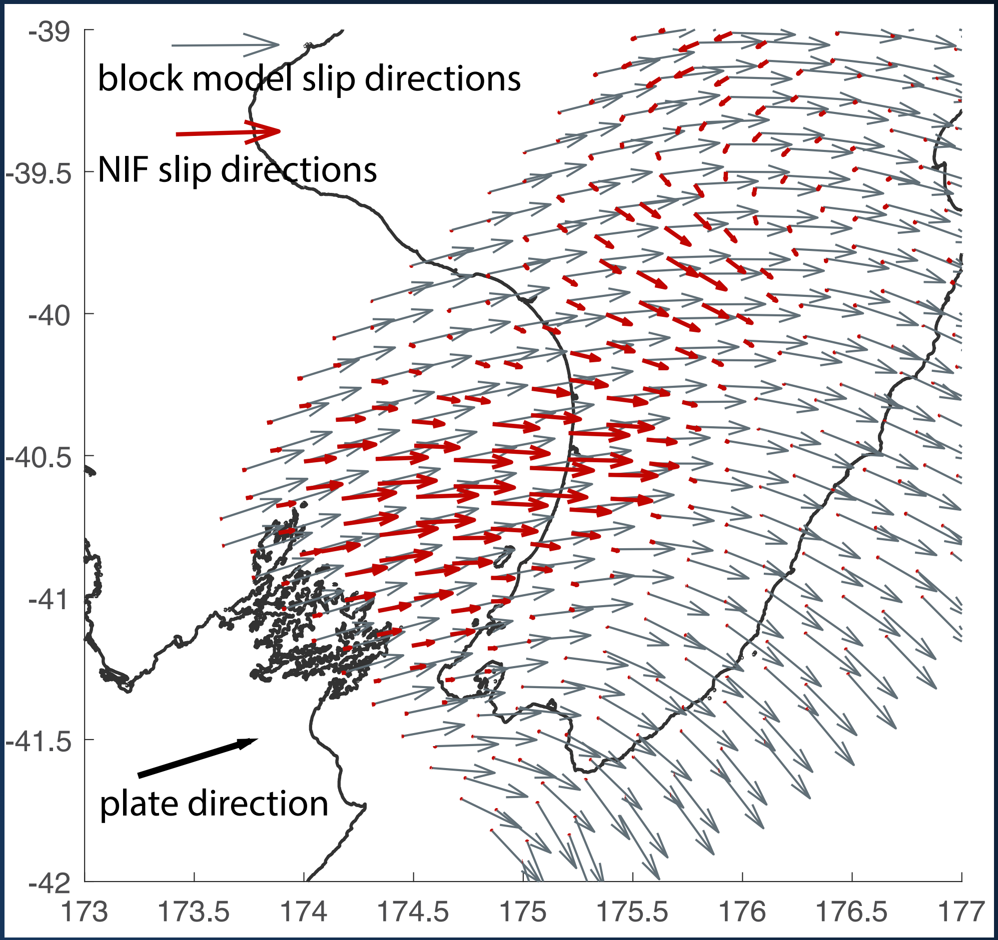


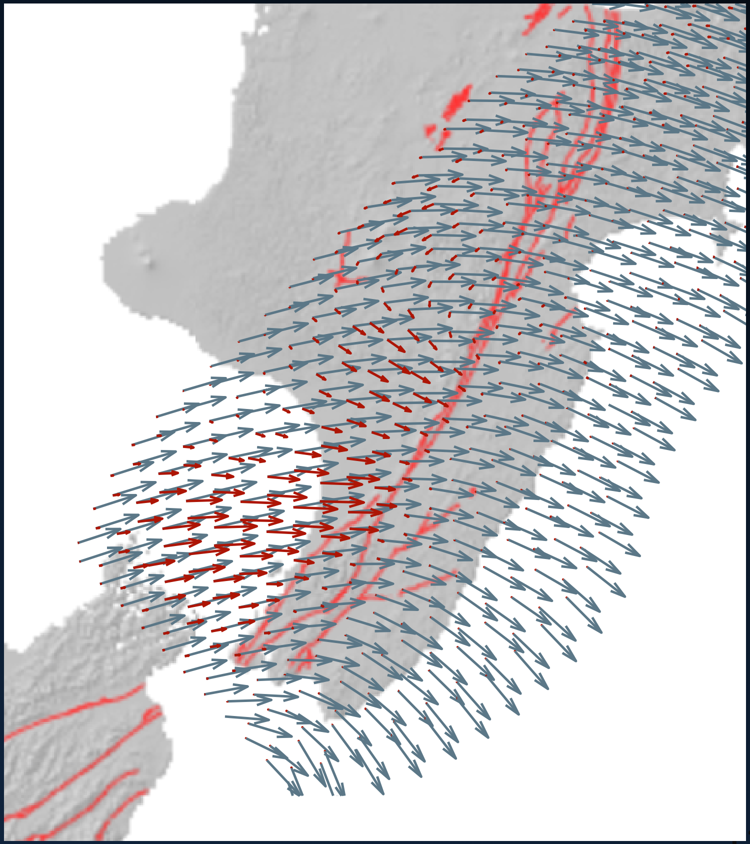
Slip-rate Movie



What does this mean?

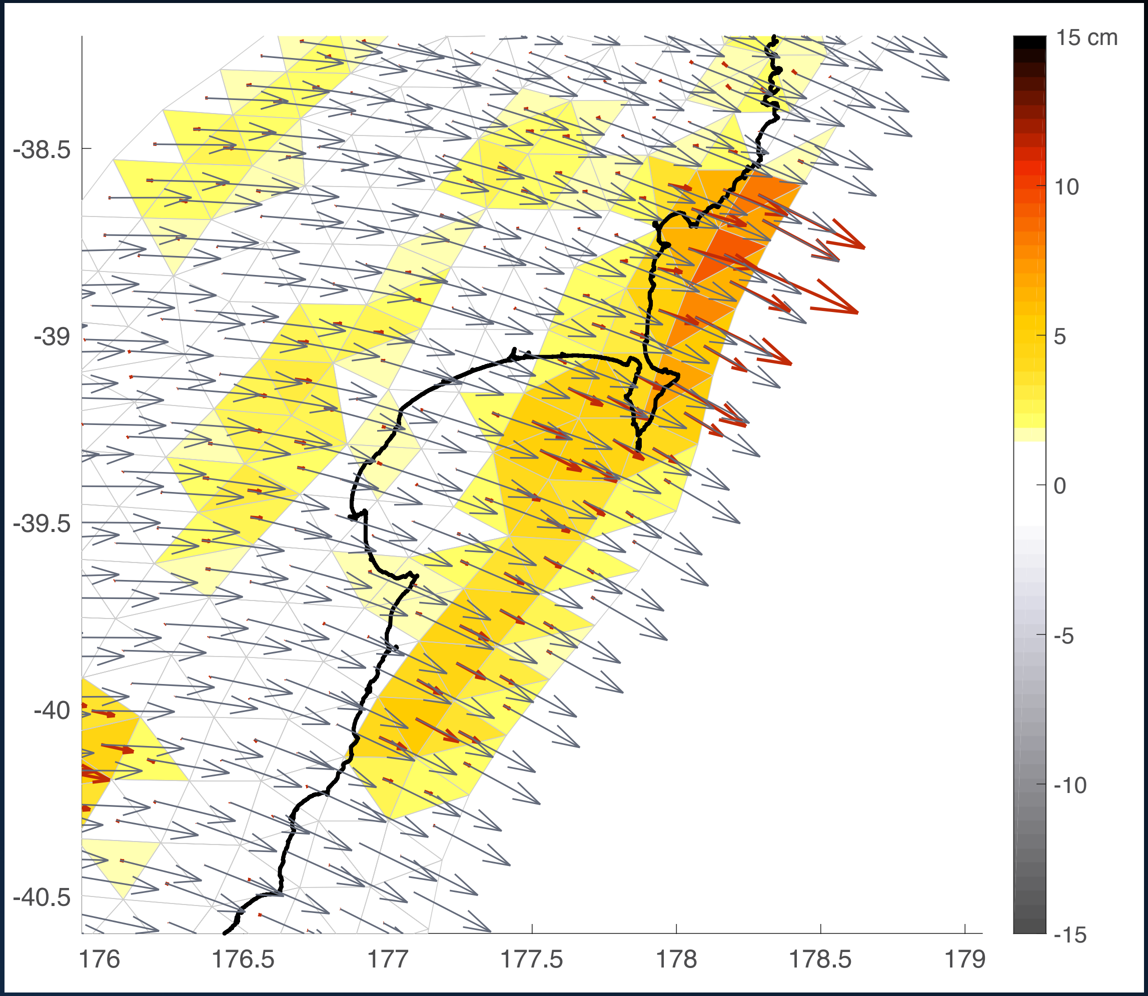
- The Manawatu region may have more dip-slip than previously thought
- One possible interpretation: Shallow faults intersect plate interface deeper than previously thought





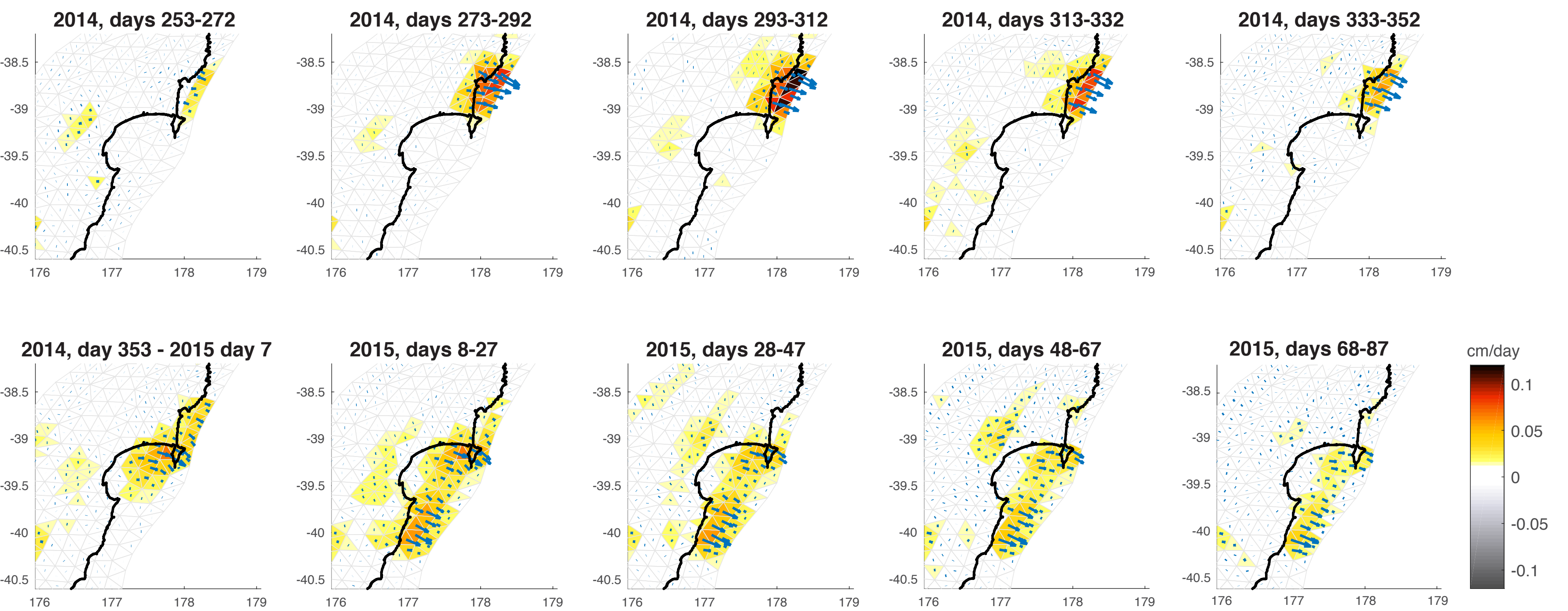
Results for Shallow Slow Slip

- Shallow region shows nearly pure dip-slip
- Good match with block model slip directions



Results for Shallow Slow Slip

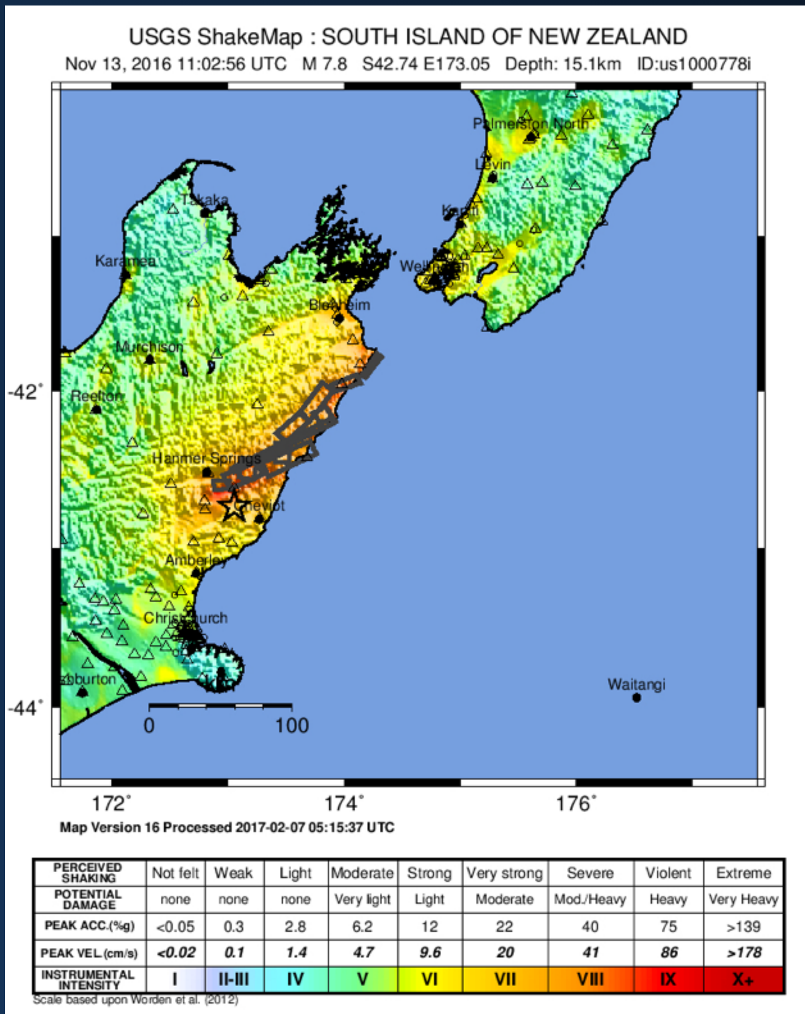
- For more on the 2014 Gisborne SSE, see poster 15

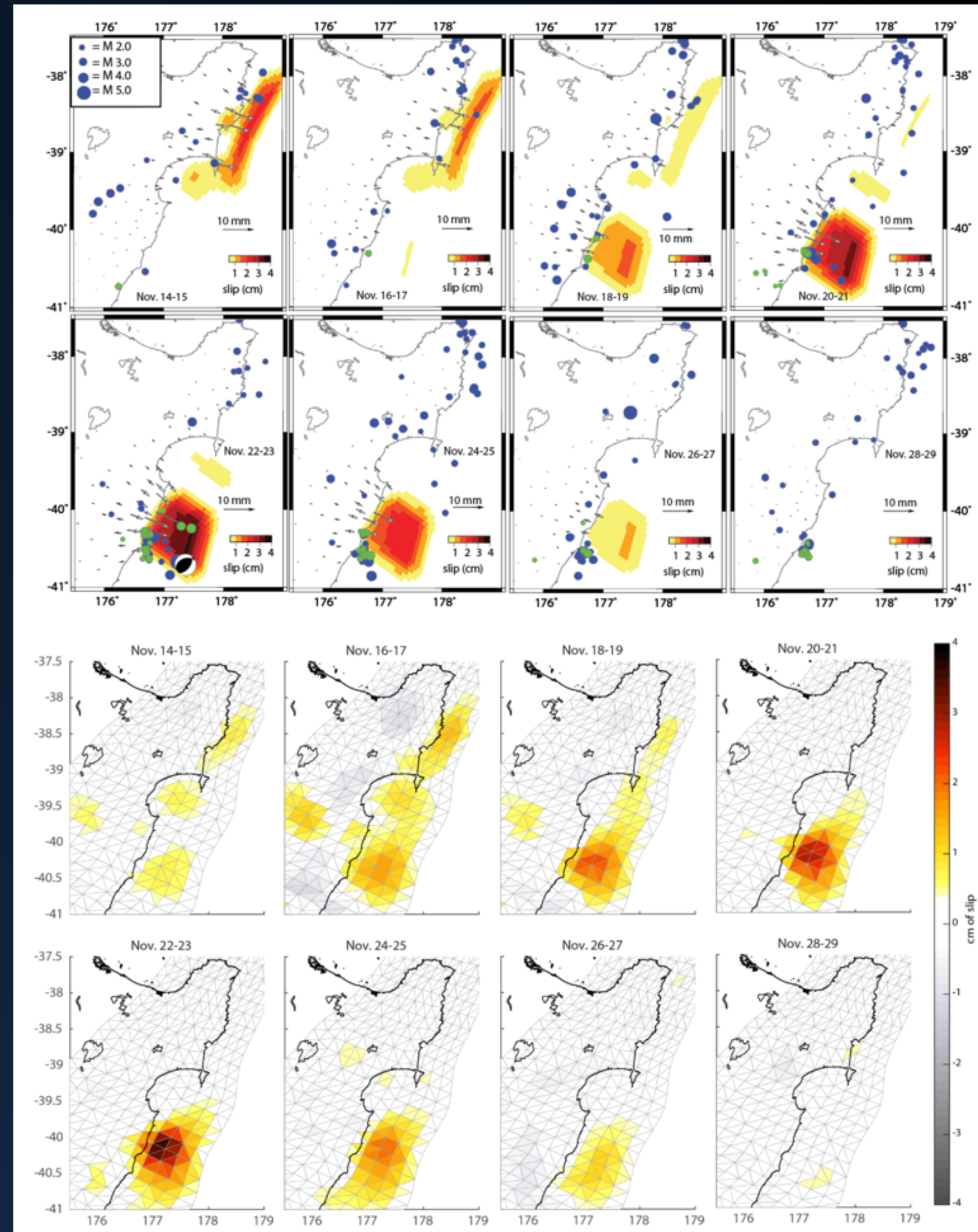


Conclusions

- We can use slow slip events to isolate slip on the plate interface in a complex region with oblique convergence accommodated on many faults
- Transition from plate convergence parallel slip to dip slip may occur deeper than previously thought on part of the plate interface
- Possible interpretations:
  - More shallow strike-slip faults in upper plate
  - Shallow faults intersect plate interface deeper than previously thought

Kaikoura earthquake triggered SSEs



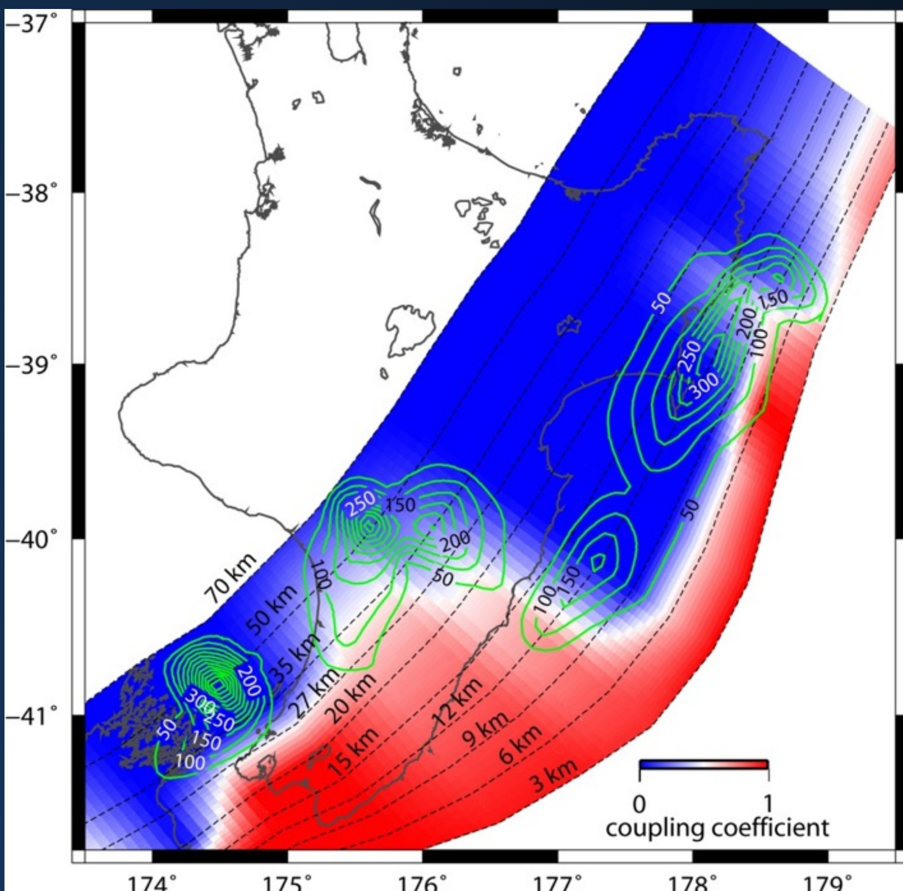


Wallace et al., submitted

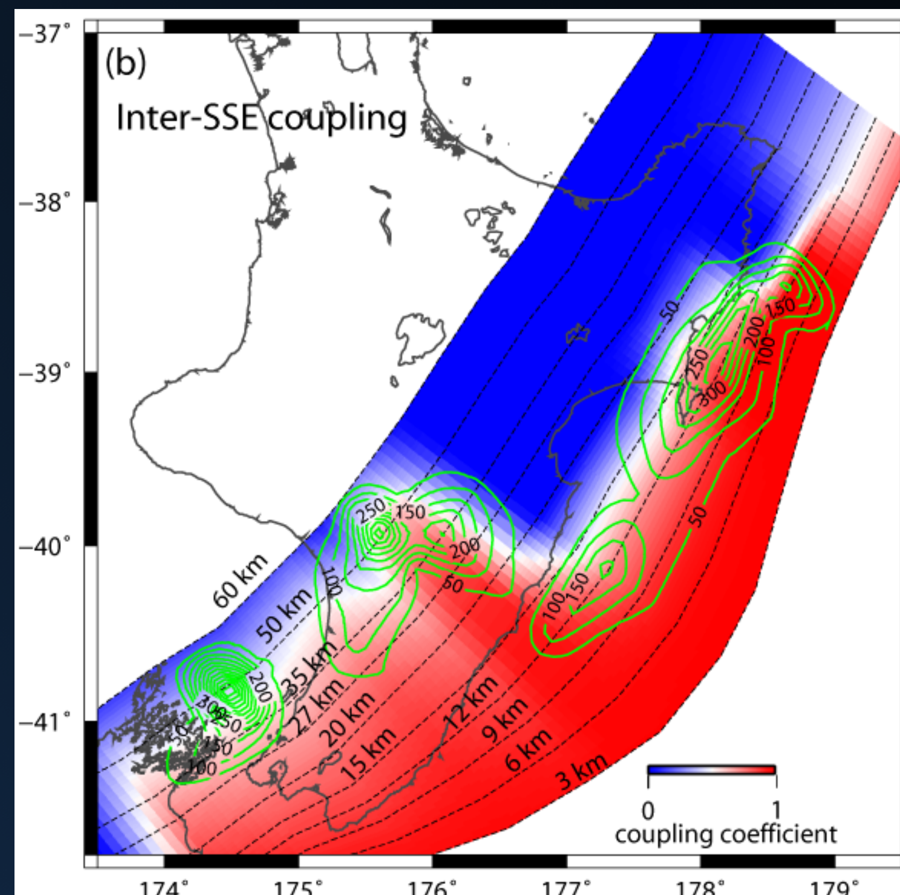
Extra Slides

Interseismic vs. Inter-SSE coupling

Interseismic coupling using campaign GPS velocities averaged over the last ~15 years



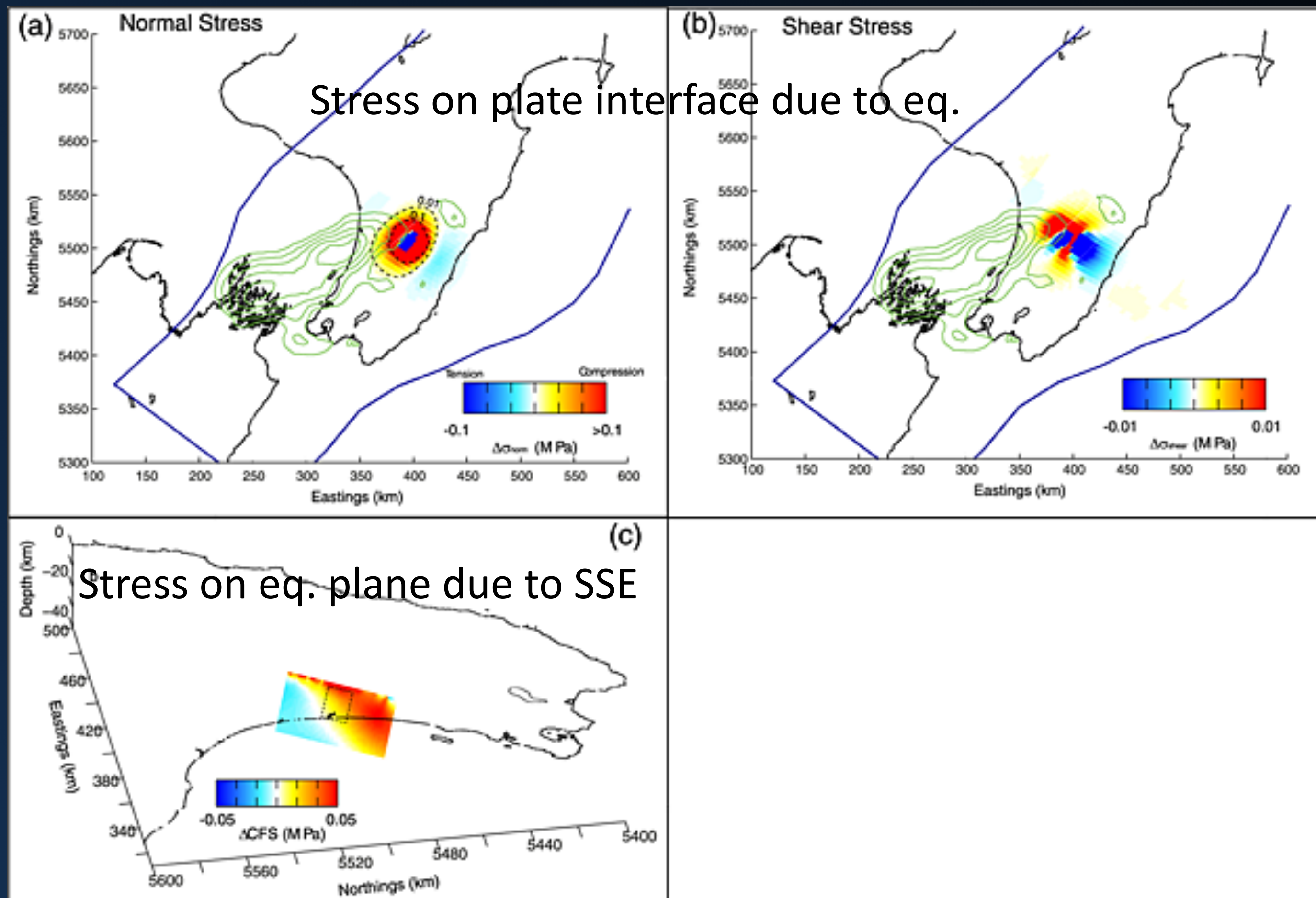
Interseismic coupling using "inter-SSE" velocities from the continuous GPS network.
Slow slip takes a huge amount of the moment release budget in NZ (40%) compared to Cascadia



Wallace and Beavan, 2010, JGR

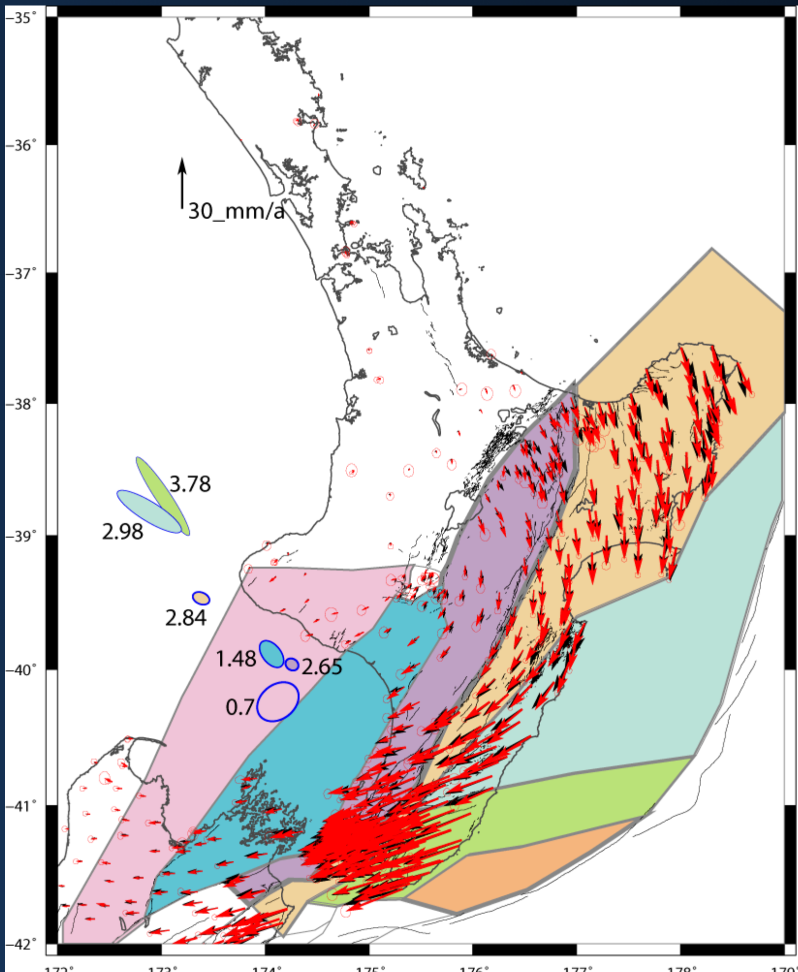
2014 Eketahuna earthquake

- Occurred Jan. 20, M 6.3 normal faulting event within slab
- ~100 kPa clamping stress applied to slipping region

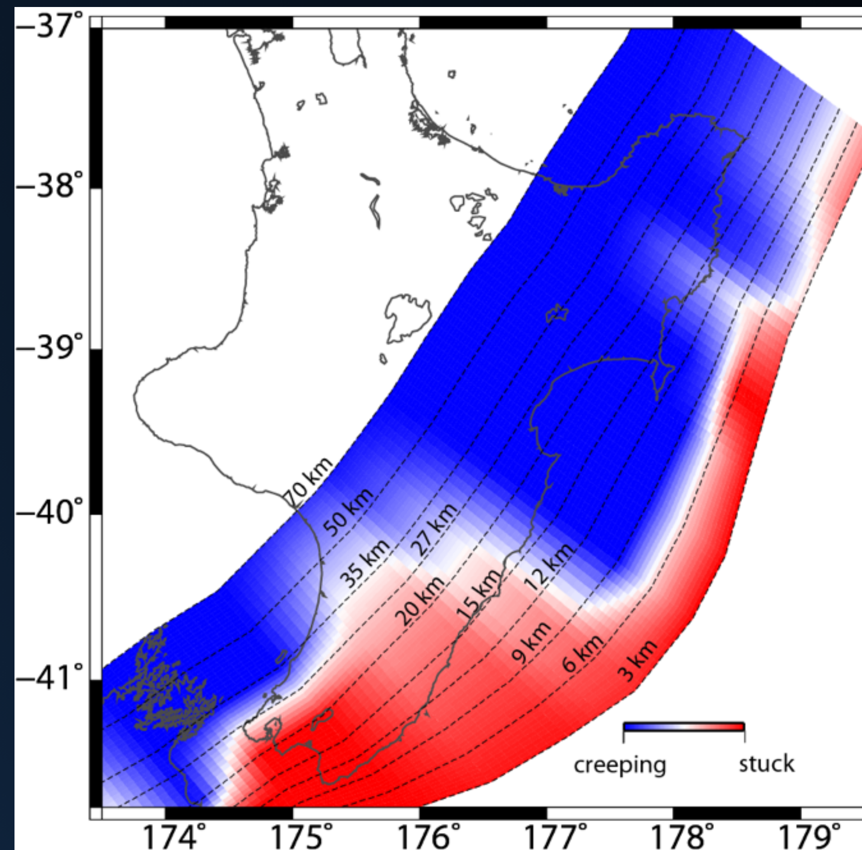


Wallace, L. M., N. Bartlow, I. Hamling, and B. Fry (2014), Quake clamps down on slow slip, GRL.

Interseismic coupling on the subduction interface



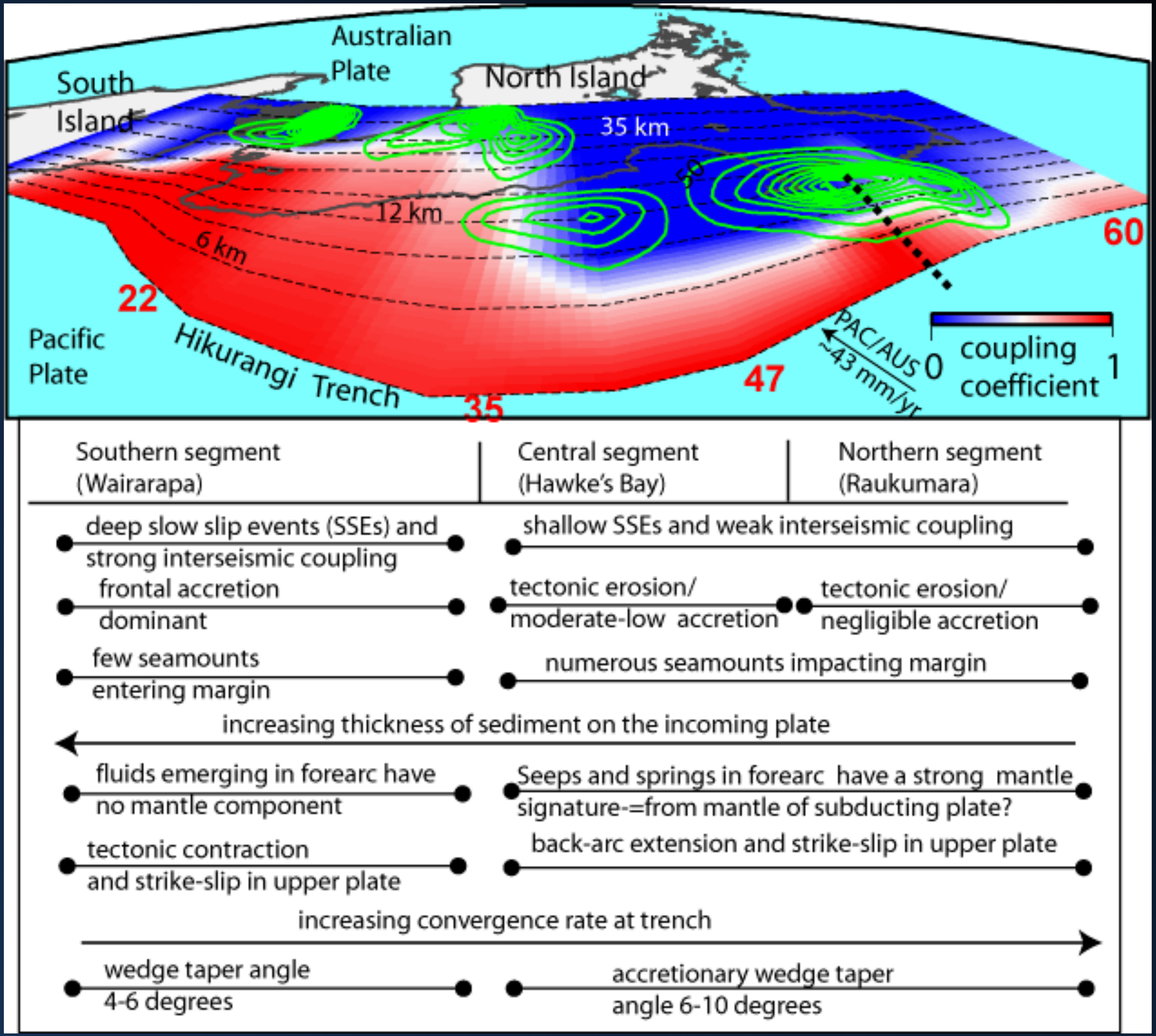
Interseismic coupling



GPS data also reflect long-term tectonic rotation of the forearc. Invert for locking and rotation using elastic block modelling (Defnode; McCaffrey, 2002)

Wallace et al., 2004, 2012 (JGR)

Variations along strike



Block model Fault Slip Rates

- Convergence rate at trench increases 3-fold along the margin, with ~20 mm/yr at the southern Hikurangi margin, and up to 60 mm/yr.
- The block model slip rates for the upper plate faults agree extremely well with geological studies
- Clockwise rotation of the forearc contributes substantially to the slip partitioning process

Wallace et al., 2012 (JGR)