OVERVIEW OF HIKURANGI SUBDUCTION MARGIN TECTONICS

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Acknowledgements

GNS Science: Kate Clark, Ursula Cochran, Stephen Bannister, Bill Fry, Martin Reyners, John Beavan, Susan Ellis, Donna Eberhart-Phillips, Agnes Reyes, Nicola Litchfield, Kelvin Berryman, Dan Barker, Stuart Henrys, Rupert Sutherland

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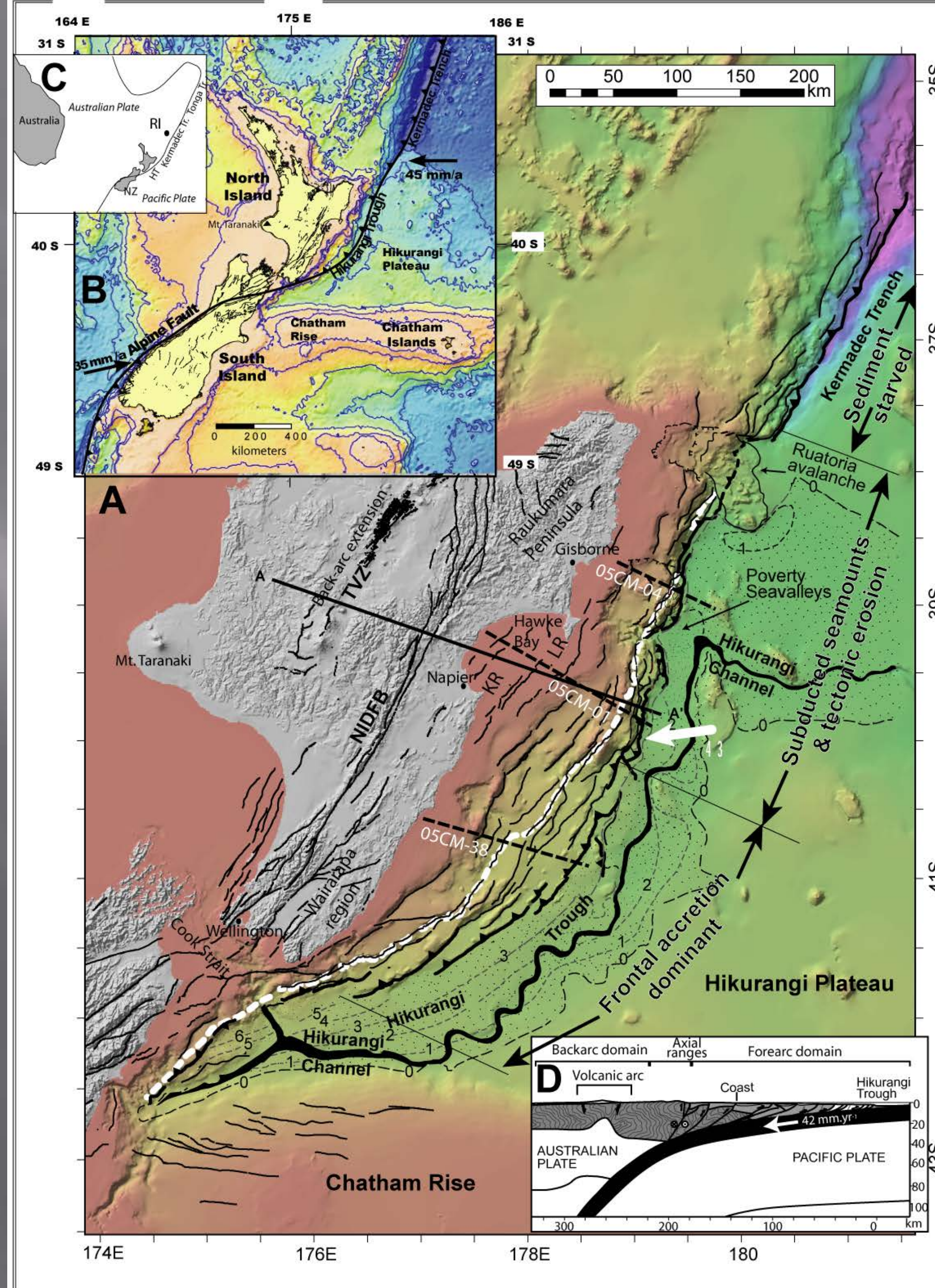
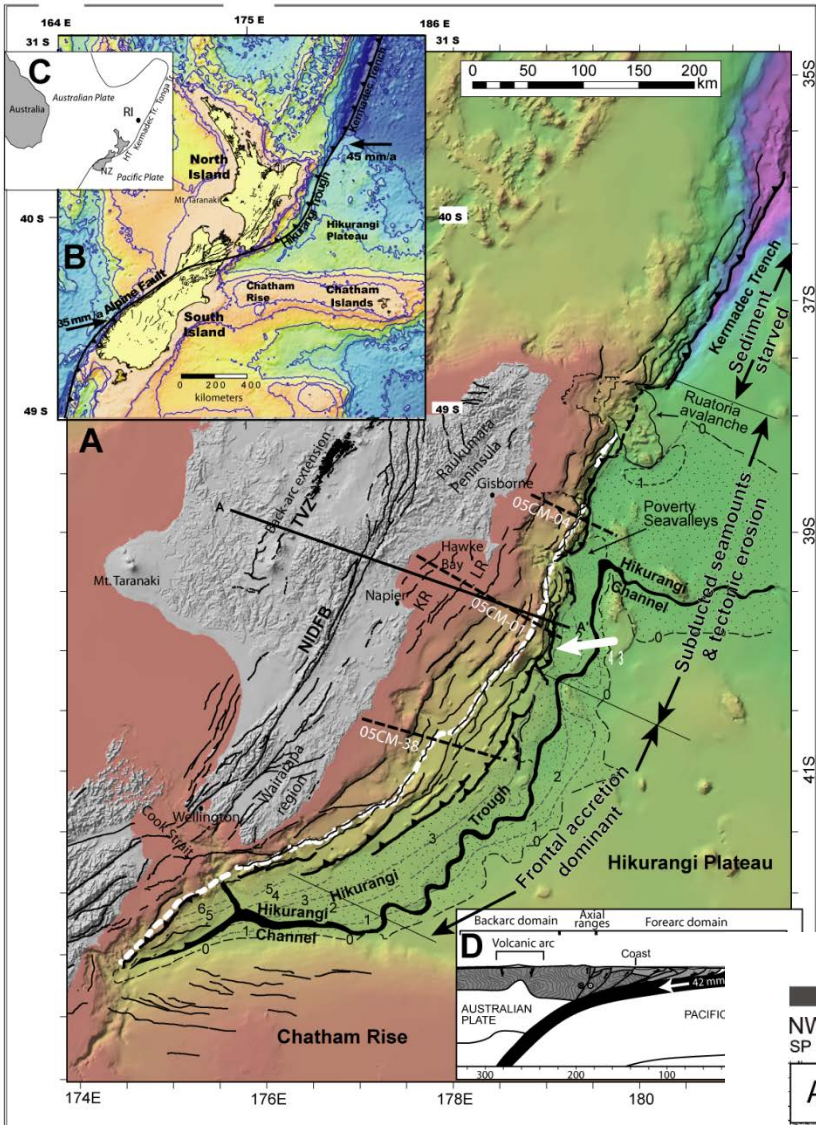
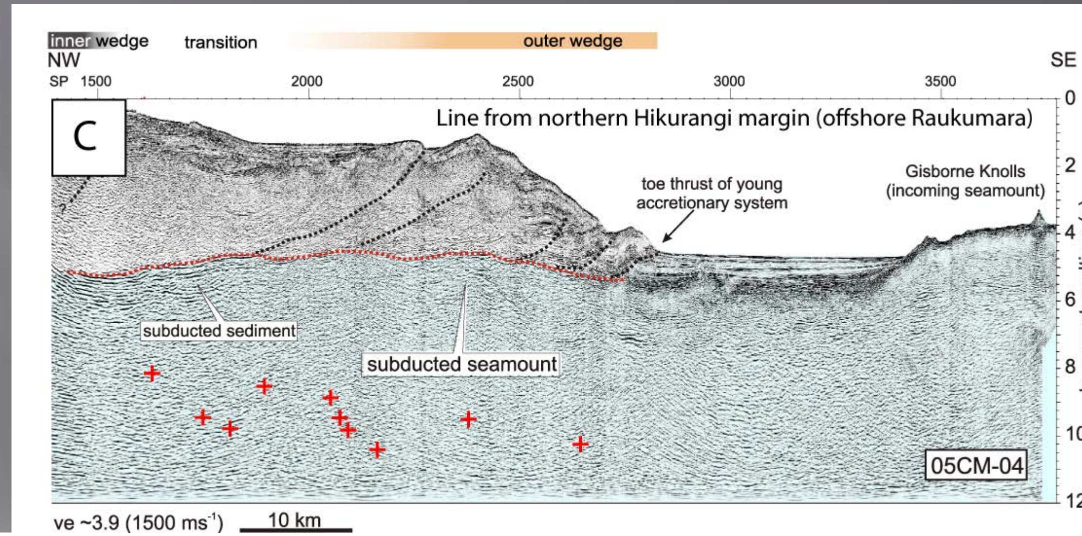
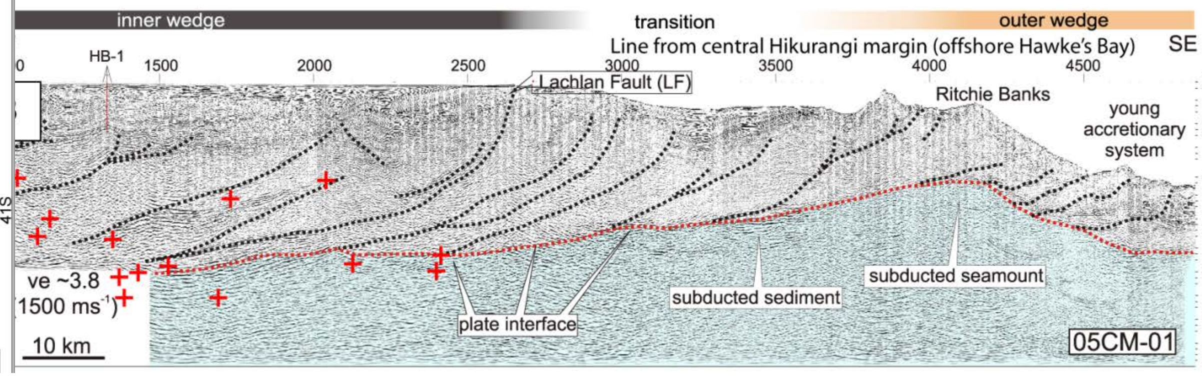
The Hikurangi subduction margin

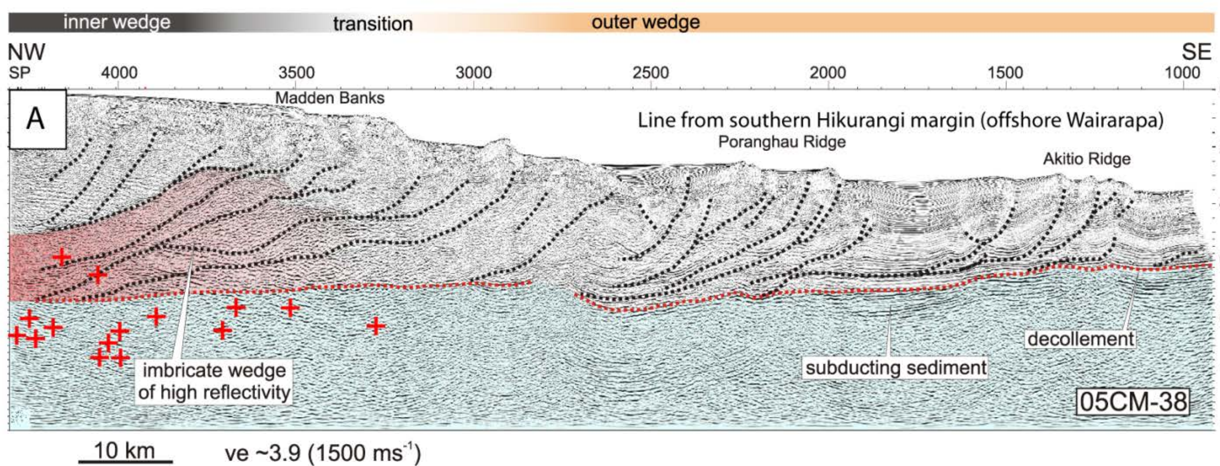
- The Hikurangi Plateau (a Cretaceous oceanic Plateau) is being subducted at the Hikurangi Trough
- Plate motion is oblique, and is partitioned all along the margin via strike-slip faults and clockwise rotation of the margin. Rotation leads to a northward increase in convergence rates.
- Active back-arc rifting occurs in the central North Island (in the Taupo Volcanic Zone)
- The southern Hikurangi margin has a well-developed accretionary wedge, while the northern portion of the margin is dominated by tectonic erosion and seamount subduction.
- The sediments on the lower plate are much thicker at the southern Hikurangi margin, due to sedimentation being funnelled along the Hikurangi channel from the South Island





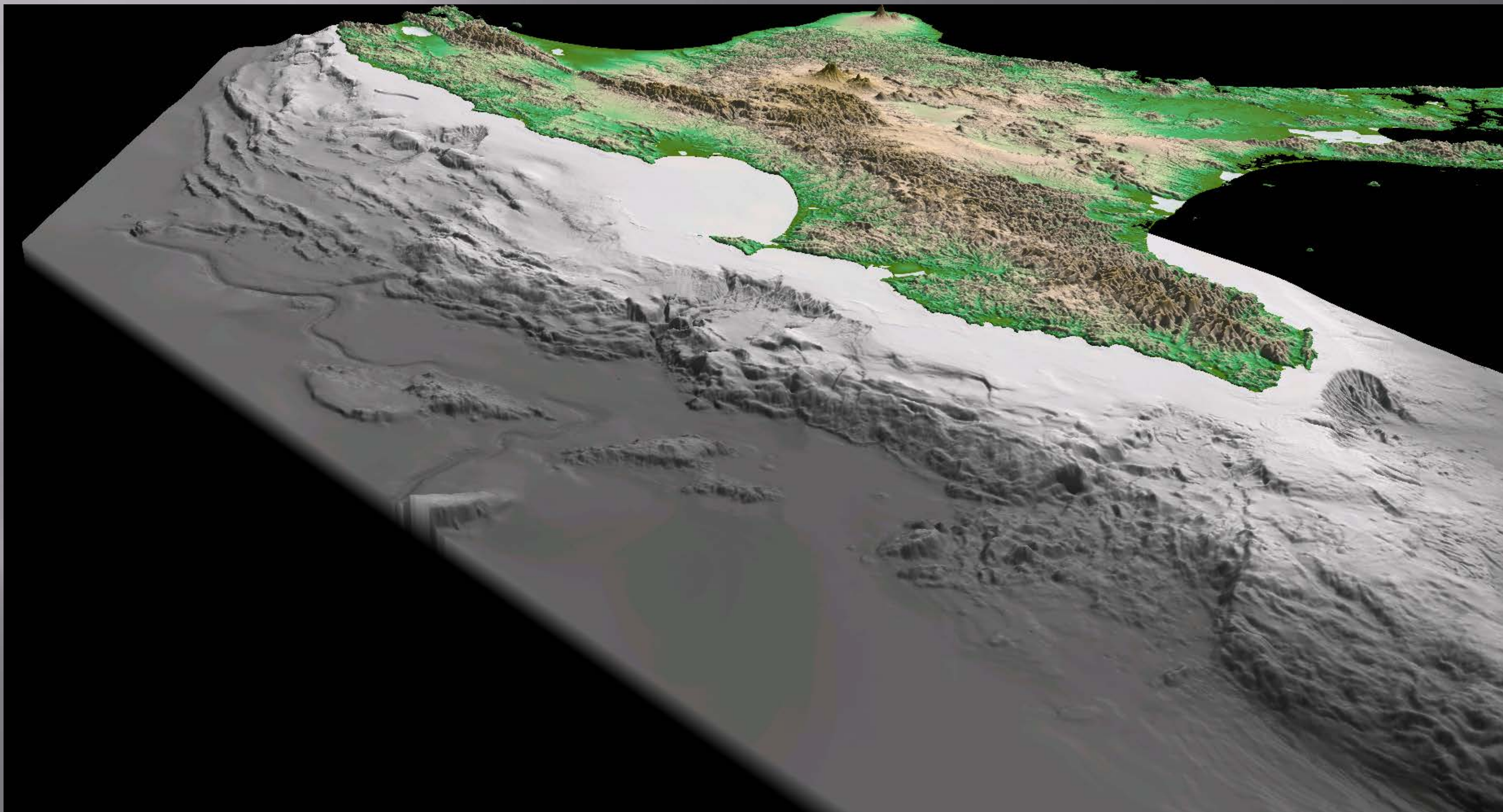




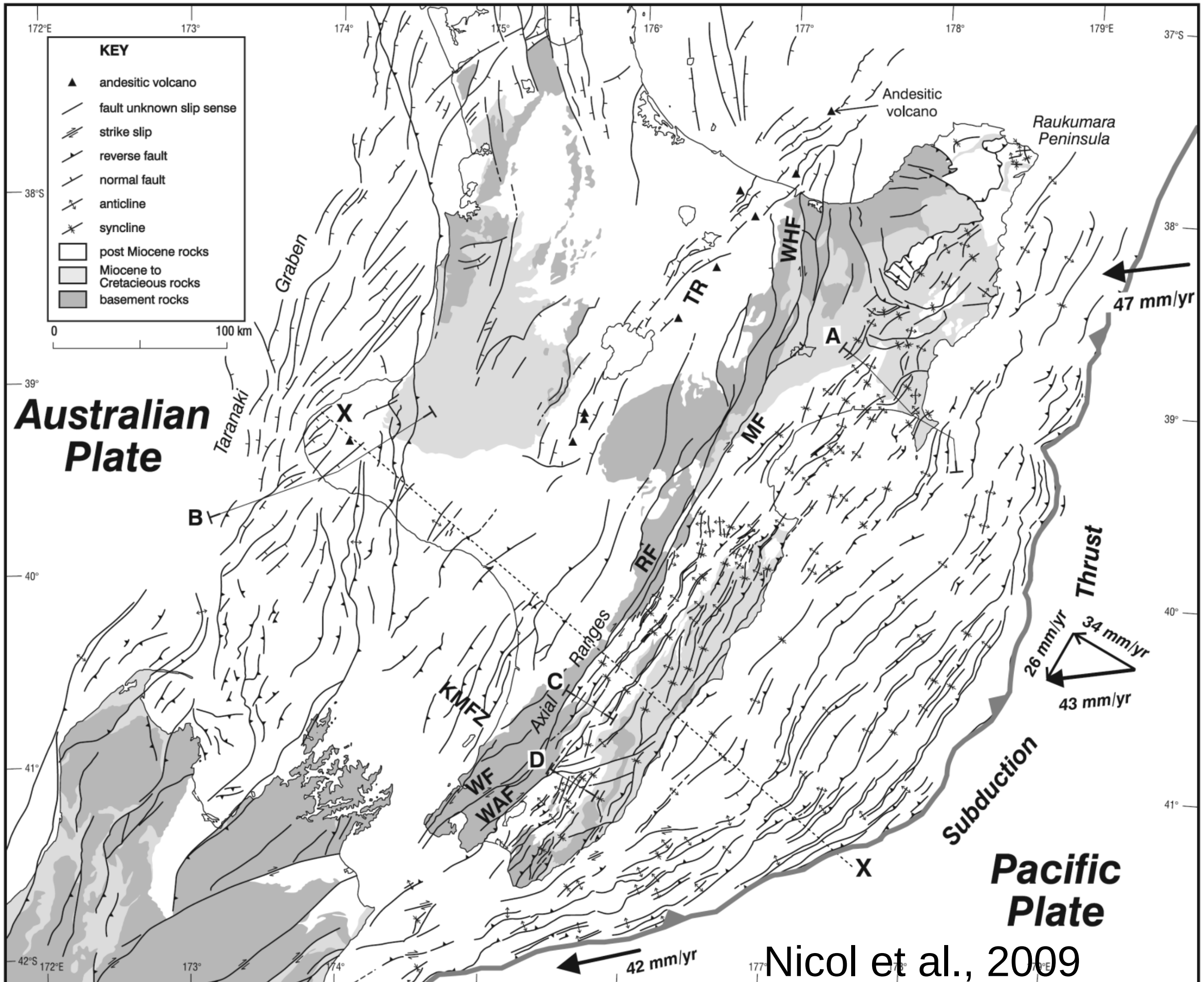


Seismic reflection lines from Barker et al., 2009 (G-cubed)

An oblique view of changes in margin characteristics

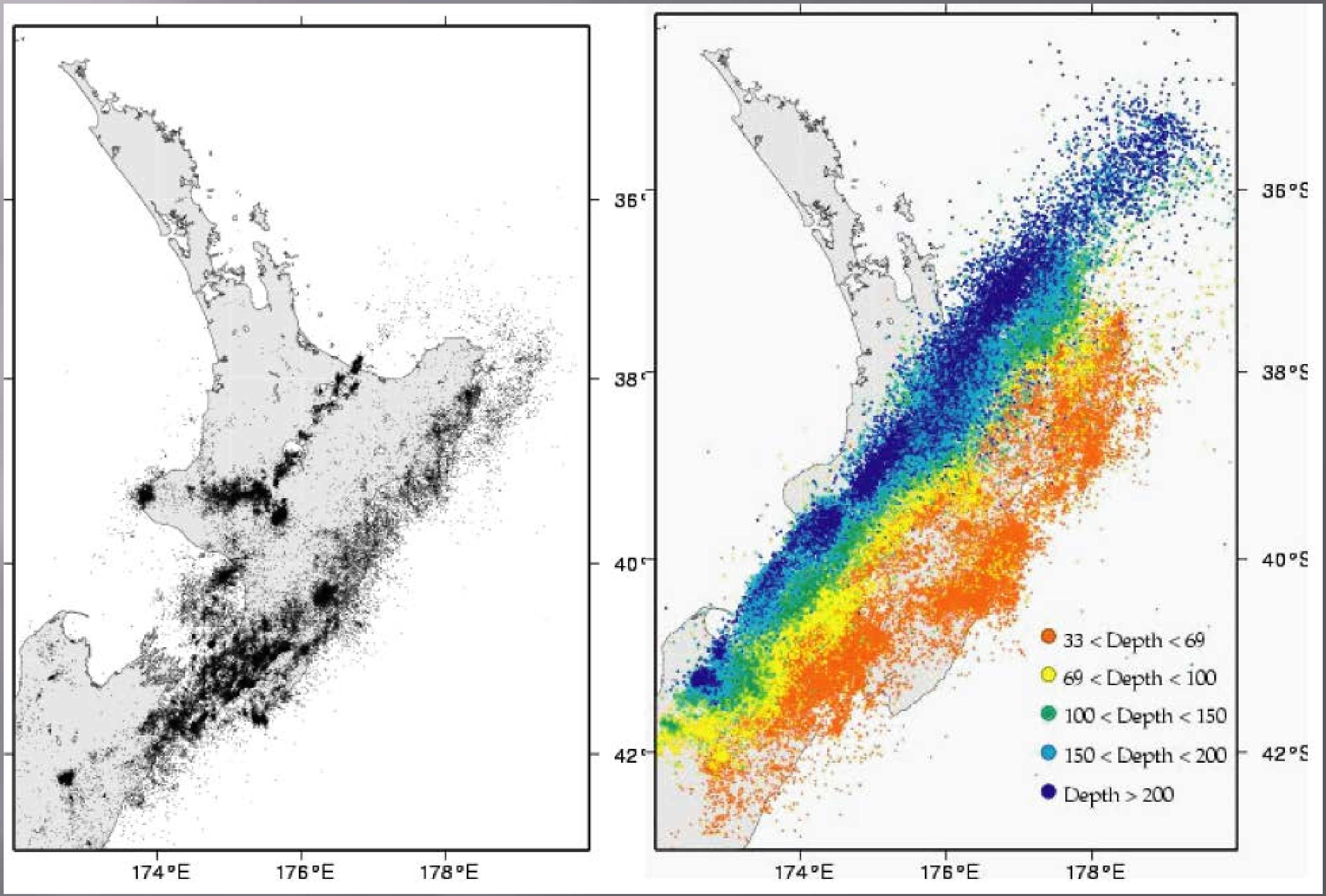


Complex onshore and offshore faulting



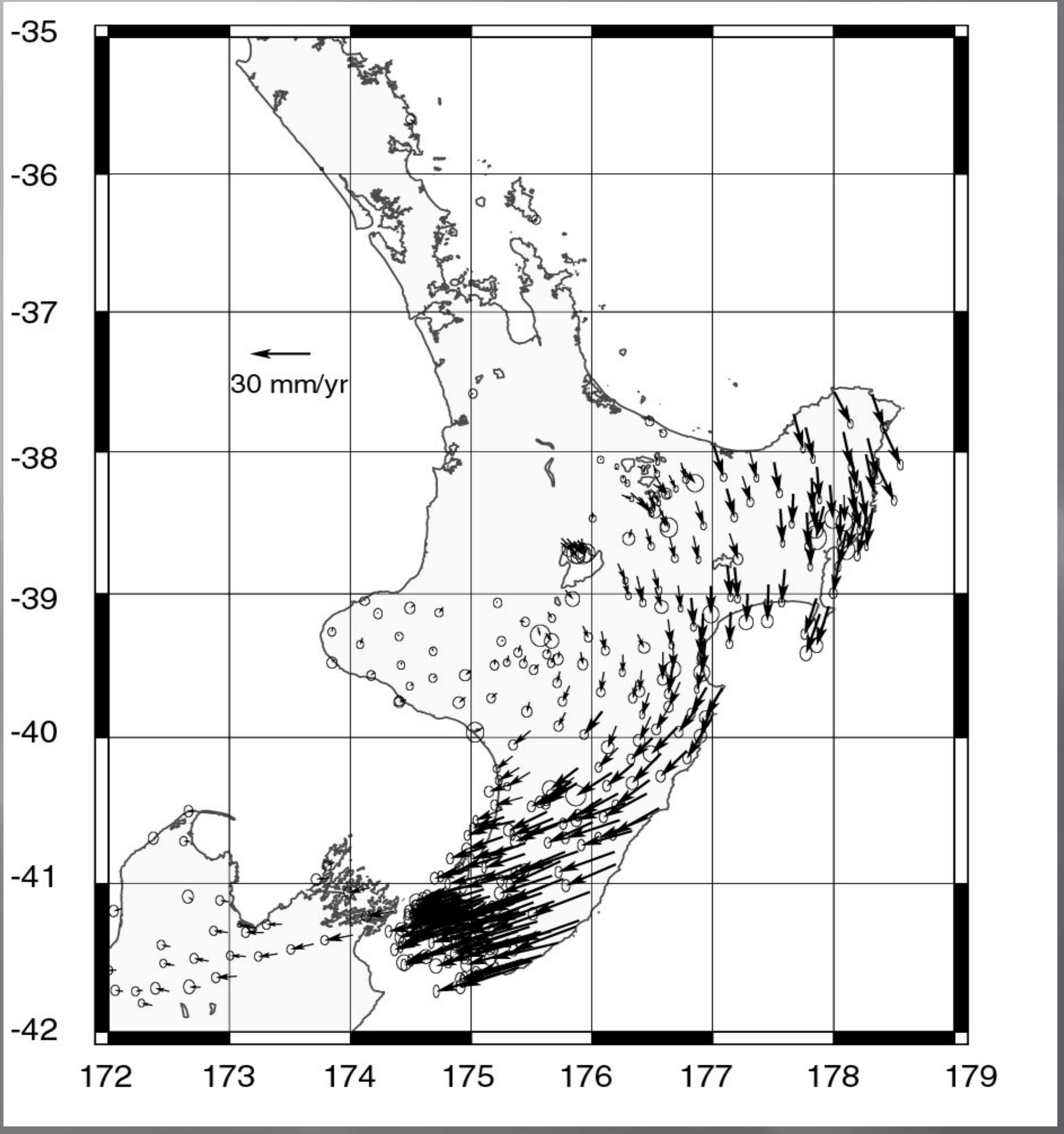
Nicol et al., 2009

Seismicity in the North Island (1990-2007)



Importantly, there have been no historical events on the subduction thrust > Mw 7.2

The GPS velocity field in the North Island

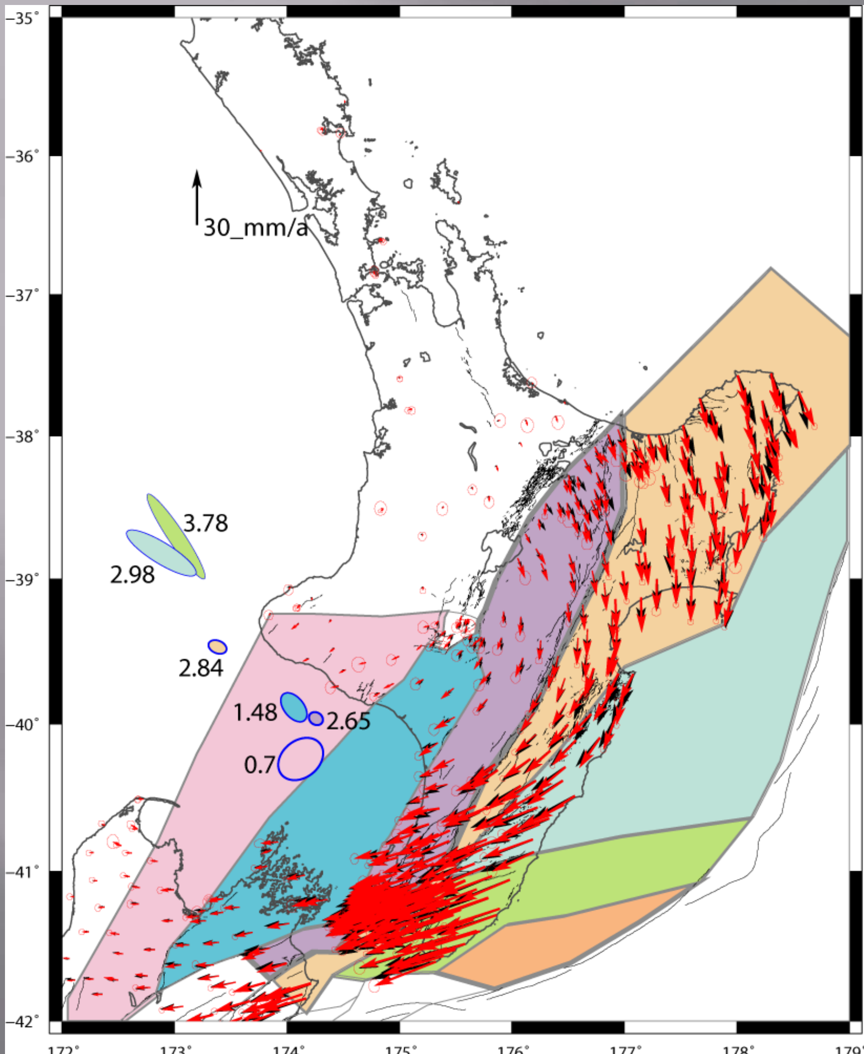


GPS velocities here are
a product of:

(1) long-term clockwise rotation of the eastern North Island (resulting in backarc rifting in the Taupo Volcanic Zone)
(2) Effects from interseismic coupling on faults, especially the subduction zone

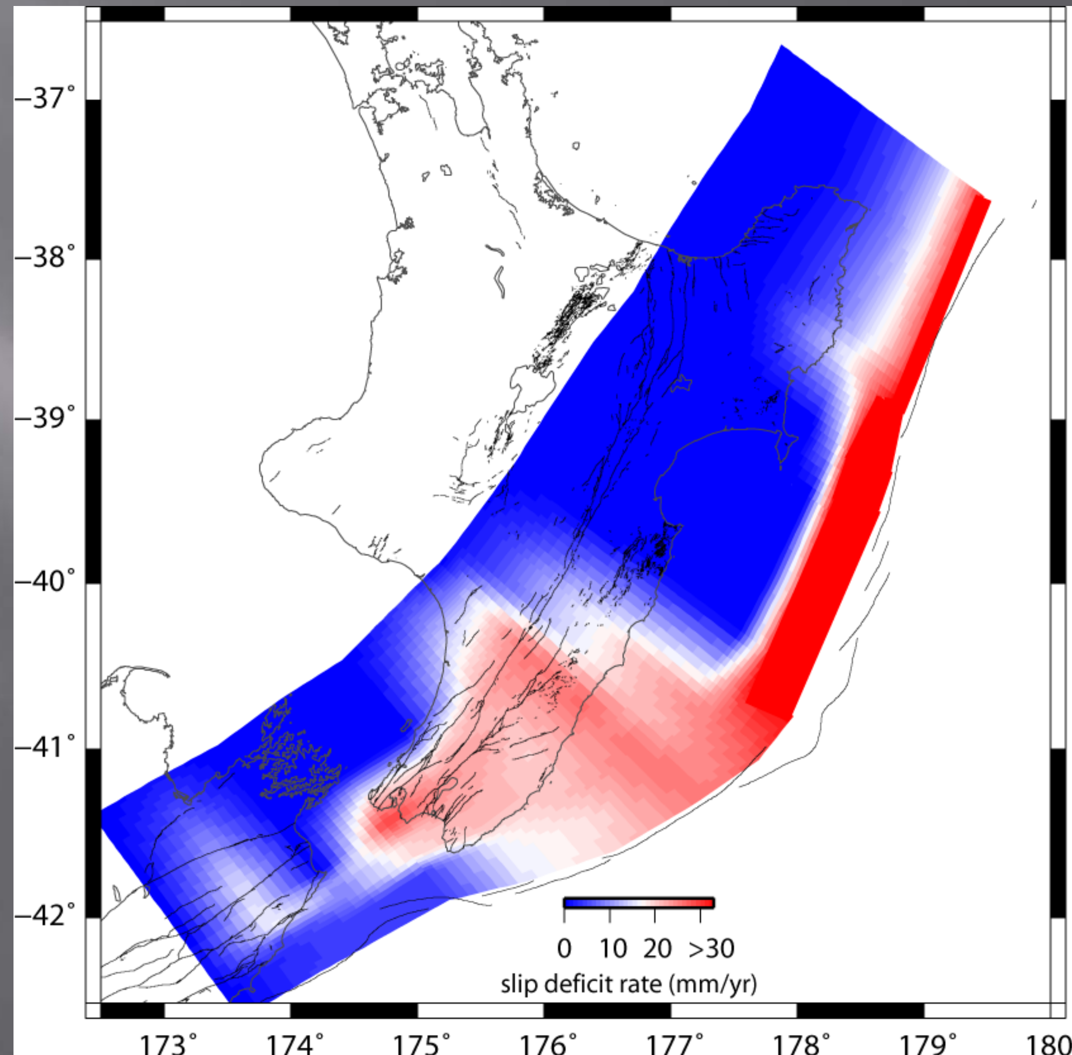
To interpret the GPS velocities in the North Island we use a block modeling method developed by Rob McCaffrey (DEFNODE) which simultaneously inverts for block rotations and interseismic fault coupling

Campaign GPS used to assess interseismic coupling on the subduction interface



GPS data also reflect long-term tectonic rotation of the forearc

Interseismic coupling (in terms of slip deficit rate)



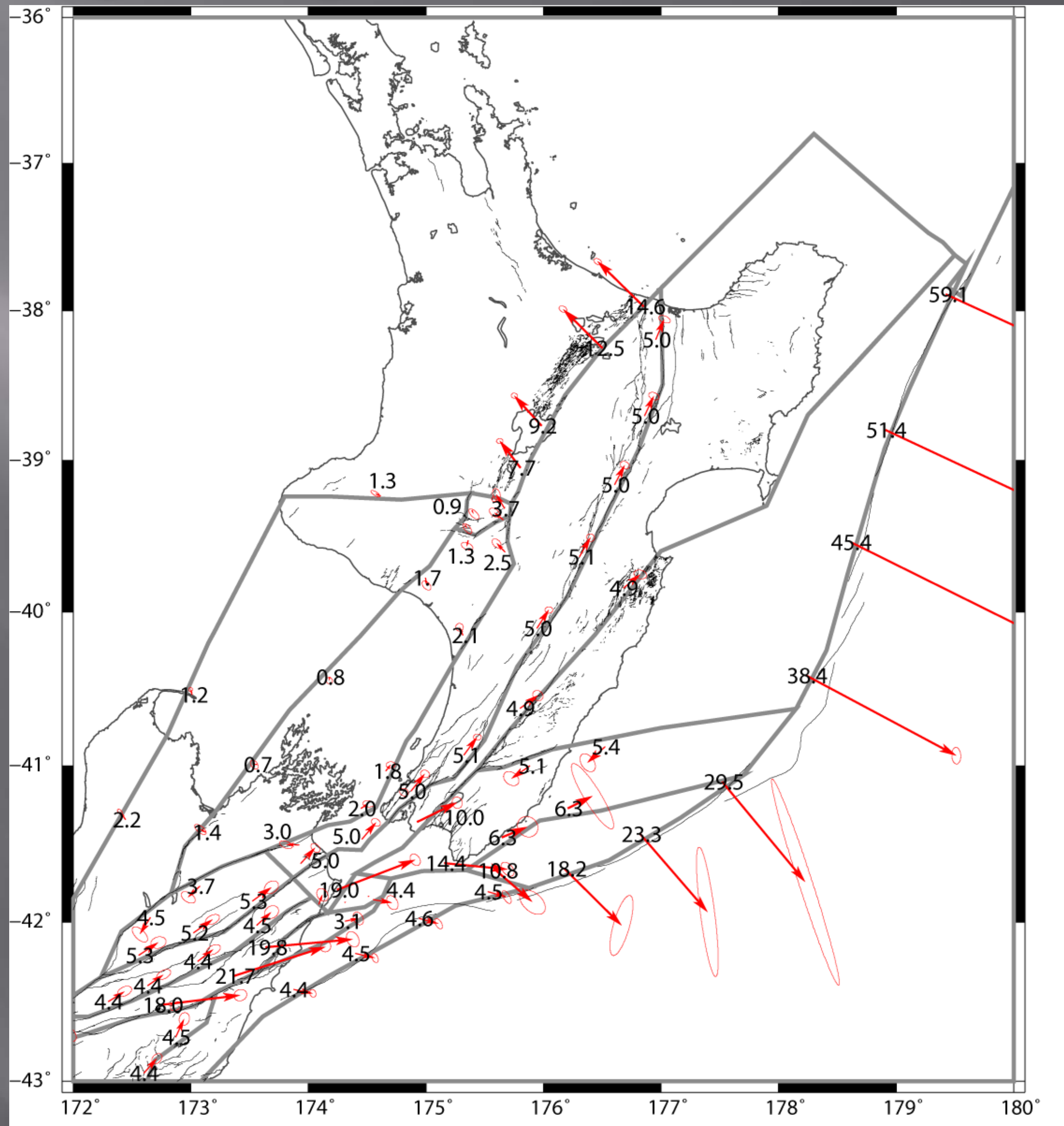
Wallace et al., 2004 (JGR)

Slip rates from GPS for upper plate faults agree well with geological studies

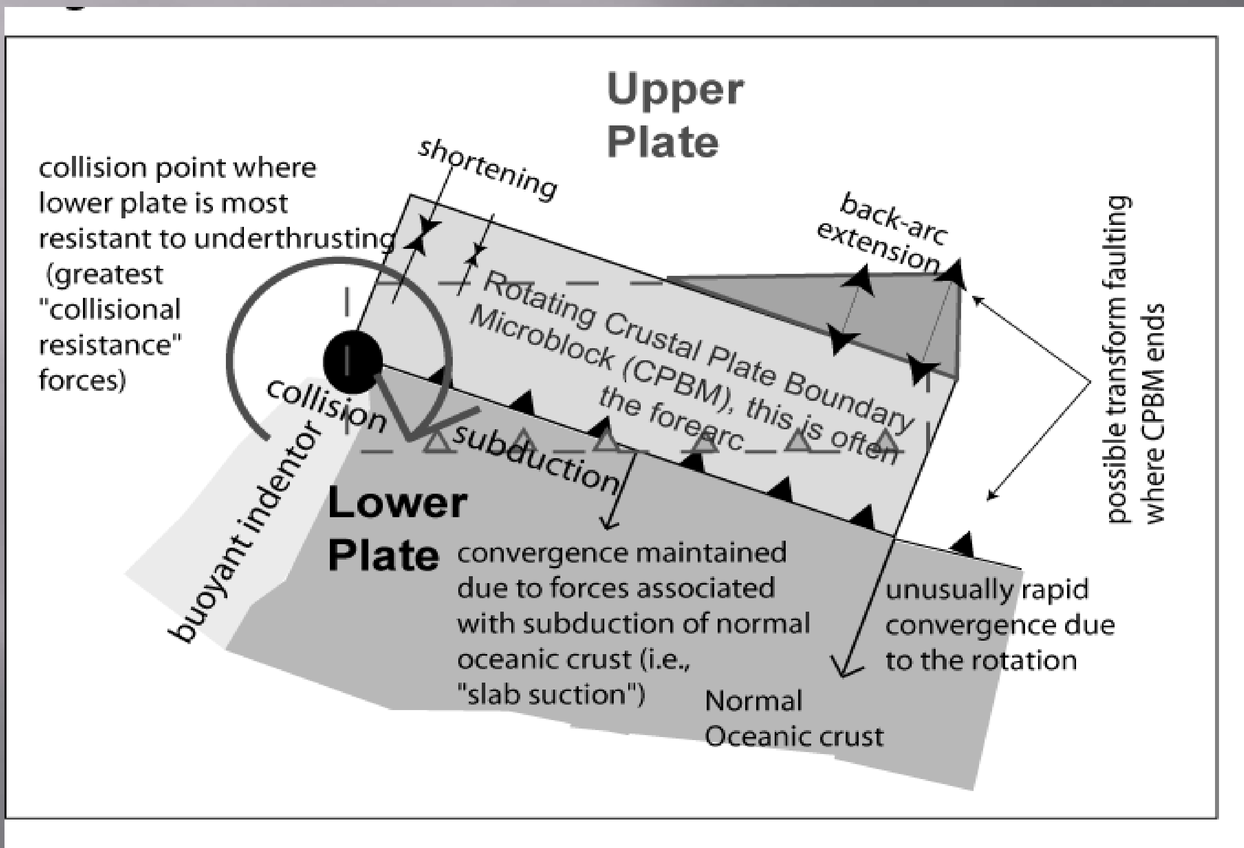
- Convergence rate at trench increases 3-fold along the margin, with ~20 mm/yr at the southern Hikurangi margin, and up to 60 mm/yr offshore the Raukumara peninsula. This is related to rapid tectonic rotation of the forearc.

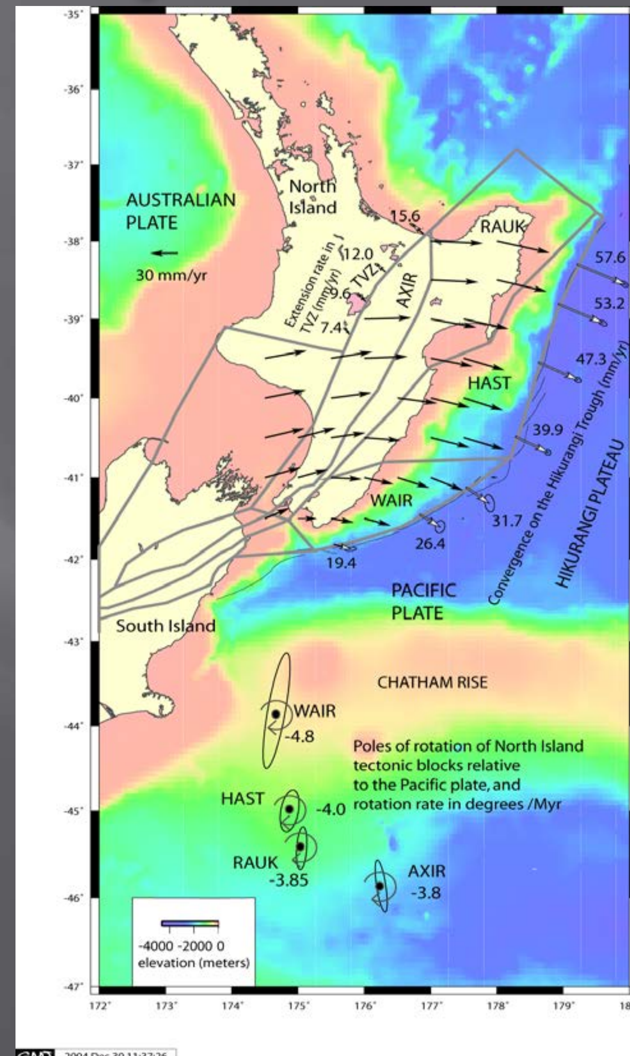
- The block model slip rates for the upper plate faults agree extremely well with geological studies

- Clockwise rotation of the forearc contributes substantially to the slip partitioning process



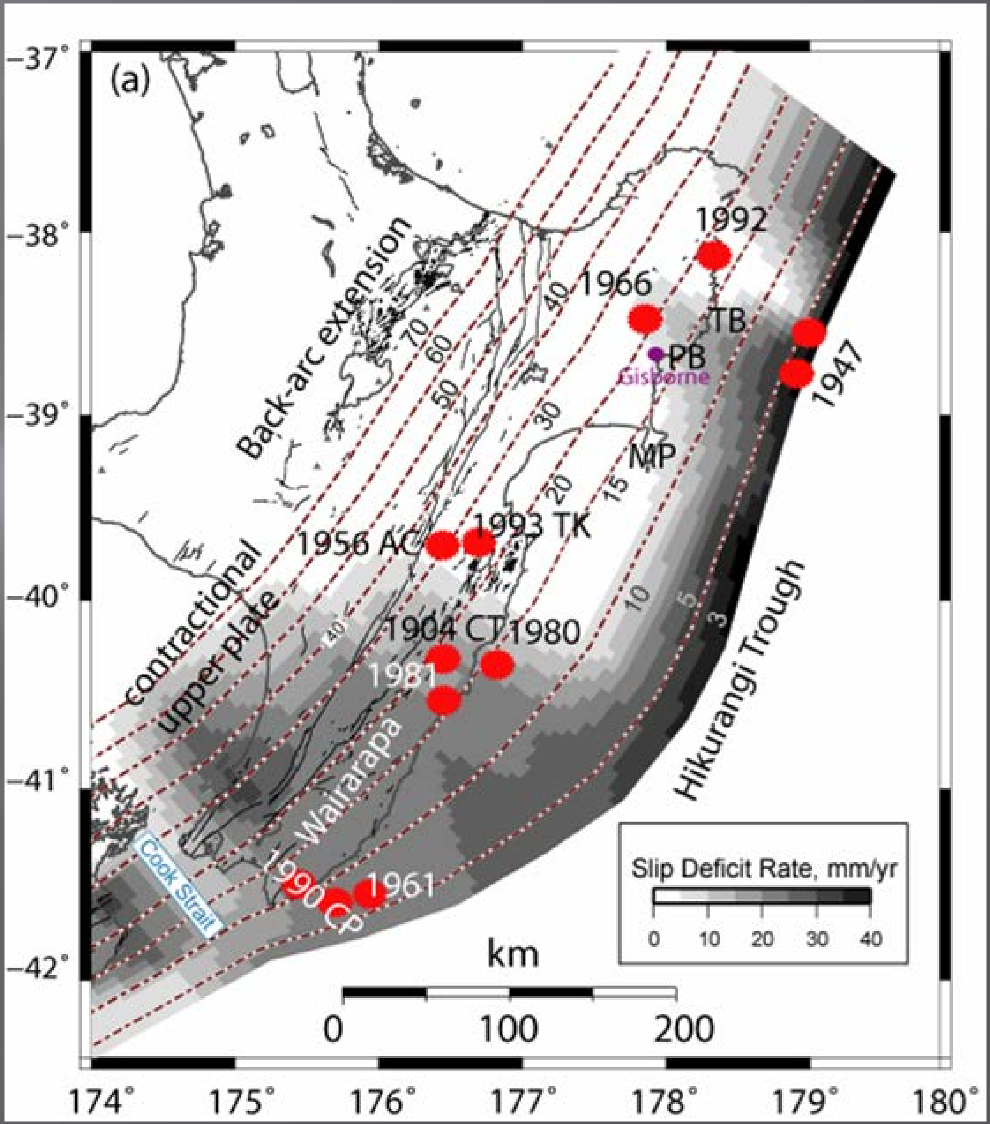
Why is the eastern North Island rotating so rapidly?





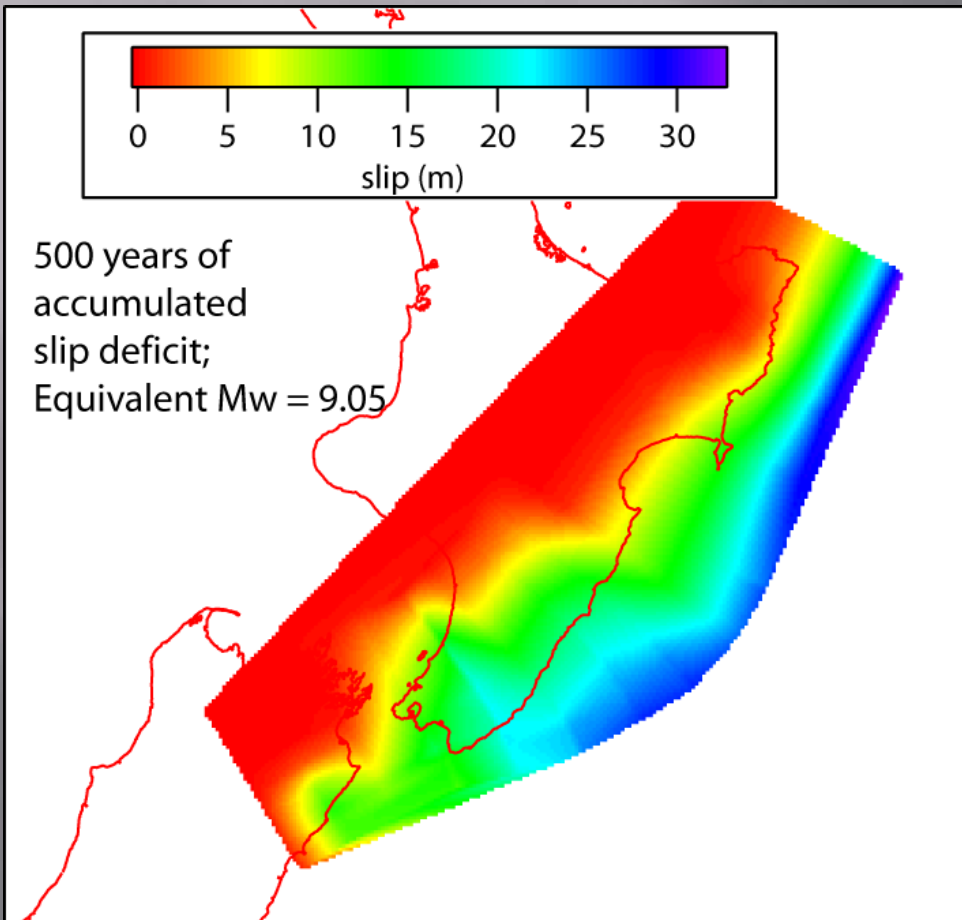
Historical earthquakes on the subduction interface

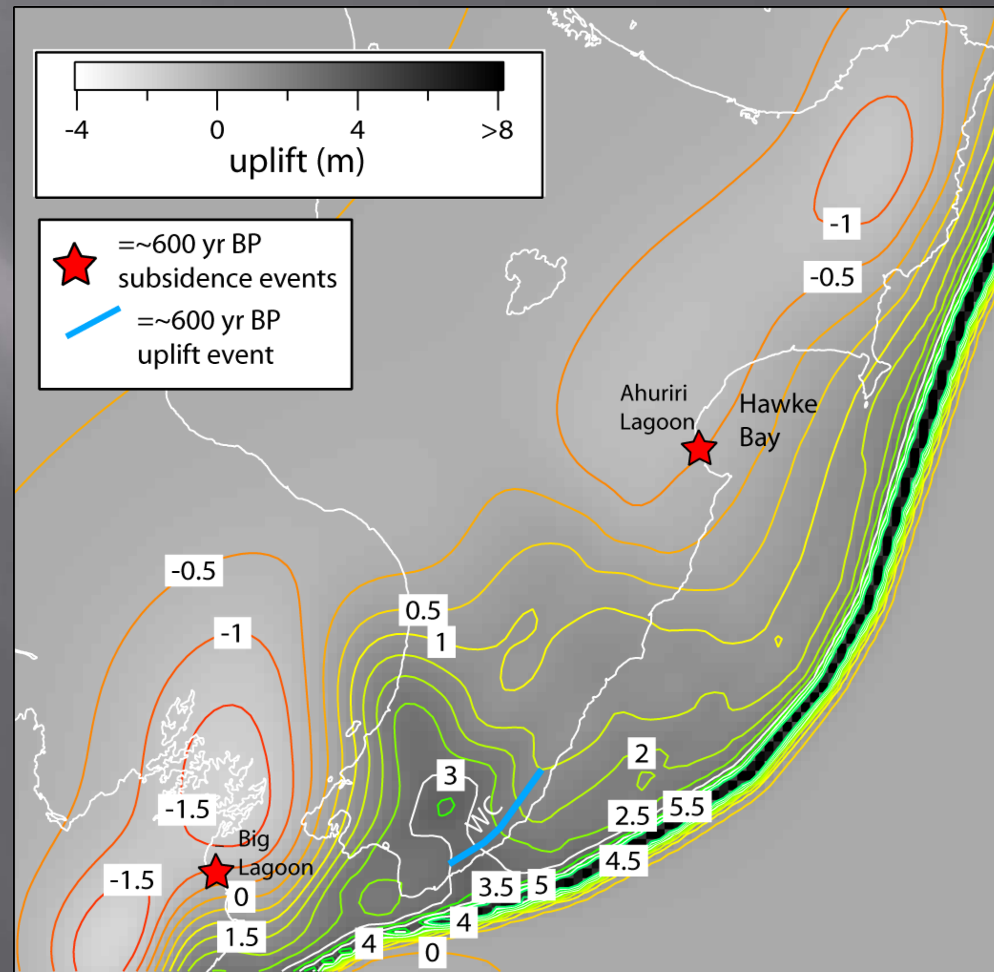
- No Great (Mw > 8.0) subduction thrust events have occurred on the Hikurangi interface in historical times (e.g., last 170 years)
- Moderate magnitude (Mw < 7.2) historical interface earthquakes occur on the edges of the strongly coupled portion of the interface, or in the region of weak, shallow interseismic coupling
- If the southern portion of the margin ruptures in events with 6-10 m of slip, it could produce Mw >8-8.5 events. BUT, we have NO idea if such events occur here.
- If the whole margin goes in a single event, we could be looking at Mw > 9.0



Possible paleoseismic evidence for rupture of much of the Hikurangi margin ~600 years ago?

600 yr BP subsidence event in Big Lagoon correlates with ~600 yr BP uplift event along the Wairarapa coast (Berryman et al., 2011) & subsidence event in Ahuriri Lagoon (Hawkes Bay; Hayward et al., 2006)



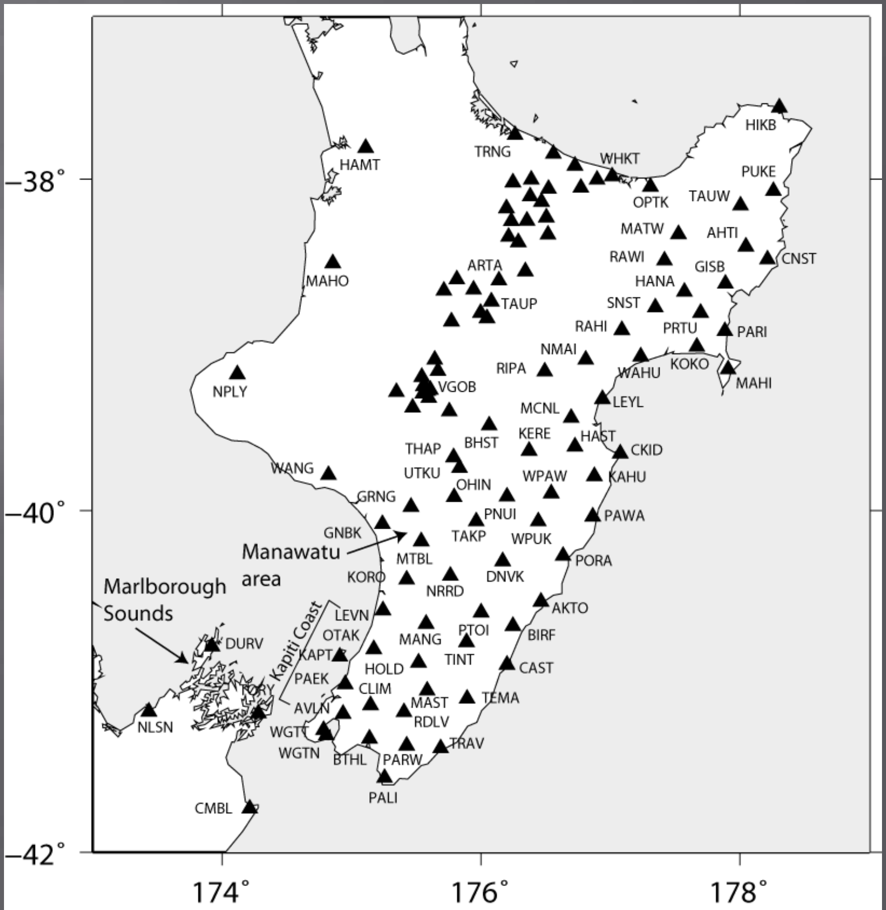


Kate Clark et al., in prep.

Operational continuous GPS sites: NZ GeoNet, www.geonet.org.nz

Since 2002, we have observed ~20 distinct slow slip events at CGPS sites in the North Island

Current CGPS network configuration

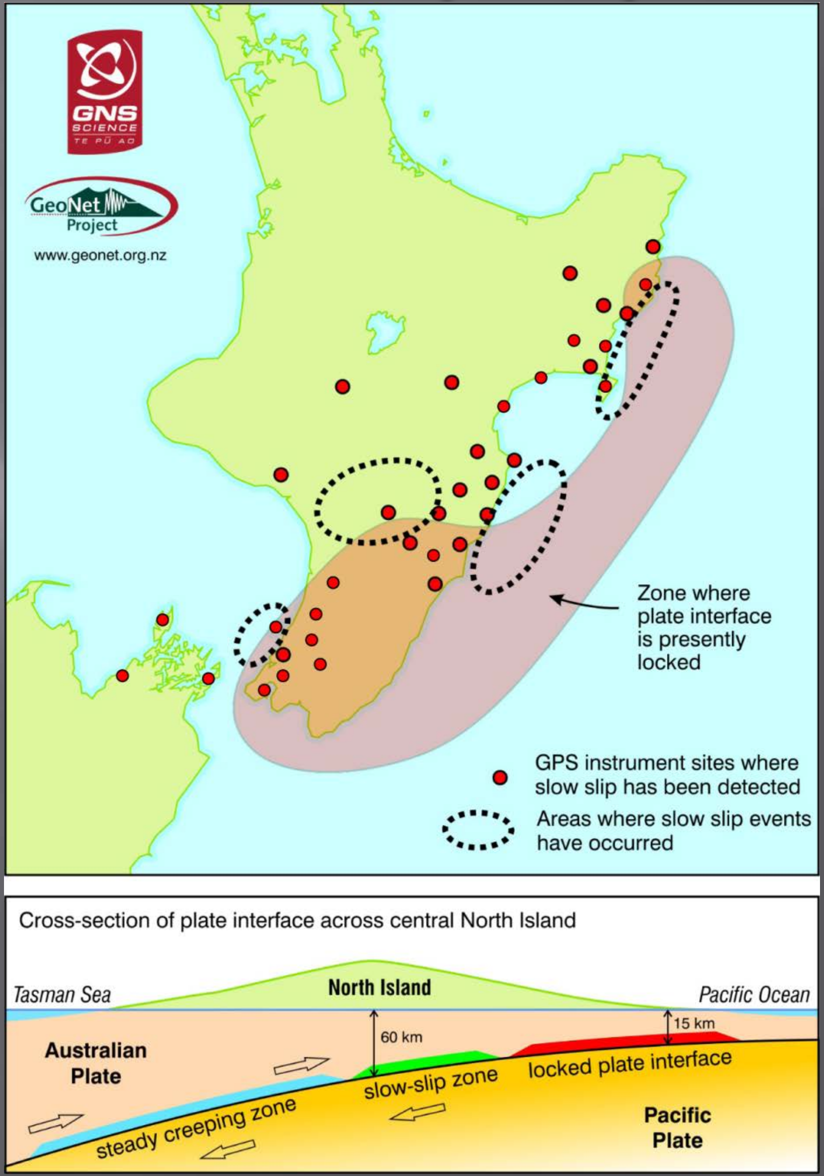


Slow slip events on the subduction interface beneath the North Island—they give insight into subduction earthquake potential

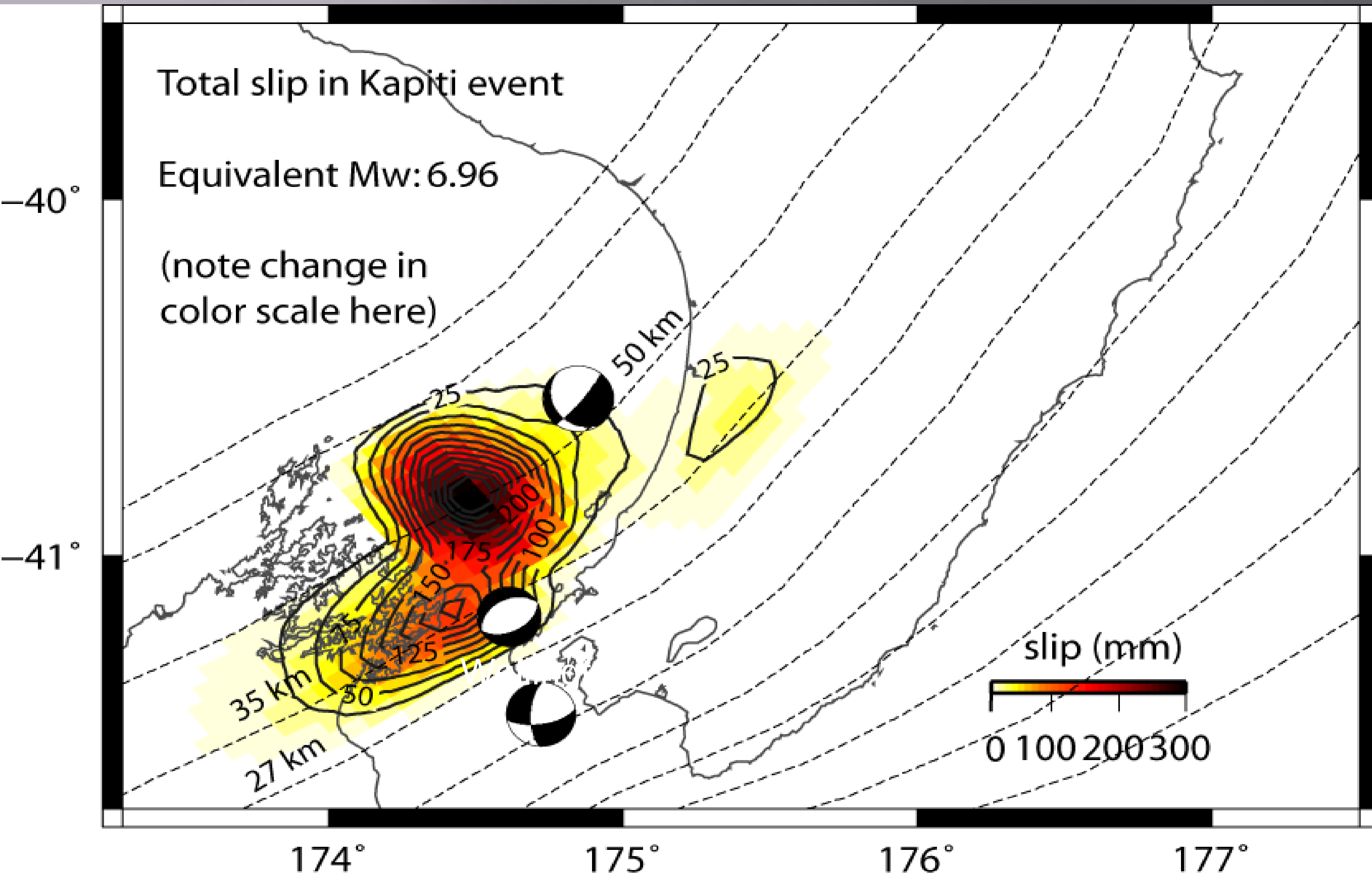
- We have observed more than twenty distinct slow slip events in four different parts of the North Island

- Worldwide, slow slip events are observed to occur at the transition zone between "coupled" and "creeping" portions of the interface

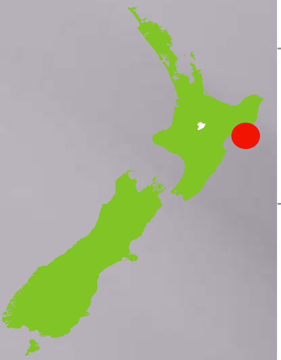
- Slow slip events have also been documented at subduction margins in Japan, northwest U.S and western Canada, Mexico, and Costa Rica

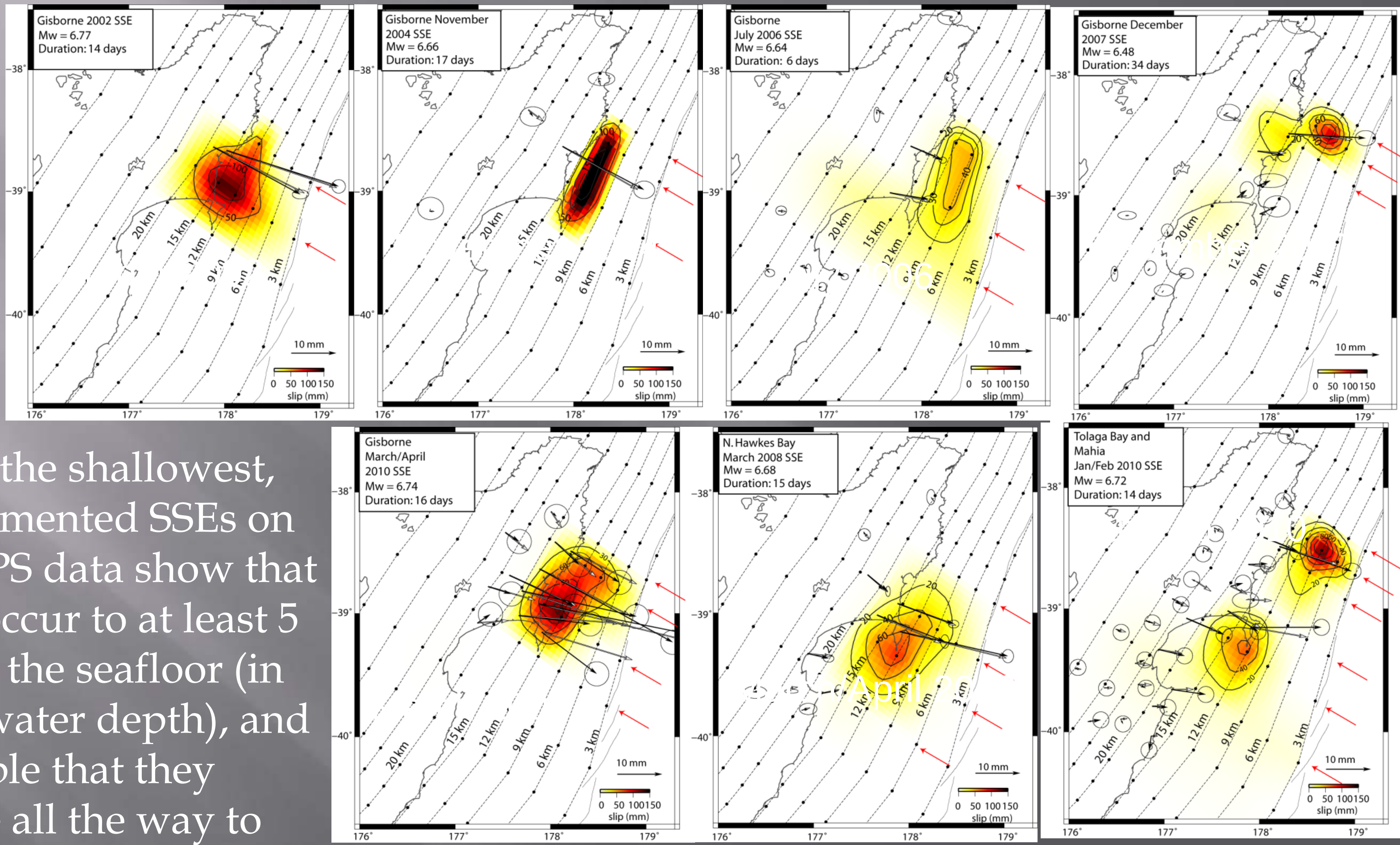


Kapiti 2008 SSE lasted ~15 months, was equivalent to an Mw 7.0, and may have involved slip on the interface up to 35-40 cm



Shallow slow slip events (<5-15 km depth) on the subduction thrust at northern Hikurangi repeat every 1.5-2 years, and last for 1-2 weeks

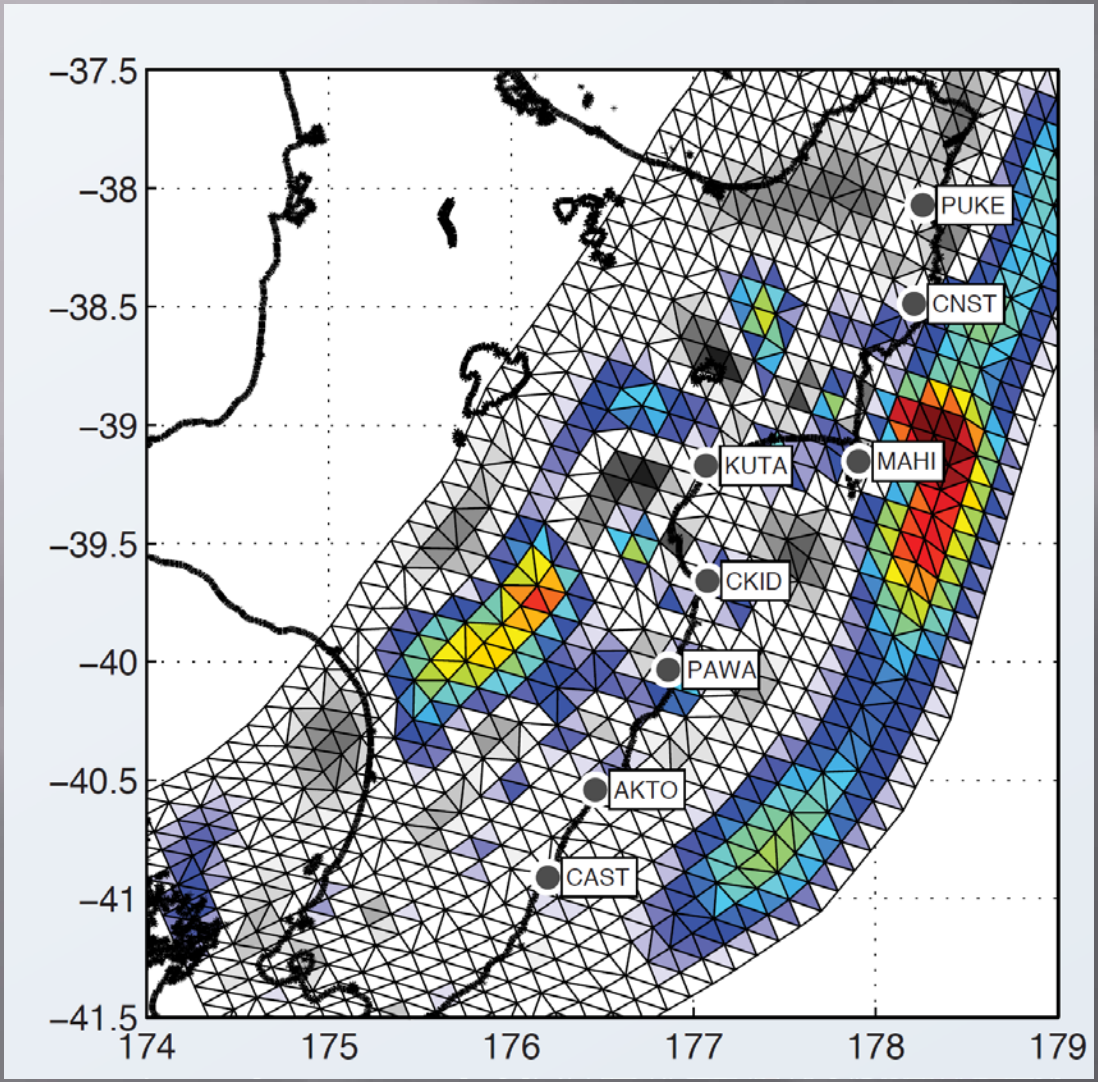




These are the shallowest, well-documented SSEs on Earth. cGPS data show that the SSEs occur to at least 5 km below the seafloor (in ~1000 m water depth), and it is possible that they propagate all the way to the trench

Wallace and Beavan, 2010, JGR

Total SSE slip in 2010-2011 period, during a complex sequence of short- and long-term SSEs



Bartlow et al., in prep.

Key features include:
The sequence released moment equivalent to an Mw >7.0

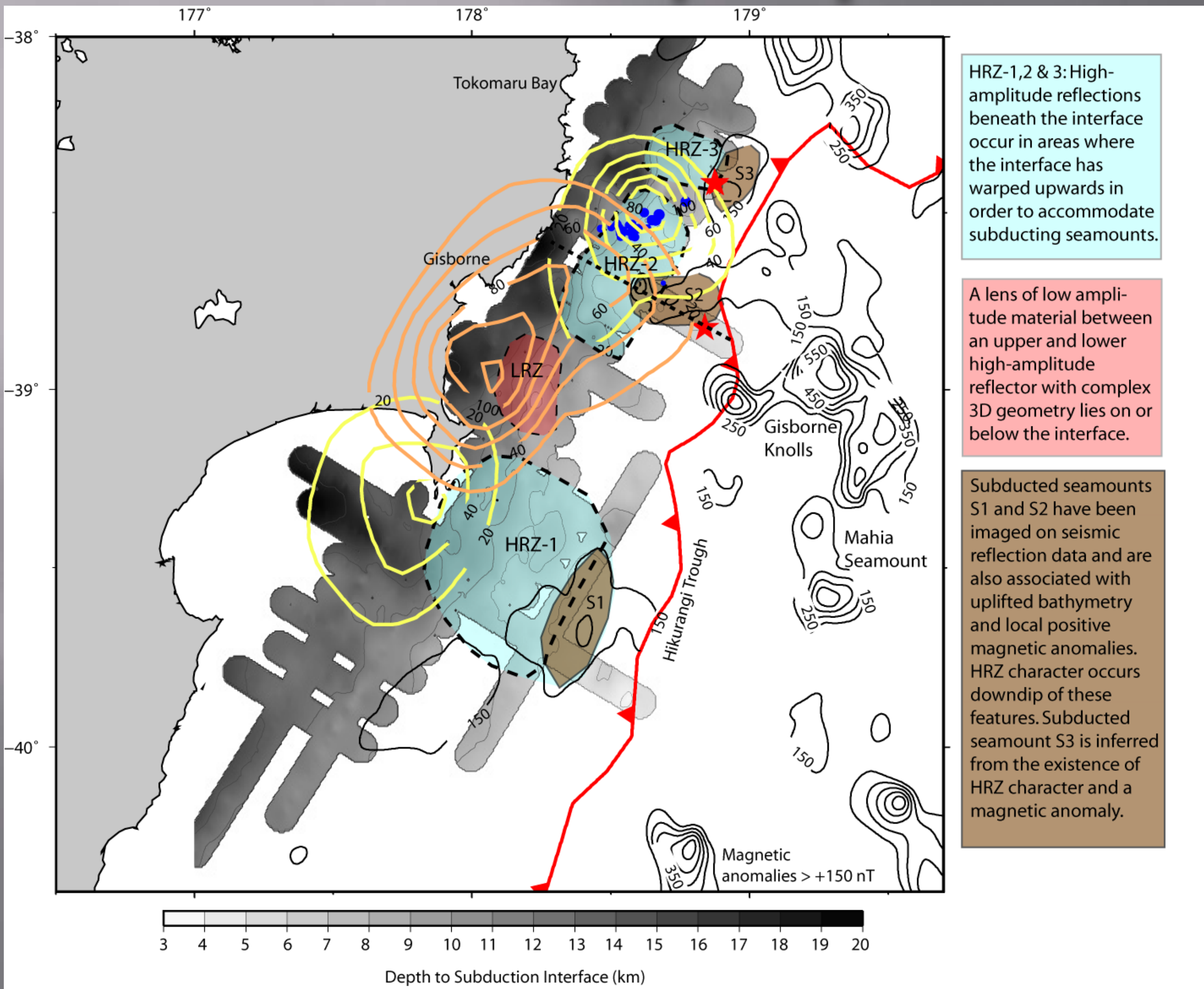
A huge depth range (<10-60 km) of the central Hikurangi interface slipped during the SSE sequence

Most of the shallow interface along the east coast ruptured in this event.

Slow slip was patchy along the margin. What controls this patchiness? This was also seen in a 2010 sequence near Gisborne

See also poster by Noel Bartlow, this meeting, and Wallace et al., 2012, JGR

Evolution of the 2010 and 2011 SSE sequences are related to interface properties?

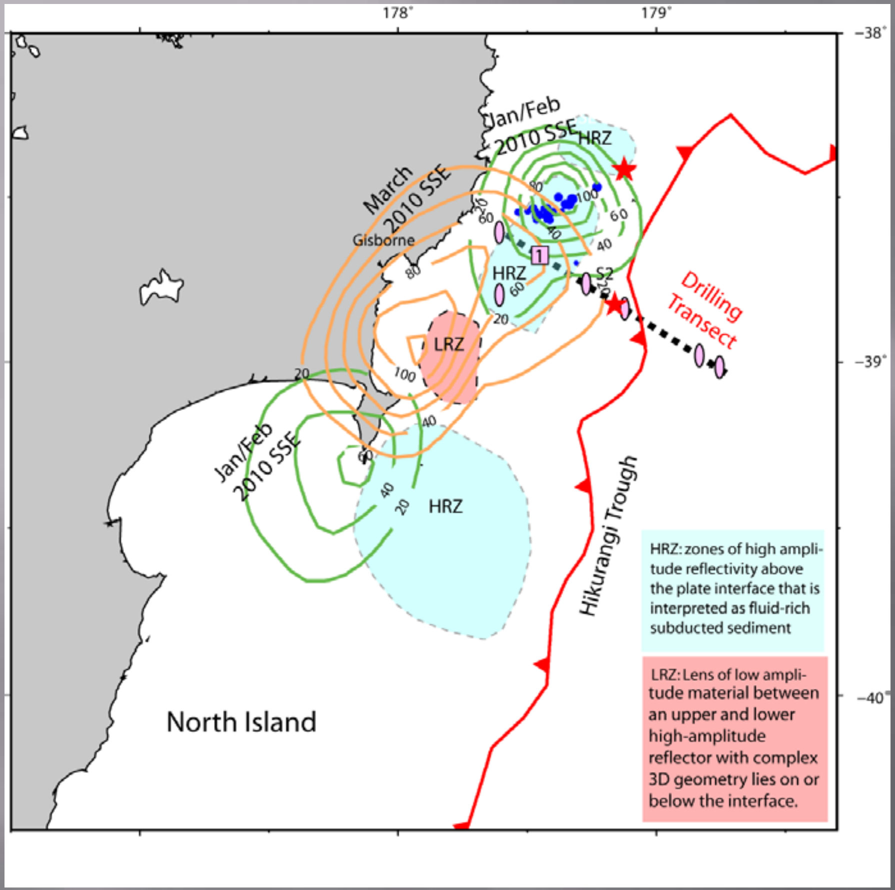


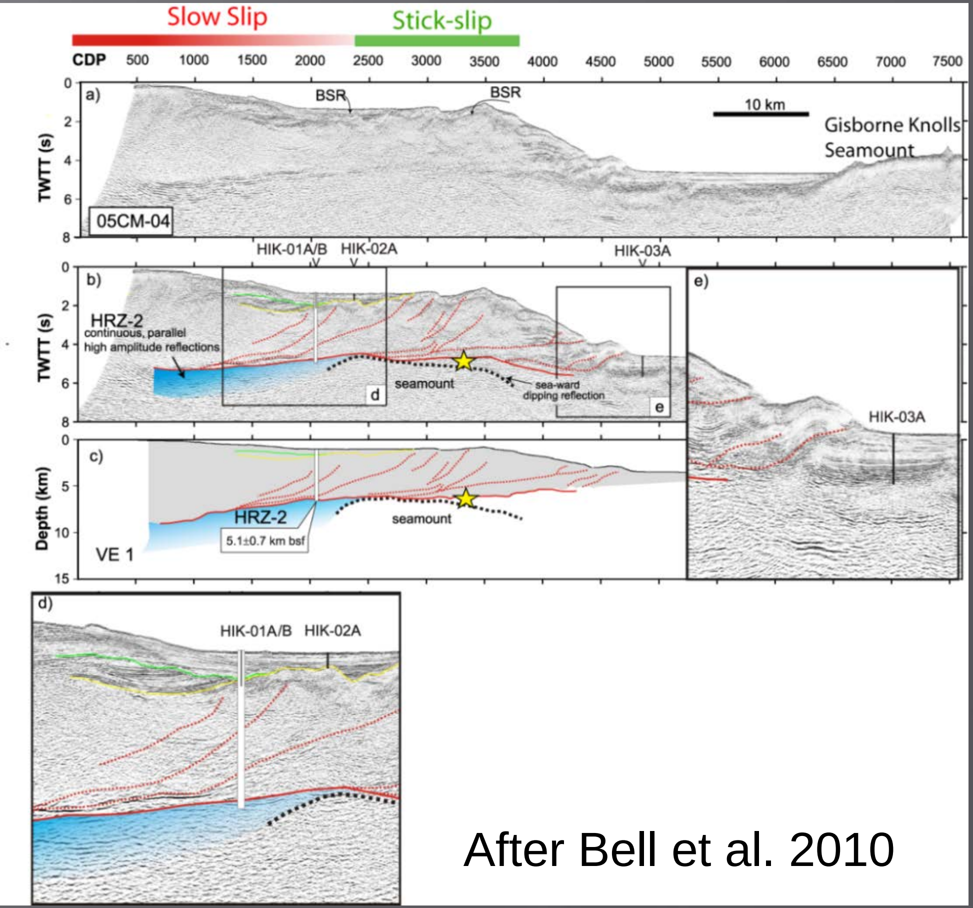
Interface properties from Bell et al. (2010)

Two recent sets of SSEs have an interesting correlation with the highly reflective zone during the first stage, and the low amplitude reflectivity zone in the second stage

If the HRZ is a region of higher fluid pressures, this could explain the initiation of the SSE in the HRZ region (less resistance to slip), and then subsequent migration of slip into the intervening low reflectivity region (possibly due to static stress triggering)

North Hikurangi slow slip events are associated with a zone of high-amplitude reflectivity at the interface, which may indicate abundant fluids at the SSE source



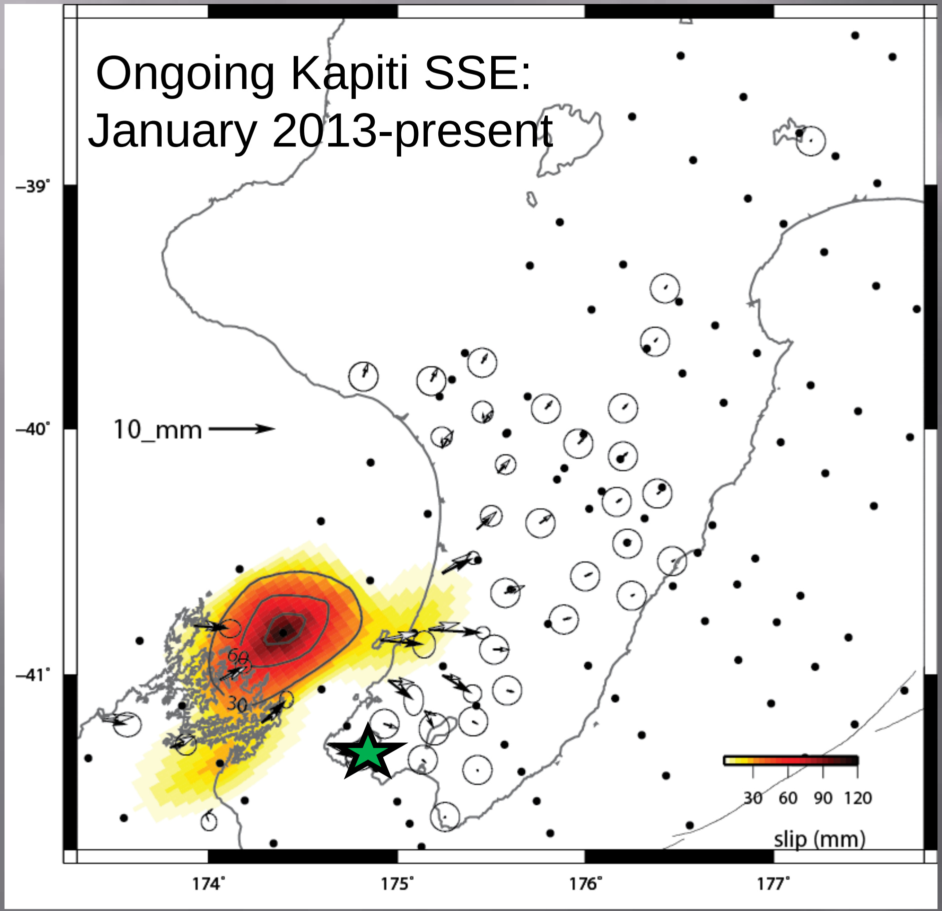


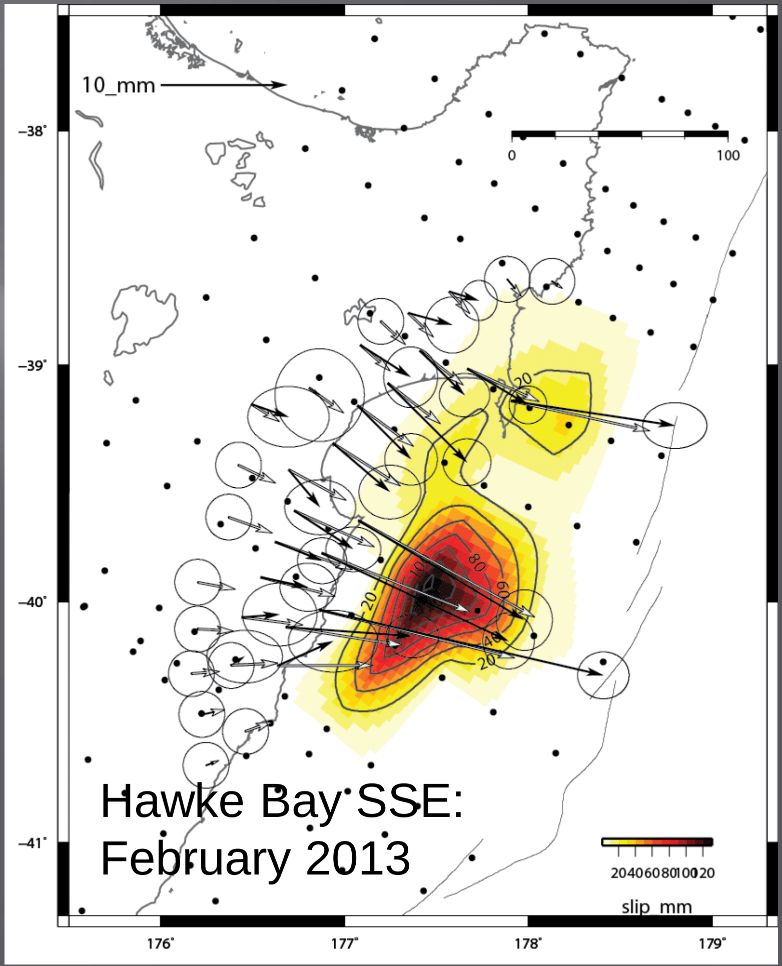
The high amplitude zone and the SSE source is the drilling target (~5 km below the seafloor, in 1 km water depth). After submitting a preproposal on the project in 2010, SSEP requested that we develop the project into a Multi-phase drilling project. We submitted the MDP and the proposal for the riserless drilling phase (781A-Full) in October 2011. The proposal for the riser phase (to intersect the source of SSEs at ~5 km bsf) was submitted on April 1, 2013.

Two major SSEs have occurred so far this year (2013)

(1) The deep, long-term Kapiti SSE (west of Wellington) has started back up since January (the last occurrence was in 2008) . Equivalent Mw so far ~6.8

(2) A large, shallow east coast SSE beneath Hawkes Bay in February: equivalent Mw ~ 6.8

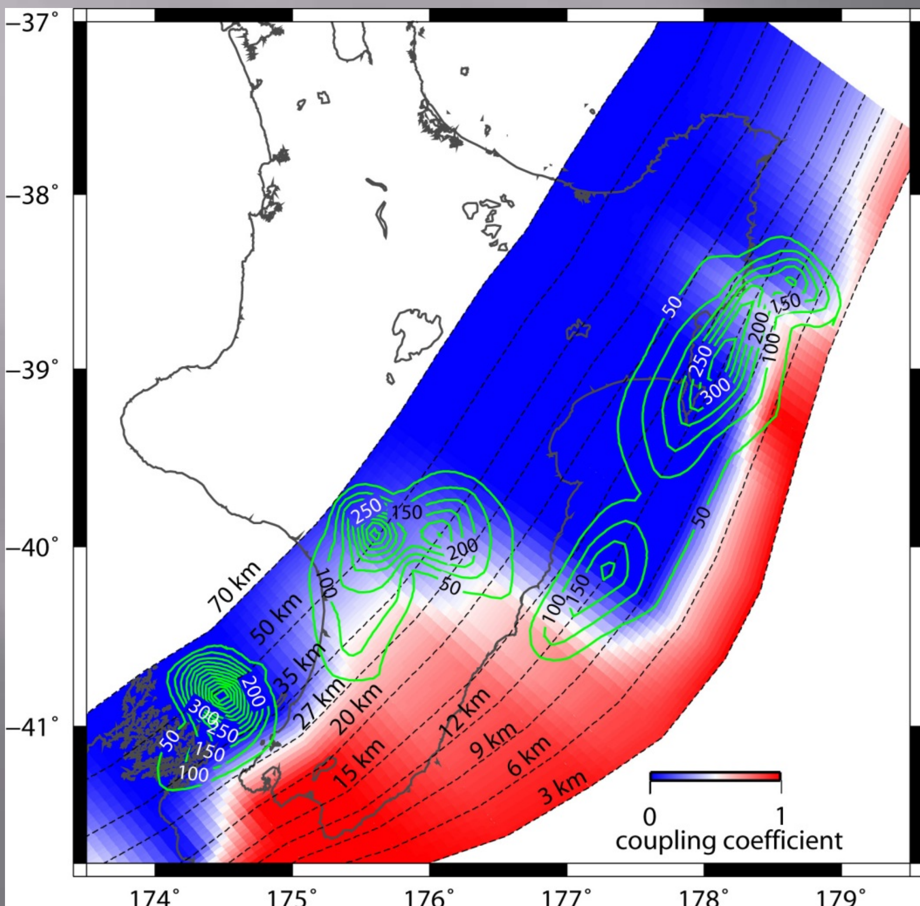


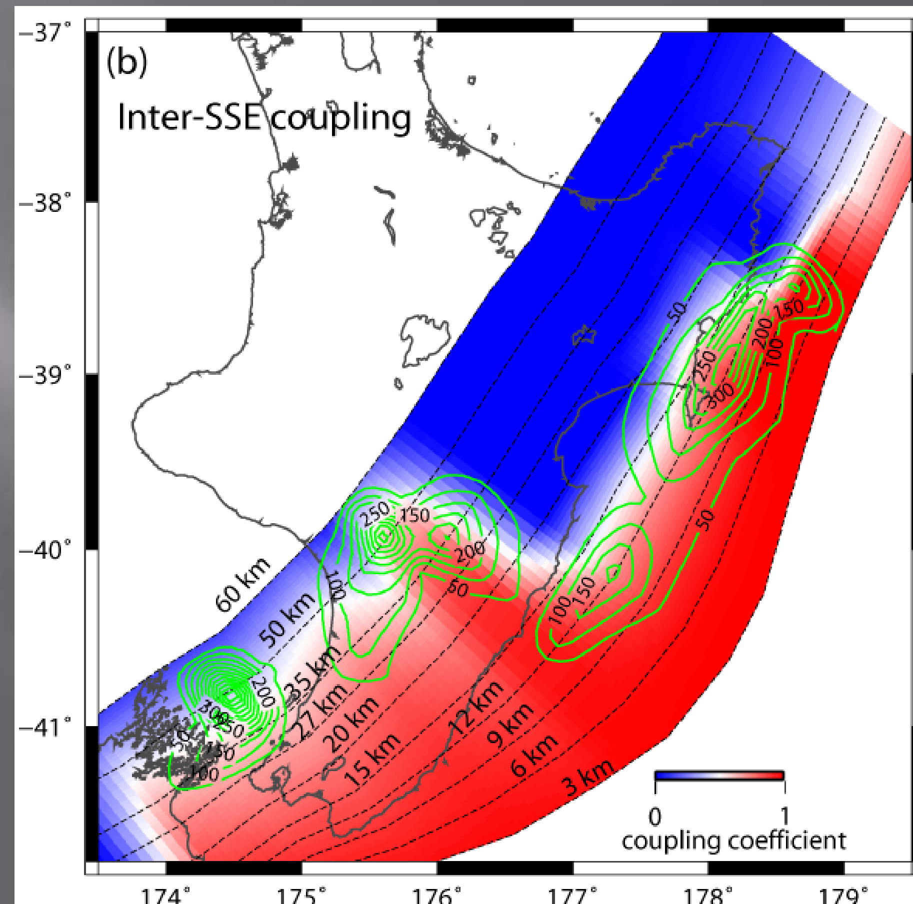


Relationship of SSEs to interseismic coupling at the Hikurangi margin

Green contours show total slip on the interface in SSEs since 2002

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

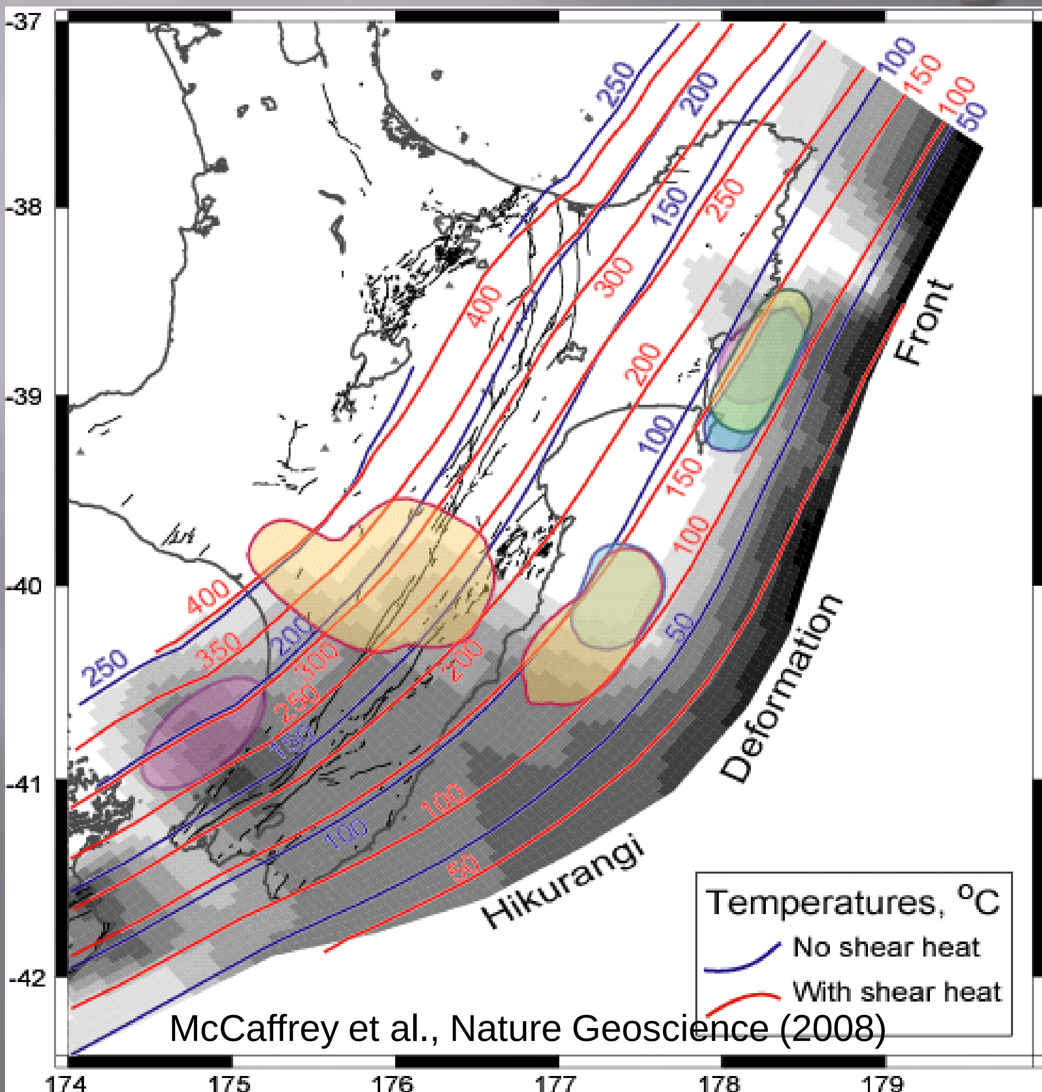




Wallace and Beavan, 2010, JGR

Interseismic coupling using "inter-SSE" velocities from the continuous GPS network

What controls the seismogenic zone geometry and location of slow slip at the Hikurangi margin?



McCaffrey et al., Nature Geoscience (2008)

Hikurangi interseismic coupling distribution (and SSE locations) CANNOT follow a simple temperature-based model, due to along-strike changes we observe in the depth to the down-dip limit of coupling and SSEs

What parameters might control the abrupt change in depth of the down-dip limit of the seismogenic zone that we observe?

There are a number of margin characteristics that vary in concert with megathrust behavior

These include:

(1) a shift from an accretionary to erosional offshore margin

(2) A northward increase in thickness of sediment on the incoming plate

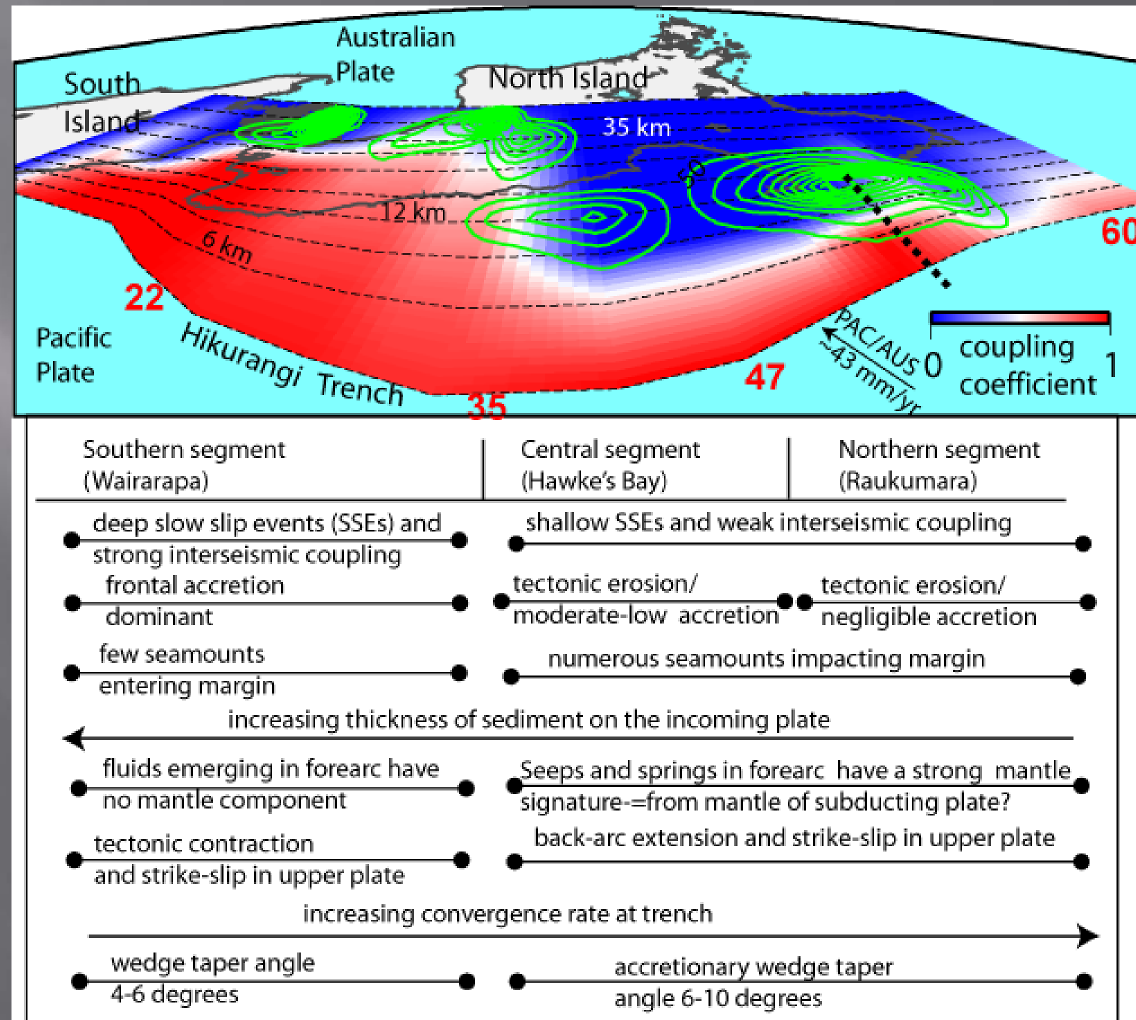
(3) A larger number of seamounts protruding above the sedimentary cover in the north vs. south

(4) An along-strike change from back-arc rifting to upper plate contraction

(5) Major change in the geochemistry and volume of fluids emerging at the onshore forearc

(6) Northward increase in convergence rate

(7) Change in Vp/Vs and Qp in the upper plate and near the interface



How do these characteristics influence the along-strike variations in megathrust behavior?

To Conclude:

- The Hikurangi margin has a number of striking along-strike variations in subduction margin characteristics

- Interpretation of campaign GPS velocities reveals that interseismic coupling is deeper beneath the southern North Island compared to further north

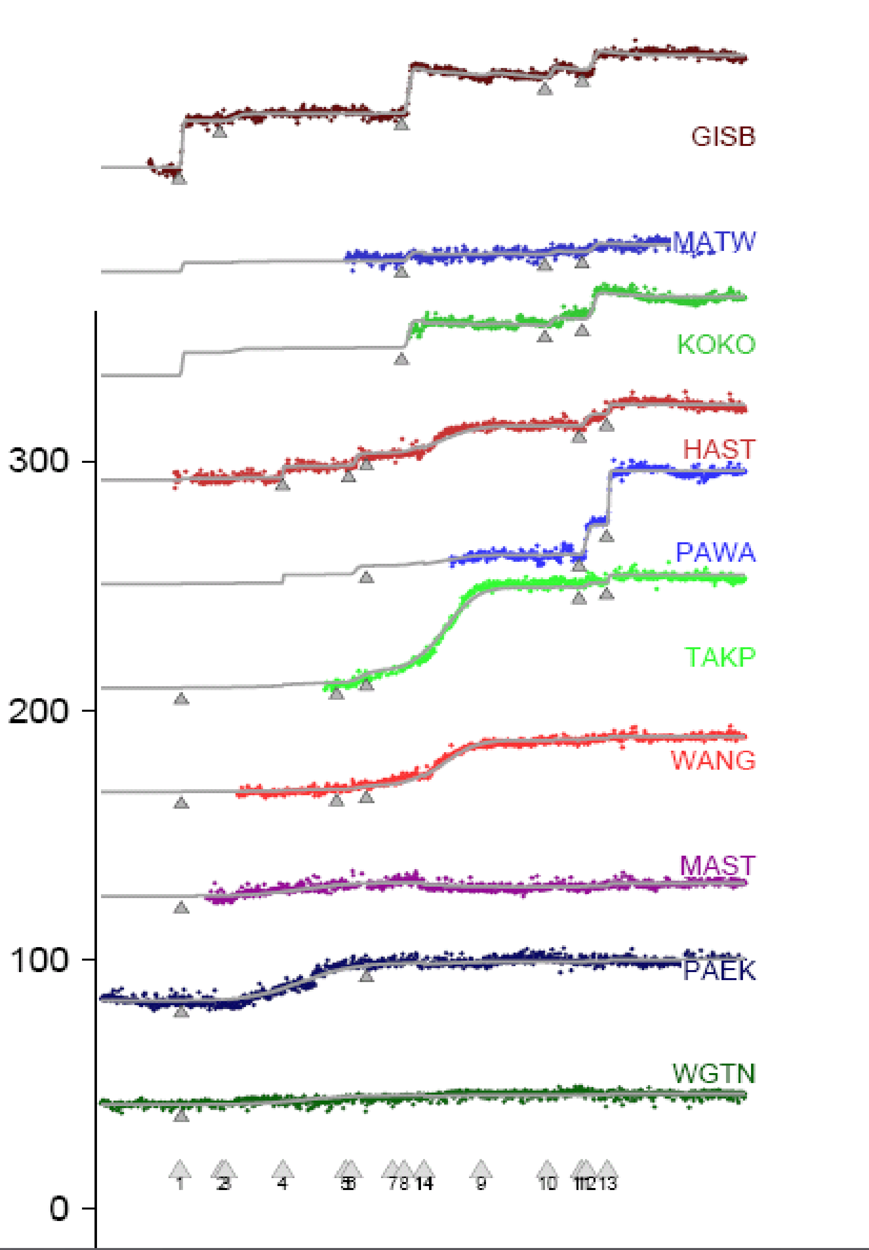
- Numerous slow slip events have been observed at the down-dip limit of interseismic coupling since 2002, with widely varying durations, sizes, and recurrence intervals, and account for a major component (~40%) of the moment release budget of the Hikurangi subduction margin

- New Zealand has a very short historical record, so we do not know if Great subduction thrust events have occurred at the Hikurangi subduction margin in the past, but GPS and preliminary paleoseismological studies suggest that they probably have

- Unlike what is assumed to be the case for other subduction margins, temperature cannot be the primary factor controlling interseismic coupling and slow slip events at the Hikurangi margin. It is likely that other processes (such as fluids, regional tectonic stresses) play a bigger role.

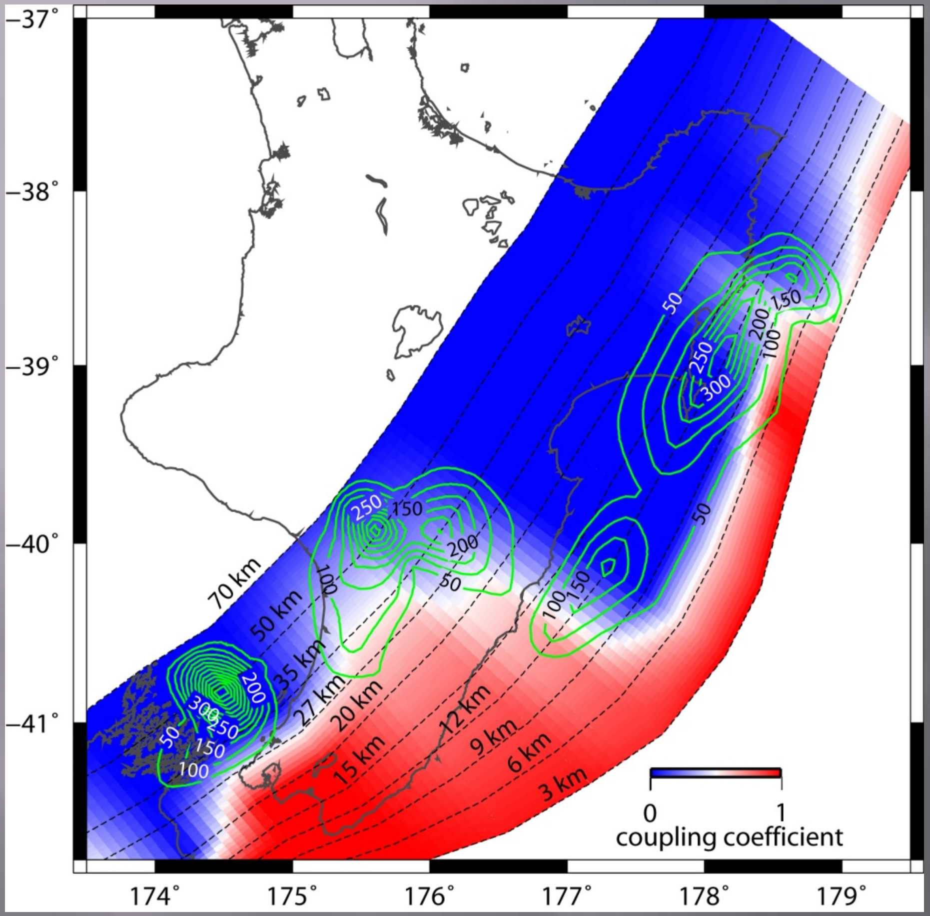
Examples of slow slip events in the cGPS timeseries

- Panel shows east component of selected stations, as measured each day by cGPS
- Traces "detrended" so that the westward inter-event motion is represented by a horizontal line
- Up to 20 SSEs, with at least half of these having displacements of 10 mm or more at the ground surface
- Short-term (days to weeks); and longer-term (many months) SSEs

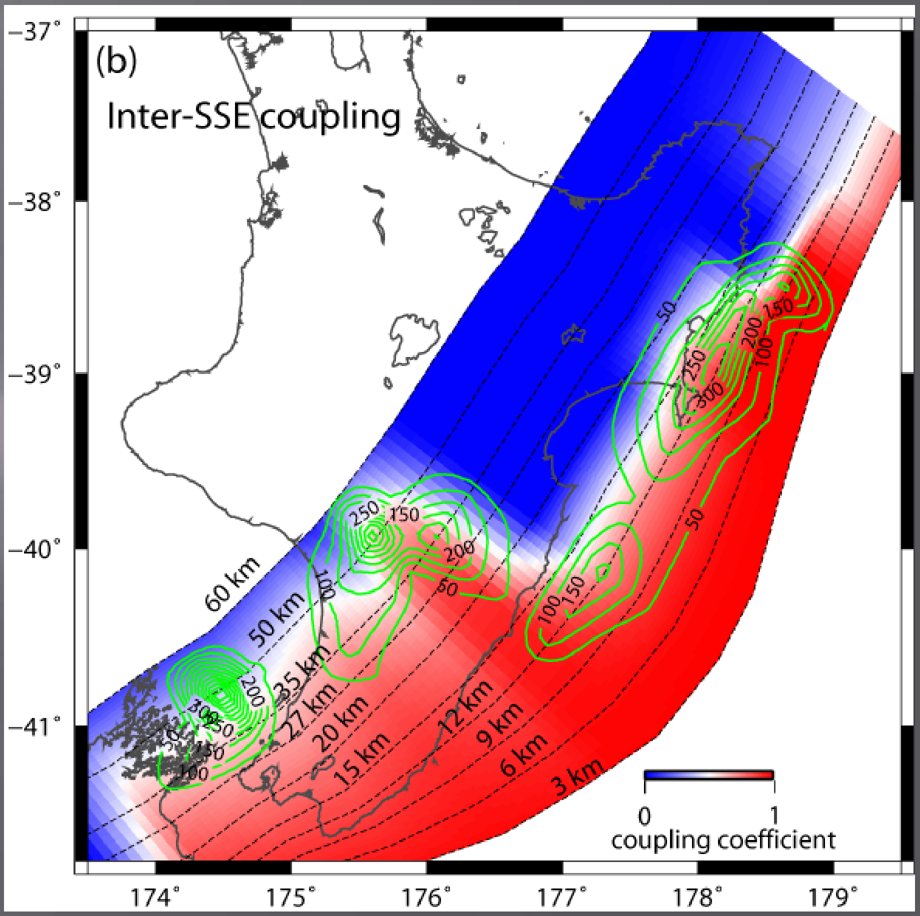


Slow slip events and their relationship to interseismic coupling at the Hikurangi margin

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



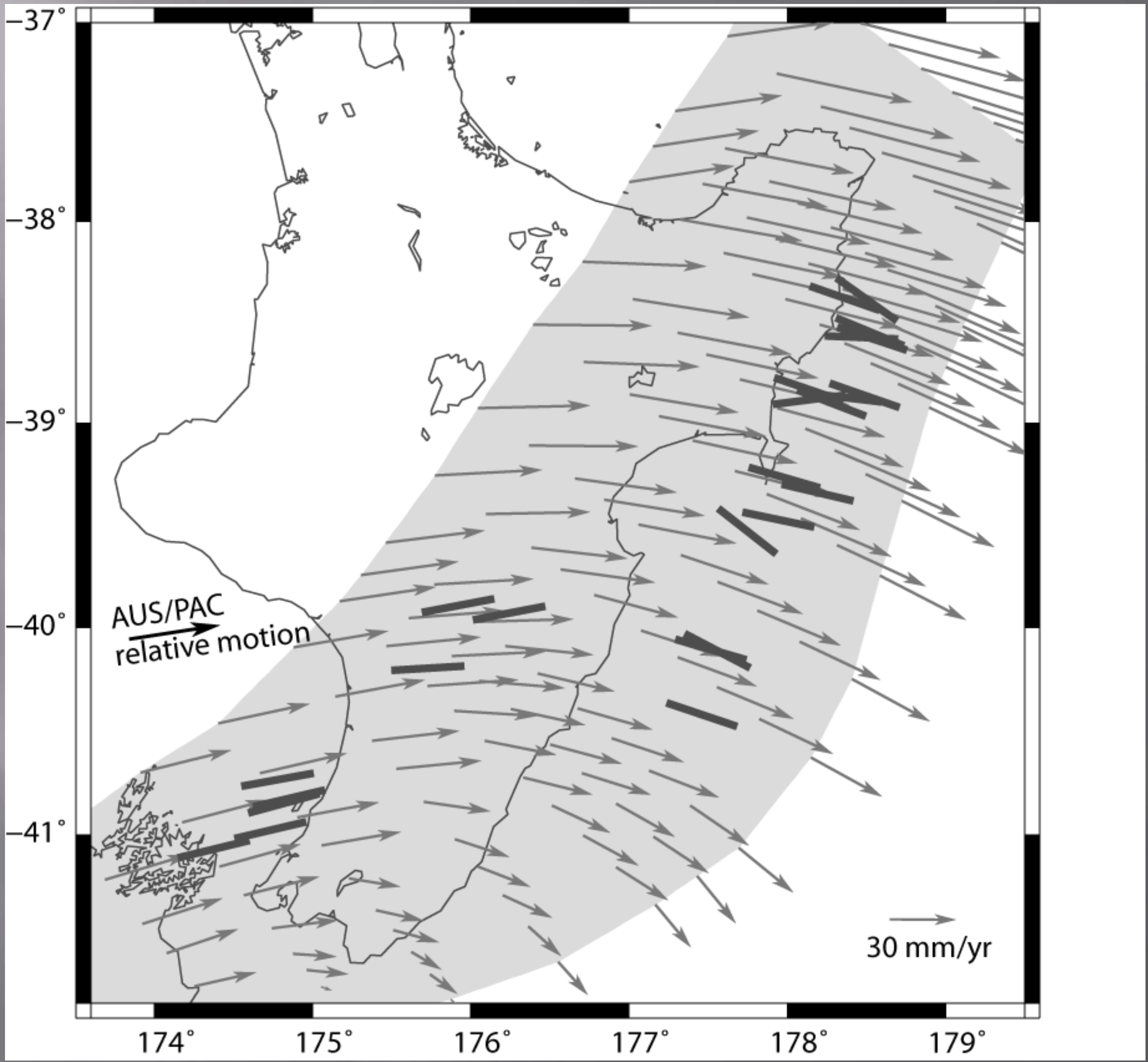
Interseismic coupling using "inter-SSE" velocities from the continuous GPS network



Wallace and Beavan, 2010, JGR

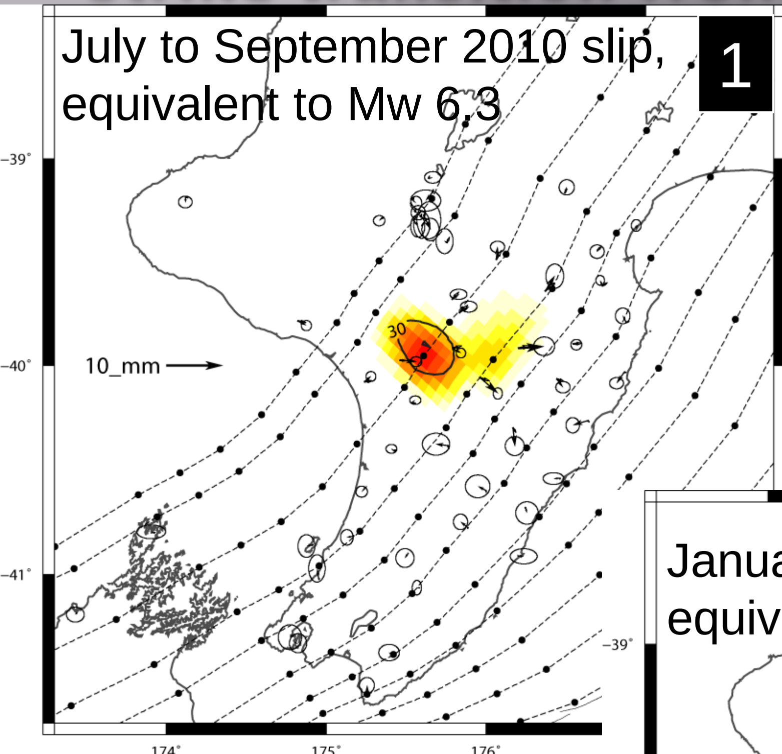
Portions of the interface that undergo slip in SSEs are mostly coupled between SSEs. 40% of the inter-SSE slip deficit is taken up by slow slip.

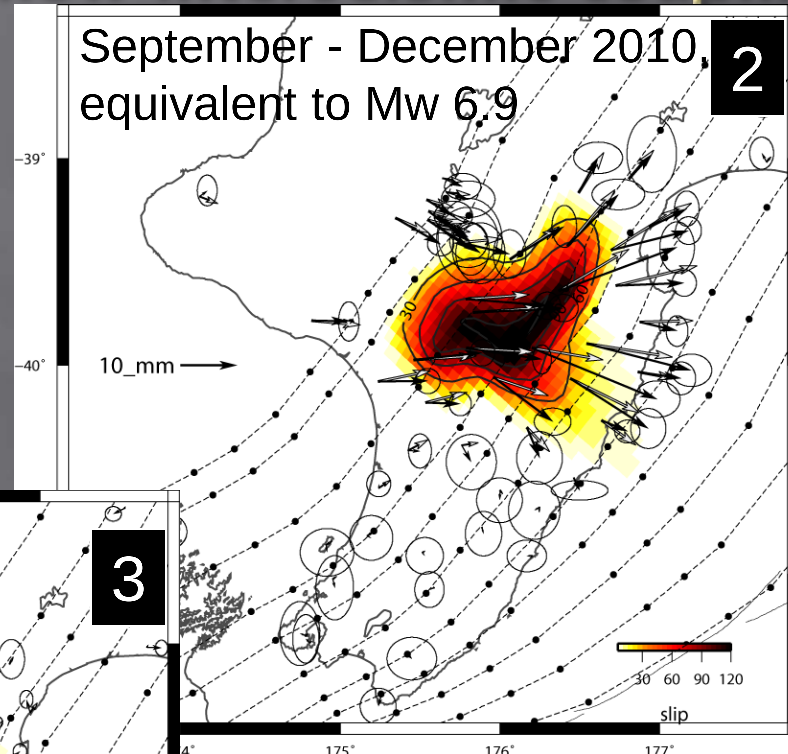
Slip directions on the interface in Hikurangi SSEs are consistent with partitioning of oblique relative plate motion

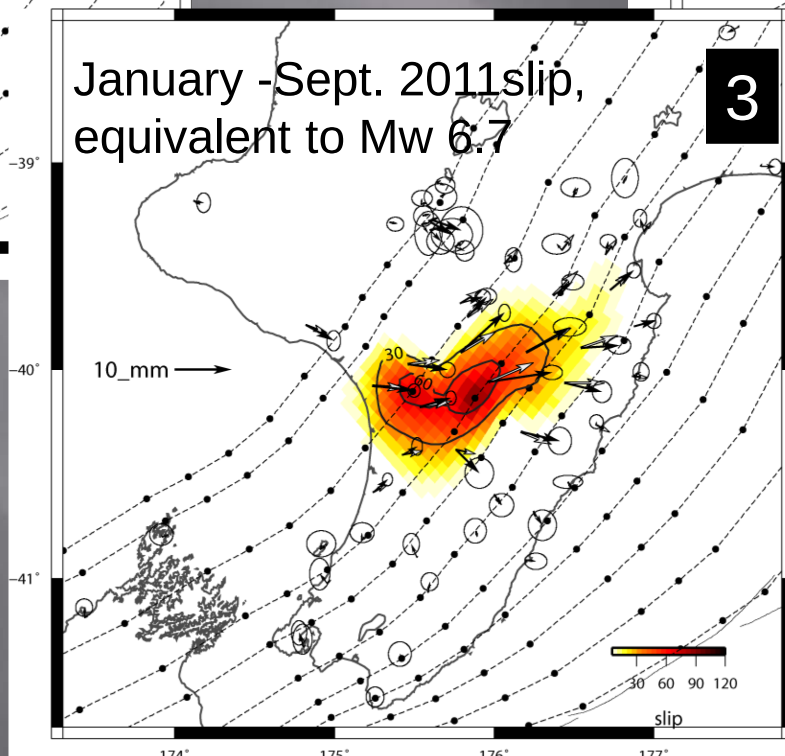


Wallace and Beavan, 2010

Large (Mw ~7.0), long-lived slow slip events in the along-strike transition from deep to shallow interseismic coupling







These SSEs bear strong similarities to those beneath Bungo Channel in southwest Japan