HIKURANGI OCEAN BOTTOM INVESTIGATION OF TREMOR AND SLOW SLIP (HOBITSS) EXPERIMENT: RESULTS AND IMPLICATIONS

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Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip (HOBITSS) Experiment

GOALS

1. Record a shallow slow slip event anticipated offshore of Gisborne, New Zealand in 2014-2015 using **seafloor absolute pressure gauges as geodetic instruments** for the first time to improve slip distribution.

2. Compare a well-located offshore slow slip event with related microseismicity recorded on **ocean bottom seismometers**.

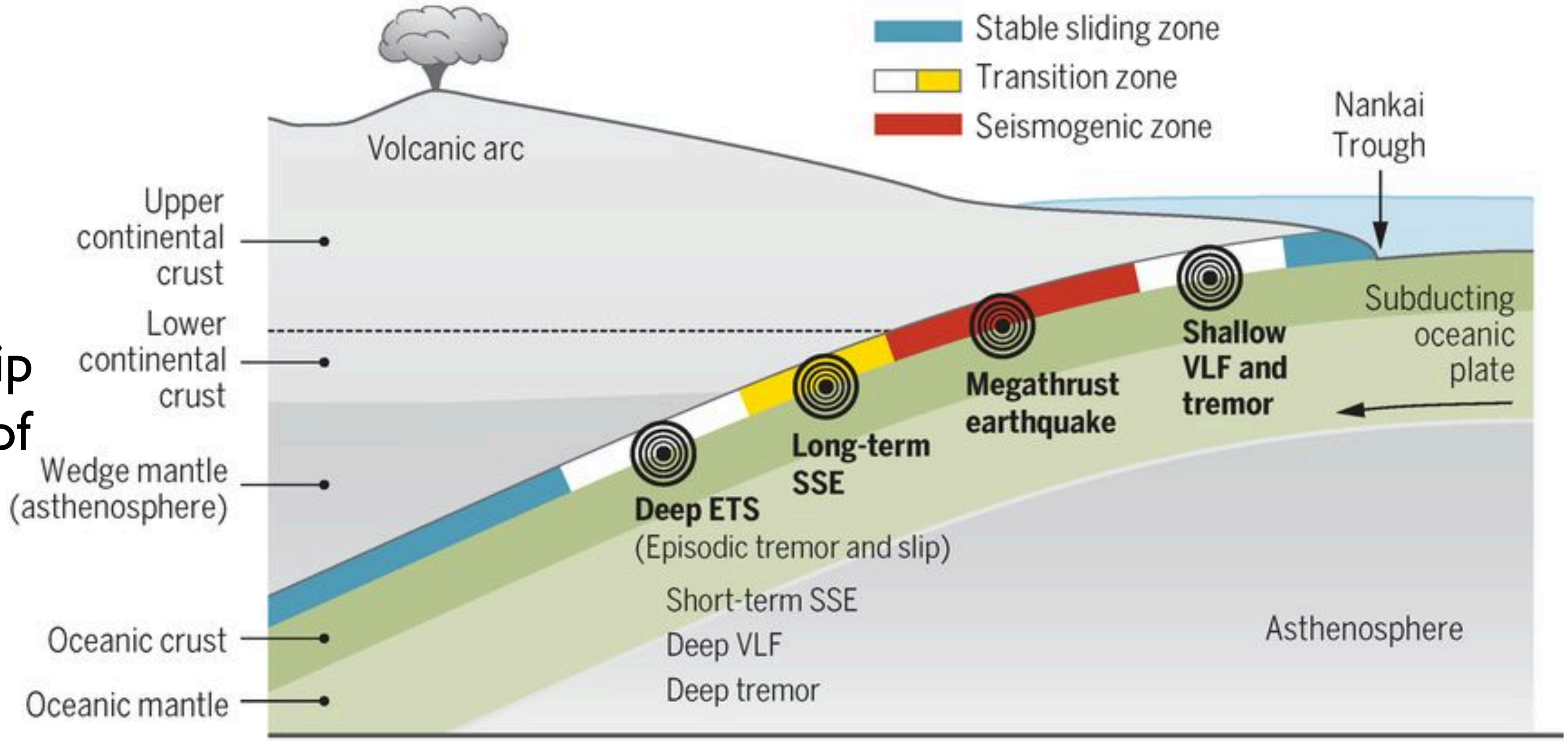
3. Provide insight into the interplay of seismic and aseismic slip in the region, as well as the **relationship between shallow slow slip and seamount subduction, fluids, and microseismicity**.

Outline

I. Shallow slow slip
II. Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip (HOBITSS) Experiment
    I. Detection of 2014 Gisborne slow slip event
    II. Microseismicity
    III. Tectonic tremor
    IV. Repeating earthquakes
    V. Implications for seamount subduction and shallow slow slip
III. Related work with offshore instrumentation
IV. Additional HOBITSS work

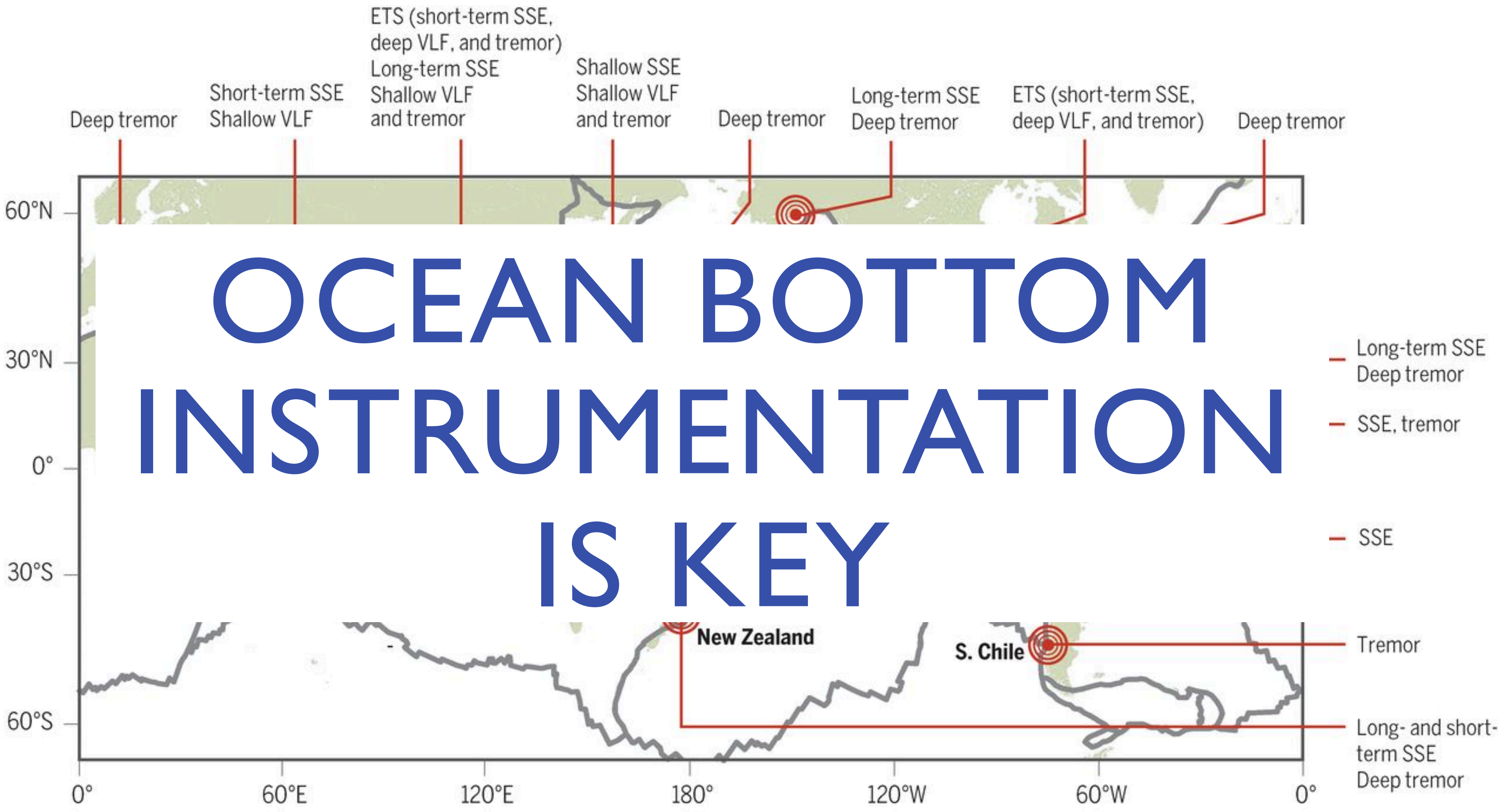
Slow Slip Events

- Slow slip events may precede and even trigger large megathrust earthquakes and are therefore critical to detect and understand.
- Detect geodetically
- Shallow, offshore slow slip events are out of range of land cGPS
- May drive secondary microseismicity



Obara & Kato, 2016, Science

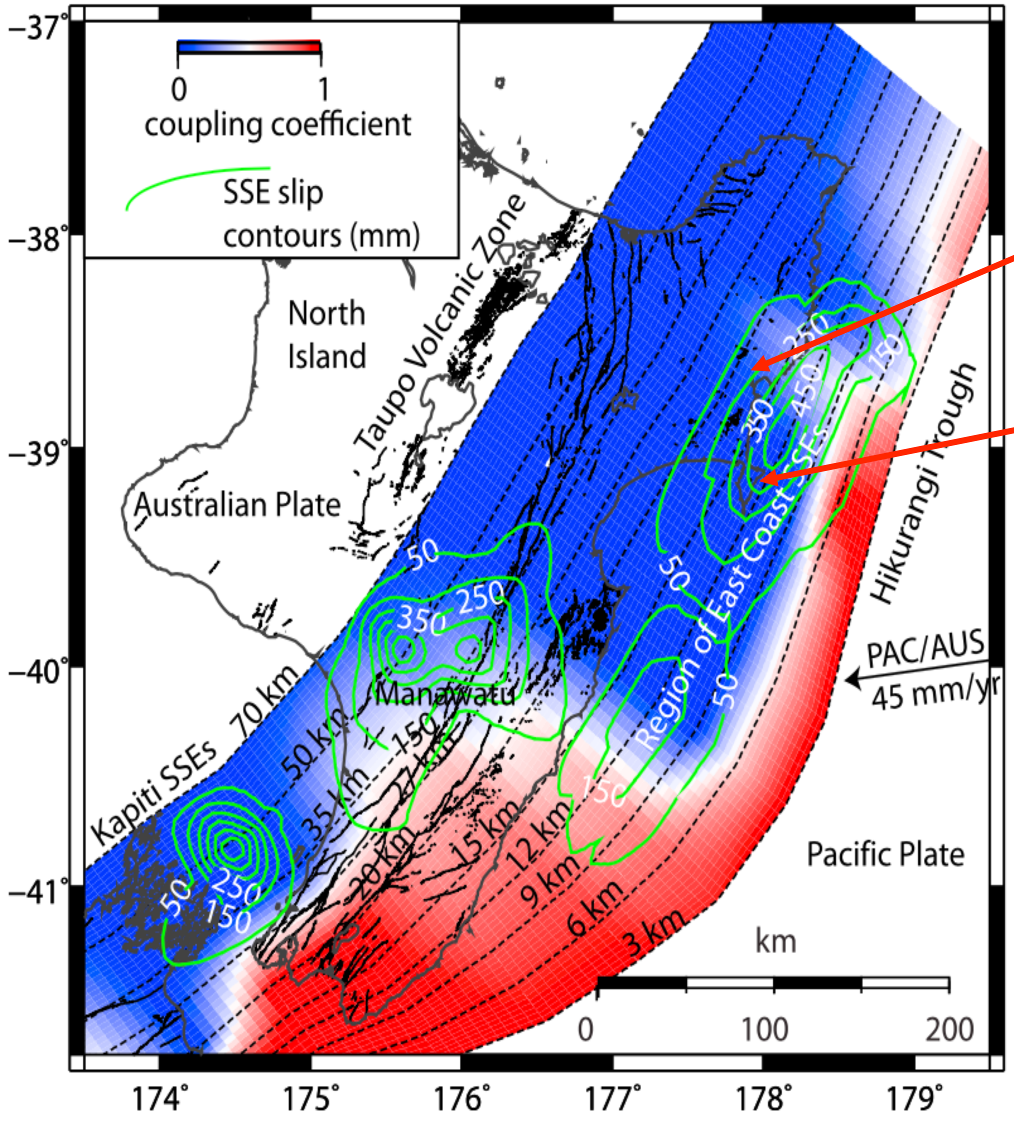
Where do slow slip events occur?



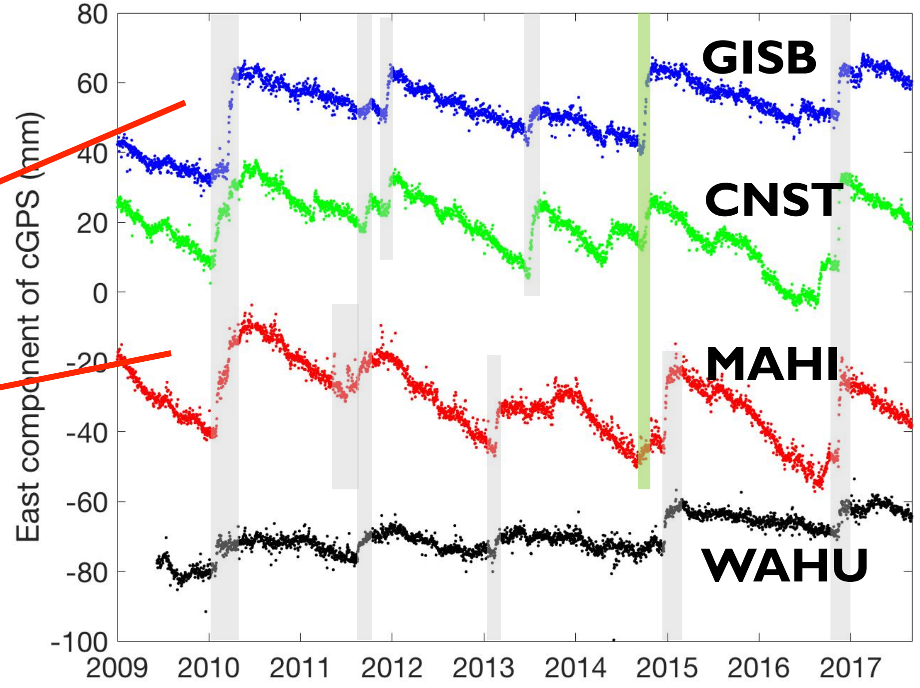
OCEAN BOTTOM INSTRUMENTATION IS KEY

Obara & Kato, 2016, Science

Slow slip at the Hikurangi Margin



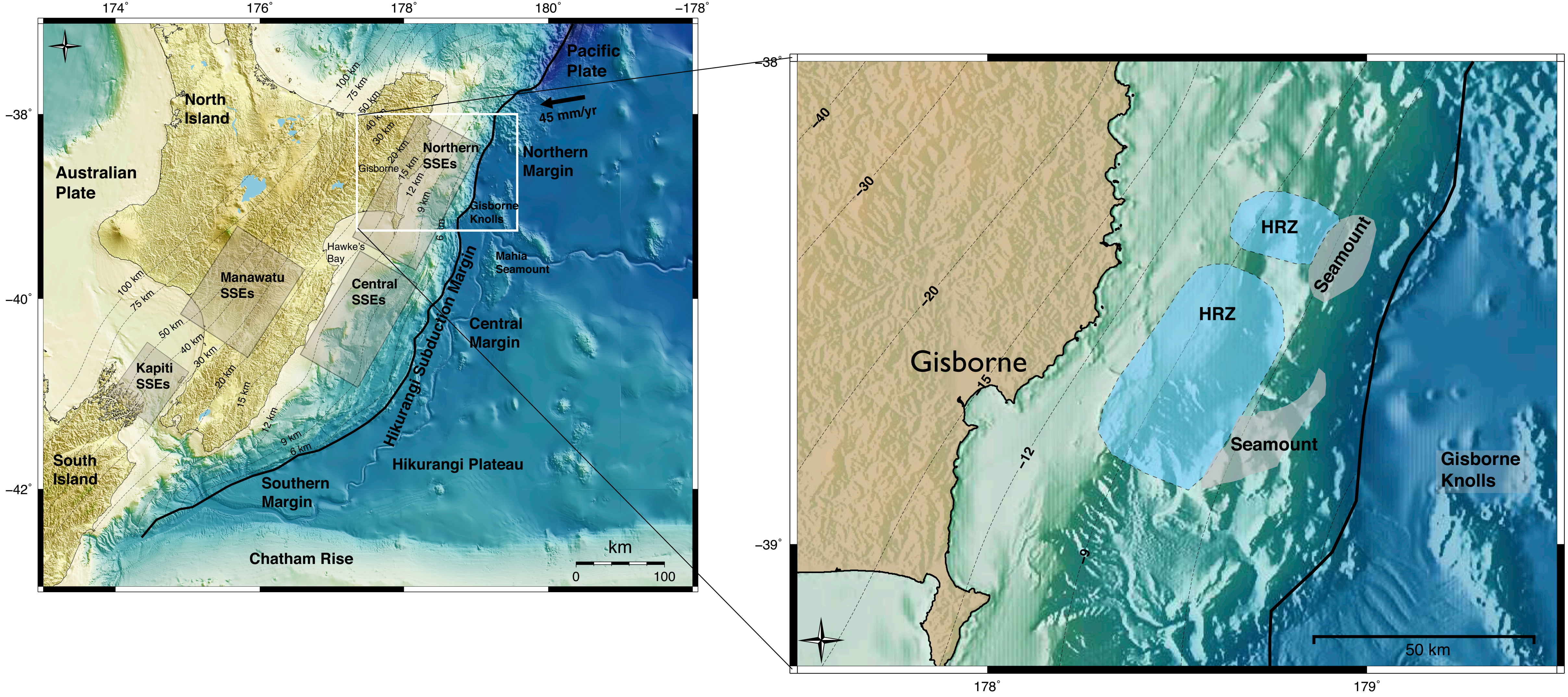
Wallace et al., 2012, JGR



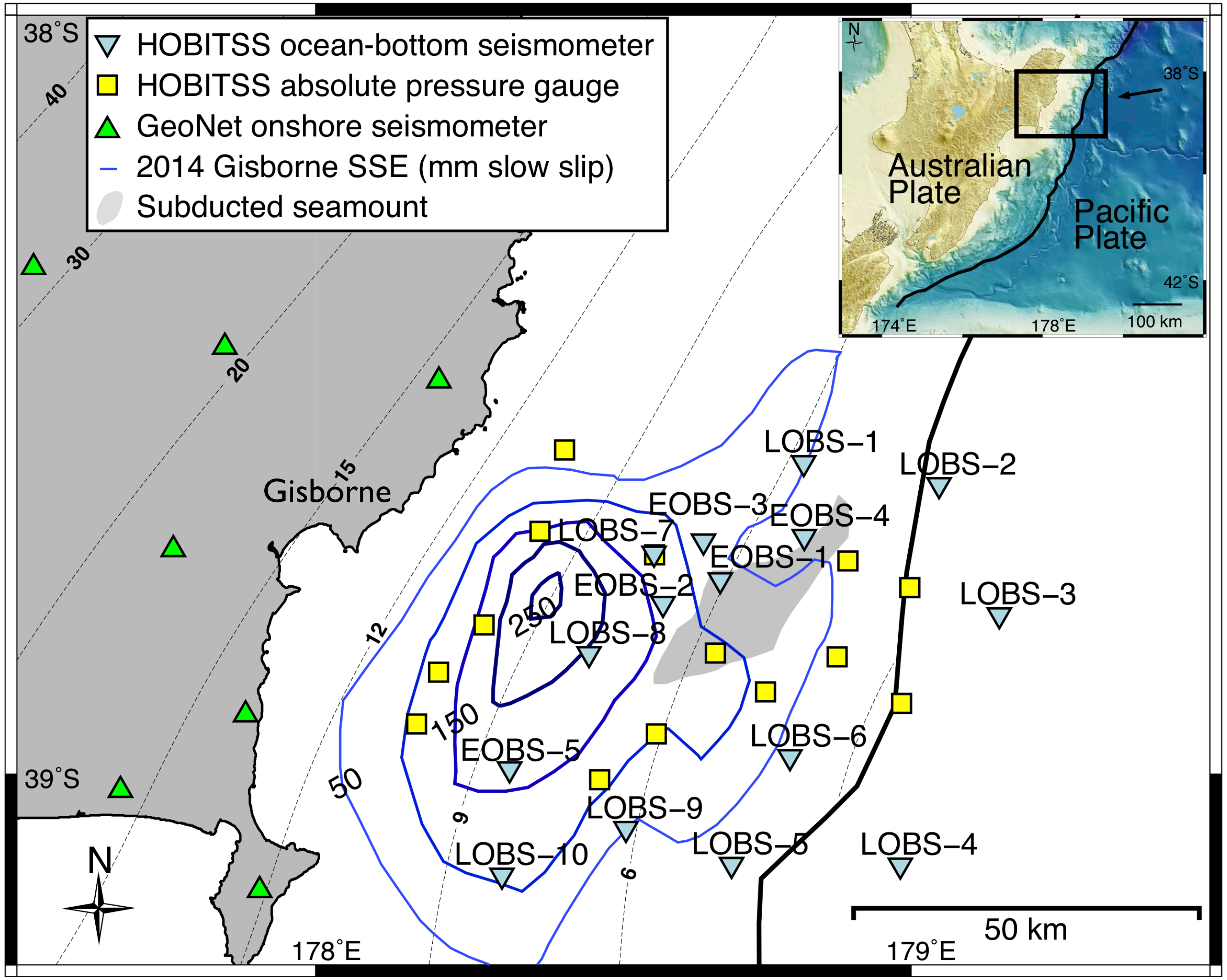
Northern margin shallow SSEs:

- <15 km; mostly offshore
- 18-24 month recurrence & 1-3 week durations
- Increase in downdip seismicity (Delahaye et al., 2009)
- Onshore/downdip tremor (Kim et al., 2011, Todd & Schwartz, 2016)

Relationship between subducted seamounts, slow slip, and fluids at the Hikurangi Margin, New Zealand



Hikurangi Ocean Bottom Investigation of Tremor and Slow Slip (HOBITSS) Experiment



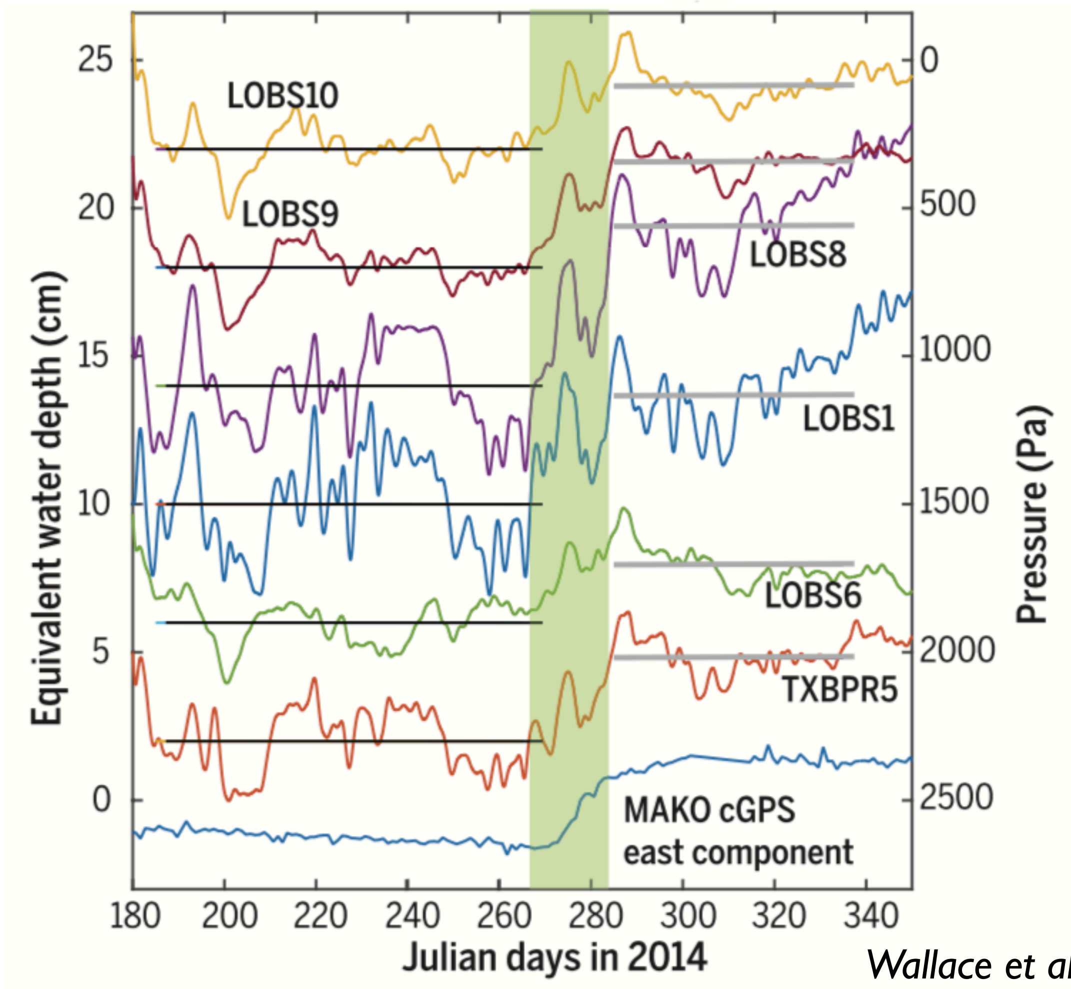
Shaddox & Schwartz, Geology, 2019

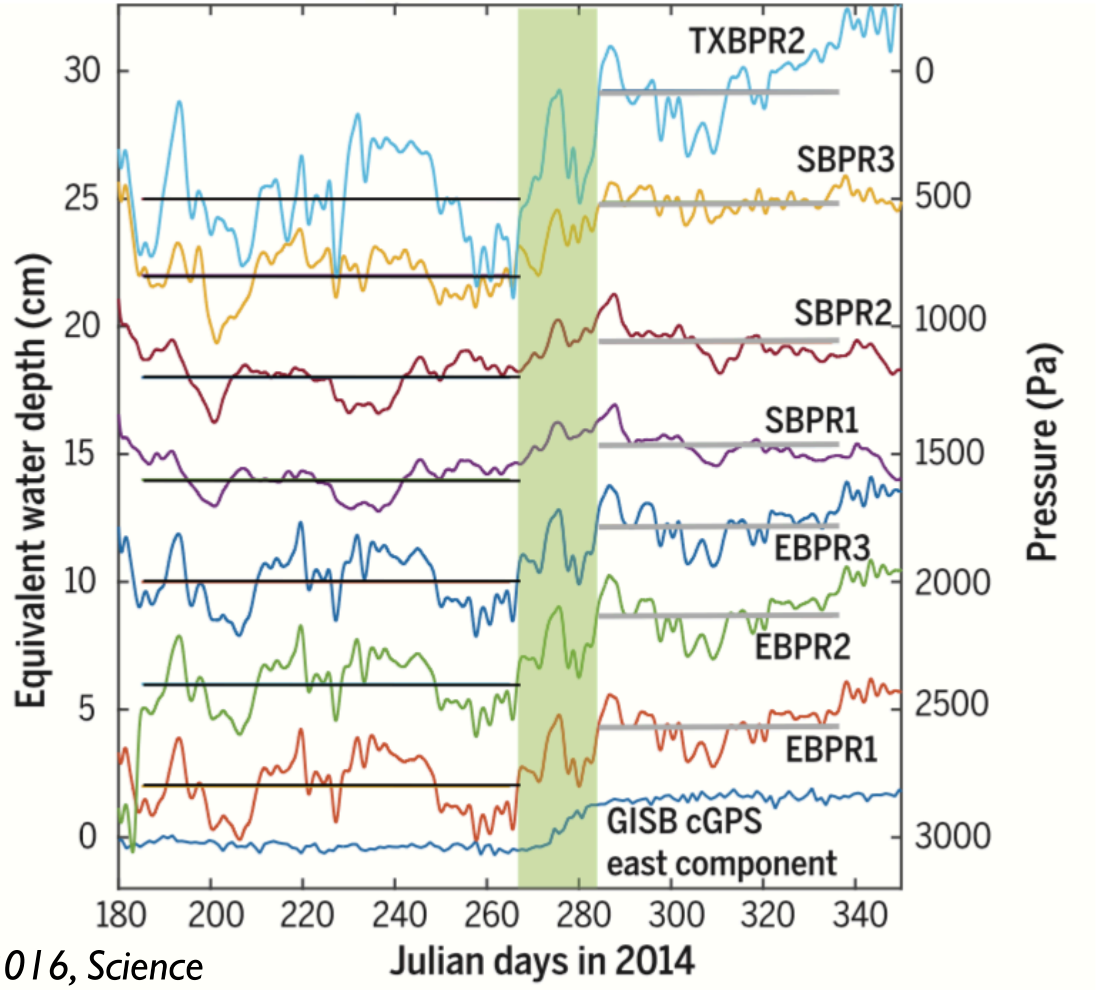
Deployed offshore Gisborne, New Zealand to record anticipated slow slip event

- May 2014 - June 2015
- 24 absolute pressure gauges (APGs)
- 15 ocean-bottom seismometers (OBS)
- First experiment to use APGs as geodetic instruments

2014 Gisborne Slow Slip Event

Wallace et al. (2016) identified a pressure decrease on absolute pressure gauges in September/October 2014

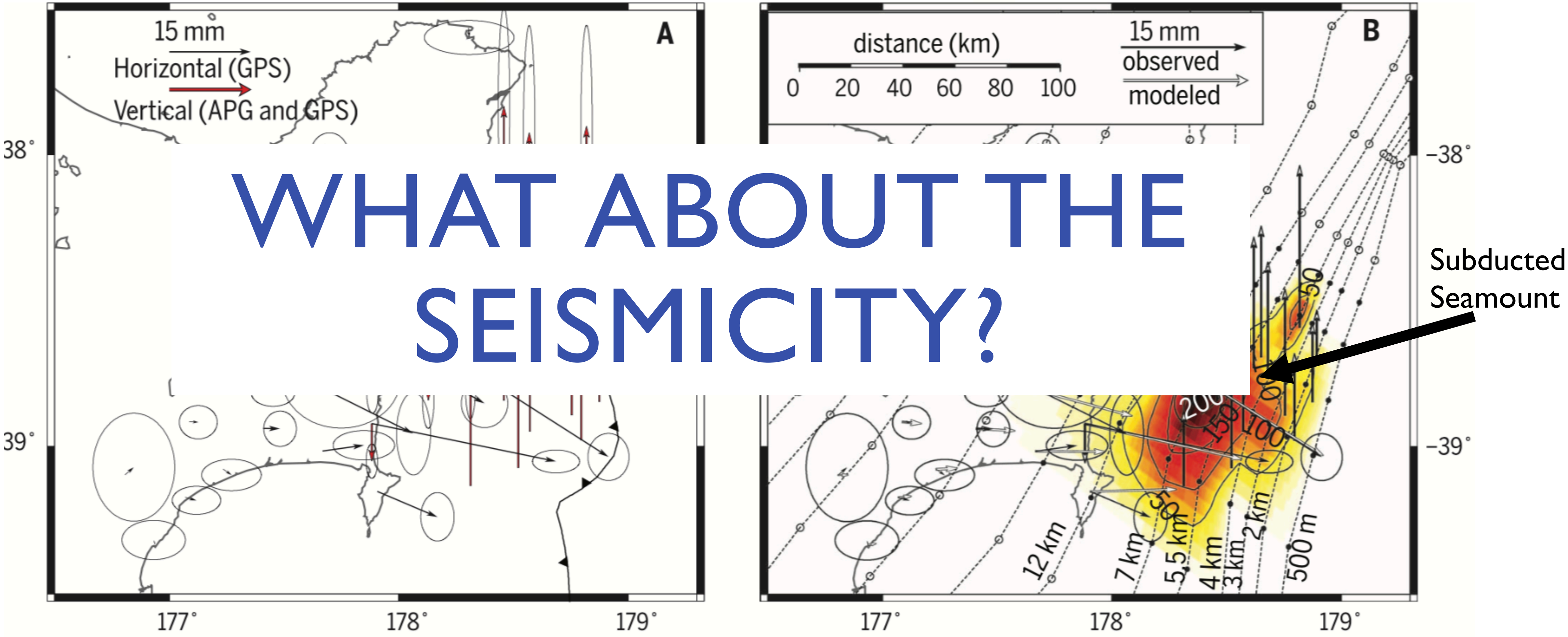




Wallace et al., 2016, Science

2014 Gisborne Slow Slip Event

Wallace et al. (2016) recorded a 2-3 week M_w 6.8 slow slip event (SSE) in September/October 2014 using the offshore absolute pressure gauges

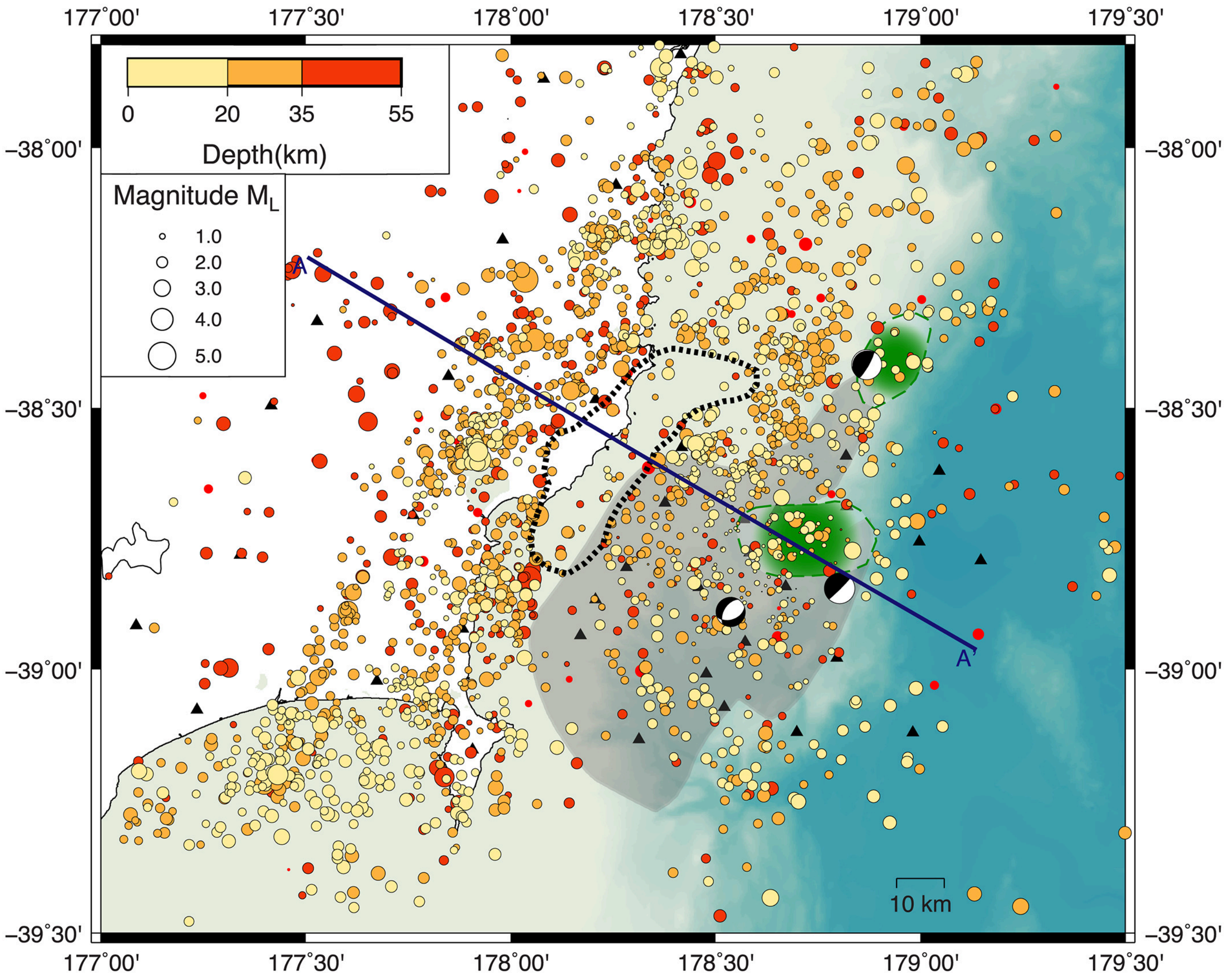


WHAT ABOUT THE SEISMICITY?

Wallace et al., 2016, Science

Microseismicity & 2014 Gisborne SSE

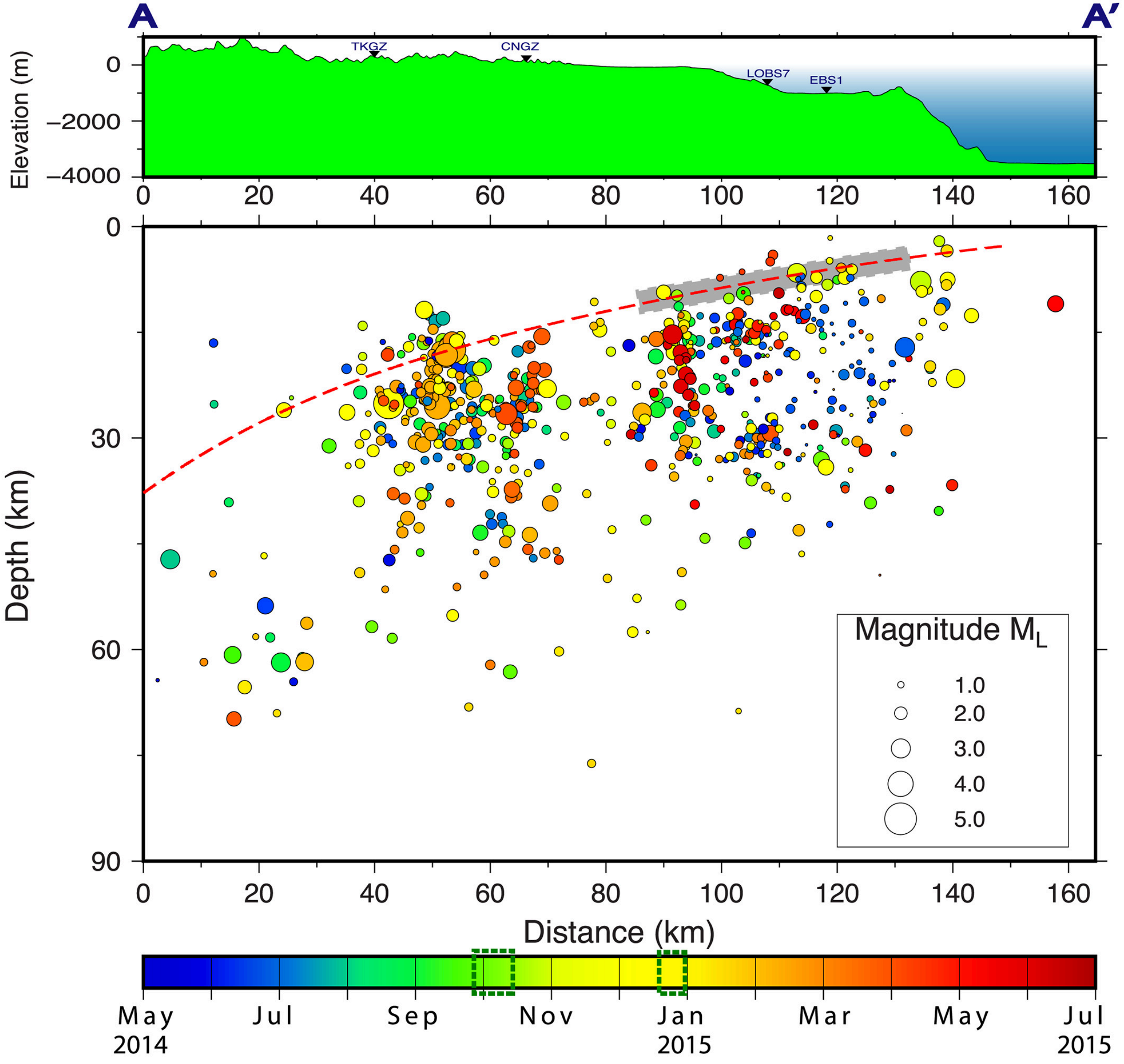
- **Yarce et al.** (2019) created a catalog of microseismicity during the HOBITSS deployment (May 2014 – June 2015) using OBS & land stations
- **2,300 earthquakes** ranging in magnitude between 0.5 and 4.7, Magnitude of completeness = 1.5
- Twice as many events as standard catalog



Yarce et al., JGR, 2019

Microseismicity & 2014 Gisborne SSE

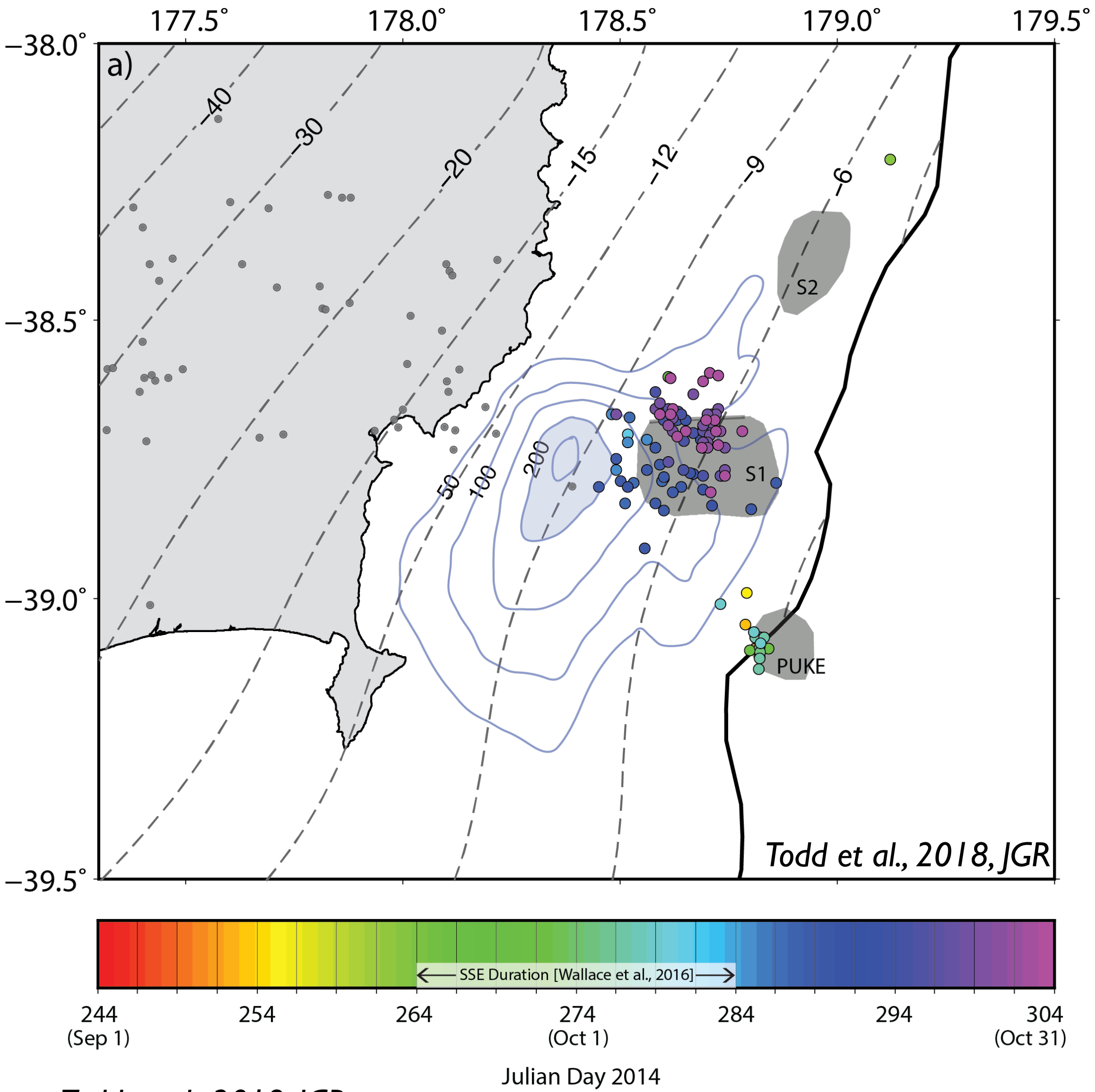
- Majority of earthquakes are within the subducting Pacific plate
- 20-km wide northeast trending gap in microseismicity borders the downdip edge of a slow slip patch.



Yarce et al., JGR, 2019

Tectonic tremor and the 2014 Gisborne SSE

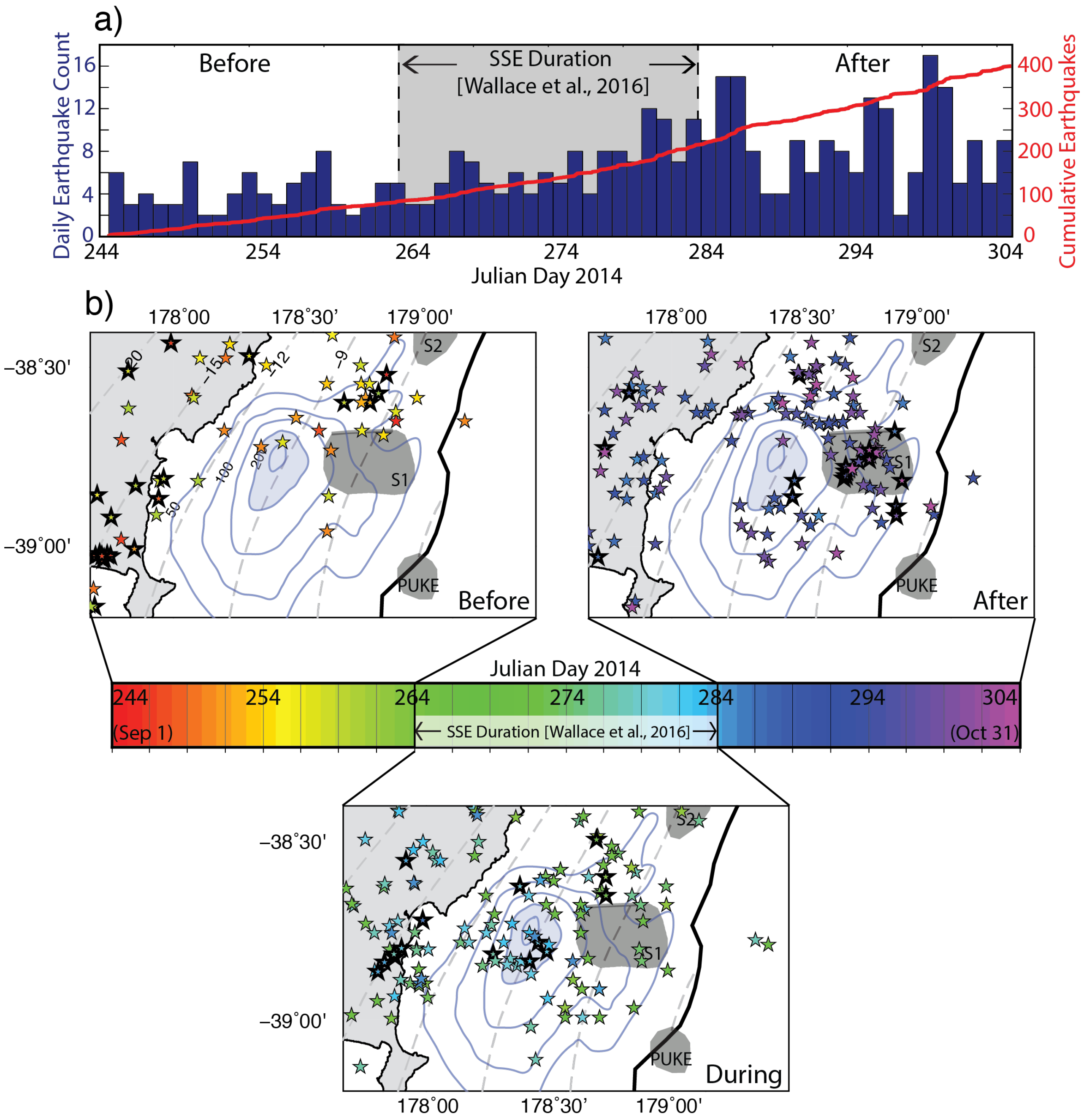
- **Todd et al.** (2018) detect offshore tremor using the HOBITSS OBS stations
- **First detection of offshore tremor in this region – because of offshore OBS!**
- Tremor activity toward the end and after the 2014 Gisborne SSE
- Concentration at a subducted seamount



Todd et al., 2018, JGR

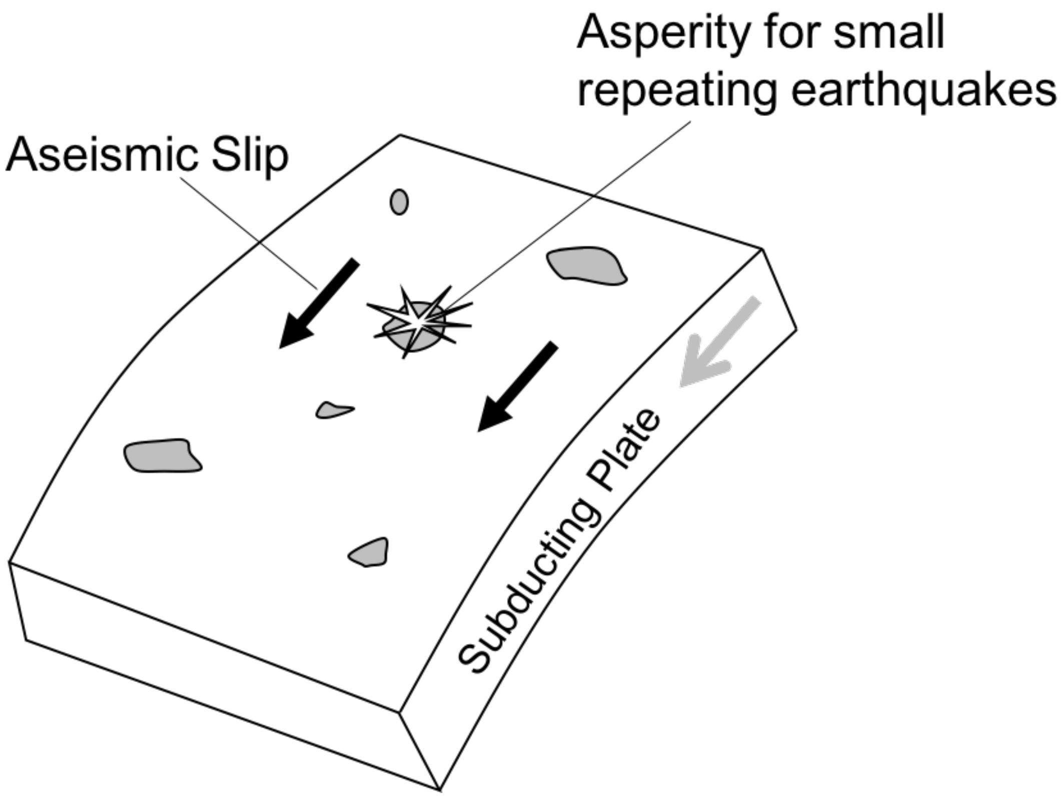
More Microseismicity & 2014 Gisborne SSE

- **Todd et al.** (2018) also created catalog of earthquakes for September & October, 2014
- Find increase in microseismicity toward the end and after the 2014 Gisborne SSE
- Concentrated at subducted seamount



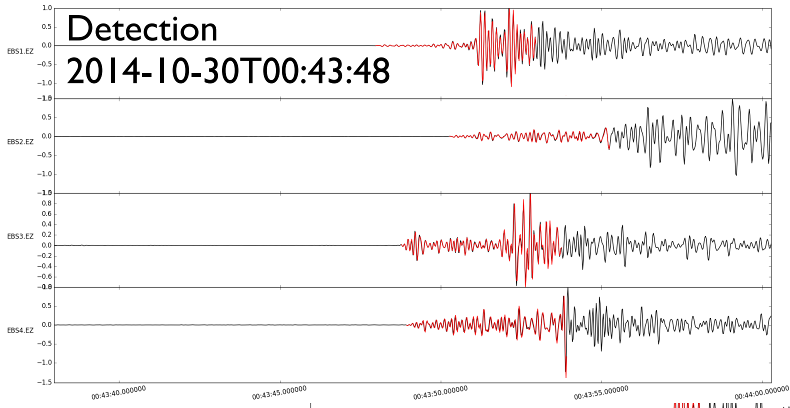
Repeating Earthquakes

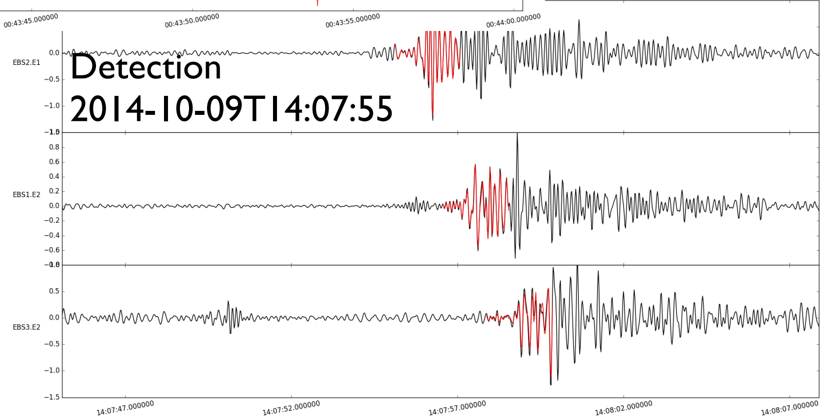
- Events with nearly identical waveforms thought to repeatedly rupture the same way in the same location
- **“Burst-type”**
  - Concentrated in time, short and irregular repeat intervals, variable magnitudes (Igarashi et al., 2003)
  - Associated with afterslip following a mainshock
  - Can be used to locate **transient aseismic slip**

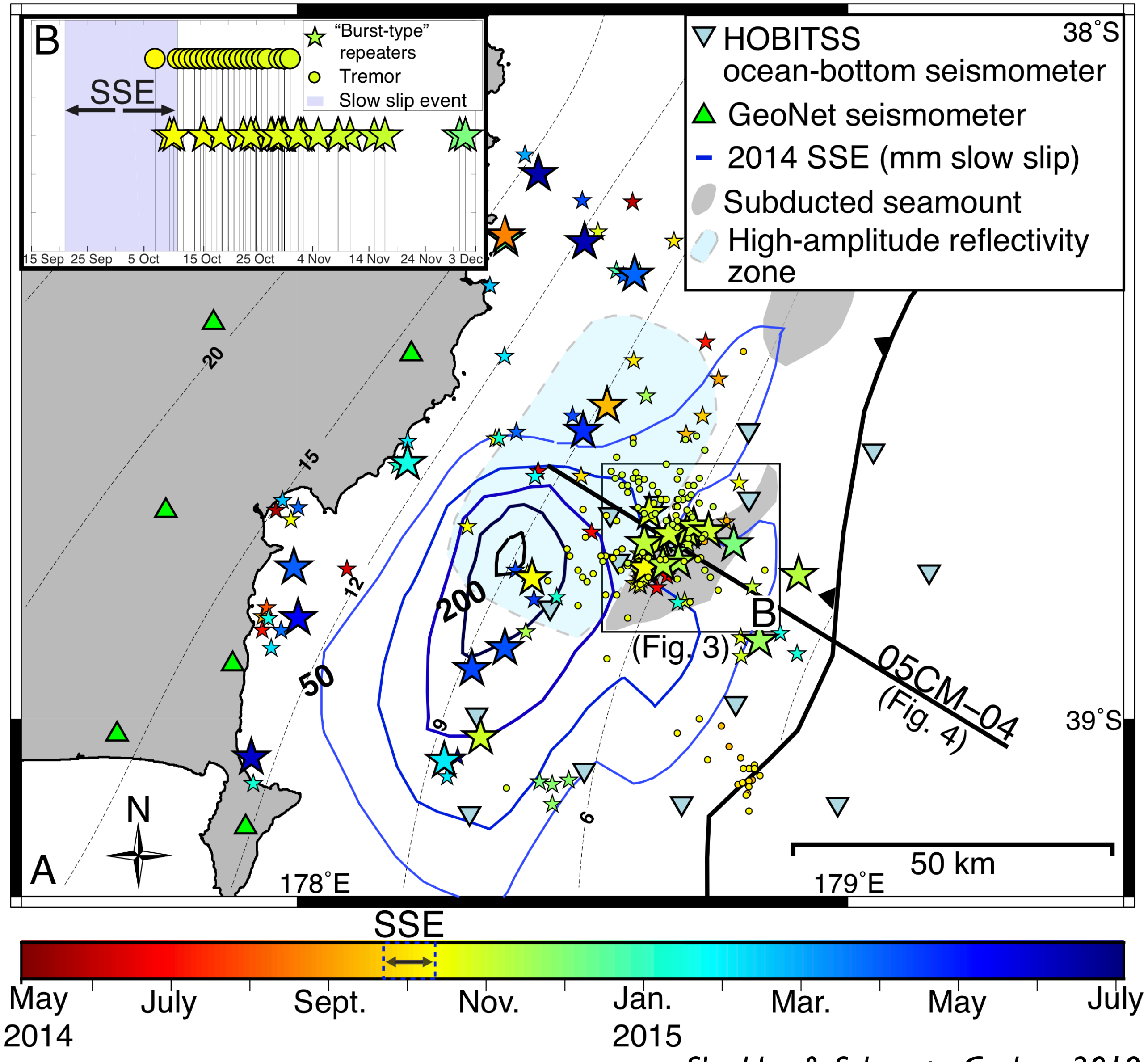


Repeating Earthquakes & 2014 Gisborne SSE

- **78 repeating earthquakes within 29 families**
- Spatial clustering at subducted seamount after SSE







Shaddox & Schwartz, Geology, 2019

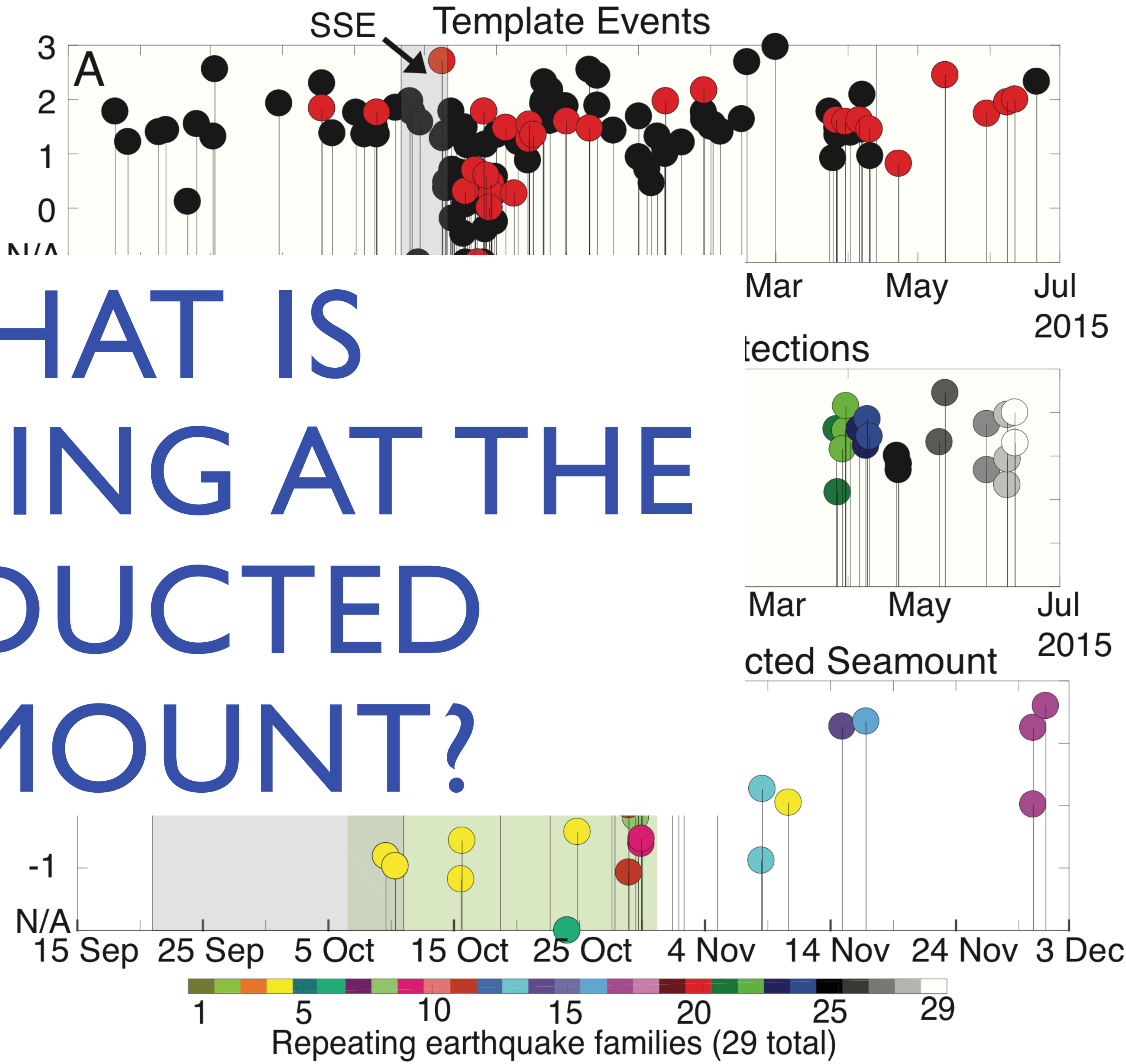
*Tremor from Todd et al., 2018

Repeating Earthquake Clustering at Subducted Seamount

- Up to 7 weel
- Short & irreg
- Varying magn

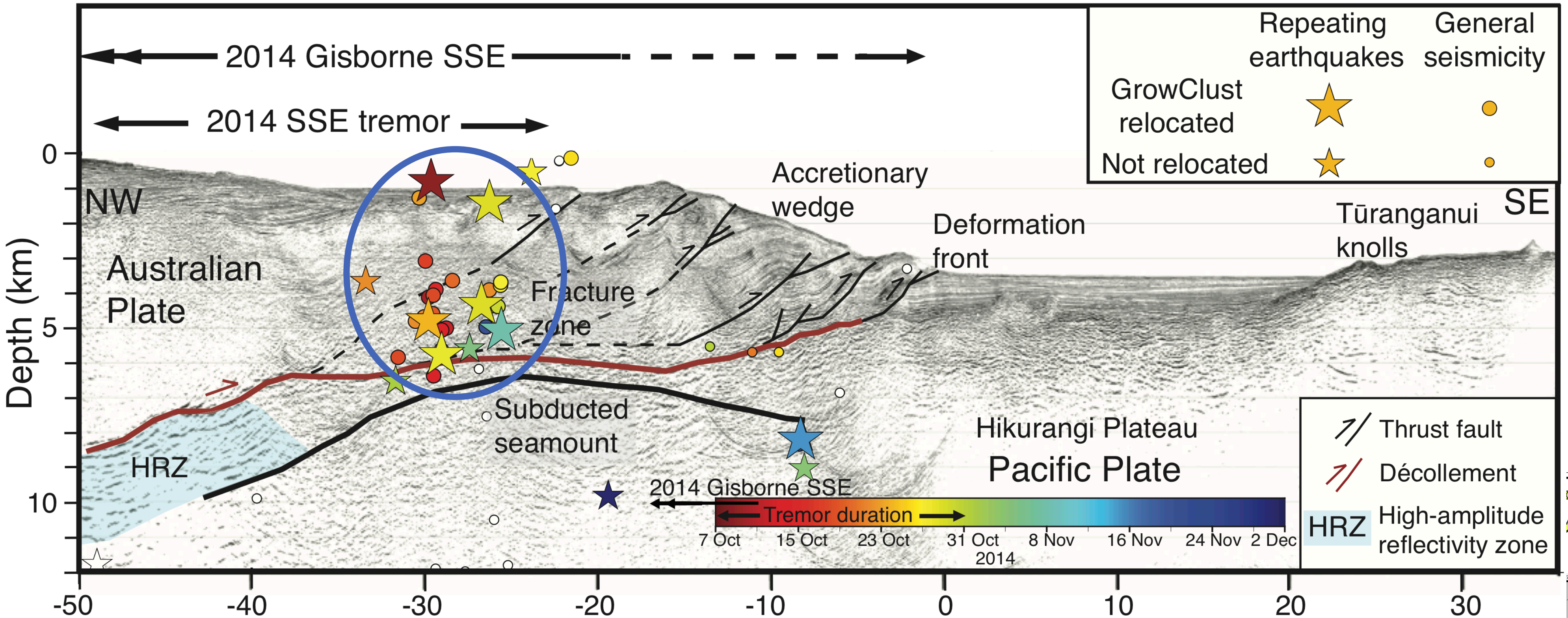
→ "Burst-type earthquake: afterslip

WHAT IS HAPPENING AT THE SUBDUCTED SEAMOUNT?



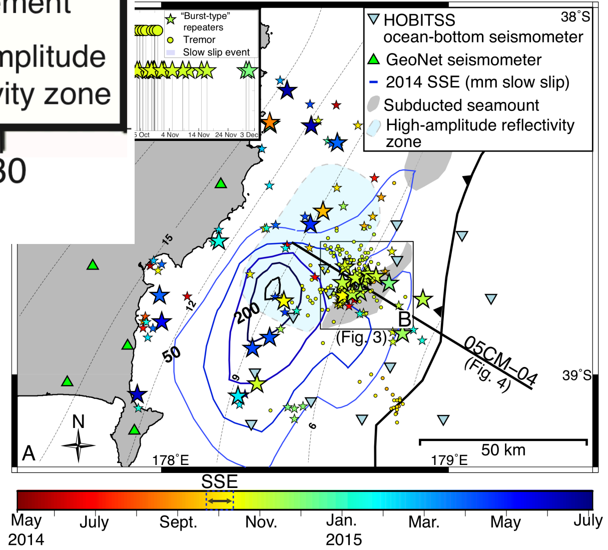
Shaddox & Schwartz, Geology, 2019

What is going on at the subducted seamount?



Shaddox & Schwartz, Geology, 2019

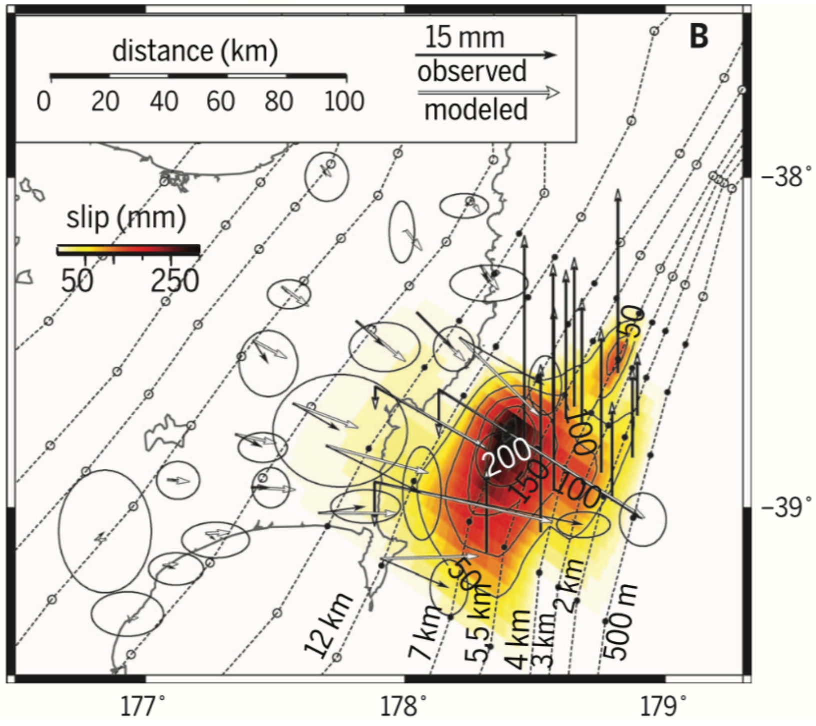
Modified from Barker et al., 2018

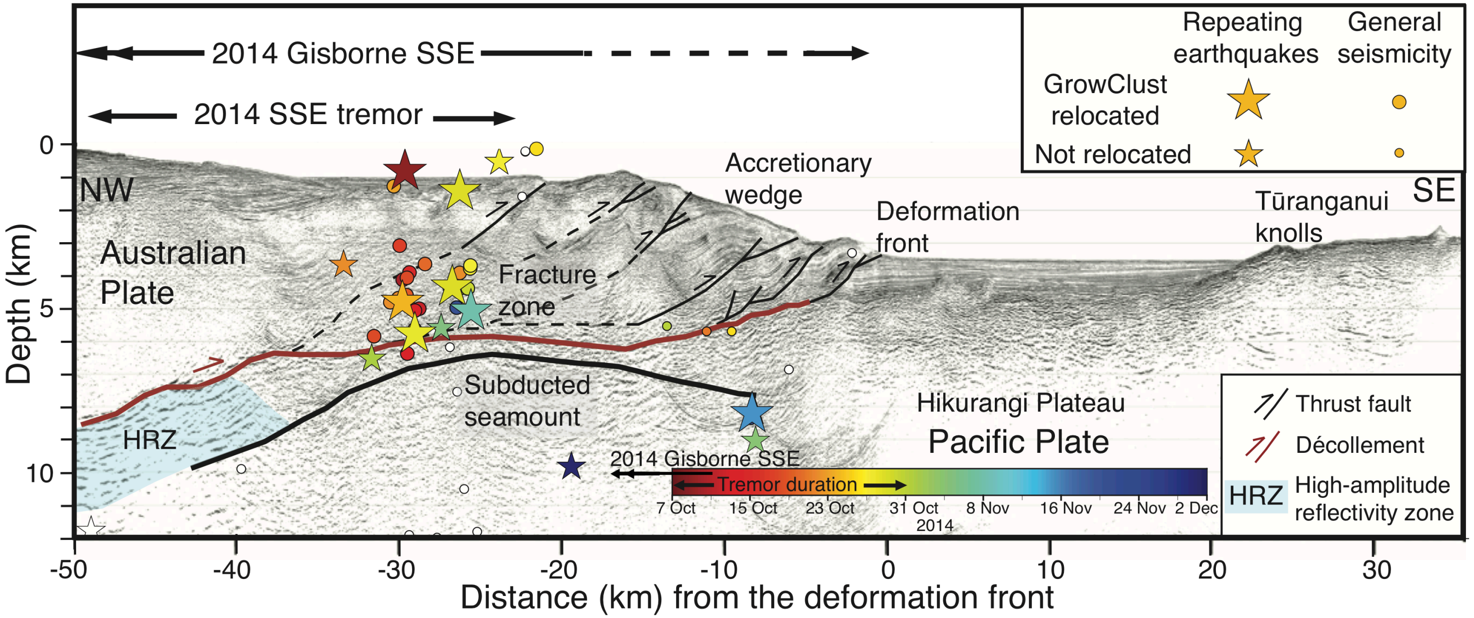


→ Further slow slip in fracture network after main SSE

HOBITSS Conclusions

1. Successfully detected and modeled offshore slow slip distribution using seafloor absolute pressure gauges, possibly extends to the trench
2. Detected and located offshore tectonic tremor, microseismicity, and repeating earthquakes using ocean bottom seismometers
3. Find tremor, repeating earthquakes, and microseismicity within upper plate fracture network above a subducted seamount after main slow slip event – **aseismic slip at the subducted seamount after the main slow slip event**



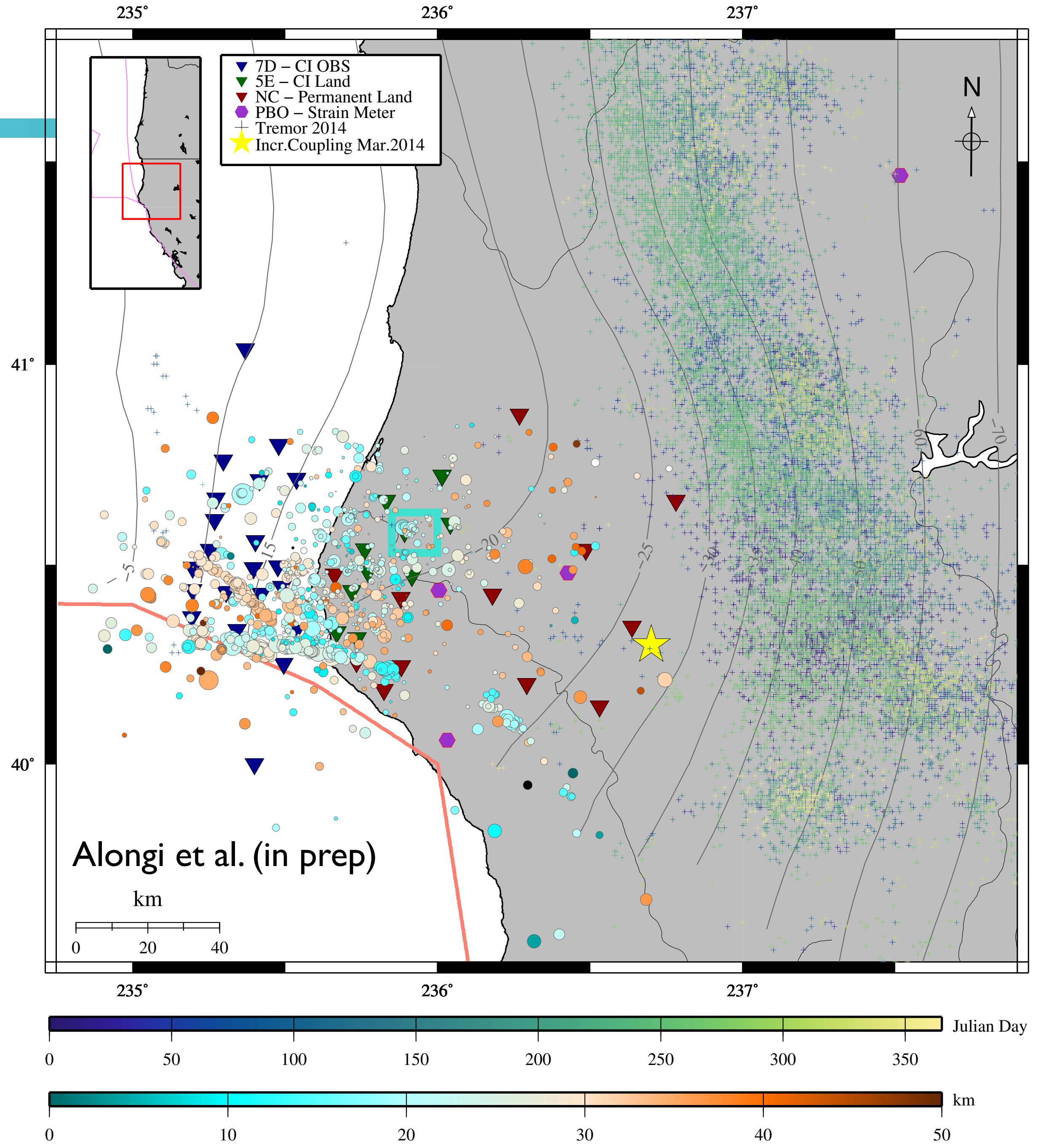


HOBITSS Implications

1. Seamount subduction plays a key role in generation of shallow slow slip and microseismicity at the Hikurangi margin.
2. "Burst-type" repeating earthquakes may be a proxy for shallow slow slip in regions of subducted oceanic relief.
3. **Combining ocean bottom seismometers, ocean bottom pressure, and offshore seismic imaging is key!**

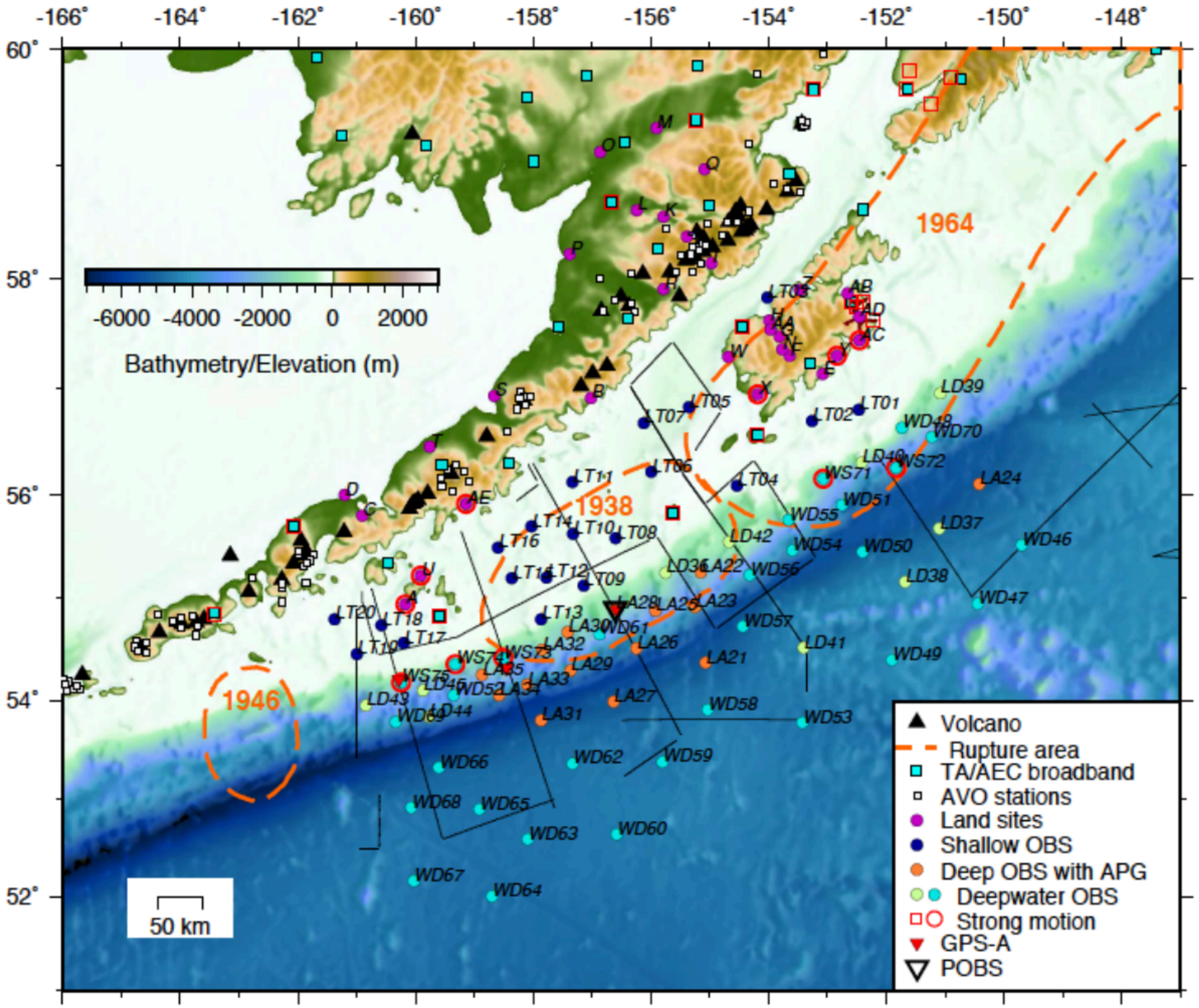
Southern Cascadia

- **Alongi et al.** (in prep) made a seismic catalog using OBS from year 4 of the Cascadia Initiative amphibious array
- Plate interface cluster of repeating earthquakes
- Potential strain transient updip of deep slow slip events



Alaska Amphibious Community Seismic Experiment

- 75 broadband ocean bottom seismometers and 14 absolute pressure gauges
- Rough incoming seafloor
- Repeating earthquakes and tremor associated with shallow, offshore slow slip & seamount subduction?



Additional HOBITSS Work

Published

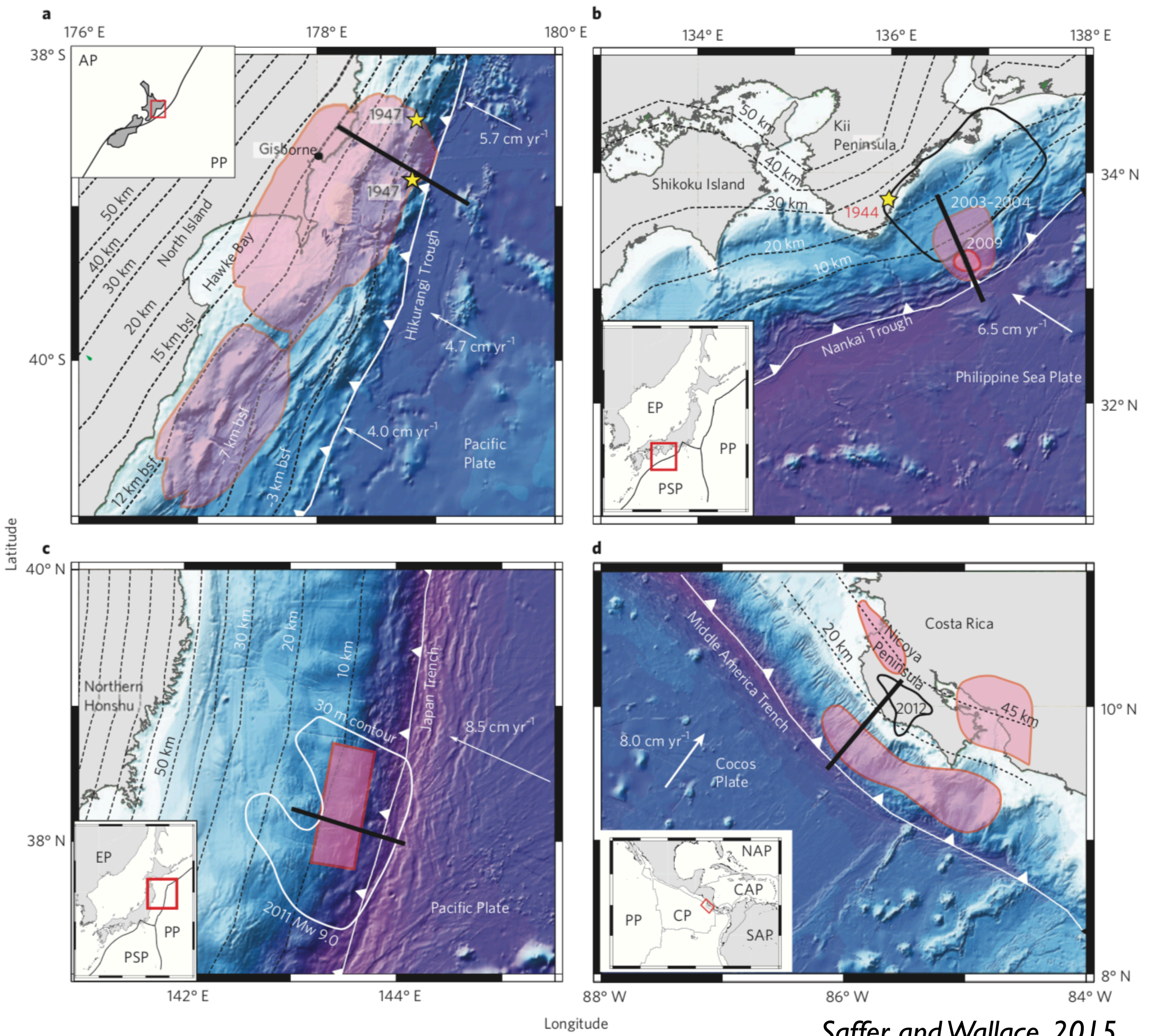
- Wallace et al., 2016, *Slow slip near the trench at the Hikurangi subduction zone, New Zealand*, Science *New Zealand Geophysics Prize!*
- Todd et al., 2018, *Earthquakes and Tremor Linked to Seamount Subduction During Shallow Slow Slip at the Hikurangi Margin, New Zealand*, JGR
- Shaddox & Schwartz, 2019, *Subducted seamount diverts shallow slow slip to the forearc of the northern Hikurangi subduction zone, New Zealand*, Geology
- Yarce et al., 2019, *Seismicity at the Northern Hikurangi Margin, New Zealand, and Investigation of the Potential Spatial and Temporal Relationships With a Shallow Slow Slip Event*, JGR
- Warren-Smith et al, 2019, *Episodic stress and fluid pressure cycling in subducting oceanic crust during slow slip*,
- Nature Geoscience *New Zealand Geophysics Prize!*
- Zal et al. (accepted), *Temporal variations in seismic anisotropy and VP/VS ratios during the 2014 HOBITSS SSE, New Zealand*

In Progress with Anne Sheehan, University of Colorado at Boulder

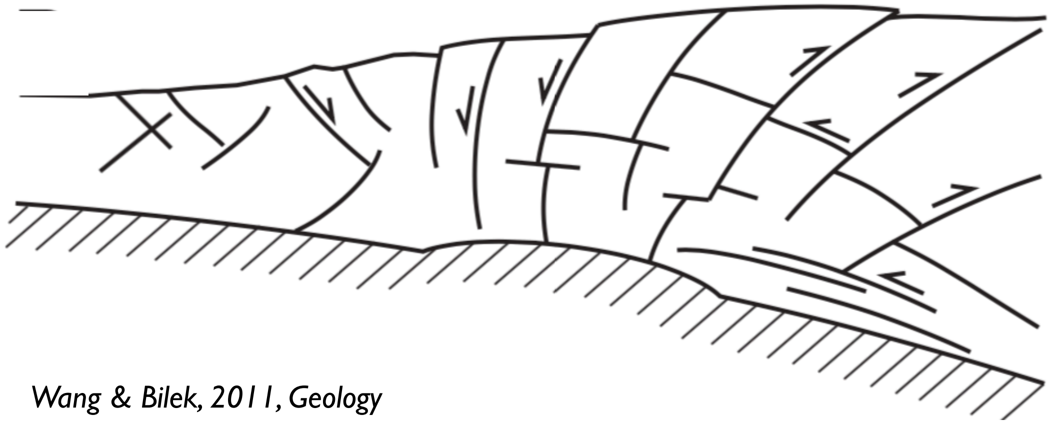
- Jenny Nakai: Attenuation tomography
- Jefferson Yarce: Body wave tomography
- Hongda Wang: Ambient noise tomography
- Melody Zhang: Slab converted phases

SUPPLEMENTAL SLIDES

Shallow SSEs and rough subducted seafloor



Saffer and Wallace, 2015



Wang & Bilek, 2011, Geology

Template Matching

- Template earthquakes:
  - Used catalogs from both Yarce et al., 2019 & Todd et al., 2018
  - Relocated in GrowClust (*Trugman and Shearer, 2017*)
  - Events with final locations in general region of 2014 Gisborne SSE & within 5 km of the plate interface are selected as templates – **<u>123 Total</u>**
- EQcorrscan (*Chamberlain & Hopp*, 2017)
- CC >= 0.95 at a minimum of 3 stations

  → **Repeating Earthquake**