Seafloor Pressure Sensors

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Types of Pressure Sensors

No sensor is adequate for all signals!

(clip level, noise floor, useful frequency band)

Hydrophones:

Typical frequency band for seismology; 10s to 100 Hz
(possible band about 100s to MHz).
Primary use detecting short period arrivals from earthquakes, Tremor.
Accurate, reach seafloor noise floor at 0.1 Hz and above.

Differential Pressure Gauge (DPG: Cox et al., 1984)

Typical band 1000s to 50Hz.
Primary use: seismology, Rayleigh wave signals, P Waves
Also used to remove wave loading noise from vertical component seismic data to improve signal to noise for Rayleigh wave signals, Ambient Noise Tomography, Rayleigh Wave Tomography.
Problems: variable and often poorly known calibration,
Only sees fluctuations in pressure not absolute pressure.
Will clip on large events or in shallow water on ocean wave signals
Reaches seafloor noise floor except for “noise notch” (0.03-0.1 Hz) and above about 2 Hz.

Types of Pressure Sensors

Bottom Pressure Recorder (BPR)
Based on Paroscientific Co. Pressure Gauges (most stable sensor).
Typical band: 0 to 0.1 Hz (RBR 1 Hz).

Absolute Pressure Gauge (APG: Webb and Nooner, 2018)
APG is a high resolution, high sampling rate version of a BPR
Typical band 0 to 50Hz.
Sensor noise level is high compared to DPG.
Seismology- same uses as DPG, but much more accurate and stable response, but a higher noise floor. Enables observations requiring precisely known calibration such as compliance.
“Infinite” dynamic range as needed for large earthquakes and tsunamis.

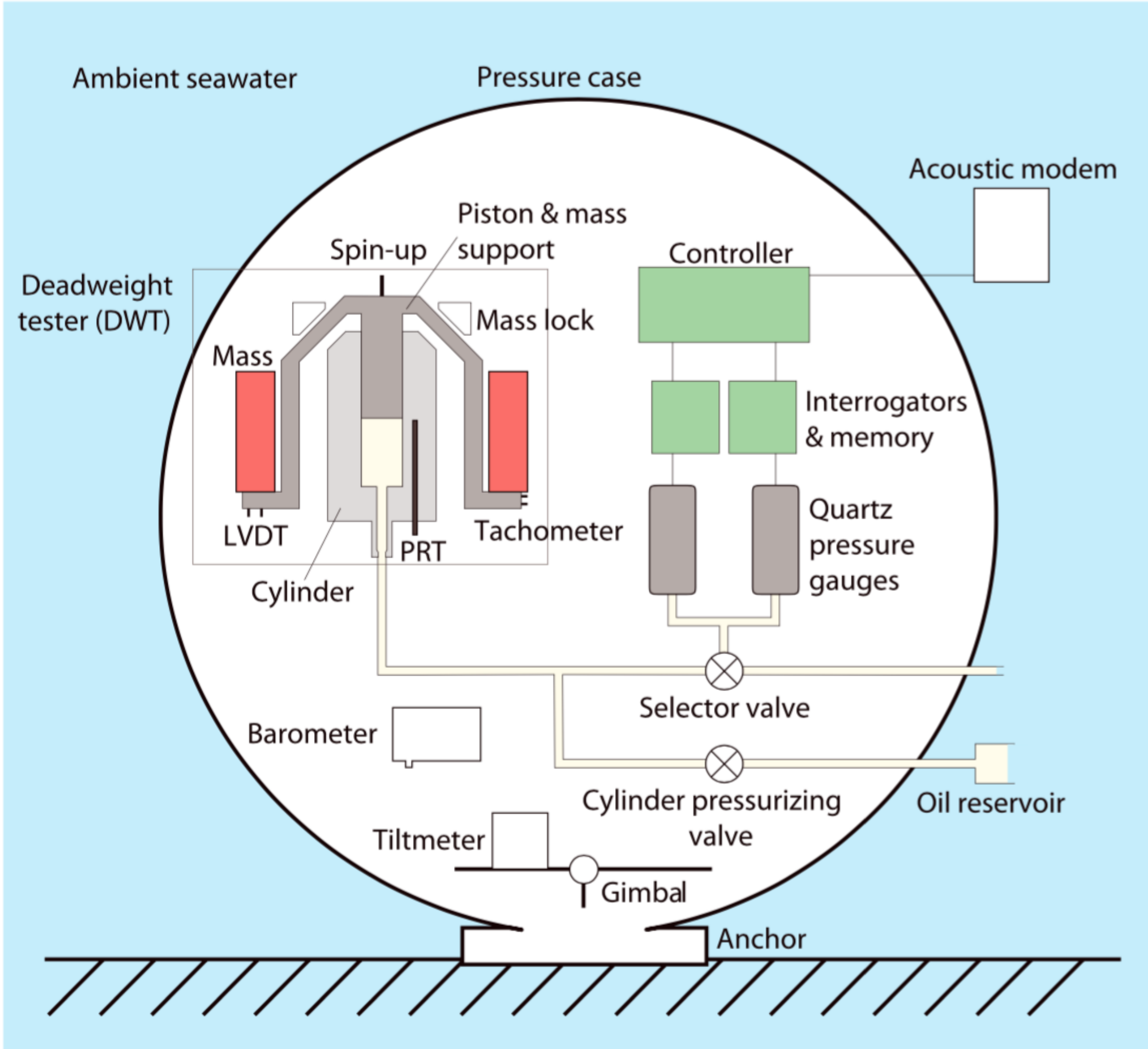
Accurate stable response to low frequency enables use for oceanography (tides, currents, waves).
Geodetic observations of vertical uplift: slow slip events, post seismic deformation, volcanic magma chamber recharge and discharge.
But long term drift and oceanographic “noise” limit use of APGs and BPRS for these applications!

Detection of Precursors

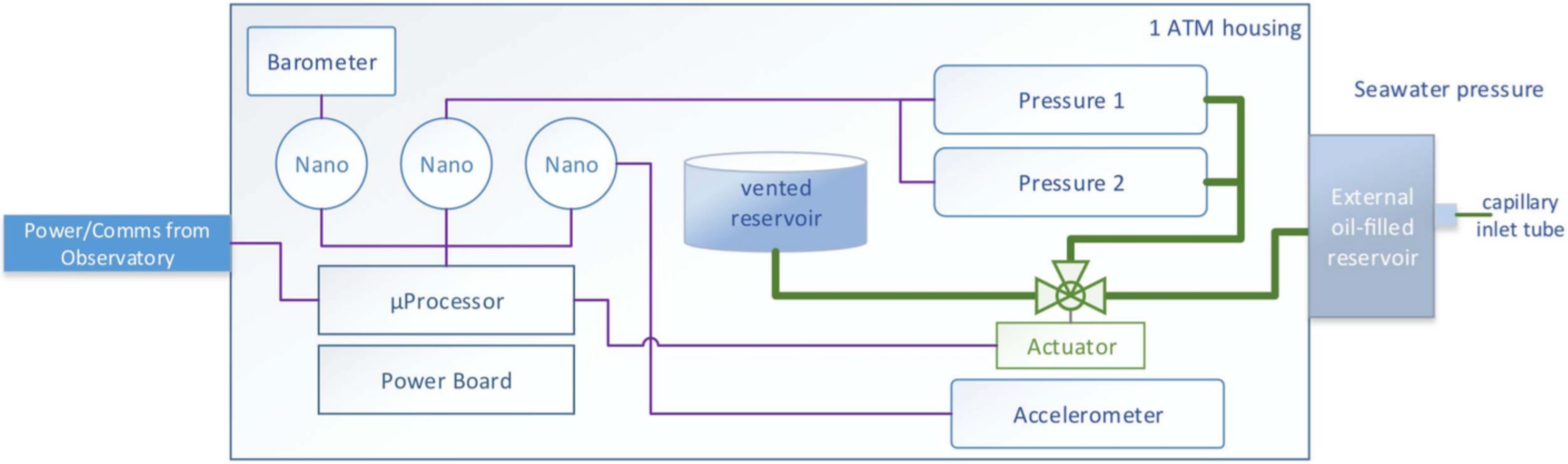
Potential precursors such as slow slip events or periods of extended slip on the interface are manifest as vertical excursions of the seafloor and thus cause changes in seafloor pressure.

Difficulties:

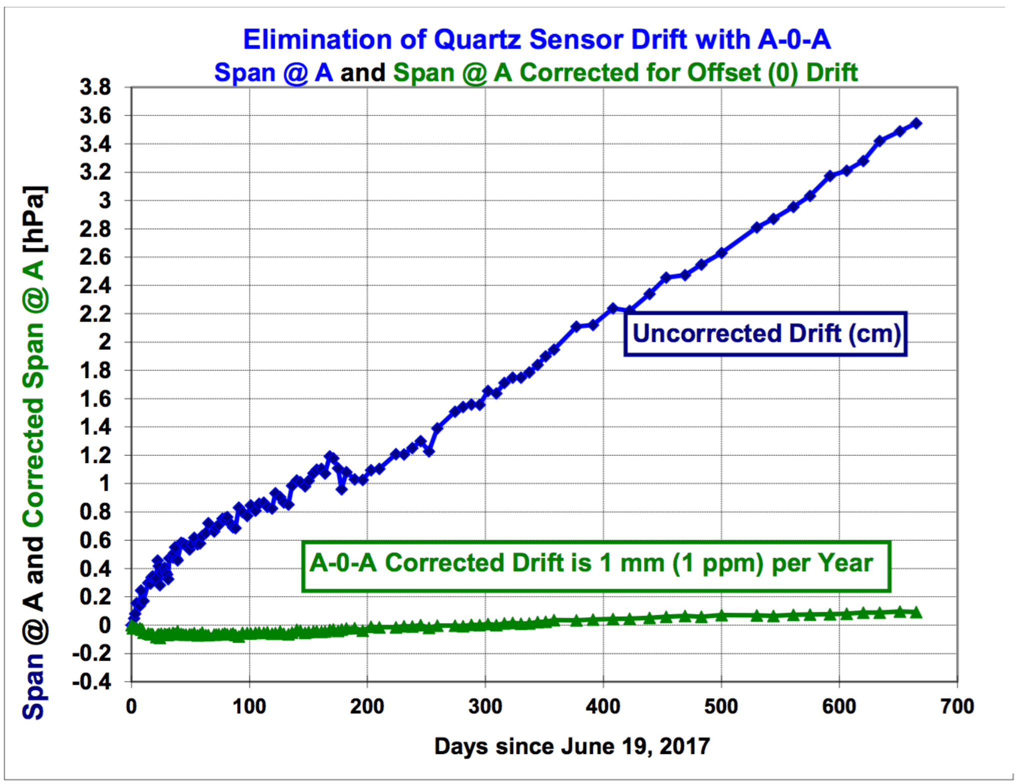
1) Drift of Pressure gauges can be large (10’s cm/yr)
   solution: “A-0-A”
2) Oceanographic signals are large
   tides and waves
   mesoscale eddies
   longer term changes in ocean currents
   solutions: reference sites
   ocean observations/ modeling

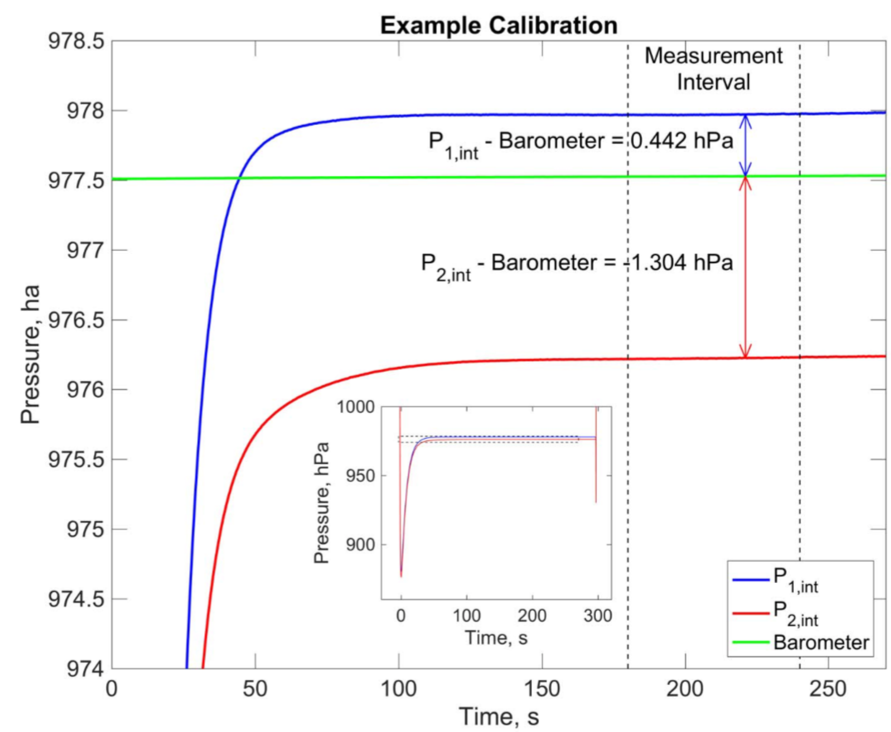


Drift Correction for APGs and BPSs, internal piston gauge calibrator (Sasagawa et al., 2018)

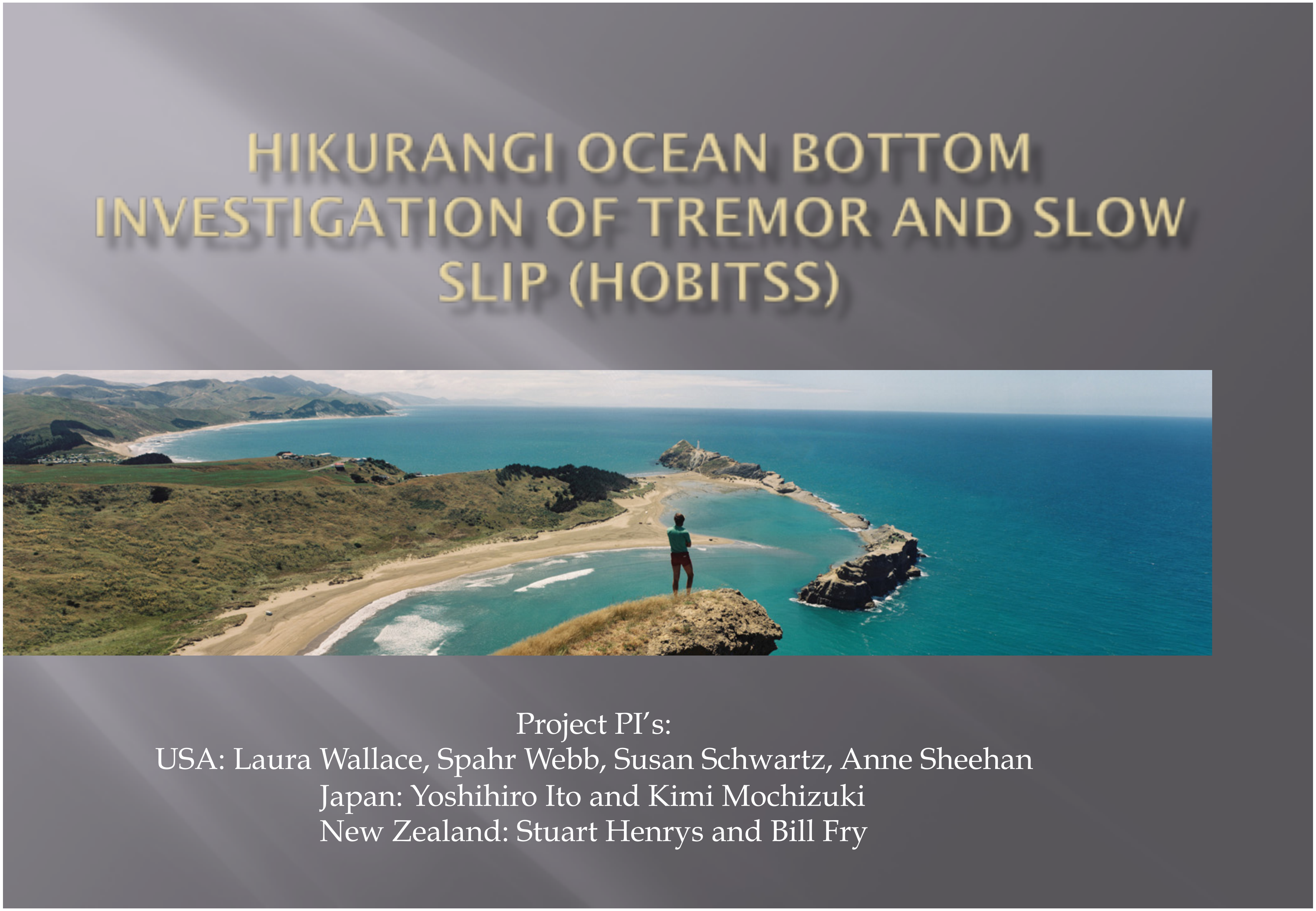


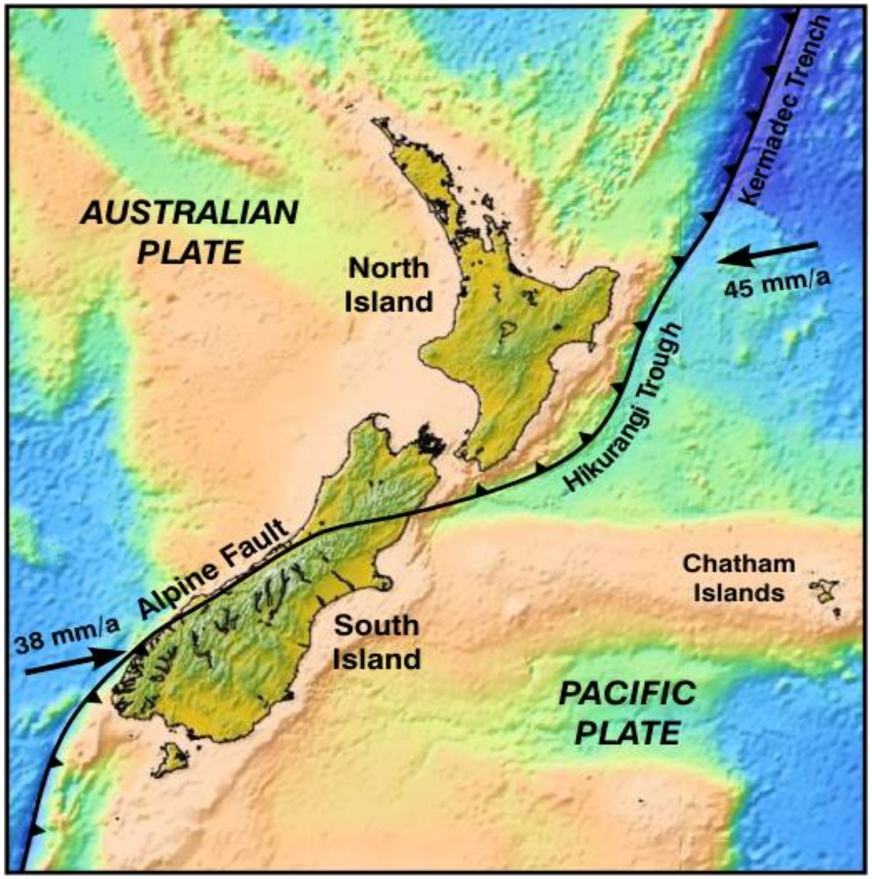
"A-0-A" switches pressure sensor from measuring seafloor pressure to pressure in case ('0") and uses drift measured at low pressure to correct drift at high pressure (Wilcock et al., 2018)

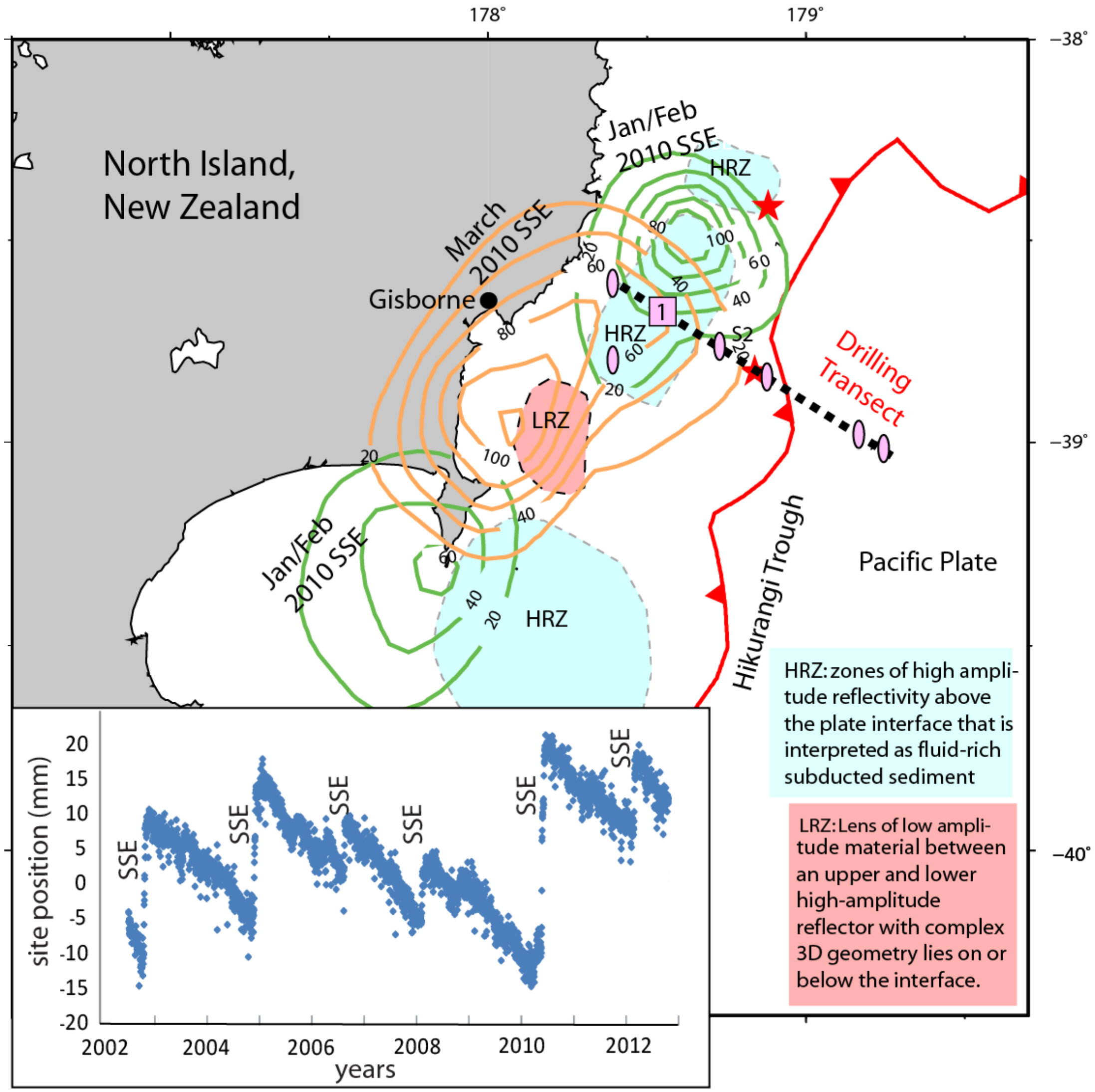




Example: Slow Slip Events offshore New Zealand

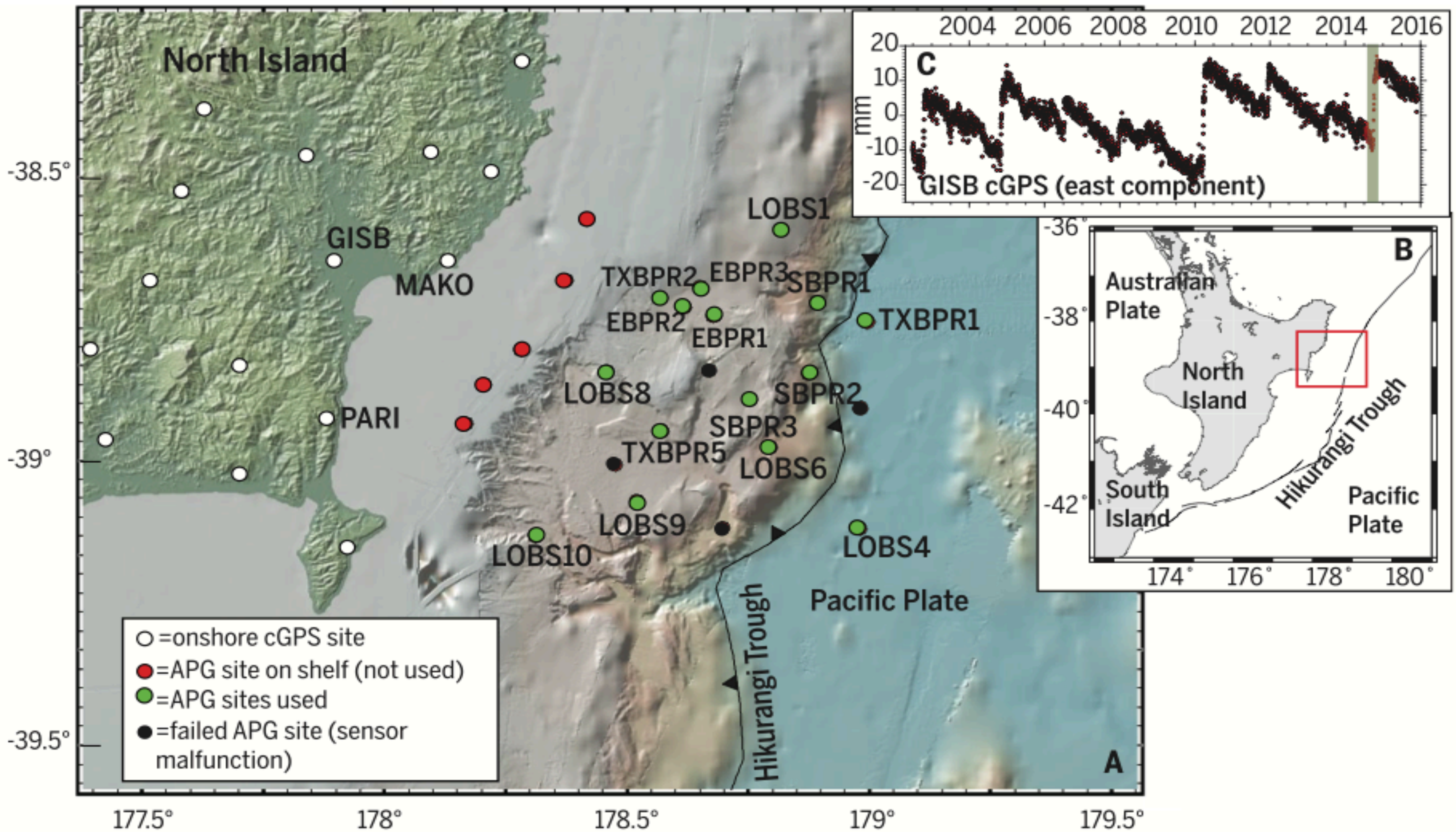




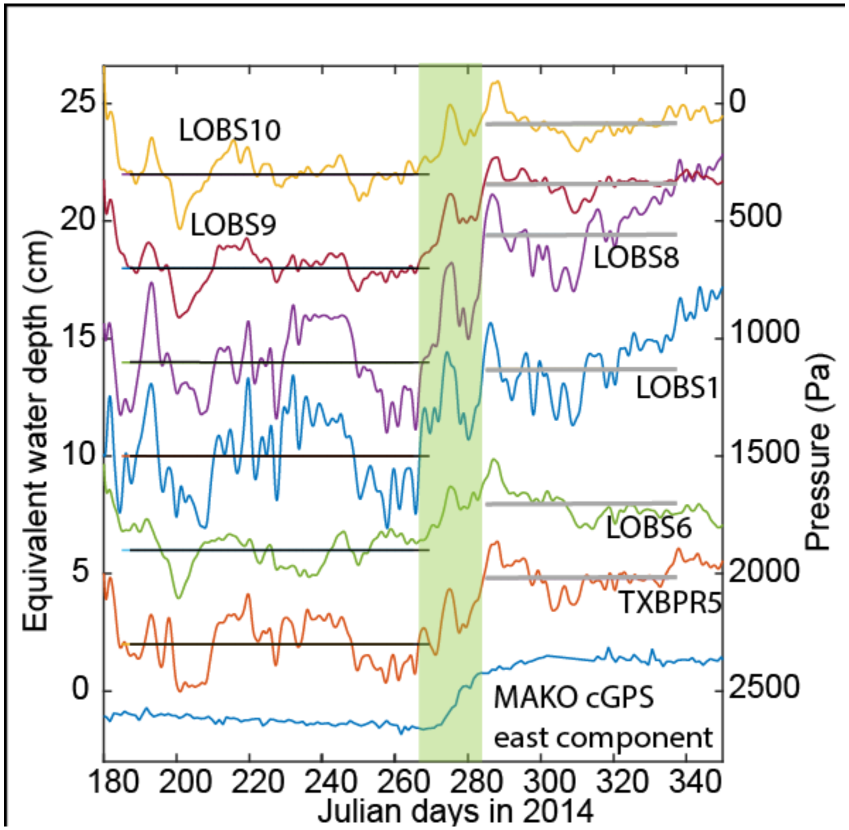


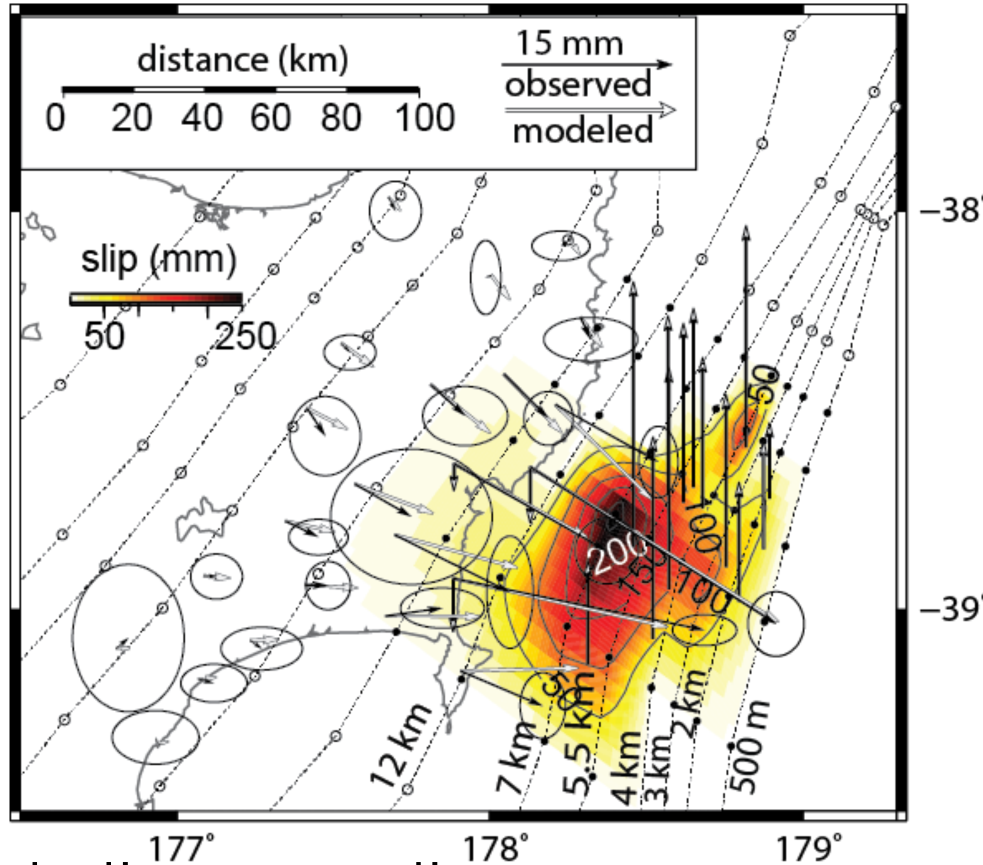
Quasi periodic slow slip events on plate interface offshore of Gisborne evident from GPS data from sites on land, but offshore extent not well resolved by land data. GPS data imply nearly unlocked plate boundary averaged over long times.

Absolute Pressure Gauges to measure Vertical Uplift from SSE



The HOBITSS experiment—resolved cm-level vertical deformation of the seafloor during a 2014 slow slip event using seafloor Absolute Pressure Gauges



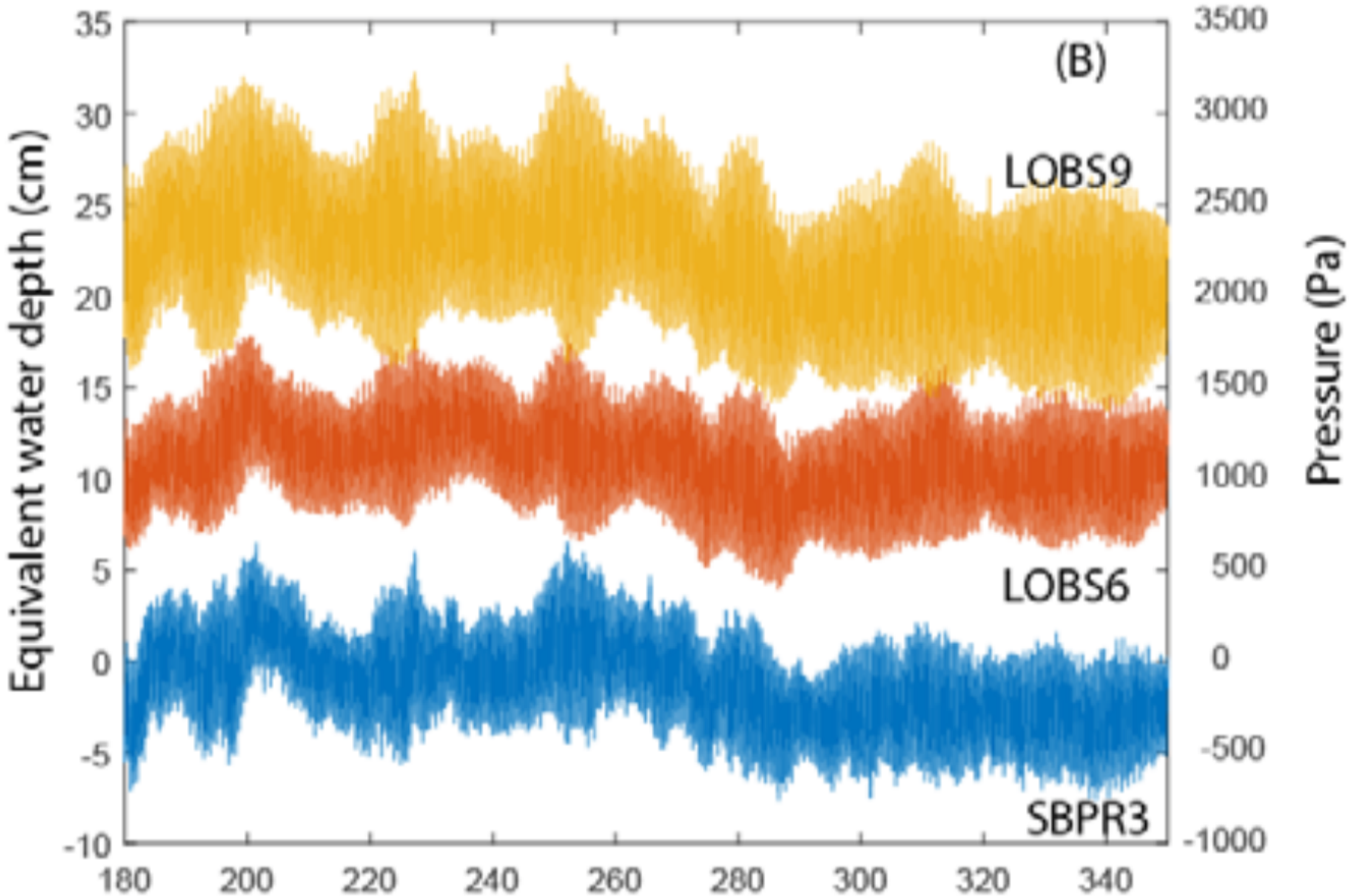


Pressure data showed slip extending to near the trench and 20cm+ slip on interface

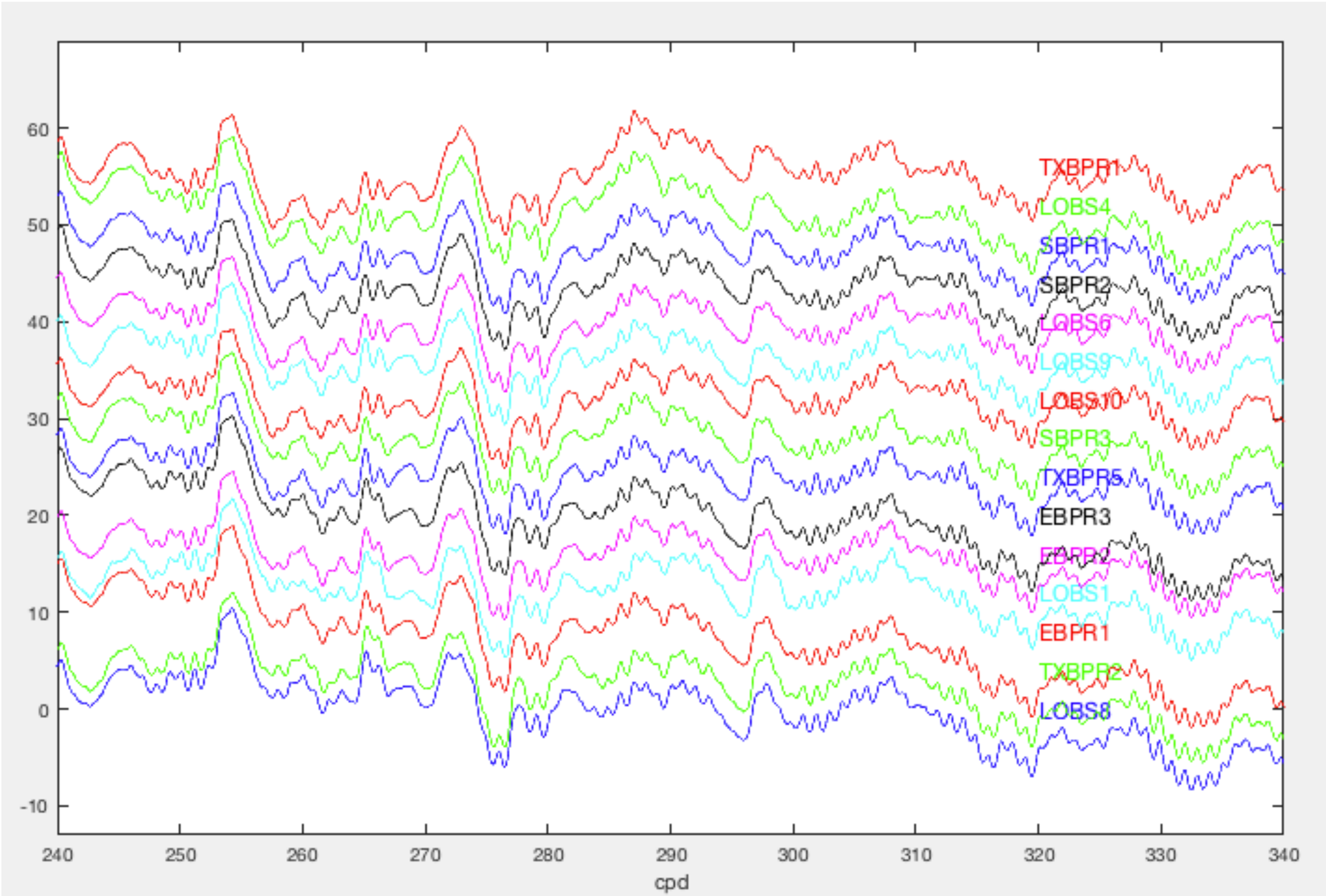
Wallace et al., (2016)

Wallace et al., (2016)

The Problem of Oceanography for Determining Vertical uplift from Seafloor Pressure Observations

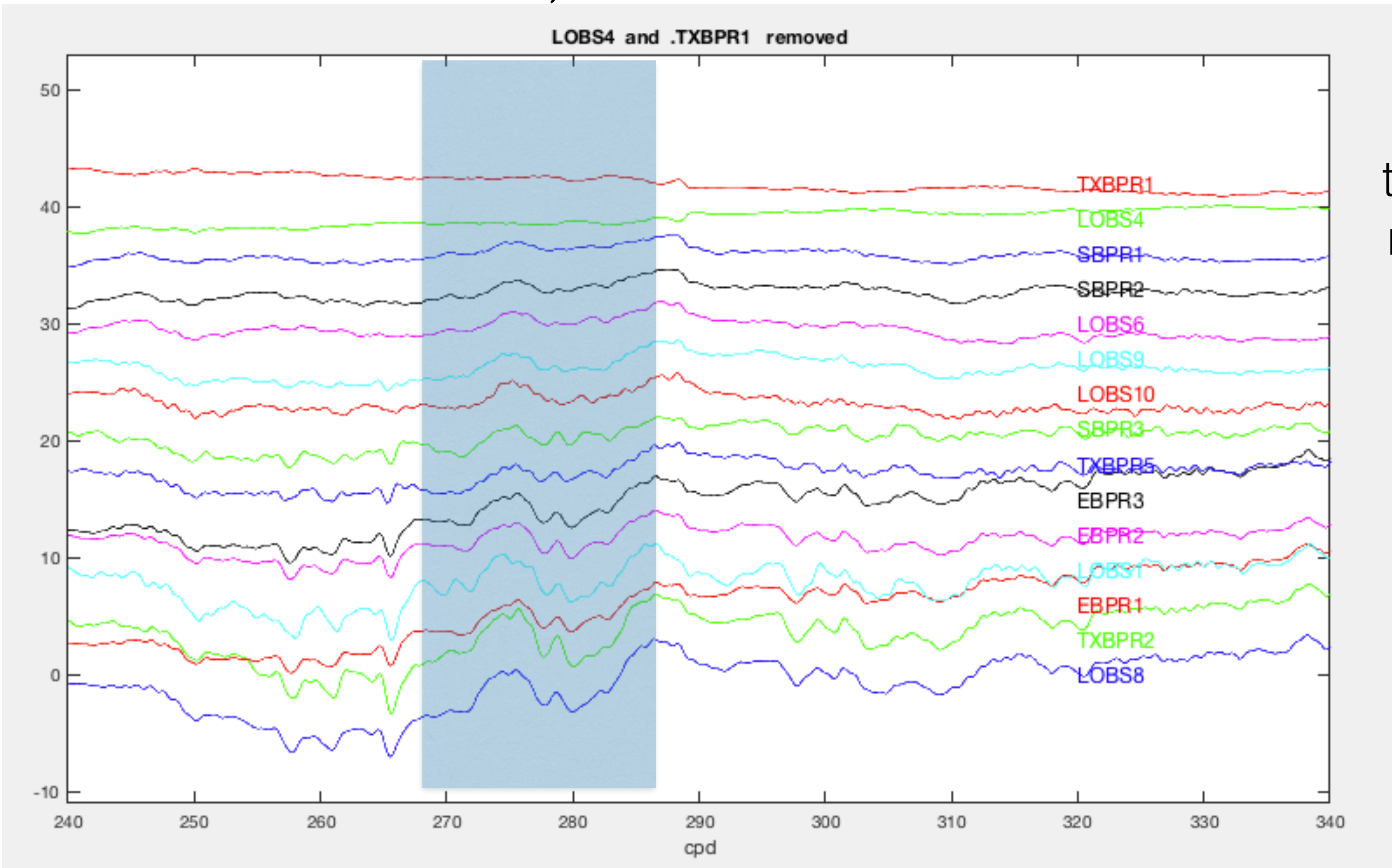


Tides: solution: low pass filter with time scale >2d



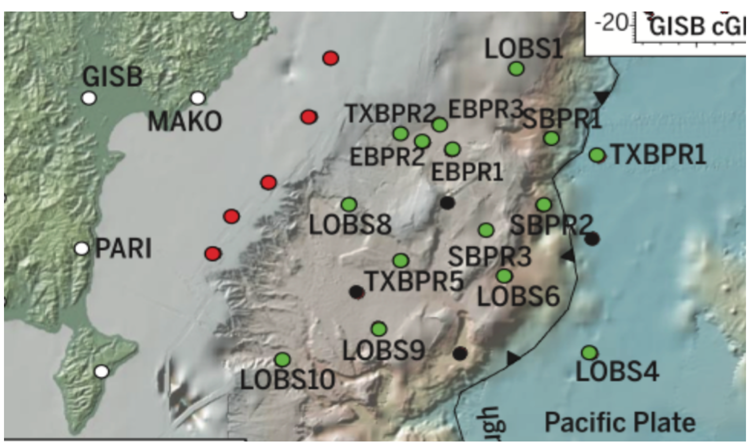
Filtered data show mesoscale eddies with amplitudes of 10+cm with much coherence across array.

A solution, use reference sites



two outer rise sites

SSE sites



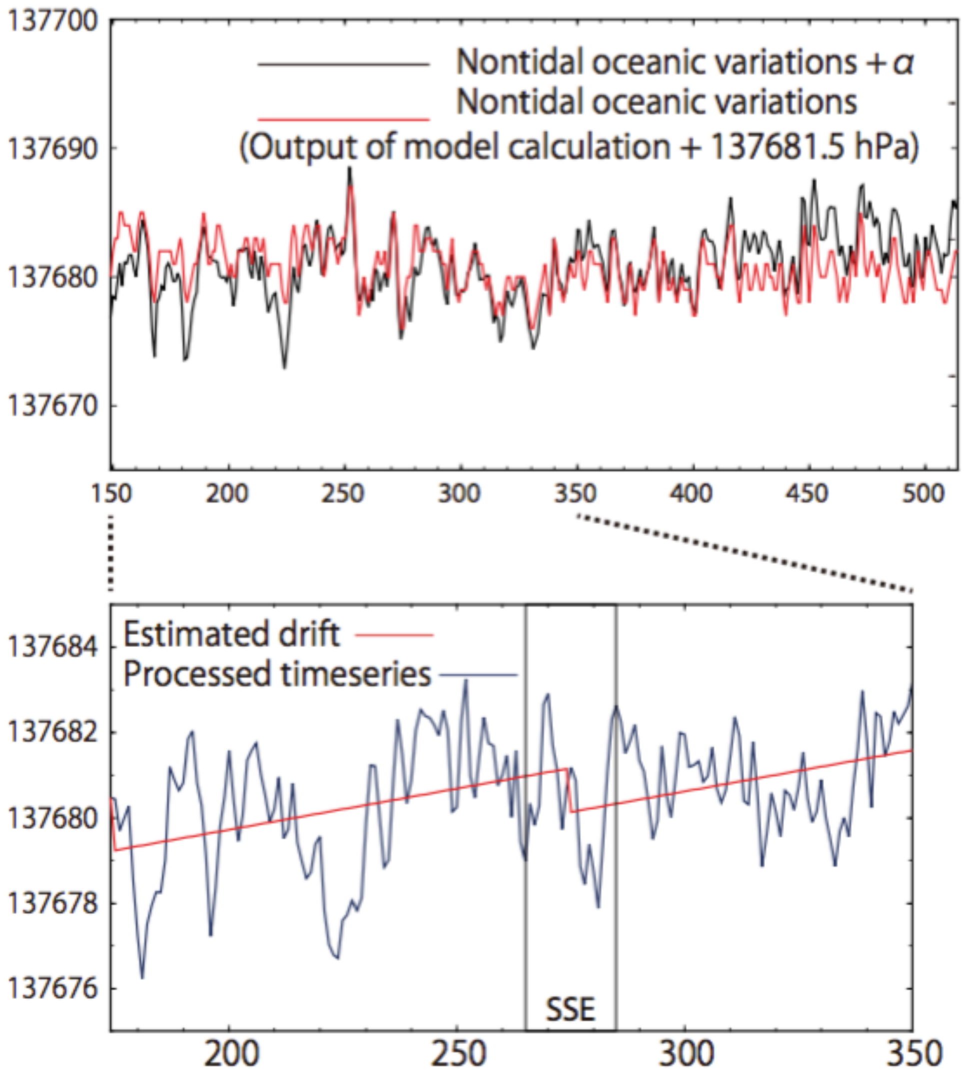
Average of two sites on incoming plate are used as reference sites to remove common mode oceanographic signal revealing slow slip event uplift, but signal to noise ratio is still small.

Other options for removing oceanographic “noise” from seafloor pressure gauge data to reveal vertical excursions of the seafloor due to possible precursor events (eg. slow slip events).

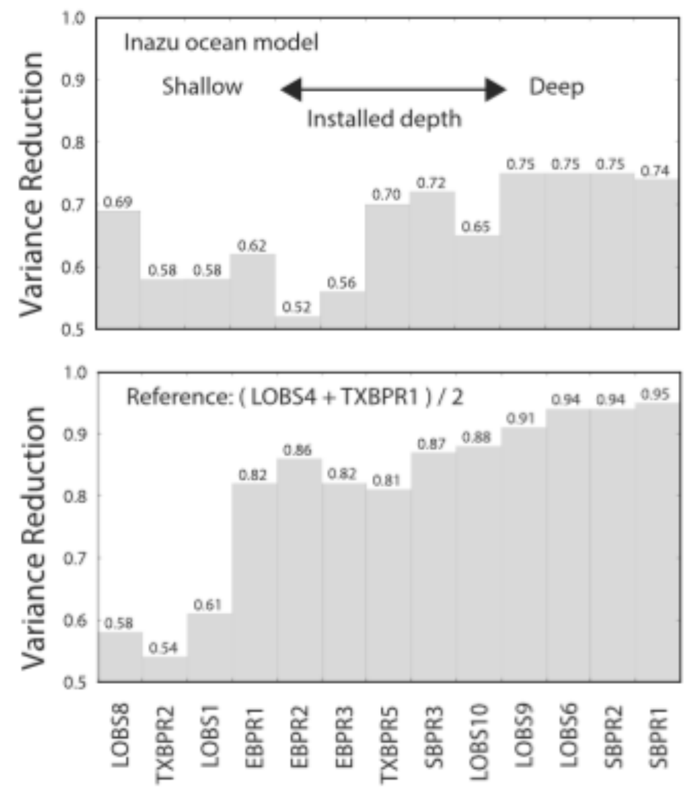
1) Predictions from oceanographic Models (eg. Muramoto et al., 2018)

2) Adding additional measurements of the oceanography- eg. CPIES and current meters and satellite altimetry.

Regional oceanographic model driven by atmospheric winds used to predict and remove oceanographic signals from seafloor pressure data from NZ (Muramoto et al., 2018)



Modeled seafloor pressure (red) variations explain about 70% of observed seafloor pressure variations (black) insufficient to clearly measure uplift association with slow slip events



Can additional observations of oceanography (current meters, CPIES, larger pressure arrays), perhaps assimilated in regional models enable removal of oceanographic signals from seafloor pressure arrays to better reveal precursor events and long term (vertical) strain accumulation rates?

In deep water, the residual pressure signals can be reduced to about 1cm rms, because of geostrophy, but on the sloping terrain near shore, this may be very hard.

Small test experiment in Cascadia (He et al., 2018) suggested a 2cm SSE could be detected and with improvement a 1cm SSE might be detected

$$fv = \frac{1}{\rho}\frac{\partial p}{\partial x}$$

$$fu = -\frac{1}{\rho}\frac{\partial p}{\partial y}$$

Conclusions

Pressure sensors exist that can resolve vertical excursions of seafloor depth associated with possible precursors.

Early results from new methods to remove drift from seafloor pressure data suggest observations with drift rates much less than 1 cm/yr are possible.

Pressure signals from mesoscale eddies with amplitudes of >10cm limit detection of small vertical excursions of the seafloor for geodetic applications

Methods to remove the eddy signal from seafloor pressure data are an active area of research and it may become possible to detect slow slip events on the day to many month time scale with amplitudes less than 1cm.

References

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