Determining slip behavior in the near-trough region of the Hikurangi subduction zone with GPS-Acoustic seafloor geodesy

Kelin Wang[1], C. David Chadwell[2], Motoyuki Kido[3]

[1]Pacific Geoscience Centre, Sidney, BC.; [2]Scripps Inst. Oceanography, La Jolla, CA.; [3]Tohoku Univ., Sendai

kwang@nrcan.gc.ca

The northern Hikurangi subduction zone is characterized by seamount subduction, a high degree of megathrust creep, and an abundance of shallow slow slip events (SSEs). Studying the relationship between these characteristics has important global implications, because it helps us understand how geological structures control megathrust slip behavior and size of subduction earthquakes. The main obstacle to this study is the paucity or lack of near-trench observations, and one of the most effective solutions is to make GPS-Acoustic (GPA-A) measurements across the trench.

At northern Hikurangi, GPS-A measurements will directly address two important questions: (1) the degree of megathrust locking near the trench and (2) the updip extent of SSEs. These two questions are closely related, because creep or "partial locking" can be an integrated effect of many SSEs of various sizes and timescales, including those too small or too slow to be detected by the present geodetic network. Currently, both questions are very poorly answered. Inversion of land-based GPS data can yield the scenario of a largely creeping megathrust with an updip narrow segment mostly locked (Wallace and Beavan, 2010) (Fig. 1, left), but the data could also allow a model of significant creep all the way to the trench because of their lack of near-trench resolution. Likewise, offshore SSEs could extend to the trench, but their updip extent cannot be reliably defined by the land-based GPS network. It has been argued that subducting seamounts and similar geometrical irregularities tend to cause creep and many small earthquakes (Wang and Bilek, 2011). At northern Hikurangi, the roughness of the subducting seafloor carrying a number of seamounts (Bell et al., 2010) makes creeping to the trench a possible scenario, with SSEs of different sizes and timescales being a likely creep mechanism.

The GPS-A approach (Fig. 1, right) has successfully captured interseismic, co-seismic and post-seismic motions along the submerged slopes of subduction zones (Gagnon et al., 2005; Kido et al., 2011). The resolution of the horizontal position approaches a centimeter or better after collecting data over a few days. To date, data have been collected primarily from ships that visit infrequently, limiting the temporal resolution. Recently, GPS-A has been adapted to moored buoys providing more continuous measurements. Potentially, GPS-A on wave-powered vehicles (e.g., Wave Glider) can replace ships for campaign measurements and even operate persistently above a seafloor site, mimicking a moored buoy. Additionally, a new type of benchmark is under development that would remain permanently on seafloor while instruments could be removed and replaced without causing an unknown offset in the time series of position. GPS-A geodetic measurements have excellent long-term stability and complement vertical deformation measurements with pressure gauges, which suffer from long-term drift.

For northern Hikurangi, we suggest deploying GPS-A sites along two trench-normal transects (Fig. 1, left) to address the two scientific questions discussed above. Top priority is given to question 1 regarding near-trench creep vs. locking. Scientifically, this question is the most critical and urgent for understanding the slip behavior and seismogenic potential of Hikurangi megathrust, and it cannot be addressed with other techniques such as seafloor pressure gauges and borehole monitoring. It also presents less operational and financial challenges than does the second question.

Primary (red squares in Fig. 1 left): Determining near-trench creep/locking with campaign-style visits using a ship or remotely-controlled, wave powered vehicle, such as a Wave Glider. The northern transect (line 05CM-04 of Bell et al., 2010) is located in an along-strike transition zone from creep to locking as defined using land-based GPS alone (Fig. 1 left). One of the three proposed sites is on the incoming plate (Fig. 2). Motion between the incoming-plate site and the overriding-plate sites over a time frame of a few years directly defines the state of near-trench locking or rate of creep. Relative motion between the two overriding-plate sites provides a rough estimate of the strain rate of the accretionary prism and facilitates comparison with other observations. The most landward site also serves to minimize the gap between land and seafloor measurements. The southern transect (line 05CM-01 of Bell et al., 2010) is located in an area where interpretation of land-based GPS indicates full locking to the trench (Fig. 1 left). We propose to have a minimum of two sites along this transect (Fig. 3). Having two transects allows the detection of along-strike changes in the monitored creep and locking behavior.

Secondary (red and yellow squares in Fig. 1 left): Near-field detection of SSE transients with continuous measurements using either a moored-buoy or Wave Glider. It involves (1) densification of the two transects by adding two more sites to each (yellow squares in Fig. 1 left) and (2) using moored-buoys for some of the sites. Most of the sites are directly above the plate interface that is updip of the SSE events defined with sub-aerial GPS and can readily detect seafloor displacements to determine whether the SSEs extend to the trench.

References:

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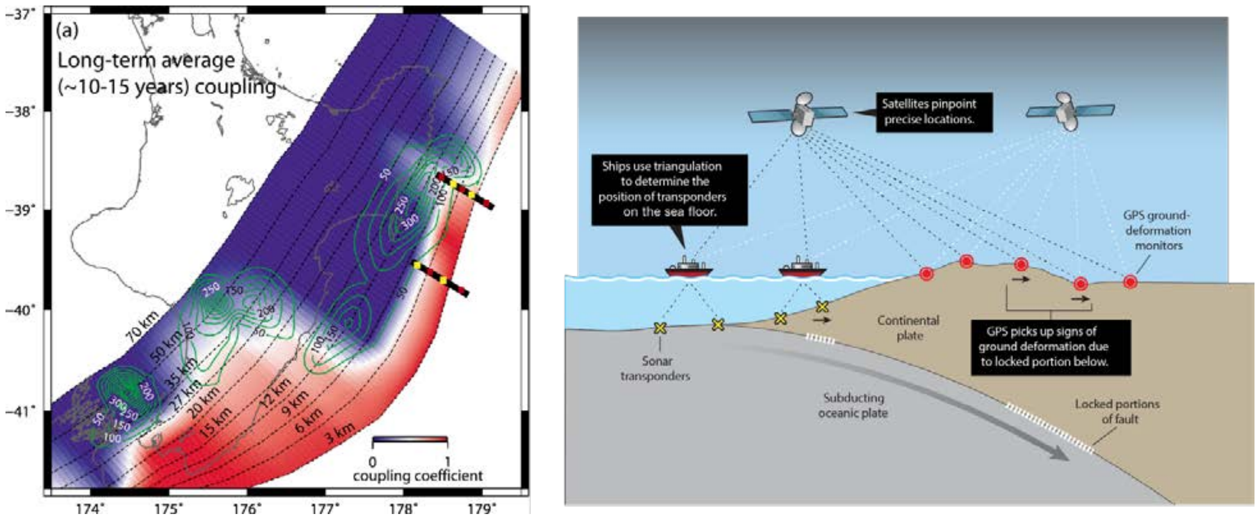

Figure 1. [Left] Near-trench locking of megathrust based on inversion of land-based data [Wallace and Beavan, 2010]. Seafloor geodetic transects (solid red squares) can directly constrain the state of locking or creep. [Right] The GPS-Acoustic technique [Newman, 2011]. While ships have been the main platform for GPS-A, moored buoys and small, remotely operated vehicles are beginning to replace ships. This will lower costs and increase access.

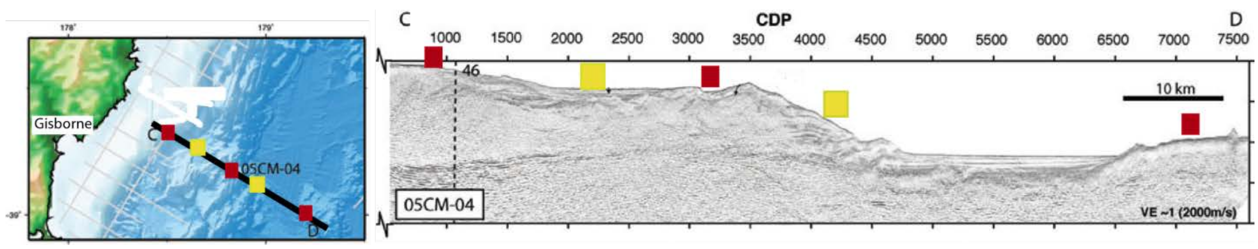

Figure 2. Proposed location of GPS-Acoustic seafloor sites of the northern transect along reflection profile offshore of Gisborne (Bell et al., 2010). Left shows map view, right shows profile. Red and yellow indicate primary and secondary sites, respectively, as explained in the text.

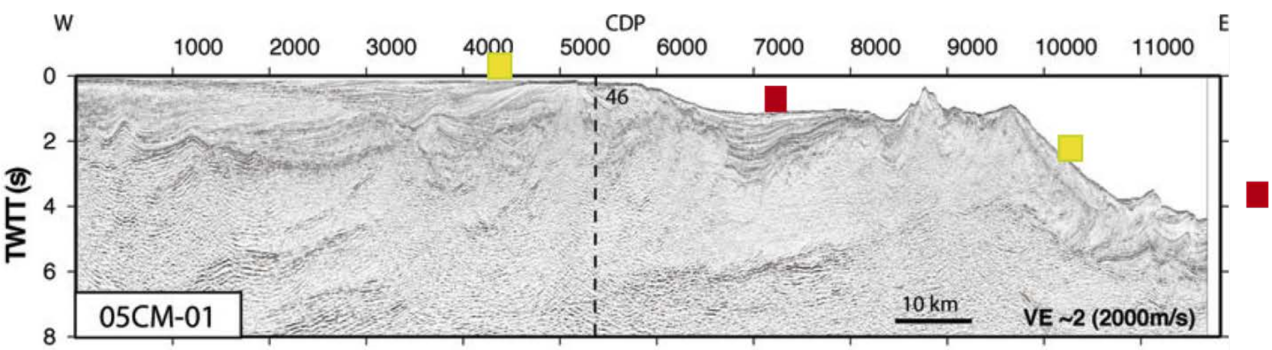

Figure 3. Proposed location of GPS-Acoustic sites of the southern transect along seismic reflection profile in the Hawke Bay area (Bell et al., 2010). See Fig. 1 left for transect location. Red and yellow indicate primary and secondary sites, respectively, as explained in the text.