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Reversals in geodetically observed surface motions suggests enhanced slab pull in the months preceding Maule Mw 8.8 and Tohoku-oki Mw 9.0 earthquakes

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It is increasingly apparent that the progression to eventual failure of large subduction earthquakes can be captured by continuous networks that record anomalous seismic and geodetic signals in the late interseismic period. Such precursory signals are generally understood to be related to a gradual decoupling of the mainshock area of the fault and can last from days to years. These natural observations are consistent with various numerical and laboratory models in which similar late-interseismic signals are generated.

Here we analyse the continuous GNSS records of the final 5 years leading to the 2010 Mw 8.8 Maule, Chile and 2011 Mw 9.0 Tohoku-oki, Japan earthquakes. We implement the Greedy Automatic Signal Decomposition - a regression approach that builds upon existing tectonic trajectory models - to model the daily GNSS displacement time series as the sum of background seasonal oscillations, step functions, linear (1st order polynomial) motion, and a sparse number of multi-transient functions. The multi-transient functions are simply the sum of decay functions (e.g. exponential, logarithmic) that begin at the same time but have different characteristic decay constants. The inclusion of these versatile multi-transients allows the model to capture a variety of transient motion. We see that both subduction margins exhibit variability in their interseismic velocities. The most striking of these motions occur in the 5-7 months directly before both the Maule and Tohoku-oki earthquakes during which the sense of motion reverses in the trench-perpendicular component. These reversals manifest themselves as wobbles in the displacement time series with a peak-to-peak displacement between 4-8 mm and occur on a spatial scale in the order of thousands of kilometres. After investigating fluid loading and possible reference frame artifacts, we conclude that the wobbles are most likely of a tectonic origin.

In the pre-Tohoku-oki case, for which we have a much denser surface coverage, kinematic models indicate an initial extension in the Philippine Sea Plate followed by a viscoelastic rebound. The spatial scale and approximate onset of this apparent extension are in agreement with the

anomalous GRACE gravity signals reported in earlier work of Panet et al. (2018, Nature Geoscience). Furthermore, the speed that the trench-wards transient migrates along-strike of the subduction zone before Tohoku-oki indicates that deep slow-slip is also occurring. In the pre-Maule case, we see a similar reversal but lack the number of measurements to track any migration of the velocity front. Nevertheless, from inclusion of vertical displacement in analyses of both networks, we suspect that these late interseismic reversal signals are caused by a sudden enhanced slab pulling. Such an enhanced slab pull might be caused by sudden densification of metastable slab. Therefore, a main message of this work is that large asperities, while they might fail gradually local to the mainshock region, might also be brought to failure by changes in the slab pull boundary conditions that can be several hundreds of km deep.