Long period GPS waveforms. What can GPS bring to Earth seismic velocity models?

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1) Abstract

It is now commonly admitted that high rate GPS observations can provide reliable surface displacement waveforms (Cervelli, et al., 2001; Langbein, et al., 2006; Houlié, et al., 2006; Houlié et al., 2011). For long-period (T > 5s) transients, it was shown that GPS and seismometer (STS-1) displacements are in agreement at least for vertical component (Houlié, et al., Sci. Rep. 2011). We propose here to supplement existing long-period seismic networks with high rate (>=1Hz) GPS data in order to improve the resolution of global seismic velocity models. GPS measurements are providing a wide range of frequencies, going beyond the range of STS-1 in the low frequency end.

Nowadays, almost 10.000 GPS receivers would be able to record data at 1 Hz with 3000+ stations already streaming data in Real-Time (RT). The reasons for this quick expansion are the price of receivers, their low maintenance, and the wide range of activities they can be used for (transport, science, public apps, navigation, etc.).

We are presenting work completed on the 1Hz GPS records of the Hokkaido earthquake (25th of September, 2003, Mw=8.3). 3D Waveforms have been computed with an improved, stabilized inversion algorithm in order to constrain the ground motion history. Through the better resolution of inversion of the GPS phase observations, we determine displacement waveforms of frequencies ranging from 0.77 mHz to 330 mHz for a selection of sites. We compare inverted GPS waveforms with STS-1 waveforms and synthetic waveforms computed using 3D global wave propagation with SPECFEM. At co-located sites (STS-1 and GPS located within 10km) the agreement is good for the vertical component between seismic (both real and synthetic) and GPS waveforms.

5) References

Becker, T.W., Boschi, L., 2002. A comparison of tomographic and geodynamic mantle models. Geochemistry, Geophys. Geosystems 3, n/a–n/a. doi:10.1029/2001GC000168

Cervelli, P., Murray, M.H., Segall, P., Aoki, Y., Kato, T., 2001. Estimating source parameters from deformation data, with an application to the March 1997 earthquake swarm off the Izu Peninsula, Japan. J. Geophys. Res. 106, 11217. doi:10.1029/2000JB900399

Houlié, N., Briole, P., Bonforte, A., Puglisi, G., 2006. Large scale ground deformation of Etna observed by GPS between 1994 and 2001. Geophys. Res. Lett. 33, L02309. doi:10.1029/2005GL024414

Houlié, N., Occhipinti, G., Blanchard, T., Shapiro, N., Lognonné, P., Murakami, M., 2011. New approach to detect seismic surface waves in 1Hz-sampled GPS time series. Sci. Rep. 1, 44. doi:10.1038/srep00044

Langbein, J., Murray, J.R., Snyder, H.A., 2006. Coseismic and initial postseismic deformation from the 2004 Parkfield, California, earthquake, observed by global positioning system, electronic distance meter, creepmeters, and borehole strainmeters. Bull. Seismol. Soc. Am. 96.

Pasyanos, M.E., 2010. Lithospheric thickness modeled from long-period surface wave dispersion. Tectonophysics 481, 38–50. doi:10.1016/j.tecto.2009.02.023

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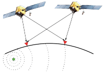
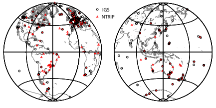


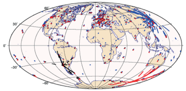
2) Motivation and Goals

We propose to use GPS networks to increase the number of sites where seismic waves are detected and to be used for tomographic inversions, especially in the range of resolution at which tomographic models tend to disagree.

GPS network collecting data at 1 Hz

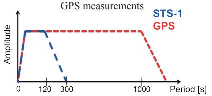


Data coverage at 200 km depth from 3 earthquakes (Hokkaido 2003, Balleny 1998, Maule Chile 2010)

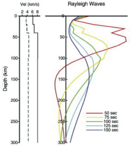


A new GPS dataset of displacement waveforms can supplement the existing seismic dataset by increasing the bandwidth of the records up to a period of ~ 1000 seconds. The expansion of the periods covered will allow to better constrain the properties of the upper- and mid-mantle.

Period ranges of broadband seismometers (STS-1) and GPS measurements



Depth of sensitivity of Rayleigh-waves depending on wavelength



Adapted from Paysanos, 2010

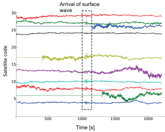
3) Methodology

GPS measurements are recordings of phases (time-delays) between each GPS station and the visible satellites. These phase signals are converted to displacement using a least-squares approach:

$$disp = (G^T * G + \varepsilon * I)^{-1} * G^T * d$$

disp: displacement in vertical, north and east direction
G: model matrix of positions of all the visible satellites
ε: uncertainty (0.002 m)
I: identity matrix
d: satellite phase signal

Phase signal of the visible satellites at 0292 GPS station

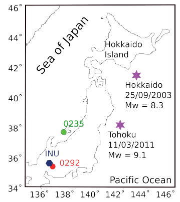


4) Results of Hokkaido Earthquake

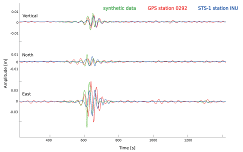
The displacement time series of GPS station 0292 (red), co-located broadband seismometer INU (blue) and synthetic data (green) are compared for vertical, north and east components within 30 - 50 second periods.

Different band-pass filters are applied on the vertical components of the different measurements and synthetic data. We observe good agreement in the 30-50 and 50-120 second band-pass ranges. Between 120 and 300 seconds the GPS data is contaminated with ionosphere noise. GPS data is recovering the energy of the earthquake at long periods (300-1300 seconds) while the broadband seismometer is not capturing the signal.

Location of Hokkaido earthquake and recording stations



Vertical, north and east components of 0292 GPS station, INU STS-1 station and synthetic data: band-passed 30-50 s



Vertical displacement of GPS, STS-1 and synthetic data with different band-pass filters applied