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Monitoring the 2011 Tohoku-Oki waves without sismometers: from rupture initiation to seismic and tsunami waves

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Seismic and tsunami waves caused by the 11 March 2011 Tohoku mega-quake generated Pacific-wide ionospheric signals from the coupling between ground/sea/atmosphere/ionosphere. High-quality observations of the ionospheric signals have been performed using the dense GPS network located in Japan, and less dense networks in Hawaii and Chile, but also for the first time with airglow measurements, which image the 630nm light emission of the ionosphere, when it is disturbed by the propagating tsunami. Signals have not only been recorded during and after the rupture and first arrivals of seismo-acoustic waves and gravito-tsunamic waves, but also possibly prior these signals, suggesting a slow-slip event prior the seismic rupture initiation.

Over Japan, all the different waves are clearly observed by GPS ionospheric sounding, and the first signals peak in the ionosphere about 8 minutes after the quake and therefore about 17 minutes prior the first arrival of the tsunami on the coast. We show that these signals provide key information on the rupture surface and the vertical sea level amplitude. We also observe clear atmospheric resonances, as well as Rayleigh and Tsunami waves, in addition to the acoustic waves.

In Hawaii and possibly in Chili, co-located GPS-airglow measurements of the ionospheric response to the tsunami have been performed for the first time, and provide an unprecedent sensitivity to very long ($\sim$1 hr-10 minutes) waves. These data provide movies of the propagating tsunami front, and show also its diffraction by the Hawaii Islands. The Hawaii observations indicate that the first ionospheric waves are observed approximately one hour before the arrival time of the tsunami.

We propose that these low-frequency signals are associated with a Slow Slip Event possibly associated to the initiation of the mega-quake and that the monitoring of atmospheric waves in the ionosphere with dense GNSS and airglow systems might open a new temporal window in the observation of tectonic deformation with typical periods of a few hours, between the rapid seismic rupture and the slow slip deformation, classically monitored by seismometers and GPS respectively.