Multiple detection of a "rapid" slow slip event before the March, 2011 Tohoku earthquake from regional and global ionospheric, ground GPS and oceanic DART observations

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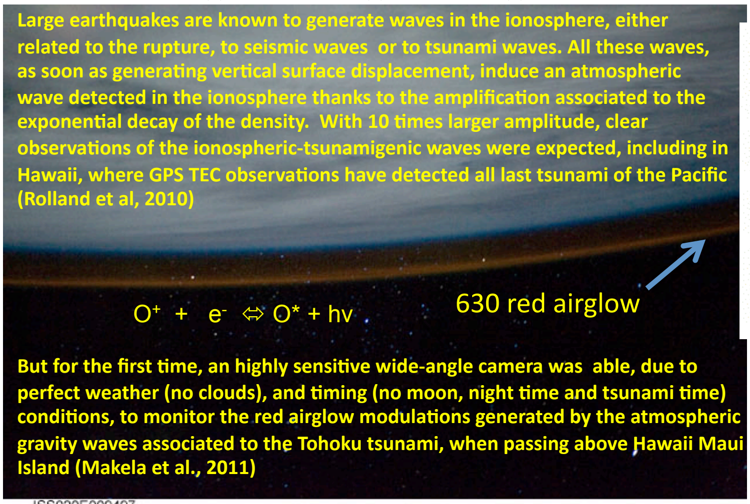
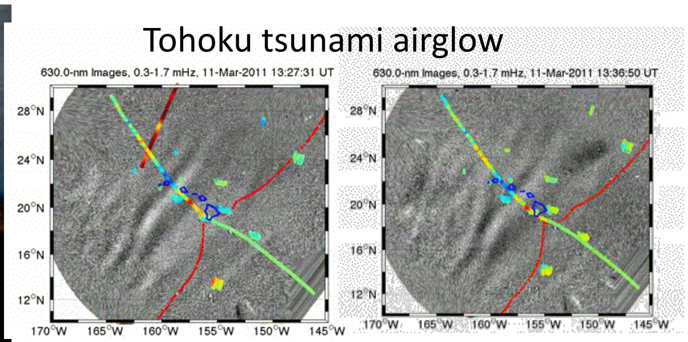
Large earthquakes are known to generate waves in the ionosphere, either related to the rupture, to seismic waves or to tsunami waves. All these waves, as soon as generating vertical surface displacement, induce an atmospheric wave detected in the ionosphere thanks to the amplification associated to the exponential decay of the density. With 10 times larger amplitude, clear observations of the ionospheric-tsunamigenic waves were expected, including in Hawaii, where GPS TEC observations have detected all last tsunami of the Pacific (Rolland et al, 2010)

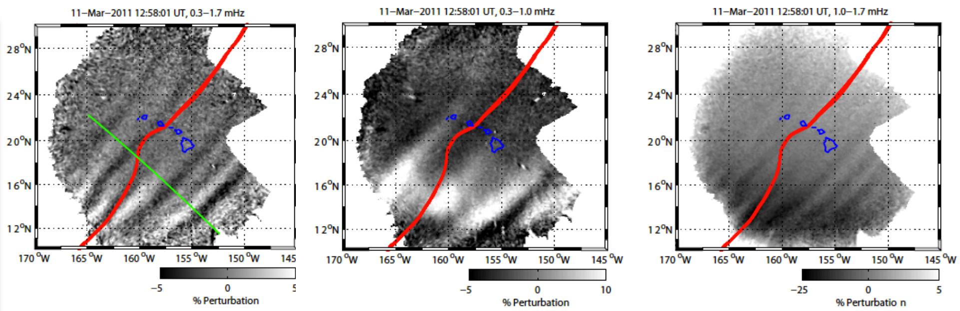


But for the first time, an highly sensitive wide-angle camera was able, due to perfect weather (no clouds), and timing (no moon, night time and tsunami time) conditions, to monitor the red airglow modulations generated by the atmospheric gravity waves associated to the Tohoku tsunami, when passing above Hawaii Maui Island (Makela et al., 2011)

Tohoku tsunami airglow



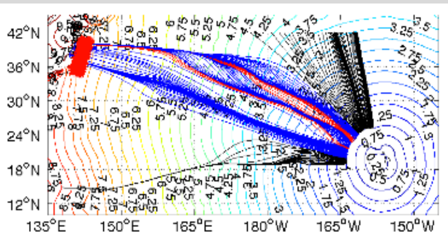
Two of the snapshots of the airglow camera showing in black and white the airglow intensity of the sky above Hawaii. The color spots are the TEC sounding of the ionosphere and are found coherent with the airglow. The red line is the Tsunami Travel Time first arrival, while the « snake » is the DART signal plotted in space, assuming therefore a propagation along the ray of the tsunami.



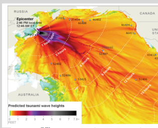
Pre-Tohoku tsunami (?) airglow observation

A clear signal appears on the airglow arriving about one hour before the first arrival, with a velocity of 185 m/s ± 34m/s and a period of 26±3.1 min. Is this an atmospheric wave? A TID not related to Tohoku? Or a signal generated by a pre-seismic « tsunami »?

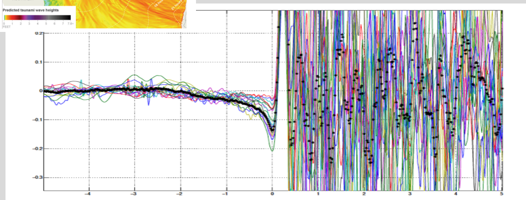
Its Azimuth (132°->134°) supports not only an origin at the North-east of the Tohoku, i.e. at the starting zone of the rupture but also propagation sensitive to the bathymetry (i.e. small tsunami) and NOT a great circle (i.e. gravity air wave, 123°)

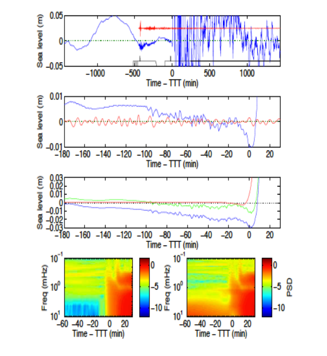


Ground truth DART



Analysis of the Hawaii DART, as well as of several DART in the radiation direction of Tohoku shows that most of the DART shown after tidal correction, a low amplitude (2 cm) sea level deflation starting 1h-2h before the main arrival

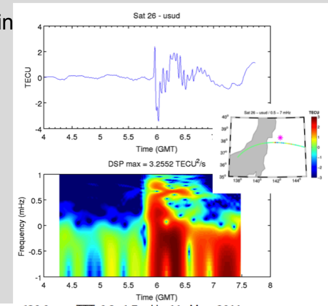




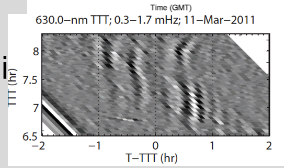
Japan Ionopheric TEC

Similarities in the timing of the ionospheric signals over Japan and Hawaii.

Japan

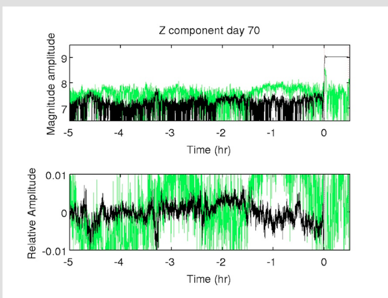


Hawaii



In order to analyse the presence of a similar signal in the GPS data, we processed the 1 Hz data of the 17 prefectures closest from Tohoku. The GPS were produced with the with the GIPSY/OASIS II v 6.0 software in Precise Point Positioning (PPP) mode. The wet delay parameters and horizontal gradients were modeled as random walk processes and a constant offset in zenith wet delay. All data were then stacked in order to search a deformation mode (black line) with the same pattern as the main Tohoku shock, superimposed to a common mode related to GPS errors (green line). Results are scaled with the Tohoku offsets. A signal similar to the DART is found with however a poor S/N ratio

Ground truth DART



Conclusion: The airglow observations have pinpointed a possible long period arriving in Hawaii 1-2hr prior the main shock. A long period trend is also found in the several DARTS and, with a poor S/N, in a stack of the GPS/ GEONET stations. We propose that this signal is associated to a Slow Slip Event, able to generate atmospheric gravity waves.

Ref: Makela et al. GRL, doi:10.1029/2011GL047860 , 2011. Rolland et al., GRL, 10.1029/2010GL044479 , 2010.