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The 2012 Haida Gwaii earthquake and tsunami: state-of-the-art GNSS ionospheric observations analysis and modeling

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Large earthquakes (Mw>6) and tsunamis are known to induce ionospheric perturbations which are frequently observed in the Total Electron Content (TEC) estimated from multi-frequency Global Navigation Satellite Systems (GNSS) data (e.g., GPS, GLONASS and soon, Galileo). The Mw 7.8 Haida Gwaii thrust earthquake occurred on 28 October 2012 along the Queen Charlotte fault off the western coast of Canada. This event triggered a transpacific tsunami having nearly 4 cm height offshore from the Hawaii archipelago. We report on ionospheric disturbances triggered both in the near-field (< 1000 km) by the sudden sea-surface uplift at the source (estimated to 2 m) and at further distances by the tsunami propagation.

The existence of dense regional GNSS networks near the source and in the tsunami propagation path provides an exceptional data set for state-of-the-art analysis of the coseismic ionospheric disturbances. We use observations from 22 stations of the Canadian Geological Survey GPS network. With these data we study the ionosphere directly above the source region. We also analyzed data from 65 stations in the Hawaiian GNSS network. Because Hawaii is located along the propagation path of many transpacific tsunamis (e.g. Kurils 2006, Samoa 2009, Chile 2010, Tohoku 2011 and Haida Gwaii 2012), this is an excellent location to observe low-frequency (~1.5 mHz) tsunamis-induced ionospheric gravity waves.

To understand source-related features, we back propagate the near-field ionospheric acoustic waves to constrain the location of the peak sea-surface uplift. We find the peak is within 50 km of epicenter locations estimated by other seismological methods. In addition, we model the GNSS-TEC perturbations in 3 steps: (1) 3D modelling of the neutral atmosphere perturbations, (2) coupling of the ionosphere with the neutral atmosphere and (3) integration of the electron density perturbation along each satellite-station ray path. The neutral atmosphere perturbations in the near field are modelled using acoustic ray tracing, while in the far field we use atmospheric normal mode summation.

We observe strong trends in the processed data which are also well reproduced with our modeling. In the vicinity of the epicenter, strong southward anisotropy of the ionospheric radiation pattern is observed and is thought to be due to the local geomagnetic effect. We show that tsunami propagation southward, parallel to the geomagnetic field lines, provides optimal coupling conditions between the tsunami-induced atmospheric gravity waves and the ionosphere. Besides the typical Doppler effect due to the GNSS satellites motion, we illustrate that satellites positioned upstream of the tsunami do not observe the tsunami-induced ionospheric waves while those positioned downstream do observe the perturbation. We demonstrate with modeling that this latter observation is related to the 3D geometrical structure of the tsunami-induced atmospheric gravity wavefront. In the near future, we anticipate that this kind of data set can be used to constrain the 3D structure of the tsunami-induced gravity wave, with the ultimate goal of achieving a real-time estimation of the tsunami amplitude at the ocean level from space geodetic data.