## GNSS Total Electronics Contents tsunami measurements and tsunami height inversions.

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GNSS Total Electronic Content (TEC) measurements provide an additional coverage of GNSS ground motion measurements to estimate the tsunami risk and tsunami amplitude off-shore. Geometrically, the ionospheric TEC measurements (sounding the ionosphere at 300 km of altitude along the station-satelite ray-path, so called ionospheric piercing points) extents the monitoring zone up to two thousands of km from the physical location of the GNSS ground stations enabling therefore remote measurements offshore. In addition, theories and modeling of the ionospheric signals have now reached a maturity to allow estimation of oceanic displacement produced by the tsunami, with errors of about 10%. Those results include moderate tsunamis with less than 5 cm of oceanic displacement. GNSS TEC measurements are therefore complementing nicely land-surface, sea-surface and sea-floor seismic, geodetic and pressure networks. Additionally, to extend the coverage, GNSS stations can be easily installed on airbornes, vessels or buoys as dual frequency ionospheric sounding are not sensitive to the displacement of the GNSS receiver .

We review first the state of the art of observations, for both ground based GNSS networks and space GNSS occultations (e.g., COSMIC), as well as the efficiency in the to reproduce the tsunami sisgnature in the ionosphere. Numerical modeling are shown with various technics, such as tsunami normal modes summation or spectral elements methods, compared to data and then used to estimate the sea-level height waveform, with excellent waveform matching compared to those recorded by DARTs.

We present observations and modeling close to the epicenter –where the ionospheric TEC perturbation is visible at 7 minutes after the rupture- in order to estimate the tsunami risk; as well as in the far-fiel, off-shore, where we show that the TEC measurement can strongly support the tsunami high estimation during oceanic propagation. We discuss also the impact of the ionospheric dynamics in the signal to noise ratio. We finally conclude by the perspectives offered by TEC measurements in the improvements of oceanic monitoring and tsunami warning systems.

Keywords: tsunami, ionosphere, TEC