Ionospheric Tsunami Early Warning System

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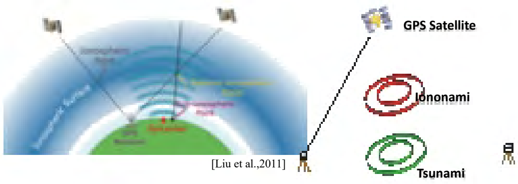
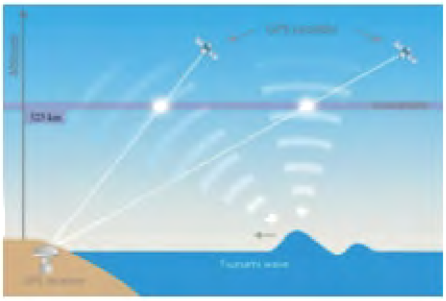
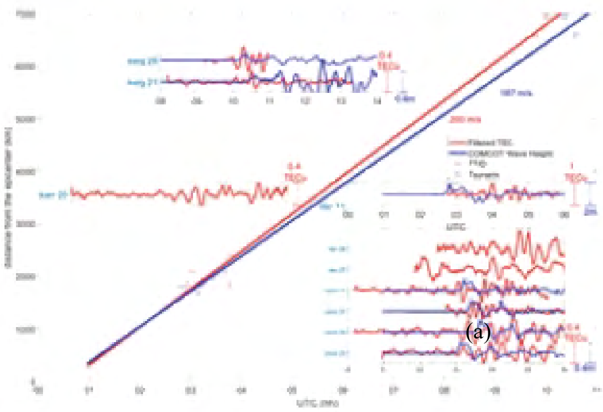
Tsunami waves can induce tsunami traveling ionospheric disturbances (TTIDs) of the total electron content (TEC). In this study, we examine the TEC derived by ground-based receivers of the global positioning system (GPS) and identify TTIDs induced by 2004 Indian Ocean tsunami. Simulations of the COMCOT (Cornell multi-grid coupled tsunami) model and analyses of the circle method, the ray-tracing technique, and the beam-forming technique are used to show that TTIDs can be quickly detected and confirmed after the tsunami occurrence. Finally, the ionospheric TEC derived by existing ground-based GNSS (Global Navigation Satellite Systems) receiving stations is demonstrated to be useful to support the tsunami early warning system



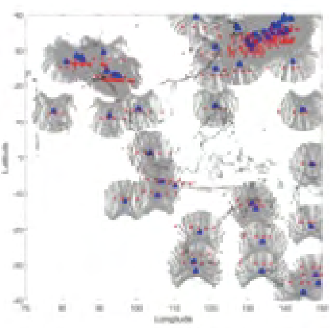
➢ **Figure 1.** The seismic surface waves and tsunami waves around the epicenter (red star) vertically launch atmospheric gravity waves that propagate into the ionosphere.



➢ **Figure 2.** Sea surface disturbances induced by tsunami propagate into ionosphere, while a ground-based GNSS receiving station monitors ionospheric disturbances. The thin-shell ionospheric (i.e. ionospheric pierce or ionospheric) height is at 325 km altitude.



➢ **Figure 4.** The propagation speeds of the TTIDs and the COMCOT tsunami waves. Seven pair of TEC/tsunami waves over the ocean area and 3 red curves over the land are presented.



➢ **Figure 6.** The coverage of ground-based GNSS receiving stations of IGS. Blue triangles are the GNSS stations. Gray curves denote the path of ionospheric pierce points. Red dots denote the ionospheric pierce points of BeiDou geosynchronous satellites.

Beam Forming Technique:

A global search of the epicenter by a given onset time.

$\Delta S_i = S_i - S_G$ $\quad \Delta t_i = t_i - t_o$

$V_i = \Delta S_i / \Delta t_i$ $\quad \sigma_j = [\Sigma(V_i)^2/N]^{1/2}$

Ray Tracing Technique:

A global search of the epicenter by a given velocity model

$\Delta T_{Hi} = S/V_H$ $\quad \Delta T_{Zi} = Z/V_Z$

$\Delta T_{Ci} = \Delta T_{Hi} + \Delta T_{Zi}$ $\quad T_{Gi} = T_i + \Delta T_{Ci}$

$\sigma_j = [\Sigma(T_{Gi})^2/N]^{1/2}$

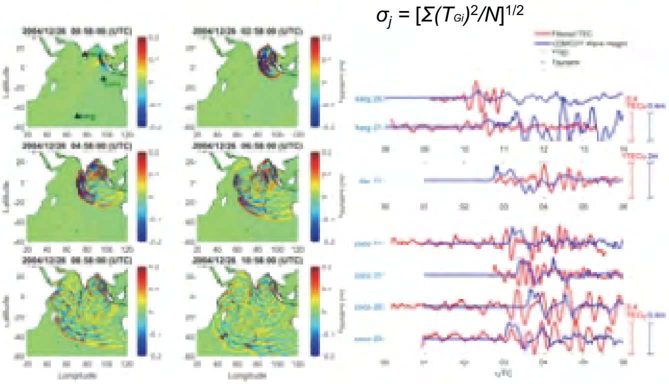
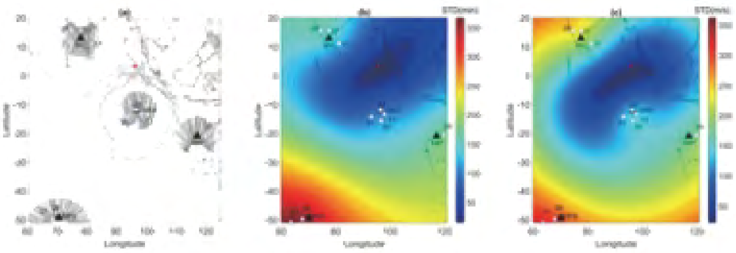
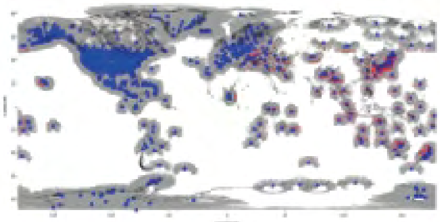


Figure 3. Tsunami wave distributions at 00:58, 02:58, 04:58, 06:58, 08:58, 10:58 UTC computed by the COMCOT model and the associated TEC variations and simulated tsunami waves. TTIDs of the TEC and COMCOT tsunami waves are denoted in red and blue curves. Seven pairs of red/blue curves are over the ocean area. The ticking times of the TTIDs and COMCOT tsunami waves are denoted by red triangles and blue squares, respectively.



➢ **Figure 5.** The tsunami origin/source detected by the circle method (a), the ray-tracing (b), and the beam-forming technique (c). Black and white triangles are the ground-based GPS stations and associated TTID locations. The red star denotes the epicenter reported by the USGS, and the cross represents the computed tsunami source.



➢ **Figure 7.** The coverage of 3189 global ground-based GNSS receiving stations of IGS and CORS. About 100+ stations of them provide data in real time.

Summary

- A seashore GNSS receiver could detect TTID up to approximately 30 minutes before the tsunami wave arrival.
- Data of 4 GPS receiving stations or 10 associated IPPs (i.e. space buoys or tide gauges) successfully detect TTIDs, locate the origin, and confirm the occurrence of the Indian Ocean tsunami activated by the 26 December 2006 M9.1 Sumatra earthquake.
- Comparisons between 10 space buoys observations and co-located COMCOT simulations show that TTIDs tend to lead the associated tsunami waves by about 19 minutes, which confirms that ionospheric GNSS TECs could detect TTIDs few minutes before tsunami waves arrive
- More two thousand ground-based GNSS receiving stations have been routinely operating and about hundreds of them provide data in real time by IGS. This gives an excellent opportunity constructing ionospheric TTID monitoring networks to support the tsunami early warning system.

Reference

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