Ionospheric Disturbances Triggered by the 26 December 2004 M9.3 Sumatra Earthquake

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The Earth's ionosphere can be affected by a variety of disturbances including, for example, solar disturbances, geomagnetic storms, severe weather, volcanoes, and earthquakes. Near-surface earthquakes causing large vertical displacement of the Earth's surface excite mechanical disturbances in the neutral atmosphere, which propagate to the ionosphere where they couple into the ionized gas. Since the atmospheric density decreases almost exponentially with altitude, energy conservation results in that the perturbation amplitude increases upward as it propagates into the atmosphere and ionosphere. For example, a 10-cm vertical displacement of the Earth's surface possibly excites a 10-km vertical motion in the ionosphere. These large amplitude vertical motions often affect electromagnetic waves propagations in the ionosphere.

The global positioning system (GPS) consists of more than 24 satellites, distributed in 6 orbital planes around the globe at an altitude of about 20,200 km. Each satellite transmits two frequencies of signals (f_1=1575.42 MHz and f_2=1227.60

MHz). Since the ionosphere is a dispersive medium, scientists are able to evaluate the associated effects with measurements of the dual frequencies recorded by ground based receivers. Figure 1 illustrates GPS signals being affected ionospheric disturbances triggered by an earthquake. From recorded broadcast ephemeris and given ionospheric height, the slant total electron content (TEC) along the ray path can be converted into the vertical total electron content (VTEC) at its associated longitude and latitude (or location). Because a ground-based receiver can simultaneously track 5 to 10 GPS satellites, a network of receivers then can be employed to observe and even locate disturbances triggered an earthquake.

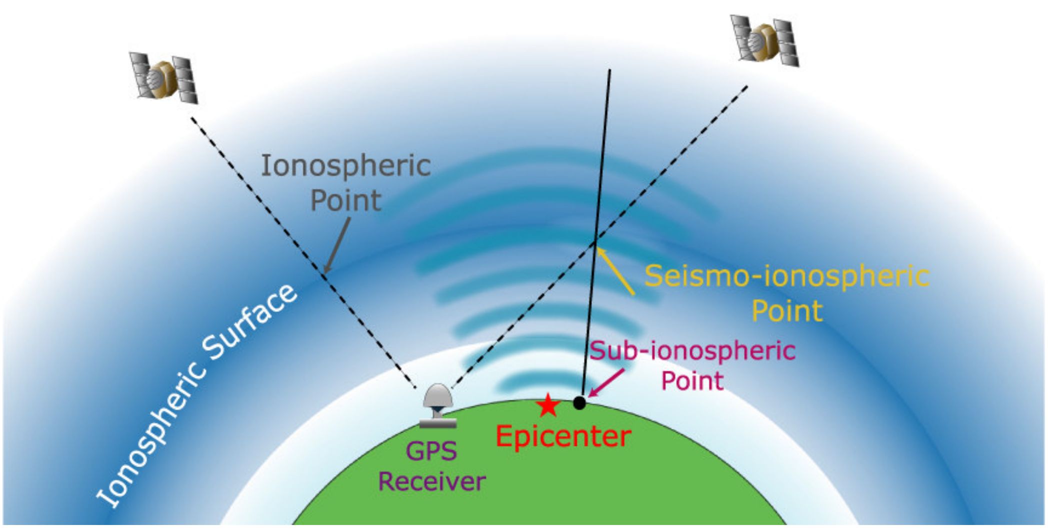

Figure 1 Disturbances induced by an earthquake may affect GPS propagations of signals.

Many types of ionospheric disturbances of GPS TEC induced by the 26 December 2004 M9.3 Sumatra earthquake have been observed. Figure 2 displays a sketch of ionospheric tsunami disturbances (iononami) being detected by the TEC of ground based receivers of GPS in the Indian Ocean area.

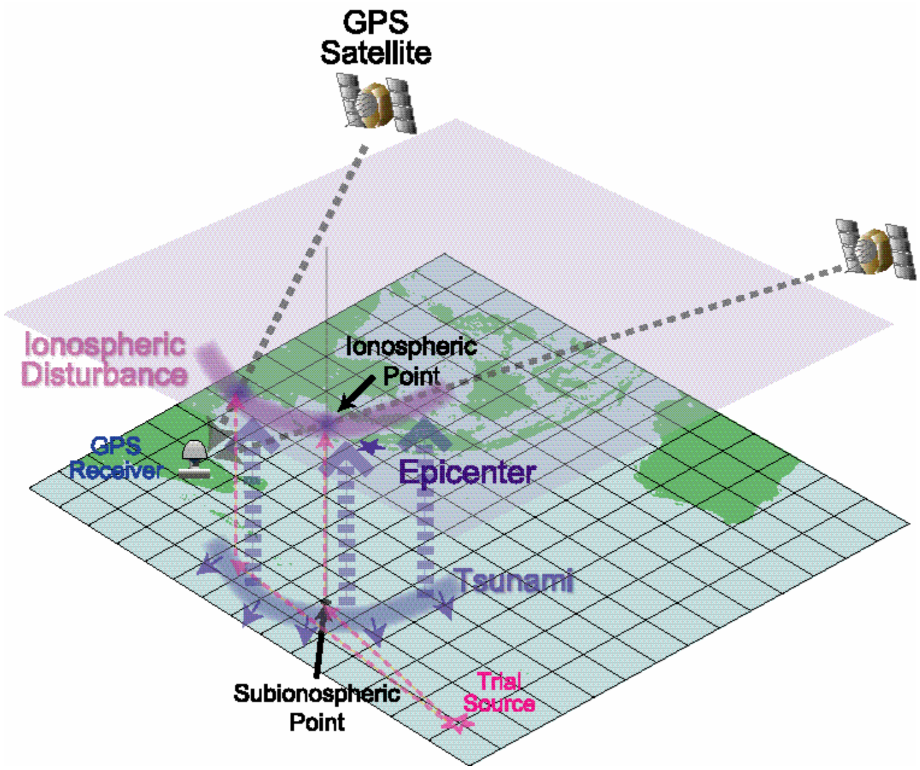

Figure 2 Tsunami activated by an earthquake travels away from the epicenter (dark blue star) along the ocean surface (blue curve) and launches atmospheric gravity waves (blue dashed arrows) which then propagate into the ionosphere and trigger the iononami (purple curve). The slant TEC (grey dashed arrow) is the integration of electron density along the path from a GPS satellite to a ground-based receiver.

Figure 3 displays the TEC disturbances (iononami) of the Indian Ocean tsunami observed by ground-based GPS receivers in the Indian Ocean area. We can further plot the distance from each disturbance to the earthquake epicenter versus the travel time (Figure 4). The slopes in Figure 4 further show the horizontal speed of the iononami being about 700km/s which agrees with that of the tsunami. Finally, a simple ray tracing technique commonly used in seismology is employed herein to estimate the arrival times at the twelve monitoring stations for locating the earthquake source (or tsunami origin) as well as to find if the observed disturbance of the ionospheric GPS TEC is triggered by the tsunami.

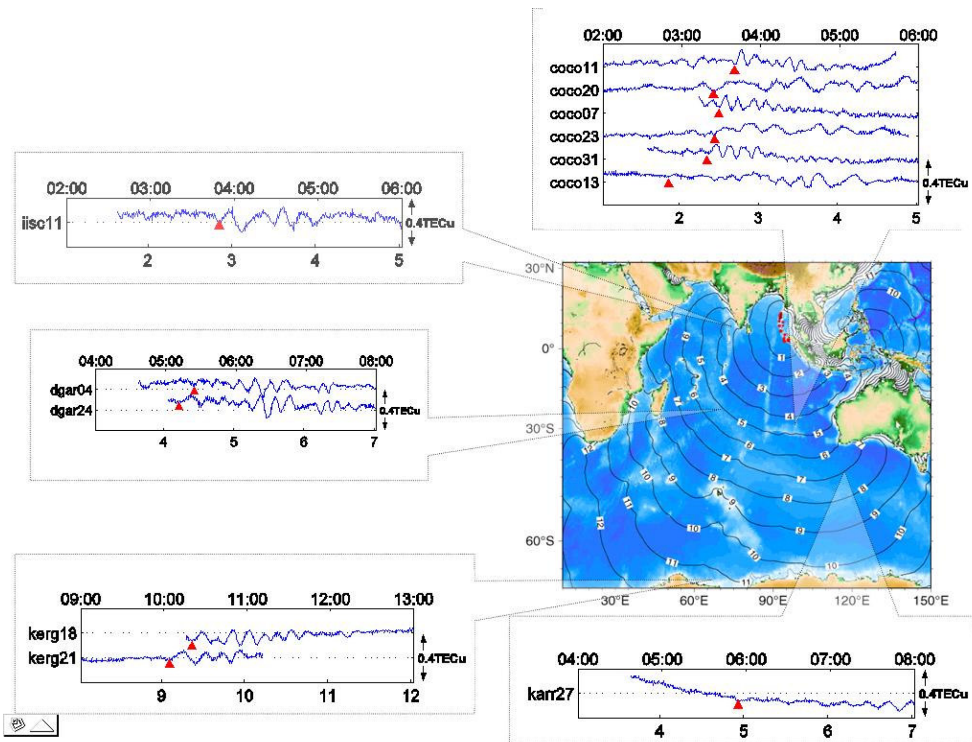

Figure 3 Locations and arrival (travel) times of the iononami waves. The red triangles denoted the arrival times. The top and bottom horizontal axes denote universal time and travel time, respectively.

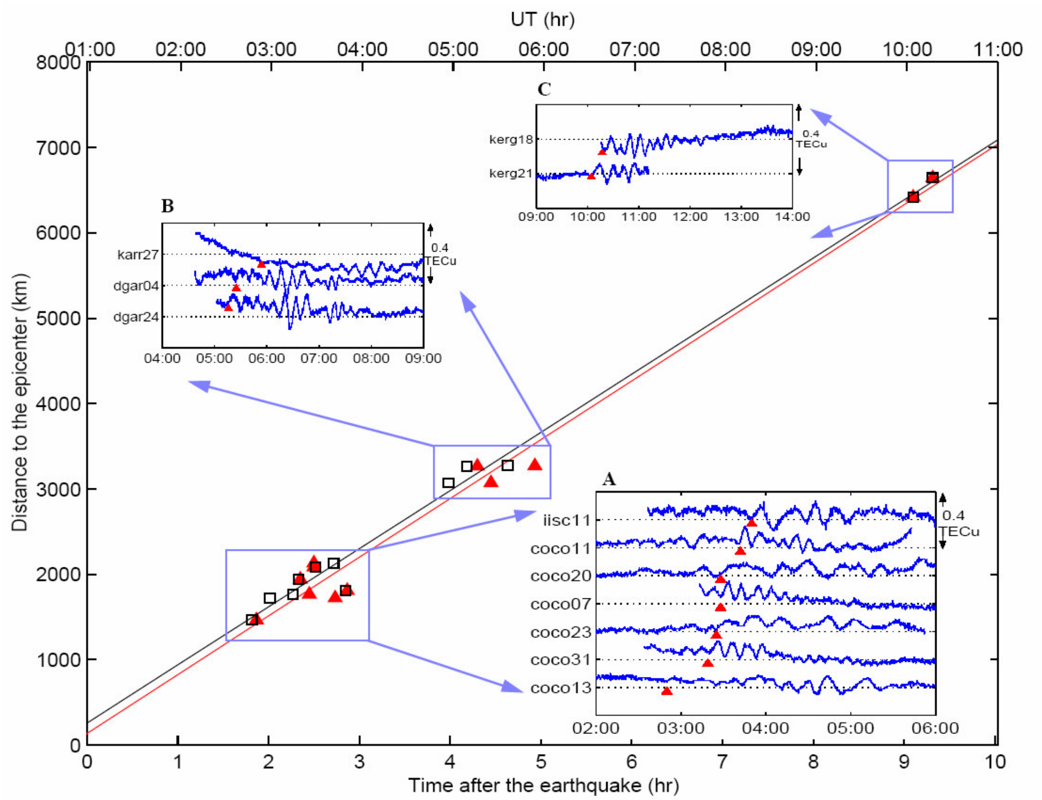

Figure 4 Iononami observed from twelve stations. The arrival time (red triangle) vs. the distance from the epicenter to each station is employed to compute the averaged horizontal speed of the iononami (red line). The arrival time (black square) of the tsunami under each stations (subinonspheric point) extracted from the simulated result is used to find the averaged horizontal speed of the tsunami (black line).