Monochromatic TEC oscillation with the period 4.5 minutes and the coupling between the solid earth and atmosphere

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Ionospheric Total Electron Content (TEC) is easily measured as the phase difference between the L1 and L2 carrier waves from Global Positioning System (GPS) satellites, and such measurements have been applied to study various phenomena including the directivity and propagation speed of coseismic ionospheric disturbances (CID) (Heki & Ping, 2005), the estimation of earthquake source processes with CID (Heki et al., 2006), evaluation of the explosion energy of volcanic eruptions (Heki, 2006), sudden increase of TEC by solar flares (Heki, 2007), and temporary vanishing of ionosphere due to chemical reactions between electrons and neutral molecules in the exhaust gas of an ascending liquid-fuel rocket (Furuya & Heki, 2008).

CID starts with the first phase, disturbances caused by the Rayleigh surface waves propagating by ~4 km/sec, and the second phase, those caused by acoustic waves directly excited above the focal region propagating by ~1 km/sec. Choosakul et al. (2007) found that quasi periodic TEC oscillations with periods of ~4.5 minutes continue for a few hours after the 2004 Great Sumatra Earthquake. Relatively poor spatial coverage of GPS points, however, did not allow them to present a physical model to explain the observed phenomenon. We analyzed the GPS data from the GRAPES GPS network (a predecessor of GEONET) after the 1994 October Hokkaido-Toho-Oki earthquake that occurred near the Shikotan Island, and confirmed the occurrence of such monochromatic TEC oscillations. They occurred after the passage of the first and the second phases, and continued for about an hour with amplitudes 0.2-0.3 TECU and a high Q value. By comparing signals from all over Japan including southwestern Japan, we found that this third phase (monochromatic oscillation) moves with the phase velocity of ~4 km/sec, a velocity similar to the surface wave. Similar phenomena are found after the 2006 Nov. and 2007 Jan. large earthquakes that occurred in the Kuril Islands.

The 3.7 mHz component (0S29, period: ~4.5 min.) of the Earth's background free oscillation is known to have larger amplitude than others (Nishida et al., 2000). This is one of the normal modes of the solid earth. Because it is similar to the period of one of the free oscillation modes of the atmosphere, they result in the resonance. The same resonance occurs for the frequency 4.4 mHz (0S37, period: ~3.8 min.). After the Pinatubo eruption, Kanamori et al. (1994) observed surface waves in these frequencies possibly excited by atmospheric oscillations associated with the explosion. The 3.7 mHz oscillation is the standing acoustic wave with the loop at the mesopause and the node at the Earth's surface. Such an oscillation is considered to have been excited by the 3.7 mHz component of the Rayleigh surface wave of the 1994 Hokkaido-Toho-Oki Earthquake, and a part of the energy leaked to the upper atmosphere. Because the vertical movements of the Earth's surface (which excites the atmospheric oscillation) moves by the Rayleigh wave velocity, the atmospheric oscillation also show the same phase velocity. This is not the atmospheric mode, a free oscillation mode of the independent atmosphere, e.g. 0P29 (Lognonne et al., 1998), but would be the atmospheric part of the surface wave mode 0S29 whose energy resides mostly in the solid earth.

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