Seismo-ionospheric transfer function: dependence on time, location and other special features

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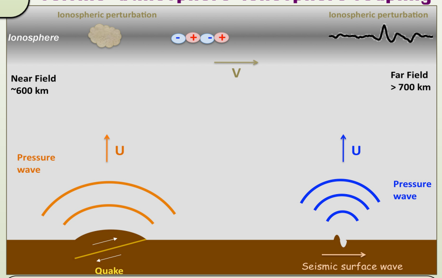
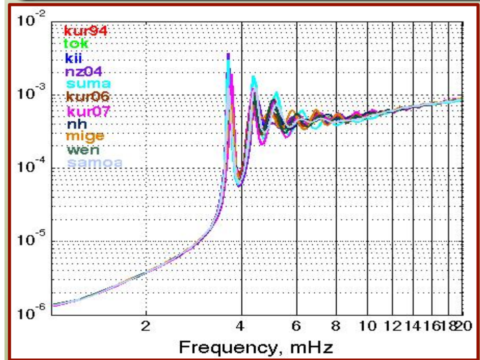
Large earthquakes are known to be a source of ionospheric disturbances. However, before the neutral waves, emitted by the ground, reach the ionosphere, they evolve due to a variety of effects provided by the propagation medium, i.e. by the atmosphere. One of the most interesting and important questions is the "transfer function" for coseismic ionospheric disturbances that provides information on evolution and transformation of the "initial" neutral waves into the ultimate ionospheric response. This study analyzes variability of the seismo-atmosphere-ionosphere coupling depending on local time, geographical location, solar activity, etc.

Seismo-atmosphere-ionosphere coupling

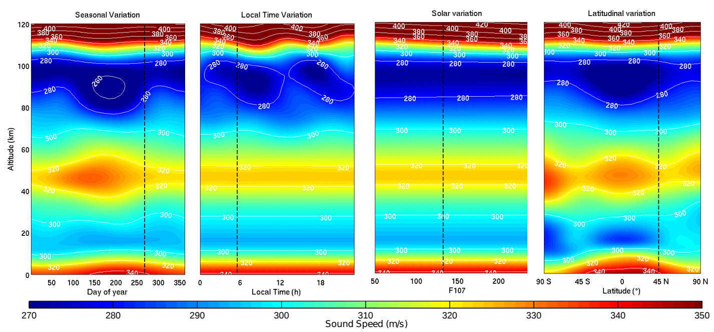


Vertical displacements of the ground induce pressure waves in the neutral atmosphere that propagate upward and grow in amplitude by several orders of magnitude as they reach ionospheric heights, since the atmospheric density decreases exponentially with height. An ionospheric perturbation is formed via the collisions between neutral and charged particles

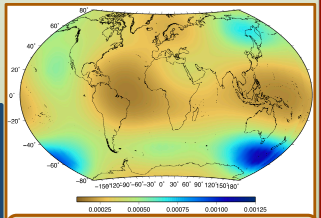
Date	UT	LT	Mw	Location	Depth	Name
04/10/1994	13:23:28	22:23	8.1	43.60;147.63	68.2	kur94
25/09/2003	19:50:38	04:50 (26/09)	8.3	42.21;143.84	28.2	tok
05/09/2004	10:07:16	19:07	7.3	32.94;137.00	16.0	kii
23/12/2004	14:59:30	01:59 (24/12)	8.1	-49.91;161.25	27.5	nz04
26/12/2004	00:58:09	07:58	9.0	03.09;94.26	28.6	suma
15/11/2006	11:15:08	22:15	8.3	46.71;154.33	13.5	kur06
13/01/2007	04:23:48	14:23	8.1	46.17;154.80	12.0	kur07
25/03/2007	00:42:03	09:42	6.8	37.28;136.61	12.0	nh
16/07/2007	01:13:29	10:13	6.6	37.50;138.47	12.0	mige
12/08/2008	06:28:40	17:28	7.9	31.44;104.10	12.8	wen
29/09/2009	17:48:10	06:48	8.1	-15.51;187.97	18.0	samoa



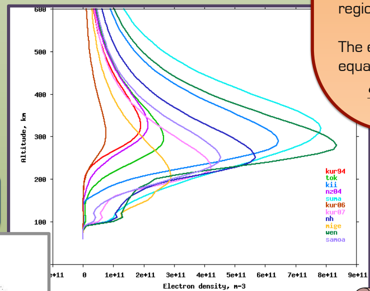
Energy ratio of the fundamendal solid Earth modes injected in the atmosphere, between 1 and 20 mHz. The modes are computed with a radiative boundary condition, and the viscosity is taken into account.



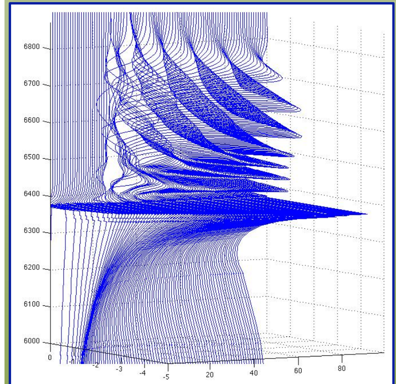
Varibility of coupling between the solid earth and atmosphere in the epicenter of the Tokachi-oki earthquake. The value of the sound speed varies with season, local time, F10.7 and latitude.



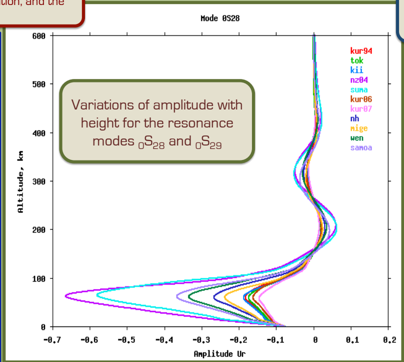
Latitudinal and longitudinal variability of the energy ratio for the resonance mode 0S29.

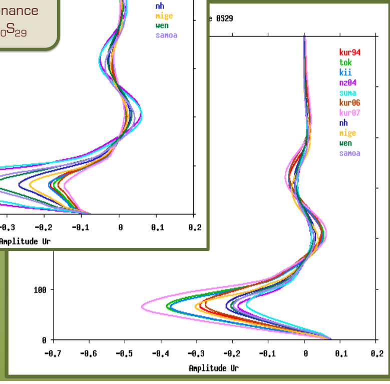


Electron density profile for the time and location of the 11 considered earthquakes.

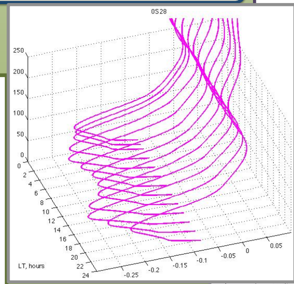


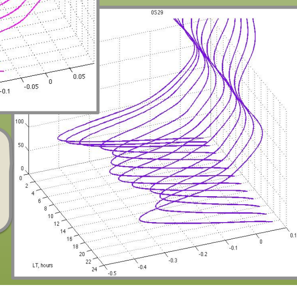
Amplitude of the fundamental spheroidal mode with respect to radius and angular order L in the upper mantle and atmosphere for radiative boundary condition at altitude of 150 km. Modes are trapped when f<3.68 mHz.





Variations of amplitude with height for the resonance modes $_0S_{28}$ and $_0S_{29}$





Amplitude variations for the modes $_0S_{28}$ and $_0S_{29}$ depending on the local time. The atmosphere is modelled on the date and in the location of the Miyage earthquake of 16/07/2007 (mige).

Method

1. Modeling of atmospheric wave by normal mode summation :

- Computation of the complete set of normal-mode functions for an elastic Earth and a free surface
- Setting of the radiation boundary condition at the top of the atmosphere to model the attenuation of the acoustic waves at larger altitudes. (Lognonne et al., 1998, Geophys. J. Int., 135,388-406).

2. Computation of seismograms - the displacement s(**r**,t) at any point **r**:

$$\vec{s}(\vec{r},t) = \mathrm{Re}\left(\sum_k (M:\varepsilon_k(\vec{r}_0))\vec{u}_k(\vec{r})\frac{1-e^{i\sigma_k t}}{\sigma_k^{\ 2}}\right)$$

where M is the moment tensor, r_0 is the source location and ε_k is the deformation associated with the eigenmode $\mathbf{u}_k$ with eigenfrequency σ_k.

3. Neutral/plasma coupling – ionospheric, geomagnetic and transport parameters are computed using the IRI, the IGRF and SAMI2. We use the following formula by McLeod (1965, J. Atmos. Sci., 23, 96-106):

$$v_i = \frac{1}{1+k^2}\left[k^2\vec{u} + k\vec{u}\times\vec{1}_b + (\vec{u}\cdot\vec{1}_b)\vec{1}_b\right]$$

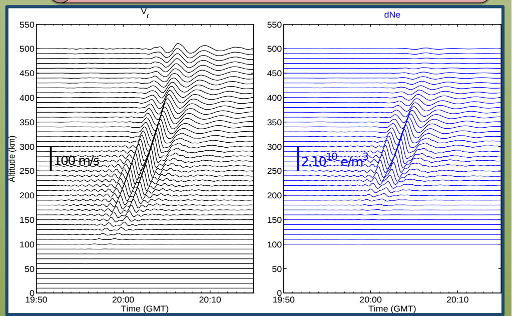
where $k=\nu_{in}/\Gamma_i$ is the ratio of the neutral-ion collision frequency to ion gyro-frequency Γ_i. As the collision frequency decreases with altitude, the parameter k can be neglected in the F-region, then the simplified expression for perturbations in the mid-latitude F-region (k~0) is:

$$\vec{v}_i = (\vec{u}\cdot\vec{1}_b)\vec{1}_b$$

The electron density fluctuation is derived from the continuity equation:

$$\frac{\partial N_e}{\partial t} + \nabla\cdot(N_e\vec{v}_i) = 0 \Rightarrow \delta Ne(t,\vec{r}) = -\int_0^t \nabla\cdot(N_{e0}\vec{v}_i(t,\vec{r}))dt$$

The ultimate shape of the ionospheric response depends on many factors. Here we show that the seismo-atmosphere coupling varies with geographical location, solar flux, season and local time. Further development of perturbation is related to the variability of the ionosphere and geomagnetic field. All these determine the perturbation and further investigations are necessary to fully understand the whole evolution.



Seismograms in the atmosphere and ionosphere modelled for the Tokachi-oki earthquake. The calculations of the vertical velocity Vr (on the left) and electron density Ne (on the right) are made at point (41.2N;140.4E)