Local Group Velocity of Ionospheric Waves Induced by Earthquakes

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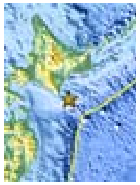
ABSTRACT:

Past studies have shown that earthquakes are one of the geophysical events disturbing the ionosphere through the interaction between the atmospheric infrasound emitted by ground movements and the ionospheric plasma. The ionospheric electron density perturbations induced by earthquakes are regularly monitored by space-based instruments like dual frequency Global Positioning System receivers. This monitoring can reach high time and space resolution above dense networks of GPS receivers providing efficient ionospheric sensors. We present a data processing method extracting the local group velocity of ionospheric perturbations from GPS receiver Total Electron Content estimates. We illustrate this method on data obtained from dense GPS networks for several earthquakes in near field (r<1000km from the source). The local group velocity of the ionospheric perturbation is interpreted in terms of infrasonic waves in the atmosphere.

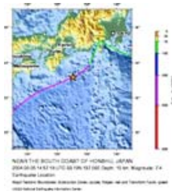
The Hokkaido earthquake 09/25/2003 Mw8.3:

On 25 September 2003, in the Tokachi Oki region, a great earthquake occurred at 19:50 (GMT) and was located at 144,1°W and 42,2°N. In this region the Pacific plate subduct beneath the Hokkaido region from the Kurile Trench at a rate of about 80 mm/year and generate large earthquakes since decades. The earthquake of the 25 September is one of them and induced strong vertical ground motion. The Centroid Moment Tensor (CMT) computed by USGS is (FP1: strike=234, slip=7, dip=103 ; FP2: strike=41, dip=83, slip=88).



The Kii earthquake 09/05/2004 Mw7.2:

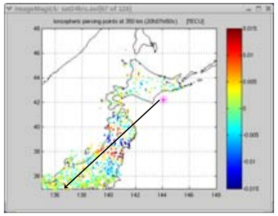
On 5 September 2004, in the South East of the Kii penninsula, an earthquake occurred at 10:07 (GMT) and was located at 136,6°W and 33°N. In this region the Philipine sea plate subduct beneath the Japanese Island Arc. The earthquake sequence of the 5 September was composed by two strong earthquakes but we focused on the first one. The Centroid Moment Tensor (CMT) computed by USGS is (FP1: strike=270, slip=35, dip=89 ; FP2: strike=91, dip=55, slip=91).

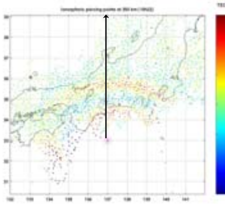


Velocity of ionospheric waves

In order to assess the local group velocity of the ionospheric waves induced by earthquakes we filtered the ionospheric GPS combination and mapped the data at ionospheric piercing points. For the both earthquakes, the data are mapped at 350 km of altitude.

Ionospheric perturbations induced by the Hokkaido earthquake

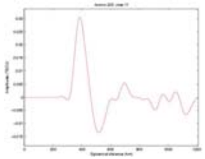


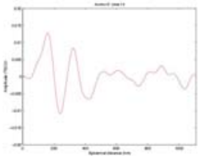


Ionospheric perturbations induced by the Kii earthquake

For selected azimuts, we define a regular sampling in epicentral distance. Thus we can define a small epicentral step (11km) that allow to reconstruct the waveform because of the high density of GPS station in Japan.

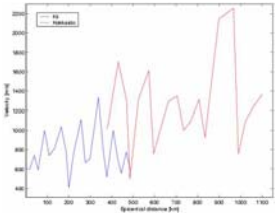
Waveform for the Hokkaido earthquake along the azimut 225°





Waveform for the Kii earthquake along the azimut 0°

Therefore we can follow the propagation of the wavefront along the selected azimut and assess the group velocity by cross-correlation of the waveform between two epoch (GPS data sampling rate: 30s).

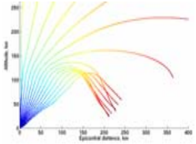


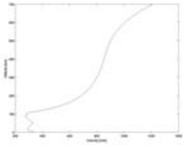
Velocity of ionospheric perturbations

These ionospheric waves are generated at near field (epicentral distance < 1000km). So they can be interpreted as ionospheric perturbations induced by acoustic pulse generated over the epicentre.

The difference of velocities between the Hokkaido event and the Kii event can be explain by a difference of altitude of the Ionosphere-Atmosphere coupling. Indeed, the Hokkaido earthquake occured during the early morning (local time) that involve a higher and more spread maximum of ionisation. Therefore, in accordance with profile of sound velocity, the acoustic waves of the Hokkaido earthquake have a higher velocity.

Propagation of acoustic waves in the atmosphere





Profile of sound velocity

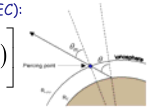
Ionospheric delay in GPS data:

The combination of the pseudo-ranges P1 and P2 and the phase data L1 and L2, respectively at F1 (1575.42 MHz) and F2 (1227.60 MHz) gives the ionospheric delay:

$$D_{iono} = (L1 - L2) - \langle (L1 - L2) + (P1 - P2) \rangle$$

The integrated TEC along ray path, or slant TEC (STEC), is multiplied by the obliquity factor F_{ob} to have the vertical TEC (VTEC):

$$F_{ob} = \cos^{-1}(\theta_m) \quad \theta_m = \sin^{-1}\left[\left(\frac{R_E}{R_E + R_{iono}}\right) \cdot \sin(\theta)\right]$$



The modelling of the GPS ionospheric combination has to account for electronic errors (Differential Code Biases, DCB) of two types:

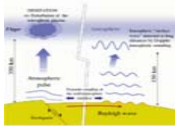
- Station (P1-P2) DCB, or Inter-Frequency Bias (IFB)
- Satellite (P1-P2) DCB or Transmitter Group Delay (TGD)

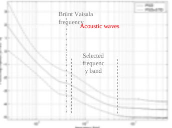
Thus, for a station-satellite observation, one has:

$$D_{iono} = \frac{VTEC}{F_{ob}} + IFB + TGD$$

Postseismic-Ionospheric perturbations:

Ionospheric perturbations can be induced by earthquakes because of the Earth-atmosphere coupling. Indeed, the exponential decrease ef the atmospheric density and the hypothesis of energy conservation evolve the amplification of the acoustic waves that reach the ionosphere. This phenomena can be model with the normal mode theory extended to an Earth with an atmosphere [Lognonné et al., 1998].





The IFB and TGD biases are avoided by filtering due to their pseudo constant values. Moreover, we filter the ionospheric combination between 3.8mHz and 15mHz to avoid the perturbation induced by gravity waves, and focused the study to acoustic waves induced by the Earth-atmosphere coupling.

$$\Delta D_{iono} = \Delta STEC$$

CONCLUSION

- This method allow to assess the local group velocity of ionospheric perturbations induced by earthquakes.
- At near field, the velocity of ionospheric perturbations match to sound velocity.
- We expect to apply this method at far field in order to assess local group velocity of Rayleigh surface waves, and specialy at oceanic margins.

Reference:

Artru J., P. Lognonné et E. Blanc, Normal modes modeling of post-seismic ionospheric oscillations, *Geophysical Res. Lett.*, **28**, 697-700, 2001.

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