Seismic waves and seismic sources in the atmosphere

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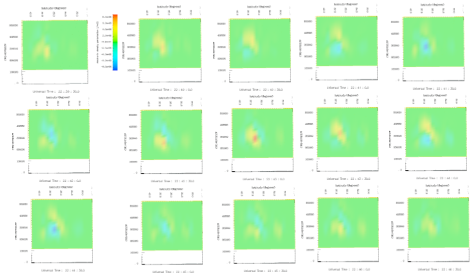
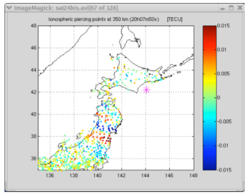
In 1995, I was initiated by H.Kanamori during a stay in the seismo lab to the exciting problem of coupling between the solid earth and its atmosphere. This led to a complete description of the theory necessary to compute normal modes in an Earth with atmosphere (Lognonné et al., 1998). Such theory is successfully able to explain seismic waves in the solid earth excited by energetic atmospheric sources, especially volcano explosions. The IPGP Ionospheric Seismology team present here recent results obtained on the detection of seismic waves in the ionosphere, We illustrate these results for a few quakes in Japan as well as for the ionospheric data recorded after the Sumatra majors quakes of 2004. Theses ionospheric data from various sources (altimetry and Demeter satellites, GPS) and from ground systems (Doppler sounders) show both the gravity waves, the Rayleigh waves and the tsunami, recorded at high altitude in the ionosphere.

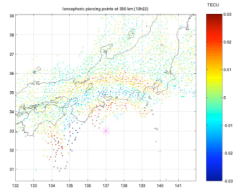
Quakes: recent studies

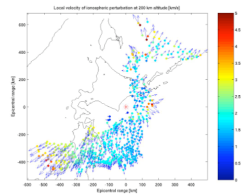
Our past studies have shown that earthquakes are disturbing the ionosphere through the interaction between the atmospheric waves and the ionospheric plasma (Ducic et al., 2003). The ionospheric electron density perturbations can be monitored by space-based instruments like dual frequency Global Positioning System receivers or altimetry satellites. We now have detailed 3D pictures of the waves and can perform advanced data processing for 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 near the source and surface waves away.

2D Tomograph: following the waves
See movies







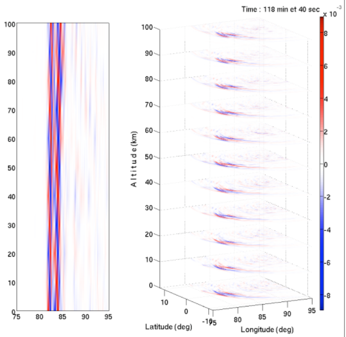


3D wavefield tomography: Loocking inside the waves!

Tsunami: neutral waves

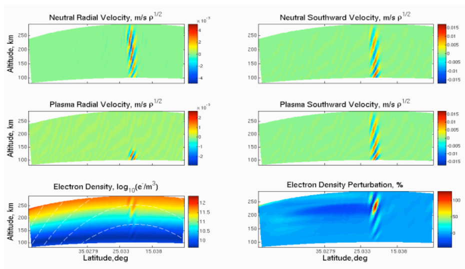
The Sumatra, December 26th, 2004, tsunami has generated internal gravity waves in the neutral atmosphere that induced large disturbance in the ionospheric plasma. These waves, detected by the dual frequency altimeters onboard in the Jason-1 and Topex/Poseidon satellites and by GPS station, confirm the hypothesis of tsunami detection in the way of ionospheric sounding proposed by Peltier & Hines [1976] and the first observation by Artru et al., 2005a.

Based on the coupling between Tsunami gravity waves (TGW) and internal gravity waves (IGW), we computes the 3D propagation of IGW in a realistic neutral atmosphere with horizontal stratification. In essence the spectral analysis of the 2D ocean time-depending displacement field allows to propagate vertically the tsunami-generated IGW conserving the geometric features that the wave had in the ocean surface.

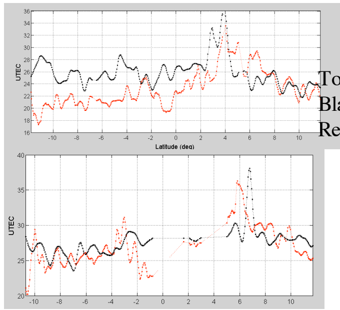


Neutral-Ionosphere coupling

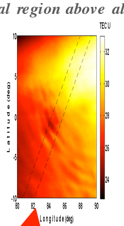
In the second step we computed the response of ionospheric plasma to the neutral motion. IGW is known to produce irregularities in the ionospheric plasma and to model it, we solved the ionospheric simulation model by [Kherami et al., 2004] under the action of gravity waves generated by tsunami activity and in the case of a stable ionospheric background.



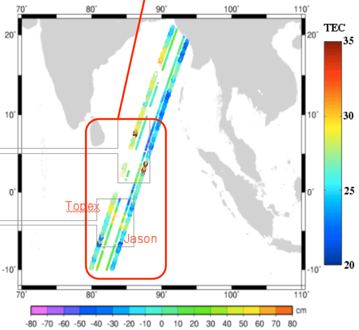
For Sumatra, we can perform the integration of Ne in the vertical satellite-ground paths to reproduce Topex/Poseidon and Jason TEC data. The position of the principal waves (around 3:00 UT for Jason and 3:05 UT for Topex), the delay between the Topex/Poseidon and Jason pics as well as the double hump in the Jason pic, are the most important proof to validate our modelling. All disagreements between synthetics and data are imputed, in our opinion, to the difficulty to know the real electron density model in the equatorial region above all in the night-day anomalies.



Topex and Jason
Black: data
Red: modeling

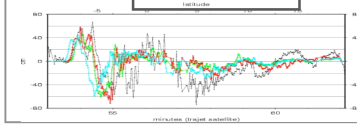


Modeling



ionospheric signature of tsunami waves

tsunami wave



Sumatra observations

We can follow in the ionosphere Rayleigh waves and as well as tsunami. These results show that the dream of remote sensing seismology could be a reality in a relatively near future. Such techniques could be applied not only on the Earth, but also on Venus. ESA Venus Express will test in 2006 this idea after its orbit insertion, and a more powerful experiment, able to record surface waves, can be foreseen for future Venus missions.

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+ more to come….