Modelling and Detection of the Ionospheric perturbation associated to the tsunami of December 26th, 2004

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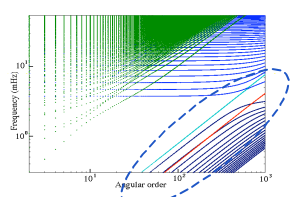
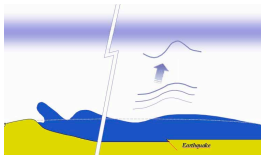
The Sumatra, December 26th, 2004, tsunami has generated internal gravity waves in the neutral atmosphere that induced large disturbance in the ionospheric plasma** ([Artru et al. 2005b], [Lognonné et al., 2005]). **These waves, detected by the dual frequency altimeters onboard in the Jason-1 and Topex/Poseidon 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]. Nevertheless, the ionosphere is a reactive medium and for example, travel ionospheric disturbances (TIDs) can induce a similar ionospheric signature of tsunami. To precise the performances of future possible tsunami warning based on ionospheric sounding, we present here a 3D pseudo-spectral modeling of gravity waves induced by realistic tsunami in a non-isothermal atmosphere, and the response of the ionospheric plasma to the consequent neutral motion. The purpose of this work is to reproduce the Total Electron Content (TEC) perturbations observed by Topex/Poseidon and Jason-1 in the case of Sumatra tsunami and asses signal amplitude.

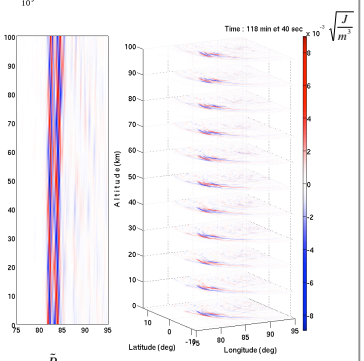
The first step

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.

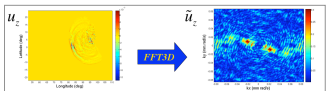




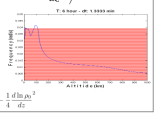
$$\frac{\partial u_x}{\partial t}+u_x\frac{\partial u_x}{\partial x}+u_y\frac{\partial u_x}{\partial y}+u_z\frac{\partial u_x}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}$$
$$\frac{\partial u_y}{\partial t}+u_x\frac{\partial u_y}{\partial x}+u_y\frac{\partial u_y}{\partial y}+u_z\frac{\partial u_y}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}$$
$$\frac{\partial u_z}{\partial t}+u_x\frac{\partial u_z}{\partial x}+u_y\frac{\partial u_z}{\partial y}+u_z\frac{\partial u_z}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}-g$$
$$\nabla\cdot\vec{u}=0 \qquad \frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}+\frac{\partial u_z}{\partial z}=0$$
$$\frac{\partial \rho}{\partial t}+u_x\frac{\partial \rho}{\partial x}+u_y\frac{\partial \rho}{\partial y}+u_z\frac{\partial \rho}{\partial z}=0$$



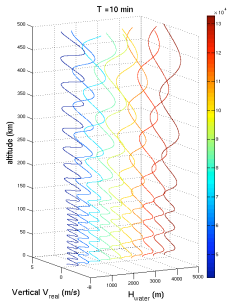
$$\frac{dV}{dz}=A\cdot V \qquad V=\begin{pmatrix}\tilde{u}_z^*\\ \tilde{P}^*\end{pmatrix} \qquad \tilde{u}_z^*=\tilde{u}_z\sqrt{\rho_0} \qquad \tilde{P}^*=\frac{\tilde{P}}{\sqrt{\rho_0}}$$



$$\tilde{P}^*=\frac{i}{\left(k_x^2+k_y^2\right)}\left(k_x\frac{\partial u_{x0}}{\partial z}+k_y\frac{\partial u_{y0}}{\partial z}+\Omega k_z-\tfrac{1}{2}\Omega\frac{d\ln\rho_0}{dz}\right)\tilde{u}_z^*$$



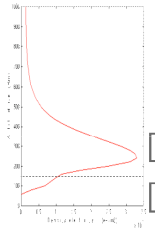
where
$k_z = i\sqrt{k_z^2}$ if $k_z^2 \geq 0$
$k_z = -\sqrt{-k_z^2}$ if $k_z^2 \leq 0$
and
$$k_z^2=(k_x^2+k_y^2)\left(-\frac{g}{\omega^2}\frac{d\ln\rho_0}{dz}-1\right)-\frac{1}{4}\frac{d\ln\rho_0}{dz}^2$$



The second step

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 [Kherani et al., 2004] under the action of gravity waves generated by tsunami activity and in the case of a stable ionospheric background.

$$\frac{\partial n_i}{\partial t}+\nabla\cdot\left(n_i\vec{v}_i\right)=\pm\ \beta n_i-\alpha n_i^2$$
$$\rho_i\frac{d\vec{v}_i}{dt}=-\nabla p_i+\rho_i\vec{g}+n_iq_i\left(\vec{E}+\vec{v}_i\times\vec{B}\right)-\rho_i\mu_{in}\left(\vec{v}_i-\vec{v}_n\right)$$
$$n_e=n_i$$



***B**dependent*

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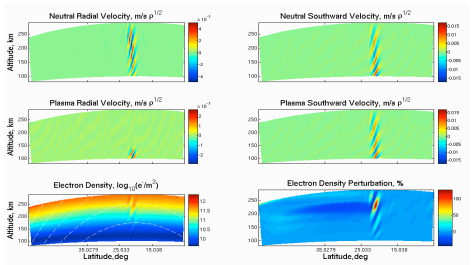
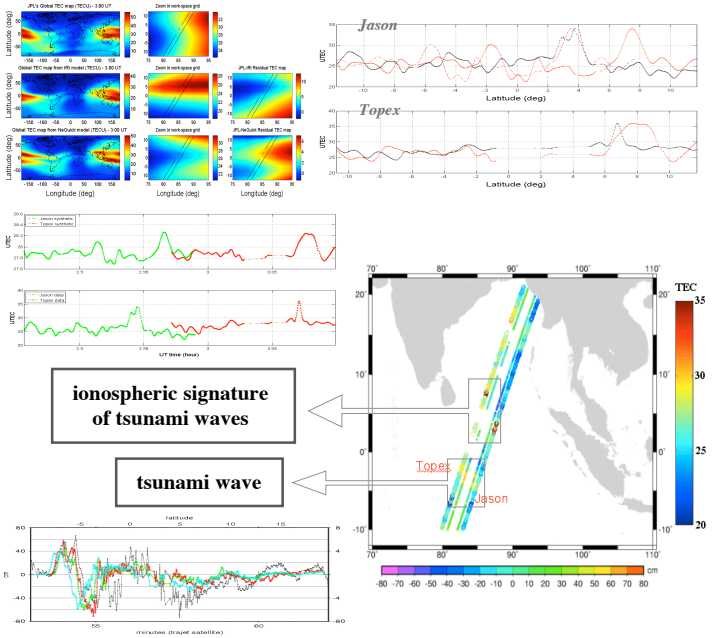


The third step

The last part of the work consist in 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.



Conclusion and references

We presented here a modelling of ionospheric signature induced in the plasma by the giant Sumatra tsunami (december 26th, 2004). This is, in our knowledge, the first time that the TEC perturbation induced by solid Earth phenomena are reproduced with a good agreement between the data and the synthetics. Differences between synthetics and data are still remaining due to the difficulty to know the electron density in the equatorial region and the limitations in the actually models (IRI and NeQuick). Notwithstanding these differences, the tsunami signature in the TEC data is clear and in this way very exciting perspectives are opened in tsunami detection offshore. The ionospheric monitoring by ground/space techniques (doppler sounding, OTH radars, GPS network, etc...) joined to the seismic network and the tide gauges can open new insights into the development of efficient tsunami warning systems.

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