Can Ionospheric Sounding Help Oceanic Monitoring ?

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References:
[Occhipinti et al., 2006] *GRL, 33*, L20104, 2006
[Occhipinti et al., 2008] *GJI, 173*, 3, 753-1135, 2008.

A series of ionospheric anomalies following the Sumatra tsunami has been reported in the scientific literature (e.g., Liu et al. 2006; DasGupta et al. 2006; Occhipinti et al. 2006). Similar anomalies were also observed after the tsunamigenic earthquake in Peru in 2001 (Artru et al., 2005). All these anomalies show the signature in the ionosphere of tsunami-generated internal gravity waves (IGW) propagating in the neutral atmosphere over oceanic regions. The strong amplification mechanism of atmospheric IGW allows to detect these anomalies when the tsunami is offshore where the see level displacement is still small. In addition, the dense coverage of ionospheric sounding instruments over the oceans increases over time and more instruments will be able to provide ionospheric measurements: i.d., Doppler sounding, over-the-horizon radar (OTH) and space-based GPS data. Most of the ionospheric anomalies are also deterministic and reproducible by numerical modeling (Occhipinti et al., 2006, 2008) via the ocean/neutral atmosphere/ionosphere coupling mechanism. In addition, the numerical modeling supplies useful helps in the estimation of expected anomalies The sensitivity of altimeters, OTH radar, ground-based and space-based GPS measurements is analyzed in this work by the way of the modeling and data. T

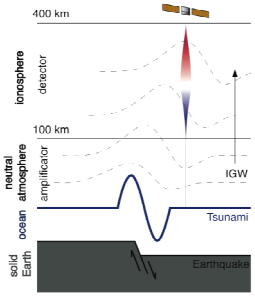
The ocean-atmosphere coupling

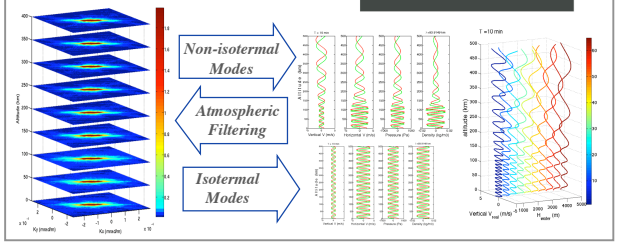
Based on the coupling between Tsunami gravity waves (TGW) and internal gravity waves (IGW), we computes the 3D propagation of IGW in a realistic neutral atmosphere with horizontal stratification. In essence the spectral analysis of the 2D ocean time-depending displacement field allows to propagate vertically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

$$\left.\begin{aligned} &\frac{\partial u_x}{\partial t}+u_x\frac{\partial u_x}{\partial x}+u_y\frac{\partial u_x}{\partial y}+u_z\frac{\partial u_x}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}\\ &\frac{\partial u_y}{\partial t}+u_x\frac{\partial u_y}{\partial x}+u_y\frac{\partial u_y}{\partial y}+u_z\frac{\partial u_y}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}\\ &\frac{\partial u_z}{\partial t}+u_x\frac{\partial u_z}{\partial x}+u_y\frac{\partial u_z}{\partial y}+u_z\frac{\partial u_z}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}-g\\ &\boxed{\nabla\cdot\vec{u}=0}\quad \frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}+\frac{\partial u_z}{\partial z}=0\\ &\frac{\partial \rho}{\partial t}+u_x\frac{\partial \rho}{\partial x}+u_y\frac{\partial \rho}{\partial y}+u_z\frac{\partial \rho}{\partial z}=0 \end{aligned}\right\}\quad \boxed{\frac{dV}{dz}=A\cdot V}\qquad V=\begin{pmatrix}\tilde{u}_z^*\\ \tilde{P}^*\end{pmatrix}$$

$$\tilde{u}_z^*=\tilde{u}_z\sqrt{\rho_0}\qquad \tilde{P}^*=\frac{\tilde{P}}{\sqrt{\rho_0}}$$

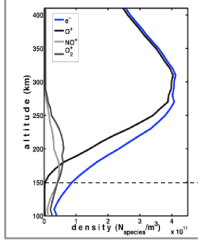
$$\tilde{P}^*=\frac{i}{\left(k_x^2+k_y^2\right)}\left(k_x\frac{\partial u_{x0}}{\partial z}+k_y\frac{\partial u_{y0}}{\partial z}+\Omega k_z-\tfrac{1}{2}\Omega\frac{d\ln\rho_0}{dz}\right)\tilde{u}_z^*$$





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



$$\frac{\partial n_i}{\partial t}+\nabla\cdot\left(n_i\vec{v}_i\right)=\pm\ \beta n_i-\alpha n_i^2$$

$$n_i\frac{d\vec{v}_i}{dt}=-\nabla p_i+\rho_i\vec{g}+n_iq_i\left(\vec{E}+\vec{v}_i\times\vec{B}\right)-n_i\mu_{in}\left(\vec{v}_i-\vec{v}_n\right)$$

$n_e=\Sigma_i\, n_i$

F

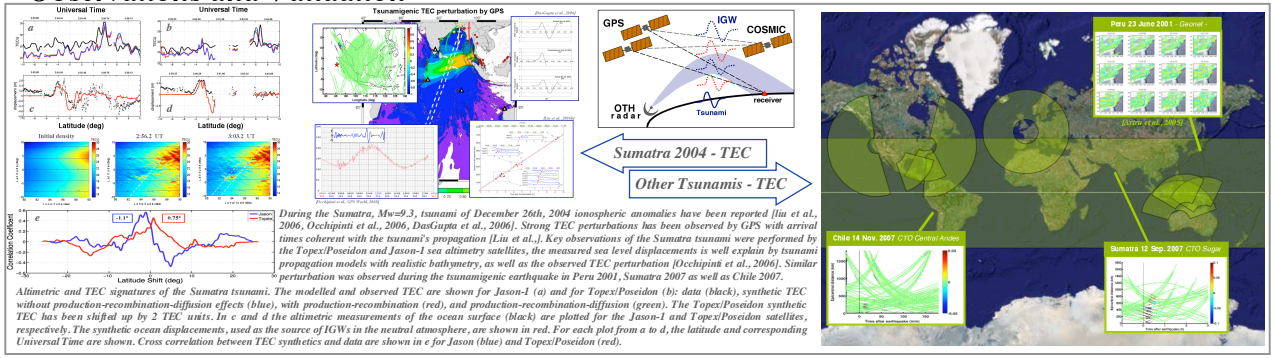
B$_{dependent}$

E

B$_{independent}$

$$\begin{aligned} O_2^+ + e^- &\xrightarrow{\alpha} O+O\\ NO^+ + e^- &\xrightarrow{\alpha} N+O\\ O^+ + O_2 &\xrightarrow{\beta} O_2^+ + O\\ O^+ + NO &\xrightarrow{\beta} NO^+ + O \end{aligned}$$

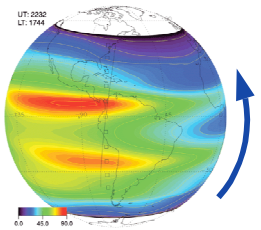
Observations and Validation

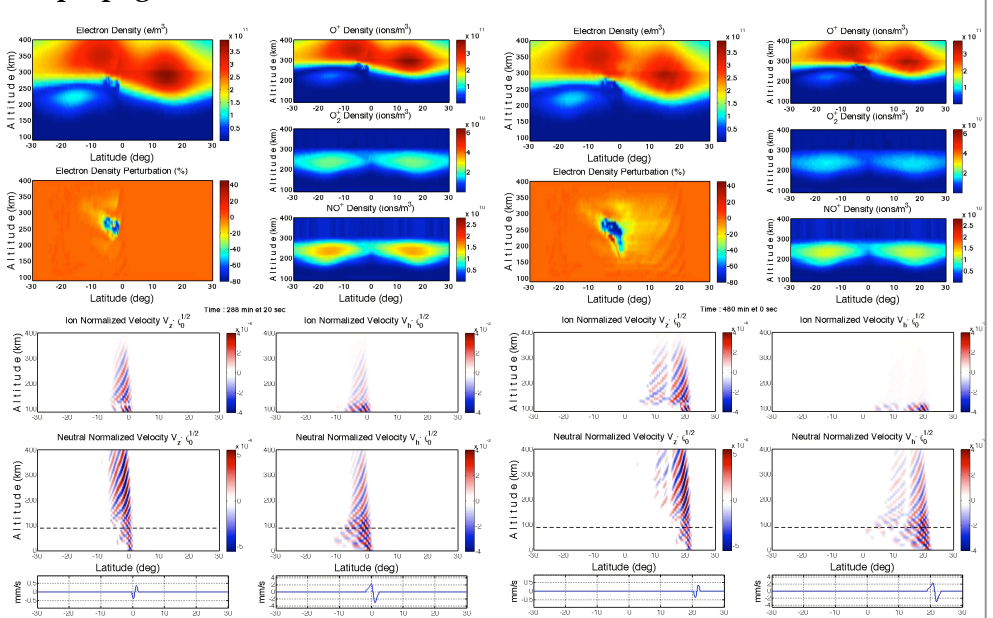


During the Sumatra, Mw=9.3, tsunami of December 26th, 2004 ionospheric anomalies have been reported [liu et al., 2006, Occhipinti et al., 2006, DasGupta et al., 2006]. Strong TEC perturbations has been observed by GPS with arrival times coherent with the tsunami's propagation [Liu et al.,]. Key observations of the Sumatra tsunami were performed by the Topex/Poseidon and Jason-1 sea altimetry satellites, the measured sea level displacements is well explain by tsunami propagation models with realistic bathymetry, as well as the observed TEC perturbation [Occhipinti et al., 2006]. Similar perturbation was observed during the tsunamigenic earthquake in Peru 2001, Sumatra 2007 as well as Chile 2007.

Altimetric and TEC signatures of the Sumatra tsunami. The modelled and observed TEC are shown for Jason-1 (a) and for Topex/Poseidon (b): data (black), synthetic TEC without production-recombination-diffusion effects (blue), with production-recombination (red), and production-recombination-diffusion (green). The Topex/Poseidon synthetic TEC has been shifted up by 2 TEC units. In c and d the altimetric measurements of the ocean surface (black) are plotted for the Jason-1 and Topex/Poseidon satellites, respectively. The synthetic ocean displacements, used as the source of IGWs in the neutral atmosphere, are shown in red. For each plot from a to d, the latitude and corresponding Universal Time are shown. Cross correlation between TEC synthetics and data are shown in e for Jason (blue) and Topex/Poseidon (red).

The sud-nord tsunami propagaation





We observe that the horizontal component of the ion velocity is strongly affected by the magnetic field term n_iB. This latter is driven by the value of ion density increasing with altitude. As a consequence of this effect, the horizontal component of ion velocity in the F-region decreases with the latitude increasing. Contrary, in the E-regions the neutral-ion coupling is independent of magnetic field term and the horizontal velocity is invariable. The same equatorial effect is observed in the electron density variation that is strongly amplificated in the equatorial F-region.