The role of magnetic equator in the Ne perturbations induced by IGW tsunami-related

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Application to Sumatra tsunami:
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Internal-gravity waves (IGWs) produced during the tsunami's propagation are known to produce identifiable signature in the overlying ionosphere. Notwithstanding several observations and one case of successful modellings, an heterogenic directivity in the ionospheric IGW propagation has been put in evidence recently using total electron content (TEC) measured by GPS receivers. To explicit the link between the anomalous propagation observed by ionospheric sounding, and the IGW propagation in the neutral atmosphere, we explore the role of magnetic field in the neutral-plasma coupling. A 3D numerical solution of closed set of non-linear hydro-magnetic equations in physical and chemical realistic hypothesis, is used, here, to reproduce the complete response of ionosphere to neutral motion. Vertical and horizontal scale of the modelled perturbed ionosphere corroborates the total electron content (TEC) observations and confirms the effective role of magnetic field in the ionospheric signature of tsunamis.

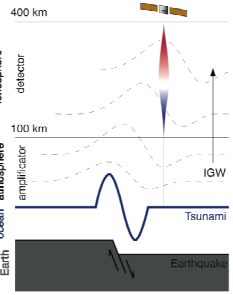
The ocean-atmosphere coupling

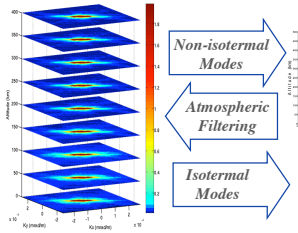
Based on the coupling between Tsunami gravity waves (TGW) and internal gravity waves (IGW), we computes the 3D propagation of IGW in a realistic neutral atmosphere with horizontal stratification. In essence the spectral analysis of the 2D ocean time-depending displacement field allows to propagate vertically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

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

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

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

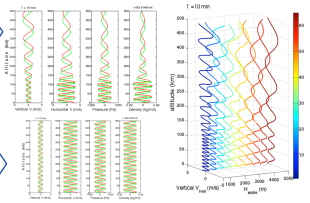




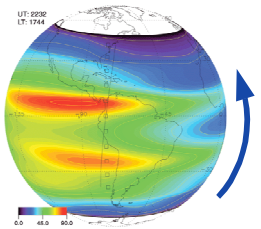
Non-isotermal Modes

Atmospheric Filtering

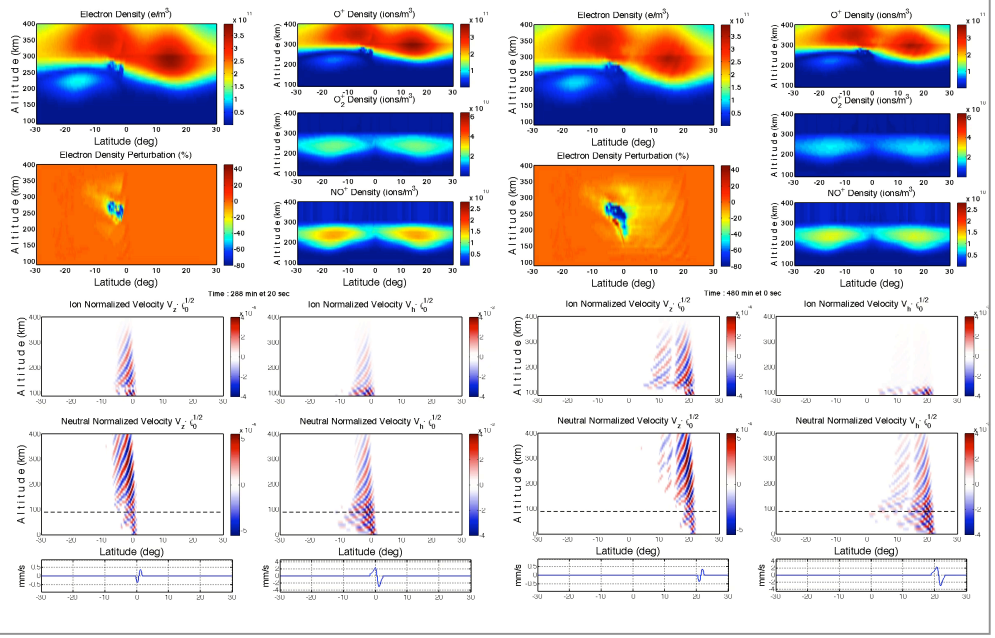
Isotermal Modes



The sud-nord tsunami propagaation

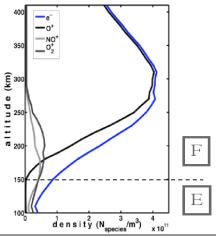


We observe that the horizontal component of the ion velocity is strongly affected by the magnetic field term $n_i B$. This latter is driven by the value of ion density increasing with altitude. As a consequence of this effect, the horizontal component of ion velocity in the F-region decreases with the 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.



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.



F

E

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

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

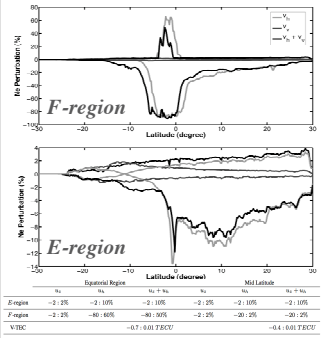
$$n_e=\Sigma_i\ n_i$$

B*dependent*

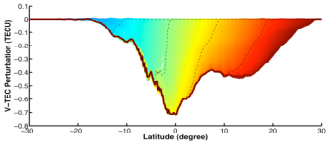
B*independent*

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

Vertical and horizontal effects



The table and figures resume Ne perturbation induced by the IGW neutral motion in the equatorial and mid-latitudes. Here the Ne perturbations produced by horizontal and vertical component of IGW have been computed separately for academic purpose. We can deduce that the plasma density variation in the high ionosphere are mainly driven by the horizontal component of IGW and that it is strongly influenced by the geomagnetic field. In the E-region the role of the geomagnetic field is less perceptible and the contributions of horizontal and vertical components of the IGW are comparable. We deduce the feeble B-dependence of vertical component: no differences are observed between E and F, equatorial and mid-latitude regions. A North-South dichotomy appears, probably driven by the northward tsunami propagation.



The perturbation is shown in terms of TEC. The modeling shows a TEC perturbation in order of a fraction of TEC-unit (TECU) coherent with the GPS observation.

We must consider here that the tsunami-geometry is not taken into account and the amplitude of vertical displacement at the sea surface is in order of 25 cm this can be a good estimation of the mean displacement produced by Sumatra tsunami in the indian ocean. In accordance with the result of realistic modeling of Sumatra tsunami [Occhipinti et al., 2006], the amplitudes of TEC and electron density perturbations shown here are strongly enlarged in the equatorial latitude. The geometrical heterogeneity induced by the tsunami waveform [Occhipinti et al., 2006] adds to the latitude dependence highlighting the difficulties in the identification of tsunami signature in the ionosphere without numerical simulation.