Detection of the Ionospheric perturbation associated to the tsunami of December 26th, 2004 with Topex and Jason-1 TEC data

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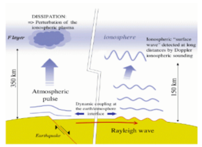
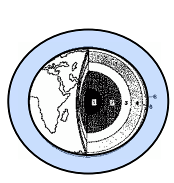
Abstract: We show that the ionosphere, as monitored by the dual frequency altimeter of the Jason-1 and Topex satellites, is strongly perturbed above the tsunami wave front generated by the Sumatra earthquake of December 26th, 2004. This perturbation is observed by both Topex and Jason-1, between 2h55 and 3h05 TU and leads to instabilities in the TEC estimates. A precise determination of the amplitude of the ionospheric perturbation is currently in progress. Such a perturbation is associated to the coupling between the gravity tsunami wave and atmospheric gravity waves. Due to a propagation delay of about one hour up to the ionosphere, it is observed at the vertical of the location of the tsunami after about 1hour of propagation, in contrary to the signal observed by other teams on the altimeter data just at the location of the tsunami. More precise timing will be given. Following a first positive result of an ionospheric detection after the, considerably weaker, tsunami of Peru, June, 23th, 2001 [Artru et al., 2005], this shows that ionospheric signatures of tsunamis can be detected, either with dense networks of GPS or with ionosphere sounding satellites. Real time ionospheric sounders, such as overhorizon radars, might in addition provide real-time ground based survey of the ionosphere over long ranges. A high resolution, real time monitoring from space of the Earth (from surface to ionosphere), together with ground-space systems, might therefore be considered in the future as a complement of the existing or future tsunami warning systems.

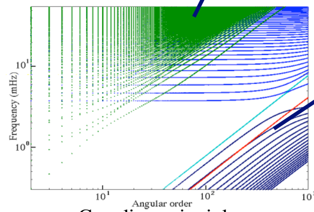


The seismic wave causes acoustic waves by dynamic coupling

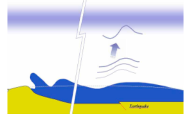


Realistic Earth: PREM + USSA models

The tsunami wave causes gravity waves by dynamic coupling



Coupling principle

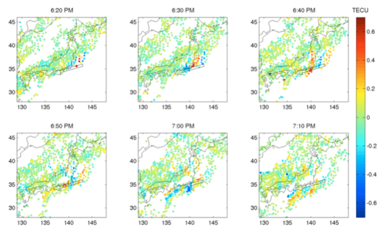


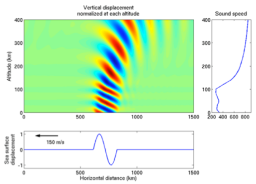
1st STEP: THEORETICAL PROPOSAL

In the '70s Hines ([Peltier&Hines, 1976]) brought the theoretical hypothesis of the detection of tsunami waves by ionospheric observations.

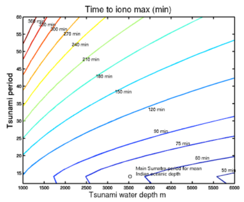
2nd STEP: FIRST DETECTION

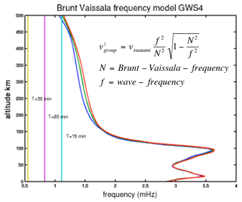
The first detection by GPS dense network was performed by *[Artru et al. 2005]* for the Peru tsunami of *June, 23th, 2001*





The conservation of kinetic energy ρ v² and the exponential decrease of density with height, generates a strong amplification with altitude in upper atmosphere. The neutral velocity is then transferred by neutration collision to the ionosphere



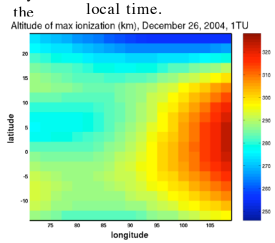


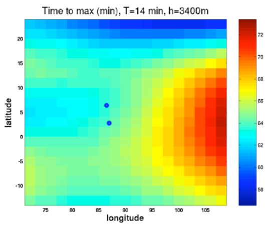
$$v_{group}^2 = v_{tsunami}\frac{f^2}{N^2}\sqrt{1-\frac{N^2}{f^2}}$$

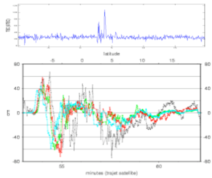
N = Brunt – Vaissala – frequency

f = wave – frequency

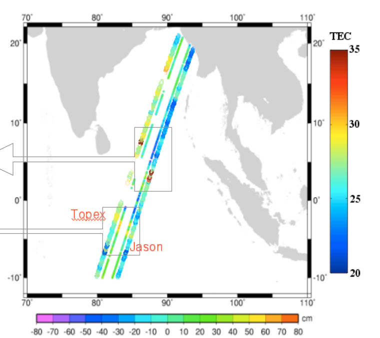
The upward group velocity of gravity waves depend on the frequency and propagation is observed only at frequencies below the Brunt Vaissala frequency. In the case of the Sumatra even, all periods below 12 minutes can be propagated toward the maximum of ionization for models obtained at this position and local time.







3rd STEP:SUMATRA DETECTION



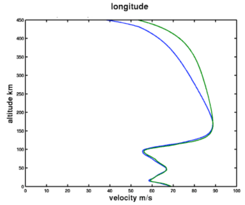
ionospheric signature of tsunami waves

tsunami wave

TOPEX and Jason data:

Rigth : altimetric measure in internal side and TEC measure in external side.

Left : Jason data (altimetric and TEC) and CEA models.

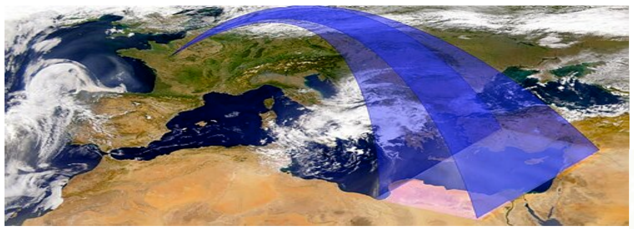


Vertical Travel times: The perturbations is observed by TOPEX and JASON about 117 min after the quake. A first analysis done with the group velocity shows that the 14 min signal need a vertical propagation of about 1h05 min to reach the ionization maximum while the 25 min signal needs about 100min. A detailed modeling of the propagation of the gravity water-atmospheric is in progress, including a coupling of the signal with the magnetic field which might translate the maximum electron density signals from the neutral density signal.

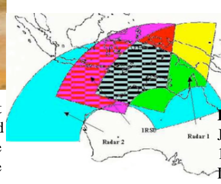
A detailed analysis of the TEC data shows a strongly perturbed ionosphere. So we can bring the hypothesis that this ionospheric perturbation lead to large perturbations in the altimetry data itself. Due to dispersion, we can expect long period perturbations to reach the ionosphere later. The effect of these perturbations need to be modelled for precise inversion of the altimetry data.

Other detection tools: GPS and OTH radars

GPS ionospheric monitoring using a dense network is a powerful tool to image small-scale perturbations of the ionosphere, over large areas, induced by different events such as earthquakes, mine blasts or explosions (Calais et al 1998, Ducic et al. 2003). In particular the detection can be extended at several hundred kilometers from the network location, thanks to oblique satellite-receiver rays. In the case of tsunami detection it provide coverage offshore, up to several hundred kilometers away from the coast. The japanese GEONET GPS network performed the first detection of tsunami ionospheric waves [Artru et al. 2005] associated to a 20-30 cm heigh tsunami wave.



The use of OTH radars in Europe and Australia to measure the vertical displacement at the see level or a variation of Doppler shift link to the ionospheric perturbation induced by gravity waves can be a new tools in the detection of tsunami waves. In addition the offshore coverage of the OTH radar located near the coast return a real interest for the warning tsunami system.



Conclusion: *While tide gauges can measure tsunami waves along the coast, detection and monitoring in the open ocean is very challenging due to the long wavelengths (typically 200 km) and small amplitudes compared to wind-generated waves. A multihazard approach would be necessary to detect the tsunami waves in open sea. Reported offshore detections involve ocean-bottom sensors (Hino et al 2001; Tanioka 1999) (pressure gauges or seismometers), sea level measurements from Global Positioning System receivers on buoys (Gonzalez et al 1998; Kato et al 2000) or satellite altimetry (Okal, Piatanesi & Heinrich 1999). The results shown in this paper show that a detection of tsunami waves by operational ionospheric observation, I.e by GPS dense networks and OTH radar, can be added to the previous techniques.*

References:

J. Artru,V. Ducic, H.Kanamori, P. Lognonné and M. Murakami , Ionospheric detection of gravity waves induced by tsunamis, Geophy. J. Int, 160, 840-848, doi : 10.1111/j.1365-246X.2005.02552.x2005.

Lognonné , P. Juliette Artru, Raphael Garcia, François Crespon, Vesna Ducic, Eric Jeansou, Giovani Occhipinti, Eric Helbert, Gilhelm Moreaux, Ground based GPS tomography of ionospheric post-seismic signal during Demeter: the SPECTRE project, submitted to Planet. Space.