Can OTH radar help tsunami monitoring?

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Introduction

Ionospheric anomalies following 2004 Sumatra tsunami have been detected and 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) and after earthquakes in Sumatra and Chile in 2007. All these anomalies show the signature in the ionosphere of tsunami-generated internal gravity waves (IGW) propagating in the neutral atmosphere over oceanic regions.

Most of these ionospheric anomalies are deterministic and reproducible by numerical modeling (Occhipinti et al., 2006, 2008; Mai and Kiang, 2009; Hickey et al. 2009) via the coupling mechanism between ocean, neutral atmosphere and ionosphere. In addition, the numerical modeling supplies useful helps in the estimation of expected anomalies and to explore and identify new techniques to detect the ionospheric tsunami signature, other than GPS and altimeters.

Here we present an overview of the physical coupling mechanism and the simulation environment that we developed to assess the capabilities of Over-The-Horizon (OTH) radars to detect these ionospheric anomalies. We use a full 3D approach, including empirical models of neutral atmosphere and ionosphere. Synthetic radar measurements are computed using HF numerical ray-tracing. The large coverage of OTH radar and its sensitivity to plasma anomalies open new perspectives in the future oceanic monitoring and tsunami warning system.

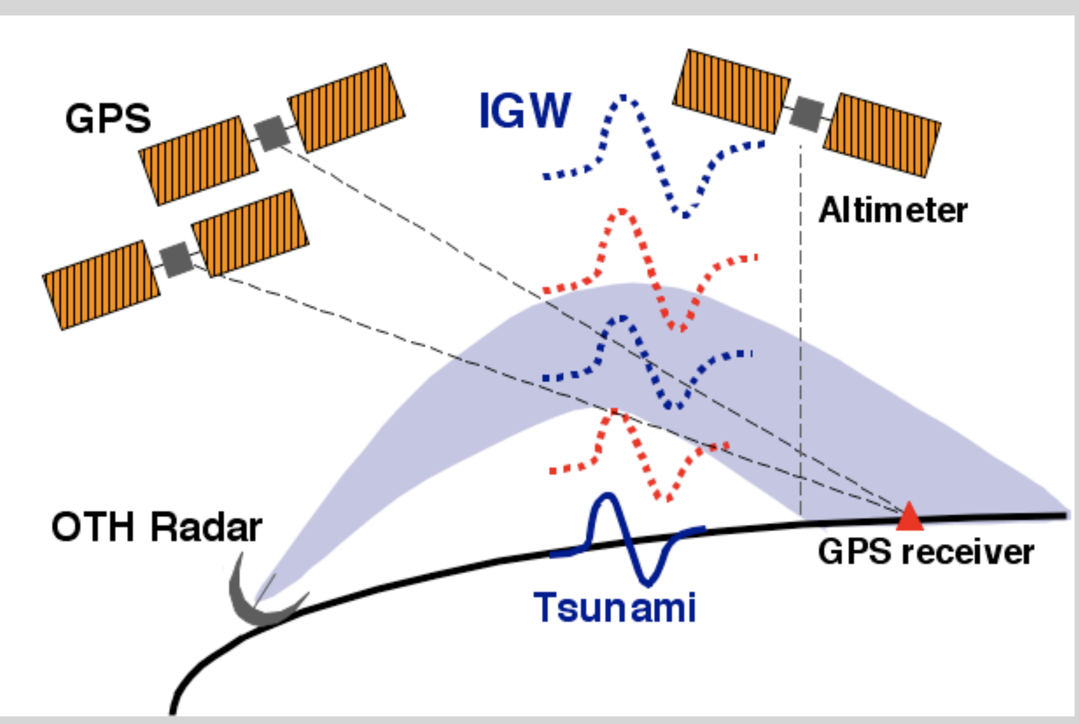

Figure 1: Schematic view of the ocean-atmosphere coupling and examples of ground-based and satellite-based detection techniques of the ionospheric IGW.

OTH radar characteristics

Over-The-Horizon radars operate in HF radio band (from 3 to 30 MHz). This frequency range covers the range of frequency that can be reflected down by the Earth ionosphere. OTH radars signals are tuned in elevation and azimuth to observe areas up to few thousands km from the source.
These instruments can be also used to sound the ionosphere and we want to develop a technique that enable the detection of the ionospheric signature of tsunamigenic IGW.
We are realizing a full 3D simulation environment to model all the elements involved in the physical system OTH radar - tsunamigenic internal gravity wave propagating from the ocean to the ionosphere.

On this topic see also poster NH43C-1352
Earthquakes & Tsunamis flirting with the Ionosphere: the Sumatra gossip !!
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Ionospheric ray tracing

TDR: Ionospheric ray-tracing software

We developed an 3D electromagnetic wave ray-tracing program based on the geometric optic linear theory and including a heterogeneous ionosphere above an ellipsoidal Earth (WGS-84). It is used along with a 3D model of electron density in the ionosphere in order to calculate the index of refraction at any point of the propagation path. Two options for the ionosphere have been included in the program to check rays response to different ionospheric representation: IRI 2007 (Bilitza, 2008) and NeQuick 2 (Nava et al., 2008).

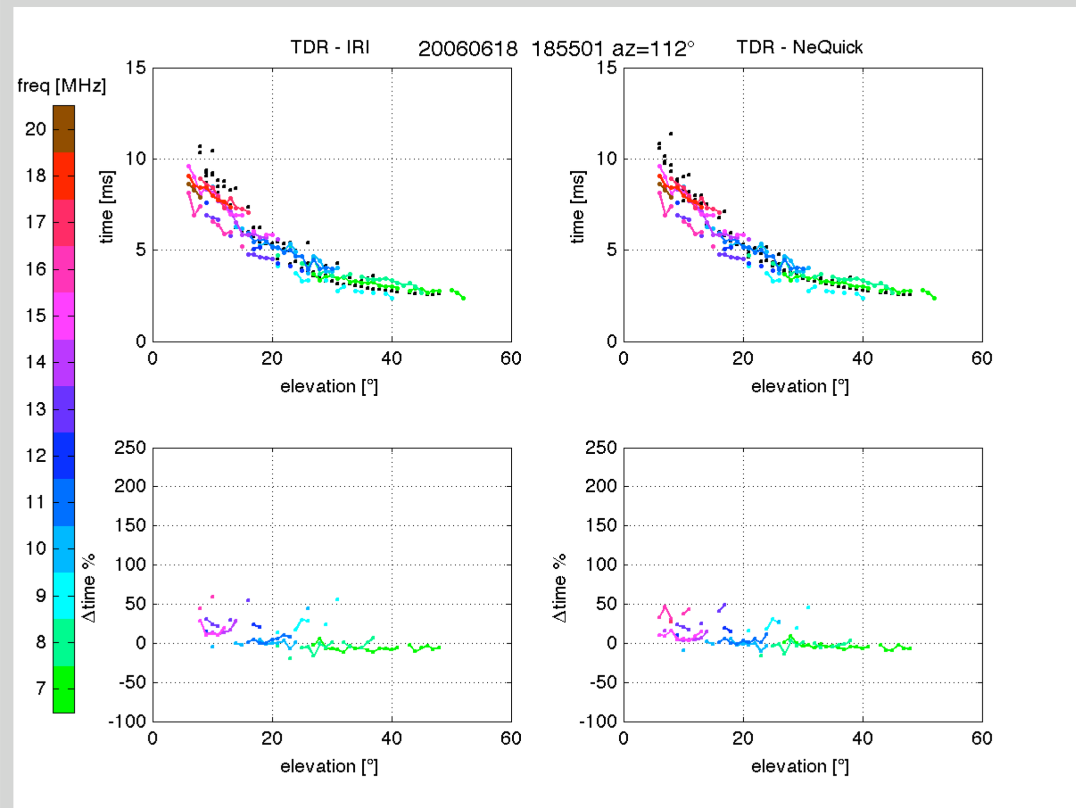

Figure 2: Comparison between OTH radar measurements (color lines) and TDR calculations using both IRI 2007 and NeQuick 2 ionosphere models (black dots). Top: radar echo time; Bottom: difference between data and models.

Validation of TDR using OTH radar data

We compared Nostradamus OTH radar measurements with the calculations of TDR software for the period 2006-2008. According to the azimuth and the local time, the agreement between experimental and modeled data can be up to 50° elevation and frequency of 15 MHz. Figure 2 shows the comparison performed using both ionosphere options: IRI and NeQuick models.

OTH radar emission lobe

OTH radar response is simulated combining ray-trace calculations on a 1°x1° grid in the central part of the emission lobe. Figure 3 shows a simulation of the radiative diagram of a typical OTH radar at 20° elevation.

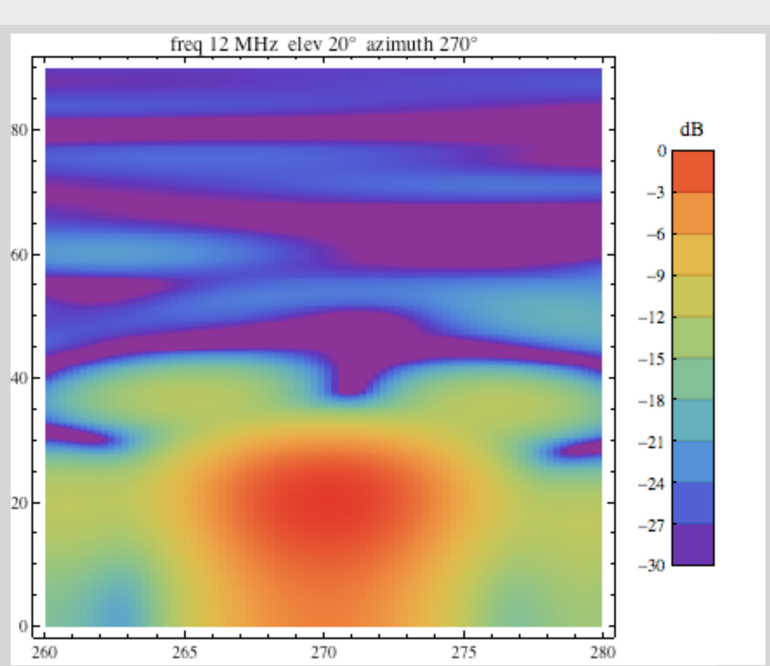

Figure 3: Calculated radiative diagram of OTH radar at 20° elevation and 270° azimuth.

OTH radar simulations

Response of OTH radar to IGW

We computed a plane wave perturbation of the electron density of the ionosphere propagating at 182 m/s, corresponding to a mean ocean depth of 3400 m. Using TDR we simulated OTH radar observation between 6 and 12 MHz at elevations between 10° and 50°.
The ray-paths that are crossing the perturbed region of the ionosphere present a deviation of the ray associated with a time-delay of the radar echo (figure 4).

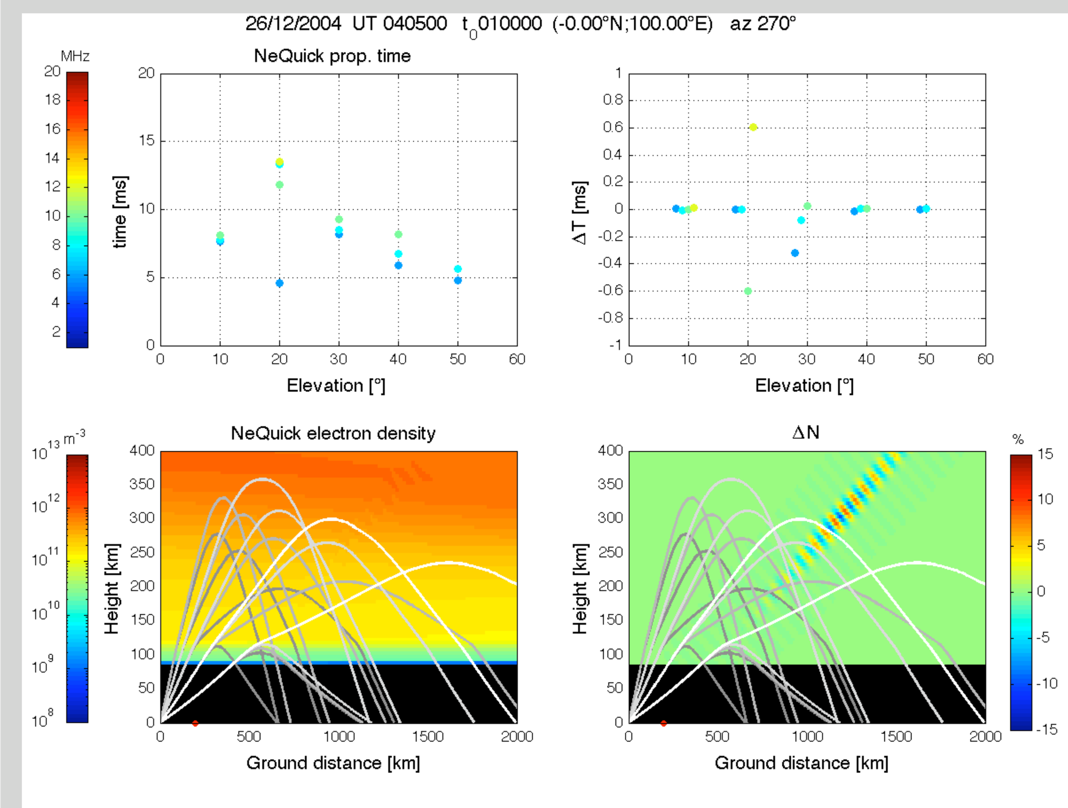

Figure 4: Propagation time and ray-paths for OTH radar signals through perturbed ionosphere. Top left: simulated radar echo time. Top right: time perturbation. Bottom left: ray-paths through the ionosphere. Bottom right: same rays plot on the ionosphere perturbation. Grayscale indicate ray frequency, with withe the highest.

The perturbation is moving towards the radar location. It is detected first at lower elevation angles for the higher frequencies and later at higher elevation angles and at many frequencies, as shown in figure 5.
This simulation has been done for a perturbation propagating during the first half of the day, when the ionosphere develops under the influence of the Sun.

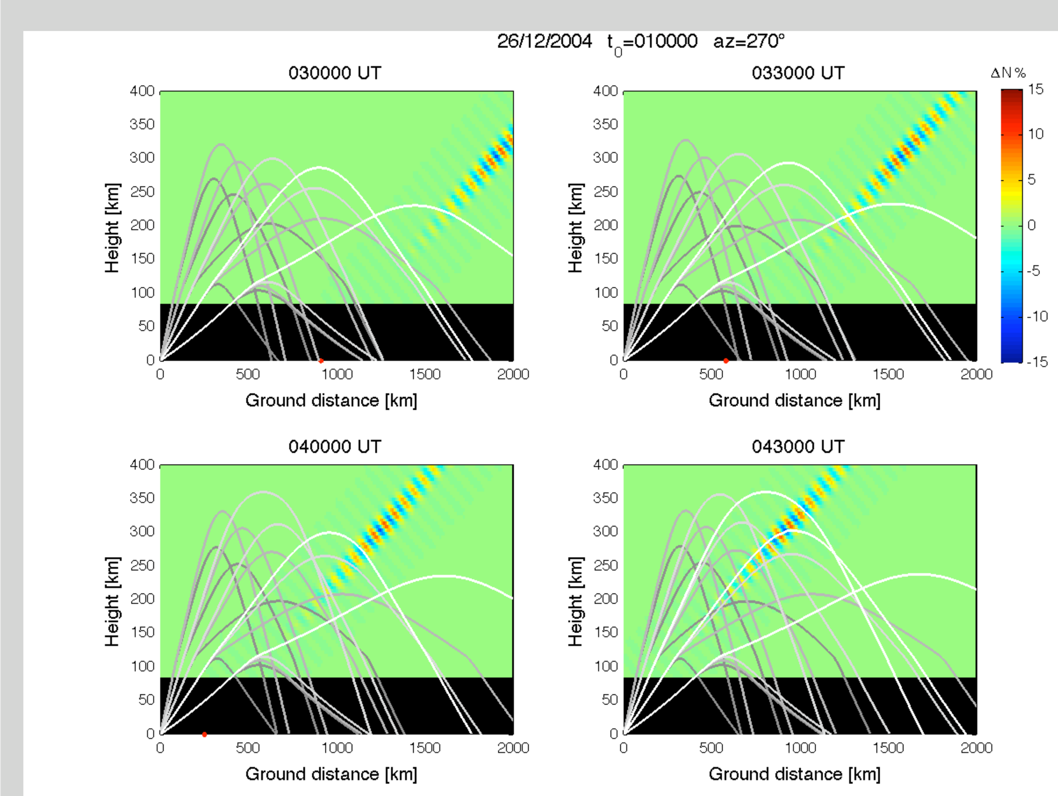

Figure 5: Ionospheric electron density perturbation snapshots and ray-traces for frequencies between 8 and 12 MHz and elevations from 10° to 50°. Red dots indicate the ground position of the wave origin at that time.

IGW detection

Simulation of OTH radar detection of tsunami event

The synthetic OTH radar has been located at (0°N, 100°E) and rays have been calculated at 60s time interval.
The HF propagation through the ionosphere perturbed by a traveling plane wave has been computed. A clear signature of the perturbation is found in the radar signal (Figure 6). Its amplitude spectrum has a peak at 1.6 mHz that corresponds to the frequency of the propagating wave.

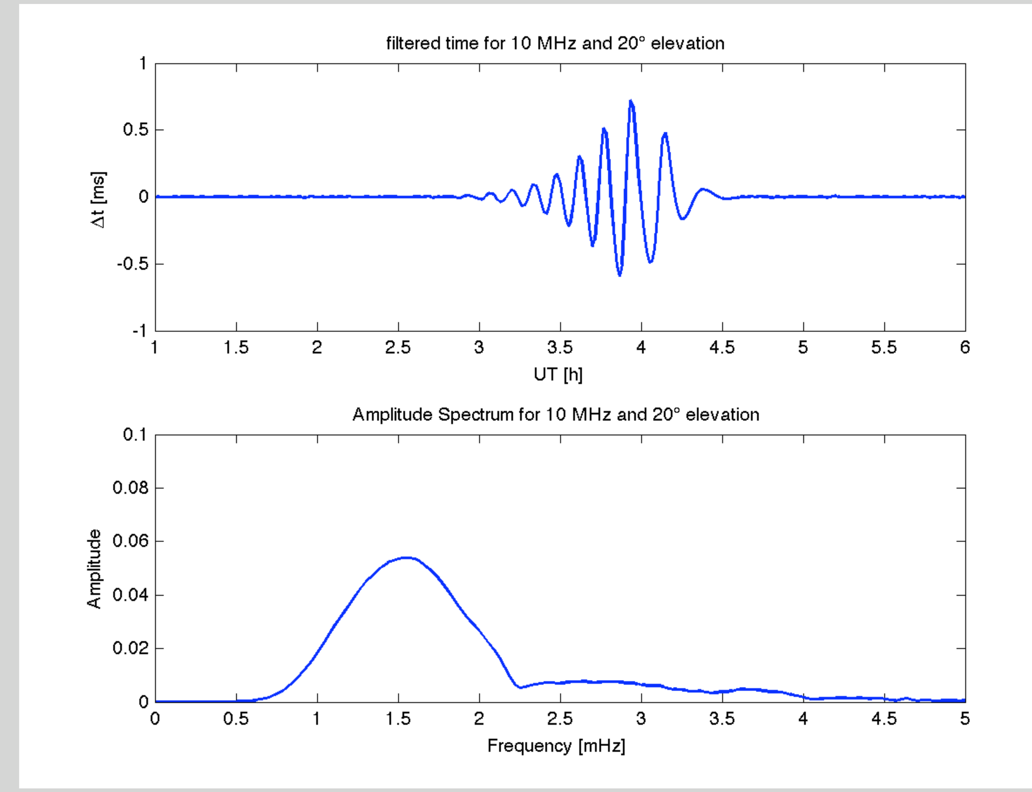

Figure 6: Top: Filtered propagation time of OTH radar signals through tsunamigenic IGW perturbed ionosphere. Bottom: amplitude spectrum. The tsunami frequency is 1.6 mHz.

Conclusions and Perspective

OTH radar can be regarded as a very promising instrument to detect tsunamigenic gravity waves, due to its capability to observe the ionosphere over very large areas.
The ionospheric ray-tracing software that we have developed for simulating OTH radar has been validated using experimental OTH data.
The tests performed confirm the possibility of detecting tsunamigenic internal gravity waves through observation of the delays of radar echoes.

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