

Subject title: Earthquake and Tsunami signature in the ionosphere by ground-based and on-boarded airglow cameras: new modelling and new observations

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Presentation of the subject: During Tohoku (2011), the 630.0-nm airglow camera located in Hawaii, observing the O^+ night density variation, showed, for the first time, the internal gravity waves forced by the tsunami (IGW_{tsuna}) in a zone of $180 \times 180 \text{ km}^2$ around the island (Figure 1). Never before the tsunami signature in the ionosphere was observed with such high spatial density, visualizing the tsunami propagation (Occhipinti et al., 2011, Makela et al., 2011). The tsunami signature was successfully identified thanks to the matching of wave-form reproduce by numerical modelling (Occhipinti et al., 2011) that also highlight the role of the bathymetry: approaching the Hawaiian archipelago, the tsunami propagation is slowed down (due to the reduction of the sea depth), but, the IGW_{tsuna} , already formed and propagating in the atmosphere/ionosphere, conserves its speed and arrives before the tsunami wave-front (white-dotted-lines, Figure 1). The Tohoku tsunami has maximum energy at two main periods of 14 min and 26 min, longer period go faster (Occhipinti et al., 2011).

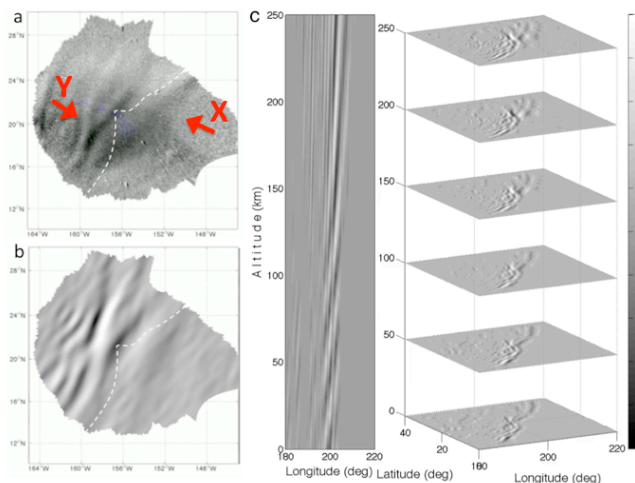


Figure 1: Tohoku (2011) IGW_{tsuna} observed by the 630nm airglow camera in Hawaii (a), modelled at the layer to of observation (250 km, b), and full 3D (c). Dotted-white-line shows tsunami wave front, Y and X the IGW_{tsuna} at period of 14 min and 26 min respectively (red arrows highlight the position, not the direction). From Occhipinti et al. (2011)

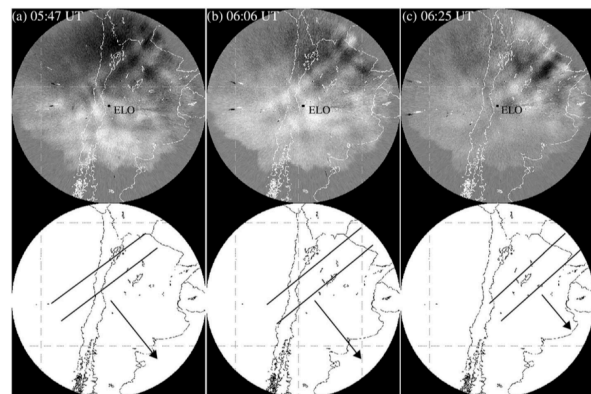


Figure 2: Sequence of three 630 nm airglow images at the El Leoncito observatory on 12 March 2011. The images show the southeastward progression of an extensive thermospheric gravity wave event that fits with the arrival time of the Tohoku tsunami (2011) in Argentina at 1800 km from the epicenter. The schematic tracings in the lower part of each panel highlight the waves clearly. From Smith et al., 2015

A visual 2D cross-correlation between the observation and modelling highlight the shift of around 2° in both directions potentially explained by the effect of the wind (not included in the modelling) as already speculated by Occhipinti et al. (2006). The airglow camera in Hawaii is unfortunately not calibrated, consequently the comparison between data and synthetic is only qualitative (based on the shape of waveform and arrival time) and don't allow yet the explicit connection between the observed number of photons and the amplitude of the

tsunami. The tsunami signature in the O^+ density was also successfully detected by the (calibrated) 630nm airglow camera located in Argentina, 18.000 km away from the epicenter (Smith et al., 2015) confirming again the potential interest and reliability of the optic detection by airglow cameras and opening new perspective for the full development of forward model and comparison with the data.

Two additional tsunamis have been successfully detected by the airglow cameras in Hawaii (Grawe & Makela, 2015): the moderate Queen Charlotte Island tsunami (M: 7.0, 28 Oct., 2012, British Columbia) creates only a few centimeters in wave amplitude and no damages, and it was successfully detected with not propitious observation conditions (quasi-full moon; the light reduce the sensitivity of the airglow camera); and the tsunamigenic earthquake in Chile (M: 8.3, 16 Sept. 2015, few fatalities and several damages).

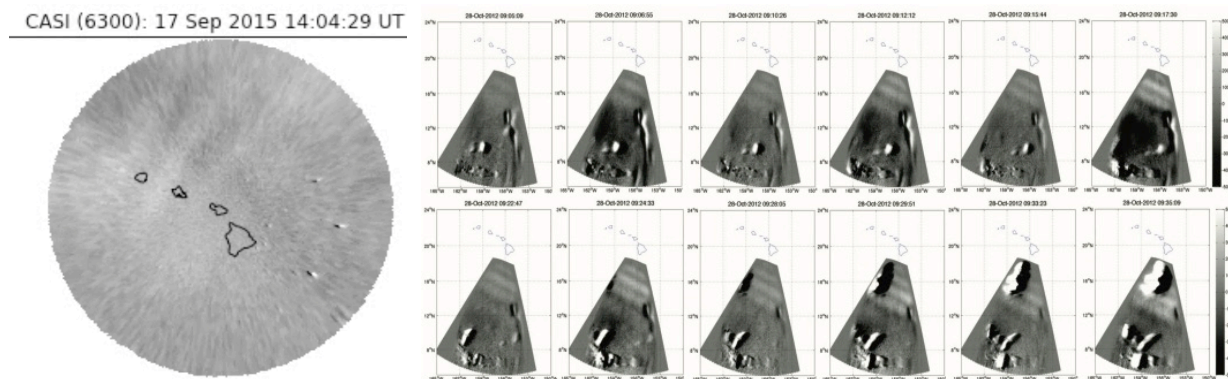


Figure 3: Airglow observation of the recent Chilean tsunami (M 8.3, 2015, left) and Queen Charlotte Island tsunami (M 7.7, 2012, right) using respectively the full-sky and south-oriented 630nm airglow cameras in Hawaii.

Those successful observations (Figures 1-3) confirm the maturity of the tsunami detection by airglow camera and open new technological perspectives in tsunami remote sensing by ground-based and on-boarded cameras. Indeed, the CNES project IONOGLOW (phase-0 at PASO from 2018, G. Occhipinti as PI) is currently exploring the possibility to fly an airglow camera hosted as payload on a commercial GEO satellite to cover the entire Pacific Ocean and to complete the coverage of the airglow cameras on global scale.

The preliminary modelling of the IGW_{tsuna} related to the Queen Charlotte Island tsunami, proved that the effect of the wind plays an important role not only in the advance/delay of the IGW_{tsuna} (as speculated by Occhipinti et al., 2006, 2011) but also in the amplification of the IGW_{tsuna} depending of the propagation direction and the direction/amplitude of the wind.

Additionally, as highlighted by Occhipinti et al. (2008), the effect of the geomagnetic field play also an important role in the neutral plasma coupling driving the amplification of the IGW_{tsuna} depending of the direction of the wave propagation (k-vector), the inclination of the magnetic field, and (recently explored by Grawe & Makela, 2015) the direction of view of the camera. Based on the observation factor O introduced by Grawe & Makela (2015) we reproduced their result around Hawaii and we extended it to global scale observation from a GEO and MEO observation points to support the IONOGLOW project. Surprisingly, tsunamis generated in Japan and Chile has favourable observation condition on the entire globe scale.

Today, the objective of the proposed Ph.D is double:

First of all, we wish to improve the modelling capability and methodology to fully include, (i) the effect of the wind, (ii) the effect of the acoustic wave, in order to reproduce the potential signal close to the epicenter appearing 8 min after the tsunami genesis and useful to estimate the tsunami risk, (iii) the full effect of the geometry (related to the magnetic field, the observation position, the propagation of the tsunami) in the neutral-plasma coupling in order to fully reproduce the airglow flux, not only for the 630nm emission but also additional potential emissions (e.g., OH and UV).

Second, we wish to explore a new database of 21 calibrated airglow cameras from University of Illinois, Boston University and Nagoya University to fully cover tsunamigenic or tsunami-risk regions: Sumatra (1 airglow camera), Japan (5 airglow cameras), Peru/Chili/Argentina (4 airglow cameras), Hawaii (3 airglow camera), Caribbean sea (2 airglow cameras), South Atlantic (3 airglow cameras), New Zealand and Australia (2 airglow cameras), Alaska (1 airglow camera). All those cameras observe several emissions, and at least the 630nm and OH. The location of the new cameras covering epicentral regions is giving us, for the first time, the possibility to fully explore the genesis of the AGW_{epi} and IGW_{tsuna} to estimate the tsunami risk and the tsunami amplitude off-shore.

Coupling together theoretical and observational objectives we wish to fully explore the potential role of airglow detection for tsunami risk and tsunami amplitude estimation, and to support the development of the ground-based network coupled together with the future observation from satellites, and mainly related to the IONOGLOW project supported by the CNES.

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