Atmospheric Gravity Waves model

P. Bobik (bobik@saske.sk), M. Putiš, Š. Mackovjak

Institute of Experimental Physics, SAS

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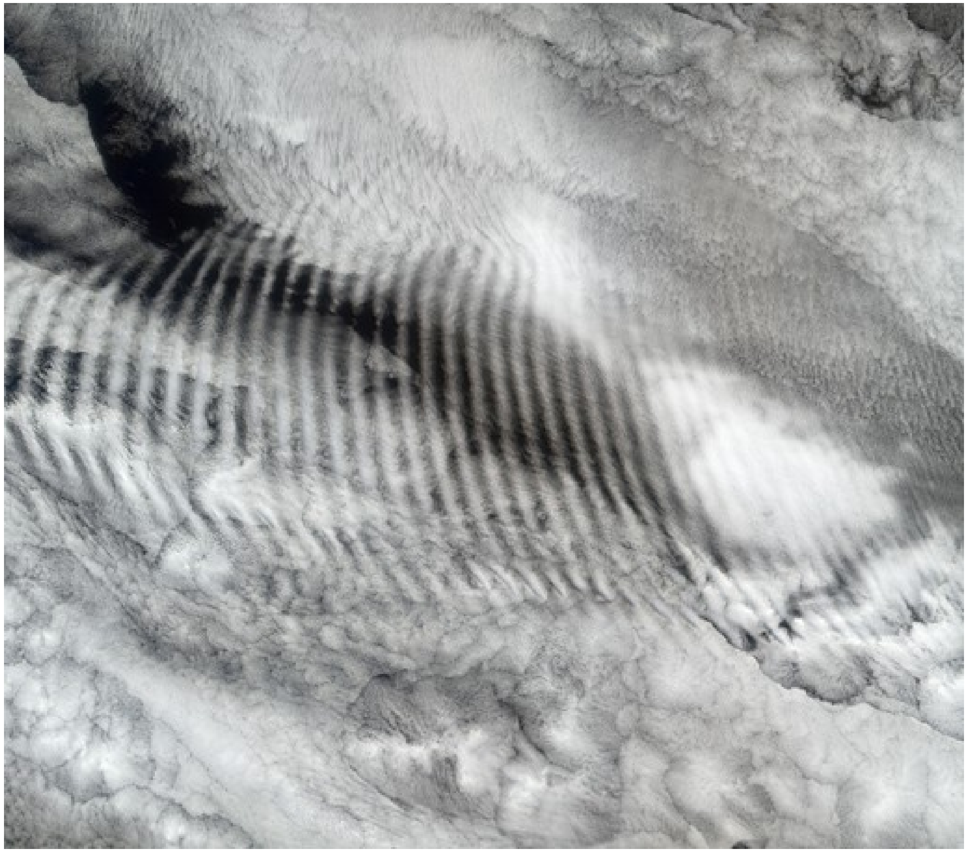
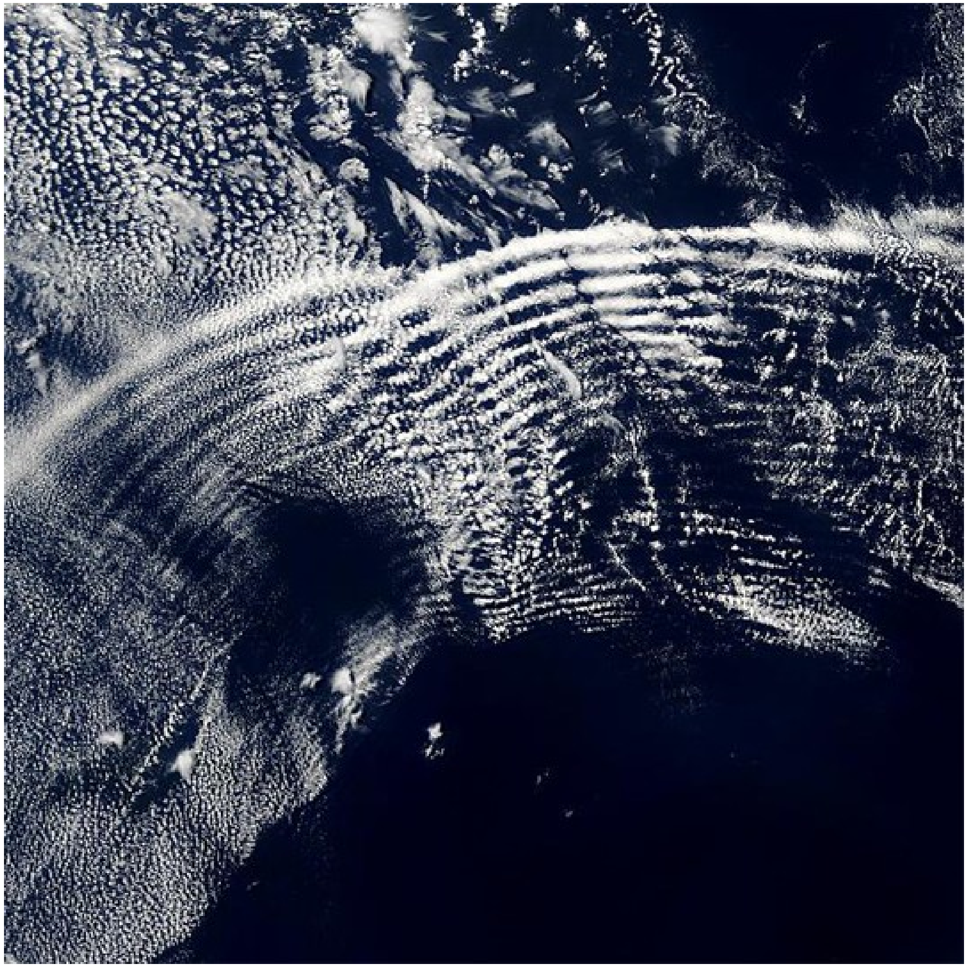
Atmospheric Gravity Waves model



NASA, MODIS (Moderate Resolution Imaging Spectroradiometer)



NASA, atmospheric gravity waves over Australia

Background : Observation

Imaging and modeling the ionospheric airglow response over Hawaii to the tsunami generated by the Tohoku earthquake of 11 March 2011

J. J. Makela,[1] P. Lognonné,[2] H. Hébert,[3] T. Gehrels,[1] L. Rolland,[2] S. Allgeyer,[3] A. Kherani,[4] G. Occhipinti,[2] E. Astafyeva,[2] P. Coïsson,[2] A. Loevenbruck,[3] E. Clévédé,[2] M. C. Kelley,[5] and J. Lamouroux[6]

Received 19 April 2011; revised 25 May 2011; accepted 25 May 2011; published 7 July 2011.

[1] Although only centimeters in amplitude over the open ocean, tsunamis can generate appreciable wave amplitudes in the upper atmosphere, including the naturally occurring chemiluminescent airglow layers, due to the exponential decrease in density with altitude. Here, we present the first observation of the airglow tsunami signature, resulting from the 11 March 2011 Tohoku earthquake off the eastern coast of Japan. These images are taken using a wide-angle camera system located at the top of the Haleakala Volcano on Maui, Hawaii. They are correlated with GPS measurements of the total electron content from Hawaii GPS stations and the Jason-1 satellite. We find waves propagating in the airglow layer from the direction of the earthquake epicenter with a velocity that matches that of the ocean tsunami. The first ionospheric signature precedes the modeled ocean tsunami generated by the main shock by approximately one hour. These results demonstrate the utility of monitoring the Earth's airglow layers for tsunami detection and early warning.

Citation: Makela, J. J., et al. (2011), Imaging and modeling the ionospheric airglow response over Hawaii to the tsunami generated by the Tohoku earthquake of 11 March 2011, *Geophys. Res. Lett.*, *38*, L00G02, doi:10.1029/2011GL047860.

Observation by highly sensitive, wide-angle camera system to image the tsunami-driven ionospheric response to the 11 March 2011 Tohoku earthquake.

From a single instrument located on the Haleakala Volcano on Maui, Hawaii, able to image a 10^6 km^2 region of the ionosphere at high spatial (1–5 km, elevation angle dependent) and temporal (5 min) resolutions.

Observing the airglow layer at approximately 250 km in altitude caused by the dissociative recombination of O^+_2 which emits photons at 630.0 nm.

J. J. Makela et.al., Imaging and modeling the ionospheric airglow response over Hawaii to the tsunami generated by the Tohoku earthquake of 11 March 2011, GRL, VOL. 38, L00G02, doi:10.1029/2011GL047860, 2011

Background : Observation

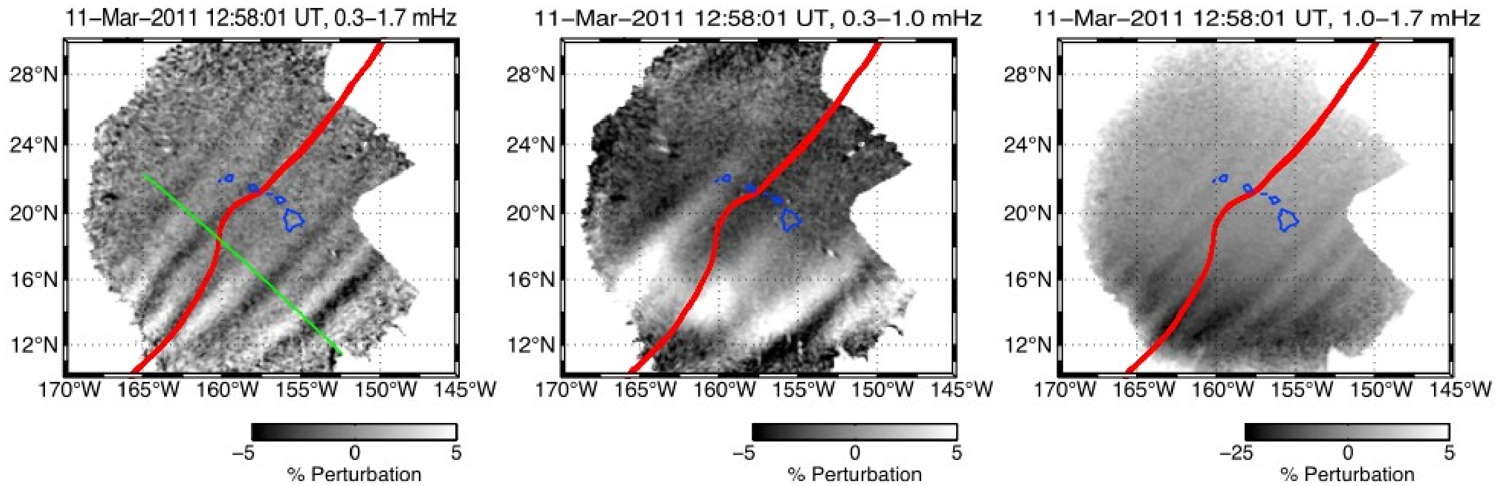


Figure 1. Example of 630.0-nm images processed using length-8 FIR filters with passbands of (left) 0.3–1.7 mHz, (middle) 0.3–1.0 mHz to highlight the 26.2-min period waves, and (right) 1.0–1.7 mHz to highlight the 14.2-min period waves. The red line in each image indicates the tsunami location at the time of the image. The green line in Figure 1 (left) indicates the line from which intensities were taken to construct Figure 2.

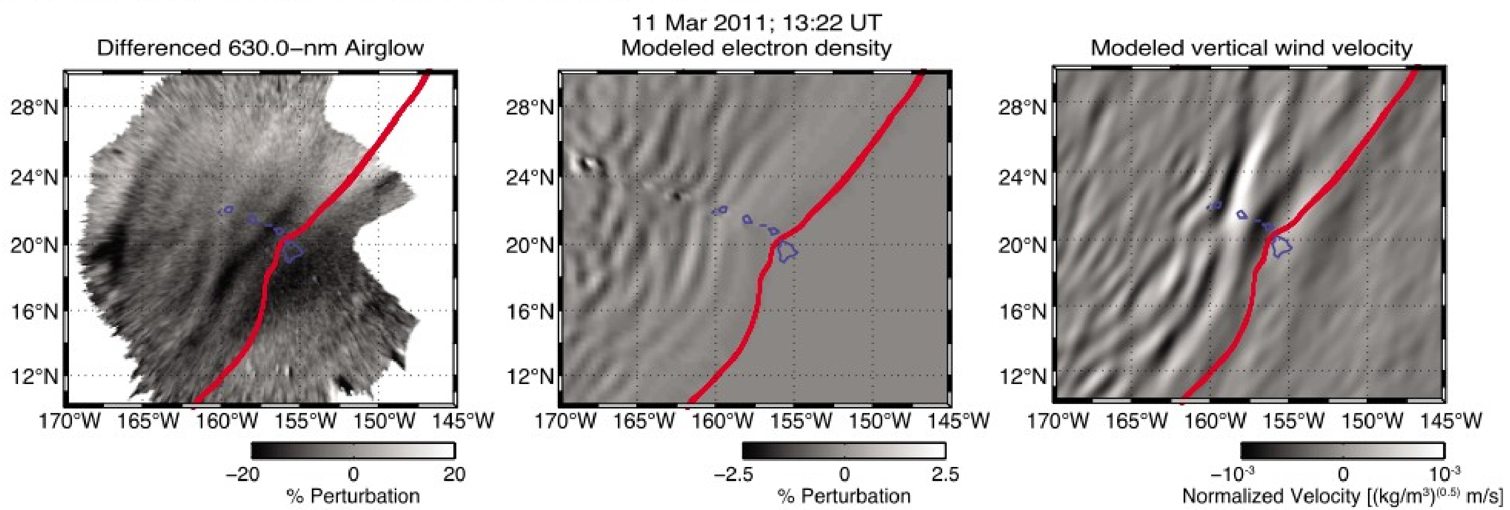


Figure 3. Comparison of (left) differenced 630.0-nm emission intensity observed at 13:20 and 13:22 UT from Hawaii, (middle) electron density at 250 km from a gravity-acoustic model [*Kherani et al.*, 2009], and (right) normalized vertical wind velocity at 250 km from a pure gravity wave model [*Occhipinti et al.*, 2006, 2008, submitted manuscript, 2011]. In each case, the red line indicates the tsunami location at the time of the image.

J. J. Makela et.al., Imaging and modeling the ionospheric airglow response over Hawaii to the tsunami generated by the Tohoku earthquake of 11 March 2011, GRL, VOL. 38, L00G02, doi:10.1029/2011GL047860, 2011

Background : Simulation

Atmospheric airglow fluctuations due to a tsunami-driven gravity wave disturbance

M. P. Hickey,[1] G. Schubert,[2,3] and R. L. Walterscheid[3]

Received 26 October 2009; revised 11 January 2010; accepted 18 February 2010; published 16 June 2010.

[1] A spectral full-wave model is used to study the upward propagation of a gravity wave disturbance and its effect on atmospheric nightglow emissions. Gravity waves are generated by a surface displacement that mimics a tsunami having a maximum amplitude of 0.5 m, a characteristic horizontal wavelength of 400 km, and a horizontal phase speed of 200 m/s. The gravity wave disturbance can reach *F* region altitudes before significant viscous dissipation occurs. The response of the OH Meinel nightglow in the mesopause region (~87 km altitude) produces relative brightness fluctuations, which are ~1% of the mean for overhead viewing. The wave amplitudes grow as the wave disturbance propagates upward, which causes the thermospheric nightglow emission responses to be large. For overhead viewing, the brightness fluctuations are ~50% and 43% of the mean for the OI 6300 Å and O 1356 Å emissions, respectively. The total electron content fluctuation is ~33% of the mean for overhead viewing. For oblique viewing, the relative brightness fluctuations are slightly smaller than those obtained for overhead viewing. In spite of this, the thermospheric nightglow brightness fluctuations are large enough that oblique viewing could provide early warning of an approaching tsunami. Thus, the monitoring of thermospheric nightglow emissions may be a useful augmentation to other observational techniques of tsunami effects in the thermosphere/ionosphere system.

Citation: Hickey, M. P., G. Schubert, and R. L. Walterscheid (2010), Atmospheric airglow fluctuations due to a tsunami-driven gravity wave disturbance, *J. Geophys. Res.*, *115*, A06308, doi:10.1029/2009JA014977.

M.P. Hickey et al.: Atmospheric airglow fluctuations due to a tsunami□driven gravity wave disturbance, JGR, 115, A06308, doi:10.1029/2009JA014977, 2010

Background : Simulation

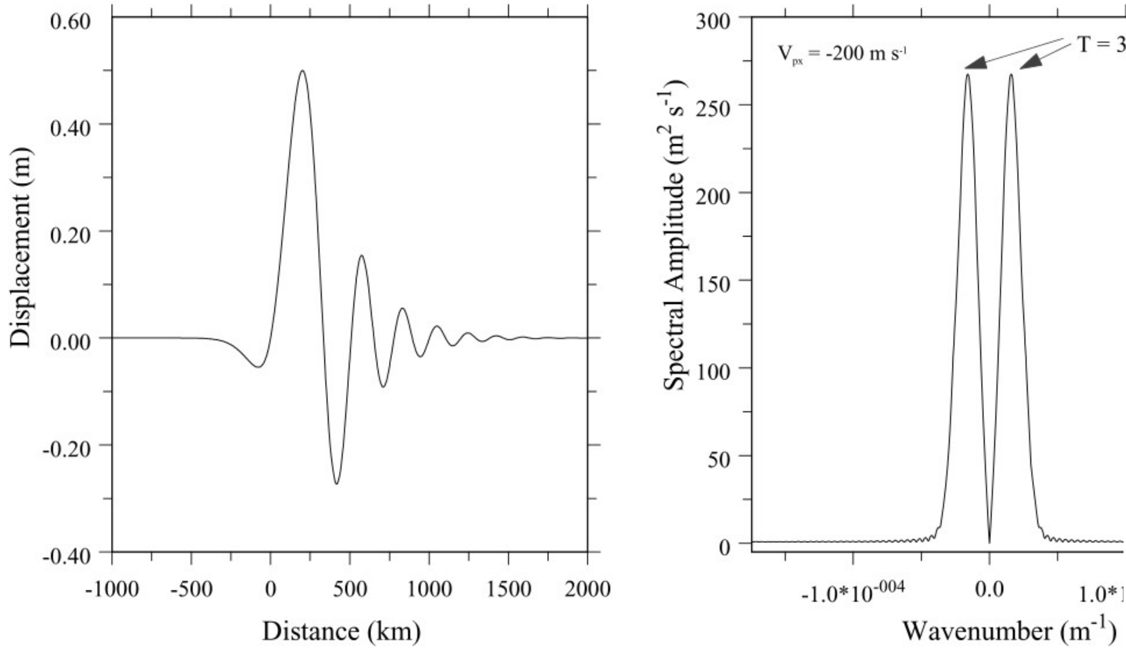


Figure 1. (a) Surface displacement (Z) calculated using equation (1) for a maximum disp
0.50 m, and (b) the vertical velocity spectrum ($\hat{W}$) associated with Z.

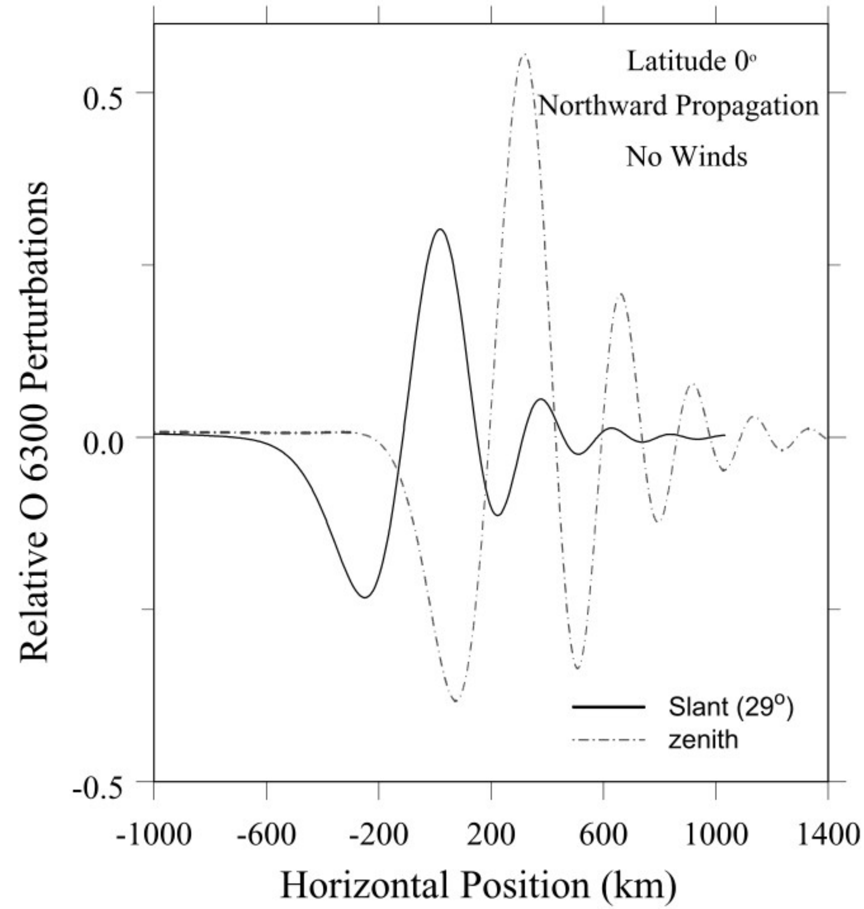


Figure 9. OI 6300 Å relative brightness fluctuations for overhead and oblique viewing. The zenith brightness of the 6300 is 5.78×10^6 R. The brightness for the 29° line of sight is 1.19×10^7 R.

- brightness fluctuations are ~50% of the mean for the OI 6300 Å

M.P. Hickey et al.: Atmospheric airglow fluctuations due to a tsunami□driven gravity wave disturbance,
JGR, 115, A06308, doi:10.1029/2009JA014977, 2010

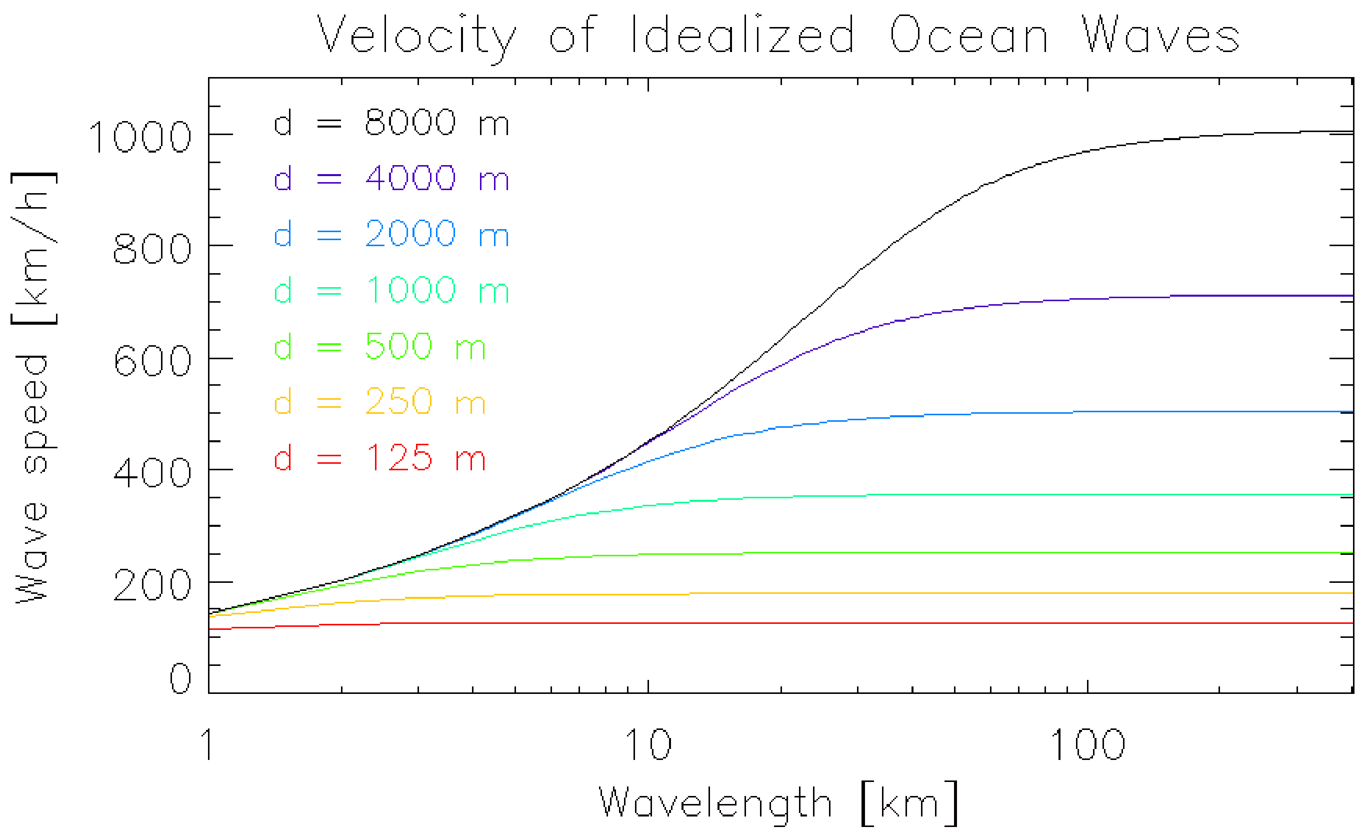
Atmospheric Gravity Waves model

Model modules :

- Ocean wave motion
- Atmospheric gravity wave dynamics
- Atmospheric gravity wave perturbation
- Airglow intensity change due to change of density : AURIC

Atmospheric Gravity Waves model

- Idealized Ocean Wave - presumes an ideal fluid, level bottom, idealized waveshape, etc.
- speed of a progressive wave with respect to the liquid and therefore does not include any current speed of the water
- deeper ocean – faster wave velocity

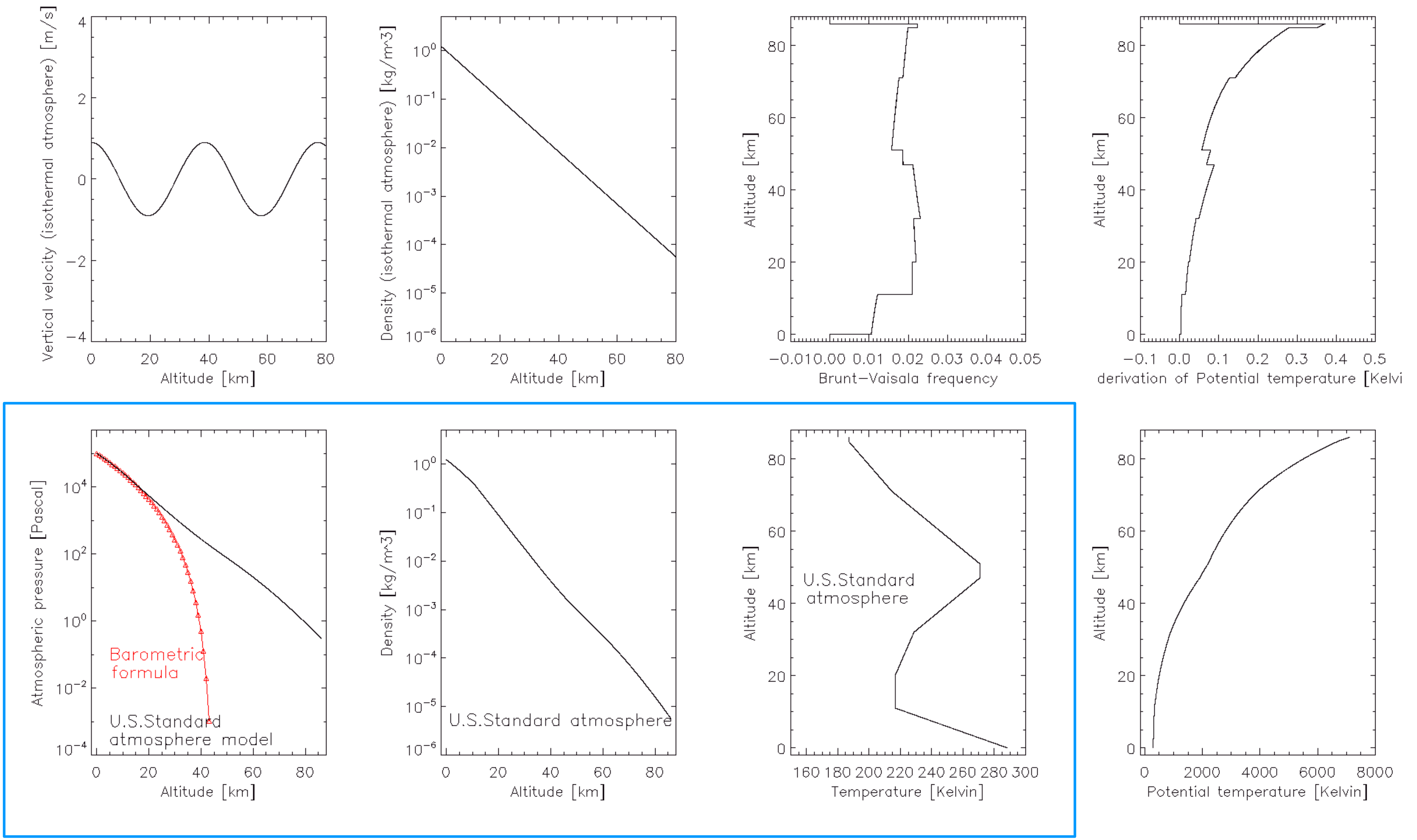


Atmospheric Gravity Waves model

- used Atmosphere models
  - U.S. Standard Atmosphere
    - The U.S. Standard Atmosphere is a series of models that define values for atmospheric temperature, density, pressure and other properties over a wide range of altitudes.
    - Version 1976
    - Till altitude 88 km
  - NRLMSISE-00
    - NRLMSISE-00 is an empirical, global model of the Earth's atmosphere from ground to space. It models the temperatures and densities of the atmosphere's components.
    - http://www.nrl.navy.mil/research/nrl-review/2003/atmospheric-science/picone/
    - Source in C language : http://www.brodo.de/space/nrlmsise/

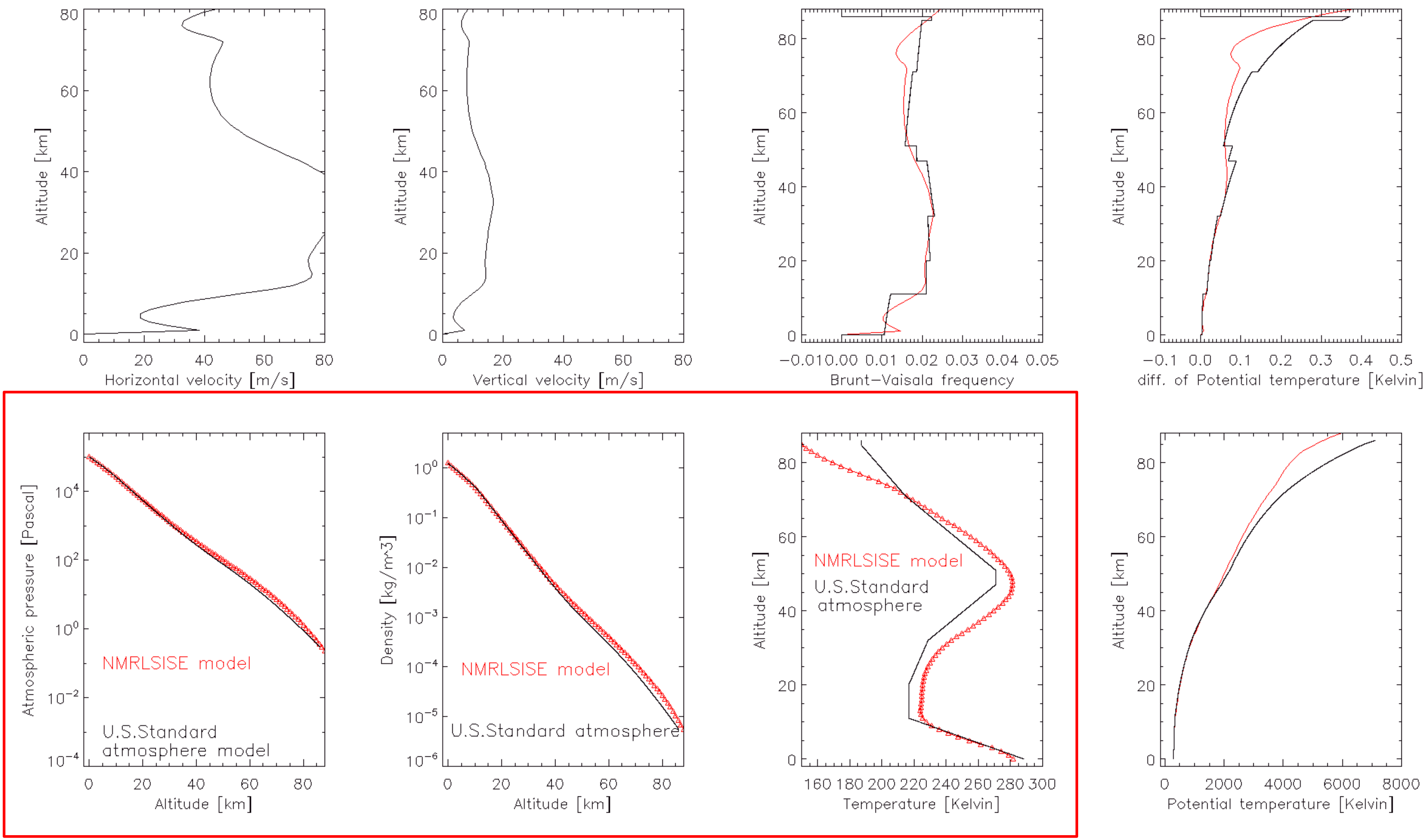
Atmospheric Gravity Waves model

U.S.Standard atmosphere model



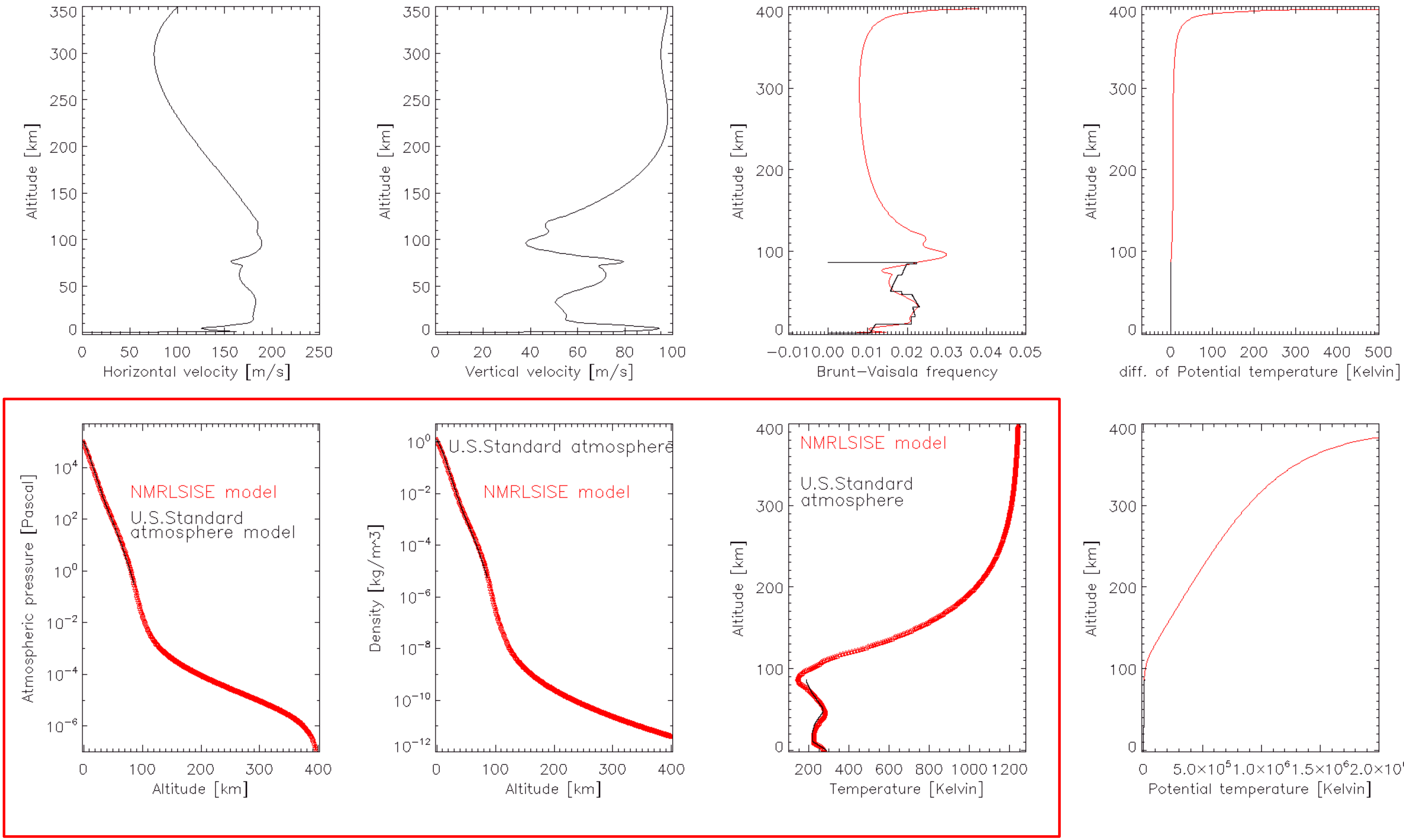
Atmospheric Gravity Waves model

NRLMSISE-00 model



Atmospheric Gravity Waves model

NRLMSISE-00 model



Atmospheric Gravity Waves model

- Vertical and Horizontal IGW group velocities in the neutral atmosphere

$$V_{Z,IGW} = \frac{k_z k_h^2 N^2}{\omega D^2}$$

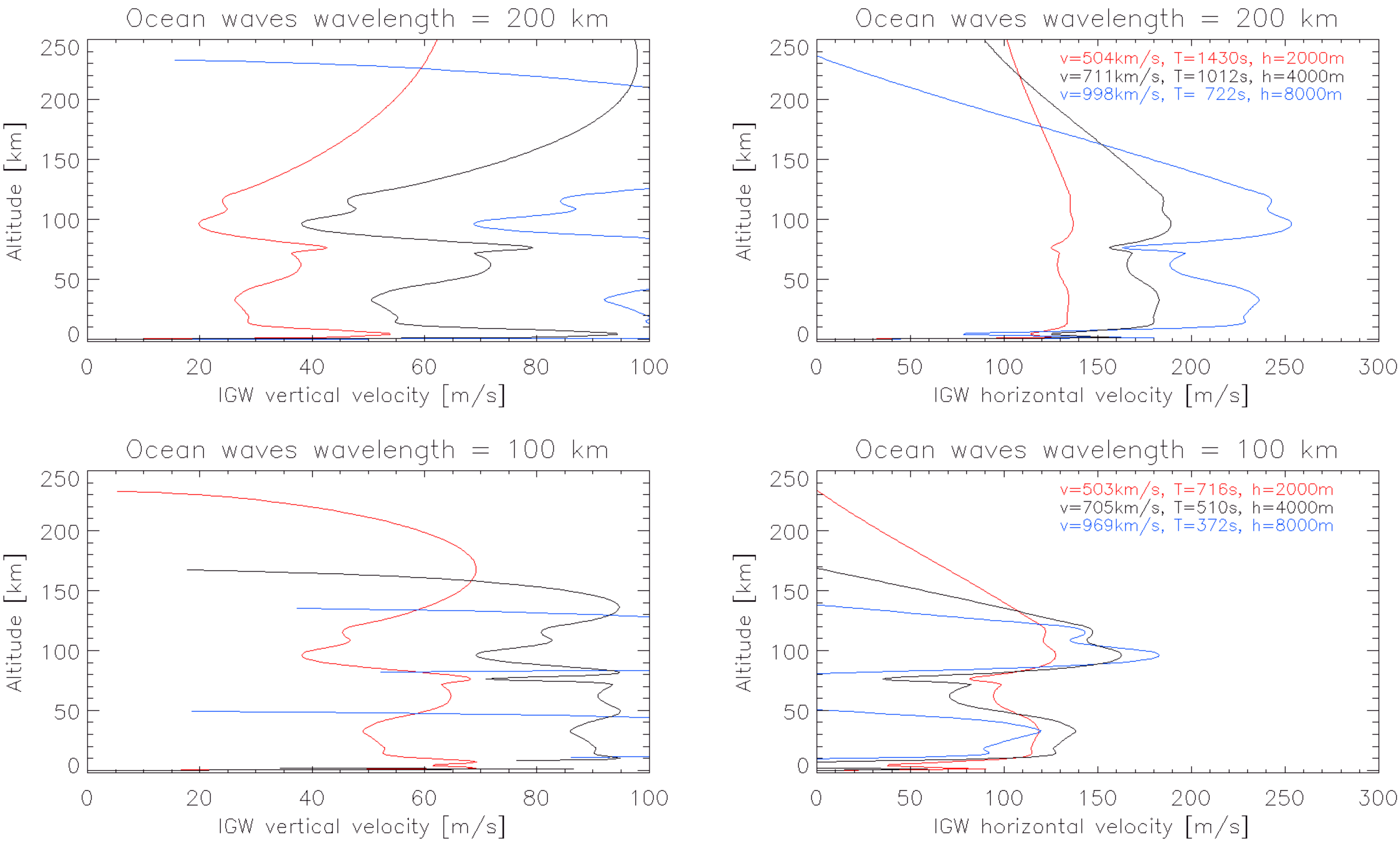
$$V_{H,IGW} = \frac{k_h N^2 \left(D - k_h^2\right)}{\omega D^2}$$

$$where \quad D = k_z^2 + k_h^2 + \frac{N^4}{4g^2}$$

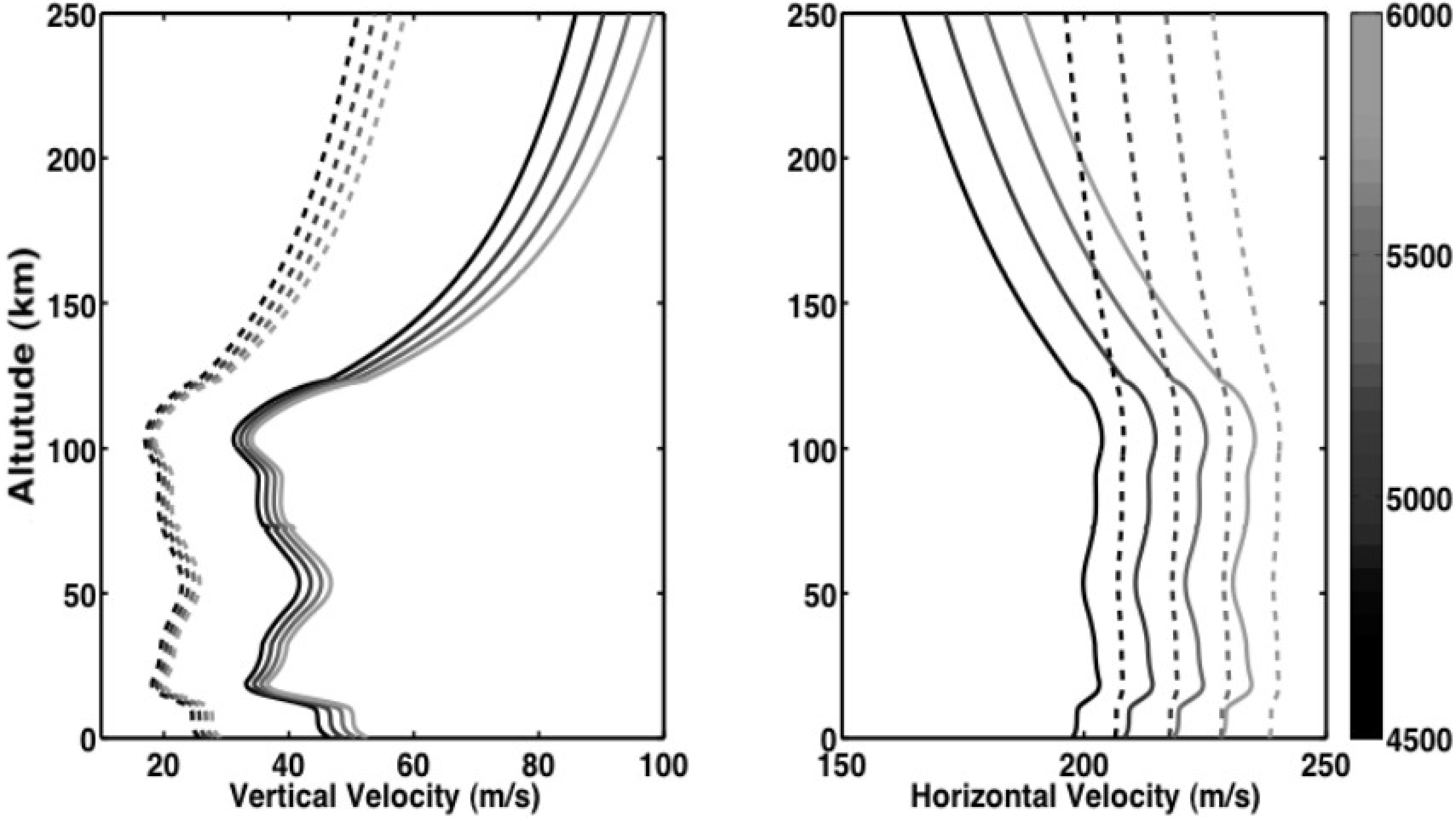
where k_z and k_h are the vertical and horizontal k−vector, g the gravity, N the Brunt-Väisälä frequency

Atmospheric Gravity Waves model

NRLMSISE-00 model



Atmospheric Gravity Waves model



- Giovanni Occhipinti et al., Three-dimensional numerical modeling of tsunami-related internal gravity waves in the Hawaiian atmosphere, Earth Planets Space, 58, 1–5, 2011, Vertical and horizontal group velocity profiles for IGW of period T1 = 14 minutes (solid lines) and T2 = 26 minutes (dashed lines) are shown; gray color indicates the speed dependence of ocean depth H(m).

Atmospheric Gravity Waves model

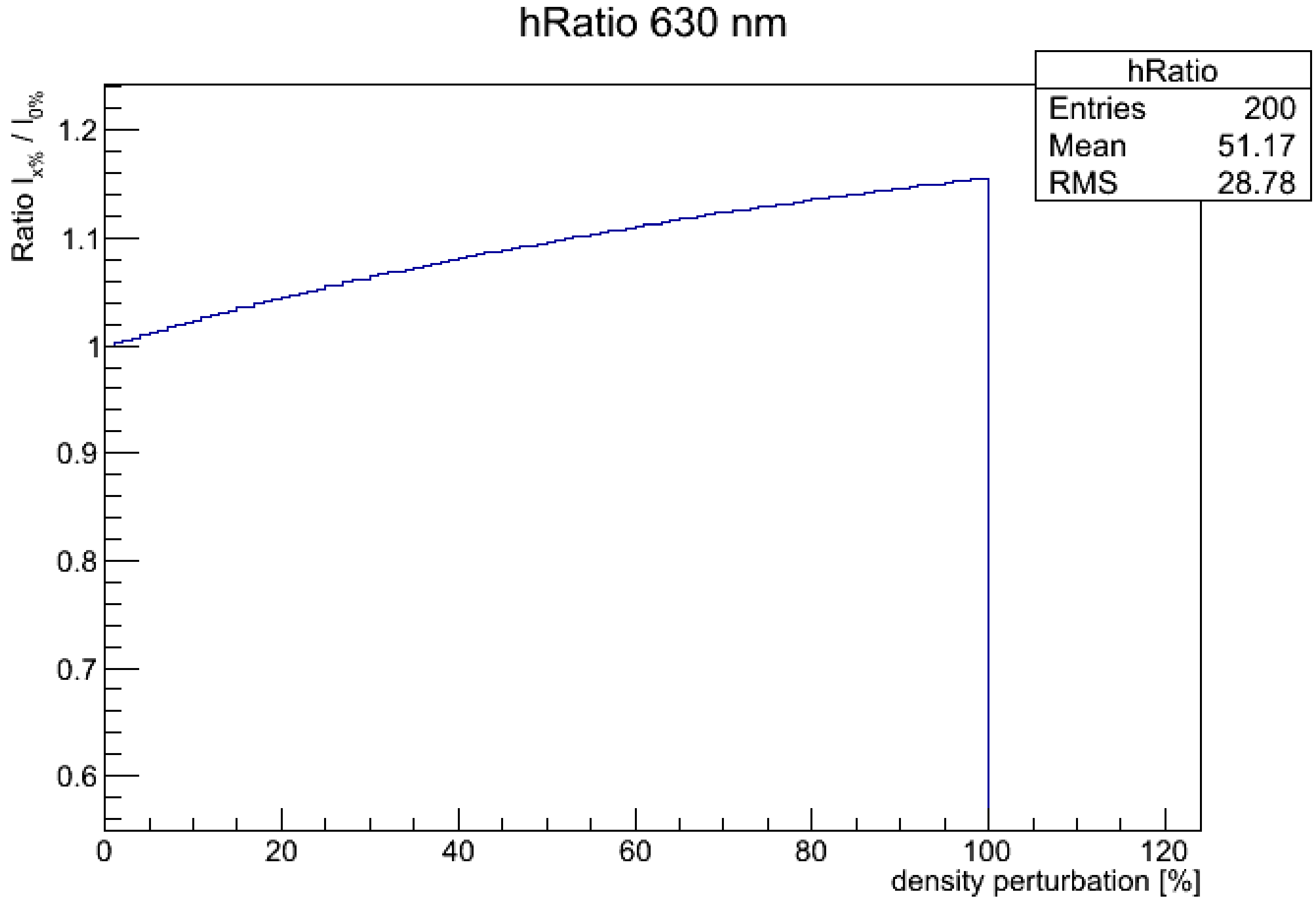
Summary – preliminary conclusion

Model modules :

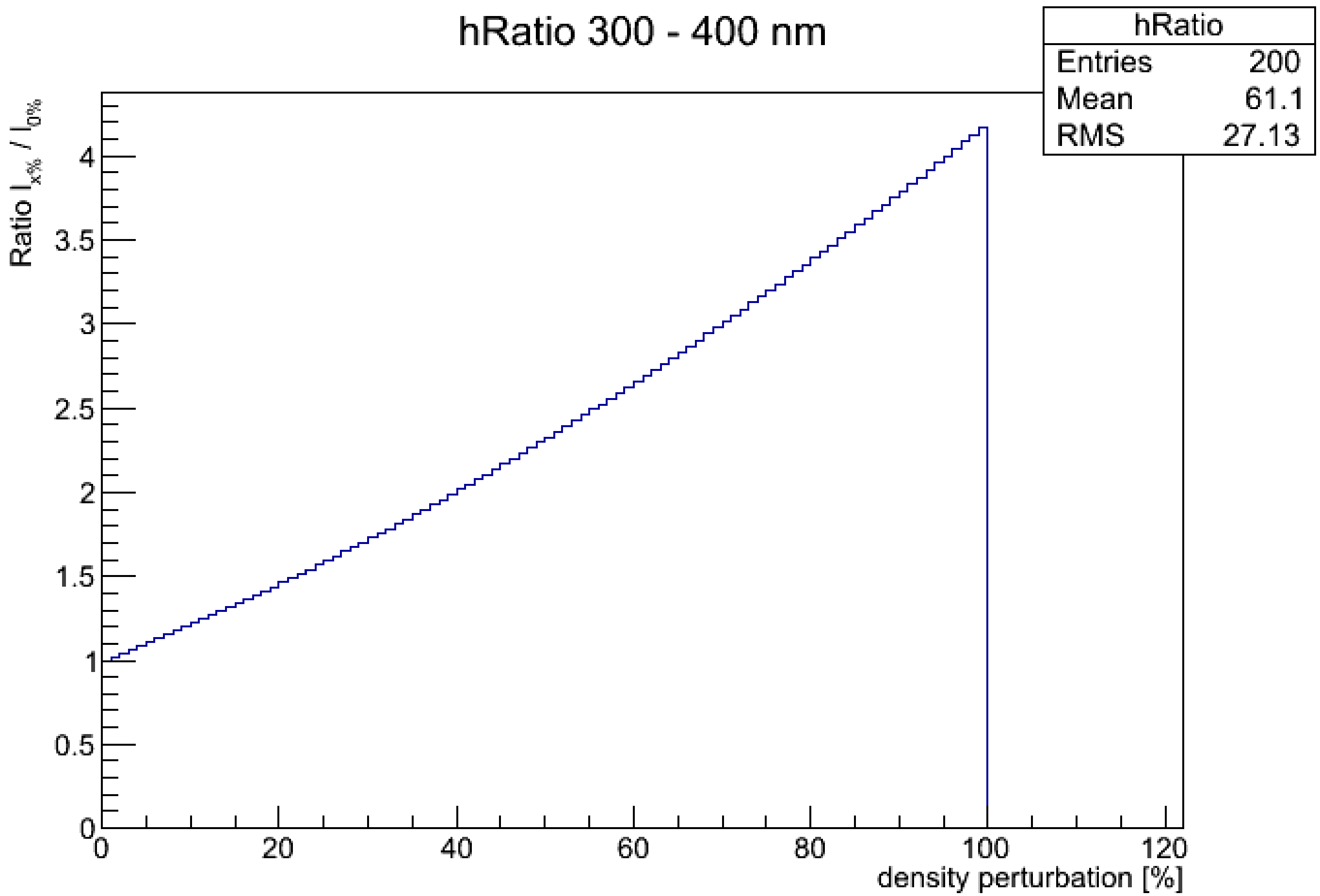
- Ocean wave motion – simple model, module ready to use
- Atmospheric gravity wave dynamics - module ready to use
- Atmospheric gravity wave perturbation – in development
- Airglow intensity change due to change of density : AURIC - model ready to use

AURIC simulation – density dependent intensity

- idea was to estimate increase of nightglow intensity caused by tsunami induced gravitation waves.
- we focus on Hawaiian measurement of nightglow emission perturbation induced by tsunami which occur after earthquake near Japan. This measurement give us reference value of 20% increase of intensity for nightglow emission for spectral line 630nm.
- we try to use AURIC code to find which increase/perturbation of density of all elements (O2,N2,O,...) in atmosphere cause 20% increase of nightglow emission for line 630 (Fig). For 100% density perturbation intensity increase around 15% (AURIC code have a internal upper limit for density increase which is 100%).



- same calculation for intensity in range from 300 to 400 nm. The same density perturbation (100%) which lead to 15% increase of 630nm emission have much bigger effect to emission in range 300 – 400 nm, which is approximately 400%.
- our understanding is that, if tsunami induced gravity waves in atmosphere are visible by observation 630 nm emission line, same phenomenon will be visible also in range 300 – 400nm and emission increase will be bigger.



Atmospheric Gravity Waves model
backup slide

- **Brunt–Väisälä frequency N [source : wikipedia]**
  - The Brunt–Väisälä frequency, or buoyancy frequency, is the angular frequency at which a vertically displaced parcel will oscillate within a statically stable environment.
  - The concept derives from Newton's Second Law when applied to a fluid parcel in the presence of a background stratification (in which the density changes in the vertical). The parcel, perturbed vertically from its starting position, experiences a vertical acceleration. If the acceleration is back towards the initial position, the stratification is said to be stable and the parcel oscillates vertically. In this case, $N^2 > 0$ and the angular frequency of oscillation is given N. If the acceleration is away from the initial position ($N^2 < 0$), the stratification is unstable. In this case, overturning or convection generally ensues.
  - The Brunt–Väisälä frequency relates to internal gravity waves and provides a useful description of atmospheric and oceanic stability.

- **Potential temperature Θ [source : wikipedia]**
  - The potential temperature of a parcel of fluid at pressure is the temperature that the parcel would acquire if adiabatically brought to a standard reference pressure, usually 1000 millibars.

$$\Theta(z) = T(z)\left(\frac{p_0}{p}\right)^{\frac{R}{c_p}} \qquad N(z)=\sqrt{\frac{g(z)}{\Theta(z)}\frac{d\Theta}{dz}}$$

  - R is the gas constant of air, and c_p is the specific heat capacity at a constant pressure