Applications of acoustic-gravity waves numerical modelling to tsunami signals observed by gravimetry satellites in very low orbit.

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Outline

INTRODUCTION

Gravito-aoustic wave propagation

- Oscillation of the Earth's surface generates gravito-acoustic waves
- Acoustic waves ($f > 4.10^{-3}$ Hz) and Gravity waves ($f < 2.10^{-3}$ Hz)
- Decrease of density with altitude $\Rightarrow$ Increase of wave amplitude (Cons. of energy)

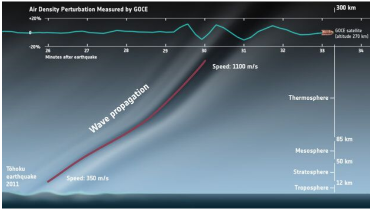
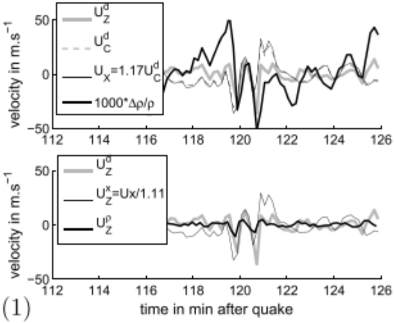


Figure: AGW propagation following earthquake and reaching GOCE.

OBSERVATION AND MODELING

Observations

- GOCE satellite (270 km altitude) in 2014 caught AGW signal from Tohoku
- Acoustic and gravity waves reached ionospheric altitudes



(1)

Figure: Comparison between data (grey line U_z^d) and synthetic waveforms (thin black U_z^x : from horizontal veloc. ; thick black U_z^ρ : from density). **[Garcia et al,** 2014]

Observation and modeling

Observations

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Next step : Comparison with modeling results

- Starting point : 2004 Sumatra event ⇒ Could AGW reach ionospheric height ?
- CHAMP satellite was hovering the indian ocean in 2004 at very low altitude
- ⇒ Forward modeling of acoustic and gravity wave propagation

NUMERICAL METHOD

Finite-Difference method

- 2D High-order staggered method with high-order upwind operators
- Propagation of linear acoustic and gravity waves
- Winds and both shear and bulk viscosity taken into account
- Perfected matched Layer technique adapted to AGW propagation
- Method validated in [**Brissaud Q., et al**, 2016]

BOTTOM BOUNDARY CONDITION : DISPLACEMENT FORCING

Input tsunami data

- Zero inital perturbation data
- Time-dependent bottom forcing from sea surface dsiplacement (Anthony Sladen's model)

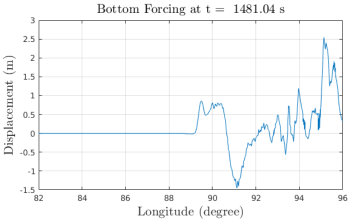
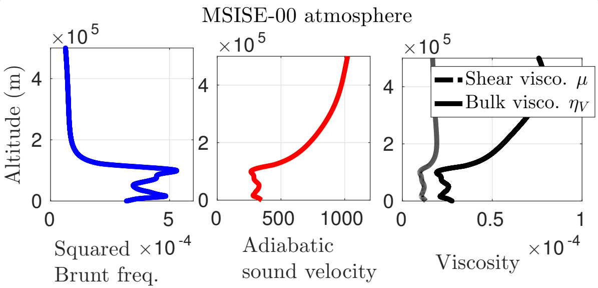


Figure: Example of sea surface dsiplacement given by Anthony Sladen's simulations.

ATMOSPHERE MODEL

MSISE-00 atmosphere model

- MSISE-00 atmosphere model [**A. E. Hedin,** 2003]
- Stratified models ⇒ No lateral variations of quantities
- Shear and bulk viscosities are implemented



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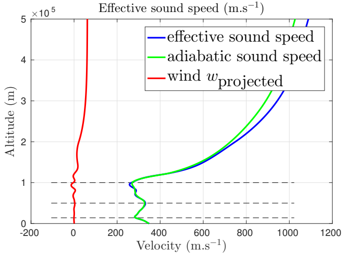
HWM-93 wind model

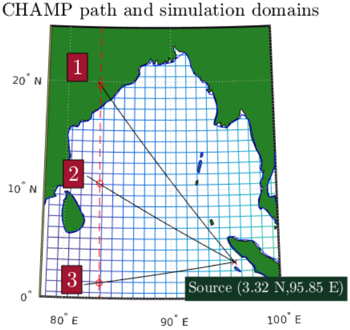
- Zonal and Meridonial winds only ($\nabla . \mathbf{V_0} = 0$)
- Projection of winds on simu. domain direction

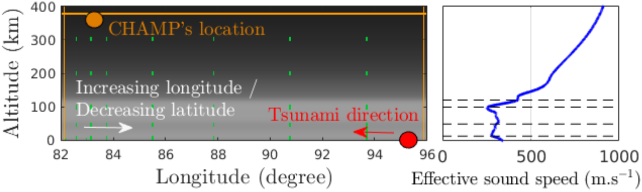


SIMULATION DOMAIN CONFIGURATION

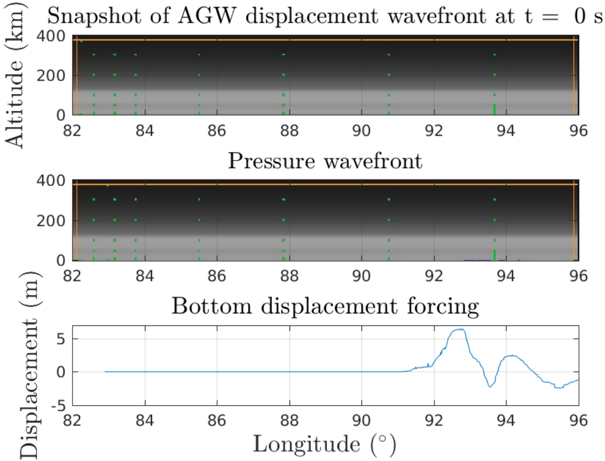
2D slice of the indian ocean

- Domains : Slices crossing seismic source location vicinity and CHAMP's path
- Zonal and Meridonial winds projected on 2D domain directions





Gravity wave propagation



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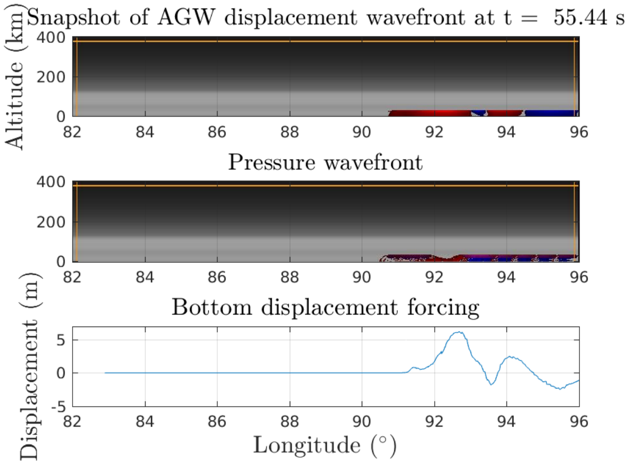

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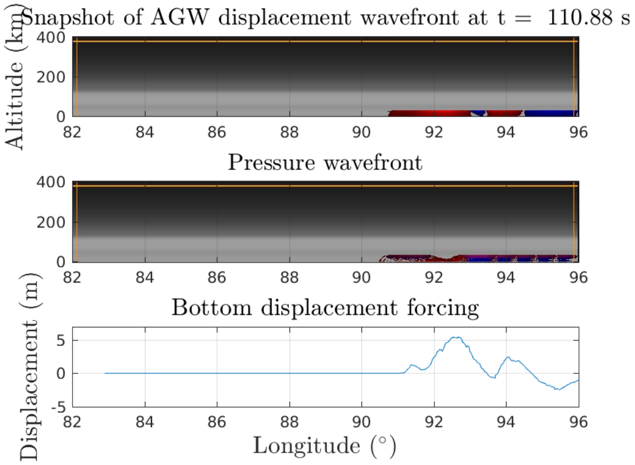

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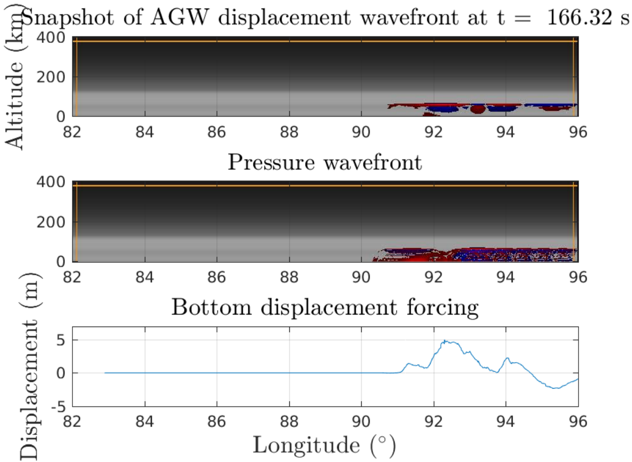

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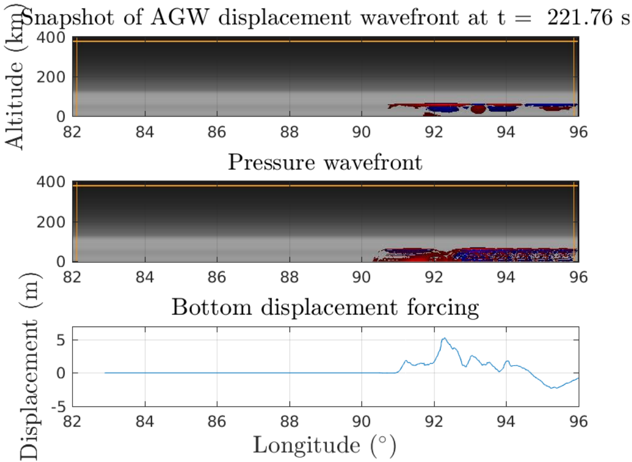

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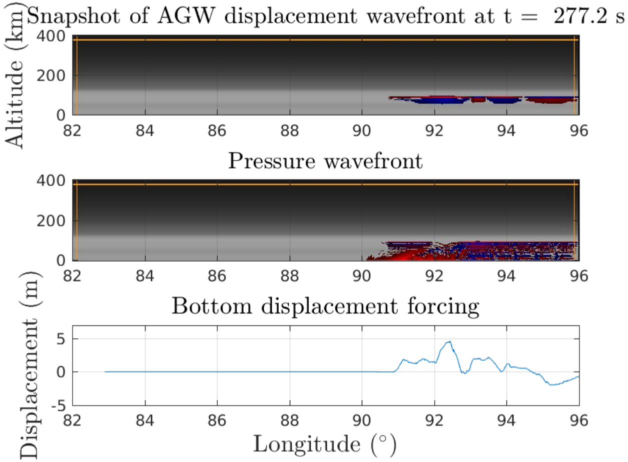

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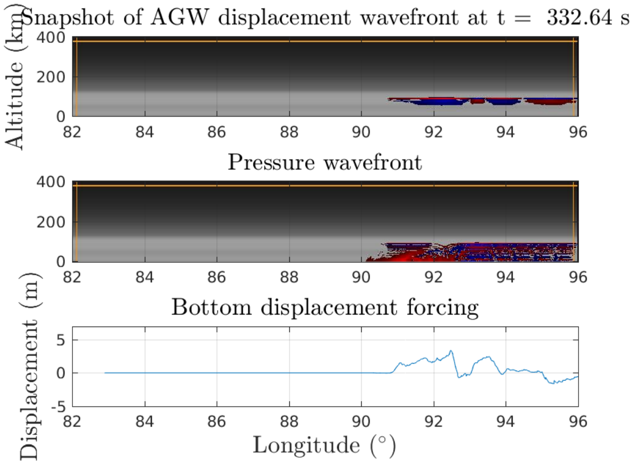

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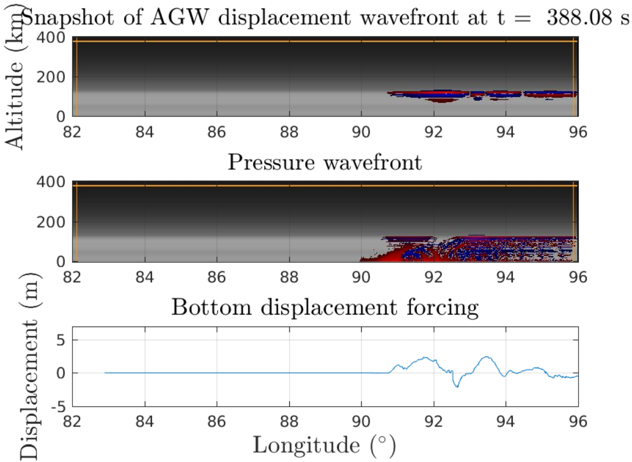

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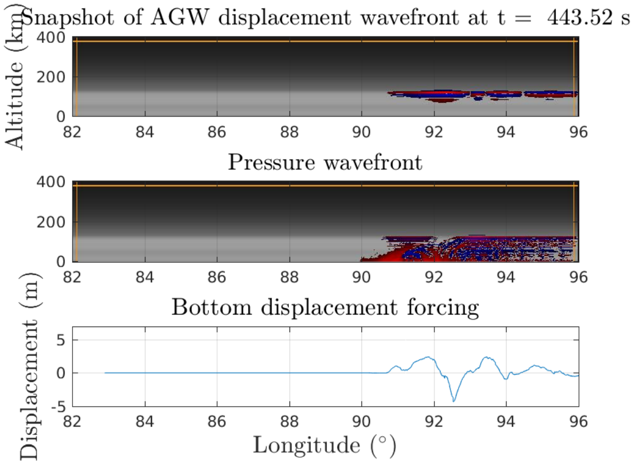

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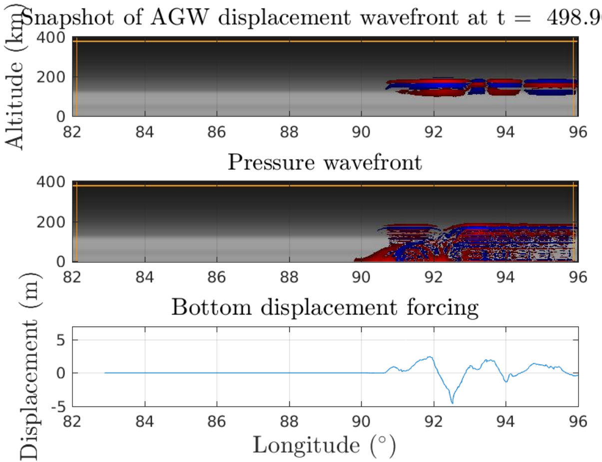

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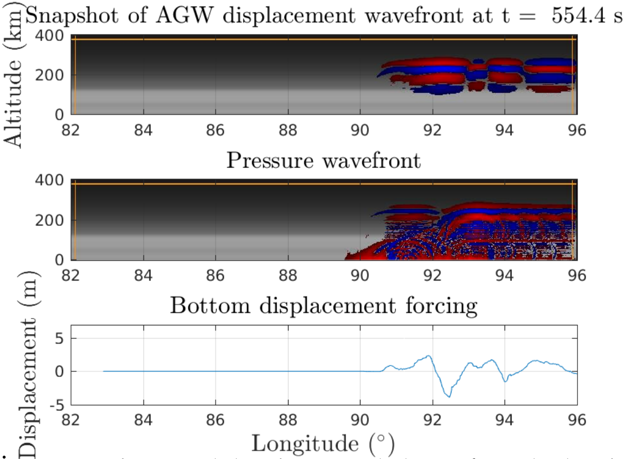

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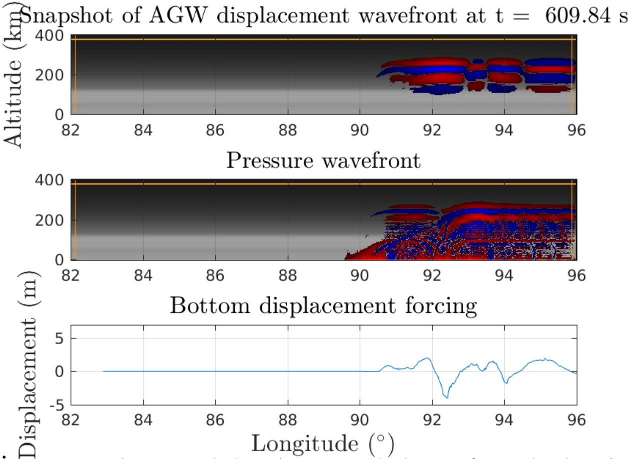

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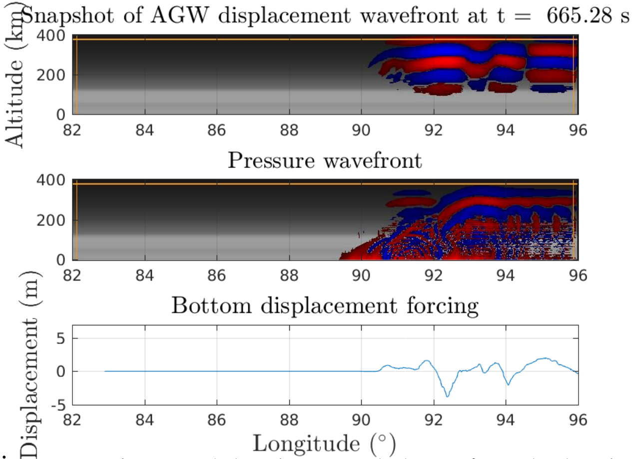

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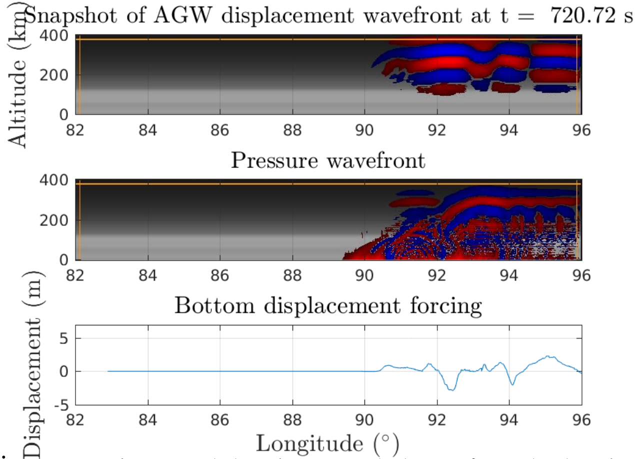

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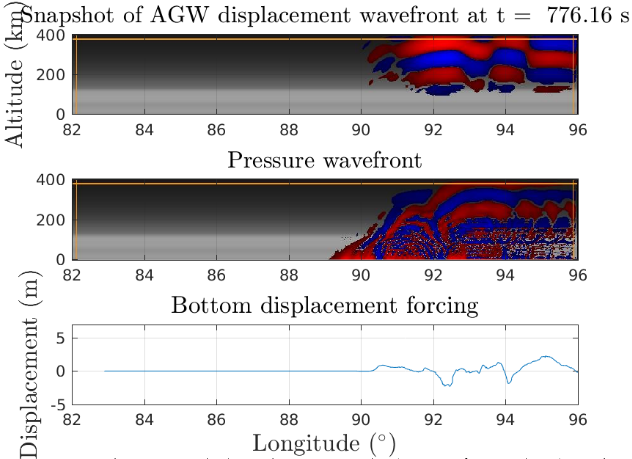

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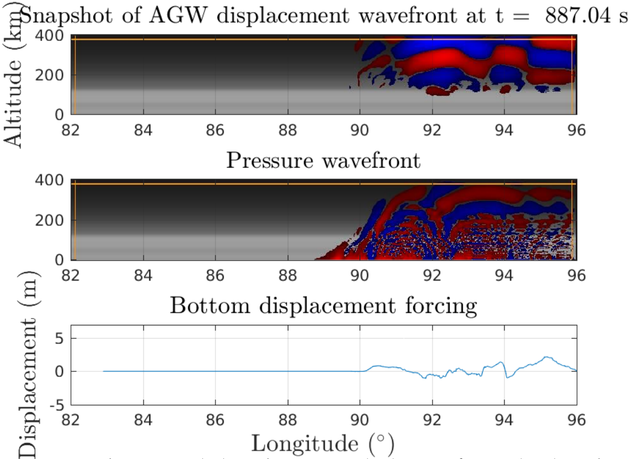

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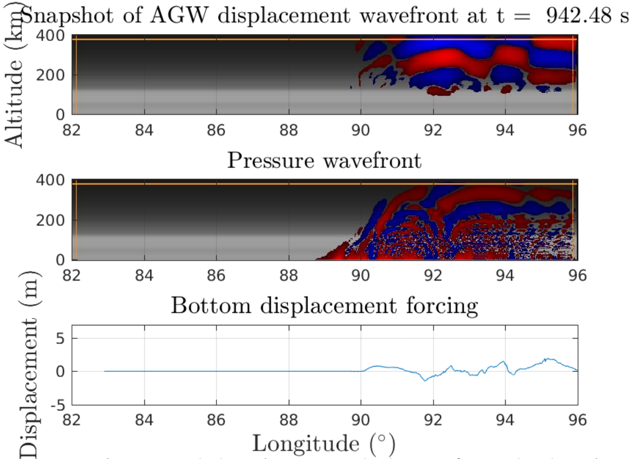

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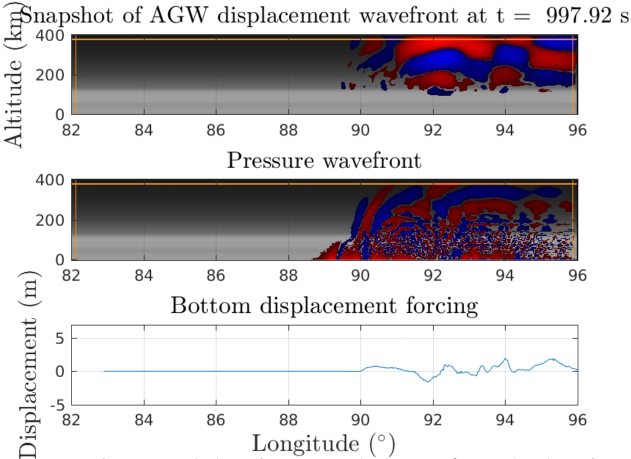

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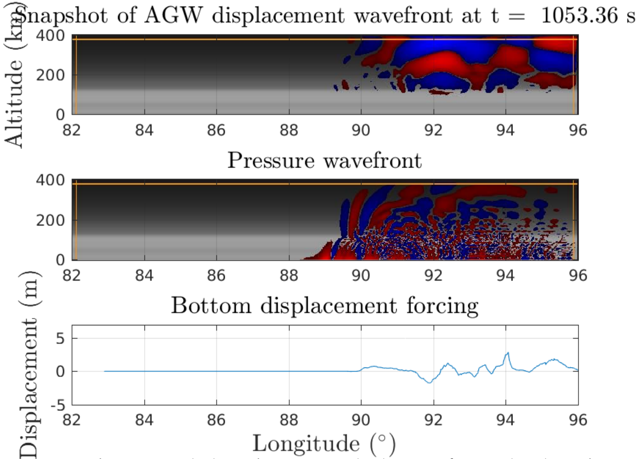

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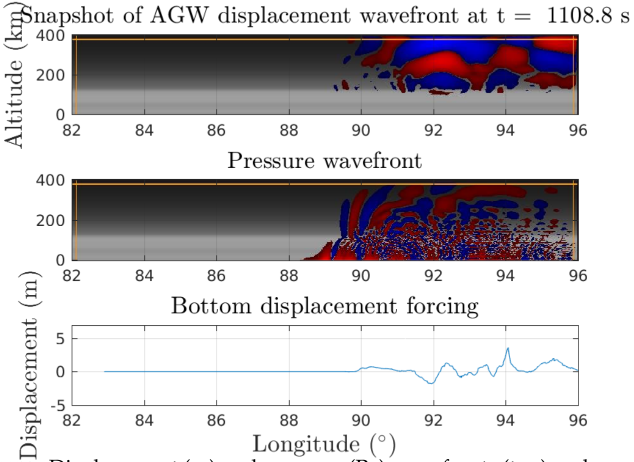

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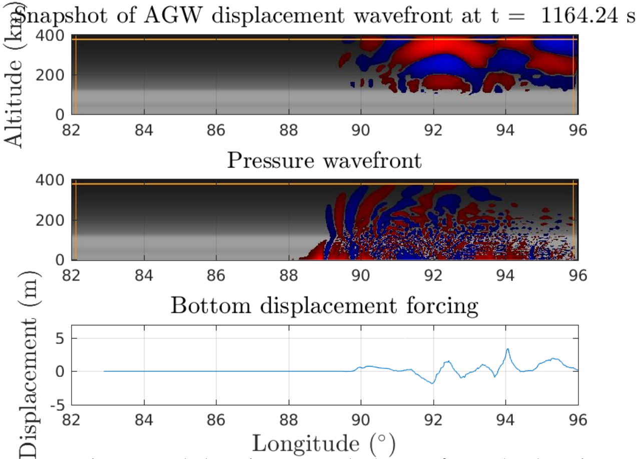

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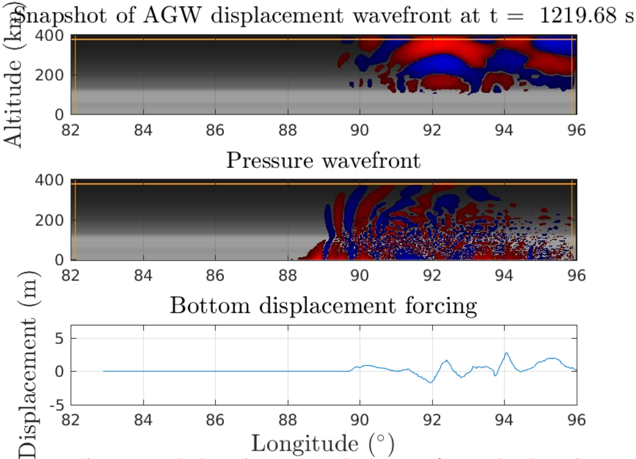

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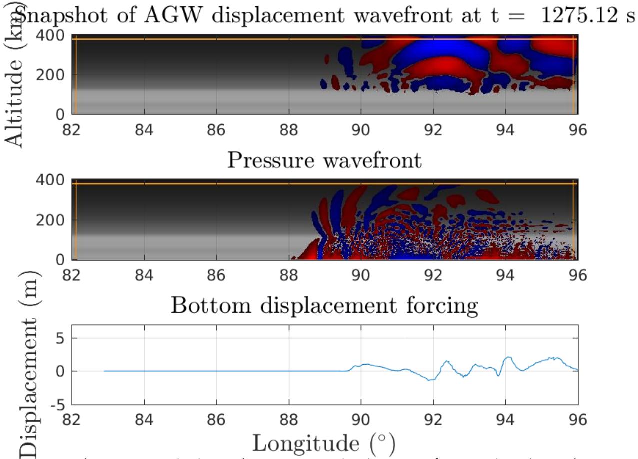

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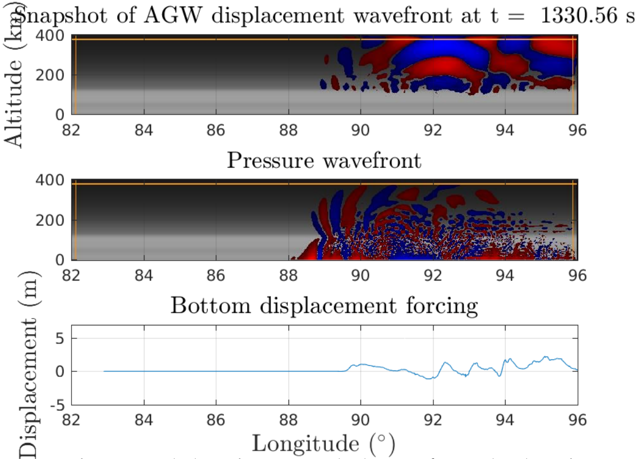

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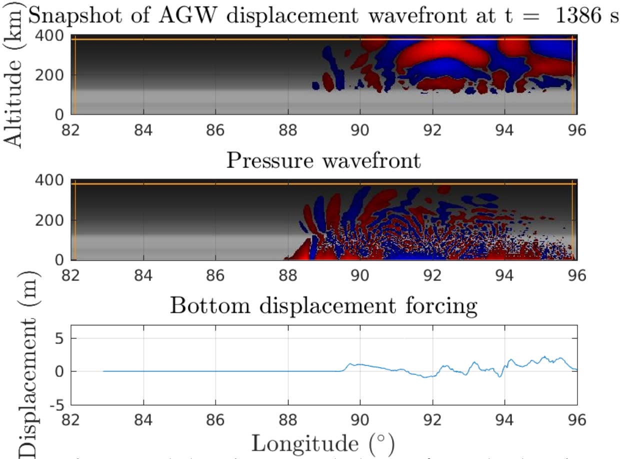

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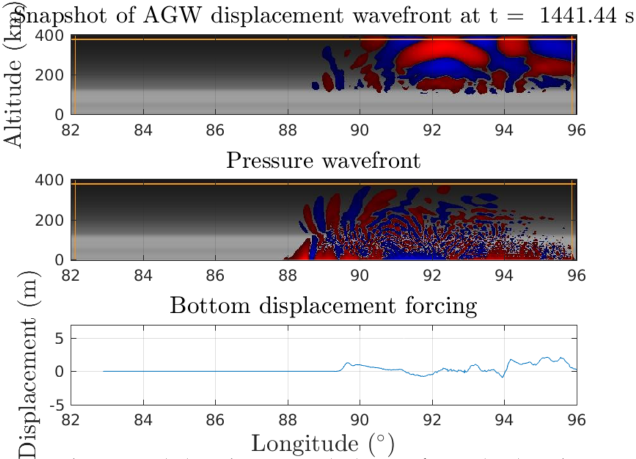

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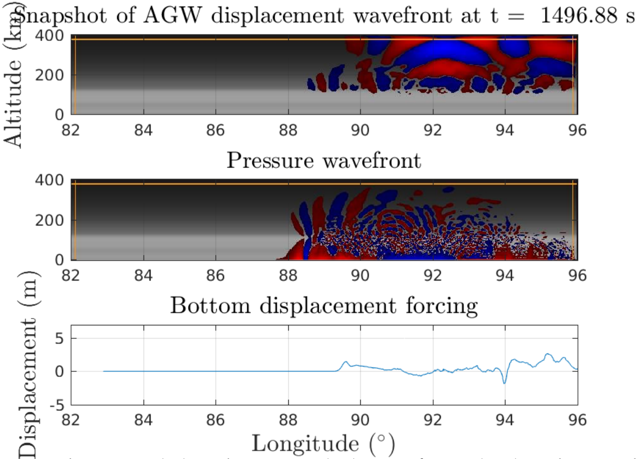

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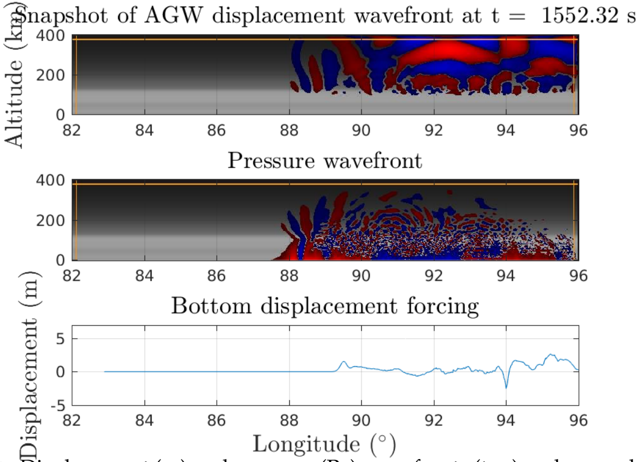

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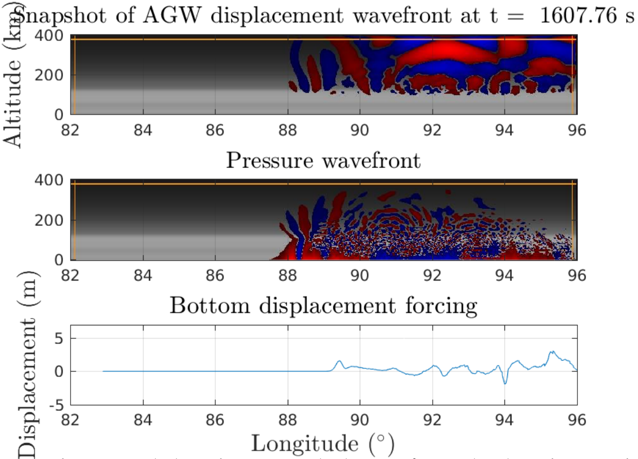

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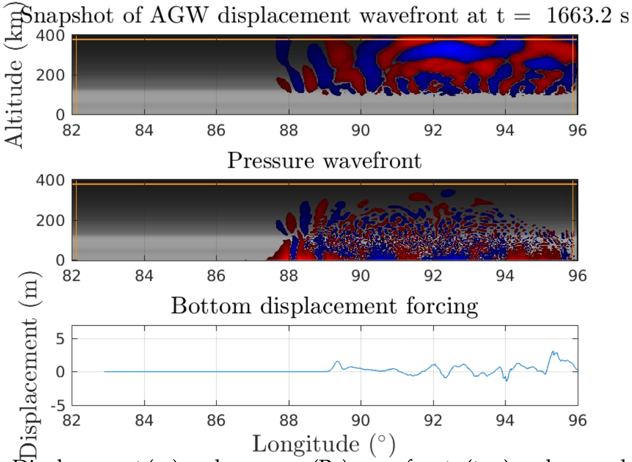

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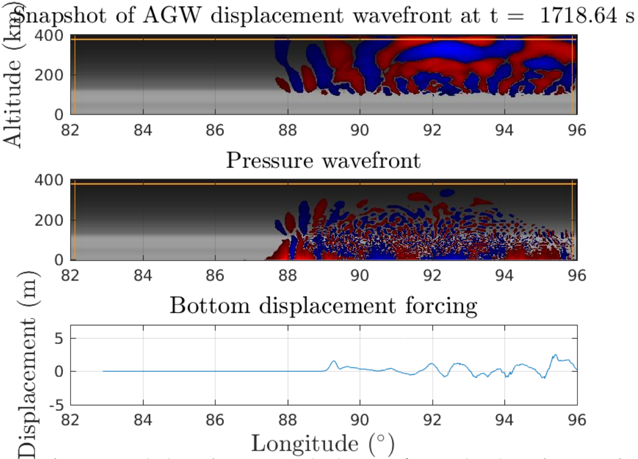

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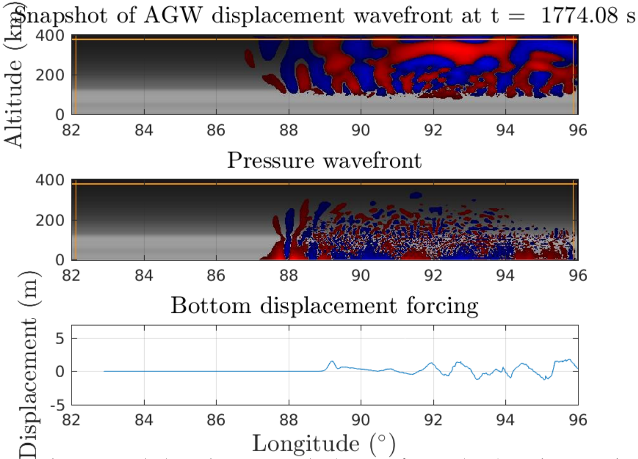

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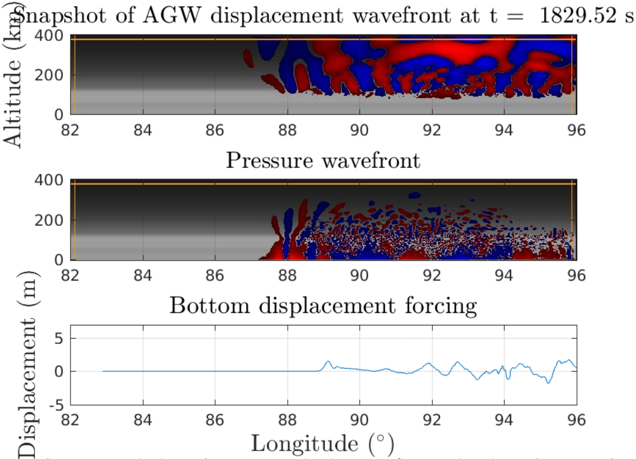

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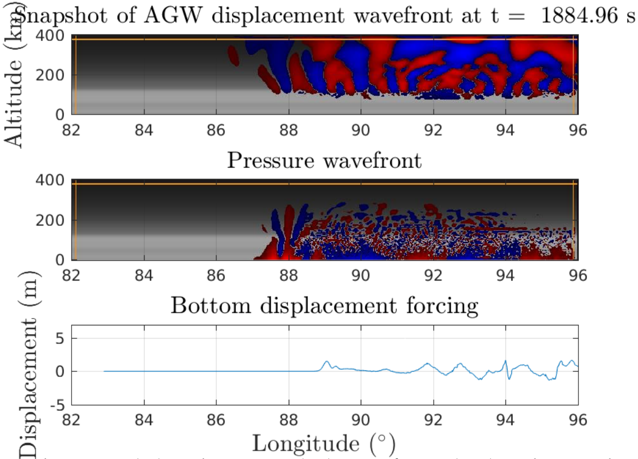

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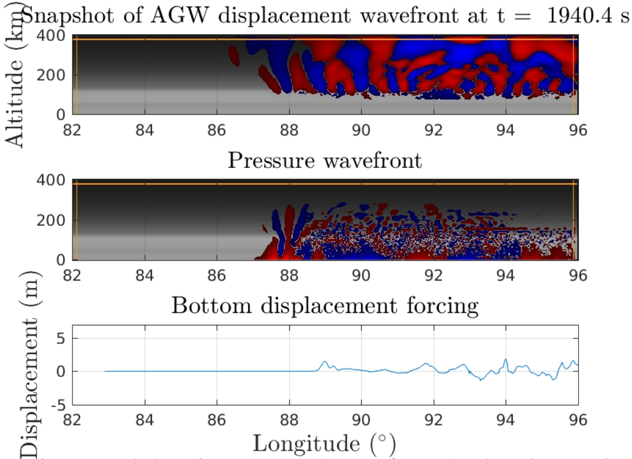

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Signal at CHAMP altitude

First gravity wave amplitude estimation

- ⇒ Work in progress !

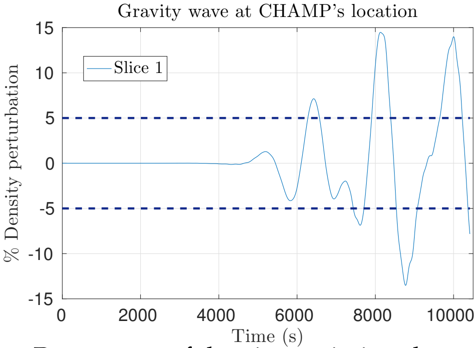
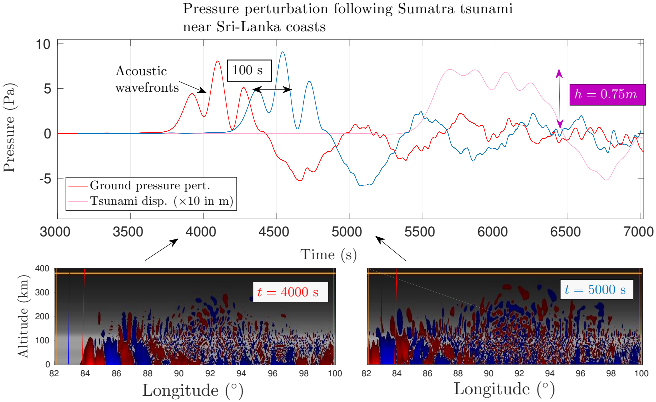


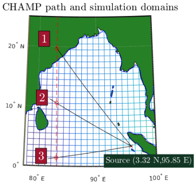
Figure: Percentage of density variation through time.

"Near-ground" acoustic waves

Acoustic wave-guide

Acoustic waves reach indian and Sri-lanka coasts before the tsunami wave





Conclusion

Summary and current work

- Easy and efficient way to study the impact of AGW in the atmosphere
- Significant amplitude at CHAMP's altitude

Future work

- 3D simulations
- Lateral variations of backgound parameters
- Ion Drag

Thanks you for your attention

SIMPLIFIED NAVIER-STOKES EQUATIONS

System of equation

N-S equations for pressure perturbation (p), velocity ($\mathbf{v}$) and density (ρ_p)

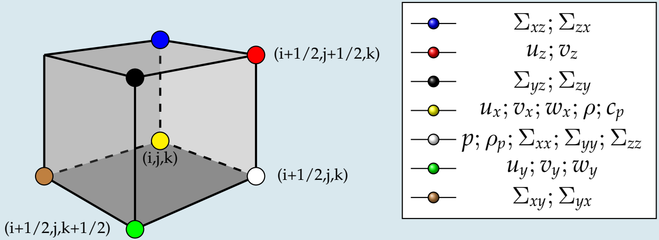
$$\begin{aligned} \partial_t p &= -\mathbf{w}.\nabla p - \rho c^2 \nabla.\mathbf{v} - \rho \mathbf{v}\mathbf{g} \\ \partial_t \rho_p &= -\mathbf{w}.\nabla \rho_p - \nabla.(\rho \mathbf{v}) \\ \rho \partial_t \mathbf{v} &= -\rho\{(\mathbf{v}.\nabla)\mathbf{w} + (\mathbf{w}.\nabla)\mathbf{v}\} + \nabla.\mathbf{S} + \mathbf{g}\rho_p \end{aligned}$$

The stress tensor $\mathbf{S}$ then reads, $\forall (i,j) \in [1,3] \times [1,3]$,

$$(\mathbf{S})_{ij} = -p\delta_{ij} + \mu(\partial_j(\mathbf{v}+\mathbf{w})_i + \partial_i(\mathbf{v}+\mathbf{w})_j - \frac{2}{3}\delta_{ij}\nabla.\mathbf{v}) + \eta_V \delta_{ij} \nabla.\mathbf{v}\,.$$

NUMERICAL METHOD

Stencil



Stencil showing where unknowns are computed in the mesh.

Numerical method

Operator discretization

For a scalar unknown u computed at time step m and at grid point (i, j, k)

$$u_m^{i,j,k} = u(i\Delta x, j\Delta y, k\Delta z, m\Delta t)\ ,$$

within the domain Ω the finite-difference operators read

$$\begin{aligned}(\partial_x u)_m^{(i,j,k)} &= \frac{27u_m^{(i+1,j,k)} - 27u_m^{(i,j,k)} - u_m^{(i+2,j,k)} + u_m^{(i-1,j,k)}}{24\Delta x}\\ (\partial_y u)_m^{(i,j,k)} &= \frac{27u_m^{(i,j,k)} - 27u_m^{(i,j-1,k)} - u_m^{(i,j+1,k)} + u_m^{(j,j-2,k)}}{24\Delta y}\end{aligned}$$

Upwind operators

$$\text{if } w_x < 0 \quad (\partial_x p)_m^{(i,j,k)} = \frac{1}{6\Delta x}\{2(p_m^{(i,j,k)} - p_m^{(i-1,j,k)}) + 6(p_m^{(i+1,j,k)} - p_m^{(i,j,k)}) - (p_m^{(i+2,j,k)} - p_m^{(i,j,k)})\}$$

COMPARISON WITH CHAMP RECORDED AMPLITUDE

Possible sources of time/amplitude incoherences

- 2D Geometrical spreading
- interpolation of 2D wind profiles on slice direction
- Ion drag

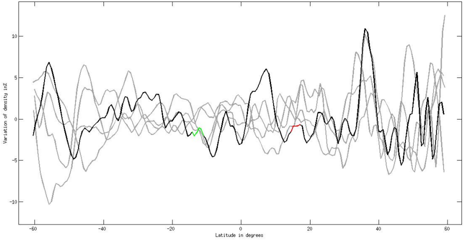


Figure: Percentage of density variation through latitude at a given time. Red indicates CHAMP's location at that time.