# Impact of Middle-Atmosphere Solar Tides on Gravity Waves

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## Objectives

***Gravity Waves (GWs)* and *Solar Tides (STs)* are main constituents of dynamical coupling between troposphere and the middle atm.**

- Diurnal heating forcing ($O_3$, water vapor, convection, condensation ...)
- *STs are large scale forced waves*, that modulate all dynamical fields in mesosph.
- *GWs are small scale free waves*, that shape mesosph. mean circulation.

***GWs* and *STs* interaction ???**

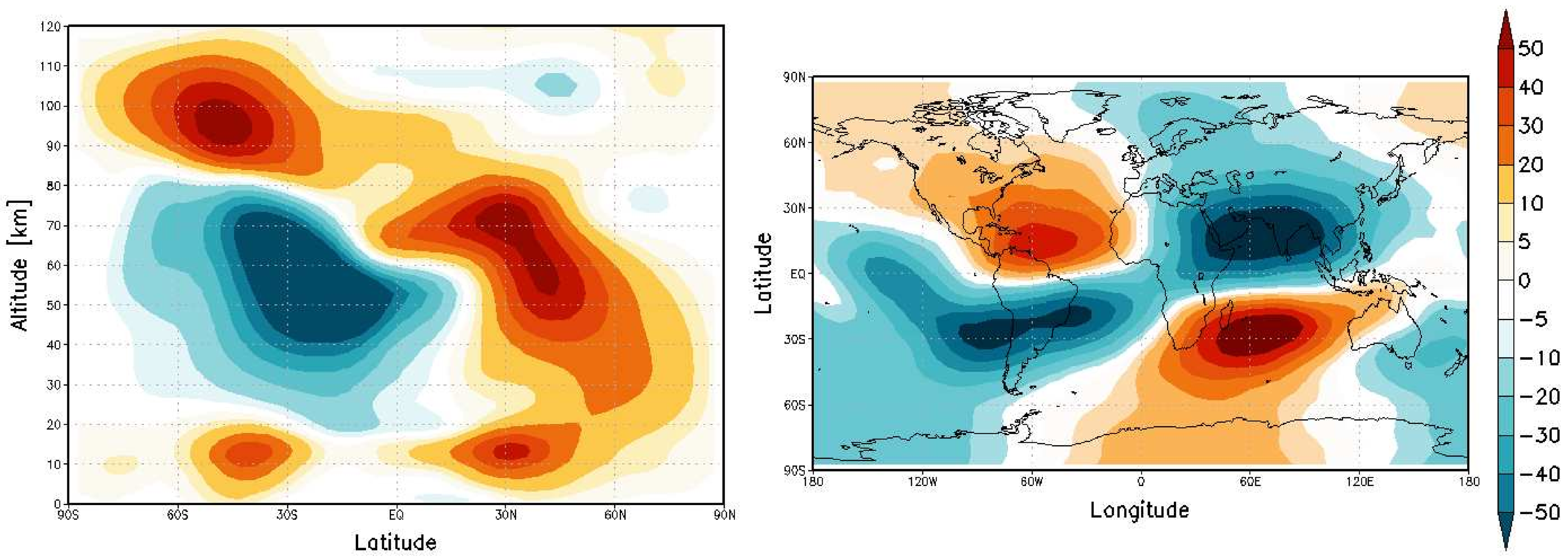


Figure 1: From $HAMMONIA-GCM$. *Left :* Climatology (January) of the zonal wind $U[m/s]$. *Right :* diurnal tides $V_{Tides}[m/s]$

## Introduction | Methodology

- *GWs* - *STs* interaction: step-by-step approach. Extension of studies [1,2].
- *GWs* propagate in a *climatology + STs* time-changing background flow, Fig. 1. Caustics problem is solved (intrinsic of all Ray tracer model).
- *STs* are solved using a *linearised GCM* with *climatology + GWs forcing*, Fig. 3

## Ray tracers model

- Model do not resolve *GWs* $\Longrightarrow$ parametrisation of *GWs*, based on *WKB*:

$$(\mathbf{X}, T) = \epsilon(x,t) \quad , \quad A(\mathbf{X},T)e^{i\phi(\mathbf{X},T)/\epsilon}$$
$$\omega(\mathbf{X},T) = -\partial_T \phi \quad , \quad \mathbf{k}(\mathbf{X},T) = \partial_{\mathbf{X}} \phi$$

$\Longrightarrow$ leads to numerical Ray tracers.

- ***GWs* propagate in time-changing background flow**, on rays parallel to $\mathbf{c_g}$.
- *"Wave-Action phase-space density Ray tracer"* is implemented, using [1,3,4], in order to solve the impossibility of Rays to cross each other.
- Each ray attached to a finite volume conserved during the propagation (Fig. 2) in the 6D *location-wavenumber phase-space.*
- Propagation of a small spectrum of *GWs*, launched at $25km$ (all direction, see Fig. 2) with a constant emission source :

NEW RAY only emitted when OLD one has left

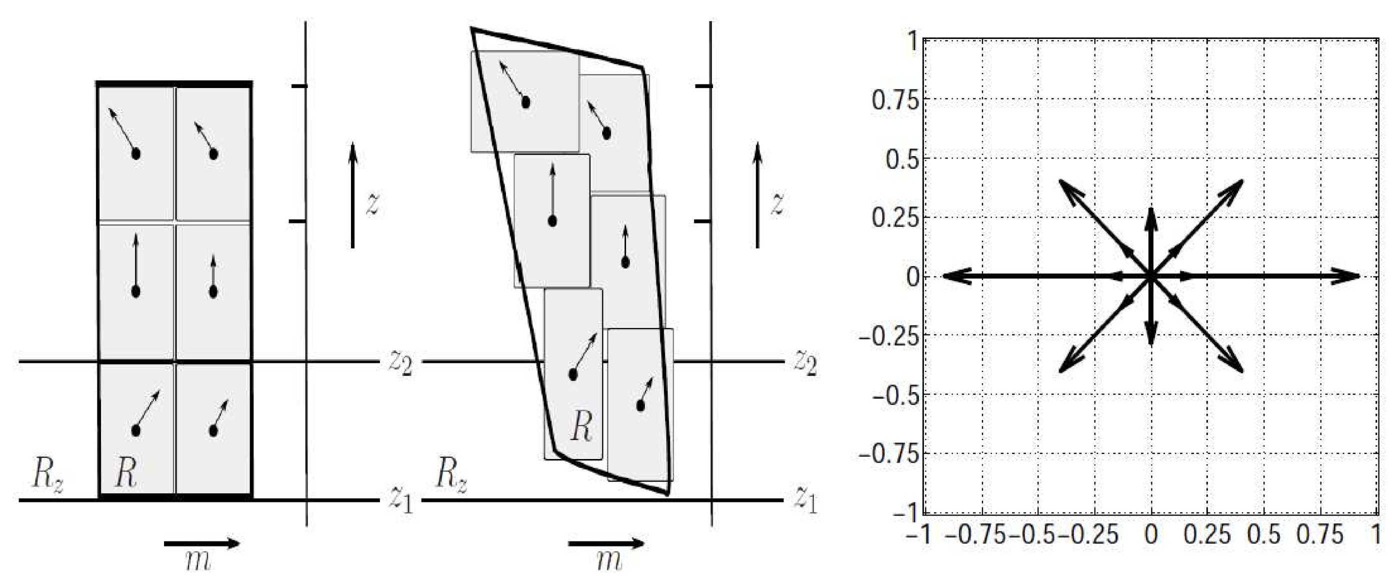


Figure 2: *Left :* Schematic illustration of the location-wavenumber conservation (from *Muraschko et al.*). *Right :* Initial phase velocity $\vec{c_\varphi}$ [nondim.]

- **The Ray tracer model evaluate :**

*momentum fluxes ; buoyancy ; GWs dynamical forcing $F_{GW}$ ; Rayleigh friction (for u and v) and newtonian cooling coef.* $(\alpha_R,\ \alpha_I)$.

$$\begin{cases} F_{GW} = \frac{1}{\rho}\Big[\partial_x(\rho u'^2) + \partial_y(\rho u'v') + \partial_z(\rho u'w')\Big] + \text{“curvature terms”} \\ \alpha_R = < F_{GW} \times U_{Tides} > / < (U_{Tides})^2 > \\ \alpha_I/\Omega = < F_{GW} \times \partial_t U_{Tides} > / < (\partial_t U_{Tides})^2 > \end{cases}$$

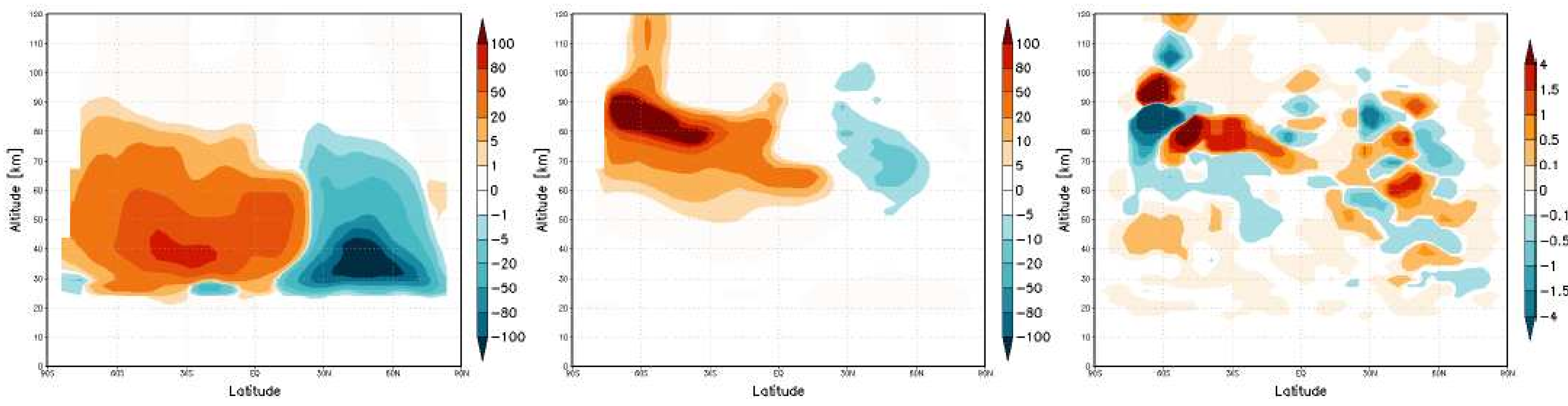


Figure 3: *Left :* deposition of momentum $< \rho u'w' >$ $[kg/m/s/day]$. *Middle :* $F_{GWs}$ [m/s/day]. *Right :* $\alpha_R$ $[day^{-1}]$.

## Dimensionalization

Values obtain for *GWs* outputs $< \rho u'w' >$, $F_{GWs}$, $\alpha_R$, $\alpha_I$ ... in good agreement with a simple scale analysis.

## Important Result

*GWs* and *STs* strongly interact together.

- *STs influence the propagation of GWs*, but also their deposition of momentum and buoyancy (Fig. 3).
- Rayleigh friction and newtonian cooling coefficients ($\alpha_R$, $\alpha_I$) quantify the strength of the *STs* - *GWs* interaction.
- *GWs influence phase and amplitude of STs* (Fig. 4), via momentum deposition.

## *STs* model

In order to obtain *STs* (Fig. 4), study [2] is used, where :

- Linearisation of $KMCM-GCM$ around the *climatology* (Background flow, Fig. 1) is considered,
- and *GWs* forcing $(\alpha_R, \alpha_I)$ from our *Ray tracer* is introduced (Fig. 3).

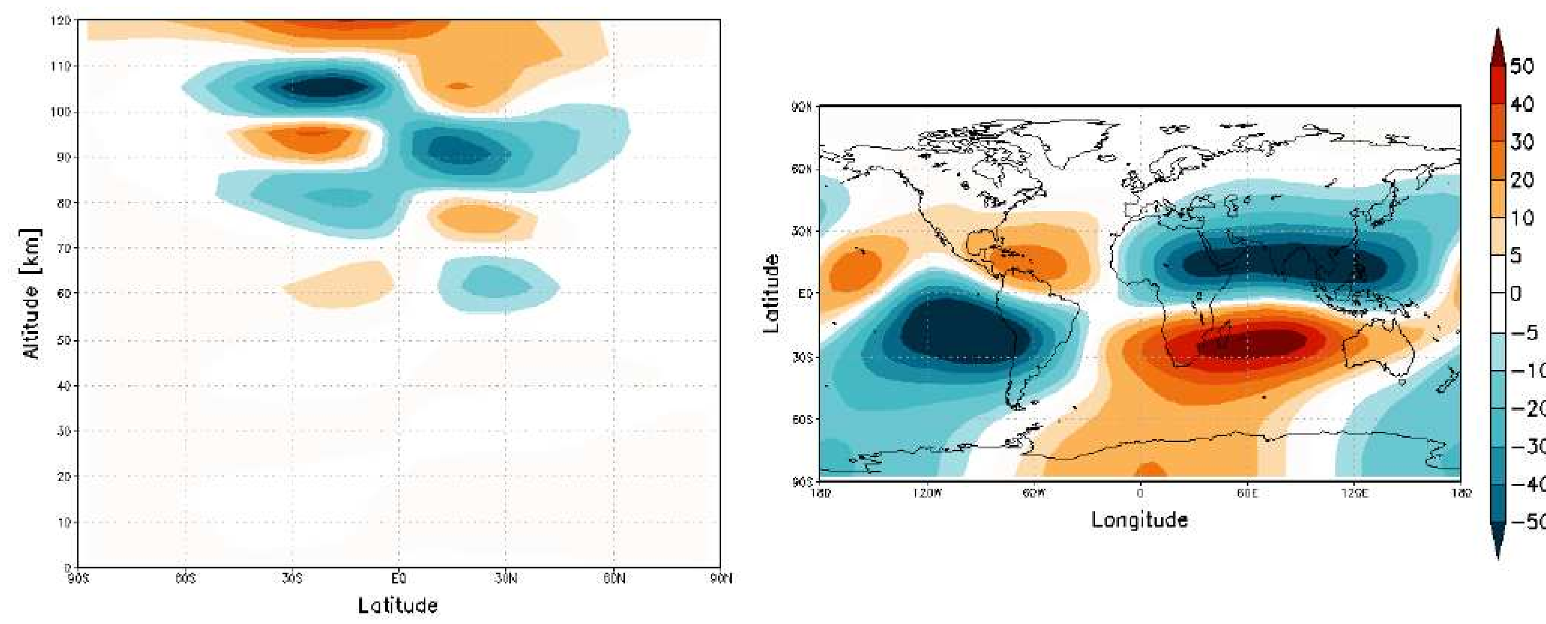


Figure 4: Diurnal tides $V_{Tides}[m/s]$ with *GWs* forcing.

## Summary & Perspectives

- Through $\alpha_R, \alpha_I$, the study quantify the *STs* - *GWs* interaction and show how one (*STs, GWs*) influence the other (*GWs, STs*).
- $1^{st}$ perspective: Convergence of the step-by-step approach.
- $2^{nd}$ perspective: Direct coupling of *STs* and *GWs*.

## References

[1] F. Senf and U. Achatz. *J. Geophys. Res.*, 116:D24110, 2011.
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[3] J. Muraschko *and al. Q. J. R. Meteorol. Soc.*, accepted:10.1002/qj.2381, 2014.
[4] A. Hertzog, C. Souprayen and A. Hauchecorne. *J. Geophys. Res.*, 107:D12, 2002.

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