ON THE IMPACT OF NON-OROGRAPHIC GRAVITY WAVES IN THE LMD MARS GLOBAL CLIMATE MODEL.

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Introduction

Gravity waves (GW) are frequently observed in terrestrial planet atmospheres even at high altitudes (Creasey et al., 2006; Muller-Wodarg et al., 2016) but they are still poorly constrained in terms of physical basic parameters. Small-scale variability, in the form of perturbations of density and temperature, have been recently detected in the upper atmosphere of Mars by MAVEN (Yiğit et al., 2015), and claimed to be induced by gravity waves (GW) propagation from the lower atmosphere. In particular, non-orographic (i.e non-zero phase velocity) GW are supposed to be emitted above the convective layer and propagate upwards, providing a significant source of momentum and energy (Spiga et al., 2012; Imamura et al., 2016), thus affecting the transport of heat and constituents. For instance, thermal effects of GW are possible candidates to explain colder observed temperatures on Mars (up to 40 K) around 100-140 km compared to model simulations (Medvedev et al., 2015).

A complete interpretation of gravity-waves induced temporal and spatial variations in the atmospheres of planets is possible only with 3D models, and the impact of GW on the global circulation of Mars is under investigation. In this work we implemented for the first time a non-orographic GW parameterisation into the Mars General Circulation Model (MGCM), developed at the *Laboratoire de Météorologie Dynamique* (LMD), and we analyse its impact on the predicted thermal structure above 50 km. In particular we focus here on the comparison between model simulations and observations by the Mars Climate Sounder (MCS) on board Mars Reconnaisance Orbiter (McCleese et al., 2010) during the MY 29. Those are the best existing systematic measurements of the martian mesosphere up to 80 km. Even if the model is able to reproduce most of the observed features, the region between 1 and 0.01 Pa (about 50-80 km) remains challenging to be predicted accurately by GCMs (Forget et al., 2014). In this study we aim to improve data-model comparison by fine-tuning non-orographic GW parameters.

GCM description

The MGCM is a finite-difference model based on the discretisation of the horizontal domain fields on a latitude-longitude grid (Forget et al., 1999), being 64 longitude x 48 latitudes (3.75° x 5.62°) the horizontal resolution used in this work. We have employed the latest version of the model which includes several recent improvements: radiative effects of CO_2 gas, dust and water ice, an improved cloud microphysical scheme (Navarro et al., 2014), plus a more physically consistent parameterisation for the non-LTE 15 μm cooling and a new parameterisation of the EUV solar radiation (González-Galindo et al., 2013), to mention a few. In addition, we have implemented for the first time into the LMD-MGCM a non-orographic GW parameterisation following the formalism developed for the Earth GCM described in Lott and Guez (2013).

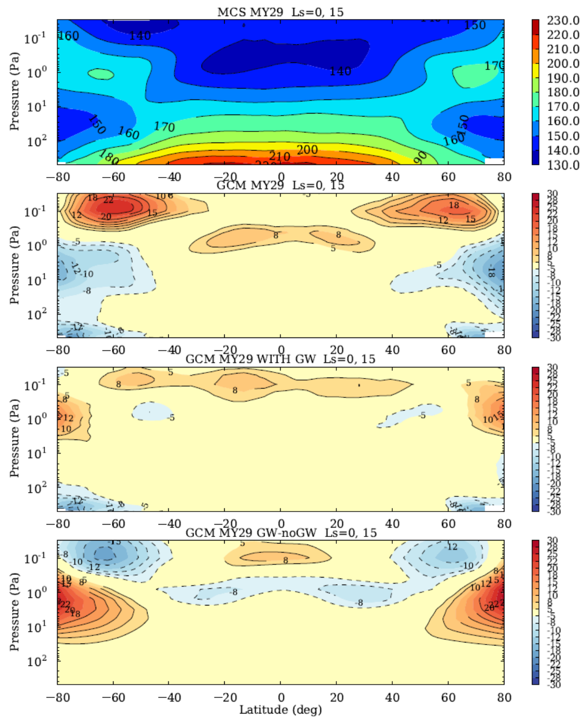

Figure 1: Zonal mean temperatures observed by the MRO Mars Climate Sounder (MCS) during the MY29 (top panel) and differences with simulations (MGCM-MCS) without (second panel from the top) and with (third panel from the top) non-orographic GW parameterisation. Temperature differences in model simulations (with GW - no GW) are shown in the bottom panel. Data and simulations have been binned here near the North Hemisphere Spring Equinox L_s=0°-15°.

- **Non-orographic GW parameterisation**

The scheme used in this work is based on a stochastic approach, where a large ensemble of monochromatic GW is generated at a fixed altitude by emitting a few waves at each time step, and by adding the effect of these waves to that of the waves launched at previous time steps. The source of the gravity waves is chosen uniform, without latitudinal variation, and fixed at roughly 10 km, above the typical convective cells. Following Lott and Guez (2013) the wave characteristics are chosen randomly, with an arbitrarily fixed probability distribution.

- *Tuneable parameters*

Since the extent of GW spectrum is not well known on Mars, as a first step, the strategy adopted in this study was to fine-tune waves parameters by comparing MGCM and MCM thermal structure, with the purpose of reducing temperature differences. The baselines parameters were chosen after several tests, and they are listed in Table 1: the absolute phase speed is between 1 and 30 m/s; the maximum value of the EP-flux (representing the vertical momentum of GW) is 10^{-4} kg m^{-1} s^{-2} at the emitting altitude (around 10 km). The horizontal wave number range was chosen within observational range, between 10 km and 300 km (Creasey et al., 2006). The parameter controlling the breaking (saturation parameter) is of order of 1, and the diffusion parameter is chosen here to be 1 kg m^{-1} s^{-1} (see Equations (11) and (12) in (Lott and Guez, 2013) for details).

Table 1: Wave characteristics used in the reference simulation. Values in the bracket indicate the extreme of the probability distribution.

Phase Velocity $[m/s]$	Horizontal wave. amplitude $[km]$	EP-flux kg m^{-1} s^{-2}
[1 - 30]	[10 - 300]	[0 - 10^{-4}]

Impact of non-ororographic GW on the upper atmosphere

One of the main goals of this study is to understand the role of non-orographic GW on the global circulation and the thermal structure of the martian upper atmosphere. What is the magnitude of GW-induced drag on the winds?Where do GWs break/saturate and deposit the maximum momentum?What is the impact of the tuneable parameters on the winds? In order to answer those questions, model simulations up to about 200 km will be analysed and a number of sensitivity tests performed. As a starting point, the results presented here correspond to model simulations extended up to 80 km, with no coupling with thermospheric layers.

- *Improving MGCM thermal structure*

Simulations with and without non-orographic GW have been contrasted with MCS database. Both MCS and MGCM results have been binned in boxes of 3° latitude x 7.5° longitude. A full martian year has been simulated, notably the MY29, from the ground up to the pressure level of about 0.05 Pa.

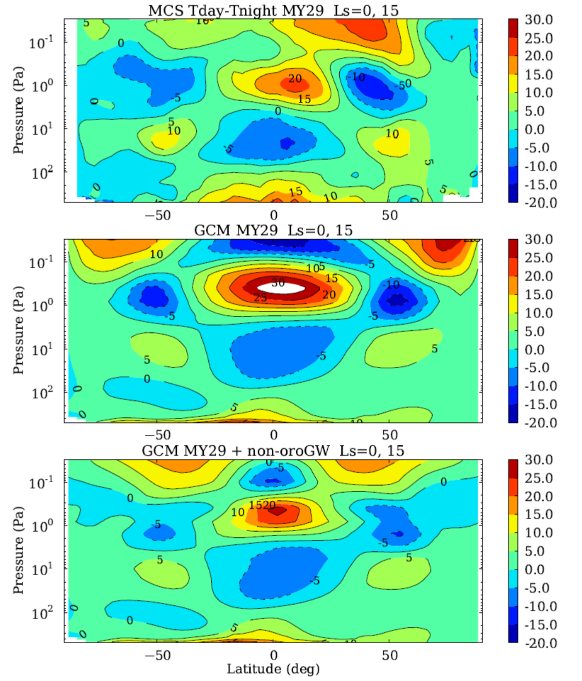

Figure 2: Zonal average temperature differences between dayside (∼ 3pm local time) and nightside (∼ 3am) observed by MCS (top panel); simulated by MGCM without (middle panel) and with (bottom panel) non-orographic GW. As in figure 1 the data are binned in the range L_s=0°-15°.

An example of the impact of the implementation of this non-orographic GW parameterisation in the mesosphere of Mars, using the baseline parameters in Table 1 is given in Figure 1. Zonal mean, day-night average $(T_{3am} + T_{3pm})/2$ of the temperature seen by MCS is shown together with temperature differences with MGCM. Without non-orographic GWs the difference exceeds 10-15 K, the model being colder at the pole below 1 Pa, and warmer in the region between 1 and 0.1 Pa (about 50-80 km altitudes). With non-orographic GWs (third panel from the top) those differences are clearly reduced. The bottom panel in Figure 1 illustrates the net effect of this GW parameterisation on the zonal mean average temperature,

near the North Hemisphere Spring Equinox. With non-orographic GW the polar region is found to be warmer below 1 Pa up to 22 K and cooler above, especially around 60 degree latitudes. The temperature in the tropical region (40°S-40°N) is also reduced by about 8K around 1 Pa, in better agreement with the data. However, an additional heating is introduced in the layers above in the equatorial region.
Those results indicate that data-model biases may be reduced in most of the cases by opportunely tuning the parameters listed in Table 1. However, seasonal effects also have to be investigated and sensitivity tests will be performed in order to help to interpret those results.

- *Improving the characterisation of diurnal tides*

  The sun-synchronous tides are wave responses of the atmosphere to the diurnal cycle and they represent an important diagnostic quantity for the analysis of observations of the martian atmosphere (Guzewich et al., 2012). This is illustrated in Figures 2, which shows the averaged temperature difference between dayside and nightside (T_{3am} - $T_{3pm})/2$) as seen by MCS (top panel) and predicted by the MGCM (middle and bottom panel). The observed quadrupole centred roughly between 30°S and 30°N latitudes is a well-known structure which corresponds to the main response of the Hough mode to the diurnal tide, trapped between 22°S and 22°N latitudes (Lee et al., 2009).

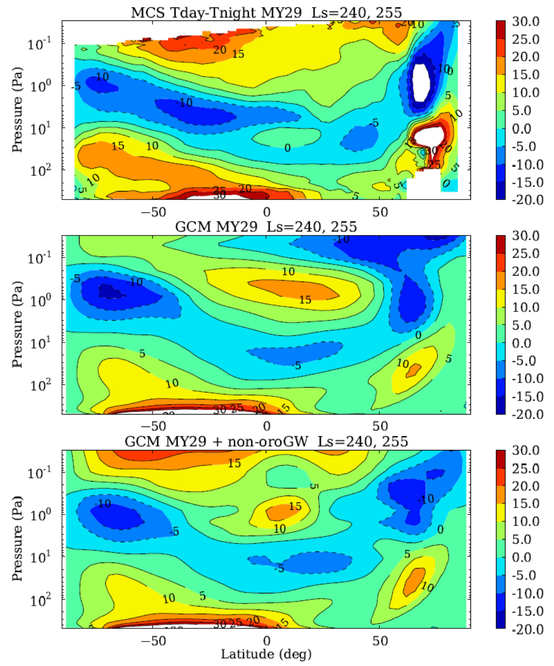

Figure 3: Same as in Figure 2 but for L_s=240°-255°

As shown in the Figure 2, the intensity and the amplitude of maximum around the equator is not well described by the MGCM: the difference with model simulations exceeds 15 K (the model being warmer than the data) and the vertical phasing is slightly shifted at higher altitudes compared to MCS results. The implementation of the GW routines clearly improves both the vertical structure of the tides and the amplitude/intensity. Another example of improvement of model-data comparison is given in Figure 3 during a different martian season, near the perihelion.
Figure 4 shows the seasonal evolution of diurnal tides for latitude band 20°S-20°N observed by MCS and predicted by the model. The overall improvement of the MGCM simulations when implementing the GW parameterisation is noticeable in the panels, especially above 10 Pa. With the non-orographic GW the maximum day-night difference value is around 20 K, comparable with observed values, as well as its amplitude.

Conclusion and perspectives

A non-orographic GW parameterisation is implemented for the first time in the LMD-MGCM, that is a 3D model able to simulate self-consistently the martian atmosphere from the ground up to thermosphere. The preliminary results are very promising: they show that the inclusion in the model of a key physical mechanism such as the propagation of GW from the convective region to the upper atmosphere may partially explain data-model biases at mesospheric layers. However, given the uncertainty in the wave basic characteristics, excitation mechanisms and sources of GW, it is difficult to quantify the impact of non-orographic GW drag in the upper atmosphere using a unique set of parameters. In this work we will analyse a number of sensitivity tests to help understanding the role of GW in the dynamics and in the thermal structure of the martian atmosphere.

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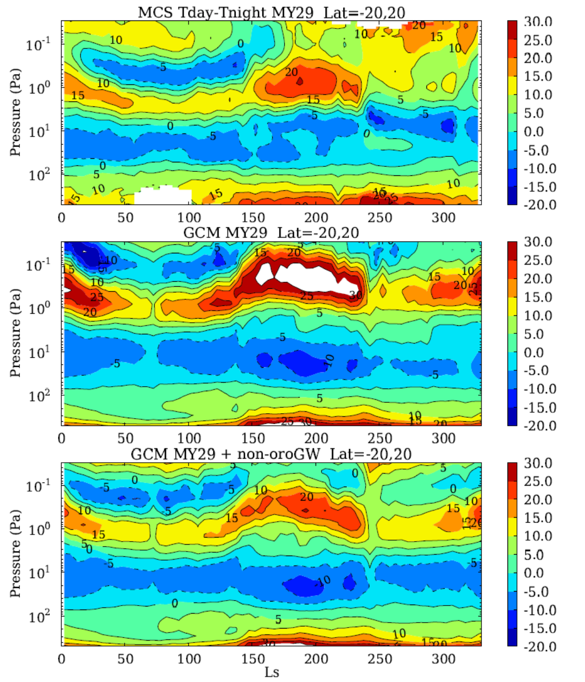

Figure 4: Zonal day-night average temperature differences as in Figures 2 and 3, but in the tropical band 20°S-20°N, as function of solar longitudes, seen by MCS (top panel) and predicted by MGCM without (middle panel) and with (bottom panel) non-orographic GW.

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