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Heating and cooling of the Martian atmosphere by gravity waves

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Abstract

Gravity wave-induced heating and cooling effects were fully and interactively incorporated into a Martian general circulation model (GCM). Simulations with an implemented spectral nonlinear gravity wave (GW) parameterization revealed significant thermal effects of GWs in the mesosphere and lower thermosphere (MLT) between 100 and 150 km. GW-induced heating and cooling rates are comparable with those due to near-IR CO_2 heating and IR CO_2 cooling, correspondingly. Simulations demonstrate colder temperatures in the MLT, with the most of cooling taking place in middle- and high-latitudes. In the winter hemisphere, the temperature decrease can exceed 45 K. These simulations are in a good agreement with the SPICAM stellar occultation measurements and Mars Odyssey aerobraking temperature retrievals. Thermal effects of GWs are probably a key physical mechanism in the MLT missing in contemporary Martian GCMs

1. Introduction

Thermal effects of GWs include a) heating of the mean flow due to an irreversible conversion of mechanical wave energy into heat [3,4], and b) differential heating/cooling due to a divergence of the induced downward sensible heat flux [1,4,7]. This study employs the Martian GCM with the nonlinear spectral parameterization of subgrid-scale GW waves of [10]. Formerly, the parameterization was extensively tested with a terrestrial GCM [8,9,11,12] as well as with a Martian GCM [6]. More details of the present study are described in [5].

2. Results

Results of simulations for L_s=270^O are plotted in Figure 1. It shows the zonal mean temperature simulated without GW scheme (a), and with the scheme, that includes thermal effects of GWs.

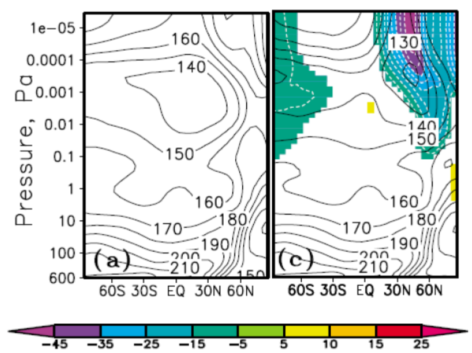

Figure 1: Mean zonal temperature simulated without GW scheme (a), and with dynamical and heating/ cooling effects of GWs included (c). Shadings denote the difference between the two fields

It is seen that GWs induce cooling in high latitudes of both hemispheres with the maximum in the winter hemisphere (up to -45 K). This is in agreement with the SPICAM measurements. GWs also enhance the winter polar warming between 1 and 0.1 Pa by up to 10 K.

3. Thermospheric winter polar warmings

Implementation of the GW scheme with heating and cooling rates has allowed reproducing the meridional temperature gradient inferred from ODY aerobraking measurements [3]. Figure 2 presents the night-time (2 am) temperature at p=0.0002 Pa (120 km) from the simulations (red dashed line) and from measurements (blue dotted line). An excellent agreement is seen except in the small latitudinal region between 60 and 75^{O}N.

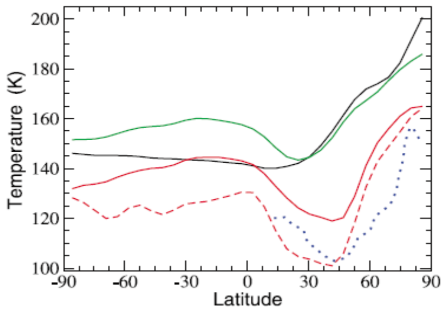

Figure 2: Zonally and diurnally averaged temperatures (solid lines) at p = 0.0002 Pa (≈120 km) from the runs without GWs (black), with only dynamical effects of GWs (“drag”) included (green), and with both dynamical and thermal effects accounted for (red). The blue dotted line presents the night-time temperature inferred from ODY aerobraking measurements [3]. The red dashed line corresponds to the night-time (near 02:00 hours) temperature from the run including both dynamical and thermal GW effects.

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