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Influence of gravity waves on the Martian atmosphere

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Abstract

Our recently developed nonlinear spectral gravity wave (GW) parameterization has been implemented into a Martian general circulation model (GCM) extending to ~130 km. The simulations reveal a very strong influence of subgrid-scale GWs with non-zero phase velocities in the upper mesosphere (100-130 km). The momentum deposition provided by breaking/saturating/dissipating GWs of lower atmospheric origin significantly decelerate the zonal wind, and produce jet reversals similar to those in the terrestrial mesosphere and lower thermosphere. GWs also weaken the meridional wind, transform the two-cell meridional equinoctial circulation to a one-cell summer-to-winter hemisphere transport, and modify the zonal-mean temperature by up to ±15 K.

1. Introduction

Although observations show that gravity waves (GWs) are strong on Mars, little is known about their dynamical significance. Few observational estimates indicate that GW momentum deposition can reach from 1000 [1] to 4500 m s^{-1} sol^{-1} [2]. The previous GCM studies had several features in common: (1) upper boundaries of models were limited to 80-100 km; (2) only terrain-generated harmonics with the observed phase velocity c=0 were considered; (3) they all utilized the Lindzen parameterization for calculating the drag produced by individual subgrid-scale harmonics. We quantify the GW momentum deposition in numerical simulations with the spectral nonlinear GW parameterization implemented into MAOAM GCM.

2. Gravity wave scheme

Our GW parameterization suitable for planetary thermospheres accounts for wave refraction by background wind and temperature, and for attenuation due to nonlinear effects (breaking and/or saturation) and dissipation (molecular diffusion and thermal conduction, ion friction, eddy diffusion) [3]. It treats the nonlinear interactions between the harmonics of the incidence spectrum, and converges to a well-known Hodges-Lindzen criterion of wave breaking for a single harmonic (but at lower amplitudes) [4]. The scheme has been extensively tested with a terrestrial GCM extending from ~15 to 400 km [5-7].

3. Martian GCM

The MAOAM GCM used in our interactive calculations is essentially same as reported in [8], but employs a spectral dynamical core as in [9]. The GCM has the relevant physics parameterizations including a non-LTE radiation scheme for CO2 heating and cooling. The upper boundary of the model has been extended to 10^{-5} Pa, or ~150 km., however without accounting for UV and EUV radiation. All calculations have been done at T21 spectral resolution (64 X 32 gridpoints in longitude and latitude) on 63 vertical levels.

3. Results

A one-year GCM simulation for the fixed dust opacity τ=0.2 in visible has been performed with the interactive GW scheme. The waves were launched from p=250 Pa (or ~8 km), just above the layers frequently affected by atmospheric convection. The source spectrum included 30 harmonics with c from -60 to +60 m s^{-1} directed along the local wind. This setup produced the best results in numerous simulations for Earth. The shape of the spectrum with smaller amplitudes for faster waves is in line with measurements on Earth and the experience gained with terrestrial GCMs. Note that no sponge layer was used in the simulations, unlike in many other GCMs. Thus, there was no other artificial physics introduced at upper levels. The main result of inclusion of the GW drag scheme is the closure of both easterly and westerly jets, and a significant reduction of the easterlies in the summer hemisphere. Another noticeable effect of GWs is the enhancement of the both winter polar warmings in the middle atmosphere.

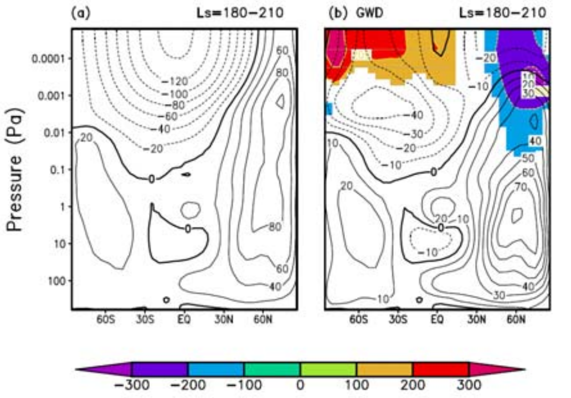

Figure 1: Mean zonal wind (contours) and zonal drag (shaded) averaged between L_s=180 and 210^{O}: (a) is for the run without GWs, (b) for the run with GWs.

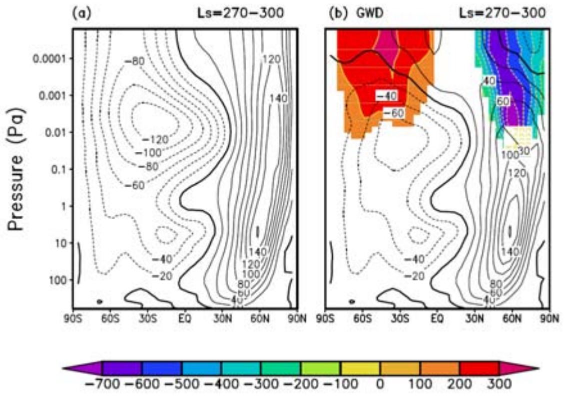

Figure 2: Same as in Fig. 1, but for the Martian solstice (L_s=270-300^{O}).

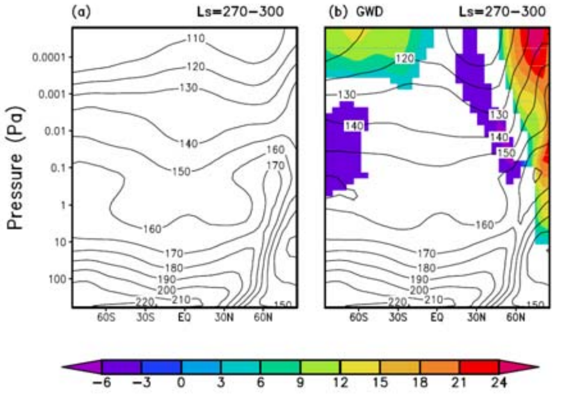

Figure 3: Same as in Fig. 2 but for the temperature (contour lines). The temperature difference between the runs is shown in color shades.

6. Summary and Conclusions

The implementation of a spectral nonlinear gravity wave (GW) parameterization [3] into the Martian GCM extended to ~130 km reveals a strong dynamical influence of small-scale GWs of lower atmospheric origin on the circulation between 100 and 130 km. Interactive simulations confirm our conclusion based on estimates with the Mars Climate Database output wind [7] that GWs give rise to deceleration of the zonal winds at all seasons, and even produce reversals in the upper part of the Martian mesosphere (100-130 km) at solstices, similar to those in the terrestrial MLT (70-110 km). These reversals are driven by the momentum deposited by dissipating/breaking/saturating GW harmonics with non-zero observed phase speeds. Such waves have not been accounted for in the previous studies of the Martian atmosphere, and, therefore, neither the zonal jet reversals nor the dominant role of GWs in the upper atmosphere dynamics of Mars have been simulated before.

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