EXPLORING MARS' ATMOSPHERE FROM THE SURFACE TO MIDDLE ATMOSPHERE: NASA AMES MARS GENERAL CIRCULATION MODEL.

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Introduction

Mars' atmosphere is continuous from the surface to the upper atmosphere. Although, it has historically been studied as isolated layers (i.e. troposphere, mesosphere, thermosphere). This segmentation has been and is done for simplicity in approaching specific questions and due to computational limits. However, with more computational power available a grander question is being addressed: is it important to have a coupled atmosphere? Recent studies have shown the importance of coupling the lower atmosphere with the upper atmosphere regarding questions related to dynamics and circulation (e.g. *Bougher et al.*, 2001; *Angelats i Coll et al.*, 2004, 2005; *Bougher et al.*, 2011).

In this study, the NASA Ames Mars General Circulation Model (MGCM) has been extended to incorporate the middle atmosphere (~80 km to ~120 km). The model extension produces an integrated framework providing a deeper domain to examine seasonal mean fields and large-scale wave activity with insight into circulation patterns in the middle atmosphere. Moreover, the MGCM will continue to be a numerical tool for comparisons with other models and observations.

NASA Ames Mars General Circulation Model

The NASA Ames MGCM is a 3D general circulation model which solves the primitive equations. The MGCM utilizes a finite difference dynamical core (based on an Arakawa "C"-grid) (*Suarez and Takacs*, 1995). The horizontal resolution is 5° in latitude by 6° in longitude. The vertical sigma-coordinate grid now contains 30 layers and extends from the surface to approximately 120 km (Ptrop = 1x10^{-7} mbar). The physics packages have been developed at NASA Ames.

MGCM includes a 2-stream radiative transfer scheme that accounts for gaseous absorption and scattering aerosols (*Toon et al.*, 1989). It uses Quadrature in the visible and Hemispheric Mean in the infrared. The gaseous opacities for CO_2 and H_2O are calculated from correlated-k (*Lacis and Oinas*, 1991). The correlated-k are offline line-by-line calculations which utilize the HITEMP data base from HITRAN. The pressure range is 10^{-8} to 10^{+4} mbar with a 0.5*log(P) resolution. The temperature range is 50 to 350 K with a 25 K resolution. The current model uses 16 gauss points per spectral interval. Lastly, there are 15 spectral intervals; 8 IR [1000 - 4.5 μm] / 7 visible [4.5 - 0.24 μm].

Table 1: Differences between the nominal MGCM and the extended MGCM.

	Nominal	Extended
IR - Cooling	LTE	NLTE
VIS - Heating	NLTE - equation	NLTE - equation
Ptrop	8E-4 mbar	1E-7 mbar
Number of Layers	24	30
IR Spectral Bands	5	8
Correlated-K Temp. Grid	50-350K; ΔT=50K	50-350K; ΔT=25K
Correlated-K Pres. Grid	10^{-6} to 10^{+4} mbar; ΔP=log(P)	10^{-8} to 10^{+4} mbar; ΔP=0.5*log(P)
Gauss Points	16	16

Extension

To properly incorporate the model extension there are several important modifications to the MGCM. One of the main modifications is the incorporation of Non-Local Thermodynamic Equilibrium (NLTE) heating (visible) and cooling (infrared). The NLTE solar heating rates correction is from Table 1 in *López-Valverde et al.* (1998). This table has been parameterized and is represented as a function which the LTE visible heating rates are multiplied by [f=(2.2E4*P)/(1+2.2E4*P); P is pressure in millibars] (*Haberle et al.*, 1999). The CO_2 15 μm cooling parameterization is adapted from *Bougher et al.* (2006), which is based upon 1-D NLTE model calculation of *López-Valverde et al.* (1998). In addition to incorporating NLTE effects, the pressure at the top of the model (Ptrop), number of sigma layers, IR spectral bands, and the correlated-k grids has been modified. Table 1 summarizes these modifications with respect to the nominal MGCM.

Extension Results

The modifications discussed in the previous section have all been tested within the 1D RT code and then tested within the 3D MGCM. The specific cases are 10 day averages and have been zonally averaged. The simulations were run from cold starts for approximately 70 sols and are representative of Ls=90. For simplicity dust is constant with τ=0.3 and microphysics has been turned

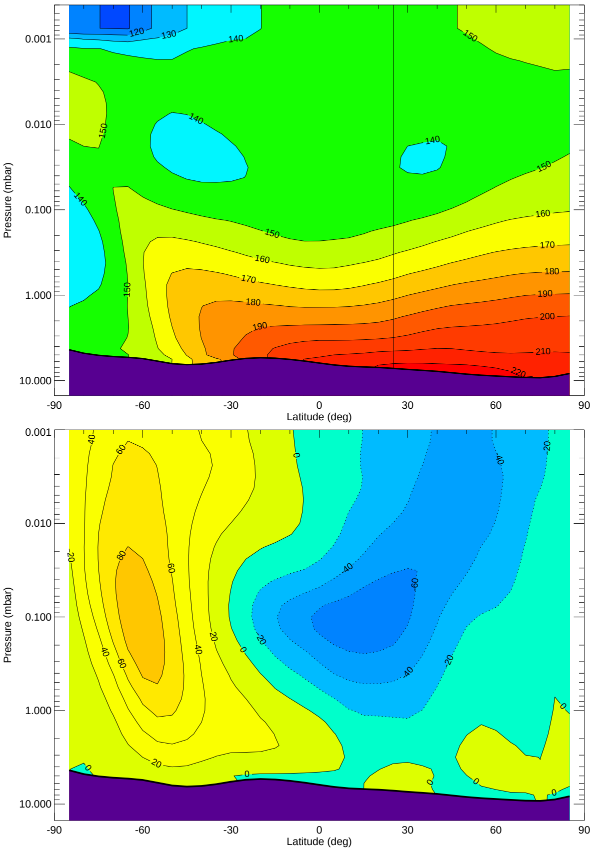

Figure 1: Nominal case: zonally averaged and 10 day average at Ls=90 (top) temperatures and (bottom) zonal winds.

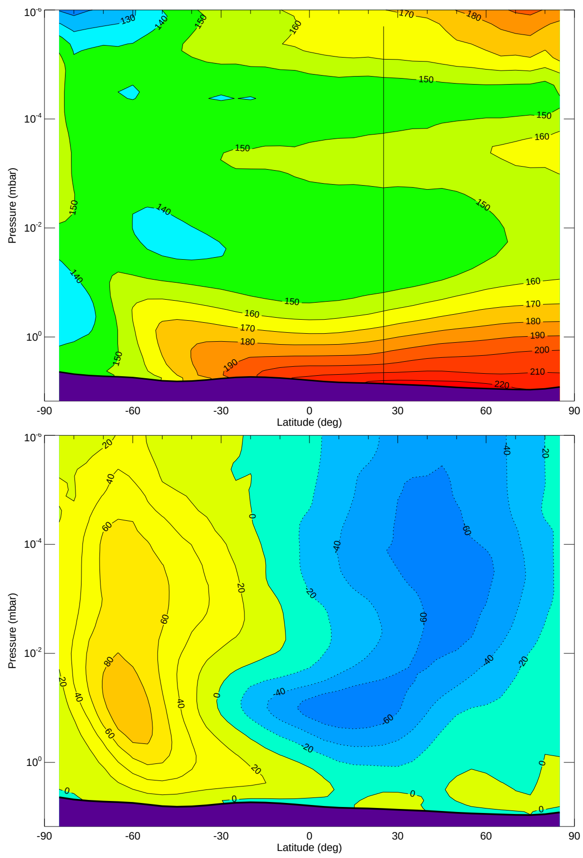

Figure 2: Extended case: zonally averaged and 10 day average at Ls=90 (top) temperatures and (bottom) zonal winds.

off. Figure 1 is temperatures and zonal winds representative of the 3D MGCM before extension and the extension modifications (nominal case shown in Table 1). Figure 2 is also temperatures and zonal winds, but it represents the 3D MGCM with the extension and the extension modifications (extended case shown in Table 1). These cases start to diverge between $\sim$1x10^{-2} and 1x10^{-3} due to the incorporation of IR NLTE effects, since both cases have the visible NLTE effects. Without the IR NLTE effects, the cooling rates in the middle atmosphere are over estimated. The nominal case has temperatures around 150 K and decrease to $\sim$120 K at 1x10^{-3} mbar to lower pressures, while the extended case has temperatures closer to 160 K and up to 190 K respectively. Furthermore, the extended case is capable of capturing the deeper convection patterns. The southern hemisphere jet in the nominal case is cut off compared to the extended case.

Sensitivity tests, specifically regarding the correlated-k grid, have been completed with the 1D RT code and the conclusions were in agreement with the Mischna et al. [2012] study. The finer resolved correlated-k grids improved the structure of the heating rates. Single profiles of the heating rates are much smoother, thus reflecting smoother temperature profiles.

Conclusion

The extended NASA Ames Mars GCM is capable of simulating a deeper atmosphere. The extension modifications are important to correctly model the continued lower atmosphere to middle atmosphere. Without the modifications, the heating and cooling rates are over estimated and circulation patterns are not fully connected. Sensitivity test representative of the discussion above and regarding dust will be shown. Furthermore, comparisons of the modified MGCM with observations and/or other GCM's will be presented.

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