MODELING POLAR WARMING AT MARS: PRELIMINARY RESULTS OF THE NEWLY VERTICALLY EXTENDED MARS-WRF GCM AND COMPARISONS WITH CONSTRAINTS FROM DATA

T. McDunn and S. Bougher, *Department of AOSS, University of Michigan, Ann Arbor, MI, USA, (tmcdunn@umich.edu)*; **M. Mischna,** *Jet Propulsion Laboratory, Pasadena, CA, USA;* **J. Murphy**, *Astronomy Department, New Mexico State University, Las Cruces, NM, USA;* **S. Nelli,** *Harris ITS, Las Cruces, NM, USA.*

Introduction: Polar Warming (PW) has been observed in the Martian atmosphere at middle and upper altitudes [e.g. 1-10]. General circulation models (GCMs) are the best tools we have to better understand observed PW characteristics as well as other atmospheric phenomena. In order for the tools to be trusted however, they must be validated; that is, they must reproduce the observed atmosphere reasonably well. Since PW is an important indicator of the structure of the global circulation on Mars, reproducing observed PW trends is a meaningful validation of a GCM. Simulating middle and upper atmosphere PW has therefore been the focus of several modeling efforts to-date [e.g. 4, 5, 11-15]. In this poster we present validation of the recently vertically extended Mars-WRF GCM by showing preliminary model results in comparison with constraints arising from observed PW trends. We then utilize the Mars-WRF GCM to explore the roles of gravity waves and lower-atmosphere dust loading in producing the observed PW trends.

Defining PW: In this paper, we define PW as:

$$\Delta T(p) = T_{hemispheric\ max}(p) - T_{eq\text{-}ward\ hemispheric\ min}(p)$$

That is, on a given pressure surface in a given hemisphere, the PW, ΔT, is the difference between the maximum temperature in that hemisphere, $T_{hemispheric\ max}(p)$, and the minimum temperature equator-ward of that maximum, $T_{eq\text{-}ward\ hemispheric\ min}(p)$.

Formation of PW: PW is a result of the global Hadley circulation. In the subsiding branch of the Hadley cell (above mid-to-high latitudes), adiabatic warming occurs, causing a reversal of the latitudinal temperature gradient one would expect from radiative considerations alone. This has been understood to be the driver of PW for some time [e.g. 11, 12]. However, other aspects of PW formation are less understood. *For instance, what governs the magnitude of the warming? What drives the warming to occur through a deeper layer of the atmosphere in some seasons than in others? What determines the pressure at which the warming will be maximized during any given season? What is responsible for a pole-ward or equator-ward extension of the warming? What roles do dust-loading and gravity waves (GWs) play in the magnitude and spatial extent of the warming?*

Role of Models: As with other studies of Mars's atmosphere, the largest obstacle to the advancement of PW understanding has been data paucity. Numerical models are the tools that have been used to fill the data gap and they can be used to address the questions of PW formation posed above. However, before that can be accomplished, GCMs must be validated by showing that they are capable of reproducing the observed atmosphere.

Constraints from Data: Previous validation of middle-to-upper atmosphere calculations has been limited. Recent observations of PW from Mars Reconnaissance Orbiter/Mars Climate Sounder (MRO/MCS), Mars Express/Spectroscopy for the Investigation and Characterization of the Atmosphere of Mars (MEx/SPICAM), Mars Global Surveyor/Accelerometer (MGS/ACCEL), 2001 Mars Odyssey/Accelerometer (ODY/ACCEL), and Mars Reconnaissance Orbiter/Accelerometer (MRO/ACCEL), however, have permitted the compilation of a set of middle-to-upper atmosphere constraints that can be used to validate simulations of the middle-to-upper atmosphere [10]. Those constraints are used here to validate the recently modified Mars-WRF GCM.

Figure 1 is an example of the type of constraints provided by these observations. Here, observed nightside (LST = 1900-0500) temperatures from L_s 90 – 100 are shown versus latitude on constant-pressure surfaces. Black points represent MCS data, green points represent SPICAM data, red points represent periapsis temperatures calculated from inbound legs of MRO/ACCEL data, and magenta represent those calculated from outbound legs. The cyan curves are the result of averaging the available MCS data over ½ °-Latitude bins. The solid blue line tracks the migration of $T_{hemispheric\ max}$. In this representation, the increase in ΔT magnitude and the pole-ward migration of $T_{hemispheric\ max}$ with decreasing pressure (from p = 10 Pa to 1×10^{-1} Pa) is clear. The SPICAM data shows signs of strong PW on the p = 1×10^{-4} Pa surface; however the data is sparse. There is no indication of PW in the MRO/ACCEL data.

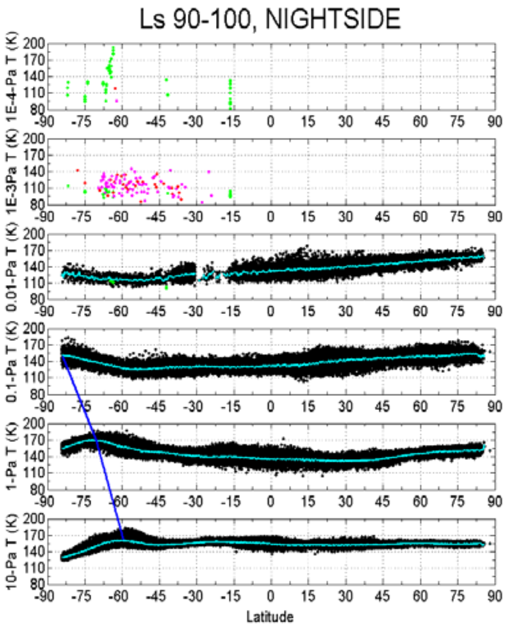

Figure 1. Nightside (LST = 1900 – 0500) observations on constant-pressure surfaces. See text for discussion.

Recent Modifications to Mars-WRF GCM:

Extended Vertical Domain. Previous modeling studies [e.g. 11, 12] have shown that in order to simulate PW at Mars, a sufficiently deep computational domain is required. The domain must capture the full depth of the Hadley circulation whose descending branch is responsible for the adiabatic warming of the poles.

The Mars-WRF GCM [16] domain has recently been extended in the vertical, now reaching from the surface to approximately 125 km altitude. 17 vertical layers have been added to accommodate the extended domain (57 layers in total). Enhanced physics packages with NLTE CO_2 15-µm cooling, UV heating, and near-IR heating effects above ~ 80 km have been added in order to simulate the physics of the extended domain (above the NLTE boundary, below the homopause). The vertical extension now permits simultaneous investigation of PW at lower, middle, and upper altitudes with one self-consistent model.

Dynamics. Previous efforts to model PW at Mars have been limited by the numerical representation of dynamical processes affecting the location and magnitude of the warming. One such process often insufficiently parameterized in models is breaking gravity waves. For example, Rayleigh friction, a linear drag term, is commonly used to parameterize this highly non-linear process.

Previously the Mars-WRF GCM employed sponge layers to absorb upward propagating waves and tides, preventing their reflection from the top of the computational domain. These sponge layers are now removed and a GW drag scheme is added to the code (the same as that being employed within the coupled NASA AMES MGCM-Michigan MTGCM [17]). Through this scheme, GWs impart drag on the zonal winds and accelerate the meridional winds. This results in an enhanced Hadley circulation, which in turn affects the magnitude and location of PW. Here we confirm that this improved representation of gravity waves is helpful for reproducing observed PW signatures.

References: [1] Deming D. et al. (1986), *Icarus, 66*, doi: 10.1016/0019-1035(86)90165-X. [2] Théodore B. et al. (1993), *Icarus, 105*, doi:10.1006/icar.1993.1145. [3] Santee M. and Crisp D. (1993), *J. Geophys. Res., 98,* doi: 10.1029/92JE01896. [4] Bougher S. W. et al. (2006), *Geophys. Res. Let., 33,* doi: 10.1029/2005GL024059. [5] Hartogh P. et al. (2007), *Planet. and Space Sci., 55,* doi: 10.1016/j.pss.2006.11.018. [6] McCleese D. et al. (2008), *Nature,* doi: 10.1038/ngeo332. [7] Kleinböhl A. et al. (2009), *J. Geophys. Res., 114,* doi: 10.1029/2009JE003358. [8] Forget F. et al. (2009), *J. Geophys. Res., 114,* doi: 10.1029/2008JE003086. [9] McCleese D. et al. (2010 submitted), *J. Geophys. Res.* [10] McDunn T. et al. (2010), *4th International Workshop on the Mars Atmosphere: modeling and observations. Paris, France.* Oral Presentation, "Polar Warming in the Martian Atmosphere: An Analysis of Data from Modern Spacecraft." [11] Wilson R. J. (1997), *Geophys. Res. Let., 24*, doi: 10.1029/96GL03814. [12] Forget F. et al. (1999), *J. Geophys. Res., 104,* doi: 10.1029/1999JE001025. [13] Bell J. et al. (2007), *J. Geophys. Res., 112, doi*: 10.1029/2006JE002856. [14] González-Galindo F. et al. (2009a), *J. Geophys. Res., 114*, doi: 10.1029/2008JE003277. [15] González-Galindo F. et al. (2009b), *J. Geophys. Res., 114*, doi: 10.1029/2008JE003246. [16] Richardson M. et al (2007), *J. Geophys. Res., 112,* doi: 10.1029/2006JE002825. [17] Bougher S. W. et al (2010), *4th International Workshop on the Mars Atmosphere: modeling and observations. Paris, France.* Oral Presentation, "Coupling of Mars Lower and Upper Atmosphere Revisited: Impacts of Gravity Wave Momentum Deposition on Upper Atmosphere Structure."