THE MARS GENERAL CIRCULATION MODEL INTERCOMPARISON STUDY. M.A. Mischna[1] and R.J. Wilson[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. M/S 183-401, Pasadena, CA 91109 (*michael.a.mischna@jpl.nasa.gov*), [2]Geophysical Fluid Dynamics Laboratory, National Oceanographic and Atmospheric Administration (*john.wilson@noaa.gov*).

Introduction: In June 2007, a call for contributions went out to the major Mars General Circulation Model (GCM) groups around the world to gauge the level of interest in participating in a rigorous Mars GCM intercomparison, with joint goals of providing NASA's Mars Exploration Program with a resource for obtaining the best-validated modeling results, as well as providing reference values for teams to use in continuing model development. On several occasions in the past decade, model intercomparisons have been initiated, though never before with such a strict set of criteria. Participation in the program is unfunded and voluntary, but provides a way for individual groups to see how well they 'stack up' against their colleagues in a controlled modeling framework. Teams are provided a series of initial model conditions, and asked to provide specific output for subsequent processing and intercomparison studies. Preliminary results from this project were presented at the 7th International Mars Conference in Pasadena, CA in July 2007. Subsequently, we have received additional results which expand the intercomparison. Here, we present these latest results and outline a plan for future work in this area.

Intercomparison Setup: The intercomparison is structured around the eponymous 'Held-Suarez' model intercomparison outlined in [1], but with several modifications making it more appropriate for the martian atmosphere. Specifically, model parameters are adapted to Mars from those given in [1] and the equilibrium relaxation temperature profile has been chosen to be a zonally averaged northern winter solstice temperature profile (Figure 1). The relaxation profile is provided on a standard grid and needs to be interpolated by each team to match the resolution of their respective model. A list of all relevant setup parameters is given in Table 1.

Certain differences between models are unavoidable or substantially inconvenient for individual teams to modify, and so certain differences are allowed, so long as they are noted. These include:

- Horizontal resolution: At a minimum, a 5°x4° (or T21 for spectral models) model is required, and a higher resolution model at 2.5°x2° (or T63 for spectral models) is encouraged. Additionally, teams are asked to provide results for what they considered their 'standard' model resolution.
- Vertical resolution: Teams can choose their own vertical resolution and structure. Terrain following coordinates are encouraged.
- Timestep: Teams can choose their own timestep.
- Upper boundary: Teams can choose their own approach to damping.
- Any filtering methods necessary for implementation of the code (e.g. high-latitude Fourier filtering) should be identified.

The goal of requesting multiple resolutions is to observe the converge of solutions as horizontal resolution increases. The rate of this convergence towards the 'true solution' is likely to vary among models, and provides an interesting metric for evaluating a model's performance under different configurations.

Temperature damping in the atmosphere was expected to be a tricky process to evaluate, yet one of great importance. Little is known about atmospheric density above 50 km, and this region is only weakly constrained by modeling, which, itself, is critically dependent upon how the damping is implemented. Additionally, the choices of damping wind and/or temperature and mean or perturbation quantities does, indeed, vary among models. Lastly, the depth and rate of damping may also vary. By prescribing fixed values to these parameters, we can minimize (though not eliminate) inter-model differences.

Past Results: At the 7th International Mars Conference, results from five separate modeling groups, comprising 8 distinct dynamical cores were shown, representing a range of model types and modeling approaches (Table 2, Roman font). Teams were asked to provide to the intercomparsion a minimum of the following four fields:

1. Zonal-mean temperature profile
2. Zonal-mean zonal wind profile
3. Eddy variance of temperature
4. Meridional wind field

which were to be averaged over the last 200 sols of the prescribed 400-sol run.

A vigorous discussion over damping approaches at the conference led to a consensus that, in addition to the 4-day (0.25 day^{-1}) Newtonian damping suggested, additional runs should be performed with 2- and 1-day damping. Results contributed by some teams with 2-day damping showed a noticeable influence on model results compared with 4-day damping.

As expected, horizontal resolution did play a role in the test. A single model run at two resolutions could yield significant changes to atmospheric wave structure. Compounded with the open selection for damping mentioned previously, a conclusion was reached that further testing would be necessary with each model to gauge model performance.

Latest Contributions: Since the last meeting, the authors have received additional contributions from both the Laboratoire de Météorologie Dynamique (LMD) and the WRF model teams (Table 2, **bold font**). The LMD contribution adds a sixth modeling team to the intercomparison, while the additional contributions from the WRF team demonstrate the role of both model-top height and grid orientation on the output. Forthcoming results from both the NASA Ames and Oxford groups will further expand the intercomparison.

WRF Results: Vertical resolution was identified as a potential issue with the WRF output, with its fewer (25) vertical layers and lower model-top height (~0.05 Pa). The consequence of this model architecture is that damping begins relatively low in the atmosphere, affecting model fields well into the middle troposphere. Following the 2007 Conference, the WRF model was rerun with a greater number of vertical gridpoints and a higher model top, providing better vertical resolution, and, consequently, results that better fall in line with other modeling groups (Figure 2).

The WRF model also has a 'rotated pole' capability, which allows for the numerical pole to be placed arbitrarily on the planet. This is useful for investigating polar processes, for example, where the necessity of polar filtering can alter or destroy subtle atmospheric features. The initial WRF results at the 7th International Mars Conference revealed a strong meridional gradient in the zonal wind across the northernmost grid point, and an uncharacteristic warm core just below the peak zonal winds in the northern poles—features that were not observed by other groups.

A revisit to the Held-Suarez problem by the WRF team with a rotated pole has largely reconciled these problems (Figure 3), suggesting that, at least for the WRF model, there is a strong grid-orientation dependence. Barring a similar ability in other models, such a dependence will be difficult to evaluate, natively, by other teams, however this should be seen as a potential future pitfall that should be revisited.

Future Work: We desire to incorporate the remaining teams into the intercomparison, such that it become as comprehensive as possible. Additional runs by current participants would also be useful, at additional model resolutions and with varying damping times, as suggested at the 2007 conference.

Beyond these initial steps, increasing levels of model physics can be introduced and evaluated, including radiation and microphysics, although pursuit of such endeavors should undoubtedly be deferred until general consensus has been reached for the idealized, Held-Suarez simulation.

References: [1] Held, I. M. and Suarez, M. J. (1994) *BAMS, 75,* 1825-1830.

Parameter	Symbol	Value
Day length	N/A	88,775 s
Rayleigh damping timescale	k_f	1 day^{-1}
Newtonian damping timescale 1	k_a	0.25 day^{-1}
Newtonian damping timescale 2	k_s	0.25 day^{-1}
Velocity damping cutoff level	σ_b	0.7 or equivalent
Surface pressure	p_0	610 Pa
Gas constant	R	191.2 J kg^{-1} K^{-1}
Specific heat, constant pressure	c_p	764.8 J kg^{-1} K^{-1}
R/c_p	κ	0.25
Angular velocity of rotation	Ω	7.09x10^{-5} s^{-1}
Gravity	g	3.72 ms^{-2}
Mean planetary radius	a	3.389x10^{6} m
Initial temperature state	N/A	200 K everywhere
Length of run	N/A	400 sols
No radiation, boundary layer or surface schemes		
No topography		
No polar caps		
No CO_2 condensation		

Table 1: A listing of all prescribed parameters for the Held-Suarez intercomparison

Model	Core Numerics	Vertical Levels
GFDL A	Spectral	28/36
GFDL B	B-Grid	32
GFDL C	Finite Volume	N/A
GFDL D	Finite Volume + Cubed-Sphere	28/36/56
Hokkaido	Spectral	48
Caltech/Cornell/JPL (WRF)	C-Grid	25/**40**
Caltech/Cornell/JPL (WRF)	**C-Grid + Rotated Pole**	**25**
CCSR/NIES	Spectral	33
York	C-Grid	88
LMD	**C-Grid**	**32**

Table 2: A list of all participating models in the intercomparison, along with information about the structure of the dynamical core numerics and number of vertical model levels. Those models/tests contributed after the 7th International Mars Conference are listed in **bold**.

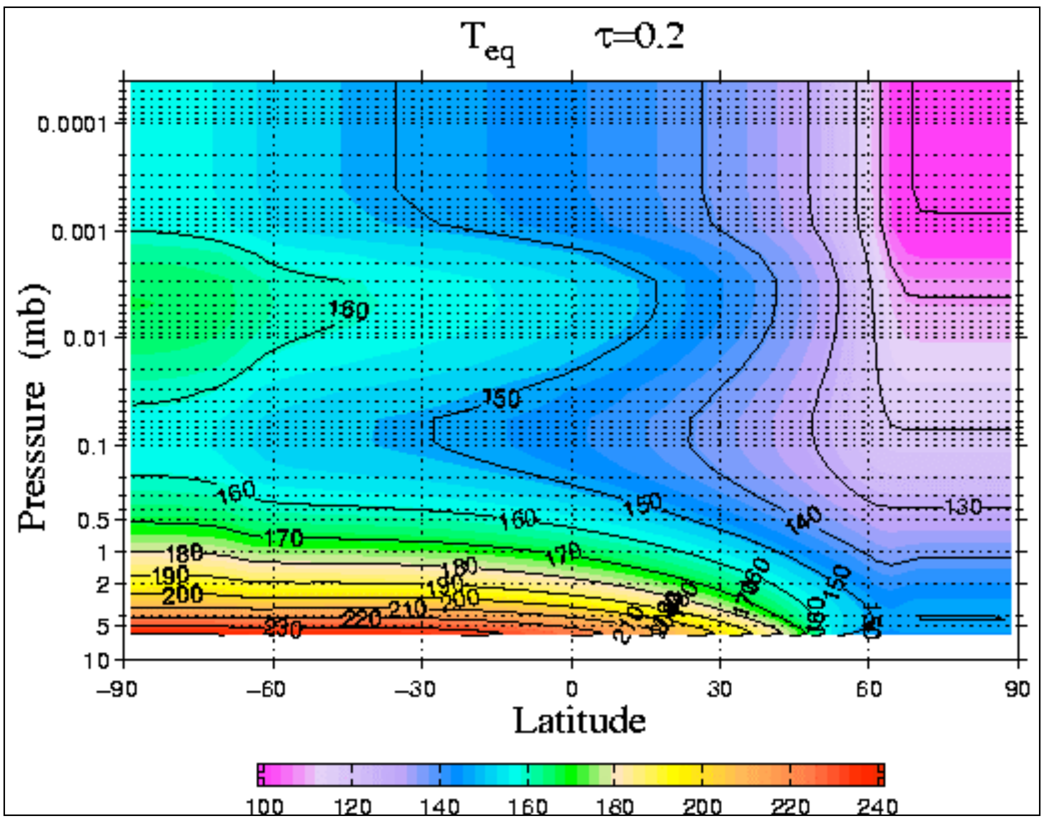

Figure 1: The standardized relaxation temperature profile used in the intercomparsion, a clear, northern winter solstice, zonally averaged profile. Pressures in mb.

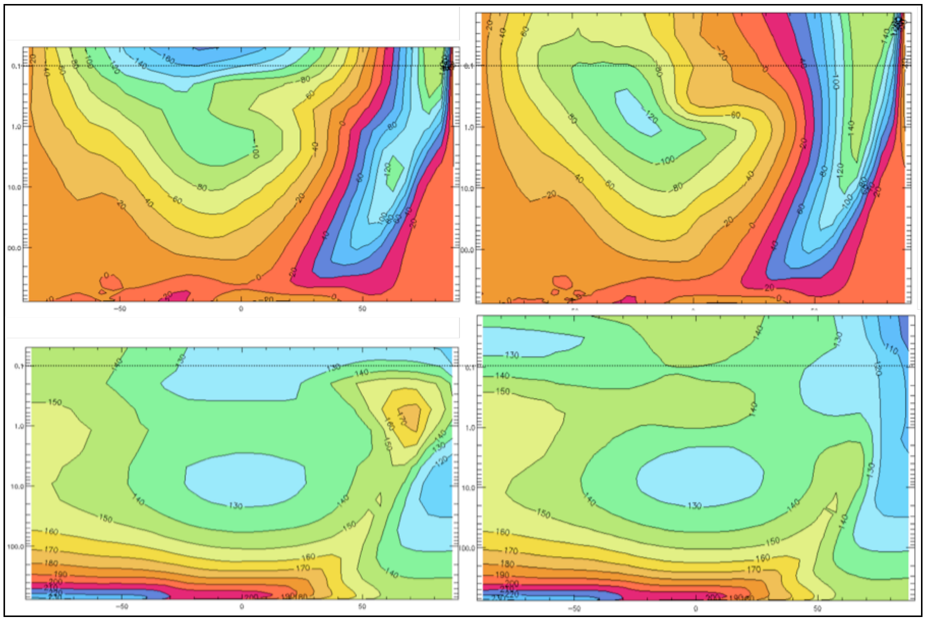

Figure 2: (left) Original contributions from the Caltech/Cornell/JPL WRF team with a 25-layer, low model top simulation showing zonally averaged zonal wind (top) and temperature (bottom). Unusual features were observed near the model top both in the tropics and northern polar regions. **(right)** Same WRF simulation with a 40-layer, high model-top architecture, showing the impact of model structure on the WRF output. Dotted lines delineate the 0.1 Pa pressure level in both simulations. Pressures in Pa.

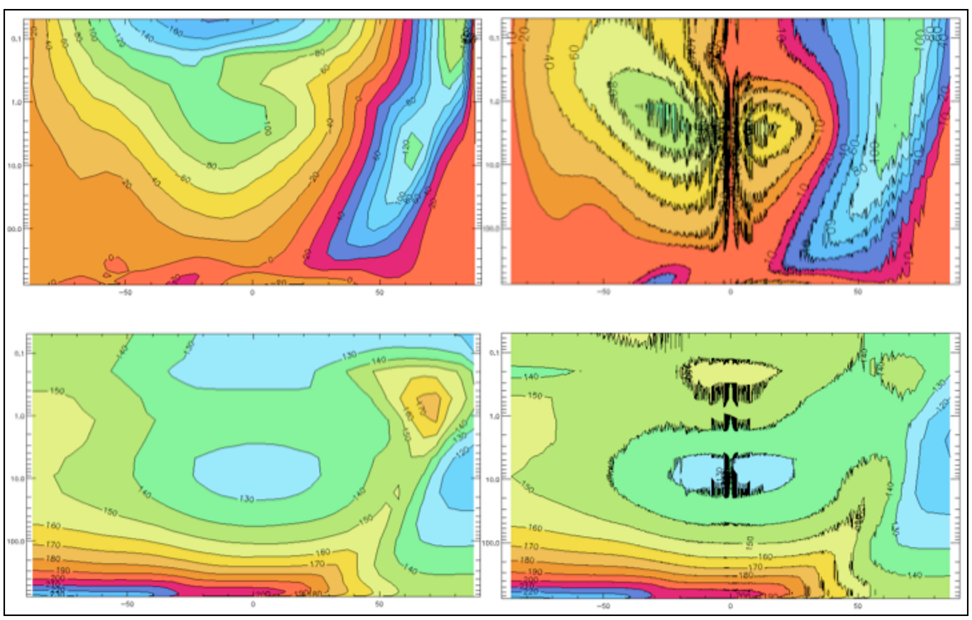

Figure 3: (left) Original contributions from the Caltech/Cornell/JPL WRF team with a 25-layer, low model top simulation showing zonally averaged zonal wind (top) and temperature (bottom). **(right)** Same WRF simulation, but with the numerical pole rotated 90° to the equator. Numerical north pole is situated at (0°,0°) and south pole at (0°,180°). Unusual model behavior at the equator is an artifact resulting from the presence of a polar singularity at this latitude. High frequency noise is a consequence of the non-axisymmetric distribution of model grid points in the rotated pole structure.