DEVELOPMENT OF THE OREGON STATE UNIVERSITY MARS MM5 AND DESCRIPTION OF OUR INITIAL RESULTS.

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Model Development: The Penn State/NCAR Mesoscale Model was modified to simulate atmospheric circulations on Mars, thus creating the OSU MMM5. Output from the NASA/Ames Mars GCM is used to generate boundary and initial conditions. Our initial phase developing the model included a series of increasingly realistic experiments where insolation was held at diurnal average values; the GCM was also run this way to generate appropriate boundary conditions. This approach allowed us to find a small problem in the GCM surface heat flux parameterization, observe that boundary conditions were generated correctly, show that the modified soil model in the MMM5 was behaving correctly and demonstrate that the radiation scheme (adopted from the Ames GCM) was indeed functioning properly in the MMM5.

After activating the diurnal cycle in both models we began comparing output with data gathered during the landed phase of the Pathfinder mission. We became familiar with the spin-up time required for the MMM5 to settle down and discovered that the diurnal cycles of wind and surface pressure in the model were noticeably dependent upon the mother domain chosen for the simulation. This sensitivity to simulation domains is to be expected given the methods by which terrestrial mesoscale modelers choose their domains and the differences between the atmospheres of Earth and Mars.

Domains and boundaries. Reflections cannot be eliminated from limited-area computer simulations; they will arise simply from differences in the numerical grids across boundaries, as well as from any other differences in the two models being used. In general, the very large diurnal cycles and thermal tides on Mars will always lead to significant problems at the boundaries of limited-area models, where models (or models and data analyses) with differing physics and resolution must interface. The Martian atmospheric thermal tides simply have no terrestrial analogue; they are as large in surface pressure amplitude as hurricanes, and they must pass through any zonal boundary each day.

In terrestrial studies, mesoscale mother domains are constructed so that the circulations being studied do not pass through these boundaries during simulation. For Earth, the circulations are generally midlatitude cyclones and the speeds at which they travel are quite slow; large mother domains contain them for periods appropriate for their study or for real-time forecasts (a few days). Nests are utilized to examine regions of interest at higher resolution, where the physics, dynamics and vertical grid structures are generally duplicated on either side of the boundary. In the MM5, computational time is used to smooth out the smaller reflections that would occur at these boundaries because of differing horizontal resolutions. Nest boundaries do not cause the large reflections that will form at mother domain boundaries.

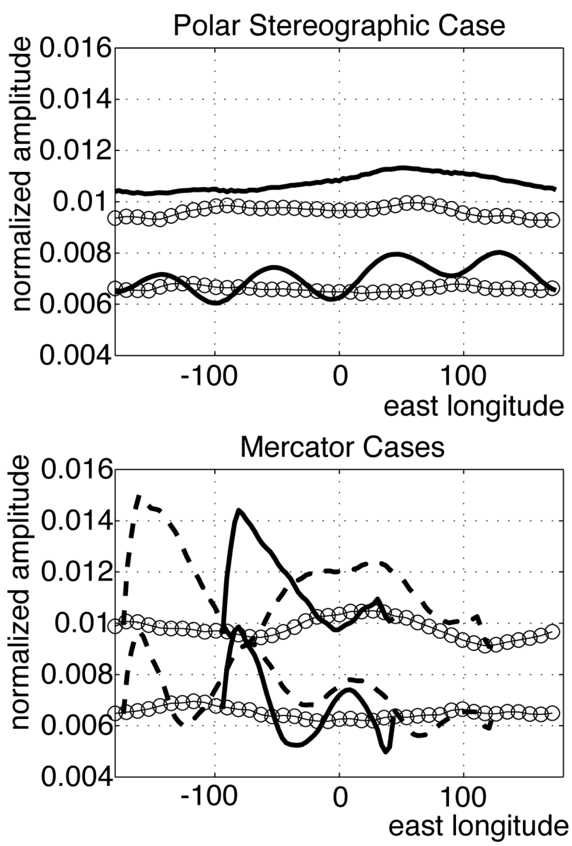

Figure 1: Longitudinal profiles of the average diurnal and semidiurnal amplitudes of surface pressure for the Mars "cue-ball" experiments. Results are shown for Pathfinder latitude (19.2° N). The curves marked with circles show the GCM diurnal (~0.0095) and semidiurnal (~0.0065) amplitudes. The MMM5 profiles were interpolated at 5° intervals.

To understand the magnitude of boundary reflections in our simulations we performed three single domain simulations, one using a semi-global polar stereographic projection and two using mercator projections. These tests were performed for a "cue ball" Mars (flat topography using constant albedo and thermal inertia maps). Averaged over a Martian week or more the diurnal and semidiurnal amplitudes of surface pressure on this fictitious planet are constant in longitude. Longitudinal profiles of the diurnal and semidiurnal amplitudes are shown in Fig. 1. Our conclusion: for the season being simulated (late NH summer), a semi-global polar stereographic mother domain is the best choice for minimizing the reflections from boundaries. The domains used for the simulations discussed below are shown in Fig. 2.

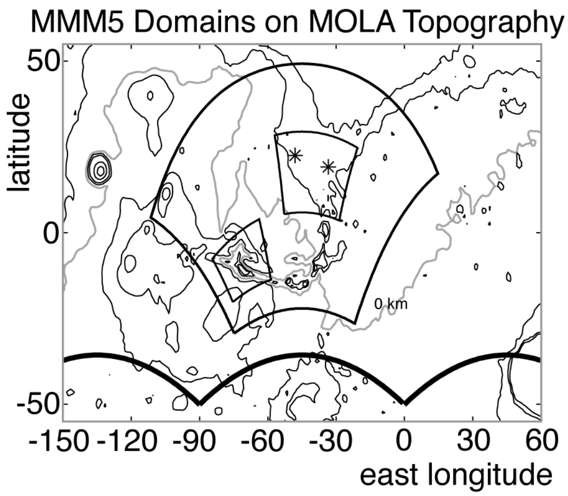

Figure 2: The mother domain boundary is shown (thick line). The 60 km nest encloses the 20 km nests. Locations of Pathfinder (19.2° N, 33.4° W) and VL1 (22.5° N, 48° W) are shown with (*) markers. Topography (MOLA 1°) is contoured to show geographical location.

Model Results: Air temperature and surface pressure data gathered by Pathfinder are compared with model results in Figs. 3 and 4. The good agreement with nighttime air temperatures is mostly a result of using TES thermal inertia and albedo data. Maximum and minimum values agree quite well, although there is noticeable disagreement when strong convection exists during the day. The reasons for this are not clear, although linear interpolation of model results to uniform height, the PBL scheme used in the MMM5 or the aliasing of actual air temperatures from lander interference are all suspected. Surface air temperatures predicted by the MMM5 are not sensitive to different mother domains, but the same cannot be said about the surface pressure cycle predicted by the MMM5.

After elimination of the largest boundary reflections from our simulations (by using the semi-global polar stereographic mother domain) we expected to find that the GCM and MMM5 surface pressure cycles were in closer agreement (the two models use the same radiation scheme). Numerous factors explain why this did not occur, and a suite of test simulations was performed to examine the individual influences of topography, model resolution, thermal inertia and albedo on the surface pressure cycle predicted by the MMM5. Some of the results from these test experiments are shown in Fig. 5.

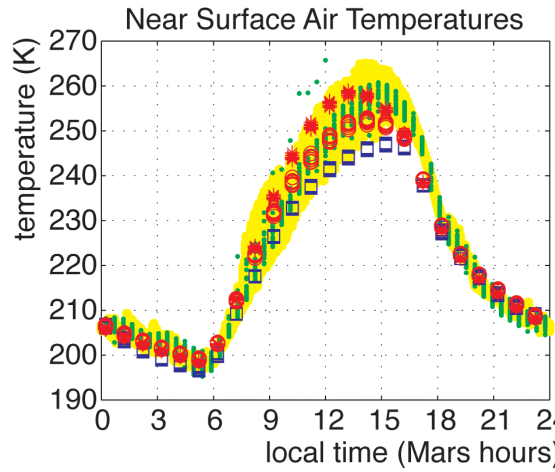

Figure 3: Lowest MMM5 sigma level temperatures (~1.7 m) are shown with red (o) markers. Red (*) markers are model temperatures at 1.27 m (top of Pathfinder MET mast). Yellow points are continuous MET temperatures for sol 25; the green points are binned (51 bins/sol) results for the entire 30-sol primary mission. Blue square markers are GCM temps (~5 m) interpolated to Pathfinder.

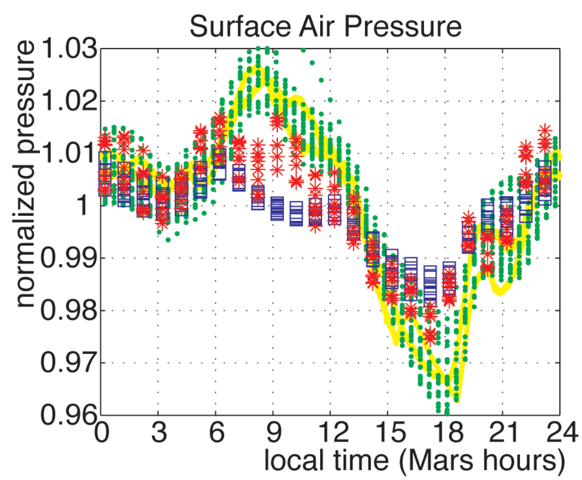

Figure 4: Normalized surface pressure. The green dots are binned MPF data (51 bins/sol) from the entire 30-sol primary mission. The red (*) markers are for the MMM5 (Pathfinder location in the 20 km Chryse Planitia nest) and the blue square markers show the GCM output interpolated to Pathfinder. Yellow points show the continuous surface pressure records from sols 25 and 32.

Large-scale thermal inertia and albedo variations were found to produce deeper longitudinal variations in the diurnal amplitude of surface pressure than topography. Since surface pressure responds to thermal inertia and albedo variations via a thermally initiated mechanism, the differences between the PBL schemes used in the two models are probably responsible for much of the resulting difference seen in the surface pressure cycles. The spatial resolution of thermal inertia and albedo are not important in this context; these surface fields affect the diurnal amplitude because of their large continental scale nature.

However, changing the spatial resolution of model topography or that of the model itself causes significant change in the longitudinal profile of the diurnal amplitude. The mechanism responsible is dynamical; different topographies excite different Kelvin modes. A different topography map certainly modifies the energy in Kelvin modes. Changing the actual resolution of the model will affect the numerical phase speeds of Kelvin modes and thus their phase relationships with other factors that afect the diurnal surface pressure cycle. The result is that in topographically interesting regions (a great fraction of Mars in this context) the predicted surface pressure cycle is quite sensitive to the configuration of the model. Some of these effects are shown in Fig. 5.

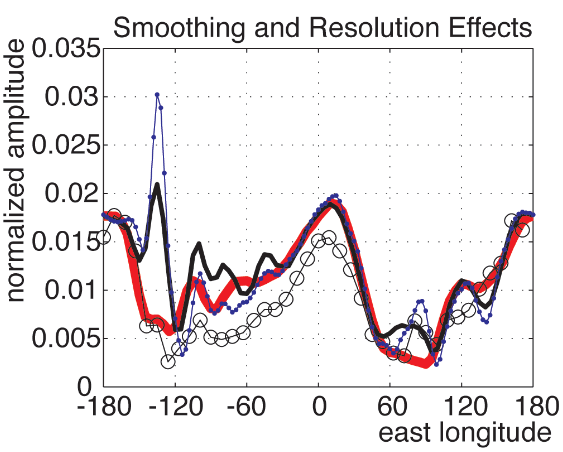

Figure 5: The effects of topography and model resolution on the diurnal amplitude of surface pressure in the mother domain at 19.2° N. Baseline GCM and MMM5 runs are shown respectively with a thin black line/circles and with the thicker black line. The heavy red line shows the diurnal amplitude of the MMM5 when using interpolated GCM topography (smooth). The blue line/dots are from a simulation that used a higher resolution MMM5 mother domain (135 km versus the baseline 180 km).

With these complications, it is difficult at best to qualify the performance of a model in simulating the Martian diurnal pressure cycle when only one or two actual data points are available for comparison, especially when these data are from regions where model results are very sensitive to how the model was configured.

Surface winds. There is good agreement between the surface wind directions predicted by the MMM5 and the Pathfinder data. Importantly, model agreement with data improves as resolution increases from the mother domain to the 20 km Chryse Planitia nest. The wind directions that were simulated are compared with data in Fig. 6. A separate examination of the surface wind field for this nest (not shown) shows that simulating slope flows in this region is important for simulating the variations of wind direction at Pathfinder. Additional simulations, using the same domains but including the effect that slope orientation and angle have on surface insolation, show additional improvement in capturing the recorded structure. We interpret this result as further indication of the importance of slope flows in the region.

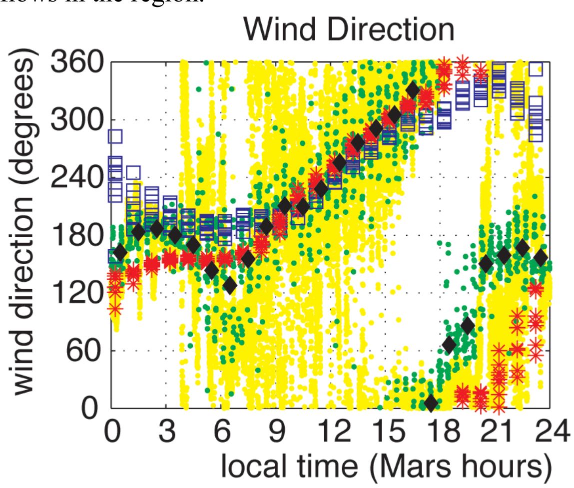

Figure 6: Comparison with Pathfinder wind data. Yellow dots show all data for sol 25. Green dots are binned data (51 bins/sol) from the 30-sol primary mission. The black diamond markers are hourly averages of all binned data. Blue squares show GCM direction data and red (*) markers show the 8 sols of MMM5 output.

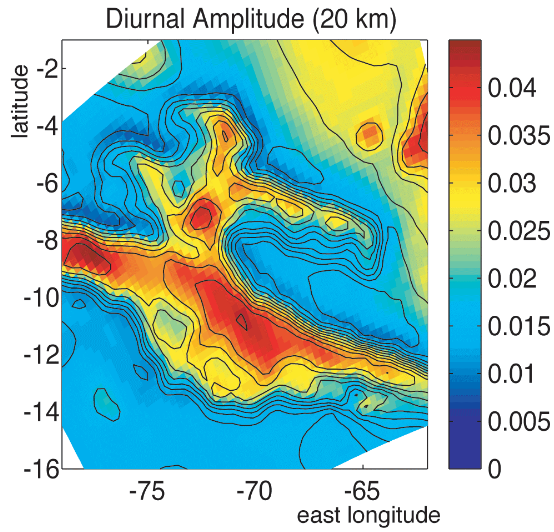

Figure 7: Diurnal amplitude from the 20 km Valles Marineris nest. The largest amplitude from this domain is 0.0457. Contours of topography are 1 km intervals.

Slope Flows and Surface Pressure: Our studies thus far suggest that slope flows essentially dominate the near surface circulation in regions of complex topography. In the Valles Marineris nest of these simulations, slope flows transport enough air mass to dramatically modify the diurnal surface pressure cycle. The canyon system is filled with cold air at night (downslope flow) and emptied during daytime (upslope flow).

A regional map showing the average diurnal amplitude of surface pressure is presented in Fig. 7. The diurnal amplitude must be a superposition of the slope flow forcing and that of the pressure tide. After examining the surrounding diurnal amplitude in this nest and in the mother domain of the simulation, we conclude that the slope flow forcing is at least as strong as the background pressure tide forcing. Valles Marineris is certainly the most dramatic location on Mars for observing this mechanism; however, at least one of us has come to believe that it is at least somewhat important elsewhere.