A MARS LES MODEL FORCED BY TIME AND HEIGHT DEPENDENT MESOSCALE MODEL GEOSTROPHIC WINDS TO SIMULATE THE EDL ENVIRONMENT FOR PHOENIX. D. Tyler¹, J. R. Barnes² and E. D. Skyllingstad¹ ¹College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA dtyler@coas.oregonstate.edu, ²College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA barnes@coas.oregonstate.edu, ³College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR, USA skylling@coas.oregonstate.edu.

Introduction: Atmospheric modeling has become an integral part of designing the Entry, Descent and Landing (EDL) phase of missions that will land on the Martian surface. For the NASA/JPL Phoenix Scout mission, Large Eddy Simulation (LES) models have recently become an important part of this modeling. LES models are most useful because they provide a direct high-resolution numerical simulation of the turbulent dynamics within the PBL (as excited by wind shear and buoyancy forcings). Thus, LES modeling provides and important compliment to mesoscale modeling: the additional means for gathering information about the structure of atmospheric Turbulent Kinetic Energy (TKE) is very useful to engineering teams as they determine reasonable and conservative ranges of atmospheric conditions that a spacecraft might encounter in the PBL as it transits the atmosphere (with a number of tasks to perform in rapid succession that are keyed to atmospheric structure) to a safe landing. For this part of the Martian atmosphere, having a huge impact on the climatology of Mars, we essentially lack any critical observational data.

Because of the design of LES models and the small horizontal coverage of their domains (~400 km² is typical), these models have some problematic limitations. The lateral boundaries of LES models are cyclic (outward flow at one “wall” of the domain requires there to be identical inward flow at the corresponding location on the opposite “wall”). The consequences of this are good and not so good: turbulent motions are fully spun-up throughout the domain (good) although the simulation is highly idealized and no large-scale circulations are able to influence the simulation (not so good). The basic forcings of an LES simulation are generally limited to control over the solar input (local time, Ls and latitude), the atmospheric mass (initial surface pressure), surface properties (thermal inertia and albedo), initial temperatures (both atmospheric and soil model) and some value for the background environmental wind (typically this is constant in height and time).

For LES models of Mars these limitations are more problematic than they are for those of the Earth; this is true simply because of the mesoscale and large-scale circulations that are expected to contribute to the local diurnal meteorological cycles at most locations on Mars. The superposition of continental slope flows, diurnal cycles in the winds (a consequence of solar thermal tides) along with large-scale cyclonic thermal circulations (a consequence of the dramatic Martian topography) are certain to affect the diurnal cycles of local meteorology. If these forcings act in superposition (which they do), an environment with a great deal of vertical structure must result (rivaling the passage of strong storms on Earth). Since the Martian Planetary Boundary Layer (PBL) seems to scale to ~5x the depth of the terrestrial PBL (based on modeling, dust devil shadows and limb observations), these large-scale forcings are likely to produce vertical gradients that have an important influence on the diurnal evolution of the turbulent mixed layer on Mars (as compared against an LES model that did not include these forcings). The new modeling performed in this work demonstrates an approach that allows for a direct simulation of PBL turbulent fluxes in an environment that is forced by time and height dependent gradients in the large-scale pressure and temperature fields (the geostrophic wind field from the mesoscale model). The results are thus quite site-specific, not simply an idealized LES run.

Our Models: In performance of this work we use the OSU Mars MM5 [1, 2] and the OSU Mars LES models [3, 4]. The LES model utilizes the same atmospheric radiation algorithms as in the mesoscale model; and, the initial conditions for the LES model (soil and atmospheric temperatures) are provided by the mesoscale model. The mesoscale model output that was used comes from a nest with an actual resolution of ~20 km (18 km nominal polar stereographic map), providing a “footprint” that is quite similar to the horizontal size of the LES domain (~25 km). The seasonal date of the mesoscale simulation is Ls ~80, the date of EDL for the NASA/JPL Phoenix Scout Mission. The modeled location is on the far northern slopes of Alba Patera (66°N, 250°E).

Hourly mean values of the diurnal cycles of the zonal and meridional wind components are shown versus height in Fig. 1. Using the mean diurnal cycles of atmospheric pressure, temperature and geometric height on sigma surfaces (for this and surrounding locations), the diurnal cycle of the geostrophic wind in the mesoscale model was constructed. The geostrophic winds are shown in Fig. 2.
The OSU Mars LES model is typically run with a uniform spatial resolution of 100 m on a large domain grid (256x256x240 gridpoints). At the conference we will present results from a higher-resolution simulation that has yet to be performed. In the present simulation (100 m resolution) the upper 4 km of the LES domain is a sponge layer, with damping that increases in strength to the top of the model (24 km). Additionally, the LES model domain “moves” with the horizontal mean wind at the height of the sponge interface; this essentially removes problematic reflections of gravity wave energy and allows us to perform long (multiple convective period) simulations. Our LES model is presently being run on the massively parallel architecture of the Columbia supercomputer at the NASA Ames Research Center.

**LES Model Results:** The results described below are for the second convective period in a run that started at ~3 AM LST and ran a total of 48 hrs. Letting the model run through the second convective period is important for spin-up of some expected dynamics. Due to the development of frictional drag in the mixed layer (the vertical turbulent mixing of momentum by convection), a nocturnal oscillation will occur in the PBL (winds accelerate to super-geostrophic speeds in the presence of a geostrophic wind at the end of heating due to the termination of frictional drag).
Results for LES Winds. Allowing for the development of these dynamics, we examine the horizontal mean components of the wind from the second convective period in the LES model, shown in Fig. 3. For comparison between models, Fig. 1 and Fig. 3 were constructed with identical axes. The agreement is very good at altitudes greater than the maximum depth of the convective mixed layer (~5 km in the mesoscale model and ~7 km in the LES model). This suggests (for this specific location at least) that the diurnal cycle of wind is driven in large part by changes in the geostrophic wind (changes in the large-scale horizontal gradients of atmospheric pressure).

Within the lowest ~5-7 km a fair agreement is observed between the two models concerning the features of the wind field and the resulting wind speeds, although timing of the prominent observable features is not so good. What is important to note is that similar shears, rates of change and amplitudes occur in the LES results in much the same way as in the mesoscale model winds. Given that the LES wind environment is in good agreement with that of the mesoscale model, it seems likely to conclude that the Turbulent Kinetic Energy (TKE) calculated in the LES model will be representative of what might be expected during EDL, especially if the mesoscale model is indeed capturing the large scale dynamics of this region (which is still a very good question to continue asking).

LES Turbulent Kinetic Energy. LES models do not have PBL schemes to parameterize the mixing of heat and momentum via turbulence, the dynamics that cause this mixing is simulated in an LES model and such parameterization is rendered unnecessary. Thus, the subgrid turbulent exchanges that are parameterized in a mesoscale model are resolved in an LES model; the mixing of heat and momentum in an LES model is a result of the model dynamics and radiative heating that is realistic for Mars, not determined by a PBL scheme that was originally written for terrestrial use. The full story (of course) is that LES models have their own subgrid parameterization and they also require similarity theory (typically Monin-Obukov) to parameterize exchanges between the ground and the lowest layer in the LES model. In the atmospheric modeling community it is generally agreed that LES models deserve greater respect than PBL schemes for their ability to realistically represent evolution of the turbulent mixed layer.

The crux of this matter rests on the degree to which an LES model can actually include the larger scale meteorological influences on atmospheric TKE, and whether or not such factors are indeed important for the specific case being examined. For this newest Phoenix case (and for some cases we will soon be applying this model and developing method to), representing the large-scale meteorological variability more realistically (at least as predicted by mesoscale models) appears to be important. For this specific Phoenix case we believe that setting the geostrophic wind in the LES model to change with that from the mesoscale model is more than sufficient to capture the large-scale forcings. The diurnal cycle of the geostrophic wind in the mesoscale model is a consequence of the diurnal cycles of large-scale circulations that are resolved in the model; and, since the regional topography is rather smooth, we do not believe that there are important forcings not included with this approach.

For the Phoenix Region A/D case the diurnal cycles are stronger than for other locations that were under consideration by Phoenix, a consequence of this location being affected by large-scale slope flows and thermally driven cyclonic circulations related to Alba Patera. A comparison with other possible landing locations (not included) shows that the amplitude of the geostrophic wind cycle is significantly weaker at the other possible landing sites. Thus, it became the opinion of this modeling team that some means to include these forcings was needed for this specific Phoenix landing region.

With the geostrophic wind forcing in the LES model, the horizontal mean TKE from the second convective period is shown in Fig. 4. The most important differences in comparison to a constant background wind case are: 1) a 20% increase in the maximum amplitude of the TKE, 2) a mixed layer that grows deeper by ~1 km and 3) the appearance of weak shear turbulence at the interface between the mixed layer and the free atmosphere above. Comparison with other LES cases will be provided at the conference.

Figure 4. Turbulent Kinetic Energy from the OSU Mars LES model.

Conclusions: At present there is growth in the use of LES models to improve our confidence in predicting the range of environmental variability that a spacecraft
might encounter during EDL. The greatest strength of an LES model is that it simulates the actual dynamics of atmospheric turbulence; its greatest weakness is that (to do this) cyclic boundary conditions must be imposed so that turbulence is “spun-up” throughout the model domain. An idealized simulation such as this is more of a problem in the Martian atmosphere for two primary reasons: 1) the PBL on Mars is far deeper (~5x) and 2) most locations of interest on Mars are under the influence of large-scale circulations that likely impose significant modification on the vertical profiles of wind and temperature in an unforced PBL environment. If the influence of large-scale circulations can be included in an LES model, then the range over which such simulations have validity is expanded dramatically. This added value may be most realized within the atmospheric community as we endeavor (without observational data from within the PBL) to improve the PBL schemes used in our general circulation and mesoscale models of Mars.

For this specific Phoenix case, Region A/D appears to experience significantly stronger diurnal cycles of wind than at the previously examined locations. This fact makes the assumption of a constant (with height and time) background wind far less valid and begged for improvements in our LES modeling. Our first attempts at solving this issue were to nudge the LES winds to those of the mesoscale model; there were two problems with this method: 1) the mismatch between the predicted depths of the convective mixed layer in the two models caused dynamic inconsistencies and 2) the fact that actual turbulent structure was being artificially modified via nudging of the winds.

Since our LES model was developed from a model that includes control over the geostrophic wind [5], it was logical to extract the geostrophic winds from the OSU Mars MM5 Phoenix results and use these data to vary the geostrophic wind components in height and time in the OSU Mars LES model. The results are certainly encouraging, although they are still quite preliminary. We look forward to conference discussions concerning various options and methods that might provide for the direct inclusion of slope-flows and the large-scale subsidence and/or lifting that we believe (via recent mesoscale model studies) plays a very important role in the depth of the PBL at many locations on Mars.

A thorough understanding of turbulent exchanges in the Martian PBL will require actual observation and measurement of the turbulent quantities, which will require a tower and sensitive instrumentation. It seems that a 10 m tower could be engineered to telescope upwards reliably from a landed spacecraft to provide these important observations. Modeling does seem to suggest that the surface layer is much deeper than ~10 m; however, observational data within the lowest ~10 m would be of great value towards understanding the surface layer and the highly super-adiabatic layer that models are suggesting is there. In agreement with many others in the Mars atmospheric community we strongly encourage the consideration and design of such a landed mission; an improved understanding of the surface layer, the mixed layer and the PBL is quite critical to so much of what is presently important in efforts to better understand the climate of Mars.

References: