The Depth of the Daytime Convective Boundary Layer on Mars: A Case of Extremes. J.R. Barnes[1], D. Tyler[1], and D.P. Hinson[2], [1]104 COAS Admin. Bldg., College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97331 (barnes@oce.orst.edu, dtyler@oce.orst.edu), [2]Carl Sagan Center, SETI Institute, Mountain View, CA 94043 (dhinson@seti.org).

Introduction: It has long been realized that the daytime convective boundary layer on Mars is generally much deeper than that on Earth [1]. This is fundamentally the consequence of the low density of the Martian atmosphere, coupled with the fact that the solar thermal forcing of the surface is not that much weaker than on the Earth. Simple consideration of these factors leads to a basic recognition that the depth of the convective boundary layer on Mars will tend to be deeper – other factors being similar – in regions of high topography. The Mars topography is enormous in size, and thus very large variations in the convective boundary layer depths can be expected on this basis alone. Mars also is characterized by large variations in the thermal properties of its surface, the albedo and the thermal inertia. These produce very substantial variations in the thermal forcing (via both infrared radiation and surface sensible heat fluxes) of the daytime boundary layer.

There has been a great lack of direct observations of the depth of the daytime convective boundary layer on Mars. Observations of dust devils (as well as some of convective clouds) can provide estimates of minimum boundary layer depths, where heights of the dust devils can be determined from shadows in the imagery [2,3]. In the case of dust devils it is important to note that regions with plentiful and more easily lifted dust may tend to exhibit the most extensive activity, regardless of boundary layer depth. The Mini-TES instruments on the Spirit and Opportunity rovers have allowed the first sampling at relatively high spatial and temporal resolutions of the lower portion of the boundary layer [4]. However, these temperature profiles only extend to about 2 km above the surface, well below the typical top of the convective boundary layer. Recently, a set of temperature profiles (~ 50) obtained from radio occultation experiments conducted by Mars Express have been analyzed [5]. These profiles lie within the ~ 15 S – 50 N region, and were obtained at local times close to 1700; the season was northern mid-spring (L_s ~ 35-70). Most of these temperature profiles are characterized by a lower region of relatively constant potential temperature overlain by a region in which potential temperature increases rapidly with height, consistent with a well-defined convective boundary layer. The determined depths of the boundary layers in the profiles range between ~ 3-10 km, with the larger values tending to occur over higher topography. There is also some correlation of the depths with surface temperature as observed by the MGS TES.

Unfortunately, except for a small number of profiles obtained in the pre-mapping phases of the MGS mission, the MGS radio occultation temperature profiles are all at local times of ~ 0300-0600, making them unsuitable for investigations of the daytime boundary layer depths. The Phoenix lidar experiment is now making observations that should be able to directly determine the depth of the daytime boundary layer at the high northern latitude landing site in summer.

Mesoscale as well as LES modeling of the Martian atmosphere has certainly shown that very large variations in the depth of the convective boundary layer are generally present. Extensive mesoscale modeling carried out in connection with the MSL EDL engineering efforts has shown this result even more explicitly than previous modeling, as it has been employed to produce global maps of the maximum convective boundary layer depth – this being a specific concern of the EDL design. The focus of this paper is on the results of modeling of this type, in order to examine the daytime convective boundary layer depth and its seasonal variations and compare it with available observational data.

Results: Figure 1 shows a global map of the maximum convective boundary layer depth as obtained from analyses of the data from two simulations performed with the OSU Mars Mesoscale Model. This model uses the MRF PBL scheme adapted from the terrestrial MM5. Comparisons of convective boundary layer profiles and depths with results from the OSU LES Model are typically quite good – under conditions of relatively weak forcing from regional and sub-regional scale circulations [6]. The simulations are 20 sols in length (after a spin-up period), and the central seasonal date of them is L_s = 120, early northern summer/southern winter. The maximum boundary layer depth was determined using data from the 1300-1700 local time period, using the actual vertical profiles of potential temperature from the model (the values shown are the means of the depths for all 20 sols). In this case, data from the semi-global model mother domain was used, in which the grid spacing was ~ 135 km; the data were first interpolated onto a one degree grid. One of the simulations employs a northern hemisphere polar stereographic projection extending well into the southern hemisphere, while the second has an oppositely-oriented mother domain. In the lower latitude region of ~ 30 S to ~ 30 N where the two domains overlap, the results from each simulation have been blended/interpolated. The simulations with the OSU Mars Mesoscale Model have a "static" dust loading, which varies in latitude in basic accordance with the MGS TES observations.

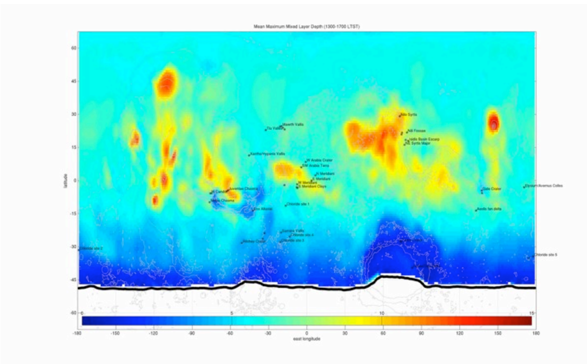

Figure 1: Semi-global (~ 65 S – 65 N) map of the mean maximum depth of the convective boundary layer, as determined using two simulations with the OSU Mars Mesoscale Model for L_s ~ 120. The color scale saturates (red) at 15 km depth; the heavy black line marks the edge of the seasonal polar cap.

It can be seen in Figure 1 that variations in the convective boundary layer depth (as defined as the layer of nearly constant potential temperature) are extremely large: ranging from very small values of ~ 1-2 km - there is no convective boundary layer over the winter seasonal polar cap - up to maximum values of more than 15 km. For this early northern summer season, the larger depths (greater than ~ 7-10 km) are only found north of ~ 15 S and are strongly correlated with topography. Extremely large depths (> 10 km) are associated with all of the Tharsis volcanoes as well as with Elysium Mons. The boundary layer depths over Alba Patera are much larger than those elsewhere at ~ 35-50 N. The boundary layer over much of eastern Arabia tends to be quite deep. Conversely, most of Isidis is a region of anomalously shallow boundary layer depths, as is the Valles Marineris canyon region. The region just to the north and east of Meridiani is one of relatively small boundary depth, despite not being anomalously low. There are also a number of regions where the correlation between boundary layer depth and topography does not hold (certainly not strongly). Examples of these include a region (near the center of Figure 1) just north and west of Meridiani as well as the Meridiani region itself, a region directly south of Elysium Mons extending to the equator, and a region centered just to the north of Valles Marineris (roughly coinciding with Lunae Planum). The Nili Fossae region is not a particularly high one (though it is at the edge of very elevated terrain), but it is a region where the boundary layer depths are quite large. In these cases, it appears that the effects of surface albedo and thermal inertia may be more important than those of topography (Nili Fossae is in the very low-albedo Syrtis Major region) – and that effects of regional circulations could also be extremely important.

The MEX radio occultation data for L_s ~ 35-70 demonstrate a strong correlation between the depth of the convective boundary layer and the height of the topography [6]. At this season the depths range from ~ 3-10 km in the ~ 15 S to 50 N region covered by the observations, as illustrated in Figure 2. There are two profiles in the not-so-elevated Nili Fossae region and they evidence very deep (~ 10 km) boundary layers. There is a profile in the region just to the northeast of Meridiani and it exhibits a relatively shallow boundary layer (~ 3.8 km). It can be noted that the boundary layer depths in the Amazonis region are relatively shallow – this can be seen to also be the case in the model results shown in Figure 1. Again, it should be noted that the MEX occultations are all at ~ 1700 local time, and they are for the northern spring season.

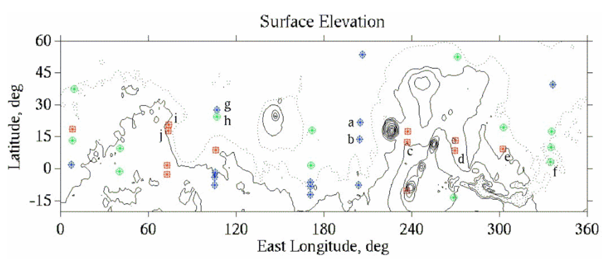

Figure 2: Locations of MEX radio occultation profiles for L_s ~ 35-70. Red indicates a boundary layer depth greater than 7.8 km, green a depth of between 5.3 and 7.8 km, and blue a depth of less than 5.3 km. Note that the longitude values are east longitude. Topography contours are shown in black and grey.

The mesoscale model simulations that we have performed show that very dramatic variations in the depth of the convective boundary layer can be present over quite small horizontal scales, in association with small-scale variations in topography and surface properties. An example of this can be seen in Figure 3, which shows the boundary layer depth distribution in the highest resolution nest (~ 4 km grid spacing, ~ 400 km on a side in extent) from a simulation of the MSL Gale candidate landing site. The depths within this fairly small region – one with very large topographic variation - range from ~ 1-2 km up to ~ 8 km. In the much lower-resolution, semi-global map in Figure 1, Gale is characterized by small boundary layer depths, with strong increases in the depth towards the south (the upper right in Figure 3). Gale crater lies on the south-eastern edge of a region of high albdo values; it also sits very near the north-south topographic dichotomy boundary.

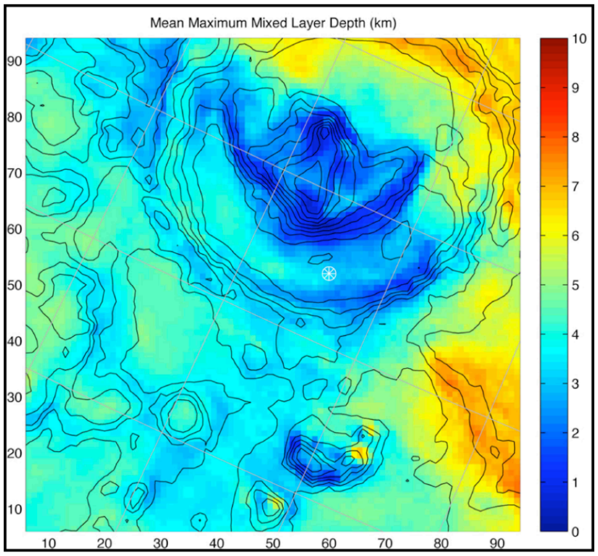

Figure 3: Boundary layer depths in the vicinity of the Gale crater MSL candidate landing site. The model gridpoint number is on each axis, and the gridpoint spacing is ~ 4 km. North is actually towards the lower left corner of the figure.

The only MGS RS profiles that are at suitable local times (~ 1800-1830) for investigation of the depth of the convective boundary layer were obtained at L_s ~ 300-310 – in the early southern summer season. Because of the proximity of this season to perihelion, it might be anticipated that boundary layer depths could be even deeper than in early northern summer. The subsolar latitude at this season is also located in the significantly higher elevation (and lower albedo) southern hemisphere. Figure 4 shows two of these MGS RS profiles, and it can be seen that both evidence very deep boundary layers (~ 14-16 km). Both locations are characterized by quite low albedo values, with the first one being fairly elevated but the second one less so. These locations are ones that do not exhibit deep boundary layers in the mesoscale model results for L_s ~ 120. Unfortunately there are less than 10 profiles having this combination of local time and season (from the pre-mapping mission). However, it seems very clear that there are large changes in the boundary layer depths and distributions between northern and southern summers – as would be expected.

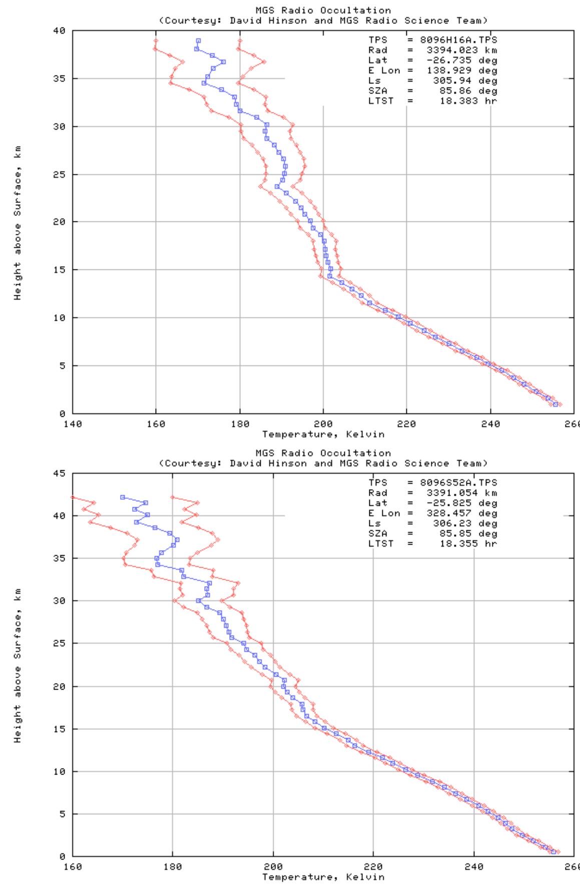

Figure 4: Two MGS RS temperature profiles: the top one is centered at ~ 27 S, 139 E, while the lower one is at ~ 26 S and ~ 328 E. Both were obtained at local times of ~ 1820, at L_s ~ 306.

Discussion: We are presently employing the OSU Mars Mesoscale Model to carry out simulations for both early southern summer (L_s ~ 300) and northern springtime (L_s ~ 60), to examine the seasonal variation in boundary layer depths. We are also planning to utilize the OSU Mars LES Model to perform some simulations of the convective boundary layer so as to better assess the extent to which the stronger solar forcing combined with topographic elevation and albedo and thermal inertia can explain the extremely deep boundary layers present in several of the MGS RS early southern summer profiles. One important issue that both the mesoscale and LES results can be used to address is the relationship between the boundary layer depths at local times of ~ 1700-1800 and the maximum depths. This will aid in the interpretation of the MEX and MGS radio occultation results.

More broadly, one can use mesoscale modeling to investigate the relationship between the dramatic variations in the depth of the daytime convective boundary layer on Mars and regional and sub-regional circulations. The boundary layer depth variations are associated with horizontal (on constant pressure surfaces) temperature differences and with horizontal gradients in the basic thermal driving of the atmosphere. These must be associated with circulations, ranging from large-scale on down to the convective scale. The other side of this problem is that the boundary layer convection can be strongly influenced by regional and sub-regional circulations – being strengthened and deepened in some areas and suppressed in others. As in the terrestrial atmosphere, there is a two-way coupling between convection and larger scale circulations. In the case of the two climatically critical constituents, dust and water, regional variations in the boundary layer depth should act to produce strong regional variations in the dust and water mixing ratios at constant pressures.

References:

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