ATMOSPHERIC CHARACTERISTICS EXPECTED AT THE PHOENIX LANDING SEASON AND LOCATION.

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Introduction or How the last decade of Mars research has influenced the Phoenix mission: In the last 10 years, two critical events took place that led to the Phoenix mission, scheduled for launch in August 2007. One was the discovery of near surface ice by the Mars Odyssey spacecraft in the polar regions [1], and the second was the creation of the first ever NASA competed Mars 'Scout' program. The Scout program provided the opportunity for the Phoenix mission to quickly respond to the Odyssey discovery. As a result, the Phoenix mission was conceived to land in the northern high latitudes on Mars and to study the surface and subsurface soils and ices. The two primary goals of the Phoenix mission are (1) to understand the current state and history of water at the landing site and (2) to understand its habitability potential. The goal of understanding the current state and history of water at the landing site involves measurements of the current weather and climate by the Phoenix mission, which must then be put into the historical context.

The relationship of past and present research on weather and climate to the Phoenix mission. The last decade of Mars research has greatly advanced our understanding of the climate and weather characteristics of the north-polar region, particularly in the sunlit spring and summer. For example, data from Mars Global Surveyor provides more than 3 Mars years of continuous water vapor [2,3], atmospheric and surface temperatures [2], and water-ice and dust optical depth [2,4] observations to compare with ~1.5 years of data from the Viking Orbiters [e.g., 5,6].

These data sets allow comparison of atmospheric quantities separated by 10+ Mars years (>20 Earth years), giving a more robust understanding of the current epoch's climate. We now have an understanding of the general behavior of the water vapor that comes off the north polar cap in the spring and summer and pervades the northern polar atmosphere, down to the Phoenix latitudes. We can approximately predict the seasonal date of the water vapor maximum and the column abundance variability as a function of location and season [3]. In addition, we have a multi-Mars-year record of the dust and water-ice cloud optical depths and the surface and atmospheric temperatures, allowing an estimate of their amounts and variability as a function of season and location [4]. We even have new examinations of older (Viking) data sets that allow us to understand the water-ice and dust optical depth changes as a function of time of day [5, 6].

All of this research has been very important as it provides the context for the Phoenix mission, which will take similar measurements. These measurements include the following climate and weather related parameters: dust and water-ice optical depths at a variety of times of day, continuous pressure and near-surface atmospheric temperature, occasional near-surface wind magnitude, column water vapor abundance at various times of day and throughout the mission, atmospheric composition, including D/H ratios, boundary layer backscatter from dust and water-ice aerosols at a variety of times of day, local humidity, surface temperature and near-surface ice content. Further, the historical context allows the Phoenix science team to more appropriately plan and design observations and campaigns to be taken during the mission.

In addition to the data analysis over the last decade of Mars research, there has been a lot of work on and improvements in modeling the Martian atmosphere. Global circulation models continue to improve and to include more aspects of the Martian atmosphere [e.g., 7], several mesoscale models have been developed for Mars [e.g., 8,9] including one focusing on the north polar region [10], and even Large Eddy Simulation (LES) models are now being run for Mars [e.g., 11,12]. These models have enhanced our understanding of the Martian system and have also been used extensively to ensure the landing safety of our spacecraft, for example for the 2003 Mars Exploration Rovers [13,14] and currently for Phoenix [e.g., 11,12]. A spacecraft must be designed to autonomously fly through the atmosphere and land safely on the surface. As such, it must be able to withstand the winds and wind shears predicted for the landing location and season. As there are few measurements of these quantities on Mars, the spacecraft engineering team relies on modeled predictions of these atmospheric quantities. The density and density variability expected in the atmosphere must also be estimated and the spacecraft must be designed to fly safely through it. Densities are estimated based on data and model output.

Phoenix spacecraft health and safety and operational capabilities during the surface mission also depend on an understanding of characteristics of the local environment. Diurnal surface and near-surface atmospheric temperatures and near-surface winds are needed for thermal design and control of the spacecraft. These thermal model inputs are often provided by atmospheric modeling that makes use of typical surface characteristics such as albedo and thermal inertia of the potential landing site. Dust and water-ice optical depth minimum, maximum and variability are needed to design the solar panel and battery capabilities and to estimate the amount of power and energy are needed to operate the spacecraft and collect science observations throughout the mission. Dust storm statistics are needed to design the spacecraft power system to withstand a certain level of storm length and optical depth, to ensure that the mission will last its mission lifetime. Most of these quantities are obtained through analysis of the current data sets for a given location and season on the surface of Mars.

Because there are both engineering and science needs for modeling and data analysis of the atmospheric characteristics of Phoenix mission's landing location and season, a lot of work has gone into understanding them over the last several years. Below, we describe some of the atmospheric characteristics expected during the Phoenix mission, which will be discussed more fully at the conference. In addition, papers are currently being written to describe this work in detail.

Atmospheric characteristics expected during the surface mission: The surface characteristics of most importance in design and operations of the spacecraft are surface pressure, visible optical depth (dust and water-ice), near-surface winds, and near-surface atmospheric temperatures. These are, of course, of also interest scientifically and therefore for the Phoenix operations. Additionally, we have measurements of the column water abundance, which is very interesting scientifically, but is not needed for spacecraft design.

The surface pressure range for the high northern latitude Phoenix landing zone (65-72 N) is estimated to be between 700-1100 Pa. While Phoenix has recently (March 2007) downselected to a 150x40 km box centered on 68.35N, 233.0E, analysis was needed for the entire longitudinal annulus, to allow for a variety of landing sites to be considered. The pressure range provided is scaled from VL1 and VL2 data via the Ames Mars Global Circulation model to the Phoenix landed elevation range and includes a 10% margin for dynamical effects and additional uncertainty. The surface pressures are highly correlated with topographic height. Within the Phoenix landing latitude band, the highest elevation is -3500 m with respect to the MOLA datum and the lowest elevation is -5419 m.

The visible optical depths are also important for designing and understanding the power system on Phoenix. Three Mars years of MGS Thermal Emission Spectrometer (TES) data were examined over the entire Phoenix landing latitude band for the entire landed mission duration of 90 sols. Since these quantities are absorption only infrared optical depths, we converted them to full extinction, visible optical depths and then combined them for a total atmospheric optical depth (see Figure 1). Details of this process can be found in [4].

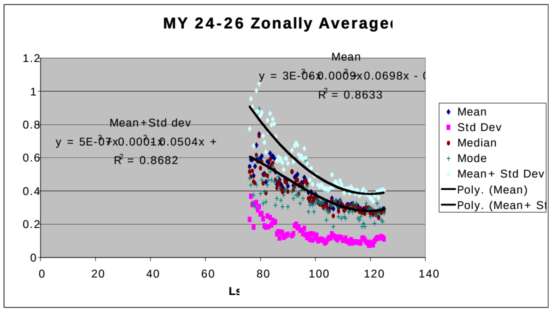

Figure 1. Visible opacity means and standard deviations for 3 Mars Years of TES dust and water-ice opacity data averaged over Latitudes=65-72° N and by 0.5 L_s (approximately 1 sol). Using Excel, a 3rd order polynomial was fit to the mean values and to the mean+standard deviation values.

Winds during the surface mission are important in terms of their thermal effect on the spacecraft. Interestingly, the engineering team desires some wind during the peak daytime temperatures, to ensure the spacecraft will stay cool. On the other hand, at night, they desire low winds so that the spacecraft will not get too cold and require too much energy for heater operation. Additionally, gusts could perhaps clean off solar panels, as happened during the MER mission, raising the total power generation back to earlier mission levels. The design requirements that Phoenix has are that the lander thermal analysis shall assume that averaged, continuous winds speeds (over all times of day and for multiple continuous sols) will vary between 0.5-15 m/s, except for a gust (defined as a period ≤4 hours) that will not be higher than 20 m/s. These averaged wind speeds are consistent with Viking lander 2 averaged wind speeds. We arrived at these estimates through examination of near surface mesoscale model output at 1.7 and 15 m altitudes [e.g., 9, 10].

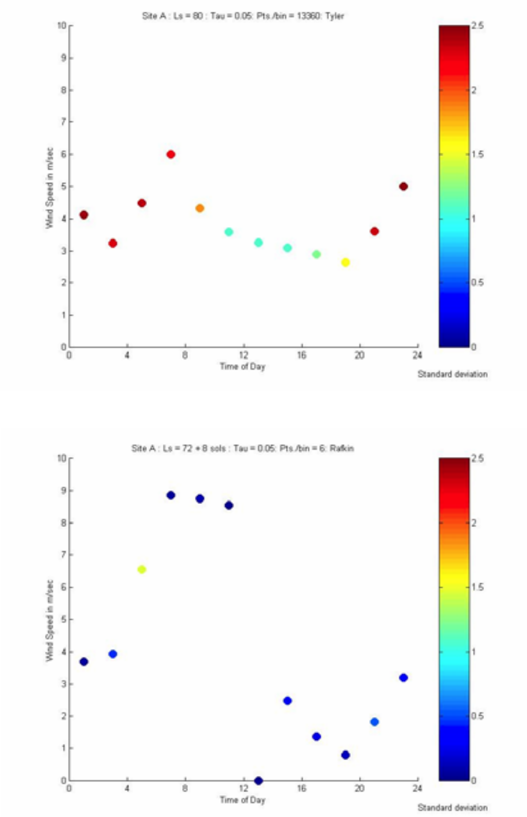

Figure 2. (Top) Mesoscale model output from D. Tyler for Ls=80, Visible Dust opacity=0.05. Region A (90-110 W) is adjacent to the current landing site. The placement of the dot is the mean winds for the region for the 2 hours centered on that point and the color bar gives the standard deviation. Each point plotted is an average of 13360 points. These points are from 1.7 m altitude. (Bottom) The same for the mesoscale model output from S. Rafkin for Ls=75.77 (Ls=72+8sols), Visible Dust opacity=0.05 for Region A. In this case, each point plotted is an average of 6 points and the points are from ~15 m altitude.

The polar circulation was found to be strongly influenced by the extent and properties of the polar cap. Additionally, numerous modeling studies were conducted to obtain bounding end-members of atmospheric circulations driven by variations in atmosphere dust.

The surface and near-surface atmospheric temperatures are also important for spacecraft thermal design. Using expected albedo, thermal inertia, and optical depth, we used at 1-D GCM to predict bounding temperature cases (65 N for daytime and 72 N for nighttime). Given these latitudes, the relevant surface characteristics, and the duration of the Phoenix mission (L_s=76°-125°), the ground temperature range is expected to be between 185.2–271.0K. Likewise, the near-surface air temperature is expected to be between 189.1–256.7K.

Understanding water vapor behavior through time in the north-polar region, the location of the main source of water vapor on Mars today, while not needed for spacecraft design, is scientifically of interest to the Phoenix mission. Water vapor measurements lend insight to the atmospheric dynamics that control the transport of water to different parts of the planet. Phoenix will measure water vapor locally and put these measurements in the broader context, provided in this presentation.

The water vapor has been mapped in the north polar region during northern spring and summer for three Mars Years, beginning L_s=105 in MY24 [15], using TES [4]. We find that water vapor varies significantly interannually and varies spatially within a season. Water vapor first increases above 50 pr µm near L_s=75 and decreases below 50 pr µm again near L_s=130-125. Throughout the northern summer, there are many locations in which the column abundance is >50 pr µm, even approaching 200 pr µm. An example is shown in Figure 3.

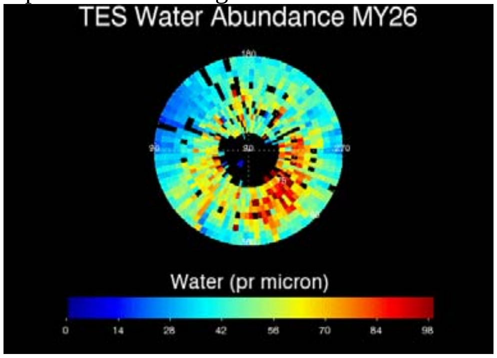

Figure 3. TES water vapor map for MY26, L_s=95-100. The color bar ranges from 0=100 pr µm. The vapor amount is averaged in boxes of 2º latitude by 4º longitude by 5º in L_s

Atmospheric characteristics expected during Entry, Descent, and Landing (EDL):

For Phoenix spacecraft landing safety, we have modeled the atmospheric density and winds following a process similar to that conducted for the MERs [16,17]. While being important for EDL, the expected conditions are also important scientifically and for context for Phoenix observation planning.

The density modeling approach essentially makes use of TES temperature profiles for the relevant location (65-72 N), the surface pressure, and surface temperature from 1-D models to calculate density profiles. Above the sensing altitude of the TES measurements, the profiles are supplemented with GCM output. For Phoenix, a few specific modifications needed to be made. In particular, the profiles provided for Phoenix needed to encompass a wider range of possible landing times of day than for MER: 12:00-17:30 local time. The TES profiles, taken near 2 pm local time, were extrapolated to this wider LT range, using MRAMS and GCM [e.g., 10] time of day tendencies. A set of 2000 profiles is constructed with the goals of encompassing variation in day-to-day surface P and T and T profile and errors and uncertainties. The engineering team uses these profiles in trajectory performance simulations. An example of one such set of 2000 density profiles is shown in Figure 4.

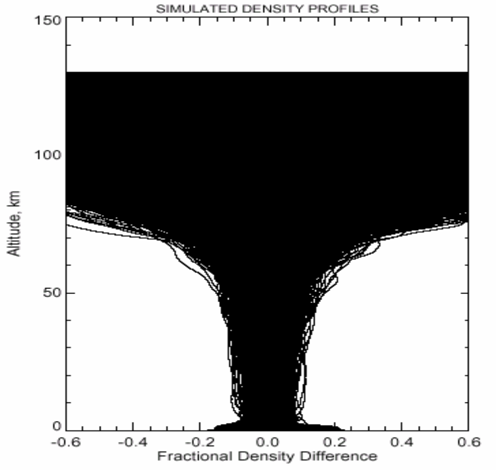

Figure 4. Simulated density profiles, relative to the mean density profile. This set is for 15:30 LT and a dust optical depth of 0.3

Winds and wind shear during EDL are an important characteristic and a nearly completely un-measured one. To provide input, we have used primarily mesoscale and LES models to estimate the winds at a variety of scales and under a variety of conditions. Like the densities, the engineering team prefers sets of 2000 profiles against which to "fly" the spacecraft. We have two approaches to providing winds. One is a combination of a mesoscale wind profile reaching up to 50 km altitude combined with an LES wind profile for the lowest ~7 km. This allows better resolution and therefore higher fidelity in the boundary layer than what is possible with the mesoscale models. The second is an attempt to capture the very highest frequency winds (shortest length scale) by using the unresolved turbulent kinetic energy from the mesoscale or LES model and creating a high frequency wind spectrum based on that energy.

Winds in the boundary layer, particularly in the vertical direction, are of concern. If the spacecraft encounters a strong downdraft for too long, it may not be able to slow itself down fast enough before impacting the surface. On the other hand, if the spacecraft encounters a strong updradt for too long, it may run out of fuel before landing, allowing it to go into freefall. It is therefore important to try to bound these wind velocities. Results from LES models to date (Figure 5) are in the range that the spacecraft can land successfully within.

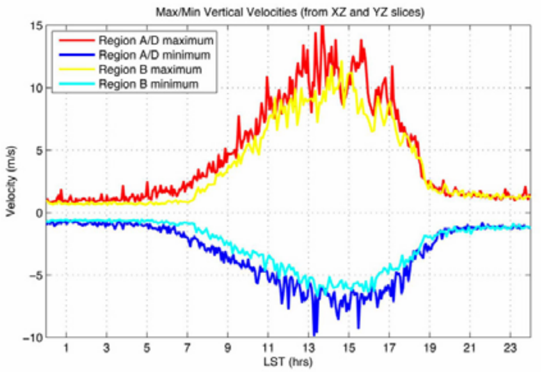

Figure 5. Example LES vertical winds. Region A/D is near where Phoenix will land and for this output, used extreme surface albedo and background winds to maximize the wind fields.

Conclusion: A summary of the atmospheric characteristics at the Phoenix landing season and location will be presented.

References: [1] I.G. Mitrofanov et al., *Science* **300**, 2003. [2] Smith, M.D., *Icarus* **167**, 2004. [3] Tamppari, L.K., *et al.*, 38th LPSC, 2007. [4] Tamppari, L.K., *et al.*, accepted by *Plan. and Sp. Sci.*, 2007. [5] Hale, A.S., *et al.*, this con-ference. [6] Martin, T.Z., *et al.*, this conference. [7] Richardson, M.I. & R.J. Wilson, *JGR* **107**, 2002. [8] Toigo, A., and M.I. Richardson, *JGR* **107**, 2002. [9] Rafkin, S.C.R., *et al.*, *Icarus* **151**, 2001. [10] Tyler, D., Ph.D. Thesis, OSU, 2004. [11] Tyler, D. *et al*, this conference. [12] Michaels, T. and S.C.R. Rafkin, *J. Royal Met. Soc.*, **130,** 2004. [13] Toigo, A., and M.I. Richardson, *JGR* **108**, 2003. [14] Rafkin, S.C.R., and T.I. Michaels, *JGR* **108**, 2003. [15] Clancy, R.T., et al. *JGR* **105**, 2000. [16] Golombek, M., *et al.*, *JGR* **108**, 2003. [17] Kass, D., *et al.*, *JGR* **108**, 2003.