IN-SITU ENVIRONMENTAL MEASUREMENTS NEEDED FOR FUTURE MARS MISSIONS.

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Introduction: Existing measurements and modeling studies indicate that the climate and general circulation of the thin, predominately CO_2 Martian atmosphere are characterized by large-amplitude variations with a wide range of spatial and temporal scales. Remote sensing observations from Earth-based telescopes and the Mariner 9, Viking, Phobos, and Mars Global Surveyor (MGS) orbiters show that the prevailing climate includes large-scale seasonal variations in surface and atmospheric temperatures (140 to 300 K), dust optical depth (0.15 to 1), and water vapor (10 to 100 precipitable microns). These observations also provided the first evidence for episodic regional and global dust storms that produce even larger perturbations in the atmospheric thermal structure and general circulation.

In-situ measurements by the Viking and Mars Pathfinder Landers reinforced these conclusions, documenting changes in the atmospheric pressure on diurnal (5%) and seasonal (>20%) time scales, as well as large diurnal variations in the near-surface temperature (40 to 70 K), wind velocity (0 to 35 m/s), and dust optical depth (0.3 to 6). These in-situ measurements also reveal phenomena with temporal and spatial scales that cannot be resolved from orbit, including rapid changes in near-surface temperatures (± 10 K in 10 seconds), large near-surface vertical temperature gradients (±15 K/meter), diurnally-varying slope winds, and dust devils (Figure 1). Modeling studies indicate that these changes are forced primarily by diurnal and seasonal variations in solar insolation, but they also include contributions from atmospheric thermal tides, baroclinic waves (fronts), Kelvin waves, slope winds, and monsoonal flows from the polar caps.

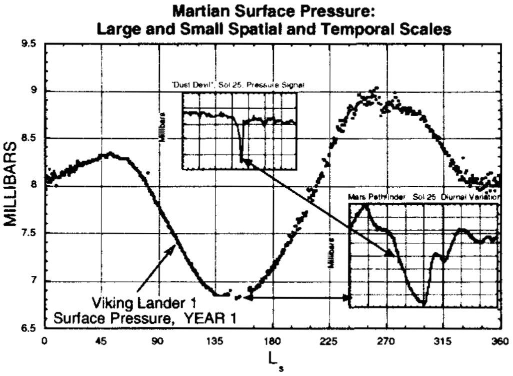

Figure 1. Seasonal, diurnal, and sub-hourly variations of pressure. The 20% seasonal cycle is driven by the sublimation of southern and northern polar caps respectively. The diurnal variation is due to day-night temperature difference. Sub-hourly variations are caused by transient events, such as dust devils.

Measurements Needed: In spite of these advances, additional measurements are needed to fully characterize the Martian atmosphere. In-situ measurements from networks of surface weather stations are needed to monitor the near-surface thermal structure because remote sensing measurements do not provide the spatial and temporal resolution needed to resolve the large gradients that characterize this environment. Other parameters, including the surface pressure, wind velocities, airborne dust and ice abundance, and electric fields cannot be reliably measured from orbit.

Long-duration measurements of atmospheric pressures are needed to monitor the seasonal pressure cycle, as well a broad range of phenomena on both large scales (dust storms, fronts, tides) and small scales (dust devils). A more complete description of the atmospheric thermal structure and dynamics is needed for studies of the processes that control the exchange of heat, mass, and momentum between the surface and the atmosphere, because these processes play an important role in the climate and general circulation.

Improved constraints on the properties of the Martian planetary boundary layer are also needed because this will be the working environment for future landers, rovers, and manned missions to Mars. For example, radiatively driven 60 to100 K temperature variations, combined with convective heat transport by winds, place severe demands on the thermal design of landers and instruments. Solar power systems are affected by both airborne and settling dust. High winds can introduce vibrations that affect sensitive instruments (e.g. seismometers, high-resolution cameras), and can place increased demands on landing systems. Atmospheric electrical phenomena may compromise surface instruments and subsystems, and may prove hazardous to Mars ascent vehicles.

An improved understanding of the thermal structure and dynamics of the middle and upper atmosphere of Mars is essential for making reliable predictions for the aerobraking and aerocapture of future Mars spacecraft. In-situ measurements of the atmospheric structure are of particular value at altitudes between 50 and 150 km because remote sensing instruments provide little reliable information there. To improve our understanding of the middle and upper atmosphere, vertical density profiles are needed for a wide altitude range at numerous locations, local solar times, and seasons. These observations should have high vertical and horizontal spatial resolution to characterize and separate the mean structure and the atmospheric waves, which can affect the heat and momentum budget of the middle and upper atmosphere.

Mission Scenarios: Instruments for in-situ atmospheric structure and surface meteorology investigations are typically small, low mass (< 1kg), low cost (<$2M), and low power (<2Watts), facilitating their implementation on both large and small landers (Figure 2). An atmospheric structure investigations (ASI) requires sensitive, (μg) 3-axis accelerometers to derive atmospheric densities from the probe deceleration during entry. These measurements can be combined with descent pressure and temperature measurements and additional accelerometer or gyro measurements to yield constraints on near-surface winds. A typical ASI experiment would provide a vertical resolution of ~60m, and generate 1-2 mbits of data.

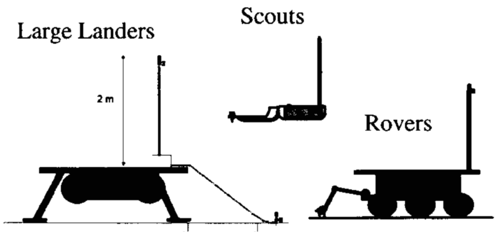

Figure 2. Candidate platforms for surface Meteorology measurements

The surface meteorology (Met) package should include instruments for making time-resolved, in-situ measurements of the atmospheric pressures, temperatures, wind velocities, humidities, and airborne dust amounts and soil temperatures at the landing site. Winds and temperatures have large spatial variations near the Martian surface. To characterize these variations and minimize the thermal contamination and dynamical obstruction by the Lander, these quantities should be monitored by sensors deployed at the surface and at several heights above the deck. Because the ambient atmospheric pressures vary more slowly, and are not subject to thermal and dynamical interference by the Lander body, the Met pressure sensors can be installed on the deck or in the warm electronics box, and exposed to the ambient atmosphere through a port. All of these instruments have flight heritage or robust backup options that reduce their risk.

Accurate pressure measurements (0.02 mbar) can be obtained with small, low-power (<50 mW), low-mass (10 to 100 g) micro-machined aneroid barometers. Pressure samples collected once every half hour throughout the day are adequate to resolve the diurnal and seasonal pressure cycles, and the passage of weather fronts, but sampling rates as high as 1 Hz are needed to detect dust devils. Soil and atmospheric temperatures can be measured by low-mass (<5g) thermocouple arrays placed at several heights between a few centimeters to a few meters on a short deployable Met mast. Winds can be measured by directional thermal anemometers or other technologies (sonic or laser Doppler anemometers) deployed near the surface and at the top of the Met mast (Figure 3). Wind and temperature sampling rates between 0.3 and 1Hz are needed to resolve the rapid temperature fluctuations superimposed on the large vertical gradients to provide constraints on the convective transport of heat and momentum between the surface and atmosphere. Dust amounts can be derived from images of the sun and scattered light measurements. Humidity can be measured by quartz microbalances or tunable diode lasers.

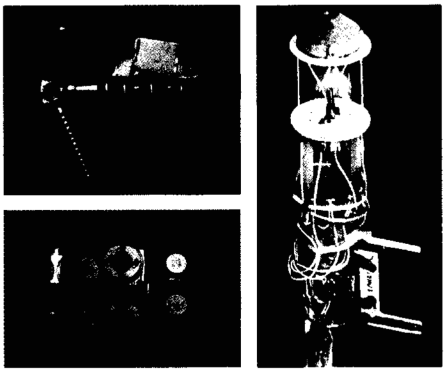

Figure 3. MPL MVACS Surface Met Instruments including the surface temperature probe (top left), the pressure instrument (bottom left) and the wind and temperature sensors on the met mast (right).

Conclusions: The need for improved constraints on the Martian environment, combined with the relatively low cost and resource requirements of the instruments suggest that ASI and surface Met instruments be included on all future Mars missions. Even though we can learn a great deal from individual stations, networks of long-lived weather stations should be a high priority for the Mars Exploration program.