The Value of Landed Meteorological Investigations on Mars: The Next Advance for Climate Science

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Presented to the Mars Community
29-30 July 2009 MEPAG Meeting
Providence, Rhode Island

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Philosophy

- A complementary paper consistent with the broader Mars science (Johnson 2009) and Mars climate science goals (Mischna 2009).
- Findings and recommendations must be science-driven and traceable to MEPAG goals document.
- Science investigations and missions must be realistic within the next decade.
- Encourage community input -> send comments to rafkin@boulder.swri.edu.

MEPAG Climate Objective

The prioritization of Mars climate science investigations is taken as is from the community Goals Document

A. Objective: Characterize Mars' Atmosphere, Present Climate, and Climate Processes Under Current Orbital Configuration (investigations in priority order)

Investigations:

1. Determine the processes controlling the present distributions of water, carbon dioxide, and dust by determining the short- and long-term trends (daily, seasonal and solar cycle) in the present climate [for upper and lower atmosphere].
2. Determine the production/loss, reaction rates, and global 3-dimensional distributions of key photochemical species (e.g., O_3, H_2O, CO, OH, CH_4, SO_2), the electric field and key electrochemical species (e.g., H_2O_2), and the interaction of these chemical species with surface materials.
3. Understand how volatiles and dust exchange between surface and atmospheric reservoirs, including the mass and energy balance. Determine how this exchange has affected the present distribution of surface and subsurface ice as well as the Polar Layered Deposits (PLD).

The Importance of Surface Science

- Surface stations can provide continuous, high frequency measurements not possible from orbit (*e.g.,* fluxes) at a fixed location.
- Orbital retrievals are valuable and necessary, but are not a substitute for *in situ* surface measurements, especially in the lowest scale height.
- Surface measurements can provide validation and boundary conditions for orbital retrievals and models.
- Surface and orbital measurements are required to capture the full range of spatial and temporal scales important for climate.
- Surface measurements are needed to reduce risk (and cost) of future missions.

Surface Measurements Have not Been Given Adequate Attention in Proportion to Their Importance.

Mission	Architecture	Atmospheric Instrumentation	Surface Measurements?	Notes	Major Atmos. Sci. Findings
Mariner 9 (1971)	orbiter	Radio Science, UV & IR Spectrometers, VIS Imager	No	First look at basic atmospheric properties and state.	Constrained atmospheric mass, identified clouds, dust storms, weather systems, polar caps.
Viking 1 & 2 (1975)	Orbiter & Lander	Orbiter: Radio Science, water vapor and thermal mapping Lander: p, T, winds	Yes	First in situ measurements at Mars surface. Longest and best surface climate record (VL1).	Initial determination of thermal structure and water distribution. Documented seasonal CO_2 cycle.
Mars Global Surveyor (1996)	Orbiter	Radio Science, IR spectrometer, VIS imager	No	Temperature profiles from ~10-40 km.	Monitoring of dust and water cycle; impacts of dust on thermal structure; identification of wave structures.
Pathfinder (1996)	Rover	T, p, horizontal winds; atmospheric density on descent	Yes	T at three near-surface levels; wind calibration problems and short history.	Large amplitude, high frequency T fluctuations; large diurnal T lapse rate variation.
Odyssey (2001)	Orbiter	None	No	Limited atmos. sci. return	N/A
Exploration Rovers (2003)	Rover	Mini-Thermal Emission Spectrometer	No	Crude thermal profiles of lowest few km.	Confirmed large vertical thermal variation measured by Pathfinder
ESA Mars Express (2003)	Orbiter	Fourier Spectrometer, VIS Imager, Radio Science	No	Carried Failed Beagle Lander; Limb profiling of T and dust.	Added to climate monitoring of thermal and dust distributions
Reconnais-sance (2005)	Orbiter	Infrared Spectrometer (Mars Climate Sounder)	No	~2x vertical resolution of MGS. T, water, dust vertical profiles	TBD
Phoenix (2009)	Lander	T, p, water, dust, wind, lidar	Yes	Very infrequent measurements; crude wind from wind sock; calibration problems with p.	TBD
Mars Science Laboratory (2011)	Rover	T, p, water, wind	Yes	Investigation not competed. Major technical issues.	TBD

Achieving the Climate Objective

- Regardless of the mission architecture, the dynamic range of the climate system mandates that the full achievement of the highest priority MEPAG Climate Investigations will require long-term, global measurements.
- Some of the key measurements can only be made at the surface while others can only be made from orbit.
- The only way to address the highest priority investigation *with a single mission* is to establish a long-lived global network capable of measuring a variety of fundamental parameters (*e.g.,* T, p, relative humidity, winds, dust) and fluxes of these quantities with the global monitoring support of one or more orbital assets.

A lofty goal that it is not realistic within the coming decade.

There is an alternative multi-mission strategy that is realistic over the next decade.

A Realistic Implementation Strategy

The Boundary Conditions:

- A meteorological network requires 16+ stations (Haberle and Catling 1996).
- Reality provides a trade space of station number versus payload complexity.
  - A few highly capable stations vs. many very simple stations.
  - A few stations is not sufficient for meteorology network science.
  - A simple station cannot provide the full array of necessary measurements.

The Solution:

- Immediate: Fly highly capable meteorological instrumentation on every future lander.
  - Obtain detailed measurements (e.g., heat, dust, water, momentum fluxes) over as many sites as possible to understand local behavior.
  - High TRL and relatively low resource instrumentation is ready to go.
- Within the decade and beyond: Plan for and execute a meteorological network.
  - Use earlier detailed measurements to leverage information from less capable network nodes.
  - Focus on technological hurdles for long-lived stations with global dispersion: EDL, power, communication.
- Combine surface information with existing long-term, global data (e.g., TES, MCS).

Suggested Prioritization of Measurements

Level 0: pressure, horiz. wind*, temperature* all at >10 Hz, dust opacity at ~1 hr^{-1}.

Level 1: dust concentration*, humidity*, vertical wind* all at >10 Hz.

Level 2: trace gases and isotopes (e.g., methane, D/H) at ~1 hr^{-1}

Level 3: E- and B-fields plus electrochemical precursors and by-products.

Level 4: Vertical profiling of above quantities (e.g., via lidar).

*Some boundary layer structure investigation require simultaneous measurements at two or more heights.

Summary

- There is high priority science that is best achieved or can only be achieved from the surface. Orbiters are alone are not sufficient.
- Full achievement of the highest priority MEPAG Climate Science Goal and Objective will require long-term, global measurements from orbit and the surface.
- A global meteorological network designed to address the global MEPAG climate objective requires ~20 nodes.
- A realistic implementation plan is to fly highly capable meteorology investigations on all future landed or in situ spacecraft and to plan for a global network with core meteorological measurements.
- Highest priority measurements can be tied to relatively low cost instruments in a state of advanced technical readiness.
- Surface measurements provide a major risk reduction and cost reduction benefit to future missions
- Credible and competed meteorological instruments must be part of every future landed package to Mars.
- Meteorology should remain as a high-priority Mars network investigation, as it was in the previous Decadal Survey.

Next Steps

- Read the draft paper, available for download from the MEPAG web site.
- Send comments to rafkin@boulder.swri.edu.
- Request to be on the meteorology surface science email distribution list.
- Schedule
  - Collect additional community input through mid-August.
  - Accumulate endorsements and support from now through submission deadline.
  - Incorporate suggestions by September 1.
  - Polish until submittal deadline.