Mars Weather and Climate: An Orbital Constellation for Atmospheric Profiling and Surface Thermophysics

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Introduction:
Over the last decade considerable progress has been made in understanding the structure of the martian atmosphere and surface-atmosphere interactions. Current efforts focus on identifying dynamical processes and radiative effects that are responsible for shaping the atmosphere of Mars. Progress in the area of weather and climate on Mars will depend on achieving two major science goals:
1. Build a Long-term Record of the Current Martian Climate to Characterize the Amazonian Epoch
2. Globally Characterize Martian Weather

Both goals require the continued monitoring of temperature, dust, water ice, and water vapor with high temporal and vertical resolution. For Goal 1 the deployment of an limb infrared radiometer with the characteristics of the Mars Climate Sounder (MCS) enhanced by the capability of measuring water vapor profiles, is suggested. This could be achieved by deploying such a regular orbiter over the Martian surface that would ensure that atmospheric and surface observations over the same areas would be performed in regular local time intervals of 3 hours.

Satellites in a CubeSat form factor could reach their desired nodes under their own propulsion within a few months if deployed from orbit (Fig. 4). If the satellites were to perform their own orbit insertion a larger format would likely be required. An ideal scenario would be the deployment of CubeSats from a large Mars orbiter in low Mars orbit. In this case the main orbiter could host a MCS-type instrument in its standard design [9,12] and also serve as a relay satellite for the CubeSats. This mission concept could be implemented during the decade of 2025-2030.

Goal 1: Build a Long-term Record of the Current Martian Climate to Characterize the Amazonian Epoch

Goal 1 addresses the question of whether there are significant changes in the martian climate on 10 to 1000 year timescales [1]. With atmospheric and surface observations by the Thermal Emission Spectrometer on Mars Global Surveyor from MY 24-26 and by the Mars Climate Sounder (MCS) on Mars Reconnaissance Orbiter (MRO) from MY 26 to the present (Fig. 1) [2] we are about to enter an era where time series of orbital measurements allow extrapolation to Amazonian time scales. Only long-term climatologies allow the characterization of interannual variabilities and systematics [3]. Global dust events have major impacts on the surface and atmosphere in some years but the hiatus in their occurrence since MY 28 emphasizes the need for long-term observations. Trends, e.g. in dust occurrences and dust fluxes, will only be uncovered by long-term and consistent measurements.

Goal 2: Globally Characterize Martian Weather

Goal 2 addresses improving understanding of short-term processes that form martian weather. One issue that limits progress in this area is the lack of coverage of observations at multiple local times. Numerous short-term atmospheric and surface processes are poorly characterized:
- The inhomogeneous vertical distribution of atmospheric dust that suggests convective activity triggered by solar heating of dust may play a crucial role in dust transport (Fig. 2) [4]. Observations performed several times over a single diurnal cycle could lead to a detailed understanding of these processes that are likely also driving the formation and growth of global dust events.
- Forcing of semi-diel gusts and higher order modes, which reveal strong radiative influences of water ice clouds and affect the general atmospheric circulation [5]. The measurements would provide simultaneous information on water vapor supply, cloud condensation, and their radiative effects over the course of a sol.
- Midday H2O and CO2 frosts that may have a significant impact on the regolith structure [6]. Surface observations at all latitudes would reveal the distribution, physical properties, and relationship with the regolith and active geomorphological landforms.
- The vertical heterogeneity of the Martian near-surface layer that could be addressed with much greater accuracy than currently possible. This could reveal the depth of permafrost, internal bedrock layering or surface dust fluxes.
- The energy balance of the Martian surface that could be evaluated with much higher accuracy. Viking orbiter observations suggest much greater diurnal variabilities than currently modeled and predicted [7], with potential implications on volatile and heat exchange between the surface and the atmosphere. Most of these science objectives cannot be addressed with current missions or future missions in development. Current missions like MRO are in sun-synchronous orbits that allow only limited local time coverage. The ExoMars Trace Gas Orbiter (TGO), currently entering it science orbit, will drift through local times only over the course of several 10s of sols, aliasing diurnal and seasonal changes. It will be unable to observe transient phenomena, such as local dust storms, more than twice per sol. Furthermore, the TGO instrumentation, as well as the instrumentation of the Hope orbiter to be launched in 2020, will only allow nadir measurements with coarse vertical resolution in temperature and no vertical information on quantities like dust, water ice or water vapor. Characterizing such processes globally at timescales of less than a sol would also provide an improved basis for assimilating data into General Circulation Models. This has proven challenging because the Mars atmosphere exhibits the globally connected features than Earth, e.g. thermal tides and remote responses to aerosol forcing [8]. Model simulations of rapidly evolving processes are not well constrained by existing observations; having simultaneous measurements at multiple local times would alleviate many of these difficulties. Simulating near-real-time atmospheric and surface data could pave the way towards forecasting martian weather in support of landing, aerocapture and surface operations of future manned and robotic missions.

References:

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Mission Concept:
The proposed goals require global profile measurements of atmospheric temperature, dust, water ice and water vapor, as well as surface temperature, at multiple local times. We suggest a constellation of 3-5 CubeSats or Smallsats in Mars orbit to perform these measurements (Fig. 4). Limb- and nadir radiometry measurements would require a low-altitude orbit of moderate to high inclination around Mars. Four satellites with a constant node spacing of 60° between orbits would ensure that atmospheric and surface observations over the same areas would be performed in regular local time intervals of 3 hours. The CubeSat itself could be used for pointing the instrument at the limb, nadir, and space. This design of the MCS telescope (Fig. 3) is very compact for the wavelength range it works in, fitting in an envelope of only 0.8 U. 0.

Instrumentation:
Measurements would be based on passive infrared radiometry in limb and nadir geometries and are best addressed with MGS, operating on MRO since 2006. Profiles of temperature, dust and water ice with 5 km vertical resolution have been retrieved from these measurements [10,11] together with atmospheric and surface observations over the same areas would be performed in regular local time intervals of 3 hours.