MARS ATMOSPHERIC PROFILING FROM AN ORBITAL CONSTELLATION – IMPROVING DATA COVERAGE FOR MARS DATA ASSIMILATION

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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 work focuses on identifying dynamical processes and radiative effects that are responsible for shaping the atmosphere of Mars.

One of the tools that promise further progress in our understanding of martian atmospheric processes is the assimilation of atmospheric data into Mars General Circulation Models. This could provide re-analyses of meteorological data similar to meteorological re-analyses on Earth, which are used for a multitude of applications and provide an accurate picture of the atmospheric state and dynamics. Assimilating near real-time data could pave the way towards forecasting martian weather in support of landing, aerocapture and surface operations of future robotic and manned missions.

Atmospheric data sets that have been available for assimilation consist of data on atmospheric state, dust and water ice opacity from orbital measurements. Assimilation efforts have been conducted using measurements by the Thermal Emission Spectrometer (TES) as well as the Mars Climate Sounder (MCS) [e.g. 1-5]. These measurements were obtained from platforms in sun-synchronous orbits such that they are typically available at only two local times per day.

Mars data assimilation has proven challenging. Due to the low atmospheric density, atmospheric variability is dominated by the diurnal variation of insolation, which leads to global thermal tides of significant magnitude [6]. The thermal effect of dust plays an important role as a driver of the atmospheric circulation. Dust is locally variable but influences the atmosphere on global scales. In addition, water ice clouds, which exert a significant radiative influence [7], are largely controlled by global temperature features rather than local transport. As a result, the Mars atmosphere exhibits more globally connected features than Earth, making data assimilation more difficult [5]. Furthermore, rapidly evolving processes (e.g. local dust storm growth) are often poorly sampled by existing observations, limiting the ability to validate model behavior. Many of these difficulties could be alleviated by simultaneous global measurements at multiple local times.

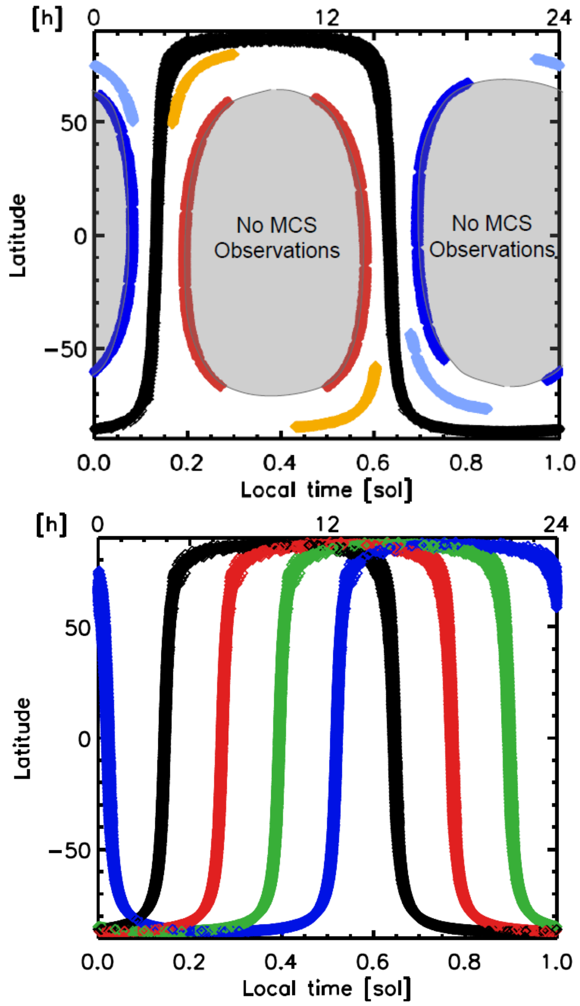

Figure 1: (Top) Positions of MCS atmospheric limb observations vs. latitude and local time. Black symbols indicate measurements along the orbit track, while red and dark blue symbols indicate measurements 90° perpendicular to the orbit track. Pale symbols indicate off-track measurements at other angles. Gray shaded areas are inaccessible to MCS measurements. (Bottom) Simulated measurement coverage that would be achieved by along-track measurements from four sun-synchronous platforms with nodal spacings of 45°, corresponding to ~3 hours in local time.

Approach: Figure 1 (top) shows the local time coverage by obtained MCS from its host platform, the Mars Reconnaissance Orbiter. Black symbols indicate standard measurements with the instrument viewing the limb in the direction of the orbit track. Through its ability of slewing in azimuth, MCS has access to local times up to ±1.5 h at low latitudes, and covers a somewhat larger local time range at high latitudes. However, large ranges in local time remain inaccessible for a measurement from sun-synchronous orbit.

Figure 1 (bottom) shows the local time coverage that would be achievable with along-track only measurements from four sun-synchronous spacecraft in low Mars orbit. A node spacing of 45° would provide pole-to-pole global coverage every 3 hours in local time. Measurements at different local times would occur simultaneously, providing much tighter constraints on atmospheric models than, e.g., measurements from a single orbiter at moderate inclination, which would drift through local times on timescales of months.

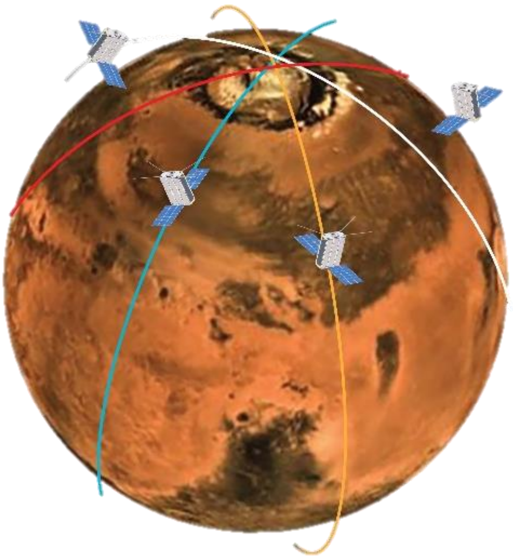

Figure 2: Graphical representation of a constellation of four CubeSats or SmallSats in low Mars polar orbits with 45° nodal spacing.

A constellation of SmallSats or CubeSats in Mars orbit could be used to perform such measurements (Figure 2). 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 45° 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 optimal number of nodes and their spacing may be determined by future Observing System Simulation Experiments.

Satellites in a CubeSat form factor could reach their desired nodes under their own propulsion within a few months if deployed from Mars orbit [8]. If the satellites were to perform their own orbit insertion a larger form factor would likely be required.

Measurements would be based on passive infrared radiometry in limb and nadir geometry as demonstrated by MCS [9] 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 atmospherically corrected surface temperatures [12]. In analogy to MCS, 8 spectral channels in the IR from 12-45 μm as well as a visible/near-IR channel would be used. MCS capabilities would be enhanced by adding a functional water vapor channel at far-infrared wavelengths. Each channel would consist of a linear array of uncooled thermopile detectors, providing instantaneous profile measurements when vertically pointed at the limb. This approach would yield measurements of atmospheric temperature, aerosols, and water vapor with dense global coverage and high vertical resolution simultaneously at multiple local times. The improved data coverage and tight constraints provided by such an approach are expected to enable improved results when applied to Mars atmospheric data assimilation.

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