Toward Predicting Martian Dust Storms and Climate

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BRIEF DESCRIPTION:

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Dust is by far the largest producer of diurnal, seasonal, and interannual variability in Mars's climate system. Large dust storms, and their impact on temperature, hence air density and wind, affect everything from aerobraking to Entry-Descent-Landing (EDL) to surface operations. Yet we remain unable to predict their occurrence or why some storms become global. The small sample size observed to date also means that we continue to be surprised, with previously unseen types of global and large regional storms found in 2001 and 2019, respectively.

The goal of this white paper is to emphasize that:

- Martian dust storms are the biggest source of Mars climate variability
- But no Mars atmospheric model can spontaneously generate dust storms at realistic times and locations, let alone predict dust storms in advance
- This also casts doubt on predictions of *past* dust cycles, climate, and atmospheric escape, which are crucial to our understanding of ancient Mars and present day geologic features
- Better understanding of and predictive capabilities for major dust storms is also vital for the success of future robotic and human missions (aerobraking, EDL, surface operations, etc.)
- Understanding dust lifting and storm growth mechanisms is crucial. Key measurements needed to improve our understanding are:
    - *Joint environmental and aeolian measurements during dust lifting at the surface;*
    - *Global and seasonal mapping of mobile surface dust/sand availability; and*
    - *Comprehensive observations of the atmospheric dust distribution and climate response during major dust storms, from orbit and from the surface*

Simulating realistic dust cycles and storms in a Mars model requires knowledge of surface dust sources, dust lifting, and relevant atmospheric processes, as well as the ability to capture the key mechanisms and feedbacks responsible for some storms growing from local to regional, and for some storms going on to become global. Due to the huge impact of dust on radiative transfer in Mars's thin atmosphere, getting the dust distribution 'right' is a necessary precursor to correctly simulating the thermal structure, circulation, and hence overall climate.

At present, however, it is common practice in Mars atmospheric models to *impose* realistic dust distributions - based on observations - in order to simulate a realistic climate. This is because we do not have sufficient knowledge of dust processes and sources to include them correctly in models. While progress has been made, to date no model can spontaneously and self-consistently simulate the realistic onset, growth, and decay of most dust storms observed on Mars - which is a critical first step toward predicting ('forecasting') a storm in advance.

This is a problem because being able to predict dust activity may be vitally important to future spacecraft and human exploration of Mars. Dust storms dramatically change atmospheric density even at very high altitudes, impacting aerobraking, and their impact on temperatures, winds, and visibility has implications for EDL also. Dust storms dramatically reduce visibility and solar power availability at the surface, potentially affecting mobility and thermal requirements of surface assets, including humans, with dust further posing a potential health risk to the latter.

The inability of models to simulate the present day dust cycle and climate also casts doubt on model predictions of *past* dust cycles - and hence, of past climate. Although the extent of the impact is unclear, particularly for past epochs that are more Earth-like, changes in dust cycle predictions would impact more than just climate. From dust storms strengthening the circulation (and hence aeolian modification of the surface), to modifying the water cycle via a range of interactions (changing both surface deposition and escape rates), getting the dust cycle wrong in past simulations could well have major geological and astrobiological significance.

In this white paper, we will argue that - in addition to further model development - certain key measurements are vital to move toward predicting Martian dust storms and climate:

<u>Dust lifting processes:</u> From the MEPAG Goals document, "Knowledge of processes that control lifting of dust from the surface into the atmosphere is insufficient." Joint *in situ* environmental and aeolian measurements are vital to connect atmospheric and surface conditions (e.g. wind stress, vortex activity, electric fields, etc.) to sand motion and dust lifting. Several light-weight, low-powered, sophisticated sensors exist that are ideally suited to making such measurements, and which could be flown on a low-cost small lander or included on a larger surface mission.

<u>Mobile dust/sand availability:</u> Knowing the surface distribution of mobile dust and sand is a vital input to dust storm models; no matter the wind strength, no lifting can occur if there is no mobile dust, nor can saltation raise the surface stress above the lifting threshold if no sand is present. In this case, new observations may be less vital than better analysis of existing datasets, which in many cases have not been sufficiently explored and can be hard to work with or access.

<u>Comprehensive monitoring during dust storms:</u> The mechanisms by which dust storms begin, grow, and decay are best revealed by a combination of observations and modeling. Outstanding questions include: How important is the interplay between microscale and large-scale processes to storm onset? How important is dust lifting versus atmospheric transport to storm growth, and how do both vary with local time? How important are dust cycle interactions with the water cycle (via ice nucleation) to dust storm decay? Orbital (global) and simultaneous ground-based measurements of dust and water ice abundance and size distribution over a range of local times, combined with model experiments, are best suited to providing answers here.

<u>STATUS OF THE EFFORT SO FAR:</u> Telecons through April and May with groups taking on writing certain sections. A complete draft will be produced by the start of June.

<u>INVOLVEMENT WE'RE SEEKING:</u> Anyone interested is still welcome to participate, especially those bringing additional perspectives (e.g. in geology, astrobiology, and/or human exploration).