# COULD THE EQUINOCTIAL DUST STORM IN MARTIAN YEAR 34 BE FORECASTED WITH DATA ASSIMILATION?

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**Introduction:** Early June 2018 (Martian Year 34, $L_S$~185°): A local storm "blasts off" in the Meridiani area, and expands to the East, becoming a large regional storm in less than a week (see Figure 1). Within two weeks, Mars sees another very intense equinoctial dust storm, which is about to be declared (at the time of writing) a new planet-encircling storm (or global dust event), after the one observed in June 2001 (MY 25, $L_S$~186°). Two equinoctial global dust events (nine Martian years apart) have now been observed by several orbiters, even by a rover on the ground (the Mars Exploration Rover "Opportunity" was caught in the middle of the MY 34 expanding storm in Meridiani), but are we any close to being able to forecast such events on Mars?

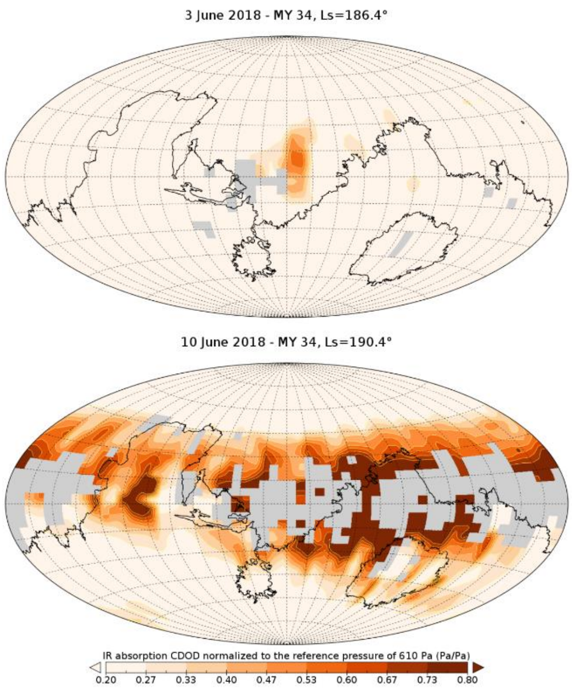


***Figure 1**: Maps of infrared (absorption at 9.3 μm) column dust optical depth (CDOD) produced with weighted gridding of Mars Reconnaissance Orbiter/Mars Climate Sounder (MCS) estimated CDODs (extinction at 21.6 μm), following the procedure detailed in [1]. Each map includes weighted averages of observations within seven sols.*

We would like to explore the possibility to use data assimilation to forecast the onset (or at least the development) of this kind of dust storms. Data assimilation techniques are used for Earth weather forecasting in order to produce initial conditions ahead of a new forecast; therefore, it is legitimate to ask ourselves whether similar techniques could help dust storm forecasting on Mars.

Why does one want to do dust storm forecasting on Mars? The answer is that robotic assets and future human explorers need to manage power supplies, plan operations, and generally keep safe. The sudden onset or arrival of a large dust storm in an area where landers/rovers/humans are located can affect all the above, as the case of "Opportunity" clearly shows.

**Why forecasting dust storms on Mars is hard:** The onset and early development of dust storms are connected to the intensity of surface winds, which can be local or, more generally, a result of the global circulation. Since the global circulation patterns have little intrinsic inter-annual variability (see e.g. [2]), the variability of dust storm occurrence is determined mostly by the inter-annual variability of the local meteorology, enhanced or reduced by a number of positive or negative feedback. Established, large-scale dust storms, however, can have a big impact on the variability itself (see, for instance, the effects of the 2001 global dust event on the surface albedo, and its consequences on daytime surface and atmospheric temperatures in [3]).

As discussed in [4], at the present state of knowledge on the Martian dust cycle, the accurate prediction of the onset of dust storms is not yet reliable. Several factors contribute to make this prediction very challenging:

- The lack of deep understanding of the mechanisms of dust lifting, including the effects of dynamical thresholds [5], electric fields, sand-dust interaction, vertical fluxes;
- The lack of knowledge on the time-variable reservoirs of surface dust available to be lifted (including the possibility of differentiating between "fresh dust" and compacted layers);
- The approximate knowledge of the dust particle sizes injected in the turbulent boundary layer and beyond;
- The approximate understanding of the radiative/dynamical feedback that make a local storm transform into a regional one, and ultimately into a global dust event, within a short time-scale (usually just a few sols).

Once dust is airborne, the transport and sedimentation processes are much better constrained than lifting and atmospheric injection, therefore we suspect it would be easier to forecast the evolution of a mature dust storm than the initiation of a new one.

However, the occurrence of dust storms on Mars is far from being random, and at least for what concerns regional storms, it clusters around certain seasons and locations (see e.g. Fig. 16 in [1] for the column dust optical depth –CDOD- or Fig. 3 in [6] for the temperature at 50 Pa). This is due to the seasonality of specific features of the Martian atmospheric circulation, such as the presence –or reduction- of baroclinic waves, and to the seasonality of the presence of surface carbon dioxide ice. These dynamical phenomena can facilitate the forecasting of dust storms, because they favor the statistical repeatability of certain types of storms. This kind of forecasting based on the knowledge of the Martian climate dynamics, and on the statistics of past observations, though, can only help to identify seasons and locations potentially affected by these types of (usually regional) dust storms in general terms. They do not help to produce a precise forecast of the onset of a specific storm, even more so of an equinoctial storm.

**The state of the atmosphere before dust storms:** If we had an operational data assimilation framework in place, we could test the skill of such framework in forecasting the equinoctial MY 34 storm. There is no such operational framework in place for Mars yet, and even if there was, we expect much work should be done to improve the accuracy of the dust cycle in current Mars Global Circulation Models (MGCMs) used for data assimilation. Nevertheless, data assimilation can at least be used to compare the state of the atmosphere at a specific time in several Martian years before the onset of a specific dust storm (e.g. the equinoctial one in MY 34). This comparison can highlight whether the atmosphere was “primed” differently in the year MY 34 at $L_S$~185° with respect to any other previous year, including MY 25.

The comparison of zonal means of CDOD between MY 25 and MY 34, for instance, seems to point towards a lesser role played by southern baroclinic waves at the very onset of the MY 34 storm (taking into account all due caveats for comparing retrieved CDODs from TES observations with estimated CDODs from MCS observations), see Figure 2.

We consider that understanding whether the atmospheric state was different at $L_S$~185° in MY 34 with respect to other years is of primary importance to test a recent hypothesis put forward to explain the global dust event variability. The orbit-spin coupling hypothesis (see [7, 8]), in fact, predicts the intensification of circulatory flows (via a specific atmospheric acceleration term) in certain years, including MY 34.

Could the MY 34 equinoctial dust storm really be expected? If so, how much time ahead of its onset or early development could it be forecasted?

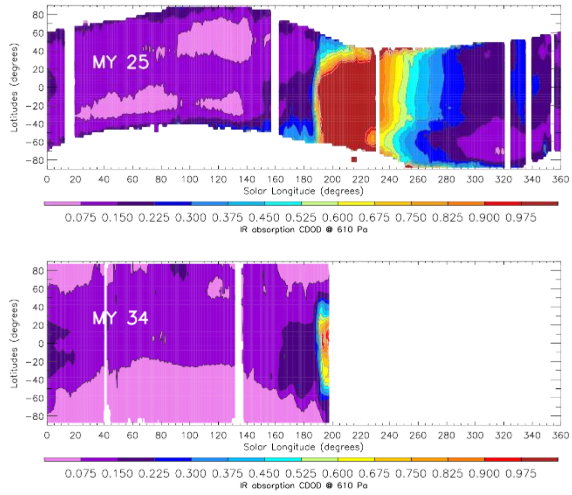


***Figure 2:*** *Zonal means of infrared (absorption at 9.3 μm) CDOD maps produced with weighted gridding of Mars Global Surveyor/Thermal Emission Spectrometer (TES) retrieved CDOD (absorption at 9.3 μm) in MY 25 and MCS estimated CDOD (extinction at 21.6 μm) in MY 34, following the procedure detailed in [1]. MY 34 observations are available until $L_S$~195° at the time of writing.*

**The need for novel observational strategies:** We seek to address these questions by using data assimilation of TES and MCS observations, which are the most extensive observational datasets currently available and publicly accessible.

We anticipate that, in order to implement (operational) dust storm forecasting in the future, there is the need for a paradigm changing in the observational strategy. No longer mapping with a single low-altitude orbiter, but monitoring with a fleet of orbiters (possibly a combination of areostationary orbiters and low-altitude polar orbiters) that can produce continuous and simultaneous observations as globally as possible. The other required paradigm changing is shifting the focus from large, comprehensive missions, to small, dedicated missions.

Both changes can be foreseen in the decadal timeframe along with the increasing attention that interplanetary CubeSats (and SmallSats in general) are receiving.

**References:**

[1] Montabone L. et al. (2015) *Icarus*, *251*, 65–95. [2] Newman C. E. et al. (2004) *QJRMS*, *130*, 2971–2989. [3] Fenton L. K. et al. (2007) *Nature*, *446*, doi:10.1038/nature05718. [4] Montabone L. and Forget F. (2018), Chapter 8 in *Dust in the Atmosphere of Mars and Its Impact on Human Exploration*, Cambridge Scholars Publishing, UK. [5] Mulholland D. et al. (2013) *Icarus*, *223*, 344-358. [6] Kass D. M. et al. (2016) *GRL*, *43*, 6111-6118. [7] Shirley J. H. (2017), *Plan. Space Sci.*, *141*, 1-16 [8] Mischna M. A. and Shirley J. H. (2017) *Plan. Space Sci.*, *141*, 45-72.