EPSC Abstracts
Vol. 13, EPSC-DPS2019-1812-3, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Martian Year 34: A Case Study for the Onset, Evolution, and Impact of Large Dust Storms on the Red Planet

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Abstract

We discuss the dust events that occurred on the Red Planet in Martian year (MY) 34, which started on May 5, 2017, and ended on March 23, 2019. We specifically focus on the equinoctial global dust event[1] (GDE) with onset at solar longitude L_S~185°.

1. Introduction

Large dust storms on Mars have dramatic impact, for instance, on the circulation of the lower atmosphere, the density of the upper atmosphere, the characteristics of the ionosphere as well as the atmospheric escape. Furthermore, they also have critical consequences for robotic missions (as the Mars Exploration Rover "Opportunity" experienced during the last GDE in summer 2018), and future human missions, see e.g. [3].

Given the importance of dust storms on Mars, there is compelling need to produce an accurate re-construction of their spatial and temporal evolution for scientific purposes, and to generate a reliable forecast of their onset for purposes linked to robotic and human exploration. This applies particularly to GDEs, which have the most dramatic impact and the least predictable variability (see e.g. [2]).

1.1 The MY 34 global dust event

The recently ended MY 34 (including an equinoctial GDE and a late-winter, intense regional dust storm) represents an extremely interesting year as a case study of the onset, evolution, and impact of large dust storms on the entire Martian atmospheric system.

The MY 34 GDE had its initial explosive growth in early northern fall (L_S~185°-190°, i.e. late May/early June 2018) near the "Opportunity" site in Meridiani Planum, before attaining the planetary scale at most latitudes. The onset and evolution of this last GDE have been closely monitored by three NASA's orbiters (including the Mars Reconnaissance Orbiter), two ESA's orbiters, ISRO's orbiter, and observed from the ground by NASA's rovers "Curiosity" and "Opportunity" (the event led to the end-of-mission of the Opportunity rover, with last communication received on June 10, 2018). Furthermore, MY 34 also features the development of a late-winter, large regional dust storm whose intensity has no equivalent in the past eleven Martian years, since global satellite monitoring resumed. The occurrence of two important dust events in the same year, however, is reminiscent of what happened in MY 12, when the Viking spacecraft successively observed two global dust events at L_S~205° and 280° (February and May, 1977), see e.g. [4].

2. Reconstructing the dust evolution

Montabone et al. [5] have developed a methodology to grid values of column dust optical depth (CDOD) retrieved from multiple polar orbiting satellite observations, such as NASA's Mars Global Surveyor, Mars Odyssey, and Mars Reconnaissance Orbiter (MRO). Using this methodology (a combination of "Iterative Weighted Binning" –IWB- and kriging spatial interpolation), they were able to produce a multi-annual dataset of CDOD daily maps extending from MY 24 to MY 33, publicly available on the Mars Climate Database (MCD) project webpage [6].

Limb observations from the Mars Climate Sounder (MCS) instrument aboard MRO have been reprocessed by the MCS team specifically during the time of the MY 34 GDE, in order to obtain better coverage in the vertical and, therefore, more reliable

[1] These events are also named planet-encircling dust storms, global dust storms, or great dust storms in the literature (e.g. [1]). Here we choose the terminology "Global Dust Event" (GDE), already used in [2].

estimates of the CDOD during this event. The quality control of these estimated values has also been refined. We have applied an improved version of the IWB methodology to grid both dayside and nightside MCS CDODs, and produce four maps per sol at four different Mars Universal Times (MUT). This improvement allows to partially reconstructing the daily variability of column dust optical depth during the MY 34 dust events [7].

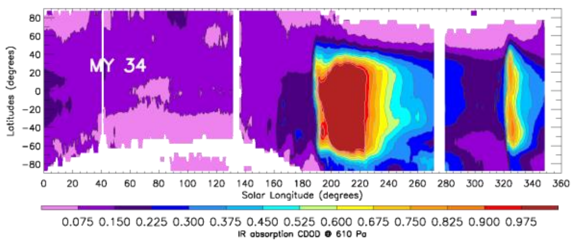

Figure 1: Zonal mean of MY 34 daily gridded maps (version 2.3) of 9.3 μm absorption column dust optical depth normalized to the reference pressure level of 610 Pa. White color indicates missing data.

Gridded maps, which are incomplete where data are missing (as in the zonal mean of Fig. 1), have been spatially interpolated using a kriging methodology. The final product can be used as dust scenario for Global Climate Model (GCM) studies of the impact of large dust storms on several components of the atmospheric system, as well as for producing specific MCD MY 34 statistics (see [8]).

3. Forecasting dust storms

Beyond the reconstruction of the dust evolution using the methodology described in the previous section, we also use a much more sophisticated methodology to produce a reanalysis of fundamental Martian atmospheric and surface variables, using data assimilation of MCS retrievals of temperature and dust opacity profiles (see [9]). This work extends the results obtained with the reanalysis of Mars Global Surveyor/Thermal Emission Spectrometer retrievals of temperature profiles and CDOD (see [10]).

The ultimate, ambitious goal is to understand in detail what dynamical mechanisms and feedback trigger the onset of large dust storms on Mars, including GDEs, in order to enable future dust storm forecasting a few sols in advance. For instance, we use data assimilation to compare the state of the atmosphere at the onset of the equinoctial GDEs in MY 25 and MY 34 (a GDE had its onset in MY 25 at approximately the same solar longitude as the MY 34 one, within ten-sol difference). This comparison can highlight whether or not the atmosphere was "primed" differently in MY 34 at L_S~185° with respect to any other previous year, including MY 25.

Acknowledgements

L. Montabone acknowledges funding received from NASA PDART and MDAP programs (grants no. NNX15AN06G and NNX13AK02G), and from the French Centre National d'Etudes Spatiales (CNES).

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