THE MARTIAN DUST CHRONICLE AND THE IMPACT ON THE ATMOSPHERIC POLAR VORTEX.

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Introduction: The dust cycle is currently considered as the key process controlling the Martian climate variability at interseasonal and interannual time scales, as well as the weather variability at much shorter time scales. The atmospheric thermal and dynamical structures, as well as the transport of aerosols and chemical species, are all strongly dependent on the dust spatio-temporal distribution, particle sizes, and optical properties. In particular, local, regional and planet-encircling dust storms strongly affect the variability on a range of spatial and temporal scales. The enhanced absorption of solar radiation during a dust storm induces a local thermal forcing. This forcing (depending on its magnitude, extension, and location) can alter the dynamical state of the atmosphere , producing effects locally and remotely.

In this paper, we describe the chronicle of the dust distribution from the Mars Global Surveyor era (Martian Year 24) to the most recent Mars Reconnaissance Orbiter era (MY 31), and we analyze the impact of large-scale dust storms on the dynamics of the polar vortices, as an example of effect at distance.

Datasets and Global Climate Model: We have used datasets based on observations of the Martian atmosphere from March 1999 to July 2013 by different orbiting instruments: the Thermal Emission Spectrometer (TES) on board Mars Global Surveyor (MGS), the Thermal Emission Imaging System (THEMIS) on board Mars Odyssey, and the Mars Climate Sounder (MCS) on board Mars Reconnaissance Orbiter (MRO).

We have reconstructed the climatology of airborne dust from MY 24 to 31 using either a gridding procedure based on iterative weighted averages of column dust optical depth retrievals ([1]), or data assimilation with an Analysis Correction scheme (AC, [2]) integrated in a Global Climate Model ('MACDA', see [3] for the description of the publicly available data assimilation dataset for MGS/TES, version 1.0) .

Data assimilation techniques have the advantage of combining state-of the-art global climate models with observations to produce a best estimate of the atmospheric state throughout a historical period ("re-analysis"). They allow access to variables which are not directly observed, such as pressure, wind components, vorticity, etc., dynamically consistent with observed variables. The application of the iterative weighted gridding technique, on the other hand, has the advantage of combining all available dust optical depth observations from several different instruments, including sparse observations like THEMIS, and providing an estimate of uncertainties which are not directly available with the AC data assimilation scheme.

The Martian Dust Chronicle: We present eight Martian years of temporal and spatial (2D) dust distribution in term of interannual and intraseasonal variability, down to the daily evolution of single dust storms [1]. We confirm that, from the statistical point of view, the years without global-scale storms are characterized by four phases in the solar longitude-latitude dust distribution (see Figure 1). Dust starts to increase in the atmosphere around northern autumn equinox in the southern hemisphere (1st phase), but the largest increase usually occurs between (solar longitude) L_s = 220° and 260°, when baroclinic activity at high northern latitudes favours cross-equatorial flushing storms (2nd phase; not all regional storms occurring at this time originate in the northern plains, though). A 3rd phase in the dust distribution is characterized by large lifting of dust occurring in the southern polar region between L_s= 250° and 300°, after the CO_2 ice has mostly sublimated away. At other latitudes, instead, there is a clear decrease of atmospheric dust in every Martian year after L_s ~260° (with the exception of MY 28, characterized by the late planet-encircling storm). This pause in large dust storms coincides with the decrease in the amplitude of low-altitude northern baroclinic waves (the so-called 'solsticial pause', see e.g. [4]). When the solsticial pause is over, and the baroclinic wave activity at low altitude reinforces again, the probability of late flushing storms increases. Every year, therefore, a 4th phase in the dust distribution starts around or after L_s~320°, producing a late peak in dust optical depth.

The dust chronicle seems therefore characterized by a 'typical' climatological year, on top of which the annual optical depth is locally increased by the evolution of single local or regional dust storms, particularly in the second half of the year, or globally increased by the irregular onset of planetary-encircling dust storms.

Impact of Dust Storms on the Polar Vortex: The increased latitudinal temperature gradients observed during the polar winters gives rise to strong westerly winds peaking at about 60° latitude N/S and around 50 km altitude in the Martian mesosphere. The swirling air mass encircled by these well developed jets is defined as the atmospheric polar vortex.

The long-term climatology of the Martian polar vortices seems to be much more stable than that of their Terrestrial counterpart ([5]). Nevertheless, regional dust storms occurring even at large distances can have a strong impact on the morphology and strength of the Northern vortex. One specific example of this ‘effect at distance’ occurred in late MY 26 winter (L_s~310°), when a dust storm originated in the North-East corner of the Tharsis Plateau, crossed the equator and expanded in the Southern hemisphere (L_s~320°). We show how this storm had a strong effect also in the Northern hemisphere, producing a transient episode of increased polar warming, associated with weakening, shrinking, and displacement of the polar vortex (see Figure 2).

This can be considered a ‘teleconnection event’, linking the radiative impact of a regional dust storm to the dynamical effect on the winter polar vortex. Given the short radiative time scale on Mars and the fast dynamical response of its atmosphere, teleconnection events originating from the onset of dust storms seem to be a significant component of the Martian atmospheric variability at short time scales (see also [6]).

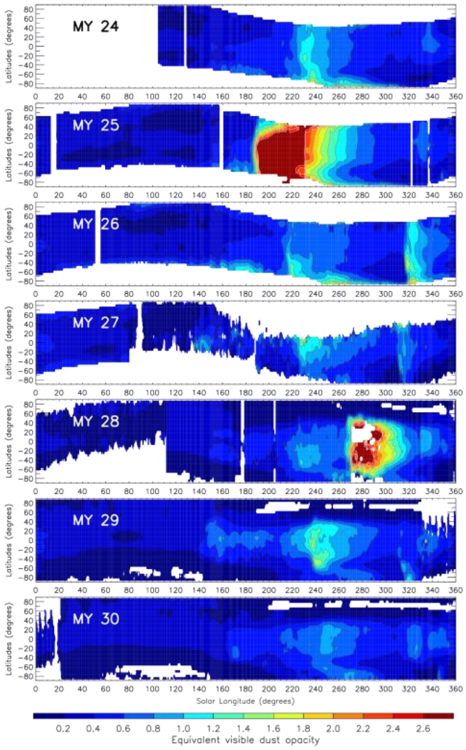

Figure 1: Zonal means of (equivalent visible) column dust optical depths at the reference pressure of 610 Pa for eight Martian years (see also [1]).

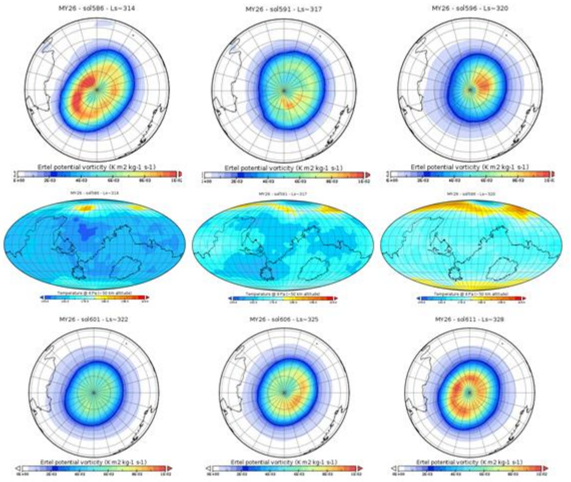

Figure 2: The orthographic maps above show the vertical component of the Ertel Potential Vorticity (PV) at 350 K potential temperature level (~35 km altitude) in the Northern hemisphere of Mars around L_s~320° in MY 26, together with maps of temperature at about 4 Pa level (~50 km altitude) for the corresponding sols. The maps highlight the effects of the MY26 L_s~320° dust storm on the polar warming and on the morphology of the Northern polar vortex.

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