THE MARTIAN POLAR VORTICES IN THE "MACDA" REANALYSIS: CLIMATOLOGY AND VARIABILITY

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Introduction:

Polar vortices seem to be ubiquitous atmospheric structures. In the Solar System, Earth, Mars, Venus, Saturn and its moon Titan are known to have well developed vortices in their polar regions. On Earth as well as on Mars, the increased latitudinal temperature gradients observed during the polar winter gives rise to strong westerly winds peaking at about 60° latitude N/S. The peaking altitudes of these circumpolar westerlies are also remarkably similar, being located around 50 km altitude in the Terrestrial stratosphere and in the Martian mesosphere.

In this paper, we use data from a multiannual reanalysis of the Martian atmosphere to characterize the climatology of the polar vortices, particularly in relation to their morphology, and to analyze episodes of variability induced by dust storms.

The "MACDA" reanalysis:

Atmospheric reanalyses combine state-of the-art global climate models with observations (using the techniques of data assimilation) to produce a best estimate of the atmospheric state throughout a historical period. They allow access to variables that are not directly observed, such as wind components and vorticity, dynamically balanced with observables such as temperature and dust optical depth.

In this study, we use the Mars Analysis Correction Data Assimilation (MACDA) dataset from 1999 to 2004 (almost three complete Martian years); this period is covered by observations of the Thermal Emission Spectrometer (TES) on board NASA's Mars Global Surveyor (MGS). See Christensen et al., (2001) for information on MGS, and Smith (2004) for information on TES retrievals.

The MACDA v1.0 reanalysis for MGS/TES (Montabone et al., 2013a) uses an earlier version (Forget et al., 1999) of the state-of-the-art Mars Global Climate Model (MGCM) that has been developed jointly by institutions in the UK, France, and Spain. In particular, the dynamical spectral solver has been adapted for Mars from the one originally developed at the University of Reading and ECMWF; The tracer transport scheme has been developed at the University of Oxford; A full range of physical parameterizations have been developed and are routinely updated by the Laboratoire de Météorologie Dynamique (Paris, France), in collaboration with the Open University, the University of Oxford (UK), and the Istituto de Astrofisica de Andalucia (Granada, Spain). The data assimilation technique uses the Analysis Correction scheme originally developed as operative scheme at the UK Meteorological Office (Lorenc et al., 1991). In v1.0 of the MGS/TES MACDA we have assimilated retrievals of thermal profiles and column dust optical depths from nadir observations. The thermal profiles are available below about 40 km altitude. The period covered by the reanalysis spans from Martian year (MY) 24 late summer (northern hemisphere) to MY 27 early spring. Three northern winters and two southern winters are available for the study of the polar vortices.

The MGS/TES MACDA v1.0 dataset is publicly available through the British Atmospheric Data Centre (BADC), see Montabone et al (2011).

Polar vortex climatology:

In order to study the climatology and variability of the polar vortices on Mars, we use potential vorticity (PV) and vortex centric diagnostics (Mitchell et al., 2011), following the type of analysis adopted for the Earth polar vortices.

PV and vortex centric diagnostics (area, aspect ratio, centroid latitude and orientation) allow us to assess the 4D morphology of the northern and southern winter vortices. The study highlights their low inter-annual variability, when compared to the variability of the stratospheric polar vortices on the Earth (but the limited available reanalysis period for Mars should be taken into account). A characteristic that seems to be robust in the Martian vortex climatology from MACDA v1.0 is their annular shape, particularly evident in the northern hemisphere. The presence of a minimum of PV around the pole poses interesting questions about the stability of the vortex, which require further investigation.

Impact of dust storms on polar vortices:

Despite showing low inter-annual variability in general, the northern Martian polar vortex seems particularly sensitive to the radiative and dynamical effects of regional dust storms, even occurring in the southern hemisphere. We have analyzed a transient episode of “enhanced polar warming” (enhanced with respect to the climatological winter polar warming), which occurred in the northern polar region during a regional dust storm in late MY26 winter (L_s~310°). This storm (see Figure 1) originated in the North-East corner of the Tharsis Plateau, crossed the Equator and expanded in the Southern hemisphere (L_s~320°). It was the storm that developed at the time the two NASA Mars Exploration Rovers (MERs) underwent their EDL procedure to land on Mars (Montabone et al., 2006).

This late winter storm expanding in the southern hemisphere had a strong effect also in the northern hemisphere, linked to the transient enhancement of the cross-equatorial cell of the mean meridional circulation. The increase of air downwelling and adiabatic compression at high northern latitudes produced an episode of enhanced warming at several altitudes, clearly visible in the temperature maps of Figure 2 (here provided at about 50 km altitude).

The shape and strength of the northern vortex have been severely affected during the evolution of this southern storm. The increased polar warming has been associated with weakening, shrinking, and displacement of the polar vortex (see orthographic maps of PV in Figure 2). No vortex breaking is occurring during this episode, nor has it been observed in the reanalysis dataset during the winter seasons covered by MGS/TES reanalysis.

Future work:

The current availability of observations from the Mars Climate Sounder on board Mars Reconnaissance Orbiter will allow extending the reanalysis of the Martian atmosphere to at least seven Martian winters, with great advantage for the study of the impact of dust storms on the inter-annual variability of the Martian polar vortex dynamics and transport.

Future work will also be devoted to improve the reanalysis dataset, by increasing the spatial resolution both in the horizontal and in the vertical, and by updating the used MGCM version to the latest available (Forget et al., 2011).

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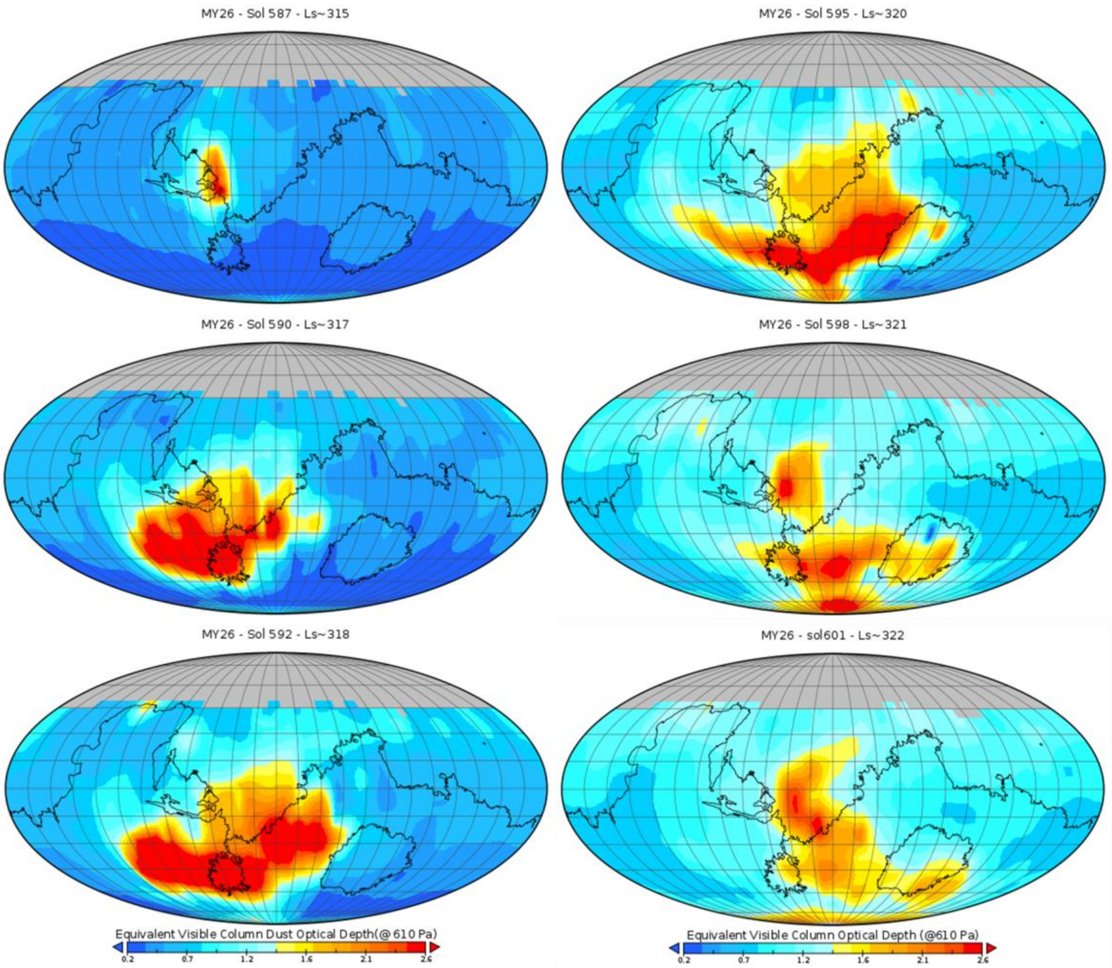

Figure 1: Maps of column dust optical depths around L_s~320° in MY 26 (from L_s~315° to L_s~322°, separated by approximately 3 sols) showing the development of the cross-equatorial storm that was encountered by the two MERs during their landing on Mars. These maps are obtained by gridding the TES column dust optical depth retrievals using the technique described in Montabone et al. (2013b, this issue).

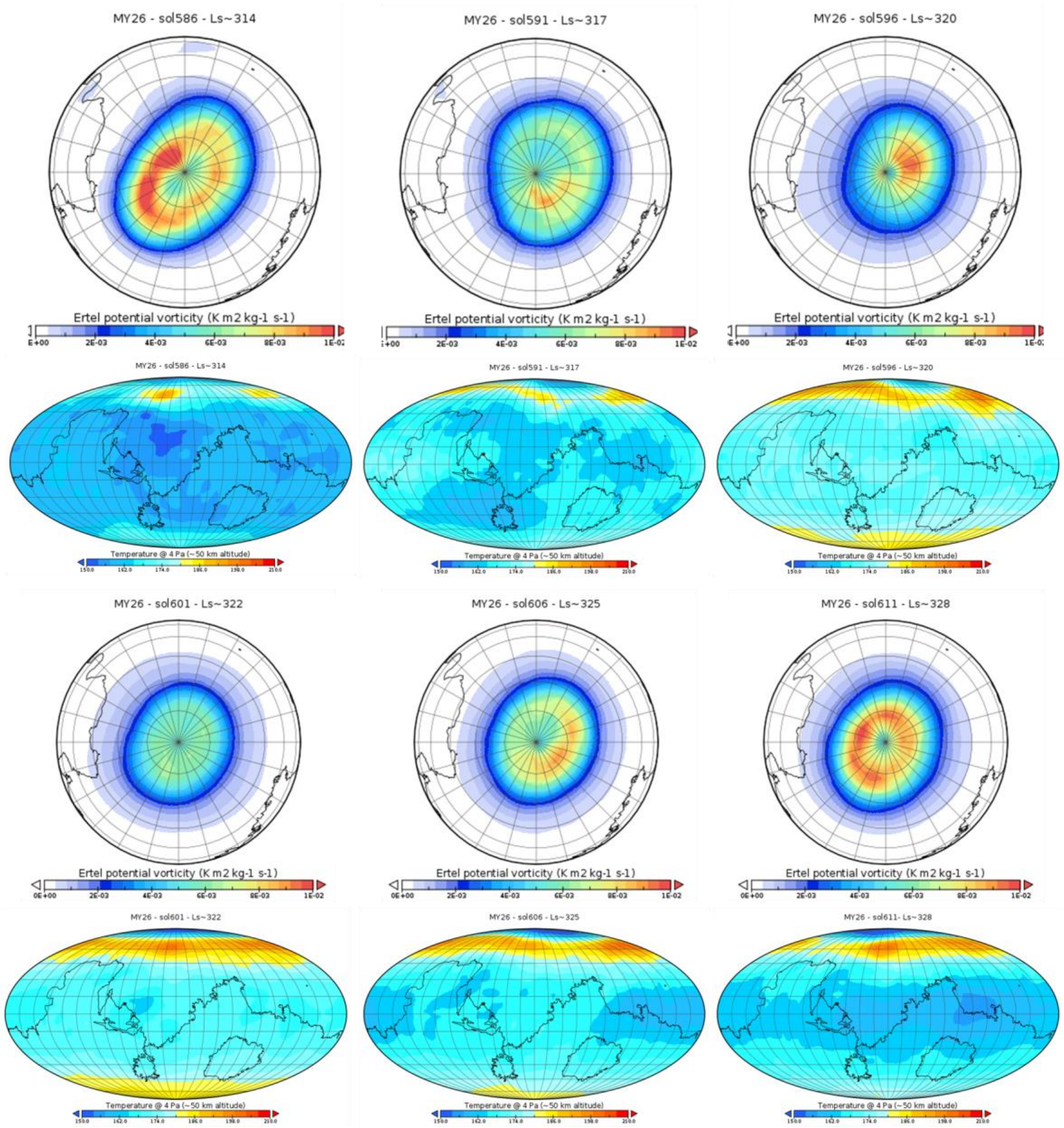

Figure 2: The orthographic maps above show the vertical component of the Ertel Potential Vorticity (PV) at 350 K potential temperature level (~35 km altitude) in the northern hemisphere of Mars around L_s~320° in MY 26, together with maps of temperature at about 4 Pa level (~50 km altitude) for the corresponding 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.