The Morphology of the Polar Vortices on Mars and Earth from Atmospheric Reanalyses

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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.

We use data from atmospheric reanalyses for both the Earth and Mars to characterize the climatology and variability of the Terrestrial and Martian polar vortices, particularly in relation to their morphology. Reanalyses combine state-of-the-art global climate models with observations to produce a best estimate of the atmospheric state throughout a historical period. They allow access to variables which are not directly observed, such as wind components or vorticity, dynamically balanced with observed variables such as temperature. For the Earth, we use the Modern Era Retrospective-analyses for Research and Applications (MERRA, http://gmao.gsfc.nasa.gov/merra/), from 1979 to 2011. For Mars, we use the Mars Analysis Correction Data Assimilation (MACDA, http://dx.doi.org/10.5285/78114093-E2BD-4601-8AE5-3551E62AEF2B) from 1999 to 2004 (three Martian years).

The comparison shows that, despite a very different thermal structure between Earth's stratosphere-lower mesosphere and Mars' mesosphere, the zonal-mean zonal wind structure and the meridional mass stream function have common features, which explain similarities in the climatological structure of Earth's and Mars' polar vortices (See Figs. 1 and 2).

In order to study the variability of the polar vortex morphology on Mars and Earth, we use potential vorticity (in the modified form proposed by Lait, 1994) and vortex centric diagnostics (Mitchell et al., 2011). This allows the relative characteristics of the polar vortices to be compared at different altitudes and across planets, providing meaningful results despite the intrinsic differences between Mars and Earth.

We show that Martian polar vortices present lower variability than their Terrestrial counterpart (at least over the available period for Mars), when looking at area, aspect ratio, centroid latitude and orientation. We also show that regional dust storms in the Southern hemisphere of Mars have profound impacts on the morphology of the Northern hemisphere vortex, causing the area and strength to reduce, and the polar air to warm up. This Martian "sudden polar warming" event will be compared to Terrestrial "Stratospheric Sudden Warming" (SSW) events, and similarities and differences will be discussed.

Lait, L., 1994. An alternative form for the potential vorticity. J. of Atmos. Sci. 51 (12), 1754-1759

Mitchell, D., A. Charlton-Perez, and L. Gray, 2011. Characterizing the variability and extremes of the stratospheric polar vortices using 2d moment analysis. J. of Atmos. Sci. 68, 1194-1213.

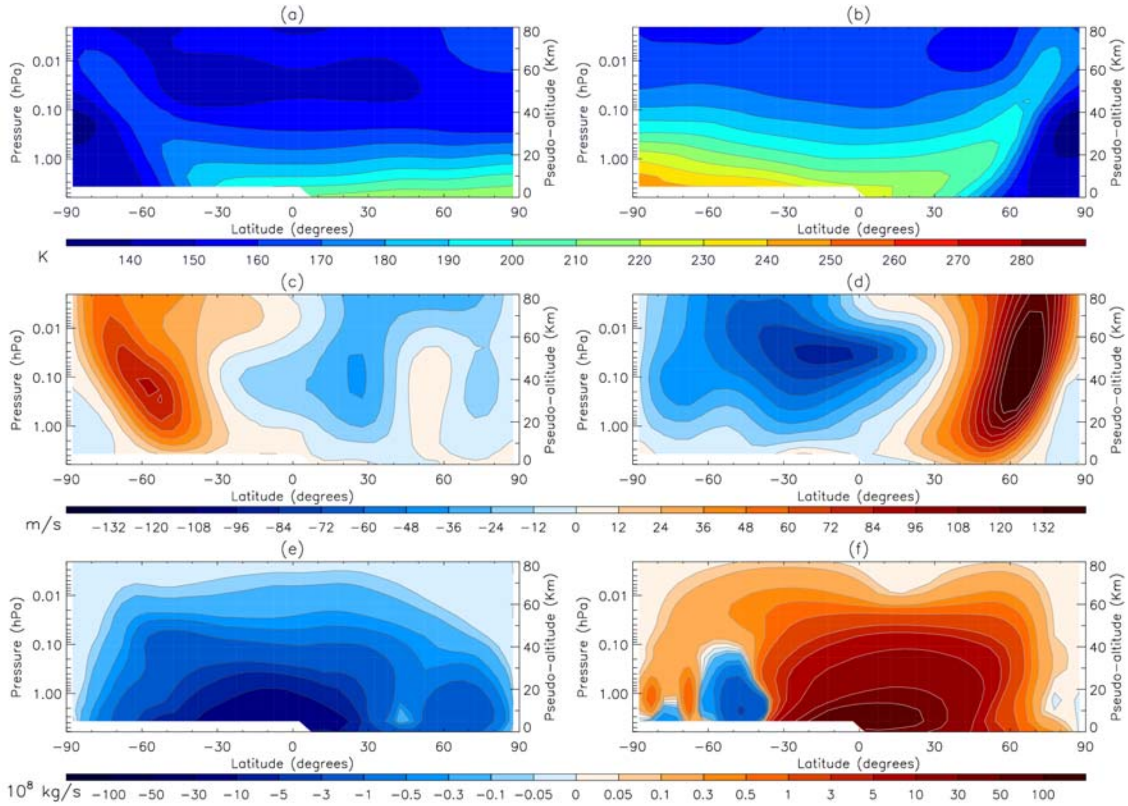

Figure 1: This picture shows climatological zonal means of temperature (panels a-b), zonal wind (c-d), and meridional mass stream function (e-f) for Mars' troposphere and lower mesosphere. Data are extracted from the MACDA reanalysis during the period 1999-2004 (Martian years 24-26). Left panels (a-c-e) are time averaged around northern summer solstice (solar longitude 85°-95°), right panels (b-d-f) are time averaged around northern winter solstice (solar longitude 265°-275°). The pseudo-altitude scale has been calculated using the formula $z_p = -H \log(p/p_{ref})$, where H=10 km (reference Martian scale height) and p_{ref}=6.1 hPa. Because of the elevated Martian topography in the southern hemisphere, the lowest pressure levels might be located below the surface. We do not plot zonal mean values at a particular latitude and pressure level when more than half of the longitude points have missing values.

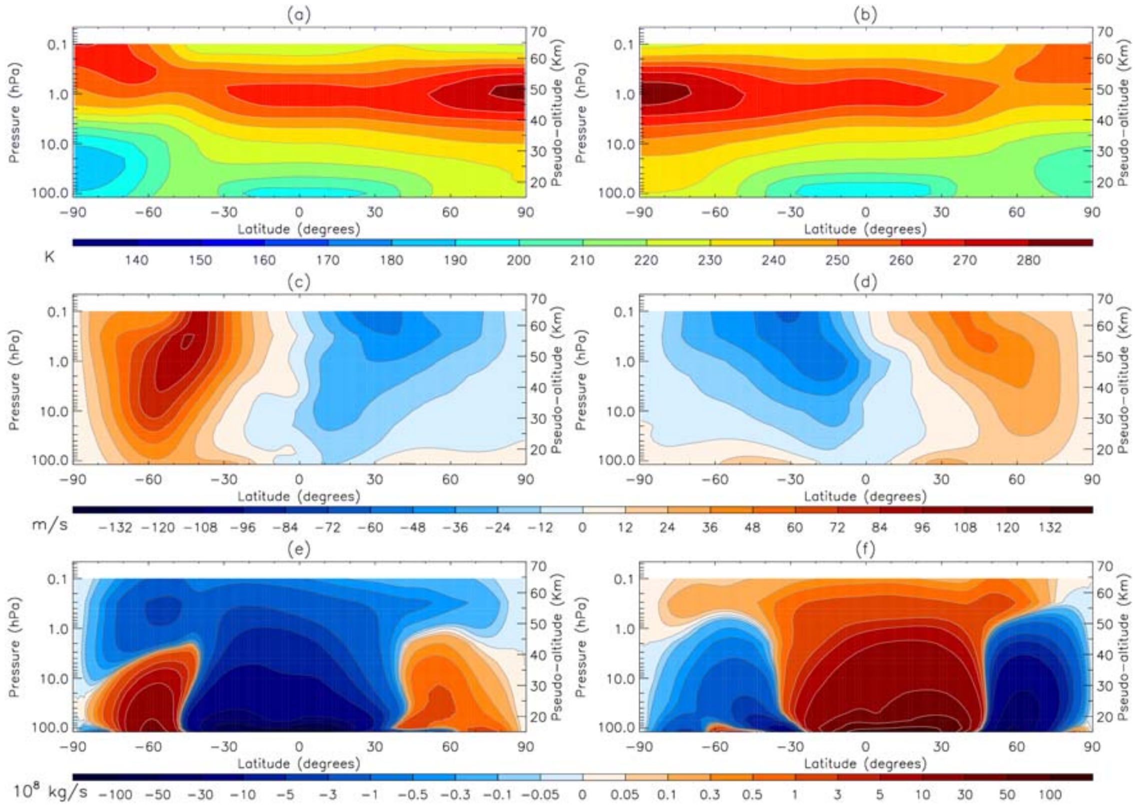

Figure 2: This picture shows climatological zonal means of temperature (panels a-b), zonal wind (c-d), and meridional mass stream function (e-f) for the Earth's stratosphere and lower mesosphere. Data are extracted from the MERRA reanalysis during the period 1979-2011. Left panels (a-c-e) are time averaged in June-July-August (JJA), right panels (b-d-f) are time averaged in December-January-February (DJF). The pseudo-altitude scale has been calculated using the formula z_p=-H log(p/p_{ref}), where H=7 km (reference Earth scale height) and p_{ref}=1013 hPa.