Martian polar vortex dynamics and the 2018 Global Dust Storm

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Introduction

Mars’ winter atmosphere is characterized by a polar vortex of low temperatures around the winter pole, circumscribed by a strong westerly jet \(\ell > 30\). These vortices are key parts of the atmospheric circulation and impact heavily on dust and volatile transport. They have a complex and asymmetrical (continuously) relationship with atmospheric dust loading \(\ell\). Regional and global dust events have been shown to cause rapid vortex displacement \(\ell_{\text{dis}}\) in the northern vortex, while the southern vortex appears more robust. This has implications for tracer transport through the zonal jets associated with the vortices \(\ell\); a more coherent and low-latitude zonal jet should provide a more effective barrier against tracers entering the polar regions. The 2018 Global Dust Storm (GDS) was observed through its lifecycle by the Mars Climate Sounder (MCS) instrument aboard the Mars Reconnaissance Orbiter \(\ell\); using data assimilation \(\xi\) to integrate MCS retrievals \(\xi\) with the LMD UK Mars Global Climate Model (MGCM) \(\xi\) offers an opportunity to examine the effects of the GDS on the polar vortices.

Global dust storm effects

\(\xi\) Fig. 1 shows the impact of the GDS on the potential vorticity (PV) and zonal wind speeds at the 300 K isentropic surface and as averaged between 20–30 km, respectively.

\(\xi\) In the north, the GDS reduced PV but in an asymmetrical fashion, with maxima in decreases at around 20°N and 40°N degrees longitude. The pattern of PV decrease indicates a poleward shift of the polar vortex.

\(\xi\) The southern zonal wind speeds decreased at lower latitudes (50–60°S degrees) and increased at higher latitudes (60–70°S degrees), with maxima in increases tracking maxima in PV decreases. Again this indicates a poleward shift of the westerly jet core.

\(\xi\) In the south, the highly asymmetric and already declining polar vortex showed a dramatic reduction, accelerating its decay.

\(\xi\) Southern zonal wind speeds decreased at all latitudes except at the location of the former PV minimum centred at 30°S degrees longitude, with residual high wind speeds at very high latitudes. This shows a remnant polar vortex remained at very high latitudes.

Temporal variation

\(\xi\) Fig. 1 shows the effect of the GDS throughout its lifespan on PV and zonal wind speeds.

\(\xi\) At the northern pole, PV decreased at latitudes centred around 60°S and increased poleward of that, indicating a poleward shift of the polar vortex. The greatest effect was between \(\ell = 20^\circ\) and \(\ell = 40^\circ\), as the GDS decayed. There was a corresponding increase in zonal wind speeds at around \(\ell = 60^\circ\) N.

\(\xi\) At the southern pole, PV simply decreased at high latitudes as the polar vortex decayed and was accelerated by high southern dust loading and corresponding warming. Wind speeds around \(\ell = 60^\circ\) S correspondingly decreased.

Vertical variation

\(\xi\) Fig. 3 shows Fig. 1 but at higher altitudes: the 300 K isentropic surface for PV and zonal winds at \(\ell = 30\) km.

\(\xi\) In the north, PV decreased closer to the lower level pattern than there is a more striking PV increase above \(\ell = 20^\circ\) of the pole itself. This suggests a higher altitude polar vortex.

\(\xi\) In the south, the results follow the lower level pattern, showing a consistent decrease in PV and a marked increase in wind speeds above the pole as the polar vortex’s annular structure collapsed.

Summary

\(\xi\) The 2018 GDS was an equinoctial event, beginning as the northern polar vortex was growing and the southern polar vortex was decaying.

\(\xi\) The GDS appeared to shift the northern polar vortex poleward, the lack of high dust loading at high northern latitudes indicates this was due to the dynamical effects of an enhanced lower level jet.

\(\xi\) The GDS drastically accelerated the seasonal decay of the southern polar vortex; this was likely due to the enhanced diabatic heating from the high southern hemisphere dust loading destroying the equator-pole temperature gradient.

\(\xi\) The poleward shift in the highest westerly wind speeds at both poles suggests that equinoctial GDS events could allow greater tracer transport to high latitudes.

References


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