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Version: Supplementary Material

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A climatology of the martian northern polar vortex

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Summary
- Eight martian years of northern polar vortex activity reveal a high degree of interannual similarity in vortex behaviour and structure.
- However some small-scale temporal variation in PV is apparent.
- Large-scale interannual variability in the vortex is linked to dust activity.
- GDS timing (equinoctial vs solstitial) is key; former caused significant disruption, latter far more limited impacts (Streeter et al., 2021).
- A and C regional storms have similar effects but the latter cause greater disruption to the annular structure of the vortex, likely due to the later seasonal timing.

Methods
- We use data assimilation to combine the LMD-UK MGCM with MCS temperature retrievals and derived column dust products.
- We investigate eight martian years, Mars Year (MY) 28-35, including two Global Dust Storms (GDS) and numerous regional dust storms.
- We use potential vorticity (PV) as a diagnostic for the polar vortex; PV is a conserved dynamical quantity related to atmospheric rotation and vertical temperature stratification.

Acknowledgements
PMS acknowledges support from the STFC and The Open University for a PhD studentship. This work was enabled through UK Space Agency grants. The authors are particularly grateful for ongoing collaborations with the MCS team (NASA-JPL), Peter Read (Oxford), and François Forget and colleagues (LMD/CNRS Paris).

Introduction
- Mars’ atmosphere contains polar vortices: regions of cold air surrounded by powerful jets.
- These play a crucial role in controlling transport of atmospheric aerosols and chemical species.
- Their intensity and morphology have a complex relationship with atmospheric dust loading.
- We combine a Mars Global Climate Model (MCGM) with eight martian years’ worth of Mars Climate Sounder (MCS) data to investigate the seasonal behaviour of Mars’ north polar vortex, and its relationship with dust storm activity, in particular A and C type regional storms.

A and C storm effects
- A storms consistently reduce PV on the outer edge of the vortex and increase PV over the pole, indicating a compressed vortex and reduced annularity.
- C storms have a similar but less consistent effect, likely linked to their later timing and the fact that the vortex is already undergoing seasonal decay.
- In general, storm effects appear closely linked to the already existing structure of the meridional circulation; storms closer in time to the strongest south-to-north Hadley cell at Lₕ=270° have the greatest compressive effect.

Multi-year climatology
- The northern polar vortex shows a high degree of interannual repeatability.
- In an average year, the vortex first develops around Lₕ=150-180° and grows in intensity, with a peak in PV intensity between Lₕ=210-330°.
- The characteristic annular PV structure of the vortex only appears around Lₕ=210°, and persists until approximately Lₕ=330°; this is visible in Fig. 1 as a PV maximum present at around 80°N, with a local PV minimum over the pole itself.
- Intermartian vortex variability is linked to dust activity at tropical/mid-latitudes.
- The MY 29 (solstitial) GDS caused large-scale disruption to the vortex, while the MY 34 (equinoctial) GDS had more limited impacts.
- There is an apparent dichotomy between A and C storm effects (see left).

Fig. 1: Zonally averaged Ertel PV on the 300 K isentropic surface (top of each panel) and averaged tropical (30° S-30° N) column dust optical depth (CDOD) at the 610 Pa reference pressure level (bottom of each panel) in the assimilated MGCM for MYs 28-35, Lₕ=150-360°. Shaded areas represent time periods when MCS data was unavailable for assimilation. Boxes show A/C storm periods, dotted lines show annular PV structure.

Fig. 2: Percentage PV difference between each MY for the case of A and C storm periods as compared to MY 30. Latitude circles are spaced at 10° starting at 80°N (innermost band).