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Super-rotating jets in a re-analysis of the martian atmosphere

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Abstract

Strong westerly, prograde jets have been identified in the martian atmosphere between about 10–20 km altitude throughout much of the year in a Mars Global Circulation Model (MGCM) study [2]. The development of data assimilation techniques for Mars [3, 5] now permits the analysis of super-rotation in less highly idealized cases using an atmospheric reanalysis, as would be done for the Earth. This paper reviews recent atmospheric reanalyses, in order to validate previous modeling results, to quantify jet amplitudes and to diagnose possible mechanisms supplying angular momentum to the jets.

1. Introduction

Super-rotation is observed in each of the four substantial atmospheres possessed by solid bodies in the solar system. The slowly rotating planet, Venus, and moon, Titan, both have atmospheres that, at least at some altitudes, rotate much more quickly than does the solid surface underneath. The more rapidly rotating planets, Mars and Earth, exhibit less spectacular global super-rotation, but both can possess prograde jets near the equator which rotate more rapidly than does the equatorial surface.

In each case the detailed mechanism, or combination of mechanisms, which produces the super-rotating jets might vary, but all require longitudinally asymmetric motions, waves or eddies, to transport angular momentum up-gradient into the jets [1, 6]. A model simulation or a re-analysis of observations by data assimilation provides an ideal data set which may be used to quantify the amount of atmospheric super-rotation and to diagnose the relative importance of each eddy forcing mechanism.

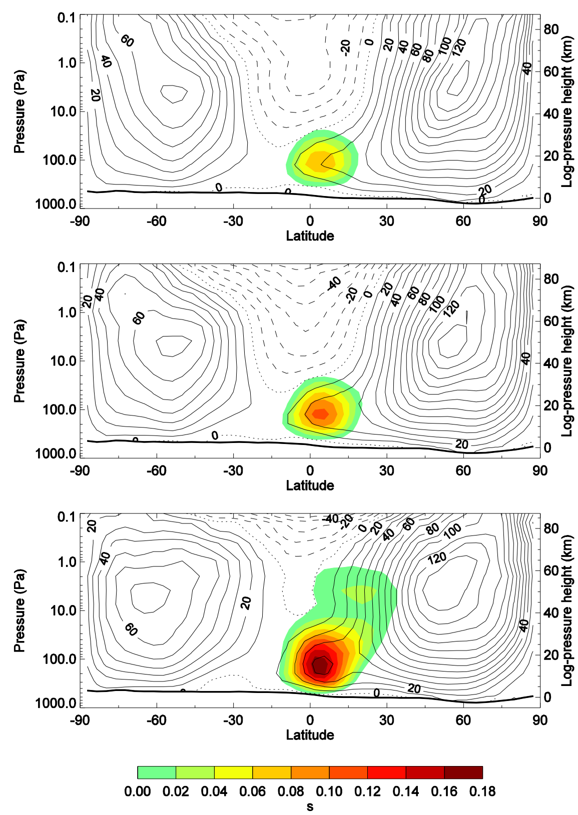

Figure 1: Zonal wind (contours) and local super-rotation index, s, (colours) at northern hemisphere autumn equinox (L_S = 180°) in the UK MGCM [2]. Only positive values of s are shaded to highlight regions of super-rotation. The dust optical depth is varied from moderate to levels approaching planet-encircling dust storms, such as the L_S = 185° event in 2001 (τ_{610Pa} = 0.6, 1.2 and 3.0 from top to bottom).

2. Model studies

Idealized Mars model studies [2, 10] have already demonstrated the formation of super-rotating jets under Mars-like conditions. Figure 1 illustrates zonal-mean wind at northern hemisphere equinox from [2] under three different, uniform dust loadings. The local super-rotation index, *s*, which is shown as a colour-scale in Fig. 1, is a measure of the excess zonal-mean angular momentum about the rotation axis, normalized by the angular momentum of air at rest at the equator [6]. If an atmosphere starts from a rest state, as was the case here, $s > 0$ is not possible through purely zonal-mean processes, such as transport by the mean meridional circulation [1]. The super-rotation in Fig. 1 increases with dust loading and may be attributed to the atmospheric sun-synchronous thermal tides [2], although an almost exactly equal global super-rotation will occur, with jets peaking elsewhere in the model if the thermal tides are artificially suppressed.

3. Data assimilation

The use of data assimilation for Mars [3, 5] now means that the atmospheric super-rotation can be diagnosed from an MGCM reanalysis spanning almost six martian years covering the period for which thermal and dust observations are available from the Thermal Emission Spectrometer on Mars Global Surveyor [7] and the Mars Climate Sounder on Mars Reconnaissance Orbiter [4]. A super-rotating equatorial jet is frequently found in the re-analysis.

4. Summary and conclusions

Local and global super-rotation require the transfer of angular momentum up-gradient with respect to the longitudinal-mean gradient of angular momentum. This transfer must be accomplished by eddy processes, which might include thermal tides, large-scale Kelvin or Rossby waves or small-scale inertio-gravity waves or even turbulent diffusive processes. On Earth, strong tropical convection will mix angular momentum and may suppress the development of clear, local super-rotating jets in the troposphere. Mars also has a deep convective boundary layer that varies strongly with surface height [8, 9] and its impact on the equatorial jet in the re-analysis will be examined.

Acknowledgements

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