Potential vorticity, angular momentum and inertial instabilities in the Martian atmospheric circulation from assimilated analyses of MGS/TES

Conference or Workshop Item

Potential vorticity, angular momentum and inertial instabilities in the Martian atmospheric circulation from assimilated analyses of MGS/TES

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Data based on re-analyses of the MGS/TES observations have been used to map distributions of potential vorticity and axial absolute angular momentum per unit mass. The data, discussed in more details in [1] and [2] stretches over nearly three Martian years and cover a wide range of atmospheric conditions. The spatial distribution and variation in time of angular momentum and potential vorticity are closely related to the zonal-mean circulation. Maps of potential vorticity distributions have been used to establish regions and times favourable for inertial instabilities. A narrow region near the equator which extends throughout the atmosphere is shown to be able to sustain inertial instabilities at different times of the year. The presence of inertial instabilities is predicted from the necessary (but not sufficient) condition for the occurrence of regions of atmosphere with PV of opposite sign to that of the planetary vorticity (PV-anomalies). These regions are characterized as being favorable to mixing on small scales, while at larger scales there may be potential links to Rossby wave breaking (Knox et. al. 2005)[3]. Analyses of the data indicates a hemispheric asymmetry where the northern hemisphere is more favorable to inertial instabilities particularly during NH winter.

Barnes et. al. (1996)[4] used a global Martian circulation model to find that, during dusty solstice conditions, the Martian tropical and mid-latitude atmospheric circulation approximates to an angular-momentum conserving Hadley circulation, and is responsible for creating regions near the equator of low potential vorticity. Using the assimilated data we re-examine these results for a wider range of atmospheric states, including the period of the 2001 planet-encircling dust storm.

Potential vorticity

The evolution of Ertel potential vorticity, $P(\mathbf{x}, t) = -g(f+\xi)\frac{\partial\theta}{\partial p}$, on $\theta = 345$ K ($\approx 2.5-3$ Pa) is shown in figure 1. The seasonal variation of P show a modulation, particularly at high latitudes while the PV distribution around the equator is well balanced through out the period.

The slope of the PV-gradient becomes relatively flat around the equator, in particular around aphelion and autumn equinox during a 'normal year' ,which shows P during a period with a global dust storm , has in contrast a steeper gradient. The variation of PV with height is shown in figure 2, where the PV gradient increases with height, (observe that PV on $\theta = 800K$ is above the range of observations and thus a product of the model).

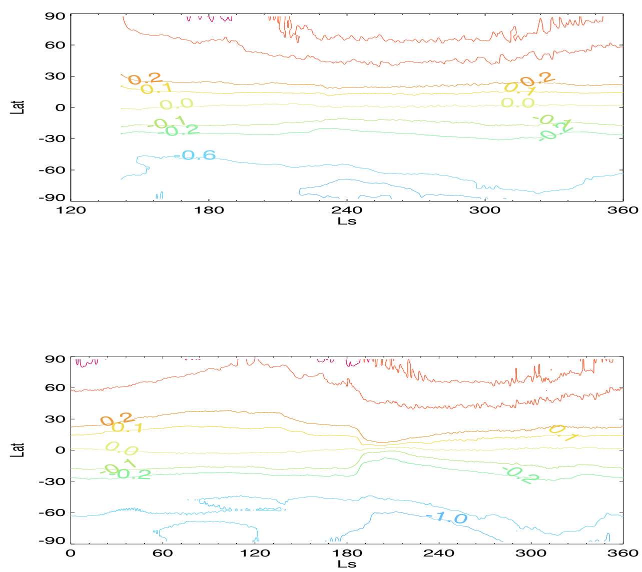

Figure 1: Zonal mean of Ertel potential vorticity, $[P]$ (in 100 PVU units) during MY24, 25, and 26 (from top to bottom) the data has been smoothed with 5-sol boxcar average.

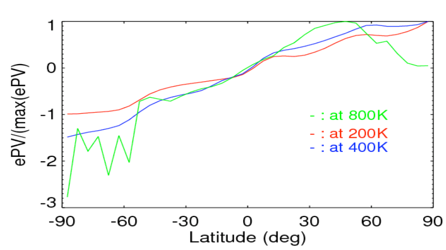

Figure 2: Zonal and temporal mean of Ertel potential vorticity at $\theta = 200, 400$ and 800 K. Fig 2a Show time average over $L_s = 186° - 206°$ (daynumber 1049-1084).

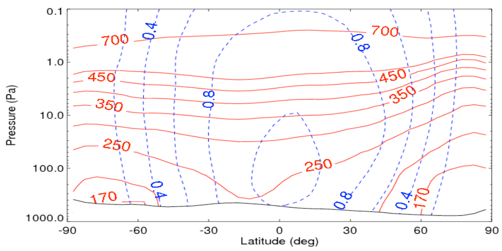

Figure 3: Zonal and temporal mean of angular momentum (blue), M normalized with ΩR^2, and potential temperature (red), θ, are shown for $L_s = 186°$

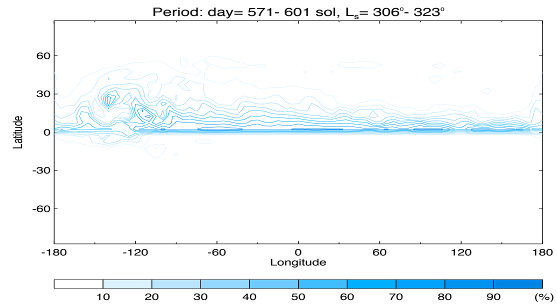

Figure 4: Frequency of $f(f+\xi) < 0$ at $\theta = 345K$

Angular momentum

The variation of absolute momentum $[\overline{M}] = R\cos(\phi)(u_{zon} + \Omega R\cos(\phi)$ and potential temperature $[\overline{\theta}]$ are shown just after autumn equinox in MY25. There is a region above the equator in $M > 1$ (super rotation), this agree with a model study [6] Further analyses of M indicates that there is significant difference between the momentum field during NH spring when the distribution resembles that of a motionless atmosphere. Closer to the winter solstice, M begins to tilt northward, The potential temperature field reflects the extent of the Hadley circulation in mid-latitudes. A step change of θ at latitudes $\approx 50° - 60°$ corresponds to the region with an intense zonal jet.

Inertial Instabilities

Inertial instability is a fundamental (symmetric) instability of strongly anticyclonic flow characterized by anomalous anticyclonic potential vorticity [3]. Presence of this type of instability has by some ([3], [5]) been linked to breaking Rossby waves, where islands of anomalous PV moving equatorward create regions and thus create regions where inertial instabilities can be generated. These processes are also closely related to mixing of air. Since detection of inertial instabilities is difficult to achive directly (requiring a relative model/data high resolution) it is common to identify regions which satisfy the criteria. To identify conditions suitable for inertial instability we use the criterion $S = f(f + \xi_g) < 0$ where f is the Coriolis parameter and ξ_g the relative vorticity [3] (calculated from geostrophic velocities) evaluated on isotrophic surfaces. To evaluate S we simply count the number of events of S on a time scale, $\tau = 2$ hours, or less (the data is sampled at a two interval) at each gridpoint. The length of τ can be estimated by the *e*-folding time $(-f(f+\xi))^{-1/2}$, for this data set $\sim 80\%$ of τ_e is shorter than 3h. The analyses reveals a hemispheric asymmetry where the northern hemisphere has a significantly higher frequency of S events (a study of the Earth's stratosphere show similar asymmetry [3]). The asymmetry manifest itself in a latitude band, extending from the equator up to 45∘N (NH winter) in where events of S with varying frequency occur. Furthermore, a region located above Mount Olympus and the Tharsis mountains shows also increased activities. Figure 4 shows the frequency of S events during the period $L_s = 306° - 323°$ MY24.

Discussion

We have examined the distribution of zonal averaged absolute momentum and PV during different atmospheric states using re-analysed data from MGS. The seasonal variabilty of momentum indicate a close link with the strong Hadley circulation. The change of sign of PV around the equator support the hyopthesis of the possible presence of inertial instabilities. While the distribution of PV at high latitudes indicates regions on both hemispheres that could sustain breaking of large scale waves.

The occurrence of inertial instabilities is by its nature usually confined to a relative narrow region centered near the equator, extending from surface to the upper regions of the atmosphere. However, there is an asymmetry between the hemispheres where the conditions for inertial instabilities are more favourable.

References

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