EPSC Abstracts
Vol. 6, EPSC-DPS2011-1478, 2011
EPSC-DPS Joint Meeting 2011

Can the Earth's atmosphere superrotate at slower rotations?

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Abstract

The atmospheric phenomenon of superrotation is closely related to the rotation rate. Venus and Titan share this behavior in which the entire atmosphere has a larger angular momentum than the solid body itself. Without considerations regarding its origin and nature, this study aims to verify the transition of the Earth's atmosphere to a superrotational state.

1. Introduction

The general circulation of slow rotation bodies, like Venus and Titan, differs from that observed in the other terrestrial planets. This regime is characterized by a single Hadley cell in each hemisphere (during the equinoctial period for Titan and the entire year for Venus) and the presence of the superrotation phenomenon, in which the atmosphere has a larger angular momentum than the underlying solid body [1,5]. Previous studies have shown that the latitudinal extension of the Hadley cell increases as the rotation decreases, and the baroclinic instability is suppressed under slower rotating regimes [2]. Also, differences among the terrestrial bodies (size, radiative forcing, gravity, obliquity, general circulation, etc) suggest that the slow rotation rate is the most important variable in driving the superrotation [3]. The objective of this study is to analyze the general circulation under different regimes of rotation and verify whether there is a transition to a superrotational state of an Earth-like atmosphere.

2. Methodology

The simulations were performed using a global-domain version of the Weather Research and Forecast (WRF) Model [4]. Starting from an idealized isothermal atmosphere in rest, the simulations were run by 10 years long in total. The model resolution in these simulations was 3.9° X 2.5° in the horizontal and 32 levels in the vertical eta-coordinate. Besides the topography, sea surface temperature (SST), land distribution, diurnal and seasonal cycles were considered.

In order to evaluate the impact of the rotation rate in the general circulation, the Earth's angular velocity was changed in each run following the relation:

$$\Omega = \frac{\Omega_E}{2^n} \qquad (1)$$

where Ω is the Earth's rotation rate ($7.292\text{x}10^{-5}$ s^{-1}) and n a changing factor. A broad set of circulation regimes was obtained by varying n from -2 to 8. With this, rotation conditions like those found in Titan (n=4) and Venus (n=8) were imposed to the model. The results were analyzed by showing differences in the scale of cells and jets averaged over the five final years of each simulation.

3. Main results

Figure 1 depicts the vertical cross-section of the zonally averaged zonal wind for four scenarios (n=0, 2, 4, and 8). For the control experiment, based on the actual Earth's rotation rate (n=0), the model reproduces the main features of the zonal winds. As expected from the observations, the jet core is located near the pressure level of 200 hPa in each hemisphere. Besides, the general pattern shows eastward winds in the subtropical- and mid-latitudes whereas the westward winds are in the equatorial region (Fig. 1a). By reducing the rotation rate the general pattern of wind changes. For n=2 the jets shift toward mid-latitudes while increasing their intensity (Fig. 1b). The Hadley cell becomes wider and its downwelling branch extends toward higher latitudes (figure not shown). At slower conditions (n=4 and n=8) the mean zonal circulation undergoes significant changes. A large portion of the stratosphere presents an eastward flow and the tropospheric jets start vanishing. The meridional circulation is dominated by just a single Hadley cell in each hemisphere and the latitudinal temperature contrasts are nearly inexistent (figure not shown). The last two scenarios correspond to those found in Titan and Venus atmospheres, but in this numerical experiment the atmosphere does not seem to superrotate.

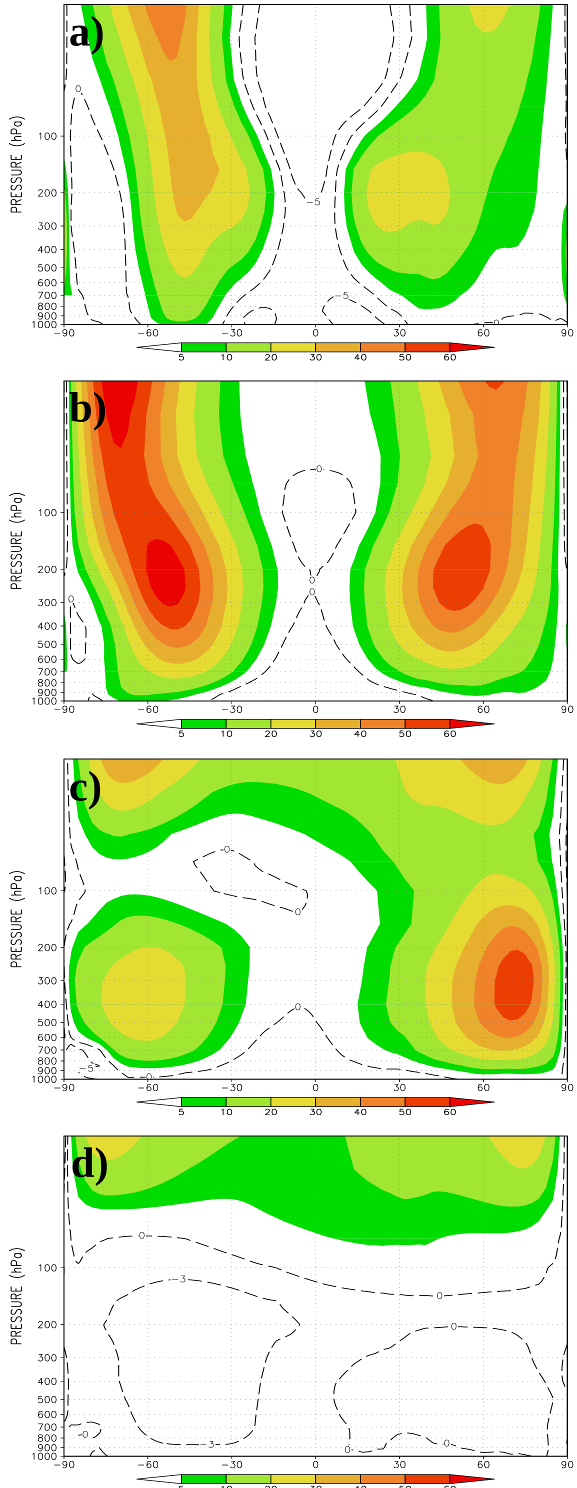

Figure 1: Cross-vertical section of the averaged zonal wind (ms^{-1}) for: a) *n*= 0, b) *n*= 2, c) *n*=4 and d) *n*=8.

4. Conclusions

The simulations show that the model is sensitive to changes in the rotation rate but it did not reproduce a superrotation at the slower regimes. In the intermediate regime the changes in the winds and temperature distribution are close to the expected results by theory. Our results show that the Earth's atmosphere in fact does not superrotate or some physical processes are not being correctly modeled. Further analysis using different schemes of difusion and resolutions are needed. Besides the theoretical considerations, this kind of study can be a very useful tool in analyzing the skills of the dynamical cores of GCM running under different parameters, which it has not been developed initially.

Acknowledgements

The authors wish to thank FAPESP for the financial support provided.

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