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The Seasonality of the Atmospheric Polar Vortices on Venus compared to Earth, Mars, and Titan

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Abstract

We use global climate models to study the seasonal variability of polar vortex strength across several planetary atmospheres. In particular, we show the presence of a "seasonal variability" induced by dynamics on Venus, a planet with negligible axial tilt, and compare with cases where the seasonality is a result of the obliquity of the planetary body.

1. Introduction

Polar vortices are ubiquitous atmospheric structures. In the Solar System, Earth, Mars, Venus, Saturn and its moon Titan are known to have well developed vortices in their polar regions at high altitude. These swirling structures are not always present in the atmosphere of a planetary body at all seasons, but they generally form in the winter hemisphere, when the latitudinal equator-to-pole temperature gradients are the strongest. For Earth, Mars, Saturn and Titan, therefore, the axial tilt determines the presence and seasonal variability of their polar vortices. This can be observed, for instance, by looking at the seasonality of the maximum speed of the circumpolar jets (see [6] for examples related to the Earth and Mars). Venus has a negligible axial tilt; therefore one would expect that the seasonality of its polar vortices is absent. Nonetheless, their seasonality seems to be induced by a dynamical phenomenon, linked to the presence of a quasi-bidiurnal oscillation at mid-latitudes, and extending to high latitudes, rather than by the obliquity of its rotation axis. This oscillation is observed in numerical simulations with global climate models, although its signature depends on the model as well as on model initialisation. A quasi-bidiurnal signal seems also to be present in some analysis of spacecraft data from Venus Express (see for instance [1]), although it has still to be understood whether its nature and origin are common to the oscillation observed in numerical simulations.

2. Models

For Venus, we use two global climate models. These are the Oxford model and the LMD (Paris) model.
The new version of the Oxford Planetary Unified (Model) System for Venus (OPUS-Vr, [5]) is an expansion and improvement of an earlier simplified version [4]. This new version includes more accurate representations of radiative transfer, convection, clouds and boundary layer processes. The LMD model [2] also takes into account a realistic radiative transfer scheme, allowing the diurnal cycle to be fully represented. Most recent simulations have been run using an improved boundary layer scheme that improves the superrotation in the deep atmosphere.

3. Results

Both the OPUS-Vr GCM and the LMD GCM show an oscillation with a period of roughly 2 Venus days at the cloud top when the zonal wind is plotted against latitude and time (Figs. 1, 2, and 3). The oscillation affects the mid-high latitudes, and "seasonally" modulates the amplitude of zonal winds located at the periphery of the polar vortices. This model oscillation could possibly be physically interpreted as a mixed Rossby-gravity wave. Nonetheless, given the present uncertainty of model results when simulations are initialised in different ways (Figs. 3, 4), or different models are compared (Figs. 1, 3), it is difficult to assess whether the amplitude of this oscillation is likely to be relevant in the real atmosphere. If this quasi-bidiurnal oscillation was confirmed in the observations from spacecraft data, it could explain at least part of the observed variance of the mid-latitude zonal wind speed, and therefore account for part of the dynamical variability of the polar vortices on Venus. In this case, even a planet with negligible axial tilt as Venus could show seasonality of its polar vortices in a way analogue to what we are used to on other planetary bodies with an atmosphere in the Solar System.

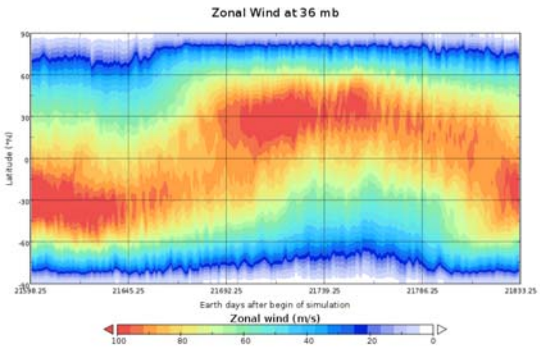

Figure 1: Zonal wind at the pressure level of 36 mb on Venus, as simulated by the OPUS-Vr GCM. The model has been integrated for roughly 260 Venus days from rest without topography before extracting the two Venus days we show here.

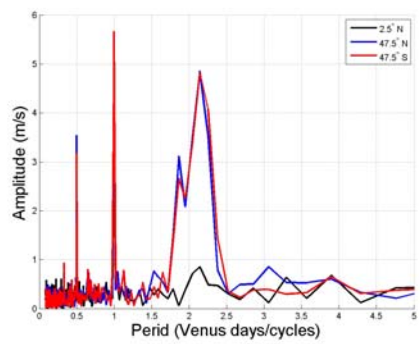

Figure 2: Spectrum of zonal wind from the OPUS-Vr GCM showing the peaks corresponding to the diurnal, semi-diurnal, and the quasi-bidiurnal oscillation at three latitudes (reproduced from [4]).

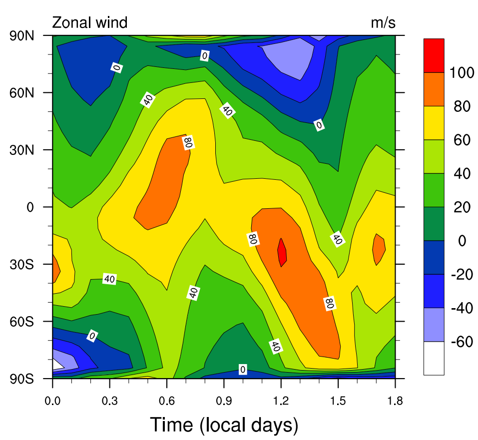

Figure 3: Zonal wind at the cloud top on Venus, as simulated by the LMD GCM. The model has been spun up for 880 Venus days from rest before extracting the two Venus days we show.

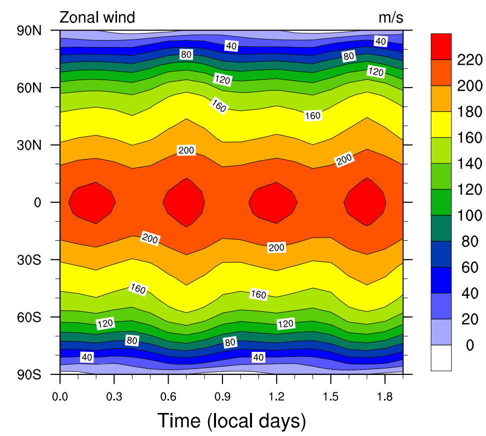

Figure 4: This plot shows the extreme sensitivity to initial conditions of some current Venus GCMs. Here we plot the zonal wind at the cloud top of Venus, as simulated by the LMD GCM when the model is spun up for 200 Venus days starting from an initial superrotating atmosphere. It is worth noting that the OPUS-Vr GCM does not show such a strong sensitivity to the initial conditions when starting from rest or from a superrotating atmosphere. The sensitivity to initial conditions is a key issue in current Venus GCM modelling [3].

References

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