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# Analysis of Titan's atmospheric circulation with the new IPSL Titan GCM

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## Abstract

The new IPSL Global Climate Model for Titan's atmosphere is presented, using the current version of the LMDZ GCM dynamical core with the physics of the IPSL Titan 2-dimensional climate model. Modifications in the boundary layer scheme has yielded strong improvements in the tropospheric zonal wind and potential temperature profiles modeled at Huygens descent position and season. The latitudinal profile of the near-surface temperature is close to observed values. The minimum of zonal wind observed by the Huygens probe just above the tropopause is also present in these simulations, and its origin is discussed by comparing solar heating and dynamical transport of energy. The stratospheric temperature and wind fields are consistent with our previous works. Compared to observations, the zonal wind peak is too weak (around 120 m/s) and too low (around 200 km). The temperature structures appear to be compressed in altitude, and depart strongly from observations above 300 km. These discrepancies are correlated, and most probably related to the altitude of the haze production (1 Pa), producing a detached haze layer located 150 km lower than observed by the Cassini instruments. This low production is due to the current limitations of the GCM at high altitudes. However, the temporal behaviour of the detached haze layer in the model may help understand the seasonal differences observed between the Cassini and Voyager 1 seasons. The tides and waves present in the GCM are analysed, together with their respective role in the angular momentum budget. Though the role of the mean meridional circulation in momentum transport is similar to previous work and the transport by barotropic waves is clearly seen in the stratosphere, a significant part of the transport at high latitudes is done all year long through low-frequency tropospheric waves, possibly baroclinic waves.

## 1. Introduction

The Cassini/Huygens mission has now allowed observations of the seasonal variations of Titan's atmosphere, from its arrival at $L_s \sim 300°$ into northern spring. To interpret the wealth of data now available, Global Climate Models arenow essential tools. The IPSL Titan GCM was initially developed in the early 90's (Hourdin et al, 1995) but further evolved in a simplified 2-dimensional version to allow for couplings with haze and photochemistry (Rannou et al, 2002). This climate model was able to interpret many features of the circulation, of the haze layer (Rannou et al, 2004) and of the stratospheric composition (Crespin et al, 2008), despite limitations inherent to its 2D restrictions.

## 2. New IPSL Titan GCM

A new version of the IPSL Titan's Global Climate Model has been developed based on the physics of the IPSL Titan 2-dimensional climate model plugged into the current version of the LMDZ General Circulation Model dynamical core. This GCM covers altitudes from surface to 500 km altitude, with the barotropic waves now being resolved and diurnal cycle included. Microphysics and photochemistry are still computed as zonal averages. The boundary layer scheme has been changed, yielding a strong improvement in the tropospheric zonal wind profile modeled at Huygens descent position and season.

## 3. Atmospheric structure

The simulations were initiated from the previous 2D-CM results. After 5 Titan years, the circulation was stable. Superrotation is maintained, though the peak amplitude of the winter jet has decreased. Stratospheric temperature and wind structures are similar to our previous works. Due to the limitations in the vertical extension of the GCM, the altitude of the detached haze layer is too low compared to observation, yielding discrepancies in the vertical structure of the temperatures and winds. Despite this difficulty, the GCM demonstrates the seasonal evolution of the detached haze layer, with a decrease in altitude after equinox that should help understand the difference between Cassini and Voyager 1 seasons.

The vertical profile of the zonal wind at the Huygens descent position (see Fig. 1 shows a good agreement of the tropospheric winds, as well as a local minimum in the lower stratosphere that could correspond to the one observed during Huygens descent. The GCM allows to analyse this in terms of interaction between opacity distributions, temperature structure and circulation.

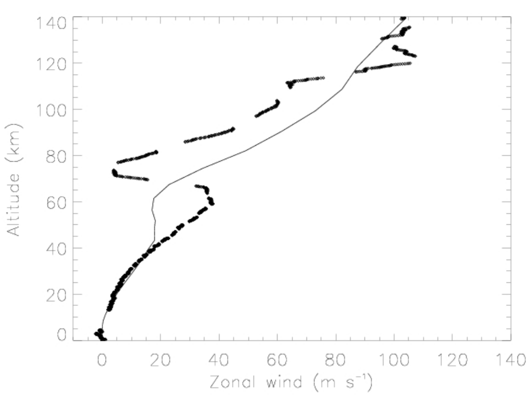


Figure 1: Modeled zonal wind at 10°S (zonal average) compared to Huygens observed profile.

Temperature and wind structures in the troposphere compare also well with available observations.

## 4. Role of tides and waves

Averaged over one Titan year, the transport of angular momentum is quite similar to previous models. The tides and waves present in the model are analysed. Stratospheric waves are present, mostly during solstice seasons between low latitudes and the winter hemisphere. They have wavenumbers of 1 and 2, frequencies around 12 cycles per Titan days, and are consistent with barotropic instabilities. Low frequency tropospheric waves are also seen and play a significant role in the angular momentum transport at high latitudes.

## 5. Conclusions

The IPSL Titan GCM is now back to full 3-dimensional capabilities. Despite difficulties related to the limitations in the altitude of the GCM upper boundary, this model confirms many features that were interpreted using our 2D-CM. The circulation in the troposphere is significantly improved, with the implementation of an up-to-date boundary layer scheme. The role of tides and waves is analysed, showing a surprising contribution of low-frequency tropospheric waves in the high-latitude transport of angular momentum.

To improve the details of the GCM and our understanding of the complex atmospheric processes occuring in Titan's atmosphere, comparisons between the results of this model and those of the recently published TitanWRF GCM (Newman et al, 2011) should prove very useful.

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