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Global Climate Modelling of Saturn's stratospheric equatorial and tropical oscillations

Deborah Bardet, Aymeric Spiga, Sandrine Guerlet, Ehouarn Millour, Alexandre Boissinot and Thomas Dubos.
Laboratoire de Météorologie Dynamique / Institut Pierre-Simon Laplace, Sorbonne Université, Centre National de la Recherche Scientifique (CNRS), Ecole Polytechnique, Ecole Normale Supérieure (ENS) (deborah.bardet@lmd.jussieu.fr)

1. Introduction

The Cassini spacecraft offered an unprecedented spatial and seasonal charaterization of Saturn's stratosphere. In particular, the CIRS infrared spectrometer on board Cassini revealed an equatorial oscillation of stratospheric temperature with semi-annual periodicity, associated with a putative vertical structure of winds similar to the Earth's Quasi-Biennal Oscillation [4]. CIRS observations exhibited anomalously high temperatures under Saturn's rings – or rather, the absence of a cold region underneath the ring's shadow [3]. To address these questions and better understand Saturn's atmospheric circulation in the stratosphere, we have extended towards higher altitudes the Global Climate Model for Saturn [5].

2. Saturn DYNAMICO GCM for stratosphere

The Saturn DYNAMICO GCM used to model Saturn's stratospheric dynamics employs the DYNAMICO icosahedral hydrodynamical core [1] coupled with the optimized physical packages tailored for Saturn, particularly radiative transfer [3]. We performed high resolution simulations (with an horizontal resolution of 1/2° in longitude/latitude) to resolve eddies arising from hydrodynamical instabilities and their forcing on planetary-scale dynamics. This Saturn DYNAMICO GCM was recently used to study the tropospheric dynamics [5], addressing topics such as tropospheric jet formation, evolution and stability, or planetary wave activity. In the present study, we performed new simulations with the model top extended to 1 μbar (instead of 3 mbar) in order to investigate Saturn's stratospheric circulations. We carry out a simulation lasting 11 Saturn years that exhibits several remarkable features in the stratosphere.

3. Equatorial oscillation

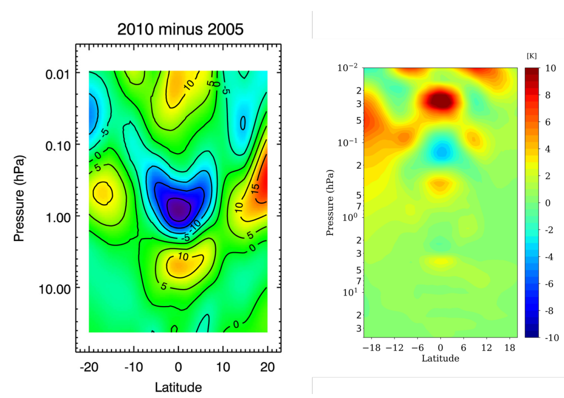

Figure 1: Latitude-pressure cross section of the temperature differences (left) between 2010 and 2005 obtained from Cassini/CIRS limb data acquired and (right) between two half-period-separated dates from Saturn DYNAMICO GCM.

There are alternatively eastward and westward jets at the equator, with a period less than half a year. The equatorial zonal jet shows a strong vertical shear, with positive and negative wind stacked on the vertical propagating downwards. However, winds are asymmetric in intensity: the eastward phase is weaker than the wesward one. It also undergoes episodes of very fast downward propagation of the zonal wind shear extrema. This pattern is similar to a QBO-like oscillation, although the downward propagation rate and period do not match exactly the observed ones [2]. Despite this difference in downward propagation, the stratospheric temperature shows similar patterns than the observed ones in altitude/latitude cross-section (Figure 1). Our simulations shows a stack of local maxima and minima of temperature at the equator, with opposite extrema at 15°N and 15°N. Hence, our Saturn GCM results are qualitatively consistent with Cassini/CIRS measurements [4].

4. Tropical oscillations

Between the bottom of the stratosphere (40 mbar) and the model top, our simulations exhibit two strong tropical (at 20°N and 20°S) oscillations of eastward and westward winds with an annual period. The eastward phase of these oscillations is correlated with the rings' shadow. By a comparison between two GCM simulations – one including the rings' shadow contribution into the incoming solar radiation and another one neglecting it – we show that these tropical oscillations are influenced by the rings' shadow. In the simulation without rings' shadow, the tropical oscillations are disturbed and the Eddies Kinetics Energy (EKE) is strongly reduced. The anomalous heating under rings' shadow revealed by Cassini/CIRS was supposedly explained by adiabatic heating due to subsidence motion [3]. However, using this Saturn GCM, we show that eddy activity linked to the rings' shadow thermal gradient significantly contributes to warming the stratosphere under the ring's shadow.

5. Conclusions and perspectives

We used a troposphere-to-stratosphere Saturn GCM to reproduce and interpret signature evidenced by Cassini/CIRS.

- We reproduce an semi-annual equatorial oscillation produced only by planetary-scale waves. This oscillation shows similar behavior in temperature than that observed, but it is irregular in period and too fast in downward propagation. To improve the physical forcings of the QBO-like oscillation in Saturn's equatorial stratophere, we will draw inspiration from Earth's atmospheric modeling. We plan to add a stochastic gravity wave drag parametrization to our GCM. This is expected to produce a more realistic wave spectrum, which would strongly impact the simulation of the equatorial oscillation and the downward propagation of winds.

- We reproduce two tropical annual oscillations which are seasonal and enhanced by the rings' shadow annual cycle. Rings' shadow increase wave activity and induce significant heating rate underneath it. These oscillations could explain the anomalously high temperature observed in Cassini/CIRS observations, but not in radiative simulations.

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