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A new Global Climate Model for Saturn's stratosphere and perspectives for other gas giants

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Introduction and Goals Giant planets are fascinating natural laboratories for geophysical fluid dynamics. Alternating jet-streams, great storms, and polar vortices, are well-known meteorological features of Jupiter and Saturn which opened new perspectives for atmospheric dynamics [1]. In the last decade, mysteries were added to the list of dynamical phenomena on gas giants, while a new vision emerged on seasonal evolution of their atmosphere. Maps of the temperature and of the distribution of hydrocarbons in Saturn's stratosphere have been obtained by the Cassini spacecraft with unprecedented details. These maps exhibit puzzling anomalies : equatorial oscillations with a period of about half a Saturn year [2], interhemispheric circulations affecting the hydrocarbons' distribution, including possible effects of rings shadowing [3], sudden warming associated with the powerful 2010 Great White Spot [4]. Those signatures cannot be explained by current photochemical and radiative models, which do not include dynamics. Hence it is suspected that 1. the observed anomalies arise from large-scale dynamical circulations and 2. those large-scale dynamical motions are driven by atmospheric waves and convection, through fundamental mechanisms giving birth to, e.g., the Quasi-Biennal Oscillation and Brewer-Dobson circulation in the Earth's middle atmosphere. Analogous phenomena are thought to occur as well in the jovian atmopshere, although with distinct properties [Quasi-Quadriennal Equatorial Oscillation 5]. Recently, Global Climate Models (GCMs) were able to provide hints of the importance of wave-driven atmospheric dynamics in gas giants, either for tropospheric jet-streams [6] or stratospheric structures [7]. Here we report the development and preliminary simulations of our new Saturn GCM which aims at understanding the seasonal variability, large-scale circulations, and wave activity in Saturn's troposphere and stratosphere, before becoming a useful platform to study atmospheric circulations in all gas giants.

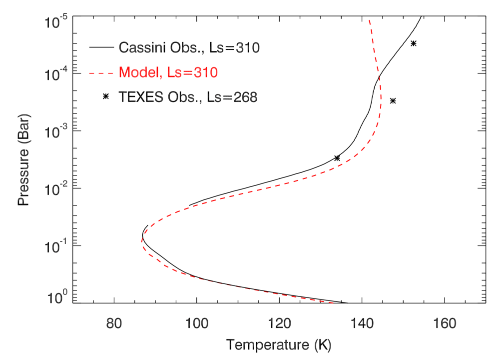

Figure 1: *Temperature profiles averaged between 40S and 40N as observed by Cassini/CIRS at* $L_s = 310°$ *(in black, combining nadir and limb observations) and as produced by the model (red dashed lines). For comparison, ground-based observations acquired at 40°S,* $L_s = 268°$ *are shown at three pressure levels. Figure extracted from [8].*

A 3D radiative model as a first step Existing modeling tools for Saturn lack either the physical parameterizations tailored to each gas giants' environment, the horizontal resolution, or the vertical extent from the troposphere to the stratosphere to fully address the wave-driven mechanisms responsible for the observed anomalies by Cassini. In order to start bridging this gap, we recently formulated dedicated physical parameterizations for Saturn's atmosphere, with a particular emphasis on radiative computations (using a correlated-k radiative transfer model, with radiative species and spectral discretization tailored for Saturn) aimed at both efficiency and accuracy, and validated them against existing Cassini observations [8]. We have also carried out an exploration of the sensitivity of modeled temperatures to spectroscopic parameters, hydrocarbons abundances, aerosol properties, and ring shadowing effects. In the troposphere, our model reproduces the observed temperature knee caused by heating at the top of the tropospheric aerosol layer. In the lower stratosphere, the overall meridional gradient between the summer and the winter hemispheres agrees with observations except in the equatorial region, where the temperature structure is governed by the dynamical equatorial oscillation. Eventually, by comparing the purely radiative model to the Cassini observations, we found several examples where Saturn's atmosphere departs from radiative equilibrium. For instance, we find that the modeled temperature profile is close to isothermal above the 2-mbar level, while the temperature retrieved from ground-based or Cassini/CIRS data continues to increase with altitude (Fig 1). Also, no local temperature minimum associated to the ring shadowing is observed in the data, while the model predicts stratospheric temperatures 10K to 20K cooler than in the absence of rings at winter tropical latitudes. These anomalies are strong evidence that processes other that radiative heating and cooling control Saturn's stratospheric thermal structure – atmospheric dynamics being a plausible cause for those signatures (Fig 2).

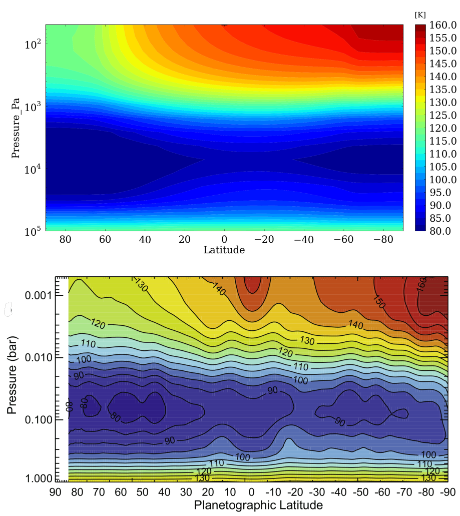

Figure 2: *Comparison between Cassini/CIRS observations for year 2005 [9] with our Saturn 3D radiative model at* $L_s \sim 300^\circ$. *The seasonal hemispheric contrast is well reproduced; remaining differences (cf. equator, midlatitudes) can be most probably attributed to atmospheric dynamics.*

Enter atmospheric dynamics Once our radiative model has been built [8], it is interfaced with the LMDz dynamical core [10] to run three-dimensional GCM runs of Saturn's troposphere and stratosphere. We set 64 vertical levels from $3\,10^5$ to 10^{-1} Pa and, as a preliminary step before running finer resolution runs, we use a typical horizontal grid of 128×96 grid points (with a few tests simulations with 256×128 horizontal grid points). We tested simulations with either nudging towards the observed zonal jets structure, or no particular dynamical forcing. We will report the results of those preliminary simulations at the conference, with an emphasis on waves and eddies arising in our Saturn GCM, and how momentum is transferred from eddy-mean flow interactions, thereby coupling the troposphere and the stratosphere. We also explored the sensitivity of our results to horizontal dissipation used in our GCM [Indurain et al., EPSC 2014, this issue]. A further objective of our project is to characterize the fundamental processes governing any giant planet's troposphere and stratosphere. Perspectives are twofold: firstly, we will broaden our knowledge of atmospheric waves and instabilities in more extreme environments than the Earth; secondly, we will use our GCM tool to interpret past and future (e.g. Juno, JUICE for Jupiter) observations of gas giants inside and outside our Solar System.

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