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A new Global Climate Model to explore the rich dynamics of Saturn's stratosphere

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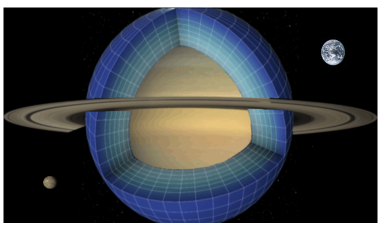
We report the development and first simulations of a new Saturn GCM which aims at understanding the seasonal variability, large-scale circulations, and waves recently observed in Saturn's stratosphere.



New observations, new questions Recent observations of the Saturn's atmosphere have shed a new light on its thermal structure, chemistry, and dynamics. In particular, a leap forward on our knowledge of Saturn's stratosphere has resulted from the combination of orbital observations on board the Cassini spacecraft and state-of-the-art ground-based observations. Maps of temperature and hydrocarbons in Saturn's stratosphere revealed puzzling anomalies: equatorial oscillations with a period of about half a Saturn year [3, 10], meridional circulations affecting the hydrocarbons' distribution, including possible effects of rings shadowing [5], "beacons" associated with the powerful 2010 Great White Spot [1]. Those signatures, reminiscent of fundamental dynamical phenomena in the Earth's middle atmosphere (e.g., Quasi-Biennal Oscillation, Brewer-Dobson circulation), cannot be explained by photochemical and radiative models. A rich, wave-driven atmospheric dynamics plays a crucial role in Saturn's stratosphere, hence the need to develop new three-dimensional dynamical models to understand it.

Modeling context Most existing Global Climate Models [GCMs] for the Saturn atmosphere focus on how tropospheric jets form [8], and their deep vs. shallow nature [7]. Recently, the GCM approach has also been adopted for Saturn's stratosphere, either to constrain large-scale advection / eddy mixing in photochemical models [4], or to build a modeling framework applicable to extrasolar hot giants [9]. Here we report the development of a new Saturn GCM aimed at characterizing the Saturn's seasonal variability, large-scale circulations, and waves evidenced by recent observations.

Building our new Saturn GCM Our Saturn GCM is based on the LMDz dynamical core [6], which has been successfully adapted to terrestrial planets and moons: the Earth, Mars, Venus, Titan, Triton/Pluton. Our radiative transfer is based on a correlated-k radiative transfer model [12] to account for heating by methane (CH_4) in Saturn's stratosphere, as well as cooling by CH_4 and hydrocarbons produced by its photodissociation (ethane C_2H_6 and acetylene C_2H_2). We include Collision-Induced Absorption (CIA) for H_2-H_2 and H_2-He [11]. We have developed parameterizations for internal heat flux, aerosol absorption, and rings shadowing. Radiative calculations in the model are carefully assessed and optimized to maximize both performance and accuracy [Guerlet et al., in preparation].

Simulations and first results At the time of writing, we achieved two kinds of preliminary three-dimensional GCM simulations of Saturn's stratosphere: "coarse-resolution runs" (64 longitude $\times$ 48 latitude grid points) to validate radiative transfer calculations and reach equilibrium, and "medium-resolution runs" (240×240) to test the performance of the dynamical core when the characteristic Rossby radius of deformation is resolved. In both cases, we set 26 vertical levels from 0.66 bars to 0.1 Pa. Results from the coarse-resolution runs [Figure 1] show that the modeled seasonal variations of the stratospheric temperature follow the observed trends [2] despite differences up to 5 K. A moderate jet-stream arises in the winter hemisphere around al-

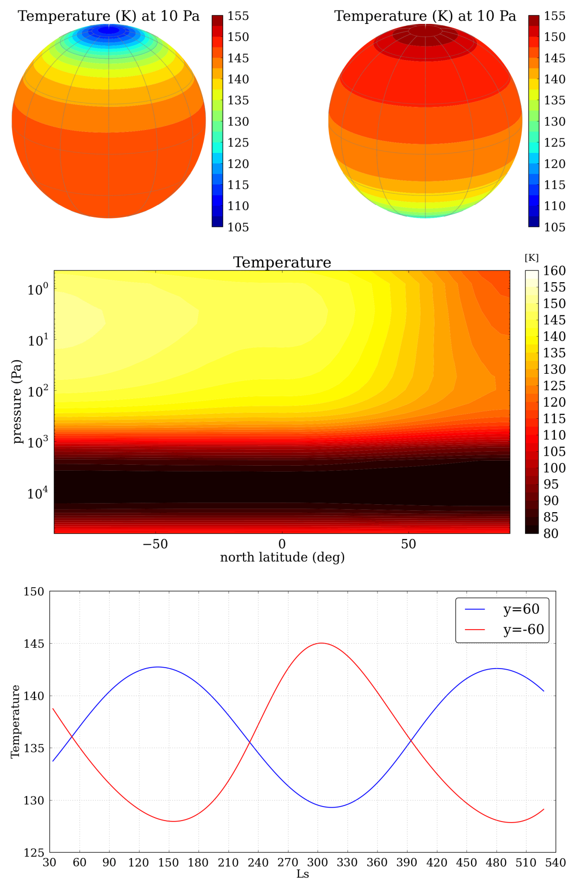


Figure 1: *Temperatures predicted by a* $64 \times 48 \times 26$ *simulation with our LMD Saturn GCM. [Top] Global maps at* 10 *Pa close to northern winter (left) and summer (right). [Middle] Section at longitude* $0°$ *for solar longitude* $Ls = 320°$. *[Bottom] Seasonal variations at latitude* $60°$*N (blue) and* $60°$*S (red), longitude* $0°$*, and altitude* 100 *Pa.*

titudes $10 - 100$ Pa as a result of latitudinal contrasts in temperature. Medium-resolution runs indicate that only low-intensity eddies appear in the stratosphere in those conditions. Additional GCM simulations conducted with prescribed alternating jets, characteristic of Saturn's troposphere and lower stratosphere, will be presented at the conference. Stronger eddies are expected to arise from barotropic instability and momentum transfer from the jets. The influence of internal heat flux, and ring shadowing, is also currently investigated and will be reported at the conference.

Perspectives Our GCM is aimed at studying Saturn's stratospheric dynamics with a broader scope in mind. For instance, we plan to study more closely the coupling between Saturn's troposphere and stratosphere, as well as photochemical-radiative-dynamical feedbacks. A further objective of our project is to characterize the fundamental processes governing any giant planet's stratosphere. Perspectives are twofold: firstly, we will broaden our knowledge of geophysical fluid dynamics by studying 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.

Support ANR (PDOC) and UPMC (Émergence).

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