Parameterizing gravity waves in the DYNAMICO-Saturn Global Climate Model to understand Saturn's equatorial oscillation

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To address questions about the driving mechanisms of Saturn's equatorial oscillation, our team at the Laboratoire de Météorologie Dynamique built the DYNAMICO-Saturn Global Climate Model to study tropospheric dynamics, tropospheric waves activity (Spiga et al. 2020) and equatorial stratospheric dynamics (Bardet et al. 2020) of Saturn. Previous studies (Guerlet et al. 2014, Spiga et al. 2020, Cabanes et al. 2020) have shown that our model produces consistent thermal structure and seasonal variability compared to Cassini CIRS measurements, mid-latitude eddy-driven tropospheric eastward and westward jets commensurate to those observed and following the zonostrophic regime, and planetary-scale waves such as Rossby-gravity (Yanai), Rossby and Kelvin waves in the tropical channel. Extending the model top toward the upper stratosphere allowed our model to produce an almost semi-annual equatorial oscillation with opposite eastward and westward phases. Associated temperature anomalies have a similar behavior than the Cassini/CIRS observations, but the amplitude of the temperature oscillation is twice smaller than the observed one. The absence of sub-grid-scale waves in the model produces an imbalance in eastward- and westward-wave forcing on the mean flow and could be an explanation to the irregularity in both the oscillating period and the downward rate propagation of the resolved Saturn equatorial oscillation.

To explore the impact of those small-scale waves on the spontaneous equatorial oscillation emerging in the DYNAMICO-Saturn GCM (Bardet et al. 2020), we add a sub-grid-scale non-orographic gravity waves drag parameterization in our model.

This parameterization is directly adapted from the stochastic terrestrial model of Lott et al. (2012). This formalism represents a broadband gravity wave spectrum, using the superposition of a large statistical set of monochromatic waves. As the time scale of the life cycles of gravity waves is much longer than the time step of our GCM, our parameterization can launch a few waves whose characteristics are randomly chosen at each time step. This stochastic gravity waves drag parameterization is applied in DYNAMICO-Saturn on all points of the horizontal grid.

A key parameter used in the non-orographic gravity waves drag parameterization is the maximum value of the Eliassen-Palm flux. The Eliassen Palm flux represents the momentum carried by waves that could be transferred to the mean flow. This value has never been measured in Saturn's atmosphere and it represents an important degree of freedom in the parameterization of gravity waves.

We performed several test simulations, lasting two Saturn years whose initial state is derived from Bardet et al (2020), with an horizontal resolution of 1/2° in longitude/latitude and a vertical
resolution ranging between 3 bar to 1 μbar. For these test simulations, the maximum value of the Eliassen-Palm flux is set to $10^{-6}$, $10^{-5}$, $10^{-4}$ and $10^{-3}$ kg m$^{-1}$ s$^{-2}$.

Preliminary results show that the appropriate value of our main parameter is between $10^{-5}$ and $10^{-4}$ kg m$^{-1}$ s$^{-2}$. Eliassen-Palm flux value of $10^{-3}$ kg m$^{-1}$ s$^{-2}$ demonstrates a too large impact: the equatorial oscillation is entirely vanished in this configuration. The simulation using the value of $10^{-6}$ kg m$^{-1}$ s$^{-2}$ is equivalent to the control simulation without the gravity waves drag parameterization.

The next step is to test other parameters, as phase velocity of the gravity waves, horizontal wavenumber, to understand how gravity waves impact the equatorial oscillation.