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A study of sensitivity to dissipation in a Global Climate Model of Saturn

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Goals Our overall goal is to build a Global Climate Model [GCM] to study the dynamics of Saturn's troposphere and stratosphere [Spiga et al. EPSC 2014, this issue]. A GCM consists basically in an interface between an hydrodynamical core which computes numerically the solution to Navier-Stokes equations, and physical parameterizations in which the various forcings (radiative transfer, latent heat exchanges within clouds, subgrid-scale mixing) applied to the atmospheric fluid are calculated. Thus, a first step was to develop tailored physical parameterizations for the Saturn's atmosphere [2]. We report here on part of the second step to build our Saturn GCM: testing the LMDz dynamical core [3] in the fast-rotating conditions of gas giants' atmospheres.

Lateral dissipation, an overlooked issue in GCMs Accounting for dissipative processes is needed in GCMs to ensure the stability of simulations and to represent the impact of unresolved processes on the global circulation of the planet. Most subgrid-scale phenomena are resolved by physical parametrizations (e.g. gravity wave drag). Nevertheless, all dynamical interactions between scales, notably the cascade of energy from large scales to smaller scales, cannot be fully accounted for. Hence those are represented by an horizontal diffusion operator in dynamical equations [6]:

$$\frac{\partial \psi}{\partial t} = Dyn(\psi) + Phy(\psi) + F_\psi$$

where ψ can be either potential temperature or horizontal wind components. $Dyn(\psi)$ represents time tendencies from the dynamics, $Phy(\psi)$ time tendencies from the subgrid scale parametrization and F_ψ is the dissipation operator:

$$F_\psi = \frac{(-1)^{q+1}}{\tau} \nabla^{2q} \psi$$

where q and τ are respectively the order and time constant of dissipation. This operator is useful to deal with the energy accumulation (namely, spectral blocking) at the smallest resolved grid scale. Moreover, possible amplification of numerical noise need such damping to prevent them from destabilizing the model integrations. Thus, understanding the impact of dissipation in a GCM [which depends on the considered planet, horizontal resolution, dynamical core, etc..., see 4, for a more detailed discussion] is an essential aspect when using this tool to address dynamical processes.

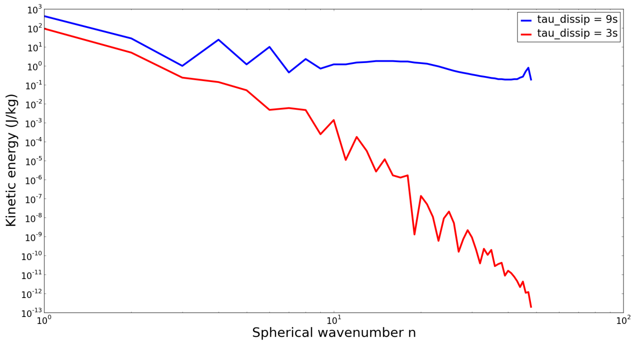

Figure 1: *Energy spectra from a stratospheric GCM simulation of one Saturn year with 64x48x64 grid points. First simulation (blue) has weaker dissipation values.*

Spectral analysis Changing the strength of dissipation operator does not have necessarily a visible impact on usually observed fields (temperature, wind, pressure...). A dedicated method to explore the impact of dissipation is needed. Regarding horizontal dissipation, spherical vectorial harmonic basis is used. The order of truncation M of this basis is correlated with the smallest space length of the grid. The surface mean of kinetic energy is given [5] at every wavenumber $1 \leq n \leq M$ by:

$$KE_n = \frac{a^2}{4n(n+1)} \Bigg[\xi_n^0 (\xi_n^0)^* + \delta_n^0 (\delta_n^0)^* \\ 2 \sum_{m=1}^{n} \xi_n^m (\xi_n^m)^* + \delta_n^m (\delta_n^m)^* \Bigg]$$

where complex scalars ξ_n^m and δ_n^m are linked to the spectral coefficients of the horizontal velocity and a denotes the planet radius. Velocity is taken at a given altitude and time and projected on the spherical vectorial harmonics basis using the Spherepack library from UCAR.

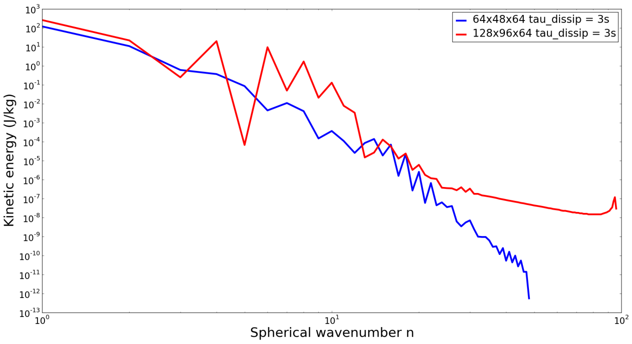

Figure 2: *Energy spectra from a stratospheric GCM simulation of one Saturn year with 64x48x64 and 128x96x64 grid points. Both simulations have the same dissipation values.*

Firsts results Given a grid resolution and a time step, different dissipation operators and dissipation values are tested. The goal is to find, for a given simulation, the set of parameters that lead to a transfer of energy from large scales to subgrid dimensions. Figure 1 shows the influence of dissipation values on the energy spectra. Strong values prevent the model from spectral blocking at small wavenumber (here M=64) which give a more realistic simulation. Increasing space resolution (figure 2) makes the dissipation operator to be less active and dissipation values must be strengthened to avoid energy accumulation at large wavenumber.

Perspectives We find that, as could be expected, the right value of dissipation is a trade-off: too weak coefficients lead to unrealistic integrations corresponding to the model going numerically unstable, and too strong damping yield an unrealistic smoothed dynamical fields (e.g., winds). The outcome of our dissipation analysis is that we are able to infer the right value of dissipation which would avoid the accumulation of energy at small scales, while not too strongly smooth out the prediction for winds, temperature, in our GCM. The analysis is carried out here for the Saturn case, but we were also able to apply it in terrestrial and Martian versions of our GCM [3, 7, 1].

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