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Global Climate Model simulations of Jupiter’s atmospheric circulation: assessing the influence of different boundary conditions and forcings

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Jupiter’s iconic banded cloud structure correlates approximately with alternating eastward and westward zonal jets located at the edges of the “zones” and “belts”, from the tropics to 70° latitude. At higher latitudes, the mean zonal flow is weak and many cyclones and anticyclones are observed, well studied thanks to the Juno spacecraft [1]. At the equator, the flow is characterized by an eastward (super-rotating) jet, reaching 100 m/s.

Zonal jets are thought to emerge through an inverse energy cascade, from small to large scales, owing to the turbulent nature of Jupiter’s atmosphere combined to its rapid rotation period [2]. However, the nature and depth of the small-scale forcing and the precise processes shaping these jets remain debated.

Although these jets extend rather deep (3000 km, or 4% of the planet’s radius [3]), evidence of inverse energy cascade has been reported at cloud level [4], suggesting that eddy forcing at meteorological scales could be an important driver for the jets.

Such jets are indeed well reproduced in shallow water models and emerge from baroclinic instabilities at scales of typically one to a few degrees in latitude x longitude, or a few thousand km [2], while it has also been suggested that convective activity at much smaller scales (20 – 100 km) can also play and important role in energy injection [5,6]. The role of moist convection (both at large scale and through small-scale storms) on large-scale circulation is also poorly known. In any case, simulating these jets with a Global Climate Model (GCM) is a numerical challenge and the resulting circulation is highly dependent on the model set-ups [eg., 7].

We are developing a GCM tuned to Jupiter’s atmosphere that solves the Navier-Stockes equations on an icosahedral grid [8], coupled to several physics “packages” including radiative transfer [9]. Radiative heating and cooling rates are computed with a correlated-k model that includes opacity by methane, ammonia, ethane, acetylene and water, along with H2-H2 and H2-He collision-induced absorption. Several radiatively active cloud and aerosols layers are included, whose optical depth vertical profile are set fixed during the simulation. An internal heat flux is included, that is either set fixed (at 7.5 W/m2) or increases with latitude. At the bottom of our model, we can either impose a Rayleigh drag (except near the equator, similarly to [7]) with a given characteristic timescale, or set a free-slip condition.

Previous work in our group investigated the impact of employing a sub-grid scale parametrization for small-scale convection, called the thermal plume model, compared to a dry case, on the mean zonal flow [10]. Here we performed additional Jupiter simulations without the thermal plume model but with dry and moist convective adjustments that instantaneously mix enthalpy. Compared to the work by [10], we have extended the model down to 20 bars (instead of 10 bars) and up to 0.1 mbar (instead of 20 mbars), with 96 vertical layers, and have included water vapour in the correlated-k tables. Simulations are performed at a horizontal resolution equivalent to 0.5° in latitude x longitude and the water specific concentration at depth is set to 0.02 kg/kg, which corresponds to 3 times the solar abundance.

In this work, we investigate several factors shaping Jupiter's zonal jets (their number, width, intensity) by varying the intensity of the bottom drag or even suppress it (free-slip condition) and by testing the influence of setting the internal heat flux constant or increasing with latitude. In these different simulations, three to four prograde jets per hemisphere emerge, while the flow is retrograde at the equator (see an example fig. 1).

Figure 1: Instantaneous zonal wind at 1 bar obtained after 3 years, for a simulation with a bottom drag (except at latitudes < 16°) and with an internal heat flux varying between 6 W/m2 at the equator to 10.5 W/m2 at the poles.

We plan to complete these preliminary results with other simulations run without moist convection, and with a non-instantaneous moist adjustment, and will discuss the dominant mechanisms shaping the atmospheric flow in our Jupiter GCM simulations by characterizing eddy-to-mean flow interactions in each experiment.

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