Modeling atmospheric dynamics in Jupiter's troposphere

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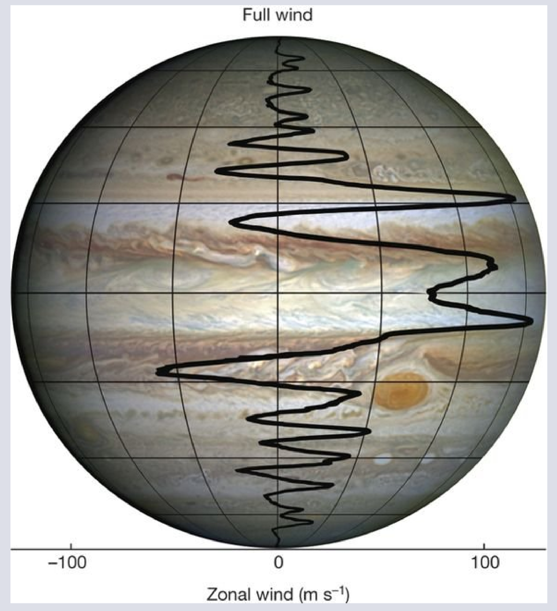
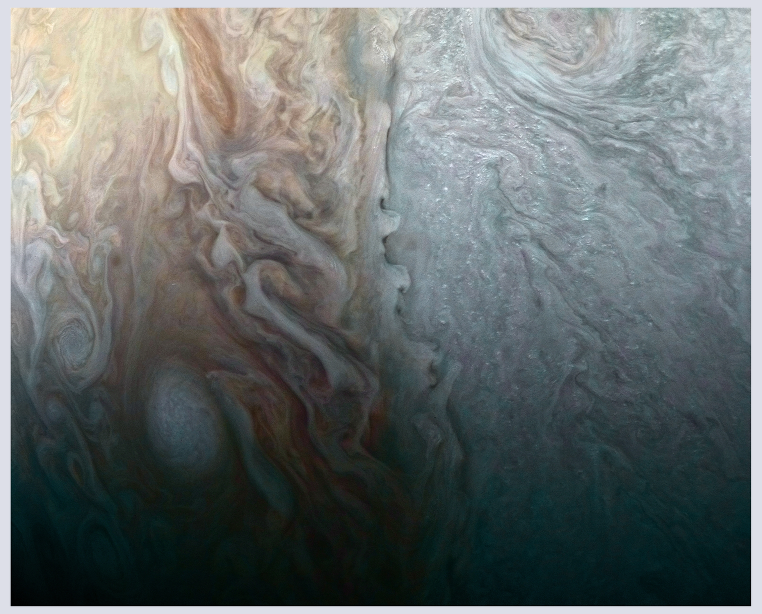
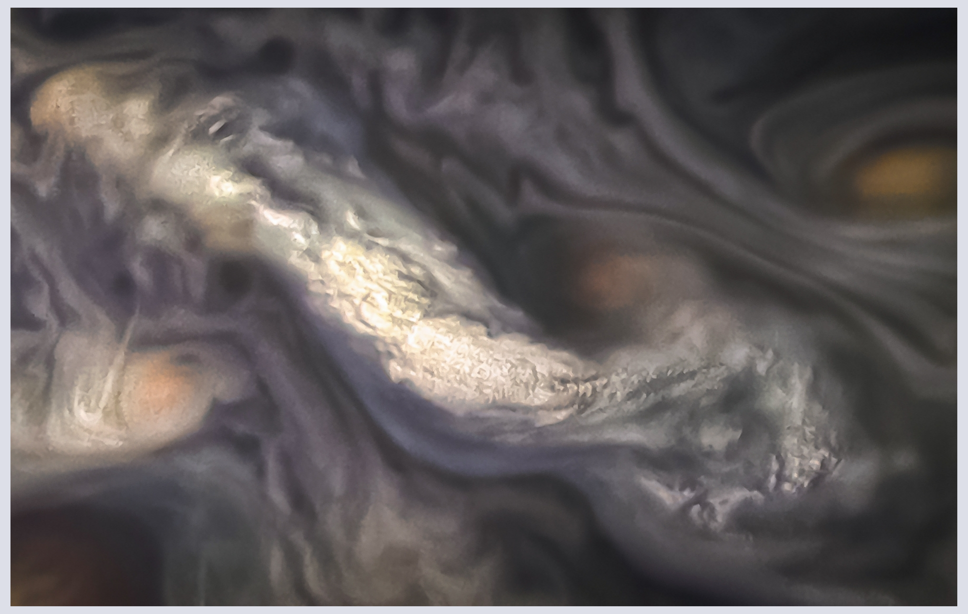
Background and motivation



Jupiter zonal wind (Kaspi, Galanti et al., Nature, 2018)



Turbulence and clouds (Juno, STSI)

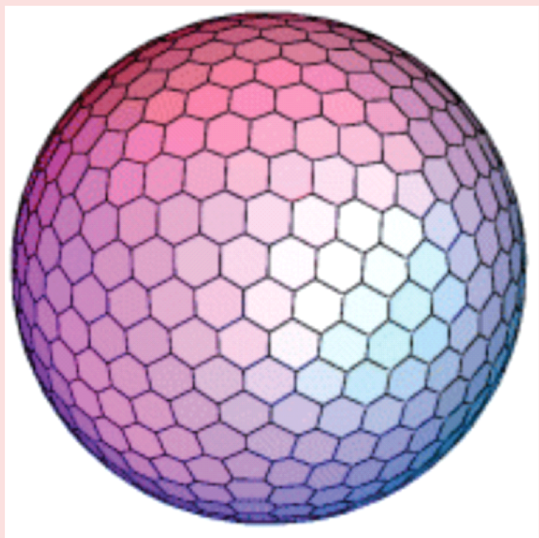


Jupiter storm (Juno, SwRI)

Jupiter's atmosphere is mainly characterised by alternately prograde and retrograde jet streams, a strong equatorial superrotation and large and long lifetime vortices. Galileo highlighted convective activity on Jupiter through ligthnings and storms observations. More recently, Juno has shown poles more turbulent than low- and mid-latitudes regions. We are seeking to understand these features by the way of a general circulation model (GCM) which models the whole Jupiter atmosphere.

Model used to simulate Jupiter's atmosphere

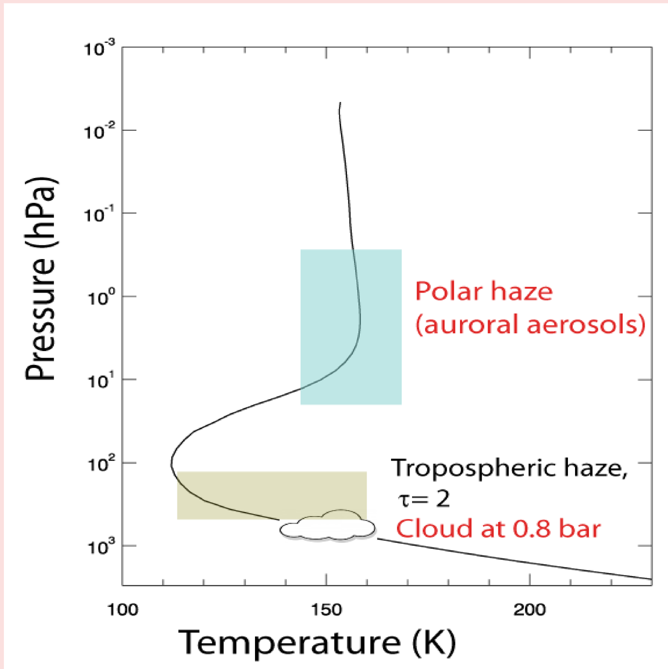
The under development Jupiter GCM was adapted from the Earth GCM Dynamico. It contains a dynamical core which solves the primitive equations under the hydrostatic and shallow water assumption (*Dubos, Dubey et al., GMD, 2015*) and several subgrid scale physics parametrisations. The model uses an icosahedral mapping which allows for efficient massively parallel computations through good scalability properties.



Model icosahedral grid

Parametrisations

- Radiative transfer (cf. *Guerlet, Spiga et al., Icarus, 2014*)
- Internal heat flux
- Convective adjustment
- Bottom drag (cf. *Liu and Schneider, JAS, 2010*)
- Dissipation



Modelled temperature profile

Reference simulation settings

Model grid

- Horizontal resolution: 1/2°
- Vertical resolution: 32 levels from 3 bar to 1 mbar

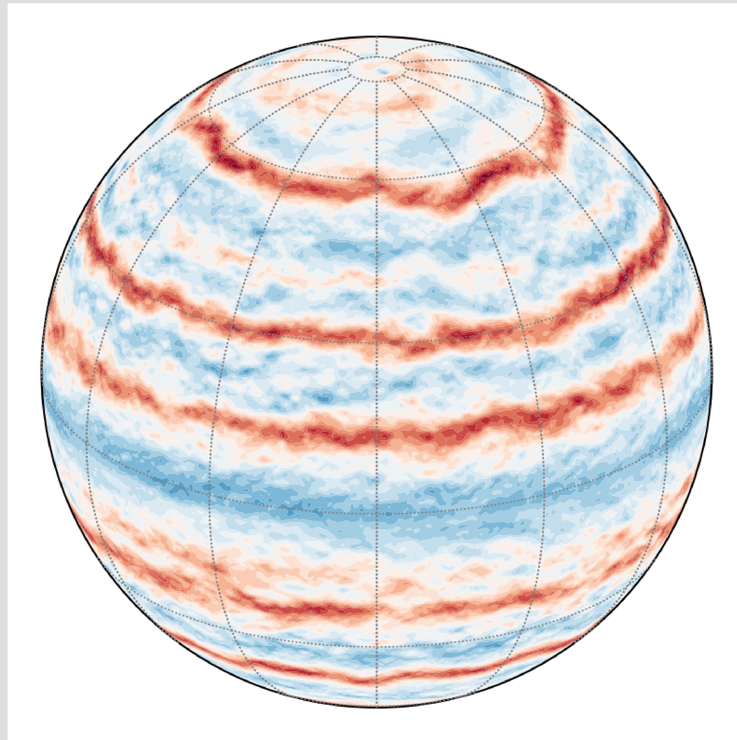
Boundary conditions

- Initial state: zero wind
- Dissipation: $\tau_d = 50\,000$ s
- Bottom drag: $\tau = 100$ jovian days

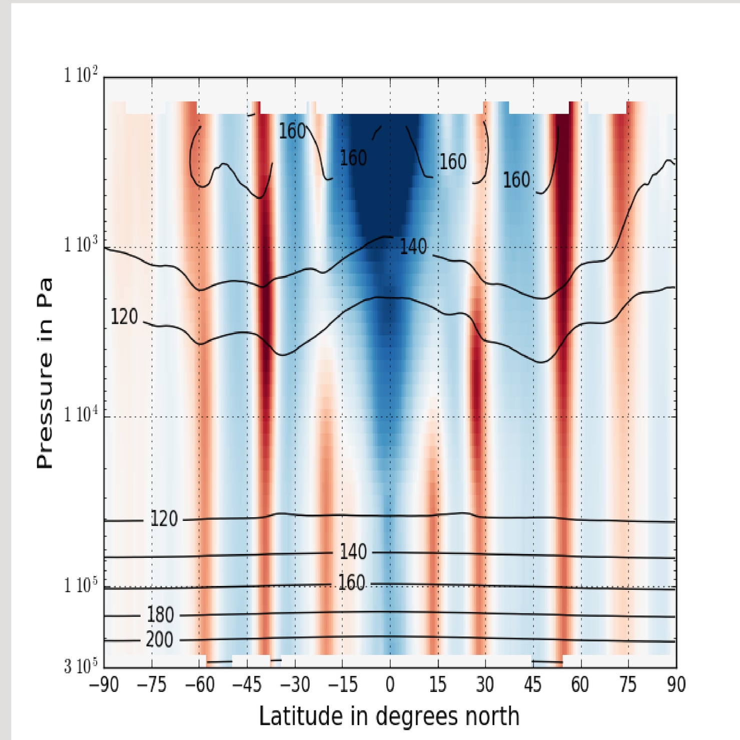
Machinery

- MPI+OMP code
- Cores: 1200
- Results are shown after a 4 jovian years integration

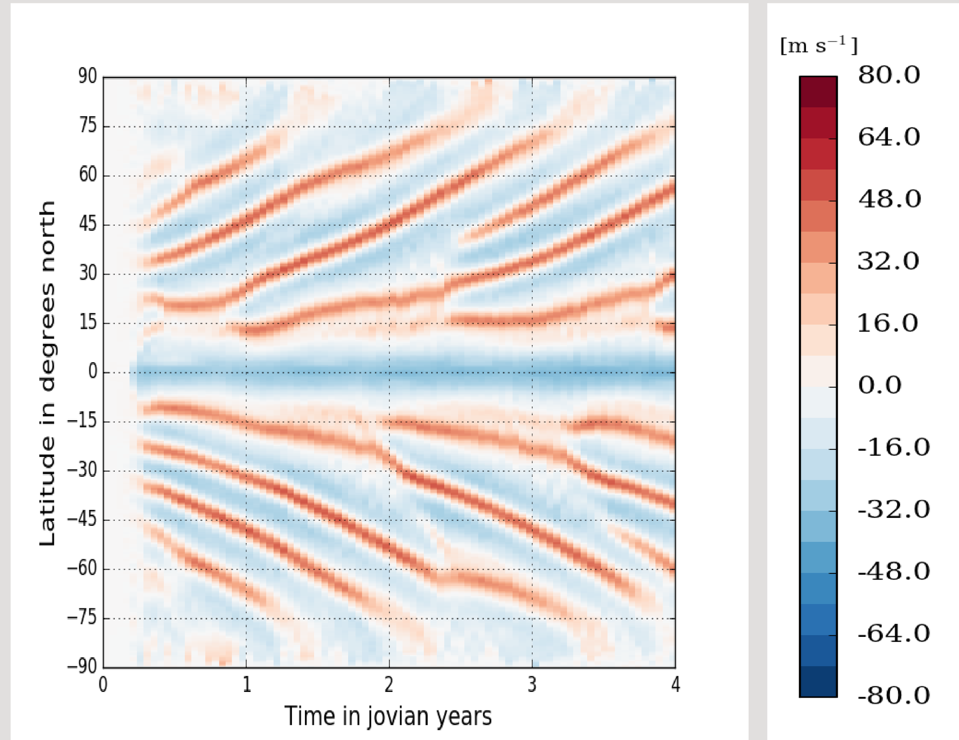
Reference simulation results



Zonal wind at 1 bar



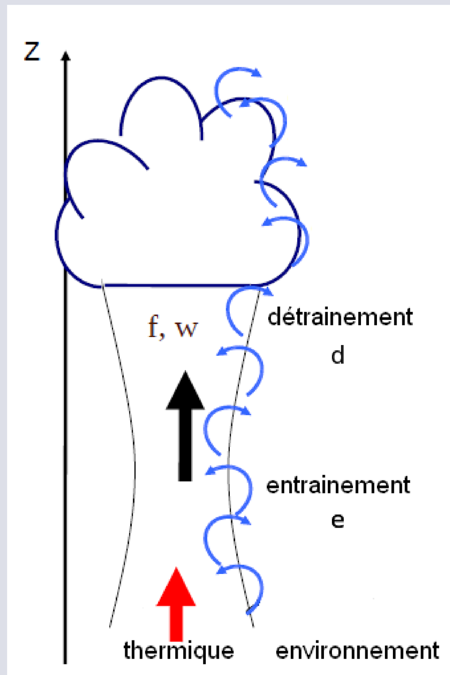
Jets vertical profile



Jets migration at 1 bar

In the reference simulation, the model produces jets alternatly progrades and retrograde whose speeds have a good order of magnitude. However, they are larger and less numerous (they are 13 instead of about 25) than the observed ones. The superrotation is also missing. These differences might be explain by an insufficient spatial resolution or by the very simple convective parametrisation we used and which is unable to create instabilities. Moreover, the reference simulation shows a jets migration caused by the baroclinic and barotropic instabilities which is not observed.

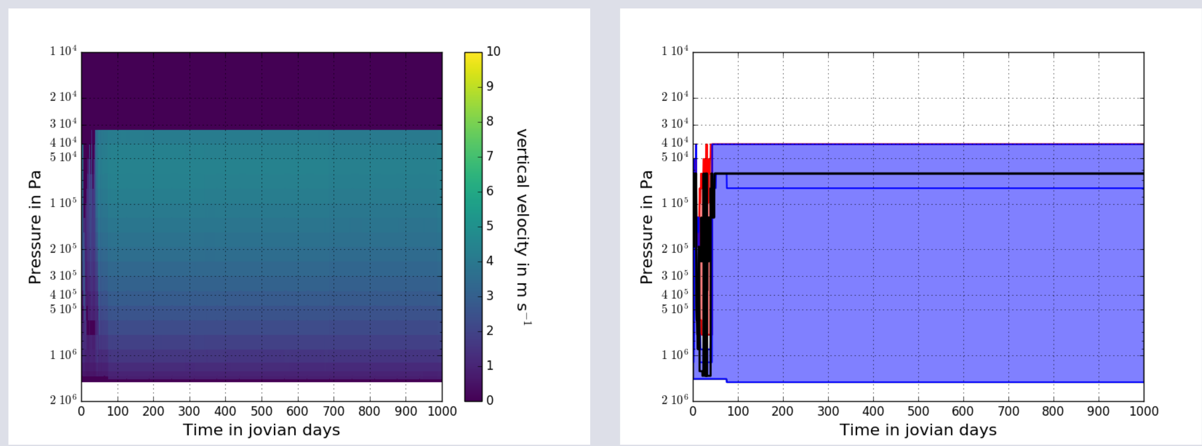
Model new moist convection parametrisation and prospects



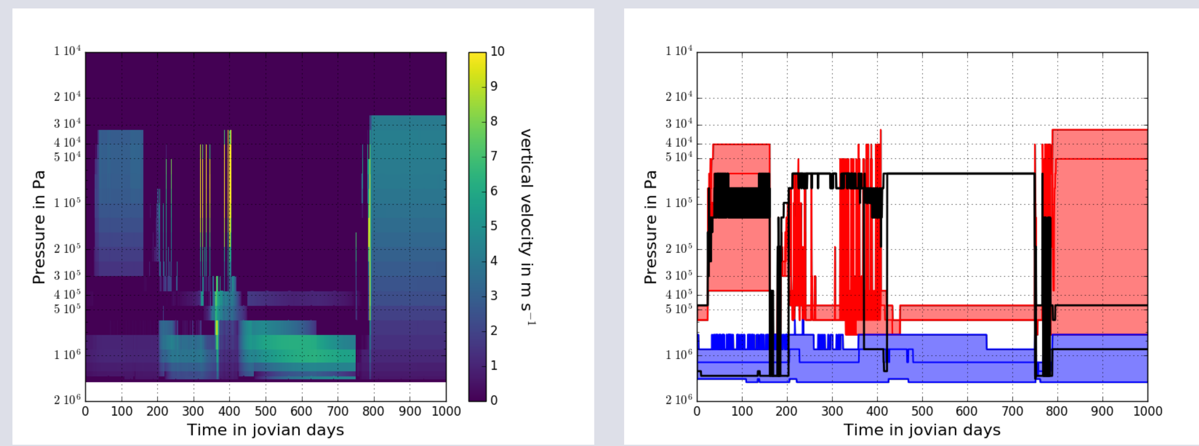
In order to investigate the previously mentioned issues, we want to replace the convective adjustment by a thermal plume model originally developed for Earth (*Rio, Hourdin et al., Bound.-lay. Meteorol., 2010*). This mass flux parametrisation constructs a representative plume for each grid point and computes its properties along the vertical. The main equations are:

$$\frac{\partial f}{\partial z} = e - d \qquad \frac{\partial fw}{\partial z} = -dw + \alpha\rho\Gamma$$

where w is vertical speed, f the vertical mass flux, e the entrainment, d the detrainment, ρ the density, α the updraft fraction and Γ a parametrisation of turbulence effects.



Vertical speed, dry case



Vertical speed, moist case (3 solar abundance)

1D results show continuous convective activity in dry cases, rising from the model bottom to a few hundreds mbar. When we add water vapor for $p < 4$ bars, we can see a transient state where mixing is assured by intermittent convective plumes driven by latent heat release. Then, when water is well mixing from the bottom to the top of the unstable region, we find a dry case-like steady state. In the near future, tests will be expended to 3D dynamical simulations.

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