Jets, eddies & waves in Saturn's troposphere and stratosphere from multi-annual high-resolution Global Climate Modeling

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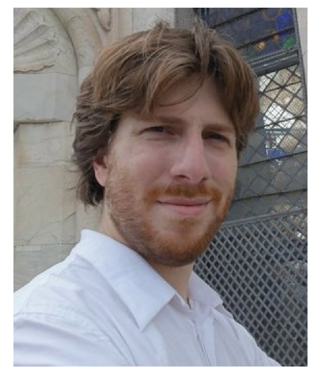
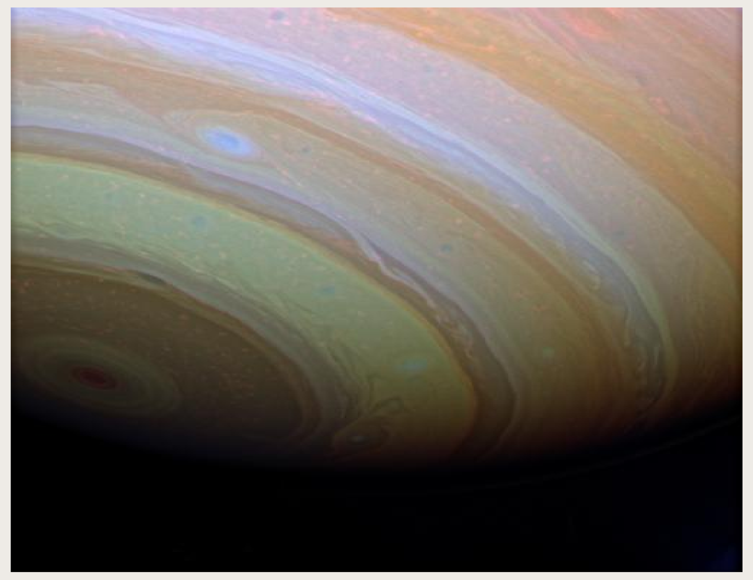
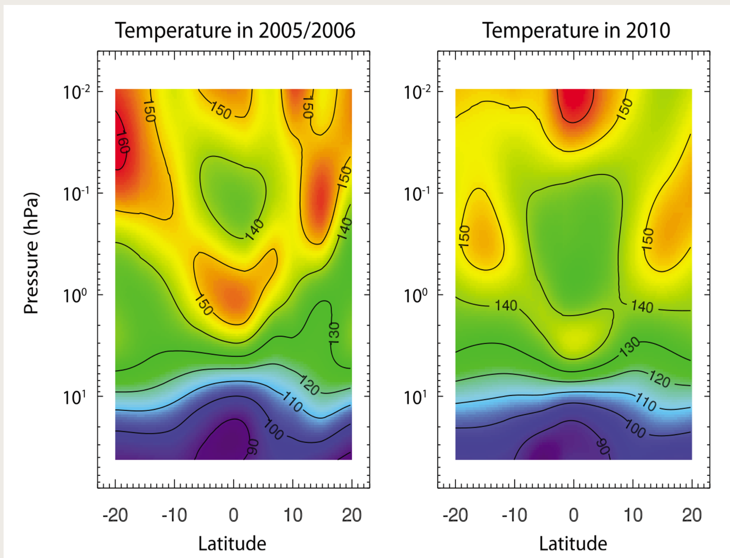


Background and motivation

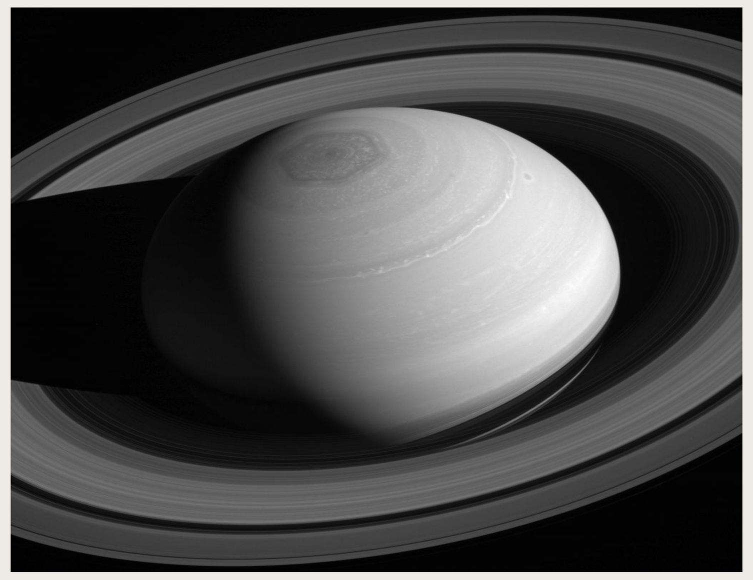
Tropospheric jet-streams



Stratospheric oscillations Guerlet et al. 2011



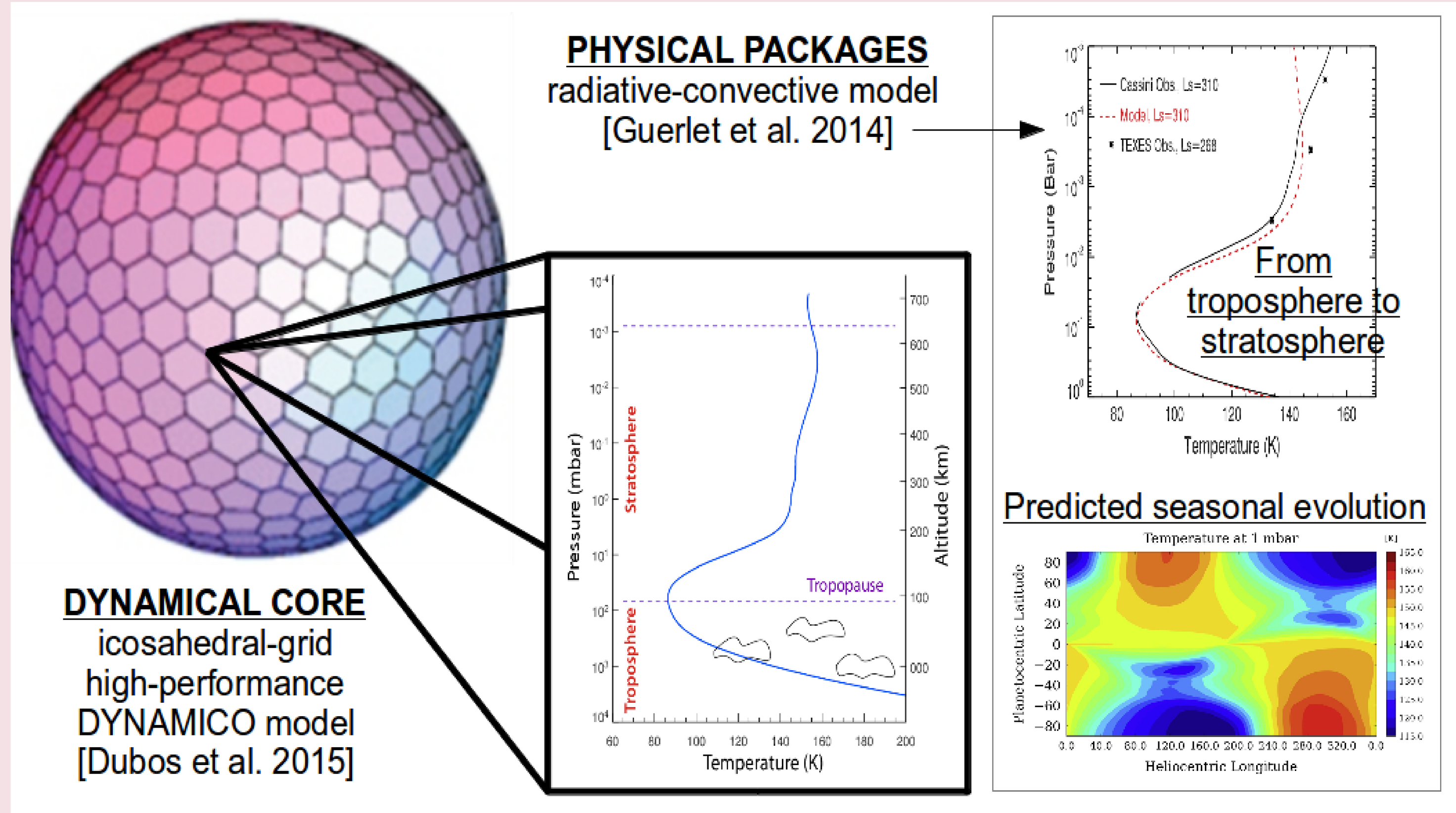
Polar hexagonal jet



The longevity of the Cassini mission permitted an exceptional coverage of Saturn's Great White Spot (and subsequent stratospheric warming), an assessment of the remarkable stability of the hexagonal polar jet, and the seasonal monitoring of Saturn's stratospheric equatorial oscillation. Those observations open new questions that add to those related to the extent and forcing of Saturn's tropospheric jets. One of the best step forward to progress is to build a Global Climate Model (GCM) for giant planets by coupling an hydrodynamical solver (dynamical core) with physical models for external forcings on the fluid.

A new GCM for Saturn: DYNAMICO-SATURN

We built a new GCM for Saturn both versatile and powerful enough to resolve the eddies arising from hydrodynamical instabilities and forcing the planetary-scale jets, to extend from the troposphere to the stratosphere with good enough vertical resolution, and to use optimized radiative transfer to predict seasonal tendencies over decade-long giant planets' years.



To that end, we coupled our seasonal radiative model tailored for Saturn with DYNAMICO, the next state-of-the-art dynamical core for Earth and planetary climate studies in our lab, using an original icosahedral mapping of the planetary sphere which ensures excellent conservation and scalability properties in massively parallel resources .

▸ S. Guerlet, A. Spiga, et al.
Global climate modeling of Saturn's atmosphere. Part I: Evaluation of the radiative transfer model.
Icarus, 238:110–124, 2014.

▸ T. Dubos, S. Dubey, et al.
Dynamico-1.0, an icosahedral hydrostatic dynamical core designed for consistency and versatility.
Geoscientific Model Development, 8(10):3131–3150, 2015.

Details on simulation settings

Model grid

- Horizontal grid: equivalent to $1/2°$
- ... plus tests $1/4°$ & $1/8°$
- Vertical: 32 levels 3 bars → 1 mbar

Boundary conditions

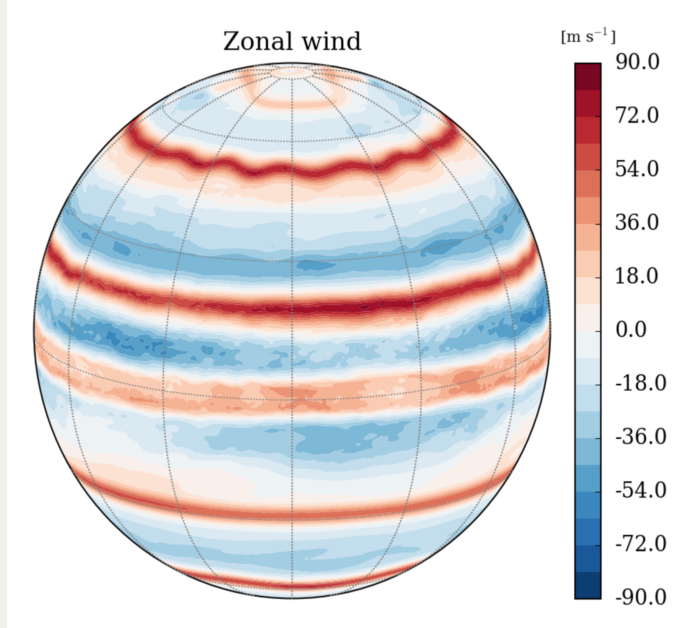
- Initial: steady-state temperature from 1D radiative-convective run, zero wind initially
- Sub-grid scale dissipation: from 500 (very strong) to 50000 (very weak); reference: 10000
- Bottom drag (Liu and Schneider JAS 2010) with $\tau = 9$ / 90 (reference) / 900 Edays

Machinery

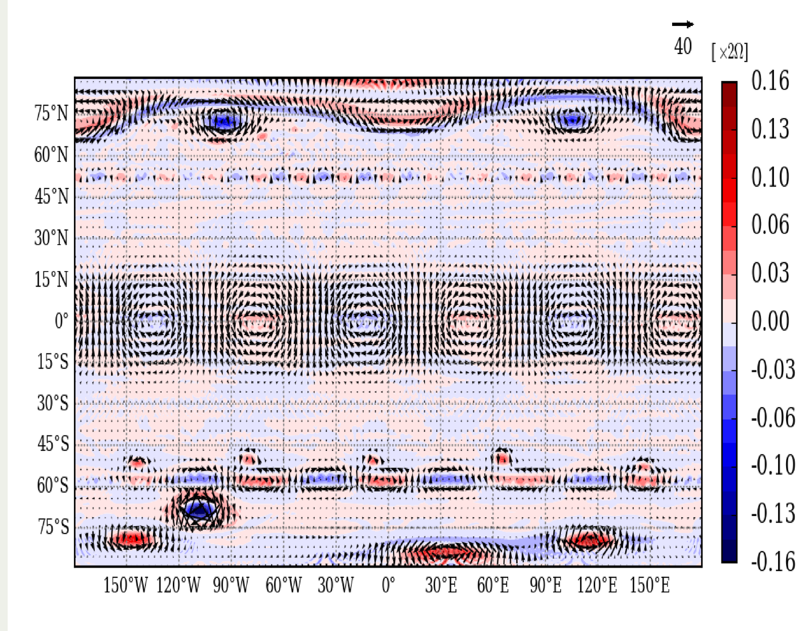
- MPI+OMP code
- 2-petaflop French CINES/Occigen cluster
- Cores: 1200 ($1/2°$), 9000 ($1/4°$), 11520-30000 ($1/8°$)

Results from reference $1/2°$ Saturn GCM simulations

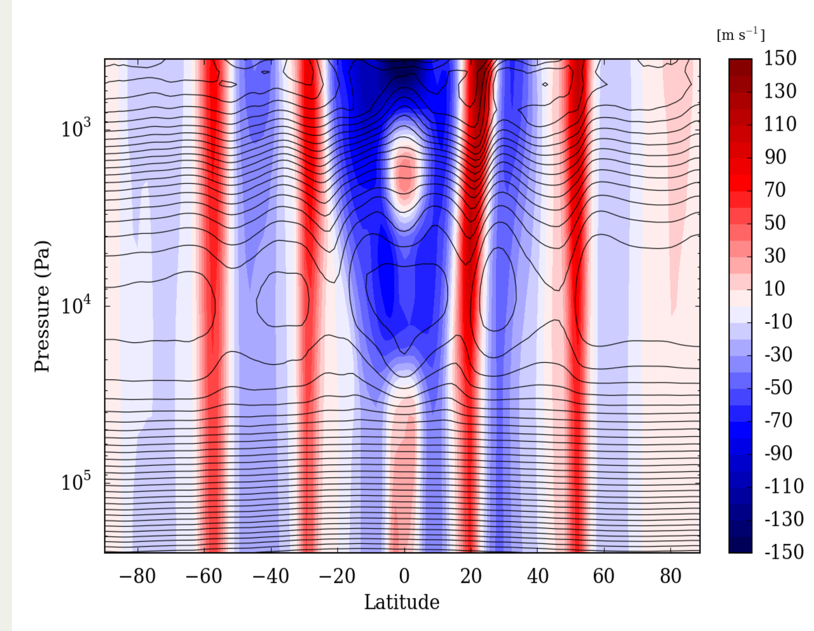
Tropospheric 1.5-bar zonal wind (9^{th} year)



Tropospheric vorticity + perturbation winds

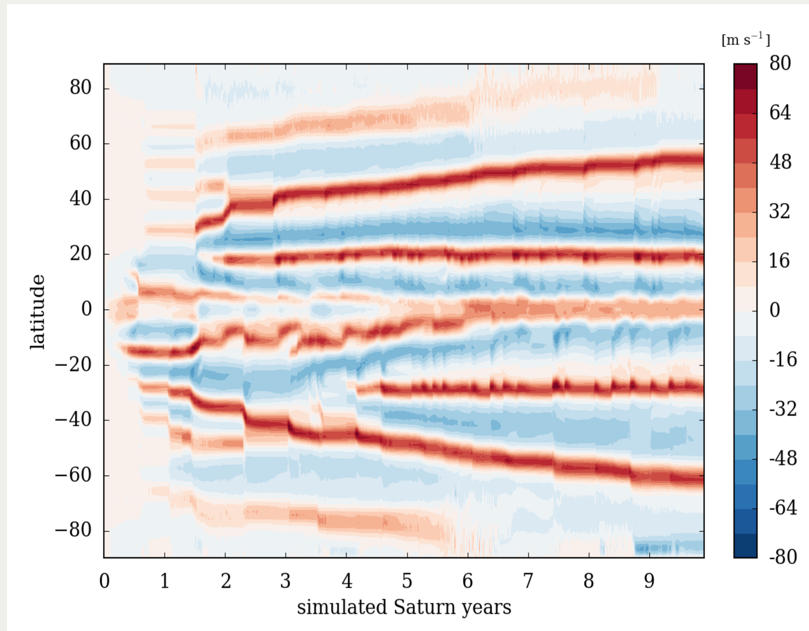


Zonal-mean zonal wind + temperature

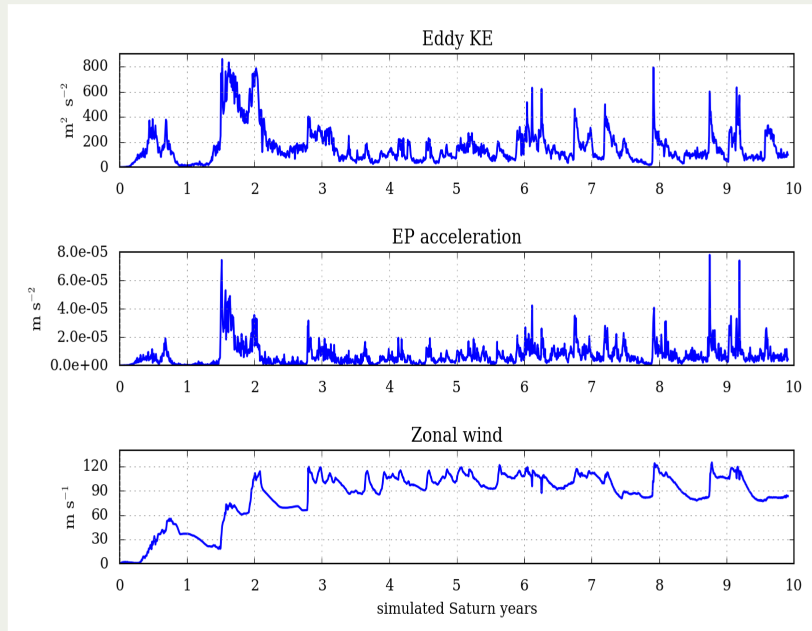


Our GCM simulations for Saturn reproduce tropospheric mid-latitude jets bearing similarities with the observed jet system (numbering, intensity, width). They also predict eastward-propagating Rossby-gravity (Yanai) waves at the equator, and high-wavenumber waves in mid-latitudes, as well as vortices. In contrast to observations, in our GCM simulations the equatorial jet is only weakly super-rotating and the polar jet is strongly destabilized by meandering. Our model predicts stacked stratospheric eastward and westward jets, but raising the model top is needed to address the equatorial oscillation.

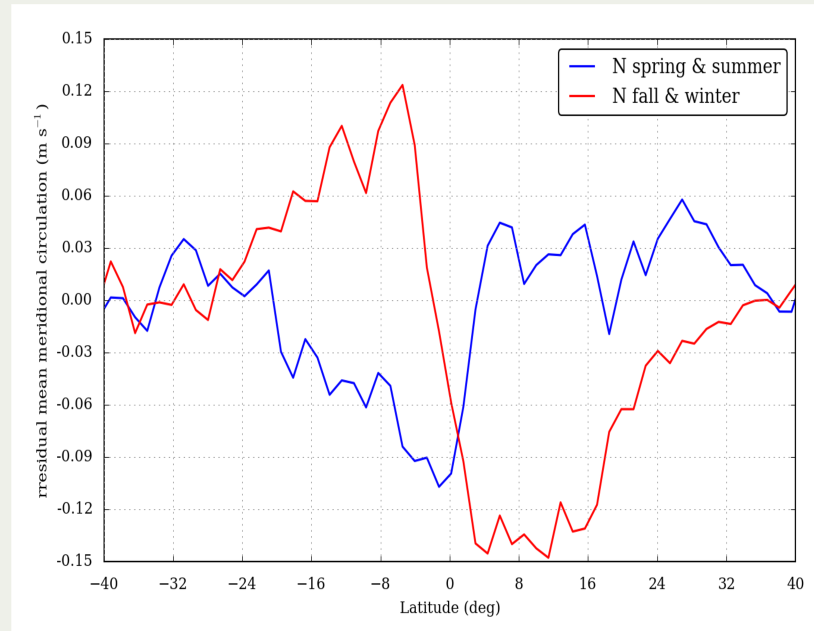
10-year evolution of tropospheric zonal jets



barotropic EKE + ∇EP + jets (max 30 – 60°N)



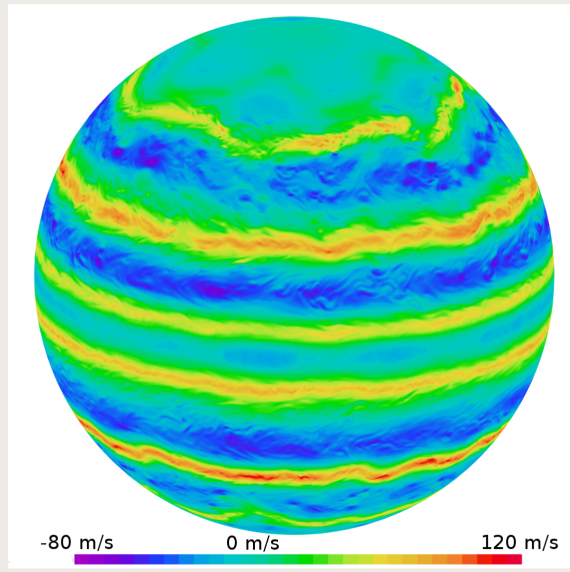
Residual stratospheric MMC (ave. 50 – 5 mb)



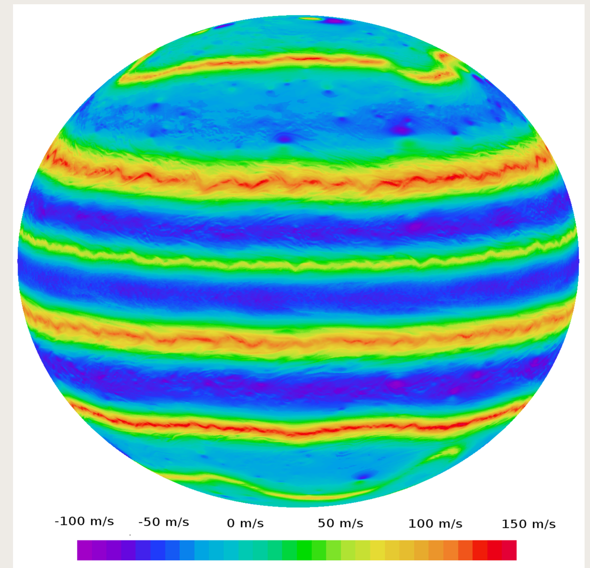
We find that jets are eddy-driven with a conversion rate from eddies to mean flow in agreement with Cassini estimates. Before reaching equilibrium, mid-latitude jets experience poleward migration, which can be ascribed to a self-destabilization of the jets by baro-tropic/-clinic instabilities. Our GCM simulations exhibit a stratospheric meridional circulation from one tropic to the other, with seasonal reversal, suggesting dynamical control on the observed variations of hydrocarbons.

Finer-resolution preliminary Saturn GCM simulations and perspectives

1.5-bar zonal winds ($1/4°$ GCM)



1.5-bar zonal winds ($1/8°$ GCM)



We carried out $1/4°$ and $1/8°$ GCM simulations with a "test" configuration (sponge layer and high dissipation). The simulated midlatitude jets' strengths are closer to observed values – and a more complete spectrum of eddies, waves, and vortices is resolved. Refining the vertical resolution is also considered as a path forward. Our Saturn GCM is only a first step towards a GCM system able to simulate all giant planet environnements: a Jupiter GCM is being developed for the JUNO and the (future) JUICE missions.

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