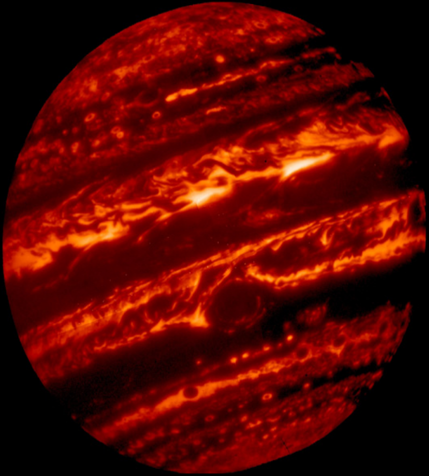
DYNAMICO et les planètes

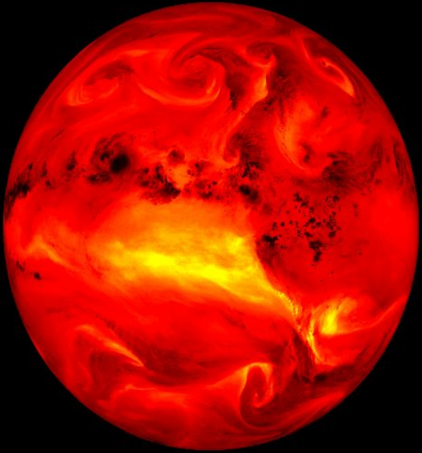
des géantes aux telluriques

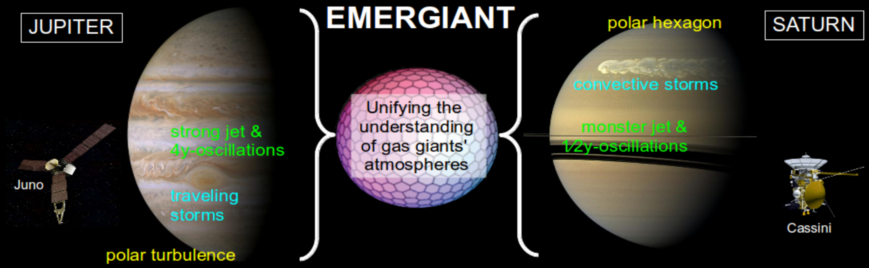
Aymeric Spiga (and many collaborators)

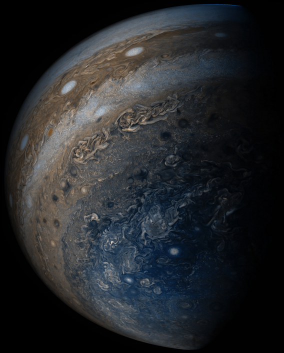
Journée PEDALONS // July 6, 2021

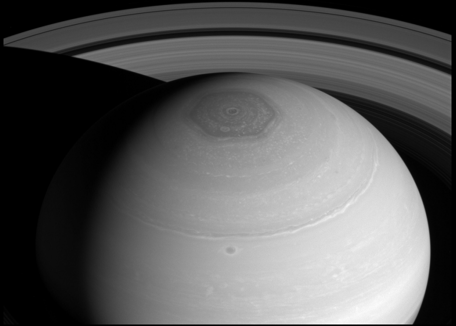
Climate and meteorology of planets





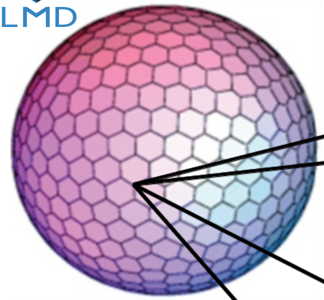

JUPITER
EMERGIANT
SATURN
polar hexagon
convective storms
Unifying the understanding of gas giants' atmospheres
strong jet & 4y-oscillations
monster jet & 1/2y-oscillations
Juno
traveling storms
Cassini
polar turbulence



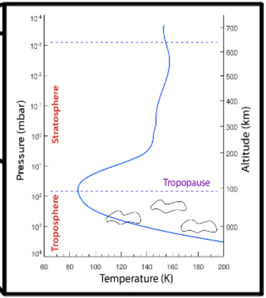


Global Climate Modeling for giant planets

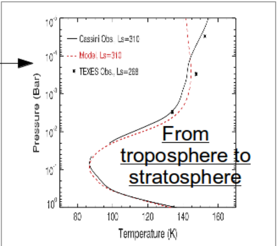
see Spiga et al. Icarus 2020



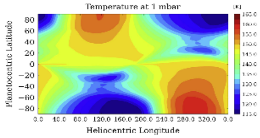
DYNAMICAL CORE
icosahedral-grid
high-performance
DYNAMICO model
[Dubos et al. 2015]



PHYSICAL PACKAGES
radiative-convective model
[Guerlet et al. 2014]



Predicted seasonal evolution



Global climate modeling of Saturn's atmosphere

Part I, Guerlet et al. Icarus 2014

evaluation of the radiative transfer model

Part II, Spiga et al. Icarus 2020

multi-annual high-resolution dynamical simulations

Part III, Cabanes et al. Icarus 2020

global statistical picture of zonostrophic turbulence

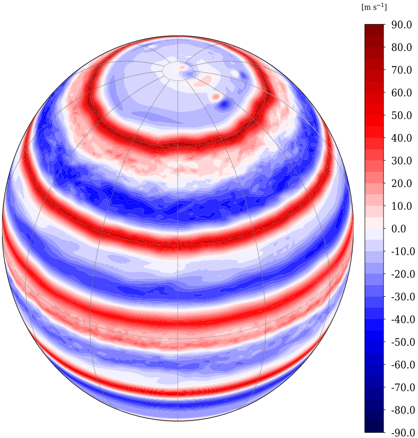
Part IV, Bardet et al. Icarus 2021

stratospheric equatorial oscillations

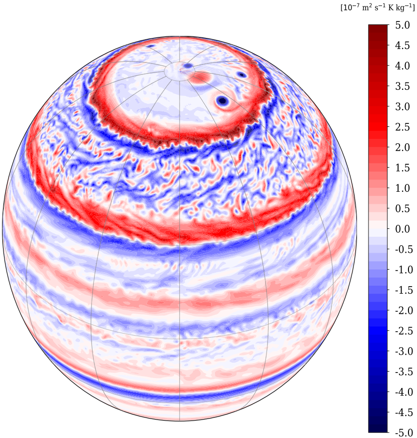
Jets, eddies and vortices in a 1/2° Saturn GCM

Beginning of the seventh simulated year (171 thousands simulated Saturn days)

Zonal velocity ($P = 1.5$ bar)



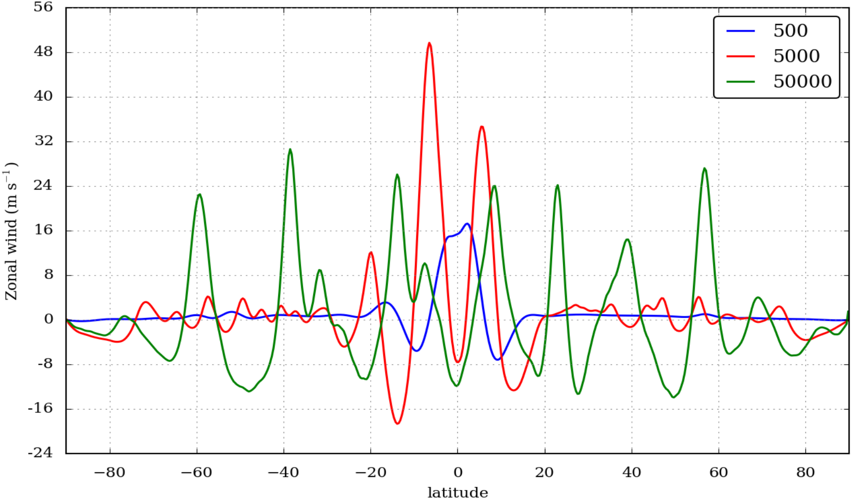
Potential Vorticity ($\theta = 205$ K)



[Spiga et al. Icarus 2020, arxiv 1811.01250]

Influence of numerical dissipation

Bottom drag 9 Edays, free-drag latitude 33°



Influence of numerical dissipation

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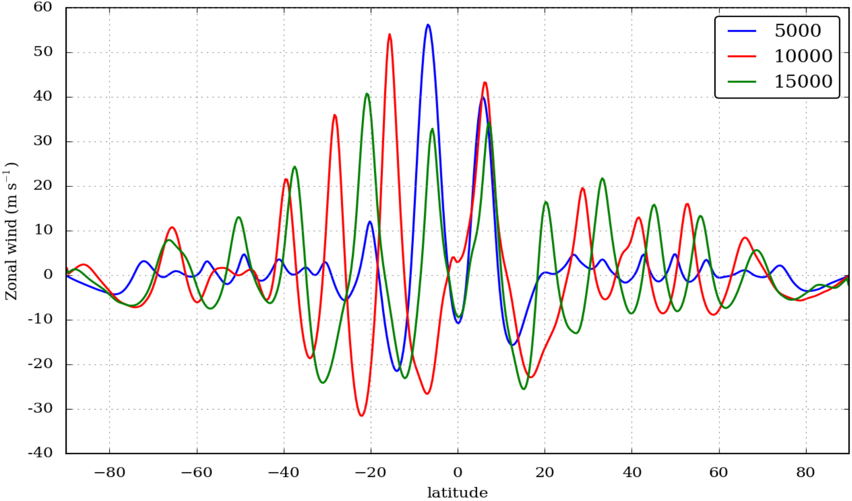
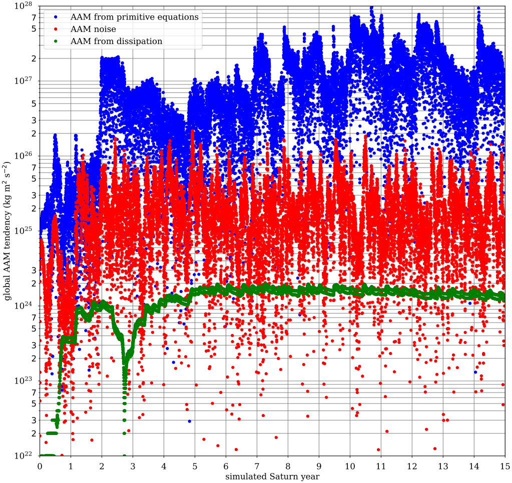


Global Axial Angular Momentum (AAM) budget

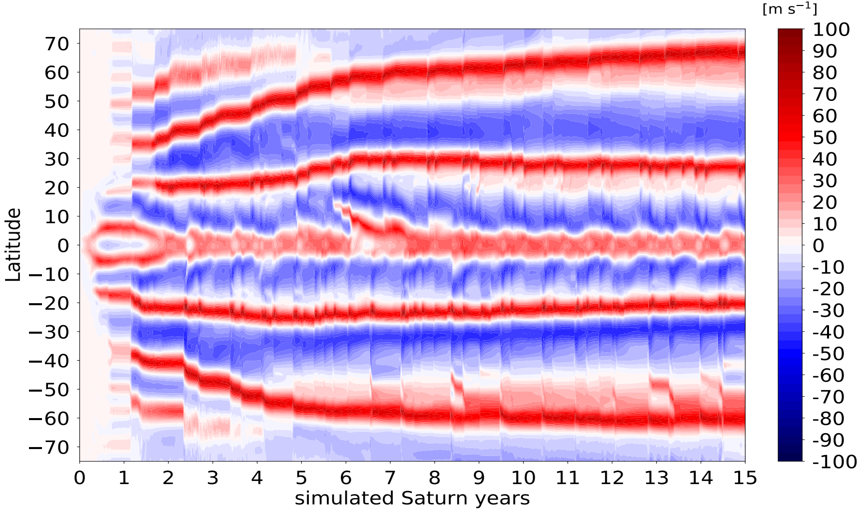


- $[\mathrm{d}\mathcal{M}^w/\mathrm{d}t]_{PE} \Rightarrow$ wind tendencies computed in the primitive equations resolved in the dynamical core.
- $\varepsilon \Rightarrow$ AAM noise, i.e. residual numerical rate of AAM variation due to conservation errors.
- $D \Rightarrow$ AAM tendencies resulting in the dissipation and Rayleigh drag scheme.

[Spiga et al. Icarus 2020, arxiv 1811.01250]

JETS: 15 years of 1/2° Saturn GCM

zonal-mean zonal winds at 800 mbar

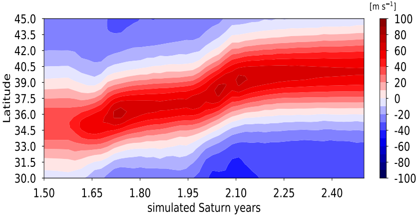


[Spiga et al. Icarus 2020, arxiv 1811.01250]

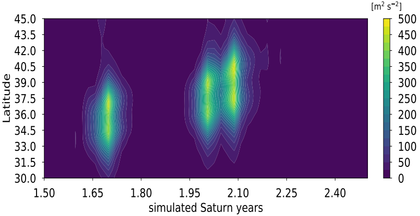
A detailed analysis of a jet migration

Using divergence of Eliassen-Palm flux $F_\varphi = a \cos\varphi \left(-\overline{u'v'} - \frac{1}{\mathcal{S}} \frac{\partial \overline{u}}{\partial p} \overline{v'T'} \right)$

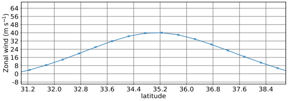
Zonal wind (200 mbar)



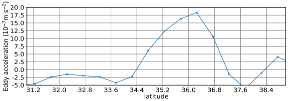
Eddies KE (200 mbar)



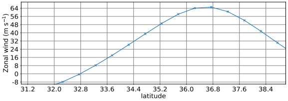
$\overline{u}(t = 1.5y)$



$$\frac{\partial \overline{u}}{\partial t} = \frac{1}{a^2 \cos^2\varphi} \frac{\partial F_\varphi \cos\varphi}{\partial \varphi}$$



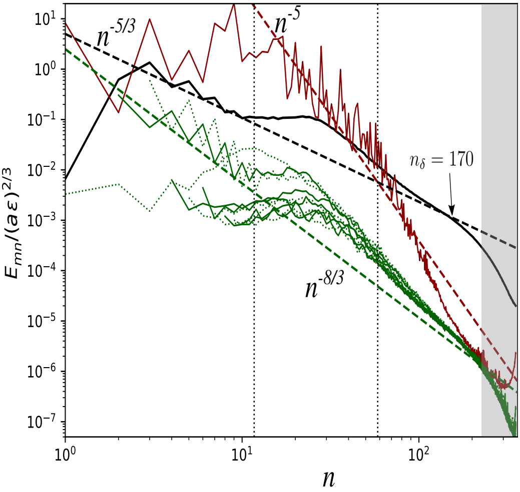
$\overline{u}(t = 1.8y)$



Energy spectra on spherical harmonics

from our Saturn GCM 1/2° wind field at 1.5 bars

[Simon Cabanes]



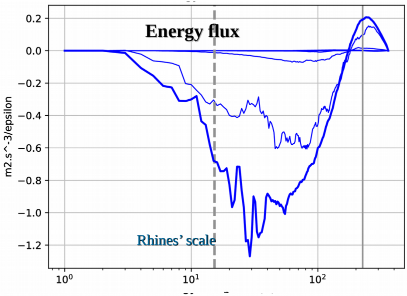
- zonal energy spectra (m=0); line: $E_z(n) = C_z \beta^2 n^{-5}$
- residual energy spectra (m>1); line: $E_R(n) = C_K \epsilon^{2/3} n^{-5/3}$
- individual modes energy spectra (m)

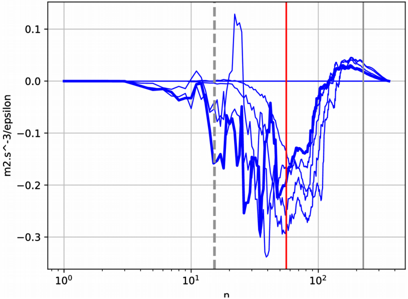
☞ $E_z(n)$ peaks at Rhines scale n_R

☞ $E_z(n)$ and $E_R(n)$ intersects at n_β

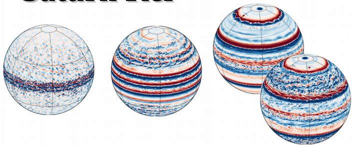
[Cabanes, Spiga and Young Icarus 2020]

Saturn Ref & Taylor-Green at kf = 56

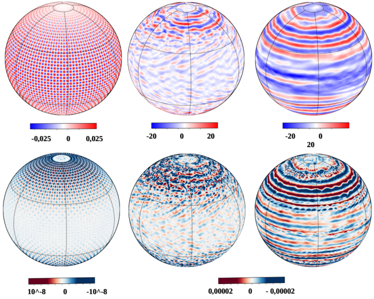




Saturn Ref



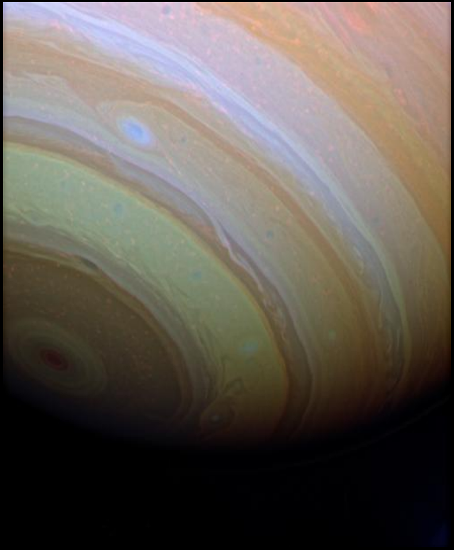
Taylor-Green at kf = 56



Gas giants: jets & eddies

Jupiter

Saturn



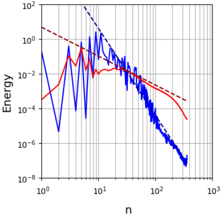
Energy transfer between scales on Jupiter

Alexandre Boissinot (PhD thesis) with Simon Cabanes

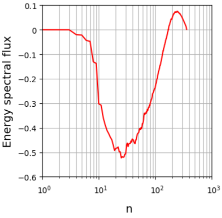
[Alexandre Boissinot]

Jupiter DYNAMICO GCM 1/2°

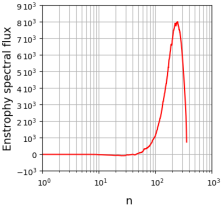
Energy spectra



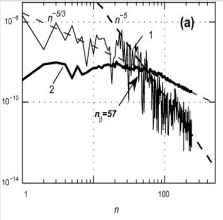
Energy fluxes



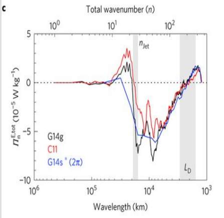
Enstrophy fluxes



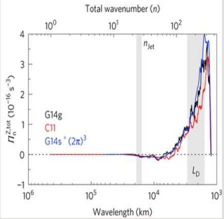
Cassini observations [Jupiter flyby]



[Galperin et al. Icarus 2014]



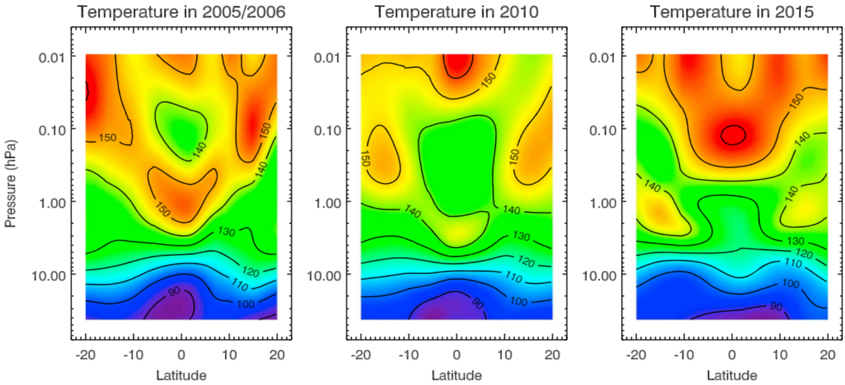
[Young+Read Nat Phys 2017]



[Young+Read Nat Phys 2017]

An equatorial oscillation in Saturn's stratosphere

Evolution with time with Cassini/CIRS



[Guerlet et al. JGR Planets 2018]

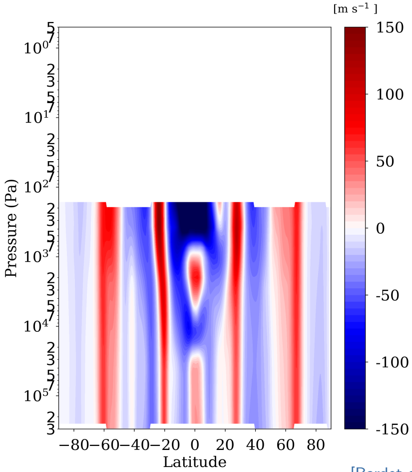
Stratospheric equatorial oscillations

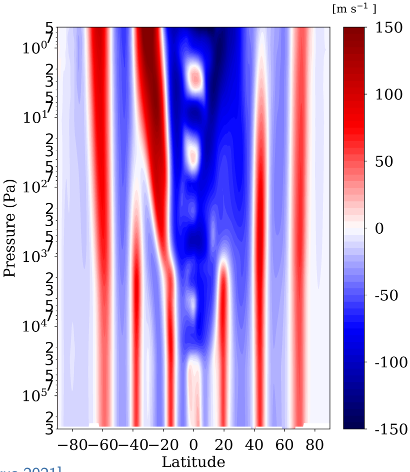
Obtained by extending the model top

[Deborah Bardet]

✗

✓



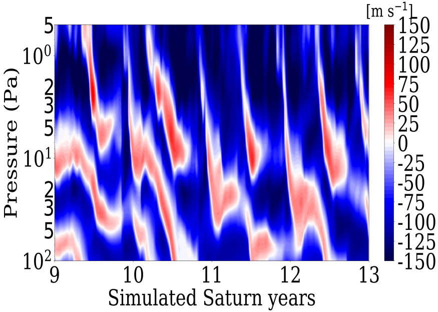


[Bardet et al. Icarus 2021]

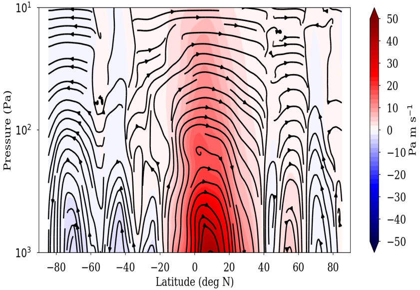
The nature of Saturn's stratospheric signatures

Tropo-to-strato high-vertical-resolution DYNAMICO-Saturn simulations

Semi-Annual Oscillation



Brewer-Dobson circulation

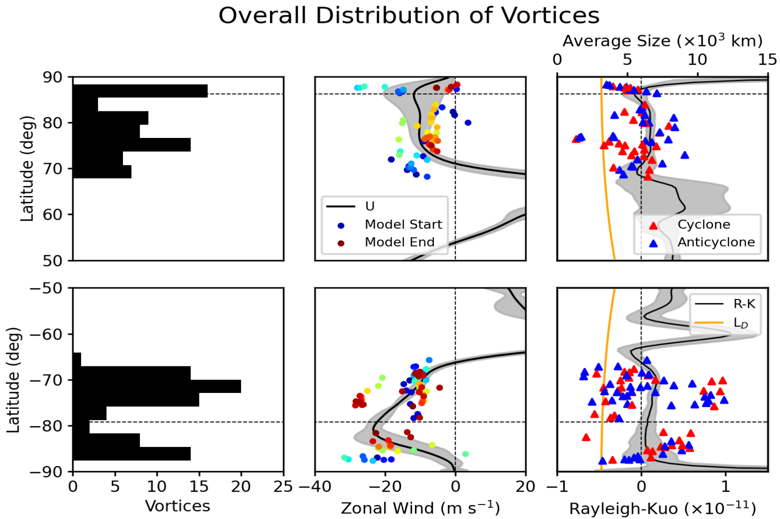


[Bardet et al. in review for Nature Astronomy]

Studying large-scale vortices for Saturn

detection on Saturn-DYNAMICO simulation from “Part II” paper

[Padraig Donnelly]

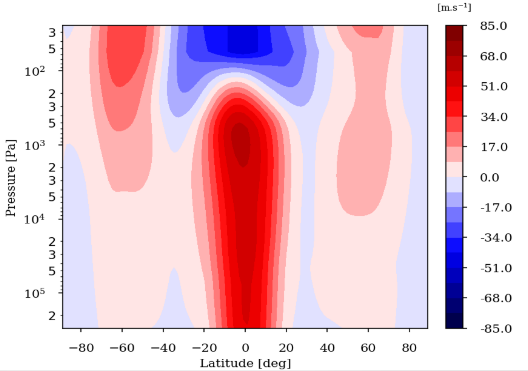


Neptune from ESO's VLT

[Narrow-Field adaptive optics mode of the MUSE/GALACSI instrument. ESO/P. Weilbacher (AIP).]

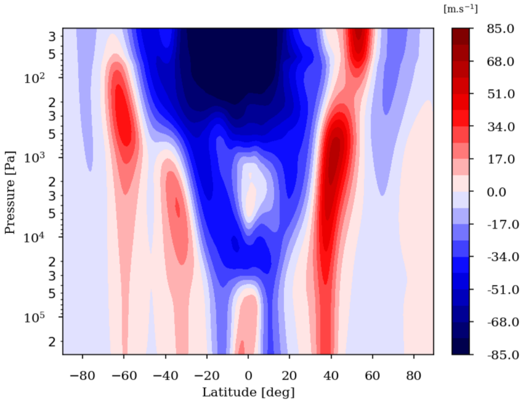
B.5 Final results (resolution = 2°)

- Vertical cross-section of zonal-mean zonal wind speed after 7 years of simulation.
- Prograde jet at the equator at ~100 mbar (10^4 Pa). But there is a retrograde jet on the observations of Voyager 2 at this pressure level.

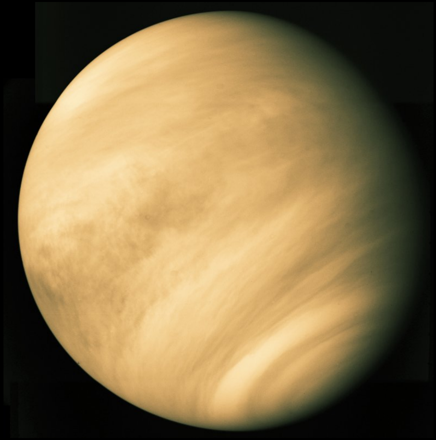


B.6 Simulation with higher resolution (1°)

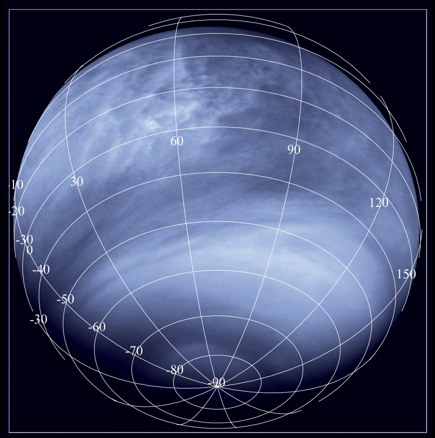
- Vertical cross-section of zonal-mean zonal wind speed (resolution : 1°)
- Intense prograde jet in the stratosphere (~130 m/s).
- More jets in this simulation.
- Important difference between 1° and 2° simulations.



Venus



[Pioneer Venus, 1979]

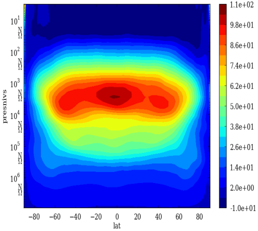


[Venus Express, 2006]

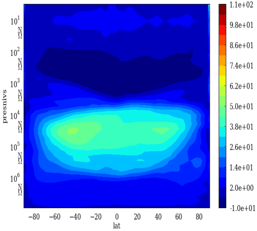
Loss of super-rotation!

Venus DYNAMICO by E. Millour and S. Lebonnois

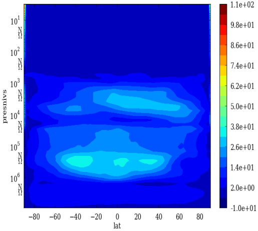
start



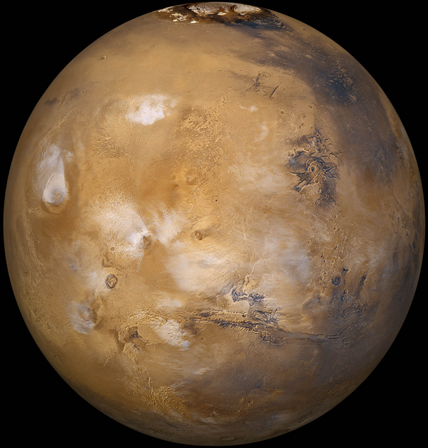
after 0.25 Vd



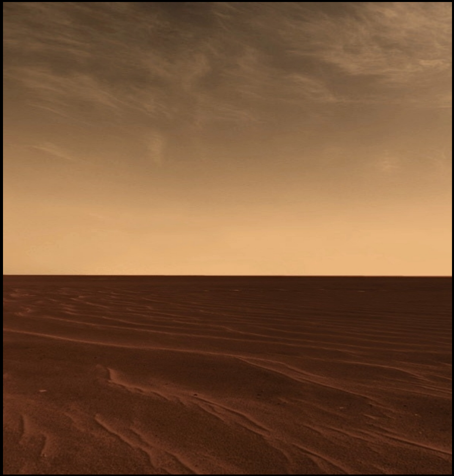
after 1 Vd



Mars



[Mars Global Surveyor, 2002]

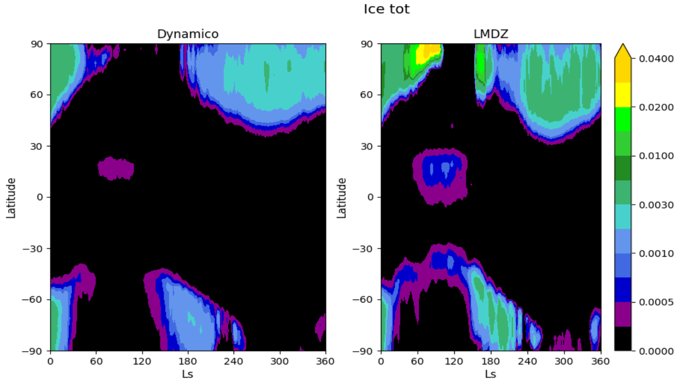


[Mars Opportunity panorama, 2006]

Mars DYNAMICO

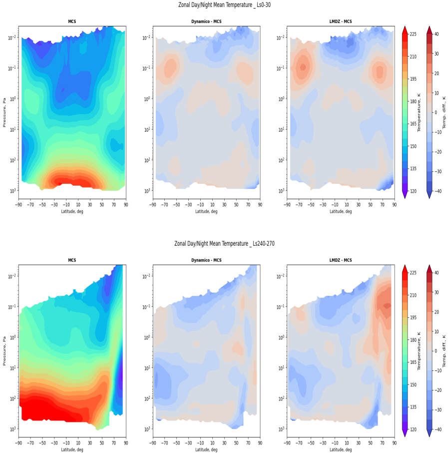
Romain Vandemeulebrouck et Antony Delavois

- Simulations équivalentes à LMDz basse résolution (nbp=20)
- Topographie, cycles eau, poussières mais sans thermosphère/chimie
- Sponge layer différentes – ainsi que dissipation...?
- Encore du travail de réglages du cycle de l'eau

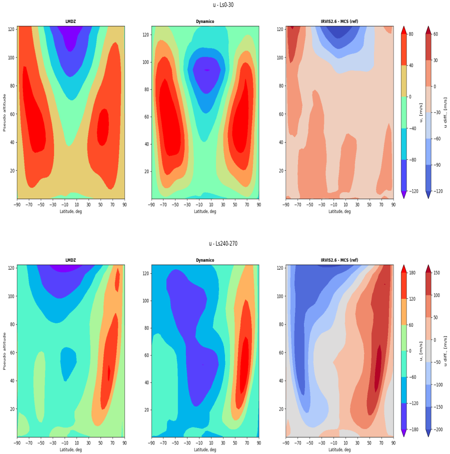


Mars DYNAMICO <> MCS (obs) <> LMDz

Temperature



Zonal wind



Conclusion

- ☞ DYNAMICO-Saturn
- ☞ DYNAMICO-Jupiter
- ☞ DYNAMICO-Venus
- ☞ DYNAMICO-Mars
- ☞ DYNAMICO-Nepturanus
- ☞ . . . et les exoplanètes (physique générique)