Max Planck Institute for
Solar System Research

From cold to warm gas giants: Atmospheric GCM modeling

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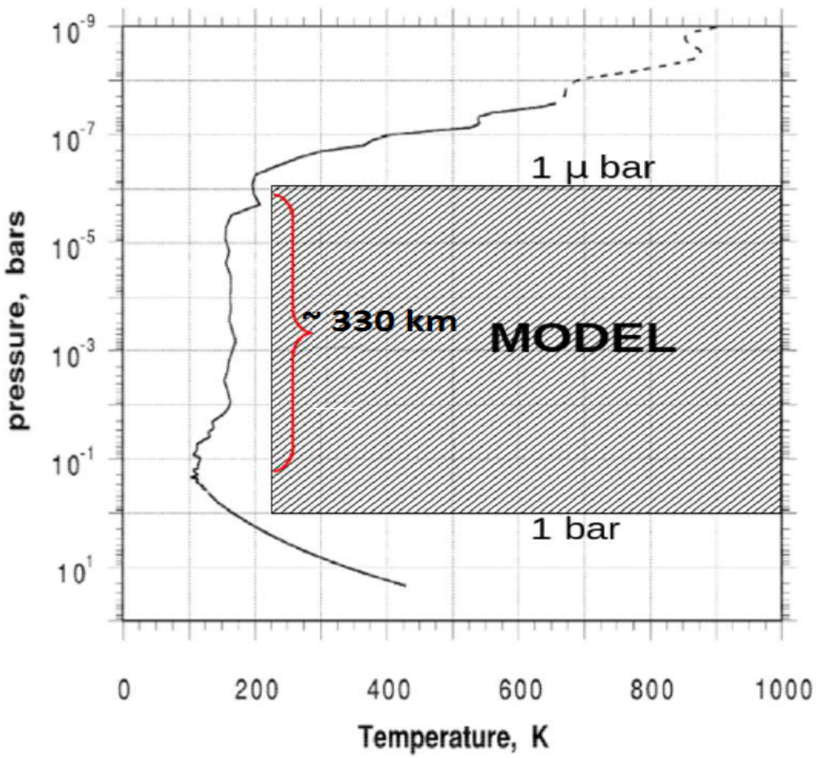
Stratospheres of gas giants



- Covers middle atmosphere from the troposphere (above the cloud-top layer) to the lower thermosphere
- This atmospheric layer is almost equally forced from below (interior) and above (Solar/star irradiation)
- That's where IR signals (to be detected by Echo) are coming from
- Free lower boundary
- 1000 – 10^{-3} mb for Jupiter
- 2000 – 10^{-3} mb for Saturn

Geostrophic adjustment tends to occur at length scales comparable to the Rossby radius of deformation:

$$\boxed{L_D = \frac{NH}{f} \propto \frac{T}{gf}}$$

N is the Brunt-Vaisala (buoyancy) frequency

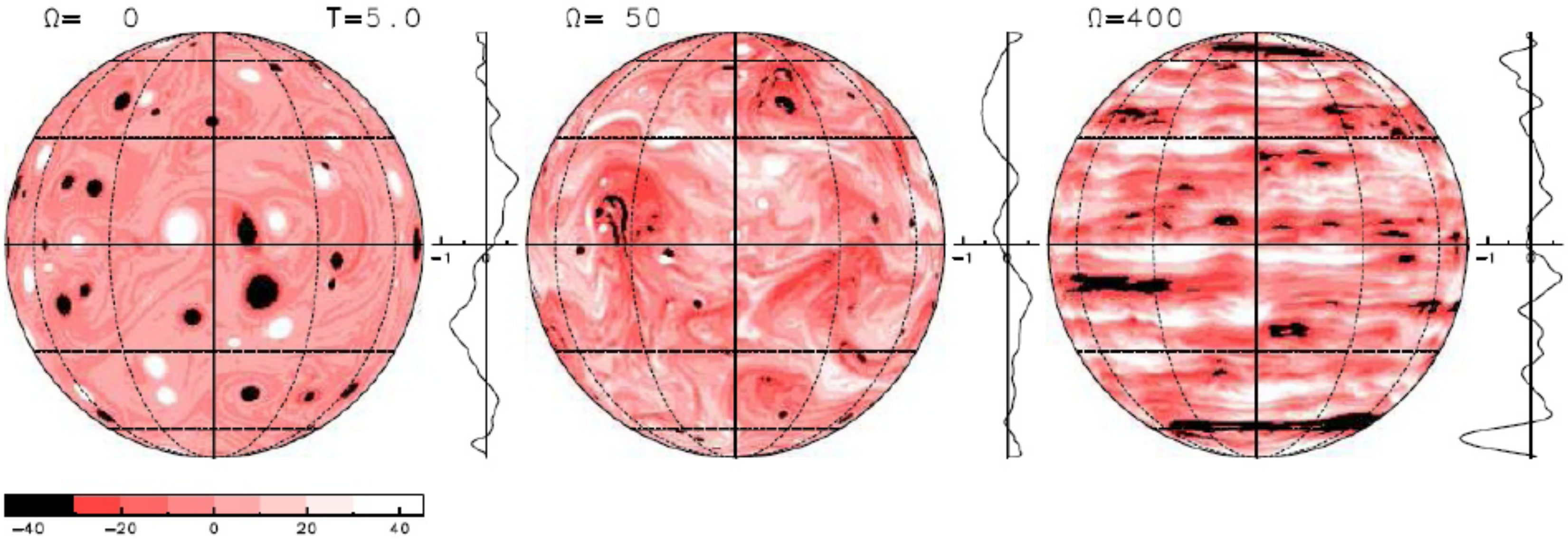
Implication for modeling: to simulate vortex formations and breakups , models must resolve L_D.

Planet	a^* (10^3 km)	Rotation period$^\sharp$ (Earth days)	Ω (rad sec^{-1})	gravity$^\aleph$ (m sec^{-2})	$F_*^\square$ (W m^{-2})	$T_e^\spadesuit$ (K)	$H_p^\dagger$ (km)	$U^\ddagger$ (m sec^{-1})	$Ro^\P$	$L_D/a^\clubsuit$	$L_\beta/a^\diamond$
Venus	6.05	243	3×10^{-7}	8.9	2610	232	5	~ 20	10	70	7
Earth	6.37	1	7.27×10^{-5}	9.82	1370	255	7	~ 20	0.1	0.3	0.5
Mars	3.396	1.025	7.1×10^{-5}	3.7	590	210	11	~ 20	0.1	0.6	0.6
Titan	2.575	16	4.5×10^{-6}	1.4	15	85	18	~ 20	2	10	3
Jupiter	71.4	0.4	1.7×10^{-4}	23.1	50	124	20	~ 40	0.02	0.03	0.1
Saturn	60.27	0.44	1.65×10^{-4}	8.96	15	95	39	~ 150	0.06	0.03	0.3
Uranus	25.56	0.72	9.7×10^{-5}	8.7	3.7	59	25	~ 100	0.1	0.1	0.4
Neptune	24.76	0.67	1.09×10^{-4}	11.1	1.5	59	20	~ 200	0.1	0.1	0.6

- GCMs for fast rotating gas giants (Jupiter, Saturn) require very high spatial resolution, almost at the limit of modern computers.
- Venus and Titan GCMs are the least demanding.

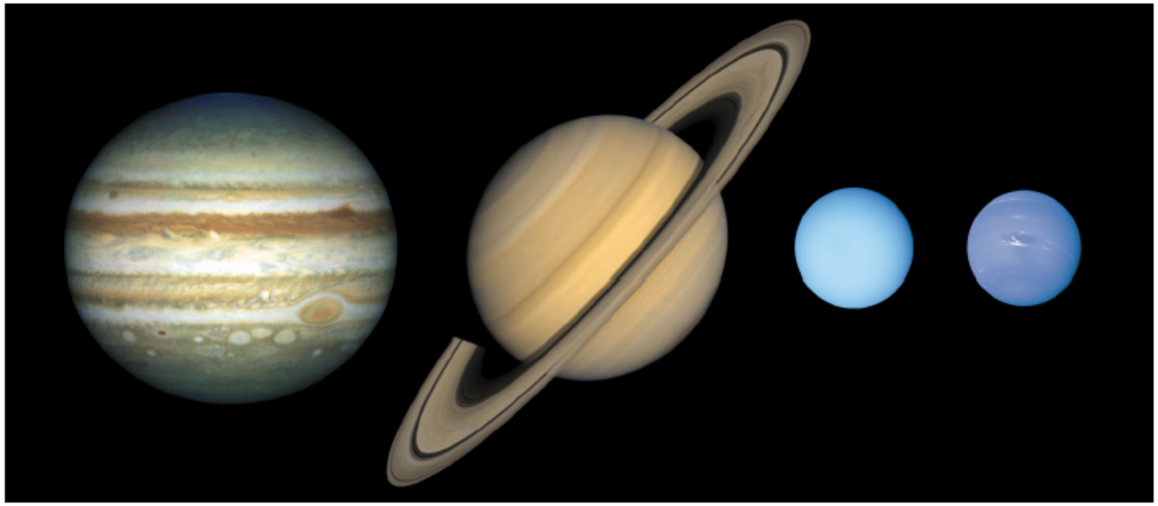
Turbulence and jet streams

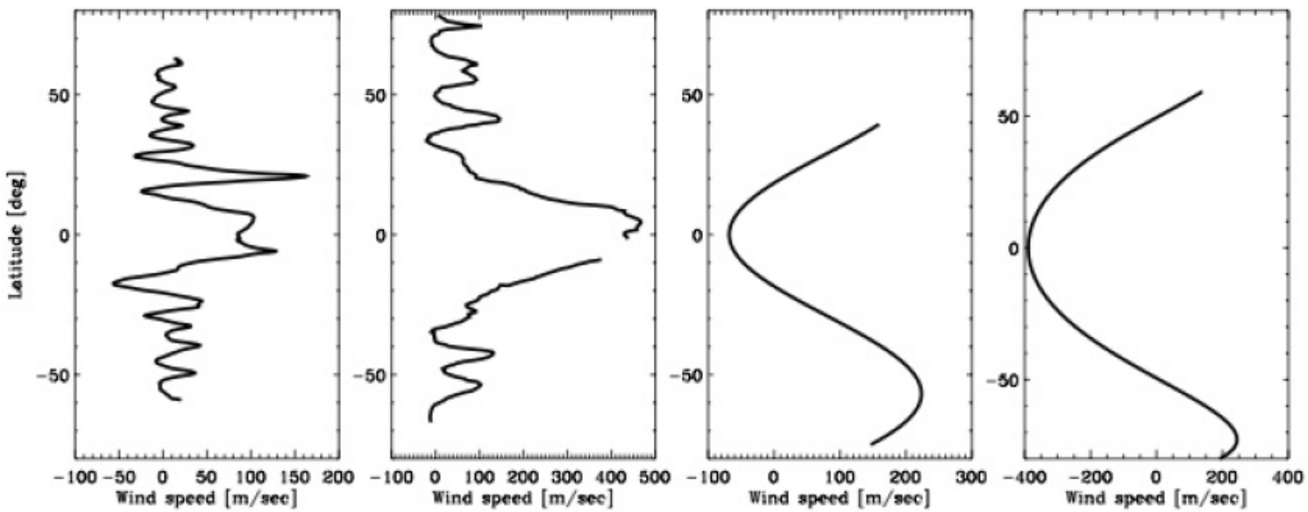
When horizontal scales become large, anisotropy due to rotation causes elongation in the east-west direction.



$$L_\beta = \pi\sqrt{\frac{U}{\beta}}$$

is the <u>Rhines scale</u>. $\beta = df/dy$ is the gradient of Coriolis parameter with northward distance *y.*





Jupiter, Saturn have ~20 east-west jets. Uranus and Neptune have 3 broad jets. This is more or less in line with the scale-based estimates.

Model setup

- **Resolution**
  horizontal: up to 240 x 180
  vertical: 3 to 4 points to a scale height (40 to 60 vertical levels)

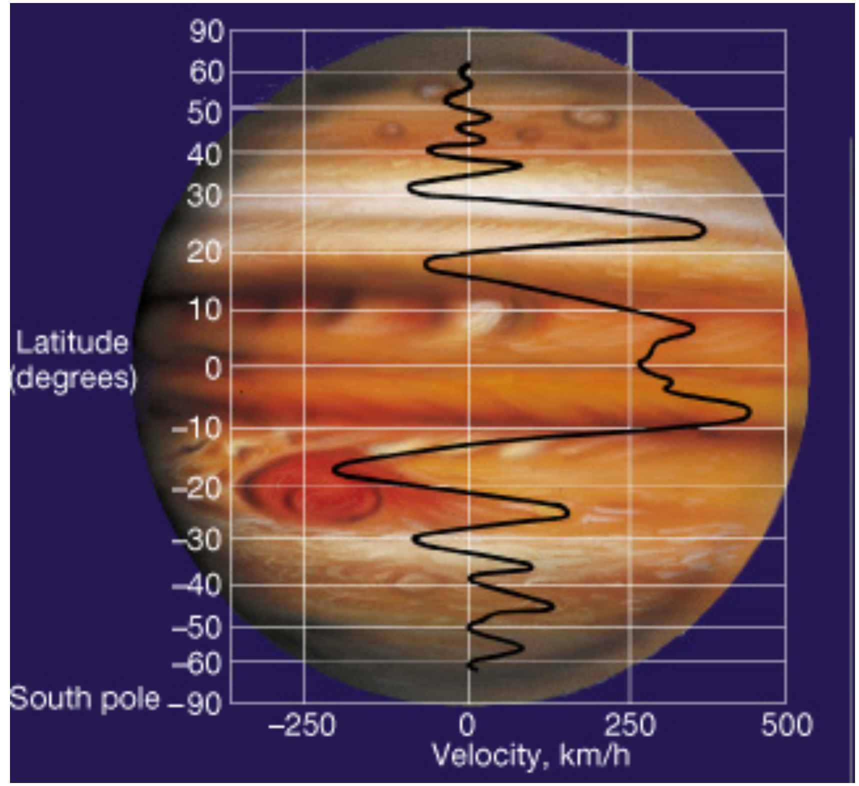
- **Wind nudging**

$$F_X = (\bar{u}_{obs} - u)/\tau_u$$

- horizontal bilinear diffusion
  vertically increasing coefficient

- **Newtonian relaxation**

$$F_T = (T_{eq} - T)/\tau_{rad}$$



Cold giants

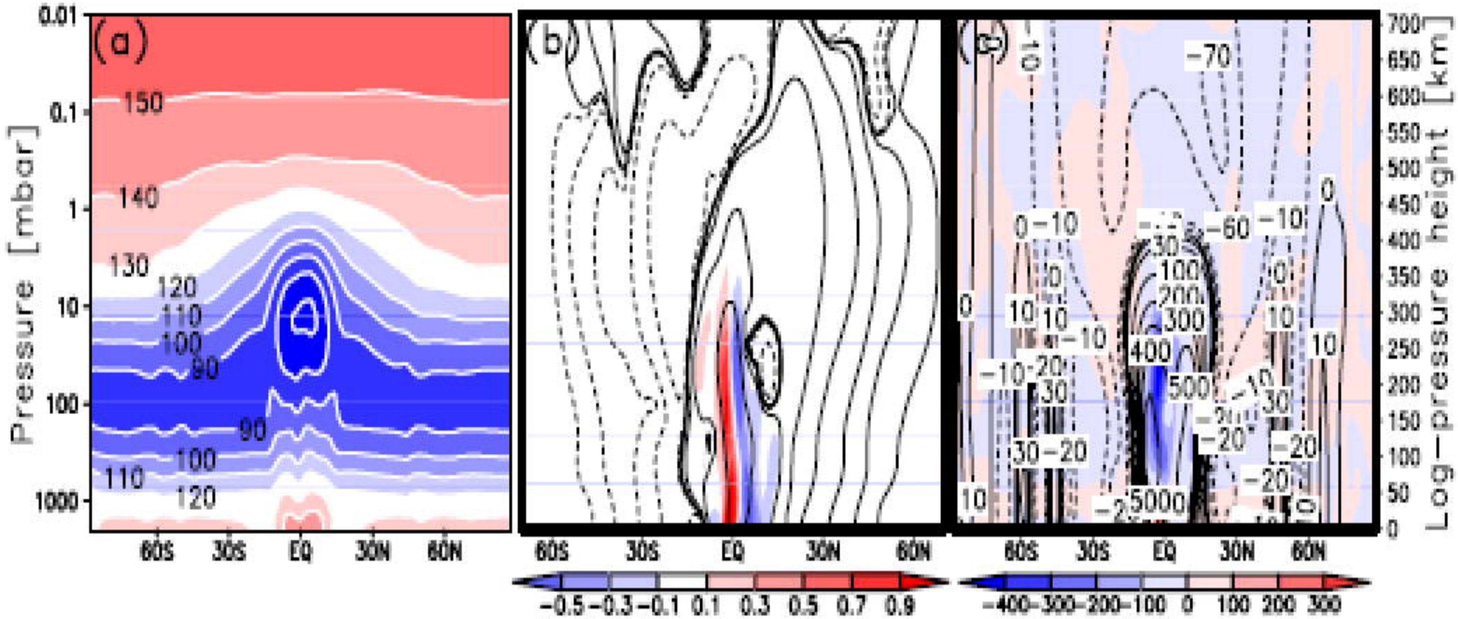
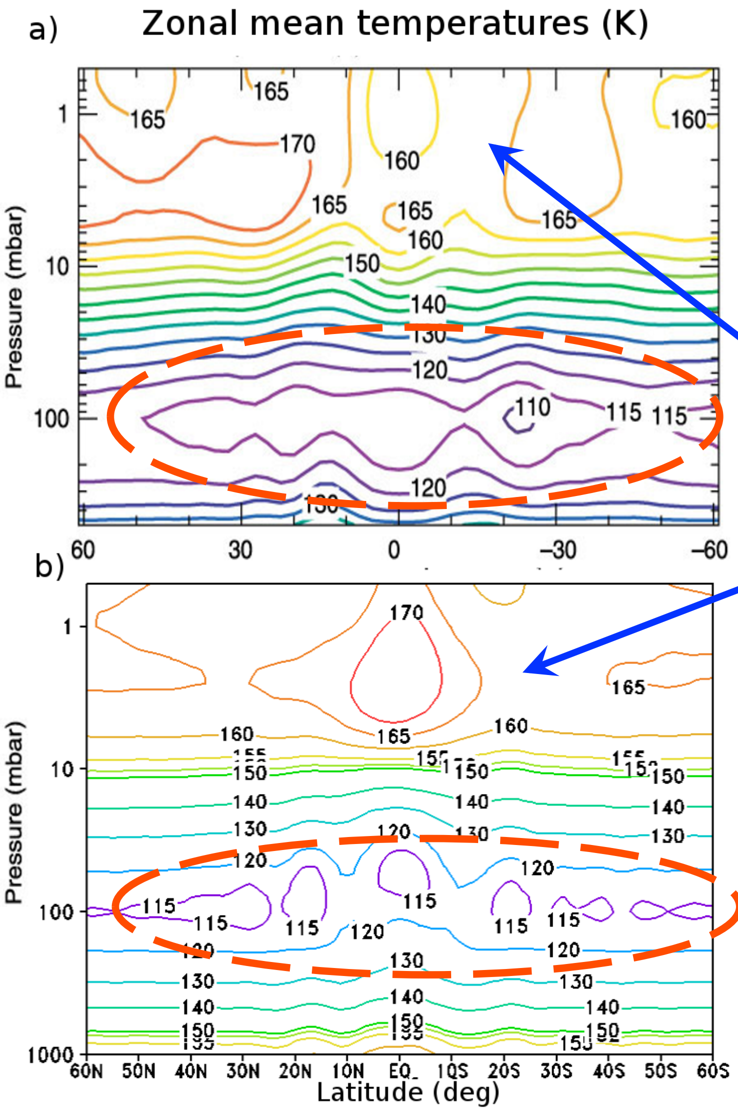
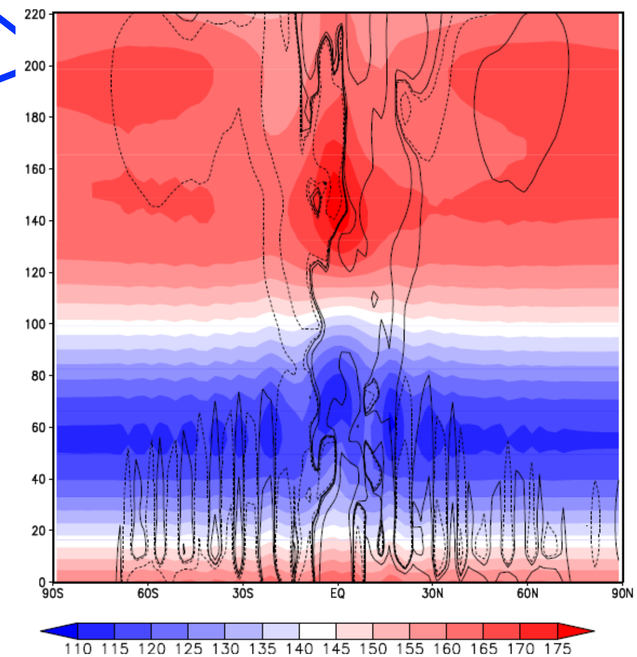


Fig. 2 One-day averaged fields from the simulation for the cold giant: (a) Zonal mean temperature (in K), (b) residual streamfunction (contour lines) and residual vertical velocity (in m s ?1 , shaded), (c) mean zonal wind (contours) and EP flux …

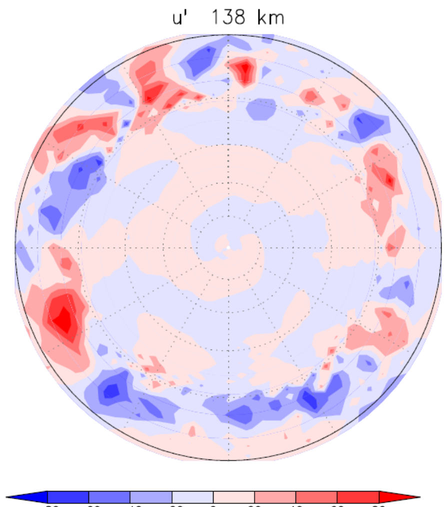
Zonal mean temperature

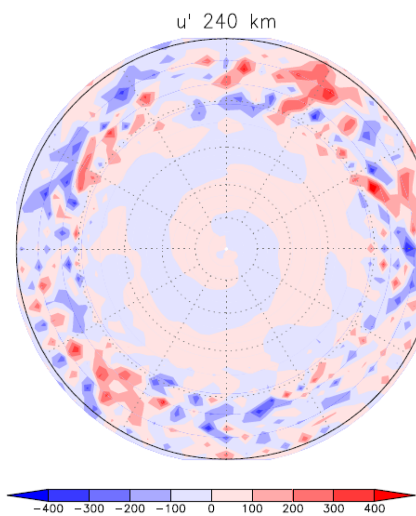


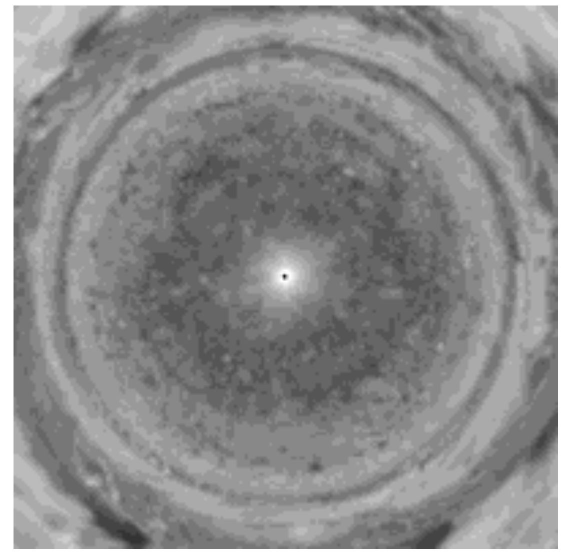
Comparison with Composite Infrared Spectrometer (CIRS) onboard Cassini (Flasar et al., 2004)



Non-zonal variations

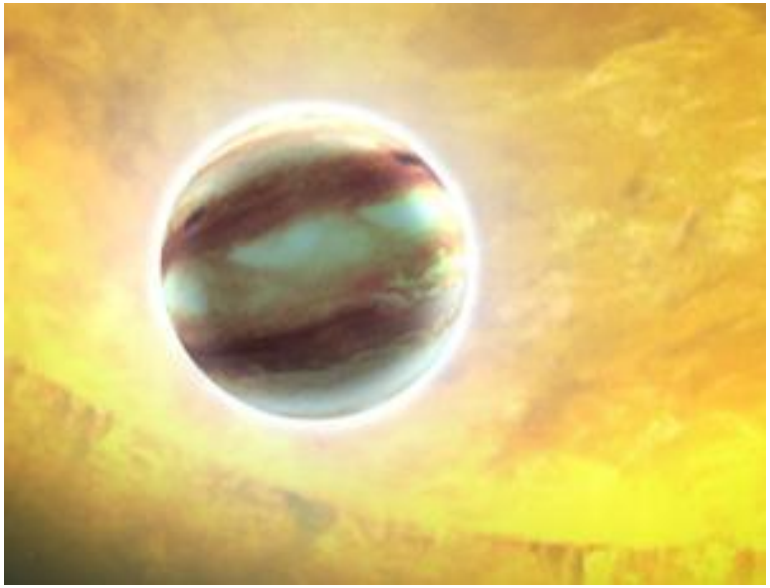






70 days of Cassini pictures

Hot Jupiters



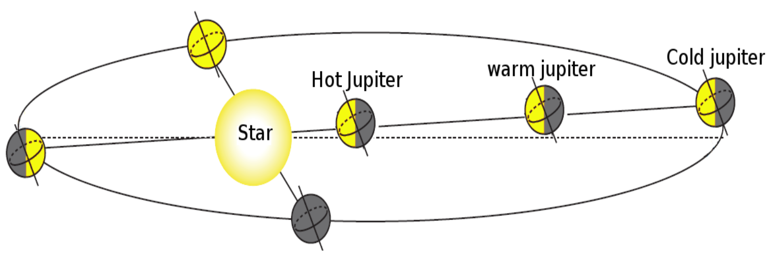
- Close to stars $\longrightarrow$ tidally locked (Ω=0). Number of jets is expected to be small.

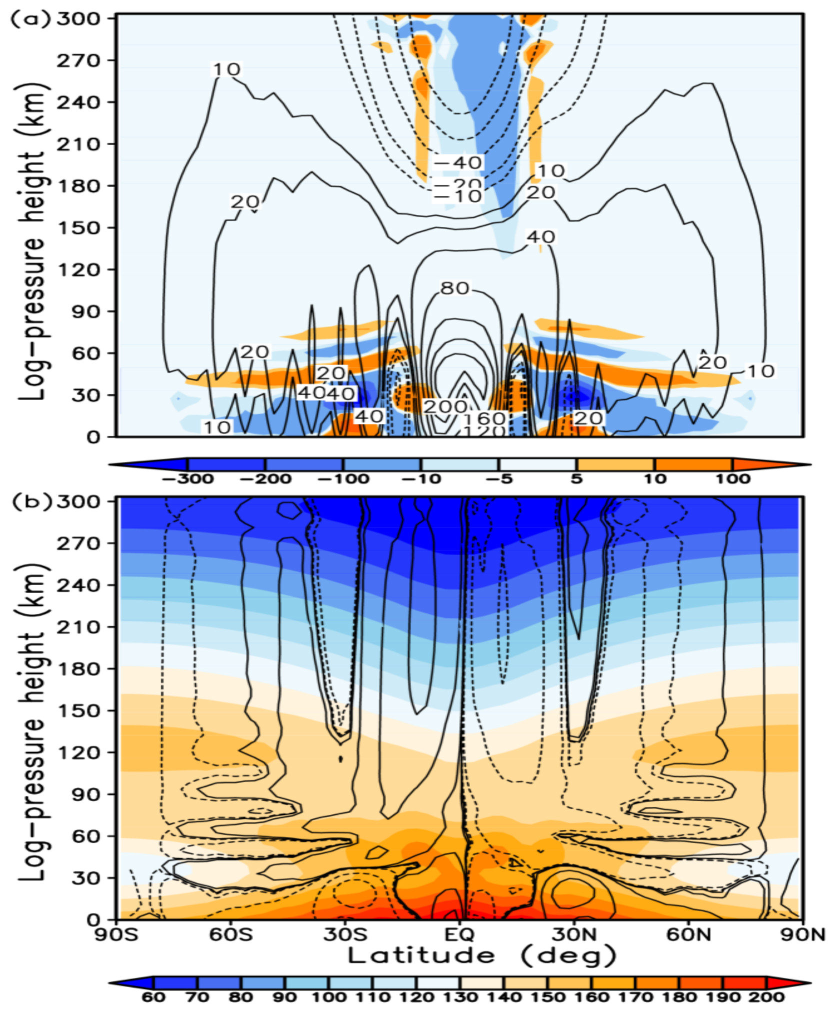
$$N_{jet} \sim \sqrt{\frac{2\Omega a}{U}}$$

- Hot and slow rotating $\longrightarrow$ Rossby radius of deformation is large.

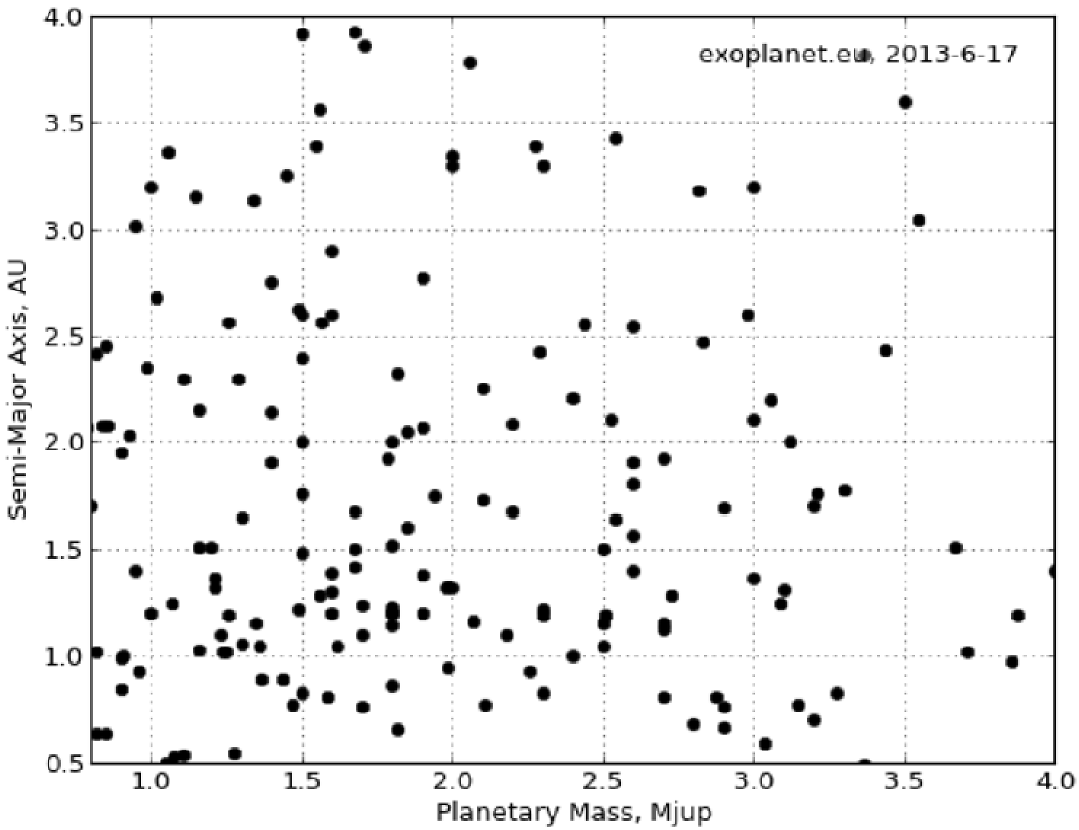
$$\boxed{L_D = \frac{NH}{f}}$$

“Warm” gas giant





Could be warm gas giants?



Sufficiently big, and sufficiently far from the stars

Warm gas giant simulation

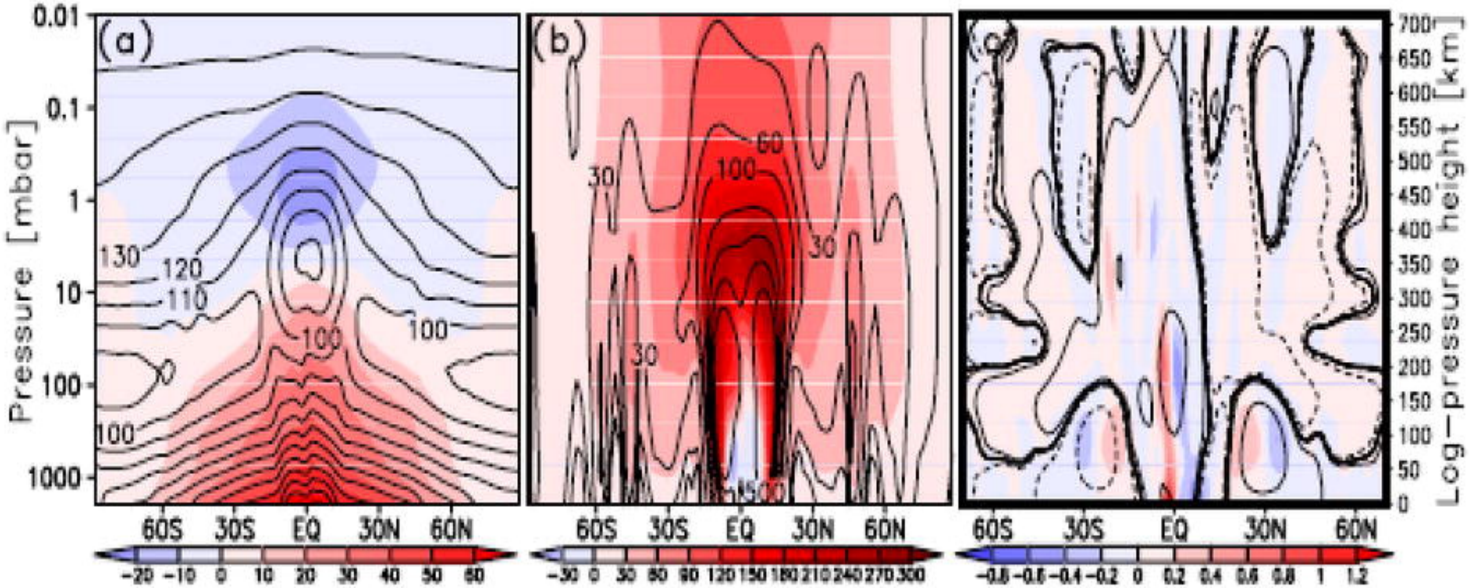
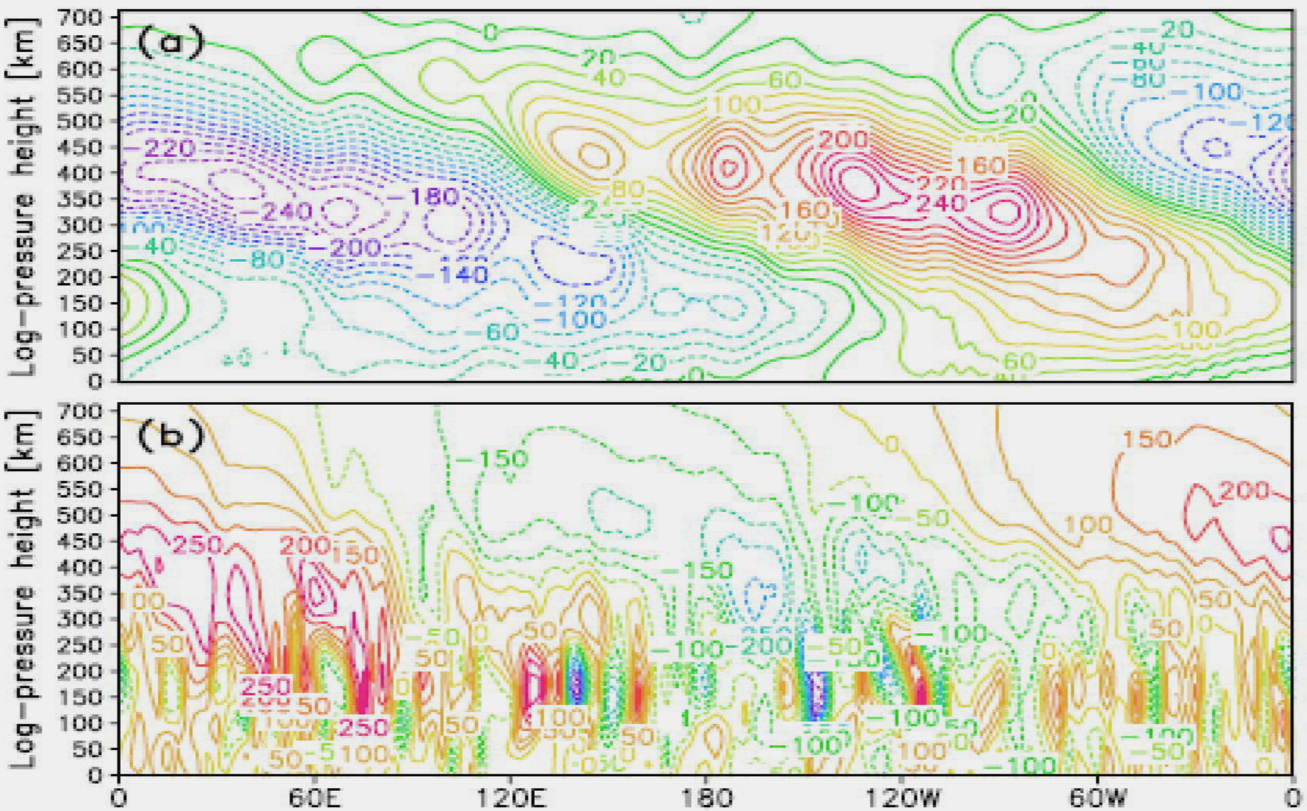


Fig. 4. Latitude-height cross-sections of the fields simulated for the warm Saturn-like (a) Temperature (contours) and deviations of the temperature from the “cold” giant case simulation (shaded); (b) mean zonal wind (contours) and deviations from the “cold” giant case; (c) residual meridional circulation (contours) and residual vertical velocity (shaded).


(a)
(b)
Log-pressure height [km]
0
60E
120E
180
120W
60W
0

Reconnection to the EChO science

- Constrain physical parameters
- Provide a knowledge of species to estimate radiative forcing
- Difference between the observed and radiative equilibrium temperature points to the atmospheric dynamics
- How GCM predictions can guide observations?
- Are circulations on super-earths distinguishable from that on warm gas giants?
- Multitude of planets would allow to update the scaling theory