Atmospheric modeling of Uranus and Neptune

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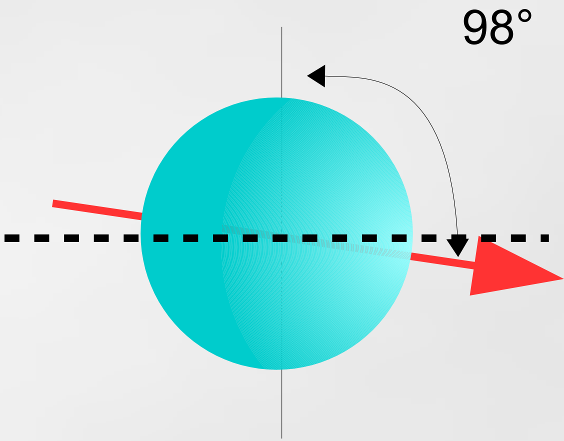
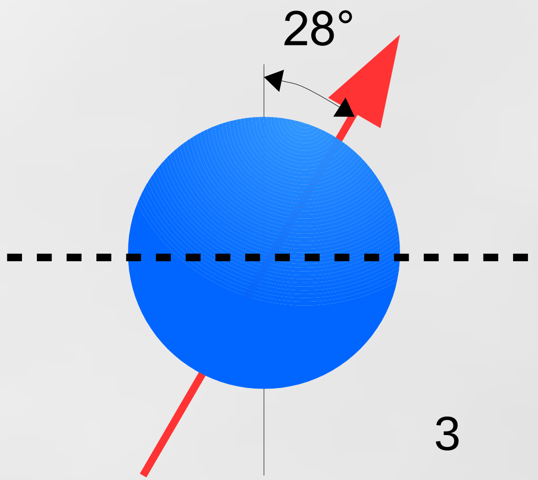
1. Characteristics of Uranus and Neptune

A. Introduction

- Uranus and Neptune have similar characteristics :
  - Ice giants ;
  - Same size, mean radius = ~25000 km ;
  - Fast rotators (rotation period between 16 and 17h) ;
  - Long orbital periods, low solar irradiance.
- But two major differences:
  - Very different obliquity ;
  - Internal heat flow equal to ~0 for Uranus.



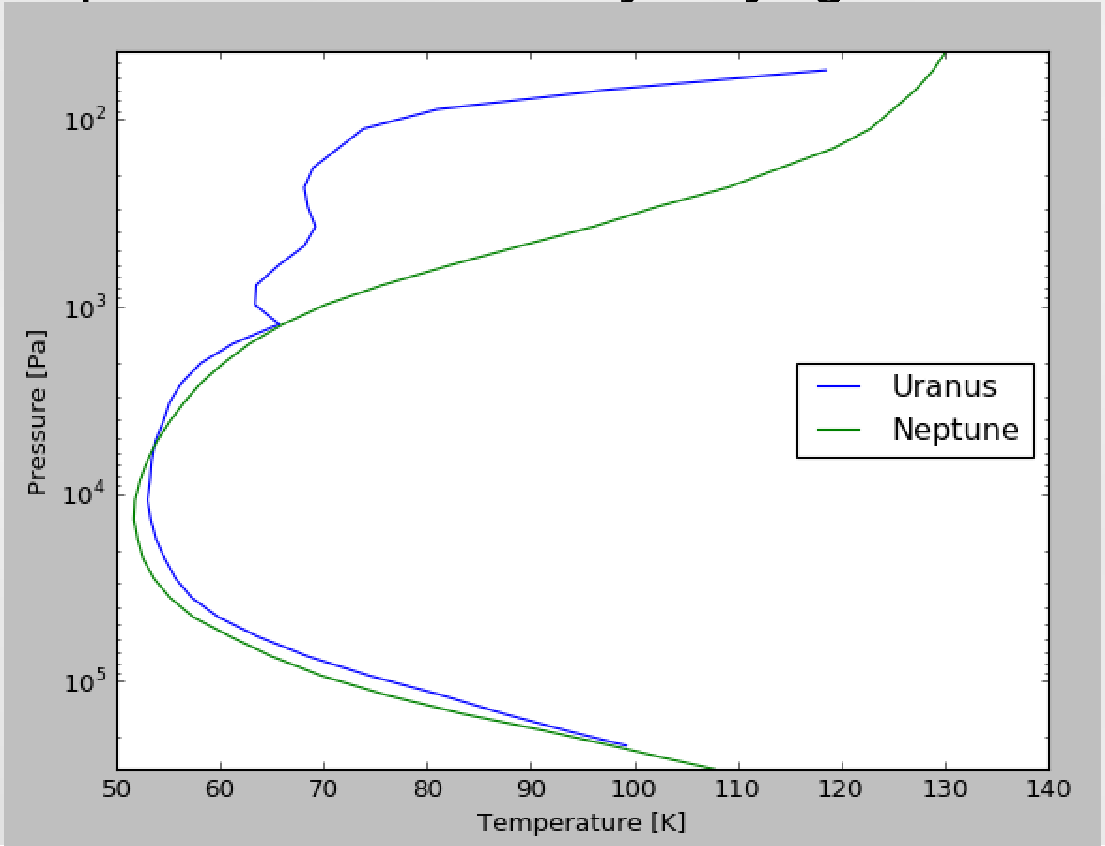


B. Composition of the atmosphere

- Atmosphere composed mainly of hydrogen and helium (H_2 : ~82 %, He : 15 %, CH_4 : ~2 à 4%).
- Cloud layers :
  - CH_4 between 0,01 and 1 bar ;
  - H_2S between 2 and 10 bars ;
  - NH_4HS between 20 and 40 bars ;
  - H_2Obetween 50 and 100 bars.
- Hydrocarbon hazes (C_2H_6, $C_2H_{2, \ldots}$) at high altitude (<0,1 bar).

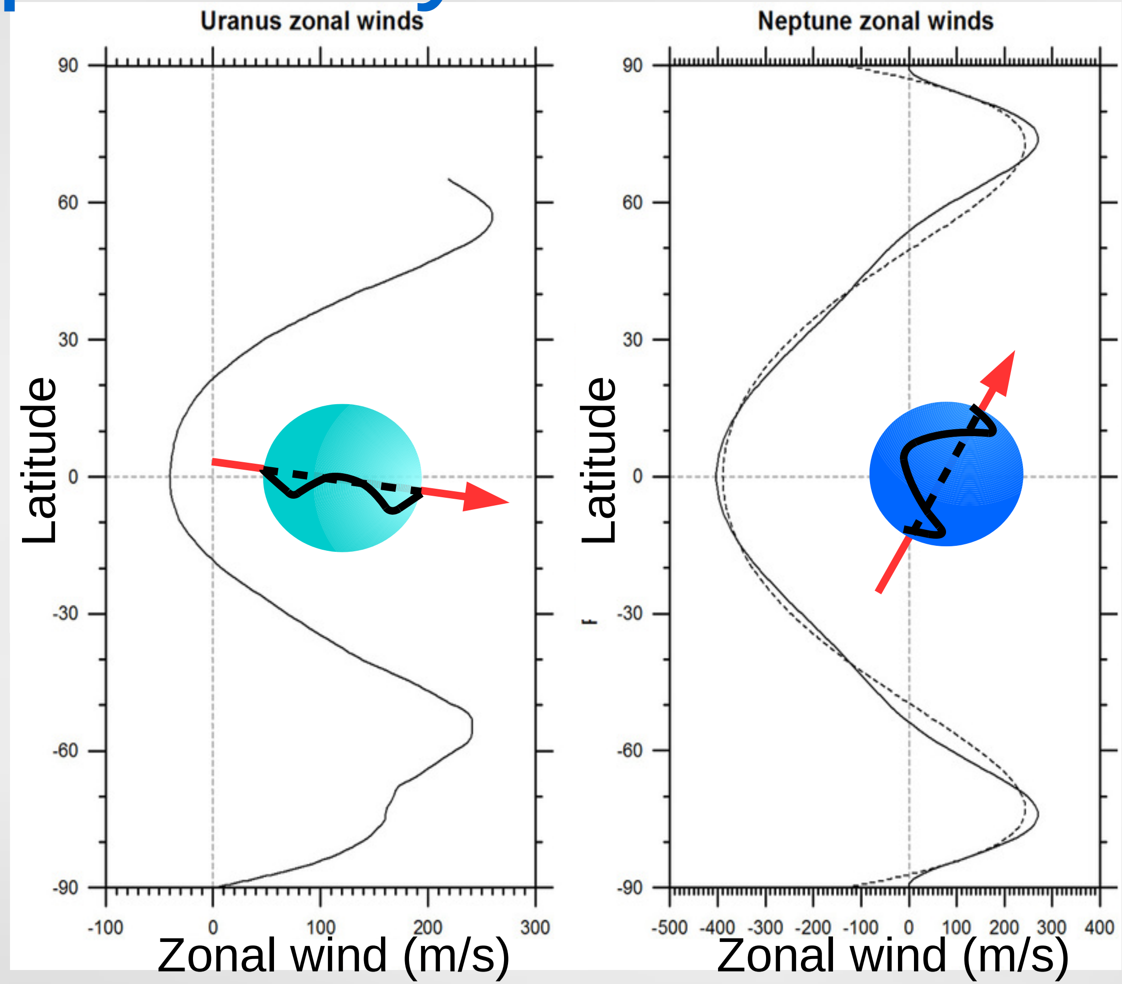
C. Temperature profile

- Temperature profiles observed by Voyager 2 :



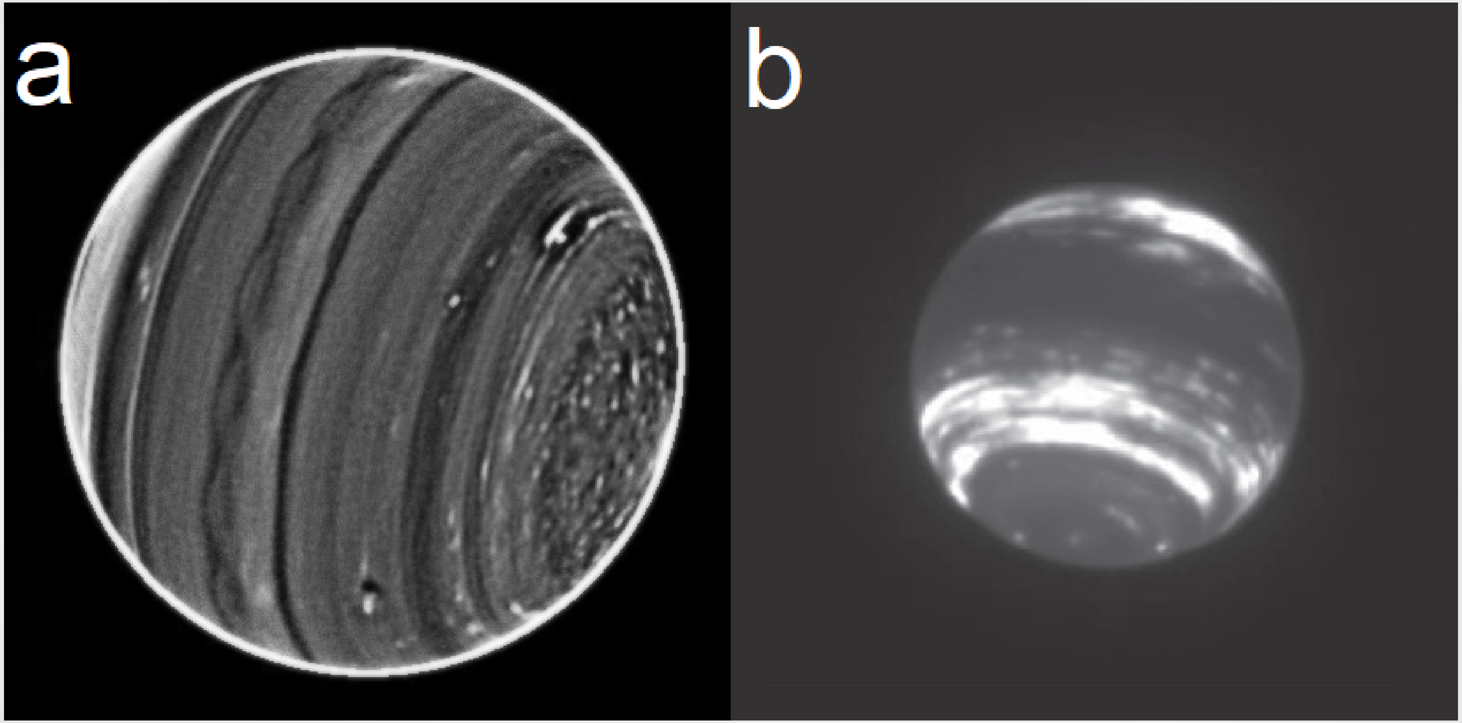
D. Atmospheric dynamics

- Fastest wind in the solar system (~ -400 m/s on Neptune).
- Retrograde jet at the equator (subrotation) and 2 prograde jets in mid-latitude.



Opposite : latitudinal profile of the zonal wind on Uranus and Neptune at ~100 mbar (Mousis et al, 2017).

D. Atmospheric dynamics

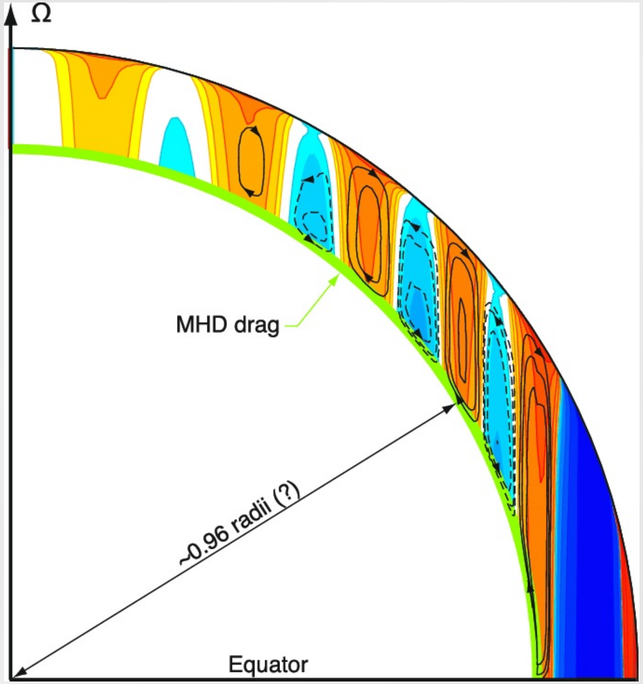


Near infrared images of Uranus (a) and Neptune (b). Light areas correspond to clouds. (Mousis et al, 2017; De Pater al, 2014).

2. Atmospheric modeling

- A. Deep-flow model
  - Presumed presence of several convective cylinders in differential rotation and parallel to the axis of rotation on rapidly rotating planets.

  - Presence of a subrotation on Uranus and Neptune with an idealized model (Aurnou et al., 2017; Soderlund et al., 2013).



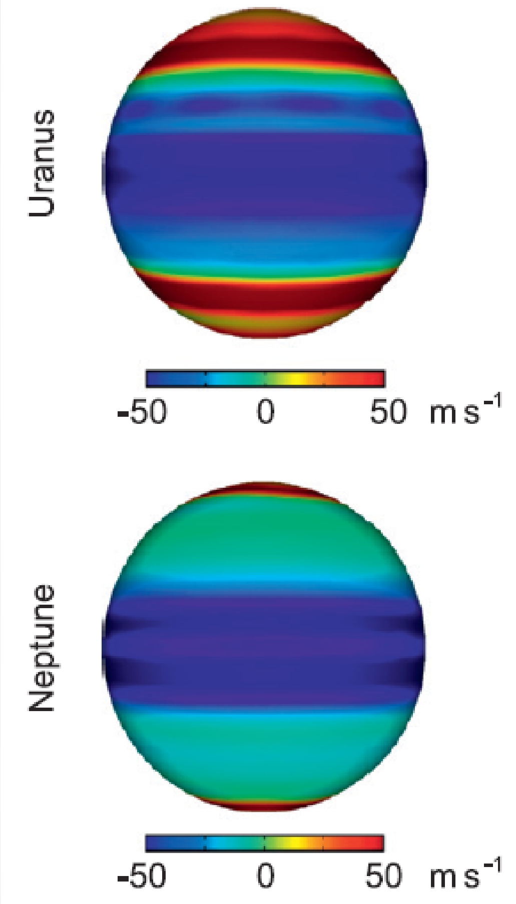
Above: diagram of the deep-flow model (Liu and Schneider, 2008).

2. Atmospheric modeling

- B. Shallow-flow model :
  - Only weather process.

  - Subrotation reproduced with prograde jets but idealized models (simplified radiative transfer and neglected seasonal effects) (Lian and Showman, 2010; Liu and Schneider, 2010).

  Opposite: zonal wind on Uranus and Neptune at 25 mbar (Liu and Schneider, 2010).

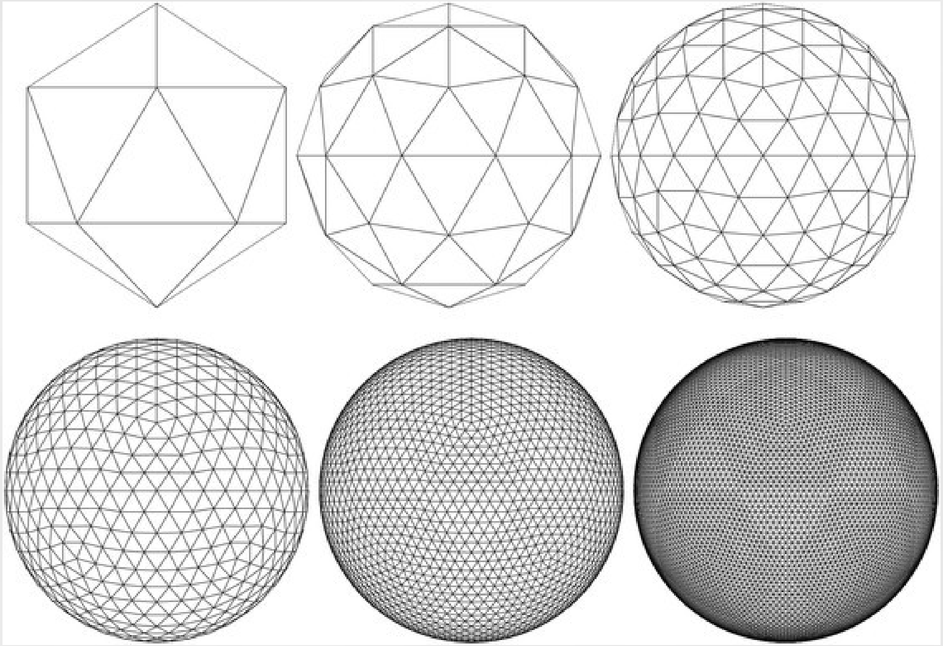


3. Objectives of the thesis

- The objectives of this thesis are:
  - to reproduce and understand the zonal jet-current structure of these atmospheres with a realistic shallow-flow model. This will include studying the role of waves and instabilities in the establishment of jet streams ;
  - to simulate the vertical structure and size distribution of aerosols and to compare them with observations.

4. Model description

- The General circulation model used in this thesis is Dynamico (LMD) :
  - Dynamic core that numerically solves atmospheric primitive equations ;
  - 1D physical parameterizations coupled to the dynamic core (for example, radiative transfer, convection, condensation, etc.) ;
  - Icosahedral grid.



- Assumptions used for Uranus and Neptune:
  - Neglected diurnal cycle and addition of a friction layer at the bottom of the model.

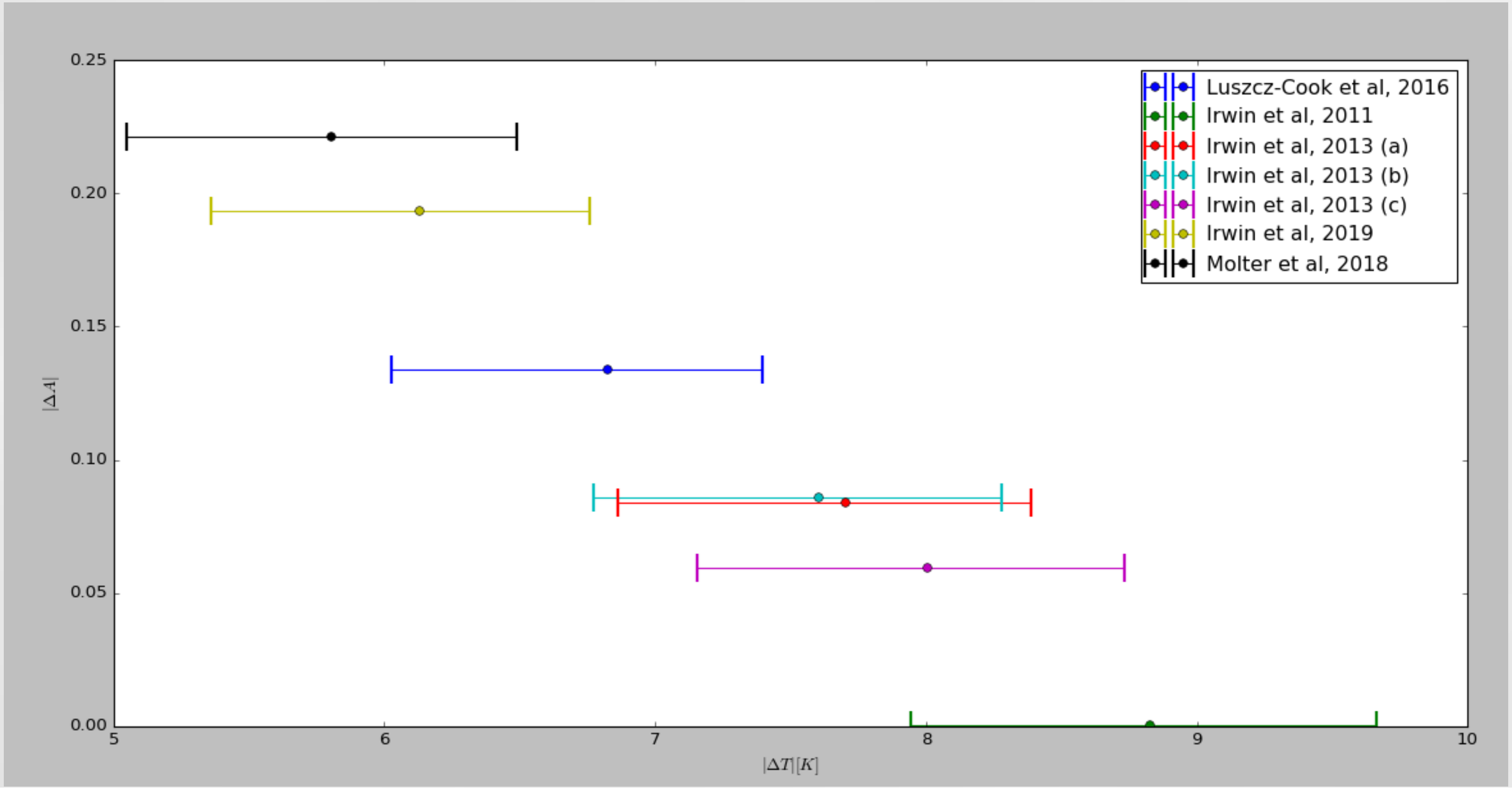
5. First results for Neptune

A. Parameterization of cloud layers

- Simulations between 3 bars and 0.0003 bars : only H_2S and CH_4 cloud layers.
- Several cloud models for Neptune.
- These models depend on assumptions about particle size, opticals constants, cloud opacity or altitude of the clouds.
- Choice of the model: we look at the difference between the temperature and albedo obtained for each cloud model with a 1D simulation and the temperature and albedo measured by Voyager 2.

A. Parameterization of cloud layers

The best model with our assumptions is Irwin et al, 2013 (b) for Neptune.

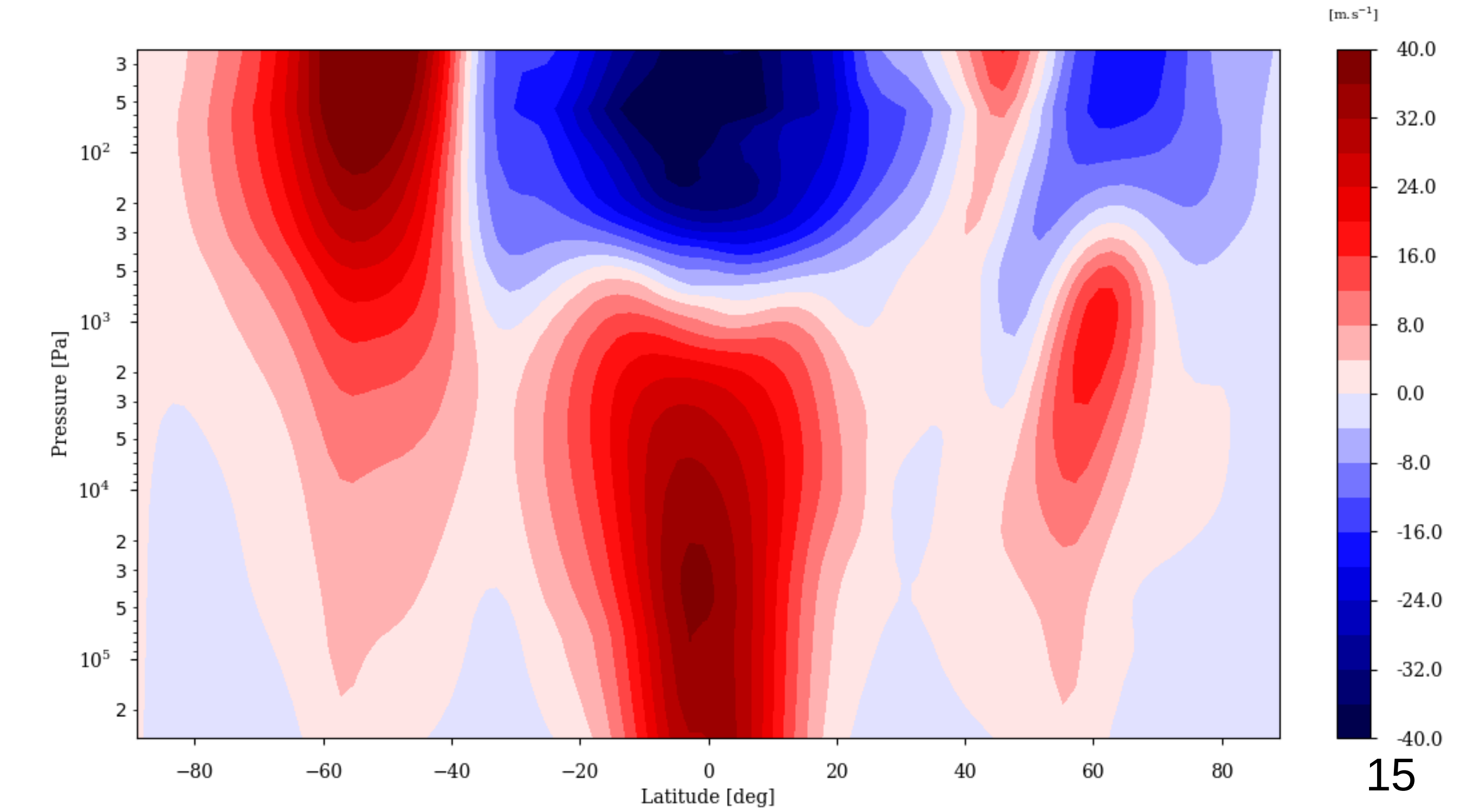


B. Atmospheric circulation (zonal wind)

- Two simulations at two different resolutions over 40 pressure levels :
  - A simulation with a resolution of 2° ;
  - A simulation with a resolution of 1° .
- The temperature profile is initialized on the whole grid.

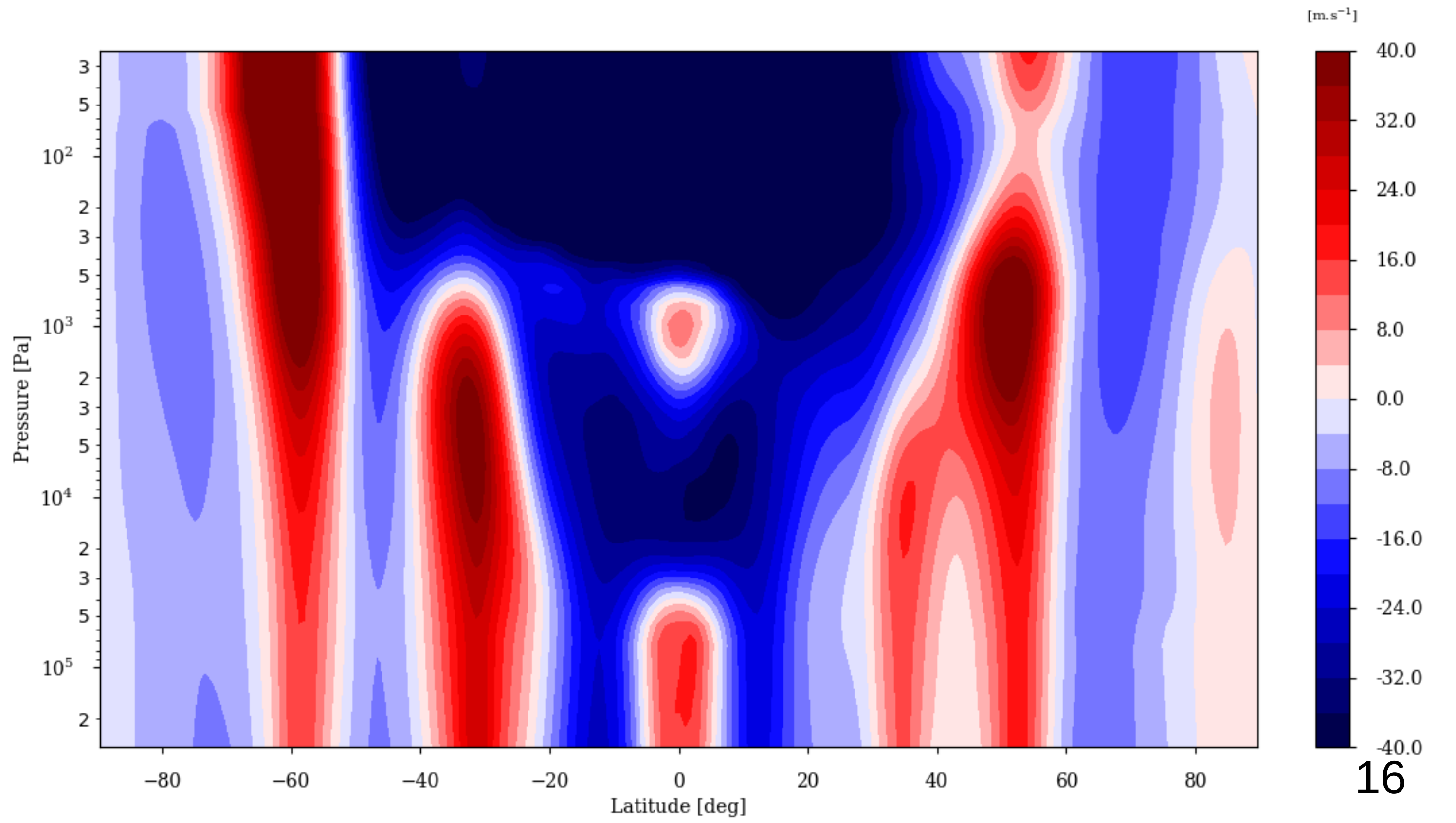
B. Atmospheric circulation (zonal wind)

- Vertical cross-section of mean zonal wind speed (resolution : 2°).
- 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. Atmospheric circulation (zonal wind)

- Vertical cross-section of 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



B. Atmospheric circulation (zonal wind)

- However, the radiative-convective equilibrium hasn't been reached in these simulations yet. It is estimated at about fifteen Neptunian years. At present, only 2 Neptunian years were simulated.
- Simulations still need to be extended to obtain a balanced temperature profile.

6. Conclusion

- For now, the simulations don't reproduce the observed zonal wind.
- The resolution affects the zonal wind (inverse energy cascade : transfer of energy by the eddies from the small scales to the large scales)
- Future work :
  - To analyze eddies activity ;
  - To analyze the effect of the friction layer at the bottom of the model.

Thank you for your attention !