Three-dimensional mesoscale modeling of the Venusian cloud layer and associated gravity waves

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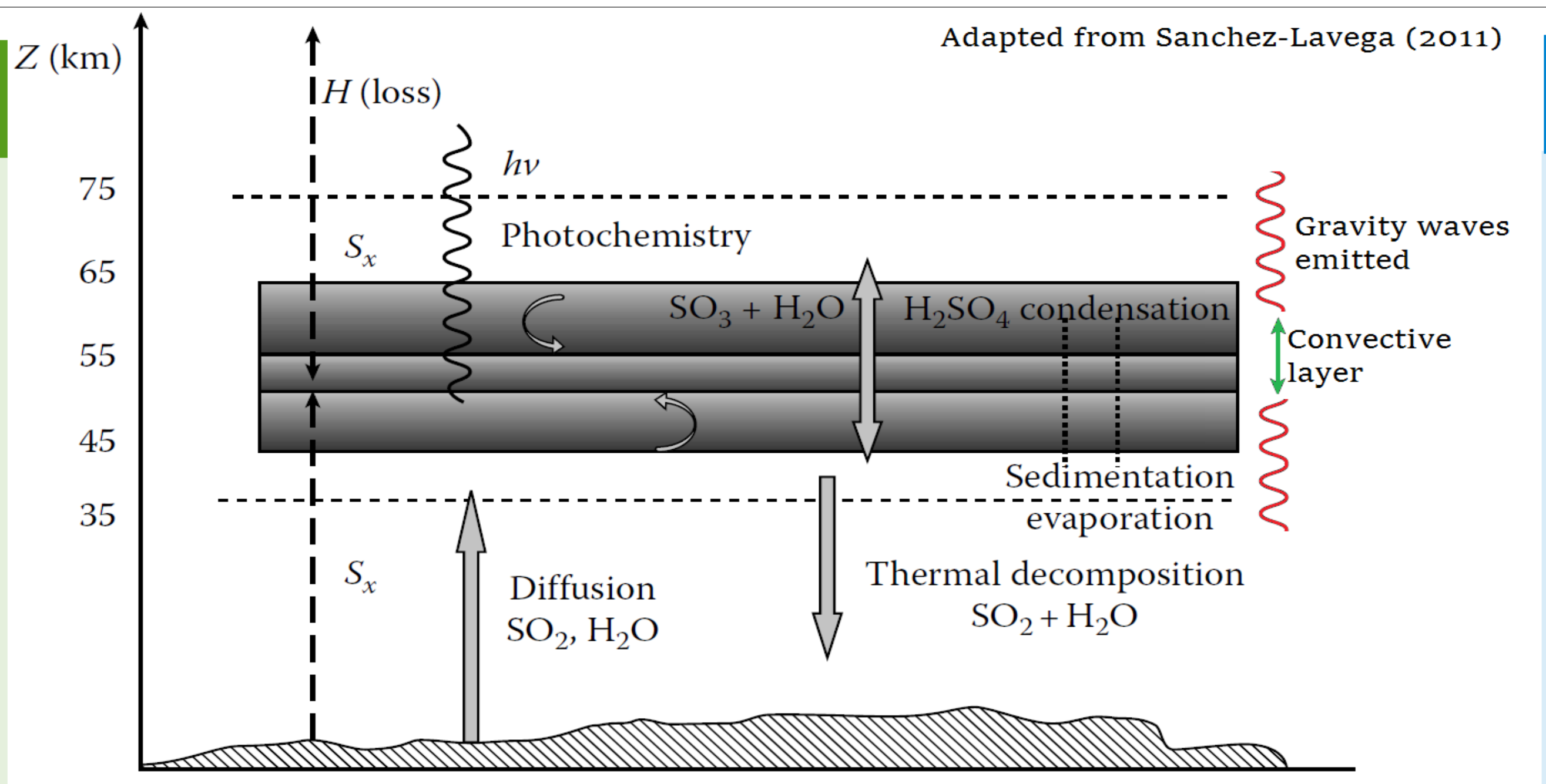
Context :

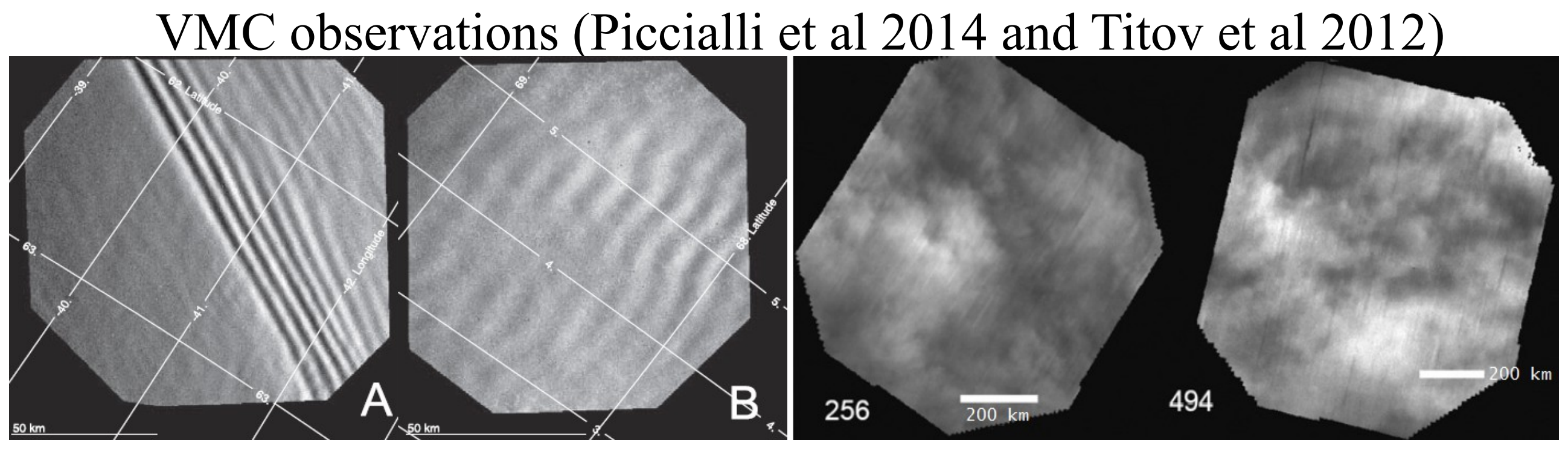
Venus hosts a global sulfuric acid cloud layer between 45-70 km which many properties have been investigated by the Venus Express mission. One of the main questions that remains unclear about the dynamics of the atmosphere and its interaction with the photochemistry is the characterization of the cloud convective layer which mixes momentum, heat and generates gravity waves observed too by Venus Express.

We propose here the first 3D mesoscale model resolving the convective layer and the induced gravity waves.



Adapted from Sanchez-Lavega (2011)

VMC observations (Picciali et al 2014 and Titov et al 2012)



Model :

The model is adapted from the LMD Martian mesoscale model (Spiga and Forget 2009). We use the ARF-WRF dynamical core to perform 3D Turbulent-resolving simulations (Large-Eddy Simulations).

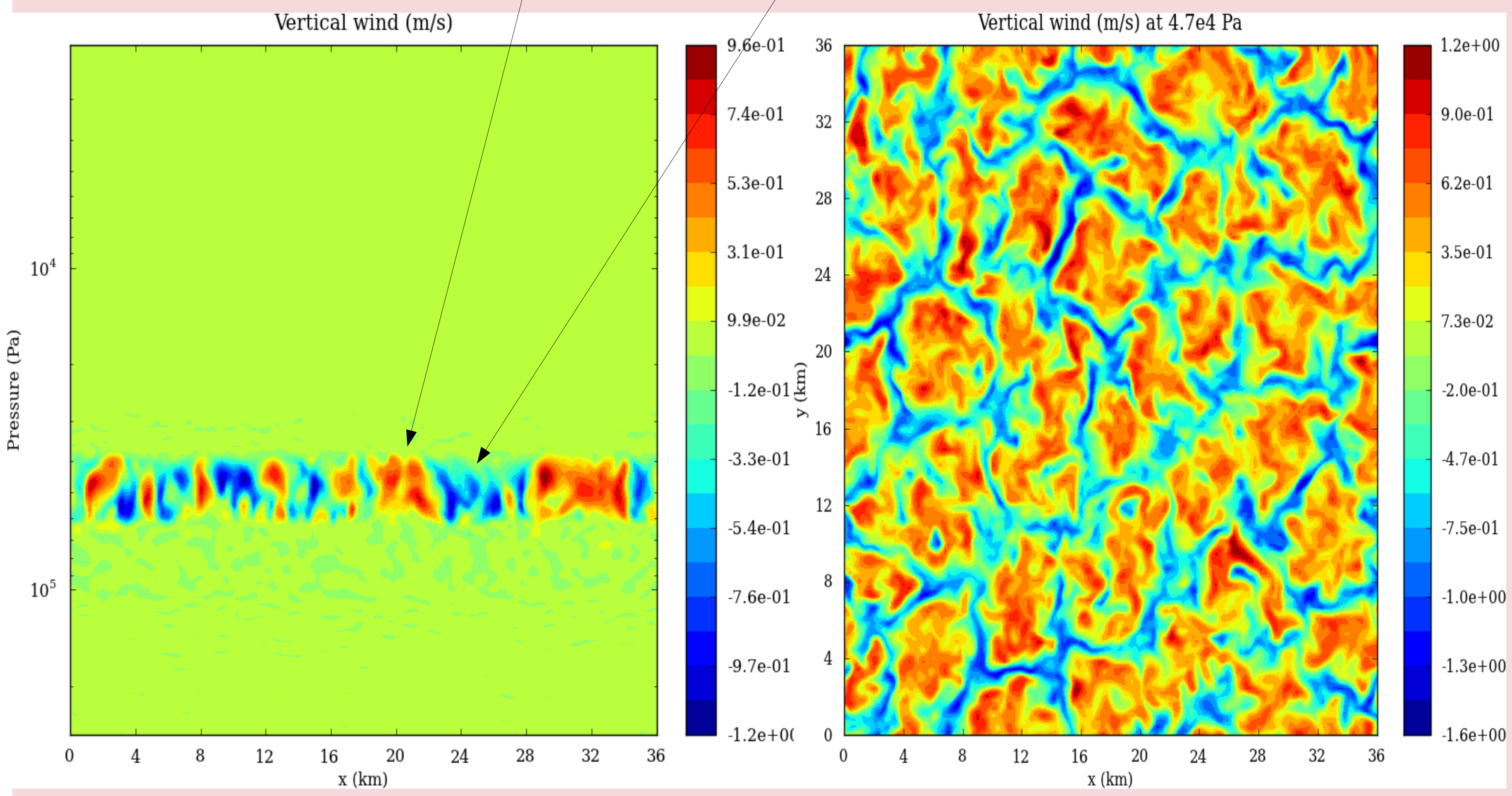
The initial temperature profile is taken from Venus GCM simulations. Then we impose a radiative forcing with heating rates extracted from the same Venus GCM simulations (Lebonnois et al 2015) at a given latitude and local time. We use 3 different heating rates : two radiative one (solar and IR) and one representing the global dynamics of the atmosphere.

Main results : 3D convective layer and gravity waves

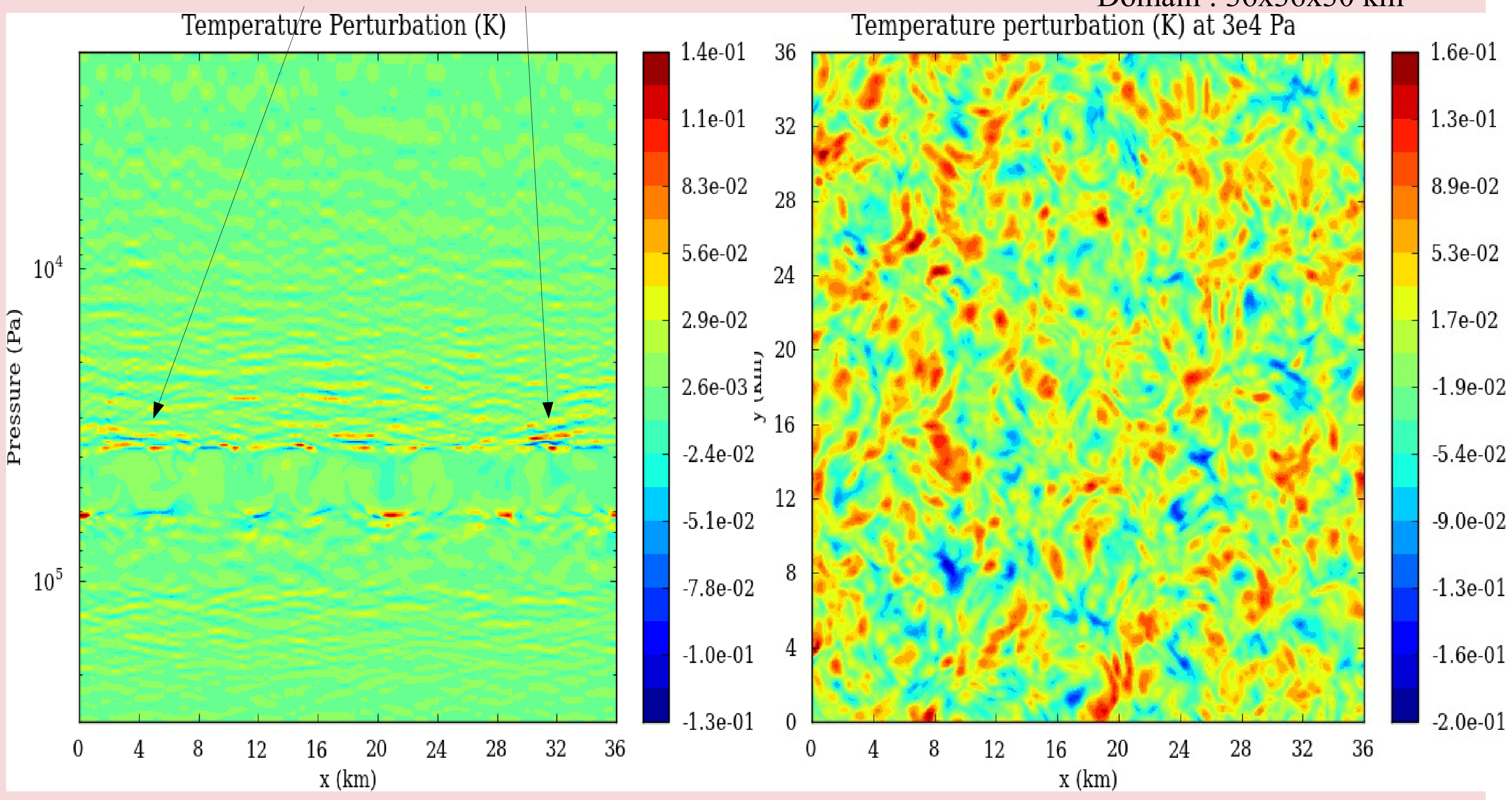
Settings :
-Horizontal resolution : 200 m
-Vertical resolution : ~170 m
-Time step : 1,2 s
-Domain : 36x36x30 km

The configuration of the following simulation is at equator at noon.

Resolved updrafts and downdrafts in the cloud layer



Induced gravity waves by resolved convection



The convection is developing between 6 10^4 and 3.8 10^4 Pa, i.e. between 50.1 and 53.3 km. In the same configuration the VeRa observations (Tellmann et al 2009) provide a thicker convective layer, between 53 and 58 km. The vertical wind obtained are also weaker than the observations from the Vega balloons (between -3 and 2 m/s). The convection is organized by hexagonal-type closed cells of diameter about 8 km.

When the vertical plumes reach the top of the convective layer, they encounter and excite the stable layers above. This leads to the formation of waves, that propagate vertically and horizontally with a circular wave front. The circular shape may be linked to the absence of wind shear. The gravity waves are visible through the temperature perturbations. As the convection is weaker we obtain also weaker temperature perturbations compared to the observations (between -2 and 2 K). From the temperature perturbations we can extract the wavelegths using a continuous wavelet transform. The vertical wavelength is about 1 km and the horizontal wavelength is a combination of wavelengths of about 1.5, 4 and 8 km. This is lower than the observations (between 2 and 30 km from VMC and from 40 to 200 km from VIRTIS). With a wider domain we can assume larger wavelengths may develop.

To summarize we obtain a realistic convection with consistent results compared with the observations. Yet the convective layer we obtain is too thin and the induced gravity waves too weak and short. Therefore we are currently working to add a complete radiative scheme into the model to perform more realistic simulations.

Variability through latitude and local time :

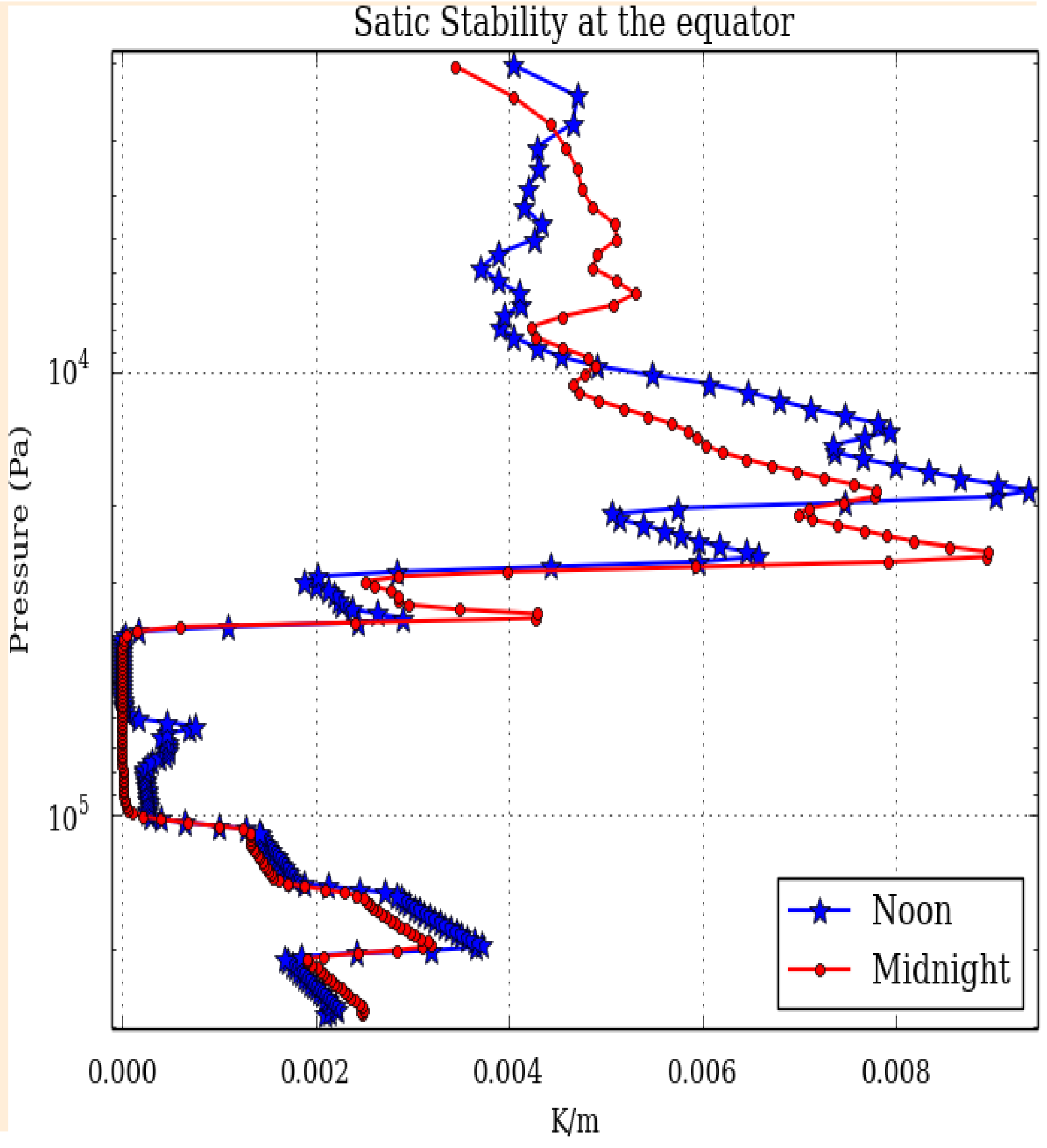
The various observations exhibit a strong variability of the convective layer with latitude and local time.

This variability is explored with the model. At the equator, the convection is thicker and stronger at night. The induced gravity waves are also stronger.

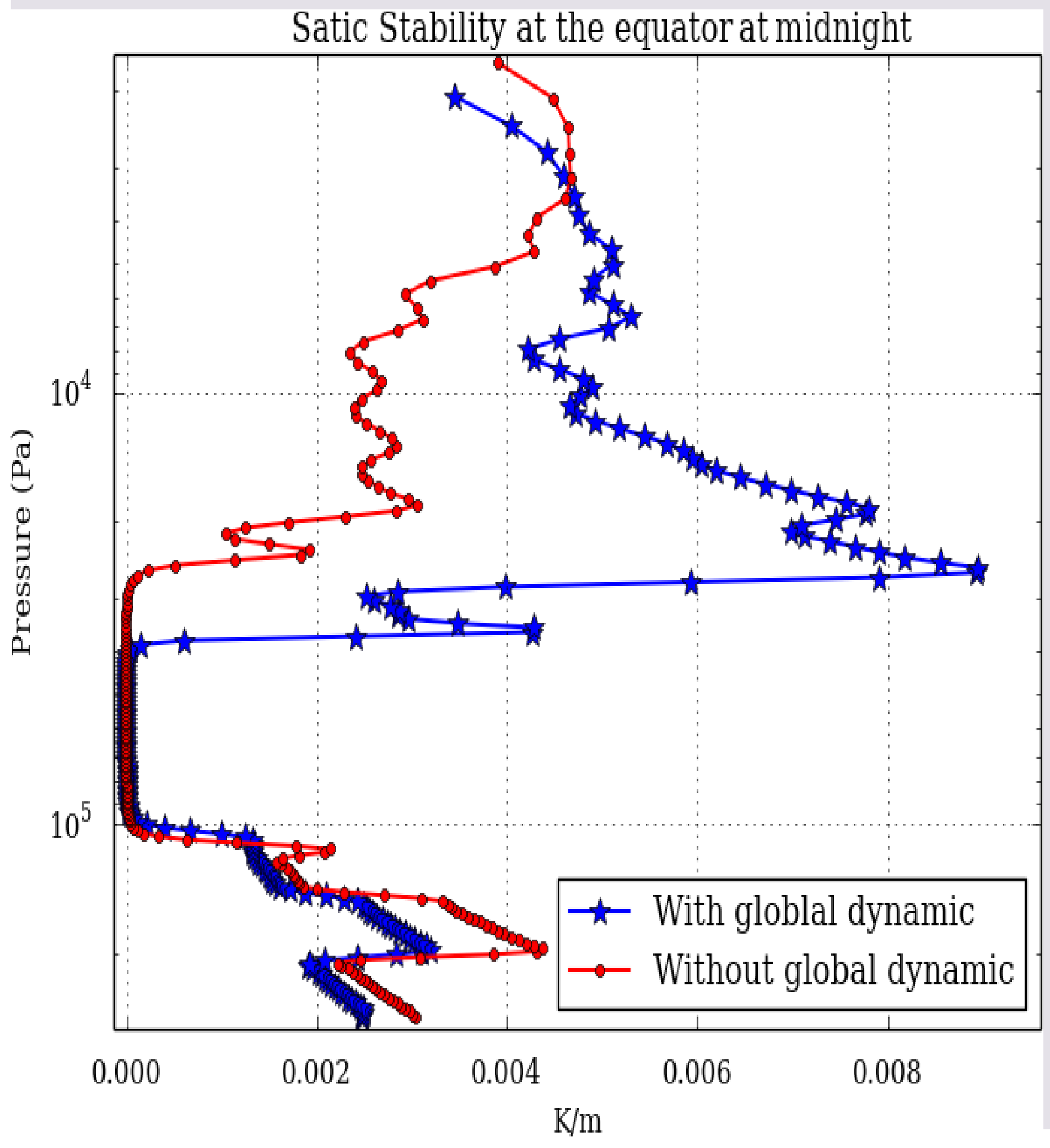
At noon the convection is very similar between the equator and 60° of latitude, behaviour not observed.

At high latitude and at night the convection is the weakest although the strongest observed.

Therefore a radiative scheme in the model in needed.



Impact of the global dynamics and the cloud model :



To show the impact of the global dynamics we ran simulations with heating rates from a 1D model without dynamics. The main effect of the global dynamics is to mitigate the convection. The convective layer is thicker without the global circulation accounted for.

We also assessed the impact of the cloud model by comparing the model of Haus et al (2014, used so far) and Zasova et al (2007) . With Haus' model we obtain a more realistic convective layer in altitude and vertical wind.

References :

- Haus, R., et al. (2014). *Atmospheric thermal structure and cloud features in the southern hemisphere of Venus as retrieved from VIRTIS/VEX radiation measurements*. Icarus
- Lebonnois, S., et al. (2015). *Analysis of the radiative budget of the Venusian atmosphere based on infrared Net Exchange Rate formalism*, J. of Geophys. Res. (Planets).
- Picciali, A., et al. (2014). *High latitude gravity waves at the Venus cloud tops as observed by the Venus Monitoring Camera on board Venus Express*, Icarus.
- Skamarock, W. C. and Klemp, J. B. (2008). *A time-split nonhydrostatic atmospheric model for weather research and forecasting applications*., J. of Computational Physics
- Spiga, A. and Forget, F. (2009). *A new model to simulate the Martian mesoscale and microscale atmospheric circulation: Validation and first results*. J. of Geophys. Res. (Planets)
- Tellmann, S.,et al. (2009). *The Structure of the Venus Neutral Atmosphere as seen by the Radio Science Experiment VeRa on Venus Express*. J. of Geophys. Res. (Planets).
- Tellmann, S., et al. (2012). *Small-scale temperature fluctuations seen by the VeRa Radio Science Experiment on Venus Express*. Icarus.
- Titov, D. V., et al (2012). *Morphology of the cloud top as observed by the Venus Express Monitoring Camera*. Icarus
- Zasova, L. V., et al. (2007). *Structure of the Venus atmosphere*, Plan. Sp. Sc