3D mesoscale modeling of the turbulence of Venus atmosphere

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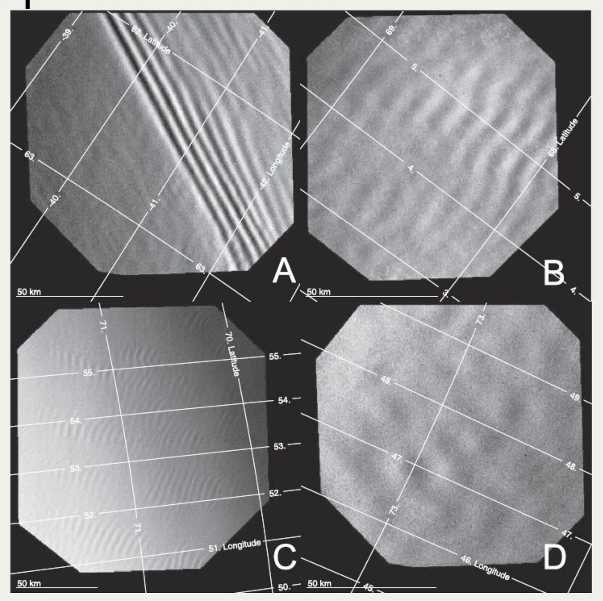
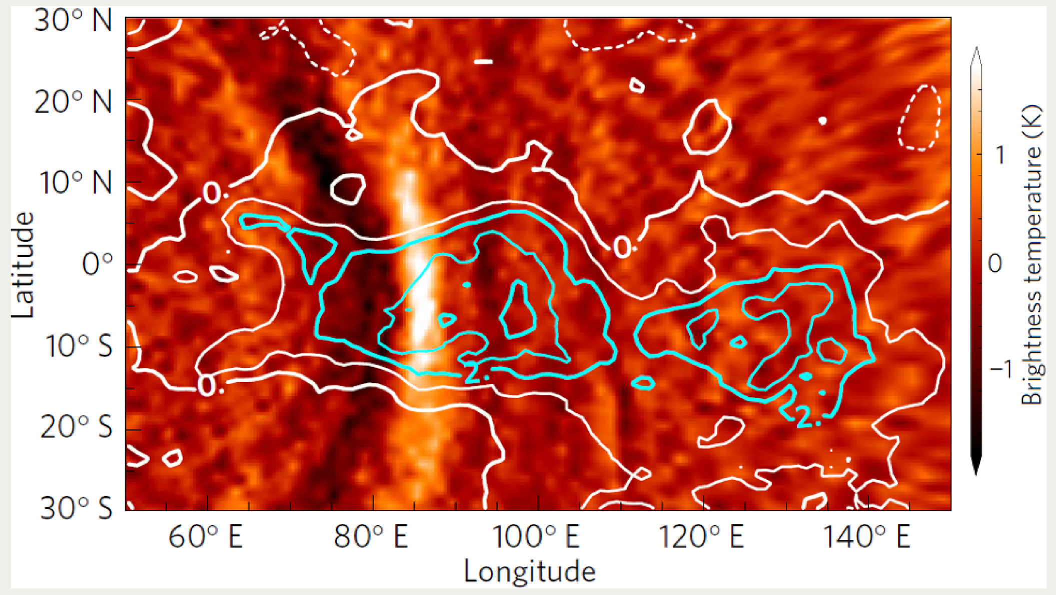
Introduction

Venus hosts a global sulfuric acid cloud layer between 45 and 70 km which many properties have been investigated by the Venus Express mission. One of the main question 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 chemical species, and generates gravity waves, observed by *Venus Express*. *Akatsuki* observed stationary bow-shape wave of 10,000 km above the main topographical features.

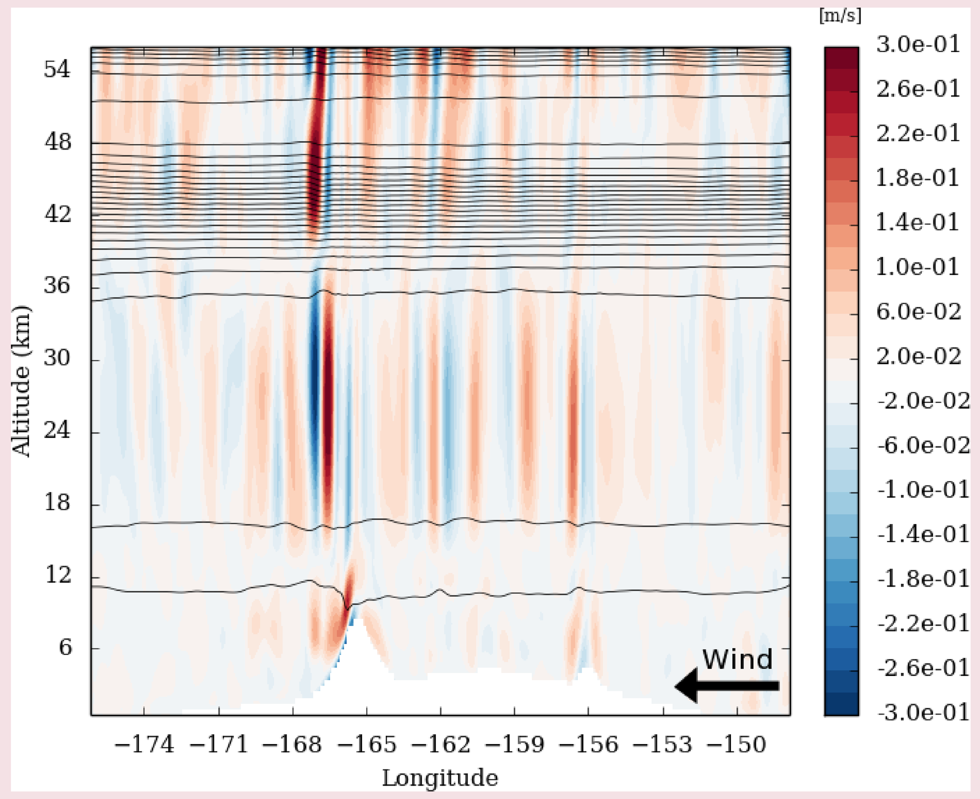


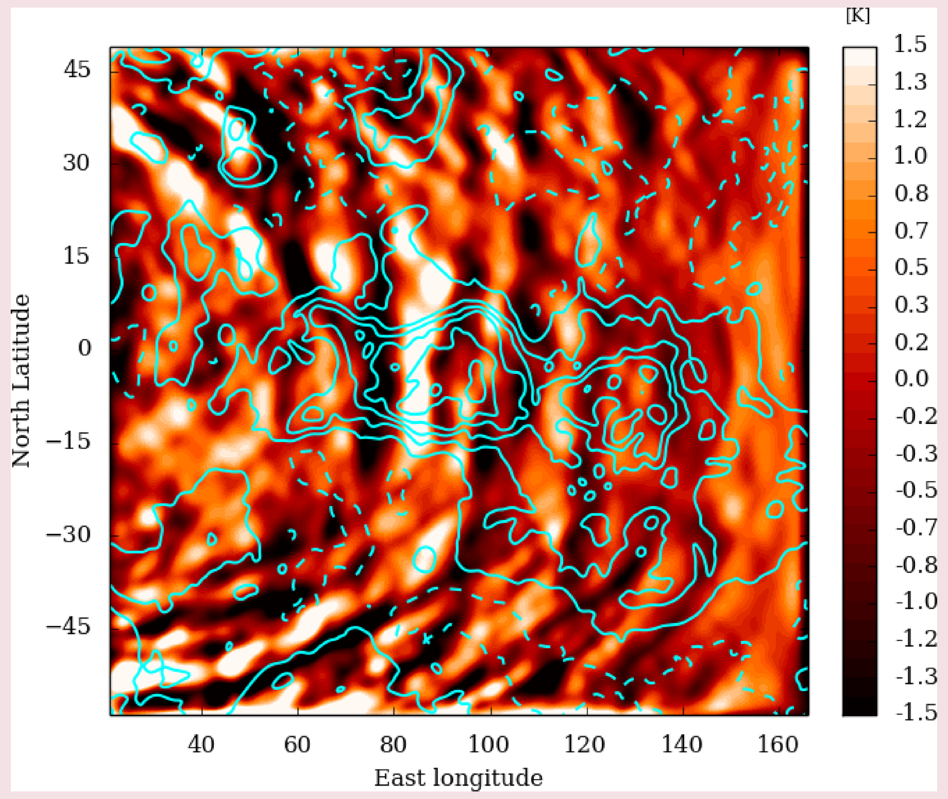


We propose here an unprecedented 3D mesoscale model to resolve the convective layer and the induced gravity waves. The model is based on the LMD Martian mesoscale model. We use the ARF-WRF dynamical core and performing 3D Turbulent-resolving simulations. We perform the simulations on CINES' machine Occigen and Sorbonne Université' HPCave.

Mesoscale model

The main topographical features block the flow and generate mountain waves propagating vertically. When the waves encounter the two layers of low static-stability, the mixing layer (20-35 km) and the convective layer (47-55 km) there is generations of trapped waves propagating horizontally. The waves vertical momentum is about 2 Pa is extracted from the surface and deposited at about 30 km. The model validates the orographic parametrizaition parameters (Navarro et al., 2018).





At the top of the cloud (70 km) the wave engenders temperature anomaly of an amplitude of 1.5 K of several decade of latitude. Signal from large-scale dynamics and small-scale waves are filtered. The waves are characteristics are consistent with observations. The waves has a lifetime of about 8 Earth days with a maximum in the afternoon. The stability of the atmosphere near the surface plays a key role in the wave propagation.

LMD Venus Mesoscale Model

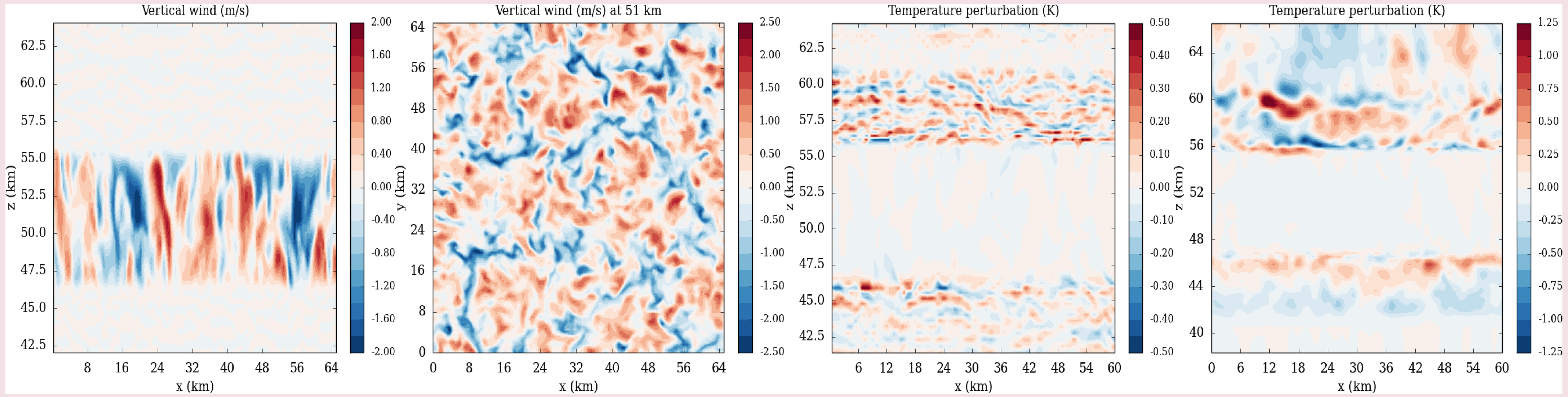
To investigate the turbulence we use 2 modes of the WRF dynamical core : the Large-Eddy Simulations (LES) model that resolves the small-scale turbulence, convection and induced gravity waves, and the mesoscale mode that model a limited area of the planet and takes into account high-resolution topography.

LES : The physical forcing is decomposed of 3 heating rates : short wave radiation, infrared radiation and large-scale dynamics. There is two of calculating these rates : off-line mode (Lefèvre et al. 2017) with constant during the simulations extracted from LMD Venus runs and on-line (Lefevre et al., 2018) using LMD Venus GCM radiative transfer. The solar heating is computed using the shortwave radiation fluxes from Haus et al. (2016). The infrared radiation transfer calculation is based on Net Exchange Rate formalism with a latitudinal varying cloud model based on Haus et al. (2013). The large-scale dynamics rates are extracted from LMD Venus GCM. The vertical domain extends from the ground to 100 km. Periodical boundary condition are used.

Mesoscale : High-resolution *Magellan* is used to model four area of interest : Aphrodite Terra, Atla Regio, Beta Regio and the poles. GCM fields are used as boundary condition and updated every 1/100 Venus day in order to model a realistic super-rotation. Radiative transfer is used to compute solare and IR heating rates.
The initial physical field profiles are taken from Venus GCM simulations (Garate-Lopez and Lebonnois, 2018) at a given latitude and local time.

Cloud convective activity modeling

The convective layer extends from 47 to 55 km against a 3 km thick for the off-line mode. These values are consistent with the radio occultation by Venus Express instrument VeRa. The amplitude of the vertical wind, about $\pm$ 3.5 m/s is also consistent with the VeGa balloon measurements. The size of the closed polygonal cells is about 15 km.



Impact of wind shear

Despite a consistent convection depth the gravity waves amplitude is still smaller than the observations. We choose to investigate the impact of wind shear on the convection and induced gravity waves. Zonal and meridional wind profile are extracted from LMD Venus GCM. The wind shear has few impact on the convection depth, it is only advected with the flow. Whereas the impact is strong on the waves. The obstacle effect generates waves with an amplitude superior to 1 K , same order of magnitude that the observations.

Cloud-top dynamics

VMC/*Venus Express* observed that near the Equator at the subsetllar point puffy clouds were present at the top of the cloud suggesting convective activity. he coupling with the radiative transfer allows for the first time modeling of the convection at cloud top. The model resolves a convective layer of 6 km depth with vertical wind up to 3 m/s. We attribute this to the strong absorption of solar heating by the unknown UV absorber at 66 km.

Conclusions and outlooks

Take home messages

- Venus LMD physics coupled with WRF dynamical core
- Realistic convective layer depth and vertical wind
- Obstacle effect enhances convective gravity waves
- Resolved large-scale stationary bow shape waves

Perspectives

- Investigate the deep atmosphere : Planetary boundary layer
- Implementation of Photochemistry and Microphysics

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