Atmospheric Gravity Waves: with Venus GCM simulations and Venus Express VMC data

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Atmospheric Gravity Waves

- Atmospheric gravity waves (AGW) are frequently observed in planetary atmospheres, being considered essential to explain some observed features in the atmosphere of terrestrial planets (Fritts and Alexander 2003). In Venus middle/upper atmosphere (70-150 km), AGW are believed to play a major role in the dynamics, and commonly referred in the literature to explain density fluctuations, and temperature and cloud structure variation.
- The Venus Global Circulation Model (GCM) developed at the Laboratoire de Météorologie Dynamique (LMD) (Lebonnois et al. 2016) is operational up to 150 km (Gilli et al. 2017), with the physical and photochemical processes relevant at those upper altitudes, with a gravity waves parametrisation scheme implemented, proving to be the only existing full self-consistent ground-to-thermosphere Venus 3D model.
- Detection and characterisation of AGW on VMC data from Venus Express (VEx) using the Planetary Laboratory for Image Analysis (PLIA) (Hueso, R., et al. 2010) to retrieve the wave properties and results from the implementation of a non-orographic AGW parameterization into Venus LMD-GCM developed are presented.
- The goal of this work is to characterize the AGW in the Venus's atmosphere using the whole existing dataset (VEx and Akatsuki), in order to constrain model simulations.

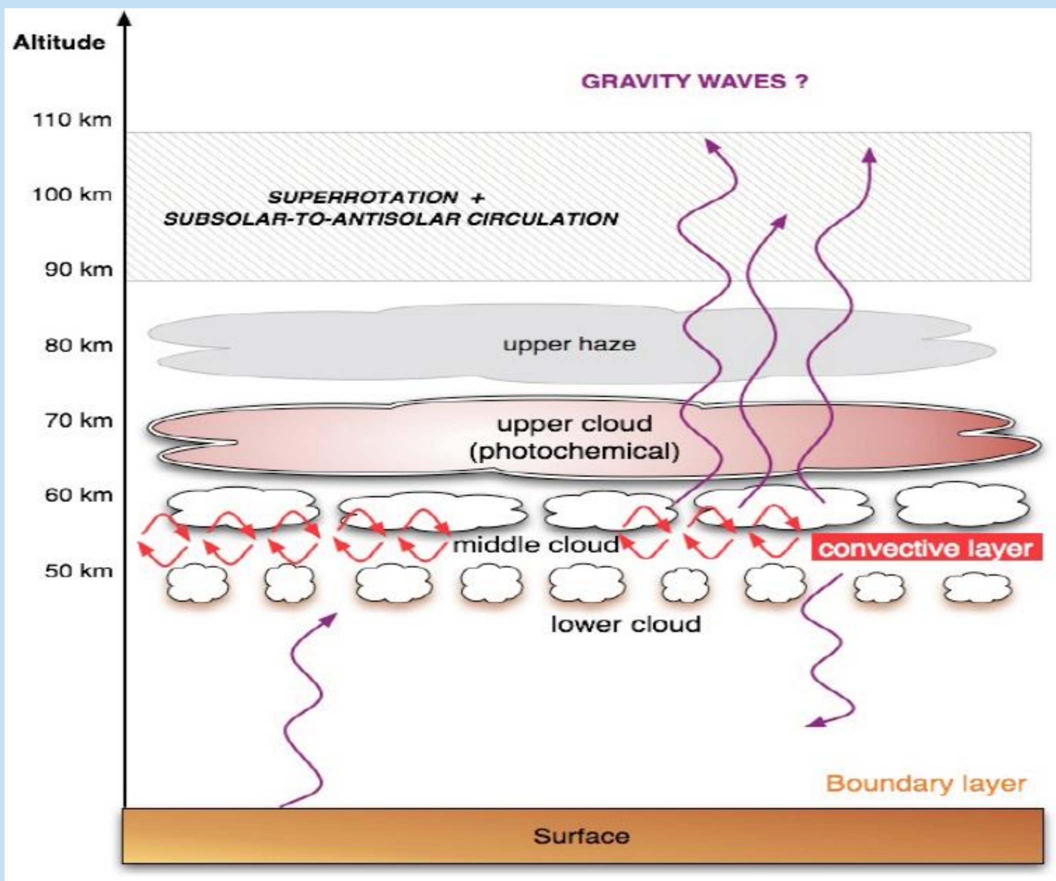


Fig 1: Schematic representation of the formation of non-orographic AGW in the middle cloud region (~55 km) above typical convective cell. AGW provide a significant source of momentum and energy at the layers where they break, thus affecting the transport of heat and constituents in the atmosphere.

Venus LMD-GCM simulations of AGW

Non-orographic GW parametrization used here:

- Stochastic approach formalism following (Lott, F., et al. 2012) ;
- Large ensemble of monochromatic GW launched just above the convective layer (at 55 km);
- At each time step, the effect of a few waves is added to that of the waves launched before;
- Source of the GW is chosen uniform (no latitudinal variation)
- Waves characteristics chosen randomly, with arbitrarily fixed probability distribution.

Table I - Wave characteristics for the VGCM GW tests used in the reference simulation.

VGCM GW TESTS	H.W. (km) [min/max]	Phase speed (m s^{-1}) [min/max]	EP-flux (kg m^{-1} s^{-2}) [min/max]	Launch level (km)
Kobs	[50-600]	[1-61]	0.005	~55
GW2	[300-6000]	[1-111]	0.005	~55
GW6	[50-1000]	[1-61]	0.005	~55

GCM for VENUS (VGCM)

- Ground to-thermosphere version of LMD-VGCM (Gilli et al. 2017)
- Horizontal resolution: 48 lon x 32 lat (7.5o x 5.62o)
- Vertical levels 78 (0-150 km)
- up to 10 Venus days (Vd) runs (1Vd = 117 Earth days)

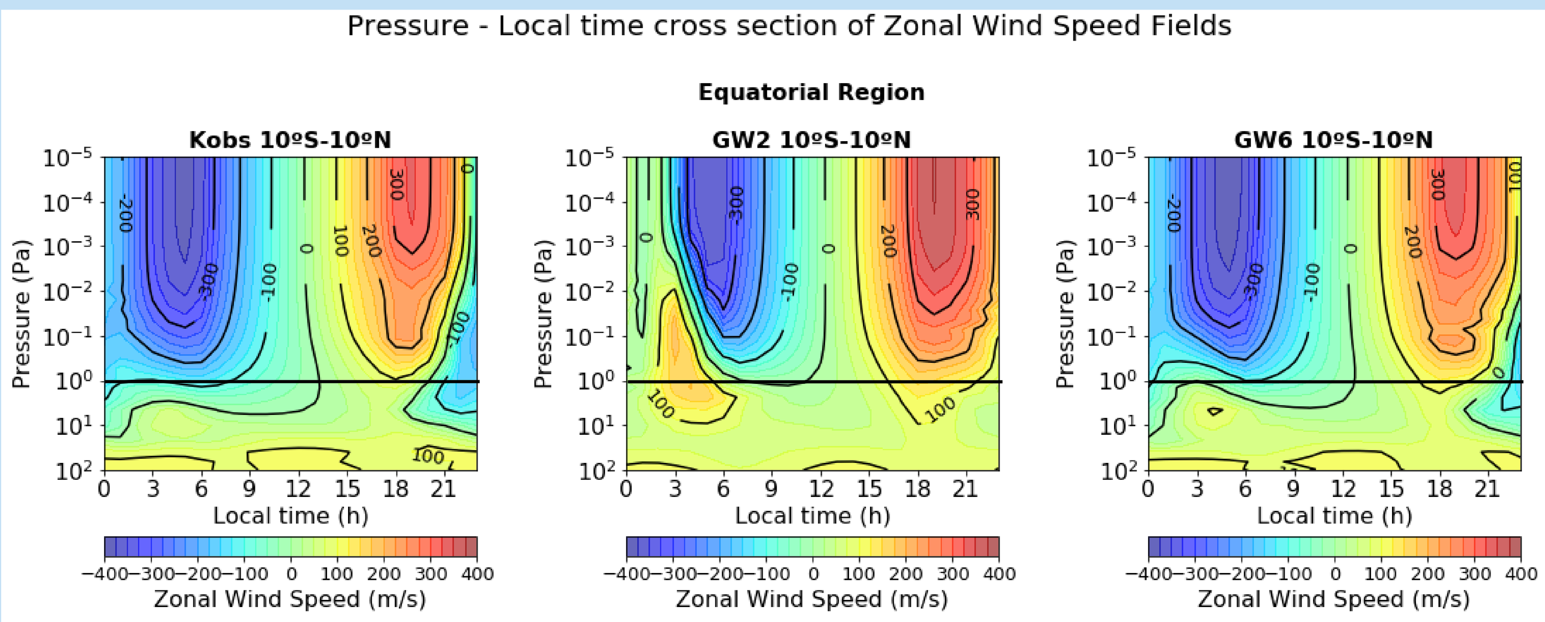


Fig 2: Examples of pressure-local time cross section of longitudinally averaged zonal winds obtained with the Venus LMD-GCM. The AGW basic characteristics used in the parameterisation are listed on table I. It is interesting to notice in the middle panel (Test GW2) the presence of remnant retrograde zonal winds (RZW) between 10 Pa and 10^{-1} Pa after midnight (LT=0). The RZW at those altitudes was suggested to explain the anti-correlation between O_2 and NO airglow in the nightside (Gerard et al. 2017).

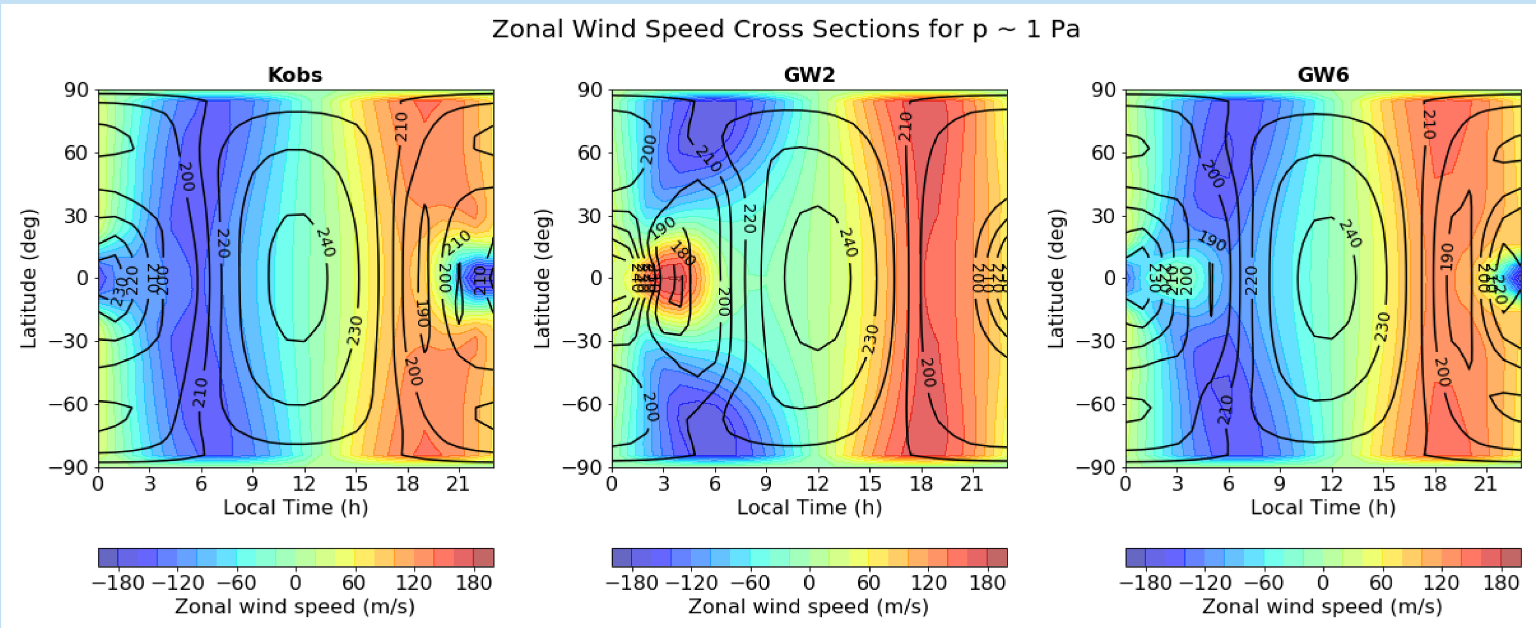


Fig 3: Examples of latitude-local time cross section of longitudinally averaged zonal winds with the Venus GCM at 1 Pa. The parameters used in the simulation are listed on Table I. As shown in figure 2 notice the presence of a strong zonal wind jet around the equator after midnight (LT between 3 and 5).

These are only a few theoretical exercises which show the strong impact of gravity waves in the middle atmosphere of Venus. However GW parameterisation is very sensitive to the detailed structure of the atmospheric flow, and more tests have to be done to make a quantitative diagnostic of AGW forcing in this region.

Detection and Characterisation on VMC

- Venus Monitoring Camera (VMC) database images were inspected and the ones with the presence of AGW were selected. Some image processing were used mainly for constrast enhancement of the wave-packets, on their detection and further charaterisation.

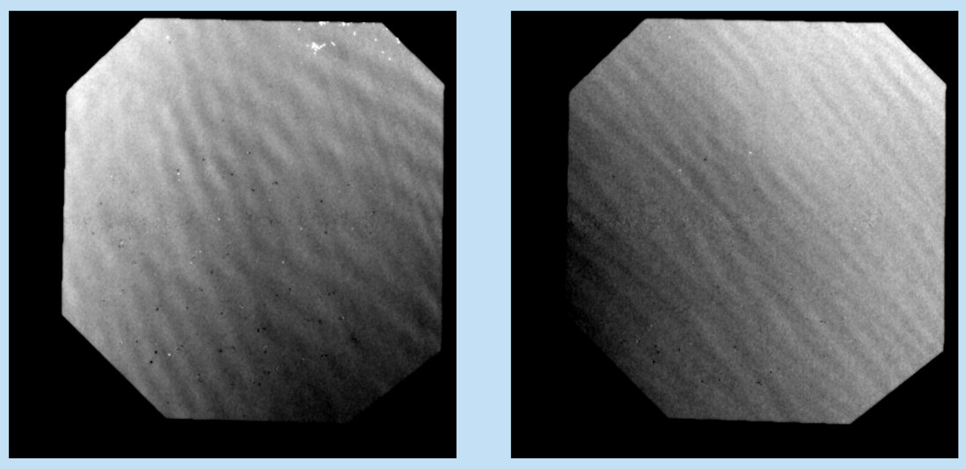
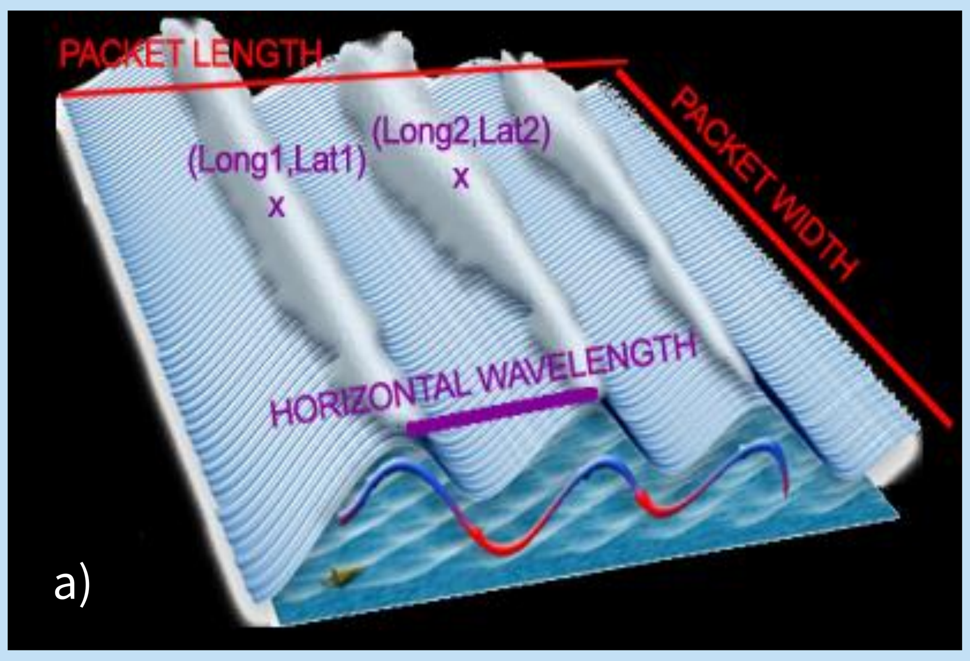


Fig 4: Wave-like patterns on the atmosphere of Venus interpreted as gravity waves, seen by VMC at 365 nm.

- Selected VMC images with the presence of AGW were manually characterised in terms of wave properties such as horizontal wavelength (HW), packet length, packet width, orientation, using PLIA software.
- To measure accurately the horizontal wavelength and packet length, several points are marked on the vicinity in each observable crest, making sure of maintaining their perpendicularity between oscillations.
- The marked points for the same crest are averaged in order to eliminate possible outliers, and to reduce the fluctuations between measurements.



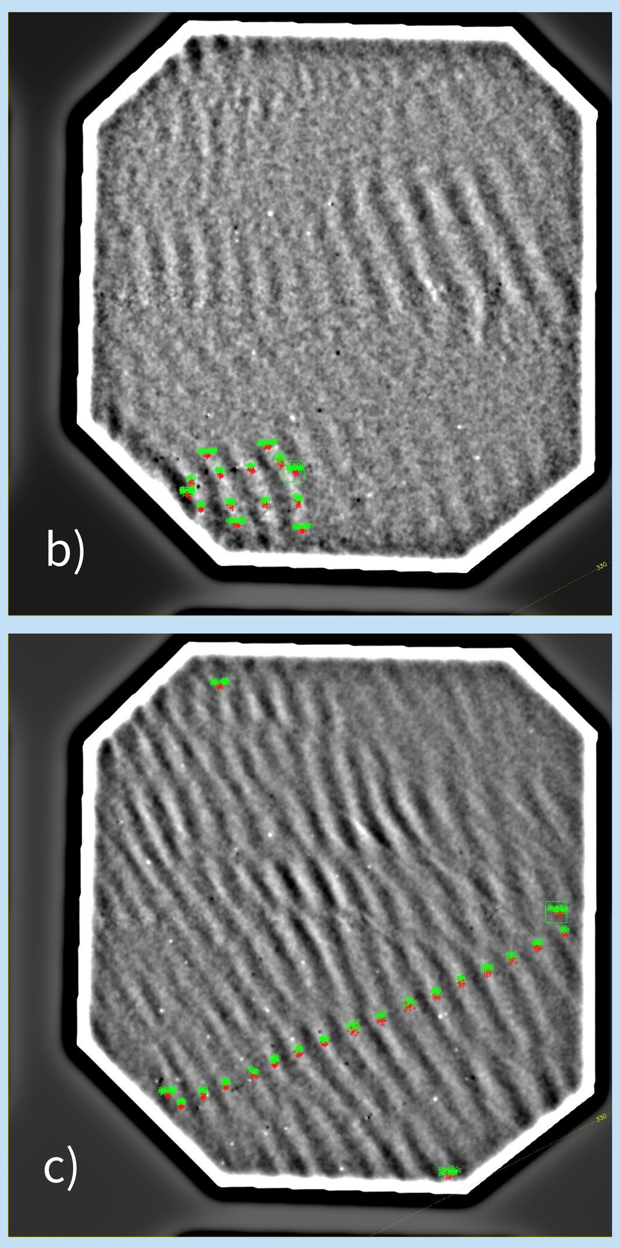


**Fig 5: Diagram for the characterization of atmospheric gravity waves, to retrieve the horizontal wavelength and packet width and packet length is shown on a).
On the right two different images of VMC are characterised. On the top (b)) a wave-packet is characterised in terms of HW and packet width (4 crests), and on the bottom (c)) can be seen a large wave-packet.**

References

Fritts, D. C., and M. J. Alexander, (2010) *Rev. Geophys., 41*(1), 1003; Lebonnois, S., et al. (2016) *Icarus*, *278*, 38–51; Gilli, G.,et al. (2017) *Icarus*, *281*, 55–72; Hueso, R., et al. (2010) *Advances in Space Research*, *46*(9), 1120–1138; Sanchez-Lavega, A. (2011). *An Introduction to Planetary Atmospheres*. Taylor & Francis; Holton, J.R., Internation Geophysics Series, vol 88, sec 7.4, Elsevier Academic Press, 4th edition, 2004; Lott, F., et al. (2012) *Geophysical Research Letters*, *39*(6), 1–5; Piccialli, A., et al.(2014) *Icarus*, *227*, 94–111;Markiewicz, W. J., et al. (2007) *Planetary and Space Science*, *55*(12), 1701–1711; Peralta, J., et al. (2008) *Journal of Geophysical Research E: Planets*, *114*(5), 1–12; Gerard et al. (2017) Space Sci Rev 212.