Characterization of Atmospheric Waves at the upper clouds in the Polar Region of Venus

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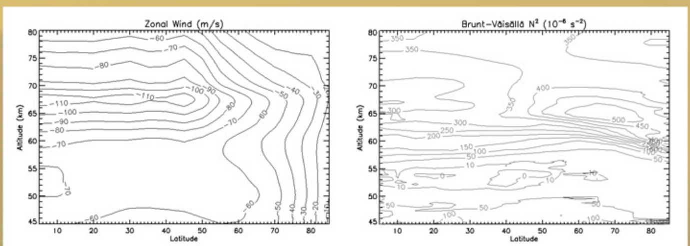
Abstract

Non solar-fixed waves at the cloud tops of the southern polar region of Venus are apparent in the winds measured with 3.9 and 5.0 μm images taken by the instrument VIRTIS-M onboard Venus Express. These global-scale waves have approximately wavenumber 1 and amplitudes of about 5.6 and 7.7 m/s for zonal and meridional disturbances respectively. In order to identify the nature of these disturbances and other mesoscale waves detected in previous works, the dispersion relation for up to seven types of atmospheric waves has been derived under reasonable assumptions. When combined with a new reference atmosphere, these equations allowed to create dispersion graphs in terms of the horizontal wavelength and phase velocity. Mesoscale waves are confirmed as gravity waves, while the global-scale ones turn out to be waves whose restoration force is the centrifugal force.

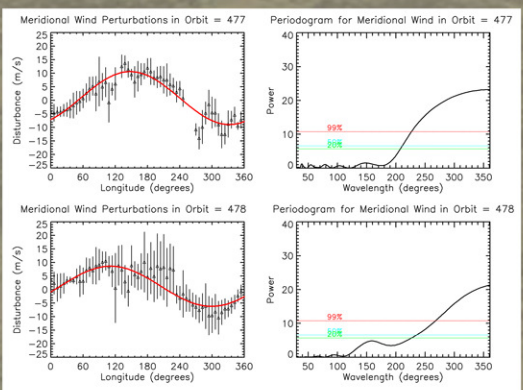
Reference atmosphere for Venus

The main aim of this work is the proper identification of the atmospheric waves of Venus prior to a deeper characterization. The success for this task requires not only a deduction of suitable dispersion relations but also a good knowledge of the environmental conditions where the waves are found. Combining recent radio-occultation data from the instrument VeRa onboard Venus Express [1] and other from previous missions [2], we created a Reference Atmosphere with those parameters involved in the dispersion relations of the waves: background zonal wind, vertical and meridional shear of the wind, static stability and its vertical variation, density scale-height, etc... In the case of the zonal wind, meridional profiles obtained at different altitudes with cloud tracking [3] were combined with the vertical profiles from Pioneer Venus probes [2] and gaps were filled by interpolation of the data.



Waves apparent in the polar winds

More than 14,000 wind measurements corresponding to 16 VEX orbits were used to carry out a search of non solar-fixed waves at the top of the clouds of Venus and latitudes between 70ºS-85ºS. These winds were obtained for previous works [4,5] using automatic cloud tracking in pairs of VIRTIS-M images covering simultaneously day and night sides at infrared wavelengths of 3.9 and 5.0 μm. Global-scale waves with approximately wavenumber 1 (λ>13,100 km) were detected in 6 orbits, with amplitudes of about 5.6 and 7.7 m/s for zonal and meridional disturbances respectively. Retrograde phase velocities were found in the only case where their calculation was plausible (orbits 477-478). A couple of examples are shown below, displaying the meridional wind disturbances averaged in longitude intervals of about 7º, the corresponding sine fit and the calculated periodogram.



Theoretical dispersion relations

The atmosphere of Venus can be regarded to be in cyclostrophic balance [1]. Applying a proper scale-analysis, we can derive a set of equations in terms of the wave amplitudes for disturbances of the form $u' = \hat{u}(z)\, e^{i(kxx+kyy-\omega t)}$, whenever we assume that the motions are adiabatic and frictionless, and that the atmosphere is at rest except for a zonal background wind that depends on latitude and height, i.e. $u_0 = u_0(y,z)$.

$$\frac{Du}{Dt} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{uv}{a}\tan\phi$$
$$\frac{Dv}{Dt} = -\frac{1}{\rho}\frac{\partial P}{\partial y} - \frac{u^2}{a}\tan\phi$$
$$\frac{Dw}{Dt} = -\frac{1}{\rho}\frac{\partial P}{\partial z} - g$$
$$\frac{D\rho}{Dt} = -\rho\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$
$$\frac{Ds}{Dt} = \frac{Q}{T} \quad \text{with } s = C_P \ln\theta$$

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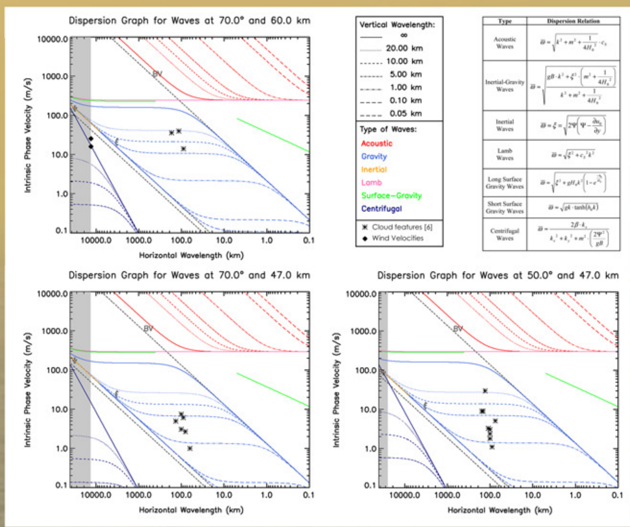
$$-i\varpi\cdot\hat{u} + \left(\frac{\partial u_0}{\partial y} - \Psi\right)\cdot\hat{v} + ik_x\cdot\frac{\hat{P}}{\rho_0} + \frac{\partial u_0}{\partial z}\hat{w} = 0$$
$$-i\varpi\cdot\hat{v} + 2\Psi\cdot\hat{u} + ik_y\cdot\frac{\hat{P}}{\rho_0} + u_0\Psi = 0$$
$$-i\varpi\cdot\hat{w} + \frac{d}{dz}\left(\frac{\hat{P}}{\rho_0}\right) - B\frac{\hat{P}}{\rho_0} - g\cdot\hat{\Theta} = 0$$
$$-i\varpi\cdot\frac{\hat{P}}{\rho_0} + ik_x\cdot\hat{u} + ik_y\cdot\hat{v} + \frac{d\hat{w}}{dz} - \frac{\hat{w}}{H_0} = 0$$
$$-i\varpi\cdot\hat{\Theta} + B\cdot\hat{w} = 0$$

where we introduced the following definitions:
- For adiabatic processes we have $s = C_P\cdot\ln\theta$, and we define $\Theta = \ln\theta$.
- The centrifugal frequency as $\Psi = (u_0/a)\cdot\tan\Phi$.
- The static stability as $B(z) = \partial\Theta/\partial z$.
- The density scale-height as $1/H_0 = -\partial\ln\rho/\partial z$.
- The intrinsic frequency as $\varpi = \omega - k_x u_0$.

Resolving the previous set of equations for the wave amplitude, it is possible to obtain the dispersion relation for different types of atmospheric waves in Venus. In this case, the centrifugal terms act as a restoration force and give birth to a "centrifugal" global-scale wave. We combined our previous reference atmosphere with these dispersion equations to obtain the following dispersion graphs at several altitudes and latitudes. The waves obtained with VIRTIS-M cloud features [6] and wind measurements can be, thus, classified in terms of their wavelength and phase velocity.



Conclusions

Under reasonable assumptions, we have deduced the dispersion relation for up to seven types of waves expected at the level of the clouds in Venus. When combined with a new reference atmosphere, these prove to be a powerful tool to identify the nature of the waves apparent in many physical magnitudes. Global-scale centrifugal waves are predicted and found in our measurements of VIRTIS-M polar winds.

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References

[1] Piccialli A. (2010): Ph.D. Thesis, Univ. of Braunschweig, Germany.
[2] Kliore A.J. et al. (1985): Adv. Space Res., vol. 5, no. 11, pp. 3-83.
[3] Hueso R. et al. (2012): Icarus, vol. 217, pp. 585-598.
[4] Luz D. et al. (2011): Science, vol. 332, no. 6029, pp. 577-580.
[5] Peralta J. et al. (2012): Icarus, vol. 220, pp. 958-970.
[6] Peralta J. et al. (2008): J. Geophys. Res., vol. 113, E00B18.