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Venus's Y-feature as a wind-distorted wave

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Abstract

Since the discovery of Venus's Y-feature in the 1960s, no model has successfully explained its shape, temporal evolution, related wind field, and relation between its dynamics and the unknown UV-absorbing aerosol drawing its dark morphology. We present the analytical model for a new type of wave that, for the first time, offers an explanation of these peculiarities simultaneously and successfully reproduces its evolution during 30 days based on distortions of the wave structure by the Venus winds.

1. Introduction

The superrotation present in slowly rotating bodies is a long-standing problem yet unsolved in atmospheric dynamics. In the case of Venus, a key question is why equatorial latitudes are not deficient in angular momentum, given that estimates of latitudinal momentum transport imply a depletion of retrograde angular momentum polewards [9]. Studying the planetary-scale wave activity at the equatorial region of Venus [1] can be, thus, crucial to understand the planet's general momentum balance.

2. An equatorially-trapped Wave

For Venus's cyclostrophic system of equations [5], we can apply the method of perturbations and get another system of wave equations [7] where the unknowns are the wave amplitude of the wind components $\left[\hat{u},\hat{v},\hat{w}\right]$ and the atmospheric pressure $\hat{P}$. To solve the wave equations at the equatorial region of Venus, we simplified them with assumptions equivalent to those employed by Matsuno [3] for the terrestrial equatorial waves: (a) the waves propagate exclusively in the west-east direction; (b) at the equator, the *centrifugal frequency* Ψ (which takes the place of the Coriolis factor in cyclostrophic regimes [5]) adopts a null value $\Psi_0 \equiv (u_0/a)\tan\phi = 0$; and (c) the β-plane approximation for the centrifugal frequency is valid on Venus equatorward of 45º [6] and, thus, we have $\Psi = \beta_* \cdot y$. Furthermore, in order to seek for a Kelvin-like wave we set $\hat{v} = 0$ and, considering the typical phase velocities for the Y-feature, we also have that the intrinsic frequency is much lower than the Brunt-Väisällä frequency $\overline{\omega}^2 << N^2$.

Under the previous considerations, we can obtain for our new equatorial wave the *polarization relations* describing the wave amplitudes on the atmospheric pressure as well as the zonal and vertical components of the wind:

$$\hat{P} \propto \exp\left[-\left(\frac{\Gamma^2}{2}+\frac{|\beta_*|}{|\overline{c}_x|}\right)\cdot y^2\right]\cdot \exp\left[-\frac{\Gamma^2 N^2}{2|\beta_*|}\cdot\frac{(z-z_0)}{du_0/dz}\right] \quad (1a)$$

$$\hat{u} = \left(\frac{\Gamma^2}{2|\beta_*|}+\frac{1}{|\overline{c}_x|}\right)\cdot e^{i\cdot\pi}\cdot\frac{\hat{P}}{\rho_0} \quad (1b)$$

$$\hat{w} = \left(\frac{|\overline{\omega}|}{N^2}m\right)\cdot\frac{\hat{P}}{\rho_0}+\left(\frac{\Gamma^2}{2|\beta_*|}\cdot\frac{|\overline{\omega}|}{du_0/dz}\right)\cdot e^{i\cdot\frac{\pi}{2}}\cdot\frac{\hat{P}}{\rho_0} \quad (1c)$$

where $\rho_0(z)$ is the atmospheric density in its basic state, du_0/dz is the vertical shear of the mean zonal flow, and z_0 is the altitude where the absolute value of the mean zonal flow adopts its maximum value. From (1a) it can be demonstrated that our new wave propagates trapped both horizontally and vertically along the equator and about the altitude z_0 [7]. Moreover, w' have a component in phase with P' and another shifted 90º, while u' and P' are phase shifted 180º, thus implying that westward acceleration is linked to increasing pressure and vertical velocity.

3. Comparison with the Y-feature

First detailed characterization of the wind field associated to the Y feature [2] shows a good correspondence with the cloud brightness distribution, with westward acceleration occurring in the dark regions. Results from VEx data [10] argue in favor of interpreting these dark contrasts observed in ultraviolet images of Venus as high concentrations of the unknown UV absorber caused by atmospheric upwelling [1,8,10]. We suggest that this upwelling can be explained in terms of the vertical wind perturbations caused over a half cycle of the wave, while bright features would be produced by the downwelling of absorber-depleted air over the other half cycle [1,2]. However, $\hat{w} \approx 1.6 \cdot 10^{-3}\ \mathrm{m\,s^{-1}}$, too small to justify the required upwelling. We propose that the upwelling could be alternatively provided by the 90º-shifted component of w' (eq. 3c), which is inversely proportional to the vertical shear of the wind, thus allowing $\hat{w}$ to shoot up close to the altitude where the zonal wind peaks.

Finally, we explain the temporal evolution of the Y-feature as the result of the distortion of the equatorial wave just derived here (Eqs. 1a-c) when propagating at an intrinsic phase velocity within a background zonal flow with constant speed between the equator and mid-latitudes [4]. Since this flow is far from solid-body rotation, the wave's period is shorter at higher latitudes. As a consequence, the coherence of the wave suffers a progressive deformation as it encircles the planet. An excellent agreement can be seen with Pioneer Venus observations [8] (Fig. 1).

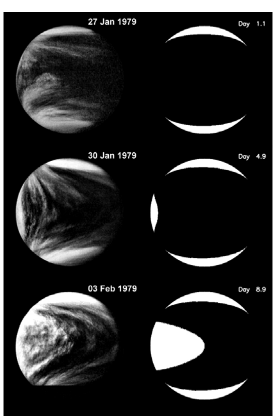

Figure 1: Evolution of Y-feature and our new wave.

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