Supporting Online Material for

Venus’s Southern Polar Vortex Reveals Precessing Circulation

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Materials and methods

The dynamics of the southern polar vortex presented in Figs. 1-4 were based on measurements from the Visible and InfraRed Thermal Imaging Spectrometer (VIRTIS) instrument, in particular its mapping spectrometer named VIRTIS-M. This measures the intensity of radiation in the wavelength range from 0.3 to 5.1 μm in two channels, VIS and IR, separated at ~1 μm. The spectral resolution is ~2 nm in the visible channel and ~10 nm in the infrared channel, within a 256x256-pixels field of view constructed by using scanning or push-broom operations. Along the elliptical 24 hour period orbit, its instantaneous field of view of 0.25 mrad per pixel allows a projected spatial resolution ranging from 16 km/pixel at apocentre, at ~65000 km above the South pole, to 62 m/pixel at pericentre, at ~250 km over the northern polar region. The exposure time can be varied to optimize the signal-to-noise ratio in each of the spectral regions: for example, the 5.0 μm wavelength, which probes the upper cloud (16), can be optimized using short exposure times, typically ~0.3 s, in order to avoid the saturation due to the internal thermal background of the instrument. In this case however, the 1.74 and 2.3 μm windows, which probe the lower clouds, and the 3.8 μm radiance, in which the upper clouds can be observed, are partially affected in quality by an underexposure. Data calibrations include dark correction and flat fielding (from both in flight and on-ground calibrations), the removal of the effect of cosmic rays, and conversion to radiance units. Ancillary data include geometry data such as latitude, longitude and local time.

We selected nadir-pointing, high-spatial resolution VIRTIS data cubes obtained from apocentre in order to minimize the geometric distortion of the polar region. On average these contain latitudes extending from the pole to 70°S. Orbits were selected so as to have in each one at least one pair of images suitable for tracking, i.e., with an acceptable spatial overlap (with the time intervals between consecutive images varying between 15 min and 1 h).

The monochromatic radiance maps were projected onto a polar stereographic grid based on the ancillary geometry data. A wind retrieval procedure was performed on pairs of monochromatic images at 5.0 μm, using a method of digital correlation similar to the one described in detail in previous work (27). The method is based on a maximum correlation algorithm applied to a pair of radiance maps, in which an area of the first image (template) is correlated with an equal size area of the second image. The best match for each template is the one which yields the higher value of the coefficient of cross-correlation and this provides the spatial displacement for that particular template. For each template one wind vector is computed by dividing the displacement by the time interval between recording of the maps. A wind vector field is thus created by multiple iterations. In this work we used templates of 40x40 pixels, with a step of 5 pixels between templates. After the matching process, a filter is applied to the wind field in order to remove outlier vectors. A total of 63 pairs of images (from orbits 448, 475, 478, 605, 638,
640, 642, 644, 666, 668, 672, 674, 676 and 678) were analyzed, yielding ~55000 vectors after filtering. Weighted temporal and zonal averages of the wind vectors were subsequently computed to obtain the latitudinal wind profile (Fig. 2) and the rates of differential rotation. Error bars in Figs. 2-4 represent one standard deviation.

The positions of the centroids of rotation for each orbit where multiple images were available (Figs. 3 and 4) were determined by a manual procedure. VIRTIS images show that the global vortex morphology is preserved over the duration of any sequence of observations within the same orbit (these sequences typically last 2–6 hours), where the rotation is approximately of solid body type, and that the motion of the centre of rotation is negligible over these short periods. These properties made it possible to retrieve the centroids of rotation by first constructing time sequences of polar-projected images for those orbits where two or more data cubes were available and through a simple animation process, the latitude, longitude and local time of the centre of rotation were determined visually by determining the point of least motion. The accuracy of this method is affected by a number of factors: poor signal-to-noise ratio of one or more of the frames in the animation, vortex morphology containing large regions of low contrast, differential motion within the vortex, and proximity of the centre of rotation to the pole (increasing the uncertainty in the assignment of the longitude). The error bar in the latitude has been estimated as 1.5º; for the longitude it was approximated as a function of latitude, where the estimated values ±60º, 30º, 15º and 10º were fixed at latitudes 89ºS, 88ºS, 85ºS and 80ºS, and intermediate values were interpolated with a cubic function.
References and Notes


15. G. Piccioni et al.; VIRTIS-Venus Express Technical Team, South-polar features on Venus similar to those near the north pole. Nature 450, 637 (2007). doi:10.1038/nature06209 Medline


18. Materials and methods are available as supporting material on *Science* Online.


25. The VIRTIS mapping IR channel provided a large data set from the Venus orbit insertion in April 2006; however, only a fraction of image sequences with exposure times optimized for observation at 5.0 μm were obtained at high spatial resolution for the polar region.

26. The local time coordinate, which is cyclical, has been linearized by adding 24h whenever a cycle was completed (for example, the sequence [-5, 10, -1, -8] turns into [-5, 10, 23, 40]).


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