The relationship between mesoscale circulation and cloud morphology at the upper cloud level of Venus from VMC/Venus Express

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Abstract

The Venus Monitoring Camera (VMC) acquired a set of ultraviolet (UV) images during the Venus Express mission unprecedented in its duration from May 2006 to September 2013. Here we present the results of digital tracking of the cloud features in the upper cloud layer at latitudes 25–75 S using images from 257 orbits with the best spatial coverage. The method relies on analysis of correlations between pairs of UV images separated in time. The bulk of data processed allows us to clarify the reasons why the mid-latitude jet is not always present in latitudinal wind profiles. Comparing VMC images with wind velocity fields we found a relationship between cloud morphology at middle latitudes and the circulation. The vector field in middle latitudes depends on the presence of a contrast global streak in the cloud morphology tilted with respect to latitude circles. The angle of the flow deflection (the angle between the wind velocity and latitudinal circles) and the difference of the zonal velocity on the opposite sides of the streak are in direct relationship to the angle between the streak and latitude circles. During such orbits the jet bulge does not appear in the latitudinal profile of the zonal wind component. Otherwise a zonal flow with small changes of the meridional velocity dominates in middle latitudes and manifests itself as a jet bulge. The relationship between the cloud cover morphology and circulation peculiarities can be attributed to the motion of global cloud features, like the Y-feature. We prepared plots of zonal and meridional velocities averaged with respect to the entire observation period. The average zonal velocity has a diurnal maximum at 15:00 local solar time and at 40 S. The meridional velocity reaches its maximum between 13:00 and 16:00 and at 50 S. The velocities obtained by the digital method are in good agreement with results of the visual method in the middle latitudes published earlier by Khatuntsev et al. (2013).

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1. Introduction

We study the atmospheric dynamics on Venus at the upper cloud level on the basis of UV images acquired by the Venus Monitoring Camera (VMC) (Markiewicz et al., 2007a) onboard Venus Express from May 2006 to September 2013 (Svedhem et al., 2009; Titov et al., 2006). The previous work by Khatuntsev et al. (2013) presented results of the digital cloud tracking method for the low latitudes. Here we extend the study to the middle latitudes and subpolar regions.

The results of wind measurements by tracking cloud features in the UV images acquired by VMC have been published by Markiewicz et al. (2007b), Moissl et al. (2009), Kouyama et al. (2013) and Khatuntsev et al. (2013). Compact and easily identifiable cloud features are typical for the low latitudes. A zonal flow dominates in the equatorial region. In the middle latitudes the cloud pattern is different. It is full of stripes stretched in the zonal direction, the so-called streaks (Titov et al., 2012). The latitudinally elongated cloud details result in greater positioning errors that in turn increase standard deviations for velocities especially for their zonal components. The main properties of the mean zonal velocity profile are well known. At the cloud top altitude of ~67 ± 2 km (Ignatiev et al., 2009) the mean zonal velocity is close to ~50 m/s in low latitudes, reaches its maximum around ~100 m/s at 40–50 S, and rapidly decreases with latitude (Khatuntsev et al., 2013). The mid-latitude jet visible in zonal velocity profiles obtained by...
the manual method (Khatuntsev et al., 2013) is not always detectable by digital methods (Moissl et al., 2009). The bulk of data processed allowed us to confirm the variability of properties of the mid-latitude jet (Khatuntsev et al., 2013) causing differences in mean zonal velocities noticed by Rosswow et al. (1990) and Limaye et al. (1988). In this work we investigated the reasons why the mid-latitude jet is not always seen in wind profiles at the middle latitudes. The increase of the meridional velocity from zero at the equator to 10–15 m/s at 50–60° in both hemispheres has been noticed by Limaye et al. (1988, 2007), Rosswow et al. (1990), as well as by Peralta et al. (2007), Sánchez-Lavega et al. (2008), Hueso et al. (2012) and Khatuntsev et al. (2013) in the southern hemisphere. The region, where the meridional velocity peaks at 50°S between 13:00 and 15:00 local time (Khatuntsev et al., 2013), was the primary focus of this study. We selected 257 orbits having the best spatial coverage with measurements.

In Section 2 we briefly introduce the VMC experiment and describe data sets. Section 3 describes the cloud tracking technique. Sections 4 and 5 present our results and discussions.

2. UV images of Venus

This work continues publications of the VMC team related to the dynamics of the Venus atmosphere. The Venus Monitoring Camera (VMC) experiment has been described in detail by Markiewicz et al. (2007a, 2007c) and Titov et al. (2012). The VMC acquires images of Venus in four narrow-band channels centered at 365, 513, 946 and 1010 nm. In this work we used only UV images (365 nm) of the southern hemisphere. Venus Express is in a high-elliptical polar orbit with an apocenter at 66,000 km and a period of 24 h. Thus VMC observes the south hemisphere of Venus every 24 h at good illumination conditions.

The imaging seasons are arranged into groups with a period of 1 Venus year equal to 224.7 days (see Table 1) that results from occurrence of good illumination conditions at the ascending arc of the orbit (Fig. 1) where most of UV images have been acquired. Spatial resolution in an orbital sequence of images increases from 50 km/pix at the apocenter (66,000 km) to 9 km/pix at a distance of 12,000 km about 3 h before the pericenter. We did not use images with better resolution because at close distance the interval between images is too short. Examples of the VMC UV images are shown in Fig. 2.

3. Digital cloud tracking

Cloud-tracking methods to investigate dynamics of planetary atmospheres have been used and described in a number of works dedicated to Venus (Suomi, 1975; Limaye and Suomi, 1981; Rosswow et al., 1990; Luz et al., 2008; Moissl et al., 2009; Khouyama et al., 2013; Khatuntsev et al., 2013), Jupiter (Choi et al., 2007; Hueso et al., 2009) and Saturn (Sayanagi et al., 2013). In this paper we applied a two-dimensional correlation method (Khatuntsev et al., 2013). In our method we use a combination of coarse/fine search for maxima of correlation functions and analyze their shapes. Alongside with computing efficiency in processing large data sets, the major drawback is the presence of false positives requiring effort to get rid of them. Sometimes it is impossible. Nevertheless, the digital correlation method we have implemented and used works well when some conditions are applied. We determined these conditions by comparing results obtained by means of the digital method with results obtained by means of the manual method (Khatuntsev et al., 2013). We filter results according to a set of criteria. The digital method provided us with vector fields for the Venus day side all the way from the equator to subpolar latitudes.

In the present work, we selected pairs of UV images separated by the time interval large enough to identify displacements of cloud features that were computed by the digital method based on searching for maxima of correlation functions. The time step Δt

<table>
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<th>Data set no.</th>
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<th>Orbits</th>
<th>Vectors</th>
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<td>0640–0750</td>
<td>84/35</td>
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<td>2442–2498</td>
<td>30/10</td>
<td>12368/5123</td>
</tr>
</tbody>
</table>

Table 1

List of VMC data sets used in the digital method to determine velocity vectors by tracking cloud features. The last two columns contain pairs of values. The first value is the number of orbits or vectors used for averaging the zonal velocity in 30°S. The second value is the number of orbits or vectors in the set of 257 orbits selected to be used in this work.
between images varied from 2 h for the images taken at the apocenter to 20–45 min for the images taken 3 h before the pericenter. Since the images taken during one orbit had different spatial resolutions, the selected images were mapped to one coordinate grid for each pair of images with constant longitudinal and latitudinal step. The mapped images were divided into regions of equal size. The grid step and the size of a correlation region depends on the distance from the pericenter. Depending on latitude, 1° along the latitudinal circle varies from 106.8 km at the equator to 36.5 km at 70°. The grid step \( \delta = 0.7° \) and the correlation region size \( 20° \times 10° \) were used for the images taken at the apocenter. For the images taken near the pericenter, we used the step \( \delta = 0.3° \) and the region size \( 10° \times 7.5° \). Images taken at intermediate distances were mapped with the step \( \delta = 0.5° \) and the region size \( 15° \times 10° \). The region was shifted in sequence, and the longitudinal shift varied from 5° to 7° depending on the region size, while the latitudinal shift was 5°. The coarse position of a correlation maximum was determined with accuracy of the grid step. Then the position was refined by using a sequence of grids of the same step but shifted by its fraction with respect to the primary grid. This technique decreases the displacement error down to a quarter of the step in both latitudinal and longitudinal directions. The velocity vector is a result of division of the displacement by the time interval between the images. In all cases the single measurement error of the wind speed does not exceed 5 m/s. Details of the algorithm were described in Khatuntsev et al. (2013).

The resulting displacements were filtered according to corresponding correlation functions. While analyzing the correlation functions we used the following criteria. (1) Only the correlations with maxima of 0.8 or higher were considered. (2) Peaks of the correlation functions \( Z(x,y) \) should be distinct in all six projections (planes \( XZ, YZ \) and planes turned through angles of \( 30°, 60°, 120° \) and \( 150° \)). More projections would decrease the probability to get...
a wrong result but will increase the computation time. The distinctiveness in any projection means that the difference between the maximum of the correlation function and the minima on both sides should be greater than 0.3 at low and middle latitudes (equatorward of 45°S), and greater than 0.05 at high latitudes (poleward of 45°S). The main selection criterion was that the correlation function should decrease at least by 0.01 at the distance of 5° on both sides of the peak. If this criterion was not fulfilled we used an alternative criterion for the correlation function to drop by more than 0.025 at the distance of 2.5° from the peak. The alternative criterion was applied at high latitudes where the correlation was usually weak. The above mentioned values were found by comparing results of the manual and digital methods (Khatuntsev et al., 2013). Fig. 3 shows the correlation functions for two regions of images 0050 and 0060 taken during orbit 0471. Image 0050 is shown in Fig. 5. The correlation function for the region at 20°S (Fig. 3a) has significantly more pronounced peak than that for the region at 60°S (Fig. 3b). The difference in criteria for low and high latitudes results from the fact that the morphology of the Venus cloud cover depends on latitude (Titov et al., 2012). Contrast cloud features at low latitudes result in the correlation functions with pronounced maxima. Bright and dark streaks in the middle latitudes and large areas of haze with poorly resolved features at high latitudes result in poorly defined correlation peaks.

The velocity vectors that passed the above described selection procedure were filtered according to additional criteria in order to eliminate erroneous values resulting from image artifacts. These criteria (see details in Khatuntsev et al., 2013) include limitations on the zonal velocity: −250 m/s < u < 0 m/s, on the meridional velocity: −50 m/s < v < +50 m/s, on the local time: 9:00 < LT < 16:00, and the condition |u/v| > 3.5 equatorward of 45°S establishing the domination of the zonal velocity over the meridional one. The latter condition eliminates vectors that strongly deviate from the zonal flow. For the latitudes poleward of 45°S we relaxed the condition to |u/v| > 1.5 that was proven by test comparisons to the results on the manual cloud tracking method (Khatuntsev et al., 2013).

The wind vectors derived from all image pairs taken during a single orbit show significant scattering. We used observations during orbit 0471 to perform a representative statistical analysis. In this section the error specified is standard deviation (SD) defined as \[ \sqrt{\sum (x - \bar{x})^2 / n - 1} \] where n is the number of samples in the group. Fig. 4 shows histograms for the zonal (a) and meridional (b) components within the latitudinal bin 20–25°S for the local time interval 11:00–14:00. The group-average zonal component in this bin is −88.6 ± 4.4 m/s and the meridional component is −13.5 ± 4.8 m/s.

The flow is not uniform in the middle latitudes, and we cannot use wide latitudinal and longitudinal bins. Fig. 4 shows histograms for the zonal (c) and meridional (d) components within an area where the velocity varies slightly (W-group described in Section 4.1). The group-average zonal component in this area is −100.7 ± 9.1 m/s and the meridional component is −24.6 ± 5.5 m/s. The images taken during orbit 0471 have pronounced morphological details thus providing a great number of image pairs suitable for image tracking compared to other orbits. Small SD values are typical for this orbit. The SD of velocity components varies from orbit to orbit and depends on latitude and local time. In low latitudes it does not exceed 20 m/s for the zonal component. We take this value as an error of a single measurement. The SD for the meridional component is usually 1.5–2 smaller than the SD for the zonal one. These SD estimates are close to those provided by the manual method (Khatuntsev et al., 2013).

We tracked UV markings originated from the uniform distribution of an unknown UV absorber at the cloud top. At that point uncertainties in the altitude of cloud details can lead to errors in the displacement determination. Following works by Ignatiev et al. (2009) and Cottini et al. (2012), we assumed that variations of the cloud top altitude which we used to compute displacements did not exceed 1–2 km during several days for the same latitude in low and middle latitudes.

4. Results

In this section we present results of the wind field measurements by tracking cloud features in UV VMC images in the middle and high latitudes. We analyzed about 200,000 vectors obtained by the digital correlation method for 257 orbits (Table 1). This work covers the observations of the Southern hemisphere performed from May 2006 to September 2013 that corresponds to about 12 Venusian years (Fig. 1).

At low latitudes, from the equator to 25°S, the wind is almost zonal. Peculiarities of the mesoscale circulation appear at the middle latitudes. Cloud patterns consisting of interleaved dark and bright long streaks are typical for these latitudes. The ramified part of the well-known Y-structure is formed by strong streaks noticeably tilted to latitude circles. The increase of the meridional wind in the afternoon is consistent with the global cloud morphology pattern that shows large-scale cloud streaks crossing latitude circles (Titov et al., 2012).

4.1. Single orbits

Fig. 5a is a perfect example of an image with a pronounced global dark streak. The wind field shown in Fig. 5a is superimposed onto a rectangular projection of UV image 0050 taken during orbit 0471 (August 5, 2007). The time interval between images in a pair was about 1 h. The velocities obtained from 42 pairs of images were averaged within bins (averaging areas) 6° × 5° in size. Each vector in Fig. 5a corresponds to one bin. While averaging zonal and meridional velocities we took into account weights of the wind vectors that depend on the error in correlation functions.

Fig. 5b shows the velocities shown in Fig. 5a superimposed onto their bivariate density histogram (numbers of samples in a bin). The areas with highest number of samples (from 30 to 49) correspond to image areas with a great number of contrast details. Correlation functions for such image regions have well-defined peaks (see example in Fig. 3a) allowing us to determine displacement vectors with high accuracy.

We define the deflection angle α as an angle between the wind velocity and latitudinal circles. It is positive when the flow is deflected to the equator. The vectors exhibiting maximum poleward deflection from the zonal flow (40–50°S, 13:00–15:00) lie on the dark streak and are shown in white (W-group). The group-average deflection angle for the W-group \( \alpha_{W} \) is equal to −13.5° ± 1.4 (SD=2°). In this section the error specified is a confidence interval (3σ or 99.7% confidence level). The flow is different left and below the global streak. The vectors shown in red and cyan have positive deflection angles. The group of red vectors has poor statistics due to small number of samples in corresponding bins. The group of vectors on the left side at lower latitudes (60–70°S, 9:00–11:00) shown in cyan (C-group) contains vectors with maximum positive deviation angles and having more than 10 samples per bin. The group-average deflection angle for the C-group \( \alpha_{C} \) is equal to 7.6° ± 2.7 (SD=4°).

Orbit 0471 is a typical case when a high-contrast streak at the middle latitudes intersects latitude circles at a great angle. During such orbits, direction of the meridional velocity is different on the
opposite sides of the streak. The flow is deflected while crossing the streak area. We found the maximum poleward deflection angle for all orbits using regions $2^h \times 15^\circ$ in size within the local time interval 11:00–16:00 and the latitudinal range 30–60°S. Depending on the orbit, the angle changed from $-18.5 \pm 1.9^\circ$ ($SD=4.7^\circ$) to $-0.4 \pm 1.7^\circ$ ($SD=3.6^\circ$). We found 30 orbits out of 257 with the deflection angle below $-13^\circ$. All the analyzed orbits exhibited relations between the value of $\alpha_W$ and the cloud morphology. The location of the region with maximum poleward flow deflection correlates with the position of a strong streak in the image.

If there are only weak streaks or strong ones almost parallel to latitude circles, the wind pattern at the cloud top is different. Orbit 0461 (July 26, 2007) illustrates this case. This orbit is separated from orbit 0471 by 11 days and demonstrates different cloud top morphology. Since the super-rotation period in middle latitudes is roughly equal to 4.5 days, we see nearly the opposite side of the Y-structure visible during orbit 0471. The wind field for orbit 0461 derived from 11 image pairs is shown in Fig. 6a.

There are also two groups of vectors shown in white (W-group) and cyan (C-group) in Fig. 6. The group-average deflection angle for the W-group $\alpha_W$ is equal to $-6.6 \pm 2.7^\circ$ ($SD=3.4^\circ$). This value is about half of the similar angle during orbit 0471. The vectors deflected to the equator (C-group) also appear during orbit 0461. The group-average deflection angle for the C-group $\alpha_C$ is equal to $12.1 \pm 9^\circ$ ($SD=8^\circ$). Although the mean deflection angle is greater than that derived from orbit 0471, the error for this group is much
higher due to smaller number of samples in corresponding bins. This is a typical situation for the C-group in the majority of orbits.

In the absence of strong tilted streaks the motion at middle latitudes appears as an almost purely zonal flow which slightly deflects poleward in the afternoon. Fig. 7 represents latitudinal profiles of the zonal wind component averaged over longitude. The figure also shows individual measurements obtained from all pairs of images taken during orbits 0471 (a) and 0461 (b). The mid-latitude jet (the bulge at 40°S) is present in Fig. 7b but is absent in Fig. 7a where the data scatter at these latitudes is higher. The latitudinal band 50°S ± 1° exhibits maximum data scatter (Fig. 7) and the best coverage within local time (Fig. 5).

Fig. 8 represents single measurements of the zonal velocity as a function of local time for orbit 0471 within this latitudinal band. Taking into account that the single measurement error does not exceed 20 m/s we can state that the mean zonal velocity is different at 10:00–12:00 and 14:00–16:00, i.e. on the opposite sides of the streak. It illustrates the fact that the zonal flow at this latitude is not permanent. Results of the manual method also show significant increase of the mean zonal velocity during this
orbit. The changing zonal component from orbit 0471 gives lesser contribution to the wind profile averaged over longitude than the permanent component from orbit 0461.

4.2. Flow deflection angle

We built a map of the mean deflection angle as a function of latitude and local time by averaging the deflection angle at each point with respect to all 257 orbits (see Table 1). Fig. 9a shows this map. The plot represents a smoothed two-dimensional function and gives a picture of the zonal flow deviation. The maximum poleward deflection was found at 14:00 local time in 50°S. In the sub-polar region the flow deflects to the equator by 1° in the average at morning hours.

Fig. 9b and c shows histograms of deflection angles built for two areas. In the area of the maximum poleward deflection (45–55°S, 13:00–14:30) the histogram is close to a normal distribution (Fig. 9b). The mean value of the deflection angle in this area is $-7.7 \pm 0.2°$ ($SD=5.6°$). The histogram built for the area 45–55°S, 10:00–11:30 (Fig. 9c) is bimodal. The mean value of the deflection angle is $-2 \pm 0.5°$ ($SD=8.6°$). But the left peak with the maximum poleward deflection angle equal to $-6.4 \pm 0.5°$ ($SD=3.5°$) means that there were many orbits (we found 46) when the flow exhibited at 10:00–11:30 the same deflection to the pole is at 13:00–14:30. The right peak with the maximum equatorward deflection angle of $4.9 \pm 1.2°$ ($SD=4.2°$) means that during other orbits the deflection of the flow to the equator dominated at 10:00–11:30. The great number of samples in the histogram proves these conclusions. The bimodality means that there are two dominating directions the cloud features moved in during 7 years of observations. The first mode is associated with a strong streak visible in this area, and the second one takes place when there were no visible streaks there.

4.3. Wind fields

We averaged zonal and meridional components with respect to all 257 orbits and built maps of mean velocities. The plots in Fig. 10 show the mean velocities as functions of local time and latitude. The mean zonal velocity (Fig. 10a) exhibits an afternoon peak as high as $-100 \text{ m/s}$ at 15:00, 40°S. There is another maximum as high as $-96 \text{ m/s}$ at 10:00, 25°S. The mean meridional velocity (Fig. 10b) exhibits a pronounced maximum as high as $-10 \text{ m/s}$ at 14:00, 50°S. Note a weak maximum as high as 0 m/s at 10:00, 75°S. All the peaks are statistically significant because even in high latitudes, where the data coverage is rather poor, the latter peak results from averaging of about 800 vectors within the area 9:00–11:00; 70–80°S. Fig. 10 shows the velocity fields averaged over all studied orbits. We note that Fig. 8 demonstrated quite different and specific dependence of the zonal wing speed on the solar time that was observed during a limited number of orbits with global streaks.

Averaged velocities obtained for the same period by manual tracking of cloud features were published by Khatuntsev et al. (2013). The results obtained by the digital method are in good agreement with those data. The mean zonal component has maximum in the afternoon at 40°S and the meridional one at 50°S. In middle and high latitudes, absolute values of velocities obtained by the digital method are slightly less than the values obtained by the manual tracking. This can be explained by morphological peculiarities in the middle latitudes. The digital method uses quite a large region $SD$ that reduces the measurement noise and, as a result, the number of false positives, but it does not detect small-scale variations. The visual method allows dealing with cloud details as small as several degrees while the digital method uses regions several times bigger.

5. Discussion

Though the spatial resolution of the digital method is lower than that of the manual method, the former allows tracking the motion of mid-scale structures comparable in size with the correlation regions. As a result, we can see changes of large-scale structures and monitor their relation to the circulation. Observing appearance and vanishing of mid-scale cloud structures, we revealed recurrence of the global wind pattern correlated with the cloud morphology. In particular, the wind pattern correlated with the appearance of the Y-feature seen in the images during
orbits 0461 and 0471 taking into account the super-rotation period of 4.5 days. As we noted, the cloud top circulation at 40–60°S changes from orbit to orbit. This phenomenon has been detected and described by Hueso et al. (2012). The high-latitude boundary of the global streak (Fig. 5) is located at about 60°S. The flow behavior changes poleward from this latitude and is dominated by the polar vortex dynamics (Luz et al., 2011). In some orbits we noticed a deflection of the flow to the equator at morning hours below 60°S. This deflection can be attributed to activity of the polar vortex but we do not have enough statistics to confirm this conclusion.

We can compare the wind field obtained from orbit 0471 with the cloud top altimetry derived from the VIRTIS-M spectroscopy. Fig. 11 shows contours of the cloud top altitude superimposed onto the VMC image. The figure shows that the mid-latitude global dark streak where the wind vectors (W-group) have greater deflection angle is located higher than the adjacent bright area by 1–1.5 km. Note that the boundary between the dark streak and the bright area approximately coincides with the isohypse at 73.5 km. The C-group of wind vectors corresponds to the cold collar region (Zasova et al., 2007) where the cloud top altitude is lower than that of the bright stripe by 1–1.5 km. Thus, the altitude difference between the C and W groups ranges from 2 to 3 km. The relation between morphological features and circulation could be revealed by the joint analysis of VMC and VIRTIS data.

**Summary and conclusions**

We developed the digital correlation method to determine the wind field from cloud features tracking. The method was applied to the UV images taken by the Venus Monitoring Camera onboard Venus Express during about 12 Venustian years. The analysis revealed correlation of the cloud top wind pattern with the cloud morphology. In particular, if a global streak tilted with respect to latitude circles is present at middle latitudes and intersects the latitude circles at a large angle, the direction of the meridional velocity is different on both sides of the streak. Thus the flow is deflected while passing the streak area. In this case the mid-latitude jet is not present in the latitudinal profiles of the mean zonal wind component. We note that simultaneous retrievals of the cloud top altitude from the VIRTIS-M spectroscopy indicated that the cloud top on the bright side of the global streak is located 2–3 km higher than that in the adjacent dark areas. In the absence of a global streak the meridional winds are generally weaker. The zonal flow is only slightly deflected to the pole in the afternoon and the latitudinal profile of the zonal wind shows a pronounced jet bulge at middle latitudes. The analysis of data from all 257 orbits revealed that the motion in middle latitudes demonstrates not only morphological dependence but also dependence on local time. At 13:00–14:30 the dominating flow direction is poleward with a mean deflection angle of $-7.7 \pm 0.2^\circ$. And there are two dominating flow directions at 10:00–11:30. One direction has a mean deflection angle equal to $-6.4 \pm 0.5^\circ$ (poleward), and the mean deflection angle of another direction is $4.9 \pm 1.2^\circ$ (equatorward). The average zonal velocity exhibits an afternoon peak as high as $-100$ m/s at 15:00, 40°S, and the average meridional velocity has a maximum as high as $-10$ m/s at 14:00, 50°S.

![Fig. 10. Contour plots of average zonal (a) and meridional (b) velocities as functions of local time and latitude. The velocities have been averaged with respect to the entire observation period from May 2006 to September 2013.](image)

![Fig. 11. The wind field superimposed onto a rectangular projection of VMC UV image 0050 taken during orbit 0471. Contours show the cloud top altimetry derived from VIRTIS-M spectroscopy.](image)
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