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An improved cloud-tracking method tolerant to streaky features

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Abstract

The high latitude of Venusian cloud top is dominated by banded streak features in the ultraviolet (UV). This structure makes cloud tracking difficult because displacements of such streaks along the streak direction cannot be identified. We have developed a method to improve the accuracy of cloud tracking by eliminating streaks from the images and applied the method to UV images taken by the Venus orbiter Akatsuki.

1. Introduction

UV images of Venus show various features of clouds due to inhomogeneously distributed UV absorbers in the cloud layer. Cloud tracking has been widely used to derive atmospheric motions. Long term variations of the super-rotation [3], the properties of atmospheric waves [4, 5], and the relationship between the cloud morphology and wind velocities [1] have been studied with cloud tracking.

The high-latitude atmosphere of Venus is considered to be dynamically unstable due to the strong latitudinal shear of the mean zonal wind associated with mid-latitude jets [7]. Momentum transport caused by eddies that arise in such regions can play crucial roles in the maintenance of the super-rotation. However, previous studies on the velocity disturbance have mostly been limited to low latitudes due to the difficulty in cloud tracking in high latitudes, where streak features are predominant. Because displacements of such streaks along the streak direction cannot be identified, uncertainties in estimated cloud motion vectors become large [2]. To solve this problem, we developed a method to improve the accuracy of cloud tracking by eliminating streaks from the images.

2. Dataset

Data obtained by the 365 nm channel of Ultraviolet Imager (UVI) onboard the Venus orbiter Akatsuki were used in this study. At this wavelength the absorption by unidentified materials dominates. Akatsuki has observed Venus since December 2015 in an equatorial orbit having a period of ~10.5 days, the apocenter located at 370,000 km altitude, and the pericenter located at ~7,000-18,000 km altitudes. The details of Akatsuki and its orbit are given in Nakamura et al. [6] and the specifications of UVI are given in Yamazaki et al. [8].

3. Elimination of streaks

We use the cross-correlation method for cloud tracking. In this method, small sub-areas called "templates" are extracted from a pair of images acquired successively. Based on the nature that the brightness gradient takes the minimum along streaks the streak orientation vector $\boldsymbol{l}$ is determined by minimizing the variance of $\nabla I \cdot \boldsymbol{l}$ in the template, where I is the observed radiance. $\nabla I \cdot \boldsymbol{l}$ corresponds to the spatial differentiation of image along the direction $\boldsymbol{l}$, and thus the streaks are eliminated in the $\nabla I \cdot \boldsymbol{l}$ maps of the templates when an optimum $\boldsymbol{l}$ is used. Figure 1 shows an example of the determination of the streak orientation and the elimination of streaks from the image by differentiation. Small-scale patchy features are seen after the differentiation. Then, cloud tracking was conducted by calculating cross-correlations between the templates in which streaks were eliminated.

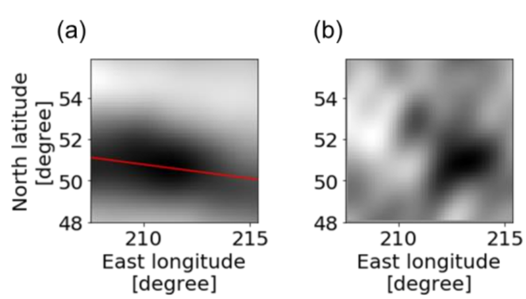

Figure 1. An example of (a) the determination of the streak orientation and (b) the elimination of streaks by differentiation along the streaks. The red line shows the determined streak orientation. A UVI image taken on July 18, 2017 was used.

4. Cloud tracking

Figure 2 shows an example of the comparison of the cross-correlation surfaces obtained without streak removal and with streak removal. In the latter, the elongated peak in the cross-correlation surface was successfully eliminated and a distinct peak can be identified. An example of the cloud-tracked velocity map is shown in Figure 3, in which motion vectors are successfully obtained up to the high latitude. In the presentation, we discuss horizontal structures of planetary-scale waves and associated momentum transports.

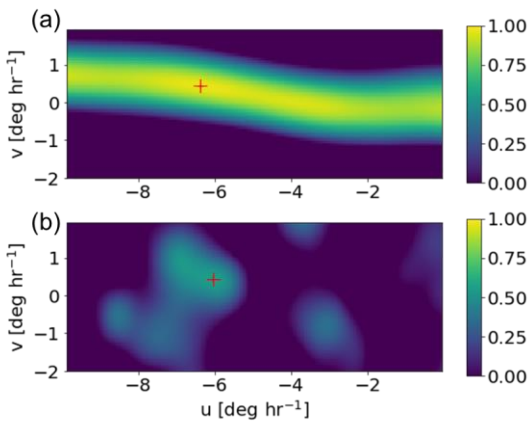

Figure 2. Cross-correlation surfaces calculated (a) without streak removal and (b) with streak removal. The horizontal and vertical axes represent the eastward and northward displacements, respectively, divided by the time interval between the images. A UVI image taken on July 18, 2017 was used.

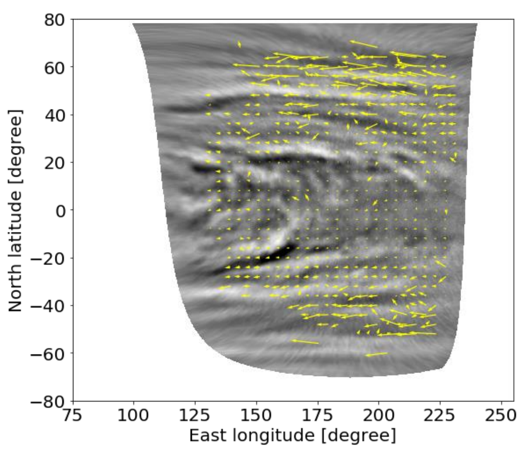

Figure 3. An example of deduced velocity field overplotted on the high-pass filtered UVI image in the longitude-latitude coordinate. A solid body component (3 [degree hr^{-1}]) was subtracted from each vector. A UVI image taken on July 18, 2017 was used.

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