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Cloud-top winds obtained from Akatsuki: three-year statistics of mean winds and momentum transport

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Abstract

From the two-wavelength UV imaging with Akatsuki, winds at the cloud top of Venus are found to vary over a time scale of several hundred Earth days. Comparison of the results from the two wavelengths suggests a variability of the unknown UV absorber and its hemispheric asymmetry. Meridional transport of zonal angular momentum by thermal tides and transient disturbances, which is important for the maintenance of the super-rotation, are quantified.

1. Introduction

Akatsuki has been observing the atmosphere of Venus since December 7, 2015. Its near-equatorial orbit enables simultaneous and equal observations of the both northern and southern hemispheres, for the first time as an orbiter. Akatsuki's UV camera, UVI, observes reflected sunlight at the cloud top by using two filters centered at 365 nm and 283 nm. The former is the traditional wavelength used by Pioneer Venus Orbiter and Venus Express, where absorption by (an) unknown substance(s) occurs. Imaging at the latter wavelength is novel, where absorption by SO2 occurs.

In our earlier study [1], we reported winds obtained by March 2017. Small-scale features obtained at the two-wavelengths are similar in many cases, and winds obtained are nearly identical when the features tracked are common. However, when they differ, the 283-nm winds are faster than the 365-nm winds in most cases. This result suggests that the altitudes of small-scale features visualized at the two wavelengths differ on the average, and that mean shear exists near the cloud top. We also reported meridional asymmetry observed from late 2016 to early 2017.

The formation and maintenance of super-rotation requires meridional transport of zonal angular momentum. Therefore, it has long been desired to constrain it from observation. However, such previous studies are very limited, and the estimates shown are far from consistent and realistic. The reason for this is presumably because the coverage and the accuracy of the data were not enough.

Here, we use data from December 2015 to December 2018. Our novel automated cloud-tracking method [2,3] provides quality-controlled wind estimates with wide coverage, and we could obtain reliable estimates of the angular momentum flux.

2. Mean winds

Figure 1 shows mean zonal winds over the five sub-periods indicated at the top of each panel. The result suggests a long-term variability that the super-rotation is relatively first (slow) in the third (fifth) subperiod. The mean 365-nm winds are faster in the southern than in the norther hemisphere, which is especially the case in the second sub-period. This asymmetry may be because the vertical distribution of the unknown UV absorber is asymmetric in the observational period; the greater symmetry at 283-nm may be because the vertical distribution of SO2 is more meridionally symmetric. Further results and discussion will be provided in the presentation.

3. Angular momentum flux

We derived meridional flux of the zonal angular momentum flux for thermal tides and the other transient disturbances. Figure 2 shows the result from the 365-nm winds. The 283-nm results are similar but slightly stronger. The results obtained independently from sub-periods did not disagree much (shading), suggesting the robustness of our result. The result suggests that thermal tide transports westward (super-rotating) angular momentum toward equator from mid-latitude, while transient disturbances broadly transport the westward angular momentum poleward. The acceleration due to the thermal tide is stronger than the deceleration by transient disturbance near the equator. The order of magnitude of the acceleration is consistent with the indication from the net radiative heating. [4]

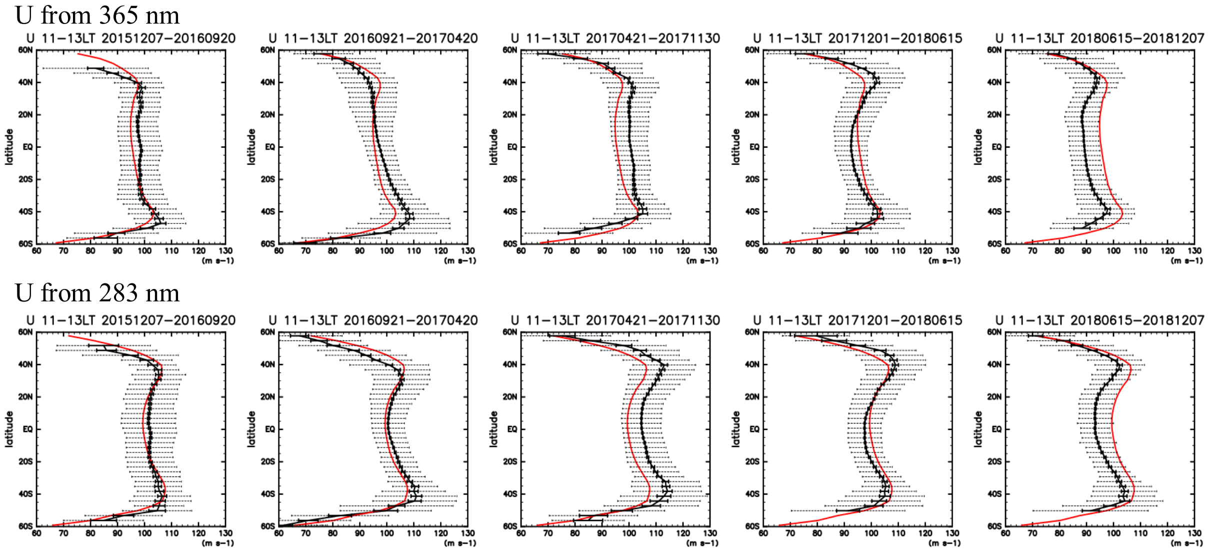

Figure 1: Mean westward zonal winds obtained for five sub-periods from (upper) 365-nm images and (lower) 283 nm (black solid curves) within local times 11—13 h. Dotted bars show ± the standard deviation with time. Thick solid bars show a precision measure. The red curves show the mean winds over the entire observational period.

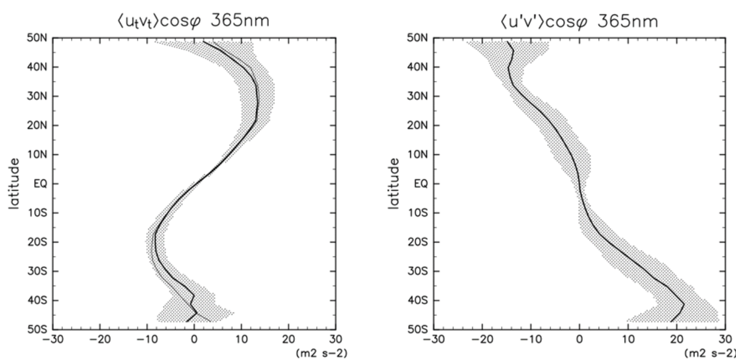

Figure 2: Meridional flux of zonal angular momentum by thermal tide and transient disturbances at the cloud top associate with (left) thermal tide and (right) transient disturbances in the form of $\overline{\langle u'v' \rangle} \cos\varphi$ where angular brackets and overbar represent zonal and temporal mean, and symbols are in the standard notation; thick solid curves show mean values over the sub-periods, and shading show ± the inter-subperiod standard deviation.

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