

Morphological Feature Extraction from Venus' Cloud Images Using Principal Component Analysis

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We applied principal component analysis (PCA) to Venus' multi-wavelength image data obtained by Venus orbiter Akatsuki, to extract latent morphological patterns for each wavelength and compare them to reveal similarities and dissimilarities between the wavelengths. Statistical approaches that extract latent features using massive amounts of data have hardly been done in Venus researches. The new analysis showed that tilted streaky features are dominant at all wavelengths, especially in mid-latitudes; this feature can be explained by the combination of the latitudinal gradient of the mean zonal velocity and the meridional circulation. Moreover, the result shows a strong morphological similarity between cloud height and ultraviolet absorbers.

We preprocessed images as follows. We used data in which images have been projected onto the latitude-longitude coordinate (Level-3 data). We used the following four wavelengths; near-infrared 2.02 μm (cloud height), thermal infrared 10 μm (cloud top temperature), ultraviolet 283 nm (SO_2 distribution at the cloud top), and ultraviolet 365 nm (an unknown UV absorber). First, we performed photometric correction using Minnaert Law (except for 10 μm images). Then these images are high-pass filtered by subtracting a Gaussian-smoothed image from each original image to extract scales smaller than 6 degrees both in latitude and longitude. Lastly, we extracted image patches from these images to increase the number of samples and extract specific spatial scale. The size of the image patches is 12 degrees in latitude/longitude. The total number of image patches is around 60,000 for each wavelength. Also, we analyzed images in low-latitudes and mid-latitudes separately.

We performed PCA for the image patches. PCA converts a set of observational data into a set of linearly uncorrelated variables called principal components and enables to extract spatial features that appear in data frequently. We focus on 20 most major principal components for each wavelength, and we also calculated the contribution ratios. As a result, it turned out that tilted streaky features are dominant both in low and middle latitudes. Considering that zonal winds have a latitudinal gradient and that a slow, poleward meridional circulation exists, cloud parcels are stretched obliquely while drifting from low latitudes to middle latitudes. Moreover, we found that SO_2 (283 nm) and the unknown UV absorber (365 nm) have spatial patterns similar to that of the cloud height (2.02 μm). It indicates that mechanisms that make the distribution of clouds and these chemical compounds in low latitudes are common. As unique patterns for a specific wavelength, it is worth noting that streaks in the north-south direction prevail in patterns of the cloud top temperature (10 μm). Considering that meridional bow-shaped structures are observed at this wavelength, it seems that these structures are appearing as the main principal component. Besides, the statistical approach could successfully extract streaky features from 10 μm as well, while we cannot recognize such features at this wavelength by our eyes because of apparent dominance of random, patchy features. In conclusion, we successfully extracted statistical spatial patterns in Venus' clouds and enabled further discussions about physical properties corresponding to each wavelength more in detail.

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