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Analysis of planetary cloud images considering local rotation

Keishiro Muto and **Takeshi Imamura**
The University of Tokyo, Graduate School of Frontier Sciences, Department of Complexity Science and Engineering, Kashiwa, Chiba, Japan (t_imamura@edu.k.u-tokyo.ac.jp)

Cloud tracking has been used to measure motions of planetary atmospheres remotely without direct observations. Cloud tracking is a method to track the movements of cloud parcels using temporally-continuous cloud images to obtain cloud motion vectors. Since it is considered in most of the cases that clouds move at the same speed and the same direction as the surrounding atmosphere, the wind direction and wind velocity can be obtained by tracking the movement of clouds. This method has been applied to the atmospheres of the planets, such as Venus and Jupiter, where direct observation is difficult as well as that of the Earth's atmosphere.

In the cloud tracking methods developed so far, only the parallel movement of the characteristic pattern is assumed, and the rotation of the pattern is not directly measured. Here we developed a new algorithm to track the parallel movement and the rotation of cloud patterns using the rotation invariant phase-only correlation method. In this method, the tracking region is Fourier-transformed before applying the phase correlation method for measuring parallel movement, and logarithmic polar coordinate conversion is performed to the amplitude spectra so that the rotation and enlargement/reduction motions can be obtained as parallel movements. With this method, not only the parallel movement but also the rotational movement of the characteristic pattern can be detected at the same time.

We first applied the newly-developed method to simulated image pairs. The rotation rate of the cloud pattern and the vorticity derived from the velocity field were compared in three velocity patterns: solid body rotation, irrotational vortex, and sinusoidal velocity field in the latitude and longitude directions. As a result, in the case of a solid body rotation, the wind speed field and the rotation angle were determined correctly. Large-scale rotations can be measured more accurately by the new method than by the calculation of vorticity from the cloud-tracked velocity. When the scale of the velocity structure is decreased, the number of missing cloud tracking vectors increases, and thus the spatial pattern of the vorticity becomes difficult to obtain. Even in such cases, the spatial pattern of the rotation rate can be relatively well retrieved although its amplitude is underestimated.

The new method was applied to Jupiter and Venus images based on the results above. For Jupiter, many small eddies were found to be distributed in the equatorial region. The spatial scales and the strengths of the eddies resemble those seen in numerical simulations. The observed vortex chains can contribute to the formation of Jupiter's equatorial jet. For Venus, though small-scale eddies are less prominent, a planetary-scale distribution of the rotation rate with a north-south reflection symmetry was seen, such that anti-clockwise rotation occurs in the northern hemisphere and clockwise rotation in the southern hemisphere. Since the large-scale rotation pattern is consistent with the latitudinal shear of the mean zonal wind, the result means that the rotation of small-scale clouds is caused by the large-scale wind. This result suggests that the small-scale streaky features at mid-latitudes, whose origin is poorly understood, are created by the deformation of clouds by large-scale winds.

The newly-developed method can extract smaller scale eddies than those observed in the previous studies; the method has enabled investigation of the interaction between different scales in a wider wavelength range. The method would also enable studies of mesoscale weather systems such as deep convection and also studies of upward energy cascade from small-scale convective storms to planetary scale motions in planetary atmospheres.