学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

A study to estimate wind distribution in the inner-core region of tropical cyclones using geostationary meteorological satellites
（静止気象衛星を用いた台風内部コア領域の風速分布の推定に関する研究）

Geostationary meteorological satellites (GMSs) are the only means to continuously observe tropical cyclones (TCs) throughout their lifecycle. Monitoring wind distribution in the inner-core region of TCs is crucial for understanding their dynamics and estimating/forecasting their intensity, which is typically measured as the maximum sustained wind speed. To observe the inner-core region of TCs, in addition to GMSs, aircraft, microwave radiometers/scatterometers and synthetic aperture radars (SAR) on low-earth-orbit satellites, and land-based radar observations are also utilized. However, it has been difficult to continuously estimate the wind distribution in the inner core region due to limitations in spatiotemporal resolution and observational coverage.

Recently, the third-generation GMSs, led by Himawari-8 which began operation in 2015, have dramatically improved spatiotemporal and wavelength resolution compared to their predecessors. They are capable of the “rapid-scan” observations of TCs at a high frequency within a few minutes.

Generally, intensity estimation of TCs in the open ocean mainly relies on subjective and empirical methods based on cloud pattern recognition using GMSs, which are known to occasionally produce significant errors. Since intensity estimation errors are reflected in the accuracy of subsequent forecasts, improving the accuracy of intensity estimation is an important task. One potential approach for improving intensity estimation using GMSs is to physically estimate the intensity from wind distribution obtained by cloud tracking in the inner-core region. Since the clouds in TCs’ eyes are mostly confined in the boundary layer where the tangential winds are maximized at its top, wind derivation from the clouds there should be useful to study and monitor TCs. However, reliable cloud tracking has not been achieved in the rapidly rotating inner-core region using conventional cloud tracking methods. This study aims to develop methods to estimate wind distribution using rapid-scan observations by GMSs and to understand TC dynamics through the obtained results.

Firstly, a method is proposed to derive the axisymmetric component of tangential winds in the eye as a function of radius using spectral analysis for azimuth-time cross-section of rapid-scan imagery. The method is applied to the visible images of boundary layer clouds in the eye of Typhoon Lan (2017) over an 8.5-hr period. The low-level tangential winds over the central two-thirds of the eye in radius were found to be close to a rigid body rotation and increased

with time. On its outside was a region with striating clouds rotating at much higher angular velocities, which might have been super gradient. Asymmetric motions are visualized as the deviation from the inner rotation, and the vorticities of some mesovortices are quantified. These mesovortices are suggested to transport angular momentum to accelerate the inner rotation.

Secondly, a TC-specific cloud tracking method is proposed using template matching with cross-correlation. First, counter-rotating image sequences are created by using preset multiple angular velocities. These sequences are rotated in the opposite direction of the TC's lower winds. Cloud tracking is then performed within a narrow search range in each image sequence. The cloud tracking results that pass a quality control are used as candidate estimates. The estimates with the highest cross-correlation coefficient at each spatiotemporal grid are used as tentative estimates. The candidates that have large differences from the surrounding tentative estimates are iteratively rejected, and the tentative estimates are also updated. The final estimates are determined at the point where the update process stops. By employing this method, wind vectors were obtained at a high spatiotemporal resolution for Typhoon Haishen (2020), Typhoon Nanmadol (2022), and Typhoon Lan (2017). The accuracies of the obtained AMVs was verified to have errors of a few meters per second. The winds in the eye of these typhoons consistently exhibited a transient wavenumber-1 pattern, which is indicative of algebraically growing wavenumber-1 disturbances. The investigation of Typhoon Lan (2017) involves examining the angular momentum transport by mesovortices and the resulting rapid increase in the angular velocity near the TC center using the obtained AMVs.

Finally, a method is proposed to estimate the radius of maximum wind (RMW) from GMSs. RMW is usually located under optically thick eyewall clouds and cannot be observed directly from GMSs. Kossin et al. showed that when TCs have clear eyes, the eye radii estimated from infrared (IR) images have a high correlation with the RMW estimated from aircraft flight-level data. The regression of the former onto the latter was shown to have a mean absolute error (MAE) of 4.7 km. The IR-based RMW estimation is revisited by using C-band SAR sea surface wind estimates. The criteria for selecting clear-eye scenes are simplified. The MAE of the Kossin et al. method is found to be smaller than previously suggested: 3.1 km when the proposed relation is used and 2.7 km when the regression is revised with the SAR-measured RMWs. An improvement of the IR-based method to estimate the eye radii is further proposed. The resultant MAE is shown to be 1.7 km, which indicates that the IR-based RMW estimation can be more accurate than has been suggested. A strong correlation between eyewall slope and eye size is confirmed. Cloud features in the eye that may be closely related to the RMW and wind structure around the RMW are also investigated. Potential applications of highly accurate RMW estimation are discussed.

The proposed methods provide previously unavailable wind distribution, contributing to a deeper understanding of TC dynamics. By extending these methods, it may be possible to estimate TC intensity in a physical and objective manner. Furthermore, the assimilation of the data into TC simulation could be a significant step towards improving the TC intensity estimation and forecasting, which are global challenges.