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Editorial: Tropical cyclone intensity and structure changes: theories, observations, numerical modeling and forecasting

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Editorial on the Research Topic
Tropical cyclone intensity and structure changes: theories, observations, numerical modeling and forecasting

Tropical cyclones (TCs) have caused billions of dollars in damage and thousands of lives lost globally over the past 50 years. Mitigating this massive socioeconomic impact requires accurate forecasts of TC evolution. Substantial progress has been made in recent years in forecasting TC position. However, progress in forecasting TC intensity and structure has been more slowly incremental. Many challenges remain in forecasting intensity and structure changes, such as rapid intensification, eyewall replacement cycles, and impacts of complex vertical wind shear. It is imperative to advance our knowledge of intensity and structure changes on theoretical, observational, and numerical modeling grounds so that TC forecasts become more accurate in the future.

The goal of this Research Topic was to collect the latest advances on theories, observations, numerical modeling, and forecasting of TC intensity and structure changes. These include intensity and structure changes resulting from environmental influences (such as ocean interactions, vertical wind shear, trough interactions, upper-level outflow, and dry/dusty air intrusions); internal influences (such as inner-core dynamic instabilities and mixing processes, eyewall replacement cycles, spiral rainband dynamics, and air-sea interactions); the mutual interaction of the internal and external processes; the role of physical processes associated with the boundary layer, clouds, and radiation; advances on quantifying intensification rate theories and intensification mechanisms; and new development of forecasting techniques for TC intensity and structure. Eighteen research articles were published in this Research Topic and a summary of these articles is provided below.

First, we describe the theoretical studies. Schubert and Taft used a theoretical framework to examine rapid intensification (RI) through internal TC dynamical processes. In particular, they found that when the potential vorticity (PV) core evolves rapidly enough, inertia-gravity waves were excited at the edges of the PV structure. If the PV core evolved slower, inertia-gravity wave activity was more negligible. An interesting finding of their work was that the intensification rate was sensitive the amount of mass removed in a time period from an absolute angular momentum surface. Schubert et al. examined baroclinic effects on the distribution of TC eye subsidence through semi-analytic solutions to the Sawyer-Eliassen balanced vortex equation. They found conditions under which large values of the radial and vertical advection of potential temperature were located at the outer edge of the eye, producing the warm ring structure.

The next set of studies investigated TC structure, intensity, and associated variability from numerical modeling and observational perspectives. Liu B. et al. used ground-based Doppler radar to investigate the rapid intensification of sheared tropical cyclone Meranti (2010). They found two periods of RI, an asymmetric period and an axisymmetric period. Vertical shear favored deep convection in the downshear-left quadrant which favored development of low-level vortices that were ingested cyclonically inward during the asymmetric episode. This study highlighted the critical importance of asymmetric convective processes in RI. Patra et al. examined the role of random initial conditions, forcing, and parameters in the intensity variability of real TCs in numerical prediction models. Random forcing produced the largest variability in intensity and fastest intensity error growth during rapid intensification. The random initial condition was most important early in the development. Jin et al. examined the role of the upper-level outflow on the RI on Typhoon Roke (2011). Roke's outflow evolved from equatorward to poleward during the RI event. The RI was likely influenced by the outflow since the outflow was enhanced prior to the RI. Finally, Liu and Tang observationally investigated the impacts of volcanic eruption on Tropical Cyclone Cody (2022), through aerosol-cloud interactions using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite and fifth generation European Center for Medium Range Weather Forecasting (ERA5) atmospheric data. They found that the precipitation and intensity of Cody were enhanced after the volcanic eruption. Even though volcanic eruptions near TCs are rare, this study points to the important implications of such events on TC evolution. Ito and Yamamoto used the multitude of Aircraft Communications, Addressing, and Reporting System/Aircraft Meteorological Data Relay (ACARS/AMDAR) observations to construct the composite mean structure of TCs. They found interesting characteristics of the TC warm core structure such as the dependence of the anomaly on intensity and that the anomalies can extend very far radially outward to 1,000 km.

An emerging area of research in TC science is the application of artificial intelligence and machine learning methods to understanding and forecasting TC structure and intensity. Zhu et al. used a machine learning method, the Gradient Boosted Regression Tree (GBRT), to predict intensity variability in the western North Pacific basin at lead times from 12–72 h. The predictors of the model were synoptic and environmental and persistence variables from reanalysis data. They showed that the GBRT was better at intensity forecasting than traditional multiple linear regression models. Yuan et al. used a machine learning method of physics-incorporated networks to estimate TC wind structure (both wind radii and intensity). The physics-incorporated network used satellite imagery and predictors from the Statistical Hurricane Intensity Prediction Scheme (SHIPS), and a neural network to generate the wind radii and intensity. The model was demonstrated to have skill in an operational environment.

Advances in understanding and modeling the TC boundary layer are welcome considering the complexity and societal importance of this region especially when TCs make landfall. Liu et al. used large-eddy simulations to show that tornado-scale vortices exist in the TC boundary layer and were important contributors to extreme wind gusts there. They showed that in the eyewall the peak gust factors associated with these vortices were near 1.8. This reenforced the importance of considering gusts in addition to the maximum sustained wind and on further understanding the coherent structures in the boundary that cause extreme winds. Li et al. used lidar data and computational fluid dynamics experiments to understand the vertical structure of the typhoon winds at landfall. Since most towers are below 100 m, the lidar data provided valuable data from 100–300 m above ground level. A local low-level jet was found in the mean wind profile between 100–300 m suggesting power laws may not always be valid. Finally, Han et al. performed a statistical study on the relationship between pre-landfall intensity change and post-landfall weakening of TCs over East and South China. Over East China, TCs often experienced pre-landfall weakening followed by post-landfall rapid decay. On the other hand, over South China, TCs typically intensified prior to landfall and weakened slowly after landfall.

The final set of studies focused on numerical modeling and forecasting of TCs. Li et al. examined the prediction skill of the Dynamical-Statistical-Analog Ensemble Forecast model for Landfalling Typhoon Gale (DSAEF_LTG model) in comparison to other numerical weather prediction (NWP) models in the South China Sea. They generally found that it was more skillful than the other models. Xie et al. applied the potential vorticity tendency (PVT) approach to very high-resolution numerical simulations (~1 km). While the PVT method has been widely used and successful in coarser numerical simulations, the utility of it in high resolution simulations was not as well known, since the PV structure is resolved to be more heterogeneous and complex, and can even be annular. The authors suggested that either smoothing of the PV field or increasing the temporal output helped to make the PVT method perform better using high-resolution output. Duan et al. examined the sensitivity of the boundary-layer schemes on reproducing the asymmetric rainfall pattern of landfalling Typhoon Lekima (2019). Broadly, they found significant sensitivity of the track, intensity, and structure to the PBL scheme. Su et al. studied the forecasting performance of Dynamical–Statistical–Analog Ensemble Forecast (DSAEF) model for Landfalling Typhoon Precipitation (DSAEF_LTP) over the Fujian Province using new values of two parameters: similarity region and ensemble method. They showed that DSEAF_LTP performed best with regard to precipitation threat scores in comparison to other NWP models. Wang et al. examined the role of a midlatitude upper-level trough on the unusual track and intensity of Typhoon Bavi (2020). Complex trough dynamics, such as the formation of the cutoff low at its base, impacted the track forecast of Bavi. The trough also contributed to its intensification through the upper-level eddy angular momentum flux convergence. Gao et al. examined an extreme rain event in Shandong Province from Typhoon Lekima (2019) using observations and numerical simulations. After landfall, Lekima moved northward along the coast producing the highest precipitation in recorded history in

Shandong Province. In numerical simulations, the intense rain was shown to be a result of the interaction of the typhoon rainbands with a mid-latitude synoptic system. The results show the multiscale characteristics and complexity of rainfall hazards resulting from TCs after landfall.

In summary, articles in this Research Topic advanced our understanding of TC structural and intensity variability using theoretical, observational, numerical-simulation, and forecasting approaches. Considering the societal implications of having accurate TC intensity and structure forecasts, future research is recommended along similar lines.

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