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EDITORIAL

Research of Super Typhoon Lekima: forecast, observation, numerical simulation and disaster survey

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1 Introduction

Tropical cyclones (TCs) are among the most destructive natural disasters in the world, and the TCs in the North-west Pacific (NWP) are most frequent among all ocean basins. The TCs that induce disastrous weather such as destructive winds, heavy precipitation, tornadoes, lightning and storm surges sometimes cause significant economic losses and heavy casualties to human beings, which are also called high-impact TCs due to their influences on human society. Generally, TCs in the NWP generate in tropical oceans and move northwestward, which then strike the south-eastern coastal regions of Asia continent, densely populated areas with developed economy. Some of them intrude deep inland or higher-latitudes, resulting in severe flooding. During the past decade, a series of high-impact TCs, including Typhoon Haiyan (1330), Typhoon Mujigae (1522), Typhoon Meranti (1604), Typhoon Hato (1713), Typhoon Mangkhut (1822) and Typhoon Hagibis (1919), hit the NWP basin and caused severe casualties and property losses. Several studies have been conducted on these high-impact weather events from different aspects (e.g., Mori et al., 2014; Bai et al., 2017; Tay et al., 2020; Yang et al., 2019; Zhang et al., 2020), but they are somewhat scattered, and thus subsequent researchers are always confused due to the lack of enough information. In other words, the research community needs to conduct synergistic studies on a typical and high-impact case to provide a more comprehensive description and to increase our knowledge about tropical cyclones.

Super Typhoon Lekima, which made its landfall in east China on August 10, 2019, is a typical case most recently. The effected regrion of which distributed from Fujian Province all the way north to Heilongjiang Province, causing severe winds and precipitation to the eastern and northeastern China. The maximum wind of 61.4 m/s was observed near the landfall site, and the maximum total precipitation reached 831 mm. Typhoon Lekima, a typical high-impact TC in 2019, has been a history record typhoon with the third highest intensity ever among all the typhoons that made landfall in Zhejiang Province.

This special issue of Frontiers of Earth Science is initiated by the hope to provide further insights and comprehensive knowledge on this high-impact TC. This issue is supported by the International Cooperation Projects of the Ministry of Science and Technology of China (No. 2017YFE0107700), the Key Special Project of the Ministry of Science and Technology (No. 2018YFC1506403), and the ESCAP/WMO International project (Experiment on Typhoon Intensity Change in Coastal Area) leaded by the Shanghai Typhoon Institute, China Meteorological Administration (CMA). A total of 16 peer-reviewed papers are selected for publication on various topics related to typhoon Lekima, including forecast techniques, observation, disaster survey, predictability and model study. Besides, studies on other high-impact cases are also invited in this issue.

2 Review of the special issue

The 17 papers in this special issue can be categorized into four groups according to their research fields.

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2.1 Forecast techniques

At 20:00 BJT on August 4, 2019, Typhoon Lekima was generated at 17.1°N, 131.5°E in the western North Pacific Ocean, about 1000 km east of the Philippines, and moved steadily along the southwestern periphery of the western Pacific subtropical high ridge to its northwest. Such atmospheric circulations were favorable for TC's development. At 02:00 BJT on August 7, Lekima reached the grade of typhoon, i.e., the maximum surface wind speed > 32.6 m/s. Animated enhanced infrared satellite imagery shows Typhoon Lekima featured by central dense overcast and an incipient eye. During the next 36 h, Typhoon Lekima intensified rapidly due to favorable conditions, including the near-radial outflow, the low vertical wind shear and the warm sea surface temperature. Typhoon Lekima reached its peak intensity (62 m/s) at 20:00 BJT on August 8, located approximately 300 km east of Taiwan, China. Note that there are significant discrepancies for Lekima's intensity among three data sets from the CMA, Japan Meteorological Agency (JMA) and Joint Typhoon Warning Center (JTWC), especially after the TC reached the intensity of super typhoon and during the period when it made landfall in Zhejiang Province, China. For detailed analyses, please refer to Bai et al. (this issue).

Chen et al. (this issue) verified the track, intensity and landfall site of Super Typhoon Lekima (1909) forecasted by official guidelines, global models, regional models and ensemble prediction systems. The results show that track errors from most deterministic methods are smaller than their annual mean errors in 2019. Among them, the ECMWF model performs the best in forecasting Lekima's track in terms of both deterministic and ensemble forecasts. Furthermore, the results of the ensemble prediction system track dispersion verification show that the NCEP-GEFS, JMA-GEPS and MSC-CENS are under dispersed, the STI-TEDAPS(Typhoon Ensemble Data Assimilation and Prediction System) are over dispersed, and the ECMWF shows adequate dispersion at all leading times. A detailed analysis is provided in Chen et al. (this issue).

To improve the current forecast techniques of precipitation, it is necessary to gain a targeted understanding of the performances of numerical models in forecasting landfalling typhoon-induced precipitation. In this issue, an object-oriented verification procedure within the framework of contiguous rain areas (Ebert and McBride, 2000) is used to explore the rainfall forecast capability of the GRAPES-TCM (Global/Regional Assimilation Prediction System-Tropical Cyclone Model) from the Shanghai Typhoon Institute, CMA. For Typhoon Lekima (1909), the sources of prediction error for the rainfall in different stages during the landfall are mainly focused on. Therefore, obtaining the performance of numerical models in forecasting landfall typhoon-induced precipitation at different stages is of great significance for forecasters and model developers to find the model deficiencies. The details are discussed by He et al. (2021) in this issue.

To improve typhoon precipitation forecast, Guo et al. (this issue) introduced a new frequency-matching method and combined the screening and the neighborhood methods.Based on this new method, the frequency of rainfall above the rainstorm magnitude increases and a sample test based on four landfalling typhoons including Typhoon Lekima was excuted. The preliminary results showed that this new method performs well with respect to the forecast rainfall area and magnitude for the four typhoons and performed a potential to utilize in the operational forecast in the future.

2.2 Observation and disaster survey

Xiang et al. (this issue) found that the heavy rainfall related to Lekima includes three main episodes after the landfall. The asymmetric component of inner rainband moved from the north (west) quadrant to the east (south) quadrant after landfall, which was related to the storm motion other than the vertical wind shear. The asymmetric component of the outer rainband experienced two significant cyclonical migrations in the northern.

For Typhoon Lekima, the Shanghai Typhoon Institute launched a special experiment by a five-point lidar observation network consisting of a mobile truck in Zhoushan and four fixed observation stations (Baoshan, Taizhou, Wenzhou and Sansha) to capture its structure evolution during its landfall. This lidar data are extremely valuable for evaluating the boundary layer structure and physical processes during Lekima's life history, since it is the first time in China to compare the lidar measurements with the observations from balloon-borne GPS radiosonde launched at the same location. The details are discussed in Tang et al. (this issue) in this issue.

Fang et al. (this issue) used a space- borne multi-polarization synthetic aperture radar (SAR) instrument at C-band in GF-3 satellite to observe Typhoon Lekima and find a maximum wind speed is 38.9 $m \cdot s^{-1}$ and proved that SAR-retrieved winds from GF-3 are enough reliable by comparison with ECMWF and Chinese Global/Regional Assimilation and Prediction Enhance System (GRAPES).

Zhang et al. (this issue) calibrated the echo intensity data collected by ground-based radar systems, with the Ku-band Precipitation Radar observations as reference. After the correction, the consistency of the echo intensity measured by multiple radar systems has been significantly improved. In addition, based on the corrected ground-based radar observations, the precipitation estimates are closer to the observations from rain gauges.

Two weeks after the landfall of Typhoon Lekima, a joint survey team conducted a post-disaster survey along the southeastern coast of Zhejiang Province from August 26 to 28 in 2019, in cooperation with the Shanghai Typhoon Institute and local meteorological bureaus. The survey focused on the rainstorms, flooding, landslides and weather services associated with Super Typhoon Lekima (1909). This investigation and return period estimation of Typhoon Lekima (1909) is proposed by Zhou et al. (this issue) in this issue.

To know the reason why Typhoon Lekima is so destructive after landfall, Xu and Liang (this issue) analyze the ECMWF based on multiscale window transform (MWT) and study the energy evolution among three difference scales, background flow, TC-scale and convection scale. And this study also found that there both barotropic and baroclinic processes during the typhoon landfall.

2.3 Predictability and model study

Xu et al. (this issue) explored the dynamic structure and predictability of the rapid intensification of Super Typhoon Lekima (1909) through a 20-member ensemble forecasts. They found that the peak intensity is most sensitive to the initial primary circulation outside the radius of maximum wind, the secondary circulation and the inner-core moisture. In addition, the model's high resolution with a 3-km grid spacing are essential to capture the characteristic of rapid intensification.

Tan et al. (this issue) introduced the forecast performances of models in the 2019 typhoon season. The GRAPES-TCM adopts the characteristic parameters from the real-time TC data released by the CMA, introduces a sixth-order horizontal diffusion scheme and adjusts the operational flowchart. For the case of Super Typhoon Lekima, the model exhibits a reliable prediction ability for the type of TC with a north-west track.

To improve the operational forecast accuracy for TCs, the impact of vertical resolution on the simulation of Typhoon Lekima (1909) is investigated by using a near-cloud-permitting model. The results show that the vertical resolution in free atmosphere can affect the simulated dynamic and thermal structures of Typhoon Lekima, thereby influencing its intensity. The investigation is proposed by Liu et al. (this issue) in this issue.

2.4 Other studies

To improve the cooperation research on high-impact TCs in the research community, studies on other cases and many other research groups are also invited in this issue, including the satellite observation for Typhoon Soulik (Lee et al., this issue), the hurricane eye morphology extracted from synthetic aperture radar images (Ni et al., this issue) and the ocean wave in Tokyo Bay during Typhoon Faxai (Takagi et al., this issue).

3 Summary

Through this special issue, scientists focused on Super Typhoon Lekima and other high-impact TCs, achieving numerous valuable results from different aspects. However, it should also be acknowledged that the research on Typhoon Lekima is still rather preliminary, and more academic questions need to be discussed in the future. It is expected that this issue will be a good start and can provide enough research background for future studies.

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