Acta Oceanol. Sin., 2020, Vol. 39, No. 8, P. 121–124
https://doi.org/10.1007/s13131-020-1639-4
http://www.hyxb.org.cn
E-mail: hyxbe@263.net

News and Views

Uniqueness of Lekima compared to tropical cyclones landed in the east coast of China during 1979–2019

Yifan Ding[1, 4], Jiping Liu[2, 4], Shengzhe Chen[2], Xiao Cheng[1, 3, 4*], Zhaojun Zheng[5]

[1] College of Global Change and Earth System Science, and State Key Laboratory of Remote Sensing Science, Beijing Normal University, Beijing 100875, China

[2] Department of Atmospheric and Environmental Sciences, University at Albany, State University of New York, Albany, NY 12222, USA

[3] School of Geospatial Engineering and Science, Sun Yat-sen University, Zhuhai 519000, China

[4] Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai 519000, China

[5] Key Laboratory of Radiometric Calibration and Validation for Environmental Satellites, National Satellite Meteorological Center, China Meteorological Administration, Beijing 100081, China

Received 23 June 2020; accepted 25 July 2020

Tropical cyclone (TC) causes huge damage to lives and properties due to strong winds, storm surge, heavy rainfall and flooding (Peduzzi et al., 2012; Zhang et al., 2009). Climate model simulations suggested that the frequency of TCs might increase during the 21st century, especially over the western North Pacific (Emanuel, 2013). Climate changes tend to double the economic damages caused by natural disaster, i.e., strong TCs. East Asia hit by TCs may suffer great damages in the future (Mendelsohn et al., 2012). As estimated by previous studies, the TCs that landed in China caused about 28.7 billion RMB (estimated in 2006) in direct economic loss and 472 deaths per year during 1983–2006 (Zhang et al., 2009). The losses caused by the landfalling cyclones are closely related to their paths and intensities.

In 2019, Lekima became a tropical storm (TS) in the western tropical Pacific on 4 August, and then intensified rapidly to typhoon (TY), severe typhoon (STY), and super typhoon (Super TY) within 4 d (Fig. S1a). It features special double eyewall structure (with TC Krosa) before making landfall. According to the Best Track Data, Lekima made the first landfall in Wenling, Zhejiang as a STY with the maximum sustained wind of ~44 m/s at 18:00 on 9 August (UTC), and subsequently moved northward along the coastline across Zhejiang, Shanghai and Jiangsu and weakened. Figure S1b shows the first landfall of Lekima using the FY-4A image on 9 August. Lekima made the second landfall in Qingdao, Shandong as a TS with winds of ~23 m/s at 12:00 (UTC) on 11 August. The duration that Lekima stayed in the eastern coast of China is nearly 2 d, including ~6 h as a STY, ~12 h as a TY, ~12 h as a severe storm (STS), and ~18 h as a TS. According to the National Climate Center of China, Lekima caused at least 51.53 billion RMB in direct economic loss. It is ranked as the second largest loss caused by TCs in China since 2000.

This study investigates the uniqueness of Lekima compared to previous TCs that landed in the east coast of the mainland of China related to the climatology. Here we focus on the TCs that made landfall between the southern boarders of Zhejiang and Shandong (between 27°N and 35°N) during 1979–2019.

According to the Best Track Data of RSMC Tokyo-Typhoon Center, 916 TCs occurred in the western North Pacific, and 244 of them made landfall in China (excluded Hainan and Taiwan) during 1979–2019 (note: we only consider the named TCs). Among those, 36 TCs landed between the southern borders of Zhejiang and Shandong (see Column 1 in Table 1). Here we classify the 36 TCs based on two criteria. First, the landfall TCs stayed on land for at least 24 h; second, the landfall TCs moved within 150 miles (1 mile=1 609 m) to the east coast for at least half of their duration on land. The definition of 24 h threshold is based on the upper limit of the average duration of the total 36 TCs (excluded tropical depression, TD) stayed in the east coastal areas of China, which is 24 h after the landfall. The definition of 150 mile threshold is based on the average distance to the east coast of the 20 TCs selected under the first criterion (see Column 2 in Table 1), which is 149.8 miles (around 150 miles) after the landfall. Additionally, previous study based on QuickSCAT (Quik Scatterometer) data showed the median radius of the TCs in the western Pacific is around 150 miles (Chavas and Emanuel, 2010). The two criteria ensure the selected TCs stayed on land for a considerable duration and moved along the east coast of the mainland of China.

Among the landed 36 TCs during 1979-2019, ten of them meet the two criteria (see Column 3 in Table 1). Figure 1 shows the detailed paths and levels of the 10 TCs along the coast. The average distance of the ten TCs to the east coast after landfall is ~73.3 miles (excluded Lekima, Table 1). Lekima has the nearest distance to the coast (23.0 miles). This suggests that Lekima moves much closer to the coast than other TCs (Fig. 1), which is one of its unique features. We further examined the strength of the 10 TCs as they made landfall. The results show that 8 TCs landed as a TS or above level, 5 TCs landed as an STS or above level, 3 TCs landed as a TY or above level, and only 1 TC landed as a STY–that is Lekima (Table 1 and Fig. 1). As demonstrated in Fig. S2, Lekima landed with the center pressure of 941 hPa and wind speed of 44 m/s, which is the strongest among the 10 TCs. This suggests that Lekima landed with

Foundation item: The National Key R&D Program of China under contract No. 2018YFA0605901; the National Natural Science Foundation of China under contract No. 41676185; the Joint PhD Program of China Scholarship Council (CSC).
*Corresponding author, E-mail: chengxiao9@mail.sysu.edu.cn

Table 1. Thirty-six TCs landed along the coast between southern boarders of Zhejiang and Shandong

Year-TC	First criteria	Second criteria	After landfall		Landfall level				
			Distance to the east coast/mile	Sustained hours	Level	⩾TS	⩾STS	⩾TY	⩾STY
2019-LEKIMA	√	√	23.0	44	STY	√	√	√	√
2018-AMPIL	√	√	39.9	30	TS	√			
2018-YAGI	√	√	114.4	48	TS	√			
2018-RUMBIA	√								
2018-JONGDARI	√	√	93.9	30	TD				
2014-FUNG-WONG									
2012-HAIKUI	√								
2007-WIPHA									
2007-KROSA									
2006-SAOMAI	√								
2005-MATSA	√	√	67.1	54	STS	√	√		
2005-KHANUN	√	√	42.5	24	TY	√	√	√	
2004-MINDULLE									
2004-RANANIM	√								
2004-HAIMA									
2002-SINLAKU	√								
2000-JELAWAT	√	√	164.1	42	TD				
1998-TODD									
1997-WINNIE	√	√	89.9	36	TY	√	√	√	
1995-JANIS									
1994-DOUG									
1994-FRED	√								
1992-TED									
1990-OFELIA									
1990-ABE									
1989-KEN-LOLA	√								
1989-HOPE									
1989-VERA									
1988-BILL	√								
1987-ALEX									
1985-JEFF	√	√	24.0	30	STS	√	√		
1985-MAMIE									
1984-ALEX									
1984-ED	√	√	23.6	42	TS	√			
1984-FREDA	√								
1981-NINA	√								
Total TCs	20	10				8	5	3	1

Note: 1 mile=1 609 m.

much higher intensity than other TCs, which is another unique feature.

Previous case studies in the north Atlantic and western Pacific suggested that the spatial pattern of geopotential height has profound effect on the cyclone paths (Horton and Liu, 2014; Sun et al., 2015). Based on this, we assessed the geopotential height anomalies at 500 mb using the ERA5 reanalysis data in the period that Lekima was on land (Fig. S3a). Compared to the previously mentioned TCs, Lekima shows anomalous high-pressures to its west, east, and north. This is very different from nearly all the other TCs (Fig. S3), except for Winnie in 1997, which however has much broader and stronger high-pressure anomalies to its northeast (Fig. S3h). Such circulation pattern inhibited Lekima from moving eastward and westward after the landfall, leading to its movement along the coast. Besides the low-pressure system associated with Lekima, there is another anomalously low-pressure system (TC Krosa) to its southeast. It tended to push the high-pressure anomalies northward and limited the strength of the high pressure on the east side of Lekima, which also inhibited Lekima from turning east early or being squeezed inland. This further helped Lekima to move directly northward along the coast. Winnie in 1997 did not show such features. The circulation pattern of Lekima most likely led to the unique path (significantly close to the coast) after the landfall.

Air-sea turbulent flux (latent and sensible) is the major energy source that allows typhoons to develop (Emanuel, 2003). Studies using numerical models found that the increase of the local or underlying sea surface temperature (SST) can result in TC development and intensification (Broccoli and Manabe, 1990; Haarsma et al., 1993; Krishnamurti et al., 1998). Based on this, we assessed the SST anomalies of Lekima using the Optimum Interpolation Sea Surface Temperature (OISST) data (Fig. S4). The results suggest that the SST was about 2°C anomalously higher along the path of Lekima in the early period (4 to 6 August). This promoted Lekima evolved to a super TY on 7 August by obtaining the energy from the warm ocean and maintained as a super TY until 9 h before landing. The anomalous

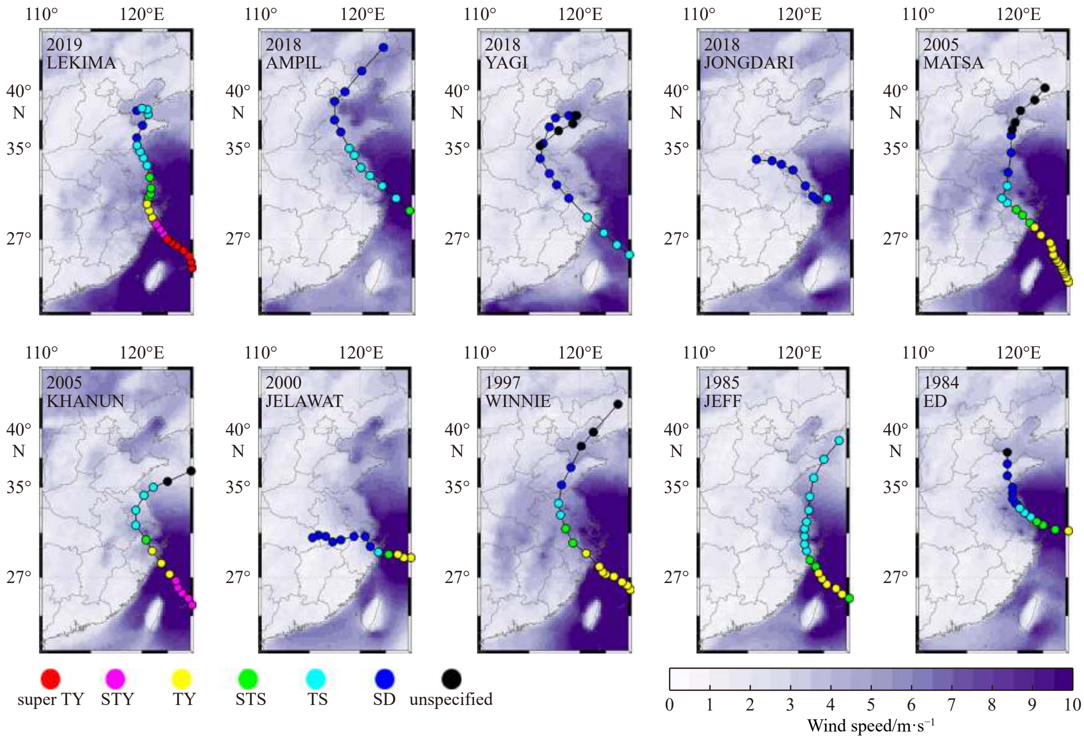

Fig. 1. Paths of the selected ten TCs along the east coast of the mainland of China. The color points indicate the TC levels. The base map is the averaged 10-m wind speed obtained from the ERA5 reanalysis in the period that each TC was on land.

warmer SST in ~20°N was on the magnitude of 1–2°C before the landfall of Lekima (7 to 8 August), which might also help Lekima gain sufficient energy from the ocean. Vecchi and Soden (2007) identified that the TC potential intensity is closely related to the SST warming. The results suggest that the high SST is in favor of Lekima landing as a STY. Studies also suggested that high waves can cause sea spray and the triggered air-sea turbulent flux is critical for the intensification of typhoons (Emanuel, 2003; Liu et al., 2011). Figure S5a shows the significant wave height (WH) anomalies of Lekima around the time of landing. Compared to the previously mentioned TCs (Fig. S5), Lekima has the largest spatial coverage of anomalously high waves (3–5 m higher than normal). This suggests that the high waves also helped Lekima to land as a STY because of the effect of sea spray (Emanuel, 2003; Liu et al., 2011). Though the waves caused by Winnie near landing area is higher than Lekima, the strongest intensity of Lekima appeared much closer (36 h) to the landing time than that of Winnie (150 h, Fig. S6), and it might be one of the reasons that Winnie landed with lower intensity than Lekima.

As shown in Table 1, Khanun in 2005 and Winnie in 1997 are the only two TCs (except for Lekima) that landed as TY and regarded to land with slightly weaker or comparable intensities as Lekima in this study. To evaluate the impacts of the strong TCs (TY and above level) on the coastal areas, we compared Lekima with Khanun and Winnie in terms of winds, precipitations, and waves after landfall. The results show that Lekima stayed for a longer duration (~ 44 h) than Khanun (~24 h) and Winnie (~36 h) on land (Table 1). The maximum sustained wind speed of Lekima on land is ~10 m/s and ~5 m/s larger than that of Khanun and Winnie (Fig. S7a). Lekima maintained as a TY for at least 12 h on land, which is two times longer than Khanun (< 6 h) and Winnie (< 6 h). In general, the intensity of Khanun and Winnie decayed faster than that of Lekima, which suggests Lekima has stronger energy than the two TCs on land. This also applies to the other previously mentioned TCs during 1979–2019. We then analyzed the impacts of the three TCs by dividing the coastal areas into four regions (Zhejiang, Shanghai, Jiangsu and Shandong). The results show that Lekima generally caused heavier precipitation than Khanun and Winnie, especially in Zhejiang and Shanghai (Fig. S7b and Fig. S7c). The max precipitations of Lekima can reach up to 4.2, 6.6, 2.5 and 3.9 mm/h in Zhejiang, Shanghai, Jiangsu and Shandong, respectively. The heavy precipitations of Lekima also had a significantly longer duration than the two TCs in Shanghai (Fig. S7c) and Shandong (Fig. S7e). The coastal WH can increase by 2 to 8 m while TCs on land (Figs S7f-i). The max waves of Lekima and Winnie are comparable in the coastal areas and are apparently higher than that of Khanun. Lekima and Winnie both have max WH above 8 m in Zhejiang at the time around landing (Fig. S7f). The max high waves decayed in Shanghai but recovered to 6 m in Jiangsu and Shandong as the TCs move northward. The high waves caused by Lekima had a longer duration of impact on the coastal areas than Winnie. Overall, Lekima is more intense than the Khanun and Winnie on land.

This study investigated Lekima, the super TY landed in Zhejiang 2019, by comparing it with other TCs that landed along the coast between Zhejiang and Shandong during 1979-2019. We discussed the processes that lead to two unique features of Lekima: (1) Lekima moved northward much closer to the coast after landfall than the other TCs; (2) Lekima landed as a STY with much stronger intensity than the other TCs. Our results suggest that the geopotential height anomalies, the high SST, and the triggered high waves are the potential reasons for the unique features. Lekima is more powerful on land in terms of winds, precipitations and waves compared to the other two TCs landed as TY (Khanun and Winnie). This study provides researchers with the unique features of Lekima, as the possible major causes for the great damage. In addition, as suggested by the previous studies, the anomalies of geopotential height and SST might be the indicators of the future strong TCs in the changing climate.

Acknowledgements

We thank RSMC Tokyo Typhoon Center and National Oceanic and Atmospheric Administration (NOAA) for providing the cyclone tracking data. We also thank Copernicus Climate Change Service Climate Data Store (CDS) and NOAA for providing the reanalysis data.

References

Broccoli A J, Manabe S. 1990. Can existing climate models be used to study anthropogenic changes in tropical cyclone climate?. Geophysical Research Letters, 17(11): 1917–1920, doi: 10.1029/GL017i011p01917

Chavas D R, Emanuel K A. 2010. A QuikSCAT climatology of tropical cyclone size. Geophysical Research Letters, 37(18): L18816, doi: 10.1029/2010GL044558

Emanuel K A. 2003. Tropical cyclones. Annual review of earth and planetary sciences, (31): doi: 10.1146/annurev.earth.31.100901.141259

Emanuel K A. 2013. Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. Proceedings of the National Academy of Sciences, 110(30): 12219–12224, doi: 10.1073/pnas.1301293110

Haarsma R J, Mitchell J F, Senior C A. 1993. Tropical disturbances in a GCM. Climate Dynamics, 8(5): 247–257, doi: 10.1007/BF00198619

Horton R M, Liu J. 2014. Beyond Hurricane Sandy: what might the future hold for tropical cyclones in the North Atlantic?. Journal of Extreme Events, 1(101): 1450007, doi: 10.1142/S2345737614500079

Krishnamurti T N, CORREA-TORRES R, Latif M, et al. 1998. The impact of current and possibly future sea surface temperature anomalies on the frequency of Atlantic hurricanes. Tellus A, 50(2): 186–210, doi: 10.1034/j.1600-0870.1998.t01-1-00003.x

Liu Jiping, Curry J A, Clayson C A, et al. 2011. High-resolution satellite surface latent heat fluxes in North Atlantic hurricanes. Monthly Weather Review, 139(9): 2735–2747, doi: 10.1175/2011MWR3548.1

Mendelsohn R, Emanuel K, Chonabayashi S, et al. 2012. The impact of climate change on global tropical cyclone damage. Nature Climate Change, 2(3): 205–209, doi: 10.1038/NCLIMATE1357

Peduzzi P, Chatenoux B, Dao H, et al. 2012. Global trends in tropical cyclone risk. Nature Climate Change, 2(4): 289–294, doi: 10.1038/NCLIMATE1410

Sun Yuan, Zhong Zhong, Yi Lan, et al. 2015. Dependence of the relationship between the tropical cyclone track and western Pacific subtropical high intensity on initial storm size: A numerical investigation. Journal of Geophysical Research: Atmospheres, 120(22): 11–451, doi: 10.1002/2015JD023716

Vecchi G A, Soden B J. 2007. Effect of remote sea surface temperature change on tropical cyclone potential intensity. Nature, 450(7172): 1066–1070, doi: 10.1038/nature06423

Zhang Qiang, Wu Liguang, Liu Qiufeng. 2009. Tropical cyclone damages in China 1983–2006. Bulletin of the American Meteorological Society, 90(4): 489–496, doi: 10.1175/2008BAMS2631.1

Supplementary information:

Fig. S1. Path of Lekima.

Fig. S2. The recorded center pressure and wind speed of the 10 TCs at the time around landfall obtained from the Best Track Data.

Fig. S3. Anomalies of 500 mb geopotential height from ERA5 reanalysis for the 10 TCs.

Fig. S4. Anomalies of sea surface temperature in the period of 4 to 12 August 2019 obtained from OISST data.

Fig. S5. Anomalies of significant wave height from ERA5 reanalysis for the 10 TCs around landing.

Fig. S6. Strongest intensity by lowest center pressure and the corresponding wind speed of the 10 TCs obtained from the Best Track Data.

Fig. S7. Impacts caused by Lekima, Khanun and Winnie after landfall.

The supplementary information is available online at https://doi.org/10.1007/s13131-020-1639-4. The supplementary information is published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.