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Record-breaking rainfall accumulations in eastern China produced by Typhoon In-fa (2021)

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1 Motivation

On July 2021, unprecedent rainfall amount occurred when Typhoon In-fa passed through the highly populated eastern China. Understanding the extreme accumulated rainfall induced by Typhoon In-fa is vital for effective disaster prevention and mitigation planning.

With global warming from greenhouse gases, extreme rainfall events are expected to be more frequent and intense. Previous studies have suggested increasing trends in annual total TC rainfall, annual TC rainfall frequency and annual average rainfall per TC in coastal eastern China during past decades. Thus, it is meaningful to investigate whether the chance of occurrence of an extreme rainfall event like Typhoon In-fa has increased in recent decades.

In this study, we aim to answer the following questions:

(1) What are the extreme characteristics of accumulated rainfall induced by Typhoon In-fa?

(2) What factors contribute to the record-breaking accumulated rainfall of In-fa in eastern China?

(3) Has the return period of an extreme rainfall event like In-fa changed during the past decades?

2 Data & Methods

a) Observational data

Observed WNP TC best-track dataset and TC-induced rainfall in mainland China are obtained from the TC database developed by the Shanghai Typhoon Institute (STI), CMA (Lu et al., 2021; Ying et al., 2014). The database records all TCs that have passed through the WNP and South China Sea since 1949 and is updated annually, providing useful information for understanding climate impacts of WNP TCs.

b) Reanalysis data

- Six-hourly 500-hPa geopotential height, and zonal and meridional winds derived from the Japanese 55-year Reanalysis Project (JRA55; Kobayashi et al., 2015)
- Hourly specific humidity, surface pressure, zonal and meridional winds derived from the latest ERA5 reanalysis dataset produced by the European Centre for Medium-Range Weather Forecast (ECMWF; Hersbach et al., 2020)

c) Method to quantify extreme characteristics (Generalized extreme value; GEV)

The GEV distribution is only conducted at the stations that have been affected by TC rainfall for more than 5 years during the period of 1980–2019. Three parameters for the GEV distribution, including location parameter μ, scale parameter σ and shape parameter ξ, are estimated using the method of Maximum-Likelihood Estimation. Then, the probability (PFD; $f(x)$) calculated as follows

$$f(x) = \frac{1}{\sigma}[1+\xi(\frac{x-\mu}{\sigma})]^{-(\xi+1)/\xi} \cdot e^{-[1+\xi(\frac{x-\mu}{\sigma})]^{-1/\xi}}$$

3 Results

3.1 Extreme characteristics of In-fa's accumulated rainfall

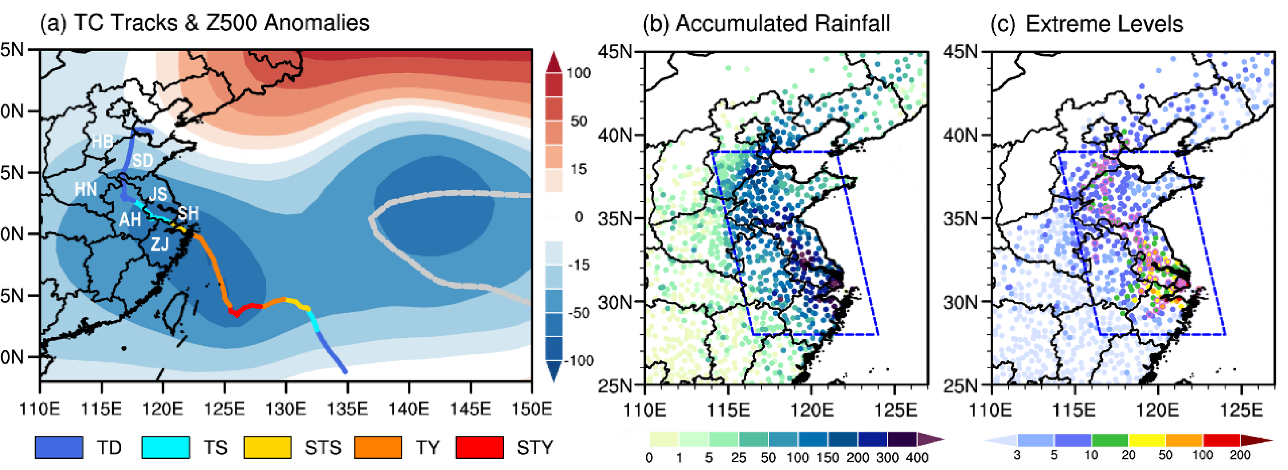


Fig. 1. (a) Observed 6-hourly track of Typhoon In-fa from 1200 UTC 16th to 0000 UTC 31st July 2021. Intensity changes are shown with different colors (dark blue, blue, yellow, orange and red denote tropical depression, tropical storm, strong tropical storm, typhoon and strong typhoon, respectively). Shadings denote the JRA55 background 500hPa geopotential height anomalies (units: m) during the 22nd-31st July 2021, relative to the 1980-2019 climatological mean. Grey dashed line denotes the climatological WNP subtropical high. (b) Accumulated rainfall produced by In-fa at surface stations from 22nd to 31st July 2021 (units: mm). (c) Return periods of In-fa's accumulated rainfall at each station. Light blue, slate blue, green, yellow, orange, red and dark red dots denote stations exceeding the 3-, 5-, 10-, 20-, 50-, 100- and 200-year return values, respectively. Orchid circles denote stations exceeding local maximum values in 1980-2019. Blue parallelograms in (b) and (c) denote the eastern China region.

3.2 Extreme characteristics of In-fa's rain rate & duration time

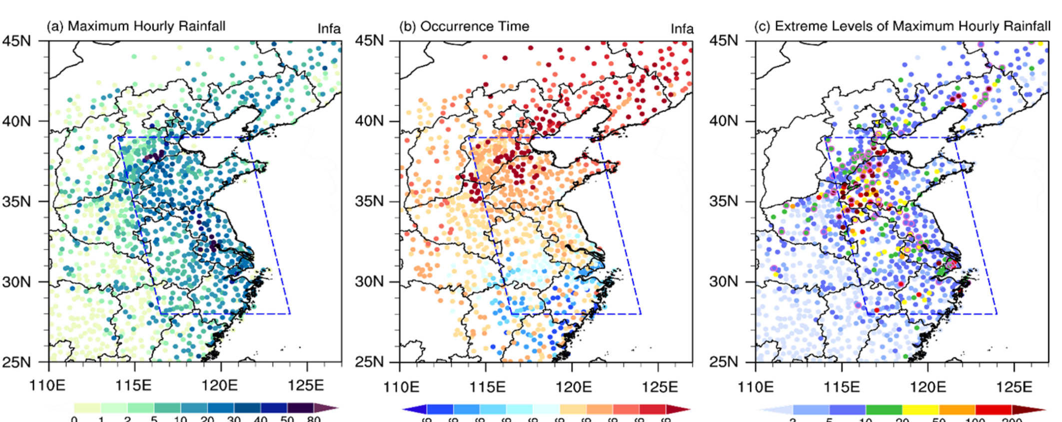


Fig. 2. Rain Rate: (a) Maximum hourly rainfall produced by In-fa observed at surface stations from 22nd to 31st July 2021 (units: mm). (b) Occurrence time of maximum hourly rainfall at each station. (c) Return periods of In-fa's maximum hourly rainfall at each station.

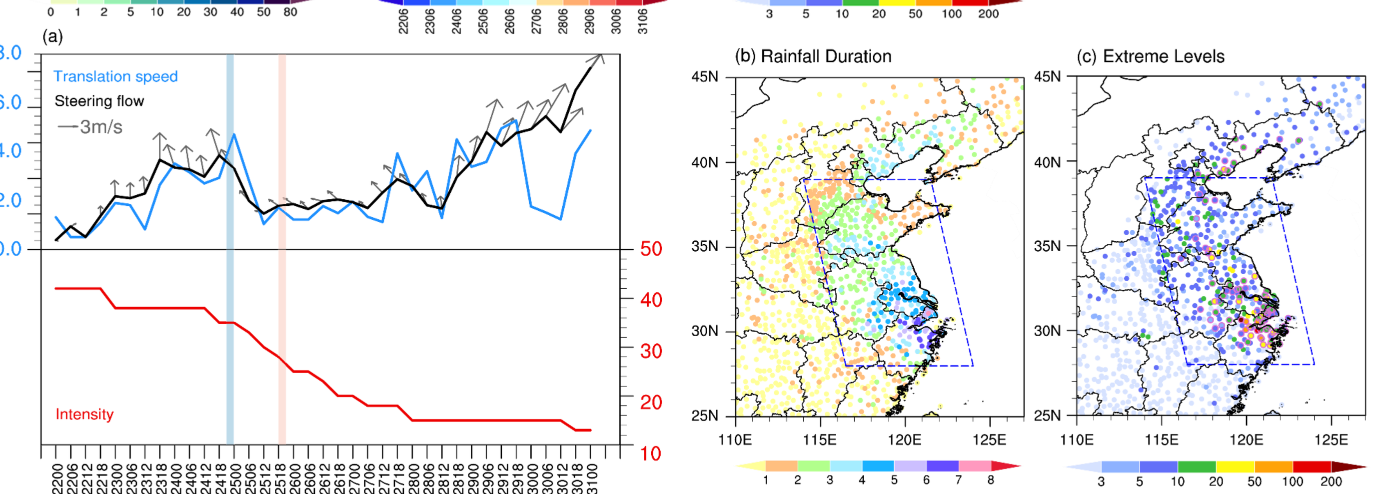
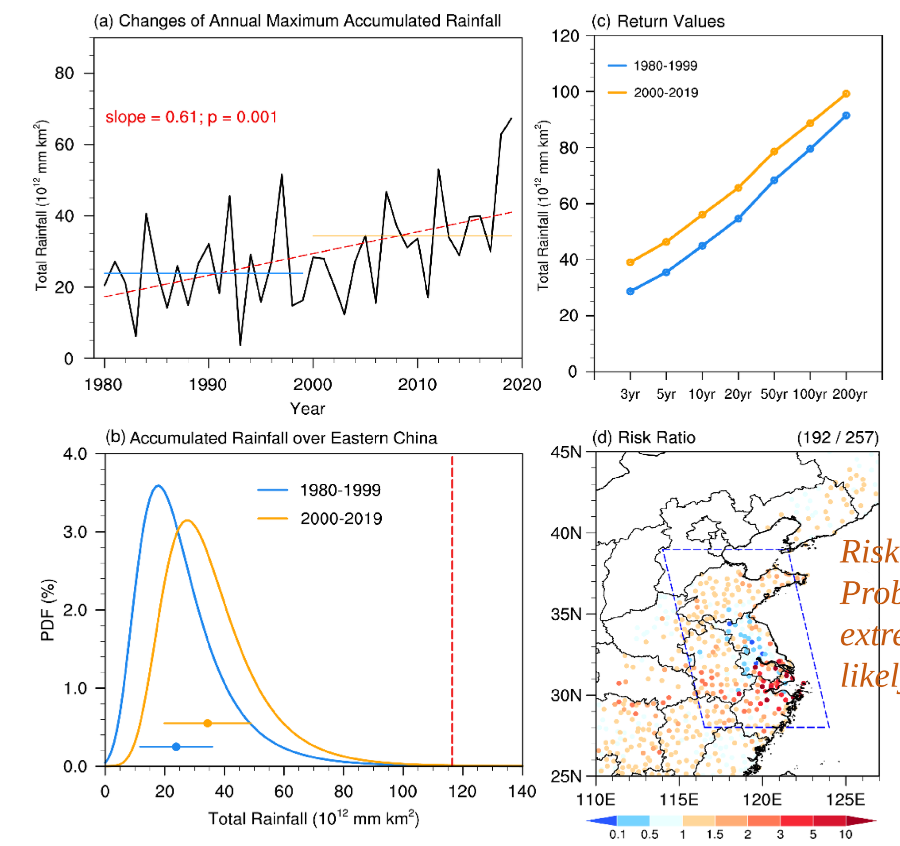


Fig. 3. Duration: (a) Variations of In-fa's translation speed (blue line) and maximum wind velocity near the TC center (red line), along with the intensity (black line) and direction (vectors) of steering flow derived from the JRA55 reanalysis data. Units: m/s. Blue and pink vertical lines denote the first and second landfall time of Typhoon In-fa.
(b) Duration of rainfall produced by In-fa at surface stations (units: day). (c) Return periods of In-fa's rainfall duration at each station. Orchid circles denote stations where rainfall duration induced by In-fa exceeding local longest TC rainfall duration in 1980–2019.

3.3 Growing threat of extreme rainfall accumulations in eastern China

Fig. 4. (a) Changes of annual-maximum rainfall accumulation over the eastern China during 1980–2019. The blue and brown horizontal lines denote the average values for the period of 1980–1999 and 2000–2019, respectively. (b) PDF of annual maximum TC rainfall accumulations in the eastern China during 1980–1999 (blue) and 2000–2019 (brown). (c) The 3-, 5-, 10-, 20-, 50-, 100- and 200-year return values of total rainfall accumulations over the eastern China for the two periods. (d) Risk ratio of extreme TC-induced accumulated rainfall at each station.



Risk ratio > 1.0: Probability of In-fa's extreme rainfall has likely increased.

4 Conclusions

a) Typhoon In-fa not only produces record-breaking rainfall accumulations at individual surface stations, but generates unprecedent rainfall amounts for the whole area of eastern China. Quantitatively, 2, 4, 11, 24 and 55 stations are exposed to once in 200-, 100-, 50-, 20- and 10-year extreme TC rainfall accumulations, respectively, and total rainfall at 75 stations reaches a record high since 1980. Overall, the return period is up to ~481 years for the total rainfall amount accumulated in eastern China during the 1980–2019 baseline.

b) The extremely long rainfall duration is identified as key to the torrential rains in the Yangtze River Delta before In-fa changes its direction of movement from northwestward to northeastward, while the extreme rain rate plays a dominant role in the northern areas afterwards.

c) Probabilities of occurrence of such an unprecedented TC rainfall event have increased in most (~75%) of the eastern China during the period of 2000–2019 compared with those during 1980–1999. Our study highlights the likely increase in risk of extreme TC-induced rainfall accumulations which should be considered in disaster risk mitigation.

5 References

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