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EDITED AND REVIEWED BY
Yuqing Wang,
University of Hawaii at Manoa,
United States

*CORRESPONDENCE
Xiefei Zhi,
xf_zhi@163.com

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Editorial: AI-based prediction of high-impact weather and climate extremes under global warming: A perspective from the large-scale circulations and teleconnections

Xiefei Zhi[1]* and Jingyu Wang[2]

[1]Key Laboratory of Meteorological Disaster, Ministry of Education (KLME), Nanjing University of Information Science and Technology, Nanjing, China, [2]National Institute of Education, Nanyang Technological University, Singapore, Singapore

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Editorial on the Research Topic
AI-based prediction of high-impact weather and climate extremes under global warming: a perspective from the large-scale circulations and teleconnections

2021 has proven to be a tough year for the entire human beings on the planet. With the COVID-19 pandemic raging on, various record-breaking weather and climate extremes also swept through many countries of the world. In February, severe winter storms caused the most expensive power crisis in Texas's history, affecting 4.5 million homes with more than 200 people killed. In June, a record-breaking heatwave scorched the Pacific Northwest United States and Canada, which led to the death toll exceeding 1,400 people. A few weeks later, Germany and China experienced record-breaking rainfall and flooding. In July 2021, severe flooding occurred across Europe due to dangerous thunderstorms and rain. Germany experienced the 100-year flood with 173 deaths. During the period from July 17 to 21, 2021, Zhengzhou in Henan Province, China, was smashed by record rainstorms, causing severe waterlogging, traffic interruptions, and power outages. The local government has upgraded the flooding emergency response level to its highest, and 380 people were killed during the extraordinary heavy rainstorm event. In December, a series of devastating tornadoes attacked nine states in the United States, producing severe to catastrophic damage in many towns with more than 100 deaths and numerous injuries. Following that, the super typhoon Rai displaced hundreds of thousands of people with more than 400 deaths.

The frequent outbreaks of high-impact weather and climate extremes have raised the global concern that the current state-of-the-art physics-based numerical models may not be able to make skillful prediction and projection of future climate, especially for the climate anomalies and extremes that bring tremendous natural hazards. The thriving development of Artificial Intelligence (AI) has greatly advanced weather forecasting, climate monitoring and prediction through the reduction of human effort and more efficient use of computing power. However, the thorough understanding and representation of physical processes that modulate the weather and climate extremes are still lacking. Therefore, this Research Topic has been convened, hoping to shed light on the AI applications in better prediction of high-impact weather and climate extremes. A total of 20 manuscripts were received for this Research Topic, covering a wide range of frontiers in AI applications.

- Understanding precipitation anomalies

Wang et al. investigated the impact of rapid urbanization on the amount, frequency, and intensity of extreme summer precipitation over Sichuan-Chongqing area of China, and concluded that the increase in urban-scale land surface temperature, moist convection, and changes in wind speeds were essential drivers that led to the intensification of extreme precipitation.

By using the empirical orthogonal function (EOF), Xia et al. revealed the linkage between preceding August Asian-Pacific Oscillation (APO) and September precipitation over Southeast China (SC). In addition to the sea surface temperature (SST) that had been widely recognized as a precursory factor for predicting precipitation variation over SC, the preceding temperature anomalies at the middle and upper troposphere also played noteworthy roles.

In a case study conducted by Ji L. et al., the high-resolution ensemble prediction system COSMO (Consortium for Small Scale) EPS was used to predict the extreme rainstorm that occurred from 27 to 31 August 2018 in Guangdong Province, China. Although the coverage and intensity of the rainstorm in eastern Guangdong were not realistically predicted, COSMO EPS still exhibited relatively higher performance than some other models by object-based spatial evaluations.

Chen et al. used FC-ZSM method to conduct the spatiotemporal downscaling of radar-based precipitation estimate. They borrowed the concept of image super-resolution in computer vision and adapted it to radar meteorology, and successfully solved the precipitation downscaling problem by deep learning.

Zang et al. diagnosed the interdecadal increase in summertime extreme precipitation over East China, and found the sensible heat changes in the Tibetan Plateau in spring and the tropical SST zonal gradient jointly affected summer extreme precipitation over East China, which subsequently led to the interdecadal increase of extreme precipitation in the late 1990s.

Based on the observational precipitation data and the ERA5 reanalysis datasets, the short-term forecasts of the warm-sector heavy rainfall with warm-type shear line (WRWS) events over the coastal areas of the Yangtze–Huaihe River (YHR) were investigated in the regional operational model Precision Weather Analysis and Forecasting System (PWAFS) by Zhang L. et al.

Lyu et al. explored the subseasonal predictability of precipitation by comparing ECMWF and CMA models. Results show ECMWF had superior forecast performance than CMA. Although both models well captured ENSO signals, their forecast of BSISO related precipitation anomalies decreased with growing lead times, which highlighted an opportunity window for further model improvement.

The application of deep learning in probabilistic precipitation forecasting was investigated by Ji et al. By comparing the forecasting results obtained from a convolutional neural network (CNN) model with the conventional ensemble prediction products, the authors showed deep-learning CNN can serve as a promising approach to the statistical post-processing of probabilistic precipitation forecasting.

Zhang et al. revisited the different responses of the following Indian summer monsoon rainfall to the diversity of El Niño events. They suggested that, in addition to the key role of the warming of the northern Indian Ocean SST, cooling of the SST over the western tropical Indian Ocean during central Pacific El Niño events should be considered carefully in understanding the El Niño–Indian summer monsoon rainfall relationship.

To answer why SC was extremely wet during January–February 2022 despite La Niña, Ma et al. employed the observational and reanalysis data to explore the main driver of the SC precipitation anomaly. They found that two factors, namely 1) the wave train propagating along the South Asian jet that intensifies the India–Burma trough and 2) the positive geopotential height anomaly over eastern Siberia that prompts southward cold air intrusion and convergence over the SC region, can account for approximately 75% of the observed SC precipitation anomaly in 2022 winter.

Xiao et al. assessed the impact of persistent anomalous precipitation in Southwest China caused by low-frequency atmospheric disturbances in different latitudes. The configuration relationship of low-frequency systems in three-dimensional space and its influence on the persistent extreme precipitation in southwest China were shown, which provided a theoretical basis for the forecast of the extended period of persistent abnormal precipitation in southwest China.

Chen et al. investigated the response of North Pacific storm tracks to spatial multiscale (large-scale and mesoscale) SST anomalies (SSTAs) in stable state of Kuroshio Extension (KE-related SSTAs) system. The results showed that storm tracks were significantly strengthened with local enhanced rainfall in the central North Pacific and near the west coast of the North American continent in response to KE-related large-scale SSTAs, while they shifted to the north and were significantly strengthened in the central-eastern North Pacific and Gulf of Alaska with remote impact on precipitation along west coast of North America continent in response to KE-related mesoscale SSTAs.

Jin et al. answered the question 'to what extent horizontal resolution improves the simulation of precipitation in CMIP6 HighResMIP models over Southwest China?' Based on their analyses, the atmospheric circulation and moisture conditions could be simulated more realistically in climate models with a finer resolution, further improving precipitation simulation performance.

- Understanding temperature anomalies

Li et al. made the future projection of extreme temperature events in Southwest China using CMIP6 (Coupled Model Intercomparison Project Phase 6) outputs under various SSP (Shared Socio-economic Pathway) scenarios, and unraveled 1) an overall warming trend, 2) a decreasing trend in diurnal temperature range, and 3) a decreasing trend in extreme cold events.

Focusing on the 2-m surface temperature forecasting over Xinjiang, Aihaiti et al. demonstrated that multi-model ensemble based on Bayesian model averaging (BMA) can best match the observation regarding the spatial distribution, providing a feasible method to correct the accuracy of the 2-m temperature forecast in Xinjiang.

Using the canonical zonal deviation algorithm, Zhang Y. et al. characterized the flows around the Tibetan Plateau (FAT) and linked the FAT anomalies to the winter climate extreme events in China.

To explore the climatic responses to short-lived climate pollutants (SLCPs) changes from the pre-industrial era to the present, Xie et al. conducted a simulation study using an online aerosol–climate model.

Their results suggested that SLCPs-induced warming should not be underestimated, which was equivalent to half of the global warming effect of CO_2, even much larger in the regions with more coal consuming (e.g., China).

- Understanding tropical cyclones

Wang Z. et al. analyzed the existing problems in forecasting tropical cyclones (TCs), provided a comprehensive review of current AI-based application in TC forecasting, and discussed the future challenges and further development directions of such applications.

By developing a typhoon vortex identification model based on deep image target detection, Zhou et al. demonstrated the potential of AI-based image recognition in improving the operational techniques for typhoon monitoring and forecasting.

- Understanding wind hazards

By using an AI-based clustering method, Zhao et al. characterized the large-scale atmospheric circulation patterns conducive to severe spring and winter wind events over Beijing in China. The results found in that study with the usage of an AI-based algorithm will benefit the operational forecasting for extreme wind events over Beijing.

Author contributions

XZ and JW contributed to conception and design of the manuscript, All authors contributed to manuscript revision, read, and approved the submitted version. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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