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Short Communication

Complex terrain causes global model prediction biases of 21.7 Zhengzhou extreme precipitation

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Extreme precipitation is one of the most severe weather of high socio-economic impact. In the warming climate, extreme precipitation has been shown to increase in both intensity and frequency over China and over the world [1–3]. On 20 July 2021, an extreme precipitation event hit Zhengzhou, a highly urbanized megacity with a dense population of 12.8 million in North China. The hourly rainfall rate was up to 201.9 mm, which broke the hourly record in mainland China. This unprecedented rainfall event caused severe flooding in Zhengzhou, resulting in 380 casualties and huge economic losses of over 100 billion RMB [4]. While many advances have been made in the understanding and numerical prediction of extreme precipitation in recent decades, accurately predicting the location and intensity of extreme precipitation events remains challenging [5]. Understanding the reasons for poor predictive skills of such events is critical for improving numerical weather prediction (NWP) models and quantitative precipitation forecasting (QPFs) [6].

Leading global NWP models significantly underpredicted the extreme precipitation near Zhengzhou. The models of the European Centre for Medium-Range Weather Forecasts (ECMWF) and of the USA predicted the maximum 12 h precipitation as 120 and 110 mm, respectively, versus the observed 548 mm (Fig. 1a–c). More importantly, the models wrongly predicted the rainfall center to occur over the Taihang Mountains rather than in Zhengzhou, which hindered the disaster risk assessment and management of the government. Our earlier study [7] found that the mountain-blocking effects on the air flows played important roles in this

extreme precipitation event. Inadequate treatment of the orography and its effects, including those of the orographically-forced gravity waves, could be an important reason for such forecast biases in global NWP models. We show in this study that the parameterized orographic gravity wave drag (OGWD) due to unresolved complex terrain [8] played an important role in forecasting the location and intensity of the extreme precipitation in Zhengzhou, China.

We produce three forecasts using the Model for Prediction Across Scales (MPAS) [9] covering the globe, with a horizontal resolution of 15 km, which is typical of mainstream global operational NWP models. The OGWD parameterization is turned off in the OGWD_OFF experiment but switched on in OGWD_ON. The third experiment OGWD_HALF is similar to OGWD_ON but with the magnitude of parameterized OGWD halved. This is to account for the uncertainties in the parameterization of OGWD [8,10]. Other model configurations can be found in [Supplementary material](#) (Text S1 online).

The MPAS model can well reproduce the amount of the 12-h rainfall (i.e., 604.8 mm) from 0000 UTC to 1200 UTC of 20 July 2021 in the OGWD_ON experiment (Fig. 1d), which is in good agreement with observation (548.1 mm). This 12-h rainfall is of particular interest because it accounts for approximately 88% of the 24-h rainfall. The location of the rainfall center is also captured which is located to the west of Zhengzhou City by ~80 km. In OGWD_HALF (Fig. 1e), the intensity of the extreme precipitation decreases to 368.4 mm, significantly less than the observation. Furthermore, the rainfall area tends to shift northwestward. The 50-mm rainband is oriented in the southeast-northwest direction, i.e., normal to the Taihang Mountains, which is also the case of

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