Regional Model Simulation of the Ice Disaster in Hunan Power Grid During January 2022: Effect of Nanling Mountains on Precipitation

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Abstract. Hunan Province is one of the regions that are mostly affected by the freezing rain and ice disaster in China, because its unique topography is conducive to the southward intrusion of cold air from the north. This hazard can cause the line icing, threaten the operation of power grid and bring great socioeconomic losses. Understanding the mechanisms related to the topography effect on precipitation near Hunan is important to improve the prediction and prevention for the ice disaster during winter. In this study, we focus on an icing event at the beginning of 2022. The frontal precipitation in central Hunan features a southwest-northeast band distribution in this event, which is caused by the strong convergence from northern cold air and southwesterly flows in the subtropics. The numerical simulations are further conducted based on WRF model to test the effect of topography near Nanling Mountains on the local precipitation in Hunan. The results show that the reduction or elimination of the Nanling Mountains has limited impact on the overall distribution and amplitude of precipitation near Hunan in this event, but the latitudinal location of precipitation band and its western range slightly change. These changes might be related to the changed local convergence caused by the enhanced southward intrusion of cold air without the blocking of the Nanling Mountains.

Keywords: Power line icing · Topography · Numerical simulation

1 Introduction

The southern region of China often suffers from persistent freezing rain events in winter, which can cause the severe icing disaster of transmission lines and significantly threaten the operation of power grid. For example, during January and February in 2008, a severe and persistent ice disaster occurred in many provinces of southern China. The thick ice accumulated on power lines led to the collapse of electricity transmission towers and caused great socioeconomic losses [1–3]. Therefore, it is significantly important to understand the factors modulating the local precipitation and temperature and mechanisms for their evolutions during winter, which can improve the ability of the power grid to predict the ice disaster and prevent or mitigate its potential damage.

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There are many previous studies that investigated the favorable conditions and formation mechanisms for the freezing rain events [4–8]. The freezing rain generally occurs when the surface temperature below 0 degrees Celsius, and is typically associated with the southward movement of the northern cold air. Hunan Province is one of the regions that are mostly affected by the icing hazard in China, because it has a unique topographic distribution, which is surrounded by multiple mountains in the east, south and west, while the north is flat and has no barrier for the cold surge from the north. Such condition is very conducive to the southward movement of cold air and the consequent formation of freezing rain. Some authors explored the effect of topography near Hunan Province on the freezing rain [9–11], and indicated that the topography (e.g., the Nanling Mountains) can block the low-level flows and influence the local distribution of surface temperature, water vapor and characteristics of inversion layer, and thus change the precipitation feature. Understanding the role of topography in winter precipitation and temperature provides helpful insights for the mechanism of freezing rain to improve the prediction ability.

At the beginning of 2022, state grid of Hunan Province experienced several icing events due to the northern cold air activity. The present study will focus on the power line icing event during 27–29 January in Hunan Province. As shown in Fig. 1a, the icing is mainly distributed at the western and northwestern part of Hunan. Figures 1b and 1c show the mean precipitation and temperature derived from multi-stations observation during this period, respectively. The precipitation is mainly located in central Hunan with a southwest-northeast band distribution, and the precipitation and low temperature at western part of Hunan together contribute to the icing there. In this study we will show the synoptic background for this event and test the effect of Nanling Mountains (the topography in southern part of Hunan) on local precipitation using the numerical model simulation, to provide insights for the icing process related to the orographic precipitation.

The rest of this paper is organized as follows: Sect. 2 describes the model setup and datasets. Section 3 examines the large-scale circulation background for this icing event. Section 4 compares the results of observation and control experiment. Section 5 shows the differences in sensitivity experiments and discusses the possible effect of Nanling Mountains. A summary is given in Sect. 6.

2 Model and Datasets

2.1 Model

The numerical simulation in this study is based on the Weather Research and Forecasting (WRF) Model version 3.8.1 [12], which is broadly used to investigate the regional atmospheric events and related mechanisms. We used two computational domains (D01 and D02) in the model with the two-way nesting technique (Fig. 2), and the horizontal grid spacing is 9 and 3 km, respectively. D01 covers China and surrounding large-scale Asian region in the low and mid latitudes, which can capture both the cold air from Siberia and warm moist air from the tropics. D02 (red box in Fig. 2a) is located over the small region near Hunan Province. The model has 51 vertical levels with the top at 10 hPa. The Noah land surface physics scheme is used to compute the diurnal cycle of surface temperature and heat fluxes. The Rapid Radiative Transfer Model (RRTM) and the Dudhia scheme are used for longwave and shortwave radiation parameterization, respectively. The Thompson scheme is used for microphysics, and the Yonsei University (YSU) PBL scheme is used for boundary processes. No cumulus parameterization is used for both domains.

The control experiment is initialized at 1200 UTC 23 January 2022 and integrated to 1200 UTC 31 January 2022. The initial and boundary conditions for the model are obtained from 6-hourly 1×1 FNL reanalysis data from National Centers for Environmental Prediction (NCEP). To test the effect of Nanling Mountains, we set the terrain height in this region (red box in Fig. 2b) as half of the original values in Half-Terrain experiment, and set the terrain height to 10 m in No-Terrain experiment.

2.2 Datasets

The NCEP-FNL reanalysis is used to drive the WRF model and provide the large-scale circulation fields including geopotential, wind, and water vapor for this event. The observed line icing data are derived from the intelligent analysis and control platform for power grid operation inspection of Hunan to show the ice disaster in this event (as shown in Fig. 1a). The in-situ multi-station observation data from China Meteorological Administration (CMA) is used to show the precipitation and temperature in this event (as shown in Figs. 1b–c) and validate our model simulation.

3 Large-Scale Circulation Background

We first examine the large-scale circulation background for this precipitation event in Hunan. Figure 3 shows the large-scale geopotential height, wind and specific humidity at different pressure levels during this event. On 27 January (Fig. 3a), there is a pressure trough and ridge near Balkhash Lake (40–60°N, 60–80°E) at 500 hPa, leading the northern cold air to move southwards between them. In the subtropical region, there is a strong pressure trough at the Bay of Bengal. The southwesterly flows at the front of trough transport abundant low-level water vapor from the tropical ocean to Hunan. The northern cold air and southwestern warm moist air strongly converge in Southwest and Central China, and the evident west-east shear line at the north of Hunan can be found at 700 hPa. Therefore, the frontal precipitation develops in this region with the abundant low-level moisture. On 28 January (Fig. 3b), the trough and ridge systems in the midlatitudes propagate eastwards gradually, but the northerly cold air and southwesterly flow at 700 hPa remain active, so the quasi-stationary front in central and northern Hunan maintains for a long time, resulting in the persistent precipitation in this region. On 29 January (Fig. 3c), the northern trough and ridge systems continue to move eastwards and strengthen, which favors stronger southward intrusion of the mid-level cold air. Meanwhile, the pressure trough near the Bay of Bengal weakens and propagates into the Southeast Asian region, which leads to weaker southwestern flows and moisture near Hunan. Therefore, the precipitation in Hunan gradually decays and disappears during this period.

In general, the precipitation process in this event is due to the strong convergence from the northern cold air that moves southwards and the subtropical trough induced southwesterly flows, which is associated with a typical frontal genesis process. The maintenance of 700 hPa shear line and quasi-stationary front cause the persistent precipitation during this event, and the strong cold air from the north reduces the surface temperature in Hunan, which further favors the freezing rain and line icing.

4 Results in Control Experiment

Figure 4 shows the mean precipitation and surface air temperature from station observation and control experiment during this event, as well as their differences. The observational precipitation is mainly located at the center of Hunan with a southwest-northeast band distribution, due to the maintenance of the frontal system as mentioned above. The precipitation maximum is at the northeastern and western side of Hunan. The simulated precipitation is also characterized by the southwest-northeast distribution, with the maximum located at the central and northern Hunan. Figure 4c shows that the location of precipitation is broadly consistent between observation and simulation (the latter slightly shifts northward), but the amplitude of simulated precipitation is much stronger especially at northwestern side of Hunan. The surface air temperature features the southward intrusion of the northern cold air, and the northern and western parts of Hunan are primarily affected (Fig. 4d). The western part of Hunan was the main area suffering from the freezing rain and icing disaster in this event (Fig. 1a) because it was affected by both precipitation and low surface temperature. The model simulation broadly reproduces the activity of cold air and overall distribution of temperature, but with a greater north-south gradient of temperature at Hunan (Fig. 4f).

In general, the control experiment reasonably captures the distribution of precipitation and temperature, but has a much stronger amplitude of precipitation. The greater north-south gradient of temperature in the simulation might destabilize the vertical stratification and produce a stronger convergence of flows, and thus result in stronger frontal precipitation. One may note that the northwestern Hunan is characterized by stronger precipitation and lower temperature in the simulation, which might result in overestimated icing in the model at this region.

5 Results in Terrain Sensitivity Experiments

Figure 5 shows the mean precipitation results in Half-Terrain and No-Terrain experiments and their differences from control experiment. While the overall distribution and amplitude of precipitation in Half-Terrain are similar as control, some local differences still exist. The precipitation in Half-Terrain slightly shifts southward and extends broader at southwestern side, while the northern precipitation weakens (Fig. 5d). The precipitation in No-Terrain weakens in central and northern Hunan, and intensifies at southwestern part of the rain band (but weakens at the southern side, Fig. 5e). These changes in precipitation might cause decreased icing at north and increased icing at west of Hunan.

In general, the reduction or elimination of the Nanling topography has limited impact on the overall distribution and amplitude of Hunan precipitation in this event. This might be partly because the precipitation is mainly located in central and northern Hunan away from the Nanling Mountains, so the terrain has little influence on the upstream cold air activity and precipitation. However, there are still some local changes in precipitation in sensitivity experiments. When the Nanling topography is reduced or eliminated, the northern cold air moves southward more smoothly, and the local detouring flow around the terrain and small-scale convergence may disappear, which weakens the precipitation at the northern flank of terrain. On the other hand, part of the enhanced northerly flow moves westward at southern Hunan, which may influence the local convergence and divergence there, leading to the precipitation changes at the southwestern side of Hunan. The important effect of Nanling Mountains topography on the local flow convergence, location of quasi-stationary front is also indicated by previous studies [13], which may lead to variations of magnitude and distribution of freezing rain and ice disaster in Hunan.

6 Summary

In this study, we focus on the line icing event during 27–29 January 2022 in Hunan Province, and investigate the large-scale atmospheric background and conduct numerical simulations using WRF model to test the effect of Nanling Mountains on local precipitation. The main conclusions are as follows:

(1) The frontal precipitation is mainly located in central Hunan with a southwest-northeast band distribution, which is caused by the strong convergence from cold air induced by the northern trough and ridge systems and the southwesterly moist flows induced by the trough at the Bay of Bengal. The cold air moves southward and reduces the surface temperature in western part of Hunan, resulting in the freezing rain and line icing there.
(2) The control experiment reasonably captures the distribution of observed precipitation and temperature, but has a much stronger amplitude of precipitation. The greater north-south gradient of temperature in the simulation might contribute to the stronger flow convergence and frontal precipitation.
(3) The reduction or elimination of the Nanling topography has limited impact on the overall distribution and amplitude of Hunan precipitation in this event, but the latitudinal location of precipitation band and its western range slightly change. These changes might be related to the changed local convergence caused by the enhanced southward intrusion of cold air without the blocking of Nanling Mountains.

In this event, the location of precipitation is not exactly in the Nanling Mountains region, which might be a possible reason that the terrain has limited effect on the precipitation. Other icing cases in Hunan (e.g., at the beginning of 2022) will be further tested in the future to further understand the effect of Nanling Mountains on precipitation, which helps improve the prediction of icing disaster and prevention for it.

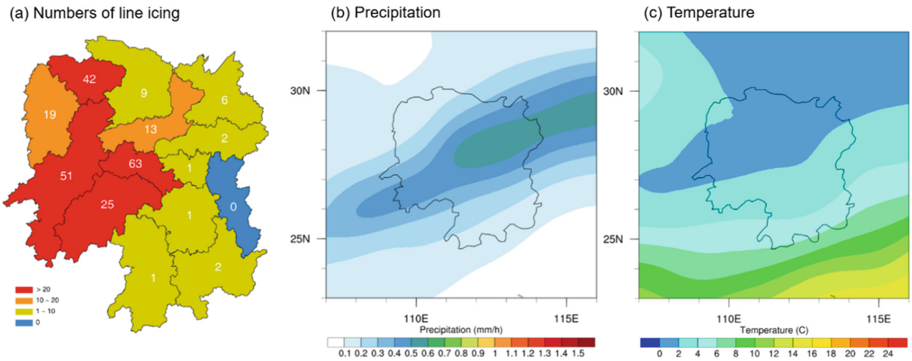

Fig. 1. The observed (a) numbers of line icing, (b) precipitation (mm/h) and (c) surface air temperature (C°) near Hunan Province during 27–29 January of 2022.

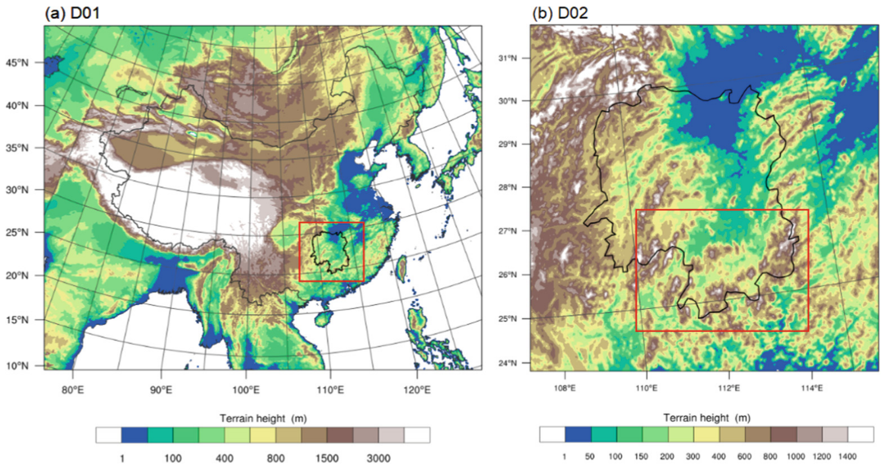

Fig. 2. (a) The WRF 9-km domain D01 and (b) 3-km domain D02 with terrain height (shading; m). Red box in (a) indicates D02, while in (b) indicates the Nanling mountain region where the terrain sensitivity experiments are performed. (Color figure online)

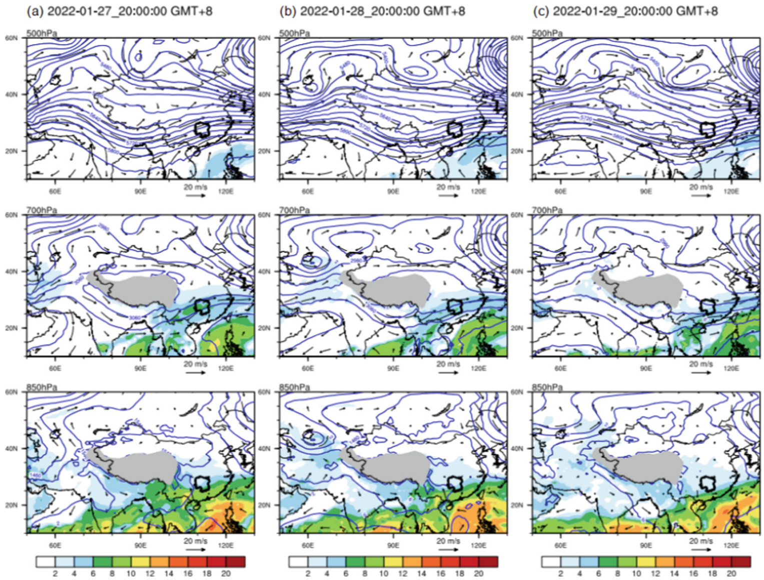

Fig. 3. (a) The large-scale background of geopotential height (contours; gpm), specific humidity (shading; g/kg), and wind (vectors; m/s) at 500-hPa (top), 700-hPa (middle) and 850-hPa (bottom) at 2000 GMT+8 on 27 January 2022. (b) and (c) are the same as in (a), but for results at 2000 GMT+8 on 28 and 29 January 2022, respectively.

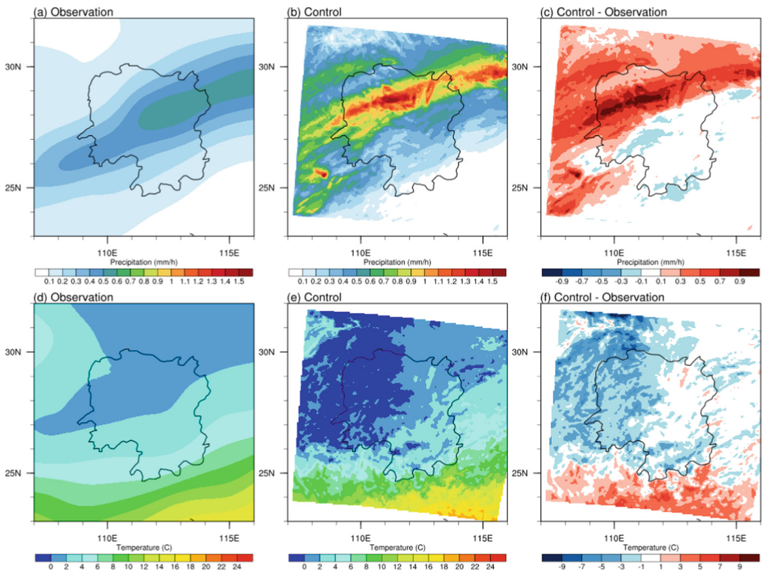

Fig. 4. Mean precipitation (mm/h) in the (a) observation, (b) control experiment and (c) their differences near Hunan Province during 27–29 January of 2022. (d)–(f) are the same as in (a)–(c), but for mean surface air temperature (C°) results.

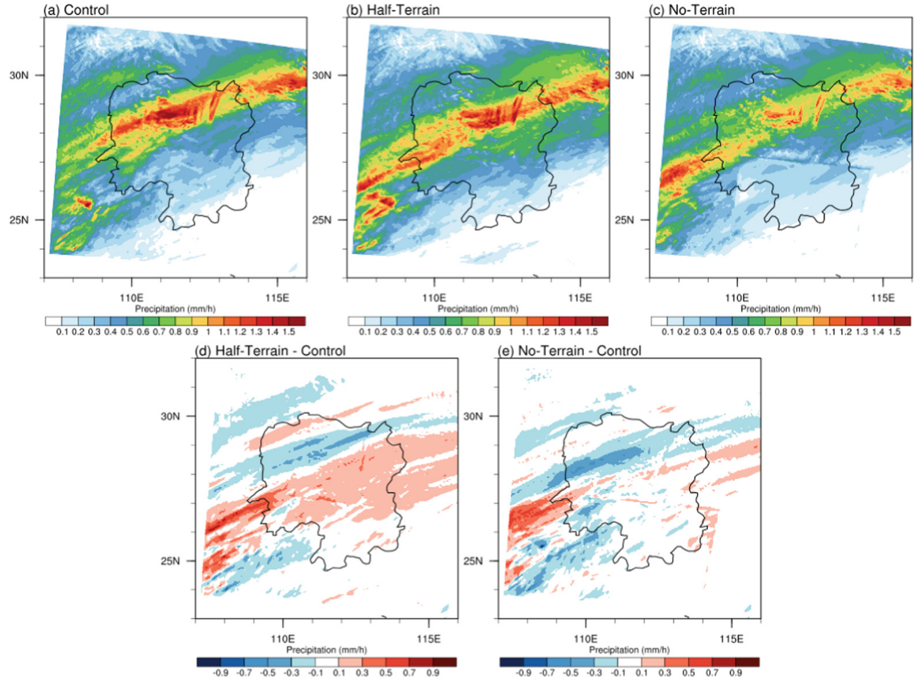

Fig. 5. Mean precipitation (mm/h) in the (a) control experiment, (b) Half-Terrain experiment and (c) No-Terrain experiment near Hunan Province during 27–29 January of 2022. Differences of precipitation between (d) Half-Terrain and control, (e) No-Terrain and control.

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