High-Resolution Numerical Simulation of Wintertime Orographic Precipitation: Representation of Snowfall Characteristics

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1. Introduction

In winter, surface avalanches often occur when extratropical cyclones moving along the south coast of Japan bring short-duration heavy snowfalls in mountain regions. Araki (2018) investigated the snowfall characteristics and meteorological conditions of a surface avalanche event in Nasu, Tochigi Prefecture, Japan on 27 March 2017. From the results of numerical simulation by the Japan Meteorological Agency (JMA) Non-Hydrostatic Model (NHM) with a horizontal grid spacing of 250 m, it is indicated that low-level supercooled water clouds were formed by orographically forced updrafts in mountainous regions in Nasu as moist northerly and easterly flows intensified due to the cyclone's approach. They suggested that localized snowfall intensification and short-duration heavy snowfalls were produced by the Seeder-Feeder mechanism associated with the low-level clouds and snow from the upper clouds of the cyclone. To forecast the potential of surface avalanches with leading time of 0.5-1 days, it is important to understand representations of the snowfall intensification by numerical weather models with different horizontal resolutions. In this study, we performed a case study on this surface avalanche event and examined model representations of snowfall characteristics at the horizontal resolutions from 250 m to 5 km.

2. Model settings

Numerical simulations were performed by the NHM with a domain covering Nasu and a horizontal grid spacing of 5 km (5km-NHM), 2 km (2km-NHM), 1 km, 500 m (500m-NHM), 250 m (250m-NHM). Detail of the description of each model is shown in Table 1. For the experiments with horizontal resolution of 1 km, both Mellor-Yamada-Nakanishi-Niino (1km-NHM) and Deardorff schemes (1kmD-NHM) were used for the turbulence closure scheme. The initial and boundary conditions were provided from the JMA mesoscale analysis data for 5km-, 2km-, 1km-, and 1kmD-NHM, and the results of 1km-NHM were used for the initial and boundary conditions in 500m- and 250m-NHM. In all experiments, the results were output at 10-minute intervals, and convection parameterization scheme was not used. Other setups were the same as those used by Saito et al. (2006).

Table 1. Description of the models.

	5km-NHM	2km-NHM	1km-NHM	1kmD-NHM	500m-NHM	250m-NHM
Horizontal grid spacing (m)	5000	2000	1000		500	250
Dimensions (x, y, z)	300×300×50	750×750×50	1500×1500×50		500×500×50	1000×1000×50
Integration time (JST)	12 JST on 26 - 15 JST on 27				21 JST on 26 - 15 JST on 27	
Turbulence closure scheme	Nakanishi and Niino (2004)			Deardorff (1980)		
Cloud microphysics scheme	Bulk cloud microphysics scheme with 2-moment cloud ice, snow, and graupel					

3. Representations of snowfall characteristics

Spatiotemporal variations of the cyclone and precipitation distributions were generally well reproduced by 5km-, 2km-, 1km-, and 1kmD-NHM (not shown), although the cyclone developed excessively in 1kmD- and 5km-NHM. Figure 1 shows elevations in each model and horizontal distributions of accumulated precipitation by snow from 12 JST (JST=UTC+9 h) on 26 to 15 JST on 27 March 2017 in the Mount Nasu region including Mt. Chausu, where the surface avalanche occurred in the southeastern side of the top. The terrain of the Mount Nasu was represented in all models, but the 5km-NHM did not resolve Mt. Chausu sufficiently. In the others, the detailed terrain was better represented as a smaller horizontal grid spacing. Although each model reproduced the localized heavy snowfall in the northeastern side of the Mount Nasu, only 500m- and 250m-NHM successfully reproduced the localized snowfall intensification close to the top of Mt. Chausu. Precipitation amount simulated by 1kmD-NHM was obviously larger than the others.

To verify the simulation results, precipitation amount at the JMA surface observation station of Nasu-kogen was compared with the results of simulations (Fig. 2). At the location of Nasu-kogen, precipitation type was almost all snow in any experiments. Although 1kmD- and 5km-NHM overestimated, the precipitation amount reproduced by the others agreed with the observation.

To investigate the differences of representation of snowfall characteristics in each model, vertical profiles averaged from 06 to 09 JST on 27 at the point of the windward (northeastern) side of the Mount Nasu were examined (Fig. 3). Firstly, updrafts at the altitude from 4 to 8 km in 1kmD- and 5km-NHM were greater than the others (Fig. 3a). Water vapor flux at the altitude from 3 to 4.5 km and mixing ratio of snow at any altitude in these experiments were also greater than the others (Fig. 3b). It is indicated that these differences were caused by representation of the cyclone development, resulting in overestimated snowfall amounts in 1kmD- and 5km-NHM.

Orographically forced updraft at the altitude from 1 to 2 km tended to get stronger as smaller horizontal grid spacing of models, and the representation of supercooled water cloud formed by the updrafts had the same characteristics (Fig. 3c). The low-level snowfall intensification at the altitude below 2 km were reproduced in 2km-, 1km-, 500m, and 250m-NHM (Fig. 3b), and the results of 500m- and 250m-NHM showed almost the same representation in the mixing ratio of cloud water in addition to snow.

These results indicate that model with a horizontal grid spacing equal to and smaller than 2 km is required for the representation of the low-level snowfall intensification associated with the orographic cloud seeding, although the localized snowfall distribution was also simulated in 5km-NHM. In this case, it is indicated that the formation of a weak layer in snowpacks associated with the difference of snowcrystal types was important for the occurrence of the surface avalanche in addition to short-duration heavy snowfalls (Araki, 2018). Therefore, the model with a horizontal grid spacing equal to and smaller than 500 m, which can explicitly represent the low-level snowfall intensification causing the modification of snowcrystal types, would be useful for the diagnosis of the potential of surface avalanches.

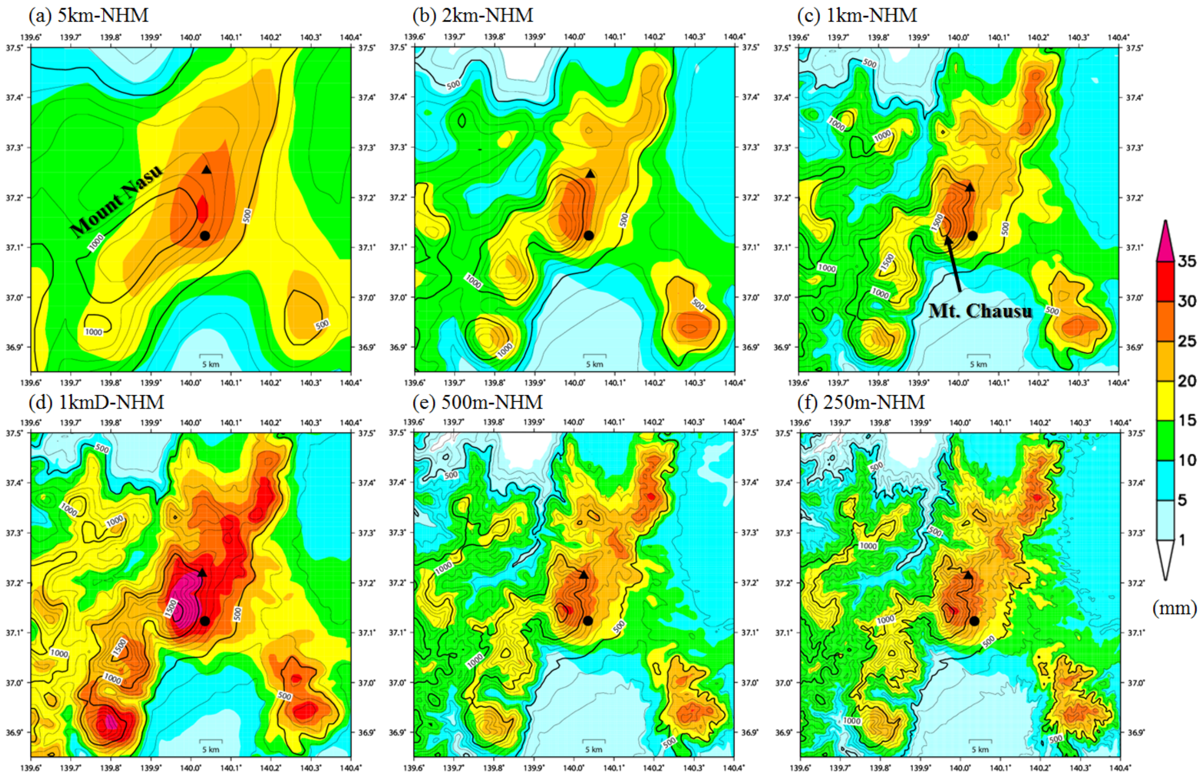

Figure 1. Horizontal distributions of accumulated precipitation of snow from 15 UTC on 26 to 06 UTC on 27 March 2017. Contour lines show elevations in each model. Black circle and triangle respectively indicate the location of the Nasu-kogen station and the analyzed point in Fig. 3.

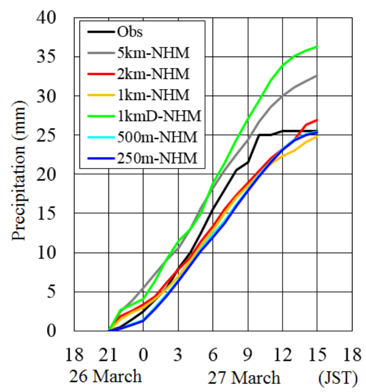

Figure 2. Precipitation amount derived from observation in Nasu-kogen (Obs) and each model.

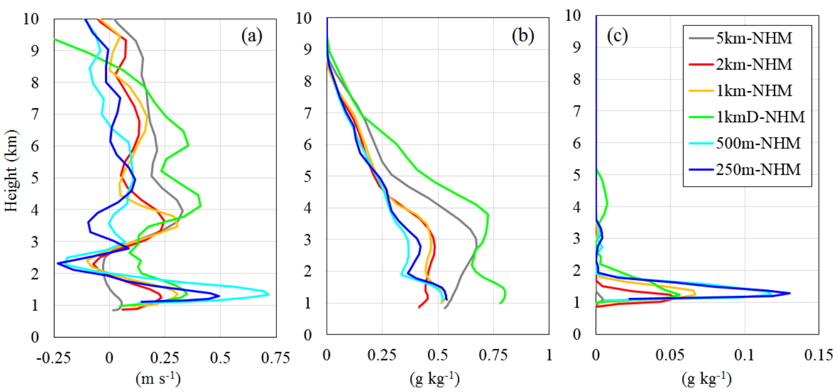

Figure 3. Profiles of (a) vertical velocity, (b) mixing ratio of snow, (c) mixing ratio of cloud water averaged from 06 to 09 JST on 27 at the windward (northeastern) side of Mt. Chausu (triangle in Fig. 1).

References:

Araki, K., 2018: Snowfall characteristics of heavy snowfall events associated with cyclones causing surface avalanche in Nasu, Japan. *Seppyo*, **80**, 131–147, (in Japanese with English abstract).