Numerical weather prediction experiment in collaboration with research activities in glaciology and snow disaster prevention

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1. Introduction

Falling snow has a large effect on water and heat transport in the atmosphere through gravitational sedimentation and diabatic processes. It also considerably affects civic life and economic activities through its accumulation on the ground. Snowpack conditions directly determine the temporal and spatial distribution of snow cover, the run-off of meltwater into river basins, snow loading on roofs, the occurrence of avalanches, and other factors. In tern, snowpack conditions are closely related to the meteorological factors such as the type of snow particles, air temperature, wind speed, and so on. However, our understanding of the link between falling and fallen snow is still insufficient for precisely predicting the state of the snowpack from meteorological conditions.

A numerical weather prediction experiment began in the winter of 2015 for the purpose of promoting the research activities across the meteorological and glaciological research field. This article describes the numerical weather prediction system, and the preliminary results of a case study for an avalanche which recently occurred close to a ski resort in Japan.

2. Numerical prediction system

The numerical prediction system was established based on the Japan Meteorological Agency's Non-Hydrostatic Model (JMA-NHM, Saito *et al*., 2006) with the option of a double-moment bulk cloud microphysics scheme to predict both the mixing ratio and concentration of particles of solid hydrometeors (i.e., cloud ice, snow, and graupel) and a single-moment scheme to predict only the mixing ratio of particles of liquid hydrometeors (i.e., cloud water and rain).

The numerical prediction is conducted twice per day. Each time, a simulation is first performed with a 5-km horizontal resolution (5km-NHM) in a 2250 km × 2250 km (450 x 450 grid squares) wide domain (Domain1 in Fig. 1). Next, two simulations with a 1-km horizontal resolution (1km-NHM-D2 and -D3) are performed in different domains embedded within Domain1 (Domain2 and 3 in Fig.1). For all three simulations, the standard latitude and longitude are at 60.00 ^{o}N and 140.00 ^{o}E, respectively, in the Lambert conformal conic projection. The center of the domain is located at (39.00 ^{o}N, 137.00 ^{o}E) for the 5km-NHM, and at (43.50 ^{o}N, 142.20 ^{o}E) and (37.00 ^{o}N, 139.00 ^{o}E) for the 1km-NHM-D2 and –D3, respectively.

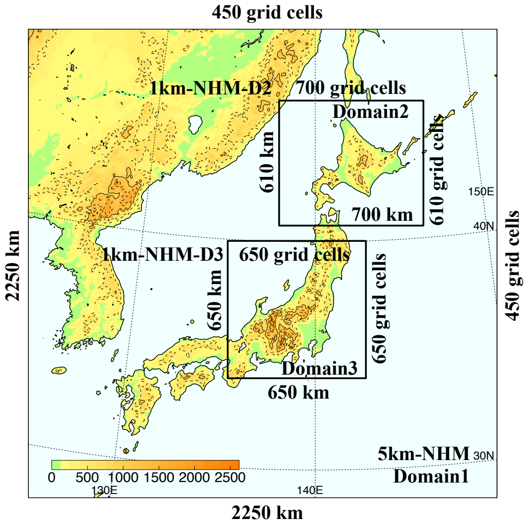

Fig. 1. Computational domains for the numerical prediction. Domain1 is for the 5km-NHM. Domain2 and Domain 3 are for the 1km-NHM-D2 and -D3, respectively.

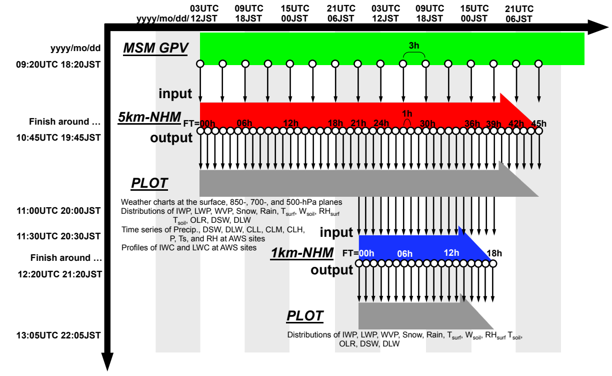

Fig. 2. Schedule for the weather prediction with the initial time of 1200 JST. Thin black arrows indicate the data flow.

For the 5km-NHM, the top height of the model domain is 22 km. Vertical grid spacing is stretched from 40 m at the surface to 886 m at the top of the domain. Fifty vertical layers in a terrain-following coordinate system are employed. The integration time is 45 h, with a timestep of 15 s. Computations of the radiative process are performed every 15 min at a horizontal grid spacing of 10 km. The initial and boundary conditions are obtained from the JMA's regional forecast by Meso-Scale Model (MSM). The initial time is 0000 or 1200 JST (UTC+9). The boundary condition is provided every 3 h. Figure 2 shows the schedule and data flow in the numerical prediction with the initial time of 1200 JST, as an example

The vertical grid arrangement in the 1km-NHM-D2 is the same as in the 5km-NHM, while the domain size is 700 km × 610 km. The integration time is 18 h with a timestep of 8 s. Computations of the radiative process are performed every 15 min at a horizontal grid spacing of 2 km. The initial and boundary conditions are obtained from the 5km-NHM. The same

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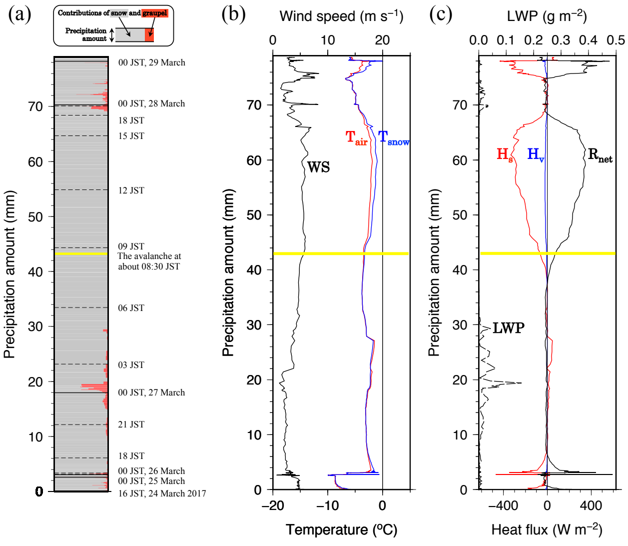

Fig. 3 Simulation results for the meteorological parameters at the avalanche site. (a) Stratigraph of water equivalent precipitation amount accumulated every 10 min from 1600 JST, 24 March 2017. Grey and red coloring indicates the respective contributions of snow and graupel particles to each 10-min precipitation amount. (b) Wind speed (black line, WS), air temperature (red line, T_{air}) and snow temperature (blue line, T_{snow}) as functions of the accumulated precipitation amount. (c) Same as (b) but for the net radiation flux (black solid line, R_{net}), sensible heat flux (red line, H_s), latent heat flux (blue line, H_v) and liquid water path (black broken line, LWP). The yellow line shows the presumed time at which the avalanche occurred.

configuration is adopted for the 1km-NHM-D3, except for the domain size, which is 650 km × 650 km. The initial time of the 1km-NHM-D2 and -D3 is 21 h later than that of the 5km-NHM (Fig. 2). The prediction results for several domestic observation sites are provided to the meteorological and glaciological research communities via a web service.

3. Computational cost

Computations are performed on the FUJITSU Supercomputer PRIMEHPC FX100 at the Meteorological Research Institute (MRI) of the JMA. Each job runs with 256 Multi Processor Interface (MPI, 32 MPI/node x 8 nodes) for the 5km-NHM simulation twice per day, which finishes in about 70 min. This costs 6,813 node-hours/year (8 nodes x 70/60 h x 2 runs x 365 days). Maximum memory usage is about 23 GB/node. For the 1km-NHM-D2 simulations, each job runs with 256 MPI (16 MPI/node x 16 nodes) twice per day, which finishes in about one and a half hours. This costs 17,520 node-hours/year (16 nodes x 1.5 h x 2 runs x 365 days). Maximum memory usage is about 22 GB/node. The computational cost for the 1km-NHM-D3 is almost same as that for the 1km-NHM-D2.

Each run of the 5km-NHM needs 29.3 GB of free disk space for I/O operation. We are archiving two-dimensional data, vertical profiles above observation sites, and plotted graphs for each simulation. The archived data size is 1.9 GB/run. This requires the storage space of 1.4 TB/year. For 1km-NHM-D2, 38.0 GB/run and 3.1 TB/year are required for running a job and archiving the data, respectively. Almost same size of disk space is required for the 1km-NHM-D3.

4. Preliminary results of the meteorological conditions for the avalanche that occurred near the Nasu Onsen Family Ski Area on 27 March 2017

On the morning of 27 March 2017, a surface avalanche hit the alpine region just behind the Nasu Onsen Family Ski Area, killing seven high school students and a teacher who were taking part in mountain skills training. In addition to the 8 killed, 40 further people were injured. Heavy snowfall had occurred at the avalanche site since the evening of the previous day. The National Research Institute for Earth Science and Disaster Resilience (NIED) reported that there was a granular snow layer at 35 cm and a layer composed of lightly compacted snow or new snow from 17 to 30 cm under the snow surface, based on the urgent in-situ snow pit survey conducted the following day (http://www.bosai.go.jp/saigai/2016/pdf/20170331_01.pdf). A weak layer was found in the lightly compacted snow layer from 22 to 25 cm under the surface. This layer was composed of weakly rimed planar crystals, in contrast to the upper and lower layers which were composed of more strongly rimed crystals. It was presumed that the layer with weakly rimed planar crystals and the subsequent short period of heavy snowfall formed an unstable snowpack.

Figure 3a shows the stratigraph of water equivalent precipitation amount at the grid point closest to “Tengu-no-hana”, the top of the avalanche slope, in the 1km-NHM-D3 simulations. The simulated snowfall was weak on 25 March and the daytime of 26 March (Fig. 3a and 3c), and the snow temperature increased during the same period (Fig. 3b), which is consistent with formation of the granular snow layer reported by the NIED. The heavy snowfall after the evening of 26 March was qualitatively well simulated. Although the simulated bulk properties of the snowfall agree well with the snow pit survey report, the simulation result did not show a change in snowfall characteristics corresponding to the transition in crystal features across the weak layer in the snowpack.

5. Summary

A numerical prediction system was established, based on the JMA-NHM for collaboration with research activities in glaciology and snow disaster prevention. The procedure of the numerical prediction is described, including the computational resources needed for performing the simulation and for archiving the data. We present preliminary results of the meteorological conditions for the avalanche near the Nasu Onsen Family Ski Area on 27 March 2017. For a comprehensive understanding of the microphysical link between snowfall and snowpack for the avalanche event, it is necessary to take a sophisticated approach to the microphysical component of the weather prediction model and to promote integrative approaches including a snowpack model.

Acknowledgement

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