

WRF ATMOSPHERIC ICING VALIDATION FOR MOUNT ZAO, JAPAN, DURING 19-29 APRIL 2009

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Abstract: A mesoscale atmospheric model Weather Research & Forecasting (WRF, ver. 3.2.1) was used to reconstruct mid-spring episodes of soft rime formation at the Mt. Zao, Japan, during 19-29 April 2009. One particularly interesting form of soft rime was observed at the Karitadake peak (1758 m). It was presented by feather-looking opaque aggregates of granular ice 15-35 cm long, called “shrimp’s tale” in Japanese. Based on an analysis of model-generated results we could 1) find a good quantitative agreement of modeled and observed wind and temperature time series at Jizosanchō ropeway station; 2) could identify two icing events (lasting for 26-41 hours each, with temperatures between -6.3° and -0.1°C , relatively constant westerly strong winds up to 26 m s^{-1} , and cloud liquid water content up to $0.72\text{-}1.05\text{ g m}^{-3}$). By considering the general synoptic situation for the simulation period, we found that both in-cloud icing episodes corresponded to a passage of low pressure systems; 3) confirm that a high resolution modeling (1.1 km) was much more accurate than simulations with coarser grids (10 and 3.3 km).

1. INTRODUCTION

Mount Zao, an active volcano at the Northern Honshu (38.14° N , 140.44° E ; 1841 m) is very famous for its impressive and well studied low density ice accretion on trees, referred in Japan as “ice monsters”, and attracting thousands of visitors every winter. An interesting form of soft rime, called “shrimp’s tale” in Japanese (Fig. 1a), was observed at one of the peaks of the mountain (Karitadake, 1758 m) at the end of April 2009. In order to validate the WRF model, we attempted to reproduce episodes of in-cloud icing for this particular locality by using 10-days simulation with a triple nested domain configuration (10, 3.3 and 1.1 km horizontal grid spacing). We employed global analysis data from the Global Forecast System, NCEP (with 1° horizontal grid spacing), derived terrestrial data from 10’-30” USGS and MODIS datasets, and used Thompson scheme for cloud microphysics. For ground control, model-generated results were compared to measured day-time series from Jizosanchō ski lift station, placed 3.4 km away (measurements of icing and cloud

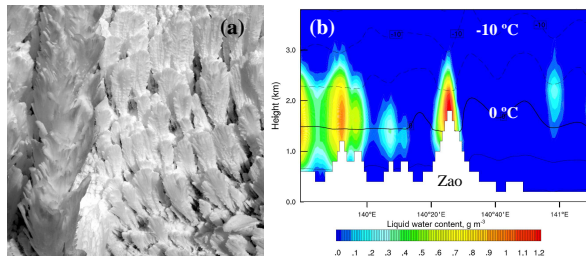


Figure 1: (a) Photograph of a so called “shrimp’s tail” soft rime on a wall of a temple, Mount Zao, Japan (29 April 2009); (b) WRF vertical cross section of liquid water content and air temperature at 20:00 pm 26 April 2009 (JST), Mt. Zao, Japan.

liquid water content were not available).

2. RESULTS AND DISCUSSION

A good agreement could be found between main meteorological elements measured at Jizosanchō ropeway station and calculated by the model in the finest domain. Periods corresponding to predicted negative air temperatures ($^{\circ}\text{C}$) and cloud liquid water content higher than zero for Jizosanchō and Karitadake were used for detection of the start and end of icing events (Fig. 1b). Two prolonged episodes (26-41 hours) were identified on 23-24 and 26-28 of April 2009, produced by passage of two low pressure systems over the Northern Honshu with predicted temperatures between -6.3°C and -0.1°C , westerly winds up to 26 m s^{-1} (Fig. 2), and cloud water liquid content reaching as high as $0.72\text{-}1.05\text{ g m}^{-3}$.

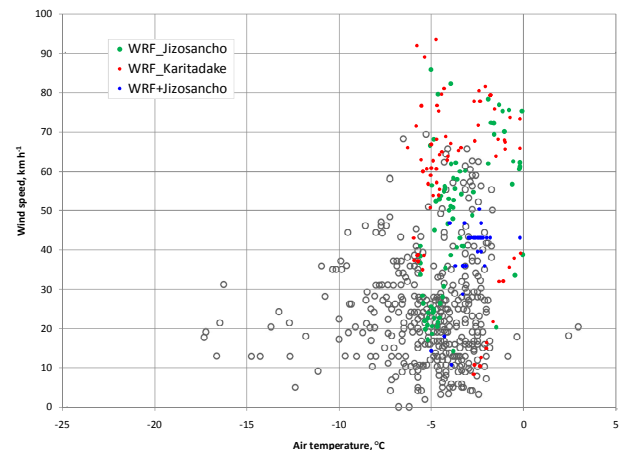


Figure 2: Joint distribution wind speed (km h^{-1}) - air temperature ($^{\circ}\text{C}$) during in-cloud icing events at the Mont Belair test site, Canada [1] and modeled for Zao (by different colors).

3. CONCLUSION

This paper summarizes results of numerical experiment with an objective to reconstruct rime ice accretion episodes at the Mount Zao, Japan, during 19-29 April 2009, by using the mesoscale atmospheric WRF model. The WRF calculations for atmospheric icing revealed a good capability and a potential for meteorological reconstructions with high degree of accuracy.

4. REFERENCES

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WRF atmospheric icing validation for Mount Zao, Japan, during 19-29 April 2009

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Abstract—A mesoscale atmospheric model Weather Research & Forecasting (WRF, ver. 3.2.1) was used to reconstruct mid-spring episodes of soft rime formation at the Mt. Zao, Japan, during 19-29/4/2009. Interesting form of soft rime was observed at the Karitadake peak (1758 m). It was presented by feather-looking opaque aggregates of ice 15-35 cm long, called “shrimp’s tale” in Japanese. Based on an analysis of model-generated results we could 1) find a good quantitative agreement of modeled and observed meteorological time series at Jizosancho ropeway station; 2) could identify two icing events (lasting for 26-41 hours each, with temperatures between -6.3° and -0.1°C , strong westerly winds up to 26 m s^{-1} , and liquid water content up to $0.72\text{-}1.05\text{ g m}^{-3}$) corresponding to a passage of low pressure systems; 3) confirm that a high resolution modeling (1.1 km) was much more accurate than simulations with coarser grids (10 and 3.3 km).

WRF model; in-cloud icing; rime; "shrimp's tail"; Mt. Zao;

I. INTRODUCTION

Importance of ice accretion modeling and lack of measured icing data have been discussed in many works ([1]-[3]). Probably, the most quoted disaster, exemplifying significance of atmospheric icing on structures occurred in January 1998 in Canada, when more than two million people were left without electricity [1]. Except transmission lines, other risks are associated with transport and a growing economy of clean power generation by wind in harsh conditions, icing of meteorological instruments [3] or in-flight hazards. Scarcity of available data and complexity with measurements of some critically important parameters for icing models, like cloud liquid water content (CLWC) or median volume diameter of the droplet size distribution [3], could be overcome by use of fine-grid weather forecast models [4]. In the present paper, we would like to perform validation of the Weather Research & Forecasting (WRF) atmospheric model and to demonstrate how some particular atmospheric icing events of ground-based structures at high-altitude mountain area could be identified by modeling means, despite an extremely small amount of supporting *in-situ* measurements. For examples on comprehensive studies using WRF for icing simulations the reader may refer to [4]-[6]. Peculiar ice deposits, discussed in this study, were observed on vertical surfaces at the top of Mt. Zao, Japan, on the 29/4/2009 [7]. These accretion forms shown at the photographs (Fig. 1) are called “shrimp’s tails” in Japanese,

due to their striking resemblance to tails [8]. Such kind of icing is known to be formed from supercooled water cloud



Figure 1. Photo showing build-up of a so called ‘shrimp’s tail’ rime.

droplets colliding with objects. It is related to a so called “dry growth”, and are being called “rime” [1]. In this particular case - “soft rime” due to its low density 0.3 g cm^{-3} [9]. Similar feathery structures can be recognized pretty often at photographs from all around the globe showing objects covered with agglomerated rime mass. Though in our case, every single formation (15-35 cm) was presented by individual independent structure, beautifully stemming out of a single point where it was attached to an ice-free surface. In this particular study, we attempted to reproduce meteorological conditions responsible for a formation of such distinct discrete rime structures (when almost nothing was known on ice accretion evolution in time).

II. AREA DESCRIPTIONS, METHODS AND MATERIAL STUDIED

A. Study site

Mt. Zao presents an active volcano at the Northern Honshu island, Japan (38.14° N , 140.44° E), located in approximately 50 km from the Pacific Ocean. It is a complex exposed ensemble of stratovolcanoes with a maximum elevation of 1841 m. Zao is famous for its impressive and well studied low density ice accretion on trees, referred in Japan as “ice monsters”. Mechanisms of rime formation at Mt. Zao and its chemical-composition could be found in [9]-[11].

B. Meteorological data

Meteorological data from Jizosancho ropeway station ($\text{N } 38.15^{\circ}$, $\text{E } 140.43^{\circ}$) we kindly provided by Zao Ropeway Company. This site is located 1661 m asl and about 3.4 km northwest of our place of interest at the Karitadake peak (1758 m asl, $\text{N } 38.12^{\circ}$, $\text{E } 140.44^{\circ}$), where photographs were

taken (Fig. 1). The measurements were based on hourly instantaneous manual records of air temperature (T_a) and wind, conducted only between 7 am and 5 pm (or 6 am and 6 pm), and for some days supported by operators notes [12]. The latter were particularly useful, since there were no measurements of precipitation, CLWC or in-cloud icing. Air temperature sensor were installed near to the station at 3 m above the ground; propeller type wind sensor were placed at the top of one of ropeway towers below the station, at ~25 m above the ground (location of the tower is ~1600 m asl). No negative effects of icing on the sensors were reported during the period of interest.

C. Weather model WRF

The atmospheric mesoscale non-hydrostatic model Weather Research and Forecasting (WRF, ver. 3.2.1) was jointly developed by US National Centre for Atmospheric Research (NCAR) and several other institutions [13]. Being developed as a community modeling system, WRF slowly replaces its predecessor, the MM5, and is widely used nowadays for a wide spectrum of weather prediction and research applications [5]. WRF includes advanced microphysical processes, in particular, the Thompson cloud microphysics scheme [14], that allows to focus on in-cloud icing. For the present study, simulation were made with a triple nested domain (10, 3.3 and 1.1 km horizontal grid spacing) for 10 days period during 19-29/4/2009 (Fig. 2a). Nested domains, centered over Mt. Zao, were large enough to avoid any lateral boundary effects. We employed global reanalysis data from the Global Forecast System, NCEP (with 1° horizontal grid spacing and 6-hourly products), and derived terrestrial data from USGS and MODIS datasets (with 10, 2 and 30 horizontal grid spacing corresponding to 1st, 2nd and 3rd domains) (Fig. 2b). Thirty five model levels were set up for vertical direction of the model, with a top at 50 hPa. Before going into icing questions, we had to perform ground control of the model results extracted at one hour intervals. Simulated T_a and horizontal wind components (U, V) were compared to *in-situ* measurements at Jizosancho. For a quantitative comparison, we had to modify reported wind speed and direction into U and V components, by assigning azimuth degree values to cardinal directions and producing vector components.

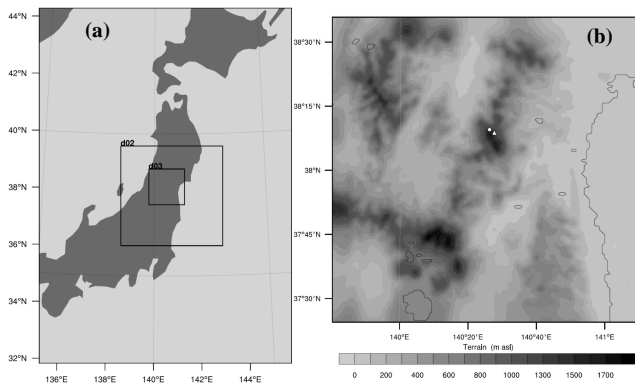


Figure 2. (a) Nesting of 3 WRF domains. (b) WRF surface topography of the finest domain, d3, with the Pacific Ocean on the eastern boundary of the domain. Karitadake is indicated with a triangle, Jizosancho - by dot.

D. Method for detection of in-cloud icing episodes

Weather elements favoring formation of in-cloud icing are known: it is $T_a < 0^\circ\text{C}$, and $\text{CLWC} > 0$ (also meaning that an altitude of an object of interest is above the cloud base) [2]. For ice accretion modeling purposes the most important factors are rate of icing and duration of icing event. We do not attempt to estimate the former, usually obtained from an equation called Makkonen model, employed for ice accretion on cylinders [1], due to a lack of any ice load or density measurements which could be used for references. Accordingly, we will determine only meteorological elements, and would try to identify duration of icing episodes by means of modeling with WRF. For details about ice accretion estimates based on modeling results the reader may refer to [4] and [14].

III. RESULTS AND DISCUSSION

A. Model output and observations

To compare simulated and observed values we are referring to the nearest grid point to real location. Validation tests were made to determine effects produced by differences between the model and real elevations (caused by smoothing). The real location of the Jizosancho ropeway station is about 1625 - 1661 m asl (see above for details), but the model height is only 1471 m asl. Similar situation with Karitadake peak, which is reduced by 364 m in the model. These reductions may affect variable fields, and we may expect harsher weather at higher altitudes, especially for Karitadake. It has been shown that under such conditions, CLWC should be extracted from the real height, rather than the lowest model layer [6]. Some previous studies on icing assumed equal temperatures for even higher altitude differences between weather station and object of interest (300–600 m), and roughly calculated wind speed by power-law relation [15]. We could not find any significant differences between liquid water content extracted from the lowest model levels. The best reproduction of T_a and wind observations could be achieved at the real height model level (though improvements were very small comparing to surface level estimations). Accordingly, we would be referring to the real height model level for T_a and wind, and to the lowest model level for CLWC.

B. Ground control

We will discuss here only results produced by the finest domain (1.1 km, d3), and just note, that the latter had the most realistic estimations. Coarser domains (10 and 3.3 km), for example, have produced similar amplitudes and shapes of the curves for T_a , but approximately 5°C higher (d1), thus showing almost no temperatures what would be below 0°C . In general, a good agreement could be found for main meteorological elements measured at the Jizosancho and predicted by the model, as shown on Fig. 3. However, a few exceptions may be noticed, namely underestimated T_a as well as overestimated on 20 and 24/4/2009, and on 25/4/2009, respectively (Fig. 3a), and wind velocities overestimated by the model on the 26/4/2009 (Fig. 3d). Though, we see that the model has produced realistic

estimations, including wind directions (Fig. 3b&c). Simulated continuous time-series and day-time measurements complement one another, allowing us to consider a continuous variation of parameters important for icing, and to fulfill lacking night time measurements. Basing on realistic WRF representation of meteorological elements for Jizosancho, we also include modeled curves for Karitadake peak (Fig. 3), and show simulated CLWC variation (Fig. 3e) for the both sites in attempt to identify potential periods of icing.

C. In-cloud icing

Periods corresponding to predicted negative T_a and $CLWC > 0$ for Jizosancho and Karitadake are shown on Fig. 4. Two prolonged episodes are clearly seen between 23 and 24/4 and between 26 and 28/4/2009. Few shorter events could be also identified (1-3 hours for Jizosancho, and 2-10 hours at Karitadake) (Fig. 4). Duration of the two longest episodes (for convenience called here ‘the first’ and ‘the second’), for Jizosancho was 36 and 41 hours, and for Karitadake 26 and 32 hours, respectively (Fig. 4). Both episodes corresponded to a passage of low pressure systems (996 and 986 hPa) over the Northern Honshu area (on 22 and 26/4/2009) [16]. In general, conditions were harsher at Karitadake, except CLWC, showing maximum values for Jizosancho (Fig. 3e). The prevailing wind direction modeled during icing events is from the West or WNW, with maximum wind speeds up to 26.0 m s^{-1} (Fig. 3d). Fig. 5 shows vertical cross-sections of simulated T_a and CLWC exemplifying the 1st and the 2nd icing episodes. It could be demonstrated that Mt. Zao is above the cloud base for both events, with maximum CLWC above the top, illustrating orographic lifting of air (Fig. 5). Icing period at Karitadake is slightly shorter due to not-continuous or disrupted conditions (Fig. 4), caused by variation of CLWC (Fig. 3e). Behavior of the latter may be associated with shading effects of Zao peak on clouds, which is located between two sites. Both icing episodes, detected by WRF, agree well with operators’ reports [12], noting presence of shrimp’s tails 15-20 cm long on trees in mornings of 24, 27 and 28/4/2009 and recognizable on 29/4/2009 at Jizosancho (Fig. 4). According to operators’ reports, rime, formed during the 1st episode, fully dropped off before morning of 26/4; total shedding of an accretion formed during the 2nd episode, happened until afternoon 30/4/2009 (Fig. 4). Shedding can be a result not only of T_a above melting, but also of rain, wind or gravity, and present not a trivial issue for cumulative ice load studies. Some studies use the T_a above zero for 3 hours or more as a simple unloading criterion [15]. If we refer to predicted T_a alone (Fig. 3a), we may suggest that shedding should have started the following day (4 hours of $T_a > 0$), and intensified during a long warming episode (up to $+3.7^\circ\text{C}$) between 25 and 26/4. Though, as it was already mentioned before, modeling results did not reproduce perfectly daytime T_a measurements on 25/4 (Fig. 3a), so our conclusion has obvious limitations. Second shedding should have started during 8 hours of positive T_a on the next day (29/4/2009) when pictures were taken, and simulation time was over (Fig. 1 & 3a). Ropeway operators’ report [12] noted a full drop off on the next day, 30/4/2009

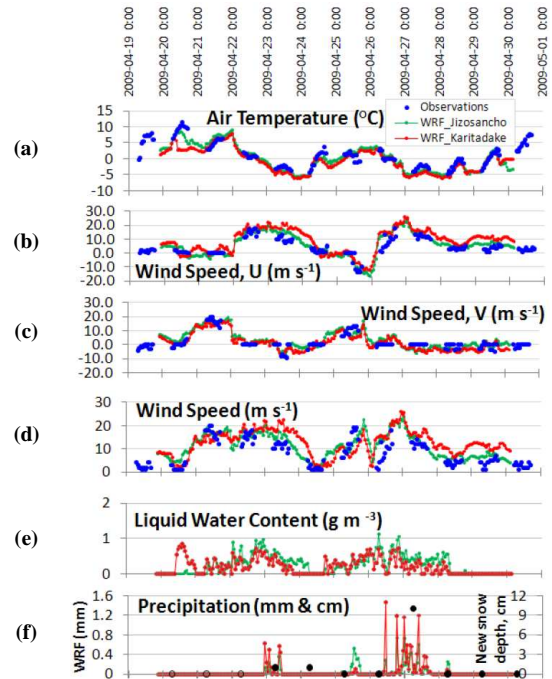


Figure 3. Meteorological elements modeled for Karitadake and Jizosancho, and measured at the latter site, during 19-29/4/2009. (a) T_a ; (b) U and (c) V components of wind (+/- correspond to W/E, or S/N directions); (d) Wind speed; (e) modeled CLWC; (f) modeled accumulated total grid scale snow and ice, and observed amount of new snow, reported in the morning [12].

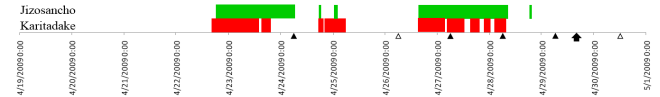


Figure 4. Timeline with periods where modeled parameters are satisfying to meteorological conditions usually associated with in-cloud atmospheric icing. Filled triangles indicate operators’ reports about rime presence [12], empty triangles – complete shedding; arrow - time when Fig. 1 was taken.

(when T_a was $+7.6^\circ\text{C}$ at Jizosancho). We should notice, that “3 hours of $+T_a$ ” approach [15] has its own limitations and seems to be too simplified, since it does not correspond to rime shedding during periods than observed T_a were positive for about 7 hours (24/4/2009) or 8 hours (29/4/2009) as it was shown above (Fig. 3a). In order to see any differences between published joint distributions of wind and T_a (used for recognition of type of icing on transmission line conductors by field data [3],[8],[17]) and results of this study, we plot the latter on Fig. 6. It should be noted, that approximate limits for the type of accreted ice is known to depend on the shape of icing object, and shift to the left of the plot (Fig. 6a) for higher values of CLWC [3]. These limits seem to be applicable to our estimations only partly for the Jizosancho (Fig. 6a). It appears that parameters obtained for Karitadake are falling mostly into ‘hard rime’ or ‘glaze’ type of icing for our case (Fig. 6a). If this is right, we have an indication that the low density ‘shrimp’s tails’ observed on buildings and other large objects are developed under meteorological conditions that would cause hard rime or even glaze on small cylindrical objects such as power line conductors. An attempt to extend our dataset and to include synthetic values (i.e., selection of data where measured wind and T_a values corresponded to times with modeled CLWC

>0), also shows a distribution more typical for hard rime or even glaze (Fig. 6a).

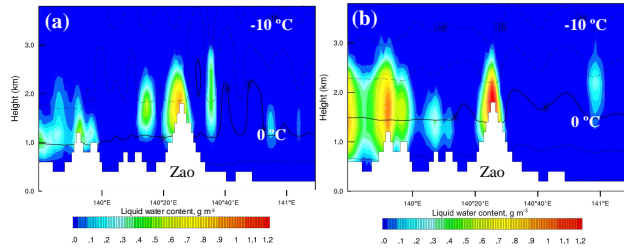


Figure 5. WRF vertical cross sections (along latitude N 38.14°) of CLWC and T_a on (a) 09:00 am 23/4/2009 (JST), corresponding to the first icing episode (wind: West), and on (b) 20:00 pm 26/4/2009 (JST), corresponding to the beginning of the second icing episode (wind: WNW).

It is not very clear how these limits (Fig. 6a) could be employed – for example, could these be used to help us with identification of correct icing period (e.g., group of dots

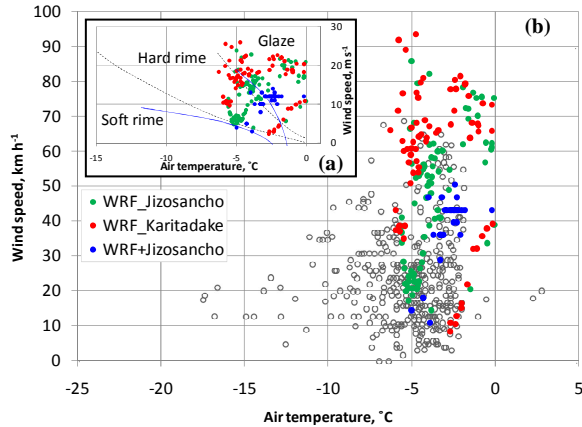


Figure 6. (a) Type of icing as a function of wind speed (m s^{-1}) and T_a (dashed lines - after [3]; solid blue lines - after [8]); blue dots - Jizosanchō synthetic selection (see text). (b) Joint distribution “wind speed (km h^{-1}) - T_a ” during in-cloud icing events at the Mont Belair [17] and Zao.

with average wind speed about 5 m s^{-1} and $T_a -5^\circ\text{C}$ for Jizosanchō; Fig. 6), or to show that observed ice accretion cannot be easily classified as a soft rime by using known criteria. To explore the icing classification issue in more details, we consider obtained distributions in comparison to known data from the Mont Belair test site in Canada [17]. Fig. 6b shows that the form of these distributions represents values typical for in-cloud icing with severe wind speeds. Finally, it is necessary to note that conditions described here for the Mt. Zao could be also found at other high mountains located within the boundaries of the finest domain (d3, Fig. 2b) (suggesting that similar rime could be formed at Azuma, Gassan, Ooasahi-dake, Iide, and Iimori Mts.).

IV. CONCLUDING REMARKS

We conducted a numerical experiment with an objective to reconstruct ice accretion episodes at the Mt. Zao, Japan, during 19-29/4/2009, by using WRF model. Obtained results illustrated that WRF had performed well, and provided new data to existing icing measurements (e.g., [3]). The model helped to detect two icing events 26-41 hours long, produced by passage of two low pressure systems over

the Northern Honshu with temperatures between -6.3° and -0.1°C , westerly winds up to 26 m s^{-1} , and CLWC reaching as high as $0.72\text{-}1.05 \text{ g m}^{-3}$. Except demonstration of a great WRF potential, the obtained meteorological constrains may be useful for scientific communities involved into stochastic or physical modeling of complex rapidly evolving rime icing objects.

ACKNOWLEDGMENT

The authors wish to acknowledge O. Abe, K. Okita, H. Ohba, K. Nishimura, A. Sakai, and H. Nagai for help. The WRF input data for this study are from the Research Data Archive, NCAR (<http://dss.ucar.edu>, ds083.2).

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