Atmospheric Research 154 (2015) 175–190

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Hybrid fine scale climatology and microphysics of in-cloud icing: From 32 km reanalysis to 5 km mesoscale modeling

Fayçal Lamraoui [a,*], Robert Benoit [b], Jean Perron [a], Guy Fortin [c], Christian Masson [b]

[a] The Anti-Icing Materials International Laboratory, University of Quebec at Chicoutimi, 555, Boulevard de l'Université, Chicoutimi, QC G7H 2B1, Canada
[b] Department of Mechanical Engineering, École de technologie supérieure, 1100, Rue Notre-Dame Ouest, Montréal, QC H3C 1K3, Canada
[c] Bombardier Aerospace, 2351, boul. Alfred-Nobel, Montreal, QC H4S 1A9, Canada

ARTICLE INFO

Article history:
Received 22 August 2014
Received in revised form 6 November 2014
Accepted 7 November 2014
Available online 14 November 2014

Keywords:
Mesoscale modeling
Reanalysis
In-cloud icing
Cloud microphysics
Climatology

ABSTRACT

In-cloud icing can impose safety concerns and economic challenges for various industries. Icing climate representations proved beneficial for optimal designs and careful planning. The current study investigates in-cloud icing, its related cloud microphysics and introduces a 15-year time period climatology of icing events. The model was initially driven by reanalysis data from North American Regional Reanalysis and downscaled through a two-level nesting of 10 km and 5 km, using a limited-area version of the Global Environment Multiscale Model of the Canadian Meteorological Center. In addition, a hybrid approach is used to reduce time consuming calculations. The simulation realized exclusively on significant icing days, was combined with non-significant icing days as represented by data from NARR. A proof of concept is presented here for a 1000 km area around Gaspé during January for those 15 years.

An increase in the number and intensity of icing events has been identified during the last 15 years. From GEM-LAM simulations and within the atmospheric layer between 10 m and 200 m AGL, supercooled liquid water contents indicated a maximum of 0.4 g m^{-3}, and 50% of the values are less than 0.05 g m^{-3}. All values of median volume diameters (MVD) are approximately capped by 70 μm and the typical values are around 15 μm. Supercooled Large Droplets represent approximately 5%. The vertical profile of icing climatology demonstrates a steady duration of icing events until the level of 60 m. The altitudes of 60 m and 100 m indicate substantial icing intensification toward higher elevations. GEM-LAM demonstrated a substantial improvement in the calculation of in-cloud icing, reducing significantly the challenge posed by complex terrains.

1. Introduction and background

Freezing precipitation and its related icing hazards have been largely investigated in previous studies (Bernstein et al., 1998, 2000; Carrière et al., 2000; Fernández-González et al., 2014; Laflamme, 1993; Stuart and Isaac, 1999). According to Fikke (2005), atmospheric icing is the accumulation of ice generated from any meteorological condition. More specifically, the current study focuses on in-cloud icing which is originated from the immediate freezing of non-precipitating supercooled cloud droplets upon contact with a solid surface (Ahrens, 2007; Cortinas et al., 2004; Debenedetti, 1996; Jacobson, 2005; Rock, 2003).

Despite the low intensity of in-cloud icing compared to freezing precipitation, economic and safety consequences on various sectors (wind turbine, electric cables, and aviation) can be devastating, especially those associated to prolonged occurrences of icing events (Laakso et al., 2010).

In addition, the precipitation is commonly considered the only element for the hydrological cycle and the unique source of water for watersheds. According to previous study

* Corresponding author at: The Anti-icing Materials international Laboratory, University of Quebec at Chicoutimi, 555, boulevard de l'Université, Chicoutimi, QC G7H 2B1, Canada.
E-mail address: faycal.lamraoui@gmail.com (F. Lamraoui).

http://dx.doi.org/10.1016/j.atmosres.2014.11.006
0169-8095/

(Schemenauer and Cereceda, 1994), this consideration can generate a serious underestimation of water input, over foggy forested high-elevation areas that are exposed to frequent advection of near surface clouds. Furthermore, a precise estimation of ice accretion from non-precipitating cloud droplets can contribute to the improvement of water budget calculations over complex terrains or areas with highly elevated obstacles (trees, building, wind turbine …) that intercept cloud advection.

The relevant meteorological factors that control the atmospheric icing are the liquid water content, air temperature, wind speed and droplet size (e.g., Shin et al., 1991). The occurrences of hazardous atmospheric icing events are associated with supercooled droplets. The supercooled liquid water (SLW) is one of the very significant elements that govern the weather. Furthermore, it is an important component for mixed phase clouds (Boudala et al., 2004), cloud microphysical (Morrison et al., 2011) and radiative properties (Bennartz et al., 2013).

The presence of supercooled liquid water in various types of cold clouds is very common (Turner, 2005; Shupe, 2011), and can be found at −40 °C (e.g., Heymsfield et al., 1991). Cober et al. (2001) found that liquid, mixed, and glaciated phases are represented by the portions of 40%, 40%, and 20% of the total clouds, respectively. The coexistence of the supercooled cloud droplets with solid hydrometeors assures maximum crystal mass growth rate (at a given temperature) and the potential for accretion of droplets by crystals.

Illingworth et al. (2007) reported that there is a challenge encountered in the representation of mixed phase cloud in numerical weather prediction and climate models.

According to Lau and Wu (2003) even in the tropics, 69% of liquid precipitations are originated from ice phase hydrometeors in higher altitudes.

Low concentration of ice nuclei causes the inhibition of glaciation process, and subsequently, favors an increase of Supercooled Large Drops (SLD) (Fernández-González et al., 2014).

Frequently, SLD refers to drop size between 50 μm and a few hundred μm (Politovich, 1996). Other studies (e.g., Sand et al., 1984) consider the range between 30 μm and 400 μm as the critical sizes of SLD that are responsible for most of the serious aircraft icing incidents. An experimental study (Politovich, 1996) found that SLW higher than 0.2 g m^{-3} with SLD larger than 30 μm generate in-flight icing that cause a significant rapid degradation. With regard to SLD data, the majority of measurements were within the range of temperatures [−24 °C to 0 °C] in stratiform and winter frontal clouds (Cober et al., 2001).

In reference to aircraft icing, even low concentrations (10 L^{-1}) of SLD that are higher than 50 μm can be seriously hazardous (Bernstein et al., 2007), when exposure time is within 10–15 min (Politovich, 1989). Furthermore, Marwitz et al. (1997) confirmed that low SLD concentrations (10 L^{-1}) are often found in the Maritime stratiform clouds. Lasher-Trapp et al. (2008) reported that giant aerosols have a very limited contribution in the formation of SLD. On the other hand, various favourable conditions can lead to accelerated formation of SLD such as: the presence of low droplet concentration with larger cloud liquid water content (Rasmussen et al., 1995; Murakami et al., 1992); the presence of vertical wind shear in stable thermodynamic profile at cloud top (Pobanz et al., 1994); and the high supersaturation (Korolev and Isaac, 2000).

Using the North American regional reanalysis data (NARR), at an extended time period of 32 years during winter months, Lamraoui et al. (2014) determined that the mean duration of icing events is approximately 6 h.

The current study provides further investigation on the effect of cloud microphysics parameters that contribute in generating atmospheric icing (Rime or Glaze) during wintertime. An earlier study (Lamraoui et al., 2013) demonstrated that NARR has limitations on representing atmospheric icing over complex terrains, due to the coarse resolution and lack of terrain-following data therein for cloud parameters and accretion calculation. Therefore, this study represents the climatology of in-cloud icing (duration of icing events, ice accumulation and Icing Severity Index (ISI)) at a finer resolution using a limited-area version of the Global Environment Multiscale Model (GEM-LAM). This regional non-hydrostatic atmospheric model of the Canadian Meteorological Center (CMC) was initially driven by NARR data and downscaled through a two-level nesting. The cloud microphysics is available in GEM through an advanced multiphase scheme (Milbrandt and Yau, 2005).

2. Method

A previous study by Lamraoui et al. (2013) analysed the climatology of atmospheric icing by mapping the ISI over the Eastern part of the province of Quebec (Canada) which spanned a 32-year period. The representation of icing severity used meteorological variables with a resolution of 32 km extracted from NARR. The use of NARR alone indicated that the lack of horizontal and vertical space resolution imposes a challenge on the calculation of icing events over complex terrains, especially during the months of November and March when air temperature is near freezing point. In order to counterbalance the lack in NARR resolution, this study aims to obtain higher resolution climatology of atmospheric icing through the use of a finer scale mesoscale model GEM-LAM with a resolution of 5 km. Although the use of a mesoscale model for a 32-year period provides more localized details it also in turn becomes a time consuming process.

Alongside this, the calculation of atmospheric icing from the NARR data neglects details within 32 km over hilly topography. For this reason, to reach an optimal compromise and to obtain detailed icing events at finer resolution with reasonable time consuming calculations, a hybrid approach was introduced. As shown in Fig. 1, this approach involves the combination between North American Regional Reanalysis and the mesoscale limited area model GEM-LAM-5 km. To identify the significant icing events, a preliminary climatology of icing events was produced based on reanalysis. Subsequently GEM-LAM-5 km was applied during the significant icing events in order to enable their higher resolution calculation of icing events. The resulted ISI mapping is an indicator of risk levels of icing events. This information will prove useful to prevent damages and economical losses due to icing events by documenting their risk factor.

To avoid the time consuming calculations for a 32-year period and without affecting the quality of the results, the climatology of a 32-year period is substituted by a comparable