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Projected changes to extreme ice loads for overhead transmission lines across Canada

Dae Il Jeong[a,*], Laxmi Sushama[a], Michael J.F. Vieira[b], Kristina A. Koenig[b]

[a] Department of Civil Engineering and Applied Mechanics and Trottier Institute for Sustainability in Engineering and Design, McGill University, Montreal, Quebec, Canada
[b] Hydrologic and Hydroclimatic Studies Section, Manitoba Hydro, Winnipeg, Manitoba, Canada

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ABSTRACT

Ice accretion on transmission lines can lead to serious damages from line breakage and flashover. This study investigates projected changes to design ice loads for overhead transmission lines for the 2041–2070 and 2071–2100 periods with respect to the 1976–2005 period over Canada, using transient climate change simulations of the fifth generation Canadian Regional Climate Model, for two driving Global Climate Models and two Representative Concentration Pathways. Projected changes to freezing rain characteristics are first evaluated and results suggest decreases in 50-year return levels of annual maximum daily freezing rain for the south-eastern inland and coastal regions and south-western and north-eastern coastal regions of North America, but increases for other regions. Consequently, the simulations suggest statistically significant increases in 50-year return levels of annual maximum ice thickness, particularly for regions of Quebec and west of the Hudson Bay (larger than 10 mm) and some scattered increases for south- central and western Canada (mostly smaller than 3 mm). This study also helped identify regions where both wind and ice loads will increase in future climate, which can be detrimental to the electric infrastructure. Results suggest that compound event assessments would be valuable, taking into consideration larger set of simulations, to obtain more robust projections.

1. Introduction

Ice storms and related ice accretion can result in severe disruptions to wind energy generation (Yang, Yu, Choisnard, Forcione, & Antic, 2015), urban functioning (Armenakis & Nirupama, 2014), forestry sector (Proulx & Greene, 2001), and electrical infrastructure including transmission and distribution structures and lines (Armenakis & Nirupama, 2014; Makkonen, Lehtonen, & Hirviniemi, 2014; Rezaei, Chouinard, Langlois, & Légeron, 2016). Ice accretion on overhead transmission lines, in particular, can result in serious damages due to line breakage, tower failure and flashover. Therefore, ice thickness and wind pressure are key environmental loads considered individually in the design of overhead transmission lines to ensure that the lines have both sufficient mechanical strength and reliability (Canadian Standards Association, 2010; Rezaei et al., 2016). According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), the global mean temperature will increase by 4.8 °C by the end of the 21st century, compared to the pre-industrial climate, if greenhouse gas emissions continue unabated (IPCC, 2013). The warmer temperatures can impact the frequency and intensity of ice storms, which are frequently associated with surface air temperatures between −10 °C to 0 °C (Cortinas, Bernstein, Robbins, & Walter Strapp, 2004), and therefore it is important to evaluate how ice loads might change in the future due to this anticipated warming or climate change. The design ice load is based on selected return levels obtained from annual maximum ice thickness time series. Projected changes to these return levels in a future warmer climate can have significant implications for existing transmission lines, which were designed based on the ice loads estimated from historical observations of freezing rain and wind speed (Panteli & Mancarella, 2015).

A number of models have been proposed to estimate ice accretion on overhead lines exposed to ice storms from meteorological data such as the amount and duration of freezing rain, wind speed and direction, and air temperature (Chainé & Castonguay, 1974; Jones, 1998; Makkonen, 1998; Yip, 1995). Using these approaches, several studies have proposed/published extreme ice accretion maps for the design of overhead transmission lines as well as ice accretion risk assessments (Canadian Standards Association, 2010; Lamraoui, Fortin, Benoit, Perron, & Masson, 2013; Nygaard, Seierstad, & Veal, 2014; Zhu, Liu, Yang, & Li, 2014). Very few studies have focused on the future changes

* Corresponding author at: Trottier Institute for Sustainability in Engineering and Design, 475E, Macdonald Engineering Building, 817 Sherbrooke Street West, Montrea, Quebec, H3A 0C3, Canada.
E-mail address: dae.jeong2@gmail.com (D.I. Jeong).

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to ice thickness/loads and associated impacts on overhead transmission lines. Rezaei et al. (2016) evaluated changes in the reliability of overhead transmission lines to changes in ice loads, based on a range of assumed changes in the mean and standard deviation of future ice thickness. They highlighted the need for local and regional scale climate change scenarios to complete a comprehensive risk analysis and a quantitative assessment of climate change impacts on transmission lines. However, regional-scale projections of ice thickness characteristics based on downscaled scenarios from global climate models (GCMs) are not yet widely available for Canada.

Regional climate models (RCMs) have been employed in many regional-scale studies to dynamically downscale GCM climate projections to analyze climate change impacts on different extreme events. The fifth-generation Canadian Regional Climate Model (CRCM5), which is based on the numerical weather prediction model of Environment and Climate Change Canada (ECCC), has been successfully applied to evaluate projected changes to different extreme events and environmental loads such as temperature extremes (Diro et al., 2014; Diro & Sushama, 2017; Jeong, Sushama, Diro, & Khaliq, 2016; Jeong, Sushama, Diro, Khaliq, Beltrami et al., 2016), precipitation extremes (Mladjic et al., 2011), floods (Clavet-Gaumont, Sushama, Khaliq, Huziy, & Roy, 2012; Huziy et al., 2012; Jeong, Sushama, Khaliq, & Roy, 2014; Poitras, Sushama, Seglenieks, Khaliq, & Soulis, 2011; Sushama, Laprise, Caya, Frigon, & Slivitzky, 2006), droughts (Jeong, Sushama, & Khaliq, 2014; Poitras et al., 2011; PaiMazumder, Sushama, Laprise, Khaliq, & Sauchyn, 2012; Sushama, Khaliq, & Laprise, 2010), rain-on-snow events (Jeong & Sushama, 2018a), and wind and snow loads (Jeong & Sushama, 2018b). Jeong and Sushama (2018b) showed some increases in design wind pressure for central and eastern Canada, due to changes in inter-annual variability of annual maximum wind speed and general decreases (increases) in design snow load for southern (northern) Canada, for the future 2071–2100 period with respect to the 1981–2010 period.

The main purpose of this study is to evaluate projected changes to ice accretion/loads (i.e., 50-year return level of radial ice thickness) used in the design of overhead transmission lines for two future periods (2041–2070 and 2071–2100), with respect to the current 1976–2005 period, across Canada, using CRCM5 simulations, driven by two GCMs (i.e., the Canadian Earth System Model 2 (CanESM2) and the Max-Planck-Institut Earth System Model (MPI-ESM)) for Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios. The RCPs are a set of greenhouse gas concentration trajectories designed to support research on the impacts of climate change, and the 4.5 and 8.5 scenarios correspond to radiative forcings of 4.5 and 8.5 W/m^2 by the end of the 21st century compared to pre-industrial values (IPCC, 2013). The 50-year return levels are considered as the National Building Code of Canada generally provides these for various regions of Canada. The extreme value assessment conducted in this study uses 3-h radial ice thickness, which is derived from freezing rain, wind speed, and air temperature. As freezing precipitation is the main climate variable determining the radial ice thickness, projected changes to freezing rain characteristics (i.e., frequency, amount, and 50-year return levels of daily freezing rain) are also assessed in this study. Finally, summary maps showing regions where both ice and wind loads are projected to increase in future climate for the scenarios considered in this study are presented.

2. Model and datasets

The CRCM5 is based on the Global Environmental Multiscale (GEM) model used for numerical weather prediction at Environment and Climate Change Canada (Côté et al., 1998). Therefore, the physical parameterizations in CRCM5 are similar to those in GEM, except for the land surface scheme. Particularly, CRCM5 uses the Kain and Fritsch (1992) deep-convection scheme and the Bélair, Mailhot, Girard, and Vaillancourt (2005) shallow-convection scheme. The resolvable large-scale precipitation is modeled by employing Sundqvist, Berge, and Kristjánsson (1989), while radiation is parameterized by Correlated K solar and terrestrial radiation of Li and Barker (2005). This model employs the interactive Flake lake model (Mironov et al., 2010) and Canadian Land Surface Scheme (CLASS) 3.5 (Verseghy, 2012), for the land part. This version of CLASS includes prognostic equations for energy and water conservation for a user-defined number of soil layers and thermally and hydrologically distinct snowpack where applicable (treated as an additional variable-depth soil layer). The thermal budget is performed over all soil layers but the hydrological budget calculations are performed only for layers above bedrock. An explicit vegetation canopy has its own energy and water balance with prognostic variables for canopy temperature and water storage. CRCM5 employs one-way nesting downscaling procedure. It interpolates lateral boundary variables (i.e., wind, air temperature, humidity and pressure) obtained from reanalysis and GCM simulations to its grid points progressively. The other climate variables such as precipitation are calculated based on the interpolated progressive variables and relevant parameterization schemes. Four precipitation types (i.e., snow, ice pellets, freezing rain, and rain) or mixtures of these types are diagnosed following Bourgouin (2000). When precipitation occurs, the vertical temperature profile is the main determinant of the precipitation type. Detailed procedure can be found in Bourgouin (2000).

The CRCM5 simulations used in this study are the same as those used in Jeong and Sushama (2018a,b). The CRCM5 experimental domain covers whole of North America and neighbouring oceans at 0.44° horizontal resolution. The three simulations considered in this study for the current 1976–2005 period are driven by ECMWF (European Centre for Medium-Range Weather Forecasts) gridded ERA-Interim reanalysis dataset (Dee et al., 2011), CanESM2 (Arora et al., 2011), and MPI-ESM (Giorgetta et al., 2013) at the lateral boundaries. The simulation driven by the ERA-Interim reanalysis (CRCM5-ERA hereafter) for the 1976–2005 period is used for the evaluation of the RCM skill. The CRCM5 simulations driven by CanESM2 and MPI-ESM for the 1976–2005 period used in this study will be referred to as CRCM5-CanHist and CRCM5-MPIHist hereafter, which are used as references of current climate as well as to evaluate boundary forcing errors, when compared to the CRCM5-ERA. Two CRCM5 simulations driven by CanESM2 for the RCP4.5 and RCP8.5 pathways and one simulation driven by MPI-ESM for the RCP4.5 pathway, for the 2041–2071 and 2071–2100 periods are also considered for assessing projected changes; these will be referred to as CRCM5-CanRCP4.5, CRCM5-CanRCP8.5, and CRCM5-MPIRCP4.5 to reflect both the boundary forcing dataset and emission pathways considered.

For validating simulated freezing rain characteristics, National Centers for Environmental Prediction (NCEP) North American Regional Reanalysis (NARR) dataset is used. NARR reanalysis is a long-term, consistent, high-resolution reanalysis dataset for the North American domain (Mesinger et al., 2006) and provides the same precipitation types as in CRCM5. Furthermore, NARR is known to provide an improved reanalysis of overall atmospheric circulation throughout the troposphere compared to previous global reanalysis (Mesinger et al., 2006). Table 1 provides a summary of all reanalysis, GCM, and CRCM5 simulations considered in this study.

3. Methodology

Prior to the investigation of future projections to the design ice load, the ability of the CRCM5 in simulating freezing rain is studied. CRCM5-ERA, -CanHist, and -MPIHist simulated freezing rain is evaluated by comparing the frequency and magnitude as well as their spatial patterns with those from NARR reanalysis over North America for the 1979–2005 period.

Eq. (1), suggested by Jones (1998), is used to calculate the amount of ice accumulation from the 3-h freezing rain, 10-m wind speed, and 2-m air temperature of CRCM5 simulations over Canada.