Sustainable Cities and Society 36 (2018) 225–236

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

Projected changes to extreme wind and snow environmental loads for buildings and infrastructure across Canada

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ARTICLE INFO

Keywords:
Building codes
Canada
Climate change
Extremes
Snow load
Wind pressure

ABSTRACT

Wind and snow are major environmental loads that are often considered in the design of buildings and infrastructure. To ensure safety of existing structures and to develop guidelines for future developments, it is important to evaluate how these design loads will be impacted by the anticipated climate change. This study evaluates projected changes to selected return levels of wind speed and snow water equivalent (SWE) and associated wind pressure and ground snow loads across Canada for the future 2071–2100 period. Canadian Regional Climate Model (CRCM5) simulations driven by two Global Climate Models (GCMs) for two future emission scenarios are used. The CRCM5 projections suggest some increases in the future 50-year return levels of wind speed and pressure, mainly due to changes in inter-annual variability of annual maximum wind speed, particularly for the central and eastern regions. As for SWE loads, results suggest general decreases for southern Canada and increases for northern Canada in the 50-year return levels. However, the projections, particularly for wind loads, vary considerably with the driving GCM and the emission scenario, suggesting that larger ensembles including more RCMs and driving GCMs will be required to better quantify uncertainties to support development of climate-resilient design standards and codes.

1. Introduction

Environmental loads should be taken into consideration in the design of buildings and infrastructure to ensure successful performance and reliability. Wind and snow loads are the major environmental loads considered in the National Building Code of Canada (NBCC) (NRCC, 2015). The design loads are based on selected return levels obtained from annual maximum time series of the respective environmental load. However, according to the Intergovernmental Panel on Climate Change (IPCC, 2012), the frequency, severity, duration, and timing of extreme events including those related to wind and snow can change in a future warmer climate. These changes might have significant implications for existing buildings and infrastructure, which were designed based on environmental loads estimated from historical observations (Steenbergen, Koster, & Geurts, 2012).

The NBCC defines wind load as the external pressure or suction due to wind on the surface of a building or structure (NRCC, 2015). The NBCC (NRCC, 2015) specifies the design wind pressure for various return periods for selected locations across Canada based on the design wind speed estimated from the Gumbel distribution fitted to the annual maximum series of hourly mean wind speed. Several studies have looked at the historical trends in the near-surface mean and extreme wind speeds, and they reported general decreasing trends across the globe (McVicar et al., 2012; Romanić, Ćurić, Jovičić, & Lompar, 2015). Vautard, Cattiaux, Yiou, Thépaut, and Ciais (2010) showed that surface wind speeds declined by 5–15% over almost all continental areas in the northern mid-latitude for the 1979–2008 period. Over Canada, Wan, Wang and Swail (2010) reported significant decreases in 10-m hourly wind speed for western Canada and most parts of southern Canada for all four seasons, while significant increases are reported for central Canadian Arctic for all seasons and for Maritimes during spring and autumn. Hundecha, St-Hilaire, Ouarda, El Adlouni, and Gachon (2008) showed increases in annual maximum wind speeds in a regional reanalysis over southern Maritimes based on 1979–2003 data. Holt and Wang (2012), Romanić, Hangan, and Ćurić (2016) and Romanić, Rasouli, and Hangan (2017) showed some positive trends in near surface wind speed for the northern US states (near the Canadian border), Great Lakes region, and an urban region in Toronto, primarily due to the increasing trend in westerly wind. Global Climate Models (GCMs), coupling atmosphere, land, ocean and sea-ice components of the earth system, are the most comprehensive tools used to assess climate-change projections. However, projected changes to extreme winds based on GCMs are less clear over Canada due to limited studies as well as the difficulties associated with their coarse resolution (IPCC, 2012). To

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http://dx.doi.org/10.1016/j.scs.2017.10.004
Received 20 December 2016; Received in revised form 30 June 2017; Accepted 5 October 2017
2210-6707/

address such constraints to some extent, Cheng, Li, Li, Auld, and Fu (2012) and Cheng, Lopes, Fu, and Huang (2014) developed a statistical downscaling model to generate future wind gust from eight GCM simulations and showed that frequency of wind gust events could increase across Canada by the end of the 21 century. Regional climate models (RCMs) are used to add physical details to GCM simulations and to investigate climate processes and extremes at fine spatial scales. However, detailed studies on regional-scale projections of extreme wind speeds based on RCM simulations and associated changes in design wind pressure of buildings/structures are not yet attempted for Canada.

Snow loading is specified to consider snow accumulation on roofs or any other building surface, and ground snow load is used as the reference to estimate roof snow loads in Canada (NRCC, 2015). The total snow load in the NBCC consists of two components: ground snow load and an associated rain load. The ground snow load is based on the 50-year return level estimated from the Gumbel distribution fitted to the annual maximum daily snow depth. The associated rain load is to consider wet snow conditions, which is constrained not to exceed the design ground snow load. Hong and Ye (2014) analyzed extreme snow load using observed snow depth data from 549 stations and suggested spatially interpolated maps for the ground snow loads for Canada. Peacock (2012) investigated projected changes to snow depth over North America using the Community Climate System Model, version 4 (CCSM4) global simulations and showed a general decrease across Canada and significant decrease over mountainous western Canada in January-March mean snow depth for the future (2080–2099) period with respect to current (1980–1999) period. On the other hand, Huziy et al. (2013) showed no significant changes in winter (DJF) mean snow water equivalent (SWE) over northeastern Canada for future 2041–2070 period with respect to the current 1970–1999 period, based on an ensemble of the Canadian RCM simulations. However, Canada-wide analyses of extreme ground snow, based on high-resolution RCMs, are still limited. Projected changes to rain-on-snow (ROS) events for the future 2041–2070 period with respect to the current 1976–2005 period over North America based on RCM simulations were studied by Jeong and Sushama (2017). Their study showed general increases in ROS frequency during November to March for most regions of Canada for the future period, due to an increase in the rainfall frequency with warmer air temperatures in the future. The rain component is not covered in the present study as it is usually smaller than 10% of the ground snow load component as reported in NBCC (Hong & Ye, 2014).

The main purpose of this study is to evaluate projected changes to the 50-year return levels of wind speed and ground snow and the associated wind pressure and ground snow load for the future 2071–2100 period, with respect to the current 1981–2010 period over Canada, using four different simulations from the fifth-generation Canadian Regional Climate Model (CRCM5). The CRCM5 is based on the numerical weather prediction model of Environment and Climate Change Canada (ECCC). The CRCM5 simulations considered in this study are driven by two GCMs (i.e., Canadian Earth System Model 2 (CanESM2) and 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 impacts to 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 21 st century compared to pre-industrial values, respectively (IPCC, 2013). As wind direction is important in determining wind pressure and the dynamic effects on buildings and structures, projected changes to wind direction of annual maximum wind speed are also assessed. Additionally, projected changes to winter snow density and probable dates of annual maximum ground snow are also evaluated in this study.

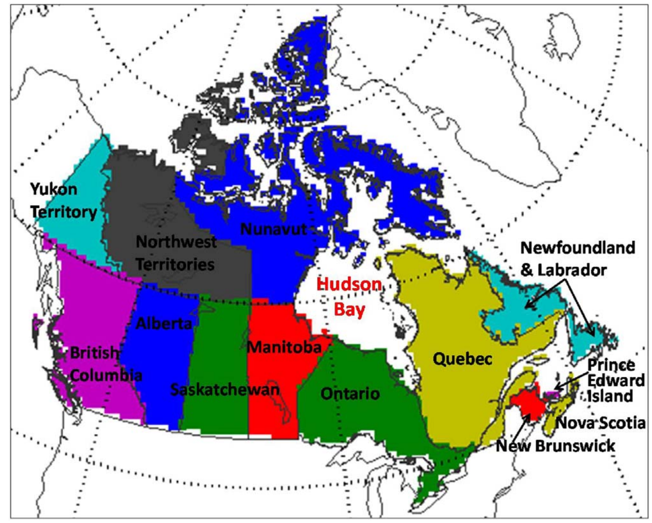

Fig. 1. Provines and Territories of Canada.

2. Model simulations and observed datasets

2.1. CRCM5 simulations

The CRCM5 is based on the Global Environmental Multiscale (GEM) model (Côté et al., 1998), and the physical parameterizations in CRCM5 are similar to those in GEM, except for the land surface and the radiation schemes. Radiation is parameterized by Correlated K solar and terrestrial radiation of Li and Barker (2005). Canadian Land Surface Scheme (CLASS) 3.5 (Verseghy, 2009, 2012) is employed 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.

The experimental domain of CRCM5 covers whole of North America and neighbouring oceans at 0.44° resolution. This study is however focused on the Canadian landmass only (Fig. 1). The atmospheric lateral boundary conditions are obtained from the ECMWF (European Centre for Medium-Range Weather Forecasts) gridded ERA-Interim reanalysis dataset at 0.75° resolution (Dee et al., 2011), the CanESM2 simulated dataset (Arora et al., 2011), and the MPI-ESM simulated data (Giorgetta et al., 2013). The simulation driven by the ERA-Interim reanalysis (CRCM5-ERA hereafter) for the 1981–2014 period is used for the evaluation of CRCM5. The CRCM5 simulations, driven by CanESM2 and MPI-ESM for the 1981–2014 period used in this study, are referred to as CRCM5-CanHist and CRCM5-MPIHist. These simulations are used to evaluate boundary forcing errors, when compared to the reference ERA-driven simulations (Jeong, Sushama, Khaliq, & Roy, 2014; Jeong, Sushama, Diro, & Khaliq, 2016; Jeong, Sushama et al., 2016). In addition to the above mentioned simulations, four CRCM5 simulations driven by CanESM2 and MPI-ESM for the RCP4.5 and RCP8.5 pathways, for the 2015–2100 period are also considered for the analysis of projected changes. For presentation convenience, these simulations are named as CRCM5-CanRCP4.5, CRCM5-CanRCP8.5, CRCM5-MPIRCP4.5, and CRCM5-MPIRCP8.5 to reflect both the boundary forcing dataset and emission pathway considered. To quantify projected changes, the simulations for the future 2071–2100 period are compared with that for the 1981–2010 period.