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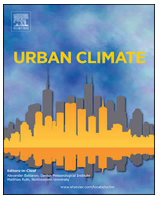

Multisite multivariate disaggregation of climate parameters using multiplicative random cascades

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ABSTRACT

The Multiplicative Random Cascade (MRC) disaggregation model has been extensively used to disaggregate precipitation in many regions across the globe. In this study, it is adapted to disaggregate a range of climate variables (CV) relevant for hygrothermal modelling of building envelopes. This generalized MRC-G model is further improved by explicitly modelling the cross-correlation structure between CVs in the MRC-G-CV model. A thorough evaluation of MRC, MRC-G, and MRC-G-CV models is performed for five Canadian cities: Ottawa, Vancouver, Calgary, St. Johns, and Winnipeg. Results indicate that the MRC model is able to simulate grid-level statistics with > 90% accuracy. Grid-level extreme magnitudes and spatial cross-correlation structures are also well simulated. Error magnitudes associated with hourly predictions indicate superior performance of the models in respect to thermal variables, followed by wind variables, and then moisture related variables. Finally, the performance of MRC-G model towards modelling cross-correlation among CVs is found to improve by > 50% in terms of energy distance by explicitly modelling these relationships in the MRC-G-CV model. Results indicate that the MRC model variants demonstrated in this study have the potential to facilitate effective hygrothermal performance evaluation of building envelopes at locations where observational sub-daily climate records are unavailable.

1. Introduction

Hygrothermal simulations have been identified as a tool for effective building envelope design (Glass et al., 2013). Heat, air, and moisture (HAM) models simulate hygrothermal response of building elements to external climate loads. As many as fifty-seven HAM models have been identified in Delgado et al. (2010) which require high temporal frequency climate observations for performing hygrothermal simulations. For example, one of the widely used HAM models, DELPHIN 5, requires hourly time-series of temperature, relative humidity, rainfall, wind-speed, wind direction, short and long wave radiation to perform coupled heat, moisture, and air transport simulation in buildings (Nicolai et al., 2007). Another HAM model is hygIRC that requires hourly time-series of temperature, relative humidity, wind speed, wind direction, cloud cover, rain, short and longwave radiation fluxes to perform hygrothermal simulations (Karagiozis, 1993; Djebbar et al., 2002).

It is already well recognized that sub-daily frequency climate observations are less abundant than the daily or monthly frequency climate observations (Westra et al., 2014). In fields such as hydrology, it is common to disaggregate readily available daily observations of precipitation into hourly values, which are then used for applications such as hydrologic modelling. Some of the common precipitation disaggregation models that have been used in the past include: Hyetos (Koutsoyiannis and Onof, 2001),

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Multivariate Disaggregation of Rainfall, MuDRain (Koutsoyiannis et al., 2003), Multiplicative Random Cascade, MRC (Thober et al., 2014; Olsson, 1998; Guntner et al., 2001; Paschalis et al., 2012), Randomized Bartlett Lewis Model (Onof and Wheater, 1993), and ClimGen (Stockle et al., 1999) among others. It is expected that precipitation disaggregation models are able to meet the minimum conditions (Thober et al., 2014) necessary for to preserving location specific climatic means, extremes, and spatial structure of the observed precipitation with acceptable accuracy.

Other variables apart from precipitation that are relevant for hygrothermal simulations of buildings have been disaggregated less frequently than precipitation. Prominent studies include that of Debele et al. (2007) where temperature, wind-speed, and relative humidity recorded at the Cedar creek watershed in Texas, USA were disaggregated from a daily to an hourly scale. Daily temperatures and wind-speeds were disaggregated using a simple cosine function, whereas disaggregated relative humidity was estimated using the disaggregated temperature values. Safeeq and Fares (2011) disaggregated temperature, wind-speed, and relative humidity to assess the performance of the *ClimGen* weather generator at four watersheds in Hawaii, USA. Temperature was disaggregated using the modified sine curve model (Waichler and Wigmosta, 2003), cosine model (de Wit, 1978), double cosine model (ESRA, 2000), and Erbs model (Erbs, 1984). Wind-speed and relative humidity were disaggregated using methodology similar to that used in Debele et al. (2007). In other studies temperature, wind-speed, and relative humidity have been disaggregated as described in Carapellucci and Giordano (2013) and Bregaglio et al. (2010), among others.

Studies have been performed to disaggregate daily solar irradiance by modelling the Clearness Index (Liu and Jordan, 1960) which is the ratio of solar radiation falling at the surface to that falling at the top of the atmosphere (Graham and Hollands, 1990; Aguiar and Collares-Pereira, 1992). Artificial Neural Network models have also been used to model hourly solar radiation directly from mean daily solar radiation, and have been found more accurate than the approaches based on modelling the Clearness Index (Hontoria et al., 2002; Ahmad et al., 2015). Yang and Koike (2002) developed a Sky Clearness Indicator coefficient to account for cloud effects and used it to account for cloud effects when disaggregating solar irradiance. Laslett et al. (2014) developed algorithms to estimate hourly cloud-fractions, developed novel indices of cloudiness, and used them to estimate hourly solar irradiance.

In the studies previously mentioned, different disaggregation techniques have evidently been used to disaggregate several different climate variables. This permitted consideration of the differences in physical processes operating at finer temporal scales for any given climatic variable. While this has been a commonly used approach, the purpose of this study is to investigate if a unified disaggregation approach can be used to model a broad range of sub-daily climate variables that are relevant to the hygrothermal simulation of building elements. The category of disaggregation models that simulate finer temporal scale data solely as a function of coarser scale data have the potential to be extended to a broad range of climate variables as climate variable specific assumptions are generally not included in them. For example, the disaggregation model MRC (Thober et al., 2014) that has been used extensively to disaggregate precipitation falls under this category. In the MRC model, weights that link coarser scale values of climate variables to finer scale values are modelled over space and time without making any specific assumptions in respect to the climate variable. Therefore the focus of this study is to determine the applicability of the MRC model to disaggregate a broad range of climate variables relevant for hygrothermal simulation of building elements, specifically, building envelopes.

This study also addresses another important aspect that is critical to hygrothermal modelling of building envelopes. Since the time-series of many different climate variables are used simultaneously in hygrothermal modelling, it is important that the disaggregated time-series of all climate variables are perfectly aligned to each other in time so that the entire set of climate loads are correctly informed to the HAM models. Accurate temporal alignment of climate variables is especially critical in hygrothermal studies that are focused on multivariable climatic extremes such as for example, wind-driven rain. Disaggregation models used in the past have not explicitly accounted for this cross-correlation among climate variables even though evidence of correlation among different climate variables have been found in many previous studies (Randall et al., 2007; Betts et al., 2014; Wang et al., 2017; Wasko et al., 2016; Westra et al., 2013; Russak, 2009). This study also adapts a more generalized version of the MRC model to explicitly account for cross-correlation among climate variables and validates if this brings an improvement in the performance of the model. The rest of the paper is organized as follows. In Section 2 the study-region considered for analysis in this study is described; disaggregation models considered and data used are described in section 3; a summary of the analysis performed and results obtained from the study is given in section 4; followed by conclusions in section 5.

2. Study region

The cities selected for analysis in this study are: Vancouver (VAN), Winnipeg (WNP), Ottawa (OTT), St. Johns (STJ), and Calgary (CLG). The geographical and demographic details (SC, 2017) of the cities are provided in Table 1 and their distribution across Canada is shown in Fig. 1. It can be seen that the cities are widely distributed across Canada, are major population centers, and are located in

Table 1

List of cities chosen for analysis and their geographical and demographic details.

City	Longitude (°E)	Latitude (°N)	Population (thousands) in 2016	Elevation (m)
Vancouver	−123.1	49.3	2548.7	82
Calgary	−114.1	51.0	1469.3	1045
Winnipeg	−97.1	49.9	811.9	239
St. Johns	−52.7	47.6	127.5	15
Ottawa	−75.7	45.4	1351.1	70