Journal of Hydrology 563 (2018) 51–64

Contents lists available at ScienceDirect

Journal of Hydrology

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

Research papers

Assimilation of near-real time data products into models of an urban basin

James M. Leach[a,*], Kurt C. Kornelsen[c], Paulin Coulibaly[a,b]

[a] Department of Civil Engineering, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4L7, Canada
[b] School of Geography and Earth Sciences, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4L7, Canada
[c] Ontario Power Generation, 14000 Niagara River Parkway, Niagara-on-the-Lake, Ontario L0S 1J0, Canada

ARTICLE INFO

This manuscript was handled by Emmanouil Anagnostou, Editor-in-Chief, with the assistance of Viviana Maggioni, Associate Editor

Keywords:
Data assimilation
Urban watershed
Ensemble forecasting
Hydrologic modeling
Soil moisture
Snow water equivalent

ABSTRACT

The goal of this study was to determine if assimilating a combination of various derived data products can help circumvent some of the difficulties associated with urban watershed modeling. Combinations of the SNODAS (Snow Data Assimilation System) snow water equivalent data, the SMOS (Soil Moisture and Ocean Salinity) L2 soil moisture, and streamflow observations were used for the data assimilation schemes. Combinations of these observation data sets were assimilated into lumped conceptual rainfall-runoff models of the highly-urbanized Don River basin (in southern Ontario) to determine if assimilation of geophysical variables will have a significant impact on simulations and forecasting in an urbanized watershed. The Ensemble Kalman Filter (EnKF) data assimilation method was used for these analyses, with various rainfall-runoff models that include GR4J, HyMod, MAC-HBV, and SAC-SMA models. The best data assimilation scheme for hydrologic modeling involved using a combination of streamflow, soil moisture, and snow water equivalent while performing both state and parameter updating. These results suggest that using a combination of soil moisture and snow water equivalent from the SMOS and SNODAS data products can improve simulations and ensemble forecasts in an urban basin.

1. Introduction

Urbanization is an increasing global trend which can have impacts on the hydrology of a watershed. These impacts include an increase in impervious surfaces, reduced infiltration, lower baseflow, increased runoff, and more flashy-ness in the hydrograph, all of which contribute to the difficulty in simulating an urbanized basin (McPherson and Schneider, 1974). Urban hydrology is important to understand and model due to the impacts it has on the often dense local population. Therefore, it is important to determine simple and easy methods which can be used to overcome the difficulties and improve rainfall-runoff modeling in urban areas. Previous studies have assessed the use of data assimilation to improve urban basin modeling by integrating one observation type such as water level or discharge (Branisavljevic et al., 2014; Hutton et al., 2014). This paper will explore the improvements data assimilation, which integrates multiple observation types, can have on urban basin modeling with various conceptual rainfall-runoff models.

Both the soil moisture and snow water equivalent (SWE) play important roles in the hydrology of a watershed and have been shown to improve streamflow estimations when assimilated into a hydrologic model (Huang et al., 2017; Moradkhani, 2008; Samuel et al., 2014). Better quantification of soil moisture in a watershed leads to a more accurate estimation of the rainfall quantity that becomes runoff or infiltration. In northern and/or snow-dominated basins snowmelt can be a large contributor to runoff, therefore better estimates of snowmelt, in the form of snow water equivalent, can lead to better estimation of streamflow (Moradkhani, 2008). These observations are available through several data products which can provide informative variables at near real-time frequency, can be used for data assimilation, and are of interest to hydrologists.

Possible data products include the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) data (Rodríguez-Fernández et al., 2017), the National Aeronautics and Space Administration's (NASA) Soil Moisture Active Passive (SMAP) data, and the National Operational Hydrologic Remote Sensing Center's (NOHRSC) Snow Data Assimilation System (SNODAS) data to name a few (Entekhabi et al., 2008; Kerr et al., 2010; National Operations Hydrologic Remote Sensing Center, 2004). The NOHRSC has provided daily gridded estimates of snow parameters such as SWE through the SNODAS program since 2004 (National Operations Hydrologic Remote Sensing Center, 2004). This paper will explore the use of the SMOS L2 soil moisture and the SNODAS snow water equivalent data products for assimilation into conceptual rainfall-runoff models to determine if they can be used to improve hydrologic modeling in an urban basin. Data assimilation will be used to help merge these datasets with the hydrologic models while

* Corresponding author.
E-mail address: leachjm@mcmaster.ca (J.M. Leach).

https://doi.org/10.1016/j.jhydrol.2018.05.064
Received 10 April 2018; Received in revised form 26 May 2018; Accepted 28 May 2018
Available online 30 May 2018
0022-1694/

also accounting for the uncertainty in both the models and the data products (Liu et al., 2012; Reichle, 2008).

The Ensemble Kalman Filter (EnKF) proposed by Evensen (1994) was used for data assimilation in these analyses. There are several examples in which the EnKF has been used for hydrologic modeling and forecasting (Abaza et al., 2014; Alvarez-Garreton et al., 2015; Clark et al., 2008; Crow and Ryu, 2009; Dumedah and Coulibaly, 2013; Komma et al., 2008; Massari et al., 2015; Moradkhani et al., 2005; Neal et al., 2007; Samuel et al., 2014; Thiboult and Anctil, 2015; Vrugt and Robinson, 2007; Wanders et al., 2014; Weerts and El Serafy, 2006). Moradkhani et al., (2005) proposed dual state parameter updating using the EnKF, and Samuel et al. (2014) found that using both streamflow and soil moisture observations together to update state and model parameters provided more accurate forecasts. Snow data assimilation, which includes assimilation of SWE, has also been examined in previous studies and has been shown to improve hydrologic simulations and forecasts (Bergeron et al., 2016; Dziubanski and Franz, 2016; Huang et al., 2017; Liu et al., 2012; Moradkhani, 2008). Building on these previous findings, this study will assess some combinations of streamflow, SWE, soil moisture in a dual state parameter updating scheme with different hydrologic models to enhance streamflow forecast in urban watershed.

2. Study area and data

The study area being focused on in this paper is the Don River basin (DRB) in Toronto, Ontario, Canada (Fig. 1). The DRB is managed by the Toronto Region Conservation Authority (TRCA). It contains several subcatchments, the largest of them being the Upper East Don, German Mills Creek, Lower East Don, Upper West Don, Lower West Don, Taylor-Massey Creek, and the Lower Don River. The DRB is approximately 350 km^2 and is a mostly urban watershed being roughly 80% developed, with the remaining area being split between crops, and pasture, forest, and wetland (Natural Resources Canada, 2009). This area has an average daily temperature of 9.4 °C (the average daily minimum and maximum temperatures are 5.9 °C–12.9 °C respectively) and an average annual precipitation of 831.3 mm/year based on the 1981–2010 Canadian Climate Normals (Environment and Climate Change Canada, 2017). Major soils in the DRB include sandy loam, loam, clay loam, and clay (Ontario Ministry of Agriculture, 2015), and its elevation ranges from 75 to 330 m above mean sea level (masl).

Daily precipitation, temperature, and snow depth data sets were obtained from Environment and Climate Change Canada (ECCC) weather stations, and evapotranspiration was estimated using the Penman-Monteith equation (Monteith, 1965). Three observation data sets were used for data assimilation, they are daily streamflow data from Environment Canada's hydrometric database (HYDAT), daily SWE from SNODAS (National Operations Hydrologic Remote Sensing Center, 2004), and daily soil moisture (SM) from the ESA's SMOS satellite (Kerr et al., 2010).

3. Methodology

3.1. Data processing

3.1.1. SNODAS snow water equivalent data

One of this study's goals is to assess the assimilation of snow data as SWE into models of an urban basin. Several SNODAS data products are available including SWE and snow depth. The SNODAS SWE data product will be the source for the data being assimilated. The SNODAS products are developed as follows. First, data from the Rapid Refresh numerical weather prediction model (Rapid Update Cycle numerical weather prediction model for dates before May 1, 2012) are downscaled from 13 to 1 km^2. Next, these data are used to drive the NOHRSC Snow Model (NSM) at a resolution of 1 km^2. Finally, available remote sensing, radar, and ground station snow observations are assimilated into the model using a Newtonian nudging technique to produce a best estimate of near real-time snow conditions (Carroll et al., 2006; Clow et al., 2012). To determine the validity of using the SNODAS data, the ECCC snow on ground (snow depth) data available at gauges within and near the DRB was used to validate and bias correct the SNODAS snow depth and SWE data. This was done since SWE and snow depth are related and there are no SWE measurements available from ECCC.

A cumulative distribution function (CDF) matching bias correction

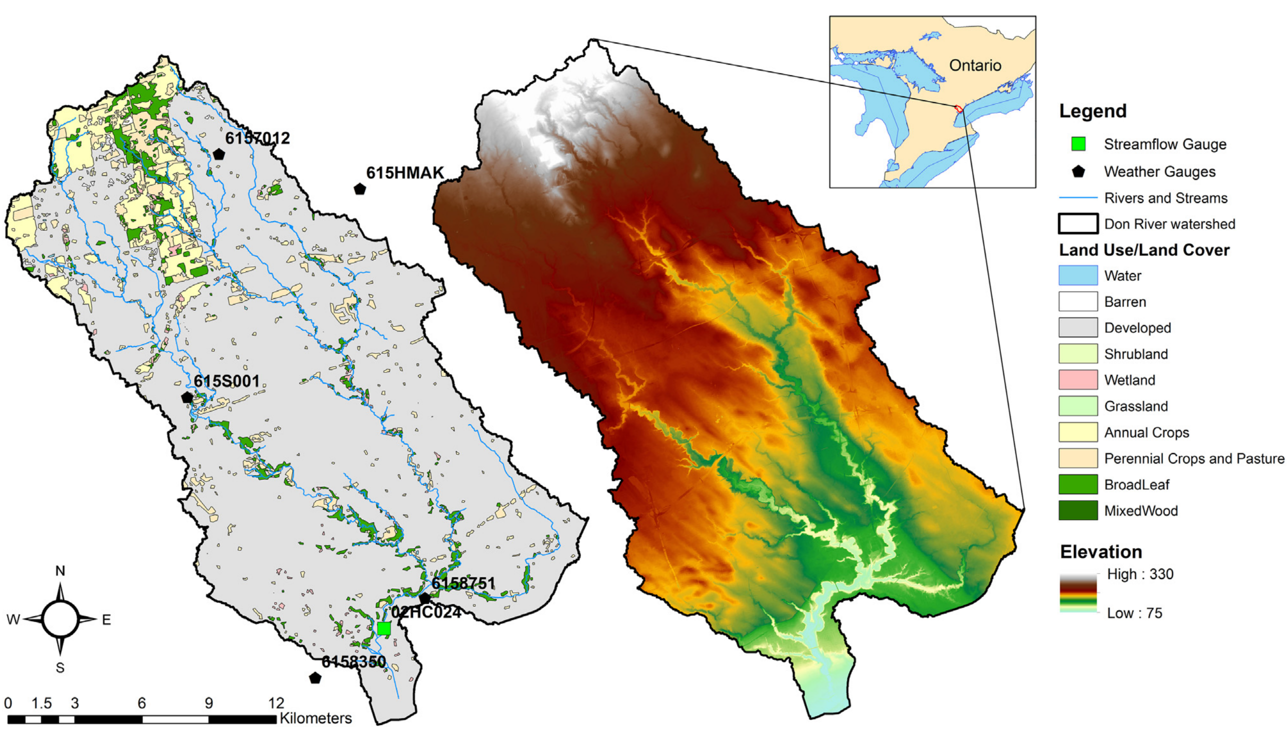

Fig. 1. Land use and land cover (left) (Natural Resources Canada, 2009), and topography (right) for the Don River basin in Ontario.