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The Great Lakes Runoff Intercomparison Project Phase 1: Lake Michigan (GRIP-M)

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SUMMARY

We assembled and applied five models (one of which included three different configurations) to the Lake Michigan basin to improve our understanding of how differences in model skill at simulating total runoff to Lake Michigan relate to model structure, calibration protocol, model complexity, and assimilation (i.e. replacement of simulated discharge with discharge observations into historical simulations), and evaluate historical changes in runoff to Lake Michigan. We found that the performance among these models when simulating total runoff to the lake varied relatively little, despite variability in model structure, spatial representation, input data, and calibration protocol. Relatively simple empirical, assimilative models, including the National Oceanic and Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory (GLERL) area ratio-based model (ARM) and the United States Geological Survey (USGS) Analysis of Flows in Networks of CHannels (AFINCH) model, represent efficient and effective approaches to propagating discharge observations into basin-wide (including gaged and ungaged areas) runoff estimates, and may offer an opportunity to improve predictive models for simulating runoff to the Great Lakes. Additionally, the intercomparison revealed that the median of the simulations from non-assimilative models agrees well with assimilative models, suggesting that using a combination of different methodologies may be an appropriate approach for estimating runoff into the Great Lakes. We then applied one assimilative model (ARM) to the Lake Michigan basin and found that there was persistent reduction in the amount of precipitation that becomes runoff following 1998, corresponding to a period of persistent low Lake Michigan water levels. The study was conducted as a first phase of the Great Lakes Runoff Intercomparison Project, a regional binational collaboration that aims to systematically and rigorously assess a variety of models currently used (or that could readily be adapted) to simulate basin-scale runoff to the North American Laurentian Great Lakes.

1. Introduction

Large-scale hydrologic models have historically been applied to a wide variety of freshwater resource and ecosystem management problems (e.g. Alcamo et al., 2003; Fekete et al., 2002; Tang et al., 2010). Specific examples range from quantifying interbasin water transfers (Hanasaki et al., 2010; Islam et al., 2007) and simulating impacts of human-induced stressors on global and regional water budgets (McCabe and Wolock, 2011; Nijssen et al., 2001a; Mao and Cherkauer, 2009), to modeling the atmospheric water balance (Xia et al., 2012), predicting soil moisture (Nijssen et al., 2001b) and crop irrigation demands (Wisser et al., 2008), simulating

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nutrient and sediment fluxes (Robertson and Saad, 2011; Seitzinger et al., 2010), and providing a streamflow boundary for coastal ocean models (Nakada et al., 2012). The geographic extent of these applications is equally broad. However, we find that the North American St. Lawrence River basin, while among the largest in the world (Fig. 1) and containing the world's largest system of lakes (i.e. the Laurentian Great Lakes), is the subject of relatively few basin-wide water budget modeling studies at a spatial resolution and across temporal scales suitable for addressing the challenges associated with managing this freshwater resource. In fact, the challenges facing the Great Lakes require an in-depth understanding, addressed in part by regional water budget modeling, of how the dynamics of the Great Lakes-St. Lawrence River basin's water budget impact Great Lakes water levels (Brinkmann, 2000), compliance with international water use agreements (i.e. the Great Lakes Compact), and the human, environmental, and economic well-being of North America (among other impacts, as described in Wilson and Carpenter (1999), Buttle et al. (2004), Millerd (2005)). For further discussion on Great Lakes basin water budget modeling and examples, see Coon et al. (2011), Lofgren et al. (2011).

1.1. Rationale for the Great Lakes Runoff Intercomparison Project (GRIP)

In recent years, the need to quantify each component of the lakes' net basin supply (i.e. runoff, over-lake precipitation, and over-lake evaporation) has gained significant attention due to recent persistent extreme low lake levels, especially in the Lake Michigan-Huron system (Gronewold and Stow, 2014). Quantifying the water balance and associated fluxes in the St. Lawrence basin (Fig. 1) is complicated by the Great Lakes themselves, which represent approximately 30% of the total basin area, and have a coastline of over 7000 km in the U.S. alone (Gronewold et al., 2013b). More specifically, modeling St. Lawrence River flows requires explicit computation of runoff, over-lake precipitation, and over-lake evaporation within the Great Lakes basin. Each of these three components is of roughly the same order of magnitude, and each is monitored at different (and, in the case of over-lake evaporation and over-lake precipitation, extremely coarse) spatial and temporal scales (for recent and historical perspectives, see Derecki (1976), Blanken et al. (2011), Holman et al. (2012)).

The uncertainty in Great Lakes basin runoff estimates and the corresponding uncertainty in the influence of runoff changes on water levels in the Great Lakes, the increasing number of runoff and water budget models being developed and applied within the Great Lakes basin, and the limited extent to which these models have been systematically evaluated and compared to one another, collectively underscore a need for Great Lakes basin runoff intercomparison studies (Gronewold et al., 2011; Coon et al., 2011; Lofgren et al., 2011). Gronewold and Fortin (2012) further emphasize the importance of improving Great Lakes basin-wide runoff estimates, and of maintaining the trajectory and momentum in regional collaborative research established during the recently-completed International Joint Commission (IJC) International Upper Great Lakes Study (IUGLS).

To address these needs, the Great Lakes Runoff Intercomparison Project (GRIP) was initiated to assess runoff models for simulation of runoff to the Great Lakes and advance the state-of-the-art in basin-scale hydrological modeling, beginning with assessing simulations of historical monthly runoff to Lake Michigan (GRIP-M). Because our study focuses on model skill for application to simulation of historical monthly runoff to Lake Michigan, the objectives differ from previous intercomparison studies, in that the skill of spatially and temporally aggregated monthly discharge is evaluated, in addition to performance at individual gages. Specifically, the objectives of GRIP-M are to compare historical runoff estimates from a group of models that are readily adaptable to Great Lakes basin-wide hydrological modeling, understand differences in data

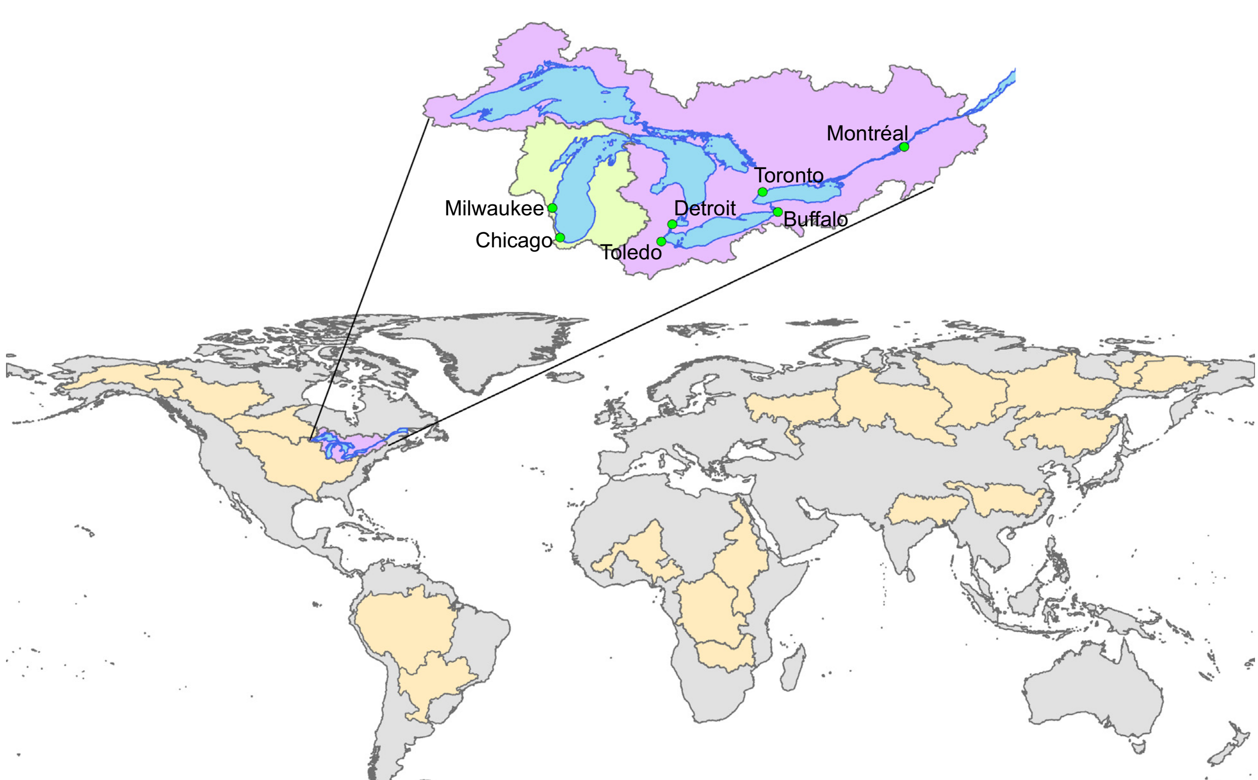

Fig. 1. Twenty largest (by basin surface area) river basins of the world, with detail of the Great Lakes – St. Lawrence River basin and the Lake Michigan basin. Derived from data provided by World Resources Institute (WRI) (2006).