Environment Canada Environnement Canada

UNIVERSITY OF WATERLOO

The Great Lakes Runoff Intercomparison Project (GRIP): Phase II - Lake Ontario

Poster: H23-1648

E. Gaborit[1], V. Fortin[1], B. Tolson[2], L.M. Fry[3], T.S. Hunter[4], and A.D. Gronewold[4,5]

[1]Environment Canada, Environmental Numerical Prediction Research (E-NPR), [2]University of Waterloo, Civil and Environmental Engineering, [3]U.S. Army Corps of Engineers, Detroit District, [4]NOAA Great Lakes Environmental Research Laboratory, [5]Univ. of Michigan, Dept. of Civil and Environmental Engineering

Introduction

The Great Lakes Runoff Inter-comparison Project for Lake Ontario (GRIP-O) is a continuation of research initiated through GRIP-M (the Lake Michigan phase of GRIP; for details see Fry et al. 2014), and aims to compare runoff estimates from different hydrological models for the international watershed of Lake Ontario (figure 1). Modeling the hydrologic response of the Lake Ontario watershed is challenging because many of its tributaries have a regulated flow regime, a significant portion of the watershed is ungauged, and because the watershed is bisected by the United States (US) – Canadian border. Consequently, meteorological and hydrological data for model forcing, calibration, and verification is derived from monitoring networks with a variable spatial density across two countries.

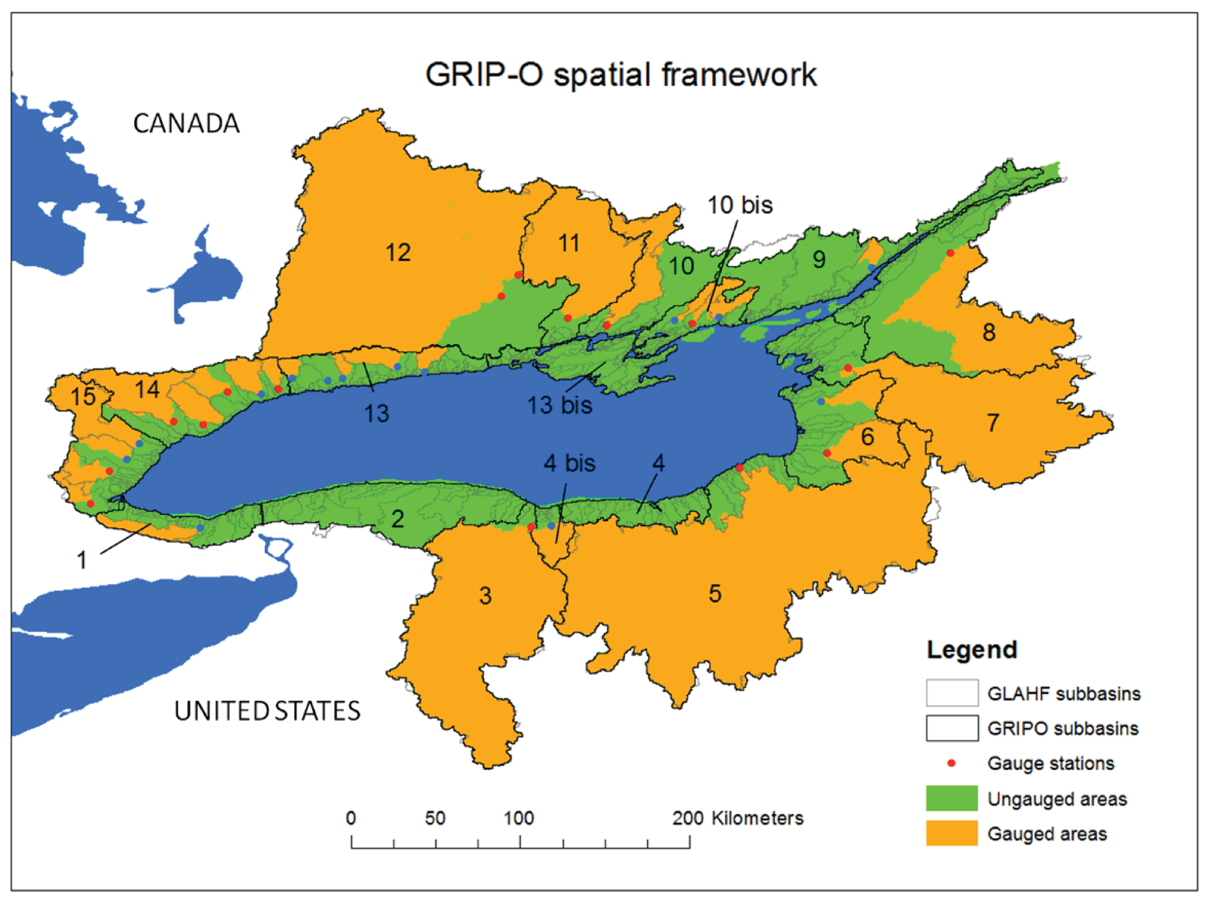

Figure 1: Spatial framework for the GRIP-O project, including watershed delineations from the Great Lakes Aquatic Habitat Framework (GLAHF), the sub-basins of the entire Lake Ontario watershed, and gauging stations. Gauging stations identified by a blue dot represent those on unregulated tributaries that are used in model calibrations, and gauging stations identified by a red dot are on regulated tributaries. The brown area represents the total gauged area of the lake Ontario watershed (see table 1 for details).

Methods

Models

We compare two global lumped models; GR4J (modèle du Génie Rural à 4 paramètres Journalier) coupled to the Cémaneige snow module, and the NOAA large basin runoff model (LBRM). LBRM was developed specifically to deal with large basins of the Great Lakes' watershed (Croley 1983), however GR4J has, to our knowledge, never been applied in this region (despite success applied in other areas; see Pagano et al. 2010, Seiller et al. 2012).

Both models require daily watershed-average values of precipitation, maximum and minimum air temperature, and catchment area. GR4J also requires the mean watershed latitude (for the potential evapo-transpiration formulation) and elevation.

Data and model calibration

We calibrated each model using two readily-available precipitation datasets; the Canadian Precipitation Analysis (CaPA: Mahfouf et al. 2007) and the NOAA National Climate Data Center (NCDC) Global Historical Climatology Network - Daily (GHCND, see Menne et al. 2012). CaPA is based on modeled precipitation fields derived from the Canadian Regional Deterministic Prediction System (RDPS) and is corrected using ground-based precipitation observations. The NOAA GHCND is based primarily on Canadian and US meteorological stations, and we interpolated both data sets on a 15 arcsec. grid (around 450 m near Lake Ontario) using a nearest neighbor method. Runoff estimates (for model calibration) were derived from USGS monitoring stations in the US and Canadian flow data from the HYDAT database.

The full suite of model forcing and calibration data was available for a period beginning in June 2004; we therefore selected June 2004 through May 2005 as a model `spin-up' period, June 2005 through May 2007 as a verification period, and June 2007 through December 2011 as a calibration period.

Our study addresses the following questions:

1. What combination of hydrological model and meteorological forcings lead to optimal simulation of hydrological response in the Lake Ontario watershed?
2. How well do hydrological models in this region account for regulation impacts on runoff?
3. How does a relatively generic model (GR4J) that has never before been applied to the Great Lakes region compare to a regionally-specific model (the LBRM)?
4. Is hydrological modeling skill related to skill of precipitation forcings at the sub-basin scale?
5. What is the best approach to comparing model simulations of total catchment runoff while accounting for ungauged flows?

Results and Discussion

Our analysis indicates that both GR4J and the LBRM performed well across the Lake Ontario watershed but that GR4J, on average, had higher skill. For example, we found that the Nash-Sutcliffe efficiency (NSE) for GR4J with GHCND precipitation (table 1) ranged from 62 to 88 in the calibration period, and from 53 to 86 in the validation period, across the 14 sub-watersheds in our study. In the sub-watershed with the highest skill for GR4J during the calibration period (sub-watershed 11), LBRM skill was also very high (NSE value was 84, see figure 2).

Table 1: Skill evaluation of GR4J with GHCND precipitation. Calibration (CAL) and validation (VAL) results are expressed as percentages.

								CAL				VAL			
country	Subbasin #	Cal. scheme	Station	%_gauged	Area(km^2)	Flow regime	mean elev. (m)	Nash	Nash sqrt	Nash Ln	PBIAS	Nash	Nash sqrt	Nash Ln	PBIAS
CA	1	2	20_mile	100	307	natural	198	77	80	76	16	82	87	86	15
USA	3	2	Genessee	100	6317	regulated	418	81	83	79	2	79	81	82	3
USA	4bis	2	Irondequoit	100	326	natural	172	67	71	66	2	53	64	69	20
USA	5	2	Oswego	100	13287	regulated	259	84	83	79	2	71	73	72	12
USA	6	1	N/A	40	2406	mixed	264	71	76	76	2	73	77	79	13
USA	7	2	Black river	100	4847	regulated	471	79	82	82	2	75	75	72	9
USA	8	2	Oswegatchie	100	2543	regulated	250	79	82	84	2	82	84	85	9
CA	10	2	Salmon_CA	100	912	regulated	196	86	88	81	7	82	86	77	3
CA	10bis	1	N/A	44.2	944	mixed	115	82	89	85	8	78	81	79	10
CA	11	2	Moira	100	2582	regulated	228	88	90	84	4	82	81	75	0
CA	12	1	N/A	88	12515.5	regulated	282	73	73	66	4	66	69	62	-14
CA	13	1	N/A	40.3	1537.5	natural	178	62	66	63	3	65	70	70	-1
CA	14	1	N/A	61.3	2689.4	mixed	209	79	78	71	5	71	77	76	9
CA	15	1	N/A	63	2245.8	mixed	263	86	84	71	1	86	87	84	-8

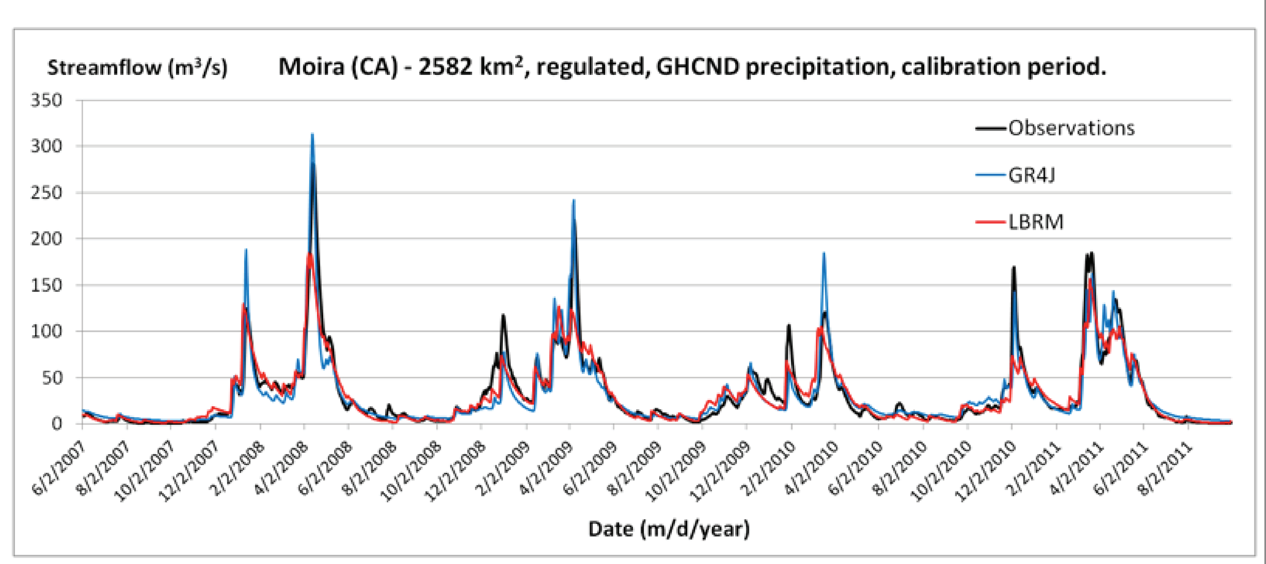

Figure 2: Hydrographs of streamflow at the Moira River gage (sub-basin 11) based on observations, as well as GR4J and LBRM simulations using the GHCND precipitation data. NSE-SQRT values for this period for GR4J and LBRM are, respectively, 89.6 and 89.6 and NSE values are 88.2 and 83.8.

A detailed comparison between the two models in sub-watershed 11 during the calibration period (figure 2) also indicates that GR4J has a tendency to predict higher peak flows during extreme runoff events relative to the LBRM. Of the 8 extreme runoff events in sub-watershed 11 between June 2007 and August 2011, GR4J simulations were noticeably high than LBRM in 5 (with no noticeable difference in the other 3). Of those 5 events, GR4J closely matched observed streamflow records in 3, while LBRM more closely match flow records in 2.

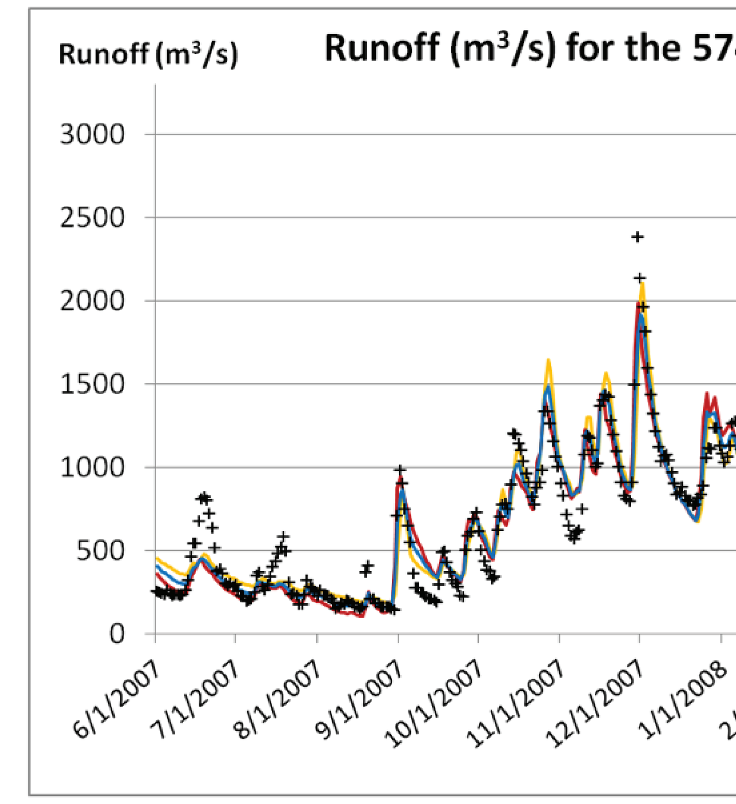

Figure 3: Comparison between ensemble of simulated runoff for the Ontario watershed during the study vaidation period.

Overall, we find that the GR4J had higher skill when compared to the LBRM (table 2). For, example, the NSE of GR4J was, on average, 3.8 percent higher than LBRM during the calibration period, and 7.3 percent higher than LBRM during the verification period when using the GHCND precipitation data. Interestingly, the overall difference in model skill was less in US watersheds when using CaPa precipitation data. Furthermore, GHCND precipitation data tended to contribute to higher skill for a given model compared to the CaPa precipitation data (table 3), with a particularly noticeable improvement in skill for GR4J in the US watersheds.

Analysis of simulated flows for the entire Lake Ontario watershed (figure 3) indicate some discrepancies between the synthetic flow estimates from the GHCND database, and the various ensembles of flow simulations from GR4J and the LBRM. Reasons for this discrepancy include the fact that there are potential errors in the meteorological forcings from both the GHCND database and CaPa, the density of the GHCND network in the Canadian portion of the Lake Ontario watershed is relatively low, and there is a tendency of the GHCND-based records to misrepresent precipitation spatiotemporal variability in summer where convective events can occur locally between rain gauges.

Table 2: Difference between Nash-Sutcliffe efficiency (NSE) of GR4J and LBRM during calibration (CALIBR) and validation (VALID) periods (values expressed as percentages) using both GHCND and CaPa precipitation forcings. NSE values are calculated using both the square root of flow (NASHSQRT) and unconverted flow measurements (NASH).

		GLERL_P.				CAPA_P.			
		NASH SQRT		NASH		NASH SQRT		NASH	
Subbasin	Country	CALIBR	VALID	CALIBR	VALID	CALIBR	VALID	CALIBR	VALID
1	CA	9.1	14.4	12.8	21.7	9.1	15.0	14.6	22.5
3	US	2.9	7.4	3.3	6.7	1.0	-0.2	1.4	1.2
4bis	US	-2.6	9.5	4.0	7.6	-1.6	4.2	3.5	11.4
5	US	-4.0	-3.8	-4.6	-3.5	-6.0	-8.4	-7.2	-15.6
6	US	8.1	5.5	10.3	9.2	2.3	0.1	4.0	1.8
7	US	4.1	1.3	5.4	7.2	-1.4	2.2	-5.5	-2.8
8	US	5.8	8.8	3.6	10.6	0.6	6.9	-0.8	9.8
10	CA	-1.9	2.6	-2.6	1.8	-1.5	1.5	-5.9	6.1
10bis	CA	2.8	0.4	4.0	-3.6	1.6	4.6	-2.0	8.1
11	CA	0.0	0.3	4.4	7.9	0.6	0.3	2.0	2.5
12	CA	-2.4	-4.3	0.4	-2.1	-2.8	-0.7	0.2	-0.4
13	CA	0.5	-1.2	9.4	-0.3	5.6	-8.4	10.5	-13.1
14	CA	0.5	0.5	4.8	3.3	2.7	-2.7	8.1	4.6
15	CA	-1.7	8.7	7.9	12.2	0.8	3.6	8.0	1.7
	median US	3.5	6.4	3.8	7.4	-0.4	1.1	0.3	1.5
	median CA	0.2	0.4	4.6	2.5	1.2	0.9	5.0	3.5
	median	0.5	1.9	4.2	6.9	0.7	0.9	1.7	2.2
	number of positive cases	9/14	11/14	12/14	10/14	9/14	9/14	10/14	10/14

Table 3: Difference in Nash-Sutcliffe efficiency (NSE) when models (LBRM and GR4J) employ GHCND precipitation estimates compared to CaPa precipitation estimates. NSE values are calculated using both the square root of flow (NASHSQRT) and unconverted flow measurements (NASH).

		LBRM				GR4J			
		NASH SQRT		NASH		NASH SQRT		NASH	
Subbasin	Country	CALIBR	VALID	CALIBR	VALID	CALIBR	VALID	CALIBR	VALID
1	CA	0.1	7.2	0.9	1.9	0.1	6.6	-0.9	1.1
3	US	1.1	5.4	0.6	5.4	3.0	13.0	2.5	10.9
4bis	US	3.9	-8.6	6.3	-5.2	2.9	-3.3	6.7	-8.9
5	US	1.8	2.5	1.9	3.1	3.8	7.0	4.5	15.2
6	US	-0.2	-5.5	1.2	-9.7	5.6	0.0	7.5	-2.4
7	US	3.9	2.6	3.5	1.5	9.4	1.7	14.4	11.4
8	US	5.8	0.4	6.4	3.4	11.0	2.3	10.7	4.2
10	CA	2.1	-0.3	2.3	2.2	1.7	0.8	5.5	-2.1
10bis	CA	1.0	-0.7	1.0	5.6	2.1	-4.9	7.0	-6.1
11	CA	2.2	-2.9	-0.2	-3.2	1.6	-2.8	2.1	2.2
12	CA	2.6	-4.1	2.1	-5.6	3.0	-7.7	2.3	-7.3
13	CA	1.6	-0.5	-1.3	-1.9	-3.5	6.7	-2.3	10.9
14	CA	1.9	6.2	2.4	11.8	-0.3	9.4	-1.0	10.5
15	CA	0.9	-1.3	1.7	-1.4	-1.6	3.7	1.5	9.1
	median US	2.8	1.4	2.7	2.3	4.7	2.0	7.1	7.6
	median CA	1.7	-0.6	1.3	0.2	0.9	2.3	1.8	1.7
	median	1.9	-0.4	1.8	1.7	2.5	2.0	3.5	3.2
	number of positive cases	13/14	7/14	12/14	8/14	11/14	10/14	11/14	9/14

Summary of key findings

1. Using a simple area-ratio method for extrapolating flows across the Lake Ontario watershed appears to provide reasonable results, particularly at the space and time scales considered in this study; similar findings were reported in the first phase of the GRIP project (i.e. GRIP-M).
2. We did not find significant relationships between model skill and catchment properties (including elevation and area, among others).
3. It is likely that GR4J has higher skill in this area because it more accurately simulates hydrologic response in regulated tributaries when compared to the LBRM.
4. In future research, we expect to employ results of this study into an analysis and comparison of models in seasonal forecasting systems for Great Lakes water budgets and water levels.

Acknowledgements

Funding for this research was provided by NOAA, Environment Canada, and the International Joint Commission International Watersheds Initiative. The authors thank Milena Dimitrijevic (E-NPR, Environment Canada, CMC Dorval) for providing scripts for calculating precipitation and temperature values across the Lake Ontario watershed.

References

Croley, T. 1983. Great Lakes basins (U.S.A.-Canada) runoff modeling. *Journal of Hydrology*, 64: 135-158.

Fry, L.M., Gronewold, A.D., Fortin, V., Buan, S., Clites, A.H., Luukkonen, C., Holtschlag, D., Diamond, L., Hunter, T., Seglenieks, F., Durnford, D., Dimitrijevic, M., Subich, C., Klyszejko, E., Kea, K., and Restrepo, P. 2014. The Great Lakes Runoff Intercomparison Project Phase 1: Lake Michigan (GRIP-M). *Journal of Hydrology*, 519(D), 3448-3465.

Hunter, T., Clites, A. H., Campbell, K. B., & Gronewold, A. D. (2015). Development and application of a North American Great Lakes hydrometeorological database - Part I: precipitation, evaporation, runoff, and air temperature. Journal of Great Lakes Research, 41(1).

Mahfouf, J.-F., Brasnett, B., and Gagnon, S. 2007. A Canadian precipitation analysis (CaPA) project: Description and preliminary results. *Atmosphere-Ocean*, 45(1): 1-17.

Menne, M.J., Durre, I., Vose, R.S., Gleason, B.E., and Houston, T.G. 2012. An overview of the Global Historical Climatology Network-Daily Database. *Journal of Oceanic and Atmospheric Technology*, 29: 897-910.

Pagano, T., Hapuarachchi, P., and Wang, Q. 2010. Continuous rainfall-runoff model comparison and short-term daily streamflow forecast skill evaluation. CSIRO Tech. Rep. EP103545, 70 pp., CSIRO, Australia.

Seiller, G., Anctil, F., and Perrin, C. 2012. Multimodel evaluation of twenty lumped hydrological models under contrasted climate conditions. *Hydrol. Earth Syst. Sci.*, 16: 1171–1189.

Wang, L., Riseng, C.M., Mason, L.A., Wehrly, K.E., Rutherford, E.S., et al. 2015. A spatial classification and database for management, research, and policy making: The Great Lakes aquatic habitat framework. *Journal of Great Lakes Research* 41(2):584-596 (DOI:10.1016/j.jglr.2015.03.017).