The Great Lakes Runoff Intercomparison Project

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Introduction

As a continuation of investments in the development of alternative methods for estimating major components of the Great Lakes water budget through the recently-completed International Joint Commission (IJC) International Upper Great Lakes Study (IUGLS), representatives from Environment Canada (EC), U.S. Geological Survey (USGS), NOAA's National Weather Service (NWS), and NOAA's Great Lakes Environmental Research Laboratory (GLERL) have formed a bi-national collaboration to assess alternative methods for simulating runoff across large lake basins. Models or modeling frameworks (and contributing agencies) participating in the project include (but are not limited to) Analysis of Flows in Networks of Channels (or AFINCH, from USGS), the Community Hydrologic Prediction System (or CHPS, from NWS), several configurations of the *Modélisation Environmentale Communautaire* - Surface Hydrology system (or MESH, from Environment Canada), the Large Basin Runoff Model (or LBRM, from GLERL) as well as the Area Ratio Method of extrapolation (or ARM, from GLERL). Initial research considers the Lake Michigan Basin (GRIP-M); a next phase will consider Lake Ontario (GRIP-O).

Models

The GRIP analysis considers eight models and model configurations that represent a variety of types of runoff models and operate at different spatial and temporal scales (Figure 1 and Table 1).

Table 1. Summary of models evaluated in the GRIP-M project.

	Regression	Lumped Conceptual	Distributed Conceptual	Coupled	Uncoupled	Temporal Resolution
ARM	X				X	Daily, aggregated to monthly
AFINCH	X				X	Monthly
LBRM	X	X			X	Monthly
CHPS		X			X	Sub-daily, aggregated to monthly
MESH-Standalone			X		X	Daily or Monthly
MEC-MESH			X	X		Daily or Monthly
MESH-HydroSHEDS with high-resolution routing			X	X		Daily or Monthly
MESH-HydroSHEDS with land surface and routing			X	X		Daily or Monthly

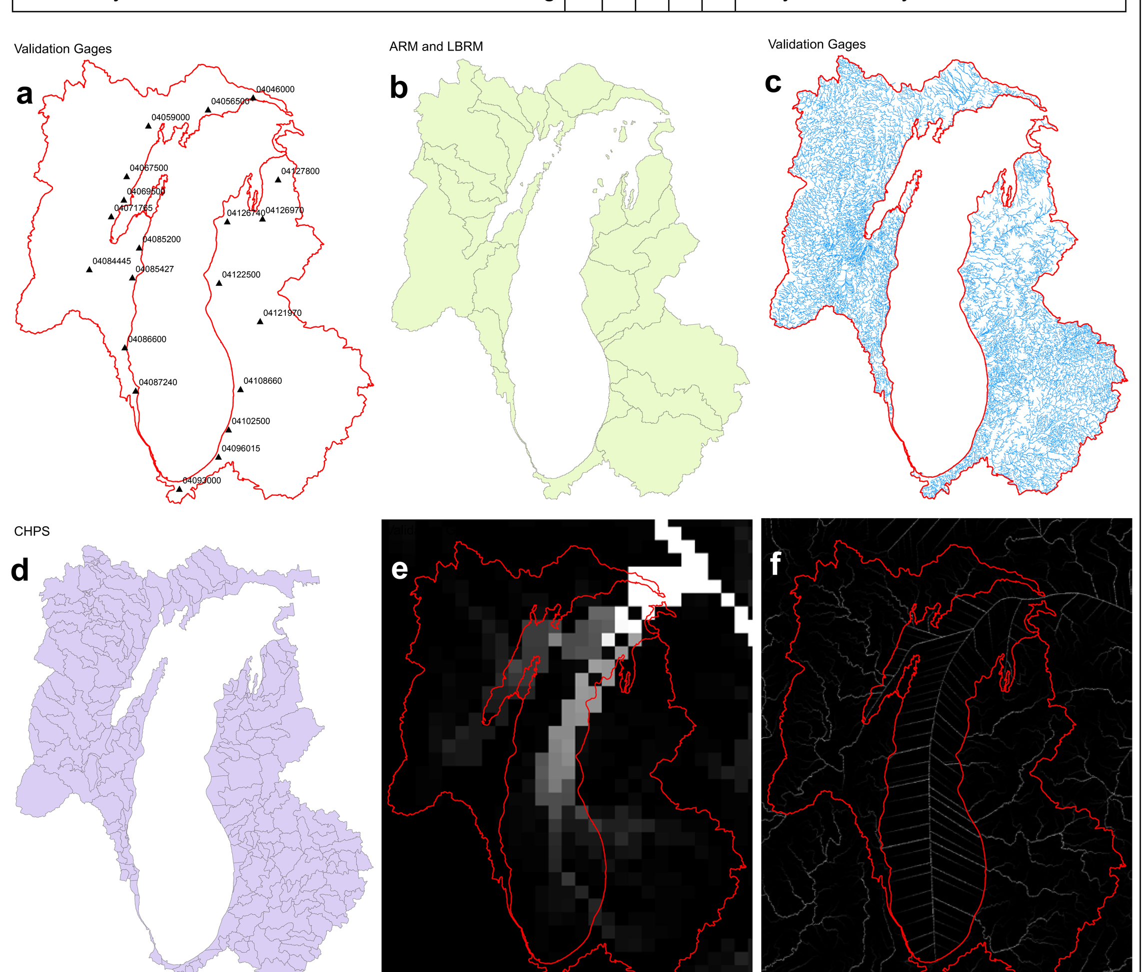

Figure 1. (a) Locations of the USGS gages used for the validation component of the project. **(b-f)** Spatial framework of each model considered in the GRIP-M analysis. **(b)** LBRM and ARM are lumped parameter and regional regression models, respectively, operating on 27 subbasins in the basin. **(c)** AFINCH applies a regression model to 31,820 NHDplus flowlines in the basin, constraining flow to observed discharge where gages provide monthly observations. **(d)** CHPS is a lumped parameter model operating on 211 hydrologic units in the basin. **(e-f)** MESH is a distributed model configured for (e) a low resolution land surface model (MESH-Standalone and MEC-MESH) or **(f)** high resolution routing or high resolution routing and land surface models (2 configurations of MESH-HydroSHEDS).

Model Descriptions

ARM

The GLERL ARM is a two-step process operating on 121 subbasins in the Great Lakes basin, 27 of which comprise the Lake Michigan basin (Figure 1b) (Croley II & Hartmann 1986; Croley II & He 2002). The first step applies the ARM in partially gaged subbasins (on each day), and the second step is to extrapolate from these partially gaged subbasins to totally ungaged basins by applying ARM a second time. Time series of subbasin monthly runoff estimates are available online, and span the period of 1898-2010 (http://www.glerl.noaa.gov/). Additionally, ARM simulations provided the synthetic subbasin runoff time series that constrained calibration of the Large Basin Runoff Model.

AFINCH

AFINCH (described by Holtschlag 2009) was developed by USGS to estimate streamflows and water yields throughout large regions as part of the Great Lakes Basin Pilot Project of the National Water Availability and Use Program. The model simulates monthly flow in each NHDplus flowline (Figure 1c) using step-wise linear regression models relating monthly water yield observations to geospatial climate and land-cover data. The model is configured to incorporate water-use data, and can be constrained to observations at gaged flowlines.

LBRM

LBRM (Croley II & He 2002) is a lumped parameter conceptual model that simulates water transport through cascading tanks, and provides forecasts of runoff to the Great Lakes Advanced Hydrologic Prediction System (described by Gronewold et al. 2011). The model, which has nine calibrated parameters, remains the only conceptual rainfall-runoff model to be systematically applied to 121 subbasins in the Great Lakes (Figure 1b) (Coon et al. 2011). The nine parameters were calibrated by conditioning the LBRM on a synthetic discharge time series provided by GLERL's ARM simulations.

CHPS

CHPS is a modeling and operational infrastructure designed to be integrated into the NWS Advanced Weather Interactive Processing System (AWIPS), and provides the basis for sharing new and existing models with the broader hydrologic community (Roe et al. 2010). Data import, storage, and display are provided by the Delft Flood Early Warning System (FEWS), and hydrologic and hydraulic models are provided by the NWS and U.S. Army Corps of Engineers (USACE). For the GRIP analysis, CHPS was implemented using the Sacramento Soil Moisture Accounting Model, operating on the hydrologic units in Figure 1d. Model parameters are estimated by calibration using regression models at gaged hydrologic units and by assignment at ungaged units, based on landscape characteristics and proximity.

Four Configurations of MESH

Environment Canada uses its *Modélisation Environmentale Communautaire* - Surface Hydrology (MESH) model (Pietroniro et al. 2007), a distributed model combining land surface models with land surface parameterization and hydrologic routing, to forecast runoff to the lakes from both the U.S. and Canadian portions of the basin. The GRIP project will consider four configurations of MESH (Table 2).

Table 2. MESH Configurations.

Configuration	Coupled	Atmospheric Forcing resolution	Land Surface Model	Routing Model	Response Unit Approach
MESH-Standalone		10 arcsec	CLASS (10 arcmin)[1]	WATROUTE (10 arcmin)[3] Figure 1e	Grouped
MEC-MESH	X	10 arcsec	ISBA (10 arcmin)[2]	WATROUTE (10 arcmin)[3] Figure 1e	Single
MESH-HydroSHEDS with high-resolution routing	X	10 arcsec	ISBA (10 arcmin) [2]	Based on HydroSHEDS (15 arcsec)[4] Figure 1f	Single
MESH-HydroSHEDS with land surface and routing	X	3 arcsec	ISBA (15 arcsec) [2]	Based on HydroSHEDS (15 arcsec)[4] Figure 1f	Single

[1] Canadian Land Surface Scheme (CLASS) (Verseghy 2000)
[2] Interactions between Surface– Biosphere–Atmosphere (ISBA) (Bélair et al. 2003)
[3] Kouwen (2010)
[4] Lehner et al. (2006)

Methods

The GRIP-M project involves side-by-side comparison of the time series of runoff to Lake Michigan, cumulative runoff to Lake Michigan for a common simulation period, and model skill at 20 validation gages in the basin. Because the analysis takes place within the context of large scale water balance modeling, we selected the 20 validation gages near the coast. These 20 gages are removed from any calibration or simulation procedures during a common validation period (2002-2010), and simulated monthly discharge time series are compared with the observed flow at these gages. For ARM, we consider two alternative simulation methods: (1) using only the area ratio estimated for the subbasin, leaving gaps in the series when no observation is available within the subbasin, and (2) during months for which no observation is recorded, the area ratio of the lake basin is applied to estimate flow at the gage, essentially the second step of the GLERL implementation of ARM.

Preliminary Results

Preliminary simulations of Lake Michigan inflow are available for ARM, LBRM, AFINCH, MESH-Standalone, and CHPS. Each model simulates similar peak and low flows (Figure 2). However, CHPS and LBRM typically simulate higher flows and MESH-Standalone flows are lower. ARM and AFINCH, which both incorporate gage information, both simulate flows in the middle of the range of model simulations. Although time series simulations may appear similar among the models, differences over time would result in accumulated error in water level simulations drawing on runoff from these models (Figure 3).

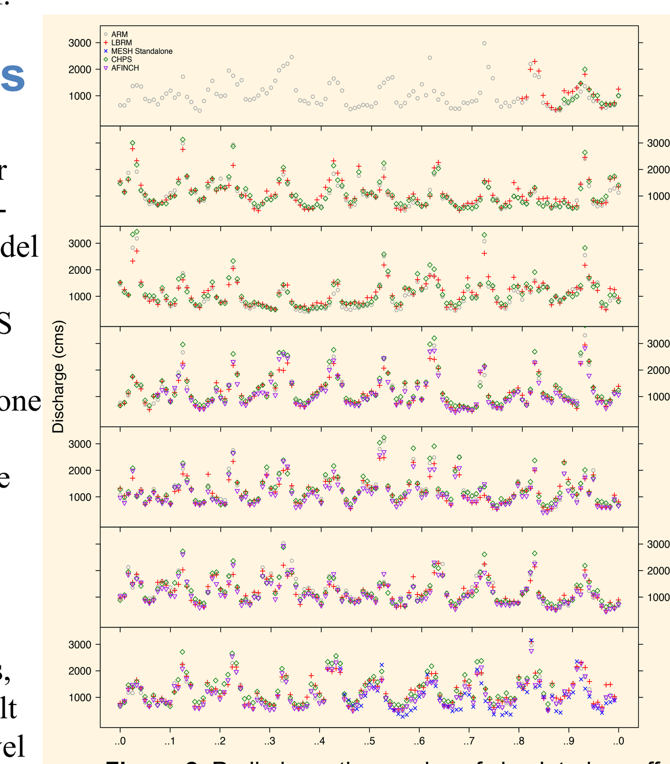

Figure 2. Preliminary time series of simulated runoff.

Preliminary validation results for CHPS, ARM, AFINCH, and LBRM suggest varying model skill (Figure 4, Figure 5, and Table 3). In general, CHPS and LBRM somewhat over-predict discharge, consistent with their positions on the plot of cumulative runoff (Figure 3). The prediction skill of ARM and AFINCH varies, with generally improved model skill when other gage observations are available within the subbasin. There does not appear to be a systematic under- or over-prediction bias associated with ARM or AFINCH simulations; however absolute bias can be large, especially from simulations produced by ARM2, which uses the basin area ratio when no observation is available within a subbasin.

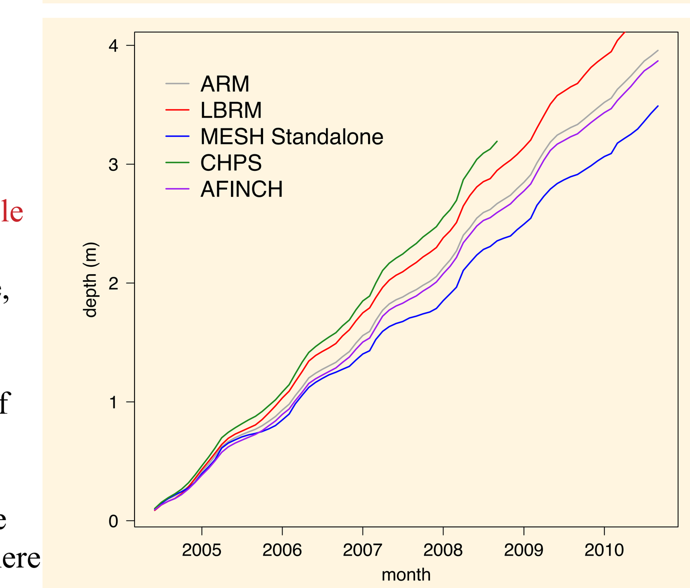

Figure 3. Cumulative runoff to Lake Michigan for the common simulation period (2004-2010) in units of depth over the lake.

Table 3. Goodness-of-fit statistics for simulations at the 20 validation gages, following recommendations by Moriasi et al. (2007) and computed with R package HydroGOF (Zambrano-Bigiarini 2011). NSE is the Nash Sutcliffe Efficiency, Percent Bias is the average percent bias (with positive values indicating overestimation), and RSR is the RMSE-observations standard deviation ratio.

	NSE					PBIAS					RSR				
Gage	ARM1	ARM2	CHPS	AFINCH	LBRM	ARM1	ARM2	CHPS	AFINCH	LBRM	ARM1	ARM2	CHPS	AFINCH	LBRM
04046000*	NA	0.32	NA	0.67	0.16	NA	11.10	NA	32.4	64.9	NA	0.82	NA	0.57	0.91
04056500*	NA	0.24	0.85	0.73	0.63	NA	-24.00	-9.90	-19.5	19.5	NA	0.87	0.38	0.51	0.61
04059000	0.92	0.92	0.75	0.85	0.71	4.50	4.50	8.30	19.5	23.6	0.28	0.28	0.50	0.38	0.54
04067500	1.00	1.00	0.25	0.64	0.67	1.30	1.30	35.10	13.9	21	0.06	0.06	0.86	0.59	0.57
04069500	0.99	0.99	0.51	0.99	0.52	2.20	2.20	36.20	2.7	27.2	0.08	0.08	0.70	0.09	0.69
04071765	0.94	0.94	0.64	0.95	0.54	5.80	5.80	26.40	5.1	27.2	0.24	0.24	0.59	0.22	0.67
04084445*	-0.44	-0.18	0.57	0.92	0.67	-38.00	14.70	22.60	1.2	2.4	1.18	1.08	0.65	0.29	0.57
04085200*	NA	0.19	0.66	0.73	0.48	NA	72.20	18.00	12.9	8.8	NA	0.90	0.58	0.52	0.72
04085427	0.47	0.47	0.65	0.74	0.5	43.90	43.90	28.50	16.2	2.2	0.72	0.72	0.59	0.5	0.7
04086600	0.01	0.01	0.56	0.93	0.73	43.80	43.80	13.40	2.2	6.8	0.99	0.99	0.66	0.26	0.51
04087240	0.71	0.71	0.79	0.93	0.17	26.80	26.80	3.60	-2.3	15.9	0.54	0.54	0.46	0.27	0.91
04093000	0.49	0.49	0.71	0.4	0.7	5.30	5.30	-15.90	-14.5	-3.7	0.71	0.71	0.53	0.77	0.55
04096015	0.53	0.53	0.73	0.64	0.72	12.70	12.70	20.30	-2	3	0.68	0.68	0.52	0.6	0.53
04102500	0.67	0.67	0.66	0.64	0.64	-8.50	-8.50	5.70	-12	-3.1	0.57	0.57	0.58	0.6	0.6
04108660	0.88	0.88	0.88	0.84	0.61	-2.10	-2.10	1.10	-9.9	-8.7	0.35	0.35	0.34	0.39	0.62
04121970	0.84	0.84	0.54	0.96	0.75	8.80	8.80	19.60	2.2	11.9	0.39	0.39	0.68	0.19	0.5
04122500	0.88	0.88	0.72	0.57	0.78	-4.00	-4.00	9.40	3.9	0.2	0.34	0.34	0.53	0.66	0.46
04126740*	NA	-11.11	-1.61	-10.06	-18.47	NA	-4.70	-11.70	18.8	44.2	NA	3.47	1.61	3.31	4.4
04126970*	NA	-1.34	-0.97	0.06	-5.59	NA	11.70	33.80	2.2	62	NA	1.52	1.40	0.96	2.56
04127800*	NA	-54.68	-0.20	-9.92	-31.14	NA	-65.90	6.90	-26.6	-50.6	NA	7.43	1.09	3.29	5.65

* Gages in ARM subbasins for which there is no observation during some period.

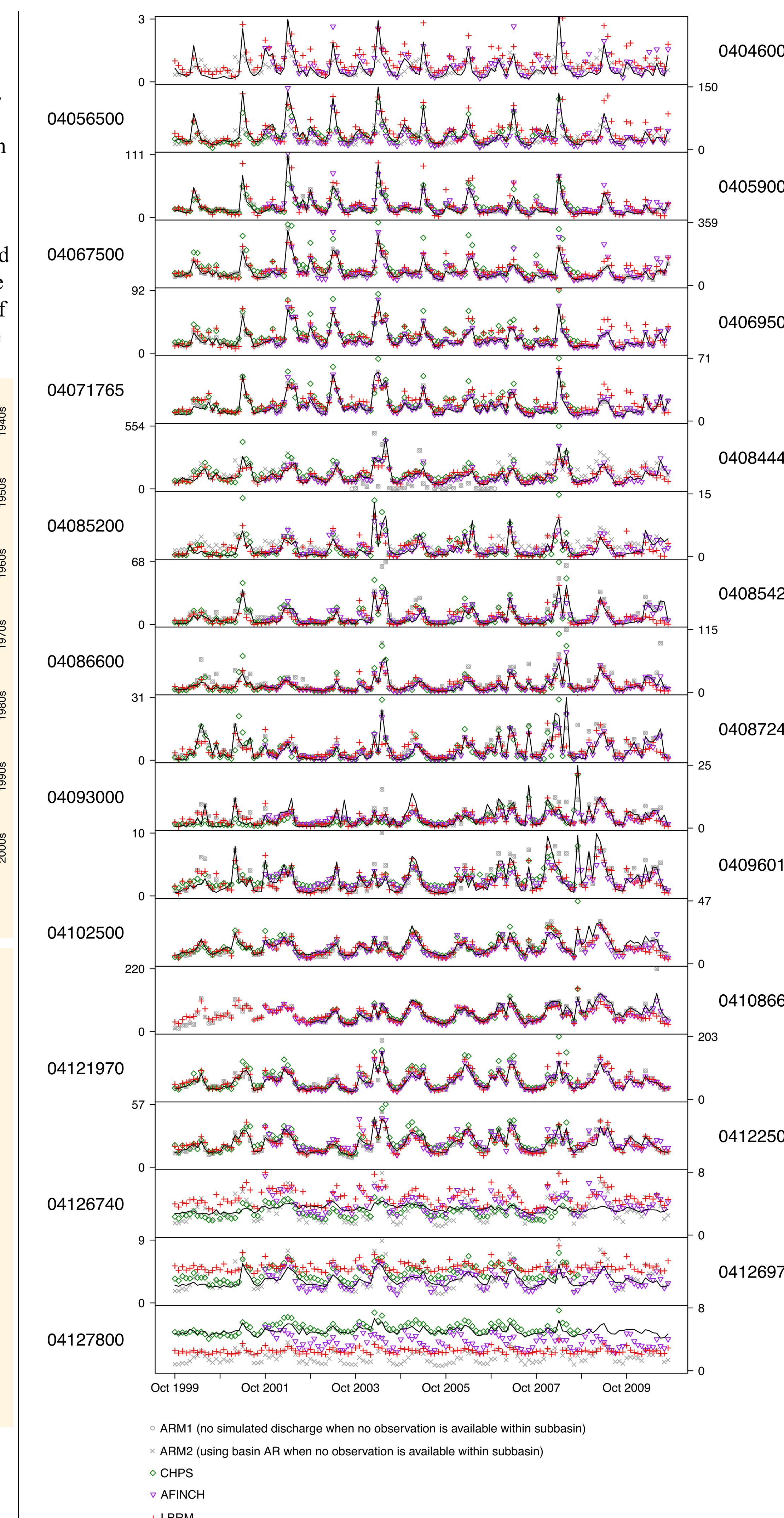

Figure 4. Time series of simulated runoff (cms) at the 20 validation gages. Gage locations are shown in Figure 1a.

Conclusions

Preliminary results indicate that all models under consideration for the GRIP-M project simulate similar timing of peak and low flows. However, plots of cumulative runoff suggest that biases among the models result in different simulated accumulated depth of runoff to Lake Michigan over time, and preliminary validation at 20 gages suggest varying model skill. Each model was developed for a different purpose (e.g. large scale water balance simulation and forecasting, investigation of impacts of land use and water withdrawals on stream flow, and flood forecasting), and the GRIP-M project is the first to compare these models for use in regional water balance simulation. Future GRIP work will involve investigating the sources of model error and the potential for each model to improve large scale water balance simulations.

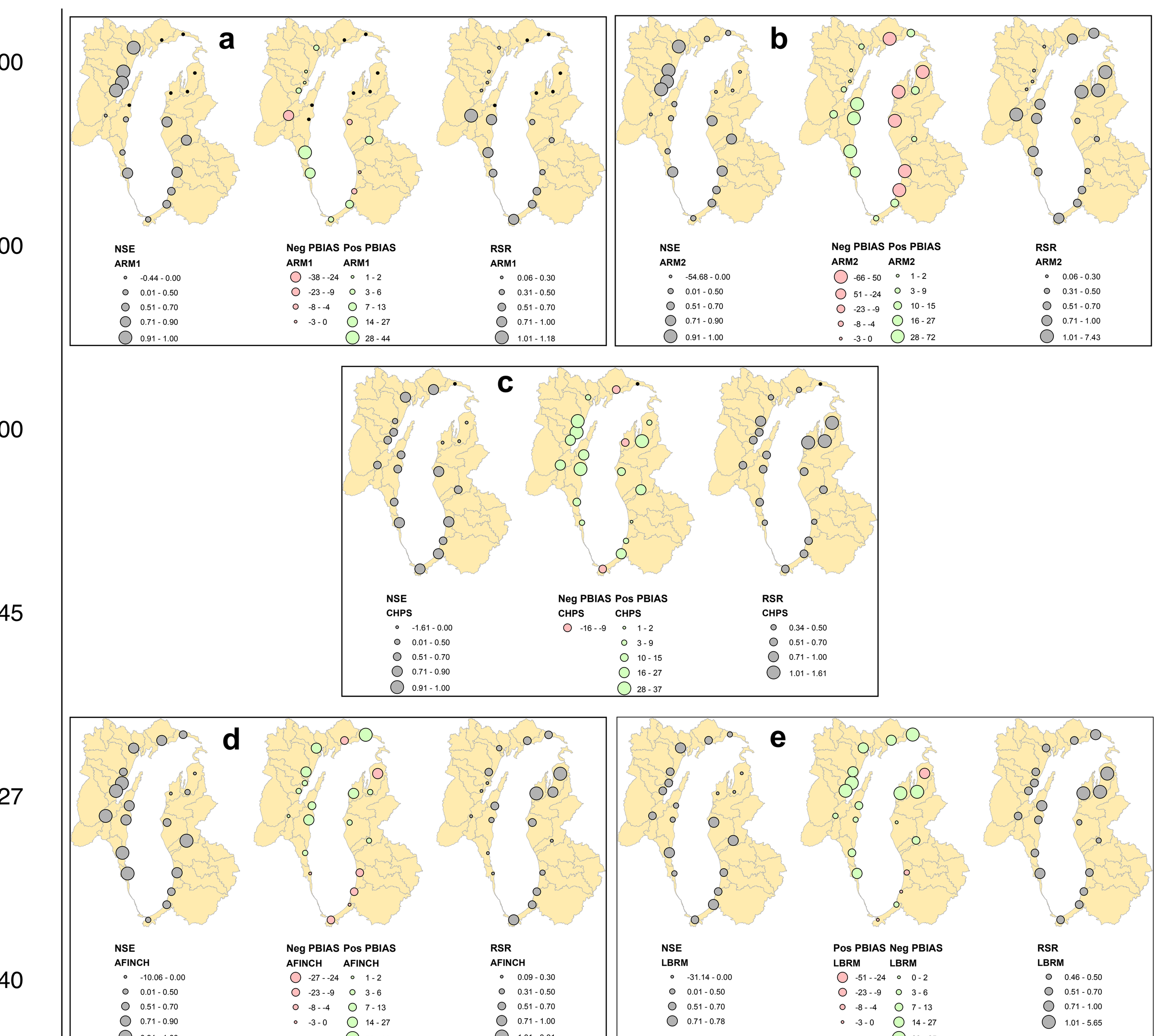

Figure 5. Spatial representation of the goodness-of-fit statistics for simulations at the 20 validation gages. **(a)** ARM1 with no simulations when no observations available within the subbasin, **(b)** ARM2 with simulation provided by basin-wide area ratio when no observations available within the subbasin, **(c)** CHPS, **(d)** AFINCH, and **(e)** LBRM. Gages for which no simulation is provided by a model are shown as black points.

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