Comparing Measurements, Simulations, and Forecasts of Snow Water Equivalent Across the Great Lakes Basin

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Introduction

Of the various components of the Great Lakes water budget, snow water equivalent (and its contribution to runoff) represents one that is estimated by a regional rainfall-runoff simulation model (the NOAA large basin runoff model, or LBRM) and by a data assimilation model (via the NOAA National Operational Hydrological Remote Sensing Center Snow Data Assimilation System or NOHRSC-SNODAS). Current regional operational water budget forecasts developed by the U.S. Army Corps of Engineers employ the use of the LBRM. While these forecasts are periodically evaluated for skill based on a comparison between water level projections and observations, little is known about the skill in the Great Lakes SWE simulations and how those estimates propagate into the runoff component of the water budget forecast.

Koster et al. (2010) analyzed the skill of streamflow forecasts over the Great Plains and Western U.S. and found that when snow observations were used to initialize the model, streamflow was more accurately simulated. One assumption is that LBRM runoff estimates over the Great Lakes region could be improved with the addition of snow observations. Clow et al. (2012) asserted that SNODAS provides the most spatially and temporally complete daily SWE dataset for the U.S. and concluded that SNODAS inputs would improve hydrological model simulations of runoff.

This study aims to answer three important questions. First, does the LBRM accurately capture snow accumulation and snow melt? Second, does the current depiction of LBRM SWE correctly propagate into runoff, compared to observations? Finally, can the inclusion of SWE observations improve LBRM runoff simulations? In order to fully answer these questions, current LBRM SWE simulations are compared to SNODAS SWE, and LBRM runoff simulations are compared with observed gaged runoff. Quantitative comparisons are made by focusing on 1) magnitude of peak SWE, 2) rate of snow melt, 3) rate of rise in daily runoff (following peak SWE), 4), magnitude of peak runoff, 5) rate of subsequent decline in daily runoff, and 6) ratio of the magnitude of peak SWE to cumulative springtime runoff. These are evaluated for long-term (i.e. ten-year) averages.

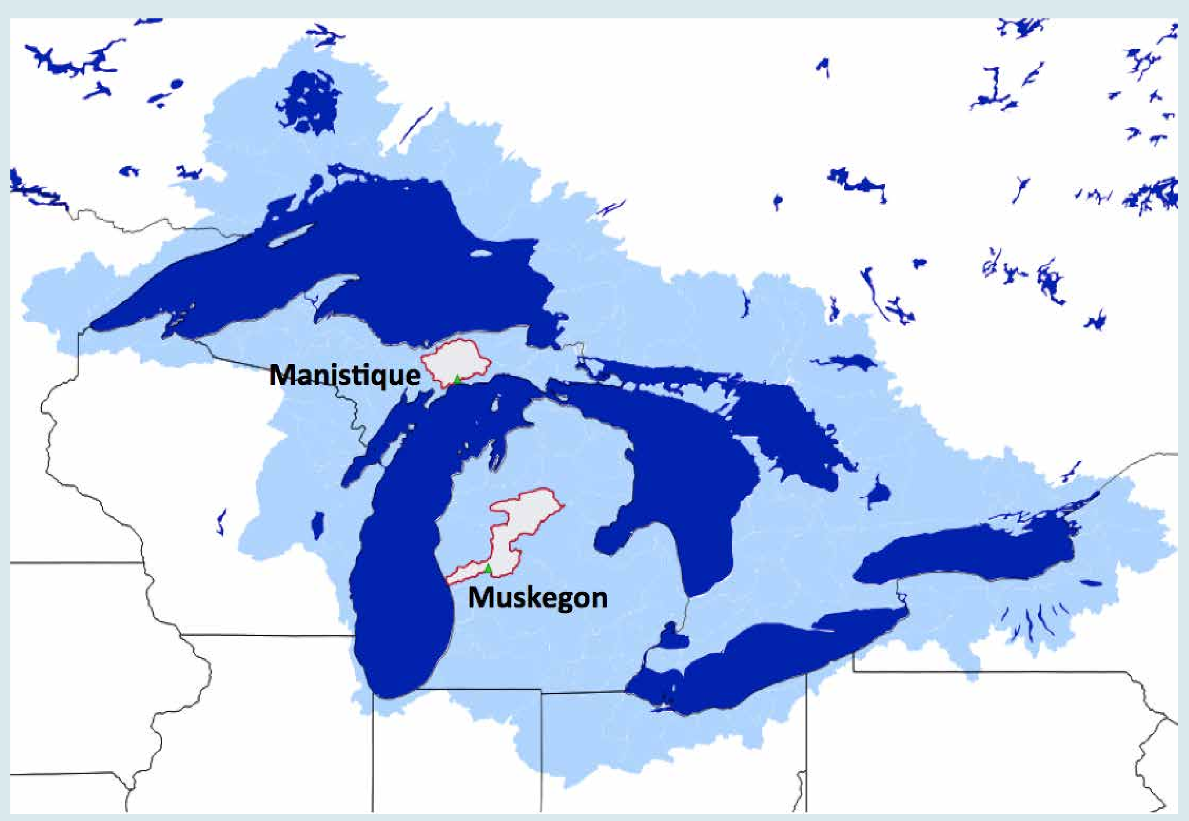

Figure 1: Map of the Great Lakes basin (basin shaded in light blue, lakes in dark blue), with the Muskegon and Manistique sub-basins outlined in red. Green diamonds show the locations of the representative USGS streamgages for each sub-basin.

Data and Methods

Figure 1 shows the Great Lakes basin and the two sub-basins of focus for this study: the Muskegon and the Manistique. Both were chosen based on longer term, reliable runoff measurements at United States Geological Survey gages (USGS, marked with green triangles) that could provide reasonable verification for model simulations. For each sub-basin, only the area of the drainage basin upstream of the USGS is considered.

SWE observations for each basin are estimated from the NOHRSC's SNODAS product, using the 25-km, equal area gridpoints that fall within the basin's boundaries. SNODAS data (details provided by Carroll et al. 2006) have previously been used to validate SWE simulations (Barlage et al. 2010; Azar et al. 2008), and due to the relative sparseness of direct observations of SWE in the Great Lakes region, is ideal for validation in this study. Because the SNODAS data are temporally limited, this study focuses on the time period of October 1, 2003 – September 30, 2013 (i.e., 10 water years).

The details and performance of the LBRM are described by Croley and He (2002) and Gronewold et al. (2011). For this study, the LBRM is calibrated using daily runoff observations for each basin from 1948 – 2000 (with a 2-year spin up). Model simulations of runoff and SWE for each basin are compared to USGS gage measurements and SNODAS observations for the verification period (WY2004 – WY2013).

Results

Muskegon

The 10-year average of daily SWE and daily runoff for Muskegon are shown in Figure. 2. SWE begins to accumulate in December, reaches its peak in early March, and quickly melts off by May. The SNODAS shows a higher peak SWE and melts out later than the LBRM. In Figure 3, there is general agreement between LBRM and SNODAS for early season snow accumulation. But between 20 and 25 weeks after the beginning of the water year (around late winter/spring) there is a bias for many of the seasons, when LBRM tends to overestimate the SNODAS snow melt (ΔSWE is more negative for LBRM than SNODAS). LBRM accumulated runoff shows a bias at the same time, where LBRM overestimates gage accumulations.

The left side of Table 1 compares the six metrics of interest using 10-year averages for the Muskegon basin. Observations show a peak SWE larger in magnitude and occurring a week later than the LBRM simulation. LBRM simulates a faster snowmelt than observations (and at a much greater rate during the first 20 days after peak SWE). One would expect the rate of snowmelt to be observable in the hydrograph—so a faster snowmelt (as seen in simulation) would result in a rapid rise and large peak in the runoff. In both Figure 2 and Table 1, this is not the case, as both simulation and observation show a similar rate in runoff at the time of snowmelt, and the observations show a higher peak. The LBRM also doesn't runoff the water as quickly as observed. While the observations show a steady decline through the first 90 days after peak runoff, simulated runoff stays virtually the same magnitude for the first 90 days. The final metric in Table 1 is the ratio of peak SWE to the cumulative runoff at the time of peak SWE and snowmelt and accumulating till the end of the water year. This says that SWE contributed to 33% of the cumulative runoff (neglecting evaporation or infiltration). However, LBRM simulates less SWE and more runoff, resulting in a smaller ratio of 0.22.

METRICS	MUSKEGON		MANISTIQUE	
Peak SWE	66.39 mm 47.27 mm	March 5 February 28	151.56 mm 155.33 mm	March 9 March 6
Rate of snow melt	-1.25 mm/dy -1.31 mm/dy	First 20 days -1.5 mm/dy -1.80 mm/dy	-2.61 mm/dy -2.77 mm/dy	First 20 days -1.13 mm/dy -0.97 mm/dy
Rate of rise in runoff	0.05 mm/dy 0.05 mm/dy		0.05 mm/dy 0.08 mm/dy	
Peak runoff	1.79 mm 1.64 mm	March 14 March 13	3.04 mm 4.70 mm	April 12 April 22
Rate of decline in runoff	First 30 days -0.01mm/dy 0.00 mm/dy	First 90 days -0.01 mm/dy -0.00 mm/dy	First 30 days -0.05 mm/dy -0.07 mm/dy	First 90 days -0.03 mm/dy -0.05 mm/dy
Peak SWE / Cumulative R	0.33 0.22		0.61 0.45	

Table 1. Quantification of the six metrics of interest for each basin, with black (red) values denoting SNODAS and gage observations (LBRM simulations) for the 10-year averages.

Manistique

Figure 4 shows 10-year average of daily SWE and daily runoff for Manistique. This northern, colder basin shows much smoother continuity in both variables. There is also better agreement between observed and simulated SWE, with a peak in early March and melting off by early May. The better agreement in SWE simulations and observations is also observed in Figure 5. The top graphic shows an insignificant bias in the ΔSWE simulations (although, similar to Muskegon, there is a short period where LBRM melts faster than SNODAS). There is a large bias observed in the accumulated runoff, where LBRM overestimates gage accumulations. Because this isn't observed in the SWE, this bias is likely due to other factors.

The right side of Table 1 compares the six metrics of interest for Manistique. Both simulation and observation have similar peak magnitudes and timing. Like the Muskegon, simulated SWE melts faster than SNODAS. However, in the first 20 days, the simulated melting rate is slower than observation. The observation displays an increase in runoff similar to the simulation and observation for the Muskegon. But the LBRM simulates a faster rise in runoff and a much greater peak runoff. The faster rise and greater peak is expected, given the much greater snow melt rate in the simulations. Unlike the Muskegon, the Manistique rate of simulated runoff decline is quicker than the observation. The ratio of peak SWE to cumulative runoff suggests that SWE contributes 61% to cumulative runoff (compared to 45% in the simulations). Compared to the Muskegon, the contribution of SWE to total runoff is much greater for the Manistique. Both basins show that the LBRM simulations of SWE do not contribute as much to runoff as the observations.

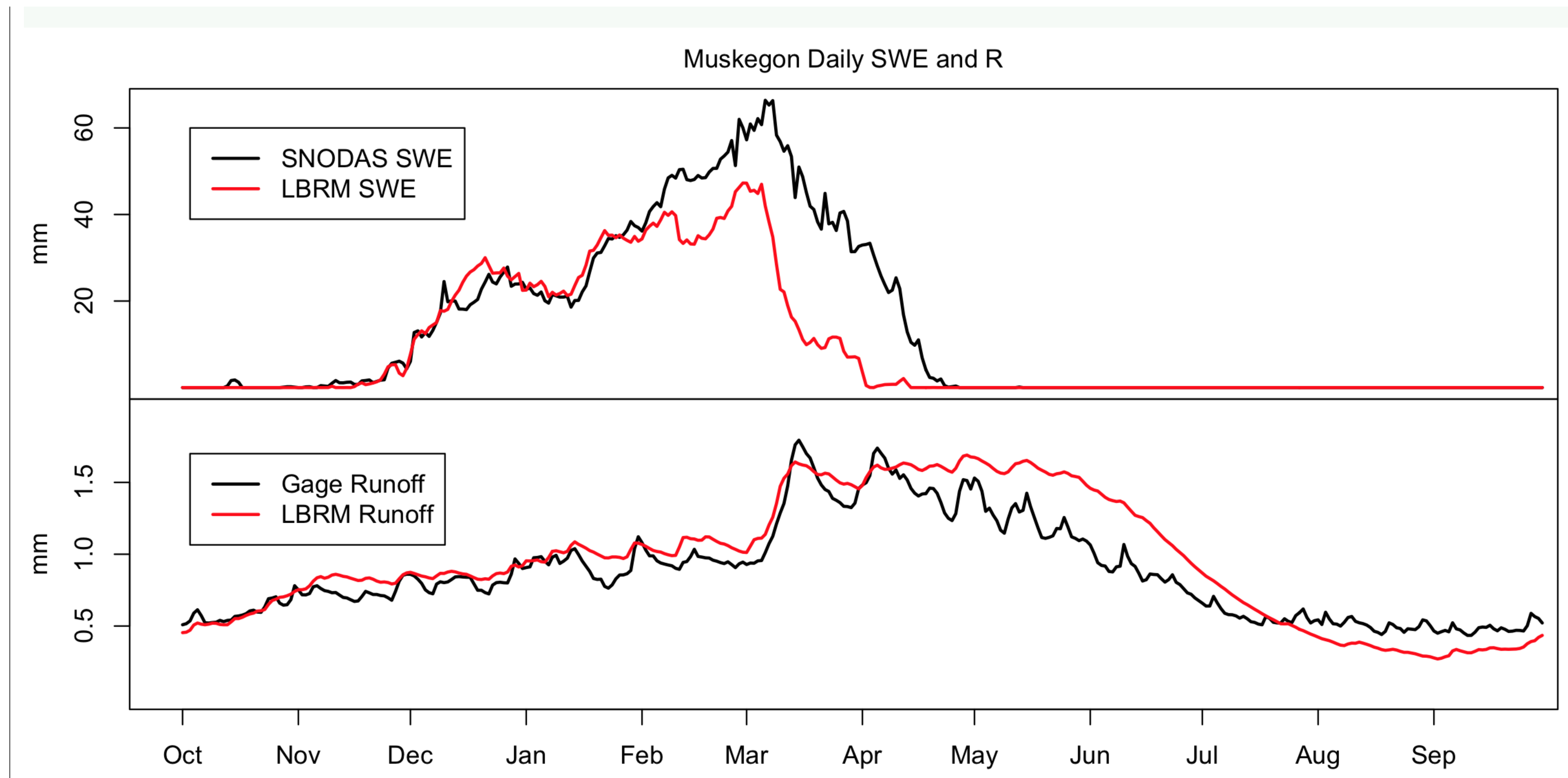

Figure 2. Ten-year average of daily SWE (top) and daily runoff (bottom) for Muskegon. The black lines represent observations from gage and SNODAS, and red lines are for LBRM simulations.

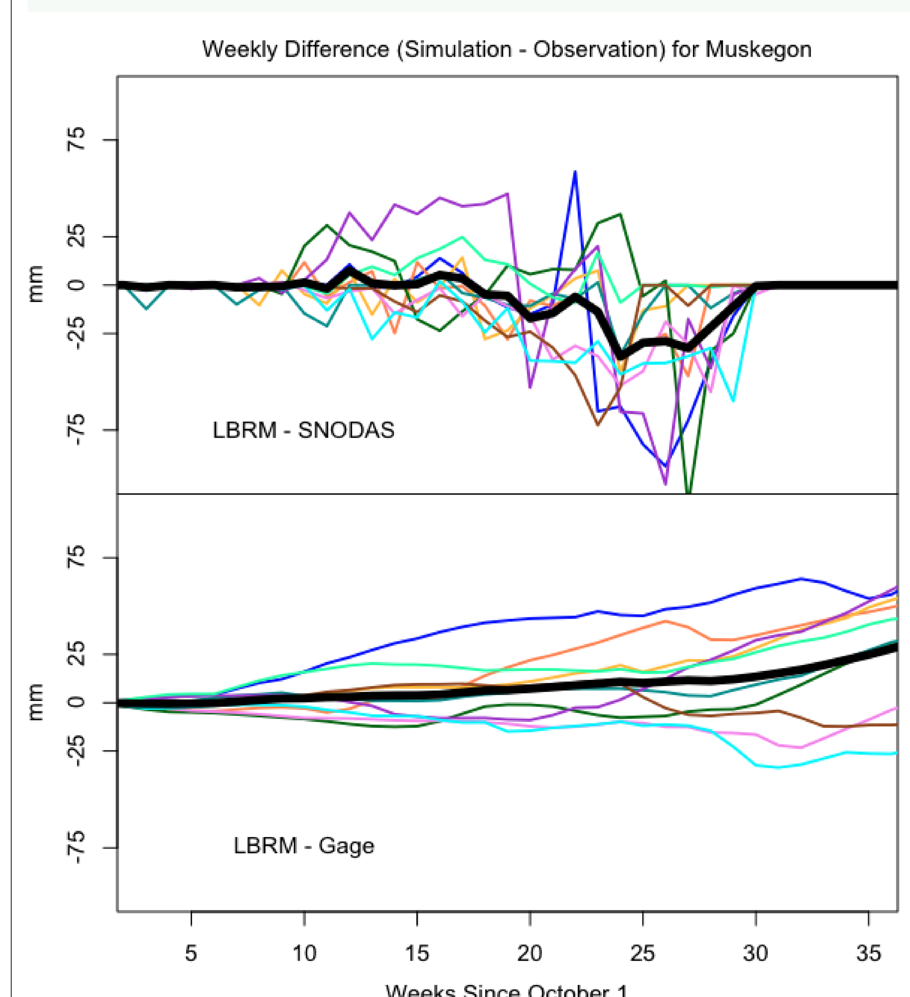

Figure 3. One week differences over time between simulated and observed [top] SWE and [bottom] runoff accumulation for Muskegon. Colored (black) lines represent individual seasons (10-year average).

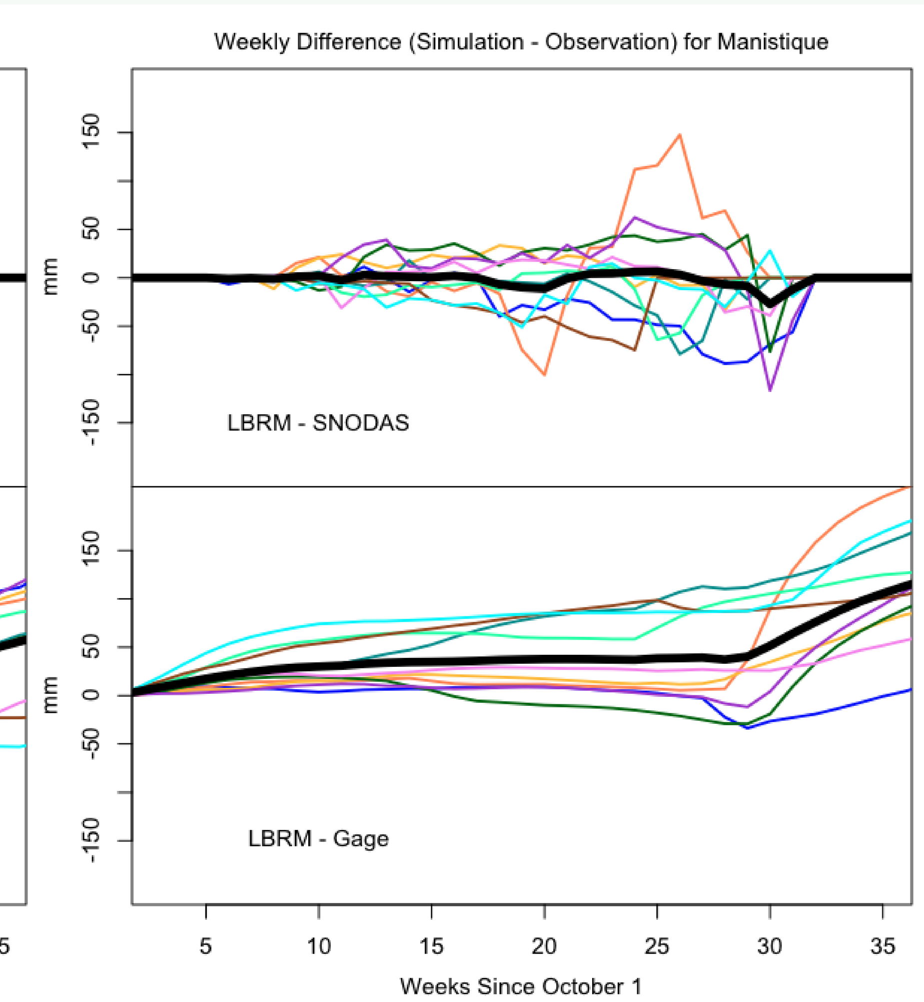

Figure 5. Same as Figure 3 but for Manistique.

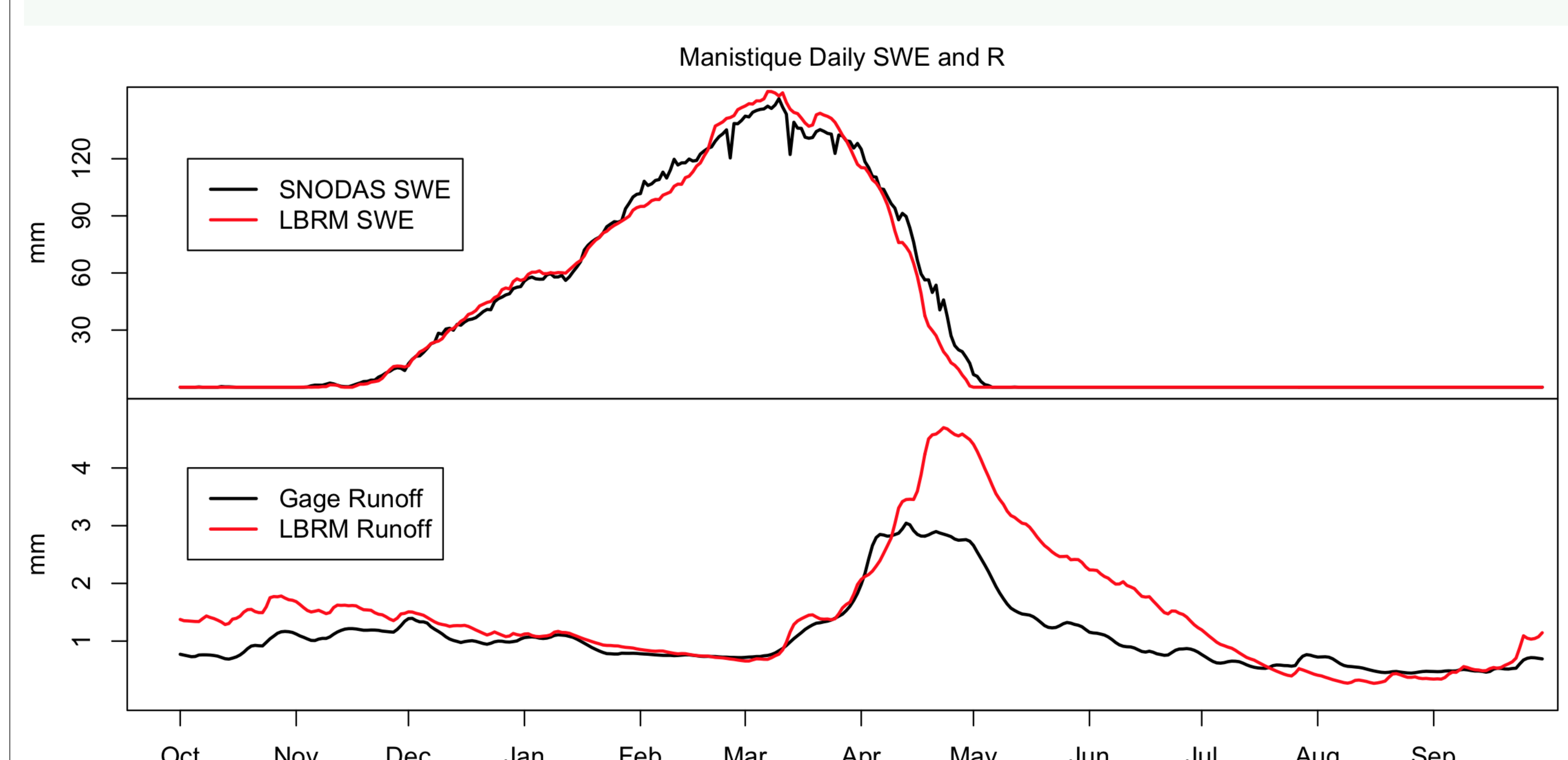

Figure 4. Same as Figure 2 but for Manistique.

Discussion

Depending on the basin, LBRM can reasonably capture the SWE accumulation, but the simulated rate of snowmelt is too fast. This faster snowmelt does not always propagate into the runoff simulations (it did for Manistique, but not Muskegon). For both basins, the simulated decline in runoff from the peak is not as quick as observations. This leads to a bias of higher cumulative runoff for both basins, and lower values for the sixth metric in Table 1. In both cases, simulations underestimate the observed ratio by approximately 30%—in other words, in observations, SWE contributes to 30% more of the cumulative runoff than what the LBRM simulations show. This bias is likely due to how the model handles the partitioning of runoff after a precipitation event (the memory of the precipitation event is too long in the simulations). However, it may still be possible to improve the initial response to runoff (and the peak runoff) with the inclusion of SNODAS in the model calibration, which is the next step in this research. Based on the two basins in this study, the authors hypothesize that snow is not the primary contributing factor to biases in runoff simulations. But for some basins where snow is not as accurately captured (in more variable, possibly warmer regions like the Muskegon), including snow observations could serve to improve peak runoff and accumulations from snow. Future work should also include a further analysis into the LBRM's general runoff regime in response to any precipitation event.

References

Azar, A.E., H. Ghedira, P. Romanov, S. Mahani, M. Tedesco, and R. Khanbilvardi, 2008: Application of satellite microwave images in estimating snow water equivalent. *J. American Water Res. Assoc.*, 44, 1347–1362.

Barlage, M., and Coauthors, 2010: Noah land surface model modifications to improve snowpack prediction in the Colorado Rocky Mountains. *J. Geophys. Res.*, 115, DOI 10.1029/2009JD013470.

Bolinger, R.A., C.D. Kummerow, and N.J. Doesken, 2014: Attribution and Characteristics of Wet and Dry Seasons in the Upper Colorado River Basin. *J. Climate*, 27, 8661–8673.

Carroll, T.R., D.W. Cline, C. Olheiser, A. Rost, A. Nilsson, G. Fall, C. Bovitz, and L. Li, 2006: NOAA's national snow analyses. Proceedings of the 74th Annual Meeting of the Western Snow Conference, 74, 13.

Clow, D., L. Nanus, K.L., Verdin, and J. Schmidt, 2012: Evaluation of SNODAS snow depth and snow water equivalent estimates for the Colorado Rocky Mountains, USA. *Hydrological Processes*, 26, 2583–2591.

Croley II, T.E., and C. He, 2002: Great Lakes Large Basin Runoff Model. Proceedings of the Second Federal Interagency Hydrologic Modeling Conference, 12 pp.

Gronewold, A.D., A.H. Clites, T.S. Hunter, and C.A. Stow, 2011: An appraisal of the Great Lakes advanced hydrologic prediction system. *J. Great Lakes Research*, 37, 577–583.

Koster, R.D., S.P.P. Mahanama, B. Livneh, D.P. Lettenmaier, and R.H. Reichle, 2010: Skill in streamflow forecasts derived from large-scale estimates of soil moisture and snow. *Nature* Geoscience, 3, 613–616.

Smith, R.A., and C.D. Kummerow, 2013: A comparison of in situ, reanalysis, and satellite water budgets over the Upper Colorado River Basin. *J. Hydrometeor.*, 14, 888–905.

Acknowledgments

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