Preliminary Verification of the Lag-Stage-Changes Routing Method on the Mainstem Mississippi River

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March 3, 2016

Introduction

The Lag-Stage-Changes Routing Method is a simplified routing scheme used by the Lower Mississippi River Forecast Center (LMRFC) to aid in forecasting river stages on the Mississippi River between Cairo, IL (CIRI2), and New Orleans, LA (NORL1). This method is based upon the simplified, hand-calculated forecasting technique used for many years by LMRFC forecasters. The hourly rate of change in river stage at CIRI2, shifted in time by a lag and reduced in magnitude by an attenuation, is applied to New Madrid, MO (NMDM7). This process continues, point-by-point, until reaching the last forecast point. Although this technique has been used for many years, no significant analysis has been undertaken to indicate potential biases or errors.

The lag and attenuation parameters utilized by the Lag-Stage-Changes technique were derived from the crest-to-crest relationships for each upstream/downstream pair of forecast points. For example, if the crest timing between CIRI2 and NMDM7 is about 12 hours, 12hrs is used for the lag parameter. For many locations, the lag time changes based upon river stage, necessitating adjustments to the lag parameter. The attenuation parameter is also derived from these relationships using the slope of the crest-to-crest linear regression. For example, if the slope of the best-fit linear regression line between CIRI2 crests and NMDM7 crests is 0.95, 0.95 is used for the attenuation parameter. Default parameters for the Lag-Stage-Changes technique are shown in Table 2. This is admittedly a very simple way of determining these values that may not be appropriate in all cases; parameter values could vary between different river stages or even from event-to-event. This document summarizes an attempt to catalogue and quantify issues with the Lag-Stage-Changes Routing Method.

Methodology

The CHPS framework used by NWS River Forecast Centers (RFCs) to issue river forecasts maintains only a limited period of both observed and simulated data within memory; for Mississippi River locations this overlap period was roughly 4 weeks. Aside from setting up a CHPS client in calibration mode, one of the easiest ways to visualize how a model would have performed for a real event with actual observations is to set the system time to a point in the past and to clear the observations and time series change (TSCHNG) modifications. Due to the limitation mentioned above, this must be done within 3-4 weeks of the event. This verification was attempted on September 26, 2015; thus, the verification period spanned from 00UTC August 30, 2015, through 12UTC September 26, 2015. This period was characterized by generally falling conditions for the first several days, then generally steady conditions for the last 3 weeks, with minor fluctuations (Figure 1). This fall at CIRI2 was a steeper drop (Table 1) within a much larger, longer period of falling conditions that begin after a long crest on about July 10.

Table 1. Magnitude of the initial drop in observed stage during the verification period. This drop was similar most of the way down the river until reaching Baton Rouge (BTRL1) where substantial attenuation began.

Site	Change in stage (ft.)
CIRI2	-5.1
NMDM7	-5.1
TPTT1	-5.0
CRTM7	-4.3
OSGA4	-4.7
MEMT1	-4.7
TRPM6	-4.6
HEEA4	-4.7
ARSA4	-4.6
GEEM6	-4.9
VCKM6	-5.1
NTZM6	-5.0
RRLL1	-4.9
BTRL1	-3.7
DONL1	-2.1
RRVL1	-1.3
NORL1	-1.0

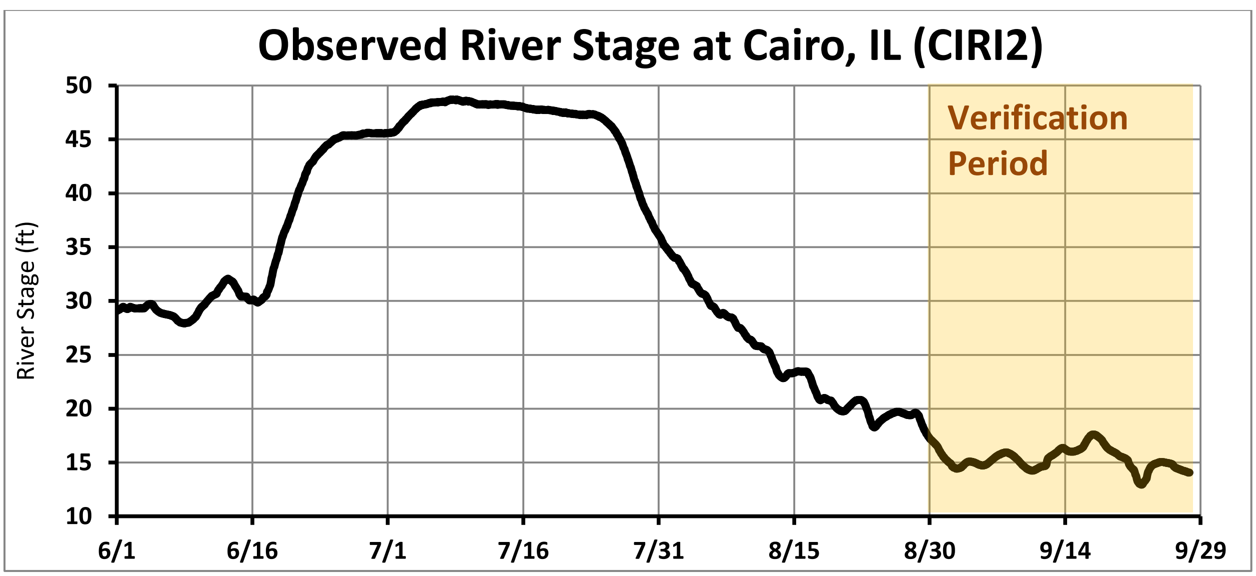

Figure 1. Observed river stages at Cairo, IL, over the summer and early fall of 2015, with the verification period highlighted.

A perfect CIRI2 forecast was assumed, so the observations were used at CIRI2 but for each downstream location the raw modeled values were ignored. This prevented the raw modeled values from being forced to match the observations. Next, the modeled time series at each forecast location was compared to the observations to determine if any adjustment to the lag parameter were required. A "best-fit" lag parameter was determined that would match each ridge and trough as close as possible in the time series (Table 2). Although changes to the attenuation parameter were also tested, this parameter was not calibrated for this verification.

Table 2. Default parameters and ranges for the Lag-Stage-Changes Routing Method. "Calibrated" best-fit values for the lag were also determined. Values marked with "*" were the same as default values.

Site	Lag (hr.), Low	Lag (hr.), Default	Lag (hr.), High	Attenuation, Default	Lag (hr.), "Calibrated"
NMDM7	6	12	24	0.95	15
TPTT1	-	12	-	0.95	6
CRTM7	6	12	24	0.95	6
OSGA4	8	12	24	1.10	15
MEMT1	8	12	24	0.95	15
TRPM6	8	12	24	0.95	12*
HEEA4	8	12	24	0.95	12*
ARSA4	12	24	48	0.95	21
GEEM6	8	12	24	0.95	9
VCKM6	18	24	48	0.95	21
NTZM6	18	24	48	0.95	24*
RRLL1	18	24	48	0.95	21
BTRL1	8	12	24	0.95	9
DONL1	8	12	24	0.70	9
RRVL1	6	12	24	0.70	9
NORL1	6	12	24	0.70	9

Results and Discussion

Clear trends in performance of the Lag-Stage-Change Routing Method were noted, as well as clear trends in the observations. Near CIRI2, the observations showed a fall which was followed by a period of fluctuations about a very slow fall. By Arkansas City, AR (ARSA4), the flat conditions over the 2-4 week period had become a slow fall, and by Red River Landing (RRLL1) generally falling conditions were noted throughout. This type of change in rising/falling tendency is not something accounted for in a simple technique such as Lag-Stage-Changes, but instead would require a hydraulic model. Due in part to this limitation, errors increased in magnitude from upstream to downstream. For the first several forecast points downstream of CIRI2, errors were small (roughly 0.5ft or less). By Greenville, MS (GEEM6), errors were on the order of 1-3ft. Somewhat surprisingly, these errors began to *decrease* over the last few forecast points with New Orleans, LA (NORL1), near 0.0ft. A summary of errors for each forecast point at the 7, 14, 21, and 28 day forecast ordinate are shown by Table 3.

Table 3. Summary of verification results from August 30, 2015, to September 26, 2015. Positive (negative) values represent a modeled value above (below) the observations. Values marked with "*" indicate missing observations.

Site	Day 7 Error (ft.)	Day 14 Error (ft.)	Day 21 Error (ft.)	Day 28 Error (ft.)
NMDM7	+0.3	+0.2	+0.2	+0.5
TPTT1	+0.2	+0.4	+0.2	+0.5
CRTM7	+0.1	+0.3	+0.2	+0.5
OSGA4	0.0	+0.2	0.0	+0.6
MEMT1	+0.3	+0.4	+0.5	+1.1
TRPM6	+0.6	+0.3	+0.9	+1.1
HEEA4	+0.7	+0.7	+1.1	+1.2
ARSA4	0.0	+1.1	+1.4	+0.8
GEEM6	+0.2	*	+3.1	*
VCKM6	+0.4	+1.6	+2.8	+2.7
NTZM6	+0.7	+2.2	+3.6	+3.3
RRLL1	+0.7	+1.7	+3.1	+3.2
BTRL1	+0.7	+1.8	+1.8	+1.7
DONL1	0.0	-0.1	+0.2	+0.4
RRVL1	0.0	-0.1	0.0	0.0
NORL1	+0.2	-0.2	-0.2	0.0

Although preliminary, these results suggest that additional scrutiny of Lag-Stage-Changes output is required for some forecast locations and forecast timeframes. Forecast values over the short term (as illustrated by the day 7 error) were reasonably similar to observations, but error almost always increased significantly by day 14. Errors were also largest between ARSA4 and DONL1. Of particular concern, some of the largest errors were noted at Natchez, MS (NTZM6), which is used by forecasters in the Mainstem1 Old River Control Structure spreadsheet to estimate potential flow diversions into the Atchafalaya River. In this particular situation it is conceivable that errors would be further compounded and could impact information shared in collaborations with the US Army Corps of Engineers. Example plots from CHPS for NMDM7, ARSA4, NTZM6, BTRL1, and NORL1 are shown by Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6, respectively.

The attenuation parameter was also looked at, although briefly. It was noted that adjustments to this parameter often caused a “catch 22” for locations at least half way down the river – increasing the attenuation value (less attenuation) would decrease longer-term errors at the expense of the short term having excessive fluctuations and increased error. When the attenuation value was reduced (more attenuation) more realistically dampen short term fluctuations, the general falling conditions noted over the period were also reduced, which had the effect of causing large errors (on the high side) over the day 14-28 period. Due to these issues, no attempt was made to determine the “ideal” attenuation parameter for this analysis. It is conceivable that different sets of attenuation parameters may be needed for different forecast types – one set of lower values (more attenuation) for short term forecasting and then a set of higher values (less attenuation) for longer term forecast.

Observations for CIRI2 were used throughout the entire verification period, assuming a so-called “perfect forecast.” This allows for the analysis of “structural uncertainty,” that is, the uncertainty merely from the Lag-Stage-Changes technique. Thus, the errors presented would not include any additional uncertainty such as upstream model performance or different types of QPF used. Regardless of whether the forecast was a zeroQPF, 24hr QPF 28 day, or 16-day QPF 28 day forecast, the errors would be the same for the same values at CIRI2.

These results should be considered very preliminary as they only look at a snapshot of the many different river conditions observed along the Mississippi. Future efforts should include a period of river stages that are generally rising, as well as a period of time that includes a well-defined, isolated crest moving down the river. It is possible that behavior noted over this analyzed verification period may not be applicable to other flow regimes.

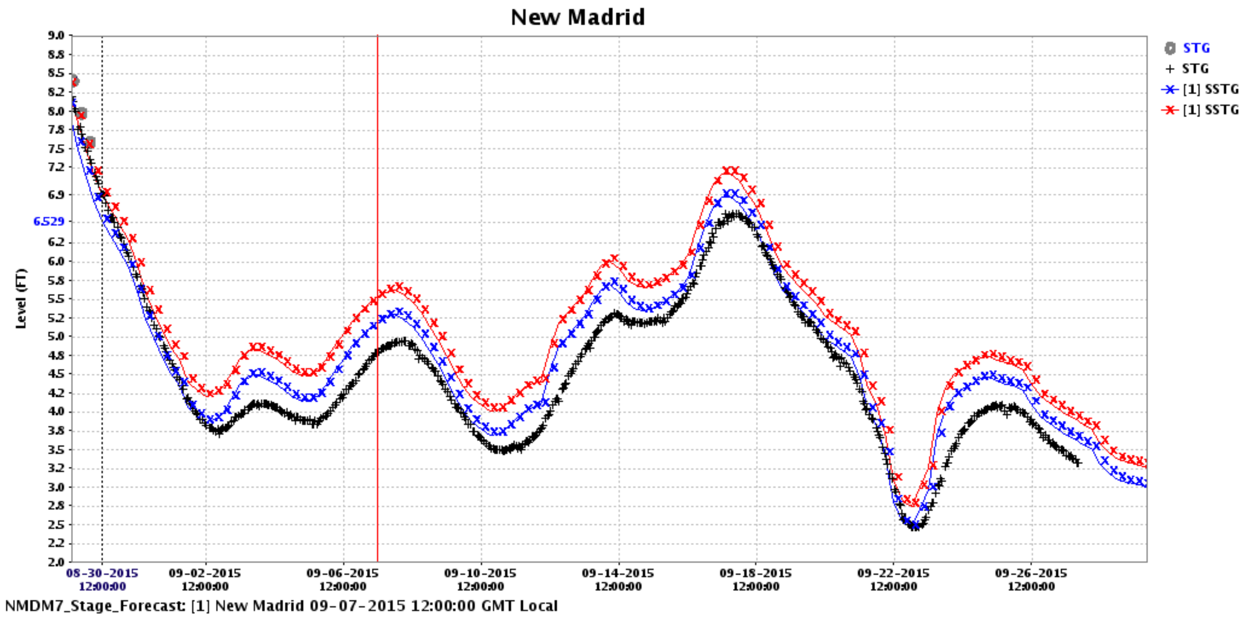

Figure 2. The Lag-Stage-Changes Routing Method compared to observations at river forecast point NMDM7 from August 30, 2015, to September 26, 2015. Blue time series is the raw routing method output, red time series is the output shifted to match the observed stage on August 30 at 00UTC, and the black time series shows the observed values.

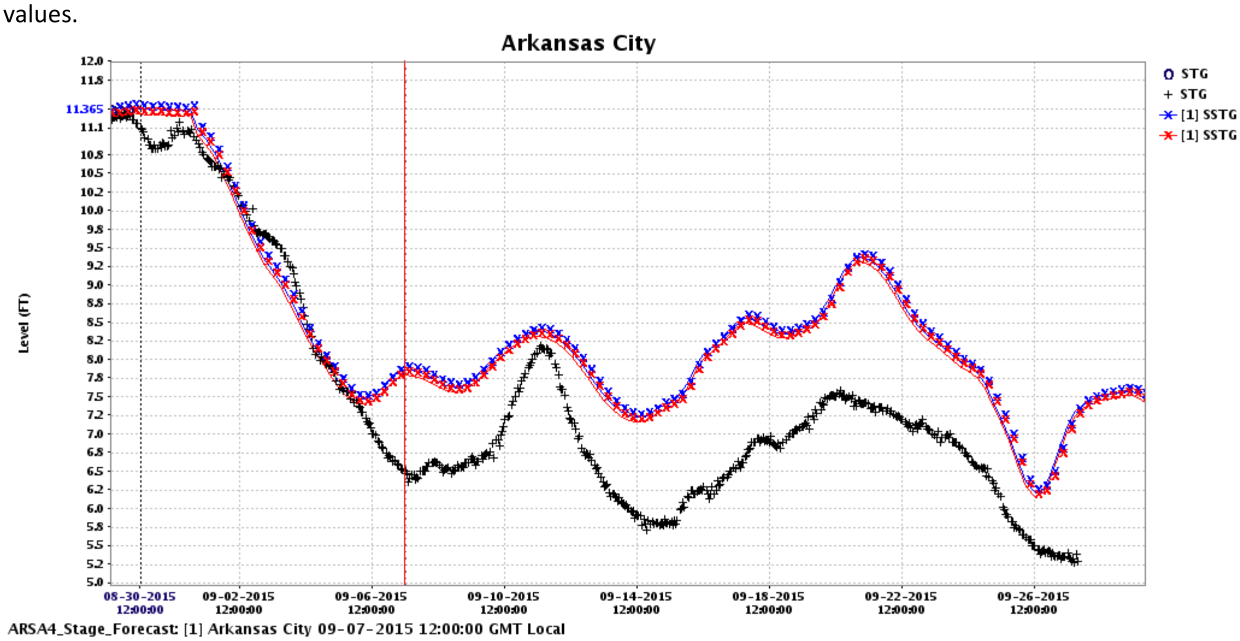

Figure 3. The Lag-Stage-Changes Routing Method compared to observations at river forecast point ARSA4 from August 30, 2015, to September 26, 2015. Blue time series is the raw routing method output, red time series is the output shifted to match the observed stage on August 30 at 00UTC, and the black time series shows the observed values.

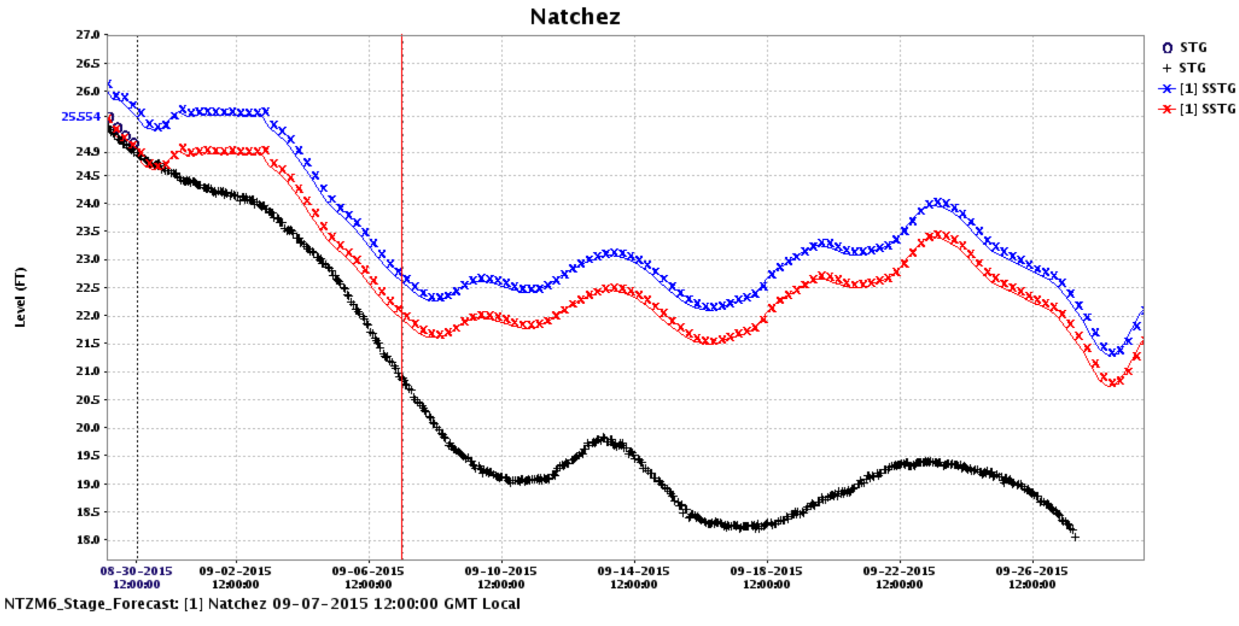

Figure 4. The Lag-Stage-Changes Routing Method compared to observations at river forecast point NTZM6 from August 30, 2015, to September 26, 2015. Blue time series is the raw routing method output, red time series is the output shifted to match the observed stage on August 30 at 00UTC, and the black time series shows the observed values.

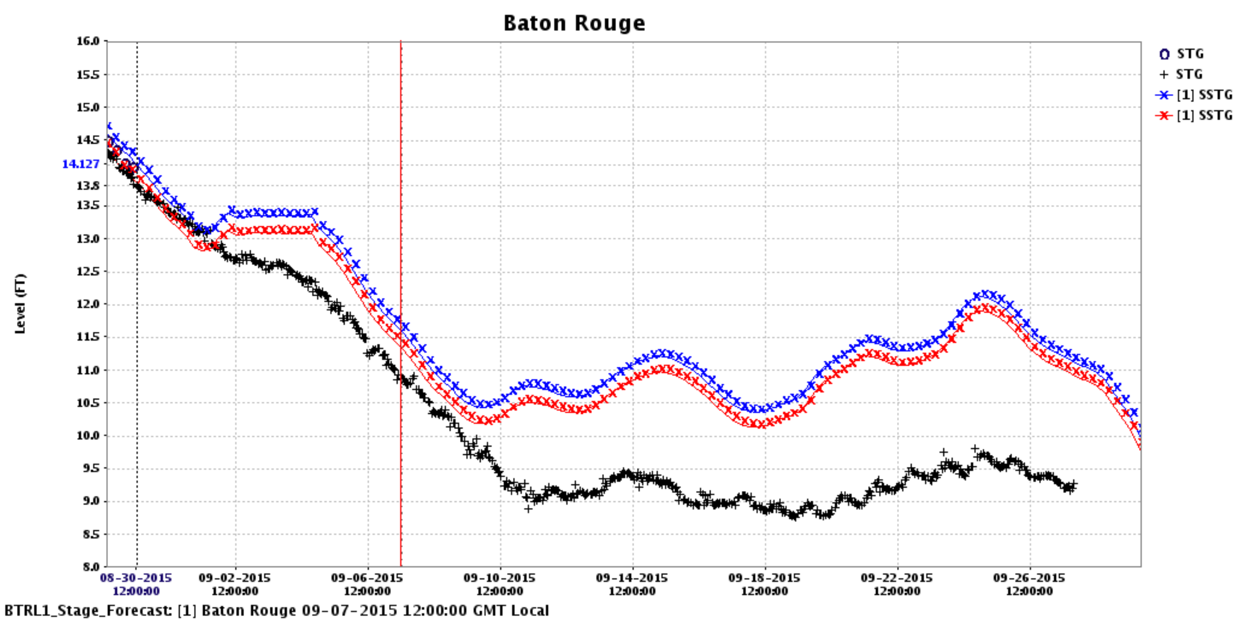

Figure 5. The Lag-Stage-Changes Routing Method compared to observations at river forecast point BTRL1 from August 30, 2015, to September 26, 2015. Blue time series is the raw routing method output, red time series is the output shifted to match the observed stage on August 30 at 00UTC, and the black time series shows the observed values.

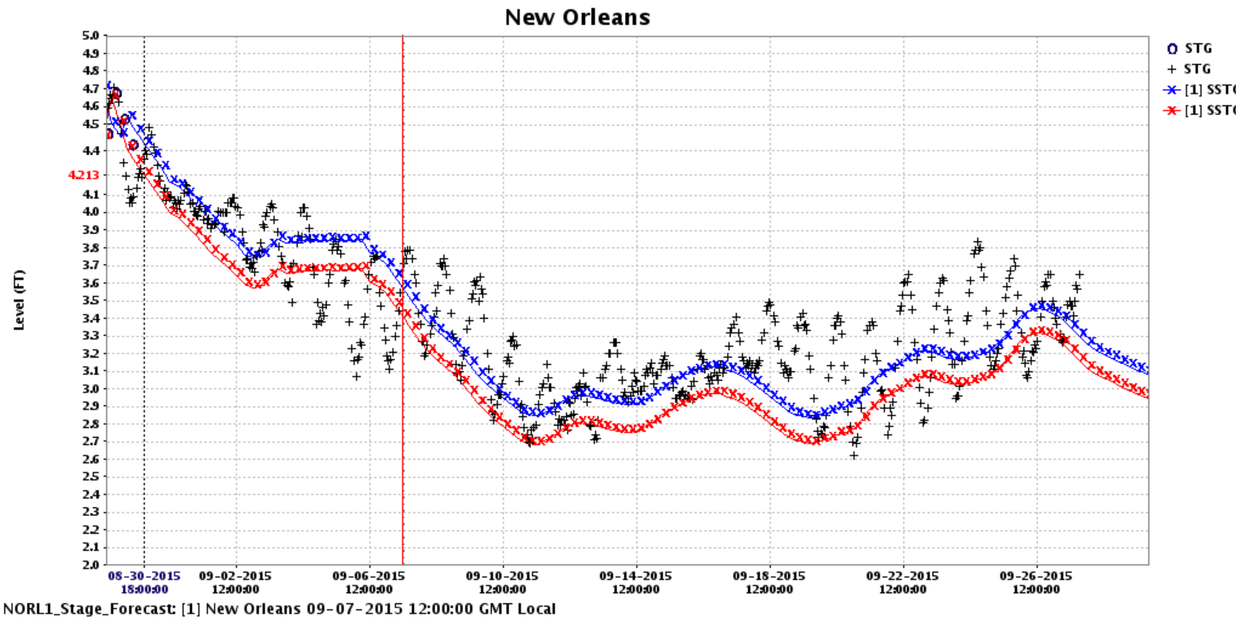

Figure 6. The Lag-Stage-Changes Routing Method compared to observations at river forecast point NORL1 from August 30, 2015, to September 26, 2015. Blue time series is the raw routing method output, red time series is the output shifted to match the observed stage on August 30 at 00UTC, and the black time series shows the observed values.

Addendum A: June 2015 Verification

This verification spanned from 12UTC June 16, 2015, to 18UTC July 1, 2015. This period was characterized by general rising trend that culminated in a long crest. Again, a perfect CIRI2 forecast was assumed. Error values for week 4/day 28 were not recorded at NTZM6 or downstream due to heavy local rainfall that caused a rise not due to upstream conditions. Results from this verification period are shown by Table 5.

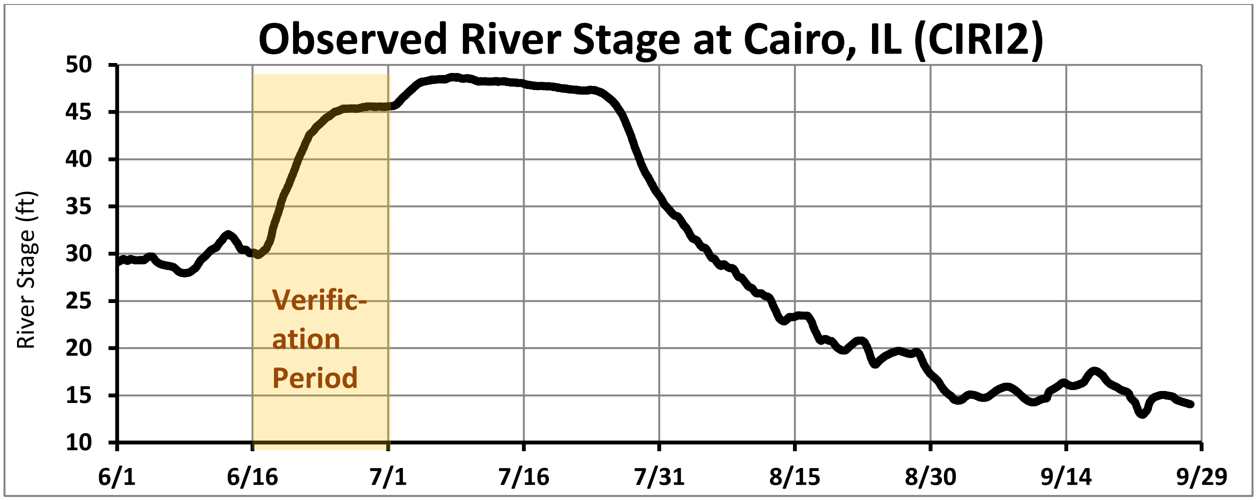

Figure 7. Observed river stages at Cairo, IL, over the summer and early fall of 2015, with the verification period highlighted.

Table 4. Summary of verification results from June 16, 2015, to July 1, 2015. Positive (negative) values represent a modeled value above (below) the observations. Values marked with "*" indicate missing observations. "Change in stage" refers to the magnitude of the rising trend during the verification period. The rise could not be calculated past HEEA4 due to rising conditions ongoing when observations ended.

Site	Day 7 Error (ft.)	Day 14 Error (ft.)	Change in stage (ft.)
CIRI2			+15.6
NMDM7	+1.0	+0.6	+14.0
TPTT1	+0.4	+0.3	+13.3
CRTM7	+0.3	+0.7	+12.7
OSGA4	-0.2	+0.4	+14.0
MEMT1	+0.8	+0.4	+13.3
TRPM6	-1.8	-0.9	+14
HEEA4	-2.2	-1.3	+13.9
ARSA4	-0.5	+3.5	
GEEM6	-1.0	+2.8	
VCKM6	-0.8	+4.1	
NTZM6	-0.4	+5.2	
RRLL1	-0.3	+6.1	
BTRL1	-0.1	+5.2	
DONL1	+0.2	+3.1	
RRVL1	+0.2	+1.7	
NORL1	0.0	+0.8	

Addendum B: October 2015 Verification

This verification spanned from 12UTC October 2, 2015, to 18UTC October 30, 2015. This period was characterized by a few feet of rise over the first couple of days followed by mostly falling conditions, with another few feet of rise toward the end of the period. Again, a perfect CIRI2 forecast was assumed. Error values for week 4/day 28 were not recorded at NTZM6 or downstream due to heavy local rainfall that caused a rise not due to upstream conditions. Results from this verification period are shown by Table 5.

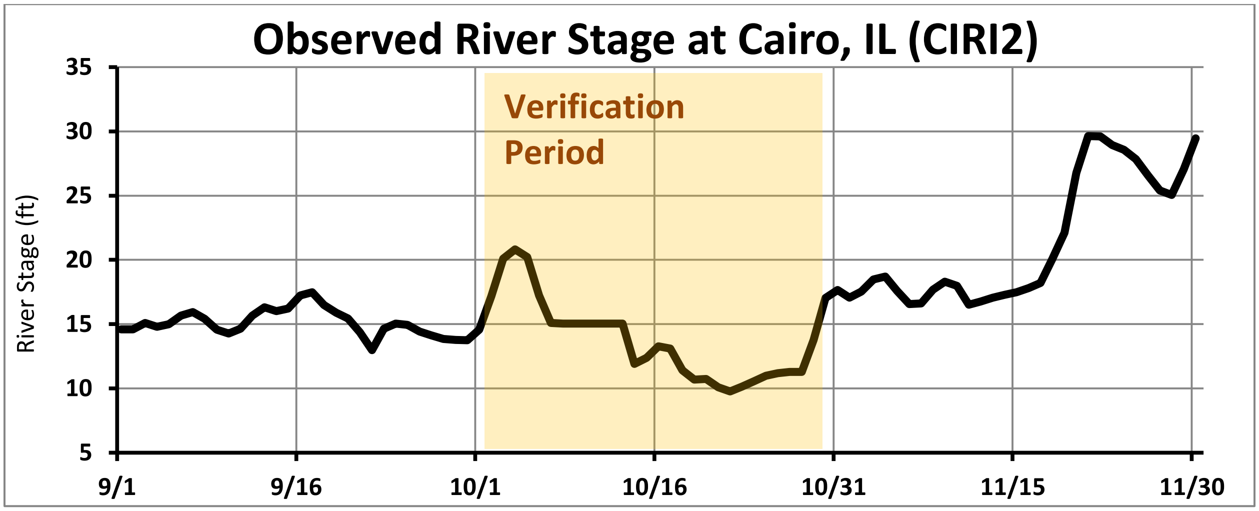

Figure 8. Observed river stages at Cairo, IL, over fall of 2015, with the verification period highlighted.

Table 5. Summary of verification results from October 2, 2015, to October 30, 2015. Positive (negative) values represent a modeled value above (below) the observations. Values marked with "*" indicate missing observations. "Heavy Locals" means that error values were not collected due to contamination by a heavy local rain event.

Site	Day 7 Error (ft.)	Day 14 Error (ft.)	Day 21 Error (ft.)	Day 28 Error (ft.)	Lag (hr.), "Calibrated"
NMDM7	-1.5	+0.1	+0.2	0.0	
TPTT1	+0.1	+0.8	+1.2	+0.3	+9
CRTM7	0.0	+0.7	+0.8	+0.2	+6
OSGA4	-0.4	+0.6	+0.7	0.0	+15
MEMT1	-0.5	+0.2	+0.4	+0.3	+18
TRPM6	-0.8	+0.3	+0.8	+0.5	
HEEA4	-0.8	+0.9	+1.6	+1.1	+27
ARSA4	+1.2	+0.6	+1.1	+1.0	
GEEM6	+1.6	-0.1	+1.3	+1.5	
VCKM6	+1.4	+0.5	+1.8	+1.2	
NTZM6	+1.4	+0.6	+2.2	[Heavy Locals]	
RRLL1	-0.1	+0.2	+1.5	[Heavy Locals]	
BTRL1	-0.1	+0.1	0.0	[Heavy Locals]	
DONL1	+0.2	+0.5	-0.3	[Heavy Locals]	
RRVL1	-0.3	+0.5	-0.6	[Heavy Locals]	
NORL1	-0.3	+0.2	-0.4	[Heavy Locals]	

Addendum C: Summary of June, August, and October 2015 Verifications

This is a summary of the 3 verifications presented in this report as well as the other addenda. The results of these verifications should be considered very preliminary and used with caution. Future work should involve a more thorough verification that steps through a multi-year period with a moving 28 day window.

Table 6. Average of 3 verifications presented in this report and associated addenda. Positive (negative) values represent an average modeled value above (below) the observations. Some error values were not able to be calculated for every location for all lead times, so some averages may include only 1 or 2 values. This verification summary is very preliminary and should be used with caution.

Location	Day7	Day14	Day21	Day28	Lag
	Error (ft)	Error (ft)	Error (ft)	Error (ft)	Calib. (hr)
NMDM7	-0.1	+0.3	+0.2	+0.3	+15
TPTT1	+0.2	+0.5	+0.7	+0.4	+8
CRTM7	+0.1	+0.6	+0.5	+0.4	+6
OSGA4	-0.2	+0.4	+0.4	+0.3	+15
MEMT1	+0.2	+0.3	+0.5	+0.7	+17
TRPM6	-0.7	-0.1	+0.9	+0.8	+12
HEEA4	-0.8	+0.1	+1.4	+1.2	+20
ARSA4	+0.2	+1.7	+1.3	+0.9	+21
GEEM6	+0.3	+1.4	+2.2	+1.5	+9
VCKM6	+0.3	+2.1	+2.3	+2.0	+21
NTZM6	+0.6	+2.7	+2.9	+3.3	+24
RRLL1	+0.1	+2.7	+2.3	+3.2	+21
BTRL1	+0.2	+2.4	+0.9	+1.7	+9
DONL1	+0.1	+1.2	-0.1	+0.4	+9
RRVL1	-0.0	+0.7	-0.3	+0.0	+9
NORL1	-0.0	+0.3	-0.3	+0.0	+9