2022 Updated Atlas of U. S. Army Corps of Engineers Historic Daily Tide Data in Coastal Louisiana

Abstract: In 2010 the U. S. Army Corps of Engineers (USACE) New Orleans District (CEMVN) analyzed data from nineteen USACE gages to develop the USACE Tide Gage Atlas for Coastal Louisiana. The purpose of this document was to develop a useful tool for analyzing the sea level change trends in the coastal areas of Louisiana, where some of the highest relative sea level rise rates in the United States are observed due to the significant subsidence in the region. CEMVN referenced the data to a common gage datum, analyzed it for shifts and accounted for all known adjustments. In the 2015 update to the Tide Gage Atlas of Coastal Louisiana five of the nineteen original gages' trends were revised by extending the record of gage data and reapplying the linear trend. Eleven new gages were added in 2015 expanding the atlas to a total of 30 gages. These additional gages were selected based on a needs assessment survey of CEMVN employees, with new gages limited to those with at least 40 years of gage data available. The 2015 updated data was evaluated in the same manner as the previously studied gages: adjustments were made to remove shifts in the data, river discharge influences were removed where necessary, and linear trends were computed. This 2022 update to the Tide Gage Atlas of Coastal Louisiana expanded off the previous updates by extending the record of gage data and recomputing the linear trend. One new gage was added based on previous selection criteria of containing at least 40 years of gage data. The new gage was evaluated with the same methodology as previous gages. Therefore, a total of 31 gages are now represented in the Tide Gage Atlas of Coastal Louisiana with the report now incorporating additional gage data from 2015 to 2021. Continual revisions of the atlas are intended to not only keep sea level change trends updated, but also to expand data resources for ongoing and future USACE projects.

Introduction

Public interest continues to grow regarding the alarming rates of land loss in coastal Louisiana, especially since Hurricanes Katrina (August 2005), Rita (September 2005), Laura (August 2020), and Ida (August 2021) devastated Louisiana's coastal marshes and communities. An understanding of the contributions of land subsidence (isostatic) and global sea level rise (eustatic) to Louisiana's wetland loss is crucial to the success of any future plans designed to protect coastal communities (Gonzalez and Tornqvist, 2006). The Louisiana coast's geography makes it especially vulnerable to the effects of relative sea level change (RSLC) (**Figure 1**). The U.S. Army Corps of Engineers (USACE) gage network's diverse geographic range allows for a better understanding of historic trends than other datasets for Southern Louisiana.

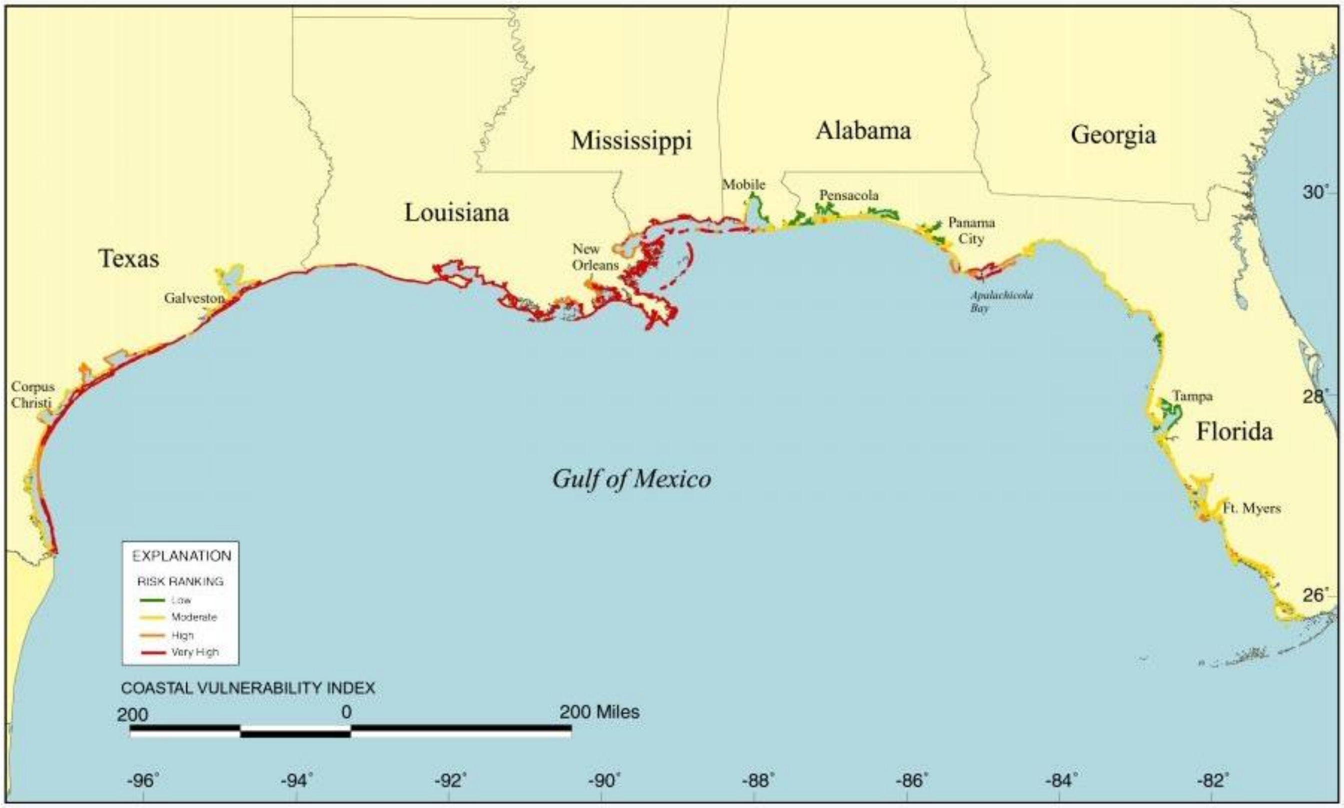


Figure 1. Map of the Coastal Vulnerability Index (CVI) for the U. S. Gulf Coast. The CVI shows the relative vulnerability of the coast to the changes due to the future rise in sea-level. Areas along the coast are assigned a ranking from low to very high risk, based on the analysis of physical variables that contribute to coastal change. (Source: http://pubs.usgs.gov/of/2000/of00-179/).

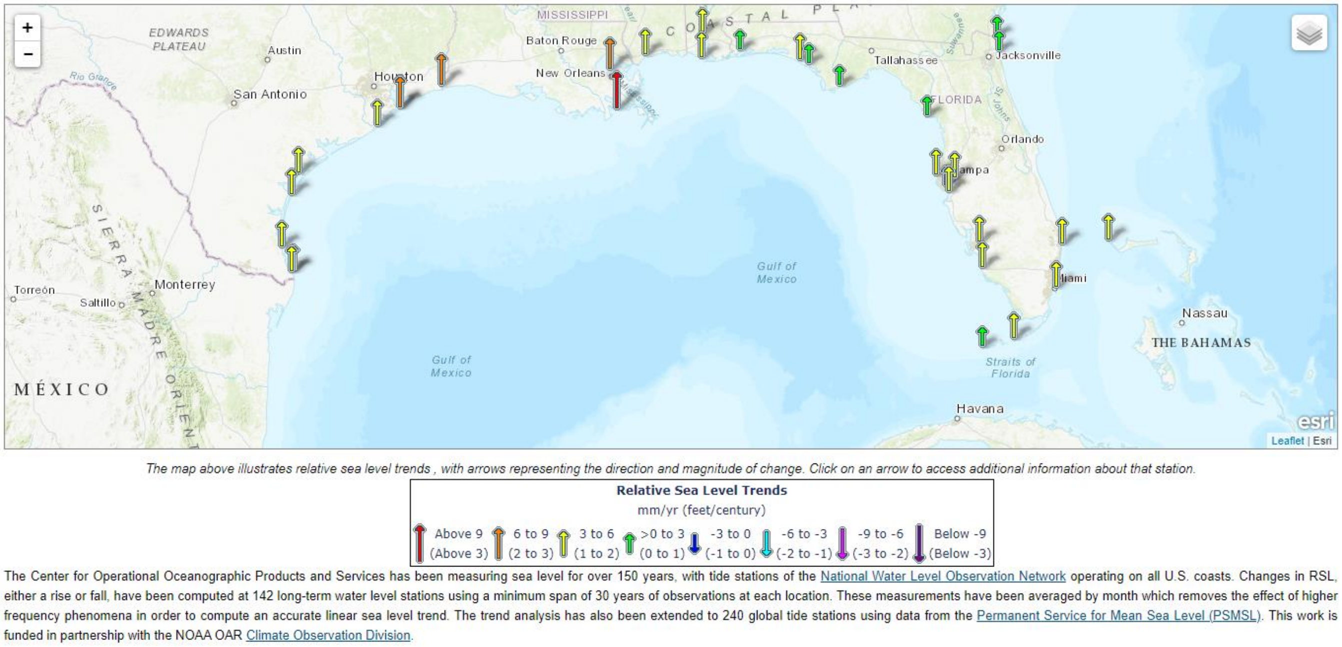
The USACE, New Orleans District (CEMVN) has historically collected daily water level data from various water bodies, rivers, and streams throughout Southern Louisiana. Some of these gages have recorded data in tidal areas and have long periods of record with some exceeding 70 years of collected data. In order to develop estimates of RSLC for coastal Louisiana projects, CEMVN engaged in a study of stage data compiled at various coastal data collection sites in 2010. In 2015 the New Orleans district updated the report to incorporate gage data between 2010 and 2014 for the previously studied gages and to include new gages that formerly did not have the required 40-years of data. The 2015 updated gages were selected by CEMVN staff based on those with sea level change estimates that would prove useful in informing nearby projects. In 2022, CEMVN continues to track the progress of sea level change with another update. The new updates include extending the record with gage data from 2015 to 2021 and adding one more gage selected by CEMVN staff. The new data was evaluated in the same manner as the previously studied gages: adjustments were made to remove shifts in the data, river discharge influences were removed where necessary, and linear trends were computed. The Tide Gage Atlas of Coastal Louisiana now contains RSLC trends for 31 USACE gages.

Relative Sea Level Change

Relative mean sea level change at a particular location includes the cumulative effects of global (eustatic) sea level change, regional variability from the global rate in semi-enclosed basins such as the Gulf of Mexico, and any local change in land elevation (isostatic movement). The long-term causes of relative mean sea level change are sixfold and include eustatic rise, crustal subsidence, seismic subsidence, auto-subsidence, man-made subsidence, and variations due to climatic fluctuations (NRC, 1987). Coastal Louisiana has some of the highest regional subsidence rates in the United States and consequently is subject to some of the highest rates of RSLC. For example, Zumberge et al. observed subsidence at an established subsidence superstation approximately one mile away from the Mississippi River near Myrtle Grove, LA. Over a five-year period (2016-2021), Zumberge's data found "a reliable rate of 2.5 ± 0.3 mm/yr deep-seated downward vertical motion, uncontaminated by shallow sediment compaction, and attributed to a combination of GIA (glacial isostatic adjustment), SIA (sedimentary isostatic adjustment), fluid extraction, tectonics, and compaction of older sediments" (Zumberge et al., 2022).

The data presented here are intended to represent the total RSLC experienced at a particular location. No attempt is made to extract the various components comprising relative sea level change or to provide further analysis of the data other than what was recorded at the site. Estimates of total vertical land movement may be made by subtracting the eustatic sea level rise rate from the data. However, due to the inherent temporal and regional variability of the eustatic sea level rise rate, that attempt was not made in the previous atlas reports nor is it made in this updated atlas.

RSLC rates change based on geographic location. Sea level trends within the U.S. Gulf Coast, according to NOAA's Laboratory for Satellite Altimetry, show variance from approximately 9 mm/yr to between 0-3 mm/yr. Trends for NOAA's Southern Louisiana gages are 9.18 mm/yr (1947-2021) and 6.25 mm/yr (1982-2021) for Grand Isle, LA (8761724) and New Canal, LA (8761927), respectively (**Figure 2**).



The map above illustrates relative sea level trends , with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

Relative Sea Level Trends

mm/yr (feet/century)

Above 9 (Above 3)	6 to 9 (2 to 3)	3 to 6 (1 to 2)	>0 to 3 (0 to 1)	-3 to 0 (-1 to 0)	-6 to -3 (-2 to -1)	-9 to -6 (-3 to -2)	Below -9 (Below -3)

The Center for Operational Oceanographic Products and Services has been measuring sea level for over 150 years, with tide stations of the National Water Level Observation Network operating on all U.S. coasts. Changes in RSL, either a rise or fall, have been computed at 142 long-term water level stations using a minimum span of 30 years of observations at each location. These measurements have been averaged by month which removes the effect of higher frequency phenomena in order to compute an accurate linear sea level trend. The trend analysis has also been extended to 240 global tide stations using data from the Permanent Service for Mean Sea Level (PSMSL). This work is funded in partnership with the NOAA OAR Climate Observation Division.

Figure 2. Sea level trends within the U.S. Gulf Coast from NOAA Tides & Currents (Source: https://tidesandcurrents.noaa.gov/sltrends/).

Estimates of historic eustatic sea level rise rates may be found in literature. One such estimate is in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report: Climate Change 2022 (AR6). The IPCC AR6 states with *high confidence* that "Sea level observations show that global mean sea level (GMSL) rose by 0.2 [0.15 to 0.25] m over the period 1901 to 2018 at an average rate of 1.7 [1.3 to 2.2] mm yr^{-1}. New analyses and paleo-evidence since AR5 show this rate is *very likely* faster than during any century over at least the last three millennia. Since AR5, there is strengthened evidence for an increase in the rate of GMSL rise since the mid-20th century, with an average rate of 2.3 [1.6 to 3.1] mm yr^{-1} over the period 1971-2018 increasing to 3.7 [3.2 to 4.2] mm yr^{-1} for the period 2006-2018 (*high confidence*). See **Figure 3** for GMSL rise projections.

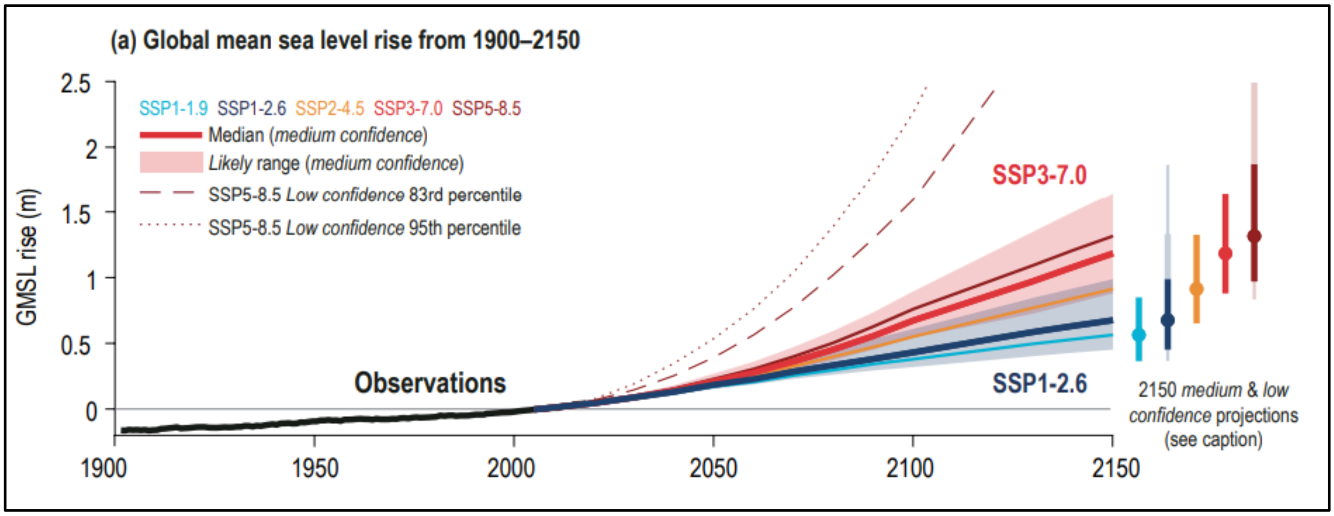


Figure 3. *Global mean sea level rise from IPCC AR6 Technical Summary (Source: Intergovernmental Panel on Climate Change (2022), IPCC Sixth Assessment Report: Climate Change 2022 (AR6), https://www.ipcc.ch/report/ar6/wg2/).*

However, the data upon which those estimates are based is highly variable by decade. For example, a rate of 3.7 ± 0.5 mm yr^{-1} has been estimated for the period 2006-2018, significantly higher than the longer-term rate. It is unknown whether the higher rate during the latest decade in the analysis is due to decadal variability or an increase in the longer-term trend. **Figure 4** is a reproduction of a figure from the IPCC 2007 report that shows the high variability in global sea level change over time.

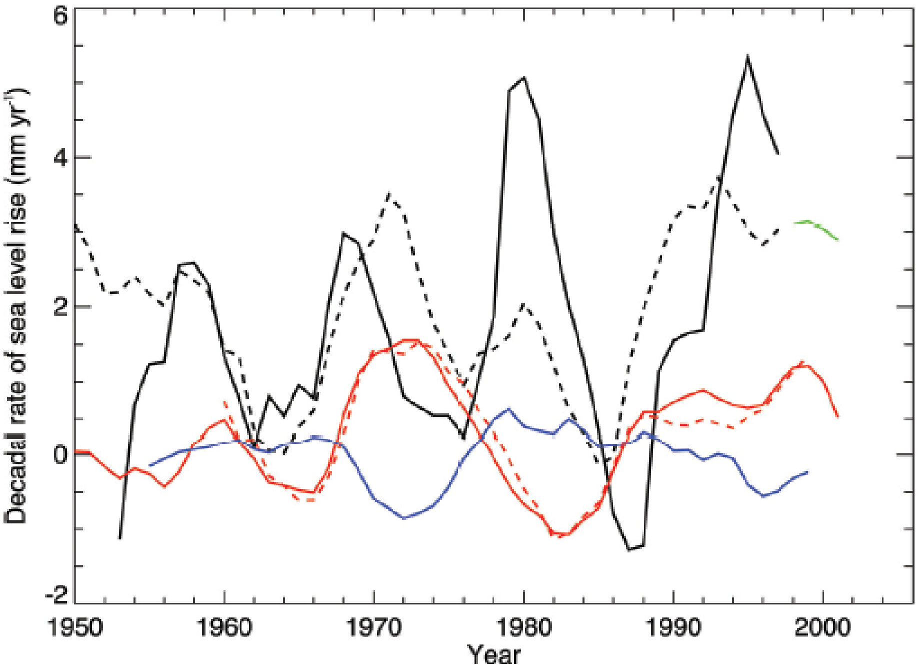


Figure 5.17. *Overlapping 10-year rates of global sea level change from tide gauge data sets (Holgate and Woodworth, 2004, in solid black; Church and White, 2006, in dashed black) and satellite altimetry (updated from Cazenave and Nerem, 2004, in green), and contributions to global sea level change from thermal expansion (Ishii et al., 2006, in solid red; Antonov et al., 2005, in dashed red) and climate-driven land water storage (Ngo-Duc et al., 2005, in blue). Each rate is plotted against the middle of its 10-year period.*

Figure 4. Reproduction of IPCC 2007 figure showing decadal variability in eustatic sea level rates. (Source: Intergovernmental Panel on Climate Change (2007), IPCC Fourth Assessment Report: Climate Change 2007 (AR4), http://www.ipcc.ch/index.htm).

Updated long term trends from the Tide Gage Atlas of Coastal Louisiana can be used to generate relative sea level change curves in accordance with ER 1100-2-8162, Incorporating Sea Level Changes in Civil Works Programs. This regulation, published in 2013 and updated in 2019, requires evaluation of three scenarios for future projections: low (historic), intermediate, and high rates of sea level rise. The low-rate curve is an extrapolation of the linear historic trend, while the other curves include an acceleration factor following the equation:

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$$

Where,

t_1 is time in years from 1992 to the start year,
t_2 is time in years from 1992 to the projection year, and
b is the intermediate or high acceleration factor 2.71E-05 and 1.130E-04, respectively

An example of the projection graph generated is given in **Figure 5**.

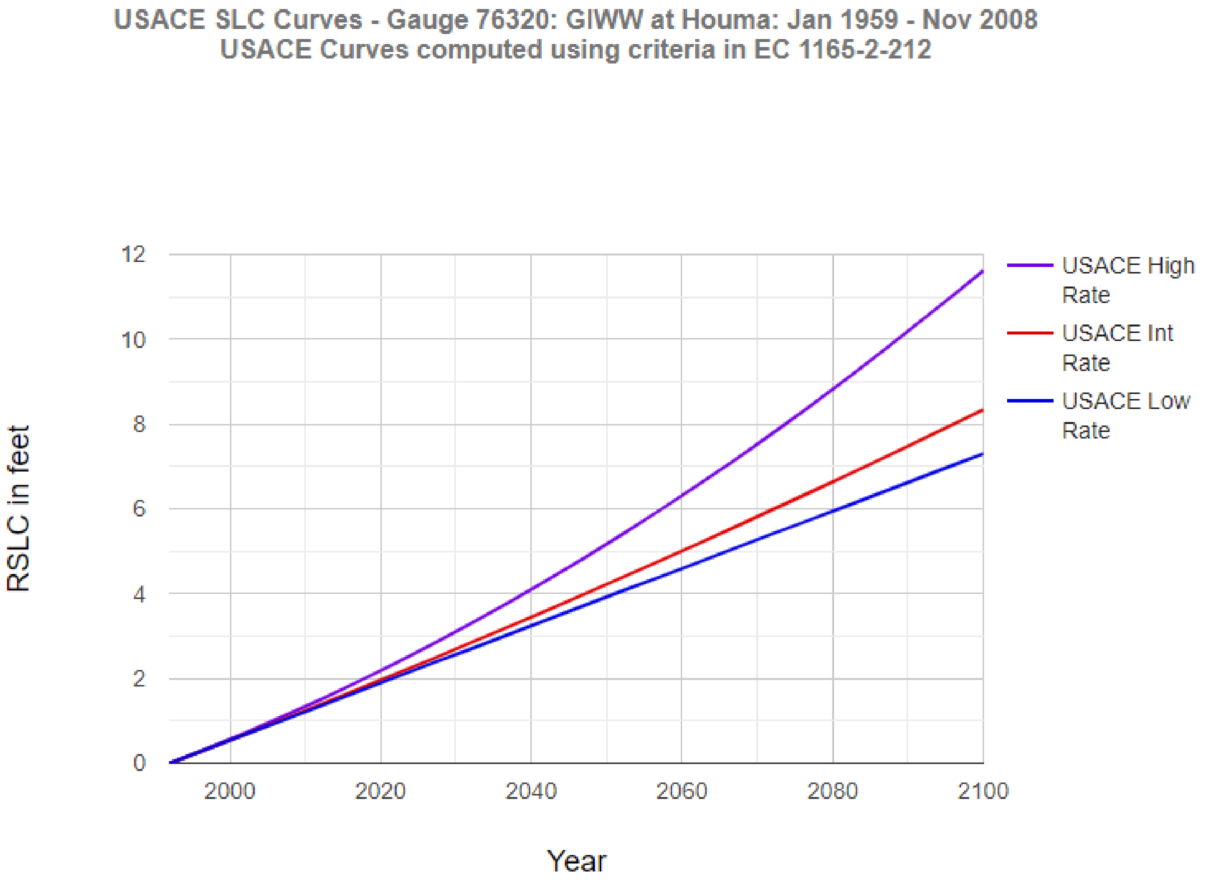


Figure 5. Estimated future sea level change projections (Source: https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html).

Methodology

Linear Trend Analysis

The purpose of the analyses conducted for this study was to determine the RSLC at particular USACE gage sites. This necessitated having all recorded stages for the gages in a common vertical datum. In many cases a gage shift or reset was documented with the surveyed amount that that gage was moved upwards or downwards. However, records for all datum shifts and corrections applied to the gage records were not always available. In those situations, vertical shifts in the data had to be determined by other means.

One technique used to estimate unrecorded vertical gage adjustments was by comparison of the data with data recorded at a nearby gage site that was not shifted during the time frame of the suspected shift. Plotting the two gage records together provided a means of determining significant shifts by visual inspection and correlating the suspected vertical shift amount to the known nearby gage that was not shifted. This special treatment was applied to two of the gages in this analysis Southwest Pass at East Jetty and Lake Pontchartrain at Mandeville.

Some unrecorded gage shifts were estimated by determining the linear trend of the data sets before and after the shift was applied, usually during a protracted period of missing data and adjusting the data after the data gap so that the linear trends matched through the data gap. In other words, the linear equations of the two trends were solved for the variable y using the same variable x representative of the time (or year) when the shift was thought to have been applied. The resulting difference is the value of the vertical shift applied at time x (see **Figure 6 and Figure 7** for example).

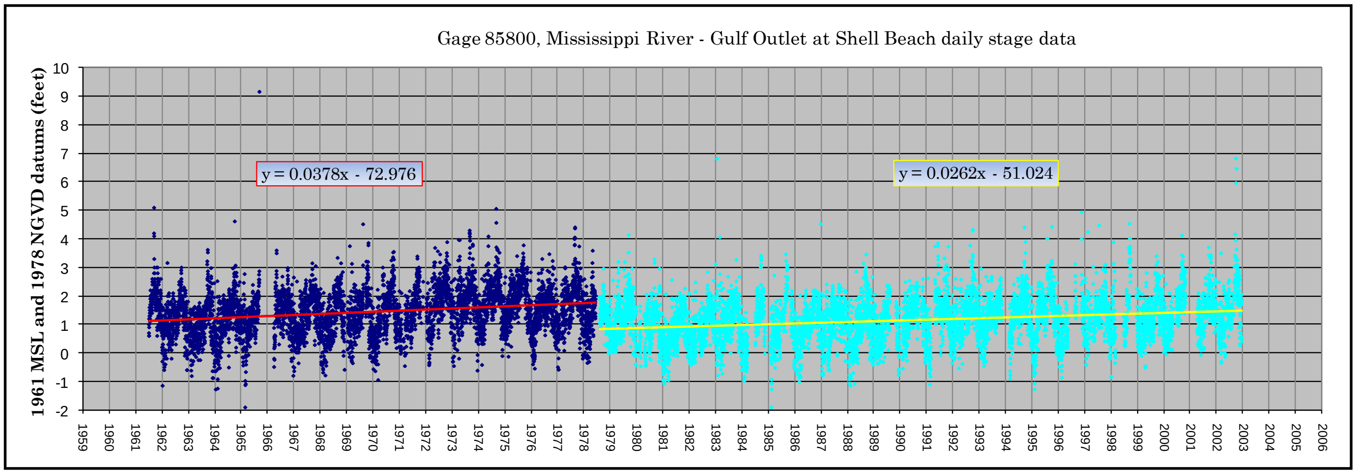


Figure 6. Example of record with unknown gage shift.

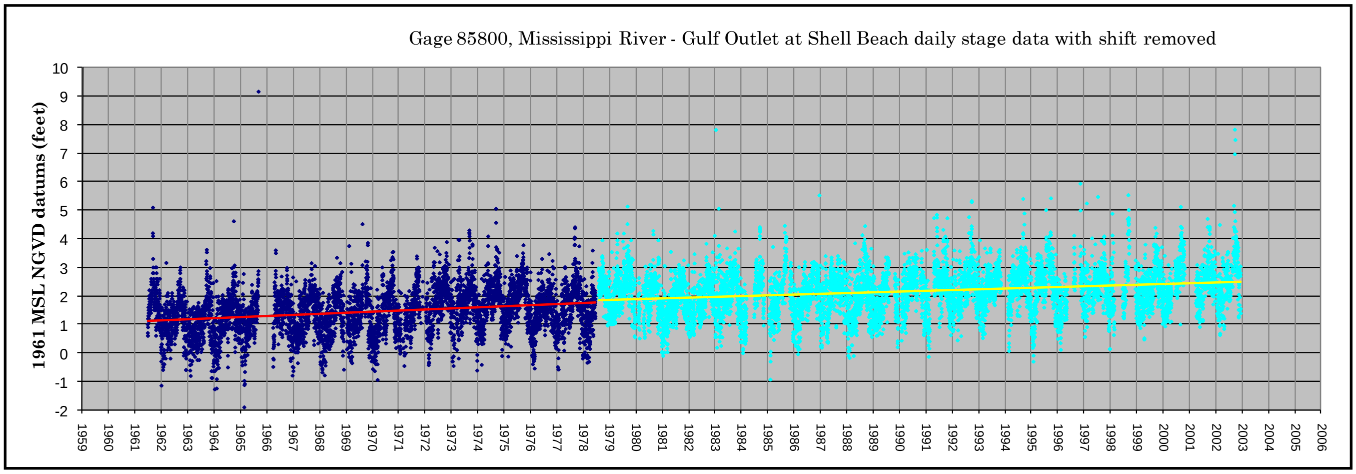


Figure 7. Example of record with gage shift removed.

Mississippi River Extraction

Some Mississippi River gages had reliably long and consistent periods of record which is valuable for long-term trend analysis. A portion of the variability in stage for gages on the Mississippi River is a result of variable river discharge. In order to extract that portion of the stage record that is due to tidal effects only, a special analysis was conducted on the Carrollton, Harvey Lock, Inner Harbor Navigation Canal (IHNC) Lock, West Pointe a la Hache, and Venice gages because these gages are located on the river and a significant portion of the variability in their stage records is due to river discharge rather than coastal influences. The analysis consisted of comparing observed stage data to the stage derived from a 6-year moving linear stage-discharge relationship between stage at the local gage of interest and Mississippi River discharge measured at Tarbert Landing near the Old River Control complex. Adjustments were made to the flow data to account for withdrawals at the Bonnet Carré and Morganza Floodways as well as temporal shifts applied to account for travel time from Tarbert Landing to the gage site being analyzed.

As an example, the procedure is shown here for the Carrollton gage analysis. First, Tarbert Landing discharges were translated to the Carrollton gage site by accounting for any withdrawals made at the Bonnet Carré and Morganza Floodways and the discharges were shifted one day ahead to account for travel time from Tarbert Landing to Carrollton. Daily stage/discharge relationships were developed using a moving ± 3 years moving linear trend. The resultant stage/discharge points are shown in **Figure 8** for 1 July 1975.

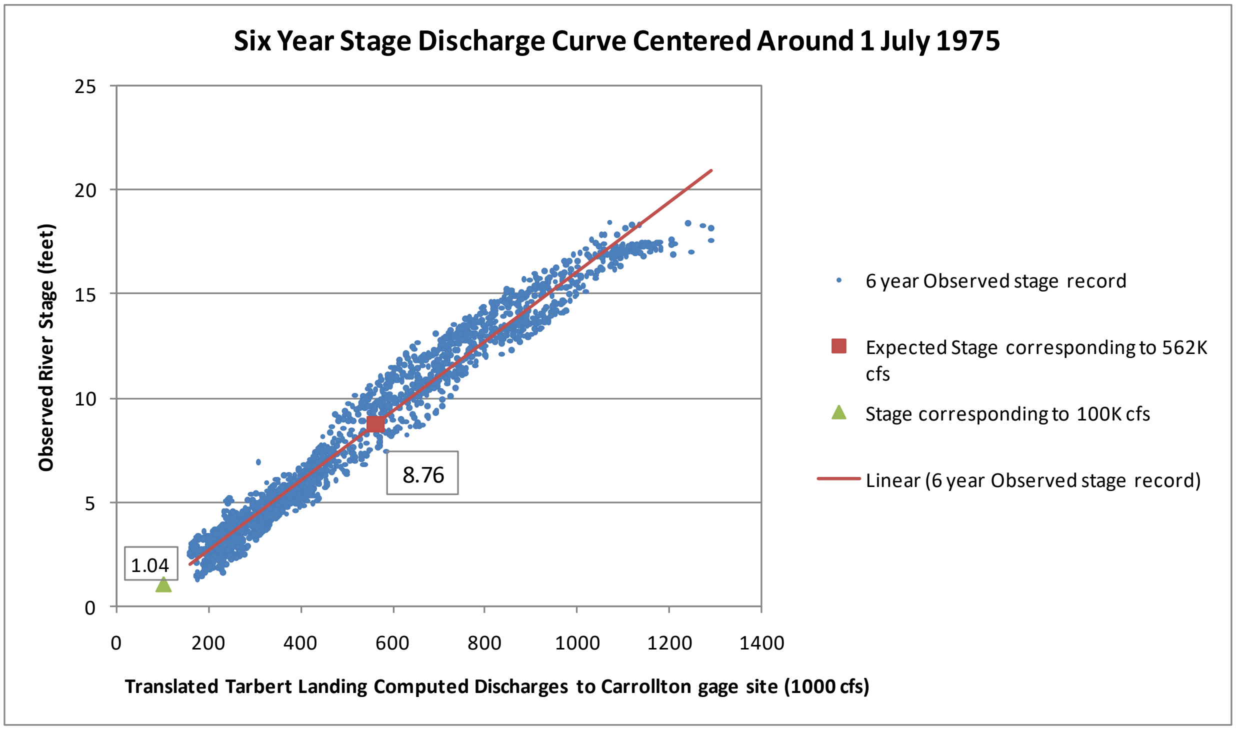


Figure 8. Example plot demonstrating procedure to extract tidal signal from observed Mississippi River stages.

The expected stage from this linear stage/discharge relationship for the corresponding Carrollton discharge on 1 July 1975 of 562,000 cubic feet per second (cfs) was 8.76 feet. The stage corresponding to a base flow of 100,000 cfs, or 1.04 feet, was subtracted from this stage to get a stage adjustment of 7.72 feet, which is considered to be an estimate of that portion of the stage record attributable to Mississippi River discharge variance. The use of 100,000 cfs as the base flow was selected because that is the lowest computed discharge on the Mississippi River during the period of record and as such, the lowest discharge for which a river-influenced stage could be estimated empirically. The daily stage adjustment was then subtracted from the observed stage to build the daily synthetic tide record, i.e., for 1 July 1975, the result is 9.78 feet minus 7.72 feet, which is 2.06 feet. The slope of this synthetic tide record is considered to represent the RSLC for that particular gage. The resultant synthetic tide is shown in **Figure 9** for a portion of the Carrollton stage record. In **Table *1***, the extracted tide-based linear trend is shown in parentheses.

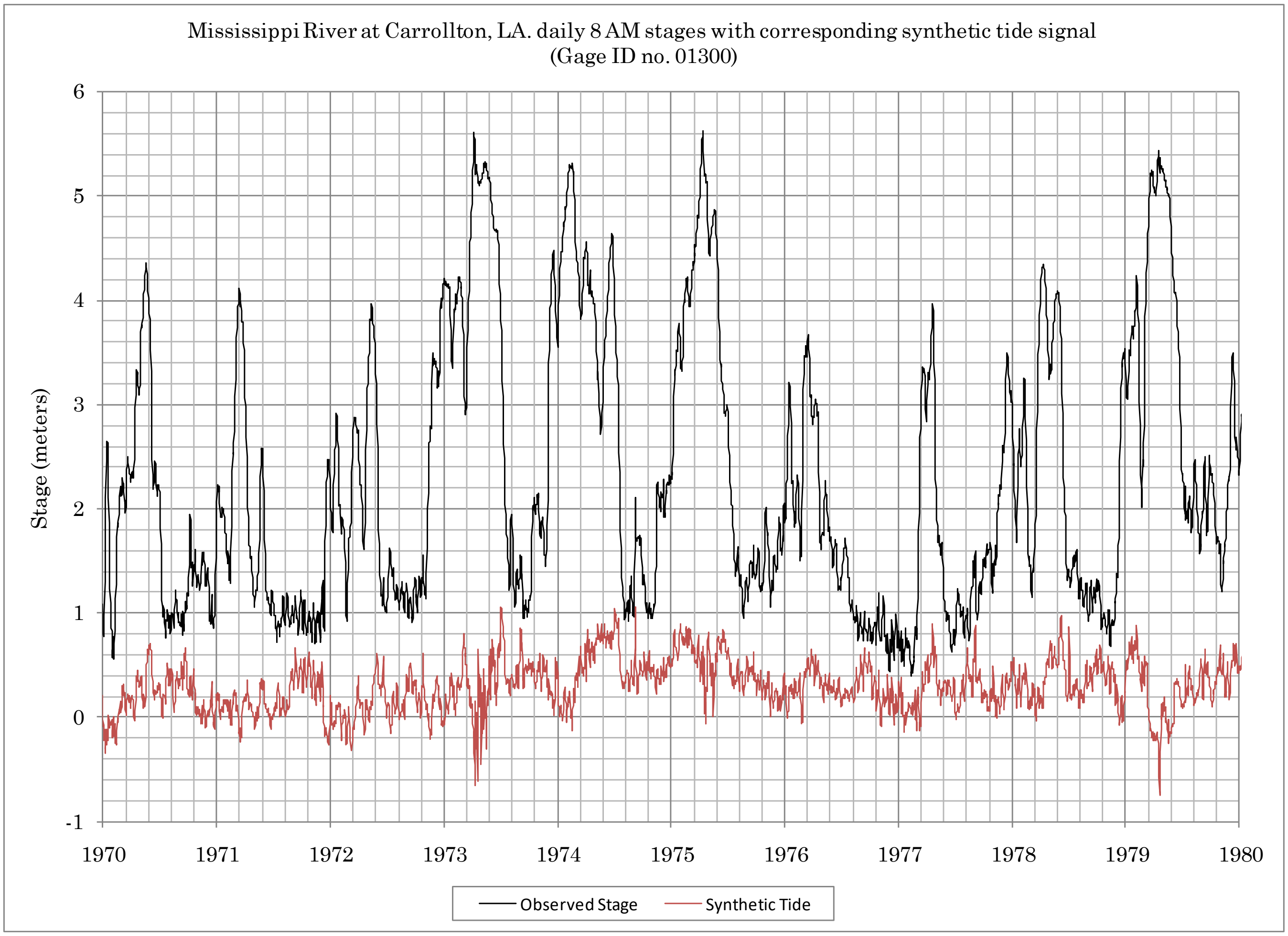


Figure 9. Example stage record and resultant synthetic tide from the tide extraction process for a portion of the Carrollton daily stage record.

Results

The results of the linear trend analyses performed on the daily tide data recorded at 31 USACE gages is summarized in **Table 1** and on **Figure 10 and Figure 11**. **Appendix A** contains charts of the daily tide data used in the analyses, along with the linear trend lines developed for each gage site.

Sites for which the 2022 linear trends changed the most from the 2015 update were given extra scrutiny to verify identify the reasons for the apparent change. Those locations and their probable explanation for the apparent change are contained in the table below.

Gage Name	USACE MVN GAGE ID	Period of Record Analyzed	2010 Linear Trend for Period of Record (mm/year)	2015 Linear Trend for Period of Record (mm/year)	2022 Linear Trend for Period of Record (mm/year)	Probable Explanation for Change
Mississippi River at New Orleans (Carrollton)	01300	Jan 1950-Dec 2021	18.6 (9.2)	9.6 (7.1)	12.9 (6.88)	The increase in the linear trend using as-observed data is related to the high river discharge years during the period added in the current update. An increase in the as-observed data's linear trend is seen at other Mississippi River gage.
Mississippi River at IHNC Lock	01340	Jan 1945-Dec 2021		8.18 (6.80)	17.8 (13.7)	The 2022 update brought to light an adjustment to the gage of 1.01 ft starting in 1975 that was not present in the 2015 update.
Southwest Pass at East Jetty	01670	Jan 1953-Dec 2014; Jan 1975-Dec 2021	25.7	26.8	34.8	Previous updates used a comparison with data from nearby gages for stage estimates 1953 to 1975. Because this update includes 45 years of data at Gage 10670, the 1953-1975 comparison estimates were omitted.
Calcasieu River and Pass at Lake Charles	73550	Jan 1950-Dec 2021	6.1	6.1	4.39	Gage was re surveyed and the data adjusted beginning Nov 2013.
Calcasieu River and Pass near Cameron	73650	Jan 1950-Dec 2021	3.9	3.9	5.39	No data 2005-2013. This 2022 update incorporates observed data beginning in 2013.
Freshwater Canal at Freshwater Bayou Lock (south)	76593	Jul 1968-Aug 2020	5.4	3.6	5.79	The 2022 update is more in line with the 2010 update.
Lake Pontchartrain at Mandeville	85575	Aug 1957-Dec 2021	6.6	6.6	8.92	No Data between 2002-2007. This 2022 update incorporates observed data beginning in 2007.

Conclusion

Historic daily tidal water level measurements of USACE gages have been analyzed to determine relative sea level trends that are representative of the gage sites using daily observed data through calendar year 2021 where available. This data is provided to supplement relative sea level change rates provided by other sources (see http://tidesandcurrents.noaa.gov/ for example), to conduct analyses and future projections of sea level trends for project planning purposes, and may be used to assist in the estimation of the components of relative sea level rise (eustatic and isostatic).

Acknowledgements

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Table 1. Summary Table of 2022 Updated Relative Sea Level Trends in mm/year for U. S. Army Corps of Engineers Gages

	USACE MVN Gage ID number	Latitude	Longitude	Period of Record Analyzed	2010 Linear trend for Entire Period of Record (mm/year)	2015 Linear trend for Entire Period of Record (mm/year)	2022 Linear trend for Entire Period of Record (mm/year)
Mississippi River at New Orleans (Carrollton)*	01300	29.93472222	-90.13611111	Jan 1950 - Dec 2021	18.6 (9.2)	9.6 (7.1)[1]	12.9 (6.88)
Mississippi River at Harvey Lock*	01320	29.91010000	-90.08404000	Jan 1959 - Dec 2021			16.5 (7.07)
Mississippi River at IHNC Lock*	01340	29.96441380	-90.02743330	Jan 1945 - Dec 2021		8.18 (6.80)	17.8 (13.7)
Mississippi River at West Pointe a la Hache*	01400	29.57111110	-89.79694440	Jan 1950 - Dec 2021	12.6 (13.1)	11.75 (11.52)	12.0 (11.9)
Mississippi River at Venice*	01480	29.27583333	-89.35277778	Jan 1953 - Dec 2021	21.8 (23.0)	21.8 (23.0)	20.7 (21.0)
Southwest Pass at East Jetty	01670	28.93230550	-89.40711110	Jan 1975 - Dec 2021	25.7	26.8	34.8
South Pass at Port Eads	01850	29.01472220	-89.16583330	Jan 1953 - Dec 2021	25.5	25.5	25.1
Avoca Island Cutoff South of Morgan City	03820	29.53333300	-91.24944440	Feb 1956 - Aug 2018		20.5	20.4
Catfish Point Control Structure - North	70675	29.86358610	-92.84843050	Jan 1955 - Dec 2021		1.61	2.01
Catfish Point Control Structure - South	70750	29.86293330	-92.84924160	Jan 1955 - Dec 2021		3.83	3.80
Calcasieu River and Pass at Lake Charles	73550	30.21308330	-93.25694440	Jan 1950 - Dec 2021	6.1	6.1	4.39
Calcasieu River and Pass near Cameron	73650	29.77580550	-93.34791660	Jan 1950 - Dec 2021	3.9	3.9	5.39
IHNC at New Orleans	76160	29.96648050	-90.02675000	Jan 1945 - Aug 2020		10.47	10.6

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[1] The change from the original Tide Gage Atlas to this update in the apparent rate of sea level change at the Carrollton gage, based on raw stage data, is large enough (18.6 mm/yr to 9.6) that it caught the attention of several reviewers and deserves a special note. It should be noted that this change is in the raw data, rather than the synthetic data with river discharge influences removed. The change in the synthetic data (from 9.2 mm/yr to 7.1) is also substantial in a relative sense but is comparable in absolute terms to changes observed at other gages. Because this gage is located on the Mississippi River, the raw data is subject to influence from river discharge, so it does not reflect sea level change alone and should not be used for most purposes. District staff investigated this dataset closely to ensure that no datum shifts or other errors were missed in the analysis, finding none. It appears that the apparent fall in stage is related to relatively lower river discharge in the years 2011-2015, which included periods of severe drought in 2012 and 2013 (though it also included floods in 2011 and 2015). This, combined with random variations in the data, is the most likely explanation for the apparent slowdown in subsidence being greater at this gage than other gages nearby.

Bayou Petit Caillou at Cocodrie	76305	29.25425000	-90.66352800	Mar 1969 - Dec 2021	6.4	6.3	7.09
GIWW at Houma	76320	29.59805550	-90.71000000	Jan 1959 - Nov 2008		20.6	20.6
Bayou Boeuf Lock - East	76360	29.68303880	-91.17109440	Jan 1955 - Jan 2020		6.99	7.85
Freshwater Canal at Freshwater Bayou Lock (South)	76593	29.55244720	-92.30502500	Jul 1968 - Aug 2020	5.4	3.6	5.79
Schooner Bayou Control Structure - East	76600	29.75781940	-92.26376940	Jan 1955 - Oct 2020		5.96	6.97
Schooner Bayou Control Structure - West	76680	29.75778880	-92.26418610	Jan 1961 - Oct 2020		4.75	5.79
IWW at Leland Bowman Lock - East	76720	29.78521110	-92.20413610	Jan 1959 - Jan 2021		5.42	5.81
IWW at Leland Bowman Lock - West	76800	29.78701940	-92.20925000	Jan 1951 - Jan 2021		3.02	3.54
Intracoastal Waterway at Calcasieu Lock (West)	76960	30.08871940	-93.29488610	Jan 1951 - Aug 2020	5.2	4.8	5.32
Bayou Lafourche at Leeville	82350	29.24800600	-90.20896700	Nov 1955 - Apr 2000	10.8	10.8	10.8
Bayou Barataria at Barataria	82750	29.74187900	-90.13202000	Jan 1950 - Nov 1992	7	7	7.00
Lake Pontchartrain at Frenier	85550	30.10611111	-90.42138889	Jan 1950 - Jun 2005	8.4	8.4	8.84
Lake Pontchartrain at Mandeville	85575	30.36579720	-90.09228880	Aug 1957 - Dec 2021	6.6	6.6	8.92
Lake Pontchartrain at West End	85625	30.02216380	-90.11564440	Jan 1950 - Dec 2021	9.1	8.81	8.53
Rigolets near Lake Pontchartrain	85700	30.16338610	-89.73790550	Jan 1950 - Dec 2021	4.7	4.7	4.45
Bayou Terre Aux Boeufs at Delacroix	85780	29.75786400	-89.78377800	May 1975 - Aug 2005	6.1	6.1	6.09
Mississippi River Gulf Outlet at Shell Beach	85800	29.86206700	-89.67873400	Jun 1961 - Dec 2002	10.2	10.2	10.2
East Cote Blanche Bay at Luke's Landing	88800	29.60107770	-91.53997500	Feb 1957 - Oct 2002	13.3	13.3	13.3

* The Mississippi River stage records for the Carrollton, Harvey Lock, IHNC Lock, West Pointe a la Hache, and Venice gages were analyzed to account for Mississippi River discharge stage influences. Estimates of the Relative Sea Level Change using only the extracted tidal portion of the records are shown in parentheses.

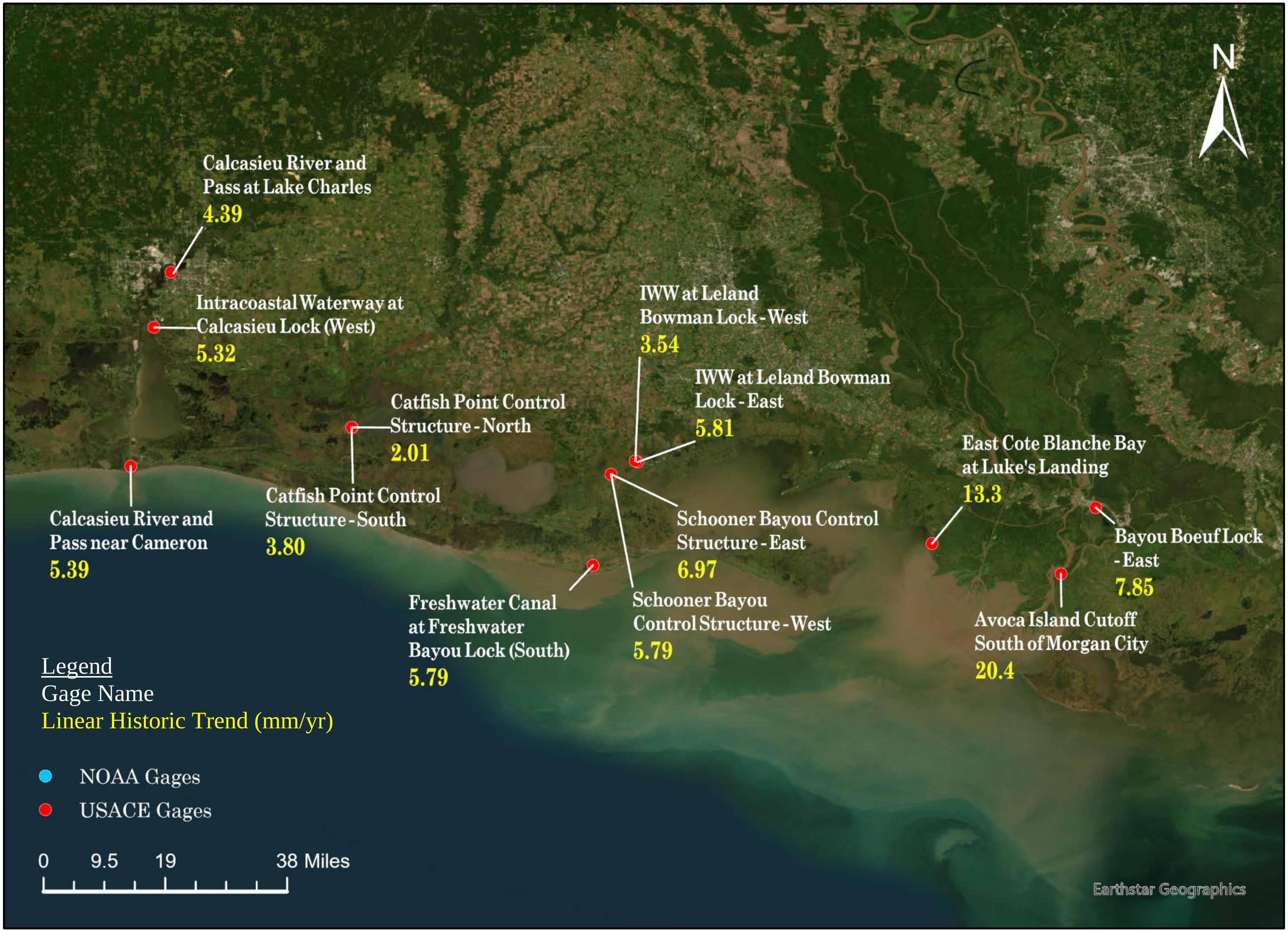

Figure 10. Locations of USACE gages analyzed for relative sea level trends in Southwest Louisiana

Figure 11. Locations of USACE gages analyzed for relative sea level trends in Southeast Louisiana

Table 2. Summary Table of 2022 Updated Relative Sea Level Trends in inches/decade for U. S. Army Corps of Engineers Gages

	USACE MVN Gage ID number	Latitude	Longitude	Period of Record Analyzed	2010 Linear trend for Entire Period of Record (inches/decade)	2015 Linear trend for Entire Period of Record (inches/decade)	2022 Linear trend for Entire Period of Record (inches/decade)
Mississippi River at New Orleans (Carrollton)*	01300	29.93472222	-90.13611111	Jan 1950 - Dec 2021	7.32 (3.62)	3.78 (2.8)	5.08 (2.7)
Mississippi River at Harvey Lock*	01320	29.91010000	-90.08404000	Jan 1959 - Dec 2021			6.5 (2.78)
Mississippi River at IHNC Lock*	01340	29.96441380	-90.02743330	Jan 1945 - Dec 2021		3.22 (2.68)	7.0 (5.39)
Mississippi River at West Pointe a la Hache*	01400	29.57111110	-89.79694440	Jan 1950 - Dec 2021	4.96 (5.16)	4.63 (4.53)	4.72 (4.69)
Mississippi River at Venice*	01480	29.27583333	-89.35277778	Jan 1953 - Dec 2021	8.58 (9.06)	8.58 (9.06)	8.15 (8.27)
Southwest Pass at East Jetty	01670	28.93230550	-89.40711110	Jan 1975 - Dec 2021	10.12	10.55	13.7
South Pass at Port Eads	01850	29.01472220	-89.16583330	Jan 1953 - Dec 2021	10.04	10.04	9.88
Avoca Island Cutoff South of Morgan City	03820	29.53333300	-91.24944440	Feb 1956 - Aug 2018		8.07	8.03
Catfish Point Control Structure - North	70675	29.86358610	-92.84843050	Jan 1955 - Dec 2021		0.63	0.79
Catfish Point Control Structure - South	70750	29.86293330	-92.84924160	Jan 1955 - Dec 2021		1.51	1.5
Calcasieu River and Pass at Lake Charles	73550	30.21308330	-93.25694440	Jan 1950 - Dec 2021	2.4	2.4	1.73
Calcasieu River and Pass near Cameron	73650	29.77580550	-93.34791660	Jan 1950 - Dec 2021	1.54	1.54	2.12
IHNC at New Orleans	76160	29.96648050	-90.02675000	Jan 1945 - Aug 2020		4.12	4.17
Bayou Petit Caillou at Cocodrie	76305	29.25425000	-90.66352800	Mar 1969 - Dec 2021	2.52	2.48	2.79
GIWW at Houma	76320	29.59805550	-90.71000000	Jan 1959 - Nov 2008		8.11	8.11
Bayou Boeuf Lock - East	76360	29.68303880	-91.17109440	Jan 1955 - Jan 2020		2.75	3.09

Freshwater Canal at Freshwater Bayou Lock (South)	76593	29.55244720	-92.30502500	Jul 1968 - Aug 2020	2.13	1.42	2.28
Schooner Bayou Control Structure - East	76600	29.75781940	-92.26376940	Jan 1955 - Oct 2020		2.35	2.74
Schooner Bayou Control Structure - West	76680	29.75778880	-92.26418610	Jan 1961 - Oct 2020		1.87	2.28
IWW at Leland Bowman Lock - East	76720	29.78521110	-92.20413610	Jan 1959 - Jan 2021		2.13	2.29
IWW at Leland Bowman Lock - West	76800	29.78701940	-92.20925000	Jan 1951 - Jan 2021		1.19	1.39
Intracoastal Waterway at Calcasieu Lock (West)	76960	30.08871940	-93.29488610	Jan 1951 - Aug 2020	2.05	1.89	2.09
Bayou Lafourche at Leeville	82350	29.24800600	-90.20896700	Nov 1955 - Apr 2000	4.25	4.25	4.25
Bayou Barataria at Barataria	82750	29.74187900	-90.13202000	Jan 1950 - Nov 1992	2.76	2.76	2.76
Lake Pontchartrain at Frenier	85550	30.10611111	-90.42138889	Jan 1950 - Jun 2005	3.31	3.31	3.48
Lake Pontchartrain at Mandeville	85575	30.36579720	-90.09228880	Aug 1957 - Dec 2021	2.6	2.6	3.51
Lake Pontchartrain at West End	85625	30.02216380	-90.11564440	Jan 1950 - Dec 2021	**3.58**	3.47	3.36
Rigolets near Lake Pontchartrain	85700	30.16338610	-89.73790550	Jan 1950 - Dec 2021	1.85	1.85	1.75
Bayou Terre Aux Boeufs at Delacroix	85780	29.75786400	-89.78377800	May 1975 - Aug 2005	2.4	2.4	2.4
Mississippi River Gulf Outlet at Shell Beach	85800	29.86206700	-89.67873400	Jun 1961 - Dec 2002	4.02	4.02	4.02
East Cote Blanche Bay at Luke's Landing	88800	29.60107770	-91.53997500	Feb 1957 - Oct 2002	5.24	5.24	5.24

* The Mississippi River stage records for the Carrollton, Harvey Lock, IHNC Lock, West Pointe a la Hache, and Venice gages were analyzed to account for Mississippi River discharge stage influences. Estimates of the Relative Sea Level Rise using only the extracted tidal portion of the records are shown in parentheses.

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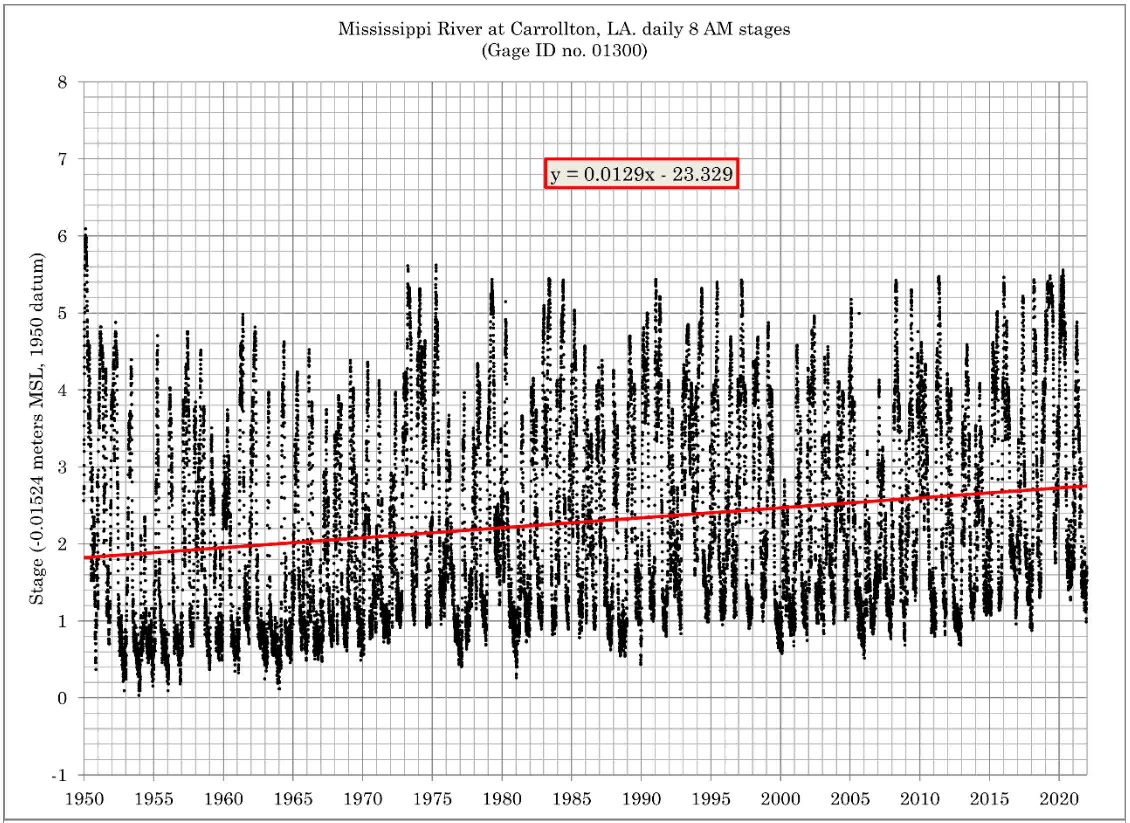
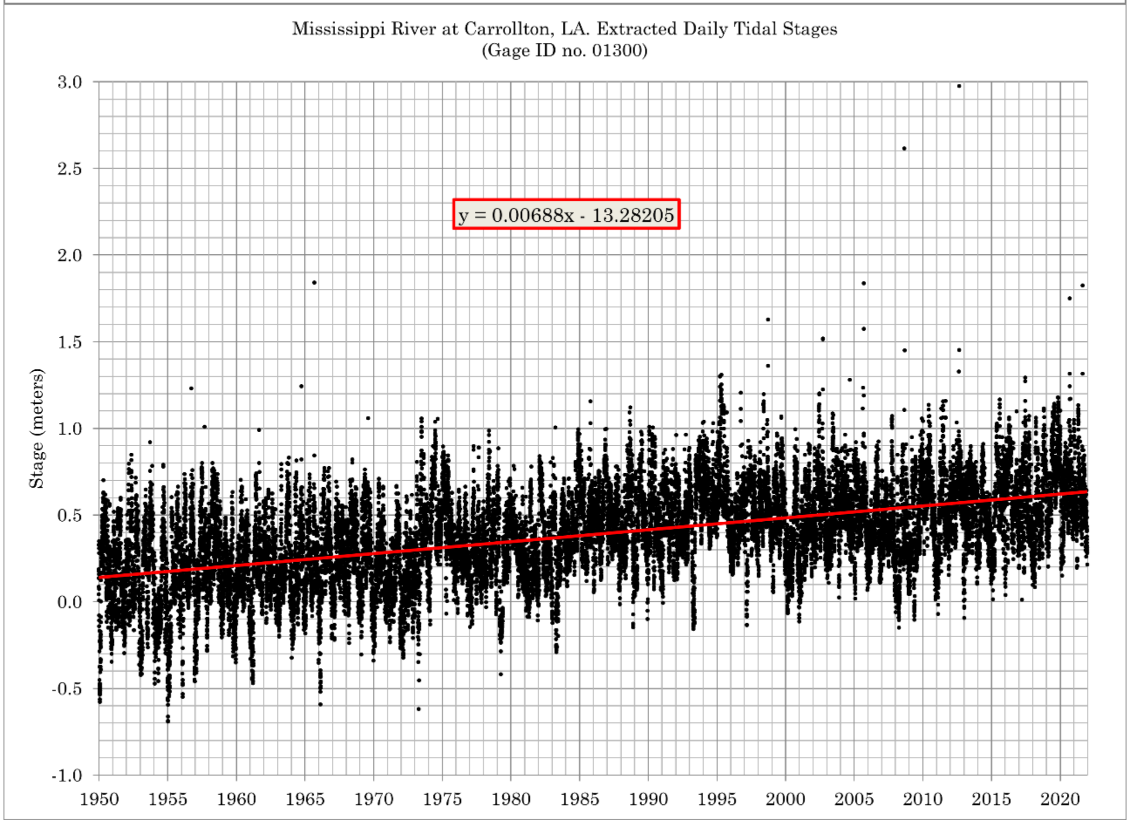
Appendix A

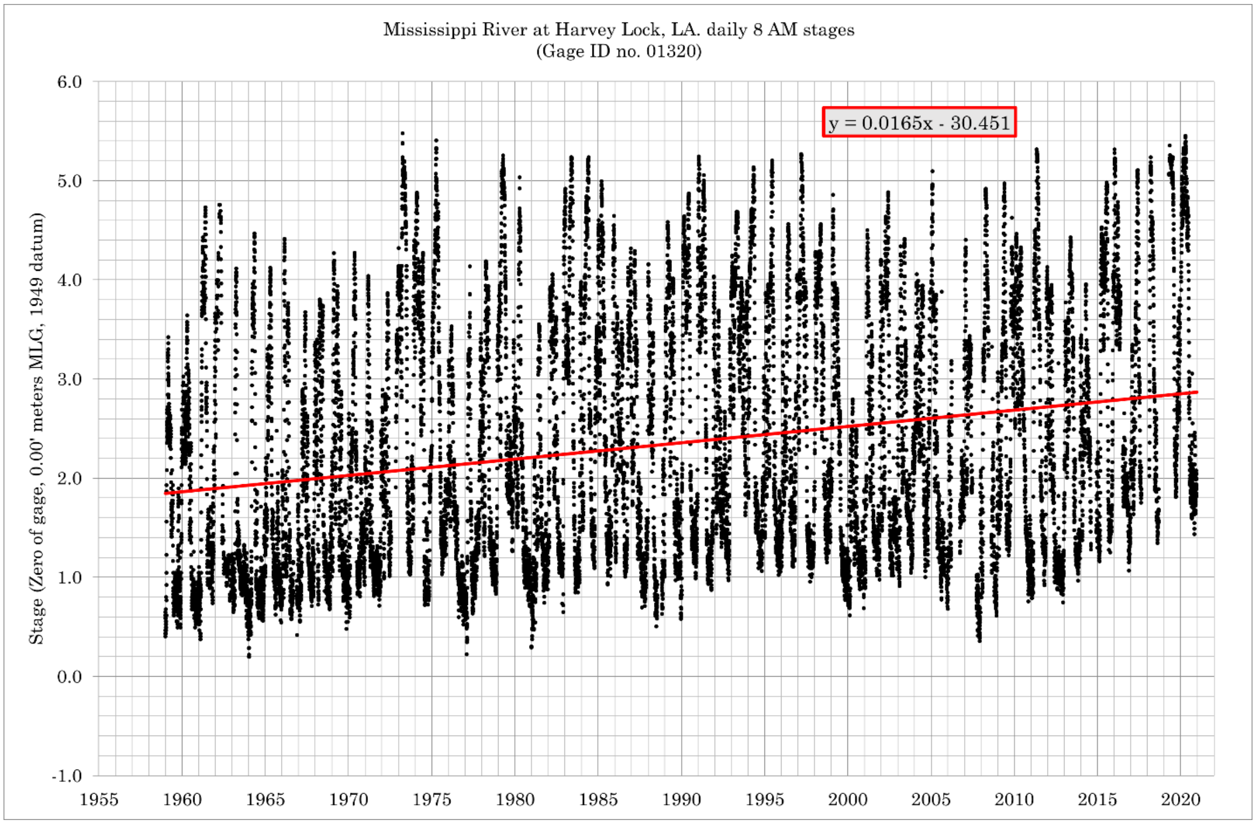
USACE Gages Daily Stage Graphs and Linear Trends

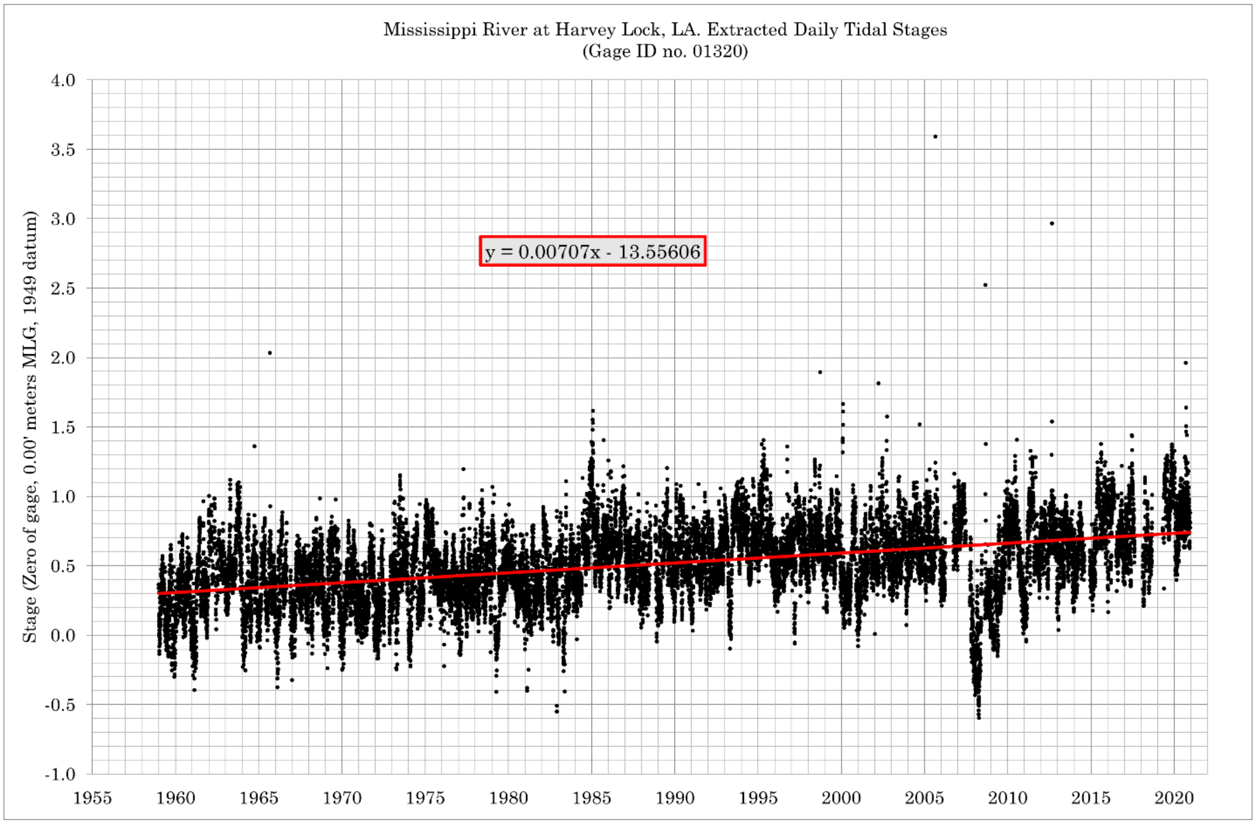


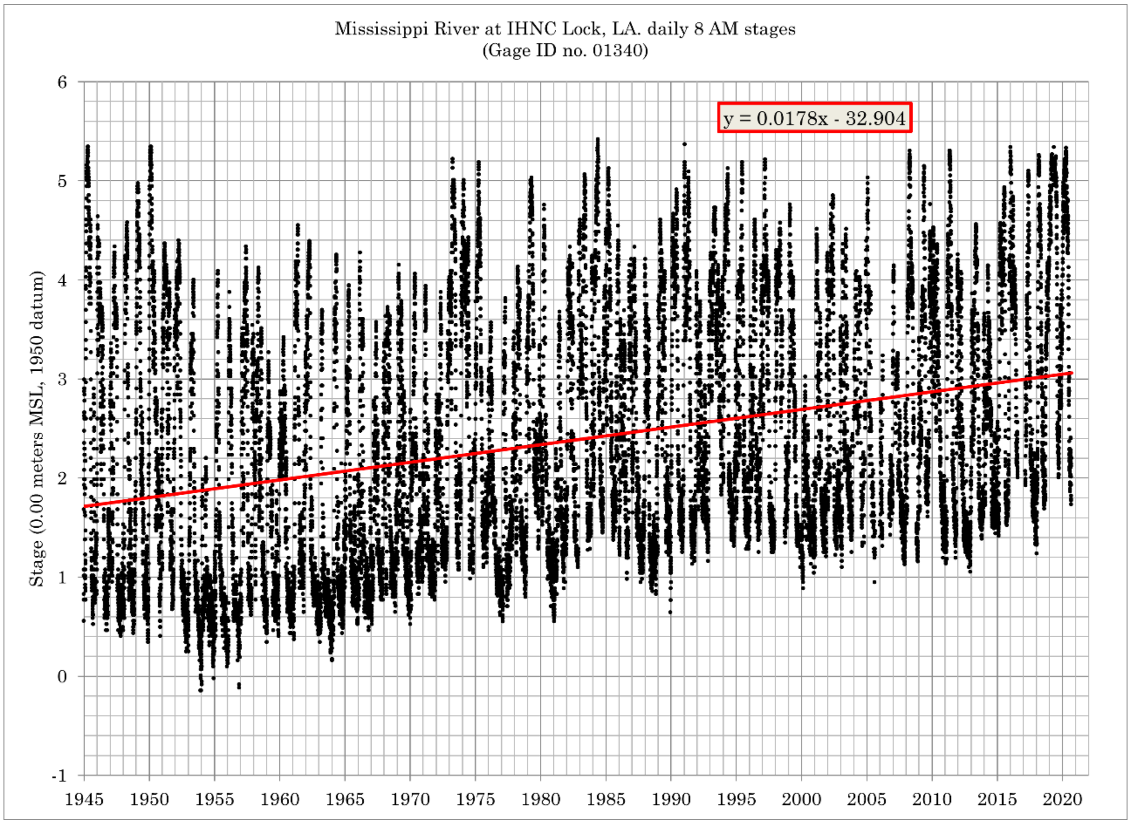
Mississippi River at Carrollton, LA. daily 8 AM stages
(Gage ID no. 01300)

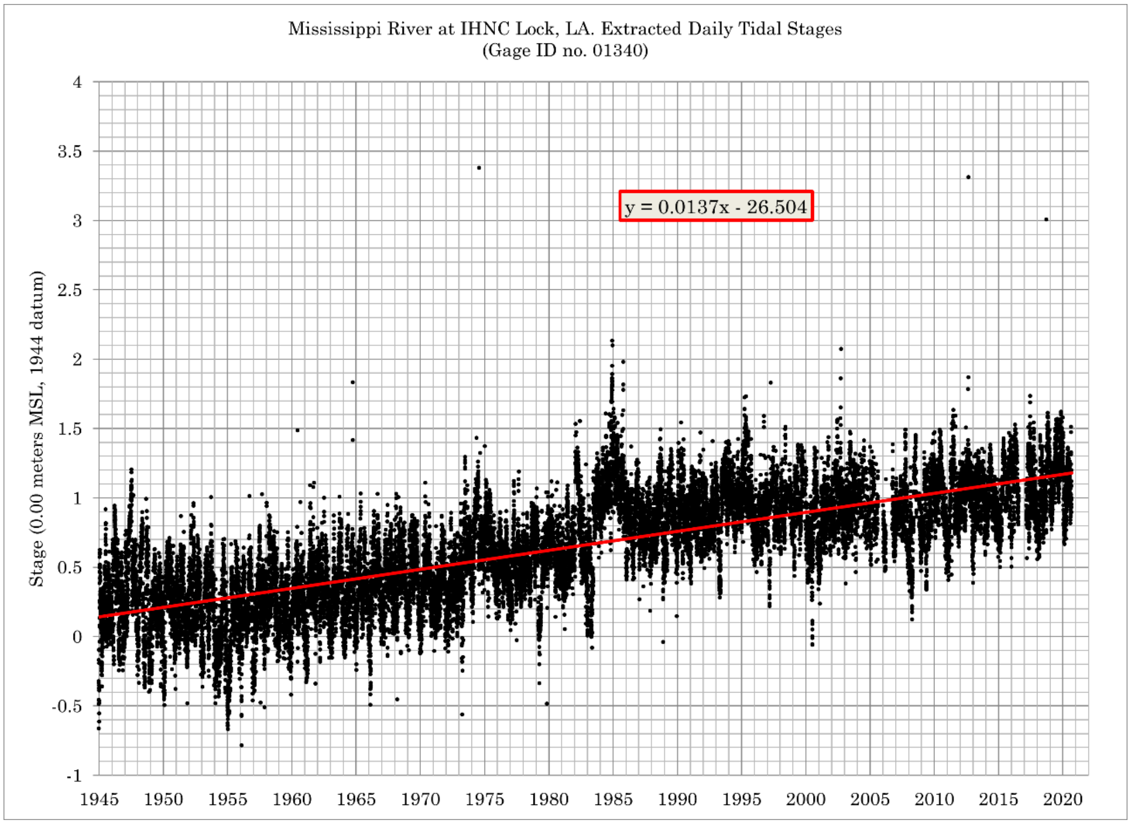


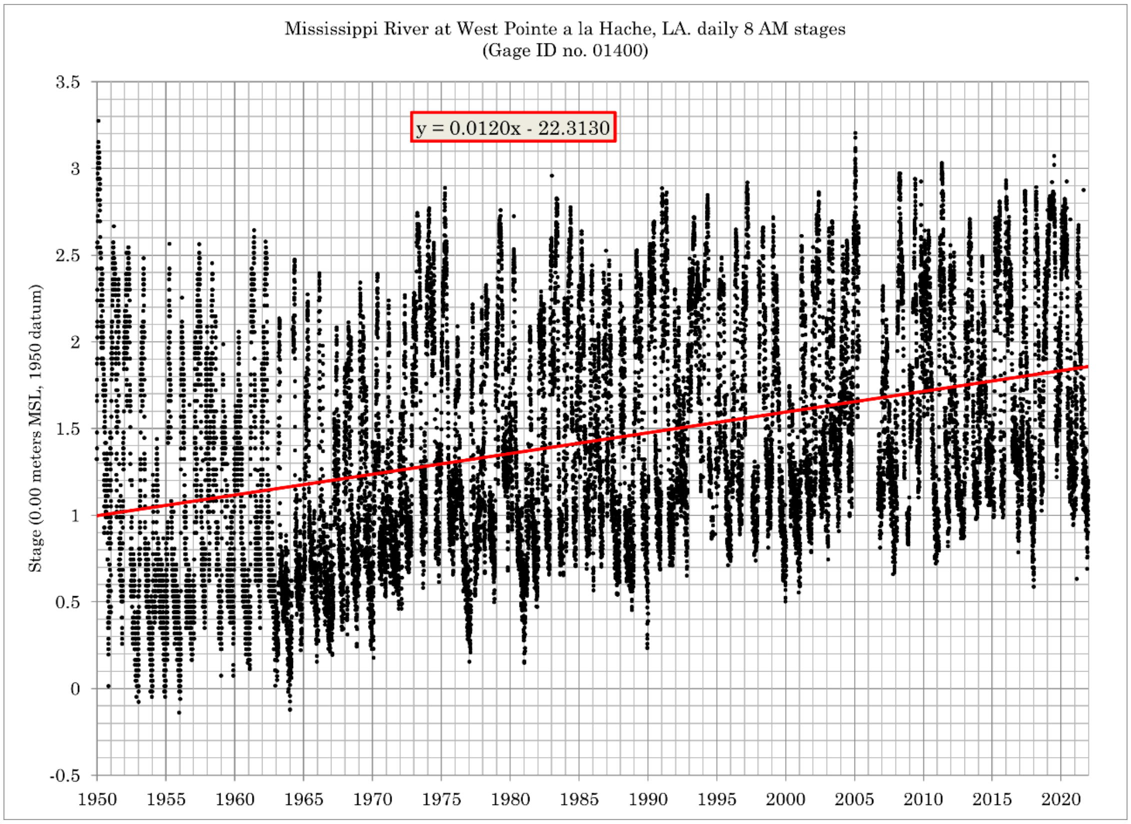
Mississippi River at Carrollton, LA. Extracted Daily Tidal Stages
(Gage ID no. 01300)

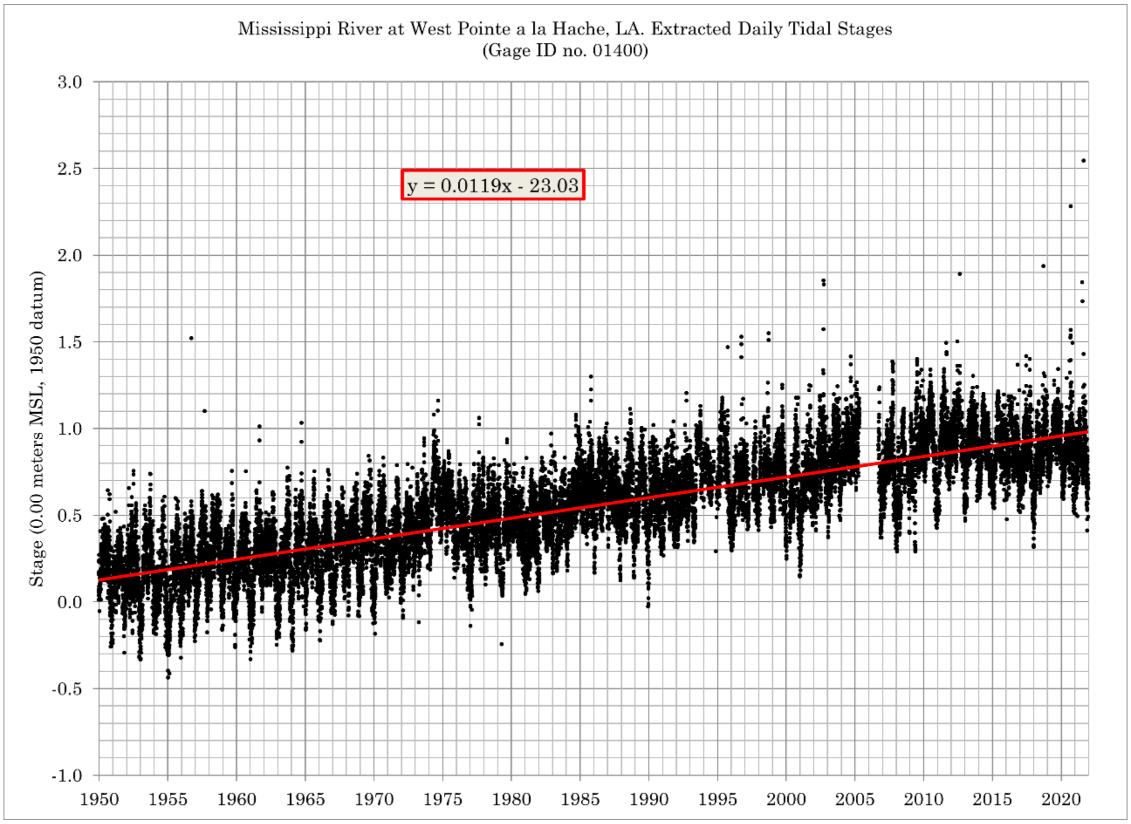

Mississippi River at Harvey Lock, LA. daily 8 AM stages
(Gage ID no. 01320)
y = 0.0165x - 30.451
Stage (Zero of gage, 0.00' meters MLG, 1949 datum)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

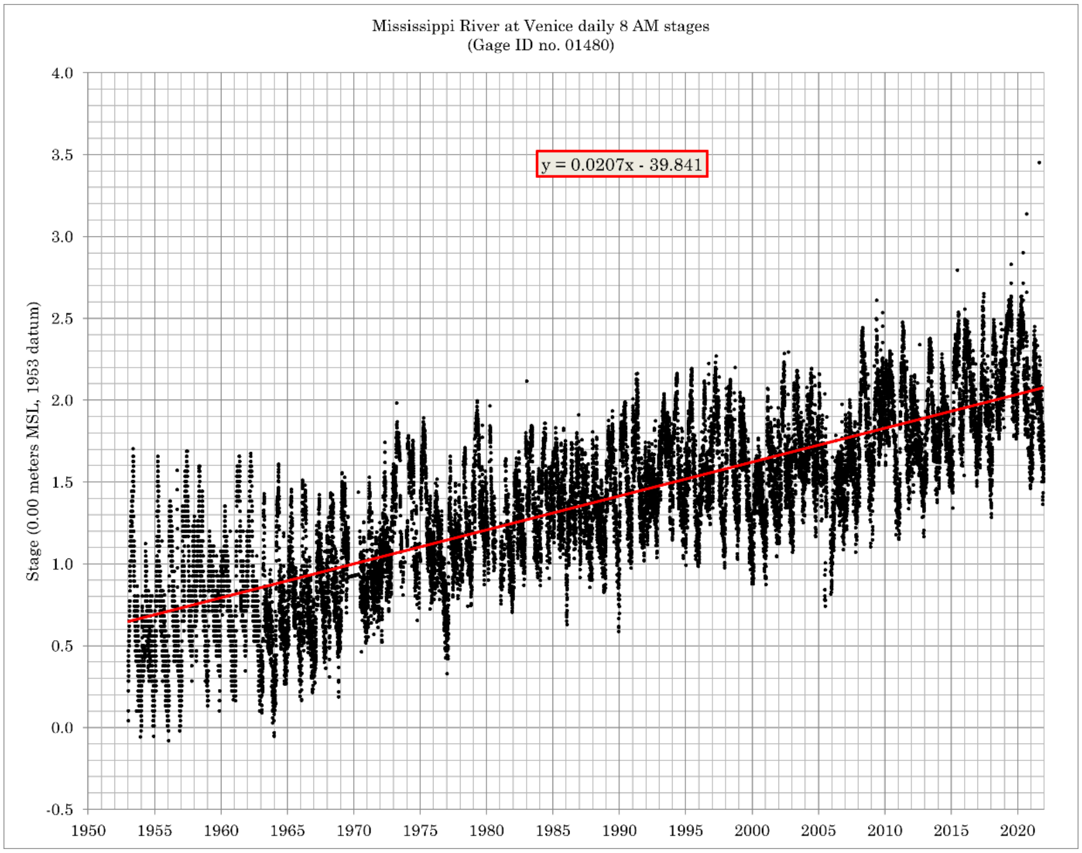

Mississippi River at Harvey Lock, LA. Extracted Daily Tidal Stages
(Gage ID no. 01320)
y = 0.00707x - 13.55606
Stage (Zero of gage, 0.00' meters MLG, 1949 datum)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

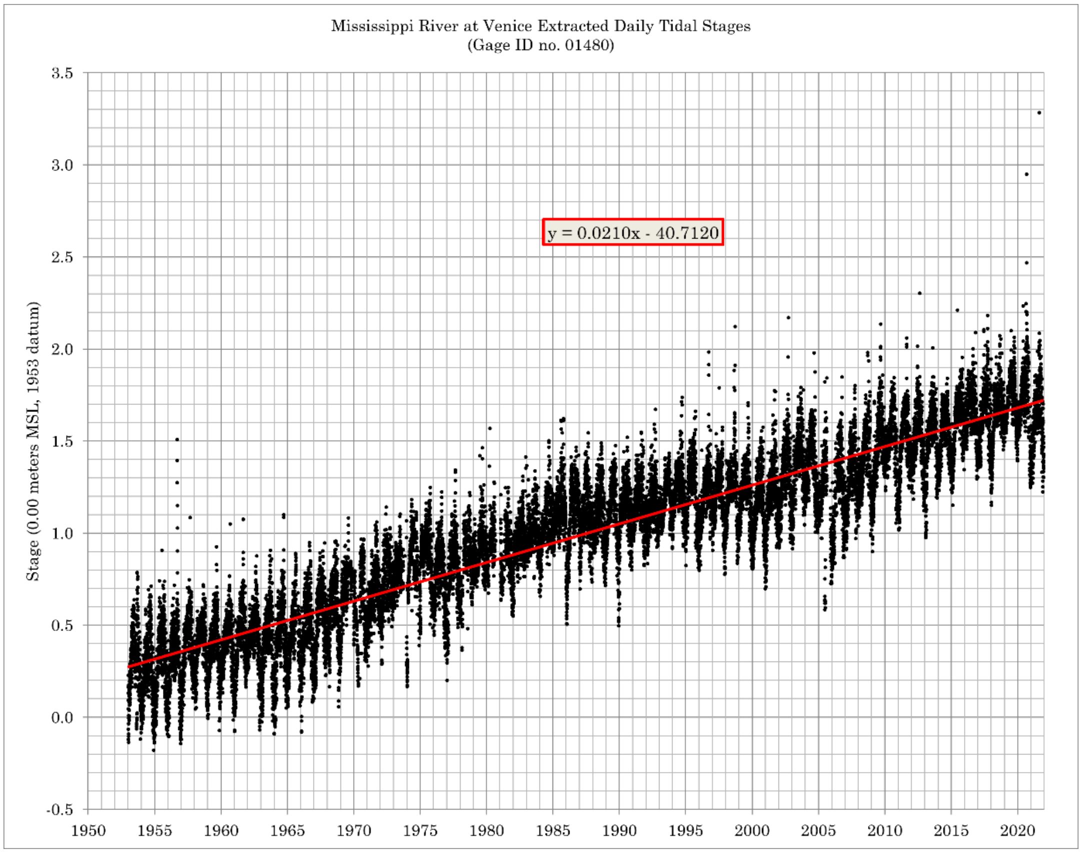

Mississippi River at IHNC Lock, LA. daily 8 AM stages
(Gage ID no. 01340)
y = 0.0178x - 32.904
Stage (0.00 meters MSL, 1950 datum)
6
5
4
3
2
1
0
-1
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

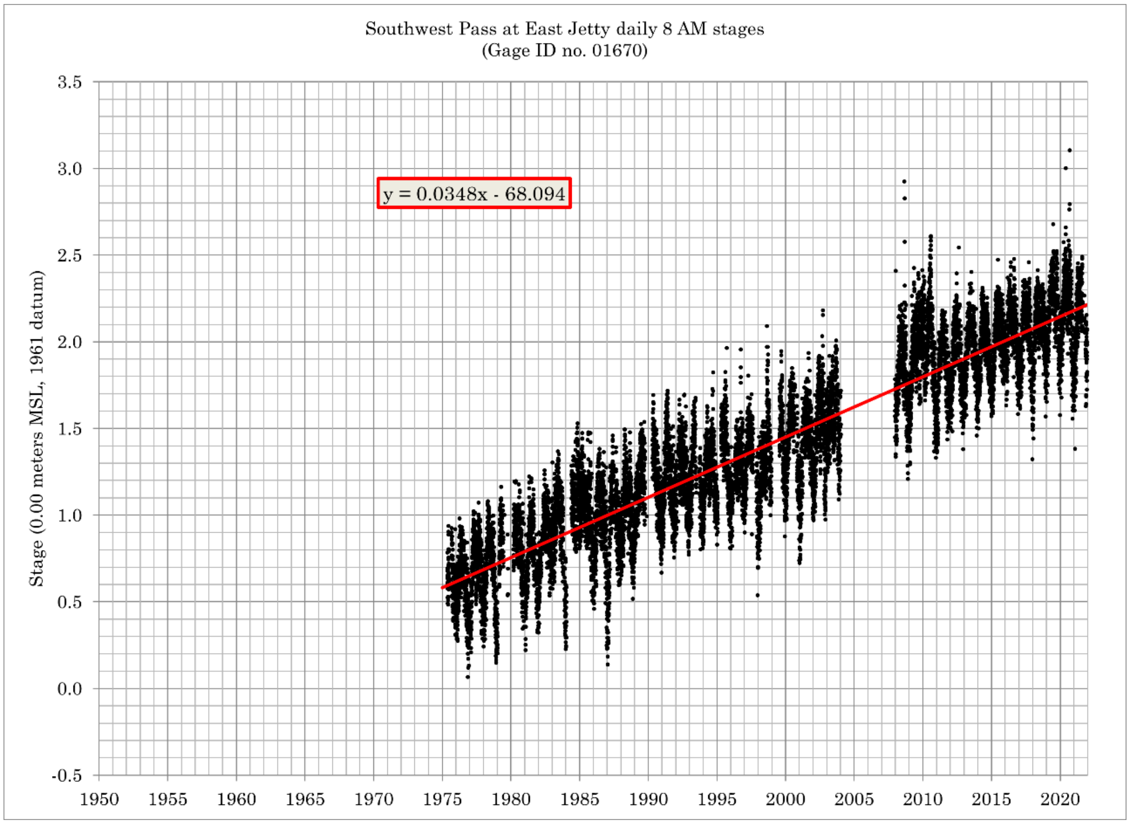

Mississippi River at IHNC Lock, LA. Extracted Daily Tidal Stages
(Gage ID no. 01340)
y = 0.0137x - 26.504
Stage (0.00 meters MSL, 1944 datum)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

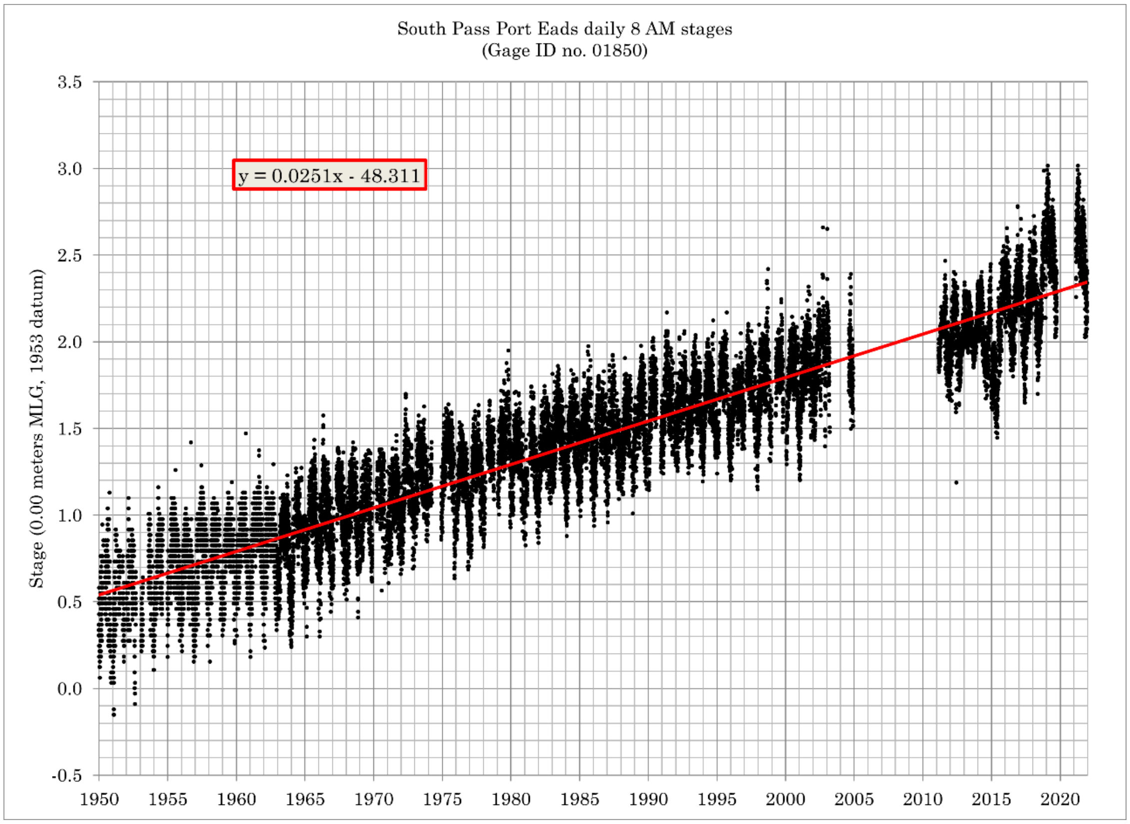

Mississippi River at West Pointe a la Hache, LA. daily 8 AM stages
(Gage ID no. 01400)
y = 0.0120x - 22.3130
Stage (0.00 meters MSL, 1950 datum)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

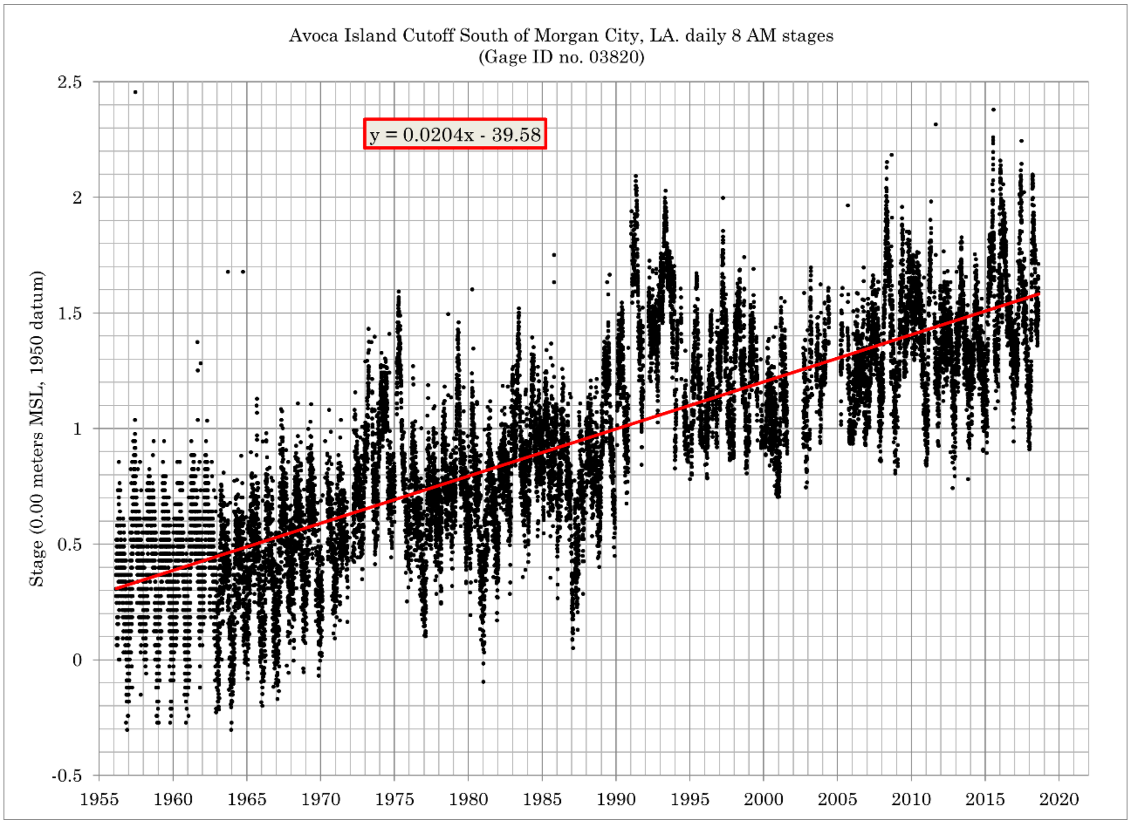

Mississippi River at West Pointe a la Hache, LA. Extracted Daily Tidal Stages
(Gage ID no. 01400)
y = 0.0119x - 23.03
Stage (0.00 meters MSL, 1950 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

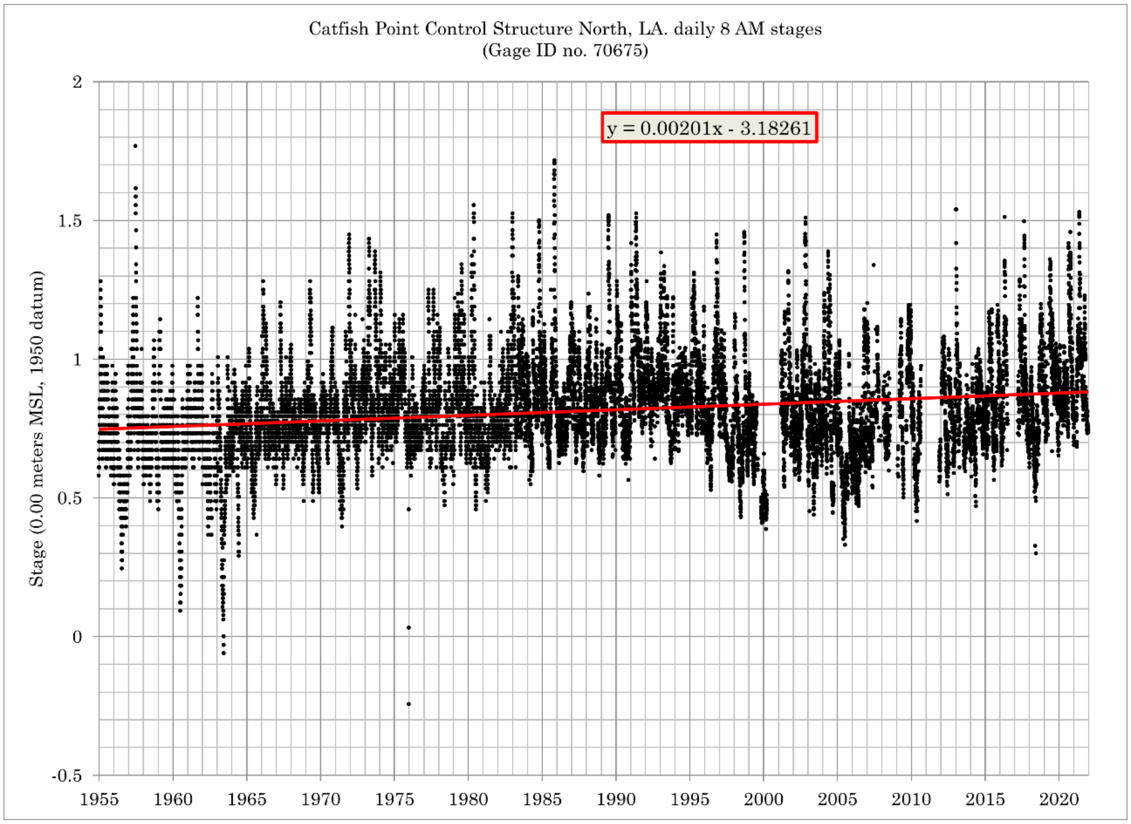

Mississippi River at Venice daily 8 AM stages
(Gage ID no. 01480)
y = 0.0207x - 39.841
Stage (0.00 meters MSL, 1953 datum)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

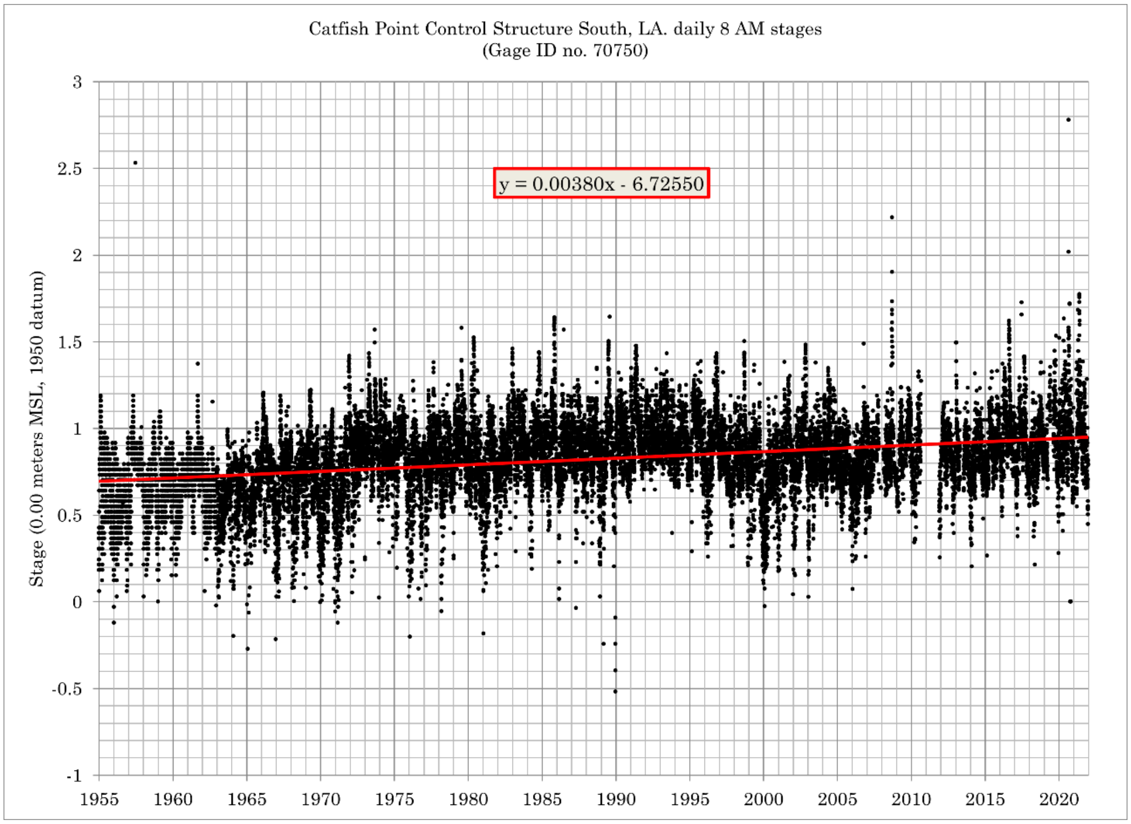

Mississippi River at Venice Extracted Daily Tidal Stages
(Gage ID no. 01480)
y = 0.0210x - 40.7120
Stage (0.00 meters MSL, 1953 datum)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

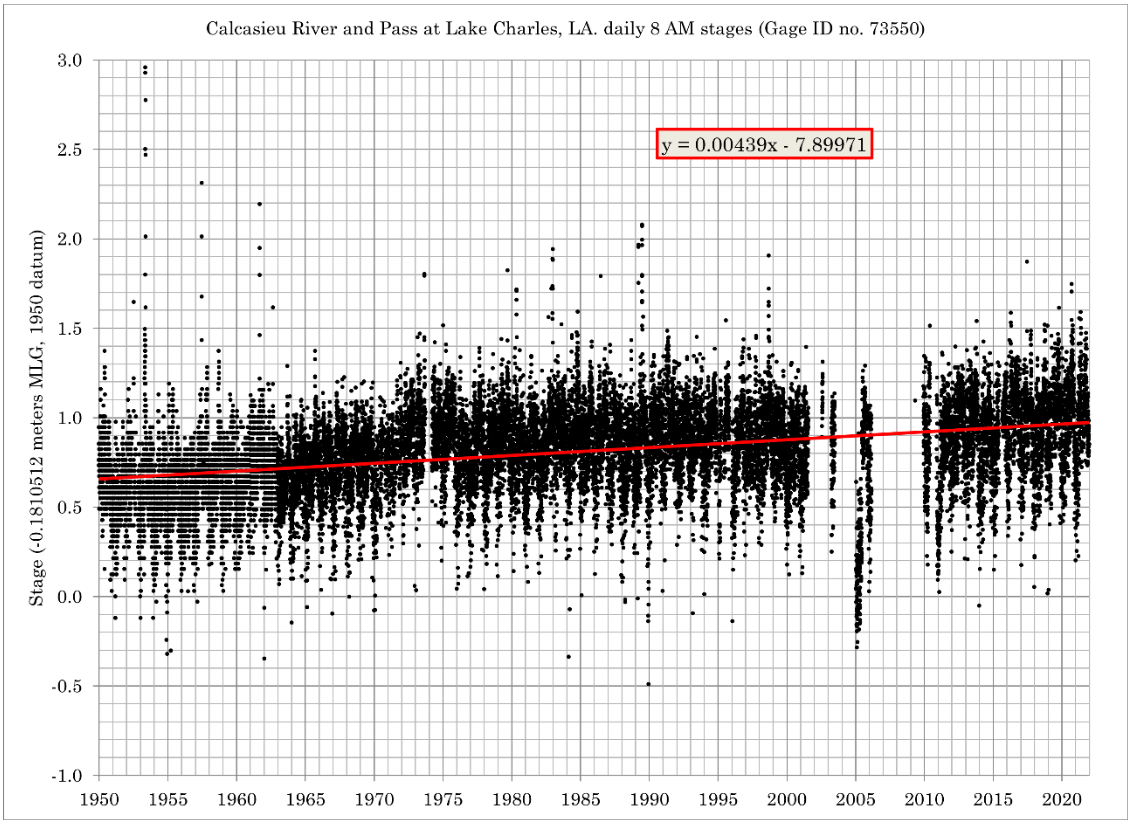

Southwest Pass at East Jetty daily 8 AM stages
(Gage ID no. 01670)
y = 0.0348x - 68.094
Stage (0.00 meters MSL, 1961 datum)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

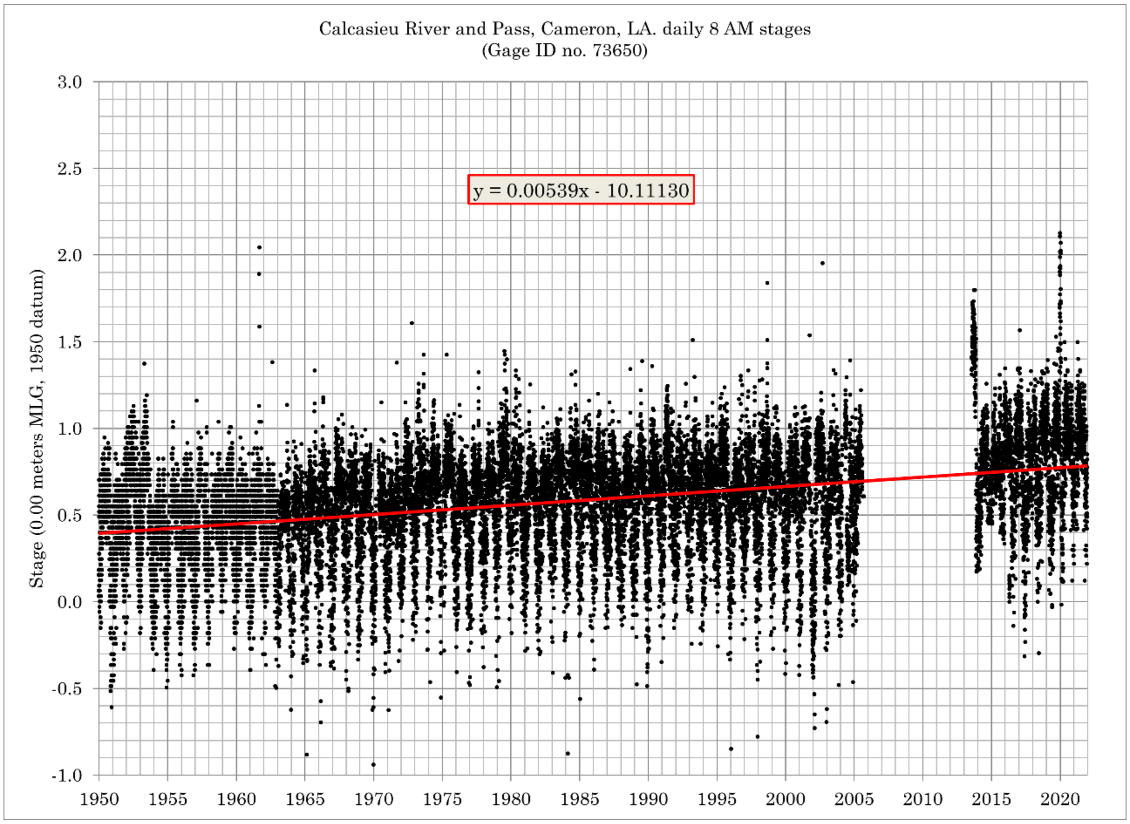

South Pass Port Eads daily 8 AM stages
(Gage ID no. 01850)
y = 0.0251x - 48.311
Stage (0.00 meters MLG, 1953 datum)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

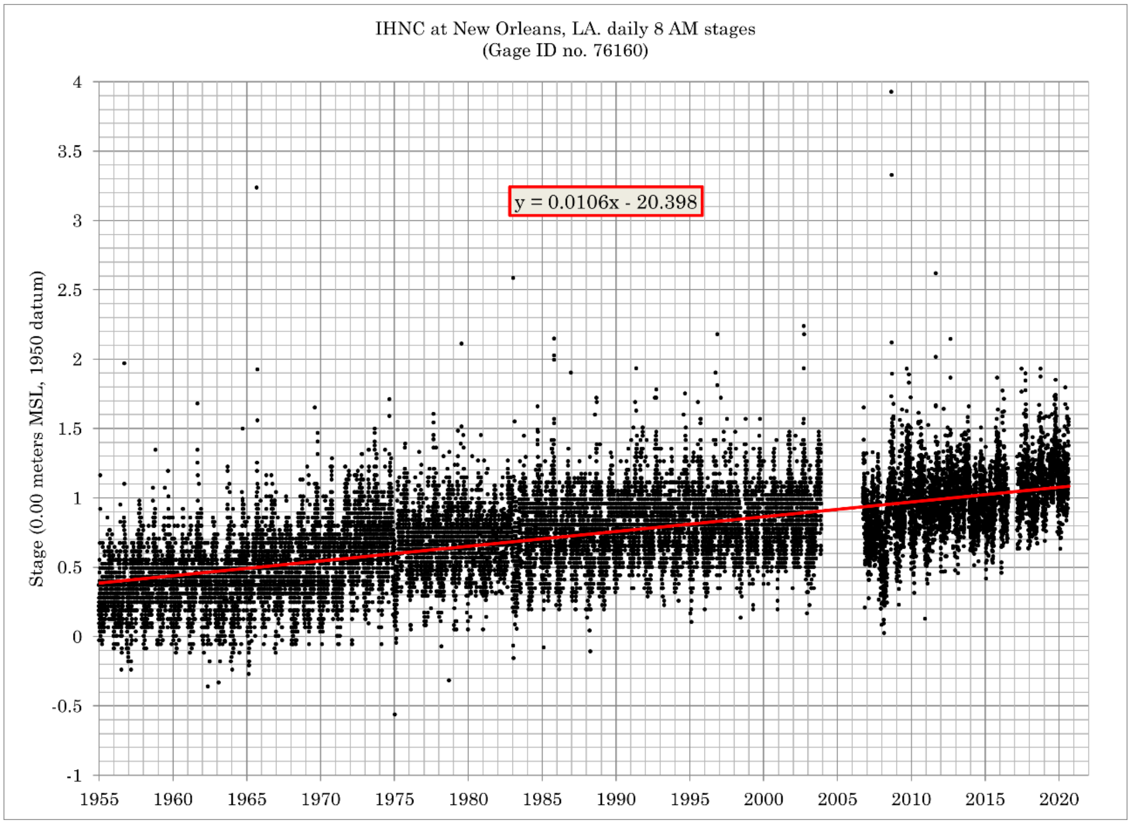

Avoca Island Cutoff South of Morgan City, LA. daily 8 AM stages
(Gage ID no. 03820)
y = 0.0204x - 39.58
Stage (0.00 meters MSL, 1950 datum)
2.5
2
1.5
1
0.5
0
-0.5
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

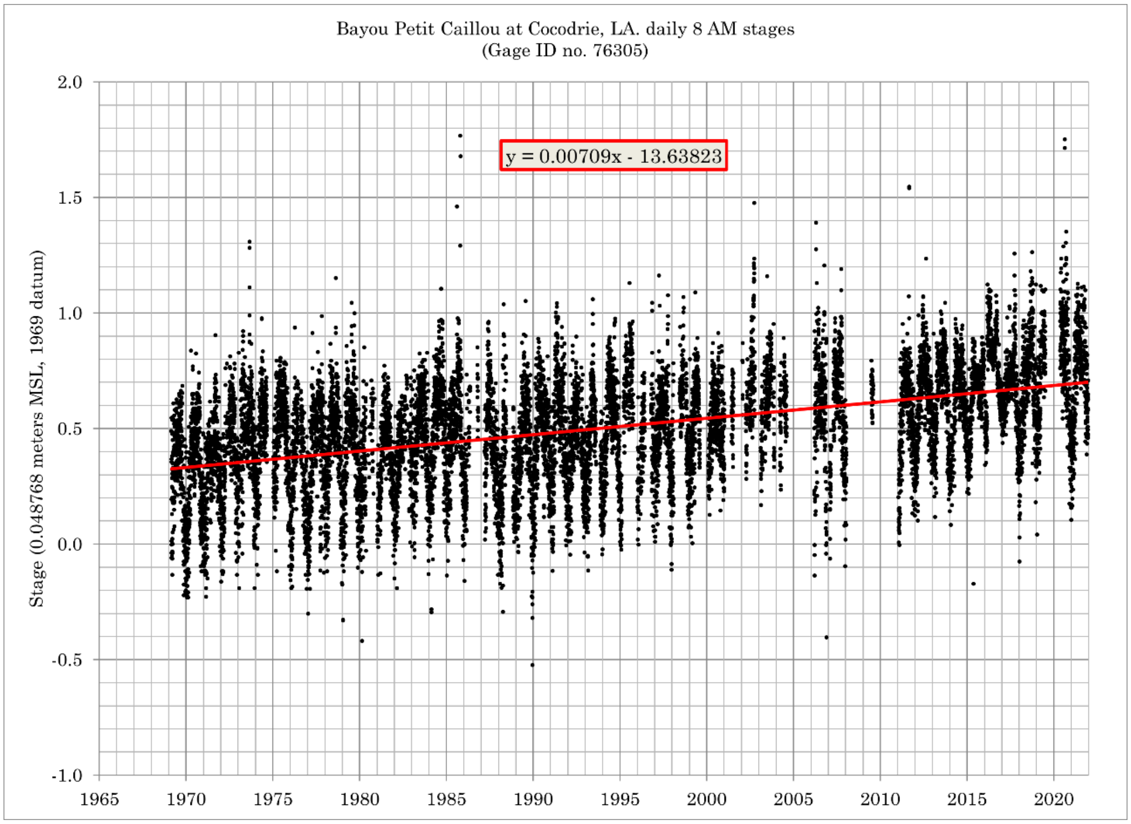

Catfish Point Control Structure North, LA. daily 8 AM stages
(Gage ID no. 70675)
y = 0.00201x - 3.18261
Stage (0.00 meters MSL, 1950 datum)
2
1.5
1
0.5
0
-0.5
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

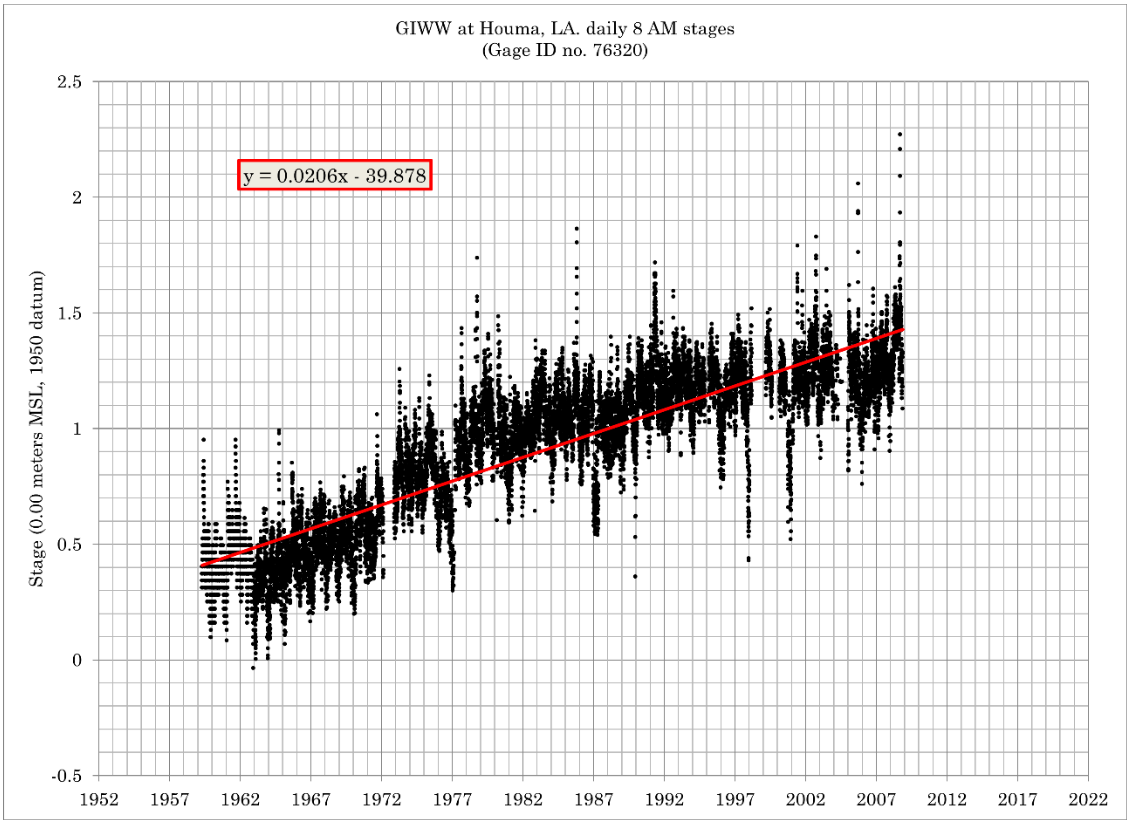

Catfish Point Control Structure South, LA. daily 8 AM stages
(Gage ID no. 70750)
y = 0.00380x - 6.72550
Stage (0.00 meters MSL, 1950 datum)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

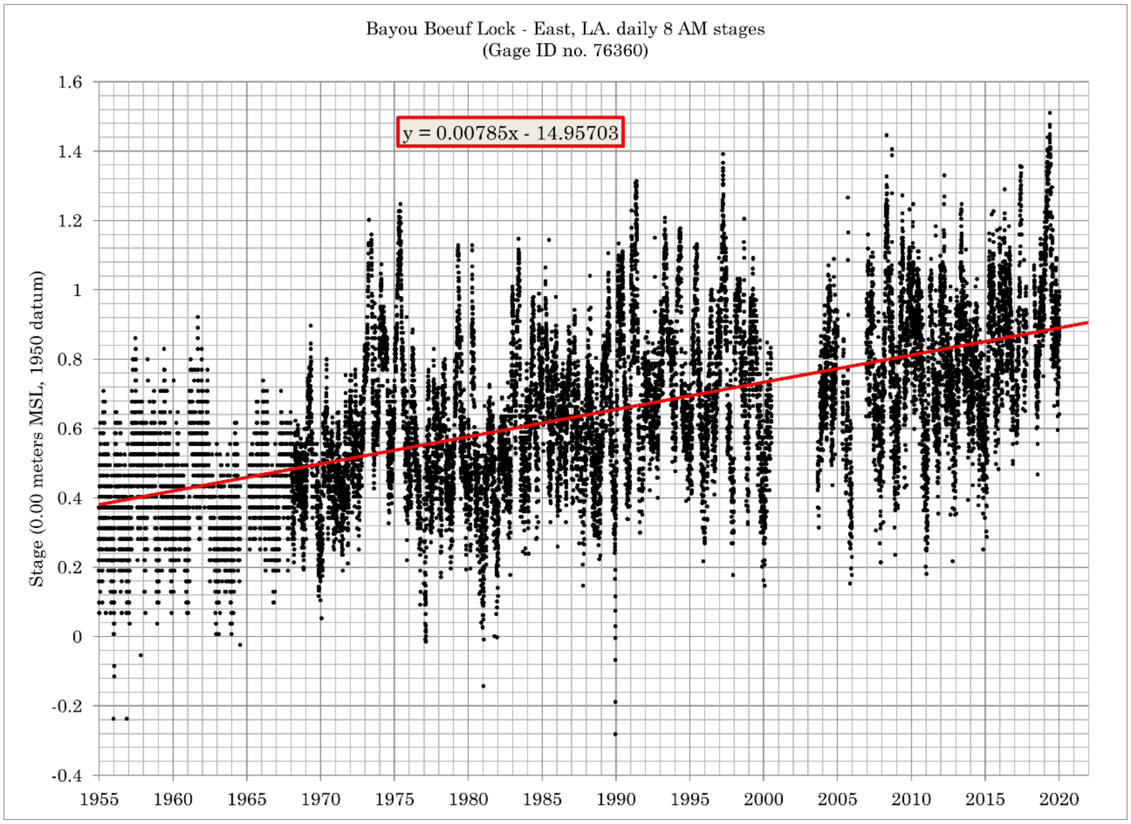

Calcasieu River and Pass at Lake Charles, LA. daily 8 AM stages (Gage ID no. 73550)
y = 0.00439x - 7.89971
Stage (-0.1810512 meters MLG, 1950 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Calcasieu River and Pass, Cameron, LA. daily 8 AM stages
(Gage ID no. 73650)
y = 0.00539x - 10.11130
Stage (0.00 meters MLG, 1950 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

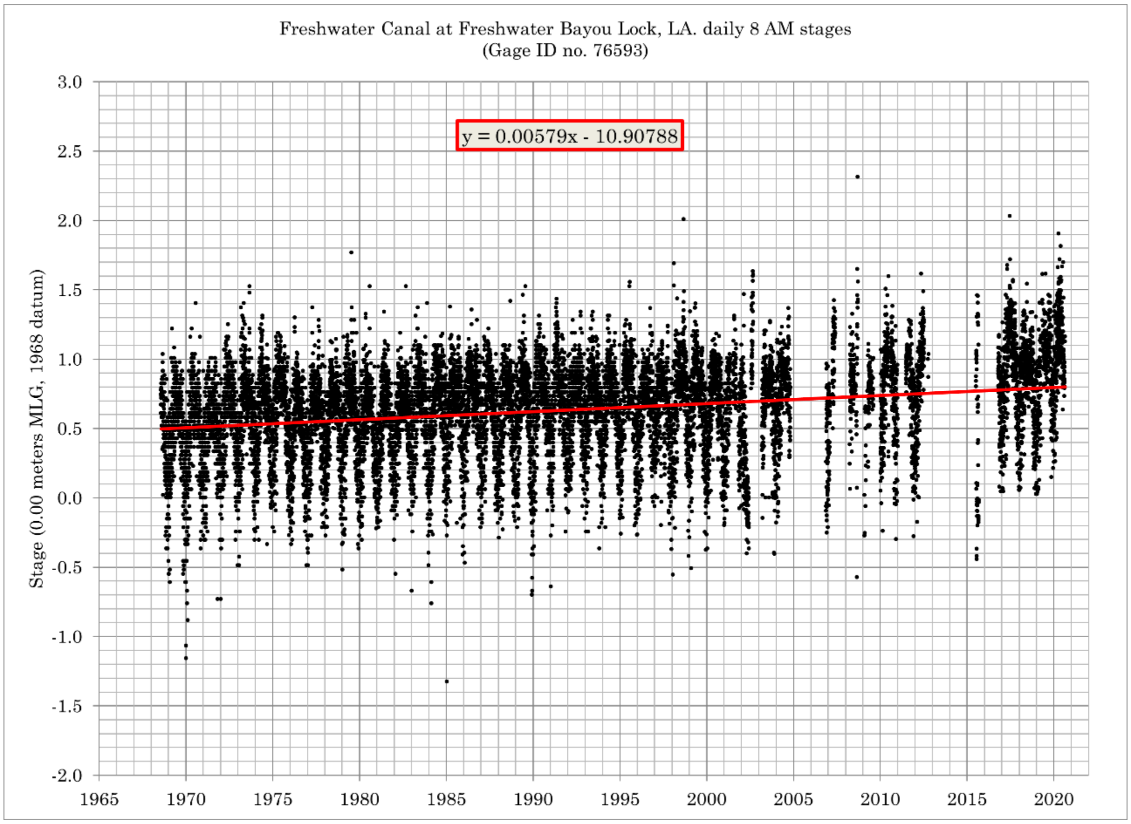

IHNC at New Orleans, LA. daily 8 AM stages
(Gage ID no. 76160)
y = 0.0106x - 20.398
Stage (0.00 meters MSL, 1950 datum)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Bayou Petit Caillou at Cocodrie, LA. daily 8 AM stages
(Gage ID no. 76305)
y = 0.00709x - 13.63823
Stage (0.048768 meters MSL, 1969 datum)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

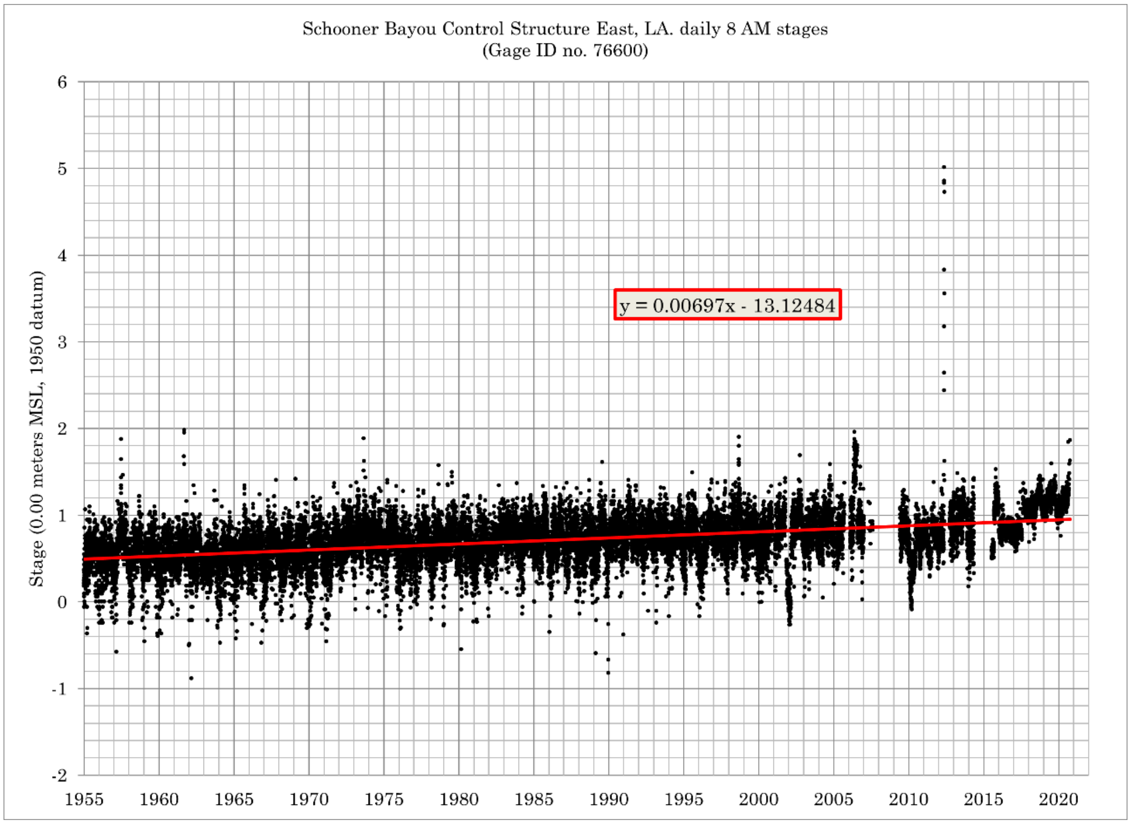

GIWW at Houma, LA. daily 8 AM stages
(Gage ID no. 76320)
y = 0.0206x - 39.878
Stage (0.00 meters MSL, 1950 datum)
2.5
2
1.5
1
0.5
0
-0.5
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

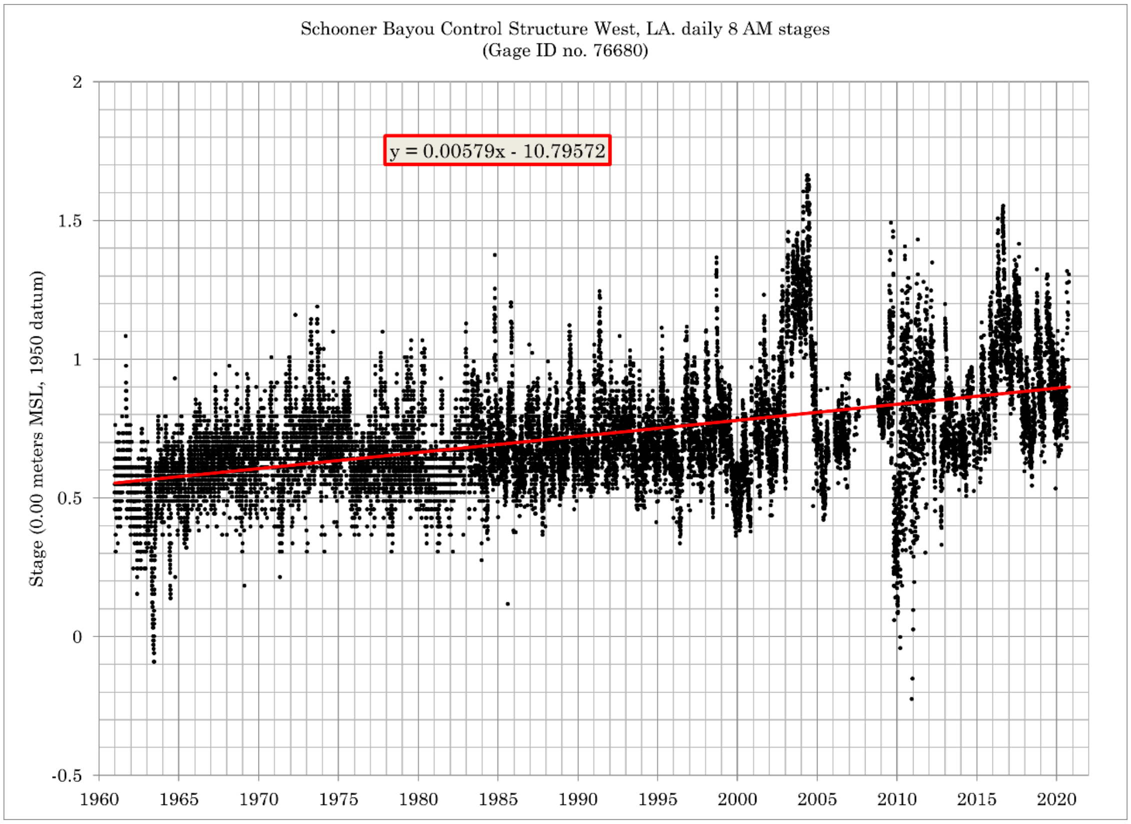


Bayou Boeuf Lock - East, LA. daily 8 AM stages
(Gage ID no. 76360)

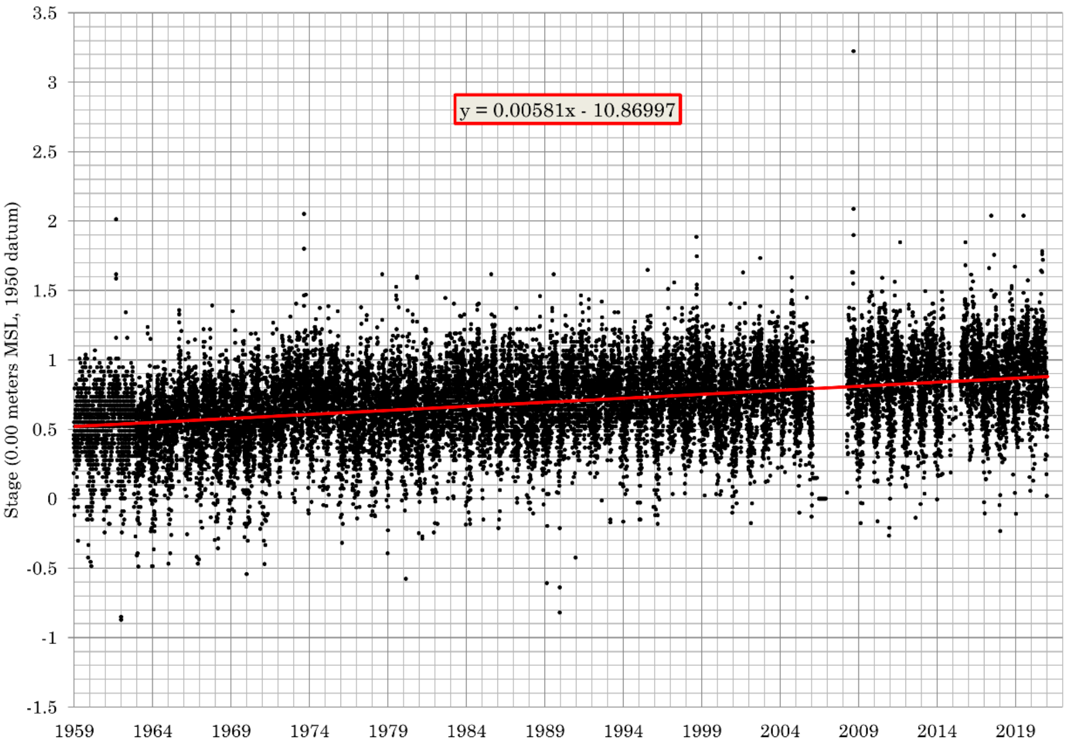


Freshwater Canal at Freshwater Bayou Lock, LA. daily 8 AM stages
(Gage ID no. 76593)

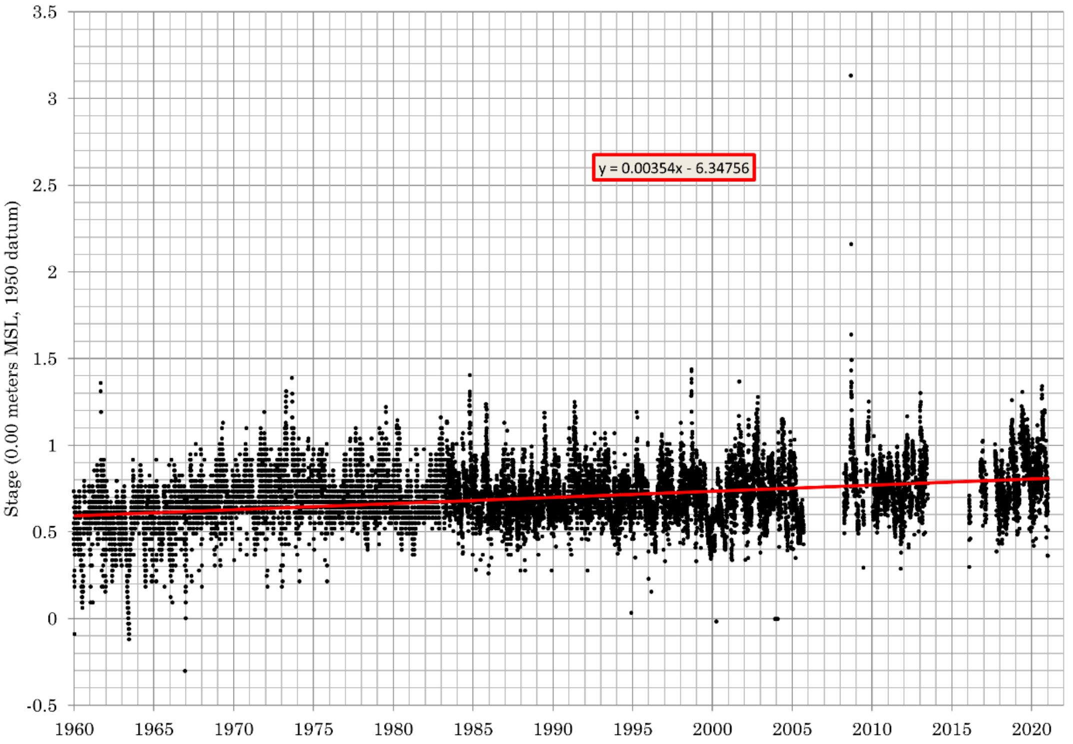

Schooner Bayou Control Structure East, LA. daily 8 AM stages
(Gage ID no. 76600)
y = 0.00697x - 13.12484
Stage (0.00 meters MSL, 1950 datum)
6
5
4
3
2
1
0
-1
-2
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

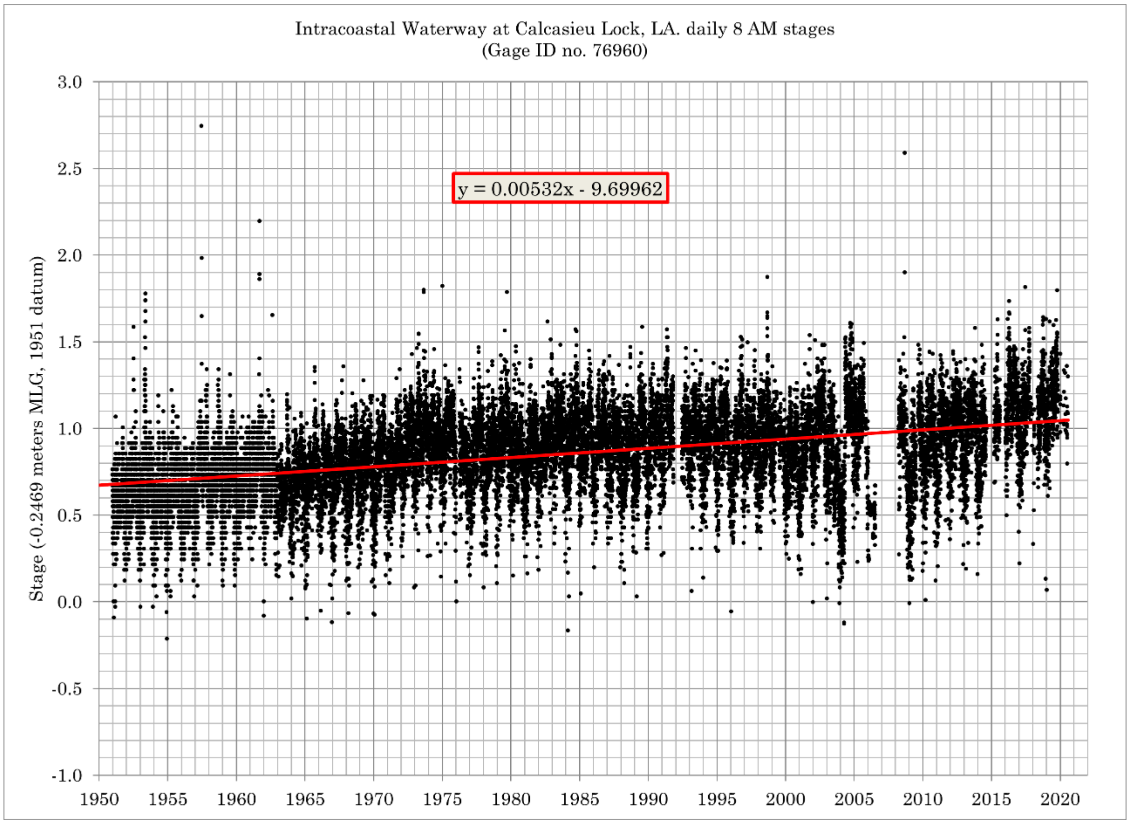

Schooner Bayou Control Structure West, LA. daily 8 AM stages
(Gage ID no. 76680)
y = 0.00579x - 10.79572
Stage (0.00 meters MSL, 1950 datum)
2
1.5
1
0.5
0
-0.5
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

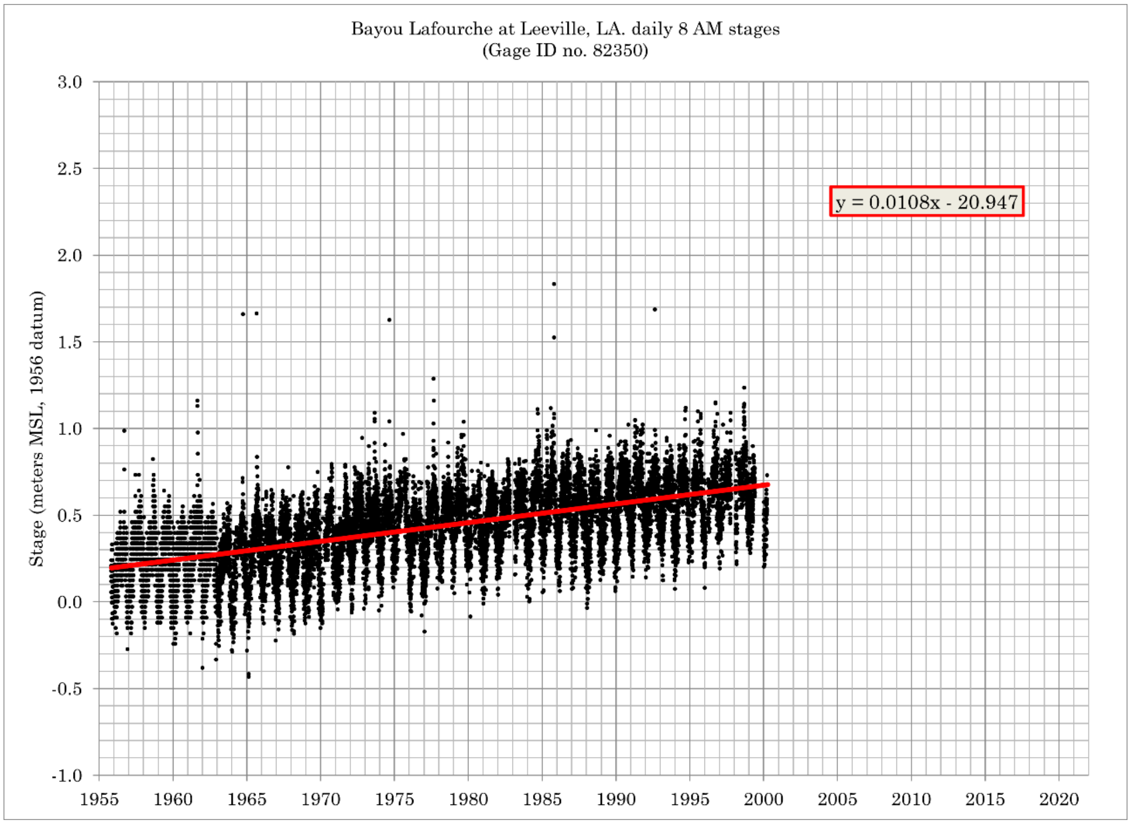
Leland Bowman Lock East, LA. daily 8 AM stages
(Gage ID no. 76720)

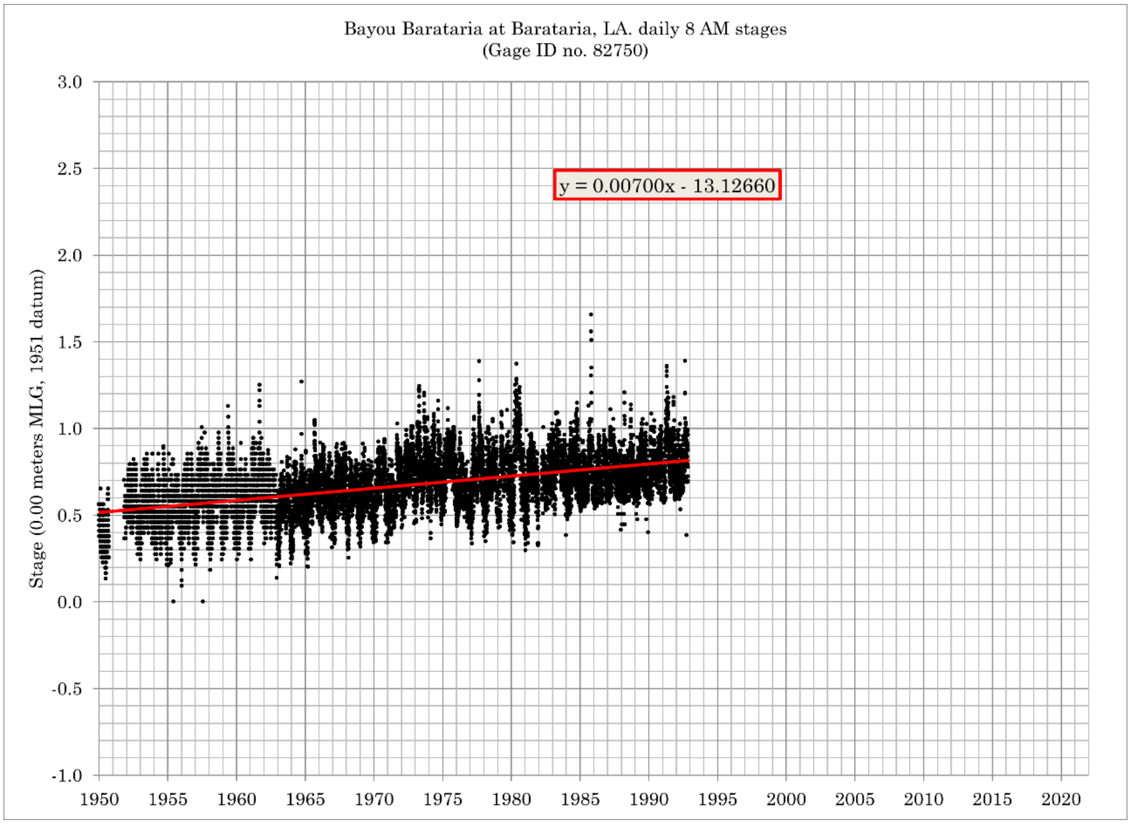


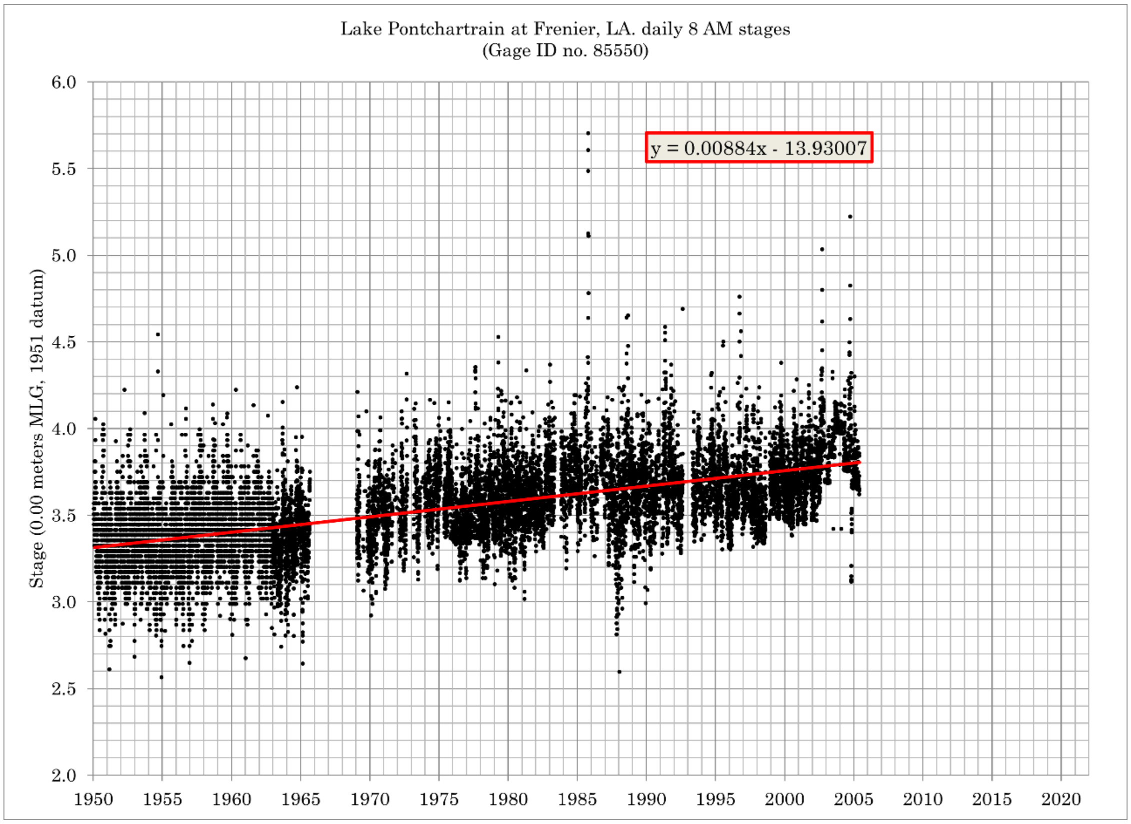
Leland Bowman Lock West, LA. daily 8 AM stages
(Gage ID no. 76800)

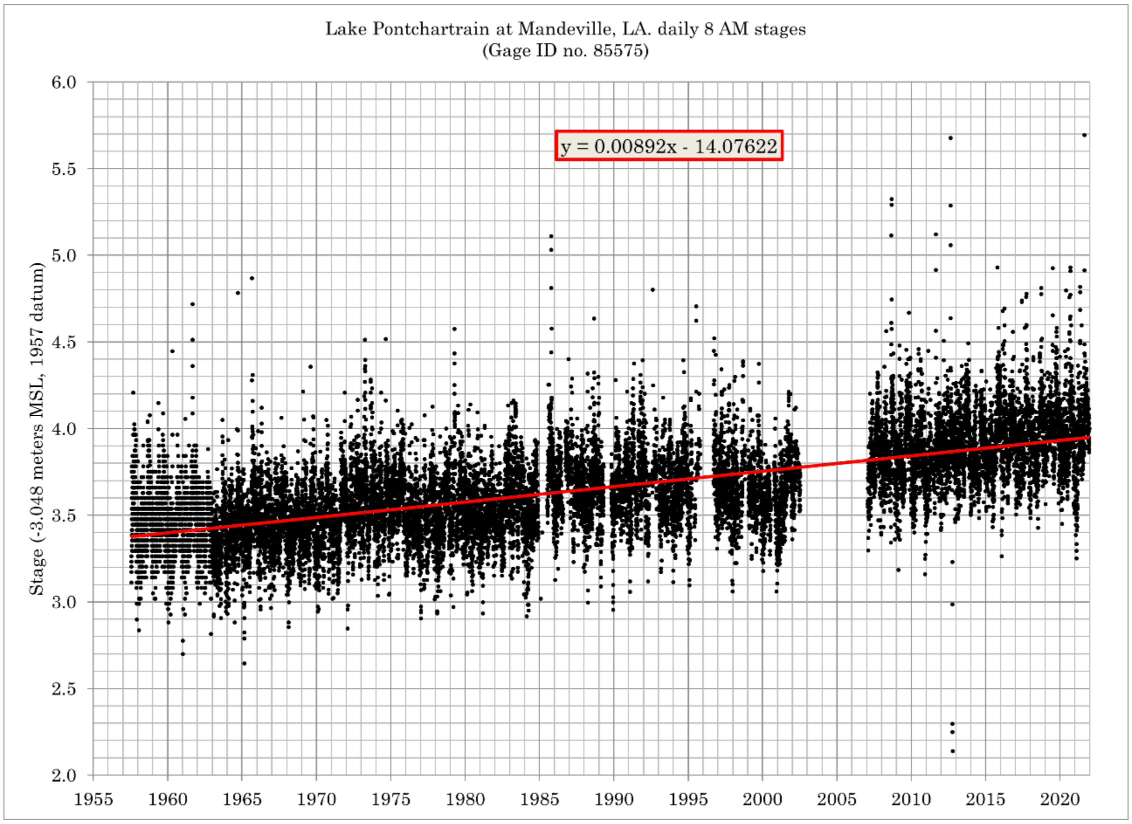


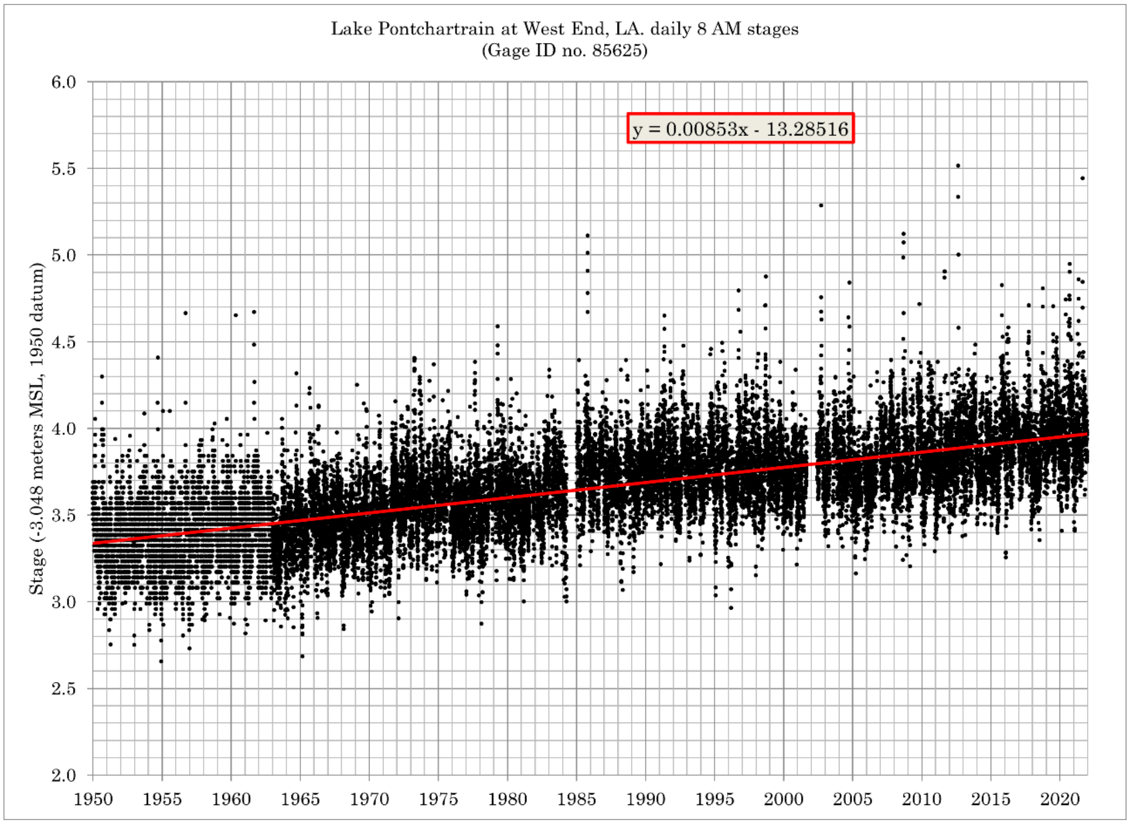

Intracoastal Waterway at Calcasieu Lock, LA. daily 8 AM stages
(Gage ID no. 76960)
y = 0.00532x - 9.69962
Stage (-0.2469 meters MLG, 1951 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

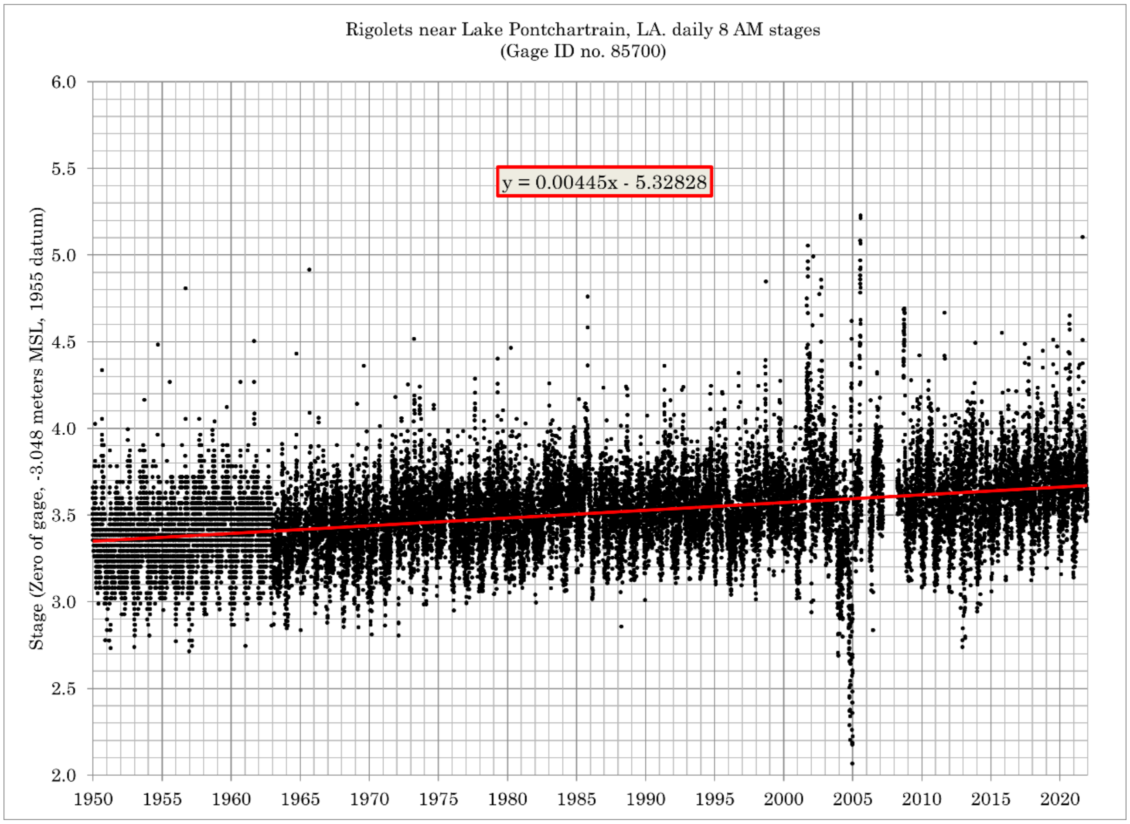

Bayou Lafourche at Leeville, LA. daily 8 AM stages
(Gage ID no. 82350)
y = 0.0108x - 20.947
Stage (meters MSL, 1956 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

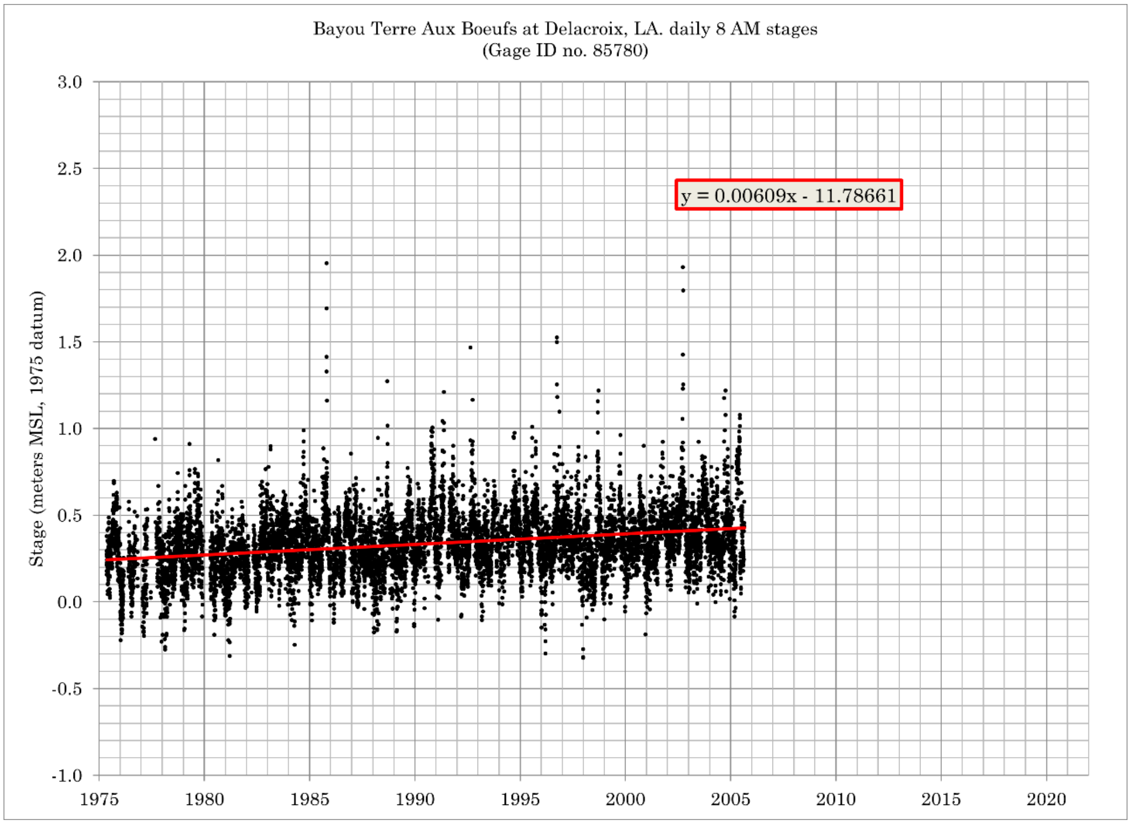

Bayou Barataria at Barataria, LA. daily 8 AM stages
(Gage ID no. 82750)
y = 0.00700x - 13.12660
Stage (0.00 meters MLG, 1951 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

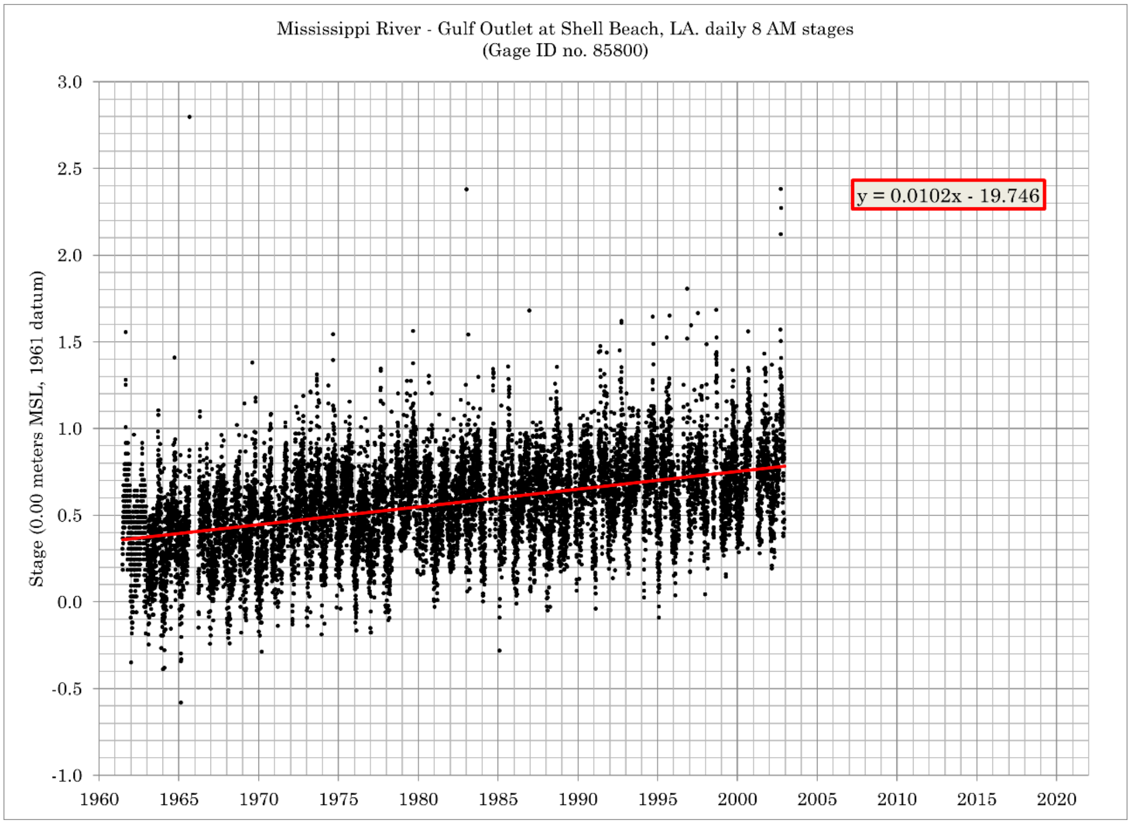

Lake Pontchartrain at Frenier, LA. daily 8 AM stages
(Gage ID no. 85550)
y = 0.00884x - 13.93007
Stage (0.00 meters MLG, 1951 datum)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

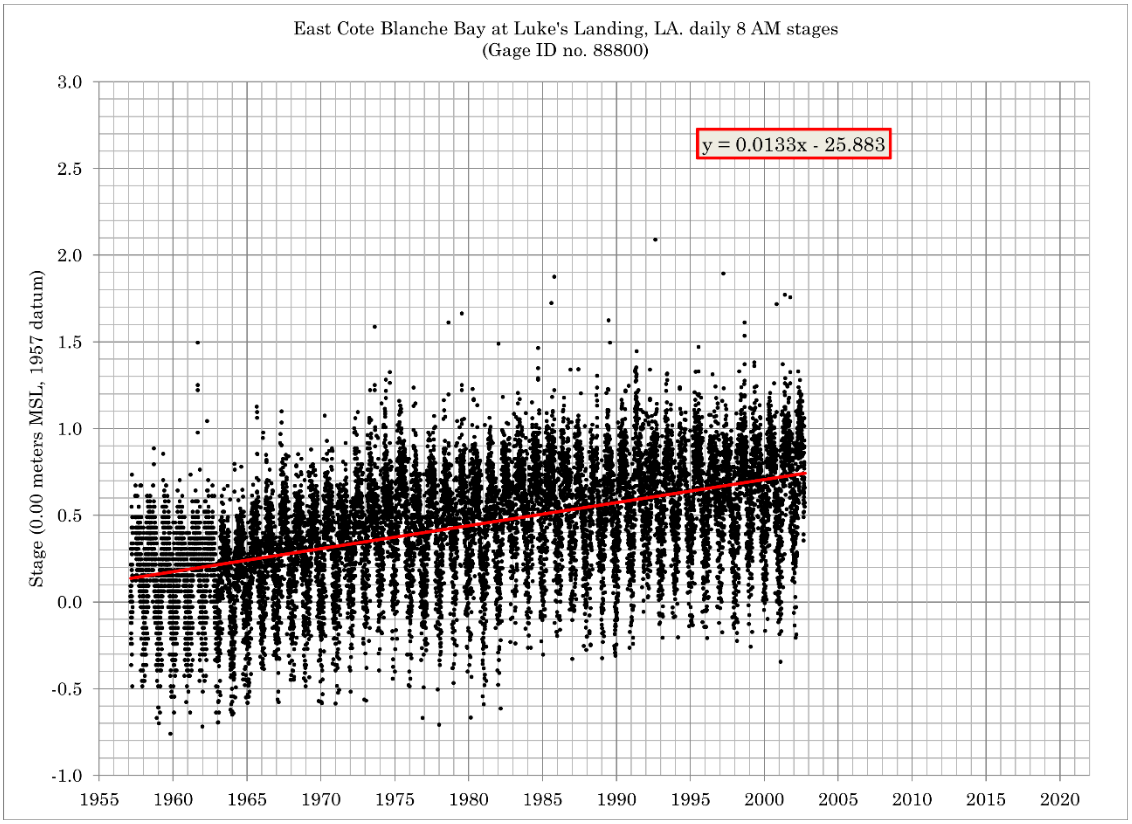

Lake Pontchartrain at Mandeville, LA. daily 8 AM stages
(Gage ID no. 85575)
y = 0.00892x - 14.07622
Stage (-3.048 meters MSL, 1957 datum)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Lake Pontchartrain at West End, LA. daily 8 AM stages
(Gage ID no. 85625)
y = 0.00853x - 13.28516
Stage (-3.048 meters MSL, 1950 datum)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Rigolets near Lake Pontchartrain, LA. daily 8 AM stages
(Gage ID no. 85700)
y = 0.00445x - 5.32828
Stage (Zero of gage, -3.048 meters MSL, 1955 datum)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Bayou Terre Aux Boeufs at Delacroix, LA. daily 8 AM stages
(Gage ID no. 85780)
y = 0.00609x - 11.78661
Stage (meters MSL, 1975 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


Mississippi River - Gulf Outlet at Shell Beach, LA. daily 8 AM stages
(Gage ID no. 85800)
Stage (0.00 meters MSL, 1961 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
y = 0.0102x - 19.746


East Cote Blanche Bay at Luke's Landing, LA. daily 8 AM stages
(Gage ID no. 88800)
Stage (0.00 meters MSL, 1957 datum)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
y = 0.0133x - 25.883