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Mid-Breton Sediment Diversion (MBrSD) Assessment – Final Report

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Mid-Breton Sediment Diversion (MBrSD) Assessment – Final Report

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Executive Summary

The Mississippi Department of Marine Resources (MDMR) tasked ocean scientists and engineers at the University of Southern Mississippi (USM) with developing an assessment of potential environmental impacts to Mississippi jurisdictional waters and resources from the Mid-Breton Sediment Diversion (MBrSD), proposed by the Louisiana Coastal Protection and Restoration Authority (CPRA). The MDMR requested this assessment to guide its response to this proposed action.

Louisiana has the highest rate of wetlands loss in the country. The MBrSD seeks to build new wetlands by reconnecting the linkage that would allow deltaic sediment to be deposited into the Breton Sound Basin (in the Western Mississippi Bight) using an engineered diversion designed to deliver up to 75,000 cubic feet per second (cfs) of sediment-laden Mississippi River freshwater.

Concern about the proposed MBrSD stems from impacts to Mississippi waters and resources – particularly decreased salinity and oyster mortality – experienced from previous freshwater diversions, such as when the Bonnet Carré Spillway (BCS) opened twice in 2019 (to reduce flooding in downstream Louisiana communities) and in 2011.

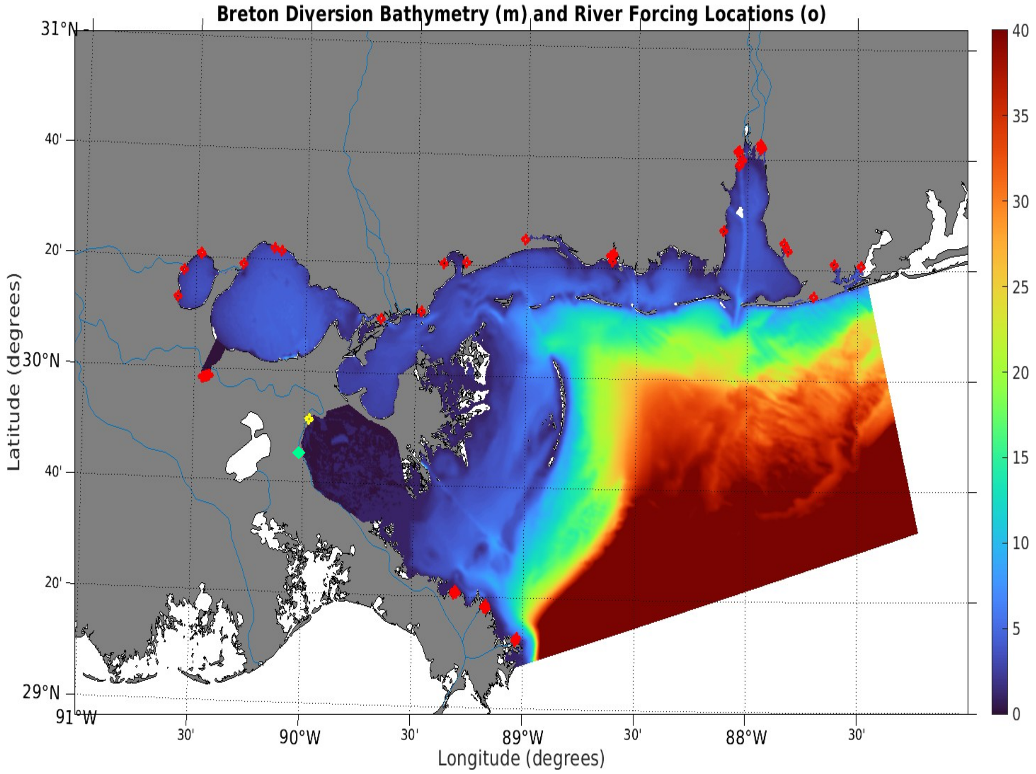

Figure E1. The USM ocean modeling system applied to assess potential impacts from the Mid-Breton Sound Diversion accounts for coastal water depth (bathymetry) in meters (see color legend) and freshwater inflows from surrounding rivers and the Bonnet Carré Spillway (red diamonds). Data from the USGS gauge station at Belle Chasse (yellow diamond) is the basis for inputs of MS River water at the Mid-Breton Sediment Diversion (green diamond) and along the Birdfoot Delta (red diamonds).

The USM team applied their detailed physical modeling system, driven by realistic atmospheric conditions and river inflows (Figure E1), to address the question that MDMR asked: *How would this inflow of freshwater into the Western Mississippi Bight affect the well-being of the aquatic ecosystems of the Western and Central Mississippi Sound?*

The USM team's assessment focused on oyster reefs in the Mississippi Sound because they are key ecological health indicators and economic drivers for the State of Mississippi and their survival is jeopardized during extended periods of very low bottom salinity conditions. The USM ocean modeling system provides bottom salinity distributions at high temporal (hourly) and spatial (400m) resolution, making it well-suited to reveal how the introduction of the proposed MBrSD will impact these critical oyster reef communities.

The MDMR requested that the ocean modeling experiments include three scenarios:

1) A climatological MBrSD discharge scenario based on the 11-year average Mississippi River hydrograph, to assess the impact of this diversion under typical conditions. This climatological scenario serves as a representative state for the Mississippi Sound and Bight.

2) A scenario, based on 2019 conditions, that incorporated both the impact of that year's double opening of the Bonnet Carré Spillway (BCS) and a variable MBrSD discharge based on the 2019 Mississippi River hydrograph, to assess the relative and combined impacts of the BCS and MBrSD.

3) A continuous maximum design flow of the MBrSD discharge (75,000 cfs; flowing 24/7 for 9 months), to assess the impact on Mississippi coastal waters of the MBrSD operating at full capacity in concert with the 2019 spring freshet.

To isolate the influence of the MBrSD within these three diversion scenarios, numerical model experiments were performed with and without the MBrSD included, revealing the net influence of the MBrSD.

To characterize whether bottom salinity conditions provide a healthy environment for oysters, maps were generated depicting the difference in total (cumulative) number of days of low bottom salinity (S<5 ppt, the critical ecological threshold for oyster health and survival) from January to September for each scenario when the MBrSD is active (Figure E2):

- For scenario 1, the model projects a significant increase in cumulative days of S<5 within the Western and Central Mississippi Sound when the MBrSD is active. A notable increase in cumulative days is also indicated in eastern Mobile Bay.
- For scenarios 2 and 3, the model reveals mixed results of minor increases and decreases throughout the Mississippi Sound, indicating that the MBrSD did not further degrade the already low bottom salinity conditions in place during this extremely atypical year.

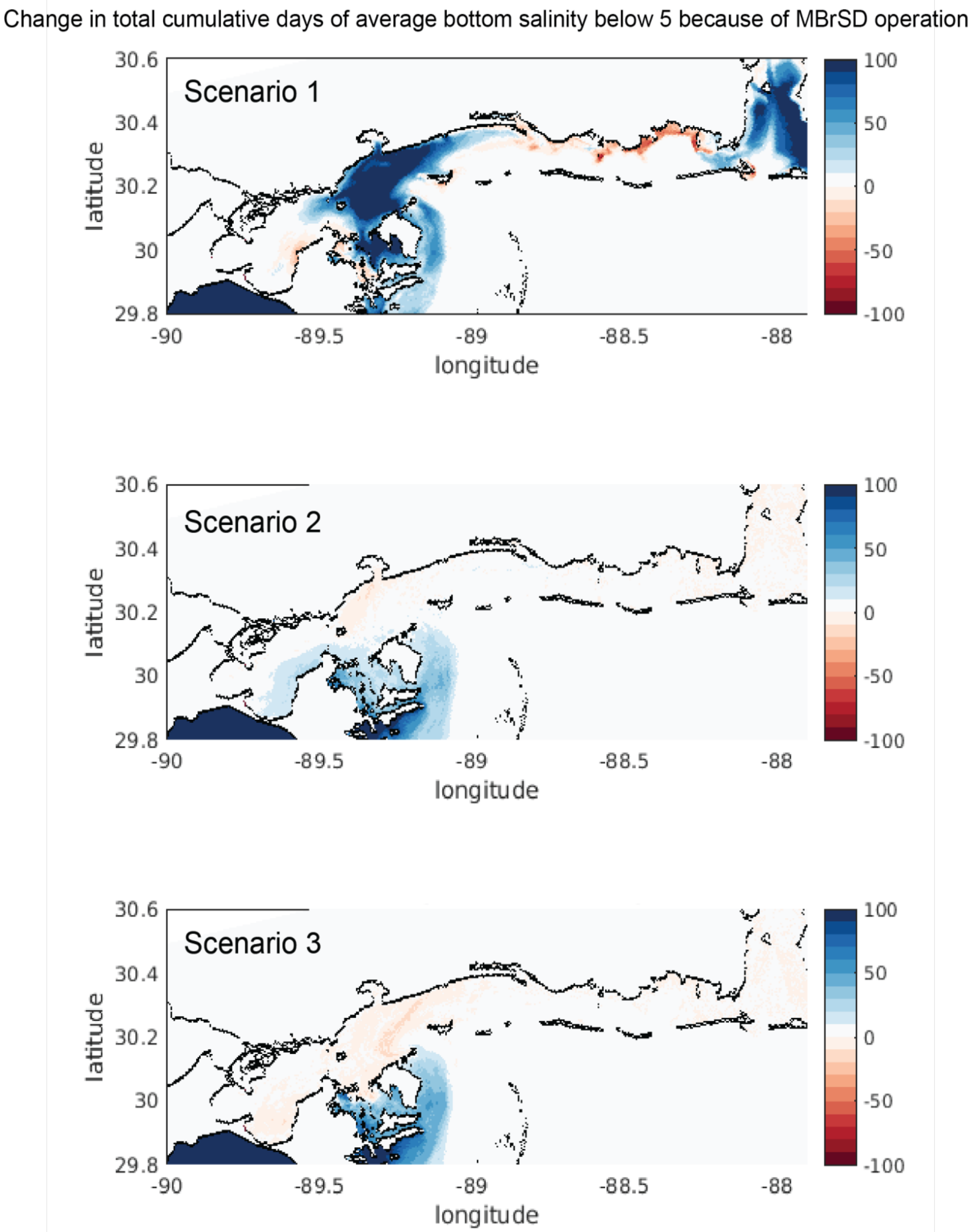
Change in total cumulative days of average bottom salinity below 5 because of MBrSD operation

Figure E2. Maps of the difference in total cumulative days (over January – September) where average bottom salinity is below 5 ppt, with and without active Mid-Breton Sound Diversion (MBrSD) for the three scenarios described above. When the MBrSD is active, the positive values (blue, fresher water) indicate there are more cumulative days when salinity is below 5 ppt, and the negative values (red, saltier water) indicate there are less cumulative days when salinity is below 5 ppt.

In summary, overall key findings (from Scenario 1) include:

- During elevated freshwater influx of the spring freshet, combined with the dominant prevailing wind direction, additional freshwater flowing into Western Mississippi Sound from an activated MBrSD is projected to shift bottom salinities below the critical ecological threshold for oyster health and survival over the January – June timeframe.
- The Western and Central Mississippi Sound regions are projected to experience a significant increase in the number of cumulative days when salinity levels are below the critical ecological threshold for oyster health and survival. A notable increase in cumulative days of low salinity levels is also indicated in eastern Mobile Bay.

Based on these overall findings, the following recommendations are offered with the assumption that the MBrSD will be a gated / controllable structure:

- To avoid causing salinity conditions to be pushed beyond a tipping point that adversely and possibly permanently affect the ecosystem services provided by key species residing in Mississippi jurisdictional waters, exercise caution if a full opening of the MBrSD is being considered during high river discharge, especially during BCS openings.
- Conduct short-term near real-time forecast modeling, currently in development, to assess risks based on relevant weather and riverine conditions as the timing and flow level of a freshwater diversion are key factors that affect impacts on Mississippi jurisdictional waters. Surface wind plays a key role in influencing whether freshwater becomes trapped in the nearshore or is flushed out to the shelf and broader Northern Gulf of Mexico region.

Full Summary

Purpose

The purpose of this project is to provide managers at the Mississippi Department of Marine Resources (MDMR) with the scientific information needed to accurately address public concerns regarding the potential effects of the Louisiana Coastal Master Plan / Coastal Protection and Restoration Authority (CPRA) Mid-Breton Sediment Diversion (MBrSD) on the jurisdictional waters and resources of Mississippi. The stated design purpose of the MBrSD is to reconnect and re-establish the deltaic sediment deposition process between the Mississippi River and the Breton Sound Basin through a diversion that will deliver up to 75,000 cfs of sediment-laden freshwater. The report presented herein provides model-based guidance on the impact that the introduction of the MBrSD will have on salinity conditions in the Mississippi Sound (MSS) and Mississippi's jurisdictional waters that encompass oyster reef locations. Oysters are key ecosystem health indicators and economic drivers for the State of Mississippi and freshwater diversions into the western MS Sound (WMSS) have recently led to significant, unprecedented environmental impacts resulting in oyster mortality. The potential addition of a new pathway for additional freshwater to be introduced into the MSS requires careful assessment of the potential impacts that may be incurred.

This project is designed to assess the impact of implementing the MBrSD on the physical environment in the WMSS. The primary aim is to understand the connectivity between MBrSD-derived freshwater input to Breton Sound on the environmental conditions impacting the oyster reefs of the WMSS near Bay St. Louis. A physical ocean modeling system based on the Coupled Ocean Atmosphere Wave Sediment Transport (COAWST) has been used to simulate the circulation and dynamics over the entire MSS with the analysis presented herein focusing particularly on the western to central MSS. This project demonstrates the importance of applying modeling-based scientific research and the capability of physical ocean circulation models for assessing aquatic ecosystem health, particularly in key oyster reef areas.

Background and Approach

Prior to this project, no hydrodynamic model provided high-resolution spatial and temporal coverage of the Mid-Breton Sound extending into Mississippi waters that enables a detailed evaluation of a set of requested freshwater diversion scenarios (listed below). Motivation for conducting this modeling study has been engendered by: 1) the potential implementation of the Mid-Breton Sediment Diversion (MBrSD), that has been recommended by the Coastal Protection and Restoration Authority of Louisiana (CPRA, 2017); and 2) the double opening of the Bonnet Carré Spillway (BCS) that occurred in 2019. In 2019 the Mississippi River stage remained high despite opening the BCS, which created a real-life, worst-case hydrograph which has been applied in creating our hypothetical scenarios for the MBrSD.

The University of Southern Mississippi (USM) modeling group employs a structured grid, 400 m resolution, 24-layer circulation model of the MS Sound / Bight region that resolves the complex estuarine / inner shelf exchanges that are prevalent throughout the region. A fundamental aspect of this shallow estuarine system is that its circulation patterns and pathways, and associated estuarine-shelf exchange, are fundamentally determined by the combined effect of riverine inflows, human-implemented diversions, and surface winds. The atmospheric forcing applied to the model is critical for capturing the complex current variability and advective pathways required to realistically simulate freshwater flow within the WMSS associated with the proposed MBrSD. This project's findings will:

- Provide a refined model application that enables independent, Mississippi-based assessments,

- Evaluate critical scenarios regarding potential impacts on Mississippi waters and resources,

- Equip MDMR and key decision-makers within Mississippi with the tools and resources needed to better evaluate complex scientific issues.

Project Tasks

The project deliverable is a peer-reviewed enhanced version of the existing USM model based upon new forcing and boundary conditions that reflect 3 scenarios originally requested by MDMR.

1. The first scenario entails application of an 11-year average (2010-2020) Mississippi River hydrograph that serves as a climatological scenario for flow through the MBrSD. This climatological scenario provides a useful baseline for how the activation of the MBrSD will influence the coastal waters of the region under typical hydrologic conditions.

2. The second scenario entails application of both 2019 Bonnet Carré Spillway (BCS) conditions and variable MBrSD discharge based upon the actual (extreme) 2019 Mississippi River hydrograph. This realistic scenario is actually rather atypical, given that it encompasses the double BCS opening of 2019, and is uniquely suited for exploring the combined influences of the BCS and MBrSD when both are operating at (or near) full capacity.

3. The third scenario entails application of continuous maximum design flow from the MBrSD (75,000 cfs) flowing 24/7 for 9 months. This maximum scenario replicates a talking point introduced by special interest groups and is useful for revealing how operation of the MBrSD at full capacity will impact Mississippi coastal waters following the spring freshet.

In order to isolate the impact of the MBrSD for these three scenarios, we have designed a suite of numerical model experiments that in combination (i.e., twin experiments) reveal the net effect of the MBrSD on advective pathways and hydrographic properties. In a twin experiment implementation, two model runs are created to be identical in all ways except one. This ensures that differences between two model solutions are due to one unique feature between otherwise identical numerical experiments.

Key Findings and Recommendations (We have assumed that MBrSD would be actively controlled).

The numerical modeling-centered study presented here provides the means to assess the potential for amplifying ecological stressors in the Mississippi Sound (MSS) and adjacent coastal/shelf waters of the Mississippi Bight region as a result of both controlled and natural freshwater inflows. Project results obtained and presented herein are expected to inform policy and decision makers regarding the impact of controlled freshwater influxes on the Mississippi Sound and Bight. A process-based analysis of developed scenarios reveals how the timing and discharge through the Mid-Breton Diversion will propagate throughout the region. To do this we consider the 3 scenarios listed as project tasks above. In our analysis, we consider a bottom salinity of 5 ppt as a stress point for oyster populations to assess coastal ecosystem health and reveal the geographic extent and severity of freshwater impacts.

Average bottom salinity results reveal that the largest differences due to the introduction of MBrSD freshwater take place in the Western Mississippi Sound (WMSS) and Breton Diversion / Sound (BRDS), where monthly average salinity is up to 8.4 ppt (WMSS; Climatological Scenario) and 10.9 ppt (BRDS; Maximum Scenario) lower when the MBrSD is active. In comparison, the maximum freshening for Lake Borgne, and Central / Eastern Mississippi Sound is less than 4.4 ppt for all scenarios with active MBrSD. Universally across all scenarios, Breton Sound experiences significant freshening when the MBrSD is active.

When the Breton Diversion is active in concert with the 2019 BCS opening period (March through July), regional averages over Central and Eastern MSS see up to 1 additional cumulative days of low bottom salinity (<5 ppt) water per month. Over the March-July BCS opening parts of these regions experience up to 10 more cumulative days of low bottom salinity, while parts of Biloxi Marsh and Chandeleur Sound accrue up to 20 additional cumulative days of low bottom salinity. With both diversions active, freshening in Lake Borgne and the Western Mississippi Sound during February - March period is potentially due to the impact of the MBrSD waters inhibiting the propagation of BCS waters further south and into the Breton and Chandeleur Sounds.

Within the limited number of numerical experiments performed for this study, there was only one instance identified where the addition of MBrSD impacts shifted the average monthly bottom salinity down to a critical threshold for the four 2019 hindcast experiments (WMSS in February). However, while realistic, the 2019 time frame was an extreme scenario in terms of BCS operation and it is known that salinities within the MSS were at historically low values. The climatological scenario provides more telling insight into MBrSD operations, with the most pronounced impact on bottom salinities and a 4-month period (March – July) when values shift below the critical ecological threshold (salinity of 5 ppt), coincident with the peak of the spring freshet and subsequent recovery. Consequently, full opening of the MBrSD during high river discharge, and particularly during BCS openings, should be considered with caution so as not to push salinity conditions beyond a tipping point that will adversely, and possibly permanently, affect the ecosystem services provided by key species residing within Mississippi Sound. We make this recommendation in light of the broad range of environmental influences at play in the region that can contribute to the ultimate fate of a significant freshwater diversion injection into these coastal waters.

Our results suggest that salinity conditions in the WMSS are rather sensitive to the timing and magnitude of local riverine, BCS and MBrSD influences, that again are highly convolved with the governing wind forcing conditions. Through a fuller exploration of scenarios, a more comprehensive understanding could be obtained for how this area, which is critical in terms of fisheries production and ecosystem services, would be influenced by human-engineered freshwater diversions. Year to year, the results may vary widely, driven by the highly variable freshwater discharge and wind forcing in this area. While the influence of MBrSD on MSS salinities is measurable in this study, whether a deleterious ecological impact is realized is subject to the net influence of these forcing factors. Another recommendation in this context would be to employ short-term modeling forecasts that could be used to assess the impacts of potential BCS openings based on relevant forcing conditions and knowledge of MS River stage. Our research group is currently developing a near real-time and short-term forecasting capacity that could be used to provide such guidance to local resource managers.

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Figure A4: Interannual daily river discharge data for the Styx River (Station 02377570) (a) and the corresponding daily climatological discharge (b).

Figure A5: Interannual daily river discharge data for the Wolf Creek (Station 02378170) (a) and the corresponding daily climatological discharge (b).

Figure A6: Interannual daily river discharge data for the Perdido River (Station 02376500) (a) and the corresponding daily climatological discharge (b).

Figure A7: Interannual daily river discharge data for the Fish River (Station 02378500) (a) and the corresponding daily climatological discharge (b).

Figure A8: Interannual daily river discharge data for the Magnolia River (Station 02378300) (a) and the corresponding daily climatological discharge (b).

Figure A9: Interannual daily river discharge data for the Chickasaw River (Station 02471001) (a) and the corresponding daily climatological discharge (b).

Figure A10: Interannual daily river discharge data for the Fowl River (Station 02471078) (a) and the corresponding daily climatological discharge (b).

Figure A11: Interannual daily river discharge data for the Pascagoula River (Station 02479000) (a) and the corresponding daily climatological discharge (b).

Figure A12: Interannual daily river discharge data for the Red Creek (station 02479300) (a) and the corresponding daily climatological discharge (b).

Figure A13: Interannual daily river discharge data for the Mississippi River (Station 07374525) (a) and the corresponding daily climatological discharge (b).

Figure A14: Interannual daily river discharge data for the Black Creek (Station 02479130) (a) and the corresponding daily climatological discharge (b).

Figure A15: Interannual daily river discharge data for the Biloxi River (Station 02481000) (a) and the corresponding daily climatological discharge (b).

Figure A16: Interannual daily river discharge data for the Wolf River (Station 02481510) (a) and the corresponding daily climatological discharge (b).

Figure A17: Interannual daily river discharge data for the East Pearl River (Station 02492110) (a) and the corresponding daily climatological discharge (b).

Figure A18: Interannual daily river discharge data for the Amite River (Station 07378500) (a) and the corresponding daily climatological discharge (b).

Figure A19: Interannual daily river discharge data for the Tickfaw River (Station 07376000) (a) and the corresponding daily climatological discharge (b).

Figure A20: Interannual daily river discharge data for the Tangipahoa River (Station 07375500) (a) and the corresponding daily climatological discharge (b).

Figure A21: Interannual daily river discharge data for the Blind River (Station 07377000) (a) and the corresponding daily climatological discharge (b).

Figure A22: Interannual daily river discharge data for the West Pearl River (Station 02489500) (a) and the corresponding daily climatological discharge (b).

Figure A23: Interannual daily river discharge data for the Tchefuncte River (Station 07375000) (a) and the corresponding daily climatological discharge (b).

Figure A24: Comparison of sea surface height boundary condition extracted from NCOM-GOM (black) and NCOM-AMSEAS (red) along the southern boundary of the msbCOAWST model at different times during January 2019.

Figure A25: Comparison of temporal evolution of sea surface height boundary condition extracted from NCOM-GOM (black) and NCOM-AMSEAS (red) at a point location along the southern boundary of the msbCOAWST model during January 2019. This illustrates how tidal forcing is introduced into the model.

Figure A26: Comparison of salinity boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

Figure A27: Comparison of temperature boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

Figure A28: Comparison of zonal velocity boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

Figure A29: Comparison of meridional velocity boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

Figure A30. Monthly maximum consecutive days and the difference in maximum consecutive days of bottom salinity below 5 ppt (across twin experiments) between scenarios with and without Breton Diversion discharge within the areas defined in figure 15. Abbreviations are as follows: WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, and EMSS=Eastern Mississippi Sound.

Figure A31. The maximum consecutive days where average bottom salinity is below 5 ppt in all scenarios (columns 1 and 2) and the difference across twin experiments (column 3) in cumulative days when comparing Breton Sound scenarios with the non Breton Diversion scenarios. In the difference plots, positive values (blue, fresher) indicate there are more consecutive days below 5 ppt in the Breton Diversion scenario while negative values (red, saltier) indicate there are fewer consecutive days below 5 ppt.

Figure A32. Monthly cumulative days of bottom salinity below 5 ppt (columns 1 and 2), and the difference across twin experiments (third column), between scenarios with Breton Diversion discharge and those without within the areas defined in figure 14b. Abbreviations are as follows: WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, and EMSS=Eastern Mississippi Sound.

Figure A33. The total cumulative days where average bottom salinity is below 5 ppt in all scenarios (column 1 and 2) and the difference across twin experiments (column 3) in cumulative days in the Breton Diversion scenarios when compared with the scenarios not including the Breton Diversion. In the difference plots, positive values (blue, fresher) indicate there are more consecutive days below 5 ppt in the Breton scenarios while negative values (red, saltier) indicate there are fewer consecutive days below 5 ppt in the Breton Diversion scenarios.

Figure A34. Mississippi Department of Marine Resources continuous monitoring locations plotted over model depth.

Figure A35. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 5 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

Figure A36. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 6 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

Figure A37. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 7 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

Figure A38. Time series from 2019 of: a) HRRR wind vectors; b) model salinity (ppt) (surface (blue) and bottom (red)); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 9 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

Figure A39. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 10 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

Figure A40. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 14 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

Table A1: List of USGS gauge stations used for extracting the daily interannually varying river discharge from which the daily climatology is calculated and applied as model boundary conditions. Time frame of the data applied in developing the climatologies is 01/June/2010 - 31/December/2020.

Project Description

Primary Objectives and Goals

This project will provide managers at the Mississippi Department of Marine Resources (MDMR) the scientific information needed to accurately address public concerns regarding the potential effects of the proposed Louisiana Coastal Master Plan / Coastal Protection and Restoration Authority (CPRA) Mid-Breton Sediment Diversion (MBrSD) on the jurisdictional waters and resources of Mississippi. In particular, this information will be used to either verify or refute information being relayed to Mississippi stakeholders by special interest groups.

The core objective is to develop model-based guidance, provided in this report and ongoing consultation with MDMR leadership, on the impact that the introduction of the Mid-Breton Sediment diversion could have on water quality in the MS Sound (MSS) and Mississippi's jurisdictional waters that contain living natural resources, particularly those that encompass oyster reef locations, that are key ecosystem health indicators and economic drivers for the State of Mississippi. Freshwater flowing into the Western MS Sound (WMSS) from currently existing human-engineered diversion and flood control structures have recently led to significant, unprecedented environmental impacts. The potential addition of a new pathway for additional freshwater to be introduced into the MSS requires careful assessment of the potential impacts that may be incurred.

Study Area

The MSS and Bight is a complicated coastal marine system that experiences tropical storms, influx from freshwater diversions, seasonal stratification, frequent bottom hypoxia, harmful algal blooms and diverse fluvial inputs. This system also contains several complex coastal features, including Lakes Maurepas, Pontchartrain and Borgne, Biloxi Marsh, Bay St. Louis, Biloxi Bay, Mobile Bay and numerous barrier Islands separating the Sound and Bight including Cat, Ship, Horn, Petit Bois, and Dauphin, as well as the Chandeleur Island chain (Figure 1). The bathymetry of the MSS and inner shelf of the Mississippi Bight is shallow, averaging 3 meters and under 20 meters respectively, with the exception of 20 meter deep shipping channels that extend seaward from Gulfport and Pascagoula (Figure 2, see caption for bathymetry source and datum details). Tides within the MSS and Bight are mainly diurnal microtides (less than 0.6 m) propagating from east to west in a shore-parallel wave, with a semidiurnal component that enhances currents at the inlets between barrier islands (Seim et al., 1987). The weather along the coast of Mississippi includes a typical sea breeze and a more variable land breeze circulation that influences the areal extent of convectively driven summertime precipitation (Hill et al., 2010). The land-sea breeze circulation cycle also drives currents within MSS and through the tidal inlets between barrier islands where lateral advection facilitates exchanges of water, suspended particulates, and dissolved nutrients between the Sound and Bight (Bouchard, 2021).

The Lake Pontchartrain Estuary is located north of New Orleans and the Mississippi River (MSR). The estuarine system stretches from Lake Maurepas to Lake Borgne (Figure 1). The largest freshwater diversion influencing the MSS and Bight, the Bonnet Carré Spillway (BCS), has the capacity to divert up to 7080 $m^3 s^{-1}$ (250,000 cfs) of fresh water from the Mississippi River (United States Army Corps of Engineers 2021). The BCS was designed to prevent the flooding of New Orleans by relieving water pressure on the levees and is opened when the Mississippi River discharge exceeds 35,396 $m^3 s^{-1}$ (1.25 million cfs). When the BCS is active, MSR waters are diverted into the southwest corner of Lake Pontchartrain and propagate through the estuarine system into western MSS.

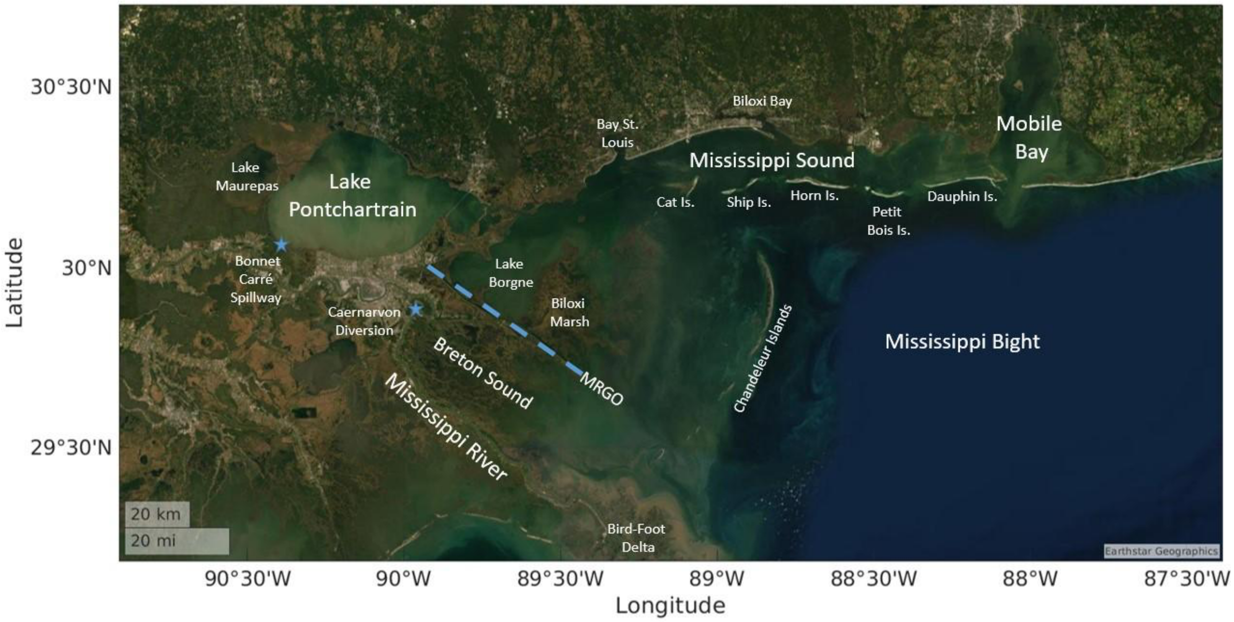


Figure 1. The study area and complex coastal features including the Bonnet Carré Spillway and Caernarvon Diversion, marked with blue stars. The path of the Mississippi River Gulf Outlet (MRGO) navigation channel, which is no longer operational, is indicated by the blue dashed line.

The Breton Sound Estuary is located in southeast Louisiana, north of the MSR bird foot delta and south of Lake Borgne on the Mississippi Deltaic Plain (Figure 1). The hydrologic boundaries of the estuary are the levees along the MSR to the west and the spoil banks of the Mississippi River Gulf Outlet (MRGO) navigation channel to the east. The Caernarvon diversion flows into the northern part of the estuary that serves as a settling basin for the sediments entrained within the diverted waters (Figure 3).

In addition to seasonal and diurnal wind patterns, exchange between the estuarine and shelf waters of the Sound and Bight is influenced by an abundance of buoyant freshwater plumes from coastal sources. These freshwater plumes combine with seasonal thermoclines in establishing water column stratification. The degree of water column stability achieved is a measure of the contrast between the stabilizing influence of buoyant plumes and the destabilizing force of turbulence. Due to the freshwater lens that covers much of the MSS and Bight, water column stability within the Mississippi Bight is modified by wind-driven Ekman dynamics where downwelling acts to mix in freshwater that lowers stratification and water column stability while upwelling drives the freshwater lens further offshore increasing stratification and water column stability (Dzwonkowski, Fournier, Park, et al., 2018). Such upwelling favorable winds commonly occur during summer, following the spring freshet.

Water masses influencing the MSS and Bight include shelf seawater, Mississippi River water (including Bonnet Carré Spillway and Caernarvon diversions), and local river waters including the Pearl River, Pascagoula River and other rivers flowing into Lake Pontchartrain, Mississippi Sound and Mobile Bay (Parra et al., 2020). Buoyant river waters can increase vertical stratification and drive lateral mixing between fresh and salt waters as well as gravitational estuarine circulation (Deignan-Schmidt & Whitney, 2018). Local rivers, excluding the Mississippi River, are the main source of buoyant freshwater plumes within the MSS and Bight (Dzwonkowski, Fournier, Reager, et al., 2018; Greer et al., 2018; Sanial et al., 2019). However in years when BCS discharge meets or exceeds the volume of Lake Pontchartrain (6.4 km^3), diverted Mississippi River water and sediment can quickly flush into WMSS, leading to rapid declines in water quality and the infilling of dredged shipping channels (Hendon et al., 2020).

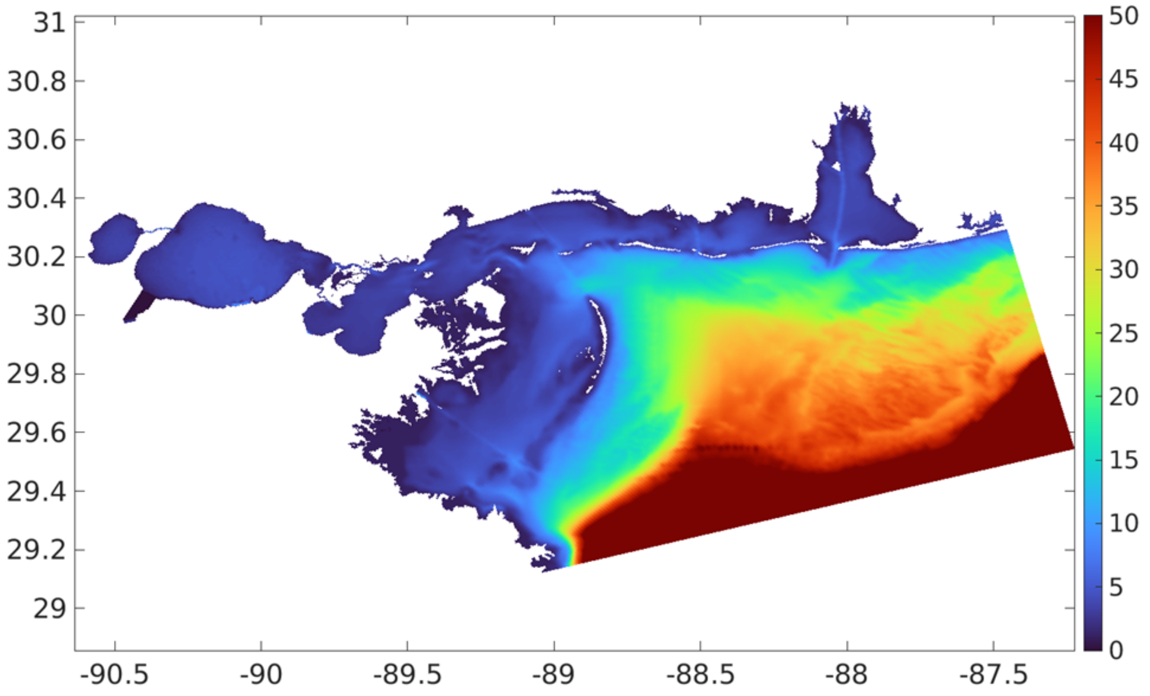


Figure 2. Bathymetry in meters within the study area, including the Mississippi Sound and Bight. The digital elevation model (DEM) source for this map is documented in Wiggert et al. (2018). All depths noted herein are drawn from this DEM for which the applied datum is NAVD88 (North American Vertical Datum of 1988).

Atmospheric forcing and wind conditions drive circulation as well as estuarine shelf exchange and consequently strongly impact the bottom salinity in the estuarine system (Dzwonkowski et al., 2017; Cambazoglu et al., 2017). Seasonal winds determine whether BCS waters travel eastward into the MSS and Bight or propagate south and west to mix with estuarine and coastal waters of Louisiana. For example, the 2016 BCS opening had minimal impact in Mississippi Sound because the atmospherically driven circulation caused the freshwater plume to be directed into Biloxi Marsh and Chandeleur Sound while being trapped in near-coastal waters (Parra et al., 2020). Local rivers and existing freshwater diversions from the Mississippi River affect salinity regimes, nutrient concentrations and ratios, turbidity, temperature and estuarine residence times, all of which can influence water quality, manifestations of hypoxia, and phytoplankton community dynamics in the MSS and Bight (Bargu et al., 2019; Bouchard, 2021).

Freshwater Diversions

There are several existing and proposed freshwater diversions (Figure 3) which could potentially introduce freshwater and nutrients from the MS River into the MSS and Bight (Bargu et al., 2019). The BCS, which is located ~52 km upriver of New Orleans, has the most direct influence on MSS and Bight, though its impacts are not yet fully understood. In years where the BCS is not opened or BCS discharge is low, local rivers (rather than the MSR) are the main source of buoyant freshwater plumes in the MSS and Bight (Dzwonkowski, Fournier, Reager, et al., 2018; Greer et al., 2018; Sanial et al., 2019).

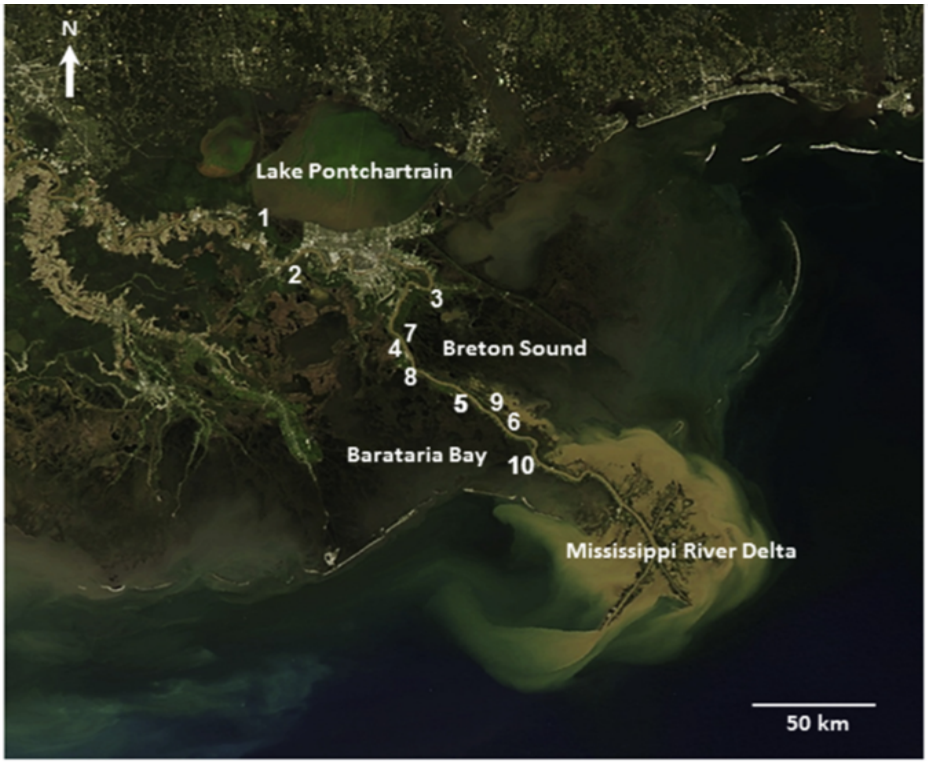


Figure 3. Existing and proposed freshwater diversions in the study area (CPRA 2017); 1– Bonnet Carré Spillway; 2– Davis Pond Diversion; 3– Caernarvon Diversion; 4- Naomi Siphon; 5– West Pointe a la Hache Siphon; 6– Bohemia Spillway; 7– Mid-Breton Sound (proposed); 8– Mid-Barataria (proposed); 9– Lower Breton Sound (proposed); 10- Lower Barataria (proposed). (Figure 2 from Bargu et. al 2019).

The MBrSD, recommended by the Coastal Protection and Restoration Authority of Louisiana (CPRA) in fall of 2015, was included in the 2017 Coastal Master Plan (CPRA, 2017). The existing Caernarvon diversion, operating since 1991 ~32 km south of New Orleans, was designed and constructed to control saltwater intrusion and has a maximum diversion rate of 226 $m^3 s^{-1}$ (7,981 cfs), which is about 10% of the capacity of the proposed MBrSD. The MBrSD is designed primarily as a sediment diversion structure with a constant diversion flux of 142 $m^3 s^{-1}$ (5,000 cfs), which can be increased to a maximum diversion flux of 2,124 $m^3 s^{-1}$ (75,000 cfs) when MSR discharge exceeds 28,320 $m^3 s^{-1}$ (1,000,000 cfs) (US Army Corps of Engineers, 2022). In 2019 it was decided to expand the scale of the MBrSD from 991 $m^3 s^{-1}$ (35,000 cfs) to 2,124 $m^3 s^{-1}$ (75,000 cfs) to build more coastal wetlands. The MBrSd has been designed to build and maintain an estimated 16,000 acres of new land in the Breton Basin during its first 50 years of operation.

New diversions proposed on the east side of the river, including the MBrSD and lower-Breton Diversion, could potentially influence the MSS and Bight. This is of particular concern in light of the unprecedented 2019 double opening of the BCS, equivalent to nearly 6 times the volume of Lake Pontchartrain, which devastated oyster populations throughout MSS and led to multi-state disaster declarations.

Project Objectives

Previous studies make it clear that the new diversions proposed on the east side of the river, including the MBrSD, will influence freshwater fluxes into the MSS and Bight. This project seeks to understand how increasing freshwater inputs to the MS Sound and Bight region, both controlled and natural, will affect salinity conditions critical for the viability of the region's oyster beds. In this study, we apply a circulation model to focus on the physical movement of water and changes to salinity during hypothetical Breton Diversion opening scenarios designed to assess changes to hydrographic conditions of the MS Sound and Bight. To obtain a "normal" scenario of seasonal evolution of the coastal ocean's physical environment as a means of assessing how inclusion of the MBrSD affects hydrographic conditions, climatological forcing conditions are applied. As a result of the 2019 double BCS opening, multiple disaster declarations occurred for states along the Northern Gulf Coast. The 2019 double BCS opening events provide the motivation and backdrop for our other model scenarios, which incorporate observed river flow, wind forcing and BCS freshwater flux conditions across numerical experiments designed two experimental cases that seek to isolate these influences relative to the introduction of the MBrSD. Furthermore, this extreme event has served as motivation to establish the capability to more fully assess past events with an eye toward holistically projecting the impact that restoration and / or mitigation strategies being considered now, and in the future, will have on the hydrographic conditions of coastal waters of the State of Mississippi.

We have obtained observed river, wind, BCS activation and the MSR hydrograph from 2019 and applied them in model experiments designed to examine hypothetical scenarios for the Mid-Breton Diversion. Project results can be used to inform policy and decision makers regarding controlled freshwater influx that influences the MSS and Bight. A process-based analysis of prescribed scenarios (described above) reveals the impact of background conditions, timing and discharge through the Mid-Breton Diversion.

Methods: Model Framework

The University of Southern Mississippi (USM) Ocean Modeling Group developed an application (structured grid, 400 m horizontal resolution, 24 vertical layers) of the Coupled Ocean Atmosphere Wave Sediment Transport (COAWST, Warner et al., 2010) modeling system during the Gulf of Mexico Research Initiative (GoMRI)-funded Consortium for Coastal River-Dominated Ecosystems (CONCORDE, Greer et al., 2018). Within the COAWST modeling system, the Regional Ocean Modeling System (ROMS, Shchepetkin & McWilliams, 2005) is the core circulation model that serves as the central framework. Depending on the specific research interest, the COAWST modeling system can be implemented to leverage additional fully interactive modeling capability, such as the Community Sediment Transport Model (CSTM), the Weather Research and Forecasting (WRF) Model, surface wave models such as SWAN (Simulating Waves Nearshore) or WAVEWATCH III (Warner et al., 2010), or biogeochemical modules (e.g., Wiggert et al., 2017). Biogeochemical, sediment, and wave modeling are not activated for the model implementation employed for the work presented here, though our modeling group has employed them in separate research efforts.

Our COAWST implementation for the Mississippi Sound and Bight (msbCOAWST), specific for the 2019 hindcast experiments, is summarized in Figure 4. The model domain includes the MS Sound / Bight southward to the continental shelf break and eastward to Perdido Bay, FL. Lateral boundary conditions along the southern and eastern edges of our domain are drawn from the NCOM Gulf of Mexico (NCOM-GOM) model (Jacobs et al., 2016), which also provides the necessary initial condition fields. Surface boundary conditions of momentum, heat and buoyancy fluxes are obtained from the NOAA High

Resolution Rapid Refresh (HRRR) model (Benjamin et al., 2016). Specifics of the model forcing fields for 2019, and generation of the climatological forcing fields, are provided below.

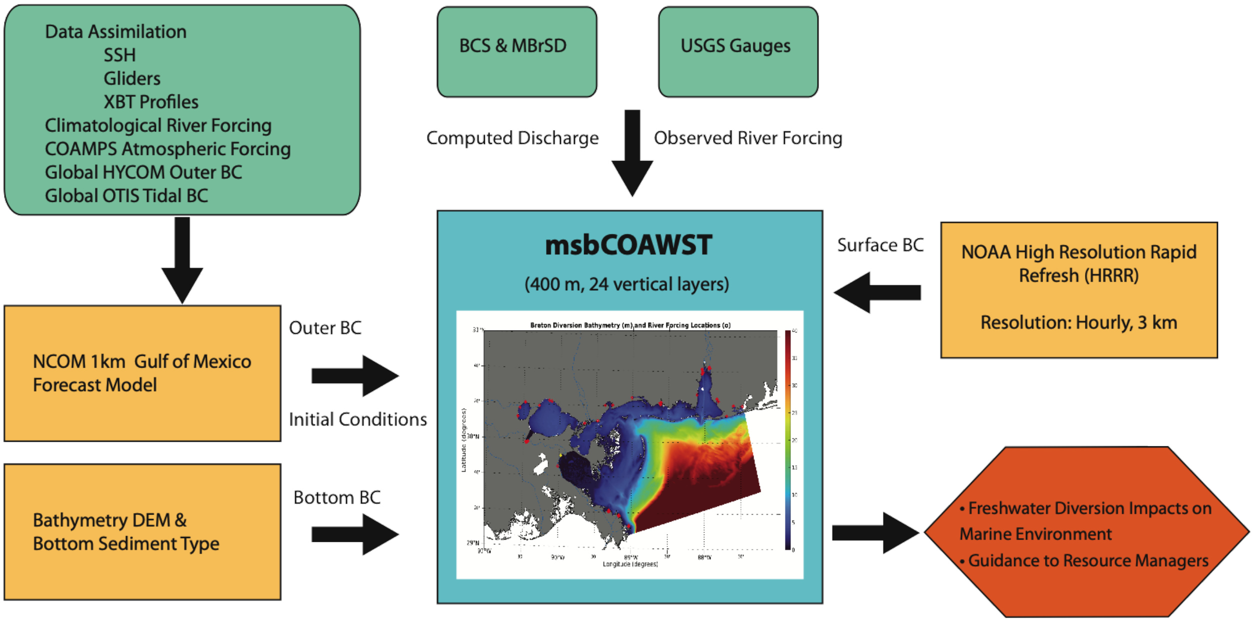


Figure 4. Diagram of the elements that comprise the msbCOAWST model. The model grid for this study encompasses the MS Sound / Bight region where a structured 400 m grid with 24 vertical layers is applied. This domain is nested within the NCOM Gulf of Mexico model, which provides initial and outer boundary conditions (3-hourly, 1 km). Surface momentum, heat and buoyancy conditions are provided by the NOAA-HRRR model (hourly, 3 km), which resolves the land-sea breeze circulation. Realistic river forcing is provided by USGS stream gauges at the sites indicated (red dots) indicated on the bathymetry map. Freshwater inputs from river diversion infrastructure (BCS and MBrSD) are computed from US Army Corps of Engineers flow records. The forcing details shown in this diagram are specific for the 2019 scenarios. For the climatological scenarios, climatological freshwater, BCS flow, outer boundary and surface boundary conditions are applied.

The model application has been run with improved river forcing, keeping the Mississippi River and other local rivers flowing into the estuarine systems of MSS and Mobile Bay, dividing the Pearl River into its East and West branches, and adding the rivers that flow into Lakes Pontchartrain and Maurepas (Figure 5). Freshwater forcing is obtained from US Geological Survey (USGS) River Gauge stations while freshwater discharge through the Bonnet Carré Spillway is obtained from the U.S. Army Corp of Engineers (Figure 4). The model bathymetry is based upon the 3 arc second digital elevation model (DEM) developed by our group as part of the Northern Gulf Coastal Hazards Collaboratory (Twilley et al., 2014). Bonnet Carré Spillway and Mid-Breton Sediment Diversion elements have been implemented in the original model domain to simulate physical processes in subtidal and intertidal areas along the Louisiana and Mississippi coast while the diversions are open (Figure 5).

The Bonnet Carré Spillway and the Breton Sound wetlands components of our model serve as a means to create a realistic boundary condition of freshwater flowing into the model domain when these diversions are active. Our setup allows the water to mix before flowing into Lake Pontchartrain or Breton Sound proper, which prevents introduction of instability into the model. The model is not attempting to resolve the fine details of the Bonnet Carré Spillway or Breton wetlands, so the 400 meter resolution is retained to maintain computational efficiency. The 400 meter resolution produces the expected exchange of water between Lakes Pontchartrain and Borgne. The Breton Sound and Bonnet

Carré Spillway are unmasked and impacted by wetting and drying in the model to enable realistic boundary condition flow into the model domain. Other shallow areas along the coast are masked. The minimum depth for wetting and drying is 0.20 meters.

USGS continuous recorder instrumentation sites in the Mississippi Sound provide hydrological data and real-time access for monitoring and managing Mississippi's marine fisheries (Figure A34, https://dmr.ms.gov/hydrological-monitoring/). These sites have available data for the year 2019 which has been plotted against the msbCOAWST 2019 Bonnet Carré Spillway opening hindcast (Figures A35 through A40). The exact depth of the USGS stations is not known, so comparison plots include salinity and temperature at both surface and bottom. Station 9 has temperature data but no salinity data for the time period covered. Model salinity captures USGS station salinity trends and model salinity values bracket USGS salinity values at most sites. Model temperature captures USGS station trends and the root mean squared error between the model surface temperature in degrees Celsius (°C) and observed temperature ranges from 0.62 degrees at station 10 to 1.3 degrees at station 14 (Armstrong et al., 2021). These model-data comparisons provide insight into the skill of the msbCOAWST model. We are currently in the process of documenting a thorough skill assessment of the model that will leverage several comprehensive sampling efforts in the MS Bight / Sound region starting from our GoMRI-funded CONCORDE consortium activities (Greer et al., 2018)

This study is looking at daily and monthly averages and the movement of sub-mesoscale and mesoscale water masses in the sound, focusing on averages in regions of influence. The 400 meter resolution of the model allows it to resolve sub-mesoscale processes (<10,000 meters) and reproduce features in the area which are visible in satellite imagery and so is appropriate for this type of study.

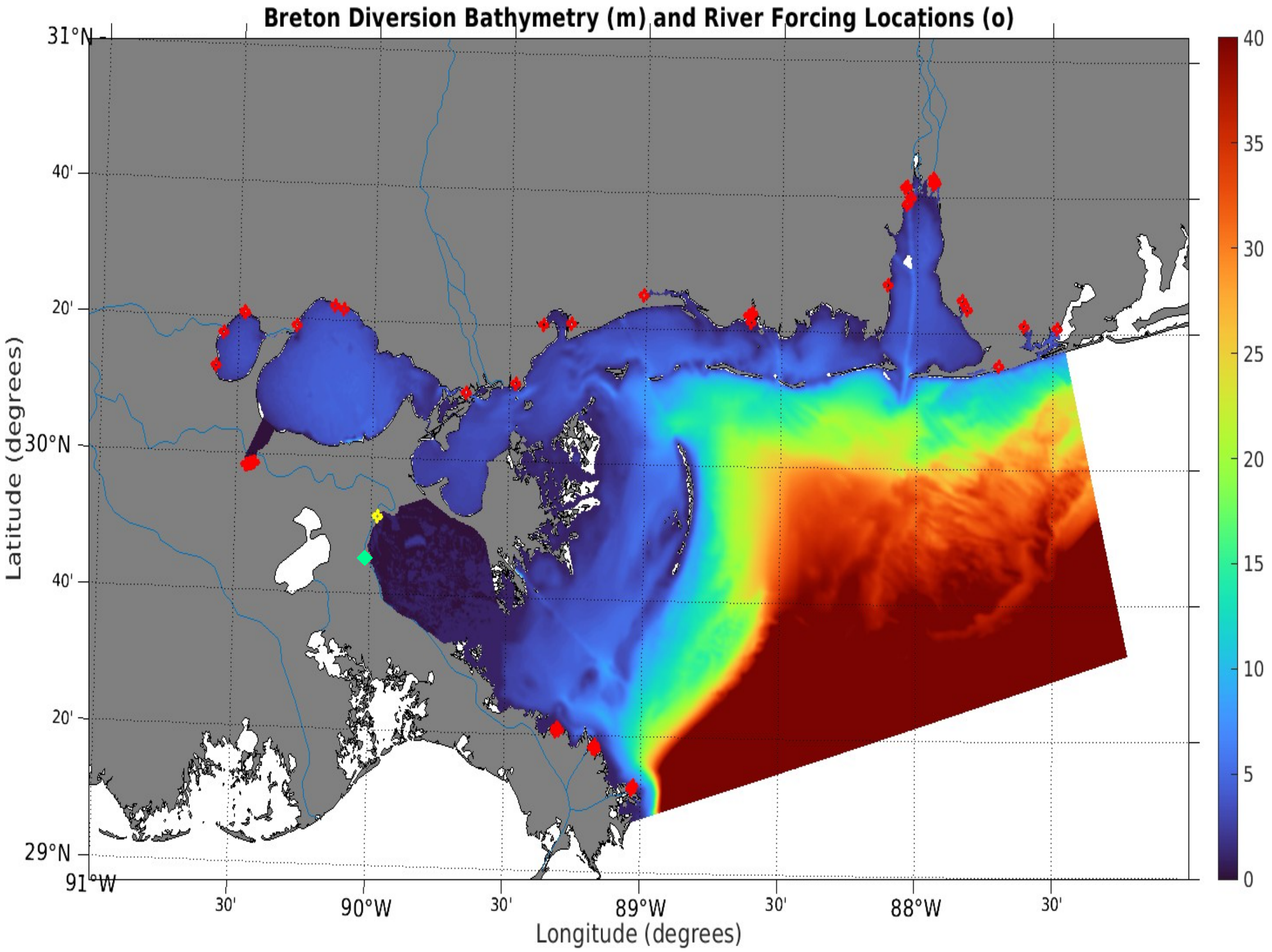


Figure 5. The msbCOAWST grid bathymetry in meters for the model domain. River inflow locations into the msbCOAWST domain are marked as red diamonds. River names and their USGS gauge station IDs are noted in Figure A1 and Table A1, respectively. Further details of these river discharge locations and applied processing methods are provided in the Appendix. The location of the USGS gauge station at Belle Chasse is marked (yellow diamond). The three discharge locations along the Birdfoot Delta that flow directly into the WMSS are set to discharge 10%, 12.5% and 10% of the total MS River discharge at Belle Chasse. When it is active in the model, variable discharge at the Mid-Breton Sediment Diversion (green diamond) is also based on Belle Chasse discharge. The bathymetry applied for this modeling application is drawn from the NGCHC 3 arc second DEM (Wiggert et al., 2018). The applied datum for this DEM is NAVD88.

Methods: Model Application Scenarios

In order to isolate the impact of the mid-Breton Diversion, the three scenarios noted above were addressed through six numerical experiment cases that encompassed various model domains and freshwater diversion applications (Figure 6, Table 1). The various model domains were established to allow for isolating the impacts of the Bonnet Carré Spillway, the proposed mid-Breton Sediment Diversion (operating at maximum capacity), and the combined effects of those two control structures. When both the Bonnet Carré and mid-Breton Diversion are active, then the flow through the latter is dependent upon the total Mississippi River flow at the Belle Chasse USGS station.

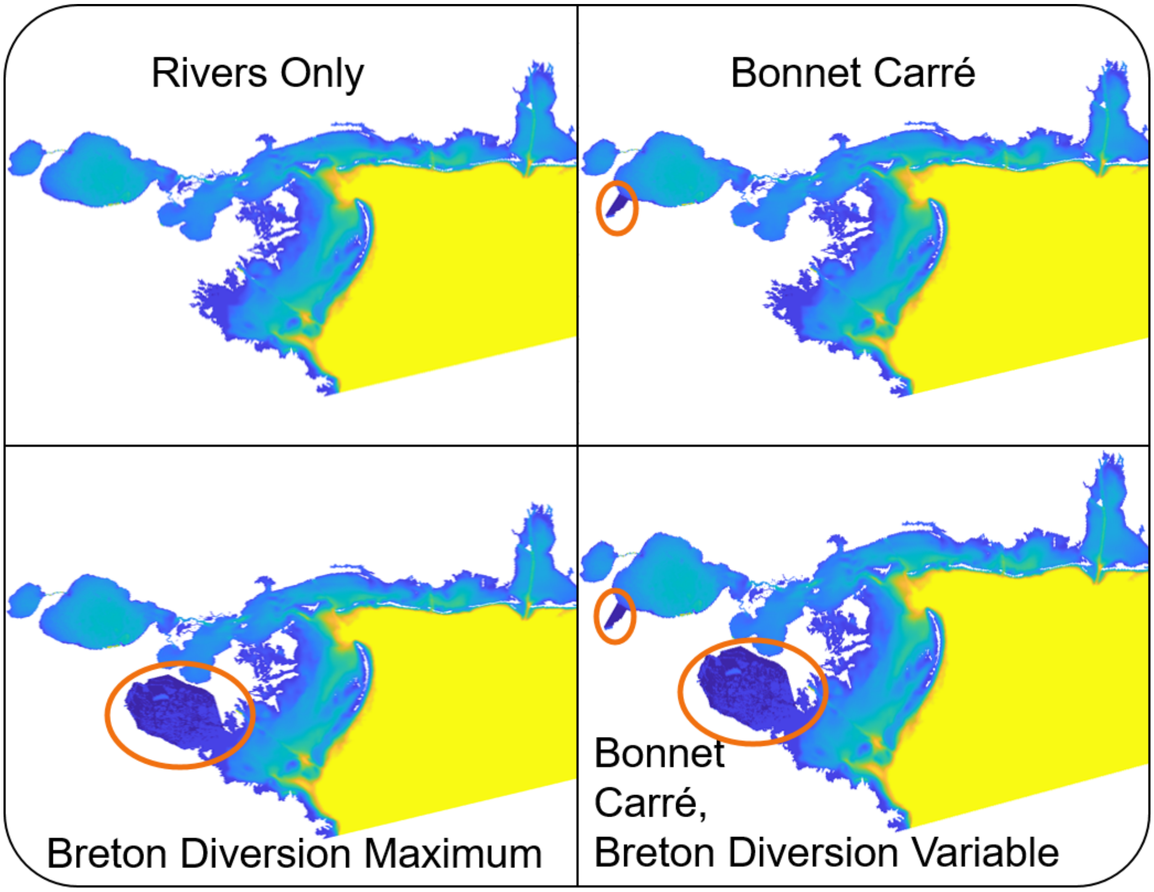


Figure 6. The msbCOAWST model domain for each of the scenarios, illustrating when the Bonnet Carré Spillway and / or the mid-Breton Sediment Diversion are included in a given numerical experiment. The climatological experiments use the Breton Diversion Maximum and Rivers Only domains.

The climatological scenarios (Table 1) consist of climatological conditions with no freshwater diversion application (CLIM) and climatological conditions with a variable Breton Diversion application (CLIM BD or BDCLIM) where MBrSd consists of minimum constant of 5,000 cfs and ramp up to 75,000 cfs that is based upon the climatological MSR discharge condition (details below).

To establish a baseline for the other 2019 scenarios, a Rivers Only (RO) experiment is conducted. The freshwater diversion scenarios (Table 1) consist of the realistic Bonnet Carré conditions for 2019 (BC), a maximum Breton Diversion (BD MAX) application for the 2019 calendar year, and a variable Breton Diversion with realistic 2019 Bonnet Carré (BCBD VAR) application where the MBrSD consists of a minimum constant of 5,000 cfs and ramp up to 75,000 cfs that is based upon the MSR discharge condition (details below). The focus of these numerical experiments on the 2019 time frame is due to the historically high Mississippi River levels that occurred and which resulted in the first-ever double opening of the Bonnet Carré spillway.

Table 1. Numerical experiments run for this study and the comparison and isolation objective for each. Abbreviations: Bonnet Carré (BC), Breton Diversion (BD), maximum discharge for the mid-Breton Diversion (MAX), variable discharge (based on MSR level) for the mid-Breton Diversion (VAR), climatological forcing (CLIM). X indicates no tracer release performed. Expanded descriptions of each scenario can be found in the preceding paragraphs.

	Objective	**Tracer Release**	**Abbreviation**	**Dates**
Climatological Scenarios				
CLIM Rivers	CLIM Base Case	Isolate MS River	CLIM	one calendar year
CLIM Rivers & BD	Isolate BD	Isolate BD Impact	CLIM BD or BDCLIM	one calendar year
2019 Scenarios				
Rivers Only	2019 Base Case	X	Rivers or RO	1/1/2019 to 12/31/ 2019
Rivers & BC Real	Isolate BC	Isolate Freshwater sources	BC	1/1/2019 to 12/31/2019
Rivers & BC Real & BD VAR	Isolate BD VAR	X	BCBDVAR or BDVar	1/1/2019 to 12/30/2019
Rivers & BD MAX	Isolate BD MAX	X	BDMAX	1/1/2019 to 9/28/2019

A twin experiment terminology and logic will be used throughout the results and discussion in order to isolate and understand the influence of MBrSD on advective pathways and hydrographic properties. In a twin experiment two model runs are created to be identical in all ways except one. This ensures that differences between the two model outputs are due to one unique feature in one of the two otherwise identical numerical experiments. In our experiments the unique feature is the inclusion of redirected freshwater through the BCS and/or the MBrSD. The six numerical experiments (Table 1) can be used to create a series of twin experiments which can be thought of as simple equations when comparing values like salinity.

1) Climatology Difference (BDCLIM - CLIM) => (CLIM + BD) - CLIM = BD
2) BC Difference (BC - RO) => (RO + BC Real) - RO = BC Real
3) BCBDVAR Difference (BCBDVAR - BC) => (RO+ BC Real + BD VAR) - (RO + BC Real) = BD VAR
4) BDMAX Difference (BDMAX - RO) => (RO + BD MAX) - RO = BD MAX

The twin experiments considered here to address the project objectives are fully described in “Methods: Analysis Tools” section below.

Methods: Model Forcing Fields

The numerical experiments summarized in Table 1 all require application of forcing fields applied as surface or lateral boundary conditions. These include: 1) the surface atmospheric forcing that captures the relevant momentum, heat, and buoyancy fluxes; 2) the lateral boundary conditions that capture the hydrodynamic environment; and 3) the freshwater and temperature conditions associated with riverine inflows throughout the model domain. For all of these forcing data sets, the 2019 conditions were obtained and applied for the four 2019 scenarios noted in Table 1. In addition, climatological analogues were developed from relevant data sets for the 11-year period (2010-2020) of interest for establishing the “typical” conditions (i.e., atmospheric forcing, lateral boundary conditions, and riverine inflows) for the MS Bight / Sound coastal ocean domain. Finally, the 2019 and Climatological Mid-Breton freshwater diversion applications were derived from the Mississippi River data sets acquired for the riverine inflows just noted. Table 2 provides a summary of source information for the data sets accessed to develop the 2019 forcing fields, which are described in detail below.

Table 2. Source information for the model forcing parameters applied in performing the 2019 hindcast simulations.

Model Forcing	Provider	Spatial Resolution	Temporal Resolution	Reference and Web Link (if available)
River Forcing	USGS Stream Gage Data	point data	daily averages	U.S. Geological Survey, 2021 http://waterdata.usgs.gov/nwis
River Temperature	Group for High Resolution Sea Surface Temperature (GHRSST)	6 km 0.05°	daily averages	Govekar et. al., 2022 https://opendap.jpl.nasa.gov/opendap/allData/ghrsst/
Atmospheric Forcing	NOAA High Resolution Rapid Refresh (HRRR)	3 km	hourly	Benjamin et. al., 2016 https://rapidrefresh.noaa.gov/hrrr/
Open Boundary Conditions	Navy Coastal Ocean Model - Gulf of Mexico (NCOM - GOM) regional model	1 km	3 hourly	Jacobs et al. (2016) Jacobs (2017)

2019 Hindcast Forcing Data

Atmospheric Forcing

Atmospheric forcing for the 2019 model runs is drawn from the archived hourly output from the NOAA NCEP High Resolution Rapid Refresh (HRRR) model at 3-km resolution for zonal and meridional wind, humidity, surface air pressure, surface air temperature, cloud cover, precipitation, and short-wave radiation (Blaylock et al., 2017). Our model requires high spatial and temporal resolution surface wind forcing provided by HRRR to resolve the atmospheric circulation over complicated coastal features

(Figures 7 and 8). Circulation in the shallow water estuarine system and the exchange between the estuarine and shelf waters are influenced by winds and other atmospheric forcing. Higher frequency dynamics such as the diurnal variability of winds (i.e. the land-sea breeze cycle) and inertial motion are captured by high resolution atmospheric forcing reproducing the high variability of hydrodynamics (Bouchard, 2021).

Another aspect of this region is the frequency with which tropical storm systems impact our coastal waters. During 2019, three such systems (Hurricane Barry (July 11-15), TS Nestor (October 18-19), and TS Olga (October 25)) tracked through the Northern Gulf. Of these events, TS Olga had the closest proximity to our domain as its storm track followed a northward trajectory over eastern Louisiana. With their elevated winds, and potential for heavy precipitation and storm surge, such events can have significant impacts on salinity and other aspects of the coastal marine environment. While we have not explicitly explored the impact of these events, their atmospheric impacts are represented in our meteorological forcing fields. Three kilometer radar data is assimilated in the HRRR every 15 min over a 1-h period. HRRR wind fields include tropical storms and hurricanes, so any storm activity in the model domain during 2019 is included in the HRRR model’s output. It has been noted that the HRRR representation of such systems can exhibit shortcomings. For example, Dowell et al. (2022) found that when verified against Hurricane Harvey in 2017, HRRR could capture periods of strengthening and weakening in hurricane minimum pressure and maximum surface winds, but had large errors in storm intensity. Nevertheless, given that these three events were short-lived and not direct impacts on our model domain, we consider that their influences are reasonably represented in our results that are primarily focused on monthly time scales.

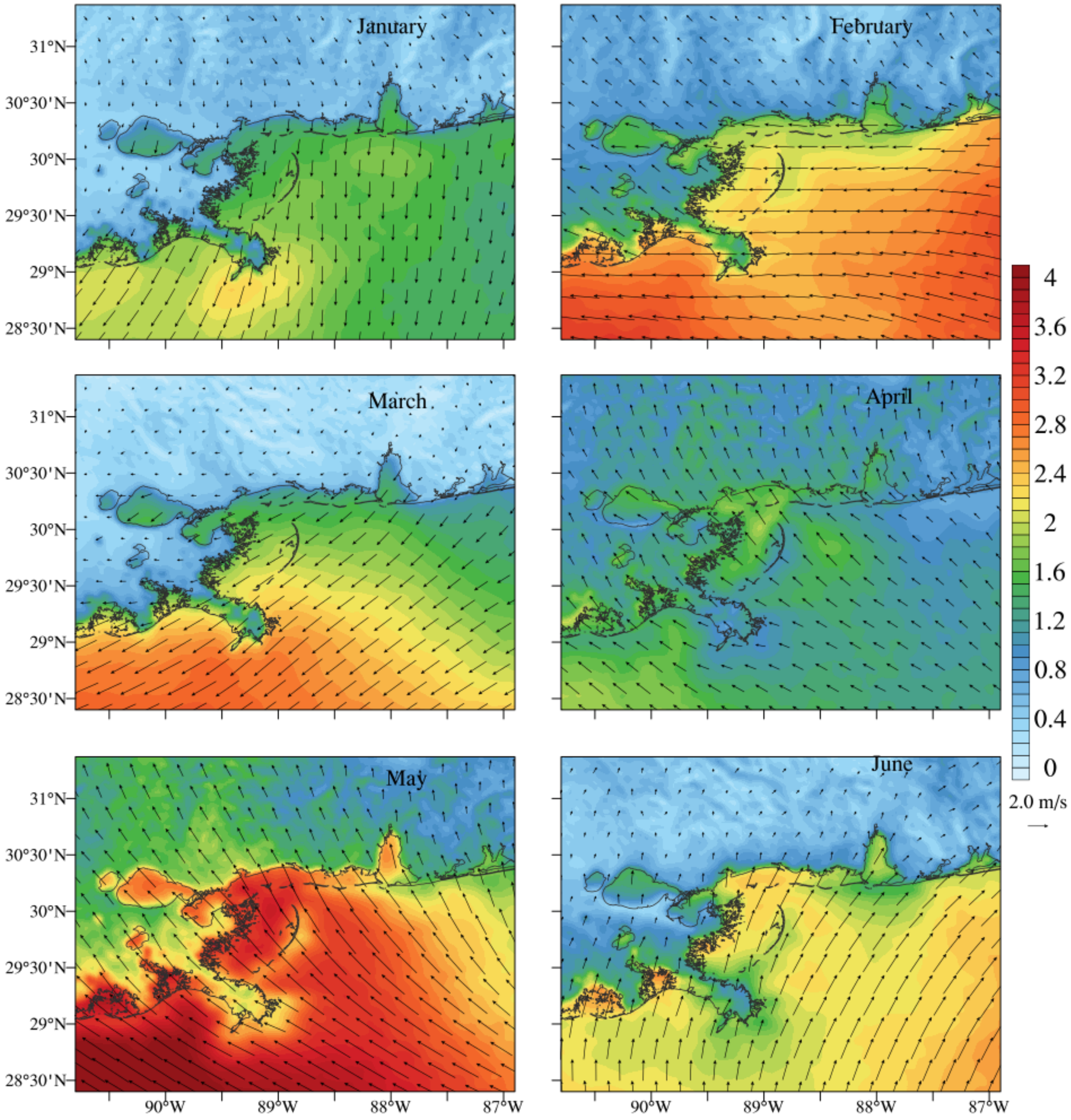


Figure 7. Spatial pattern of monthly mean wind distribution over the study region estimated from HRRR for the year 2019. Wind speed (m/s) is indicated by the colored field and the scaled wind vectors reveal both wind direction and magnitude for January to June (Contd).

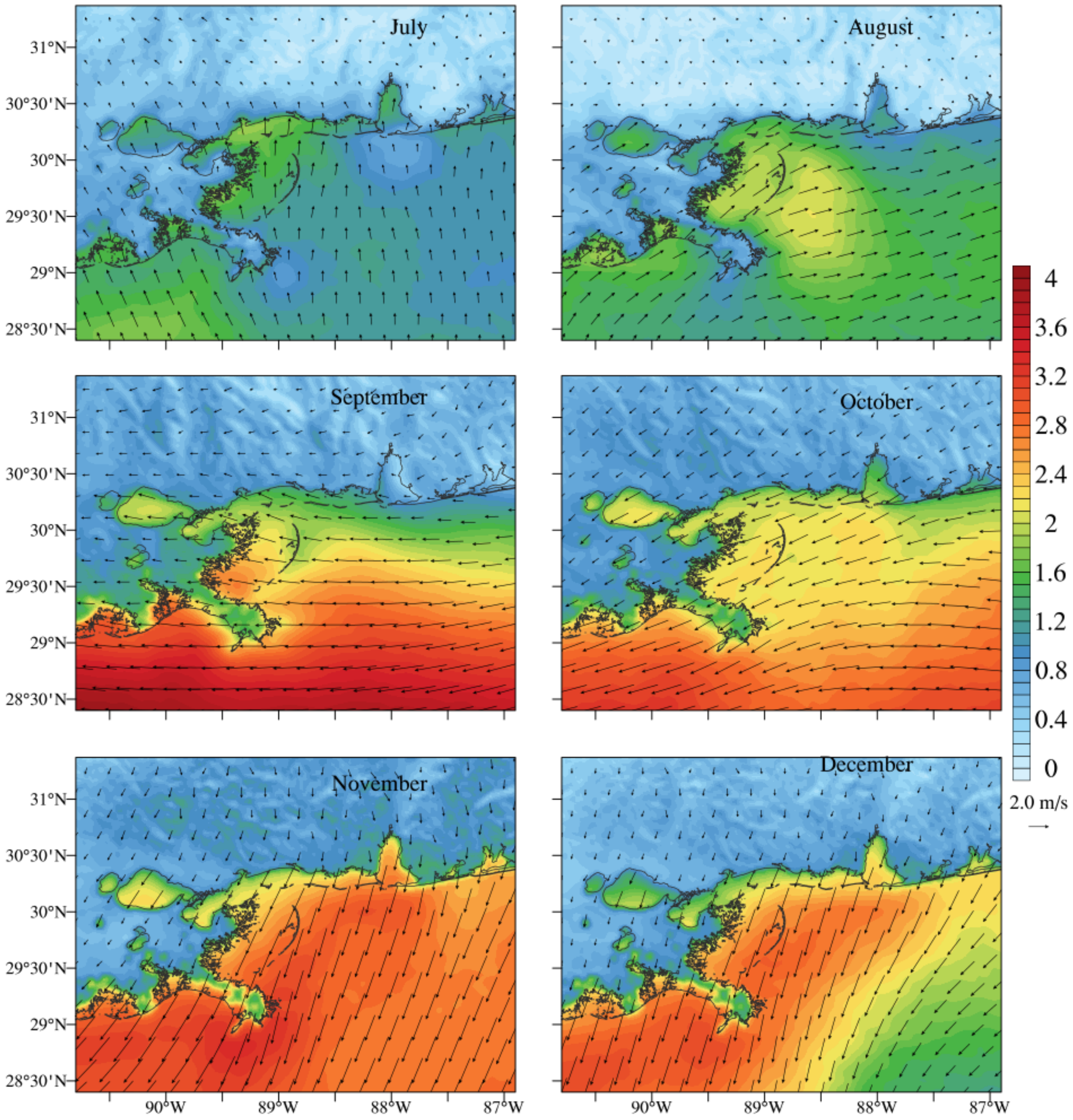


Figure 8. Spatial pattern of monthly mean wind distribution over the study region estimated from HRRR for the year 2019. Wind speed (m/s) is indicated by the colored field and the scaled wind vectors reveal both wind direction and magnitude for July to December .

Lateral Boundary Conditions

A regional 1-km resolution application of the Navy Coastal Ocean Model (NCOM) to the Gulf of Mexico (Martin, 2000, Barron et al., 2006) is used as the source of three-hourly current velocity, salinity, temperature, and water level (tides) that are used as open boundary forcing for the 2019 hindcast scenarios (Table 1). Examples of these lateral boundary condition data that are applied to the open model boundary along its southern and eastern flanks (Figure 5) are provided in the appendix (Figures A23-A28). With this setup, our COAWST application is effectively acting as a nest within the NCOM model. The decision to design our model domain in this fashion was to leverage the NCOM model for capturing MS River plume influences from the inflows around the portions of the Birdfoot Delta not modeled explicitly. These inflows to the Northern Gulf of Mexico region can be subject to interaction with dynamical features offshore, such as the Loop Current and Loop Current Eddies, that may entrain and advect MS River water in plumes that extend into the open Gulf waters and in some cases may retroflect back on to the MS Bight (Schiller et al., 2011; Jones & Wiggert, 2015). To maintain consistency with the NCOM model, the three MS River inflows within our model domain along the northeastern side of the Birdfoot Delta that flow directly in the western MS Bight (Figure 5) are set to discharge 10%, 12.5% and 10% of the total MS River discharge at Belle Chasse. This total percentage discharge (32.5%) is consistent with the partitioning of discharge through passes and channel diversions along the lower Mississippi River reported by Allison et al. (2012). Nesting within NCOM allows for capturing the hydrodynamic impact of instances where retroflected offshore plume waters or lower MS River discharge through the other Birdfoot Delta outflows advect into the msbCOAWST domain and enables our model application to be focused on more finely resolved shelf to shore exchange mechanisms.

River Forcing

Discharge values (Figure 9) are collected from USGS river gauges available through the National Water Information System (USGS, 2021). River temperature values are extracted using the Group for high resolution sea surface temperature (GHRSST) obtained from the NASA Physical Oceanography Distributed Active Archive Center (Chin et al, 2017). Salinity for all river sources is set to zero. Rivers included in the model: Styx, Wolf Creek, Perdido, Fish, Magnolia, Tensaw, Mobile, Chickasaw, Fowl, Black Creek, Red Creek, Pascagoula, Biloxi, Wolf, Jourdan, East Pearl, West Pearl, Tchefuncte, Tangipahoa, Tickfaw, Amite, Blind, MSR Baptist Collette Bayou, MSR Cubit's Gap Pass, and MSR Pass-a-Loutre (Table A1, Figure 5). Bonnet Carré Spillway discharge data are provided by the United States Army Corps of Engineers (United States Army Corps of Engineers, 2021).

Initial Conditions and Tides

The 2019 runs were forced with interpolated NCOM 1 km spatial resolution sea surface height as tidal forcing on the boundary (Figure A25). Initial conditions for the spin-up period (December 1 to 31 2018) were obtained from the 2018 msbCOAWST realistic hindcast run. This spin-up period was necessary to ensure a realistic initial condition for Lake Pontchartrain.

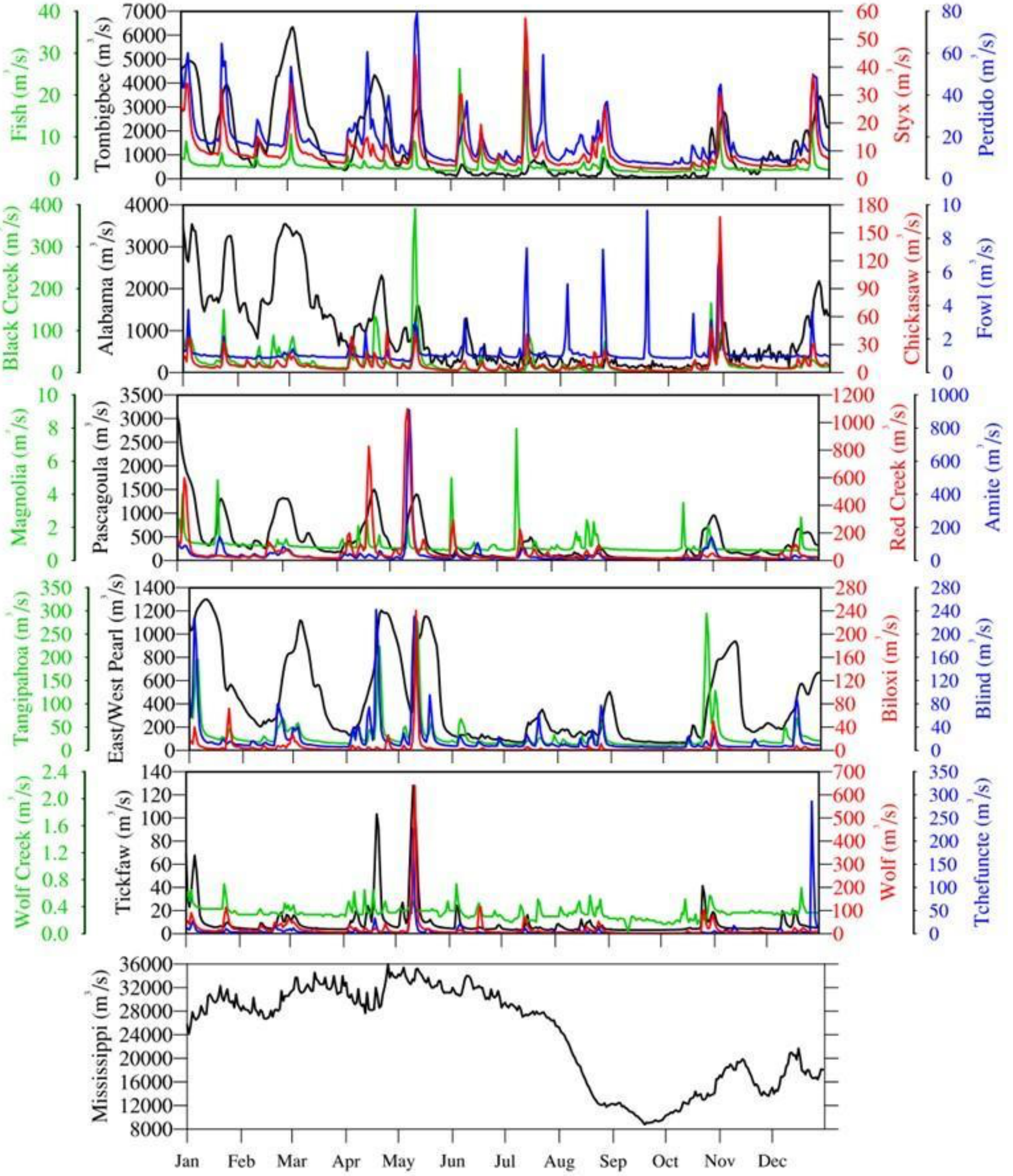


Figure 9. Daily river discharge (m^3 s^{-1}) included in the model for hindcast simulation for the year 2019.

Climatological Forcing Data

A climatological ocean model simulation is carried out to obtain a model solution that represents a typical annual evolution of currents, temperature and salinity within the study region. To obtain this solution, climatological forcings (atmospheric, lateral boundary and river) are determined and applied to drive the model. In this case, an eleven-year period (2010-2020) has been defined for developing the climatological forcing fields. Table 3 provides a summary of source information for the data sets accessed to develop the climatological forcing fields, the details of which are provided in the sections that follow.

Table 3. Source information for the model forcing parameters applied in performing the climatological simulations.

Model Forcing	Provider	Spatial Resolution	Temporal Resolution	Reference and Web Link (if available)
River Forcing	USGS Stream Gage Data	point data	daily averages	U.S. Geological Survey, 2021 http://waterdata.usgs.gov/nwis
River Temperature	Group for High Resolution Sea Surface Temperature (GHRSST)	6 km 0.05 degree	daily averages	Govekar et. al., 2022 https://opendap.jpl.nasa.gov/opendap/allData/ghrsst/
Atmospheric Forcing	North American Regional Reanalysis (NARR)	32 km	3 hourly	Mesinger et al., 2006 ftp://ftp.cdc.noaa.gov/Datasets/NARR/
Open Boundary Conditions	Navy Coastal Ocean Model - Gulf of Mexico (NCOM - GOM) regional model	1 km	3 hourly	Jacobs et al. (2016) Jacobs (2017)
	NCOM - American Seas (NCOM - AMSEAS)	3 km	3 hourly	Zaron et al. (2015) https://www.ncei.noaa.gov/thredds-coastal/dodsC/

Climatological Atmospheric Forcing

At the surface, the ocean model is forced with three-hourly climatology of meteorological parameters obtained from the North American Regional Reanalysis (NARR) (Mesinger et al. 2006) data sets, including zonal and meridional winds, heat fluxes, precipitation, humidity, air temperature, and surface atmospheric pressure. NARR is a regional reanalysis product with assimilation of observational data using National Centers for Environmental Prediction/Department of Energy (NCEP/DOE) reanalysis (Kanamitsu et al., 2002). The atmospheric variables obtained from NARR have a horizontal resolution of approximately 0.3 degrees (~32km). The spatial pattern of climatological monthly mean surface winds over the model domain is shown in Figures 10 and 11. It can be seen from the figures that the surface wind pattern exhibits strong seasonality over this region. The wind direction during October-January features a northerly component, while wind direction during April-August features a southerly component. The intervening periods, February / March and September, are transitional states with dominant easterly wind components.

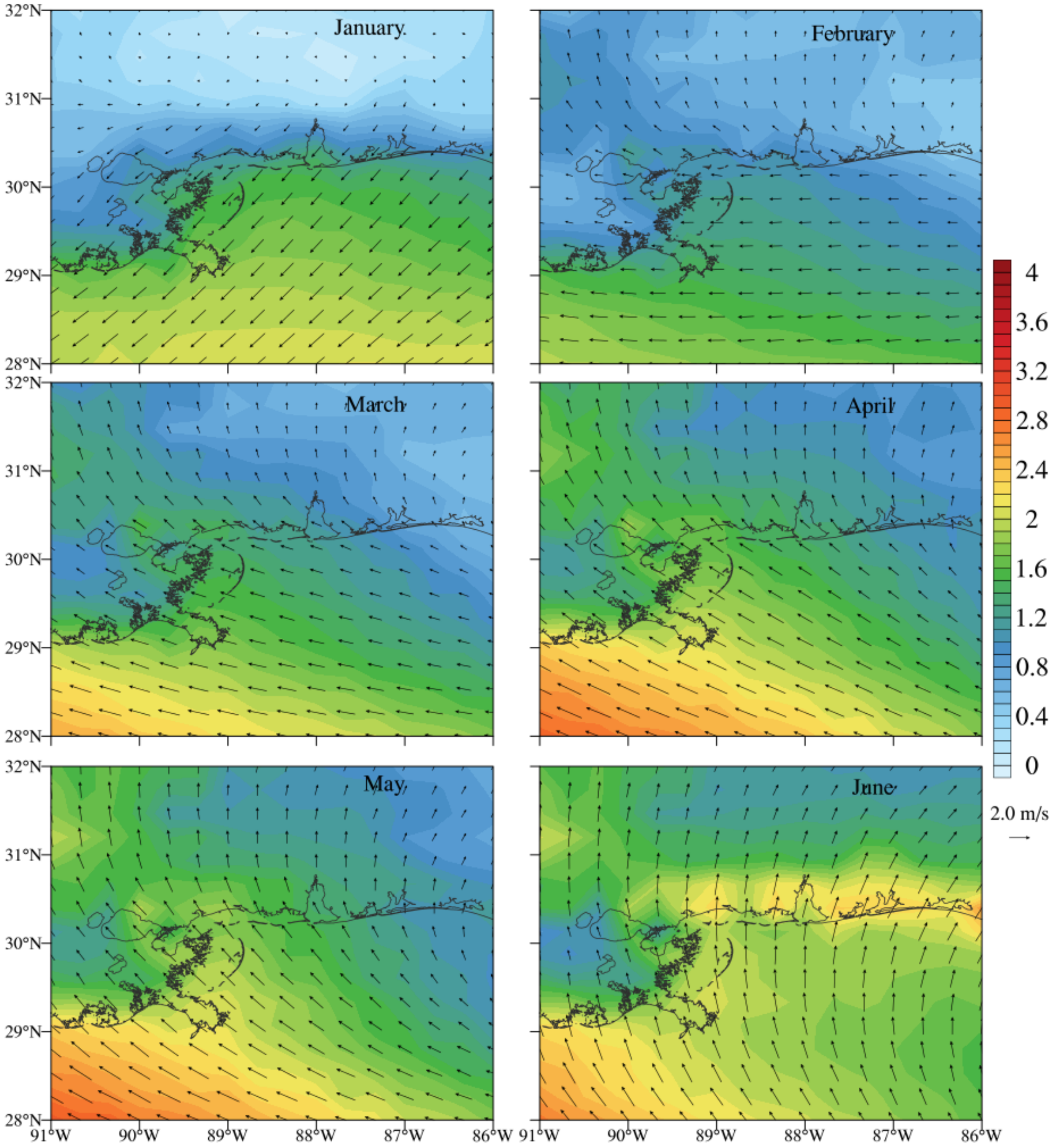


Figure 10. Spatial pattern of climatological (2010-2020) monthly mean wind distribution over the study region estimated from NARR. Wind speed (m/s) is indicated by the colored field and the scaled wind vectors reveal both wind direction and magnitude for January to June (Contd). The spatial resolution of the NARR wind field is 32 km, which is represented by the spacing of the wind vectors.

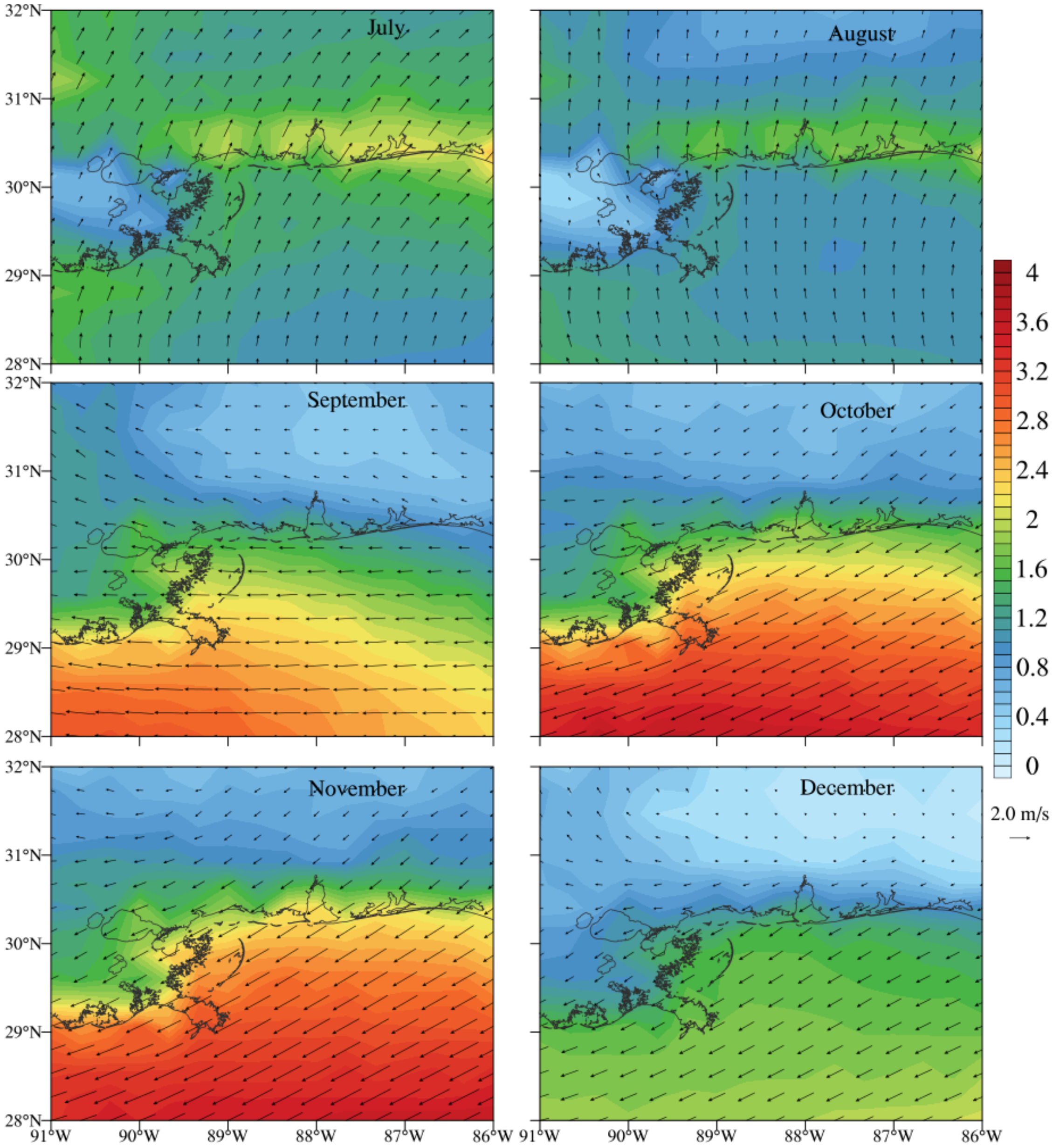


Figure 11. Spatial pattern of climatological (2010-2020) monthly mean wind distribution over the study region estimated from NARR. The Wind speed (m/s) is indicated by the colored field and the scaled wind vectors reveal both wind direction and magnitude for July to December. The spatial resolution of the NARR wind field is 32 km, which is represented by the spacing of the wind vectors.

Climatological Lateral Boundary Conditions

At the lateral boundaries, the three-hourly climatology of temperature, salinity, velocity components, and surface height data are provided. These boundary variables are obtained from two variants of the Navy Coastal Ocean Model (NCOM; Barron et al., 2004; 2006) regional applications. The first one is denoted as NCOM-GOM, which is a high-resolution implementation of NCOM configured over the entire Gulf of Mexico with a horizontal spacing of 1 km. The second one is NCOM-AMSEAS which encompasses the American Seas region covering the Gulf of Mexico and the Caribbean Sea with a horizontal resolution of approximately 3 km (Zaron et al., 2015). The boundary condition parameters are extracted from these two model simulations based on the availability of data for the 11-year period of interest.

Climatological River Forcing

The daily river discharge data are obtained from the USGS gauge stations for the rivers draining into the model domain. The daily climatological riverine freshwater input at each of these stations are estimated after filtering out the discharge values greater than the mean value plus three standard deviation margin for each day of the year. This method is utilized for filtering out the abnormally high discharge events that happened through the time period and thus to obtain a smooth discharge curve for each river. Figure A2 in the appendix illustrates the impact of the various filtering applications that were tested prior to establishing the three standard deviation method as our standard filtering implementation. The daily climatology of river discharge included in the model for climatological simulations is shown in Figure 12. It can be seen from the figures that most of the rivers have maximum discharge during the spring season and minimum during September-November.

The list of USGS gauge stations accessed for developing the river forcing climatology, including their USGS identifier and full naming convention, is provided in Table A1. The full set of river flow time series used in developing the climatological river forcing (Fig. 12) are provided in the appendix (Figs. A1 - A 22). Further detail on the methods applied for generating the climatological river time series is also provided in the appendix.

Climatological Initial Conditions and Tides

The Climatological run was forced with NCOM-AMSEAS tides on the boundary. December 2019 tides were used during the one-month model spin-up and 2020 tides were used for the year-long climatological run. Initial conditions for the spin-up period (December 1 to 31 2019), were from the 2019 msbCOAWST realistic hindcast run.

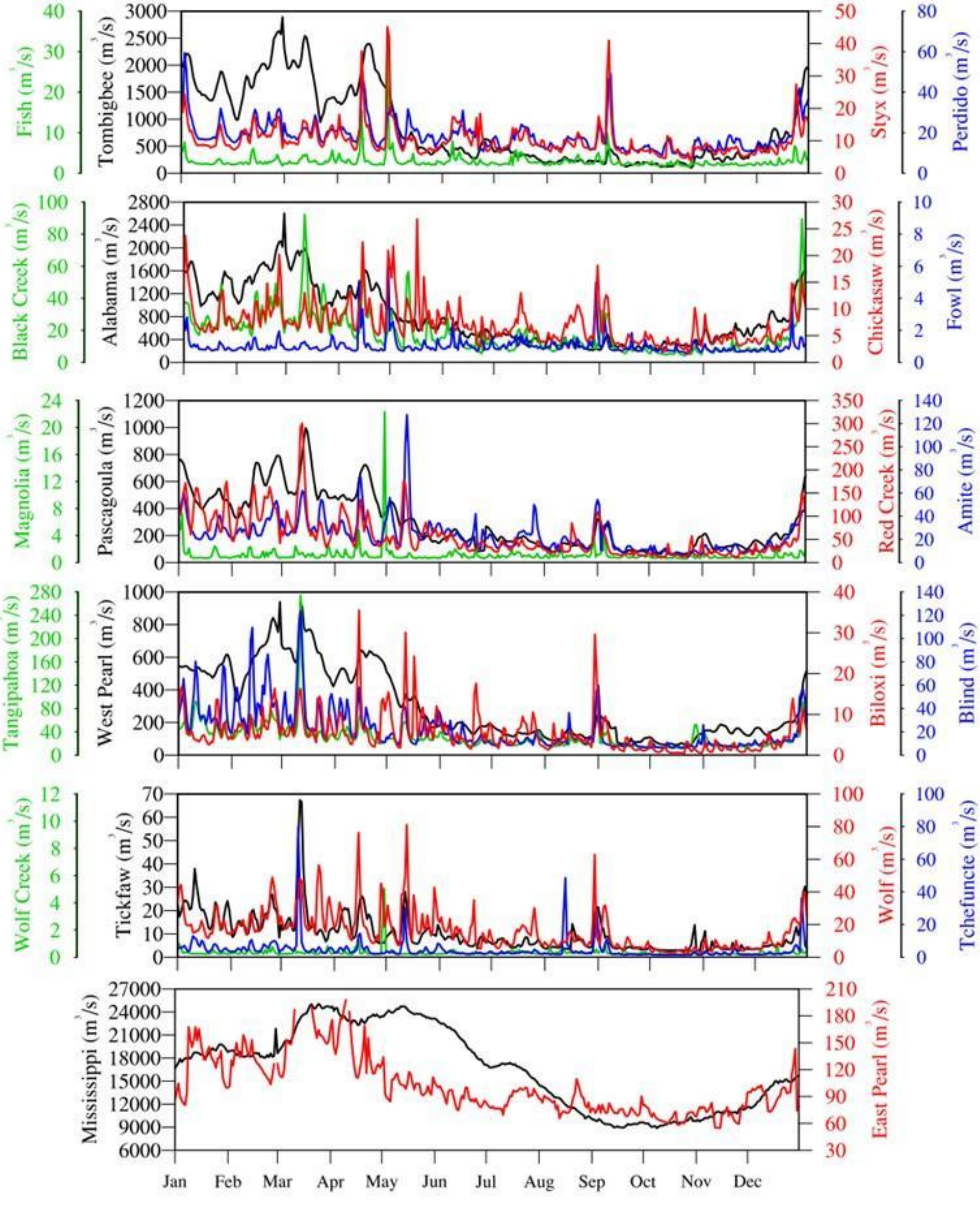


Figure 12. Daily climatology of river discharge (m^3 s^{-1}) included in the model for climatological (i.e. typical river discharge) simulations.

Mid-Breton Sediment Diversion Discharge

Calculations are based on operational parameters as described in the Character of Work in the Joint Public Notice issued March 18, 2019 by the United States Army Corps of Engineers New Orleans District and the State of Louisiana Department of Environmental Quality Water Permits Division:

"Operation: The proposed Mid-Breton SD is considered to be a large scale, complex ecosystem restoration project that would operate at a base flow of 5,000 cubic feet per second (CFS); when the Mississippi River gage at Belle Chasse exceeds 450,000 cfs the diversion structure would "open" and operate at varying cfs volumes based on water levels in the Mississippi River channel. Maximum discharge would be 75,000 cfs when the Belle Chasse gauge is at 1,000,000 cfs. The proposed Mid-Breton SD would be designed in a manner that would allow the peak discharge to be 75,000 cfs for the 50-year project life." (US Army Corps of Engineers, 2019).

Mid-Breton Sediment Diversion Maximum

The discharge through the MBrSD is set to a maximum capacity of 75,000 cubic feet per second (2,124 m^3s^{-1}) for the length of the BDMAX scenario.

Variable Breton Diversion Discharge

Variable discharge for the Mid-Breton Diversion (BD) was calculated based off of 2019 Mississippi River discharge (dMSR19) or climatological Mississippi River discharge (dMSRCLIM) in cubic feet per second at the Belle Chasse USGS station (USGS, 2021) for the BDVAR and BDCLIM scenarios, respectively. The Belle Chasse station (yellow circle, Figure 5) is downstream from the Bonnet Carré spillway, so discharge accounts for water released through the spillway in 2019. Water discharged through the MBrSD in our numerical experiments was not removed from Mississippi River discharge at Belle Chasse (MSRD) to enable a direct comparison with scenarios not including MBrSD discharge. In this variable scenario there is always discharge through the diversion (D_{BD}), with a minimum (5,000 cfs, or 142 m^3s^{-1}) and maximum (75,000 cfs, or 2,124 m^3s^{-1}) discharge based on lower (450 kcfs) and upper (1,000 kcfs) limits for MSRD, and varying with the river discharge in between these thresholds.

Variable discharge for the BD was calculated as follows:

If MSRD < 450,000 cfs then D_{BD}= 5,000 cfs

If MSRD>1,000,000 cfs then D_{BD}= 75,000 cfs

If 450,000 cfs < MSRD < 1,000,000 cfs then

$$D_{BD} \quad = 5000cfs + \frac{(MSRD \; - \; 450{,}000cfs)}{(1{,}000{,}000cfs - 450{,}000cfs)} x(70{,}000cfs)$$

The resulting variable discharge time series of the MBrSD for 2019 (dBD19) and climatological (dBDCLIM) scenarios, based on dMSR19 and dMSRCLIM, respectively, are shown in Figure 13.

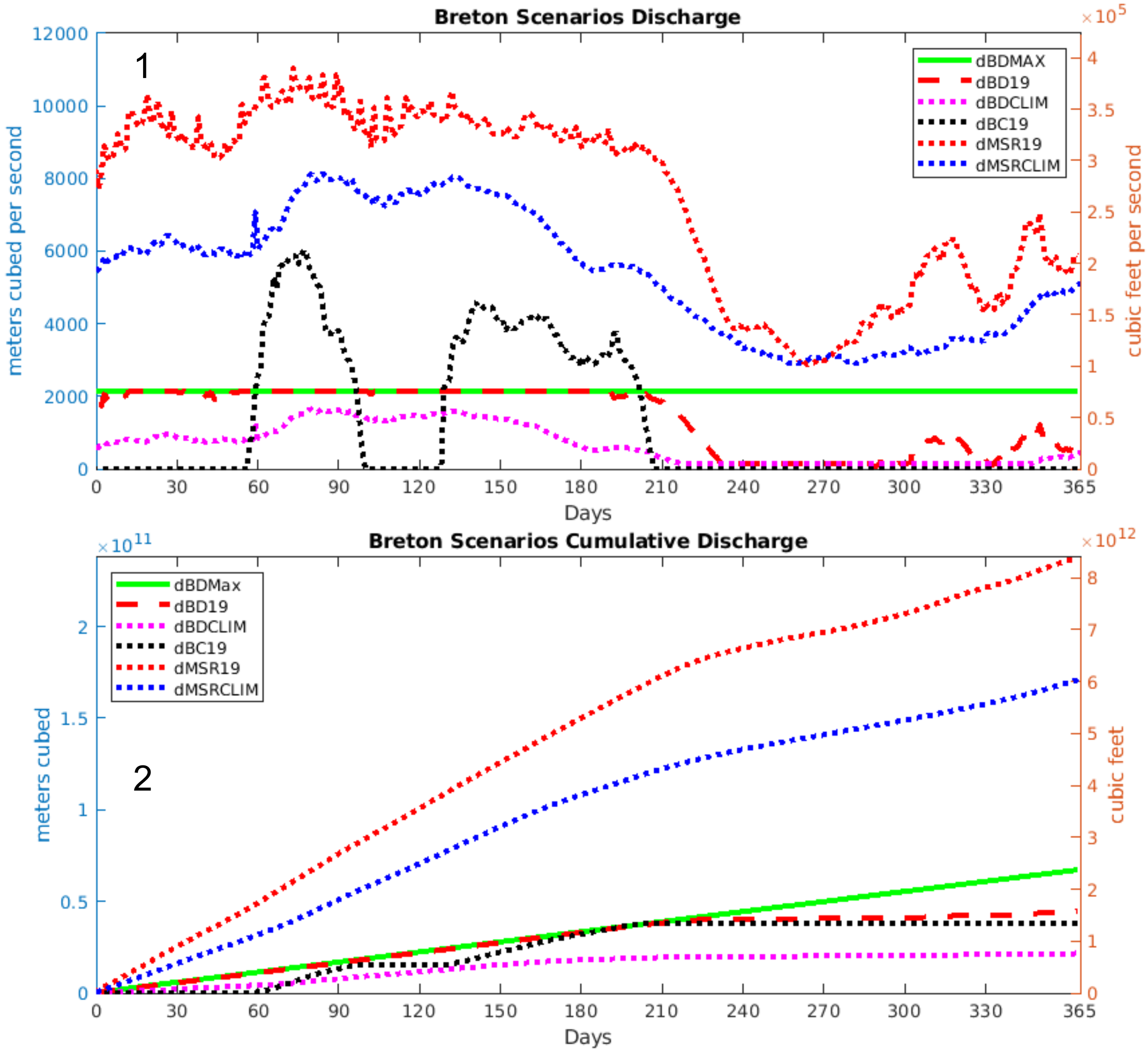


Figure 13. Daily Mississippi river, Breton Diversion, and Bonnet Carré Spillway transport (1) and cumulative discharge (2) included in the model for hindcast simulations and scenarios for the year 2019 and Climatological scenarios. Mississippi River (dMSR19 and dMSRCLIM) time series shown here only account for river discharge within the model domain and not the total Mississippi River discharge (i.e., discharge along SW side of Birdfoot Delta is not represented). Maximum Breton Diversion Transport is 75,000 cubic feet per second (cfs) or 2124 cubic meters per second. Forcing abbreviations are as follows: maximum discharge for Breton Diversion (dBDMAX), variable discharge for Breton Diversion in 2019 (dBD19 as used in the BCBDVAR scenario), variable discharge for Breton Diversion based on climatology (dBDCLIM), discharge for the Bonnet Carré Spillway in 2019 (dBC19), discharge for the Mississippi River in 2019 (dMSR19), and discharge for the Mississippi River in the climatological scenario (dMSRCLIM).

Methods: Tracer Experiments

Passive tracer releases in the model experiments are used to isolate and track freshwater sources in several model runs (Table 1). Tracer is introduced at river forcing locations in all 24 vertical levels at a concentration of 1. Tracer continuously enters the model domain from river sources when river water is flowing into the model. Tracer can leave the model domain through the open boundaries on the south and east side of the model domain. Employing passive tracer releases allows us to track specific freshwater sources of interest throughout a numerical experiment. This technique also allows us to identify a specific water source when two freshwater sources are interacting, such as how MBrSD discharge could influence the propagation of Mississippi River waters that source from the BCS or Birdfoot Delta.

Methods: Analysis Tools

Salinity can be used to track freshwater plumes within the msbCOAWST model by using a simple twin experiment as described earlier in the "Methods: Model Application Scenarios" section. Bottom salinity, in particular, is an important factor that can be used for assessing habitat suitability index (HSI) for key species (e.g., oysters). Such HSI assessments have been one focal point for our group, as part of our investigations into the identification of suitable restoration locations for eastern oyster (*Crassostrea virginica*) reefs in MSS. Prolonged freshwater exposure can result in pervasive shellfish mortalities, as seen in the MSS following the 2011 and 2019 BCS openings (Pace et. al., 2020). A bottom salinity of 5 ppt has been identified as a stress point for oyster populations in models to assess coastal ecosystem health (Ahn and Ronan, 2020). In the model-based study presented here, daily average bottom salinity is examined to determine the geographic extent and severity of freshwater impacts during each of the targeted scenarios detailed in Table 1.

At each model grid point, a time series was created to track cumulative and consecutive days when bottom salinity is less than 5 ppt. These two metrics are defined below and illustrated in Figure 14-1. Note that in the figure, the boxes are representing a single model grid point.

1) Cumulative day count continuously increases. Within a given month, the number of cumulative days at the beginning of the month is subtracted from the cumulative days at the end of the month to obtain the cumulative days for the month, which will be less than or equal to the total days in the month.
2) Consecutive day count will continue to increment until the salinity rises above 5 ppt, at which point the count resets to zero. Within a given month, there may be several periods of consecutive days with salinity below 5 ppt. The maximum consecutive days for the month would be the longest of these periods. There can also be instances of persistent low salinity for which the consecutive day count extends across multiple months. Depending on the circumstances, subtracting the value at the beginning of the month from the value at the end of the month can provide a meaningless value.

It should be recognized that these conceptual definitions apply to a single model grid point and result in integer values. Within prescribed regions of interest (Figure 14-2), an average (non-integer) value for cumulative days or consecutive days is obtained for the grid points within that spatial domain.

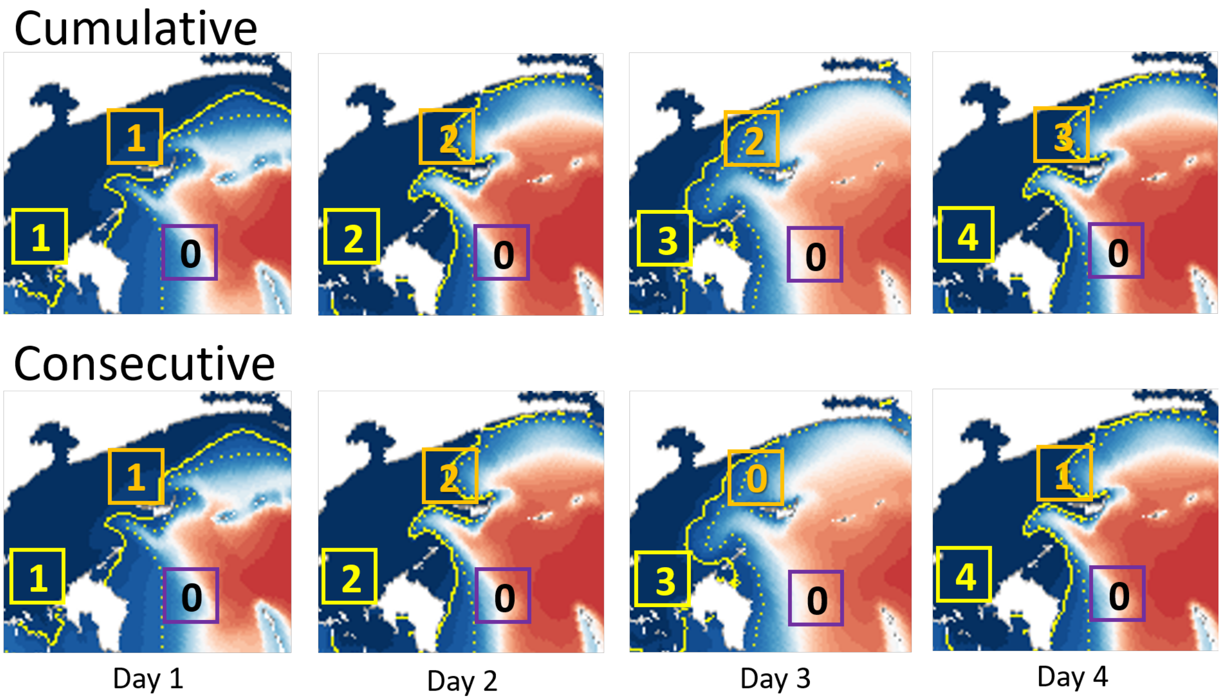


Figure 14-1. Four sequential daily average bottom salinity distributions from the model are shown. The solid and dashed isolines delineate salinity values of 2 ppt and 5 ppt respectively. The numbers in the three box locations illustrate how cumulative time series (top row) and consecutive time series (bottom row) for salinity < 5 ppt are determined for each model grid cell.

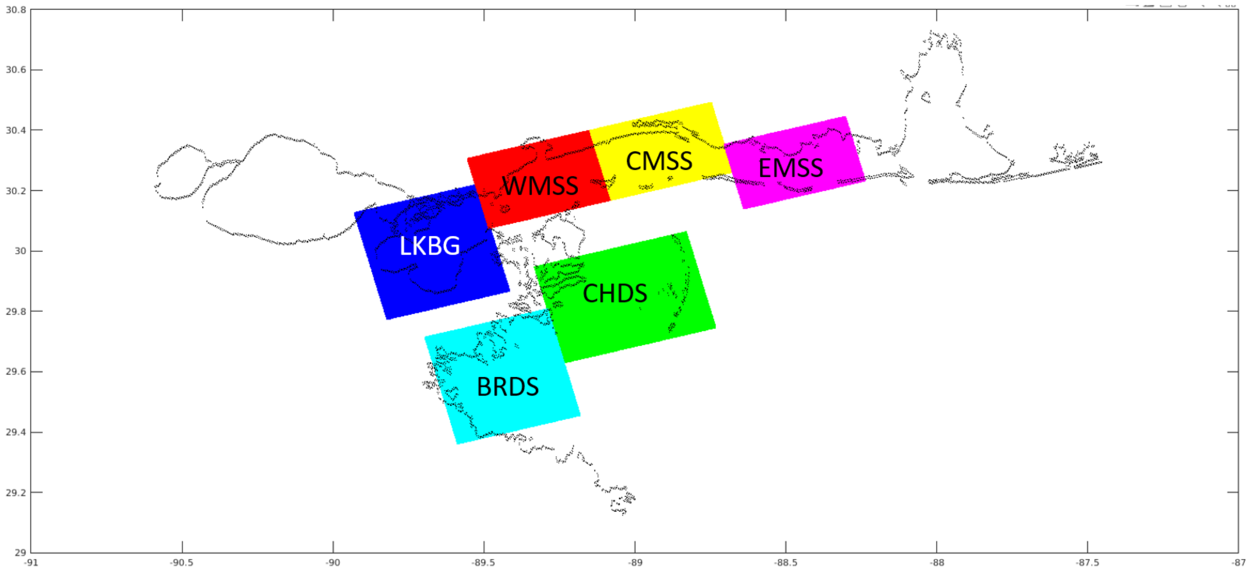


Figure 14-2. Bounding boxes used to calculate area statistics for salinity. Abbreviations are as follows for the six ROIs: LKBG=Lake Borgne, WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, EMSS=Eastern Mississippi Sound, CHDS=Chandeleur Sound, and BRDS =Breton Diversion/Sound.

Six specific regions of interest (ROI), which encompass areas that demonstrate sensitivity to environmental perturbations (e.g., winds, freshwater) in our past modeling studies, have been defined. These are used to systematically reveal average changes in salinity over monthly time periods for each of the model scenarios (Figure 14-2). These ROIs are as follows: LKBG=Lake Borgne, WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, EMSS=Eastern Mississippi Sound, CHDS=Chandeleur Sound, and BRDS =Breton Diversion/Sound.

Table 4. Definition of Twin Experiment pairs that are referenced herein. Abbreviations: Rivers Only (RO), Bonnet Carré (BC), Breton Diversion (BD), maximum discharge for the mid-Breton Diversion (MAX), variable discharge (based on MSR level) for the mid-Breton Diversion (VAR), climatological forcing (CLIM).

	Difference	**Objective**
Climatological Twin Experiment		
Climatology Difference	BDCLIM - CLIM	Enables tracking of variable MBrSD influence on water movement and physical properties under a climatological scenario when BCS is not active
2019 Twin Experiments		
BCBDVAR Difference	BCBDVAR - BC	Enables tracking of variable MBrSD (BDVAR) influence on water movement and physical properties when BCS is active
BD difference	BCBDVAR - BDMAX	Enables tracking of MBrSD influence on water movement and physical properties when the BCS is active
BC difference	BC - RO	Enables tracking of BCS influence on water movement and physical properties when MBrSD is not active
BCBD difference	(BCBDVAR - BDMAX) - (BC - RO)	When BDMAX=BDVAR during the BCS opening, this twin experiment reveals BDMAX influence on BC water movement and physical properties during the BCS opening
BDMAX Difference	BD MAX - RO	Enables tracking of maximum MBrSD (BDMAX) influence on water movement and physical properties when BCS is not active

Breton Diversion Impact on Salinity: Climatological Scenario

In the climatological twin experiment comparing CLIM to BDCLIM, which isolates the climatological MBrSD impact (dBDCLIM, Figure 13-1), bottom and surface average monthly salinity plots using the ROI bounding boxes defined in Figure 14-2 consistently reveal an overall seasonality of freshening in Mississippi Sound through April associated with the Spring freshet, and increasing salinity from May through August (Figures 15-1, 15-2, 17-1 and 17-2). From September through November, there is not a consistent trend, with increasing salinity in the CMSS and EMSS ROIs and freshening in the WMSS ROI; this pattern is apparent in both bottom and surface waters (Figures 15-1, 15-2, 17-1 and 17-2). From August to September there is a consistent freshening at all locations and depths, which reflects the short duration peak in climatological riverine flow (Figure 12). In the CLIM solution, bottom salinity is always below 5 ppt in the LKBG ROI and always greater than 5 ppt across the three MSS ROIs (Figure 15-2). These characteristics are also apparent in the BDCLIM solution with active MBrSD, except in the WMSS ROI where bottom salinity falls below 5 ppt for January through June (Figure 15-1). The WMSS ROI sensitivity to MBrSD influence is also apparent in the monthly salinity differences, where the most prominent freshening instances occur from January through July for the four ROIs shown (LKBG, WMSS, CMSS, EMSS; Figure 15-3). The pronounced freshening of bottom waters across these four ROIs during the March - July period, coincides with persistent easterly to southeasterly winds (Figures 10 and 11)

Across all six ROIs, the monthly salinity differences from the climatological twin experiment shows freshening in bottom waters throughout the year when the MBrSD is active, except for EMSS in winter (December - February) and WMSS in the fall (October - November) (Figure 16-1). It is also worth noting that while the BRDS ROI is consistently subject to elevated freshening relative to the other ROIs in the climatological bottom salinity differences, the largest difference occurs for the WMSS ROI in June (Figure 16-1). In surface waters, WMSS salinity decreases when the MBrSD is active in 7 out of 12 months of the year (February, April - September), in CMSS for 5 out of 12 months (May - September) and in EMSS for 4 out of 12 months (July - October; Figure 17-3).

Breton Diversion Impact on Salinity: 2019 Realistic Scenario

The twin experiment comparing BC to BCBDVAR, which isolates the variable MBrSD impact (dBD19, Figure 13-1), is the only twin experiment that includes both the BCS and MBrSD discharge. The general seasonal trend noted for climatological bottom salinities is also apparent in these 2019 model experiments that include the BCS, though the minimum salinity condition occurs in May rather than April because of the stronger than climatological winds of May 2019 (Figure 15, panels 4 & 5). Comparing the salinity differences caused by BCS in scenarios with and without active MBrSD (BCBDVAR and BC, respectively), we see that the influence of MBrSD waters leads to a consistent freshening of bottom waters (LKBG, WMSS, CMSS and EMSS ROIs) during months of BCS operations (February thru July) with a more pronounced decrease in salinity in LKBG and WMSS in February and March of 2019 (Figure 15-6). After an initial freshening from January through March in LKBG and WMSS, caused by MBrSD waters preventing the movement of BCS and Pearl River waters further south, the salinity in LKBG and the rest of the MSS remains fresher but only slightly until Fall, then the difference in salinity is sometimes positive (i.e., saltier) in the WMSS and CMSS from September through December (Figures 15-2 & 17-2).

Breton Diversion Impact on Salinity: 2019 Maximum Scenario

In the twin experiment comparing RO to BDMAX, which isolates the maximum MBrSD impact (dBDMAX, Figure 13-1), strong southerly winds during May, June, and July (Figures 7 and 8) combined with low local river influx in June and July (Figure 9) result in MBrSD waters reaching WMSS and Biloxi Marsh. For both bottom and surface salinities for this twin experiment, the consistent freshening trend through May across all ROIs in MSS, seen in the other two scenarios, no longer holds (Figure 15, panels 7 & 8; Figure 17, panels 7 & 8). In particular, in February bottom waters in WMSS and surface waters across the Sound exhibit higher salinities than in January. Further, in contrast to the other two twin experiments, from January through April the monthly salinity difference plots reveal that the MBrSD leads to saltier conditions in the WMSS (both surface and bottom) and saltier surface waters in the CMSS (Figs. 15-9 & 17-9). Like the other twin experiments, the active MBrSD acts to freshen both bottom and surface salinity in MSS from June through September (Figs. 15-9, 16-3, 17-9). The maximum difference between the BDMAX and RO experiments (i.e., inclusion of MBrSD discharge has resulted in lower salinities) in monthly averaged bottom salinity in the MSS takes place in June and July in the WMSS (Figure 15-9). These tendencies during the June through September time frames are also apparent in the monthly averaged surface salinities, and generally exhibit more pronounced freshening impact (Fig. 17-9).

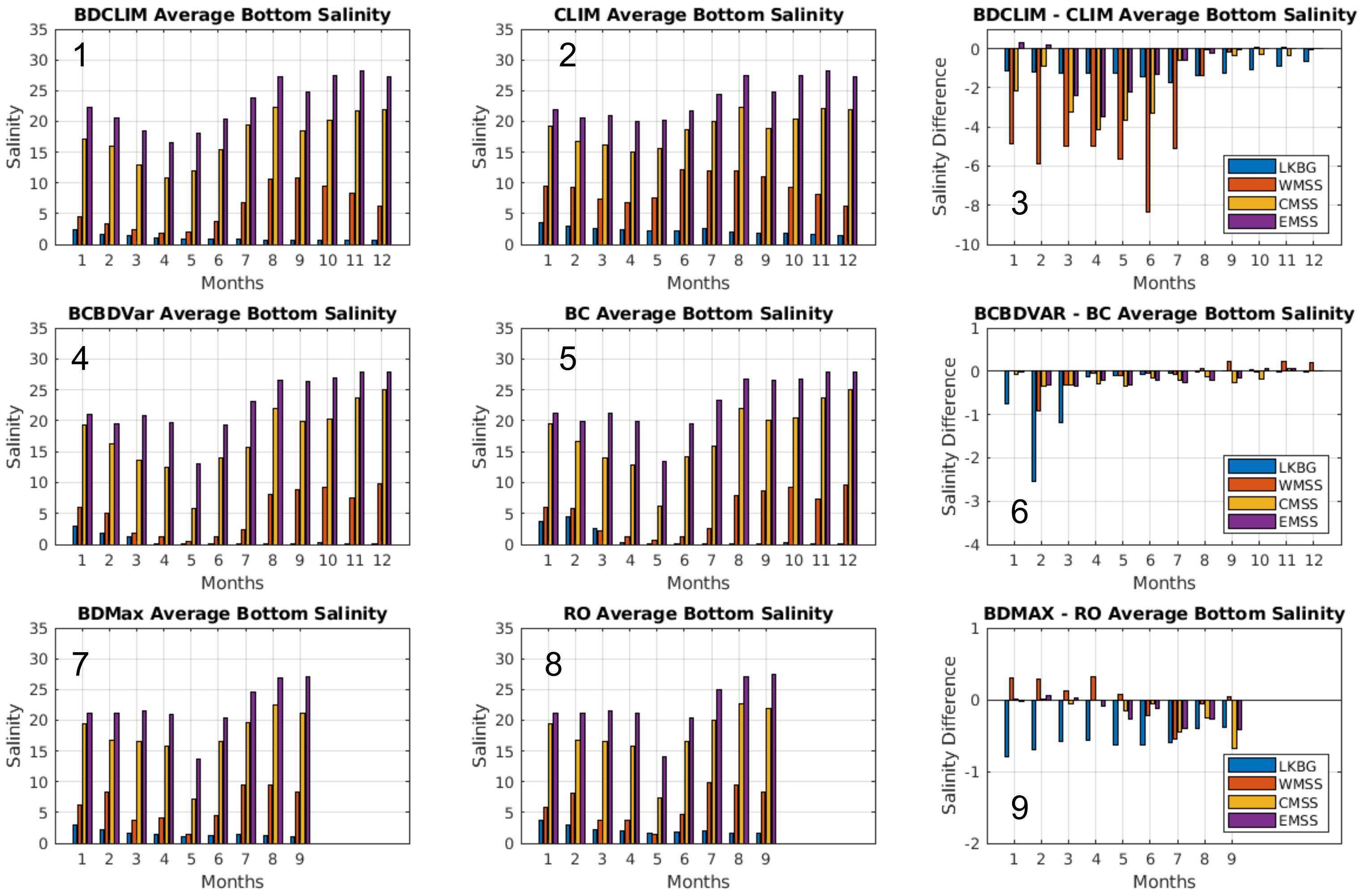


Figure 15. Monthly average bottom salinity and differences (across twin experiments) in monthly averages of bottom salinity for ROIs defined in figure 14-2. For the plots in the third column, the scenario without the Mid-Breton Diversion discharge is subtracted from the scenario containing the Mid-Breton Diversion discharge (Table 1) resulting in: Climatology Difference (BDCLIM-CLIM, panel 3), BCBDVAR Difference (BCBDVAR-BC, panel 6) and BDMAX Difference (BDMAX-RO, panel 9). Negative values in column three indicate fresher conditions associated with active MBrSD. Abbreviations are as follows: LKBG=Lake Borgne, WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, EMSS=Eastern Mississippi Sound.

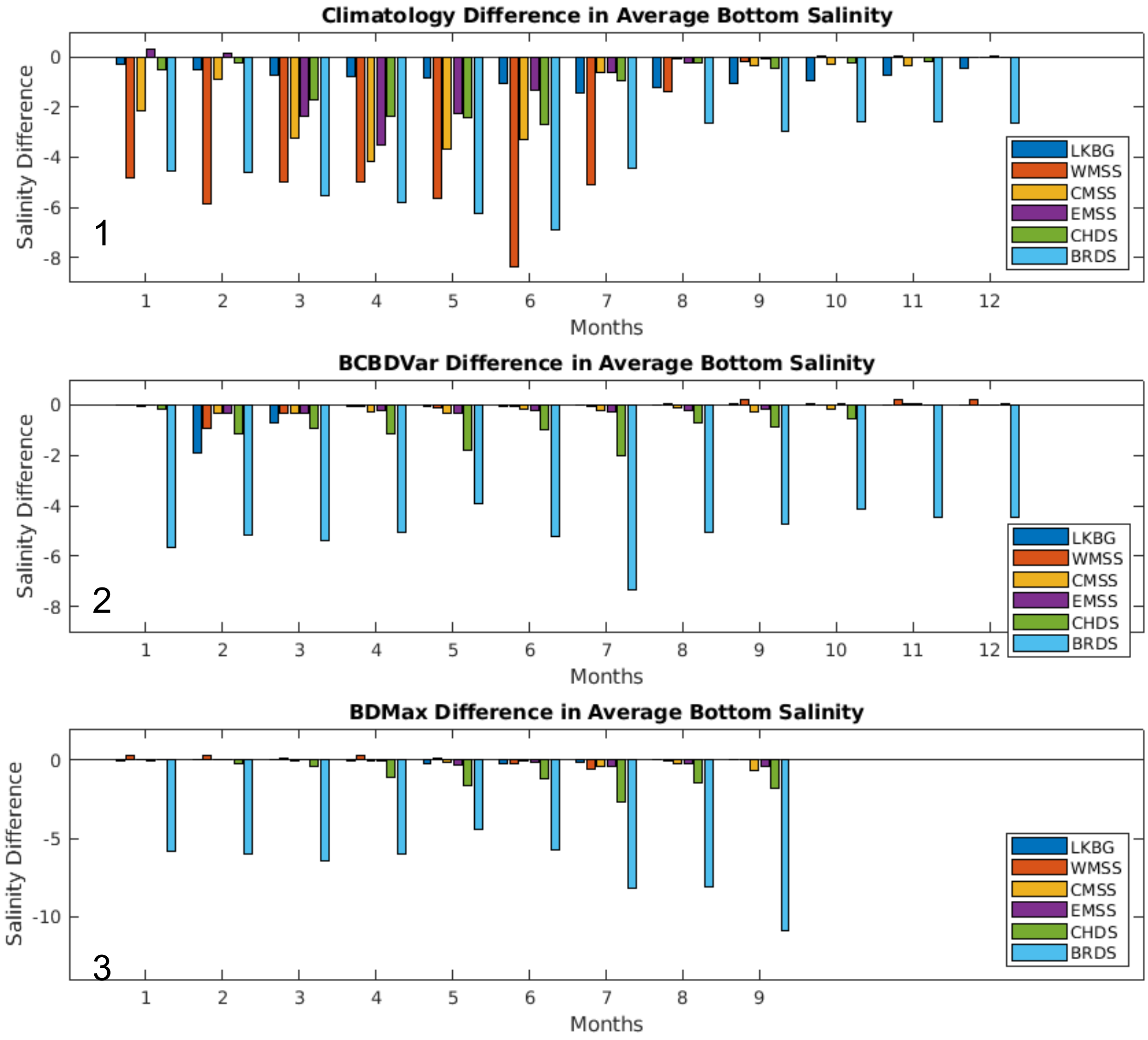


Figure 16. Differences (across twin experiments) in monthly averages of bottom salinity for each of the areas defined in figure 14-2. In each plot, the scenario without the Mid-Breton Diversion discharge is subtracted from the scenario containing the Mid-Breton Diversion discharge (Table 1) resulting in:Climatology Difference (BDCLIM-CLIM, panel 1), BCBDVAR Difference (BCBDVAR-BC, panel 2) and BDMAX Difference (BDMAX-RO, panel 3). Negative values indicate fresher conditions associated with active MBrSD. Abbreviations are as follows: LKBG=Lake Borgne, WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, EMSS=Eastern Mississippi Sound, CHDS=Chandeleur Sound, and BRDS =Breton Diversion/Sound. This plot is identical to the third column of Figure 15, but with the two areas exhibiting highest salinity differences (BRDS, CHDS) included.

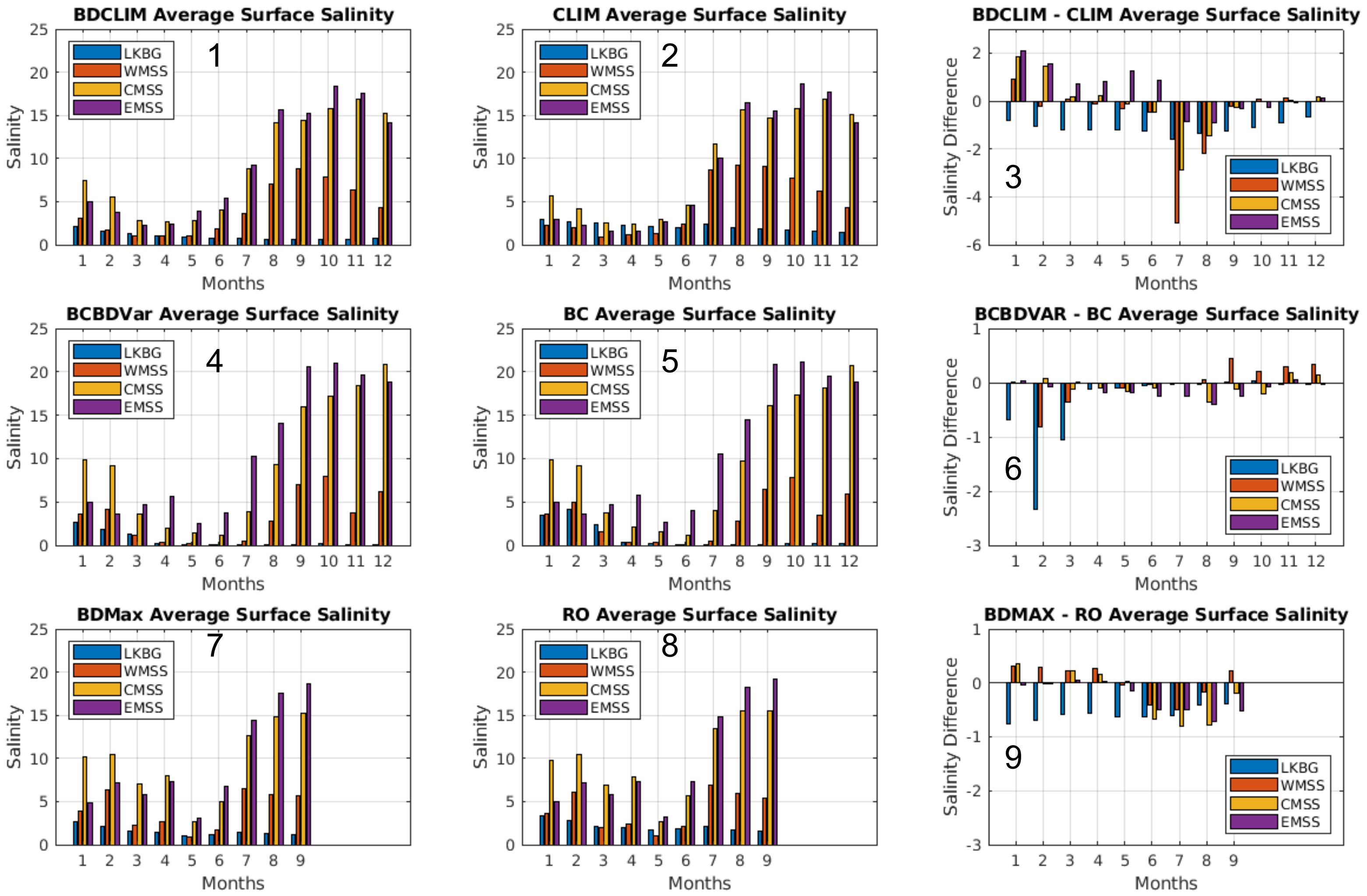


Figure 17. Monthly averages of surface salinity and differences (across twin experiments) in monthly averages of surface salinity for ROIs defined in figure 14-2. For the plots in the third column, the scenario without the Mid-Breton Diversion discharge is subtracted from the scenario containing the Mid-Breton Diversion discharge (Table 1) resulting in: Climatology Difference (BDCLIM-CLIM, panel 3), BCBDVAR Difference (BCBDVAR-BC, panel 6) and BDMAX Difference (BDMAX-RO, panel 9). Negative values in column three indicate fresher conditions associated with active MBrSD. Abbreviations are as follows: LKBG=Lake Borgne, WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, EMSS=Eastern Mississippi Sound.

Summary of Breton Diversion Impacts: All Scenarios

A comparison of average bottom salinity using the ROI bounding boxes defined in Figure 14-2 reveals that the largest differences due to the introduction of MBrSD freshwater take place in the Western Mississippi Sound (WMSS) and Breton Diversion / Sound (BRDS), where monthly average differences in salinity are up to 8.4 ppt (WMSS; Climatological Scenario) and 10.9 ppt (BRDS; Maximum Scenario) lower than in simulations where the MBrSD is not active (Figure 16). In comparison, the maximum freshening indicated in differences of average bottom salinity for Lake Borgne (LKBG), CMSS, and EMSS areas is less than 4.4 ppt for all scenarios with active MBrSD (Figure 15). Universally across all scenarios, the Breton Sound ROI experiences significant freshening when the MBrSD is active (4-11 except in the Climatological Scenario during August - December; Figure 16).

The salinity in WMSS decreases in all but October and November in the BDCLIM experiment but increases by 0.2 in the latter part of the year for the BCBDVAR experiment (September, November and December, Figure 15-3 & 15-6). During the period when salinities in WMSS see the highest decrease in (between -4.7 and -8.4 in January through July; Figure 15-3), MBrSD discharge (dBDCLIM) is greater than the minimum 142m^3 s^{-1} (5,000 cfs; Figure 13-1) and local river discharge is higher than in the latter part of the year (Figure 12). During the period when salinity increased in the BCBDVAR experiment, MBrSD discharge (dBD19) is less than 1200 m^3 s^{-1} (42,377 cfs; Figure 13-1) and local river discharge into the MSS in 2019 (Figure 9) is lower than in the first half of the year. In contrast, in the BDMax experiment freshening of the Chandeleur Sound, EMSS and CMSS is apparent in the July - September time frame (Figure 16) despite the low river discharge (Figure 9). Further, in the January - April time frame, the WMSS and CMSS tend toward increased salinities (surface and bottom) for the BDMax experiment, which contrasts the results obtained for the BDCLIM and BCBDVAR experiments (Figures 15 and 17).

The monthly average bottom salinity for the three MSS ROIs (WMSS, CMSS, EMSS) and Lake Borgne (LKBG) is generally fresher during the first half of the year (Figure 15). While Central and Eastern MSS bottom salinities remain well above the lower salinity threshold (S=5) for oyster stress, Lake Borgne bottom salinities are well below this threshold. Bottom salinity values in the WMSS ROI are near or below this threshold for at least four months in all but the CLIM experiment during the January - July time frame (Figure 15). During January through June in the BDCLIM experiment and February of the BCBDVAR experiment the introduction of MBrSD waters tips the already low bottom salinity value to below 5 (Figs. 15-1, 15-2, 15-4, 15-5). In general, the introduction of MBrSD waters in the model experiments BCBDVAR and BDMAX (Figures 15-4 and 15-7) showed minimal effect in terms of triggering an oyster stress tipping point on bottom salinity condition, compared to experiments that did not include the MBrSD. However, the climatological experiment that included MBrSD water (BDCLIM) exhibits a large decrease in bottom salinities throughout the MSS and did lower salinities below an oyster stress tipping point in the WMSS, in comparison to the climatological experiment that did not include MBrSD.

Breton Diversion Impact on Consecutive Days of Low Bottom Salinity

Figures 18 and 19 show the difference in maximum consecutive days of salinity less than 5 between twin experiment pairs with MBrSD (BDCLIM, BCBDVAR, BDMAX) and those without (CLIM, BC, RO) to isolate the impact of the MBrSD discharge operations on prolonged exposure to low salinity. The seasonality of consecutive day evolution is generally consistent across all six model experiments, with values increasing from January (10-15 consecutive days) to June/July (55-80 consecutive days) and then decreasing into mid-Fall (see Figure A30).

The difference in the maximum consecutive days during each month for the Western, Central and Eastern MSS is shown in Figure 18. Within the MSS for the BCBDVAR and BDMAX experiments, the active Breton Diversion results in no more than 3 additional consecutive days of low bottom salinity each month. Within the WMSS for the BDCLIM experiment, the active Breton Diversion results in between 5 and 61 additional consecutive days of low bottom salinity from January through December. However, for all but the climatological twin experiment, active Breton Diversion leads to fewer consecutive days of low bottom salinity (i.e., negative values) in the WMSS for two or more months of the year, with the timing of these instances varying between the BCBDVAR and BDMAX experiments (Figure 18). The spatial distribution of maximum consecutive days over the first 9 months shows the highest differences in WMSS and Biloxi Marsh (more consecutive days, fresher) in the BDCLIM experiment (Figure 19-1). The BDMAX and BCBDVAR experiments also show the highest differences in WMSS (less consecutive days, saltier) and Biloxi Marsh (more consecutive days, fresher). Further, the spatial patterns for these two features within the difference plots vary considerably across the three twin experiments presented here (Figure 19), which indicates salinity conditions in these waters south of Bay St. Louis are sensitive to the magnitude, timing and source location of riverine, spillway, and diversion freshwater inflows. This sensitivity is also indicated in the contrast between the BCBDVAR and BDMAX twin experiments (Figs. 18-2 & 18-3), where the former features an increase in consecutive days of low salinity in WMSS over the March - June time frame while the latter indicates a decrease. The distinguishing element between these two twin experiments is the inclusion of the Bonnet Carré within the BCBDVAR experiment (Table 4).

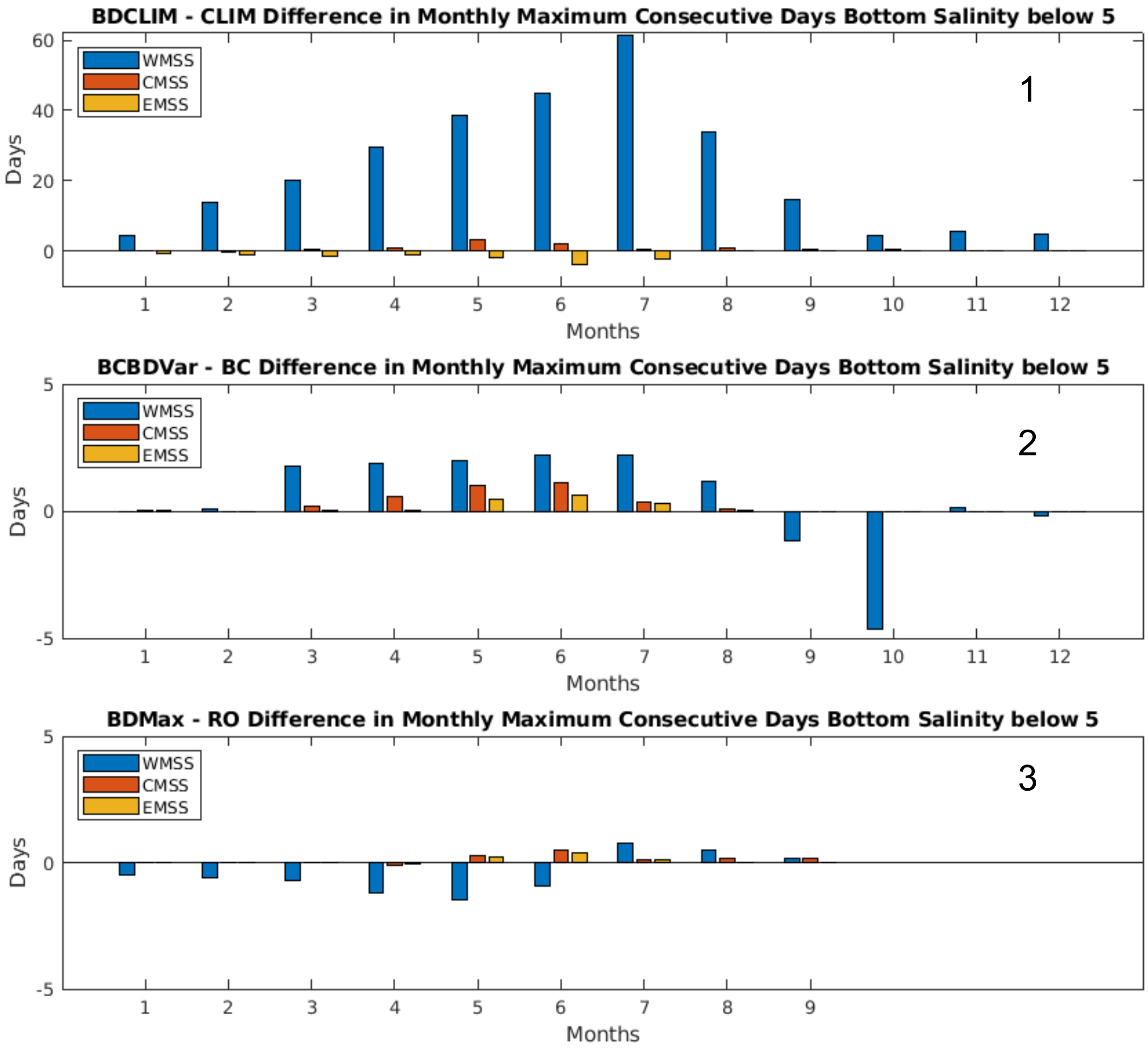


Figure 18. Difference in monthly maximum consecutive days of bottom salinity below 5 ppt (across twin experiments, Table 4) between scenarios with and without active Breton Diversion. Positive values indicate that the active Breton Diversion resulted in additional days of bottom salinity below 5 ppt. The spatial areas reported here are the three Mississippi Sound areas defined in figure 14-2. Abbreviations are as follows: WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, and EMSS=Eastern Mississippi Sound.

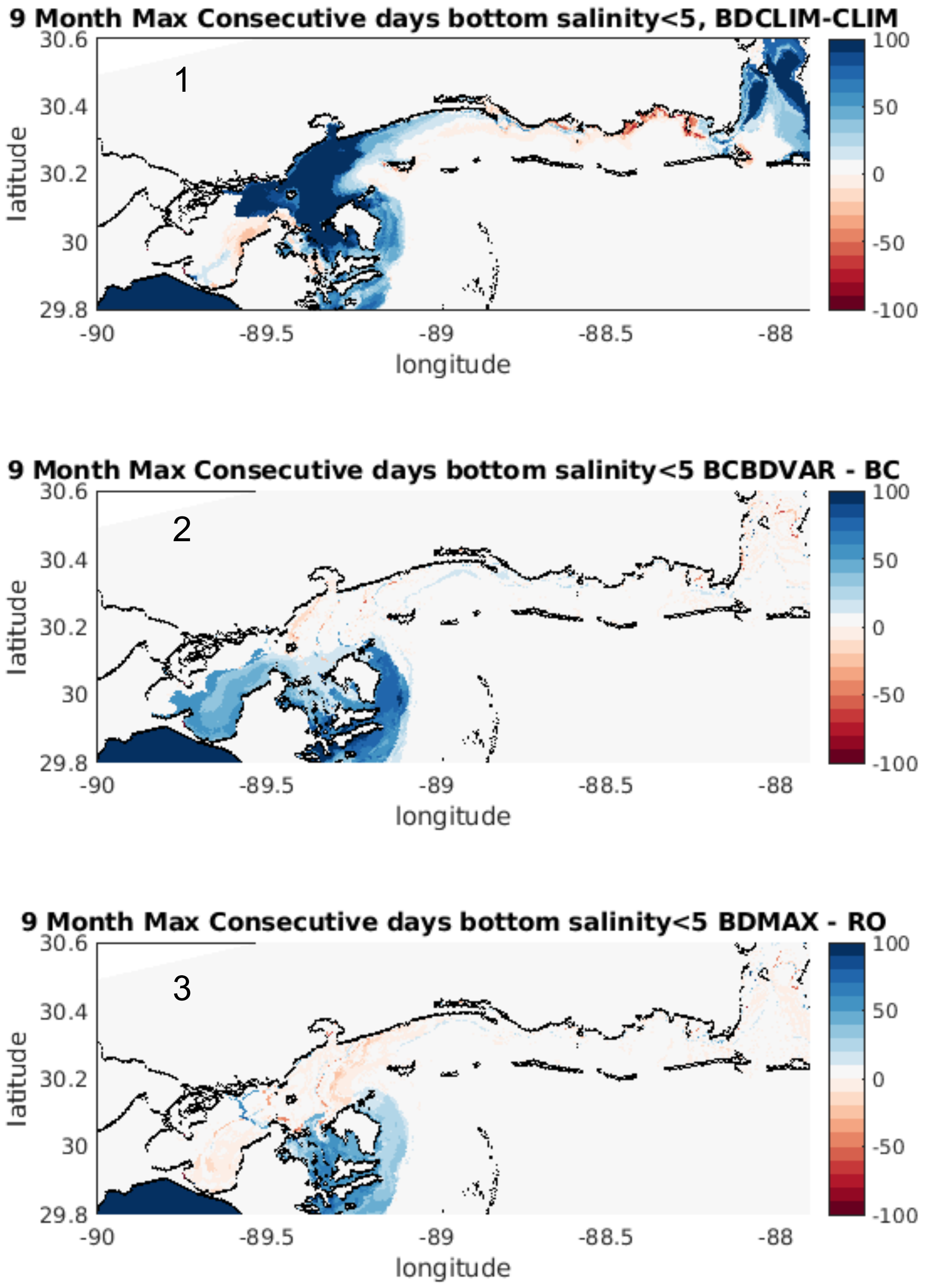


Figure 19. Difference in the maximum consecutive days where average bottom salinity is below 5 ppt (across twin experiments, Table 4) between scenarios with and without active Breton Diversion. Positive values (blue, fresher) indicate there are more consecutive days below 5 ppt when the Breton Diversion is active, while negative values (red, saltier) indicate there are less consecutive days below 5 ppt.

Breton Diversion Impact on Cumulative Days of Low Bottom Salinity

Figures 20 and 21 show the difference in monthly cumulative days of salinity less than 5 ppt between twin experiments with MBrSD (BDCLIM, BCBDVAR, BDMAX) and those without (CLIM, BC, RO) to isolate the impact of the MBrSD discharge operations on the total time of low bottom salinity exposure at every grid point in the domain. In the MSS ROIs (Figure 14-2), the difference in monthly averaged cumulative days where daily average salinities are below 5 ppt is less than 2 additional days (fresher) or 2 fewer days (saltier) per month in all but the climatological scenario (Figure 20).

The spatial distribution of maximum cumulative days over the first 9 months in the difference plots shows, for the BCBDVAR and BDMAX experiments, that bottom waters in the WMSS outside of Bay St. Louis are more saline when the Breton Diversion is active (Figure 21-2, 21-3). Consistent with the consecutive days maps (Figure 19), the pattern of more saline waters adjacent to the mouth of Bay St. Louis varies between the two twin experiments. For the climatology case (Figure 21-1), notably fresher bottom waters extend from WMSS southward into Biloxi Marsh, westward into Lake Borgne, and along the coast into CMSS. In contrast, for the BDMAX case, more saline bottom waters penetrate into Lake Borgne and extend eastward along the coast into CMSS, but intrude less into Biloxi Marsh (Figure 21-3). When both the MBrSD and the Bonnet Carré are active, the more saline bottom waters are confined within the WMSS (Figure 21-2). Finally, in the BDCLIM experiment freshening occurs in Mobile Bay, while more saline waters manifest from Biloxi Bay and eastward along the coast in the EMSS (Figure 21-1).

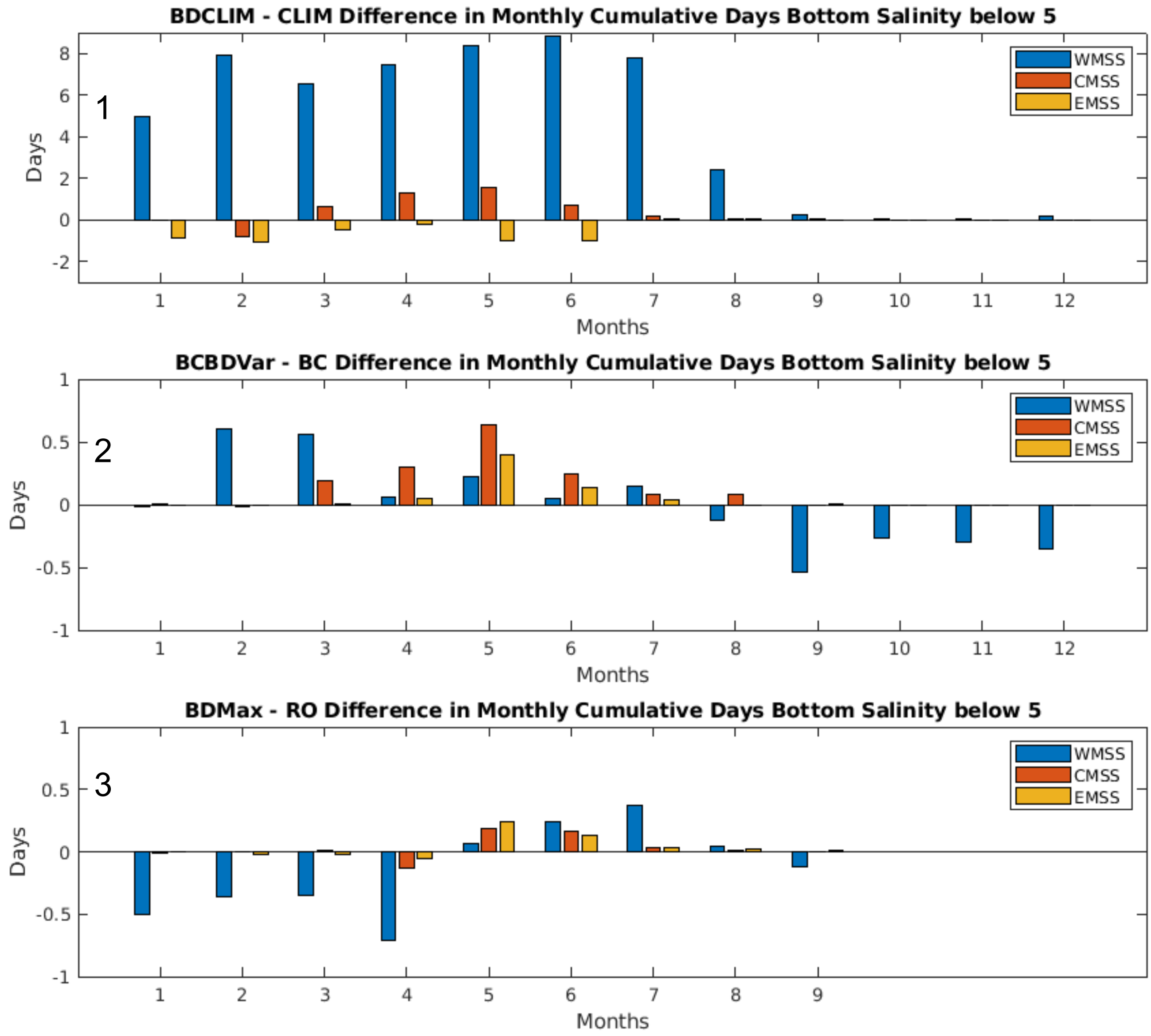


Figure 20. The difference in cumulative days of bottom salinity below 5 during each month (across twin experiments, Table 4) between scenarios with and without Breton Diversion discharge impact within the areas defined in Figure 14b. Abbreviations are as follows: WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, and EMSS=Eastern Mississippi Sound.

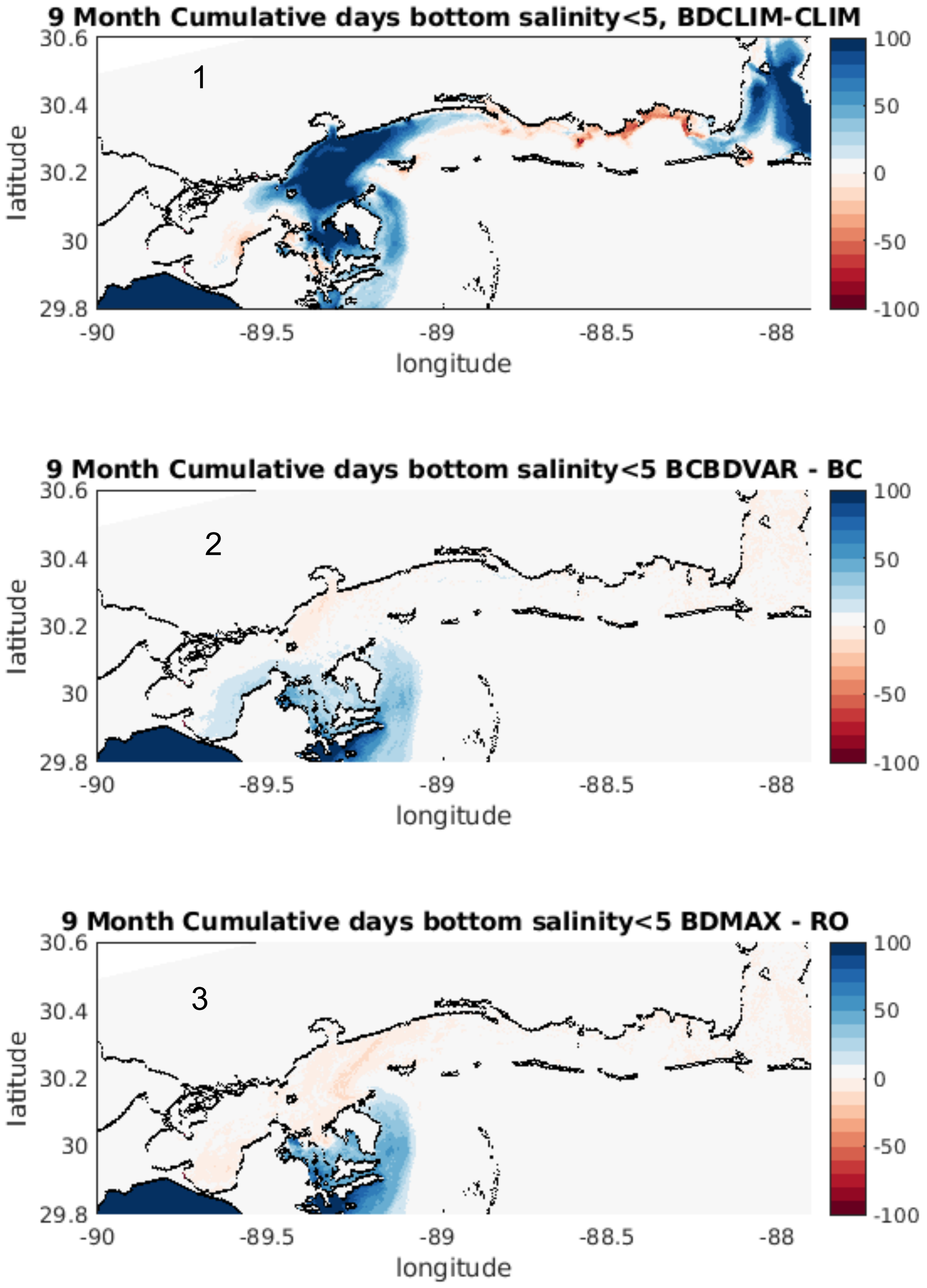


Figure 21. Difference in total cumulative days where average bottom salinity is below 5 (across twin experiments, Table 4) between scenarios with and without active Breton Diversion. Positive values (blue, fresher) indicate there are more cumulative days below 5 in the Breton Diversion scenarios while negative values (red, saltier) indicate there are less cumulative days below 5 in the Breton Diversion scenarios.

Influence of the Breton Diversion on Exchange Pathways

Effect of the MBrSD when the Bonnet Carré is Not Active

Figures 22 and 23 show the tracer pathway for MBrSD waters and the differences in monthly averaged bottom salinity for the climatology twin experiment. The primary freshening influence of the MBrSD waters is apparent in Breton Sound south of Biloxi Marsh over the full April - October period and in WMSS and Mobile Bay during the April to June time period. During the April - June period, when MSR and MBrSD discharge is high (Figure 13-1), average bottom salinity differences for the climatology twin experiment (BDCLIM - CLIM) indicate freshening in the Western, Central and Eastern MSS in BDCLIM (Figure 22) resulting in lower average salinities in the MSS ROIs (Figures 15-3 and 17-3) and an increase in average cumulative days below 5 ppt in the MSS ROIs (Figure 20-1). The tracer flowing with the MBrSD waters reveals there is a strong front between MBrSD waters and MSR waters during months 4 through 6 that aligns with lower bottom salinity extending from the Breton sound into Biloxi Marsh and suggests that there is a significant displacement of MSR waters that flows into the Western MSS and propagates eastward (Figure 22).

During the August - October period, when MSR and MBrSD discharge has dropped (dMSRCLIM & dBDCLIM; Figure 13-1), the magnitude and spatial extent of MBrSD influence bottom salinity within MSS and Biloxi Marsh is significantly reduced (Figures 23-2, 23-4 and 23-6). The tracer of MBrSD continues to exhibit a strong front in Breton Sound with some diffusion within the Chandeleur Sound and Biloxi Marsh (Figure 23-1, 23-3, and 23-5). Related to this more diffuse dispersion of the MBrSD, higher average salinities in the ROI of WMSS (Figure 15-1) and a decrease in average cumulative days below 5 ppt in the Western MSS ROI (Figure 20-1) occur. In the October period, the bottom salinity differences also reveal an area along the Birdfoot Delta of saltier waters when the Breton Diversion is active that suggests a disruption to the shoreward (northwesterly) propagation of oceanic shelf waters (Figure 23-6).

The difference between cumulative days of bottom salinity below 5 ppt during the period of the BCS opening (BDMAX vs RO, Figure 24-6) shows the MBrSD influence is strongest (>10 fewer cumulative days of low salinity) in the Biloxi Marsh and WMSS. The difference in cumulative days due to MBrSD influence in the rest of MSS exhibits little change (Figure 24-6). A prior study isolating the 2019 BCS influence utilizing the BC and RO scenarios found that historically productive oyster reef locations in Central and Western MSS received an additional 50 to 100 days of bottom salinity below 2 ppt (Armstrong et al, 2021), a more extreme condition than the bottom salinity below 5 ppt case shown here (Figure 24-8). Although the MBrSD and the BCS had comparable cumulative discharge over the first 210 days of simulation (Figure 13-2), a comparison of the cumulative days of bottom salinity below 5 ppt in the BDMAX vs RO (Figure 24-6) and BC vs RO (figure 24-8) twin experiments shows very different results in WMSS, 10 less cumulative days and 50-100 more cumulative days respectively, indicating that bottom salinity in this area is sensitive to the location of freshwater input.

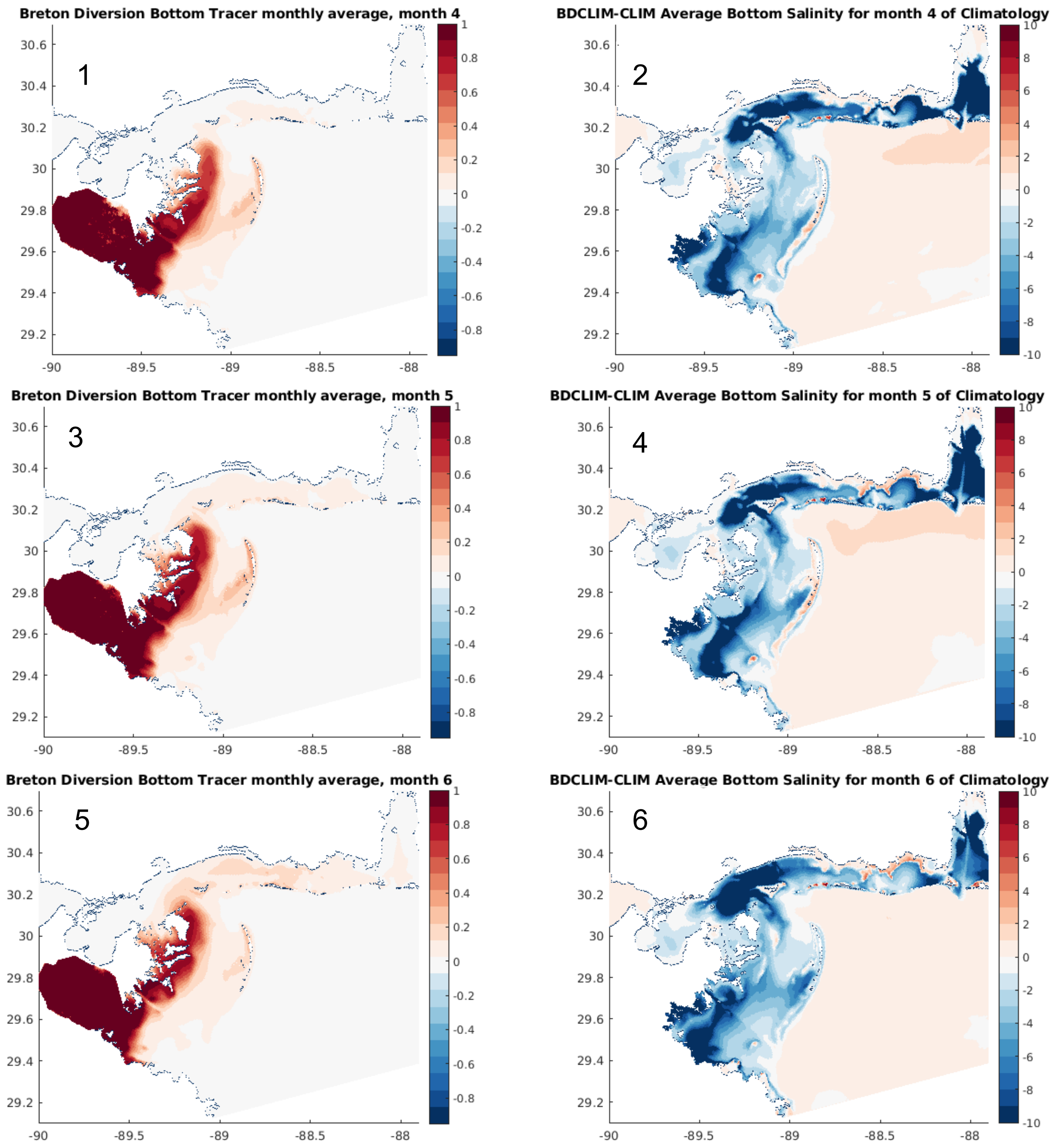


Figure 22. Monthly averaged Breton Diversion tracer (left column) and bottom salinity difference between climatological twin experiment scenarios BDCLIM and CLIM (right column) for months 4 to 6. In the difference plots (panels 2, 4 and 6) negative values (blue) indicate where bottom salinity is fresher as result of the active Breton Diversion.

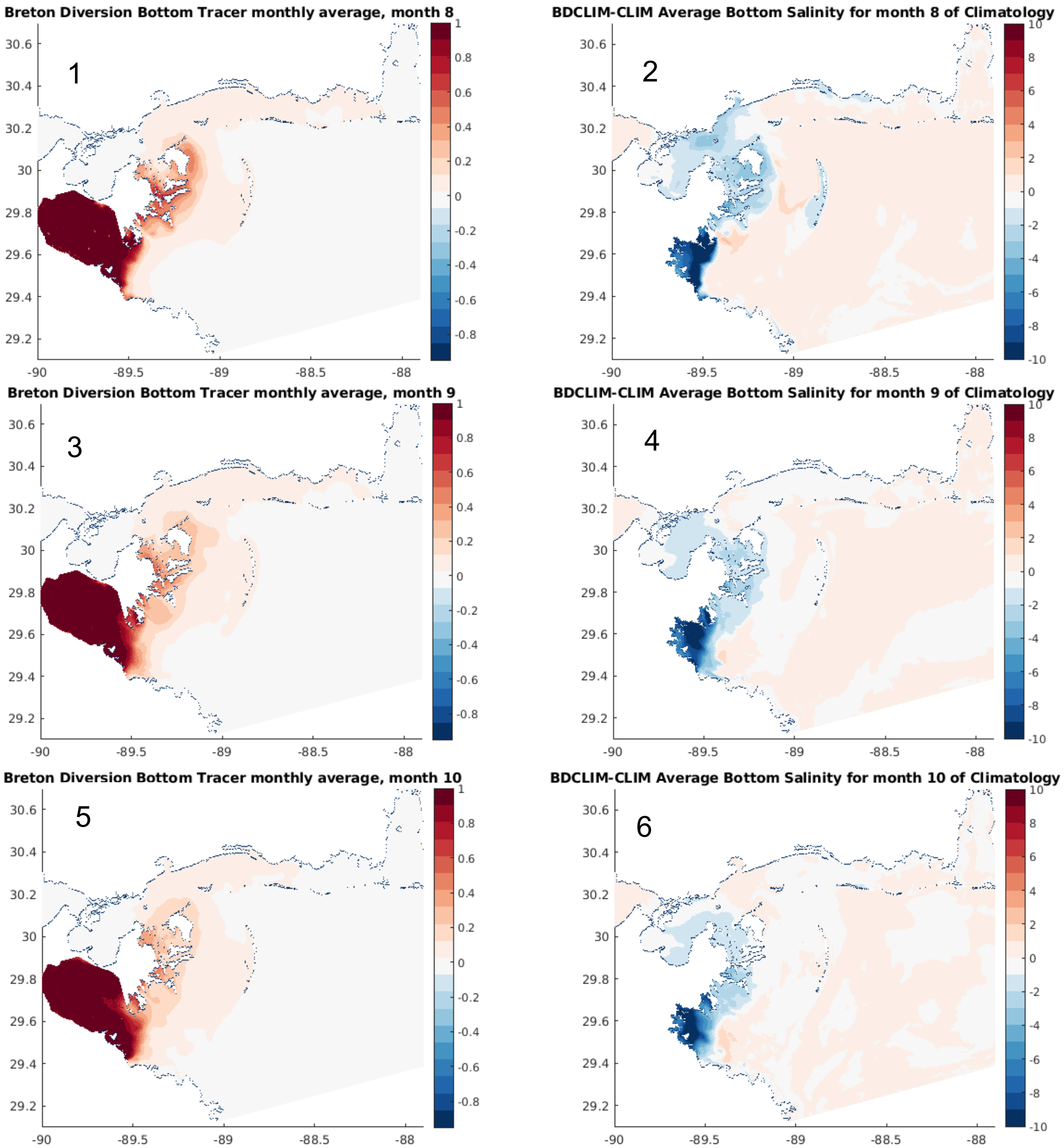


Figure 23. Monthly averaged Breton Diversion tracer (left column) and bottom salinity difference between climatological twin experiment scenarios BDCLIM and CLIM (right column) for months 8 to 10. In the difference plots (panels 2, 4 and 6) negative values (blue) indicate where bottom salinity is fresher as result of the active Breton Diversion.

Effect of the MBrSD when Bonnet Carré is Active

In Figures 25-1 and 25-2, depth integrated salinity changes resulting from the BCS are displayed without (BC-RO) and with (BDVAR-BDMAX) the influence of the MBrSD, respectively. Figure 25-3 shows that the discharge coming from MBrSD in March is identical for BDVAR (red line) and BDMAX (green line) experiments. Taking the difference between these two results (BC-RO vs BDVAR-BDMAX, Figure 25-4) shows the additional effect of the freshwaters added to the region by the MBrSD when the Bonnet Carré is also active.

In the distribution of depth integrated salinity difference representing this Breton Diversion additive impact for March (Figure 25-4), blue is additional BCS freshwater and red is displacement of BCS (or MSR) freshwater due to the MBrSD influence. This results in additional BCS freshwater in the Biloxi marsh and mainly southern portions of LKBG and WMSS (Figure 25-4). This suggests that the decrease in salinity in LKBG and the WMSS in months 2 and 3 of the BCBDVAR experiment (Figures 15-6 & 16-2) is likely due to the impact of the MBrSD waters preventing BCS waters from moving further south and into the Breton and Chandeleur Sounds (Figure 25-4).

The difference between cumulative days of bottom salinity below 5 ppt during the BCS opening (BC-RO vs BCBDVAR-BDMAX, Figure 24-9) shows the MBrSD influence is strongest (>20 cumulative days of bottom salinity below 5 ppt) in the Biloxi Marsh and the southeastern part of Lake Borgne. The additional cumulative days due to MBrSD influence in the rest of MSS is low, less than 20 additional days of bottom salinity below 5 ppt over the course of the double BCS opening (Figure 24-9).

Figure 26 shows monthly averaged bottom salinity distributions for the March - May period of 2019 for the BCBDVAR experiment (panels 1, 4 & 7) and the BC experiment (panels 2, 5 & 8). For all these bottom salinity distributions, the 2 ppt and 5 ppt isohalines (dashed and solid yellow lines, respectively) are shown to illustrate how low (and ecologically impactful) bottom salinity distributions evolve and are affected by these two freshwater diversion operations.

With the BCS and MBrSD both open during the March - April period, distinct freshwater masses form. In the BCBDVAR experiment, the noted isolines reveal how the resulting low salinity fronts propagate during March and April (Figures 26-1 & 26-4) and ultimately merge in May (Figure 26-7). In comparison, when the MBrSD is not open, the BCS freshwater flows south into the western Chandeleur and Breton Sounds (Figures 26-5 & 26-8) to merge with MSR freshwater entering from the Birdfoot Delta. The bottom salinity difference maps for the BCBDVAR twin experiment (Figures 26-3, 26-6 & 26-9) indicate that when both diversion operations are active, the Breton Diversion influence is most prominent in the Breton and Chandeleur Sound areas, with some impacts also suggested in southeastern Lake Borgne and the Central and Eastern MSS areas.

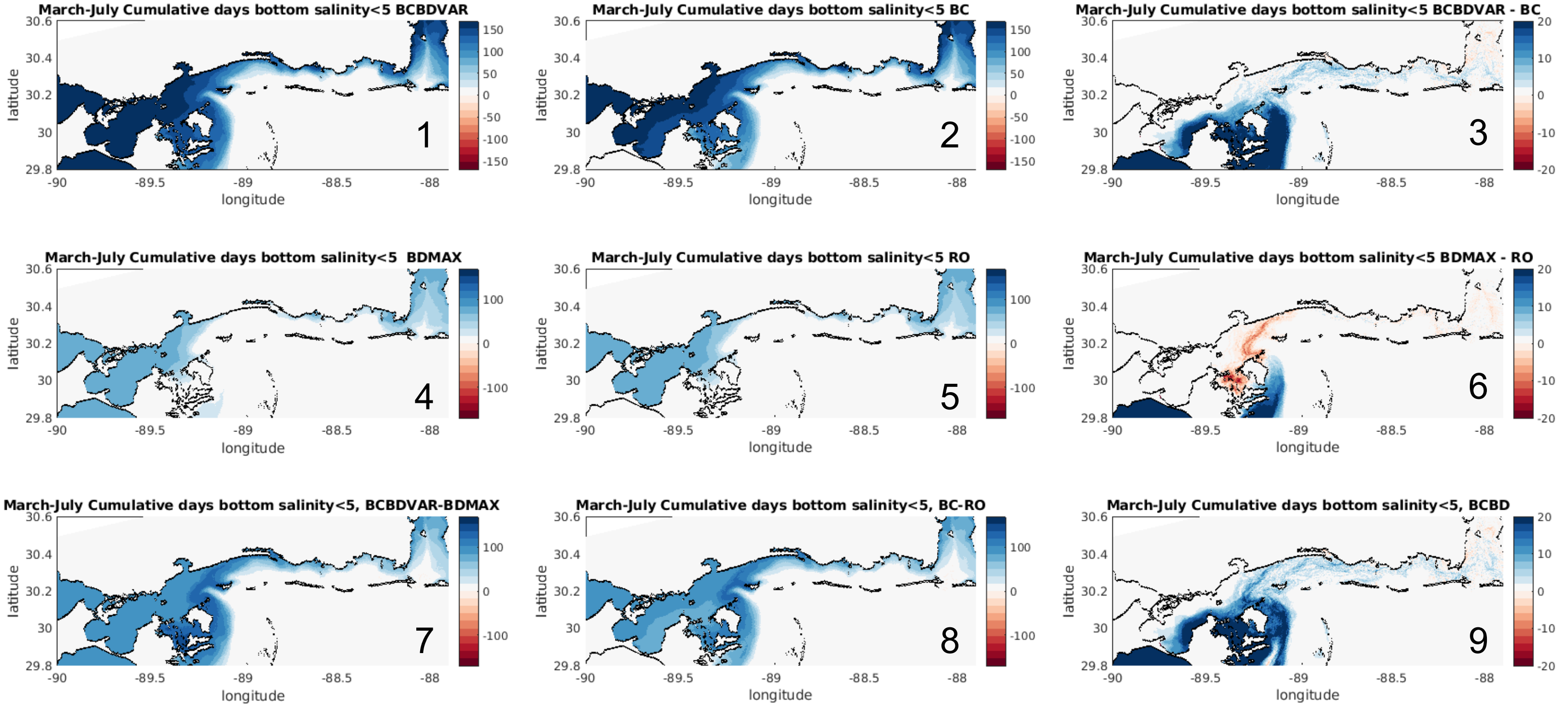


Figure 24. Cumulative days of low salinity and difference in cumulative days of low salinity across twin experiments which contain Bonnet Carré Spillway (BCS) and Mid-Breton Sediment Diversion (MBrSD) discharge are compared for March through July of 2019 (during the BCS opening). The individual cases targeted for this exploration of twin experiments are in the upper left portion of the graphic (Panels 1 (BCBDVAR), 2 (BC), 4 (BDMAX), and 5 (RO)). Differences across twin experiments are shown in the third column and along the bottom row. These twin experiment presentations isolate: (3) the influence of MBrSD when BCS is open, (6) the influence of MBrSD at maximum capacity when BCS is not active, (7) the influence of BCS when MBrSD is active, (8) the influence of BCS when MBrSD is not active. The bottom right panel (9) represents the difference of these differences across twin experiments (BCBD((BCBDVAR-BDMAX)-(BC-RO))) and shows the MBrSD influence on the BCS. See Table 4 for further details. In all panels the units are cumulative days of bottom salinity below 5 ppt. Note that panels 3 and 6 are the March-July temporal subset of panels 21-2 and 21-3.

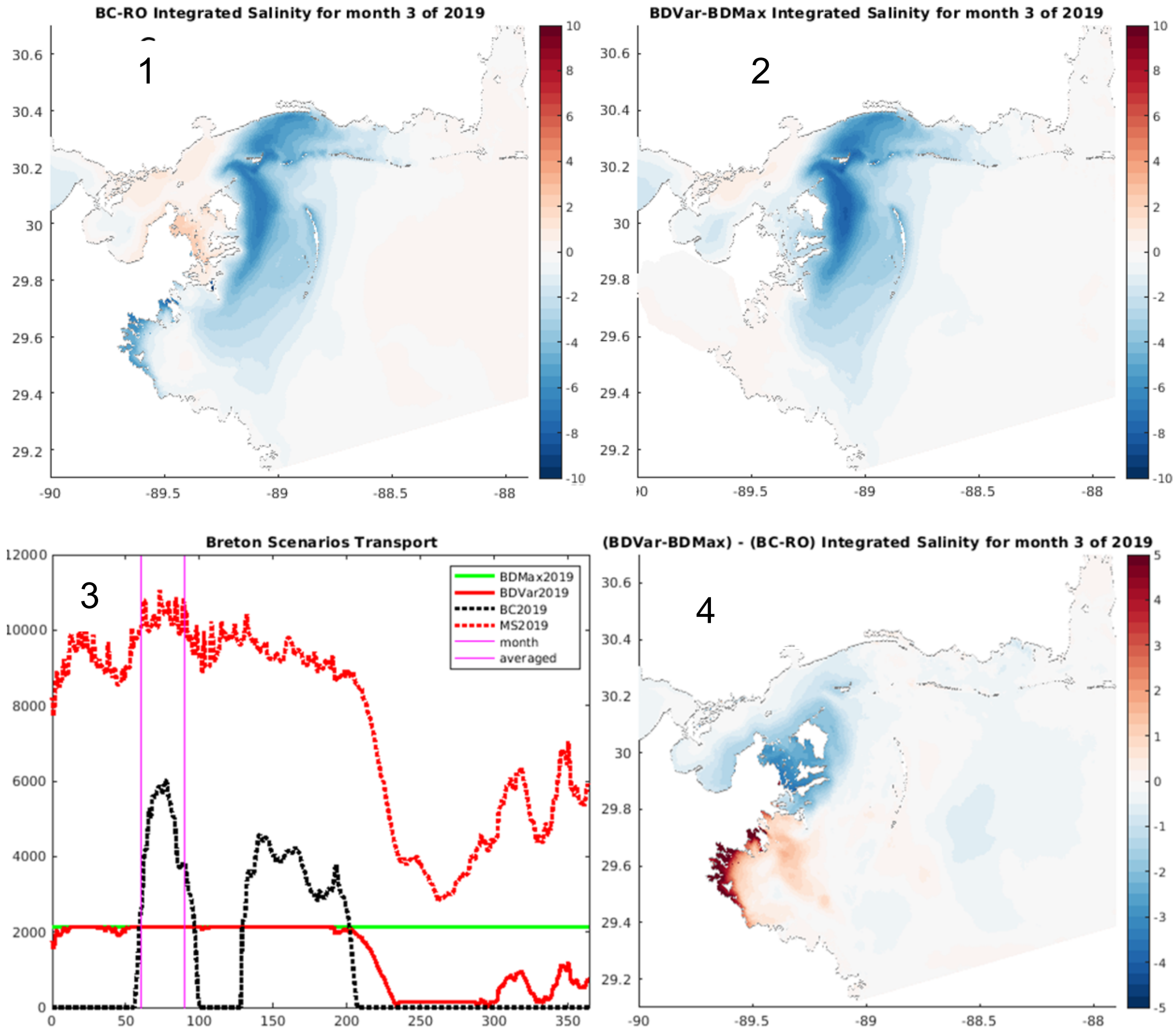


Figure 25. Monthly average depth integrated salinity differences in the scenarios which contain Bonnet Carré Spillway (BCS) and Mid-Breton Sediment Diversion (MBrSD) discharge are compared. Differences across twin experiments (1) BC and RO and (2) BCBDVAR (BDVAR) and BDMax depth integrated salinities show the influence of the BCS on salinities in scenarios without and with the MBrSD respectively. Comparing the difference of these differences across twin experiments ((BDVAR-BDMAX)-(BC-RO), panel 4) isolates the influence of the MBrSD on BC.

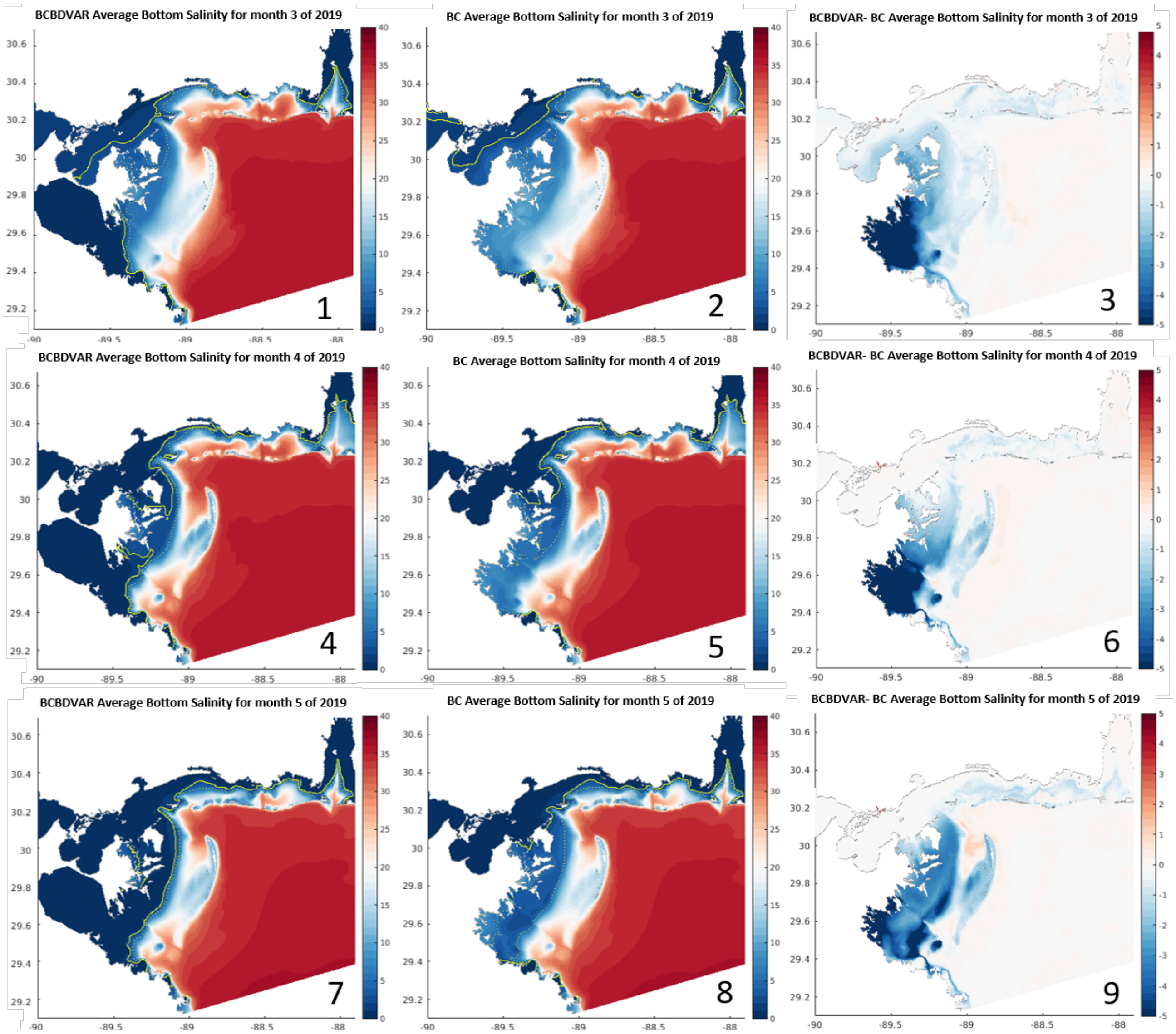


Figure 26. Monthly average bottom salinity for months 3 through 5 of the BCBDVAR (left column) and BC (middle column) cases and the difference across the twin experiment (BCBDVAR-BC, right column). This twin experiment allows for tracking the influence of variable Breton Diversion application when the BCS is active (Table 4). Solid and dashed yellow lines for panels in the left and middle columns track the 2 ppt and 5 ppt isohaline contours, respectively.

Summary and Conclusions

A fundamental aspect of the shallow estuarine system encompassed by the coastal MS Sound and Bight region is that its circulation patterns and pathways, and associated estuarine-shelf exchange of dissolved and particulate materials, are fundamentally determined by the combined effect of riverine inflows, human-implemented diversions, and surface winds. Indeed, the latter can exert dominant control over whether freshwater from the noted sources remains trapped nearshore or is efficiently flushed out to the shelf and broader Northern Gulf of Mexico region.

Through its base level 400 m lateral resolution and 24-layer vertical structure, the ocean modeling application used for this study was specifically designed with the capacity to illuminate the fine details of such processes as: 1) the timescale of flushing or trapping of freshwater in the river-dominated MS Bight region; 2) the complex coastal circulation response (e.g., multi-layer estuarine circulation and river plumes) to highly-resolved wind patterns; and 3) the biophysical interactions that govern onset / persistence of bottom hypoxia, sediment resuspension and transport, advection and recruitment success of larvae.

The numerical modeling study presented here was conducted to assess the increasing freshwater stressors in the Mississippi Sound (MSS) and adjacent coastal / shelf waters of the Mississippi Bight region, both human-controlled and natural. This investigation was motivated by both the potential implementation of the Mid-Breton Sediment Diversion (MBrSD), recommended by the Coastal Protection and Restoration Authority of Louisiana (CPRA, 2017) and the 2019 double Bonnet Carré Spillway (BCS) opening.

In 2019 the Mississippi River stage remained high despite opening the BCS, which created a real-life worst-case hydrograph which has been applied in creating our hypothetical scenarios for the MBrSD. Project results obtained and presented herein are intended to inform policy and decision-makers regarding the impact of controlled freshwater influxes to the Mississippi Sound and Bight. A process-based analysis of developed scenarios reveals how the timing and discharge through the Mid-Breton Diversion will propagate throughout the region.

To do this, 3 scenarios were considered:

1. The first scenario entails application of an 11-year average (2010-2020) Mississippi River hydrograph that serves as a climatological scenario for flow through the MBrSD. This climatological scenario provides a useful baseline for how the activation of the MBrSD will influence the coastal waters of the region under typical hydrologic conditions.

2. The second scenario entails application of both 2019 Bonnet Carré Spillway (BCS) conditions and variable MBrSD discharge based upon the actual (extreme) 2019 Mississippi River hydrograph. This realistic scenario is actually rather atypical, given that it encompasses the double BCS opening of 2019, and is uniquely suited for exploring the combined influences of the BCS and MBrSD when both are operating at (or near) full capacity.

3. The third scenario entails application of continuous maximum design flow from the MBrSD (75,000 cfs) flowing 24/7 for 9 months. This maximum scenario replicates a talking point introduced by special interest groups and is useful for revealing how operation of the MBrSD at full capacity will impact Mississippi coastal waters following the spring freshet.

Six numerical experiments within a twin experiment logic were performed to isolate and understand the influence of MBrSD on advective pathways and hydrographic properties for all scenarios. Six specific regions of interest (ROI) were defined to focus on critical areas in the study domain (Figure 14-2). For each of the model scenarios, average changes in salinity over monthly time periods, and both cumulative and consecutive days of bottom salinity below 5 ppt, were used in our analysis of the ROIs as well as the broader study area. Cumulative time series of days when bottom salinity is below 5 ppt identify the spatial extent and total time of low bottom salinity exposure, while consecutive time series of days when bottom salinity is below 5 ppt identify areas where oyster bed populations would experience drastic stress due to prolonged exposure to low salinity.

The climatological scenario provides a useful baseline for how the activation of the MBrSD will influence the coastal waters of the region. The nominal impact is that bottom salinities are reduced in the shallow waters east of the Mid-Breton inflow (Breton and Chandeleur Sound, Figure 16-1). In surface waters, WMSS salinity decreases when the MBrSD is active in 7 out of 12 months of the year (February, April - September) and in CMSS for 5 out of 12 months (May - September) and in EMSS for 5 out of 12 months (July - November; Figure 17-3). Bottom salinity in the WMSS exhibits very interesting sensitivity. During the January - July period governed by southerly winds (Figures 10 & 11), the WMSS ROI realizes pronounced freshening that is only matched in the BRDS ROI that is adjacent to the MBrSD inflow. It is also worth noting that across the six experiments performed in this study (Table 1), only in the CLIM experiment does bottom salinity in the WMSS remain above five throughout the year (Figures 15-1, 15-2, 15-4, 15-5, 15-7, 15-8).

For the other two scenarios, the Breton Diversion discharge has a stronger impact on the salinity of the Biloxi Marsh, Chandeleur Sound, and Breton Sound. MBrSD freshwater does influence MSS and the impact is measurable in monthly salinity averages from the first month of simulations. The influence of MBrSD waters on MSS monthly average bottom salinity over the areas of interest are generally less than +/- 1 (Figures 15-6, 15-9).

When the Breton Diversion is active in concert with the 2019 BCS opening period (March through July), regional averages over Central and Eastern MSS can see up to 1 additional cumulative days of low bottom salinity (<5 ppt) water per month (Figure 20-2) and parts of these regions experience up to 10 more cumulative days of low bottom salinity over the March - July period (Figures 24-3, 24-6, 24-9). With both diversions active, freshening in LKBG and the WMSS during February - March period (Figures 15-6 & 16-2) is potentially due to the impact of the MBrSD waters inhibiting the propagation of BCS waters further south and into the Breton and Chandeleur Sounds (Figure 25-4). In terms of MBrSD water impacts, the bottom salinity difference maps for the BCBDVAR twin experiment (Figures 26-3, 26-6 & 26-9) indicate that when both diversion operations are active, the Breton Diversion influence is most prominent in the Breton and Chandeleur Sound areas, with some impacts also suggested in southeastern Lake Borgne and the Central and Eastern MSS areas. Under the influence of both of these freshwater inflows, low salinity fronts shift location, which has potential for consequential impacts on the salinity environment experienced by extant oyster reefs (Figures 19-2, 21-2, 26).

Within the limited number of numerical experiments performed for this study, there was only one instance identified where the addition of MBrSD impacts shifted the average monthly bottom salinity down to a critical threshold for the four 2019 hindcast experiments (WMSS in February, Figures 15-4 & 15-5). However, while realistic, the 2019 time frame was an extreme scenario in terms of BCS operation and it is known that salinities within the MSS were at historically low values. The climatological scenario provides more telling insight into MBrSD operations, with the most pronounced impact on bottom salinities and a 6-month period (January – July) when values shift below the critical ecological threshold (salinity of 5 ppt), coincident with the peak of the spring freshet and subsequent recovery (Figures 15-1, 15-2, 15-3). Consequently, full opening of the MBrSD during high river discharge, and particularly during BCS openings, should be considered with caution so as not to push salinity conditions beyond a tipping point that will adversely, and possibly permanently, affect the ecosystem services provided by key species residing within Mississippi Sound. We make this recommendation considering the broad range of environmental influences at play in the region that can contribute to the ultimate fate of a significant freshwater diversion injection into these coastal waters.

During 2019, both anomalously high MSR discharge, as well as wind forcing during February and May that is ~ 2-3x stronger when compared with the climatological winds, are in effect. And expected hazardous salinity conditions in the WMSS are realized in the model solution. It should be recognized that the results of this study are dependent on the scenarios which have been enacted and the attendant diversion operations and atmospheric, river and lateral boundary conditions. Year to year, the results may vary widely, driven by the highly variable freshwater discharge and wind forcing in this area. While the influence of MBrSD on MSS salinities is measurable in this study, whether a deleterious ecological impact is realized is subject to the net influence of these forcing factors. For example, the climatological scenario presented herein reveals a significant impact on WMSS bottom salinities with active MBrSD that would put oyster reefs at risk; however, if the wind field was shifted to an oceanward direction it is likely that this threat would be minimized or eliminated.

In particular, our results suggest that salinity conditions in the WMSS are rather sensitive to the timing and magnitude of local riverine, BCS, and MBrSD influences, that again are highly convolved with the governing wind-forcing conditions. Through exploration of a broader suite of numerical experiments, a more comprehensive understanding could be achieved for how fisheries production within this key area would be influenced by human-engineered freshwater diversions. Another recommendation in this context would be to employ short-term modeling forecasts that could be used to assess the impacts of pending BCS openings given the upstream knowledge of MS River stage. Our modeling group is currently developing a near real-time and short-term forecasting capacity that could be used to provide such guidance to local resource managers.

References

Ahn, J.E., Ronan, A.D., 2020. Development of a model to assess coastal ecosystem health using oysters as the indicator species. Estuarine, Coastal and Shelf Science 233. https://doi.org/10.1016/j.ecss.2019.106528

Allison, M. A., C. R. Demas, B. A. Ebersole, B. A. Kleiss, C. D. Little, E. A. Meselhe, N. J. Powell, T. C. Pratt, and B. M. Vosburg (2012), A water and sediment budget for the lower Mississippi–Atchafalaya River in flood years 2008–2010: Implications for sediment discharge to the oceans and coastal restoration in Louisiana, J. Hydrol., 432-433, 84-97, doi:https://doi.org/10.1016/j.jhydrol.2012.02.020.

Armstrong, B.N., Cambazoglu, M.K. and Wiggert, J.D., 2021, Modeling the impact of the 2019 Bonnet Carré Spillway opening and local river flooding on the Mississippi Sound, *OCEANS 2021: San Diego – Porto*, 2021, pp. 1-7, doi: 10.23919/OCEANS44145.2021.9705854.

Bargu, S., Justic, D., White, J. R., Lane, R., Day, J., Paerl, H., & Raynie, R. (2019). Mississippi River diversions and phytoplankton dynamics in deltaic Gulf of Mexico estuaries: A review. *Estuarine, Coastal and Shelf Science*, *221*. https://doi.org/10.1016/j.ecss.2019.02.020

Barron, C. N., Birol Kara, A., Hurlburt, H. E., Rowley, C., & Smedstad, L. F. (2004). Sea surface height predictions from the global Navy Coastal Ocean Model during 1998–2001. *Journal of Atmospheric and Oceanic Technology*, *21*(12), 1876-1893.

Barron, C. N., Kara, A. B., Martin, P. J., Rhodes, R. C., & Smedstad, L. F. (2006). Formulation, implementation and examination of vertical coordinate choices in the Global Navy Coastal Ocean Model (NCOM). *Ocean Modelling*, *11*(3-4), 347-375.

Benjamin, S. G., Weygandt, S. S., Brown, J. M., Hu, M., Alexander, C. R., Smirnova, T. G., Olson, J. B., James, E. P., Dowell, D. C., Grell, G. A., Lin, H., Peckham, S. E., Smith, T. L., Moninger, W. R., Kenyon, J. S., & Manikin, G. S. (2016). A North American Hourly Assimilation and Model Forecast Cycle: The Rapid Refresh, Monthly Weather Review, 144(4), 1669-1694. Retrieved Oct 11, 2022, from https://journals.ametsoc.org/view/journals/mwre/144/4/mwr-d-15-0242.1.xml

Blaylock, B. K., Horel, J. D., & Liston, S. T. (2017). Cloud archiving and data mining of High-Resolution Rapid Refresh forecast model output. *Computers & Geosciences*, *109*. https://doi.org/10.1016/j.cageo.2017.08.005

Bouchard, C. (2021). *Exploring the Influence of Diurnal Forcing on Tidal Inlet Exchange and the Impact on the movement of Oxygen Depleted Waters in the Mississippi Sound and Bight Region*.

Cambazoglu, M.K., Soto, I.M., Howden, S. D., Dzwonkowski, B., Fitzpatrick, P.J.,Arnone, R.A., Jacobs, G.A., Lau, Y.H. (2017). Inflow of shelf waters into the Mississippi sound and mobile bay estuaries in october 2015, *J. Appl. Remote Sens.*, 11 (3) (2017), 10.1117/1.JRS.11.032410

Chin, T. M., J. Vazquez-Cuervo, and E. M. Armstrong (2017). A multi-scale high-resolution analysis of global sea surface temperature, Rem. Sens. Env., 200, 154-169, doi:https://doi.org/10.1016/j.rse.2017.07.029.

Coastal Protection Restoration Authority, Louisiana's Comprehensive Master Plan for a Sustainable Coast, Coastal Protection and Restoration Authority of Louisiana, Baton Rouge, LA (2017), p. 171, accessed August 12, 2022 at http://coastal.la.gov/wp-content/uploads/2017/04/2017-Coastal-Master-Plan_Web-Book_CFinal-with-Effective-Date-06092017.pdf

Coastal Protection Restoration Authority (2021). Mississippi River Mid-Basin Sediment Diversion Program, accessed October 21, 2021 at URL https://coastal.la.gov/our-work/key-initiatives/diversion-program/about-sediment-diversions/

Deignan-Schmidt, S. R., & Whitney, M. M. (2018). A Model Study on the Summertime Distribution of River Waters in Long Island Sound. *Estuaries and Coasts*, *41*(4). https://doi.org/10.1007/s12237-017-0348-5

Dowell, D.C., Alexander, C.R., James, E.P., Weygandt, S.S., Benjamin, S.G., Manikin, G.S., Blake, B.T., Brown, J.M., Olson, J.B., Hu, M., Smirnova, T.G., Ladwig, T., Kenyon, J.S., Ahmadov, R., Turner, D.D., Duda, J.D., Alcott, T.I., 2022. The High-Resolution Rapid Refresh (HRRR): An Hourly Updating Convection-Allowing Forecast Model. Part I: Motivation and System Description. Weather and Forecasting 37, 1371-1395, https://doi.org/10.1175/waf-d-21-0151.1

Dzwonkowski, B., Fournier, S., Park, K., Dykstra, S. L., & Reager, J. T. (2018). Water Column Stability and the Role of Velocity Shear on a Seasonally Stratified Shelf, Mississippi Bight, Northern Gulf of Mexico. *Journal of Geophysical Research: Oceans*, *123*(8). https://doi.org/10.1029/2017JC013624

Dzwonkowski, B., Fournier, S., Reager, J. T., Milroy, S., Park, K., Shiller, A. M., Greer, A. T., Soto, I., Dykstra, S. L., & Sanial, V. (2018). Tracking sea surface salinity and dissolved oxygen on a river-influenced, seasonally stratified shelf, Mississippi Bight, northern Gulf of Mexico. *Continental Shelf Research*, *169*. https://doi.org/10.1016/j.csr.2018.09.009

Dzwonkowski, B., A.T. Greer, C. Briseño-Avena, J.W. Krause, I.M. Soto, F.J. Hernandez, A.L. Deary, J.D. Wiggert, D. Joung, P.J. Fitzpatrick, S.J. O'Brien, S.L. Dykstra, Y. Lau, M.K. Cambazoglu, G. Lockridge, S.D. Howden, A.M. Shiller, W.M. Graham (2017) Estuarine influence on biogeochemical properties of the Alabama shelf during the fall season, *Continental Shelf Research*, Volume 140, 2017, Pages 96-109, ISSN 0278-4343, https://doi.org/10.1016/j.csr.2017.05.001.

Fennel, K., J. Wilkin, J. Levin, J. Moisan, J. O'Reilly, and D. Haidvogel (2006), Nitrogen cycling in the Middle Atlantic Bight: Results from a three-dimensional model and implications for the North Atlantic nitrogen budget, Global Biogeochem. Cycles, 20(3), doi:10.1029/2005GB002456.

Govekar, Pallavi Devidas, Christopher Griffin, and Helen Beggs. 2022. "Multi-Sensor Sea Surface Temperature Products from the Australian Bureau of Meteorology" Remote Sensing 14, no. 15: 3785. https://doi.org/10.3390/rs14153785

Greer, A., Shiller, A., Hofmann, E., Wiggert, J., Warner, S., Parra, S., Pan, C., Book, J., Joung, D., Dykstra, S., Krause, J., Dzwonkowski, B., Soto, I., Cambazoglu, K., Deary, A., Briseño-Avena, C., Boyette, A., Kastler, J., Sanial, V., … Graham, W. (2018). Functioning of Coastal River-Dominated Ecosystems and Implications for Oil Spill Response: From Observations to Mechanisms and Models. *Oceanography*, *31*(3). https://doi.org/10.5670/oceanog.2018.302.

Hendon, J. R., J. D. Wiggert, and J. Hendon (2020), Monitoring 2019 Bonnet Carré Spillway Impacts - Final Report, 49 pp, The University of Southern Mississippi, https://doi.org/10.18785/sose.002.

Hill, C. M., Fitzpatrick, P. J., Corbin, J. H., Lau, Y. H., & Bhate, S. K. (2010). Summertime Precipitation Regimes Associated with the Sea Breeze and Land Breeze in Southern Mississippi and Eastern Louisiana. *Weather and Forecasting*, *25*(6), 1755–1779. https://doi.org/10.1175/2010WAF2222340.1

Jacobs, Gregg A.. 2017. Gulf of Mexico 1 km resolution numerical model simulation with USGS observed river flows, January-February 2016. Distributed by: Gulf of Mexico Research Initiative Information and Data Cooperative (GRIIDC), Harte Research Institute, Texas A&M University–Corpus Christi. doi:10.7266/N7542KZP

Jacobs, G. A., H. S. Huntley, A. D. Kirwan, B. L. Lipphardt, T. Campbell, T. Smith, K. Edwards, and B. Bartels (2016), Ocean processes underlying surface clustering, J. Geophys. Res., 121(1), 10.1002/2015jc011140, 180-197.

Jones, E. B., and J. D. Wiggert (2015), Characterization of a High Chlorophyll Plume in the Northeastern Gulf of Mexico, Rem. Sens. Env., 159, 152-166, doi:http://dx.doi.org/10.1016/j.rse.2014.11.019.

Kanamitsu, M., Ebisuzaki, W., Woollen, J., Yang, S. K., Hnilo, J. J., Fiorino, M., & Potter, G. L. (2002). Ncep–doe amip-ii reanalysis (r-2). *Bulletin of the American Meteorological Society*, *83*(11), 1631-1644.

Martin, P. J. (2000) A description of the Navy Coastal Ocean Model Version 1, Naval Research Laboratory, Stennis Space Center, MS, p. 42 (Technical Report NRL/FR/7322-00-9962)

Mesinger, F., DiMego, G., Kalnay, E., Mitchell, K., Shafran, P.C., Ebisuzaki, W., Jović, D., Woollen, J., Rogers, E., Berbery, E.H. & Ek, M.B., (2006). North American regional reanalysis. *Bulletin of the American Meteorological Society*, *87*(3), pp.343-360.

Pace, S.M., Powell, E.N., Soniat, T.M., Kuykendall, K.M., 2020. How Oyster Health Indices Vary between Mass Mortality Events. Journal of Shellfish Research 39, 603-617, 615.

Parra, S. M., Sanial, V., Boyette, A. D., Cambazoglu, M. K., Soto, I. M., Greer, A. T., Chiaverano, L. M., Hoover, A., & Dinniman, M. S. (2020). Bonnet Carré Spillway freshwater transport and corresponding biochemical properties in the Mississippi Bight. *Continental Shelf Research*, *199*. https://doi.org/10.1016/j.csr.2020.104114

Sanial, V., Shiller, A. M., Joung, D., & Ho, P. (2019). Extent of Mississippi River water in the Mississippi Bight and Louisiana Shelf based on water isotopes. *Estuarine, Coastal and Shelf Science*, *226*. https://doi.org/10.1016/j.ecss.2019.04.030

Schiller, R. V., V. H. Kourafalou, P. Hogan, and N. D. Walker (2011), The dynamics of the Mississippi River plume: Impact of topography, wind and offshore forcing on the fate of plume waters, J. Geophys. Res., 116(C6), doi:10.1029/2010jc006883.

Seim, H. E., Kjerfve, B., & Sneed, J. E. (1987). Tides of Mississippi Sound and the adjacent continental shelf. *Estuarine, Coastal and Shelf Science*, *25*(2), 143–156. https://doi.org/10.1016/0272-7714(87)90118-1

Shchepetkin, A. F., and J. C. McWilliams (2005), The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model, Ocean Modelling, 9(4), 347-404.

Twilley, R. R., Rick, S., Bond, D. C., & Baker, J. (2021). Benthic Nutrient Fluxes across Subtidal and Intertidal Habitats in Breton Sound in Response to River-Pulses of a Diversion in Mississippi River Delta. *Water*, *13*(17). https://doi.org/10.3390/w13172323.

Twilley, R., S. Brandt, D. Breaux, J. Cartwright, J. Chen, G. Easson, P. Fitzpatrick, K. Fridley, S. Graves, S. Harper, C. Kaiser, A. Maestre, M. Maskey, W. McAnally, J. McCorquodale, E. Meselhe, T. Miller-Way, K. Park, J. Pereira, T. Richardson, J. Tao, A. Ward, J. Wiggert, and D. Williamson, Simulation Management Systems Developed by the Northern Gulf Coastal Hazards Collaboratory (NG-CHC): An Overview of Cyberinfrastructure to Support the Coastal Modeling Community in the Gulf of Mexico, in Remote Sensing and Modeling, edited by C. W. Finkl and C. Makowski, pp. 365-394, 10.1007/978-3-319-06326-3_15, Springer International Publishing, 2014.

United States Army Corps of Engineers, 2019, Joint Public Notice for Mid-Breton Sediment Diversion (Mid-Breton SD) Project, Mississippi River, in Plaquemines Parish, Louisiana, accessed August 9, 2022 at https://www.mvn.usace.army.mil/Portals/56/docs/regulatory/publicnotices/2018_01120_PNall.pdf?ver=VlmU5KiTyRclE2EIYM5XMA%3D%3D

United States Army Corps of Engineers. (2021, April 14). *Bonnet Carré Spillway Overview, Spillway Pace*. Https://Www.Mvn.Usace.Army.Mil/Missions/Mississippi-River-Flood-Control/Bonnet-Carré-Spillway-Overview/Spillway-Operation-Information/.

United States Army Corps of Engineers, 2022, Environmental Impact Statement: Mid-Breton Sediment Diversion>Documents>Initial Documents>Permit Application, accessed May 25, 2022 at https://www.mvn.usace.army.mil/Missions/Regulatory/Permits/Mid-Breton-Sediment-Diversion-EIS/

U.S. Geological Survey, 2021, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), accessed October 8, 2021, at https://waterdata.usgs.gov/monitoring-location/07374525/#parameterCode=72255&period=P7D. http://dx.doi.org/10.5066/F7P55KJN

Warner, J. C., Armstrong, B., He, R., & Zambon, J. B. (2010). Development of a Coupled Ocean–Atmosphere–Wave–Sediment Transport (COAWST) Modeling System. *Ocean Modelling*, *35*(3). https://doi.org/10.1016/j.ocemod.2010.07.010

Wiggert, J. D., R. R. Hood, and C. W. Brown (2017), Modeling Hypoxia and Its Ecological Consequences in Chesapeake Bay, in Modeling Coastal Hypoxia: Numerical Simulations of Patterns, Controls and Effects of Dissolved Oxygen Dynamics, edited by D. Justic, K. A. Rose, R. D. Hetland and K. Fennel, pp. 119-147, Springer International Publishing, doi:10.1007/978-3-319-54571-4_6.

Wiggert, J., O'Brien, S. J. and Dodd, D.W. (2018) Bathymetric Dynamic Digital Elevation Model for the Northern Gulf of Mexico. Distributed by: Gulf of Mexico Research Initiative Information and Data

Cooperative (GRIIDC), Harte Research Institute, Texas A&M University-Corpus Christi. doi: 10.7266/N747488G.

Zaron, E.D., Fitzpatrick, P.J., Cross, S.L., Harding, J.M., Bub, F.L., Wiggert, J.D., Ko, D.S., Lau, Y., Woodard, K., Mooers, C.N.K., 2015. Initial evaluations of a Gulf of Mexico/Caribbean ocean forecast system in the context of the Deepwater Horizon disaster. Frontiers of Earth Science, 1-32.

Appendix

River Forcing: Discharge Locations

The rivers included in the model are: Styx, Wolf Creek, Perdido, Fish, Magnolia, Tensaw, Mobile, Chickasaw, Fowl, Black Creek, Red Creek, Pascagoula, Biloxi, Wolf, Jourdan, East Pearl, West Pearl, Tchefuncte, Tangipahoa, Tickfaw, Amite, Blind, MSR Baptist Collette Bayou, MSR Cubit's Gap Pass, and MSR Pass-a-Loutre (Figure A1, Table A1).

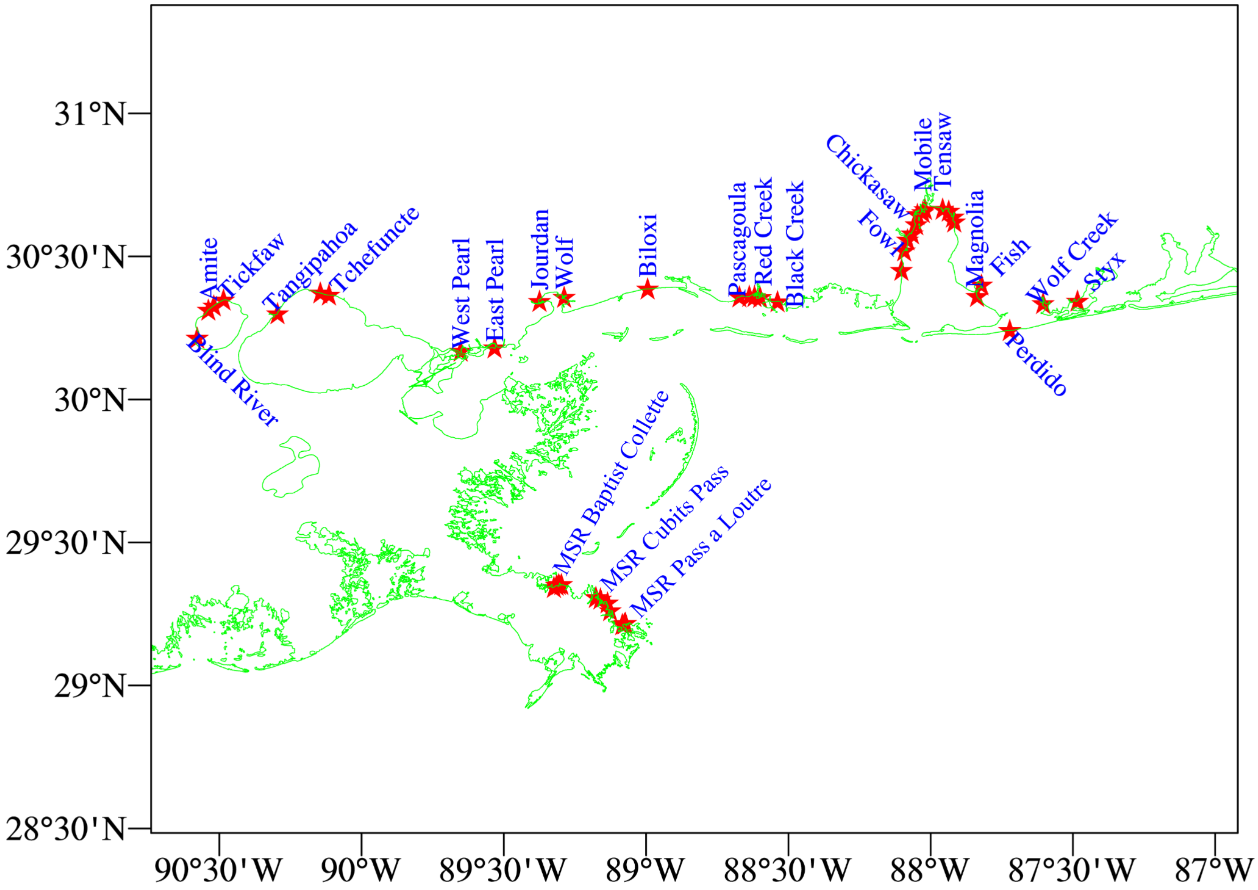


Figure A1: River inflow locations for the msbCOAWST model.

Methodology followed for the preprocessing of the climatological simulation

The daily climatological riverine freshwater input at each USGS station is determined from eleven years of discharge time series (2010-2020). To reduce the impact of isolated outlier values we tested three filtering scenarios, where daily values for a given year were eliminated if they exceeded 1, 2 or 3 standard deviations of the mean value (Figure A2). We settled on applying the 3 SD filtering scheme and applied that for generating the hourly climatology time series at all of our river discharge boundary locations (Figures A2-A23). This method is utilized for filtering out abnormally high discharge events that happened through the eleven-year time period and thus to obtain a smoothed standard discharge time series for each riverine input location. The missing values within the interannual daily discharge data are replaced with the nearest neighbor value during the initial data processing.

Table A1: List of USGS gauge stations used for extracting the daily interannually varying river discharge from which the daily climatology is calculated and applied as model boundary conditions. Time frame of the data applied in developing the climatologies is 01/June/2010 - 31/December/2020.

Serial Number	USGS station ID	USGS station name
1	02469761	TOMBIGBEE R AT COFFEEVILLE L&D NR COFFEEVILLE, AL.
2	02428400	ALABAMA RIVER AT CLAIBORNE L&D NEAR MONROEVILLE
3	02377570	STYX RIVER NEAR ELSANOR, AL.
4	02378170	WOLF CREEK BELOW FOLEY, ALA
5	02376500	PERDIDO RIVER AT BARRINEAU PARK, FL
6	02378500	FISH RIVER NEAR SILVER HILL AL
7	02378300	MAGNOLIA RIVER AT US 98 NEAR FOLEY, ALABAMA
8	02471001	CHICKASAW CREEK NEAR KUSHLA AL
9	02471078	FOWL RIVER AT HALF-MILE RD NEAR LAURENDINE, AL.
10	02479000	PASCAGOULA RIVER AT MERRILL, MS
11	02479300	RED CREEK AT VESTRY, MS
12	07374525	MSR AT BELLE CHASSE, LA
13	02479130	BLACK CREEK NR BROOKLYN, MS
14	02481000	BILOXI RIVER AT WORTHAM, MS
15	02481510	WOLF RIVER NR LANDON, MS
16	02492110	EAST PEARL RIVER AB WILSON SL AT WALKIAH BLUFF, MS
17	07378500	AMITE RIVER NEAR DENHAM SPRINGS, LA
18	07376000	TICKFAW RIVER AT HOLDEN, LA
19	07375500	TANGIPAHOA RIVER AT ROBERT, LA
20	07377000	BLIND RIVER

21	02489500	PEARL RIVER NEAR BOGALUSA, LA
22	07375000	TCHEFUNCTE RIVER NEAR FOLSOM, LA

At the lateral boundaries, the three-hourly climatology of temperature, salinity, velocity components, and surface height data are provided (Figures A22-A24). These boundary variables are obtained from two distinct regional implementations of the Navy Coastal Ocean Model (NCOM; Barron et al., 2004; 2006). The first one is denoted as NCOM-GOM, which is a high-resolution implementation of the NCOM model configured over the entire Gulf of Mexico with a horizontal resolution of 1 km. The second one is NCOM-AMSEAS, which encompasses the American Seas region covering the Gulf of Mexico and the Caribbean Sea (Zaron et al., 2015). The NCOM-AMSEAS has a 3 km horizontal resolution and 40 vertical levels. The boundary condition parameters are extracted from these two model simulations based on the availability of data for the periods of interest along the msbCOAWST open boundaries. A bilinear interpolation method is used to interpolate the extracted variables from their respective inherent resolution to the horizontal and vertical model grid points along the boundary. The climatological three-hourly boundary state is then estimated from the interannual boundary condition variables along the open boundaries of the msbCOAWST model.

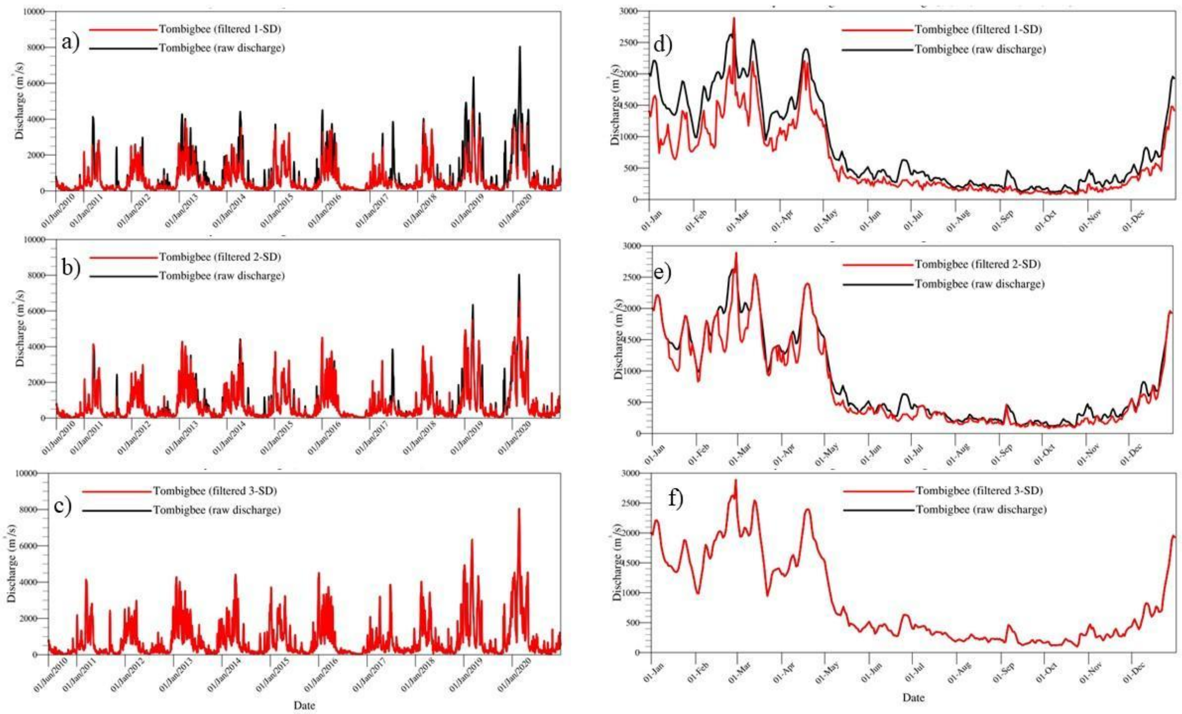


Figure A2: Interannual daily river discharge data for the Tombigbee River (Station 02469761) (a). The raw discharge (black) is overlaid with filtered data using mean value with an addition of incremental standard deviation (SD) windows (red); mean plus one SD (1-SD, a), mean plus two SD (2-SD, b), and mean plus three SD (3-SD, c). The corresponding daily climatological discharges are shown in (b).

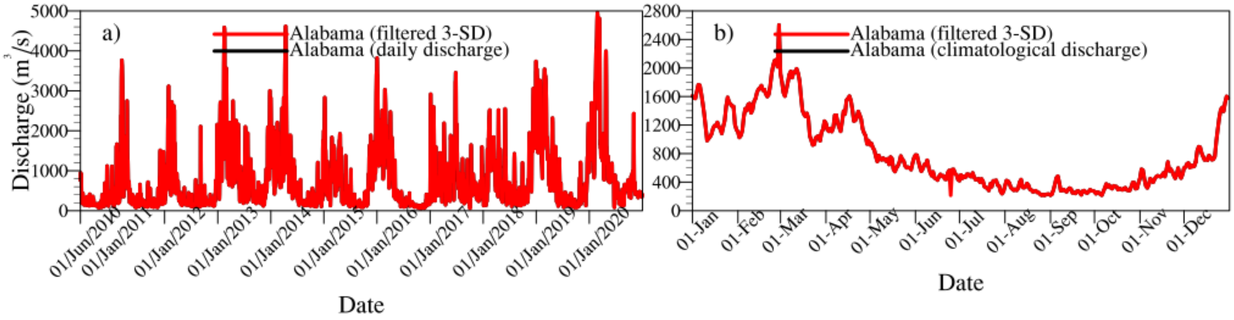


Figure A3: Interannual daily river discharge data for the Alabama River (station 02428400) (a) and the corresponding daily climatological discharge (b).

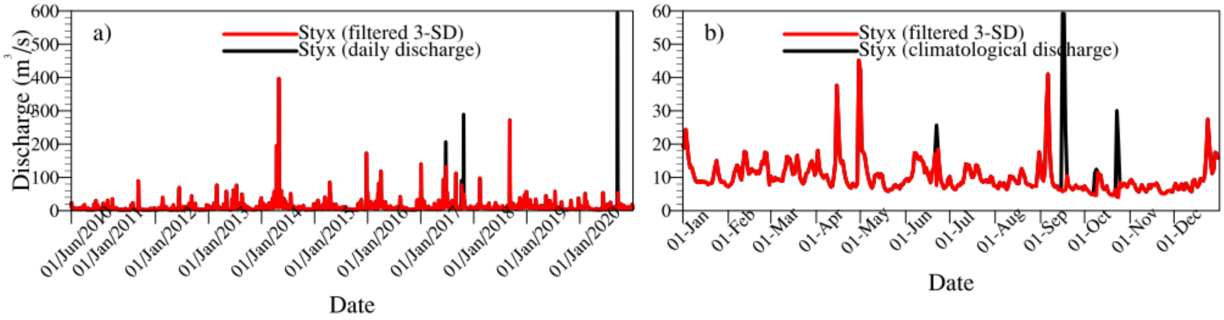


Figure A4: Interannual daily river discharge data for the Styx River (Station 02377570) (a) and the corresponding daily climatological discharge (b).

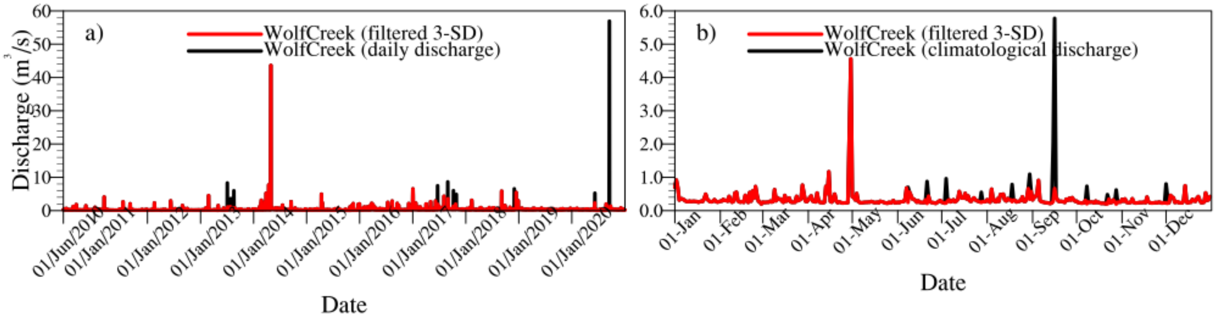


Figure A5: Interannual daily river discharge data for the Wolf Creek (Station 02378170) (a) and the corresponding daily climatological discharge (b).

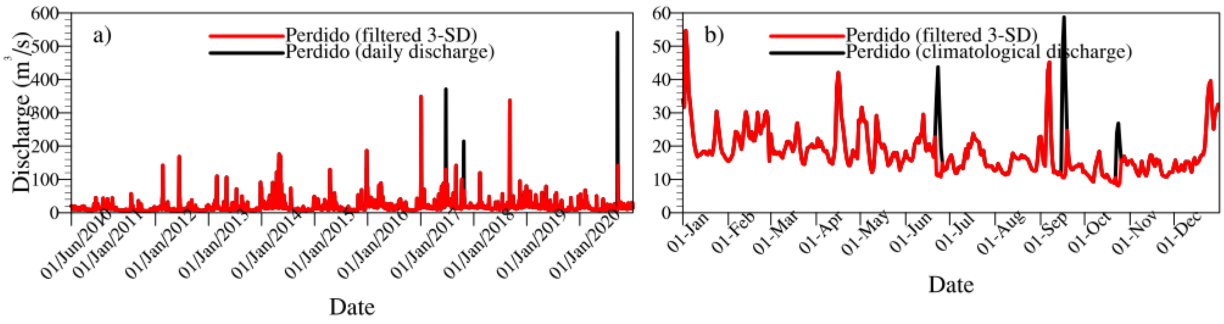


Figure A6: Interannual daily river discharge data for the Perdido River (Station 02376500) (a) and the corresponding daily climatological discharge (b).

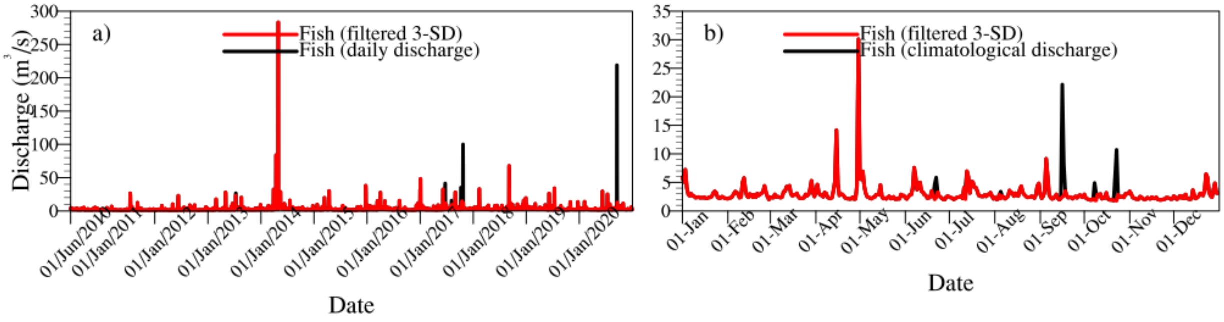


Figure A7: Interannual daily river discharge data for the Fish River (Station 02378500) (a) and the corresponding daily climatological discharge (b).

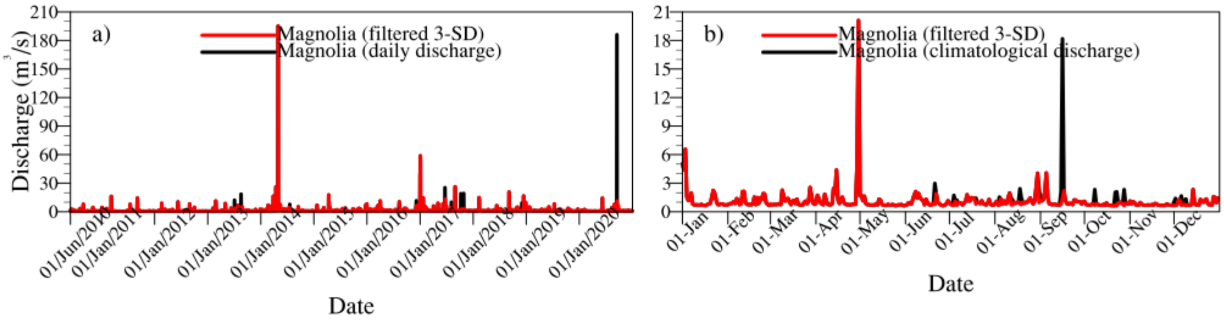


Figure A8: Interannual daily river discharge data for the Magnolia River (Station 02378300) (a) and the corresponding daily climatological discharge (b).

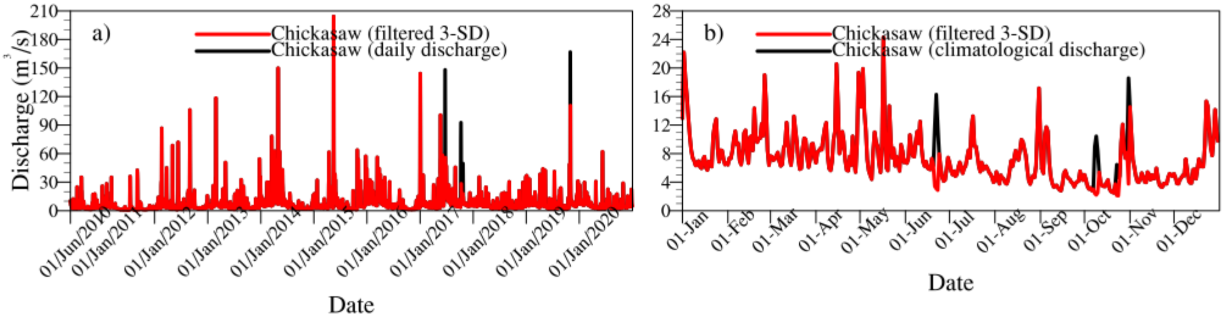


Figure A9: Interannual daily river discharge data for the Chickasaw River (Station 02471001) (a) and the corresponding daily climatological discharge (b).

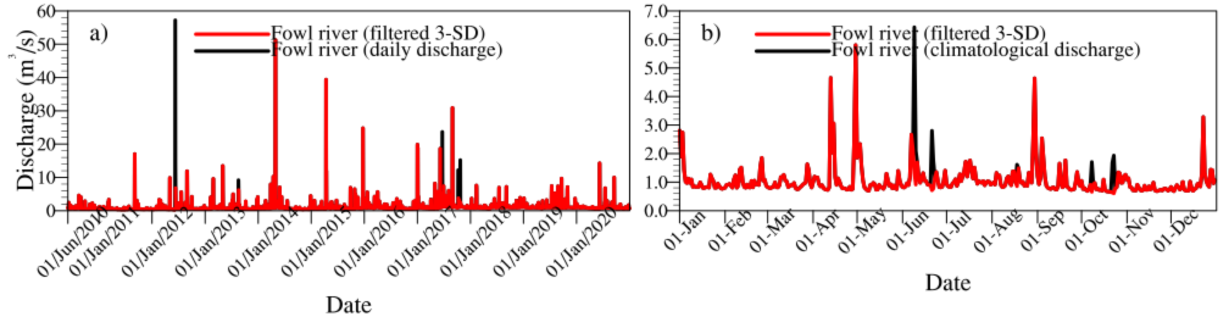


Figure A10: Interannual daily river discharge data for the Fowl River (Station 02471078) (a) and the corresponding daily climatological discharge (b).

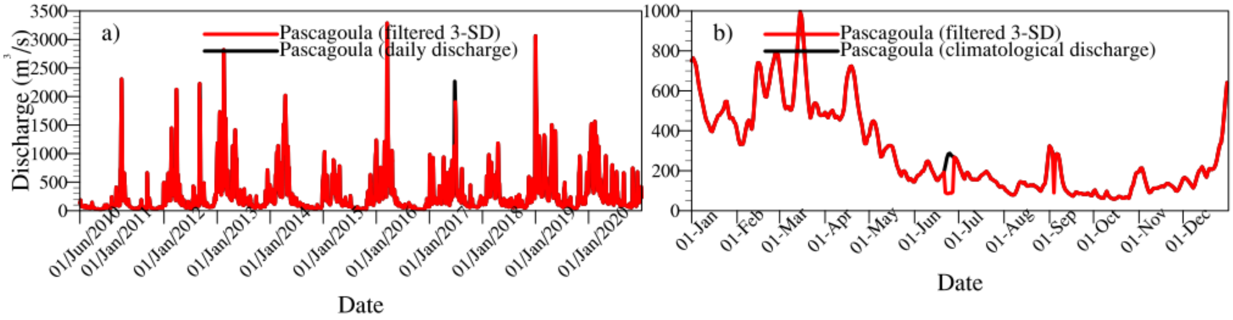


Figure A11: Interannual daily river discharge data for the Pascagoula River (Station 02479000) (a) and the corresponding daily climatological discharge (b).

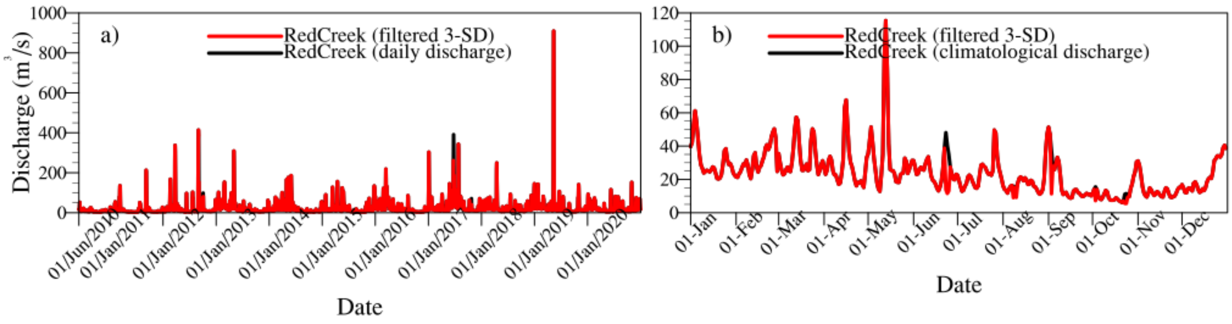


Figure A12: Interannual daily river discharge data for the Red Creek (station 02479300) (a) and the corresponding daily climatological discharge (b).

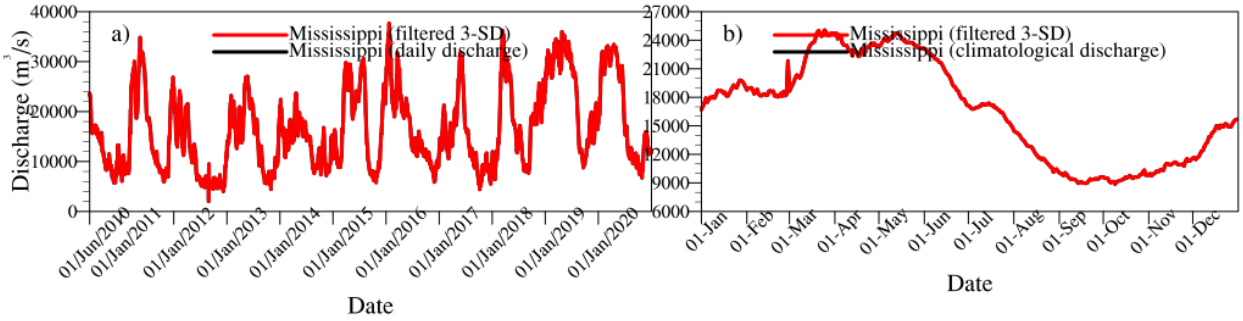


Figure A13: Interannual daily river discharge data for the Mississippi River (Station 07374525) (a) and the corresponding daily climatological discharge (b).

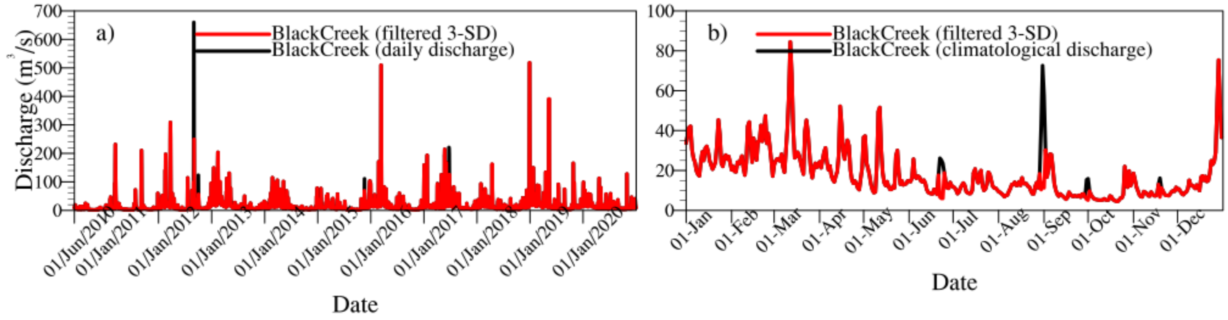


Figure A14: Interannual daily river discharge data for the Black Creek (Station 02479130) (a) and the corresponding daily climatological discharge (b).

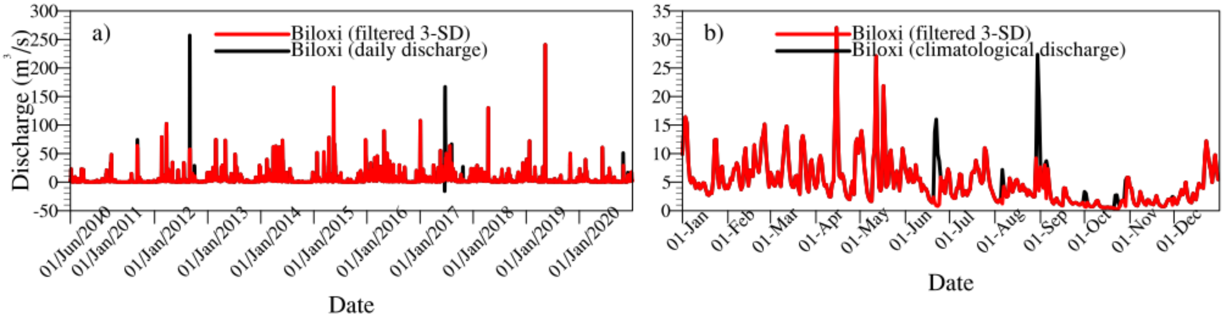


Figure A15: Interannual daily river discharge data for the Biloxi River (Station 02481000) (a) and the corresponding daily climatological discharge (b).

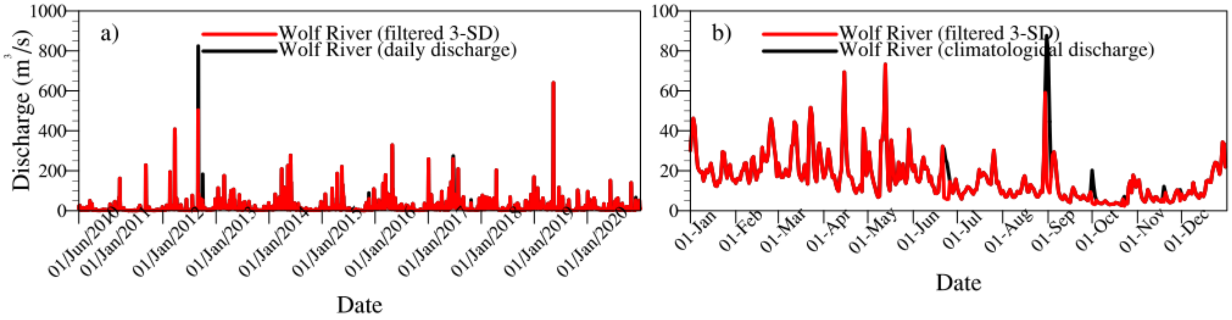


Figure A16: Interannual daily river discharge data for the Wolf River (Station 02481510) (a) and the corresponding daily climatological discharge (b).

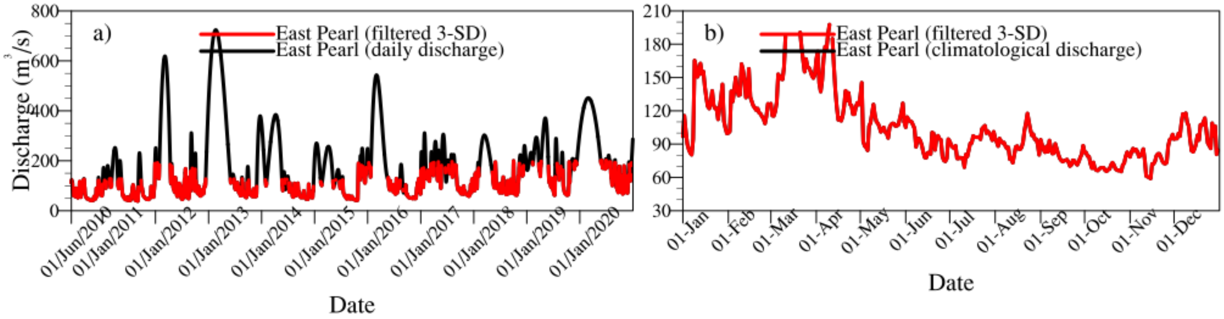


Figure A17: Interannual daily river discharge data for the East Pearl River (Station 02492110) (a) and the corresponding daily climatological discharge (b).

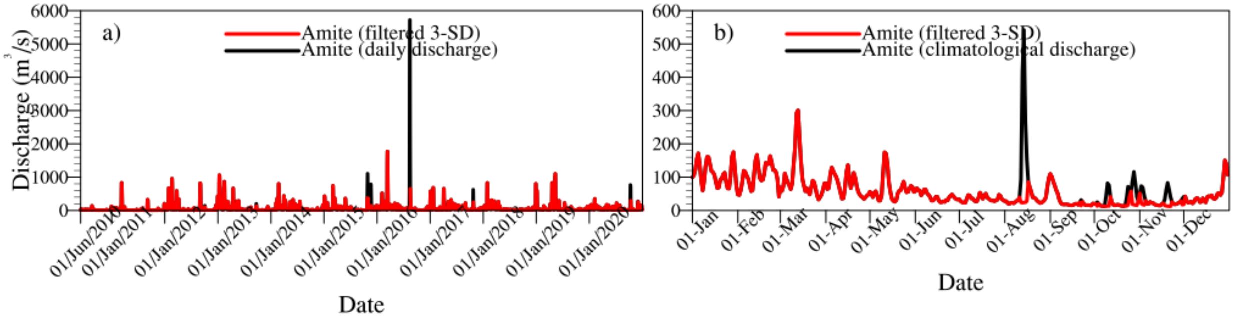


Figure A18: Interannual daily river discharge data for the Amite River (Station 07378500) (a) and the corresponding daily climatological discharge (b).

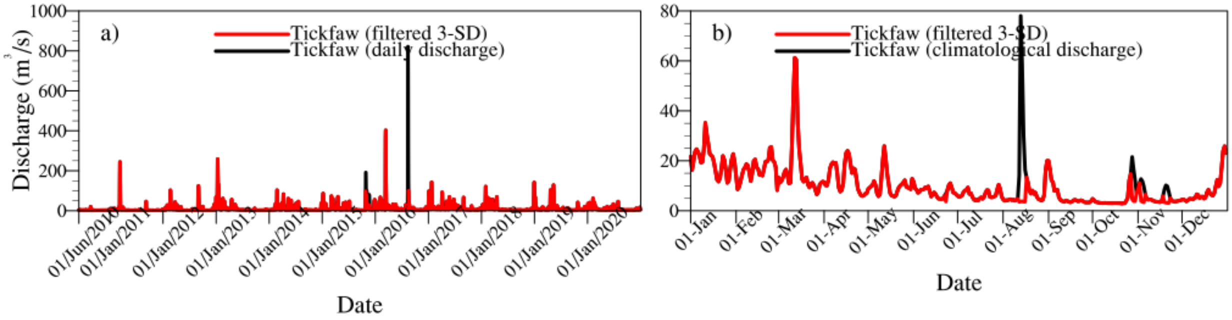


Figure A19: Interannual daily river discharge data for the Tickfaw River (Station 07376000) (a) and the corresponding daily climatological discharge (b).

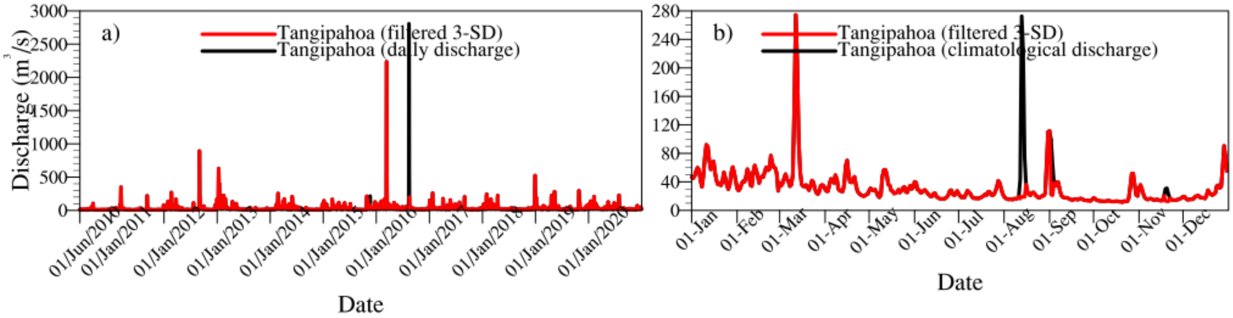


Figure A20: Interannual daily river discharge data for the Tangipahoa River (Station 07375500) (a) and the corresponding daily climatological discharge (b).

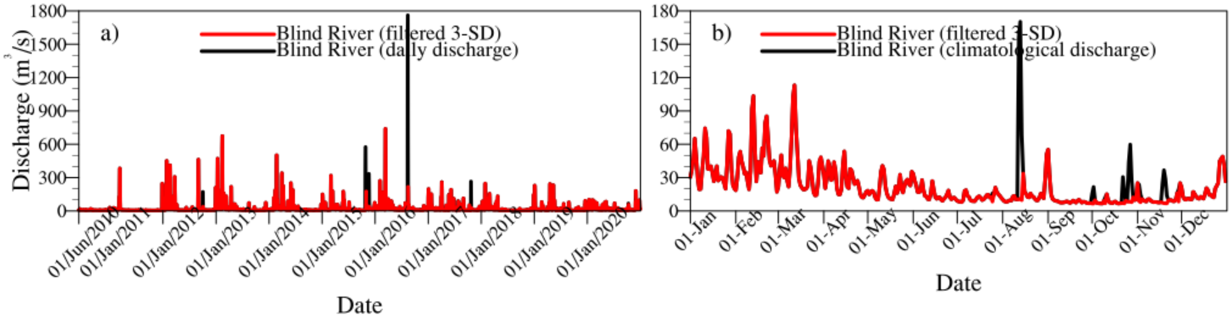


Figure A21: Interannual daily river discharge data for the Blind River (Station 07377000) (a) and the corresponding daily climatological discharge (b).

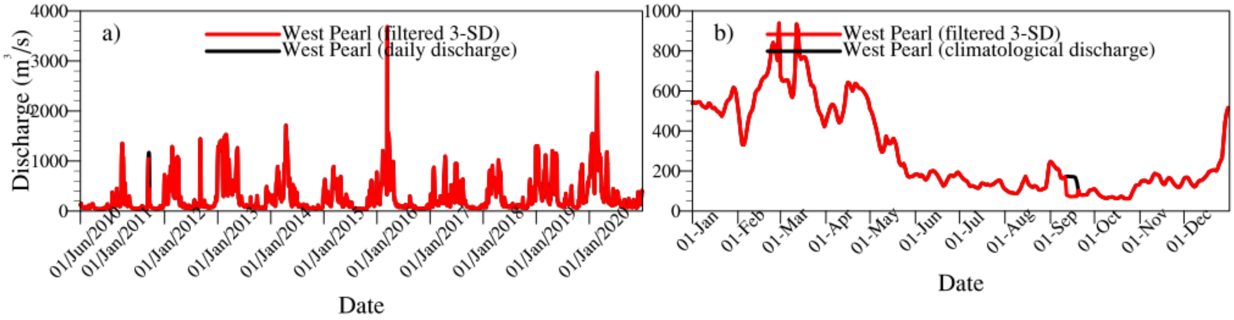


Figure A22: Interannual daily river discharge data for the West Pearl River (Station 02489500) (a) and the corresponding daily climatological discharge (b).

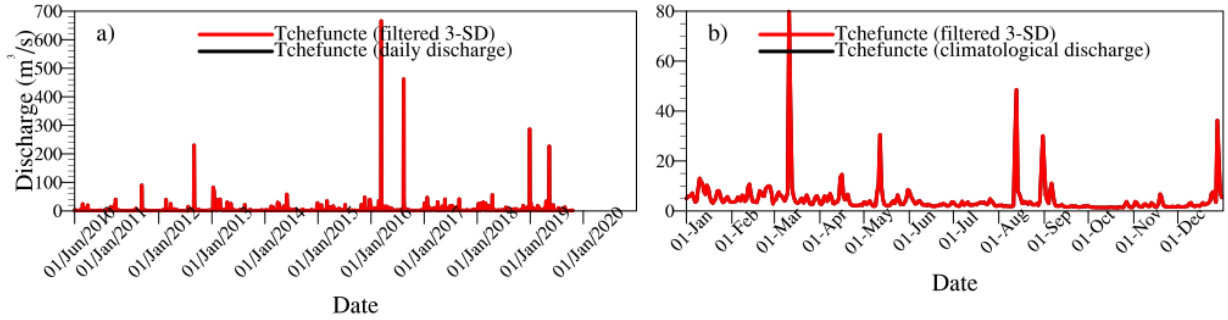


Figure A23: Interannual daily river discharge data for the Tchefuncte River (Station 07375000) (a) and the corresponding daily climatological discharge (b).

Examples of 2019 boundary condition forcing

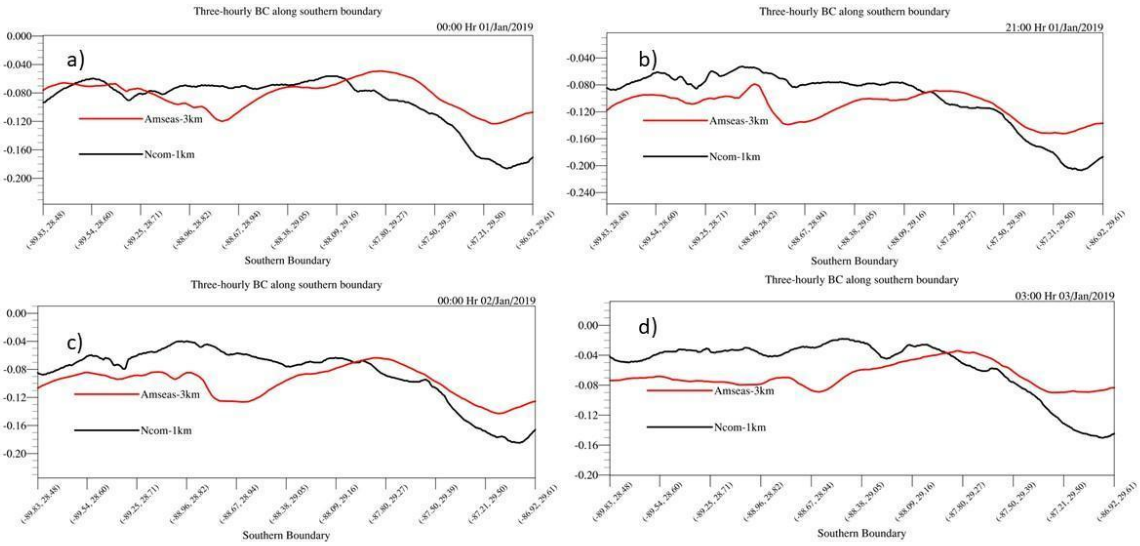


Figure A24: Comparison of sea surface height boundary condition extracted from NCOM-GOM (black) and NCOM-AMSEAS (red) along the southern boundary of the msbCOAWST model at different times during January 2019.

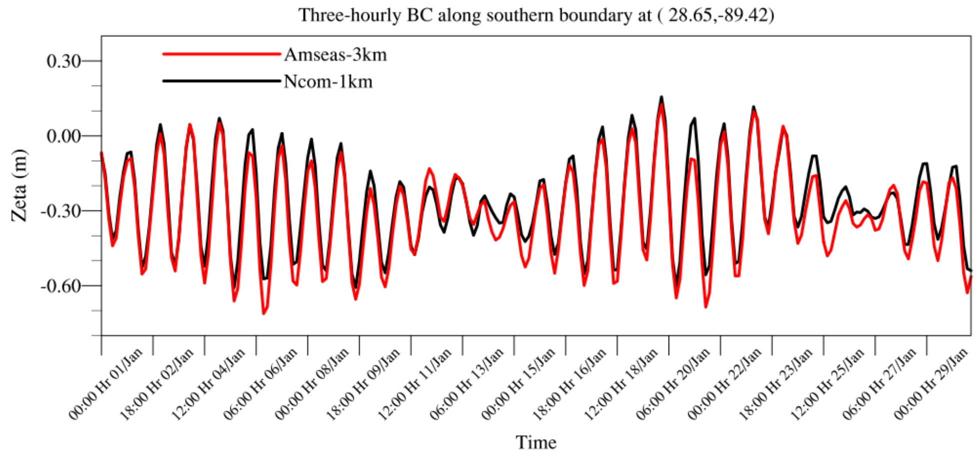


Figure A25: Comparison of temporal evolution of sea surface height boundary condition extracted from NCOM-GOM (black) and NCOM-AMSEAS (red) at a point location along the southern boundary of the msbCOAWST model during January 2019. This illustrates how tidal forcing is introduced into the model.

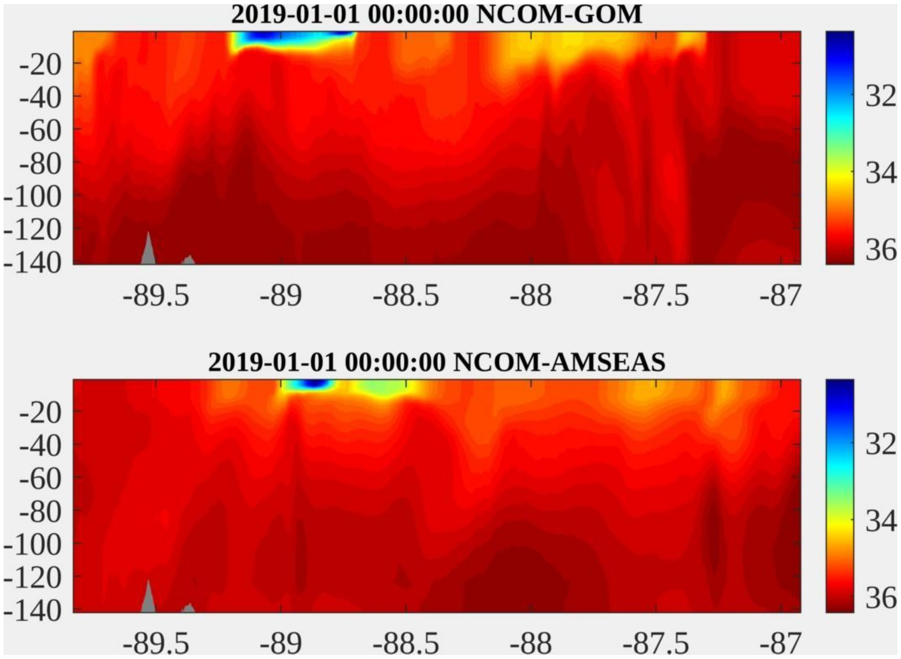


Figure A26: Comparison of salinity boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

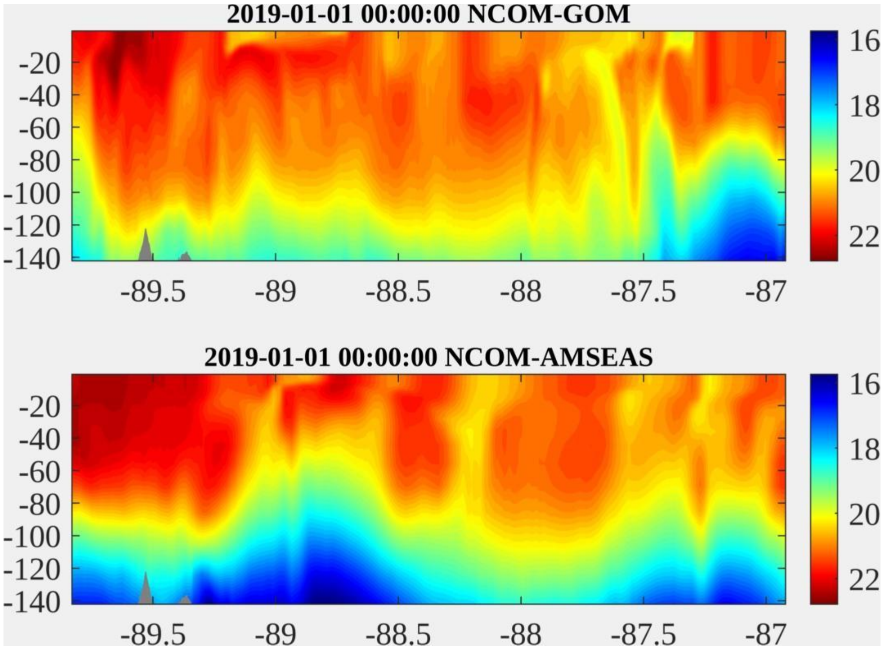


Figure A27: Comparison of temperature boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

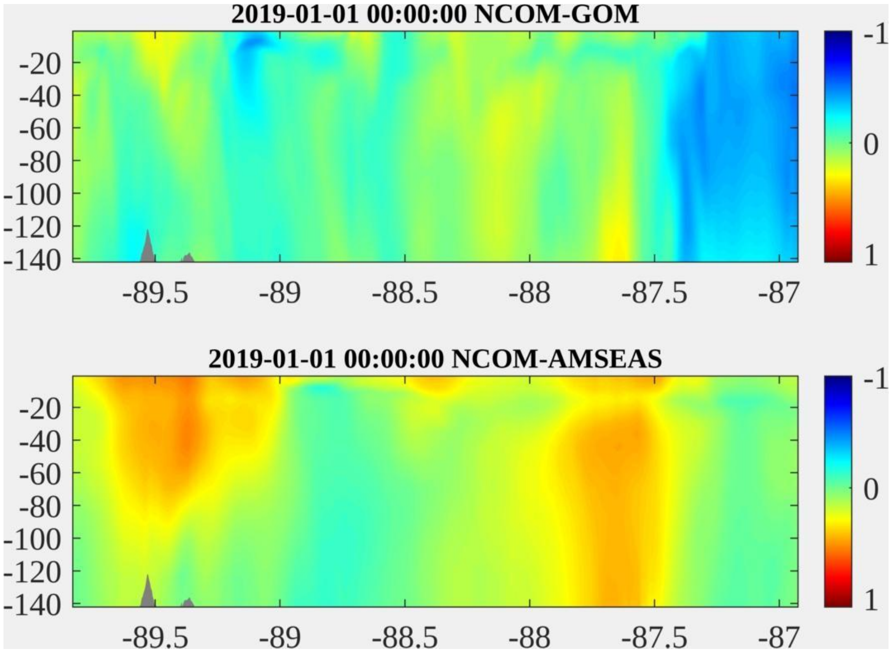


Figure A28: Comparison of zonal velocity boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

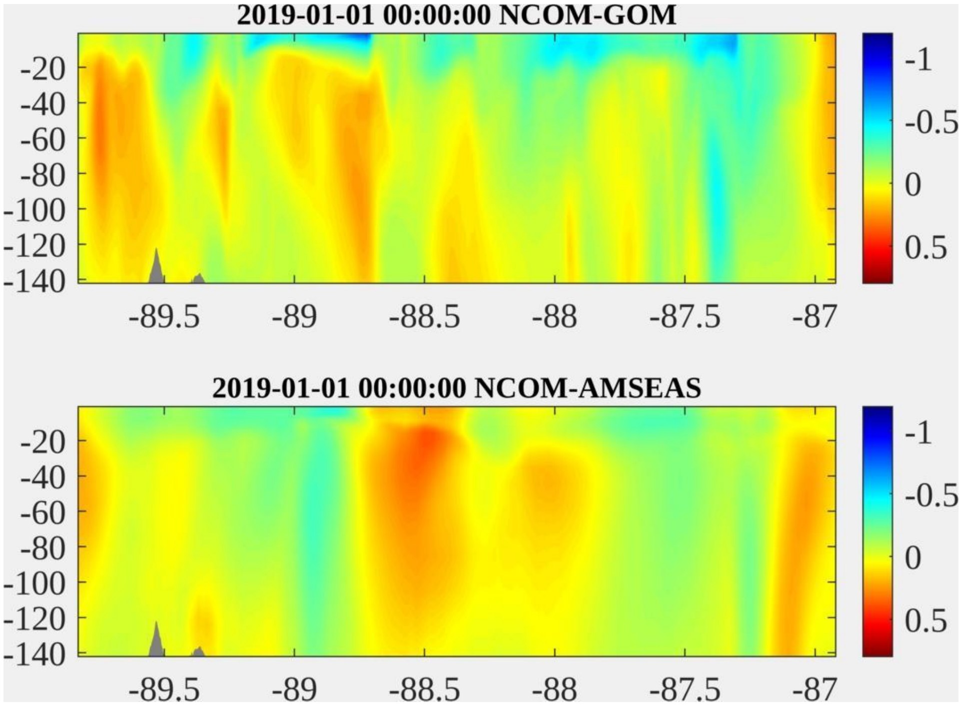


Figure A29: Comparison of meridional velocity boundary condition in January 2019 extracted from NCOM-GOM (top) and NCOM-AMSEAS (bottom) along the southern boundary of the msbCOAWST model.

Consecutive days of bottom salinity below 5 in all scenarios

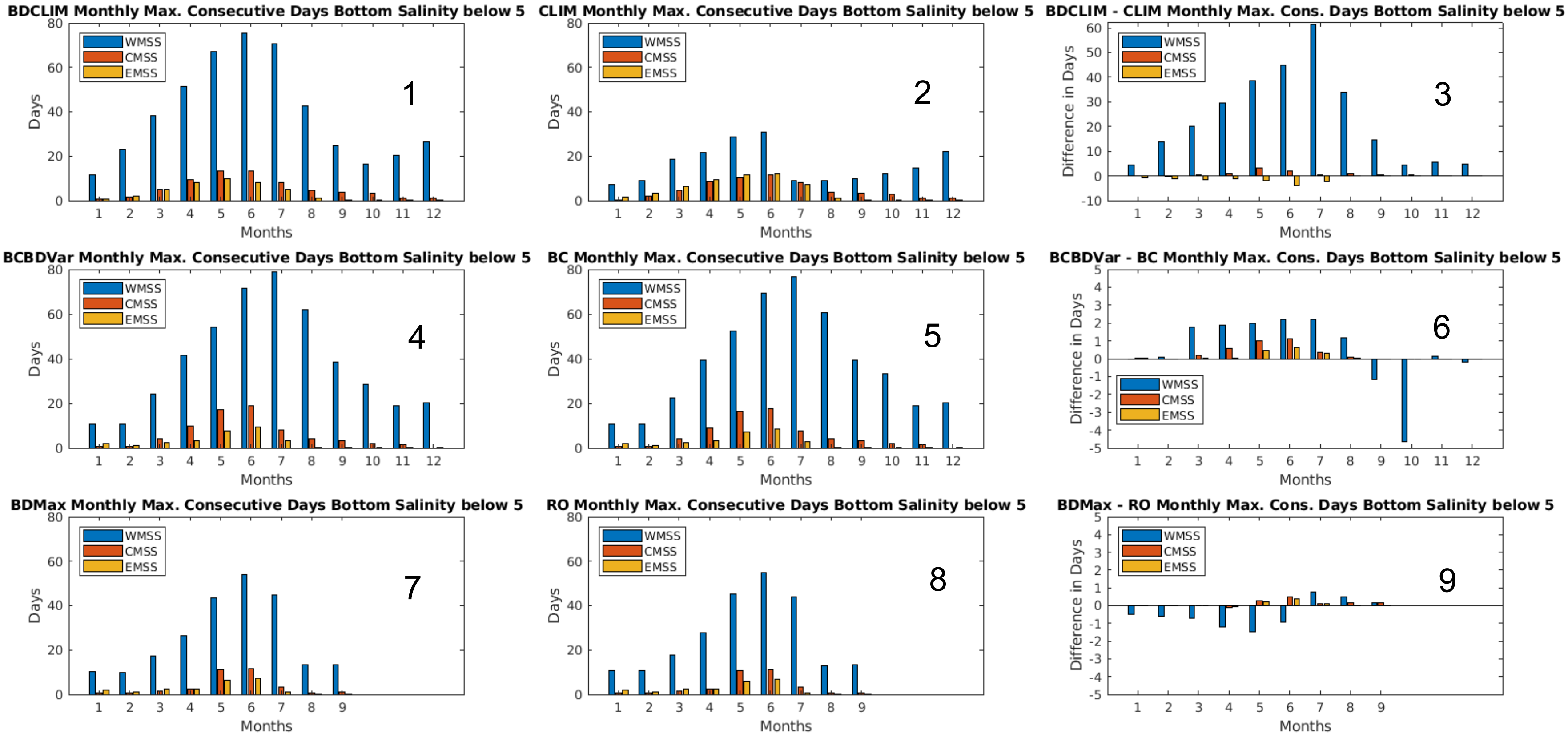
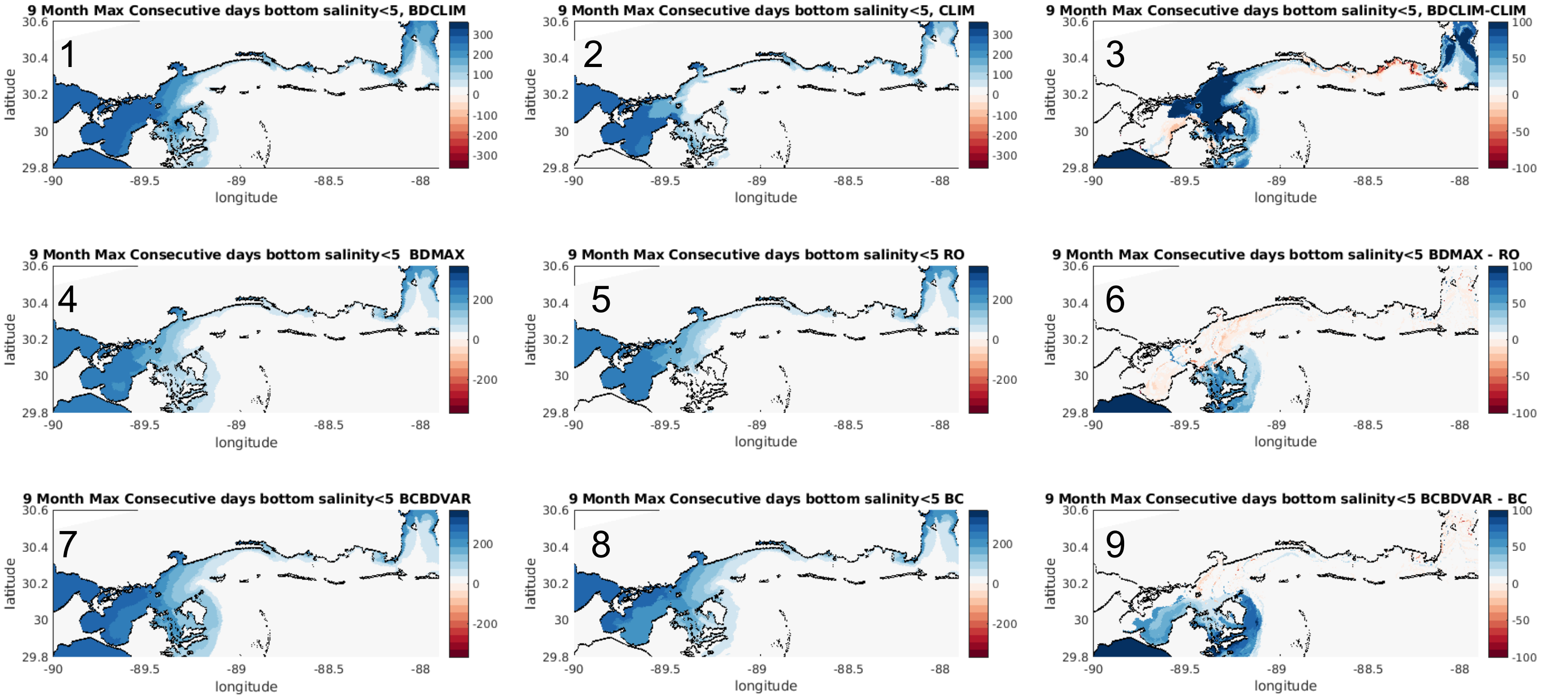


Figure A30. Monthly maximum consecutive days and the difference in maximum consecutive days of bottoms salinity below 5 ppt (across twin experiments) between scenarios with Breton Diversion discharge and those without within the areas defined in figure 15. Abbreviations are as follows: WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, and EMSS=Eastern Mississippi Sound.


9 Month Max Consecutive days bottom salinity<5, BDCLIM

9 Month Max Consecutive days bottom salinity<5, CLIM

9 Month Max Consecutive days bottom salinity<5, BDCLIM-CLIM

9 Month Max Consecutive days bottom salinity<5 BDMAX

9 Month Max Consecutive days bottom salinity<5 RO

9 Month Max Consecutive days bottom salinity<5 BDMAX - RO

9 Month Max Consecutive days bottom salinity<5 BCBDVAR

9 Month Max Consecutive days bottom salinity<5 BC

9 Month Max Consecutive days bottom salinity<5 BCBDVAR - BC

Figure A31. The maximum consecutive days where average bottom salinity is below 5 ppt in all scenarios (columns 1 and 2) and the difference across twin experiments (column 3) in cumulative days when comparing Breton Sound scenarios with the non Breton Diversion scenarios. In the difference plots, positive values (blue, fresher) indicate there are more consecutive days below 5 ppt in the Breton Diversion scenario while negative values (red, saltier) indicate there are fewer consecutive days below 5 ppt.

Cumulative days of bottom salinity below 5 in all scenarios

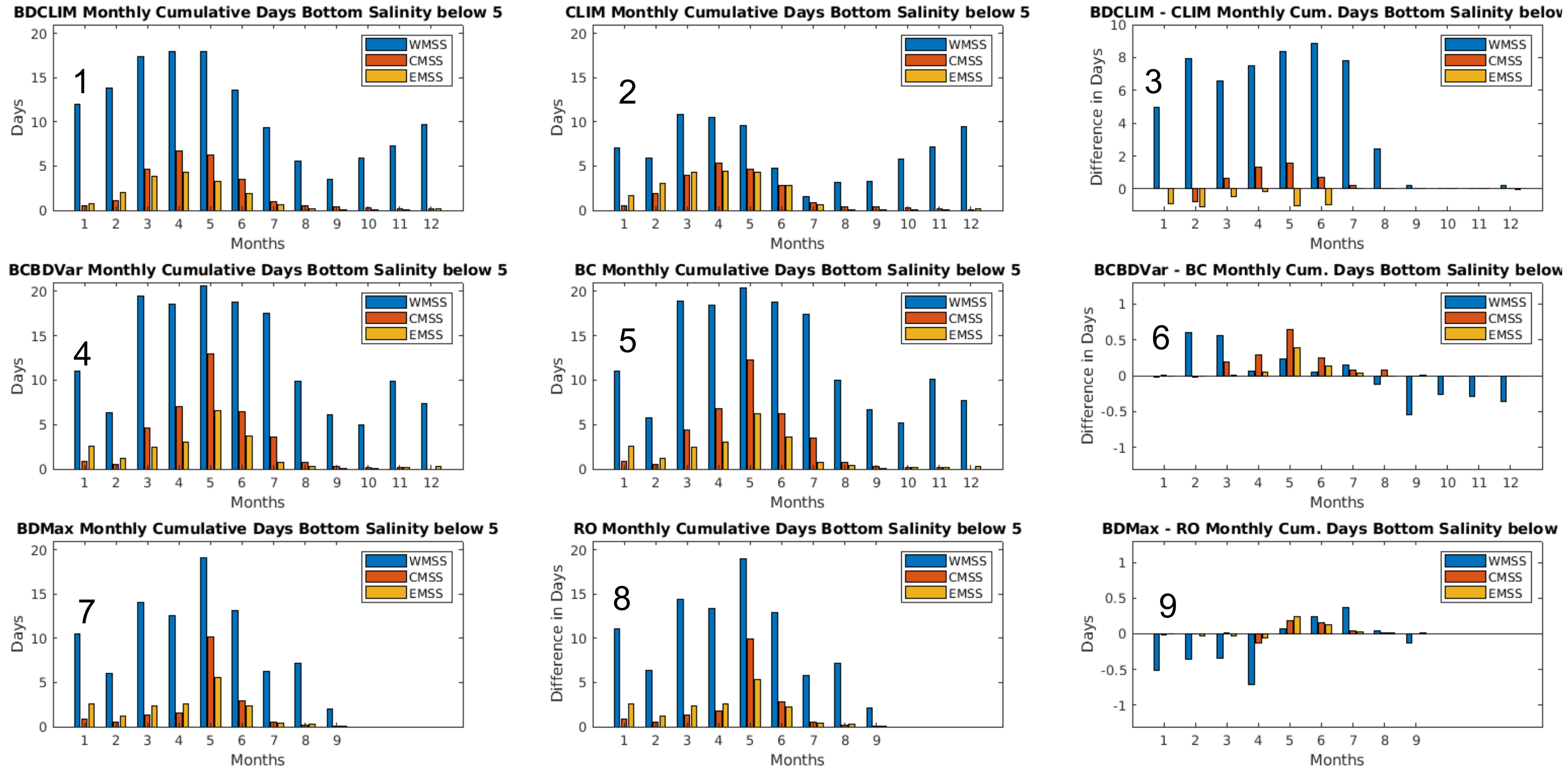


Figure A32. Accumulated days of bottoms salinity below 5 ppt during each month, and the difference across twin experiments (third column), between scenarios with Breton Diversion discharge and those without within the areas defined in figure 14b. Abbreviations are as follows: WMSS=Western Mississippi Sound, CMSS=Central Mississippi Sound, and EMSS=Eastern Mississippi Sound.

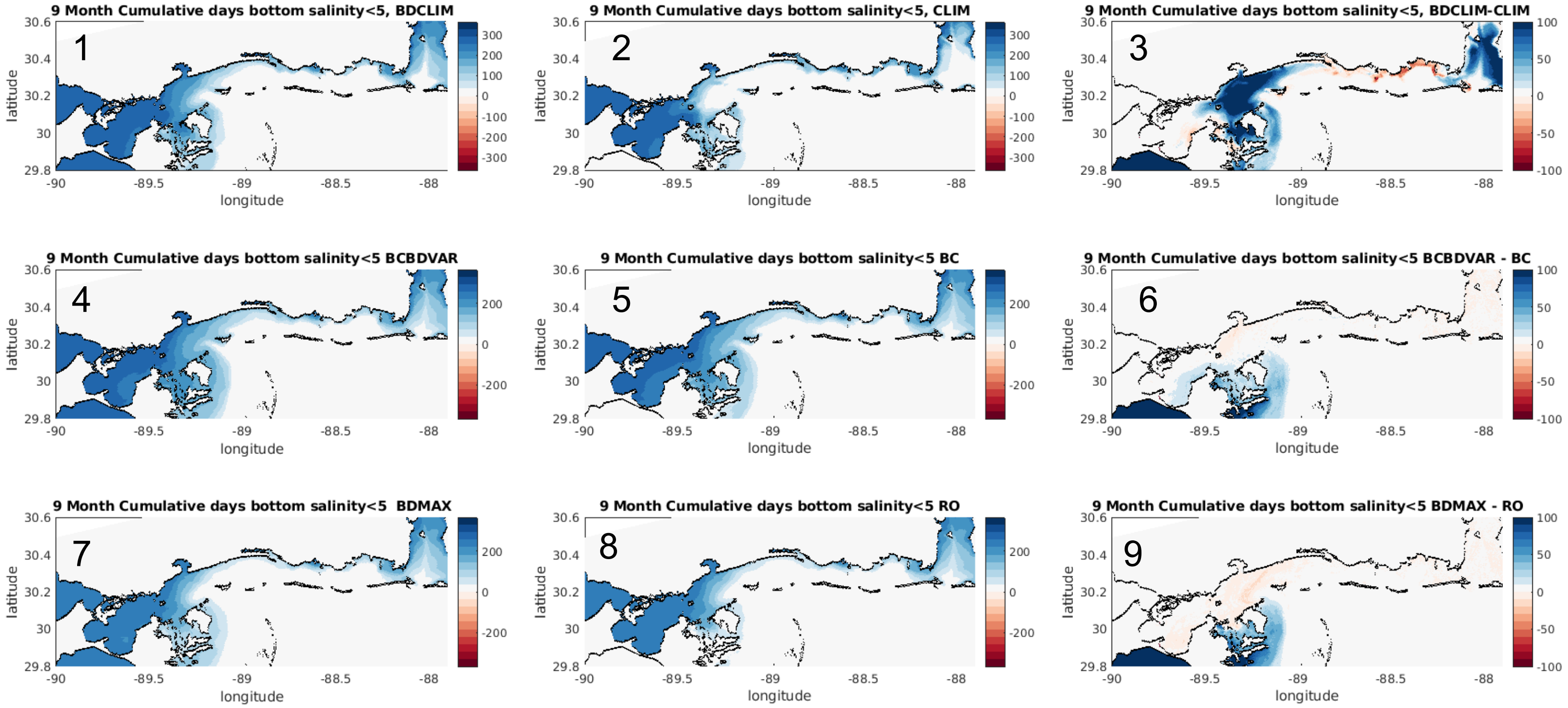


Figure A33. The total cumulative days where average bottom salinity is below 5 ppt in all scenarios (column 1 and 2) and the difference across twin experiments (column 3) in cumulative days in the Breton Diversion scenarios when compared with the scenarios not including the Breton Diversion. In the difference plots, positive values (blue, fresher) indicate there are more consecutive days below 5 ppt in the Breton scenarios while negative values indicate there are fewer consecutive days below 5 ppt in the Breton Diversion scenarios.

Preliminary Model - Data Comparison to USGS Time-series Stations.

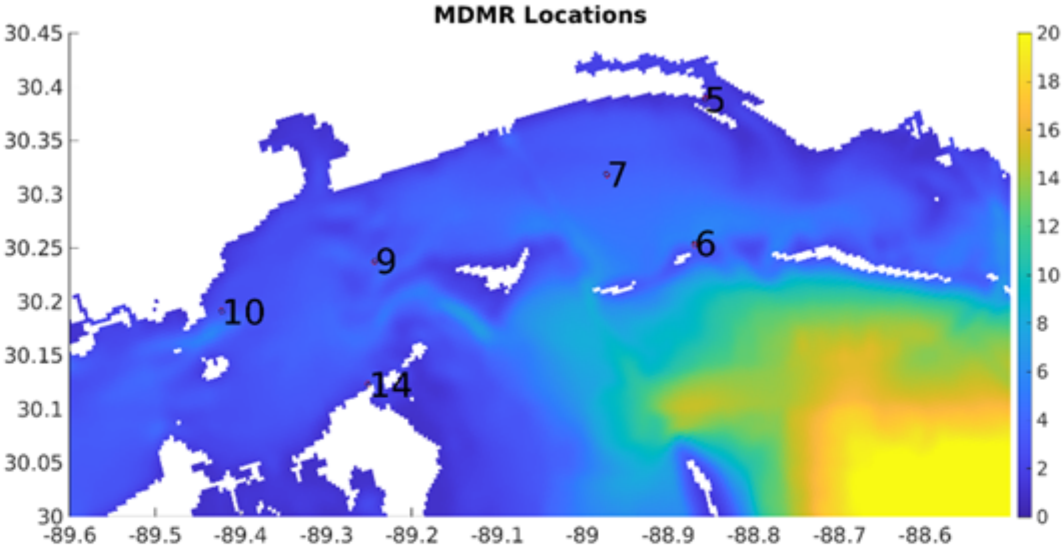


Figure A34. Mississippi Department of Marine Resources continuous monitoring locations plotted over model depth.

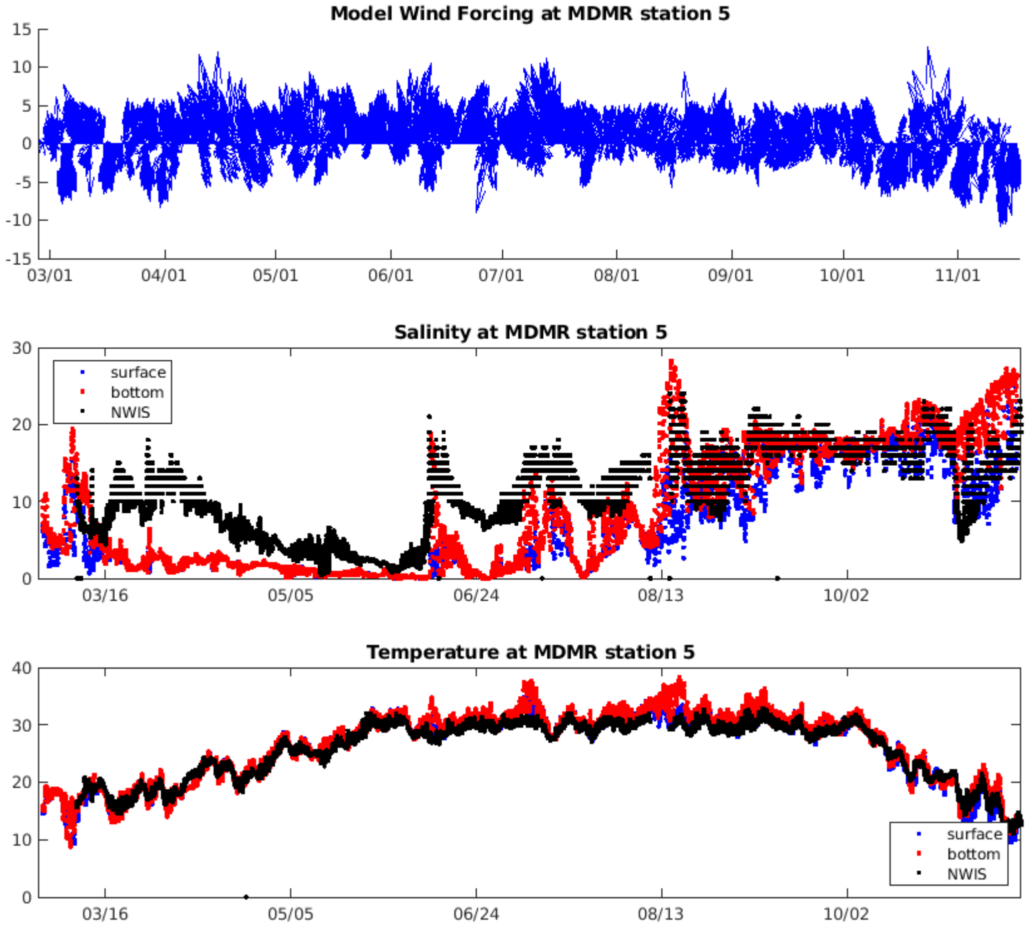


Figure A35. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 5 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

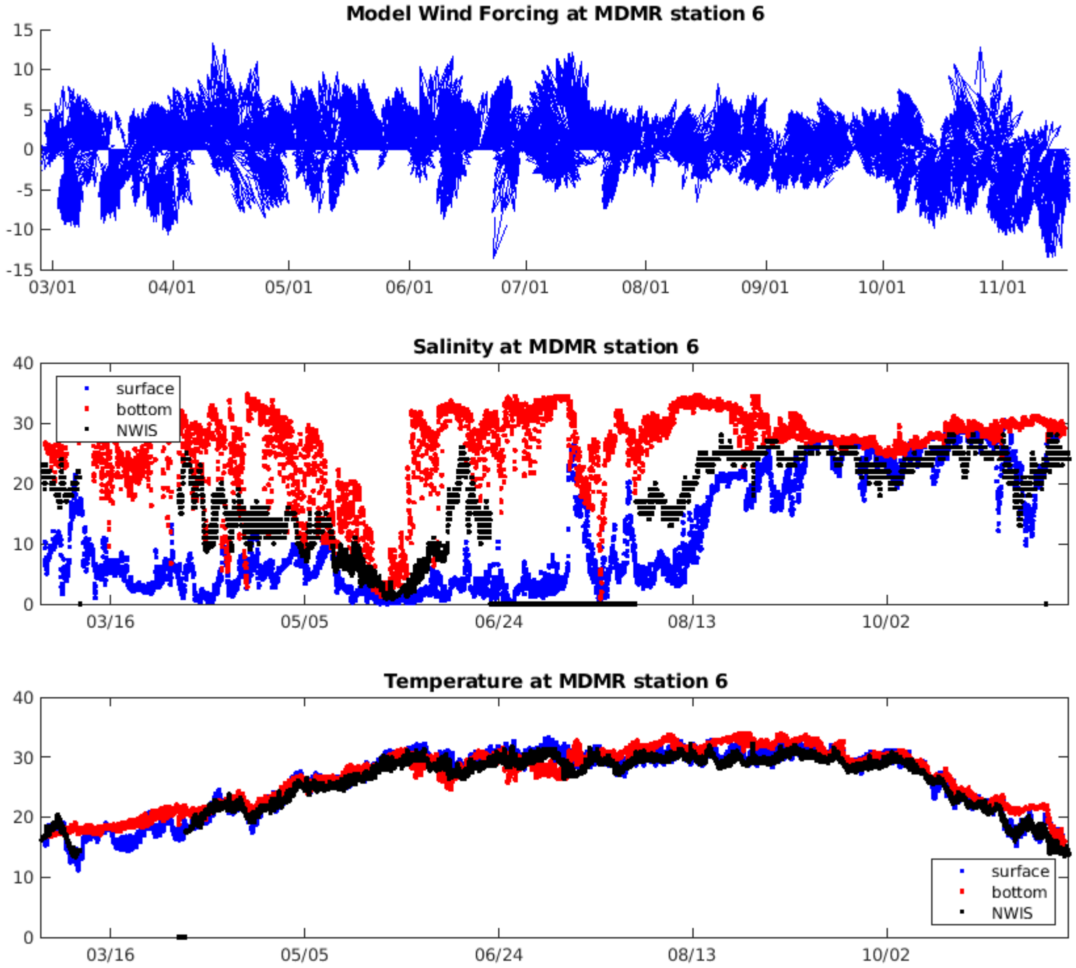


Figure A36. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 6 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

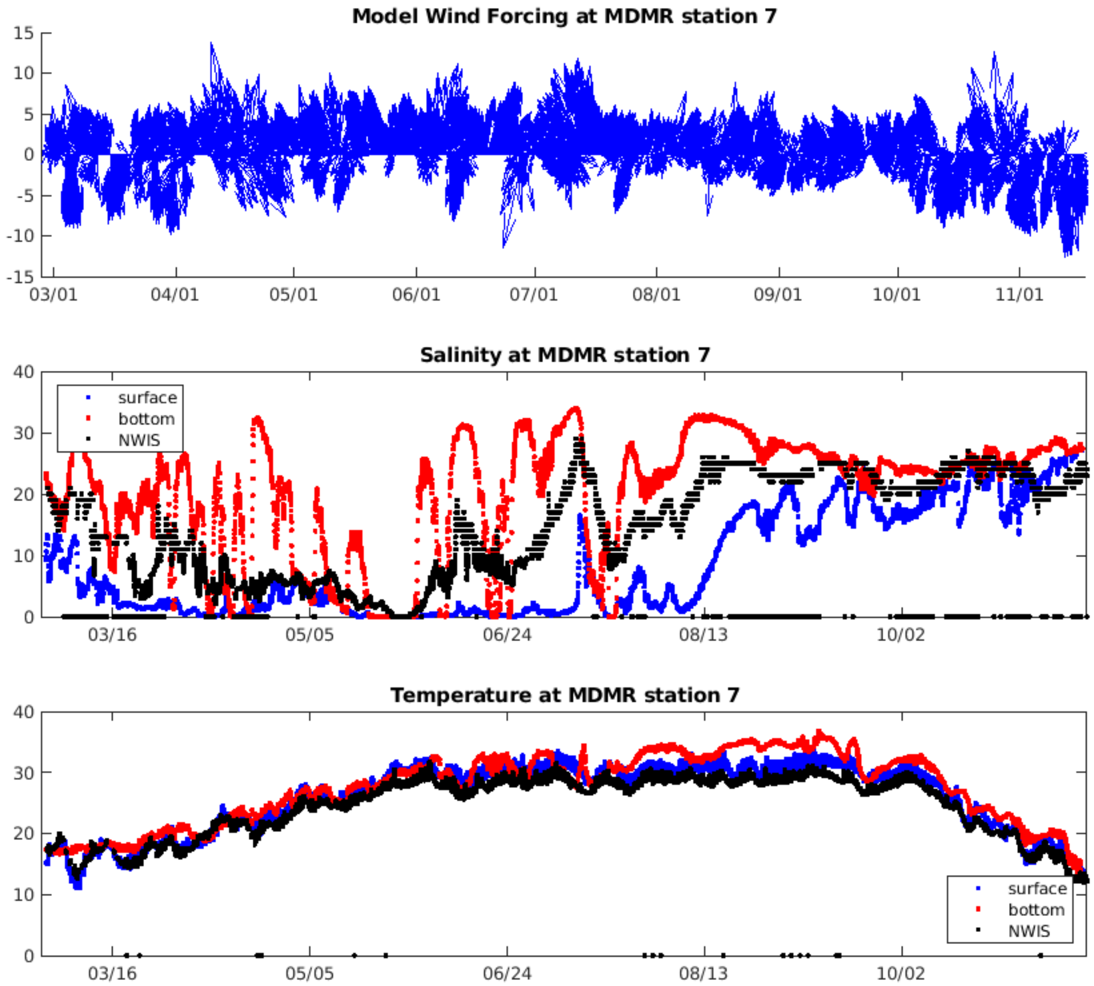


Figure A37. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 7 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

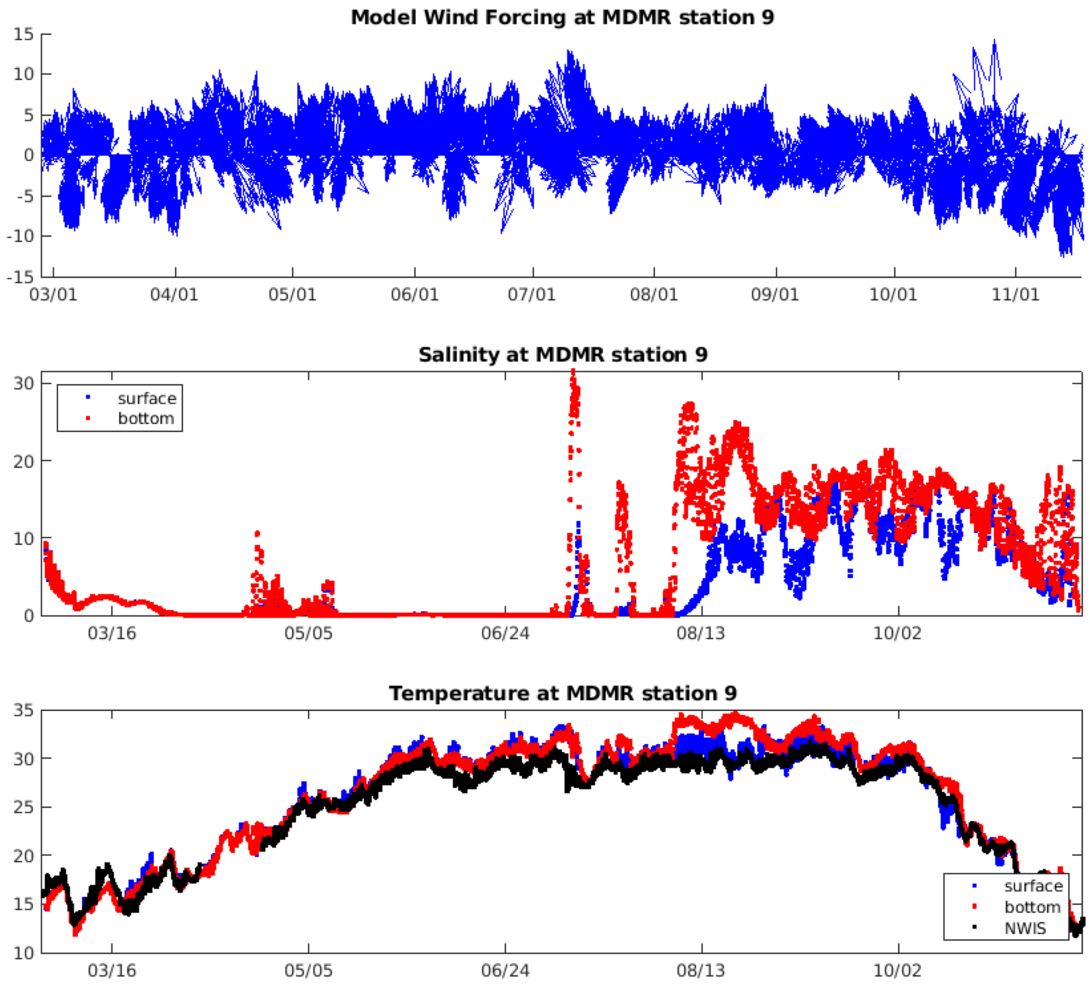


Figure A38. Time series from 2019 of: a) HRRR wind vectors; b) model salinity (ppt) (surface (blue) and bottom (red)); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 9 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

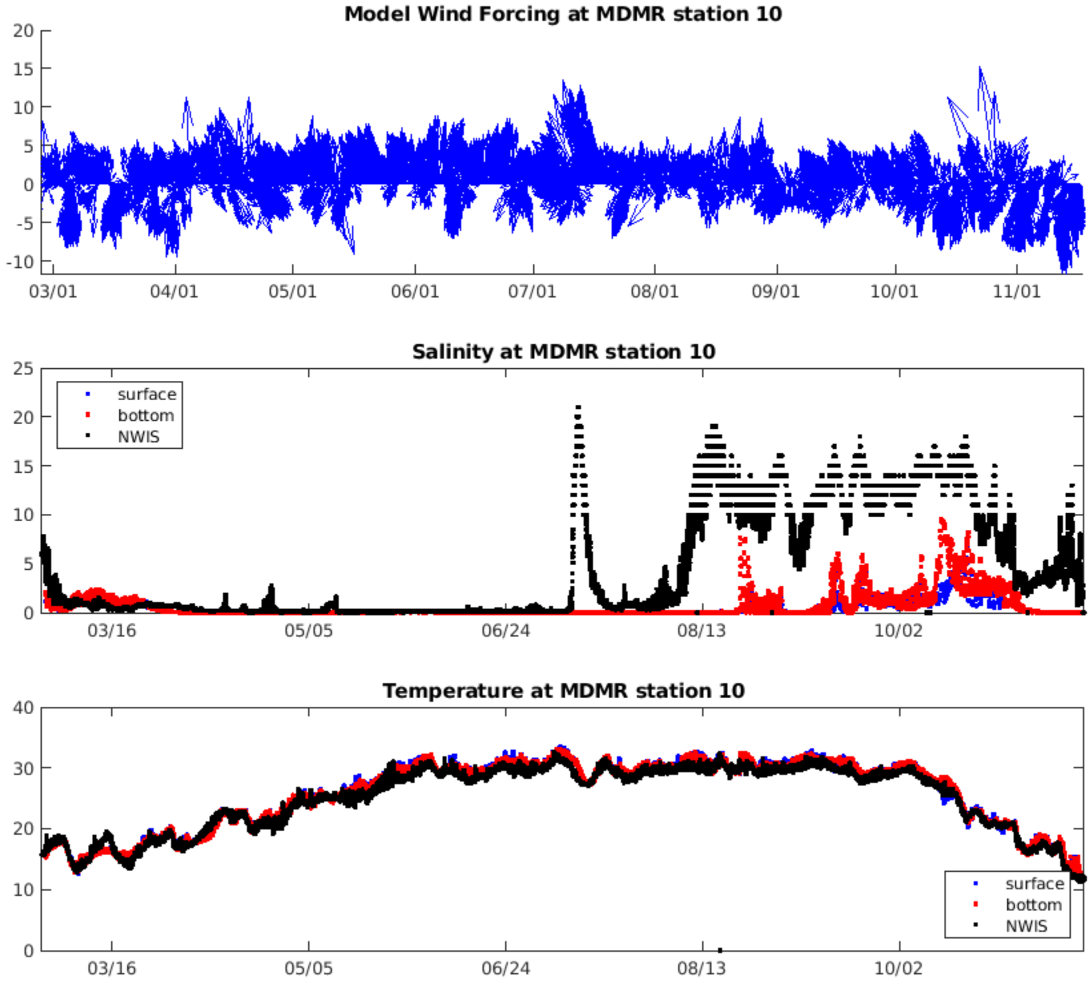


Figure A39. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 10 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).

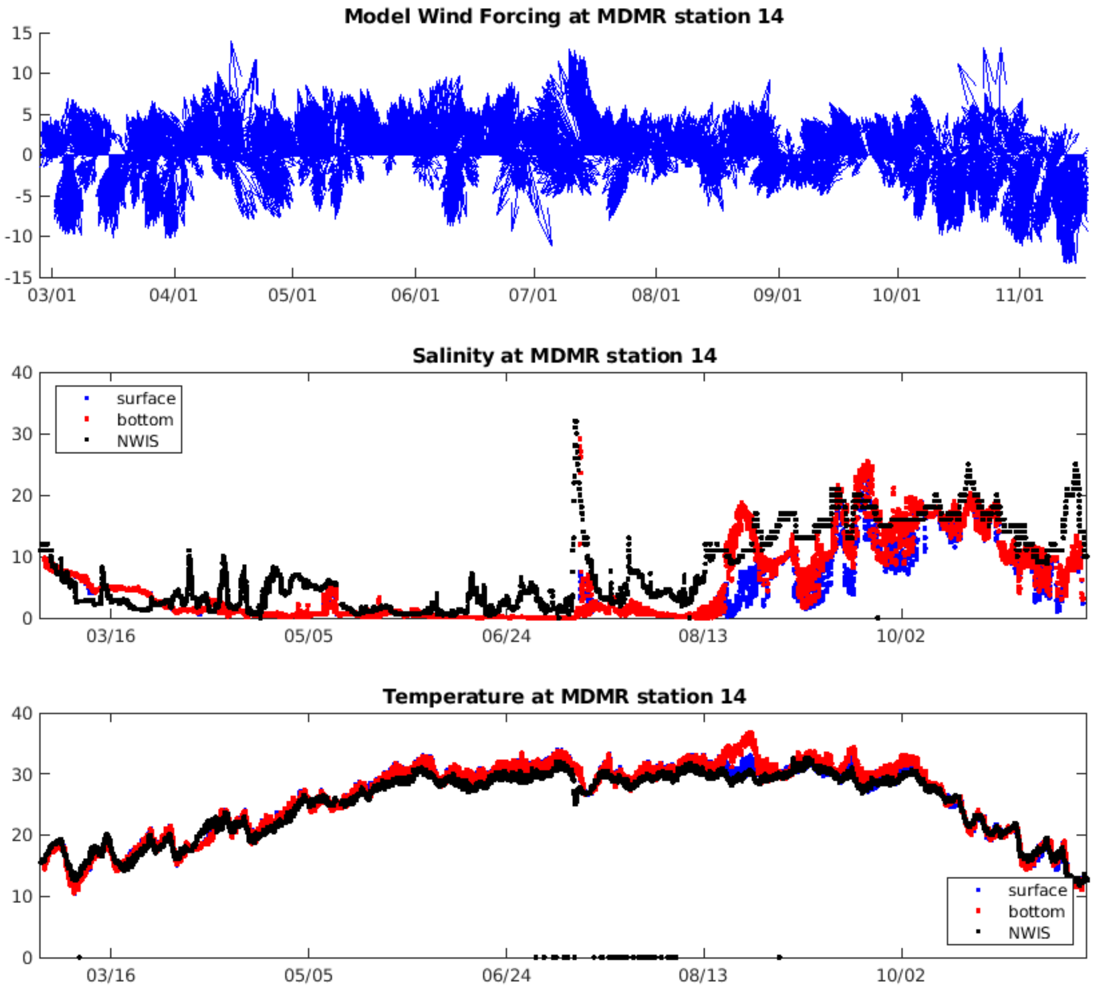


Figure A40. Time series from 2019 of: a) HRRR wind vectors; b) comparison of model salinity (ppt) (surface (blue) and bottom (red)) with observed salinity (black); and c) comparison of model temperature (surface (blue) and bottom (red)) in degrees Celsius (˚C) with observed temperature (black). The observed hydrological time series are from USGS station 14 (Figure A34) in Mississippi Sound. The model output is from the Bonnet Carré (BC) run (Table 1).