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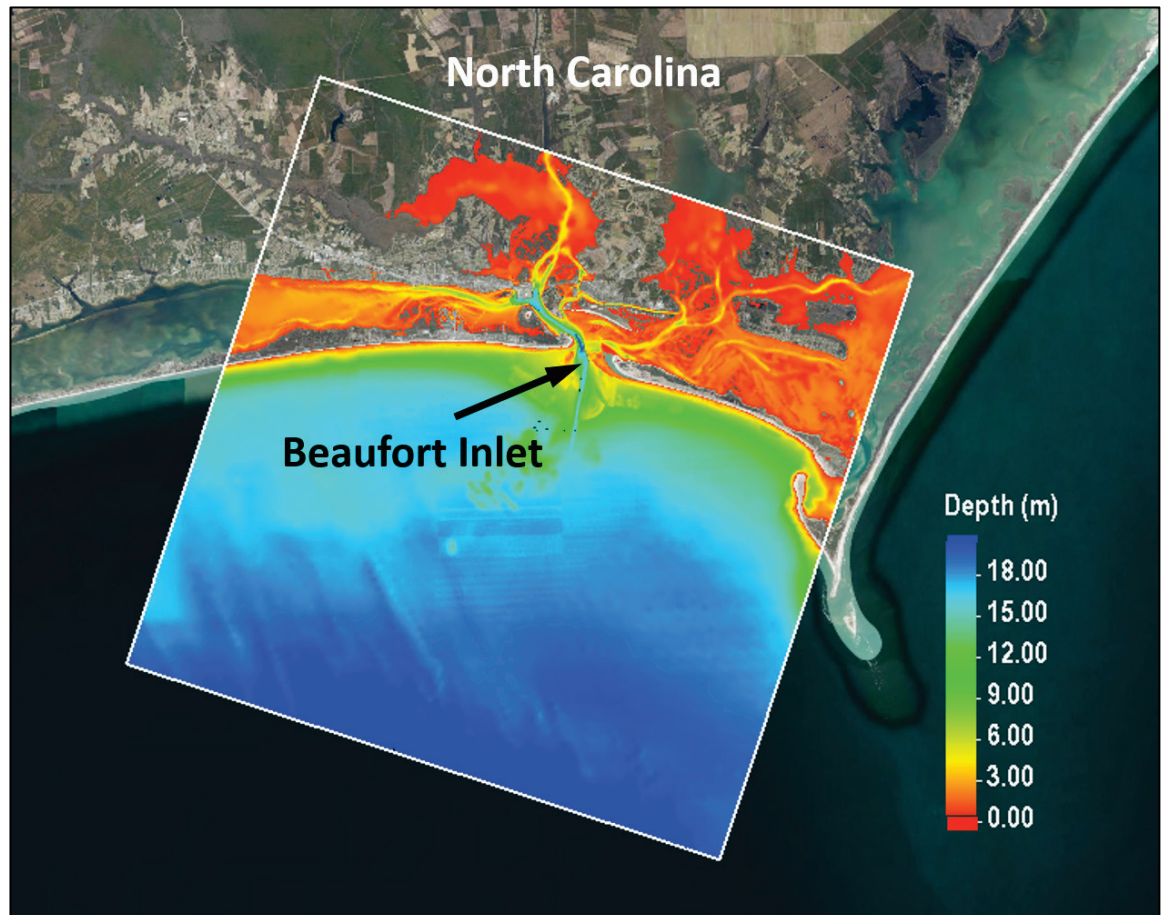


Coastal Inlets Research Program

Use of Sediment Tracers to Evaluate Sediment Plume at Beaufort Inlet and Adjacent Beaches, North Carolina

Honghai Li, Carter A. Rucker, Lihwa Lin, and Kevin B. Conner

April 2024



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Use of Sediment Tracers to Evaluate Sediment Plume at Beaufort Inlet and Adjacent Beaches, North Carolina

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Abstract

This report documents a numerical modeling investigation on the transport of sediment material placed on designated disposal sites adjacent to Beaufort Inlet, North Carolina. Historical and newly collected wave and hydrodynamic data around the inlet are assembled and analyzed. The data sets are used to calibrate and validate a coastal wave, hydrodynamic and sediment transport model, the Coastal Modeling System. Model alternatives are developed corresponding to different material placement sites. Sediment transport and sediment plume distribution are evaluated within and around the immediate vicinity of the Beaufort Inlet estuarine system for a representative summer and winter month. Results of model simulations show that high flows occur along navigation channels and low flows occur outside the inlet in open ocean area. Sand materials placed in nearshore sites tend to be trapped in and move along navigation channels entering the inlet. In offshore placement sites the sediment plume shows slow spreading and no significant sand migration from its release locations. Simulations for the summer and winter month present similar distribution patterns of sediments originating from placement sites.

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Preface

This study was conducted for the US Army Corps of Engineers (USACE), Wilmington (SAW) District, by the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL), funding provided by SAW under MIPR W81EWF13548380.

The field data collection program was completed by the Field Data Collection and Analysis Branch and the Coastal Engineering Branch of CHL.

The Coastal Inlets Research Program (CIRP) performed the study. The CIRP is administered for Headquarters, USACE (HQUSACE), by ERDC-CHL, Vicksburg, Mississippi, under the Navigation Program of HQUSACE. Ms. Tiffany Burroughs is HQUSACE Navigation business line manager. Mr. Charles E. Wiggins, CHL, is ERDC technical director for Navigation. Dr. Tanya M. Beck, CHL, is the CIRP program manager.

This work was conducted under the general administrative supervision of Ms. Lauren M. Dunkin, chief of the Coastal Engineering Branch; Mr. William Butler, chief of the Field Data Collection and Analysis Branch; and Ms. Ashley Frey, chief of the Navigation Division. Mr. Keith W. Flowers and Dr. Ty V. Wamsley were the deputy director and director of CHL during this study period, respectively.

At the time of publication of this report, COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was ERDC director.

1 Introduction

1.1 Background

Beaufort Inlet lies approximately 2.7 km * (1.7 mi) south of Beaufort, North Carolina, between Bogue Banks and Shackleford Banks. Bogue Banks is an island bound to the west by Bogue Inlet and to the east by Beaufort Inlet. Shackleford Banks, bound to the west by Beaufort Inlet and to the east by Barden Inlet, is part of the Cape Lookout National Seashore and is uninhabited by humans. Beaufort Inlet, approximately 2.7 km (1.7 mi) wide, has a maintained channel of 14 m (45 ft) depth, mean lower low water, with an allowable overdepth of 0.61 m (2 ft) and varying width typically ranging from 137 to 244 m (450 to 800 ft) and reaching 411 m (1,350 ft) at the harbor. The dredged channel extends seaward through inlet ebb shoals to the open ocean and connects to the Morehead City Harbor and the Atlantic Intracoastal Waterway. Material dredged from the channel is beach-quality sand and is suitable to place in the nearshore placement areas to the east and west of Beaufort Inlet along the shoreline or in the designated ocean dredged material disposal site (ODMDS). Other notable adjacent features include Morehead City Harbor, Bogue Sound, Back Sound, Newport River, and North River (Figures 1-1 and 1-2).

* For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–347, respectively. <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

Figure 1-1. Beaufort Inlet (BI) vicinity with navigation channels and placement sites.

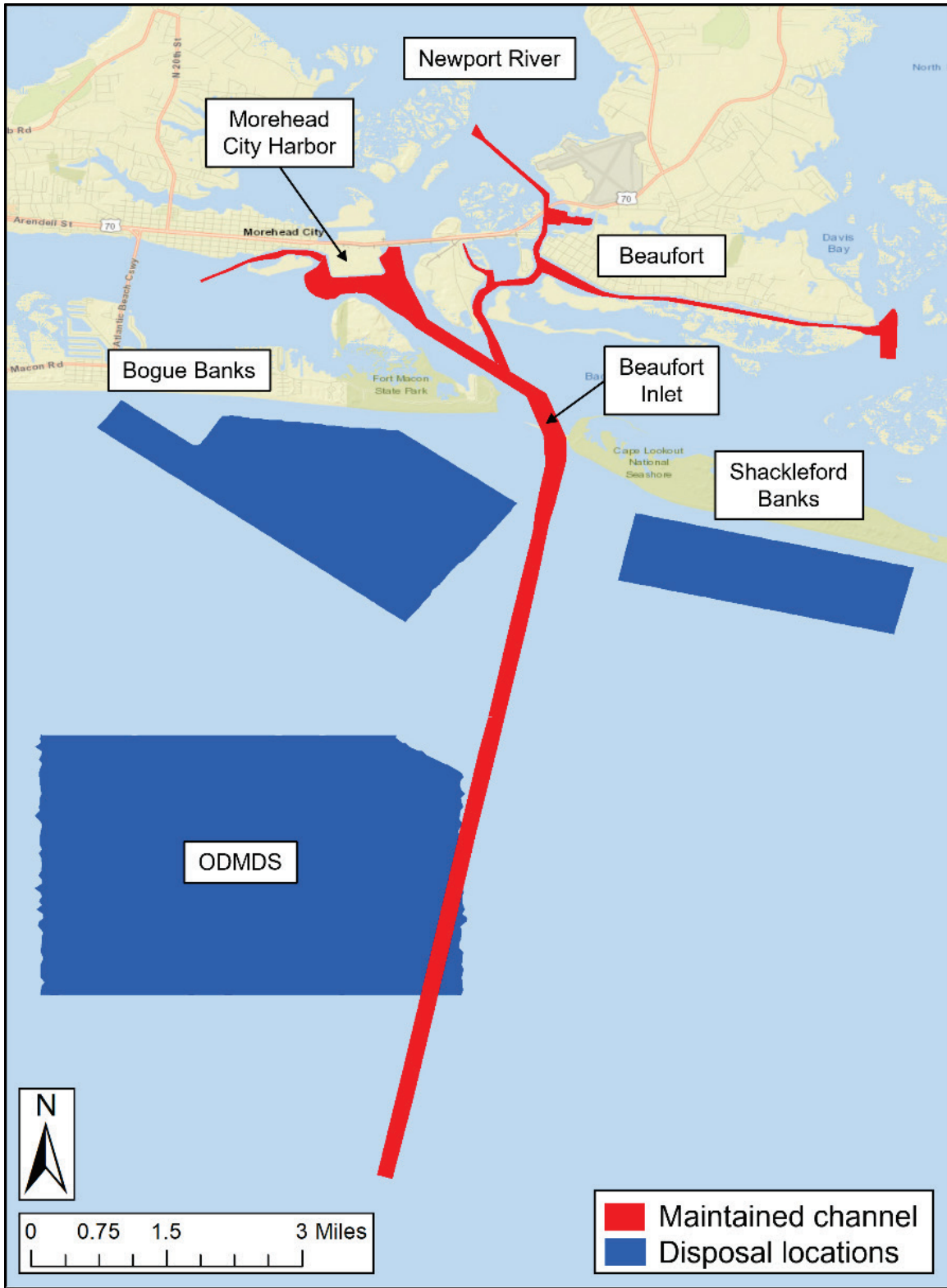


Figure 1-2. BI estuarine system.



1.2 Objectives

Dredge and placement activities are required for maintaining a navigable depth for vessels passing through Beaufort Inlet. The current dredging window is assumed to be 1 December to 15 April (USACE 2021), but the need for risk-based management of dredging has caused interest in exploring year-round dredging rather than operating within these given environmental windows. Eliminating the window of hopper-dredging operations would increase efficiency of dredging operations by minimizing issues with dredge availability, thus also reducing cost. Because dredges have typically operated within the environmental window, there is an uncertainty of the environmental effects resulting from operating outside this window. Dredging activities at Beaufort Inlet can negatively affect nearby species by changing the suspended sediment concentrations and can cause sediment deposition in atypical locations. The purpose of this study is to evaluate the transport of sediment material placed at designated nearshore and offshore areas and to model activity of suspended sediment with representative summer and winter conditions to determine whether these activities would have negative environmental impacts.

1.3 Approach

Coastal numerical modeling is conducted to simulate waves, current, tide, and sediment transport within and around the immediate vicinity of Beaufort Inlet, Morehead City Harbor, and nearshore and offshore sediment disposal locations. The modeling includes sediment mapping to predict sediment plume spreading emitted from dredged material placement sites. This study analyzes sand placement area alternatives, the effects of forcing conditions (hydrodynamics, waves, and wind) on sediment movement, and the effects of alternate placement activities on sediment plume distributions around Beaufort Inlet during typical summer and winter months.

The report is organized as follows. Section 2 introduces historical data that were applied to configure the numerical model and drive the numerical simulations. Section 3 describes the methods for the numerical study. Section 4 presents the results of numerical modeling including the calibration and validation of the calculated waves and hydrodynamics to the field measurements. Section 5 summarizes the results of the study and provides conclusions regarding sediment transport and environmental effects around the Beaufort Inlet estuarine system.

2 Data

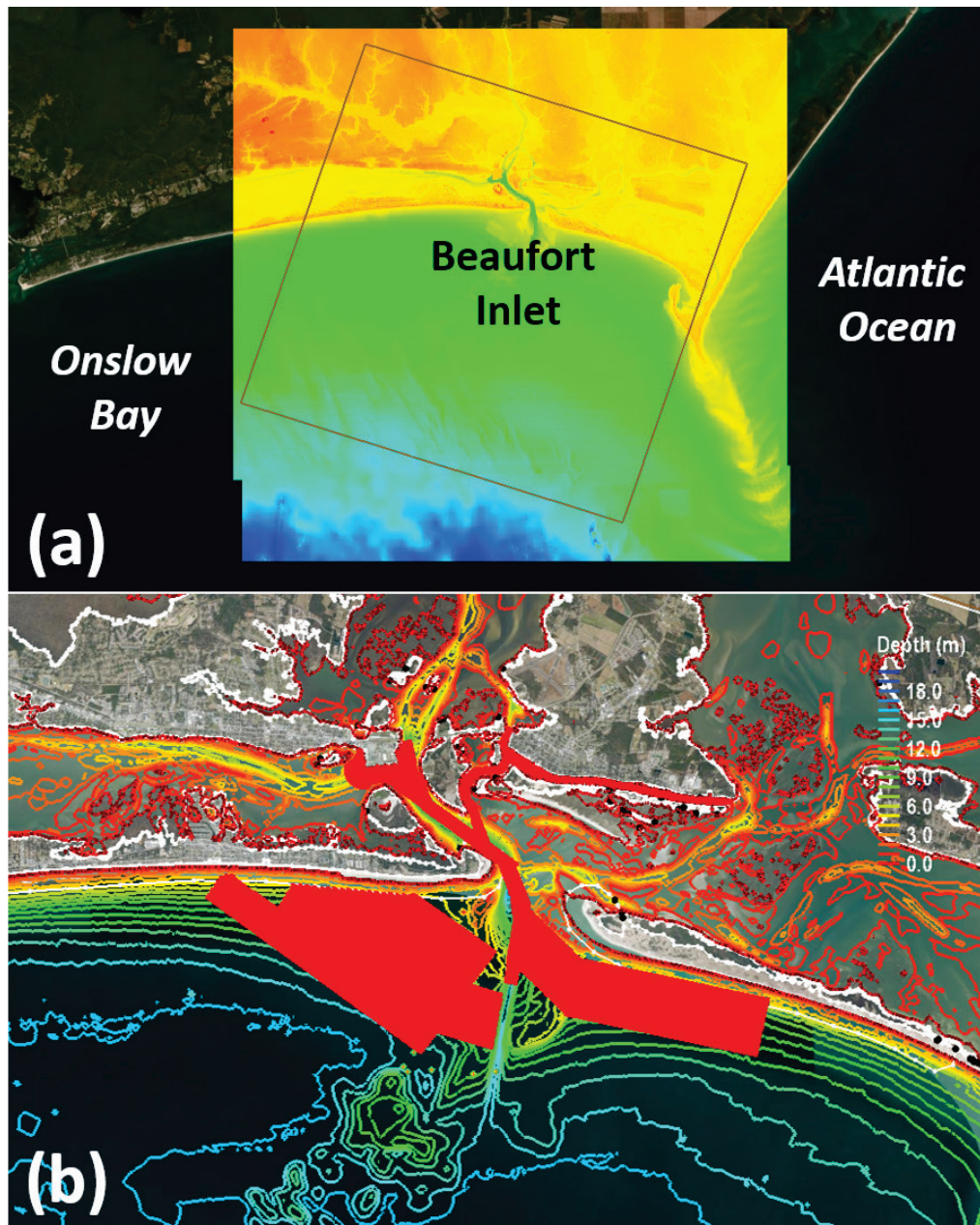
A variety of physical and environmental data for the Beaufort Inlet study area are assembled and analyzed in the present study. Historical data available include open ocean, inlet channel and estuarine bathymetry, tidal variations, coastal wind and waves, and sediment composition.

2.1 Bathymetry

The bathymetry and topography data are compiled from a combination of the high-resolution Coastal Digital Elevation Model (DEM) (1/9 arc-second) and the 3 arc-second Coastal Relief Model (CRM) data sets developed at the NOAA National Centers for Environmental Information (NOAA NCEI 2022). Channel conditional surveys and placement area surveys were conducted by US Army Corps of Engineers, Wilmington District, in 2021 and 2022, which are used to update areas of overlap with the DEM and CRM data sets for the model setup by Surface-water Modeling System (SMS 13.0) (Aquaveo 2020). Shoreline data are used from the latest Google Earth images.

Figure 2-1 shows the spatial coverages and the depth (land elevation) contours of the merged data sets in the study area. The DEM and CRM data sets have more thorough coverage of land, coastal, and offshore areas with a high spatial resolution. The extent of the spatial coverage of the DEM and CRM data are shown in Figure 2-1. Using the datum information from NOAA tide gauge #8656483 at Beaufort, Duke Marine Lab, North Carolina (NOAA 2022), all data sets are converted to local mean sea level (MSL) and incorporated in numerical wave and flow models.

Figure 2-1. (a) NOAA Digital Elevation Model (DEM) / Coastal Relief Model (CRM) bathymetry and (b) conditional survey data coverage with depth and land elevation contours of the merged data set.



2.2 Tides

Water-surface elevation (WSE) data are downloaded from NOAA Beaufort tide gauge #8656483 (BFTN7) and Wrightsville Beach gauge #8658163 (JMPN7) (NOAA 2022). Figure 2-2 shows the location of these gauges. A record of WSEs at Beaufort tide gauge from 11 January to 13 February 2022 is plotted in Figure 2-3, which indicates a mixed, predominantly

semidiurnal tidal regime with relatively small tidal ranges. According to the NOAA Beaufort gauge, the mean tidal range (mean high water–mean low water) is 0.95 m (3.12 ft), and the maximum tidal range (mean higher high water–mean lower low water) is 1.08 m (3.54 ft).

Figure 2-2. Locations of (a) NOAA coastal gauges; NOAA (National Data Buoy Center [NDBC] and Coastal Data Information Program [CDIP]) buoys; and (b) two acoustic wave and current (AWAC) profiler gauges, BI and Beaufort Inlet offshore (BIOS), deployed around Beaufort Inlet.

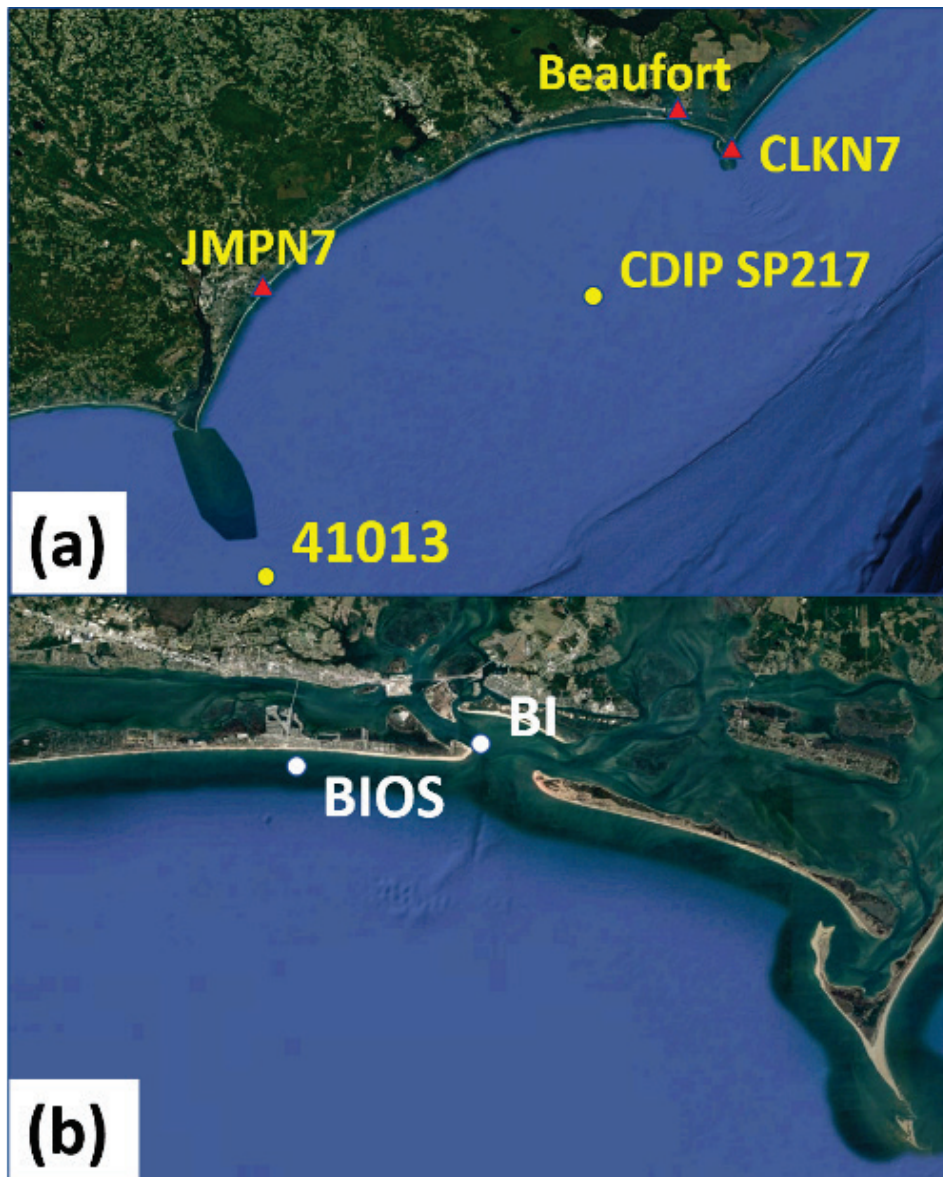
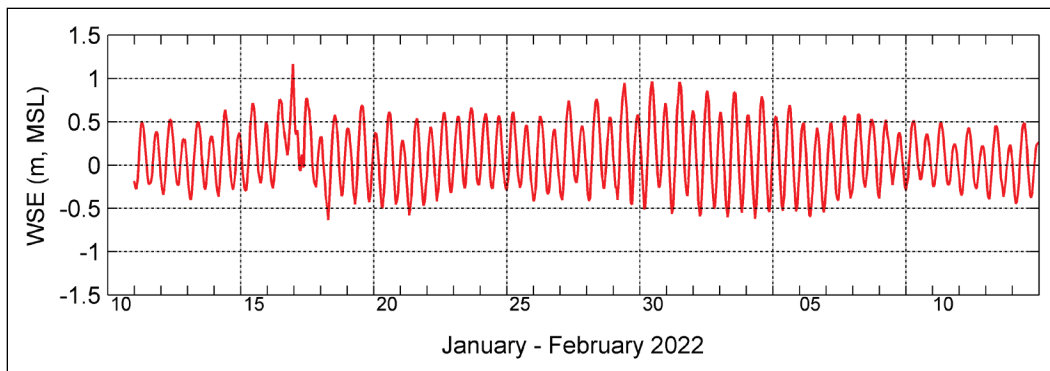


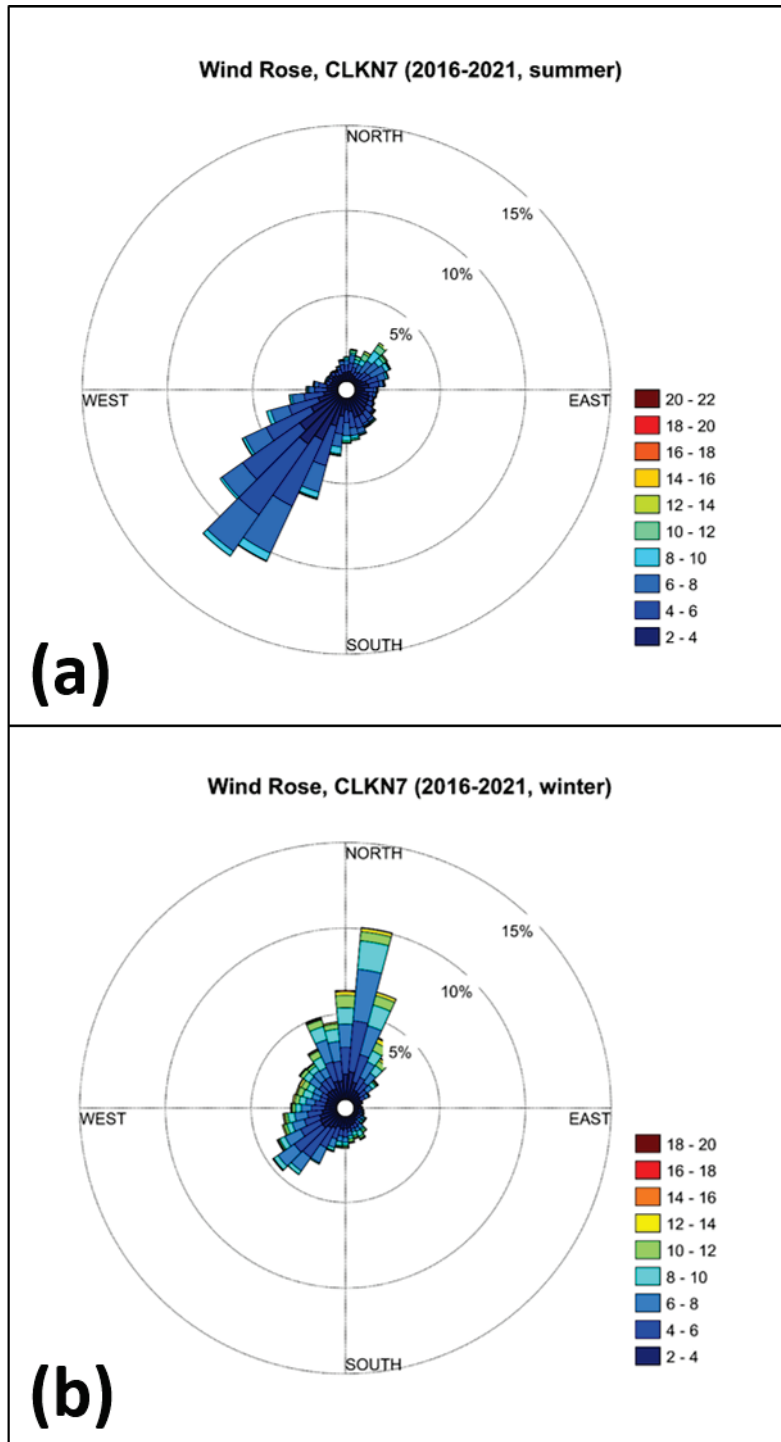
Figure 2-3. Water-surface elevation (WSE) measured at #8656483 from 11 January to 13 February 2022.



2.3 Wind and Waves

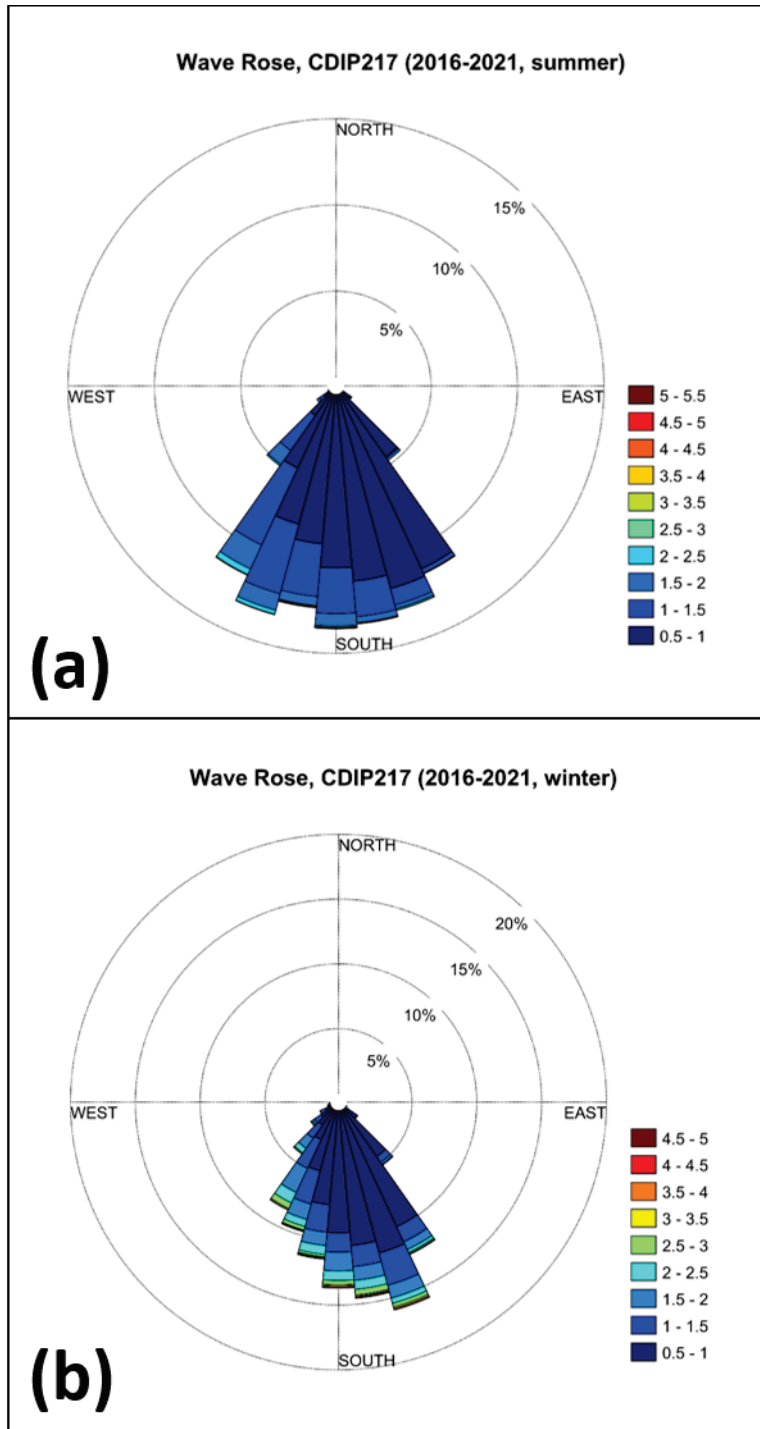
Wind data are obtained from a National Data Buoy Center (NDBC) (NDBC 2020) land station, Station CLKN7, which is located at Cape Lookout, North Carolina, approximately 15 km (9.3 mi) east-southeast of Beaufort Inlet (Figure 2-2). Figure 2-4 shows wind roses using the summer (June–August) and winter (December–February) data from 2016 to 2021. The 6 yr data set indicates seasonal changes of wind pattern. Southwesterly wind is dominant during summer season (more than 50% of the time). Frequency of occurrence of north-northeasterly wind increases during winter season, which occurs more than 30% of the time while southwesterly wind occurs approximately 30% of the time. On average, the northeasterly wind has a stronger speed. When wind blows from the northeast direction, more than 11% of time the wind speed reaches 10 m/s (22.4 mph) and above. The 6 yr seasonally averaged wind speed is approximately 5 m/s (11.2 mph) for summer and 6 m/s (13.4 mph) for winter, respectively.

Figure 2-4. Wind roses at the NDBC coastal station CLKN7 at Cape Lookout, North Carolina, for (a) summer months and (b) winter months from 2016 to 2021.



Spectral wave data are downloaded from one nearshore buoy and one offshore buoy. The nearshore coastal buoy is Coastal Data Information Program (CDIP) SP 217, Onslow Bay Outer, North Carolina, located approximately 58 km (36.0 mi) south-southeast of Beaufort Inlet and the offshore buoy is NDBC 41013 located 168 km south-southwest of Beaufort Inlet (Figure 2-2). Figure 2-5 shows wave roses at Buoy SP 217 using the summer (June–August) and winter (December–February) data from 2016 to 2021. The measurements indicate that all summer waves propagate from the southwest and southeast sectors, close to the shore normal direction. During winter months, more waves propagate from the south-southeast direction (more than 60% of the time) and waves propagating from the south-southwest direction occur approximately 40% of the time. The region experiences mild wave conditions during summer months. Significant wave heights above 2 m (6.56 ft) occur more frequently, and the peak wave height can be above 4 m (13.1 ft) during winter months. High-energy wave conditions usually correspond to the passages of extratropical storms. The 6 yr averaged significant wave height is approximately 0.82 m (2.8 ft) and 0.95 m (3.1 ft) for summer and winter months, respectively.

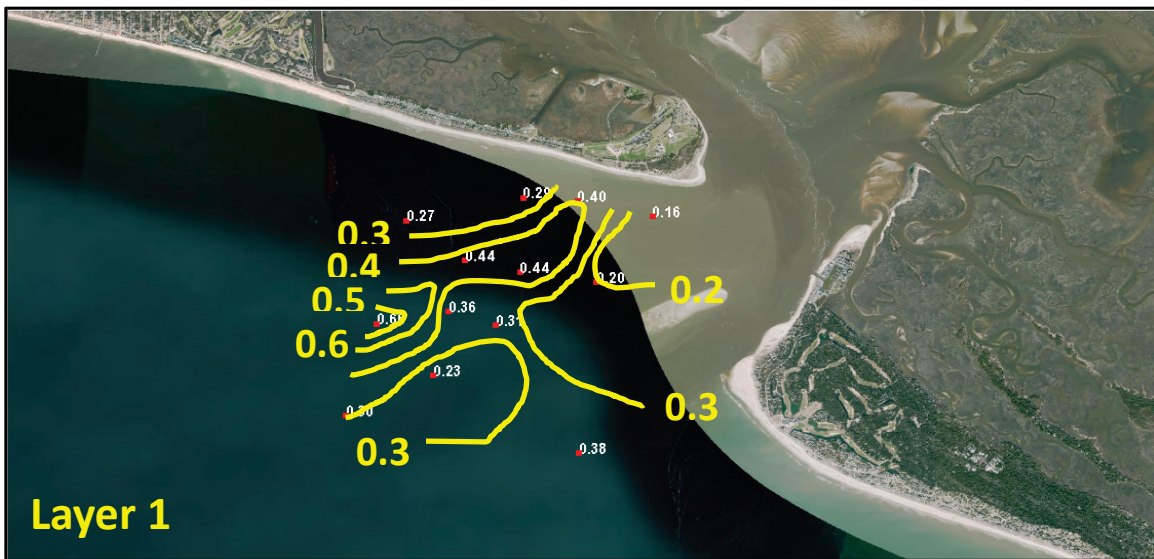
Figure 2-5. Wave roses at the CDIP buoy SP 217, Onslow Bay Outer, North Carolina, for (a) summer months and (b) winter months from 2016 to 2021.



2.4 Sediment

Sediment data are compiled from vibracore samples taken from 2002 to 2019 around Beaufort Inlet. Median grain size, D_{50} , at the top bed layer is available at sample locations as summarized in Figure 2-6. Within the inlet, the average D_{50} is 0.36 mm, and outside the inlet in the open area the average D_{50} value is 0.24 mm.

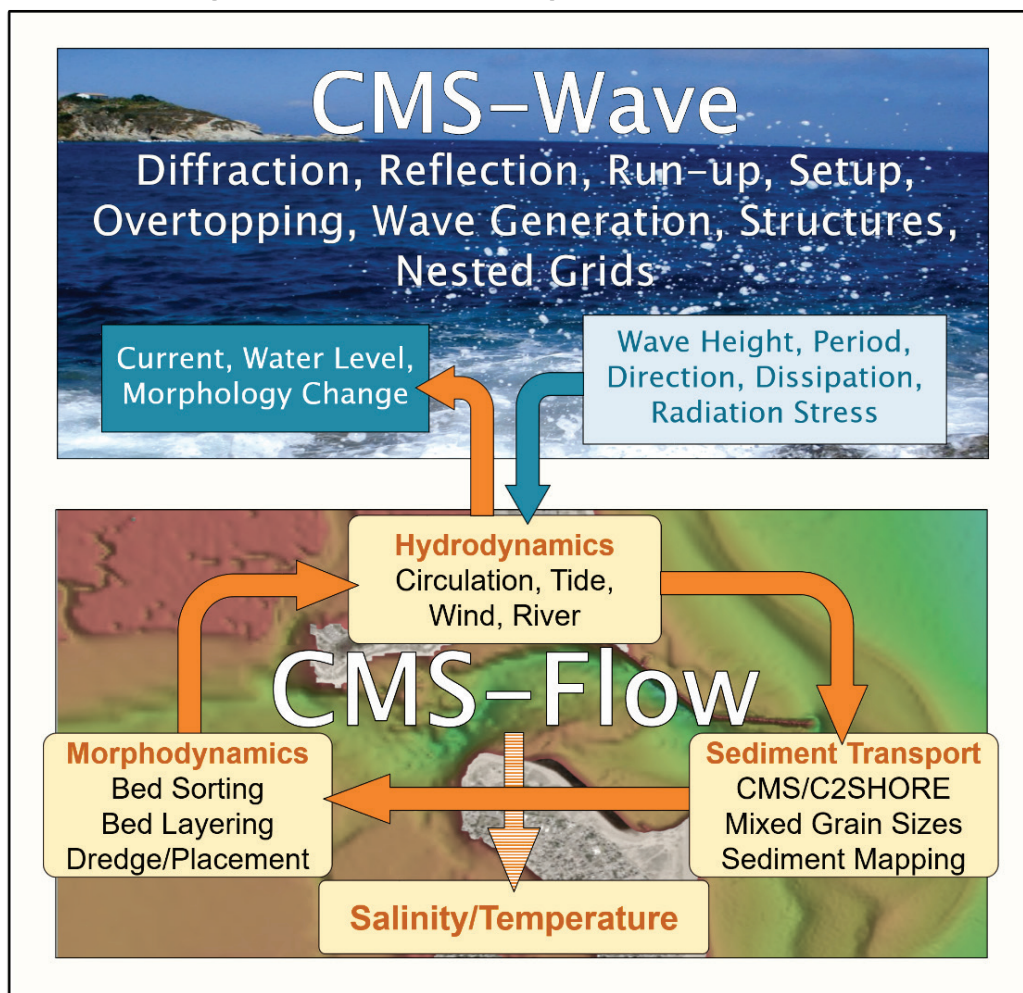
Figure 2-6. Location of sediment grab samples and contours of median grain size (mm), D_{50} .



3 Coastal Modeling System (CMS) Modeling

The Coastal Modeling System (CMS) is an integrated suite of numerical models for waves, flows, sediment transport, and morphology change in coastal and inlet applications. This modeling system includes representation of relevant nearshore processes for practical applications of navigation channel performance and sediment management at coastal inlets and adjacent beaches. The CMS consists of a hydrodynamic and sediment transport model (CMS-Flow) and a spectral wave transformation model (CMS-Wave) (Sanchez et al., “Report 3,” 2011; Sanchez et al., “Report 4,” 2011; Lin et al. 2008). All pre- and postprocessing for these models is performed within the US Army Engineer Research and Development Center SMS interface (Aquaveo 2020). The framework of CMS is shown in Figure 3-1.

Figure 3-1. The Coastal Modeling System (CMS) framework.



CMS-Flow is a 2D depth-integrated finite-volume model that solves the mass conservation and shallow-water momentum equations of water motion on a nonuniform Cartesian grid. CMS-Flow calculates hydrodynamics, sediment transport, and morphology change due to tide, wind, and waves. Wave radiation stresses and other wave parameters are calculated by CMS-Wave and supplied to CMS-Flow for hydrodynamic and sediment transport calculations.

CMS-Wave is a 2D spectral wave transformation model. It solves the steady-state, wave-action balance equation on a nonuniform Cartesian grid and is designed to simulate wave processes with ambient currents at coastal inlets and in navigation channels. The model can be used either in half-plane or full-plane mode and includes coastal wave processes, such as wind wave generation and growth, refraction, diffraction, reflection, dissipation due to bottom friction, white-capping and breaking, wave-current interaction, wave runup, wave setup, and wave transmission through structures.

CMS-Flow and CMS-Wave have a dynamic coupling at a certain time interval specified by users. For the Beaufort Inlet application, CMS-Wave is run at a 2 hr interval between CMS-Flow simulations.

3.1 Sediment Plume Modeling

To assess sediment migration from dredged material placement sites, the current study needs to trace sediment and demonstrate sediment plume spreading originated from those sites. This process can be specified and computed using the CMS feature of sediment tracer simulations (Li et al. 2019).

Sediment transport model in CMS-Flow combines bed load and suspended load as total load. The nonuniform sediment mixture is divided into a suitable number of size classes. In the case of low sediment concentration, the influence among the size classes of moving sediment is assumed negligible.

The CMS includes the calculation of multiple-sized sediment transport, bed mixing and multiple-bed layering, and bed-material gradation (Sanchez et al. 2014). Considering the heterogeneity of bed-material size composition, the sediment bed can be divided into multiple layers, and the

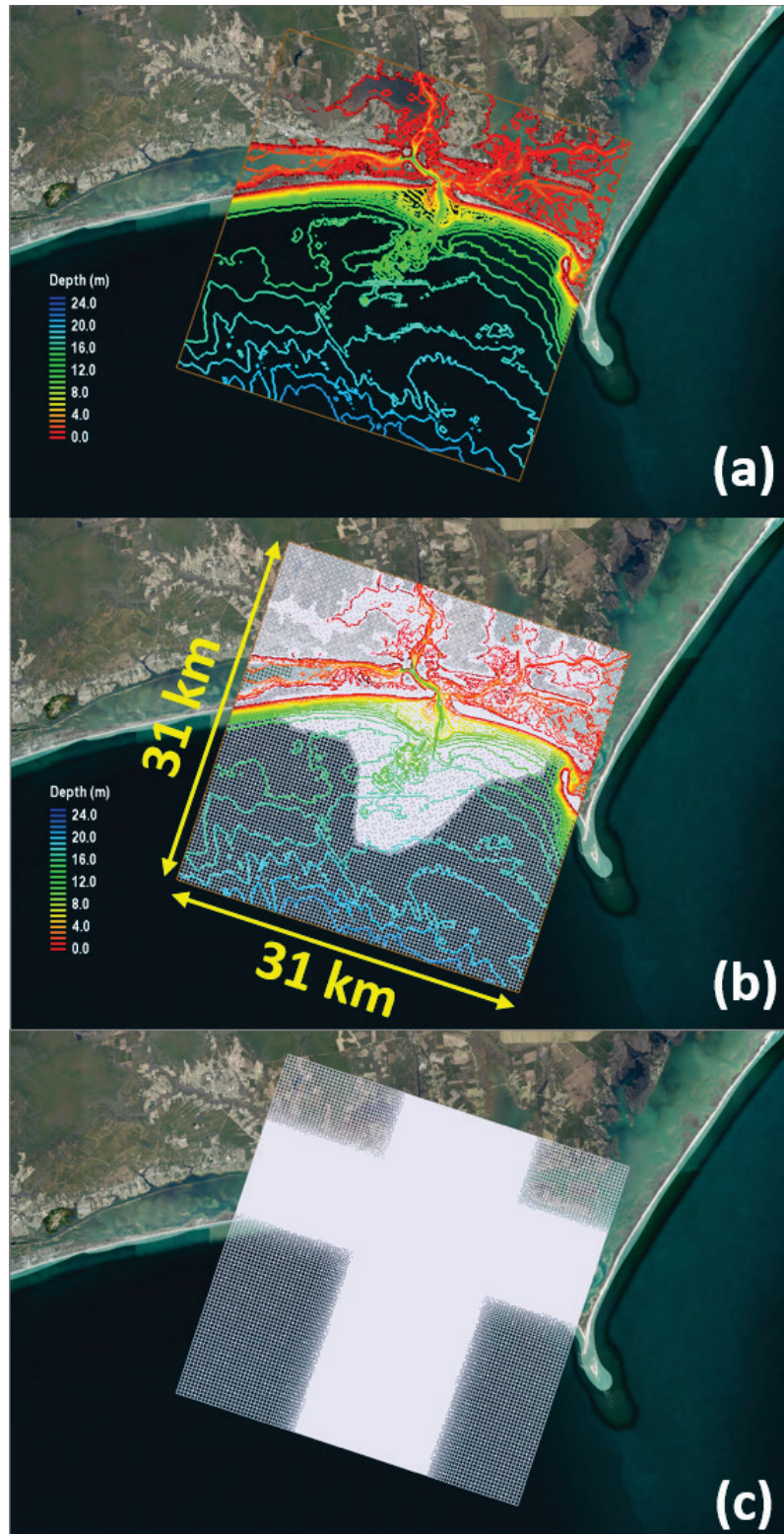
fraction of each size class can be calculated and stored in each layer. The sediment in the active or mixing layer, that is, the top layer of the bed, directly exchanges or contacts with the sediment moving in the water column and is buried or assigned to deeper layers as a part of the deposition process. The sediment tracer with a certain grain size can be specified as one class of multiple-size sediment. By tagging the sediment tracer and accounting the history of bed composition within each layer, a multiple-size sediment transport simulation can represent the movement of the sediment tracer with varying grain sizes, perform the tracking of traced volumes (masses) of sediments, and map sediment plume distribution across a model domain (Li et al. 2019).

3.2 Model Domain and Model Setup

A telescoping variable-resolution CMS-Flow grid is developed for Beaufort Inlet and adjacent beaches. The modeling domain is approximately a square area of 31 by 31 km (19.3 mi) in alongshore and cross-shore direction, respectively. The CMS domain consists of 125,000 ocean cells, which cover Beaufort Inlet, Bogue Banks, Shackleford Banks, Bogue Sound, and Back Sound (Figure 3-2).

The water depth ranges from 1 to 2 m (3.28 to 6.56 ft) above MSL at tidal marsh areas to 15 m (49.2 ft) at the Beaufort Inlet Navigation Channel and further increases to 21 m (68.9 ft) below MSL at the seaward boundary of the CMS domain. The telescoping grid system permits much finer local grid resolution to resolve hydrodynamic and sediment features in areas of high interest. For this study, the cell sizes vary from 20 to 40 m (65.6 to 131.2 ft) in front of nearshore beaches and the navigation channel to 320 m (1,050 ft) in the open ocean. The CMS-Wave grid with varying cell sizes is generated for wave modeling, covering the same domain and with similar spatial resolution as the CMS-Flow grid (Figure 3-2).

Figure 3-2. The CMS domain: (a) bathymetry at the inlet entrance channel and the bay, (b) CMS-Flow telescoping grid, and (c) CMS-Wave variable rectangular grid.



3.3 Simulation Periods

The field survey is conducted from 11 January to 11 April 2022. Corresponding to the survey period, simulations for the CMS calibration and validation are set up to cover the entire data collection period. For the investigation of sediment plume distribution, a representative summer and a winter month are selected, and monthly sediment tracer simulations are set up for transport of dredged material placed at designated disposal sites.

The selection of representative months is based on analysis of wind conditions downloaded from NDBC coastal station CLKN7 at Cape Lookout, North Carolina, (Figure 2-2). Figures 3-3 and 3-4 show the wind roses of three summer months (June, July, August) and three winter months (December, January, February) for each year from 2016 to 2021, respectively.

Figure 3-3. Wind roses of summer months at NDBC coastal station CLKN7 from 2016 to 2021.

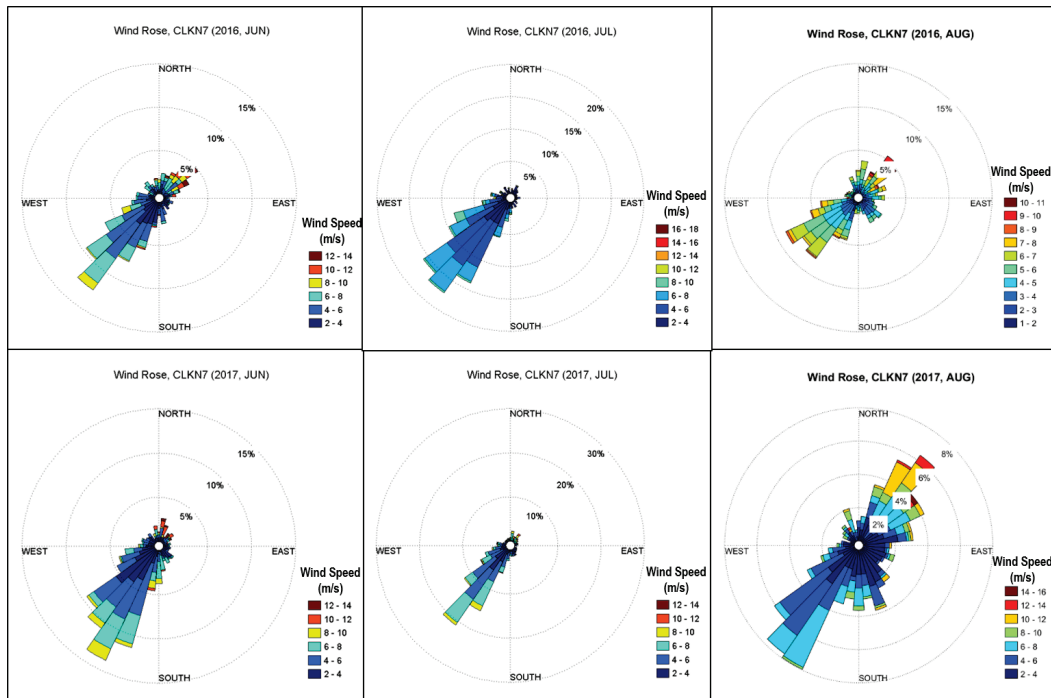


Figure 3-3 (cont.). Wind roses of summer months at NDBC coastal station CLKN7 from 2016 to 2021.

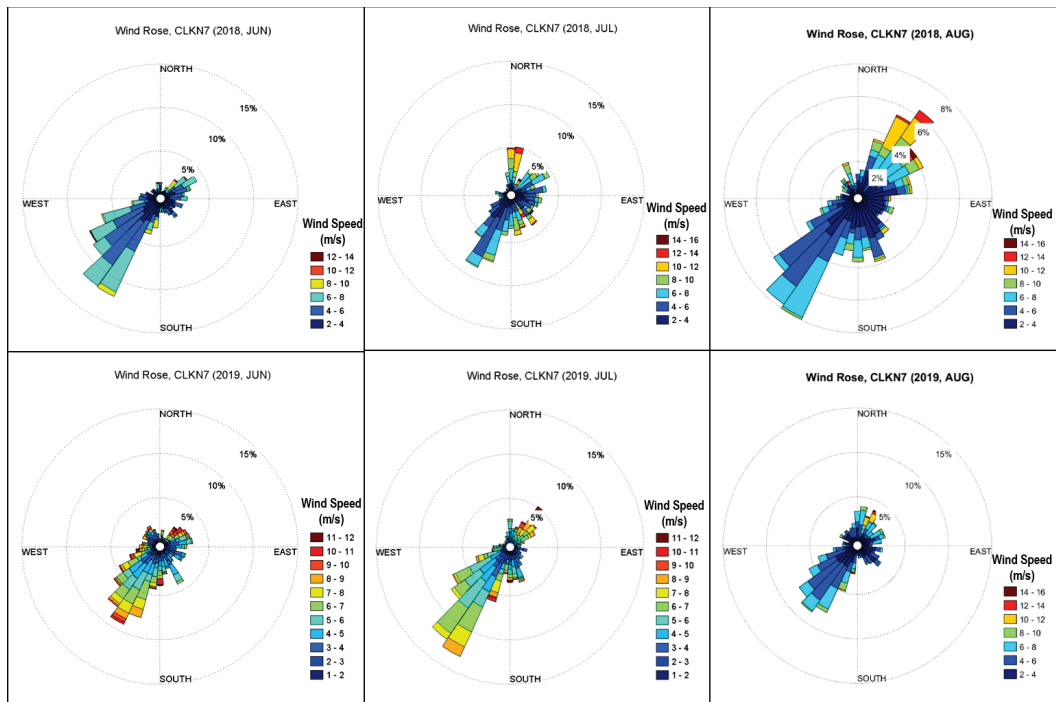


Figure 3-3 (cont.). Wind roses of summer months at NDBC coastal station CLKN7 from 2016 to 2021.

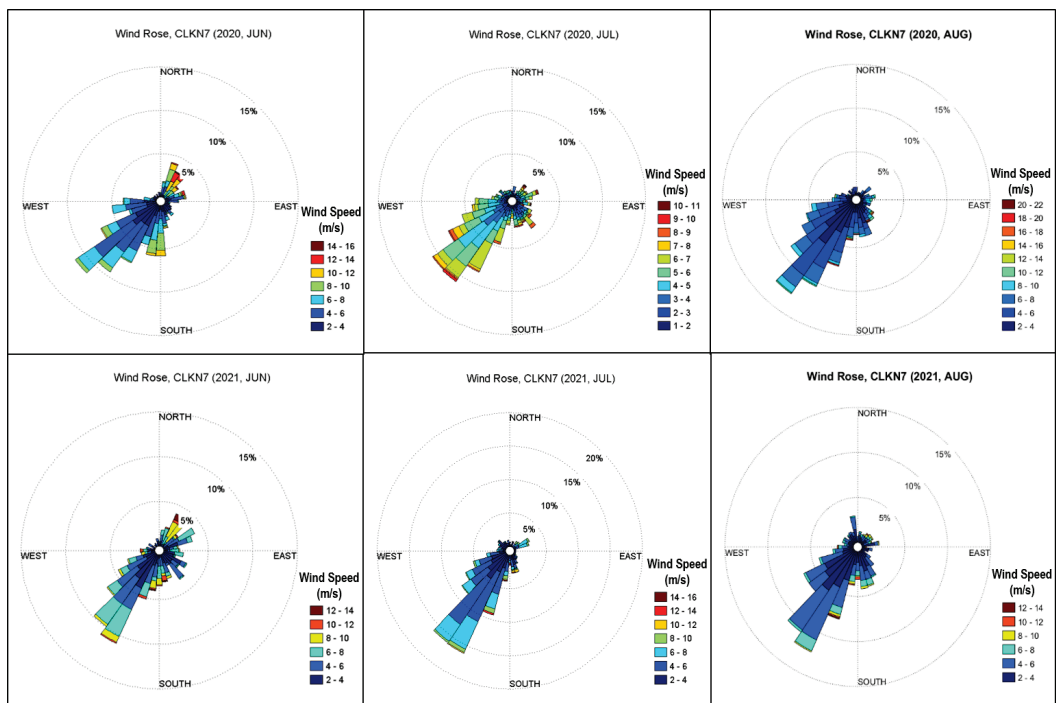


Figure 3-4. Wind roses of winter months at NDBC coastal station CLKN7 from 2016 to 2021.

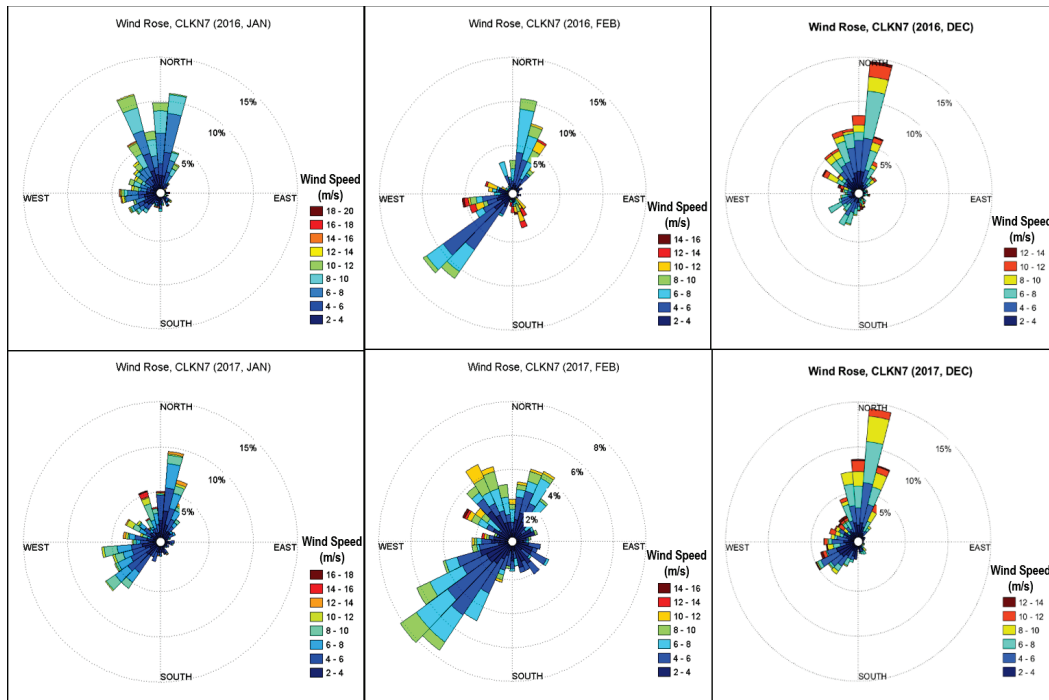


Figure 3-4 (cont.). Wind roses of winter months at NDBC coastal station CLKN7 from 2016 to 2021.

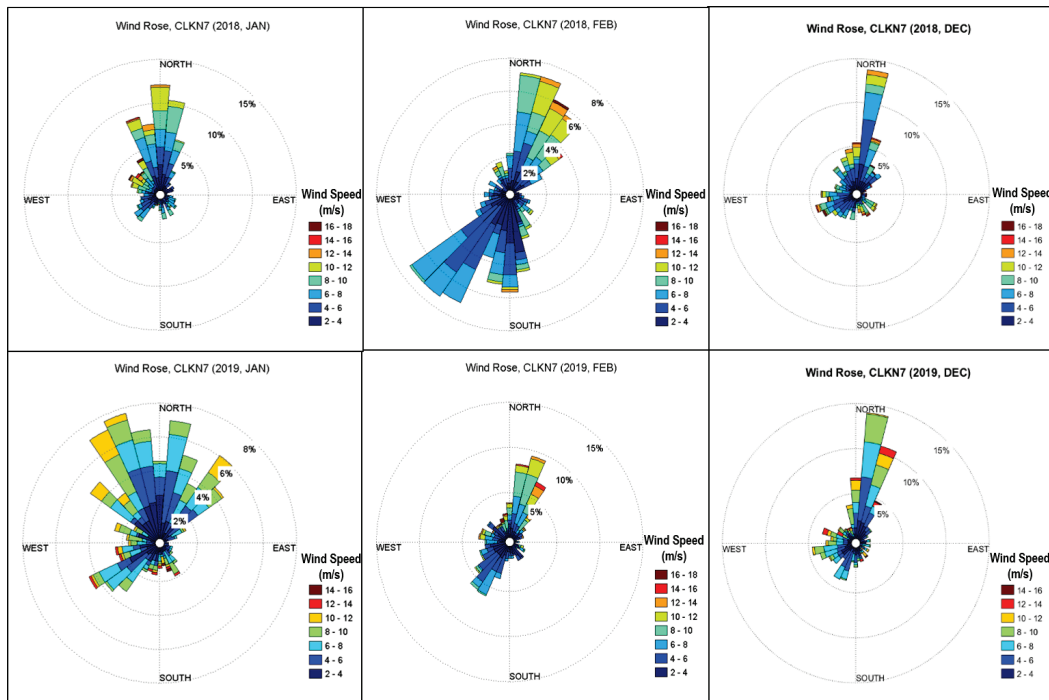
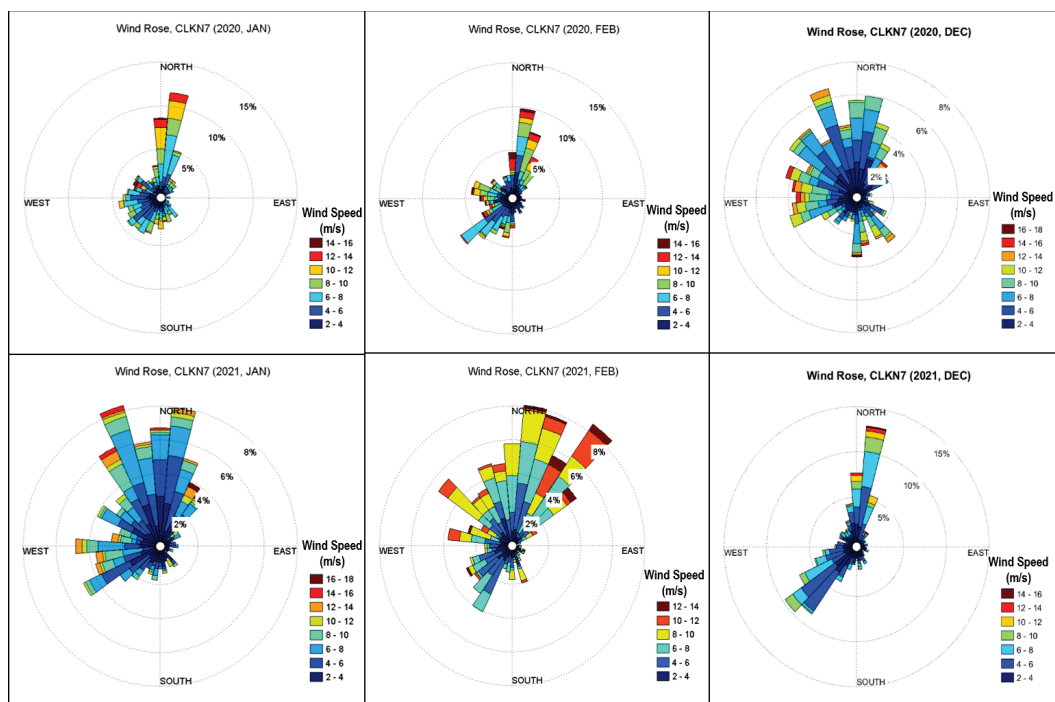


Figure 3-4 (cont.). Wind roses of winter months at NDBC coastal station CLKN7 from 2016 to 2021.



Monthly wind roses in Figures 3-3 and 3-4 are compared with seasonal wind roses as shown in Figure 2-4. Similar to the 2016–2021 summer wind rose, the August 2020 wind rose displays the dominant southwesterly wind directions in the area. Both roses show that the southwesterly wind directions occur close to 60% of the time. The monthly averaged wind speed of August 2020 is 4.8 m/s (10.7 mph), which is close to the 6 yr averaged wind speed for summer months.

For the winter case, Figure 3-4 shows that the December 2018 wind rose is the closest one to the 2016–2021 wind rose for winter months (Figure 2-4). Both roses demonstrate that the north-northeasterly wind blows more than 30% of the time and the north-northeasterly wind occurs with wind speed above 10 m/s approximately 11% of the time. The monthly averaged wind speed is approximately 6.3 m/s (14.1 mph) for December 2018. Generally, the wind speed and direction of December 2018 is similar to the 6 yr averaged wind for winter months.

Figures 3-5 and 3-6 show the wave roses of three summer months (June, July, August) and three winter months (December, January, February) at CDIP buoy SP 217 for each year from 2016 to 2021, respectively.

Figure 3-5. Wave roses of summer months at CDIP buoy SP217 from 2016 to 2021.

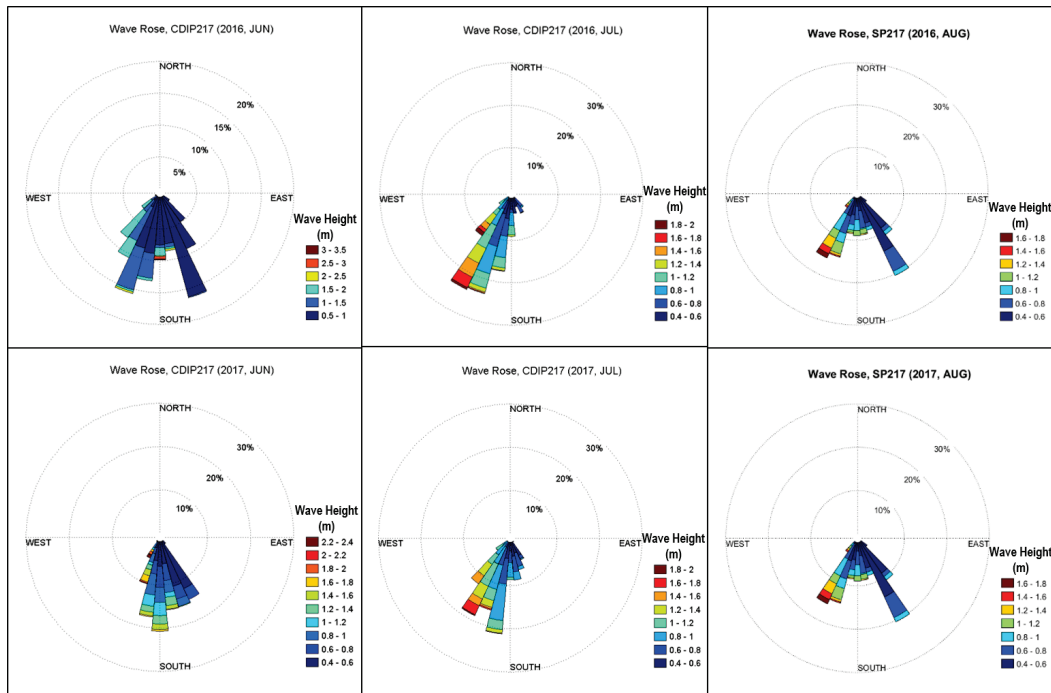


Figure 3-5 (cont.). Wave roses of summer months at CDIP buoy SP217 from 2016 to 2021.

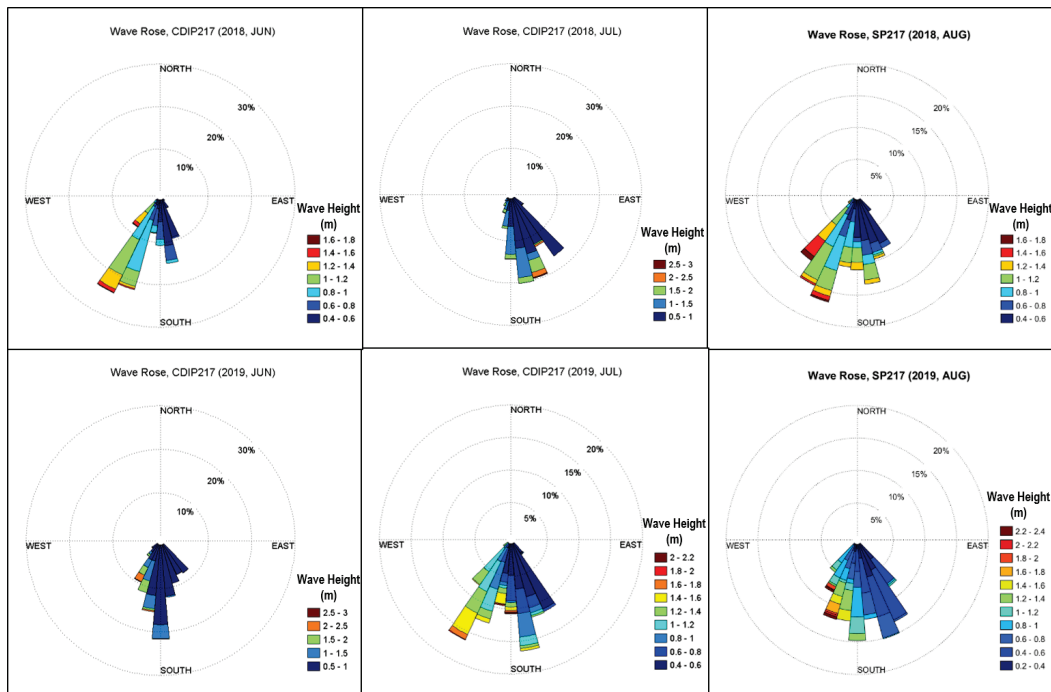


Figure 3-5 (cont.). Wave roses of summer months at CDIP buoy SP217 from 2016 to 2021.

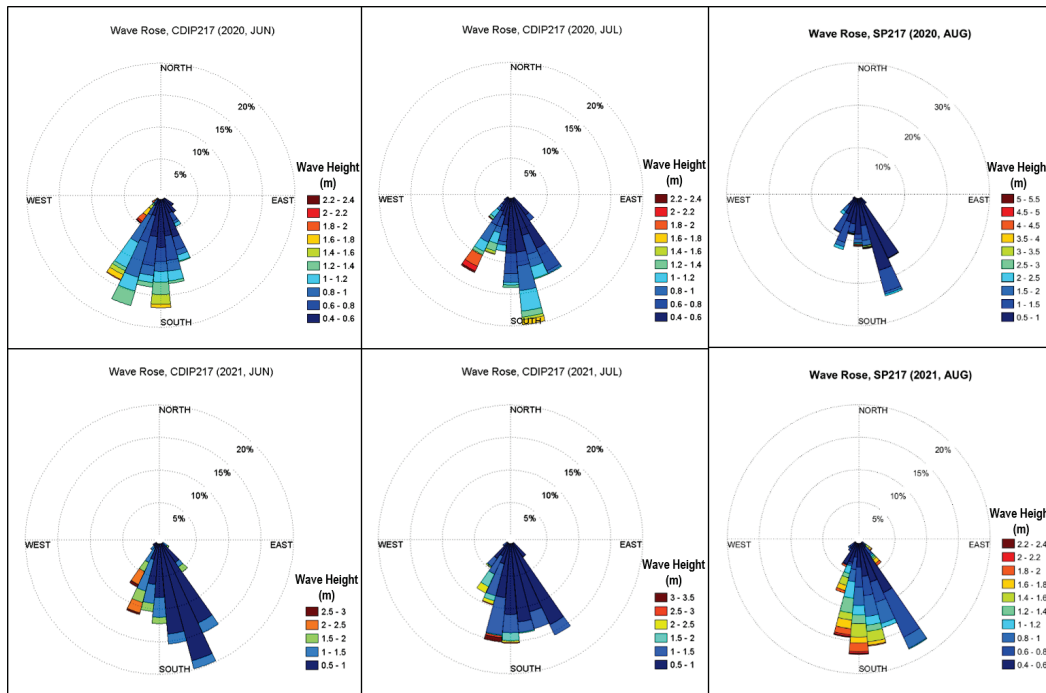


Figure 3-6. Wave roses of winter months at CDIP buoy SP217 from 2016 to 2021.

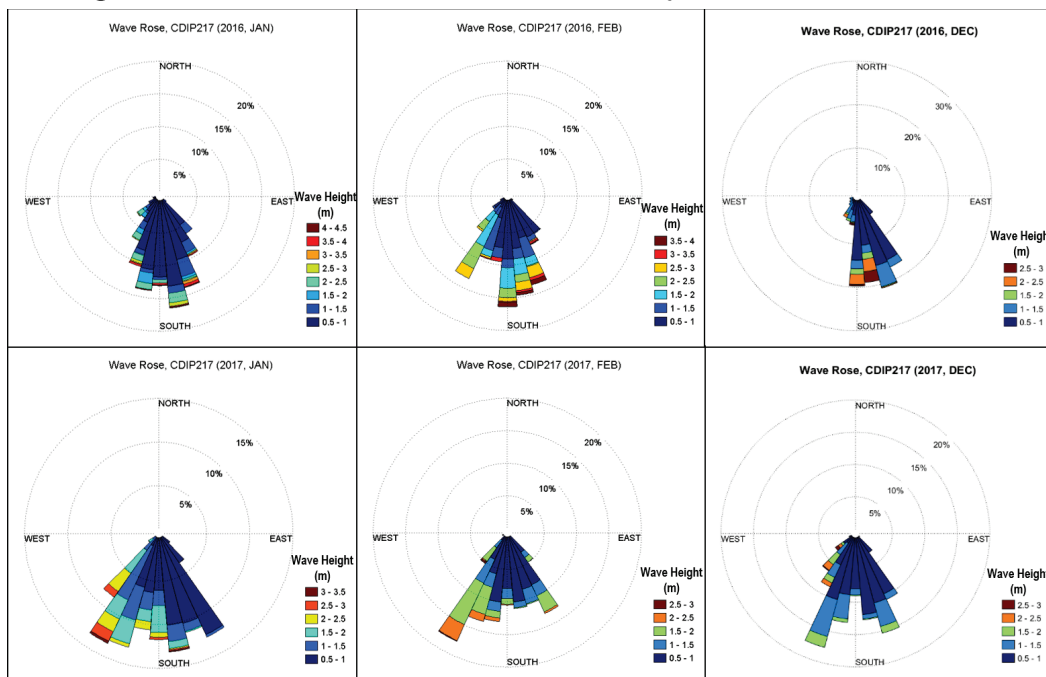


Figure 3-6 (cont.). Wave roses of winter months at CDIP buoy SP217 from 2016 to 2021.

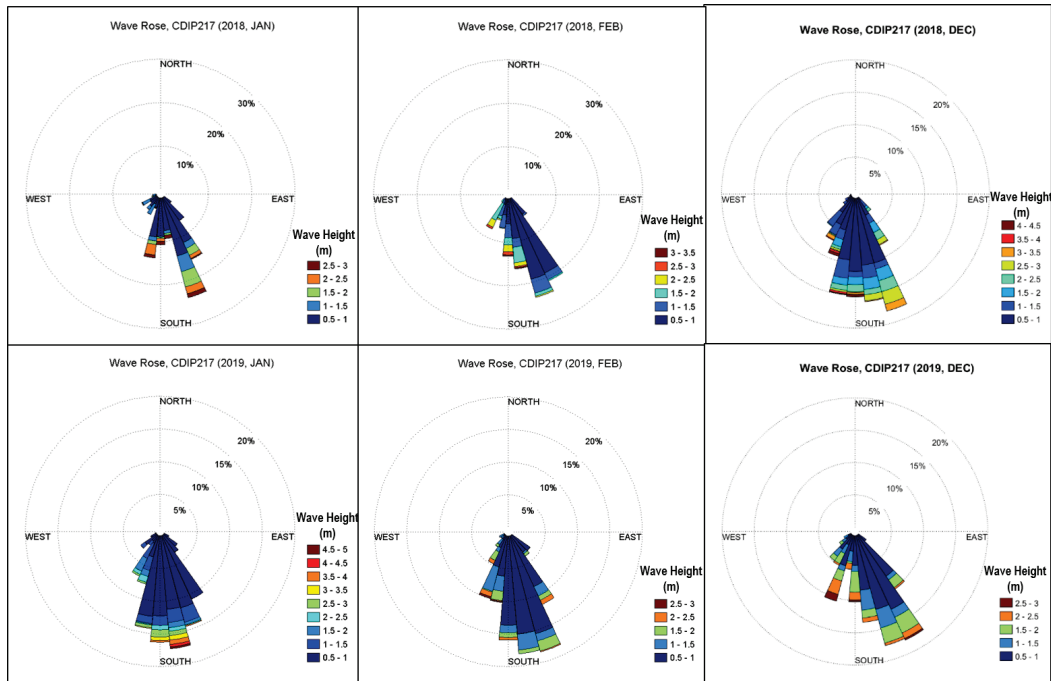
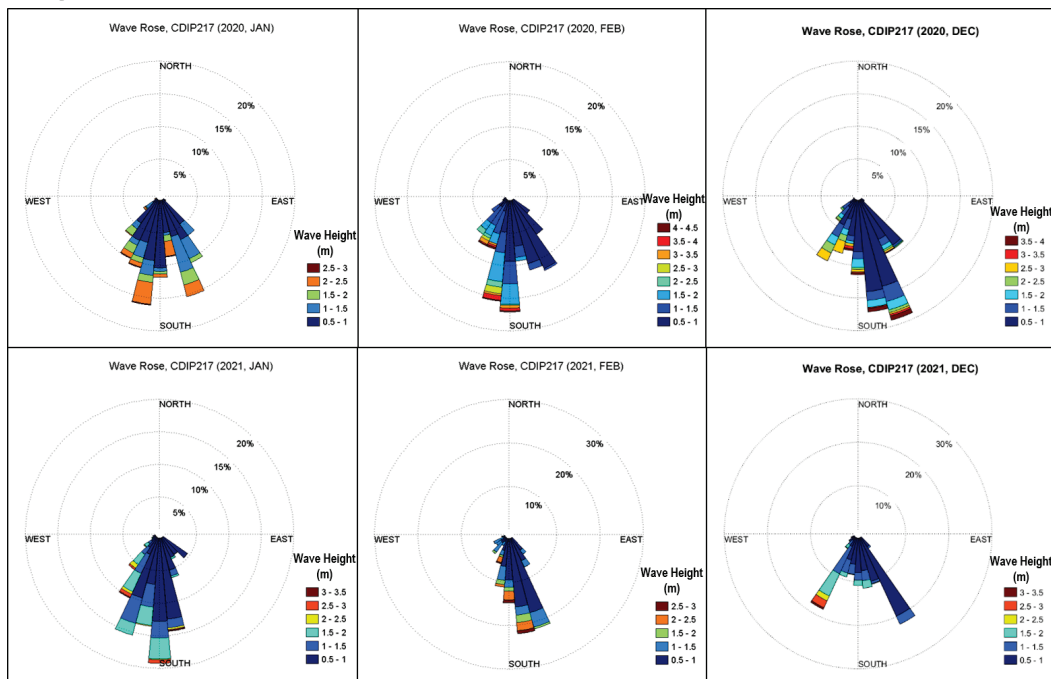


Figure 3-6 (cont.). Wave roses of winter months at CDIP buoy SP217 from 2016 to 2021.



Seasonal and monthly wave roses in Figures 2-5, 3-5, and 3-6 show that all waves measured at CDIP SP 217 propagate from the southwest and southeast sectors. For August 2020 and December 2018, the monthly averaged significant wave heights are 0.88 m (2.9 ft) and 1.06 m (3.5 ft), respectively, which are slightly higher than the 6 yr averaged significant wave heights for summer and winter months.

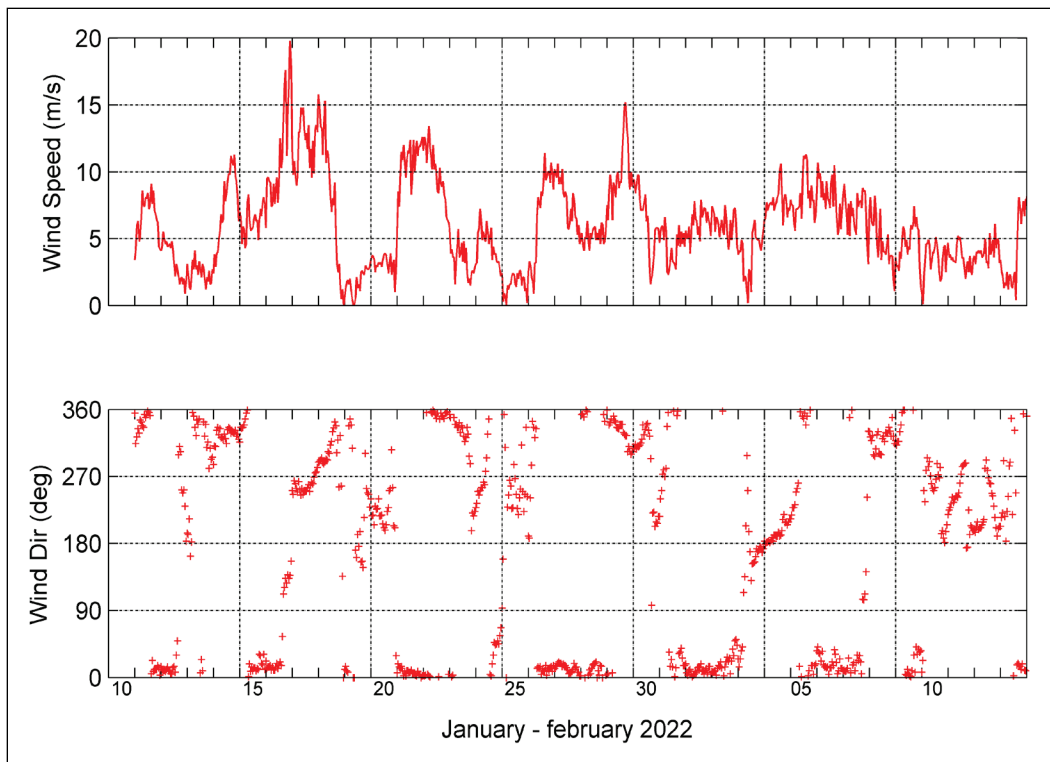
The August 2020 and December 2018 wind and wave data present similar rose patterns and statistical properties as the 2016–2021 data. Therefore, the 2 months are selected as the representative summer and winter month, respectively, to configure production simulations. Thus, three simulation periods are set up for the modeling study: (1) the calibration and validation (January–March 2022), (2) the summer month (August 2020), and (3) the winter month (December 2018).

3.4 Model Forcing

The physical forcing to drive the CMS includes WSE along the open boundaries, wind stress at the surface boundary of CMS-Flow, and wave spectra at the seaward boundary of CMS-Wave.

NOAA tide gauge (#8658163) at Wrightsville Beach, North Carolina, (JMPN7) and tide gauge (#8656483) at Beaufort, Duke Marine Lab, North Carolina, provide the complete water level records for calibration and validation period and for summer and winter month simulations, respectively. Wind data are downloaded from the coastal station CLKN7 at Cape Lookout, North Carolina. Wind speeds and directions for 11 January to 13 February 2022 are shown in Figure 3-7. The time series illustrate wind variations in the study area. During this winter period, strong, north-northwesterly wind is dominant. The monthly averaged wind speed is 5.0 m/s (11.2 mph), and the peak wind speed is close to 15 m/s (33.6 mph).

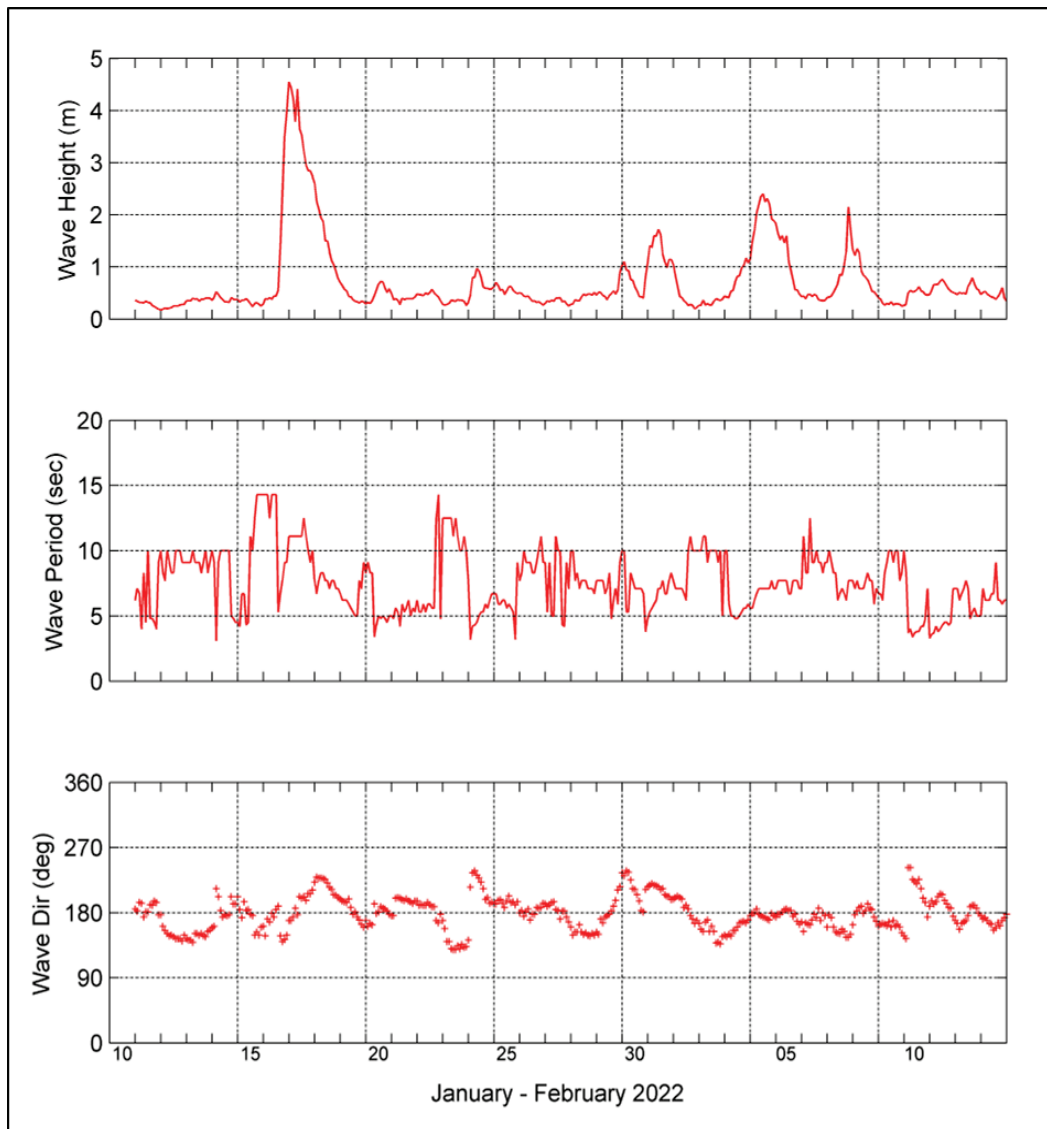
Figure 3-7. Wind speeds and directions at the coastal station CLKN7 from 11 January to 10 February 2022.



Directional wave spectral data contain total wave energy and are often used to drive a wave model. For model calibration and validation, model incident waves are based on data from NDBC Buoy 41,013. For production simulations during summer and winter months, the directional wave spectra measured at CDIP buoy SP 217 are transformed to the seaward open boundary of CMS-Wave.

Time series of wave parameters (significant wave height, peak wave period, and mean wave direction) at CDIP SP 217 are shown in Figure 3-8. Dominant wave direction is from south, southwest, or southeast with an averaged peak wave period of 7.7 s. The mean significant wave height at the buoy site is 0.9 m (3.0 ft).

Figure 3-8. Wave parameters at CDIP buoy SP 217 from 11 January to 10 February 2022.



3.5 Model Alternatives

Sediment materials from regular channel maintenance dredging are placed in designated areas. To investigate the spreading of sediment plume originated from the placement sites, the model alternatives are developed by specifying three sites as selected sediment sources, within which sediment materials in the top bed layer are tagged and tracked as sediment tracer.

Figure 3-9a shows the sketch of three designated placement sites, Shackleford Banks, Bogue Banks, and ODMDS.

Table 3-1 lists the physical scales of the placement areas for corresponding model alternatives.

Figure 3-9. Sketch of (a) three designated placement sites and (b) ten polygon (sediment trap) areas around the inlet system.

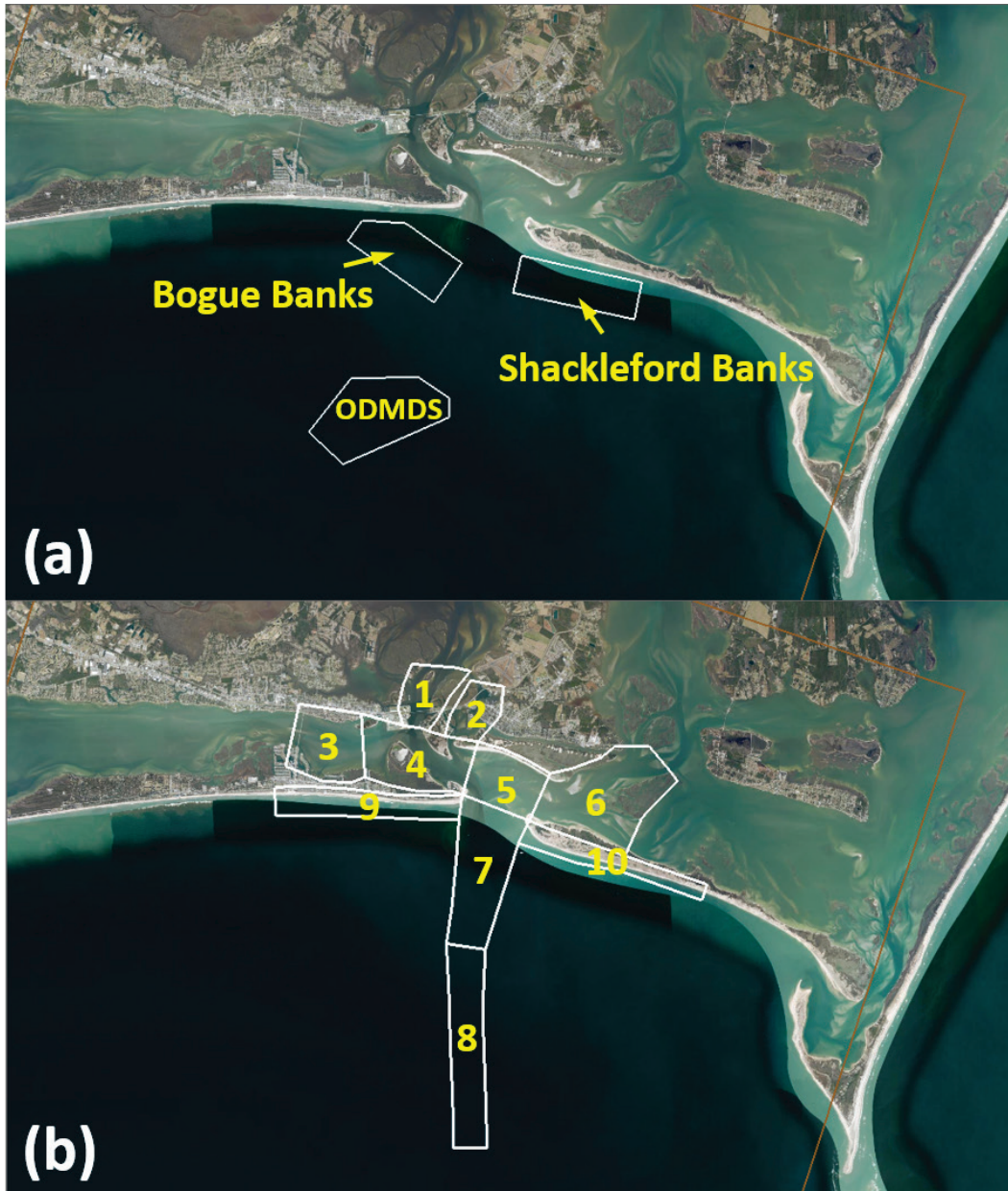


Table 3-1. Model alternatives: physical scales of three placement areas.

Alternative	Placement Site	Area (km ²)	Average Depth (m)	Mass Tracked (kg)
1	Shackleford Banks	5.32	7.3	423,000
2	Bogue Banks	5.31	7.8	422,180
3	ODMDS	8.65	15.1	687,390

Alternatives 1 and 2 correspond to two nearshore sites (Shackleford Banks and Bogue Banks) for the release and track of sediment materials, which cover an area of about 5.3 km² (2 mi²) and have an area-averaged water depth of approximately 7.5 m (24.6 ft). The offshore site (ODMDS) is designated as Alternative 3, covering a much larger area of 8.7 km² (3.4 mi²) with an averaged water depth of 15.1 m (49.5 ft). Sediment materials released and tracked from the ODMDS are also 60% more than from the nearshore site.

To trace sediment transport and conduct a sediment plume analysis around the Beaufort estuarine system, 10 polygons are drawn in Figure 3-9b, which act as sediment traps for counting sediment mass moving into the areas. The polygon areas include Newport River marsh (Traps 1 and 2), Bogue Sound (Traps 3 and 4), Back Sound and North River marsh (Trap 6), Beaufort Inlet and navigation channel (Traps 5, 7, and 8), and open nearshore zone (9 and 10).

4 Simulation Results and Analysis

4.1 Model Calibration and Validation

The CMS models are calibrated and validated using water level, current, and wave data collected around Beaufort Inlet (BI and Beaufort Inlet Offshore [BIOS]) during January to April 2022 (Figure 2-2). Data collected by the BI gauge represent conditions within the inlet complex and back bay environments, while data collected by the BIOS gauge represent nearshore beachfront conditions.

Figures 4-1 and 4-2 compare the computed wave heights, periods, and directions with the data collected at BIOS and BI gauge locations, respectively, for 15 January to 13 April 2022. Table 4-1 presents the bias, root-mean-square error (RMSE), and correlation coefficients of model wave heights. The statistics of accuracy for modeled wave period and directions are not calculated, as there is too much noise observed in wave period and direction measurements.

Figure 4-1. Model waves and data comparison at the BIOS gauge location.

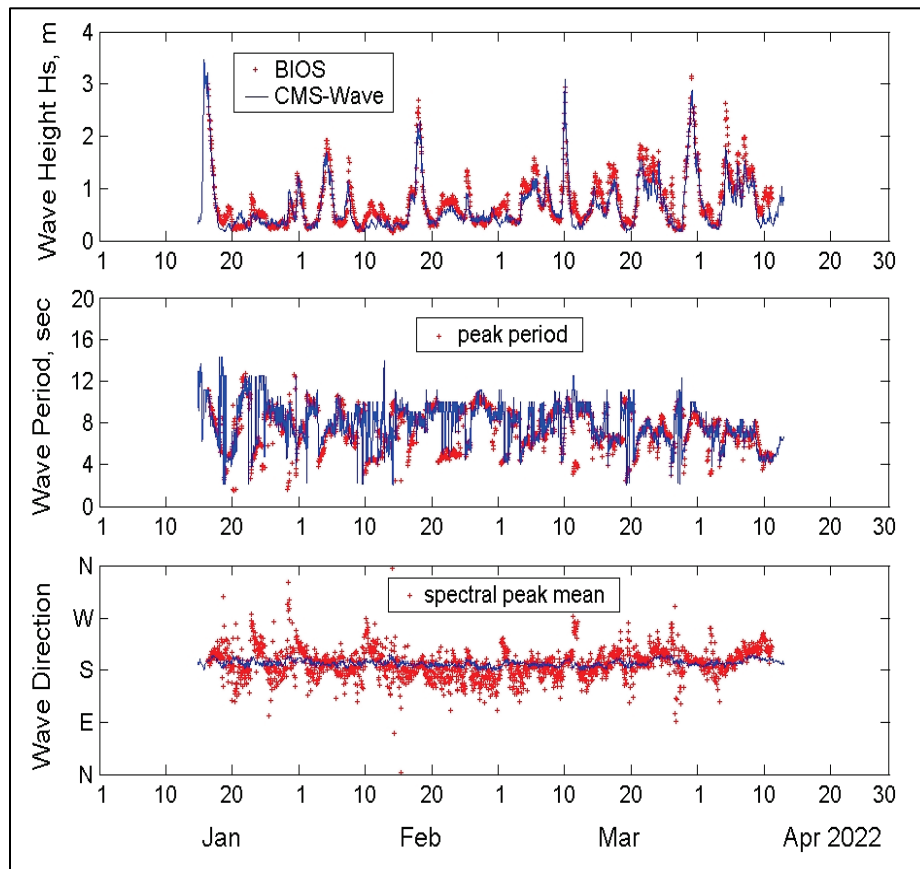


Figure 4-2. Model waves and data comparison at the BI gauge location.

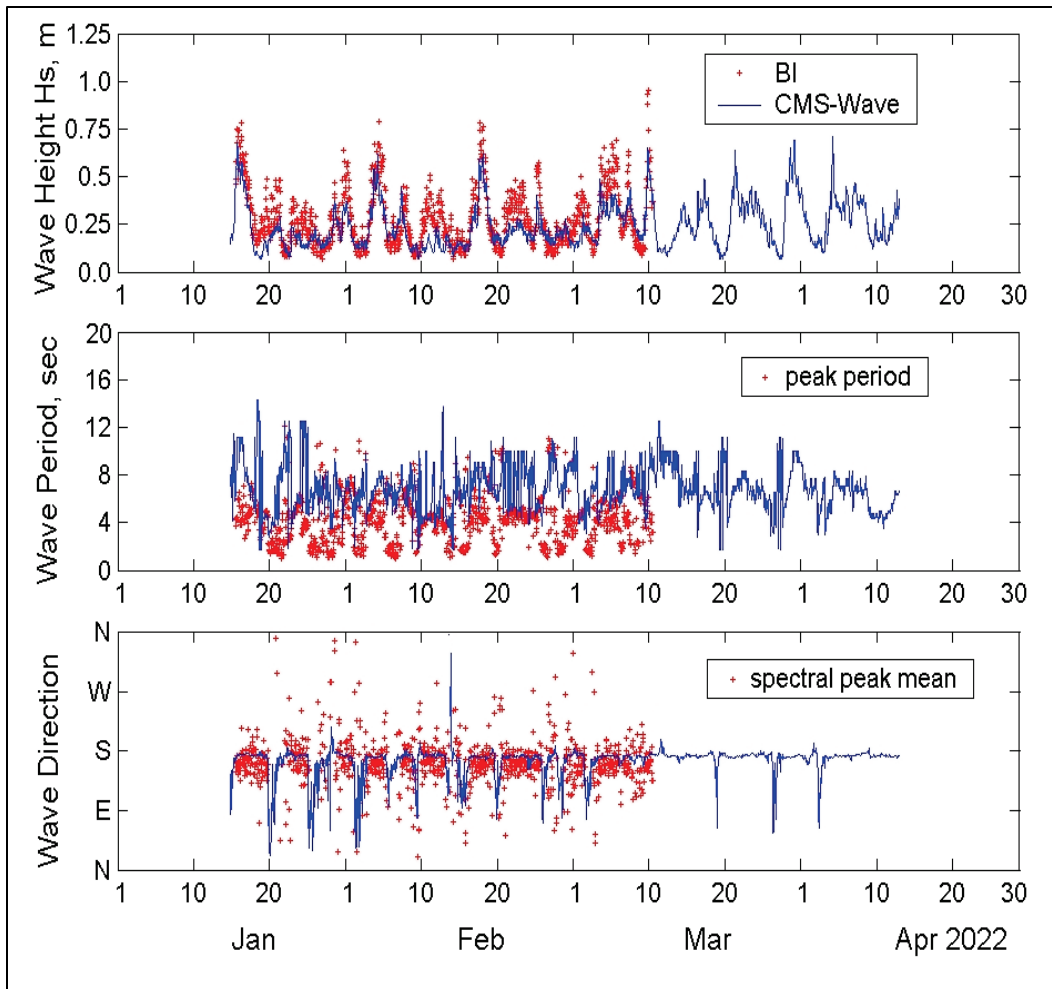


Table 4-1. Statistics of model wave heights at BIOS and BI for January–April 2022.

Location	Bias (m)	RMSE (m)	Correlation Coefficient
BIOS	-0.08	0.19	0.94
BI	-0.05	0.1	0.84

Figures 4-3 and 4-4 compare model water levels versus data at BIOS, BI, and BFTN7 locations for January–February and March–April, respectively, 2022. Table 4-2 presents the bias, RMSE, and correlation coefficients of model water levels.

Figure 4-3. Model water levels and data at BIOS, BI, and BFTN7 locations for January–February 2022.

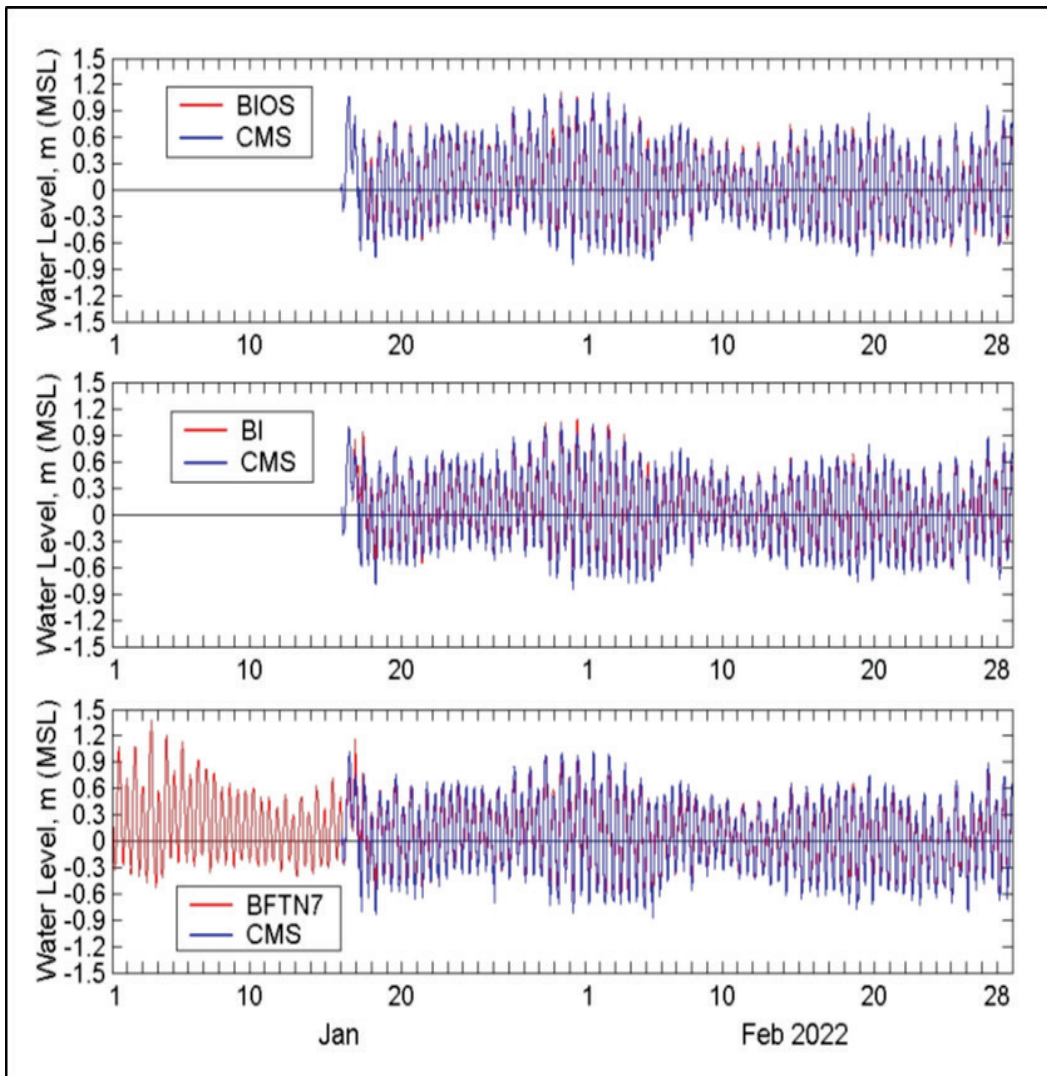


Figure 4-4. Model water levels and data at BIOS, BI, and BFTN7 locations for March–April 2022.

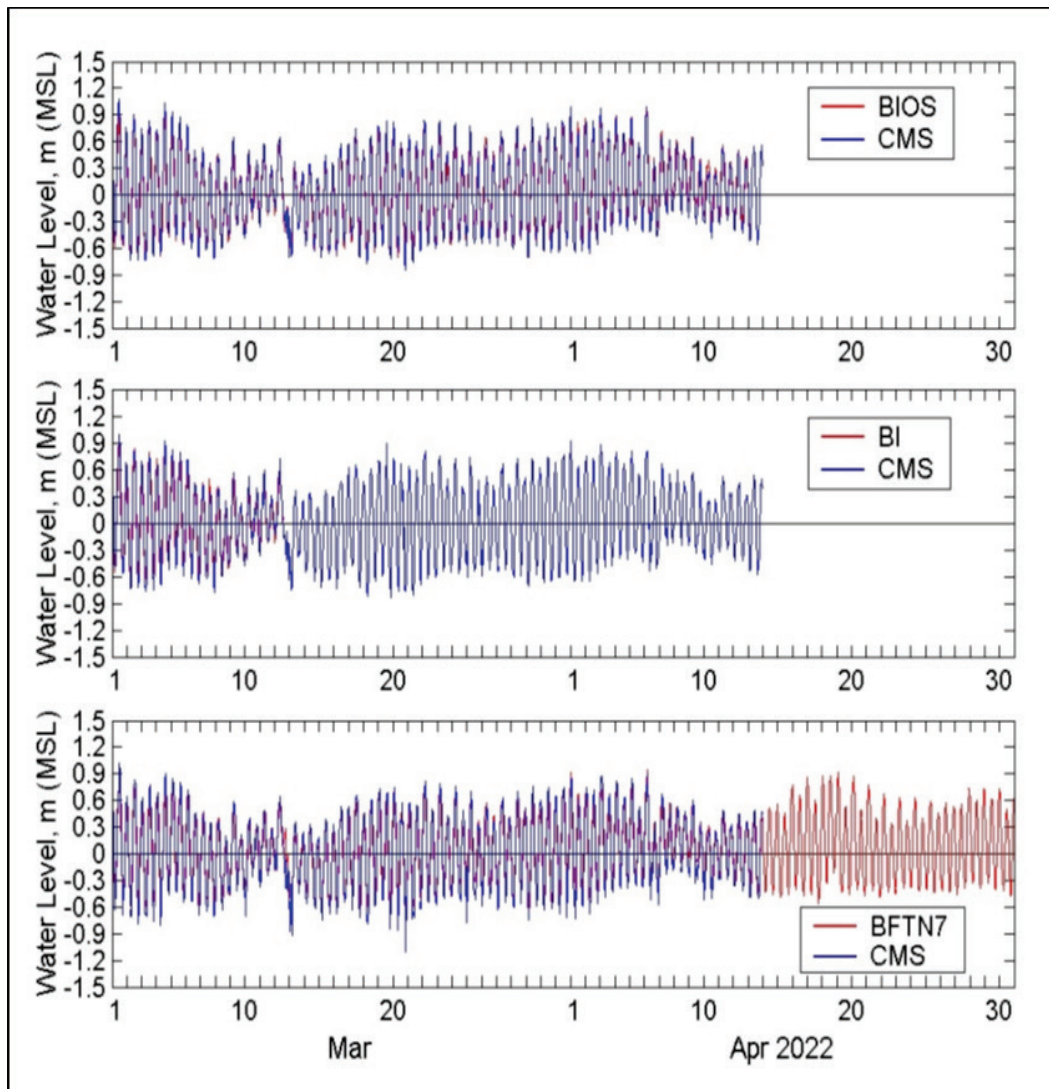


Table 4-2. Statistics of model water levels at BIOS, BI, and BFTN7 for January–April 2022.

Location	Bias (m)	RMSE (m)	Correlation Coefficient
BIOS	-0.006	0.094	0.98
BI	0.003	0.139	0.94
BFTN7	-0.01	0.141	0.95

Figures 4-5 and 4-6 compared model current magnitudes and directions versus data at BIOS for January–February and March–April, respectively, 2022. Figures 4-7 and 4-8 compared model current magnitudes and directions versus data at BI for January–February and March–April, respectively, 2022. Table 4-3 presents the bias, RMSE, and Correlation Coefficients of model current speeds. The statistics of accuracy for model current directions was not calculated as there is too much noise observed in current direction measurements.

Figure 4-5. Model current magnitudes and directions versus data at BIOS for January–February 2022.

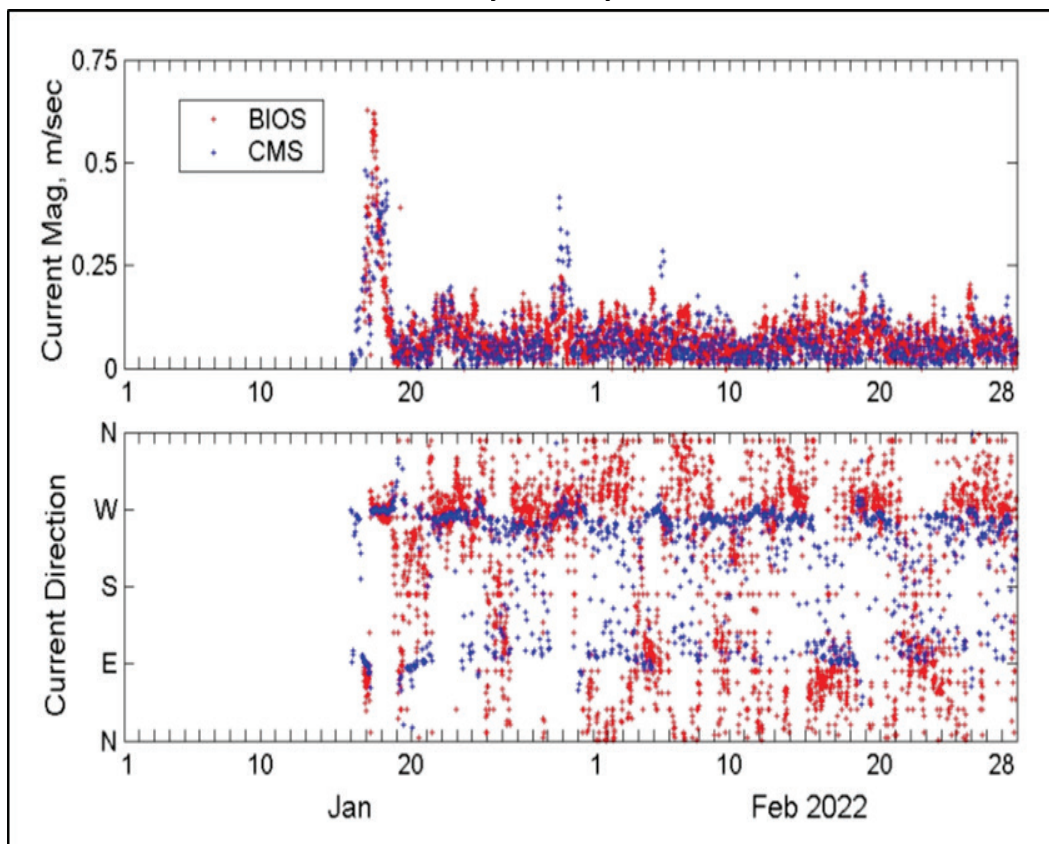


Figure 4-6. Model current magnitudes and directions versus data at BIOS for March–April 2022.

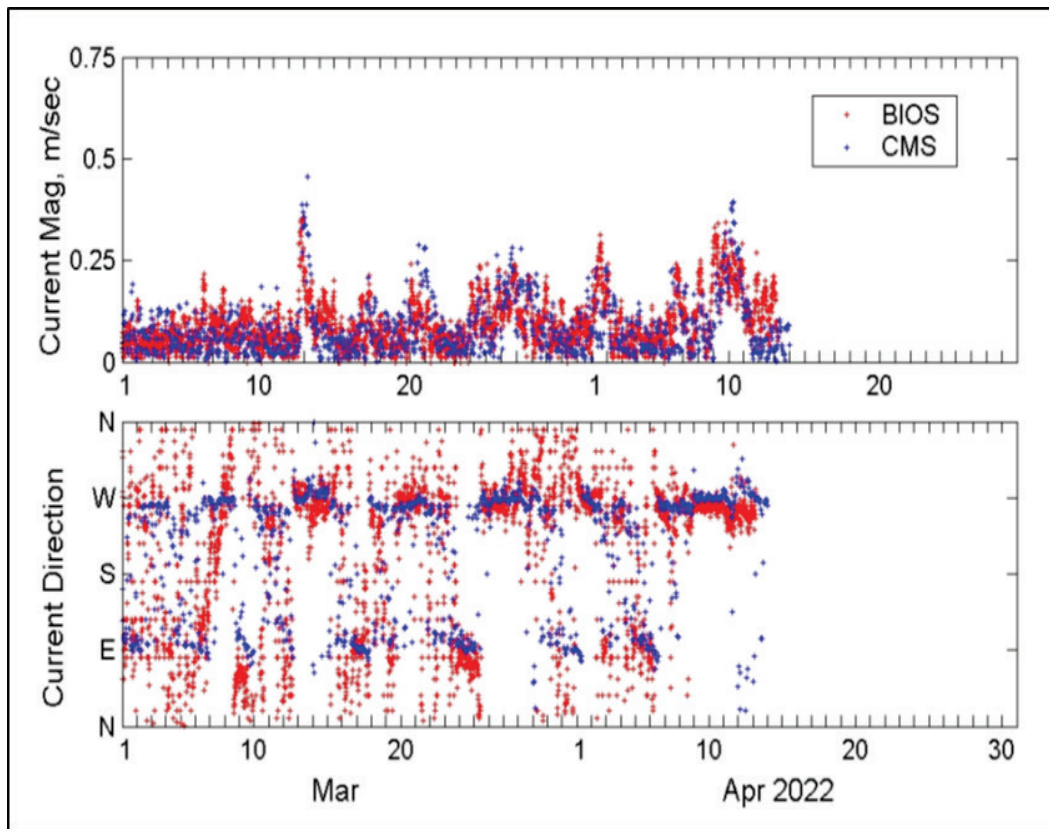


Table 4-3. Statistics of model current speeds at BIOS and BI for January–April 2022.

Location	Bias (m)	RMSE (m/s)	Correlation Coefficient
BIOS	-0.026	0.13	0.21
BI	-0.114	0.47	0.15

Figure 4-7. Model current magnitudes and directions versus data at BI for January–February 2022.

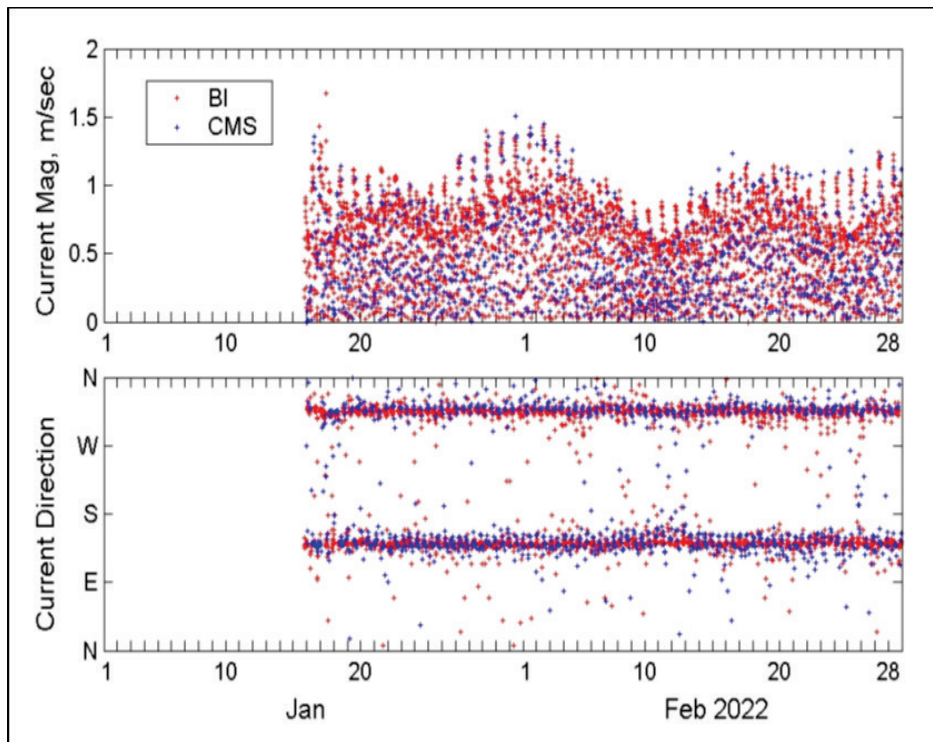
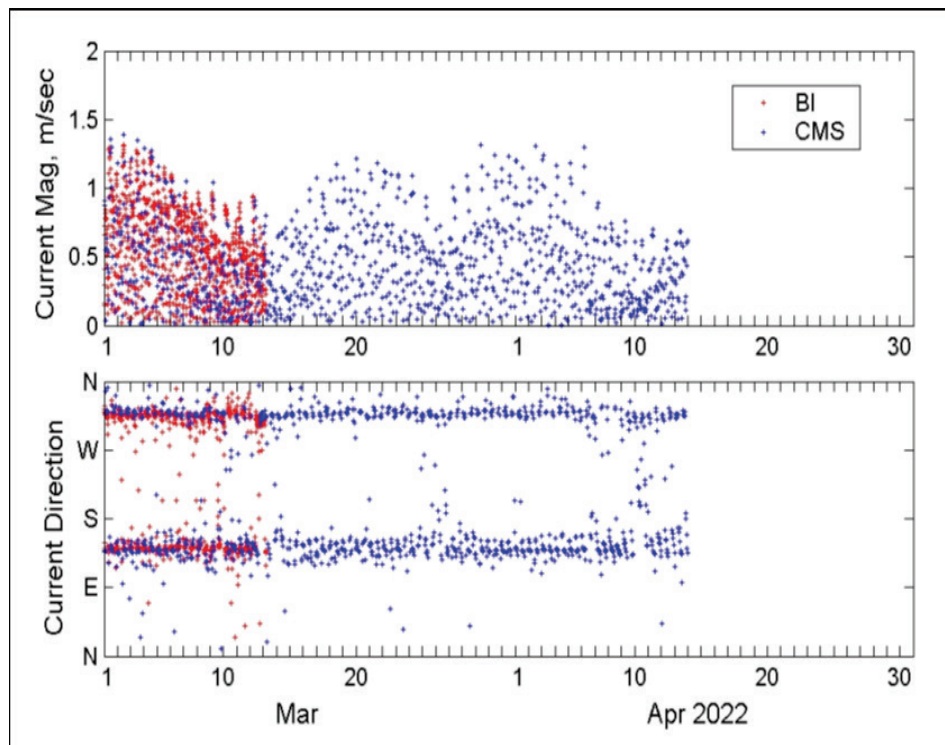


Figure 4-8. Model current magnitudes and directions versus data at BI for March–April 2022.

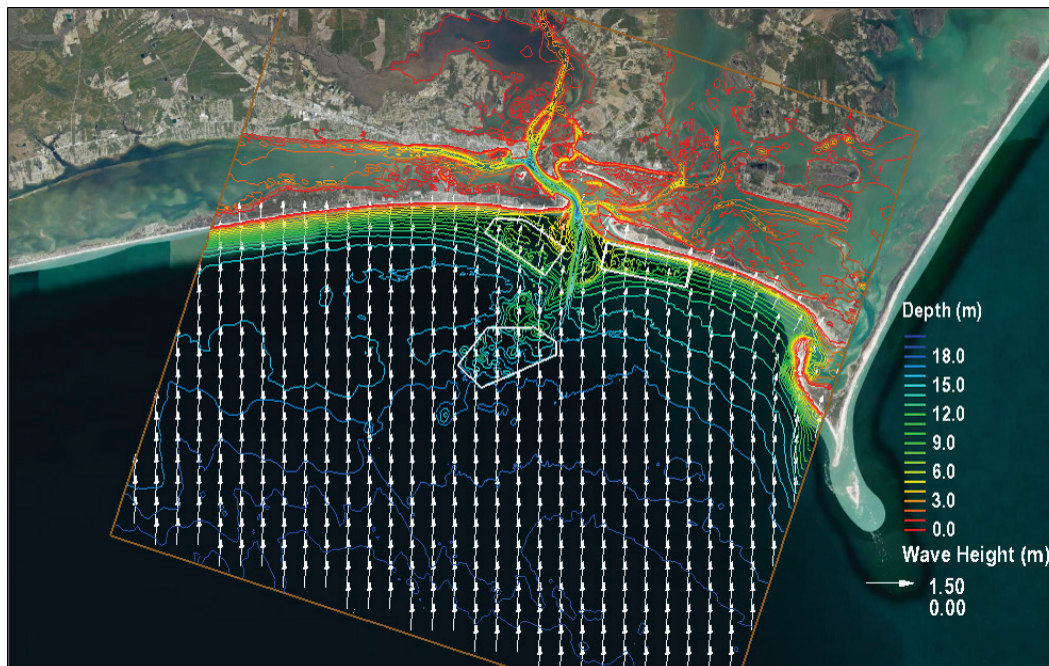


4.2 Summer Month

4.2.1 Waves

Significant wave height vectors are averaged for the summer month (August 2020) and spatial distribution of wave height and directions is shown in Figure 4-9. Dominant wave directions are from the south and incident waves are refracted approaching the shoreline. Monthly averaged wave heights are approximately 0.85 m (2.8 ft) in the offshore area. In nearshore open area significant wave heights are between 0.55–0.70 m (1.8–2.3 ft). Propagating to the inlet entrance channel, wave heights are further reduced to 0.3 to 0.4 m (1.0 to 1.3 ft). Behind Bogue Banks and Shackleford Banks in Bogue Sound and Back Sound, averaged wave heights overall are small, less than 0.05 m (0.16 ft).

Figure 4-9. Calculated monthly averaged significant wave heights for August 2020.



4.2.2 Current

Previous observational and numerical modeling studies demonstrated that currents in the Beaufort Inlet estuarine system are dominated by tidal flows (Klavans 1983; Logon 1995; Churchill et al. 1999). Asymmetric flow regime at the inlet channel and nearshore jet flows were also indicated by various researchers, which features the strongest flood currents on the eastern side of the channel and the strongest ebb currents on the western side (Klavans 1983; Logon 1995; Logon et al. 2000).

Figures 4-10 and 4-11 show the distribution of calculated depth-averaged flood and ebb currents for 4 August 2020 at 02:00 GMT and 19:00 GMT, respectively. The flood current period corresponds to the landfall of Hurricane Isaias on the North Carolina coast, when the measured significant wave height at CDIP SP 217 is approximately 5.0 m (16.4 ft) propagating from south-southwest (Figure 4-12), and the measured wind at Cape Lookout is greater than 21.4 m/s (47.9 mph). The interaction between tidal and storm conditions enhances the flow features at the inlet system.

Figure 4-10. Calculated flood currents on 4 August 2020 at 02:00 (GMT). Polygons indicate dredged material placement areas.

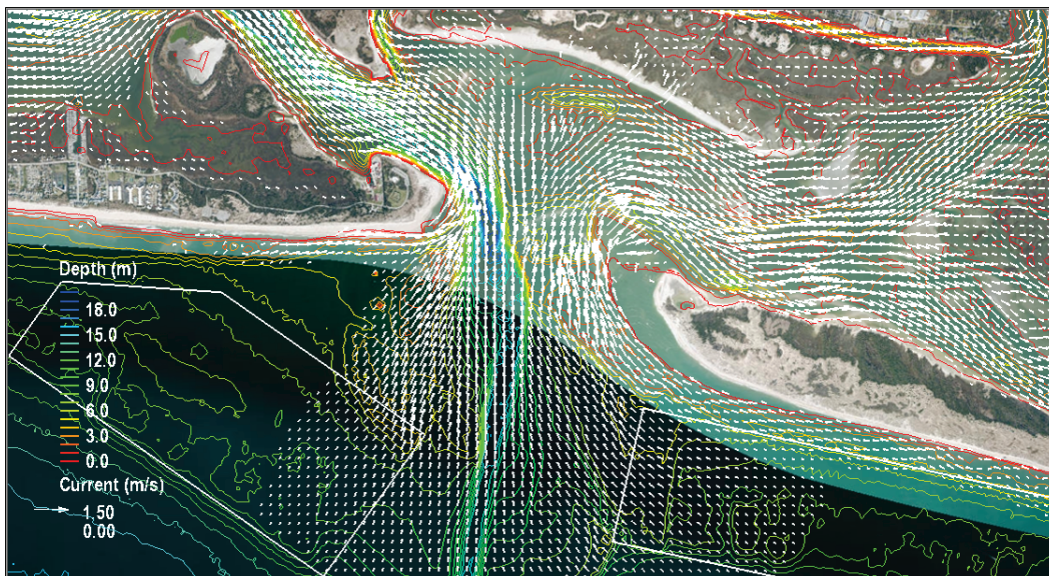


Figure 4-11. Calculated ebb currents on 4 August 2020 at 19:00 (GMT). Polygons indicate dredged material placement areas.

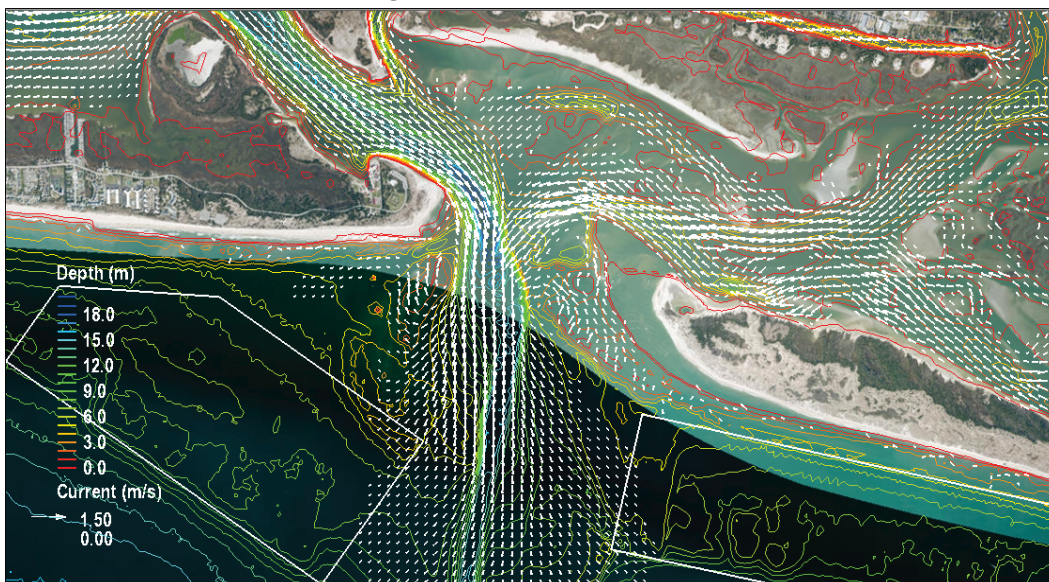
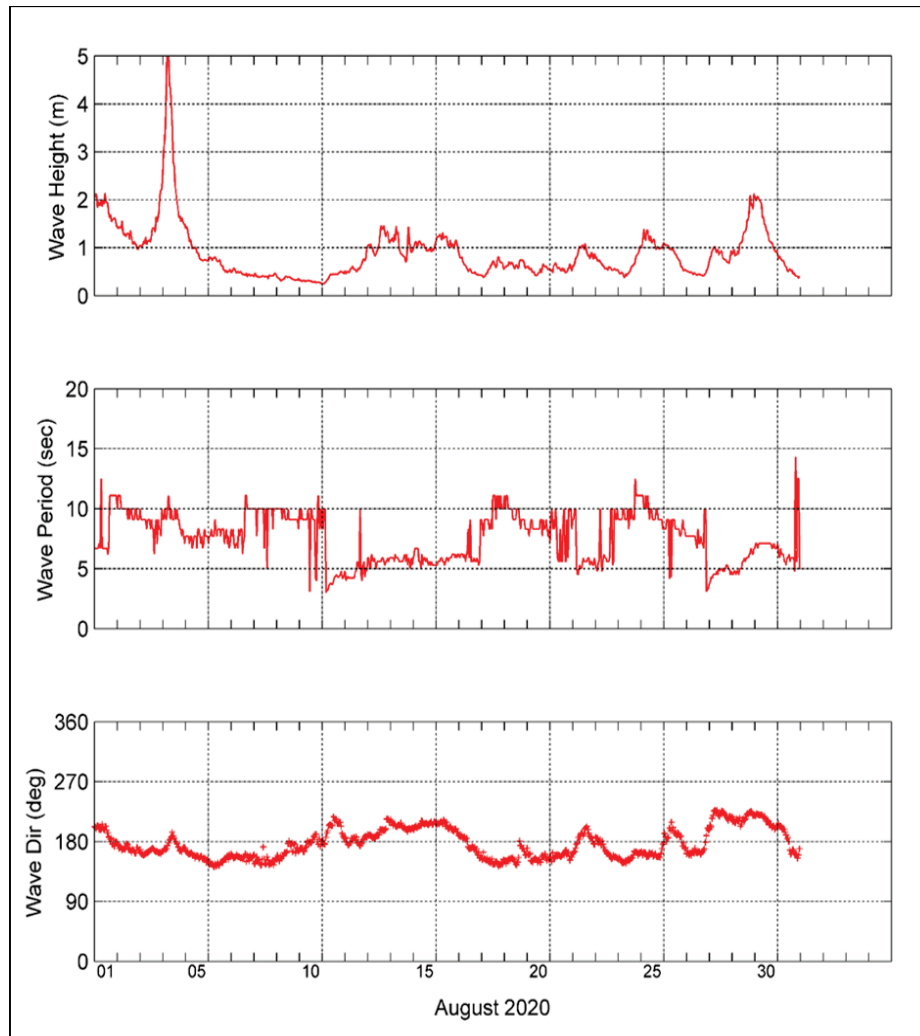


Figure 4-12. Wave parameters at CDIP buoy SP217 from 1 to 31 August 2020.



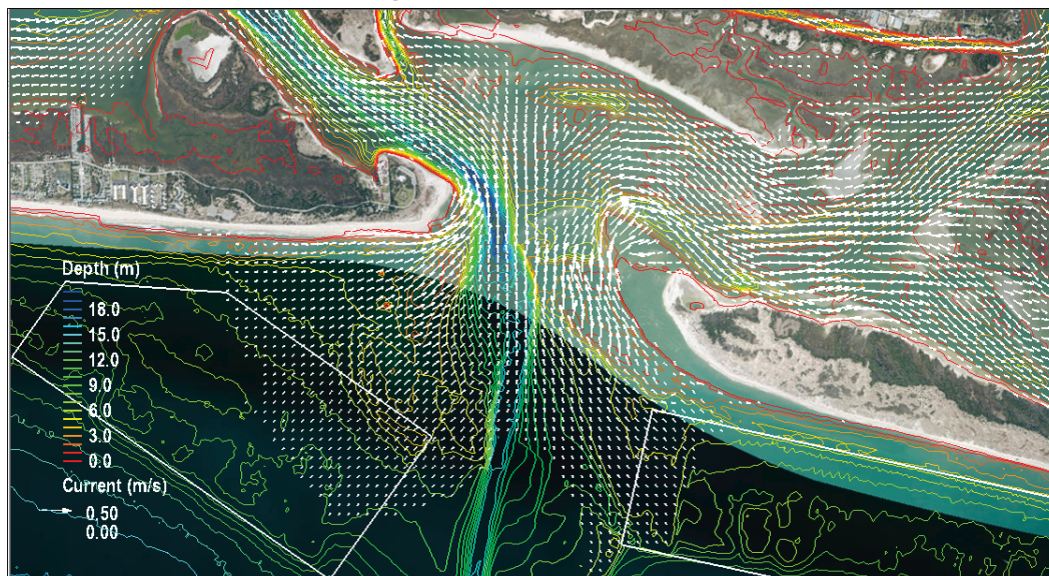
During flood currents, channel flows have a speed between 1.2 and 1.4 m/s (3.94 and 4.59 ft/s). Higher speeds occur on the eastern side of the inlet channel and lower speeds on the western side. Flood currents, flowing into the bay and splitting towards Back Sound and Bogue Sound, slightly decrease to less than 1.2 m/s (3.94 ft/s). Longshore currents are also noticeable outside the inlet at approximately 0.4 m/s (1.31 ft/s) in nearshore areas. The currents are flowing from west to east along Bogue Banks and from east to west along Shackleford Banks, and joining and strengthening the flood channel flows eventually.

As shown in Figure 4-11, ebb currents are relatively weaker compared with the flood currents. Current speeds in the inlet channel and the bay are between 0.8 and 0.9 m/s (2.62 and 2.95 ft/s). Longshore currents in the nearshore open area have a similar flow pattern to that during the flood

current period but with a smaller flow speed between 0.2 and 0.3 m/s (0.66 and 0.98 ft/s).

Monthly averaged current pattern during August 2020 is demonstrated by the spatial distribution of current vectors as shown in Figure 4-13. The average current field illustrates net water transport from the ocean side to the bay side through the inlet and presents the Beaufort Inlet estuary as a flood-dominated system. After filtering out tidal signals, monthly averaged current speeds are much smaller than instantaneous tidal currents. However, the calculated values still confirm the early described flow features around the inlet system. Currents on the eastern side of the inlet channel have a peak speed of 0.45 m/s (1.48 ft/s) and on the western side a peak speed of 0.37 m/s (1.21 ft/s). Flow split occurs into the bay behind Shackleford Banks and Bogue Banks and peak current speeds decrease to 0.25 m/s (0.82 ft/s). Although longshore currents have a small speed of approximately 0.1 m/s (0.33 ft/s) in nearshore areas, the flow directions are towards the inlet from both sides of the channel along Bogue Banks and Shackleford Banks.

Figure 4-13. Calculated monthly averaged currents for August 2020. Polygons indicate dredged material placement areas.



4.2.3 Sediment Plume

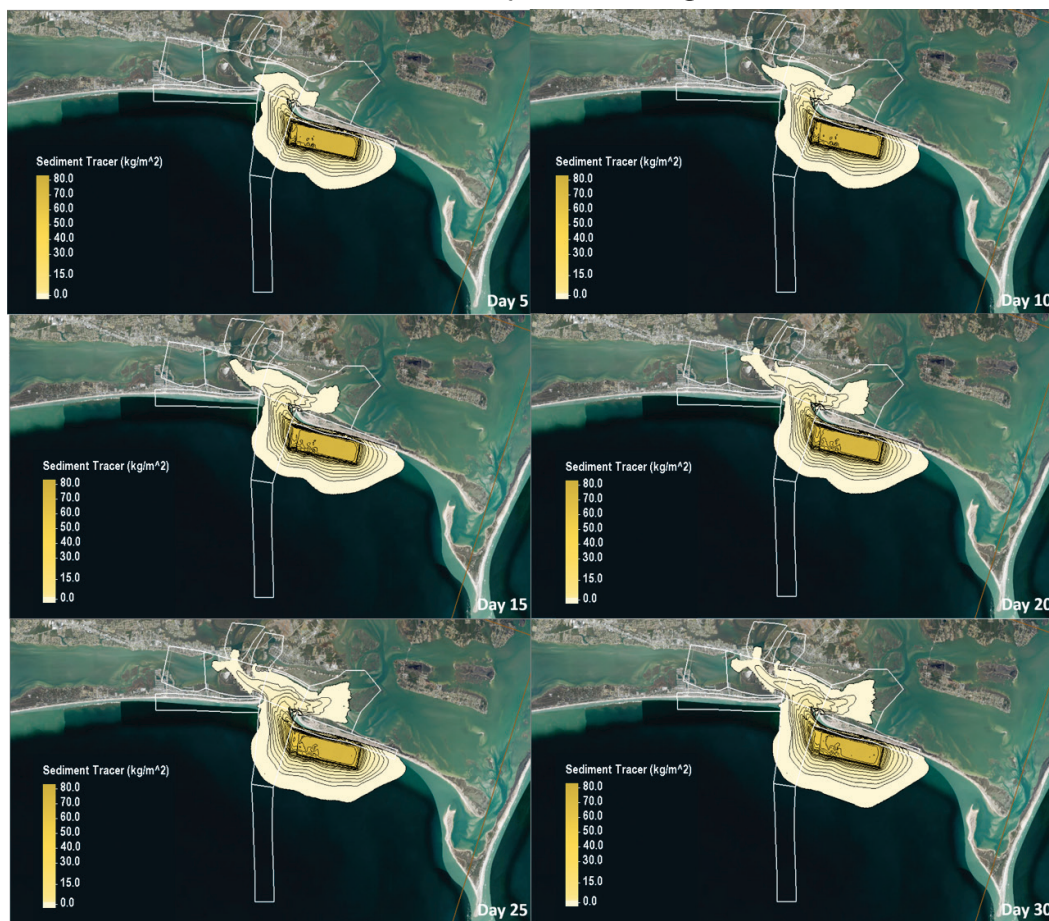
Sediment plume simulations are set up for the period of August 2020. Referring to the sediment grab samples (Figure 2-6), transported sediment is assigned a median grain size of 0.3 mm. Five bed layers are

specified in the CMS, and sediment materials are tracked from the beginning of simulations.

4.2.3.1 Alternative 1: Shackleford Banks

Sediment is released at the Shackleford Banks site for Alternative 1. Figure 4-14 shows temporal variations in transport and dissipation of sediment in the top (active) bed layer at a 5-day interval starting at Day 5.

Figure 4-14. Temporal evolution of the sediment plume originating from the Shackleford Banks site in the 5-day interval for August 2020.



At the initial stage of the simulation, the sediment plume is featured by spreading surrounding the releasing site in the open nearshore area. The maximum longshore spreading is approximately 2.2–2.3 km and the offshore spreading 2.0 km at Day 5. Corresponding to stronger tidal flows on the eastern side of the inlet channel and the passage of Hurricane Isaias, the plume intrusion to the bay is also shown in Figure 4-14, and the center of the plume is moving northward through the eastern portion of

the channel along Shackelford Banks. The expansion of the plume continues in the open area and inside the bay. In longshore direction, the eastward plume spreading is extended to 2.9 km and in cross-shore direction is to 2.4 km at Day 30. On the bay side, the plume moves in both directions towards Back Sound and Bogue Sound and it almost reaches the maximum coverage extending to North River Marsh on the east of and Newport River Marsh on the west of the inlet at Day 25.

Quantitative movement of sediment is also estimated by counting total mass in all five bed layers within 10 polygon (trap) areas at the end of the simulation (Figure 4-15). The percentage for each polygon area is the sediment mass originating from the Shackelford Banks site relative to the total sediment mass placed in the top bed layer of the site.

Figure 4-15. Sediment total mass (kilogram) within 10 polygon (trap) areas and percentages relative to materials placed at the Shackelford Banks site in August 2020.



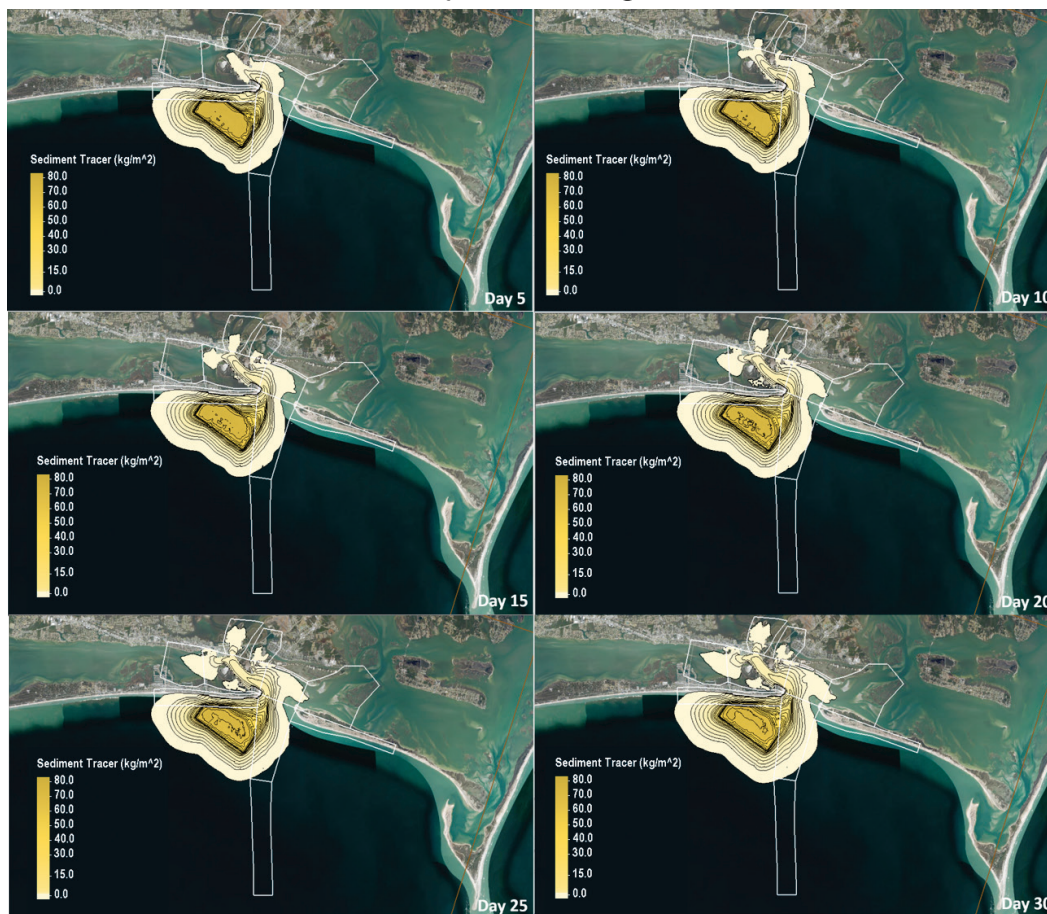
Figure 4-15 indicates that more than 95% of sediments stay in the placement site after the 1-month simulation. Of the remaining 5%, 3% of materials move to the inlet entrance channel and the nearshore zone along Shackelford Banks (close to the placement site) receives 0.7% of the sediment mass. A small amount of sediment is transported into the bay area, but traced sediment mass in Back Sound is 10 times more than

that in Bogue Sound. The asymmetric distribution of sediment is clearly related to the asymmetric flow pattern through the inlet channel.

4.2.3.2 Alternative 2: Bogue Banks

Sediment is released at the Bogue Banks site for Alternative 2. Figure 4-16 shows temporal variations in transport and dissipation of sediment in the top (active) bed layer at a 5-day interval starting at Day 5.

Figure 4-16. Temporal evolution of sediment plume originating from the Bogue Banks site in the 5-day interval for August 2020.



Similar to Alternative 1, the sediment plume at the initial stage of sediment tracing shows primary sediment dissipation surrounding the releasing site in the open nearshore area. The maximum longshore plume spreading is approximately 2.6 km westward and the offshore spreading is less than 2.0 km at Day 5. Considering the dominant tidal flow pattern at Beaufort Inlet (Figure 4-13), the longshore plume migration towards west might be related to storm driven flows due to the passage of Hurricane Isaias.

The hurricane forcing is also responsible for the strength of the plume intruding to the bay, which is illustrated by the center of the plume shifting on the western side of the channel along Bogue Banks and westward spreading of the sediment plume in Bogue Sound. From Day 5 to Day 30, the expansion of the plume continues in the open area and inside the bay. However, the westward longshore and southward cross-shore spreading is not significant and the sediment plume mainly migrates eastward from 1.8 km at Day 5 to 2.4 km at Day 30, reaching to the eastern side of the inlet channel. On the bay side, the center of the plume primarily moves in west direction. The Newport River Marsh area shows trace of the plume at Day 10 and the far west side of Bogue Sound at Day 20 of the simulation.

Total mass is counted in all five bed layers within 10 polygon (trap) areas at the end of the simulation (Figure 4-17). The percentage for each polygon area is the sediment mass originating from the Bogue Banks site relative to the total sediment mass placed in the top bed layer of the site.

Figure 4-17. Sediment total mass (kilogram) within 10 polygon (trap) areas and percentages relative to materials placed at the Bogue Banks site in August 2020.

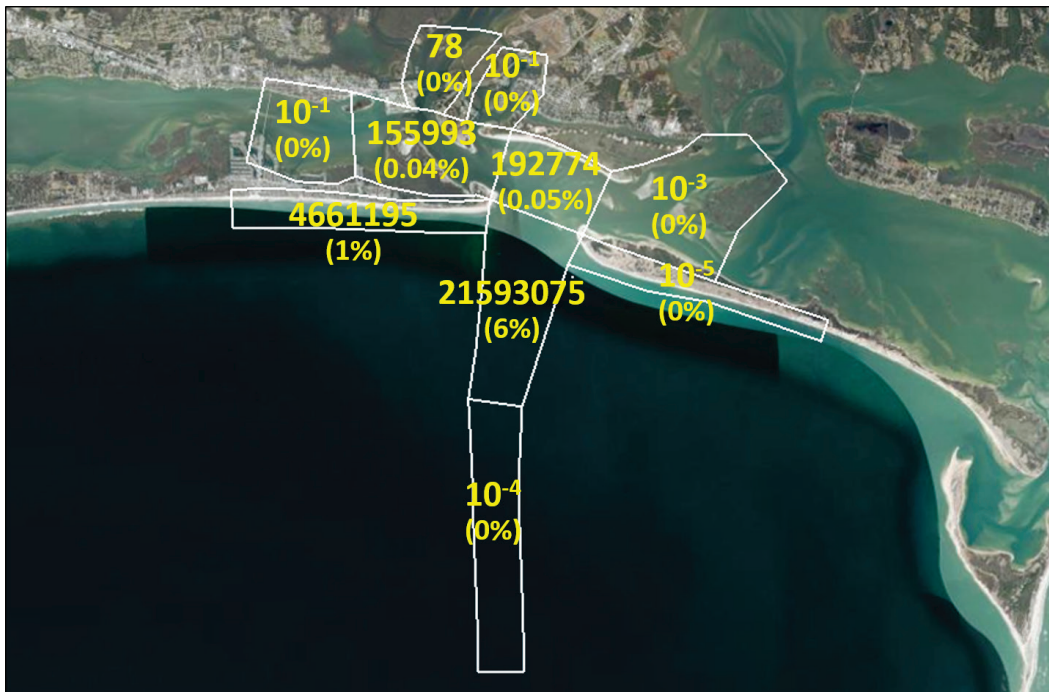


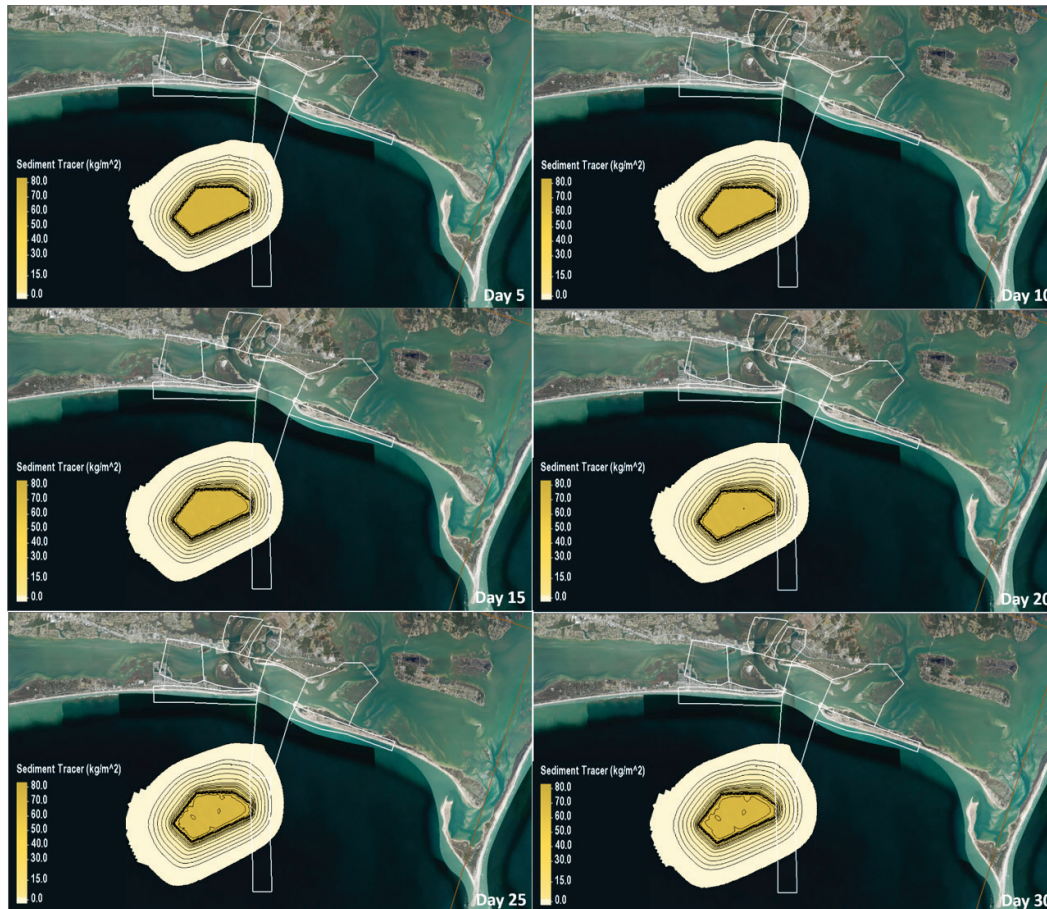
Figure 4-17 indicates that more than 90% of sediments stay in the placement site after the 1-month simulation. A total of 6% of materials move to the inlet entrance channel. Close to the placement site, the

nearshore zone along Bogue Banks receives 1.0% of the sediment mass. Comparing with the Shackleford Banks placement, more sediment is transported into the bay area for the Bogue Banks placement (0.03% versus 0.09%). Most of the sediment mass is found in Bogue Sound and only trace of sediment material in Back Sound.

4.2.3.3 Alternative 3: Ocean Dredged Material Disposal Site (ODMDS)

Sediment is released at the ODMDS site for Alternative 3. Figure 4-18 shows temporal variations in transport and dissipation of sediment in the top (active) bed layer at a 5-day interval starting at Day 5.

Figure 4-18. Temporal evolution of sediment plume originating from the ocean dredged material disposal site (ODMDS) in 5-day interval for August 2020.



Model results indicate that the calculated depth-averaged flow speeds around the ODMDS site are generally less than 0.1 m/s during August 2020. Therefore, temporal evolution of sediment plume is mostly dominated by the diffusion of suspended sediment materials for the sediment placed in this offshore site. The sediment plume at Day 5 shows

initial sediment spreading between 2.0 and 3.0 km in all directions. Moving towards nearshore north side and west side of the ODMDS site, water becomes shallower, current speed stronger, and the plume expansion reaches to a distance of 3.0 km. Towards south side and east side of the ODMDS site, the plume expansion is approximately 2.0 km. From Day 5 to Day 30, the plume continues to grow, but the maximum expansion is less than 800 m towards south-southwest direction.

Figure 4-18 illustrates that sediment placed in the ODMDS site moves within a 3.5 to 5.0 km circle outside the inlet during the 30-day summer month. Figure 4-19 indicates that more than 99% of sediments stay in the ODMDS site and tracked sediment is found in only two channel polygon (trap) areas after the 1-month simulation. Next to the placement site, the offshore channel trap receives approximately 0.4% of traced sediment materials. Trace of sediment is transported into the channel trap close to the inlet entrance. No sediment from the placement site is detected in the nearshore and the bay polygon (trap) areas within the simulation period.

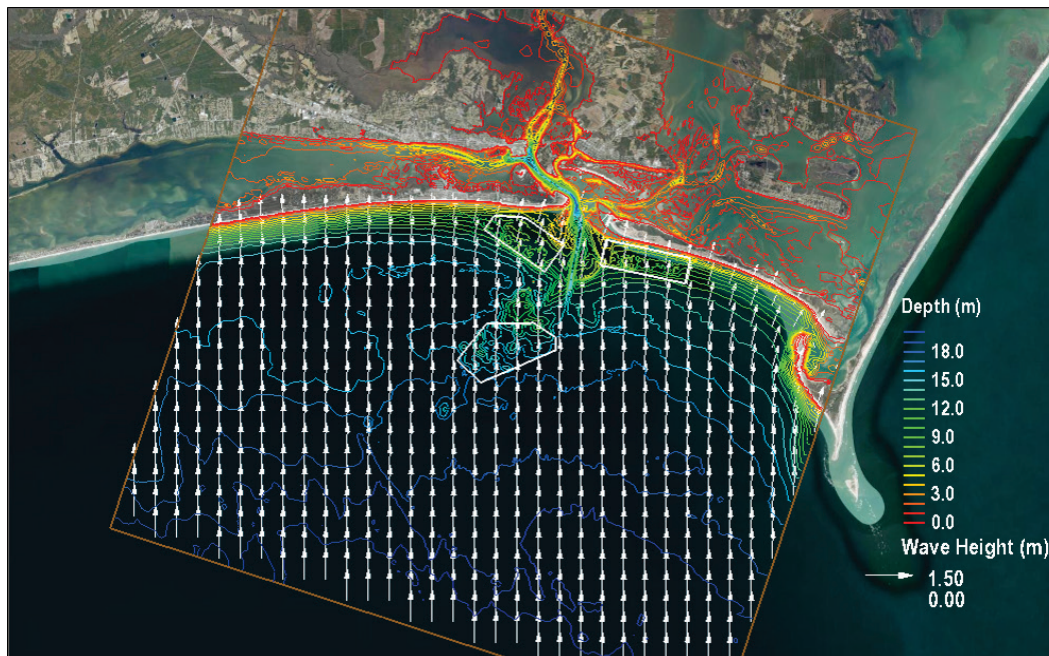
Figure 4-19. Sediment total mass (kilogram) within 10 polygon (trap) areas and percentages relative to materials placed at the ODMDS site in August 2020.



4.2.4 Waves

Significant wave height vectors are averaged for the winter month (December 2018), and spatial distribution of wave height and directions is shown in Figure 4-20. The figure displays that dominant wave directions are from south and incident waves are refracted approaching to shoreline. Monthly averaged wave heights are greater than 1.0 m (3.3 ft) in the offshore area. In nearshore open area significant wave heights are between 0.7–0.8 m (2.3–2.6 ft). Propagating to the inlet entrance channel towards Bird Shoal, wave heights are further reduced to 0.3 to 0.4 m (1.0 to 1.3 ft). Behind Bogue Banks and Shackleford Banks in Bogue Sound and Back Sound, averaged wave heights are with a value of less than 0.05 m (0.16 ft).

Figure 4-20. Calculated monthly averaged significant wave heights for December 2018.



4.2.5 Current

Figures 4-21 and 4-22 show the distribution of calculated depth-averaged flood and ebb currents for 23 December 2018 at 13:00 (GMT) and 19:00 GMT, respectively. No winter storms occur and tide is the dominant process corresponding to this period. During flood currents, channel flows have a speed between 1.0 and 1.1 m/s (3.3 and 3.6 ft/s) and no significant speed difference on the eastern and the western side of the inlet channel. Similar to the summer month, flood currents flow into the bay and split towards Back Sound and Bogue Sound. Longshore currents appear outside the inlet in nearshore areas, which are approximately 0.3 m/s (1.0 ft/s)

and are flowing along the shoreline towards the inlet entrance from both east and west directions.

Figure 4-21. Calculated flood currents on 23 December 2018 at 13:00 (GMT). Polygons indicate dredged material placement areas.

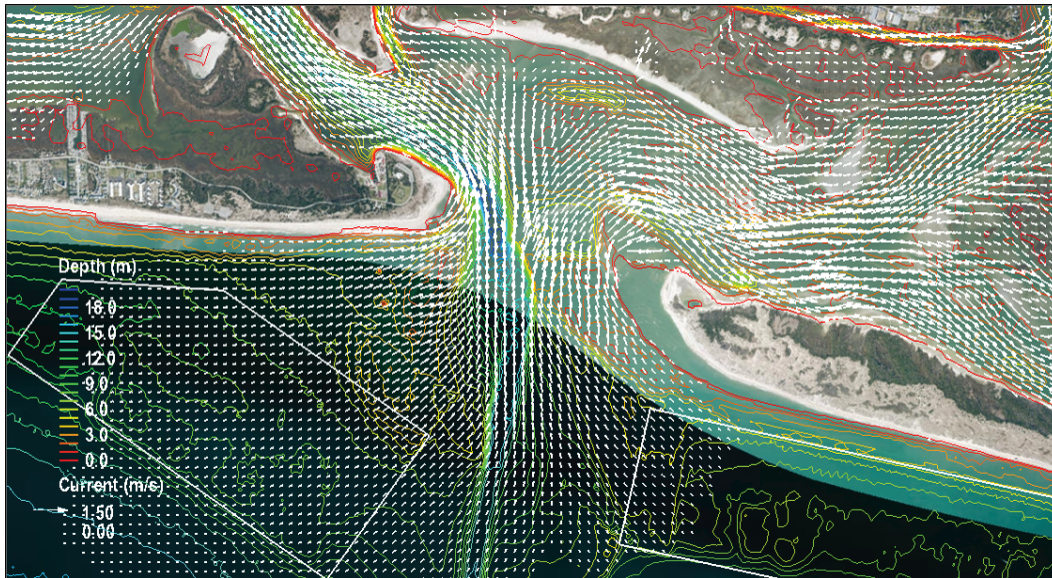
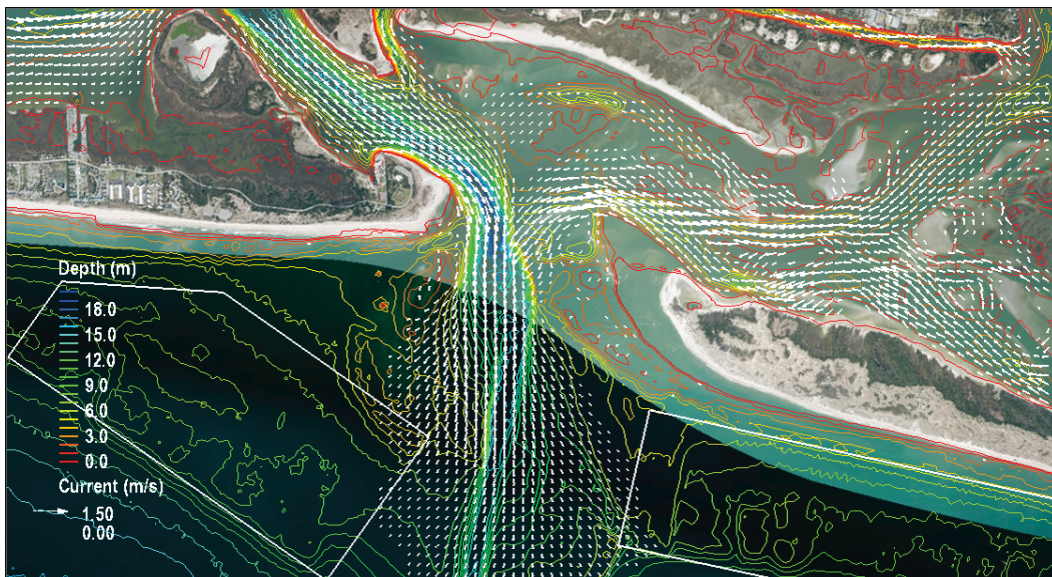


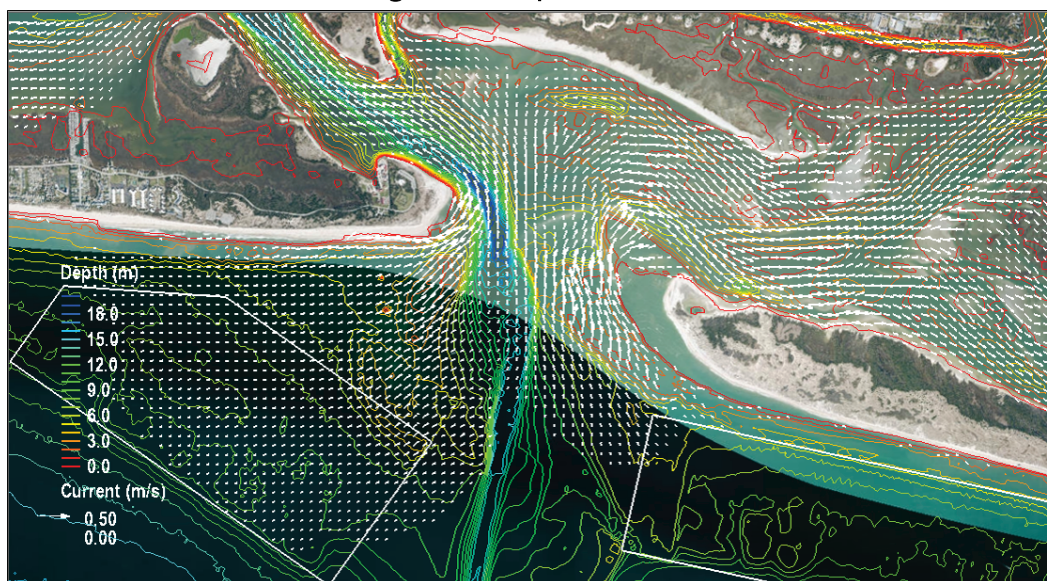
Figure 4-22. Calculated ebb currents on 23 December 2018 at 19:00 (GMT). Polygons indicate dredged material placement areas.



As shown for the summer case, ebb currents are relatively weaker comparing with flood currents. Current speeds in the inlet channel and the bay are between 0.7 and 0.8 m/s (2.3 and 2.62 ft/s). Longshore currents in the nearshore open area do not show up in Figure 4-22 during the ebb current period.

Monthly averaged currents during December 2018 are demonstrated by the spatial distribution of current vectors as shown in Figure 4-23. Like the summer month, the current field also indicates a flood-dominated estuarine system. Removing tidal signals from the time series output, monthly averaged current speeds are between 0.3 m/s (1.0 ft/s) and 0.4 m/s (1.31 ft/s) along the inlet entrance channel. Currents on the eastern side of the channel have a peak speed of 0.37 m/s (1.21 ft/s) and on the western side a peak speed of 0.35 m/s (1.15 ft/s). Splitting into the bay, two branches flow to Back Sound and Bogue Sound separately. The peak current speeds in Back Sound are reduced to 0.25 m/s (0.82 ft/s) and in Bogue Sound reduced to 0.2 m/s (0.66 ft/s). Longshore currents have a speed of less than 0.1 m/s (0.33 ft/s) in nearshore areas.

Figure 4-23. Calculated monthly averaged currents for December 2018. Polygons indicate dredged material placement areas.



4.2.6 Sediment Plume

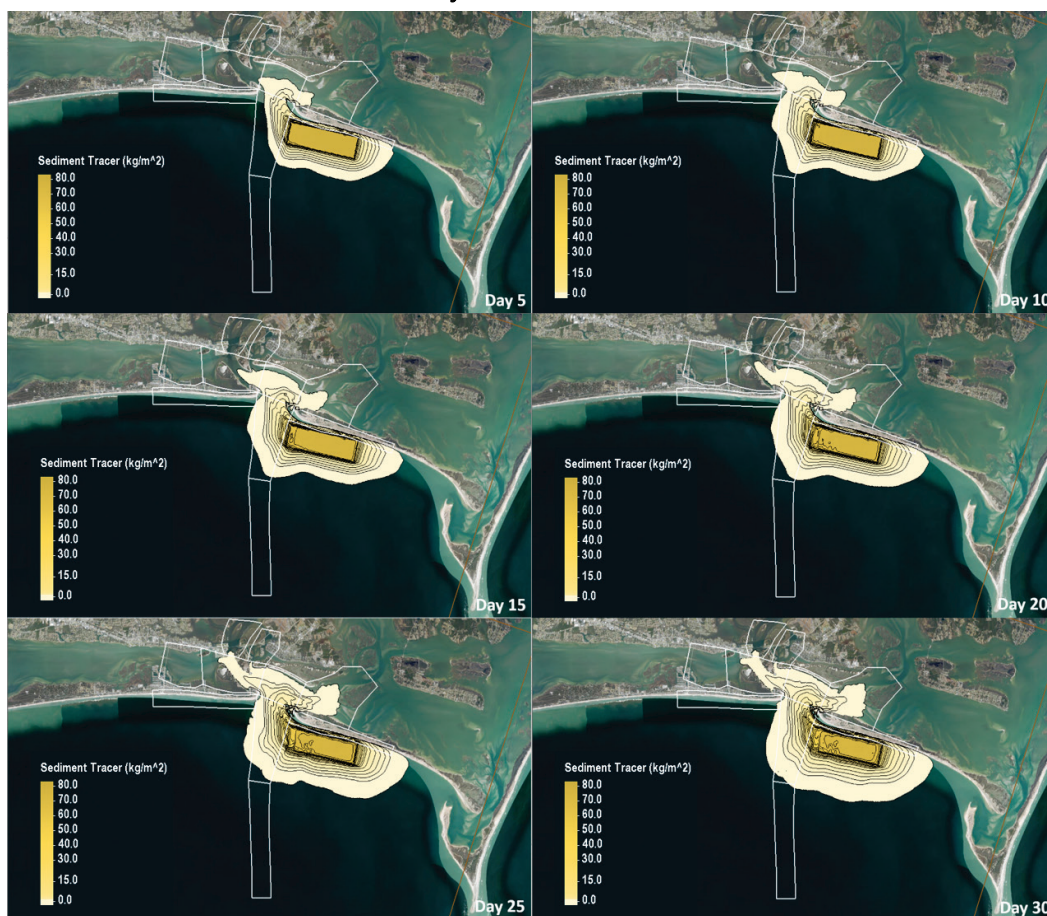
Specifying the same mean transport grain size of 0.3 mm, the sediment plume simulation is set up for the period of December 2018. Five bed layers are specified in the CMS and sediment materials are placed in

three dredged material disposal sites and tracked from the beginning of simulations.

4.2.6.1 Alternative 1: Shackleford Banks

Sediment is released at the Shackleford Banks site for Alternative 1. Figure 4-24 shows temporal variations in transport and dissipation of sediment in the top (active) bed layer at a 5-day interval starting at Day 5.

Figure 4-24. Temporal evolution of sediment plume originating from the Shackleford Banks site in the 5-day interval for December 2018.



As in the summer month, the sediment plume is initially spreading by dissipation surrounding the placement site in the open nearshore area. The maximum longshore eastward spreading is approximately 2.2–2.3 km, similar to the summer month, and the offshore spreading is 1.3 km, less than the summer month, at Day 5. The plume spreads westward towards the inlet entrance and is carried by dominated flood tidal flows to the bay. At the early stage of the simulation, the center of the

plume is moving northward through the eastern portion of the channel along Shackleford Banks and then migrating eastward in Back Sound.

From Day 5 to Day 30, the plume continues to grow in the open area. It is extended to 3.2 km eastward and 2.7 km westward beyond the inlet channel in the longshore direction and to 2.4 km southward in the cross-shore direction. The westward plume expansion results in the sediment being entrained in two branches of tidal flows in the bay side towards Back Sound and Bogue Sound later in the simulation. Traced sediment materials can be seen reaching North River Marsh on the east of the bay and Newport River Marsh on the west of the bay.

Figure 4-25 shows the total sediment mass in all five bed layers within 10 polygon (trap) areas and the percentage of the total mass within each polygon area relative to the total sediment mass placed in the top bed layer of the site at the end of the simulation.

Figure 4-25. Sediment total mass (kilogram) within 10 polygon (trap) areas and percentages relative to materials placed at the Shackleford Banks site in December 2018.



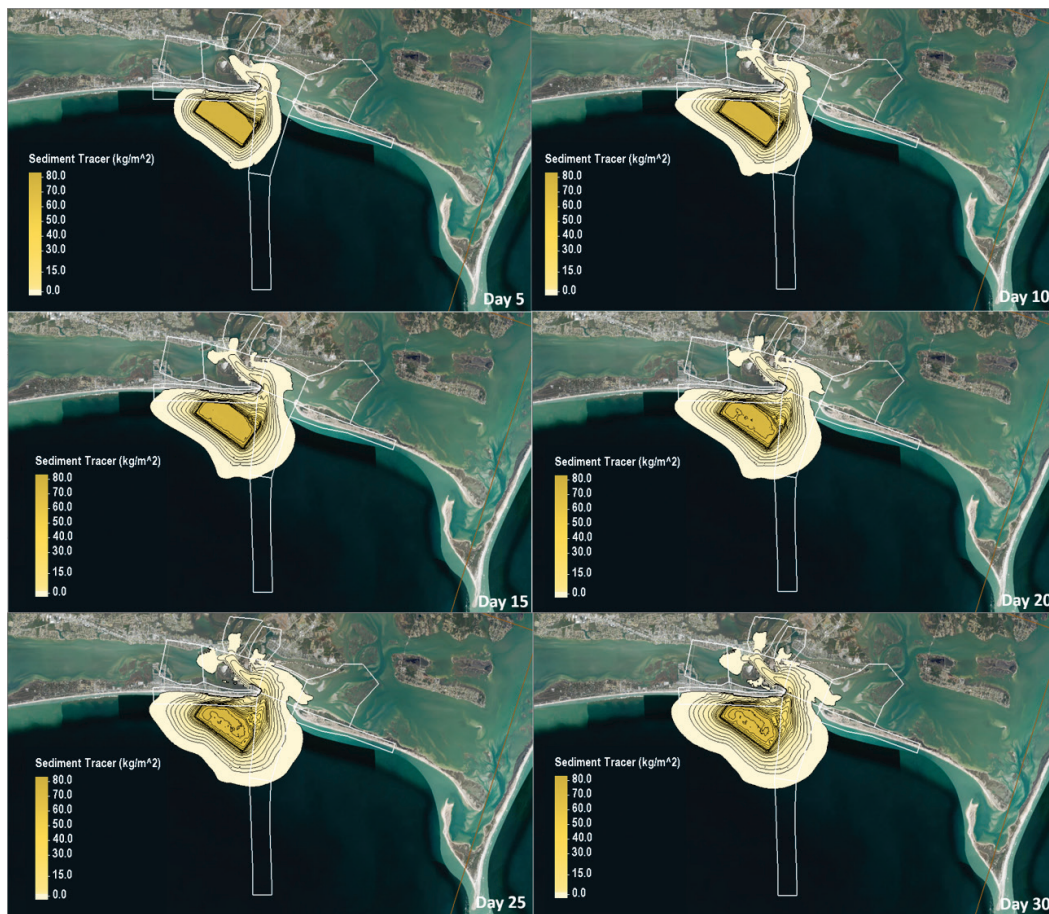
Figure 4-25 indicates that up to 5% of the sediment moves away from the Shackleford Banks placement site after the 1-month simulation. A total of 3% of the material moves to the inlet entrance channel. Close to the placement site, the nearshore zone along Shackleford Banks receives 1% of the sediment mass. Comparing with the summer month, more traced

sediment is transported into the bay area (approximately 5%), but a relatively small amount moves into Back Sound and Bogue Sound.

4.2.6.2 Alternative 2: Bogue Banks

Alternative 2 is to examine the distribution of sediment plume for the materials placed at the Bogue Banks site during December 2018. Figure 4-26 shows temporal variations in transport and dissipation of sediment in the top (active) bed layer at a 5-day interval starting at Day 5.

Figure 4-26. Temporal evolution of a sediment plume originating from the Bogue Banks site in the 5-day interval for December 2018.



During December 2018, the initial sediment spreading is relatively low in the open nearshore area. The maximum longshore and cross-shore plume expansion only reaches to a distance between 1.2 and 1.4 km surrounding the placement site at Day 5. Strong tidal flows at the inlet are responsible for the plume intrusion to the bay, which is illustrated by the center of the plume shifting on the western side of the channel along Bogue Banks and

westward spreading of the sediment plume in Bogue Sound. From Day 5 to Day 30, the expansion of the plume is significant in the open area and inside the bay. Outside the inlet, the plume shows approximately larger than 1.0 km growth, which reaches 2.2 km in cross-shore direction and 2.8 to 2.9 km in longshore direction. On the bay side, the center of the plume moves towards the west in Bogue Sound.

Comparing with August 2020, more storm events occur during December 2018 (Figure 4-27). Corresponding to the winter condition, the total mass is counted in all five bed layers within 10 polygon (trap) areas at the end of the simulation (Figure 4-28). The percentage for each polygon area is the sediment mass originating from the Bogue Banks site relative to the total sediment mass placed in the top bed layer of the site.

Figure 4-27. Wave parameters at CDIP buoy SP217 from 1 to 31 December 2018.

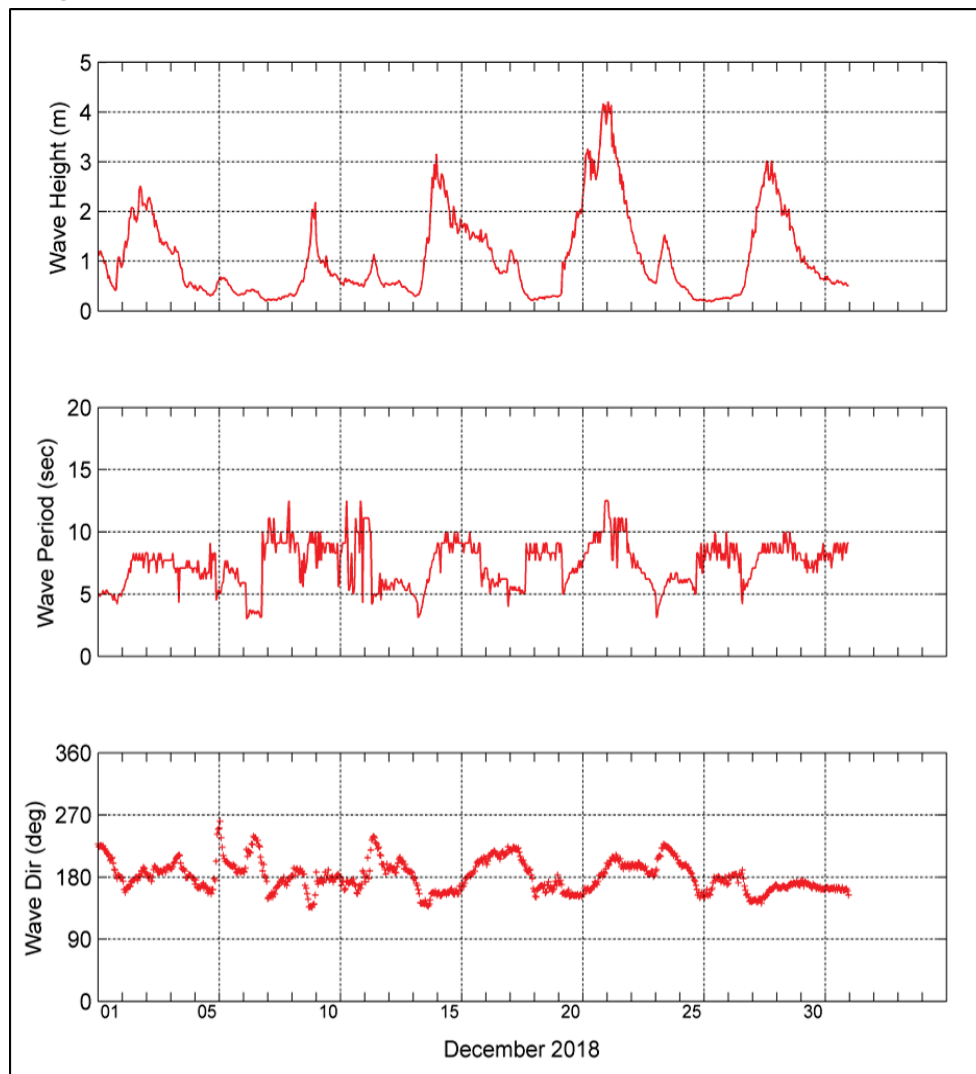


Figure 4-28. Sediment total mass (kilogram) within 10 polygon (trap) areas and percentages relative to materials placed at the Bogue Banks site in December 2018.

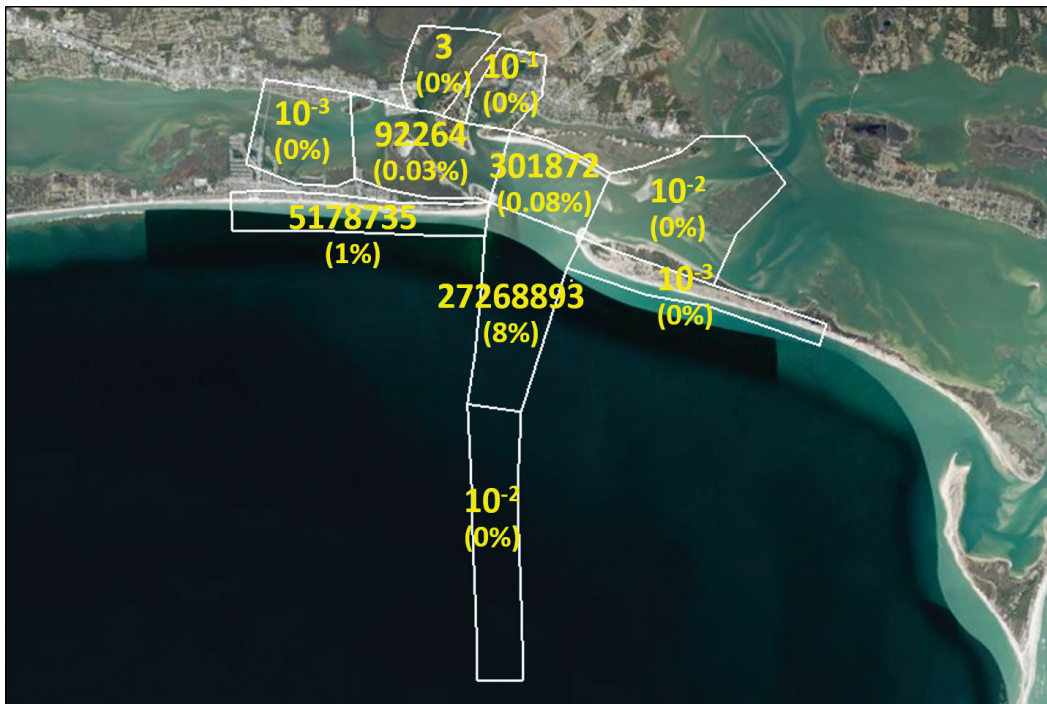


Figure 4-28 indicates that almost 10% of sediments move away from the placement site after one month. A total of 8% of materials move to the inlet entrance channel. The nearshore area along Bogue Banks receives 1.0% of the sediment mass. Comparing with the summer condition, much more sediment is transported into the bay area. Most of the sediment is moving towards the west in Bogue Sound.

4.2.6.3 Alternative 3: ODMDS

Different from the summer case, the calculated depth-averaged flow speeds around the ODMDS site can be between 0.1 and 0.2 m/s (0.33 and 0.66 ft/s) during the passage of a winter storm. The frequency of the winter storms for December 2018, as indicated in Figure 4-27, implicates a different trend of temporal variations in transport of sediment during the winter month.

Figure 4-29 shows that initial sediment spreading around the placement site is between 1.6 to 1.8 km in the east and south directions, and 1.1 to 1.2 km in the west direction. The largest expansion is approximately 2.7 to 2.8 km in the north direction, towards the inlet entrance. The pattern of sediment movement reflects the mean flow pattern for the winter month. From Day 5 to Day 30, the plume continues to grow but the expansion rate

is different for each direction of travel. The maximum plume expansion is from 1.1 to 4.2 km towards the west and the north-south expansion is only approximately 500 m (1,641 ft). During the winter month, more sediment moves to the channel and beyond and the plume expansion rate in east-west direction is much greater than that during the summer month.

Figure 4-29. Temporal evolution of sediment plume originating from the ODMDS site in the 5-day interval for December 2018.

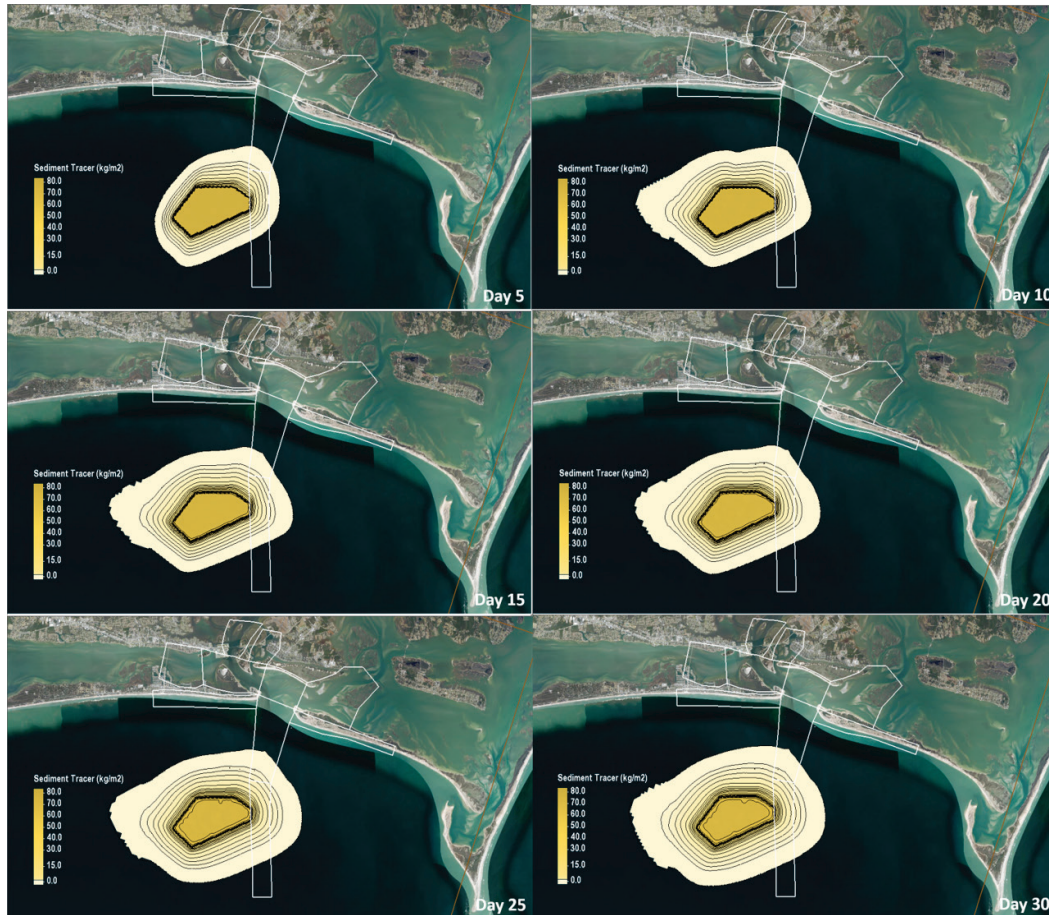


Figure 4-29 illustrates that sediment plume for sediment material placed in the ODMDS site only covers two channel polygon (trap) areas during the 30-day winter month and the total mass is counted within these two areas in Figure 4-30, which indicates that more than 99% of sediments stay in the placement site after the 1-month simulation.

Figure 4-30. Sediment total mass (kilogram) within 10 polygon (trap) areas and percentages relative to materials placed at the ODMDS site in December 2018.



5 Conclusions

With the implementation of a field-survey program, a coupled wave, hydrodynamic, sediment transport model, the CMS is developed and applied to investigate sediment transport and evolution of sediment plumes around the Beaufort Inlet estuarine system. Field data collection includes the deployment of two AWACs to measure waves, water level, and current within the inlet channel and the open water in the nearshore Atlantic Beach area. Driven by tide, waves, and wind, the CMS simulations include a 90-day model calibration and validation, and one representative summer (August 2020) and one winter (December 2018) month simulation. Three alternative placement sites are configured for the summer and winter month simulations, respectively, including tracking sand tracers originated from the placement areas, the Shackleford Banks site, the Bogue Banks site, and the ODMDS site. From model results, the migration of sediment plume is evaluated and compared among three placement alternatives for the simulated summer and the winter month. The major conclusions are presented as follows:

1. Field data program is an integral component to the successful implementation of the numerical model. The calibration of the CMS provides the representation of physical forcing factors that drive sediment transport at the Beaufort Inlet estuarine system. Features of tidal flows are captured through spatial and temporal field data collection of water levels, currents, and waves at the Beaufort Inlet channel and the open coast outside the inlet.
2. Primary driving forcing in the areas includes tide, wind, and waves. Tidal currents are the dominant flow component in the Beaufort Inlet estuary, and wave-driven currents during a storm are dominant in the open coastal area.
3. Among three sediment material placement sites, two nearshore sites, the Shackleford Banks site, the Bogue Banks site, are under large influence of longshore and cross-shore currents. Sediments originated from these two sites move to the inlet entrance channel and are carried over to Back Sound eastward and Bogue Sound westward by the split flood dominated tidal currents into the bay.
4. The ODMDS site is located in a deeper offshore area, where coastal currents are relatively weak and migration of the sediment plume is primarily controlled by diffusion processes.

5. Storm conditions (tropical and extratropical storms) have a major impact on spreading of the sediment plume, which is demonstrated by further westward expansion of the sediment plume in Bogue Sound during the summer month and relatively larger east-west plume growth around the ODMDS site during the winter month.

The conclusions provided above have been based on sediment tracer simulations. To improve our understanding of suspended sediment behavior around a coastal inlet and estuarine system, further numerical modeling effort would be required accompanying with a comprehensive data collection program and in-depth laboratory work. The modeling study would involve more extensive analyses of physical conditions and sediment movement. In addition to that, field data and laboratory experiments would help to better validate numerical models and understand sediment properties and sediment transport.

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Abbreviations

AWAC	Acoustic wave and current profiler
BI	Beaufort Inlet
BIOS	Beaufort Inlet Offshore
CDIP	Coastal Data Information Program
CMS	Coastal Modeling System
CRM	Coastal Relief Model
DEM	Digital Elevation Model
MSL	Mean sea level
NDBC	National Data Buoy Center
ODMDS	Ocean dredged material disposal site
RMSE	Root-mean-square error
SMS	Surface-water Modeling System
WSE	Water-surface elevation

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