NOAA Technical Report NOS CO-OPS 089

Cape Fear, North Carolina Current Survey 2016

Silver Spring, Maryland

June 2019

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Center for Operational Oceanographic Products and Services

National Ocean Service

National Oceanic and Atmospheric Administration

U.S. Department of Commerce

The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) provides the National infrastructure, science, and technical expertise to collect and distribute observations and predictions of water levels and currents to ensure safe, efficient and environmentally sound maritime commerce. The Center provides the set of water level and current products required to support NOS' Strategic Plan mission requirements, and to assist in providing operational oceanographic data/products required by NOAA's other Strategic Plan themes. For example, CO-OPS provides data and products required by the National Weather Service to meet its flood and tsunami warning responsibilities. The Center manages the National Water Level Observation Network (NWLON), a national network of Physical Oceanographic Real-Time Systems (PORTS®) in major U. S. harbors, and the National Current Observation Program (NCOP) consisting of current surveys in near shore and coastal areas utilizing bottom mounted platforms, subsurface buoys, horizontal sensors and quick response real time buoys. The Center establishes standards for the collection and processing of water level and current data; collects and documents user requirements, which serve as the foundation for all resulting program activities; designs new and/or improved oceanographic observing systems; designs software to improve CO-OPS' data processing capabilities; maintains and operates oceanographic observing systems; performs operational data analysis/quality control; and produces/disseminates oceanographic products.

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September 2018

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) works to promote safe navigation throughout U.S. waterways. As part of this effort, the CO-OPS National Current Observation Program (NCOP) acquires, analyzes, and disseminates information on tidal currents in the coastal U.S. that is used to update the NOAA Tidal Current Tables. Tidal current data are collected to help increase the repository of tidal current observations and predictions and also to update previous observations and predictions with increased quality and accuracy at historical stations based on validated user requirements. The data products generated are utilized by NOAA and the user community to help ensure safe navigation, make informed coastal zone management decisions, and support the protection of life and property.

NCOP conducts internal assessments of locations that need updated tidal current predictions. The Cape Fear River was identified through this process. In meetings with stakeholders, CO-OPS determined that existing predictions did not serve the needs of the navigational community. Therefore, a current survey was planned and conducted, and its results were made available online and in print.

This report summarizes the data collection and analysis completed by NCOP for the 2016 Cape Fear River Current Survey in North Carolina. In 2015, a reconnaissance was conducted to gather information about the physical characteristics of proposed sites. Based on this reconnaissance, a total of 26 stations were installed for at least one lunar month between mid-March and June 2016. At each station, currents were measured with an acoustic Doppler current profiler (ADCP) using a mooring configuration determined by factors such as station depth, seafloor composition, expected maritime activities, anticipated currents, and available inventory. Concurrent with each deployment and recovery of an ADCP, a conductivity, temperature, and depth (CTD) vertical profile was taken using a CastAway-CTD to ascertain physical properties of the seawater at the approximate location of each station.

Each ADCP was configured to collect data in 6-minute ensembles of averaged acoustic pulses. Twenty-five of the 26 stations collected data of sufficient quality, including vertical current profiles (speed and direction), water temperature, pressure, and additional quality control variables. The 25 stations include two new reference stations (USS North Carolina (CFR1605) and Southport (CFR1624)) and four stations located in the Intracoastal Waterway. These stations were analyzed for tidal constituents using harmonic analysis of the current time series data collected by the ADCP. Tidal current predictions for each station were made available online via the NOAA currents web interface, and updates were published in the 2018 Tidal Current Tables. Follow-up meetings will be held with the local navigation community to receive feedback on these updates.

1. INTRODUCTION

The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) manages the National Current Observation Program (NCOP). The program's main goal is to improve the quality and accuracy of tidal current predictions. Improving this information is a critical part of NOS's efforts toward promoting safe navigation in our nation's waterways. Mariners require accurate and dependable information on the movement of the waters in which they navigate. As increasingly larger ships utilize our ports and as seagoing commerce continues to increase, there is an increased risk to safe navigation in the nation's ports (NOAA, 2018f). CO-OPS acquires, archives, and disseminates information on tides and tidal currents in U.S. ports and estuaries, a vital NOS function since the 1840s. The main sources of this information for the public are the CO-OPS Tides and Currents website (NOAA, 2018a) and the National Oceanic and Atmospheric Administration (NOAA) Tidal Current Tables (TCTs) (NOAA, 2018d), which are published annually as required by the Navigation and Safety Regulations section of the U.S. Code of Federal Regulations (33CFR§164.33). Both the collection and analysis of current observations, as well as the dissemination of the data, fall under the authority of the Navigation and Navigable Waters title of the U. S. Code (*33USC§883a-b*).

The flow dynamics of an estuary or tidal river can be modified by changes in natural factors, such as land motion and other morphologic changes, or through man-made alterations, such as the deepening of channels by dredging, harbor construction, bridge construction, the deposition of dredge materials, and the diversion of river flow. Changes in water flow and tidal dynamics can affect the accuracy of tide and tidal current predictions; therefore, new data must be collected periodically to ensure that predictions remain reliable and to adjust them when necessary.

CO-OPS has developed expertise in deploying current profilers throughout the nation's coastal waters via the NCOP program. These data are used for a number of products. In addition to updating existing tidal current predictions (NOAA, 2018d) and establishing new tidal current prediction locations (Fanelli et al., 2014), data collected through this program are utilized by NOAA and the user community in the production and refinement of other products, such as the validation of hydrodynamic forecast systems (Lanerolle et al., 2011) and integration into commercial navigation software. These products are used to ensure safe navigation, make informed coastal zone management decisions, and protect life and property.

The data described in this report were collected by NCOP personnel during a survey in 2016. A total of 26 stations were occupied for at least one lunar month. Of the 26 stations, 25 produced time series of good quality data of sufficient length (generally greater than 29 days) to perform harmonic analysis and generate tidal current predictions. The US 74-74 Memorial Bridge station (CFR1606), which appeared to flip upside down shortly after deployment, was the lone exception. Data collected for the remaining 25 stations contain 6-minute time series of vertical current profiles (speed and direction), water temperature, pressure, and additional quality control variables, such as echo intensity and correlation magnitude. The collected data were analyzed, and reports were generated detailing statistical and harmonic analyses to ensure high quality tidal current predictions. All data and analysis reports presented herein are available on the Tides and Currents website (NOAA, 2018a) or by contacting CO-OPS User Services directly (NOAA, 2018b).

2. PROJECT DESCRIPTION

The Cape Fear River (CFR) was identified by internal assessments within CO-OPS as a high-priority location for an NCOP current observation project utilizing modern acoustic Doppler current profilers (ADCPs). This tidal river was previously surveyed in 1959 and 1976 using outdated and much less accurate sensors. For example, the 1976 data were collected using the Tidal Current Survey System (TICUS), which consisted of rotary-type sensors suspended from buoys at discrete, preselected depths. These sensors determined direction from small directional vanes, which can give false directions due to their size, and measured speeds using Savonius rotors, which can induce currents from wave motion (Parker, 2007). Site locations were proposed based upon feedback from users and professional mariners and also considered the internal needs of NOAA; then they were finalized based on oceanographic needs, engineering restrictions, and criteria set forth by the International Hydrographic Organization (IHO S-44 §4.5).

In 2015, a reconnaissance was conducted, where proposed sites were visited to gather information about their physical characteristics such as depth, bottom type, and climatological water temperature and salinity. This information was then used to plan the platform and sensor configurations for each current observation station. During the reconnaissance operations, each site was visited using a vessel equipped with: a fathometer to determine the depth of the site; a conductivity, temperature, and depth (CTD) sensor to determine salinity and water temperature; and a Ponar-style bottom sampler to determine the nature of the seabed at the site (e.g., mud, silt, sand). Based upon the reconnaissance, 26 deployment locations were identified and, during the summer of 2016, occupied using methods described in section 3. This technical report focuses on the results of these current profiler deployments.

2.1 Geographic scope

Tidal current measurements were collected from the northernmost station in the Cape Fear River at the Hilton Railroad Bridge (CFR1601) and continued over 46 river kilometers (km) south through the mouth of the river to the entrance channel south of Bald Head Island at Bald Head Shoal (CFR1626). Tidal current measurements in the Intracoastal Waterway (ICW), which connects to and follows the Cape Fear River, were also collected at four stations, from Carolina Beach Inlet (CFR1615) to the east to the Oak Island Bridge (CFR1623) to the west.

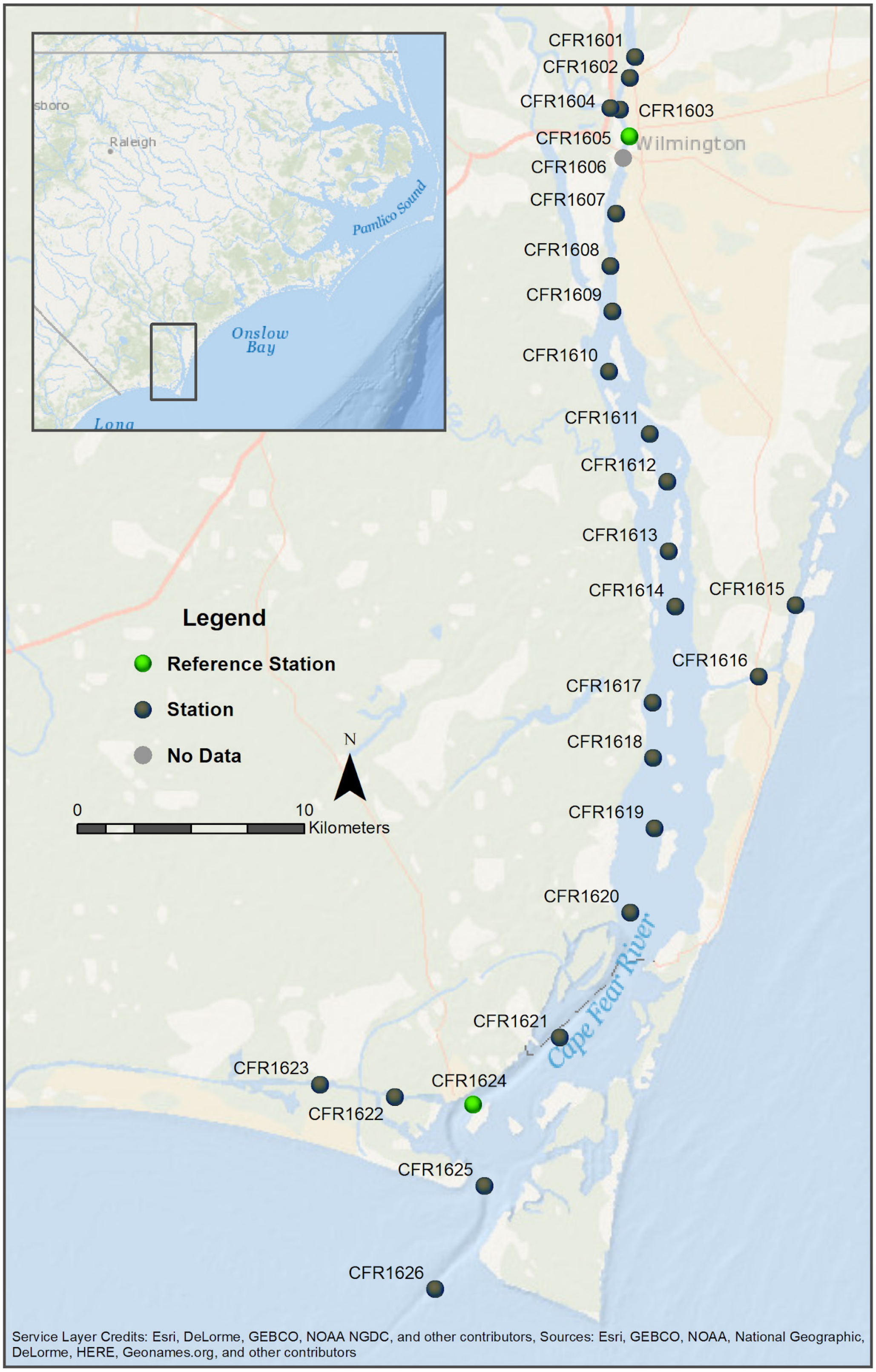


Figure 1. Cape Fear River 2016 current survey station locations.

Table 1. Station list with position (+ is north and east, - is south and west), depth as recorded at deployment, and station occupation start and end dates. The two stations highlighted are reference stations. The US 74-74 Memorial Bridge station (CFR1606, italicized) was occupied but did not collect sufficient quality data and will not be discussed further in this report.

Station ID	Name	Latitude	Longitude	Depth (m)	Deployed	Recovered
CFR1601	Hilton RR Bridge, 0.1 nautical mile (NM) N of	34.2592	-77.9481	9.0	3/18/2016	5/6/2016
CFR1602	Isabel Holmes Bridge	34.2524	-77.9501	12.0	5/7/2016	6/21/2016
CFR1603	Wilmington	34.2419	-77.9539	10.8	3/16/2016	5/9/2016
CFR1604	Point Peter	34.2425	-77.9577	8.8	3/18/2016	5/4/2016
CFR1605	USS North Carolina	34.2335	-77.9503	12.6	5/9/2016	6/16/2016
CFR1606	*US 74-74 Memorial Bridge*	*34.2258*	*-77.9522*	*11.5*	*3/16/2016*	*6/16/2016*
CFR1607	State Pier, N end	34.2078	-77.9554	10.4	5/5/2016	6/14/2016
CFR1608	Dram Tree Point	34.1906	-77.9577	13.6	5/11/2016	6/16/2016
CFR1609	Port of Wilmington, South End	34.1758	-77.9569	10.0	3/16/2016	5/3/2016
CFR1610	Lower Brunswick Range	34.1559	-77.9583	14.0	3/18/2016	5/9/2016
CFR1611	Upper Big I Range	34.1355	-77.9421	13.9	3/18/2016	5/8/2016
CFR1612	Campbell Island, East Side	34.1199	-77.9352	13.2	3/17/2016	5/11/2016
CFR1613	Keg Island, West Side	34.0970	-77.9346	11.3	5/9/2016	6/19/2016
CFR1614	Doctor Point, 0.6 NM NNW of	34.0788	-77.9321	11.4	5/9/2016	6/17/2016
CFR1615	ICW at Carolina Beach Inlet	34.0793	-77.8844	3.5	5/10/2016	6/15/2016
CFR1616	Snows Cut, ICW	34.0558	-77.8990	3.0	5/5/2016	6/21/2016
CFR1617	Orton Point, 0.5 NM S of	34.0473	-77.9410	14.2	5/11/2016	6/20/2016
CFR1618	Upper Midnight Channel	34.0291	-77.9408	13.5	3/17/2016	5/9/2016
CFR1619	Reaves Point, 0.9 NM NE of	34.0060	-77.9402	13.5	5/9/2016	6/19/2016
CFR1620	Sunny Point, 0.5 NM SE of	33.9782	-77.9499	12.2	3/19/2016	5/7/2016
CFR1621	Snows Marsh Channel	33.9372	-77.9779	12.9	5/8/2016	6/15/2016
CFR1622	ICW - Southport at Dutchman Creek	33.9176	-78.0431	5.1	3/17/2016	5/6/2016
CFR1623	Oak Island Bridge	33.9217	-78.0728	5.6	5/6/2016	6/15/2016
CFR1624	Southport	33.9154	-78.0122	13.6	3/17/2016	5/11/2016
CFR1625	Fort Caswell	33.8883	-78.0076	9.0	5/7/2016	6/15/2016
CFR1626	Bald Head Shoal	33.8544	-78.0272	10.1	3/19/2016	5/7/2016

3. METHODS

3.1 Description of instrumentation and platforms

On-water operations were conducted on the Research Vessel (R/V) Tornado, a 25-foot Parker (Figure 2) owned and operated by NOAA. These operations consisted of deploying a calibrated ADCP in an appropriate platform at each station location and recovering it after the planned station occupation period (Table 1). For each station deployment and recovery, the water depth from the vessel's fathometer was recorded, and a CTD vertical profile was taken using a CastAway-CTD to ascertain the physical properties of the seawater at the approximate location of each station. All station metadata were recorded on station log sheets. The ADCP compass for each station was calibrated after the batteries were installed and before deployment.

Currents were measured at each station using a moored ADCP with a platform configuration (Table 3) determined by factors such as station depth, seafloor composition, expected maritime activities, anticipated currents, and available instrument and platform inventory. All stations were equipped with one of the following: Teledyne RD Instruments (TRDI) Workhorse Sentinel with frequencies of either 600 kHz or 1200 kHz, Nortek Aquadopp with a frequency of 1 MHz, or a SonTek ADP with a frequency of 470 kHz. The maximum distance of an ADCP profile is a function of the instrument frequency, with lower frequency instruments capable of longer profiles. The instrument frequency for each station was therefore determined primarily by anticipated platform depth below the surface at mean higher high water (MHHW) plus an added buffer to account for uncertainties in depth and potential significant events (Table 2).

At each station, the ADCP was mounted in one of four types of bottom-mounted platform configurations, onto an Aids to Navigation (ATON) buoy, or onto a fixed structure, such as an I-beam attached to a pier (Table 3).

Figure 2. NOAA R/V Tornado, a 25-foot Parker Pilothouse, used to complete the field work.

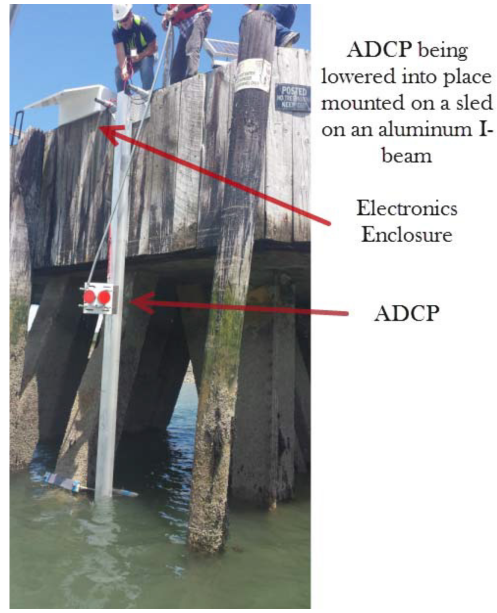
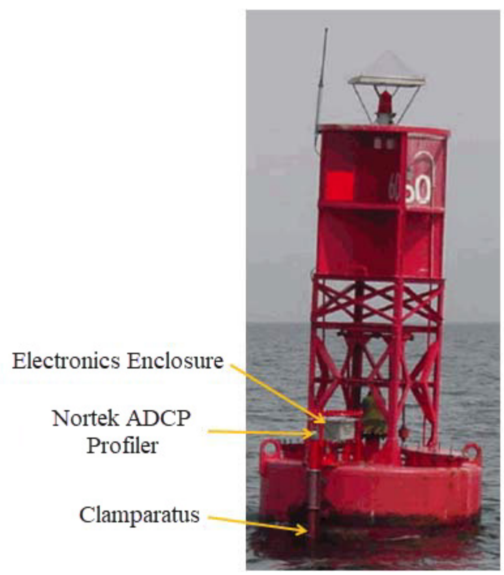
Table 2. ADCP approximate range by model and frequency.

0.5	15	1200	TRDI Workhorse Sentinel
10	40	600	TRDI Workhorse Sentinel
12	20	1000	Nortek Aquadopp
70	120	470	SonTek ADP

Table 3. Platform configurations.

Platform	**Specifications**	**Deployment and recovery method**	**Picture of platform**
MTRBM	Base: 2.5-cm Fiberglass grate Shell: Fiberglass or Urethane cover with Length: 178 cm Width: 122 cm Height: 47 cm Weight in Water (without ballast): 23 kilograms (kg)	Platform is lowered to place and released. Recovery is by acoustically releasing a float to the surface with a line tethered to the base.	 Standard MTRBM system manufactured by MSI Image: MSI
microTRBM	Base: 2.5-cm Fiberglass grate Shell: Fiberglass Length: 132 cm Width: 107 cm Height: 36 cm Weight in Water (without ballast):14 kg	Platform is lowered to place and released with a ground line attached to a nearby structure. Recovery is performed with the ground line.	

Platform	Specifications	Deployment and recovery method	Picture of platform
GP35	Base: 2.5-cm Fiberglass grate Shell: Polyethylene Frame: Aluminum Height: 43 cm Weight in water (with ballast): 41 kg	Platform is lowered to place and released with a ground line attached to a nearby structure. Recovery is performed with the ground line.	
Tripod	Frame: Aluminum Height: 0.5 m Diameter: 1.5 m Weight (with ballast): Air: 68 lb (31 kg) Water: 56 lb (25 kg) Standard Ballast (lead): 30 lb (13.6 kg)	Platform is lowered to place and released with a ground line attached to a nearby structure. Recovery is performed with the ground line.	 Image: MSI

Platform	Specifications	Deployment and recovery method	Picture of platform
Side-Lookers	There are two methods that were used to mount a side-looking ADCP in Cape Fear: The first (depicted here) has the ADCP on a trolley that can be lowered from the surface down an I-beam that has been secured to a pier. The second method clamps the ADCP directly to a structure using a band clamp.		
ATON buoy mounted	An Oceanscience Clamparatus holds the ADCP in the tube and is mounted to the USCG buoy through an eye bolt. For the Cape Fear current survey, the ADCP had a communications cable attached and secured in the Clamparatus tube. Data were collected internally, with no communications enclosure present.		

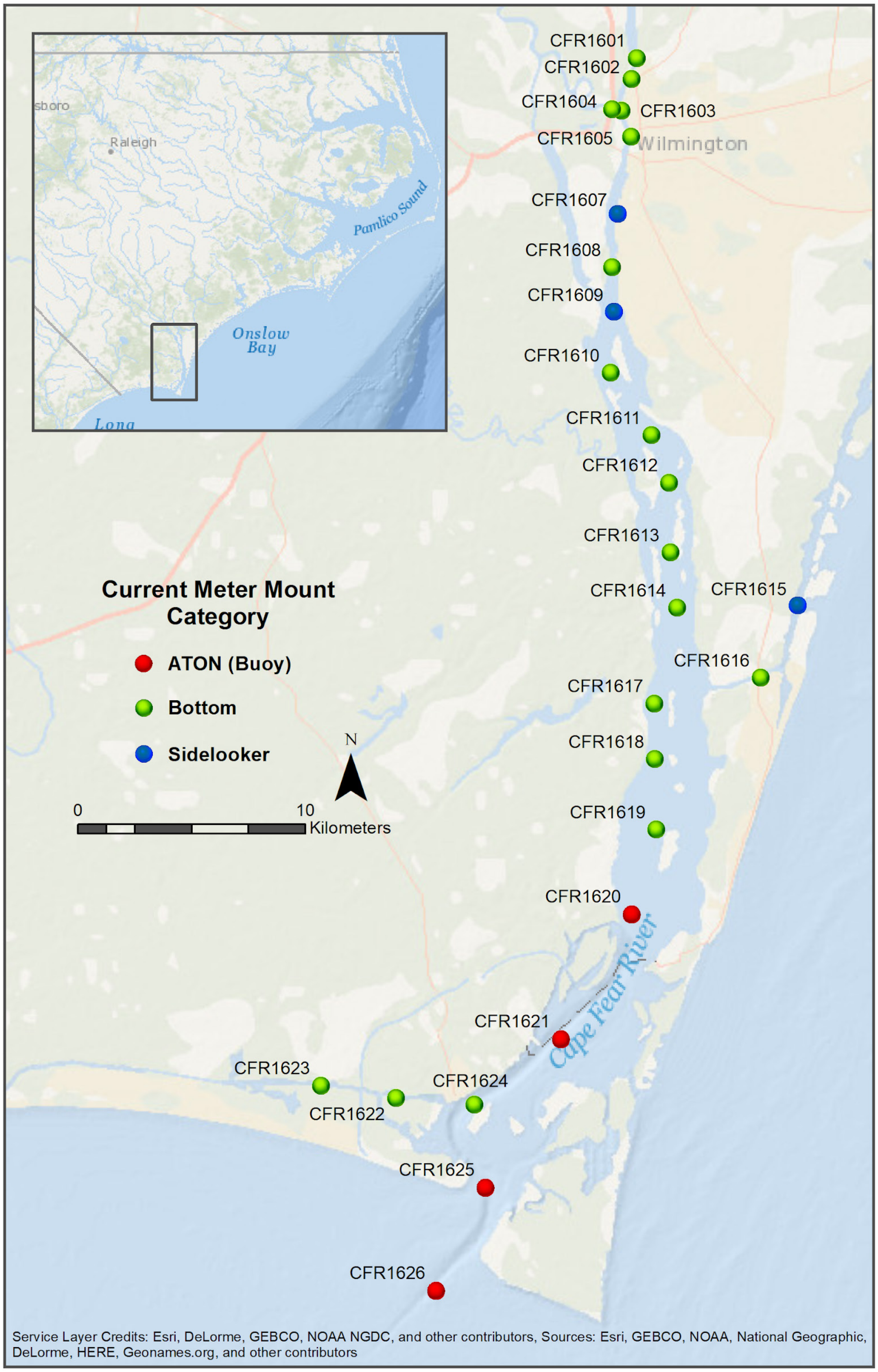


Figure 3. Cape Fear Current Survey 2016 stations by mooring configuration.

3.2 Bottom mounts

Bottom mounts are designed to rest on the seafloor and provide a stable platform for an upward-facing ADCP during station occupation. All bottom-mounted platforms were positioned on the seafloor with no surface presence and were recovered by enabling an acoustic release. In the event that the acoustic release failed to work properly, a secondary means of recovery, such as dragging or the use of divers, was employed. All four bottom-mount platform configurations used during this project were manufactured by Mooring Systems, Inc. (MSI) and include a miniaturized-TRBM (MTRBM), a micro-TRBM, a Tripod, and a GP35. Table 3 provides general specifications as well as deployment and recovery methods for each platform. Table 4 lists the ADCP configuration in each bottom-mounted station.

Table 4. Instrument (TRDI Workhorse Sentinel) and platform configurations for stations equipped with bottom mounts. All bottom-mounted ADCPs were set up to have 120 pings per 6-minute ensemble.

Station ID	Depth (m)	Sensor height above bottom (m)	Sensor depth (m)	Freq. (kHz)	Total no. of bins	No. of bins with good data	Bin size (m)	Mount type
CFR1601	9.0	0.5	8.5	600	20	8	1.0	Tripod
CFR1602	12.0	0.5	11.5	600	20	9	1.0	Tripod
CFR1603	10.8	0.4	10.4	1200	30	20	0.5	MTRBM
CFR1604	8.8	0.5	8.3	1200	30	13	0.5	Tripod
CFR1605	12.6	0.4	12.2	1200	20	10	1.0	MTRBM
CFR1608	13.6	0.4	13.2	600	20	10	1.0	Tripod
CFR1610	14.0	0.5	13.5	600	20	11	1.0	MTRBM
CFR1611	13.9	0.5	13.4	600	20	11	1.0	MTRBM
CFR1612	13.2	0.5	12.7	600	20	10	1.0	MTRBM
CFR1613	11.3	0.5	10.8	600	20	8	1.0	MTRBM
CFR1614	11.4	0.5	10.9	600	20	9	1.0	MTRBM
CFR1616	3.0	0.5	2.5	1200	20	4	0.5	GP35
CFR1617	14.2	0.5	13.7	600	20	11	1.0	MTRBM
CFR1618	13.5	0.5	13.0	600	20	10	1.0	MTRBM
CFR1619	13.5	0.5	13.0	600	20	9	1.0	MTRBM
CFR1622	5.1	0.4	4.7	600	20	7	0.5	MTRBM
CFR1623	5.6	0.5	5.1	1200	20	3	0.5	Micro-TRBM
CFR1624	13.6	0.5	13.1	600	20	11	1.0	MTRBM

3.3 Side-lookers

There were two methods used to mount the side-looking ADCPs in Cape Fear. In the first, the ADCP is mounted on a trolley that is lowered from the surface down an I-beam to a designated depth, which is secured to a pier (Table 3). The second method clamps the ADCP directly to a structure (i.e., band clamp). Table 5 lists the instrument configurations for both of the side-looking mount types.

Table 5. Instrument and platform configurations for side-looking stations.

CFR1607	10.4	4.4	6.0	Continental	470	180	20	20	5	I-beam
CFR1609	10.0	6.3	3.7	Continental	470	180	25	25	4	I-beam
CFR1615	3.5	1.0	2.5	Aquadopp	1000	120	10	7	4	band clamp

3.4 Buoy mounted (ATON)

An Oceanscience Clamparatus (Bosley et al., 2005) holds the downward-facing ADCP in a tube below the surface and is mounted to the USCG buoy through an eye bolt (Table 3). A communications cable was attached to the ADCP and secured in the Clamparatus tube. Data were collected internally, with no communications enclosure present. The ADCP is calibrated on the ATON during deployment to ensure the metal buoy does not interfere with the ADCP compass and magnetic variation.

Table 6. Instrument (Nortek Aquadopp 1 MHz Profilers) and platform configurations for buoy mounts (ATON). All buoy-mounted ADCPs were deployed using a Clamparatus of equal size, and therefore the sensor depth (2.2 m) was the same at these stations. The ADCPs at all ATON stations were set up to have 300 pings per ensemble and collect 20 bins, each 1 m in size.

CFR1620	12.2	10.0	8	ATON
CFR1621	12.9	10.7	9	ATON
CFR1625	9.0	6.8	6	ATON
CFR1626	10.1	7.9	6	ATON

3.5 ADCP setup and data collection

ADCPs compute water velocity by sending out a series of acoustic pulses, or pings, and measuring each acoustic ping's return signal for Doppler shift. Unlike single-point current meters, ADCPs are generally configured to measure profiles of the water column. Profiles consist of a number of discrete 'bins' of data where all the acoustic returns from a single ping are sorted and collected (binned) by return time and converted into a distance from the instrument transducer using the speed of sound in water to convert the two-way travel time into distance. Bins therefore represent the spatially averaged subdivisions along the profile. Optimal bin size is a compromise between higher spatial resolution (smaller bins) and lower standard deviation of the velocity ensemble (larger bins mean more ping returns in the spatial average). Bin size, like profile distance, is also a function of ADCP frequency. Higher frequency instruments can measure smaller bins than lower frequency instruments with the same standard deviation.

Velocity profiles can be collected either vertically (upward- and downward-facing ADCPs) or horizontally (side-looking ADCPs). Because the ADCP is measuring either a 3-D (bottom and ATON platforms) or 2-D (side-looking) flow field, the acoustic transducer heads are set at an angle to instrument measurement profile. For the ADCPs used in this survey, the angle is either 20 degrees or 25 degrees. For 3-D flow measurements, a minimum of three acoustic transducers are necessary. The Doppler-shifted velocities along each beam can then be transformed mathematically into any orthogonal coordinate system, such as an east-north-up orientation (with the help of a compass).

Each ADCP was configured to collect profiles of data in 6-minute averages, called ensembles, of acoustic pulses (pings) (Tables 4–6). The pings per ensemble, which are the number of transmitted acoustic pulses whose returns, as described above, are averaged in time to form a single velocity measurement for each bin, should minimize the theoretical standard deviation of expected velocity within an ensemble with respect to the engineering constraints of the system. This was determined using PlanADCP, DeployADP or Aquadopp software, which calculates the ensemble standard deviation, battery usage, and memory usage for the anticipated duration of the deployment for a specified number of pings per ensemble, number of bins, and bin size. All these factors affect battery life.

The optimal number of pings is a compromise between reducing the ensemble standard deviation and choosing an appropriate bin size and number of bins to ensure sufficient battery life and data storage for the expected conditions at each station. TRDI Workhorse Sentinels, Nortek Aquadopps, and SonTek ADPs are self-contained ADCPs with internal data storage and battery packs. Nortek Continentals have external data storage and batteries. For this project, stations were configured to leave enough battery life to allow the instrument to be used for two deployment cycles (~80 days). This negated the need to switch batteries and perform new compass calibrations, thus minimizing the time required to recover a unit and redeploy it in another location.

There are some additional constraints on velocity profiles from ADCPs. Because of the angled beams, a portion of the water column near the water surface (or bottom), will be lost to sidelobe interference, (approximately 6 percent of the profile depth for a 20-degree beam angle). Transducer ringing, resulting from noise of the transmit pulse on the co-located transducer and receiver, leads to the loss of part of the profile nearest the ADCP head. Blanking distance accounts for this and varies as a function of ADCP frequency and transducer properties. The manufacturer's recommended default settings for blanking distance on the TRDI Workhorse were used: 44 centimeters (cm) for 1200 kHz and 88 cm for 600 kHz, except ICW – Southport at Dutchman Creek (CFR1622), which used 44 cm with a 600 kHz. The Nortek Aquadopp 1MHz ADCPs were set to 41 cm, except Bald Head Shoal (CFR1626), which used 40 cm. The SonTek ADP 470 kHz used 100 cm.

In bottom-mounted platforms (Table 4), the ADCPs have an upward orientation; thus, bin 1 is the bin closest to the ADCP near the seafloor, and the profile (nearly) reaches to the surface. In ATON configurations (Table 6), the ADCPs are downward facing; thus, bin 1 is the closest to the surface, and the profile (nearly) reaches to the seafloor. Side-looking ADCPs (Table 5), are deployed at a given depth; thus, bin 1 is closest to the ADCP transducer head at the depth of sensor deployment, and the profile measures distance horizontally across the channel.

The following ancillary measurements were collected and used as data quality assurance parameters: water temperature and pressure (depth) collected at the sensor head, instrument tilt and orientation, and beam echo and correlation magnitude for each transducer at each bin of the water profile.

ADCPs were calibrated and tested for proper operation using built-in internal testing algorithms. Upon completion of these procedures, a unique configuration file was uploaded to each instrument based upon settings derived from the manufacturing software, such as PlanADCP, DeployADP or Aquadopp. A unique five-character deployment name and a time to start pinging were also programmed. For all instruments that were redeployed for the second half of the survey, an examination of each ADCP's performance was conducted, and a setup file was uploaded based upon new configuration settings for the new location. Instruments were not recalibrated between deployments, as the battery packs were not changed.

3.6 Description of data processing and quality control

The sampling rate for the ADCP data was ten times per hour (centered every 6 minutes from the top of the hour through 54 minutes past the hour). Each sample was an average of between 120 and 360 evenly timed pings based on the ADCP setup and frequency. Even though the shortest tidal constituent period is about 2 hours, 6-minute samples are frequent enough to enable the high-resolution estimation of the maximum and minimum tidal currents and the ability to capture short duration nontidal events. This rate also provides a statistically sound time series in which erroneous records are less likely to influence the overall longer series.

Quality control measures were used to mark each record as bad, good, or questionable based on best practices implemented by CO-OPS (Paternostro et al., 2005) and the community-accepted QARTOD (Quality Assurance/Quality Control of Real-Time Oceanographic Data) standards and recommendations (U.S. IOOS, 2015). Quality control measures consist of boundary threshold checks for speed, tilt (pitch and roll), echo amplitude, correlation magnitude, and rate of change checks for speed, pitch, roll, and heading. An automated algorithm flagged the records that failed any of these thresholds. Questionable data were reviewed by an experienced analyst and marked as either bad or good. Only good data are used for harmonic analysis and disseminated to the public.

The principal flow direction is calculated utilizing a principal component analysis (PCA) to determine the direction of maximum variance. This calculation enables an orthogonal transformation from an east-north coordinate system to major and minor flow direction axes (generally along- and cross-channel, respectively). Representing the currents in the major and minor axes components is especially beneficial in coastal and estuarine areas, which exhibit a rectilinear reversing flow rather than a rotary flow. In these cases, a significant majority of energy is along the major axis, and we can effectively represent the tidal currents with a single variable (major axis current speed).

All ADCP data collected were analyzed to separate the harmonic tidal part of the signal from the residual or nontidal flow (Parker, 2007). Data were extracted from the binary instrument output into columnar ASCII data and then were further processed by NOAA's harmonic analysis routines (Zervas, 1999). Harmonic analyses were then performed upon the current velocity time series in the major and minor flow directions.

The preferred analysis method for tidal current data is the harmonic least squares optimization technique (Parker, 2007). The least squares technique allows for the presence of data gaps and can be used on time series of varying lengths. Using this method, amplitudes and phases of a given set of tidal constituents are resolved explicitly. The frequencies and number of tidal constituents for each station are determined by the length of the time series. The least squares method was used to calculate harmonic constituents at 23 of the 25 Cape Fear stations that had good data. The remaining two stations (Port of Wilmington [CFR1609] and Snows Cut [CFR1616]) required use of the Fourier harmonic analysis method (Harm29 and Harm15, respectively, which are programmed to analyze data periods of 29 and 15 days) to resolve the tidal constituents. Using this method, either 10 (HARM29) or 9 (HARM15) tidal constituents are explicitly resolved, and the remaining terms are inferred using established relationships between the constituents. The analysis of the Port of Wilmington station (CFR1609) used only 31 days, as the first 15 days of the deployment were not usable because of data recording difficulties. Generally, longer time series use least squares analysis, which allows the platform to settle, plus more data add to the stability of the results. In this case, HARM29 analysis was used due to the shorter than expected data set. The Snows Cut station (CFR1616), a 1200-kHz ADCP mounted in a GP35 bottom mount, was displaced on May 26, 2016 after only 21 days of deployment, possibly because of a cut line. This necessitated using the HARM15 analysis, as the time series was too short for a least squares analysis to resolve the 24 harmonics that are normally used to produce a prediction.

Predictions provided online (NOAA, 2018e) by CO-OPS are generated directly from harmonic constituents and are more accurate than the information provided in the tidal current publications. Due to the legal requirement to publish paper TCTs and the need to limit the physical size of these publications, a 'reference' and 'subordinate' relationship was created. Daily-predicted tidal currents are provided by NOAA every year for select stations in Table 1 of the TCTs. Stations listed in this section are considered reference stations. They were selected for navigational significance due to geographic location, heavy traffic, hazardous locations, strong currents, or a combination of these factors. For this project, two stations, USS North Carolina (CFR1605) and Southport (CFR1624), were selected to be reference stations and were added to NOAA Current Predictions website (NOAA, 2018e).

4. PHYSICAL OCEANOGRAPHIC OVERVIEW OF THE REGION

4.1 Region overview of tides and tidal currents

The Cape Fear River estuary is located on the southeastern coast of North Carolina. The estuary is fed by the Cape Fear River and its tributaries, which has a 2.3-million-hectare basin (NOAA, 2018c). The estuary starts near Wilmington and continues south for about 50 km, where it discharges into the northeastern corner of Long Bay in the Atlantic Ocean. Along the Cape Fear estuary lie the ports of Wilmington, the Marine Ocean Terminal Sunny Point, and numerous privately owned and operated piers and marine facilities. Tides within the region are semidiurnal and micro-tidal (tidal range <2 m). NOAA (or its predecessor) has measured water levels at Wilmington (station 8658120) since 1908 (Station Home Page, 2018) and presently has a published mean tide range (MN) of 1.305 m (4.28 ft) and a great diurnal tide (GT) range of 1.427 m (4.68 ft) (Figure 4). Observed currents within the Cape Fear River estuary are entirely semidiurnal, and a majority of their total energy is tidal for all stations.

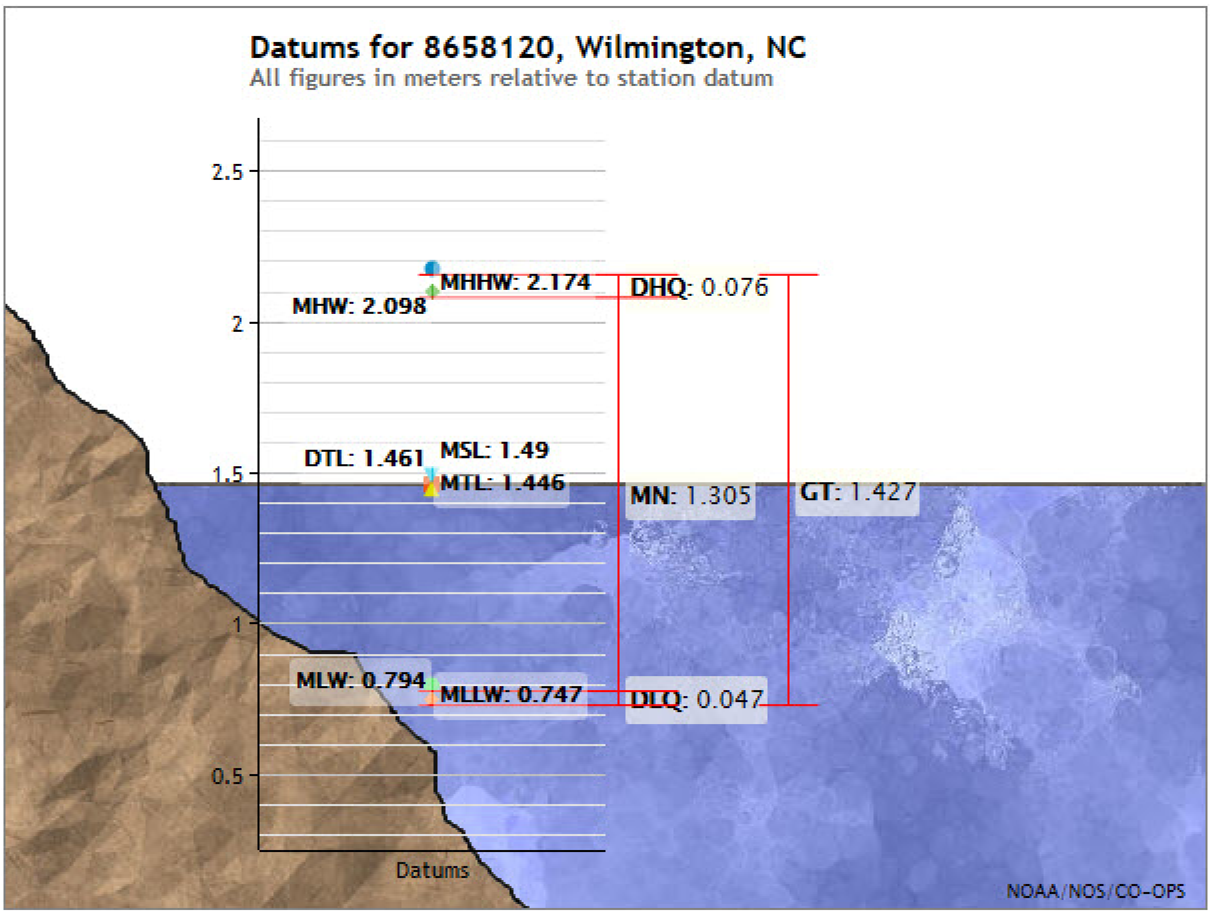


Figure 4. Tidal datums for Wilmington, North Carolina (1983–2001 Epoch). (NOAA, 2018g),

4.2 Climatological overview of water temperature and salinity

The temporal variability in the water quality conditions over the summer deployment can be seen in Figure 5 at ICW at Carolina Beach Inlet (CFR1615). Throughout the 1-month deployment (5/5/2016 - 6/15/2016), the water temperature increased as summer air temperatures increased.

The region experienced higher than normal precipitation during the study period (Table 7). Note that normal precipitation is generally defined as the 30-year average of precipitation, and these averages are from the latest three-decade (1981–2010) Climate Normals calculated by the National Centers for Environmental Information (NCEI, 2018).

Table 7. Wilmington, North Carolina monthly precipitation totals and departures from normal, in inches, during the time of the current survey (National Weather Service, 2016).

Month (2016)	Observed rainfall	30-Year mean (1981-2010)	Departure
March	2.83	4.21	-1.38
April	1.91	2.82	-0.91
May	5.88	4.49	+1.39
June	6.63	5.18	+1.45

Similarly, the water temperature at USS North Carolina (CFR1605) increased over the 1-month deployment (5/9/2016–6/16/2016), as expected with summer heating (Figure 6). Figures 5 and 6 do not have the same scales for temperature, salinity, and depth due to their spatial differences in physical characteristics. USS North Carolina (CFR1605) is located in the northern section of the river, dominated by freshwater input (0–10 practical salinity unit or PSU), while Carolina Beach Inlet (CFR1615) is located on the ICW and therefore has a large salt water influence (15–35 PSU). CFR1615 is shallow, and the change in temperature (~7.5 °C) over the one-month duration is larger than the deeper, fresher station (~5.2 °C), which can be explained by the difference in required energy for the increased surface heating throughout the summer to heat and mix shallower water versus deeper water. The spatial gradient in near-surface and bottom salinity across all stations for the week of May 3–11, 2016 in the survey can be seen in Figure 7. As expected, the salinity increases moving down the river away from the freshwater runoff inputs and toward the estuary mouth.

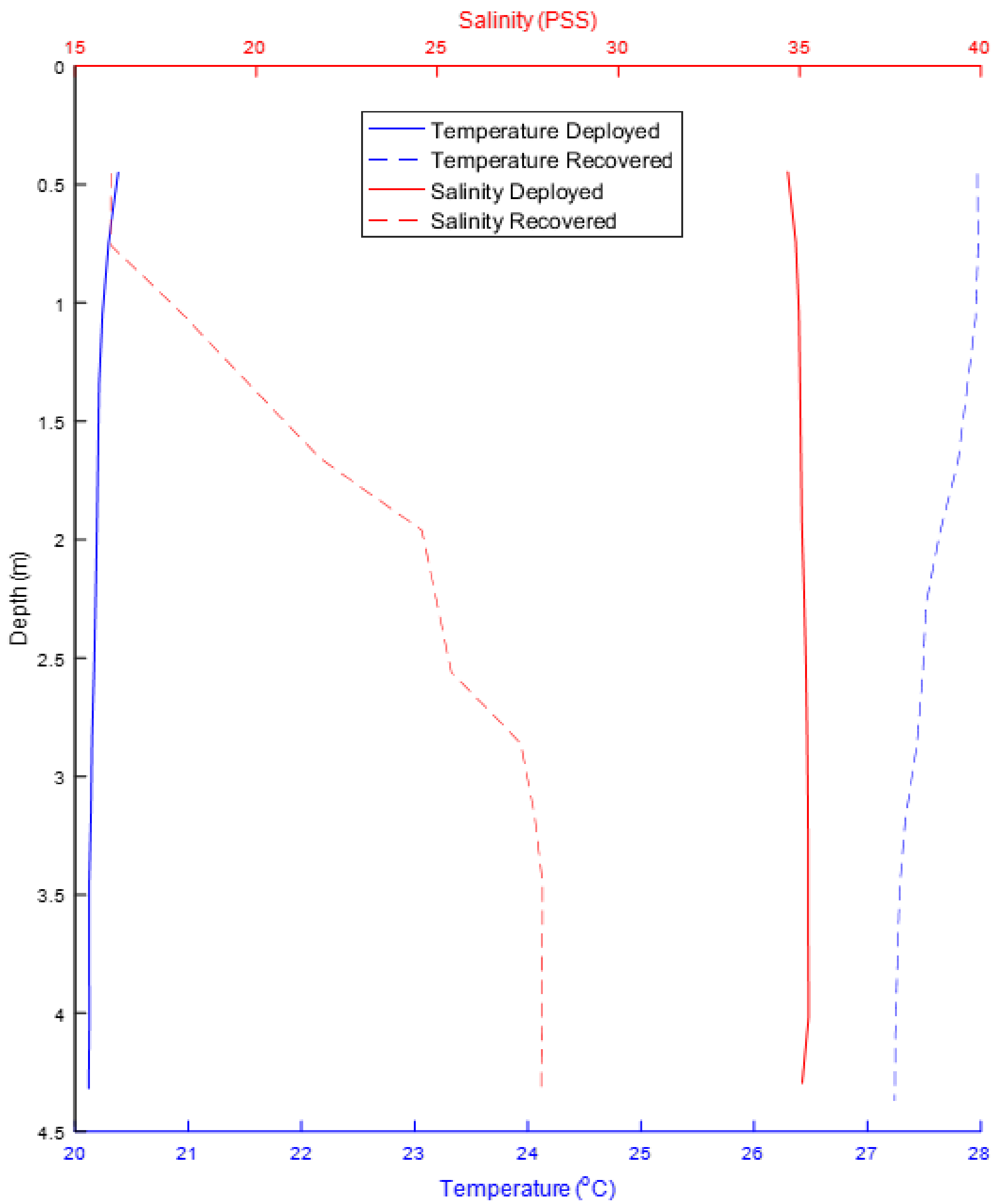


Figure 5. CFR1615, ICW at Carolina Beach Inlet, temperature and salinity profiles over depth collected using a CastAway-CTD timed with the deployment (5/5/2016 at 13:39) and recovery (6/15/2016 at 12:37) of the current profiler on station. Note: The use of electrical conductivity measurements to estimate the ionic content of seawater led to the development of the unitless scale called the *practical salinity scale 1978* (PSS-78).

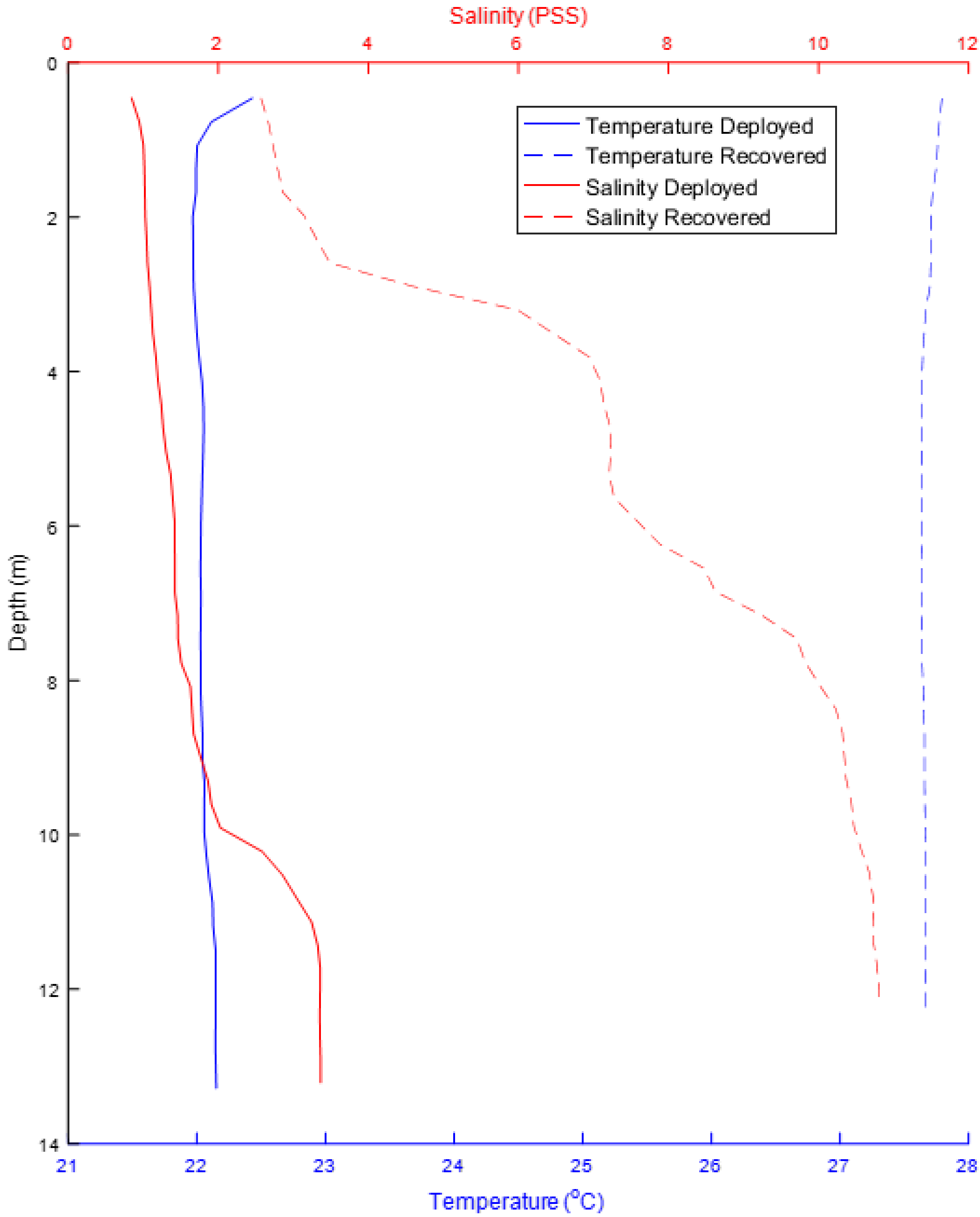


Figure 6. CFR1605, USS North Carolina, temperature and salinity profiles over depth collected using a CastAway-CTD timed with the deployment (5/9/2016 at 13:56) and recovery (6/16/2016 at 14:51) of the current profiler on station.

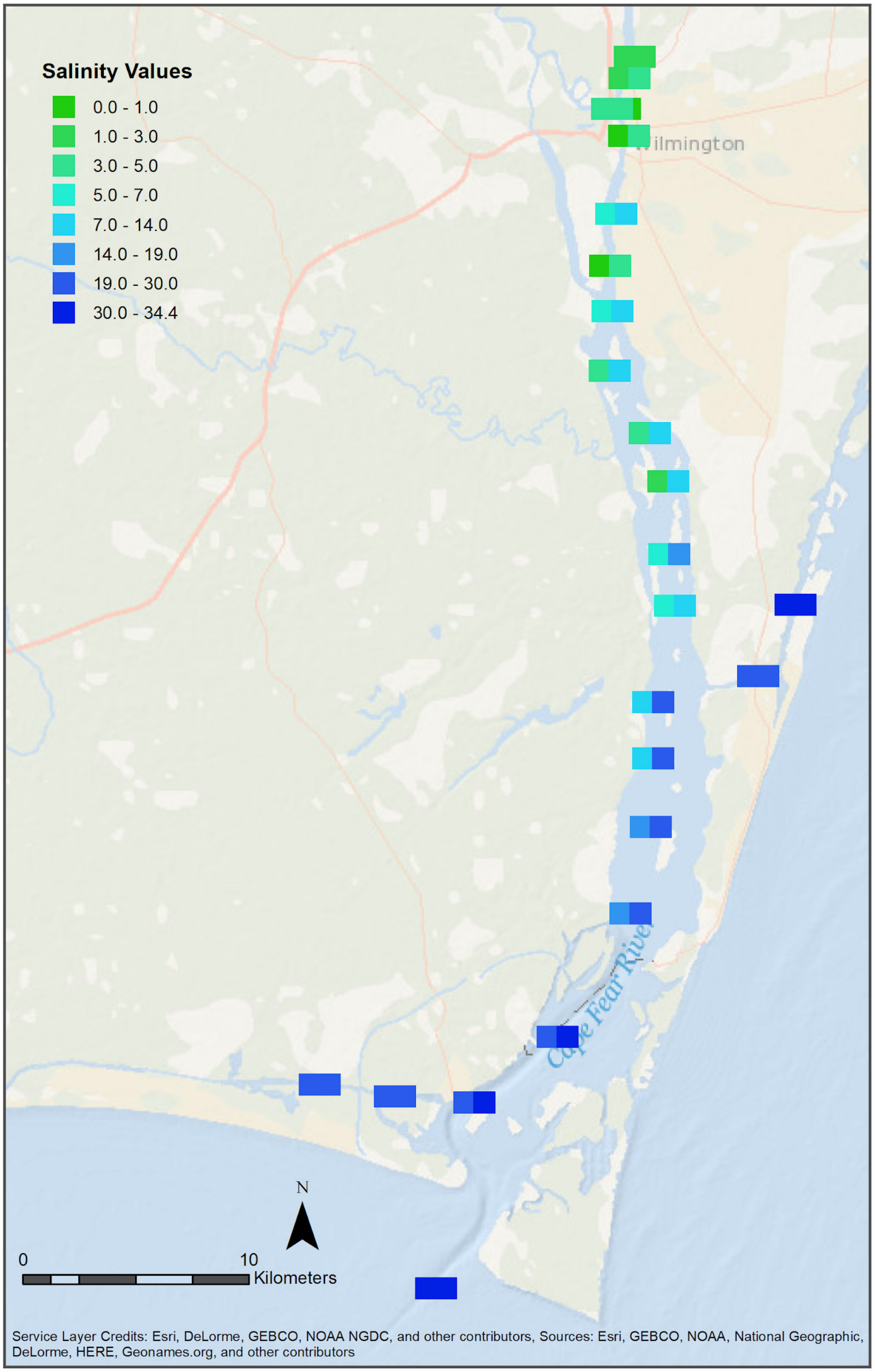


Figure 7. The near-surface (left box) and near-bottom (right box) salinity (PSU) for each station in the survey taken from CTD casts during the turnaround cruise. Note that CTD data were collected at different times during the tidal cycle, which pulsed the salinity up and down the river.

5. DATA ACQUIRED

Data were acquired at 25 of the 26 stations occupied during the summer of 2016. The lack of good data at CFR1606 was due to a platform inversion throughout most of the deployment and is not discussed in the report. Table 8 lists station data used in the analysis. Additionally, all stations have CTD data from vertical profile casts taken at deployment and recovery.

Table 8. Data acquisition. Reference stations are highlighted.

Station ID	Station depth (m)	Total no. of bins	No. of bins with good data	Bin size (m)	Sensor depth (m)	Upper good bin depth (m) (vertical mounts only)	Total % water column measured (vertical mounts only)	Deploy-ment No. 1 or 2	No. of days deployed
CFR1601	9.0	20	8	1.0	8.5	0.9	85%	1	49
CFR1602	12.0	20	9	1.0	11.5	0.9	88%	2	45
CFR1603	10.8	30	20	0.5	10.4	0.8	89%	1	54
CFR1604	8.8	30	13	0.5	8.3	1.0	83%	1	47
CFR1605	12.6	20	10	1.0	12.2	0.5	92%	2	38
CFR1607	10.4	20	20	5.0	6.0	-	-	2	40
CFR1608	13.6	20	10	1.0	13.2	1.8	84%	2	36
CFR1609	10.0	25	25	4.0	3.7	-	-	1	48
CFR1610	14.0	20	11	1.0	13.5	1.8	84%	1	52
CFR1611	13.9	20	11	1.0	13.4	1.1	88%	1	51
CFR1612	13.2	20	10	1.0	12.7	1.6	84%	1	55
CFR1613	11.3	20	8	1.0	10.8	2.0	78%	2	41
CFR1614	11.4	20	9	1.0	10.9	1.8	80%	2	39
CFR1615	3.5	10	7	4.0	2.5	-	-	2	41
CFR1616	3.0	30	4	0.5	2.5	-	-	2	47
CFR1617	14.2	20	11	1.0	13.7	1.5	86%	2	40
CFR1618	13.5	20	10	1.0	13.0	2.0	82%	1	53
CFR1619	13.5	20	9	1.0	13.0	2.0	82%	2	41

Station ID	Station depth (m)	Total no. of bins	No. of bins with good data	Bin size (m)	Sensor depth (m)	Upper good bin depth (m) (vertical mounts only)	Total % water column measured (vertical mounts only)	Deploy-ment No. 1 or 2	No. of days deployed
CFR1620	12.2	20	8	1.0	2.2	3.6	71%	1	49
CFR1621	12.9	20	9	1.0	2.2	3.6	72%	2	38
CFR1622	5.1	20	7	0.5	4.7	0.6	80%	1	50
CFR1623	5.6	20	3	0.5	5.1	3.2	33%	2	40
CFR1624	13.6	20	11	1.0	13.1	1.2	88%	1	55
CFR1625	9.0	20	6	1.0	2.2	3.6	60%	2	39
CFR1626	10.1	20	6	1.0	2.2	3.6	64%	1	49

6. STATION RESULTS

A brief, qualitative description of a subset of survey stations are provided in this section. These include the newly established reference stations for the region (USS North Carolina [CFR1605] and Southport [CFR1624]) and those that exhibit characteristics of different flow regimes. Table 9 lists the historical tidal current stations that were superseded by 2016 stations and their respective reference stations.

Table 9. List of historical stations in Cape Fear river that were superseded with 2016 stations and their corresponding reference station, both of which are new.

Historical station NOS ID	Historical station name	Superseded by 2016 station ID	2016 Cape Fear station name	Reference station
11732	Wilmington, NE Branch, Cape Fear River, NC	CFR1602	Isabel Holmes Bridge	CFR1605
6426 / 6427	Wilmington, Cape Fear River, NC	CFR1603	Wilmington	
6431	Point Peter, Cape Fear River, NC	CFR1604	Point Peter	
6411	Dram Tree Point, 0.5-mile SSE of, Cape Fear River, NC	CFR1608	Dram Tree Point	
11505	Barnard Creek, off of, Cape Fear River, NC	CFR1610	Lower Brunswick Range	CFR1624
6406 / 6407 / 6408	Campbell Island, East Side, Cape Fear River, NC	CFR1612	Campbell Island, East Side	
6401 / 6402 / 6403	Doctor Point, 0.6-mile NNW of, Cape Fear River, NC	CFR1614	Doctor Point, 0.6 NM NNW of	
6391	Myrtle Sound, Intracoastal Waterway, NC	CFR1615 (side-looking, one location)	ICW at Carolina Beach Inlet	
6386	Snows Cut, Intracoastal Waterway, North Carolina	CFR1616	Snows Cut, ICW	
6396	Upper Midnight Channel, Cape Fear River, NC	CFR1618	Upper Midnight Channel	
6357 / 6358	Sunny Point, Cape Fear River, North Carolina	CFR1620	Sunny Point, 0.5 NM SE of	
6341	Southport, ICW, North Carolina	CFR1622	ICW - Southport at Dutchman Creek	
6346 & 6351 / 6352	Southport	CFR1624	Southport	

The estimated station depth of the current profiler is given in meters relative to an approximation of mean lower low water (MLLW). Due to the lack of contact with the surface while deployed, the sensor depth for bottom-mounted stations are made using the ADCP's pressure sensor. The sensor depth of the buoy-mounted and side-looking ADCPs is made from a known distance (i.e., Clamparatus length, I-beam, and trolley specifications), which is then verified using the ADCP's pressure sensor. The calculated depth is a best approximation, which is compared to the station depth taken using the ship's fathometer during deployment and/or recovery.

A description of the mean maximum flood current (MFC) and mean maximum ebb current (MEC) is given for the deepest-measured depth, a depth near the middle of the water column, and a near-surface depth. For bottom-mounted ADCPs, bin 1 refers to the deepest measurement, and the bin number increases as you approach the water surface. For buoy-mounted ADCPs, bin 1 is the measurement closest to the surface, and the bin number increases as you approach the sea floor. For side-looking ADCPs, bin 1 is closest to the instrument transducers; the bin numbers increase as you move horizontally across the channel (i.e., away from the sensor). The principal flood direction is the predominant axis of flow as described in section 3. Directions are provided in degrees from true north. The variance along this axis is provided to give an indication of how confined the flow is along the axis; a high percentage variance implies a rectilinear flow.

Five stations, two new reference stations (USS North Carolina [CFR1605] and Southport [CFR1624]) and three historical stations (Lower Brunswick Range [CFR1610], Upper Midnight Channel [CFR1618], and ICW at Carolina Beach Inlet [CFR1615]), are described in the following sections. Figures for each station show the following:

- North versus east velocity component scatter plot at the uppermost good bin.
- Velocity time series at the uppermost good bin separated into two plots. In the upper plot, a comparison of observed (green dots) and predicted (red line); in the lower plot the residual flow (the difference between observed and predicted current).
- Vertical profile of the mean velocity along the major (red) and minor (blue) axis of the water column. This represents the approximate mean residual (non-tidal) circulation throughout the water column. The surface level is estimated (shown as a blue wavy line).
- Vertical profile plot showing the timing and speed of MFC throughout the water column.
- Vertical profile plot showing the timing and speed of the MEC throughout the water column.

The results presented below are a small subset of the full analyses conducted on the data sets.

6.1 CFR1605, USS North Carolina (reference station)

This station was deployed for 38 days (May 9–June 16, 2016) in 12.6 m (41.3 ft) of water. A TRDI Workhorse 1200 kHz ADCP mounted in an MTRBM collected 20 1-m bins of data, 10 of which met quality control criteria for further analysis. Bins 3 and 9 were published in the TCTs, representing approximate depths of 7.6 m and 1.6 m (24.8 ft and 5.1 ft) MLLW, respectively.

Currents at this location are very rectilinear and semidiurnal. Least squares harmonic analysis (LSQHA) resolved 24 constituents and 96–98 percent of total current energy. The semidiurnal currents have stronger ebbs than floods for all analyzed depths, with a permanent ebb current (Figure 10). Mean MFC range is from 77.9 cm/s (1.5 kn) at the bottom to 87.5 cm/s (1.7 kn) in bin 4 (6.6 m [21.5 ft] depth). Mean MEC range is from 80.8 cm/s (1.6 kn) near the bottom to 106.5 cm/s (2.1 kn) near the surface.

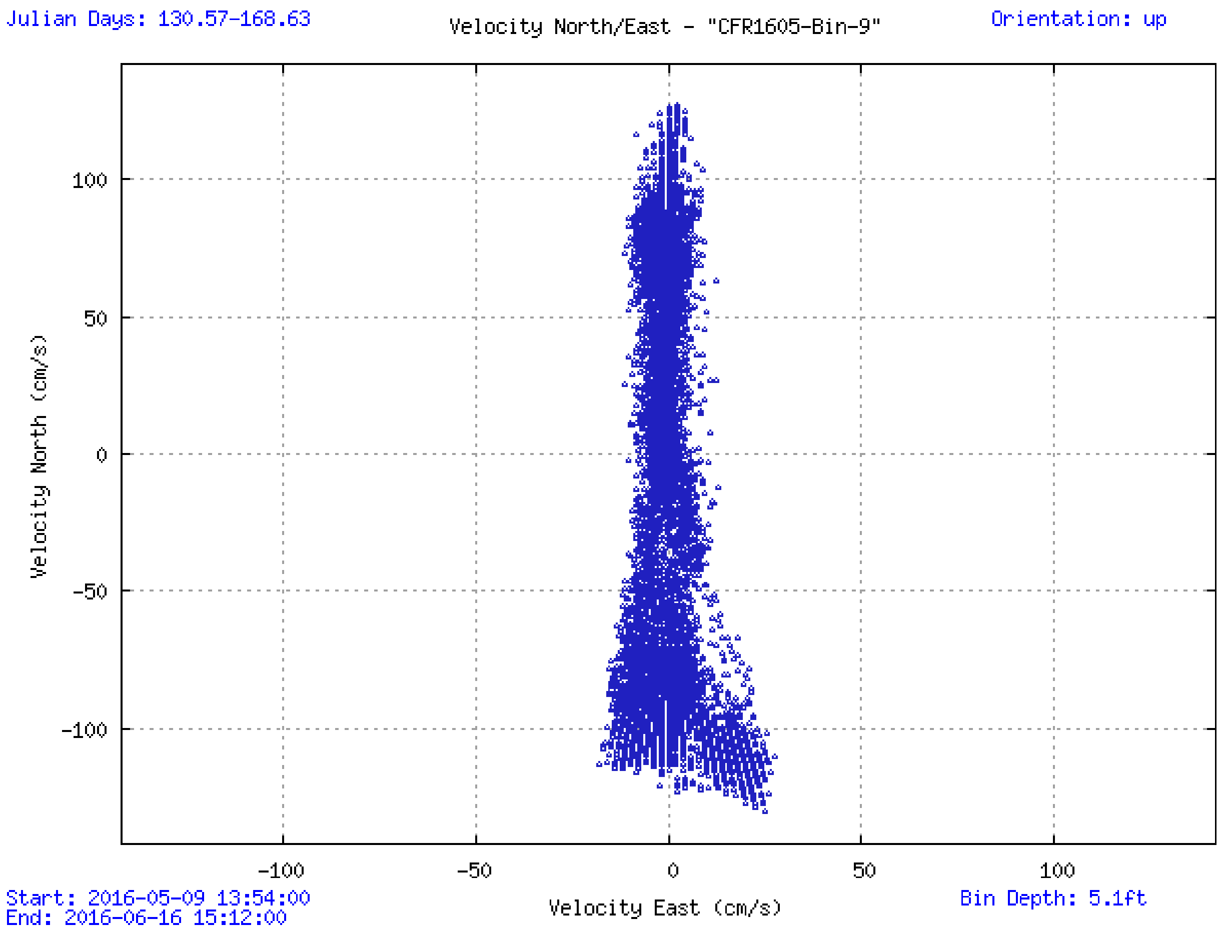


Figure 8. CFR1605 north versus east scatterplot, which shows the northern versus eastern components of the current in bin 9 (1.6 m [5.1 ft] below MLLW).

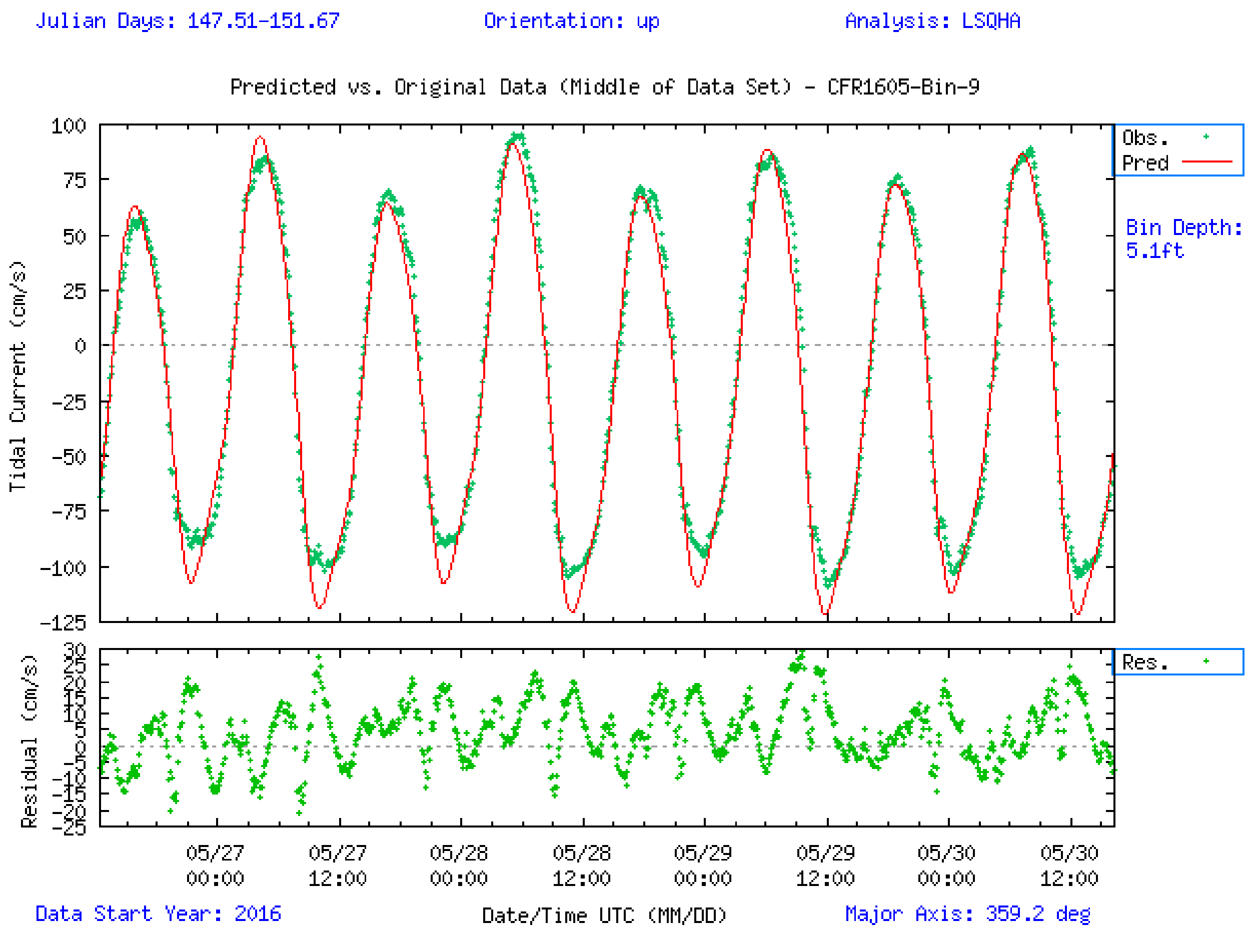


Figure 9. Representative CFR1605 observed versus predicted currents with residuals at bin 9 (1.6 m [5.1 ft]) May 27–30, 2016.

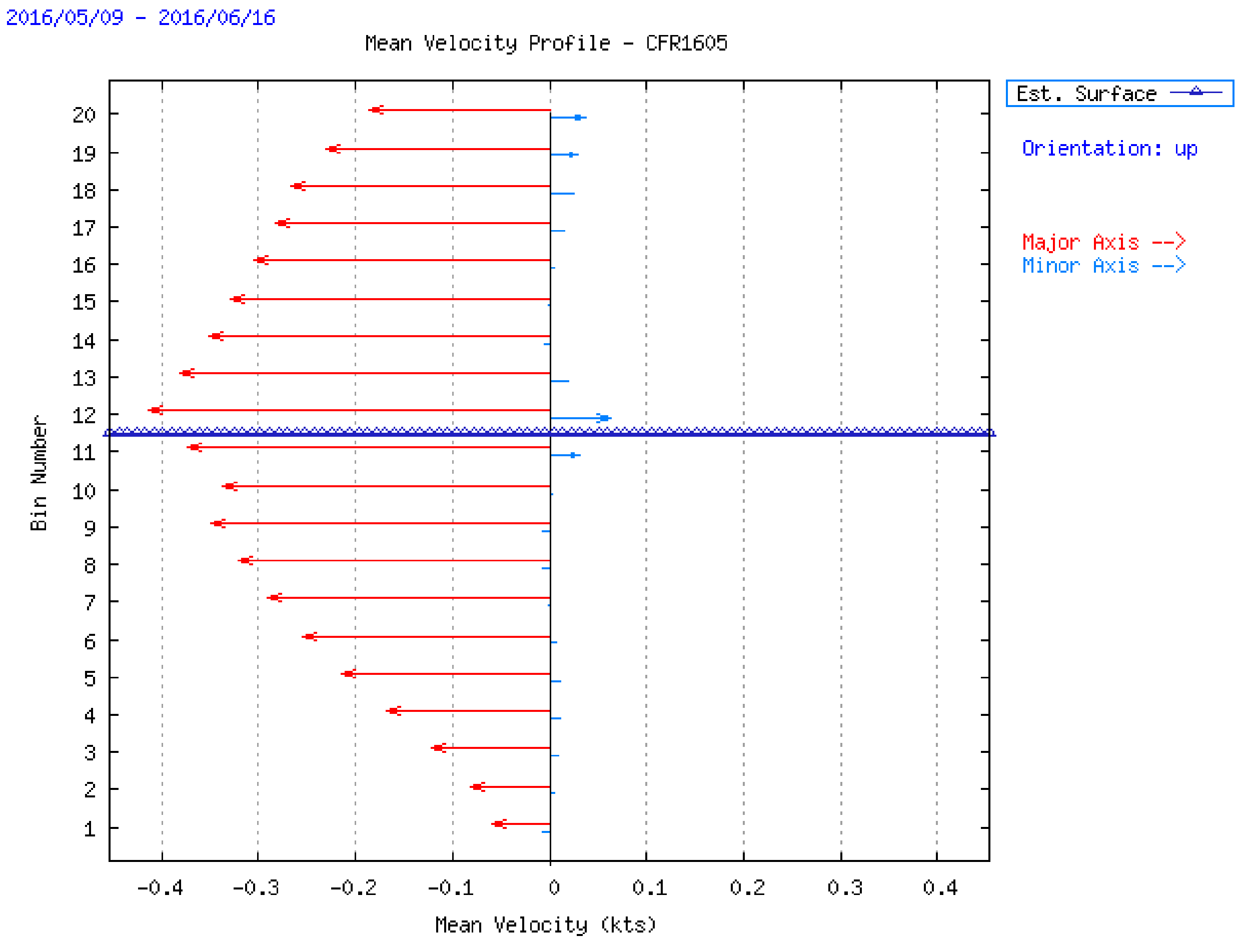


Figure 10. CFR1605 mean velocity profile by bin number. Bin 1 is approximately 9.6 m (31.3 ft) deep and represents the deepest bin observed; bin spacing for this station was 1.0 m (3.3 ft). Although 20 bins are represented, bin 11 is the highest bin normally under water. The highest bin passing quality control criteria for further analysis was determined to be bin 10.

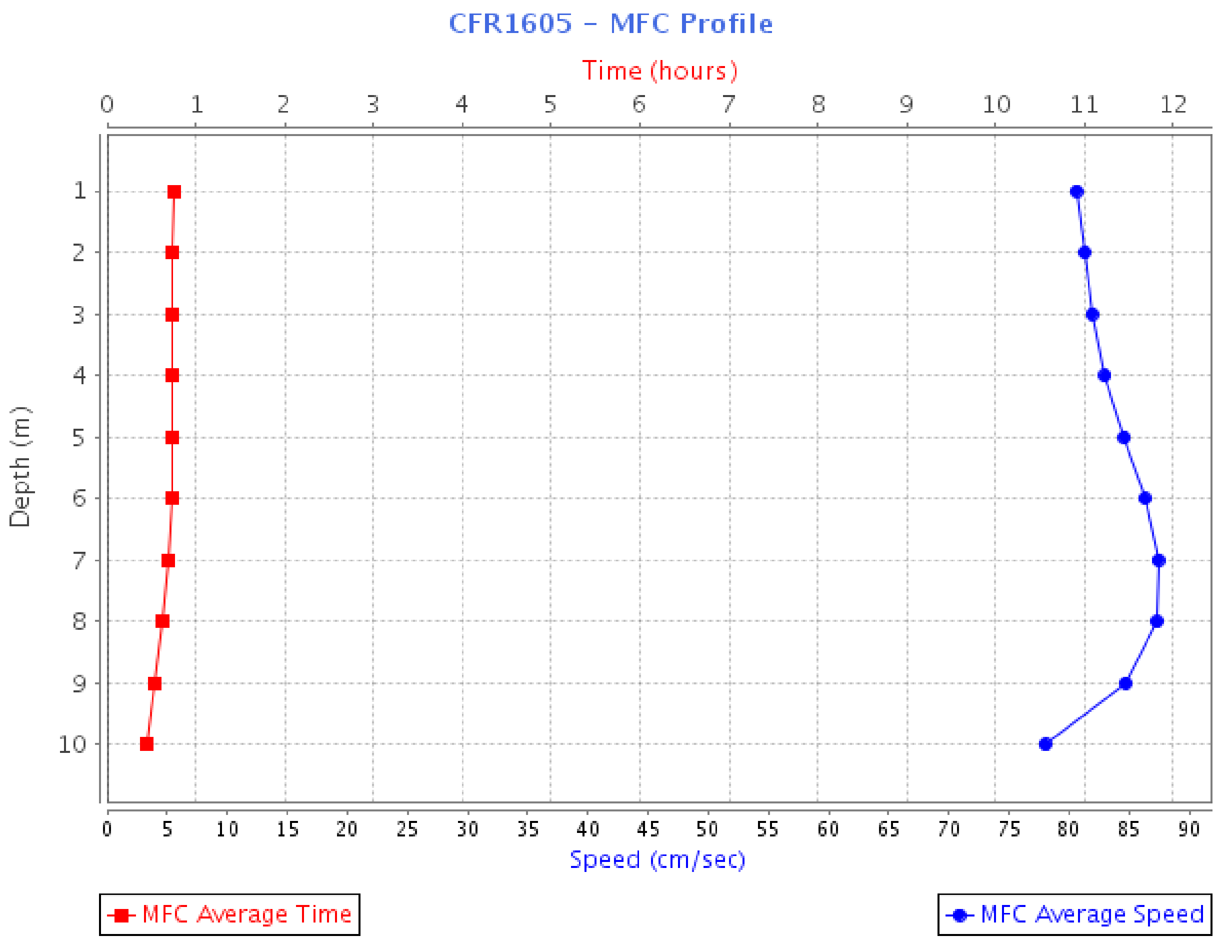


Figure 11. CFR1605 MFC timing (GI- in red) and speed (blue) by bin. Bin 1 is the deepest bin observed at approximately 31.3 ft (9.6 m) deep, and the top-most surface bin is bin 10.

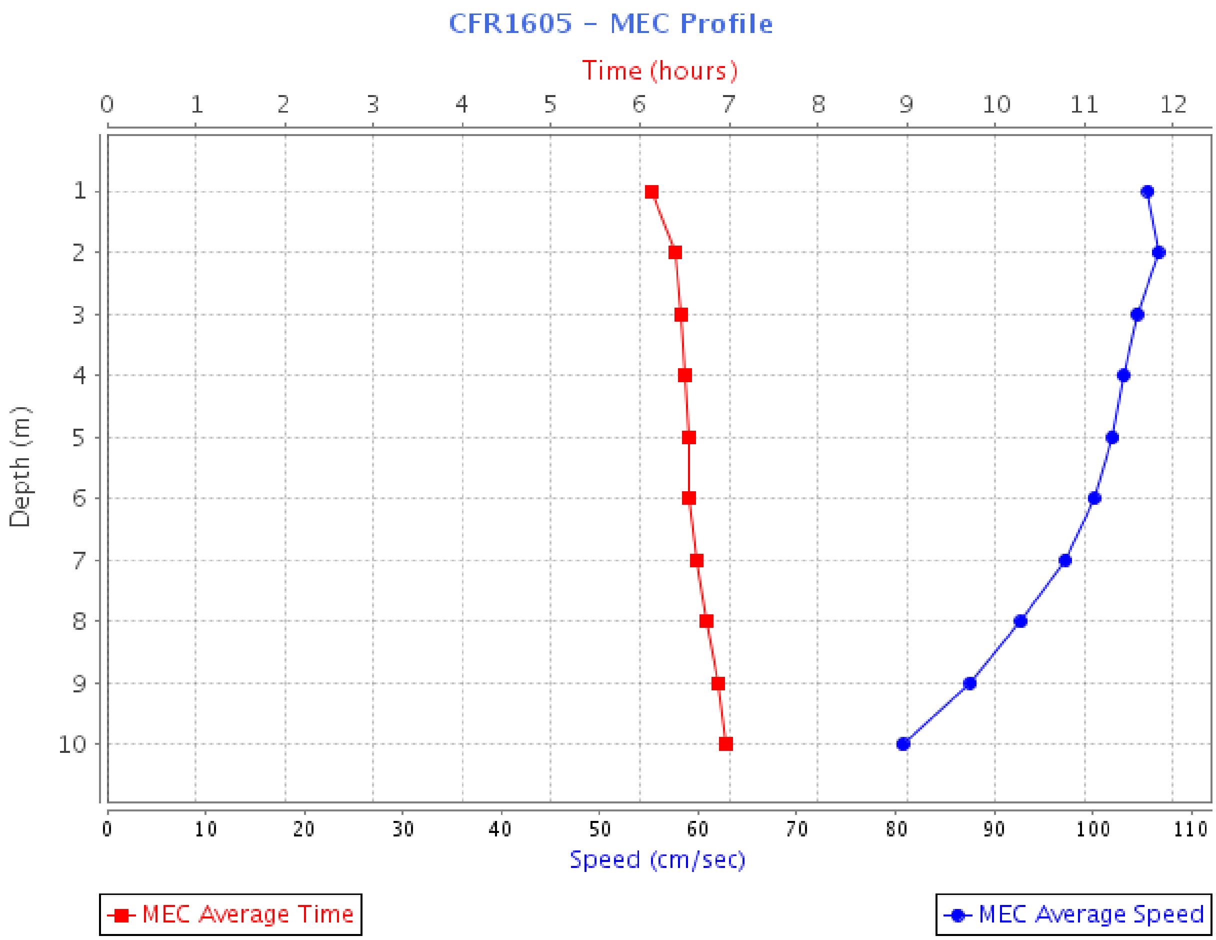


Figure 12. CFR1605 MEC timing (GI - red) and speed (blue) by depth bin. Bin 1 is the deepest bin observed at approximately 31.3 ft (9.6 m) deep, and the top-most surface bin is bin 10.

6.2 CFR1624, Southport (reference station)

This station was deployed for 55 days (March 17–May 11, 2016) in 13.6 m (44.6 ft) of water. A TRDI Workhorse 600 kHz ADCP mounted in a MTRBM collected 20 1-m bins of data, 11 of which met quality control criteria for further analysis. Bins 1, 6, and 10 were published in the TCTs, representing approximate depths of 11.2 m, 6.2 m, and 2.2 m (36.7 ft, 20.2 ft, and 7.1 ft) MLLW, respectively. Information from Bin 10 serves as a new reference station denoted in Table 1 of the TCTs.

Currents are semidiurnal and very rectilinear at this location, which lies in a channel between Southport and Battery Island to the southeast. This station is very tidal. LSQHA resolved 25 constituents and accounted for 97–98 percent of the total current energy. Peak flood range is 84.9–97.7 cm/s (1.7–1.9 kn), with the strongest floods near the middle of the water column. Peak ebbs are much stronger near the surface (3.3 kn [169.8 cm/s]) than at depth. However peak floods are similar in magnitude at both the surface and near the bottom (1.7 kn [87.5 cm/s]). There is a permanent ebb flow at all depths reaching 30.9 cm/s (0.6 kn) near the surface, due to discharge from Cape Fear River.

This station supersedes the nearby historical stations with the same name (Table 9) located 0.11 km and 0.37 km (0.06 nm and 0.20 nm) away. In comparison to the historical stations, the recently measured currents in 2016 show stronger floods occurring later than historical observations by 10 to 15 minutes. Ebb times are similar between the historic and new station.

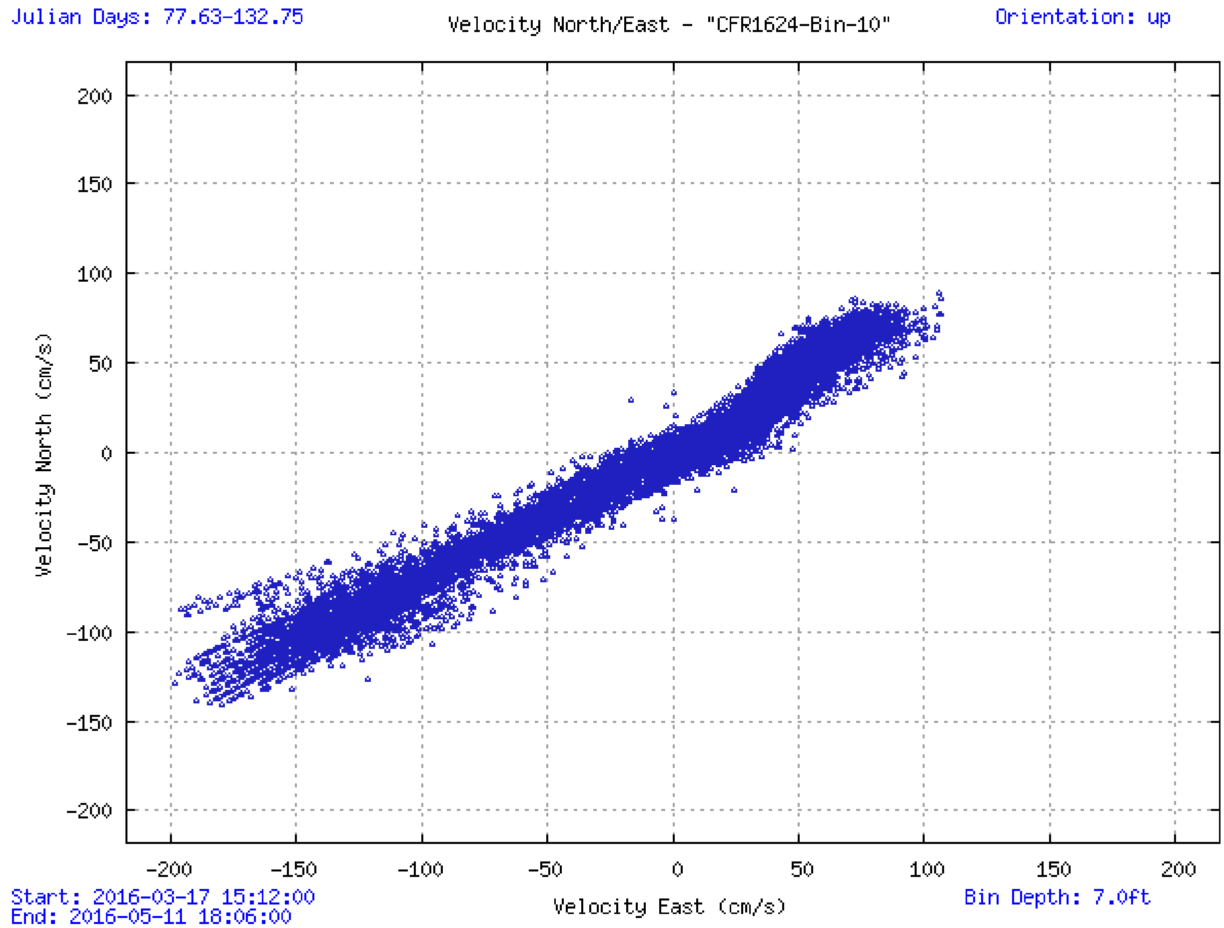


Figure 13. CFR1624 north versus east scatterplot, which shows the northern versus eastern components of the current in bin 10 (2.2 m [7.1 ft] below MLLW.

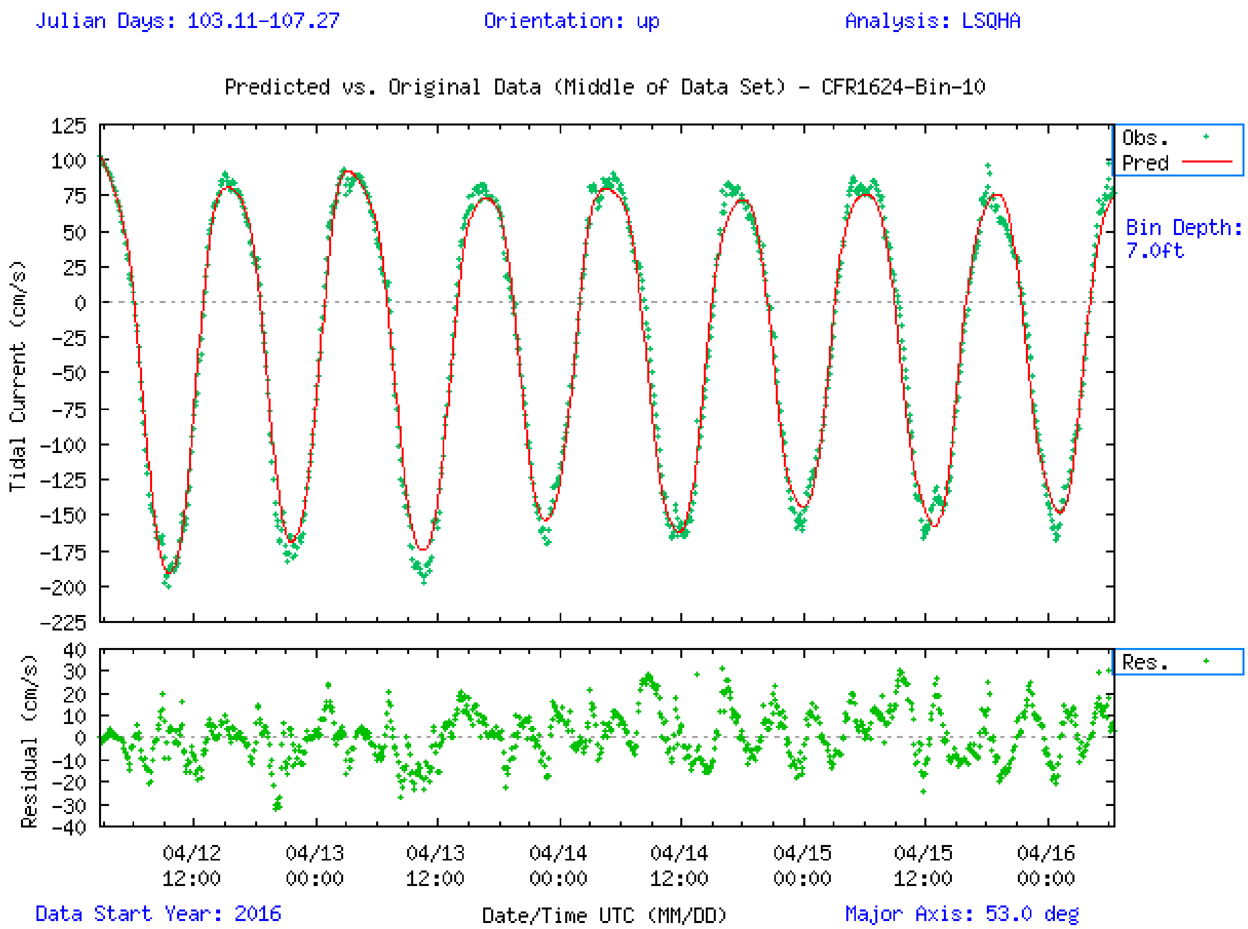


Figure 14. Representative CFR1624 observed versus predicted currents, with residuals, at bin 10 (2.2 m [7.1 ft]) April 12–16, 2016.

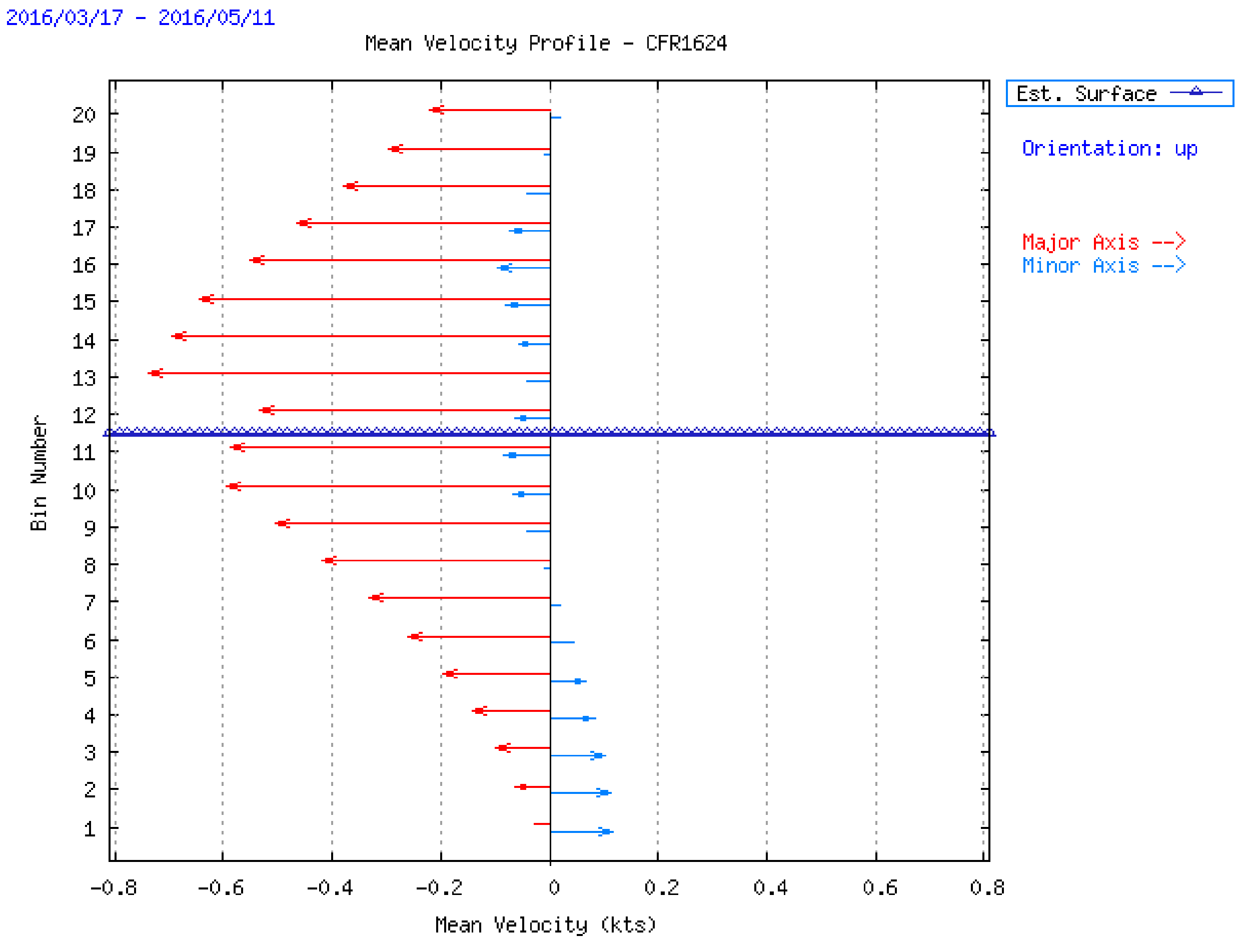


Figure 15. CFR1624 mean velocity profile by bin number. Bin 1 is approximately 11.1 m (36.5 ft) deep and represents the deepest bin observed; bin spacing for this station was 1.0 m (3.3 ft). Although 20 bins are represented, bin 11 is the highest bin normally under water. The highest bin passing quality control criteria for further analysis was determined to be bin 11.

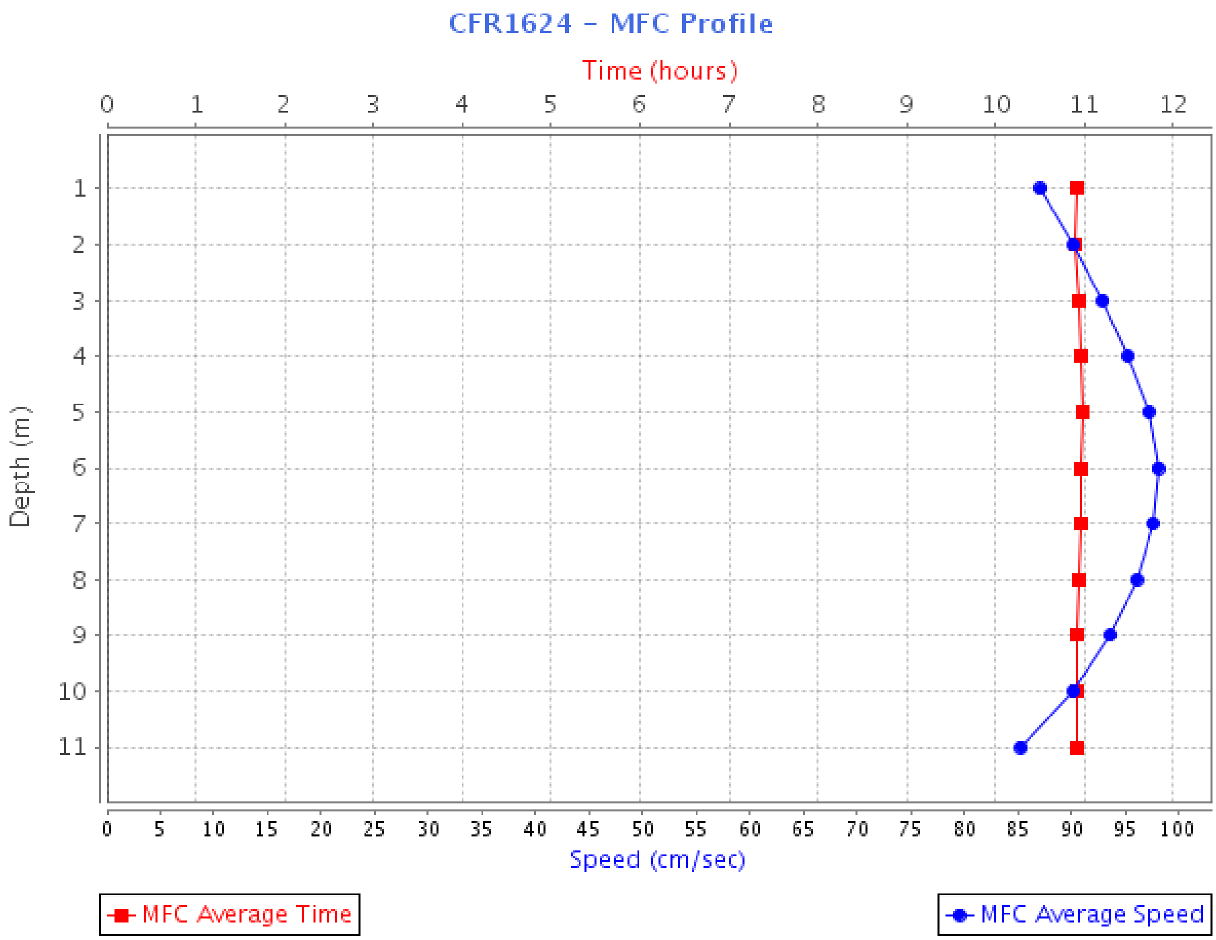


Figure 16. CFR1624 MFC timing (GI - red) and speed (blue) by depth bin. Bin 1 is the deepest bin observed (11.1 m [36.5 ft] deep), and the top-most surface bin is bin 11.

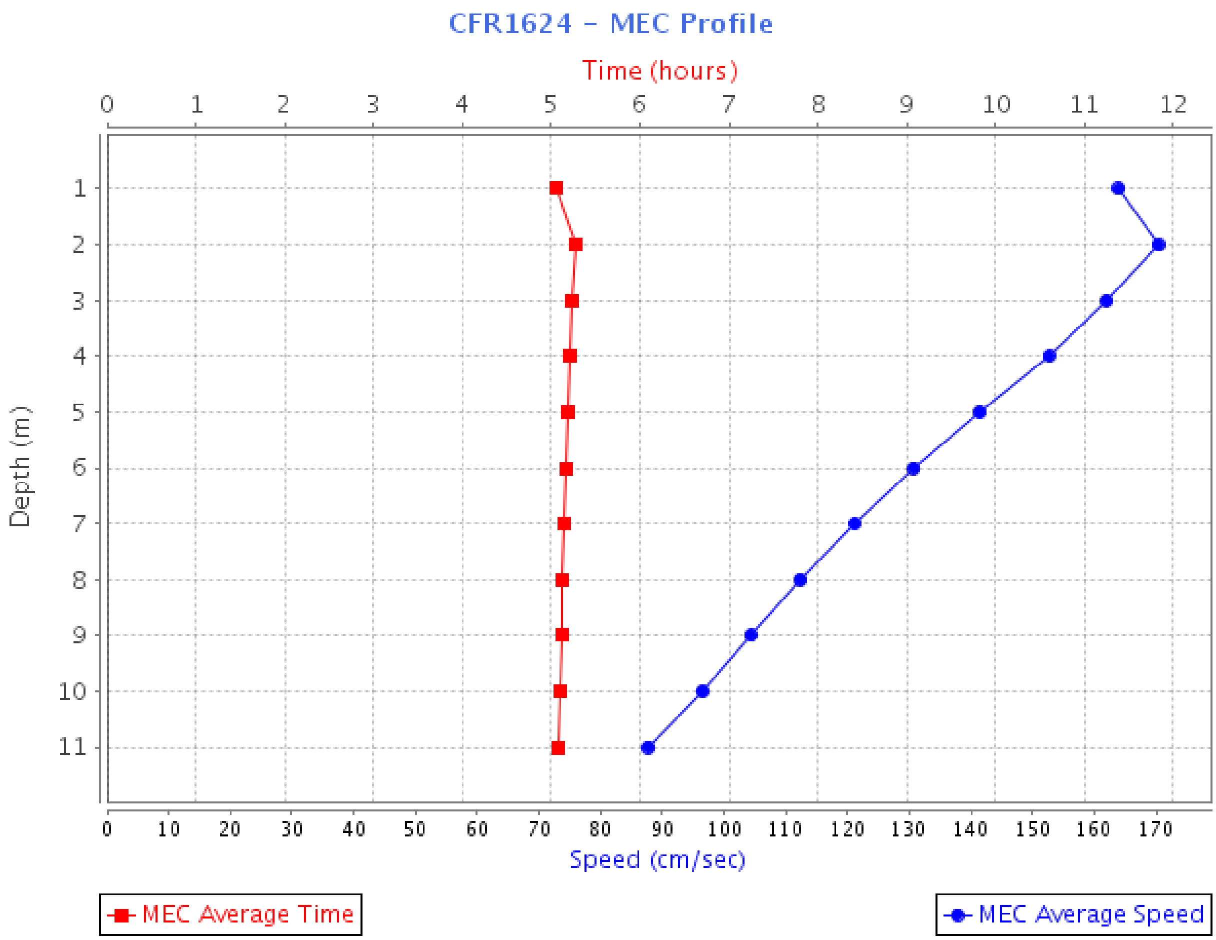


Figure 17. CFR1624 MEC timing (GI - red) and speed (blue) by depth bin. Bin 1 is the deepest bin observed (11.1 m [36.5 ft] deep), and the top-most surface bin is bin 11.

6.3 CFR1610, Lower Brunswick Range

This station was deployed for 52 days (March 18–May 9, 2016) in 13 m (45.9 ft) of water. A TRDI Workhorse 600 kHz ADCP mounted in a MTRBM collected 20 1-m bins of data, 11 of which met quality control criteria for further analysis. Bins 1, 8, and 10 representing approximate depths of 11.8 m, 4.8 m, and 2.8 m (38.7 ft, 15.8 ft, and 9.2 ft), respectively, can be found on the Tides and Currents website (NOAA, 2019a).

Currents are semidiurnal and rectilinear following the northwest-southeast channel orientation with an extremely strong tidal signal. LSQHA resolved 25 constituents and accounted for 95–98 percent of the total current energy. Floods are stronger at depth (bins 1–5) and ebbs are stronger at the surface (bins 6–11), which can be seen in the mean velocity profile (Figure 19). Mean MFC range is from 63.3 cm/s (1.2 kn) at the bottom to 82.3 cm/s (1.6 kn) mid-water column (bin 7, 19.1 ft). Mean MEC range is from 43.2 cm/s (0.8 kn) near the bottom to 93.6 cm/s (1.8 kn) at the surface (bin 11, 1.8 m, 5.9 ft). The MFC GI timing is approximately 30 minutes earlier at depth than at the surface. The MEC GI timing occurs about 20 minutes earlier at depth and at the surface than in the mid-water column.

This station will supersede the nearby historical station “Barnard Creek, off of” (NOS ID 11505, Table 9) located 0.2 km (0.1 nm) away. The historical station predictions were based on 4 days of observations collected in 1959 at 1.8 m (6 ft) and 4.9 m (16 ft) depths. Compared to the historical station, the recently measured currents in 2016 show stronger floods and ebbs, and the MEC GI timing is approximately 50 minutes earlier than the historical timing.

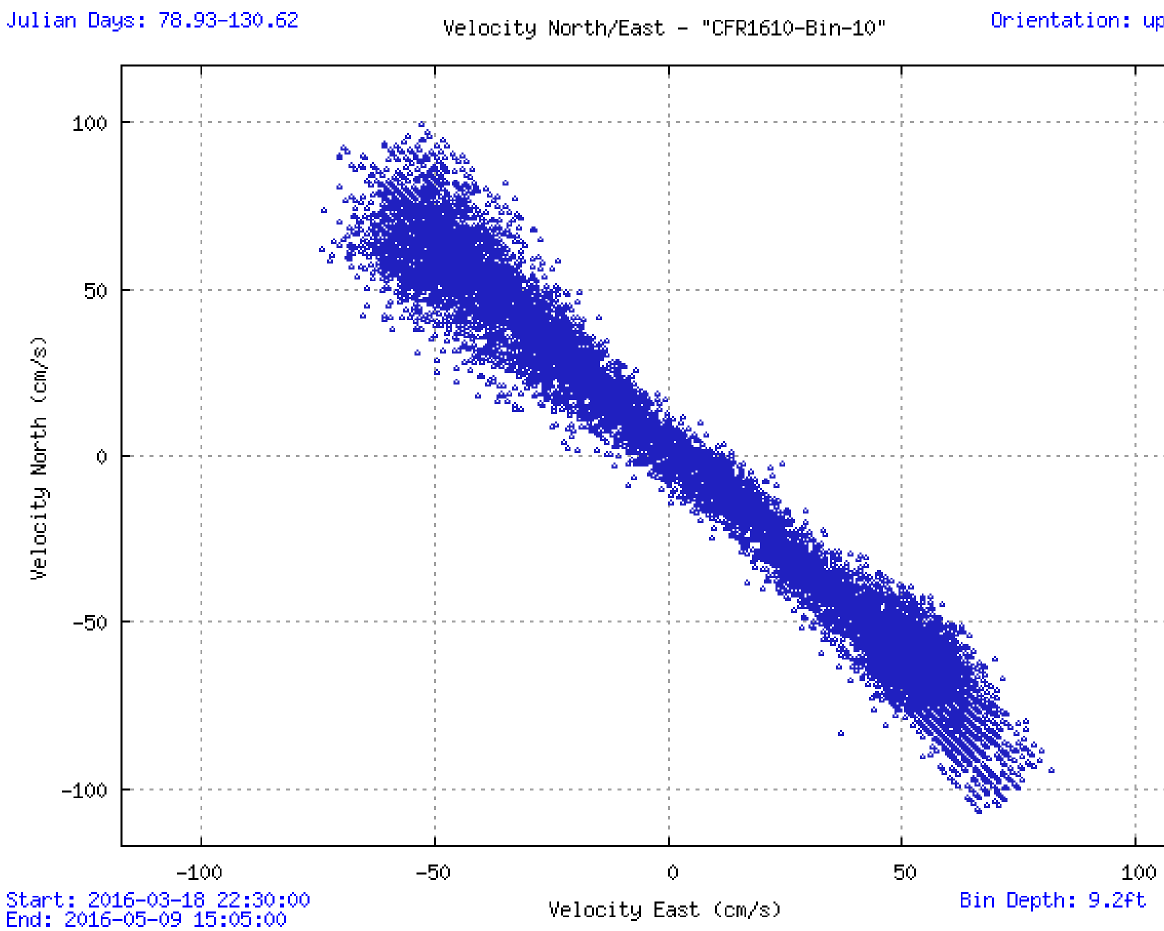


Figure 18. CFR1610 north versus east scatterplot, which shows the northern versus eastern components of the current in bin 10 (2.8 m [9.2 ft] below MLLW).

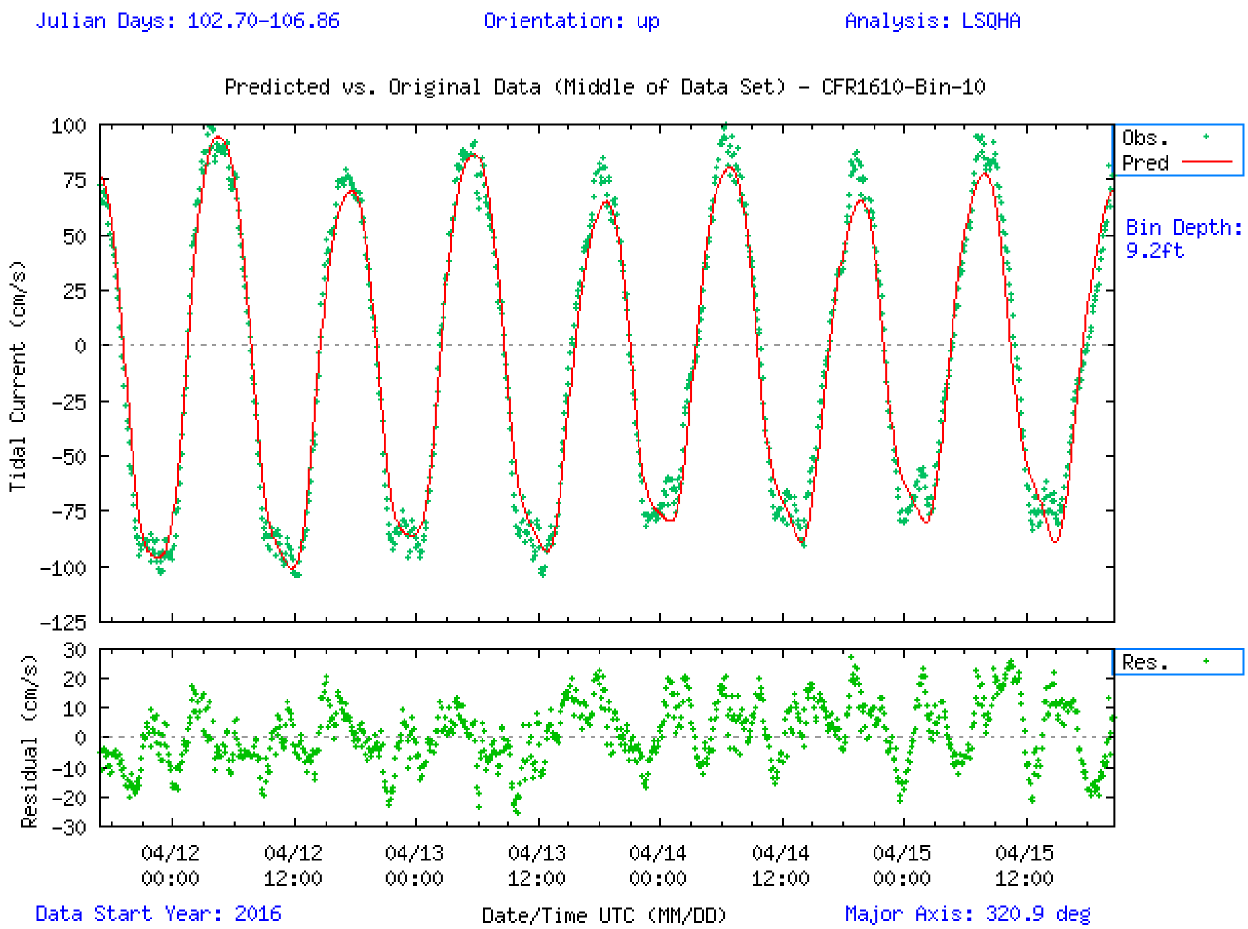


Figure 19. Representative CFR1610 observed versus predicted currents, with residuals, at bin 10 (2.8 m, 9.2 ft) April 12–15, 2016.

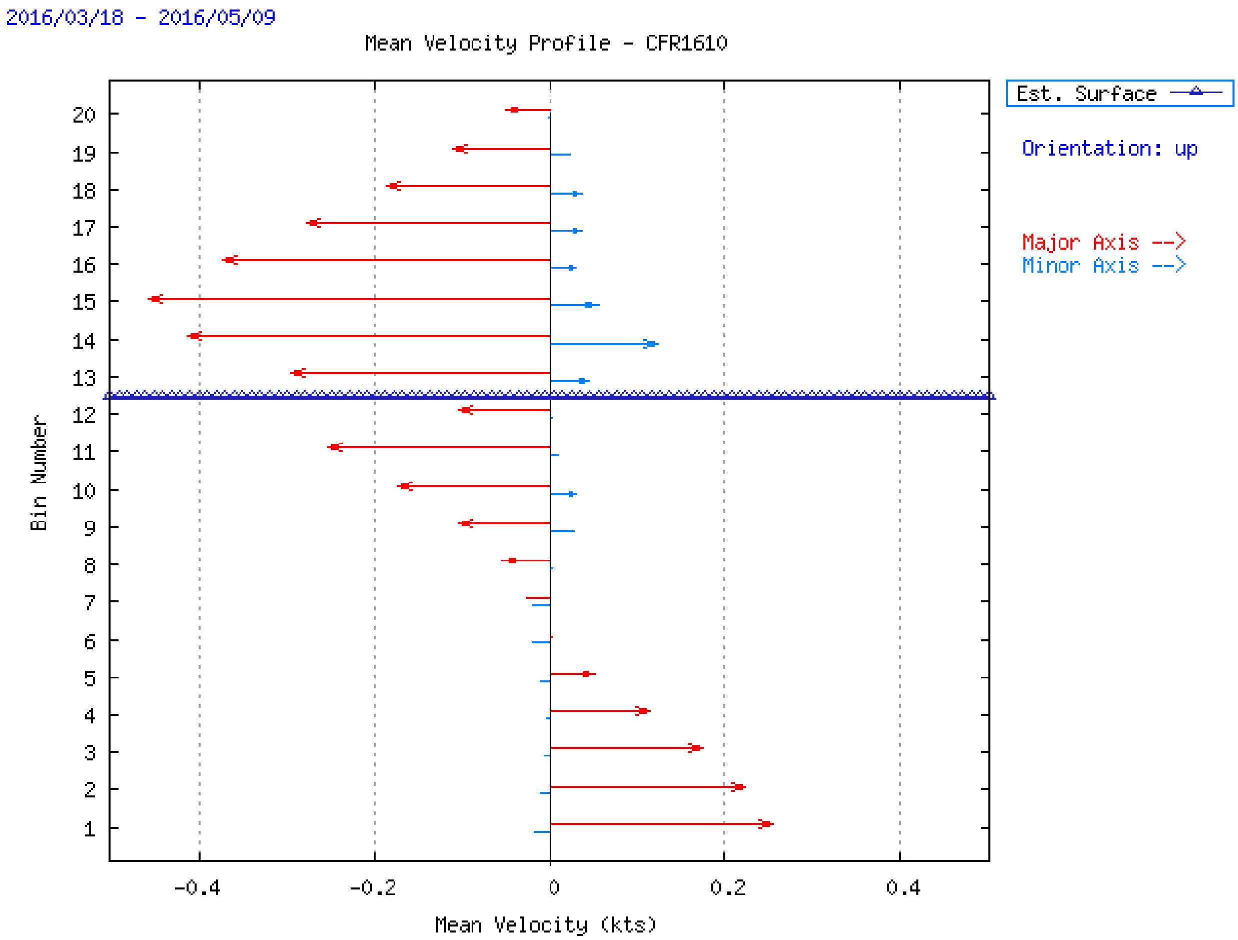


Figure 20. CFR1610 mean velocity profile by bin number. Bin 1 is approximately 11.8 m (38.7 ft) deep and represents the deepest bin observed; bin spacing for this station was 1.0 m (3.3 ft). Although 20 bins are represented, bin 11 is the highest bin normally under water and the highest bin passing quality control criteria for further analysis.

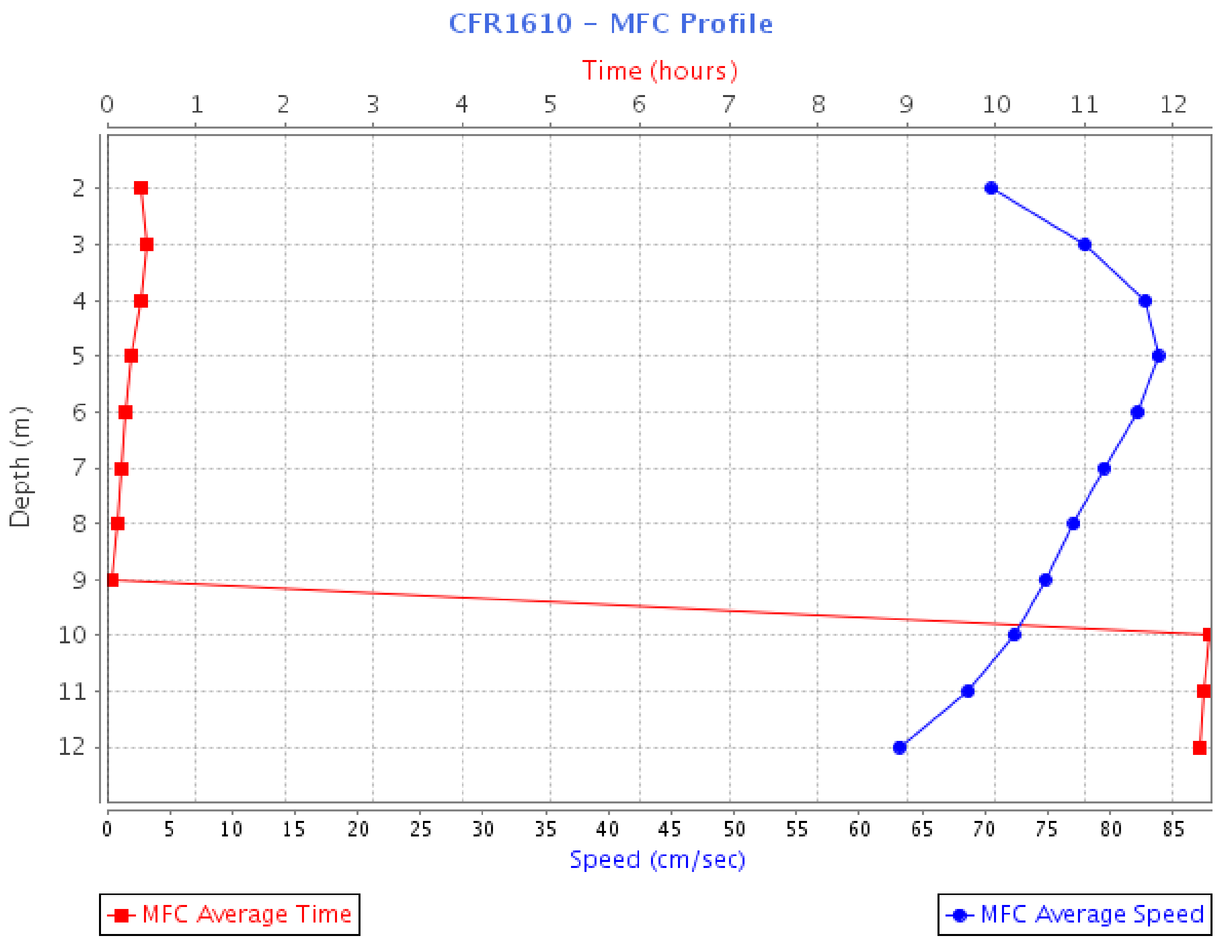


Figure 21. CFR1610 MFC timing (GI- red) and speed (blue) by depth bin. Bin 1 is the deepest bin observed (11.8 m (38.7 ft) deep), and the top-most surface bin is bin 11.

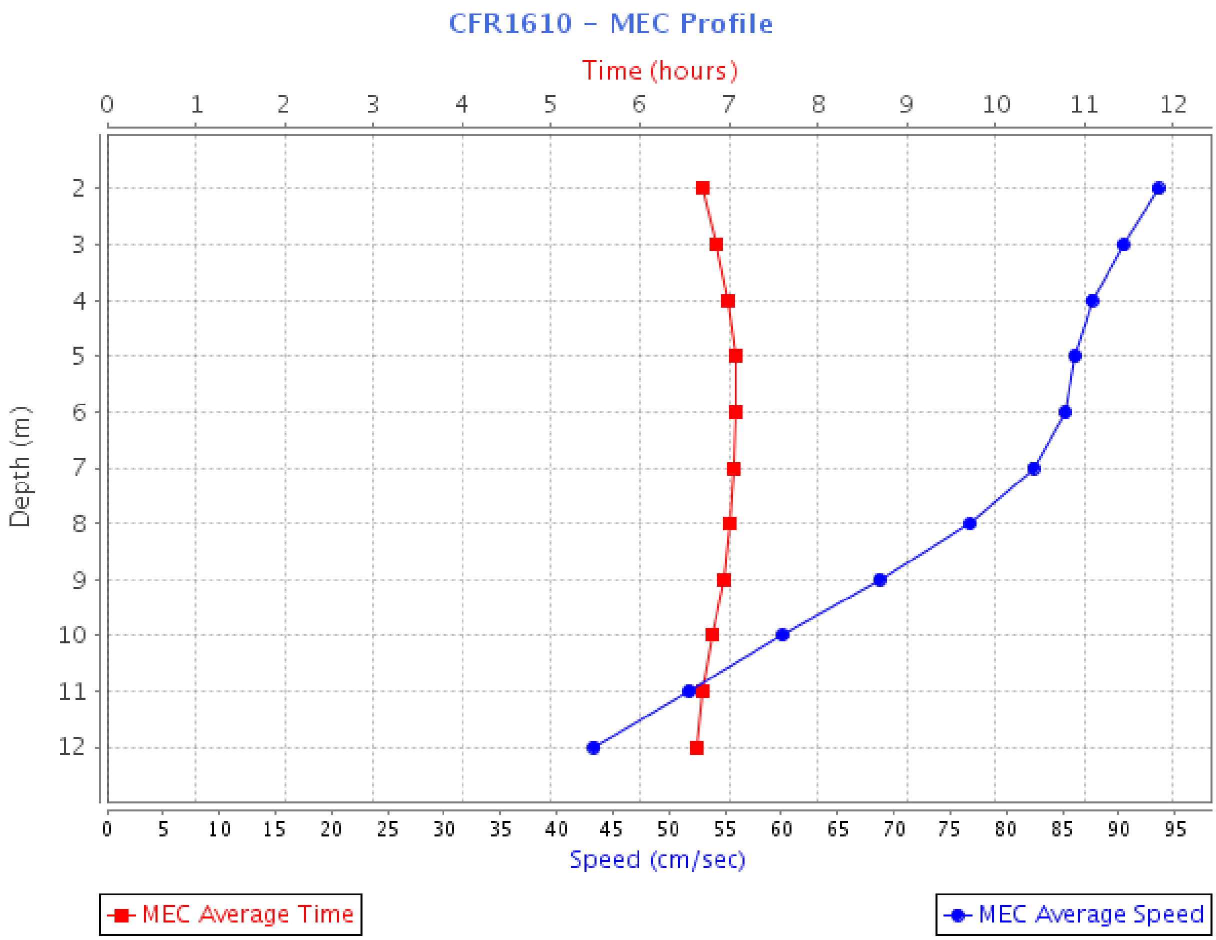


Figure 22. CFR1610 MEC timing (GI - red) and speed (blue) by depth bin. Bin 1 is the deepest bin observed (11.8 m [38.7 ft] deep) and the top-most surface bin is bin 11.

6.4 CFR1618, Upper Midnight Channel

This station was deployed for 53 days (March 17–May 9, 2016) in 13.5 m (44.3 ft) of water. A TRDI Workhorse 600 kHz ADCP mounted in a MTRBM collected 20 1-m bins of data, 10 of which met quality control criteria for further analysis. Harmonic predictions are available for bins 2, 6, and 10 representing approximate depths of 10.0 m, 6.0 m, and 2.0 m (32.7 ft,19.6 ft, and 6.5 ft), respectively, on the Tides and Currents website (NOAA 2019b).

Currents are semidiurnal and rectilinear following the north-south channel orientation with an extremely strong tidal signal. LSQHA resolved 25 constituents and accounted for 98.999.4 percent of the total current energy. Ebbs are stronger than floods at all depths, which can be seen in the mean velocity profile (Figure 25). Mean flood currents range from 56.6 cm/s (1.1 kn) in the mid-water column to 63.8 cm/s (1.2 kn) at depth. Mean ebb currents range from 56.1 cm/s (1.1 kn) near the bottom to 106.5 cm/s (2.1 kn) at the surface.

This station will supersede the nearby historical station with the same name (NOS ID 6396, Table 9) located 0.11 km (0.06 nm) away. The historical station predictions were based on 5 days of observations collected in 1959. The recently measured currents show approximately the same ebb magnitude as and slower flood currents than the historical observations. The historical directions are approximately 20 degrees different from the 2016 analysis. The recent and historical MFC GI timings are similar, while the recent MEC timing is slightly later than the historical timing.

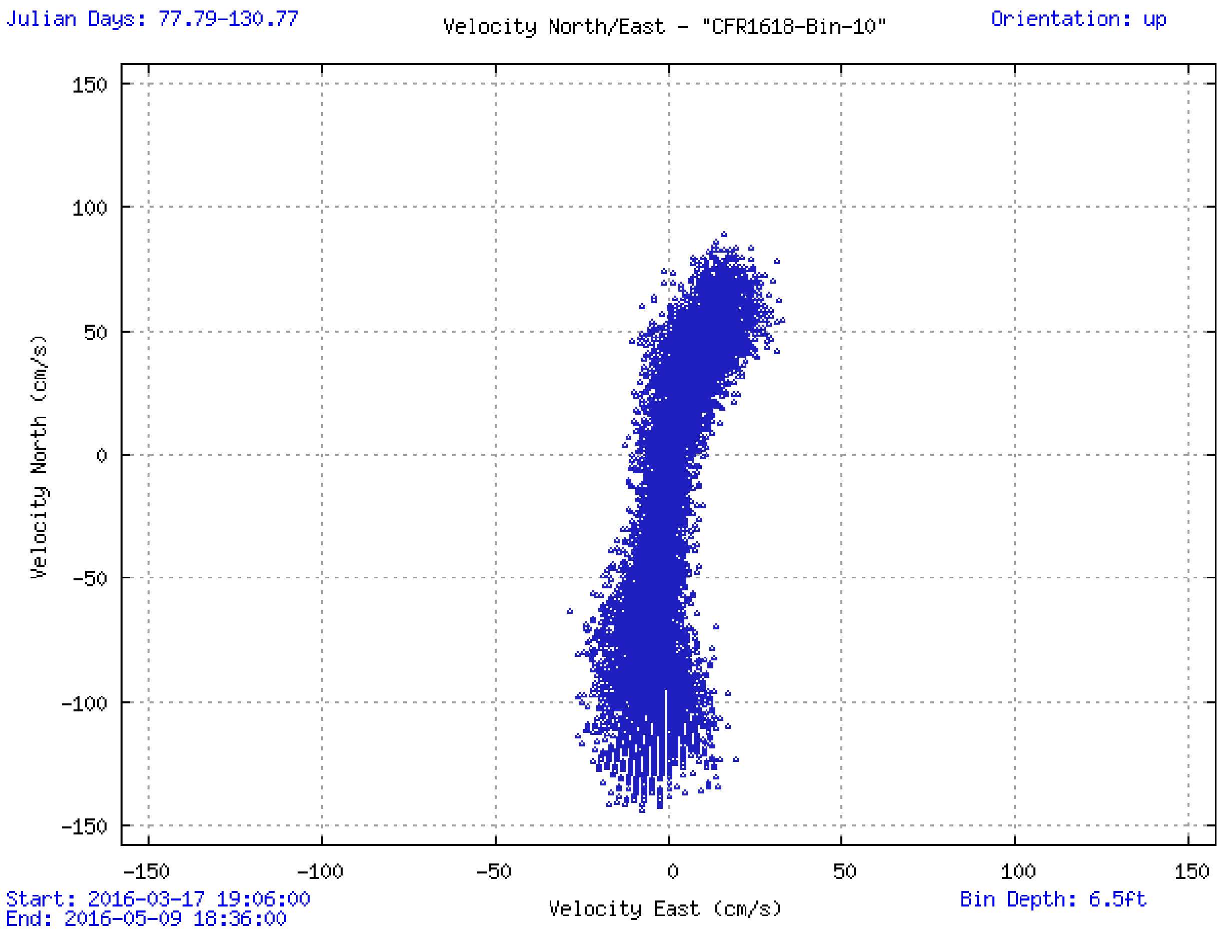


Figure 23. CFR1618 north versus east scatterplot, which shows the northern versus eastern components of the current in bin 10 (2.0 m [6.5 ft] below MLLW).

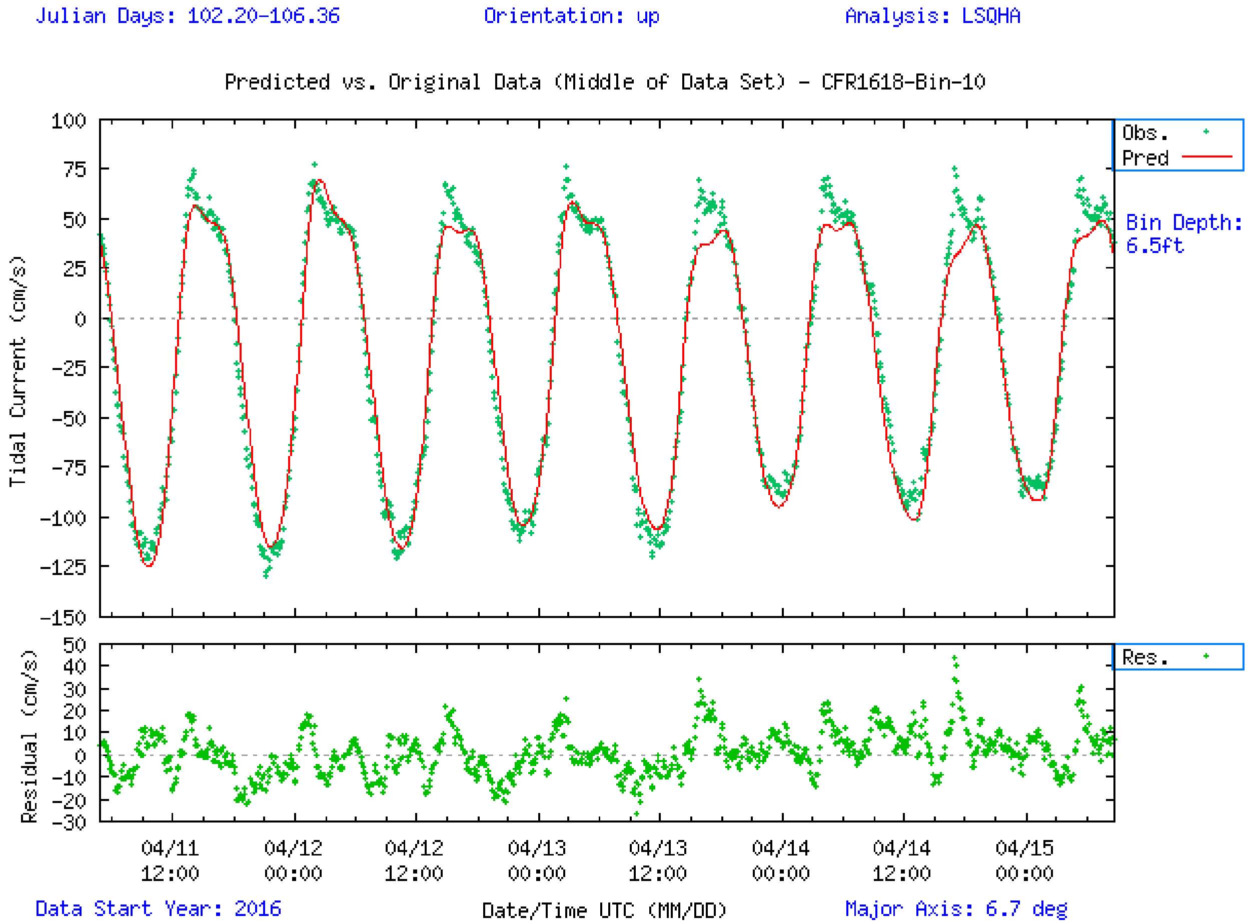


Figure 24. Representative CFR1618 observed versus predicted currents, with residuals, at bin 10 (2.0 m [6.5] ft) April 11–15, 2016.

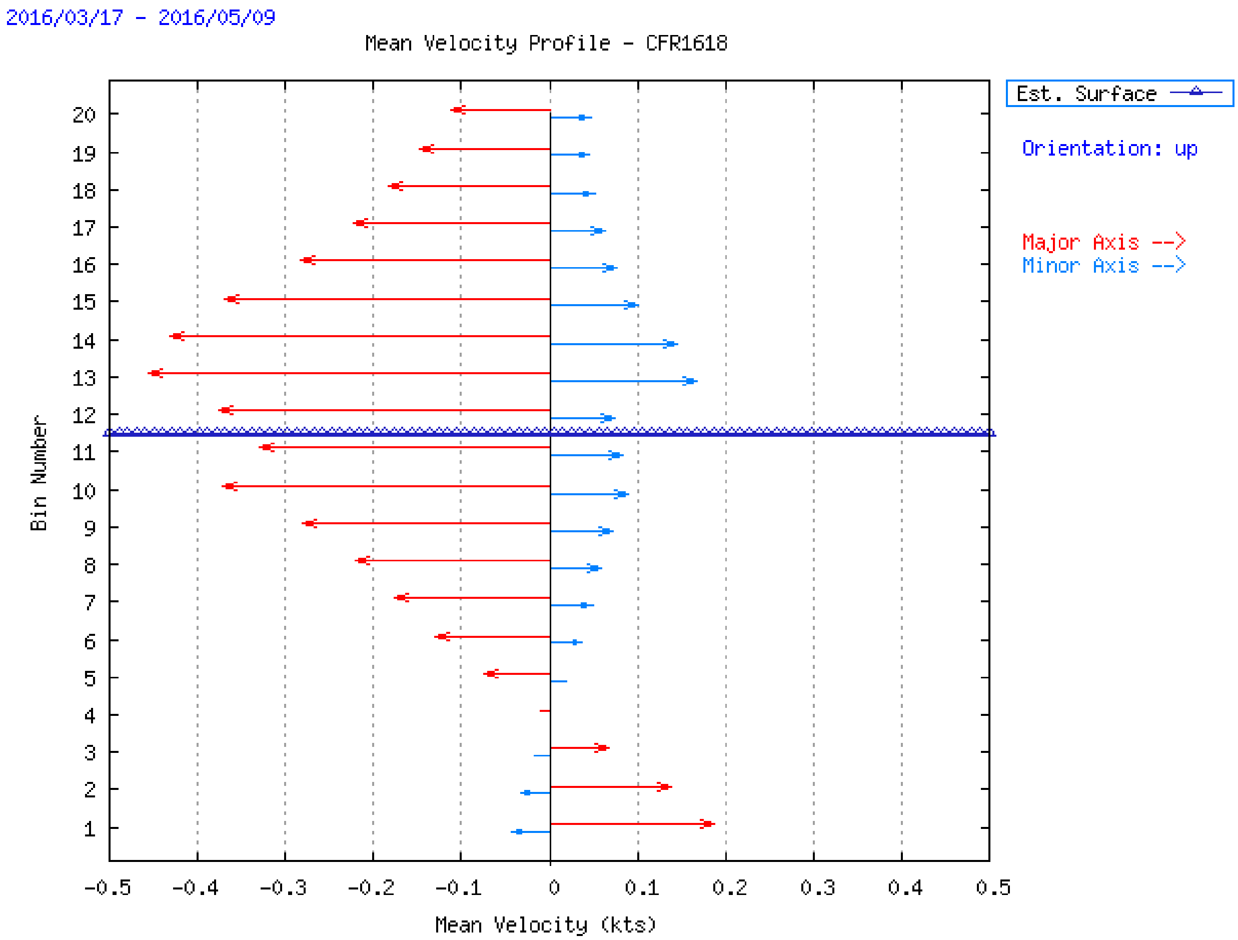


Figure 25. CFR1618 mean velocity profile by bin number. Bin 1 is approximately 11.0 m (36.1 ft) deep and represents the deepest bin observed; bin spacing for this station was 1.0 m (3.3 ft). Although 20 bins are represented, bin 10 is the highest bin normally under water and the highest bin passing quality control criteria for further analysis.

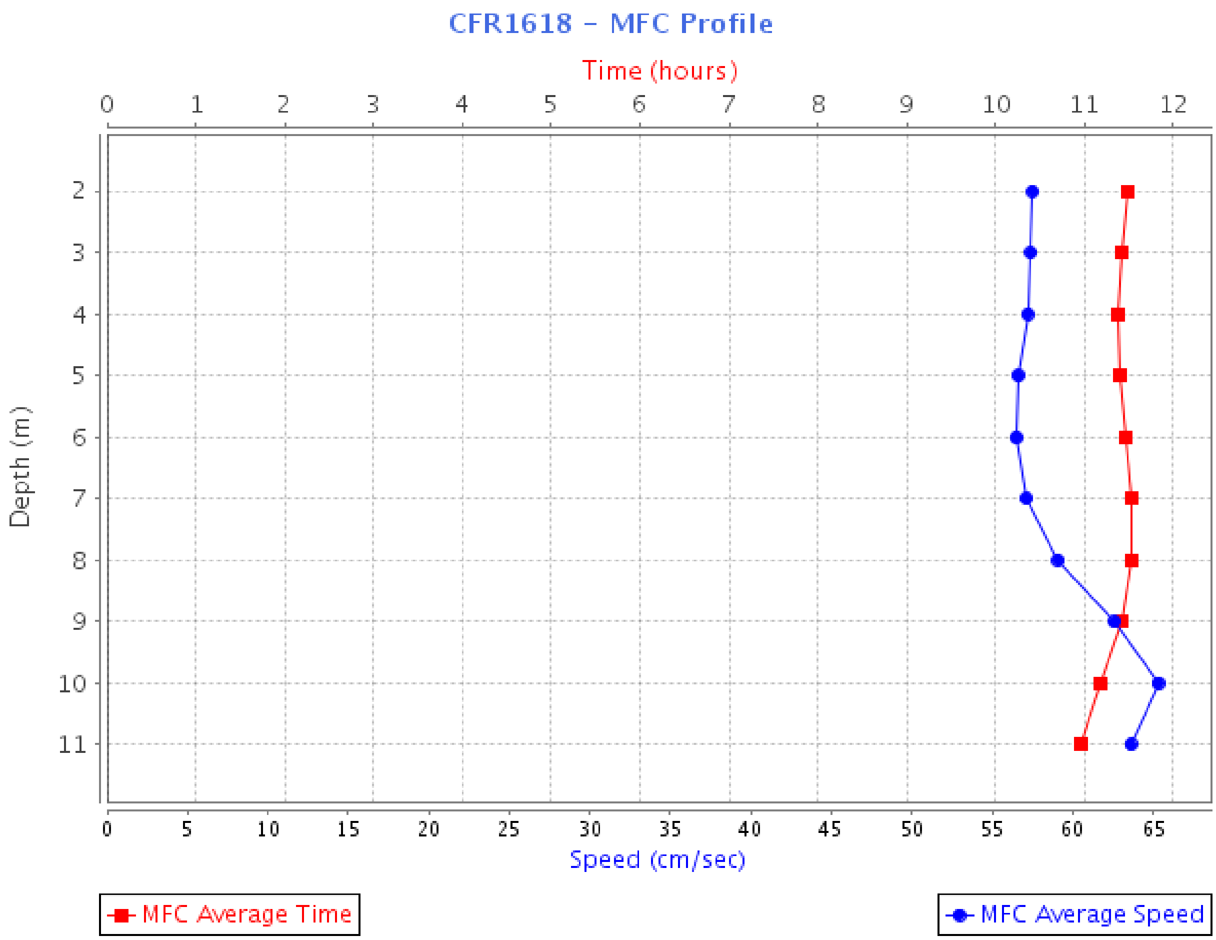


Figure 26. CFR1618 MFC timing (GI - red) and speed (blue) by depth bin. Bin 1 is the deepest bin observed (11.0 m [36.1 ft] deep) and the top-most surface bin is bin 10.

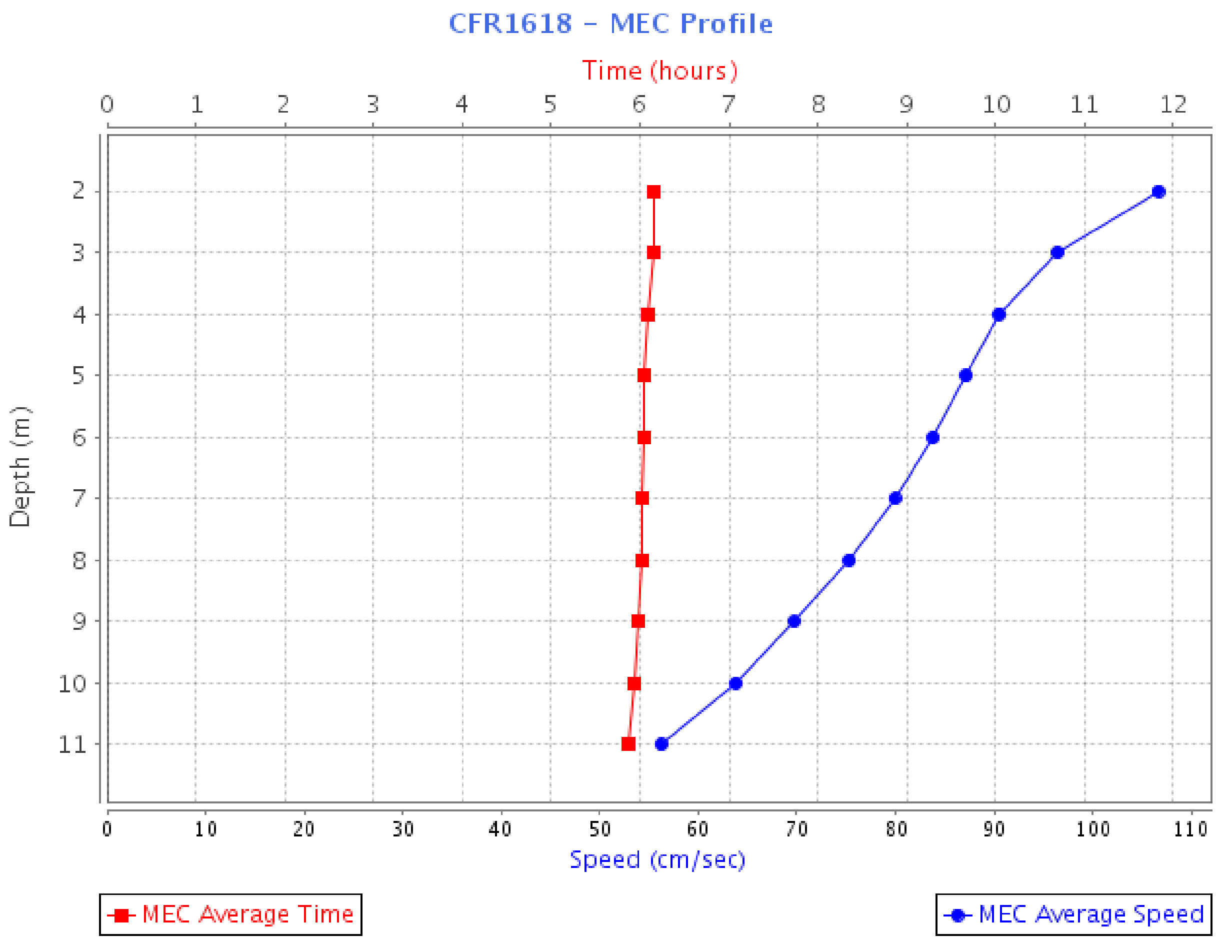


Figure 27. CFR1618 MEC timing (GI - red) and speed (blue) by depth bin. Bin 1 is the deepest bin observed (11.0 m [36.1 ft] deep) and the top-most surface bin is bin 10.

6.5 CFR1615, ICW at Carolina Beach Inlet

This station was deployed for 35 days (May 10–June 15, 2016) in 3.5 m (11.5 ft) of water across the ICW from Myrtle Sound. A Nortek Aquadopp 1 MHz ADCP was mounted in a side-looking orientation onto a pier using a band clamp. The ADCP collected 10 4-m bins of data, 7 of which met quality control criteria for further analysis. Data in all bins were measured at approximately 2.5 m (8.2 ft) depth. The increasing bin numbers represent the increasing horizontal distance from the ADCP transducer head. The profiler did not reach the center of the navigational channel. Data from bin 1 are closest to the ADCP at 5.0 m (16.4 ft) away from the transducers and harmonic predictions for this location are provided on the Tides and Currents website (NOAA 2019c).

Currents at this station are semidiurnal. Shallow-water effects are evident in the prediction curve (Figure 29). Currents from Myrtle Sound are merging with the ICW, leading to cross-flow and MFC/MEC directions slightly different from the channel orientation. Myrtle Sound inflow seems to have a greater influence on the currents observed in the bins farther away from the ADCP. The cross-flow is also suggested by the low tidal-signal at this station. LSQHA resolved 25 constituents and accounted for 46–81 percent of the total current energy in bins 7 and 1, respectively. The mean MFC ranged from 16.5 cm/s (0.3 kn) in bin 7 (29.0 m) to 34.5 cm/s (0.7 kn) in bin 1 (5.0 m from transducer head). The mean MEC ranged from 19.6 cm/s (0.38 kn) in bin 1 to 22.1 cm/s (0.43 kn) in bin 7. The MFC GI timing ranges over 2 hours between bins 1 and 7.

This station will supersede the nearby historical station with the same name (NOS ID 6391, Table 9). The historical station predictions are based on 1 day of observations collected in 1976. The recently measured currents show slower ebbs and slightly later GI timing for slacks and floods than the historical station.

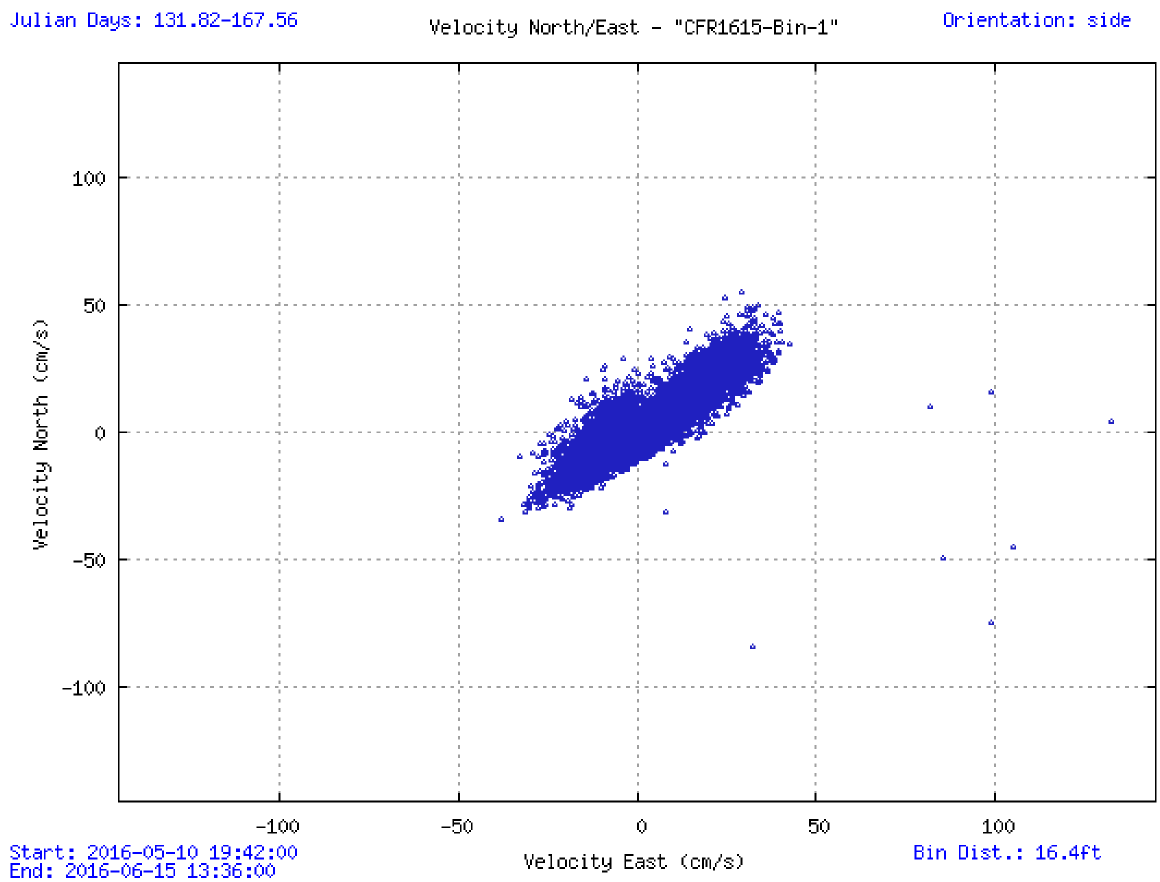


Figure 28. CFR1615 north versus east scatterplot, which shows the northern versus eastern components of the current in bin 1 (2.5 m [8.2 ft] below MLLW).

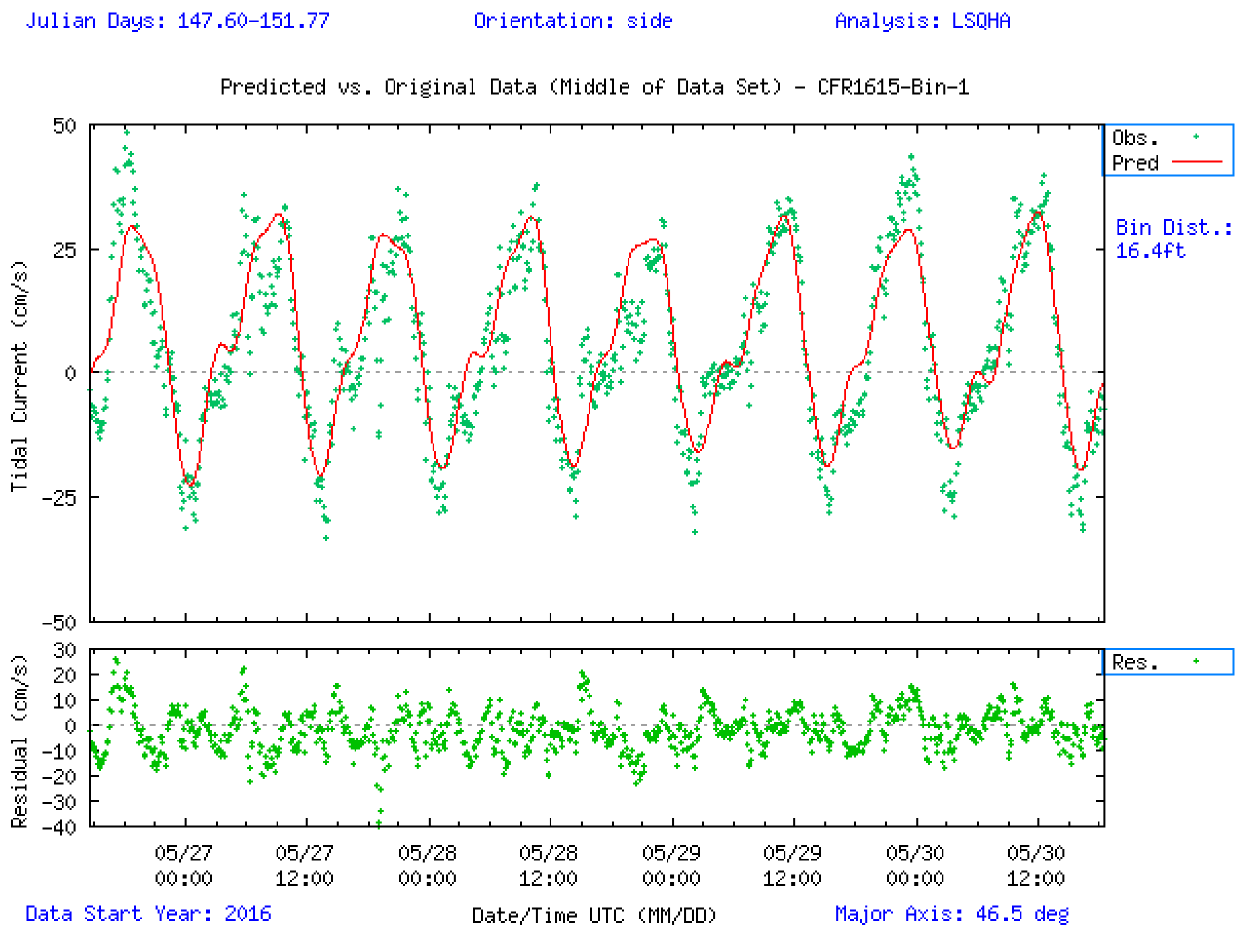


Figure 29. Representative CFR1615 observed versus predicted currents, with residuals, at bin 1 (2.5 m deep [8.2 ft]) May 27–30, 2016.

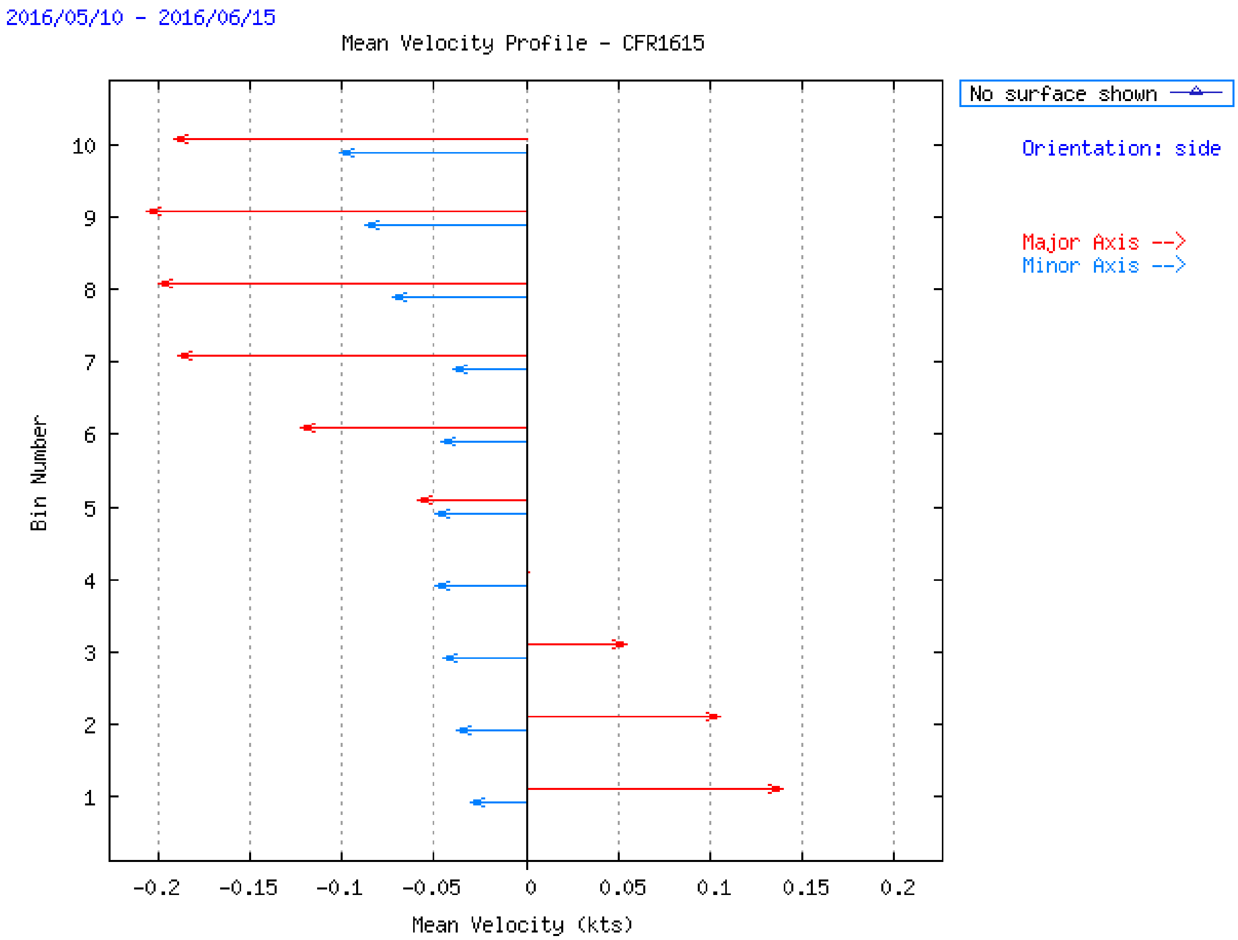


Figure 30. CFR1615 mean velocity profile by bin number. Bin 1 is the bin closest to the ADCP transducer (5.0 m [16.4 ft] from the sensor head). The horizontal configuration of the sensor allows for measurements in each bin at the same depth (2.5 m [8.2 ft]). The increasing bin numbers represent the increasing horizontal distance across the channel from the ADCP transducer head, at 4.0-m increments. Although 10 bins are represented, bin 7 is the farthest bin passing quality control criteria for further analysis.

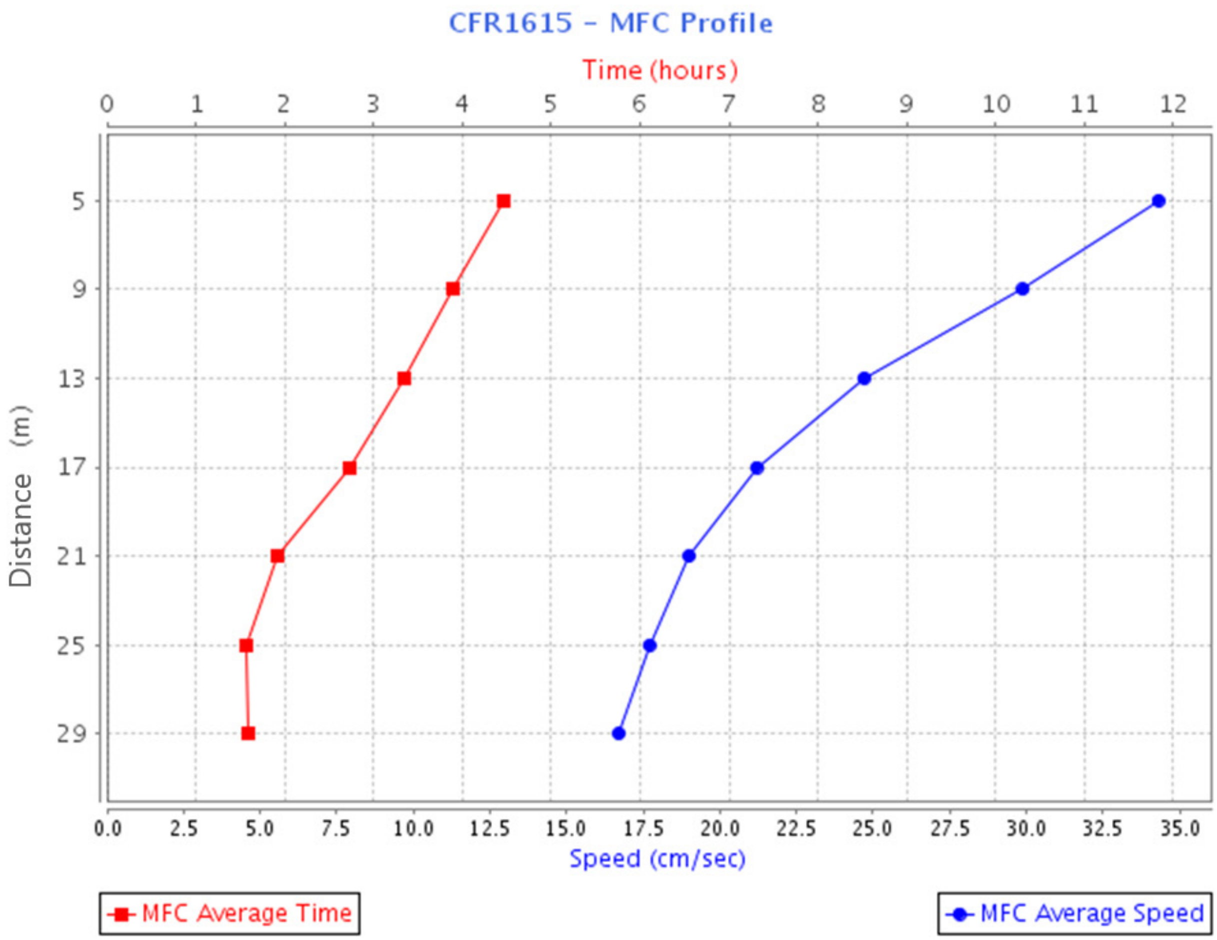


Figure 31. CFR1615 MFC timing (GI -red) and speed (blue) by distance from sensor head. Bin 1 is the bin closest to the ADCP transducer (5.0 m [16.4 ft]) and Bin 7 is the farthest at (29.0 m [95.1 ft]). The horizontal configuration of the sensor allows for measurements in each bin at the same depth (2.5 m [8.2 ft]). The increasing bin numbers represent the increasing horizontal distance across the channel from the ADCP transducer head at 4.0-m increments.

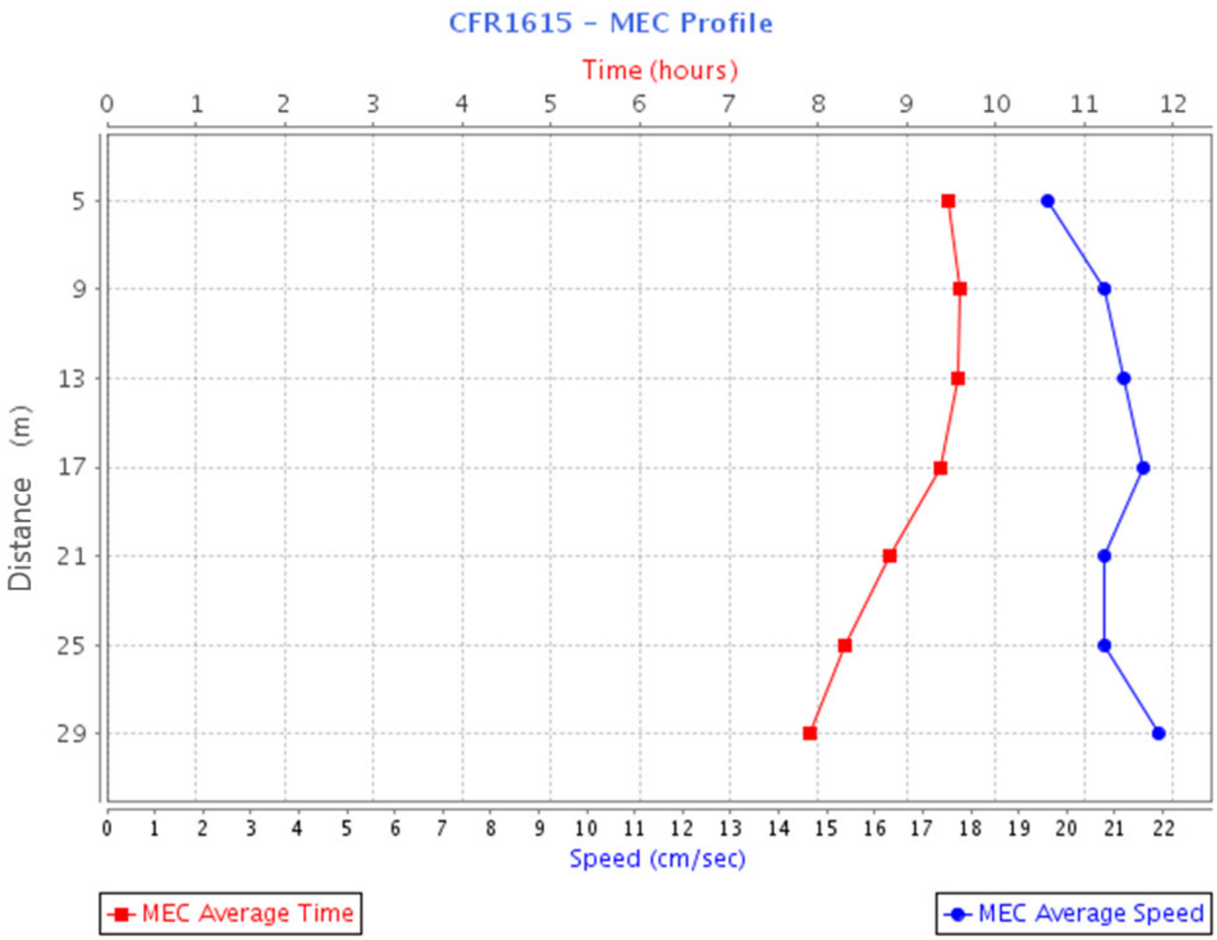


Figure 32. CFR1615 MEC timing (GI - red) and speed (blue) by distance from sensor head. Bin 1 is the bin closest to the ADCP transducer (5.0 m [16.4 ft]) and Bin 7 is the farthest (29.0 m [95.1 ft]). The horizontal configuration of the sensor allows for measurements in each bin at the same depth (2.5 m [8.2 ft]). The increasing bin numbers represent the increasing horizontal distance across the channel from the ADCP transducer head.

7. SPATIAL VARIATION

7.1 Harmonic constituents

Tidal harmonic constituents generated for the Cape Fear River survey stations show that in general, observed tidal currents were dominated by the M_2 tidal constituent (the principal lunar semidiurnal constituent) and strongly influenced by the channel geometry of the river. In general, tides on the East Coast of the United States are semidiurnal or mixed semidiurnal, and the Cape Fear River falls into this classification (Thurman, 1994). Local bathymetric changes along the river correlate with differences in constituent amplitudes. The four most energetic constituents (M_2, S_2, O_1, and K_1) are mapped (Figures 33–40), and amplitudes and phases are provided in Table 10. The stations within the river are all extremely rectilinear and M_2 dominated, with only stations at the mouth and along the barrier island showing slight deviations from this pattern. Analysis of the spatial variation of both the along-channel amplitudes and the tidal ellipse shapes for the four major tidal constituents supports this analysis of the Cape Fear River tidal currents.

On average, the observed amplitude of M_2 along the principal axis was about eight times greater than the principal solar semidiurnal constituent (S_2), which was the next strongest constituent. The amplitude of M_2 was on average 16.5 times greater than O_1 and 10.9 times greater than K_1 along the principal axis. This general trend in the relationship between M_2 and other constituents was consistent for all of the stations along the river and the barrier island system. The Dietrich ratio (the ratio of the principal diurnal constituents to the principal semidiurnal component of the tides) is defined as: $(K_1 + O_1)/M_2$. This ratio describes the type of tide: for a Dietrich ratio of less than 0.25, the tides are semidiurnal; for a Dietrich ratio between 0.25 and 1.5, the tides are mixed, primarily semidiurnal; for a ratio between 1.5 and 3, the tides are mixed but mostly diurnal; and for a ratio greater than 3, the tides are diurnal (Defant, 1958). The average Dietrich ratio for the along-axis component was 0.17 with a range of 0.12–0.29. All stations are semidiurnal except Dram Tree Point (CFR1608) at 0.29 (mixed semidiurnal region). This is due in part to a relatively low M_2 amplitude combined with a higher O_1 amplitude than at the other stations. The highest values tended to be in the region of the confluence of the Brunswick and Cape Fear Rivers near stations CFR1604 to CFR1609 and at the barrier island inlet (stations CFR1615 and CFR1616).

Table 10. Major constituent amplitudes and phases along the major axis. Amplitudes are in cm/s.

CFR1601	40.28	240.70	4.84	262.10	3.04	108.90	2.16	85.60	0.13
CFR1602	74.34	243.60	6.89	262.50	7.46	135.90	6.69	126.70	0.19
CFR1603	68.52	238.20	9.05	255.00	6.17	105.80	4.58	107.60	0.16
CFR1604	74.80	236.20	12.04	264.70	9.47	120.00	6.74	118.30	0.22
CFR1605	94.30	231.40	9.11	251.80	8.49	119.60	8.95	115.00	0.18
CFR1607	37.45	237.20	3.45	177.50	4.99	85.50	0.72	162.30	0.15
CFR1608	53.04	226.50	4.84	244.10	9.67	92.60	5.97	132.80	0.29
CFR1609	47.43	214.60	8.33	244.00	3.81	101.80	6.22	133.60	0.21
CFR1610	83.96	230.40	13.53	254.00	8.54	97.40	6.79	101.30	0.18
CFR1611	80.77	222.50	11.37	248.50	7.51	89.80	6.33	102.10	0.17
CFR1612	98.62	221.90	14.97	250.40	9.52	98.70	6.58	108.80	0.16
CFR1613	95.53	217.30	10.19	231.90	7.67	88.20	5.92	107.40	0.14
CFR1614	100.63	213.90	10.19	238.50	9.05	94.50	6.17	106.50	0.15
CFR1615	23.10	331.50	3.60	102.30	2.78	261.30	1.70	202.10	0.19
CFR1616	79.17	329.20	4.42	50.20	6.64	203.70	8.90	293.40	0.20
CFR1617	93.32	189.90	12.50	212.00	8.85	73.80	5.71	82.90	0.16
CFR1618	79.43	206.20	12.40	235.50	5.35	79.40	3.81	83.70	0.12
CFR1619	66.57	201.30	6.48	226.80	7.15	60.00	3.34	77.30	0.16
CFR1620	77.12	191.30	12.50	234.80	5.14	42.40	4.37	76.50	0.12
CFR1621	104.02	185.80	13.53	215.70	9.47	75.60	6.64	90.80	0.15
CFR1622	40.33	151.60	6.79	163.20	3.70	40.10	2.83	53.10	0.16
CFR1623	32.20	134.50	3.55	155.90	2.21	39.60	1.80	42.90	0.12
CFR1624	126.91	185.00	18.83	213.60	8.64	53.50	6.84	61.20	0.12
CFR1625	71.71	172.00	22.94	161.50	9.77	83.70	2.62	92.60	0.17
CFR1626	55.30	164.30	12.60	204.40	5.40	359.40	3.70	25.30	0.16

Tidal ellipses enable examination of the along- and cross-channel tidal components at each station and between stations. The four principal tidal constituents can be represented by an elliptical path, traced around each station. These representative ellipses relate an average magnitude and direction of the major and minor axes of flow for each constituent. In the open ocean, a tidal ellipse is typically nearly circular, as there are no significant bathymetric changes to alter the flow. However, the Cape Fear River is narrow, and therefore the motion along the minor axis of flow is constricted to where it is almost negligible in most locations. Figures 33–40 show the relative speed of constituents M_2, S_2, O_1, and K_1. Note that the scales for the Wilmington regions for all constituents except M_2 are the same, so that direct comparisons between constituents in these figures are possible.

For the M_2 constituent, the resulting elliptical path is largely rectilinear along the principal axis of flow, which is often the central river channel as seen in Figures 33 and 34. The only station that differs is Bald Head Shoal (CFR1626) outside the mouth of the river, which is less topographically constrained and more influenced by open ocean effects. Wilmington (CFR1603) and Point Peter (CFR1604) show the change in principal direction at the bifurcation of the river just north of Wilmington. While these stations are closely located, their principal directions differ by over 30 degrees. The S_2, O_1, and K_1 constituents also serve to highlight changes due to topographic and bathymetric effects, with the amplitudes of all three responding to the bifurcations, curves, and narrowing of the river. The difference in amplitude between M_2 and the other constituents is also very clearly seen in the tidal ellipses.

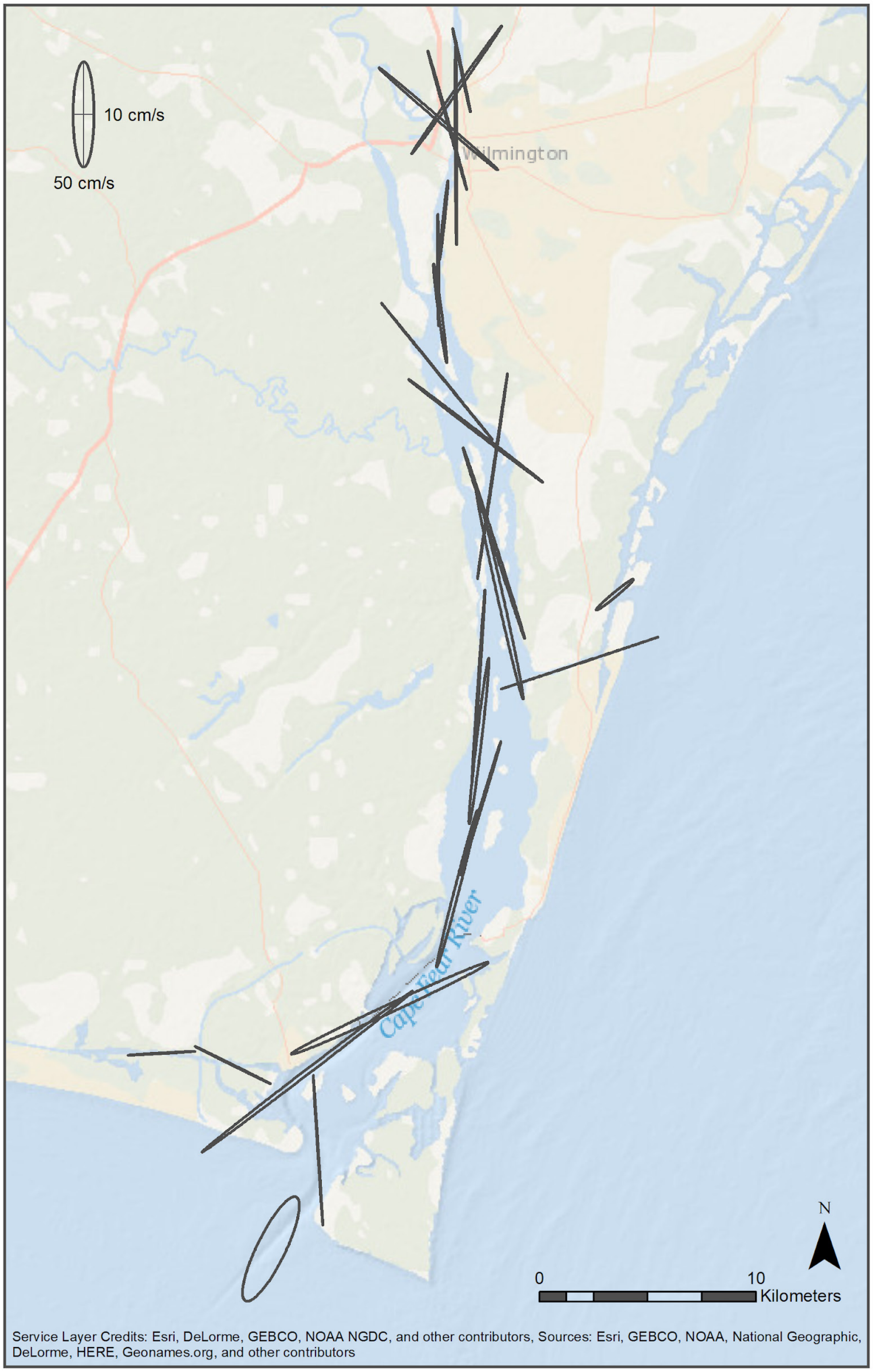


Figure 33. Map of near surface M_2 tidal constituent ellipses for the entire survey area. M_2 - Principal lunar semidiurnal constituent (speed: 28.984 degrees per mean solar hour).

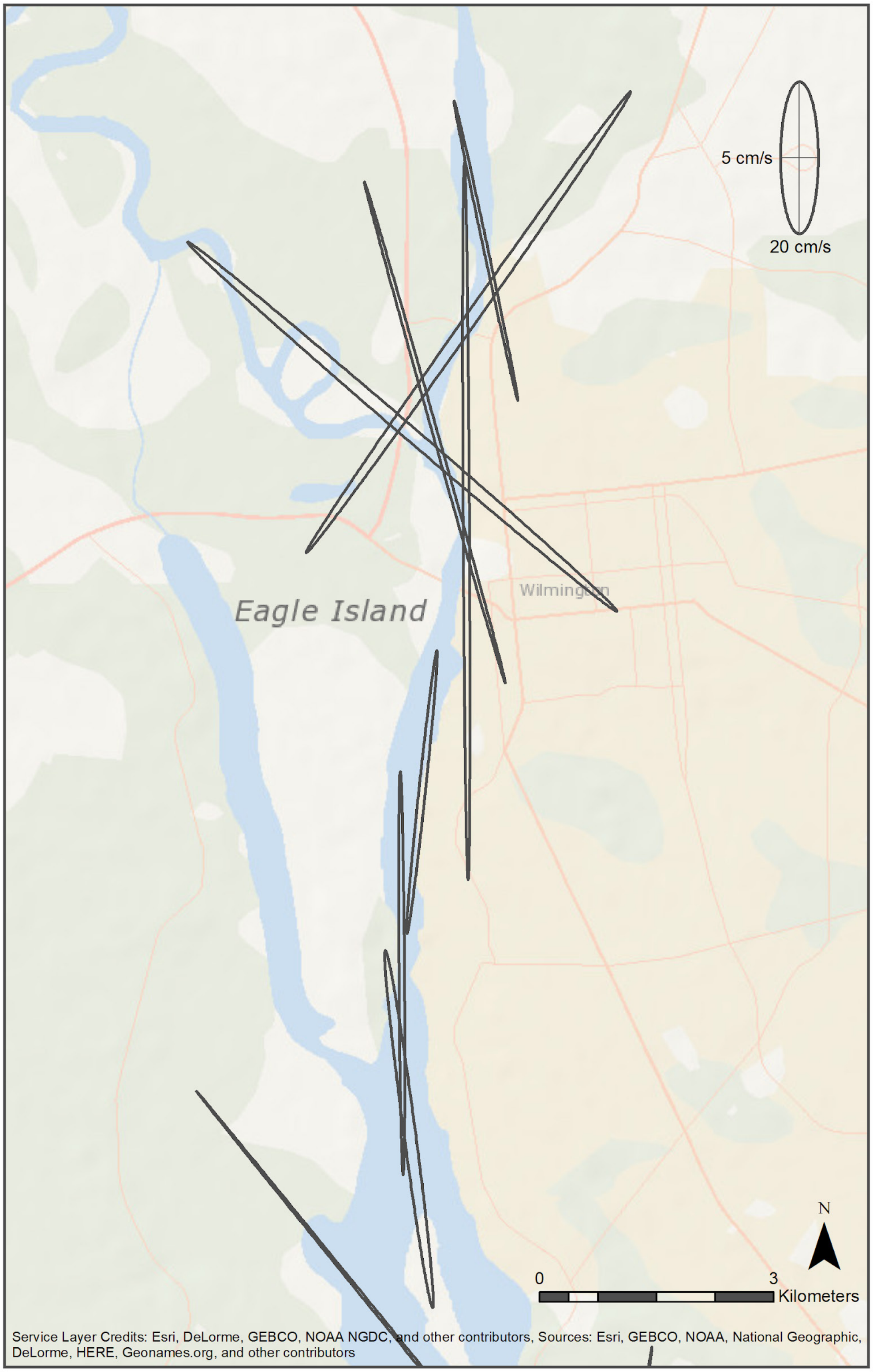


Figure 34. Map of near surface M_2 tidal constituent ellipses in the vicinity of Wilmington, North Carolina M_2 - Principal lunar semidiurnal constituent (speed: 28.984 degrees per mean solar hour).

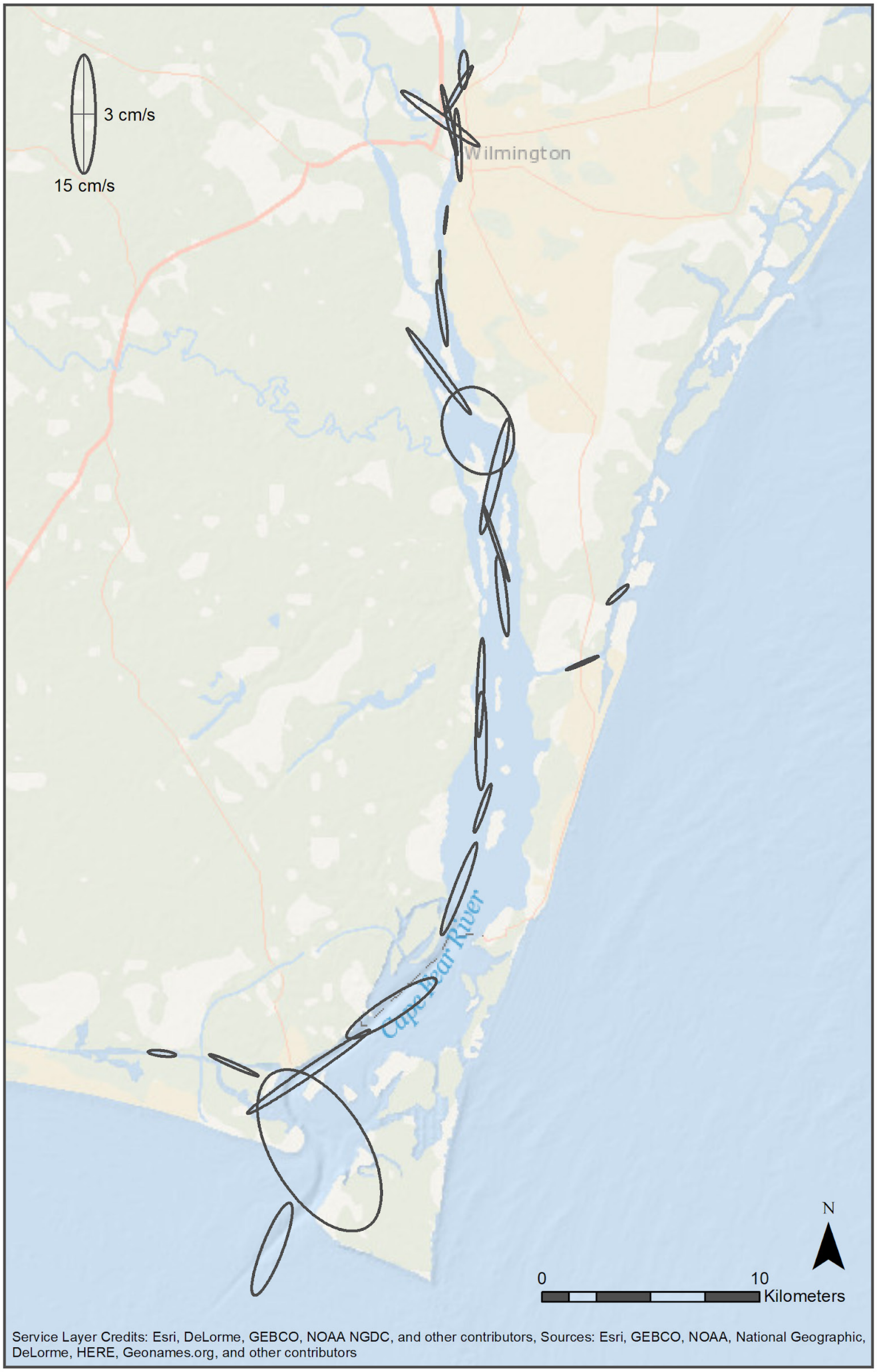


Figure 35. Map of near surface S_2 tidal constituent ellipses for the entire survey area. S_2 - Principal solar semidiurnal constituent (speed: 30.000 degrees per mean solar hour).

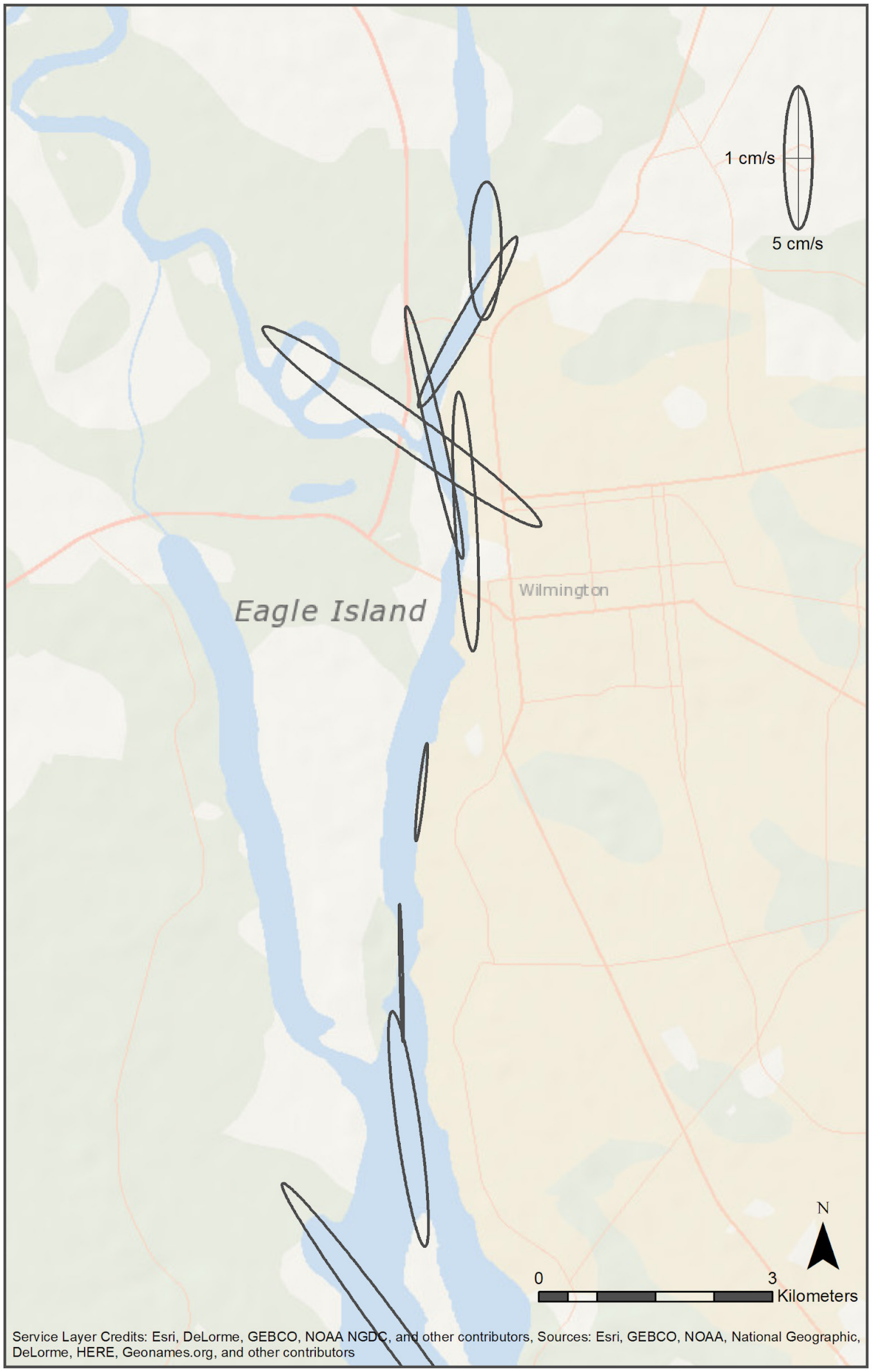


Figure 36. Map of near surface S_2 tidal constituent ellipses in the vicinity of Wilmington, North Carolina. S_2 - Principal solar semidiurnal constituent (speed: 30.000 degrees per mean solar hour).

Figure 37. Map of near surface O_1 tidal constituent ellipses for the entire survey area. O_1 - Lunar declinational diurnal constituent (speed: 13.943 degrees per mean solar hour).

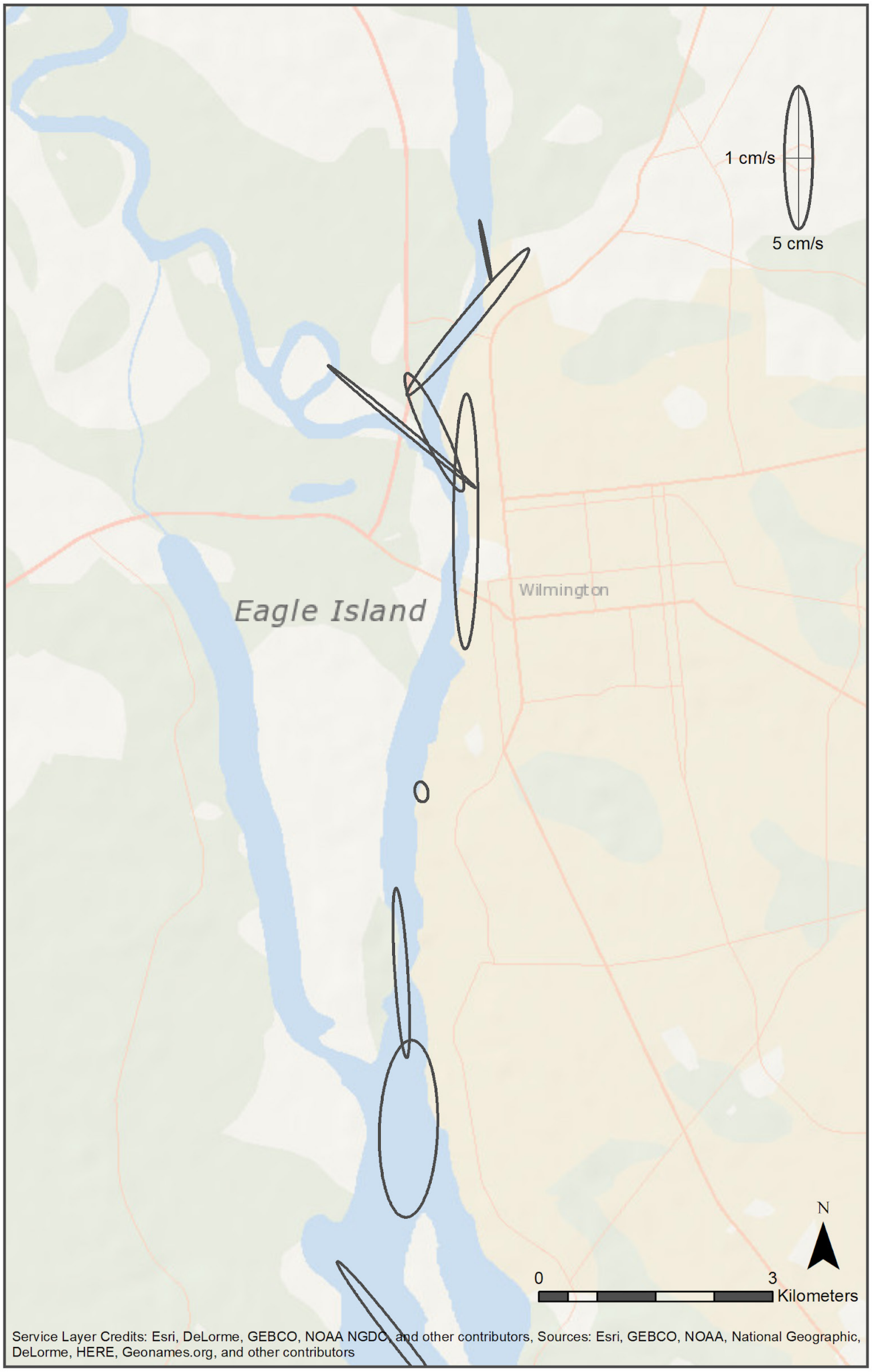


Figure 38. Map of near surface O_1 tidal constituent ellipses in the vicinity of Wilmington, North Carolina. O_1 - Lunar declinational diurnal constituent (speed: 13.943 degrees per mean solar hour).

Figure 39. Map of near surface K_1 tidal constituent ellipses for the entire survey area. K_1 - Lunisolar declinational diurnal constituent (speed: 15.041 degrees per mean solar hour).

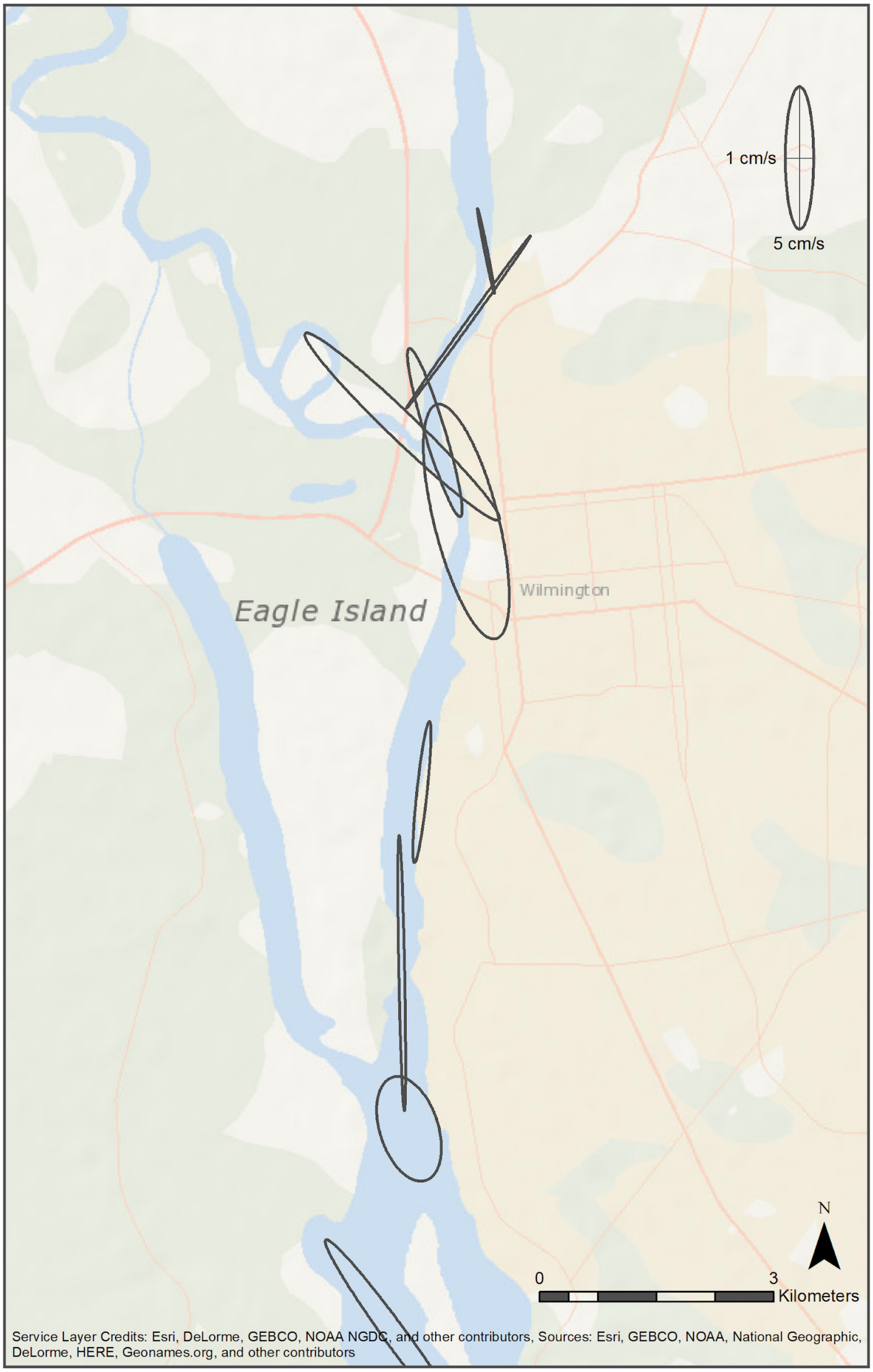


Figure 40. Map of near surface K_1 tidal constituent ellipses in the vicinity of Wilmington, North Carolina. K_1 - Lunisolar declinational diurnal constituent (speed: 15.041 degrees per mean solar hour).

7.2 Near-surface phases of the tide (timing and speed)

Spatial representation of the magnitude and timing of mean ebb and flood currents show the progression of the tides to the head of the estuary and the changes in amplitude due to bathymetry. The following maps (Figures 41–43) show the spatial distribution of the mean current speed and direction at each station during the maximum flood and ebb currents, and Figure 44 shows the corresponding timing. These currents are derived from the bin nearest to the surface passing quality control criteria. All three maps show the current vectors on the same scale so that they can be compared. It is evident that the bathymetry influences the maximum flood and ebb speed and direction. Stations near the mouth show distinct direction differences between flood and ebb based on bathymetry. Care must be used in interpreting the observed currents at Bald Head Shoal (CFR1626), which may not be indicative of currents in the channel or other nearby features. An example of this is Dram Tree Point (CFR1608). In this case, placement at the edge of the channel resulted in relatively lower observed current speeds, indicating the importance of cross-channel position on current speed. Figure 44 shows the GI timing of ebb and flood. Table 11 and Figure 44 show the temporal progression of the tidal currents up the river. Note that ICW at Carolina Beach Inlet (CFR1615) and Snows Cut (CFR1616) are near the barrier island and do not follow this trend.

Table 11. Speed and timing relative to the tidal day of MFC and MEC at the near surface at all stations.

STATION_ID	Depth (m)	Bin Depth (m)	MFC (cm/s)	MEC (cm/s)	MFC GI (hours)	MEC GI (hours)
CFR1601	9.0	1.9	20.1	61.3	1.04	6.96
CFR1602	12.0	1.9	73.7	74.3	1.11	7.07
CFR1603	10.8	1.3	71.0	69.4	0.95	6.89
CFR1604	8.8	1.5	74.8	81.8	1.06	6.21
CFR1605	12.6	1.6	81.3	106.6	0.73	6.39
CFR1607	10.4	6.4	20.9	55.0	0.90	6.90
CFR1608	13.6	1.8	37.7	70.0	0.70	5.96
CFR1609	10.0	7.6	40.2	54.2	12.22	5.77
CFR1610	14.0	2.8	78.0	90.4	0.44	6.85
CFR1611	13.9	2.0	74.5	88.6	0.03	6.32
CFR1612	13.2	2.6	92.3	107.6	12.34	6.62
CFR1613	11.3	2.0	70.9	119.2	12.10	6.53
CFR1614	11.4	1.8	76.4	125.8	12.04	6.28
CFR1615	3.5	5.0	34.3	19.6	4.47	9.46
CFR1616	3.0	1.7	78.9	81.7	3.62	9.64
CFR1617	14.15	2.5	77.3	115.4	11.23	5.62
CFR1618	13.5	2.0	57.5	106.6	11.48	6.15
CFR1619	13.5	3.0	78.7	54.5	11.61	5.20
CFR1620	12.2	3.6	92.2	64.3	11.10	5.37
CFR1621	12.9	3.6	112.7	109.8	11.07	5.23
CFR1622	5.1	1.1	36.7	47.3	10.89	3.22
CFR1623	5.6	3.2	19.5	47.9	10.12	3.15
CFR1624	13.6	2.2	90.2	170.3	10.9	5.27
CFR1625	9.0	3.6	63.7	83.1	11.00	4.74
CFR1626	10.1	3.6	30.5	87.0	10.01	4.45

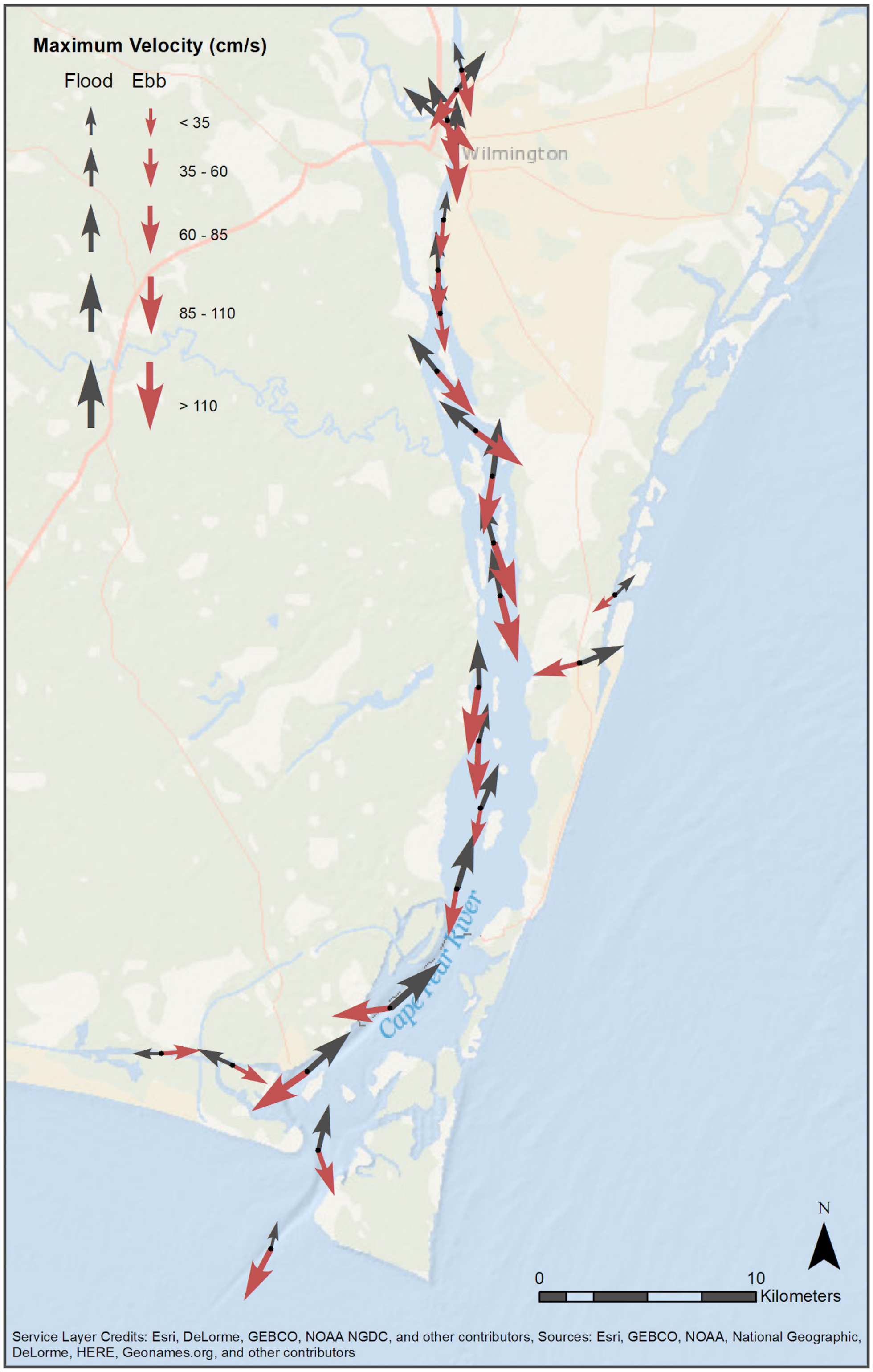


Figure 41. Flood and ebb (near surface) current velocity and direction for each station of the survey.

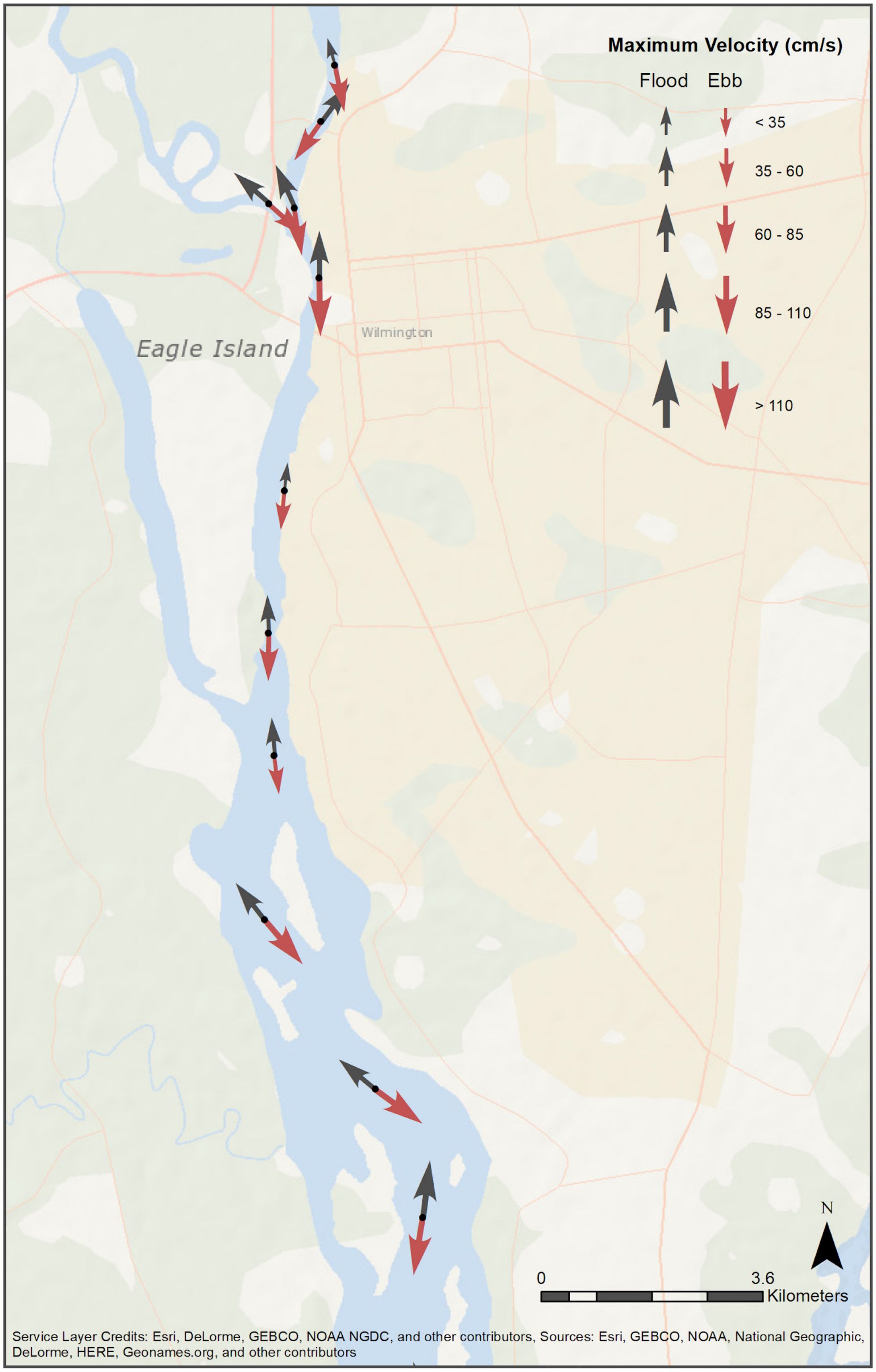


Figure 42. Flood and ebb (near surface) current velocity and direction for stations in the vicinity of Wilmington, North Carolina.

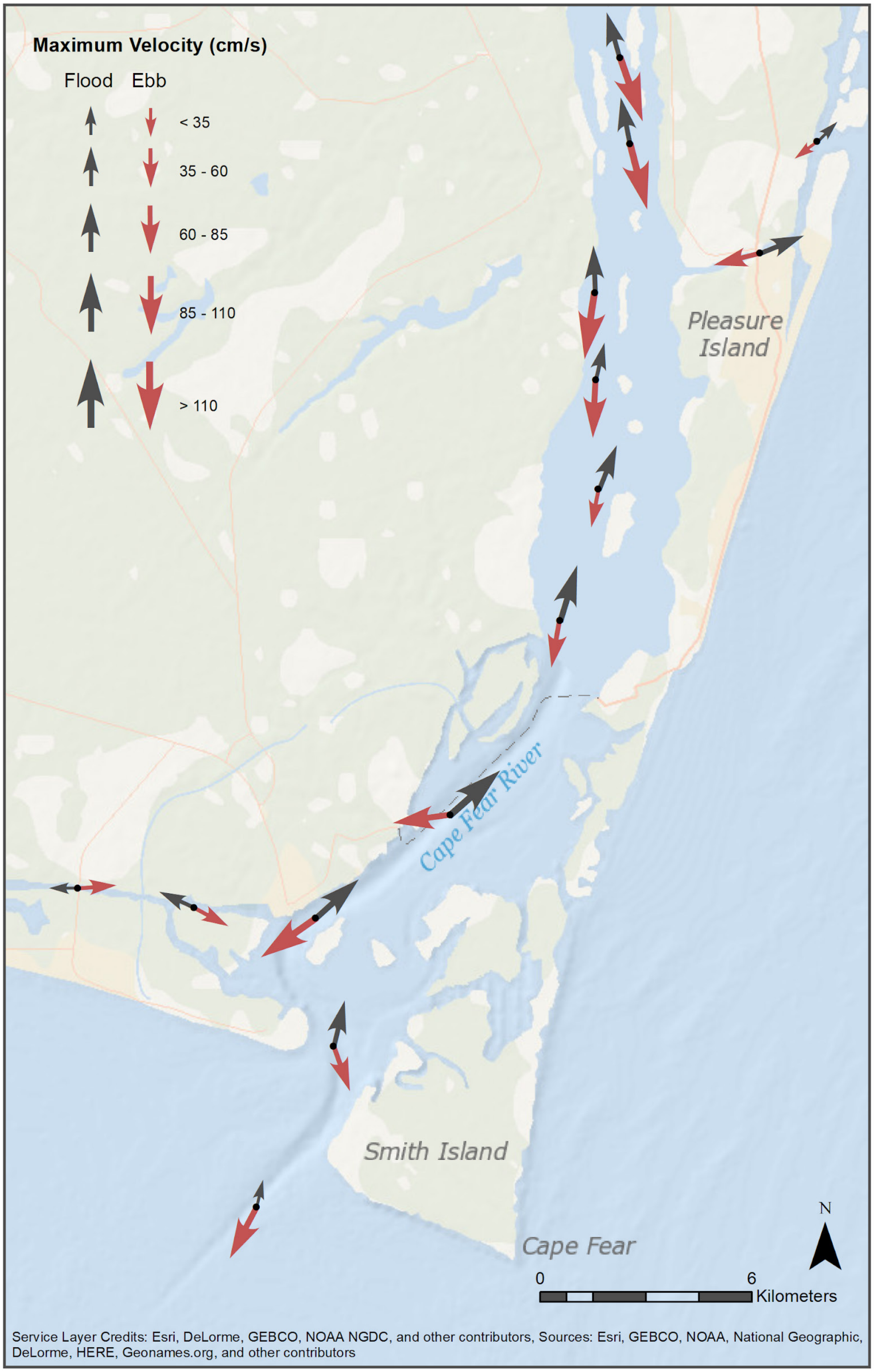


Figure 43. Flood and ebb (near surface) current velocity and direction for stations in the vicinity of the mouth of Cape Fear River.

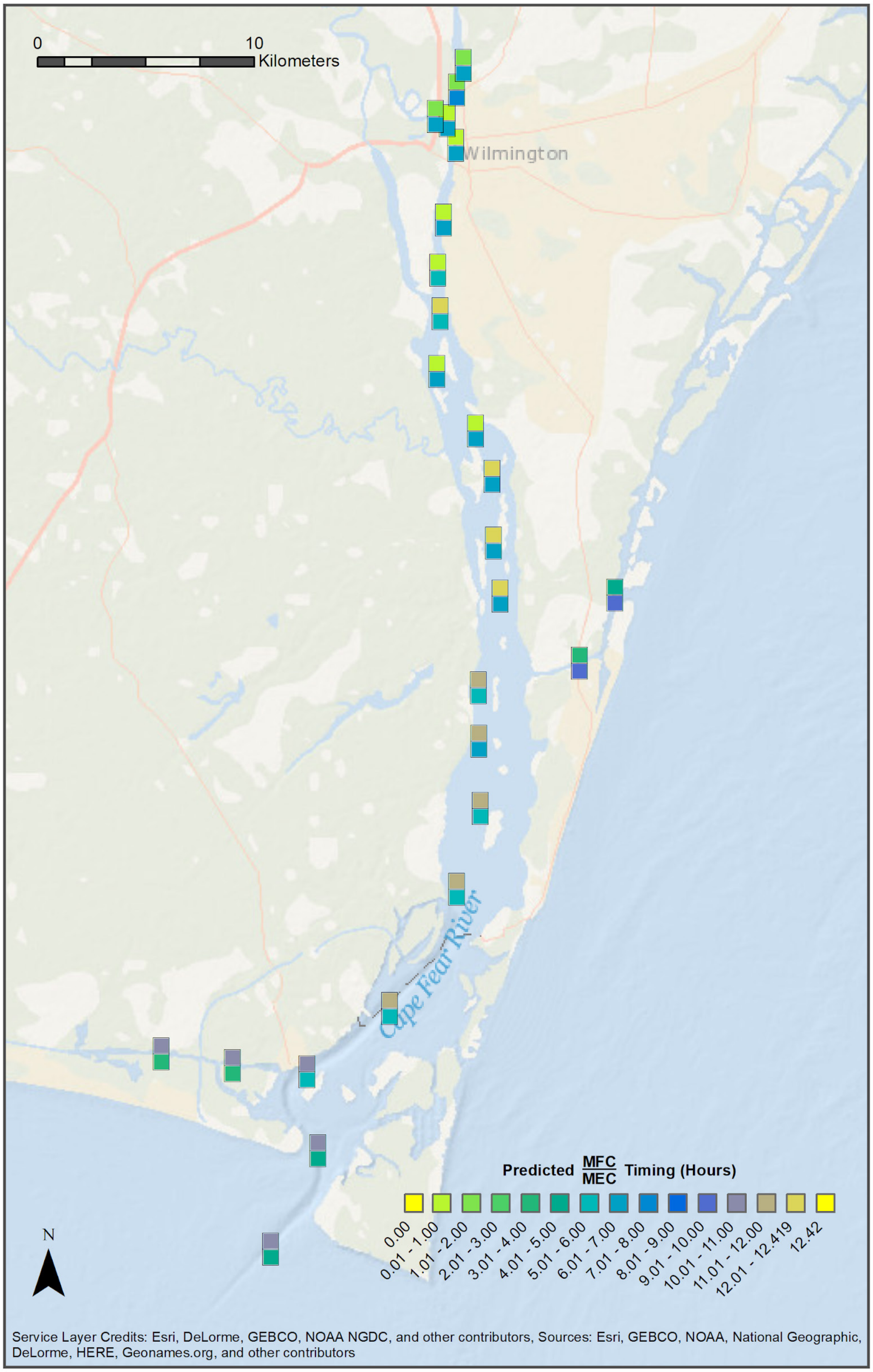


Figure 44. Near-surface GI for each station of the survey. The GI of the MFC is on top and the MEC is on bottom.

8. SUMMARY

CO-OPS NCOP successfully occupied 25 stations from mid-March through June 2016 throughout the Cape Fear River in North Carolina. This included two new reference stations and four stations in the ICW. In addition to the current data obtained by the ADCPs, CTD profiles were collected during deployment and recovery of the ADCP at each station. This current survey resulted in a comprehensive four-month data set of currents, water temperature, salinity, and pressure observations. The tidal currents data were used to update the NOAA Tidal Current Tables helping insure safe and efficient navigation by improving the accuracy of observations and providing a higher density of predictions in the region.

All analyses and plots for the entire time series at all depths are available in detailed station reports by contacting CO-OPS User Services directly (NOAA, 2018b). Updated tidal current predictions for each station are also available online via the NOAA Currents Web interface, and updates were published beginning in the 2018 TCTs. This data set is available to the public and research community to further investigate the circulation of Cape Fear River or aid in safe navigation.

9. ACKNOWLEDGMENTS

We would like to thank CO-OPS colleagues Patrick Burke, Carolyn Lindley, David Lane, Eddie Roggenstein, Rich Edwing, Kirk Glassmire, Seth Moulton, Lacey Barwick, Trent Savage, Jory Bunn, Jack Marshall, Sean Toungate, Kevin Harrison, Max Ivanov, Paul Fanelli, Chris DiVeglio, Rhyan Lange, Surafel Abebe, Mason Casanova, Kiera O'Donnell, and Jill Reddick. Special thanks to Katerina Glebushko for her oversight in the processing of data and Helen Worthington for manuscript editing.

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11. ACRONYMS

ADCP	acoustic Doppler current profiler
ADP	acoustic Doppler profiler
ATON	Aids to Navigation
C	Celsius
cm/s	Centimeters per second
CO-OPS	Center for Operational Oceanographic Products and Services
CTD	conductivity, temperature, and depth
CFR	Cape Fear River
ft	feet
GI	Greenwich Interval
GT	great diurnal tide
ICW	Intracoastal Waterway
kg	kilogram
kHz	kilohertz
km	kilometer
kn	knots also kts in some figures
LSQHA	Least squares harmonic analysis
m	meter
MEC	maximum ebb current
MFC	maximum flood current
MHz	megahertz
MHHW	mean higher high water
MLLW	mean lower low water
MN	mean tide range
MSI	Mooring Systems, Inc.
MTRBM	miniature trawl-resistant bottom mount
NCOP	National Current Observation Program
NM	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
PSU	Practical salinity unit
QARTOD	Quality Assurance/Quality Control of Real-Time Oceanographic Data
R/V	Research Vessel
s	second
SBE	Slack before ebb
SBF	slack before flood
TCTs	(published) Tidal Current Tables
TRBM	trawl-resistant bottom mount
TRDI	Teledyne RD Instruments
USCG	United States Coast Guard