UMERC+METS
2024 Conference

*7-9 August | Duluth, MN, USA*

# Comparative Evaluation of Ocean Current Flow Feature Detection Success based on Data Type within the Florida Straits

Loius DeVito[a], James VanZwieten[a], Yufei Tang[b]

[a]*Florida Atlantic University, Department of Ocean and Mechanical Engineering, 101 North Beach Road, Dania Beach, FL 33441, USA*
[b]*Florida Atlantic University, Department of Electrical Engineering and Computer Science, 777 Glades Road, Boca Raton, FL 33431, USA*

**Abstract**

As the demand for electrical energy increases, it is becoming a necessity to find alternatives to nonrenewable resources due to their eventual depletion and environmental impacts. Therefore, exploiting renewable energy sources to provide electrical energy presents a solution to fulfill this energy demand. One of these renewable energy sources is ocean current energy. Although numerous ocean current resource assessments have been performed, these have focused on quantifying ocean current flow statistics through the direct measurement of ocean currents or numerical models. To understand the flow features more clearly within these currents, it is important to both identify and track them. No concurrence was found within literature regarding the best data sources for conducting such an assessment. Consequently, this paper provides a comparison of detection tools for both ocean eddies and the edges of the Florida Current. Satellite data encompassing sea surface temperature, salinity, height, and chlorophyll-a are evaluated for feature detection, and bottom-mounted acoustic Doppler current profiler (ADCP) datasets are used to measure current velocities throughout the water column to quantify the impacts of identified flow features.

*Keywords:* Ocean Current Resource Assessment; Eddy Detection; Western and Eastern Edges, Feature Detection

## 1. Introduction

Worldwide energy demand continues to accelerate at a rapid pace. According to [1] global energy demand is expected to increase 3.4% annually through the year 2026. The primary sources of electrical energy encompass nonrenewable sources, such as coal, oil, and natural gas. However, there are disadvantages associated with producing electricity from nonrenewable sources because of their finite supply and contribution to greenhouse gas emissions. Due to these inadequacies, harvesting electrical energy from renewable sources has been explored, with one example being ocean current energy. Ocean current energy assessments have been conducted, such as an evaluation done by the Georgia Institute of Technology discovering that up to 13 GW of electrical energy potential can be generated from ocean current energy in the Gulf Stream [2].

Although open ocean currents continuously circulate, they exhibit instabilities that alter their strength and flow directional profiles. Understanding these perturbations is important for harvesting ocean energy as they will impact power production. There are several factors that contribute to these instabilities, including baroclinic and barotropic factors. These instabilities can result in the formation of ocean features, such as meandering characteristics, oceanic gradients sometimes called fingers, and rotational motions called eddies. Some scientific publications reveal general patterns and features within the Florida Current. Customary oceanographic features include meandering flows and small-scale eddies, which are mostly less than 10 kilometers, along the western edge of this current in the Florida Straits [3]. Additionally, [4] noted that upwelling is widespread in the Florida Current due to meandering flows and discovered that such patterns are responsible for the majority of intermittencies amongst factors like ocean temperature. Wind stress is also prevalent in this area with relations to Sverdrup transports, peaking in the months of June, July, and August [5]. Since instabilities in ocean currents like the Florida Current impact surface temperature, height, salinity, and nutrient concentrations, oceanographic data procured from various instruments can be employed to identify features present within the Florida Straits using these properties.

Bottom-mounted ADCPs are useful for quantifying how ocean current speeds alter at a particular location with the progression of time. Sea surface temperature has been implemented in copious studies related to oceanic feature detection. For instance, sea surface temperature data from satellite technology has been illustrated for eddy detection off the Korean Peninsula [6]. The satellites retrieving sea surface temperature information rely upon diverse instruments, including infrared spectroradiometers and sometimes microwave radiometers [7]. Furthermore, there are advantages and disadvantages associated with both kinds of sensors. For instance, one advantage for infrared sensors entails their ability to collect data with high spatial resolutions but they are unable to gather useful information when clouds are present [7]. Conversely, microwave sensors possess the ability to garner sea surface temperature data when clouds are present, but these data are recorded at lower spatial resolutions. A notable limitation for both infrared and microwave technology encompasses their incapability of collecting meaningful data in low bathymetric regions.

Sea surface height and salinity primarily rely upon microwave technology to procure meaningful data. For instance, sea surface height is measured by emitting radar pulses from radar altimeters that reach the ocean surface. Sea surface height can be ascertained by acknowledging the time the radar pulse reaches the ocean surface and is retrieved back to the satellite. There have also been several studies delineating the application of height and salinity for ocean feature detection. For example, the analysis in [8] displayed how sea surface height can be used as well as processed to detect eddies in the Mediterranean Sea. Sea surface salinity has also been extensively reviewed for eddy detection, such as in [9] where worldwide salinity transport was analyzed utilizing observations from two different satellites. Sea surface chlorophyll-a concentrations have also been analyzed in [10] for their usefulness in detecting eddies in the Gulf of Mexico. To help detect features within these datasets, Canny edge detection can be used to identify strong gradients, an approach that is known for its reduction of noisy outputs. Canny edge detectors have been utilized in [11] to observe the western and eastern edges of the Gulf Stream off the coast of North Carolina.

The remainder of this paper is organized as follows. First, the area of interest for ocean current energy projects are identified in Section 2. Next, events of particular interest within this region are identified using bottom mounted ADCP data (Section 3). Then, data sets used for feature detection, feature detection algorithms, and feature detection results are presented in Section 4 for one identified event. Finally, conclusions are presented in Section 5.

## 2. Southeast Florida Area of Interest

The Gulf Stream Current runs along the east coast of Florida and approximately follows the 300-500m depth contour [12]. This current is closest to the coast around 26º N and then intensifies and gradually moves further offshore up to about 27º N. North of this latitude the distance from shore increases significantly and further increases in available energy are minimal. Therefore, targeted regions for ocean current production off Florida typically fall between 26º N and 27º N and therefore feature detection within and upstream from this region are our focus.

Longitude ranges of interest for US based energy production include high energy regions within the Gulf Stream from the center of the current where the highest energy densities are found and slightly westward from the center of the Gulf Stream. The optimal placement of systems will depend on system design and sub-sea cabling cost/challenges, with shallower waters and shorter distances to shore obtained moving westward at a cost of reduced energy production and increased flow variability. Two vessel-mounted ADCP instruments were employed during the Walton Smith research vessel operations along the 27°N transect line traversing the Florida Straits. One ADCP has collected data at an operating frequency of 75 Hz encompassing most of the water column while the other instrument cumulated data at an operating frequency of 600 Hz for sections closer to the surface. Average kinetic energy flux densities of ocean currents in the Florida Straits are evaluated at longitudinal ranges between 79.9º W and 79.2º W. Results have shown the strongest kinetic energy flux densities between 79.98º W and 79.68º W. This range corresponds to approximate total water depth ranges between 200 and 500 meters as well as an approximate distance between 3 and 19 nautical miles from the Florida Coastline.

## 3. Identification of Events of Interest

Ocean current speed data procured from Florida Atlantic University's bottom-mounted ADCPs deployed near the core of the Gulf Stream between 26º N - 27 º N latitude [13]. Measurements are available from a total of seven ADCP deployment locations collectively measuring 4,067 days of data. For this evaluation, preprocessing has been done to remove inaccurate retrievals obtained by the instruments. Certain data is viewed as unpreferable due to factors like sea surface contamination and a correlation of over 64 counts for three or more vertical data bins were removed. After the removal of undesirable data, the raw data is analyzed based on flow speeds detected from the instruments. These measurements recorded current speeds between the years 2009 and 2017 at a depth of 75 m, with a summary of unusually strong or weak currents within the Florida Current provided by [13]. In this study, speeds are examined at depths of around 75 meters to avoid contaminated data from the sea surface. For instance, one of the bottom-mounted ADCP instruments detected a weak current of 0.135 m/s at a depth of approximately 75 meters on May 25, 2012. Satellite data from this day is subsequently analyzed with feature detection tools in Section 4 to possibly identify a unique ocean feature corresponding to this weak current.

## 4. Flow Feature Detection

### *4.1. Utilized Data Sets*

Due to some of the aforementioned shortcomings involving the technology utilized to collect sea surface temperature data, products that contain sea surface temperature measurements from several sources are preferable. For this study, the Multi-scale Ultra-high Resolution sea surface temperature analysis is employed [14]. Datasets from this source contain a spatial resolution of 0.01º x 0.01º and a daily temporal resolution. These datasets are level 4 products, meaning that gridded data has been further preprocessed to remove possible gaps in the raw data and methodologically combine observations from multiple technological sources. The various forms of technology used, such as infrared sensors on NASA's Aqua MODIS satellite, microwave sensors on the NASA Advanced Scanning Radiometer-EOS satellite, and in-situ technology from buoys associated with the iQuam project. Raw sea surface temperature measurements are taken at nighttime to remove biases from diurnal warming. To effectively combine the temperature observations from the various sources, optimal interpolation is applied.

Sea surface height anomaly data utilized in this study has been procured by the Copernicus Marine Environment Monitoring Service (CMEMS) database [15]. Sea surface height anomaly datasets contain a spatial resolution of 0.25º x 0.25º spatial resolution in conjunction with a daily temporal resolution. Furthermore, the sea surface height anomaly data are regarded as level 4 products with raw data collected from multiple satellites, including the Envisat, CryoSat-2, and Sentinel-3 satellites. With measurements from multiple satellites, the coverage of data obtained from the radar technology is substantially improved. The datasets have been preprocessed to provide the anomalies of sea surface height, which means that the sea surface height values in each grid are subtracted by the mean value of all sea surface height quantities. Optimal interpolation is also employed to the datasets to reduce possible gaps present within the raw data and effectively combine the measurements that were taken from all the satellites.

Sea surface salinity intermittencies in this study have also been evaluated utilizing data from CMEMS [16]. Sea surface salinity data have a spatial resolution of 0.125º x 0.125º and a daily temporal resolution. These datasets are also level 4 products that contain sea surface salinity measurements from copious sources, such as the Soil Moisture Ocean Salinity (SMOS) satellite from the ESA and the Soil Moisture Active Passive (SMAP) satellite from NASA. Data collected from these satellites undergoes an optimal interpolation algorithm to combine the measurements taken from the different satellite technologies. The primary technology that these satellites employ to garner sea surface salinity data are microwave radiometers. Additionally, in-situ technology is employed to assist in gathering measurements near coastal areas with high variability in tidal mixing.

Sea surface chlorophyll-a concentrations in this study have been examined with data from CMEMS [17]. Analogous to the datasets relevant to temperature, height, and salinity, the sea surface chlorophyll-a concentration data analyzed is a level 4 product combining satellite and in-situ technology. These datasets contain a spatial resolution of 0.25º x 0.25º and a daily temporal resolution. After quality control procedures are completed, such as masking out contaminated data due to the presence of clouds and aerosols, raw data is assimilated for the purpose of effectively combining all the observations from the technology mentioned priorly.

### *4.2. Procedural Steps Regarding Data Evaluation*

Sea surface temperature perturbations are analyzed by first removing error values from the raw sea surface temperature data. Additionally, raw sea surface temperature is multiplied by the scale factor at which the data is collected. Supplementary procedures include adding an offset value specified in the dataset file to the raw data and converting the raw sea surface temperature from Kelvin to degrees Celsius. Latitude and longitude variables associated with the sea surface temperature data are of different sizes. Due to disparities in the variable sizes pertaining to latitude and longitude, the sea surface temperature data has been re-gridded to produce a rectangular grid displaying the variations in sea surface temperature with a latitudinal range from 22º N to 27º N and longitudinal range from 77º W to 81º W. Then, sea surface temperature data are incorporated on a cartographic diagram to show the intermittencies with respect to latitude and longitude locations. Areas consisting of land masses have been displayed in white to distinguish the land and sea boundaries.

To analyze sea surface height anomalies, error values within the raw data are removed and the raw data is multiplied by a scale factor listed in the dataset file. Although the sea surface height anomaly data has already been gridded, the analyzed data had to be re-gridded because the variables regarding latitude, longitude, and height anomalies are of disparate sizes. Then, sea surface height anomaly data is illustrated with respect to latitude and longitude on a cartographic plot displaying the location encompassing the Florida Current. The respective data was displayed within a specified range relating to anomaly values to effectively capture small-scale variations.

For evaluating sea surface salinity, the first step entails removing error values in the raw data. Sea surface salinity data is provided in units of parts per thousand and like the sea surface height anomaly data, sea surface salinity values are re-gridded due to the latitude, longitude, and salinity values being different sizes.

To evaluate sea surface chlorophyll-a concentrations, error values are first removed and units for chlorophyll-a concentrations in milligrams per cubed meter have been maintained. As done with the previous forms of satellite data, sea surface chlorophyll-a data has been re-gridded to account for disparities in sizes relating to the variable's latitude, longitude, and chlorophyll-a concentrations in the datasets.

Other resources that have been employed include a Canny edge detector. In this study, the Canny edge detector has been applied by first applying a Gaussian blur filter to the output data by setting a specific standard deviation associated with the filter. Then, the Canny edge detector is used to detect the locations on the cartographic diagrams with the largest gradients in the pixels that make up the output.

### *4.3. Feature Detection Results*

Figure 1 shows sea surface temperature (left-top), height anomalies (tight-top), salinity (left-bottom), and chlorophyll-a (right-bottom) maps for May 25, 2012. In each map "x" designates the bottom-mounted ADCP that recorded the abnormally slow current speed with a minimum flow speed of 0.135 m/s at 9:50 PM on this day and had been around 0.5 m/s in the 2 days prior from May 23, 2012, to May 24, 2012. Near the location of the bottom-mounted ADCP, the sea surface temperature dataset seems to portray temperature disparities that differ by approximately 1º C. The temperature surrounding the bottom-mounted ADCP location maintains a temperature close to 27º C, while the northern and southern edges of the Florida Current comprise of a temperature around 26º C. This would be indicative of a warm-core eddy traversing through the Florida Current.

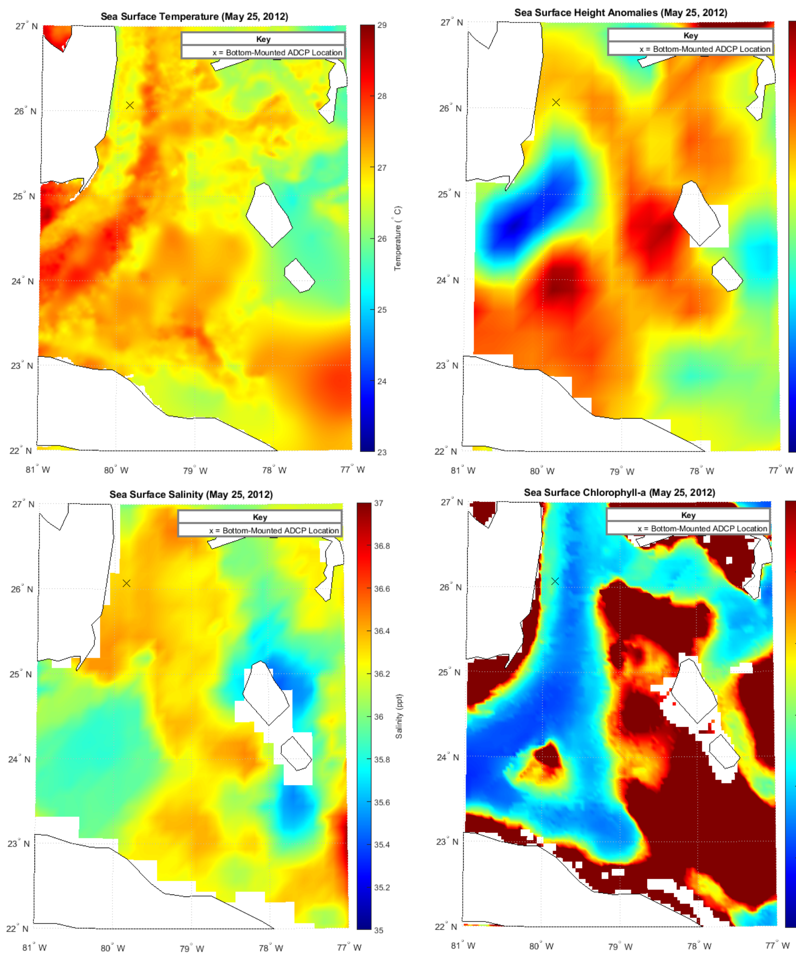


*Figure 1: Representations of satellite data procured on May 25, 2012.*

The sea surface height anomaly data does not seem to indicate the presence of a particular ocean feature near the location of the bottom-mounted ADCP. However, there are significant anomalies between the 26º N and 26.8º N latitude transects in the Florida Current. Throughout this section of the Florida Current, the height anomalies seem to increase by approximately 0.05 m. Although some unique observations are shown, such as disparities in height anomalies that are present downstream and upstream, there is no clear feature detected to cause such an unusually slow current speed. The sea surface salinity data shows copious variations throughout the Florida Current as well as off the coast of the Bahamas. However, these variations are not as extreme since this data is scaled between 35 and 37 parts per thousand. Although the sea surface salinity data illustrates some intermittencies near the location of the bottom-mounted ADCP, there is not a clear distinction regarding the possibility of a small-scale eddy or other oceanographic feature being responsible for such a slow current speed.

The sea surface chlorophyll-a concentrations show clear distinctions between the western and eastern edges of the Florida Currents, with lower bathymetric regions closer to the coast containing concentrations of 0.3 milligrams per cubed meter or greater. Conversely, the Florida Current mostly maintains a chlorophyll-a concentration of 0.05 milligrams per cubed meter or less. Near the location of the bottom-mounted ADCP, there does seem to be small perturbations closely matching the description of small-scale eddies. Furthermore, the western edge of the Florida Current seems to be extended more eastward, reaching an offshore distance at a longitude of approximately 79.7º W. Analogously to the sea surface temperature data, the sea surface chlorophyll-a concentration depiction displays small-scale features clearly. One primary reason for this is that height and salinity data are limited with respect to their spatial resolutions. Another factor involves the differences in technology used, such as the infrared sensors that were used for the temperature and chlorophyll-a data as opposed to microwave technology for the height and salinity data.

For visualizing the western and eastern edges of the Florida Current more descriptively, Figure 2 shows two outputs of sea surface temperature data with the Canny edge detector results on two disparate days. To clarify, the sea surface temperature datasets utilized in conjunction with the Canny edge detector are derived from the same database mentioned in subsection 4.1. One of the days corresponds to the unusually slow moving current and the other day was arbitrarily selected as March 1st of 2023 as it is not a day when an extreme event has been recorded by an ADCP instrument. The Canny edge detector has been applied to sea surface temperature data since the temperature data contains a high spatial resolution and is most effective at observing data in low bathymetric regions. There are fascinating observations regarding how the Canny edge detector captures the boundaries of the Florida Current. The edges are not as clearly defined on May 25, 2012, due to several large gradients in the sea surface temperature. For instance, the Canny edge detector shows the western edge of the Florida Current at a longitude of around 79.7º W, which is also shown from the sea surface chlorophyll-a data. However, the Canny edge detector captures another significant temperature gradient around 79.9º W. Similarly, the eastern edge of the Florida Current does not show a consistent boundary. For example, the Canny edge detector displays the eastern edge of the Florida Current around 79.3º W. However, the Canny edge detector also detects boundaries within the Florida Current where higher temperatures are present. This output from the Canny edge detector provides a striking contrast with the output from March 1, 2023. On this day, the Canny edge detector captures a clear boundary between 79.8º W and 79.9º W at the western edge of the Florida Current. In addition to this, the Canny edge detector displays a well-defined boundary between 79º W and 79.2º W. In both cases, the Canny edge detector illustrates how the eastern edge of the Florida Current is further eastward at higher latitudes. Additionally, both outputs display how the eastern edge branches off eastward near the Bahamas between the latitudes 25.7º N and 26.2º N.

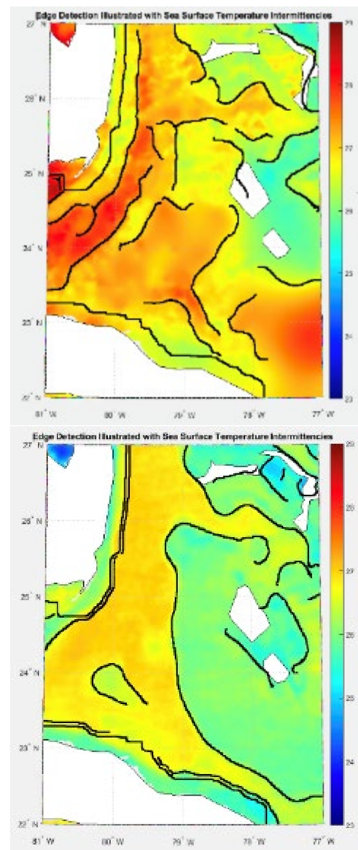


Figure 2: SST with edge detection showing western and eastern edges of the Florida Current on May 25, 2012 (top) and on March 1, 2023 (bottom).

## 5. Conclusion

This study employs copious tools to detect ocean features while conducting an ocean current energy resource assessment of the Florida Current. Bottom-mounted ADCPs assist in providing insight into when abnormal oceanic events occur. As for the comparison amongst satellite data, sea surface temperature and chlorophyll-a concentrations detect small-scale features like small-scale eddies and meandering characteristics superior to sea surface height and salinity in this region. The main factor for this disparity arises from the form of technology used and the higher spatial resolutions from sea surface temperature data. Additionally, meandering characteristics are further analyzed using a Canny edge detector to better understand flow characteristics along the western and eastern edges of the Florida Current. Our findings show the eastern edge maintains higher variability when compared to the western edge. Future tasks include implementing WERA and CODAR high-frequency radar data to this analysis for ocean current prediction and feature detection and incorporating additional tools for verifying small-scale oceanic features in the Florida Current.

**Acknowledgements**

This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the Water Power Technologies Office (WPTO) Award Number DE-EE0011382. This work was also supported in part by the Florida Power & Light (FPL) Center of Intelligent Energy Technologies (InETech).

**References**

[1] International Energy Agency, Executive Summary, *IEA*; 2024.
[2] Yang X, Haas, KA, Fritz HM. Theoretical Assessment of Ocean Current Energy Potential for the Gulf Stream. *Marine Technology Society Journal*; 2013.
[3] Kourafalou V-H, Kang H. Florida Current meandering and evolution of cyclonic eddies along the Florida Keys Reef Tract: Are they interconnected? Vol. 117. *Journal of Geophysical Research*; 2012.
[4] Jiang M, Alsenas G, Busold E, Farrington S, Reed J. Short-terms variability of water properties and phytoplankton blooms along the central eastern Florida shelf edge. *Deep-Sea Research I*; 2024.
[5] Rousset C, Lisa B-M. On the seasonal variability of the currents in the Straits of Florida and Yucatan Channel. Vol. 116. *Journal of Geophysical Research*; 2011.
[6] Woo H-J, Park K-A. Inter-Comparisons of Daily Sea Surface Temperatures and In-Situ Temperatures in the Coastal Regions. *Remote Sensing*; 2020.
[7] Ricciardulli L, Wentz FJ. Uncertainties in sea surface temperature retrievals from space: Comparison of microwave and infrared observations from TRMM. *Journal of Geophysical Research*; 2004.
[8] Aguiar E, Mourre B, Reyes E, Hérnandez-Lasheras J, Cutolo E, Mason E, Tintoré J. Multi-platofrm model assessment in the Western Mediterranean Sea: impact of downscaling on the surface circulation and mesoscale activity. *Springer Nature*; 2019; 70:273-288.
[9] Melnichenko O, Hacker P, Müller V. Observations of Mesoscale Eddies in Satellite SSS and Inferred Eddy Salt Transport. *Remote Sensing*; 2021.
[10] Li G, Wang Z, Wang B. Multidecade Trends of Sea Surface Temperature, Chlorophyll-a Concentration, and Ocean Eddies in the Gulf of Mexico. *Remote Sensing*; 2022.
[11] Banesh D, Peterson MR, Ahrens J, Turton TL, Samsel F, Schoonover J, Hamann B. An Image-Based Framework for Ocean Feature Detection and Analysis. *Springer Nature*; 2021.
[12] Sadoughipour M, VanZwieten J, Tang Y, Almeida L. Measurement-Based Global Ocean Current Energy Resource Assessment. *University Marine Energy Research Community*; 2023.
[13] DaSilva M, DeVito L, VanZwieten J, Tang Y. Evaluation of Flow Features Responsible for Extreme Events at a Potential Ocean Current Energy Extraction Location within the Gulf Stream. *University Marine Energy Research Community*; 2024.
[14] GHRSST Level 4 MUR Global Foundation Sea Surface Temperature Analysis (v4.1). Jet Proulsion Laboratory; California Institute of Technology; Physical Oceanography Distributed Active Archive Center; Dataset accessed: [2012-05-25] and [2023-03-01]; Available: https://podaac.jpl.nasa.gov/dataset/MUR-JPL-L4-GLOB-v4.1
[15] Global Ocean Gridded L 4 Sea Surface Heights And Derived Variables Reprocessed 1993 Ongoing. Copernicus Marine Service; https://data.marine.copernicus.eu/product/SEALEVEL_GLO_PHY_L4_MY_008_047/services
[16] Multi Observation Global Ocean Sea Surface Salinity and Sea Surface Density. Copernicus Marine Service; https://data.marine.copernicus.eu/product/MULTIOBS_GLO_PHY_S_SURFACE_MYNRT_015_013/services
[17] Global Ocean Colour (Copernicus-GlobColour), Bio-Geo-Chemical, L4 (monthly and interpolated) from Satellite Observations (1997-ongoing). Copernicus Marine Service; Dataset accessed: [2012-05-25]; Available: https://data.marine.copernicus.eu/product/OCEANCOLOUR_GLO_BGC_L4_MY_009_104/services