Surface currents in Raritan Bay, New Jersey: Importance of HF radar first-order Doppler settings

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A surface current observation system based on high-frequency Coastal Ocean Dynamics Application Radar (CODAR) has been developed for Raritan Bay and the coastal waters of New York and New Jersey. This unique oceanographic tool is capable of measuring currents and waves at the ocean surface using resonant Bragg scatter return from transmitted radio signals. Surface current is measured by analysing the high-frequency (HF) radar sea-echo for the Doppler frequency shift where the frequencies of the first-order (FO) Doppler peaks that separate the surface current reflectance from the higher-order receiver signals are empirically determined. The presence of strong currents and horizontal shear in the near-surface flow results in spreading of the FO Doppler region, making it difficult to distinguish FO Doppler peaks from higher-order signals.

Differentiating the FO Doppler region using empirical frequency cut-off parameters is one of the important steps in spectral processing of the HF radar receiver signals. The present work focuses on the surface current circulation in Raritan Bay and the New York Bight (NYB) Apex using HF radar observations, and to understand the importance of empirical determination of the FO Doppler region of the HF radar system in a strong, tidally dominated estuarine-ocean circulation.

Comparison of HF radar observations with historic mooring observation and three-dimensional ocean model simulation shows that the HF radar system is highly sensitive to FO Doppler region settings. Strong tidal currents and wave-current interaction introduces spreading of the FO Doppler spectrum which results in underestimation of surface currents near the mouth of the New York/New Jersey (NY/NJ) harbour estuary.

AUTHORS' BIOGRAPHIES

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INTRODUCTION

The coastal ocean is being studied by oceanographers with a focus on maritime security, growth and balance of the marine eco-system, recreation, beach erosion, and maritime safety. The combined system of rivers, estuaries and continental shelf waters represent a complex hydrodynamic environment, governed by astronomical tides, surface meteorology (wind, heat and salt fluxes), river discharge, geophysical variability (Ekman drift, Stokes drift, and baroclinicity), bottom topography, earth rotation, and large scale ocean circulation. Ocean currents are one of the critical parameters in coastal oceanography, responsible for the various physical and dynamic processes in the coastal zone. They are important in terms of vessel navigation, search and rescue operations, heat and mass transport, plankton ecology, ocean circulation and mixing processes.

High frequency (HF) radar has emerged as one of the important technologies in the ocean observation system. It provides a unique land-based ocean observation platform which is capable of dynamically mapping near-surface ocean currents. The HF radar system works on the principle of radio wave backscatter by ocean surface gravity waves in the frequency band 3~30MHz, and provides surface current maps in near real-time over a spatial scale of the O(200km), depending upon the transmitting frequency.[1,2,3,4] A good general overview of HF radar systems and a selection of results with specific applications have been presented.[2]

The hydrodynamic circulation in Raritan Bay and the New York Bight (NYB) Apex are interlinked with the estuarine circulation of the New York/New Jersey (NY/NJ) harbour estuary, and large scale continental shelf circulations of the NYB and the Middle Atlantic Bight (MAB). The circulation in the NY/NJ harbour estuary is driven by the tides with predominant semi-diurnal (M_2) variability; other processes that affect the hydrodynamic circulation include fresh water outflow from the Hudson River and Raritan River, and surface winds including sea-breeze and land-breeze effects. Since direct measurement of the strong tidal circulation in a spatio-temporal scale is not practically feasible, novel shore-based HF radar can be utilised to remotely measure and monitor surface current circulations in the NY/NJ harbour estuary. This present work is an attempt to study the estuarine circulation in Raritan Bay and the NYB Apex using HF radar surface current measurements in conjunction with a three-dimensional ocean circulation model - the New York Harbour Observation and Prediction System (NYHOPS). This work also attempts to understand the problems associated with the empirical determination of the first-order (FO) Doppler region of the HF radar system in the presence of a strong tidal circulation.

This paper describes the HF radar network used in the present study with a brief discussion of the FO Doppler regions settings of HF radar system, and then compares the radar observations with historic mooring observations and with NYHOPS model simulations. Surface current circulation in Raritan Bay from HF radar observations is then presented, followed by summary and general conclusions.

HIGH FREQUENCY RADAR NETWORK

A HF radar network using Coastal Ocean Dynamics Application Radars (CODAR) has been established in Raritan Bay, the waters of the NY/NJ harbour and the NYB Apex. CODAR consists of compact and collocated antennas[1] and works on a direction finding (DF) algorithm patented as multiple signal classification (MUSIC).[5] Over the past two decades, HF radar has emerged as one of the important

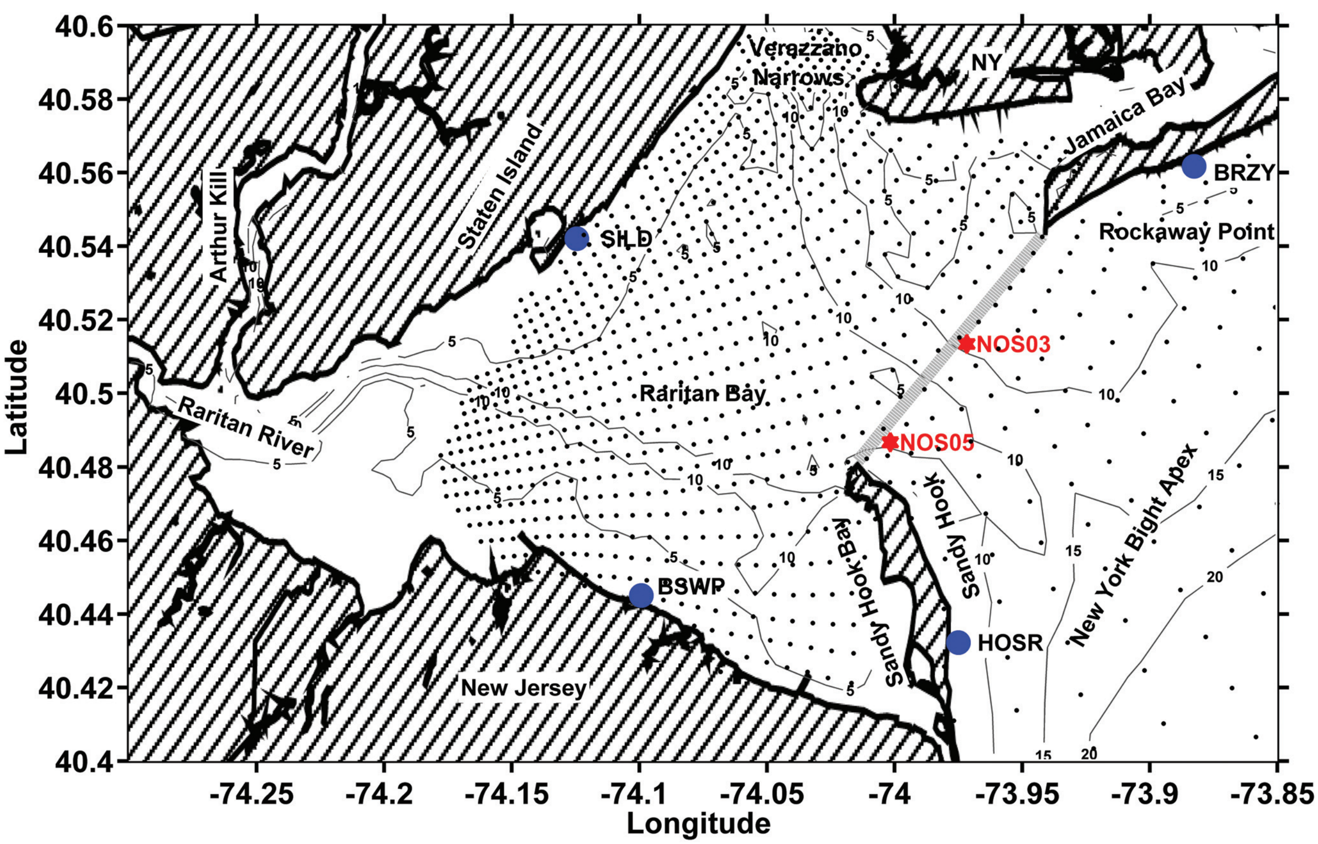


Fig 1: Location map showing the present study domain. Blue circles marks the four monostatic standard-range CODAR SeaSonde stations. Red star marks the two National Ocean Service mooring stations,[11] dashed gray line indicates the Sandy Hook-Rockaway Point (SHRP) transect. HF radar data footprint is shown by black dots. Contour lines indicate the water depths in metres, HF radar data points with temporal data coverage greater than 50% were only used in this study

oceanographic observation tools capable of measuring near-surface ocean currents over a spatial range of O(200km). HF radar works on the principle of radio wave backscatter by ocean surface gravity waves and the surface current is measured by analysing the sea-echo for the Doppler frequency shift (Δf) contributed by the ocean currents. The Doppler frequency shift is measured by analysing the sea-echo for the FO Doppler peaks that separate the surface current reflectance from higher-order receiver signals. The HF radar network employed in this study consists of four monostatic standard-range CODAR SeaSonde systems, located at Sandy Hook, NJ [HOSR: owned and operated by Rutgers University (RU)]; Breezy Point, NY [BRZY: owned and operated by RU]; Bayshore Water Front Park, NJ [BSWP: mobile system, owned and operated by National Ocean Atmospheric Administration (NOAA)]; and on the south shore of Staten Island, NY [SILD: owned and operated by Stevens Institute of Technology (SIT)]. The HF radar sites and the present study domain are shown in Fig 1.

The HF radar system works on the underlying assumptions of linear wave theory and deep water conditions. A single HF radar site measures only the radial component of the surface current with predominant Bragg scatter return. The HF radar system maps the radial component of the surface current with respect to spatial domain defined by a polar coordinate system. The spatial domain is divided into annular bins called range cells (~1.5km, for standard-range CODAR SeaSonde) extending circularly from the HF radar site as the origin, and the azimuth ranges from 0°~360°, incremented at every 5°. The total vector field of the surface currents is computed by combining the radial vectors measured by individual HF radar sites. This computation of the total vector field from the radial vectors follows a suggested method of least squares.[6] A minimum of two or more radial vectors measured by the spatially separated HF radar sites, with at least one radial vector from each of the two different HF radar sites, were combined to obtain the total surface current field. Surface currents measured using HF radar are near-surface depth averaged (d~0.5m, for standard-range CODAR SeaSonde) and the depth of influence is a function of the transmitting frequency of the HF radar system.[7]

In the present study, radial vector fields generated by the four HF radar sites were combined with respect to a pre-defined grid using the least squares method to generate the total vector field. The grid used to create the total vector field was based on that of NYHOPS (http://stevens.edu/maritimeforecast).[8] The HF radar network provided good coverage of surface currents in NY harbour, Raritan Bay and the NYB Apex, with a temporal resolution of 30 min.

One of the quality control measures used in the HF radar total vector processing is the geometric dilution of precision (GDOP), which is defined as the spatial error associated with geometric combination of the radial vectors.[9,4] The GDOP error increases with the distance from the HF radar stations and reaches a maximum along the periphery of the HF radar data footprint, and along the baseline (line connecting the HF radar stations). In order to improve the HF radar data quality, the present study used a GDOP error threshold value of less than 1.5cm s^{-1}, and the maximum radial and total current magnitudes were limited to 1.5m s^{-1}. Another quality control measure used in the HF radar total vector processing is the temporal data coverage threshold, where HF radar data with a temporal data coverage threshold value of greater than 50% were only used in this study. The HF radar data footprint for the period of Jan–April 2007 and the bathymetric contours are shown in Fig 1.

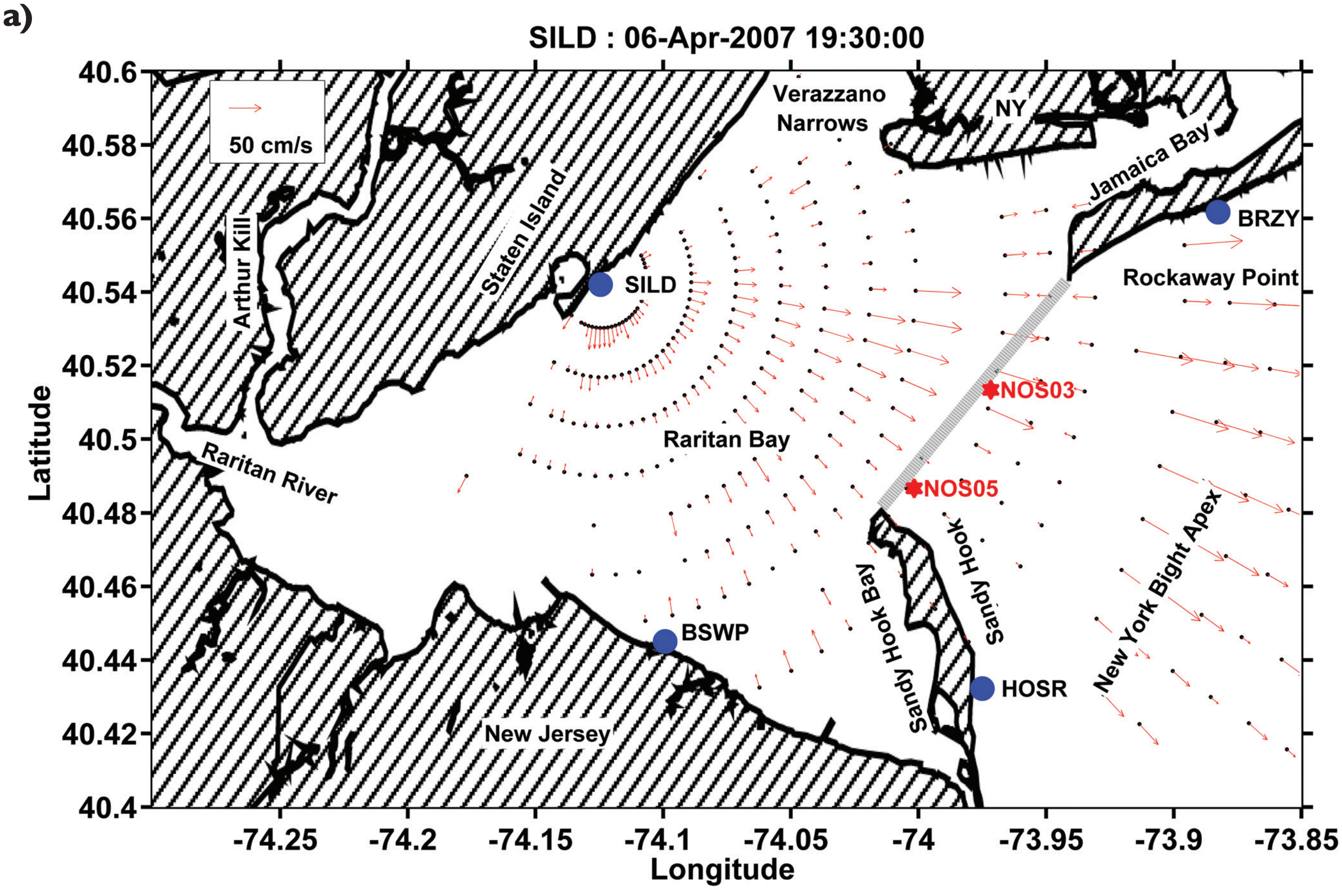
First-order Doppler region settings of the HF radar

The empirical determination of the frequencies of FO Doppler peaks which defines the Bragg scatterance is important in the HF radar (CODAR) spectral analysis. The FO Doppler peaks are separated from the higher-order signals by well-defined minima which are referred as 'nulls'.[10] The first-order peaks of the HF radar return signal represent the energy contribution from near-surface ocean currents, whereas the higher-order peaks represent the energy contribution from ocean surface waves. The FO Doppler peak settings of the frequency cut-off parameters is important for the accurate measurement of surface current vectors. A higher FO frequency setting will result in erroneous current vectors due to inclusion of higher-order spectral energy while a lower FO frequency setting will result in the elimination of good data. The empirical FO frequency settings of the 'nulls' are highly sensitive to the local oceanographic circulation. Occurrence of extremely strong currents and horizontal shear in the near-surface water column will result in spreading of the FO Doppler region over the surrounding higher-order spectrum.[10] The FO Doppler region settings of the HF radar need to be precisely defined in a tidally dominated region in order to capture the high energy tidal currents.

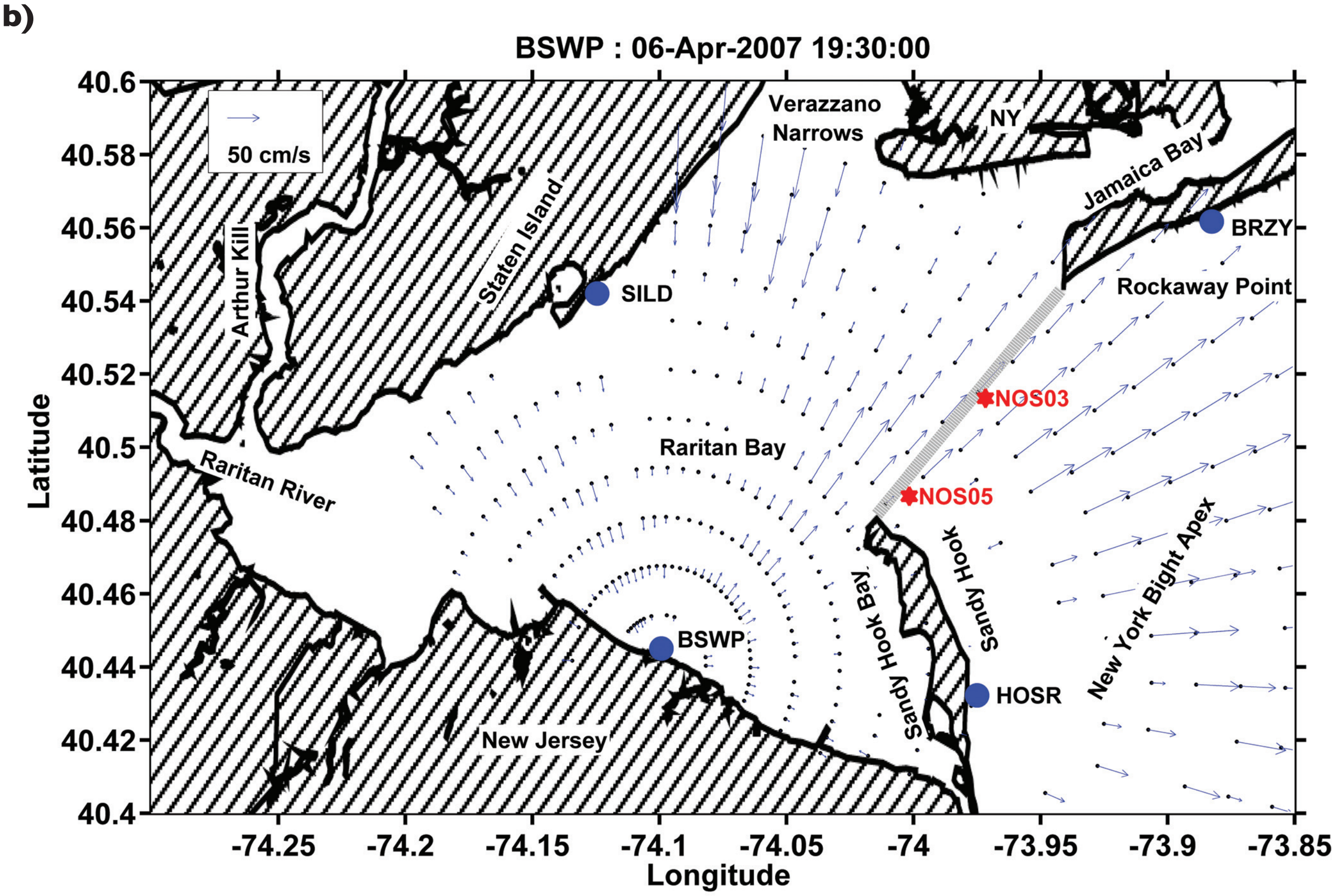
Out of the four HF radar stations in the HF radar network, two of them, Staten Island (SILD) and Bayshore Water Front Park (BSWP) are directed towards areas of extremely strong tidal currents[11] of 1~2m s^{-1} near the mouth of the NY/NJ harbour estuary – known as the Sandy Hook-Rockaway Point (SHRP) transect, as shown in Fig 1 – and at the Verazzano Narrows. The SHRP transect falls at the 10th range cell from the SILD site and the Verazzano Narrows falls at the 12th range cell from the BSWP site. A careful analysis of the SILD HF radar sea-echo revealed that the presence of strong tidal currents across the SHRP transect results in spreading of the FO Doppler spectrum (not shown), which occurs especially during the period of strong ebb tide when the buoyant Hudson River plume flows out into the Atlantic Ocean.

The topographic features of deeper channels as well as the geographic constriction at the SHRP transect and the Verazzano Narrows results in a strong tidally dominated estuarine-ocean circulation. These strong tidal flows with a predominant semi-diurnal (M_2) variability across the SHRP transect and the Verazzano Narrows get intensified during ebb tide as the Hudson River plume flows out as a jet into the Atlantic Ocean. Since the FO Doppler settings of the HF radar system remains the same for all range cells, the SILD site and BSWP site fail to capture these strong tidal energies across the SHRP transect (at range cell 10 from SILD station) and the Verazzano Narrows (at range cell 12 from BSWP station).

The total vector field computed by combining the radial vectors from the two HF radar sites (SILD and BSWP) exhibited an unusual flow pattern at the SHRP transect, a)


SILD : 06-Apr-2007 19:30:00
50 cm/s
Verazzano Narrows
NY
Jamaica Bay
BRZY
Rockaway Point
Staten Island
Arthur Kill
SILD
NOS03
NOS05
Raritan Bay
Raritan River
Sandy Hook Bay
Sandy Hook
New York Bight Apex
BSWP
HOSR
New Jersey
Latitude
Longitude
40.6
40.58
40.56
40.54
40.52
40.5
40.48
40.46
40.44
40.42
40.4
-74.25
-74.2
-74.15
-74.1
-74.05
-74
-73.95
-73.9
-73.85

b)


BSWP : 06-Apr-2007 19:30:00
50 cm/s
Verazzano Narrows
NY
Jamaica Bay
BRZY
Rockaway Point
Staten Island
Arthur Kill
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NOS05
Raritan Bay
Raritan River
Sandy Hook Bay
Sandy Hook
New York Bight Apex
BSWP
HOSR
New Jersey
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Longitude
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40.56
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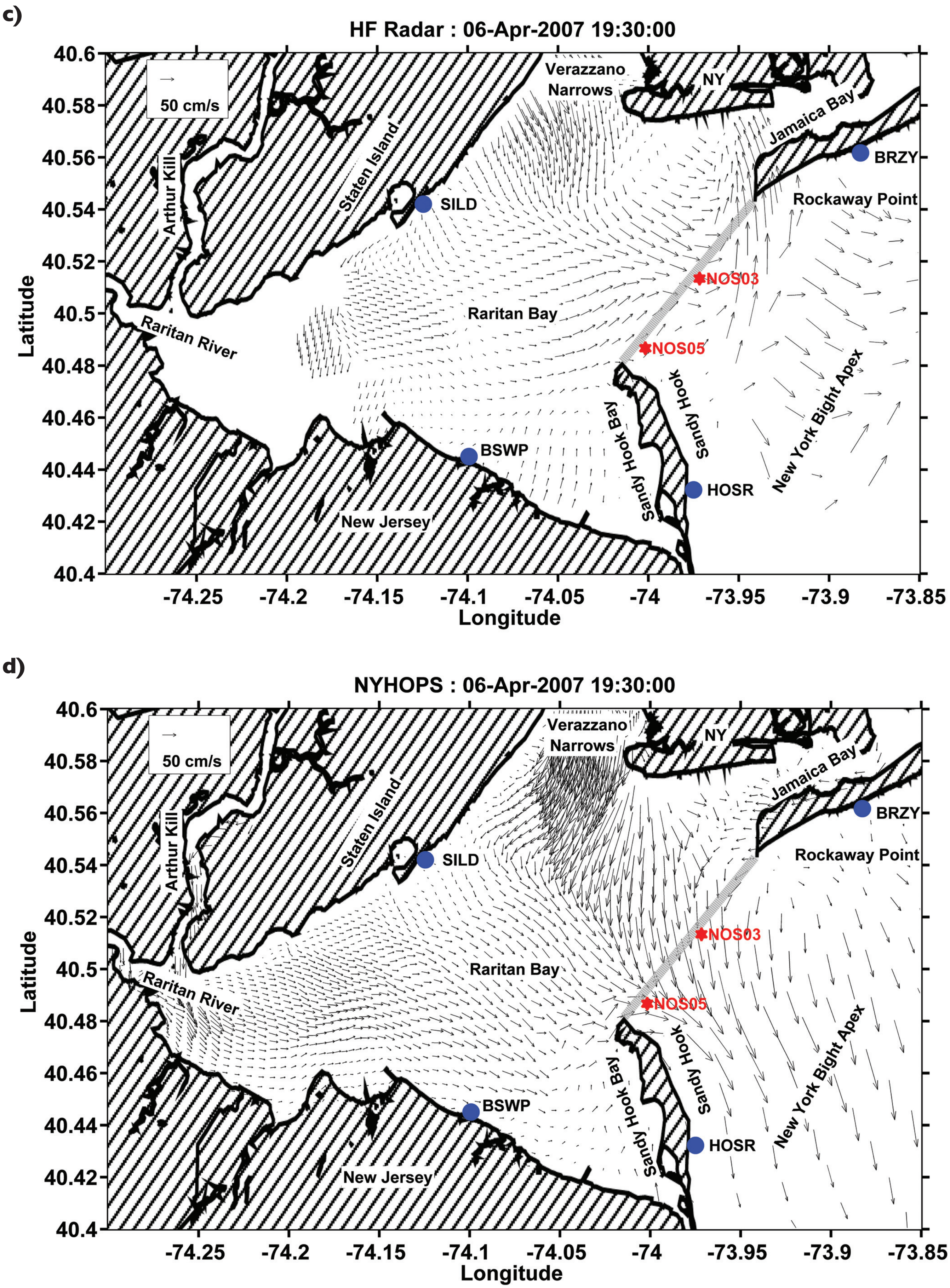
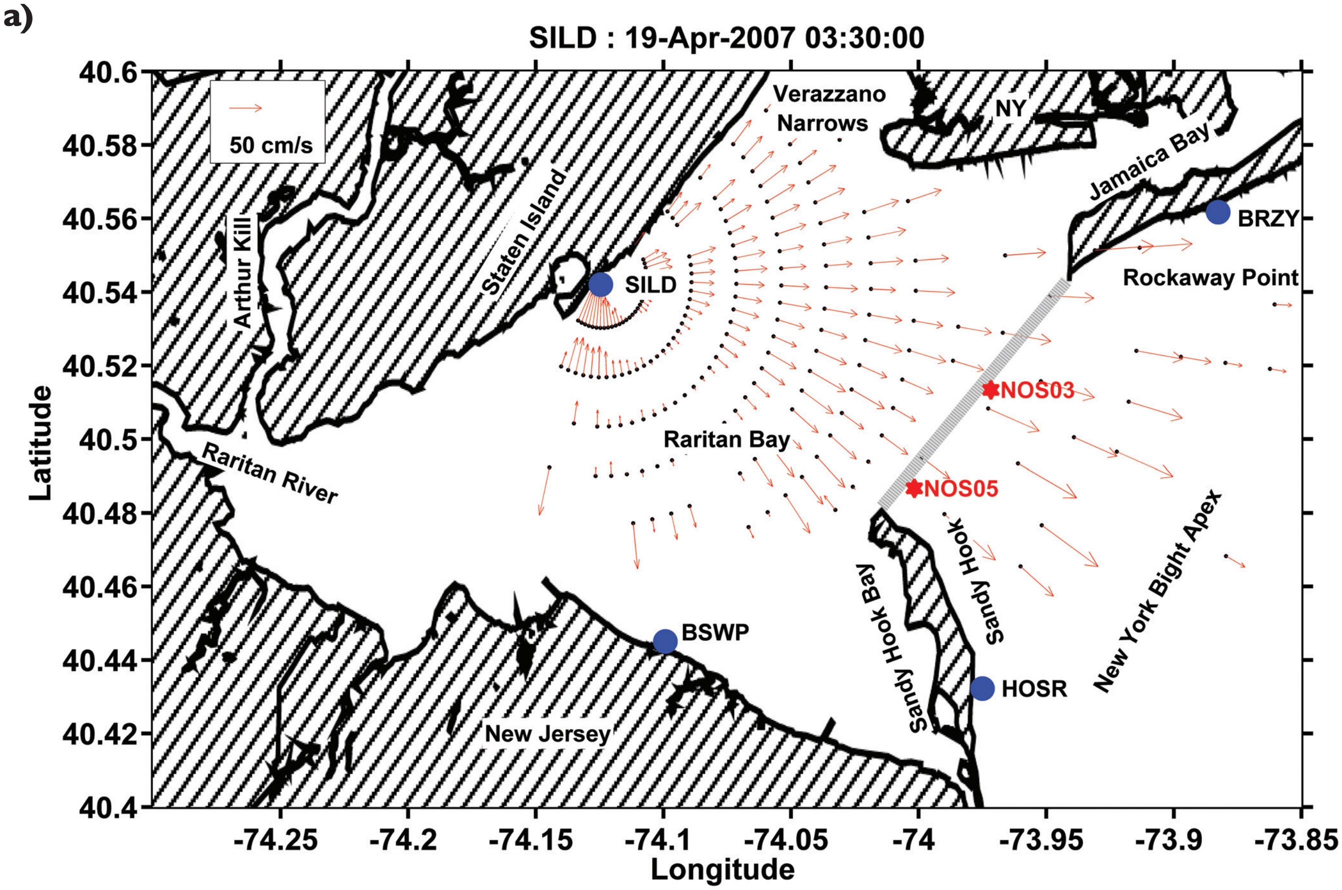


Fig 2: HF Radar radial currents for Sandy Hook (SILD) station (a), and Bayshore Water Front Park (BSWP) (b). Total surface current field obtained by combining these radials (c), and the surface currents from the NYHOPS ocean model (d) for 6 April 2007 at 19:30



a)
SILD : 19-Apr-2007 03:30:00
50 cm/s
Verazzano
Narrows
NY
Jamaica Bay
BRZY
Rockaway Point
Staten Island
Arthur Kill
SILD
NOS03
NOS05
Raritan Bay
Raritan River
Sandy Hook Bay
Sandy Hook
New York Bight Apex
BSWP
HOSR
New Jersey
Latitude
Longitude
40.6
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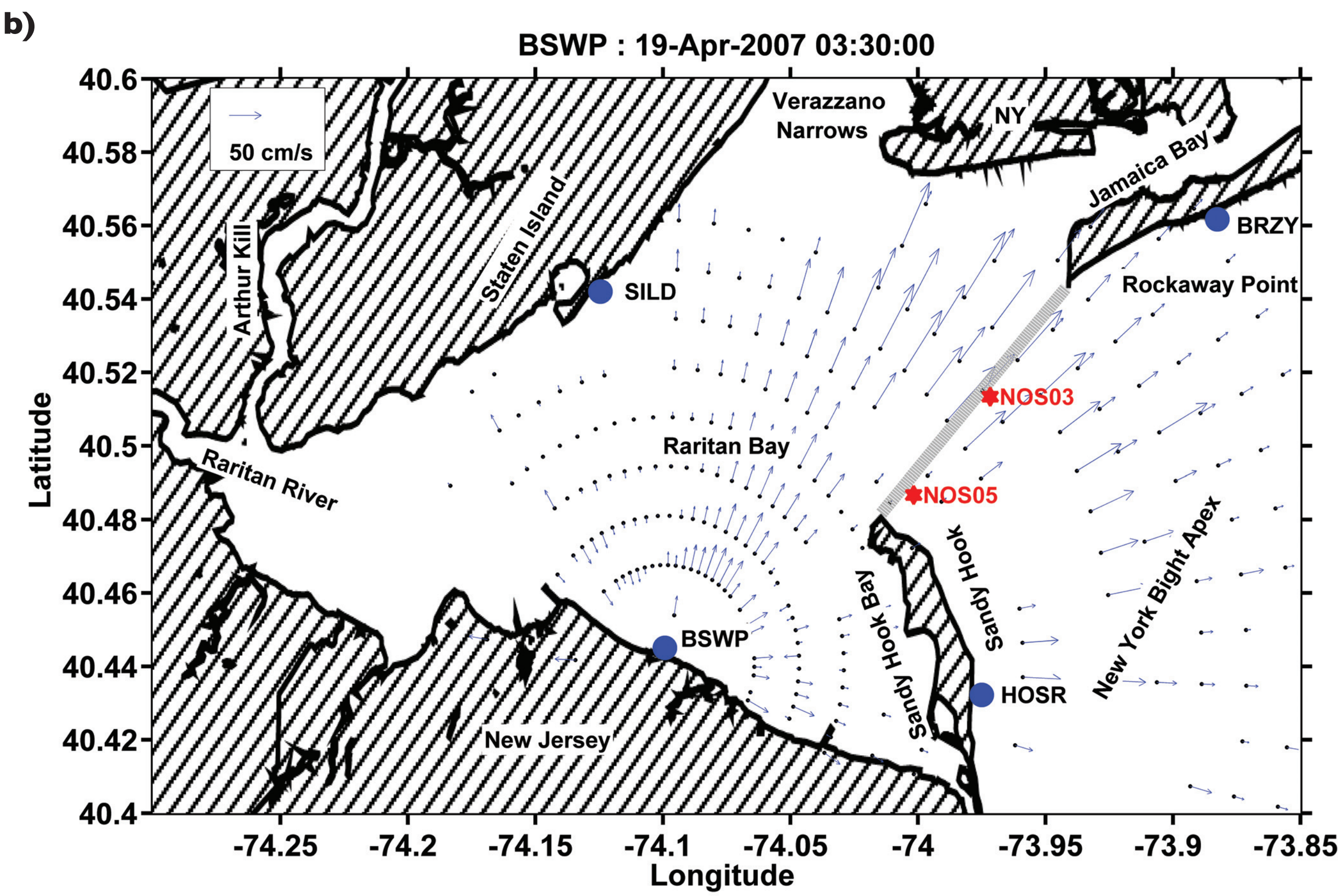

b)
BSWP : 19-Apr-2007 03:30:00
50 cm/s
Verazzano
Narrows
NY
Jamaica Bay
BRZY
Rockaway Point
Staten Island
Arthur Kill
SILD
NOS03
NOS05
Raritan Bay
Raritan River
Sandy Hook Bay
Sandy Hook
New York Bight Apex
BSWP
HOSR
New Jersey
Latitude
Longitude
40.6
40.58
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-73.95
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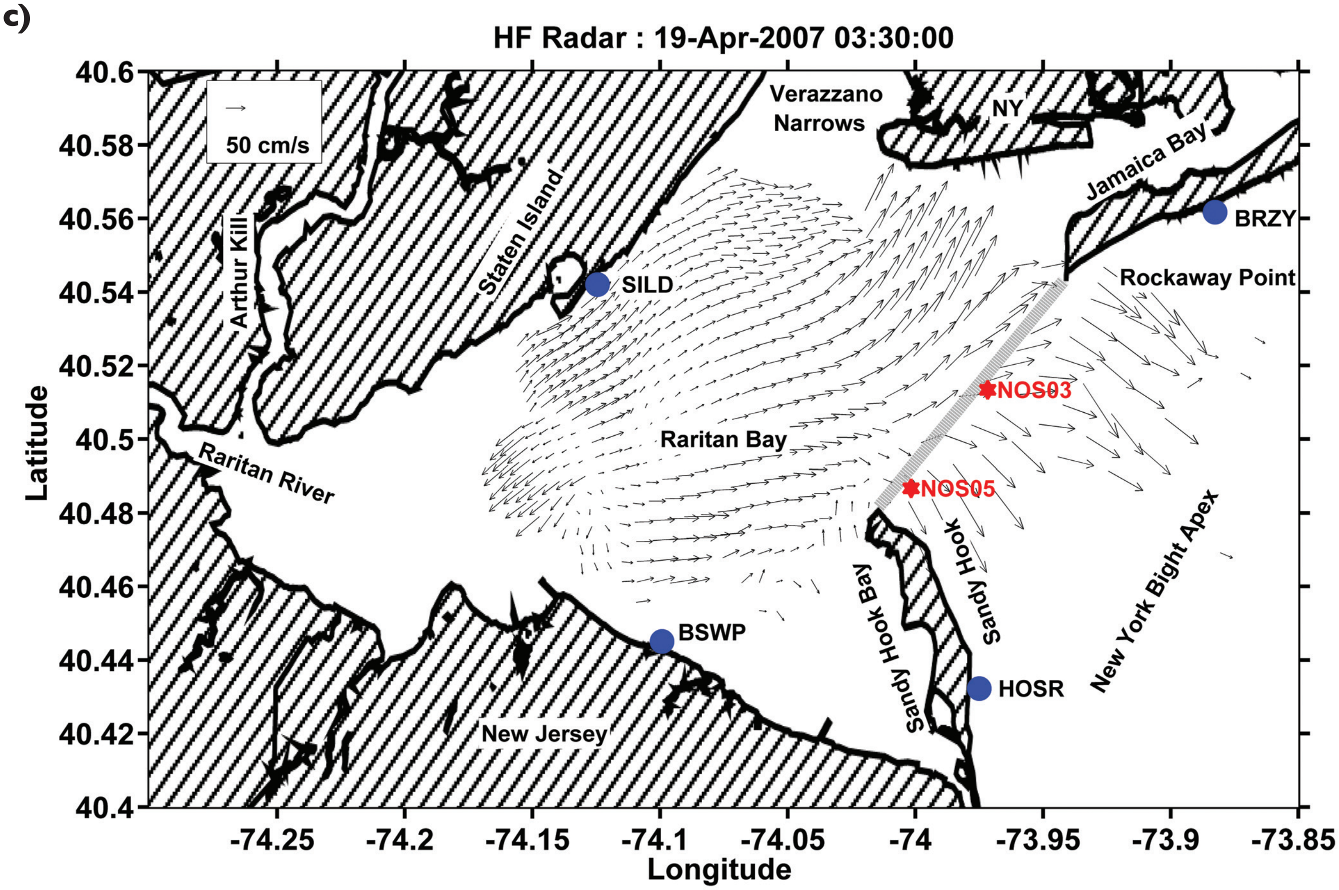
c)



d)

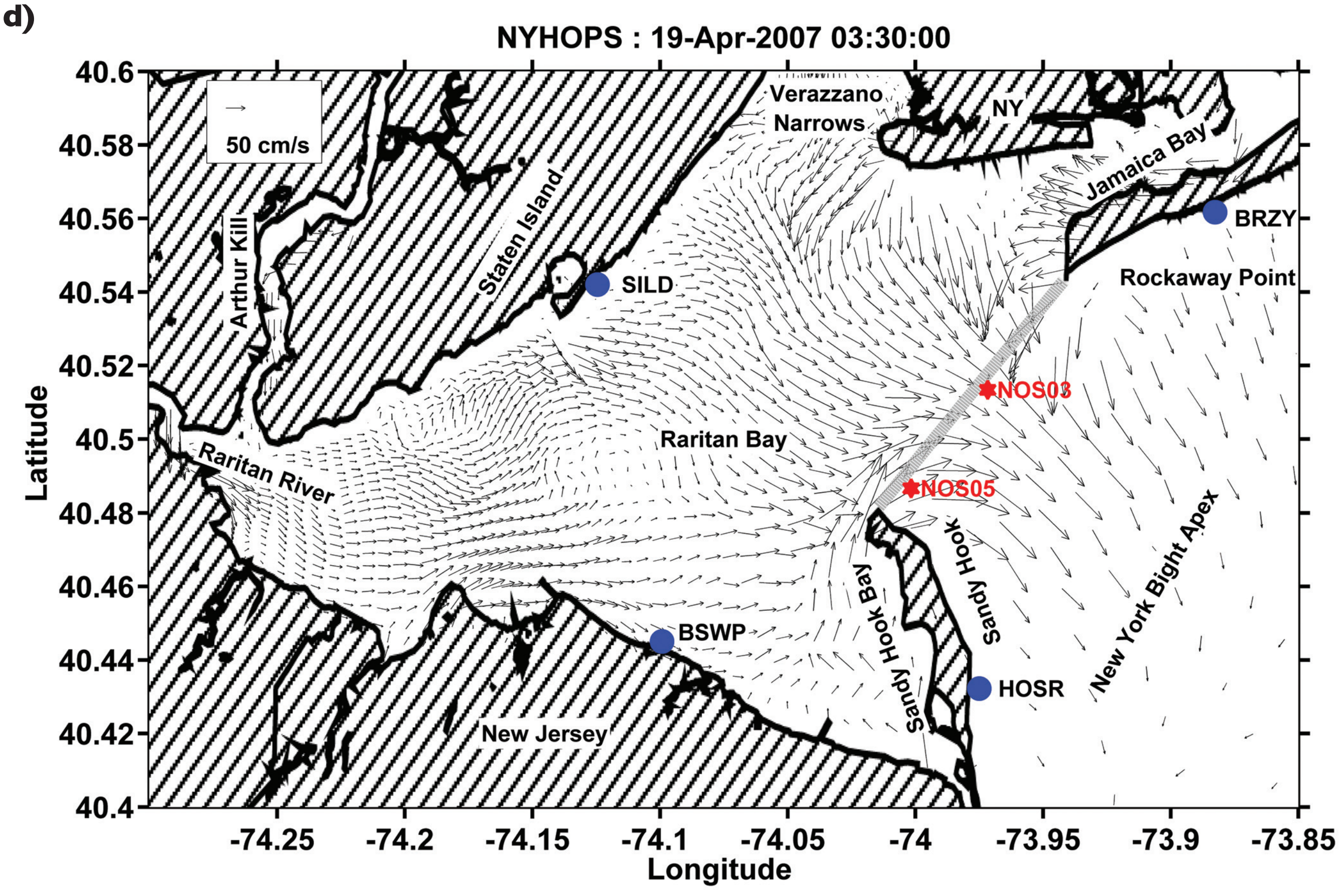


Fig 3: Caption as Fig 2, but for a different time 19 April 2007 at 03:30

where a strong flow directed from Sandy Hook towards Rockaway Point along the transect was observed near the mouth of the NY/NJ harbour estuary. The HF radar currents tend to align themselves parallel to the SHRP transect instead of a more expected flow, that is out of the Raritan Bay and normal to the transect.

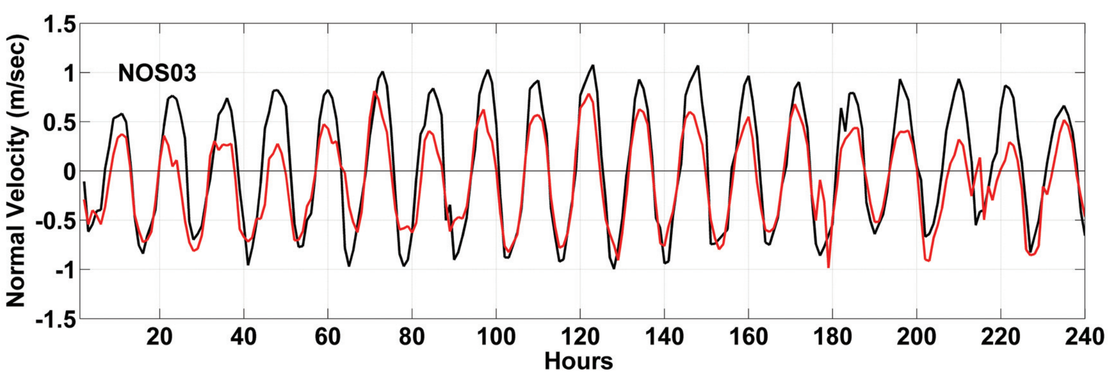
A typical HF radar total current field on 6 April 2007 at 19:30 exhibits this peculiar flow structure near the mouth of the estuary, as shown in Fig 2 (c). The radial currents measured by SILD and BSWP HF radar stations at the same time are also shown in Fig 2 (a - SILD and b - BSWP). Surface currents obtained from the NYHOPS ocean model at the same time are also shown in Fig 2 (d) for completeness. An analysis of the outflow structure of HF radar total surface currents near the mouth of NY/NJ harbour estuary for the period of Jan–June 2007 found that the unusual flow pattern of HF radar currents near the SHRP transect are dominant during strong ebb flows. This peculiar feature of the HF radar current circulation can be due to the elimination of good data measured by SILD site at the mouth of the estuary owing to the spreading of FO Doppler spectrum during strong ebb tidal currents. This ebb flow problem can also be related to HF radar's limited capability in resolving wave-current interaction where the ebb flow from the Hudson River interferes with the incoming waves from the Atlantic Ocean. A similar comparison of HF radar radial and total surface currents along with NYHOPS model currents for a different time on 19 April 2007 at 03:30 is shown in Fig 3. This comparison also shows the peculiar HF radar current pattern near the SHRP transect.

COMPARISON OF HF RADAR CURRENTS WITH HISTORIC MOORING OBSERVATIONS

In this study, a direct comparison of HF radar derived surface currents and *in-situ* current measurements across the SHRP transect was not possible because of the paucity of reliable field measurements. An extensive comparison study[11,12] was made of ocean model solutions and National Ocean Service (NOS) observations (for the year 1980) in the NY/NJ harbour estuary and the NYB Apex. The NOS observations depicted a strong tidal current of 1.0m s^{-1} across the SHRP transect and the Verazzano Narrows, oriented normal to the cross-section;[12] the NOS moorings are also detailed.

In order to understand the magnitude and orientation of the HF radar derived currents across the SHRP transect, hourly HF radar surface currents were compared with these historic NOS observations for a period of ten days, showing high (spring-tide) and low (neap-tide) currents. HF radar surface current component normal to the SHRP transect were compared with the NOS observations. Since the NOS observations are for a different year and season, HF radar surface currents were compared with NOS observations with their peaks aligned in order to highlight the relative current magnitudes. For the comparison purpose, NOS observations were recreated from the published work[12] for the two NOS stations (shown in Fig 1), NOS03 and NOS05.

Although the NOS observation varies with respect to HF radar currents in the year and seasonality, this comparison gives a broader understanding of HF radar derived surface



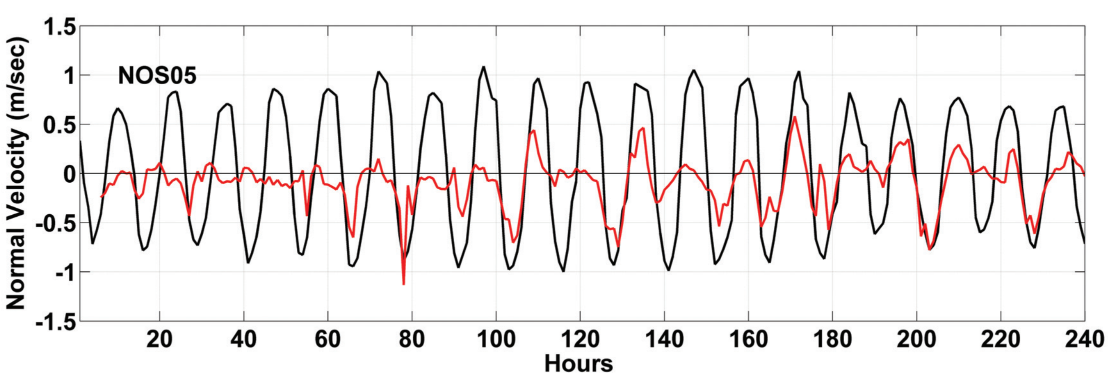


Fig 4: Time-series comparison at the SHRP transect for NOS03 location (top) and NOS05 location (bottom). Black lines indicate historic NOS observations (recreated[12]) and red lines indicate currents measured by HF radar. The HF radar data is from 17–27 March 2007 and the average depth of measurement is ~0.5m. The NOS observation is from 13 Aug–2 Sept 1980 and the average depth of measurement is ~5.5m (NOS03) and ~4.6m (NOS05)

currents in this region. A time-series comparison of currents normal to the SHRP transect obtained using HF radar at NOS03 location (17–27 March 2007, average depth of measurement ~0.5m) and NOS03[12] observation (23 Aug–2 Sept 1980, average depth of measurement ~5.5m) is shown in Fig 4 (top panel). The NOS03 station is located at the centre of the SHRP transect and the comparison of currents normal to the transect shows that HF radar derived currents fails to capture the stronger outflow across the mouth, especially during strong spring-tide, while during weak neap-tide the comparison shows a marginal agreement.

A similar comparison of HF radar currents at NOS05 location (17–27 March 2007, average depth of measurement ~0.5m) and NOS05[12] observation (23 Aug–2 Sept 1980, average depth of measurement ~4.6m) is shown in Fig 4 (bottom panel). In this case, NOS05 is located very close to Sandy Hook, and comparison for both high and low currents show very poor alignment between HF radar derived currents and historic NOS observations.

COMPARISON OF HF RADAR SURFACE CURRENTS WITH NYHOPS MODEL CURRENTS

NYHOPS, created at the Stevens Institute of Technology (SIT) in 2004, permits real-time and forecast assessments of the environment throughout the NY harbour and coastal waters of New York and New Jersey. The hydrodynamic forecast model is based on the Princeton Ocean Model (POM).[13] It is being run at SIT daily, to provide a hindcast (–24h) and two-day forecast (+48h) of the hydrodynamic circulation and wave conditions in the coastal (<200m deep), estuarine, and freshwater zones from coastal Maryland to Cape Cod, Massachusetts. The hydrodynamic model is initiated at 0 hours local every day, and completes a –24h hindcast cycle based on observed forcing followed by a +48h forecast cycle based on forecasted forcing. NYHOPS provides forecasts of water level, 3D circulation fields (currents, T, S, density, sound speed), significant wave height and period.

The 3D hydrodynamic code includes significant features not included in the original POM, such as wetting-and-drying (W&D) and thin-dam formulations, data assimilation,[14] as well as coupled wave and fully-2D atmospheric modules.[15] A high-resolution curvilinear model grid is used to encompass the entire Hudson-Raritan (NY/NJ harbour) estuary, the Long Island Sound, and the New Jersey and Long Island coastal ocean. The resolution of the grid ranges from approximately 7.5km at the open ocean boundary to less than 50m in several parts of the estuary. The current vertical resolution of the grid is 10σ (terrain-following) layers.

An extensive hydrodynamic model skill assessment has been applied to quantify the hindcasting and forecasting skill of the NYHOPS. Model results were compared to *in-situ* observations of water level, currents, temperature, salinity, and waves from over 100 locations, collected over a two-year period. The model's ability to describe the hydrodynamic conditions in the extensive area it is employed for is quite good. The average index of agreement for water level is 0.98, for currents is 0.87, for water temperature is 0.98, for salinity is 0.77, and for significant wave heights is 0.88. Respective, average root-mean-square errors are: 10cm for water level, 13cm s^{-1} and 9° for currents, 1.4°C for water temperatures, 2.8 psu for salinities, and 32cm for significant wave heights.[16]

The NYHOPS model hindcast surface currents were compared with HF radar currents in the NYB Apex, and typical snapshot comparison plots are shown in Figs 2 and 3 (c and d). Aside from the above snapshot comparison, a tidal analysis comparison has been performed for the HF radar surface currents as well as the NYHOPS model daily hindcast surface currents for a period of 120 days (2 March–29 June 2007) in the NYB Apex. The tidal analysis was performed using MATLAB T_TIDE toolbox,[17] in which seven major tidal constituents (K_1, O_1, Q_1, K_2, M_2, S_2, N_2), and two overtides ('shallow water' tide M_4, M_6) were considered.

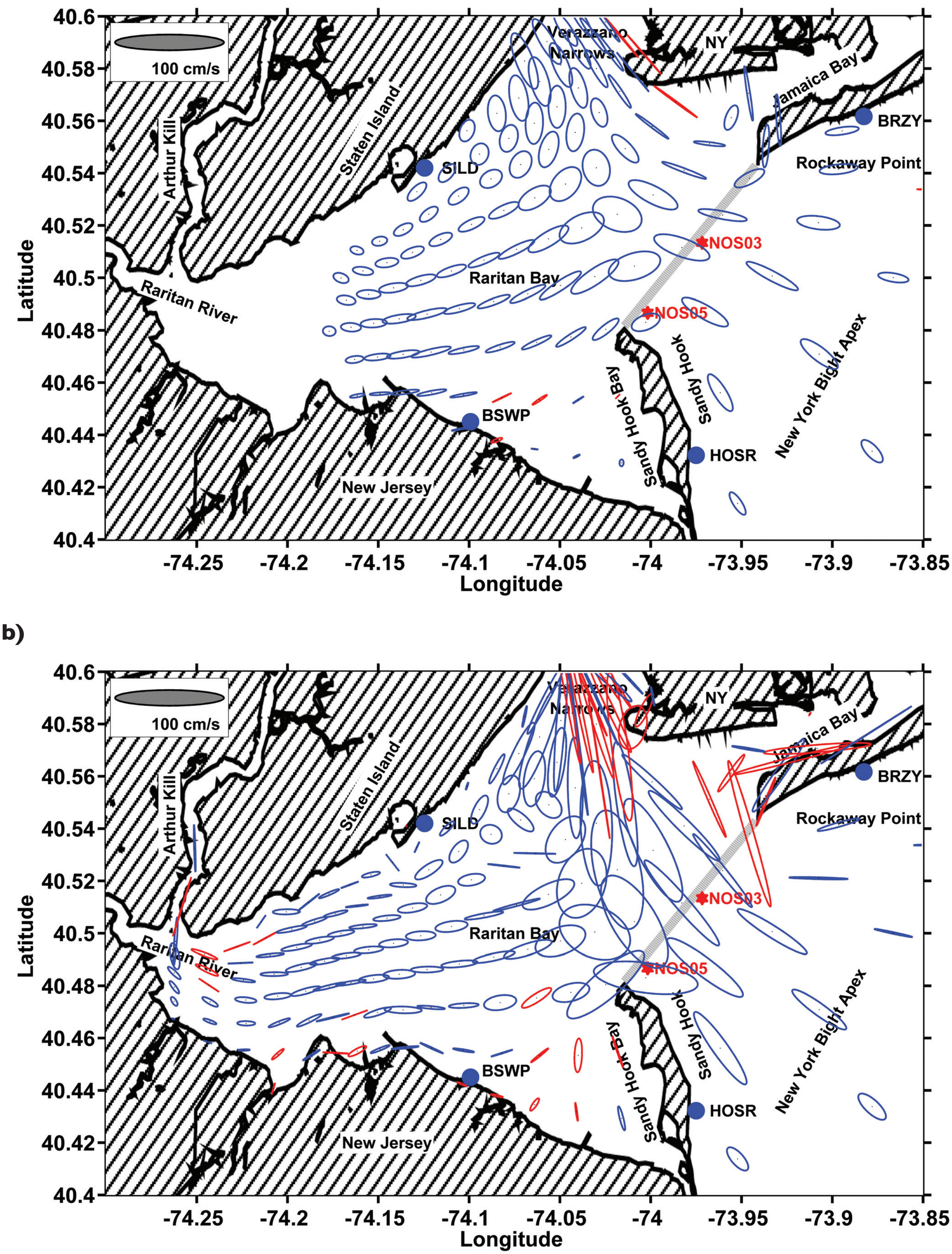
Tidal ellipses for the predominant M_2 tidal constituent are plotted for the NYB Apex domain for both HF radar currents and NYHOPS model surface currents. The M_2 tidal ellipses for HF radar and NYHOPS are shown in Fig 5. Tidal ellipses were only plotted for every third model grid point to improve figure clarity. While the M_2 tidal ellipses for the NYHOPS model hindcasts and HF radar currents shows similar sense of rotation at most of the locations inside Raritan Bay, the modelled current represents a stronger tidal amplitude of 1~1.5m s^{-1} and oriented normal to the SHRP transect and the Verazzano Narrows while the tidal ellipses for HF radar surface currents exhibits a weaker amplitude of 0.6m s^{-1} at the SHRP transect and the Verazzano Narrows, and are mostly oriented in the east-west direction.

SURFACE CURRENT CIRCULATION IN RARITAN BAY

The Raritan Bay and Sandy Hook Bay form the south-eastern portion of the NY/NJ harbour between the northern shoreline of Staten Island, NY and the southern shoreline of Monmouth County, NJ. Its head is located at the confluence of the Arthur Kill and the Raritan River, which flows into the bay from the west. The Arthur Kill and Kill Van Kull are tidal straits that connect Newark, NJ to Raritan Bay and to NY harbour. It is reported[18] that Raritan Bay was formed by a system of bays and lagoons which extended ~40km in length and oriented in the east-west direction. Raritan Bay can be divided into three parts progressing seaward as Raritan River, Raritan Bay and Lower New York Bay. Water depths are relatively shallow, increasing gradually from either shore to 7m in Raritan Bay and 9m in Lower New York Bay. Raritan Bay has a triangular shape like a flattened funnel with relatively shallow water depths, forming an 'ideal estuary' with fresh water source from Raritan River and saline water from Lower New York Bay entering into the basin at opposite ends with a tendency for each to flow to its respective right side.

Estuarine mixing produces a great counter-clockwise gyre of slow circulating water masses inside the Bay.[18] The net currents in Raritan Bay and Lower Bay[18] represented local clockwise eddies at the Great Kills harbour point of Staten Island shore and at the Monmouth shore. A net along-shore

a)



b)

Fig 5: Tidal ellipses for predominant M_2 tidal constituent for HF radar surface currents (top) and NYHOPS model daily hindcast surface currents (bottom) for 120 days (2 March–29 June 2007). Blue ellipses indicate clockwise component and red ellipses indicate counter-clockwise component. Tidal ellipses were only plotted for every third model grid point to improve figure clarity

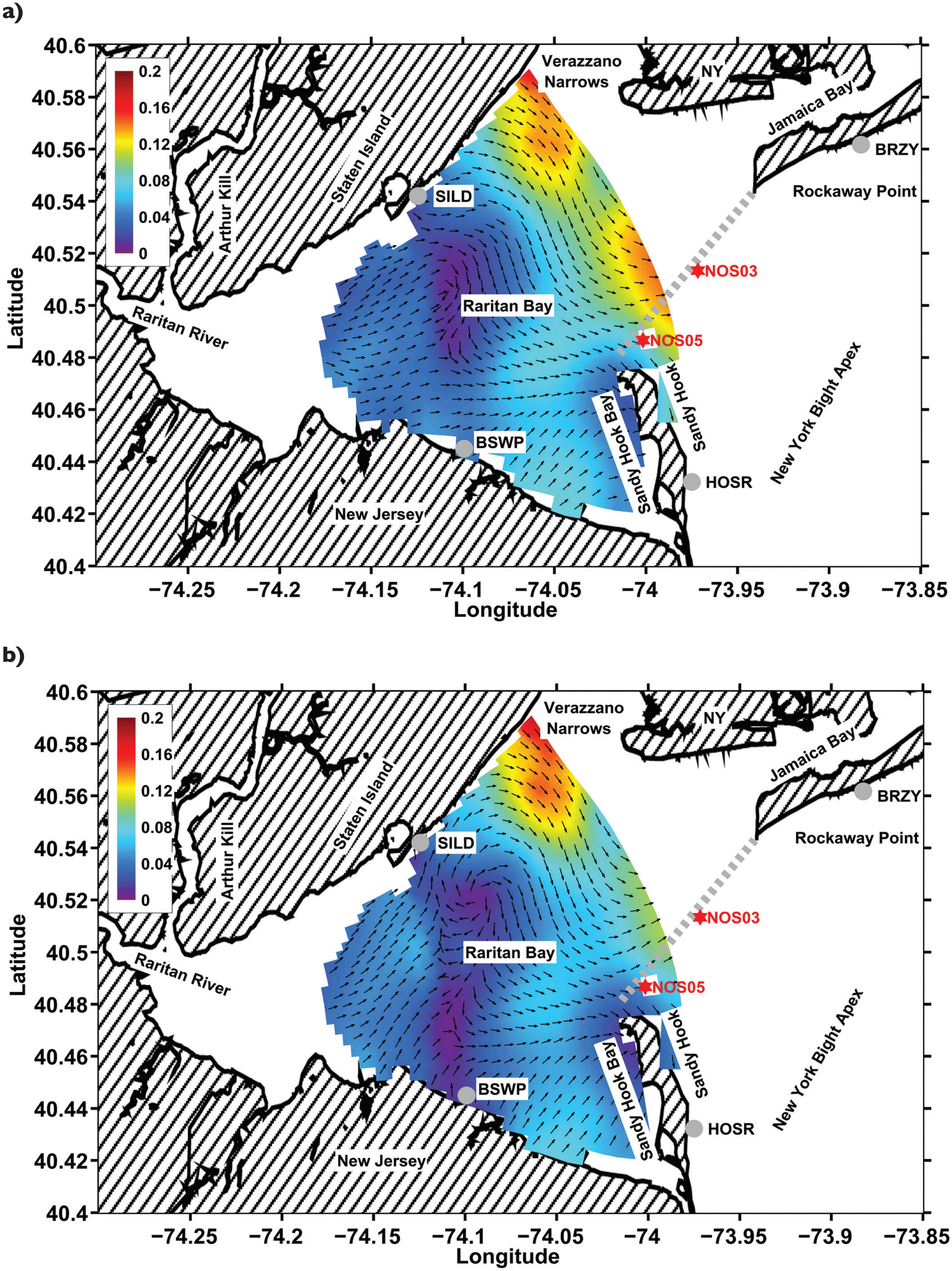


Fig 6: Mean surface current circulation in Raritan Bay measured using HF radar for spring 2007 (Jan–March) (top) and summer 2007 (April–June) (bottom). Colours denote current speed, normalised arrows show direction

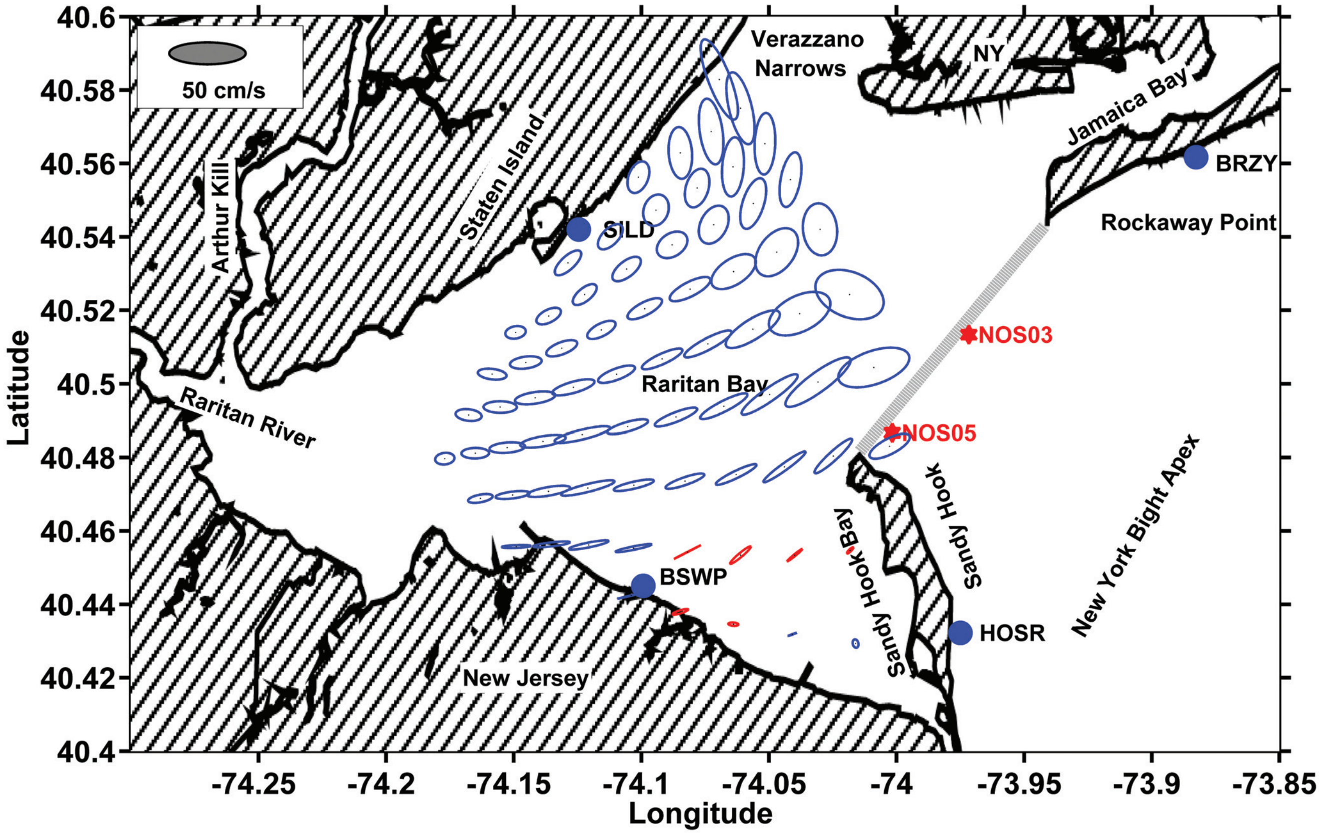


Fig 7: Tidal ellipses for predominant M_2 tidal constituent for HF radar surface currents in Raritan Bay for the period of Jan–June 2007. Blue ellipses indicate clockwise component and red ellipses indicate counter-clockwise component. Tidal ellipses were only plotted for every third model grid point to improve figure clarity

current, directed eastward was observed along the Sandy Hook Bay, which flowed southward along the Sandy Hook and the NJ shore. Earlier modelling efforts reported that the three-dimensional circulation in the Raritan Bay were primarily wind driven due to its shallow water features.[12,19]

Surface current observations inside Raritan Bay were obtained for the period Jan–June 2007 by combining HF radar radials from the SILD and BSWP stations. The BSWP HF radar station was deployed as an experimental mobile station during Aug 2006–June 2007, and provided continuous radial measurements only during Jan–June 2007. The mean circulation for spring and summer season for the year 2007 obtained using HF radar observations is shown in Fig 6. The mean flow consisted of a 5cm s^{-1} anti-cyclonic circulation at the centre of the bay with stronger currents of 20cm s^{-1} near the corridor connecting the Sandy Hook-Rockaway Point transect with the Verazzano Narrows, for both spring and summer season. The mean circulation computation excluded the region of strong tidal flow along the corridor connecting the SHRP with the Verazzano Narrows, where the HF radar currents exhibited an unusual flow pattern as discussed earlier. The M_2 tidal ellipses obtained by analysing HF radar surface currents for the same period (Jan–June 2007) is shown in Fig 7. Tidal ellipses were only plotted for every third model grid point to improve figure clarity. The tidal ellipse plot show a predominant anti-cyclonic flow in the bay with their major axis oriented in the east-west direction with magnitude of 20cm s^{-1} at the centre of the bay, and gradually increases to a value of 50cm s^{-1} near the corridor connecting the SHRP with the Verazzano Narrows.

SUMMARY AND CONCLUSIONS

The present study revealed the importance of the FO Doppler region settings of the HF radar (CODAR) in a tidally dominated NY/NJ harbour estuary and Raritan Bay circulation. The FO Doppler spectrum surrounding the ideal Bragg frequencies are separated from the neighbouring lower-amplitude, second-order spectrum and noise using empirical methods. This empirical method identifies the local minima which defines the FO Doppler region from which the surface current information is derived. The FO Doppler region settings defined for the HF radar system remain the same for all the range cells. A higher FO setting will result in erroneous current vectors due to inclusion of higher-order spectral energy while a lower FO setting results in the elimination of good data. The FO settings of the HF radar are highly sensitive to the local oceanographic circulation and are site specific. The occurrence of strong tidal current results in spreading of the FO Doppler region in the sea-echo, and a higher FO setting is required to capture those stronger currents. Since the FO region settings remain the same for all the HF radar range cells, HF radar fails to capture the stronger tidal currents which occur only at a particular range cell from the station, adjacent to range cells representing weaker currents.

The standard-range HF radar network used in the present study consists of four HF radar systems in which two (Staten Island: SILD, Bayshore Water Front Park: BSWP) of them overlook extremely strong tidal currents of magnitude of 1~2m s^{-1}. HF radar surface currents exhibited an unusual flow pattern near the mouth of the NY/NJ harbour estuary, which is different from the historic NOS mooring observations,[12] as well as from the NYHOPS ocean model simulations. The HF radar surface currents near the SHRP transect are found to be weaker than the observational findings[12] and the NYHOPS model hindcasts, and are aligned mostly parallel to the SHRP transect. This can be due to the elimination of good data at the mouth of the estuary as observed by the SILD HF radar station. This present work suggests the need for improved FO Doppler peak settings for the SILD and the BSWP HF radar stations, which may improve the HF radar surface current measurements near the mouth of the NY/NJ harbour estuary.

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