Application of Radial and Elliptical Surface Current Measurements to Better Resolve Coastal Features

Robert Forney, Hugh Roarty, Scott Glenn
Center for Ocean Observing Leadership
Rutgers University
New Brunswick, NJ USA
robert.k.forney@gmail.com

***Abstract*— The ephemeral nature of sea breeze makes it a challenging phenomenon to study. The sea breeze is an important wind resource that could potentially be harnessed to enhance coastal wind energy development. It is also an important force in coastal ocean dynamics and warrants further study. It would be convenient and inexpensive to study the sea breeze with HF radar, over broad spatial and temporal scales, if it can only be adequately differentiated from other stronger signals and noise. We seek to isolate the sea breeze signals in ocean surface currents using bistatic HF radar. Bistatic measurements can help increase the spatial resolution of sampling and help resolve features like the effects of sea breeze on the sea surface. The elliptical and radial data were consistently in statistical agreement with each other. This is the case across all analyses performed. This indicates that the elliptical data produced by the bistatic systems validates the radial data, which had been previously validated by drifter data. In turn, elliptical data has been shown to be a reliable measure of surface current velocity. Elliptical data continues to be valuable for increasing surface current velocity measurement density. More sophisticated statistical tests may reveal differences between radial and elliptical measurements. An important next step would be determining the finest spatial and temporal resolution available with combined elliptical and radial data, and then changing the spatial and temporal averaging radii in the SeaSonde software. This could potentially reveal finer features that are currently lost in averaging.**

Keywords—radar, remote sensing, oceanography, bistatic, MARACOOS

I. INTRODUCTION

The geometrical difference between elliptical and radial SeaSonde coastal radar measurement patterns may give rise to different abilities to resolve coastal features between the two systems, since they have different spatial distributions of dilution of geometric precision [1]. The key difference, the shape of the contour of constant time delay, gives each mode of collecting sea surface velocity measurements an independent perspective, each theoretically with a better ability to resolve velocities in either the cross-shore or along-shore direction. Higher accuracy measurements are made when the observation is made in the same direction as the current; measurements should produce better decomposed velocity vectors along the direction in which the velocity is most perpendicular to the contour of constant time delay. For radials, this is the same in all directions, but for ellipticals the cross-shore velocity vectors would be measured more accurately since the contours are more parallel to the shore.

This difference in the shape of the contours of constant time delay between monostatic and bistatic systems can be exploited to attempt to resolve cross-shore phenomena such as sea breeze, coastal upwelling, and storm-related surface currents better than before. However, the significance of this difference may be small compared to other confounding signals in practice, so it is the aim of this study to determine whether or not the theoretically different measuring abilities implied in the geometrical difference between monostatic and bistatic systems can be discerned and made useful.

To test the hypothesis, we collected CODAR SeaSonde coastal radar data in the Strathmere and Wildwood offshore regions (Figure 2)—specifically, in the area covered by the 13-MHz systems in place there—and compared the total surface current vectors as measured by radials and ellipticals to one another, their composite, and expected values based on meteorological data for the time frame August through September 2012.

II. BACKGROUND

Radar was first developed for military applications. Bistatic systems were among the first, implemented in the 1930s during World War II to detect objects crossing the baseline between the transmit and receive antenna [2]. The development of radar systems was almost simultaneous across Europe as well as in the United States and Russia [3]. Since then, it has been used in the operation of semi-active missile seekers, experimental lunar surface mapping, grounded aircraft intruder detection (security), and ionosphere observation [4].

The SeaSonde Coastal Ocean Dynamics Applications Radar (CODAR) used in monitoring ocean surface currents is different from most radars in a few respects—it operates in the High-Frequency (HF) range, like amateur radio, as opposed to the microwave range that airplane detection and mapping applications use; it has low directivity as a result of

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this high frequency; and direction scanning is limited due to the fact that the radar units are limited to the azimuthal direction [3]. The fundamental measurements of the radar are range to target, direction to target relative to reference azimuth, Doppler frequency of target, and power returned from target.

It is important to understand how exactly these oceanographic radar systems work. The instrument consists of a transmit and receive antenna positioned on a coastline connected to a computer that stores the collected data and controls the antenna settings. The form of the SeaSonde antenna varies—in the past it was more common for receive antennas to have large "whips" but the most recent version has no horizontal ground plane—but the concept of its operation remains mostly unchanged. The transmit and receive antennas can be collocated (monostatic) or geographically separated (bistatic); this is the key difference between monostatic and bistatic systems, respectively. In either system, transmit antenna emits a HF radio pulse, which travels at the speed of light in all directions, and is reflected off of ocean surface waves, which is what we want to happen in order to measure sea surface quantities such as wave velocity. The pulse can also reflect off of or be deflected by other conductors, which is why it is important to install the equipment in a relatively isolated place. Some fraction of the energy is reflected and received at the receive antenna, which carries with it some information about the surface it reflected off of which can be made meaningful through some spatial and temporal averaging and processing in the computer.

A bistatic CODAR system consists of multiple spatially separated SeaSonde HF RADAR units operating on the same frequency allowing sea echo from one site's transmission to be received coherently at the others [5]. Similarly, a monostatic system is the same in all respects except that the receiving antenna is collocated with the transmitting antenna. All stations (or sites) employ a linear frequency sweep to resolve range to target, and can be timed to begin their sweeps with high precision—no less than 10 microseconds. This enables backscattered echo and bistatic echoes to be discerned from background noise [5]. The SeaSonde stations emit radio waves, which go out a certain distance then bounce back off of wave fronts, and can be 'heard' at nearby stations. With this in mind, it should be apparent that the transmit and receive sites act as the focal points of an ellipse from which the region of coverage emanates (Figure 3)—and when the transmitter and receiver are co-located, the ellipse becomes a special case, a circle. Measurements are taken perpendicular to these "contours of constant time delay" [6], which are different between monostatic and bistatic systems—this is a key difference between radial and elliptical measurements.

It is important to advance our understanding of HF radar because at present this is the most efficient method for measuring surface current velocities over large spatial regions in the coastal ocean. Data concerning surface current direction and speed are very important in applications such as marine search-and-rescue operations, remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV), piloting, meteorology, and vessel detection [7]. The HF radar has significant civilian, military, and scientific value. HF RADAR SeaSondes are reliable and cost-effective due to their terrestrial nature, portable because of their relatively small size and low weight, easy to use because of user-friendly SeaSonde software and remote control capability, and inexpensive to set up [8]. They can also observe a wide area of ocean and collect data continuously over time. All of these are benefits over in-situ surface buoys and drifters that perform the same function of collecting current velocity data.

Consistency between radials, ellipticals and drifters, buoys has already been explored in [6]. It was found that radials and ellipticals were both similar to drifter and buoy measurements in accuracy. Ellipticals are not strictly better or worse than radials, although they are somewhat hindered by the region of high uncertainty around the baseline between transmitter and receiver [9]. Both ellipticals and radials yield high error in shallow water, and have problems with resolving three-dimensional features [10]. The SeaSonde software does have problems with placing vectors in the right places for elliptical data: the bearing determination algorithm is designed to accommodate radial data [11-13] but for ellipticals it has a tendency to place vectors over land if a mask is not used to force vectors to be placed over the ocean. Using measured antenna patterns to calibrate the direction-finding algorithm can improve both radial and elliptical measurements [14, 15].

III. METHODS

Four 13 MHz radars were installed along the southern coast of New Jersey. The average spacing between the radars was 29 km. The radars were installed in the municipalities of Brant Beach (BRNT), Brigantine (BRMR), Strathmere (RATH) and North Wildwood (WOOD). Each of the radars operated in monostatic mode where the radar received the signal it transmitted.

There were also two bistatic data sources used in the study. Both of these sources used RATH as the receive station. The first used WOOD as the transmit station and the second used the transmit signal from BRNT. The naming convention for the bistatic data sources uses the first two letter of the receive station and the first two letters of the transmit station. So the bistatic signal RAWO is received at RATH and transmitted from WOOD and RABR is received at RATH transmitted from BRNT. The transmit and receive stations are the focii of concentric ellipses around the two stations.

The radial and elliptical data were combined on a 2 km total grid [16] using the optimal interpolation combining algorithm [12, 17].

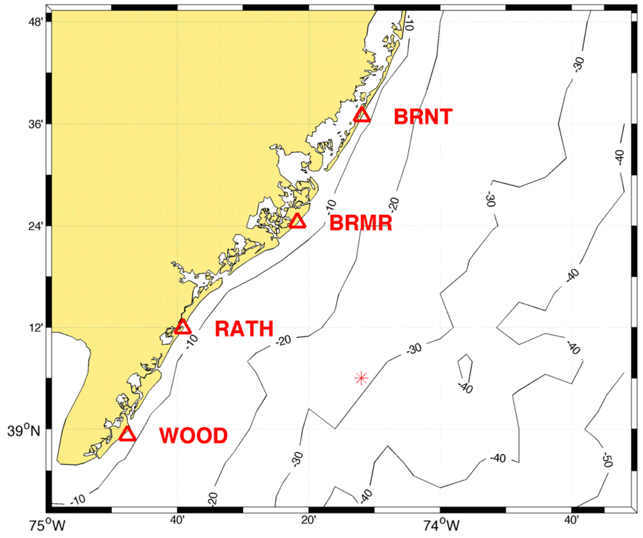

Figure 1: Map of the study area showing the location of the radar stations (red triangles). Each station is identified with a four-letter site code. The red star indicates the location of the time series analysis shown later.

IV. RESULTS

Before the radials and ellipticals were combined into total vector solutions, we first analyzed the temporal and spatial variability of the two measurement types. To analyze the temporal fluctuation of the measurement, the average velocity for each hourly file was calculated and plotted as a time series. The results are shown in the top half of Figure 2. The lower panel of Figure 2 shows the number of vector solutions per file type over the three-week period. This plotting technique was put forth as a low level quality control technique for the HF radar stations[18]. Each of the four measurements shows a fluctuation that is closely linked to the M2 principal lunar semidiurnal tidal constituent. The one exception being the RABR elliptical data file shows a deviation from this signal on 8/30 and from 9/11 to 9/15. Each of these instances is coincident with a drop in the number of vector solutions for this data source (lower panel of Figure 2). These two time periods should be flagged for further analysis of the bistatic processing. But overall the temporal variation of the signals is in good agreement and indicates high data quality from each of the four measurements.

To analyze the spatial variability a mean vector map was calculated for each data type. This is performed by temporally concatenating the hourly files from each data type and calculating the mean and standard deviation at each radial or elliptical grid cell. The results for the monostatic systems are shown in Figure 3 for RATH and Figure 4 for WOOD. The average elliptical velocity from RABR is shown Figure 5 and Figure 6 shows the average for RAWO. The color of the dot indicates the average velocity at the grid point where the size of the marker is representative of the standard deviation or uncertainty. Blue indicates currents that are flowing toward the radar station and red indicates currents that are moving away from the stations. This convention was adopted to follow the phenomena that light displays when moving relative to an observer.

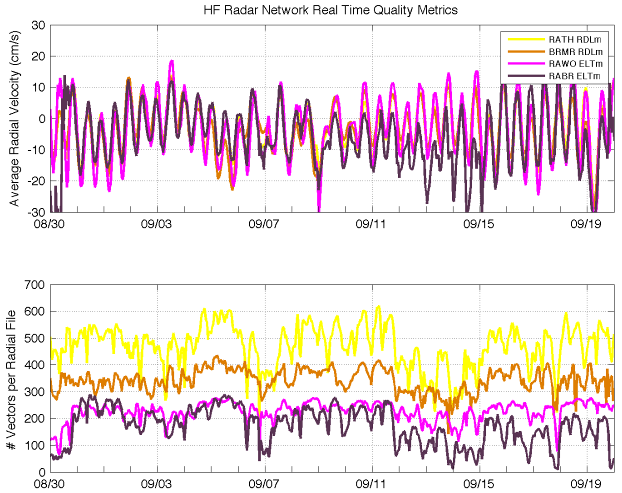

Figure 2: Plot of average radial velocity for the four radar signals used in this study (top) and plot of the number of vector solutions per file (bottom). The X axes are month/day (mm/dd) for 2012.

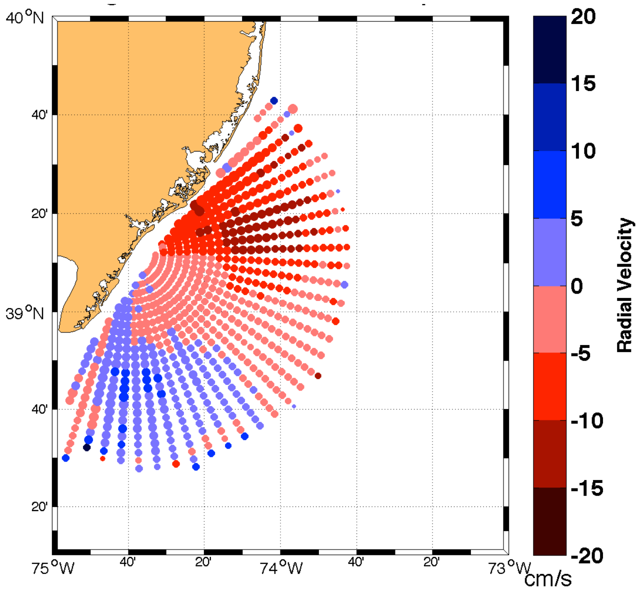

Figure 3: Average radial velocity measured by the radar at RATH from August 30, 2012 to September 20, 2012.

Each of the maps exhibits similar structure with currents flowing away from the radar in the northeast quadrant and flow towards the radar from the south. One area for further analysis is the first elliptical cell in Figure 6. The standard deviations of the vectors in this cell are noticeably higher and they are towards the radar when the measurements in the next outward cell are away from the radar. This cell is closest to the direct signal from the transmit station so care must be taken to ensure that the software is processing sea echo and not direct signal from the transmit station.

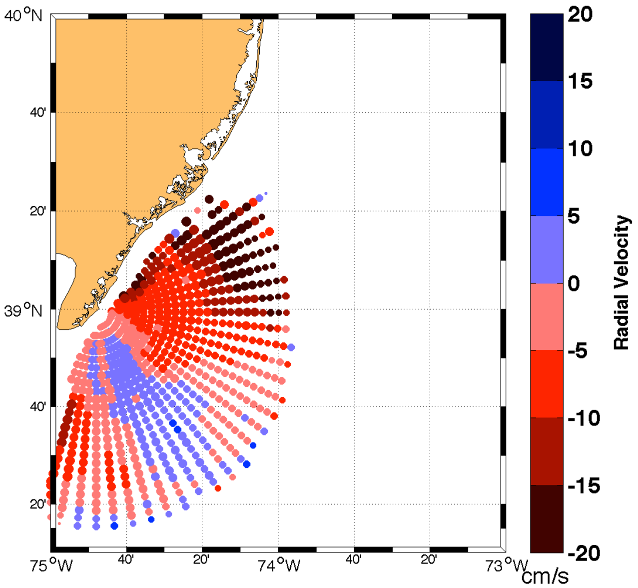

Figure 4: Average radial velocity measured by the radar at WOOD from August 30, 2012 to September 20, 2012.

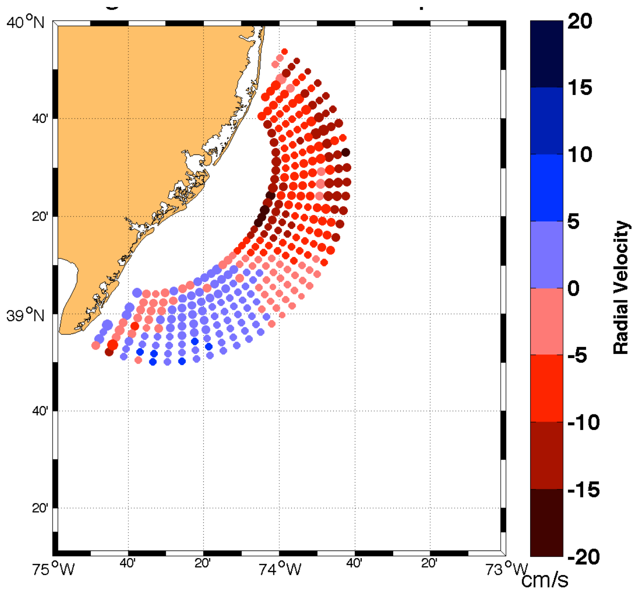

Figure 5: Average elliptical velocity measured by the radar at RATH transmitted from BRNT from August 30, 2012 to September 20, 2012.

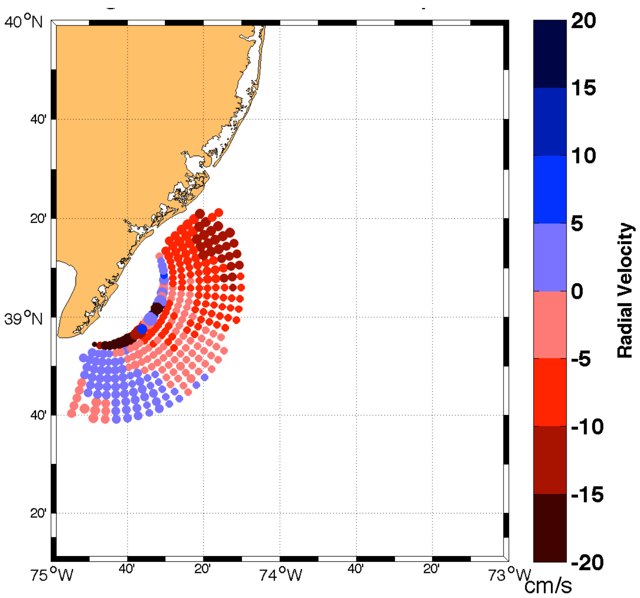

Figure 6: Average elliptical velocity measured by the radar at RATH transmitted from WOOD from August 30, 2012 to September 20, 2012

To gauge the impact of the elliptical measurements on the total vector product a time series was analyzed at a single grid point. The point chose was 74.2 W and 39.1 N (red star Figure 1), as this point would contain vectors from both the monostatic and bistatic data sources. Figure 7 shows a time series plot of the cross shore (top) and along shore (bottom) flow only using the measured radial data type. For these figures positive cross-shore flow is offshore and positive along shelf flow is towards the north. The M2 tide is clearly visible in the cross shelf flow as this is the dominant axis for this tidal constituent. The interesting finding comes from the along shelf measurement that shows the average flow for the three week period is towards the north. This is counter to the climatological flow, which is down the shelf [19, 20].

The time series using the radial and elliptical vector measurements is shown in Figure 8. There are only slight differences between the two figures. The comparison between the detided and low pass filtered (32 hour period) time series of the two measurement types were also similar. This indicates that the addition of the elliptical data source did not impact the measurement of the flow at this particular location. A next step would be to measure the difference between the radial only and radial-elliptical product to gauge the impact of the elliptical measurements on the flow characterization. It was shown in [21] that the addition of elliptical measurements can increase the coverage of a radar network considerably.

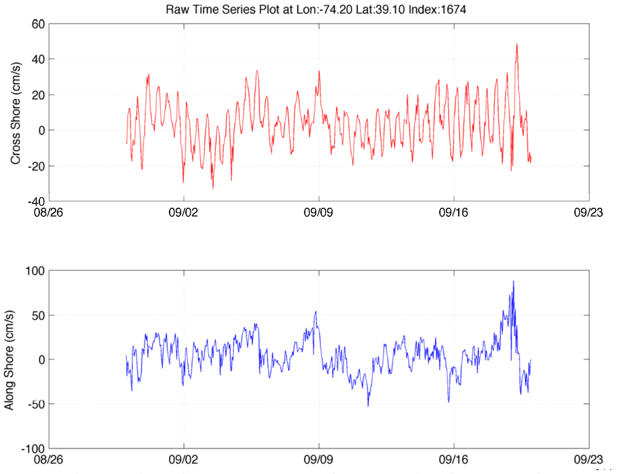

Figure 7: Time series plot at 74.2 W and 39.1 N for the cross shore (top) and along shore (bottom) using only the measured radial vectors.

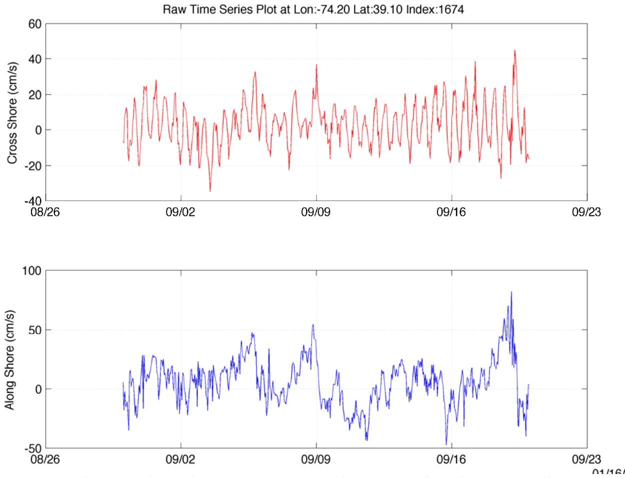

Figure 8: Time series plot at 74.2 W and 39.1 N for the cross shore (top) and along shore (bottom) using the measured radial and elliptical vectors.

V. CONCLUSIONS

HF radarElliptical SeaSonde coastal radar data has proven to be just as reliable as radial radar data in providing a measure of ocean surface currents across broad spatial and temporal scales. Further, a combination of elliptical and radial data decreases the error of surface current measurements, increases coverage and increases data density per unit area and time. This suggests that a finer grid could be used to achieve greater spatial resolution. At greater resolutions, the geometric differences between radial and elliptical data collection may become more significant than confounding signals and enable the detection of cross-shore phenomena such as sea breeze. Changes in how SeaSonde software processes elliptical data to accommodate its eccentric geometry could lead to further improvements.

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