A Study of Surface Currents in the Coastal Ocean Outside Chesapeake Bay Using HF Radar

Teresa G. Updyke and Larry P. Atkinson
Center for Coastal Physical Oceanography
Old Dominion University
Norfolk, VA, USA
garner@ccpo.odu.edu

***Abstract*—Surface circulation in the coastal ocean outside of the Chesapeake Bay was studied using high frequency radar. Radar data were collected and analyzed from three long range HF radar sites operating at 5 MHz: 1) LISL located at Little Island Park in Virginia Beach 2) CEDR on Cedar Island, a barrier island offshore of Wachapreague, Virginia and 3) DUCK located in Duck, NC. These sites are long-term monitoring stations, part of a regional ocean observing system funded under the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS). This study reports on surface current data collected from mid-August to mid-September 2011. Radial data were compared with ADCP current data measured at NOAA National Data Buoy Center station 44014. R^2 correlation values ranged from 0.61 to 0.76 and rms differences ranged from 12 to 14 cm/s. Total velocity data were also compared with the ADCP data. A complex correlation analysis of the ADCP data compared with radar total vector currents yielded a correlation amplitude of 0.6 and a correlation angle of 8 degrees. Circulation patterns during the study period, before the passage of Hurricane Irene, are illustrated with particle trajectories. Subtidal circulation has been described in terms of principal direction of flow. Locally averaged coastal surface subtidal currents were correlated with winds measured at the NDBC CHLV2 station (Chesapeake Light Tower). East-west (across-shelf) subtidal currents in the area offshore of the Bay are highly correlated with north-south winds (R^2 = 0.85)**

***Index Terms*—HF Radar, Mid-Atlantic, currents.**

I. Introduction

The antennas used in the study are SeaSonde antennas manufactured by Codar Oceans Sensors, Inc. These antennas transmit radio signals across the water and listen for strong return signals reflected off of ocean waves. The measured Doppler shift between the transmitted and received signals is related to an observed water speed which represents a sum total of wave speed and the speed of surface currents underlying the wave. The theoretical wave speed is calculated and subtracted out leaving the speed of the surface currents. Each antenna site supplies "radials" or current velocity information going directly towards or away from the antenna in all directions. Radial information from two or more sites is combined on a user defined grid in order to produce a map of total current velocities. Figure 1 displays the locations of the three land based radar sites as well as two National Data Buoy Center (NDBC) stations within the coverage area of the radar data.

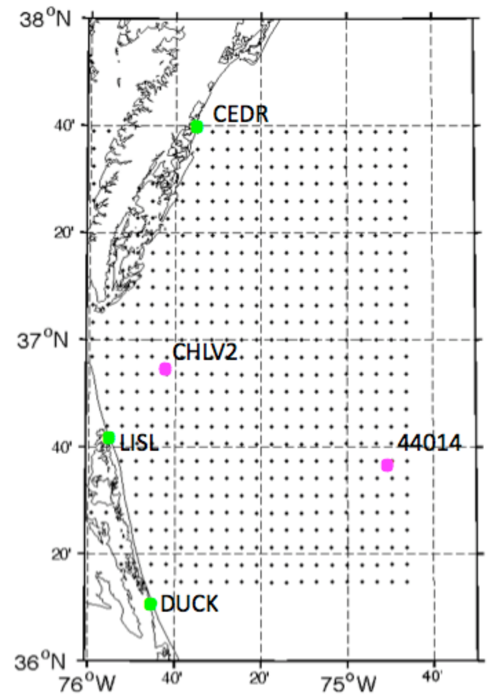

Fig. 1. Map of the study area showing radar stations (green), NOAA NDBC stations (pink) and grid point locations for total velocity vectors (black).

II. Radial Current Observations

A. Radial Coverage

The 5 MHz systems report radial velocities (toward and away from the receive antenna) in 5 degree directional bins at 6 km intervals. The percent radial coverage plots in Fig 2 generally show the highest concentrations of radials at closer ranges and for angular bins directed more offshore. Along the angular directions closest to the coast, the transmit signal

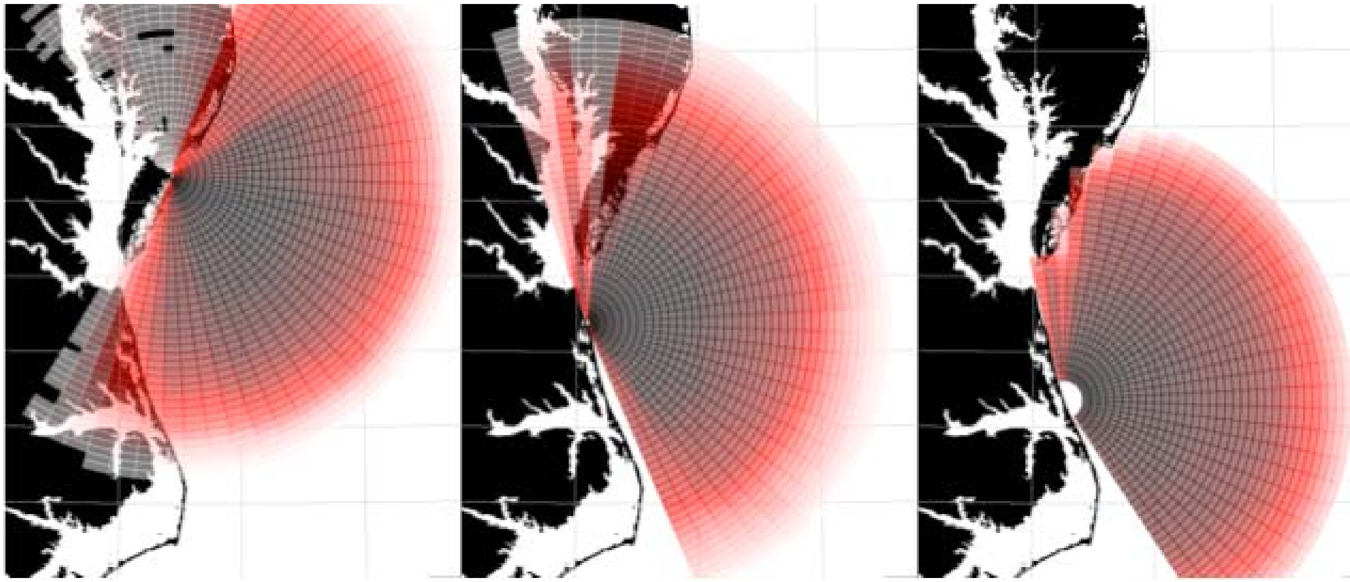

Fig. 2. Radial coverage maps for CEDR, LISL and DUCK (left to right). Darker colors represent greater percent coverage.

travels a greater distance over land and experiences more attenuation. The areas of poorer coverage immediately outside the Bay mouth lie within the baseline region where the geometry of vectors does not allow for reliable computation of total currents.

The study period was interrupted by the passage of Hurricane Irene. The DUCK radar station operated through the storm. Unfortunately there is a large gap in data from CEDR for the time period Aug 27 20:00 to Sep 06 19:00 UTC and data missing at LISL from Aug 27 13:00 to Aug 30 04:00 UTC.

B. Across-Shelf Flow

The east-west component of current measured by the LISL site is shown in Fig 3. This is a spatial average of currents over a range from the coast out to 72 kilometers. Positive values represent currents moving towards the coast.

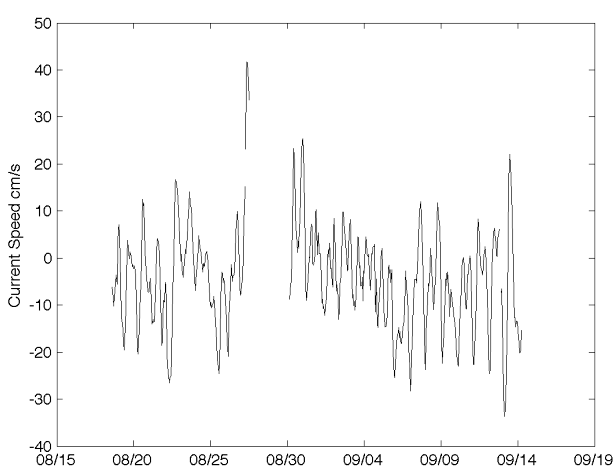

Fig. 3. Average east-west component of flow measured by LISL radar.

C. Comparisons with Buoy Data

Radials at the 5 MHz sites were compared with NOAA NDBC 44014 station ADCP data taken from the depth bin centered at 3.8 meters below the sea surface. For each radar station, comparisons were made with the directional component of the ADCP data aligned with the radial direction at the radial grid point closest to the buoy location. Distances from the buoy to the closest radials were 3.3, 2.6 and 1.4 kilometers for CEDR, LISL and DUCK respectively. Results for radials produced with ideal antenna patterns and measured antenna patterns are listed in Tables 1 and 2.

TABLE I. RADIAL COMPARISONS WITH BUOY 44014 ADCP DATA

Station	Comparison Statistics (Ideal Pattern)		
	# Values	***R2***	***RMS Difference cm/s***
CEDR	350	0.70	12.2
LISL	488	0.61	12.2
DUCK	596	0.76	13.9

TABLE II. RADIAL COMPARISONS WITH BUOY 44014 ADCP DATA

Station	Comparison Statistics (Measured Pattern)		
	# Values	***R2***	***RMS Difference cm/s***
CEDR	347	0.72	12.7
LISL	484	0.64	11.9
DUCK	602	0.75	13.4

D. Baseline Comparisons

A check of data consistency between two CODAR HF radar instruments is a comparison of data along the baseline, the line between the sites. Along this line the radial velocities ought to agree well in magnitude and have opposite signs. In particular, at the middle of this baseline, where the radial coverage areas are very similar, the data should match within the velocity errors of the measurements [1]. Correlations between DUCK and CEDR radials at the midpoint of the baseline between the stations were generally not as strong as correlations with the buoy data. The R^2 values were 0.45 (310 points) and 0.44 (229 points) for ideal pattern and measured pattern radials respectively. Root mean square differences were 24.2 and 22.8 cm/s.

III. Total Vector Current Observations

The radial data from the three radar sites were combined using a standard least squares technique to produce velocity vectors on a grid with approximate 6 kilometer spacing [2]. At each grid point, radial data falling within a radius of 10 kilometers were combined to generate the total vector for that location. This method of combining allowed for the calculation of an error estimate based on the geometric dilution of precision (GDOP) [2]. In the following analyses, only grid points with low error estimates, specifically GDOP values < 1.25, were included. Moreover, grid points had to contain data at least 80% of the time.

A. Regional Subtidal Flow

Data were low pass filtered with a 40 hour Butterworth filter to remove tidal effects and other high frequency components. The principal axes of the subtidal flow shown in Fig 4 indicate the influence of the Chesapeake Bay. The greatest variances in subtidal flow in the southern offshore section of the coverage area are directed more along-shelf. In the northern section of coverage, closer to the entrance of the Bay, the major axis of subtidal flow is oriented more in the east-west or across-shelf direction. The colors in Fig 4 represent the percent variance explained by the principal axes. At most locations, the principal axes explained more than 70% of the variance. Areas in the transition zone in the middle and northeastern areas have a slightly weaker relationship with the principal axis.

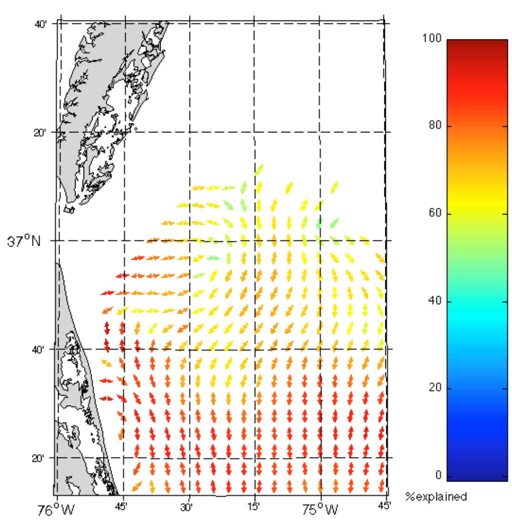

Fig. 4. Major axes of subtidal current data. Colors represent percent variance explained by the axes.

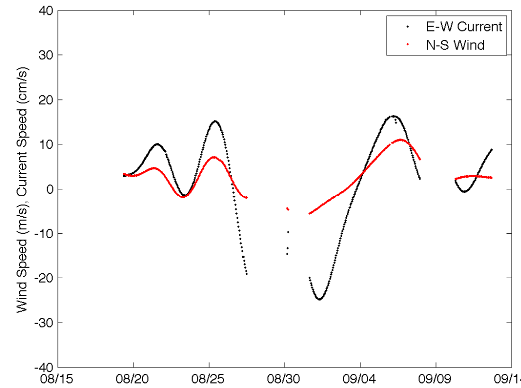

Fig. 5. The U component of spatially averaged mean sub-tidal current in the northwest section of the study area was compared to the north-south component of wind at CHLV2.

Subtidal flow was compared with wind speed at the NDBC Chesapeake Light station (CHLV2). Considering the distinct differences in flow within the region, a local spatial mean was calculated for the northwest section in order to make this comparison. Radar subtidal east-west currents were well correlated with the north-south component of wind (Fig 5). The R^2 value was 0.85 (N=431).

B. Comparison with Buoy Data

A comparison of unfiltered ideal pattern total currents with buoy 44014 ADCP currents is shown in Fig 6. Complex correlations, following Kundu 1975, gave a correlation amplitude of 0.60 and a correlation angle of 8.2 degrees. Simple correlations with U and V components yielded R^2 values of 0.65 and 0.49 (N=543) [3]. Root mean square differences were 11.6 and 16.8 cm/s. Results for the measured pattern total currents comparison were very similar. Complex correlations between measured pattern totals and ADCP data had a correlation amplitude of 0.60 and a correlation angle of 9.1 degrees. Correlations with U and V components had R^2 values of 0.64 and 0.54 (N=541). Root mean square differences were 11.6 and 16.1 cm/s.

C. Particle Trajectories

The particle trajectories shown in Fig 7 are based on unfiltered surface currents containing the tidal components and illustrate surface movement starting Aug 18 until particles exit the high data density coverage area of the radars.

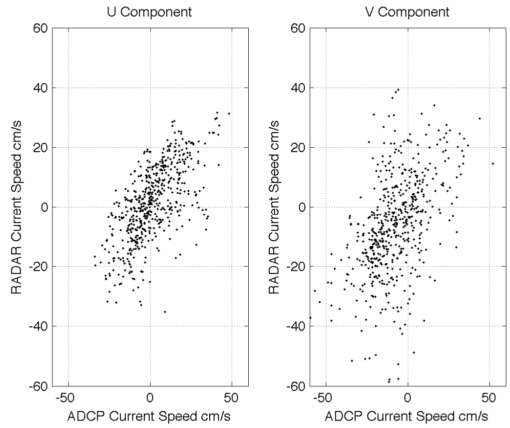

Fig. 6. Buoy 44014 ADCP at bin depth 3.8 meters plotted against unfiltered ideal pattern totals at grid location closest to the buoy.

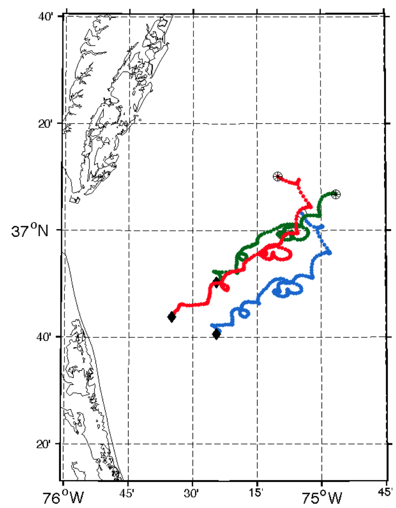

Fig. 7. Particle trajectories for three particles. Starting time is August 18 2011 14:00 UTC. The particles move out of range at Aug 27 14:00, Aug 26 10:00 and Aug 27 11:00 for the blue, green and red tracks respectively.

IV. Summary

HF radar radials and total velocity vectors showed good correlation with buoy 44014 ADCP measurements. In this study, ideal and measured pattern radials yielded similar results in comparison analyses. The principal axis of flow for the subtidal current within the study region is north-south in the southern offshore areas and east-west near the Chesapeake Bay mouth. Low pass filtered north-south winds were well correlated with the east-west component of local average subtidal currents in the northwest section of the study area.

Acknowledgment

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