Extreme and Non-Tidal Events in the Chesapeake Bay High Frequency Radar Surface Currents Record

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***Abstract*— The lower Chesapeake Bay high frequency radar (HFR) surface currents record now spans more than eight years from April 2007 to present day. In that time, the surface circulation has been observed during the passage of severe storms and other significant non-tidal events including those associated with periods of sustained high winds, high volume river discharge and complete reversals of tidal current direction. Tides are the dominant forcing mechanism for currents in the area; however, this paper focuses on the frequency and characterization of events representing the largest deviations from tidal flow. The data record is scrutinized during the passage of significant named storms including Ida (2009), Earl (2010), Irene (2011), Sandy (2012) and Arthur (2014).**

Storm events can disrupt data flow in observational networks for various reasons. Equipment may suffer damage and the power supply to equipment may be interrupted. Radar station outages and surface current map data quality are evaluated when storms passed through the area. For completely different reasons related to the complexity of the physical forcings, extreme events often present challenges for numerical modeling. An anticipated benefit of this study is that insights gained by describing the important non-tidal episodes may serve as a starting point for future work in analyzing the performance of numerical models and improving predictive capabilities for these events.

***Keywords*—surface circulation; currents; high frequency radar; Chesapeake Bay.**

I. Introduction

The Chesapeake Bay radar network effectively measures surface current in the upper meter of the water column for an area of roughly 200 square kilometers inside the Bay mouth. Surface current velocity maps are generated by combining radial velocity data collected at two to four radar stations, depending on which stations are operating at any given time. The velocity vectors are calculated on a two kilometer spaced grid. Maps are produced each hour and represent a 75-minute window of data collection. The data are collected for dissemination in near real-time as part of the Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS).

Oceanographic and meteorological data collected by NOAA's Physical Oceanographic Real-Time System (PORTS) in the lower Chesapeake Bay provide context for the present research. PORTS data including water levels, winds and currents are used to identify periods of and causes of non-tidal events. Acoustic Doppler Current Profiler (ADCP) data offer a separate independent measurement of currents at three different locations within the footprint of the radars.

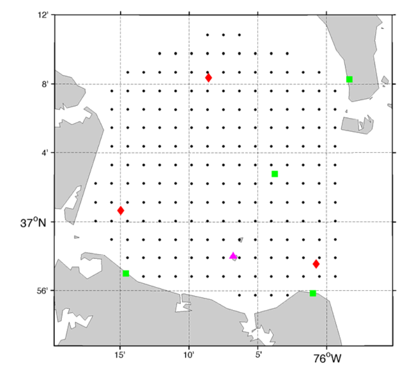

Fig. 1. Map of the study area showing radar stations (green squares), the NOAA Chesapeake Bay Bridge Tunnel station (pink triangle), NOAA ADCP stations (red diamonds) and grid point locations for radar velocity vectors (black dots).

II. Methods

A. Radar Data

Hourly surface current maps have been calculated from the radial velocity observations of radar stations located at the Chesapeake Bay Bridge Tunnel (CBBT), Ocean View Community Beach (VIEW), Cape Henry (CPHN) and Sunset Beach Resort (SUNS) (Fig. 1). Gridded vector maps of currents represent the velocity in the upper meter of the water column and were computed by an un-weighted least squares method of combining radial velocity data using standard routines from the Matlab HF radar community toolbox HFR-

Progs. The grid used is a subset of the National HF Radar Network 2 kilometer spaced grid for the U.S. East and Gulf coast. Only grid points inside the Bay mouth are considered for analysis.

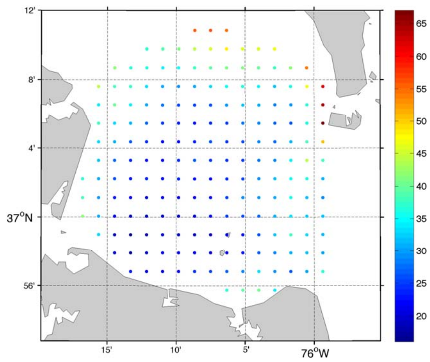

Fig. 2. Major axis percentage of variance for the residual time series after tidal analysis.

Velocities associated with geometric dilution of precision error estimates greater than 1.25 were discarded and replaced with spatially interpolated values using a linear interpolation method. Following this procedure, a percent coverage was calculated for each grid point and those locations where data was missing over 20 percent of the time (excluding time steps with no maps) were not analyzed further.

A linear temporal interpolation was performed on this reduced data set to fill in missing values for time gaps lasting no longer than three hours. In the case of longer time gaps, a tidal prediction generated using tidal constituents from a harmonic analysis of 2013 data was used to fill in missing values. The 2013 data were chosen because this year had the least number of data gaps as well as the highest numbers of vector counts in the map files.

A harmonic analysis of the currents time series at each grid point using t_tide shows that for most of the coverage area 20-40% of the current velocity variance is not explained by tidal forcing (Fig. 2) [1]. This provides a context upon which to view individual non-tidal events. In the middle of the coverage area, the mean for the entire data record is 8.3 cm/s on the major axis (positive values for ebb current) and the standard deviation is 40.35 cm/s.

The following section describes the surface current deviations from predicted tidal current during five named storm events: Ida, Earl, Irene, Sandy and Arthur. The most significant non-tidal effects in terms of currents are seen during Ida and Arthur. All of the times given in the text below and in the figures are UTC time.

III. Storm Events

A. Ida

Ida was a Gulf of Mexico hurricane that became extra-tropical as it reached the U.S. Gulf coast but as the storm broke up and moved northward, its impacts combined with another low pressure system that affected the East Coast for several days [2]. Around 18:00 on November 11, 2009, the effects of the storm appear in the data record (Fig. 3). At that time, the observed flow begins to significantly deviate from predicted

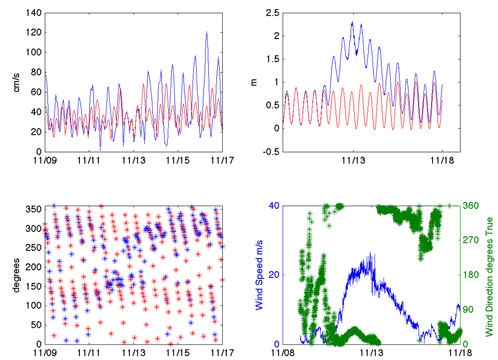

Fig. 3. Observations during Ida. The top left and bottom left panels are radar speed and direction for the middle of the Bay coverage area (observations in blue and tidal current predictions in red). The top right panel shows NOAA PORTS Bay Bridge Tunnel station observed (blue) and predicted (red) water levels. Wind speed and direction at the same NOAA station are shown in the bottom right panel.

flow and there is a persistent surface flow into the Bay driven by winds from the north northeast. There are current direction changes to the south and then more flow into the Bay. Water levels rise well above their predicted level and by the second high tide late on November 12 waters at the NOAA Bay Bridge Tunnel station are 1.5 meters higher than predicted. Another flow pattern of faster than predicted ebb flows takes over for the next several tidal cycles as water levels slowly decrease. The maximum ebb flow differences were mostly in the range of 40-50 cm/s and the ebb was 70 cm/s faster than predicted on November 16 2009.

The CPHN radar station went offline on November 14 03:30, but the CBBT and VIEW stations remained operational for the duration of the storm event. ADCP data from the NOAA station near Cape Henry shows similar patterns. The current speeds are faster in the ADCP data record. Differences between the radar and the ADCP data could possibly be explained by differences in the spatial and temporal sampling but further investigation is needed.

B. Earl

Earl was a category 4 hurricane at its peak intensity on September 2 approximately 440 miles southeast of Wilmington, NC and it weakened quickly to a category 1 strength by September 3 as it moved away from the coast [3]. The effects of the storm are seen in the Chesapeake Bay data water level record and the winds pick up significantly on September 3 (Fig. 4). Water levels were higher than predicted but there was much less of a difference between observed and predicted than in the case of Ida. The high water levels were 0.26 to 0.39 meters higher than predicted on September 3-4. Faster than predicted ebb currents (26 to 57 cm/s faster) occurred on September 4 and 5.

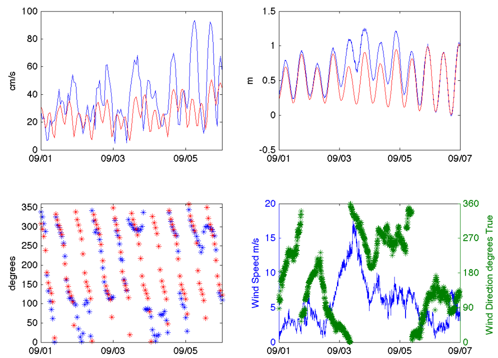

Fig. 4. Observations during Earl. Refer to Fig 3 for panel description.

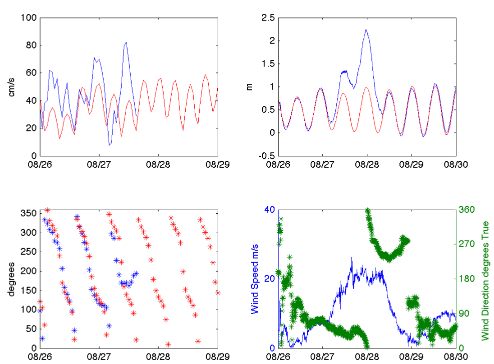

Fig. 5. Observations during Irene. Refer to Fig 3 for panel description.

C. Irene

Irene weakened before it hit the North Carolina coast near Cape Lookout with winds of category 1 strength on August 27 12:00. The storm then followed a path offshore of the coast of the Eastern Shore before coming inland again near Atlantic City, NJ on August 28 9:35 [4]. Unfortunately the radar record is not complete for Hurricane Irene. The CPHN station went offline at Aug 27 15:30 and data at the SUNS station begins to look suspect shortly after. Before the radar data are lost, there is a recorded flood of 82 cm/s, which is 40 cm/s faster than the tidal current prediction (Fig.5). The latest radar maps show the water being pushed into the Bay and the two high water levels on August 27 are 0.49 and 1.26 meters over the predicted tide level.

D. Sandy

Hurricane Sandy was located a few hundred miles southeast of North Carolina on October 28 2012. Its track turned to the north instead of going out to sea; it strengthened and hit land near Atlantic City, NJ early on October 29 [5]. The storm did not have as much impact on tidal currents in the lower Chesapeake (Fig. 6). The major effects are seen in water levels and winds.

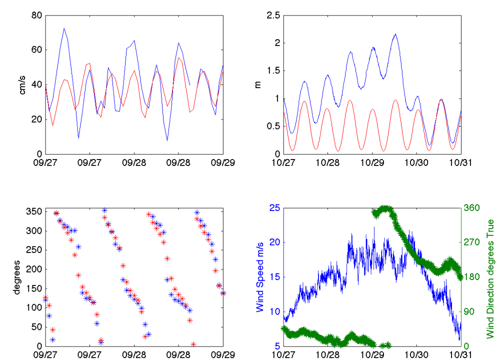

Fig. 6. Observations during Sandy. Refer to Fig 3 for panel description.

E. Arthur

Arthur reached hurricane status off the coast of Georgia on July 3 and by July 4 was at a peak intensity of 85 knots offshore of North Carolina. The hurricane passed over the Outer Banks and then veered off to the northeast heading into the Atlantic late on July 4 [6]. Water levels were higher than normal at the Bay Bridge Tunnel on July 4 and 5 (Fig. 7). There is a prolonged ebb current on those days and the ebb speed reaches 118 cm/s, which is 80 cm/s faster than the tidal current prediction.

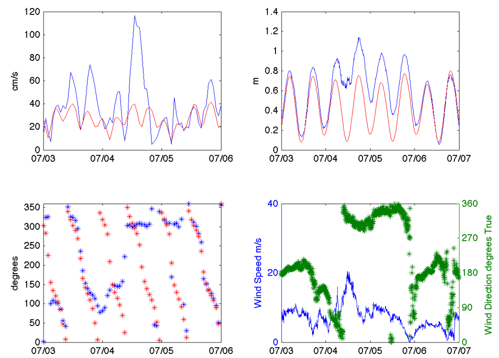

Fig. 7. Observations during Arthur. Refer to Fig 3 for panel description.

IV. Discussion

Collecting observations during extreme events is challenging. During Ida and Irene, radar stations lost power. Under high wave conditions, the radar spectra can also become saturated making it difficult to extract the first order Bragg signal for processing. Background noise levels in the radar spectra increase during extreme events, which can negatively impact signal to noise and if the radar station processing is not able to correctly distinguish first order echo from background or other noise in the Doppler spectra, then the data will be unreliable. It is important to carefully check the radar spectra and radial data during storm events.

V. Conclusions

The surface flow in the lower Chesapeake Bay is largely dominated by tidal flow but non-tidal influences are also important. Future work will focus on looking at other significant non-tidal events over the entire data record in context with ADCP, wind and river discharge data.

Acknowledgment

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References

[1] R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical Tidal Harmonic Analysis Including Error Estimates in MATLAB using T_TIDE," *Computers and Geosciences*, 2002.

[2] L. A. Avila and J. Cangialosi, "Tropical Cyclone Report Hurricane Ida (AL112009)," National Hurricane Center, Jan 1 2010.

[3] J. Cangialosi, "Tropical Cyclone Report Hurricane Earl (AL072010)," National Hurricane Center, Jan 13 2011.

[4] L. A. Avila and J. Cangialosi, "Tropical Cyclone Report Hurricane Irene (AL092011)," National Hurricane Center, Dec 14 2011.

[5] E. S. Blake, *et al*. "Tropical Cyclone Report Hurricane Sandy (AL182012)," National Hurricane Center, Feb 12 2013.

[6] R. Berg, "Tropical Cyclone Report Hurricane Arthur (AL012014)," National Hurricane Center, Apr 20 2015.