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Shelf circulation prior to and post a cold front event measured from vessel-based acoustic Doppler current profiler

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ABSTRACT

Shelf circulation impacted by a shift in wind regime during the passage of an atmospheric cold front system is studied with a field survey over the mid-shelf of the South Atlantic Bight between Oct 4 and 9, 2004. Weak southerly winds preceded the cold front for a few days, followed by a rapid shift in wind direction and strengthening of northeasterly winds over a few more days. More than 93 h of acoustic Doppler current profiler (ADCP) data were obtained along an equilateral triangle of 105 km in perimeter, which was continuously occupied for 11 times. A harmonic analysis was applied to extract tidal and subtidal wind-driven flow components by collapsing the 93 hour data into one M2 tidal period. It was found that the cross-shelf flow was barely affected by the wind while the along-shelf flow responded with a spatially uniform and almost steadily increasing mean flow velocity, superimposed on an oscillatory tidal current. The wind induced along-shelf transport was estimated to be ~0.3 Sv over the inner and middle shelf. The net cross-shelf transport was negligible. Apparently, the northeasterly wind causes an along-shelf current which was subject to Coriolis force that sets up an increasing coastal sea level pressure gradient as the water kept piling up against the coast, which was confirmed by tide gauge data. The observations found that the flow field prior to the strong winds had more complicated structures including eddy-like features, while after the strong northeasterly winds, the flow became eddy free and uniform in space. A theoretical model solved by a Laplace Transform was used to examine the wind-driven flow mechanism and the results were compared with the observations of net along-shelf flow velocity.

1. Introduction

The mid-latitude synoptic weather systems frequently move along the US continent roughly from the northwest to the southeast (and sometimes back to the northeast along the edge of the east coast, particularly with severe storms). One of the major processes within such weather systems is the atmospheric cold front, which is often preceded with a warm air mass characterized by moist and relatively warm southerly winds. As the cold front approaches, air pressure drops and precipitation may occur. After the passage of the front, the air pressure starts to increase again; air temperature drops quickly with the drop of humidity; the sky clears and the wind shifts to northerly. The shift in wind regime can have a significant effect on the flushing of bays (e.g. Feng and Li, 2010; Li, 2013), saltwater intrusion (Li et al., 2011), and sediment transport (e.g. Walker and Hammack, 2000). On the shelf, wind in general (whether it is from a cold front system or not) is mainly responsible for the generation of along-shelf currents and its effect on the cross-shelf transport is usually found to be small (e.g. Mitchum and Sturges, 1982), even with a cross-shelf wind component. Gill and Schumann (1974) showed that the along-shelf current on the coast was proportional to the maximum along-shelf wind stress for idealized square wave wind forcing and propagating oscillatory wind forcing.

Much of the observational data of early studies on wind-induced flows were obtained in large lakes. For example, Csanady (1973) showed that the "initial" period of the depth-integrated transport in "long lakes" increased linearly with time, followed by a frictional effect, which slowed down the increase subsequently. Although the cross-shelf transport is generally considered to be negligible, some model studies (Tilburg, 2003) suggest that the cross-shelf velocity influenced by cross-shelf wind may be significant on the surface, facilitating the onshore or offshore transport of surface water and waterborne materials. Observational data of such along-shelf and cross-shelf flows, especially those during wind events over an area on the shelf, resolving spatial structures, are however scarce. The impact of this dynamical change on the spatial structure of shelf circulation has not been explicitly investigated with a field survey during a frontal passage, which is the subject of this study.

The main objective of this study is to determine the flow field, including its spatial and temporal variabilities, over the mid-shelf affected

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by wind with vessel-based observations. Our flow data obtained in the South Atlantic Bight (SAB) spanned over a 93-hour period between October 4 and October 9 of 2004 before and after a cold front passage that brought a strong northeasterly wind. In this paper, we will examine both the along and across-shelf flows and spatial structures in response to the wind forcing. A vessel-based observational study in the SAB mid-shelf for spatial characteristics encompassing a cold front event has not been reported before. This is largely due to the fact that most vessel-based surveys try to avoid adverse weather, not to mention a prolonged survey under stormy conditions.

2. Study area and observations

The study area is at the SAB (Fig. 1a). This area has a strong semi-diurnal tide over a broad inner- and mid-shelf: about 80% or more of the tidal energy is semi-diurnal. The mid-shelf is also strongly influenced by wind (Atkinson and Menzel, 1985; Atkinson et al., 1983). Tidal motion is mostly onshore–offshore, i.e. in the cross-shelf directions. In contrast, the mean water transport is mostly along the shelf (Lee et al., 1991) although episodes of apparent cross-shelf transport have been suggested based on satellite observations in winter–spring time (Chen, 2000; Chen et al., 1999; Li et al., 2003).

Aimed at the quantification of the along and cross-shelf transports, we conducted a survey on a 92-ft research vessel R/V Savannah between Oct 4 and Oct 9, 2004. We continuously obtained velocity profile data along an equilateral triangle, which was repeatedly occupied, in the mid-shelf (20–40 m in depth) around 31.6° N and 80.5° W with a perimeter of 105-km in length (Fig. 1a). A 300 kHz RD Instruments acoustic Doppler current profiler (ADCP) mounted at the bottom of the vessel was used in the survey. In addition to the measurements of the velocity profiles, a surface thermosalinograph (SBE 21) was used to record surface temperature and salinity continuously. An SBE 25 was also used to measure the vertical profiles of water temperature and salinity. The vertical bin size for the ADCP was set to be 1 m. The first useful data point near the surface was about 4.5 m below the surface (after excluding the depth of the ADCP and the blanking distance). Vessel speed was maintained at 5–8 knots to ensure the ADCP data quality. Data were averaged with an interval of 90 s. We had a total of 11 repetitions along the triangle in a 93-hour period. On average, we have only about 1.4 data points along the triangular transect within each 12 hour semi-diurnal tidal period. These data points are thus sparse and they are not enough for resolving the tidal constituents if a conventional Fourier analysis is applied based on the sampling theorem (e.g. Proakis and Manolakis, 1992).

Weather maps (Fig. 2) from NOAA showed that prior to the survey on Oct. 2 and Oct. 3, a couple of cold fronts were approaching the coast from inland moving toward the east–southeast. During this pre-frontal time, southerly winds dominated, as often the case (e.g. Hsu, 1988; Li, 2013; Li et al., 2011; Roberts et al., 1989; Walker and Hammack, 2000). Time series data from a nearby NOAA buoy (NOAA

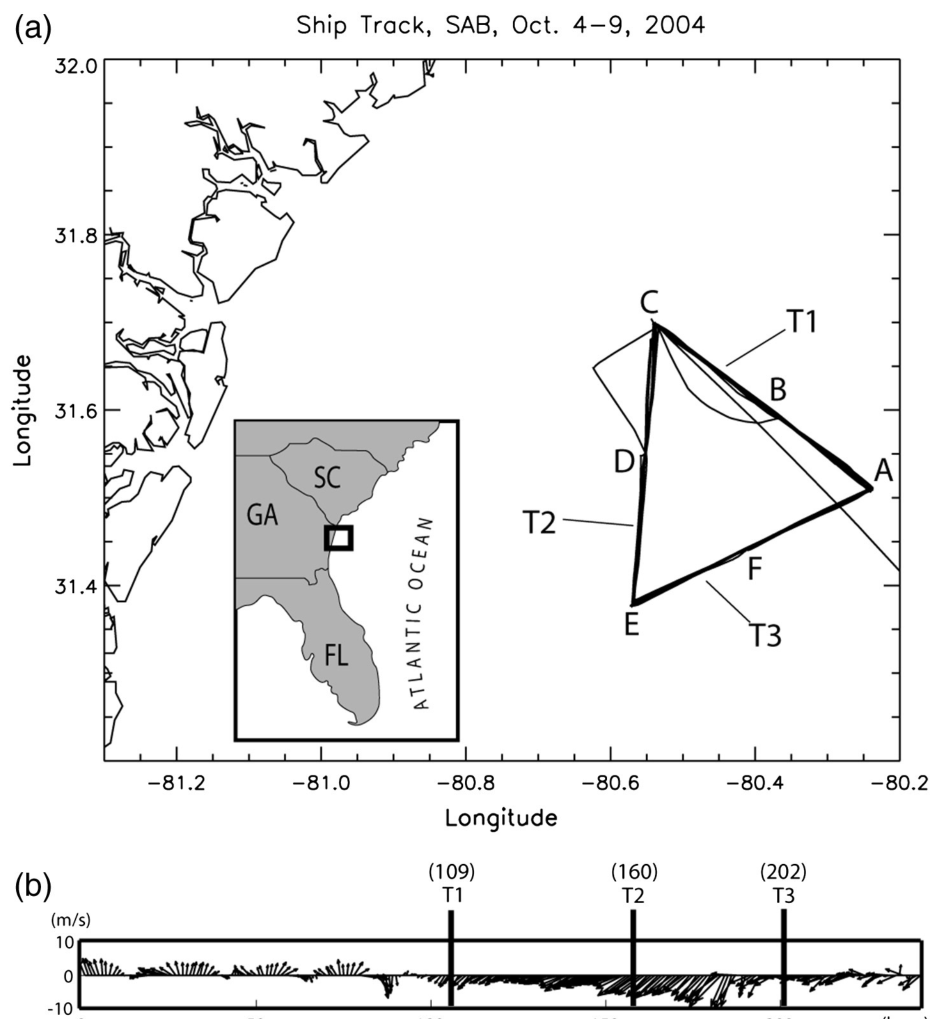

Fig. 1. (a) Study area and the ship track of the observations. The lines that roughly form a triangle are the actual ship tracks. The letters A through F indicate the stations for CTD casts. The timing of these casts is shown in Table 1. (b) The wind vector during the observations (data obtained from NOAA buoy 41008). T1, T2, and T3 represent transects 1, 2, and 3, respectively.