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Variability in along-shelf and cross-shelf circulation in the South Atlantic Bight

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ABSTRACT

Variability in along-shelf and cross-shelf circulation in the South Atlantic Bight (SAB) is investigated using altimetry observations. Satellite-derived along-shelf velocity anomalies are in good agreement with independent near-surface current measurements from moored acoustic Doppler current profilers and surface velocities from high frequency radar at adjacent locations. This is especially true if wind-driven Ekman velocities are added to the geostrophic velocities, suggesting that the influence of Ekman dynamics to surface along-shelf flow in the SAB is unusually large. The decade-long time series reveals substantial seasonal variability in surface velocities, with peak poleward anomalies during late spring and summer and strong equatorward flow during autumn. Convergences and divergences in the along-shelf transport between two cross-sections are compared with three-dimensional numerical model results and used to estimate cross-shelf transport across the 50 m isobath in the SAB. The calculation suggests a pattern of weak offshore flow during spring followed by prolonged and relatively stronger offshore flow during summer and early autumn, while cross-shelf velocity anomalies during winter are weak and slightly onshore. Prolonged offshore flow following the peak in river discharge that generally occurs in spring indicates the potential for the establishment of a conduit for offshore export of riverine material. The long-term time series also reveals several large events of interannual variability, including the 2003 cold event observed in the SAB.

1. Introduction

Off the U.S. Southeast Coast, the South Atlantic Bight (SAB) is characterized by a wide continental shelf bounded between the coastline and the 60 m isobath, varying in width from a minimum of 30 km off Cape Hatteras to a maximum of 120 km off the Georgia coast and then narrowing again off the Florida coast to 50 km (Atkinson et al., 1983). The Gulf Stream is found immediately adjacent to the continental shelf. Along the coast, nine major rivers deliver freshwater to the continental shelf with an annual mean of 2000 m^3s^{-1}, peaking in spring (Blanton and Atkinson, 1983). With respect to dynamics, the SAB shelf is thought to be strongly influenced by buoyancy input on the inner shelf, by wind forcing on the mid-shelf, and by the Gulf Stream on the outer shelf (Blanton, 1981; Lee and Atkinson, 1983; Lee et al., 1991).

Long-term *in situ* measurements (especially of velocity) are relatively sparse in the SAB, despite several field programs over the last decades (e.g., GABEX (Lee and Atkinson, 1983), GALE (Blanton et al., 1987), FLEX (Werner et al., 1993) and CORE (Lee et al., 1989)). Using drift-bottle and moored current meter observation, Bumpus (1973); Weber and Blanton (1980) and Atkinson et al. (1983) suggested that surface flow generally follows the seasonal wind regime in the SAB region, which is strong poleward during summer, equatorward in fall, and offshore in winter. Along-shelf volume transport has been estimated during several field programs using current meter data from moorings or ship-based transects. Using year-long mooring observations off St. Augustine, FL, Lee et al. (1985) showed that the typical instantaneous along-shelf volume transport is 0.3–0.4 Sv (1 Sv=10^6 m^3s^{-1}), reaching a maximum of 0.85 Sv between the 15 m and 70 m isobaths during an intense event in early March.

Cross-shelf transport plays an important role in shelf circulation, helping control the fate of freshwater delivered by rivers (and as such influencing salinity variability and density gradients over the shelf), exporting river-borne contaminants, nutrients and carbon, flushing inshore water and thus ultimately influencing shelf-slope exchange. Since cross-shelf velocities are at least one order of magnitude smaller than along-shelf velocities and are highly variable along the continental shelf, quantifying cross-shelf volume transport is very challenging. This

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is especially true for the SAB, where the availability of observations is relatively small. The characteristics and mechanisms controlling cross-shelf transport over the SAB shelf have therefore been severely understudied. Using wind-driven model solutions, Blanton et al. (2003) estimated that the surface flow is onshore during January and offshore during July along the 70 m isobath. Seim et al. (2008) used point-measurements from two moorings off Georgia spanning four years (2000–2003) to show that, at those two locations, net flow was offshore during summer. During fall and winter, the net cross-shelf flow at those two locations was found to be small, characterized by onshore flow in the upper half of the water column and by offshore flow in the lower half (Seim et al., 2008).

Although sampling frequency and coverage have improved substantially over the last decade or so (e.g., South Atlantic Bight Synoptic Offshore Observational Network - SABSOON, Seim (2000); Southeast Coastal Ocean Observing Regional Association - SECOORA), with multiple buoys, moorings and high-frequency (HF) radar systems collecting observations of wind, temperature, salinity and velocity, the SAB region remains under sampled compared to other coastal regions in the United States (e.g., California Current System, Middle Atlantic Bight). As such, long-term satellite altimetry provides a great opportunity to investigate variability in shelf circulation using sea surface height (SSH) information. Altimeter-derived SSH has been successfully used in various investigations of long-term characteristics of coastal near-surface geostrophic currents over the last few years (Han, 2007; Vignudelli et al., 2005). Comparisons with *in situ* acoustic Doppler current profiler (ADCP) and/or high frequency radar measurements demonstrated that altimeter-derived surface velocities are capable of representing near-surface currents in coastal systems (Strub and James, 2000; Powell and Leben, 2004; Vignudelli et al., 2005), especially when improved post-processing algorithms or re-track techniques that allow for along-track SSH data to be obtained much closer to the coast (Han et al., 1993, 2002; Han, 2004; Vignudelli et al., 2005). While many of those efforts were focused on narrow continental shelves, Liu et al. (2012) and Strub et al. (2015) recently showed that similar approaches can be successfully adopted over wide continental shelves. Here, we use 12 years of continuous altimeter data to investigate variability in along-shelf circulation and to obtain, in combination with model results, a measure of non-local cross-shelf exchange in the SAB region for the first time. The geometry of ground tracks in the SAB (Fig. 1) allows for estimating cross-shelf transport by computing the difference in along-shelf transports between two cross sections. Limitations of the calculation and possible implications of the assumptions used here are also discussed.

2. Data and methods

2.1. Satellite altimetry

The altimetry data used here were processed and distributed by Radar Altimeter Database System (RADS: http://rads.tudelft.nl/). The sea level data for Jason-1 (J1: 2002–2008) and Jason-2 (J2: 2008–2013) missions provide a 12-year long-time series with 9.9156-day exact repeat. Data from the predecessor TOPEX/Poseidon (T/P) mission were not used in the present study because of the relatively larger cutoff close to the coast due to the use of a radiometer with larger footprint, which results in a wider band near the coast where observations are not available [*Remko Scharroo, personal communication*]. The percentage of missing data inshore of 50 km from the coast increases from approximately 10% during J1 and J2 period to about 50% in T/P mission. RADS is based on the use of 1 Hz estimates of sea surface height (SSH), corresponding to a 6 km along-track resolution. Several previous studies have successfully used 1 Hz or higher frequency along-track observations (e.g., RADS; X-TRACK, produced by Center de Topographie des Océans et de l′Hydrosphére (CTOH) at 1 Hz or 10 Hz) to investigate circulation in multiple coastal settings (Birol et al., 2010; Le Hénaff et al., 2011; Liu et al., 2012; Strub et al., 2015). Comparisons between sea level anomalies in the SAB between RADS 1 Hz and X-TRACK 1 Hz data show that they are highly correlated to each other. The standard corrections used (e.g., instrument effects, orbit errors, dry and wet tropospheric effects, ionospheric effects, sea state bias, tides), as well as detailed altimeter data pre-processing and database content, are described in Scharroo et al. (2013).

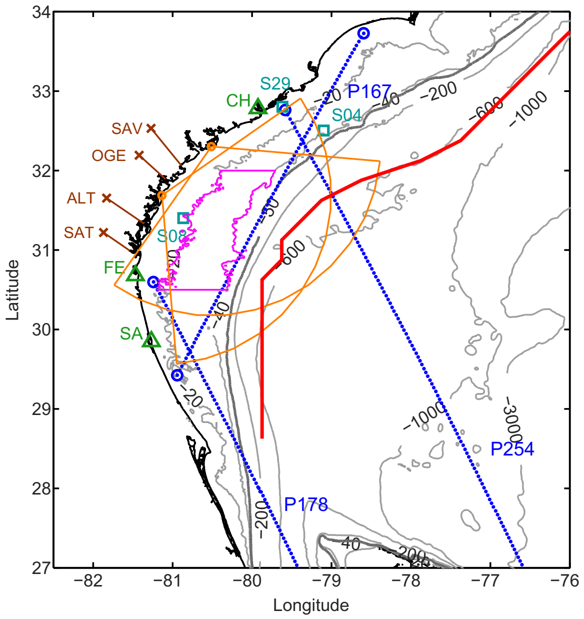

Fig. 1. South Atlantic Bight region showing altimeter ground tracks of Jason1 and Jason2 phase A. Tracks with valid data are shown by blue dots, with the first valid point near the coast indicated by blue circles. The 20, 40, 50, 200, 600, 1000, 3000 m isobaths are shown in gray, with the thick gray line indicating the 50 m isobath. NDBC buoys with buoy numbers are shown by cyan squares. HF radar coverage is shown by orange arcs, while the area used in the present study is indicated using magenta lines. Four major rivers located between Charleston (CH), South Carolina and St. Augustine (SA), Florida are shown by the brown lines along the coast, with the cross markers indicating the USGS stream site location. SAV: Savannah River; OGE: Ogeechee River; ALT: Altamaha River; SAT: Satilla River. The mean Gulf Stream position during 2002–2013, averaged over 1 latitudinal bins, is indicated by the red thick line. Locations of tide gauges are shown by the green triangles. FE: Fernandina Beach.

Two descending (P254 and P178) and one ascending (P167) satellite ground tracks were used in the present analysis (Fig. 1). The angle between the along-shelf direction, obtained by fitting a straight line through a 100 km section of coastline centered at Charleston, and the direction across track P254 is small (3°). Therefore, we consider the along-shelf and the cross-track directions for P254 as equivalent in this paper. The other descending ground track (P178) is almost parallel to the coast to the south of Fernandina Beach. The ascending ground track P167 provides additional information to the cross over descending tracks.

A single time series from January 2002 to December 2013 was constructed from J1 and J2 time series at each spatial location along each altimeter track. The average difference between J2 and J1 time series estimated during the period when both satellites flew in the same orbits with 1 min lag (15 July 2008–19 January 2009; 0.64 cm) was added to the J2 time series. During the period when the two satellites flew in the same orbit, J1 SSH data were always used. Finally, the 12-year temporal mean (estimated between January 2002 to December 2013) at each location was removed to obtain the full sea level anomaly (SLA) time series. SLA data that exceeded three sample standard deviations at each location were eliminated. The low-frequency component of the SLA time series, which captures seasonal and interannual variability, was calculated by applying a 120-d low-pass filter to the full SLA data.