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Seasonal and interannual cross-shelf transport over the Texas and Louisiana continental shelf

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ABSTRACT

Numerical drifters are tracked in a hydrodynamic simulation of circulation over the Texas-Louisiana shelf to analyze patterns in cross-shelf transport of materials. While the important forcing mechanisms in the region (wind, river, and deep eddies) and associated flow patterns are known, the resultant material transport is less well understood. The primary metric used in the calculations is the percent of drifters released within a region that cross the 100 m isobath. Results of the analysis indicate that, averaged over the eleven years of the simulation, there are two regions on the shelf – over the Texas shelf during winter, and over the Louisiana shelf in summer – with increased seasonal probability for offshore transport. Among the two other distinct regions, the big bend region in Texas has increased probability for onshore transport, and the Mississippi Delta region has an increase in offshore transport, for both seasons. Some of these regions of offshore transport have marked interannual variability. This interannual variability is correlated to interannual changes in forcing conditions. Winter transport off of the Texas shelf is correlated with winter mean wind direction, with more northerly winds enhancing offshore transport; summer transport off the Louisiana shelf is correlated with Mississippi River discharge.

1. Introduction

Cross-shelf transport is important for understanding when and where seaborne material – for example spilled oil, harmful algae, or sargassum patches – may reach the coastline. Additionally, complementary processes cause river-borne materials and biogeochemical constituents to be transported offshore (e.g., Bianchi et al., 2013). Alongshore currents are generally observed to be much larger than cross-shelf currents; relatively small cross-shelf flow is an assumption underlying most coastal ocean circulation theory (e.g., Brink, 1991). Alongshore currents over the Texas-Louisiana shelf are predictable, responding rapidly and strongly to alongshore winds (Zhang et al., 2014). While the processes that control alongshore transport are relatively well characterized, cross-shelf circulation patterns are generally not. Further, the resultant material transport due to the combined along- and across-shelf dynamics is yet less well-characterized. Cross-shelf circulation patterns over the Texas-Louisiana shelf are complex, and are driven by processes such as convergent alongshore currents due to wind and modulated by fresh river water (Cochrane and Kelly, 1986; Cho et al., 1998; Zhang and Hetland, 2012), small-scale eddies over the shelf within the river plume (Marta-Almeida et al., 2013; Hetland, 2017b), and interactions with large-scale eddies that sit off the shelf (Oey, 1995; Ohlmann and Niiler, 2005; Walker, 2005). Patterns indicative of cross-shelf transport are occasionally visible in satellite data in both the winter and summer seasons (Fig. 1).

Offshore transport by mesoscale and sub-mesoscale activity is well documented in upwelling regions around, for example, the US west coast (Marchesiello et al., 2003; Combes et al., 2013), the Iberian peninsula (Rossi et al., 2013; Bettencourt et al., 2017), the eastern Australian coast (Archer et al., 2017), and in eastern boundary upwelling regions in general (Capet et al., 2008). In contrast, river plumes are known to carry materials along shore (Hetland and Signell, 2005, e.g), but are generally not considered to be independent major drivers of offshore transport outside of the ‘bulge’ region (Horner-Devine et al., 2015). One reason for this is that river plumes move off- and onshore primarily in response to up- and downwelling winds (Hetland, 2005; Chant et al., 2008; MacCready et al., 2009). The Mississippi/Atchafalaya River plume is an exception. Unlike other river plumes (Horner-Devine et al., 2015), the Mississippi/Atchafalaya plume is subject to baroclinic instabilities during summer (Hetland, 2017b), generating a strong eddy field that is a significant source of variability in surface salinity (Marta-Almeida et al., 2013), with the potential to induce strong offshore transport in a manner analogous to instabilities – jets, squirts and filaments – present in upwelling systems.

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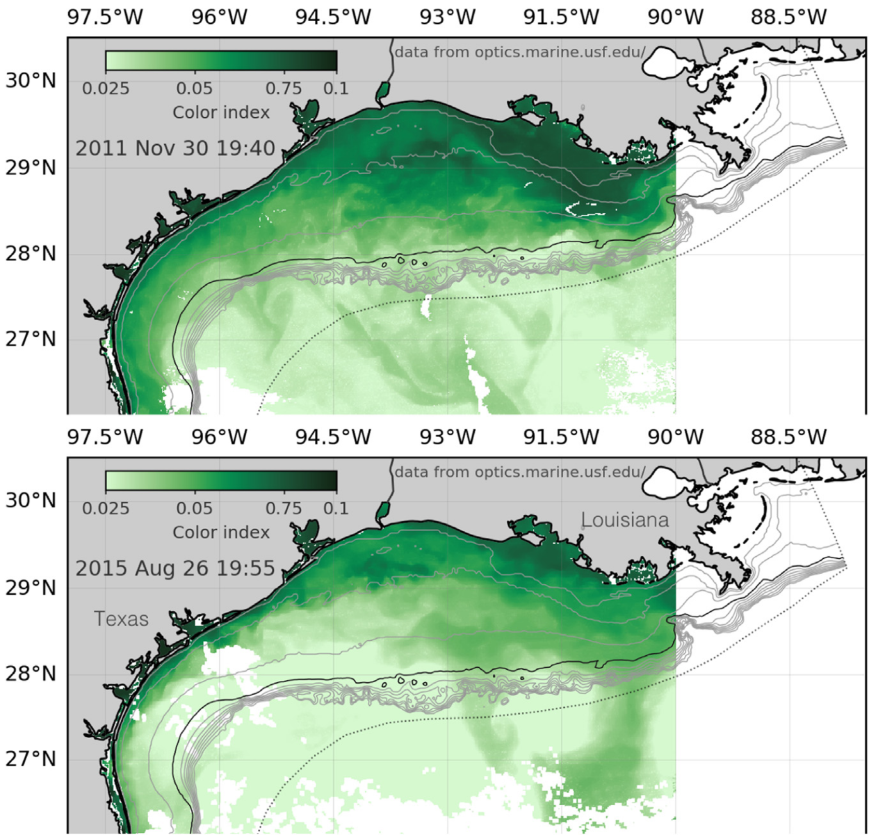

Fig. 1. Evidence for cross-shelf transport is visible in color index satellite data in both the winter and summer. Data algorithm from Hu (2011) and distributed by Hu et al. (2014). Gray lines indicate the 10, 20, 50, 150, 200, 250, 300, 350, 400, and 450 m isobaths, and the black line is the 100 m isobath. The dotted line indicates the extent of the numerical domain.

The Texas-Louisiana continental shelf break is a barrier to transport due to the strong bathymetric gradients, as planetary vorticity inhibits cross-bathymetric flow (e.g., Cushman-Roisin and Beckers, 2011). Additionally, the constraint of no cross-shore flow at the coast generally inhibits cross-shore flow in waters near the coast; because of this, there is relatively weak cross-shelf exchange over much of the inner shelf. The shelf break serves as a boundary between different dynamical regions, also inhibiting cross-shore exchange. Thus, the inner-, outer-, and off-shelf regions all have distinct dominant forcing mechanisms, and interaction between these regions is often limited (Nowlin et al., 2005). Inshore of the 50 m isobath – the inner shelf – wind forcing dominates the circulation dynamics. The region between the 50 and 100 m isobaths – the outer shelf – is a transition region where mesoscale eddies influence the circulation and winds are also important. Offshore of the 100 m isobath, at the start of the shelf break, the mesoscale eddies in the deep Gulf dominate and the effect of wind-driven coastal currents is negligible. Discharge from the Mississippi and Atchafalaya Rivers can span the continental shelf area, transiting all three regions.

The circulation in the northern Gulf of Mexico has a strong seasonal cycle. Winds are on average shoreward in the summer – June, July, and August – and downcoast (i.e, from Texas toward Mexico, in the direction of Kelvin wave propagation) the rest of the year (Cochrane and Kelly, 1986) (Fig. 2). The summer winds can cause upcoast transport depending on their orientation relative to the coastline. Small deviations in the mean direction and strength of the wind in different years can have significant consequences. For example, annual differences in the mean winds have been linked with the occurrence of harmful algal blooms along the Texas coastline (Forrest et al., 2011; Thyng et al., 2013). The seasonal cycle in the mean winds causes a seasonal cycle in the river plume location on the shelf (Fig. 2; the river plume is outlined by the 33 psu isohaline, which has been used in Hetland et al., 2012 to define river plume presence). In the summer, upcoast winds pool river water on the broad western Louisiana shelf; the rest of the year the downcoast winds stretch the plume westward along the coastline toward Mexico (Nowlin et al., 2005; Zhang et al., 2012b). Baroclinically-driven flows co-occur with the river plume: instabilities along the plume edge enhance cross-shelf transport during the summer (Hetland, 2017b). The discharge from the Mississippi and Atchafalaya also varies throughout the year and between years; discharge typically peaks in spring, when snow melts in the northern reaches of the watershed, but also varies annually with the amount of rainfall and snowpack (Walker, 1996).

We use drifters in this study to investigate the impacts of the shelf circulation patterns on material transport pathways, as have authors of other studies. Mitarai et al. (2009) examined connectivity of the southern California Bight for application to fisheries management and better understanding the transport connections and time scales in the region. NOAA's Oil Spill Response group runs a particle tracking system (GNOME) for emergency response (NOAA, 2014). Many groups have evaluated results from numerical circulation models combined with a numerical drifter model to recreate the trajectory of oil from the 2010 Deepwater Horizon oil spill (Barker, 2011; Huntley et al., 2011; Liu et al., 2011; North et al., 2011; Weisberg et al., 2011; Dietrich et al., 2012). A recent large release of drifters – the GLAD experiment – was used to investigate whether drifter motion near the Mississippi River Delta is controlled by local, submesoscale features or by nonlocal, mesoscale features (Poje et al., 2014; Beron-Vera and LaCasce, 2016).

There are fewer studies on the northwest Gulf of Mexico. A recent numerical study examined connectivity between the Texas-Louisiana shelf and the coastline, pointing out areas with increased likelihood of material aggregation such as Port Aransas (Thyng and Hetland, 2017). That work used the same numerical model and trajectories as the present study, but focused on transport to the coast instead of cross-shelf transport. In the Surface Current Lagrangian Program (SCULP) experiment, drifters were released over the Texas-Louisiana and Florida-Alabama shelves; subsequent analysis showed drifter movement within the two areas, but limited connectivity between the regions (LaCasce and Ohlmann, 2003; Ohlmann and Niiler, 2005). The SCULP drifters