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GULF STREAM REMOTE FORCING OF SHELFBREAK CURRENTS IN THE MID-ATLANTIC BIGHT

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Abstract. The "Slope Sea" is a narrow band of ocean that lies between the Gulf Stream and the continental shelf edge in the Mid-Atlantic Bight. It is composed primarily of slopewater, and a closed cyclonic gyre circulates within the upper few hundred meters of its western end. A two-year time series of current measurements in this region has shown that the southwestward flowing shelfbreak currents along the shoreward flank of the gyre are directly related to the position of the Gulf Stream, which is typically some 150 to 300 km seaward of the shelfbreak. The mean monthly shelfbreak currents are strongest, towards the southwest at about 30-40 cm s^{-1}, when the Stream is within 150 km of the shelf edge, whereas those currents are close to zero when the Stream is about 300 km away.

Introduction

The Gulf Stream separates from the continental margin as it flows northeastward past Cape Hatteras, North Carolina. It usually follows a trajectory of about 070° True leaving Hatteras, and by about 800 km downstream the current is typically 300 to 400 km from the shelfbreak of the Mid-Atlantic Bight, that portion of the continental shelf between Cape Hatteras and Cape Cod. Between the shelfbreak and the Stream is the "Slope Sea", a narrow band of ocean which is composed primarily of slopewater, and that oftentimes has warm core Gulf Stream rings embedded within it. *Csanady and Hamilton* [1988] have described the closed cyclonic gyre that circulates in the upper few hundred meters of the western end of the Slope Sea, and which supports a volume transport of about 3×10^6 m^3 s^{-1} (Figure 1). This gyre is driven by a combination of local wind forcing, the inflow of Coastal Laborador Sea Water from the northeast, and Gulf Stream forcing along the gyre's seaward boundary [*Rossby*, 1936; *Sverdrup et al.*, 1942; *McLellan*, 1957; *Beardsley and Winant*, 1979; *Csanady and Hamilton*, 1988].

The instantaneous path of the Gulf Stream in this region may be complex. Several mechanisms exist that cause the path to move laterally [*Watts*, 1983], and in particular, interactions between the Stream and cold core and warm core Gulf Stream rings near Cape Hatteras may induce shifts of 100 km or more in the Stream's path. Such shifts may take place in a few days, but the shifted Stream position may last for several months [*Bane and Watts*, 1985]. The proximity of current systems in Figure 1 suggests that such large lateral movements of the Stream will affect the circulation of the Slope Sea gyre.

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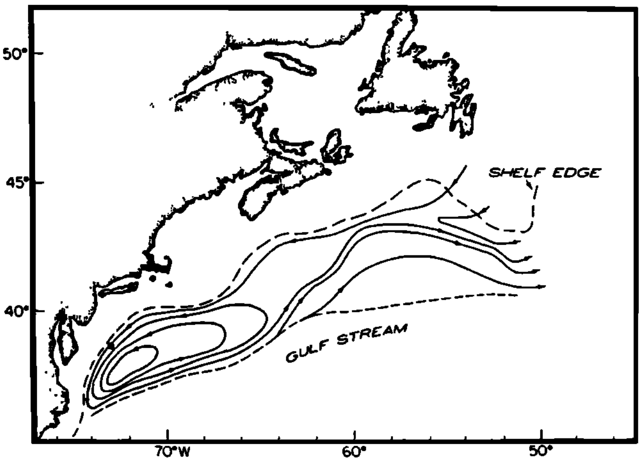

Fig. 1. Surface circulation within the Slope Sea, showing the cyclonic gyre located in its western end. The position of MASAR mooring B is indicated by the dot near the shelf edge at about 73°W. (This flow scheme was determined by *Csanady and Hamilton* [1988] using primarily hydrographic data. Figure reprinted with permission.)

Observations

The recently conducted Mid-Atlantic Slope and Rise (MASAR) study provided an opportunity to observe the relationship between gyre currents and the Gulf Stream's position. An array of current meter moorings was in place for two years beginning in March 1984, and it extended from about the shelfbreak across the gyre and into the edge of the Gulf Stream. The mean, cyclonic gyre circulation may be clearly seen in the upper layer record-long mean currents measured during MASAR (Figure 2). Mean southwestward and southward flows along the shoreward flank of the gyre were about 10-20 cm s^{-1}, while the northeastward flow along the seaward boundary at mooring H was much higher due to occasional incursions of the Gulf Stream over that mooring. Satellite observations of Gulf Stream position (based on sea surface temperatures) showed that the Stream underwent considerable lateral movement during MASAR, including three dramatic shifts in position that were associated with strong ring/Gulf Stream interactions near Cape Hatteras. (All MASAR current meter and hydrographic data are documented in *SAIC* [1987].)

The three occasions when the Stream encountered a cold core ring approaching from its seaward side were during April 1984, September 1984 and December 1985. In the first two cases each ring was ultimately absorbed by the Stream as the

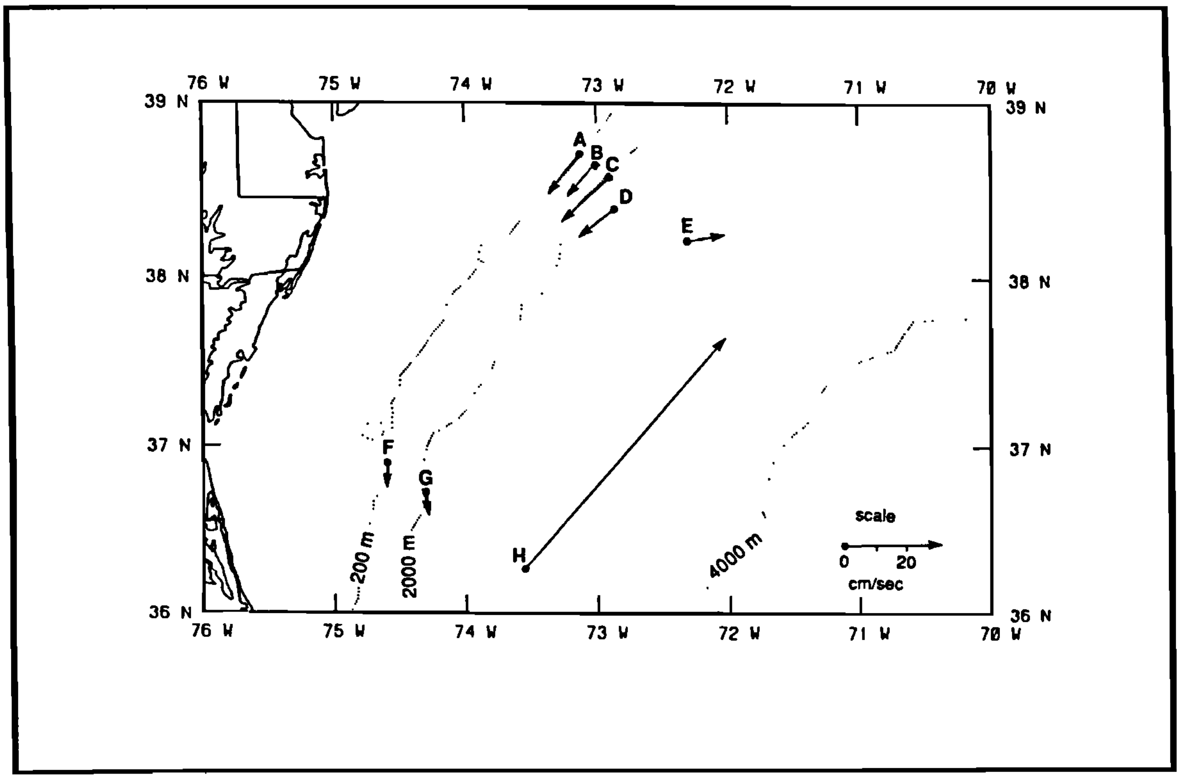

Fig. 2. Record-long mean currents measured within the upper 200 m during the two-year MASAR study. The signature of the cyclonic Slope Sea gyre is evident. (Insturment depths range from 80 m to 200 m.)

ring moved downstream. Insufficient data exist to unambiguously show if there was a ring absorption in the third encounter. In the MASAR study area the change in Gulf Stream path associated with a ring encounter was different in each of these three cases. In April the Stream shifted rapidly seaward following the downstream progression of the ring that was being absorbed then, and it stayed in a seaward position for about four months, until the September ring/Stream interaction occurred. Following the September interaction the Gulf Stream shifted shoreward and meandered about for the next few months [*Bane and Watts*, 1985]. The December interaction was complicated by a warm core ring/Gulf Stream interaction that was occurring at about the same time [*SAIC*, 1987], and was followed by an offshore Gulf Stream shift of almost 200 km.

Gulf Stream Forcing of Shelfbreak Currents

Velocity data from MASAR mooring B and satellite-derived information on the position of the Gulf Stream's shoreward surface thermal front have revealed a clear relationship between the shelfbreak currents and Stream position. Figure 3 shows the two-year-long time series of monthly averaged along-isobath flow at 270 m on mooring B (instrument B9) along with the monthly averaged Gulf Stream position on a line extending directly offshore from that mooring. [Current data shown in Figures 3 and 4 are from MASAR instrument B9, which was moored at a depth of 270 m over the 1000 m isobath, approximately 15 km seaward of the shelfbreak. This time series is used because it is continuous for the entire two-year MASAR study period. These currents show little difference from those measured at the shelfbreak by instruments on mooring A (see position of mooring A in Figure 2) when both instruments returned data.] Negative along-isobath velocities indicate southwestward flow, and the Stream position is taken to be the distance from the 200 m isobath (essentially the shelfbreak) to the Gulf Stream surface front. Another display of these data is given in Figure 4, which presents velocity vs. Stream position. Note that velocity magnitudes vary from about zero to over 40 cm s^{-1} while Stream positions vary from over 300 to less than 100 km from the shelfbreak.

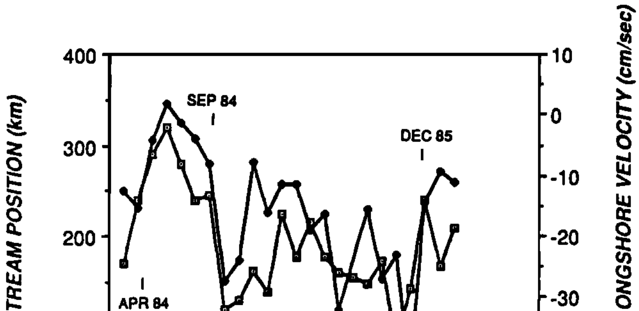

Fig. 3. Time series of monthly averaged Gulf Stream position and monthly averaged alongshore upper layer flow at the B mooring during MASAR. The Gulf Stream position is taken to be the distance from the shelf edge to that point where the Stream's shoreward SST front crosses a line running seaward (130° T) from mooring B. Note that negative alongshore velocities indicate southwestward flow at mooring B. The times of the three Gulf Stream/cold core ring interactions at Cape Hatteras (April 1984, September 1984 and December 1985) are indicated.

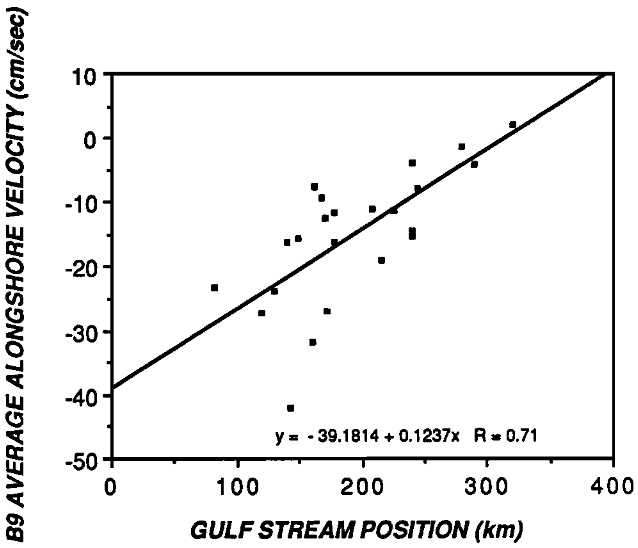

Fig. 4. Same data as in Fig. 3, but plotted as alongshore velocity vs. Gulf Stream position. The best fit straight line through the data is also shown, and indicates that the shelfbreak currents reach about 30-40 cm s^{-1} when the Stream is about 150 km from the shelf edge, whereas those currents essentially cease when the Stream is about 300 km away.

Agreement between the two time series is remarkable. These data show that the B9 currents were strongest, toward the southwest at about 30-40 cm s^{-1}, when the Gulf Stream was within 150 km of the shelfbreak, and those currents were close to zero when the Stream was about 300 km from the shelfbreak. Note in particular that during the four months between the April and September 1984 ring/Stream interactions, the Stream was well offshore and the shelfbreak currents were very weak, occasionally reversing and flowing northeastward.

This relationship demonstrates that a change in the structure of the Slope Sea gyre is caused by changing Gulf Stream position, and suggests that there may be a change in the circulation strength of the gyre as well. In either case the shelfbreak currents are forced "remotely" by the Gulf Stream through its effect on the gyre. One important aspect of this remote forcing phenomenon is that large changes in shelfbreak currents may occur as a result of ring/Stream interactions that occur several hundred km away, since these interactions are associated with large shifts in the Gulf Stream's position. Exchange processes that occur at the shelf edge will be dependent upon the position of the Gulf Stream as well, especially those processes driven by instability and eddy processes along the shelfbreak front. Clearly a complete understanding of, and predictive capability for the shelfbreak currents in this region will require knowledge of Gulf Stream processes within the surrounding oceanic domain.

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