The Effect of the New England Seamounts on Gulf Stream Meandering as Observed from Satellite IR Imagery

PETER CORNILLON

Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882

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ABSTRACT

It is a commonly held belief that meandering of the Gulf Stream increases dramatically downstream of the New England Seamount chain. In fact this appears not to be the case. The envelope of Gulf Stream northern edges derived from 30 months of satellite data remains constant from 65° to 58°W. Only the mean of the integrated path length normalized by the mean path length appears to increase downstream of the seamounts, but at very nearly the same rate as upstream of them.

The literature presents a clear and consistent picture of meander statistics for the Gulf Stream from the Florida Straits past Cape Hatteras to approximately 70°W (Olson et al., 1983; Halliwell and Mooers, 1983; Bane and Brooks, 1979; Watts and Johns, 1982). The same is not true for the region downstream of 70°W. Fuglister (1963), citing a multi-vessel, 2½ month period over which repeated surveys of the Gulf Stream were made from 50° to 70°W, concluded that the meander patterns observed "do not suggest a series of waves gradually increasing in amplitude from west to east, but rather, a quasi-stationary pattern with an abrupt change, near 62°W, from small amplitude to very large amplitude waves." Hansen (1970), on the other hand, from a series of monthly surveys of the Gulf Stream made in 1966 from 75° to 55°W, found that the envelope of Gulf Stream northern edges increased approximately linearly through the entire region surveyed, not abruptly at 62°W. Richardson (1981) cited data from 35 surface drifters and agreed with Fuglister, arguing that the observed float trajectories added further evidence to Fuglister's assertion of an abrupt increase in meander amplitude near 62°W.

Both Fofonoff (1981) and Watts (1983), in review papers dealing with general characteristics of the Gulf Stream, cited the above results in support of the concept that large meandering begins at the New England Seamounts. More recently, Richardson (1983) reported on the eddy kinetic energy field in the western Atlantic derived from 110 float tracks collected over a ten-year period and observed that (i) different years showed very different patterns; the eastward velocity profile at 55°W (averaged in 1° latitude × 10° longitude bins) was only slightly broader than that at 65°W, and (ii) the major axis of variance was very nearly east–west at 65°W and north–south at 55°W, "presumably due to the extremely large amplitude meanders" at 55°W.

Despite obvious discrepancies, two general observations may be extracted from the literature. First, all the studies show an increase in meander amplitude across the New England Seamounts. Second, except for Richardson's (1983) recent work, there is general agreement that the envelope of Gulf Stream northern edges increases across and downstream of the seamounts, although the rate of increase is unclear. These two observations are distinctly different in that the first applies to individual realizations of the Gulf Stream while the second applies to statistics of the Gulf Stream location (meander envelope) obtained from a number of observations. This difference results from the fact that the envelope is made of two components: meandering of a given realization of the Gulf Stream and meandering from realization to realization. The entire wave structure of a given realization can be moved either to the north or south. This will tend to increase the envelope as will the meandering of individual realizations.

In this paper the statistics from 30 months of Gulf Stream northern edges are shown to support the first observation—an increase in meander amplitude across the seamounts—but not the second. The data were derived from the Advanced Very High Resolution Radiometer flown on the TIROS-N series of meteorological satellites. Every U.S. east coast pass from 12 April 1982 through 31 September 1984 of the NOAA-7 spacecraft was used. In addition, all NOAA-6 passes from 7 January to 31 March 1983, from 11 April to 30 June 1983, and from 22 June to 30 September 1984, and all NOAA-8 passes from 21 April 1983 to 15 June 1984 were included. Each of the passes was decimated by 4 in scan element and scan line. Channels 4 and 5 of NOAA-7 were used to obtain sea surface temperature fields from the radiometric data. For NOAA-6 and NOAA-8 the channel 4 radiometer values were converted to brightness temperatures. The data were then remapped to a common coordinate system covering the Gulf Stream from 75° to 58°W. Finally, all the images were grouped into two-day intervals and composited by selecting the warmest pixel on a pixel-by-pixel basis for the images in the group, thus reducing the number of images covering the period from approximately 4000 to 402, while at the same time reducing the effect of clouds but retaining the important Gulf Stream structure.

The northern edge of the Gulf Stream was then digitized from each of the composited images, yielding 402 more or less complete depictions of the Gulf Stream's path. The Gulf Stream northern edge was located subjectively by a trained analyst using a color monitor on which the satellite images were displayed. (The relationship between the edge defined in satellite imagery and that defined by the 15°C isotherm at 200 m, an accepted measure of the location of the Gulf Stream, is discussed elsewhere (Hansen and Maul, 1970).) These 402 depictions are presented chronologically in Fig. 1 relative to the line through 36°N, 74°W and 39°N, 60°W. The temporal and spatial coverage of data is clear. Also clear is the alongstream propagation of meanders. Examples of such propagation are shown by heavy lines in the figure. The line with a relatively small slope in the interval July 1984 to the end of the record is an example of a meander propagating rapidly (13.4 cm s^{-1}) downstream, while the line from August through October 1982 suggests a meander propagating *upstream* at approximately 4.6 cm s^{-1}. Also of interest are the frequent occurrences of an abrupt change in slope and hence in the speed of propagation of meanders. A good example of this is the meander beginning in mid-April 1983 and continuing to early December 1983 with two changes in slope. The phase speed of this meander decreased from 7.6 to 2.1 cm s^{-1} on 7 June and then increased to 6.1 cm s^{-1} on 3 September. Large meanders that eventually break off to form Gulf Stream rings are also evident, e.g., at 69°W in April 1984. Regions in which extended cloud cover or low thermal contrast prohibit delineation of the northern edge appear blank, e.g., east of 63°W in October 1983.

The data have been replotted in Fig. 2 to display better the statistical characteristics of the distribution. The interannual variability is evident from the upper two plots. The 1982 data show a significantly wider envelope compared to the 1983 data. Furthermore, the data in 1982 show a quasi-permanent meander (displayed well by the mean track, indicated by the white line) present throughout most of the year. This meander does not exist in 1983. The 1984 data (not shown) also have a quasi-stationary meander downstream of 66°W approximately 180° out of phase with the 1982 meander (although it is not as well defined as that of 1982). All three years show similarities as well, for example, the relative minimum in the width of the envelope at approximately 70°W. This minimum is evident in all frames of Fig. 2. It is also clear in the dashed curve of Fig. 3, which represents the standard deviation of the Gulf Stream realizations at the given meridians. The data of Halliwell and Mooers (1983), covering the period 1975 through 1978, are also presented in Fig. 3 (dotted curve); they show a minimum at very nearly

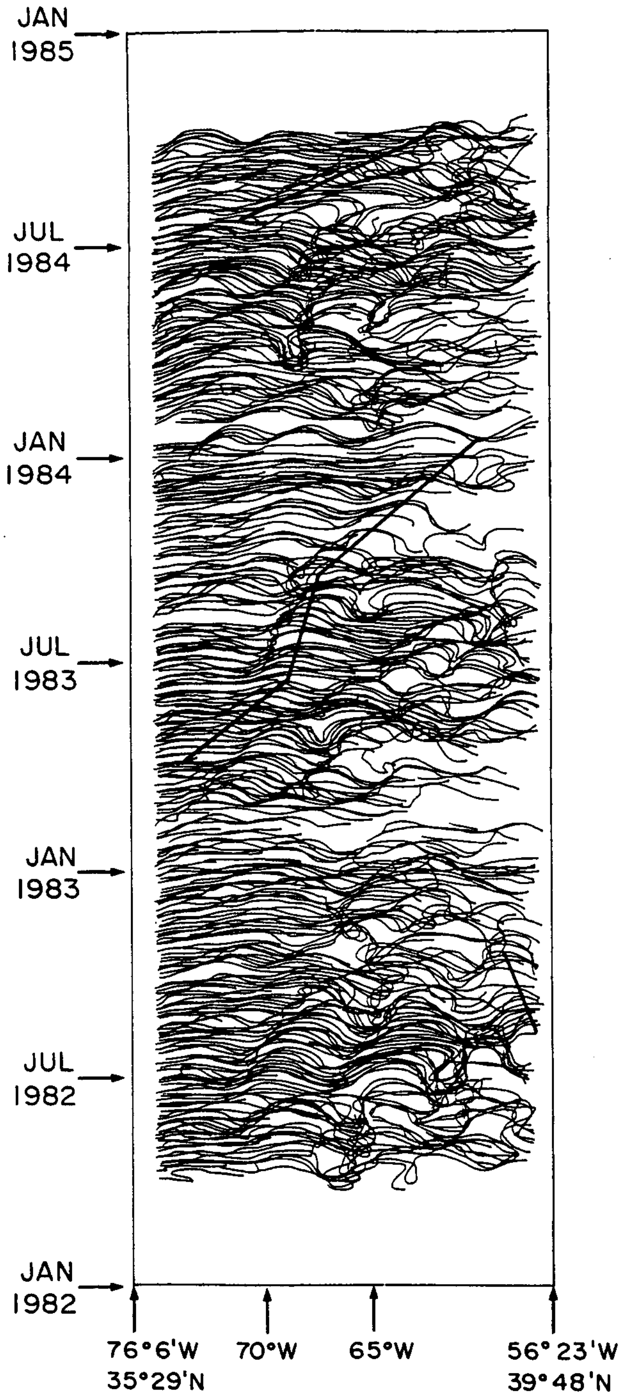

FIG. 1. Gulf Stream northern edge displacements relative to the rhumb line from 36°N, 74°W to 39°N, 60°W. One realization is presented for every two days.

the same location. Maul et al. (1978) present a plot (their Fig. 14) of Gulf Stream path positions extending from the Loop Current to 64°W obtained from nine months of 1976 GOES images. Qualitatively the path positions which they obtained downstream of Cape Hatteras are similar to those shown here (Fig. 2) and those discussed by Halliwell and Mooers (1983) in that all three studies show a significant increase in the envelope of Gulf Stream paths at about 69°W.

Upstream of the seamounts, the results obtained here are in close agreement with previous work. Downstream of the seamounts, however, where previous results are less quantitative, the results of this research are in disagreement with some of the commonly held perceptions. In particular, from 68° to 58°W, there is *no* significant increase in the envelope of meandering in any given year or in all 30 months combined. This is clear from both Figs. 2 and 3.

To determine whether or not meandering *within* the envelope increases downstream of the seamounts, an additional statistic is calculated as a function of longitude. The solid curve in Fig. 3 is a plot of the integrated path length between pairs of lines of longitude (separated by 1°) averaged over all realizations of the Gulf Stream (continuous on the interval) and then normalized by the length of the mean path between the same lines of longitude. As the path becomes more convoluted, this ratio will increase. In fact it does increase fairly linearly from 75° to 58°W with a dip in the curve between 66° and 63°W (over the seamounts). When compared with the standard deviation of the envelope, it appears that between 75° and 66°W the degree of convolution increases as the envelope increases. Over the seamounts, the envelope and the degree of convolution (the magnitude of the ratio defined above) are both about constant. Downstream of the seamounts, the envelope remains approximately constant but the degree of convolution again increases. This means that downstream of the seamounts the meandering continues to increase but is constrained to an envelope that does not increase.

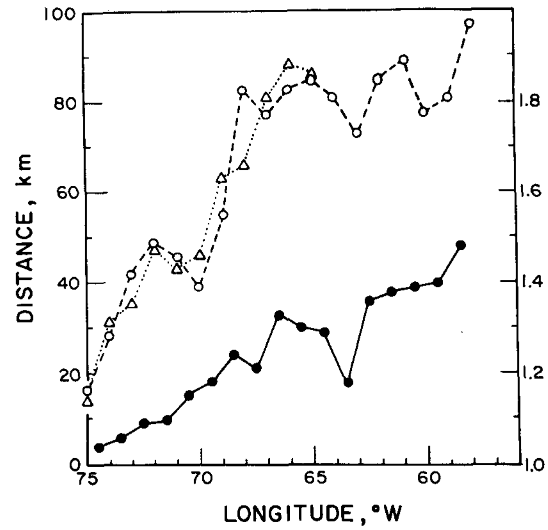

FIG. 3. Standard deviation of the Gulf Stream envelope normal to the mean path of the Gulf Stream for the 30-month interval shown in Figs. 1 and 2: this study, dashed curve with open circles; Halliwell and Mooers (1983), dotted curve with open triangles. The scale to the left corresponds to these two curves. The ratio of the mean of the integrated path length to the mean path length between integer degree values of longitude is shown by the solid curve with solid circles. The scale to the right corresponds to this curve.

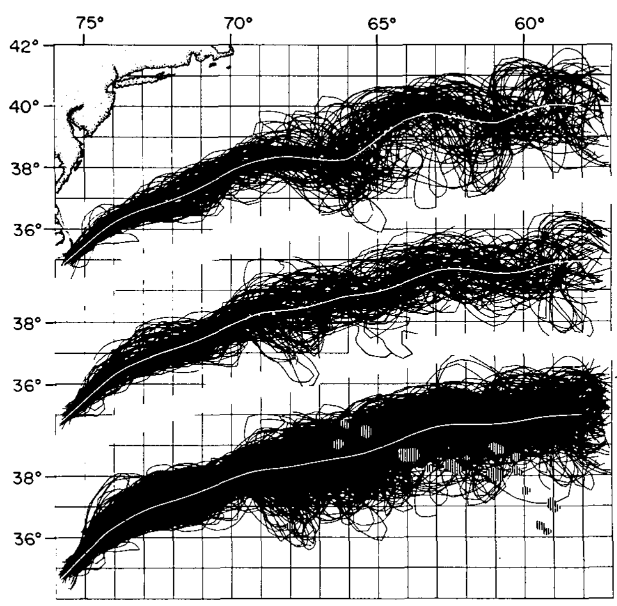

FIG. 2. Gulf Stream northern edges superimposed on one another. The upper set is for the period from 19 April to 31 December 1982. The middle set is for all of 1983. The lower set is for 19 April 1982 to 30 September 1984. The grey spots on the lower plot represent water shallower than 3000 m (i.e., the New England Seamounts). The white lines in the middle of each set represent the mean track for that set.

The results presented above demonstrate that the envelope of meandering does not increase linearly from Cape Hatteras past the seamounts to 60°W as suggested by Hansen (1970), nor is there a step increase in meandering at 62°W as suggested by Fuglister (1963) and Richardson (1981). In contrast the envelope remains constant from 68° to 58°W while the convolution within the envelope continues to increase at very nearly the same rate as it did upstream of the seamounts. In summary, the impact of the New England Seamounts on Gulf Stream meandering appears to be small in a statistical sense. This does not mean that the impact on all realizations of the Gulf Stream path is small. The impact on specific paths is currently under investigation.

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