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Investigations of the Mean, Seasonal and Interannual Variability in the Position of the North Wall of the Gulf Stream 45°W to 75°W

by

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ABSTRACT

Twenty years of satellite thermal imagery have been digitized to obtain time series of the position of the northern boundary of the Gulf Stream. A brief description is provided of the objectives of the study, the data and data treatment, and some initial results. The Gulf Stream is shown to under go a seasonal variability of order 20 km being south of its annual mean position from January to July and north the remainder of the year. The maximum onshore location occurred in October-November. On an interannual time scale, the Stream was displaced to the south in the early eighties but rose steadily until 1985. Since then it fluctuated lying primarily north of its mean position. In recent years it has been at or near its maximum northward location. Between the early 1980s and early 1990s the north wall of the Stream moved northward by 70-80 km.

INTRODUCTION

The Gulf Stream is the major oceanographic feature in the Atlantic Ocean. It is important for several reasons, including the large heat transport to the northern North Atlantic and the formation of Gulf Stream rings, principally between Cape Hatteras and the Tail of the Banks. Several studies have been conducted on the variability of the Gulf Stream. The wavelike meanders of the stream northeast of Cape Hatteras with periods of one to several weeks are well known (Hansen 1970; Halliwell and Mooers 1979; Tracey and Watts 1986). The position of the stream also undergoes seasonal and interannual variations. The earliest studies of these changes were based upon hydrographic data. Hachey (1939) demonstrated that northeast of Bermuda the stream's position was furthest southward in early spring and northward in late summer-early fall. He related this seasonal movement to the strength of the Gulf Stream, the northward migration associated with the geostrophic adjustment to a decrease in current strength and the southward migration with an increase. A similar seasonal shift in the Gulf Stream position was later found in the same area by Iselin (1940) and from data collected between 50°W and 75°W by Fuglister (1972), but with slight differences in the precise timing of the maximum northward and southward positions. Tracey and Watts (1986) used inverted echo sounders to monitor the Gulf Stream fluctuations at four transects off the mid-Atlantic Bight (71°-74°W). They confirmed earlier findings but noted that the timing of the peak northward position varied slightly with longitude. This longitudinal variation was also found from analysis of satellite imagery by Zheng et al. (1984) in the region between 64°W and 71°W and is evident in the data between 40° and 70°W presented by Auer (1987). Most of these studies also noted significant interannual variability of a magnitude equal to or larger than the seasonal cycle but their time series were of too short a duration to comment in detail on any trends or patterns. However, Taylor and Stephens (1980) examined the latitudinal displacements of the Gulf Stream between 1966 to 1977 at six longitudes between 79° and 65°W. They found southward movement during 1966 to 1971 followed by a return northward after 1973. Also, Auer (1987) found a progressive northward trend in the position of the Gulf Stream from satellite data collected between 1980 and 1985.

Our interest in the Gulf Stream is primarily in its possible influence on the ocean climate of the continental shelves. Of particular relevance is the interannual variability of the Stream. To investigate this we have digitized upwards of 20 yr of satellite data to obtain time series of the position of the northern boundary, or "north wall", of the Gulf Stream between 75°W (Cape Hatteras) and 50°W (Tail of the Banks). It is the longest dataset on the position of the Stream yet produced. This paper describes the data set and treatment as well as some initial results of our investigation into the seasonal and interannual variability.

DATA

Satellite Imagery

Sea-surface temperature (SST) data from Florida to the Scotian Shelf have been collected since the early seventies using advanced very high resolution radiometers (AVHRR) on the NOAA TIROS series of satellites. Initially these data were interpreted by the U.S. Naval Oceanographic Office which produced weekly experimental ocean frontal analysis (EOFA) charts. Surface temperature fronts (shelf/slope front, Gulf Stream, and Gulf Stream eddies) were depicted on the EOFA charts based on the satellite imagery of the thermal gradients for the day closest to the date of issue and augmented by SST data collected from ships of opportunity during the preceding week. A similar product using the same data was published by the U.S. National Oceanic and Atmospheric Administration (NOAA) under the title "Gulf Stream Analysis". The NOAA charts showed cloud positions, whereas in the EOFA charts if clouds prevented good imagery the frontal positions were estimated based on previous data.

Beginning in 1980 these products were replaced by the Oceanographic Analysis charts published by NOAA through the National Weather Service and the National Environmental Satellite Service. At the same time the aerial coverage was expanded to include the Grand Banks and Flemish Cap regions and the frequency of publication increased to three times per week for the area from Cape Hatteras to Newfoundland. In all three products the satellite imagery was augmented by temperature observations from ships. The EOFA chart and copies of their field sheets used in the present study were obtained directly from the Naval Oceanographic Office, while the Gulf Stream Analysis charts and the Oceanographic Analysis charts were obtained from NOAA.

We have used the EOFA charts from 1973 until May 1980 and the Oceanographic Analysis charts after May 1980. From January 1973 until May 1978, the EOFA only covered the region northward to Georges Bank, but in June 1978 the areal coverage was extended to include the Scotian Shelf and the Grand Banks. The positions of the shelf-slope front and Gulf Stream were consistent among all three analyses. These satellite-derived frontal positions also agree well with *in situ* measurements (Olson et al. 1983; Vazquez and Watts 1985; Auer 1987).

Satellite Imagery Analysis

The position of the north wall of the Gulf Stream was digitized from the various charts described above, checked for consistency, edited where necessary and time series of the latitude for each degree of longitude were generated. Because of the meandering nature of the Stream, the north wall sometimes crossed a given degree of longitude more than once. In such cases the latitudes were averaged. Comparisons with time series based upon either the maximum (northern most position) or the minimum latitude showed similar results. In the following discussion the time series refer to the average positions. The sampling frequency for clear images averaged about once per week. The coverage was less frequent before 1980 and in areas with a higher incidence of cloud and fog, e.g. the Grand Banks (Auer 1987).

Possible errors due to occasional incorrect assignment of water masses by operational analysts are felt to be minimized by the rigorous error checking we undertook. This quality control included close scrutiny for inconsistencies in the labeling of water masses from chart to chart.

For each region, all available data within a month were averaged arithmetically to obtain monthly means. For the seasonal analysis these in turn were averaged to provide an overall monthly mean for the Gulf Stream. This analysis was based upon the period June 1978 to December 1992 when data were available for the entire region. The annual mean was determined from the average of the monthly means. At each degree of longitude, the monthly means were subtracted from the available records to obtain monthly anomalies. To examine long-term variability the monthly anomalies were low-pass filtered (Ormsby filter with 25 weights, a cutoff frequency of 15 months and a rolloff frequency of 12 months; Colacino and Rovelli, 1983) to remove most of the fluctuations with periods of 1 y or less.

RESULTS

Mean Position

The mean position of the north wall of the Gulf Stream is shown in Fig. 1 together with the maximum and minimum positions of the monthly menas. The Stream leaves the shelf break near Cape Hatteras (75°W) running towards the northeast. East of approximately 62°W, the average position lies almost along 41°N.

Seasonal Variability

From the monthly means for the 26 longitudes, overall monthly averages were calculated (Fig. 2). They show the Stream is typically located south of its mean position from January to July and north from August to December. Whereas there is a detectable northward peak during October-November, there was no statistical difference in the southward locations during the first seven months of the year. Our results are consistent with earlier studies. The displacement anomalies ranged from approximately 5 km south of the annual average to upwards of 15 km north in October.

There is large spatial variability in the position of the Stream, however. This is clearly shown in the monthly displacement anomaly during February and November (Fig. 3). Although over the majority of the region (55°W to 70°W) the Stream was south of the mean in February and north in November, consistent with the overall pattern (Fig. 2), this did not occur everywhere. Indeed, at either end of the longitudinal range, the seasonal variability was different than the average. The range of the monthly displacements over the year also varies with longitude, generally increasing eastward (Fig. 4). It varied from near 20 km between 73-75°W to upwards of 80 km in the eastern half of the region.

Interannual Variability

The filtered data for each of the 26 degrees of longitude were averaged to obtain the mean low-frequency variability in the Stream. We have only used the time period during which data were available throughout the entire longitudinal range, i.e. from June 1978 to December of 1992. The Stream was located near its southern most point in the late 1970s and early 1980s, approximately 40 km south of its long-term mean position (Fig. 5). It rose rapidly around 1982-83 reaching a position north of the mean. In the mid-1980s it fluctuated with an amplitude of approximately 10 km before briefly retreating southward in the late 1980s. Since then the Gulf Stream has moved northward and is now at or near its northern most position, about 30 km from the long-term mean location. It is noted that the amplitude of the low-frequency variability is approximately 3-4 times that of the seasonal fluctuations. Our low-frequency results are consistent with those of Auer (1987) who analyzed 5 y of data from 1980 to 1985 and observed a northward trend in the position of the Stream over this period.

Similar to the seasonal variability, there is spatial differences between different degrees of longitude. This is evident in the filtered data shown in Fig. 6.

FUTURE WORK

In future, we plan to examine the spatial structure of the variability in detail. Also, we will investigate possible causes of the changes in the location of the Stream's northern boundary including the curl of the wind stress over the North Atlantic. We have also digitized the Shelf/Slope Front which separates the Slope Waters from the waters over the continental shelf. We plan to investigate the relationship between the low-frequency variability of the Shelf/Slope front with that observed in the Gulf Stream.

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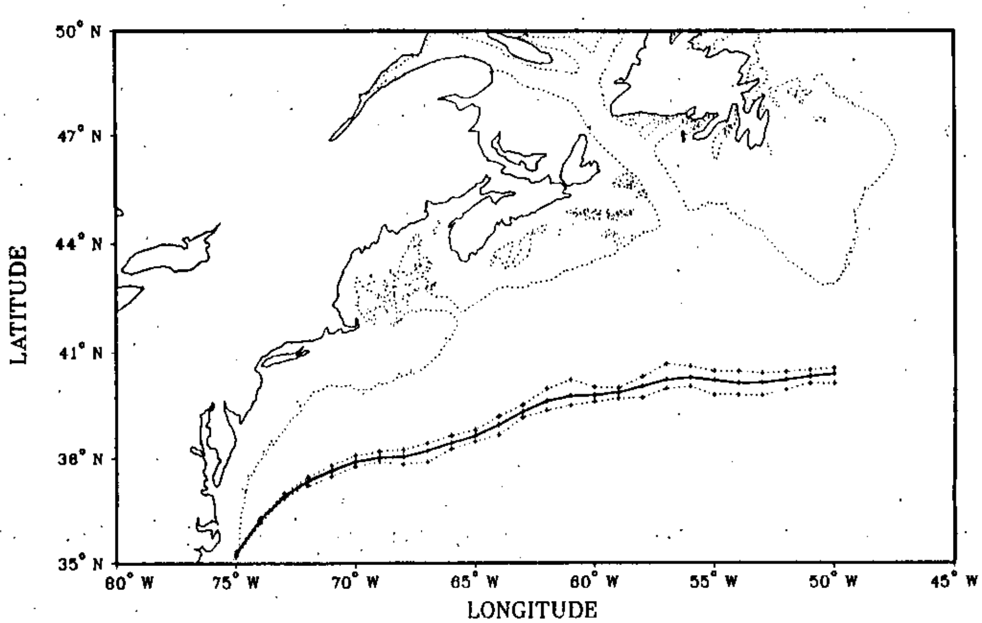

Fig. 1. The mean position of the northern boundary of the Gulf Stream. The maximum northward and southward monthly mean locations are also shown.

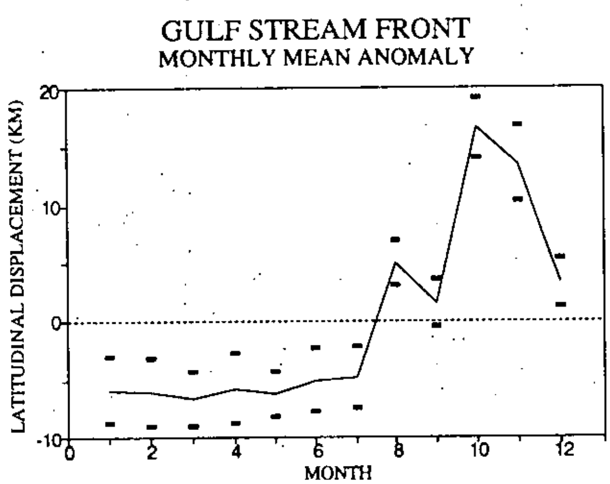

Fig. 2 The monthly variations in the average displacement of the northern boundary of the Stream between 50°-75°W. The horizontal bars represent the error of the means.

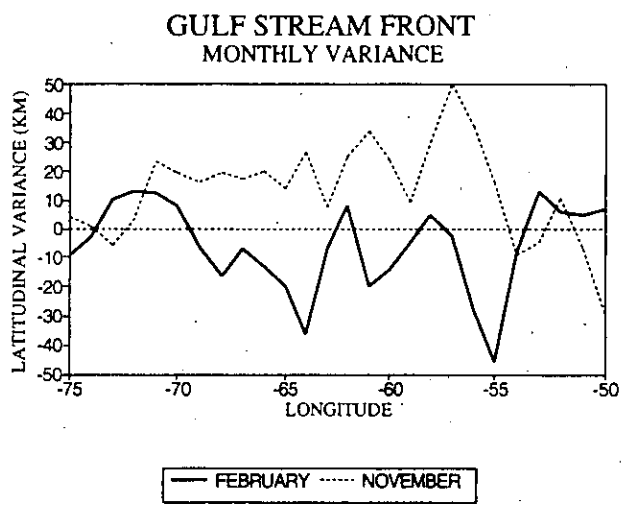

Fig. 3 The latitudinal displacements in km of the northern boundary of the Gulf Stream as a function of longitude during February and November.

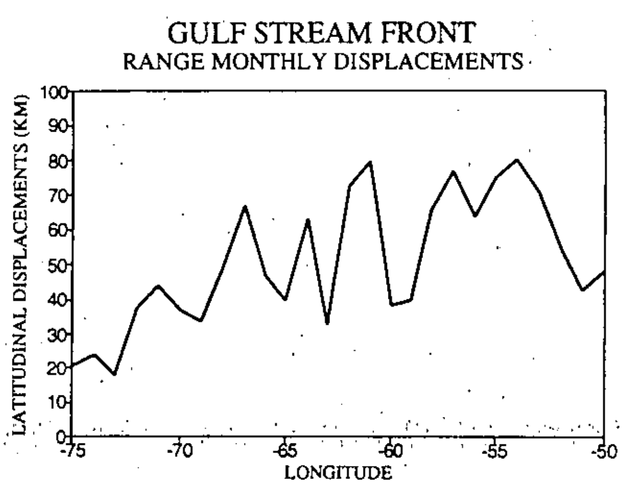

Fig. 4 The range between the maximum north and south monthly mean positions of the northern boundary of the Gulf Stream as a function of longitude.

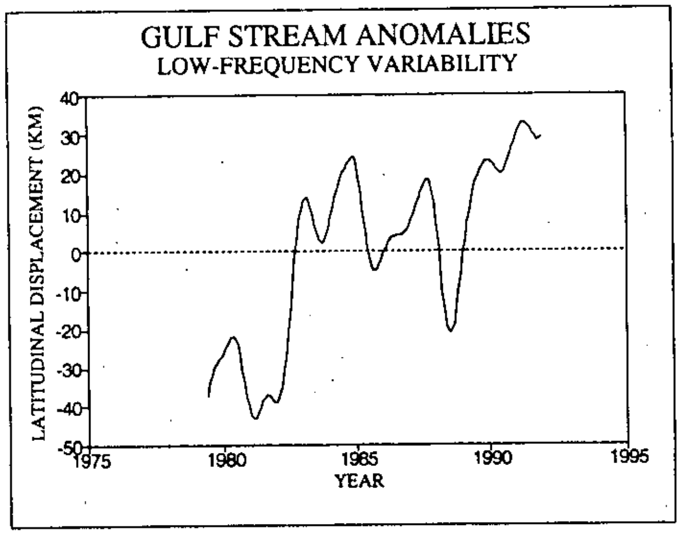

Fig. 5 The low-frequency variability of the northern boundary of the Gulf Stream.

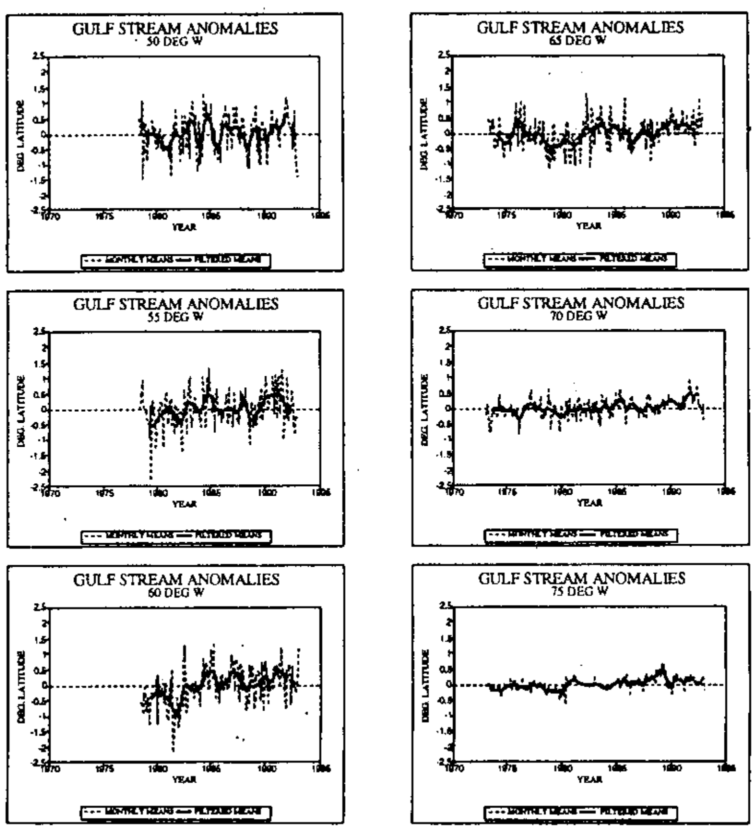

Fig. 6 The monthly and filtered anomalies of the position of the northern boundary of the Gulf Stream for every 5 degrees of longitude between 50° and 75°W..