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Some features of spatial-temporal variability and WCE's formation in the Gulf Stream area from Florida to 55°W in 1975-82

by

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Abstract

Based on the analysis of the mean monthly sea surface temperature anomaly values (°C) by 1-degree squares main features of the spatial and temporal (for periods longer than 1 month) variability in the sea surface temperature field in the Gulf Stream effected waters as far east as 55°W are described for 1975-82. Scales of the above mentioned variability and the reasons that may cause anomalies in the temperature field are discussed. Information on frequency and sizes of WCE's formed in the above mentioned area in 1977-82 is presented and the effect of WCE's on SST is estimated.

Introduction

In the area under investigation a sea surface temperature and hence its anomaly value is determined in the first place, by the advective processes connected with the Gulf Stream dynamics. Those processes are as follows: a) the Stream meandering, b) formation and existence of the anticyclonic warm-core and cyclonic cold-core eddies, c) changes in the mean yearly Gulf Stream position. These processes seem to be interrelated although the type and strength of those relations are still basically unknown.

The formation of the sea surface temperature field is also effected by both the air-sea interactions and the changes in the radiation balance on the sea surface.

For the area adjacent to the Gulf Stream the importance of the air-sea interactions for SST anomaly formation is presumably significantly lower than that of the advective processes. The effect of the radiation balance is eliminated since it has a well defined seasonal change and disappears when mean anomalies are calculated.

Based on the above, the SST anomaly value and its sign can be used as a parameter characterizing the intensity of the advective processes in the waters adjacent to the Gulf Stream.

There is also an information indicating that the SST as well as the mean monthly anomalies in the area correlate with some biological characteristics for the short-finned squid population (Dawe and Hurley, 1981; Fedulov and Amaratunga, 1981) and thus can serve as predictors for forecasting the latter.

Type and magnitude of the variability in the above mentioned advective processes of meandering and eddy-formation for various time intervals are not equally well studied. Our knowledge on the intra-monthly variability is more extensive than that on the intra-year one (on the scale of a month to a year), and very little is known about the inter-year variability.

Changeability in meandering and eddy-formation

The analysis of the satellite-derived positions of the Gulf Stream meanders for a 9-month period from March through November 1975 (Maul et al., 1978) showed that the latitudinal variability of the Gulf Stream positions during this period in the area from Florida to 65°W changes along the Stream (Fig. 2). Minimum latitudinal variability is observed in the south in the region off Miami, Florida. Further north it increases downstream reaching 150km in the area from 32° to 34°N. In the region off Cape Hatteras this variability decreases again down to 80 km and increases downstream being 400 km at 65°N.

Similar scales in the intra-year variability of the northern Gulf Stream edge positions was observed for the period from 1980 to 1981 (Auer, 1981; Fig. 1).

Least square spectral analysis revealed that the maximum spectral energy of the Gulf Stream position variability along 70°W (Fig. 2, heavy line 11A) is in the lower frequency band (periods longer than 200 days), while the lowest frequency where statistically significant peaks were obtained (due to the limited data series) lie within the ranges of 30 to 50 days (Maul et al., 1978).

The Gulf Stream variability in the area south off Cape Hatteras (Fig. 2; heavy line 11B) has a markedly different spectrum (Maul et al., 1978). There is much less spectral variability at low frequencies (periods greater than 40 days), whereas in the higher frequencies there are peaks at 30 days.

The record at 70°W shows a linear northward Gulf Stream displacement during the period from January 1976 to April 1977; the northern edge of the Gulf Stream was at least 100 km further north in April 1977 than in March 1976 (Maul et al., 1978).

Mean monthly SST for the waters between the Gulf Stream and the continental slope may be influenced to some extent by numbers, lifespans and sizes of the anticylonic eddies.

In the area west of 60°W 4,8,7,9,9 (Celone and Chamberlin, 1980) and 11 (Fitzgerald and Chamberlin, 1980) eddies were formed in 1974, 1975, 1976, 1977, 1978 and 1979, respectively. The frequency of eddy formation during a year also varies. Thus, in a 9-month period, from mid-July 1977 to mid-April 1978 in the area west of 60°W no warm-core eddies were produced (Celone and Chamberlin, 1980), whereas 6 eddies were formed from mid-April to mid-June 1978.

Average longevity of 1978 eddies was only 84 days with a maximum value of 199 days. In 1977 warm-core eddies lived on average for 152 days, whereas the three longest-lived ones lasted about 211, 273 and 334 days (Celone and Chamberlin, 1980). In 1979 the longest-lived for a 6-year period warm-core eddy was registered; its lifespan was about 401 days (Fitzgerald and Chamberlin, 1980). The shortest lifespan for a 1979 eddy was 22 days.

Estimates for average eddy diameter obtained by different authors (Pickett, 1972; Gotthardt, 1973; Bisagni, 1976) are in the range of 60 to 100 km. Gotthardt (1973) showed that a close correlation exists between the eddy area and the latitude of its formation which he formalized by a linear regression equation: $S\ (km^2) = k - 329{:}y$, where k equals 26197 km^2 and y is a latitude in terms of degrees.

Materials and Methods

Present paper is fully based on the data monthly published by N.W.S., NOAA and N.E.S.S. in Gulfstream (till 1981) and Oceanographic Monthly Summary (since January 1981).

Monthly SST anomaly values within 1-degree squares were taken as a parameter characterizing the sea surface temperature field. The monthly SST anomaly is the difference between the monthly mean sea surface temperature and the historical (approximately 100 years) mean monthly value. Data for January 1975 through May 1982 were used for the analysis. Data for July 1976, December 1980, and June 1981 were, unfortunately, absent from the file.

For the analysis 10 zones were chosen within the waters adjacent to the Gulf Stream (Fig. 1). Zones I and II incorporate 6 1-degree squares each, while those numbered III to X are composed of 10 squares (excluding zone IV comprising 8 1-degree squares). Mean monthly SST anomaly value was estimated for each of those 10 zones.

In some months there were temperature observational gaps for a number of 1-degree squares, although, in general, the zones during the period under analysis were well covered by observations.

Using the charts published by Gulfstream and Oceanographic Monthly Summary numbers of newly formed anti-cyclonic WCE's within the area from 55° to 75°W were calculated for each of 1975-82 years, while for the years 1977-82 the diameters of those eddies were also measured using the charts. According to our estimation, the error of diameter measurements using the charts may reach 10%. For each month of 1977-82 the areas in the zones IV, V, and VI covered by warm-core eddies were calculated (in km^2). Total areas of zones IV, V, and VI are 7.4×10^4, 9.0×10^4, and 9.0×10^4 km^2, respectively.

Results and Discussion

The formation of WCE's in the area west of 55°W in 1977-82 seems to be most intensive in 1979 and 1980, when, according to our calculations, equal numbers of eddies were formed - 15 ones (Table 1); minimum number of eddies was registered in 1977 - 7. This estimate is qualitatively consistent with the estimate by Fitzgerald and Chamberlin (1980) except for 1977 when they registered 9 eddies. The difference between two estimates for 1977 is so much more strange that the above mentioned authors counted only eddies formed in the area west of 60°W.

Maxmimum number of newly-formed eddies per month for 1977-82 was registred in November 1979 and May 1980; there were four of them (Table 1).

The diameters of the eddies recorded during this time period ranged from 44 to 263 km with mean values being from 115 to 158 km (Table 2), which is much higher than the estimates published by other authors (Pickett, 1972; Gotthardt, 1973; Bisagni, 1976).

Comparison between minimum, maximum and mean eddy diameters in zones IV, V, VI, and VII suggests that the more easterly the zone is the greater are the diameters of the eddies formed within that zone which is fully consistent with the conclusions drawn by Gotthardt (1973).

Comparison of numbers of yearly formed WCE's (Table 1) with average diameters of those eddies (Table 2) allows to suggest that the correlation may exist between those parameters of the eddy-formation process: the greater is the number of WCE's formed per year smaller their mean diameter is.

Total number of WCE's formed from January 1977 to April 1982 (64 months) was 62, that is, average frequency of eddy-formation in the Gulf Stream area west of 55°W is approximately one eddy per month. It is worth noting that statistically significant peaks of spectral variations in the Gulf Stream northern edge positions are registered at practically the same frequency (Hansen, 1970; Maul et al., 1978). It is highly probable that a frequency of one cycle per month is a critical frequency (or may be, one from a set of critical frequencies) for the Gulf Stream meandering. In this case when meandering at this frequency the Gulf Stream generates WCE's more intensively.

We suggest that the scales of both spatial and temporal processes forming the SST field are comparable to the scales of SST anomalies resulted from those processes. Hence, the scales of temporal changes in SST anomaly in each zone can be used to qualitatively estimate the scales of spacial and temporal variability in the events forming those anomalies.

It should be noted, that in all zones the anomalies till 1978 are mainly positive (Fig. 3). For the majority of the zones this phenomenon is still evident in late 1980 to early 1981 which means that the whole period between 1975 and 1980 was characterized by anomalous development of the processes determining the SST. The only exceptions are the first halves of 1978 and 1979 when relatively high negative anomalies were observed in most zones (Fig. 3). Since late 1980 a tendency has clearly developed of shifting the anomaly values from positive to negative ones. This pattern of inter-year changes in SST for the area adjacent to the Gulf Stream is not consistent with the scales of the Stream meandering and eddy formation and is, presumably, related to the multi-year variations in the climate characteristics of an oceanic or even a planetary scale.

A linear displacement of the Gulf Stream latitudinal position northward along 70°W from January to April 1977 observed by Maul et al. (1978) is logical to be reflected as a similar change in the anomaly values for zones III, IV, and VIII; judging by our data, however, this is not the case.

Temporal changes in temperature anomalies over the sea surface in the zones selected for the analysis have similar patterns on the scales of 6-12 months. Some of these patterns are detectable in significantly distant from one another zones; for example, positive anomaly for the second half of 1979 and a positive one for the first half of 1978 are evident in all zones except for the most easterly one - zone VII. The origin of both anomalies is related to the eddy-formation intensity. The period of the negative anomaly in 1978 was preceeded and overlapped by a 9-month period when none of the eddies were formed west of 60°W (Celone and

Chamberlin, 1980), while a positive anomaly in 1979 coincides in time with a period of active eddy-formation process when 11 eddies were generated for 6 months (Table 1). In other words the anomalies of such a scale result from the changes in eddy-formation intensity of the same scale.

2-4-month scale patterns of the SST anomaly changes are not far always evident in the adjacent zones. The best coincidence in fine features is observed in zones I and II and more seldom - for other neighbouring zones. Changes of such a scale are induced by single meanders and eddies which mean life span coincides well with the above-mentioned 2-4-month scale. Eddies of mean size (diameter 140 km, area - approximately 15 thousand km^2) are much smaller than the areas of the zones selected for the analysis (from 70 to 90 thousand km^2) and hence, the effect of a single eddy practically can not be detected in several zones simultaneously.

At the same time, the comparison of the areas occupied by eddies with SST anomalies for the same zone reveals their high correlation for some time periods (Fig. 4). These parameters highly correlate in zone IV, but their correlation is markedly lower in zones V and VI. This phenomenon is attributed to the location of the zones relative to the boundary of a maximum Gulf Stream northern positions (Fig. 1). Zone IV is practically not subject to the influence of a meandering process and the SST changes there result from a "net" WCE's effect. In zones V and VI the SST fluctuations result from a combined effect of meanders and eddies.

Location of zones relative to the Gulf Stream mean position (Fig. 1) leads to a phenomenon when a dispersion of the SST anomaly fluctuations in zones VIII, IX, and X lying on the Gulf Stream axis is a little smaller than that in zones III-IV which a line representing maximum northern Gulf Stream position crosses. In reality this line is an interface between the Gulf Stream (warmer) and slope (colder) waters.

It should be noted, that high correlation between small-scale features in zones I ande II should be fully attributed to the meandering process since south of Cape Hatteras the WCE's are not formed.

There are some exceptions from the rule when fine-scale changes can be traced along a significant distance, for example, a negative anomaly with a minimum value for January 1981 is clearly seen in all zones but II and IV. Since the anomaly peak falls on January for all zones it is evident that this anomaly is a result of events existing over the whole area and hence, it can not result either from a meandering or an eddy-formation. Its origin is difficult to explain based on the data used in the present paper.

Acknowledgements

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Table 1. Number of newly-formed eddies per month for 1977-1982 year.

Month	1977	1978	1979	1980	1981	1982
Jan	3	1	0	0	2	1
Feb	0	0	1	0	0	1
Mar	0	1	1	2	1	1
Apr	1	2	1	1	0	0
May	0	0	1	4	2	-
Jun	1	2	1	2	1	-
Jul	1	0	2	1	2	-
Aug	1	1	1	1	1	-
Sep	0	0	2	0	0	-
Oct	0	2	1	2	1	-
Nov	0	1	4	0	1	-
Dec	0	1	0	2	0	-
Total	7	11	15	15	11	-

Table 2. Minimum, maximum and mean eddy diameters by zones in 1977-1982 year.

	1977			1978			1979			1980			1981			1982		
Zone No.	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
IV	73	190	127	73	175	138	73	117	105	73	160	140	44	131	96	88	131	112
V	88	233	150	102	175	132	58	190	117	88	219	136	102	234	168	102	146	127
VI	175	248	220	131	180	146	58	204	116	102	204	143	117	263	185	102	146	124
VII	-	-	-	-	-	-	-	-	160	116	248	159	117	263	186	88	233	134
For whole area	73	248	154	73	175	135	58	204	115	115	248	137	44	263	158	88	233	124

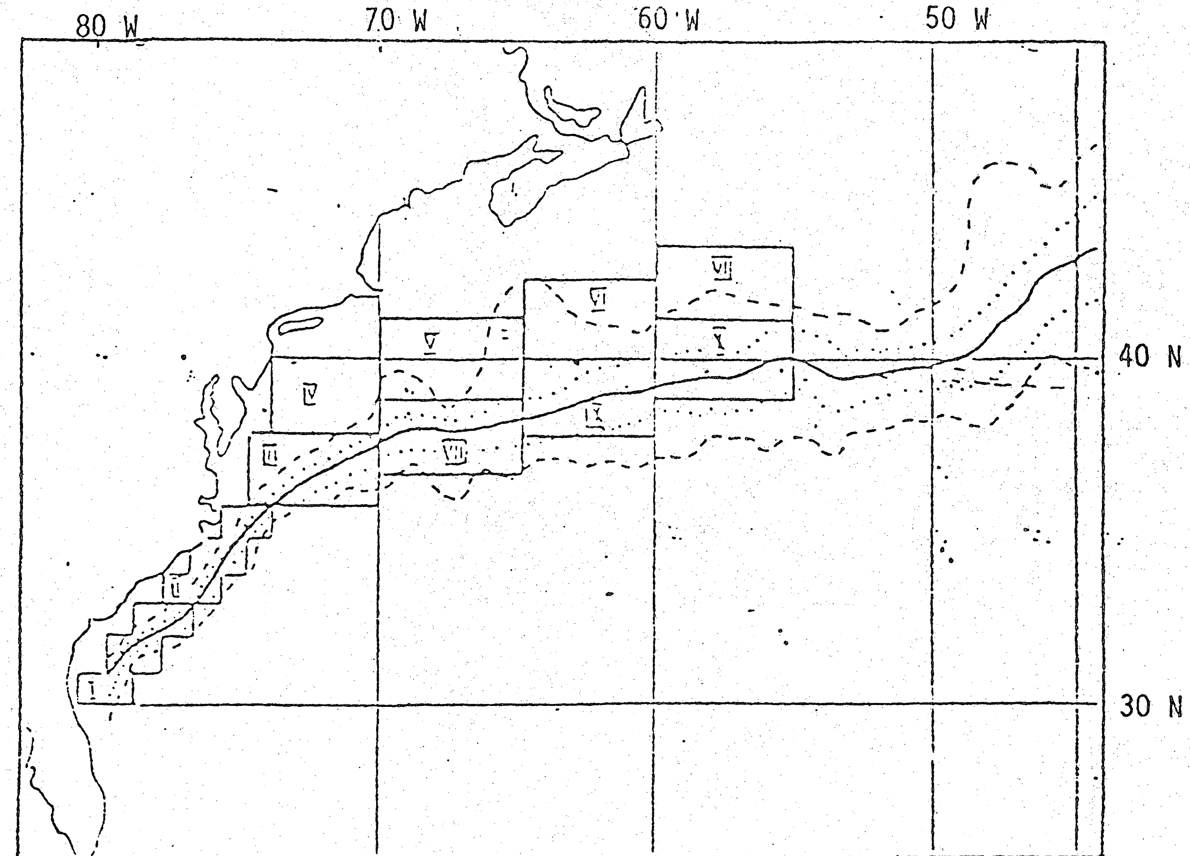

Fig. 1. Location of zones used to calculate the SST anomalies. (Zones are numbered by Roman numerals.) The maximum and minimum (dashed line), mean (heavy solid line), and standard (plotted line) deviations of the Gulf Stream System's landward surface edge are determined using the initial year of NWS/NESS daily Oceanographic Analysis (after Aver, 1982).

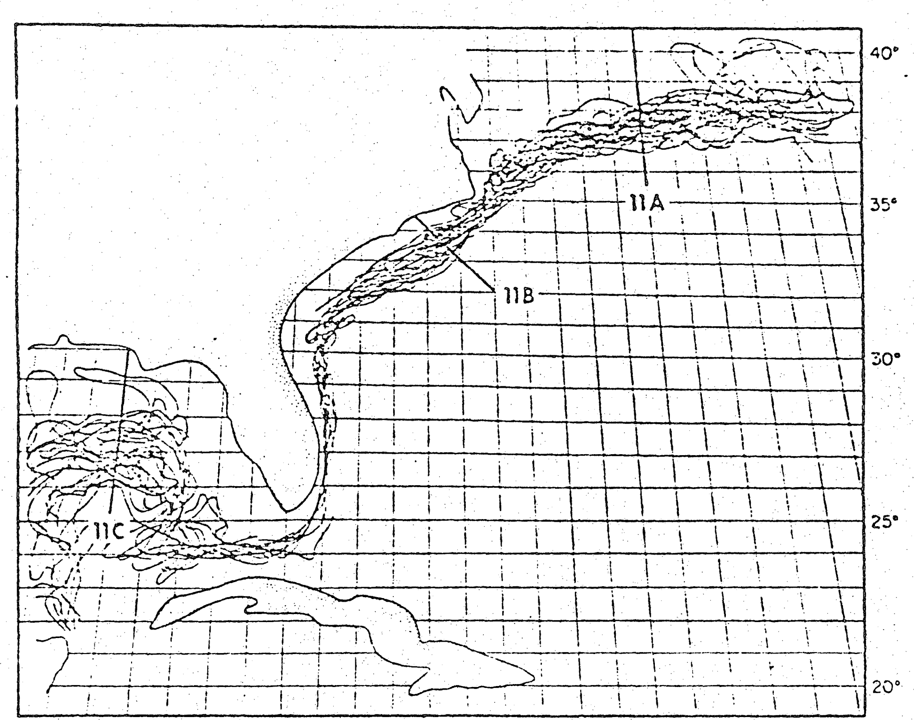

Fig. 2. Nine-month composite of locations of Gulf Stream front from Goes between February and November 1976, based on weekly compositions (after Maul et al., 1978).

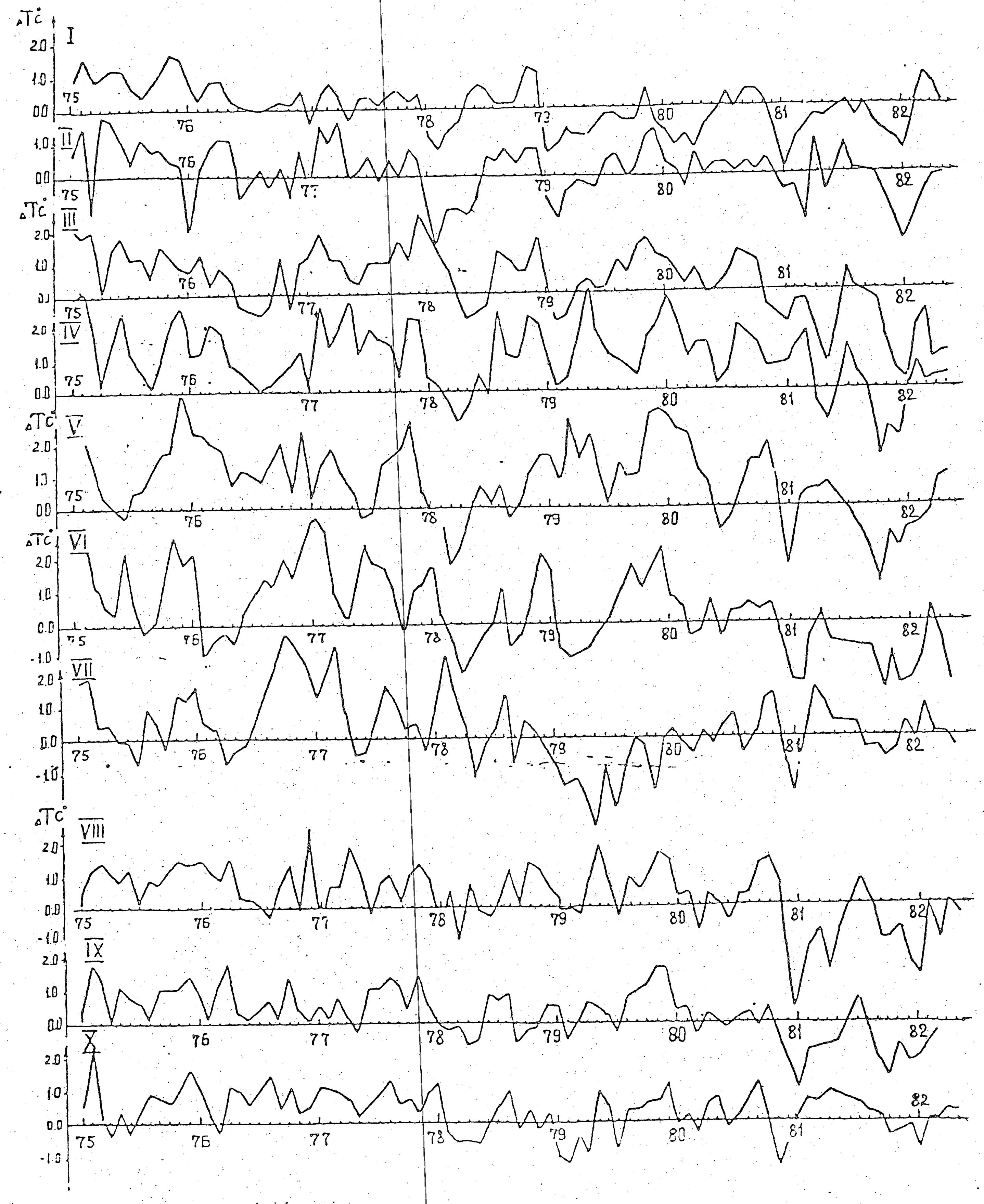

Fig. 3. Changes in SST anomalies, by zone, 1975-82. The zones are numbered by Roman numberals.

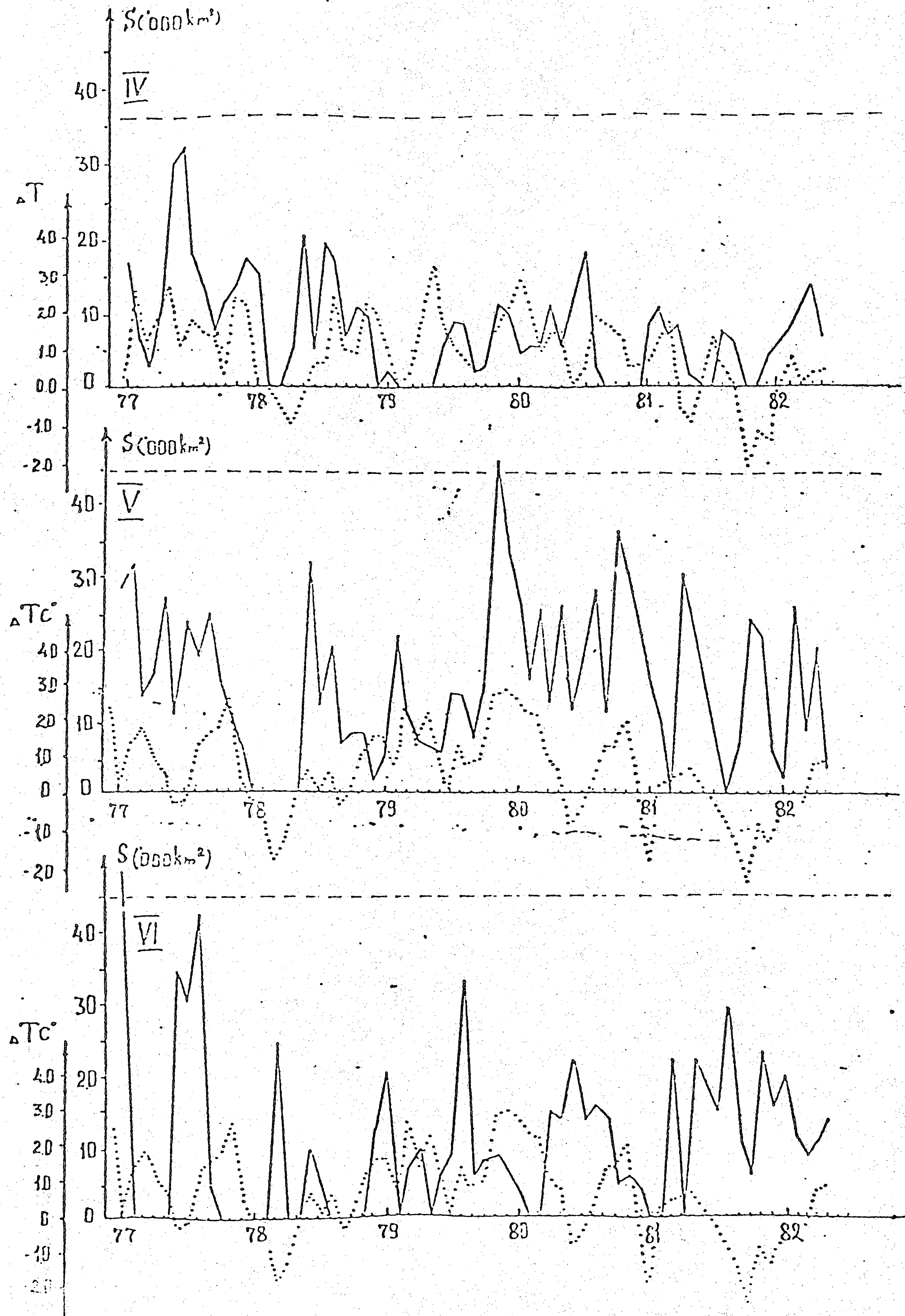

Fig. 4. Changes in SST anomalies as compared with changes in areas occupied by WCE's, by zone (zones IV,m V, and VI), 1977-82. Solid line indicates changes in areas; plotted line indicates changes in SST anomalies; dashed line is a 50% area of a zone.