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Sea-Surface Wind Stress Anomalies in 1981-87 off the Northeastern U.S.A.

by

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Abstract

Monthly wind stress data for 1981-1987 for three locations off the U. S. northeast coast were compared with averaged values for the 30 years: 1951-1980. Stress values for the 1980's did not show any distinct long-term, seasonal or persistent patterns of anomalous conditions. However, extremes in the magnitudes of stress components occurred much more frequently in spring months and in the zonal (east-west) component. About 60% of the months during 1981-1987 were of below average wind stress magnitude throughout the area. Geographically, at the grid point location over eastern Georges Bank, there was a shift in the 1980's toward lower wind stress magnitude, resulting from decreased southwestward stress. Near Cape Hatteras, NC an opposite pattern of a shift toward greater frequency of high stress magnitude developed because of increased incidence of higher southwestward wind stress.

Introduction

If significant, broad-scale alterations in the atmosphere developed in the early and mid-1980's and affected the waters of the northwestern Atlantic, these alterations should be reflected in changes in wind patterns or wind strength. Winds directly affect ocean currents, upwelling potential along coastal and shallow water regions, and stratification of the upper water column through mechanical mixing. These effects then have impacts on the distribution of water masses, transport and distribution of plankton, larvae and food for living marine resources, and the distribution of nutrients, oxygen and other physical-chemical constituents in the waters. The force of the wind on the ocean surface is given by wind stress, which is proportional to the square of wind velocity.

The U. S. Navy's Fleet Numerical Oceanographic Center (FNOC) routinely prepares synoptic analyses of surface atmospheric pressure, based on a model incorporating observations from land-based stations and ships and buoys. From the FNOC analyses, the Pacific Fisheries Environmental Group (PFEG) of the U. S. National Marine Fisheries Service derives monthly values for marine locations on a 3° latitude by 3° longitude grid of wind stress and other parameters of wind and wind-driven transport, using methods described by Bakun (1973). Derived values can be generated for the period 1946 to present. Wind stress values are presented as meridional (north-south) and zonal (east-west) components.

For this examination, monthly values of wind stress for the period 1951-1987 were provided by the PFEG for grid points in the western North Atlantic. Wind stress data for three grid points (Fig. 1), located over eastern Georges Bank (42°N, 66°W), off the New York Bight (39°N, 72°W) and off Cape Hatteras, NC (36°N, 75°W) were selected for evaluating the potential of unusual wind-driven conditions during 1981-1987 affecting the waters of the major fishery areas off the coast of the northeastern United States. In an analysis of trends in climatological conditions off the northeastern U. S. during the 1970's, Ingham (1987) examined wind stress patterns, including data for these three grid point locations.

Methods of Analysis

To examine for significant, unusual events in surface wind energy over the ocean during the early and mid-1980's, the monthly wind stress data were separated into two time series: 1951-1980 and 1981-1987. From the values of meridional and zonal stress, the magnitude of the resultant vector was also calculated for each month in both time series sets of data. For a historic base for comparing wind stress conditions during the 1980's, 30-year monthly means and standard deviation values were calculated from the 1951-1980 records for each of the three wind stress components (meridional, zonal and vector magnitude) at each of the three grid point locations. Also tabulated were means and standard deviation values of seasonal and annual averages for the 30-year period (Table 1).

For the 1981-1987 data, anomalies (departure from the mean) were calculated by subtracting the 30-year (1951-1980) monthly means from the monthly values for the corresponding month in the 1980's time series. Monthly anomalies were computed for each grid point and for each of the three wind-stress components and are shown in Figures 2, 3 and 4.

To examine for temporal patterns in the anomalies of wind stress during the 1980's, the monthly anomalies for 1981-1987 were averaged by season (Table 2), by year (Table 3) and for the entire seven year period (Table 2). As a measure of persistence of patterns, Tables 2 and 3 include the number of months during 1981-1987 when the sign of the anomalies were positive and negative, regardless of the magnitude of the anomaly.

To evaluate and compare modes in wind stress energy during 1981-1987 with the 1951-1980 base period, percent frequency of occurrence of the monthly wind-stress values were calculated for the two time series. Comparative displays of the frequency distributions for the 7-year (1981-1987) and 30-year (1951-1980) records are shown in Figure 5.

Results

Long-Term Mean Patterns

Based on the 30-year (1951-1980) monthly means and standard deviation values of wind stress, as summarized by seasonal averages in Table 1, the winds and wind stress at the two northern grid points (42°N, 66°W and 39°N, 72°W) were typically directed toward the SE and SSE during autumn and winter, and toward E and ENE in spring and summer. Wind stress and its variability (standard deviation values) at these two locations were highest in winter and least in summer. At the southern grid point location, near Cape Hatteras, NC (36°N, 75°W), winds were typically toward the SSE in winter, ENE during spring, and toward the S in the summer and autumn seasons. At this southern grid point location, wind stress magnitude and its standard deviation were highest in autumn and winter and least in spring.

Wind Stress and Anomalies during 1981-1987

In the time-series plots of monthly anomalies of wind stress for 1981-1987 (Fig. 2, 3, 4), there are no distinct trends or persistent patterns of anomalous conditions. Extreme values of stress over the seven years for each component (meridional, zonal and vector magnitude) were less than extremes in the 30-year (1951-1980) base period. However, maximum values in the 7-year record of the 1980's exceeded extremes for the same month in the 30-year record for a total of 36 occurrences, during 17 separate months (listing of months of occurrences in Table 4). For many of the cases, the largest anomalies in Figures 2, 3 and 4 match the listing in Table 4. Considering that the 7-year record for 1981-1987 represents about 23% of the number of values in the 30-year base period, the number of occurrences listed in Table 4 is less than might be expected statistically, but almost three times as many of the occurrences were in the zonal component (east-west component) as in the meridional (north-south component), and more than half of all occurrences were during the spring months (April, May, June). Extreme conditions in 1981-1987 seem to be geographically limited, since the largest anomalies in Figures 2, 3, 4 and the months of occurrence of extremes in Table 4 rarely match in time at the three grid point locations.

When the wind stress anomalies for 1981-1987 are averaged by season (Table 2), by year (Table 3) and for the total seven years (bottom of Table 2), there are no strong or clear patterns of unusual conditions. Comparing the seasonally and annually averaged anomalies with the values of standard deviation from the 30-year record (in Table 1), none of the seasonally averaged anomalies exceeds the value of 1 standard deviation in the 30-year seasonal record. The annually averaged anomalies exceeded 1 standard deviation of the 30-year annual averages for 1-2 years in the 1981-1987 series for each component at each grid point, as would be expected if there were no significant differences in the 1980's as compared with the 30-year record. These occurrences were generally localized in time and space. The most prominent annually averaged anomaly was in 1987 for the meridional stress at 42°N, 66°W (eastern Georges Bank), when the average anomaly for the year was almost 3 standard deviation units away from the 30-year annual average. This large anomaly in 1987 resulted mainly from the strong, southward directed wind stress in February (Fig. 2).

Included in Tables 2 and 3 is the number of months when the anomalies were of negative and positive sign, regardless of magnitude. Although there are some distinct groupings in these calculations (e.g. in the winter months of zonal stress anomalies for the grid point 36°N, 75°W), the clearest signal is the prevalence at all three grid points of the number of months with negative anomalies in vector magnitude, totaled for the full seven years of the 1980's, (bottom of Table 2). This implies that, although the seven year averaged anomalies for 1981-1987 of stress magnitude (average, all seasons values in Table 2) are very small, wind stress during about 60% of the months in the 1980's was below the 30-year averages, and that prevalence of occurrence was offset in average value by a relatively few months of well above average winds and wind stress.

Dominant times for below average wind stress magnitude at the three grid point locations seemed to be concentrated during two periods: November 1982-March 1984 and August 1985-January 1987 (Figures 2, 3, 4). During these two periods, about 75% of the months experienced winds (wind stress magnitude) that was below the 30-year means.

The frequency distributions of wind stress in Figure 5 generally show only minor shifts in the 1980's from the 30-year base period. The most distinctive change appears to be an opposite shift at the northern grid point (42°N, 66°W) and the southern location (36°, 75°W) in the distribution of vector magnitude frequencies. In the 1980's at the northern location, there is an increase in frequency at low magnitudes with a decrease in the 300-500 units interval, whereas at the southern position, frequency of occurrence near zero magnitude decreased with increased incidence near 400 units of stress magnitude, appearing as a secondary mode. These changes appear to result mainly from decreased southward (meridional component) and eastward (zonal) stress at the northern position and, at the southern position, increased occurrences at higher magnitudes in southward and westward stress (Fig. 5). Wind stress distributions at the central position (39°N, 72°W) appear to be transistional between the reversed patterns at the northern and southern grid point locations.

REFERENCES

Bakun, A. 1973 Coastal upwelling indices, west coast of North America 1946-71. U. S. Dept. Commerce, NOAA Tech. Rep. NMFS-SSRF-671, 103 p.

Ingham, M. C. 1982. Weather conditions and trends in the Maine-Virginia coastal and offshore areas during 1970-79. NAFO Sci. Coun. Studies No. 5, p. 33-37.

Table 1. Means and standard deviation of seasonal and annual averages of wind stress for 30 year (1951-1980) base period for meridional (+ northward) and zonal (+ eastward) components and for resultant vector magnitude (10^{-3}dynes/cm^2).

	42°N-66°W			39°N-72°W			36°N-75°W		
	Merid. Stress	Zonal Stress	Vector Magnitude	Merid. Stress	Zonal Stress	Vector Magnitude	Merid. Stress	Zonal Stress	Vector Magnitude
Winter (J,F,M)									
Mean	-299	178	429	-353	183	449	-218	120	295
Stand. Dev.	±213	±162	±197	±217	±120	±202	±167	±90	±167
Spring (A,M,J)									
Mean	44	155	204	3	111	142	18	75	103
Stand. Dev.	±71	±98	±104	±64	±61	±71	±52	±55	±54
Summer (J,A,S)									
Mean	82	146	182	15	44	100	-11	1	121
Stand. Dev.	±61	±60	±78	±39	±42	±48	±53	±61	±69
Autumn (O,N,D)									
Mean	-109	131	220	-205	90	278	-236	-17	293
Stand. Dev.	±94	±131	±129	±109	±108	±116	±140	±103	±159
Mean of Annual Averages	-70	153	259	-135	107	242	-112	45	203
Stand. Dev. of Annual Averages	±77	±76	±74	±69	±53	±65	±73	±52	±73

Table 2. Seasonal averages for 1981-1987 of wind stress <u>anomalies</u> from the 30-year (1951-1980) means for meridional (+ northward) and zonal (+ eastward) components and for resultant vector magnitude (10^{-3}dynes/cm^2). Also tabulated are the number of months during 1981 -1987 with positive and negative anomalies.

	42°N-66°W			39°N-72°W			36°N-75°W		
	Merid. Stress	Zonal Stress	Vector Magnitude	Merid. Stress	Zonal Stress	Vector Magnitude	Merid. Stress	Zonal Stress	Vector Magnitude
Winter (J,F,M) Value	-23	-12	9	-41	-29	12	12	-69	-47
No. Months	11+,10-	10+,11-	9+,12-	12+,9-	8+,13-	7+,14-	13+,8-	3+,18-	8+,13-
Spring (A,M,J) Value	10	-20	98	11	23	41	41	53	50
No. Months	10+,11-	7+,14-	11+,10-	10+,11-	10+,11-	12+,9-	14+,7-	12+,9-	10+,11-
Summer (J,A,S) Value	-10	-4	-8	-12	17	-9	12	49	-2
No. Months	7+,14-	9+,12-	8+,13-	6+,15-	10+11-	7+,14-	9+,12-	15+,6-	8+,13-
Autumn (O,N,D) Value	7	-36	-62	1	-14	-32	11	16	-20
No. Months	14+,7-	4+,17-	4+,17-	13+,8-	9+,12-	6+,15-	14+,7-	9+,12-	7+,14-
Average all Seasons	-4	-18	9	-10	-1	3	19	12	-5
Total No. Months	42+,42-	30+,54-	32+,52-	41+,43-	37+,47-	32+,52-	50+,34-	39+,45-	33+,51-

Table 3. Annual means for 1981-1987 of wind stress <u>anomalies</u> from the 30-year (1951-1980) means for meridional (+ northward) and zonal (+ eastward) components and for resultant vector magnitude (10^{-3} dynes/cm^2). Also tabulated are the number of months in each year during 1981-1987 with positive and negative anomalies.

	42°N-66°W			39°N-72°W			36°N-75°W		
	Merid. Stress	Zonal Stress	Vector Magnitude	Merid. Stress	Zonal Stress	Vector Magnitude	Merid. Stress	Zonal Stress	Vector Magnitude
1981									
Value	12	55	30	-108	119	144	-51	90	76
No. Months	5+,7-	4+,8-	4+,8-	2+,10-	8+,4-	7+,5-	5+,7-	7+,5-	6+,6-
1982									
Value	18	53	27	38	-11	-57	35	-52	-58
No. Months	6+,6-	6+,6-	6+,6-	7+,5-	5+,7-	4+,8-	9+,3-	4+,8-	3+,9-
1983									
Value	64	-121	-102	15	-46	-22	51	-12	-19
No. Months	8+,4-	2+,10-	3+,9-	7+,5-	4+,8-	3+,9-	6+,6-	7+,5-	6+,6-
1984									
Value	93	-63	-44	41	-35	-24	49	1	14
No. Months	8+,4-	3+,9-	4+,8-	7+,5-	3+,9-	6+,6-	8+,4-	5+,7-	7+,5-
1985									
Value	3	56	17	0	28	-9	22	62	7
No. Months	6+,6-	6+,6-	5+,7-	8+,4-	6+,6-	4+,8-	8+,4-	7+,5-	4+,8-
1986									
Value	-11	-58	-20	40	-31	-64	76	-8	-81
No. Months	5+,7-	5+,7-	5+,7-	7+,5-	6+,6-	3+,9-	10+,2-	5+,7-	2+,10-
1987									
Value	-207	-48	155	-98	-29	52	-48	5	28
No. Months	4+,8-	4+,8-	5+,7-	3+,9-	5+,7-	5+,7-	4+,8-	4+,8-	5+,7-

Table 4. Months during 1981-1987 when wind stress components exceeded extremes for the month in 30-year (1951-1980) base period.

Location	Merid. Stress	Zonal Stress	Vector Magnitude
42°N	Apr 1981	Apr 1981	Apr 1981
66°W		Jan 1982	
	Apr 1982	Apr 1982	Apr 1982
	Oct 1982		
	Jul 1984	Jul 1984	July 1984
		Jan 1985	
		Apr 1986	
	Feb 1987	Feb 1987	Feb 1987
		Apr 1987	
39°N		Mar 1981	
72°W		Apr 1981	
			Dec 1981
		May 1984	May 1984
			Jul 1984
		Jun 1986	Jun 1986
		Mar 1987	
		Apr 1987	
36°N		Jun 1981	
72°W	May 1983		May 1983
	May 1984	May 1984	May 1984
		Jan 1985	
		Jun 1987	Jun 1987

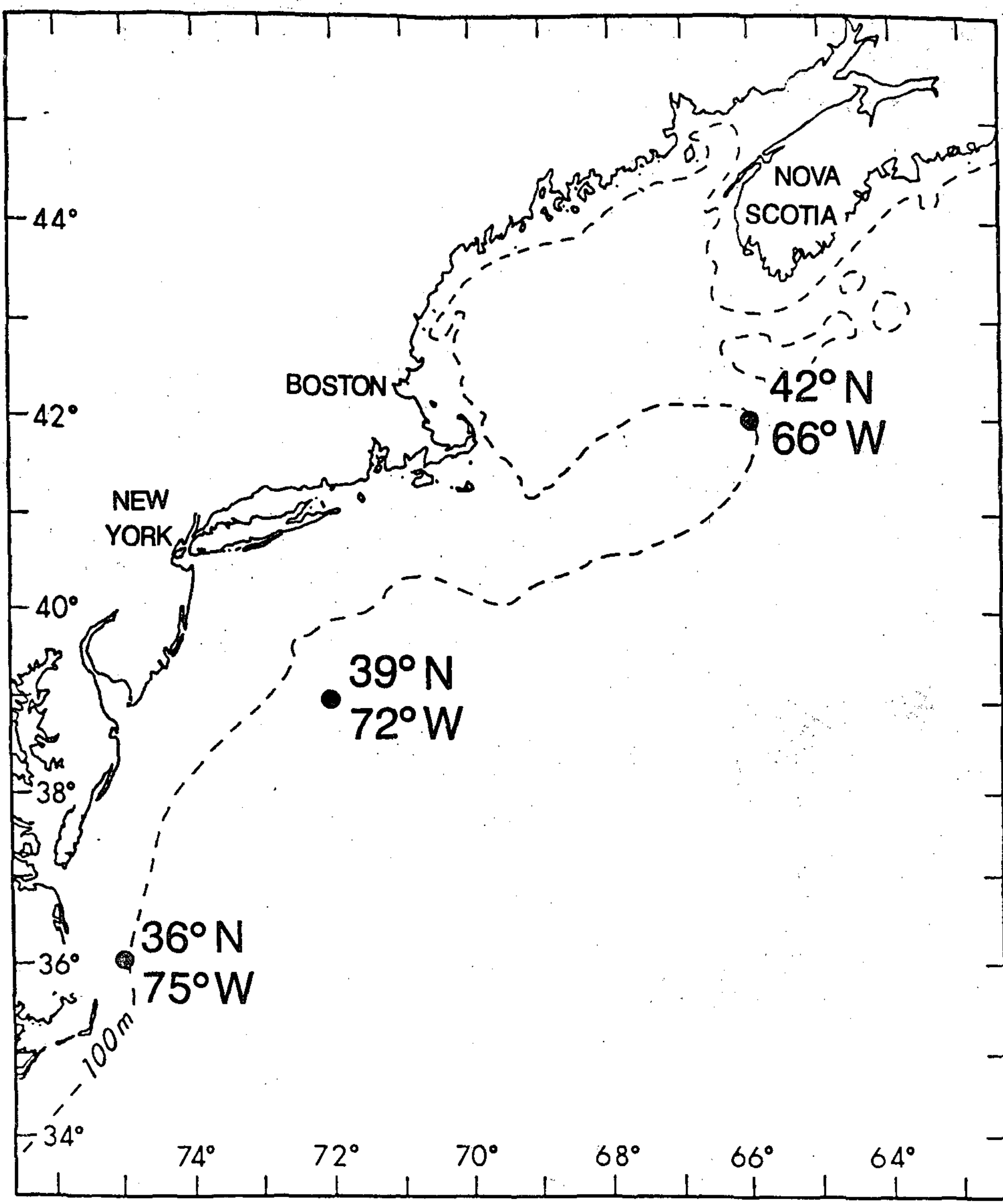

Figure 1. Locations of grid point positions for wind stress data.

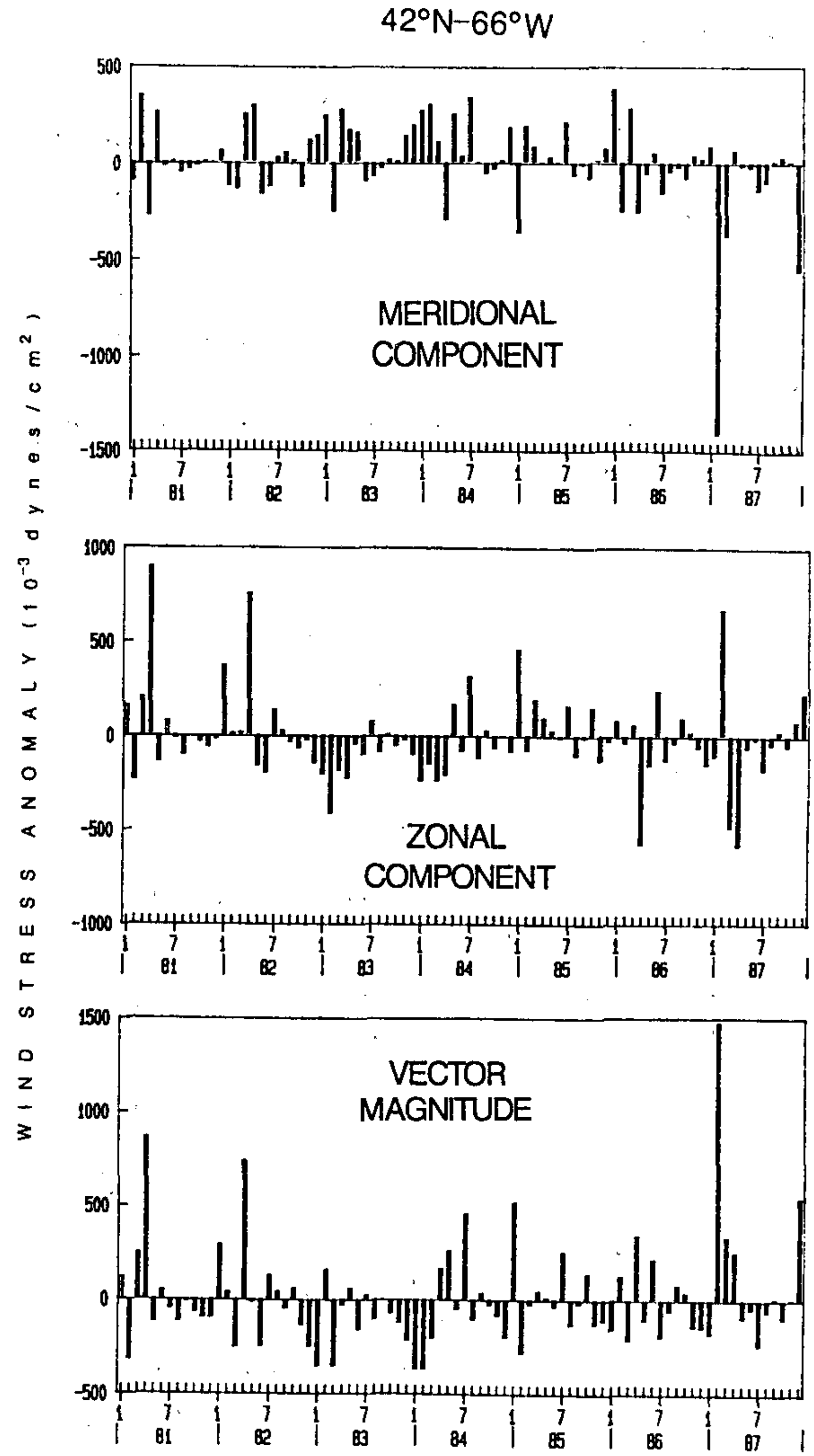

Figure 2. Monthly anomalies of wind stress for 1981-1987 (departures from 1951-1980 monthly means) for location over eastern Georges Bank (see Fig. 1). Positive components in the anomalies are more northward, or less southward (meridional) and more eastward, or less westward (zonal) than the 30-year means for the month.

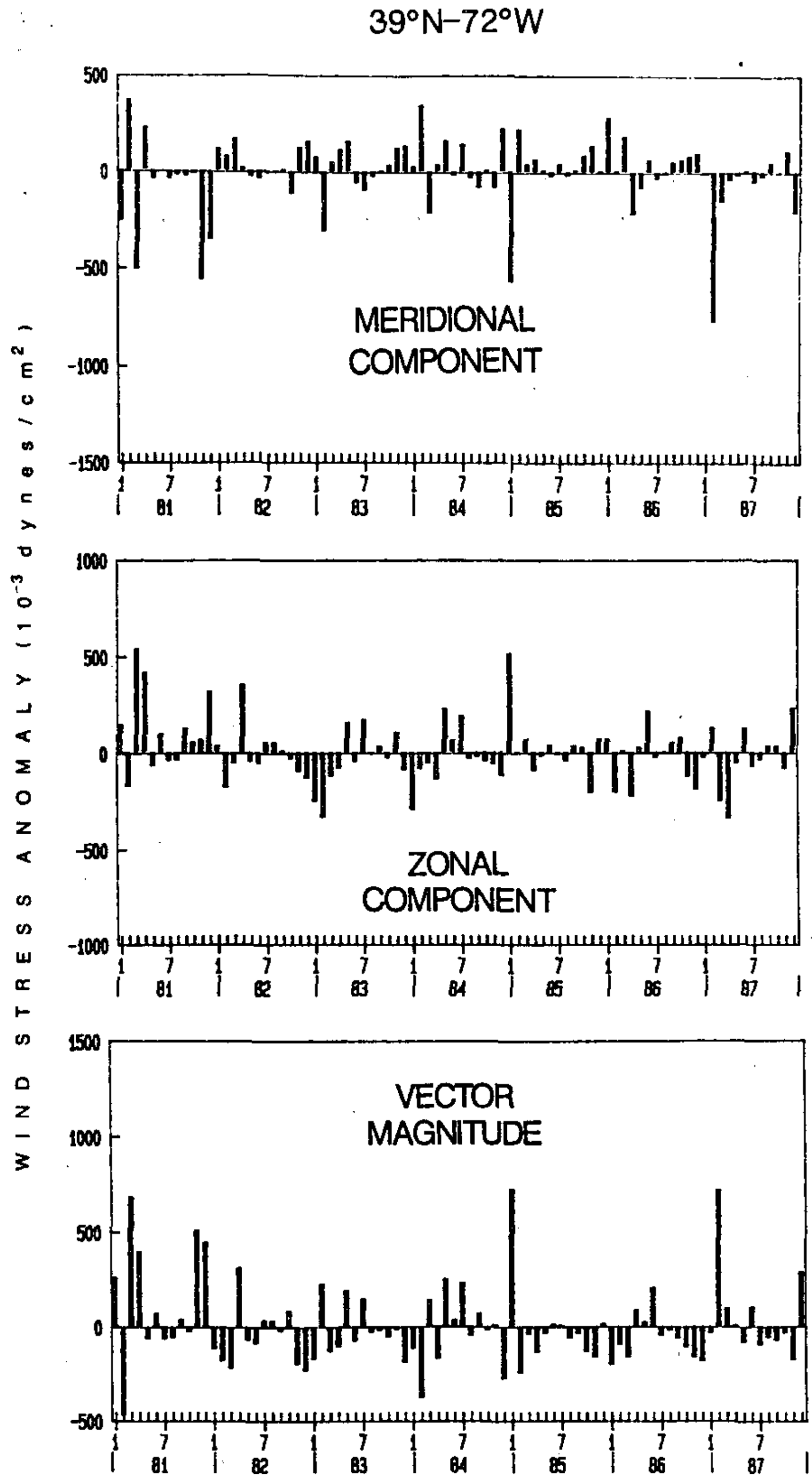

Figure 3. Monthly anomalies of wind stress for 1981-1987 (departures from 1951-1980 monthly means) for location off the New York Bight (see Fig. 1). Positive components in the anomalies are more northward, or less southward (meridional) and more eastward, or less westward (zonal) than the 30-year means for the month.

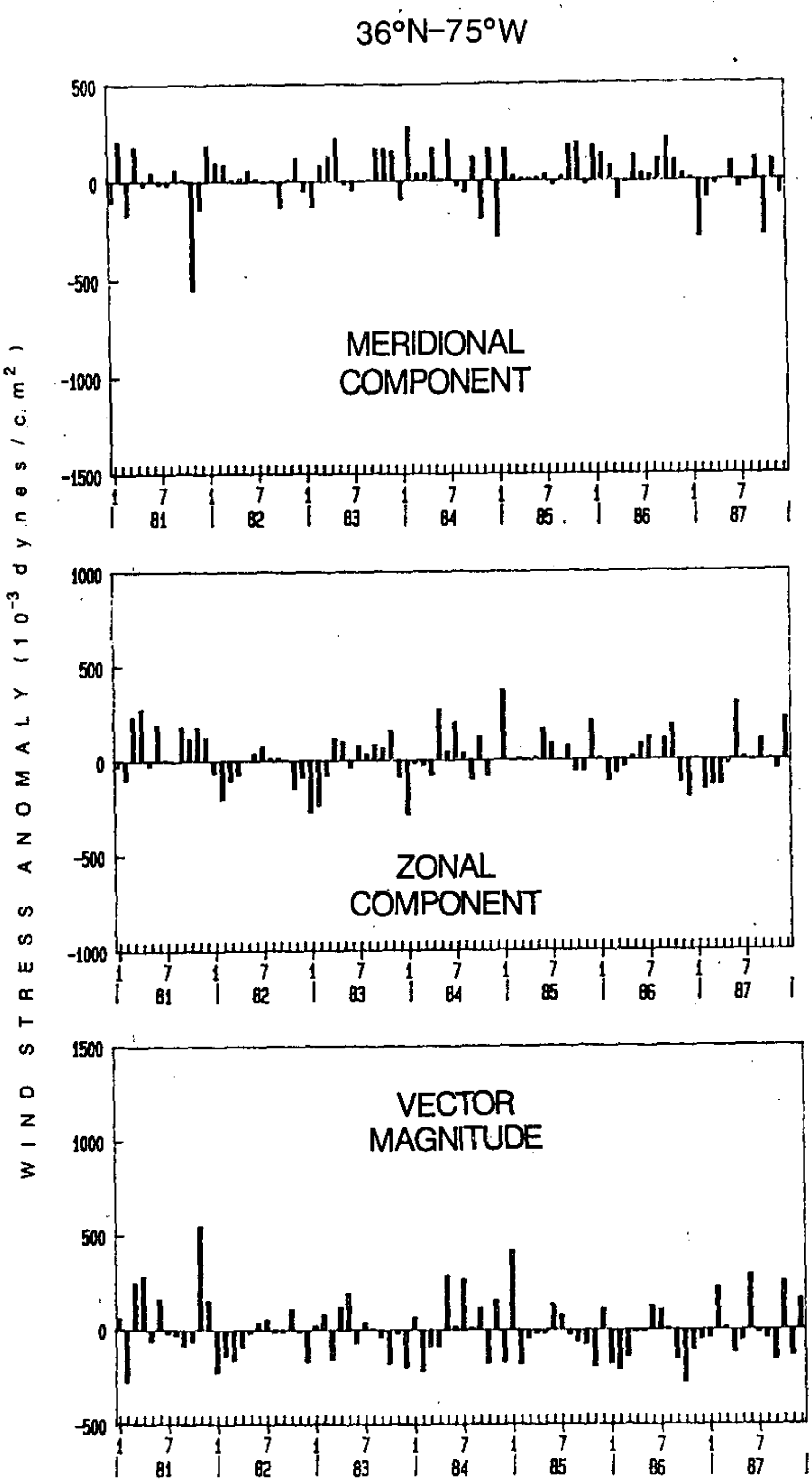

Figure 4. Monthly anomalies of wind stress for 1981-1987 (departures from 1951-1980 monthly means) for location near Cape Hatteras, NC (see Fig. 1). Positive components in the anomalies are more northward, or less southward (meridional) and more eastward, or less westward (zonal) than the 30-year means for the month.

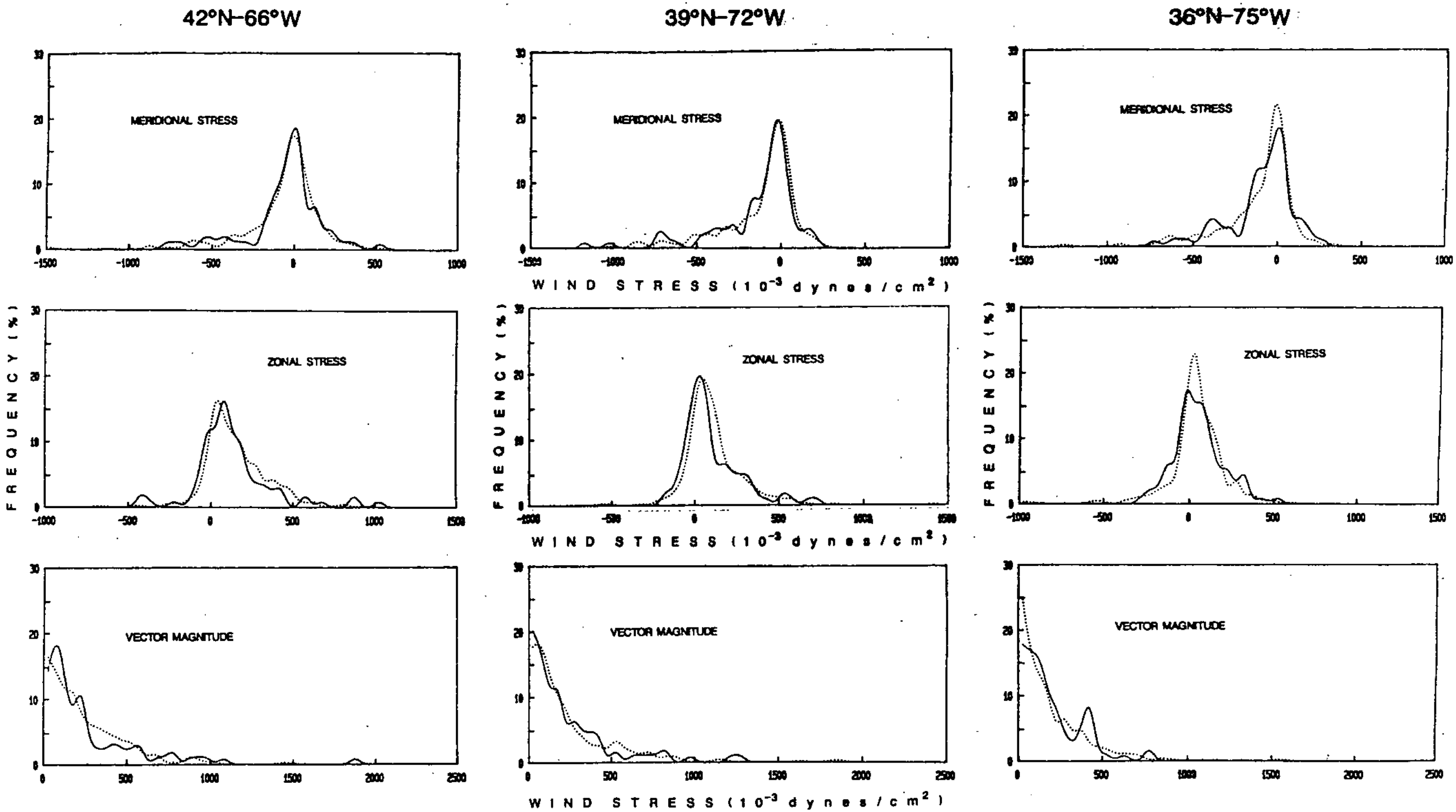

Figure 5. Frequency distributions of monthly wind stress for meridional and zonal components and for resultant vector magnitude for 1981-1987 (solid lines) and 1951-1980 (dotted lines) at the three grid point locations in Figure 1. Positive component values are northward (meridional) and eastward (zonal). Data were grouped in 50-unit increments for the analyses.