Statistical Analyses of COADS Wind Data in Coastal Regions of the United States

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Abstract

Climate is the result of effects from air temperature and many other variables but air temperature records, compared to records of other measurements, are available over relatively long periods. Air temperature observation records show the northern hemisphere climate has warmed and cooled over periods of varying length in the past. In this study, wind data from the Comprehensive Ocean-Atmosphere Data Set(COADS) are used to determine atmospheric circulation changes which are empirically associated with the air temperature changes. Some understanding of the natural processes which produce climate change is anticipated from our study of these associations.

Systematic changes of wind in U.S. coastal regions with periods of climate warming and cooling suggest circulation changes, in addition to carbon dioxide controlled radiation effects, could produce the climate changes indicated by air temperature.

A statistical procedure for analyses of COADS was used to determine decade period vector wind-field differences from the COADS record period. The statistical procedure for these analyses is explained and the wind differences are compared to summaries of mid-Atlantic coast island-station observations.

Introduction

Climate is the result of an ensemble of many variables many of which are not regularly measured. The measurement record periods for most of these variables is relatively short compared to changes of climate in the past (Godshall and Walker, 1992). Surface air temperature and wind are variables that produce climate but they are effected by feed-back processes from other variables in the ensemble. With tacit recognition of the lack of total independence, these variables are commonly treated as indicators of climate because records of air temperature, in particular, are generally the longest of the climate variables. Surface air temperature records summaries within selected latitude bands in the northern hemisphere (Fig. 1) show a period of climate warming began during the late 1800s, that was followed by a period of climate cooling that began about 1940, and then climate warming beginning about 1970. This graph also shows an apparent variation of amplitude in the change of temperature with latitude. Figure 2, a graph of air temperature at New Haven, CT with the temperature-summary of Figure 1 from New Haven latitudes, shows the northern hemisphere climate changes were changes which also occurred in the U.S. mid Atlantic region.

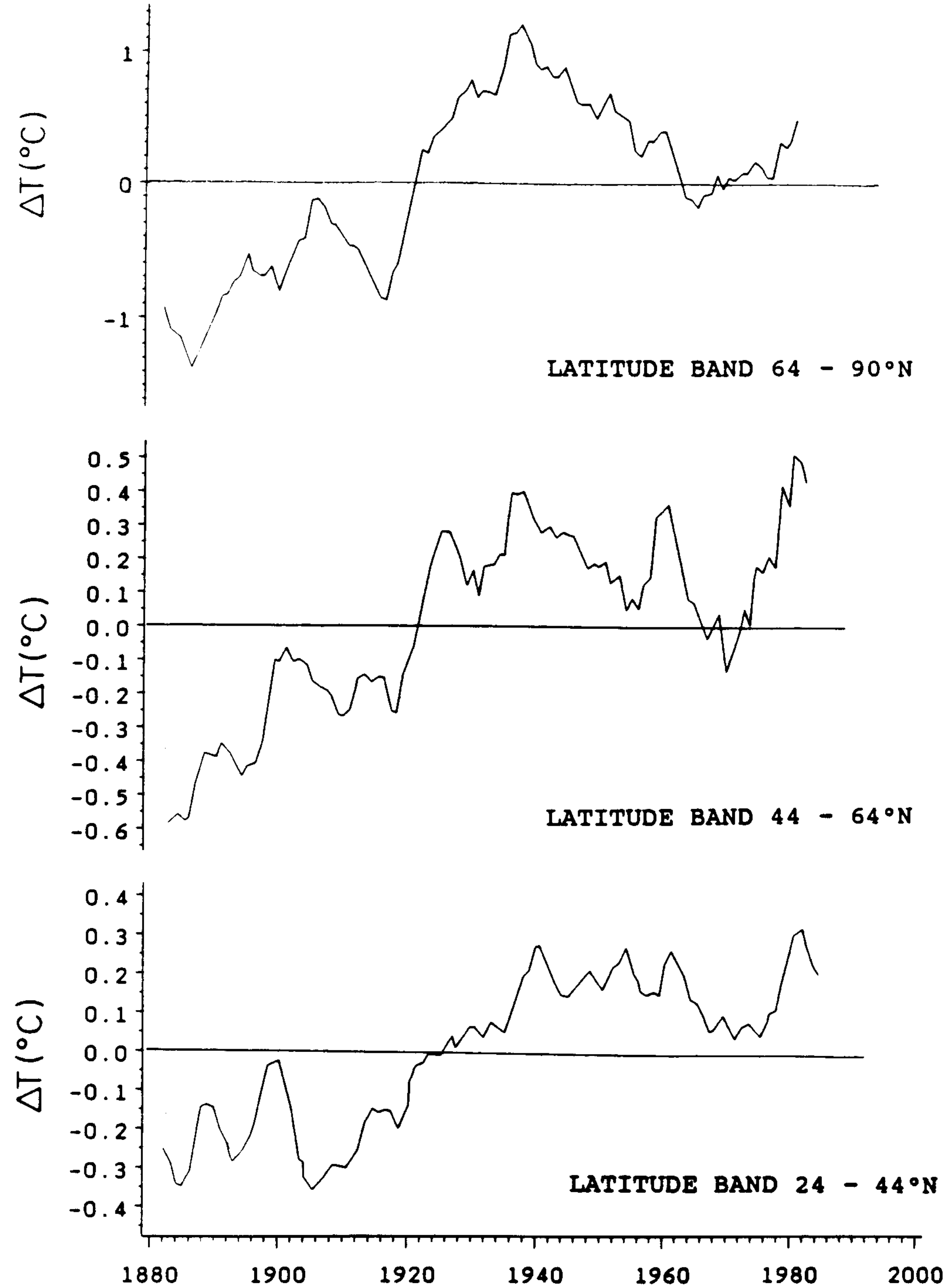

Figure 1. Northern Hemisphere surface air temperature variations averaged for selected bands (Hansen and Lebedeff, 1987).

A climate study based on COADS (Godshall and Walker, op. cit.) compared the vector change of wind in decade summaries for each 2° area of the Pacific and Atlantic oceans, between the equator and 40°N, with summaries of these winds over the entire archive of COADS (NOAA, 1985), 1854-1979. The periods chosen for summary were the periods which occurred at the beginning of the major climate changes of the northern hemisphere, i.e. 1890-1899, 1935-1944, and 1970-1979. The 1890s and 1970s periods wind direction differences (Fig. 3) show winds from most 2° along the Pacific and U.S. Gulf coasts turn clockwise (white dots on Figure 3) with climate warming. In the northeast U.S. coast region the results are mixed with some 2° winds directions turning counter-clockwise (black dots on Figure 3). The climate cooling, 1935-44 period, 2° wind directions tend to turn in opposite directions from the changes with northern hemisphere warming.

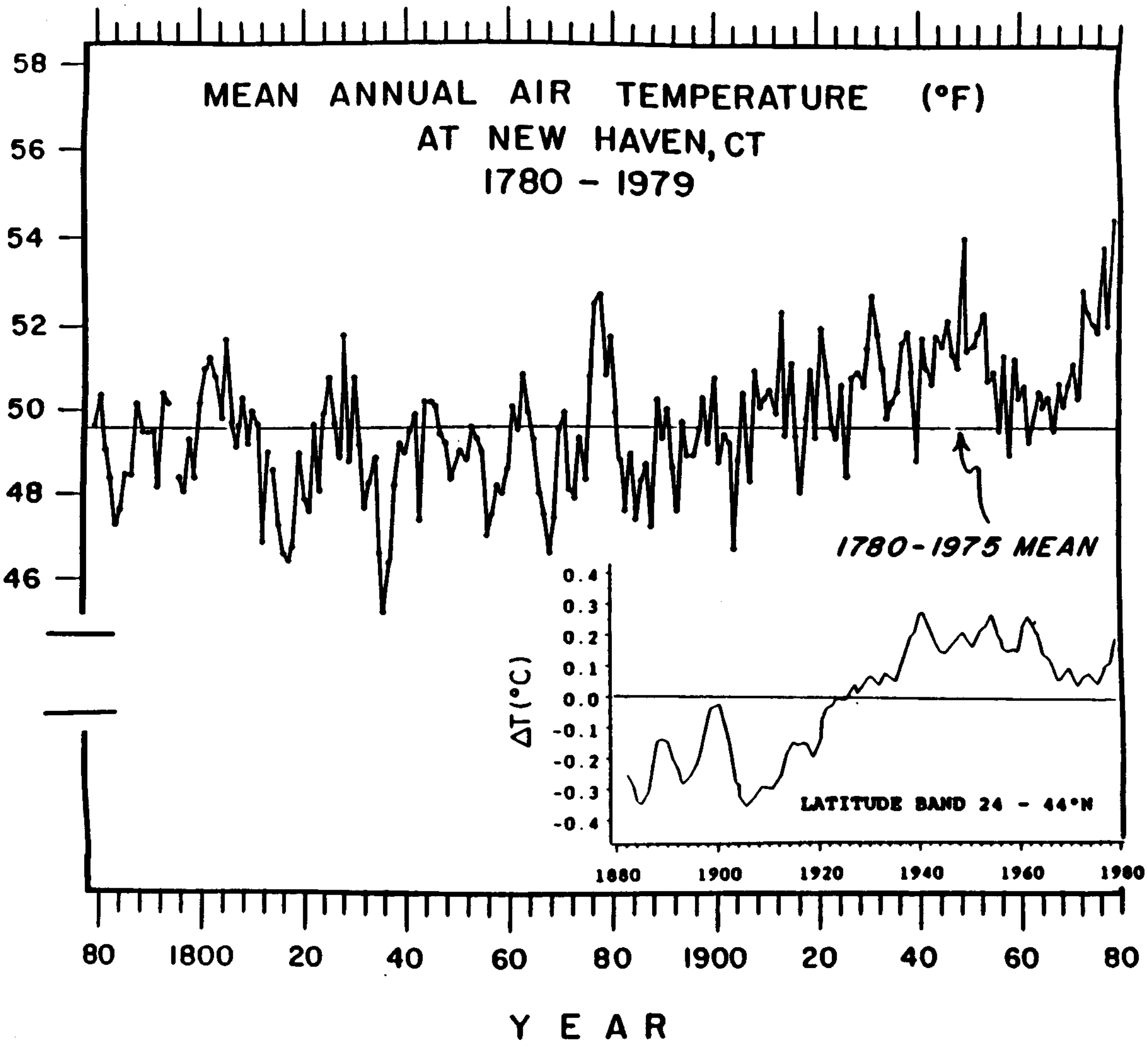

Figure 2. Air temperature measured at New Haven, CT. Ingham, 1982

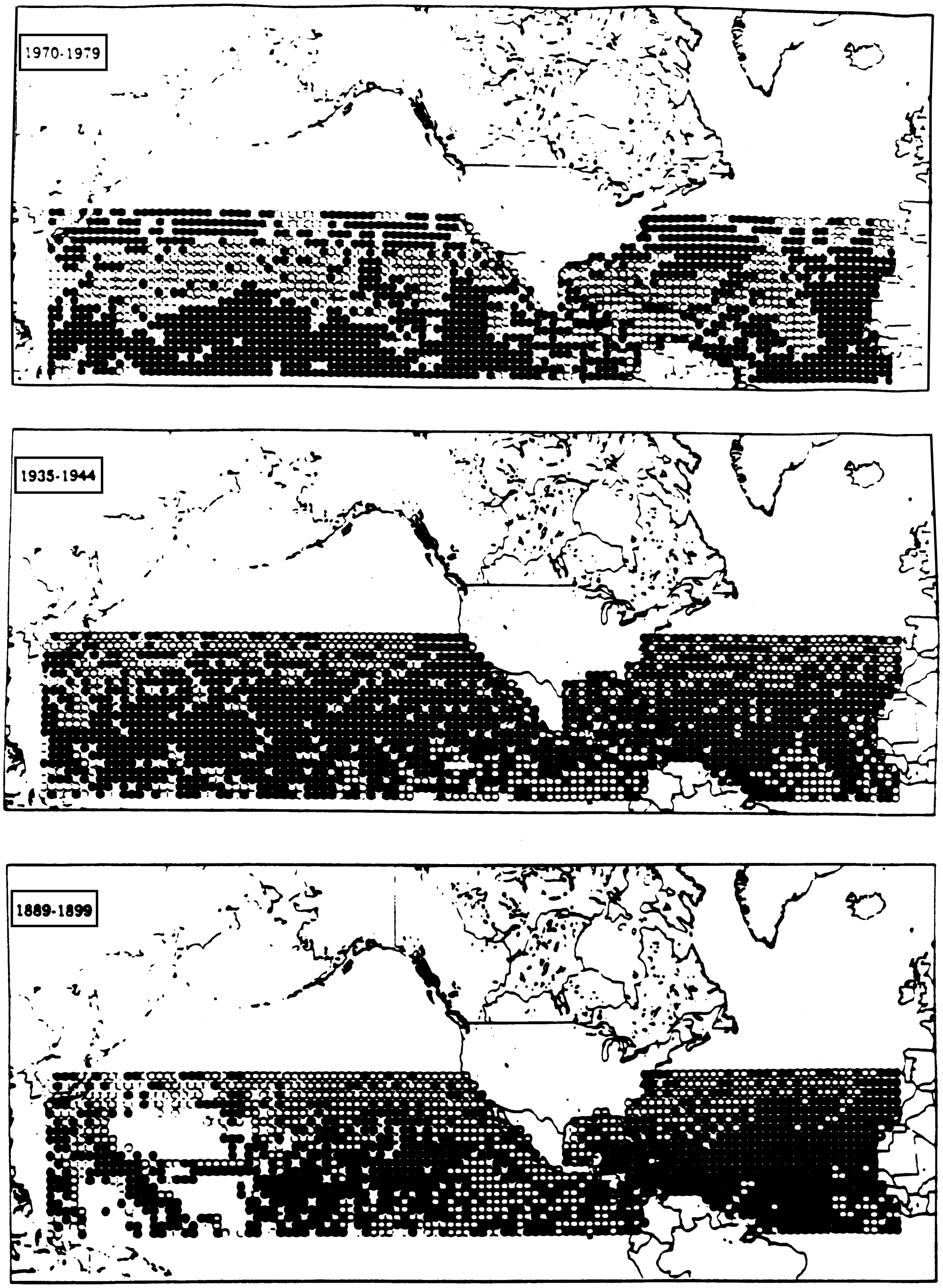

Figure 3. Wind direction differences for selected decade periods compare to long period averaged direction (1854-1979) computed from COADS 2n data. Counter-clockwise wind direction) black dots), clockwise change (white dots). Godshall and Walker, (1991).

Table 1. Decadal averages of wind direction (dir.) and speed (spd.)[1]

Season	Decade	Nantucket Is. Dir	Nantucket Is. Spd	Block Is. Dir	Block Is. Spd	41°N, 71°W Dir	41°N, 71°W Spd
Winter[2]	1900	287	5.6	289	7.5	298	3.3
Summer[3]		220	5.4	223	5.7	214	1.3
Winter	1910	279	5.3	288	6.8	293	3.4
Summer		225	4.6	228	5.8	212	0.7
Winter	1920	269	6.2	278	7.8	293	2.9
Summer		223	5.1	223	5.2	213	1.1
Winter	1930	271	5.0	272	6.8	301	3.4
Summer		218	4.5	216	5.0	223	1.1
Winter	1940	288	4.3	297	6.7	302	3.2
Summer		225	3.5	225	5.1	243	0.7
Winter	1950	292	5.4	304	6.4	301	3.4
Summer		225	5.2	226	4.9	230	1.3
Winter	1960			279	3.9	307	3.8
Summer				200	4.0	223	0.9
Winter	1970					293	3.4
Summer						216	1.5

[1] wind speed reported m/sec

[2] inter averages over January, February, and March

[3] summer averages over June, July, August, and September

Statistical Methods for Wind Climatology

Wind observations are reported as vector quantities with magnitude and direction. The analysis procedure used in computation of decade changes of wind uses sets of paired wind observations. Wind speed and direction are assumed to vary independently with regard to each observation of wind. From the computations, a Wind speed factor nu(v) and a wind direction factor phi(ϕ) are derived which adjust the set of one of the paired wind observations for a minimum sum of squared differences between paired observations.

The wind vectors (R_1) from one set, $R_1 = \rho_1 \exp(i\theta_1)$ are paired with a second set of winds, $R2 = \upsilon\rho_2 \exp(i(\theta 2 + \phi))$. the wind observation sets have j = 1 through N pairs with wind speeds ρ_1 and ρ_2, wind direction θ_1 and θ_2, (i) is the imaginary number of exponents of the complex representation of the wind vectors and, E represents the number amount of squared difference between the sets of N paired R_1 and R_2.

$$\sum_{j=1}^{N} \rho_{1j}\exp(i\theta_{1j}) - \nu p_{2j}\exp \quad (i(\theta_{2j}+\phi))^{2} = \sum_{j=1}^{N} E_{j}$$

After expanding the squared difference, differentiating E sum with respect to nu and then with respect to phi, and setting the differentials equal to zero, the differential equations may be solved algebraically to produce equations for nu and phi. These nu and phi factors to make the squared vector differences a minimum.

$$NU = \frac{\sum_{j=1}^{N} (\rho_{1j}\rho_{2j}) \quad COS(\theta_{1j} - \theta_{2j} - \phi)}{\sum_{j=1}^{N} (\rho_{2j})^{2}}$$

$$PHI = ARC\ TAN \frac{\sum_{j=1}^{N} SIN(\theta_{1j} - \theta_{2j})}{\sum_{j=1}^{N} COS(\theta_{1j} - \theta_{2j})}$$

Mid-Atlantic Wind Climatology

The Figure 3 maps of the 2° COADS wind direction variation are based on computed values of phi where positive phi values indicate counter-clockwise direction changes from the long-term mean and vise versa. For purposes of comparing wind changes at coastal Island stations, with changes mapped in Figure 3, and with northern mid-Atlantic areas, decade period average winds from the northern area are listed in Table 1 and graphed in Figure 4. The clockwise turning of winter wind direction at the island stations during the period of climate cooling is apparent and the subsequent counter-clockwise turning of winter wind about 1970 is coordinated with the recent period of climate warming. In general, the COADS data shows these same systematic changes but the 1960s decade COADS (ship reports) winds are more northerly than the Islands reports. Annual averages of COADS (ship reports) are used to produce Figure 3 but seasonal averages of wind are used in these mid-Atlantic area analyses (Table 1) because larger climate associated effects seem to occur in winter. Analyses comparing ship-reported wind speed with regular observations from stationary NOAA buoy 4401 (Quayle, 1984) found considerable difference (on the order of 15% differences) between averaged ship reports in the nearby mid-Atlantic area and the averaged buoy reports. With such differences in reported wind speed, comparable differences in wind direction are also expected. Therefore, the island station data are likely to be the most accurate, provide a better measure of the wind changes with respect to climate variation, and the “salt and pepper” look to the mapped mid-Atlantic direction changes (Figure 3) are not unexpected.

Phi and nu values (Table 2) were computed for specified decade period averages which are compared to the long-period means. These computations provide a measure of the statistical computation scheme as well as the climate analysis. Negative phi indicate the decade period average wind direction was clockwise of the mean direction and positive phi indicate the decade period average wind direction was turned counter-clockwise relative to the long-period mean. Nu values larger than 1.0 indicate the decade period mean wind speed was less than the long-period mean speed and, when multiplied by nu, the decade period wind speeds will be similar to long-period average speed. These computations of phi and nu quantize intercomparison of different decade period summaries in the mid-Atlantic region.

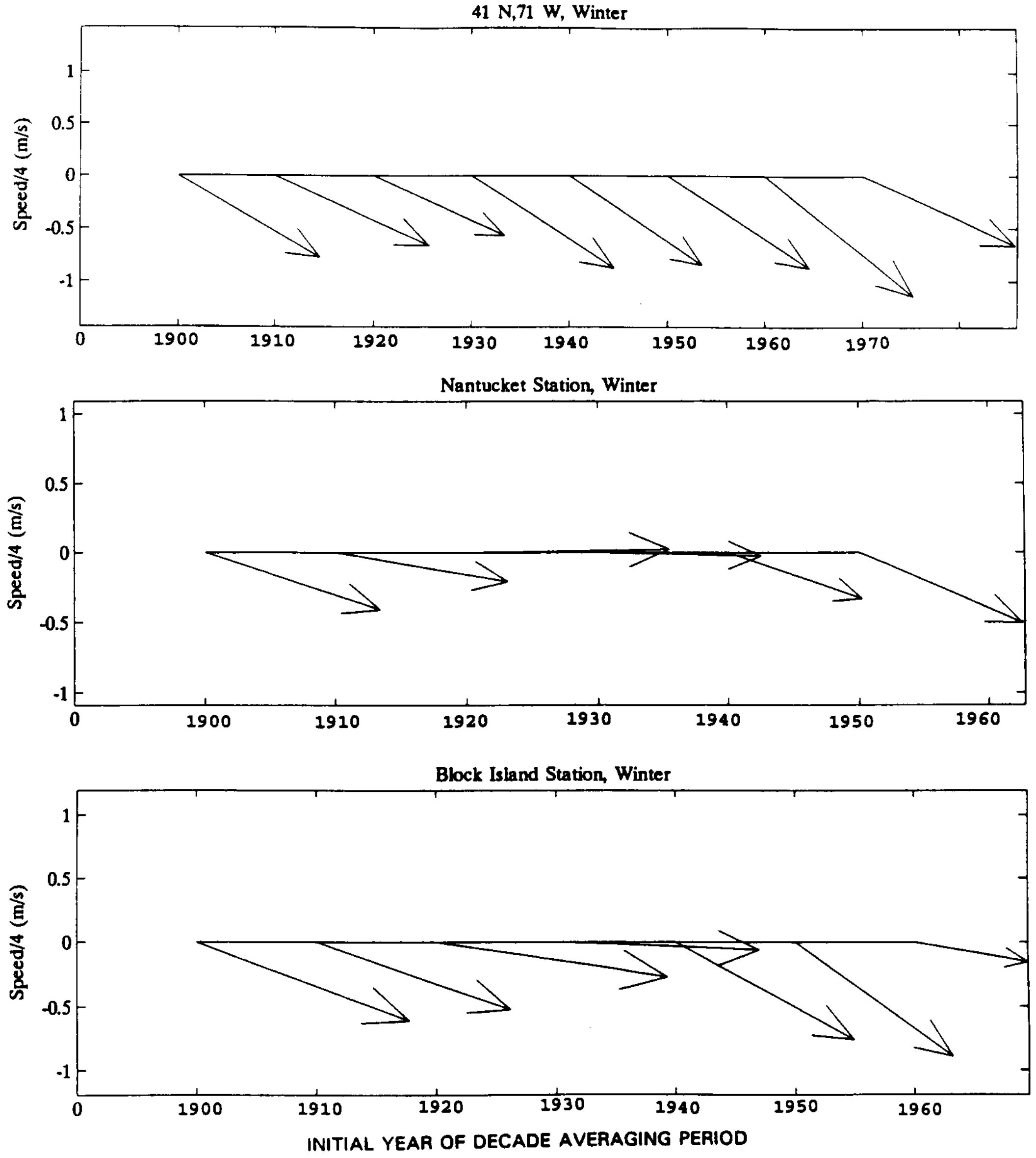

Figure 4. Decade wind directions computed from COADS (area centered at 41°N,71°W) and wind observations from Block Island and Nantucket Airports.

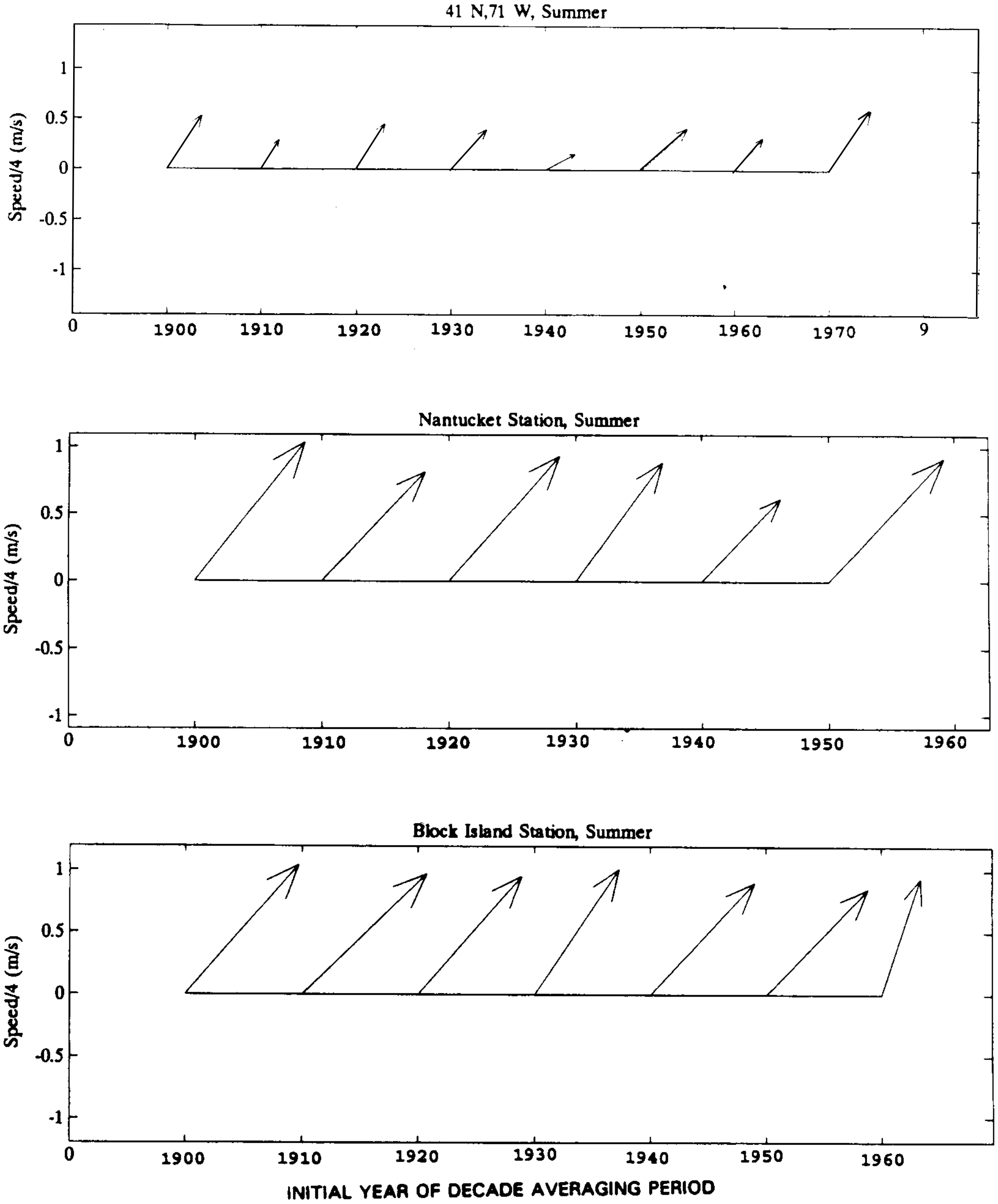

Figure 4. (Continued)

Table 2. COADS area 41°N, 71°W, phi and nu wind factors

Decades Compared to Long Term	Winter[1]		Summer[2]	
	Phi[3]	Nu	Phi3	Nu
1890-1899	-11.3	0.7	0.3	1.2
1935-1944	-5.5	1.0	-18.5	0.8
1940-1949	0.7	1.1	-0.7	0.9
1950-1959	0.4	1.0	3.8	0.9
1960-1969	-6.1	1.1	-2.6	0.7
1970-1979	8.2	1.0	19.7	0.8

[1] Winter wind comparisons included data from months January, February, and March.

[2] Summer wind comparisons included data from months June, July, August, and September.

[3] Phi values are expressed in degrees of angular difference.

Average Wind	direction	speed (m/s)
Winter	301.3	3.4
Summer	219.3	1.1

Clockwise shifts of wind direction shown at Nantucket Island, MA and Block Island, RI and the COADS area 41°N,71°W (the area in which these stations are located), are coordinated with climate cooling. The phi values computed for these decades, from the COADS data, also indicate the northward turned wind. After 1970 wind direction turns counter-clockwise, more westerly, in winter (January, February, March) and the phi value is positive. Although there are changes during the summer season (June, July August, September), the winter changes are most significant because of the coastal circulation changes that are produced (Godshall and Walker, 1992). Turning of winter wind clockwise orients the wind across the coast and across the near shore bathymetry but counter-clockwise turned winter wind orients the wind direction approximately with the coast and bathymetry. The resulting wind stress along the shore is expected to produce upwelling and bring relatively saline deep-water shoreward. The significance of the wind change is shown by the change in salinity at Montauk, NY and Woods Hole, MA (Figure 5). These salinity changes and inferred coastal circulations are coordinated with the wind change and the periods of climate change.

Conclusions

The clockwise turning of winter wind direction during the 1950s and 1960s decades is evident on the vector wind graphs for Block Island and generally for the 2° ocean summary area in which the Island is located. Nantucket wind conditions are very similar to the Block Island data through the 1950s as expected. During the 1970s, wind direction from ship reports within the surrounding ocean area turned counter-clockwise in apparent association with climate warming that began about that time. These wind changes caused significant change in coastal circulation as shown by the salinity changes on Long Island and Nantucket Island coasts. The shelf deep water seasonal change of temperature lags the changes in shallow coastal water, therefore, the upwelling circulation also causes increase of coast water temperature with salinity (Godshall and Walker, 1992). Because of the orientation of these mid-Atlantic coasts these changes in the marine environment are not found in more southern areas.

The coordination of the nu and the phi values with demonstrated changes of the wind validate the statistical computations presented here and the wind comparisons presented in the work by Godshall and Walker (1992).

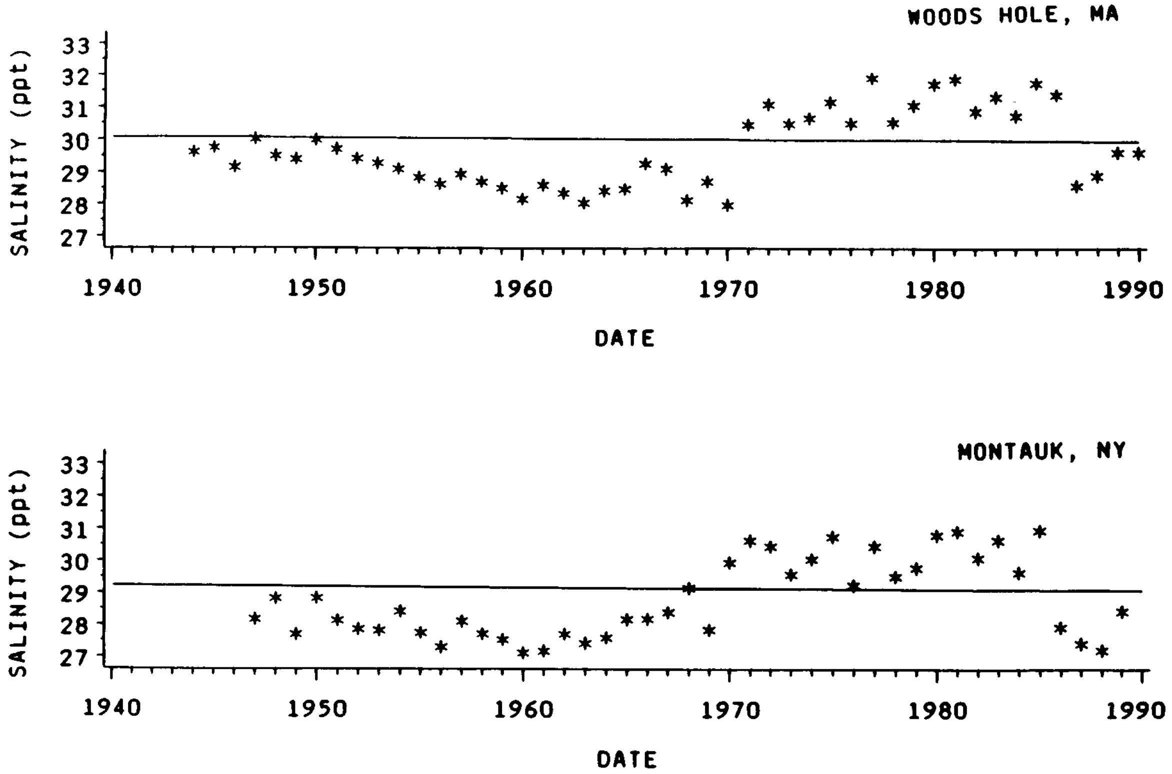

Figure 5. Salinity computed from winter (January-March) water temperature and density measurements at two NOAA tide measuring stations: Woods Hole, MA and Montauk, NY.

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