Scales of Coastal Wind Variability Addressed by COADS Wind Summaries in 2° Square Areas

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Abstract

Randomly selected periods of COADS archive wind data in U.S. Mid-Atlantic 2° square summary areas are a basis for estimates of wind variability between decades of wind summary periods. Similar treatment of coastal observations provide estimates of decades variability which is compared with the COADS summaries variability. The variability is expressed in terms of speed and direction components of the wind as vector parameters. Spatial variability is also examined to determine the representativeness of 2° COADS spatial summaries in coastal gradients of wind variation. The representativeness of decade COADS summaries, to define intra-regional scales of climate variability, is tested by comparing observed change with change expected from theoretical boundary layer processes. Periods of northern hemisphere air temperature variation are used as indicators of climate variability and these periods are used to evaluate the resolution of such variability with COADS wind data. Wind constancy computed from COADS wind summaries is used to evaluate possible long period changes of wind over the North Atlantic.

Introduction

The coastal zones are known to be areas with large spatial changes because of physical differences between land and water surfaces that affect the atmosphere boundary layer. The temporal changes are related, in the short term, to boundary layer adjustment from contrasting land and water surfaces and, over longer periods, to responses of the coastal zone to influences of air-sea interaction and meteorological regimes. These regimes might include wind direction or speed changes and atmospheric circulation with different meteorology.

Wind forces are important parameters of environmental change in the coastal zone where marine circulation in shallow water may be controlled by wind effects. Wind forced circulation influences coastal navigation, fisheries productivity, and water quality of coastal embayments. Therefore understanding wind variation along coastal regions and trends which may obscure optimum coastal resource management are topics to be served by data archives. This paper will evaluate how 2° square area summaries of wind data in COADS serves coastal analyses in the mid-Atlantic region of the United States (Fig. 1). The evaluation is offered as an example of COADS use to define climate related change in any coastal region.

Wind change and comparison of wind records is based on the treatment of wind as vector quantities. Wind vector comparisons between locations (spatial changes) and between decade and long-term means (temporal changes) are quantified by their direction and speed differences through a least-squares procedure (Godshall et al., 1976; Fig. 2). The comparison results are estimates of direction and speed adjustments which could be applied to one of data sets to make the wind similar to the basis of comparison, i e. the long-term mean or the basic station, Boston, MA. When these direction (phi) and speed (nu) adjustment factors are mapped they provide a measure of the spatial variability of the wind and when these factors are compressed between different decades, temporal variations are quantified. These factors from the vector comparisons are computed as if no correlation between changes of speed and direction exist. Any climate variation with feed-back effects on wind is assumed to envelope the whole study area but physical differences in each 2° study area are assumed to produce a local orientation to any wind regime over the area.

The temporal variability in each COADS 2° square are based on decade summaries of wind data compared to long-term monthly averaged data from the period 1900 to 1989. Although the use of decade summary periods for wind circulation analysis is empirical, decade summaries by Budyko(1977) have shown wind circulation and Godshall et al. (1991) have defined change in U.S. coastal regions from decade summaries. In this paper, the statistical significance of temporal change from decade wind summary is based on comparison of summary results with wind variations from ten-year data groups of randomly selected dates.

Spatial changes of decade summarized COADS 2 winds are quantified by change relative to Boston, MA an observation station located northwestward and up-wind of the study area. Observed spatial changes are related to expected changes in the atmospheric boundary layer from ocean surface temperature variations and surface-drag characteristics. The significance of these changes is based on geographic distribution of wind summaries characteristics relative to the geographic distribution of surface changes.

Spatial Changes

COADS 2° square wind summaries for each month were computed from derived U (east/west) and V (north/south) wind components (NOAA, 1985). We mapped long-term means from these resultant wind data over the period 1900 to 1992 and these resultant U and V components are the basis for winter (average of COADS data from January, February and March) wind direction and speed (Figs. 3a, b). The distribution of winter wind is produced from the broad-scale pressure distribution over the western Atlantic. The area of the subtropical anticyclone (the Bermuda High) and the area of low pressure over the north Atlantic (the Iceland Low) are the primary features of the pressure distribution. These wind maps also show the average wind speed and direction of winter season wind at Boston, MA, Providence, RI New York, NY, Baltimore, MD, and Norfolk, VA. Visual comparison of the wind from these on-land stations with the wind characteristics offshore from COADS indicates the wind characteristics are similar over the whole mid-Atlantic region. Therefore, spatial changes of wind within the region are interpreted to be caused by local influences.

Over the mid Atlantic region, the COADS winter wind data are compared with Boston winter winds within decade periods. Figures 4a, b, c, and d show the regional-scale spatial change of wind, measured by the phi and nu. factors, during the decades from 1950 through 1990. All these decade summaries of COADS winds show the same general spatial distribution of change which we attribute to atmospheric boundary layer changes. The mean position of the winter season Gulf Stream (NOAA, 1975-1992) is within the area of negative or low positive magnitude phi factors. The relationship between Gulf Stream and these phi values is interpreted to indicate areas where the atmospheric boundary layer vertical mixing is forced by surface heating. Vertical mixing brings the influence of upper-level winds to the surface which is expected to cause cyclonic (counter-clockwise) turning of surface wind fields in the mid-Atlantic region (U.S. Navy, 1958). Nu factors increase in these same areas with relatively low phi factors which indicate the winter winds increase relative to wind in areas westward and north of Gulf Stream influence. The local increases in wind speed are expected from the vertical exchange of momentum in air from aloft with the air near the surface. These effects from relatively warm surface water temperatures which are shown over decades are also shown by Figs. 3a, b the long-term mean directions and speed

Temporal Changes

Temporal variability of decade averaged-wind at each station or COADS summary area is the basis used for climate variability description. The temporal variation is measured by the relative change of each decade from the long-term mean conditions at that same station or area Estimates of significance of these changes are based on expectation that multiple data samples, such as numerous decades, will have statistical quantities, means and standard deviations, which will vary from data set to data set. For each station and COADS summary area we produced multiple ten-year data sets by randomly selecting the data years to be included in each set. The frequency distributions of 30 ten-year periods wind factors from Boston, from a 2° summary area centered at 39°N, 71°W are shown in Table 1. Table 2 lists the nu and phi factors computed from the decades of data (1950-1959, 1960-1969, etc.). The significance of the decade nu and phi are judged relative to the distribution of these factors frequency distributions. For example, the Boston winter change in wind direction relative to the long-term mean, given as phi, is 6.7883° in the decade 1960-1969. From Table 1 we see that a phi of this magnitude is expected from less than 5.0 percent of ten-year periods. Therefore, the change in this decade averaged wind at Boston is significant at a confidence level better than 95 percent. The phi factors from the COADS 2° square area decades 1920-29 and 1970-79 and the nu from the decades 1900-09 and 1920-29 are significantly different from expected factors at the 95 percent confidence level. However, the lack of association of these wind changes with another changing parameter of climate, such as air temperatures (Fig. 5), reduces the physical significance of these COADS indicated changes.

The decade summary for wind analysis was tested by computing nu and phi factors from the multiple data sets (set sizes 5, 10, 15, 20, 25, 30, 35 and 40) of randomly chosen dates from the Boston data record 1949-1992 (NOAA, 1949-1992) and from the data records 1900-1992 from the COADS summary area centered at 39°N, 71°W. The standard deviation of nu and phi factors from these data sets are graphed with data sets sizes in Figs. 6a, b. As expected, these examples show the magnitude of standard deviation of nu. and phi changes little when large sets are increased by the magnitude of standard deviation changes significantly when small data sets are increased. We recognize the convergence of standard deviations to constant value as the random set size approaches the data record size but we hope the principle expectation for a consistent statistic from large data sets is demonstrated. We fit an empirical function with power of data-set-size as independent variable and factor standard-deviation the dependent variable. The magnitude is decreasing through the decade size data set. Therefore, the decade size data set is not quite large enough to provide a stable statistic but relatively consistent statistical measure is expected from data sets of about 20-30 years. The data records are not very long from on-land observation stations and data sets larger than decade would prevent interpretation of temporal change. However since the decade summaries are known to be effective for analysis of climate, we have elected to use these summaries also even though variation from one period to another may be increased by this choice.

Climate is a condition resulting from many environmental variables but, considering climate change to be a change in any of the variables, changes of air temperature are indicators of climate change. The periods of temperature changes at New Haven, CT (Fig. 5) are used here to indicate periods of change in the mid-Atlantic region. Decade summaries of wind data from island stations (Table 3) indicate a northward wind shift, relative to long-period average wind conditions during the period of cool air temperatures, roughly 1945 to 1970. However, none of the COADS 2° square decade summaries show these same periodic changes in wind.

The COADS Summaries

The COADS wind data summaries for each summary area were produced with quality control which prevented data values of a magnitude greater than 3.5 standard deviations(3.5 sigma) from entering the summaries (NOAA, 1993). Review of these “standard” summaries revealed the possibility of storm-wind exclusion from the summaries and, during the period 1980-1992, “enhanced” wind data summaries were produced that allowed 4.5 sigma wind magnitudes into the summaries. Quantitative comparison of the “standard” and the “enhanced” winter summaries in the 2° square areas in the mid-Atlantic region (Table 4) indicate little difference between these summaries results from the different quality controls. However, the Nu factors less than 1.0 indicate the enhanced summaries generally have lower speeds than the standard summaries. This suggests the summarization processes allowed low speed winds into the enhanced summaries, however all the COADS standard and the enhanced sets were positively skewed relative to normal distribution.

Wind Constancy

In Fig. 5b the long-term mean COADS wind speeds generally decrease northward of 50°N, these northward Atlantic regions are known to be regions of frequent storms and high wind speeds. The relatively low wind speeds on this map are probably the effect of resultant wind computation in regions were the wind constancy is low (Fig. 7). A map of wind factors for speed (nu values) computed from COADS 2° square area wind comparisons with Boston, MA (Fig. 8) suggests the spatial distribution of nu values is similar to constancy. These winter wind speed factors and the wind constancy percentages are compared in Fig. 9. The functional relationship between the factors and constancy in the trade wind zone is evidently different in the westerly wind regime that encompasses Boston. The mapped distribution of phi factors extend the geographic regions shown on Figs. 4a-d is extended across the Atlantic in Fig. 10. This map of factors simply illustrates the changes of wind regimes across the Atlantic.

We discovered no significant change in wind constancy from decade to decade based on the 2° square winter months COADS summaries (Fig. 11).

Summary and Conclusions

The vector wind comparison computations from COADS produced estimates of differences between decade summaries of wind and long-term means. In an attempt to assess the utility of COADS 2° area wind summaries in climate analysis of coastal regions we defined periods of climate variation in the mid-Atlantic regions from air temperature changes. Comparison of the wind variation from island stations and the COADS summaries with these periods of temperature change indicates that singly, COADS 2° area summaries are poor sources of data to evaluate climate variability from decade to decade. However, changes over groups of 2° areas provide information about climate.

The relatively low mean wind speeds mapped in 2° square areas north of 50° are suspected to be a product of summarization processes. These latitudes are associated with stormy conditions and high wind speeds but these conditions are not well defined by computation of resultant wind vectors. Wind comparison factors computed from Boston appear to be closely related to wind constancy.

The comparison factors from Boston depict regional scales of change in air-sea interaction and the factors from the mid-Atlantic region appear to be part of the broadscale distribution of factors of the North Atlantic.

Computation of enhanced COADS summaries probably does not provide unbiased summaries which include storm wind because of the inclusion of very low wind speeds in the summaries. Perhaps special summaries which only contain the infrequent but important high wind data are necessary.

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Table 1: Distribution of Nu and Phi Factors from Multiple (n=30) Decade Data Sets of Random Dates.

Boston MA		Nu	Phi
	1st Quarter	0.964	-6.035°
	median	1.000	-2.623°
	3rd Quarter	1.018	0.605°
	95 percent	1.037	4.350°
COADS 2° area centered 39°N, 71°W		Nu	Phi
	1st Quarter	0.920	-2.457°
	median	0.970	0.631°
	3rd Quarter	1.074	7.119°
	95 percent	1.172	12.204°

Table 2: Nu and Phi Wind Factors for Decades of Wind Data.

Boston, MA		Nu	Phi
	(1950-59)	1.0433	5.429°
	(1960-69)	1.0545	6.788°
	(1970-79)	1.0026	-7.790°
	(1980-89)	0.9437	0.604°
COADS 2°area centered 39°N, 71°W		Nu	Phi
	(1900-1909)	1.1961	1.0260°
	(1910-1919)	0.8066	2.2772°
	(1920-1929)	0.6965	-7.6314°
	(1930-1939)	0.8968	10.7698°
	(1940-1949)	1.1378	7.0156°
	(1950-1959)	1.0178	-0.5424°
	(1960-1969)	0.9848	-1.3274°
	(1970-1979)	1.0700	-10.7744°
	(1980-1989)	1.0253	8.7477°

Table 3: **Decade summaries of wind data from Islands in the Mid-Atlantic compared to long-period average wind.**

Nantucket Island		Nu	Phi
	(1900-1909)	1.51	-4.41°
	(1910-1919)	1.40	-13.17°
	(1920-1929)	1.65	-20.45°
	(1930-1939)	1.29	-18.55°
	(1940-1949)	1.08	-2.03°
	(1950-1959)	0.52	19.18°
	(1960-1969)	0.61	14.60°
	(1970-1979)	0.61	9.05°
	(1980-1989)	0.59	35.26°
Block Island		Nu	Phi
	(1900-1909)	1.27	-5.28°
	(1910-1919)	1.15	-6.36°
	(1920-1929)	1.32	-15.48°
	(1930-1939)	1.11	-20.24°
	(1940-1949)	1.15	1.38°
	(1950-1959)	0.91	12.62°

Table 4: Comparison of Standard and Enhanced COADS Wind Summaries for Winter

Location of 2° Summaries	Nu[1]	Phi
37°N, 73°W	0.998	0.791°
37°N, 71°W	1.000	0.378°
37°N, 69°W	0.981	0.221°
39°N, 73°W	1.004	0.803°
39°N, 71°W	0.962	-1.527°
39°N, 69°W	1.004	1.811°
41°N, 73°W	0.969	1.248°
41°N, 71°W	1.006	0.531°
41°N, 69°W	0.908	0.531°

[1] Wind comparison factors are applied to Standard summaries.

Figure 1: Geography of middle Atlantic 35°- 43°N and 68° - 78°W.

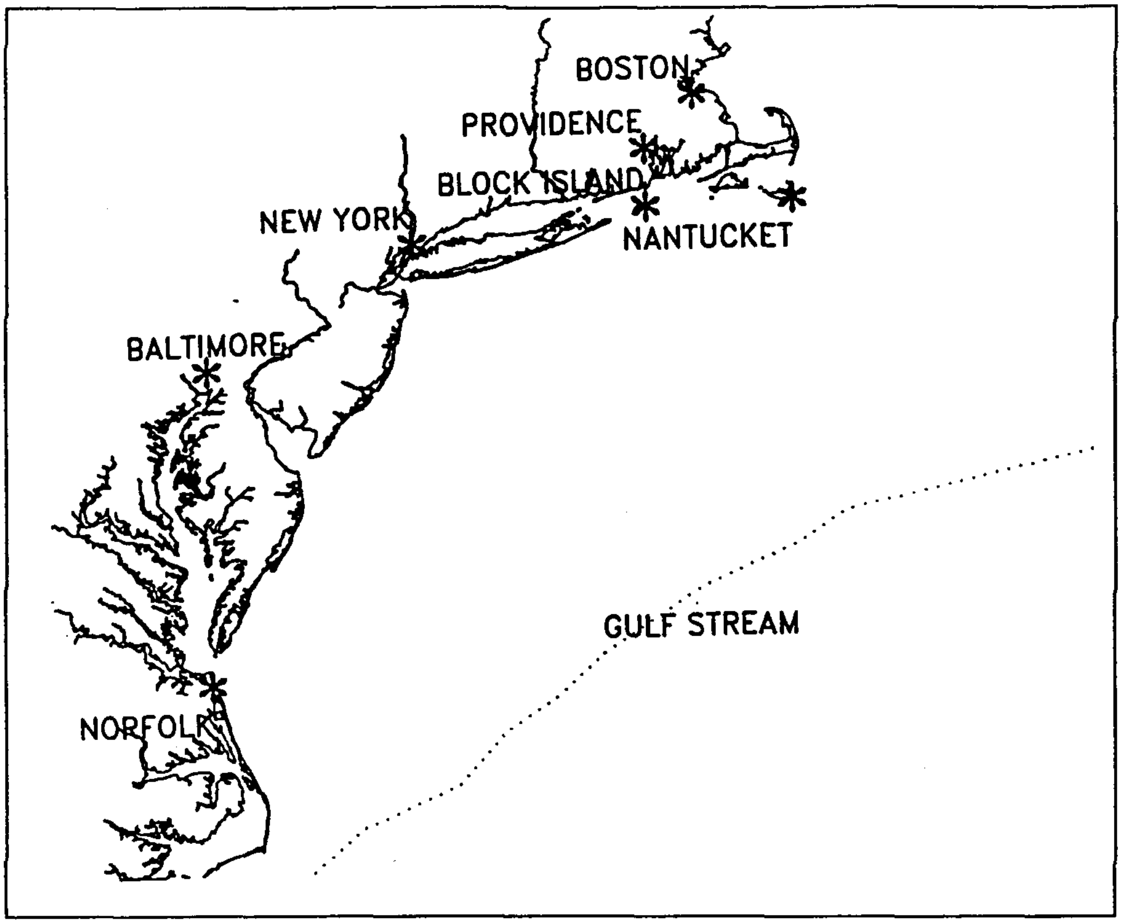

Figure 2: Wind Vector Differences and Ratio.

$$R_k = \rho_k e^{i\theta_k}$$

$$D_j = \rho_{1j} e^{i\theta_{1j}} - \eta \rho_{2j} e^{i(\theta_{2j}+\phi)}$$

$$S = \sum_{j=1}^{N} |D_j|^2 = \sum_{j=1}^{N} D_j \overline{D_j} = \sum_{j=1}^{N} \left[(\rho_{1j} e^{i\theta_{1j}} - \eta \rho_{2j} e^{i(\theta_{2i}+\phi)})(\rho_{1j} e^{-i\theta_{1j}} - \eta \rho_{2e} e^{i(\theta_{2i}+\phi)} 0 \right]$$

$$S = \sum_{j=1}^{N} |D_j|^2 = \sum_{j=1}^{N} \left[\rho_{1j}^2 + \eta^2 \rho_{2j}^2 - 2\eta(\rho_{1j}\rho_{2j}) \cos(\theta_{1j} - \theta_{2j} - \phi) \right]$$

$$\frac{\partial S}{\partial \eta} = \sum_{j=1}^{N} \left[2\eta \rho_{2j}^2 - 2(\rho_{1j}\rho_{2j}) \cos(\theta_{1j} - \theta_{2j} - \phi) \right]$$

$$\frac{\partial S}{\partial \phi} = -2\eta \sum_{j=1}^{N} \left[(\rho_{1j}\rho_{2j}) \sin(\theta_{1j} - \theta_{2j} - \phi) \right]$$

$$\eta = \frac{\sum_{j=1}^{N} (\rho_{1j}\rho_{2j}) \cos(\theta_{1j} - \theta_{2j} - \phi)}{\sum_{j=1}^{N} \rho_{2j}^2}$$

$$\phi = \tan^{-1} \left[\frac{\sum_{j=1}^{N} \rho_{1j}\rho_{2j} \sin(\theta_{1j} - \theta_{2j})}{\sum_{j=1}^{N} \rho_{1j}\rho_{2j} \cos(\theta_{1j} - \theta_{2j})} \right]$$

Figure 3a: Winter Wind Direction from COADS 2° Summaries (1900-1992).

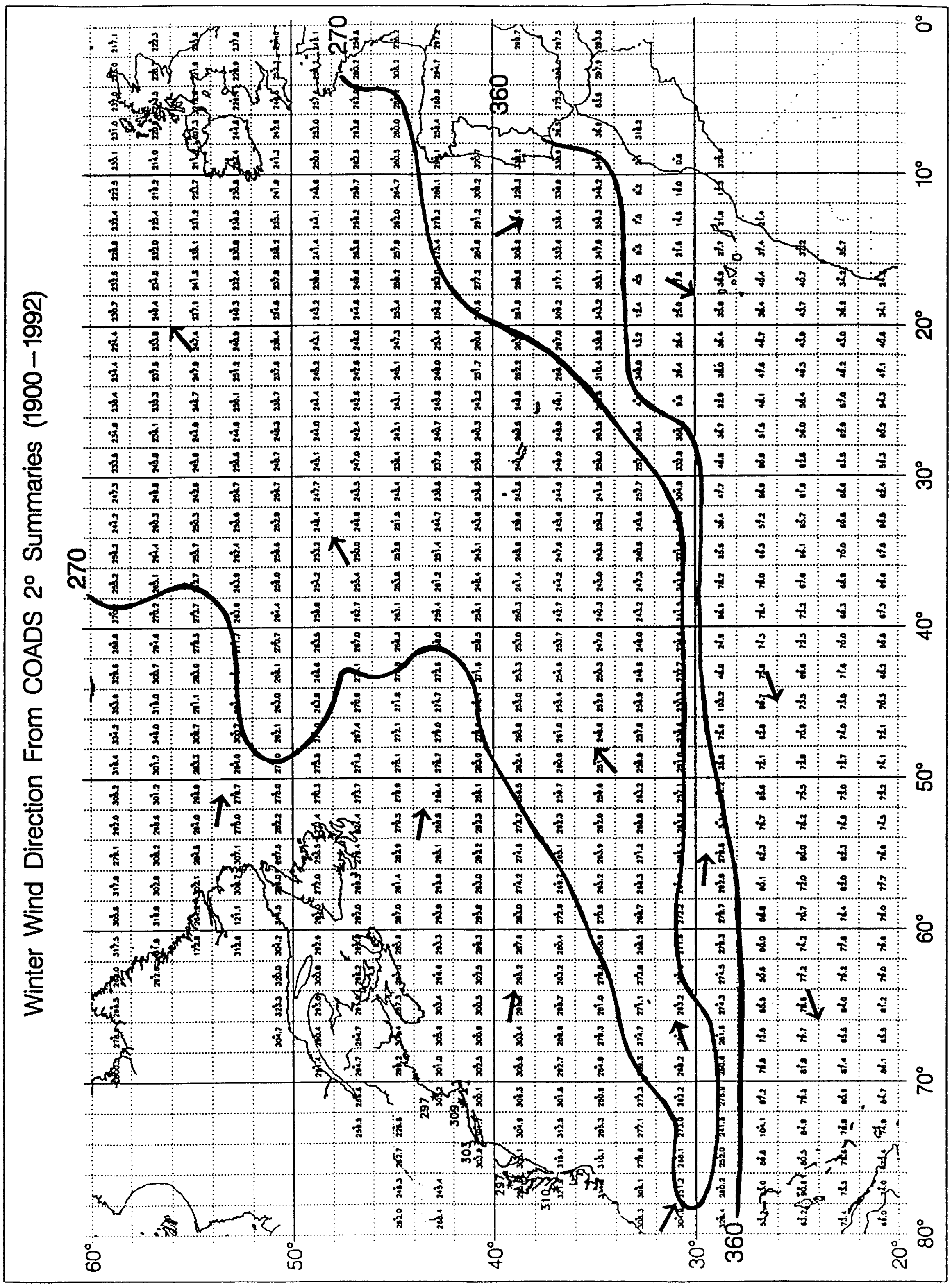

Figure 3b: Winter Wind Speed from COADS 2° Summaries (1900-1992).

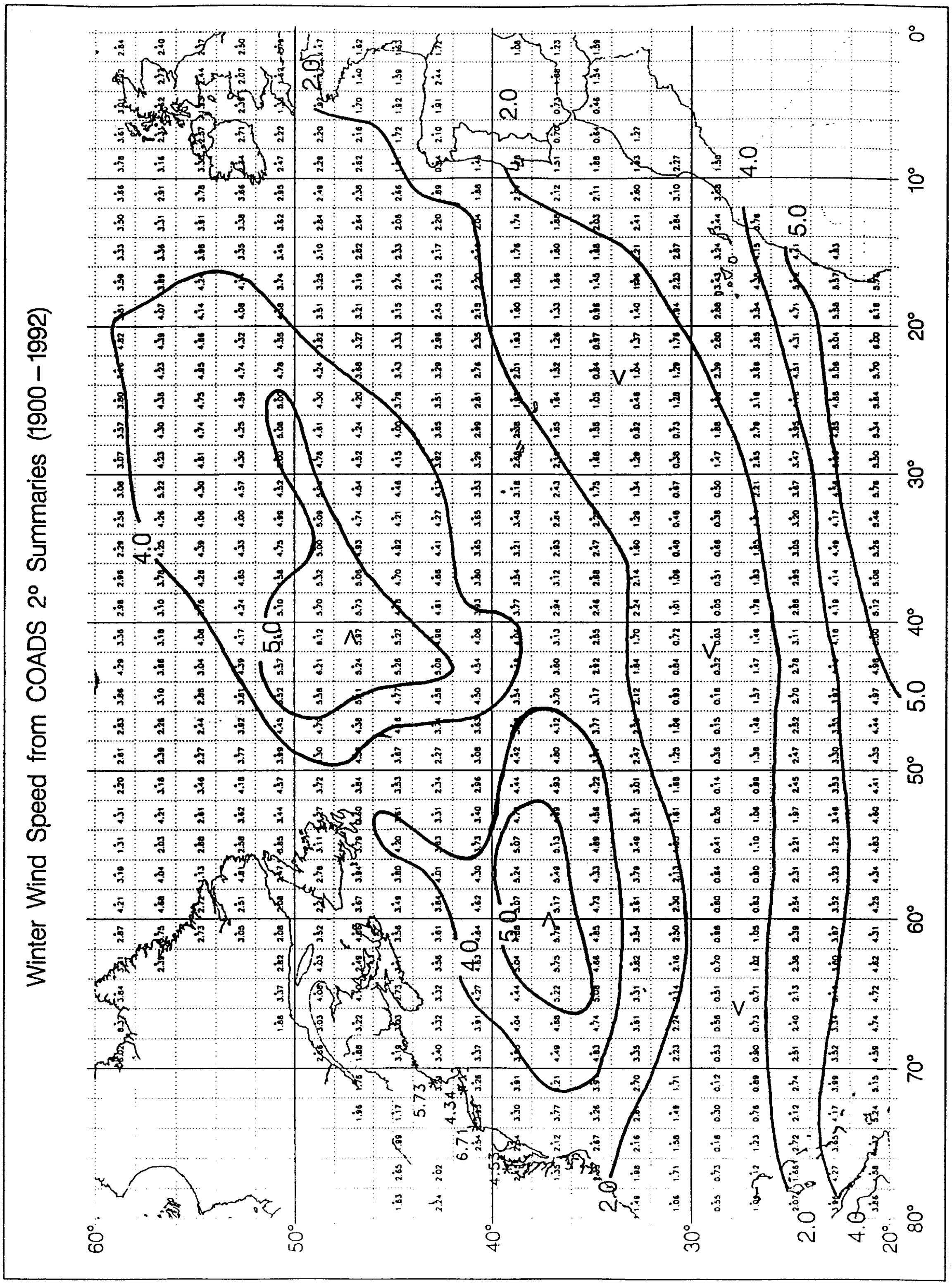

Figure 4a: Comparison of phi and nu between selected 2° square and Boston, MA (1950-59).

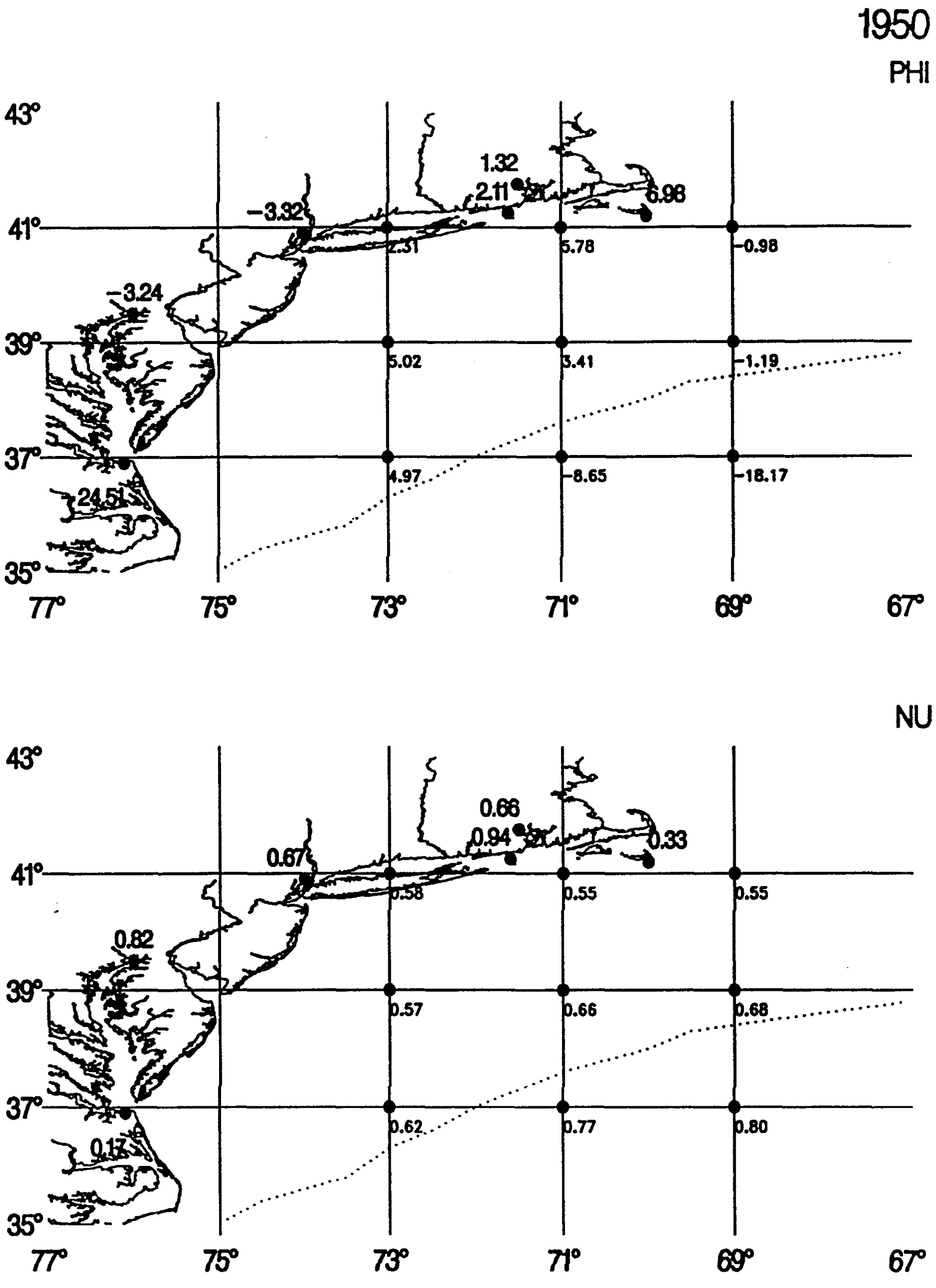

Figure 4b: Comparison of phi and nu between selected 2° square and Boston, MA (1960-69).

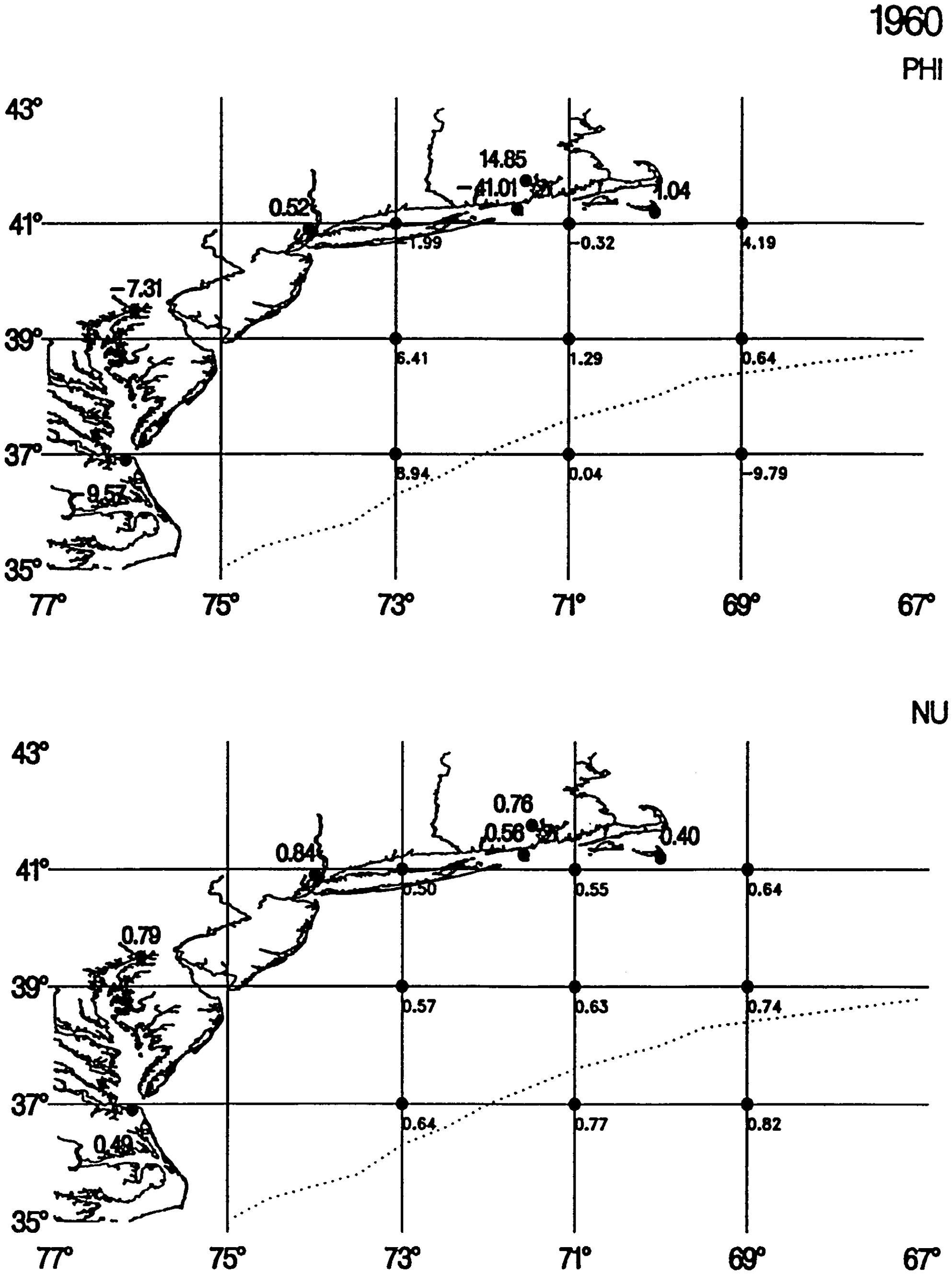

Figure 4c: Comparison of phi and nu between selected 2° square and Boston, MA (1970-79).

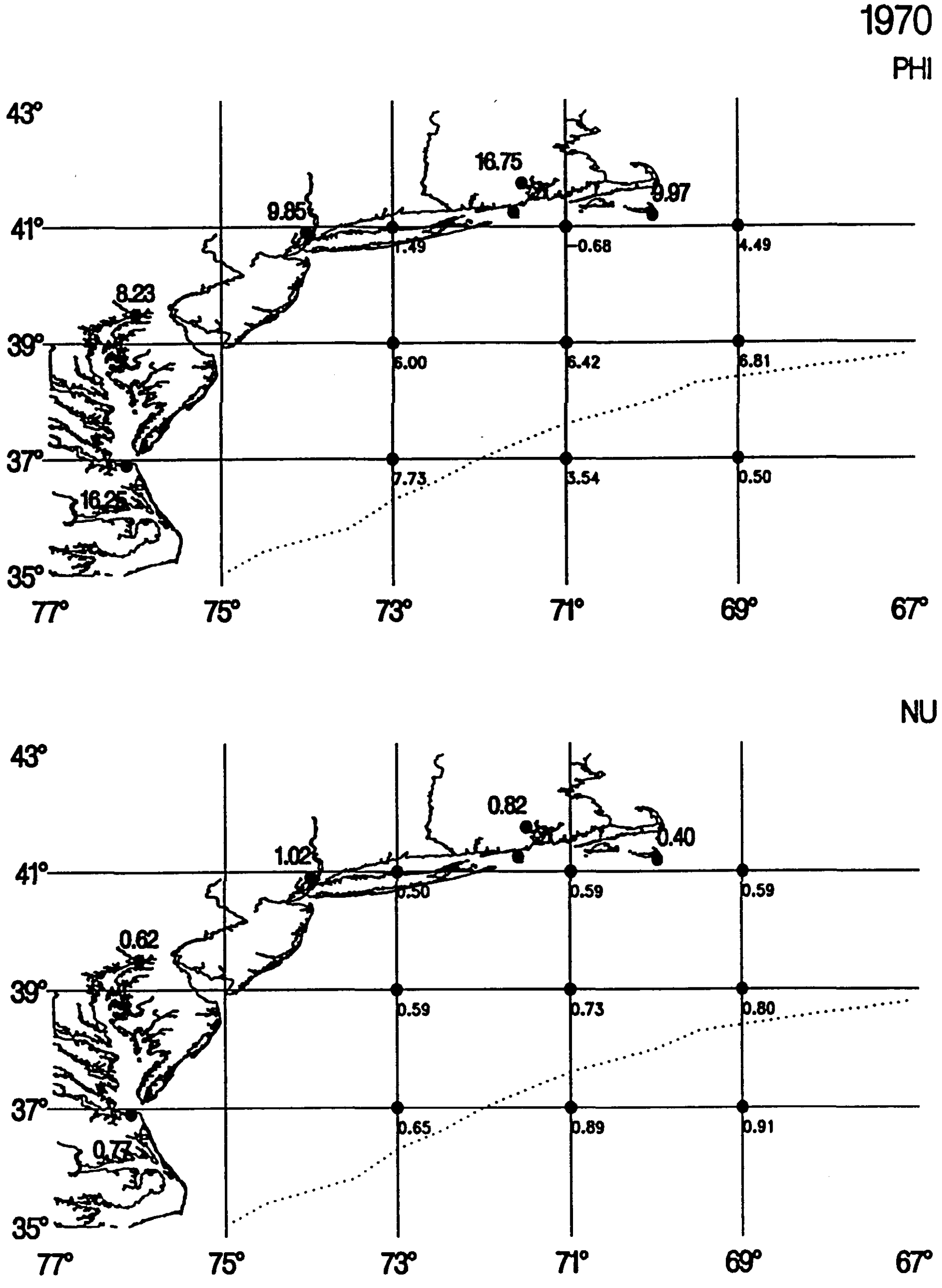

Figure 4d: Comparison of phi and nu between selected 2° square and Boston, MA (1980-89).

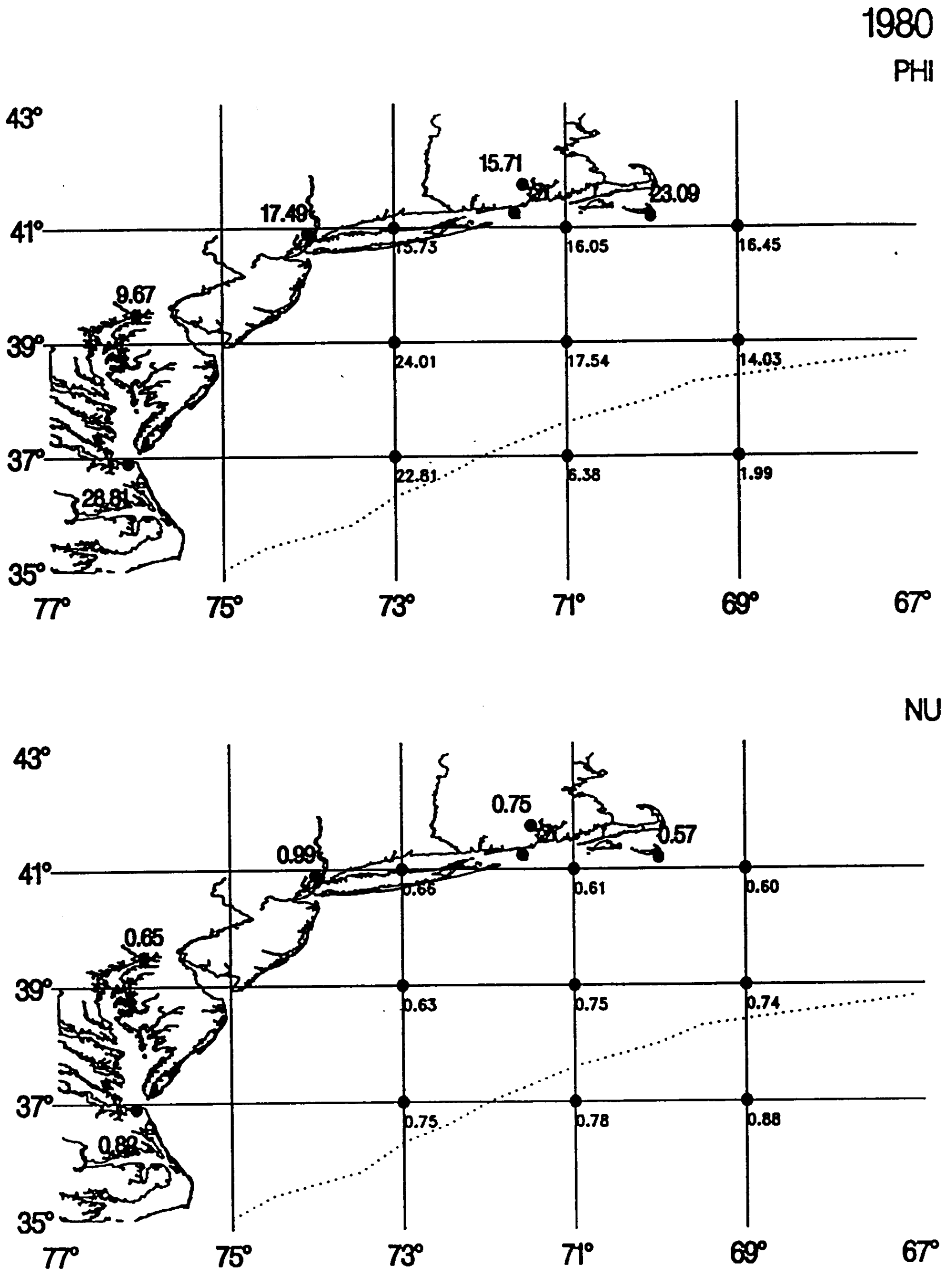

Figure 5: Air temperature at New Haven, CT with longitudinal average air temperature anomaly from the latitude band of the mid-Atlantic region (from Ingham, 1982, and Hansen and Lebedeff, 1987).

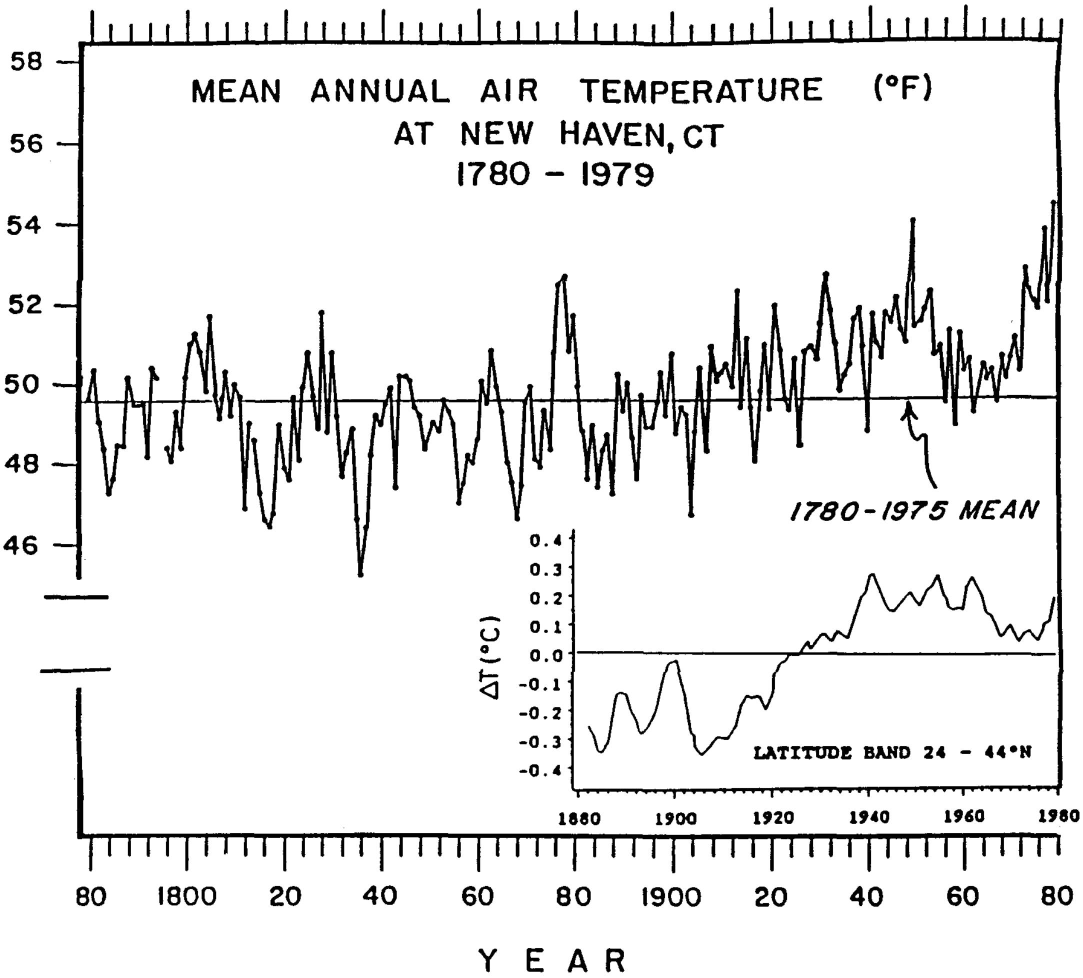

Figure 6a: Standard deviation of winter nu and phi factors from multiple (n=20) data sets from randomly selected dates.

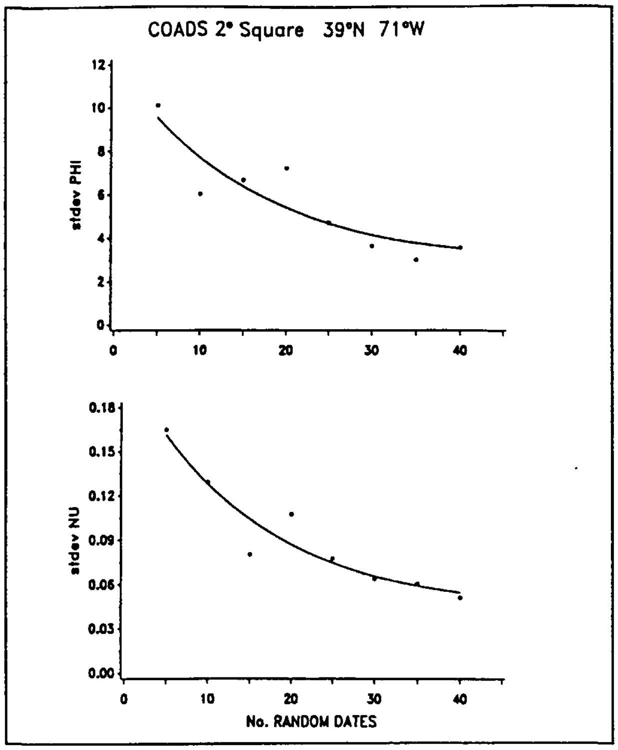

Figure 6b: Standard deviation of winter nu and phi factors from multiple (n=30) data sets from randomly selected dates.

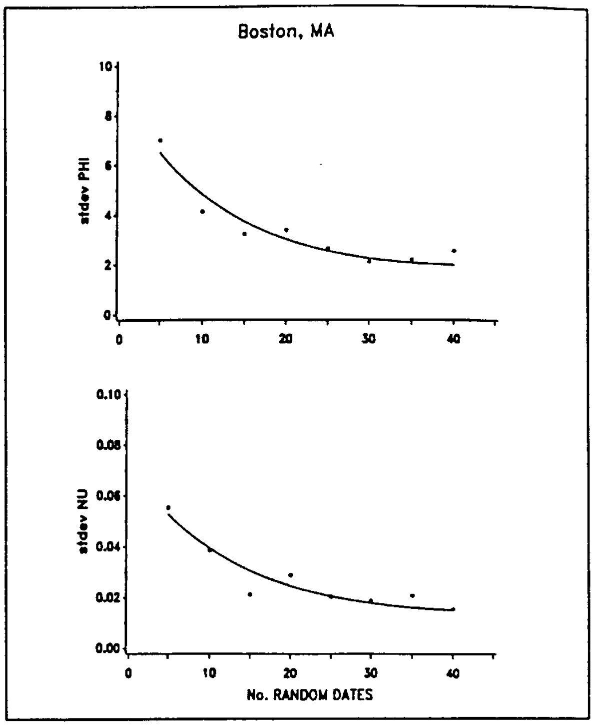

Figure 7: Wind Constancy.

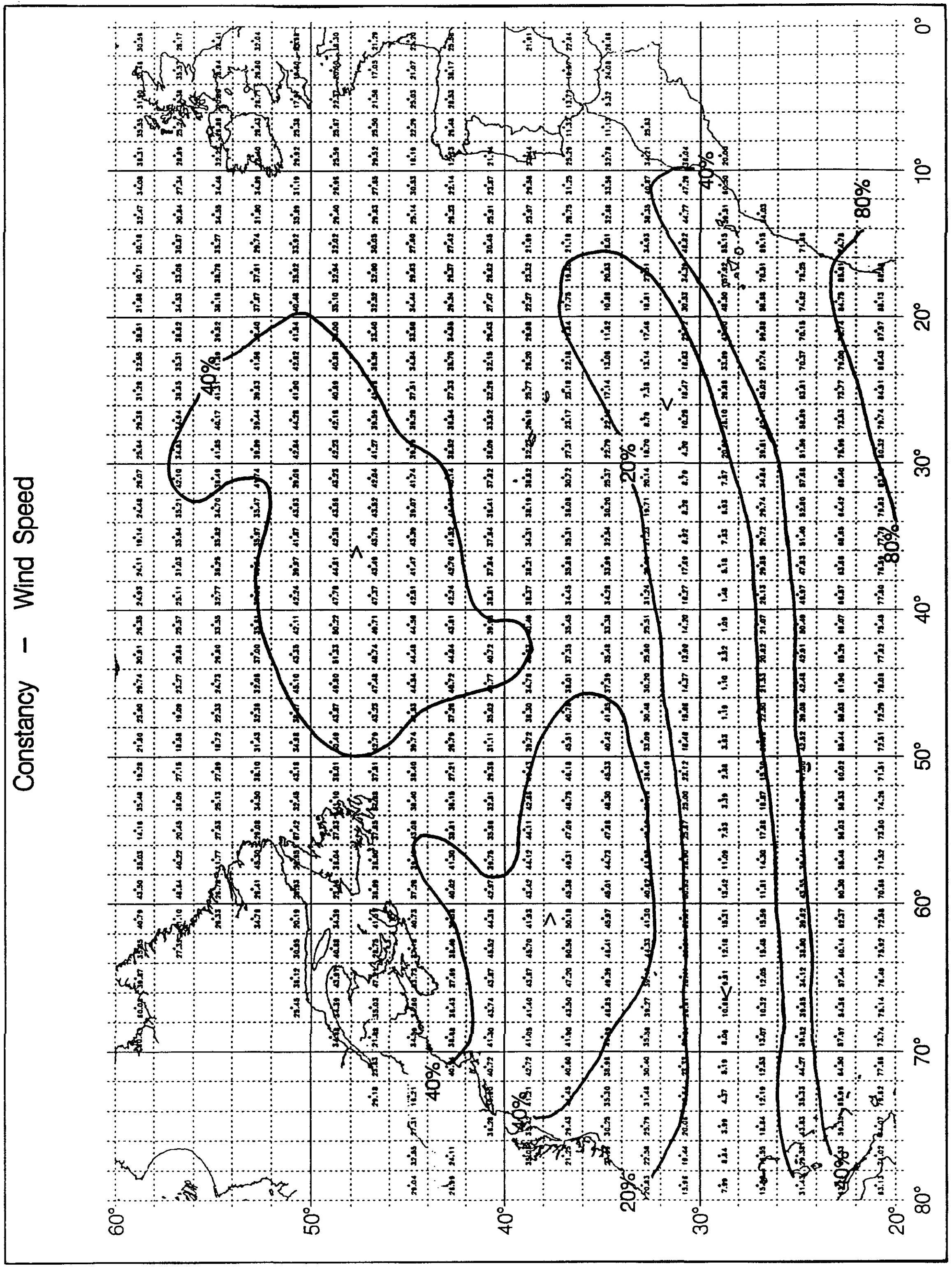

Figure 8: Comparison of Wind Direction between the Atlantic 2° squares and Boston, MA.

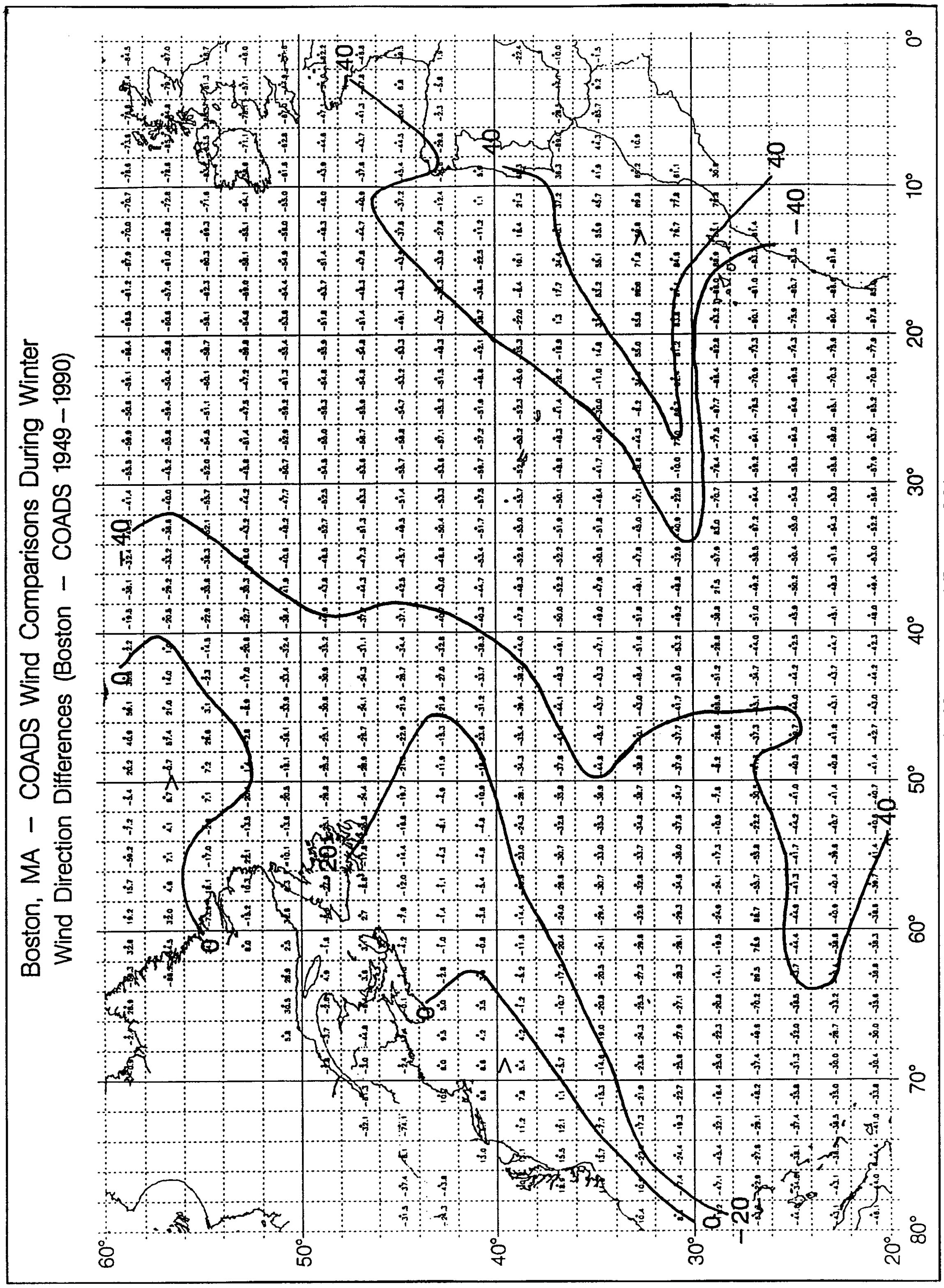

Figure 9: Wind constancy and wind factors from winter COADS summaries in the North Atlantic.

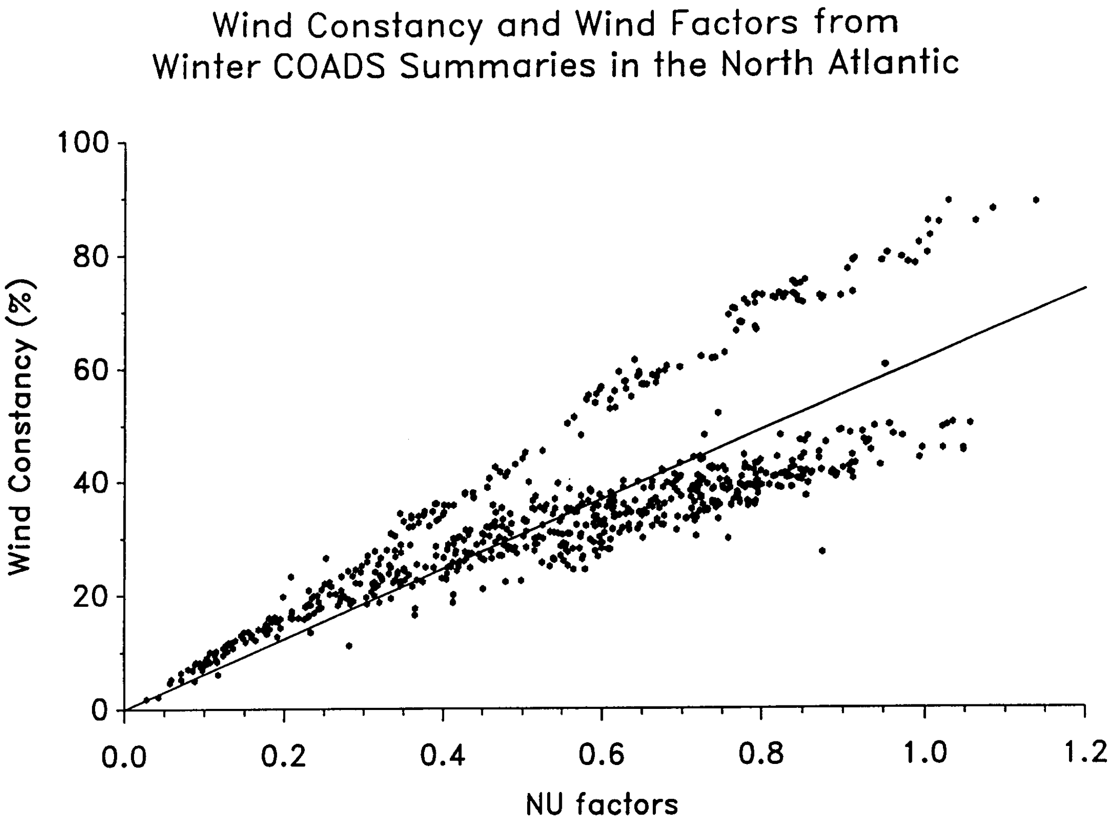

Figure 10: Comparison of wind speed between the Atlantic 2° squares and Boston, MA.

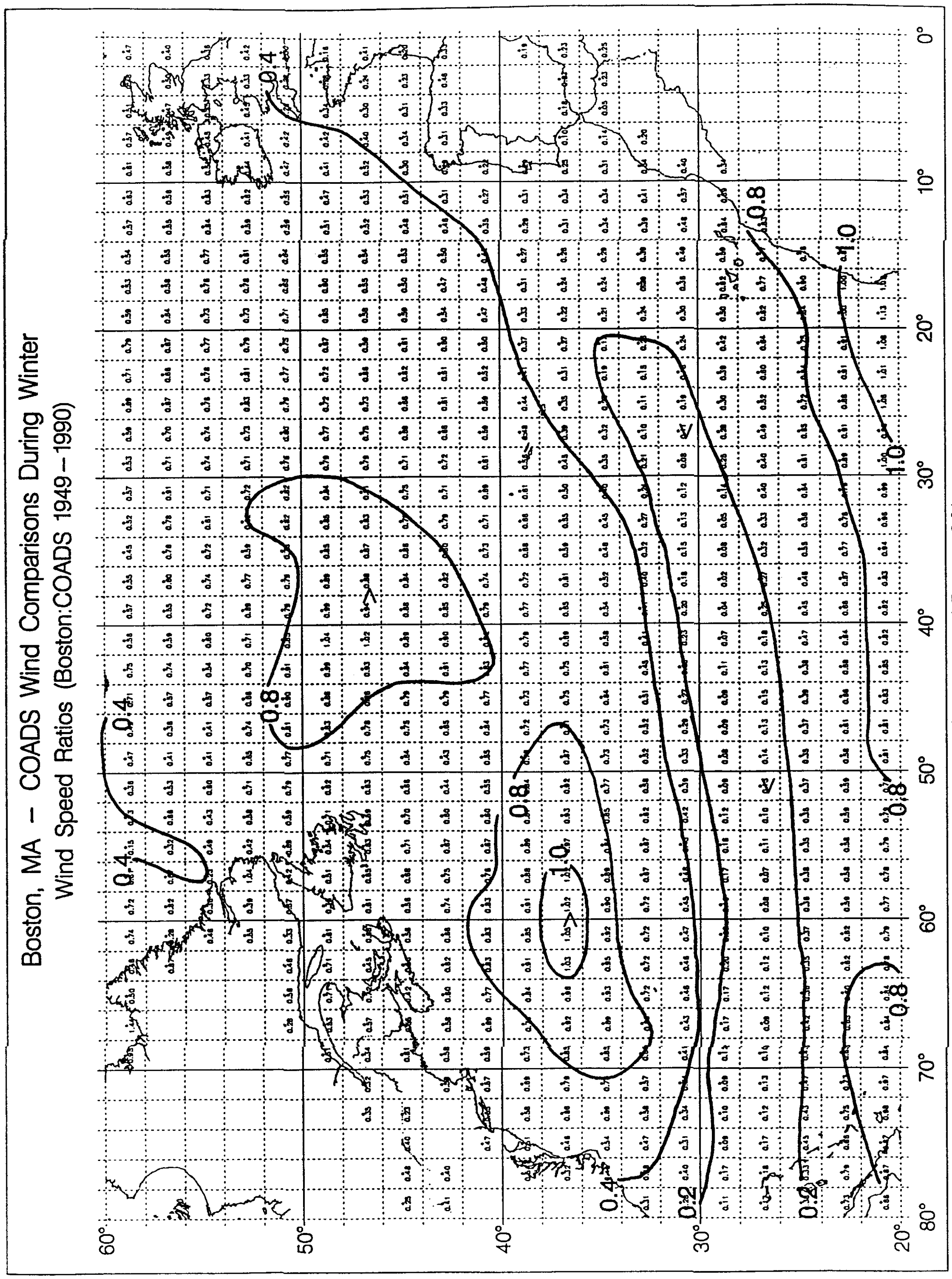

Figure 11: Winter wind constancy in the North Atlantic by decade.