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Northwest Atlantic Fisheries Organization

Serial No. N855

NAFO SCR Doc. 84/VI/66

SCIENTIFIC COUNCIL MEETING - JUNE 1984

Environmental Variability in the Northwest Atlantic

by

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INTRODUCTION

The purpose of this report is to present new analyses of the 'Marine Deck' sea surface temperatures (SST's) for selected areas of the Northwest Atlantic. Recently Koslow (in press) has found strong empirical orthogonal function (EOF) patterns among Northwest Atlantic fish stocks from the Scotian Shelf to Greenland. Prior to seeking relationships between environmental signals (e.g. SST) and these fish stock patterns, it was decided that the SST's should themselves be analyzed, summarized, and interpreted. This report is a first step in this direction.

The 'Marine Deck' is the set of weather and sea observations principally collected from cooling water intakes of merchant ships and archived at the National Climatic Center, Asheville, North Carolina. This data base has previously been used by us to calculate monthly SST anomalies by 1° squares and by fishing bank areas in an overview of conditions for the decade of the 1970's (Trites, 1982). In another study, we have also used the 'Marine Deck' to follow at fortnightly intervals the vernal progression of SST isotherms for purposes of predicting the arrival of mackerel along the inshore area of Nova Scotia (Loucks, 1982). Most recently Trites and Drinkwater (1983) have presented a map of SST anomalies which foreshadows the patterns to be identified below.

DATA BASE

The 'Marine Deck' observations were obtained for Marsden squares 113-116, 149-152, and 185-187 in the Northwest Atlantic (latitudes 30°N to 60°N and west of 40°W) from the time of earliest observations up to 1981. The individual records in this set have been reformatted to include only atmospheric pressure, air temperature, SST, and cloud cover, as well as time and location. They have been sorted by month, year and SST, checked for duplication, and archived by Fisheries Oceanography Division, Marine Ecology Laboratory, Bedford Institute.

For purposes of analysis, data since 1940 were compiled from these archives for selected areas. The areas, shown in Figure 1, were chosen to include fishing banks where possible and portions of large oceanographic features, such as the Gulf Stream, Labrador current, etc. For each month, 1940 to 1980, the number of observations in a particular area, and the average and standard deviation were computed for atmospheric pressure, air temperature, SST and cloud cover. In addition the median SST was computed. The following analyses are based on these monthly (and sometimes three-month) averages; programs from the IMSL package were used (IMSL, 1982).

EOF'S CALCULATED FROM SST ANOMALIES

Empirical orthogonal functions (EOF) analysis (also called principal component analysis) is a technique for summarizing or extracting patterns from data. As an illustration, if a data set consisted of winter average SST's from three sites for ten years, and if these data were plotted on the 3-dimensional scatter diagram, then the first mode EOF (or eigen vector) would be that combination (pattern) of the three sites which defined the major axis of the scatter 'cloud' of data points. The most important axis orthogonal to that major axis would define the combination or pattern of the second mode EOF. A shortcoming of this technique is that the propogating or time lag aspects of the SST patterns are not revealed, (except by extending the EOF technique to operate on cross-spectral information). Alternatively, one can examine the lagged co-variances; we are doing this.

First Mode EOF: Figure 2 (a to d) shows the pattern of the EOF first mode responses or loadings by season for 22 of the 24 areas identified in Figure 1. Two Scotian Shelf areas, Yarmouth and LaHave were omitted. Since the Scotian Shelf was already well represented, and since the EOF program was set up for 22 signals, the omissions were used as a test for the stability of eigen vectors which showed strong responses on the Scotian Shelf with or without these areas included. The loadings (Figure 2) show considerable uniformity geographically, and between seasons. The loadings almost all have the same sign and their magnitudes often exceed 0.5, signifying that the most important pattern in the data is a relatively uniform increase (or decrease) in SST coherently on a large geographic scale. A chronological EOF analysis, supressing seasonal effects, was also carried out; the resulting patterns were similar.

The first mode accounts for approximately 30% of the total variance in year-to-year seasonal SST anomalies. The region of maximum loadings does shift somewhat with season; from the Scotian Shelf in winter to the Grand Banks in spring to the Scotian Shelf again in summer and to the mid-Altantic Bight in autumn.

Figure 3 shows the first mode EOF time series formed by convolving the monthly SST anomalies with the eigen vector loadings. The warm period of the early 1950's and the cool period of the mid 1960's are identified. As an aside, the spring-time series identifies warm and cool years which is in good agreement with the ranking carried out previously in connection with predicting arrival dates of the 7°C isotherm along the Nova Scotian coast and hence mackerel (Loucks, 1982).

Second Mode EOF: Figure 4 (a to d) shows the eigen vector loadings for the second mode EOF, accounting for approximately 19% of the total variance in seasonal, year-to-year SST anomalies. This mode describes a contrast or negative correlation between temperatures on the Grand Banks and those for the mid-Atlantic Bight. The time-series amplitudes of the second mode EOF are shown in Figure 5. To illustrate, the relatively extreme values for the winters of 1950 and 1970 reflect the fact that there were strong geographic contrasts in SST anomalies; SST's were very warm in the mid-Atlantic Bight and very cool on the Grand Banks in 1950 and just the opposite in 1970.

It is important to note that, whereas sometimes higher modes are to some extent artifacts of the orthogonality constraint, here the contrast or tilt mode is directly interpretable because the correlations between SST's on the Grand Banks and the mid-Atlantic Bight are actually negative.

First and Second Modes for EOF Taken Together: In Figure 6, the first and second mode responses are plotted; natural groupings are identified - a Grand Banks group, a Scotian Shelf group and a New England group. These diagrams are useful in identifying the organizing drivers. For example, the Gulf of Maine (GOM), South Shore (SS) and Eastern Scotian Shelf (ESS) areas all have especially high first mode loadings in winter; this is attributed below to winds. The New England group shows second mode responses similar to those of the Gulf Stream area, which suggests offshore forcing may be important. In autumn the South Shore area SST's appear to be organized by the same drivers organizing the New England group, while the Eastern Scotian Shelf and Sable Island (SI) areas show responses more like those of the Grand Banks group.

The third and fourth modes are not shown; they have not yet been examined in detail but tend to involve single areas e.g., Cape Farewell. the first four modes together account for some 70% of the variance in the SST field.

DISCUSSION

We have examined EOF patterns of SST with resolutions of 3 months and 100 to 1000 kilometers. In overview, the SST patterns exhibit season-to-season persistence and a degree of spatial coherence modified by consistent north/south contrast. We suggest that the above SST patterns are produced by varying combinations of pattern-organizing drivers, which themselves may have strong seasonal variability but which are loosely synchronized with each other to achieve the season-to-season persistence and the spatial coherence and contrasts in SST.

Such SST organizing drivers might include insolation, winds, river runoff via an advective pathway, and offshore forcing due to Gulf Stream meanders and eddies. The synchronization could arise because for example winter wind anomalies not only establish winter SST anomaly patterns but also are associated with snowfall and subsequent river runoff anomalies which may influence summer SST patterns by tending to reinforce the patterns of the previous winter - 'dynamic connectedness'.

At a more detailed level, while still speculative, a preliminary identification of drivers associated with the SST EOF modes by season is given in Table 1. For winter, local winds (Thompson and Hazen, 1983) explain up to 50% of the Mode 1 year-to-year variability (Figure 7). In the Gulf of Maine and on the Scotian Shelf, northwest winds are associated with negative SST anomalies while southeast winds are associated with positive SST anomalies. These are the most effective wind directions for influencing SST (1^{st} mode); 50% of the first mode EOF variance is thereby explained by Gulf of Maine winds, 43% by Scotian Shelf winds. In the Mid-Atlantic Bight winter winds are not significantly influencing the mode 1 pattern; on the Grand Banks winds explain up to 20% of the 1^{st} mode variability; on the Labrador Shelf, up to 36% of 1^{st} mode variability is explained by winds. With the effect of winds removed, the Mode 1 residual series (smoothed with a seven-year normally-weighted running mean) resembles closely the similarily smoothed series of Gulf-stream area SST annual anomalies (subtracted from the median).

Winter temperatures from the Western Slope Water region, similarly smoothed, show close correspondence with the smoothed series of St. Lawrence River discharges from the previous spring. This fact suggests an answer to the puzzling observation (Sutcliffe et al., 1976) that sea surface temperature anomalies are coherent and advectively linked down the Atlantic seaboard but positive temperature anomalies are associated with salinity minima on the Scotian Shelf and salinity maxima off New England. If perturbations in the discharge from Gulf of St. Lawrence Rivers and in temperatures of the Gulf Stream have common parentage in large-scale atmospheric variability and if, where they meet in the vicinity of the Gulf of Maine Area, the temperature anomalies are of the same sign, albeit arising via different circumstances, then the large-scale coherence of SST anomalies follows. We also expect to find a strong link between the offshore local geostrophic winds and the discharge of the St. Lawrence Rivers. The scale of weather patterns is such that one might reasonably expect winds on say the Scotian Shelf to affect the precipitation patterns over the St. Lawrence drainage basin, and in turn to affect subsequent freshwater discharge from the river.

The second EOF mode in winter can be partially (30%) explained by the geostrophic winds over the Scotian Shelf, Gulf of Maine and mid-Atlantic Bight. However, it is suggested that the second mode pattern is also organized by the perturbations in configuration of shelf and slope waters and of the shelf/slope front associated with the formation and propagation of Gulf Stream eddies (Smith & Petrie, 1982). We note that the space scale and time resolutions of this second mode are approximately 1600 kilometres and three months respectively while the drift rate of a shelf/slope front perturbation and of a Gulf Stream eddy is approximately 5 km/day (Smith & Petrie, loc cit) or 450 km in 3 months, so that an eddy could produce contrasting influences northeastward and southwestward which would persist over three months.

Referring again to Table 1, insolation has high potential for organizing SST patterns in the heating seasons. Since we have not yet examined the cloud cover patterns, we have no information on the possible role of insolation in creating the Mode 2 pattern; we do anticipate that it is important in the large scale Mode 1 pattern. Local winds show reduced strength in summer; although the calculations are incomplete, we do not anticipate that these winds will account for a significant fraction of the first mode variance. They do, however, explain as much as 30% of the second mode variance.

In summary, the speculation is that the observed large-scale persistant SST patterns are organized by several seasonal drivers which are themselves linked.

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TABLE 1: Preliminary identification of seasonal drivers that may be associated with the first two EOF modes of SST.

FIRST EOF MODE:	Winter (Jan-Mar)	Spring (Apr-Jun)	Summer (Jul-Sep)	Autumn (Oct-Dec)
- % of total variance explained	32	35	29	28
Possible drivers - insolation	Doubtful	Yes	Yes	Doubtful
- local winds	Yes	Yes	?	Yes
- currents arising from Hudson Bay and St. Lawrence River discharge	Yes	Doubtful	Yes	Yes
- offshore forcing - (Gulf Stream system)	Doubtful	Doubtful	Doubtful	Yes

SECOND EOF MODE:				
- % of total variance explained	19	19	19	19
- insolation	Doubtful	?	?	Doubtful
- local winds	?	?	Yes	?
- currents arising from Hudson Bay - and St. Lawrence river	Doubtful	Doubtful	Doubtful	Doubtful
- offshore forcing - (Gulf Stream system)	Yes	Yes	Yes	Yes

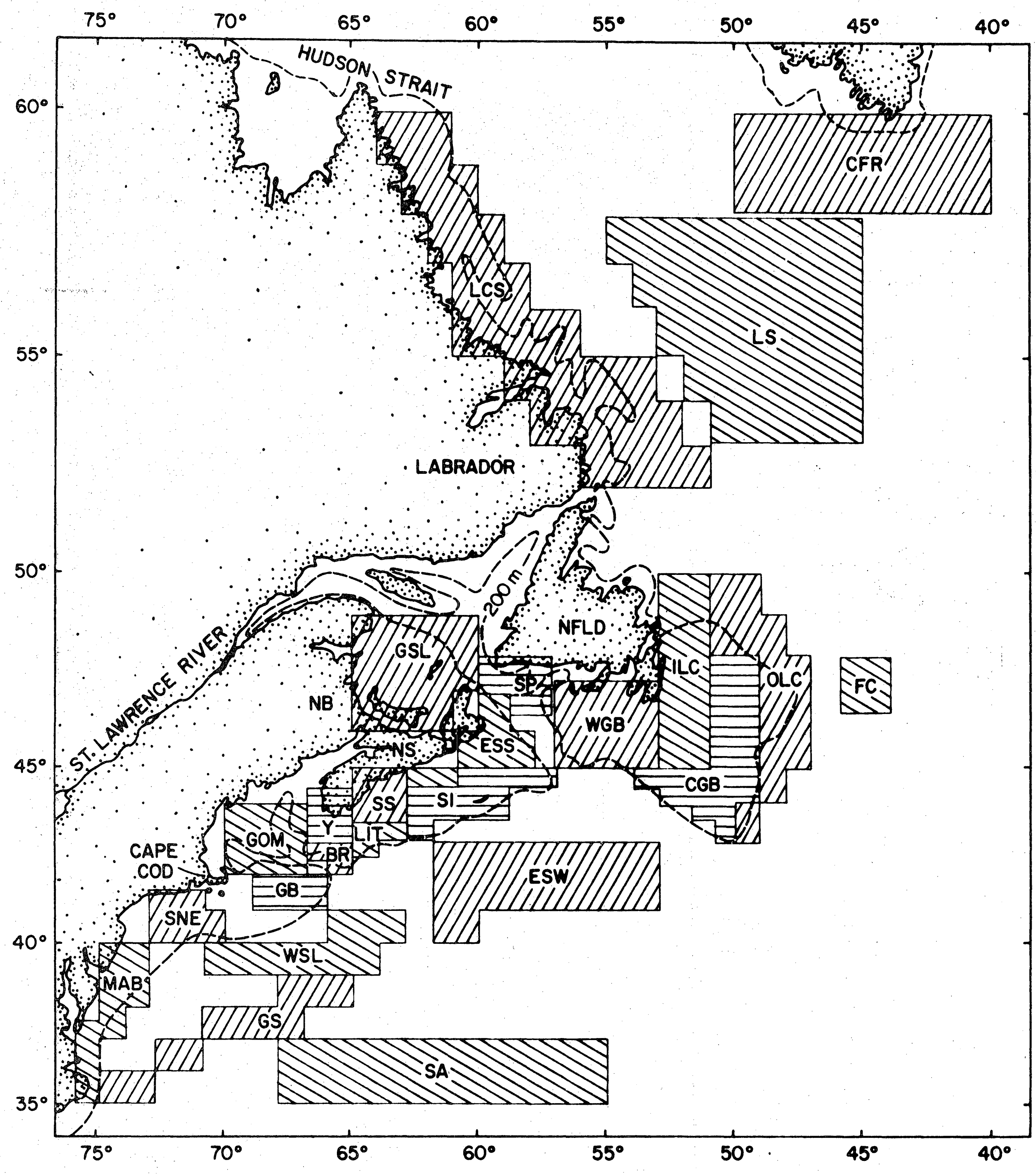

Figure 1. Chart showing the areas over which SST observations have been averaged monthly.

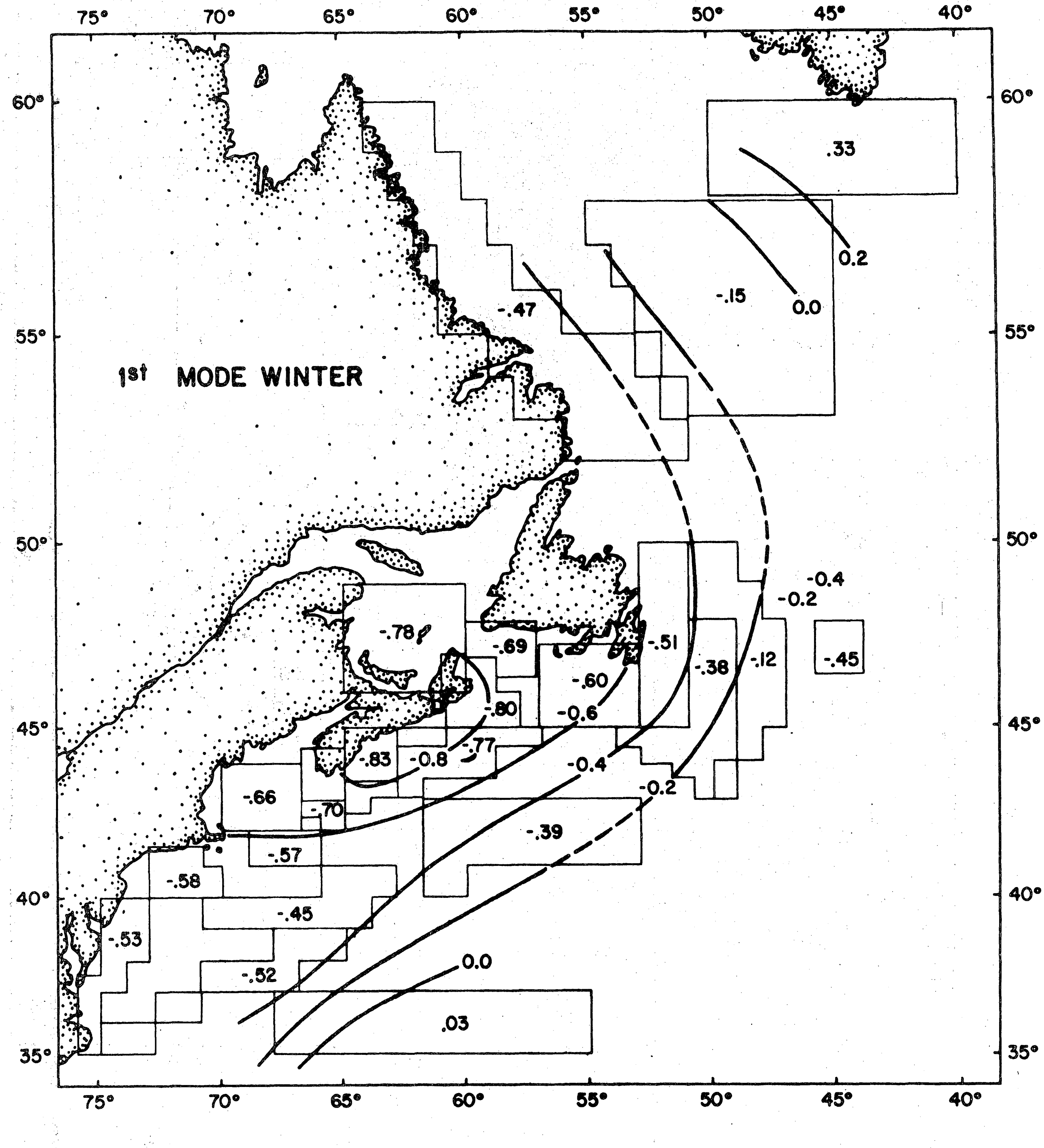

Figure 2a. Charts showing the eigenvector loadings for the first mode EOF's of SST for Winter (Jan-Mar).

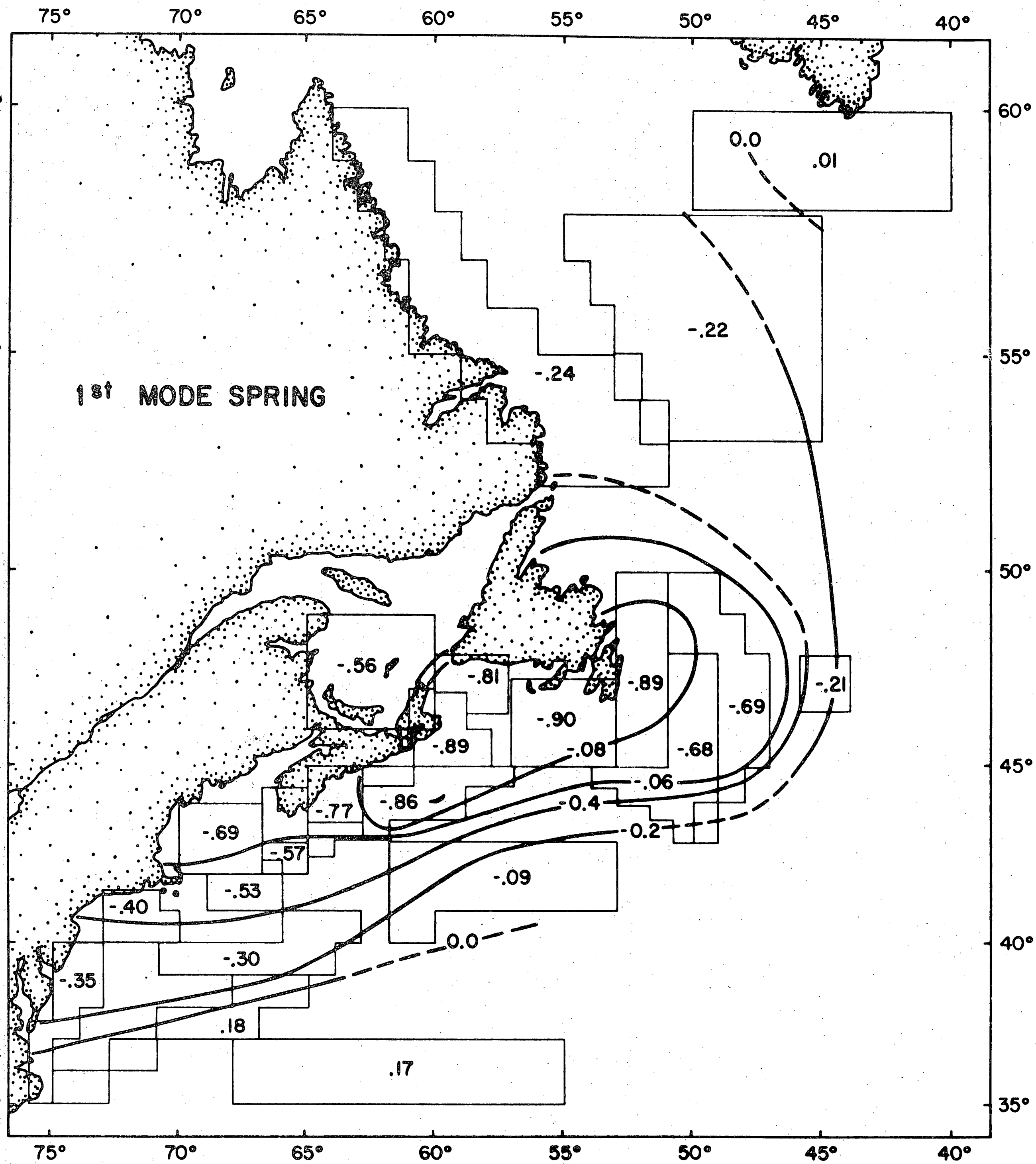

Figure 2b. Charts showing the eigenvector loadings for the first mode EOF's of SST for Spring (Apr-Jun).

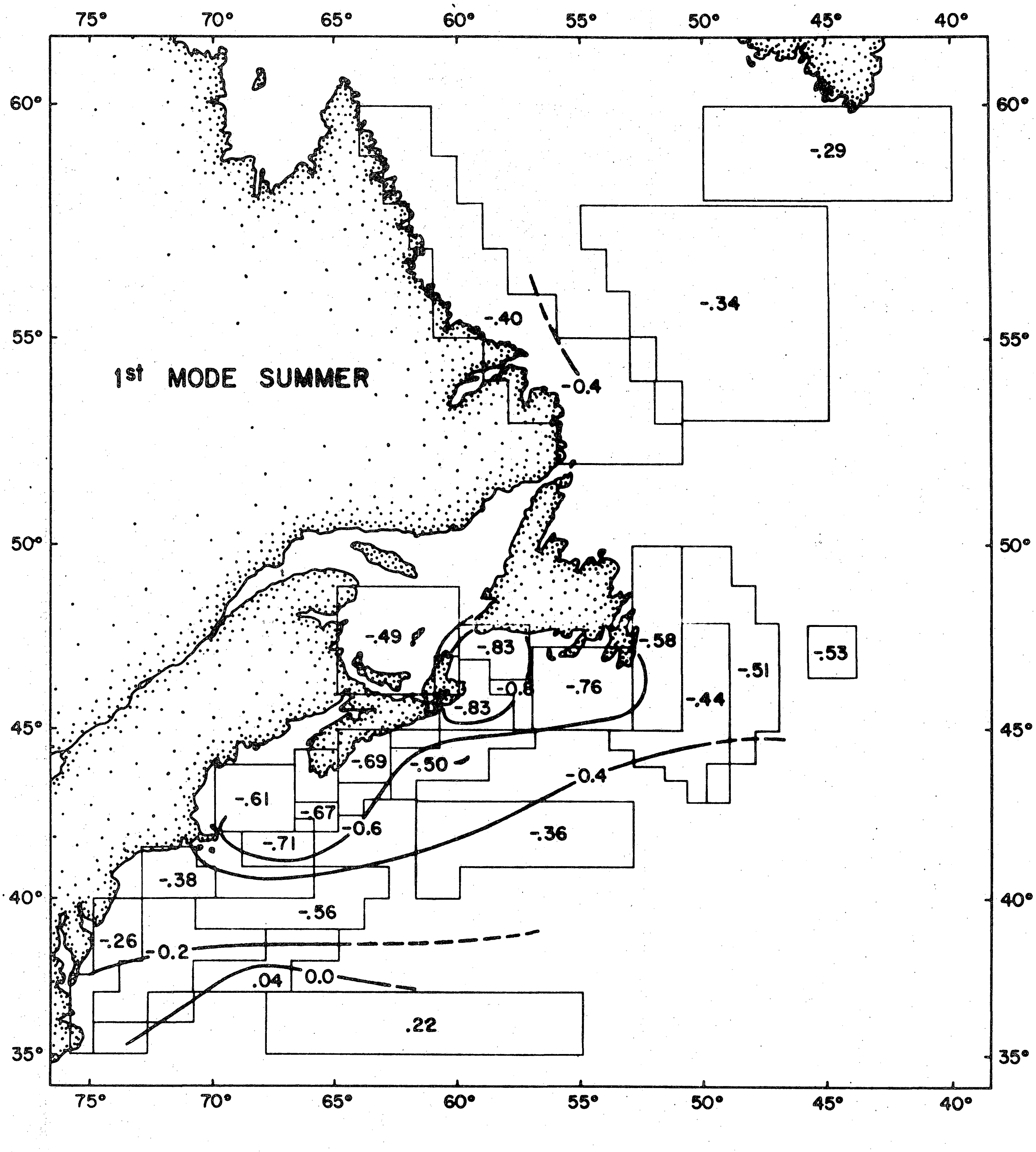

Figure 2c. Charts showing the eigenvector loadings for the first mode EOF's of SST for Summer (Jul-Sep).

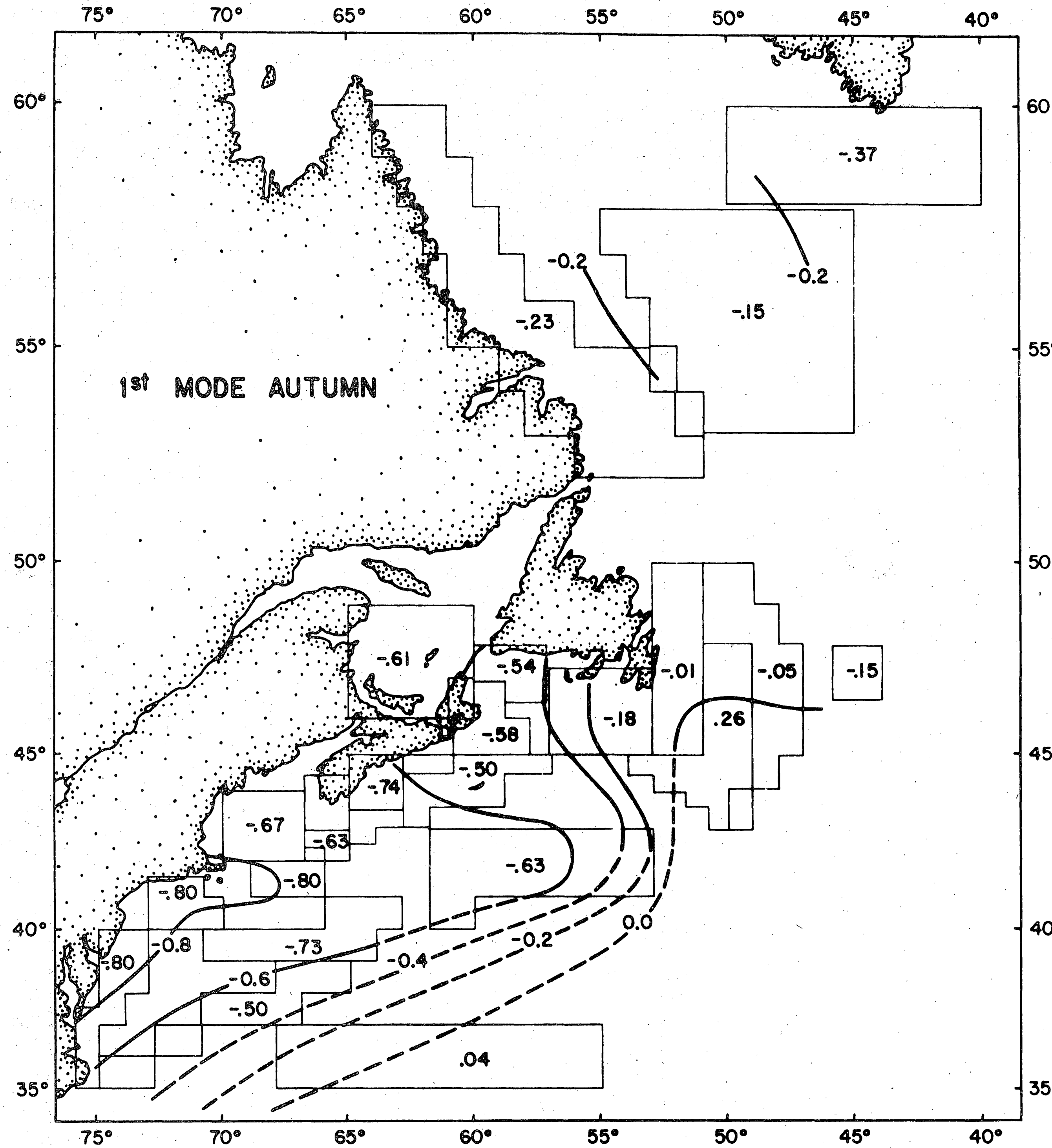

Figure 2d. Charts showing the eigenvector loadings for the first mode EOF's of SST for Autumn (Oct-Dec).

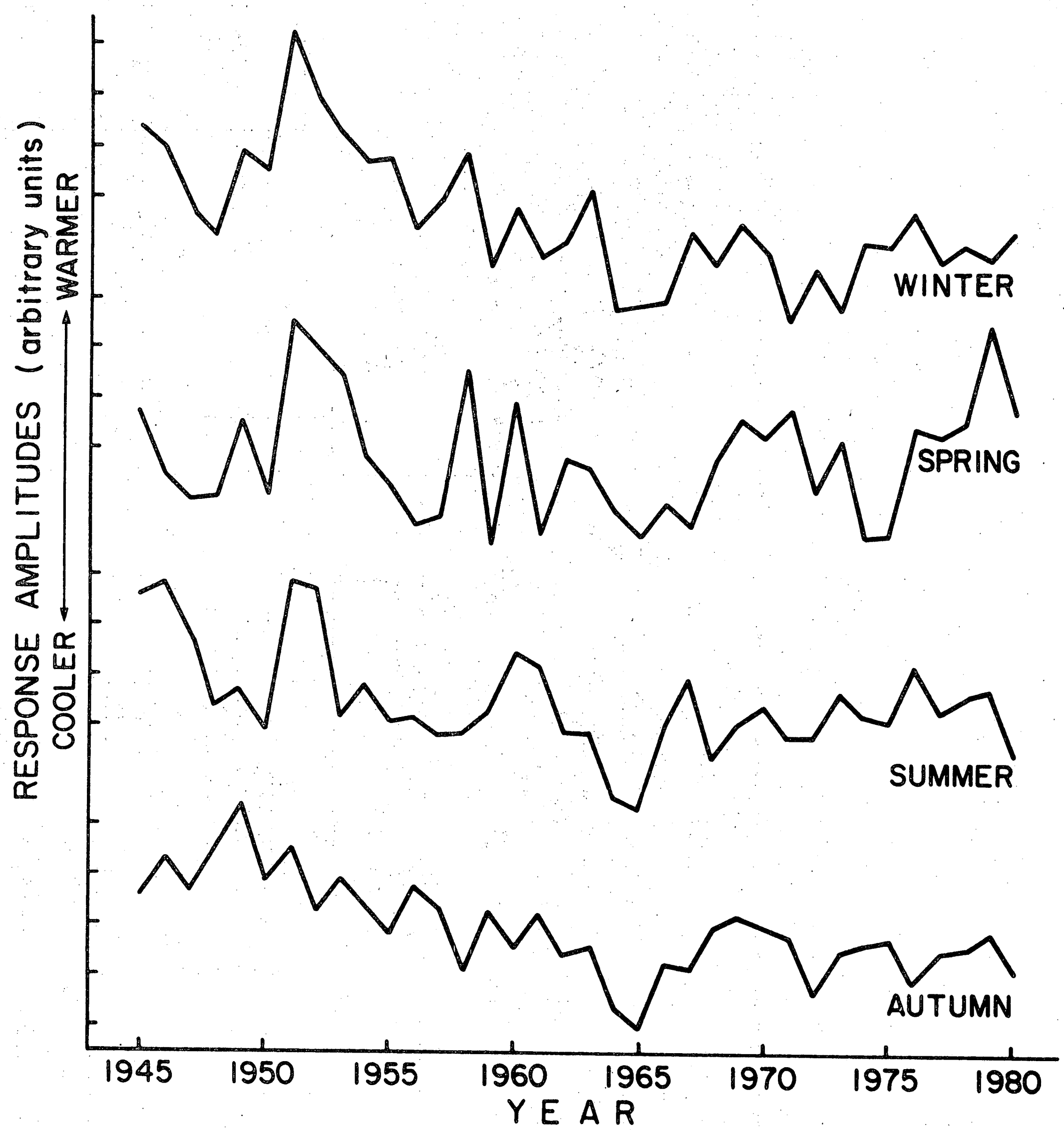

Figure 3. Amplitudes of the first mode EOF's of SST by season. Peaks reflect warm years and troughs, cool years.

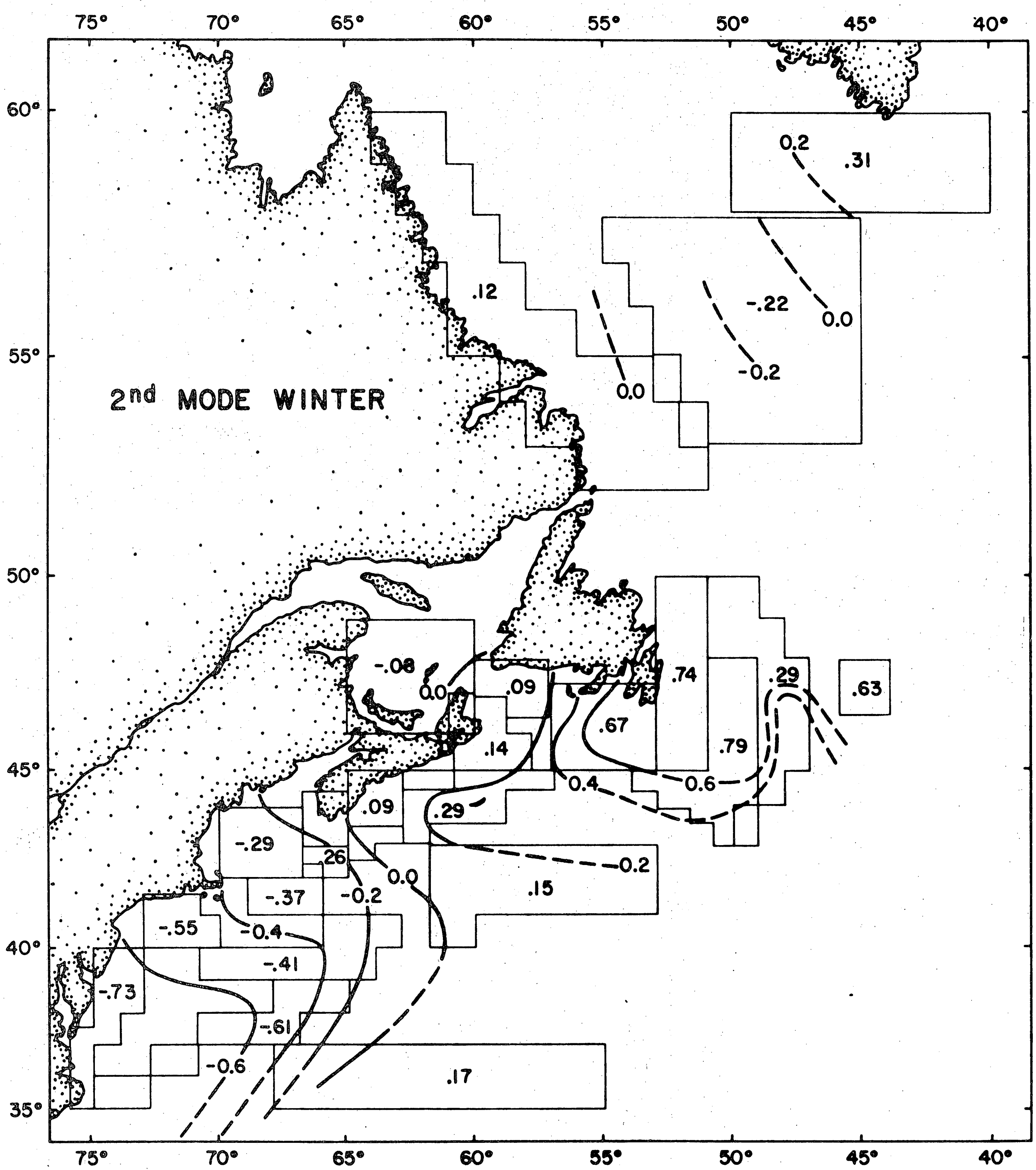

Figure 4a. Charts showing the eigenvector loadings for the second mode EOF's of SST for Winter (Jan-Mar).

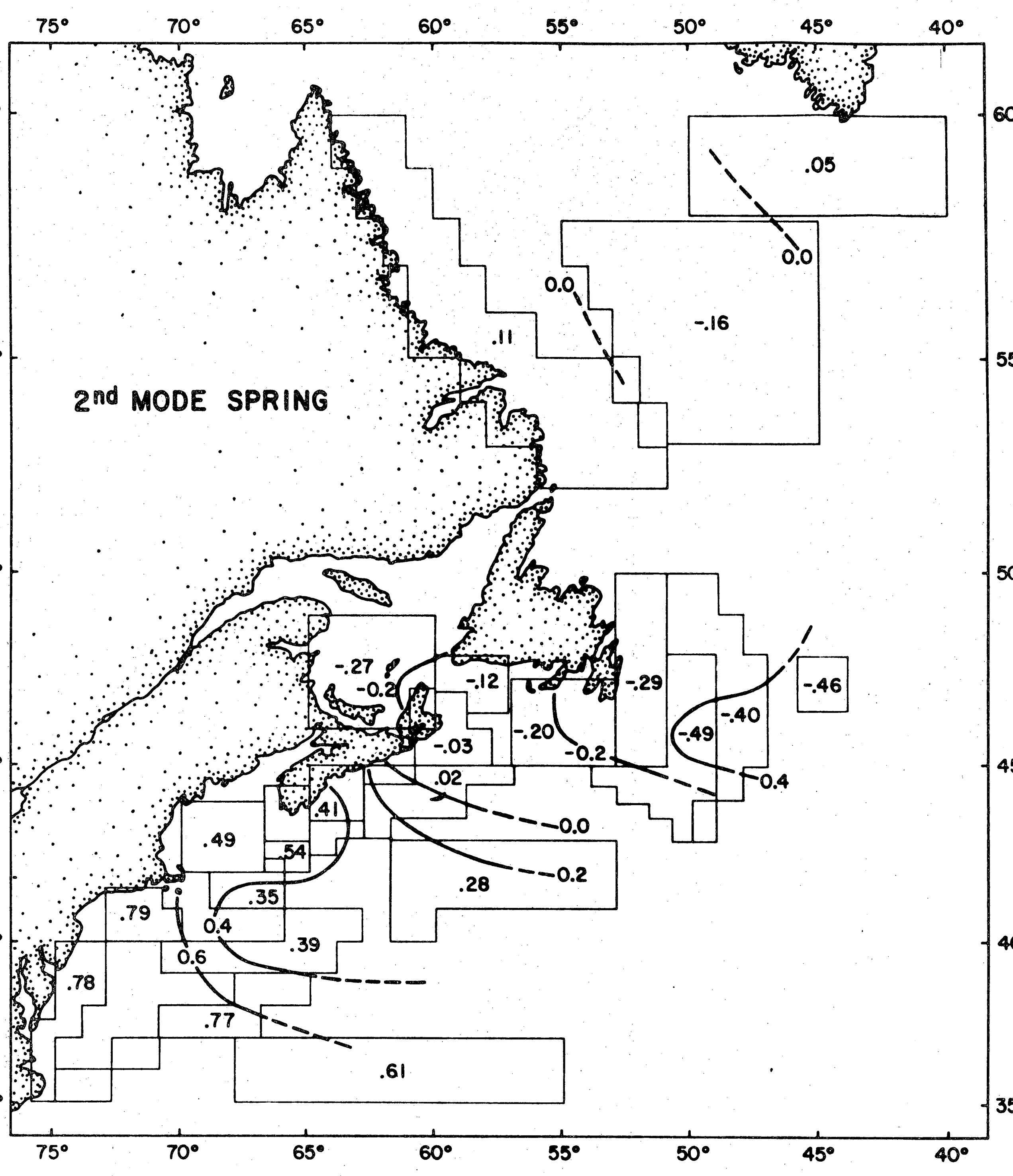

Figure 4b. Charts showing the eigenvector loadings for the second mode EOF's of SST for Spring (Apr-Jun).

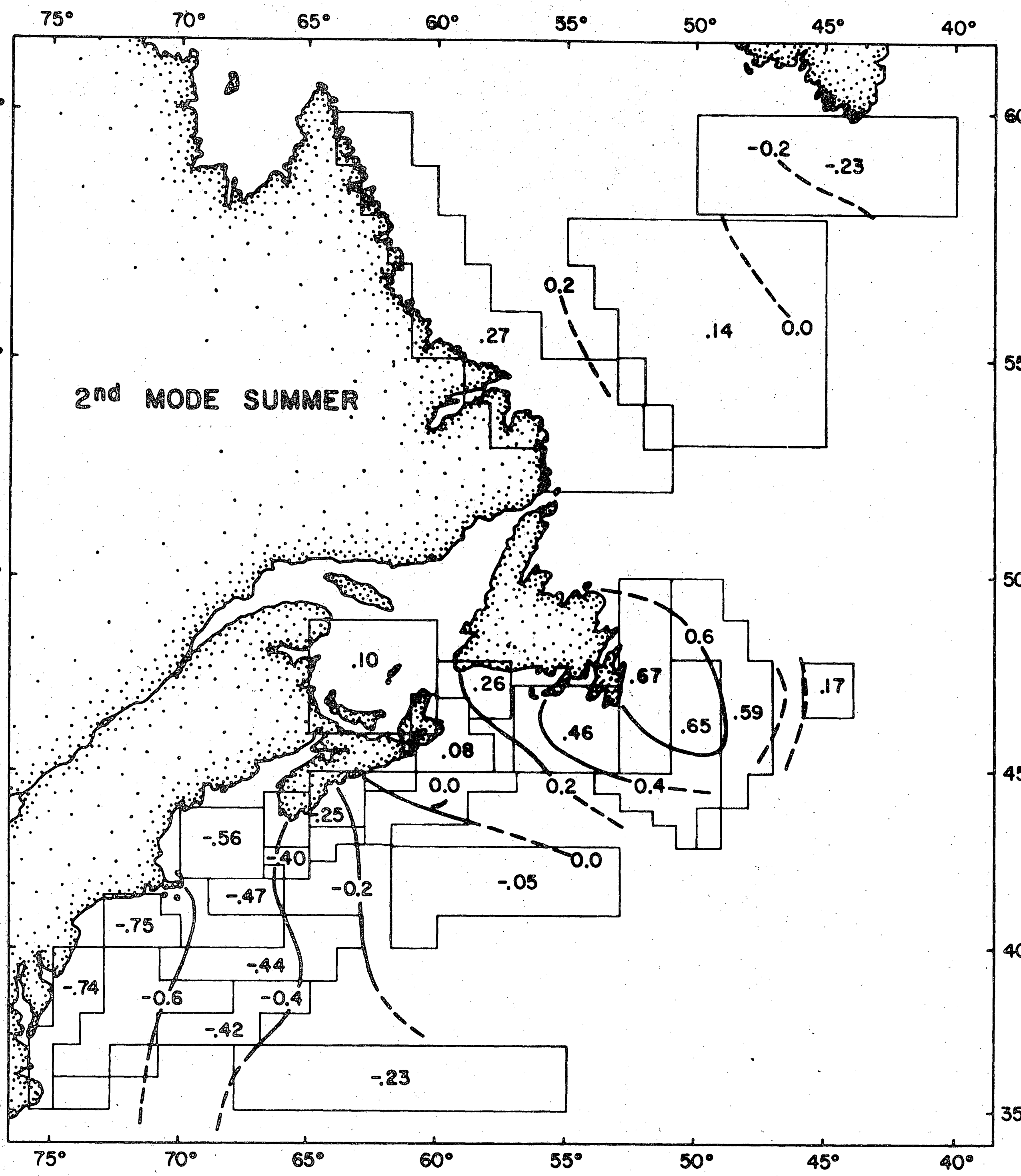

Figure 4c. Charts showing the eigenvector loadings for the second mode EOF's of SST for Summer (Jul-Sep).

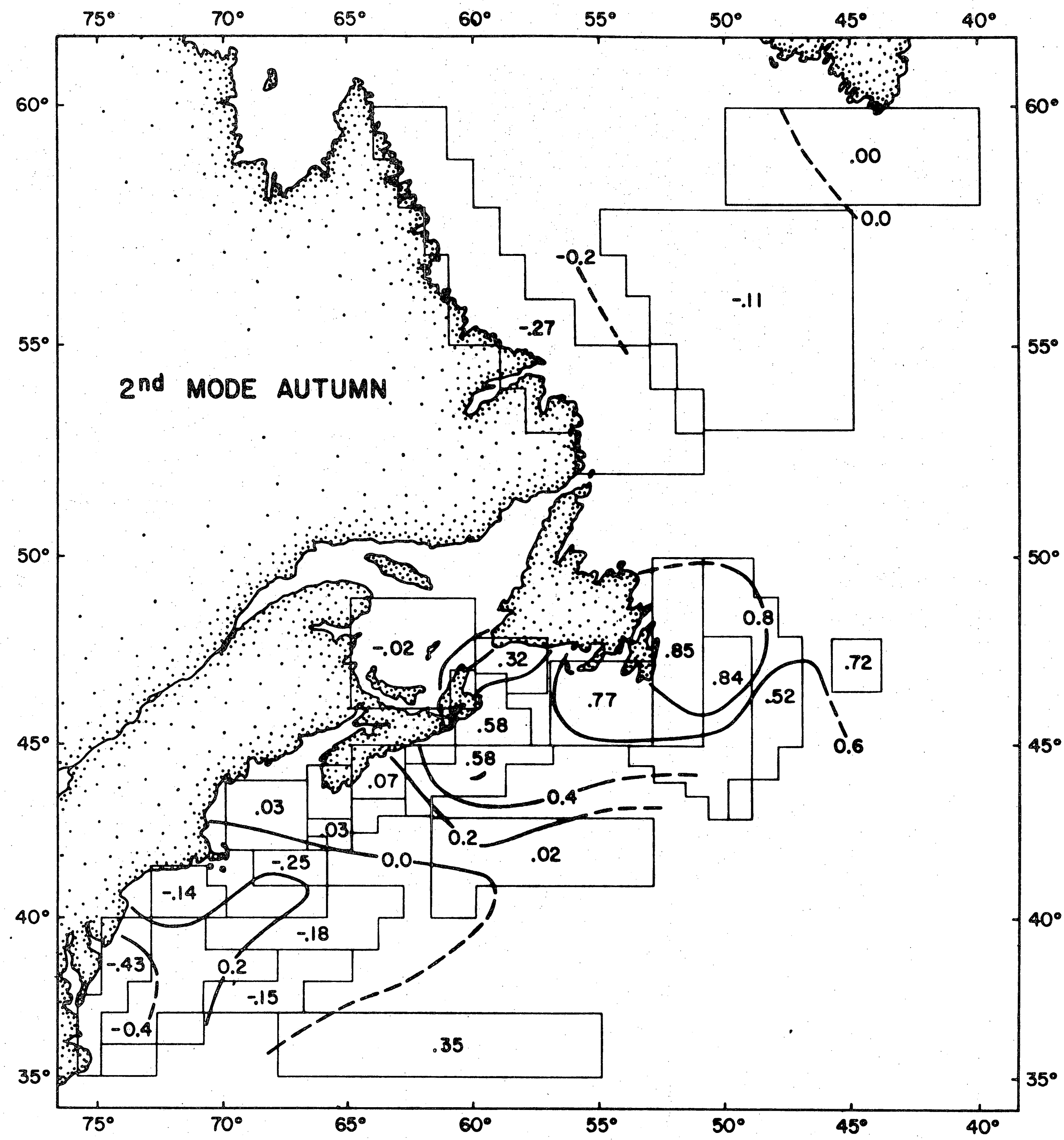

Figure 4d. Charts showing the eigenvector loadings for the second mode EOF's of SST for Autumn (Oct-Dec).

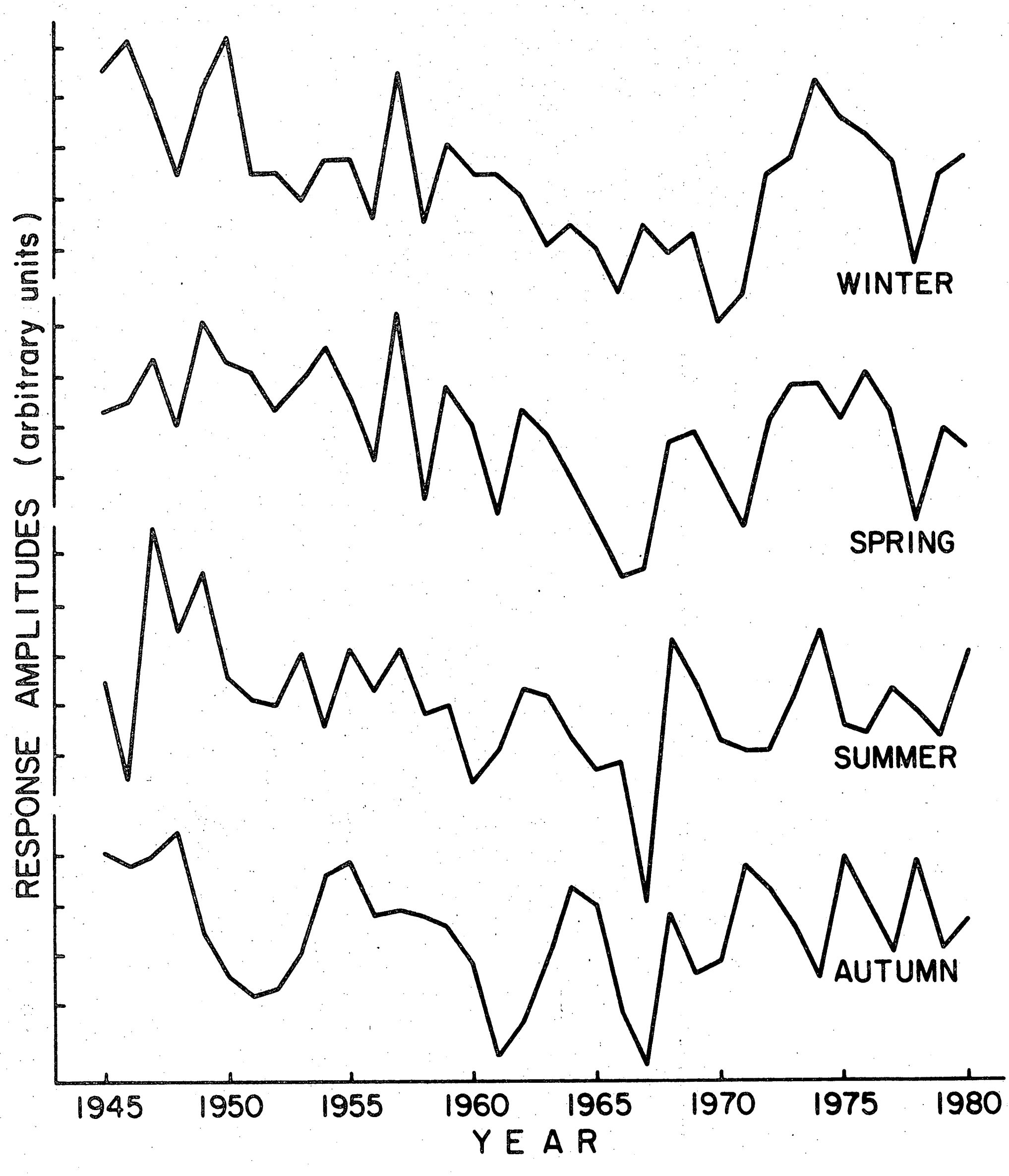

Figure 5. Amplitudes of second mode EOF's of SST by season. Peaks reflect positive anomalies in the New England region and negative anomalies in the Grand Banks region.

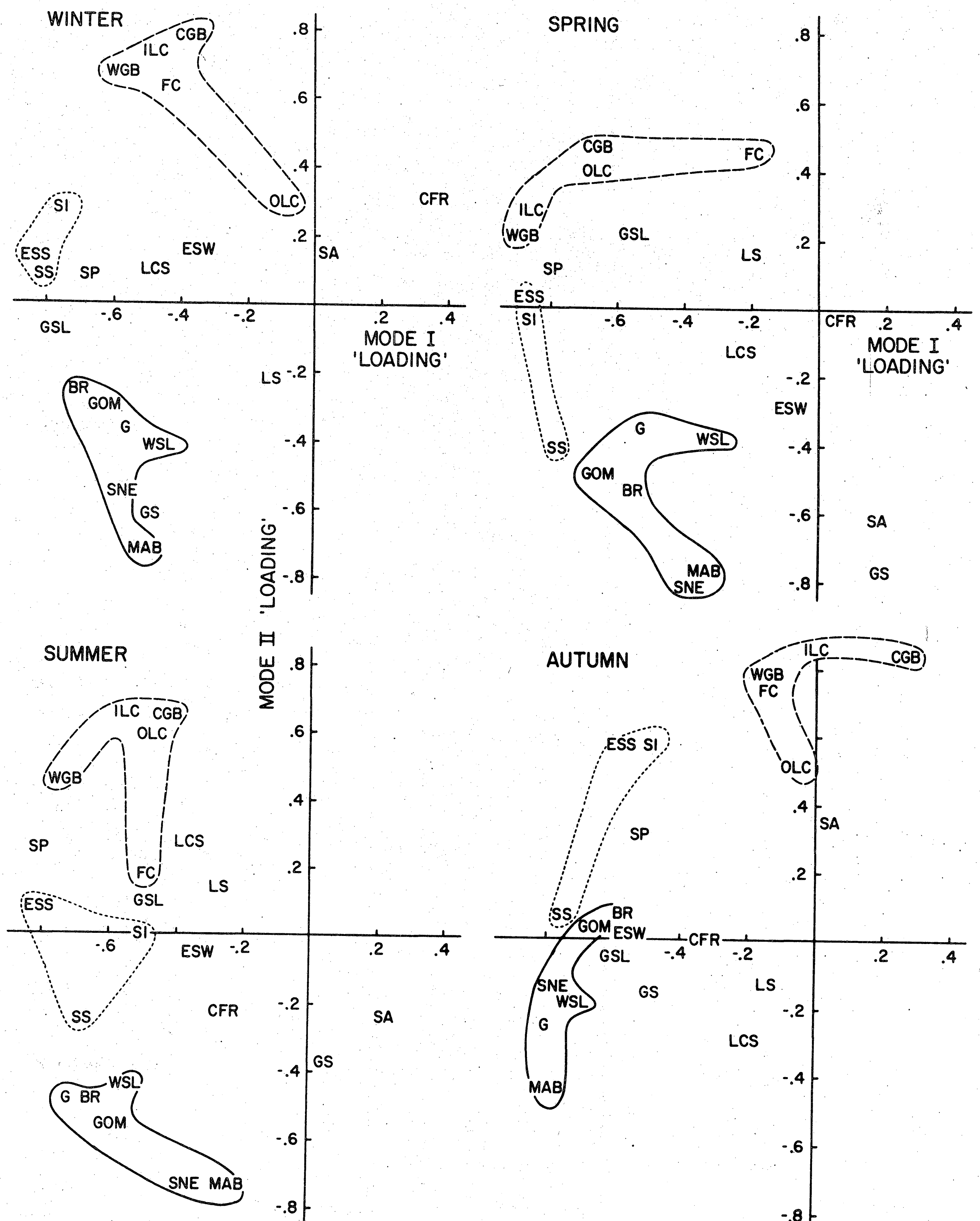

Figure 6. Plots of first vs second mode EOF loadings of SST for selected ocean areas showing natural groupings.

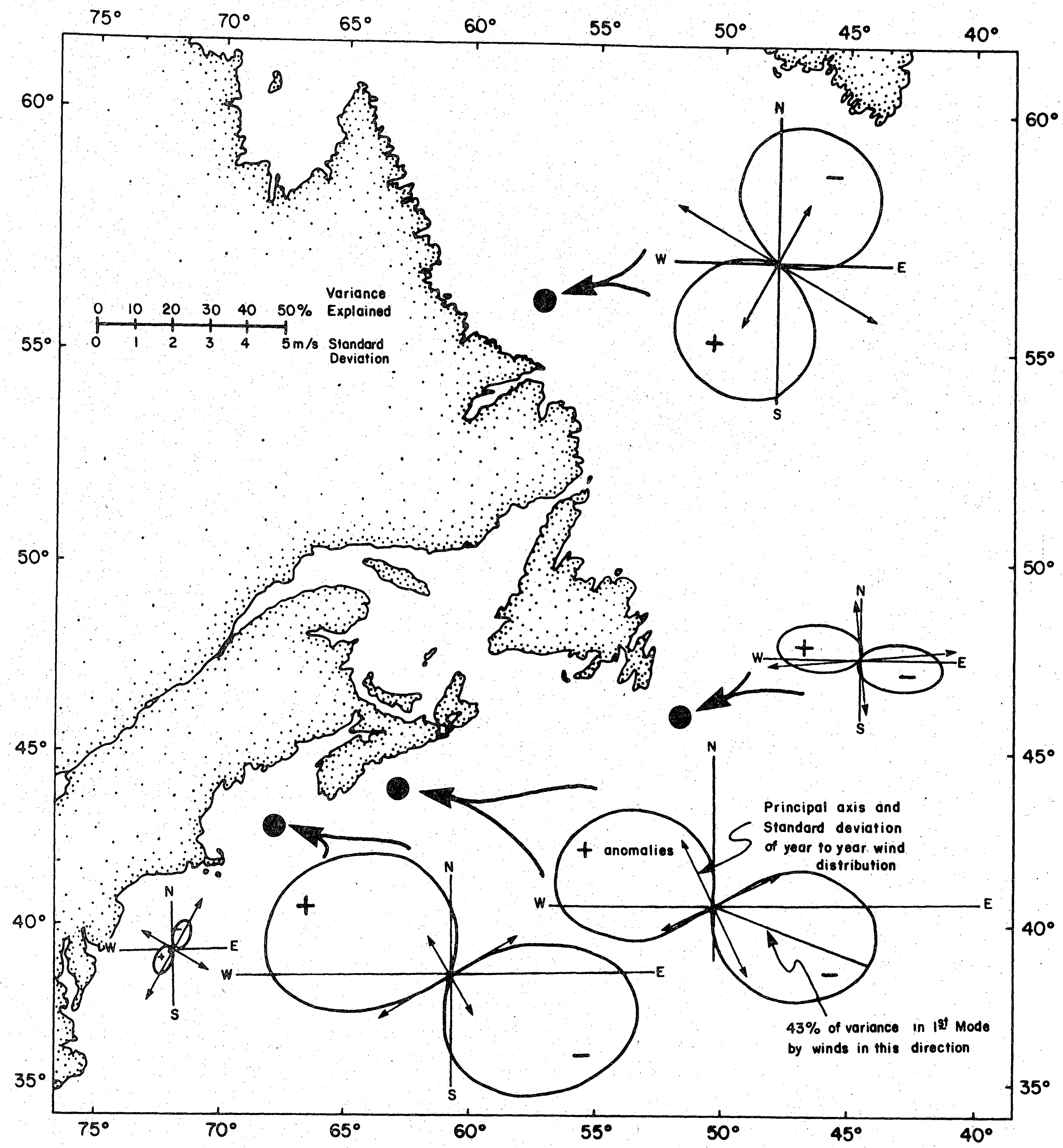

Figure 7. Envelopes showing percentage variance of first EOF mode (winter) 'explained' by winds in any direction at five sites. This figure is constructed using the auto-and cross-covariances between the easterly and northerly components of the geostrophic wind (computed for five sites along the seaborad) and the first mode EOF time series for the period 1950 to 1980. The principal axes components for wind variance are shown. The components of gain are not shown; these are the regression coefficients which predict the contribution of the wind components to the first mode EOF. The gain and wind variance components are combined to yield the percentage variance in the first mode EOF 'explained' by winds from any direction; this percentage variance 'explained' is plotted.