JANUARY-FEBRUARY TROPOSPHERIC CLIMATE FOR THE NORTHERN HEMISPHERE AND THE 11-YEAR SOLAR CYCLE, THE QBO AND THE SOUTHERN OSCILLATION

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1. INTRODUCTION

This study examines a recently discovered association between the 11-year solar cycle and the atmosphere that is most easily detectable when the two phases of the Quasi-biennial Oscillation (QBO) are considered individually rather than pooled. The influence of the Southern Oscillation (SO) for either of the two QBO phases is then combined with that of the solar cycle in the form of two-predictor multiple regression.

Documentation of a solar cycle-QBO-atmosphere relationship in Northern Hemisphere winter began for the stratosphere near the North Pole (Labitzke 1987) and was subsequently extended to cover the extratropical Northern Hemisphere for the lower stratosphere and middle troposphere (Labitzke and van Loon 1988), and finally for the lower troposphere and the surface (van Loon and Labitzke 1988). The last paper reported statistically highly significant QBO-stratified solar cycle-atmosphere relationships at a number of locations; these involved surface air temperature, sea level pressure, and geopotential height. Further study indicated effects during other seasons and in the Southern Hemisphere (Labitzke and van Loon 1989). The field significance (Livezey and Chen 1983) of the solar-atmosphere correlation fields reported in van Loon and Labitzke (1988) was evaluated in Barnston and Livezey (1989)--to be called BL89--and found to be quite strong for both east and west QBO phases for the January-February period.

In January-February of 1989, however (which was not included in the analyses in BL89) the climate pattern strongly opposed that expected for the solar/QBO conditions. This exception was attributed to the strong SO situation: a cold tropical Pacific Ocean and a high SO index. In fact, there had never been even a moderately strong high SO episode coincident with a solar maximum during the west QBO phase since QBO records first became available in 1951. The need to stratify by QBO phase results in sample sizes of only about 20 years per phase, leaving some very noticeable vacant sectors in the two-dimensional sample space of solar flux and SO.

The 1989 event helped provide evidence that the SO needs to be considered as well as the solar cycle and QBO information in developing predictive relationships with the climate. This study incorporates both the solar and SO factors in predicting the Northern Hemisphere 700mb height anomalies for the January-February period, separately for west and for east QBO phases. The study is also extended to United States surface temperature in certain analyses.

2. DATA AND ANALYSIS METHODS

The data used in this study are essentially identical to those described and used in BL89, extended to include 1989 and the SO. They include January-February means for 1951-89 of 10.7 cm wavelength solar flux, surface temperatures at 92 continental U.S. stations, and 700mb heights at 358 approximately equal area Northern Hemispheric grid points from 20^{o}N northward. January mean values of the 45mb u-component of the equatorial wind over the equator led to a dichotomous definition of the QBO phase - west or east - for this same period. Further details about these data are available in BL89 and references thereof. A Southern Oscillation Index (SOI) was computed from two equally weighted components: the standardized anomaly of Tahiti minus Darwin sea level pressure (SLP) and that of the average sea surface temperature (SST; multiplied by -1) in the highly associated east-central tropical Pacific area of 10^{o}S-10^{o}N, 120-160^{o}W. The January-February averaging period was used for SST, but some noise filtering was applied to SLP by using a weighted average of (Jan + Feb)/3 + (Dec + Mar)/6. The SST and SLP were combined to capture a more balanced, stable and complete index of the SOI than either provides alone.

Many of the 2-variable relationships discussed in this paper, described by spatial fields of correlation coefficient, are statistically tested for field significance with Monte Carlo techniques that are detailed in BL89. The major considerations in these statistical tests are the temporal autocorrelations of the two variables (e.g. the solar flux has a strong autocorrelation associated with its 11-year cycle, and any variable that is well correlated with the flux probably does also) and the spatial correlation among neighboring grid points of the field variables. Both factors reduce the degrees of freedom in the time-space system and make chance occurrences of high amplitude correlation patterns more likely. As in BL89, the integrated t-statistic, or average of the t-values over all grid points of the correlation field, is used as the test statistic. A Monte Carlo procedure that randomly shuffles an appropriate variable is used to generate a distribution of such statistics that would be expected by chance, with which to compare the observed result. The significance level, or probability that the observed relationship is of a strength that could have occurred by chance, is then obtained. This method is a refined version of that of Livezey and Chen (1983) in that it represents the integrated significance level using the local t-values themselves rather than a count of how many of them exceed a given local significance threshold, as was done in Livezey and Chen (1983). Using the t-values themselves allows for more accurate evaluations of irregularly shaped distributions of local significance, should they happen to occur.

QBO phase-stratified bivariate multiple linear regression models are developed to predict grid point values of 700mb height on the basis of the SOI and the solar flux. In the presentation of results the regression coefficients are normalized as partial correlations between either of the two predictors and the predictand, accounting for the effect of the other predictor in the equation.

3. IMPACT OF 1989 ON SOLAR FLUX-CLIMATE RELATIONS FOR WEST QBO PHASE

The January-February correlation field between 10.7 cm solar flux and the Northern Hemisphere 700mb height is shown in Fig. 1, for the 21 west QBO phase years for the 1951-88 period. The field significances are strong, as shown at the top of Table 1. (The QBO phase assignment shuffle Monte Carlo significance test and the alternative option of a solar flux phase/shape shuffle test are described in BL89 on pages 1298 and 1304, respectively. The QBO phase assignment shuffle is random and does not restrict the phase sequences to the observed alternating patterns; this produces a maximally stringent significance test.) The strong dipole with centers in Canada and the western Atlantic near 30^{o}N and the associated anomalous circulation pattern would be a helpful index for developing long-range forecasts for west QBO phase years for January-February in North America.

In January-February 1989 the QBO phase was west and the flux anomaly was high, but the North American climate strongly opposed that expected from the

1951-88 relationship (Fig. 2). This weakened the west phase flux-climate correlation fields considerably (Fig. 3) as well as the associated field significances (bottom of Table 1). Note that the significance for east QBO phase relationships also changed slightly with the inclusion of 1989. This is because the near-record high amplitude 1989 pattern became available for random selection in the Monte Carlo background distribution-generating QBO phase shuffle process, changing the relative extremeness of the observed patterns. A possible clue to the cause of the strong 1989 exception is found in the January-February 39-year (1951-89) correlation between the SOI (where low SOI values correspond to El Niños or warm episodes) and 700mb height (Fig. 4). Note that over North America and the eastern Pacific this pattern is quite similar (but of opposite sign) to that of the flux-height correlation field for west QBO phase (Fig. 4), although elsewhere in the Pacific they differ. One explanation for the 1989 exception is that the cold event of 1988-89 superseded the solar/QBO situation in forcing the January-February North American climate pattern. Hence, the patterns of Figs. 2 and 4 are relatively similar, and Fig. 4 did not change very much as a result of 1989. Inspection of the data reveals that for west QBO phase years in the 1951-88 period there was a weak negative correlation (-0.26) between the SOI and the flux, and that no year had flux and SOI values both at least 0.5 standard deviations above their means (in 1989 they were above by 1.80 and 1.24 standard deviations, respectively). Before 1989, warm events tended to occur slightly more frequently during high than low flux winters, perhaps bolstering the apparent association between flux and North American climate. After 1989 the SO-flux correlation is largely neutralized (-0.11), presumably having been due to chance.

The global significance of the Fig. 4 SOI versus height correlation field was tested by systematically shifting the phase of the SOI by one month increments to generate a null (or no-effect) distribution. This phase shuffling approach (which generates 468 trials) is designed to preserve most of the autocorrelational features of the SOI (which are weak interannually) in generating the null distribution of integrated t-statistics (Sec. 2) against which to compare the observed integrated t to estimate the field significance. The resulting p-value is 0.004 for the correlation with Northern Hemisphere 700mb height, providing evidence of stability of the Fig. 4 pattern.

4. MULTIPLE REGRESSION PREDICTING CLIMATE FROM FLUX AND SOI, FOR WEST QBO PHASE

In Section 3 it was suggested that during west QBO phase January-Februarys the solar flux and the SOI both help to determine the North American climate, and can either work in the same direction or oppose one another. Their near-independence makes them suitable for a two predictor multiple linear regression model predicting 700mb height or surface temperature at a given location or over a relevant area.

The result of such a multiple regression is shown in Fig. 5 for January-February 700mb height and Fig. 6 for U.S. surface temperature, with only the significant ($p < 0.05$) SOI (flux) regression coefficients indicated by solid (dashed) contours. The coefficients are normalized; i.e., they are partial correlations with the predictand. Asterisks denote statistically insignificant individual predictor coefficients but a significant regression equation, implying some participation on the parts of both predictors. The stippled areas have R^2 values of 0.5 or higher.

The correlations with height (Fig. 5) suggest that the SOI has overall a more pervasive effect on the climate, but the solar effect is strong in several locations and thus worthy of consideration. Areas that appear to be affected significantly by both factors are (1) the western Atlantic near 30^{o}N, (2) Canada and (3) North Africa. The correlations with U.S. surface temperature (Fig. 6) indicate significant effects from both SOI and flux in the southeastern U.S. despite the relative domination there by SOI in the heights. It is found that the 22-year west QBO phase sample correlation between the SOI and 700mb heights (which enters into the present multiple regression) is similar to Fig. 4 (all 39 years) except that the southeast U.S. positive center is emphasized at the expense of the Canadian negative center; the correlations with U.S. temperature reflect this feature.

On the basis of the regression results, a general SO/flux-related regional index over North America is defined for illustrative purposes for the west QBO phase years. One "pole" of the index is over Canada, comprising the area 35-120^{o}W, 55-65^{o}N, and the other is in the southeast U.S./western Atlantic, with area 45-100^{o}W, 25-35^{o}N. The corners of these areas are shown in Fig. 5. Within the area of either pole each of the two predictors acts (significantly or subsignificantly) in the same direction, and at some grid points one predictor may overshadow the other. The Aleutian Islands area is not used as a third component of the index because the two predictors combine differently there (the flux affects the heights in the same sense as in Canada, whereas the SOI affects this area oppositely from Canada). The North African area is technically eligible for inclusion in the index, but is ignored in order to concentrate on North America. An appropriate index for the Atlantic-Canadian dipole, based on the corresponding seesaw feature in the relationships of both the SOI and the flux with the heights, is the 700 mb height difference between the Atlantic and the Canadian areas. Either a high flux or a low SOI (warm event) would tend to produce negative difference anomalies (i.e., positive height anomalies in Canada and negative anomalies in the Atlantic), and vise versa.

When the multiple regression model is applied to the Atlantic-Canadian difference index itself, the relationship is of approximately the same strength as near the center of one of the dipole areas. Specifically, R^2=0.43, the SOI coefficient is 0.46, the flux coefficient is -0.42, and the significance p-values for the SOI, the flux, and the regression equation as a whole are 0.008, 0.026 and 0.005, respectively. The strength of the relationship between the dipole difference index and each of the two predictors is shown in Fig. 10, where the abscissa is the standardized SOI, the ordinate the standardized solar flux, and the body of the figure contains individual year values of the standardized (X100) dipole height difference index. Values greater than +1 standard deviation are encircled (implying subnormal Canadian heights and/or above-normal southeast U.S./Atlantic heights), and those more negative than -1 standard deviation are enclosed in squares. Dotted enclosures denote greater than three-quarters standard deviation departures. Some broad clustering is apparent, with years having high positive height differences tending toward the lower right portion of the domain. The 1989 value defies this, being in the upper right portion. While the 1989 predictand value might be expected to be much weaker (being forced oppositely by the flux and the SOI), its high positive value can at least be explained by the high SOI value, leaving the suggested relationship with the flux much less damaged than it would be in a univariate regression model based on the flux alone. Note the weak negative correlation between flux and SOI when the 1989 point is removed, and the associated lack of points with low values for both predictors (which still remains after including 1989).

The 700 mb height difference index should be regarded as an a posteriori predictand in the sense that it was defined on the basis of an exhaustive series of multiple regression experiments using each of 358 grid points of 700 mb height as a predictand.

5. MULTIPLE REGRESSION PREDICTING CLIMATE FROM FLUX AND SOI, FOR EAST QBO PHASE

The exercise described in the previous section is now applied to the 17 years of mean January-February data for the east phase of the QBO, using the SOI and the solar flux as predictors for the Northern Hemisphere 700mb height at each of 358 grid points and the U.S. surface temperature at each of 92 stations. The east phase zero-order correlations between flux and 700mb height, shown in Fig. 8, emphasize the Pacific Ocean, Arabia, Europe and Mexico rather than the heart of North America as was noted for west phase years. The strength of the currently sampled flux versus height correlation field is stronger than that for west phase, as reflected in the significance levels given in the bottom half of Table 1. The flux versus U.S. temperature correlation field (not shown) is generally weak except for a small, intense (>0.60) area in the southern Rockies.

Results of the east phase multiple regression are shown for 700mb height in Fig. 9, in which we note a significant influence from both predictors in the Kamchatka/Bering Sea area and, to a lesser degree, in the subtropical Pacific just west of the date line. No regions of the continental U.S. have overlapping significant surface temperature predictability (not shown); moreover, even areas of significant single predictor influence are limited.

A SO/flux-related dipole was defined for the east QBO phase regression results analogous to that for the west phase described in Sec. 4. One pole is in the Kamchatka/Bering Sea area defined by 150^{o}E-155^{o}W, 45-70^{o}N, and the other in the subtropical Pacific at 155^{o}E-160^{o}W, 20-25^{o}N. The corners of these areas are shown in Fig. 9. To the west of both the northern and southern areas there is more area strongly associated with the SO, but this is excluded from the dipole index because of an insufficient strength of association with the flux. The dipole index in this case is the subtropical Pacific area average 700mb height minus that in the northern area; either a low SOI (an El Niño or warm episode) or a low flux will tend to create high index values during east QBO phase January-February periods.

Application of the multiple regression to the dipole difference index itself results in a relationship of strength comparable to the average of that found near the center of the two poles, which is high in the east phase case. The R^2 is 0.77, the SOI and flux normalized coefficients (followed by p-values) are -0.60 (0.0004) and -0.62 (0.0003), respectively, with an overall equation p-value of less than 0.0001. It must be stressed once again that the dipole difference index and its multiple regression significance are highly <u>a posteriori</u> in character and are used for illustrative rather than statistical evaluative purposes. The 3-way multiple regression scatterplot (analogous to Fig. 7) for east phase years, shown in Fig. 10, exhibits a marked tendency for clustering of negative predictand values in the upper right sector (high SOI, high flux) and positive values in the opposite corner. Although the correlation between flux and SOI is 0.02 which quells suspicions that one of the predictors may be redundant with the other, there are relative "holes" in the two high flux corners of the flux-SOI sample space. This leaves the presently sampled relationships subject to some reordering should nonconforming future predictand values appear in the vacant sectors of the predictor plane.

6. MORE GENERAL STATISTICAL ASSOCIATIONS AMONG FLUX, QBO, SO AND THE CLIMATE.

In this section the statistical relationships among the climate and the three potential predictors (flux, QBO, SO) are examined in a more general way in order to place the regression results of the previous section in an appropriate perspective.

a. Modulation of the effect of the SO on climate by flux and QBO phase

The effect of the SO on the January-February Northern Hemisphere 700mb height (and, by implication, US surface temperature), illustrated in Fig. 4, was found to be highly statistically significant for height (Sec. 3). We ask whether the solar flux or the QBO appear to condition the SO-height relation to an extent beyond that of the expected sampling variability. When the hemispheric SOI versus 700mb height correlation field is recomputed separately for the cases of above and below average solar flux (regardless of QBO phase), differences from the 39-year correlations are statistically insignificant.

When the SOI and 700mb height data are correlated separately for west and east QBO phase years, results are roughly similar to those of the pooled 39-year analysis of Fig. 4. However, the individual QBO phase results (shown indirectly in Figs. 5 and 9) differ sufficiently for the west phase pattern to resemble the Pacific/North American (PNA) rotated principal component pattern markedly more than the Tropical/Northern Hemisphere (TNH) pattern and the east phase pattern to most strongly resemble the TNH and West Pacific Oscillation (WPO) patterns (Barnston and Livezey 1987). Statistical tests suggest that the QBO may indeed modulate the influence of the SO on the climate. Because the solar flux is not directly involved in this three-way association, details of the latter will not be presented here but are found in Barnston et al (1990).

b. Modulation of flux-climate relationships by SO

The Northern Hemispheric field of correlation between the solar flux and 700mb height using all 39 years in the 1951-89 period is fairly weak and produces insignificant p-values in Monte Carlo significance tests. Results here are in agreement with van Loon and Labitzke (1988) who stated that flux-climate relationships in the troposphere are detectable only for QBO phase-stratified data. It has been shown that stratification of the flux and climate data by QBO phase leads to stronger relationships.

The relationship between QBO phase itself and 700 mb height (regardless of the flux or the SOI), depicted by a composite height anomaly field for either phase, is a globally insignificant, fairly weak and partly fragmented but recognizable version of the vigorous zonally symmetric pattern (with a negative anomaly over the pole for west phase) found by Holton and Tan (1980) in a similar analysis for the stratosphere.

When stratification of the flux-climate data by low versus high SOI is carried out, resulting correlation fields are fairly similar to the overall field and differences between the two are statistically insignificant.

The final idea explored is that of the SO as a mediator within the QBO phase-stratified relationships between flux and hemispheric 700mb height. The west and east QBO phase data were further stratified into 7-member samples of highest versus lowest SOI, and flux-height correlation fields were computed for each of the four groups. The flux ranges for each of the groups are minimally adequate (there is never a lack of low or high flux values) but poorly sampled. A systematic mediating role of the SOI in QBO phase-stratified flux-climate associations is not apparent from either of the two sets of small sample comparisons.

7. SUMMARY AND DISCUSSION

The strong and well-defined relationship between the 11-year 10.7 cm solar flux cycle and the lower troposphere Northern Hemisphere January-February climate for QBO phase-stratified samples (van Loon and Labitzke 1988, Barnston and Livezey 1989) failed for the west QBO phase in 1989. In this report the opposing 1989 event is explained, at least in part, on the basis of the phase of the SO (the cold tropical Pacific SST event of 1988-89). It is demonstrated that both the SO and the solar flux have moderate and quasi-independent correlations with the climate over certain regions, and where there is strong overlap they can work either in harmony or in opposition. In 1989 in North America the influences of the SO and the flux conflicted to an unprecedented extent, and the SO was the controlling influence in most regions of the continent (western Canada being one exception). The 1989 event draws attention to the smallness of the QBO phase-stratified samples and the still more serious "holes" in the two-dimensional sample space of flux and SO when both factors are viewed as predictors within one QBO phase.

Bivariate linear regression equations were developed separately for each QBO phase using the SOI and the solar flux as predictors, and each of several hundred grid point values of 700mb height and 92 stations of U.S. surface temperature as predictands. An a posteriori-developed height dipole difference index was also used as a predictand. Within each of the two QBO phase conditions, the flux and the SOI are approximately independent. The spatial distributions of the numerous significant regression coefficients for the flux and SO predictors in the prediction of height or temperature help indicate where each predictor is of value and should enable more skillful overall forecasts to be made than would be possible using only one of the predictors. These spatial patterns may aid in the search for physical underpinnings for the solar effect with its currently unexplainable dependence on the phase of the QBO. A more general exploration of statistical associations among the solar flux, the QBO, the SO and the climate was pursued to help complete the description created by the regression equations. No noteworthy relationships were uncovered except for a suggestion of a preference for a PNA (TNH) 700mb circulation pattern in response to the SO in the west (east) QBO phase, the details of which are forthcoming in a separate paper by the present authors. The effect of the SO on the climate was found to remain broadly the same regardless of the flux level.

A major question underlying this study is that of the authenticity of the influence of the solar cycle on the climate. The west phase failure of 1989 can be explained partly by the SO situation. The part that cannot be readily explained is why the effects of the SO were so prominent and those of the solar situation so weak. The solar effects in the stratosphere in January-February 1989 were much more in keeping with the previously established relationship than in the tropos-phere (K. Labitzke, personal communication; Fig. 10 of van Loon and Labitzke 1990). Perhaps this suggests that the solar effects work initially or most directly in the stratosphere and secondarily or indirectly in the troposphere where SO effects would dominate when forced strongly. If the solar-climate effects are nonlinear, then the present regression approach would underestimate the strength of the association.

The most prohibitive barrier to establishing the strength of a solar-climate association is the severe sampling problem brought about by (1) the need to stratify by QBO phase, effectively halving the sample sizes, (2) the need to use two predictors rather than one (as demonstrated by the strong effect of the SO in 1989), and (3) the somewhat asymmetric distribution of the flux with its relatively infrequent but large excursions above its mean. Monte Carlo statistical testing can largely overcome the spatial and temporal dependence problems that violate the assumptions of classical statistical assessment tools, but it cannot help at all with insufficient sampling. Because of the small sample size, the truth (i.e., population statistic) about the solar-climate association must remain unknown except for the annual updates of sample associations with fairly wide error bars. In 40 years there will be a doubling of the present sample sizes and a clearer picture of the relationships, coupled with a hopefully greater understanding of the physical mechanisms through which the solar flux may affect the tropospheric climate.

In the meantime, the apparent effects may be cautiously accepted and used in a statistical mode to help develop operational winter long-range forecast tools at the Climate Analysis Center (CAC). Such efforts are already in progress, both in an analog system (Livezey and Barnston 1988, Barnston and Livezey 1989) and in a regression scheme as shown here.

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1951-88

	700mb height		U.S. Surface Temperature	
QBO Phase	QBO Phase Shuffle	Flux Phase/Shape Shuffle	QBO Phase Shuffle	Flux Phase/Shape Shuffle
West (N=21)	.003	.12	.07	.018
East (N=17)	.025	.019	.41	.07
Joint (21, 17)	.001	—	.033	—
Pooled (N=38)	—	.52	—	.26

1951-89

	700mb height		U.S. Surface Temperature	
QBO Phase	QBO Phase Shuffle	Flux Phase/Shape Shuffle	QBO Phase Shuffle	Flux Phase/Shape Shuffle
West (N=22)	.14	.23	.12	.39
East (N=17)	.053	.019	.28	.07
Joint (22, 17)	.055	—	.044	—
Pooled (N=39)	—	.41	—	.45

Table 1. Comparison of field significance with and without 1989 for January-February correlation fields for solar flux versus Northern Hemisphere 700mb height or U.S. surface temperature, using both a QBO phase assignment shuffle and a solar flux phase/shape shuffle Monte Carlo significance test. Results are for west and east QBO phases, for the joint result of the set of two individual phase results, and for pooled (unstratified) samples.

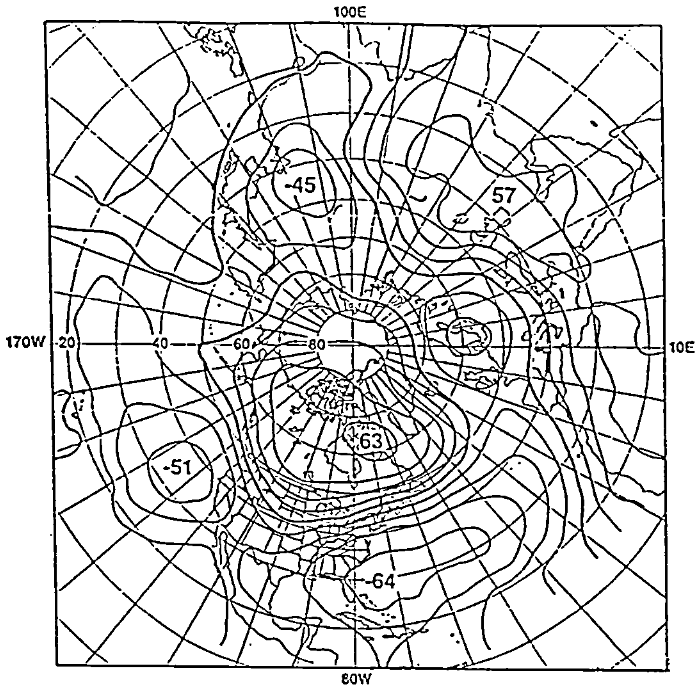

FIG. 1. Correlation (X100) between 10.7 cm solar flux and 700mb height for the west QBO phase for the January-February period, 1951-88 (21 years). Contour interval 15.

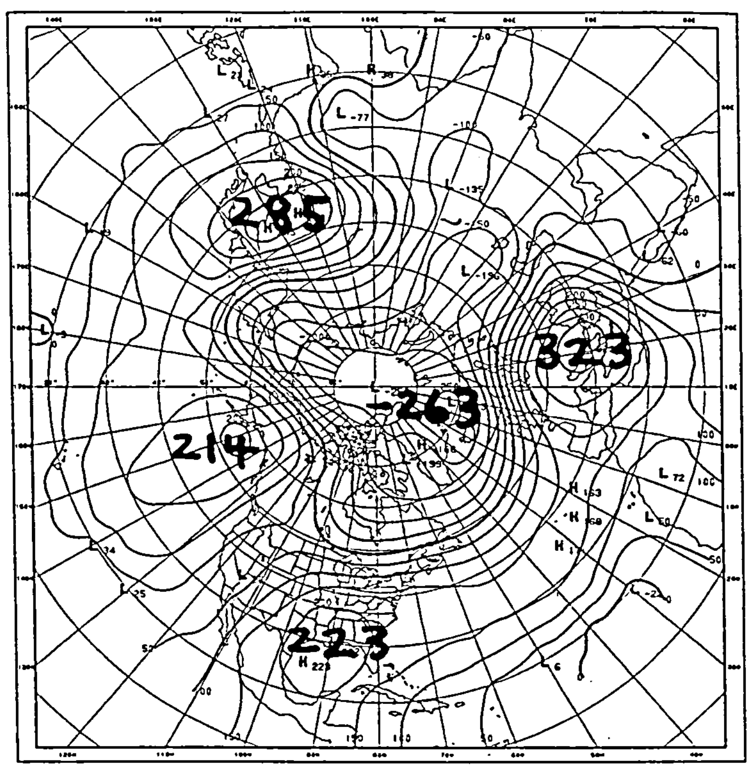

FIG. 2. Standardized anomalies (X100) of the 700mb height for January-February 1989

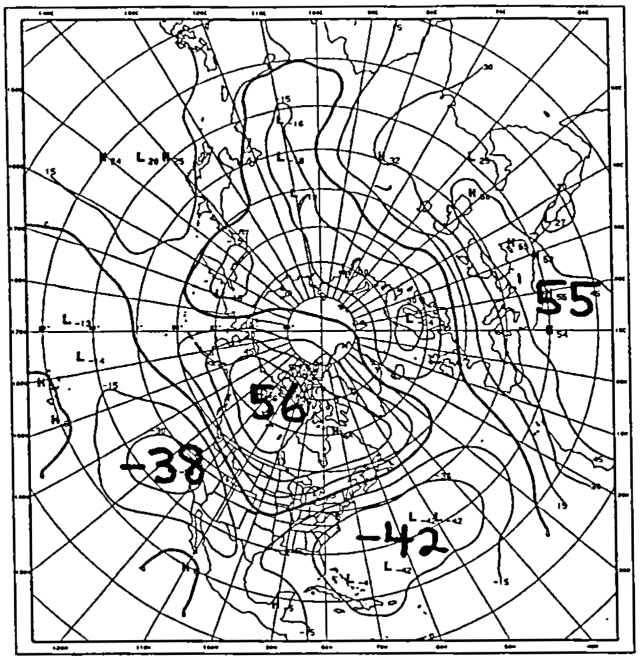

FIG. 3. As in Fig. 2 (west QBO phase), except for 1951-89 (22 years).

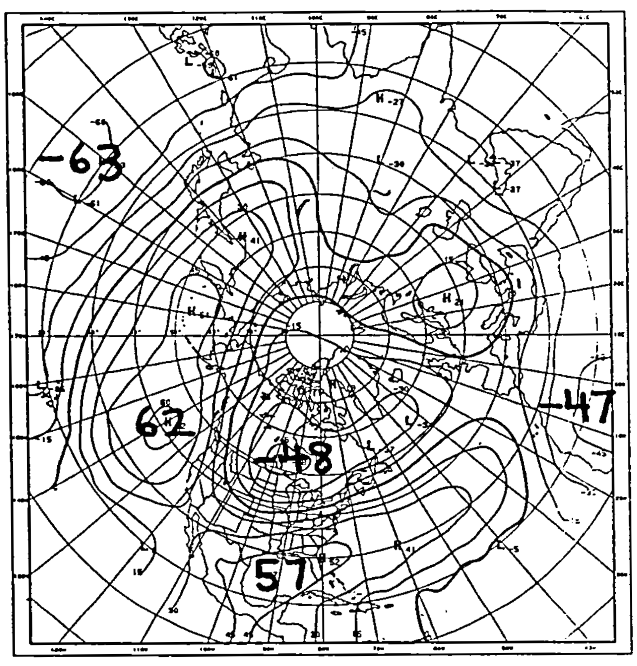

FIG. 4. Correlation (X100) between a Southern Oscillation Index (SOI; based on both Tahiti minus Darwin SLP and on SST in area 120-160^oW, 10^oN-10^oS) and 700mb height for the January-February period, 1951-89 (39 years).

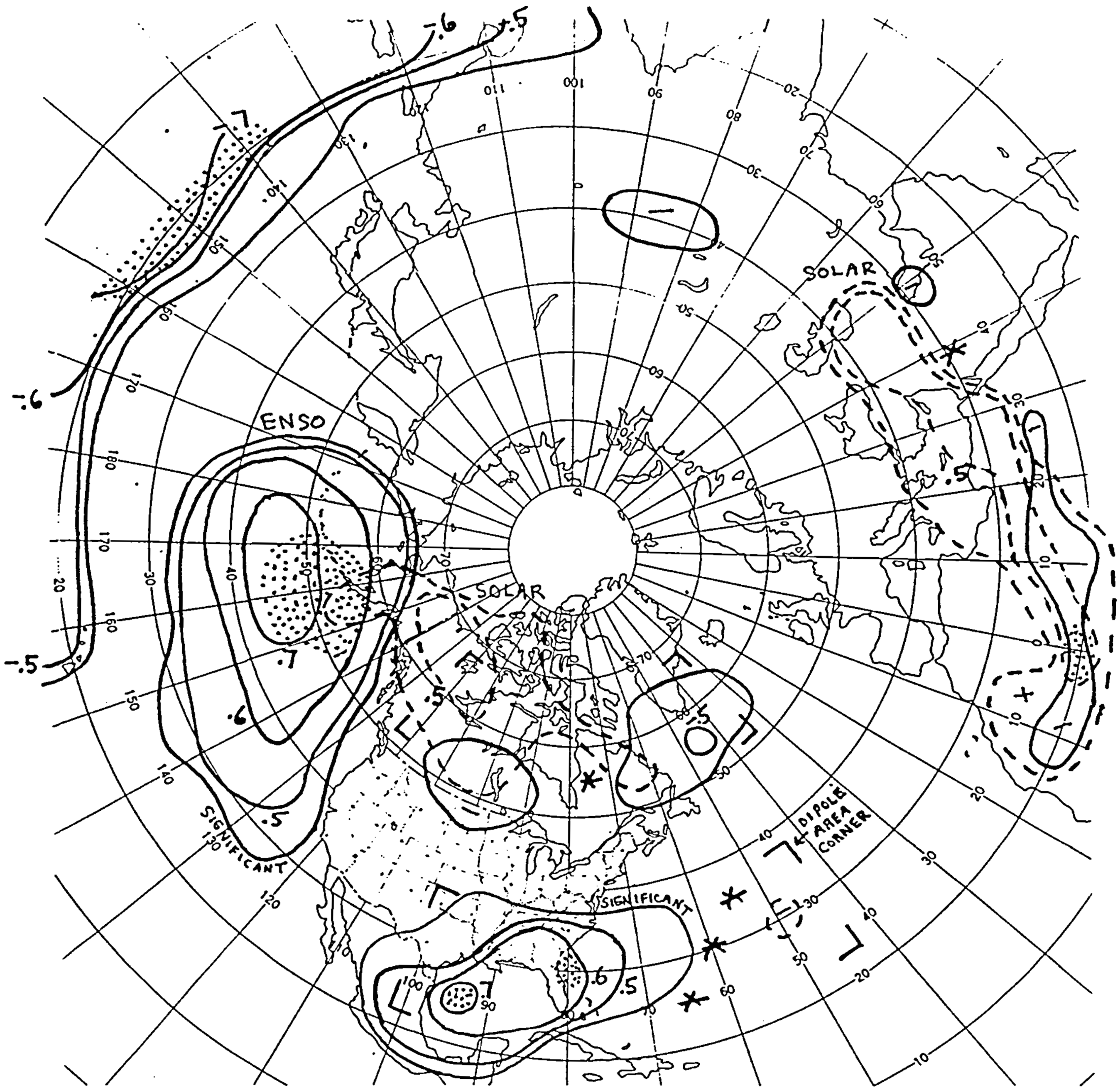

FIG. 5. Two predictor multiple linear regression predicting January-February 700mb height at 358 grid points from (1) a Southern Oscillation Index (SOI) and (2) 10.7 cm solar flux, for the 22 west QBO phase years from 1951 to 1989. Normalized regression coefficients (i.e., partial correlations) are plotted only if significant ($p < .05$); solid contours are for SOI, dashed contours for flux. Stippling denotes R^2 values of 0.5 or higher, and the asterisk indicates that the individual predictor coefficients are insignificant but the equation is significant. The corners of the two rectangular areal poles of an SOI/flux-related dipole (see text) are shown.

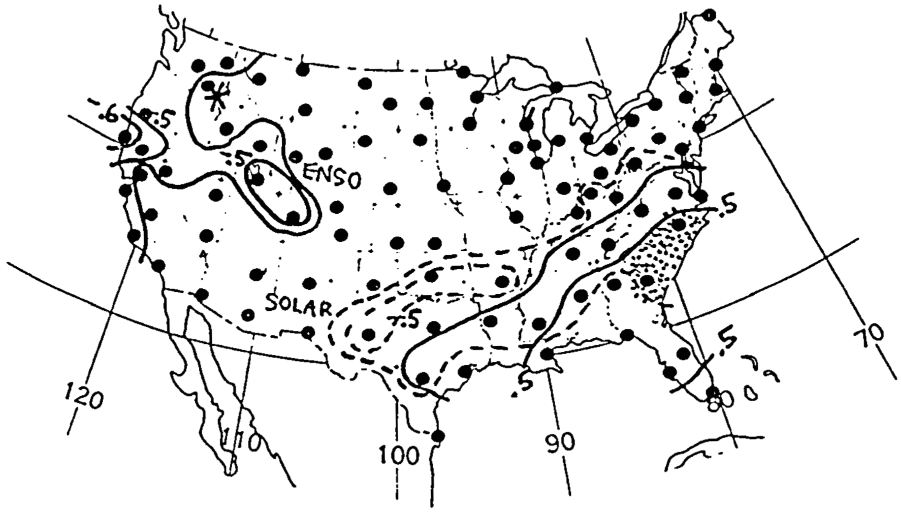

FIG. 6. As in Fig. 5 (west QBO phase multiple regression) except for 92 stations of U.S. temperature (22 years).

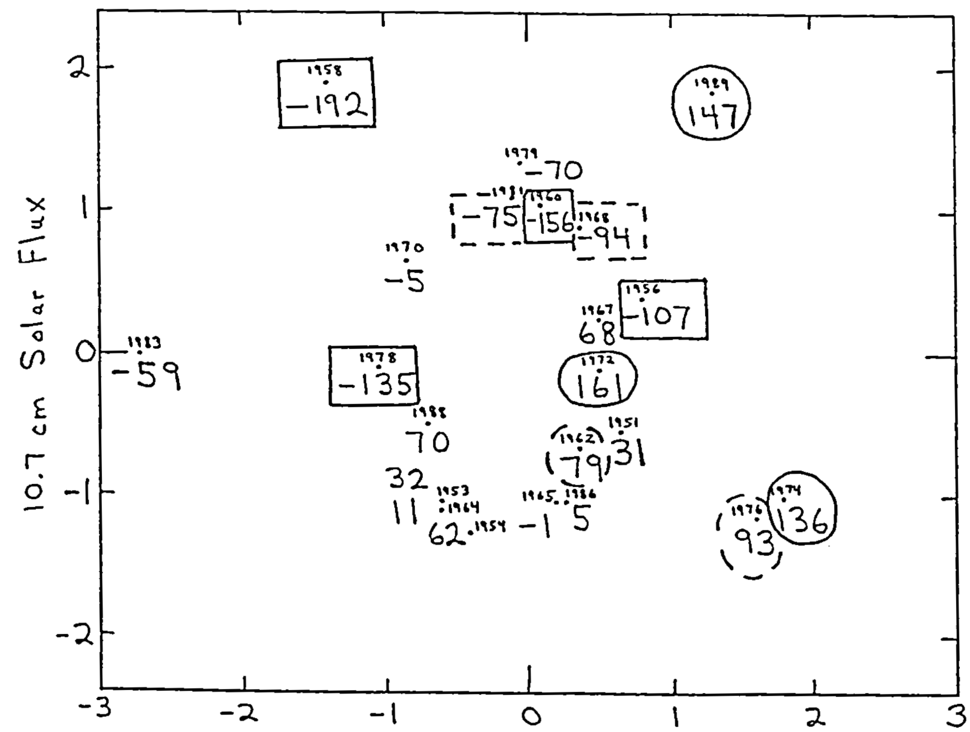

FIG. 7. Three-way individual year scatter plot for west QBO phase multiple regression predicting the 700mb height dipole difference anomaly (southeast U.S./ western Atlantic minus Canada), shown by printed value in body of figure (with year shown) using as predictors the SOI (abscissa) and the solar flux (ordinate). All variables are standardized; predictand values are also multiplied by 100.

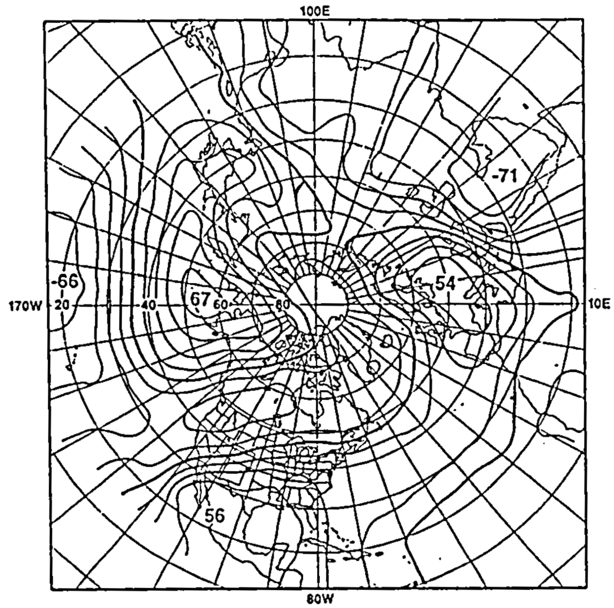

FIG. 8. As in Fig. 1 except for the east QBO phase for 1951-89 (17 years).

(FIG. 9 is on following page.)

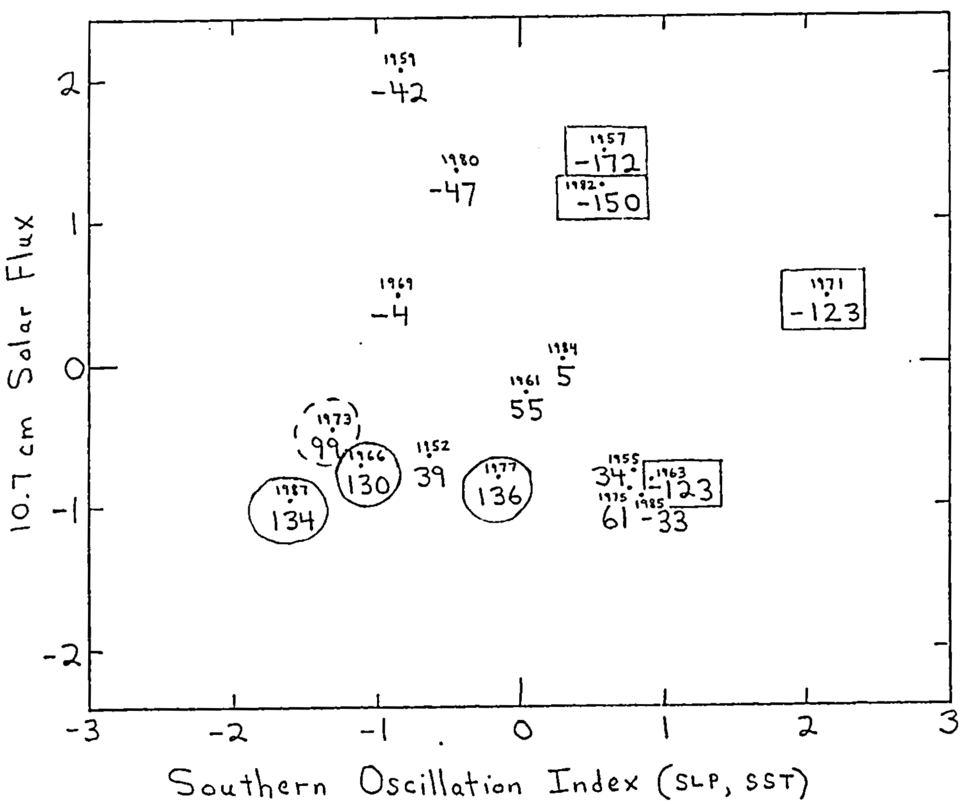

FIG. 10. As in Fig. 7 except for the east QBO phase with its 700mb height dipole difference anomaly (subtropical Pacific minus Kamchatka/Bering Sea).

(Fig. 9 is on following page.)

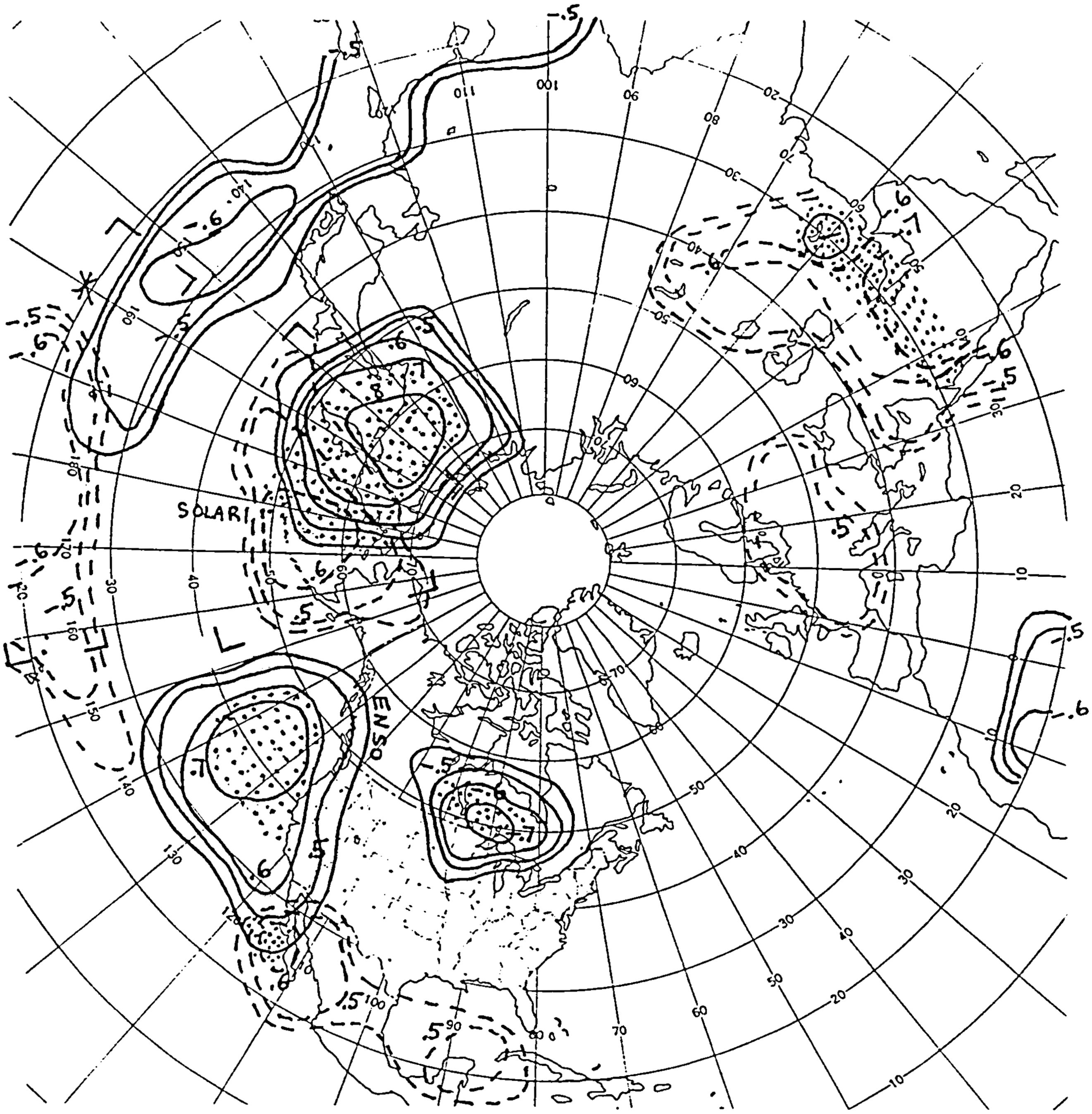

FIG. 9. As in Fig. 5 (multiple regression) except for the 17 east QBO phase years.

(FIG. 10 is on previous page.)