Hemispheric Anomalies of 700 mb Height Related to Mean Temperature for Fall, Winter and Spring in the United States

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ABSTRACT

Zonally averaged composite anomalies of 700 mb height for years preceding and during four warm winters in the contiguous United States show generally positive anomalies over subtropical and middle latitudes and generally negative anomalies over high latitudes. The overall composite hemispheric height anomaly was positive for the years with warm winters. For four years with cold winters, generally inverse composite patterns are noted. In both composites, pattern reversals with respect to latitude occur during the following spring seasons. The four warm and four cold winters were those whose average temperature anomalies, nationwide, were the largest in the 33-year period 1948–80. The occurrence of consecutive severe winters within this relatively short record places limits on interpretation.

More generally, based on 33 years of data and Monte Carlo testing procedures, a statistical relation that is marginally significant at the 95% level appears to exist between the overall pattern of zonally averaged 700 mb height anomalies and mean winter temperatures in the United States. The relation is weaker and less coherent than that previously found with respect to mean summer temperatures. However, as with summer, the individual coefficients that are statistically significant are overwhelmingly positive in sign.

The overall correlation patterns with respect to spring and fall mean temperatures in the United States are obviously not significant. In terms of area-weighted percentages, the totals of individually significant coefficients for spring and fall are even less than to be expected from chance.

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1. Introduction

In a previous paper (Erickson, 1983, hereafter E), hemispheric anomalies of 700 mb height and sea level pressure were found to be related to mean summer temperatures over the United States. In particular, zonally averaged 700 mb height anomalies at tropical and subtropical latitudes were found to be positively correlated with subsequent mean summertime temperatures over the contiguous United States at lead times of up to 12 months. The overall correlation pattern was statistically significant to at least the 95% level.

The present paper describes the results of similar but less intensive investigations relating zonally-averaged 700 mb anomalies to mean temperatures in the United States for fall, winter and spring. Similarity is desirable so that results from different seasons may be compared. Less intensive investigations seem appropriate because the relation involving mean winter temperatures is less well defined than that for summer (although still statistically significant at the 95% level), while relations involving spring and fall temperatures are obviously not statistically significant. The latter are interesting mainly because of their differences from the relations involving winter and summer temperatures.

In a previous paper (E), there was reason to anticipate some of the observed contemporaneous positive correlation between mean summer temperatures in the United States and the strength of the subtropical anticyclone belt. In addition, because of the greater tendency toward persistence of the planetary-scale circulation and temperature anomalies during summer than during other seasons, there was also some reason to anticipate that lagged relationships of up to a few months might also exist during the warmer half of the year. This idea was supported by the earlier work of Namias (1952, 1959, 1978), Madden (1977) and others. However, because of spatial and serial correlation in the 700 mb data and also because the observed lagged relations between summer temperatures in the United States and 700 mb anomalies at middle and high latitudes were not well anticipated, the *a priori* expectations were not sufficient to justify immediate acceptance of the observed correlation pattern. Therefore, a Monte Carlo test of significance was necessary. The Monte Carlo procedure and its applicability to geophysical data sets is discussed in detail by Livezey and Chen (1983). Its application to specific cases is given in Chen (1982) as well as in E.

In the present paper, as with the earlier analogous work related to summer, there is some reason to anticipate a contemporaneous positive correlation between mean *winter* temperatures in the United States and the zonally-averaged 700 mb height anomalies at corresponding latitudes. However, this expectation for winter is less well founded than that for summer. Klein (1962, 1965) reported positive concurrent relations between mean winter surface temperatures at selected cities in the United States and 700 mb mean heights at nearby points. However, the relations usually also involved negative correlations with 700 mb heights at more distant points. Recently, Diaz and Namias (1983) have shown generally positive correlations between regional temperatures and sector-averaged 700 mb heights over middle latitudes. But there were also a few negative correlations for those latitudes during all seasons other than summer. Therefore, extension of those combined results into a conjecture involving mean 700 mb heights over all longitudes is somewhat uncertain for winter.

One may note that phases of the zonal "index cycle" are related to middle-latitude continental temperatures during winter. Middle-latitude continental winters tend to be warmer than average during periods of above normal zonal flow (high index) that bring warm maritime air from the west (e.g., Blasing and Lofgren, 1980, their type 1). Conversely, continental winters tend to be colder than average during periods of large scale meridional flow (low index) that permit invasions of cold Arctic air from the north. The latter situations often are characterized by blocking anticyclones at high latitudes and negative height anomalies in middle latitudes. But this "index cycle" reasoning relates mean temperature more directly to the orientation of the basic flow than to the sign of the 700 mb height anomalies themselves. Therefore, the possible existence of a contemporaneous positive correlation between winter temperature and zonally averaged 700 mb height anomaly is again suggested but not firmly indicated.

On the positive side, one may note that the very large scale of the zonal and hemispheric anomalies used in this study suggests that these anomalies should change more slowly than the regional anomalies of Klein (1962, 1965) and Diaz and Namias (1983). If so, the regional wintertime teleconnections and out-of-phase relations noted by those authors may tend to mask real longer-period anomalies on the hemispheric scale. Thus, the possibility of meaningful lagged relations involving the zonal or hemispheric scale has a degree of rational basis.

For the purpose of similarity with E, we continue the same measure of temperature—the seasonal mean anomaly for the United States as a whole. For winter, this may be less meaningful than for summer. Diaz and Quayle (1978) and Dickson and Namias (1976) have shown that winter temperatures over the eastern and western halves of the United States tend to fluctuate out of phase with each other. Moreover, the natural variability of the atmosphere is greater in winter than in summer (Madden, 1977), baroclinicity is greater, and the influence of local thermal anomalies is less (Webster, 1982). For all of these reasons, the *a priori* expectation of a contemporaneous positive correlation between mean winter temperatures in the United States and 700 mb zonally averaged height anomalies is tenuous, and the possible existence of meaningful lagged relations is, *a priori,* quite speculative. Consequently, the Monte Carlo evaluation procedure was needed even more with winter than with summer.

For the spring and fall seasons, there was some *a priori* reason to suspect a positive contemporaneous correlation between mean surface temperature and the 700 mb height anomaly over the United States, but it was not known whether any such relation would extend to the zonally-averaged anomaly around the hemisphere. Moreover, there seemed little reason to anticipate any significant lagged relation. Some years ago, Namias (1952, 1954) presented evidence of a tendency for minimum month-to-month persistence for April–May and October–November. As previously mentioned, the relations involving mean temperature for spring and fall seasons in the United States in the present study turned out to be not statistically significant for the patterns as a whole. These patterns are presented because they are quite different from those of winter and summer. Composites of selected spring seasons and fall seasons are not shown.

2. Data

The basic data and the period of record (1948–80) are the same as described in E. Both 700 mb height data and SLP data are obtained from monthly mean grid point values for the Northern Hemisphere, on file on magnetic tape in the National Meteorological Center. Seasonal mean temperatures are derived from area-weighted monthly means for each of the 344 climate divisions of the contiguous United States.

3. Comparison of zonally averaged composite anomalies for years with warm winters versus years with cold winters

Over the 33-year period of record 1948–80, the four warmest winters for the United States as a whole, in rank order, have been those of 1954, 1953, 1976 and 1957 (winter is defined as December–January–February, with the listed year corresponding to January–February). The four coldest winters have been those of 1979, 1978, 1977 and 1964. Figs. 1a and 1b are time–latitude composites of zonally averaged 700 mb height anomalies for the warm winters and cold winters, respectively. In both composites the abscissa covers a 14-month period before, during and after the composite winter. Anomalies are expressed in terms of normalized deviation of the 4-year composite monthly mean from the 33-year period-of-record monthly mean (i.e., the anomaly is divided by the standard deviation of the 33-year monthly mean) for the appropriate latitude. The anomalies are for overlapping 30-day periods, calculated every 15 days.

The selection of four warm winters and four cold winters is analogous to the procedure followed in E. It is continued here for comparative purposes. However, the unprecedented nature of the recent back-to-back cold winters introduces additional uncertainties in interpretation, as will be discussed.

A comparison of Fig. 1a with 1b shows crudely opposite gross patterns. The warm winter composite has generally above normal heights at subtropical and middle latitudes and below normal heights at high latitudes in months preceding and during the warm winters, with a general reversal of that pattern during the following spring. The cold winter composite shows a generally opposite sequence. However, these differences between warm winter and cold winter composites are not as well defined as with similar composites for hot and cool summers (E). As with those summer composites, here there is an overall preponderance of positive anomaly in Fig. 1a and negative anomaly in Fig. 1b.

Sea level pressure composites for the four warm and four cold winters (not shown) reveal significant differences between warm winter and cold winter composites only in the months during and after those winters (not before), and only in middle and high latitudes. Over those areas, the anomaly patterns are similar to those for 700 mb heights (Fig. 1). Elsewhere, the SLP composite patterns appear not meaningful.

Diaz and Quayle (1980a) have shown that the behavior of seasonal mean temperatures over the United States during recent decades is not entirely comparable to that of some earlier decades. The recent occurrence of three consecutive cold winters in the United States

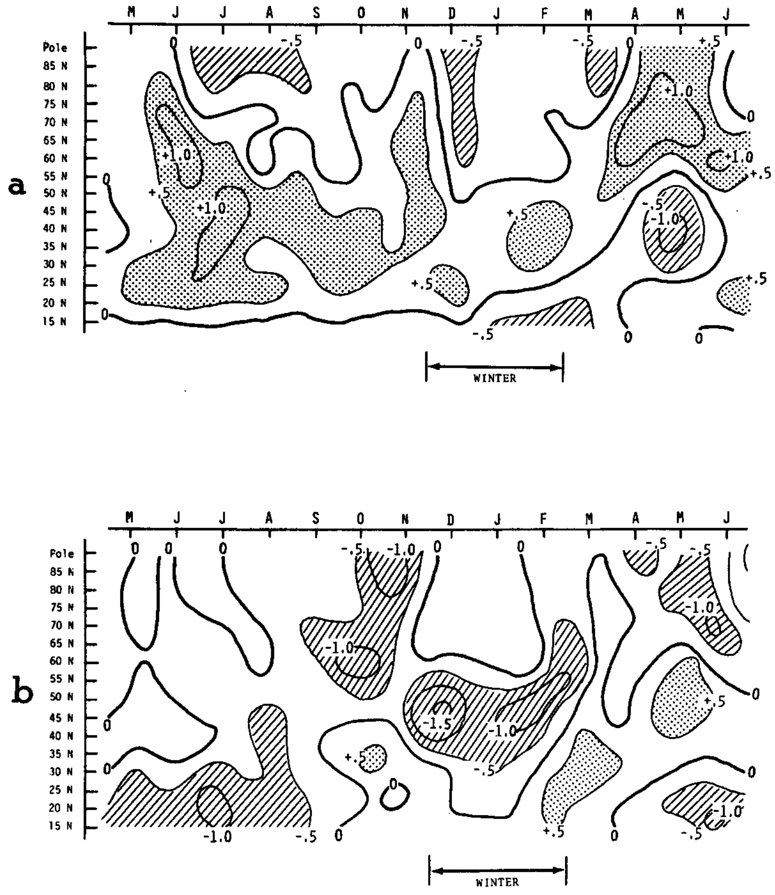

FIG. 1. Time-latitude composites of zonally averaged and normalized 700 mb mean monthly height anomalies for: (a) four years with warm winters in the United States (1953, 1954, 1957, 1976), and (b) four years with cold winters (1964, 1977, 1978, 1979). The normalized anomalies are based on the 33-year period 1948–80. Areas > +0.5 are stippled; areas < −0.5 are hatched. Abscissa is a composite 14-month period from the preceding May through winter and the following June of the four listed years.

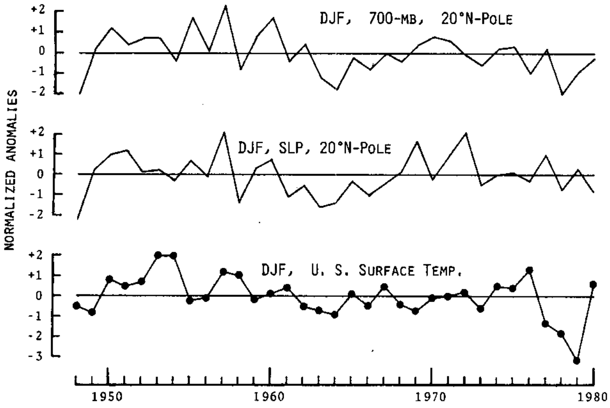

FIG. 2. (Upper) 700 mb mean height anomaly for winter (DJF) for the Northern Hemisphere, 20°N–Pole. (Middle) Corresponding anomaly for sea level pressure. (Lower) Mean surface air temperature anomaly in the United States for winter. All anomalies are for December–January–February and are normalized. Abscissa indicates the year of January–February.

is unprecedented in this century (Diaz and Quayle, 1980b). In this light, the arbitrary selection of the four coldest winters in the last 33 years is a considerable limitation.

It has been suggested that the three consecutive cold winters of 1977, 1978 and 1979 be experimentally ignored and the next coldest winters of 1949, 1969 and 1973 be substituted. This was done. A figure (not shown here) analogous to Fig. 1b was constructed, and the two were compared. There were similarities over the composite months preceding winter, but during and following the winters, the differences were as great as the similarities. Altogether, it must be concluded that the 33-year record may be too short for reliable winter composites from small samples. Nevertheless, Fig. 1 is retained partly because the latter *were* the four coldest winters on record in the United States, and partly because the results tend to be supported by those of Diaz and Namias (1983).

4. Some relations between seasonal, zonally-averaged 700 mb height anomalies and surface temperatures

Before relations involving zonally-averaged 700 mb anomalies are discussed, it is useful to present a few data on hemispheric 700 mb and SLP anomaly averages for winter. Two reasons exist: 1) a comparison may be made with the hemispheric averages for summer, presented in E; and 2) the very broad scale hemispheric relations during winter may serve as limited background for relations involving the somewhat more detailed and lesser-scale zonally averaged anomalies and winter temperatures in the United States. Hemispheric averages for spring and fall are not shown.

Figure 2 shows three time series of normalized winter (DJF) anomalies: hemisphere average 700 mb height, hemisphere average SLP, and mean surface temperature over the United States. This figure is analogous to the one previously presented for summer (Fig. 11 in E). However, unlike those time series of summer data, these time series of DJF data do not display the long-period variations of ~20–30 years (with minima tending to occur during the 1960s). Also, contemporaneous correlations between winter temperatures in the United States and these two hemisphere averaged quantities are smaller than the corresponding coefficients for summer. The contemporaneous correlation between hemispheric average 700 mb height and the DJF surface temperature is +0.38; the correlation between SLP and temperature is only +0.10. Because of autocorrelation of DJF temperature, the former probably is not statistically significant at the 95% level. Lag 1 autocorrelation coefficients for the three quantities in Fig. 2 (top to bottom) are +0.06, +0.03, and +0.36, respectively (Table 1).

Comparison (as to sign) of temperature anomalies for the United States with hemispheric monthly mean temperature anomalies (Jones *et al.*, 1982) also shows differences between winter and summer. For the four hot and four cool summers in E, agreement was good. For the four warm and four cold winters of the present study, agreement is mixed. The indifferent agreement during winter (results not shown here) probably reflects the larger variance of temperature in winter.

Figure 3 presents two modified time–latitude diagrams in which the field values are correlation coefficients. The correlations relate the DJF (upper) and JJA (lower) mean surface temperature to zonally-averaged 700 mb height anomalies for various belts and for a range of three-month periods before, during and

TABLE 1. One-year lag autocorrelation coefficients for overlapping three-month means of hemispheric mean 700 mb height, hemispheric mean SLP and mean surface temperature in the United States. Period of record 1948–80.

	Overlapping three-month means*											
	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
Hemispheric 700 mb height	0.06	−0.04	−0.07	−0.09	0.24	0.53	0.57	0.32	0.37	0.23	−0.04	0.12
Hemispheric SLP	0.03	0.13	0.17	0.10	0.25	0.52	0.51	0.25	0.34	0.20	−0.07	−0.01
Mean temperature in the United States	0.36	0.26	−0.09	−0.10	0.04	−0.05	0.13	0.29	0.19	−0.08	−0.16	0.13

* The first three-month mean in each group represents the seasons of winter, spring, summer and fall, respectively.

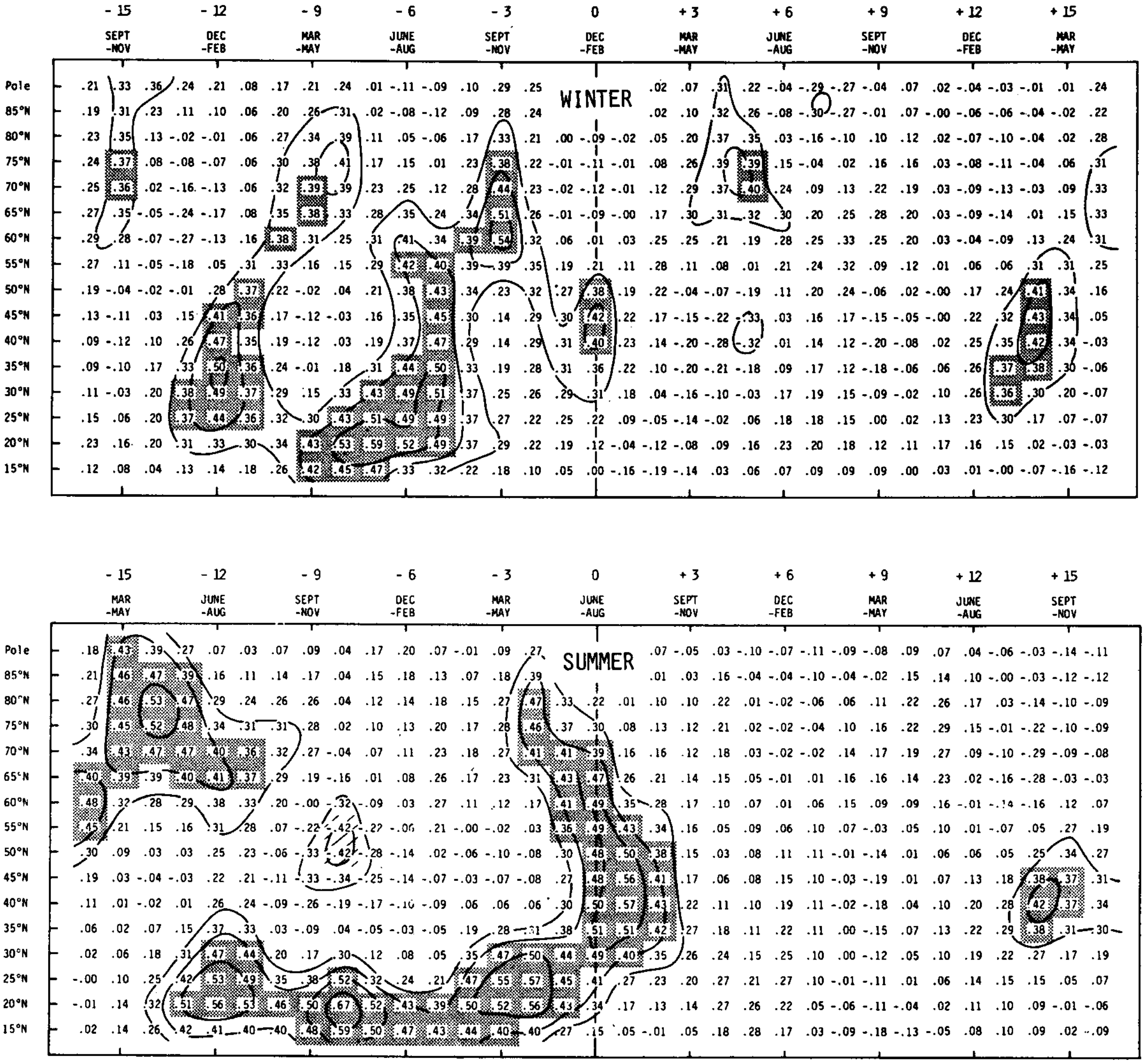

FIG. 3. (Upper) Lag correlations (annual cycles removed) between zonally averaged 700 mb height anomalies and surface air temperatures for winter in the United States. (Lower) As in upper but for summer temperatures. Period of record 1948–80. Three-month means, all quantities. Abscissas indicate 3-month period of the 700 mb anomaly and the lag in months (negative lag denotes 700 mb anomaly *leading* the United States mean temperature). Correlations of absolute value > 0.30 are enclosed by isolines; those statistically significant at the 95% level are shaded.

after the DJF or JJA period of mean temperature in the United States (−16 months to +16 months lag). The lower half of Fig. 3 (summer) was also presented in E. It is reproduced here, for easier comparison with winter.

Figure 4 is the same as Fig. 3, except that it is for spring (upper) and fall (lower). For a more nearly complete explanation of the details of both Figs. 3 and 4, the reader is referred to E. That explanation of course applies specifically to summer (the lower half of Fig. 3), but through analogy it also applies to the other parts of the two figures.

In Fig. 3, the shading indicates those individual coefficients that retain statistical significance at the 95 percent level after adjustments for autocorrelation. Overall, the area-weighted percentage of such coefficients is somewhat less for winter than for summer (13.4 versus 19.1%). However, results from the Monte Carlo tests of the winter simulation (Fig. 5) indicate a 95 percent level of statistical significance for the overall pattern. The lower bound of the upper 5% tail (from 1000 Monte Carlo trials) was at 12.0%, area weighted. Details of the Monte Carlo testing procedure and of the summer simulation analogous to Fig. 5 are presented in E.

Given that the histogram of Fig. 5 represents a skewed distribution and that the upper 5% tail is even longer and more irregular than that of the summer

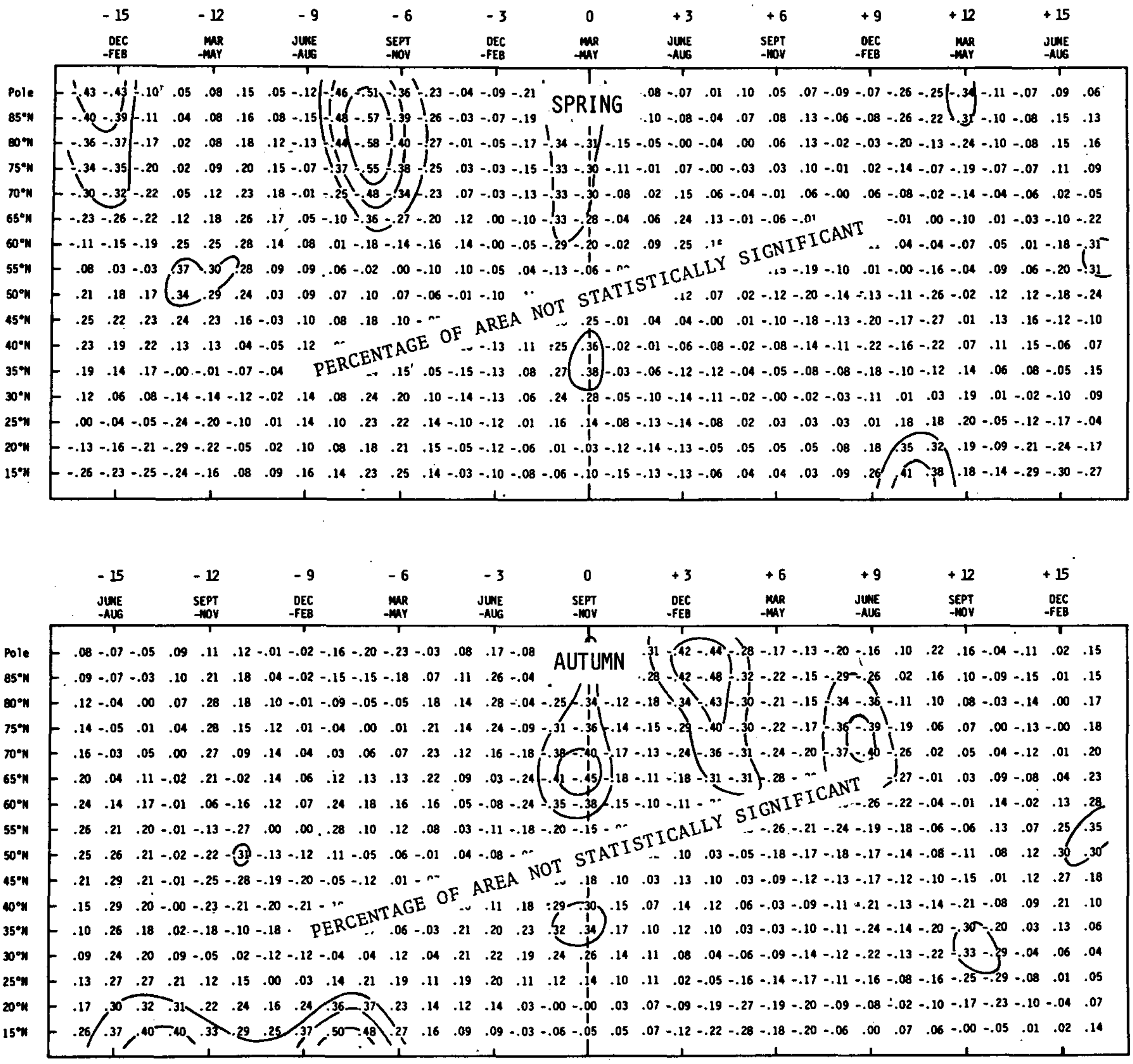

FIG. 4. As in Fig. 3, but for spring (upper) and autumn (lower) mean surface air temperatures in the United States. Shading is omitted. In both diagrams, the percentage of total area having correlations exeeding 95% significance is itself not statistically significant.

simulation in E, it is probably fair to say that the overall winter pattern (upper part of Fig. 3) is only marginally significant at the 95% level. Note that the uppermost extreme result in the Monte Carlo simulation in Fig. 5 exceeded 28%, area weighted.

Also note that the "area weighting," as applied to Figs. 3 and 4, is geographic. That is, individual correlations representing high-latitude zonal averages are accorded less weight than those representing lower-latitude zonal averages in determining the overall percentage of the "area" (the space–time domains of Figs. 3 and 4) represented by individually significant coefficients. The Monte Carlo simulations for summer and winter, of course, used the same cosine weighting function. In the case of spring and fall (Fig. 4), most of the larger coefficients are at high latitudes where the area weighting is low. Consequently, the overall weighted percentages for those seasons are even smaller than the unweighted percentages.

In Fig. 3, a comparison of winter with summer shows two gross similarities: 1) individual coefficients are overwhelmingly positive, and 2) they are largely on the left (lead) side of the figure. It is remarkable that for the winter relation, all shaded coefficients are positive, and for the summer relation all but two are also positive. Two lesser similarities between winter and summer also appear: 1) a contemporaneous positive correlation between middle-latitude 700 mb heights and mean winter (summer) temperatures in the United States and 2) a positive correlation between mean win-

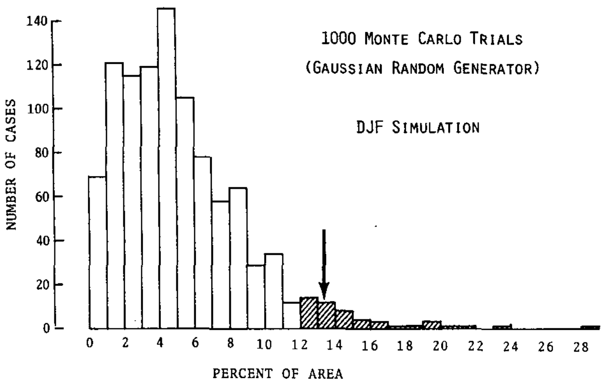

FIG. 5. Histogram of percent of area (winter simulation) having correlations of zonally averaged 700 mb height anomaly and random numbers statistically significant at the 95% level. Ordinate is number of cases, from 1000 trials, for each 1% interval. Abscissa is percent of area. Shading denotes the 5% tail (the 50 largest percentages of the 1000 trials). Arrow indicates result for correlations of the same 700 mb data with DJF averaged temperatures in the United States (the percent of area significant at the 95% level).

ter (summer) temperatures and subsequent middle latitude 700 mb heights approximately 14 months later.

Differences between the winter and summer patterns of Fig. 3 are: 1) a lesser degree of coherence in the winter pattern with positive areas spread over all latitudes; and 2) at low latitudes weaker and more variable positive correlations during the 12 months preceding winters in the United States than during the 12 months preceding summers.

The correlation fields involving spring and fall mean temperatures (Fig. 4) obviously are not statistically significant, overall. In each case, less than 5% of the (weighted) area covered by the 528 coefficients exceeds the 95% level of significance, even before any adjustments for autocorrelation are applied. Therefore, shading on Fig. 4 was omitted, and Monte Carlo tests were not performed.

Figure 6 is a summary of the results already presented for winter and summer, as well as a graph of the uncorrected results for all overlapping three-month periods of mean surface temperature (the latter are shown by open circles connected by solid lines). For winter (DJF) and summer (JJA) periods, the *corrected* results are indicated by solid circles (DJF is repeated for visual continuity). Monte Carlo results at the 95 percent significance level are indicated by short horizontal lines. Shading indicates the difference between Monte Carlo results and those from DJF and JJA mean U.S. temperatures.

The reader should keep in mind that the summary results in Fig. 6 are for all lags combined. Each open circle and filled circle is based on a space–time domain similar to those displayed in Figs. 3 and 4, in which all lags from −16 months to +16 months are included. The abscissa of Fig. 6 corresponds to all 3-month periods of U.S. surface temperature.

As stated earlier, adjustments for autocorrelation and the Monte Carlo tests were performed only for winter and summer. However, because adjustments for autocorrelation must necessarily operate to reduce

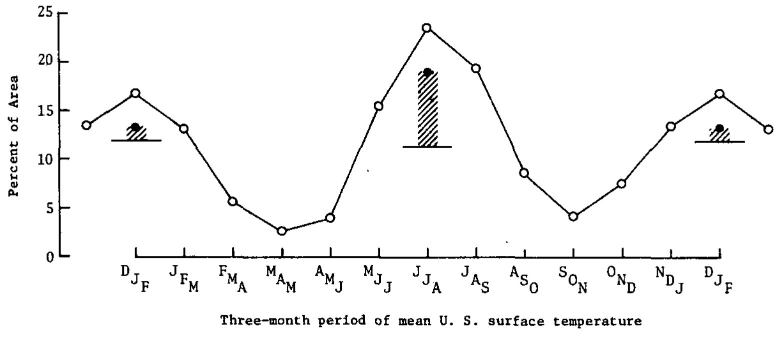

FIG. 6. Percentages of area (scale at ordinate) having correlations statistically significant at the 95% level. Area is that of space–time domain of 700 mb data covered by 528 correlation coefficients, as illustrated in Figs. 3 and 4. Legend:

Continuous line with open circles—Three-month mean, zonally averaged 700-mb height anomalies vs. 3-month mean U.S. surface air temperature, *uncorrected* for spatial and temporal interdependence of the 700-mb data. For overlapping 3-month periods of U.S. mean temperature, as shown on abscissa.

Solid dot—Real data (same as above) *corrected* for data interdependence. (DJF and JJA U.S. mean temperatures, only.)

Line segment—Results from 1000 trials with Gaussian random deviate generator, corrected for data interdependence. (DJF and JJA simulations, only. Level of results indicated by short horizontal lines.)

Hatched area—Amounts by which results from real data exceed results from 1000 trials with random numbers. (DJF and JJA periods, only.)

the overall percentage of area retaining statistical significance, it is obvious in Fig. 6 that except for the winter (DJF) and summer (JJA) three-month periods, only their adjacent overlapping three-month periods (NDJ, JFM, MJJ, JAS) could possibly achieve overall statistical significance at the 95 percent level. Spring (MAM) and Fall (SON), together with *their* adjacent overlapping three-month periods (FMA, AMJ, ASO, OND), obviously would not achieve significance at the 95 percent level. Given the indication from Fig. 5 that the winter (DJF) relation has only marginal significance at the 95 percent level, it appears unlikely that the two overlapping periods adjacent to winter (NDJ and JFM) could achieve overall statistical significance at that level.

In summary, the annual march of overall areal significance between zonally averaged 700 mb height anomalies and surface temperatures in the United States has two peaks—one definitely significant with respect to midsummer mean temperatures, and one marginally significant with respect to midwinter mean temperatures. Intervening troughs occur in spring and fall, with the overall areal significance for those periods even less than to be expected from chance.

These results are qualitatively consistent with indications of predictability from earlier studies. Namias (1952, 1959, 1978) and Walsh and Mostek (1980) have presented evidence of greater month-to-month persistence of temperature and pressure during summer than during other seasons. Namias (1952) also noted a tendency for minimum month-to-month persistence of temperature for October–November and April–May. Madden (1977) has shown that there is greater potential predictability of temperature in summer than in winter, due to less natural variability or climate noise during summer.

Since the signs of the individually significant coefficients with respect to both winter and summer (Fig. 3) are overwhelmingly positive, it might be expected that lag relations between the hemispheric average 700 mb height anomaly and mean winter and summer temperatures in the United States likewise would be predominantly positive. Fig. 7 shows that to be true. In fact, the positive nature at nearly all individual latitudes in Fig. 3 yields hemispheric average correlations that are generally larger than most of the corresponding zonally averaged values. For negative lags in Fig. 7 (hemispheric mean anomaly leading mean temperature), the winter relation is more consistently positive

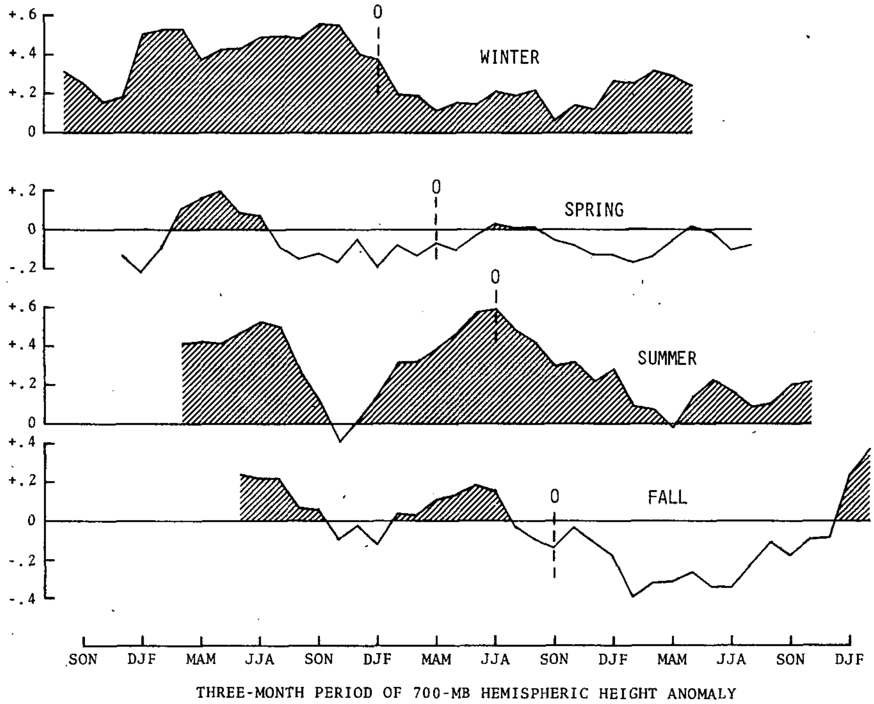

FIG. 7. Lag correlations (scales at ordinate) between 700 mb mean height anomalies for the Northern Hemisphere (20°N–Pole) and mean surface air temperatures for the United States for each of the four seasons. Three-month means, all quantities; annual cycles removed. Correlations are plotted for lags of −16 to +16 months, with the position of zero lag indicated on each graph. Abscissa indicates period of the 700 mb anomaly. Periods to the left of zero lag denote 700 mb anomaly *leading* the seasonal mean temperature in the United States. Areas of positive correlation are shaded.

than the summer relation. However, the latter attains a higher peak at zero lag.

5. Postscript

Recent data indicate that the winter of 1982–83 has been the third warmest winter, nationwide, since 1948 and the warmest since 1953–54. It is interesting to assess this recent warm winter against results from the present study, specifically Figs. 3 and 7. However, direct comparisons are not possible, but one can plot the time series of the running 3-month 700 mb height anomalies and qualitatively compare those patterns with the left halves of Figs. 3 and 7 (winter portions of both figures).

The time–latitude distribution of the zonally averaged 700 mb anomalies, when compared with Fig. 3 for winter, shows both areas of agreement and areas of disagreement. Nevertheless, the overall distributions are positive in both cases. The time series of hemispheric anomalies for the period September 1981–January 1983 is overwhelmingly positive (13 of the 17 overlapping 3-month periods). Therefore, qualitative agreement with Fig. 7 is quite good, overall. Two of the four negative 3-month anomalies are for the two most recent 3-month periods—November–December–January and December–January–February 1982–83.

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