

## NOTES AND CORRESPONDENCE

## Geographical Distribution and Seasonality of Month-to-Month Correlation of Monthly Mean 700 mb Heights

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## ABSTRACT

A description is given of the geographical and seasonal distribution of month-to-month correlation of anomalies in monthly mean 700 mb height. The data base is 33 years (1949–81), covering the area poleward of 20°N. In general, correlations are high (0.3 or more) in low latitudes and low (0.0–0.2) in midlatitudes. The correlation is positive nearly everywhere in all seasons and there is little evidence that antipersistence occurs at any other season or place than in spring over the United States and the Atlantic Ocean. Although low, the month-to-month correlation in midlatitudes shows clear seasonality with maxima shortly after the solstices and minima in spring and fall.

## 1. Introduction

Knowledge of month-to-month correlation of anomalies in time-averaged atmospheric quantities may be helpful in producing long-range weather forecasts. Furthermore such correlations are quite interesting for their own sake because they indicate a fundamental characteristic—the damping time scale of anomalies. Therefore, it is important to document both the geographical distribution and the seasonality of such month-to-month correlation from observations. In this note we will be concerned with monthly mean 700 mb height over most of the Northern Hemisphere.

## 2. Data and calculations

The dataset consists of 33 years of monthly mean 700 mb height ( $H$ ) in a grid representation over the area north of 20°N.<sup>2</sup> The period is from January 1949 up to and including January 1982. The monthly means are based on twice daily analyses made at the National Meteorological Center (NMC), Washington, DC. The data over the oceans, low latitudes and Asia are likely to be poor in the earlier part of the period; data representativeness is also problematical over the highly elevated Himalayan Plateau. Other problems arising from changes in analysis procedures have been discussed by Wahl (1972).

For each grid point and two adjacent months (say  $i$  and  $j$ ) time series of  $H$  are available with a record length of 33. The correlation is defined here by

$$\rho_{ij} = \frac{\frac{1}{33} \sum_{k=1}^{33} (H_{i,k} - \bar{H}_i)(H_{j,k} - \bar{H}_j)}{\left[ \frac{1}{33} \sum_{k=1}^{33} (H_{i,k} - \bar{H}_i)^2 \frac{1}{33} \sum_{k=1}^{33} (H_{j,k} - \bar{H}_j)^2 \right]^{1/2}},$$

where  $H_{i,k}$  is the monthly mean 700 mb height in month  $i$  of year  $k$  and  $\bar{H}_i = \left(\frac{1}{33}\right) \sum_{k=1}^{33} H_{i,k}$  and so on.

The correlation shows essentially how quickly (or slowly) an anomaly at a given location tends to disappear. The  $H$  time series were not detrended.

The correlations were determined at each of the grid points for 24 pairs of neighboring months, i.e., for January/February, mid-January–mid-February/mid-February–mid-March, and so on. We denote this by J/F, MJ/MF, F/M, . . . . The results were then averaged to form four seasonal means of month-to-month correlation. Symbolically: Winter = (N/D + MN/MD + D/J + MD/MJ + J/F + MJ/MF + F/M)/7; Spring = (F/M + MF/MM + M/A + MM/MA + A/M + MA/MM + M/J)/7, etc. A yearly mean was obtained, again gridpointwise, by averaging over 24 individual estimates (J/F, MJ/MF, F/M, . . . , MD/MJ). The advantage of using 24 neighboring months, rather than the more natural 12, is an increase of statistical reliability in any of the four seasonal mean and one yearly mean maps. The autocorrelation of  $H$  at lag 1 month is small (as we shall see) and therefore a more dense sampling of  $H$  (in time) adds information.

## 3. Results

## a. Spatial distribution

The results are shown in map form (Fig. 1) for the year and the four seasons (Figs. 2–5). For individual

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<sup>2</sup> Grid points are spaced every 5° of latitude and 10° of longitude with points on adjacent latitude circles staggered by 5° longitude.

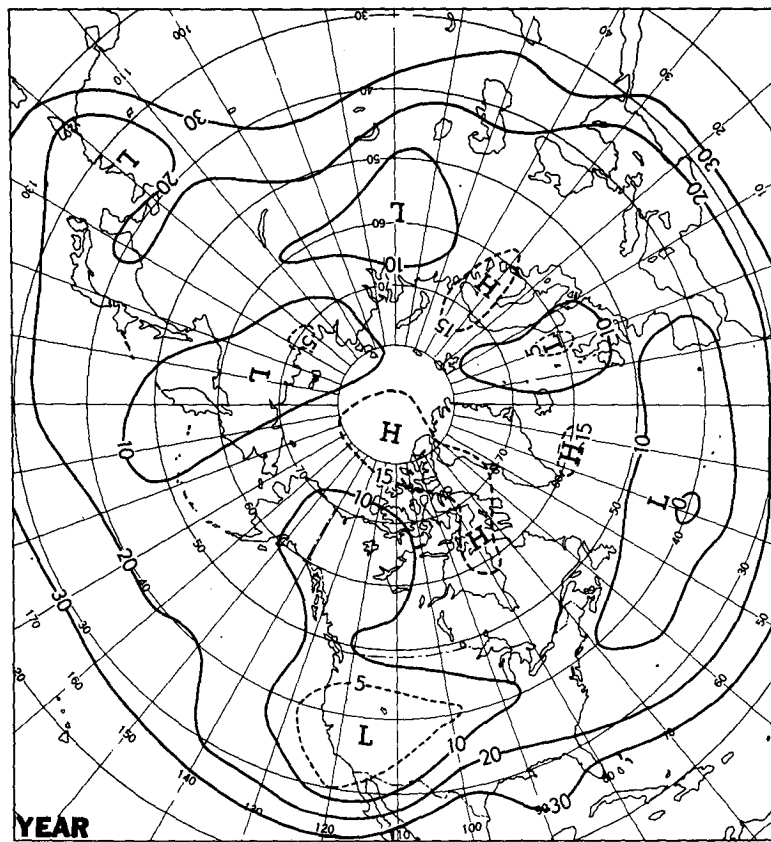


FIG. 1. The yearly mean of the month-to-month correlation ( $\times 100$ ) of anomalies in the monthly mean 700 mb height. Isopleths are drawn at intervals of 10; the unit is percent (dimensionless). Isopleths higher than 30 at low latitudes are omitted.

lagged pairs (J/F say) the noise-level is very high. An estimate for the standard deviation of averaged correlation is given approximately by  $1/[N(M-2)]^{-1/2}$  (c.f., Panofsky and Brier, 1968), where  $M$  is the number of years (33) and  $N$  the effective number of elements in the average. With  $N = 1$  the uncertainty (plus and minus two standard deviations) is  $\pm 0.36$ . By averaging over a whole season ( $N$  at least 3) or over a whole year ( $N$  at least 12), we can reduce this uncertainty to at least  $\pm 0.21$  and  $\pm 0.10$ , respectively. Even then, only the very largest scale features of these maps (especially for the seasonal averages) can be resolved with confidence.

The yearly averaged map shows the following features:

1) The correlation is larger than zero at all grid points (with a minor exception at  $40^\circ\text{N}$ ,  $40^\circ\text{W}$ ). In other words, anomalies may damp differently at different places, but there is no indication of systematic antipersistence over the entire year.

2) The correlation decreases with latitude when going from the subtropics to the midlatitude. The  $\rho = 0.2$  isopleth straddles  $\phi = 30^\circ\text{N}$ , except over central

Asia where it reaches  $\phi = 50^\circ\text{N}$ . To the north of this isopleth all values of  $\rho$  are small ( $0 < \rho < 0.2$ ), but definitely larger than zero. 3) Within the vast low-correlation area in the middle and high latitudes,  $\rho$  is not uniform, but it is hard to say whether the spatial variations are real.

The four seasonal maps (Figs. 2–5) show the following characteristics:

1) In all seasons at almost all grid points the correlation seems to be larger than zero with the exception of a fairly large belt straddling  $\phi = 40^\circ\text{N}$  from  $130^\circ\text{W}$  to  $10^\circ\text{E}$ , where the correlations go down to  $-0.1 < \rho < 0$  in the spring.

2) In all seasons the correlation decreases with latitude in somewhat the fashion described in the yearly mean. There is a suggestion, however, that north of  $\phi = 75^\circ\text{N}$  the correlations go up again to reach a maximum at the pole of about 0.2.

3) To the north of the nearly circumpolar  $\rho = 0.2$  isopleth, there are two areas where  $\rho$  is locally extreme throughout all seasons: first, an area of low  $\rho$  over western North America near  $30\text{--}40^\circ\text{N}$ ; and a second

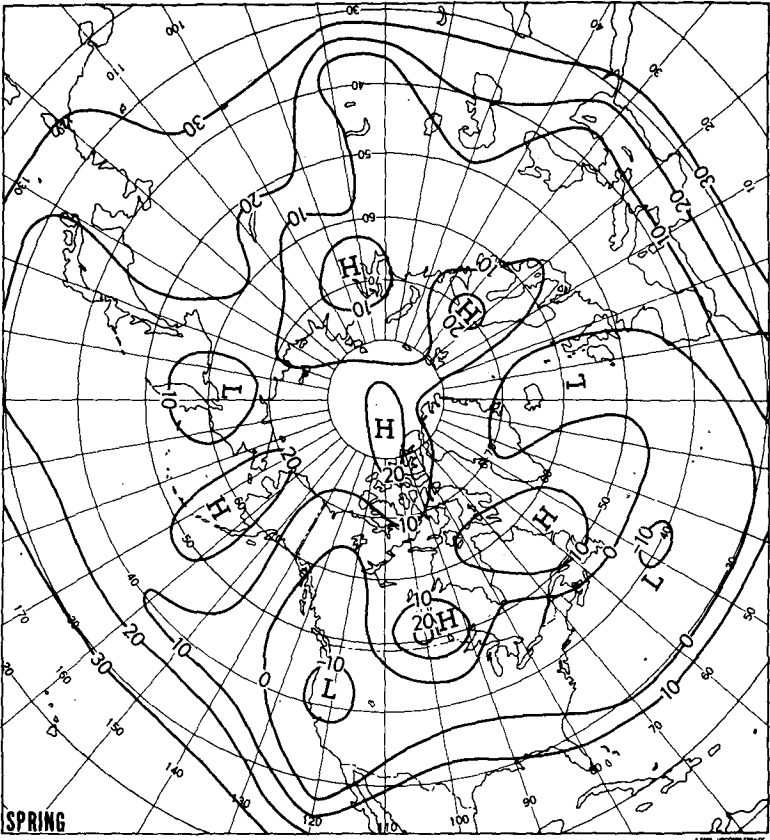


FIG. 2. As Fig. 1, but for spring.

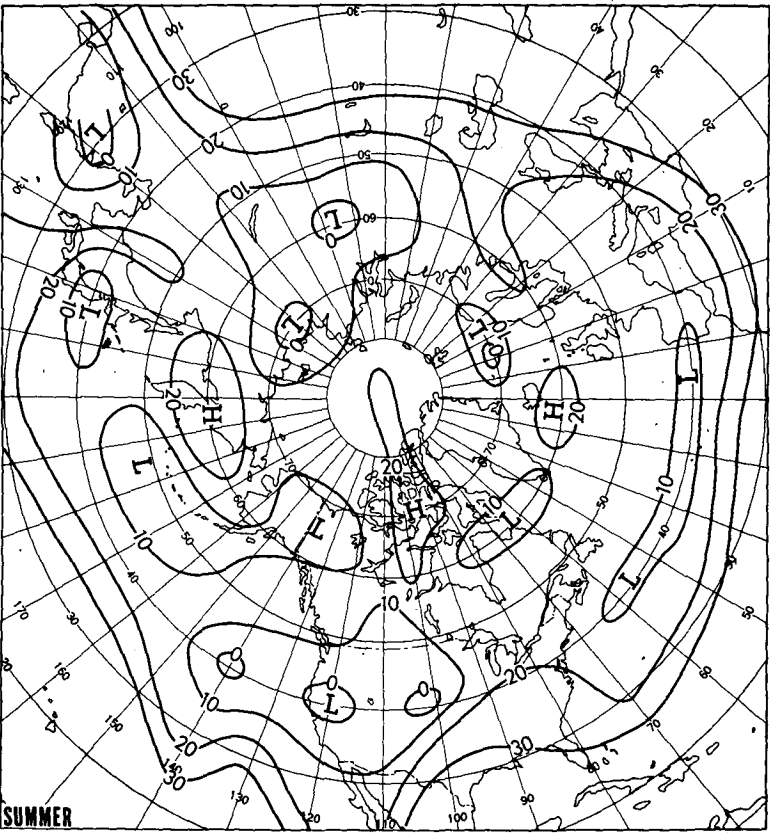


FIG. 3. As Fig. 1, but for summer.

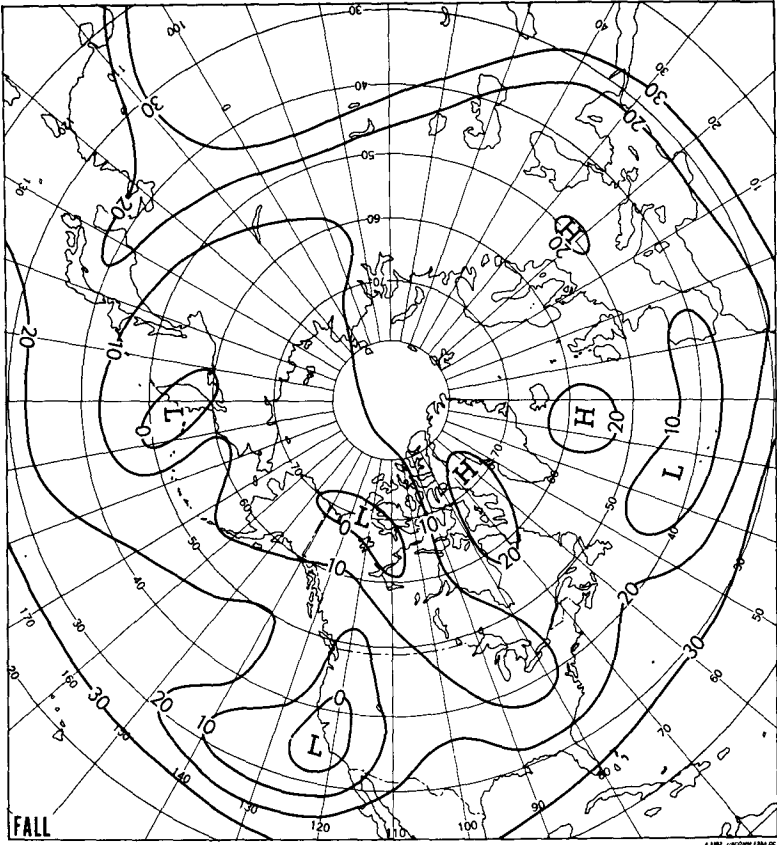


FIG. 4. As Fig. 1, but for fall.

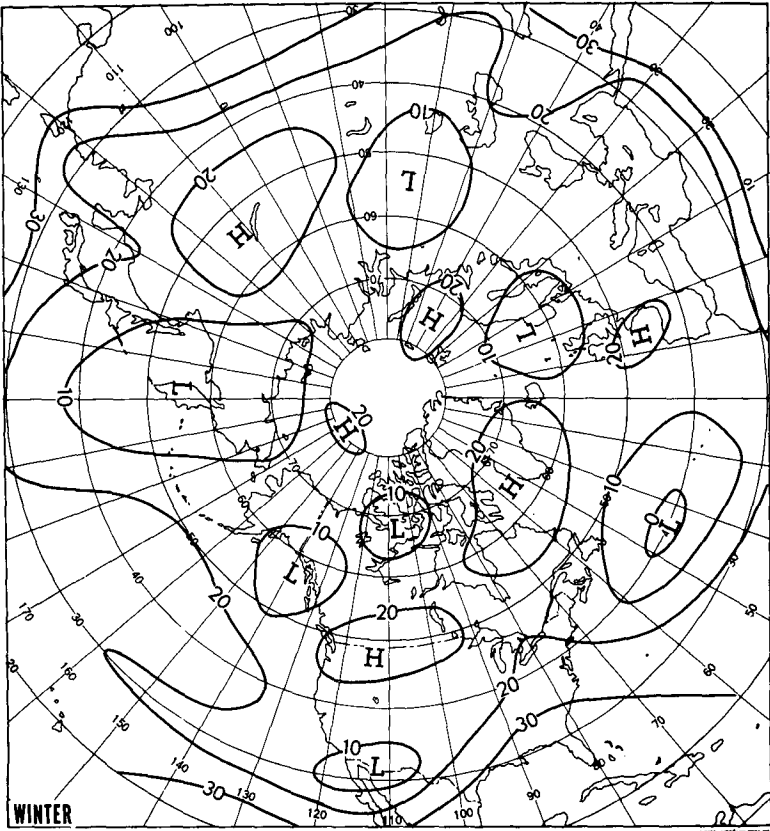


FIG. 5. As Fig. 1, but for winter.

area of low  $\rho$  along  $\phi = 40^\circ\text{N}$  over the Atlantic Ocean. All other features north of  $\phi = 30^\circ\text{N}$  in the yearly map are not consistently present in all of the seasonal maps.

### b. Seasonality

In order to bring out seasonality in the midlatitude we now consider the belt between  $37.5$  and  $72.5^\circ\text{N}$ . For each of the individual cases,  $\rho_{ij}$  was averaged over all grid points in the sectors  $0-80^\circ\text{W}$ ,  $90^\circ\text{W}-170^\circ\text{W}$ ,  $180^\circ\text{E}-100^\circ\text{E}$ ,  $90^\circ\text{E}-10^\circ\text{E}$ , and all around. Fig. 6 shows the value of these spatially smoothed  $\rho_{ij}$  as a function of the time of the year. The dashed line shows the same calculations for 1000 mb height (for the same 33 years and the same areas).

Again the uncertainty (plus and minus two standard deviations) in  $\rho_{ij}$  is estimated by  $\pm 2/\sqrt{N(M-2)}$ , where  $M$  is 33 and  $N$  is now the number of independent grid points per sector. The latter should be at least 9 for a sector and 35 for the whole strip. Livezey and Chen

(1983) found  $N \approx 35-55$  for seasonally averaged 700 mb height anomalies from almost the identical dataset. These data should be smoother spatially than their monthly averaged counterparts, so the estimates for  $N$  given above are probably conservative. With these estimates the uncertainties for a sector or the whole strip become  $\pm 0.12$  and  $\pm 0.06$ , respectively.

When zonally averaged over the whole strip (Fig. 6e),  $\rho_{ij}$  shows maxima shortly after the solstices and minima in the transitional seasons, the minimum in spring being the deeper. For each of the four sectors (Figs. 6a-d) this behavior is less obvious. For example, sectors b and c show a lot of ups and downs but no clear seasonality. The seasonality of  $\rho$  is shown clearest in sectors a and d (western Atlantic to central Asia). The 1000 mb (dashed) and 700 mb (solid) results follow one another very closely throughout the year.

### 4. Discussion

In the midlatitudes smoothed (over a season) month-to-month correlations of 700 mb monthly mean heights definitely are mostly positive.<sup>3</sup> However, the correlations are so low that little or no variance of the coming month can be captured; explained variances in no case exceed 7%. It is not impossible, though, that individual month-to-month correlations are actually higher than suggested by the four maps. For example, areas of extreme  $\rho$  on individual maps are in different locations but there is no way to conclude whether these shifts are significant from the present data base of 33 years.

The only season where month-to-month correlation may be negative is spring. A fairly large area from  $140^\circ\text{W}$  to  $0^\circ\text{W}$  near  $40^\circ\text{N}$  shows antipersistence in the dataset that we considered. It apparently is strong enough that Erickson (personal communication, 1983) also detected it for spring in the midlatitudes in lag correlations of zonally averaged 700 mb heights (for the 1948-80 period).

South of roughly  $\phi = 30^\circ\text{N}$ , the correlations are much larger than farther north. At many grid points  $\rho$  exceeds 0.5. Even though the data in low latitudes, especially for the early years, may not be very reliable, this is probably a real feature. It was found in exactly the same way in a similar study of 29 years of 500 mb height analyses prepared in Offenbach (FRG), but this is not a completely independent check of course. Namias (1959) also found a similar variation with latitude, though for seasonal mean 700 mb heights. The strong difference in correlations between the midlatitudes and

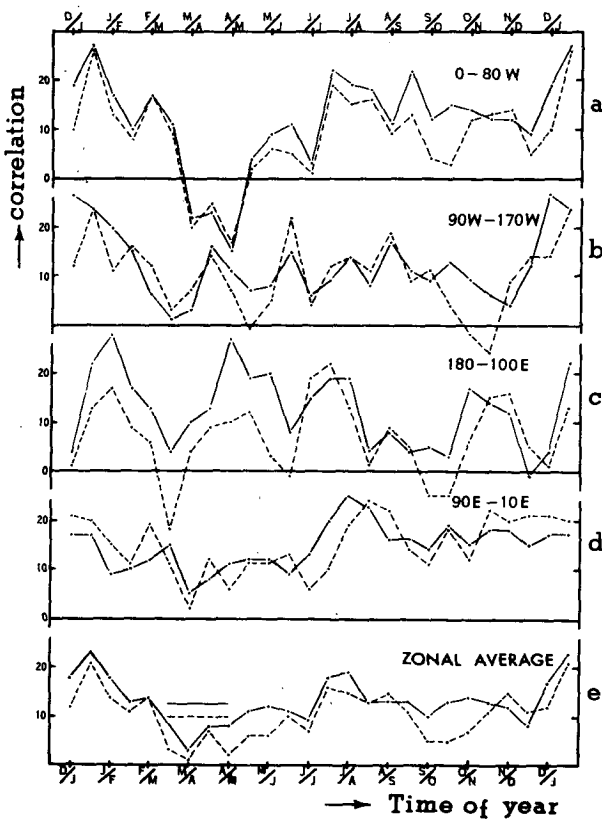


FIG. 6. Area-averaged month-to-month correlation ( $\times 100$ ) of anomalies in the monthly mean 700 (solid) and 1000 (dashed) mb height, as a function of time of year. The area average is taken over (a)  $40^\circ\text{N}-70^\circ\text{N}$ ,  $0^\circ-80^\circ\text{W}$ ; (b)  $40^\circ\text{N}-70^\circ\text{N}$ ,  $90^\circ\text{W}-170^\circ\text{W}$ ; (c)  $40^\circ\text{N}-70^\circ\text{N}$ ,  $180^\circ-100^\circ\text{E}$ ; (d)  $40^\circ\text{N}-70^\circ\text{N}$ ,  $90^\circ\text{E}-10^\circ\text{E}$ ; and (e)  $40^\circ\text{N}-70^\circ\text{N}$ , zonal average. The horizontal lines in (e) indicate the yearly averaged values for 700 and 1000 mb.

<sup>3</sup> Extensive statistical tests (Livezey, 1983) are required to show that there is nonzero correlation in individual monthly maps. Here however, the filtering process of combining a number of maps (7 for the seasonal averages) increases degrees of freedom considerably. Thus rejection of a null hypothesis that month-to-month persistence is zero can be done with confidence with over 80% of the correlations positive in the spring, and practically all of them positive in the other seasons.

the subtropics fits in with estimates of potential predictability of monthly mean surface pressure made by Madden (1976) from observations, and by Manabe and Hahn (1981) from a comparison of observations and the output of a 15-year run with a general circulation model. Both studies have indicated that the potential predictability of monthly means (of surface pressure) decreases with increasing latitude. A low/high month-to-month correlation is consistent with low/high potential predictability of the monthly mean.

A reasonable synoptic picture of the latitudinal distribution of  $\rho$  seems to be the following: in midlatitudes transient disturbances (including blocks) are the most important features of the circulation. Most of the variability in monthly means appears due to these "high" frequency disturbances. However, in lower latitudes (the subtropics) almost-stationary systems dominate the picture. Their time scale seems to be long enough to cause anomalies in monthly means that have a reasonably high correlation from month-to-month. It is not inconceivable that this is a manifestation of the El Niño-Southern Oscillation complex.

The synoptic picture given above is certainly not complete. Comparing correlation of daily values (Gutzler and Mo, 1983) of 500 mb height for winter to our Fig. 5, one can see that month-to-month correlations are not just a reflection of day-to-day correlation. Extremes have moved relative to those in Gutzler and Mo's Figs. 1 and 2 and, more importantly, the month-to-month correlations are much too large in many places (even in the midlatitudes) to be explained from a first-order linear Markov chain of correlated daily values. Shukla and Gutzler (1983) have excluded the intraseasonal periods reflected in these month-to-month correlations in their estimates of "climate noise."

The seasonality of month-to-month correlations of 700 mb (and 1000 mb) heights fits in with results concerning the height of 500 mb, 1000–500 mb thickness and sea-level pressure as reported by van den Dool (1983), and also with results concerning 700 mb heights for the years 1933–52 over the United States and adjacent areas by Namias (1952); i.e., anomalies in circulation parameters are most persistent shortly after the solstices and least persistent in the transitional seasons. van den Dool (1983) computed pattern correlation coefficients rather than correlations per grid point but it appears that a spatial average of grid-point correlations is almost the same as the multiyear mean of pattern correlations calculated per year. In that paper the seasonality of  $\rho$  was explained from linear dynamic theory. Specifically, anomalies are most (least) persistent if the basic state of the atmosphere changes least (most). If the anomalous forcing that causes the atmospheric anomalies is placed in the tropics, we may even anticipate that the spring minimum is more negative than the fall minimum (cf. van den Dool, 1983). A factor that might contribute, in the real atmosphere,

to the deep and long lasting spring minimum is the stability of the air over the sea in spring. A sea surface temperature anomaly (SSTA) overlaid by a stable (warmer) atmosphere cannot be communicated to the free atmosphere; therefore SSTAs in spring may not be that important as a memory external to the atmosphere. While these considerations suggest that month-to-month correlations may be low in spring, they cannot account for the large area of negative correlations at that season over the United States and the Atlantic Ocean.

These negative correlations may have something to do with a 40–50 day traveling disturbance studied by Madden and Julian (1972) and most recently by Anderson and Rosen (1983). However, it is not clear how this global phenomenon could be responsible for the seasonal and areal preference. A plausible kinematic explanation is planetary wave phase adjustments as the midlatitude westerlies decline and the jet axis moves north in the spring. These adjustments might lead to height anomaly reversals on a month-to-month time scale often enough to produce the negative lag correlations. Clearly, the reason for this feature of the lag correlation pattern requires further study.

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