The Seasonal Cycle over the United States and Mexico

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ABSTRACT

The annual cycle occupies a unique position in the spectra of meteorological time series. This cycle and its first three harmonics are extracted from the series as a seasonal cycle. The distributions of the annual and seasonal cycles are studied for the United States and its immediate surroundings, using four years of data.

The results show that the annual and seasonal cycles are extremely important contributors to the observed temperature and wind fields at the 850, 500 and 250 mb levels. In winter, the annual cycle establishes a west wind maximum in the subtropics, quite akin to the winter-average jet stream. The annual cycle in the horizontal wind constitutes a trough over the central parts of the United States in winter and a ridge in the same area in summer.

1. Introduction

The seasonal cycle constitutes an important temporal variation of the atmosphere, as it is the response of the atmosphere at the forcing frequency of one cycle per year. Hence it is legitimate to consider the seasonal cycle to be deterministic and the remaining time variations to be stochastic. Such an approach to the study of meteorological changes has received some attention, as may be seen, for example, from Blackmon (1976), Blackmon *et al.* (1977) and Straus and Halem (1981).

Many of the studies dealing with the seasonal cycle (e.g., van Loon, 1972a,b; Hsu and Wallace, 1976; White and Wallace, 1978) have used harmonics of monthly mean data to derive the annual and semiannual cycles, which are the major components of the seasonal cycle. A disadvantage of this is that the percent of the variance of monthly means explained by the seasonal cycle (van Loon, 1972a) does not indicate the relative importance of the seasonal cycle against the stochastic variations associated with the weather. A determination of the percent variance due to the seasonal cycle by using daily meteorological data would very nearly overcome this problem since, assuming no aliasing, daily data contain all fluctuations with periods greater than 2 days.

The existing analyses of the seasonal cycle have tended to concentrate on the horizontal variations of a few variables, especially near the surface, rather than on the vertical structure of the seasonal cycle. Thus, basic issues such as the relative importance of the seasonal temperature cycle in the upper troposphere remain unexplored. Any amplitude and phase changes of the seasonal temperature cycle in the vertical will affect static stability and may be of use in clarifying the influence of the seasonal cycle in determining the characteristic weather of each season.

It is also essential that numerical models of the atmospheric circulation simulate the seasonal cycle properly. If the seasonal cycle is not simulated properly, then the stochastic fluctuations may also be improperly simulated.

The chief aim of this paper is to indicate systematically the importance of the seasonal cycle in temperature and horizontal wind components at various levels in the lower atmosphere. We have confined ourselves to the immediate neighborhood of the contiguous United States. Nevertheless, we believe that the analyses presented here will serve the essential purpose of further stimulating interest in the seasonal cycle.

In defining the seasonal cycle, we have used the general method of harmonic analysis adopted by many of the previous contributors to this subject. Thus, by the estimated seasonal cycle we mean the sum of the annual cycle and its first three harmonics.

2. Data and analysis technique

The temperature and wind data for this study are taken from the National Meteorological Center (NMC) tropical grid analyses. We have chosen to analyze these data at 850, 500 and 250 mb for the area between 60 and 130°W, and 14.8 and 48.1°N.

There are 15 grid points in the east–west direction and 9 in the north–south direction. Their locations can be inferred from the diagrams. For each of the 135 grid points we performed a harmonic analysis of the series, which consisted of data at 1200 GMT for

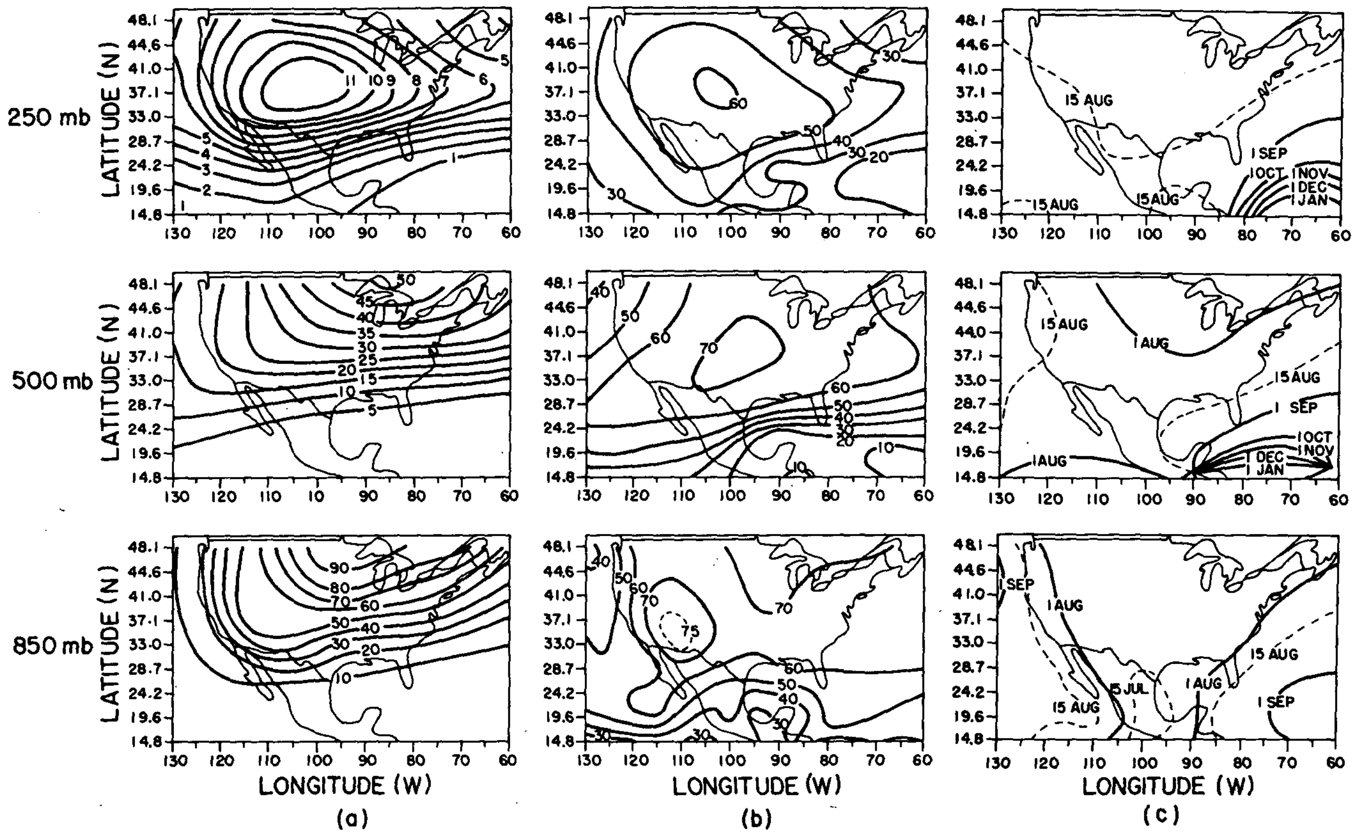

FIG. 1. (a) The variance contained in the estimated seasonal cycle, (b) the percent of total variance in daily data explained by the estimated seasonal cycle, and (c) the date of the maximum in the annual cycle, for temperature. Units of variance are (°C)^2.

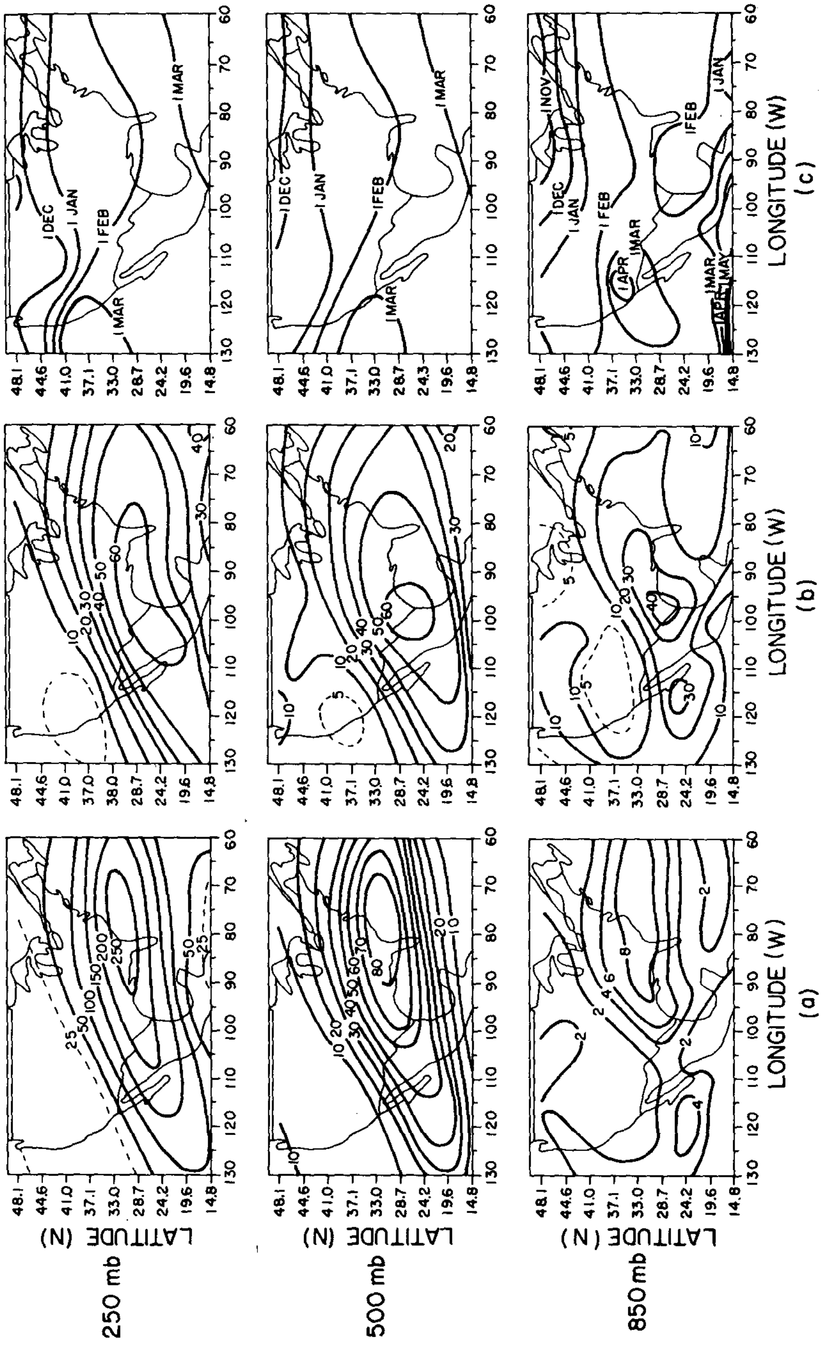

FIG. 2. As in Fig. 1, except for the zonal wind component. Units of variance are $m^2 s^{-2}$.

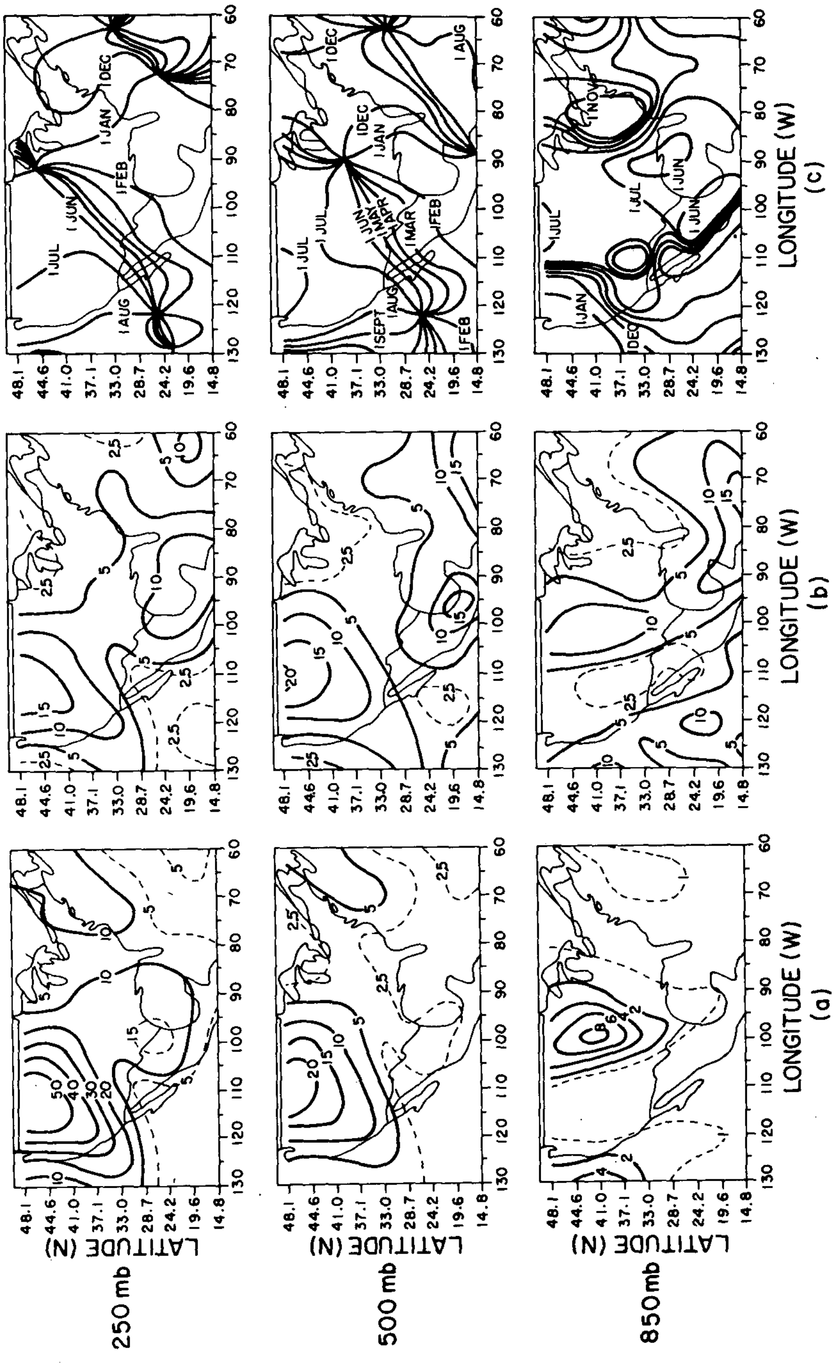

FIG. 3. As in Fig. 1, except for the meridional wind component. Units of variance are $m^2 s^{-2}$.

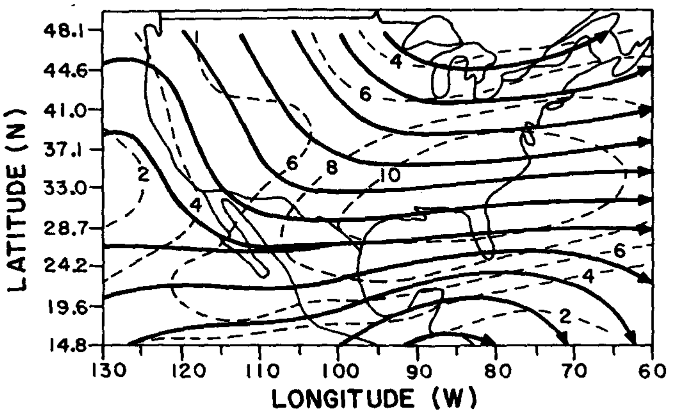

FIG. 4. The 500 mb streamline and isotach analyses of the annual cycle for 1 January. Isotachs are drawn at 2 m s^{-1} intervals.

the period 1 July 1975 to 30 June 1979. The estimated seasonal cycle is defined as the sum of the harmonics 4, 8, 12 and 16, with the first of these being the annual cycle.

We calculated the variance contained in the estimated seasonal and annual cycles for each grid point; in each case, the percent of total variance in daily data explained by each of these cycles was also calculated. In addition, for the annual cycle, we calculated the phase, indicated by the date on which the maximum in the cycle occurs.

3. Results and discussion

The harmonic analysis revealed that in those regions where a substantial seasonal cycle occurs, nearly all of the seasonal cycle variance is contained in the annual cycle. Since the patterns of variance and of percent variance explained are nearly the same for the estimated seasonal and annual cycles, we will present only those for the seasonal cycle. However, on account of the dominance of the annual cycle, its phase will be shown together with the variance of the seasonal cycle.

Fig. 1a contains the variance due to the seasonal temperature cycle.The isopleths of constant variance follow the continental coastline, except along the Atlantic coast. This resembles the pattern that the annual range of surface temperature possesses (see Rumney, 1968, p. 92 and Monin, 1975). Thus the continent–ocean differences along the West Coast extend through the depth of the troposphere. However, the variance in the seasonal cycle diminishes with altitude. This indicates that the overall static stability of the troposphere is controlled primarily by temperature changes in the vicinity of the surface. Further, assuming there are only small changes in phase with increasing height, the reduction in variance with height means an increased lapse rate in the summer and an increased static stability in the winter.

The percent of the total variance in daily temperature data, which is explained by the seasonal cycle,

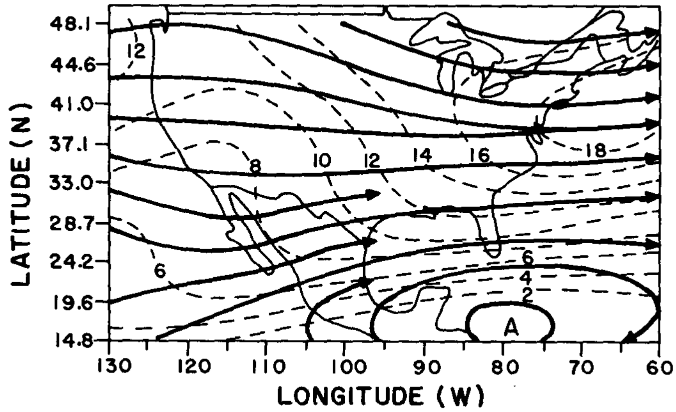

FIG. 5. The 500 mb arithmetic mean flow for the period 1 July 1975 to 30 June 1979. Isotachs are drawn at 2 m s^{-1} intervals.

is contained in Fig. 1b. Over the United States this percent is quite high at all levels, although it decreases slightly from 500 to 250 mb.

The annual temperature cycle reaches its maximum earlier over the central portion of the continent at all levels, as seen from Fig. 1c. However, everywhere in Fig. 1c the dates are later than the summer solstice. Thus the thermal response of the atmosphere to the solar radiative forcing is always a delayed one. The delay is least at 850 mb, and increases with altitude. Since the earth's surface acts radiatively as a blackbody, the continental boundary layer may be expected to respond with a minimum delay to the seasonal changes in solar altitude. The air above the boundary layer, however, receives its energy indirectly from the earth's surface and the boundary layer, by radiative and convective processes, and therefore the response there to changes in solar altitude is more delayed.

Fig. 2a, representing the variance contained in the seasonal zonal wind cycle, shows a somewhat similar pattern at all three levels, with variance increasing rapidly with height. The pattern in Fig. 2a suggests the importance of the seasonal cycle in the winter mean jet stream, as depicted, for example, in Blackmon and Lau (1980). The percent of total variance explained by the seasonal cycle in the zonal wind (Fig. 2b) resembles Fig. 2a. The percent variance increases from 850 to 500 mb, and remains nearly the same between 500 and 250 mb.

The date of the maximum in the annual cycle of the zonal wind component (Fig. 2c) advances with decreasing latitude. From the position of the isopleth for 1 February and its coincidence with the maxima in Fig. 2a at 500 and 250 mb, it is obvious that the strongest jet associated with the seasonal cycle must occur at this time of the year. From the positions of the other isopleths, it is seen that they are over regions where the seasonal cycle has less variance. This means that the jet associated with the seasonal cycle would be more diffuse for dates away from 1 February. This observation agrees with the changes noted in the monthly and zonally averaged jet (see Oort and Rasmusson, 1971, pp. 234–235).

Data concerning the seasonal meridional wind (v) cycle are presented in Fig. 3. The variance of the seasonal cycle in v (Fig. 3a), at 500 and 250 mb, has much the same pattern, with a maximum over the Rockies; at 850 mb the maximum is over midcontinent. The upper-level distributions are in notable agreement with the expected features of the North American summer anticyclone and the wintertime continental trough. The distribution of variance at 850 mb is different from the distributions at higher levels, perhaps because of the presence of the Rocky Mountains, which intersect the 850 mb surface.

It may be seen by comparing the distributions of Figs. 1a and 2a that the large variance in the seasonal zonal wind cycle over the eastern United States agrees well with the large meridional temperature gradient there. Similarly, the maximum variance in the seasonal meridional wind cycle over the northern Rockies (Fig. 3a), at 500 and 250 mb corresponds with the east–west temperature gradient in this region (Fig. 1a). Therefore it seems that the seasonal wind cycle is in qualitative thermal wind balance.

The percent of total variance explained by the seasonal cycle in v, presented in Fig. 3b, has a pattern quite similar to the variance distribution shown in Fig. 3a.

The phase lines in the annual cycle of v (Fig. 3c) have a more complicated pattern than those shown in Figs. 1c and 2c. Once again, the 500 and 250 mb distributions are alike, but differ from the distribution at 850 mb. It may be noted that the dates on Fig. 3c represent the dates of local maximum *southerlies* associated with the annual cycle. Thus, at 250 mb, one sees a gradual westward shift of southerlies from December to August. Therefore, at the eastern and western continental margins, the meridional wind associated with the annual cycle shifts from northerlies to southerlies in half a year. This is in accord with the existence of a continental trough in the winter and a ridge in the summer.

We have combined the zonal and meridional wind components of the annual cycle to produce streamline and isotach patterns for selected dates. The analysis for 1 January is shown in Fig. 4. On this date the

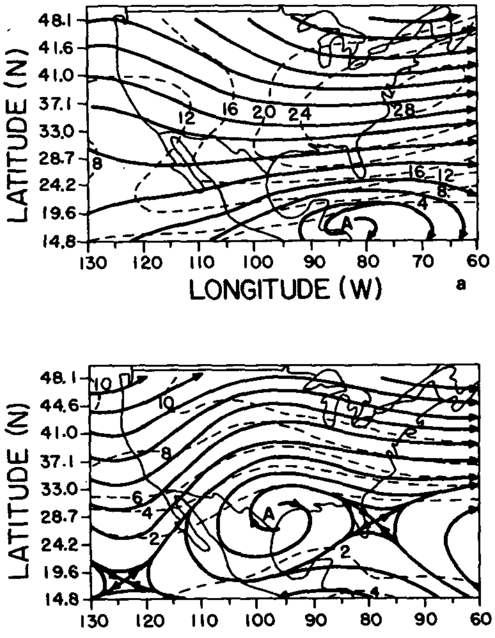

FIG. 6. The 500 mb flow resulting from the sum of the arithmetic mean flow and the annual cycle for (a) 1 January and (b) 1 July. Isotachs are in m s^{-1}.

annual cycle produces a trough which extends from the upper Great Lakes to the southern Rockies. The pattern for 1 July (not shown) is characterized by anticyclonic conditions over the central United States.

Combining the analyses for 1 January and 1 July with the arithmetic mean flow for the entire four-year period (Fig. 5), we obtain the analyses shown in Fig. 6. It is evident that the annual cycle plays an important role in producing a winter trough and a summer ridge over the central portions of the United States. These features may be considered as stationary or standing eddies and are clearly manifestations of the atmospheric response at the frequency of solar thermal forcing.

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