Climatology of 500 mb Cyclones and Anticyclones, 1950–85

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ABSTRACT

The geographical and monthly frequencies of 500 mb cyclones and anticyclones in the National Meteorological Center analyses over the western half of the Northern Hemisphere are investigated for the period 1950–85. These cyclones and anticyclones, defined by the appearance of at least one closed (approximately) 6-dekameter contour around relatively low or high heights in the 500 mb height field, are generally observed less than ten percent of the time in any 10° by 10° latitude–longitude quadrangle, with cyclones being more numerous than anticyclones. The 500 mb cyclones are found primarily at middle and high latitudes, while anticyclones are observed most frequently over the subtropics. Cyclone frequency increases over the northern oceanic regions during summer, while anticyclone frequency increases throughout the subtropics during summer, especially over southwestern North America. Exceptions to these rules are observed; relatively high springtime 500 mb anticyclone frequency is found over the northeastern Atlantic Ocean while relatively high 500 mb cyclone frequency is found over the central subtropical Pacific Ocean and near Alaska during summer, southwestern North America during winter, and near southwestern Europe throughout the year. Abnormally strong diffluent flow over southwestern North America is suggested as an antecedent condition for 500 mb cyclogenesis in this same region. The correlation between 500 mb cyclone frequencies and 300 mb westerly momentum transports is also investigated, revealing that 500 mb cyclones may be associated with the convergence of westerly momentum into the 300 mb westerly jet. Finally, temporal trends in the frequencies indicate that 500 mb cyclone frequencies declined from 1950 through 1970 but increased from 1971 through 1985, while 500 mb anticyclone frequencies declined from 1950 through 1985.

1. Introduction

The climatology of surface cyclones and anticyclones has been well documented in the scientific literature. Geographical and seasonal frequencies of cyclones and anticyclones on different space and time scales have been presented by Hosler and Gamage (1956), Klein (1958), Reitan (1974), Colucci (1976) and Zishka and Smith (1980), while Hayden (1981a) has examined temporal trends in surface cyclone frequencies.

Similar attention, however, has not been systematically directed to the study of cyclones and anticyclones found *above* the earth's surface, i.e., in the geopotential height fields on constant pressure surfaces aloft. These systems are important because they may be arranged in blocking patterns, which are of considerable interest from both scientific and forecasting perspectives. The traditional view of a blocking pattern is one of a split in the zonal westerlies, for example, at 500 mb, around a high latitude anticyclonic ridge aligned meridionally with a lower latitude cyclonic trough. A block may be defined quantitatively by the persistence of such a split (Rex 1950; Sumner 1954; Lejenas and Okland 1983); if this circulation feature is stationary and persistent it will obstruct the normal zonal progression of smaller-scale disturbances associated with daily weather events. Usually, but not necessarily, an anticyclonic vortex evolves in the northern portion of the block, coincidentally with one or more lower latitude cyclonic vortices. In fact, some definitions of blocking (e.g., Treidl et al. 1981) require the persistence of closed height contours around this anticyclonic vortex in order for the split to be regarded as a block.

While the structure, climatology and dynamics of blocking patterns have been the subjects of numerous investigations, comparatively little is known about the

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TABLE 1. Contour intervals during the study.

Period	Time of analysis (UTC)	Contour interval
Jan 50–Jun 57	1500	200 ft
Jul 57–Dec 58	1200	80 m
Jan 59–Feb 63	1200	200 ft
Mar 63–Jun 71	1200	60 m
Jul 71–Dec 85	0000	60 m

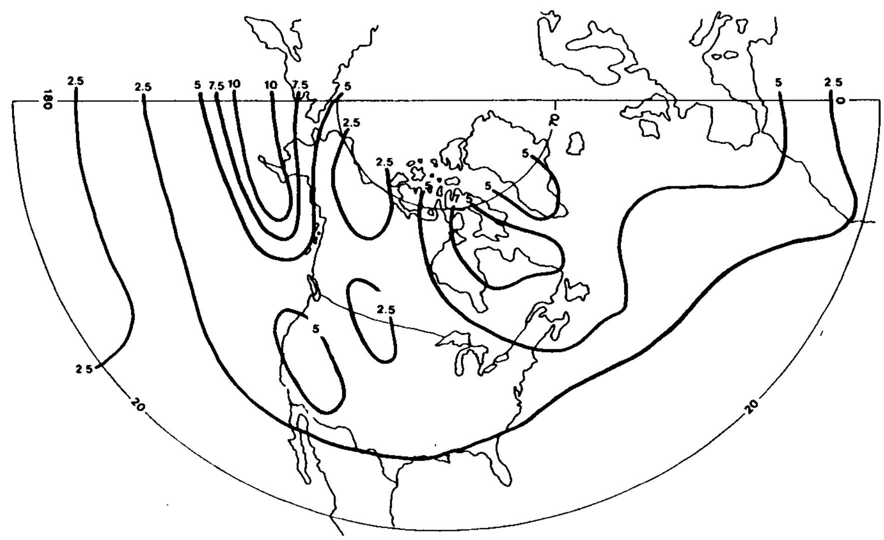

FIG. 1. Percentage of days in which 500 mb cyclones were observed in each 10° by 10° quadrangle, 1950–85.

larger class of generic 500 mb cyclones and anticyclones, the more persistent of which may in some cases be regarded as blocks. It is therefore the purpose of this paper to document the seasonal and geographical frequency distributions of these 500 mb cyclones and anticyclones in order to better understand their nature. This climatology will be constructed from a 36-year record of daily 500 mb heights over the Northern Hemisphere. Regions and times of high 500 mb cyclone or anticyclone frequencies will be contrasted with spatial and temporal maxima in surface cyclone and anticyclone frequencies. Antecedent conditions are examined for the formation of 500 mb cyclones in one such maximum frequency region. The correlation between 500 mb cyclone frequencies and 300 mb westerly momentum transports is also investigated.

2. Data

A 500 mb cyclone or anticyclone in this study is defined by the existence of at least one closed (approximately) 6-dekameter height contour around low or high heights, respectively, on the once daily National Meteorological Center Northern Hemispheric 500 mb analyses from 1950 through 1985. The contour interval and time of analysis varied during the period of study

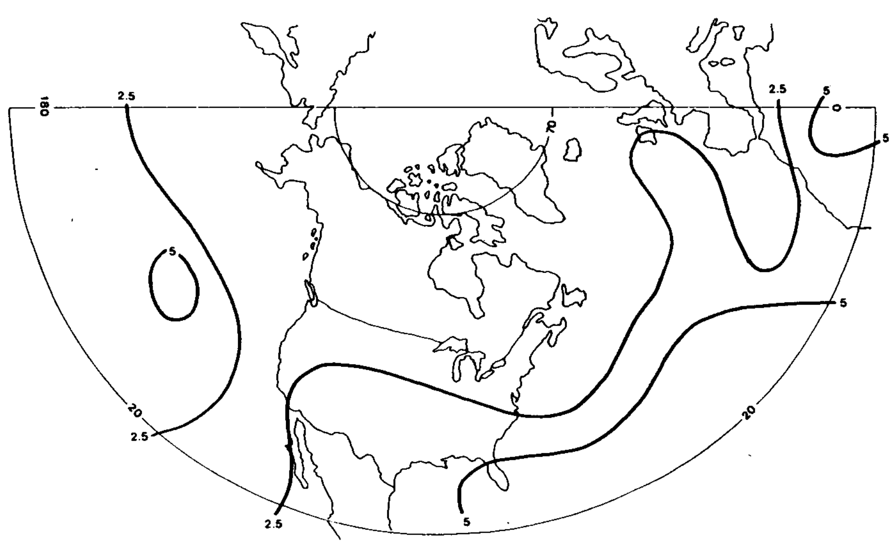

FIG. 2. As in Fig. 1, except for 500 mb anticyclones.

(see Table 1). Through 1970, the data were obtained from the once-daily hand-drawn 500 mb maps in the Daily Synoptic Chart Series. From January 1971 through December 1985, the twice-daily objectively analyzed Northern Hemispheric 500 mb maps, available on microfilm and from the facsimile circuit, were used for data. The 0000 UTC analysis time was chosen since facsimile maps were more frequently missing at 1200 UTC. No systematic difference was found between results obtained from 1200 versus 0000 UTC analyses in a sample period investigated (1971).

The data were tabulated on a grid extending from 20° to 70°N latitude and from 180° eastward to 0° longitude, divided into 10° by 10° grid quadrangles. The tropics and Arctic were excluded, following most surface cyclone and anticyclone climatologies (e.g., Zishka and Smith 1980). System location was taken to be the geometric center of the innermost closed height contour, regardless of the analyzed height center (when available). Systems centered directly on longitude boundary were included in the quadrangle to the east and those centered directly on a latitude boundary were included in the quadrangle to the south, following the procedure of Hawes and Colucci (1986). No consideration is given to the persistence of these systems in our cyclone/anticyclone definition. The number of days with a center in each grid quadrangle was then summed over all days in each month, with separate sums constructed for cyclones and anticyclones. The monthly totals were then each summed over the entire period (i.e., all Januarys, Februarys, etc.) for both cyclone and anticyclones. A total grid cell frequency, summed over all months for each type of system, was also constructed.

3. Results

Total 500 mb cyclone and anticyclone frequencies during the period of investigation are presented in Figs. 1 and 2. Note that the frequencies are not area normalized, since this introduces a latitudinal bias to the data (Ballenzweig 1959; Hayden 1981b). Specifically, dividing the raw frequencies in each 10° quadrangle by the quadrangle area, then multiplying by the area of a midlatitude grid, artificially increases the high latitude frequencies while decreasing the low latitude frequencies. Instead, the frequencies are analyzed as the number of events per 10° latitude–longitude quadrangle. It is readily seen that 500 mb cyclones are, in general, more frequently observed than 500 mb anticyclones. In particular, cyclones are more commonly found than anticyclones at middle and high latitudes, while the opposite is true in the subtropics.

Principal geographical maxima in 500 mb cyclone frequency are found near the Aleutian Islands and over northeastern Canada. A secondary maximum is found over southwestern North America. Relatively high frequency is also observed over the northeastern Atlantic Ocean. The 500 mb cyclones are least frequently found over the subtropical oceans and over northwestern North America.

Maximum 500 mb anticyclone frequencies are observed over the subtropical Atlantic and midlatitude Pacific, with a poleward extension over the Atlantic Ocean toward the British Isles. Minimum 500 mb anticyclone frequency is found over northern and central North America, at low latitudes over the eastern oceans and the northern oceanic regions.

Considerable month-to-month variability in 500 mb cyclone and anticyclone frequencies is observed; these monthly frequencies for the period of investigation are presented in Figs. 3 and 4. The cyclone frequency maximum over the northeastern Pacific Ocean is observed throughout the year, increasing in magnitude from January to a peak frequency in May, June and July then decreasing thereafter except for a secondary maximum in September and October. Cyclones at 500 mb over southwestern North America, on the other hand, are most frequently observed in May and October, with minimum frequencies noted in February and during the summer. The autumnal peak represents an inland shift of the oceanic 500 mb cyclone frequency maximum. The frequency maximum over northeastern Canada shifts southeastward to the Canadian Maritimes from January to March, then eastward over the Atlantic by May. Relatively high 500 mb cyclone frequency returns to northeastern Canada during the summer, persisting along with north Atlantic maximum, for the rest of the year. A frequency maximum is also observed near Spain from October through April. Cyclone frequency minima over northwestern North America and the subtropical oceans are roughly constant throughout the year, except for relatively high frequency over the mid-Pacific during the summer, possibly reflecting tropical cyclone activity. Examination of the frequency data for individual years reveals qualitatively similar patterns from one month in one year to the same month the next year, suggesting that these are robust findings.

Inspection of Fig. 4 reveals that 500 mb anticyclones are more numerous during the warm season than during the cold season, although this could be due to the northward migration of anticyclones from south of 20°N rather than new anticyclones being generated within the domain. This seasonal contrast is particu-

FIG. 3. Percentage of (a) Jan, (b) Feb, (c) Mar, (d) Apr, (e) May, (f) Jun, (g) Jul, (h) Aug, (i) Sep, (j) Oct, (k) Nov and (l) Dec days in which 500 mb cyclones were observed in each 10° by 10° quadrangle, 1950–85. Areas within zero contours experienced no 500 mb cyclones.

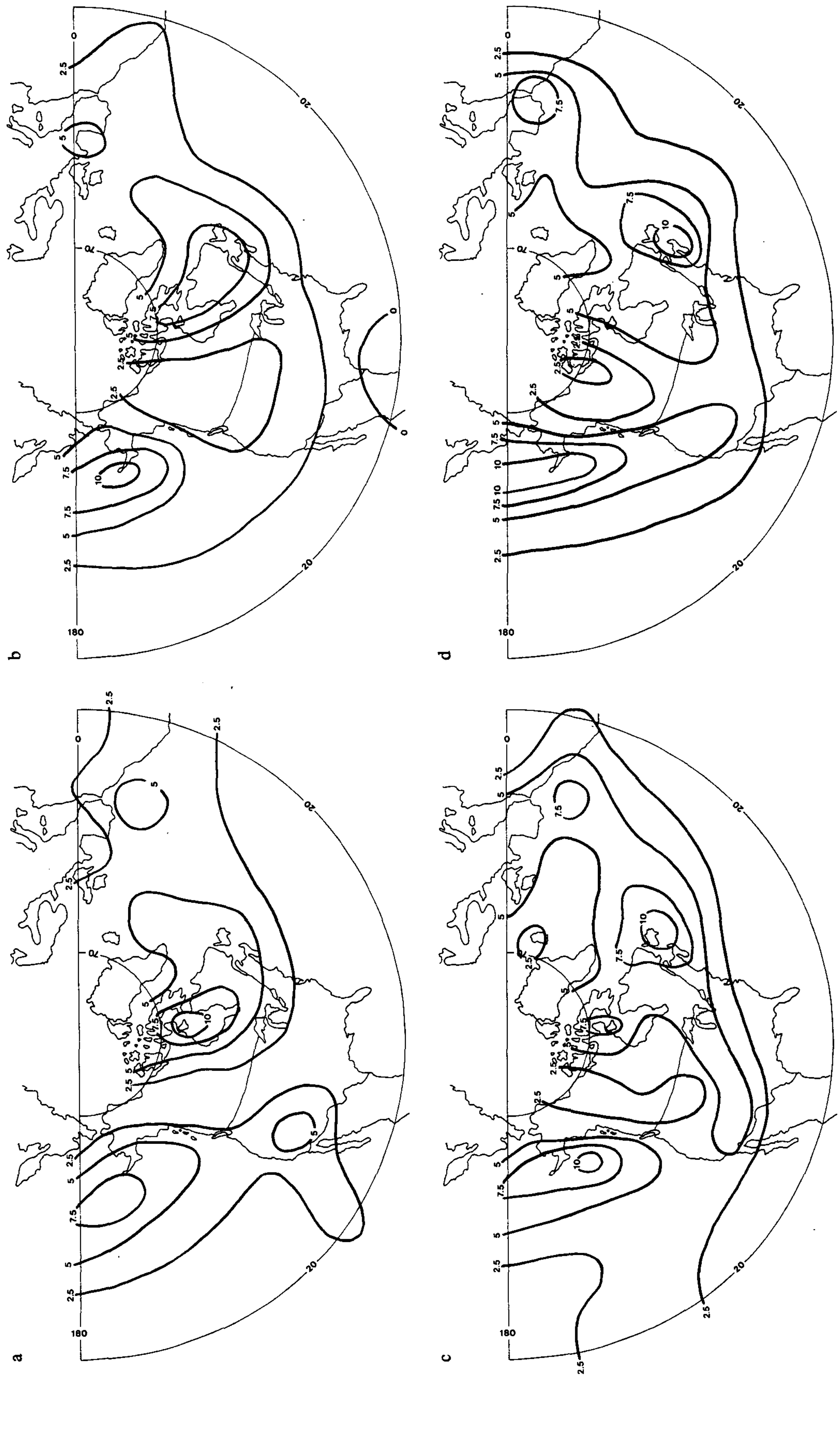

FIG. 3. (a) Jan–(d) Apr.

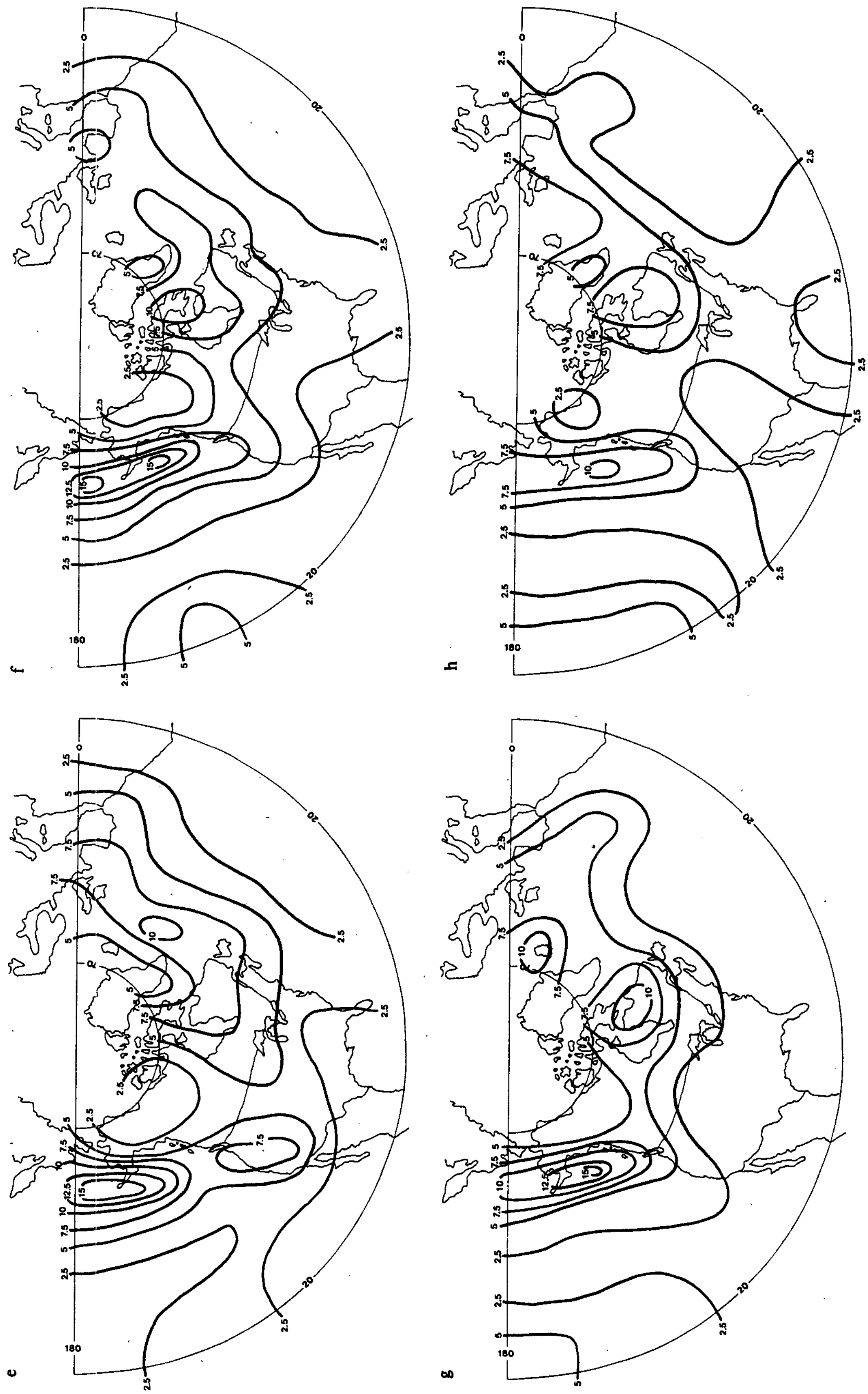

FIG. 3. (*Continued*) (e) May–(h) Aug.

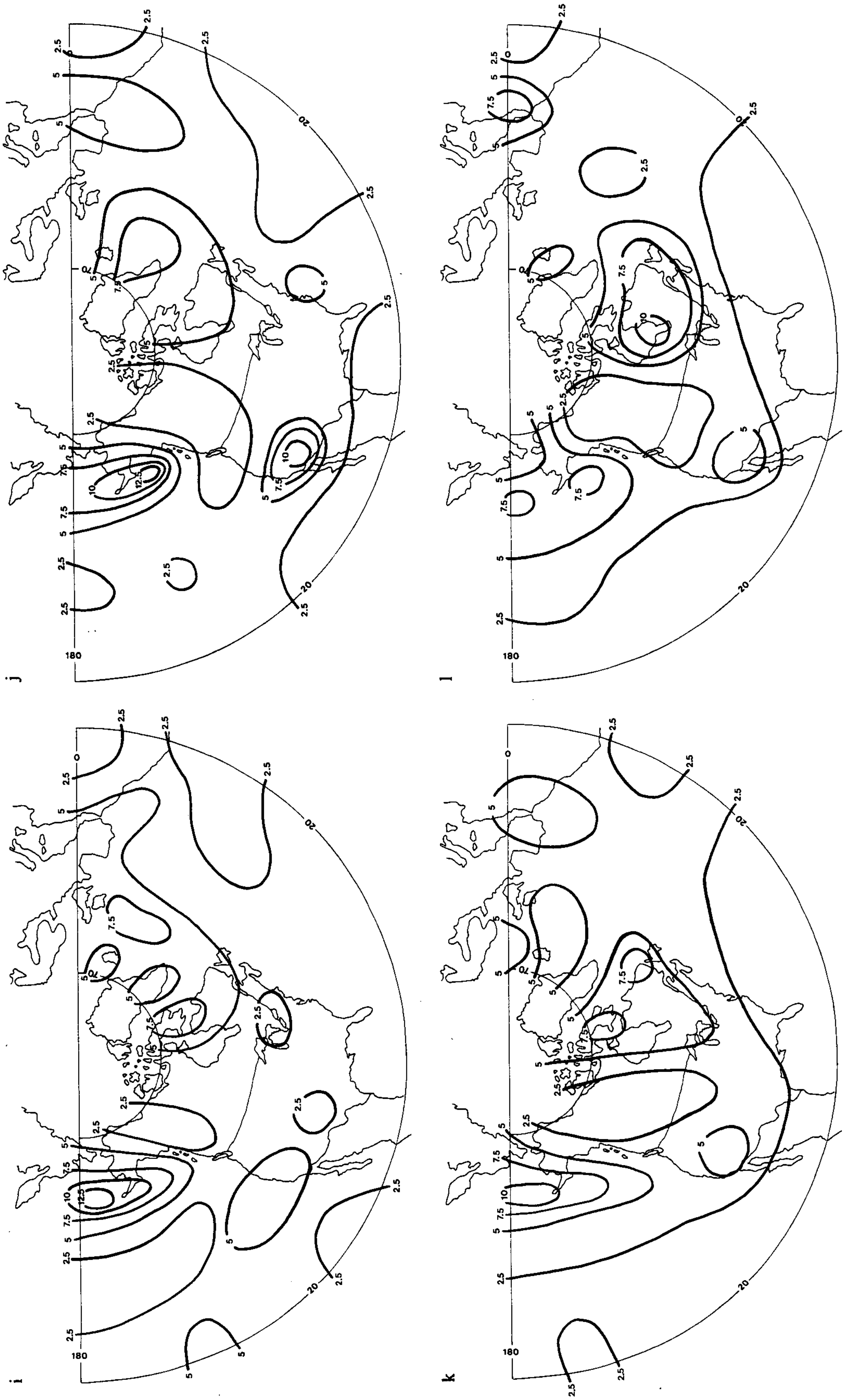

FIG. 3. (*Continued*) (i) Sep–(l) Dec.

larly apparent over southwestern North America where grid quadrangles in which 500 mb anticyclones have never been observed during January in the period of investigation experienced them on about 15 percent of the sample July days. High summertime (June through September) 500 mb anticyclone frequency is also observed over northwestern Africa. Secondary frequency maxima are noted over the northeastern Atlantic from October through June, reaching a peak in April, and near Alaska in January and February and from May through July.

4. Discussion

Cyclones and anticyclones in the 500 mb geopotential height field are observed infrequently in any given quadrangle over the domain of investigation, generally on less than ten percent of the sample days. This is reflected in other climatological studies; for example, the time averaged 500 mb maps of Lahey et al. (1958) reveal only a closed low over northeastern Canada during January, February and March, and closed highs over the subtropical Atlantic ocean during July and August. Since these systems are usually observed to be stationary, then regions of high frequency may also be regarded as genesis regions. Comparison of Figs. 1 and 3 with surface cyclogenesis statistics (e.g., Zishka and Smith 1980) suggest that surface and 500 mb cyclogenesis regions do not generally coincide. The southwestern North American maximum in 500 mb cyclone frequency is observed slightly upstream from the major surface cyclogenesis region in the lee of the Rocky Mountains but coincident with a weakly cyclogenetic area over Nevada (Zishka and Smith, Fig. 2b). The northern oceanic 500 mb cyclone frequency maxima, on the other hand, are downstream from the western oceanic surface cyclogenesis regions. Perhaps these surface cyclones evolve into occluded lows, with closed circulations at 500 mb, after they migrate into the northern oceanic regions.

No connection is seen between surface anticyclogenesis regions and 500 mb anticyclone frequency maxima (compare Figs. 4a and 4g with Zishka and Smith, Figs. 4b and 5b). However, the northeastern Atlantic maximum in 500 mb anticyclone frequency is found downstream from the western Atlantic surface cyclogenesis region and, notably, a maximum in the frequency of occurrence of explosive surface cyclogenesis (Sanders and Gyakum 1980). Furthermore, the central Pacific and Alaskan maxima in 500 mb anticyclone frequency are downstream of the western Pacific bomb frequency area. A possible relationship between these surface "bombs" and downstream 500 mb anticyclones, as part of blocking patterns, has been proposed by Colucci (1985). These oceanic 500 mb anticyclone frequency maxima, especially during the spring, are congruent, seasonally and geographically, with 500 mb blocking pattern climatology (Rex 1950).

The 500 mb cyclones and anticyclone frequencies appear to complement one another. Highest anticyclone frequencies are observed over subtropical latitudes, while highest cyclone frequencies are found at high latitudes. Important exceptions include the anticyclone frequency maxima over the northeastern Atlantic Ocean, corresponding to "cutoff" or "blocking" highs as discussed above, and cyclone frequency maxima near southwestern Europe and southwestern North America. These latter systems are most frequently "cutoff" lows south of the principal westerlies (Palmen 1949).

Southwestern North America experiences a comparatively high frequency of 500 mb closed circulations, with relatively high anticyclone frequency during the summer being replaced by high cyclone frequency in fall and spring. While the summertime anticyclone frequency maximum may represent a shift in the subtropical 500 mb anticyclone toward the relatively warm continent, the origin of the cyclone frequency maximum here is more mysterious. Hawes and Colucci (1986) have noted that 500 mb cyclones in this region tend to be poorly forecast by National Meteorological Center prediction models. Our impression is that these systems form under a strong diffluent-flow regime at 500 mb over western North America and the eastern Pacific Ocean.

In order to test this idea, we have examined 22 cases of 500 mb cyclogenesis over southwestern North America during 1980–85. The average latitude of the 5340 and 5640 m contours at 500 mb for every 2.5° of longitude over the domain of interest was calculated, along with the standard deviation of these latitudinal positions, 24 h prior to the closing of a contour around relatively low heights in the region confined by 30° and 50° north latitude and 90° and 120° west longitude. These average contour positions, shown in Fig. 5, demonstrate a strong diffluent geostrophic flow regime over southwestern North America 24 h prior to 500 mb cyclogenesis in that region.

The utility of this diffluent flow as a predictor of 500 mb cyclogenesis over southwestern North America was investigated in an independent sample during 1986. "Diffluence" at 500 mb over western North America was defined by the 5340 m contour lying north of 50°N from 110° through 130°W concurrently with the 5640 m contour lying south of 40°N from 100° through 120°W. "Southwestern North American 500 mb cyclogenesis" was defined by the closure of at least one contour, at 60 m intervals, around relatively low 500 mb heights within the domain 30°–50°N, 90°–120°W. Fourteen diffluence events, thus defined, were identified

FIG. 4. As in Fig. 3, except for 500 mb anticyclones.

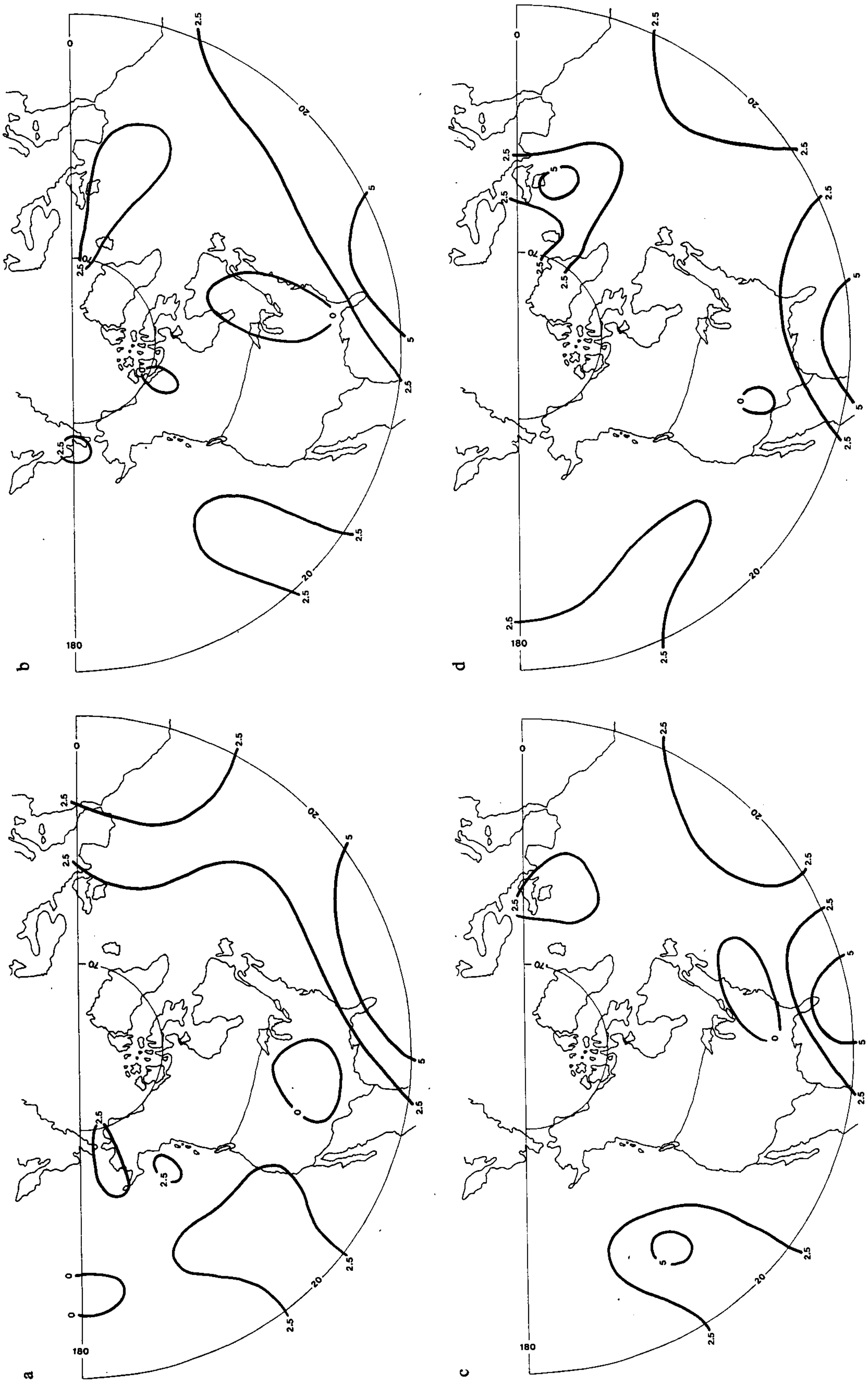

FIG. 4. (a) Jan–(d) Apr.

FIG. 4. (*Continued*) (e) May–(h) Aug.

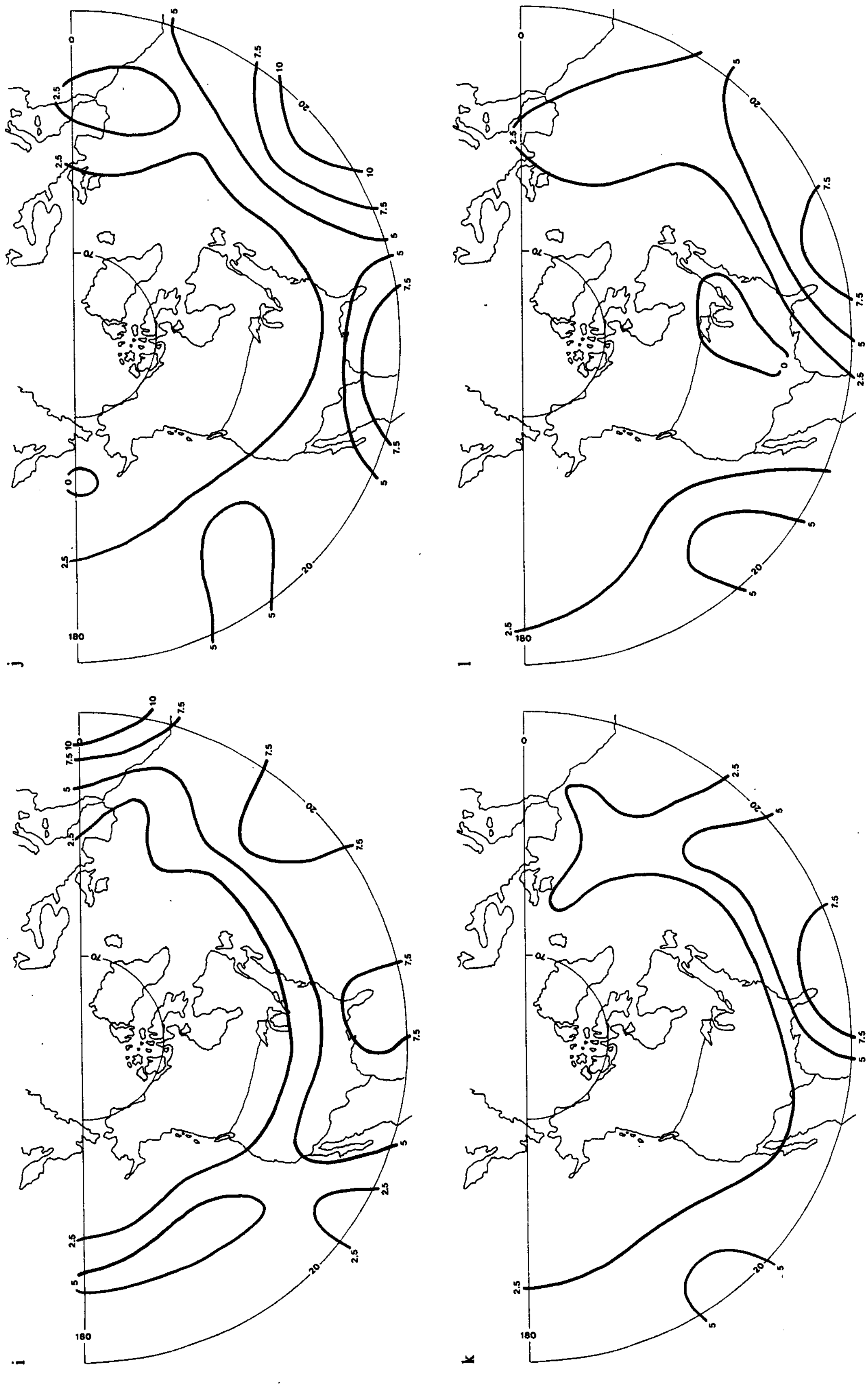

FIG. 4. (*Continued*) (i) Sep–(l) Dec.

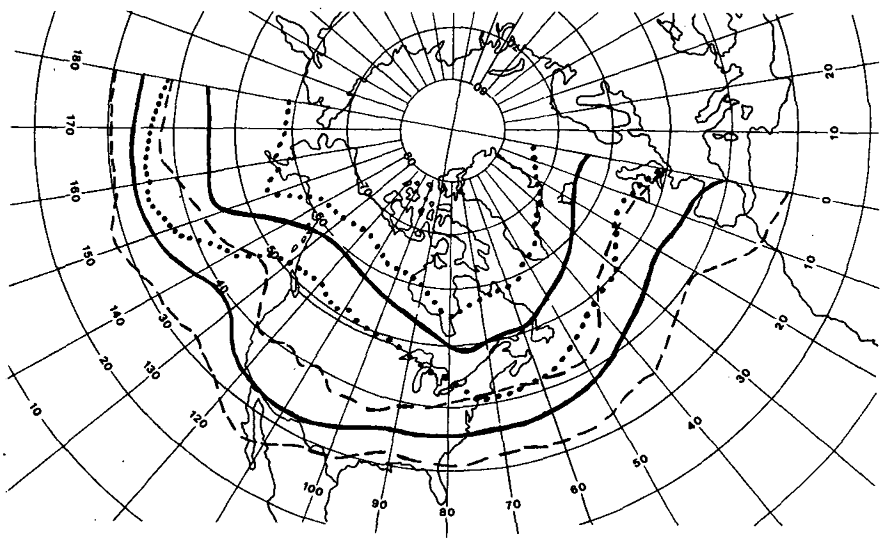

FIG. 5. Average position (solid line) of the 5640 and 5340 m contour at 500 mb, with standard deviations (dashed and dotted lines, respectively) 24 h prior to 500 mb cyclogenesis within 30°–50°N, 90°–120°W.

during 1986; all were followed, not more than 72 h and at an average interval of 24 h after diffluence inception, by 500 mb cyclogenesis. Two additional 500 mb cyclone events were not preceded by diffluence. Thus, all diffluence events in the sample were followed by 500 mb cyclogenesis, while most 500 mb cyclones in the sample were preceded by diffluence. The dynamics and climatology of diffluent regimes and their relationship to 500 mb cyclogenesis obviously deserve further research attention.

We have investigated the relationship between 500 mb cyclone activity and 300 mb eddy westerly momentum transports by correlating 500 mb cyclone frequencies for January, February and March during the 1950–57 time period with monthly mean 300 mb eddy westerly momentum statistics obtained from Lahey et al. (1960). Here, "eddy westerly momentum transport" is defined by $\overline{\rho u'v'}$, for density ρ, zonal wind u and meridional wind v. Overbar denotes time average and primes denote departure from time average. When frequencies and transports are averaged over time and 5° latitude bands, 500 mb cyclone frequencies north (south) of 40°N are negatively (positively) correlated with eddy westerly momentum transports (Fig. 6). Since 40° corresponds to the approximate zonally averaged position of the 300 mb jet, then on the average, 500 mb cyclones north of the westerly jet are associated with southward transport of westerly momentum (or northward transport of easterly momentum) at 300 mb, while 500 mb cyclones south of the jet are linked with northward transport of 300 mb westerly momentum (or southward transport of easterly momentum). Hence, we may hypothesize that 500 mb cyclones are associated with the convergence of westerly momentum into the 300 mb jet on the average. Longitudinally, the correlations are significant south of the Aleutian Islands, over eastern North America, and over the central Atlantic Ocean (not shown). These correspond to regions south of the principal 500 mb cyclone frequency maxima (see Figs. 3a–c). The relationship between these 500 mb centers and jet systems should be investigated further.

Temporal trends in 500 mb cyclone and anticyclone frequencies have also been investigated. A precipitous decline in 500 mb cyclone and anticyclone frequencies occurred in 1971 during the switch from manual to automated analyses in the period of our study. Specifically, the total number of cyclone events averaged 1568 per year from 1950 through 1970 but 1075 per year from 1971 through 1985. Here one event is defined by the observation of one 500 mb cyclone on one map within the domain of interest. Similarly, anticyclone events dropped from an average of 805 per year from 1950–70 to 566 per year from 1971–85. Thus, the automated analyses do not account for as many closed 500 mb systems as did the earlier manual analyses. Often the automated analysis fails to draw the innermost closed contour. This may be the only contour in weak systems, which are therefore not analyzed. Comparison of manual and automated analyses during 1971 revealed no qualitative differences in locations of frequency maxima and minima, suggesting a proportional decline in frequency throughout the domain.

Within the periods of manual and automated analysis, further temporal trends are noted, especially for anticyclones. Linear regression reveals that 500 mb cyclone frequency declined by two events per year from 1950 to 1970, and increased by five events per year

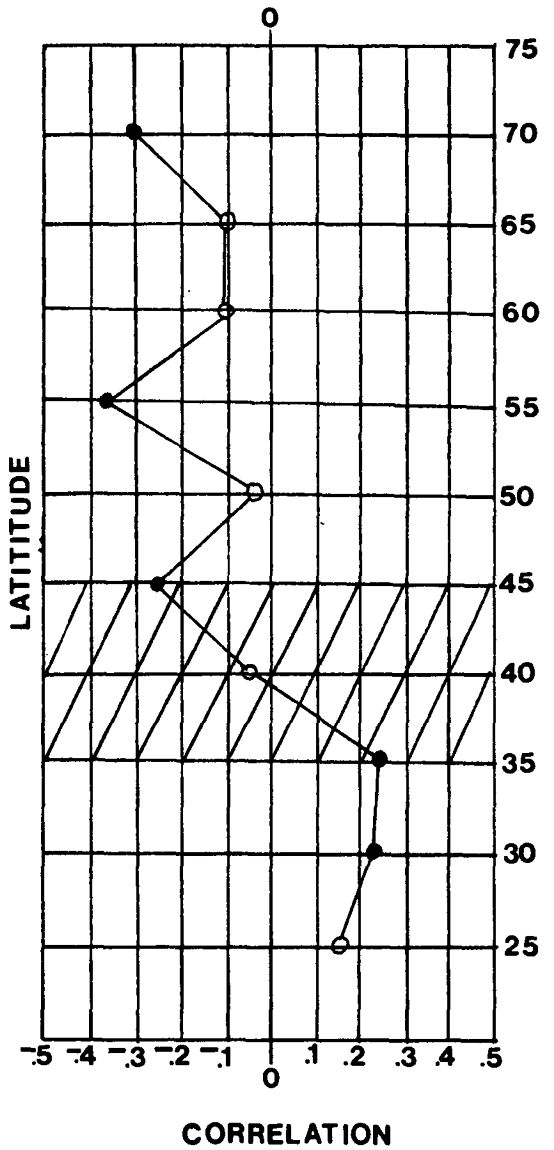

FIG. 6. Correlation between zonally averaged 500 mb cyclone frequencies and 300 mb eddy westerly momentum transports, Jan–Mar 1950–57. The filled circles denote statistical significance with 95% confidence.

from 1971 to 1985. Anticyclone frequency declined by 19 events per year from 1950 to 1970 and by 15 events per year from 1971 to 1985. A recent temporal decline in frequency of surface cyclones and anticyclones has been previously found by Zishka and Smith (1980) and Hayden (1981a). It is beyond the scope of this paper to speculate about reasons for these temporal trends.

Thus, given the sensitivity of the frequency distribution to the method of map analysis plus the possibility of temporal trends in frequency as well as interannual variability, our findings should be interpreted with caution. That is, the data presented provide information on relative geographical and seasonal locations of frequency maxima and minima rather than a quantitative likelihood of system observations at a particular location and time.

5. Conclusions

We have investigated the geographical and monthly frequencies of 500 mb cyclones and anticyclones from 1950 through 1985 over the western half of the Northern Hemisphere from 20°N through 70°N. The principal findings of this research are as follows:

1) Overall, 500 mb cyclones and anticyclones are infrequent events, observed generally less than ten percent of the time in any given 10° latitude–longitude quadrangle. Cyclones at 500 mb are more common than anticyclones.

2) Geographically, 500 mb cyclones are found primarily at middle and high latitudes, while 500 mb anticyclones are observed most frequently at subtropical latitudes. The frequency of 500 mb cyclones over northern oceanic regions increases during the summer, while 500 mb anticyclone frequency increases throughout the subtropics during the summer, especially over southwestern North America.

3) Interesting departures from these geographical generalities are observed. Relatively high 500 mb anticyclone frequency extends northward from the subtropics to the northeastern oceanic regions; this is most pronounced during the springtime, probably corresponding to "blocking highs" north of the principal westerlies. Similarly, southward extensions of relatively high 500 mb cyclone frequency are observed over the central subtropical Pacific Ocean during the summer, southwestern North America during the spring and fall, and near southwestern Europe throughout the year. These are probably "cutoff lows" south of the principal westerlies.

4) An investigation of twenty-two 500 mb cyclones over southwestern North America revealed that 500 mb cyclogenesis in these cases was preceded in that region by abnormally strong diffluent flow, defined by a pair of contours in the 500 mb geopotential height field. In an independent sample, all occurrences of this diffluence over southwestern North America were followed by 500 mb cyclogenesis in that region.

5) The 500 mb cyclones at middle and high latitudes are correlated with southward transport of 300 mb westerly momentum, while those at subtropical latitudes are correlated with northward transport of 300 mb westerly momentum. This suggests that 500 mb cyclones are, on the average, associated with the convergence of westerly momentum into the 300 mb jet stream.

While it appears that, historically, much more effort has been directed toward understanding surface cyclogenesis rather than anticyclogenesis, the opposite is apparently true at 500 mb. The nature and formation of blocking highs (a subset of the generic 500 mb anticyclones) have attracted much more attention than those of cutoff lows (a subset of generic 500 mb cyclones). Research on the latter phenomenon has been limited to case studies (Palmen 1949; Colucci 1985; Hoskins et al. 1985). It would therefore be appropriate to thoroughly investigate the nature of 500 mb cyclogenesis, particularly that observed in locations identified here as having high cutoff low frequencies: the central subtropical Pacific, southwestern North American and near southwestern Europe. The isentropic potential vorticity method of Hoskins et al. (1985) may prove to be particularly illuminating in approaching this problem. In fact, it may be preferable to *define* closed 500 mb circulations by vorticity or potential vorticity because of the arbitrariness of the traditional closed contour definition employed here.

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