MEAN NORTHERN HEMISPHERE CYCLONE ACTIVITY AND 500 MB GEOSTROPHIC WIND (1958-1977)

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ABSTRACT

The distributions of cyclogenesis, cyclone frequency and 500 mb geostrophic wind speed over the Northern Hemisphere extratropics (poleward of 20°N) are examined for the twenty year period 1958-1977. The annual cycle is characterized by a smooth decrease in wind speed from winter to summer but a less smooth variation in cyclone frequency and cyclogenesis, particularly cyclogenesis which lags by 2 to 3 months.

Latitudinal plots of the annual and seasonal distributions of the three parameters show the strongest 500 mb wind speeds slightly south of the cyclogenesis peak except in fall when they nearly coincide. The peak in cyclone frequency is located farther north with the smallest separation between it and cyclogenesis in summer. Plots of the three parameters as a function of month and latitude provide more detailed information concerning the latitudinal and monthly variations.

Hemispheric maps for the four mid-season months are used to show the 20 year mean relationship between 500 mb wind speed and major areas of cyclogenesis. The cyclogenetic areas off the east coasts of Asia and North America are closely related to wind maxima; however, the cyclogenetic area in the lee of the North American Rocky Mountains is not related to a wind maximum. Meridional profiles of wind speed and cyclogenesis in areas of frequent cyclogenesis are used to further establish the relationship between wind speed and cyclogenesis.

1. INTRODUCTION

The geographical distribution of cyclogenesis and cyclone tracks and their seasonal variations are of major interest to the meteorologist and climatologist. The operational meteorologist commonly focuses on the primary geographical locations of cyclone formation; for example, in interior North America major attention is given to the Colorado and Alberta cyclogenetic areas. The climatologist uses information concerning the sites of cyclone formation and most frequent paths followed by the cyclones to aid in explaining the climate of a region. Climatic variations are commonly accompanied by changes in the frequency of cyclogenesis in certain areas and shifts in the major paths followed by cyclones. Investigators using general circulation models to simulate the general circulation and its synoptic scale features are interested in the actual distribution of cyclogenesis and cyclone frequency.

Because a variety of atmospheric scientists are concerned with the spatial distributions of cyclone activity, it is not surprising that a number of studies have been devoted to this topic. (In the general discussion in this paper the term "cyclone activity" will be used to include both cyclogenesis and cyclone frequency. It is from the latter that the common cyclone paths are determined.) Petterssen (4) studied the geographical distribution of surface cyclone and anticyclone activity over the Northern Hemisphere for winter and summer for the period 1899-1939. Klein (5) compiled similar statistics covering the Northern Hemisphere for each month of the 20 years 1909-14 and 1924-37. Studies confined to North America and its ocean environs have been done by Reitan (6) who primarily studied cyclone activity for the four mid-season months of the years 1951-70, Zishka and Smith (7) who investigated activity during January and July 1950-77 and by Whittaker and Horn (8) who studied the latitudinal and seasonal distributions of cyclogenetic events for all months of 1958-77. Studies covering other limited regions of the Northern Hemisphere have been conducted by Hayden (9), Chung et al. (10) and Colucci (11). Recently Whittaker and Horn (12, 13) extended their cyclone census to include all of the extratropical Northern Hemisphere. The basic cyclone activity data used in this paper were obtained from the Whittaker and Horn census. These data are combined with 500 mb geostrophic wind data for the same period (1958-77) to relate surface cyclone activity to the 500 mb geostrophic wind speed.

Although there has been considerable work done on the distribution of cyclone activity, there have been relatively few studies relating surface cyclone activity to upper atmospheric parameters such as wind. Klein (5) compared normal 700 mb zonal geostrophic wind to the 20 year zonal mean cyclone and cyclogenesis frequency for the 1909-14 and 1924-37 periods. He found correlations between these quantities; however, upper level data were very scarce during these early periods. Reitan (14) attempted to relate an apparent decrease in cyclone frequency over North America during the 1949-76 period to changes in the mean monthly 700 mb height field. In comparing individual years of high and low cyclone frequency he found "no apparent circulation type associated with many or few cyclones."

In this paper the relationship between the 500 mb geostrophic wind speed and cyclone activity during the 1958-77 period is examined (the 20 Decembers used were from 1957 through 1976). Primary attention is given to the latitudinal and seasonal variations in cyclone activity and 500 mb geostrophic wind; however, the longitudinal relationship is also examined for the four mid-season months. In addition, latitudinal profiles of cyclogenesis and 500 mb wind speed are examined for some of the principal cyclogenetic areas of the Northern Hemisphere.

2. DATA SOURCES AND PROCEDURES

The data used in this study consisted of cyclone frequency and cyclogenesis counts from Whittaker and Horn (12) for the period December 1957 - November 1977 and mean 500 mb geostrophic wind speeds calculated for a similar period from daily 500 mb height data compiled by the National Center for Atmospheric Research (15). A 5° latitude-longitude grid between 20°N and 85°N was used for cyclone counts and between 20°N and 90°N for the height fields. Cyclogenesis was defined as the point at which an extratropical cyclone center appeared with at least one closed isobar (4 or 5 mb intervals). Centers were tracked if they maintained their identity for at least 24 hours. Semi-permanent features such as heat lows, etc. were not counted. Cyclone frequency was defined as the number of low centers which passed through the grid box during a given month (no individual low was counted more than once in a grid box). See Whittaker and Horn (12, 13) for a more detailed discussion of data sources, plotting procedures, etc.

The use of a latitude-longitude grid requires that some provision be made for the variation in area with latitude of the grid boxes. In this study, scale factors consisting of the ratio of the area of a 5° latitude-longitude grid box centered at 42.5°N to the area of a 5° grid box in each of the latitude belts were calculated. These scale factors were applied to the cyclogenesis counts in each grid box only when looking at a hemispheric distribution of the values. Because cyclone frequency counts depend upon the number of boxes through which cyclones pass, the inverse of the scale factor was needed to de-emphasize the higher latitudes in the monthly Totals (Figure 1).

The 20-year mean 500 mb geostrophic wind field for each month was determined directly from the 20-year mean height fields computed by Guetter (19). Wind speed values at each grid point were calculated using a simple centered difference approximation to the geostrophic relation. Calculations of the eastward (u_g) and northward (v_g) wind components at a grid point involved height values at points 5° of latitude and 5° of longitude on either side of the grid point, respectively. A variable Coriolis parameter was employed. The wind components were combined to form the total geostrophic wind speed. Since the zonal wind speed components could not be calculated on the north and south boundaries of the grid except through the use of one-sided differencing, the resulting wind data only extended from 25°N to 85°N.

The procedures outlined above were used to obtain results which describe various aspects of the geographical and temporal relationships between cyclogenesis, cyclone frequency and the 500 mb geostrophic wind. They include 1) the hemispheric annual cycle of these quantities, 2) their latitudinal distributions (both annually and seasonally), 3) the hemispheric distribution of 500 mb wind speed and cyclogenesis for four mid-season months and 4) latitudinal profiles of cyclogenesis and 500 mb wind speeds for certain cyclogenetically active areas. We first turn to the hemispheric annual cycle.

3. THE HEMISPHERIC ANNUAL CYCLE

In referring to the "Hemispheric Annual Cycle" we are actually focusing on the Northern Hemispheric area between 20°N and 85°N. This area, of course, includes essentially all of the hemispheric regions which experience extratropical cyclone centers. The annual variation of the hemispheric means of 500 mb geostrophic wind speed, cyclogenesis and cyclone frequency is presented in Figure 1. The cyclogenesis counts are the hemispheric totals for each month, but as previously noted, the cyclone frequency numbers shown were obtained by multiplying the counts by the inverse scale factor prior to summation. This procedure de-emphasizes the influence of small grid boxes at high latitudes, which is only necessary when looking at the annual cycle.

An examination of Figure 1 shows that the 20-year mean hemispheric 500 mb wind speed (dashed line) decreases from a January maximum of almost 12 meters per second (m/s) to less than 6 m/s during July and August. The hemispheric cyclone frequency trend (solid line) is similar to that of the wind speed except between December and March when the cyclone frequency curve is relatively flat during the three winter months (DJF) then rises to a distinct maximum in March despite a significant wind speed decrease (and implicitly, baroclinity decrease). The cyclone frequency decreases by 31% of its July minimum from its March maximum as opposed to a 47% decrease of the wind speed during this same period.

The annual trend in the mean cyclogenesis (dotted line) lags that of the mean wind speed (and cyclone frequency) by one to three months with a maximum in April and a minimum in September. Figure 1 also reveals that the number of cyclogenetic events does not entirely depend upon the strength of the mean wind. It is likely that factors such as static stability also influence the concentration of cyclogenesis over the hemisphere. For example, Hovanec and Horn (20) found that the static stability over North America was weaker during the spring (a condition favoring cyclogenesis) than that during the fall. This may partly explain the April maximum in the mean cyclogenetic activity. However, because oceanic areas, which have different seasonal trends in static stability occupy a large portion of the study area, the interpretation of the influence of static stability should be treated with some caution. Nevertheless, the September minimum for the Northern Hemisphere occurs at a time when the 500 mb winds are relatively weak and when the static stability over the continents is beginning to increase as the fall season develops. If stability values were available for the entire hemisphere a more complete interpretation of its role could be made.

Figure 1 also shows that during some periods of the year the mean hemispheric cyclone frequency decreases as the cyclogenetic activity increases and vice-versa. For instance, examine the relative trends of the two curves between March and September; the minimum in frequency occurs in July but the minimum in cyclogenesis is postponed until September. The ratio of cyclone frequency to cyclogenesis for each month can provide information concerning the changing path lengths of cyclones during the course of the year. For example, assume that in January only 10 cyclones are born in the Northern Hemisphere and they pass through a total of 120 grid boxes before dissipating. The hemispheric cyclogenesis value is 10 while the cyclone frequency is 120. The resulting cyclone frequency to cyclogenesis ratio is 12. On the other hand, if July has 8 cases of cyclogenesis and a cyclone frequency of 80 the resulting ratio of 10 indicates that the mean path length of cyclones in July is less than in January. Therefore a larger cyclone frequency relative to the number of cyclogenetic events for a given month implies a longer mean path length. Such ratios were calculated for each month from the data shown in Figure 1 and are presented in Table 1.

The cyclone frequency to cyclogenesis ratios of Table 1 indicate longer path lengths in the colder months compared with the summer months. The maximum of 9.5 in March is nearly matched by the large values in November and December. The summer season minimum, reflecting shorter path lengths, is quite pronounced. The shorter path length of the summer cyclones probably reflects both the influence of a shorter life span (presumably because of weaker baroclinity) and a slower movement of summer cyclones (i.e., even if a summer cyclone had the same life span as a winter cyclone, it would pass through fewer grid boxes yielding a lower frequency). It is beyond the scope of this paper to fully interpret the causes of the seasonal changes in path lengths. Finally, it should also be noted that the area weighting given to the cyclone frequency could introduce some complications to interpretation of the ratios shown in Table 1. If during the year the paths followed by cyclones were in approximately the same direction, this complication would not arise. Since only the relative monthly and seasonal changes in path length are being considered, this complication is probably minor.

4. LATITUDINAL AND SEASONAL DISTRIBUTIONS

The latitudinal distributions of the mean annual 500 mb wind speed and cyclone activity for the 1958-77 period are shown in Figure 2. The most prominent characteristics of the curves are the relative latitudinal positions of the peaks. The peak mean cyclogenetic activity lies slightly north of the mean 500 mb wind speed maximum which confirms the observation that cyclones form in the cyclonic shear zones of the mid-tropospheric wind maxima. Figure 2 also shows that cyclogenetic activity drops off much more rapidly to the south than to the north of the latitude of peak cyclogenesis. This indicates that the southern limits of the polar front and jet are rather clearly defined. The mean anticyclonic shear south of the wind maxima inhibits cyclone activity. However, at times the 500 mb wind maximum is south of its mean position shown in Figure 2. It is at these times that the cyclogenesis shown south of the mean wind maxima occurs.

In the case of cyclone frequency, the peak lies slightly north of 50°N (i.e. 10° north of the peak wind). The northward displacement of this peak from the wind speed maximum reflects the tendency of surface cyclones to have a northward component of movement from a region of relatively strong thermal contrast to one of a colder yet more thermally homogeneous nature. The zone of peak cyclone frequency, rather than aligning itself with the wind speed maximum, coincides with the latitude of the strongest mean cyclonic wind shear (i.e., strong positive relative vorticity) at 500 mb (as indicated by the slope of the wind speed profile).

Although Figure 2 reveals the latitudes of peak cyclone activity relative to the annual mid-tropospheric wind speed profile, it contains no information on the seasonal variations of the parameters. Therefore the annual data were partitioned into seasons and displayed in Figures 3a-d.

A comparison of Figures 2 and 3 shows that the peaks of the 500 mb wind speed, cyclogenesis, and cyclone frequency maintain their same <u>relative</u> latitudinal positions. Also, the latitudinal positions of the wind speed and cyclogenesis peaks remain close in each season, with the cyclogenesis peak just north of the wind maxima except during fall (Figure 3d) when they nearly coincide. Cyclogenesis and cyclone frequency peaks do show somewhat larger seasonal variations in the degree of latitudinal separation. The degree of separation of the curves north of the peaks suggests the mean latitudinal extent of cyclone paths during a given season. For example, the approximately 10° latitudinal separation of the curves in winter (Figure 3a) implies that winter cyclones generally travel farther north from their point of origin than do those in summer when the cyclone frequency and cyclogenesis curves are only 5° of latitude apart (Figure 3c).

An alternative and more complete representation of the latitudinal and seasonal variation in wind speed, cyclogenesis and cyclone frequency can be obtained by plotting these quantities as a function of latitude and month. Zonally averaged wind values and zonal totals of cyclogenesis and cyclone frequency are plotted as a function of month in Figures 4a-c. The dashed curve on each figure delineates the axis of maximum values for the parameter. To facilitate comparisons, these three axes are reproduced in Figure 4d.

The 500 mb geostrophic wind speed displayed in Figure 4a shows the northward displacement and steady weakening of the maxima from winter to summer and early fall. This north-south migration reflects the northward retreat of the polar front. Comparing Figures 4a and b one notes that the cyclogenesis does not decrease in a similar manner as the seasons progress. A strong concentration of cyclogenesis exists between 35-40°N during the winter and early spring. Following this period of strong activity cyclogenesis then decreases and the zone of maximum activity commences a rapid northward migration. As a result the axes of maximum cyclogenesis and cyclone frequency (Figure 4d) are in relatively close latitudinal proximity from April to September, suggesting the decreased mean north-south extent of cyclone paths during this period. The cyclogenesis axis then shifts southward again from its most poleward location (about 47°N) to 37°N in December. In Figure 4d the nearly coincident axes of maximum wind speed and cyclogenesis from October to December is in agreement with the results shown in Figure 3d (fall season).

Figures 4a and b show another interesting feature at high latitudes during the summer. The mean geostrophic wind speed significantly decreases during June and July while the cyclogenetic activity north of 50°N slightly increases during the same period. (Note the bulge in the 180 isopleth north of the axis of maximum cyclogenesis.) This enhanced activity may be due to lee-side effects at high latitudes (e.g. Alberta and Northwest Territories lee-side cyclogenesis). However, the absence of increased cyclone frequency values (Figure 4c) at these latitudes during the period suggests that the resulting cyclones do not travel far.

5. HEMISPHERIC ANALYSES

The analyses up to this point have involved only zonal distributions of the data with east-west variations disguised. However, there are significant longitudinal variations in all three parameters largely due to continent-ocean thermal contrasts. To study these variations in the 20-year mean, hemispheric analyses of cyclogenesis (from Whittaker and Horn, (12)) were superimposed on similar analyses of the 500 mb wind speed for the four mid-season months (January, April, July, and October; Figure 5). The wind speed data were analyzed for every 4 m/s. The shaded regions of each analysis represent areas of more than 10 cyclogenetic events per grid box over 20 years for each of the four mid-season months. These are areas of relative cyclogenetic maxima.

Figure 5 reveals that the sites of strongest cyclogenetic activity commonly lie upstream of the stongest mean wind speeds. This is especially true off the Asian and North American east coasts; the relationship being most obvious in January and April (Figures 5a and 5b). The relative positions of the two parameters may reflect the fact that a 500 mb jet is often weaker during the initial development of an associated surface than during the period of maturation when both entities progress eastward and intensify. This is in agreement with the energetics concept that developing cyclones are the major sites of the conversion of available potential energy to kinetic energy. It is also interesting to note that in January, particularly in the western North Pacific, the area of primary cyclogenesis tends to extend from the right-rear quadrant of the wind maximum to the left-front quadrant (Figure 5a). These are the two quadrants of upper- and mid-tropospheric transient jet maxima in which cyclone development commonly occurs. See Uccellini and Johnson (21) for a discussion of the mass adjustments around jet maxima. A similar, but less obvious, arrangement exists in the western North Atlantic during January. Similar configurations are not apparent in the other three mid-season months. This may be due to less well defined mean wind maxima and the somewhat subjective criteria used for shading cyclogenetic areas.

The relationships between mean wind speed and cyclogenesis noted above are not as clear in the lee of the Rocky Mountains. Figure 5a indicates that Alberta cyclogenesis is associated with a meager mean wind speed maximum in January. In April (Figure 5b), a broad region of lee-side cyclogenesis extending from Northern Alberta to Colorado and the Great Basin occurs during a period when the strongest wind at these longitudes has shifted to slightly south of the Colorado cyclogenetic region. Inspection of Figures 5c and 5d also reveals significant lee-side cyclone development despite weak mean 500 mb winds in July and October. This suggests that baroclinity plays a relatively less significant role in the lee of the mountains than is the case over the east coasts of Asia and North America. A more detailed analysis of the relationship between the mean wind and cyclogenetic activity in these regions is provided below.

6. CYCLOGENETICALLY ACTIVE REGIONS

To facilitate comparisons of the relationship between the mean 500 mb wind speed and cyclogenesis, meridional profiles of the two parameters were constructed through the three main cyclogenetically active regions of the hemisphere: the East Asian coast (EAC), the lee of the North American Rocky Mountains (NAR, including both Colorado and Alberta regions), and the east coast of North America (NAC). The sectors chosen for the profile study are delineated in Figure 6. Each sector is four grid boxes (20 longitudinal degrees) wide and covers the latitudinal extent of the study area (20°-85°N). It was felt that the sectors were wide enough to include most of the cyclogenetically active portions of each region; yet narrow enough to exclude data unrepresentative of the regions of interest. The data north of 45°-50°N in the two east coast sectors will not be discussed since the cyclogenetic activity in these areas is continental, not east coast, in nature.

The results in Figure 7a show that the January peak cyclogenetic activity is closely associated with maximum mean 500 mb wind speeds in all three sectors. The wind speed maxima reside at the same latitudes as, or slightly south of, the latitudes of peak cyclogenetic activity. The strong cyclogenetic maximum in Alberta located much farther north than the east coast maxima (52°N vs. 35°N) is associated with a much more moderate mean wind speed maximum (20 vs. 30 or 35 $m\ s^{-1}$). Note also the secondary cyclogenesis maximum in the Colorado area (37°N) despite the lack of a mean wind maximum. This highlights the importance of orographic effects as noted in the literature (e.g., in Chung et al., (10)). It should be emphasized that the lack of a mean wind maximum does not preclude the existence of occasional jet maxima propagating through this region and aiding cyclone development.

Although the mean 500 mb wind speed decreases by more than 30% from January to April in both east coast sectors (Figure 7b), the magnitudes of the peak cyclogenetic activity remain the same or slightly increase. This effect is most spectacular in the lee of the Colorado Rocky Mountain region where the cyclogenetic activity increases more than 100% between January and April. The relative April positions of the mean wind max and peak cyclogenetic activity in Colorado are similar to those found by Hovanec and Horn (21) during April and May (1964-71).

The wind speed maxima in all sectors shift northward and decrease significantly in July (Figure 7c). A concurrent northward displacement of the major cyclogenetic activity (i.e., the primary peak) is also evident in the EAC sector while the dominant site of lee-side cyclogenesis (NAR) shifts northward to Alberta. However, in the NAC sector, the peak cyclogenetic activity remains near Cape Hatteras despite the northward displacement of the wind maximum. Between July and October the mean wind speed maxima within the east coast sectors show moderate increases, reflecting the increased pole-to-equator tropospheric thermal gradients. However, the cyclogenetic activity continues to decrease in the east coast regions during the same period. Furthermore, the peak cyclogenesis off the North American east coast remains anchored to the same latitudinal position as it is in the three other mid-season months. Apparently additional forcings are active in this region.

Thus it appears that although dynamics (in terms of the 500 mb winds) play a large role in determining the sites (and the strength) of major cyclogenetic activity, other factors also play an active role. For example, the major sites of lee-side cyclogenesis are mainly fixed to two regions of the Rocky Mountains (Colorado and Alberta); both known for their relatively high elevations and the steep eastward descent of their terrain. The strength of the mean wind seems to be less important in determining the degree of cyclogenetic activity in these areas than off the east coasts of Asia and North America. The major difference between the two east coast regions is that the site of maximum cyclogenetic activity in the NAC sector is tied to the same latitude throughout the year.

7. SUMMARY

The relationships between cyclogenesis, cyclone frequency and the 500 mb geostrophic wind speed have been examined for the period 1958-1977. The more prominent relationships have been discussed in the body of this paper and are apparent in the figures. They include the following. The annual cycle of the hemispheric values of these parameters is characterized by a rather smooth decrease in wind speed from winter to summer, with less uniform trends in cyclone frequency and cyclogenesis. In particular, cyclogenesis tends to lag the others by 2 to 3 months. The ratio of hemispheric cyclone frequency to cyclogenesis was used to gain some insight into seasonal variations in the path lengths of cyclones. The longest path lengths occur in the colder season with the mid-summer path lengths about 20% shorter.

Latitudinal plots of the annual and seasonal distributions of the parameters showed the latitude of the maximum 500 mb wind speed slightly south of the peak in cyclogenesis except in fall when the two are nearly coincident. The cyclone frequency maximum is located the farthest north in all four seasons, but the difference is smallest in summer. Figures showing each of the three parameters plotted as a function of latitude and month reveal that cyclogenesis remains concentrated near latitude 35-40°N until mid-spring, at which time the maximum values are displaced quite rapidly northward to 45-50°N where they are found until October when a rather sharp southward displacement occurs. Seasonal displacements in cyclone frequency are less pronounced.

To gain some insight into longitudinal variations in 500 mb wind speed and cyclogenesis, hemispheric maps of these quantities were prepared for the four mid-season months. Most striking, as expected, is the relationship between the wind maxima and cyclogenesis over the Western Pacific and Western Atlantic, especially during January and April. For the most part the primary cyclogenetic areas are in close proximity to, and slightly upstream of, the wind maxima. A second noteworthy feature of these charts are the extensive areas of significant cyclogenetic activity in the lee of the Rocky Mountain chain despite a lack of relatively strong wind maxima. It was noted that this is indicative of the important role of orographic influences on cyclogenesis.

For a more detailed assessment of the wind speed-cyclogenesis relationships in the primary cyclogenetic areas, meridional profiles for limited sectors were prepared for the four mid-season months. The profiles confirm that seasonal wind speed fluctuations are more closely related to fluctuations in east coast cyclogenesis than to those in lee-side cyclogenesis. Of the three areas studied (the east Asian and North American coasts and the North American Rocky Mountains), there is a distinct July poleward displacement of both wind and cyclogenesis maxima over the East Asian coast and in the Rockies. By contrast, the strong cyclogenetic activity over the North American east coast remains near the same latitude during all four mid-season months regardless of the latitudinal displacement of the mean wind speed maximum.

8. ACKNOWLEDGEMENTS

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TABLE 1. Ratios of hemispheric sums of cyclone frequency (area weighted) and cyclogenesis.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
9.0	9.0	9.5	8.7	8.3	8.0	7.1	7.8	8.6	9.2	9.3	9.4

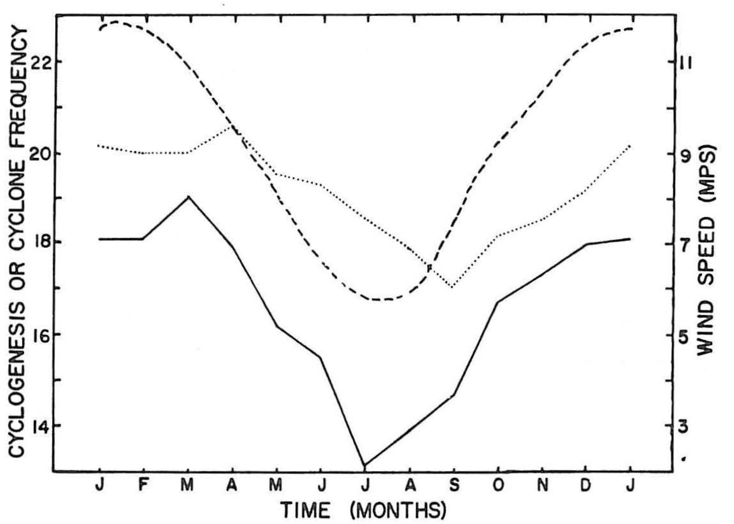
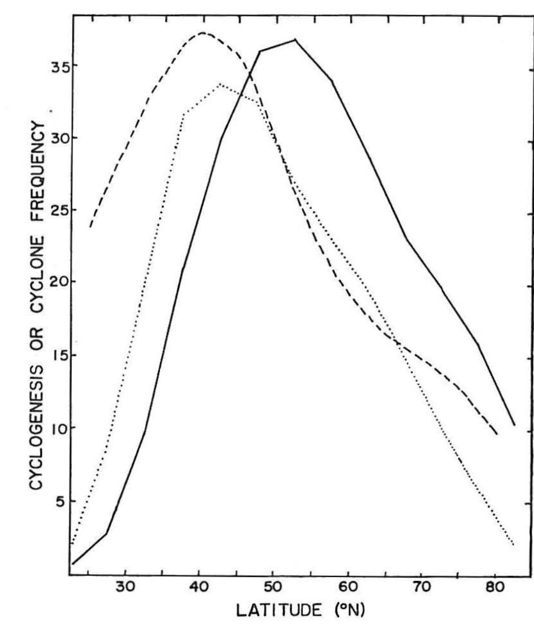


Figure 1. Annual variation of Northern Hemisphere mean 500 mb geostrophic wind speed (m s $^{-1}$; dashed), surface cyclogenesis counts x 10 $^{-2}$ (dotted), and area-weighted cyclone frequency x 10 $^{-3}$ (sol-id).

Figure 2. Zonal distributions of mean annual 500 mb geostrophic wind speed (m s $^{-1}$; dashed) surface cyclogenesis counts (per 5° latitude belt) x 10 $^{-2}$ (dotted), and cyclone frequency (per 5° latitude belt) x 10 $^{-3}$.



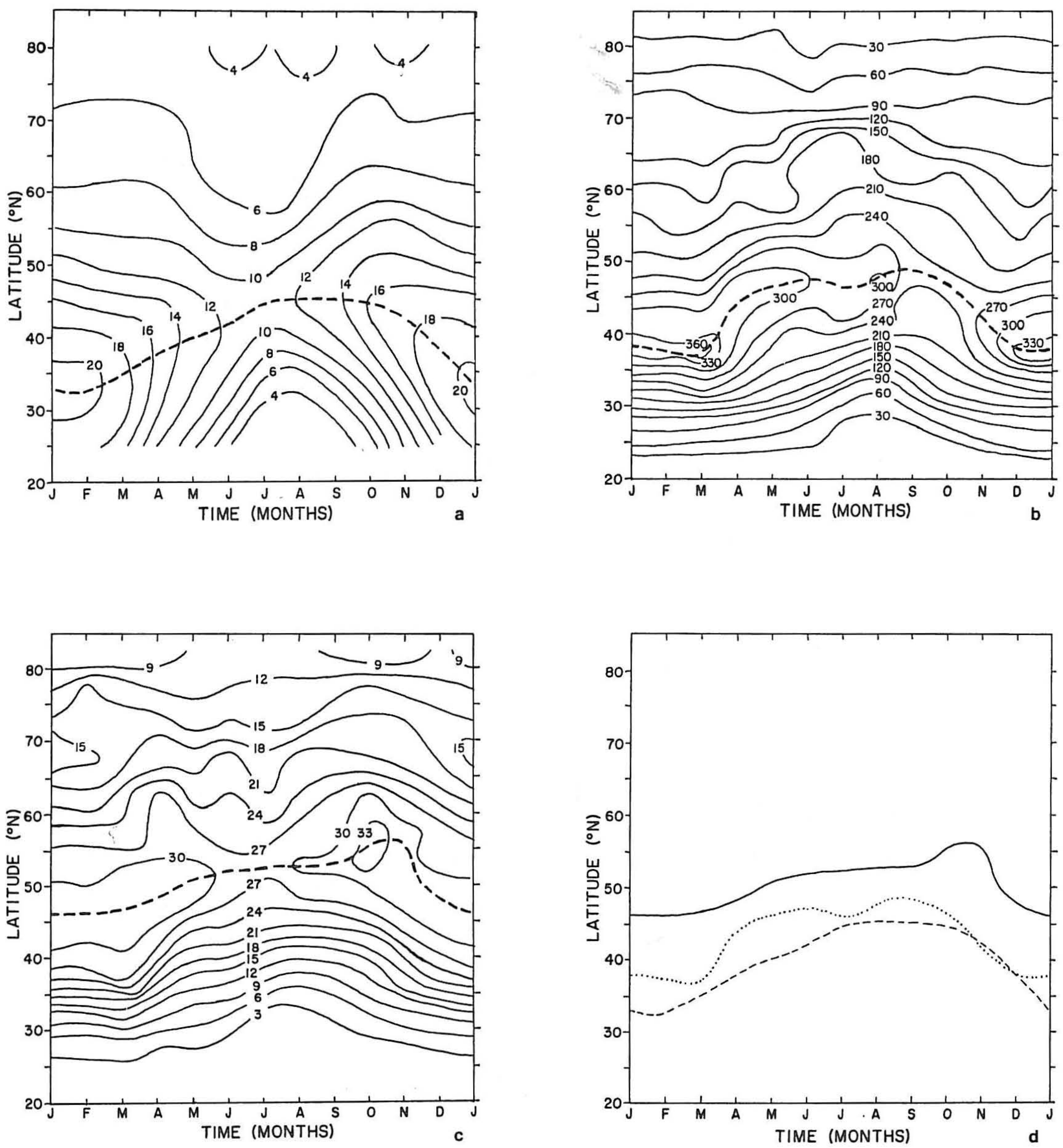


Figure 4. Isopleths of a) zonally averaged mean 500 mb geostrophic wind speed (m s $^{-1}$), b) zonal sums of cyclogenesis per 5° latitude belt, c) zonal sums of cyclone frequency x 10^{-2} per 5° latitude belt. Dashed line delineates axis of maximum values. [Cyclone data normalized for 30-day months.] d) Axes for maximum values of mean 500 mb wind speed (dashed), cyclogenesis (dotted), and cyclone frequency (solid) reproduced from a) - c).

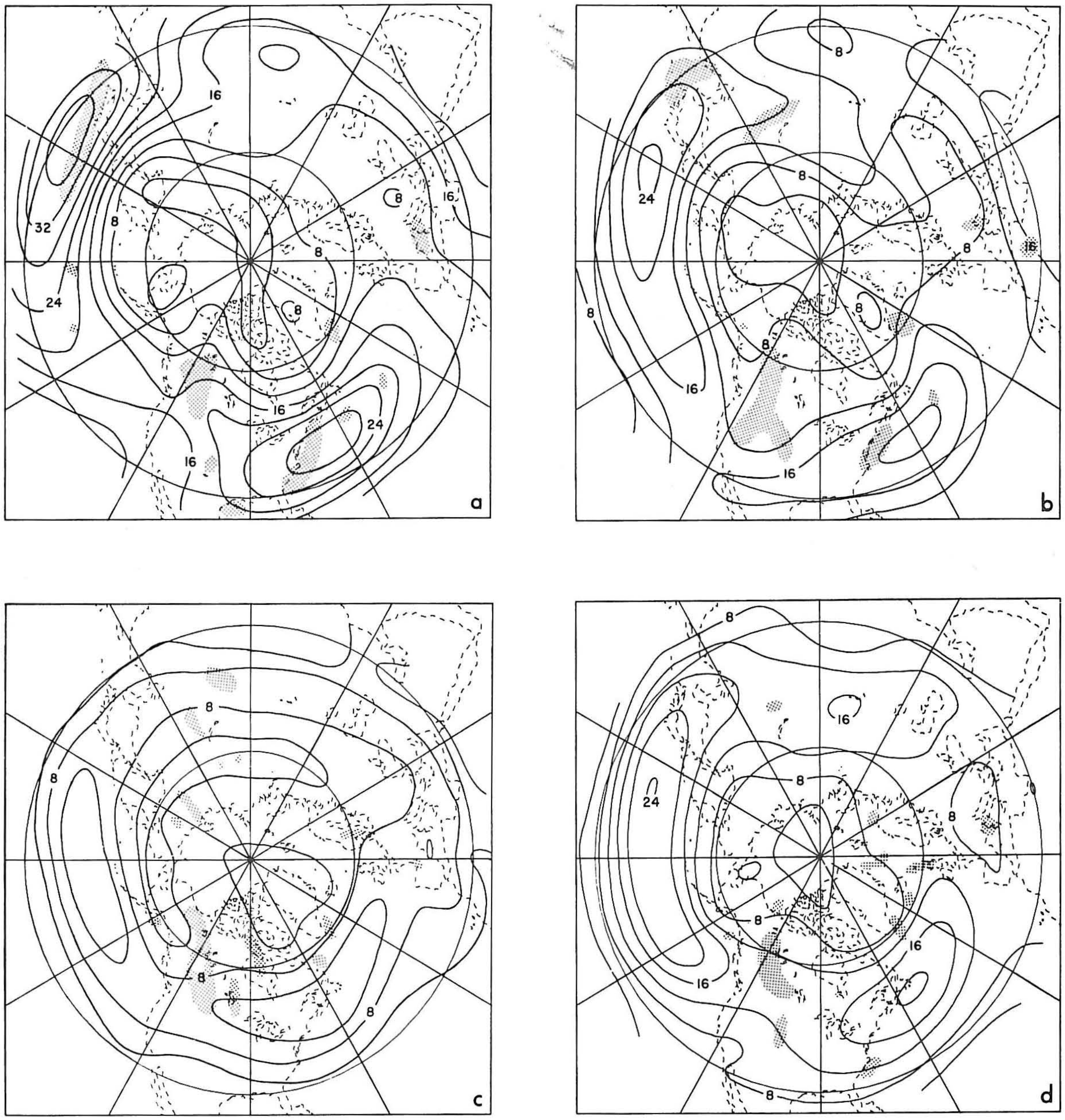


Figure 5. Hemispheric analyses of mean 500 mb geostrophic wind speed (m s^{-1}; dashed) and primary cyclogenetic areas (shaded) for a) January, b) April, c) July, and d) October.

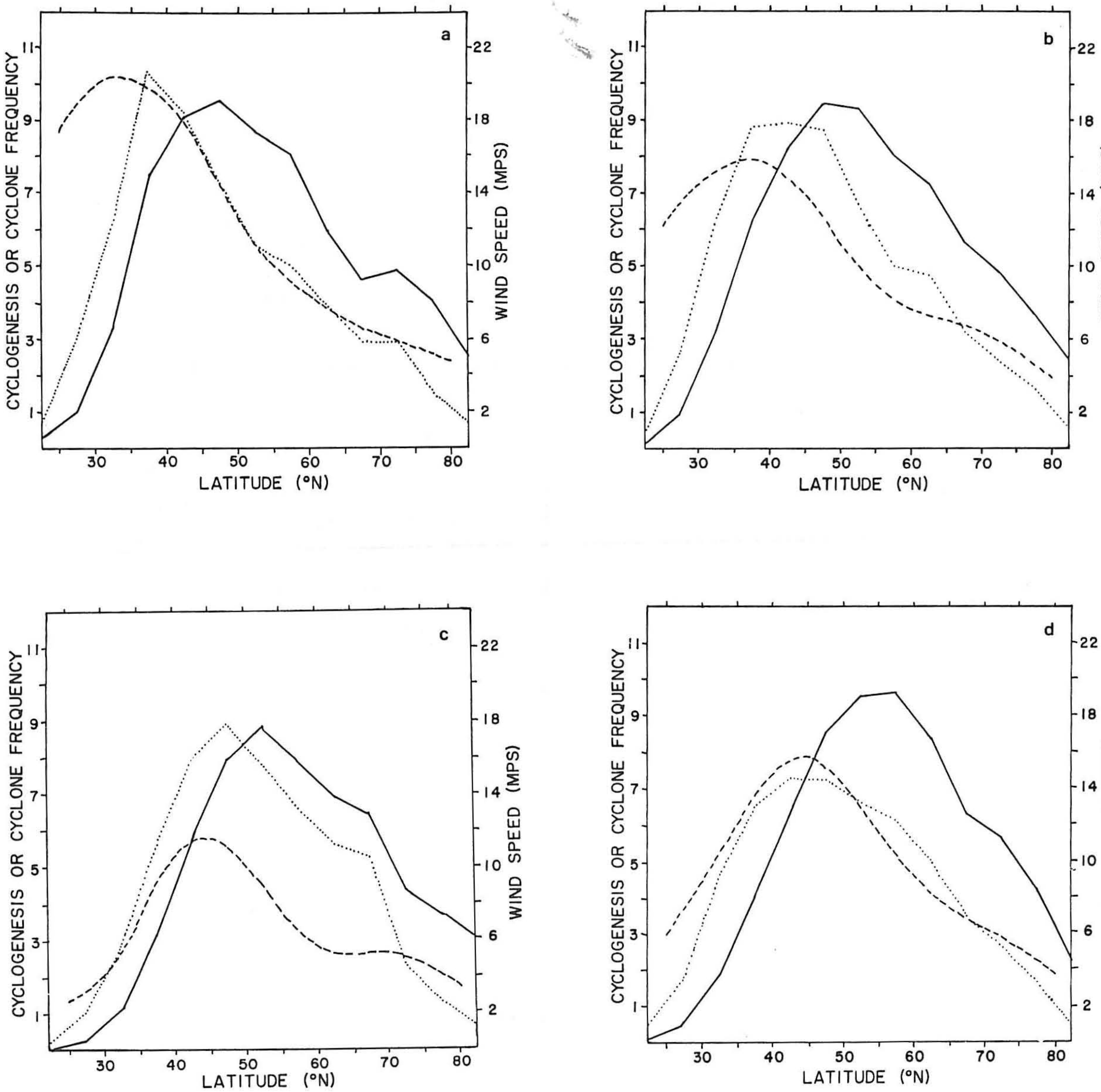


Figure 3. Same as Figure 2 except for a) winter, b) spring, c) summer, d) fall. Cyclone data normalized for 90-day seasons.

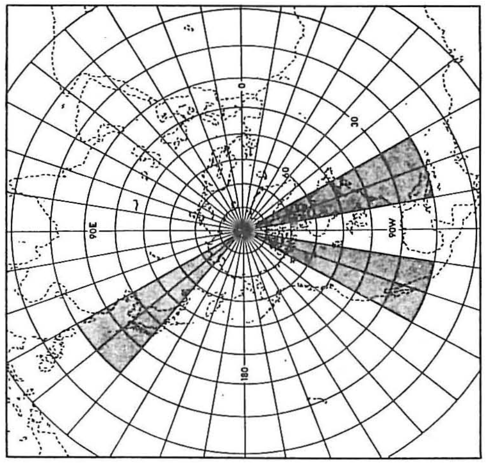


Figure 6. Sectors used to construct meridional profiles of wind speed and cyclogenetic activity.

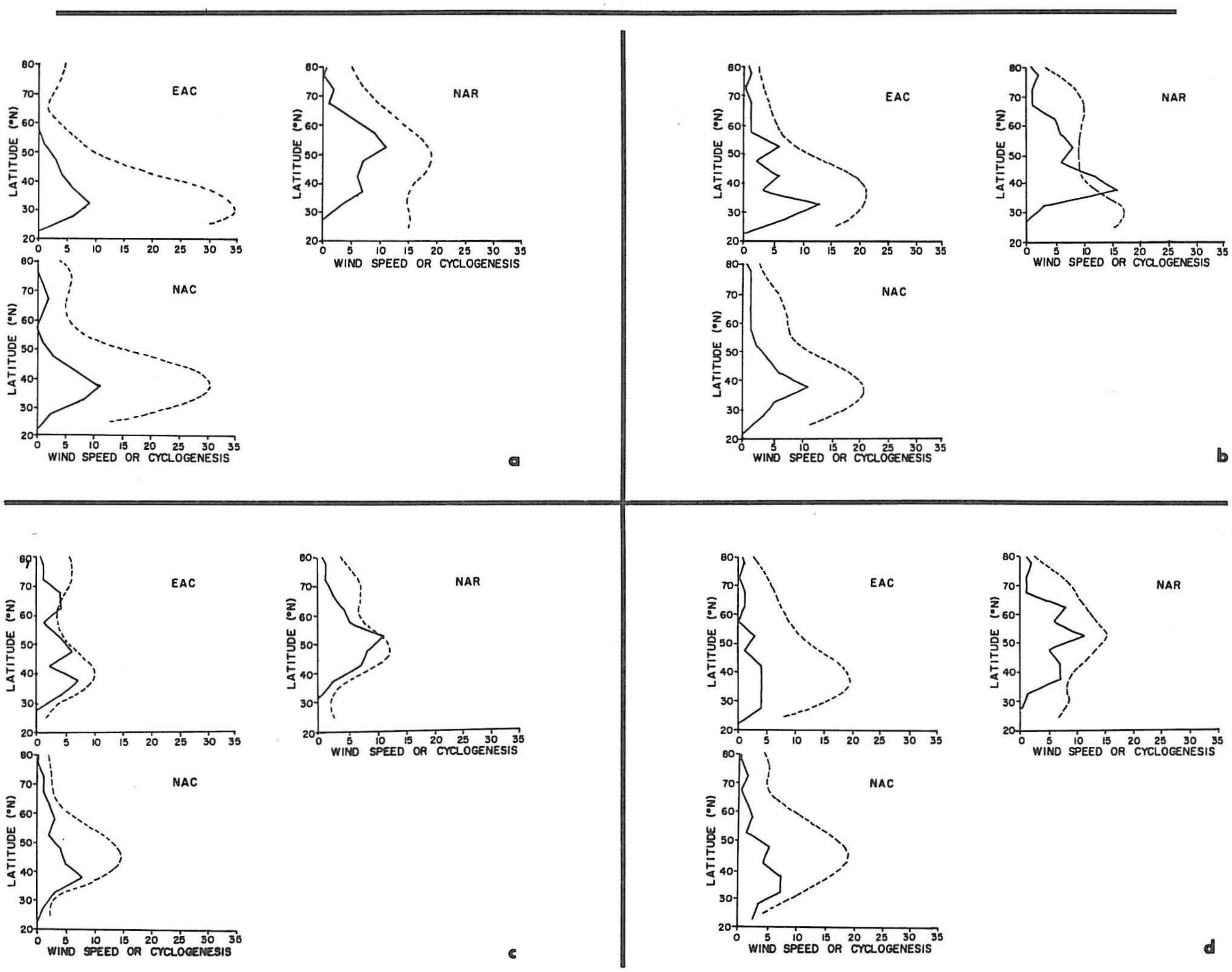


Figure 7. Meridional profiles of cyclogenesis (normalized for 30-day months; solid) and 500 mb geostrophic wind speed (m s $^{-1}$; dashed) for: East Asian coast (EAC), North American Rockies (NAR) and North American east coast (NAC). Data averaged for each 5° latitude belt. a) January, b) April, c) July, and d) October.

FOOTNOTES AND REFERENCES

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