INCREASED MERIDIONALITY AND WEATHER ANOMALIES

(Based on the Study of the Winter

1976-77 over North America)

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

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Montreal, Quebec

January, 1979

ABSTRACT

The abnormal winter of 1976-77 over North America is examined in this paper. From the point of view of the general circulation it was found that a negative 500 mg height anomaly over the Pacific Ocean, a positive deviation over the Northwest America and a negative deviation over the Mid-eastern United States were associated with an amplified trough-ridge-trough pattern over Pacific-W. coast-Mid-eastern United States. It was also found that the "blocking" activity over the West coast, as a function of the increased meridionality of the zonal flow, was the highest in the last 28 years resulting in the extreme climatic characteristics which took place over North America during this period.

RESUME

Cette étude porte sur l'hiver anormal de 1976-77, au-dessus de l'Amérique du Nord. Du point de vue de la circulation générale, la hauteur de la surface isobare 500 mb présente une anomalie négative au-dessus de l'Océan Pacifique, une dénation positive au-dessus du Nord-Ouest de l'Amerique du Nord et une déviation négative au-dessus du Mid-Est des Etats-Unis. Ces anomalies sont associeés avec un patron amplifié creux-crête-creux au-dessus du Pacifique, de la côte Ouest et du Mid-Est des Etats-Unis. On montre aussi que l'action de blocage sur la côte Ouest, en fonction du flux méridional accru, est la plus grande des 28 dernières années. Ceci entraîne les conditions climatiques extrêmes qui sévirent au-dessus de l'Amérique du Nord durant cette période.

ACKNOWLEDGEMENTS

This study was conducted under the supervision of Dr. E. Vowinckel, to whom I wish to express the deepest gratitude for his assistance and guidance.

I am also indebted to Dr. J. Derome for his beneficial advice.

I wish to express my thanks to Mr. A. Schwartz who often helped me with programming advice. I am grateful to the Department of Meteorology of McGill University whose financial support made this study possible.

I am also grateful to my colleague, A. Gergue, for discussion and to Miss Susan Lambe for corrections of the language. I also wish to give my appreciation to Ms. U. Seidenfuss and Ms. E. Karanicola who prepared part of the drawings and to Mrs. Kathy Peterson who typed the manuscript.

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Gas constant	R	287 J/Kg·k (for dry air)
Earth's angular velocity	$\underline{\Omega}$	7.292×10^{-5} sec^{-1}
Mean radius of the earth	a	6.371×10^{6} m
Specific heat at constant pressure	C_p	1005 J/Kq·k (at 273 K)
gravity	g	9.81 m/sec^2

LIST OF ABBREVIATIONS

dm - decameters

mb - milibars

"m.h.v." - mean hemispheric value

CHAPTER 1

INTRODUCTION AND DATA MANIPULATION

1.1 INTRODUCTION

During the end of 1976 and the beginning of 1977 a severe weather anomaly took place over North America The experience of meteorology ascertains that a weather abnormality is something that is not unusual. Despite this, rigorous weather patterns over large and important regions of the earth immediately draw our attention. One of them is indisputably the one under examination.

Some current descriptions of the 700 mb circulation and also of the variability of the circulation during each month of this period, are given in Monthly Weather Review by Wagner (1977 b, c), Dickson (1977) and Taubence (1977), stressing the importance of a ridge over the West coast. Other numerous statistics of observed temperatures and precipitation accompany these reports. Namias (1978) examining mainly January 1977 pointed out that the abnormality was connected with a sea surface temperature anomaly generated over the Pacific Ocean in spring and summer.

This work attempts, at first, to define the duration of the negative temperature anomaly at the surface, over the Mid-eastern United States as well as the most affected regions, based on the use of monthly means. The persistence of the anomaly must be investigated using a shorter time interval. The question whether an anomaly can exist alone or is connected with a certain wave structure over the hemisphere or is a local phenomenon (meaning that an anomaly may be connected with other nearby anomalies) should be examined. Another point which is investigated is whether the existance of a ridge, as previously mentioned by other authors, is a necessary condition to cause this abnormality and the associated climatic characteristics. The final question which will be investigated is whether there is a certain synoptic situation which usually results in this type of abnormality In the case that such a synoptic situation does exist, another area with similar synoptic conditions will be investigated to determine whether there is again a connection between the synoptic condition and the climatic characteristics.

1.2 METHOD

Practically speaking, it is rare that a particular area will experience a "normal" surface or circulation pattern over a time span of say a week or a month. The point which distinguishes one abnormality from another is first its persistence, second its intensity and third its areal extent.

An anomaly of any parameter pres upposes that there is something called "normal." The value of the parameter has to deviate by a certain amount in order for the anomaly to be significant. The simplest of definitions is that an anomalous condition is significant if the value of the parameter differs from the mean value by a certain amount. In this definition, no statements are made about the shape of the frequency distribution of the parametric values (i.e. whether it is guassian or not). A number of meteorological parameters, temperature for instance, have reasonably normal distributions. Therefore, a statistically more satisfying method of defining an anomaly would be in terms of exceeding the mean value by one or more standard deviations.

The disadvantage of using this method of definiton is that generally the standard deviation varies not so much locally but over larger areas (latitude belts for example). Data over some areas sometimes may not be available, therefore the data must be bogused in some way. This has the consequence that the intensity of the anomaly centre as well as the longest persistences will be found in an area with the largest standard deviation. Also, if for instance temperature is considered, its variability changes sharply in different geographic regions, generally lower variability in low latitudes. The opposite is true for precipitation, which reaches its maximum variability on either side of the sub-tropical high belt, and is the least in the westerlies. It is apparent then that difficulties will be encountered if one deviation parameter is to be related to another deviation parameter as will be attempted in this study.

A further difficulty with this definition of the abnormality is that it assumes that no long term trend exists in data chosen for calculations. However, for an extended time series, there is no doubt that trends do exist. Trends must be eliminated, however, the decision as to what is regarded as a long term trend or simply a short term fluctuation would need further definition. It was therefore decided to sidestep the problem in that the investigation will be based on a case where the fact of the abnormality is beyond the doubt of any definition. This was the cold winter 1976-1977 in North America.

The second question to be investigated is the period of averaging of the original temperature observations. The shortest time interval which could be considered is probably the day. The cold anomaly would then be defined, in its duration, as the period during which the temperature at a certain place remained continuously below a fixed amount. Figure 1 shows, for the station Sault St. Marie[1], the temperature variation against the normal duringthe period from October to January using different time intervals. The thick solid line is the normal temperature. The dashed line shows the mean monthly observed temperature. The thin solid line represents the observed 5-day mean and the dotted line the observed daily temperature. It is apparent from this figure what effect the choice of a time interval will have to the duration of the anomaly. The monthly means show that all four months from October to January are below normal. Using 5-day means three 5-day periods were above normal; while using daily values 25 days recorded above normal.

In order to understand what an anomaly is, it would be best to adjust to the everyday meaning. However, the human weather memory is certainly longer than one day, but shorter than a year. Here subjective impression and objective calculations start to differ. Usually months or seasons can be recalled.

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[1]According to the "Monthly Record" series of 1976 and 1977 the cold anomaly was considered intense at this station.

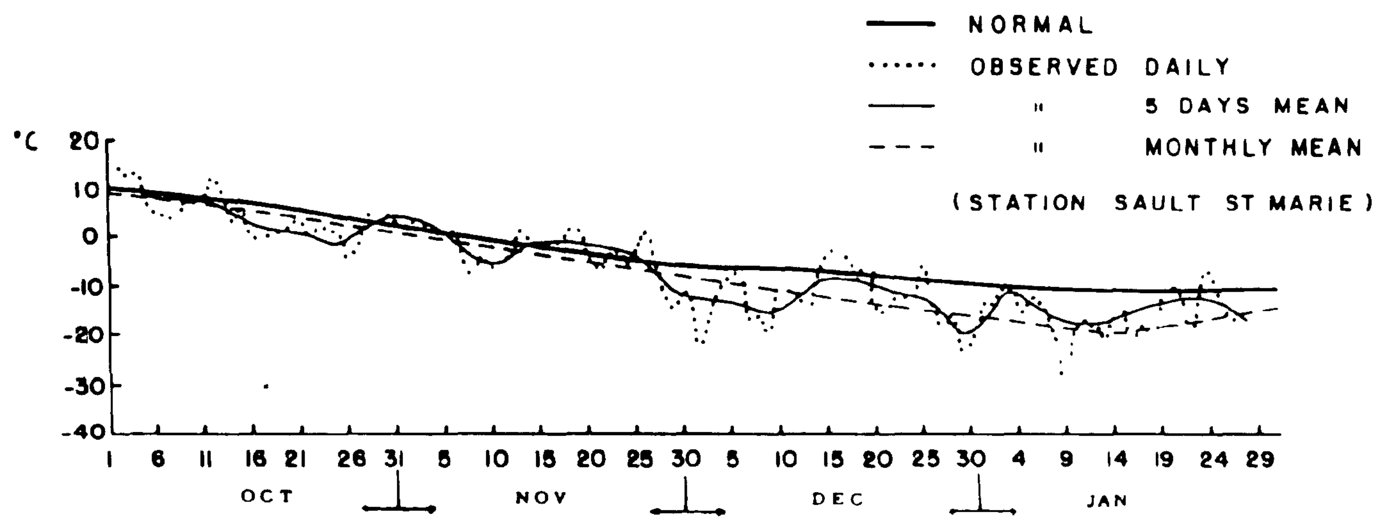

Figure 1 Observed daily, 5-day mean and monthly temperatures versus normal at Sault St. Marie

This is aided by the fact that most climatic data are published in the form of monthly means. It was therefore decided to use the monthly means as the main time period to represent the duration of the temperature anomaly.

The disadvantage of this choice is that a monthly mean is, or may be, composed of highly different synoptic periods. The synoptic period or "grosswbbetage tage" is the longest period for which causal (i.e. physical reasoning) is, at present, reasonably based. This investigation must therefore break down the monthly period into shorter intervals. The 5-day period was chosen as this interval. It has the advantage of eliminating the quick moving synoptic highs and lows, while the large-scale circulation patterns are maintained.

The final point which has to be taken under consideration is the area which remains under the anomaly. An anomaly over a small area could either be accidental or a purely local phenomenon (usually caused by a geographical abnormality). Thus the area which remains under the anomaly should not be smaller than a limit. This limited area is a function of the available data and it will be defined in Chapter 2.

1.3 DATA DESCRIPTION

The available data which will be used is mainly 500 mb height field and 1000-500 mb thickness, given in a daily and in a pentade scale as 5-day-mean. This data was distributed from England to the Atmospheric Environment Service of Canada. The data set is organized in grid points of 5° of latitude and 10° of longitude from 25°N up to the North Pole, as Figure 2 shows.

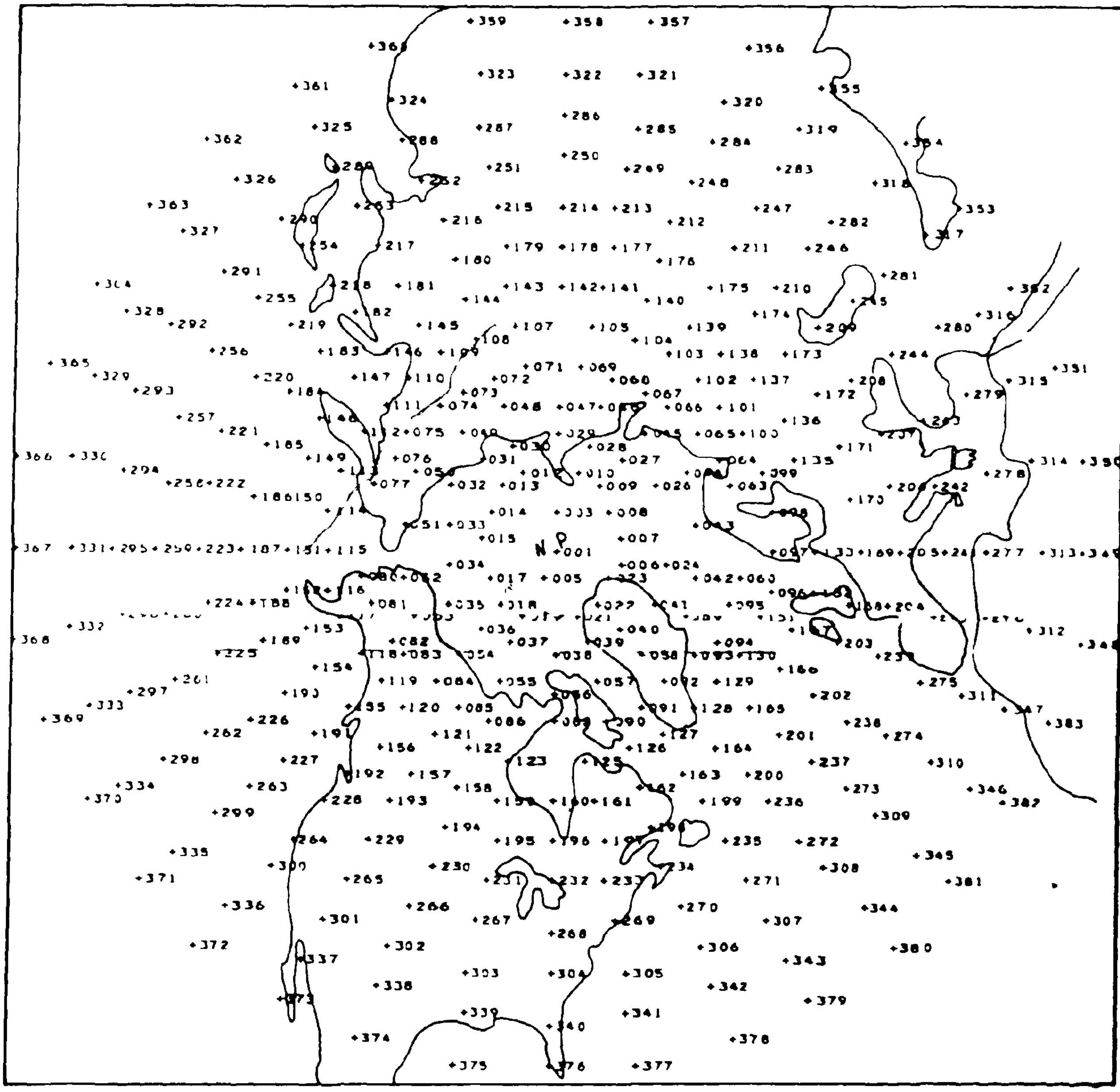

Figure 2 Distribution of grid points around the Northern Hemisphere (polar stereographic projection true at 60° N Map scale 1:60,000,000)

The data contained a complete set of daily grid point values for the years 1972-1976. Twenty-eight years from 1949 to 1976 were also available from the same source but were missing data over the Pacific Ocean previous to 1972. In addition, during this investigation complete 500 mb height values were added for 1971 and 1977. Monthly weather maps were also available from the German Die Grosswetterlagen Europas which give upper air circulation at the 500 mb level as well as surface conditions. 500 mb height and 1000-500 mb thickness anomalies are given, from the same source, on a monthly basis everywhere except the Pacific Ocean, as a departure from a normal value calculated from the years 1949-1973. Monthly temperature and precipitation anomalies are also available on the same basis. Daily weather maps at 00z G.M.T. from the German Europaischer Wetterbericht were also available. In addition, data for certain stations were found in the "Monthly Record" (Meteorological observations in Canada), available in the library of the Department of Meteorology at McGill University.

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[2] Inspecting these data for possible erros it was found that, during the 5-day period from the 2nd until the 6th of November 1976, the 500 mb height values appear significantly lower than the values of the previous and next 5-day period. A comparison between these values and values extracted from the German maps, shows that there is a significant difference. In order to avoid possible implications the data of this 5-day period were replaced from values obtained by a linear interpolation between the values of the previous and the next 5-day period. On the average this did not affect the "mean" monthly picture. Comparison with monthly pictures given from the German maps gives very close results.

CHAPTER 2

THE COLD IN THE MID-EASTERN UNITED STATES

2.1 DEFINITION OF TEMPERATURE ANOMALY - DURATION AND THE MOST AFFECTED REGION

It was mentioned in the discussion in Chapter 1 that the area which remains under the temperature anomaly should not be smaller than a defined limit. The defined limit in this case is a function of the available data. Since only grid-point data are available, distributed every 5° of latitude and 10° of longitude, this limited area is arbitrarily defined to be the area which included between a 20° longitude belt and a 10° latitude belt at the middle latitudes.

Figure 3 was produced using the German Die Crosswetterlagen Europas maps, showing the individual monthly $0^{\circ}C$ temperature anomaly isoline and the centre of the negative temperature anomaly from October 1976 to January 1977. There is also negative anomaly in September 1976 and in February 1977, but these were not indicated simply because it confuses the figure rather than adding useful information. Previous to September and after February there is no negative anomaly at all over this area. It is apparent from this figure that, in general, the anomaly was shifting or extending its position in time with the result that only certain areas remained continuously under a negative influence. It is further evident from the individual monthly anomaly isolines that this shifting or extension was not a steady progression but simply an oscillation about a main position. Moreover, what will be defined as the duration of the anomaly must be of a certain length in order for the area

Legend

October
November
December
January

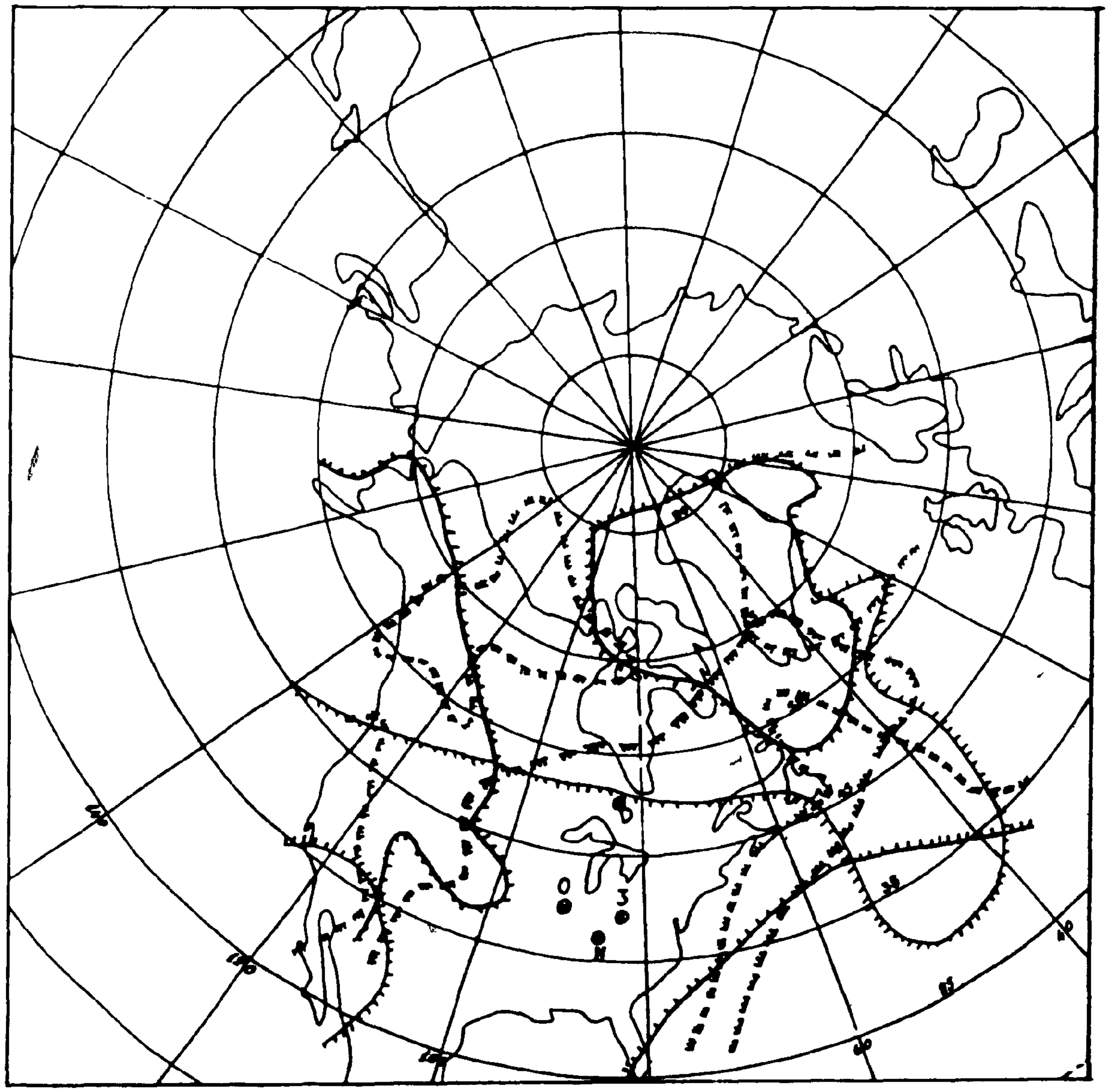

Figure 3 0° C. isoanomalies for the months of October to January inclusive to remain larger than the defined limit. It will be observed that by increasing the length of the duration of the anomaly smaller and smaller areas remain under the influence of any negative value, such that after an extended period of time the area will be smaller than the defined limit. It must, however, be emphasized that there may be more than one definition of the temperature anomaly which could satisfy the area criterion. In this case the most restrictive case will be considered.

According to these standards let us test at first the $0^{\circ}C$ departure from normal as a definition of the temperature anomaly. In other words an area is considered under the anomaly if the departure from the normal is just less than zero. The technique which was used to find the area was based on the utilization of mean monthly means. By taking the $0^{\circ}C$ isoanomaly for each month and finding their intersection one can get the area which remains under the anomaly for any time period. If the area after a certain time period becomes smaller than the defined limit the anomaly ended. This way the duration will be found as well. Figure 4 shows the area which remains under $0^{\circ}C$ anomaly from October to January indicated by the thick solid line. This area is large enough and satisfies the area criterion. If February will be considered this area becomes smaller than the limited area (not shown in the figure). If September will be considered, the area which is indicated by the dotted line is taken to be the area which remains from September to January under the anomaly. This area satisfies

Legend

—— Area under 0° C. anomaly from Oct. to Jan.

...... Area under 0° C. anomaly from Sept. to Jan.

– – – Area under -4° C. anomaly for October

—— Area under -4° C. anomaly for November

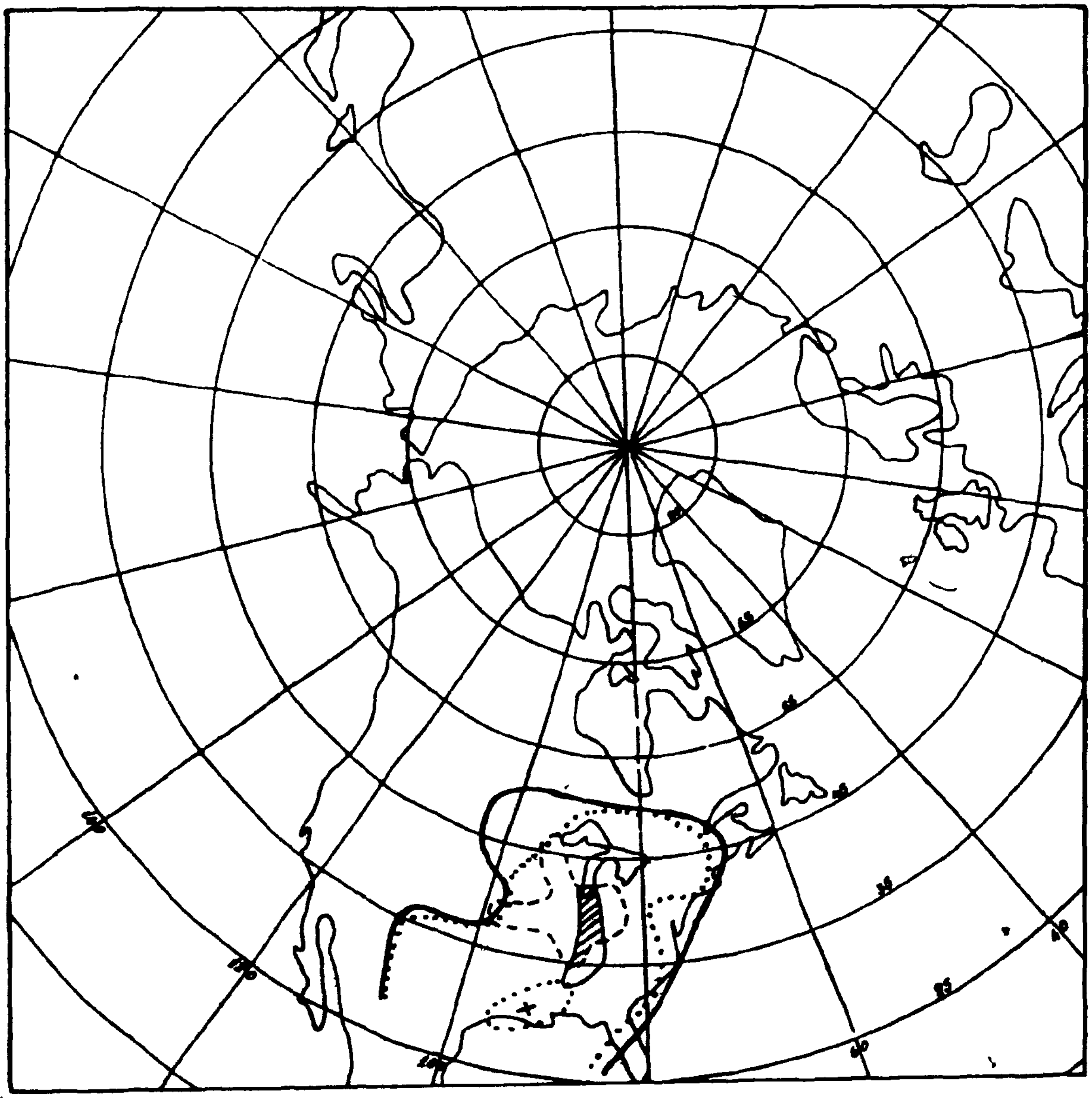

Figure 4 Area enclosed by isoanomalies for certain periods (positive area denotes positive temperature deviation for September only)

also the area criterion.

Let us now test as a definition of temperature anomaly the $-4^{o}C$ departure from normal. Working similarly as in the previous case, the area which is shown in Figure 4 by the dashed line is taken to be the area which is under negative temperature anomaly in October. (There is no $-4^{o}C$ anomaly in September.) For November the area which is shown, in the same figure, by the thin solid line is taken. Both areas are small and they get smaller by increasing the time, as can be seen by considering the area which remains under the negative influence in both October and November (indicated by horizontal lines in the figure).

Finally let the definition of the temperature anomaly be the $-2^{o}C$ departure from normal. In Figure 5, the region which was under temperature anomaly for four months (October 1976 to January 1977) is indicated by the horizontal lines. The vertical lines indicate the area which was under anomaly for five months (October to February), and the solidly shaded area shows the area which remained for six months (September to February). The two last areas are relatively small while the first is large enough to satisfy the requirements for the area criterion.

It is then apparent that during the period from October to January, two definitions, the $0^{o}C$ and the $-2^{o}C$ departure from normal satisfy the area criterion.[1]

[1] The $-3^{o}C$ definition was tested but it was not satisfactory as the $-2^{o}C$ definition, from the area point of view.

Legend

═══	Area under -2° C. anomaly from Oct to Jan
ǀǀǀǀǀǀ	Area under -2° C. anomaly from Oct to Feb
▬	Area under -2° C. anomaly from Sept. to Feb

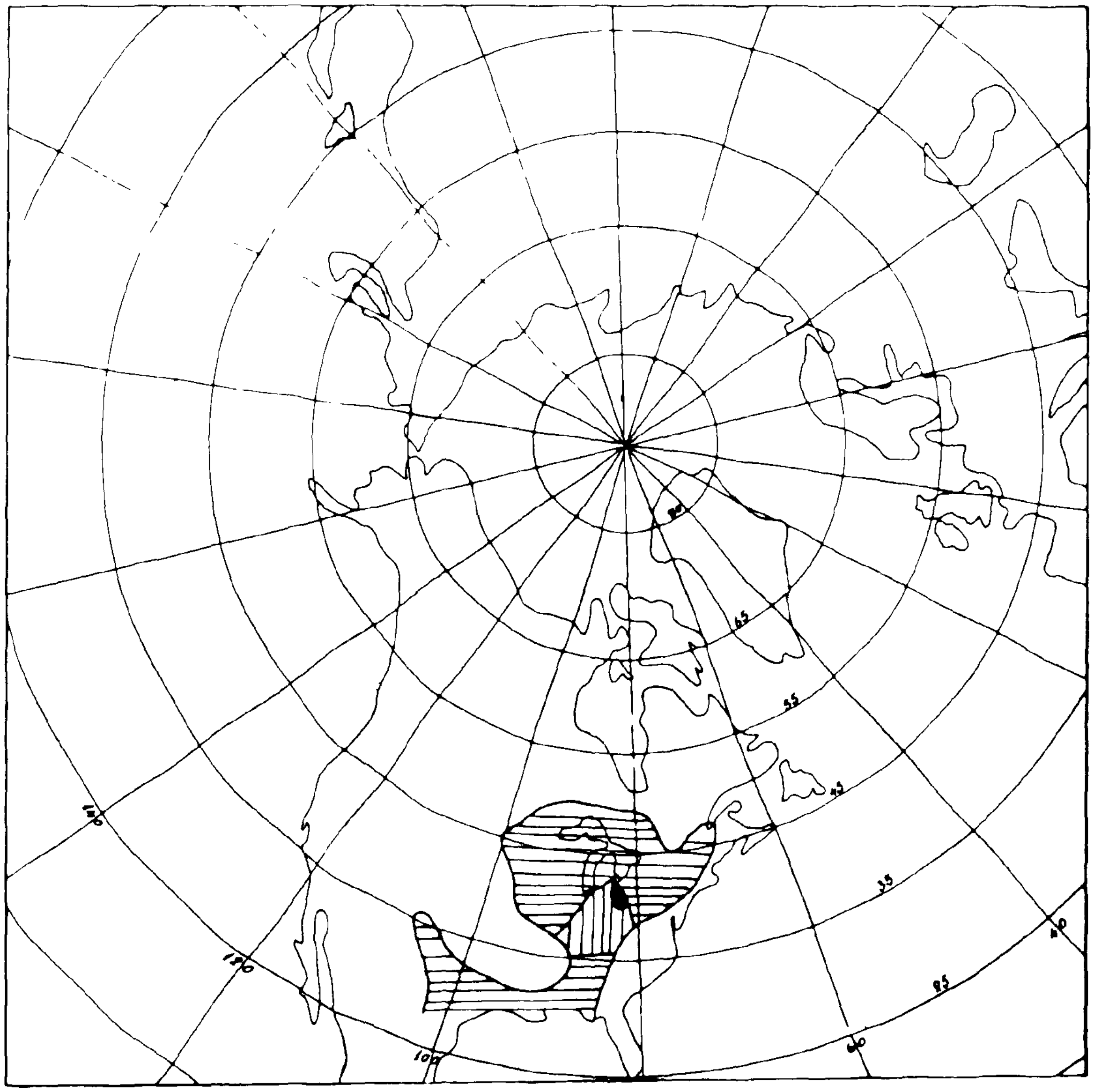

Figure 5 Area under -2° C. anomaly for 4, 5, and 6 months

(It is obvious that the $-1^{\circ}C$ definition will satisfy the same criterion.) It is also apparent that the area given by the $0^{\circ}C$ definition, is a somewhat greater area than the corresponding of the $-2^{\circ}C$ definition. Both areas are large enough and the region where the intensity of the cold was more pronounced[2] (Great Lakes and the area just to the south of them) is included in both definitions. Of course, it was shown that the $0^{\circ}C$ definition can give also a duration from September to January. It was the author's decision not to consider this case, first, because in September the negative temperature anomaly is very weak and secondly because as it will be seen the 500 mb height anomaly started mainly in October. To this decision contributes, also, the fact that the $-2^{\circ}C$ definition gives a reasonably long duration and is more restrictive. Thus, the definition of the temperature anomaly was decided to be the $-2^{\circ}C$ departure from the normal. According then to area criterion the duration of the anomaly is four months, from October 1976 to January 1977.

2.2 COLD RECORDS

According to Figure 5 the most affected region is that which contains all or part of. Minnesota, Michigan, Indiana, Ohio, New York, Pennsylvania, Wisconsin, Kentucky, West Virginia and southern Quebec and Ontario, an area of 1.5×10^6 km^2 approximately. Table 1 gives a first impression of the intensity of the cold spell[3].

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[2] According to "Monthly Record" series for 1976 and 1977.

[3] This table was constructed using statistics given by Wagner (1977a, b), Dickson (1977) and Taubence (1977).

TABLE 1

PLACES	OCTOBER	NOVEMBER	DECEMBER	JANUARY
Cincinnati	one of the coldest	the coldest	coldest	coldest
Buffalo	2nd coldest in last 50 years	the coldest	coldest	coldest
El Paso	the coldest	the coldest	one of the coldest	one of the coldest
Tallahassee	the coldest	2nd coldest	one of the coldest	2nd coldest since 1940
Chicago	one of the coldest	coldest	one of the coldest	coldest
Tulsa	one of the coldest	coldest	one of the coldest	5th coldest since 1918
Dayton	coldest since 1925	coldest	coldest	coldest

2.3 DESCRIPTION OF THE COLD SPELL IN KEY STATIONS

In this section the monthly temperature departure from the normal in some key stations will be examined in order to determine:

a) <u>where</u> it had the maximum intensity

b) <u>when</u> it had the maximum intensity for each station.

Table 2 gives the departure of the mean monthly temperature from the normal for certain stations from August 1976 to February 1977.

TABLE 2

STATION	AUG	SEPT	OCT	NOV	DEC	JAN	FEB
Sudbury	-0.9	-1.2	-3.2	-3.7	-5.3	-3.5	-0.2
Minneapolis	0.0	-0.6	-4.0	-3.5	-5.2	-6.8	3.1
Chicago	-1.7	-1.0	-3.9	-4.0	-5.0	-8.9	-0.5
Detroit	0.3	-1.6	-3.5	-3.5	-4.6	-7.0	-1.5
Buffalo	-0.4	-1.5	-2.5	-3.2	-4.7	-5.6	-0.9
Cincinnati	-1.7	-2.8	-4.2	-3.6	-3.7	-10.1	-1.5
Toledo	-0.6	-2.5	-4.0	-3.5	-4.4	- 9.0	-2.8
							4.2 for Mar.

Using this table "accumulated curves" were drawn for each station separately. These "accumulated curves", as shown in Figure 6, indicate the following: The value for every month itself plus the sum of the values of the previous months for the period of August through February.

Because it was defined that a station was under negative anomaly when the mean monthly temperature departure from normal is at least -2^{O}C the "accumulated curves" indicate that anomaly started and continued when both of the following conditions were satisfied:

a) the curve becomes more negative as a function of time;

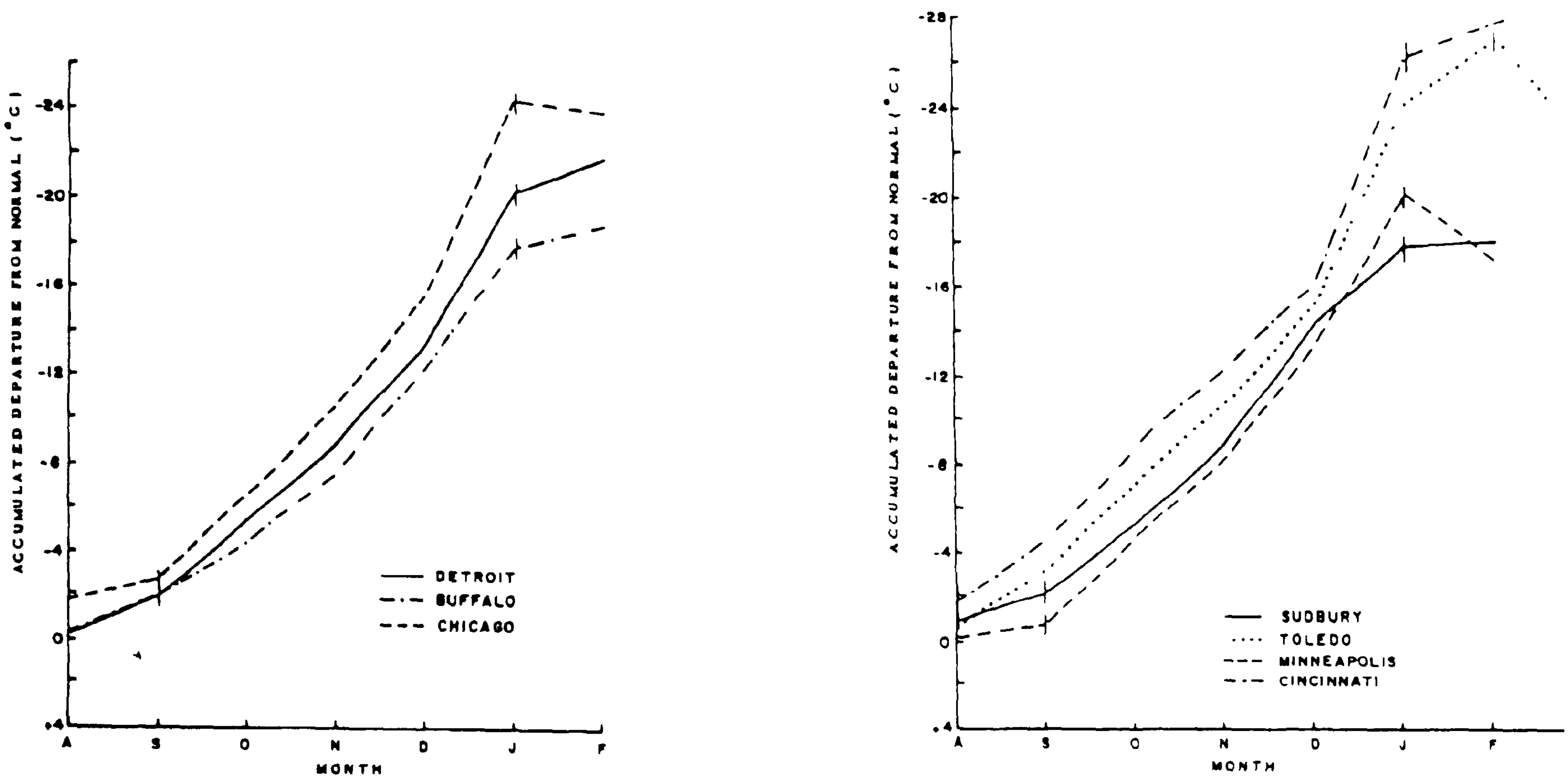


Figure 6 Accumulated curves

b) the slope of the curve between two months satisfies the condition (only for scale of this figure)

$$\tan\phi \geq \frac{1}{2}$$

where ϕ is the angle of the line between two months, and the x-axis.

Then the maximum total accumulated amount could give the maximum mean intensity, and the maximum slope could indicate when the maximum intensity for each station occurred. The small parallels to y-axis lines show the start and the end of the anomaly in these specific stations. As can be seen by investigating these curves the anomaly started in October and ended in January everywhere except in Cincinnati and Toledo, where the anomaly lasted longer as is also indicated in Figure 5. It is also observed that everywhere the intensity of the cold increases almost linearly from October to December. In January the slope of the curves appear greater than in the previous months. Since these curves show the accumulated departure from the normal, their linearity from October to December means that the anomaly stayed almost at the same intensity during the months October, November and December, and presented an increase of its intensity in January. It will be seen in Chapter 4 that this is due to the circulation during this period.

CHAPTER 3

THE 500 MB HEIGHT PATTERN

3.1 DEFINITION OF THE 500 MB HEIGHT ANOMALY

Thus far, only the conditions of the surface temperature field have been considered. If this anomaly is caused by a large scale shift in the circulation, a similar anomaly would have to be found by examining the large scale circulation pattern at 500 mb, and thus deducing the weather situation which took place. Moreover, if a circulation anomaly could be defined it should become clear, how and what other parts of the hemisphere are affected in terms of the specified definition.

The endeavor here is, at first, to make the definition of the 500 mb height anomaly correspond, as much as possible, to the definition of the surface temperature anomaly. In other words the purpose is to define an appropriate value for a 500 mb height anomaly such that the duration and the area of this anomaly correspond to those of the surface temperature anomaly. Of course it must also satisfy the criteria stated on page 9 .

Repeating the method which was used to find the duration and the most affected area in the case of the surface temperature anomaly, the most satisfactory definition of the 500 mb height anomaly was found to be a ±4 dm departure from normal. Figure 7, which shows the area which remains under the -4 dm anomaly during different periods, was obtained using, once again, the monthly means according to the German maps. The dashed line shows the area which remains under -4 dm anomaly

Legend

Area under -4 decameters 500 mb height anomaly from Oct. to Jan.

Area under -4 decameters 500 mb height anomaly from Oct. to Feb.

Area under -4 Decameters 500 mb height anomaly from Sept. to Jan.

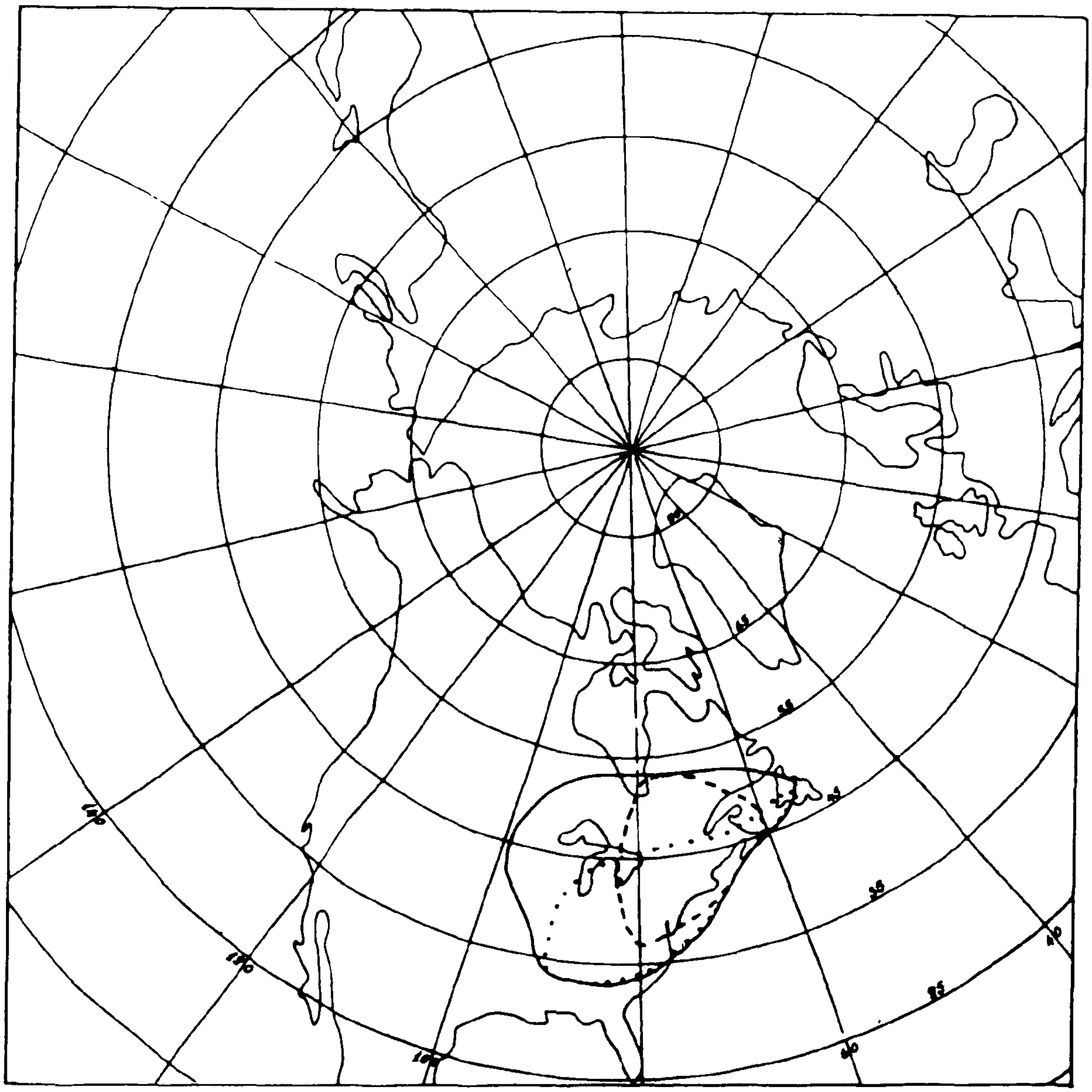


Figure 7 Areas enclosed by -4 decameter 500 mb height isoanomaly for 4 and 5 month period

from September through January, the dotted line from October to February and the solid line from October through January. As can be seen, according to the area criterion, the anomaly lasted four months. In addition comparing Figure 7 and 5 the area which remains under 500 mb height anomaly, from October to January, is well related to the area of the surface temperature anomaly for the same period.

Given this information it would be interesting to see if there are any other 500 mb height anomalies associated with the negative 500 mb height anomaly over the mid-eastern United States. Moreover, if these anomalies exist, to see if they are related to a hemispheric or a smaller scale phenomenon. In other words whether there is a stable wave pattern over the Northern Hemisphere (with data given from 25°N up to the North Pole) which may or may not result in a hemispheric anomaly pattern.

3.2 "MEAN ANOMALY MAP"

For each grid point, the monthly 500 mb height anomaly is given. Averaging this value for the period from October to January the mean anomaly, for each grid point, is found. Drawing the isoanomals Figure 8 is given which shows the distribution of the "mean anomaly" over the Northern Hemisphere. Solid isolines correspond to negative anomaly and dashed isolines to positive anomaly. It is obvious that the maximum "mean anomaly" values define the "mean centres" of the anomalies, which is a reasonable approximation, indicating that the centres

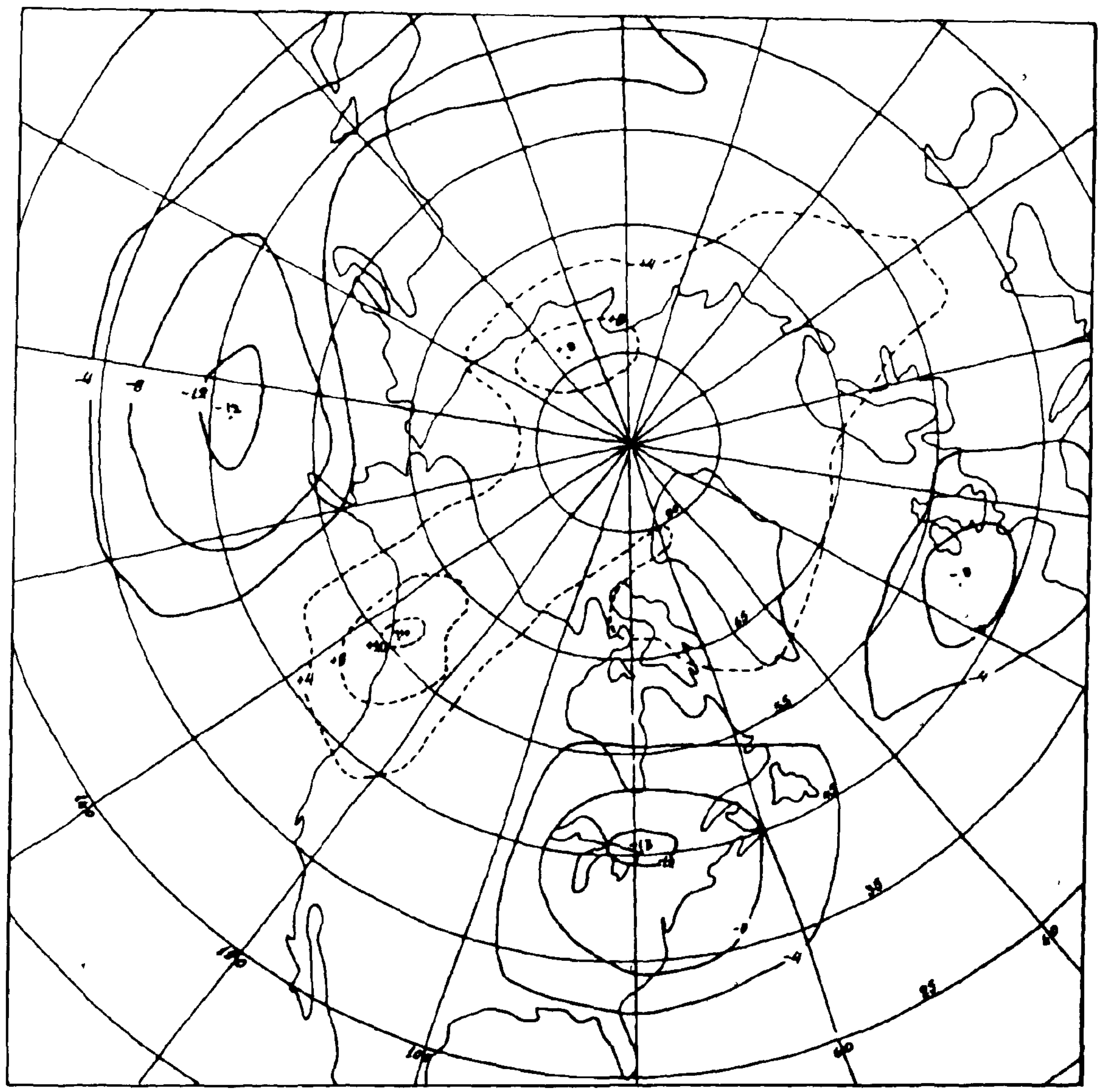


Figure 8 Mean anomaly map

of the anomalies were during this period, positioned most of the time there. Since this figure, called "mean anomaly map", is the averaged map for the whole period it could be used as a first indication of the relation between the anomalies around the Northern Hemisphere during this period. The criterion for the relationship will be, of course, the average magnitude of the anomalies, or the "mean centre" value; in other words the intensity of the mean anomalies. From this point of view the first interesting observation is the fact that the magnitude of the maximum "mean" values, over the mid-eastern United States, over the Pacific and over the Northern W. coast are very close to each other (-12 dm, -13 dm, +10 dm respectively). Also, a mean negative anomaly with a "mean centre" of -8 dm over the eastern Atlantic and western Europe, together with a small positive anomaly near the North Pole ("mean centre" of +8 dm) is included on the "mean anomaly map."

3.3 THE CORRESPONDING MEAN OBSERVED AND NORMAL CIRCULATION

Figure 9 gives the corresponding observed mean circulation at 500 mb from October through January. Figure 10 shows the normal mean circulation for the same period. Comparing these two figures with the "mean anomaly map" it is observed that the three anomalies, over Pacific-West Coast-Mid-eastern United States, are in phase with the normal pattern while the other anomalies over the Northern Hemisphere are not. In other words, these anomalies were under an intensified trough-ridge-trough pattern in a pregiven position of the normal trough-

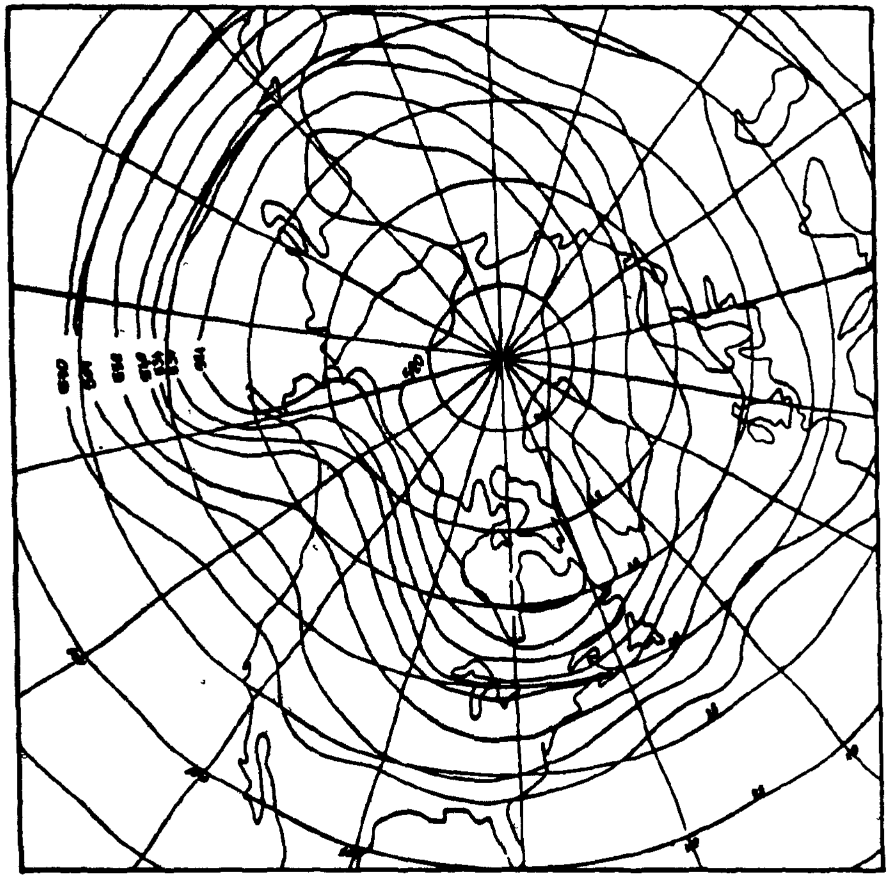


Figure 9 **Mean observed 500 mb circulation for the period of Oct. to Jan.**

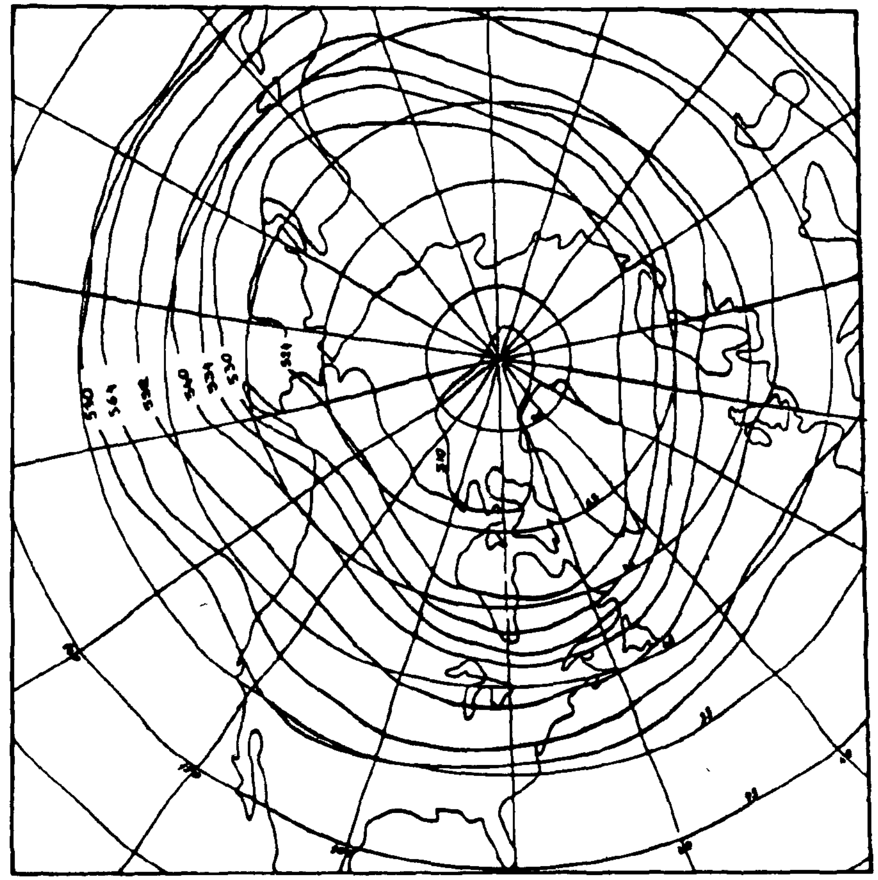


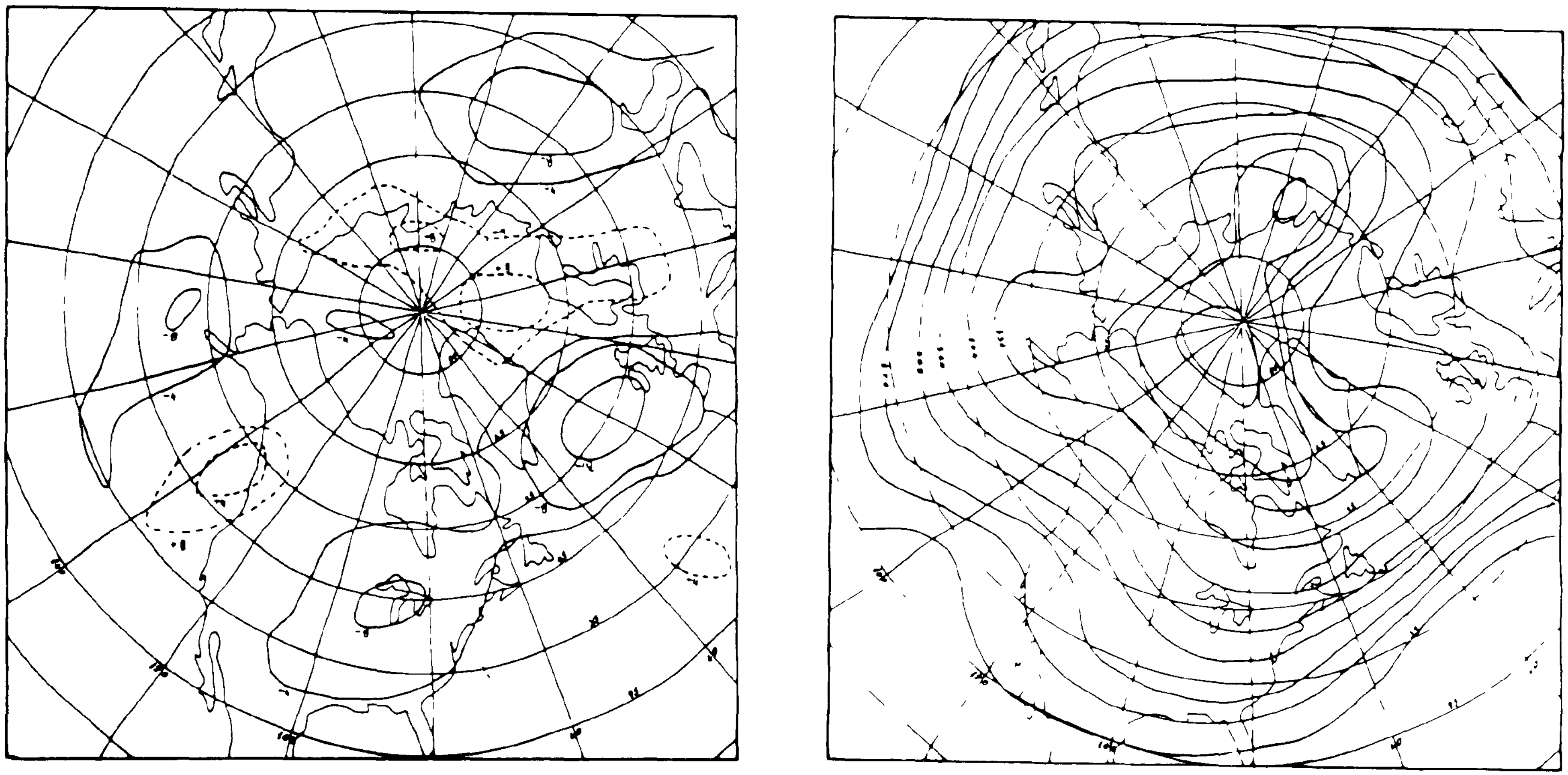
Figure 10 Normal 500 mb circulation for the period of Oct. to Jan.

ridge-trough pattern, resulting in an increased northernly flow over the area of the negative temperature anomaly. The negative anomaly over eastern Atlantic and western Europe was under a slight trough which replaced the normal slight ridge; in other words being out of phase with the normal pattern. The same can be applied for the small positive anomaly near the North Pole.

3.4 MONTHLY ANOMALIES AND THE CORRESPONDING CIRCULATION

Moving now to the monthly time base, Figures 11 - 14 show the anomalies and the corresponding circulation for each month from October to January. Figure 15, which was produced using Figures 11 - 14, shows the distribution of the anomaly centres as well as the 548 dm height isoline for each month. A plus sign corresponds to a positive centre and a minus to a negative one. The letter in parenthesis indicates the month (O for October, N for November, etc.).

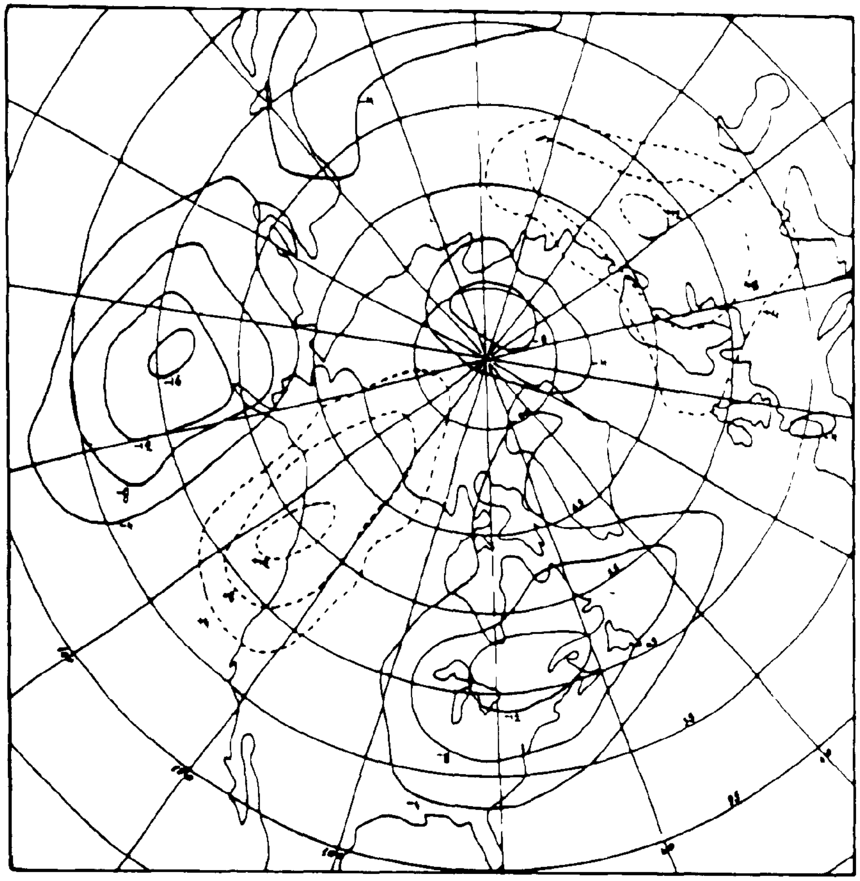
As can be seen, by examining these maps, during the whole period a negative anomaly over the Pacific, a positive anomaly over the northern part of the W. coast and a negative anomaly over the mid-eastern United States prevails while over the rest of the Northern Hemisphere nothing seems to be so permanent. As shown, from the distribution of the centres around the Northern Hemisphere, the negative-positive-negative anomaly pattern over Pacific-W. coast-Mid-eastern United States is quite permanent, while elsewhere the distribution seems to be rather random. Over the eastern Atlantic and western Europe, for



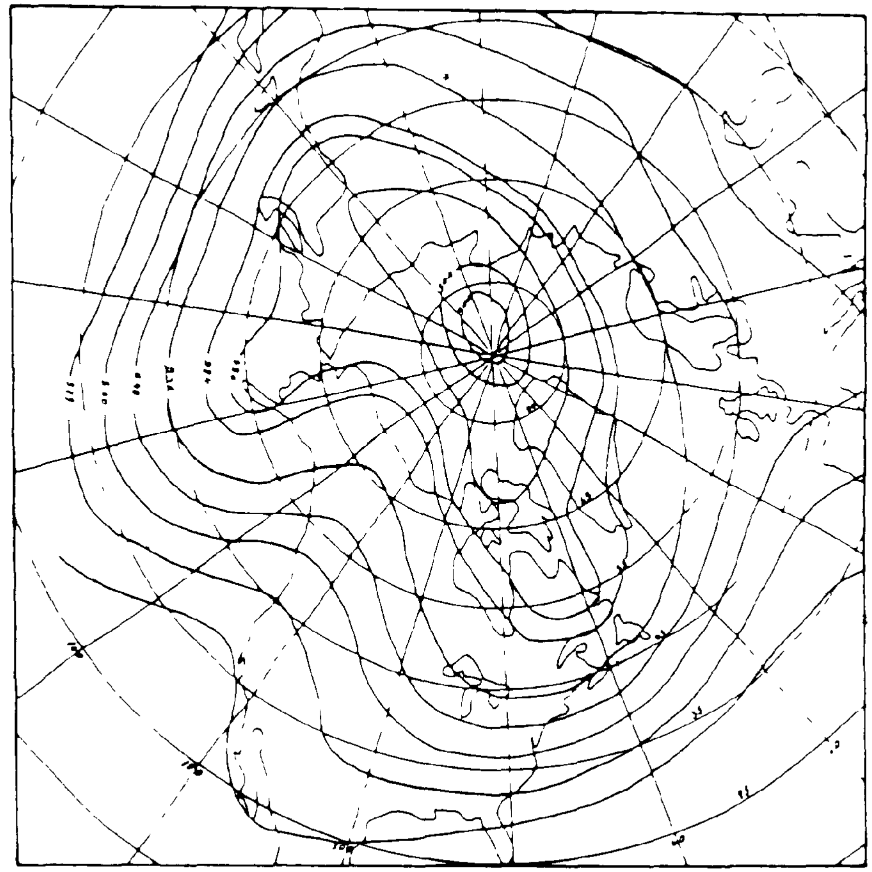
(a)

(b)

Figure 11 500 mb a) height anomalies for October and b) circulation for October

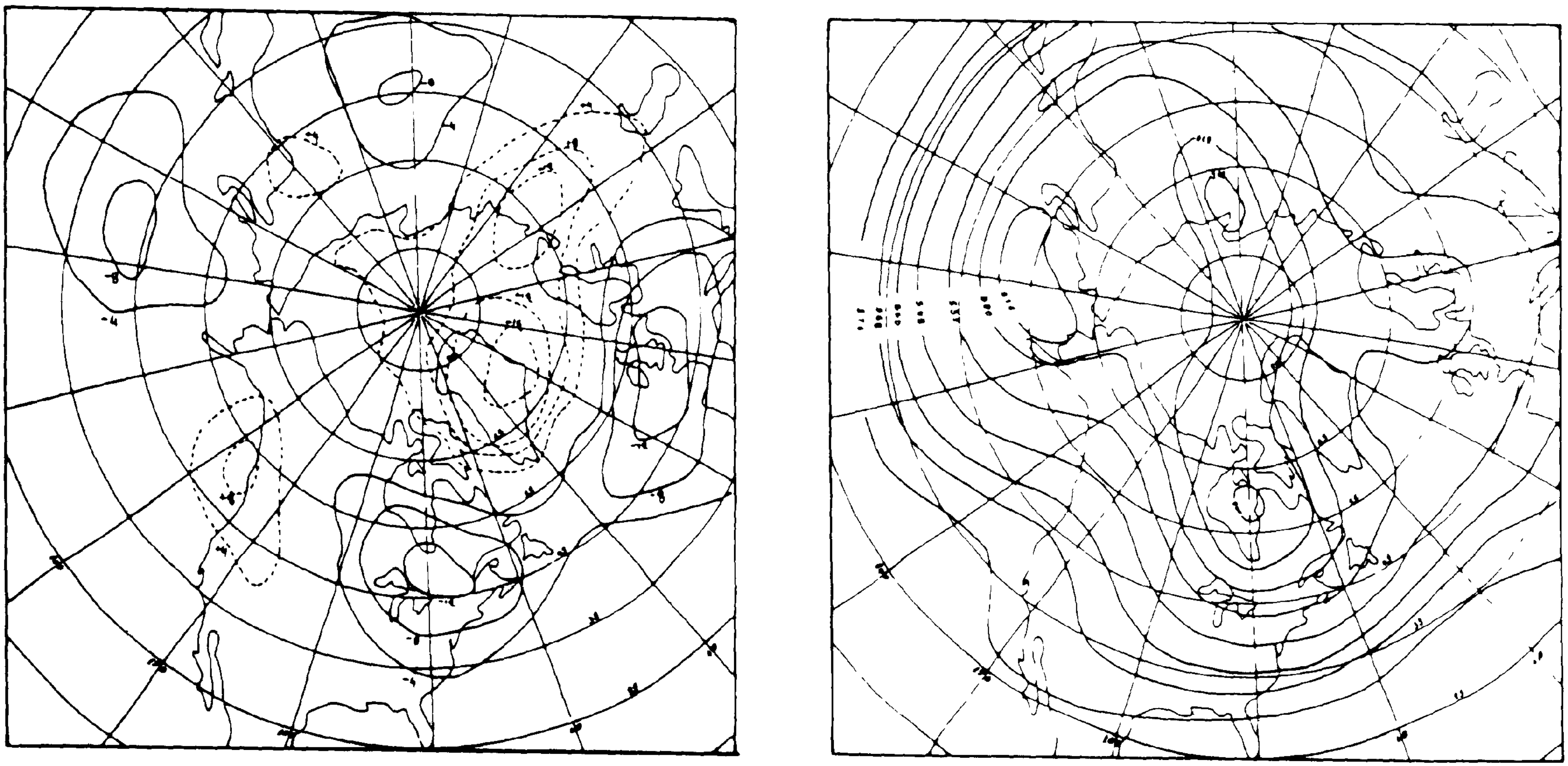


(a)



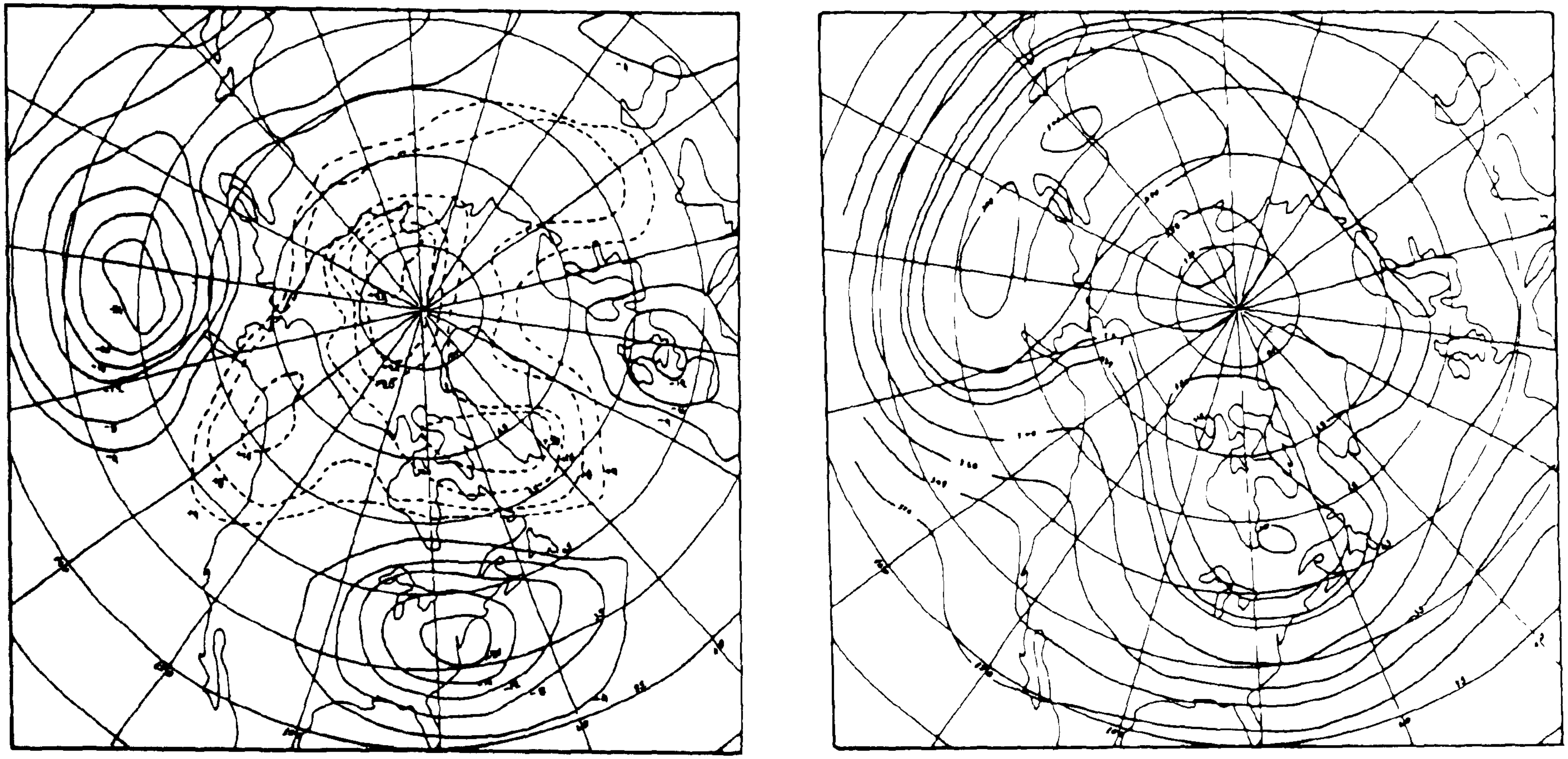
(b)

Figure 12 As in figure 11 except for November



(a) (b)

Figure 13 As in figure 11 except for December



(a) (b)

Figure 14 As in figure 11 except for January

Legend

——	500 mb 548 decameter iso-line for Oct.
. . . .	" " " " " Nov.
- - -	" " " " " Dec
━━━	" " " " " Jan.

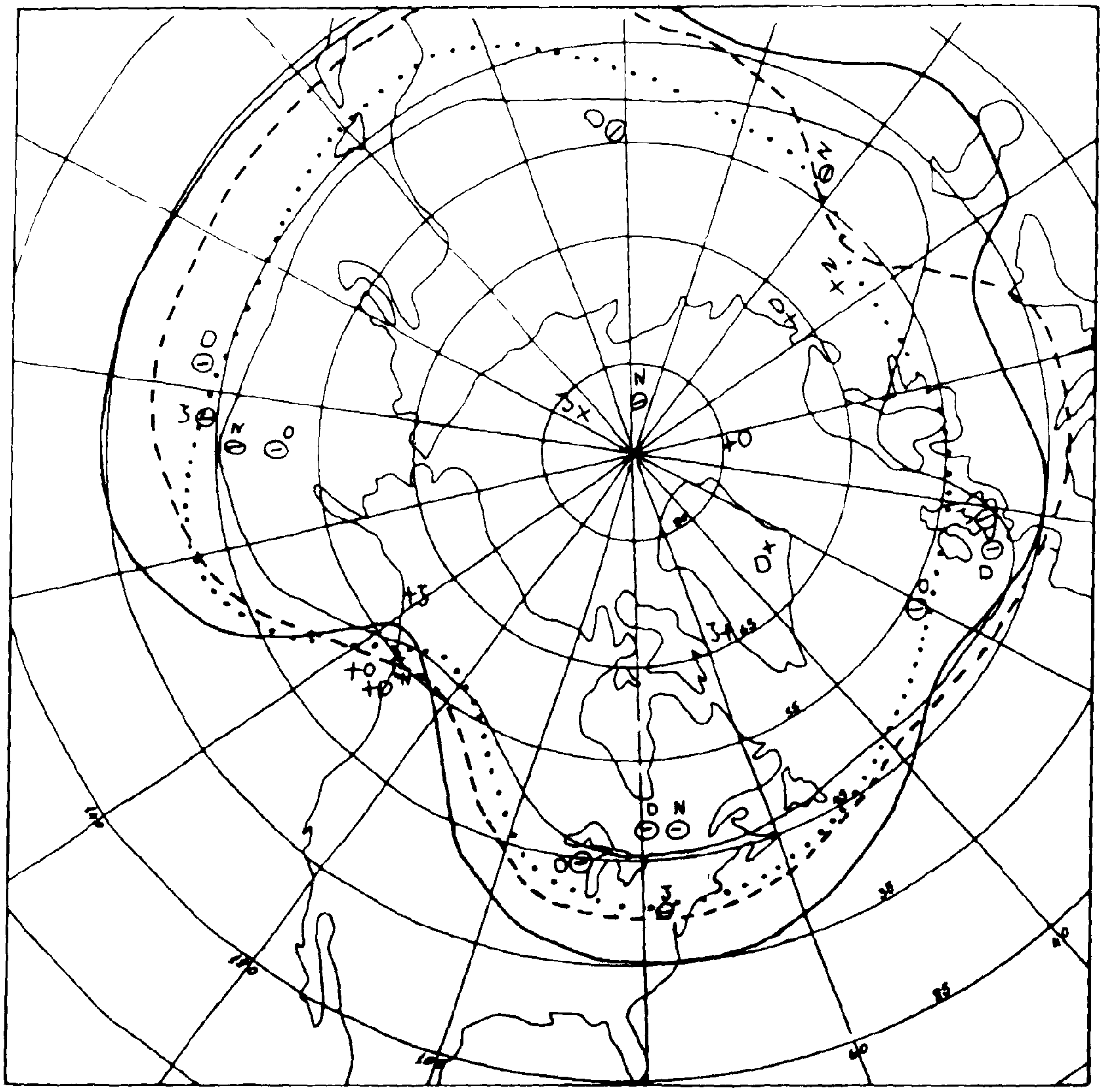


Figure 15 Distribution of 500 mb height anomaly centres around the Northern Hemisphere during the period of Oct. to Jan.

example, the negative anomaly disappeared in November, but reappeared during the rest of the period. Elsewhere the situation is not clear, with changes occurring every month. From the point of view of the upper flow, the three anomalies over Pacific-W. coast-Mid-eastern United States, correspond to an intensified trough-ridge-trough pattern visible throughout this period. It is apparent then, that the points which distinguish these anomalies from the other anomalies over the Northern Hemisphere, are:

1) they are continuously in phase with the normal pattern, while the rest are not;

2) their persistence.

It is also indicated from what has been mentioned above that a hemispheric phenomenon does not seem to be involved during this period. On the contrary, it seems reasonable to accept that only these three anomalies are related to each other. This will also be supported by the examination of the 500 mb circulation using 5-day means in Chapter 4.

3.5 CLIMATIC CHARACTERISTICS CAUSED BY AN INTENSIFICATION OF A PREGIVEN RIDGE-TROUGH PATTERN

Examining the intensification of the pregiven ridge-trough pattern over North America it was already shown that a negative temperature anomaly was lying continuously for four months under the trough over the Mid-eastern United States. This temperature anomaly is associated with a flow at the surface of cold air into the well developed trough, and reached its greatest value below the position of the trough.

Figure 16 shows the position of the centres and their central value of the temperature anomaly over North America for each month from October to January. Figure 17 which was produced using the monthly precipitation patterns given from the German Grosswetterlagen Europas maps, shows the average precipitation over the same period. According to these figures it can be concluded that the following climatic characteristics are associated with the intensified ridge-trough pattern:

1) Over the W. coast, and generally in the underlying area of the intensified ridge, the precipitation amount is remarkably less than normal, while over the south-eastern United States an amount above the normal is observed. This is due to the fact that the precipitation systems cannot pass through the intensified ridge, which is prevailing over the West coast, but simply track north;

2) Also, over the W. cost, a positive temperature anomaly accompanies the drought, due to warm air advection from the south along the strong ridge. This positive temperature anomaly appears as a system with a double centre. One, the primary, over Alaska and another one, the secondary, over Southwest United States. This phenomenon, which usually appears under a ridge, is probably due to the clockwise mechanism of air circulation from the corresponding high at the surface. This results in a relative cooling over the corresponding area and the creation of a secondary centre to the south of that area.

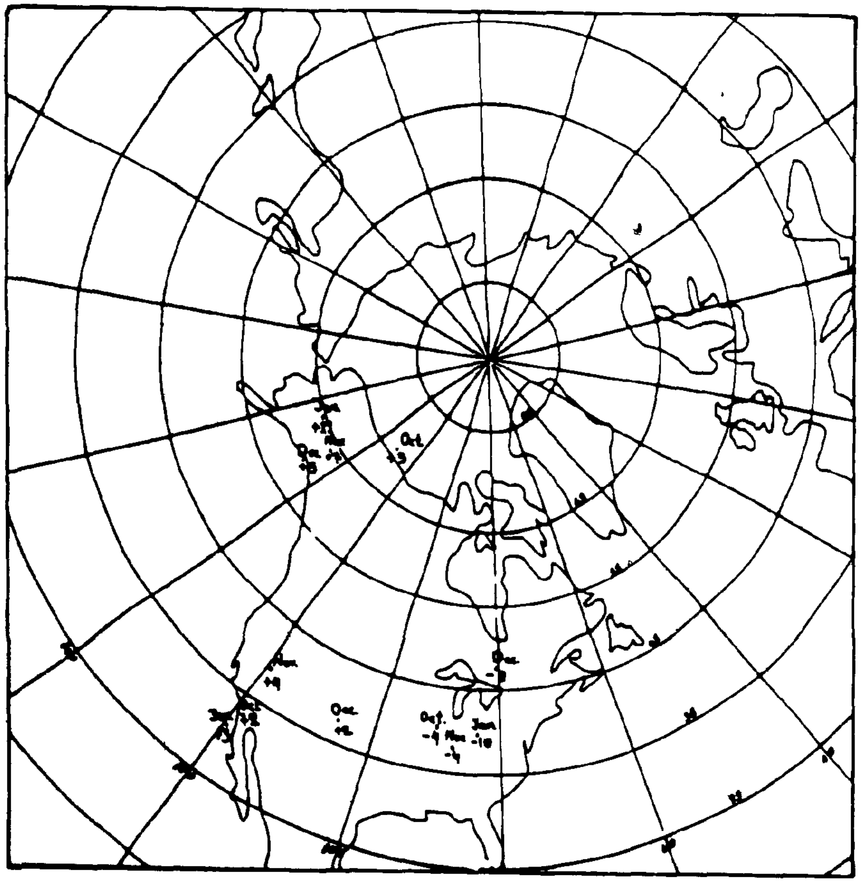


Figure 16 Centres of temperature anomaly over North America for the months of Oct. to Jan. inclusive

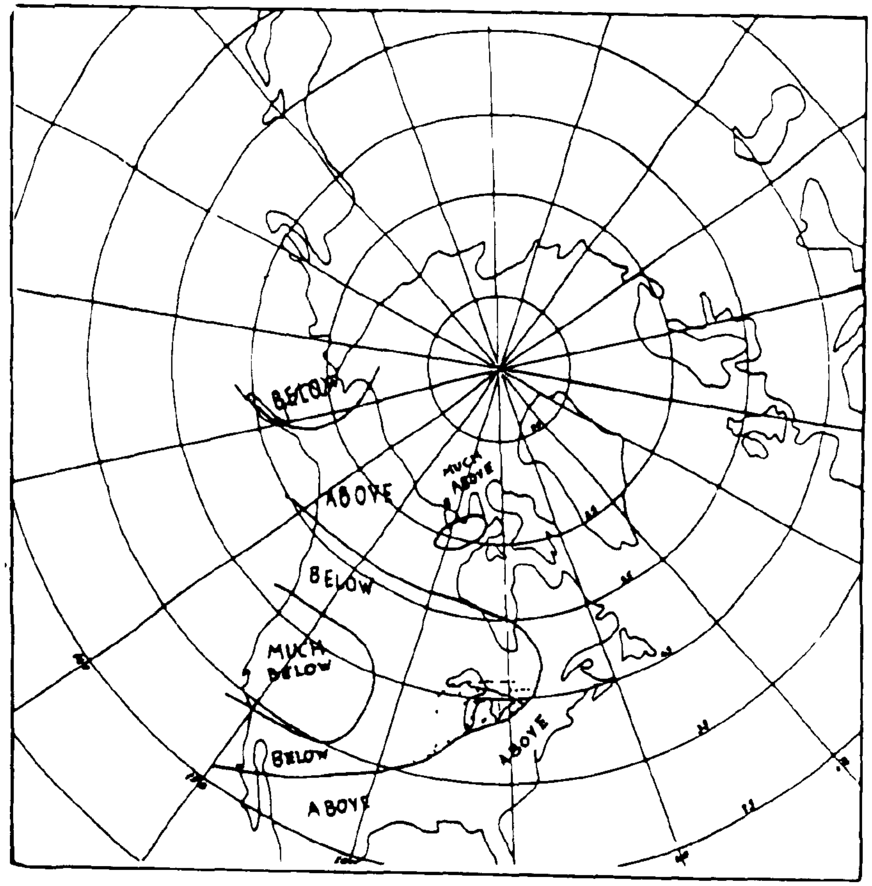


Figure 17 Mean observed precipitation over the period of Oct to Jan
Legend:

⁝⁝⁝ Below but close to normal

CHAPTER 4

THE 5-DAY MEANS

4.1 INTRODUCTION

It was established in the previous chapters that the negative temperature anomaly over North America was indeed associated with a marked change in the mean circulation maps. In view of the discussion in Chapter 1; since it may be that a monthly circulation pattern is composed of a few periods of very intensified ridges and troughs with periods of normal circulation in between, it is necessary to investigate to what degree the circulation anomaly was continuous. This will be done using the 5-day means of the 500 mb height circulation.

Using 5-days for the period from October to January one gets twenty six maps which show the anomalies and the corresponding 500 mb height circulation. As it was mentioned in Chapter 1, these maps include the portion of the Northern Hemisphere from 25°N to the North Pole, with data distributed every 10° of longitude and 5° of latitude.

4.2 "PERCENTAGE OF TIME MAP" - "MEAN HEMISPHERIC VALUES"

Use of the 5-day means is first to see what their effect is to the duration of the anomaly. Using the results of the twenty-six anomaly maps. the computer was asked to print out two maps which would show how many times each grid point was in negative, and how many times in positive anomaly during this twenty-six pentade period. In other words it gives the probability of a grid point to be under positive or negative anomaly. The results are shown in Figures 18 and 19 respectively.

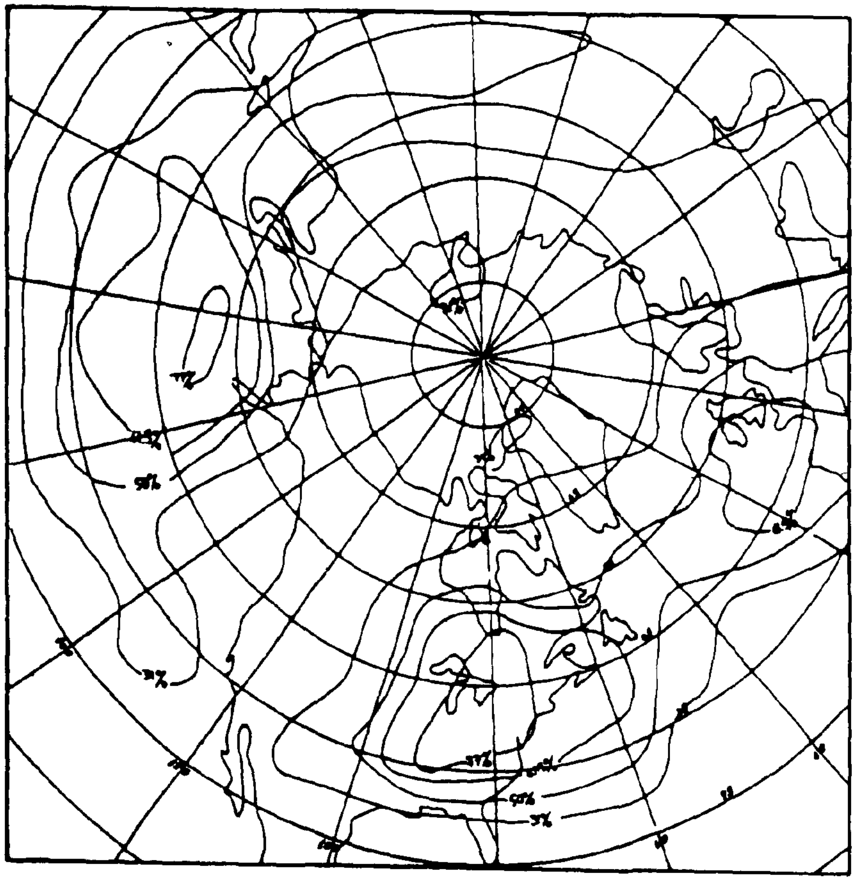


Figure 18 Percentage of time an area is under a negative anomaly

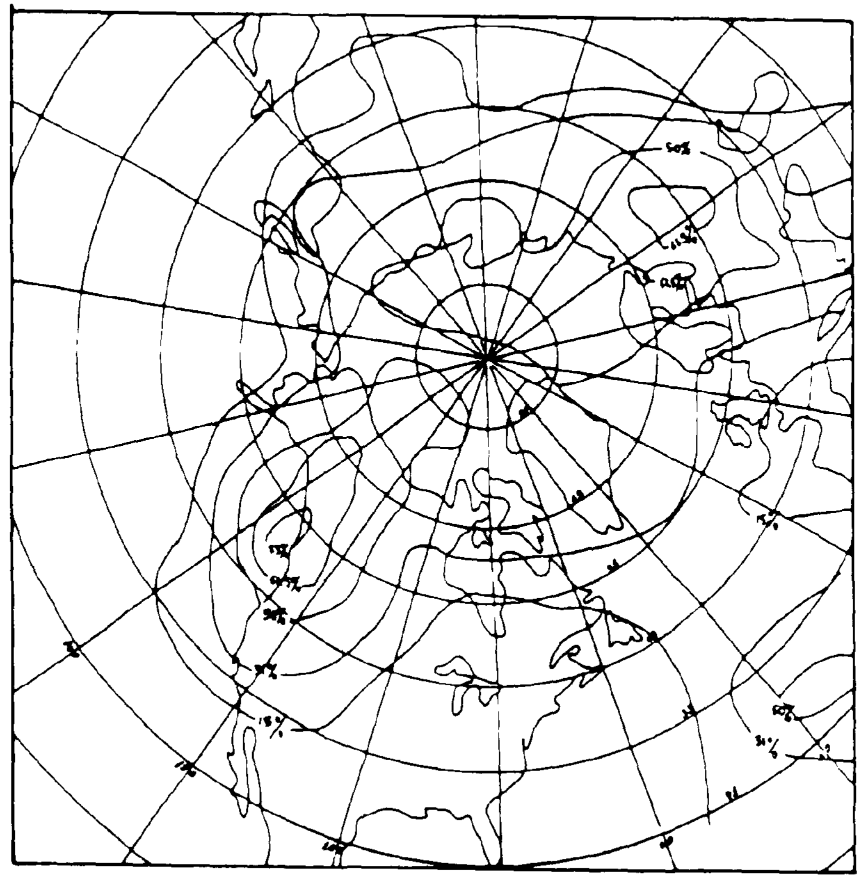


Figure 19 Percentage of time an area is under a positive anomaly

Each isoline shows the percentage of the time an area was under negative or positive anomaly. Using these two figures a composite figure was constructed using 50% of percentage as the lower limit of consideration. The result is Figure 20 which was called "percentage of time map." Solid lines correspond to negative and dashed lines to positive anomaly. The value at the centre of each anomaly shows the maximum of percentage of time. This figure gives also a measure of the preference of an anomaly (positive or negative) to appear over an area during this period. A better look at this figure gives the impression that a positive anomaly predominates most of the time at high latitudes and that the Northern Hemisphere tends to appear more under the influence of negative anomalies than under positive ones.

To visualize the last statement the "mean hemispheric value" was introduced. Each map includes 14 latitudes (North Pole included) with a certain number of grid-points for each latitude. Let $S(25^{\circ})$ denote the sum of the 500 mb height anomalies around the latitude 25°N, and $N(25^{\circ})$ the number of the grid points at this latitude. Then $S(30^{\circ}) \ldots S(90^{\circ})$ and $N(30^{\circ}) \ldots N(90^{\circ})$ are defined similarly. The "mean hemispheric value" (m.h.v.) is defined then as follows:

$$M.H.V = \frac{\frac{S(25^{\circ})}{N(25^{\circ})}\cos 25^{\circ} + \frac{S(30^{\circ})}{N(30^{\circ})}\cos 30^{\circ} + \ldots + \frac{S(90^{\circ})}{N(90^{\circ})}\cos 90^{\circ}}{\cos 25^{\circ} + \cos 30^{\circ} + \ldots + \cos 90^{\circ}}$$

As a result the "m.h.v." shows whether the Northern Hemisphere (from 25°N up to the North Pole) is below or above its normal

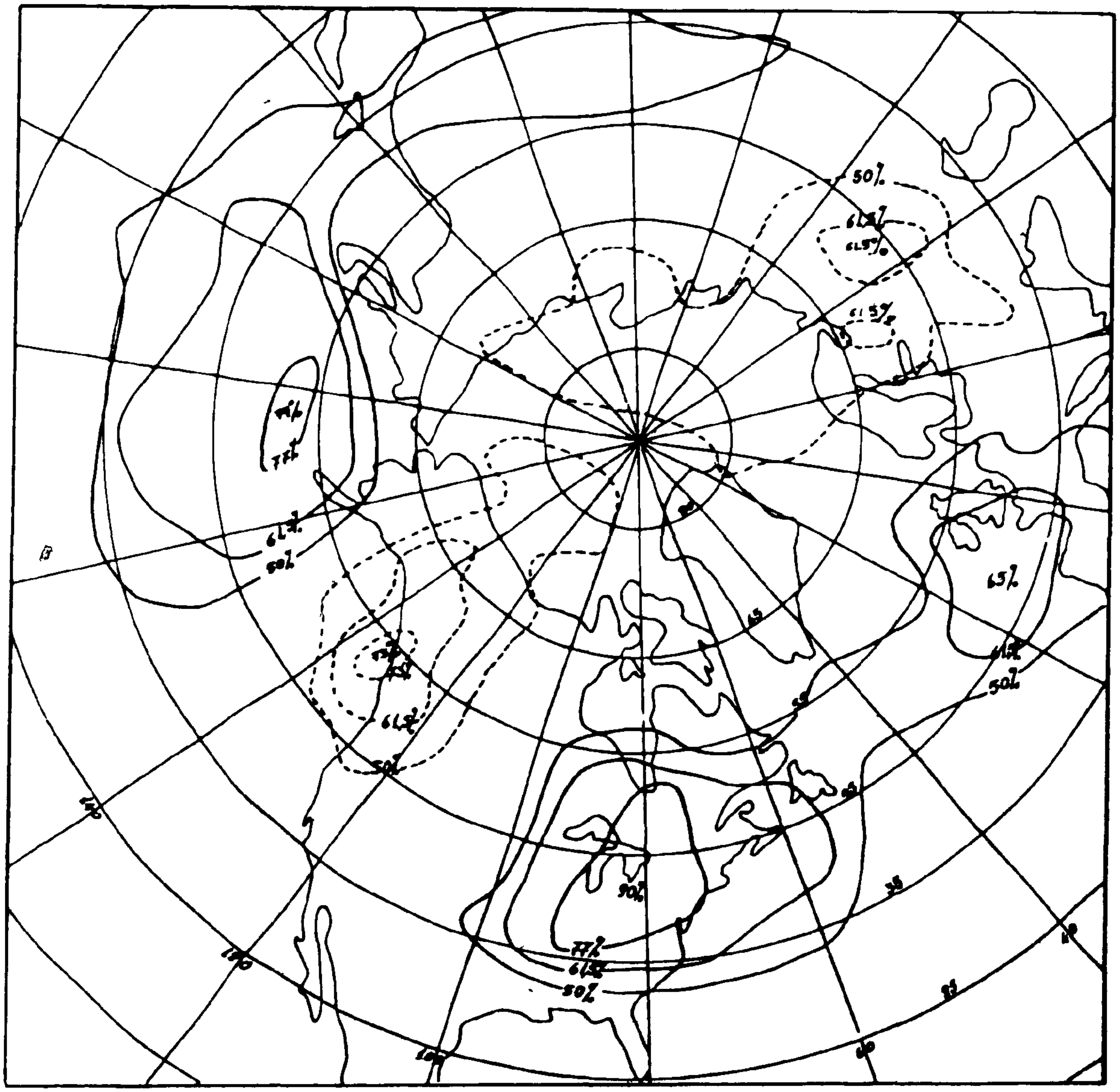


Figure 20 Percentage of time map

value, that is zero. As an extension the sign of the "m.h.v." shows what predominates over the Norther Hemisphere in the sense that a negative value indicates that negative anomalies predominate and vice-versa.

In Figure 21[1] the "m.h.v." for each 5-day period, during the period of October - January, is indicated by the solid line. The value in the parenthesis shows the average "m.h.v." over this period. As can be seen from Figure 21 on the average the Northern Hemisphere is covered mostly by negative anomalies, which was also indicated in Figure 20. The dashed line in Figure 21 corresponds to the "mean hemispheric thickness" which was obtained if one repeats the same using instead of 500 mb height anomalies, 1000-500 mb thickness anomalies. This curve goes until the end of 1976 because of lack of thickness data for 1977. The purpose of doing this is to determine whether the negative "m.h.v." corresponds to a cooling of the atmosphere during that period. Indeed it is apparent that the negative "m.h.v." corresponds to a negative "mean hemispheric thickness", in other words to a cooling, on the average, of the atmosphere. Finally, in order to compare the average "m.h.v." of the period October 1976 - January 1977 with other similar periods, Table 3 was produced. Table 3 gives the average "m.h.v." for the corresponding period of the years 1972-1973, 1973-1974, 1974-1975 and 1975-1976.

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[1] It was mentioned in the data description that the data for the 8th 5-day period were possibly wrong. For the 8th 5-day period a linear interpolation between the 7th and the 9th 5-day period was made.

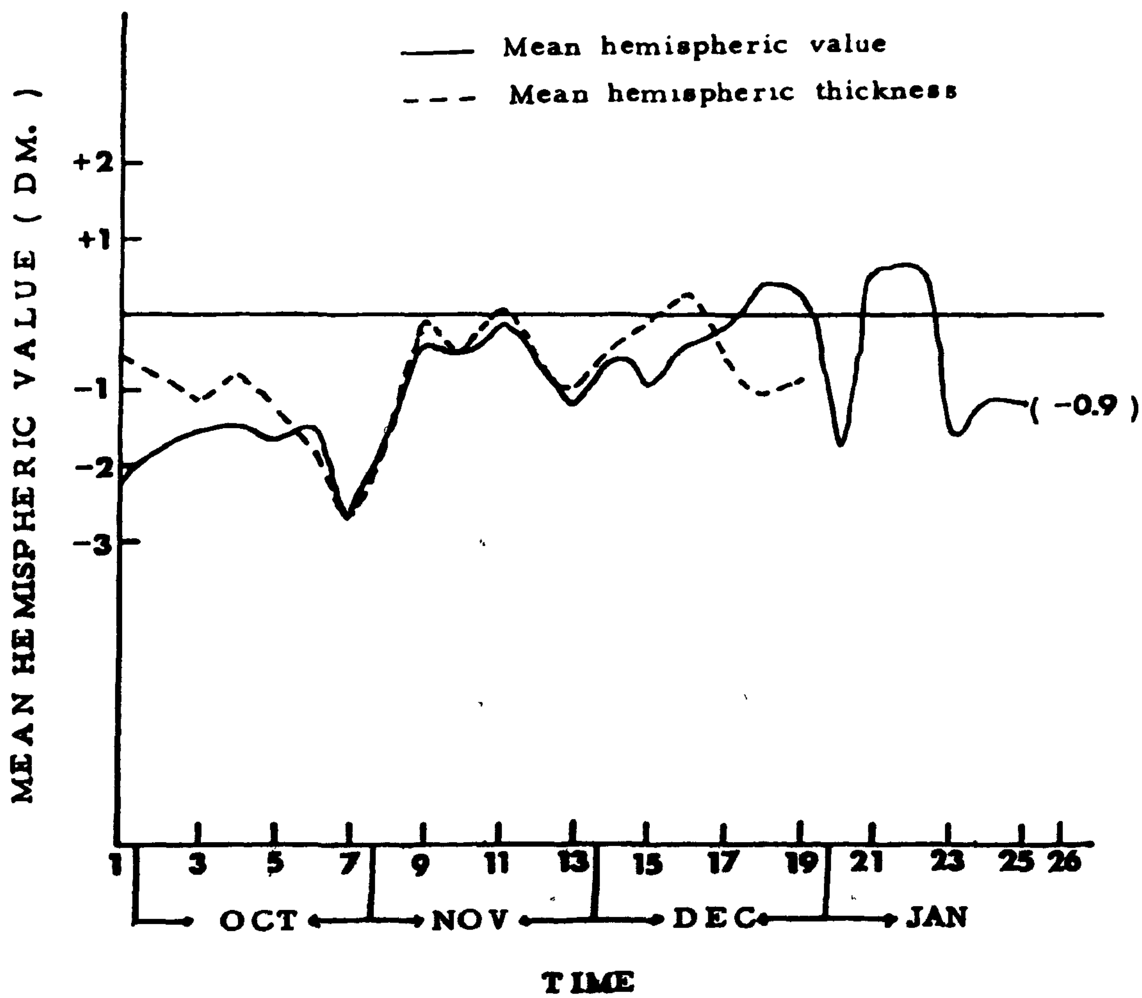


Figure 21 Mean hemispheric value and mean hemispheric thickness (decameters) versus time

TABLE 3

YEAR (dm)	1972-73	1973-74	1974-75	1975-76	1976-77	NORMAL
Average "m.h.v." during the period Oct.-Jan	-0 2	+0.5	+0 8	-0.2	-0.9	0.0

In general the "m h.v " does not seem to deviate significantly from the normal (recall that the definition of a 500 mb height anomaly is +4 dm) In any case, the "m h.v." of 1976-77 appears to be the lower one in the last 5 years. About this, one possibly can declare that on the average the negative "m.h.v." is due to the two negative anomalies, over the Pacific and over the Mid-eastern United States, which as can be seen from the "percentage of time map," are the major negative anomalies around the Norther Hemisphere (see also "mean anomaly map", page 23).

4.3 RELATION BETWEEN THE ANOMALIES

It has been mentioned previously in the presentation of the monthly anomalies and the corresponding 500 mb circulation that three anomalies, namely over the Pacific, N-W America and Mid-eastern United States, seem to be the most permanent phenomena during the known period, while over the rest of the Northern Hemisphere nothing seems to be as constant. One of the purposes of the use of the 5-day means is to see more accurately the relationship between the anomalies over the Northern Hemisphere.

The relation, or "coupling" or "tel econnections," of the anomalies has been studied extensively by authors in the past (O'Connor, 1969, Martin, 1955, etc.). Their method is usually to locate a reference anomaly cetre (positive or negative) at a certain grid point and then they find the probability for an area to be under positive or negative anomaly, given that an anomaly (positive or negative) will occur at that grid point. From their results it seems that usually a local "coupling" between the anomalies is more favorable than a hemispheric one. This method could give better results if there was a large sample of occurances of anomaly centers at the given grid points. It is obvious that in the case under examination twenty-six anomaly maps do not make for a significantly large sample. These especially become less significant if one takes into account that a reference anomaly (over Mid-eastern United States for example) will not necessarily remain continuously at the same grid point during its life. To start with, the "percentage of time map" could be used as an indication of the relation between the anomalies. The way it was computed approaches to a degree, the way the other authors determine possible relations between the anomalies. The difference is that in computing this map no restrictions were made on the position of the centre of the reference anomaly (over the mid-eastern United States, for instance). Therefore, from the point of view of the relation between the anomalies, this will give false results if, during this period, breaks or motion of the reference anomaly took place. As a result it was decided, in this case, to approach the relation between the anomalies as follows: the sector between 90^{o}W to 70^{o}W longitude and 35^{o}N to 55^{o}N latitude is considered. This is the area where the negative anomaly over Mid-eastern United States was most often positioned. When, and only when, the anomaly has its centre in this sector, the positions of the centres of the other anomalies around the Northern Hemisphere are considered. Then by definition the probability that a negative centre will occur in this sector is 100%. After that it will be possible to find the probability that a centre (positive or negative) will occur over the other areas around the Northern Hemisphere. In addition since the reference anomaly is the negative one over the Mid-eastern United States it will be shown how much an anomaly (positive or negative) elsewhere, is related to the reference anomaly.

Figure 22 is the result when this method is applied. A negative probability corresponds to the probability that a negative centre will occur and a positive to the probability that a positive centre will occur. In this figure probabilities of less than 50% are not included. Also, it must be emphasized that a ±P% probability does not necessarily imply a (100∓P)% probability. For example if the probability that a positive centre will occur over an area is +50% that does not mean that the probability that a negative centre will occur over the same area is (100-50) = 50%. It could very well be, that there were cases where there were not any centres over this area. Finally, in the endeavor to translate these probabilities to a "coupling" or to a relation between the anomalies the limit of 75% probability was considered as a restriction. In other words a "coupling" is considered significant if the probability is

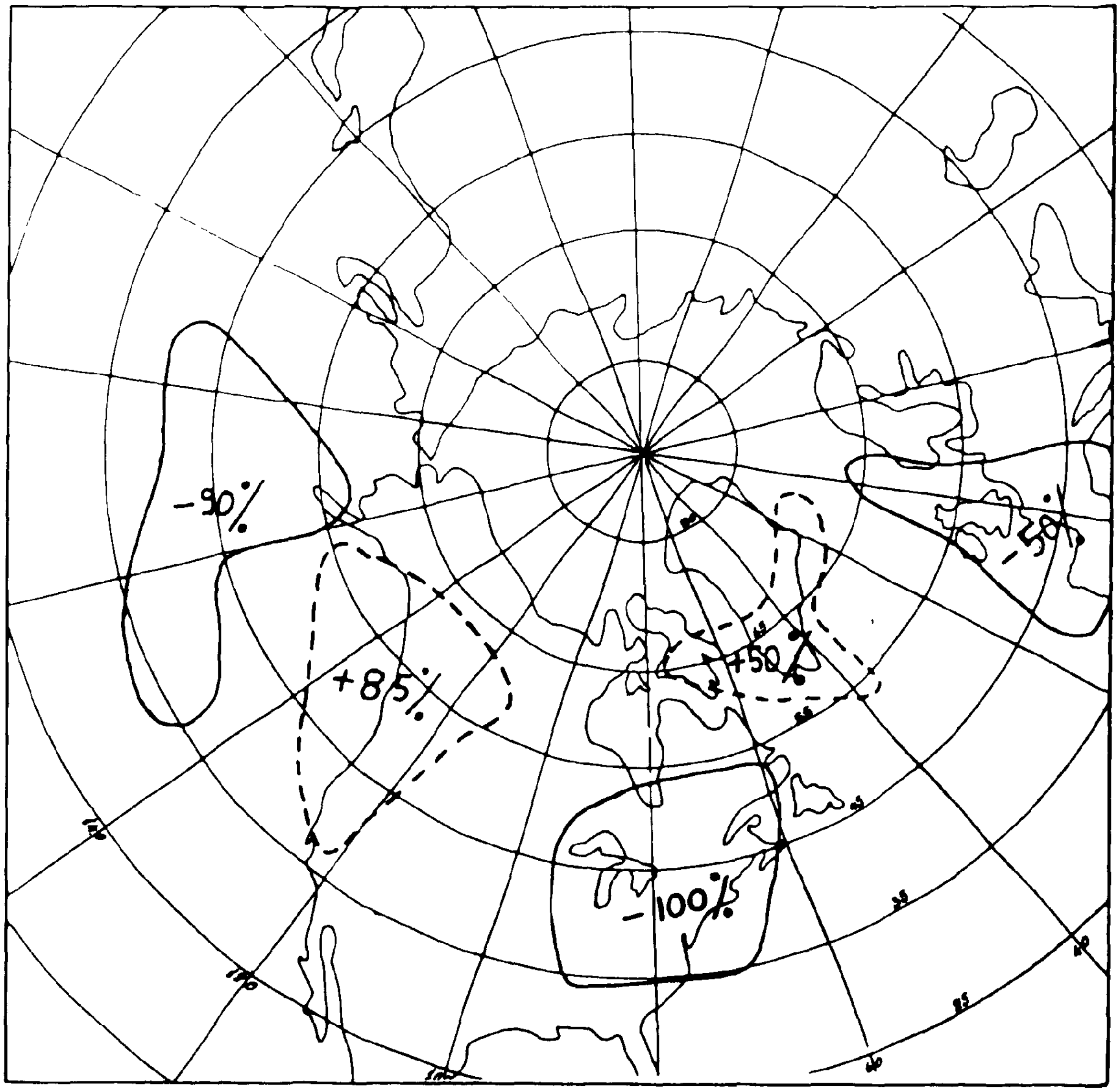


Figure 22 Coupling between anomalies

at least 75% (independently of the sign). Returning to Figure 22 each signed number shows the probability that an anomaly centre, of the same algebraic sign, will occur in the indicated region. From this figure it is quite apparent that only a negative anomaly centre over the Pacific and a positive anomaly centre over North-West America are related to the negative anomaly over the Mid-eastern United States. The probabilities indicate a strong "coupling" between these three anomalies. In the rest of the Northern Hemisphere such a "coupling" is not apparent.

Consequently it can be concluded that during the period from October 1976 to January 1977 there is not a hemispheric anomaly or wave pattern associated with the abnormality over the Mid-eastern United States. On the other hand a local "coupling" between a negative, a positive and a negative anomaly over Pacific, North-West America and Mid-eastern United States respectively, is a fact. As was shown, in the monthly presentation of the anomalies and the corresponding circulation, this anomaly pattern corresponds to a trough-ridge-trough pattern over that area, which is the major characteristic of the 500 mb circulation during the period from October to January. It is then interesting to examine in more detail the circulation over these areas, and to determine whether there were any breaks or lulls in this anomalous pattern.

4.4 TYPES OF CIRCULATION WHICH CAUSED THE PERSISTENCE OR BREAK OF THE ANOMALY OVER THE MID-EASTERN UNITED STATES

A) Breaks

As was mentioned previously the use of the 5-day means serves the purpose of verification of the relation between the anomalies, as well as of the continuity of the anomalies. Taking the negative 500 mb height anomaly over the eastern United States as a guide, Figure 23 shows the oscillation of the centre of the anomaly. The number to the left indicates the 5-day period and the number to the right (in the parenthesis) is the corresponding centre value of the negative anomaly. The anomaly came over the Mid-easter United States on the 3th 5-day period (from 8 - 12 of October). Except for one major break, where there is no negative anomaly (17 - 21 of December), the anomaly exists and oscillates about its mean position which is at 42°N latitude and 80°W longitude (see also the "mean anomaly map"). From this figure it can be seen that the maxima of the intensity of the anomaly occur rather when the anomaly is around its mean position. Also it is apparent that some times the centre of the anomaly moved far enough to indicate a break of the anomaly over the defined area.

Defining that a break is significant when at least one third of the defined area is out of the anomaly, the following breaks were reported.[1]

1) 12 - 16 of November (10th 5-day period)

2) 7 - 11 of December (15th 5-day period)

3) 12 - 16 of December (16th 5-day period)

[1] It was observed that, more or less, two-thirds of the defined area approached the limited area as it was defined in Chapter 2.

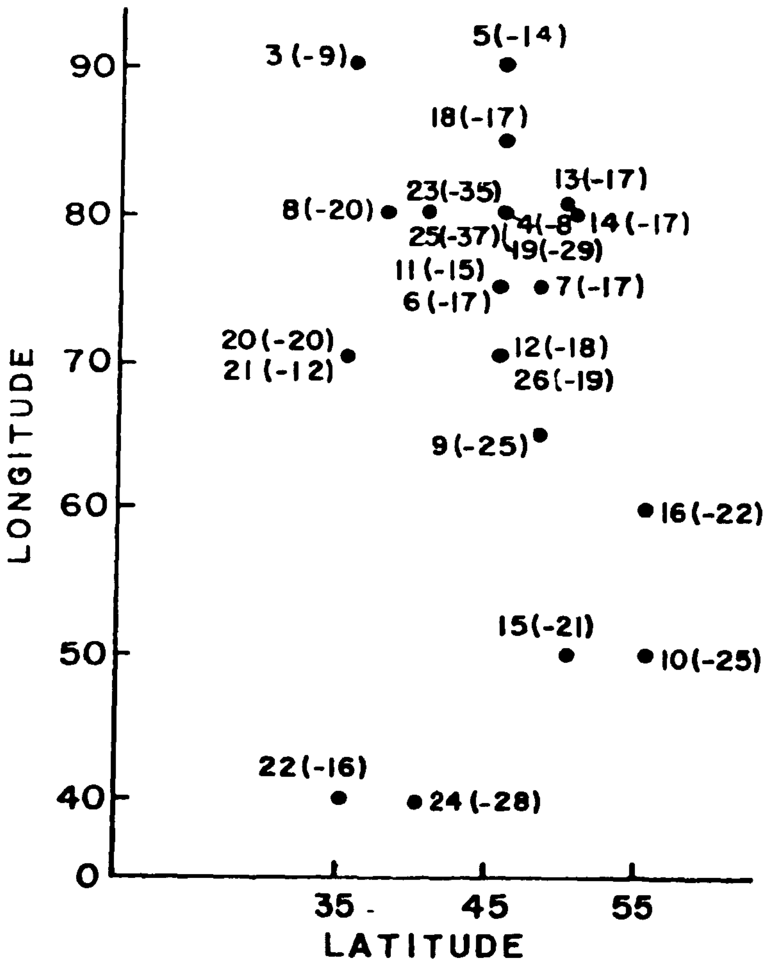


Figure 23 Oscillation of the centre of the negative 500 mb height anomaly over the mid-eastern United States as a function of time

4) 17 - 21 of December (the major break)

5) 1 - 5 January (20th 5-day period)

6) 21 - 25 of January (24th 5-day period)

Comparing these breaks with Figure 23, indeed a break corresponds to a motion of the centre of the negative anomaly far enough from the mean position. The striking point that the 20th 5-day period classified as a break, even though the centre of the anomaly was not very far from the mean position, is due to the fact that the anomaly is not very extensive with the result that it does not cover two-thirds of the defined area. On the contrary the 22nd 5-day period did not classify as a break even though the centre was far from the mean position, the reason being that the anomaly was very extensive and covered more than two-thirds of the defined area.

Figure 24 shows the corresponding 540 dm height isolines of the zonal flow during these breaks as well as, shown by the heavy dashed line, the typical 540 height isoline when there is no break. From the point of view of the circulation, these breaks correspond to a flattening or a breakdown of the ridge over the West Coast. This results in a change to a West or South-West situation from the North-West situation which is associated with the existence of an intensified ridge. As an example, Figure 25 gives the typical circulation which corresponds to the breaks.

Recalling Figure 1 from Chapter 1 it can be seen that a break of the negative 500 mb height anomaly corresponds to a break of the neative temperature anomaly. Possible differences

Legend

First break
Second break
Third break
Fourth break
Fifth break
Sixth break
No break

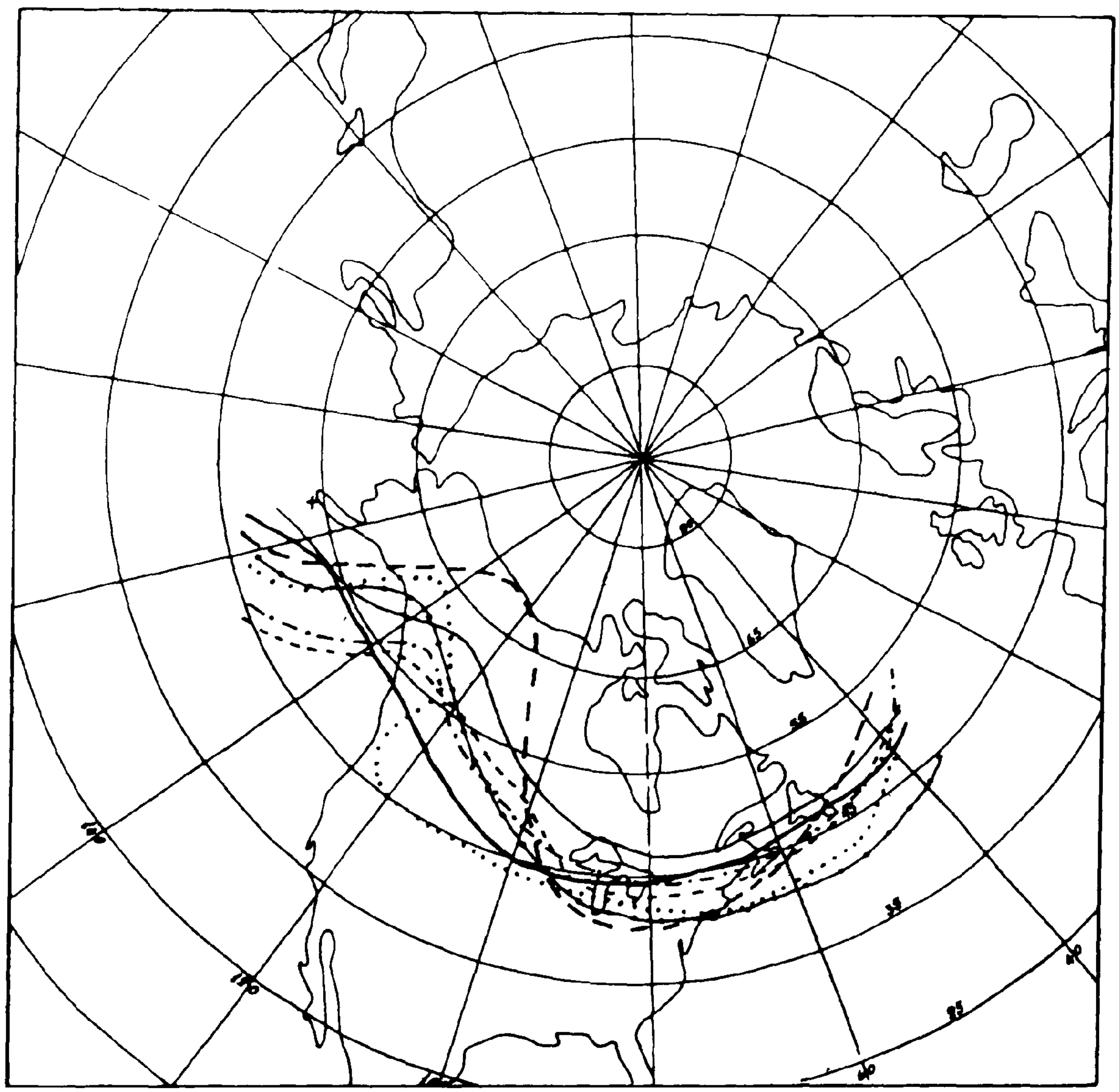


Figure 24 540 decameter iso-lines corresponding to the breaks

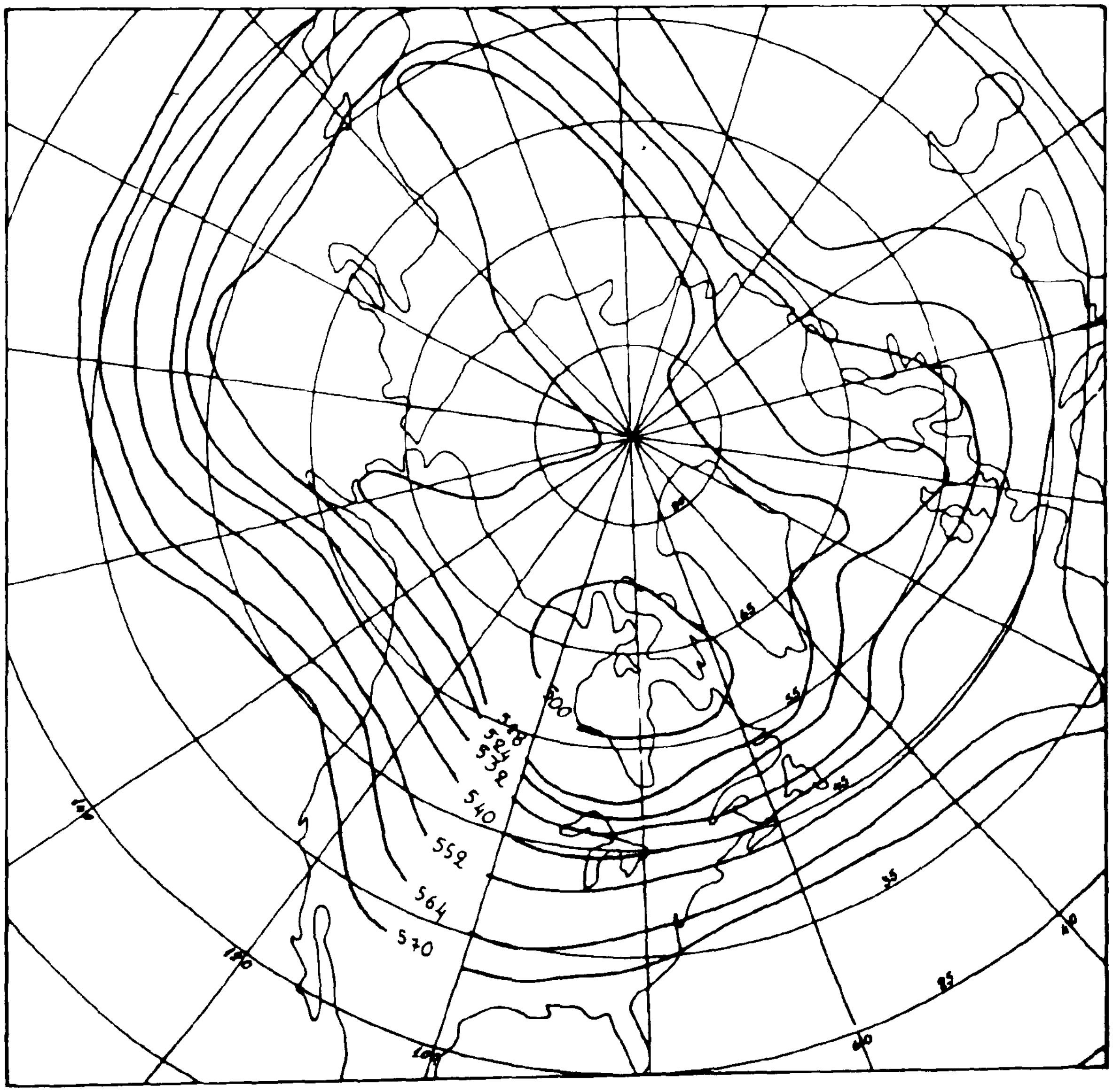


Figure 25 Typical circulation corresponding to a break (17th pentade - 17-21 December 1976)

are allowed, since it was not considered that a certain one-third of the defined area must be out of the anomaly region in order to get a break, but any one-third of the area. Thus it is possible for an individual station to get below normal temperatures at a certain time period even if this time period classified as a break, simply because this station happened to be in an area which remained under the influence of the 500 mb height anomaly. Of course, the opposite is also a possiblity.

B. The persistence of the anomaly.

It was already shown previously that there is a strong "coupling" of a negative anomaly over the Pacific and a positive anomaly over the North-West America with the negative anomaly over the Mid-eastern United States (Figure 22). Excluding the breaks, examination of the maps gives even stronger relation between these three anomalies. The reason for this is that the method to find the "coupling" was restricted to centres with a consequence, in very few cases, that it was possible for an area (over the Pacific, for instance) to be under anomaly, but the centre to be out of this area. In genreal it is observed:

1. The negative anomaly over the Mid-eastern United States is always associated with a negative anomaly over the Pacific. In two cases there is also a positive anomaly (but not a centre) over the Pacific, but this is due to an intensification or motion of the positive anomaly over North-West America to a position over the Pacific. The Pacific's anomaly also oscillates about its mean position which is about at $170^{\circ}W$ and $47^{\circ}N$ (see also the mean anomaly map).

2. The negative anomaly over the Mid-eastern United States is always (with an exception of two cases) associated with a positive anomaly. One interesting point about this is that the position of the centre of the positive anomaly varies from a position over the North-West coast and at a latitude of 55^{O}N, to a position over the North Pole. Most of the time when the centre is situated over the North Pole the anomaly is very strong and covers North-West America as well.

This relation would fit perfectly were it not for two cases (two 5-day periods) from the 28th of October to the 6th of November, where the negative anomalies over the Mid-eastern United States and over the Pacific exist but no significant positive anomaly over North-West America is associated.

Summarizing, basically there are two major types of circulation anomaly patterns which caused the known weather situation over North America. Minor cases as the previously discussed two cases were not considered as a type.

1. Type 1

Centres of negative anomalies over the Pacific and Mid-eastern United States and a centre of positive anomaly over the northern part of the West Coast.

Corresponding circulation:

A well organized ridge over the West Coast extends up to 75^{O}N latitude, and two well-developed troughs over the Pacific and the Mid-eastern United States (Figure 26).

2. Type 2

Centres of negative anomalies over the Pacific and Mid-eastern United States and a large positive anomaly centred over the North Pole which covers North-West America as well.

Corresponding circulation:

An intensified ridge over the West Coast exists, positioned more to the west than in Type 1, and two developed troughs over Pacific and Mid-eastern United States (Figure 27).

Looking now at the Figures 26 and 27, it can be seen that the point which makes the difference to the circulation is the most intensified ridge. Circulation pattern Type 2 has the most intensified ridge giving as a result the most developed trough over the Mid-eastern United States as well. Circulation Type 1 is present in 62% of the cases while Type 2 is 28% of the cases. Type 1 is the most pronounced type, but Type 2 which appears mostly in January results in an increase of the intensity of the cold over the Mid-eastern United States (recall Figure 1), and an increase of the temperatures over the West Coast (Alaska included). This also, can be seen in Figure 16. where both negative and positive temperature anomalies are more intensified in January than in the previous months. This is due to the fact that the southernly flow over the West Coast and the northernly flow over the area of the negative anomaly is greater, resulting respectively in warmer and colder termperatures. According to these two types, the slope of the accumulated curves (Figure 6) can be explained. The appearance of Type 1 during the period from October to December results in an almost constant intensity of the temperature anomaly, since in January Type 2 results in the increase of its intensity.

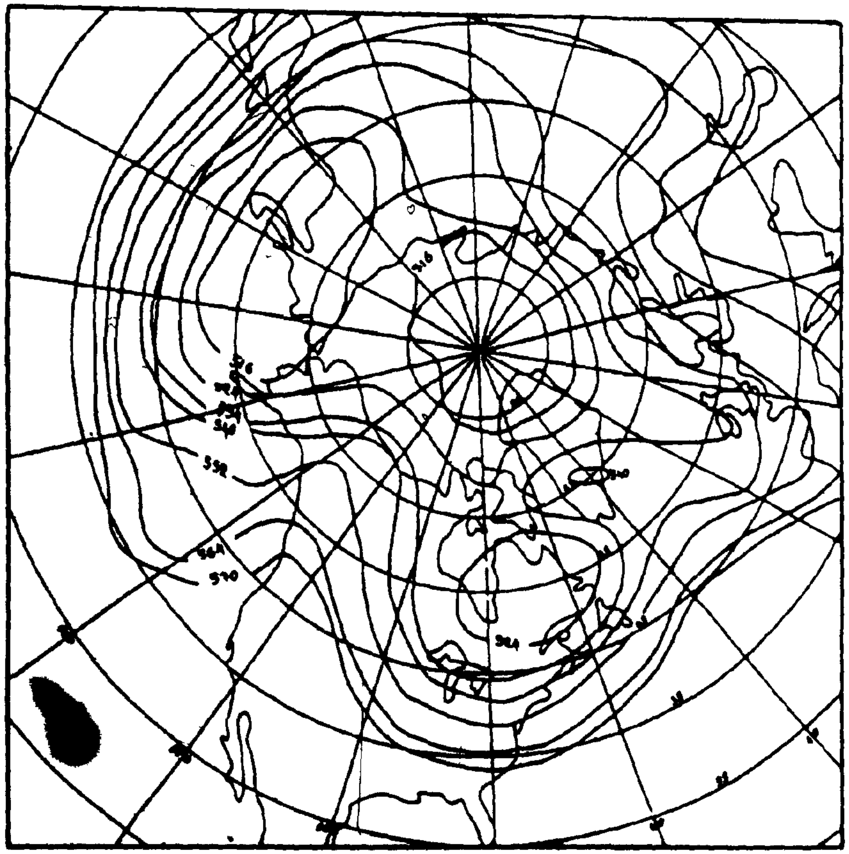


Figure 26 Circulation type 1

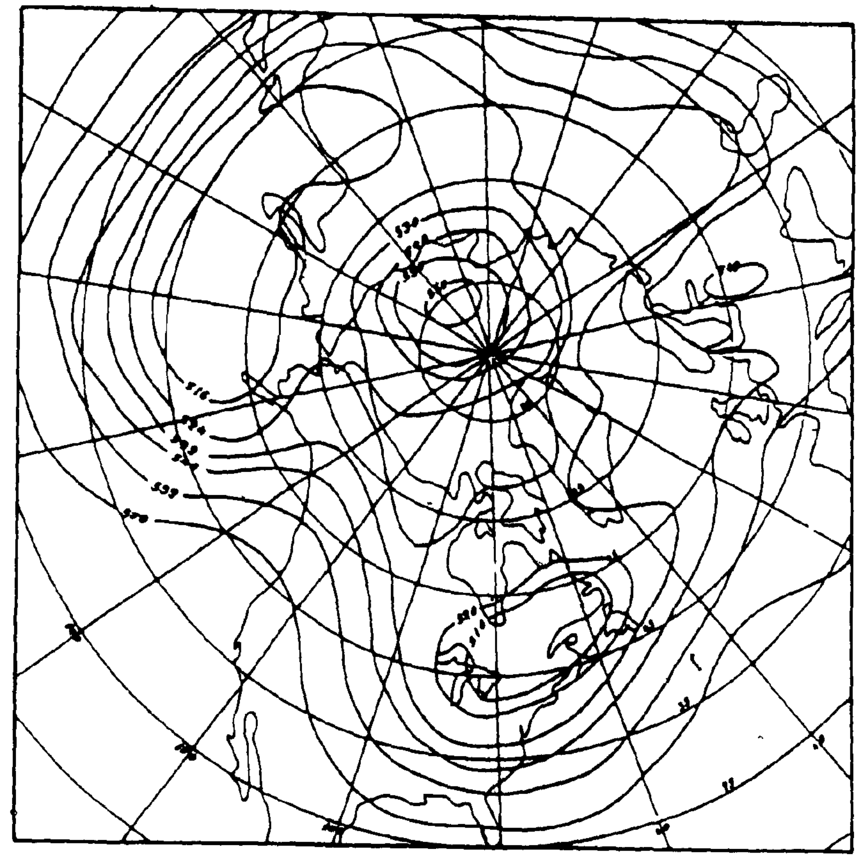


Figure 27 Circulation type 2

Recapitualing, the ridge over the West Coast where its normal position is, appears as an intensified ridge and it depends on how strong this ridge is in order to have the centre of the positive 500 mb height anomaly over North-Western America or over the North Pole. A flattening or a breakdown of the ridge, results in a break of the temperature anomaly since a West or South-West situation replaces the North-West situation The two troughs, which are again situated over their normal positions, are deeper and appear on the deviation maps as negative anomalies. The resumé is that in general the main characteristic of the flow during the period from October to January is the intensification of the normal trough-ridge-trough pattern over Pacific-West-coast-Mid-eastern United States, or, in other words the increase of the meridional flow over this region. Finally, from the use of 5-day means it is apparent that the main characteristics of the flow, compared with those observed using the monthly means, are maintained. Therefore in this case the mean monthly maps represent the actual circulation and they are not the result of averaging.

CHAPTER 5

PHYSICAL CHARACTFRISTICS OF THF CIRCULATION

5.1 INTRODUCTION

Thus far it has been seen that the circulation pattern over the Pacific - West coast-Mid-eastern United States is the major characteristic over the Northern Hemisphere during the given period. It was also shown that the corresponding 500 mb height anomalies are independent of the anomalies in the rest of the N. Hemisphere in the sense that they exist together whereas elsewhere the situation is not as constant Until now only synoptic conditions during this period where examined and it will be of interest to investigate some physical characteristics associated with these synoptic situations. For this purpose the heat and momentum transports, during the given period, will be presented in an endeavor to see how a strong meridional type of flow expresses itself in terms of heat and momentum transports to the North or to the South.

5.1a Heat Transport

The heat transport across the latitude ϕ from the top of the atmosphere to the standard pressure $p = p_o$ is given by:[1]

$$TH(\phi) = \frac{1}{g} \int_0^{p_o} \int_0^{2\pi} c_p T v a \cos\phi \, d\lambda \, dp \qquad (1)$$

where: g is the gravity

c_p is the specific heat at constant pressure

T is the temperature

v is the meridional component of the wind velocity

a is the radius of the earth

[1]Wiin-Nielsen, A, J.A. Brown, M. Drake, Tellus (1963), 261-279.

The contribution to the heat transport across the latitude circule from some layer of pressure Δp is :

$$TH_{\Delta}(\phi) = \frac{\Delta p}{g} c_p a \cos\phi \int_0^{2\pi} \tilde{T}\tilde{v}\, d\lambda \qquad (2)$$

where $\tilde{T}$, $\tilde{v}$ are the vertical mean quantities in the layer Δp. It is known that $\tilde{T}$ is related to the thickness h of the layer by the formula

$$h = \frac{R}{g}\tilde{T} \ln\left(\frac{p_2}{p_1}\right) \qquad (3)$$

where p_1 is the pressure at the upper boundary of the layer

p_2 is the pressure at the lower boundary of the layer.

Using (3), (2) becomes:

$$TH_{\Delta}(\phi) = \Delta p \frac{c_p}{R} a \cos\phi \frac{1}{\ln\left(\frac{p_2}{p_1}\right)} 2\pi \overline{h\tilde{v}} \qquad (4)$$

The bar over the product $h\tilde{v}$ means the zonal average (average around the latitude circle):

$$\overline{(\quad)} = \frac{1}{2\pi}\int_0^{2\pi} (\quad)\, d\lambda$$

In equation (4) the product $\overline{h\tilde{v}}$ is equal:

$$\overline{h\tilde{v}} = \overline{\bar{h}\bar{\tilde{v}}} + \overline{\bar{h}\tilde{v}'} + \overline{h'\bar{\tilde{v}}} + \overline{h'\tilde{v}'}$$
$$= \bar{h}\bar{\tilde{v}} + \bar{h}\overline{\tilde{v}'} + \overline{h'}\bar{\tilde{v}} + \overline{h'\tilde{v}'}$$

where it was considered that $h = \bar{h} + h'$ and $\tilde{v} = \bar{\tilde{v}} + \tilde{v}'$.

The prime indicated the deviation from the zonal average:

$$(\quad)' = (\quad) - \overline{(\quad)}$$

Assuming that the wind is geostrophic, i.e.

$$\int_0^{2\pi} \tilde{v}\, d\lambda = 0$$

then:

$$\overline{h\tilde{v}} = \overline{h'\tilde{v}'}$$

Thus, (4) can be written

$$TH_\Delta(\phi) = \Delta p \frac{c_p}{R} a \cos\phi \frac{1}{\ln\left(\frac{p_2}{p_1}\right)} 2\pi\, \overline{h'\tilde{v}'} \tag{5}$$

Then, according to (5) positive heat transport will mean that on the average warm air is transported to the North or cold air transported to the South. Physically the result is the same, i.e. a warming of the North. A negative value will mean the reverse.

Consider now that v_1 and v_2 are the meridional velocities at the two pressure boundaries p_1 and p_2. Then the mean meridional velocity of the layer $\tilde{v}$ is defined simply as:

$$\tilde{v} = \frac{v_1 + v_2}{2} \tag{6}$$

The thermal wind is defined as:

$$v_T = v_1 - v_2 \tag{7}$$

From (6) and (7) it follows that:

$$\tilde{v} = v_1 - \frac{v_T}{2} \tag{8}$$

Using the fact that

$$v_T = \frac{g}{2\Omega \sin\phi \cos\phi\, a} \frac{\partial h}{\partial \lambda} \tag{9}$$

(8) becomes:

$$\tilde{v} = v_1 - \frac{g}{4\Omega \sin\phi \cos\phi a} \frac{\partial h}{\partial \lambda} \tag{10}$$

At the pressure level p_1 the two components of the geostrophic wind in spherical coordinates are given by:

$$u_1 = -\frac{g}{2\Omega \sin\phi a} \frac{\partial z}{\partial \phi} \qquad \text{(zonal velocity)} \tag{11}$$

$$v_1 = \frac{g}{2\Omega \sin\phi \cos\phi a} \frac{\partial z}{\partial \lambda} \qquad \text{(meridional velocity)} \tag{12}$$

Where z is the height of the pressure level p_1.

Using (12), (10) becomes:

$$\tilde{v} = \frac{g}{2\Omega \sin\phi \cos\phi a} \left(\frac{\partial z}{\partial \lambda} - \frac{1}{2} \frac{\partial h}{\partial \lambda} \right) \tag{13}$$

Equation (13) shows that $\tilde{v}$ can be calculated if the height and thickness fields are known. Return then to (5) the heat transport can be calculated from the same fields.

5.1b Momentum Transport.

The momentum transport at the pressure level p_1 is defined as:

$$MT(\phi) = \overline{u_1 v_1} \tag{14}$$

or, for the same reason as in the case of heat transport (page 58)

$$MT(\phi) = \overline{u_1' v_1'} \tag{14a}$$

The bar and the prime have the same meaning as before. Using equations (11), (12) and (14a), (14) can be expressed as follows:

$$MT(\phi) = \overline{u_1 v_1} = \overline{u_1' v_1'} = -\overline{\frac{g^2}{4\Omega^2 \sin^2\phi \cos\phi\, a^2} \frac{\partial z}{\partial \phi} \frac{\partial z}{\partial \lambda}}$$

$$= -\overline{\frac{g^2}{4\Omega^2 \sin^2\phi \cos\phi\, a^2} \frac{\partial z'}{\partial \phi} \frac{\partial z'}{\partial \lambda}} \tag{15}$$

Again, the momentum transport can be calculated from the height fields and a positive value will mean transport to the North.

5.1c Changes in the Mean Zonal Flow

The first equation of motion can be written in the following form:

$$\frac{\partial u}{\partial t} + \frac{u}{a\cos\phi}\frac{\partial u}{\partial \lambda} + \frac{v}{a}\frac{\partial u}{\partial \phi} + w\frac{\partial u}{\partial p}$$
$$= -\frac{1}{a\cos\phi}\frac{\partial \Phi}{\partial \lambda} + fv + \frac{uv\tan\phi}{a} + F_x \tag{16}$$

where: F_x is the frictional force

Φ is the geopotential

f is the Coriolis parameter

w is the vertical "velocity" (w = dp/dt)

Note that u and v in the horizontal part of the advective acceleration are going to be considered non-divergent, i.e. $\bar{v} = 0$. Note also that v in the term fv on the right hand side of (16) has divergence so there $\bar{v} \neq 0$.[2] Making use of the continuity equation in spherical coordinates,

$$\frac{1}{a\cos\phi}\frac{\partial u}{\partial \lambda} + \frac{1}{a}\frac{\partial v}{\partial \phi} - \frac{\tan\phi}{a}v + \frac{\partial w}{\partial p} = 0 \tag{17}$$

and averaging along the latitude circle, (16) becomes:

$$\frac{\partial \bar{u}}{\partial t} = -\frac{1}{a\cos^2\phi}\frac{\partial M\cos^2\phi}{\partial \phi} - \frac{\partial \overline{uw}}{\partial p} + \bar{F}_x + f\bar{v} \tag{18}$$

[2] Phillips (1963)

where: M is the momentum flux ($M = \overline{uv}$). Equation (18) would give the contribution by the momentum flux to the change in the mean zonal wind. This can be done from the momentum transport by computing the first term on the right hand side of (18).

5.2 RESULTS

5.2a Heat transport

Considering the layer from the surface to 500 mb, the heat transport for every 5-day period was calculated for the latitudes 35°, 40°, 45°, 50°, 55°, 60°N, from October to December 1976. January 1977 was not included in the calculations due to the lack of thickness data.

Figure 28 gives the neat transport as a function of longitude and time (every pentade) around the 45°N latitude, as calculated according to (5). The white area corresponds to a positive value of heat transport and shaded areato a negative one. The thick solid line in the same figure shows the position in time of the trough-ridge-trough pattern. The way this position was determined, was based on the criterion that the average meridional velocity along this part of the latitude circle should be zero. In other words:

$$\int_{\lambda_1}^{\lambda_2} \tilde{v}\, d\lambda = 0$$

where λ_1, λ_2 are the longitudes which present the beginning and the end of the trough-ridge-trough pattern. This way a similar expression as (5) can be used replacing 2π by the difference $(\lambda_2 - \lambda_1)$ expressed in radians. In this case suppose that this pattern is represented as follows:

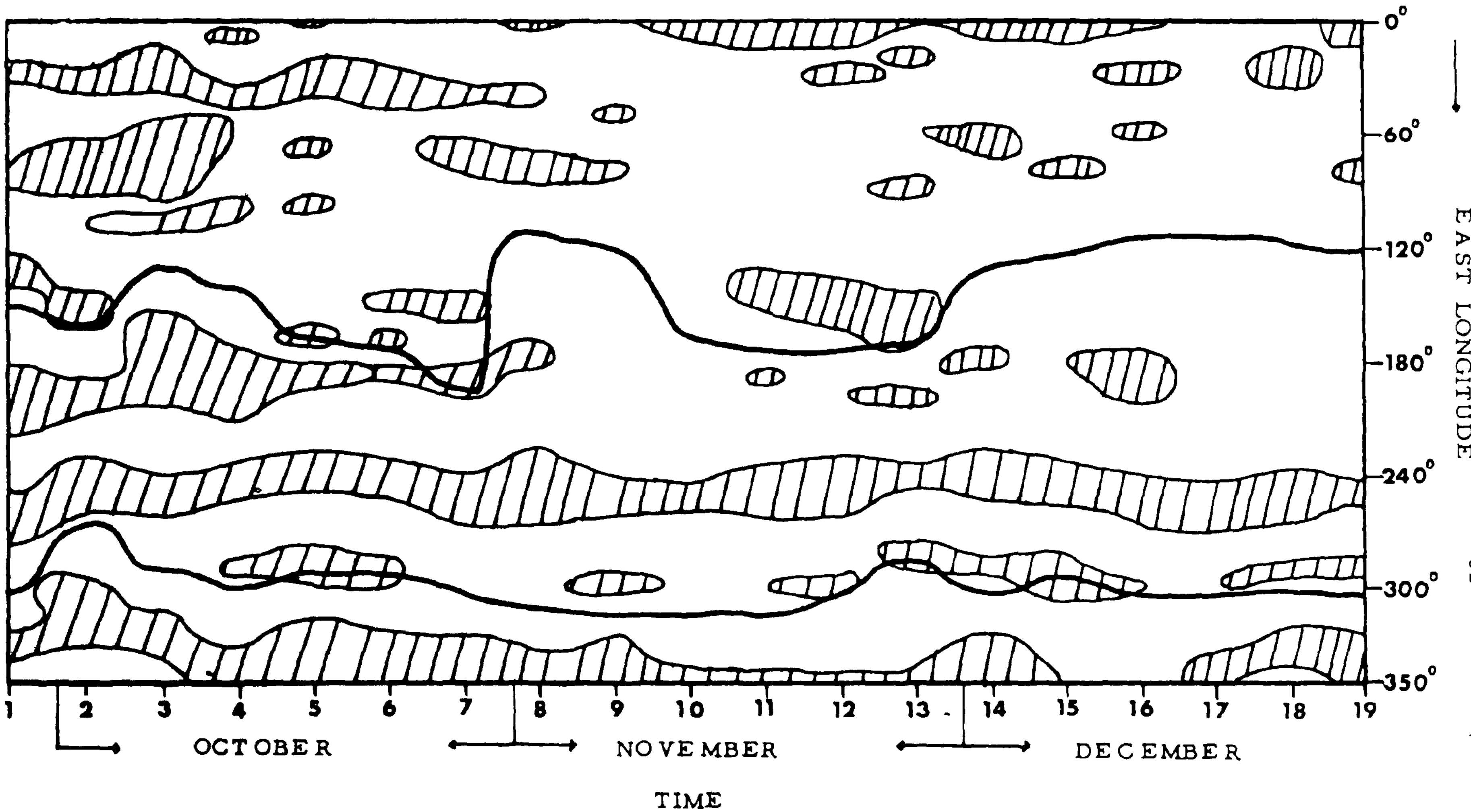
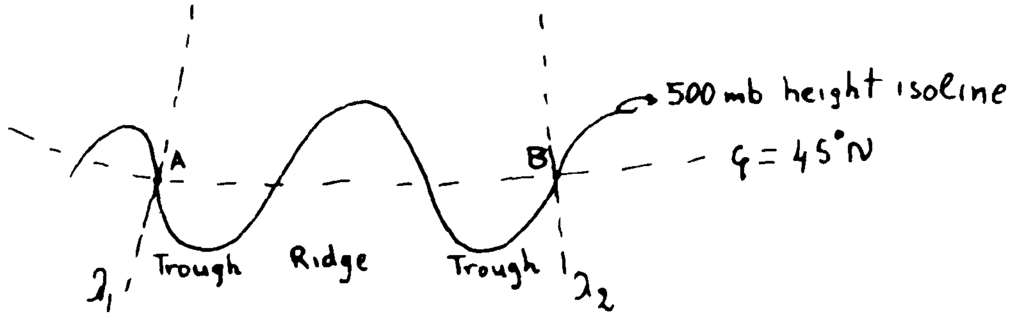


Figure 28 Heat transport as a function of longitude and time around the 45° N latitude



For the purpose of this section the beginning and the end of the trough-ridge-trough pattern are defined to be A and B respectively. It is obvious that from A to B the sum of the meridional velocities, i.e. the average over this sector, is zero. Because of available data, every 10^{o} of longitude, in order to determine the exact position of the pattern, a linear interpolation of the velocities between two grid points was some times necessary.

Returning to Figure 28 it is observed that most often a warm air transport to the north ($v' > 0$, $h' > 0$) or a cold air transport to the south ($v' < 0$, $h' < 0$) is taking place. A cold air transport to the north ($v' > 0$, $h' < 0$) or a warm air transport to the south ($v' < 0$, $h' > 0$) is also observed in some places. This especially, seems to be almost constant in time over about 250^{o}E (110^{0}W) longitude. For this case it was found that $v' < 0$ and since the heat transport has a negative value that means that $h' > 0$, i.e. a warm air transport to the south. In general the sign of the heat transport depends on both v' and h' (or T'), i.e. the deviations of the wind and thickness (or temperature). It is also obvious that the sign of T' is a function of the longitudinal distribution of the temperature around a latitude circle. If the temperature appears to be very cold over a large region of the hemisphere, it will probably have the result that T' over the rest of the hemisphere will be positive. In other words, the sign of the heat transport over an area depends upon the longitudinal distribution of the temperature (or thickness) around the latitude circles.

Figure 28 can be produced for every latitude and thus one could calculate, for this period, the average heat transport across each latitude, as well as the average heat transport due to the trough-ridge-trough pattern. It is obvious that knowing these two, the average heat transport across the rest of the latitude can be found. Let these transports be represented as total transport, transport 1 and transport 2, respectivity. Table 4 gives the total transport, as a function of latitude, averaged over the period from October to December 1976. In the same table the "mean" total transport, as a function of latitude, is given calculated using the available data from 1972 to 1976. For comparison "mean" total transport values for the same months are given, calculated by A. Oort and E. Rasmusson (1971). The data they used covers the period from May 1958 to April 1963.

TABLE 4*
October-December

Latitude	Total Transport	"Mean" total transport 1972-1976	"Mean total transport after Oort & Rasmusson
35	0.05	0.07	0.08
40	0.12	0.11	0.12
45	0.18	0.15	0.16
50	0.22	0.18	0.19
55	0.20	0.18	0.19
60	0.16	0.17	0.18

*Units: 10^{16} Joules sec^{-1}.

As can be seen from Tabel 4 across each latitude there is a warm air transport to the North or a cold air transport to the South both having the common result of warming the North and cooling the South. It is also observed that the heat transport appears to be somewhat higher than the mean at 40^{o}, 45^{o}, 50^{o} and $55^{o}N$ latitudes, while at 35^{o} and $60^{o}N$ appears below the mean. It would then be interesting to examine the heat transport due to the trough-ridge-trough pattern (transport 1) as well as the heat transport across the rest of the latitude (transport 2). Table 5 gives transport 1 and transport 2 as a function of latitude. The total transport is again given from comparison. The units are same as in Table 4.

TABLE 5

Latitude	Total Transport	Transport 1	Transport 2	"Normalized" Transport 1
35	0.05	0.022	0.028	0.027
40	0.12	0.053	0.067	0.066
45	0.18	0.080	0.100	0.100
50	0.22	0.095	0.125	0.120
55	0.20	0.085	0.115	0.110
60	0.16	0.070	0.090	0.090

For all transports a maximum around $50^{o}N$ is observed. The interesting point about the results in Table 5 is that transport 1 and transport 2 are of the same sign with transport 2 a little higher than transport 1. This observation could have the consequence that the increase of the meridional flow over Pacific-W. coast - Mid-eastern United States is not a factor which results in more heat transport to the North. Transport 2 is higher, even if over this sector there is not a strong meridional type of circulation, which is the case as it is known from previous discussion. Rather it is possible that the heat transport is a function of space. This can be seen in Table 5 comparing transport 2 and "normalized" transport 1. On the average the sector which transport 2 comes across is about 1.25 times greater than the sector which transport 1 comes across. The "normalized" transport 1 is obtained by multiplying the values of transport 1 by 1.25. Then, it can be seen that transport 2 and "normalized" transport 1 are almost equal at each latitude. Therefore, transport 2 appears greater simply because it is the transport across a sector which is bigger than the sector which transport 1 comes across. In an endeavor to search for a solid answer to these questions, results from the next chapter were introduced. These results represent the increase of the meridionality of the flow as a function of time. Knowing the heat transport across latitudes as a function of time, one can possibly deduce a relation between increased meridionality and heat transport. Table 6 gives the average heat transport across the 55^{o}N latitude as a function of the year , for the period of October-December. It also gives the increase of the meridionality of the flow, for the same period, in the latitude belt between 50^{o} and 60^{o}N, as a function, again, of the year. Each number gives a measurement of how increased the meridionality is. Actually it indicates the number of days or the total duration of the increased meridionality in this period.

TABLE 6

YEAR	1972	1973	1974	1975	1976
Average over the period of Oct-Dec. H.T across $55^{o}N$ Units: 10^{16} Joules sec^{-1}	0.19	0.10	0.19	0.135	0.20
Duration in days of the increased meri-dionality in the period of Oct-Dec.	28	42	29	35	60

Let X represent the heat transport and Y the increased meridionality. Then using statistics the correlation coefficient between X and Y is given by

$$r_{xy} = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \Sigma y^2}} \tag{19}$$

where x and y stand for the deviations of X and Y from their mean values:

$$x = X - \bar{X}$$

$$y = Y - \bar{Y}$$

Using Table 6 and working as it is shown in Table 10 in the Appendix from (19) it was found that:

$r_{xy} = +0.03$

Therefore, it can be concluded that the heat transport is not a function of the increased meridionality of the flow. The trough-ridge-trough pattern on the average transports heat to the North but this is not due to the fact that the meridional flow was increased over this sector.

5.2b <u>Momentum Transport</u>

It is known that in order to get a northward momentum transport from a wave the axes of its troughs and ridges must tilt on the average from the southwest to northeast (positive slope). A negative slope will give a southward momentum transport respectively. It is apparent that an intense wave or an increase of the meridional flow could result in both northward or southward momentum transport depending on the slope. It is also possible, for an intense wave will transfer no momentum at all (zero slope) while a weak wave transfers some. Thus, one cannot really relate beforehand increase of the meridional flow and increase of the momentum transport. Of course, a higher amount of momentum transport with increasing meridionality is always a possibility.

Considering the 500 mb level the same procedure to find total transport, transport 1 and transport 2 was repeated. Table 7 gives the results for the momentum transports averaged over the period of October - December, obtained using (15)

TABLE 7*

Latitude	Total Transport	Transport 1	Transport 2
35	12.0	7.0	5.0
40	12.1	10.0	2.1
45	10.0	9.0	1.0
50	1.5	5.0	-3.5
55	- 3.0	- 2.0	-1.0
60	- 9.0	- 5.0	-4.0

*Units: m^2/sec^2

From these results it is apparent that across the latitudes 35°, 40°, 45°, 50° a northwards transport of momentum is taking place. Above 50°N a transport to the South is observed. About transport 1 (due to the trough-ridge-trough pattern) it is observed that up to 50°N a transport to the North is taking place. That means that up to 50°N the pattern tilts, on the average, its axes of the troughs and ridge from the southwest to the northeast. Afterwards it op erates in the opposite direction. Comparing now transport 1 and transport 2 it is apparent that at each latitude transport 1 is greater than transport 2. This difference can be determined by a combination or by either of the following factors:

1) the increased meridionality over the sector of the trough-ridge-trough pattern,

2) the persistence of this pattern.

It is known that transport 2 comes across a sector where the meridionality was not increased. It is also known that during the given period, over this sector, nothing was as constant as the trough-ridge-trough pattern over Pacific-W coast-Mid-eastern United States It is then possible that transport 2 is a result due to different wave patterns over this sector during that period Obviously, that difference is not due to the difference in sector size, as was the case in the heat transport. Here, transport 1 is greater than transport 2 even if transport 1 comes across a sector which is smaller in size than the corresponding of transport 2. Also, in order to state whether or not transport 1 appears higher than a mean value is probably not possible since one cannot find similar patterns over the same sector very often. Whatever the reason for this difference, one thing is certain and important. That is, in fact, the trough-ridge-trough pattern contributes the most to the total momentum transport across each latitude.

Considering then this pattern, the contribution by the momentum to the change in the mean zonal flow wascalculated. This was done by computing the first term on the right hand side of equation (18), and the result is shown in Figure 29 by the solid line. The scale is the one to the left expressed in m/sec day. The scale to the right corresponds to the dashed line which gives the mean zonal wind (m/sec) observed during this period, as a function of latitude. Comparing the solid line of this figure with Table 7 it can be concluded that an

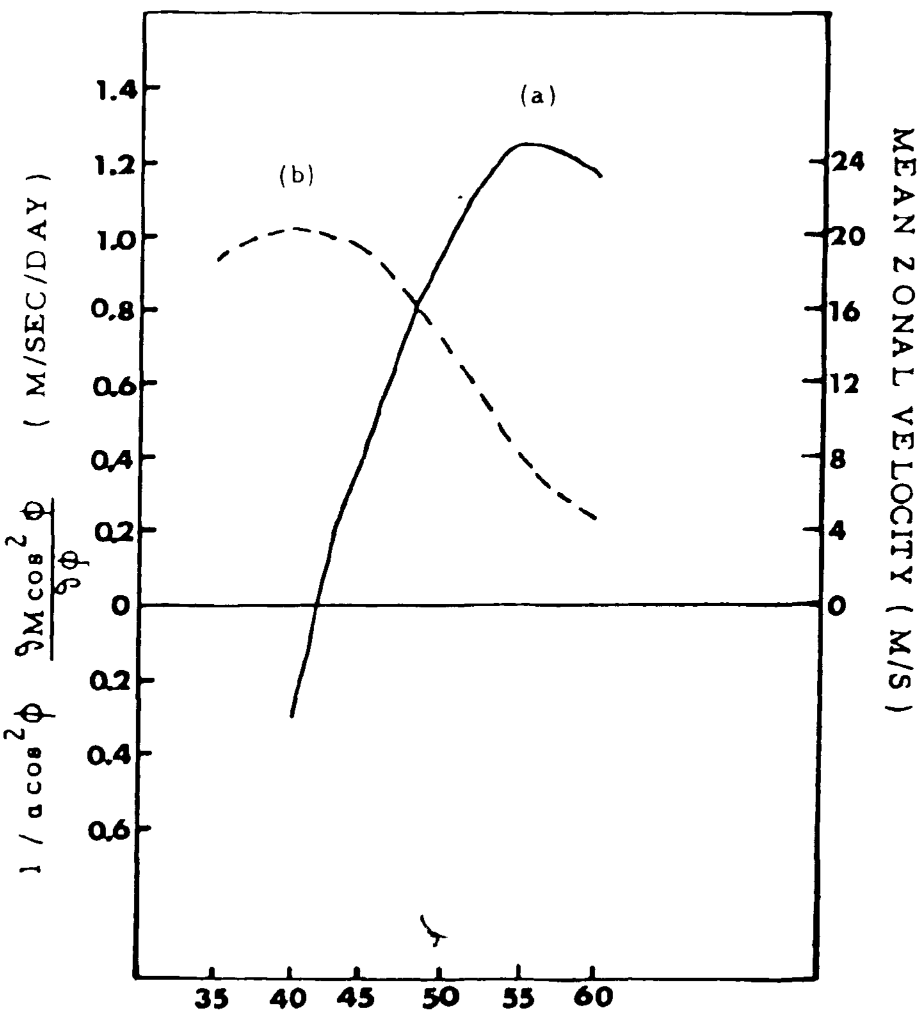


Figure 29 (a) Contribution by the momentum to the change in the mean zonal flow
(b) Mean observed zonal wind

increase of the momentum with latitude contributes to a tendency of the mean zonal flow to decrease and vice-versa. Furthermore a comparison between the two curves in Figure 29 shows that the effect of the momentum transport is to tend to move the jet stream maximum to the North.

Concluding, the increase of the meridional flow over Pacific-W. coast-Mid-eastern United States did not affect the heat transport to the North which does not seem, in the average across each latitude from 35^{O}N up to 60^{O}N, to be "abnormal." On the other hand, the trough-ridge-trough pattern contributes the most to the momentum transport across each latitude. Finally, the effect of the contribution of the momentum transport, due to this pattern, to the change in the mean zonal flow over this area, is to move the maximum of the jet stream to the North.

5.3 SUMMARIZED REMARKS

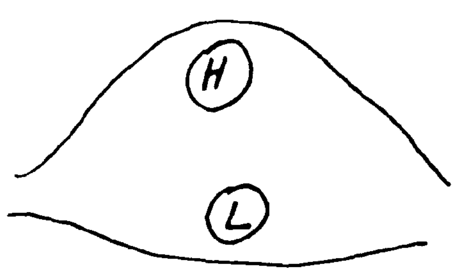
For what has been mentioned in previous chapters an abnormal existence of a ridge may cause some characteristics upon the regional climate which appear as weather anomalies, sometimes severe, depending on the intensity of the ridge. An extensive ridge results in direct flow of polar air which falls in the following trough which simulataneously is developing. The result, then, is cold temperatures and precipitation. On the other hand the ridge, with its persistence and extension, is blocking the circulation, preventing this way the motion of the precipitation systems. The result then is drought over the underlying area. Also, as a consequence of the increased southerly flow on the left side of the ridge, warm air advection gives high temperatures. From the case which was under examination it can be concluded that the severe negative temperature anomaly was causally connected with the positive 500 mb height anomaly to the west, which is connected with a warm spell and drought. This description is qualitatively the same as the one given by Rex (1950b) for weather sequences in the "blocking" ridges and highs. Obviously, the increase of the meridional flow over the West Coast has all the characteristics of a "blocking" ridge or high. It would then be interesting to investigate to what degree the existence of the "blocking" ridge over the West Coast is abnormal. In order to determine this, an investigation of "blocking" ridges and highs based on the increase of the meridionality of the flow is the next step.

CHAPTER 6

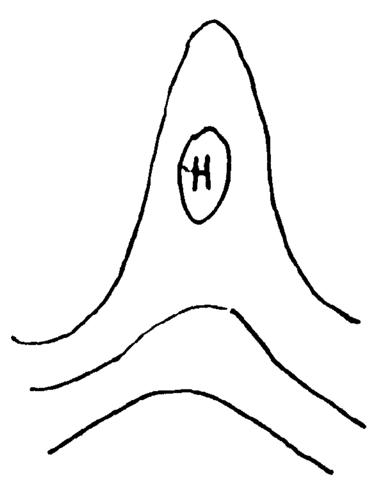
AN INVESTIGATION OF "BLOCKING" ACTION

6.1 INTRODUCTION

Since the time that the "blocking" situation was first noted by Garriott (1904), many investigators have examined it and its effects on synoptic situations. Namias (1947), Elliot and Smith (1949), Berggren, Bolin and Russby (1949), Rex (1950 a, b) and more recently, Sumner (1954, 1963), Kikuchi (1971) and others have given geographical and seasonal distribution of the "blocking" action. There are significant differences between the definitions and restrictions about a "blocking" action adopted by the investigators. For example, Rex (1950a) formulated the very restrictive definition that the spliting of the jet stream should extend over at least 45° of longitude and that the pattern must exist for at least 10 days. On the other hand, Sumner (1954) without any restriction on the extension or the persistence of the blocking action classified it into diffluent and meridional types as below.



Diffluent Type

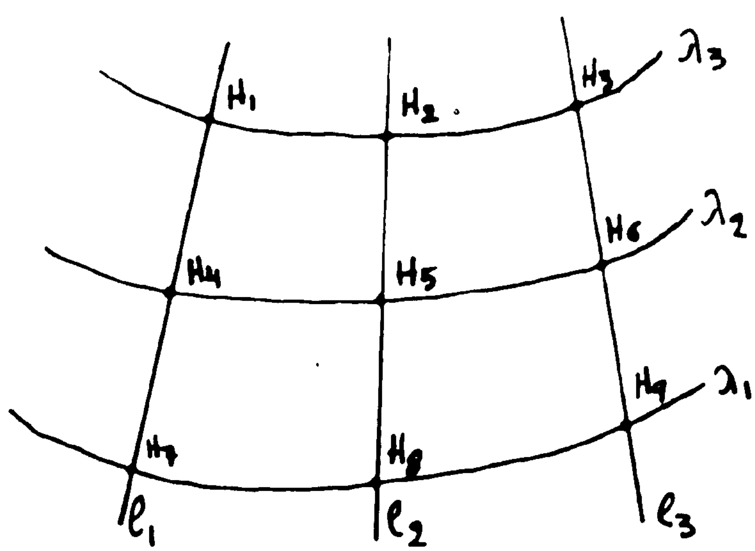


Meridional Type

In general the common denominator to all definitions is that the meridionality of the flow is increased. A "blocking" situation is nothing more than an increase of the meridional flow over an area and it depends on how increased this meridionality is in order to get an intense or a very intense "blocking" situation. Recalling results from these investigations the longitudinal distribution of the "blocking" activity presents two maxima: one, the more frequent, about 0° (360°E) longitude and another one about 150°W. The seasonal distribution indicates a maximum in April.

6.2 A METHOD OF DEFINING "BLOCKING" RIDGES AND HIGHS

Suppose that the following grid-point model is given where ℓ is the longitude every 10° and λ is the latitude every 5°.



Suppose that for each grid-point its 500 mb height value (H) in decameters is given. Now, let us consider grid-point number

5. If $H_5 > H_4$, $H_5 > H_6$ and $H_5 > H_2$ then at longitude ℓ_2 a ridge is positioned. If in addition $H_5 > H_8$ then at longitude ℓ_2 a closed high is found. In order to avoid flat ridges the following arbitrary restrictions were made:

1. The east-west gradient should be greater than 4 decameters;

2. The north-south gradient should not be greater than 8 decameters, because it is known that the north-south gradient in ridges is not very strong.

Following this method it is possible to locate on a daily time scale the longitudinal position of ridges and highs at the 500 mb level. It is also possible to find how extensive a ridge, or a high, is. In order to more comprehensively present the increase of the meridional flow, a "blocking" ridge or high divided into three types as follows:

a) Type 1: Ridge extending over 3 latitude belts, or more

b) Type 2: Closed high over 2 latitude belts

c) Type 3: Closed high over 3, or more, latitude belts.

No restriction was made on the duration of each type. It is obvious that according to the definition Type 3 includes Type 2 which includes Type 1. In other words, when Type 3 is reported over an area, a Type 2, although existing there, is not.

From these types a new type was contructed by putting a restriction on the duration. This new type, <u>Type 4</u>, is defined to be any of the other types but with a persistance of 5 or more days. A motion of 10° of longitude is permissible.

This type comes closer to fitting the definitions of other authors and has as a further purpose the checking of the results. In the continuation when Type 4 is examined, neither the longitudinal position of the initiation nor the end are considered, but its position every day. As a result the number of selected cases or occurrences of Type 4 shows the total duration of its activity. When Types 1, 2, or 3 are examined every case (or occurrence) is considered independently of the duration. For example, if Type 2 is found at 320^{O}E for one day, this is considered as one occurrence.

This investigation covers the years 1971-1976 for the Northern Hemisphere, from 25^{O}N latitude up to the North Pole, and the years 1949-1970 only for the part of the Northern Hemisphere which is included between 120^{O}W and 60^{O}E longitudes. The restriction in the latter case is due to missing information for these years. This restriction has as a consequence that for the longitude 120^{O}W the number of cases, or occurrences, of Type 4 can not be accurate. The reason is that, according to the definition of Type 4, information west of 120^{O}W should be available. Of course, in this case Types 1, 2 or 3 can be used,

6.3 RESULTS FROM THE INVESTIGATION OF THE YEARS 1971-1976.

Using the results of this investigation Figure 30 was produced. It shows the longitudinal distribution of Types 3 and 4, as well as the summation of Types 3 and 2 and the summation of Types 3, 2 and 1. The purpose of presenting this graph in this manner is to determine whether the different

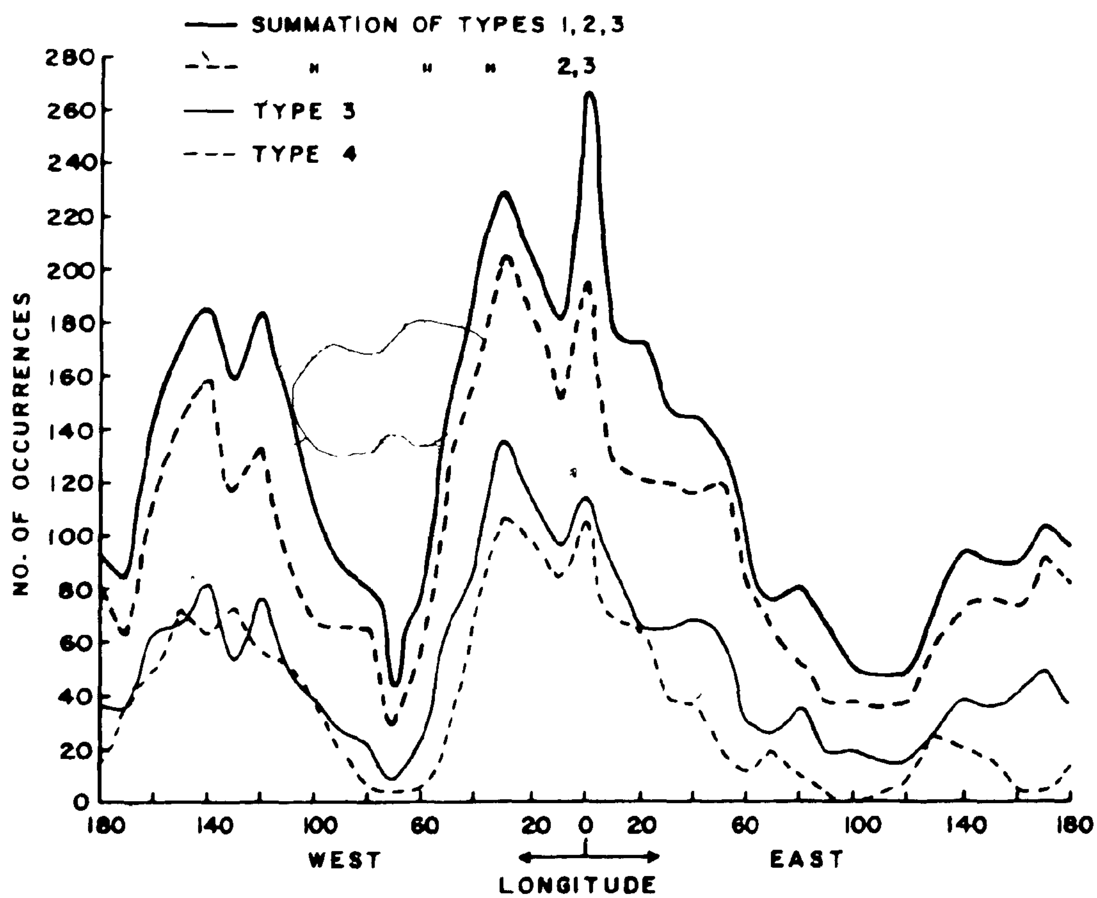


Figure 30 Longitudinal distribution of type 4, type 3, summation of types 2, 3 and summation of types 1, 2, 3 (results for the years 1971-76)

types result in a different distribution of the increased meridionality. As it turns out this longitudional distribution remains exactly the same independent of the way of presenting it. This gives the ability to present the "blocking" activity as a summation of different types or as Type 4, which as it was mentioned previously approaches more the definiton of other investigators.

As can be seen from Figure 30 the longitudinal distribution of "blocking" activity obtains a maximum at the longitude belt 0^{O} - 30^{O}W and a second maximum at the longitude belt 120^{O} - 150^{O}W, with the first maximum being more frequent than the second one. The minima are located over 70^{O}W and 100^{O}E longitudes. Figure 31 shows the seasonal variation of observed Type 4 in 1971-1976, indicated by the solid line. The figure shows a maximum between March and May and a second one in August. The dashed line, indicating the peak around April, represents an approximation which was obtained using the method of the semi-averages. These results are found to be in agreement with results obtained by Rex (1950b), Sumner (1954) and others.

6.4 RESULTS FROM AN INVESTIGATION OF 28 YEARS (1949-1976).

This investigation, as it was mentioned before, refers to the longitude belt 120^{O}W to 60^{O}E. In the results from the years 1949-1970, the results from the year 1971-1976 (considering the same longitude belt) were added. Using these results one can find "normal" frequency of occurrences for each longitude, or longitude belt, and compare these with the frequency of occurrences in any year.

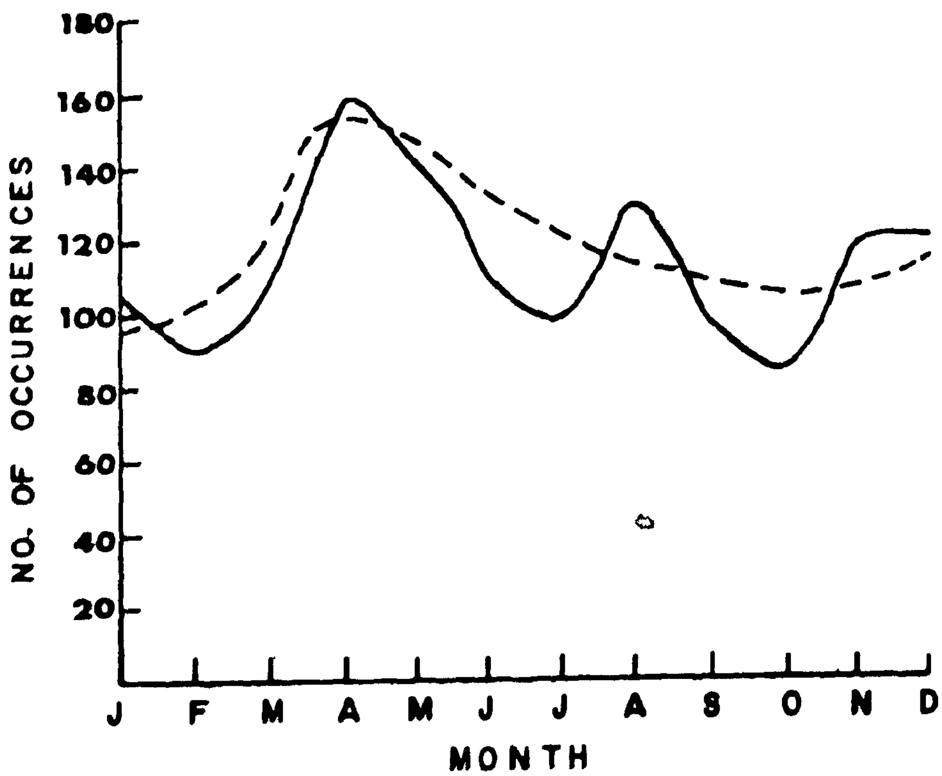


Figure 31 Seasonal variation of type 4

Figure 32 shows the longitudinal distribution of Type 4, as well as the summation of Types 3, 2 and 1. Note that for Type 4 over 120°W longitude there is no accuracy, therefore this is indicated with dots instead of a continuation of the dashed line. Comparing these results with the result in Figure 30 it can be seen that the longitudional distribution remains almost the same. The maximum is over the longitude belt from 0° - 30°W and the minimum is at 70°W longitude. About the next maximum and minimum there can be no accuracy, since there was no information available, but an increase of the activity over 120°W and a decrease at 60°E is visible. A difference appears only at the longitude belt from 30°E to 50°E, where now an increase instead of a decrease of the "blocking" activity is observed. Also it can be observed that there is a relative decrease of the activity, compared with that of 1971-1976, at longitudes 120°W, 110°W and 100°W and a relative increase at longitudes 80°W, 70°W, 60°W and 50°W.

6.5 EXAMINATION OF THE "BLOCKING" ACTIVITY OVER THE WEST COAST IN 1976

It is known that during the period from October 1976 to January 1977 an abnormal ridge was prevailing over the West Coast. The purpose of this investigation is to compare the activity of the increased meridionality, during this period and over this region, with the normal. Using the results of this investigation Figure 33 was produced giving the observed frequency of occurrences, of the summation of Types 3, 2 and 1 in 1976, against the normal. The first interesting point from

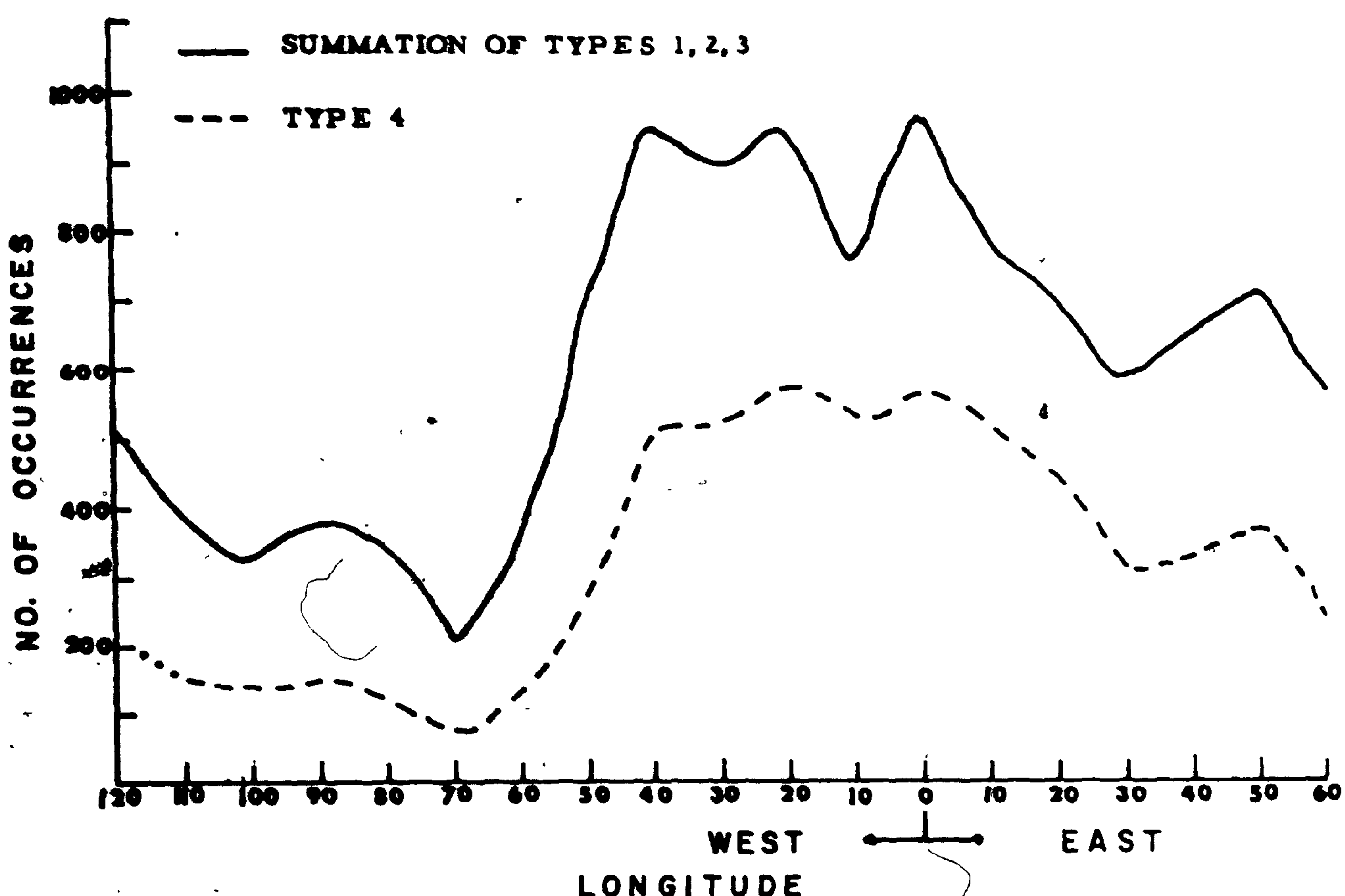


Figure 32 Longitudinal distribution of type 4 and the summation of types 1, 2, 3 (28 years of results for 1949-76)

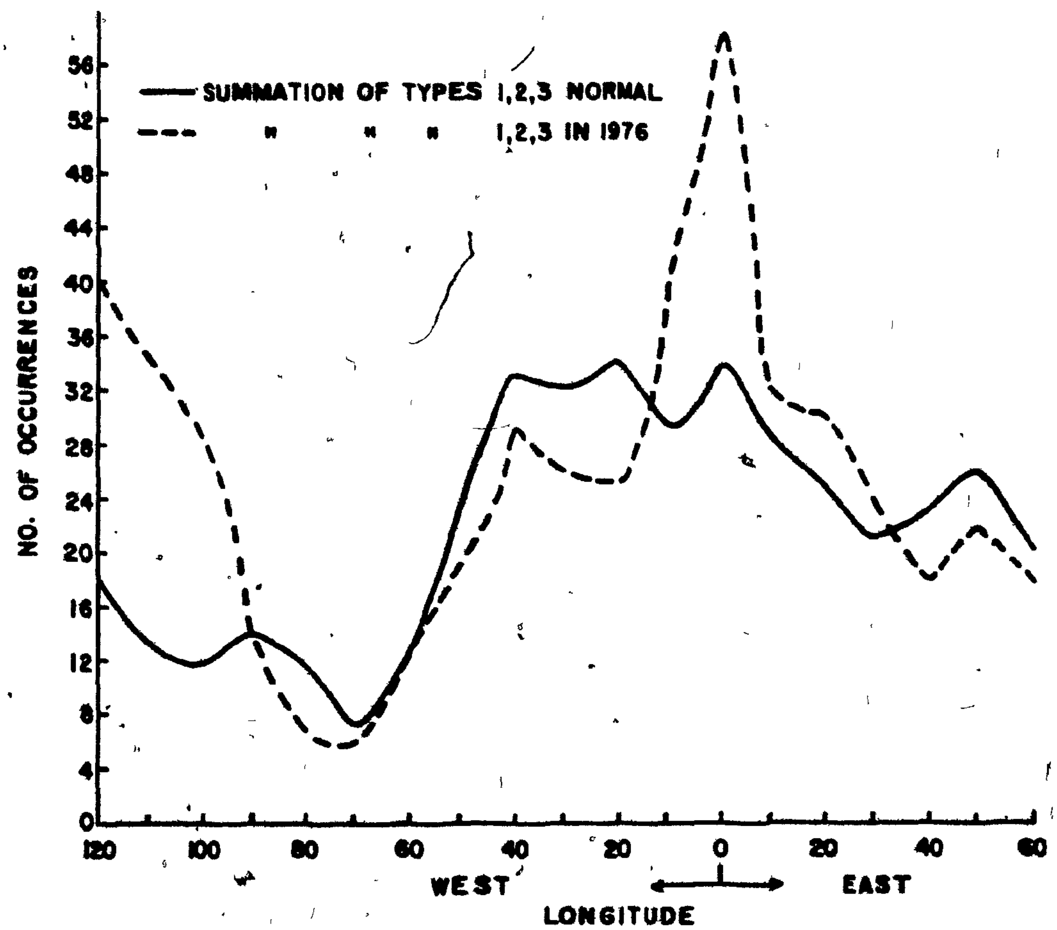


Figure 33 Observed longitudinal distribution of the summation of types 1, 2, 3, in 1976 versus the normal

this figure is that in 1976 the "blocking" activity over 120°W longitude sharply increases compared to the normal. It would then be interesting to determine whether that increase appeared in the period where the known abnormality took place. Figure 34 gives the number of occurrences of the summation of Types 3, 2 and 1 at 120°W longitude as a function of time (the time step is in months), as well as the normal frequency. In this figure, January 1977 was included.[1] Examining Figure 34 it is quite apparent that the "blocking" activity is much more than normal during the period from October 1976 to January 1977. Also, it is interesting that this abnormality is taking place in a period where the normal minimum is observed. Converting this abnormality into numbers, a number of 16 cases is observed from October 1976 to January 1977, while normally a number of 4 cases is reported. A striking point in this figure is that in September the "blocking" activity is also much greater than normal but is not associated with the known climatic extremes over the area which was affected during the period from October 1976 to January 1977. The reason is, that this "blocking" activity is located further north than during the period from October to January, thus not affecting the area which is under discussion. A presentation of the latitudinal distribution of the "blocking" activity was not attempted in this work, but for cases as this results were recalled. In fact, during

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[1]Only data for the first months of 1977 were available to the author in the first instance. Complete data for 1977 were added later.

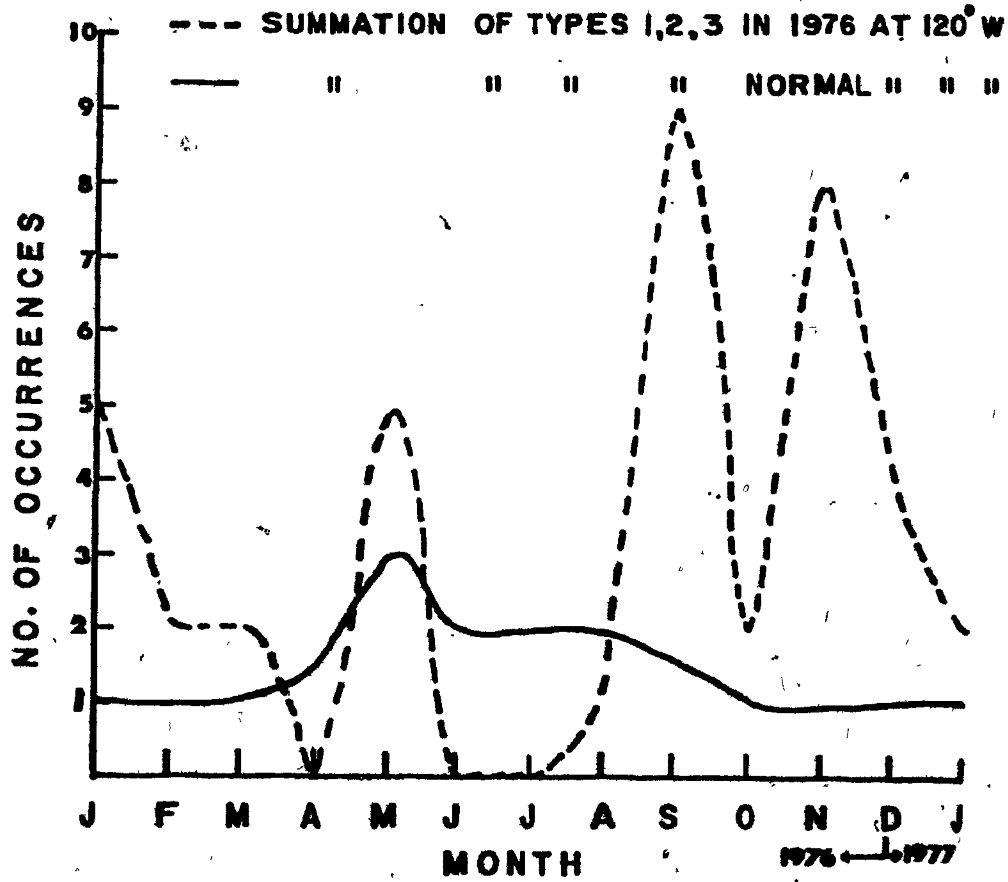

Figure 34 Observed seasonal distribution of the summation of types 1, 2, 3 in 1976 at 120° W. longitude versus the normal

September 1976 the drought-cold pattern is located over Northern Canada. On the other hand, during September, the Western United States reported a large amount of precipitation and the Mid-eastern United States was not very cold. Also, from the same figure an increase of the "blocking" action is indicated in January 1976. In this case the activity is located over the same region compared with that during the period from October 1976 to January 1977. Now, in fact, this activity is associated with the same climatic characteristics over the known areas. That is, the synoptic maps for January 1976 indicate drought over the West Coast and cold over the Mid-eastern United States.

Working with the same period for all years on which data were available, Table 8 gives the observed frequency of occurrences of the summation of Types 3, 2 and 1 at longitude 120^{o}W. This serves the purpose of a better estimation of the abnormality during the period of October 1976-January 1977. As can be seen the frequency of 16 cases in 1976-77 is the highest ever observed.

Concluding, indeed during the period of October 1976 to January 1977 the "blocking" action is remarkably greater than normal, appearing also as the highest observed frequency of occurrences in the last 28 years. Such a high appearance of "blocking" action could give severe climatic effects upon the regional climate such as drought over the underlying area and cold over the area of the following developed trough. It must, however, be emphasized that this relation may not be one to one in all cases, depending on the latitudinal position

TABLE 8

LONGITUDE 120°W

Number of occurrences of the summation of Types 3, 2, and 1 in the period from October to January.

YEAR	NUMBER OF OCCURRENCES
1949-50	1
1950-51	0
1951-52	1
1952-53	0
1953-54	1
1954-55	2
1955-56	1
1956-57	1
1957-58	1
1958-59	1
1959-60	0
1960-61	1
1961-62	0
1962-63	1
1963-64	0
1964-65	11
1965-66	4
1966-67	2
1967-68	6
1968-69	10
1969-70	11
1970-71	9
1971-72	3
1972-73	5
1973-74	6
1974-75	7
1975-76	12
1976-77	16

of the "blocking" activity. A verification and a test of these results could be an examination of the climatic characteristics somewhere, where a higher than normal frequency of "blocking" action is observed. This could be done for the same region since results are already given (Table 8), but it was desirable to perform a test over the region where the maximum of the "blocking" activity was observed. In other words over the 0^o (360^oE) longitude. In order to choose the period in this case, the restriction was made that the frequency of "blocking" activity during this period, must be at least two times greater than the corresponding normal. This way only strong cases will be considered. At first, it was attempted to find a period of four consecutive months, but without success. After that a three month period was considered and Table 9 gives the most abnormal cases which occurred over the longitude belt from 10^oW to 10^oE, in the years from 1949 to 1976. Finally, it was decided to examine the abnormality of the period of June - August 1976, solely because it is more recent and all relative synoptic maps and data were available.

6.6 THE 1976 CASE OVER WESTERN EUROPE

In this case since more information is available, the previous presentation was repeated for the 0^o longitude as well as for the longitude belt from 10^oW to 10^oE. Figure 35 shows the observed frequency of occurrences of Type 4 against the normal, at 0^o longitude and over the longitude belt from 10^oW to 10^oE. As it is observed from this figure the frequency

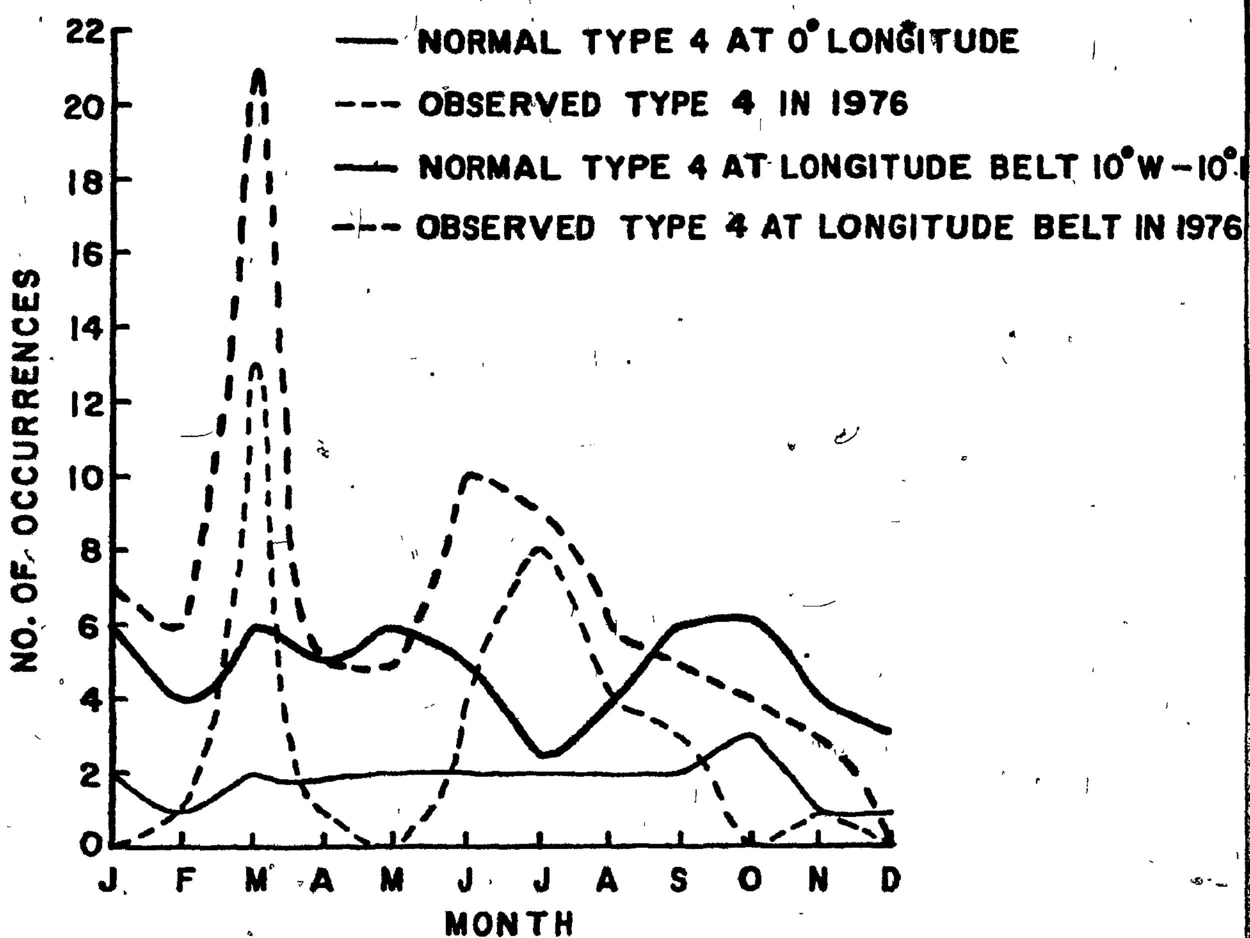

Figure 35 Observed seasonal distribution of type 4 over the longitude belt of 10° W. - 10° E. and at 0° longitude in 1976, versus the normal

TABLE 9

Longitude belt $10^{o}W - 10^{o}E$
Three month periods where the "blocking" activity appears to be much higher than normal

YEAR	PERIOD
1949	June - August
1952	March - May
1953	October - December
1959	February - April
1961	September - November
1976	June - August

of occurrences in 1976, for both 0° longitude and the longitude belt $10^{\circ}W - 10^{\circ}E$, is higher than normal during the period from June to August as well as in March. It can also be seen from this figure that when the longitude belt is considered a relative decrease of the activity is observed, compared with that at 0° longitude. This shows that the "blocking" activity over the longitude belt $10^{\circ}W - 10^{\circ}E$ has its maximum at 0° longitude. This is further evidence that the abnormal frequency of occurrences is taking place in a period where, again, the minimum normal frequency is observed. It is then interesting to examine the climatic characteristics which were associated with this abnormal frequency of "blocking" activity during the summer 1976, over Western Europe.

CHAPTER 7

SYNOPTICS OVER EUROPE DURING THE SUMMER 1976

7.1 CIRCULATION OVER EUROPE DURING THE PERIOD OF JUNE-AUGUST 1976

Examining the abnormal winter 1976-77 over North America it was shown that higher than normal frequency of "blocking" activity was associated with the circulation, and the climatic characteristics. If this increase of the meridional flow is the common denominator of such synoptic patterns it would be expected that in the European case similar circulation and climatic characteristics would be found.

Figure 36 shows the mean average 500 mb height flow for the period of June - August 1976, this is indicated by the solid lines. The corresponding normal circulation is also shown in this figure by the dashed lines. It is clear that on the average, the flow is more developed during this period with a ridge building up over Western Europe (about at 0° longitude) and a developed trough situated over Eastern Europe. In addition the trough over the Atlantic also appears stronger than the normal. This picture of the trough-ridge-trough pattern is almost always visible in the German "Europaischer Wetterbericht" daily weather maps as well as in the monthly maps from June to August. A similar picture, to that of the abnormal winter over North America, seems to appear again with an increased frequency of "blocking" action expressing itself by the building of a ridge over Western Europe.

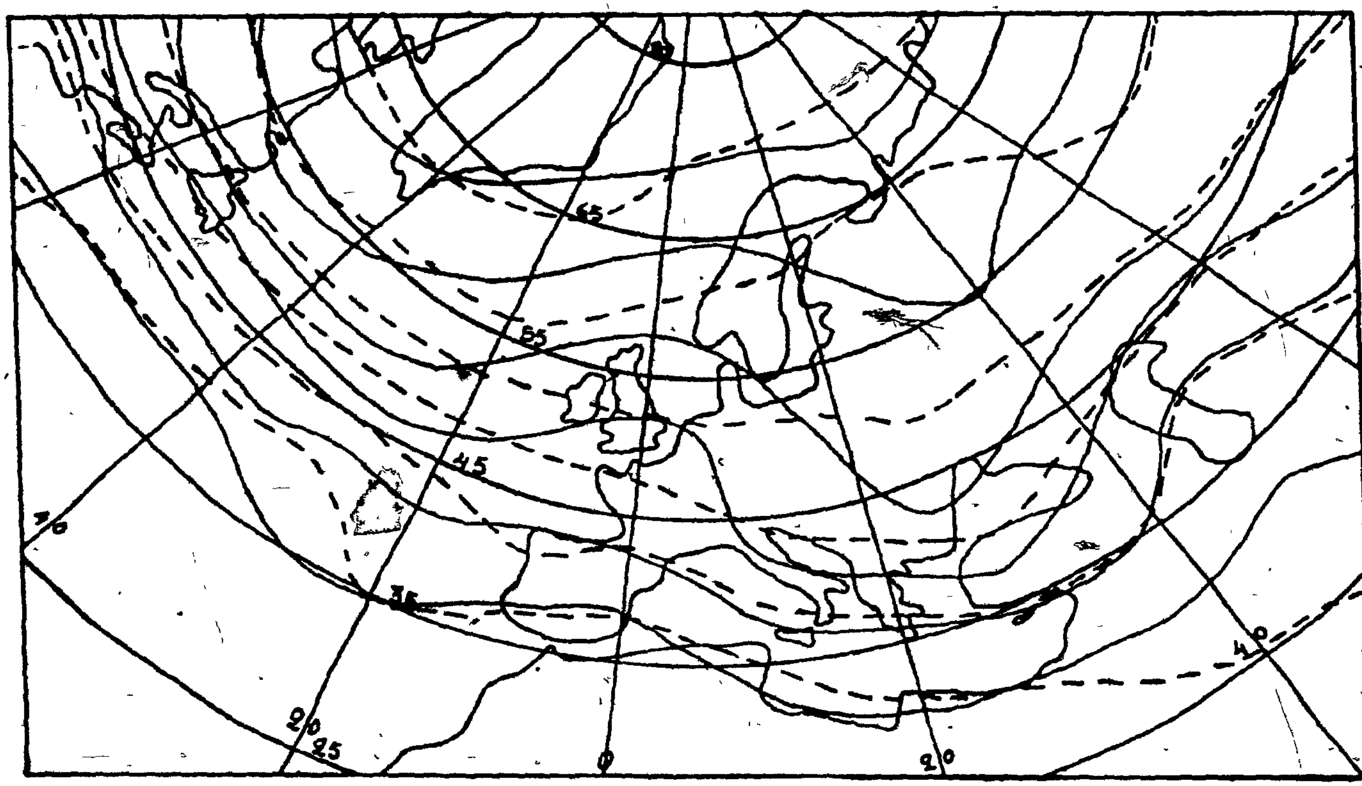

Figure 36 Mean observed 500 mb circulation over the period of June-August versus the normal

7.2 CLIMATIC CHARACTERISTICS ASSOCIATED

Figures 37 and 38 show respectively the temperature anomaly and the precipitation anomaly, as functions of longitude moving along the 50^{O}N latitude, for the months June, July and August. As it is shown from these figures, over the underlying area of the increased meridionality a positive temperature anomaly is observed, as well as a negative one under the developed trough over Eastern Europe. For the precipitation again, a high drought accompanies the "blocking" activity, since under the trough a more than normal or normal amount of precipitation is a fact.

The picture of these figures remains almost the same if one repeats the procedure along the 55^{O}N or the 45^{O}N latitude. Referring also to the German maps for the months June, July and August 1976, the above picture is very distinguished and connected with the ridge-trough-system over Europe.

Recapitualting, the similarity of the results, given that an abnormal appearance of increased meridionality of the flow is taking place, indicates that this is a factor associated with the appearance of such weather situations.

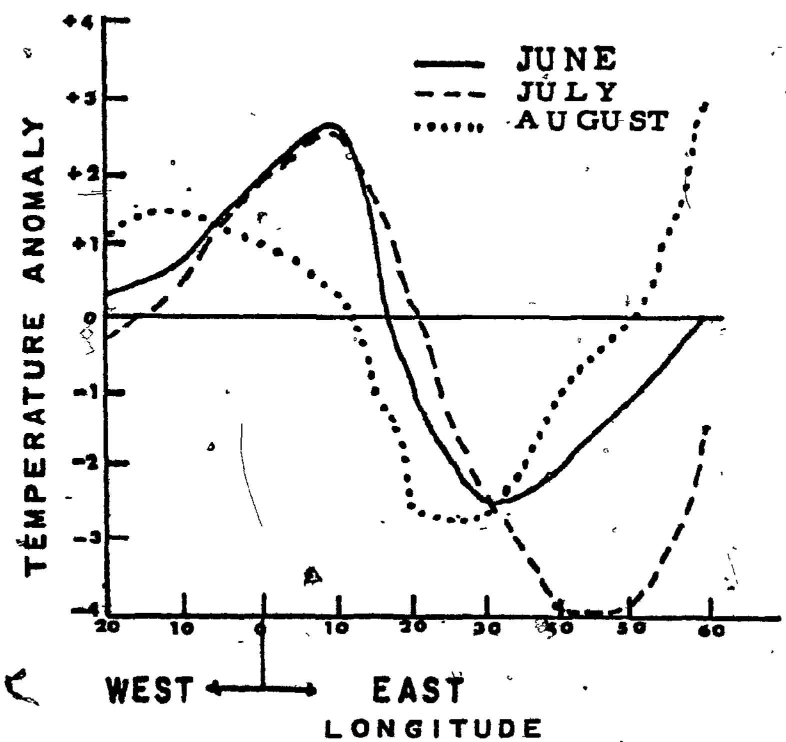

Figure 37 Temperature anomaly as a function of longitude moving along the 50° N. latitude

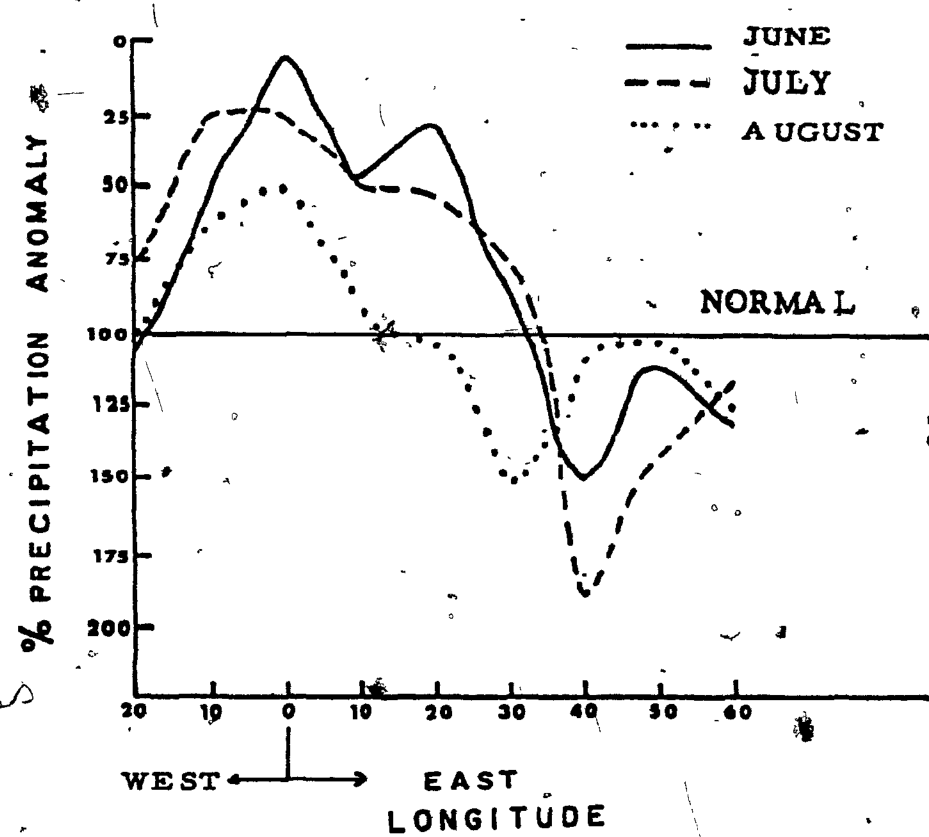

Figure 38 Precipitation anomaly as a function of longitude moving along 50° N. latitude

CHAPTER 8

SUMMARY

8.1 DISCUSSION

Results obtained by Namias (1978) indicate that a sea surface temperature anomaly over the Pacific, generated early in spring and summer, resulted in an increased South-North upper level flow east of 140°W, and the creation of an extensive ridge over the West Coast. The question which may arise here is whether a sea surface temperature anomaly can result in an abnormal frequency of "blocking" activity. This is not very well known and needs further investigation. However, it is the author's hope that this study will be a useful guide to the investigation of climatic anomalies and the factors which are involved in the appearance of such weather situation.

8.2 CONCLUSION

A very well known weather anomaly was examined, namely the abnormal winter 1976-1977 over North America. The 500 mb height anomalies were examined and it was found that a severe weather situation does not depend by necessity on a hemispheric wave pattern but may very well be the result of a smaller scale phenomenon. In this case an anomaly can not exist alone but must be found in relation with other associated anomalies. For the weather situation which was under examination it was found that the abnormality was caused by a strong meridional type of circulation which expressed itself by a very well organized ridge over the West Coast accompanied by two developed troughs, one over the Pacific and the other over the Mid-eastern United States. This type of circulation resulted by necessity not in one abnormality but in several ones related to each other via the circulation type. This pattern was found to be sensitive to slight shifts in position of the meridional type. Examining some physical characteristics of this pattern it was found that the heat transport to the North was not a function of the increase of the meridional flow. However, the persistence of this pattern contributes the most to the momentum transport across each latitude from 35° up to 60°N. The increased meridionality was examined by defining "blocking" ridges and highs. It was found that the persistence of the ridge over the West Coast was quite abnormal, concluding that a higher than normal frequency of "blocking" activity causes the known climatic characteristics over the underlying area of the intensified ridge and over the underlying area of the corresponding developed trough. A test which was performed for the period of June - August 1976 over the western Europe showed that similar circulation and climatic characteristics are associated, again, with a high frequency of increased meridionality of the flow.

APPENDIX

Computation of the correlation coefficient r_{xy}

TABLE 10

X days	Y 10^{16} J.sec^{-1}	x	10^{16} J.sec^{-1}	x^2	10^{29} J.sec^{-1}	xy
28	0.19	-11	0.027	121	0.729	-0.297×10^{16}
43	0.10	+ 4	-0.063	16	3.969	-0.252×10^{16}
29	0.19	-10	0.027	100	0.729	-0.270×10^{16}
35	0.135	- 4	-0.028	16	0.784	$+0.112\times10^{16}$
60	0.20	+21	0.037	441	1.369	$+0.777\times10^{16}$
MEAN: 39	MEAN: 0.163			$\Sigma x^2 =$ 694	$\Sigma y^2 =$ 7.58×10^{29}	$\Sigma xy =$ 0.07×10^{16}

$$r_{xy} = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \Sigma y^2}} = +0.03$$

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