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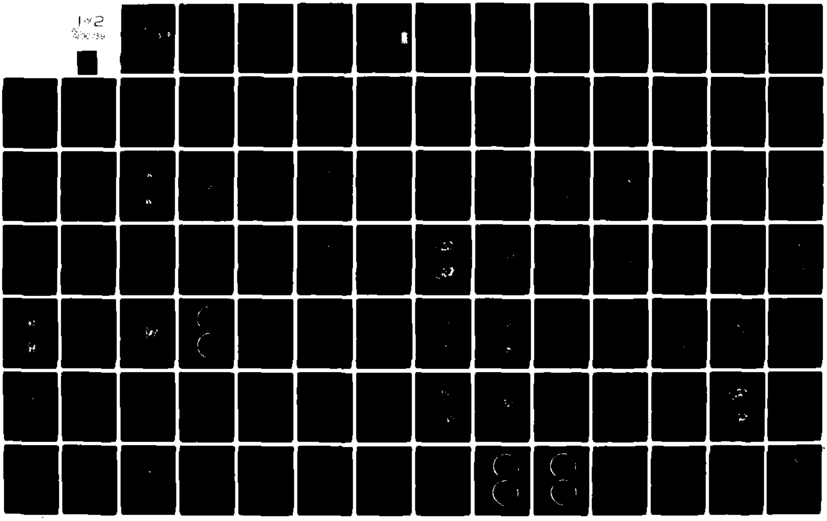

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Abstract

AN OBSERVATIONAL STUDY OF BLOCKING

By Michael Lindley D'Spain

Chairperson of the Supervisory Committee: Professor Dennis L. Hartmann
Department of Atmospheric Sciences

The initial purpose of this paper was to use the original concept developed by Hartmann and Ghan (1979) of separating the anomalous ridges solely on the basis of duration and proceed to formulate 3-dimentional pictures from the 1000, 850, 500, and 100mb pressure levels of the long and short lived ridges, observing any differences which might exist. The three areas of ridge formation studied were defined as the Pacific Ocean (175E-155W), the Pacific Coast (140W-115W), and the Atlantic Ocean (65W-25E). The Pacific regions were characterized by a well developed upstream trough, the ridge itself, and the downstream wavetrains. Both Pacific cases appear consistent with the idea of enhanced production of wave energy due to heating over either the mid-latitude or tropical ocean as suggested by Hoskins and Karoly (1981). The Atlantic cases did not exhibit the same downstream influences as the Pacific cases. The similarity in the height fields over North America between the short and long-lived ridges and the differences in the thermal fields suggests a relationship between the cold temperatures over North America and the long-lived ridges over the Atlantic.

This paper, entitled An Observational Study of Wintertime Blocking, was submitted by Michael Lindley D'Spain, Captain, USAF, in the year 1981 in partial fulfillment for a Masters of Science degree at the University of Washington and contains approximately 120 pages.

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An Observational Study of Wintertime Blocking

by

Michael Lindley D'Spain

A thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Science

University of Washington

1981

Approved by ____________________
(Chairperson of Supervisory Committee)

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to Offer Degree Department of Atmospheric Sciences

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Master's Thesis

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University of Washington

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AN OBSERVATIONAL STUDY OF BLOCKING

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Chapter 1

INTRODUCTION

The occurrence of long-term, quasi-stationary, anomalous high pressure systems which are commonly called blocks, have been of interest to many over the years (Namias, 1947, Rex, 1950, Sumner, 1959). This interest is justified by the short and long-term effects such systems may have on the atmosphere and the underlying land masses. One of the earlier papers by Namias (1947) shows clearly the dramatic atmospheric changes that take place with the formation of a block on the Pacific coast of North America. He described how the Northwest, under the domination of the block, will experience warmer than normal temperatures while the downstream area of the Mid-West will experience much colder temperatures as the cold polar air mass is allowed to migrate south behind the anticyclone. The results can be snowstorms or flooding in the East and droughts in the West.

The European blocks were likewise discussed by Rex (1950). When the block forms around Great Britain, warm maritime air from the Central Atlantic is transported into the northern latitudes causing appreciable warming. Accompanying the warmer temperatures on the upstream side of the block is a greater transport of moisture resulting in larger than normal precipitation in the North Atlantic. At the same time, on the downstream side of the block, cold polar air invades much of western Russia and central Europe. The precipitation is accordingly reduced when the colder, drier polar air enters the area of central Europe. Because of the above effects on the atmosphere, interest in blocks has remained high with recent papers continuing the attempt to find the controlling mechanisms for their development.

In one paper, Rowntree (1971) uses a nine-level hemispheric model of the atmosphere to investigate the effects of tropical sea surface temperature forcing on the mid-latitude atmosphere. Assuming the Bjerknes' (1964) hypothesis that warming of the equatorial water will lead to the intensification of the local Hadley Cell and thereby increase the sub-tropical jet to the immediate north, Rowntree proceeds to construct a sequence of events leading to the formation of a block. He argues that local tropical sea surface temperature anomalies will result in a greater flux of latent heat which will percolate upward, increasing the atmospheric humidity. The local warming will then be forced northward and eastward. His studies showed that the warmest anomalies occurred around 170W in the tropics with a trough around 150W. Rowntree concludes that one possible interpretation of his data could suggest the atmosphere's ability to place another wave between the western Pacific trough and the trough over the Northwest, but not without forcing from the tropical sea surface temperatures and the subtropical jet. The study by Rowntree, however, does not address the problem of explaining those blocks which form over the West Coast from the central Pacific Hadley Cell.

Hoskins and Karoly (1981) used a linearized steady-state, 5 layer baroclinic model to investigate the atmospheric responses to various subtropical and middle latitude thermal and orographic forcings. For low levels, the response to thermal forcing was confined to the neighborhood of the source. With a subtropical thermal forcing, the long wavelengths tended to propagate northward and eastward, resulting in a series of crests and troughs roughly along a great circle, which we will call a wavetrain. The shorter wavelengths are trapped equatorward of the jet. Orographic forcing tends to position an anticyclone over the mountains while a trough generally overlies a heat source.

Another possible mechanism might include that of multiple equilibrium states as presented in Charney and DeVotre (1979) and Charney and Strauss (1980). In essence, they use first a barotropic channel model and then a two-layer baroclinic model to study the planetary-scale motions of the atmosphere. By assuming a quasi-geostrophic atmosphere (one in which the vertical motion w and the geopotential tendency $\frac{\delta \Phi}{\delta \tau}$ can be computed solely from direct observations of the geopotential field, Φ), they were able to show the existence of more than one zonal wave pattern, perturbation combination. There were three steady states, two with high amplitudes resembling blocking ridges. The papers go on to conclude that the atmosphere seems to change from one stable state to another when a discrete amount of forcing is applied for some critical amount of time, and that orographic instability, while not necessary to maintain the stable state, is a catalyst for these free standing waves!

Therefore, we find as we scan the literature, some well grounded theories pertaining to blocking. Clearly it would be desirable to perform observational studies which might support or deny some of these theories. What is needed is an objective criterion for determining the occurrence of a block so that statistical studies can be made on such cases. One such definition has been proposed by Hartmann and Ghan (1979). In that paper, they attempted to isolate the dynamical features by dividing the high pressure anomalies into two categories determined solely on the basis of their duration. Those cases lasting 6 days or longer were called blocking ridges (BK); those shorter were called transient ridges (TR). The study was divided into the Pacific (150E-110W) and Atlantic (65W-25E) regions. Because of a strong relationship between amplitude and duration in the Pacific region, certain high amplitude, long duration cases were called strong blocks and not used in the study. This was in an effort to eliminate those effects based only on amplitude. The Atlantic region did not exhibit this particular relationship so an upper limit on amplitude was not required. The vorticity budgets and heat budgets were averaged over the 50, 55, and 60N latitude circles and then analyzed at the 850, 500, and 300mb levels. They concluded that a strong relationship exists between the development of a block and the zonal wind field and observed a reduction of the zonal wind in the region of the block. They also found some support for the hypothesis that the Atlantic blocks, due to reduced upstream zonal winds, have a larger upstream region of rising motion and are therefore more influenced by baroclinic processes than the transient ridges. That paper, while bringing out some important dynamical aspects of blocking, was limited in its two-dimensional view of the problem since zonal but not meridional variations were considered.

Therefore, we find as we canvass the past literature, that although much is known about the characteristics and effects of these blocks, much less is known about their dynamics. And, where the paper by Hartmann and Ghan does provide a possible means of gaining insight into this area by comparing ridges of comparable amplitudes but different duration, it was limited to two dimensions. What is needed, then, is a more detailed picture of their large scale features. By using the definition in Hartmann and Ghan, this paper will construct a three-dimensional picture of these systems in hopes of gaining a greater understanding of those structures which lead to the dynamical findings of the original paper. To that end, Chapter 2 will discuss the data analysis procedures; Chapters 3, 4, and 5 will compare the blocks and transient ridges in the Pacific Ocean, Pacific Coast, and Atlantic regions respectively. Chapter 6 summarizes the results and conclusions which can be drawn from this study.

Chapter 2

DATA COLLECTION PROCEDURES

In order to perform a statistical study of the data and obtain estimates of statistical significance, an objective definition had to be established that would yield both a definition usable by the computer and one also able to form two distinct categories that could be statistically compared. The defining criteria was applied on the 500mb height field at 55N latitude since observation places the high pressure anomalies associated with blocking ridges between the 50N and 60N latitudes in the Northern Hemisphere. The data base for the study was made available through the efforts of Dr. Maurice L. Blockmon of NCAR. The data consists of 11 years of twice daily NMC analysis charts of height and temperature at the 1000, 850, 500, and 100mb pressure levels for the 120-day winters beginning on 15 November 1965.

A case of ridging was initiated when the 500mb geopotential height exceeded the mean height within the specified region by a specified amount (250m in the Pacific region and 220m in the Atlantic region). The event was continued until one of the following occurred: the height fell below the minimum; it traveled more than 10 degrees in longitude within any 12-hour period; or its total movement exceeded 30 degrees of longitude. Figure 1 shows a scatter diagram of the maximum height anomalies versus duration for each of the cases. Those cases lasting six days or longer were called blocking ridges; those of shorter duration were called transient ridges. Because of the correlation between amplitude and duration, some cases were eliminated so that only those

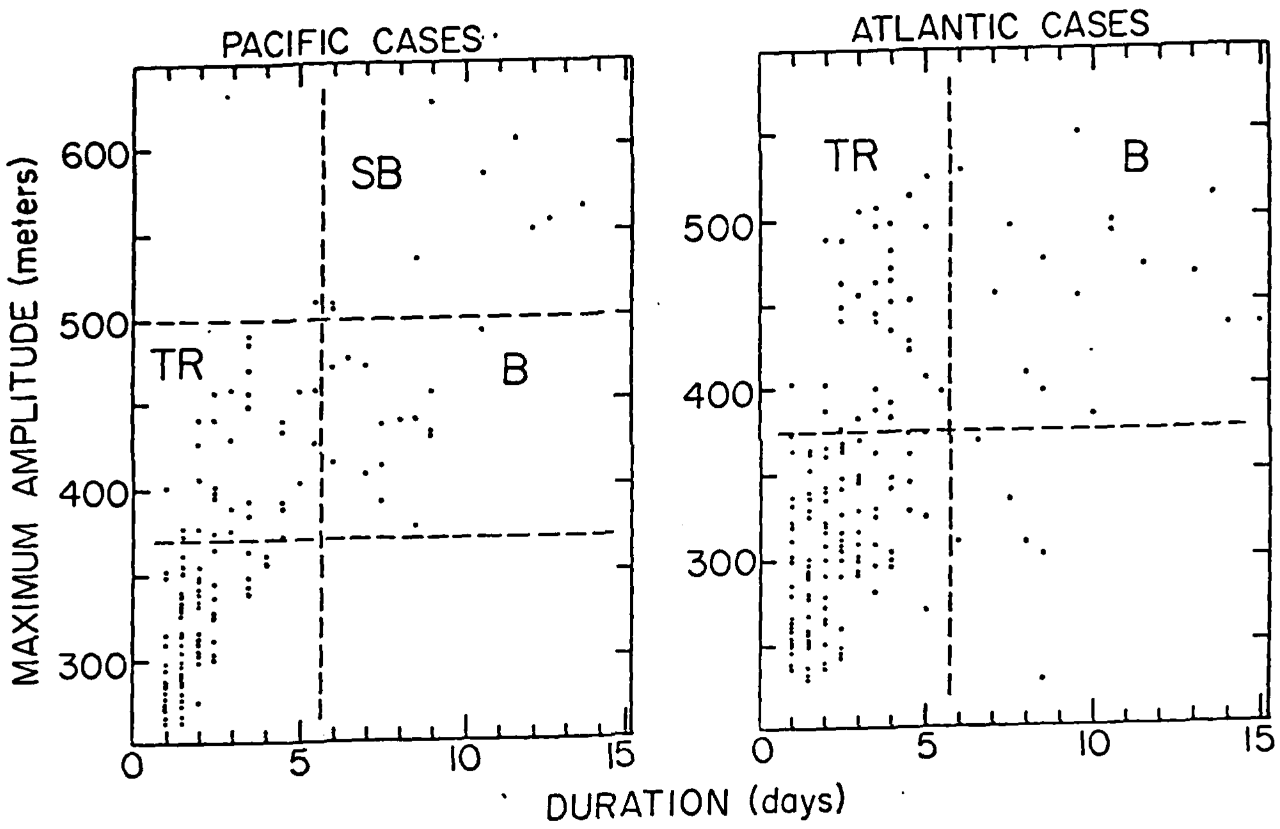


Fig. 1. Scatter diagrams of maximum amplitude versus duration for the individual cases. Dashed lines divide the cases into transient ridges (TR), blocks (B) , and strong blocks (SB). The Pacific cases appear on the left with the Atlantic cases on the right.

cases of similar amplitude were compared in each region. Therefore, only those Atlantic cases with a maximum height anomaly greater than 375m were used. In the Pacific region, some large amplitude, long duration cases needed to be eliminated as well as the smaller amplitude, shorter duration cases. So, in the Pacific, only those cases with maximum heights between 370m and 500m were used.

In order for a comparison to be made between a blocking ridge and a transient ridge in each region, a statistical block (BK) and transient ridge (TR) had to be generated for each region. To accomplish this, a compositing scheme was applied to each case using the following procedure. For a case initiated, the maximum height at 55N latitude on the 500mb pressure surface was found and the corresponding longitude was defined as the center of the ridge for the time of observation. All longitudes were then shifted to move the center of the ridge to zero degrees longitude. Each properly shifted field for each observation period was then time averaged over the duration of the case and the mean center longitude was recorded. Based on the duration, it was defined as a block or transient ridge. After all the individual cases were time averaged, the blocking cases and transient ridge cases were linearly averaged yielding a composite block and composite transient ridge for each region. The average longitudes and the total number of cases for each region are shown in Table 1.

The histograms of the occurrences of blocks and transient ridges in the Pacific and Atlantic regions as a function of longitude are

CASES	LONGITUDE	EVENTS
Pacific Ocean (175E-155W)		
Block	175W	9
T.R.	170W	11
Pacific Coast (140W-115W)		
Block	130W	5
T.R.	135W	16
Atlantic (65W-25E)		
Block	15W	19
T.R.	20W	42

Table 1. This lists the center longitude for each composite block and transient ridge in the three areas of study. Also listed are the number of cases which were used to generate each respective com posite field.

shown in Figure 2. The double maximum in the Pacific reveals two primary areas of block formation. Those cases over what we will call the Pacific Ocean (175E-155W) will produce a major downstream trough just off the West Coast bringing mild temperatures and an increase in precipitation to that area. However, when a blocking ridge forms in what will be referred to as the Pacific Coast (140W-115W) the block is directly over the West Coast, preventing the entrance of any moist, marine air into the area. This causes warmer temperatures with clear skies and no precipitation to prevail while downstream much colder air invades the eastern United States. Due to the drastically different effects of these two maxima and because their dynamical causes may be different, they are treated separately in the current study.

This study will then investigate separately the Pacific Ocean, Pacific Coast, and the Atlantic regions constructing a three-dimensional picture of the block and transient ridge of each of the three regions. We will start in each instance at 500mb, and confine our attention throughout to the composite height field, the zonal component of the geostrophic wind computed from the composite height field, and the composite temperature field. After the 500mb level is described, the 850, 1000, and 100mb levels will be discussed in turn.

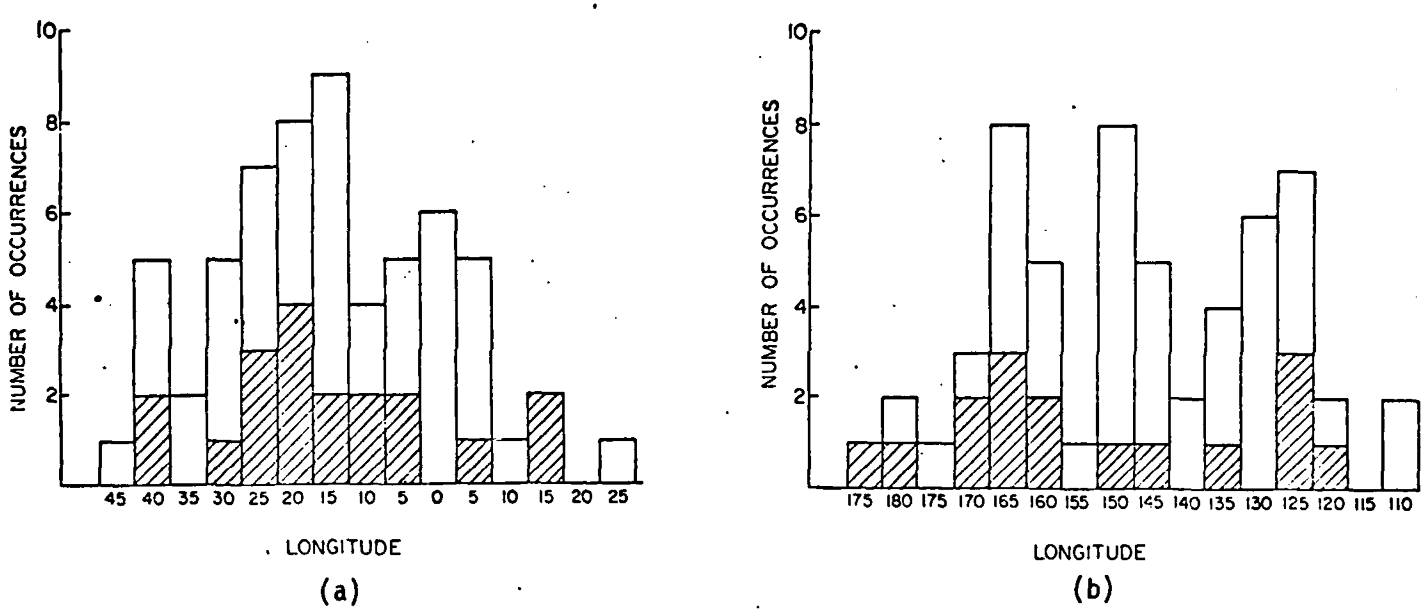


Fig. 2
The histograms of the total number of cases used in this study, represented as the sum of blocking (hatched) and transient (unhatched) ridges, as a function of longitude for the two oceans; (a) Atlantic (65W-25E) and (b) Pacific (175E-110W).

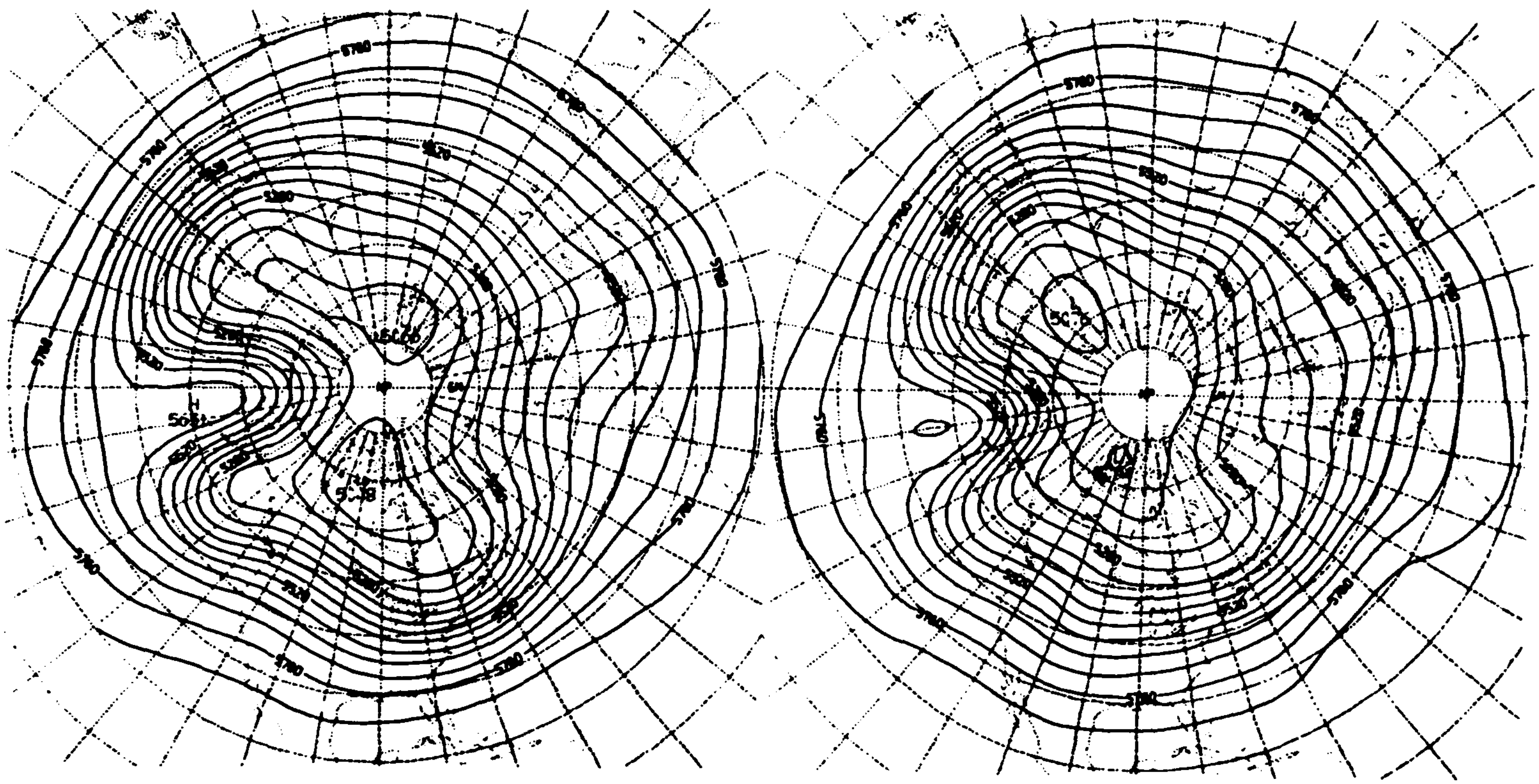
Chapter 3

ANALYSIS OF THE PACIFIC OCEAN REGION (175E-155W)

Once the height composites have been generated from the time averaged fields of the individual cases, a comparison of the composite blocking and transient ridges can be made in each region. Figure 3 shows the 500mb composite geopotential height fields for the block and transient ridge for the Pacific Ocean (175E-155W) region. The height minus zonal mean fields are shown in Figure 4 which simply consists of the composite height fields with the zonal mean height removed. The different field in Figure 5 is the composite block field minus the composite transient ridge field.

Looking at Figure 3, the three areas which will be of interest throughout this study become apparent: the ridge itself, the upstream trough, and the downstream trough with its accompanying wavetrain as explained earlier. We find the wavetrain during blocking influencing the downstream region by tending to place a ridge over the West Coast of the United States and a deep trough over the East Coast of the United States, while the transient ridge case produces a similar but much dampened wavetrain downstream.

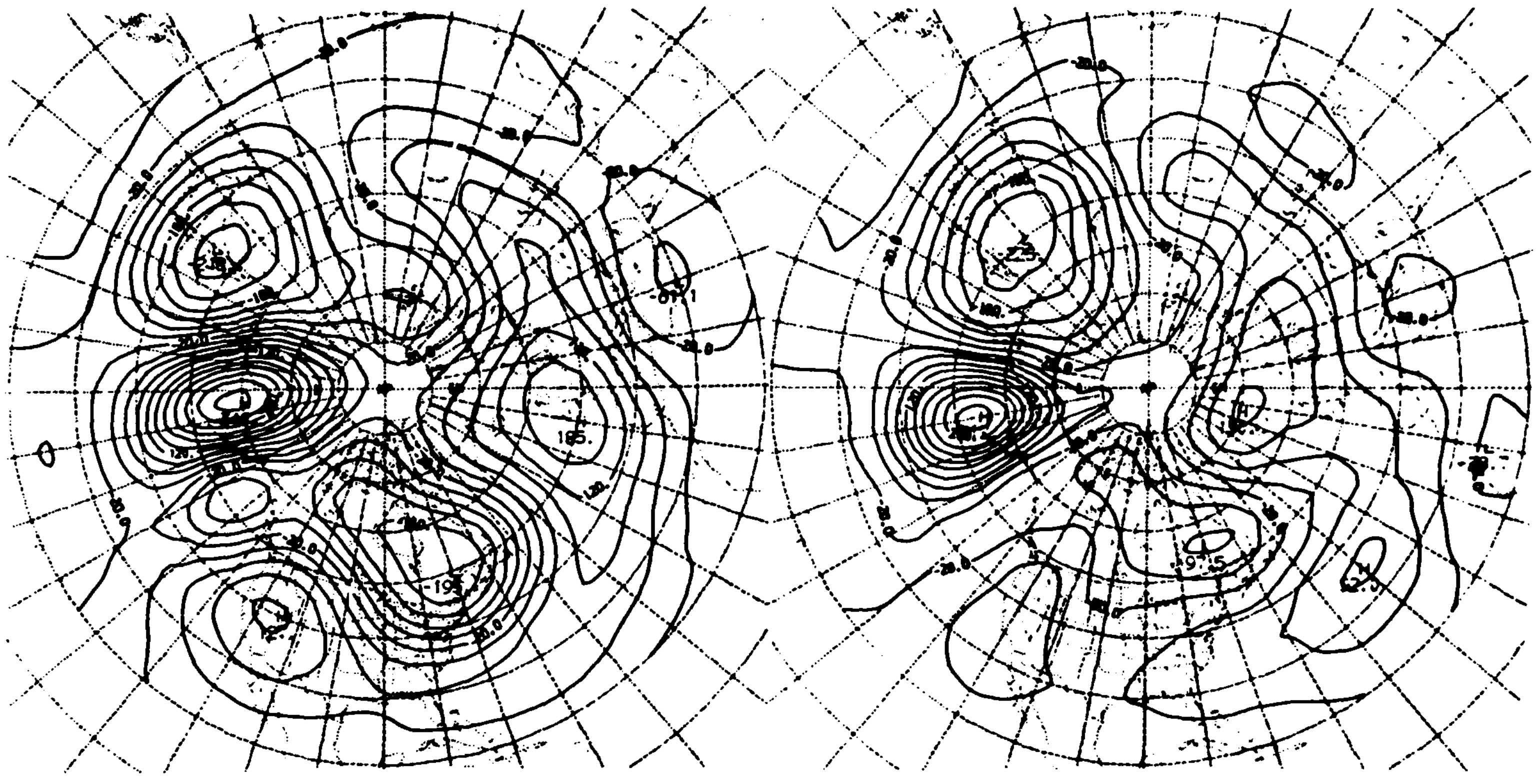
The height minus zonal mean field in Figure 4, as mentioned previously, provides a clearer view of the wave perturbations. One of the most striking contrasts between the two fields is the greater downstream wave effects shown by the block. The wavetrain during the blocking ridge places a larger trough over eastern North America and



(a)

(b)

Fig. 3
The 500mb Pacific Ocean composite height fields (contours 60m):(a)Block;(b) T. Ridge.



(a) (b)

Fig. 4
The 500mb Pacific Ocean composite height minus zonal mean fields (contours 35m): (a) Block;(b) T. Ridge.

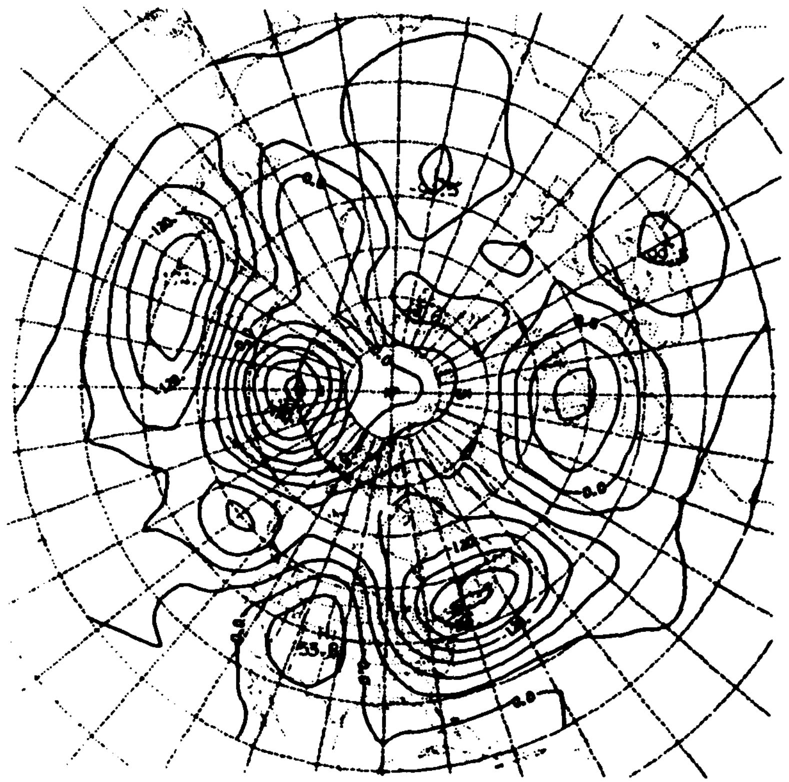


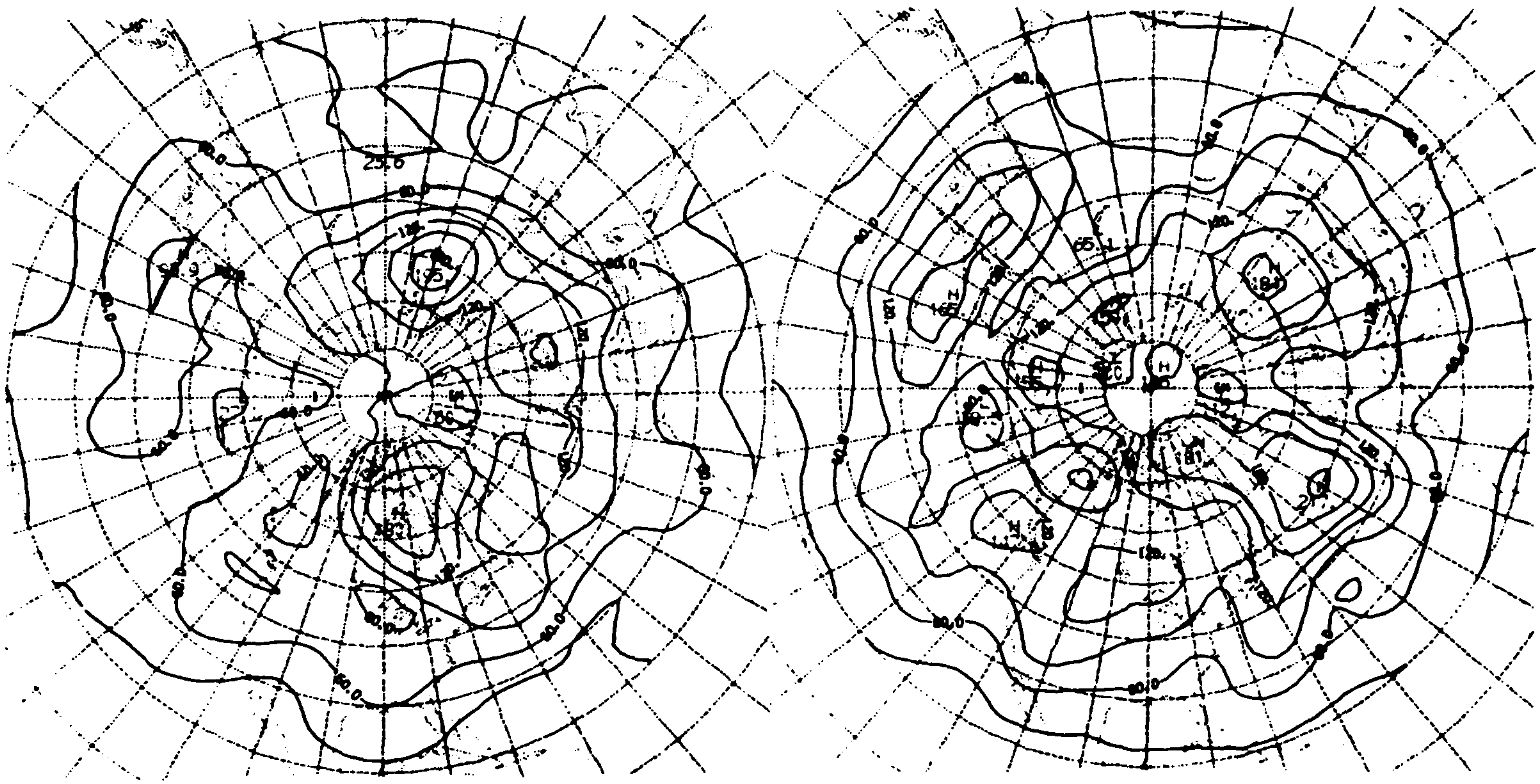
Fig. 5
The 500mb Pacific Ocean composite height difference field (BK-TR) (contours 30m): (a) Block; (b) T. Ridge.

a ridge over western Europe and western North America.

The differences in the downstream wavetrains for the blocks and transient ridges are vividly brought out in Figure 5. The difference field also reveals the deeper upstream trough and the more poleward extension of the ridge associated with blocking. In a sense it is not unexpected that the blocking ridges should have better developed downstream wavetrains than that of the transient ridges since it takes several days for the downstream wavetrain to be set up (Hoskins and Karoly, 1981). However, the amplitude of the difference field (Figure 5) over eastern North America and western Europe seems larger than would be expected from downstream wave energy propagation alone.

When a difference such as Figure 5 is constructed from two statistically averaged elements, there is always the question whether the differences are significant or occur simply by chance. It is important, therefore, to have a method of determining how much importance should be placed on any differences which might appear. One could use the respective standard deviations for the block and transient ridge shown in Figure 6. They are a measure of the scatter of the values around the computed mean. So, by looking at the standard deviations, one can determine, in a general sense, how realistically the mean values reflect the individual cases.

However, in order to objectively test the statistical significance of the differences, Student T statistics were computed,



(a) (b)

Fig. 6
The 500mb Pacific Ocean standard deviation fields (contours 30m): (a) Block; (b) T. Ridge.

$$T = \frac{\sqrt{N-1}\,(x_1 - x_2)}{S}, \quad \text{where } S = \text{standard deviation.}$$

The confidence limits generated by the Student T significance test depend on the sample size N and reflect the extent to which any differences between the composite block and transient ridges can be considered real. Since for a given confidence level a larger difference $x_1 - x_2$ is required for smaller sample sizes N, this study was conservative and chose the number of blocking cases for the value of N which was always the smaller of the two samples. For the Pacific Ocean region the magnitudes of the confidence limits for the 90, 95, and 99% confidence levels were 1.38, 1.83, and 3.25, respectively.

From Figure 6 it is apparent there is less variation among the blocking cases than among the transient ridges. This is of course expected since the transient ridges are migratory by definition and their field would therefore be expected to fluctuate accordingly. The significance test, Figure 7, reveals the welcome result that our major areas of interest: the ridge, the upstream trough, and the downstream wavetrain, are significant to the 99% confidence level. This allows a fairly optimistic assumption that any differences between our composite fields are meaningful and not simply due to chance.

From the composite height field, the geostrophic wind field can be computed, which in spherical coordinates becomes

$$\nu_g = \frac{g}{f} \frac{1}{a \cos \phi} \frac{\delta \Phi}{\delta \lambda}, \qquad \mu_g = \frac{g}{fa} \frac{\delta \Phi}{\delta \phi}$$

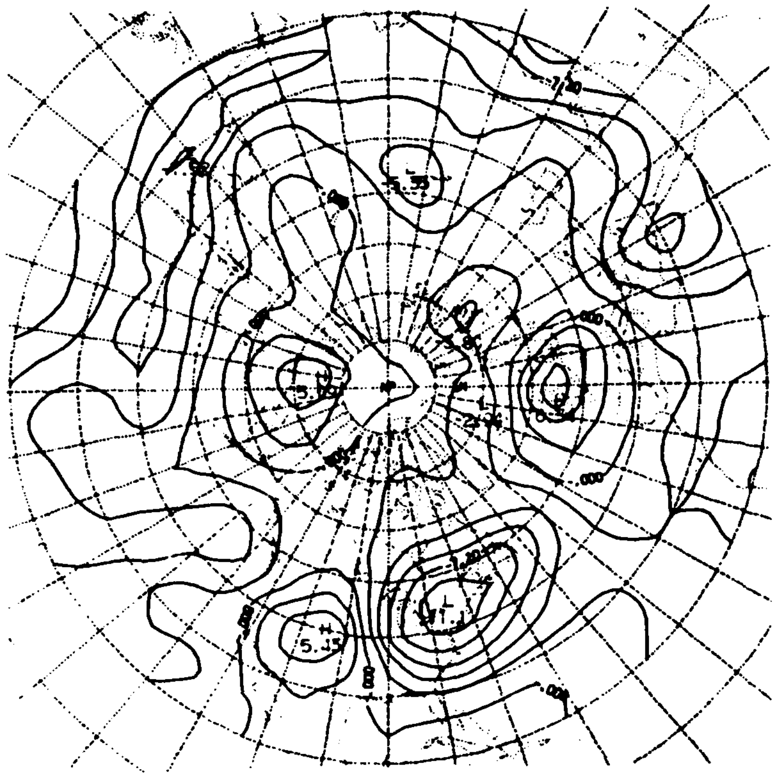


Fig. 7
The 500mb Pacific Ocean height field Student T significance results (contour interval 1.8) with confidence limits 1.38,1.83, and 3.25 corresponding to 90,95,and 99% confidence levels respectively.

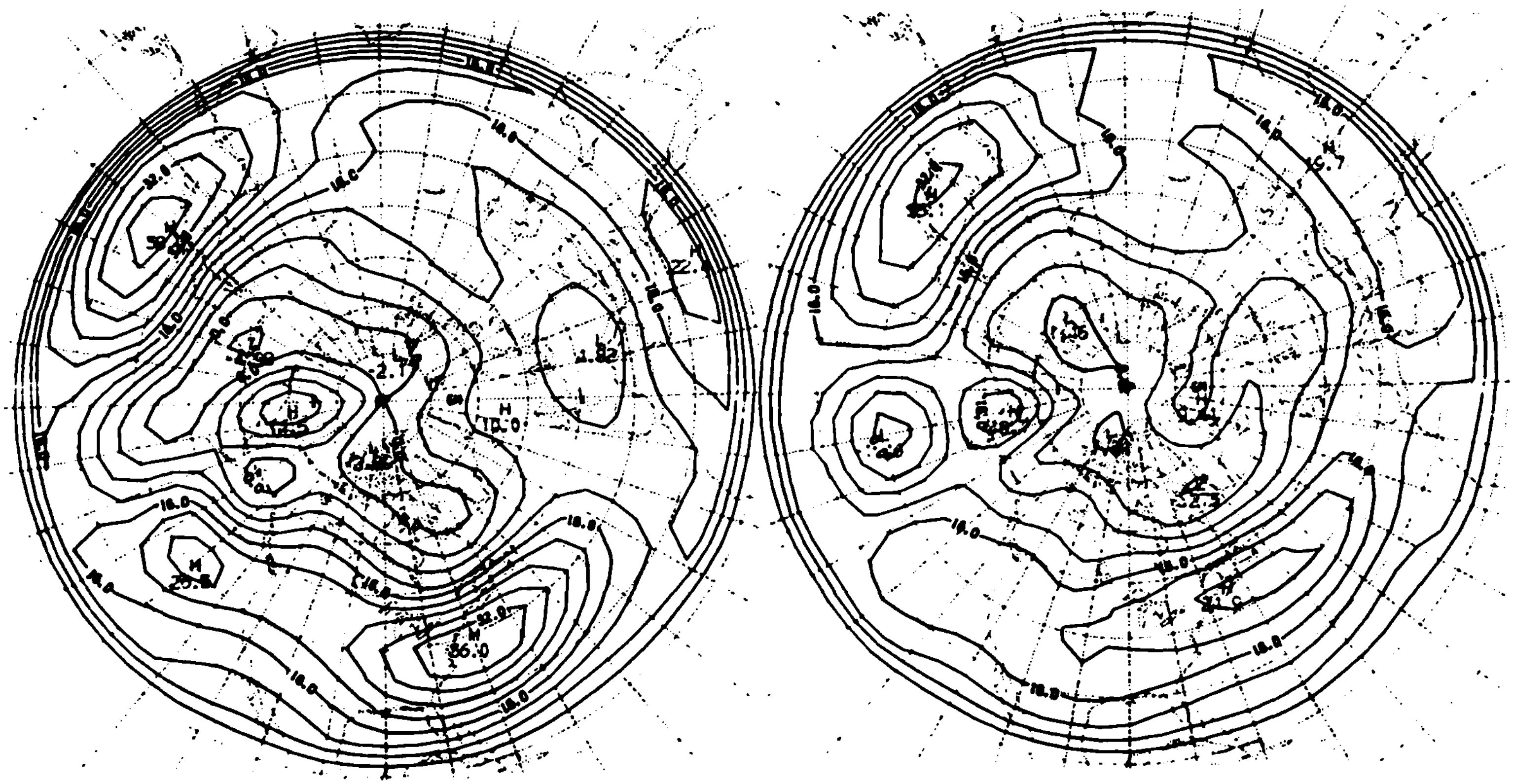
for the meridional and zonal components respectively, where f = coriolis parameter; λ = longitude; ϕ = latitude; Φ = geopotential; g = gravity; and a = mean radius of the earth.

The zonal component of the geostrophic wind can be computed from the composite height fields and graphed in relation to the 500mb ridge locations, Figure 8. The different field, Figure 9, is constructed in the same manner as with the height field; the transient ridge zonal wind field is subtracted from the block zonal wind field.

The different field, Figure 9, brings out some important points. The weaker zonal winds which are stated by Hartmann and Ghan to exist in the center of the block extend outside the ridge itself to include the entire North Pacific. The stronger zonal winds upstream of the ridge in the subtropical South Pacific during blocking are also confirmed.

Table 2 shows the zonally averaged zonal winds for the composite block and transient ridge of the Pacific Ocean region. Comparing this with Figure 9 suggests that one must use caution in interpreting zonal mean wind changes. Although the table shows significant zonal mean wind changes, Figure 9 reveals that these changes are really associated with much stronger regional features over the central Pacific and over eastern North America. The changes in the zonal wind over the continents are rather small and often not in the same direction as the zonal mean change at the same latitude.

The composite temperature fields for the Pacific Ocean cases shown in Figure 10 exhibit the general features expected of waves with



(a) (b)

Fig. 8
The 500mb Pacific Ocean computed zonal geostrophic wind fields (contours 8 m s^{-1}): (a) Block; (b) T. Ridge.

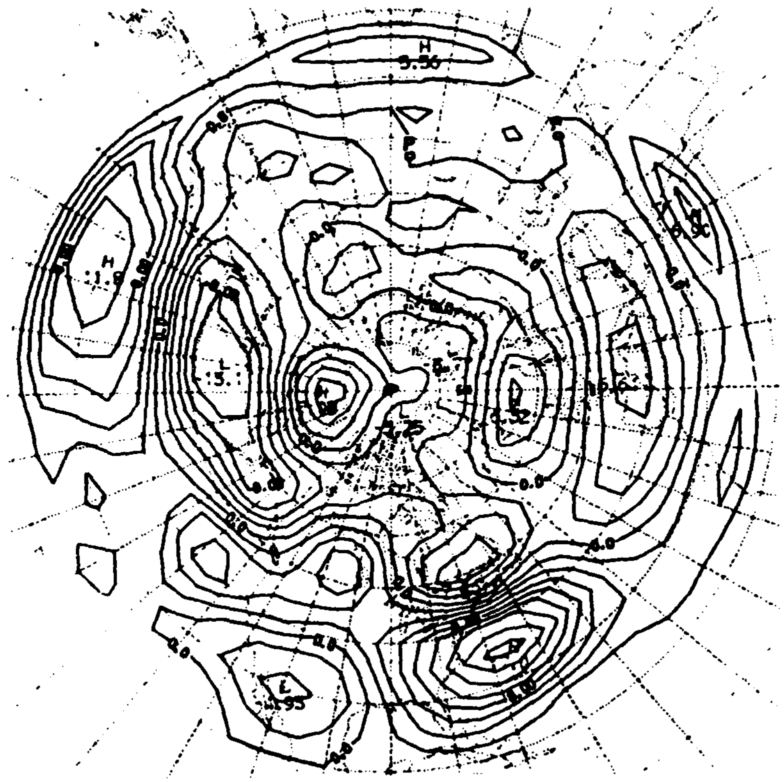
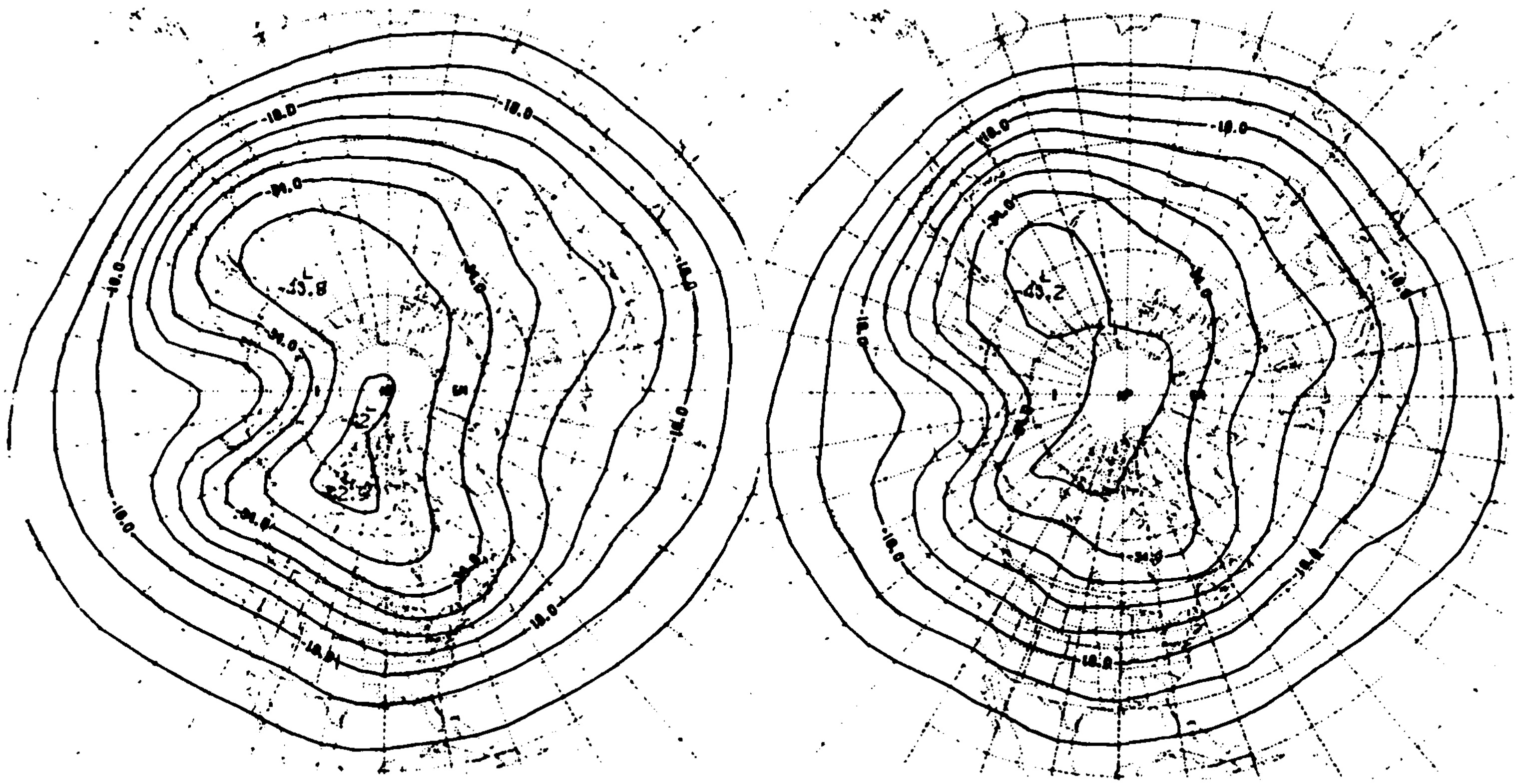


Fig. 9
The 500mb Pacific Ocean zonal wind difference field (contours 2 m s^{-1}).

Table 2. The 500mb Pacific Ocean zonally averaged zonal geostrophic winds (m s^{-1}) for the Block, T. Ridge, and Climatology.

Latitude	Block	T. Ridge	Climatology
25	17.3	13.5	16.0
30	19.3	16.6	18.7
35	19.7	17.4	19.3
40	18.6	17.7	18.5
45	15.1	16.4	15.9
50	10.5	13.1	12.3
55	7.4	9.9	9.3
60	5.9	7.2	7.2
65	4.9	5.2	5.8
70	4.1	4.5	4.8
75	2.9	3.7	3.7
80	1.8	2.6	2.5
85	.8	1.8	1.4

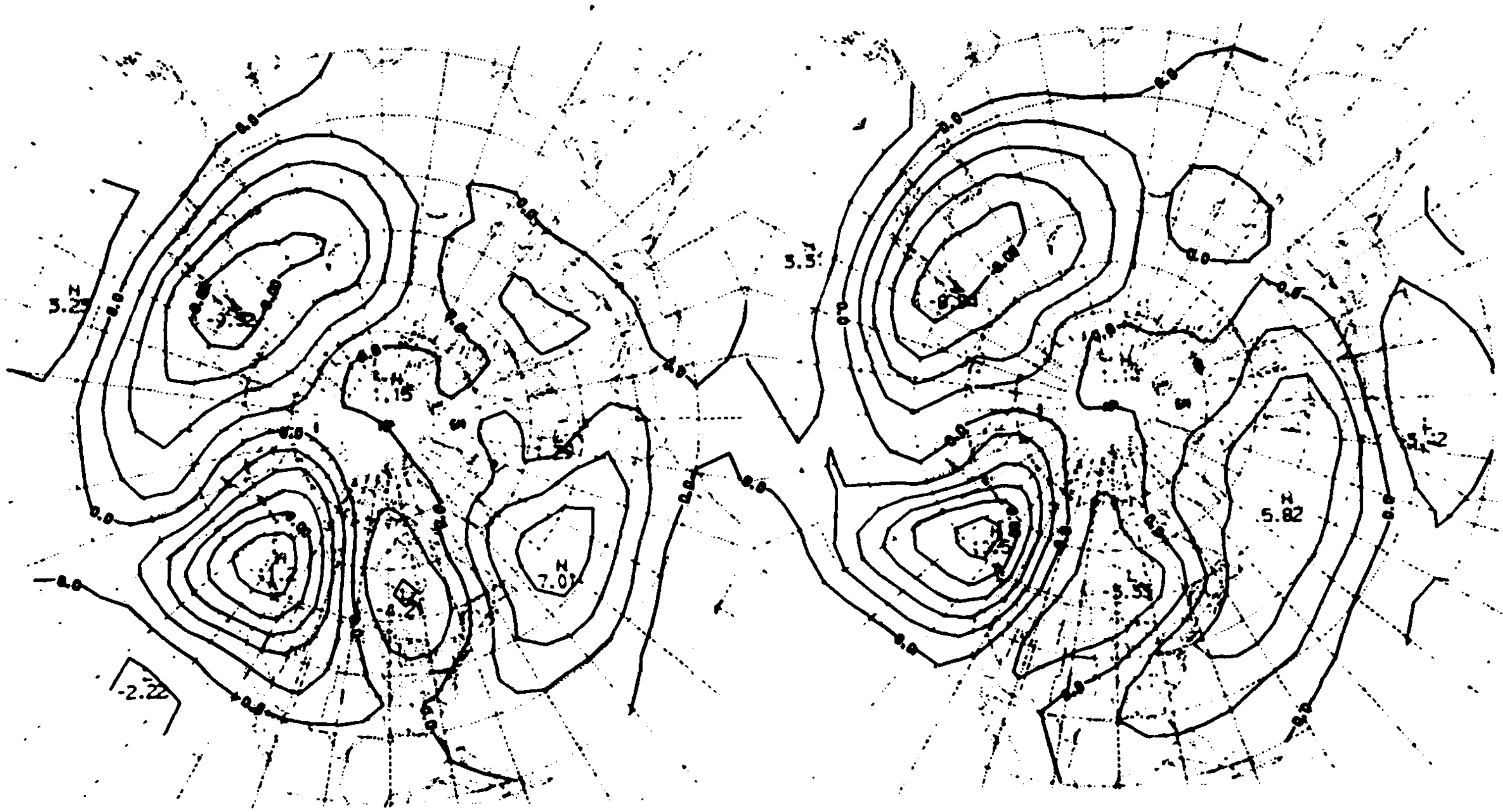


(a) (b)

Fig. 10
The 500mb Pacific Ocean composite temperature fields (contours 4° C): (a) Block; (b) T. Ridge.

an equivalent barotropic structure (e.g., Haltiner, 1971): the cooler upstream temperature, warmer temperatures in the ridge, and the contrasting downstream effects. The anomalous temperature perturbations are more easily distinguished in Figure 11 where the zonal mean values have been removed. As with the height minus mean maps in Figure 4, the temperature minus mean maps reveal the unusually large downstream effects over eastern North America and western Europe. This suggests that a secondary local forcing in the Atlantic may be coupled with the Pacific Ocean ridging events. Figure 11 reflects the relatively weak downstream wave field during the transient ridge, in great similarity with the corresponding height minus mean fields of Figure 4. The temperature different field, Figure 12, accentuates the thermal contrasts. The cooler temperatures in the upstream blocking trough with warmer temperatures in the block itself is what might be expected from the height field analysis. The block with its associated larger downstream influence produces larger differences in the composited temperature over the United States than the shorter duration transient ridges.

The temperature field helps to tie together the general characteristics of the 500mb blocking and transient ridges. While the two cases are centered in basically the same area, the downstream influences are very different as reflected in the different wavetrain patterns. The trough westward of the ridge is consistent with subtropical thermal forcing in the vicinity of the upstream trough with the blocking cases exhibiting a deeper trough. Likewise, the downstream effects during



(a) (b)

Fig. 11
The 500mb Pacific Coast temperature minus zonal mean fields (contours 2^{o} C): (a) Block; (b) T. Ridge.

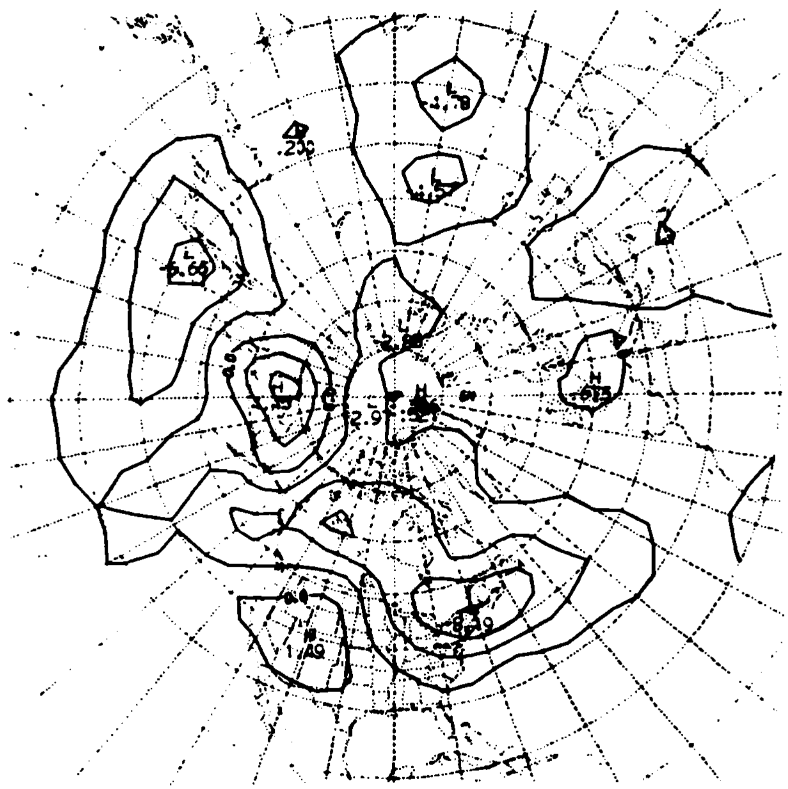


Fig. 12
The 500mb Pacific Ocean temperature difference field (BK-TR) (contours 2^{o} C).

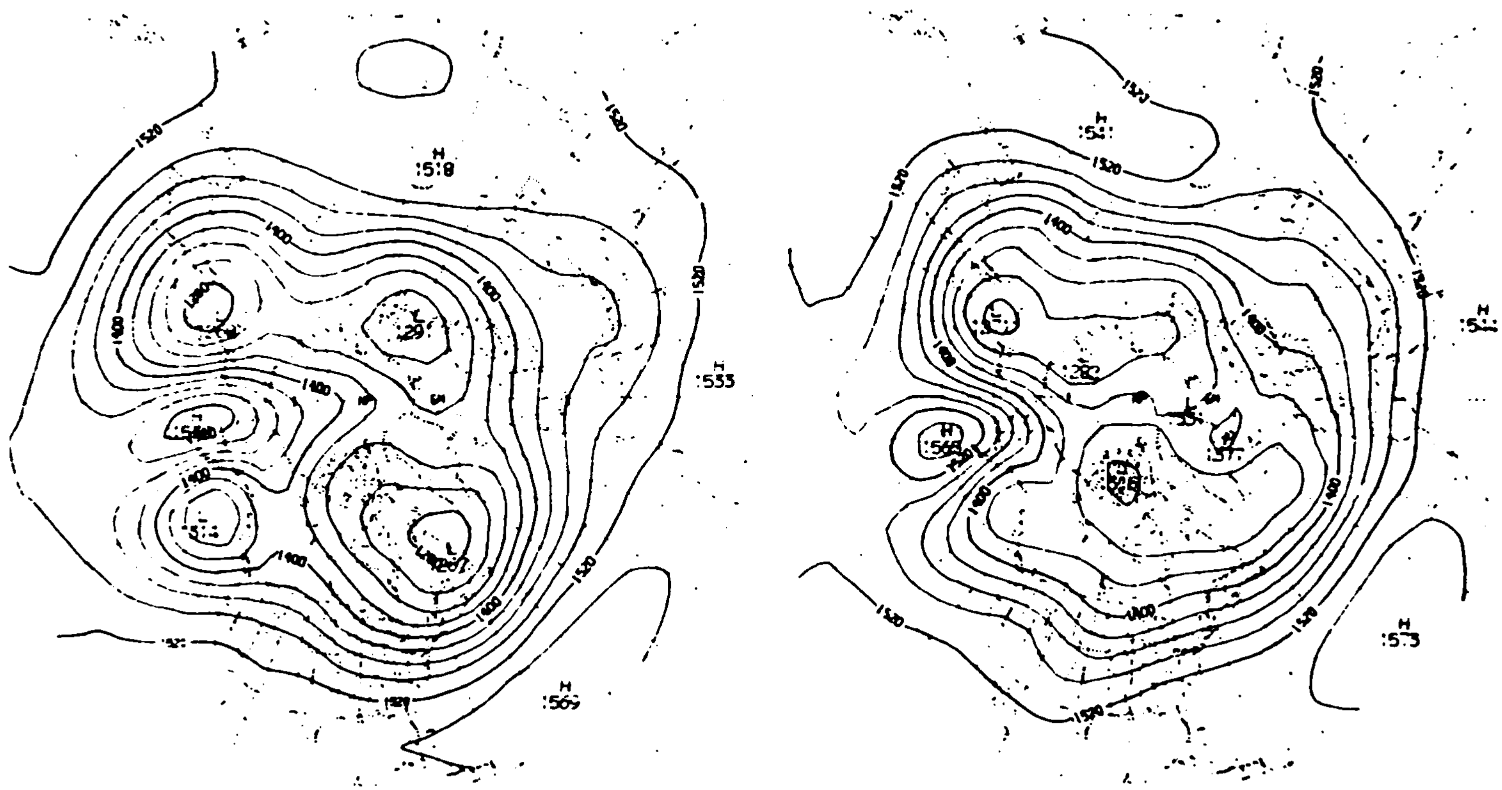
blocking have a more consistent impact in the North American continent than during the transient ridges because the atmosphere is allowed time to respond to the development of the trough-ridge pattern in the mid-Pacific.

After outlining the general horizontal features of both composites at 500mb, a study of the other levels will point out the vertical characteristics. For ease of compositing and for continuity, the fields at all levels have been referenced according to the average center longitudes computed at the 500mb levels. We therefore proceed to the 850mb composite height fields in Figure 13. When comparing the ridges at this level, the block appears greatly constrained between the adjoining troughs as the ridge moves into the northern latitudes. As at the 500mb level, the 850mb height difference field, Figure 14 shows the greater downstream responses produced during blocking. We notice the similarity between these differences and those at 500mb.

The zonal component of the geostrophic winds as computed from the 850mb height fields are mapped in Figure 15. The wind difference field is shown in Figure 16, which is similar in structure to the 500mb level differences shown in Figure 9.

The 850mb temperature composites are shown in Figure 17. The difference field shown in Figure 18 indicates warmer air in the northern part of the ridge and colder air over Japan and Canada in the blocking composites.

The 1000mb height fields and difference field are shown in Figures 19 and 20, respectively. Comparing these with Figures 3, 5, 13 and 14



(a) (b)

Fig. 13
The 850mb Pacific Ocean composite geopotential height fields (contours 30m): (a) Block; (b) T. Ridge.

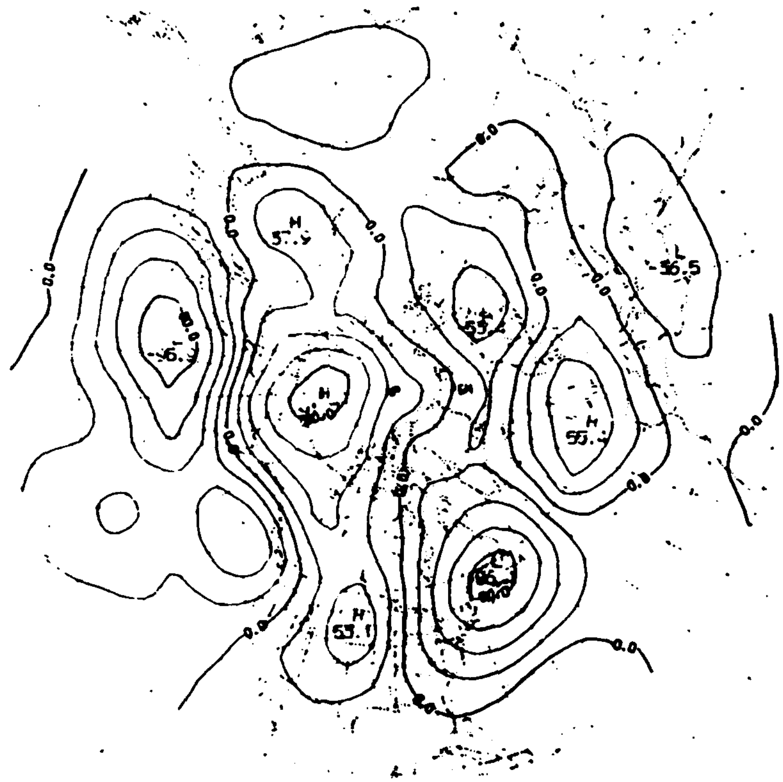


Fig. 14
The 850mb Pacific Ocean geopotential height difference field (contours 20m).

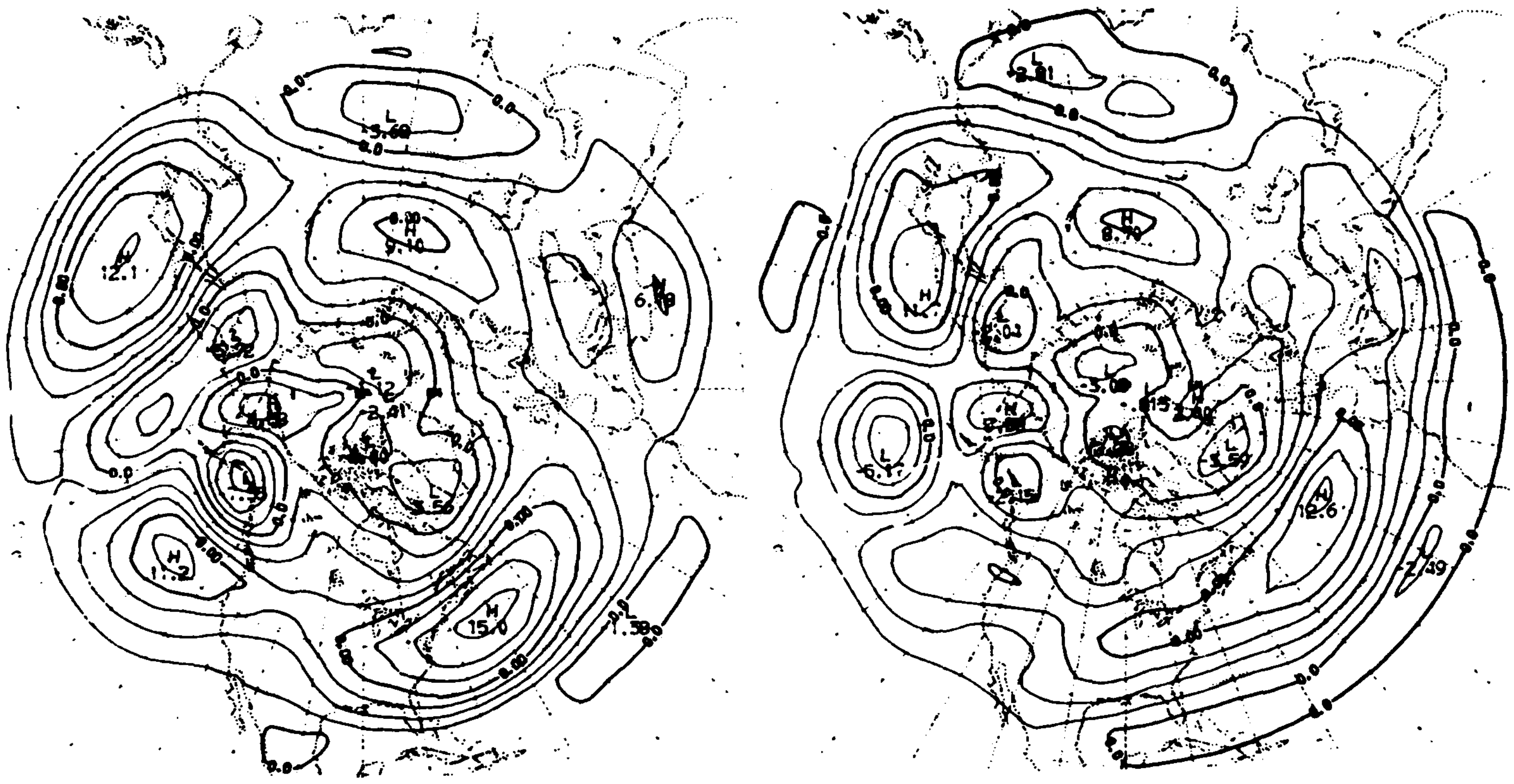
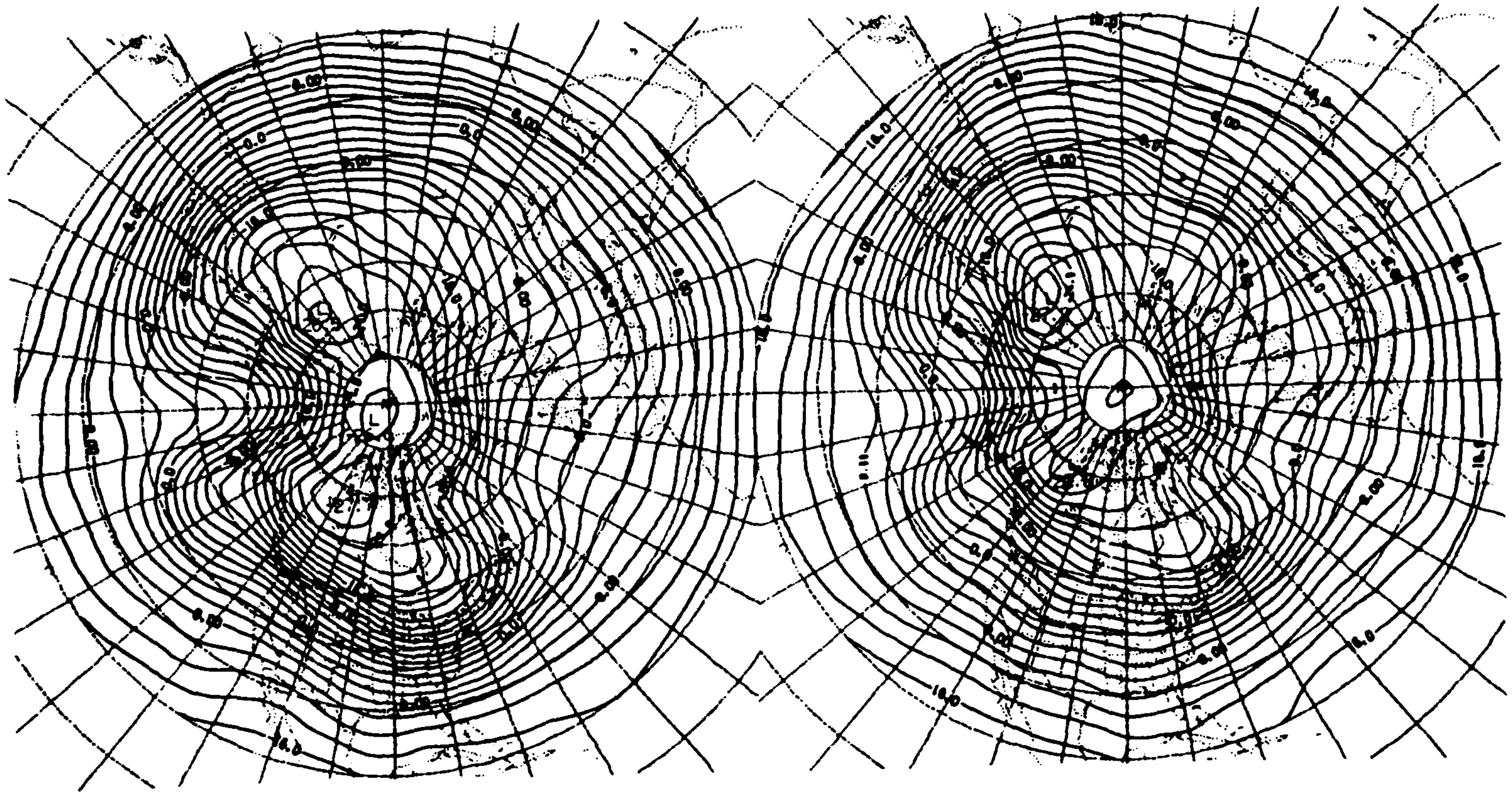


Fig. 15
The 850mb Pacific Ocean computed zonal geostrophic wind fields (contours 2 m s^{-1}): (a) Block; (b) T. Ridge.

Fig. 16
The 850mb Pacific Ocean zonal wind difference field (contours 2 m s^{-1}).



(a) (b)

Fig. 17
The 850mb Pacific Ocean composite temperature fields (contours 2° C): (a) Block; (b) T. Ridge.

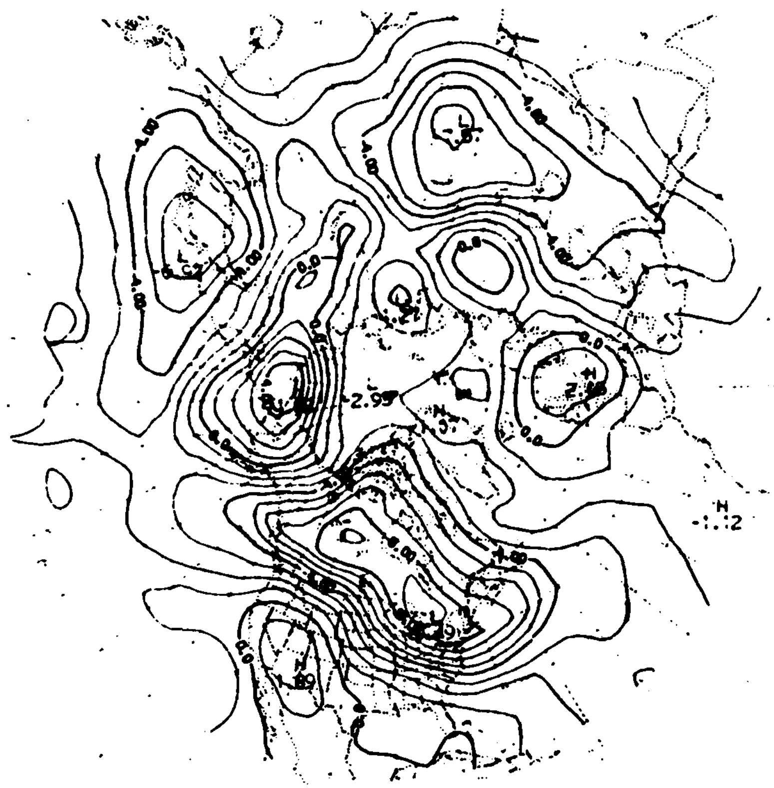


Fig. 18
The 850mb Pacific Ocean temperature difference field (contours 1° C).

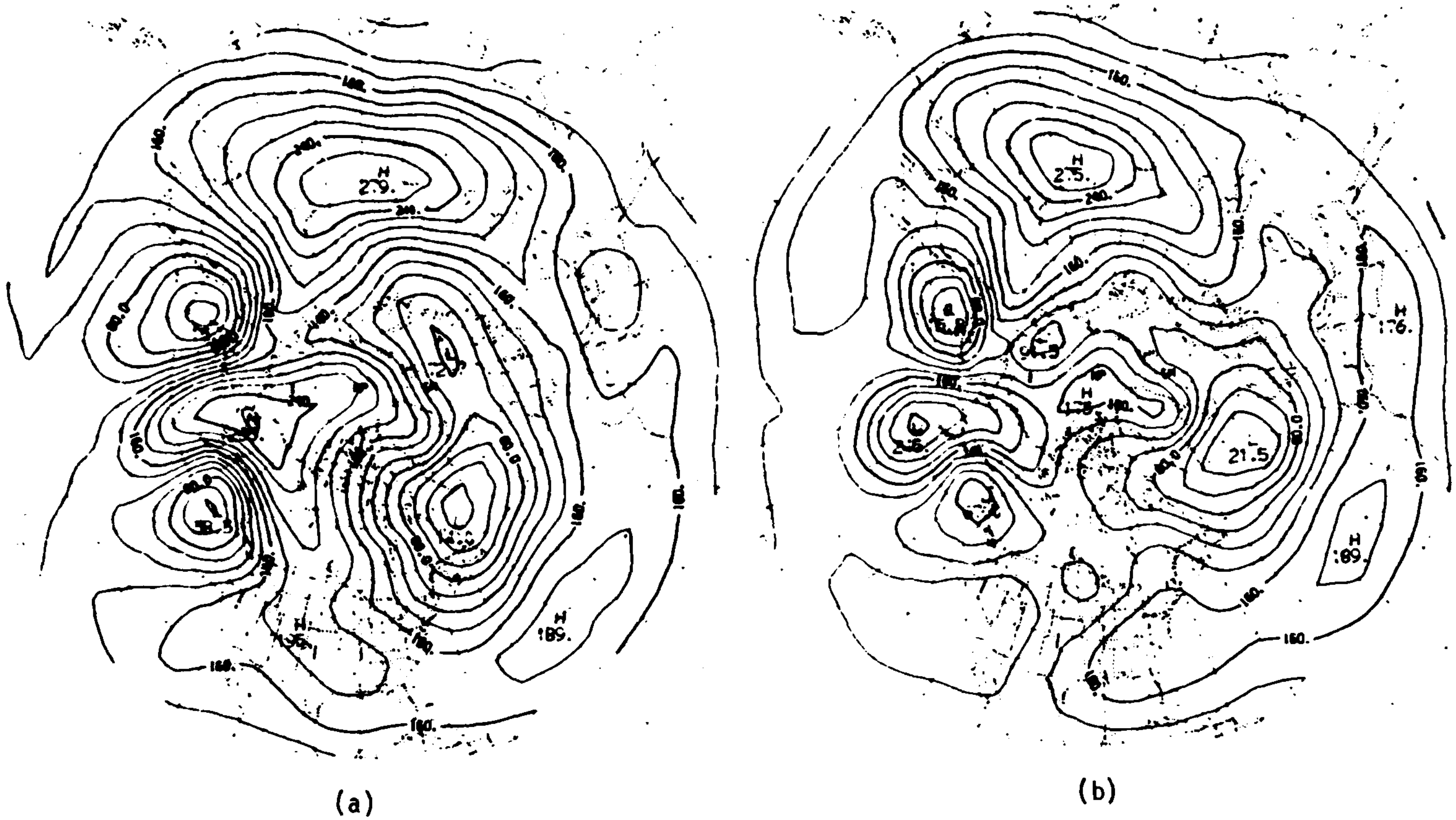


Fig. 19
The 1000mb Pacific Ocean geopotential composite height fields (contours 20m): (a) Block;(b) T. Ridge.

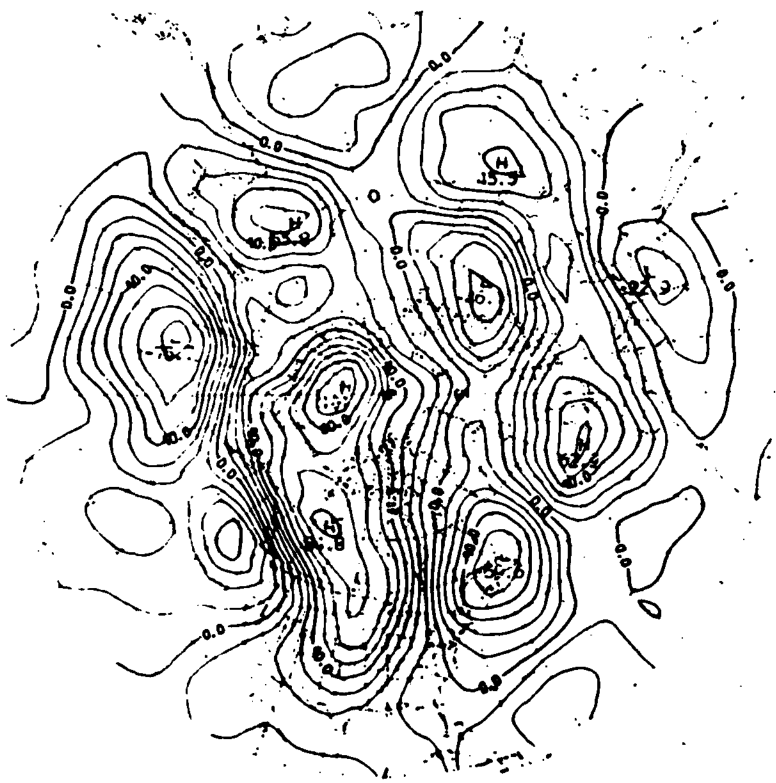


Fig. 20
The 1000mb Pacific Ocean composite height difference field (BK-TR) (contours 10m).

shows that the structure of the differences are very similar at all heights in the lower troposphere. The block, however, shows a large northward displacement in its center at 1000mb. The troughs on either side of the block seem impressive until they are compared with the climatological height field, Figure 21. It is then apparent that the centers of both troughs vary from climatology in extent, but not in magnitude for location, and that the ridge splits the normal Aleutian low.

These contrasting features between the block and transient ridge show up more clearly in the difference field, Figure 20. The transient ridge is barely able to separate the broad Pacific trough but does not effectively impact the downstream regions. The greater downstream wave development is seen over the North Atlantic. The dominant upstream effect is, again, the broader extent of the upstream trough in the blocking case.

To finish the discussion of the Pacific Ocean region, a view of the 100mb level is appropriate. The height field, Figure 22, appears to be very zonal in both cases due to the strong zonal winds at this level. The transient ridge shows little downstream effect and tends to place a very zonal pattern over the United States. The similarities and differences are more easily depicted in Figure 23 by the elimination of the zonal mean and focusing on the eddies. The blocking ridge induces a downstream wavetrain with little downstream decrease of amplitude and a very strong zonal wavenumber 2 in high latitudes. The transient ridge has the same basic pattern in the vicinity of the ridge, but

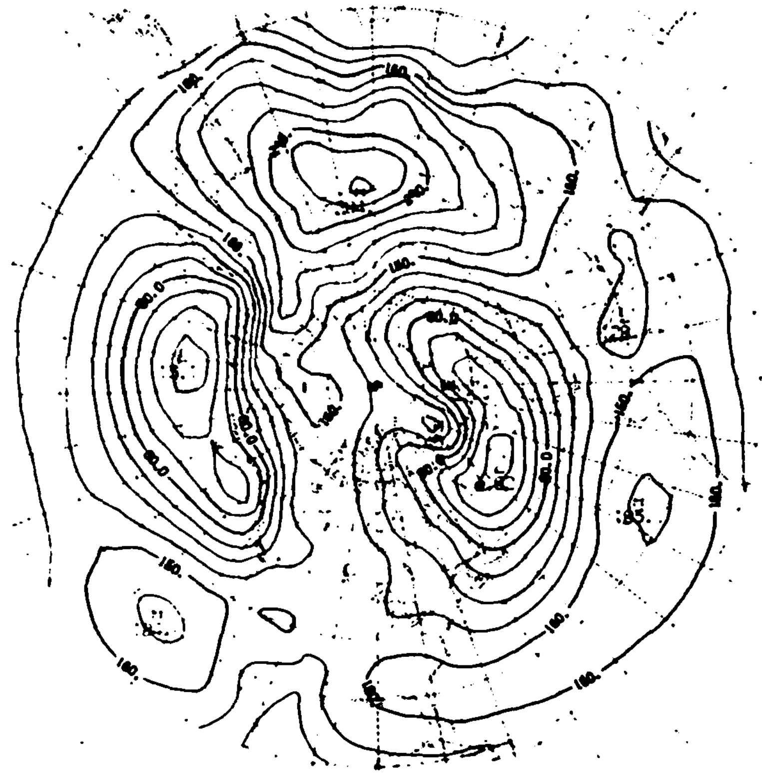
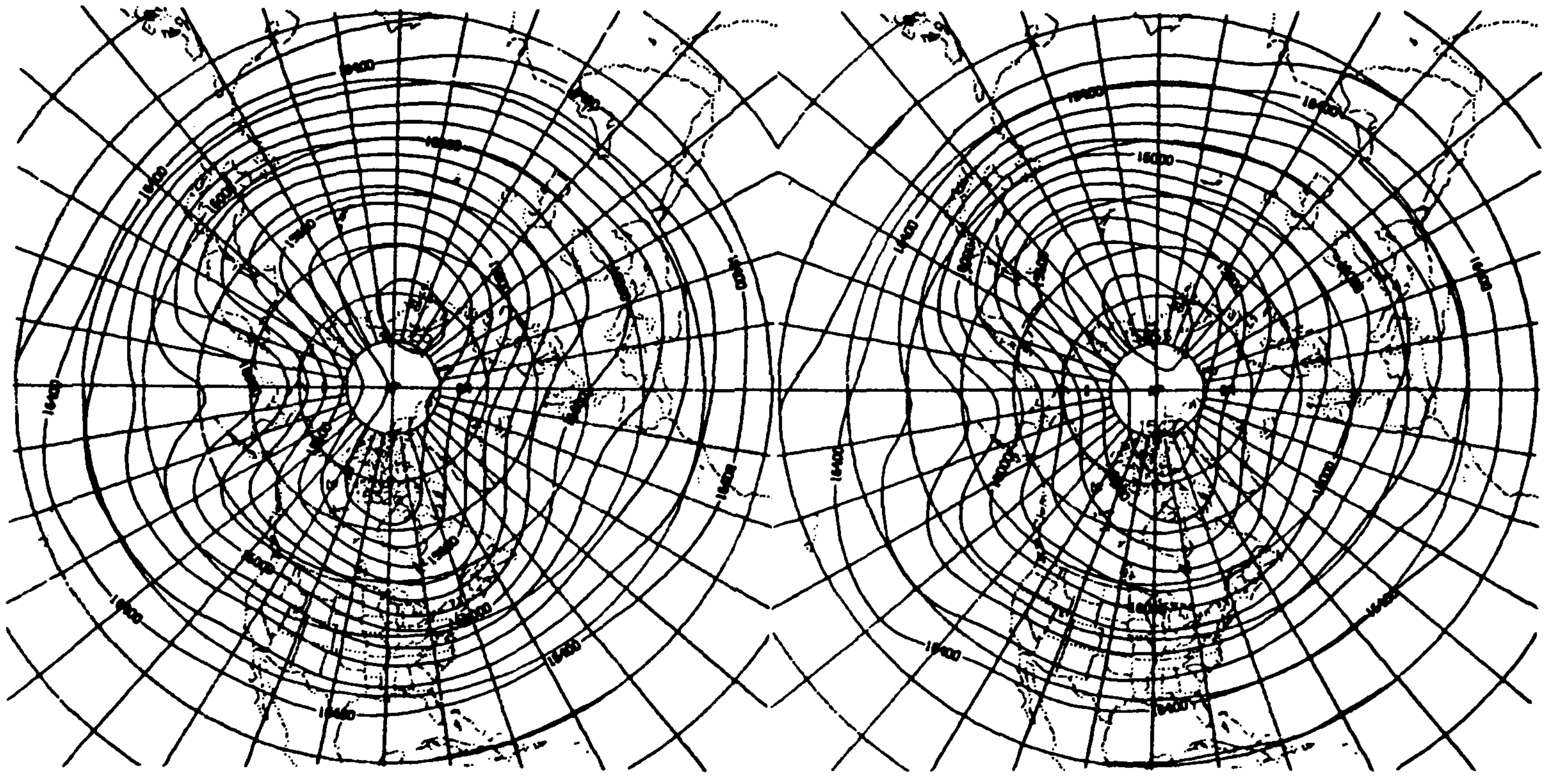
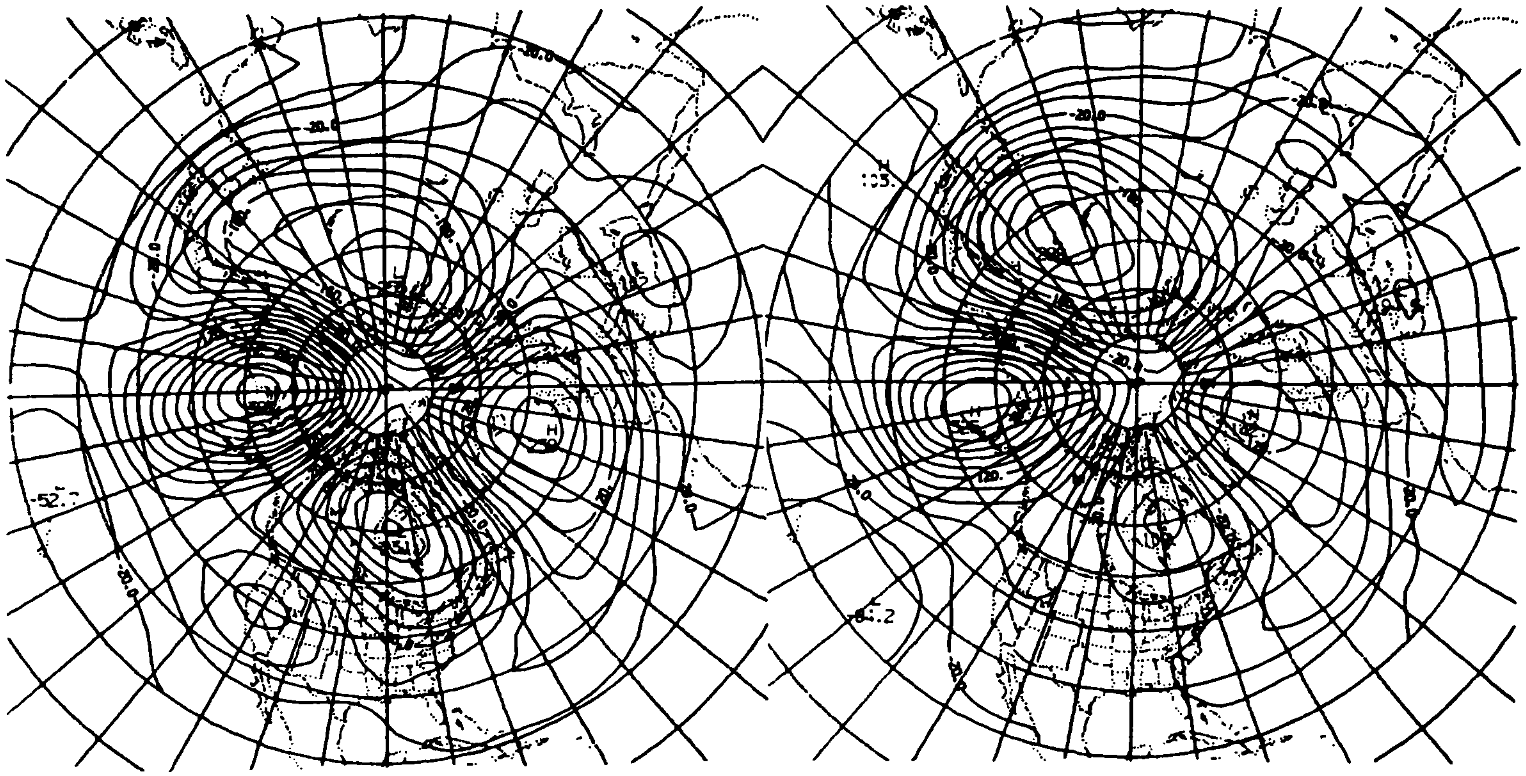


Fig. 21
The 1000mb composite Climatological geopotential height field derived from 11 years of 120 day winters.



(a) (b)

Fig. 22
The 100mb Pacific Ocean composite geopotential height fields (contours 100m): (a) Block; (b) T. Ridge.



(a) (b)

Fig. 23
The 100mb Pacific Ocean geopotential height minus zonal mean fields (contours 35m): (a) Block; (b) T. Ridge.

without the strong downstream influence.

The height difference field, Figure 24, shows the greater northward extension of the blocking ridge. The contrasts between the more extensive wavetrain which accompanies the blocking ridge and the weaker, less organized one during a transient ridge, are brought out in the figure which shows a larger anomaly over eastern North American than over the Pacific Oean.

The wind field at 100mb, Figure 25, reveals little new. Weak winds are still the rule in the middle of the block, but the easterlies of the lower levels have been replaced by moderate westerlies. The block continues to have weaker westerlies upstream of the block at middle latitudes, Figure 26, as well as over southern Europe. The subtropical jet streams over the southwest Pacific and southwest Atlantic are both stronger during blocking.

Bringing all of this together, what then can be said of the Pacific Ocean cases? The transient ridge has a weaker upstream trough than the blocking ridge at all levels. This in combination with the undeveloped downstream wavetrain evident during the transient ridges means that, while the two systems form in basically the same location, they have much different effects on the downstream areas, principally the eastern United States and Europe. The wind fields show the weaker winds which we would expect to find in the center of the blocks actually extending up and downstream throughout the Pacific at the middle latitudes. The Pacific Ocean blocking case also seems to be associated with strengthening of the subtropical jetstreams east of Asia and North America. The

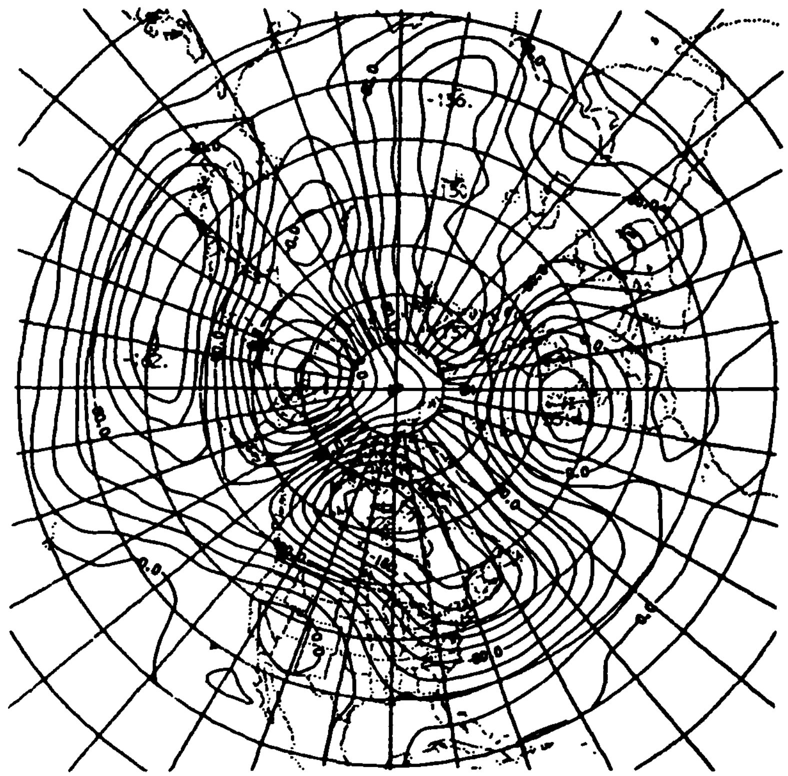
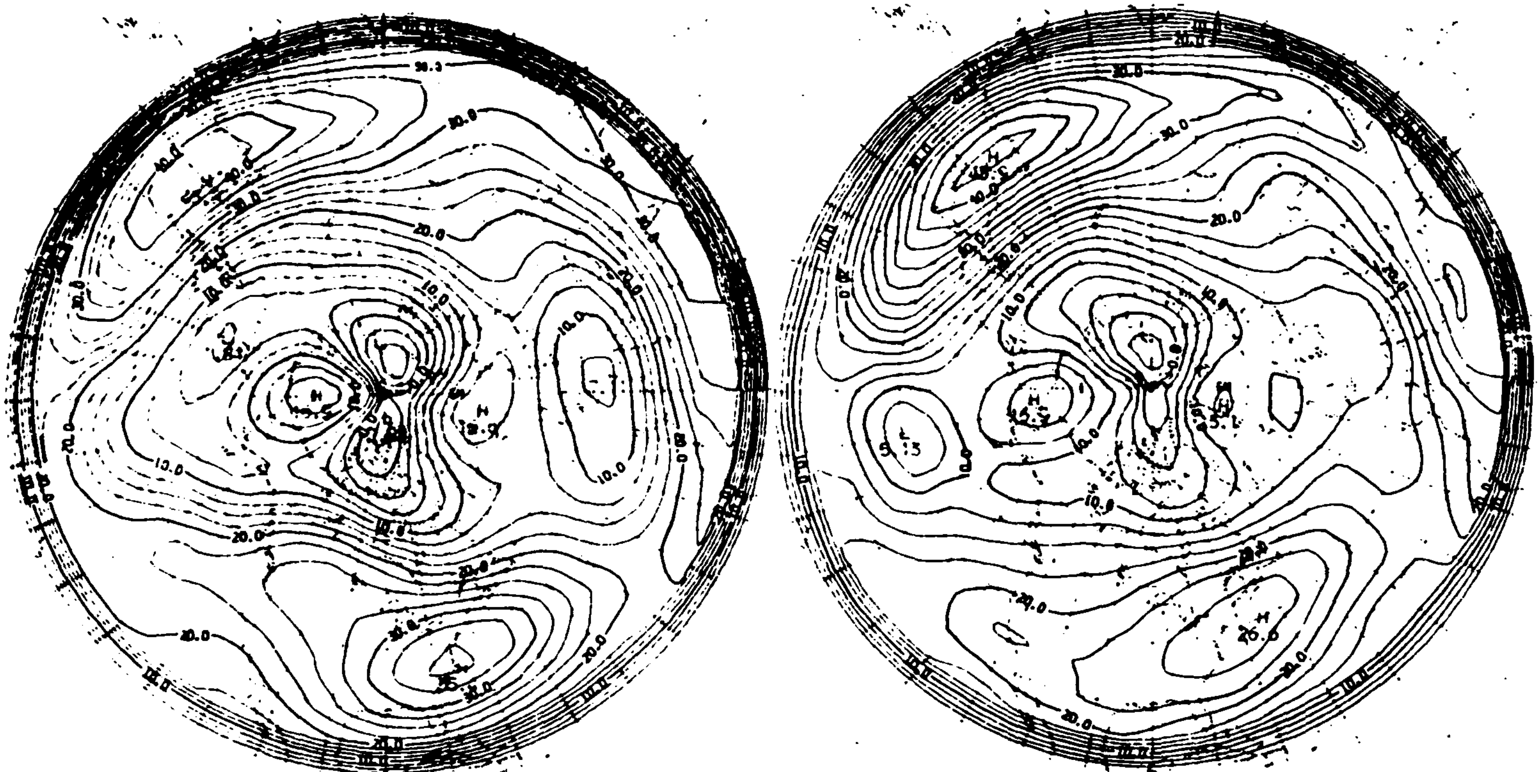


Fig. 24
The 100mb Pacific Ocean composite geopotential height difference field (BK-TR) (contours 20m).



(a) (b)

Fig. 25
The 100mb Pacific Ocean computed zonal geostrophic wind fields (contours 2.5 m s^{-1}): (a) Block; (b) T. Ridge.

Fig. 26
The 100mb Pacific Ocean zonal wind difference field (contours 2 m s^{-1}).

strengthening of the subtropical jets and the weakening of the zonal winds at mid-latitudes at the longitude of the block results in a smaller but similarly appearing change in the zonal mean wind.

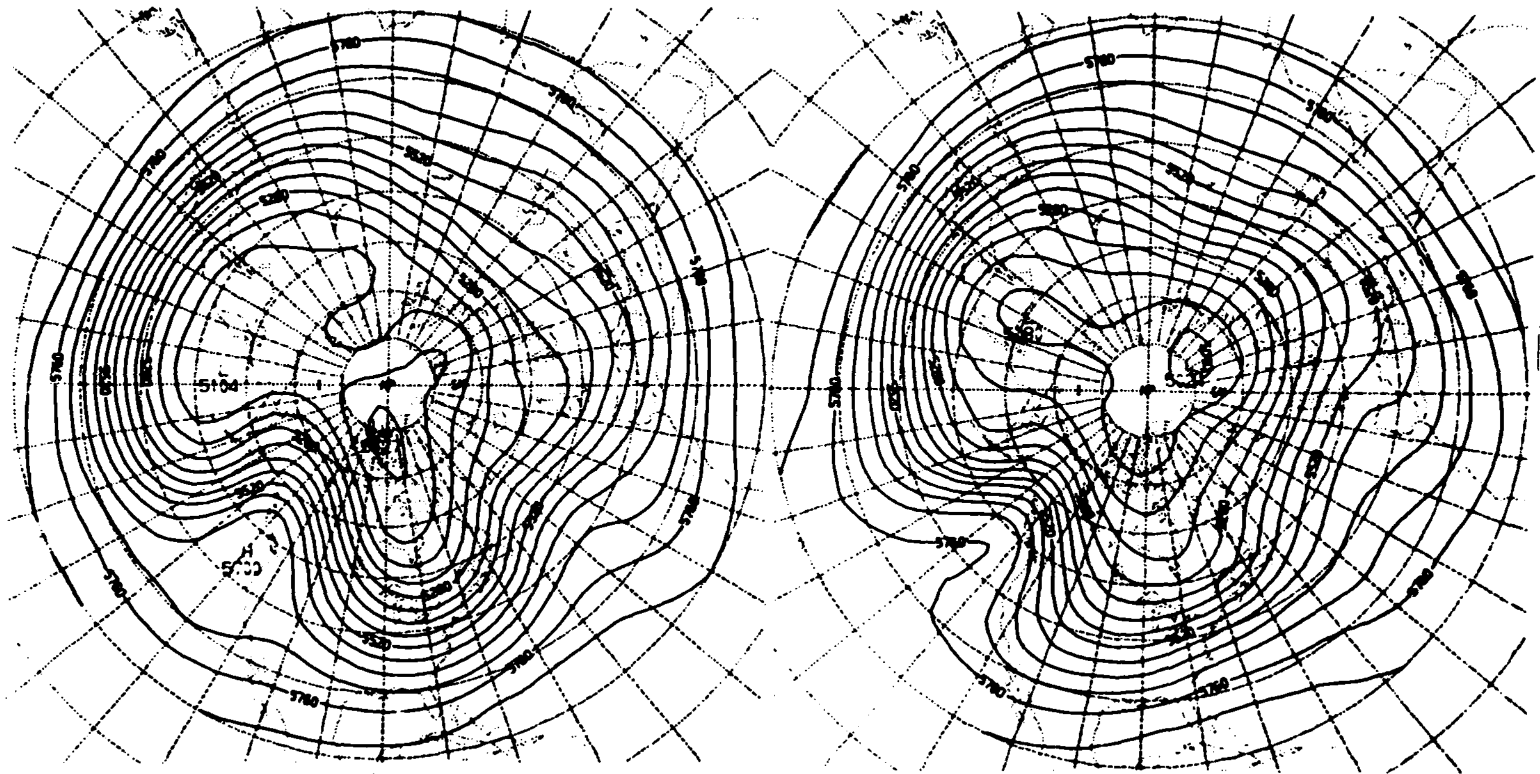
From the temperature fields, we learn the transient ridge has a minimal effect on the United States while the longer lasting blocks allow cold air to migrate deep into the middle states. The advantages of being able to distinguish these two systems before the fact are obvious!

Chapter 4

ANALYSIS OF THE PACIFIC COAST REGION (140W-115W)

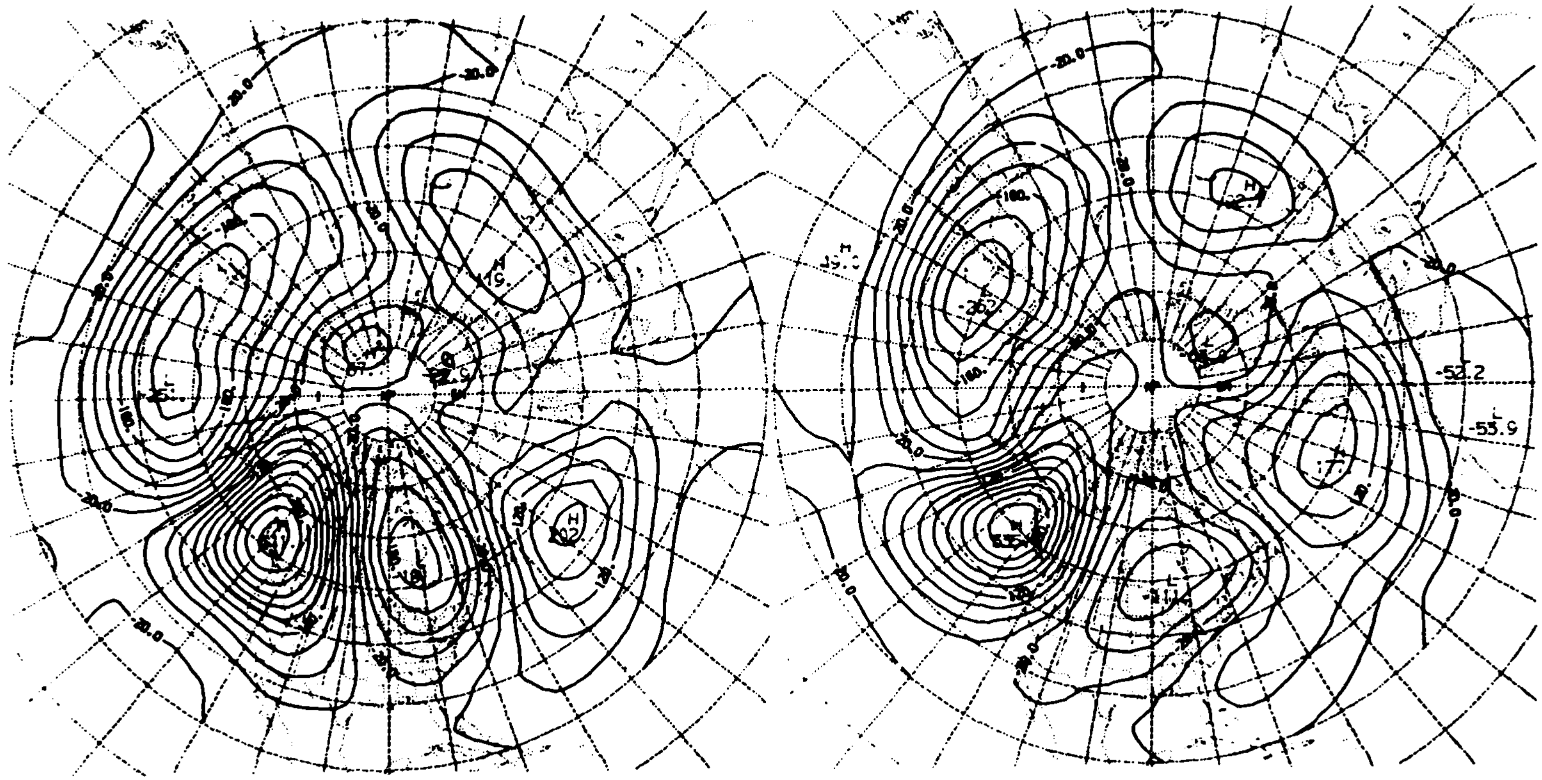
It would be expected for the ridges which form over the west coast of the United States to have different effects, characteristics, and possibly different causes than those ridges forming over the ocean. Again, to get an overview of the systems, the 500mb height fields are addressed in Figure 27. Figures 28 and 29 show the height minus mean and height difference fields as described in the previous chapter.

As we approach the height fields, Figure 27, the same three areas of interest will be discussed as with the Pacific Ocean region: the upstream trough, the ridge itself, and the downstream wavetrain. Immediately noticeable is the broad zonal extension of the upstream trough over the central Pacific. The ridges are positioned just off the West Coast at 130W and 135W for the blocking and transient ridge cases respectively. Both cases follow the coastline developing a slight westward tilt with latitude. In the case of West Coast blocking ridges, the ridge suggestively follows the general position of the Rocky Mountains and is slightly west of them. Figure 27 along with the height minus mean fields in Figure 28 reveal the downstream effects of the respective wavetrains. The wavetrain associated with blocking appears to be of greater amplitude and shorter wavelength than the wavetrain associated with the transient ridge. This contrast does not affect the United States as much as it impacts Europe, as is evident from the



(a) (b)

Fig. 27
The 500mb Pacific Coast composite geopotential height fields (contours 60m): (a) Block; (b) T. Ridge.



(a) (b)

Fig. 28
The 500mb Pacific Coast geopotential neight minus zonal mean fields (contours 35m): (a) Block; (b) T. Ridge.

difference map, Figure 29. Although the amplitude of the downstream trough and ridge are greater during blocking, both blocks and transient ridges place high heights over the West Coast and a trough over the East Coast. However, the two cases produce opposite effects over Europe. The phasing is such that the block places a trough over Europe while the transient ridge shifts the trough into eastern Europe.

To determine which differences are statistically significant, Figures 30 and 31 present the standard deviations and the Student T confidence limits respectively. Since fewer cases of blocking occur in this region than in the Pacific Ocean region, the confidence limits for the 90, 95, and 99% confidence levels are raised to 1.48, 2.02, and 3.36 respectively. By comparing Figure 31 with Figure 7, it is very interesting to find the same general downstream areas being highlighted. The only major redistribution has been for the two significant areas associated with the Pacific Ocean ridge and upstream trough to be shifted westward to correspond to the positions of the Pacific Coast ridge and its upstream trough.

The accompanying wind field, Figure 32, reveals a blocking pattern familiar from the previous chapter: weak winds in the center with a relatively weak gradient, westerlies to the north and easterlies to the south of the ridge. The upstream jet is positioned south of the Pacific trough, Figure 27, as would be expected. The easterly winds south of the blocking ridge extend around and upstream into the middle latitudes. The contrasts in the wind field are brought out in the difference field shown in Figure 33. Associated with the generally lower heights across

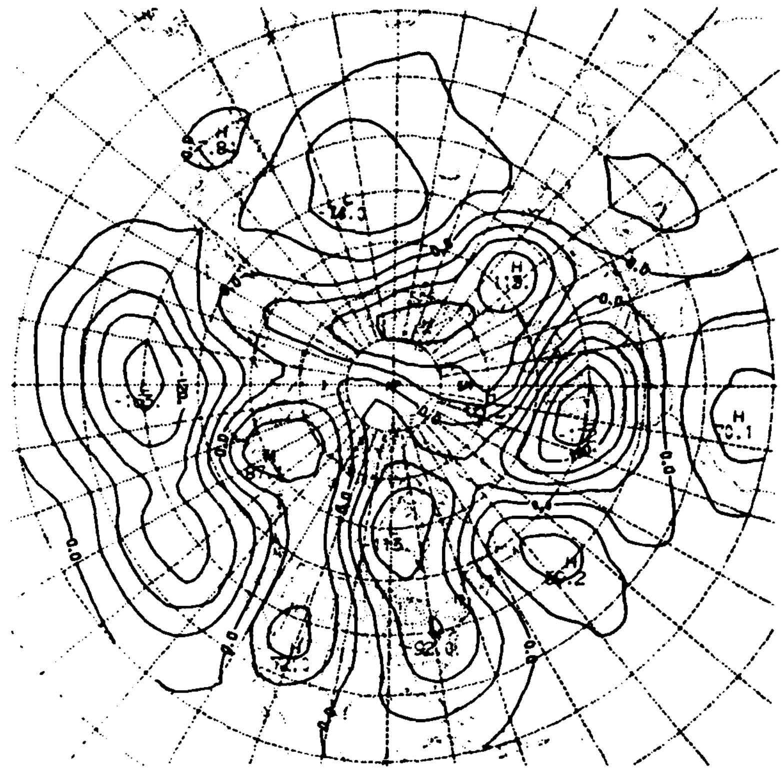


Fig. 29
The 500mb Pacific Coast composite height difference field (BK-TR) (contours 30m).

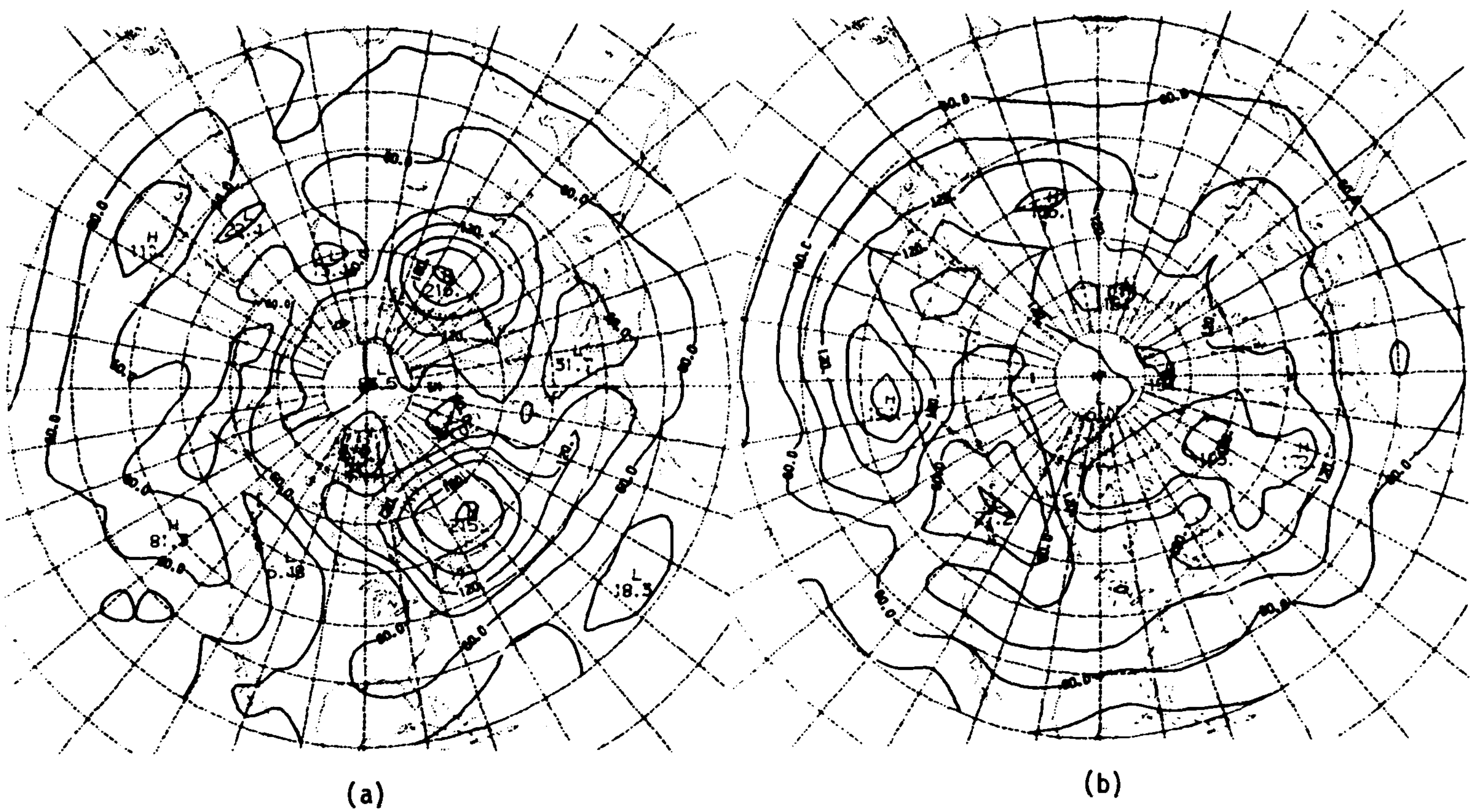


Fig. 30
The 500mb Pacific Coast standard deviation fields (contours 30m).

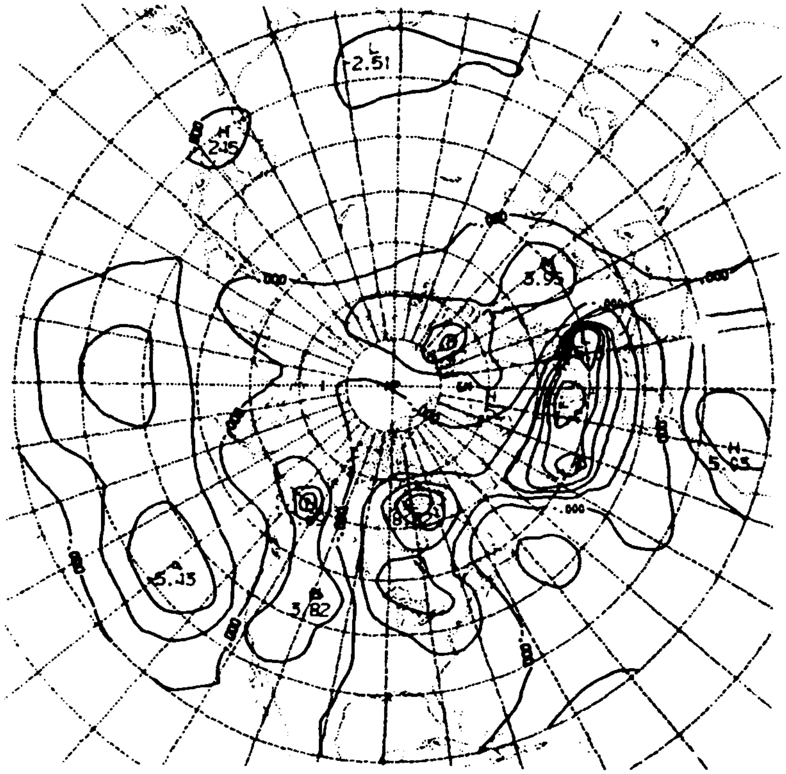
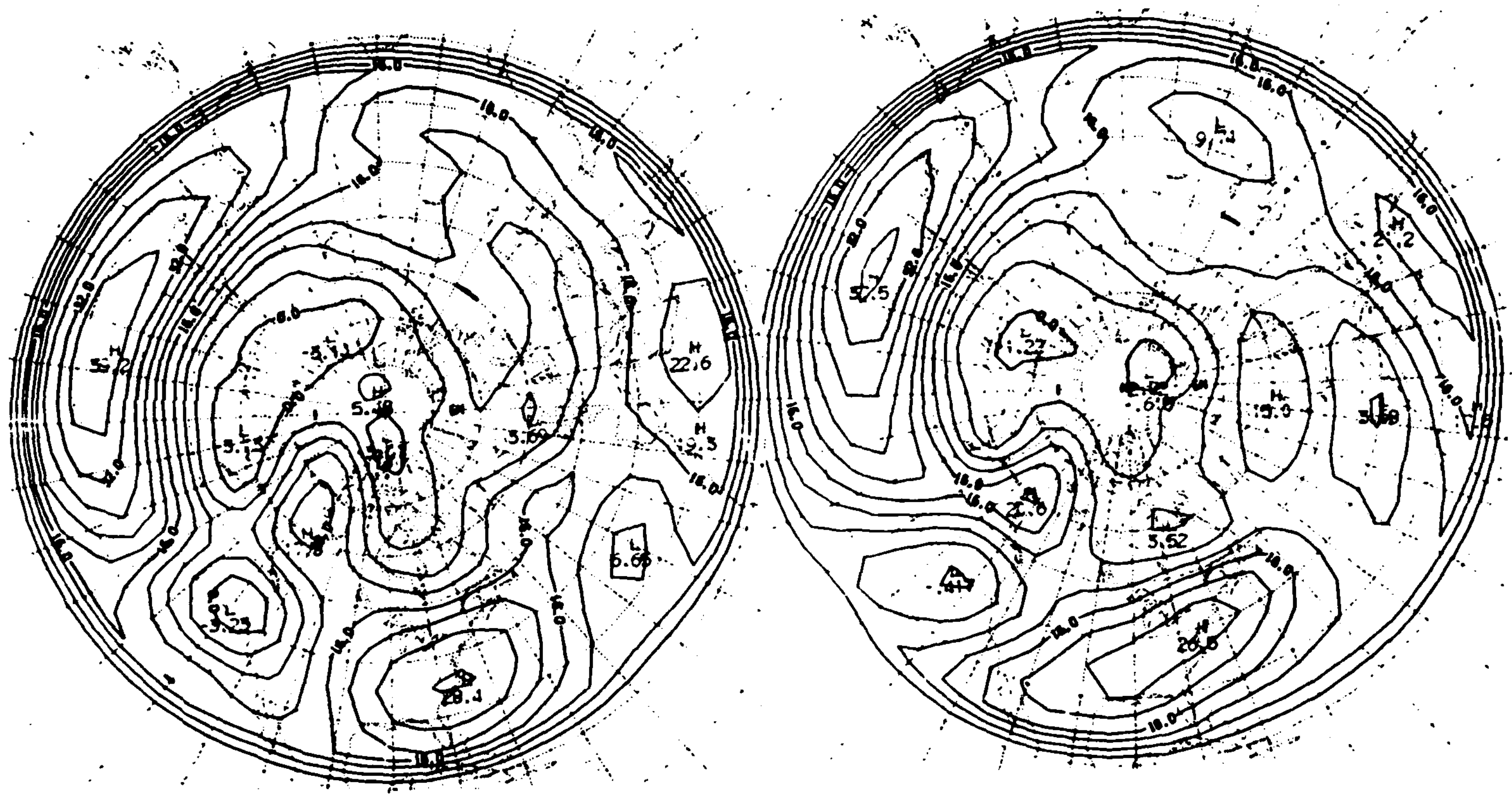


Fig. 31
The 500mb Pacific Coast height field Student T significance results (contour interval 1.8) with confidence limits 1.48,2.02, and 3.36 corresponding to 90,95, and 99% confidence levels respectively.



(a) (b)

Fig. 32
The 500mb Pacific Coast computed zonal geostrophic wind fields (contours 8 m s^{-1}): (a) Block;
(b) T. Ridge.

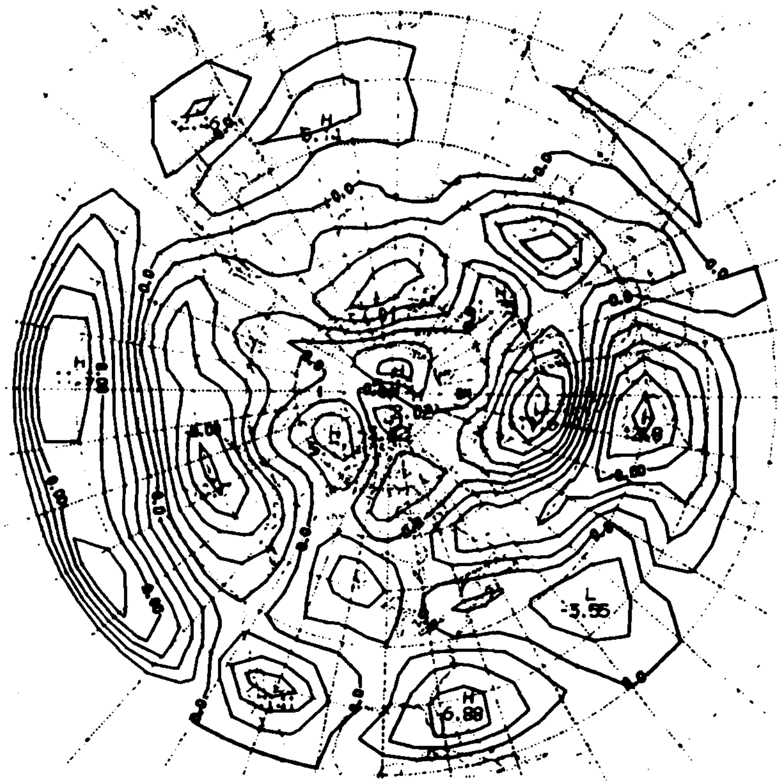


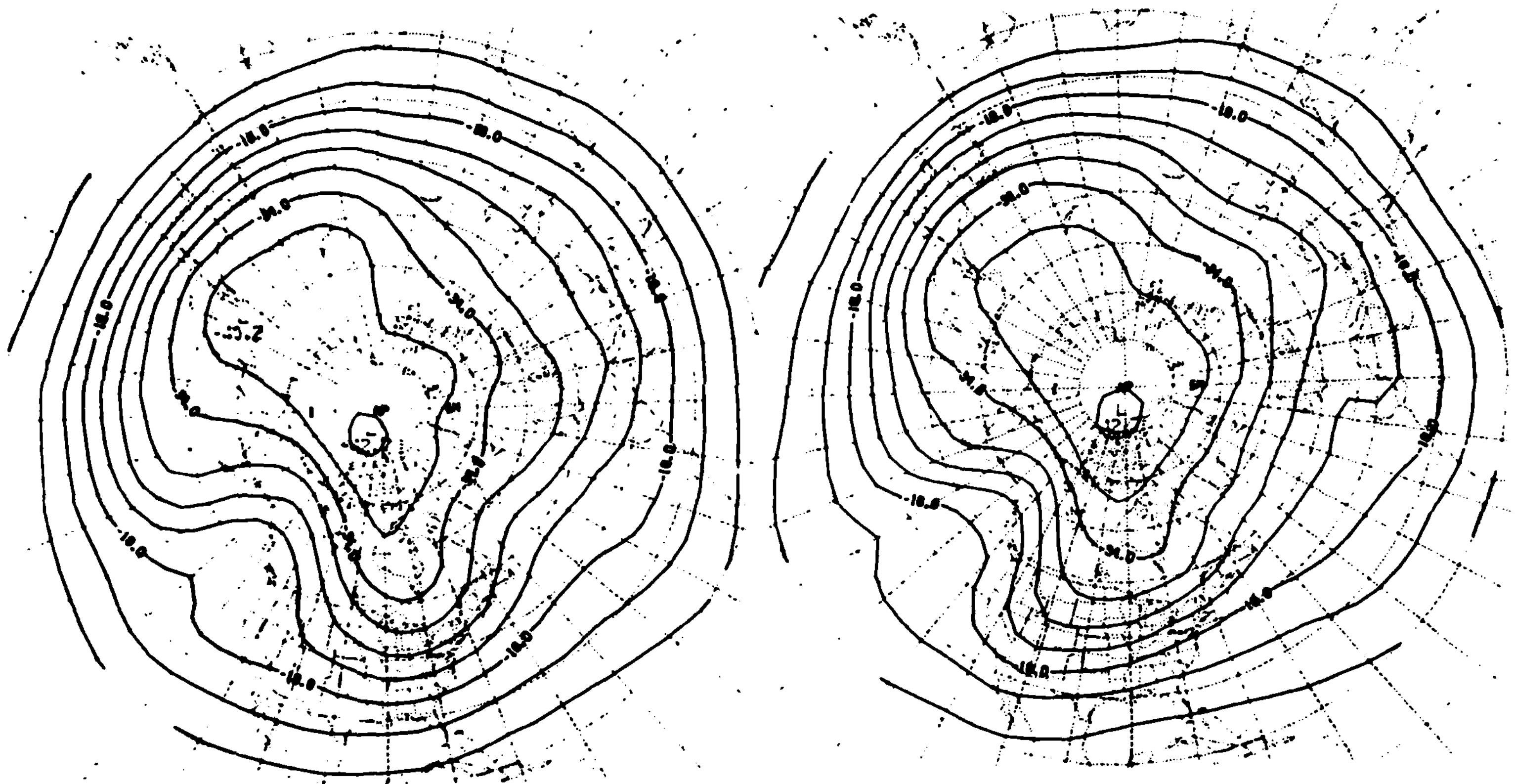
Fig. 33
The 500mb Pacific Coast zonal wind difference field (contours 2 m s^{-1}).

the Pacific is a 10 m s^{-1} strengthening of the subtropical westerlies at about 30N latitude together with a weakening of the westerlies of about 8 m s^{-1} at about 50N latitude across most of the ocean. These large zonal wind differences are almost entirely upstream of the ridge itself. As with the Pacific Ocean case, these differences can be compared with the zonally averaged zonal winds in Table 3. There is a similar distribution of wind anomaly associated with the low heights over western Europe.

The westward tilt with latitude evident in the height field is similarly reflected in the composite temperature fields, Figure 34. Complementing the westward tilt during blocking is the substantial southeasterly movement of the upstream thermal trough. The wavetrain associated with the block continues to be a more dominant influence downstream than that of the transient ridge. The transient ridge, in contrast, is positioned slightly further west and tilts slightly southwest-northeast, allowing the downstream thermal trough to move southwesterly into the western United States. This shift in the transient ridge allows a redistribution of the polar air mass which invades North America. The very distinct thermal contrast which exists between these two regimes stands out in Figure 35, the 500mb temperature difference field. Keeping our three areas of interest in mind, we find during blocking, the southwest movement of the upstream trough brings cooler temperatures to all but the very southeastern portion of the Pacific Ocean. Accordingly, the westward latitudinal slant produces anomalous warm temperatures along the West Coast which extent up into Alaska.

Table 3. The 500mb Pacific Coast zonally averaged zonal geostrophic winds (m s^{-1}) for the Block, T. Ridge, and Climatology.

Latitude	Block	T. Ridge	Climatology
25	19.1	15.8	16.0
30	21.0	18.0	18.7
35	20.1	17.8	19.3
40	17.7	16.7	18.5
45	13.9	14.5	15.9
50	10.2	11.8	12.3
55	7.9	10.0	9.3
60	6.5	8.8	7.2
65	5.4	7.7	5.8
70	4.8	6.3	4.8
75	4.1	3.8	3.7
80	2.8	1.5	2.5
85	1.4	.4	1.4



(a) (b)

Fig. 34
The 500mb Pacific Coast composite temperature fields (contours 4^{0} C): (a) Block; (b) T. Ridge.

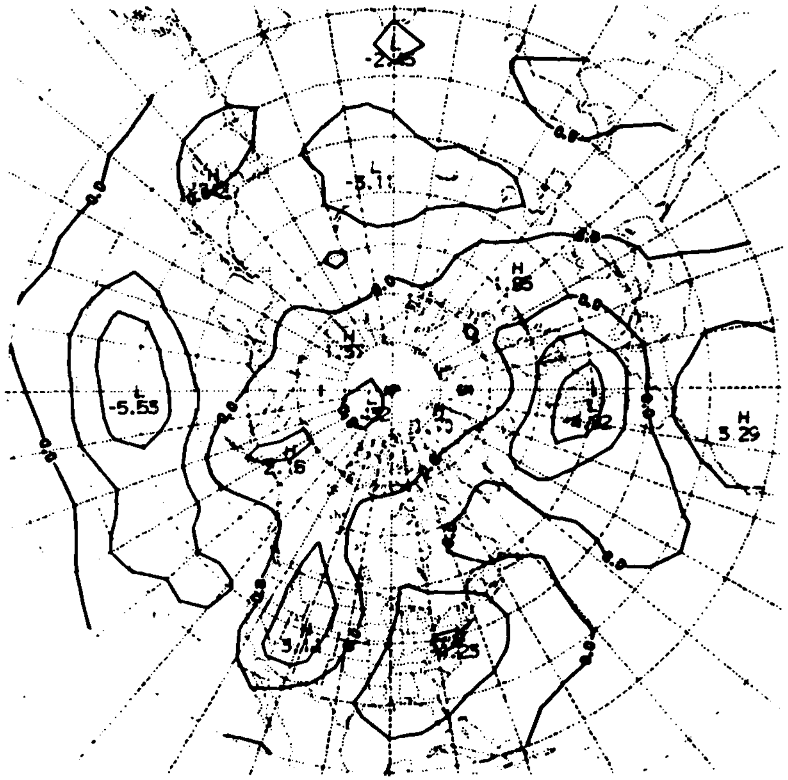


Fig. 35
The 500mb Pacific Coast temperature difference field (BK-TR) (contours 2° C).

The southwest migration of the thermal trough during the transient ridge makes the warm temperature difference along the coast associated with the block expand to include the entire western United States, while the deeper downstream trough during blocking causes cooler temperatures in the East. The trough over Europe in the blocking composite produces a cool temperature anomaly in that area. The thermal contrasts mentioned above agree nicely with the height differences, Figure 29, mentioned earlier.

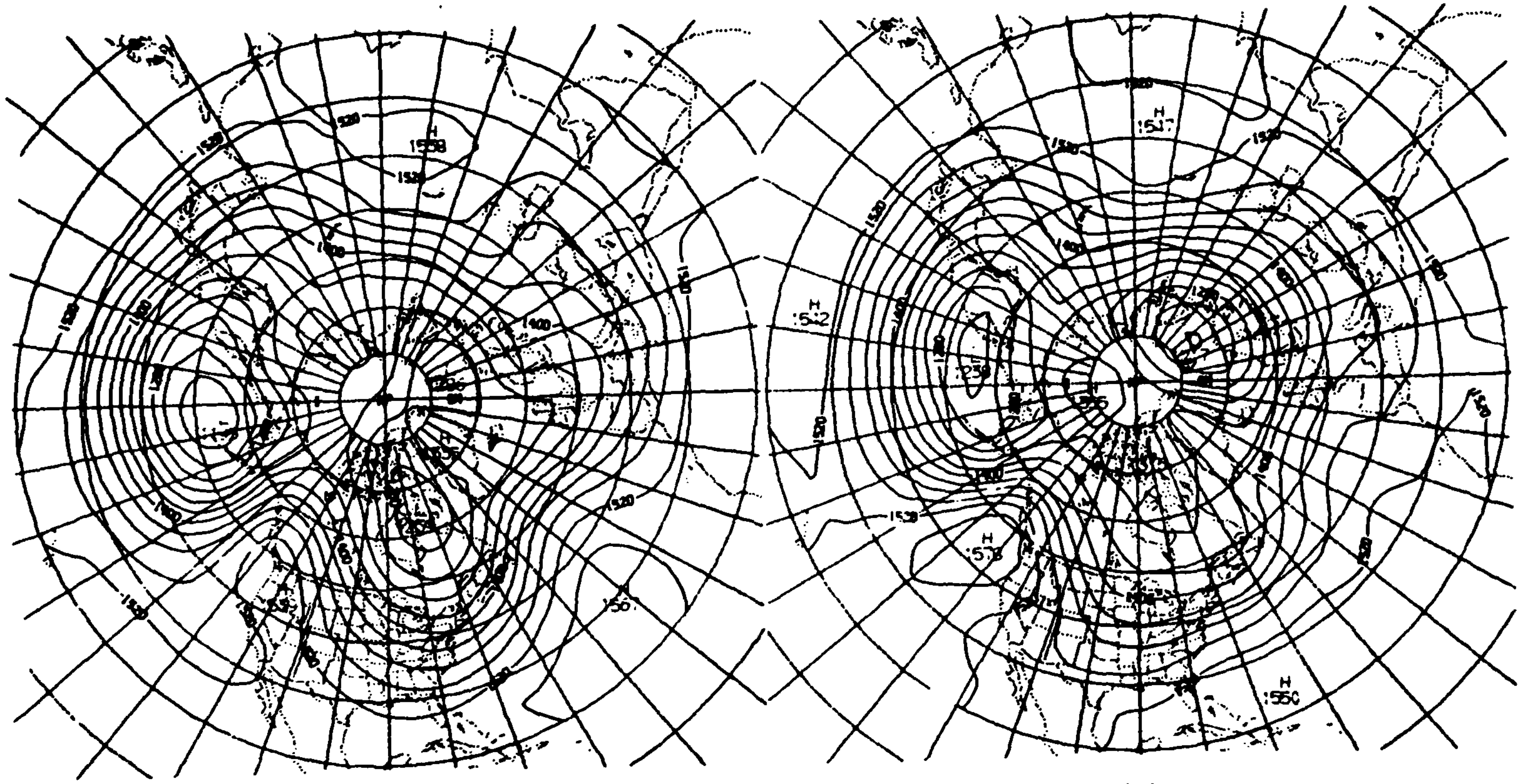
Some relationships common to the Pacific Ocean cases are evident also in the Pacific Coast 500mb fields. The wavetrain in the height field which forms downstream during blocking appears again to be more fully developed than during the transient ridge case. But, unlike the previous study, this wavetrain does not exhibit a large downstream anomalous maximum over Europe. Reviewing Figure 28, a more expected picture is presented with the anomalous amplitudes diminishing further downstream from the source. And it appears that although anomalous amplitudes are slightly different between the two cases, the major areas of contrast in the downstream height field result from the apparent shifting of the wavelength. During the block, the wavelength appears to be shorter and the apparent wavetrain curves more toward the tropics, which would be consistent with linear theory (Hoskins and Karoly, 1981). It is this apparent shortening and turning of the wavetrain which results in the large differences over Europe.

While there is some agreement between the height and temperature composites in the oceanic and coastal cases, there is an interesting difference in the wind anomalies. The extensive weaker winds to the north of the extensive areas of higher winds which characterized the wind difference field both up and downstream in the Pacific Ocean study, Figure 9, appear only upstream of the Coastal block, i.e. only over the ocean.

The 500mb analysis would then suggest a similarity between the two Pacific regions, particularly with respect to the upstream influences. In the Pacific Coast ridges, however, the orographic effect of the West Coast appears to provide a strong additive influence. This added influence may contribute to the different wavelength in the downstream wavetrains of the block and transient ridge cases. Let us find out how these differences are manifested in the vertical structure.

Our attention is now turned to the various fields at the 850mb level. The composite height fields are shown in Figure 36. The block is displaced eastward about 10 degrees to 120W longitude with the southeast extension of the upstream trough reaching the West Coast. The transient ridge does not exhibit an eastward shift with latitude at this level. The blocking ridge shows a pronounced northwest-southeast slant perhaps revealing the orographic influence on the height fields as the ridges align themselves with the coastline. Similar differences prevail at the 850mb as at the 500mb level and are shown in Figure 37. The block has a deeper upstream trough and the downstream wavetrain has larger amplitudes and shorter wavelengths.

The zonal component of the geostrophic wind is computed from the height fields and mapped with the corresponding difference field in



(a) (b)

Fig. 36
The 850mb Pacific Coast composite geopotential height fields (contours 30m): (a) Block; (b) T. Ridge.

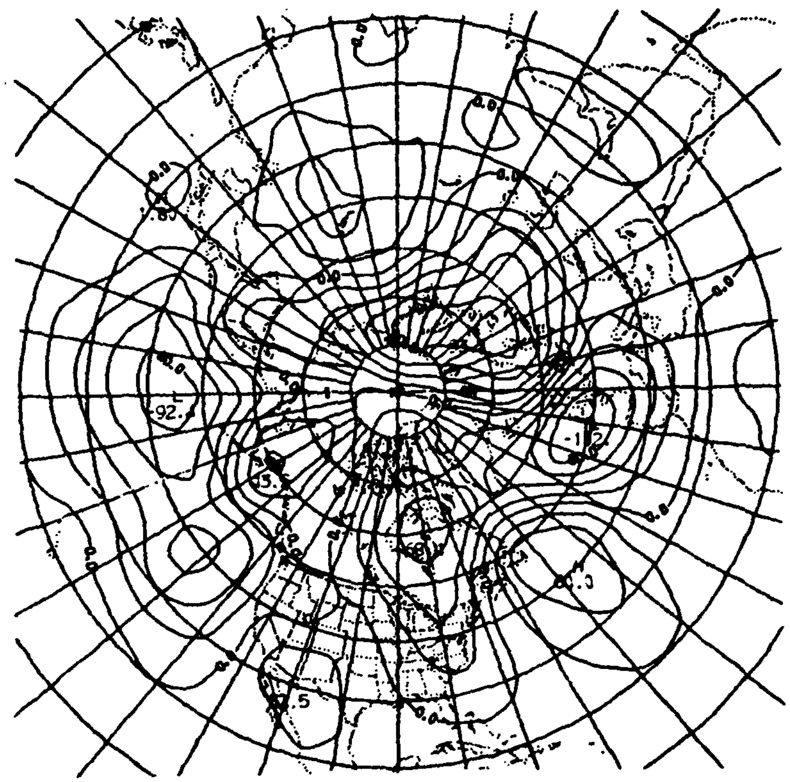
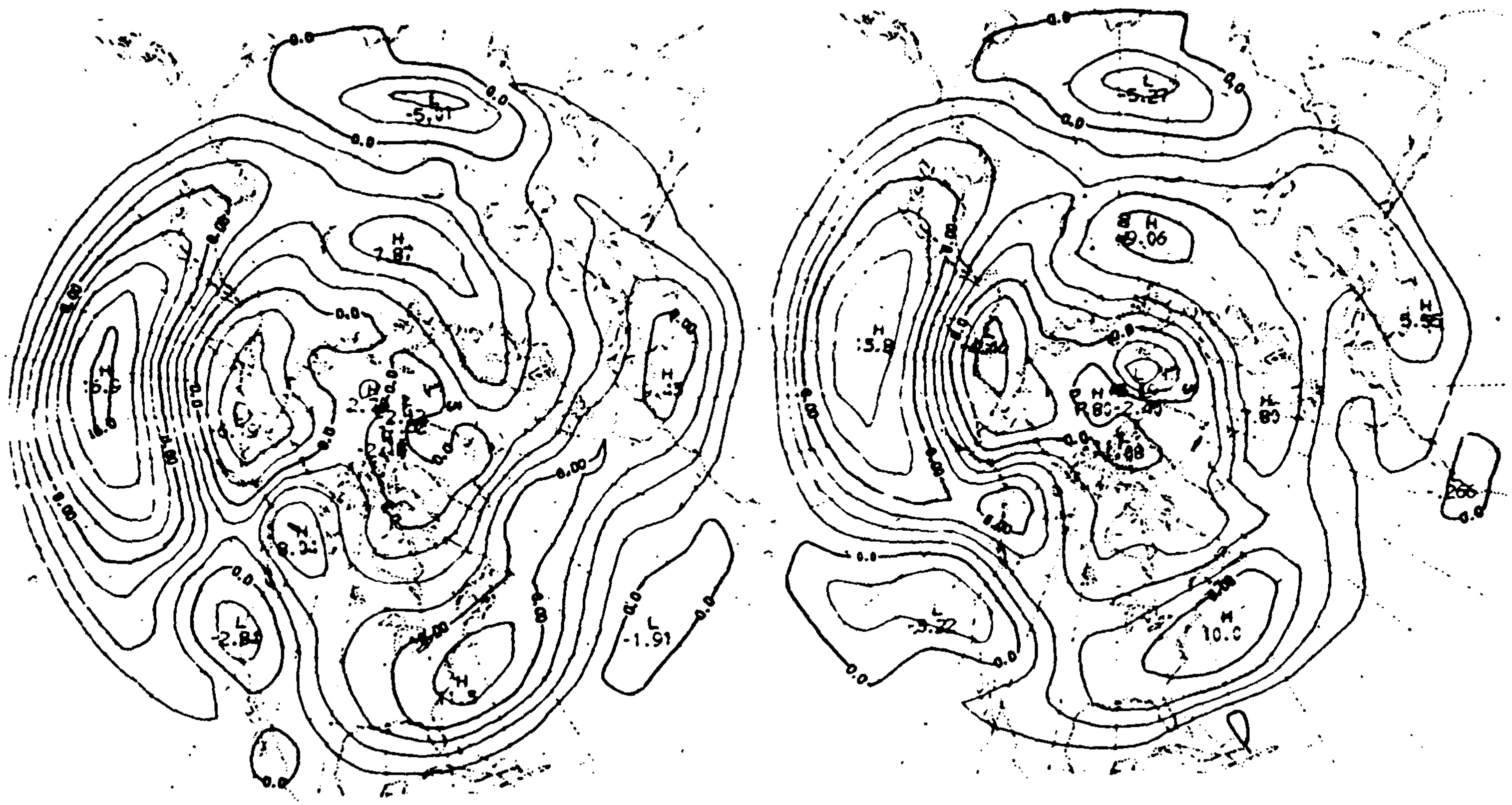


Fig. 37
The 850mb Pacific Coast geopotential height difference field (contours 20m).

Figures 38 and 39 respectively. The wind fields in Figure 38 reveal great similarity to those at the 500mb level. While some high latitude anomalies occur downstream as reflected in the wavetrains, the most important contrasts appear upstream of the ridges. Figure 39 shows the winds increase by as much as 6 m s^{-1} during blocking south of 40N latitude and decrease by a nearly equal amount to the north of 40N latitude. Comparing this wind difference field with the wind difference field in the Pacific Ocean study, we find an interesting contrast. While the general relationship of stronger winds to the south and weaker winds to the north of the ridge remains, the relation to the position of ridge is different. The mid-Pacific Oceanic blocking ridge is imbedded in the weakened westerlies, whereas the West Coast ridge is downstream of the zonal wind change. In both studies, the weaker winds during blocking extend across the Pacific Ocean. The stronger winds in the subtropical latitudes are, however, sensitive to the ridge location as can be seen by comparing Figures 39 and 9. By that comparison, we find the stronger winds are confined to the western Pacific for mid-Ocean blocks, whereas for Coastal blocks they extend across the South Pacific to the West Coast of North America.

We would expect the close similarity which exists between the height and temperature fields at 500mb to remain at the 850mb level also. Figures 40 and 41, the composite temperature fields and associated temperature difference field respectively, show this to be the case. In both cases, Figure 40 reveals a broad zonal extension of the upstream trough as well as the orographic influence on the slope of the ridge. The thermal trough



(a) (b)

Fig. 38
The 850mb Pacific Coast computed zonal geostrophic wind fields (contours 2 m s^{-1}): (a) Block; (b) T. Ridge.

Fig. 39
The 850mb Pacific Coast zonal wind difference field (contours 2 m s^{-1}).

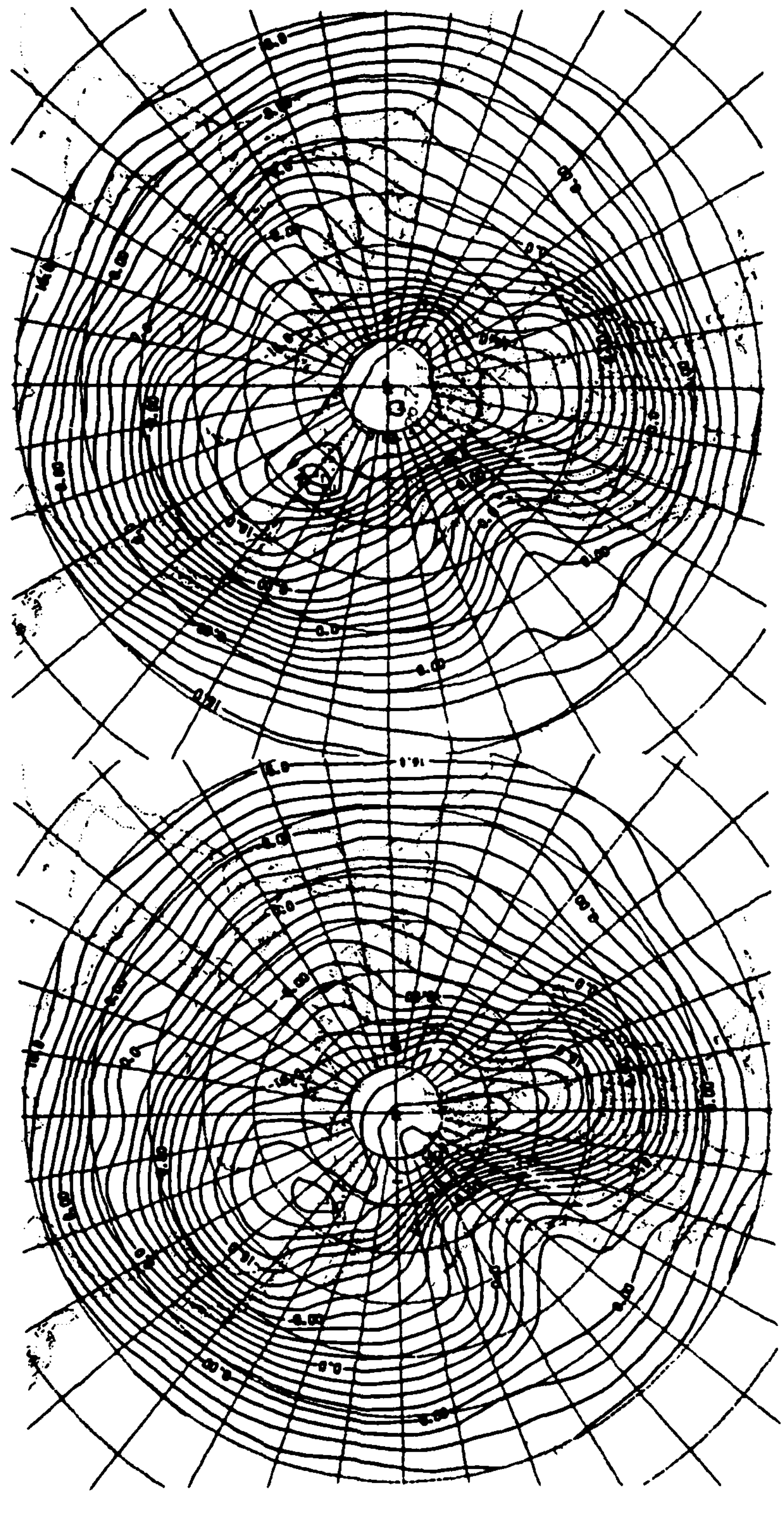


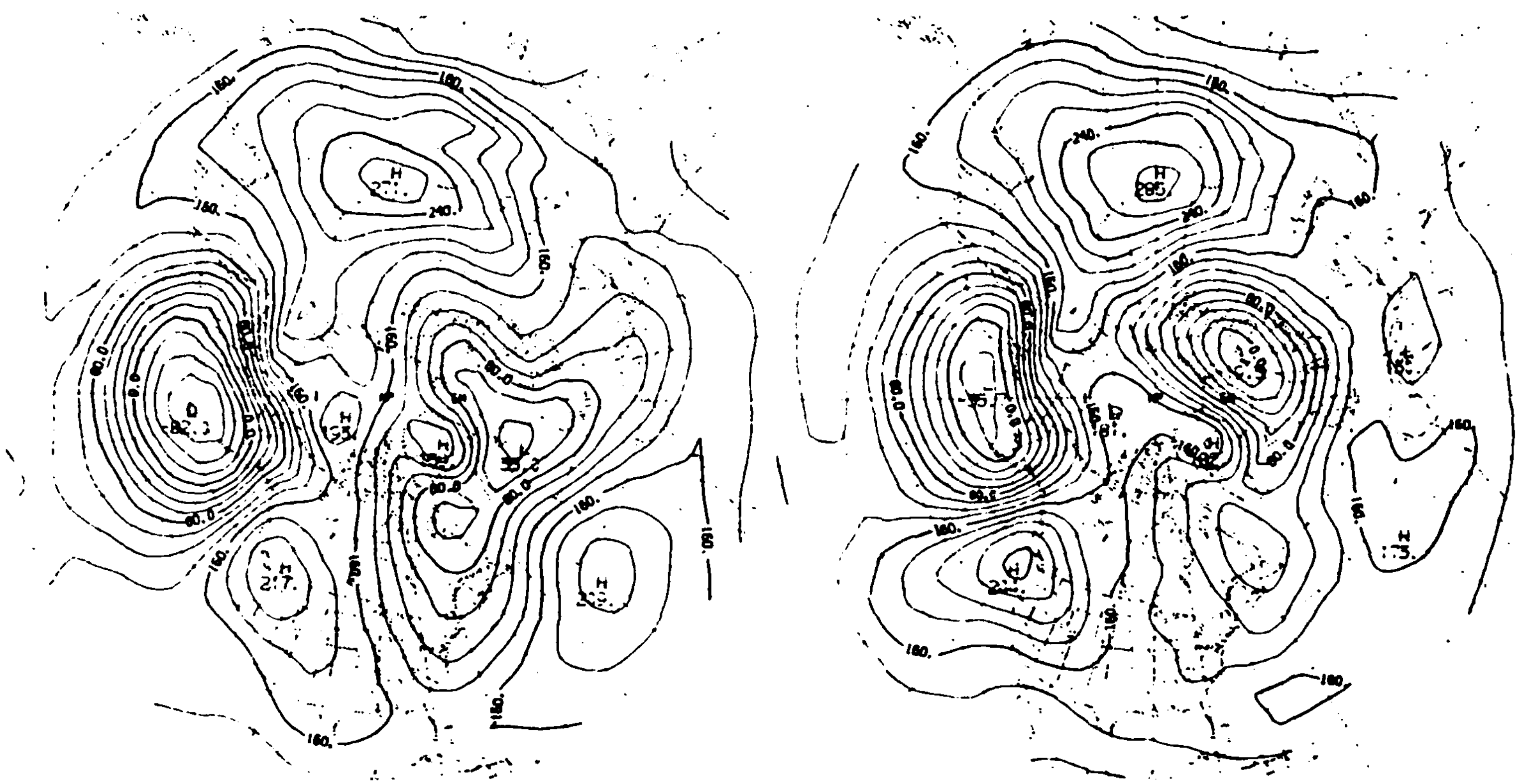
Fig. 40
The 850mb Pacific Coast composite temperature fields (contours 2^0 C): (a) Block; (b) T. Ridge.

Fig. 41
The 850mb Pacific Coast temperature difference field (contours 1^0 C).

downstream of the block is extensive over the East Coast with an accompanying tight thermal gradient. From Figure 41, the block can be characterized by colder air over the Pacific Ocean with warm air along the West Coast from Baja to the Beaufort Sea. The southward extent of the downstream thermal trough places cold air over Hudson Bay and down over the eastern United States. The trough placed over Europe in the height field is also mirrored in the thermal field.

Continuing down to the lower level, Figures 42 and 43 show the 1000mb composite height fields and their difference field respectively. The general appearance matches that at 850mb. We continue to see the dominant upstream trough which accompanies blocking together with downstream patterns similar to those seen at the upper levels. We especially notice the North Atlantic trough which dominates the entire area and varies considerably between the two cases. During blocking, a fork actually exists with the northern extension of the trough following the warmer ocean surface into the Arctic Ocean, while the southern extension extends down through Europe into North Africa. This is in sharp contrast to the transient ridge trough which sits centered over northern Europe. The difference field, Figure 43, vividly points out the contrasting effects of this trough on the European land mass. The downstream differences between the block and transient ridges at this level appear both large and extensive!

The 100mb level will end our study of the Pacific Coast ridging. The respective composite height fields and the height minus mean fields are shown in Figures 44 and 45. The height fields show a westward



(a) (b)

Fig. 42
The 1000mb Pacific Coast composite geopotential height fields (contours 20m): (a) Block; (b) T. Ridge.

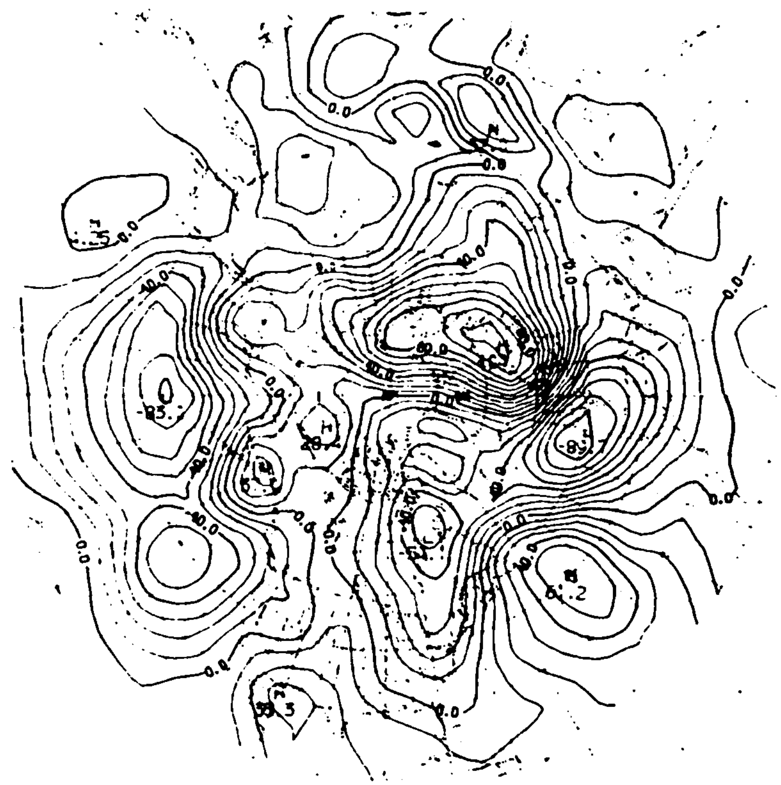


Fig. 43
The 1000mb Pacific Coast composite height difference field(BK-TR) (contours 10m).

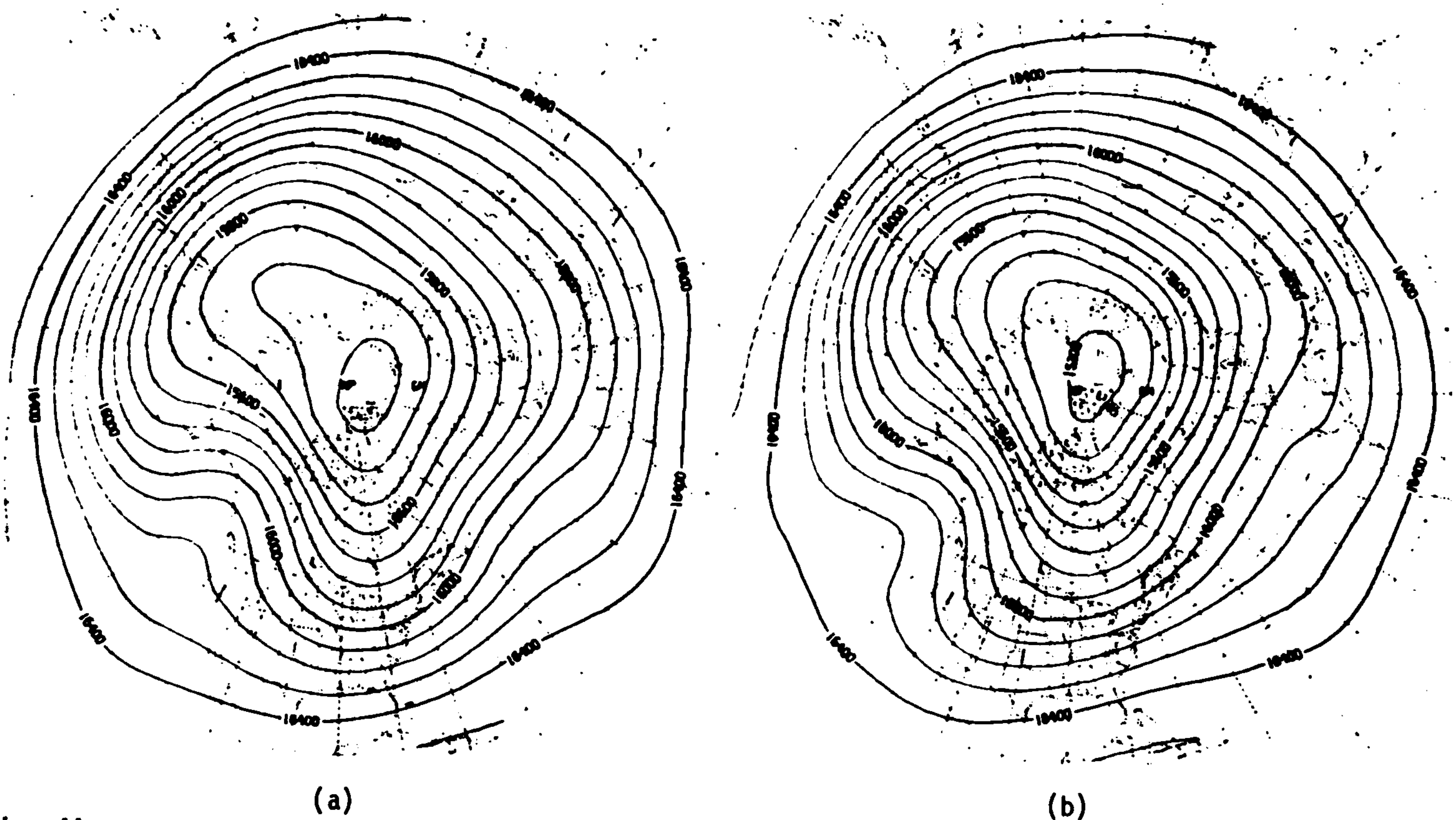
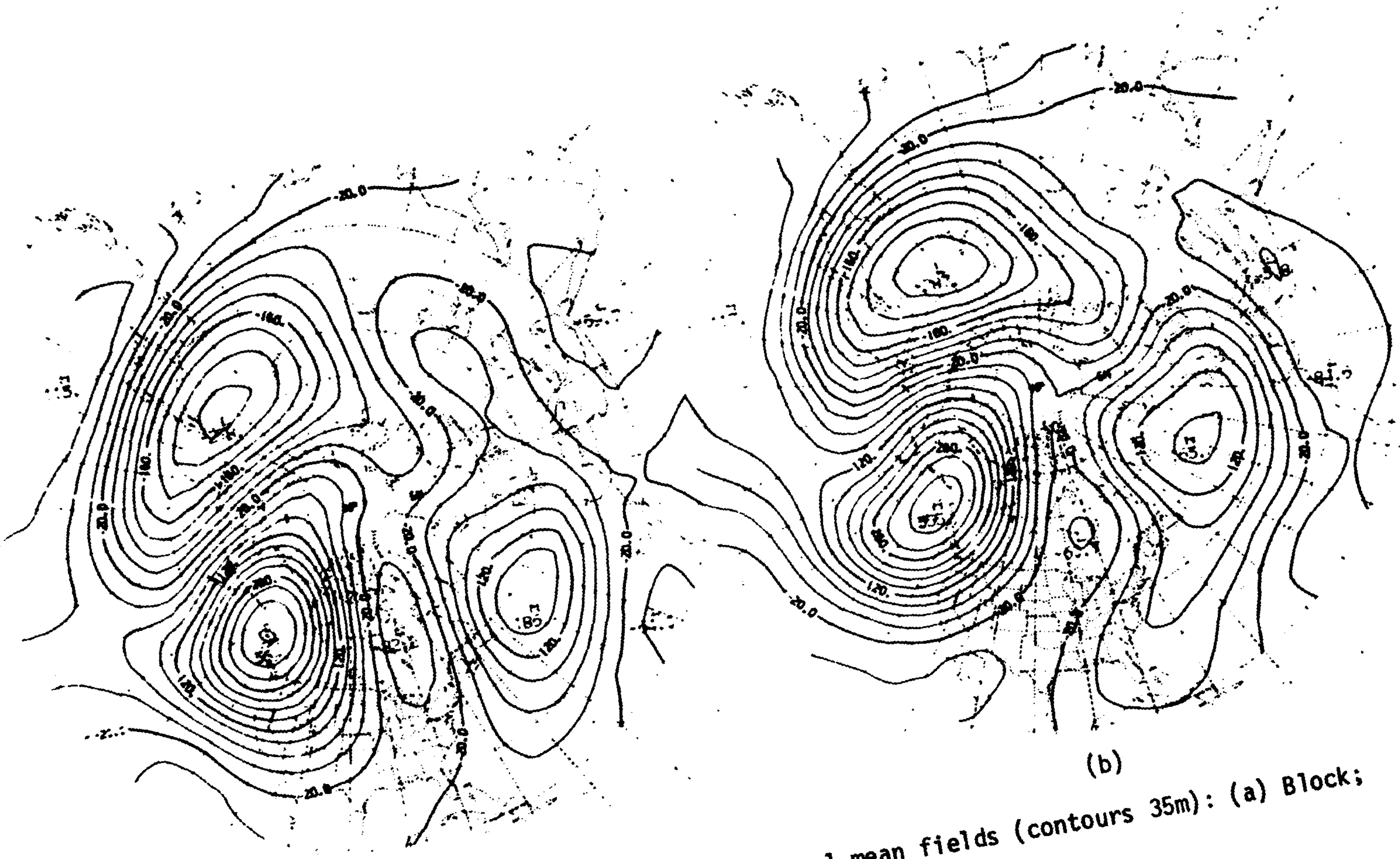


Fig. 44
The 100mb Pacific Coast composite geopotential height fields (contours 100m); (a) Block; (b) T. Ridge.



(a) (b)

Fig. 45
The 100mb Pacific Coast geopotential height minus zonal mean fields (contours 35m): (a) Block;
(b) T. Ridge.

shift in the longitude of both fields with respect to the 500mb fields. The upstream trough is now shown to extend through all levels. The downstream wavetrains show greater similarity than at previous levels. The difference field, Figure 46, shows that while the same general features exist as before, they are more zonally symmetric. The Russian high has moved poleward while the middle latitude and the subtropical highs have decayed with height. The significance field appears in Figure 47. For the Pacific Coast study we remember the confidence levels of 1.48, 2.02, and 3.36 are needed for a 90, 95, and 99% confidence in our results. The major features in the difference field correspond to areas of greater than 90% confidence.

The computed geostrophic wind fields are mapped in Figure 48 with the zonal mean difference field in Figure 49. At this level the zonal mean wind is different than seen previously. What remains from lower levels is the stronger winds south of 50N latitude and weaker winds north of 50N latitude in the region of the ridge and also over western Europe. Now, however, there is the appearance of a general, almost zonally symmetric reduction in the zonal wind at high latitudes together with a less general but fairly consistent increase of the zonal wind in the low to mid-latitudes.

As we conclude our study of the Pacific Coast ridges, what can we glean from the above observations? The height fields indicate that both ridges have only a slight westward tilt in the vertical being primarily barotropic in nature. The block does show a strong westward tilt with latitude. There also appears to be a west European trough present with

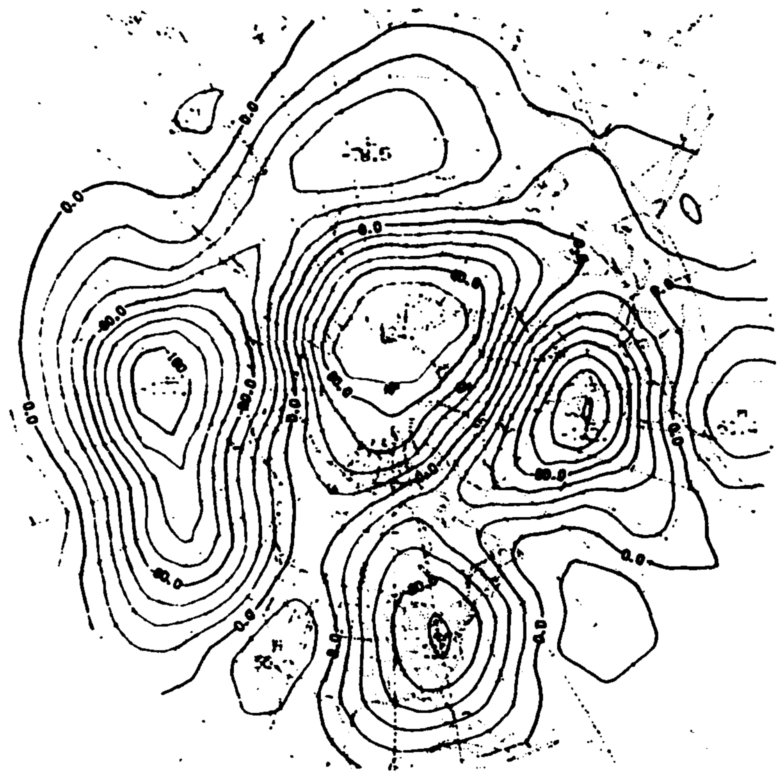


Fig. 46
The 100mb Pacific Coast geopotential height difference field (contours 10m) (BK-TR).

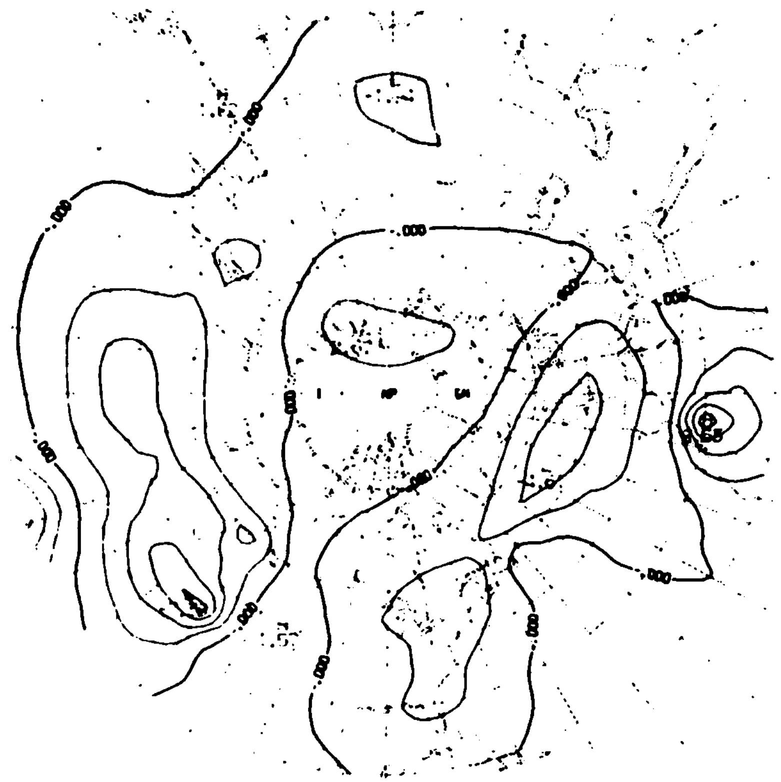
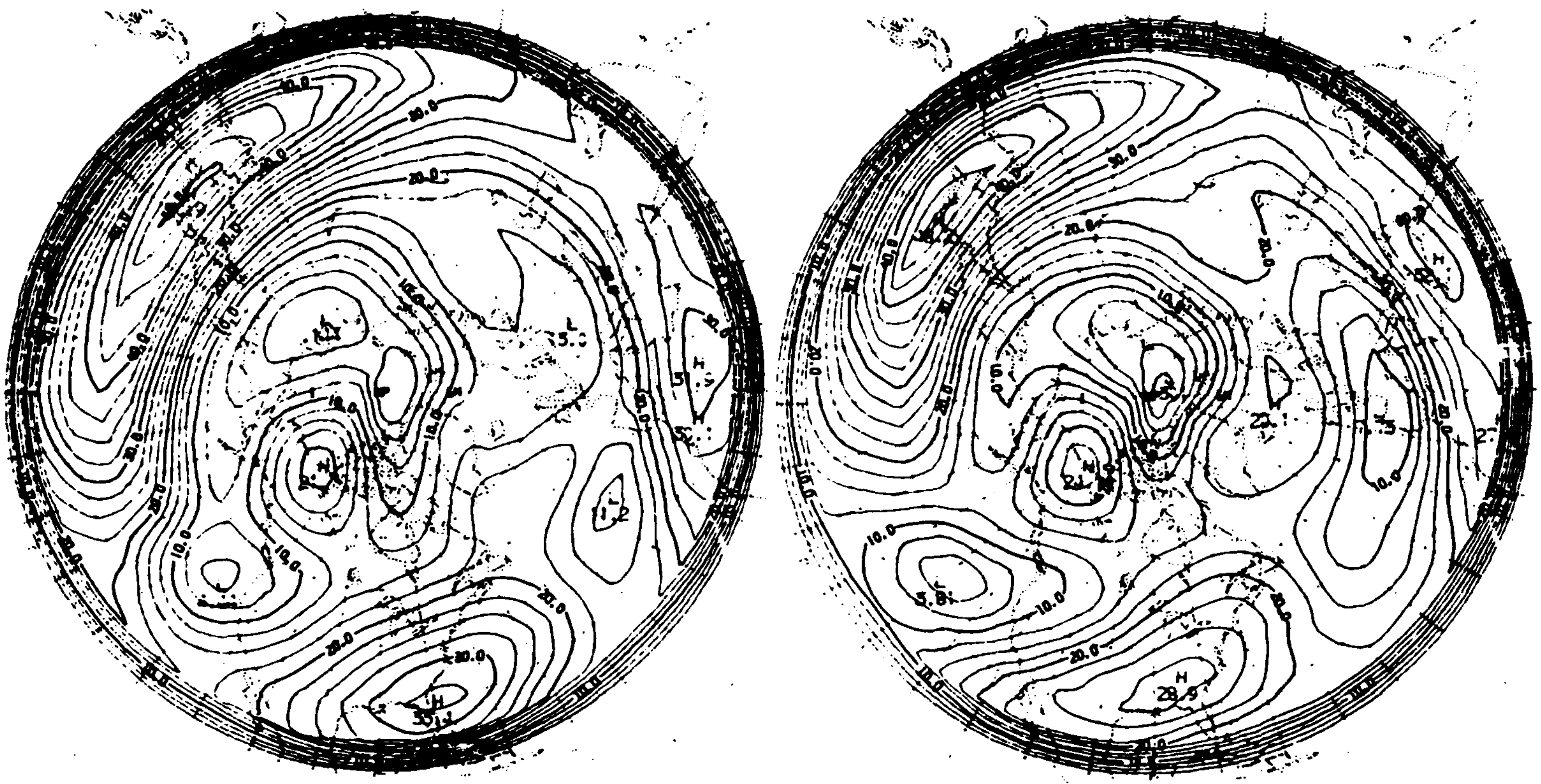
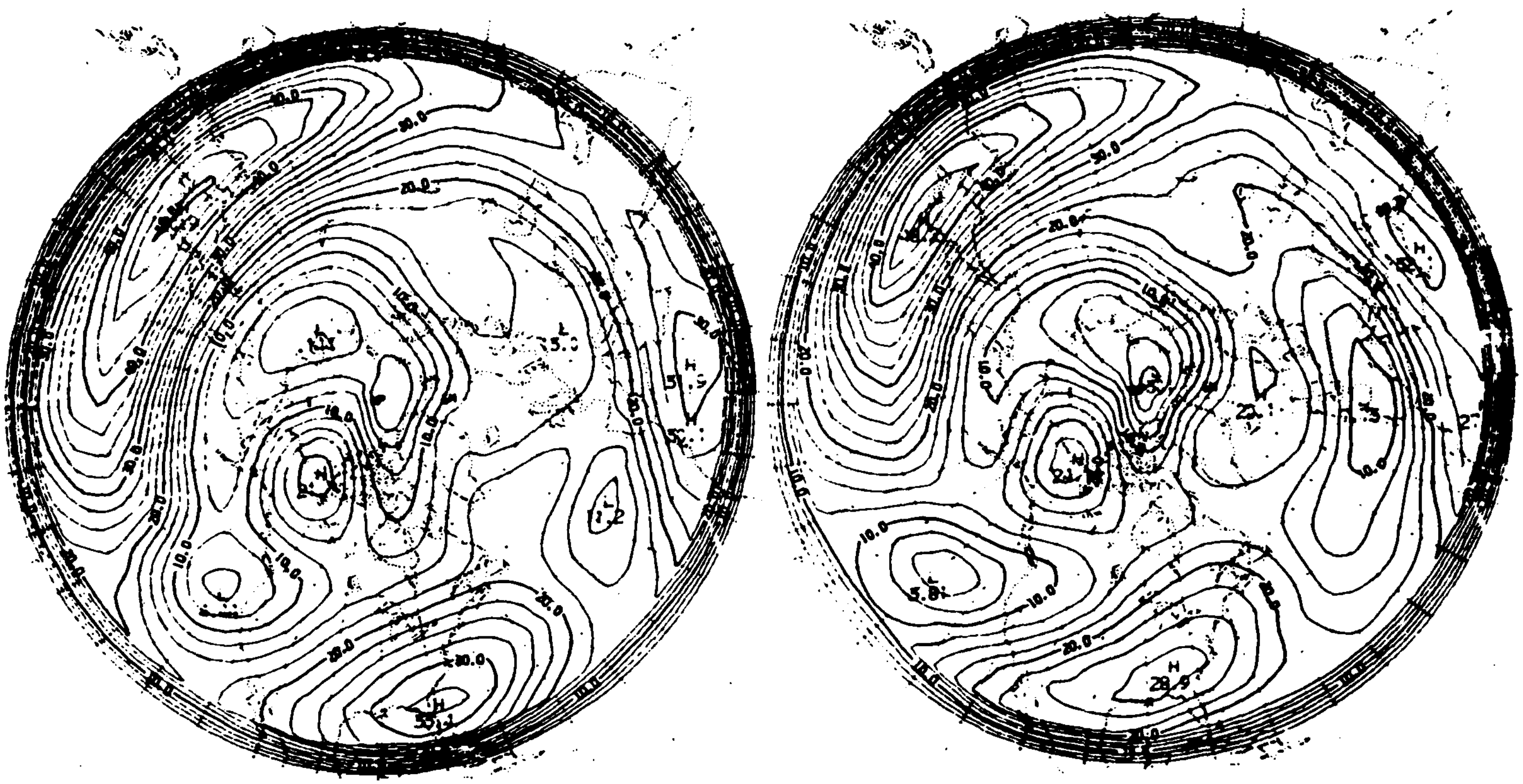


Fig. 47
The 100mb Pacific Coast height field Student T test results (contour interval 1.8) with confidence limits 1.48, 2.02, and 3.36 corresponding to 90,95,and 99% confidence levels respectively.



(a) (b)

Fig. 48
The 100mb Pacific Coast computed zonal geostrophic wind fields (contours 2.5 m s^{-1}): (a) Block; (b) T. Ridge.



(a) (b)

Fig. 48
The 100mb Pacific Coast computed zonal geostrophic wind fields (contours 2.5 m s^{-1}): (a) Block; (b) T. Ridge.

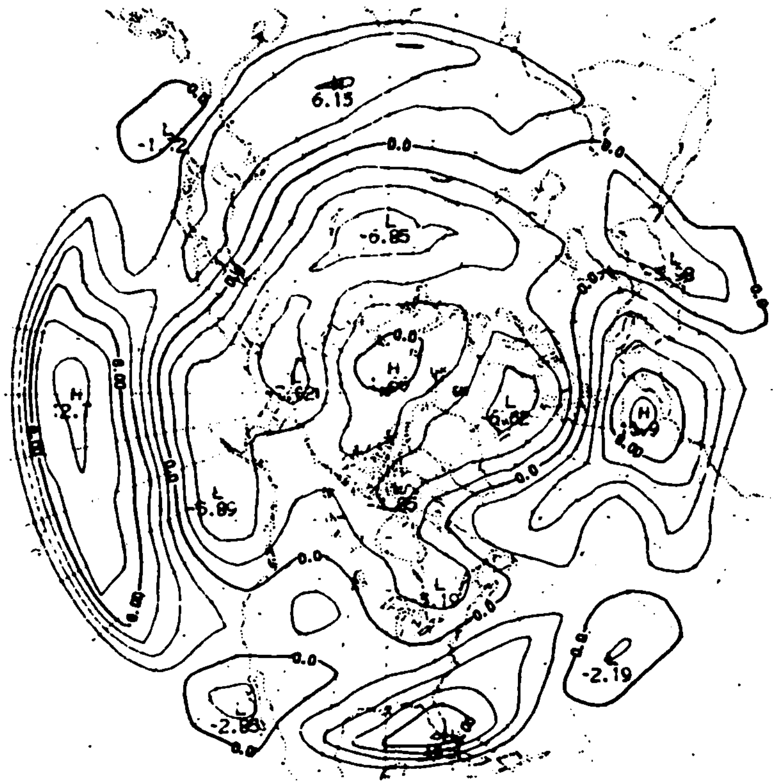


Fig. 49
The 100mb Pacific Coast zonal wind difference field (contours 2 m s^{-1}).

the blocking cases which extends throughout the atmosphere. The wavelength of the downstream wavetrain during blocking appears to be slightly shorter than that associated with the transient ridge. This results in different downstream patterns arising from both wave amplitude and position.

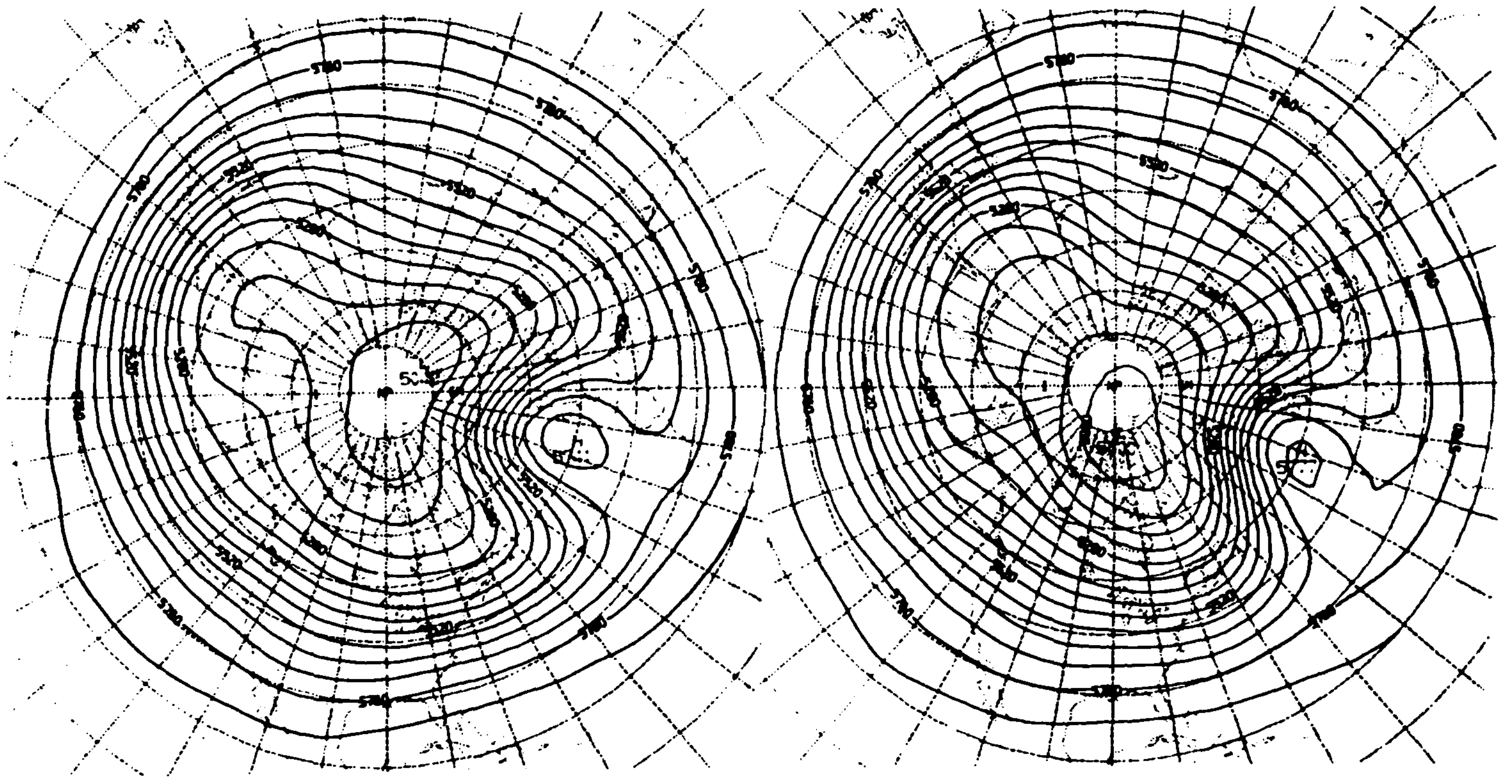
Chapter 5

ANALYSIS OF THE ATLANTIC REGION (65W-25E)

Having discussed the comparisons between the long-lived and transient ridges in the central Pacific Ocean and the Pacific Coast region, let us now turn our attention to the Atlantic Ocean region. We anticipate that the large amplitude ridges in the Atlantic region may behave differently than those in the Pacific because of the greatly different arrangement of the land-ocean thermal contrasts and tropography.

Following the same basic procedure as before, we will get an overview from the 500mb composite fields of height, wind and temperature before proceeding to the other levels. Figures 50, 51, and 52 present the 500mb composite height fields, the height minus zonal mean fields, and the block minus transient ridge height difference field for the Atlantic sector. The height field shows the block centered at 50N, 15W with a slight northwest-southeast tilt, while the transient ridge has a northeast-southwest tilt and is centered at 50N, 20W. Looking at our three areas of interest: the upstream trough, the ridge itself, and the downstream wavetrain, we immediately notice the lack of any significant effects outside of the Atlantic area itself. This seems to indicate a far more regional influence by these systems than those positioned in the Pacific.

The difference field, Figure 52, brings out the interesting contrast between these and the Pacific cases. In the Pacific cases the difference field could be interpreted in part as an intensification of



(a) (b)

Fig. 50
The 500mb Atlantic composite geostrophic height fields (contours 60m): (a) Block; (b) T. Ridge.

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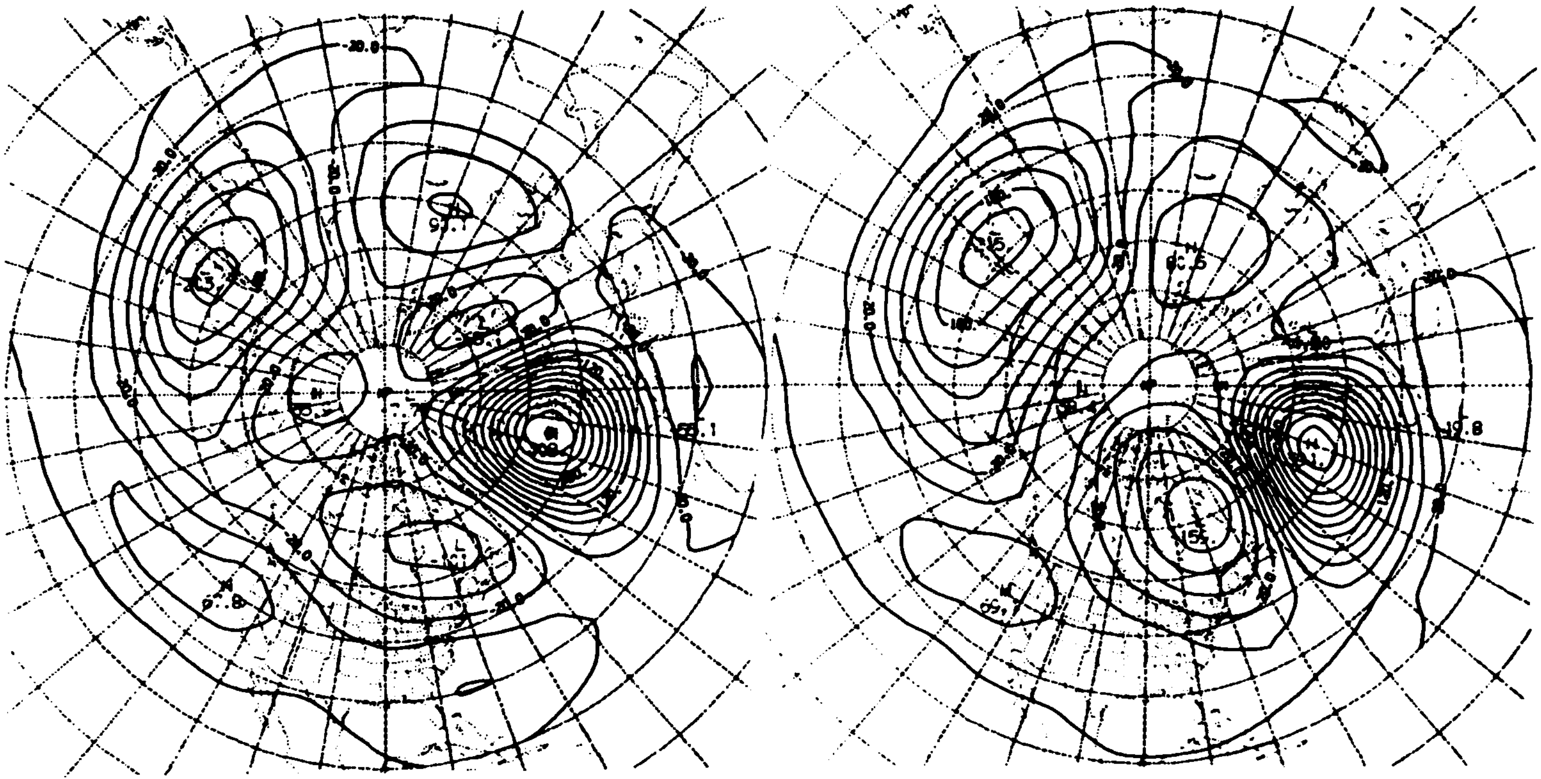


(a) (b)

Fig. 51
The 500mb Atlantic geopotential height minus zonal mean fields (contours 35m): (a) Block; (b) T. Ridge.

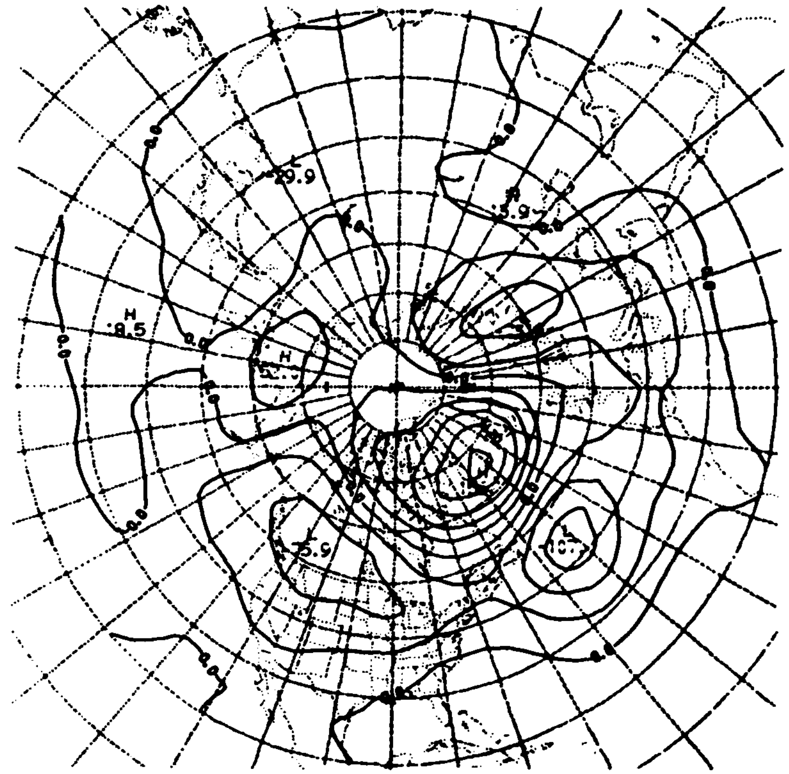
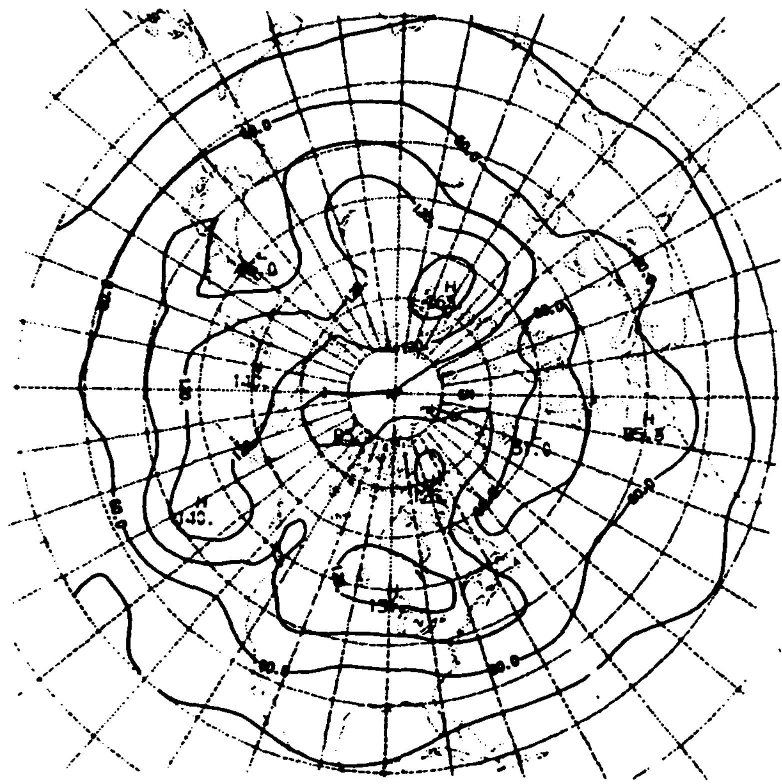


Fig. 52
The 500mb Atlantic composite height difference field (BK-TR) (contours 30m).

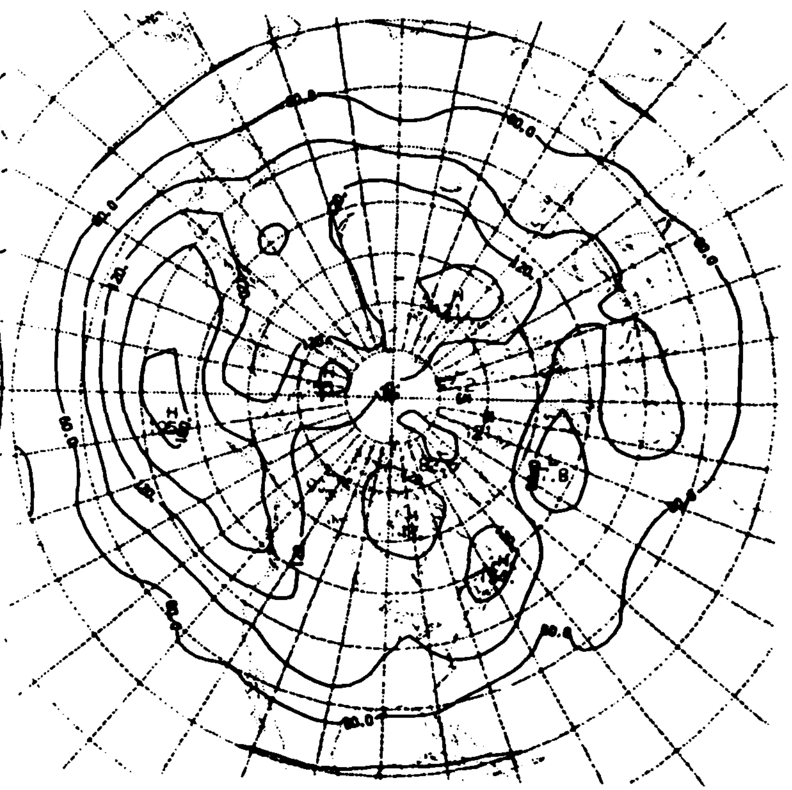
the upstream low and the development of a concomitant downstream wavetrain. In the Atlantic, however, the largest anomaly is the increased heights to the northwest of the ridge center which is flanked by three connected low anomalies. This is due primarily to the greater northward extension and the westward tilt with latitude of the blocking ridge compared to the transient ridge. There is little evidence of a downstream wavetrain either in the composites or the difference field.

Figures 53 and 54 present the standard deviations and the Student T confidence limits with 1.33, 1.73, and 2.54 being the limits for the 90, 95, and 99% confidence levels respectively. The significant differences are limited to the low over the North American region, the low and high slightly upstream of the block in the central Atlantic, and the downstream low over eastern Europe.

The zonal component of the computed geostrophic wind field, Figure 55, reveals a pattern in the ridges similar to those found in the Pacific Coast study. We notice a definite splitting of the westerlies which synopticans associate with blocking. As we saw with the transient ridge in the Pacific Coast study, we see in the Atlantic transient ridge the easterly winds below the ridge allow the westerly flow to ride over it. One of the most obvious distinguishing characteristics between this wind field and the Pacific cases is the minimal downstream effects. Figure 56 shows the difference field with the block having weaker winds north of 40N latitude which extend upstream across North America. But outside the Atlantic-North American region, the difference between the wind fields is



(a)



(b)

Fig. 53
The 500mb Atlantic height standard deviation fields (contours 30m): (a) Block; (b) T. Ridge.

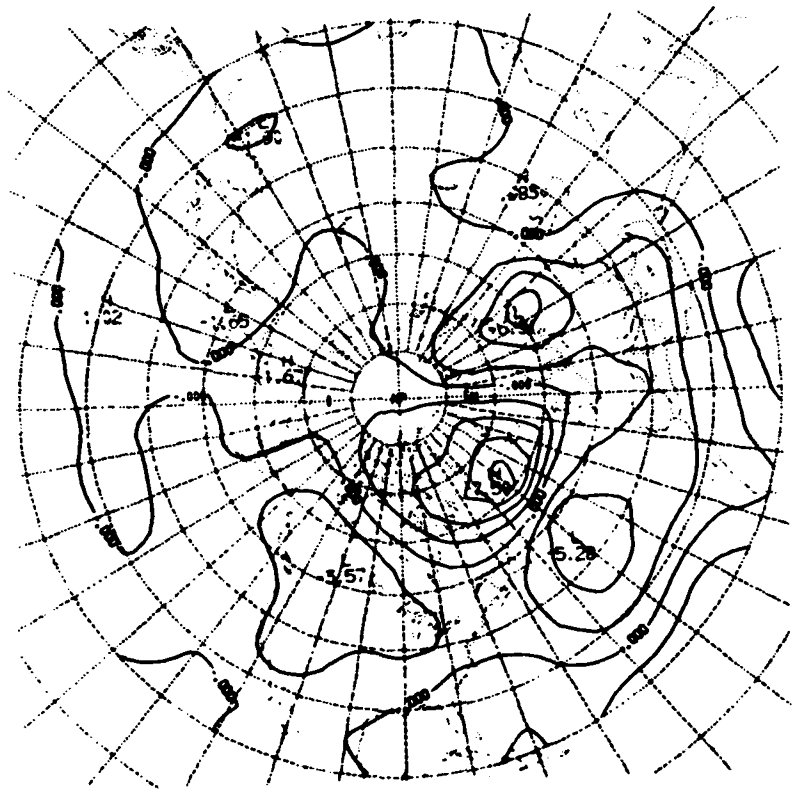
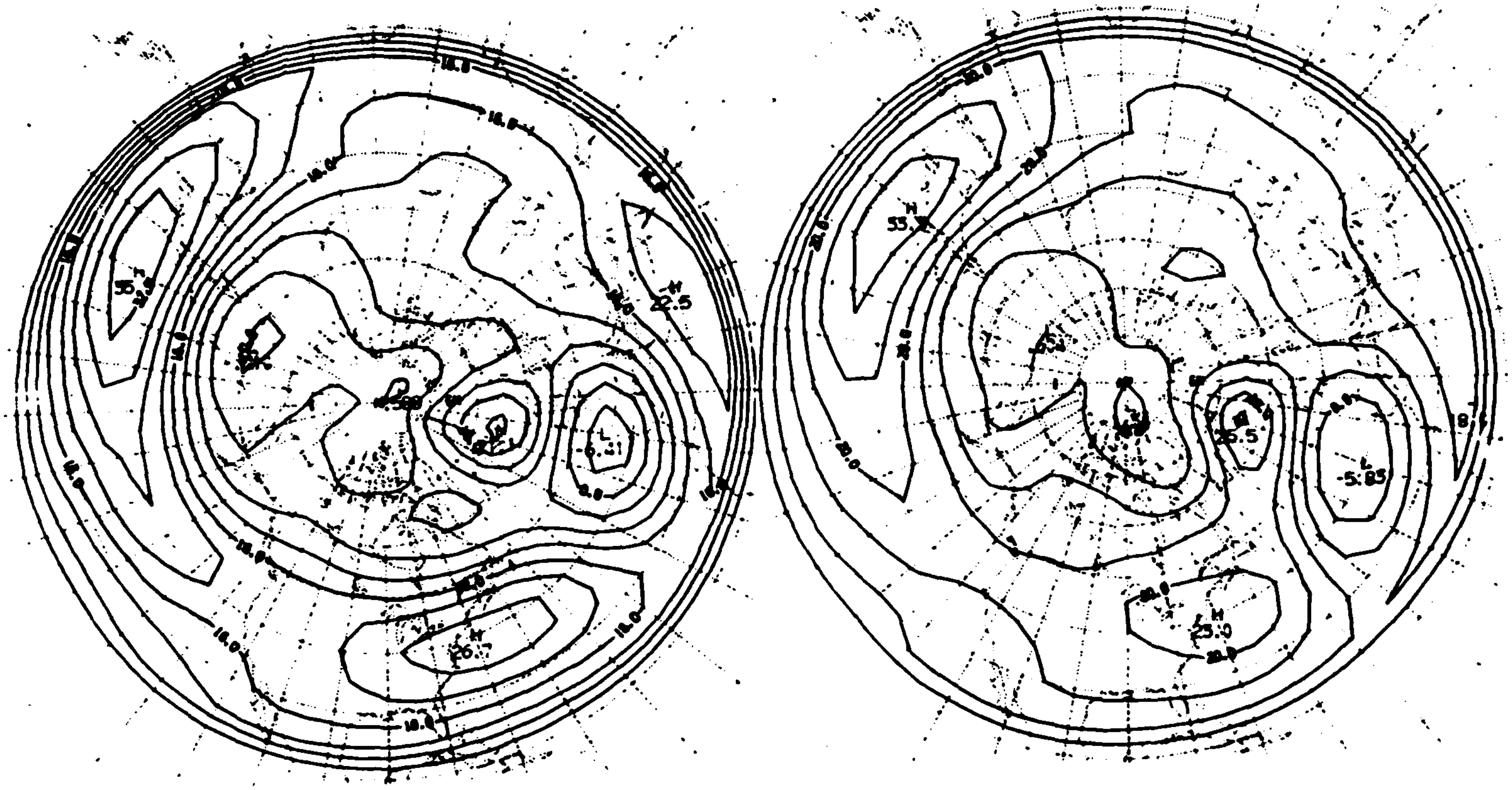


Fig. 54
The 500mb Atlantic height field Student T significance results (contour interval 1.8) with confidence limits 1.33,1.73, and 2.54 corresponding to 90,95,and 99% confidence levels respectively.



(a) (b)

Fig. 55
The 500mb Atlantic computed zonal geostrophic wind fields (contours 8 m s^{-1}): (a) Block; (b) T. Ridge.

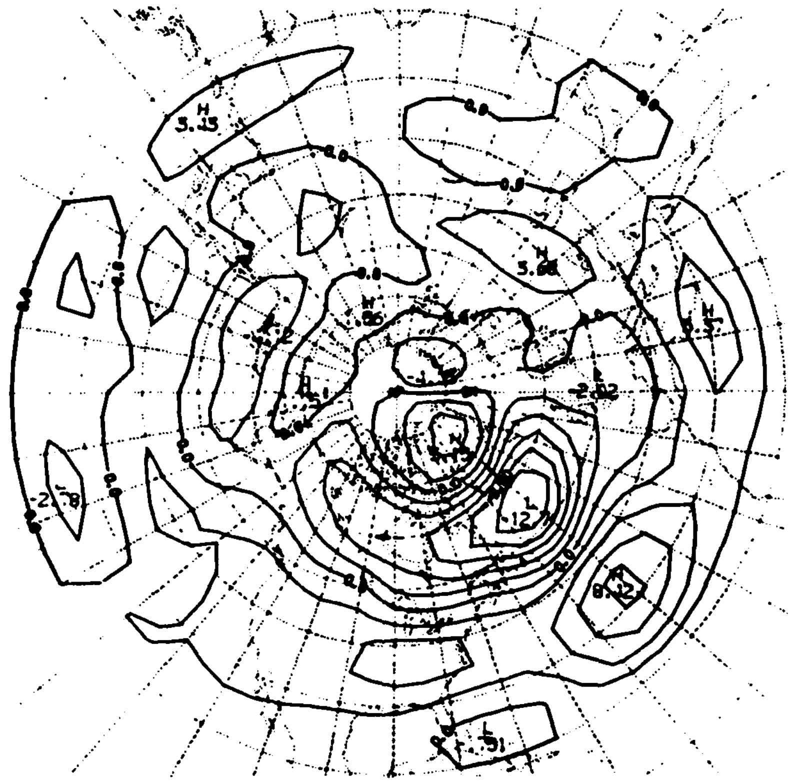


Fig. 56
The 500mb Atlantic zonal wind difference field (contours 2 m s^{-1}).

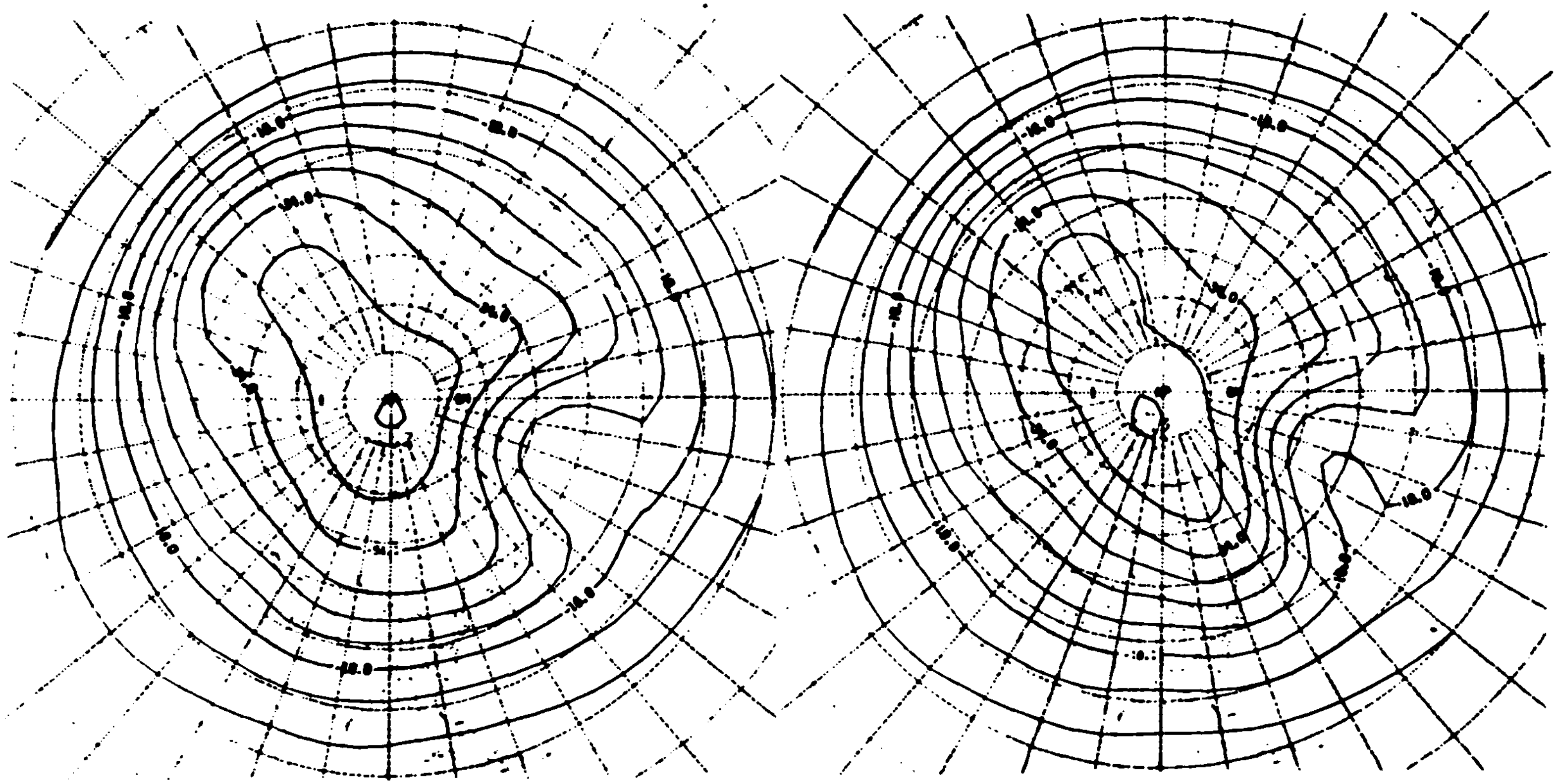
small. These regional differences can be compared to the zonally averaged zonal winds in Table 4.

Turning to the composite temperature field, Figure 57, we notice the thermal field is very much like the height field in appearance. It would seem the Atlantic composites are very equivalent barotropic at the 500mb level. The downstream trough in both cases extends southward and moves southwest through Spain. The transient ridge thermal field is skewed to the northeast, as is the height field. The thermal difference field in Figure 58 looks very much like the difference map in the height field. As with the height field, the major thermal contrasts appear slightly upstream of the ridges and are due primarily to the differences in the slopes. By comparing Figure 58 with Figures 12 and 35, it is important to notice that what differences do exist between the Atlantic ridges, even within the ridges themselves, are small compared to the Pacific cases.

To reflect back and summarize at this point, the 500mb fields indicate the Atlantic cases to be highly equivalent barotropic as were the Pacific cases. The influence of the ridges is very regional in scope with essentially no other consistent hemispheric effects. As with the Pacific cases, the blocking ridge is accompanied by a deepening of the upstream trough in relation to the transient ridge which is skewed in a northeast-southwest direction. A noteworthy observation would be the great similarity that exists between the block and transient ridge as opposed to the differences which exist during the Pacific studies.

Table 4. The 500mb Atlantic zonally averaged zonal geostrophic winds (m s^{-1}) for the Block, T. Ridge, and Climatology.

Latitude	Block	T. Ridge	Climatology
25	16.1	15.0	16.0
30	19.3	17.2	18.7
35	19.5	17.4	19.3
40	18.1	16.5	18.5
45	14.6	14.3	15.9
50	10.6	11.6	12.3
55	8.0	10.4	9.3
60	6.9	9.8	7.2
65	6.8	8.4	5.8
70	6.6	6.5	4.8
75	5.3	5.0	3.7
80	3.6	3.8	2.5
85	1.9	2.3	1.4



(a) (b)

Fig. 57
The 500mb Atlantic composite temperature fields (contours 4^{o} C): (a) Block; (b) T. Ridge.

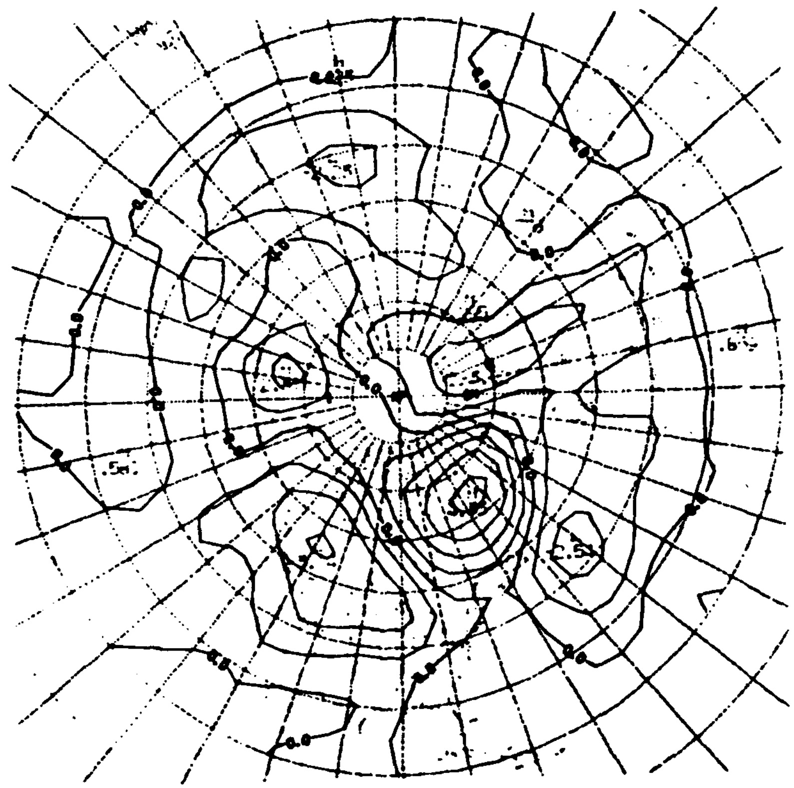
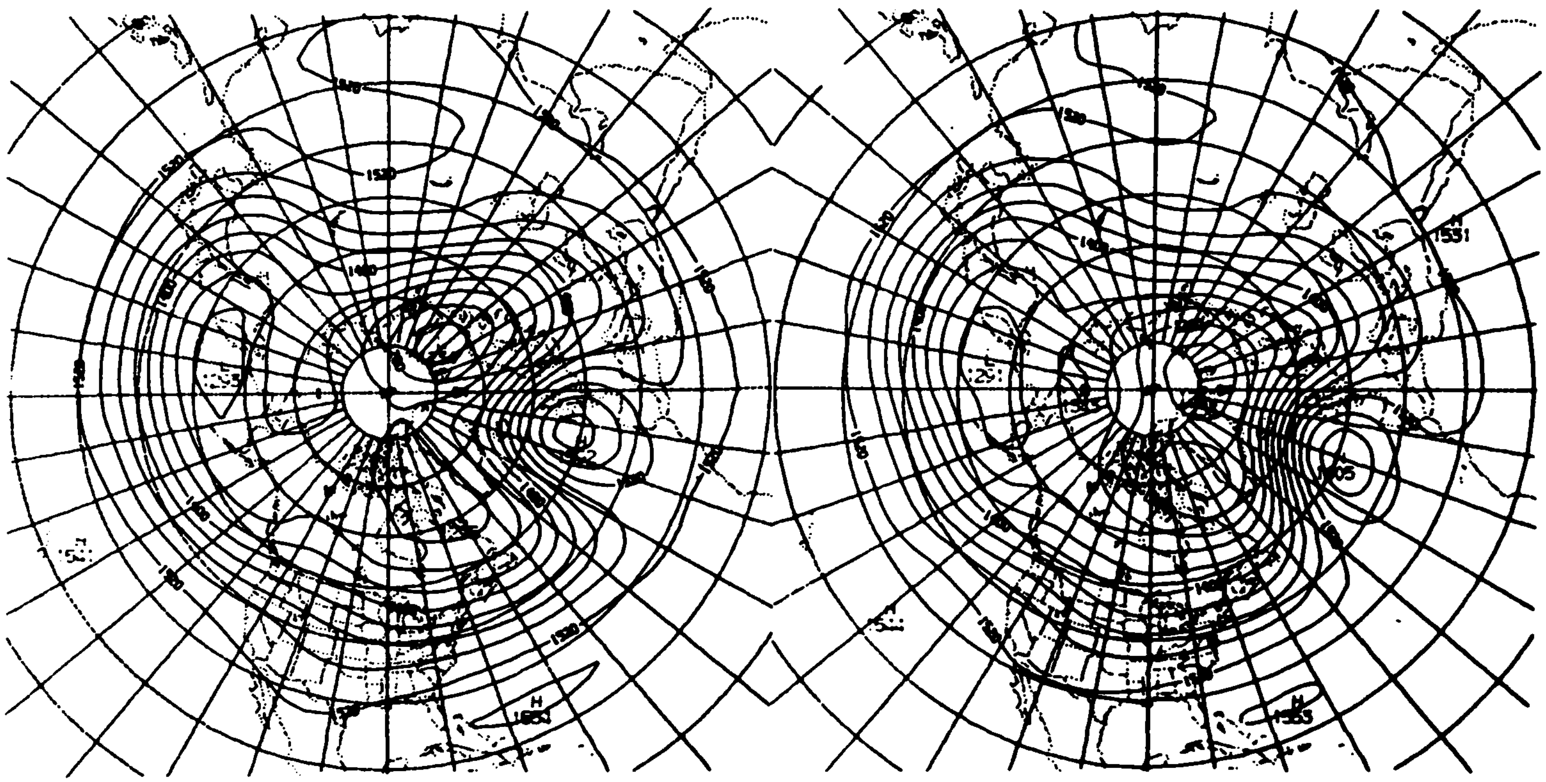


Fig. 58
The 500mb Atlantic temperature difference field (BK-TR) (contours 2° C).

We would anticipate, at this point, for the observed similarities in the 500mb fields to be reflected at other levels. Viewing the 850mb height fields in Figure 59 indicates this to be the case. At this level, many of the climatological features appear: the ridging over the Himalayas; the Pacific trough; slight ridging over the west coast; and the northeastern trough directly upstream. As brought out in Figure 57, the major difference appears to be the greater northward extension of the blocking ridge and the extent and magnitude of the trough upstream and to the south of the block, Figure 60. In contrast to the Pacific studies, the upstream trough during blocking is actually not as deep as during ridging. However, its southward extent into the central Atlantic is greater. This sharp contrast between the Atlantic and Pacific upstream troughs could be due to the types of blocks which exist in the two oceans. The blocks that form in the Atlantic may have a greater proportion of the so-called diffuant blocks as opposed to the omega type blocks (Sumner, 1959). Also, in contrast to the Pacific cases, we do not find an eastward movement of the ridge centers as we go from 500mb to the 850mb level.

To really establish the regional influence of these cases, a comparison with the 850mb climatological field seems appropriate, Figure 61. When this comparison is made noticing the contours over the Atlantic and Pacific, the ridge over the Himalayas, and the Northeastern trough, the only significant differences appear in the Atlantic sector. We further notice, however, that both ridges seem to flatten the ridge normally



(a) (b)

Fig. 59
The 850mb Atlantic composite geopotential height fields (contours 30m): (a) Block; (b) T. Ridge.

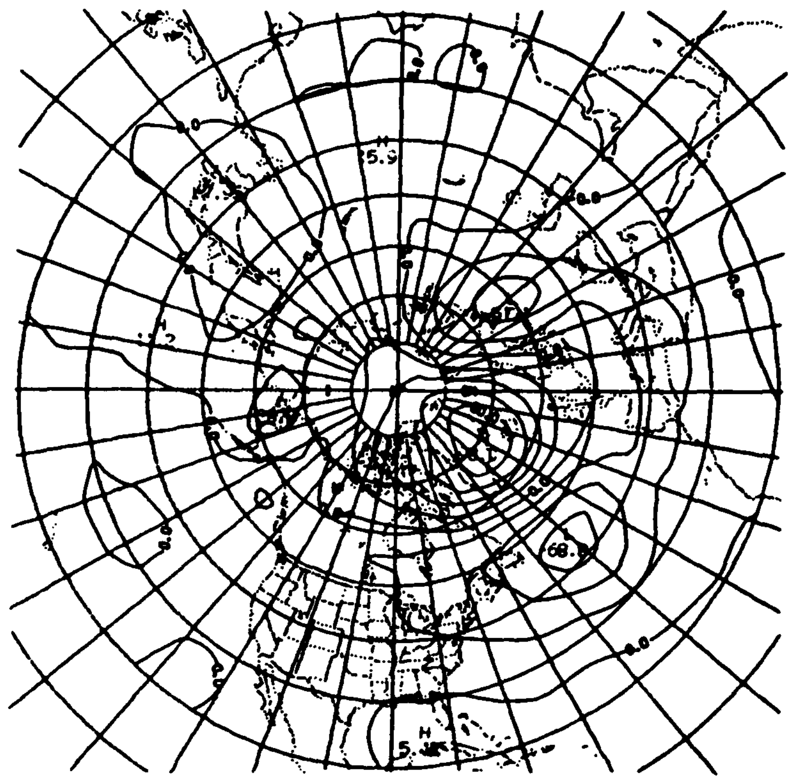


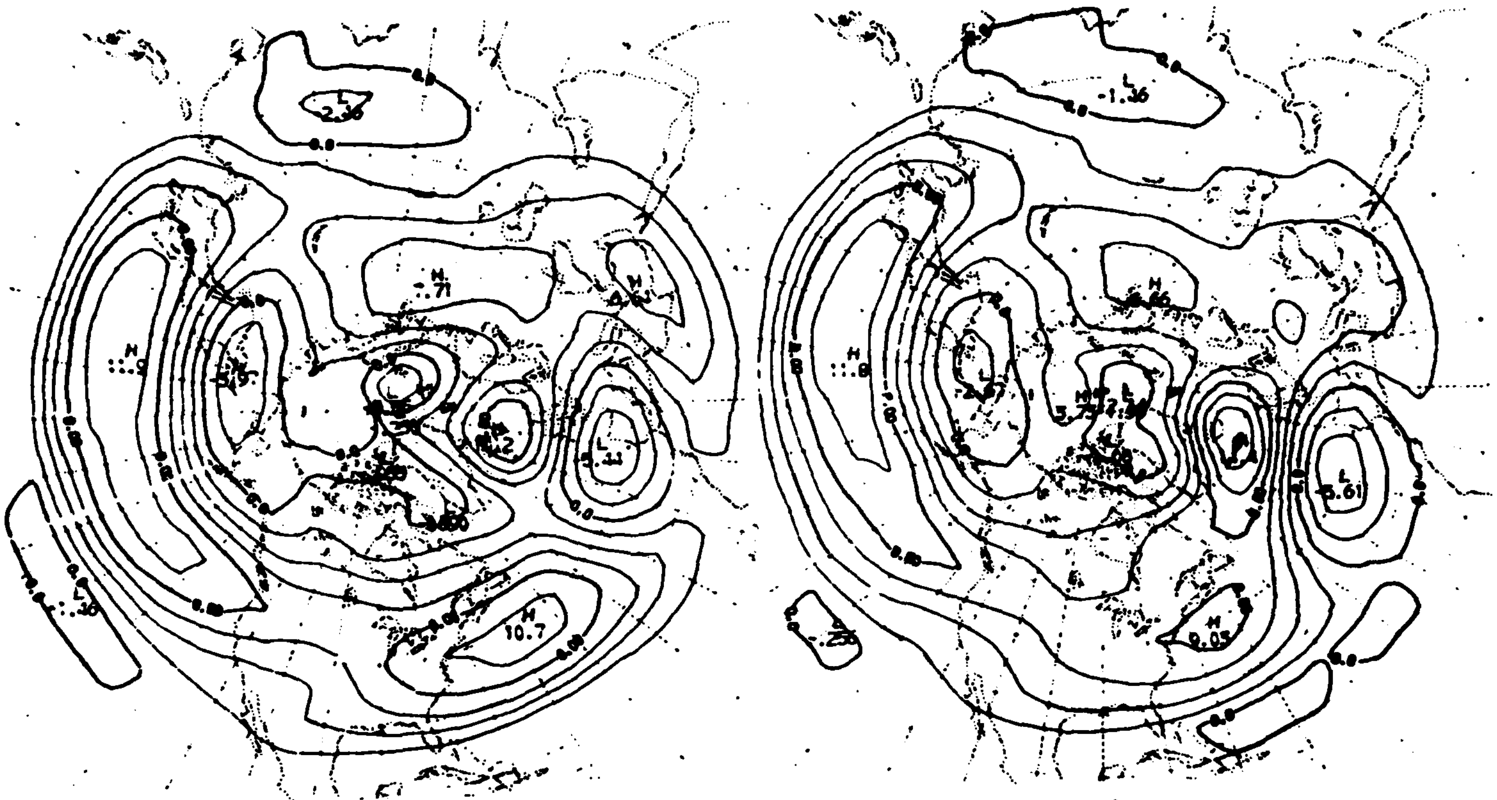
Fig. 60
The 850mb Atlantic geopotential height difference field (BK-TR) (contours 20m).

Fig. 61
The 850mb Climatological geopotential height field (contours 30m).

present over the West Coast.

The accompanying zonal wind fields, Figure 62, also show large differences only in the Atlantic region. The block clearly shows a southward shift and intensification of the jet stream off the East Coast of the United States. The absence of any significant differences in the downstream effects is brought out in the difference field, Figure 63. Also apparent are the weaker winds and more relaxed height gradient in the block which is manifested in the figure by low values throughout the North Atlantic north of 45N latitude.

The corresponding temperature field, Figure 64, shows the blocking case with a broad thermal trough over Canada with a relatively relaxed gradient. The block tends to move up into the Norwegian Sea as the downstream trough tries to undercut it. The transient ridge exhibits a tighter gradient in the upstream area with the thermal trough not as broad nor zonal in appearance. The slope with latitude is now very discernable as it moves right into the Norwegian Sea. The difference field, Figure 65, again reflects the wave influence of the blocks. The upstream figures show the effect of the broad thermal trough over North America in the blocking case. Eastern Canada experiences a relative warming while western Canada and the United States receive substantially cooler air. Away from the warm-high pressure anomaly over Greenland, the 850mb height and temperature anomalies show a very baroclinic structure. South of 60° N the greatest height anomaly is the low anomaly over the Atlantic Ocean, whereas the greatest temperature anomaly occurs over North America. This is consistent with the



(a) (b)

Fig. 62
The 850mb Atlantic computed zonal geostrophic wind fields (contours 2 m s^{-1}): (a) Block; (b) T. Ridge.

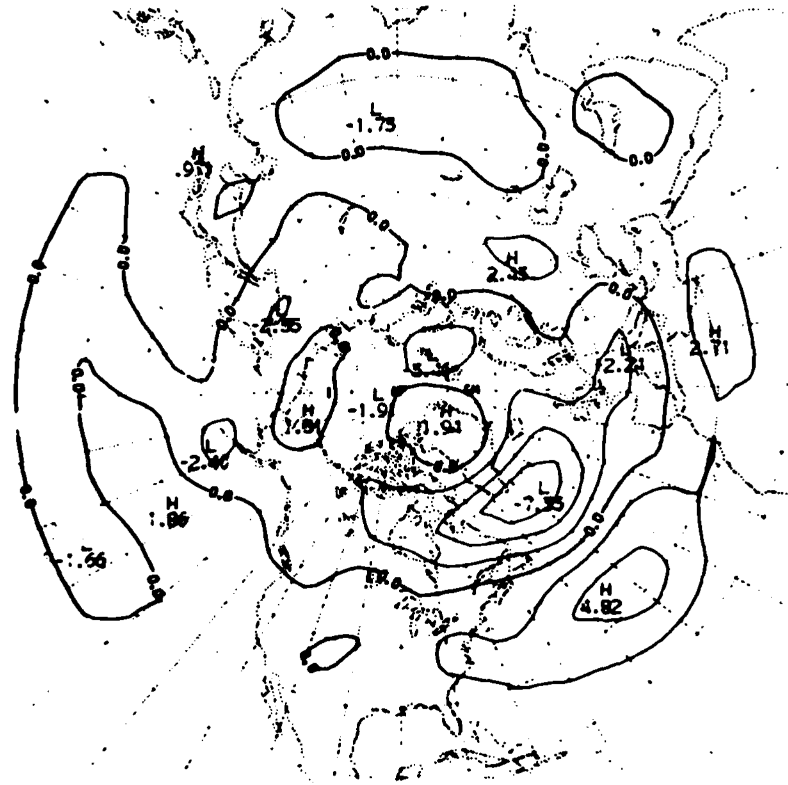
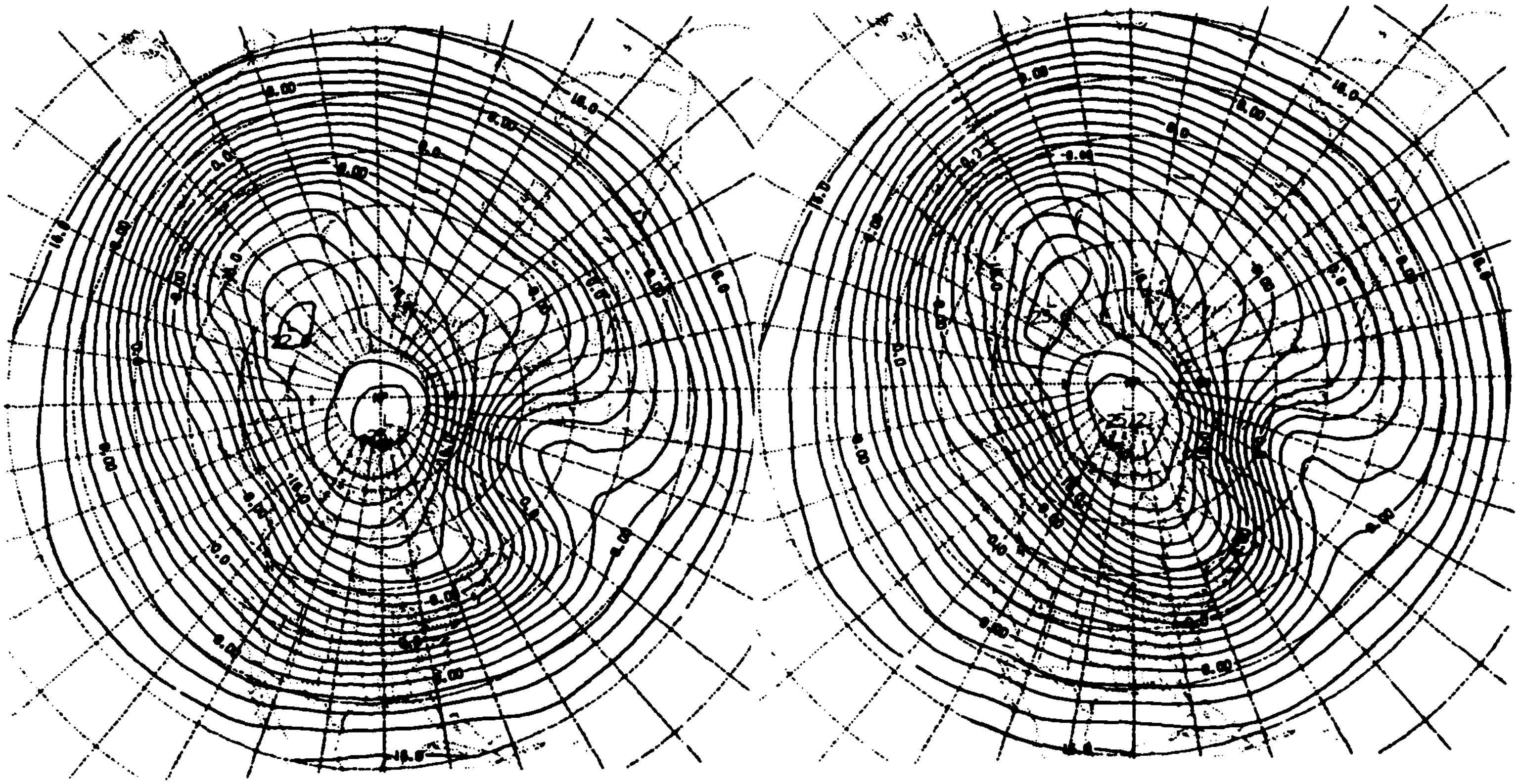


Fig. 63
The 850mb Atlantic zonal wind difference field (contours 2 m s^{-1}).



(a) (b)

Fig. 64
The 850mb Atlantic composite temperature fields (contours 2^{o} C): (a) Block; (b) T. Ridge.

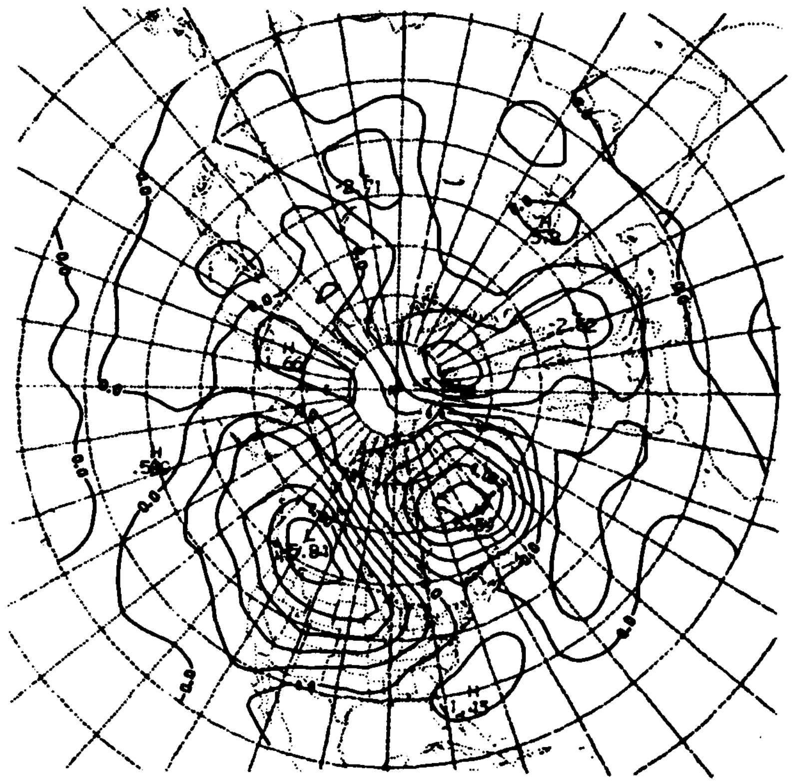
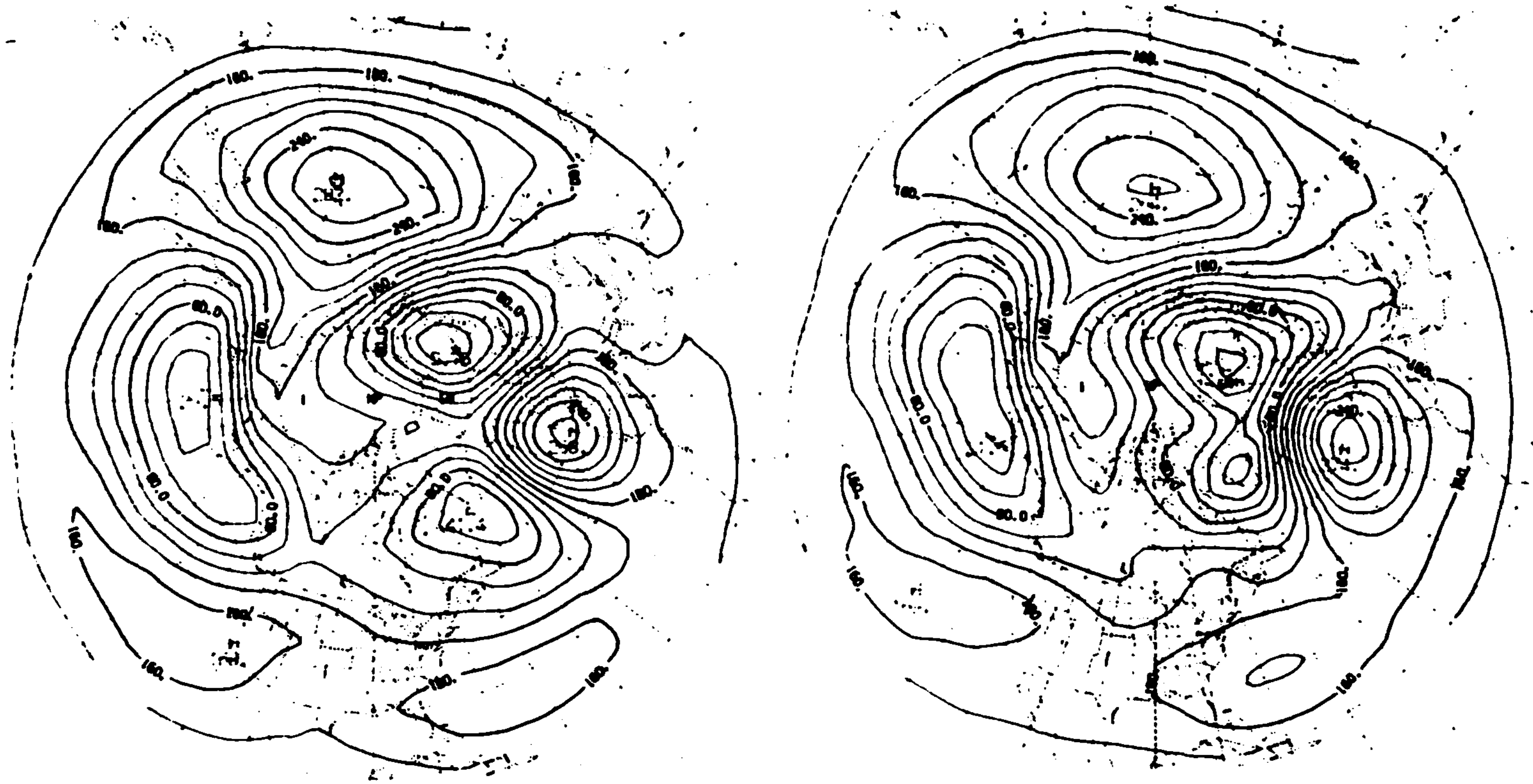


Fig. 65
The 850mb Atlantic temperature difference field (contours 1^{o} C).

study of Harmann and Ghan (1979) which suggested that the differences in the Atlantic cases had an important baroclinic component.

Continuing to 1000mb, the influences due to long wave displacements are clearly seen in Figure 66 which shows the composite 1000mb height fields. The block is tightly constrained and is able to split the Icelandic trough. The block spreads out enough downstream to cover most of western Europe which at 850mb is under a trough. The transient ridge in contrast is not able to split the trough at all. The transient ridge at 1000mb is of larger amplitude than the block but is restricted to the lower latitudes. The results of this restricted movement are shown in the difference field, Figure 67, where it is shown that the blocking composite has higher heights to the north of 55N latitude and lower heights to the south of 55N latitude. The anomalies are displaced slightly upstream of the longitude of the center of the high. This low level view brings out best some of the apparent distinctive features of both cases.

Moving to 100mb, we again find the field very smooth. Comparing Figure 68 with Figures 50, 59, and 66, we notice both cases maintain a relatively constant phase through all levels. The block is nearly symmetric in the east-west direction while the transient ridge continues to exhibit its north-east tilt. The anomaly field is shown in Figure 69. Any significant differences are best illustrated by use of Figure 70. Aside from the obvious and expected results in the Atlantic, the greater zonal extension of the upstream trough during blocking is enough to produce a significant lowering of the height field over the United States.



(a) (b)

Fig. 66
The 1000mb Atlantic geopotential composite height fields (contours 20m): (a) Block; (b) T. Ridge.

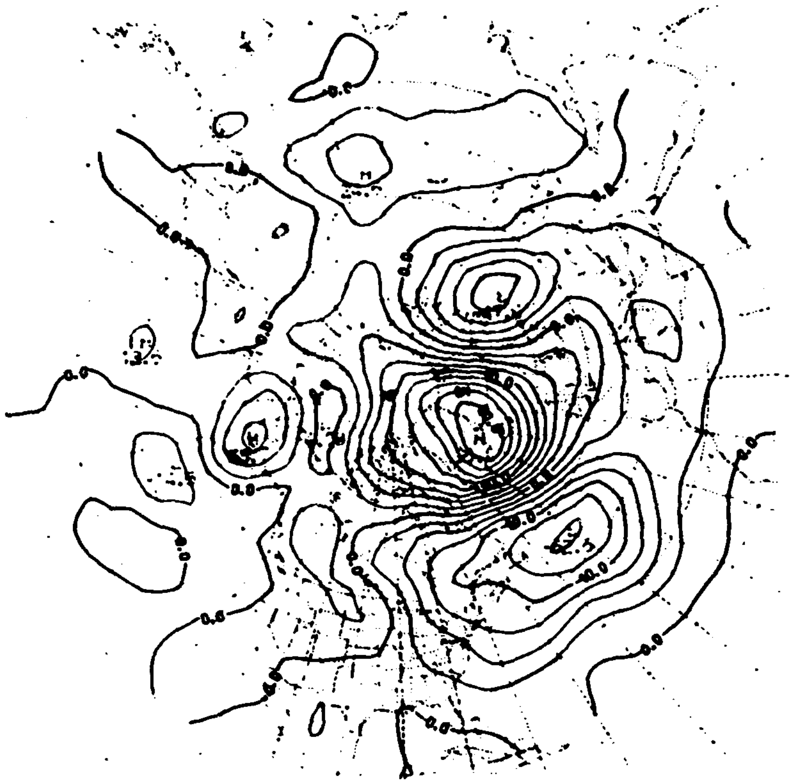
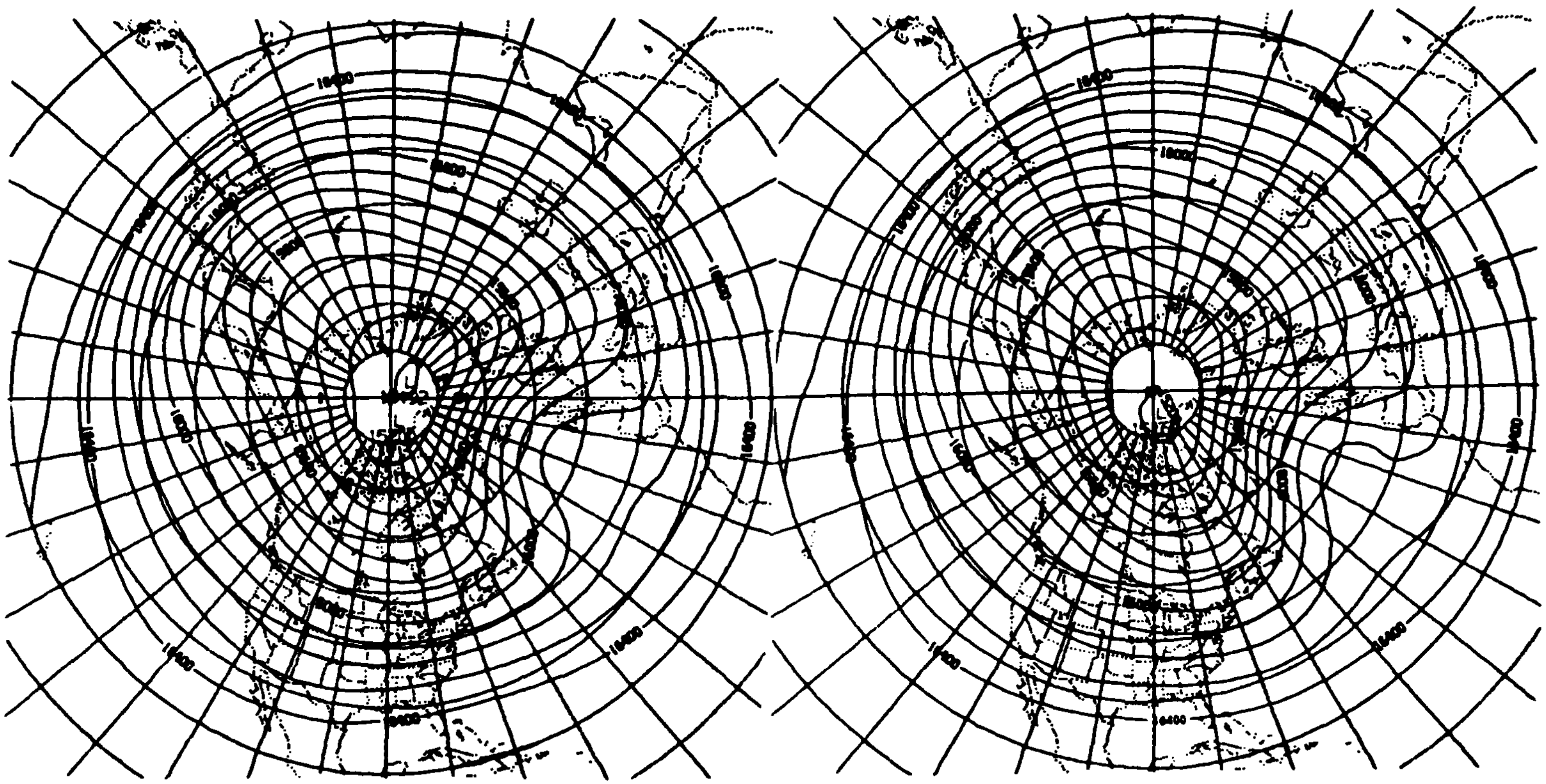
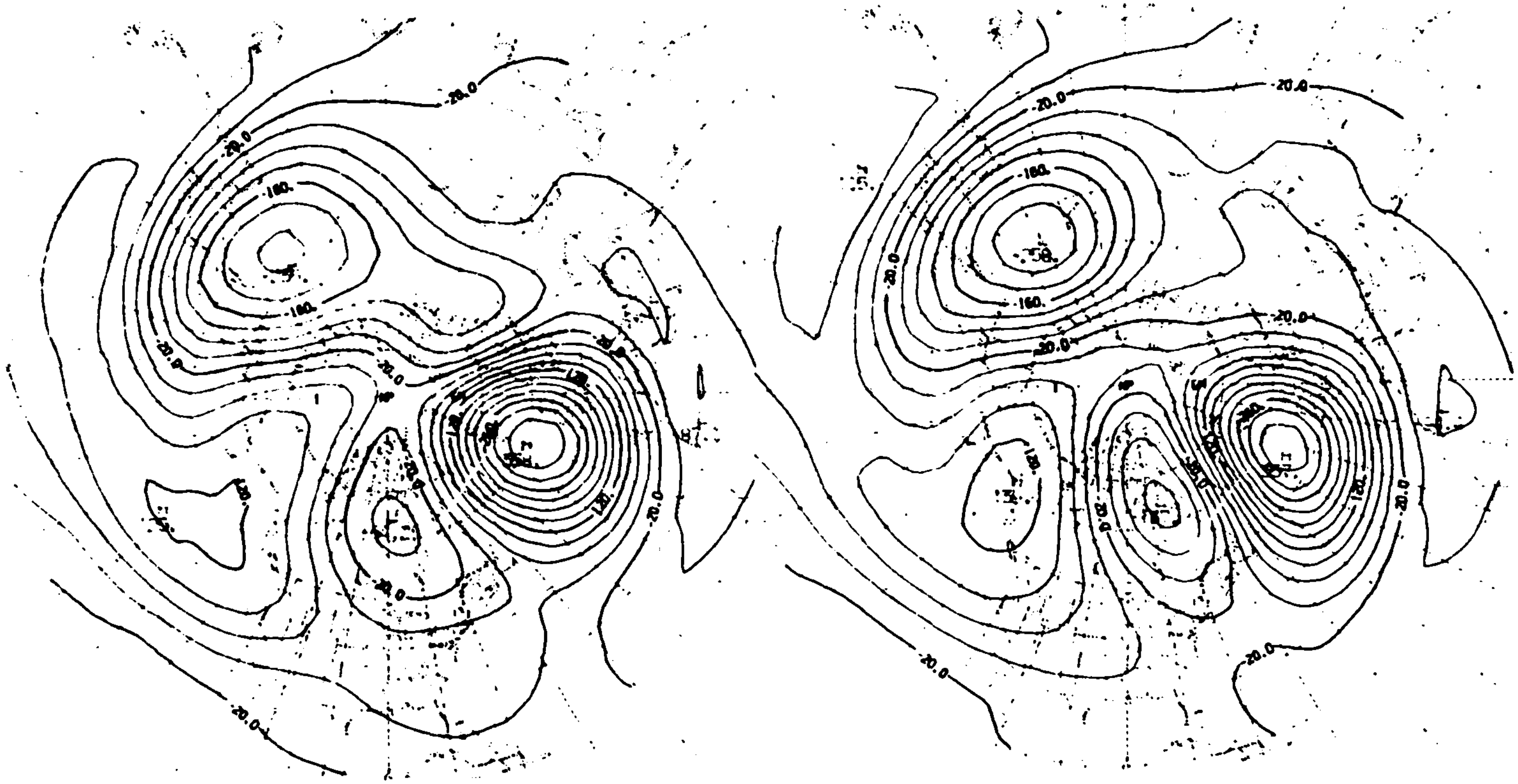


Fig. 67
The 1000mb Atlantic composite height difference field (BK-TR) (contours 10m).



(a) (b)

Fig. 68
The 100mb Atlantic composite geopotential height fields (contours 100m): (a) Block; (b) T. Ridge.



(a) (b)

Fig. 69
The 100mb Atlantic geopotential height minus zonal mean fields (contours 35m): (a) Block; (b) T. Ridge.

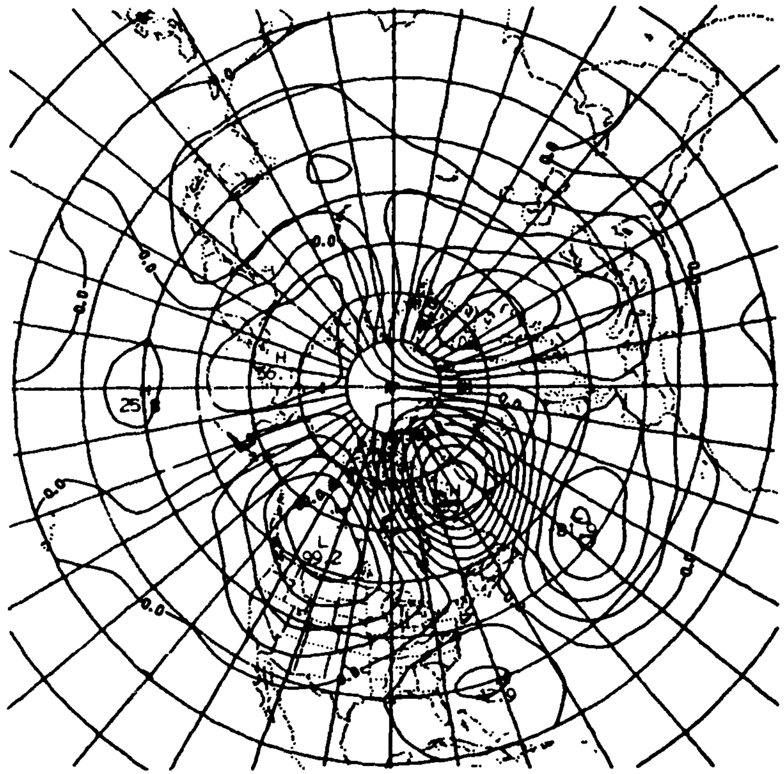
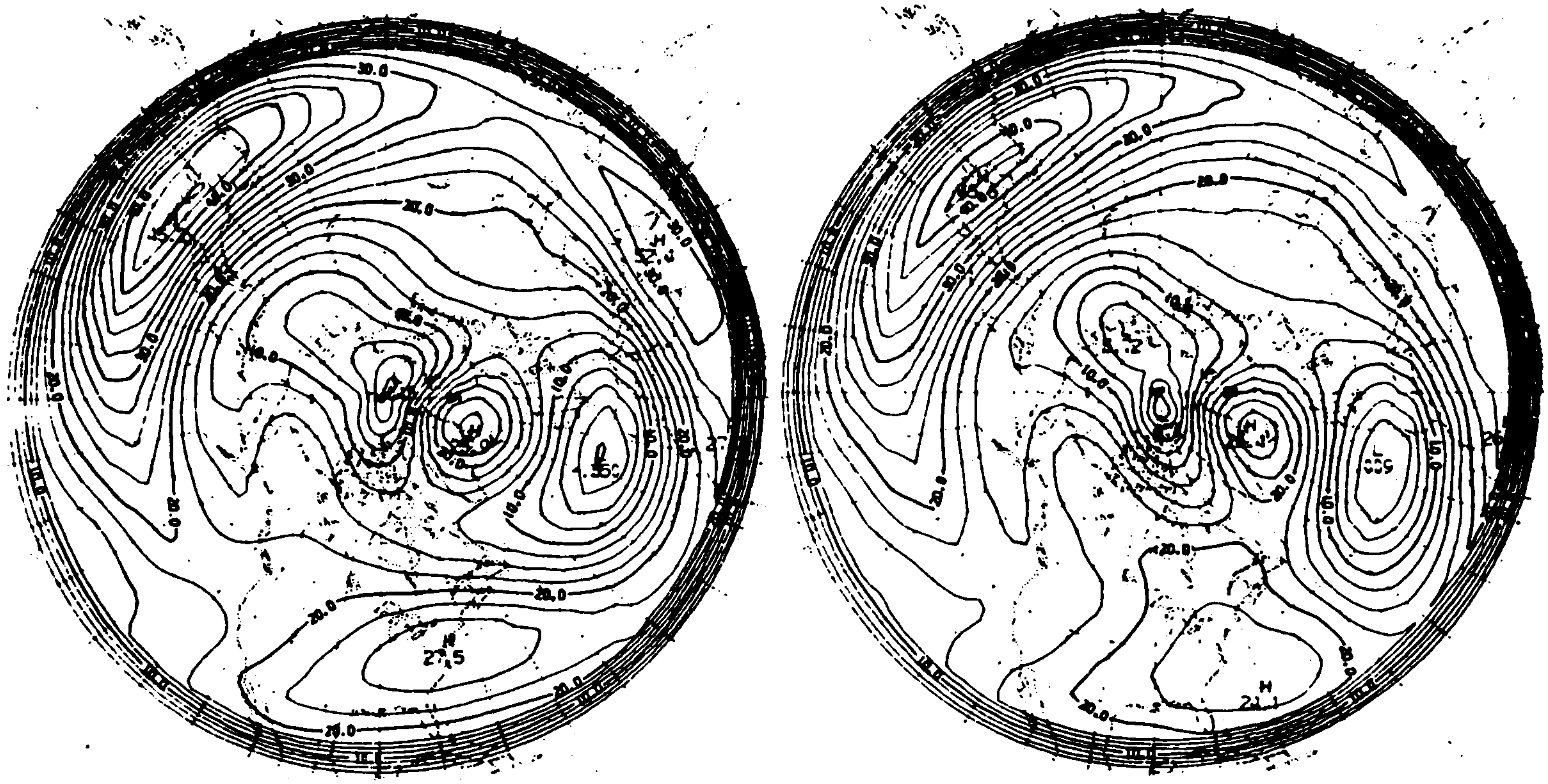


Fig. 70
The 100mb Atlantic composite geopotential height difference field (BK-TR) (contours 20m).

We also find that the downstream trough accompanying the transient ridge, while appearing more substantial, is in fact not as deep as during periods of blocking. So the deeper trough of the block accompanied by higher heights in the Atlantic mid-latitudes combine to produce a blocking field which has high values upstream over eastern Canada at the expense of lower values throughout the surrounding area!

The 100mb zonal wind fields reinforce the previous observations. In Figure 71, the westerly flow is pushed southward by the reduced flow in the southern portion of the block. In contrast, the transient ridge pattern shows the reduced flow actually creates a barrier to the westerly jet forcing it over the ridge. The westerly jet cannot remain that constricted for very long! The transient ridge, at this level, completely disrupts the westerly flow over the eastern United States, essentially changing it from a zonal to meridional flow. The difference field, Figure 72, shows this quite clearly with weak winds not only throughout the North Atlantic and Canada, but the entire East Coast as well!

In summary, the following has been observed in the Atlantic cases. At all levels, the differences between the blocks and transient ridges are limited to the region near the ridge. These differences are similar at the 100, 500, 850, and 1000mb levels. This is best illustrated by use of the difference fields in Figures 70, 67, 60, and 52. The basic height relationships remain fixed at the 100 and 500mb levels. At 850mb and 1000mb, the broader, more zonal trough over the West Coast is washed out, but the other features remain. A very strong cold anomaly



(a) (b)

Fig. 71
The 100mb Atlantic computed zonal geostrophic wind fields (contours 2.5 m s^{-1}): (a) Block; (b) T. Ridge.

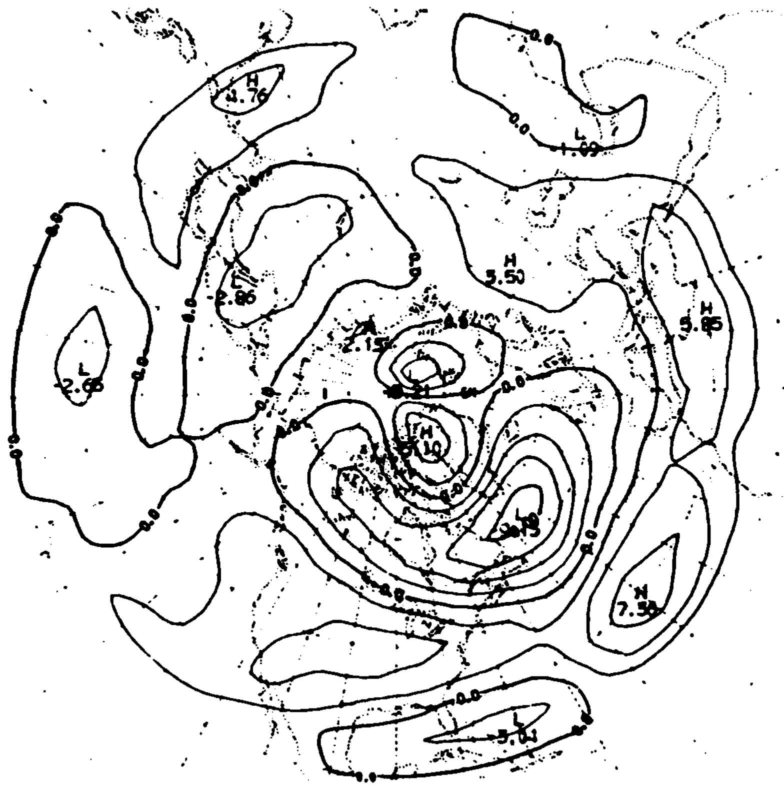


Fig. 72
The 100mb Atlantic zonal wind difference field (contours 2 m s^{-1}).

appears over North America at 850mb which supports the low height anomaly which appears at higher levels. In spite of the fact that the ridge consistently has a greater amplitude, the block exhibits greater southern extensions of both up and downstream troughs at most levels. And only at 1000mb is the European trough replaced by a ridge. Both cases are similar at all levels with the transient ridge exhibiting much more of a northeastern tilt with latitude. The wind fields yield basically the same results. In the case of the block, weaker winds prevail upstream in the northern latitudes to include most of Canada. To partially offset this, the block is characterized by stronger flow in the subtropics.

Chapter 6

SUMMARY AND CONCLUSION

The initial purpose of the paper was to use the original concept developed by Hartmann and Ghan (1979) of separating the ridges solely on the basis of duration and expand the field of observation to three dimensions, observing the differences between the blocks and transient ridges. Due to the various mechanisms possible for development and the corresponding effects, three separate areas of study were identified: the Pacific Ocean, Pacific Coast, and Atlantic. From this observational approach to the subject of blocking, we were able to show that some differences do exist between the blocks and transient ridges in each of the three regions.

The Pacific Ocean cases were characterized by an enhanced trough upstream of the blocking ridge. This was also accompanied by a more poleward extension of the blocking ridge when compared to the transient ridge. Confirming the finding by Hartmann and Ghan (1979), reduced zonal winds were found to the north of 50° N in the vicinity of the blocking ridge with stronger zonal winds evident to the south. The differences between the downstream wavetrains show that both ridges, block and transient, can form in the same general location with vastly contrasting atmospheric patterns downstream. The large contrast between the wavetrains, especially over eastern North America, suggests some secondary amplification of the wavetrain.

A large similarity exists between the Pacific Ocean and the Pacific Coast composites. The same general conclusions are reached in the Pacific Coast studies with the additional suggestion of some topographic influences. These topographic influences may also be connected with the changes we observe in the zonal wind structure between the two areas. Unlike the Pacific Ocean region where the differences in the zonal wind actually occurred within the ridges themselves, the differences in the Coastal cases occur upstream. We also find a difference in the wavelength which appears downstream in connection with the wavetrains. The wavetrain during blocking shows a shorter wavelength and a more equatorward direction downstream, which causes large differences over Europe.

The characteristics exhibited by both the Pacific areas appear consistent with the idea of enhanced production of wave energy due to heating over either the mid-latitude or tropical ocean. This enhanced production is reflected in the downstream wavetrains as suggested by Hoskins and Karoly (1981).

In the Atlantic region, however, the characteristics exhibited by the block and transient ridges stood in sharp contrast to those observed in the Pacific regions. Essentially, no wavetrains appear connected with the Atlantic cases. It is also observed that both Atlantic cases show much more latitudinal tilt and northward expansion than their Pacific counterparts. These differences in the Atlantic cause the maximum anomalies in the height difference fields to appear northwest of the blocks themselves. Viewing the 850mb height difference field, we conclude that no significant contrasts exist between the blocks and transient ridges over North America. However, the corresponding 850mb thermal difference field shows a large low thermal anomaly exists over the same area of North America, leading to low anomalies at higher levels. This would seem to suggest a relationship between cold temperatures over North America and the formation of blocking ridges over the Atlantic.

There is now a need for more definitive, diagnostic studies which can be correlated with the observations made from this study, and which may give some suggestion of the root causes of long lived ridges. Also, a study like this one should be applied to an independent data set to test whether the features of blocking ridges inferred from these data are reproducible.

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APPENDIX

Table A1. The ridges used in the Atlantic study

Year	Dates	Height(m)	Longitude	Type
66-67	15-19 Nov	513	20W	T
	18-22 Dec	463	25W	T
	1-14 Jan	512	25W	B
	15-18 Jan	400	5E	T
	6-10 Feb	427	20W	T
67-68	15-18 Nov	441	25W	T
	18-20 Nov	441	5E	T
	21-24 Nov	496	5E	T
	30 Nov-3 Dec	463	5W	T
	3- 5 Dec	487	5W	T
	5-14 Dec	454	25W	B
	23-27 Dec	383	30W	T
	18-21 Jan	435	0W	T
	23-26 Jan	471	25W	T
	26 Feb-3 Mar	398	5E	T
	4-13 Mar	549	20W	B
68-69	25 Dec-2 Jan	398	20W	B
	6-20 Feb	436	40W	B
69-70	15-18 Nov	481	35W	T
	19-29 Nov	492	40W	B
	1- 8 Dec	495	30W	B
	8-11 Dec	455	0W	T
	4- 6 Feb	462	45W	T
	27 Feb-3 Mar	495	35W	T
70-71	25-27 Nov	488	45W	T

Year	Dates	Height(m)	Longitude	Type
70-71	6- 9 Dec	504	15W	T
	9-12 Dec	507	5E	T
	20 Dec- 3 Jan	436	25W	B
	8-15 Jan	456	15W	B
	1-11 Feb	498	5W	B
71-72	15-15 Nov	402	10W	T
	21-25 Nov	524	30W	T
	2- 6 Dec	423	5W	T
	7-12 Dec	528	10W	B
	15-19 Dec	392	10E	T
	11-13 Mar	448	25W	T
72-73	23-26 Nov	451	15W	T
	12-24 Dec	467	15E	B
	31 Dec- 2 Jan	402	25W	T
	3-14 Jan	471	5E	B
	24-25 Jan	387	5E	T
	31 Jan- 3 Feb	444	15W	T
	18-21 Feb	387	10W	T
73-74	18-21 Nov	383	15W	T
	23-30 Nov	408	20W	B
	1- 5 Dec	451	20W	T
	11-14 Dec	434	30W	T
	18-22 Jan	407	0W	T
74-75	10-12 Dec	376	25W	T
	1- 9 Jan	475	0W	B
	19 Feb- 1 Mar	384	10E	B
75-76	15-16 Nov	476	40W	T

Year	Dates	Height(m)	Longitude	Type
75-76	16-23 Nov	400	15W	B
	1- 2 Dec	425	40W	T
	3-10 Dec	462	20W	B
	11-19 Dec	445	25W	B
	20-21 Dec	417	10W	T
	24-26 Dec	448	20W	T
	23-26 Jan	383	25W	T
	24 Feb-1 Mar	385	10W	T

Table A2. The ridges used in the Pacific Ocean study.

Year	Dates	Height(m)	Longitude	Type
65-66	16-17 Nov	420	165W	T
	23-24 Dec	377	165W	T
	3- 9 Mar	471	180W	B
66-67	15-18 Nov	485	165W	T
	18-21 Nov	489	160W	T
67-68	5-13 Jan	377	165W	B
	15-18 Jan	388	175W	T
68-69	31 Dec- 6 Jan	406	180W	B
	7-14 Jan	471	165W	B
70-71	15-18 Nov	456	160W	T
	19-20 Nov	377	165W	T
	9-17 Jan	439	165W	B
	24-31 Jan	391	175E	B
	26-28 Feb	375	155W	T
71-72	20-26 Dec	475	160W	B
	20-28 Feb	431	170W	B
72-73	13-15 Dec	458	175W	T
73-74	26-30 Nov	443	165W	T
74-75	29 Jan- 5 Feb	412	160W	B
	7-11 Feb	371	165W	T

Table A3. The ridges used in the Pacific Coast study.

Year	Dates	Height(m)	Longitude	Type
65-66	15-15 Nov	379	140W	T
	15-17 Jan	373	125W	T
66-67	6- 8 Feb	427	130W	T
67-68	12-15 Dec	469	135W	T
	22-24 Jan	402	120W	T
	6-14 Feb	455	125W	B
69-70	26 Nov-4 Dec	439	120W	B
	31 Dec-2 Jan	398	135W	T
	7-14 Feb	436	125W	B
	19-24 Feb	414	125W	B
70-71	2- 7 Jan	457	135W	T
	5- 9 Feb	403	130W	T
71-72	16-19 Nov	392	130W	T
72-73	20-23 Feb	384	125W	T
73-74	5- 9 Feb	389	130W	T
74-75	15-16 Nov	372	125W	T
75-76	24-25 Nov	383	140W	T
	15-19 Dec	400	130W	T
	30 Dec-2 Jan	406	135W	T
	18-22 Jan	378	125W	T
	29 Jan-7 Feb	427	135W	B

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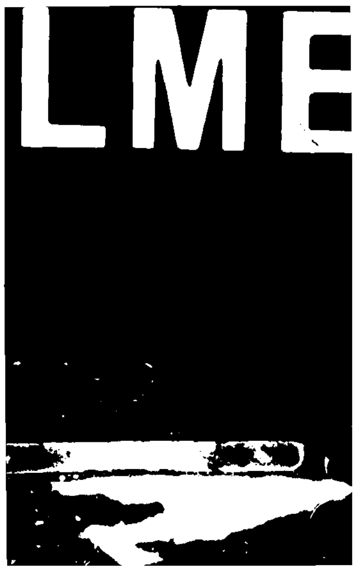
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