Influence of Mountains and Land-Sea Distribution of Blocking Action

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ABSTRACT

In order to obtain some information concerning the relationship between blocking action and the effects of mountains and land-sea distribution, numerical experiments were performed with four models. One of these models includes both the effects of mountains and land-sea distribution, two models contain one or the other and the remaining model neither of them.

Statistical analysis of the results thus obtained leads to the following conclusions:

1. Even in the case including neither of the effects of mountains and land-sea distribution, blocking action occurs and its behavior is very similar to that observed in the actual atmosphere.

2. The duration period of the blocking action in the model atmosphere is remarkably short compared to that in the actual atmosphere. However, there is a tendency for the duration to become somewhat longer if the effect of the mountains is included in the model.

3. The most frequent existence of blocking highs in the areas from 150°E eastward to 150°W (including Alaska) and from 30°W eastward to 30°E (including the Atlantic) results from the effect of the mountains. The additional incorporation of the effect of land-sea distribution contributes to yield a result that the blocking highs are more frequently found in the area from 30°E eastward to 150°E (including the Eurasian

Continent) than from 150°W eastward to 30°W (including the North American Continent).

4. It is not likely that the effects of mountains and land-sea distribution play a primary role to yield the fact seen in the actual atmosphere that blocking highs exist most frequently in the latitudinal belt between 50°N and 70°N.

1. INTRODUCTION

Since the blocking situation was first noted by Garriott (1904), the description of the blocking phenomenon and its effects on the synoptic situation have been presented by Namias (1947), Elliott and Smith (1949), Berggren, Bolin and Rossby (1949), Rex (1950a) and others. In more recent papers, Rex (1950b), Brezowsky, Flohn and Hess (1951), Van Loon (1956), Sumner (1954, 1963) and Katayama and Sakurai (1971) have performed statistical analyses concerning geographical and seasonal distribution, the duration period and the movement of blocking action. The fact that blocking action occurs very frequently in some fixed areas is one of the interesting results obtained from the studies mentioned above. This makes us infer that the mechanism of the blocking phenomena is connected with the effects of mountains and land-sea distribution.

In an attempt to explain the mechanism of the blocking phenomenon, Yeh (1949) has adopted the idea of the interference of dispersive waves and Rossby (1950) has developed the analogy with the hydraulic jump. In a previous paper, the author (1959) has shown that blocking action is associated with baroclinic growth of disturbances with wave number 2. In these theoretical considerations of the blocking action, however, the role played by the effects of the mountains and the land-sea distribution is not explained distinctly. At present, what we know about the relationship between blocking action and the influence of mountains and land-sea distribution is very little and uncertain.

The purpose of the present study is to provide some information on this problem. To that end, numerical-experiments were performed by use of four models which will be described in the subsequent section.

2. DESCRIPTION OF MODELS

The detailed description of the models used in the numerical experiments of this study have been given already in other papers (1969, 1971). Therefore, we shall describe them only briefly here.

The motion of the model atmosphere confined to the northern hemisphere is governed by the vorticity equation with diffusion terms, the thermodynamic equation with diffusion and the heating terms and the linear balance equation expressing the relationship between the stream function and the geopotential. The solar radiation which is the main energy source of atmospheric motion is fixed to the state of January 22. Therefore, it should be noted that the following discussion is associated with a winter situation.

The four models used in the numerical experiments were termed ML, MT, LS and BC. Among these models there is a difference in incorporation of the dynamical effect of the mountains and the thermal effect of the land-sea distribution. In Model BC, the earth's surface is assumed to be formed by smooth land everywhere. Although the earth's surface of Model MT is formed by the land everywhere, it is not smooth but includes the mountains. Model ML includes both the effects of mountains and land-sea distribution. When the mountains are removed from Model ML, we have Model LS.

As initial conditions for the time integration of the governing equations, the resting isothermal atmosphere was adopted for Models ML, MT, and LS including the external forcing effects. For Model BC these effects were not included, and the 150-day situation of Model MT was taken as the initial condition. The characteristics of each model mentioned above are tabulated in Table 1.

Table 1. Characteristics of the models used in this study.

MODEL	INSOLATION	CONDITION OF THE EARTH'S SURFACE	OROGRAPHY	INITIAL CONDITION	PERIOD FOR ANALYSIS
ML	Fixed (January 22)	Land-sea	Included	Resting, isothermal atmosphere (258°K)	101-250 days
MT	"	Land	Included	"	191-340 days
LS	"	Land-sea	Not Included	"	101-250 days
BC	"	Land	Not included	150-day state of model MT	71-220 days

After beginning the time integration of the governing equations for these models, it takes about 40 to 50 days until the atmospheric situation and motion reach the quasi-equilibrium state. The analysis of the computed results is performed for a 150-day period after reaching the quasi-equilibrium state. In the last column of Table 1, the first and last days of the period thus chosen for each model are shown.

3. DEFINITION OF BLOCKING ACTION

For the 150-day period chosen for analysis, a series of daily 400-mb charts were produced for each model. In these charts, contour lines were drawn at intervals of 100 meters starting from a contour line the height of which is equal to the hemispherical average of the daily 400-mb height. This procedure was performed by machine.

We now define a blocking situation lying in the flow patterns on the daily 400-mb charts in order to select the blocking action appearing in the model atmosphere. When ridges are developed in the westerly flow in the middle and high latitudes, we frequently encounter cases such that a jet stream is separated into two branches of stream and a warm anticyclone is formed downstream from the breakdown point of the jet. This situation is commonly called blocking. Sumner (1954) classified such blocking situations into diffluent and meridional types. As shown schematically in Fig. 1, in the diffluent type cut-off cyclones accompany the blocking anticyclone, but no cyclones appear in the meridional type.

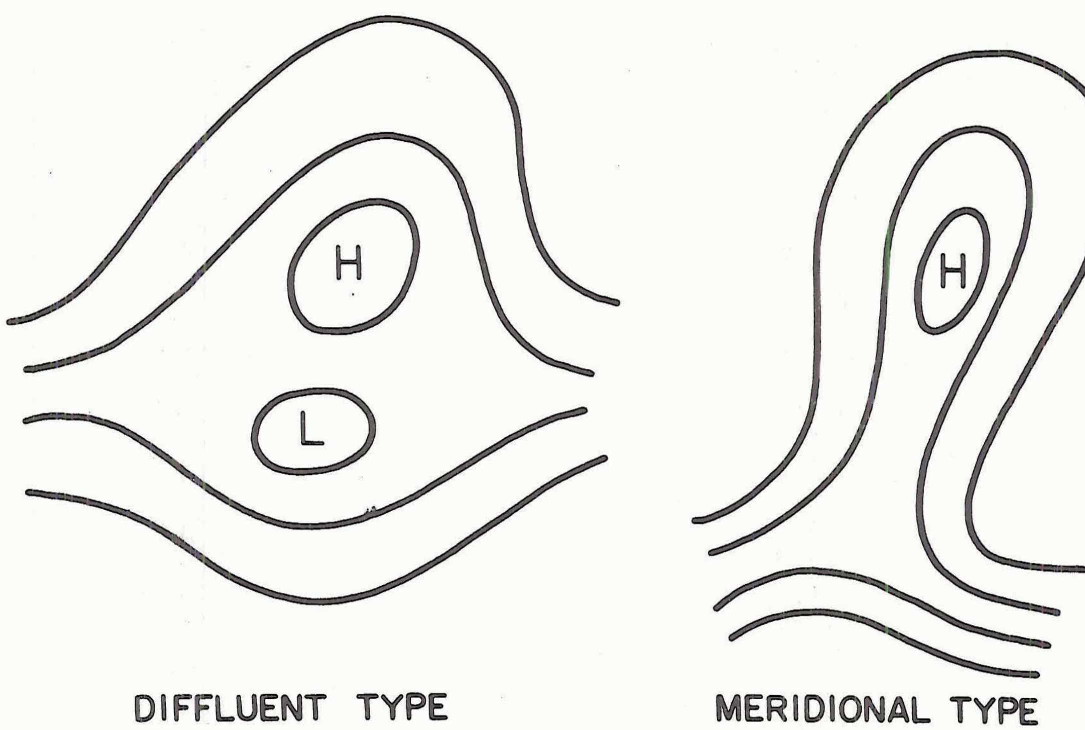


Figure 1. Schematic representation of the two types of blocking situation.

There is a significant difference in the restrictions placed on the spacial extension and persistence of the blocking situation among the hitherto adopted definitions of blocking action. For example, Rex (1950a) placed the most severe restriction by requiring that the splitting of the jet stream extend over at least 45° of longitude and that the pattern persist for at least 10 days. On the other hand, Sumner's definition (1954) without restriction of the spacial extension or persistence of the blocking situation seems to be most flexible.

In this study, the definition of the blocking action is almost in accordance with that of Sumner; that is, the blocking situation is characterized by a flow pattern as shown in Fig. 1 without restriction on the spacial extension or persistence. The only restriction is that the blocking high in the flow pattern must be distinctly indicated by at least one closed contour line drawn at intervals of 100 meters. Although there are many cases when we would be able to recognize a blocking high enclosed by at least one closed contour if the contour lines were drawn at intervals of 50 meters, these are removed in defining the blocking situation here. Therefore, according to the definition adopted here, the blocking action selected has a tendency for supressed persistence.

The position of the center of the blocking high is taken as the representative position of the blocking action in the analysis of this study. Any blocking action south of 40°N is excluded from consideration. However, if a blocking high moves into or out of the area north of 40°N at some time during its life-time, the blocking action belonging to that spell is taken into account despite its location south of 40°N.

3. STATISTICAL RESULTS OF BLOCKING ACTION

A. Duration period

In Fig. 2, the frequency distributions of the duration period of blocking action are shown for Models ML, MT, LS and BC with a corresponding result obtained by Sumner (1963). The data used in his statistics are within the area from 100°W eastward to 60°E and north of 50°N, for the 8-year period 1949-1956. Sumner's result shows that blocking action with a duration of about 7 days occurs most frequently.

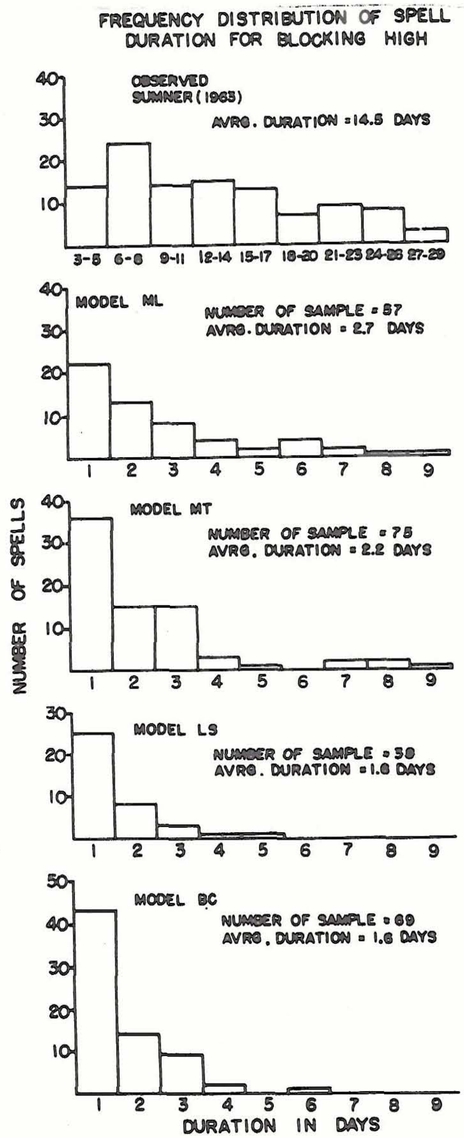


Figure 2. Frequency distribution of spell duration of blocking action. The number of the sample indicates the total number of spells selected.

From comparison between the computed and observed results, it turns out that the spell duration of the blocking action is much shorter in the model than the actual atmosphere. Although the definition adopted here seems to supress the persistence of the blocking action selected as mentioned in the last section, the main reason for the descrepancy in spell duration between the computed and the observed results would be due to the deficiency of the models used in the numerical experiments. From comparison of the spell duration of the blocking action among the four models, we can see that there is a general tendency for the spell duration to become somewhat longer in the cases including the effect of mountains than in the other cases.

It should be noted that blocking action occurs in the model atmosphere including neither the effects of mountains nor land-sea distribution. In this case, the longest spell duration of the blocking action was 6 days.

B. Movement behavior

There are progressive (eastward moving), quasi-stationary and retrogressive (westward moving) blocking highs in the model atmosphere as well as in the actual atmosphere. Roughly speaking, Sumner (1963) placed the eastward or westward moving blocking highs with an average longitudinal speed greater than or equal to 5° of longitude per day. in the progressive or the retrogressive class and those remaining in the quasi-stationary class. The frequency distribution of blocking highs with these three classes obtained by Sumner (1963) using the same data as described in the subsection A is shown in the uppermost part of Fig. 3.

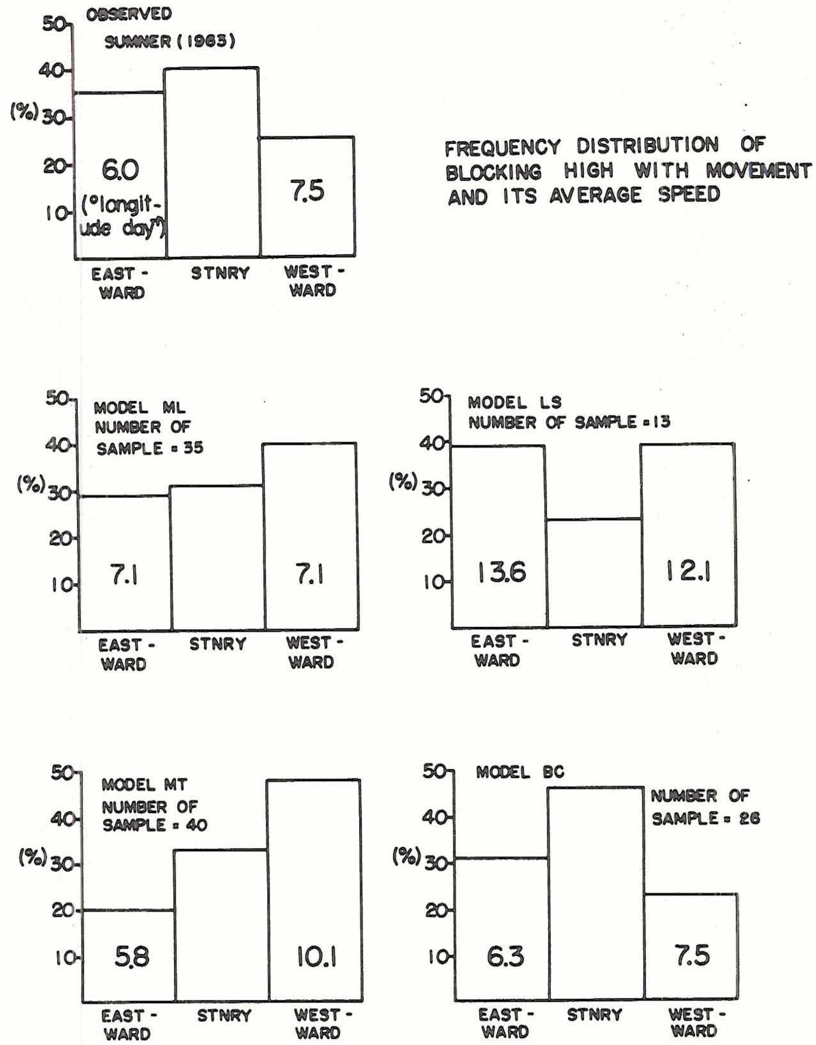


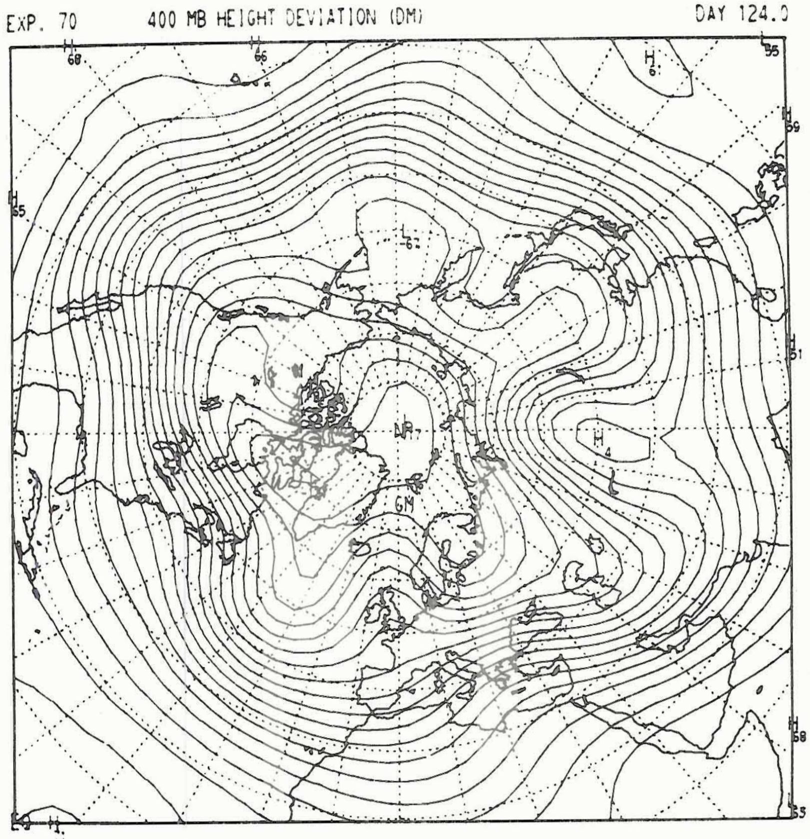
Figure 3. Frequency distribution of the blocking high from observation and the spell of blocking action for the models with movement and the average longitudinal speed which is shown by the number in the column. The number of the sample indicates the total number of spells with duration greater than or equal to 2 days

The average longitudinal speed of the blocking high in the model atmosphere was estimated from its position at the first and last day of its period. In this case, it is not the number of blocking highs but the number of spells that is counted in taking the frequency statistics.

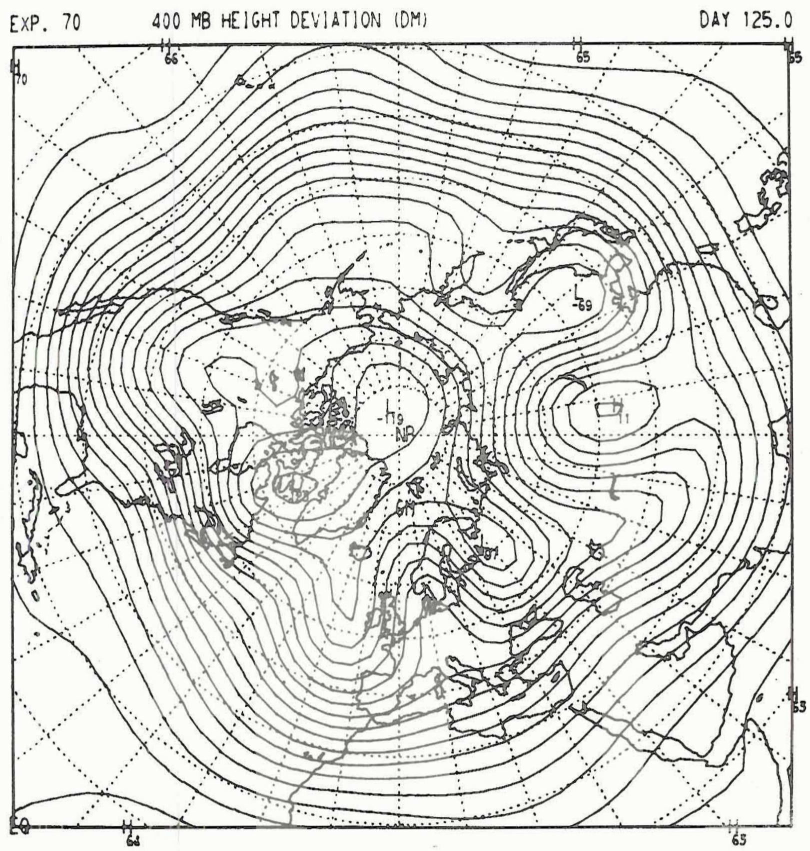
The spells of blocking action with average speed greater than or equal to 3° of longitude per day are classified into the progressive or retrogressive class and the remaining spells are placed in the quasi-stationary class. The frequency distributions of the spells of the blocking action with movement for the four models are shown in Fig. 3.

We can see from the figure that the difference in frequency between the three classes of blocking highs is not too large in the actual atmosphere. This feature can also be seen in the frequency distributions of the spells of blocking action with movement in the model atmosphere.

As for the eastward or the westward moving blocking highs, the average longitudinal speed in the model atmosphere except Model LS coincides approximately with that of about 7° of longitude per day in the actual atmosphere. It is very interesting that the longitudinal movement of the blocking high in the model including neither the effects of mountains nor land-sea distribution is very similar to that in the actual atmosphere. This is also confirmed by examining the behavior of the blocking highs in the daily 400-mb charts (Figs. 4 (a) - (f)) of Model BC.

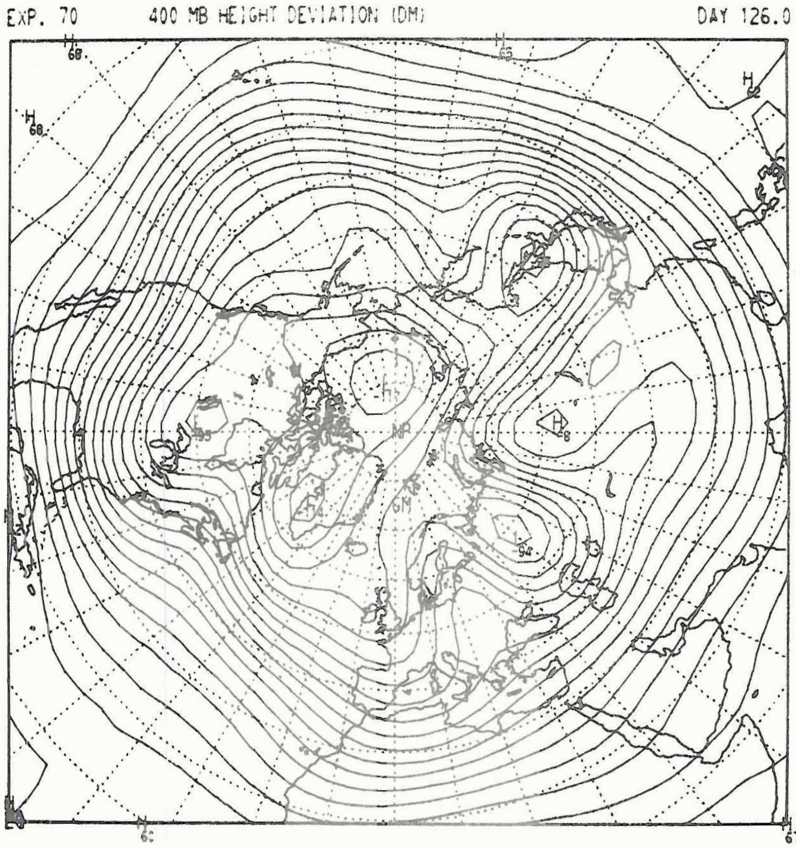


(a) 124 days

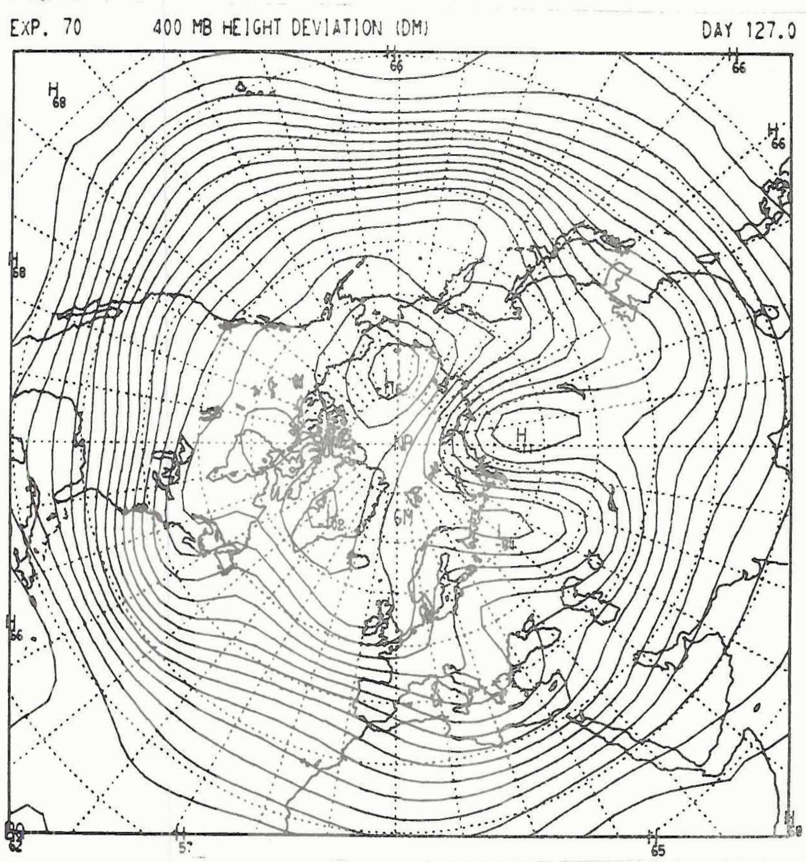


(b) 125 days

Figure 4. 400-mb contour charts for Model BC from 124 days to 129 days.

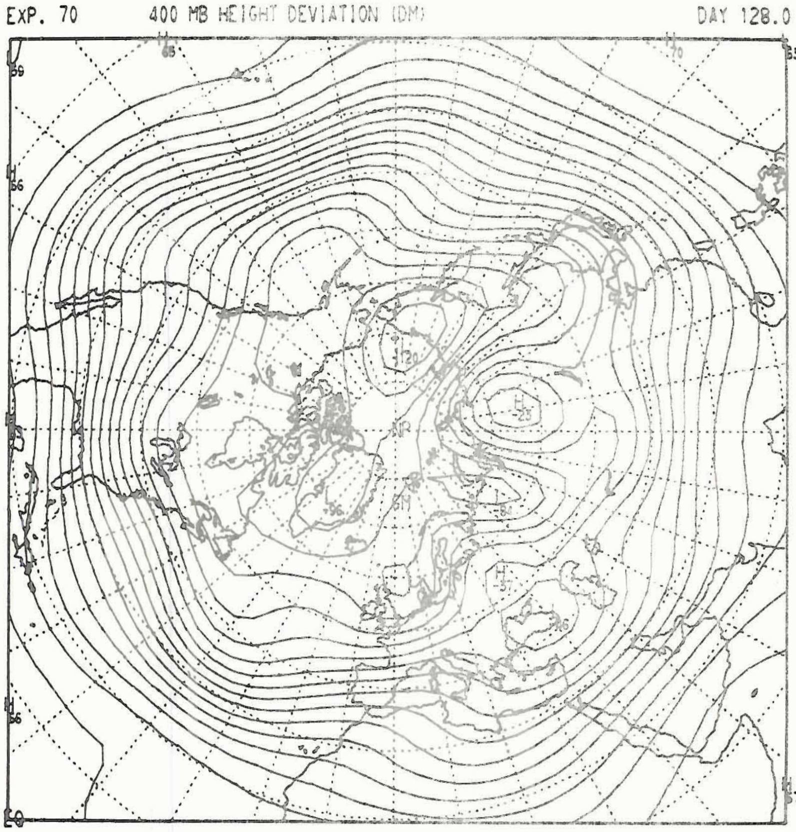


(c) 126 days

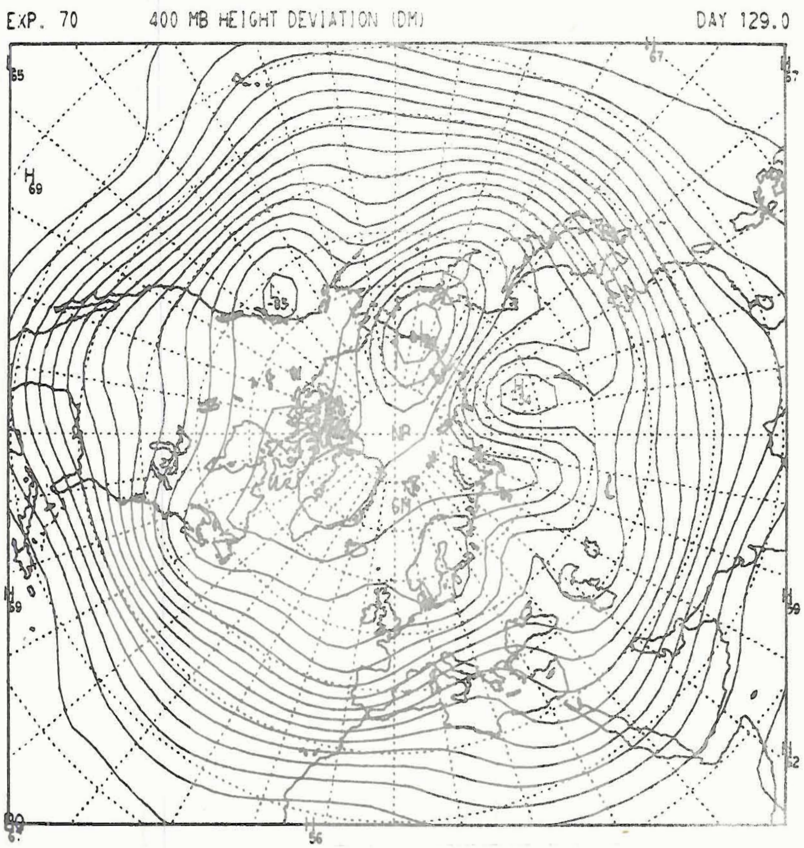


(d) 127 days

Figure 4. 400-mb contour charts for Model BC from 124 days to 129 days.



(e) 128 days



(f) 129 days

Figure 4. 400-mb contour charts for Model BC from 124 days to 129 days.

C. Distribution with longitude

In Fig. 5, the frequency distributions of blocking highs with longitude for the four models are shown, with the corresponding result obtained by Katayama and Sakurai (1971) using the 5-day mean 500-mb charts for the winter season during 21 years. The longitudinal frequency distribution of the blocking high in the actual atmosphere is characterized by the fact that blocking highs are found most frequently in the areas from 150°E eastward to 150°W (including Alaska) and from 30°W eastward to 30°E (including the Atlantic), with more frequent existence in the area from 30°E eastward to 150°E (including the Eurasian Continent) than from 150°W eastward to 30°W (including the North American Continent).

As evident from Fig. 5, this feature in the latitudinal frequency distribution of blocking highs is reproduced very well for Model ML including both the effects of mountains and land-sea distribution. Although the frequency distribution of blocking highs with longitude for Model MT including the effect of mountains alone has two peaks in the areas including Alaska and the Atlantic as seen in the actual atmosphere, the relative magnitude in the frequency of the existence of blocking highs in the areas including the Eurasian Continent and the North American Continent is different from that observed. In Model LS, the blocking highs are least frequently found in those areas where the frequency distribution of the actual atmosphere indicates a maximum. Although it is expected that the blocking highs in Model BC would distribute longitudinally with equal frequency because the effects of neither mountains nor land-sea distribution are included, the result obtained is contrary to our expectation.

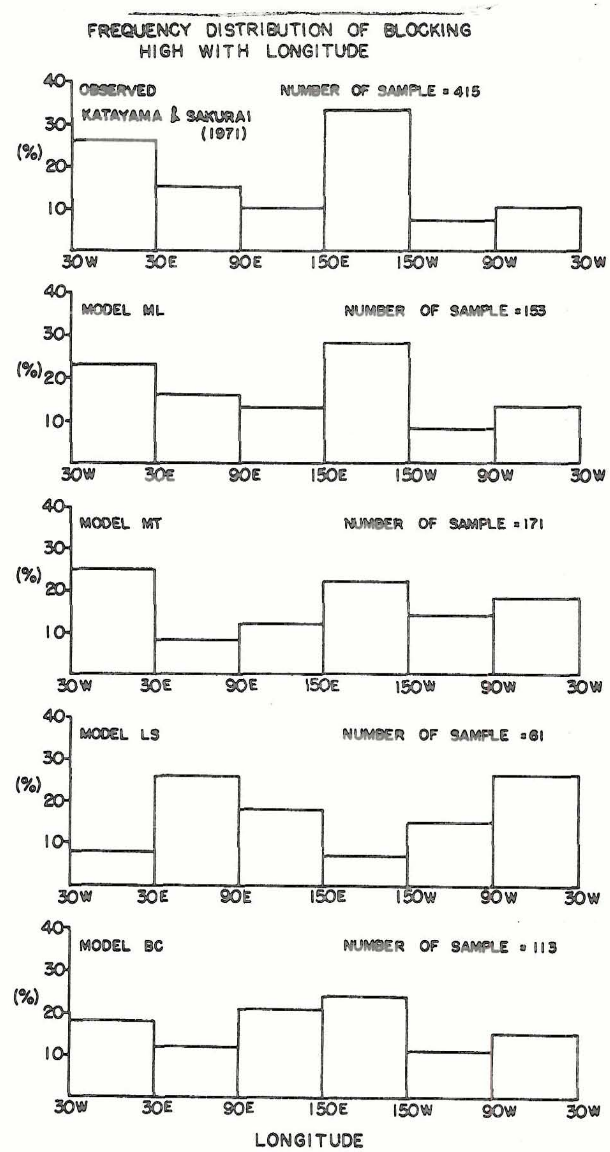


Figure 5. Frequency distribution of blocking highs with longitude. The number of the sample indicates the total number of blocking highs selected.

In order to see the persistency of the longitudinal frequency distribution of blocking highs for the four models, the 150-day period chosen for analysis was divided into two 75-day periods and a comparison between the frequency distributions for the two half periods was made. In Fig. 6, the longitudinal frequency distributions of blocking highs for Model BC are shown for the whole period and the two half periods.

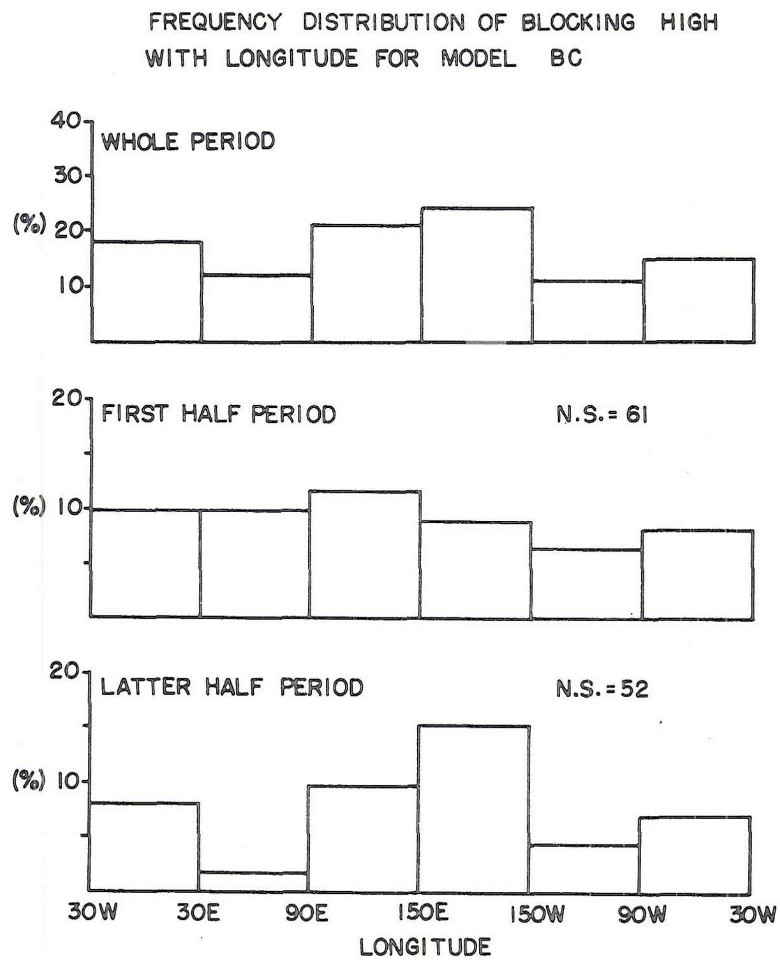


Figure 6. Longitudinal frequency distribution of blocking highs for Model BC. N. S. indicates the total number of blocking highs selected.

We can see from this figure that the fluctuation of frequency with longitude is very small for the first half period but becomes surprisingly large in the latter half period. This means that the characteristics of the frequency distribution for the whole period may possibly change if the period taken for the statistics is extended. On the other hand, in the case of Model ML, the frequency distribution for the first half period is very similar to that for the latter half period as shown in Fig. 7. Thus the frequency distribution for the whole period in Model ML

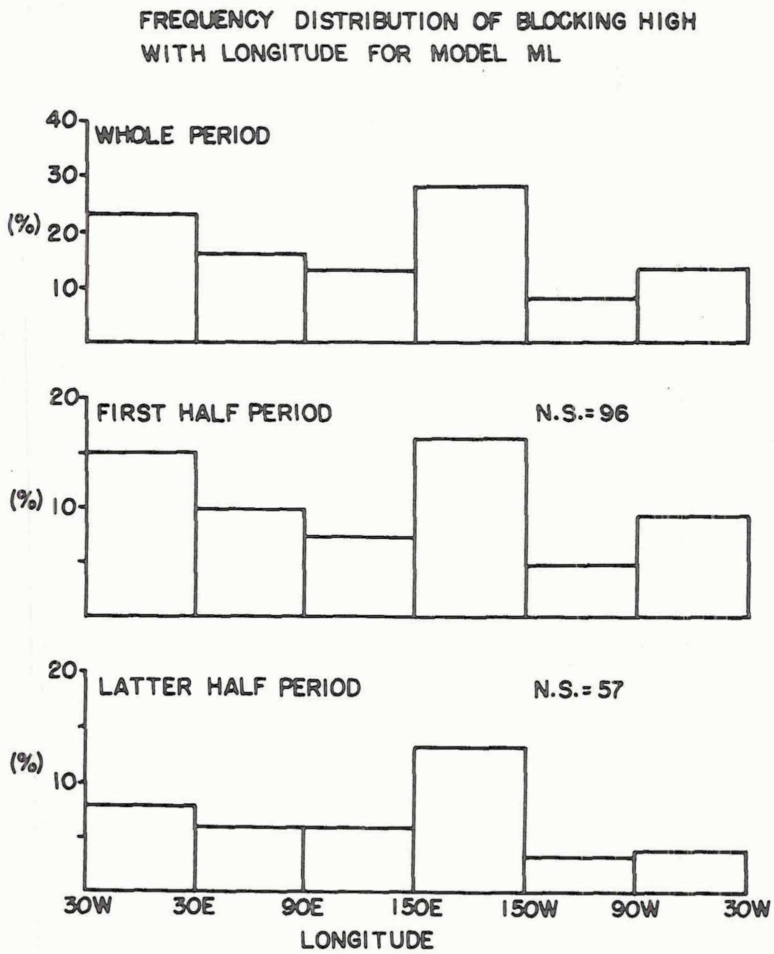


Figure 7. Longitudinal frequency distribution of blocking highs for Model ML. N. S. indicates the total number of blocking highs selected.

could be considered to be significant. Although not shown here, we also find this similarity between frequency distributions for the first and latter half periods in Model MT and Model ML, but not in Model LS.

D. Distribution with latitude

In Fig. 8, the frequency distributions of blocking highs with latitude are shown for the four models with the corresponding result obtained by Katayama and Sakurai (1971) using the same data described in the last subsection. According to this figure, blocking highs exist most frequently in the latitudinal belt between 50°N and 70°N in the actual atmosphere. It is interesting that this feature can be seen in the atmosphere of all models except Model LS, for which the number of the sample used in the statistics seems to be too small. From Fig. 8, we cannot find any relationship between the latitudinal frequency distribution of blocking highs and the effects of mountains and land-sea distribution.

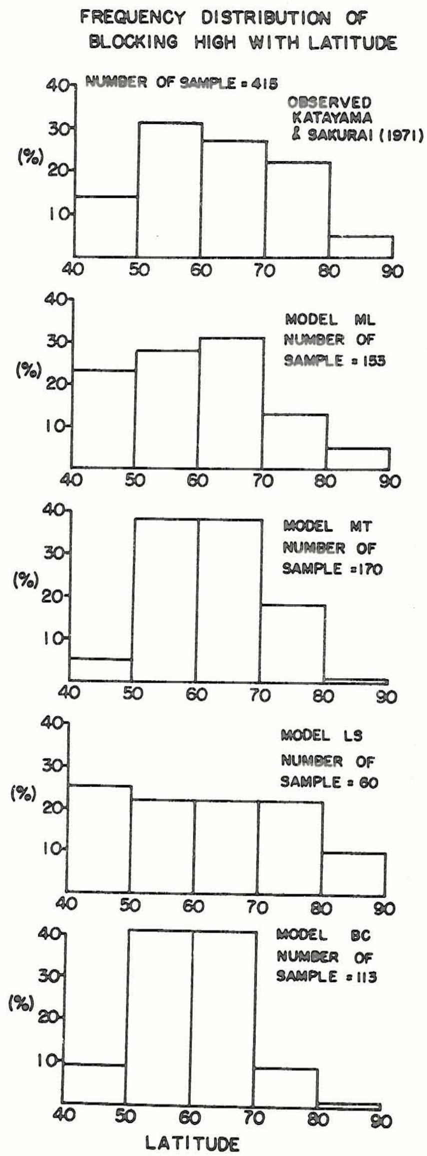


Figure 8. Frequency distribution of blocking highs with latitude. The number of the sample indicates the total number of blocking highs selected.

4. CONCLUSION

It should be noted that blocking action occurs even in the model including neither the effects of mountains nor land-sea distribution and its movement behavior is very similar to that observed in the actual atmosphere as shown in the last section. In this case, however, the duration period of the blocking action is remarkable short compared to that observed in the actual atmosphere. Although there is a tendency for the spell duration to become somewhat longer when including the effect of mountains, improvement of the models seems to be necessary to obtain spell durations such as those observed in the actual atmosphere.

Concerning the longitudinal frequency distribution of blocking highs, the feature that blocking highs are most frequently found in the ares from 150°E eastward to 150°W (including Alaska) and from 30°W eastward to 30°E (including the Atlantic) results from the dynamical effect of the mountains. However, another feature that the blocking highs are in more frequent existence in the area from 30°E eastward to 150°E (including the Eurasian Continent) than from 150°W eastward to 30°W (including the North American Continent) seems to result from the combination of the thermal effect of land-sea distribution and the dynamical effect of mountains.

It is unlikely that the effects of mountains and land-sea distribution play a primary role in yielding the fact--observed in the actual atmosphere--that blocking highs are most frequently found in the latitudinal belt between 50°N and 70°N.

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