A comparative climatology of blocking action in the two hemispheres

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Blocking action in the northern hemisphere is a well-documented phenomenon and several climatological studies have been carried out which show it to be most commonly initiated in the northeast Atlantic and northeast Pacific oceans. Other features such as its tendency to occur most frequently in spring and the movement of its central location both seasonally and during a single event are well described. In contrast, the phenomenon in the southern hemisphere has received little attention, most likely because its manifestations are on average less intense and less long lasting than its counterpart north of the equator.

The existing statistics of blocking action in both hemispheres are reviewed and compared, although the multiplicity of definitions and a lack of common techniques blur some of the frequency and duration comparisons. Since its occurrence in both hemispheres appears to be determined by selective longitudinal forcing of the large-scale circulation, the temporal and spatial relationships between blocking and the mean phases and amplitudes of the long waves are described. Finally, statistics are presented which suggest that thermal forcing may play a dominant role in blocking action in both hemispheres.

Introduction

The term 'blocking action' in synoptic scale meteorology has a spectrum of meanings amongst research workers and practical weather forecasters. To some, particularly those involved with theoretical studies of the problem and numerical modellers, it is manifested as any large-scale flow in which there is an enhanced north/south meridional component and a weakened west/east zonal component in middle latitudes e.g. Charney and de Vore (1979). The interpretation adopted by most practical forecasters tends to be more specific and requires that pressure anomalies associated with blocked flow show a characteristic meridional displacement from the average zonal tracks of stationary and travelling eddies in the subtropics and mid-latitudes. High pressure anomalies are displaced significantly poleward of the normal track of anticyclones, leaving a corresponding negative or low pressure anomaly equatorward of the high pressure anomaly. In well developed blocks the negative anomaly will appear as a cold low 'cut-off' from the main belt of mid-latitude westerlies. The main belt of westerlies is deflected poleward of the blocking anticyclone indicating that the anticyclones are warm cored, and thermal wind considerations dictate also that another maximum in the westerlies exists equatorward of the cut-off cold low. This double maximum in the zonal wind component or jet may appear as a split or diffluence in the upper level westerlies upstream of the block and a confluence downstream (Fig. 1).

The most significant feature common to both the meridional and diffluent blocking types is that they obstruct the normal passage of smaller scale baroclinic weather systems through the 'blocked' zone hence the name. In the case of diffluent blocks

Fig. 1 Schematic representation of the 500 mb pressure pattern for a 'split' flow blocking pattern (southern hemisphere).
there are also strong seasonal and geographical preferences while enhanced meridionality in the flow is a more global phenomenon (Austin 1980). From this observation alone it is likely that from a theoretical point of view they have similar origins but additional temporal and spatial forcing mechanisms lead to the development and maintenance of the diffiient type of block.

Since well developed diffiuent blocks are slow moving, are likely to occur preferentially in certain seasons, and tend to recur more often in the season of one year than in the corresponding season of another year, the weather in the blocked and surrounding regions can be affected one way or another for considerable periods. Seasonal precipitation may fail or be well above normal; temperatures may also be extreme. It is this potential for longer term seasonal/climatic effects such as drought or floods on agricultural productivity and other weather sensitive industries which has prompted a renewed and wider interest in blocking action.

Examples of extreme seasonal anomalies in the northern hemisphere ('extreme' in the context of available climatic statistics) e.g. drought in the United Kingdom (Green 1977), abnormal seasonal conditions in the United States (Wagner 1981) attest to the havoc that persistent blocking action can wreak on national economies. While the evidence for the southern hemisphere is less dramatic and may even be equivocal (Ohis 1980) any persistent occurrence of blocking action ought to produce some repercussions for communities living in the subtropics and mid-latitudes south of the equator.

This paper will review the statistics of blocking action in both hemispheres and examine those spatial and temporal variations of the broadscale climate which appear to be associated with its geographical and seasonal propensity. For the latter examination more emphasis will be given to the southern hemisphere. An Appendix contains some of the definitions employed by various investigators of blocking action. It is felt that no good purpose would be achieved here by adding to the list.

Statistics of blocked atmosphere flow
Northern hemisphere

The results of the first comprehensive study of blocking action were published over thirty years ago in a series of papers by Rex (1950a, 1950b, 1951). In one of these papers, Rex (1950b) examined the climatology of blocking action for the northern hemisphere using as reference material analyses covering the period November 1932 to March 1930 published by a number of analysis centres. Rex confirmed that there were two regions of the hemisphere where blocking action was most commonly initiated. These two regions were the northeastern Atlantic around 10°W and the northeastern Pacific around 150°W. In his following paper Rex (1951) concentrated on the Atlantic blocks and found that it was common for the centre of the blocked region to retrogress, i.e. move westwards, slightly in the early stages and then to progress slowly into Western Europe during the remainder of the period of the block. He observed also that the frequency of Atlantic blocks was around double that of Pacific blocks, and that there was a definite peak in the occurrence of blocking action during the spring months in both regions.

Since Rex's studies, further climatological examinations of blocking action in the northern hemisphere have been carried out, e.g. Sumner (1954); Tang Mou-tsong (1957); Geb (1966); White and Clark (1975); Knox (1979) and Treidl et al. (1981).

The 664 cases of blocking highs identified by Treidl et al. (1981) form probably the most comprehensive published catalogue and its compilation involved the examination of around 23,000 analyses for the northern hemisphere covering the period 1945 to 1977. The data confirm the general results of Rex (1950b) and other earlier workers that the region for most frequent block initiation is the area extending from the northeast Atlantic to Europe; the secondary peak in the northeast Pacific was also confirmed (Fig. 2).

A study of the seasonal variations revealed systematic shifts in the initial location of blocks in both major regions, from a maximum westward location in winter to a maximum eastward location in summer. Blocking frequency was highest in spring, followed by winter, summer and autumn in the approximate ratios 1.5:1.25:1:1:1:0 respectively. The general tendency for blocking highs to migrate slowly and disperse downstream (eastward) was also

Fig. 2 Blocking statistics as a function of longitude in the northern hemisphere (Treidl et al. 1981). Histogram of starting longitude.
evident with a weakest tendency to drift in summer. Blocks initiated at higher latitudes (>54°N) show a greater propensity for retrogression during their lifetime than those at lower preferred latitudes (45-54°N). Overall, the most frequent latitude for blocking anticyclones is around 56°N (Fig. 3).

Treibl and his colleagues imposed a lower limit of 5 days as a minimum duration for a blocking event, and overall the frequency distribution was strongly skewed towards lower values, resembling a Gamma distribution. The most common frequency (mode) of 8 days had almost twice the probability of occurrence as the mean of 12 days. Blocks of longest duration were more likely in spring and of shortest duration in summer. There was also some evidence that the passage of shorter space-scale baroclinic disturbances around the periphery of the blocked region, typically occurring at 6-day intervals, modulated the duration of blocks.

Of equal significance to the locations of highest blocking frequency are the locations of lowest blocking frequency. The latter are to be found near the two major northern hemisphere upper air troughs. This recurring duality in the climatology of northern hemisphere blocks extends finally to the incidence of multiple blocks, i.e. the simultaneous occurrence of blocks in more than one region. Again the northeast Atlantic and northeast Pacific regions show up as the most common pair in multiple block statistics.

Southern hemisphere

The relatively large number of statistical studies of blocking action in the northern hemisphere is contrasted by the almost total neglect of the phenomenon in the southern hemisphere. Since van Loon’s (1956) study, there appear to have been only two other investigations, Wright (1974) and Hirst (1979), neither of which was hemispheric in scope.

Van Loon (1956), using methods similar to Rex (1950b), however on surface charts only, identified three regions of predominant blocking occurrence: namely, the eastern Australia southwest Pacific region (PAC); the southwest Atlantic (Falkland South Georgia Islands) region (ATL); and the southwest Indian Ocean (Marion, Crozet Islands) region (IO) (Fig. 4). Van Loon’s definition of blocking (Appendix) differed slightly from Rex’s, mainly in that he relaxed the minimum duration from 10 days to 6 days which is slightly longer than the 5 days set down by Treibl et al. (1981). Van Loon found further relaxation of the minimum duration for a blocking episode led to an almost hemispheric occurrence of blocking activity thus providing southern hemisphere support for Austin’s (1980) assertion that enhanced meridional flow is not an abnormal state for the atmosphere. Van Loon noted several features common to blocking in both hemispheres, in particular the seasonal preference for late winter early spring, at least in the PAC and ATL regions; and the tendency for a blocking pattern to migrate downstream during the lifetime of each episode. The possibility of multiple-blocks, i.e. triple blocks, was also noted with the observation that in such occurrences blocking in the ATL and IO regions followed its initiation in the PAC region.

Of more significance are the apparent differences between northern hemisphere and southern hemisphere statistics. The existence of at least three dominant regions as opposed to the two of the northern hemisphere is the most obvious. A tendency for a secondary maximum in autumn, particularly in the IO region where it was an equally dominant season for blocking, contrasts with the minimum occurrence in autumn for the northern hemisphere. The observation that northern hemisphere blocks are initiated predominantly upstream of the two major land masses while those of the southern hemisphere are most frequently initiated immediately downstream or at least in the same longitudes of the three major land masses belied ideas of any simple land/sea contrast mechanism forcing a block. An early theory of orographic triggering suggested by Rossby (1950), and taken up by Rex (1950a) and others, also could not be applied so readily to the southern hemisphere.
where any downstream ridges forced by the only two major orographic influences, the Andes and New Zealand Alps, would be incorrectly located (van Loon 1956). Knox (1979) has also noted in his analysis, which was similar in its general conclusions to others for the northern hemisphere, that orographic forcing was inadequate as an exclusive mechanism for the forcing of Pacific blocks.

In a more detailed study of blocking in the Australasian region (essentially van Loon’s PAC region), Wright (1974) produced a further modification of the ‘blocking’ definition to incorporate his use of upper air data from NMC Melbourne analyses. An important consequence of Wright’s definition (Appendix) was that it now allowed a blocking episode to continue without the maintenance of a stationary surface anticyclone. It was possible for anticyclones to move into a blocked region, identified by a quasi-stationary 500 mb ridge at 45°S, intensify, weaken and move eastwards to be replaced by a new centre from the west. Overall the system would move slowly eastwards except during the replacement process when the central longitude of the block would often retrogress by a few degrees. Of the 299 episodes Wright identified for the period 1950 to 1971, only one-quarter were of the single surface anticyclone type and one-half of these occurred in the western Pacific sector of his four sub-regions. In contrast, no single high events were recorded for the east Indian Ocean sector. Overall, Wright confirmed van Loon’s finding that the Australasian region was a major area of blocking action (Fig. 5) but noted that in addition to the longitude of the primary mode in the Tasman Sea sector, there was a secondary maximum in the eastern Indian Ocean sector leaving a relative minimum in the longitudes of Western Australia. Adjusting the shorter record for the east Indian Ocean sector, Wright showed that blocked flow was occurring somewhere in the whole region 50 per cent of the time on average. Wright did not comment on any seasonal movement between the sectors although early spring (September) and early and late summer recorded the highest relative frequencies.

Hirst and Linacre (1981) in a further analysis of Wright’s data suggested an eastward progression of blocking frequency throughout the year and further identified a half-yearly cycle in the occurrence of blocking throughout the region (Fig. 6) in confirmation of van Loon’s (1956) earlier observation of two maxima. Hirst (1979) had tentatively explained the seasonal eastward progression in terms of a continuous migration in the location of wave number three around the hemisphere.

Wright, using a technique of mapping cyclonicity and anticyclonicity used extensively by Karelsky (1961), examined also the spatial relationship between the blocking anticyclones and the accompanying equatorward cut-off low which is often present in blocking events in this region*. Cyclonicity (anticyclonicity) is defined as the time in hours during which cyclonic (anticyclonic) centres occupy a given 5 degree square during the period of a blocking episode. The results of the spatial relationships for the four sectors are present in Fig. 7. The diagrams reveal that the highest values of cyclonicity associated with blocking action occurred in the eastern Indian Ocean sector and that blocking occurred there at a generally lower latitude. All patterns indicate the track of the accompanying cyclone into the blocked region from the southwest. This is most evident in the Australian and Tasman Sea sectors and underlines the strong link between cut-off low development and blocking action in this area (Taljaard 1972b). The occurrence of the so-called ‘tilting trough’ phenomenon with its

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*It should be noted that the occurrence of a cut-off low is less frequently accompanied by a blocking anticyclone.
Fig. 7 Distribution of average surface anticyclonicity (solid lines) and cyclonicity (dashed lines) per blocking occurrence in the Australasian region. Central longitude of block specified by 500 mb 5-day mean ridge at 45°S. Isopleths drawn at 3-hour intervals (after Wright 1974). (a) Eastern Indian Ocean; (b) Australia; (c) Tasman Sea; (d) Western Pacific.

Implication of equatorward transfer of angular momentum (Green 1977) is also a feature of at least incipient blocking in this area. However, it is also true that the subtropical jet is at a maximum across the whole region particularly in the cooler months and is thus a source of westerly angular momentum to enhance or maintain the equatorward arm of the split or double jet structure characteristic of diffuent blocks.

One other significant feature of these diagrams is that the mean latitude of the blocking high is in the vicinity of 45°S, being slightly north of this latitude in the eastern Indian Ocean sector and slightly south of it in the western Pacific Ocean sector. This is in marked contrast to the most typical latitude of about 56°N, for blocking highs in the northern hemisphere. No statistics are available on the preferred latitudes for blocking highs in the Marion/Crozet Island and Falkland Island/Scotia Sea areas but from casual inspection of a number of blocking situations in these regions, the favoured latitudes of the blocking highs are also further equatorward than the northern hemisphere case. One can infer that this significant difference between the two hemispheres is associated with major differences in the structure and intensity of the meridional circulations associated with the large-scale eddies and the mean circulation, which in turn depend on the large-scale topographic forcing.

Blocking and long waves

Northern hemisphere

Austin (1980) in her investigation of northern hemisphere blocking action concluded that blocks occur when enhanced stationary planetary waves retain their normal phase but interfere to ‘split’ the jet at 500 mb causing the mid-latitude baroclinic disturbances to be steered to the north and the south of the blocked zone. The interaction process is non-linear and from the spread of wave numbers produced, one will resonate, its speed being close to the value of the barotropic stationary wave. The scale of the blocked wave will be of order zonal wave number four, i.e. the blocking high will presumably occupy at least 45 degrees of longitude which accords with the criteria set down by Rex (1950a) for the minimum longitudinal extent of the split flow.

The phases of the major long waves in winter at 50°N in January (winter) are presented in Fig. 8 (van Loon et al. 1973) together with the winter blocking statistics (Treibl et al. 1981); the preferential regions for blocking action agree well with the ridges of the standing components of wave numbers one to four, at least for the two major blocking zones in the northeast Atlantic and northeast Pacific. There is some suggestion that longitudes 50°E to 100°E ought to represent a third and separate preferred blocking zone where the
Fig. 8 Mean height of the 500 mb surface (Jan) at 50°N. Locations of the ridges (R) and troughs (T) of wave numbers 1-4 are superimposed (after van Loon et al. 1973).

<table>
<thead>
<tr>
<th>Wave number one</th>
<th>Wave number two</th>
<th>Wave number three</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic blocking</td>
<td>large</td>
<td>large</td>
</tr>
<tr>
<td>Pacific blocking</td>
<td>small</td>
<td>large</td>
</tr>
<tr>
<td>Double blocking</td>
<td>large</td>
<td>large</td>
</tr>
</tbody>
</table>

It is interesting to note that wave number two, required to be enhanced in all three cases, shows an eastward tilt with decreasing latitude (Fig. 9 (a)). The significance of this becomes apparent if one considers the split flow to be an extreme example of a 'tilted' trough in which angular momentum is transferred from higher latitudes to lower latitudes.

Southern hemisphere

The southern hemisphere counterpart of Fig. 8, at Fig. 10 for July (winter) and January (summer), shows that similar relationships between blocking regions and the stationary long waves apply. The annual statistics for blocking from van Loon (1956) and Wright (1974) are included notionally in Fig. 10 and the phases of the ridges of the long waves correspond well with these zones. The only exception is the eastern Indian Ocean region identified by Wright where only a wave number four ridge seems able to account weakly for the incidence of blocking there. However Wright’s statistics show that blocking in this region is more common during the intermediate months and similar curves for these months may show more clearly which long wave components are involved. The application of Austin’s method for obtaining criteria for blocking

ridges of wave numbers two to four coincide. The winter statistics presented by Treidt et al. (1981) (Fig. 9 (b)) would seem to provide some support for this suggestion.

Austin (1980) has developed criteria for the incidence of single and double blocks in the two major northern hemisphere zones according to whether the amplitudes of wave numbers one, two or three are enhanced in their climatologically averaged locations. Summarised, the criteria are as follows:

Fig. 10 Mean height of the 500 mb surface at 50°S. Locations of the ridges (R) and troughs (T) of wave numbers 1-4 are superimposed. Blocking statistics from Fig. 4 (mid-period), (van Loon 1956) and Fig. 5 (Wright 1974) are presented along the bottom.
in each of the three major regions identified by van Loon emphasises the importance of an enhanced wave number three in blocked flow in the southwest Atlantic and west Indian Ocean regions. In the Australasian, west Pacific region enhanced wave numbers one through four would be favourable for blocking action attesting to the dominance of this region in the overall statistics. Enhanced amplitudes of wave numbers one and two, particularly the former, in their preferred phase locations would lead to suppression of ridge activity and presumably blocking activity in the other sub-zones.

Figures 11 and 12 give a clearer indication of the seasonal variations in the phases and amplitudes of wave numbers one to four. The phase of wave number four is given in Fig. 11 only for latitude 45°S, where it approximately has its maximum amplitude for most of the year. The most striking
Throughout all seasons wave numbers one to four all contribute ridges in the Australasian region south of 40°S. It is evident then that only in this area are the long waves so consistently located at low latitudes and middle latitudes to suggest the characteristic split flow of the blocking pattern. In other areas the ridges and the troughs tend to interfere destructively for much of the time except in the other two areas identified by van Loon (1956) where, as suggested earlier, blocking is most likely associated with an enhanced wave number three.

To an extent the foregoing discussion on Fourier decomposed mean flow begs the question on what is forcing the flow fields described. The method after all is merely a mathematical artefact without necessarily any a priori justification for its use. This is evident in some of the seasonal shifts in amplitude between wave numbers together with slight phase shifts as the data is forced to fit the technique. Nevertheless it has helped to highlight a number of significant features pertinent to the blocking question. For example, although there is a marked decoupling of the large scale mean flow between low and mid-latitude regions in the southern hemisphere, the orientation of the major troughs are such as to suggest the importance of transfer of momentum equatorward by mid-latitude eddies and secondly the importance of interaction with flow from lower latitudes. Nowhere in the southern hemisphere is this so evident as in the Australasian area.

Blocking and sea surface temperature

In mid to high latitudes the standing long wave patterns in the atmosphere are forced by asymmetries in the underlying earth's surface. The forcing may be either through orographical features e.g. mountain ranges or raised land plateaus, or through variations in the thermal characteristics of the earth's surface, e.g. land-sea contrasts. Kikuchi (1969) in a series of computer model experiments demonstrated that blocking action in the northern hemisphere was probably associated more with the direct forcing by orography since land-sea contrasts alone, while producing blocking episodes, placed the blocked zones in the wrong locations.

In the southern hemisphere mid-latitudes, orographic asymmetries are much reduced except for the southern tip of South America and the South Island of New Zealand. Orography then seems an unlikely candidate for forcing the long waves on a scale necessary to produce blocked flow. As van Loon (1956) has pointed out, the location of the major blocking zones are generally not in the right locations downstream of the Andes and the New Zealand Alps. The absence of any major land mass in the middle latitude regions of the southern hemisphere suggests that land-sea contrasts too are not a primary forcing mechanism for blocking action as suggested by the experiments of Kikuchi (1969).
The major asymmetry then in the underlying surface of the southern hemisphere middle latitudes is the longitudinal variation in sea surface temperature. The nature of this asymmetry at 50°S is depicted in Fig. 13. The most significant feature is the wave number one type zonal anomaly with cold temperatures in the eastern half of the hemisphere and warmer temperatures in the western half. The reason for this is the asymmetric location of the Antarctic continent about the pole (Taljaard 1972a). To obtain information about the seasonal variation of sea surface temperature in middle latitudes, the latitudes of the 8°C isotherm at 10 degree longitude steps were extracted from the US Navy Marine Climatic Atlases for the southern hemisphere; a time-longitude contour analysis of the data is at Fig. 14. The 8°C isotherm intersects a land mass only in the South American Sector in late winter and early spring and some interpolation was necessary. If one relates now the statistics for blocking action given earlier it is evident that the major zones correspond with longitudes where sea surface temperatures are warmest. However, it is the seasonal variation in longitudinal gradient upstream of the warmest longitude which would appear to be the more important feature in forcing blocking action. It is possible the argument is circular in that enhanced blocking may lead to enhanced sea surface temperature contrasts. Nevertheless it is the permanent positive gradient in west-east sea surface temperatures upstream of the Australasian sector which adds the greatest weight to this factor being causal. This feature has been noted also by Hirst and Linacre (1981). A numerical experiment by Simpson and Downey (1975) in which a rather large 5°C middle latitude sea surface temperature anomaly in the western Pacific produced a blocking episode adds further weight to the argument. However, it is suggested that it is not the warm anomaly per se that is required, but the longitudinal gradient. Thus the effect of the rather abnormal 5°C anomaly could be achieved for example by a much more realistic 2–3°C positive anomaly downstream of an equally realistic 2–3°C negative anomaly. It is interesting to note there are strong west-east positive sea surface temperature gradients in the North Atlantic and north Pacific upstream of the major blocking zones. The significance of these suggestions could best be tested by a series of modelling experiments in which various configurations of sea surface temperatures are applied, firstly with an atmospheric general circulation model and subsequently with a fully coupled ocean/atmosphere model to examine the feed-back processes.

Summary and conclusions

The statistics for blocking action in both hemispheres have been reviewed and examined. Although the most intense blocking episodes are generally less intense and less long lasting in the southern hemisphere than their northern hemisphere counterparts, the frequency of occurrence is of comparable magnitude particularly in the Australasian sector. The role of orography has hitherto been considered the most significant factor forcing blocking in the northern hemisphere but the reduced orographic forcing and land-sea contrasts in the southern hemisphere middle latitudes leads to the suggestion that topographic thermal forcing, particularly by longitudinal variations in sea surface temperature may be at least as important.
The significance of the cut-off low in the overall development of a blocking episode has received relatively little attention in northern hemisphere studies possibly because it tends to be at latitudes well equatorward of the regions most socio-economically affected by the anticyclones of protracted blocking episodes which may lead to drought and other extreme events. The role of the so-called tilted trough with its effect of transferring momentum equatorward into the region of the cut-off low is also evident in both hemispheres. Finally, interaction between high latitudes and the tropics which in the southern hemisphere at least appears to occur most strongly in the regions just downstream of the major blocking zones (Streten 1973) is also one of the many pieces in the overall pattern of blocking action which has yet to be clarified.

References


APPENDIX

Criteria for blocking by selected authors

Northern hemisphere

Rex (1950a)
(a) The basic westerly current (at 500 mb) must split into two branches;
(b) each branch current must transport an appreciable mass;
(c) the double-jet system must extend over at least 45 degrees of longitude;
(d) a sharp transition from zonal type flow upstream to meridional type downstream must be observed across the current split; and
(e) the pattern must persist with recognisable continuity for at least ten days.

Treidl et al. (1981)
(a) Closed isopleths (presumably around the high) must be present simultaneously in the surface and 500 mb charts, splitting the westerly current aloft into two branches;
(b) the latitude belt where the high occurs extends northward from 30°N; and
(c) the minimum duration of the high must be five days.

Southern hemisphere

van Loon (1956)
(a) The displacement of the blocking system, as given by the movement of the centre of the high, must be less than 25 degrees of longitude at 45°S during the total period of blocking;
(b) the centre of the blocking high must be at least 10 degrees south of the normal positive of the subtropical high pressure belt as given by Vowinckel (1955); and
(c) the blocking must last for at least six days.

Wright (1974)
(a) The basic westerly current (at 500 mb) splits into two branches;
(b) the 5-day mean 500 mb ridge at 45°S (defining the longitude of the block) has a rate of progression of less than 20 degrees of longitude per week and progresses no more than 30 degrees of longitude during the entire blocking occurrence;
(c) the ridge of high pressure at the longitude of blocking is at least 7 degrees south of the normal position of the subtropical high pressure belt (as derived by Taljaard et al. 1968) and is maintained with recognisable continuity; and
(d) the occurrence lasts for at least six days.

References


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