A note on the relationship between large scale energy functions and characteristics of climate

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SUMMARY

A study has been made of large-scale energy functions using 500 mb height and 500-1,000 mb thickness data for 1954-1956 and associated synoptic charts in order to consider further the relationship between blocking anticyclones and eddy kinetic energy ($K'$) as proposed by Everson and Davies (1970). For the winter of 1955-1956, $K'$ displayed much larger amplitude variations with a longer period than those for the winter 1954-1955. The difference in weather was also quite marked, the 55-56 winter being dominated by blocking anticyclones whilst the 54-55 winter was comparatively mild. The onset of large-scale blocking activity generally coincided with minima of $K'$ as anticipated.

It was further found that a minimum of $K'$ coupled with a relatively low value of zonal kinetic energy ($K$) and a significant land-sea temperature contrast was generally followed by European blocking, whereas a minimum of $K'$ in other circumstances was not.

1. INTRODUCTION

Anticyclonic blocking in certain regions of the Northern Hemisphere is a problem of some importance to meteorologists at present, and for two reasons. Firstly, it is a recurrent phenomenon for which there is as yet no complete physical explanation, although various quite plausible suggestions have been put forward. Secondly, now that long range forecasts are produced by national meteorological services, and there is also some suggestion of seasonal forecasts being made, it is vitally important that the onset and behaviour of blocking anticyclones, which, if they are persistent, can radically alter the characteristic weather of a season, should be predicted as accurately as possible.

In experimenting with a simple model of the atmosphere Everson and Davies (1970) found, with model heating roughly corresponding to winter over a half-land, half-sea domain, that in certain circumstances anticyclonic blocking occurred and further that in every case the onset of blocking coincided with a broad-scale minimum of the eddy kinetic energy $K'$. An analysis was then made of kinetic energy for the real atmosphere over a period of about one month (December 1956) during which blocking occurred, and this also was found to coincide with a minimum of eddy kinetic energy. However, the analysis involved the counting of isobars crossing the sides of grid-squares on synoptic charts and was extremely tedious and time consuming. Subsequently magnetic tapes of data and the relevant synoptic charts were made available by the Meteorological Office and it is on these that this study is based.

Although studies have been made of energy variations over long periods, most notably by Kreuger, Winston and Haines (1965) and Win-Nielsen (1967), little attempt has been made to link the energy functions with synoptic characteristics.

2. METHOD OF ANALYSIS

The data consist of 500 mb heights and 1,000-500 mb thickness values for the two years June 1954-May 1956 over that part of the Northern Hemisphere between 15°N and the North Pole. The grid points at which the data were specified were intersections of lines of longitude at 10° intervals with latitude circles at 5° intervals. Between 70°N and 80°N (inclusive) only the intersections at 20° intervals of longitude were used, and at 85°N four points at 90° intervals. Finally the polar value was given. A fairly considerable area
(especially over the Pacific Ocean) provided no data so that typically 336 out of a possible maximum of 455 values were used.

It was decided to extract the zonal and eddy kinetic energies at 500 mb, the zonal and eddy available potential energy at 750 mb, the zonal and eddy kinetic energy at 1,000 mb and the meridional temperature difference between 30°N and the Pole. In order to obtain a temperature which was reasonably representative of the polar area an average was taken of the polar value and the values at the four equally spaced points at latitude 85°N.

The parameters calculated were:

\[ K = \frac{1}{N} \sum w u'^2, \quad \text{zonal kinetic energy}, \]

\[ K' = \frac{1}{N} \sum w (u'^2 + v'^2), \quad \text{eddy kinetic energy}, \]

\[ P = \frac{1}{N} \sum w \bar{\sigma}^2, \quad \text{zonal available potential energy}, \]

\[ P' = \frac{1}{N} \sum w \bar{\theta}^2, \quad \text{eddy available potential energy}, \]

\[ \Delta T = T_{\text{pole}} - T_{\text{st}}, \]

The notation used is:

- \( u, u' \) mean and eddy velocity in the east-west direction;
- \( v' \) eddy velocity in the north-south direction;
- \( w \) weighting associated with each grid point (proportional to area);
- \( \bar{\sigma} \) deviation of mean thickness round a latitude circle from domain mean thickness;
- \( \bar{\theta} \) deviation of local thickness from mean thickness round a latitude circle;
- \( N = \sum w \);
- \( T_{\text{pole}} \) representative polar temperature;
- \( T_{\text{st}} \) mean temperature on 30°N latitude circle.

In view of the available data the velocities were naturally computed from the geostrophic relationship (with the Coriolis parameter dependent on latitude) so that \( \bar{v} \) is necessarily zero.

Since the effect in which we are interested arose in a model which was half-land and half-sea we also selected for study two sub-domains of the Northern Hemisphere with very roughly similar land-sea distributions. These were 50°W to 60°E and 170°W to 60°W, again between 15°N and the pole. These areas roughly correspond to the Atlantic/western Europe and the east Pacific/United States respectively. Identical parameters were calculated for these two sub-domains, the zonal means in this case being taken as the zonal means over the relevant sub-domain.

3. Results

After this analysis we had available two one-year time series of the energy functions. It was immediately apparent that direct comparison with a two-level model would require the removal of the annual trend, since the two-level model results were obtained with a heating function which did not vary with time. Nevertheless, superimposed on the trend several minima were quite clear even without any smoothing. Perusal of the charts for what we considered to be blocking situations was quite difficult. Rex (1950) has defined blocking in terms of splitting of the jet stream and retrograde motion. Miles (1961) discussed the behaviour of anticyclones lasting more than a given number of days in a specific region, but it does not seem possible to apply any such definition in this case. We can merely pick certain occurrences which we regard as being indisputably blocking and
consider the energy parameters at those times. As far as blocking over the United States is concerned it is difficult to select any clear cut blocks over the period studied, as high pressure seems to dominate this area in winter and the problem is complicated by the fact that very few cyclones manage to cross the Rocky Mountains, so that there is in a sense a permanent state of mechanical blocking over this period.

Examination of the charts revealed several blocks of the kind we were seeking. The strongest of these occurred on 27 January 1956, and appeared as a movement of a Greenland anticyclone south-eastwards to the North Sea, producing a cut-off low over eastern Germany. This anticyclone agglomerated with a north-eastward extension of a high over north-west Africa, settling as a high with central pressure of about 1,050 mb over Scandinavia. On 31 January a small low which had been forced south-eastwards over France extended up to 500 mb reinforcing the trough at 500 mb which was growing behind the ridge over Scandinavia. By this stage clear splitting of the jet stream was evident, and, while blocking behaviour predominated at the surface over the British Isles until 26 February, at 500 mb a succession of highs became detached from the mid-Atlantic High and travelled round the edge of the European shelf transporting very large masses of warm air to polar regions. Fig. 1 shows the synoptic situation at 1230 GMT on 27 January 1956, and Fig. 2 that at 1230 GMT the following day.

![Figure 1. Synoptic situation at 1230 GMT on 27 January 1956. Contours are of sea level pressure at 5 mb intervals. Major fronts are indicated by broken lines. The blocking anticyclone over Scandinavia and the North Sea has a central pressure of 1,025 mb. (Based on US Weather Bureau Daily Weather Maps.)](image)

Fig. 3(a) to (g) show the energy and temperature functions for the two years. A trend of the form $A + B \cos [(t - \epsilon) (2\pi/365.25)]$ (where $A$ represents the mean value of the function, $B$ the amplitude of the variation with period one year, $t$ the time of the year in days and $\epsilon$ the phase lag also in days) has been removed and the harmonic part of this is indicated by the dotted line. This is done to eliminate seasonal effects as we are interested in smaller time scales, of the order of 12-20 days. As may be seen from Fig. 3 these trends lag about one month behind the solar cycle, as noted by Wiin-Nielsen (1967) who studied energy distributions for the years 1900-1962. Table 1 gives the (approximate) dates of commencement of blocking situations indicated on Fig. 3(a). The solid line indicates values, over the sub-domain 50°W to 60°E, for the period June 1954-May 1955, and the
broken line for the period June 1955-May 1956. The patterns are similar to those for the whole domain. It is immediately apparent that 27 January 1956 is close to the most pronounced large-scale minimum of $K^s$ in the whole two year period, and this coincides with the initiation of large-scale European blocking.

The synoptic conditions preceding the blocking situations listed in Table 1 are of several different patterns. 4 January 1956 is remarkable in that it coincides with a maximum of eddy kinetic energy. Synoptically an anticyclone travelled from the west coast of Spain to merge with the winter Asian high. Although some splitting of the jet occurred most of the flow was northward and it was not properly a blocking anticyclone in that it did not substantially impede the eastward progress of baroclinic waves. The situation of July and August 1955 is a summer blocking (the most persistent of the year) and arises as the

### TABLE 1. The dates and approximate durations of the blocking situations indicated by arrows in Fig. 3(a)

<table>
<thead>
<tr>
<th>Date</th>
<th>Duration (days)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 Nov. 1954</td>
<td>8</td>
<td>Persistent summer blocking</td>
</tr>
<tr>
<td>6 Jul. 1955</td>
<td>(49)</td>
<td></td>
</tr>
<tr>
<td>1 Nov. 1955</td>
<td>8</td>
<td>Driven eastwards into Europe</td>
</tr>
<tr>
<td>12 Nov. 1955</td>
<td>15</td>
<td>Advances westwards until 22nd</td>
</tr>
<tr>
<td>4 Jan. 1956</td>
<td>(3)</td>
<td>Travelling anticyclone</td>
</tr>
<tr>
<td>27 Jan. 1956</td>
<td>30</td>
<td>Advances westwards and is reinforced on 18 February</td>
</tr>
<tr>
<td>7 Mar. 1956</td>
<td>13</td>
<td>Driven eastward to Asia but extends westwards as next blocking</td>
</tr>
<tr>
<td>27 Mar. 1956</td>
<td>6</td>
<td>Forces baroclinicity north of Scandinavia</td>
</tr>
<tr>
<td>17 May 1956</td>
<td>7</td>
<td>Overtaken by high pressure covering the east Atlantic</td>
</tr>
</tbody>
</table>
mid-Atlantic high extends north-eastwards. In contrast the anticyclones of November 1954, mid-November 1955, January-February 1956, 7 March 1956, and May 1956 are all initiated by the joining of anticyclones from Greenland and the Atlantic (or the Atlantic coast of Africa). March 27 is of another kind being a retrograde motion of the Asian high, and on 1 November 1955 an anticyclone from the Atlantic settles over Europe.

It is evident from Fig. 3(a) and Table 1 that although blocking activity is closely associated with minima in $K'$ it is by no means associated with every such minimum. Everson and Davies (loc. cit.) found, in their two-level model, that minima associated with a large-scale longitudinal land-sea temperature difference in excess of 2°C led to blocking, whereas minima associated with much smaller differences did not. Namias (1964) also associated anomalies in the east to west temperature gradient with subsequent blocking over Europe. Examinations were therefore made of the flow charts but it was found impossible objectively to find quantifiable differences without returning to the magnetic tape data.

It was finally decided to compare the 1,000 mb-500 mb thickness for the regions 50°N to 10°W and 0° to 40°E between the latitudes of 45°N and 65°N (inclusive) since these two areas correspond fairly well to sea and land areas in the approximate latitudes of anticyclonic blocking. It was also noticed, when comparing the minimum of $K'$ of December 1955 with that of January 1956 that in the first case $K$ was very high, whereas in the latter case it was low. Since it is quite plausible that strong zonal flow (a high value of $K$) should preclude blocking, this was also investigated.

![Figure 3 (a)–(d). Caption on page 698.](image-url)
Figure 3. The seven energy and temperature functions for the domain 50°W-60°E. In each case the solid line refers to the period June 1954-May 1955 and the broken line to the period June 1955-May 1956. The dotted line is the harmonic part of the trend for the two years. Arbitrary units. (a) Eddy kinetic energy at 500 mb, $K'_{500}$. Blocking situations are marked by arrows; the solid arrow refers to 1954-55 the hollow arrows to 1955-56. (b) Zonal kinetic energy at 500 mb, $K_{500}$. (c) Eddy kinetic energy at 1,000 mb, $K'_{1000}$. (d) Zonal kinetic energy at 1,000 mb, $K_{1000}$. (e) Eddy available potential energy at 750 mb, $P'$. (f) Zonal available potential energy at 750 mb, $P$. (g) Temperature difference between 30°N and the pole, $4T$.

<table>
<thead>
<tr>
<th>Date</th>
<th>$T_{SL}$</th>
<th>$\tilde{T}_{SL}$</th>
<th>$T_{SL} - \tilde{T}_{SL}$</th>
<th>$\bar{K}$</th>
<th>Blocking</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Sept. 1954</td>
<td>-1.1</td>
<td>-1.7</td>
<td>0.6</td>
<td>H</td>
<td>NO</td>
</tr>
<tr>
<td>2 Feb. 1955</td>
<td>-3.8</td>
<td>3.8</td>
<td>-7.6</td>
<td>H</td>
<td>NO</td>
</tr>
<tr>
<td>16 Mar. 1955</td>
<td>4.4</td>
<td>3.1</td>
<td>1.3</td>
<td>H</td>
<td>NO</td>
</tr>
<tr>
<td>25 June 1955</td>
<td>-2.7</td>
<td>0.4</td>
<td>-3.1</td>
<td>M</td>
<td>NO</td>
</tr>
<tr>
<td>31 Oct. 1955</td>
<td>7.0</td>
<td>1.1</td>
<td>5.9</td>
<td>L</td>
<td>1 Nov</td>
</tr>
<tr>
<td>18 Dec. 1955</td>
<td>5.5</td>
<td>3.2</td>
<td>2.3</td>
<td>H</td>
<td>NO</td>
</tr>
<tr>
<td>25 Jan. 1956</td>
<td>5.1</td>
<td>2.1</td>
<td>3.0</td>
<td>L</td>
<td>27 Jan</td>
</tr>
<tr>
<td>17 May 1956</td>
<td>3.0</td>
<td>-1.7</td>
<td>4.7</td>
<td>L</td>
<td>17 May</td>
</tr>
</tbody>
</table>

Table 2 shows in column 1 eight minima of $K'$ which seem to the author to be extensive in time. Columns 2, 3 and 4 show respectively the land-sea temperature difference at 750 mb ($T_{SL} = T_{SEA} - T_{LAND}$) for the area specified above, the monthly average of that value ($\tilde{T}_{SL}$) and the difference $T_{SL} - \tilde{T}_{SL}$. Column 5 indicates whether $K$ was high, medium or low ($H, M, L$) for the time of year (see Fig. 3(b)) and column 6 shows the date of commencement of blocking, if any. It is immediately noticeable that in all three of the cases in which blocking occurs the zonal kinetic energy is low and there is a temperature contrast in excess of $3^\circ$ between the sea and land. In the cases where no blocking occurs the zonal kinetic energy is in every case higher but the temperature contrast is not necessarily lower, although when considered in relation to the relevant monthly
Figure 4. (a) $K_{300}$. (b) $K_{500}$.

Figure 4. (c) $K_{850}$. (d) $K_{e}$. 

ENERGY FUNCTIONS AND CLIMATE
average the anomaly is less than 3°C (see Table 2 column 4). The large reversed temperature contrast of February 1955 is caused by a highly complex low pressure system covering Europe and the Atlantic, and sweeping warm maritime air over the land.

It is interesting to compare the characteristics of the energy functions for the two one-year periods (June-May), as the difference is quite marked. In particular:

(i) The winter variations in eddy kinetic energy $K'$ (Fig. 3(a)) and $P'$ (Fig. 3(e)) are much larger in year 2 (1955-1956) than in year 1 (1954-1955) and have a longer and more clearly defined period.

(ii) There is a period of two months (October and November) in year 2 in which the Equator-Pole temperature gradient is consistently higher than the trend value (Fig. 3(g)).

(iii) The zonal available potential energy in year 1 falls from September to December whereas in year 2 it rises (Fig. 3(f)).

(iv) After a maximum in mid-December 1955 the zonal kinetic energy at 500 mb has a minimum at the beginning of January and slowly builds up again through the month. This minimum of $K$ coupled with a maximum of $K'$ and low values of $dT$ at the turn of the year suggests that the waving of the jet stream, which tends to reduce the Equator-Pole temperature gradient, is a régime which is liable to break down into a blocking flow pattern.

The general character of the weather near the British Isles was also markedly different for the two years. The winter months of early 1955 were warm and relatively free from cold anticyclonic periods. On the other hand, anticyclonic weather developed during the
Figure 5. (a) \( K'_{50a} \). (b) \( K_{50a} \).

Figure 5. (c) \( K'_b \). (d) \( \bar{K}_f \).
second half of the year, and, commencing with the long blocking period mentioned above, the first half of 1956, which was particularly dry, was dominated by anticyclones (see for example the Meteorological Office Monthly Weather Reports, summaries for the years 1955, 1956).

Since the winter of year 1 was characterized by baroclinicity over Europe, in contrast to year 2 which was largely anticyclonic, one is immediately prompted to ask what the essential differences are between these two years. Fig. 4(a) to (g) and 5 (a) to (g) are attempts to highlight the differences in terms of the monthly means of energy functions. An interesting feature in the Atlantic-European domain is the phenomenon of a double maximum in year 2 of all the parameters except $K$ at the surface (Fig. 4). In terms of these monthly averages the earliest divergence between the years seems to be in September when in year 1 the Equator-Pole temperature gradient increased quite sharply (leading to an early rise in $P$) and was then steady until December, whereas in year 2 this rise came later leading to a maximum in November and a secondary maximum in March. The much longer, though later, rise in $P$ in year 2 was followed by the maxima in December of the remaining energy functions before their minima in January when major blocking developed.
ENERGY FUNCTIONS AND CLIMATE

Kreuger et al. (1965) also noted differences between monthly averages of energy functions but without associating them with seasonal fluctuations. It is also likely that considerably larger differences would have been evident had they considered the energy associated with particular sub-domains of the Northern Hemisphere. The differences between the eddy energy curves for the Atlantic-European domain (Fig. 4(a), (c) and (e)) and for the whole hemisphere (Fig. 5(a), (c) and (e)) certainly indicate that this is so.

4. Conclusions

Although the process of blocking is considerably less clear-cut in the atmosphere than in a two-level model it appears that the onset of blocking generally coincides with a minimum of global-scale or, more conclusively, continental-scale K'. Large seasonal anomalies caused by blocking may on the basis of the data studied here, be presaged by marked minima of K' coupled with low energy of zonal flow and large longitudinal temperature differences between sea and land. The two winters selected for study are remarkably different as far as weather characteristics are concerned and it does seem possible that examination of large-scale energy functions and the associated (European) climate may reveal links which suggest physical causes or pointers to an ensuing winter of long-period blocking.

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