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AIR MINISTRY

METEOROLOGICAL OFFICE

Scientific Paper No. 8

Factors Associated with the Formation and Persistence of Anticyclones over Scandinavia in the Winter Half of the Year

by M. K. MILES, M.Sc.

LONDON: HER MAJESTY'S STATIONERY OFFICE

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Contents

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by M. K. Miles, M.Sc.

SUMMARY

All surface anticyclones spending more than one day in the Scandinavian region during the twelve years 1946–57 (inclusive) have been studied synoptically. It was found that somewhat less than a fifth of the anticyclones appearing in the region persisted beyond three days. Nearly all of the strong anticyclones developed some 600 nautical miles to the east of a large-amplitude thermal ridge. Continued growth of this ridge for at least twenty-four hours after the anticyclone appeared in Scandinavia was usually required for persistence of the anticyclone.

Several other factors which appear to be relevant to the persistence of these anticyclones have been elucidated. The strength and position of the major thermal troughs upwind to 110°W longitude, the strength of any warm anticyclones to the south and southwest of Scandinavia and the maintained growth of the large-amplitude thermal ridge appear likely to have the greatest prediction value.

INTRODUCTION

Winter anticyclones over Scandinavia appear to have received little systematic study though they are regarded by British forecasters as highly important factors in determining the weather over the British Isles.

An examination of their frequency has been made by Sigurd Evjen.[1]* His count covered the five years 1946–1950 and was for the whole Scandinavian region including Finland and the Baltic States. He included only cells with a central pressure greater than 1030 millibars and Table I shows the number of days with anticyclones for the six winter months, deduced from his data.

TABLE I. *Monthly distribution of anticyclones over Scandinavia*

(number of days in 5 years)

October	November	December	January	February	March
29	7	15	34	21	12

The high January and October values occur mainly in the latitude belt 60–65°N. It is evident from the yearly figures that the incidence of these strong anticyclones varies greatly from year to year. Since they are mostly blocking anticyclones according to the definition by Sumner,[2] it is possible to use his latest data[3] to get a further idea of their monthly distribution by taking his figures for the longitude zones 1–20°E and 21–40°E for the period 1949–1956 (inclusive) as given in Table II.

* The superscript figures refer to the Bibliography on p. 18.

TABLE II. *Monthly distribution of days of blocking in zone* 1–40°*E for the period* 1949–56 (*incl.*)

	October	November	December	January	February	March
1–20°E	43	15	16	33	25	40
21–40°E	24	35	23	12	23	34

Again there is an October peak but the January peak is not so well marked, though it is the highest of the three main winter months for the zone 1–20°E. Moreover Sumner finds that more of the blocking anticyclones of January are in the latitude band of 60–70°N than those of October.

This study has the following main aims:

(i) to establish the monthly distribution over a longer period than Evjen has used, and over a more restricted area than Sumner has done.

(ii) to examine the synoptic conditions at the surface and in the troposphere associated with the formation of anticyclones over Scandinavia.

(iii) to discover what factors determine the persistence of these anticyclones once they are formed, with a view to providing prediction criteria.

(iv) to discover the circumstances under which these anticyclones lead to persistent easterly winds over the British Isles.

The investigation is conducted, so far as tropospheric conditions are concerned, mainly in terms of large-scale 1,000–500-millibar thickness patterns and their anomalies. Some attention is also paid to broad southerly currents at 500 millibars since these appear to be associated with the formation of large-amplitude contour and thickness patterns in the troposphere.

Finally, some ideas about the relationship of the large-scale circulation to Scandinavian anticyclogenesis are tested especially in the light of the division into persistent and non-persistent classes.

DATA

All anticyclones over Scandinavia in the winter half of the year between 1946 and 1957 inclusive were noted and dates and durations are given in an appendix. The area taken to represent the Scandinavian region is shown in Figure 1, and was divided into four equal area parts. Table III shows the monthly distribution of anticyclones of varying durations (but excluding one day) which were in the area on the 0001 G.M.T. charts for 1946–49, and on 1200 G.M.T. charts for 1950–57.

TABLE III. *Monthly distribution of Scandinavian anticyclones for the years* 1946–57

	October	November	December	January	February	March
No. of anticyclones lasting 2 days or more in the region	19*	9	9	20	11	16
Total no. of days in the region	61	32	29	83	49	40
No. of anticyclones lasting 4 days or more	8	2	3	7	5	2

(Days are allocated to the month in which the anticyclone formed.)

* Including an anticyclone which formed on 30th September, 1951, and lasted five days.

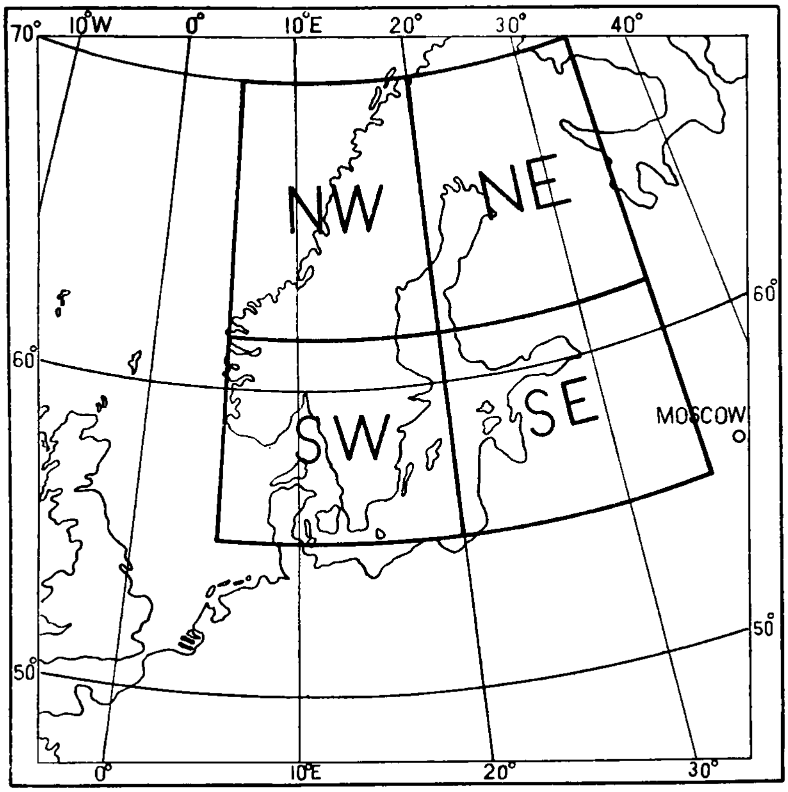


FIGURE 1. Region taken as Scandinavian showing the four sub-divisions

The numbers of days bears out Evjen's sample well and it is also apparent that the time each anticyclone spent in the Scandinavian region was greatest on average in January. The lower frequency in December and February compared with January may be to some extent an unusual feature of this particular twelve years. The occurrences of anticyclones over Scandinavia—the HF and HNF of the *Katalog der Grosswetterlagen Europas*[4]—over a longer period leads to the monthly distribution of spells lasting four days or more shown in Table IV.

TABLE IV. *Monthly distribution of HF and HNF (i.e. anticyclones over Scandinavia and Norwegian Sea)* 1881–1958

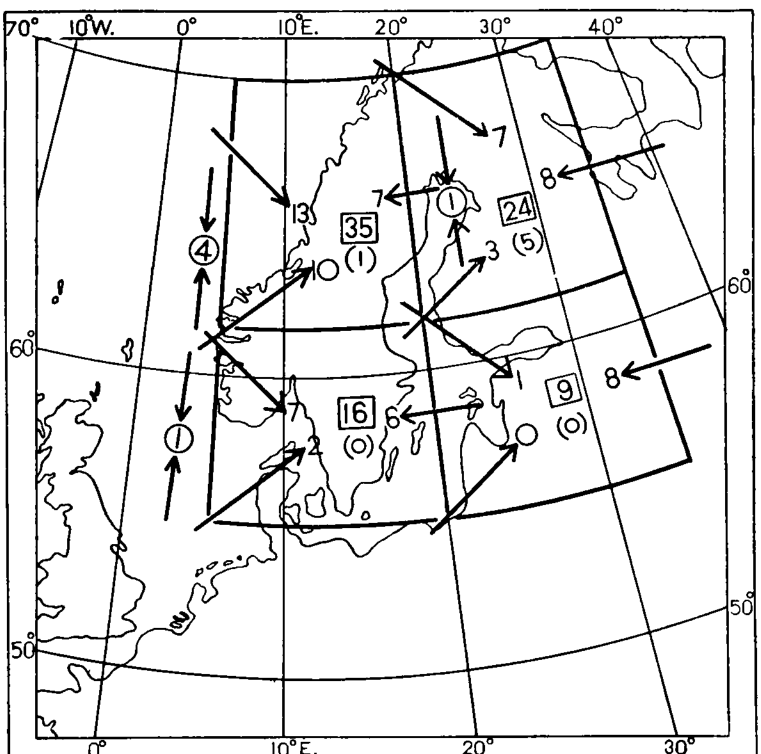
	October	November	December	January	February	March
1881–1899	4	7	4	3	9	4
1900–1919	7	2	4	8	4	7
1920–1939	4	2	6	5	5	6
1940–1958	8	5	5	15	8	3

There is a strong indication from these figures that Scandinavian anticyclones lasting four days or more were significantly more frequent in the last nineteen years than in any previous group of twenty years, but the difference arises almost entirely from the greater frequency of January anticyclones in the period 1940–58. Table V shows the probability of an anticyclone staying at least one day longer at each stage of its life based on the data for 1946–57.

TABLE V. *Probability of persistence for a further day during the life of a Scandinavian anticyclone*

No. of days in the region	2	3	4	5	6	7	8
Percentage probability of staying one more day	56	58	84	48	82	55	20

These figures indicate that if an anticyclone remains four days in the region there is a high probability of it going on to have a duration of five or more days. This, and the fact that an anticyclone moving across the region at about 20 knots could be three days in the region, suggest that it might be useful to regard anticyclones of two and three days' duration as non-persistent and those of four or more days as persistent for the purpose of subsequent analysis. It was found that only a minority of these anticyclones, and those mainly the weak ones, formed completely *in situ*. They most frequently arose from building of pressure near the crests of ridges of high pressure extending into Scandinavia from various directions. Usually there was only a single ridge involved on each occasion, but on a few occasions there were two ridges extending from opposite directions. As Table VI and Figure 2 show, these ridges had their roots mainly to the northwest and southwest of Scandinavia, though ridges extending westwards from the east of Scandinavia were as frequent in February, March and October. About 40 per cent of the anticyclones moved in as closed cells which



Numbers in brackets indicate formations in situ
→○← indicates ridges from both directions

FIGURE 2. Direction of arrival of anticyclonic "nuclei" into Scandinavian region

as a rule intensified over Scandinavia. These came in most often from the northwest quadrant, though in October and March a higher proportion came in from the east, but of these only two remained more than three days.

TABLE VI. *Mode and direction of origin of Scandinavian anticyclones*

Mode of origin	Persistent cases		Non-persistent 1–3 days	Non-persistent 2 and 3 days		All	Totals 2 or more days	
Ridge from SW	1		22	9		23	10	
„ „ NW	5	14	21	15	34	26	20	48
„ „ E	8		27	10		35	18	
Cell from SW	3		3	2		6	5	
„ „ NW	6	11	21	8	19	27	14	30
„ „ E	2		17	9		19	11	
In Situ	2		29	4		31	6	

Table VII shows that highs originating from the west were more common than those originating from the east, with little difference between persistent and non-persistent in this respect.

TABLE VII. *Direction of origin of Scandinavian anticyclones*

	From West	From East	*In Situ*
Persistent	15	10	2
Non-persistent	34	19	4
Both classes	49	29	6

There is, however, a marked difference between persistent and non-persistent anticyclones in their location on the first day in the Scandinavian region. Twenty-three out of 27 persistent anticyclones first appeared in the western half compared with 28 out of 57 non-persistent. That is, out of 33 anticyclones which were east of 20°E longitude on the first day only four persisted into or beyond the fourth day.

The most common reason for non-persistence was found to be steering eastwards and southeastwards out of Scandinavia. Nearly 60 per cent of the anticyclones moved out of the region towards the east and southeast, and about 30 per cent collapsed within the region. In October and November, however, the southeastward movement was a relatively more frequent cause of non-persistence than in the other months. March also showed a higher ratio of movement to collapse than did the three winter months December to February. Measurements of the geostrophic thermal wind over the centre were made in order to throw some light on this seasonal variation.

THICKNESS ANOMALIES OVER SCANDINAVIA

For all anticyclones lasting more than one day measurements were made of the 1,000–500-millibar thickness over the centre and the lowest value within the circulation of the system, for the first two days the anticyclone was over Scandinavia, which we will for the sake of brevity refer to as D and D+1.

These measurements were compared with five-year means for the appropriate region of Scandinavia and the results are given in Table VIII in terms of departures from normal in decametres.

TABLE VIII. 1,000–500-*mb thickness anomalies (Dm) associated with Scandinavian anticyclones*

	Oct.		Nov.		Dec.		Jan.		Feb.		Mar.		
	C	M	C	M	C	M	C	M	C	M	C	M	
Persistent	−1	−6	−5	−17	−9	−16	−5	−13	−11	−19	+10	+1	C = Centre
Non-persistent	−9	−15	−7	−14	−10	−19	−1	−9	−8	−15	+1	−5	M = Minimum

In general it is probably true to say that from November to February (inclusive) the thickness over the centre tends to be some 5 to 10 decametres below normal. The coldest air involved in the anticyclonic circulation was in general some 15 to 20 decametres below normal which means that it is of a coldness which for an anticyclone forming about 20 degrees longitude farther west would be very rarely available. The March and October persistent anticyclones, however, appear to occur with average or warm conditions. This is probably due to their occurring in association with pre-existent warm blocking situations.

IMPORTANCE OF LARGE THERMAL RIDGES IN THE EAST ATLANTIC

Nearly all of the winter anticyclones over Scandinavia formed in association with large thermal ridges in the east Atlantic. The exceptions were a few shallow cold anticyclones mainly in the northeast quadrant which usually did not grow above 1,020 millibars or last more than a day or two, and some formations in October and March associated with blocking situations over eastern Europe or western Russia, i.e. where the blocking anticyclone was out of the Scandinavian region. For a sample of 25 cases (11 persistent and 14 non-persistent) in the months November to February (inclusive) the positive thickness anomalies in the thermal ridges at D–1 and D were determined. The mean maximum anomaly was at about latitude 60°N at D–1 and amounted to 12 decametres for the persistent class and 16 decametres for the non-persistent. At D it was 16 decametres for the persistent class and almost at latitude 70°N, and 17 decametres for the non-persistent class and at about latitude 65°N. As these figures indicate, the thermal anomaly was in comparatively high latitudes and the thermal ridge usually had an amplitude of at least 15° latitude at D–1. The larger positive anomalies with the non-persistent class at D–1 is in part due to their being frequently associated with an existent strong warm anticyclone just to the southwest of the British Isles or, in some cases, over central Europe. It is noteworthy that the thermal ridges associated with the persistent class displayed greater growth from D–1 to D, and this was continued in the interval D to D+1, as the 1,000–500-millibar thickness changes at Bear Island (74½°N 19°E) given in Table IX indicate. With only two persistent anticyclones was the thickness change less than 6 decametres and in 50 per cent of cases it equalled or exceeded 12 decametres.

TABLE IX. 1,000–500-*millibar thickness changes D to D+1 at Bear Island for November to February cases*

24 hr change in Dm	⩽0	1–5	6–10	11–15	⩾ 16
Persistent class	1	1	5	3	3
Non-persistent class	4	5	4	1	0

There was usually an interval of at least 24 hours, cf. Rafailova,[5] from the appearance of a thermal ridge with an amplitude of 15° latitude and a positive thickness anomaly of 10 decametres to the occurrence of a closed anticylonic cell over Scandinavia.

The mean longitude separation of the surface anticyclone at D from the axis of the thermal ridge at D–1 was 31° longitude (usually measured about 65°N) with 50 per cent of the cases in the range 25–35°. The ridge axes were usually near Iceland at D–1 (two-thirds were between 15 and 25°W) indicating that most of the anticyclones first appeared well west of longitude 20°E.

The crest of the thermal ridge which was usually about the latitude of Iceland at D–1 was in the vicinity of Jan Mayen (71°N 8½°W) by D day and at D+1 was tilted over towards Bear Island, i.e. growth was just over 5° latitude each day.

RELATION TO OTHER SYNOPTIC FEATURES

There was usually, though not invariably, a broad southerly current (width about 15° longitude) of at least 50 knots at 500 millibars at D–1. It was always centred north of 50°N (usually north of 55°N) and most often in the longitude zone 20° to 35°W. On the western edge of this current and at about latitude 60°N there was commonly a deep surface low which had very often moved north or north-northeast in the preceding 24 hours. The separation of this low pressure centre from the axis of the thermal ridge at D–1 was measured for 21 cases. In 14 of them it lay in the range of 20–30° longitude (measured usually between latitudes 60 and 65°N), in five it was 15–19° longitude and only two were less than 15°. This rather large displacement constitutes a favourable situation for effective warm advection leading to the continued growth of the thermal ridge in the following 48 hours.

The centre of the warm surface current at D–1 was usually somewhere in the region of 60°N 20°W, and at D about 60°N 10°–15°W. The direction was usually between S and SSW: anything more veered than this was apt to lead to too much mobility of the thermal ridge in too low a latitude. Equally a current with direction backed as much as SSE especially if it was still at about 20°W (or farther west) on D–day is likely to develop the thermal ridge too far west to allow a warm upper high to develop over west Scandinavia by D+1 or D+2. Similarly a thermal ridge which reaches an amplitude of, say, 15° latitude west of 30°W is unlikely to be favourable. The anticyclogenesis is likely to occur north or north-west of Scotland: too far west to draw on the cold air supply from northeast Scandinavia.

On the basis of these facts we can construct schematic diagrams, Figures 3(*a*) and 3(*b*), of the synoptic situations at D–1 and D. We have seen that at D-day the positive anomaly in the thermal ridge was more or less of the same magnitude as the negative anomaly over

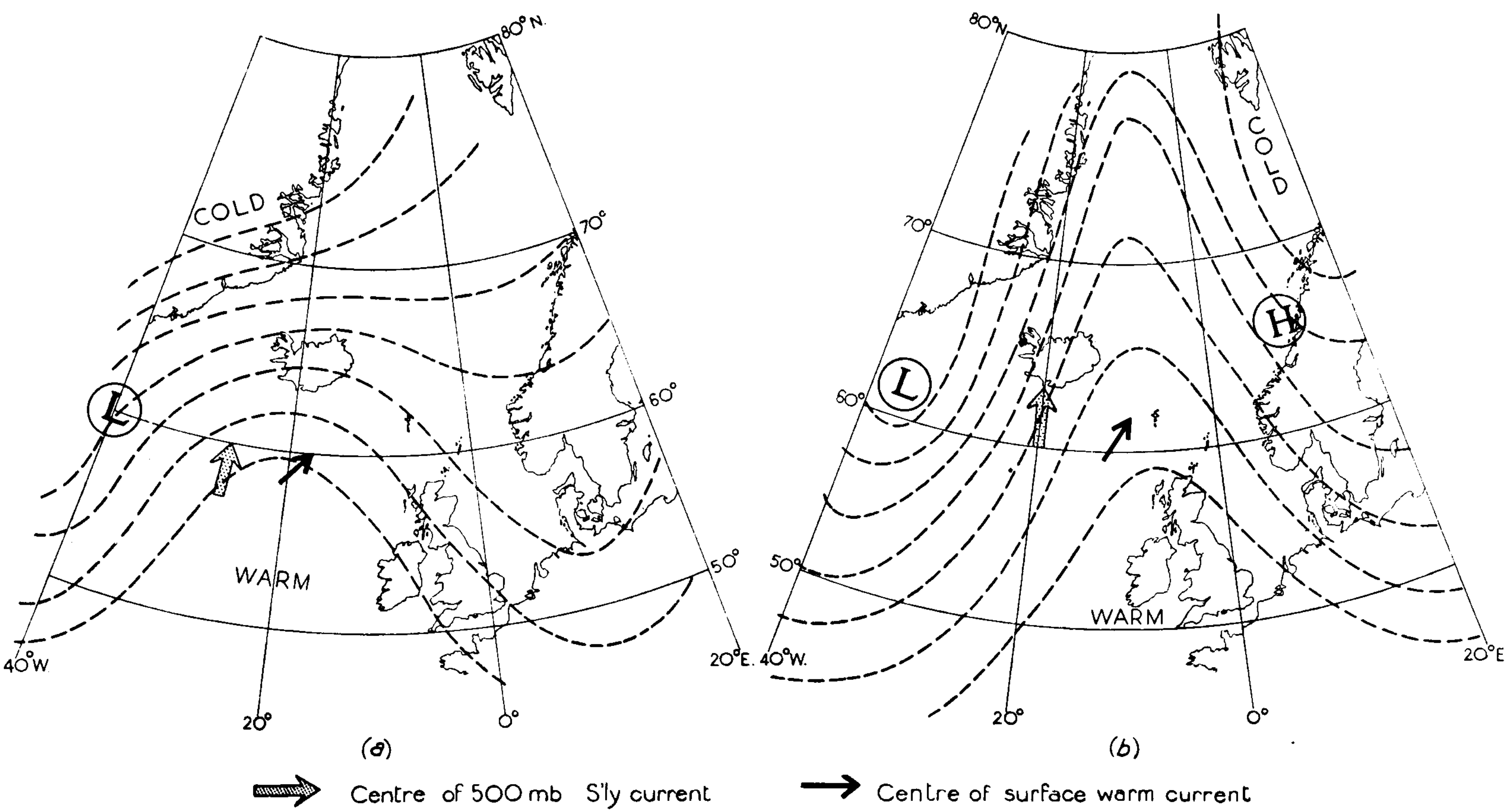


FIGURE 3. Schematic synoptic situation at (*a*) day D–1, (*b*) day D
— — — Thickness Lines, L Surface Low, H Developing High

eastern Scandinavia (see Table VIII). It is worthy of mention that at D–1 the anomaly in the ridge was clearly the greater. The negative anomaly over eastern Scandinavia, however, strengthens rapidly while the anticyclogenesis is going on.

THERMAL WINDS OVER THE ANTICYCLONES DURING AND AFTER FORMATION

These were measured over a distance of 500 nautical miles (normal to the thickness lines) centred over the surface anticyclone on the day before it entered Scandinavia (where possible) and on the first two or three days it was within the region. If the strongest belt of thermal wind was displaced at least 200 nautical miles from the centre, the amount of the displacement was noted.

For a sample of 30 strong anticyclones the mean thermal wind associated with the development stage was 340°/33 knots (18 out of 26 values between 320° and 360°). The normal thermal wind over Scandinavia at this time of the year is 300°/15 knots, indicating that the west-east thermal gradient was increased approximately four times. The mean value of the magnitude of the thermal wind for all anticyclones which spent more than one day in the region was 23 knots.

There was a noticeable tendency for the thermal wind over the centre to be more veered on the second day the anticyclone was in the region. This tendency was a little more marked in the period December to February (inclusive) than in the other three months.

RESPONSE TO THERMAL STEERING

From the measurements of thermal wind over the anticyclone centre and its movement in the following 24 hours it is possible to get some idea of how these growing systems reacted to the quite strong thermal gradients across them. The mean values of the ratio between the mean speed in the following 24 hours and the thermal wind are shown in Table X, omitting cases where the thermal wind was less than 20 knots.

TABLE X. *Distribution of ratio (Speed/Thermal wind) for Scandinavian anticyclones*

	Day before entering Scandinavia	1st Day	2nd Day over Scandinavia	3rd & 4th Days
Persistent	0·51 (14)	0·36 (19)	0·27 (11)	0·30 (8)
Non-persistent	0·44 (17)	0·41 (26)	0·54 (8)	N/A

(The number of cases for each is shown in parentheses.)

The mean ratio for all cases is 0·4, and frequently a substantial component of the motion was normal to the thermal wind so that for both classes the response to thermal steering was rather low. The most marked difference between the two classes appears on the second day, i.e. D+1, and this can probably be attributed to the greater extension of the thermal ridge north-northeastwards across the Norwegian Sea which occurred from D to D+1 with the persistent anticyclones. The southeastern part of a closed surface isobar near the centre was sometimes found to move, say south-southeast, at nearly the speed of the thermal wind while the northern part remained nearly stationary or moved northeast implying an increase in size and intensity of the anticyclone.

It is noteworthy that the mean magnitudes of the thermal winds were nearly the same for the two classes, at about 24 knots for all cases and 30 knots for the sample which excluded thermal winds less than 20 knots.

To provide a basis for comparison with the ratio representing response to thermal steering, similar ratios were worked out for anticyclones south of 50°N, on the Atlantic, and for blocking anticyclones in the longitude zone 0–30°W approximately. For the anticyclones south of 50°N the mean ratio for 51 cases was 0·75 and for the blocking anticyclones it was 0·50 for 52 cases. The value for the blocking anticyclones (35 cases) occurring in the period October to March was 0·45, which is quite comparable with the value for Scandinavian anticyclones.

An interesting difference however arises if we compare the figures for the three-month periods October, November, March and December, January, February as given in Table XI.

TABLE XI. *Ratio (Speed/Thermal Wind) for two classes of blocking*

	Scandinavian Highs	Blocking Highs 0–30°W
Oct, Nov, Mar.	0·53 (40)	0·33 (16)
Dec, Jan, Feb.	0·30 (48)	0·55 (19)

(Figures in parentheses are number of cases.)

The difference in the means for the Scandinavian highs is certainly significant, and it is noteworthy that the mean magnitude of the thermal winds is 31 knots for both periods. One might be tempted to conclude that the cold snow-covered terrain of Scandinavia in December, January and February was the cause of this low response to thermal steering, were it not for the similar low ratio for a sample of anticyclones mainly over the sea during October, November and March. Moreover the snow cover is mostly still present throughout March. These data again point to a quasi-stationary tendency in the long-wave pattern from time to time which maintains an anticyclone over Scandinavia in the mid-winter months but more readily to the west or east of it in autumn and spring.

LOCATION OF THE ANTICYCLONES IN RELATION TO THE MAXIMUM THERMAL WIND BELT

Nearly 60 per cent of the anticyclones on day D were centred under the belt of strongest thermal wind on the forward side of the thermal ridge, though in October and March nearly half of them were some 200–500 nautical miles to the west of it, i.e. they formed very nearly on the axis of the thermal ridge. In January, however, the majority of the centres, especially the persistent ones, were some 200–500 nautical miles to the east of the strongest thermal wind on day D. This may be due to the cold conditions over Scandinavia inducing the surface pressure maximum to appear initially east of the main development region or, as in the case 16/17 January 1950, to the existence of a cold cell over N.E. Scandinavia. One effect of the centre being towards the deepest cold air is that the circulation is able to draw very cold air from east Scandinavia southwestwards and contribute to the veering of the thermal wind over the centre which was found to happen more readily in January than in October or November. This might well be an important factor contributing to the isolation of a closed upper high from the main warm anticyclone; a process which is generally associated with persistence.

DISTRIBUTION AND INTENSITY OF THERMAL TROUGHS AT THE TIME OF FORMATION

Brezowsky,[6] and Singleton in some unpublished work on Scandinavian anticyclones, have remarked that outbreaks of cold air south-southeastwards across Labrador and Newfoundland preceded the formation of anticyclones over Scandinavia by a day or two. To test the forecasting value of this association all northerly and northwesterly airstreams within the zone 40–80°W longitude during the six winter months of 1955–56 and 1956–57 were recorded, if they were at least 500 nautical miles wide and were still northwesterly when they reached 50° latitude. The longitude of the centre of the current and its strength (pressure difference divided by width in hundreds of nautical miles) were noted for each outbreak. As the data in Table XII show, outbreaks between 50 and 59°W longitude had clearly the closest association with Scandinavian anticyclones, although they sometimes occurred a day or two after the formation of the anticyclones.

TABLE XII. *Cold outbreaks over W. Atlantic and E. America and association with Scandinavian anticyclones*

Long. at 50°N	40–49°W	50–59°W	60–69°W	70–79°W
Associated	6 (5·2)	9 (4·4)	3 (4·2)	1 (4·8)
Not associated	12 (6·4)	10 (4·9)	8 (4·6)	5 (4·8)

(Figures in parentheses are strengths of the airstreams.)

However, there were as many and somewhat stronger outbreaks which were in no way associated. It can probably be inferred at this stage that outbreaks of cold air over and just east of Newfoundland may be a necessary but are not a sufficient condition for the development of a Scandinavian anticyclone.

Evidently strong thermal troughs may be expected over the west Atlantic in association with Scandinavian anticyclones. Measurements of their strength in terms of thickness anomalies were made, and it was found that with 75 per cent of the Scandinavian anticyclones there was a thermal trough with a negative thickness anomaly $\geqslant$ 20 decametres upwind to 110°W. Table XIII shows the distribution of these in longitude zones on D-day for the period November to February inclusive.

TABLE XIII. *Locations of thermal troughs on D-day with a negative thickness anomaly $\geqslant$ 20 decametres*

Longitude zone (°W) Class	20–29°	30–39°	40–49°	50–59°	60–69°	70–79°	80–89°	90–99°	100–109°
Persistent	0	1	2	4	2	2	1	0	0
Non-persistent	1	1	3	1	2	1	6	3	3

Again 50–59°W seems to be the optimum range for persistent occurrences, and it appears that troughs west of 80°W are decidedly unfavourable for persistence. Another significant difference between the two classes is a greater tendency for there to be two fairly well-marked troughs, i.e. with negative anomalies of order 20 decametres (one in the Atlantic and the other some 50–60° longitude farther west) on D-day with the non-persistent cases.

The distribution of the anomaly magnitudes as given in Table XIV indicates that while a negative anomaly of 20 decametres or more does not ensure a persistent anticyclone it appears to be a minimum requirement.

TABLE XIV. *Negative thickness anomalies of all thermal troughs (20° W to 110° W) on D-day*

Max. negative anomaly in Dm.	< 10	10–19	20–29	30–39	⩾ 40
Persistent	0	0	6	5	1
Non-persistent	2	12	10	8	0

These anomalies are the maximum found with the trough, from measurements made at latitudes 40°, 45°, 50° and 55°N.

Many occurrences were preceded by the meridional extension of a thermal trough (cf. Miles[7]) in the longitude zone 0–30°E two or three days earlier. This is probably symptomatic of the first attempt to form a large thermal ridge in the east Atlantic, and the cut-off cold pool which frequently resulted may have played some significant role in the later anticyclogenesis to the north of it as suggested by Sutcliffe.[8]

There was frequently but not always a high-latitude thermal trough extending southwest from the region of Novaya Zemlya, which was brought into the circulation on D-day. This can be regarded as the "third cold sector" considered by Brezowsky[6] as an essential requirement for strong high-latitude anticyclogenesis.

However, strong and persistent anticyclones can form without this, e.g. 29 December 1954 and 21 December 1956.

ROLE OF WARM ANTICYCLONES

In a number of cases where a strong anticyclone over Scandinavia moved steadily south or southeastwards it was noticed that there was also a strong warm anticyclone on the east Atlantic. Other cases of non-persistence were associated with a strong surface anticyclone over Europe or southwest Russia at the time the Scandinavian high first appeared. The data given in Table XV suggest that a warm anticyclone of over 1,030 millibars is unfavourable to persistence.

TABLE XV. *Strengths of warm anticyclones centred to the south and southwest of Scandinavia on D-day*

Central pressure (mb)	1020–29	1030–39	1040
Persistent	7	3	0
Non-persistent	1	8	2

Anticyclones centred over S.W. Russia for some days are likely to create a situation in which it is difficult to draw sufficiently cold air into eastern Scandinavia between D and D + 1.

On the other hand a northeastward displacement of the east Atlantic high pressure cell into the region of the English Channel is often accompanied by or soon leads to the growth of a large thermal ridge and the subsequent formation of a Scandinavian anticyclone. To ensure the persistence of the Scandinavian system the original warm anticyclone must not be too strong on day D. The weakening of this anticyclone between D-1 and D as happened from 16 to 17 November 1956, may be a usual accompaniment to the establishment of a high-latitude block with the new baroclinic cell over Scandinavia becoming dominant.

The strength of a closed-contour high at 500 millibars in the area bounded approximately by 40°N and 55°N latitude and 20°W to 10° E longitude may also be a useful criterion for determining persistence. No persistent case had a closed contour higher than 570 decametres in this area on D-day, while several cases, where quite strong baroclinic anticyclones moved steadily southeast across Scandinavia, had values above 570 decametres.

ASSOCIATION WITH LARGE-SCALE CIRCULATION

Displacements of Canadian Cold Pole

A study of several individual persistent cases especially in January revealed that the 500-millibar flow over eastern America was stronger than usual south of 50°N. This state of affairs might not unreasonably be supposed to arise with a southeastward displacement of the Canadian cold pole from its normal January position at about 67°N 90°W. Péczely[9] has suggested from a study of a small number of cases that such a displacement towards Labrador or Greenland favours anticyclogenesis over Scandinavia about a week later.

To test these ideas, the dates of all displacements of 500 nautical miles or more in the sector 090° to 180° from the monthly mean position were noted for the six winters (November to February inclusive) from 1953 to 1958. Considering only cases when there was such a displacement on two successive days and measuring from the second day gives the results shown in Table XVI for the ensuing ten days.

TABLE XVI. *Displacements of Canadian Cold Pole and subsequent Scandinavian anticyclones*

	Displacements followed by Scandinavian anticyclone			Displacements not followed by Scandinavian anticyclone within 10 days	Total No. of Displacements
	1–3 days later	4–6 days later	7–9 days later		
Class of anticyclone					
All lasting 2 days or more	7	5	4	25+(6)	47
Persistent only	3	2	1	35+(6)	47

(Number in parentheses in fifth column represents displacements during a persistent anticyclone.)

With such displacements (and no discrimination as to intensity) it is clear that a Scandinavian high is far from being a usual consequence. Furthermore there are cases, for example, 13 January 1957 and 28 January 1957 of intense poles (25–30 decametres below the normal for the cold pole) displaced about 1,000 nautical miles southeast which were not followed by persistent highs, though the first case was accompanied by the onset of blocking just west of the British Isles on the same day, and the second was followed in two days by a non-persistent Scandinavian high. It was the rule (6 out of 8) rather than the exception for a displacement of the cold pole to occur at some time during a persistent high and, as Table XVI shows, the most frequent association was within three days rather than a week. It may be that the displaced cold pole is part of a circulation pattern accompanying the process rather than a feature causing or leading up to it. However, it was evident from the individual cases that a strong cold pool moving away from the east coast of America in say, the latitude band 40–45°N, could be quite as effective in increasing the circulation south of 50° latitude and leading to the growth of a large-amplitude ridge in the east Atlantic.

Above-average surface circulation over the Atlantic Sector

Elliott and Smith [10] have provided evidence that an above-average surface circulation over the N. Atlantic precedes blocking over N.W. Europe by some seven to nine days.

Data representative of the daily values of the surface W'ly flow over the Atlantic and western Europe have been published by the West German Meteorological Service for the period June 1948 to December 1957. These "drift" numbers, as they are called, were described by Rudloff.[11] It seemed possible that in so far as these Scandinavian anticyclones indicate the onset of blocking the drift numbers might indicate whether the effect described by Elliott and Smith was operative.

The values in Table XVII give the mean drift numbers over a period ten days before the appearance of an anticyclone over Scandinavia for four classes of data. Class A includes all the persistent highs of December and January (the months of strongest mean surface circulation) which represented the onset of blocking, for example, 17 January 1950 and 25 January 1950 were omitted because blocking conditions existed about 9 January 1950 and on 18 January 1950 (12 December 1955 was omitted because the surface high did not grow above 1,020 millibars in marked contrast to the other six which all exceeded 1,035 millibars). Class B includes all the persistent highs from November to February, and Class C a selection of the non-persistent cases for the same period. Class D comprises all the persistent cases in October and March.

TABLE XVII. *Mean westerly circulation (drift number) preceding D-day*

Class	No. in class	No. of days before appearance of high in Scandinavia: 10	9	8	7	6	5	4	3	2	1	0	Normal drift number for periods
A	6	30	31	35	33	31	27	21	21	20	16	9	16
B	13	20	19	22	19	19	17	15	14	15	12	7	14
C	18	15	20	19	18	19	18	17	16	15	12	10	14
D	7	9	6	5	8	10	9	10	10	8	7	8	9

The peak of 35 on the eighth day in class A is 19 above the December–January mean and this represents about $1\frac{1}{2}$ times the standard deviation of the daily values so that it may be regarded as significant. Peaks of over 30 in the drift number occur only once or at most twice a month during December and January. In the eleven Januaries 1947, 1949–58 (inclusive) for which values are available, from the German data (or have been worked out) there were 13 peaks of 30 or over. Six of these were followed by blocks over Scandinavia within ten days (two by the same block), three by blocks near the British Isles and four had no blocking within ten days. A peak of over 30 in these two months thus appears to give a useful indication of blocking within the next ten days either over Scandinavia or in the region of the British Isles. Considerations of the longitude of the growing thermal ridge may then at a later stage enable the longitude of the block to be determined.

Class B shows no significant peak, which is largely a result of including four cases where blocking already existed some ten days before the Scandinavian high appeared. Similarly class C is made up of very dissimilar sequences of drift number, but in the cases where the persistent block was over the British Isles, for example 9 November 1957, 13 January 1957, 20 January 1952, there was always a peak of over 30 in the ten-day period. As the figures in Class D show, there is no sign of a peak preceding the October and March persistent cases—a further indication that these are usually associated with existing warm blocking ridges.

500-*millibar circulation over America*

As was mentioned earlier some individual cases of persistent anticyclones were associated with above-average 500-millibar circulation south of 50°N over America. To test this an index was worked out involving the geostrophic wind at 500 millibars for the longitude zone 100–50°W for two latitude bands 35–50°N and 50–65°N, for 23 persistent and 23 non-persistent cases. The indices used for the results given in Table XVIII are means for D–1 and D and the figure on the left of the solidus is for the band 50–65°N and that on the right for 35–50°N.

TABLE XVIII. 500-*millibar circulation between* 50° *and* 100° *W at D*-1 *and D-days*

	Persistent *knots*	Non-persistent *knots*	Normal for the three months *knots*
Dec.–Feb.	28/45	22/50	21/44
Oct.–Nov.–Mar.	22/37	25/36	21/33

The means certainly do not permit the generalization of the impression gained from the initial six or seven cases examined.

ASSOCIATION WITH PERSISTENT EASTERLY SURFACE WINDS OVER THE BRITISH ISLES

The temperature level over the British Isles during persistent east winds in the months December to February is so markedly different from normal that prolonged spells of this sort are of special importance.

Singleton in an unpublished study found that there were 16 occurrences of easterly winds of at least four days' duration in the months October to March during the years 1946–57 inclusive, and 14 of these were in association with blocking anticyclones over Scandinavia or northwest Europe.

Adding the occurrences starting 15 January 1946, 4 February 1947, 21 February 1955 and 11 November 1957 which satisfy the criterion, at least for the south of England, gives 20 cases. Of these, 17 can be said to be associated with Scandinavian anticyclones, two (in Decembers 1948 and 1950) were due to ridge extensions from a high over west Russia, and one was due to a high near Iceland. Looked at another way, out of 27 persistent Scandinavian highs, 14 (6 in January) were in some way associated with these easterly spells. Three of the January persistent highs maintained easterlies, two of which had been started by non-persistent highs which moved west out of Scandinavia and the other by a high north of Scotland. Eight non-persistent highs out of 57 were associated with easterlies. Two in January (mentioned above) and three more moved west and maintained the easterly from a position north of Scotland. In two other cases, 11 November 1957 and 14 January 1957, it was a warm high north of Scotland that really maintained the easterly as the non-persistent cells moved southeast across Scandinavia into west Russia. In the other remaining case there were easterly winds to the north of a low over the Channel on 4 February 1947, a day before the non-persistent high appeared.

Persistent cells are thus about four times as likely to be associated with persistent easterlies over the British Isles as non-persistent ones, and those in January and February (10 out of 12) are especially likely to influence the British Isles in this way. Of the 22 anticyclones associated with easterlies, 17 first appeared in the western half of the Scandinavian region. Those centred east of 20°E only produce an easterly flow over England if they are large and have their major axis nearly west-east. The January and February anticyclones tend to be rather large, and are in addition usually more effective in leading to a considerable fall of pressure over France and Germany, which is probably an important element in a persistent easterly régime over England.

This fall of pressure can probably be attributed to the veering of the original upper northerly or northeasterly current over the Baltic—a feature of the January anticyclones noted earlier. The greater possibility of very cold air being brought southwest into Germany and France in January and February obviously favours this kind of development. Should pressure remain comparatively high over France, Germany and the English Channel a quite strong anticyclone over Scandinavia may not extend its circulation to the British Isles. It is fairly common in October for an anticyclone over Scandinavia to give rise to southerly or southeasterly winds over the British Isles.

CONCLUSIONS

The formation of winter anticyclones over Scandinavia is found to occur usually in association with a large thermal ridge which first forms over or just to the west of Iceland and then extends north-northeastwards across the Norwegian Sea. Occasionally, cells of high pressure appear over Scandinavia associated with deep cold air with a more or less zonal circulation pattern over the Atlantic, but they do not grow above about 1,020 millibars and rarely last more than a day or two. In October and March, anticyclones occur in association with blocking situations over east Europe and west Russia, i.e. the original blocking anticyclone is centred to east or southeast of the Scandinavian region.

The cold snow-covered terrain of Scandinavia appears to play at most a secondary role. It neither initiates a development nor maintains an anticyclone if the large-scale flow pattern is unfavourable.

Besides the large thermal ridge in the neighbourhood of Iceland on day D–1 the following factors leading to its further growth are usually present:

(a) Deep surface low about 60°N and between 30 and 45°W (i.e. some 20° longitude west of the thermal ridge)

(b) Well-marked southerly current at 500 millibars north of 50°N and between longitudes 20 and 35°W

(c) The east Atlantic high pressure cell displaced northeastwards towards the English Channel

For the persistence of the resulting anticyclone the following conditions are usually required to be satisfied on D-day:

(i) A single thermal trough in the Atlantic-American sector with a negative thickness anomaly greater than 20 decametres and located east of 70°W (A second trough west of 70°W is allowed if its negative anomaly is less than 20 decametres)

(ii) The absence of a closed-contour high exceeding 570 decametres at 500 millibars in the region between 40° and 55°N, and 25°W and 10°E

(iii) The closed anticyclone over Scandinavia west of 20°E on first appearance

(iv) The main warm advection not farther west than about 20°W longitude

A rule based on (i) and (ii) for D-day would have correctly predicted the persistence of 10 out of 12 persistent highs in the period November to February and wrongly predicted 2 out of 18 non-persistent highs to be persistent.

At D+1 a further criterion that the total thickness at Bear Island should have increased by 6 decametres or more between D and D+1 would have confirmed the earlier prediction of persistence in 9 out of the 10 and corrected the previous indication of persistence in one of the two non-persistent cases.

Non-persistence arose most often (about two thirds of all cases) as a result of movement east or southeastwards out of the Scandinavian region. The eastward movement could be attributed to continued mobility (and occlusion) of the thermal ridge, and the southeastward movement to thermal steering on the forward side of the thermal ridge, when this was being maintained by a warm blocking high near the British Isles. Decline of the anticyclone accounted for about a third of the cases and this could sometimes be attributed to the intensification of a trough in the zone 0–20°E as a result of fresh ridge growth well west of Iceland.

The strength of the Scandinavian anticyclone on the day of its first appearance offers no guide to persistence. The mean central pressure for the non-persistent cases was 1,030 millibars compared with 1,028 millibars for the persistent ones.

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Appendix

Dates and durations of all anticyclones lasting two days or more in the Scandinavian region in the months October to March (inclusive) 1946–57

Figure in parentheses after each date is the number of days the anticyclone was in the region.

1946

January	1st (2), 14th (8)
March	14th (2)
October	2nd (2), 8th (2), 22nd (4)
December	15th (3)

1947

January	3rd (3), 22nd (2), 26th (8)
February	5th (3), 14th (6), 28th (2)
March	6th (2)
October	22nd (4), 29th (2)
December	30th (2)

1948

February	6th (3), 16th (5)
March	1st (2), 15th (2), 18th (2)
October	9th (3), 28th (5)
December	12th (2)

1949

March	3rd (3), 10th (2), 28th (2)
October	30th (2)

1950

January	4th (3), 9th (3), 15th (8), 25th (10)
October	24th (5)

1951

January	7th (3), 22nd (5)
February	1st (2), 14th (2)
October	11th (5), 26th (2)
November	4th (3), 15th (2)

1952

January	20th (3)
March	6th (3)
October	2nd (2), 12th (3), 18th (4)

1953

January	3rd (3)
March	18th (3)
October	15th (6), 30th (3)
November	15th (2), 22nd (3)
December	17th (2), 29th (3)

1954

January	22nd (2), 26th (8)
February	14th (7)
March	13th (2), 29th (2)
November	17th (2)
December	29th (7)

1955

January	22nd (2), 30th (2)
February	18th (4), 24th (5)
March	11th (2)
October	22nd (2)
December	12th (5)

1956

January	27th (8)
February	8th (2)
March	19th (2), 23rd (5)
October	27th (3)
November	12th (2), 17th (7)
December	21st (7)

1957

January	13th (2), 30th (2)
March	23rd (2), 28th (5)
November	9th (3), 26th (5)
December	12th (2)

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