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METEOROLOGICAL OFFICE

GEOPHYSICAL MEMOIRS No. 50
(*Tenth Number, Volume V*)

PRACTICAL EXAMPLES OF POLAR-FRONT ANALYSIS OVER THE BRITISH ISLES IN 1925-6

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Published by the Authority of the Meteorological Committee

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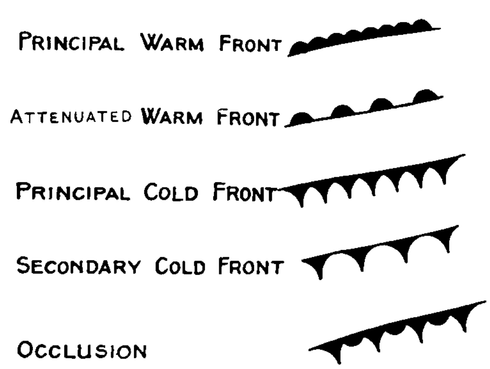
(*111). Wt. 27004—1660, 2109. 625. 7/30. T.S. 66.

PRACTICAL EXAMPLES OF POLAR-FRONT ANALYSIS OVER THE BRITISH ISLES IN 1925-6

INTRODUCTION

The following three weather sketches are intended to show the use of polar-front method on actual weather situations. Attempts are made to understand some of the physical processes responsible for the development of events observed on weather maps and autographic records. The explanations are of course not infallible and may be modified by continued research with more powerful technical aids. One such modification of the original theories is for the first time being introduced through this publication, namely : the explanation of fronts becoming diffuse as a result of adiabatic heating by descending motion on the cold side, and fronts becoming sharp by an ascending motion in the air of the zone of transition.

For the convenience of the reader the maps are enumerated with a letter, A, B or C, referring to each one of the series, and with numbers in chronological order within each series. The photographs of autographic records have the same system of letters. Their numbers within each series are in the order of first occurrence in the text. The symbols on the maps are the following :—



Hatching indicates the areas where rain is falling at the time of observation.

The maps are only of limited extent and it is therefore advisable to consult, for instance, the " International Section " of the *Daily Weather Report.*

A. MARCH 30 TO APRIL 1, 1925

On the 30th of March, 1925, a high pressure system extended from the region of Madeira to Central Europe. The British Isles were in the mild subtropical current north-west of the high. Over the Atlantic, colder air of polar origin was pushing southwards and eastwards. This colder air reached Stornoway during the forenoon of the 30th (drop of temperature from 47°F. at 7h. to 42°F at 13h). According to the autographic records, Lerwick was reached by the cold air between 15h. and 16h. Aberdeen at 21h. 25m., Leuchars and Renfrew just before midnight between the 30th and 31st. Also Malin Head came into the cold current between 18h. on the 30th and 1h. on the 31st, the wind changing from SW. to N. and the temperature dropping from 48° to 39°F. In the latter part of the night, Blacksod got the change from S.

wind with 50° to N. wind with 41°, so that on the morning of the 31st (map A 1), we may trace the polar front running south of Blacksod, Malin Head, Renfrew and Edinburgh, but north of Birr Castle, Donaghadee and Eskdalemuir. The lowest pressure was near Blacksod, so that the cold air could not push farther south from Scotland to England. Probably there was even a counter attack going on from the side of the warm air, east of the centre of low pressure, but it did not reach any of the synoptic stations north of the front. During the 31st, the low off Blacksod moved east-north-east to the North Sea and reached Norway on the 1st of April. A trough extending southwards from the centre passed meanwhile over Ireland and England. As it will be seen the passage of the trough line also marked the arrival of the cold air. Some selected autographic records will show the structure of the cold front which accompanied the trough in the various stages of its development.

The Valentia autographic records (Record A 1) show the passage of the cold front on the morning of the 31st at 4h. 45m. The sudden drop of temperature is not big, only a little more than 2°F., but it is followed by a gradual fall of about the same amount. The maximum temperature of the 31st reached only 48° (4·6 hours sunshine), whereas the 30th, when the warm current reigned, had a maximum of 53° (4·1 hours of sunshine). 5°F. can therefore be considered as the true temperature difference, between the interiors of the cold and warm currents at the surface. Higher up the difference was probably somewhat greater, because the cold air was in the state of being heated from below, which usually involves a steep lapse rate. The warm current had on the other hand, at any rate in south-east England, a small lapse rate, as can be seen from the Duxford ascents of the 31st.

The anemogram at Valentia shows a fairly steady wind direction, S. by W., up to 4h. 45m., then a somewhat irregular veer in the course of half an hour, to a little beyond SW. Later on a gradual veer continued until the wind had become northerly in the evening. Also the wind force showed a decided change at 4h. 45m. Up to then, the velocity was approximately constant about 12 m.p.h., but from 4h. 45m. to 5h. 30m. it dropped down to about 6 m.p.h.

Since the thermogram definitely fixes the arrival of the cold air at 4h. 45m., we have the result :—

(1) The warm current had steady direction and approximately constant speed just up to the cold front itself.

(2) The change of wind direction and wind velocity was going on within the foremost part of the cold wedge.

In this case it happened that the warm current had a greater average velocity than the cold. This is of course, not a general rule, it depends on the orientation of the cold front relatively to the isobars of the warm and cold currents. If the front is in the middle of the angle formed between the two sets of isobars (Fig. 1 b.), the horizontal pressure gradients on both sides become equal, which implies that the wind speeds are approximately the same in both currents. In our case the front direction was nearer to the direction of the isobars on the warm side (Fig. 1 a.), and the gradient must therefore have been stronger on the warm side. In the other case (Fig. 1 c.), when the front direction is nearer to the direction of

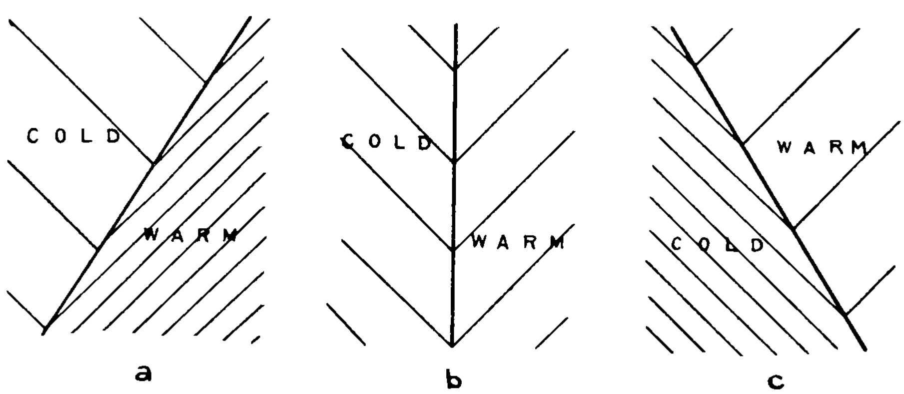


FIG. 1.—Orientation of cold front with reference to the isobars of the warm and cold currents.

isobars on the cold side, the cold current will be stronger than the warm. These purely geometrical relationships, which can easily be extended also to warm fronts, decide whether the wind speed shall increase or decrease at the passage of the front.

The typical gust at the arrival of the cold air does not appear on the Valentia anemogram, for the obvious reason that the wind was too strong before. The distribution of wind speed in the cold wedge was nevertheless normal—strongest at the foremost part and decreasing from there backwards. The rain at Valentia started 20 minutes before the cold front, but did not become heavy before 5h., that is 15 minutes after the cold air arrived at the surface. The rain then continued with decreasing intensity till about 7h. 30m. The greatest part of the rain must therefore have originated from the warm air while being lifted by the cold wedge. Also the barogram shows the cold front at 4h. 45m. The fall of pressure is at that moment suddenly replaced by a slow rise. This corner in the barogram entitles us to make a corresponding corner in the isobars where they pass the trough line.

The characteristic form of the barogram enables us to fix the time of the passage of the cold front at Roche's Point, 9h. 30m. and at Belfast, 12h. The anemogram, (only speed) at Weaver Point, close to Roche's Point, shows at 9h. 30m. the same characteristic decrease of wind force as that of Valentia.

The next synoptic station to be reached was Holyhead, the autographic records of which are given on Record A 2.

On the Holyhead anemogram the veer does not start suddenly. Already at 17h. there is a very slight veer, then a quicker one at 17h. 50m. to 18h. After some backing and renewed veer there is a sudden veer at 20h. 10m. marking the arrival of the NW. current. The thermogram shows the sudden drop of temperature at 20h. 10m. simultaneously with the last and most conspicuous veer. The temperature changes before then must have been quite minute, as the greatest part of the fall in the afternoon must be ascribed to the diurnal period.

The surprising feature is, however, that the rain is falling during the first slow veer of the wind, from 17h. 25m. to 18h. 50m. The sudden veer at 20h. 10., which also in the thermogram seems to be the most important part of the cold front, is accompanied by no rain whatever.

The results from Holyhead are verified by the other stations farther east. As an example the Andover autographics are reproduced (Record A 3). They show differences from the Holyhead ones in detail, but the two veers appear quite clearly. In the thermogram the first veer corresponds to a gradual fall, the second to a sudden fall of temperature. The entire drop of temperature appears small, because insolation starts soon after the second veer. The rain starts and is fairly strong during the first veer. At the time of the second veer the last slight rainfall has just stopped. The Scilly anemogram (Record A 4), shows the two veers farther apart, 23h. 35m. and 4h. 40m, but both well marked.

The Holyhead type of record is found on most of the stations farther east. Birmingham and Cranwell (not reproduced) have a slow veer and slow fall of temperature during the rain. A sudden veer and corresponding sudden fall of temperature comes afterwards without any clear connection with the rain strip. At Sealand (Record A 5), the first veer is accompanied by a more distinct fall of temperature, probably because that veer brought a sudden termination of the foehn from the Welsh mountains.

Southport, Fleetwood and Spurn Head (anemographs only) show two separate veers of a kind, similar to that in Holyhead—the first gradual, the second more sudden. Taking Spurn Head (Record A 6) as an example, the first cold front is represented by the gradual veer stopping at 3h. 15m., whereas the second cold front gives the much sharper veer at about 4h. (There is a variable time correction to be applied to the Spurn Head anemogram, therefore the times put on the map are a little different from those in the text.)

On maps A 6 and A 7, the times at which the two veers occurred at the various stations are shown. The first figures indicate the start of the veer, the figures after the hyphen indicate the end of the veer. The isochrones are drawn for each two hours, their breadth indicates the breadth of the zone of veer. In the case of the first veer (map A 6), the greatest breadth is found in the region Cranwell—Spurn Head. Farther south it decreases and at Scilly, Croydon, Felixstowe and Lympne, the duration of the veer is only a few minutes.

The Spurn Head anemogram (Record A 6) shows further veers at 5h. 25m. and 7h. The probable origin of these secondary cold fronts is to be found on the Eskdalemuir diagram (Record A 7). The first cold front at 17h. 20m. brings the wind round from SSW. to WSW., whereafter a period of slight SW follows. At 20h. 35m. another cold front brings a sudden veer to N. and an equally sudden increase of wind speed. Since Eskdalemuir is far from the other stations with self-recording instruments there are several possibilities of connecting up the passages of the fronts at Eskdalemuir with those farther south. The solution given on the map for 18h. on the 31st, appears however the most likely one. The first cold front is assumed to be single just as it was when passing Valentia, and the second cold front at Eskdalemuir would then really be a third cold front formed behind the centre. The shape of the cyclone on the 13h. map (map A 2), already suggests a cold front extending west-south-west through north Ireland. The cold air has completed the occlusion nearest to the centre, but there is still sufficient contrast of temperature between the cold NE. current and the air which has curved round and now moves from SW. In principle this cold front is really part of an occlusion, and is therefore indicated as such on the map.

The further movement of this third cold front can be followed on the synoptic maps and the map of isochrones (map A 8). At Spurn Head it arrives as the already mentioned couple of fronts, at Cranwell and Gorleston, it is more like one broad front, and at Felixstowe (Record A 8), it is again as sharp as it was at Eskdalemuir and has a very abrupt fall of temperature.

If this diagnosis is right, the third cold front offers an interesting example of a sharp slow-moving front being transformed to a broad (or double) front while accelerating, and again becoming sharp when slowing down.

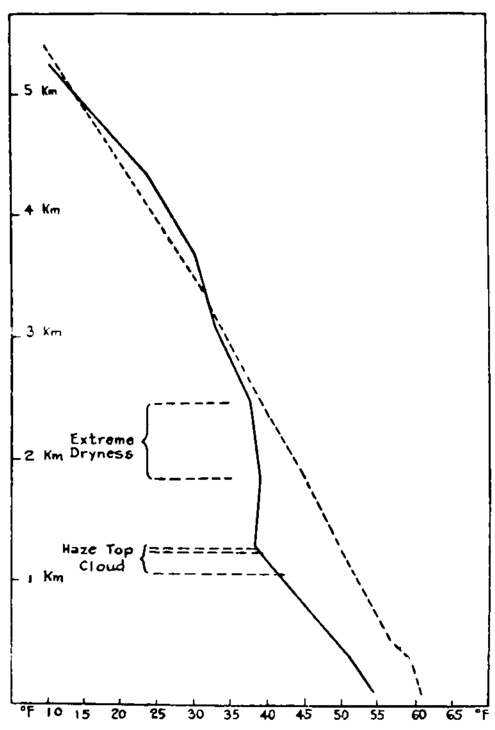


FIG. 2.—Lapse-lines before and after the passage of a line-squall.
..................observations taken in an ascent in front of the squall.
————observations taken in an ascent after the passage of the squall.

On the stations farther west, Fleetwood, Southport, Sealand and Birmingham there are only slight indications of the third cold front, and farther west and south no trace at all. This is quite natural when considering the way this front was formed —as the back-bent top of an occlusion.

Suggested Explanation of the double Cold Fronts

The change from the single cold front at Valentia to the double cold front at Holyhead, Scilly, Andover and stations farther east, and likewise the change from a single cold front at Eskdalemuir to double at Spurn Head, requires explanation. An attempt is made here to see whether the subsidence in the cold wedge may account for these phenomena.

The subsidence in the air behind a cold front has been revealed by several aerological ascents. A good description of the phenomenon has been given by M. A. Giblett in " Upper air conditions after a line squall," *Nature* 112, 1923, p. 863. In that case two aeroplane ascents were made, one immediately before and another some hours after the cold front. The two lapse-lines (temperature-height curve) are reproduced from Giblett's paper in Fig. 2. The temperature fell during the time between the two ascents in all heights below 3 km. The lowest part of the cold air up to 1·3 km. was in turbulent equilibrium with a fairly steep lapse rate. From 1·3 to 3 km., there was an almost isothermal layer with extreme dryness, which shows that this air must have descended from a considerable height. Moreover, the fact that the temperature in the dry layer was lower than that in the warm air, at the same level, shows that the descended air must have been derived exclusively from the polar air. A descending part of the warm current would naturally be warmer than those parts of the same current which have not descended.

Giblett's investigation thus proves (see Fig. 3) that the upper dry part of the cold wedge was descending (or at any rate had descended) and thereby had a temperature higher than that of the non-descending cold air at the same level, but colder than the warm air at the same level.

If the case described by Giblett is a frequent one (and there is much evidence for that especially brought forward by the Lindenburg school) it is only natural that one should occasionally find traces of the downward-sliding cold air also at the ground. On a thermogram that would appear as a dividing of the cold front into two. (See

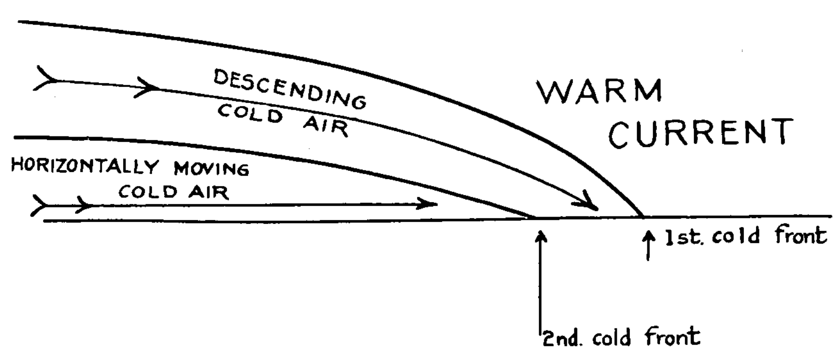


FIG. 3.—Diagrammatic representation of a double cold front.

Fig. 3). The air between the two cold fronts would have a temperature between that of the cold and warm currents. The greater the height from which the air had descended, the warmer it would be and the smaller the temperature contrast at the original cold front. The temperature contrast may eventually be completely transferred to the second cold front which separates the descended cold air from the horizontally-moving main cold current. On a hygrogram the air between the two cold fronts ought to appear drier than the air on both sides. This is shown in the case described by R. S. Read in the *Quarterly Journal of the Royal Meteorological Society*, October, 1925, p. 416, where the same dividing up of the cold front was found. It must, however, not be expected that dry air will always be found, because the air which has descended near the cold front is constantly travelling in the cold-front rain. It is therefore quite likely that the same air may have been heated by descending but yet has been kept wet by the rain. This seems to have been so in the case considered, so that the humidity registrations can neither prove nor disprove the assumed descending motion down to the ground behind the cold front.

On an anemogram both the cold fronts ought to appear as separate veers, this being a necessary effect of the close connection between temperature, pressure, and wind.

The simpler case with only one cold front can be represented schematically by Fig. 4. The vertical distance between unit isobaric surfaces must be greater on the warm side than on the cold, hence the refraction of the isobaric surfaces where they pass through the cold-front surface, hence also the sudden change of wind direction and force at the same boundary surface.

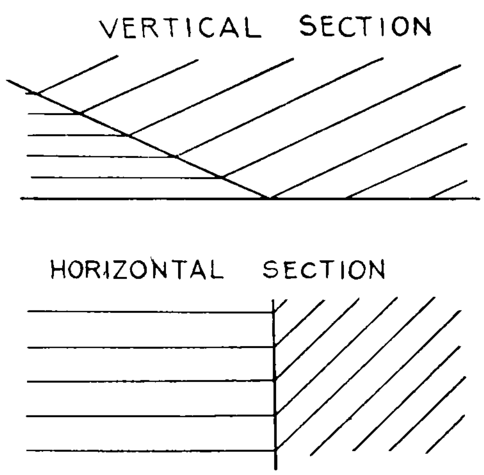


Fig. 4.—Sections across a cold front.

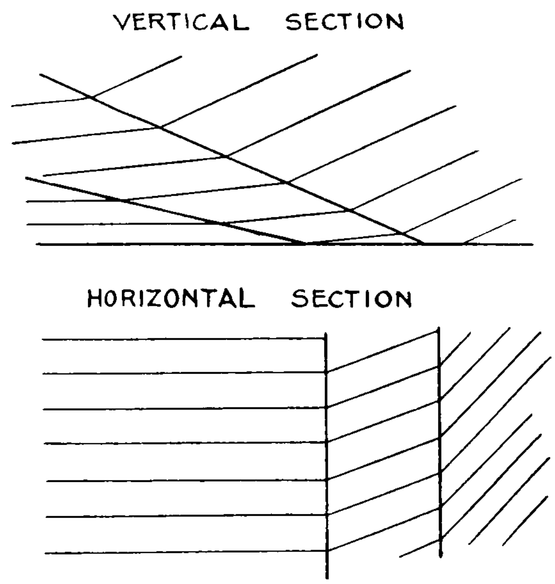


Fig. 5.—Sections across a double cold front.

If we now introduce a slab of intermediate temperature between the cold and warm currents (Fig. 5) the isobaric surfaces, will be refracted at both surfaces of discontinuity, and in the horizontal, the isobars will show the corresponding changes in direction when passing each one of the two fronts. The nearer the temperature of the intermediate air approaches that of the warm air, the smaller the refraction of isobars and the slighter the veer of wind at the original cold front. The wind contrast, like the temperature contrast, may therefore be transferred to the second cold front.

The complete knowledge of the horizontal field of motion at the cold front would enable us to use the equation of continuity for constructing the field of vertical motion in the layer nearest the ground. That can be done on any synoptic chart with a sufficient number of well observed winds, but even with the densest networks in use much detail gets lost especially at the fronts where the change from place to place is so great. We therefore get a better analysis of the structure of the front when using the particular anemograms at stations where the front has passed. This indirect method is not quite exact because it assumes :—

(1) That the structure of the front does not change materially during the passage, so that the winds as a function of time on the anemogram can be taken as representing winds as function of space in the atmosphere.

(2) That the derivatives of the wind parallel to the front (which cannot be found from the anemogram of one station alone) should be negligible as compared with the derivatives across the front.

Both conditions are likely to be reasonably fulfilled at most well marked and not too slow-moving fronts. Taking this as granted, we may build up the picture of the front as follows. Instead of the time scale on the anemogram we put a scale showing the distance run by the front simply by multiplying the time by the speed of the front perpendicular to its own direction. From this we may plot the winds at any point of a line perpendicularly across the front (Fig. 6).

Assuming that this cross-section of winds is not much different at neighbouring cross-sections to the front, we get the two-dimensional distribution of winds which is the nearest approximation to the real field of motion obtainable from one station only.

For the construction of the vertical velocity component it suffices for our rough purpose to use the simplified form of the equation of continuity: $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$

When placing the y axis along the front the derivative $\frac{\partial v}{\partial y}$ becomes negligible and we may write $\frac{\partial w}{\partial z} = -\frac{\partial u}{\partial x}$

By the aid of this equation we can find the vertical motion in the layers near the ground, positive $\frac{\partial w}{\partial z}$ means upward motion, negative $\frac{\partial w}{\partial z}$ downward motion.

We will apply this method on an ordinary cold front (Fig. 7), where we for simplicity assume the direction of the cold current everywhere perpendicular to the front, and the wind speed in the same current represented by the length of the arrows.

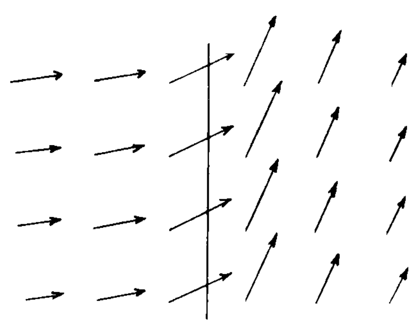


FIG. 6.—Diagram of winds across a cold front.

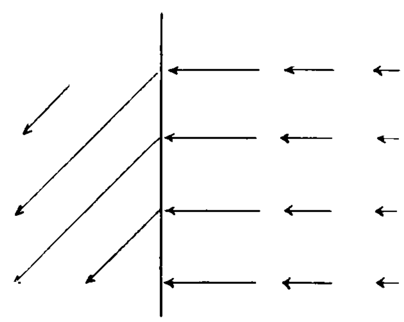


FIG. 7.—Diagram of winds across a cold front.

The vertical motion in the cold air will in this case depend merely on the distribution of wind velocity along the stream lines. We get downward velocity because on one and the same stream line a strong wind is followed by a lighter one. This will be the general case behind the gust which is so frequently found at the first arrival of the cold air (the case also included where the "gust" has a lighter wind than the warm current just before).

In the more general case where the stream lines of the cold air are not perpendicular to the front and where the veer may extend over some period of time, the gust is in itself not sufficient evidence for downward motion behind. After the decomposition in u and v components the point of strongest gust on the anemogram is not necessarily the point of the greatest u, and the region of downward motion $\left(\frac{\partial u}{\partial x} = +, \frac{\partial w}{\partial z} = -\right)$ may start farther behind the cold front. In most cases, however, the point of strongest gust is also the point of greatest u, so that the downward motion starts immediately at the cold-air gust on the anemogram.

The first cold front at Sealand (Record A 5) shows rather well the descending motion on the cold side. The orientation of the front was about north-east to south-west, so that the u component perpendicular to that direction (in this case NW. component) had its maximum at about 21h. 50m. and decreased from there to a minimum at about 22h. 40m. During these 50 minutes $\frac{\partial u}{\partial x}$ was positive and therefore $\frac{\partial w}{\partial z}$ negative; in other words there was downward motion in a zone commencing just behind the cold front. Since the front moved with a speed of 35 miles per hour the breadth of the zone of downward motion must have been about 30 miles.

The second cold front on the same diagram has not so much downward motion behind. There is a cold-front gust at 23h. 15m. but at that moment the wind has not completed the cold-front veer. At 23h. 30m., when the veer has finished, the wind speed is less than at 23h. 15m., but the *u* component perpendicular to the front is practically as big as it was at the time of strongest gust, 23h. 15m. Also in the subsequent hours *u* keeps almost constant so that the vertical motion must be insignificant in the current following the second cold front.

Such a couple of cold fronts—the first with downward motion behind, the second without—is rather often found. At Scilly (Record A 4) the first cold front at 23h. 30m. is followed by downward motion lasting $1\frac{1}{2}$ hours (breadth of zone again 30 miles) whereas the second cold front at 4h. 40m. has no appreciable downward motion behind. The same sort of couple is found at Spurn Head, the first cold front at 5h. 25m. is followed by downward motion, the one at 7h. is not.

The structure of the wind field in these and several more cases brings evidence for a zone of descending air just behind the first cold front. The descending air is colder than the warm current but warmer than the main cold current which arrives after a second cold front. This in conjunction with the previously mentioned results from aerology makes the scheme of Fig 3, the most likely structure of a cold front which has descending air in the foremost and uppermost part of the cold wedge. Since the vertical velocity must be zero at the ground, the only way to bring air particles from the free atmosphere down to the level of the instruments of ordinary observing stations is through turbulence. When we speak of heating at the ground as a consequence of subsidence in the free atmosphere, we must imagine the turbulence to be the intervening link which transports the heat down to the very bottom of the atmosphere.

Although most of the changes occurring with the cold-front system while moving from Valentia to Holyhead are accounted for in this manner, there has been given no satisfactory reason why the boundary between sinking cold air and horozontally-moving cold air should necessarily develop into such a sharp surface of discontinuity. One might just as well have expected a gradual transition. As a matter of fact the latter case is also often found and will be referred to in the other notes. It is difficult to tell what are the necessary conditions for the creation of a sharp surface of subsidence and a corresponding sharp second cold front. Perhaps it is the combined effect of sinking in the layer above, and turbulent up and down currents in the layer below the surface of subsidence. Once the surface has been formed the difference in the horizontal advection above and below may also help to keep up the existing discontinuity.

It may be of interest to consider what ought to happen if the sinking air becomes almost as warm as the adjacent warm current. While the difference in temperature decreases, the angle of inclination which gives equilibrium for the cold-front surface increases. When the difference decreases towards zero the inclination increases towards the vertical. We must therefore admit the possibility that a cold front surface becomes vertical at the places where the temperature contrast vanishes. It is true that where the temperature contrast vanishes there is no longer a thermal boundary surface. But other elements as humidity and wind (horizontal and vertical) are not likely to lose their discontinuity exactly at the same moment as the temperature. Also for temperature the perfect vanishing of the contrast is only a transitory state. A little more subsiding continuing by inertia would reverse the sign of the original temperature contrast and would let the boundary surface pass through the vertical state and assume the inclination of a warm-front surface.

This may appear rather speculative but a fairly frequent case of the kind may easily be imagined. Suppose that we have to begin with a cold front where the cold wedge in every level is colder than the adjacent warm current (Fig. 8 a). The warm current, however, will have a cooled surface layer of, say, 1 kilometre thickness (for instance as shown by Duxford on the 31st of March). The horizontal temperature

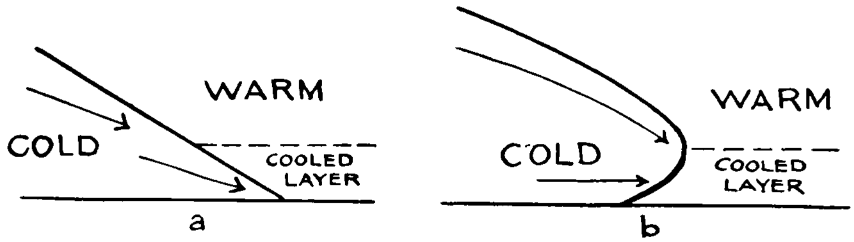


FIG. 8.—Diagram illustrating the degeneration of a cold front.

difference across the cold front will then be smaller near the ground than higher up. Let us now assume that the downwards sliding motion starts on the cold side in all levels. Provided that the cold wedge has a uniform lapse-rate smaller than the dry adiabatic, the downwards sliding will produce a uniform rise in temperature at all levels. The temperature contrast, thus being diminished by the same amount at all levels, will first vanish in the bottom layers where it was from the beginning small. The subsiding, which is still favoured by the remaining temperature contrast in the upper layers, will not stop immediately the bottom layers have had enough of it, and that will bring down air from the cold wedge which will be warmer than the cooled surface layer of the warm current. The boundary surface in that level will then have to pass through the vertical state to the forwards-tilting position of Fig. 8 b.

Such a cold front will at the surface bring a slight rise of temperature, followed later by a fall as soon as the zone of subsiding air has passed by. At a sufficiently high mountain station it would appear as a regular cold front, only more or less attenuated by subsiding on the cold side.

A cold front which has arrived in this stage of degeneration will have no sharp veer, but a zone of gradual veer. That is what we find represented where the first cold front passes Holyhead, Birmingham, Cranwell and Spurn Head.

The *rise* of temperature at the arrival of a " cold front " is not shown on any of the diagrams mentioned, but the case is quite frequent, especially in winter when the maritime polar air meets the continental air. The former may be the warmer at the ground, but the difference of temperature is very soon reversed higher up, so that we are entitled to speak of a *cold front* which is disguised by the local surface conditions.

It is a question of some importance to know when a cold front is going to degenerate in the above-mentioned way, and when it is going to retain sharpness. The full mathematical theory for these phenomena cannot yet be given, but some qualitative relationships may be indicated.

When the downward current reaches the ground it must spread forward over the region occupied by the warm air. A boundary surface which was at rest will thus start moving as a cold front as soon as the downward current reaches the ground. In the case when the cold wedge is already advancing, the start of the downward current would mean an increase of the velocity of propagation. Generally speaking the subsidence in the cold wedge should in the first instance lead to an acceleration of the cold front, and the persistence of subsidence will maintain a high speed of the front ; most fast-moving cold fronts should therefore have had so much subsidence in the cold wedge that the discontinuity at the front ought to be replaced by a zone of gradual transition (both in temperature and wind). The term " frontolysis," has been introduced by Dr. Bergeron for this transformation, from discontinuity to continuity.

For the diffuse cold front resulting from frontolysis to be transformed into a sharp one again, it is necessary for the air in the transitional zone to escape. Genuine cold and warm currents of air are then brought close to one another and the sharp front is re-established (" frontogenesis " in the terminology of Dr. Bergeron). Frontogenesis may also start in situations where no pre-existing diffuse front can be traced. It is sufficient for the field of motion to act in such a way that the isotherms aproach one another ; the final result is then a front. Fronts in the state of frontogenesis are usually slow-moving ones.

The second cold front is in this respect an exception as it was fast moving, but nevertheless sharp. This is, however, reasonable because the second cold front was formed within the moving cold current and was never accelerated afterwards. The isochrones of the third cold front furthermore show the change from sharp to broad front while accelerating, and the reverse while slowing down.

This knowledge of the behaviour of accelerated and retarding cold fronts adds new features to the picture of the " ideal cyclone."

Taking first the case of a cyclone at the moment of its birth, (Fig 9).

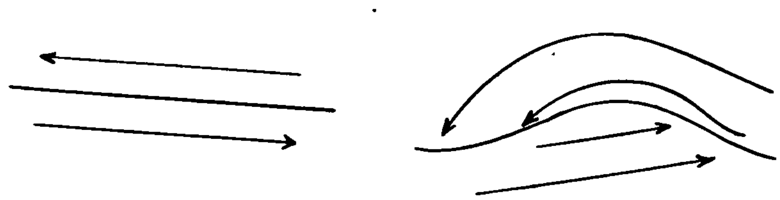


FIG. 9.—Birth of a cyclone.

The front is then to begin with stationary, with both the warm and cold currents flowing parallel to their mutual boundary. The part of the stationary front which becomes a cold front, is therefore from the first moment an accelerated cold front. While the " cyclone wave " moves east along the front, the cold air particles just north of the centre have an instantaneous motion from the E., which changes for the same particle to NE. and N. wind, when the centre has passed. This means acceleration of cold air particles perpendicularly to the front towards the warm region. The cold front immediately behind the centre is therefore an accelerated one, also after the cyclone wave has attained a finite amplitude, and should show the phenomena of downward motion and adiabatic heating in the foremost part of the cold wedge. During the further development of the cyclone the acceleration of the cold front goes on simultaneously with a further smoothing out of the discontinuity, so that as a rule in a fully developed cyclone the first cold front is fast moving but ill defined.

If a second cold front is formed behind the subsiding part of the cold current, it is usually more sharply defined than the first cold front. The precipitation is however missing, unless the subsiding air has had opportunity to pick up enough moisture after its descent to the ground. It is possible that, just as the original cold front has divided into two, one or both fronts may again subdivide. That case, however, seems to be rather rare and has not come into evidence in the examined situations.

More frequent is the case where the subsiding in the cold wedge creates a field of linearly decreasing temperature from the cold front to the interior of the cold current. This state would result from a maximum downward displacement of particles near the cold front, and gradually smaller downward displacement with increasing distance from the front. A priori that is perhaps more likely than the subdivision of the original cold front into separate small ones. It is not yet clear what conditions determine whether a cold front is to degenerate in the discontinuous or the continuous way.

Another very frequent type of cold fronts is that of the third cold front (maps A 2—A 5 occlusion) in the case discussed above. It is formed according to the scheme in Fig. 10.

The cold air near the centre has only a short distance to travel in order to complete the occlusion of the top part of the warm sector. It therefore often happens that this part of the warm sector disappears earlier than the rest. At the same time the lowest pressure will have a tendency to move to the north end of the remaining warm sector (Fig. 10 b and c). Once that has taken place the occlusion moves down behind the centre, as a secondary cold front.

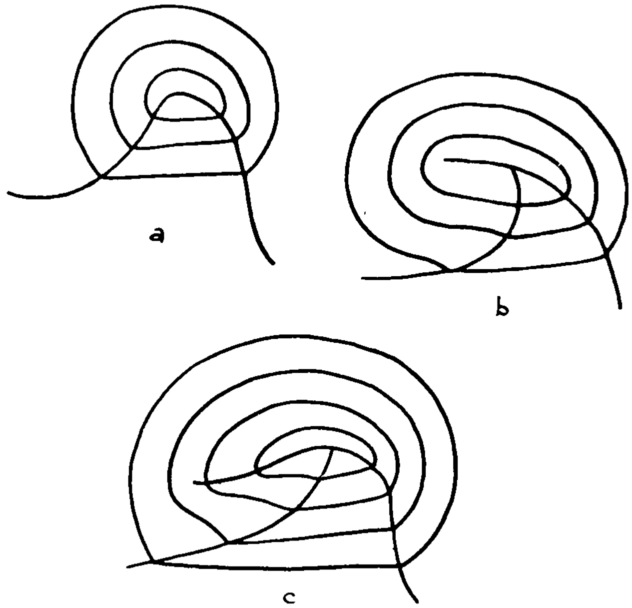


FIG. 10.—Occlusion as a secondary cold front.

This secondary cold front, which is really the top of the occlusion bent back, will have to be of limited length. In the case discussed, it was well pronounced only at Eskdalemuir and on the east coast stations down to Felixstowe, hardly visible at Sealand and not to be found farther west and south. No rain occurred with this cold front, but that must rather be considered as an exception. The rain might in the general case be quite abundant and long lasting in the part nearest the centre, but will naturally decrease towards the outer end of the cold front (see C, January 22–23, 1926).

B. FEBRUARY 10–11, 1925.

The weather situation the 10th and 11th of February, 1925, has been chosen especially to demonstrate the case in which a sharp front is formed where there was originally only a diffuse one.*

Valentia (Record B 1) shows the arrival of the cold air between 11h. and 12h. The fall of temperature is irregular and extends over more than 12 hours. (In cases like this we may agree to place the cold front at the beginning of the fall of temperature thus taking as a working hypothesis that all the air in the transitional zone originates from the cold supply. This rule has been followed in the drawing of maps. The rain lasts about 18 hours, which indicates a very broad cold-front rain. The barogram which gives a slight indication of the front between 11h. and 12h. deviates from the normal type in that a negative "surge" is superimposed. (The wind record is unfortunately defective just in the region of the front. There was evidently a veer although probably not a sharp one).

At Eskdalemuir (Record B 2) conditions were similar, with a considerable fall of temperature irregularly distributed over about 10 hours. Only the barogram shows distinctly at what time the cold front passed, namely at 14h. on the 10th. There is one noteworthy singularity in the thermogram and in the wind force at 19h.

At Holyhead (Record B 3) there is already more sign of discontinuity at 1h. on the 11th, there is a conspicuous veer coinciding with the steepest part of the fall of temperature. The cold front in the sense defined above is, however, at Holyhead already by 21h. of the 10th. At that time the fall of temperature starts and the rain begins. The quick fall of temperature at 1h. occurs in the middle of the rain ; it

* The same case has been treated from a slightly different point of view by N. K. Johnson in an interesting note in the *Meteorological Magazine*, April, 1925, p. 53. Moreover the 11th of February, 1925, is of interest because of the upper air data available. A balloon released from Sealand that day, showed a relatively high tropopause at the spot where a cyclone was being formed.

is a heavier downpour just then, but that is only a small episode in the non-stop rain from 21h. on the 10th to 6h. 20m. on the 11th. Also Southport (Record B 4) shows the same type—slight fall of temperature at 20h. 30m. where the rain starts, followed by a more marked fall at 3h. 45m. during the rain. Andover (Record B 5) also shows the same type but the sudden fall has grown immensely and there is only a little left of the gradual fall before it. Finally, at Croydon (Record B 6), where we must fix the beginning of the sudden fall at 22h. 45m., there are only small irregularities before the big drop of temperature, and the pre-frontal rain which was still to be found at Andover has practically disappeared.

Combining these observational facts, we may infer what happened.

The cold front arrived with a broad zone of transitional air through which there is on the thermogram an approximately linear fall of temperature (Fig. 11a).

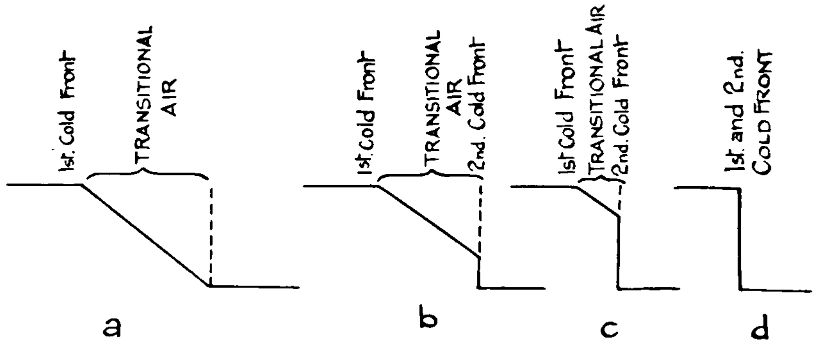


FIG. 11.—Types of thermograms corresponding with diffuse and sharp fronts.

Then the homogeneous part of the cold current pushed under the transitional air, which was forced to ascend. Once a certain part of the transitional air has ascended, a thermogram of the type in Fig. 11b will result. The cold current which is penetrating into the transitional air has met gradually warmer air and a temperature discontinuity now marks how far it has penetrated. If this process continues, there will gradually be less left of the transitional air at the ground (type of Fig. 11c), and the final effect may be that the whole change of temperature is concentrated at one point of the thermogram (type of Fig. 11d). (Hereunder we have assumed that the cold air, which pushes away the transitional air, itself retains constant temperature. This will of course only be fulfilled under special conditions and is not completely fulfilled in our case as we find a good deal of gradual fall after the sudden fall of temperature. It was probably again the adiabatic process which heated the foremost part of the cold wedge).

Fig. 11 exemplifies the essential part of the process of front formation. A diffuse front, or in other words a zone of gradual transition in temperature between a homogeneous warm and a homogeneous cold mass, becomes a sharp front if the intermediate air escapes upwards. This escaping upwards seems to start where the cold air undermines the transitional air. This new " cold front " penetrates across the zone of transition, so that cold and warm air finally come into direct contact with each other.

The veer of wind at the limit between the warm air and transitional air seems to get lost very soon, at any rate near the ground. Valentia and Eskdalemuir had some veer at that time, but Holyhead and likewise Andover already showed steady wind direction until the limit between the transitional air and the cold air passed by. In these circumstances it is quite natural that a rapid change from a diffuse to a sharp cold front took place. One can easily ascertain that the transitional air, which moved almost parallel to the front, could not escape horizontally from the cold air, which cut in at almost right angles to the same front. Consequently the transitional air had to ascend and let cold and warm air approach each other on the ground.

It might here be appropriate to remind ourselves of the limited validity of these qualitative considerations. In the equation of continuity with which we derived the formula for the vertical component of the wind in the neighbourhood of fronts, the term $\frac{\partial v}{\partial y}$ was neglected in order to get a formula merely containing quantities which could be read off autographic records at isolated stations. We are just discussing a case where the neglected term $\frac{\partial v}{\partial y}$ is perhaps not negligible, $\frac{\partial v}{\partial y} = 0$, means that when following along the front at any particular moment, the component of motion parallel to the front should be constant (although of course different on either side of the front). If tested that condition would in most cases prove unfulfilled. Taking map B 1 for 13h. of the 10th, one finds on the cold side a greater v, in the region of Edinburgh than at Valentia. To make a rough estimate, we may assume $v = 20$ mi./hr. at Valentia and 40 mi./hr. at Edinburgh. The body of air, 400 miles long, between the two places, thus during its motion becomes 20 miles or 5 per cent longer for every hour. The transitional air which covers a narrow zone along the front is thus dilating by 5 per cent per hour in the direction parallel to the front. If we for the instant abstract from the vertical motion this 5 per cent. dilation parallel to the front would correspond to a 5 per cent. contraction perpendicular to the front. In other words, without any transitional air escaping upwards, the breadth of the zone of transition would decrease at a rate of 5 per cent per hour. The term $\frac{\partial v}{\partial y}$ thus in our case assists in creating a sharp front out of a diffuse one. If starting with a thermogram of the type Fig. 12a characterised by a slow linear fall, one would subsequently get the transformation to the types b and c with a steeper linear fall. The true discontinuity would be reached asymptotically, viz., theoretically after an indefinite period of time. In this respect the thermograms of Fig. 12, differ from those of Fig. 11, where a discontinuity was created by penetrating of the cold air under the transitional air. The shape of the actual thermograms seems to indicate that the process of Fig. 11 after all has been the most important one.

Summing up we may state that the horizontal motion alone would, in the absence of other factors, have increased the temperature gradient across the zone of transition. But the discontinuity of temperature which suddenly appears together with the

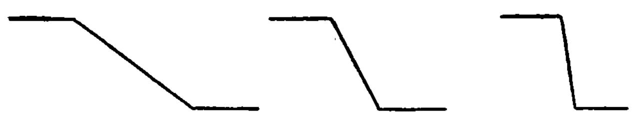


FIG. 12.—Types of thermograms corresponding with diffuse and sharp fronts.

linear fall, is a sign that some transitional air has ascended at that place and made it possible for cold and warm air to come into direct contact with each other. The latter process seems to be the quickest way to create discontinuities.

At all the stations mentioned hitherto the cold front passed once only; Sealand, however (Record B 7) represents an exception in that respect. The cold front arrived at 21h., indicated on the diagram by the beginning of slight rain and by a 2·5° fall of temperature. (Just as in the case first discussed the sudden fall of temperature is largely due to the abnormally high foehn temperature prevailing before. If Sealand had started with the same temperature as Holyhead, the cold front would have produced nothing but a continuous linear fall of temperature). After a second slight rainfall there is a sudden rise of temperature at 1h. The wind has for a while been very light from NE., but the warmer air which arrives at 1h. belongs to the SW current. In other words the cold front, after having passed Sealand, becomes retrograde and passes back as a warm front. After a rainless spell of 5 hours the cold front arrives again a little before 6h., this time accompanied by heavy rain, which becomes moderate continuous rain. The wind veers NW. and decreases.

The described succession of events shows that the cold front, which had already slowed down generally, had a wave-like disturbance travelling along it from SW. to NE. On the morning map of the 11th (map B 3) this disturbance is entered on the map as a little warm-sector cyclone north-east of Sealand. It is interesting to compare the rain records of Sealand and Southport. At the time when Sealand had the rain-free warm sector, it was raining continuously in Southport, because this latter place remained on the cold side during the passage of the small cyclone. The perfect absence of rain in the warm sector is far from being the rule, but it seems to occur rather often at Sealand, where the Welsh hills provide shelter against the lighter sorts of precipitation from SW

During the time when the warm sector passed Sealand, Southport had the afore-mentioned sudden fall of temperature which finished the " zone of transition." This shows that the zone of transition had then become a very narrow strip, a fact which is also indicated by the very sudden fall of temperature when the cold air arrived the second time at Sealand. The zone of transition which was much broader when passing Ireland, had thus contracted during the period of retardation which preceded the quasi-stationary conditions of the 11th of February. We have here one more verification of the rule that retarding cold fronts tend to become gradually sharper.

On the noon map of the 11th (map B 4) another young cyclone appears on the quasi-stationary front over the Bristol Channel. In the evening it has moved to the Midlands and has grown rapidly deeper. This time the warm sector is not entirely free from rain, at any rate we find it over a zone preceding the cold front. As already indicated, this might be the same phenomenon as we had at Valentia, Eskdalemuir and Holyhead. The original cold front may be at the beginning of the rain (gradual fall of temperature at Andover already from 18h.), although strongly masked at the ground, and the following cold front in the trough might be the one which appeared where the cold air pushed under the transitional air. But it may well be that the cold front in the trough is the only cold front, grown sharp because all transitional air has been lifted away. The gradual fall of temperature before it might be partly due to the rain itself and partly due to the time of day. For the pre-frontal rain one would then have to seek another justification which might be the following. The rapid fall of pressure increases the relative humidity of the already rather moist southerly current. This acts, at all levels, simultaneously, and thus prepares the possibility of thick cloud masses. In such a current a slight convergence might suffice for rain formation. No doubt there is always some general convergence towards the centre of a depression. The accelerated winds of the warm sector must transport air across the isobars towards the centre, and since the centre is not filling up, these masses must ascend and be transported away at some higher level.

This kind of pre-frontal cold-front rain, which is certainly very frequent in the British Isles, presents a very difficult but important problem. Upper air observations, close in time and space, would be necessary in order to see what is really happening in the layers from which the rain falls.

The newly-formed cyclone over the Midlands continued north-eastwards, and was next day a deep storm centre off the Norwegian coast. The cold front swept during the night with accelerating speed across south-east England and began to show the usual signs of degeneration met with during acceleration. The extraordinary sharpness observed at Andover (Record B 5) has already got lost a little at Croydon (Record B 6). The wind does not turn so quickly and the temperature does not fall quite so abruptly as at Andover. At Lympne (Record B 8) the entire veer lasts more than an hour, and two separate cold fronts may be distinguished both in wind direction and in temperature. We have here the same phenomenon which was discussed in the first part—a further verification that accelerating cold fronts become diffuse, or occasionally divide into two under the influence of the downward motion in the cold wedge.

The same phenomenon can be observed also on the diagrams for Cranwell (Record B 9) and Spurn Head (Record B 10). Cranwell has one cold front at 22h. 15m. and already a slight indication of a second one in the trace of wind direction just before 23h. At Spurn Head the second front at 23h. 50m. is already quite distinct and there are well defined relationships between direction and velocity variations. The first front is characterised by a quick decrease of speed which is indicative of descending motion in the foremost part of the cold wedge. The second one has constant speed of wind in the nearest region after the veer—in other words, no descending motion.

It is of interest to note that the cold-front couple does not necessarily occur all along one and the same cold front. In Felixstowe and Gorleston (not reproduced) there was instead a continuous half-hour veer. There must have been descending motion of a kind which gives continuous distribution of temperature and therefore also a continuous veer of wind instead of two separate veers.

C. JANUARY 22–23, 1926.

The series 22–23 of January, 1926, presents some typical events in the south-westerly type.

After a spell of cold weather, warm Atlantic air pushed in from WSW., climbed on the wedge of retreating cold air and produced warm-front precipitation. On the first map (map C 1) the warm air has already reached south-west Ireland, where temperatures have risen to 50° or above. The eastern part of the British Isles is still cold with slight frost inland. The temperature increases gradually from east to west through the rain area, so that the warm front does not concentrate in itself all the east-west contrast of temperature. The warm front is the line where the gradual rise of temperature is followed by a constant temperature.

The Valentia thermogram (Record C 1) exemplifies these conditions. There is a rise of altogether about 7° distributed from 21h. on the 21st to 4h. on the 22nd. In such circumstances it is only by an arbitrary definition that we can fix the position of the warm front on the thermogram. It will, just as with the cold fronts, be a rational principle to place the warm front so that it separates air of *cold origin* from air of *warm origin*. Taking this as our working principle the question arises: is the transitional air of cold or of warm origin?

There are several reasons in favour of ascribing all the transitional air to the cold origin. In analogy with the cold fronts we must expect an upward motion on the warm side and a tendency for downward motion on the cold side. There is aerological evidence for the downward motion of the cold air under the alto-stratus of the warm front; such downward motion will tend to raise the temperature of the cold side. The transitional air can accordingly be derived from the cold source by adiabatic processes but not from the warm. If the transitional air were cooled masses from the warm source, one would have to look for other processes than the adiabatic ones to explain the loss of heat which has taken place. The loss of heat in contact with the ground might be thought of, but it is not before the very end of the period of transition that the air temperature has risen above that of the sea. Through the greatest part of the zone of transition the air exhibits the usual "polar-air criterion"— air temperature below that of the sea. The trajectories must therefore lead back to a cold source, although the air is just for the moment flowing from south.

The possibility of the transitional air being a mixing product of warm and cold air deserves careful consideration. Mixing is always present, and since it works ceaselessly in destroying discontinuities its accumulated effects may be of importance. Nevertheless I am not inclined to believe that mixing alone would be able to create a zone of transition several hundred miles broad. The limited importance of mixing is best seen in the case of a front which changes from a diffuse to a sharp structure. Mixing is then present all the time and tries to hinder the creation of discontinuity, but there are obviously factors stronger than mixing which in that case determine the result. These are the air transports which bring into contact air with different life histories. The sharpest discontinuities are formed when the vertical motion also enters into action and makes the transitional air ascend. If we take the opposite case, when a downward motion on the cold side is creating transitional air, then the air transport and mixing act in the same destructive sense on the discontinuities. In this case we cannot directly see which factor is the strongest, but it seems to be a fair conclusion that then also the vertical motion with consequent adiabatic process is a much more powerful factor than pure mixing.

Although many of these questions need further and more exact investigation, we may retain as the most probable working hypothesis that the greatest part of the transitional air is of cold origin also in the case of warm fronts.

In the case of Valentia we therefore place the warm front at 3h. or perhaps even 4h., the earliest time at which the temperature reaches the level where it remains throughout the warm sector. This time also fits well with the time for the end of the veer and the end of the measurable rain. The agreement is not so good with the barogram, which indicates the change from falling to steady pressure already at 2h. There must have been something up above which has compensated the last part of the fall to be expected from surface conditions.

Perhaps the most likely explanation is that the warm front we are describing was really some time ago an occlusion. Occlusions are often shown by a trough in the barogram under the point A of Fig. 13, that is before the arrival of the front on the ground. If this is right the warm air in our case has not been warm air for a very long time. But the essential for us is to state that the air in the south-west corner of the map C 1 is the warmest air we shall have to deal with in the following development of events.

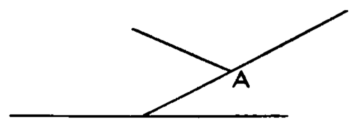


FIG. 13.—Vertical section through an occlusion.

The conditions described for Valentia are found to be rather similar at Holyhead (Record C 2). Thermogram and wind-direction trace analysed according to the above principles fix the warm front passage at 13h. A difference from Valentia is the early cessation of the rain—two hours before the warm front. On the whole the rain in this section of the warm front has been slight. Sealand (Record C 3) with its well defined warm front at 15h. only reports traces of rain during the whole passage, and several stations on the 13h. and 18h. maps have intermittent or no rain in the region where a normal warm front ought to have given continuous rain. It must be considered as an exception that the Wales and Cumberland hills are able to afford shelter against warm-front rain as they did in this case.

At Andover (Record C 4) the anemogram indicates a sort of front at 17h. and the quickest rise of temperature also occurs at that time. But there is a further slow veer and slow rise of temperature going on till 2h. in the night. It seems to be a thin layer of cold air near the surface which drags behind and only slowly becomes mixed with the air of the warm current above. This phenomenon is still more pronounced farther away from the depression, where the surface wind velocities are smaller.

Over France and south-east England a layer of relatively cold air persisted even the following day. The attenuated warm fronts on the 7h. and 13h. charts of the 23rd are intended as a reminder of the cold surface layer over the south-eastern corner of the map. Only west and north of that line was the ground swept clean of remnants of cold air. Slight rain and drizzle occurred over the region where the remnants of cold air were being absorbed and also in the warm current itself.

In the north the development of the weather was essentially different. The Hebrides also had the rain on the morning of the 22nd, but immediately behind it there is broken sky with clouds of Cu. type and occasional showers. Although this air arrives from WSW. it must evidently be polar air. At the same time the dull and drizzly type of weather persists in the south, where there is a current of the same direction (WSW.) but of subtropical origin. The limit between the two almost parallel currents can best be found by the cloudiness itself, but the temperature also gives some indication. Blacksod has 51° in the morning and 49° at noon, so that air of colder origin must have arrived during the forenoon at that place. This cold front, which is also characterised by a rise of pressure behind, is on the noon map to be found between Blacksod and Valentia and extends from there to the region of Donaghadee, where it joins with the warm front. North of the point of junction we have an occluded front as line of separation between the continental polar air from the south and the maritime polar air from the west.

The two diagrams, Eskdalemuir (Record C 5) and Aberdeen (Record C 6), show the passage of that occlusion. Eskdalemuir was rather near the point of junction, so that the beginning of the diagram is like that of stations farther south when the warm front was approaching. There is a gradual rise of temperature simultaneous with a slow veer. At 17h. the maximum of temperature is reached, but this maximum (44°) is low relatively to that of Valentia (52°) even if the greater altitude of Eskdalemuir is allowed for. But immediately afterwards the fall of temperature begins under the influence of the arriving maritime polar air from the west.

The Eskdalemuir thermogram can be considered as typical for the passage of fronts which are just recently occluded—first a gradual rise, as that experienced during the approach of warm fronts, then a gradual fall as that behind the cold fronts. In this case the rise was greater than the fall, but that is different from one case to another ; in summer one would usually find more fall behind than rise in front.

The typical little maximum at the passage of the occlusion is also found at Aberdeen, where the temperature reaches 41° at 15h. (simultaneous trough in the barogram). This is obviously a polar-air temperature for that place and it is a considerably lower maximum than that reached at Eskdalemuir. Even the second maximum, 43° at 18h. caused by sunshine and foehn, is lower than that of Eskdalemuir in spite of the difference of altitude.

The only measurable rain at Aberdeen fell very early from alto-stratus, which had passed the Scotch mountains without being affected by downward currents on the lee side. The latter part of the rain which should presumably fall from lower alto-stratus has been very slight because of the sheltering influence of the mountains.

A situation like that of the 22nd at 13h. (map C 2) with a polar westerly current in the north and a sub-tropical westerly in the south is an almost unmistakable sign that a new disturbance in the shape of a young deepening depression is due to arrive. In this case the depression must have formed not very far off the Irish coast on the continuation of the quasi-stationary front which separates cold and warm westerlies. The next morning the depression is over northern Ireland and continues north-eastwards during the day, becoming deeper from map to map.

The diagram of Valentia gives a good example of the front structure of a young depression.

The afore-mentioned limit between the polar and the sub-tropical part of the westerly current went slowly southwards during the day of the 22nd. At about 13h. the temperature starts falling at Valentia and at 19h. 30m. the temperature has gone down 4°F. It is a cold front at which all discontinuity is smoothed out. According to our previous rules the cold front is drawn at the beginning of the fall of temperature, and is thus the limit between the field of quasi-constant temperature in the warm sector and the sloping field of temperature in the nearest part of the cold air.

It is interesting to see how this diffuse cold front returns as a rather sharp warm front only some few hours afterwards. A sudden rise of temperature starts at 20h. 35m. and in less than half an hour the temperature of the warm sector is re-established. The corresponding changes in wind direction and force are also fairly sharp. This change of structure from diffuse to sharp front is in reality the same as we have seen with retarding cold fronts in the two previous cases. A cold front which slows down and then moves retrograde as a warm front is physically the same as a retarding cold front.

If we generalize this principle, a warm front which is slowing down and then changes into a cold front should be physically analogous to an accelerated cold front. In this case the structure of the front should change from sharp to diffuse. That is just what we see on the Valentia diagram at the next return of the front at 4h. of the 23rd. Although the front is then moving much more quickly, the fall of temperature is going on at a slower rate than the previous rise ; likewise the veer lasts more than 2 hours, whereas it was only 20 minutes when the same front was a warm front.

These conditions ought to be found generally near the centre of young depressions. The first cold front which arrives behind the centre has recently been a warm front during the approach of the centre. It is therefore an accelerating cold front which is changing from sharp to diffuse structure.

Eskdalemuir which was very near the path of the centre of the depression gives a further verification of the rule. There is a warm front at 7h. 20m. which is very sharp both in respect of temperature and wind. But the return of the same front as a cold front between 12h. and 13h. is much more diffuse, the veer is insignificant, and the fall of temperature is spread out to a linear fall lasting several hours.

The same cold front passed Holyhead, 10h. 30m., Sealand at 12h. 30m. and Andover at about 15h. The fall of temperature at all three places is smaller and less abrupt than at Valentia. Sealand has most left of the fall of temperature, but that is again an effect of the high temperature which is there reached in the warmer sector. From 1h. to 6h. 30m. and again just before the cold front Sealand had a foehn.

At Scilly (Record C 7, anemogram only) we find the cold-front couple typical for accelerated cold fronts; the first one at 9h. 30m. with decreasing velocity behind the second at 12h. with constant velocity behind. The second cold front is just visible at Holyhead at 12h. so that it has been possible to fix its position on the 13h. map.

It is important as well to notice the shape of the barograms. At Valentia the warm front marks a point where a rapid fall of pressure changes into less rapid fall. The static effect of the warm front alone would be a fall of pressure as long as cold air is replaced by warm air, and then no further change of pressure. In all cases where the warm front is part of a deepening depression there is, however, a negative surge superimposed, so that a fall of pressure continues all through the warm sector. The arrival of the cold air brings at Valentia a rise which just over-compensates the negative surge due to the deepening of the depression so that a slow rise results.

At Eskdalemuir it is already different; the cold front at 13h. only just suffices to stop the fall of pressure for a while, whereafter a new slight fall begins. Since the fall of pressure through the warm sector was approximately the same at Eskdalemuir as at Valentia, we may conclude that the wedge of cold air arriving at Eskdalemuir was less steep and contained probably more degenerated heated cold air than that which had arrived over Valentia. The latter is also supported by the thermograms, the fall of temperature is relatively quicker at Valentia than at Eskdalemuir. A wedge of cold air which undergoes a change in that sense must necessarily produce less pressure effect.

Both barograms suggest a further singularity: Valentia a sudden change from slow rise to rapid rise at 10h. and Eskdalemuir a change from slow fall to rapid rise at 16h. There is a corresponding veer at both places, most pronounced at Eskdalemuir. The temperature is falling during the time in question, but there is nothing particular to show a really sharp cold front at the time when the barograms indicate the troughs.

At Holyhead the same system has developed into a real cold front of great sharpness (passing at 15h.). This third cold front (if the secondary cold front on map C 5 is counted as the second) is indicated on the maps by a line of occlusion. In analogy with the third cold front in the case first described (pages 6 and 12) it can be considered as the back-bent northern end of the occlusion. In the beginning there is little contrast of temperature at this front because of the similar life histories of the various parts of the cold air close to the centre. But the more the trough develops in the region of the back-bent occlusion (maps C 5 and C 6), the more difference there will be in the life history of the air on both sides. The final temperature after the third cold front, is the same at Valentia and Holyhead—about 44°—but the temperature before it is 1° warmer at Holyhead than at Valentia; 1° has thus been added to the temperature contrast. At Sealand the temperature is still 1° higher before the arrival of the third cold front (17h. 15m.), so that a discontinuous fall of 4° and a very brisk rise of pressure result. It will usually be found that the contrast of temperature at the back-bent occlusion develops as a result of an increase of temperature in front, while it remains more or less constant behind. With the development of the trough the air in front of it, although of polar origin, has to move along a curved trajectory ending up with a motion from SW. That obviously must give a higher temperature than for the particles which arrive more directly from the N.

At Andover one might have expected a further accentuation of the third cold front, but that is not so. The fall of temperature at 21h. is probably the remainder of what was on the other stations the third cold front, but the barogram does not show any sign of a trough at that place, nor is there any rain or well marked veer connected with it. Also the other southern stations from Scilly to south-east England show the third cold front very faintly or not at all. The *third cold front* is thus *of limited length* as a back-bent occlusion ought to be.

These conditions are important to remember when analysing synoptic maps. It is often found that the cold front which has the most conspicuous trough near the centre fades away already at a limited distance from it. That is then usually the back-bent occlusion. The first cold front is in such a case to be found in a masked state without a distinct trough nearest to the centre, but farther away it may be the only important cold front with a good contrast of temperature and occasionally with a V-shaped trough.

The rainfall in the last depression needs to be specially mentioned, because there are several departures from normal conditions.

The warm-front rain was at Valentia, Holyhead and Sealand quite according to rules. It stopped just at the passage of the warm front itself and the rain in the adjacent part of the warm sector was slight and intermittent. But Eskdalemuir which was quite close to the passing centre has heavy continuous rainfall all through the warm sector. Such a downpour is only possible if the air in the warm sector is ascending bodily at a considerable velocity. That kind of ascending motion in the part of the warm sector nearest the centre must undoubtedly be admitted in many depressions.

The rain at the first cold front is chiefly pre-frontal. At Valentia for instance, the bulk of the rain is about 3h., but the cold front does not arrive before 4h. when the rain has already become very slight. An explanation may be that the veer starts somewhat earlier, which would indicate some convergence in the warm current before the arrival of the cold front. Holyhead and Andover have the same pre-frontal rain at the first cold front.

The rain of the back-bent occlusion was heavy and long-lasting at Valentia and equally long-lasting but slighter at Eskdalemuir. At both places the rain was falling both before and after the proper cold front. At Holyhead and Sealand finally one finds the classical cold-front rain—beginning exactly with the arrival of the cold front, short duration, heavy at first and then slighter. This seems to be well in harmony with the development of a sharp front from originally diffuse conditions.

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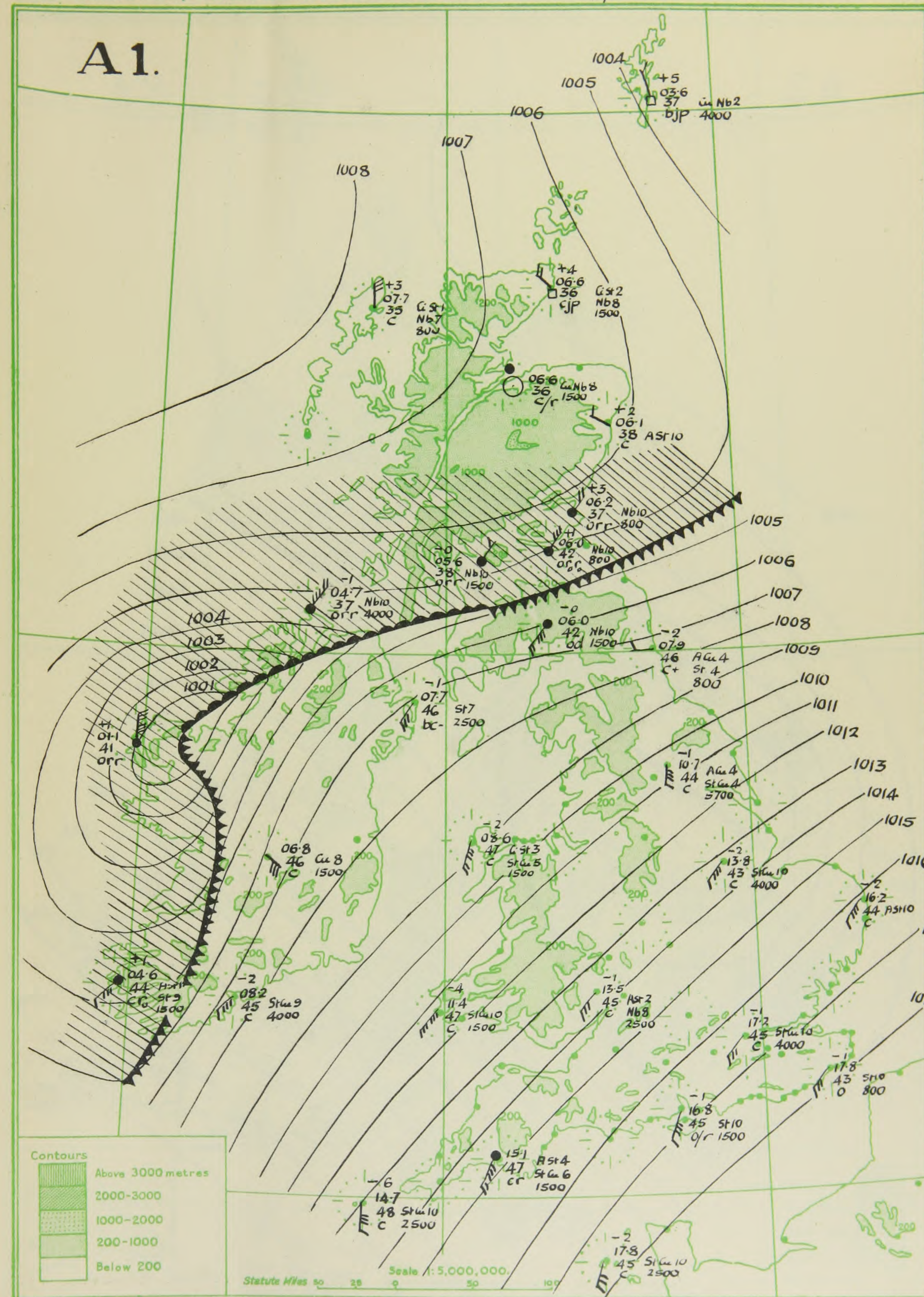
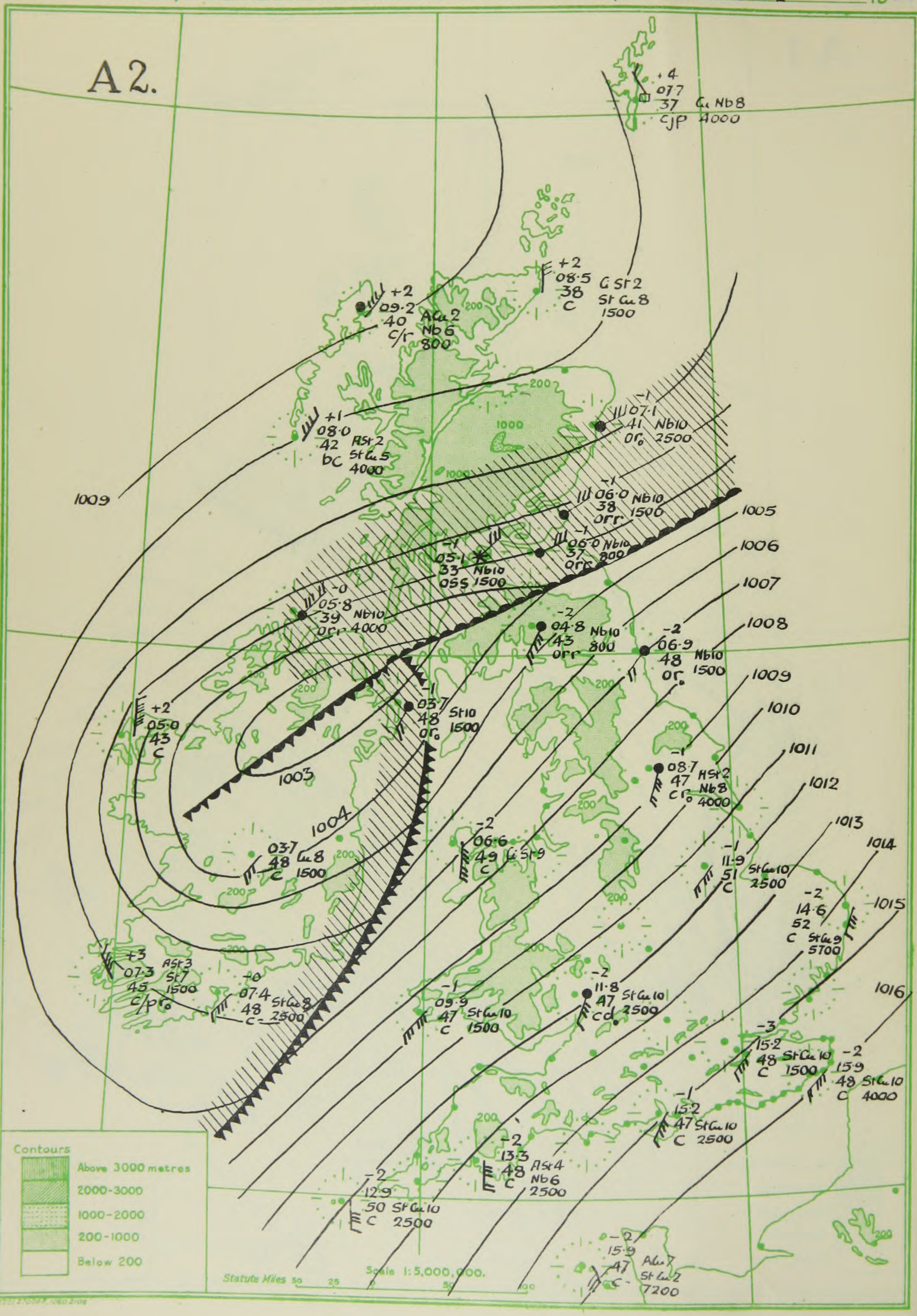
AIR MINISTRY, METEOROLOGICAL OFFICE. 7h., March 31 1925

A1.

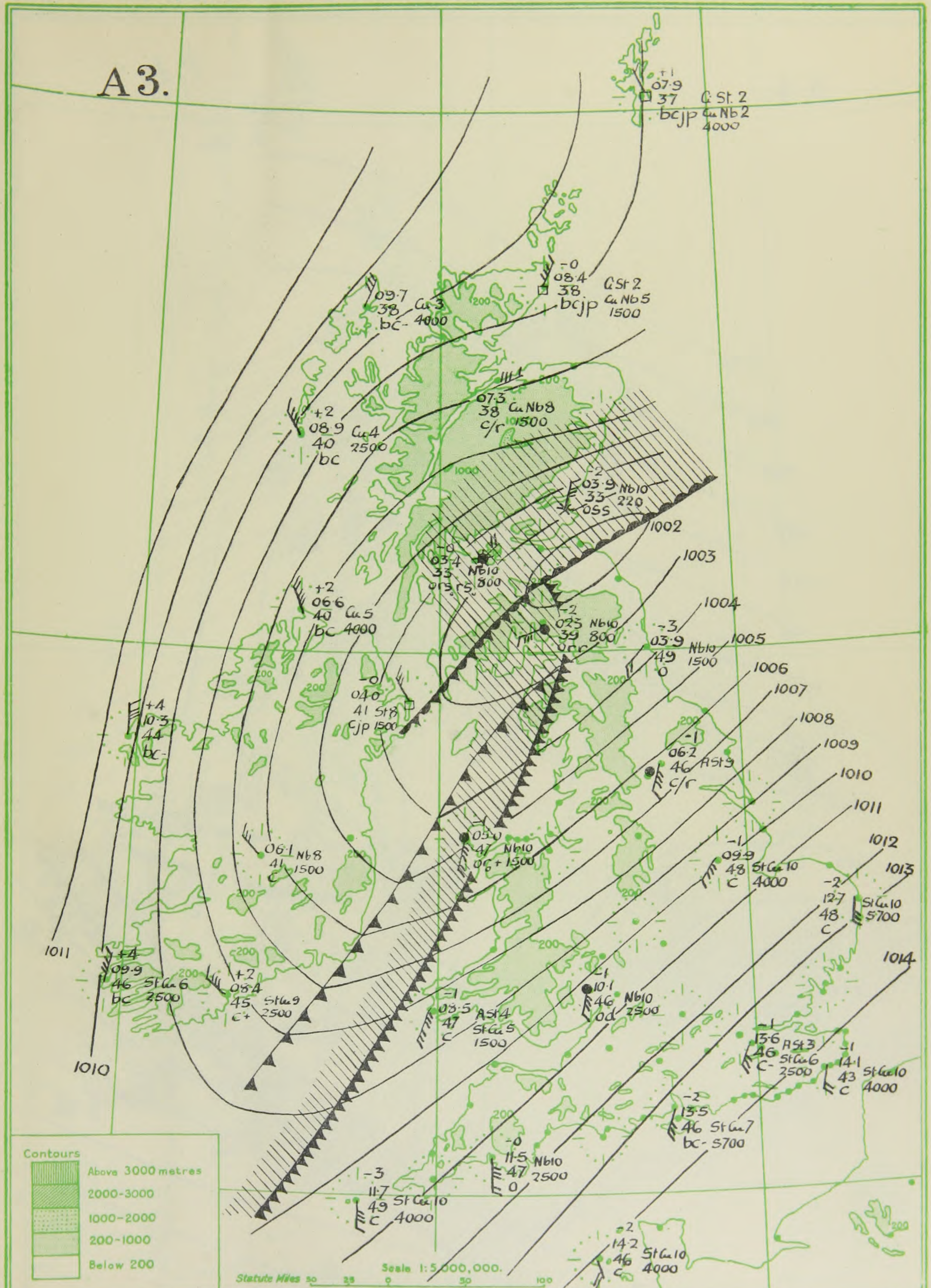


AIR MINISTRY, METEOROLOGICAL OFFICE. 13h, March 31 1925

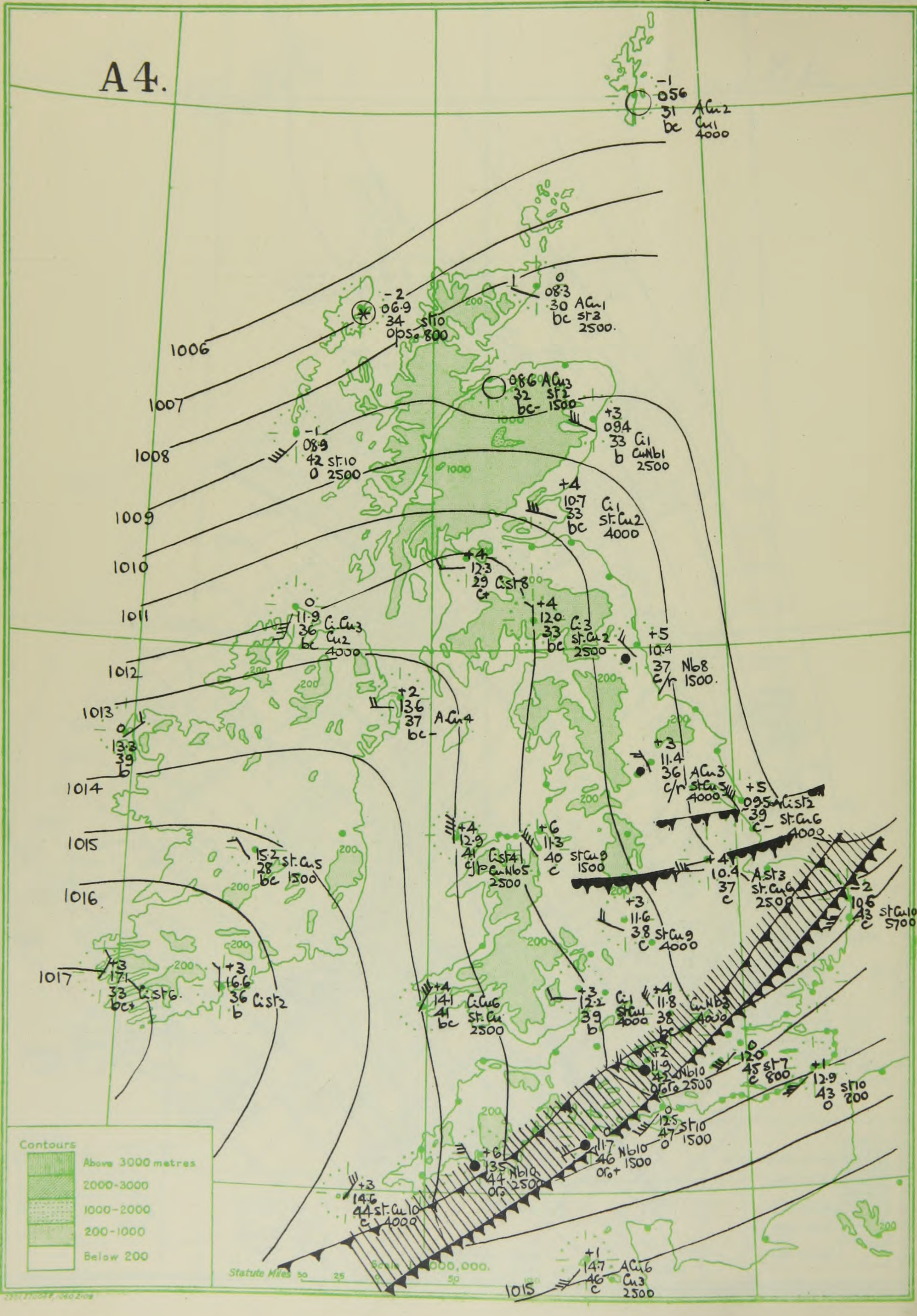


AIR MINISTRY, METEOROLOGICAL OFFICE. 18h., March 31 1925

A3.



AIR MINISTRY, METEOROLOGICAL OFFICE. 7h., April 1 1925



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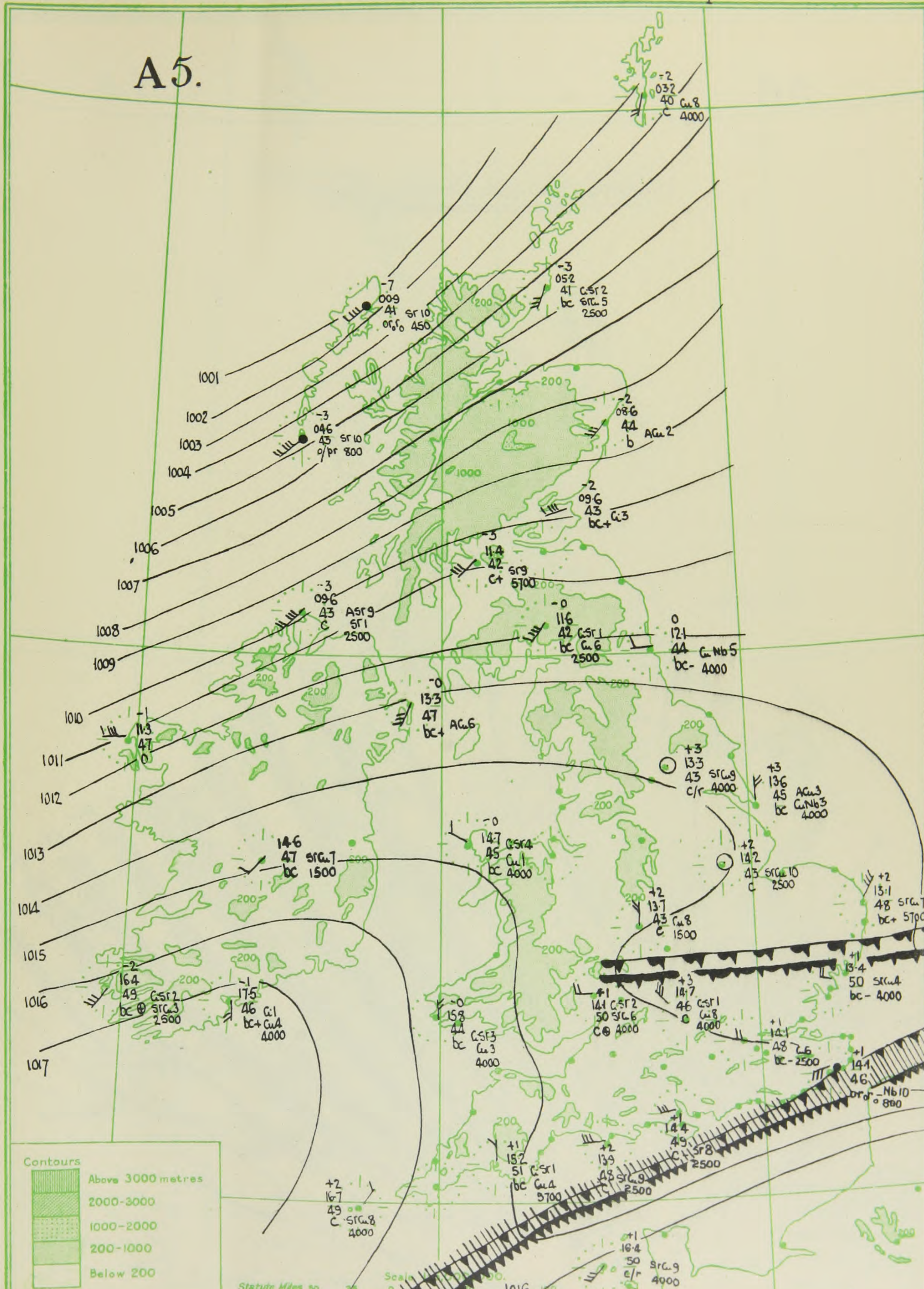
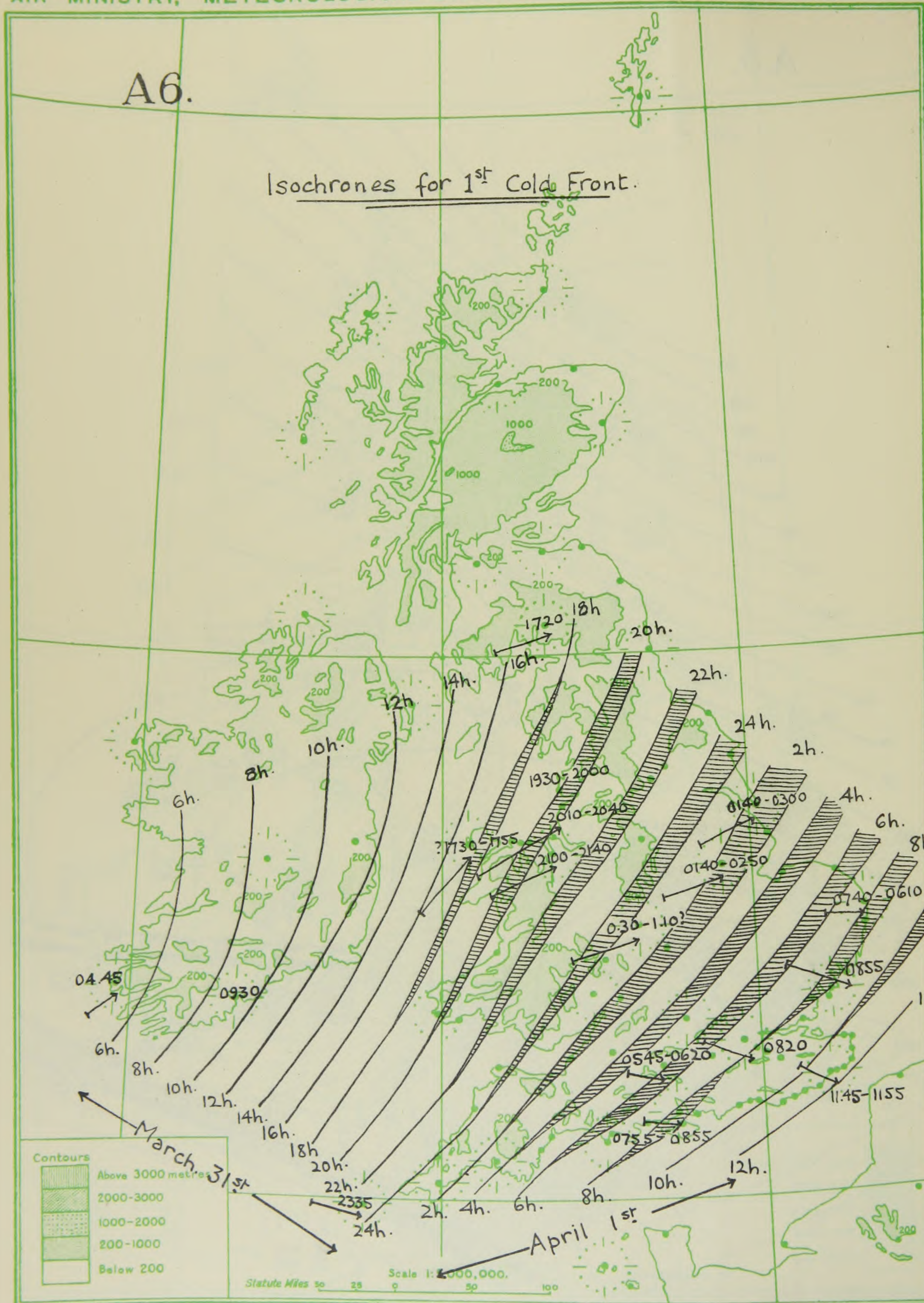
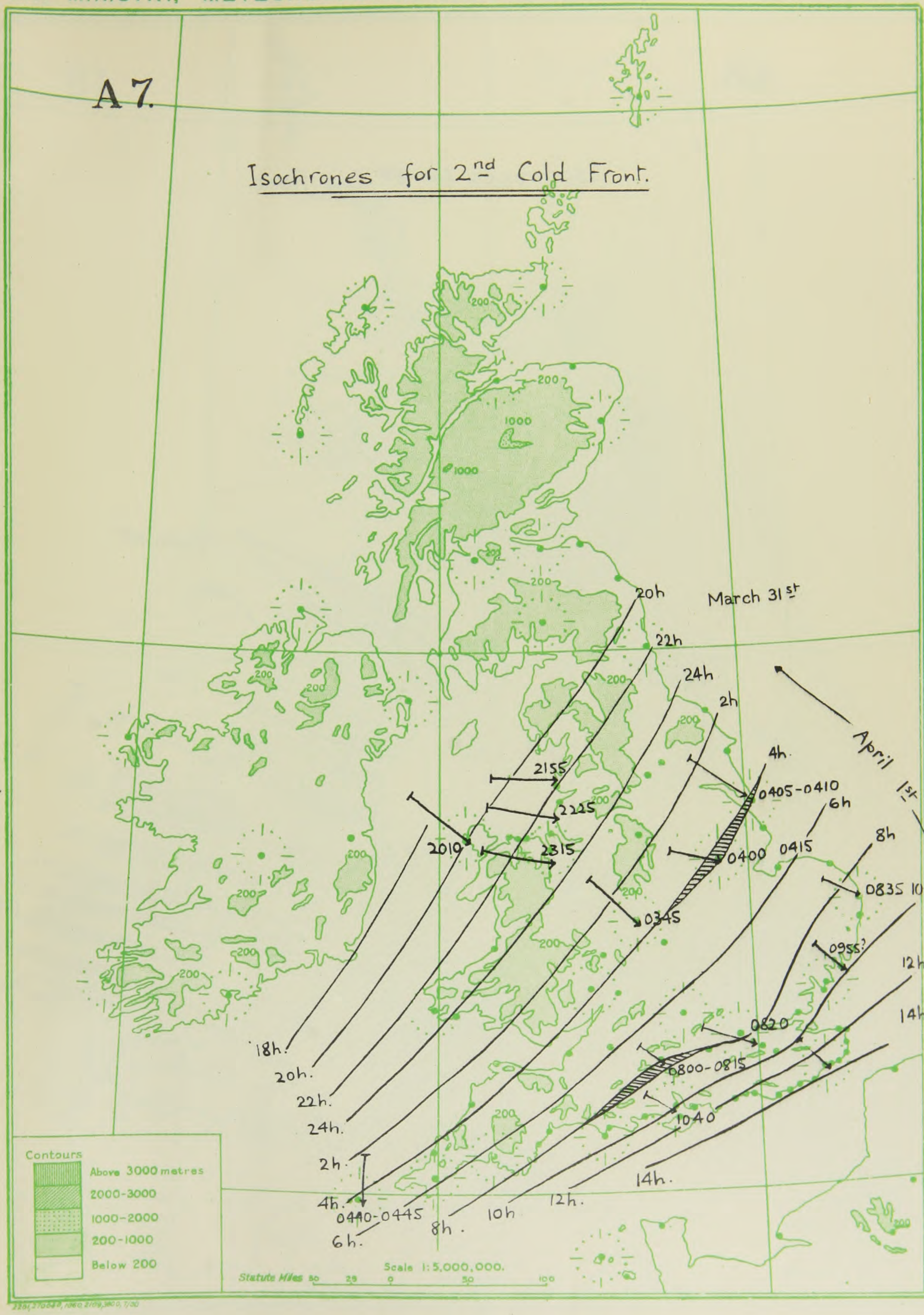
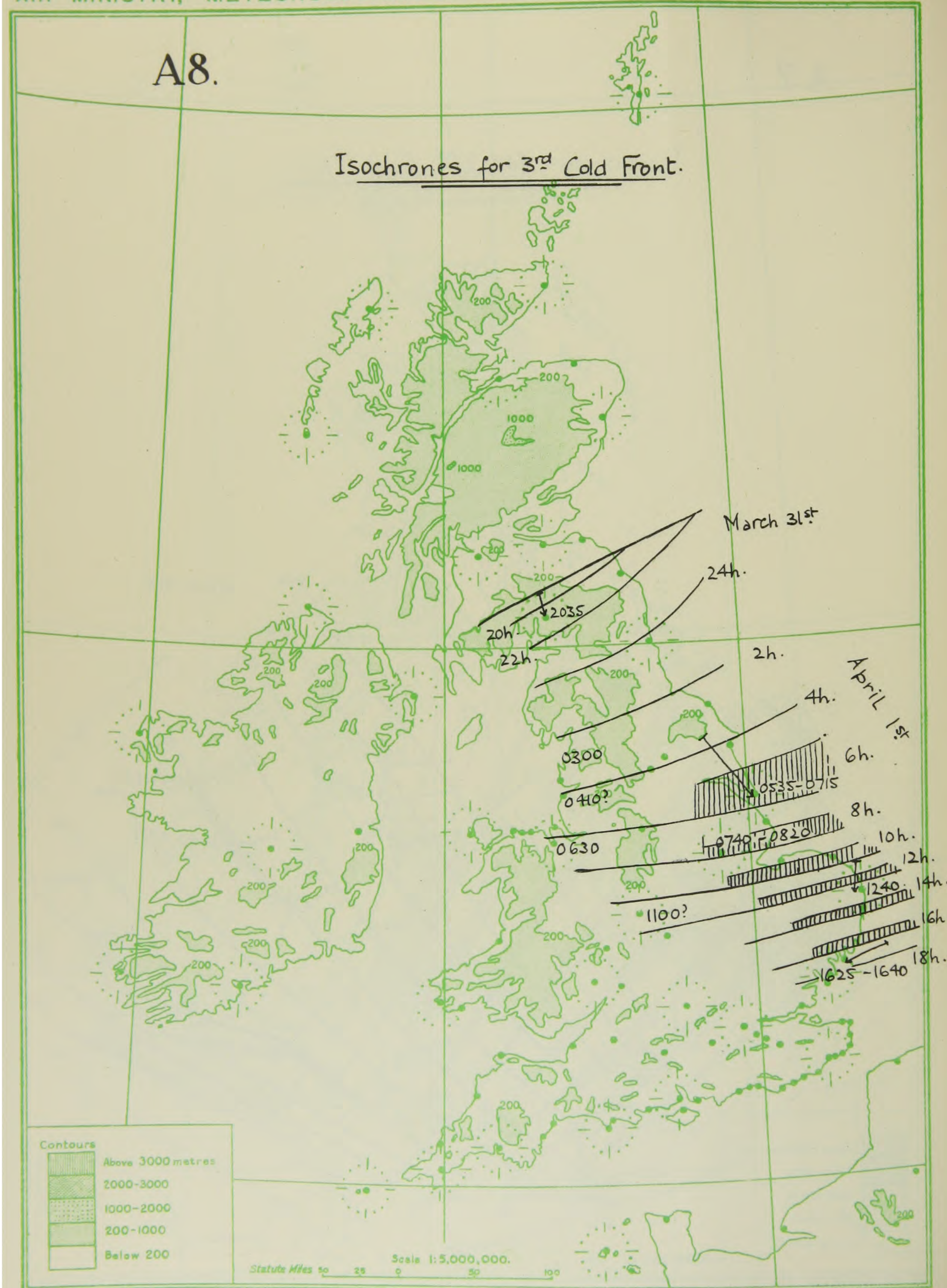


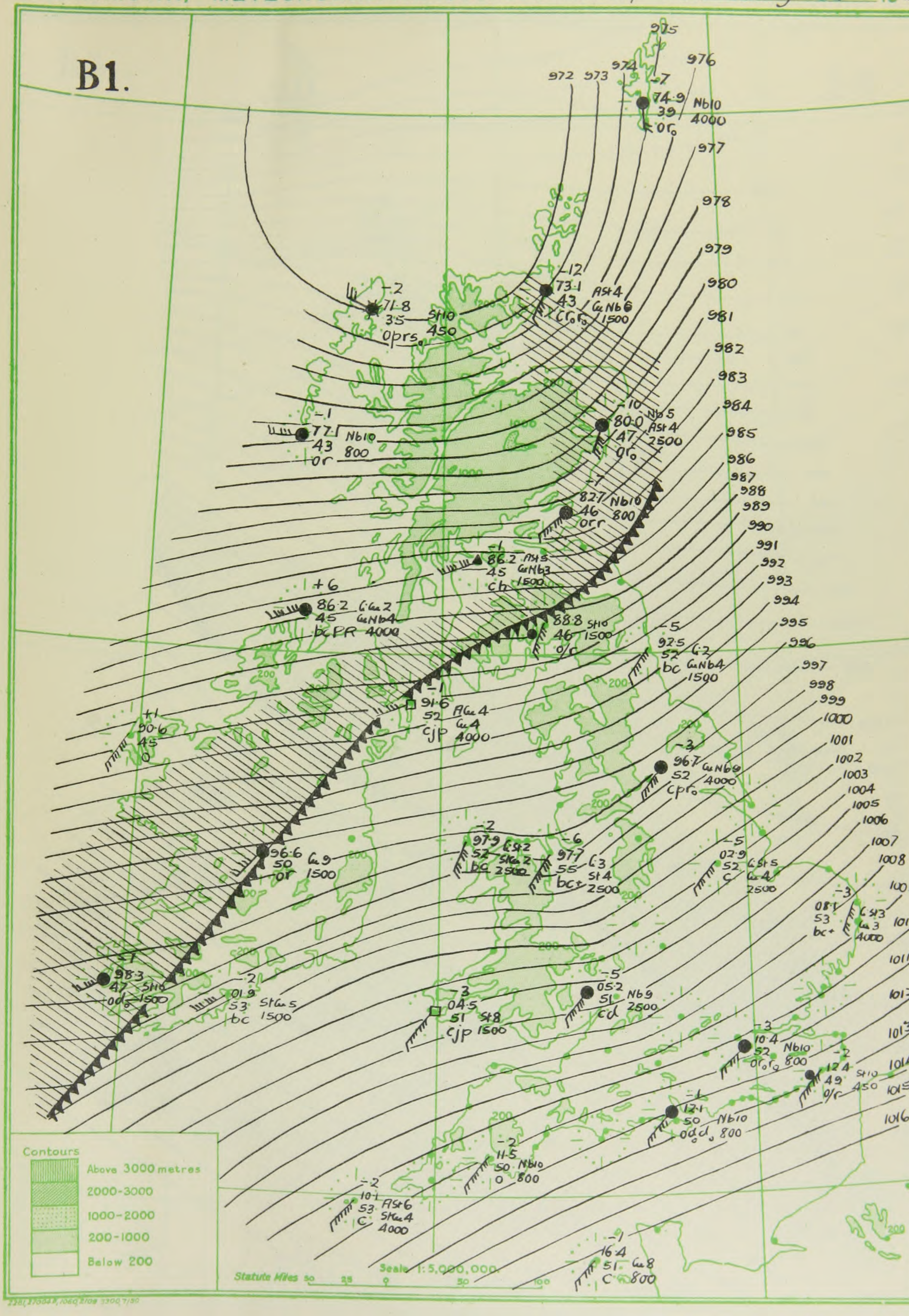

A6.
Isochrones for 1st Cold Front.
6h.
8h.
10h.
12h
14h.
16h.
18h
20h.
22h.
24h.
2h.
4h.
6h.
8h
10h
12h.
1720
1930-2000
2010-2040
2100-2140
?1730-1755
0140-0300
0140-0250
0740-0610
0.30-1.10?
0855
0820
0545-0620
11.45-1155
0755-0855
04.45
0930
2335
March 31st
April 1st
Contours
Above 3000 metres
2000-3000
1000-2000
200-1000
Below 200
Statute Miles 50 25 0 50 100
Scale 1:2,000,000.


A7.
Isochrones for 2nd Cold Front.
March 31st
April 1st
18h. 20h. 22h. 24h. 2h. 4h. 6h. 8h. 10h 12h. 14h.
20h 22h 24h 2h 4h 6h 8h 10h 12h 14h
2010
2155
2225
2315
0345
0400
0405-0410
0415
0835
0955?
0820
0800-0815
1040
0440-0445
Contours
Above 3000 metres
2000-3000
1000-2000
200-1000
Below 200
Statute Miles 50 25 0 50 100
Scale 1:5,000,000.

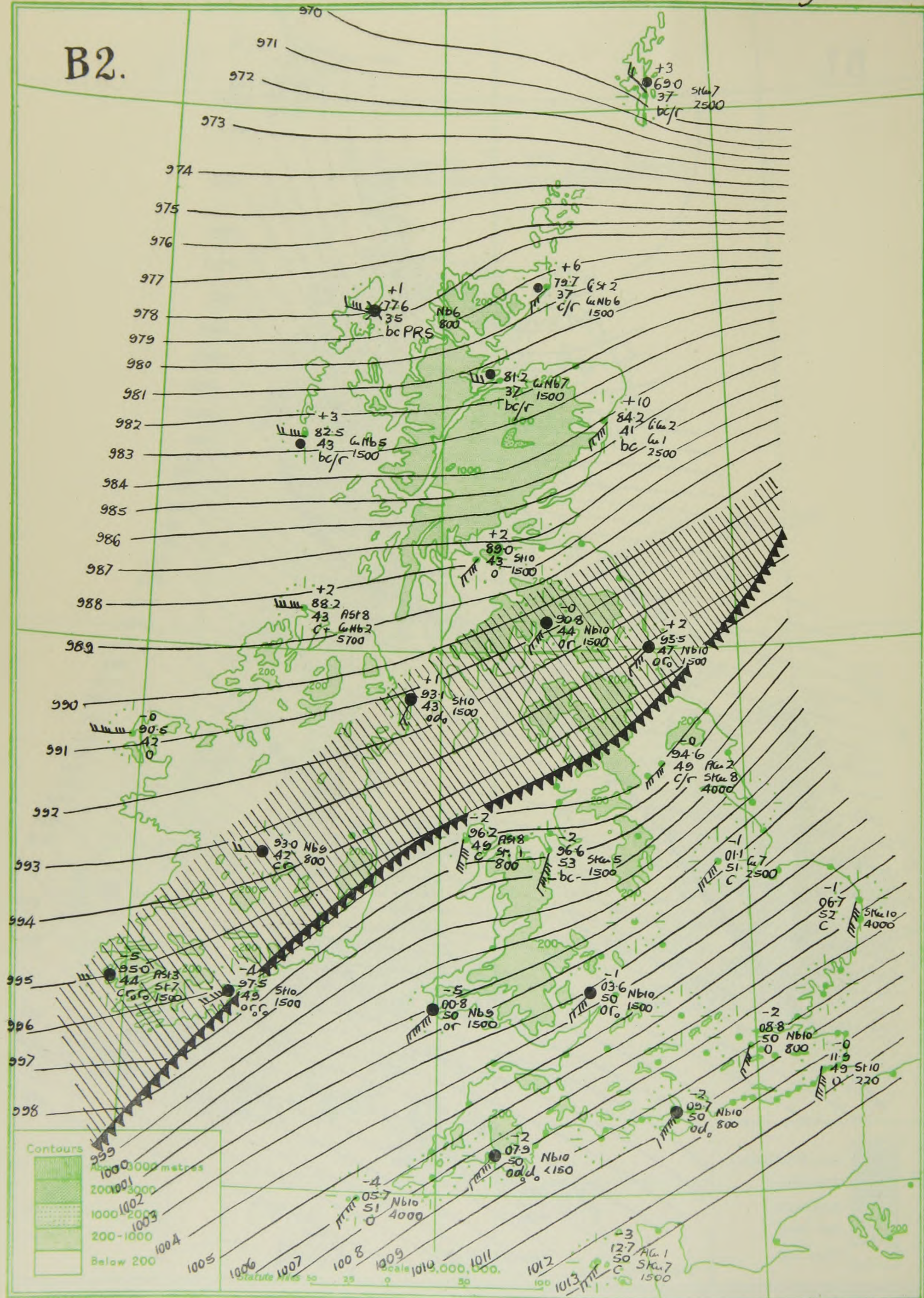

A8.
Isochrones for 3rd Cold Front.
March 31st
24h.
20h.
22h.
2035
2h.
April 1st
4h.
0300
6h.
0410?
0535-0715
8h.
0740-0820
0630
10h.
12h.
1240
14h.
1100?
16h.
18h.
1625-1640
Contours
Above 3000 metres
2000-3000
1000-2000
200-1000
Below 200
Scale 1:5,000,000.
Statute Miles 50 25 0 50 100

AIR MINISTRY, METEOROLOGICAL OFFICE. 13h., February 10 1925

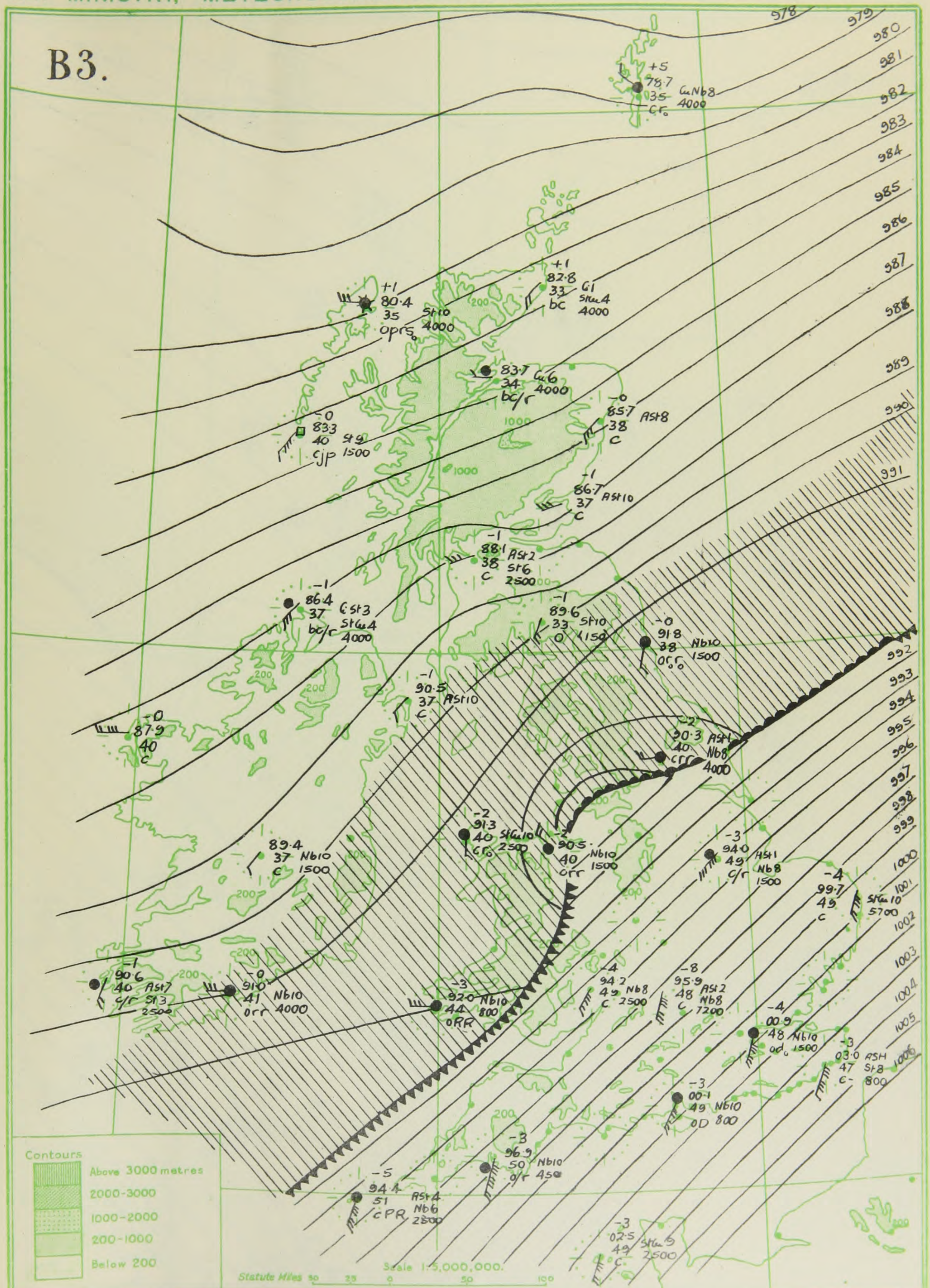
B1.



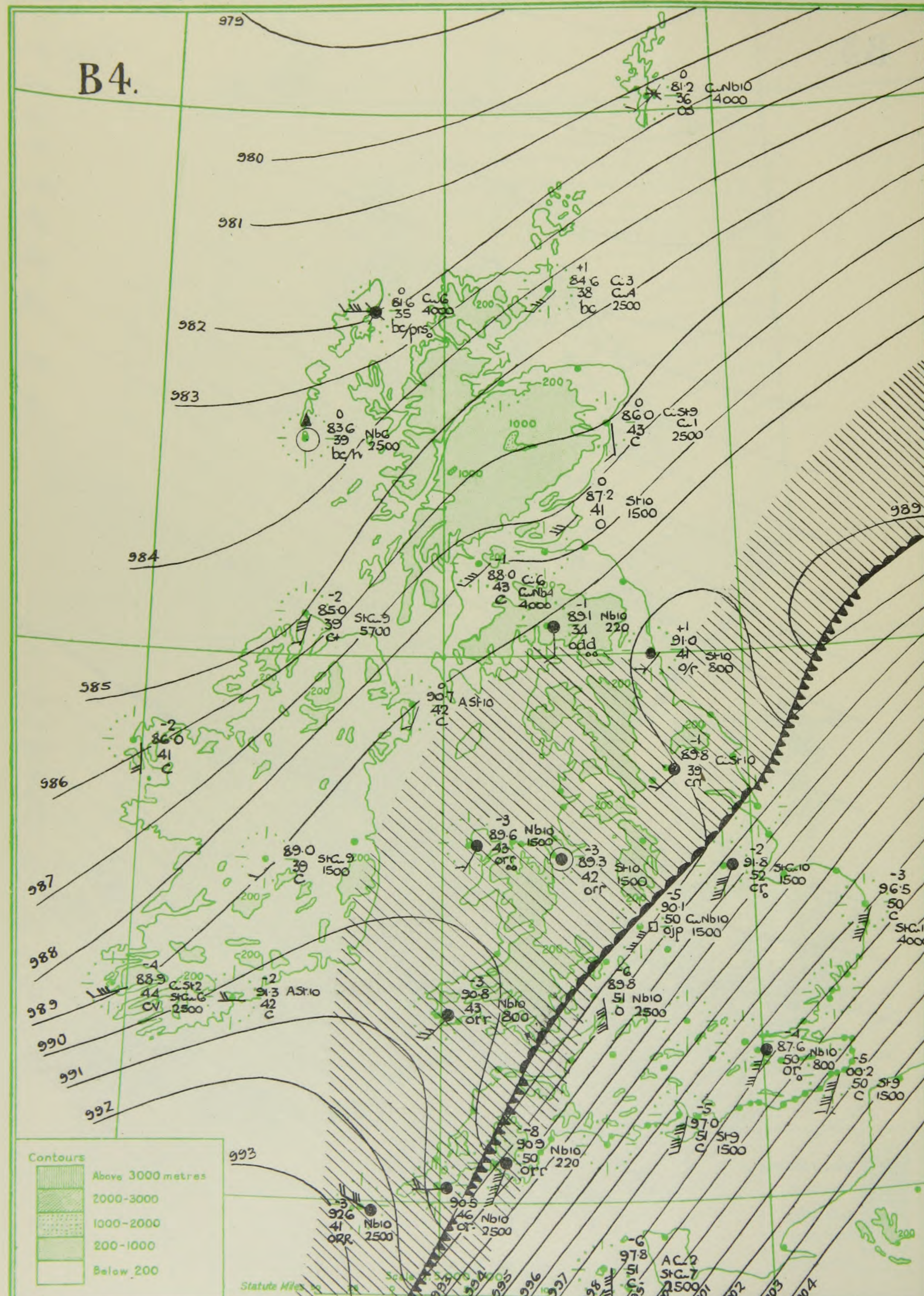
B2.


Contours
Above 3000 metres
2000-3000
1000-2000
200-1000
Below 200
Statute Miles 50 25 0 50 100
Scale 1/3,000,000.

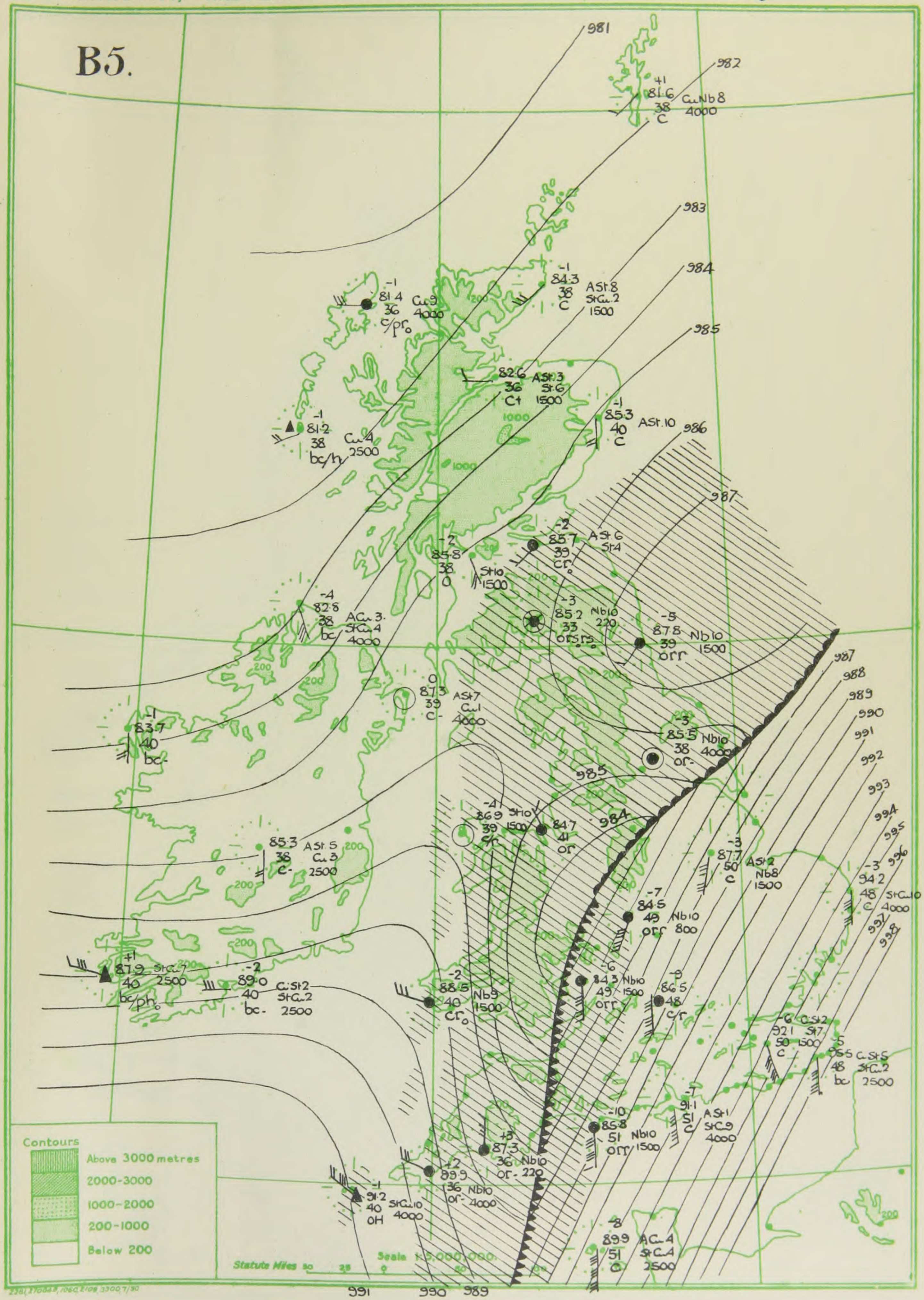
AIR MINISTRY, METEOROLOGICAL OFFICE. 7h., February 11 1925



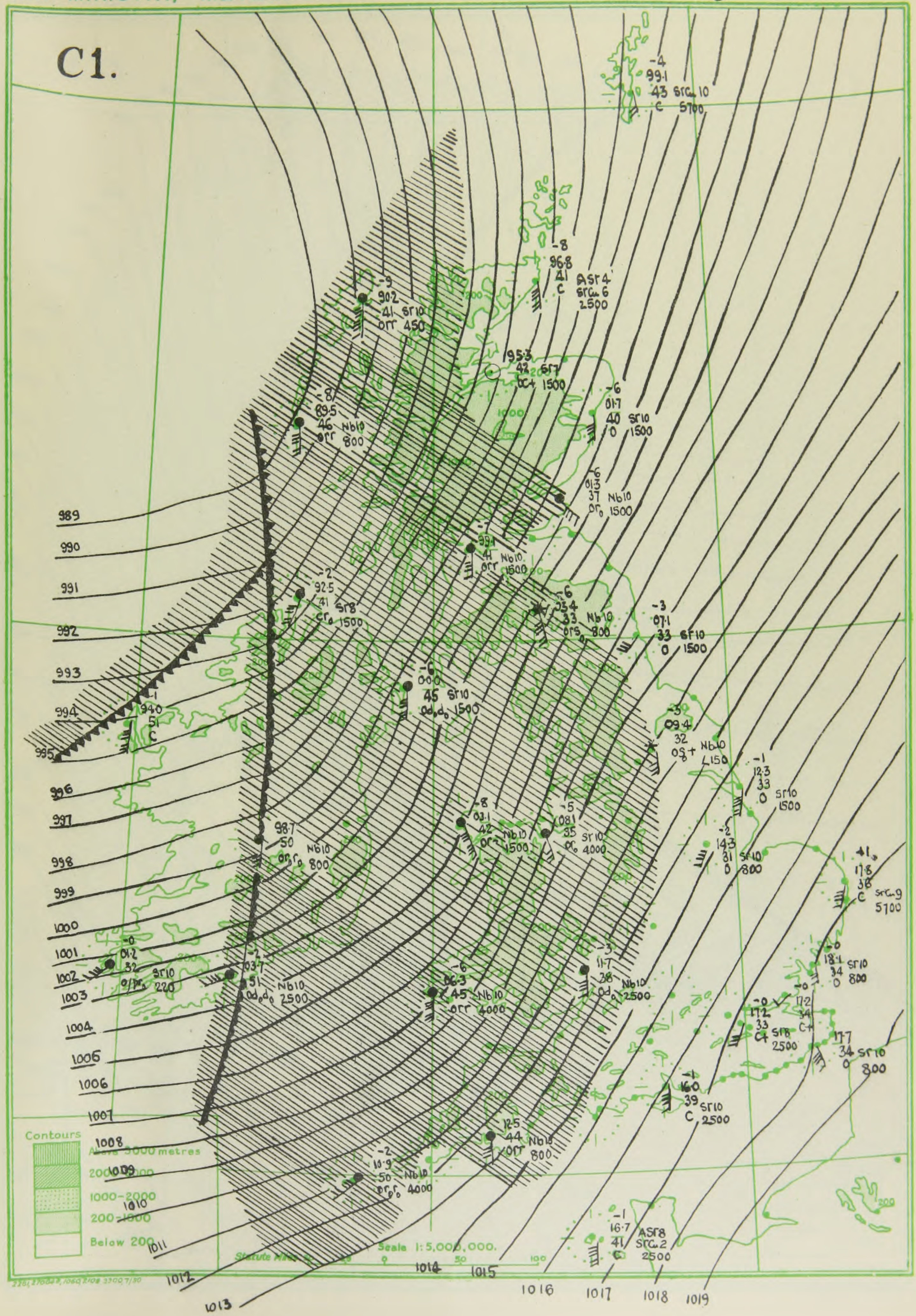
AIR MINISTRY, METEOROLOGICAL OFFICE. 13h., February 11 1925



AIR MINISTRY, METEOROLOGICAL OFFICE. 18h., February 11 1925




200
1000
1000
Contours
Above 3000 metres
2000-3000
1000-2000
200-1000
Below 200
Scale 1:5,000,000.
Statute Miles 50 25 0 50 100


C1.
Contours
Above 3000 metres
2000-3000
1000-2000
200-1000
Below 200
Scale 1:5,000,000.
Statute Miles
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
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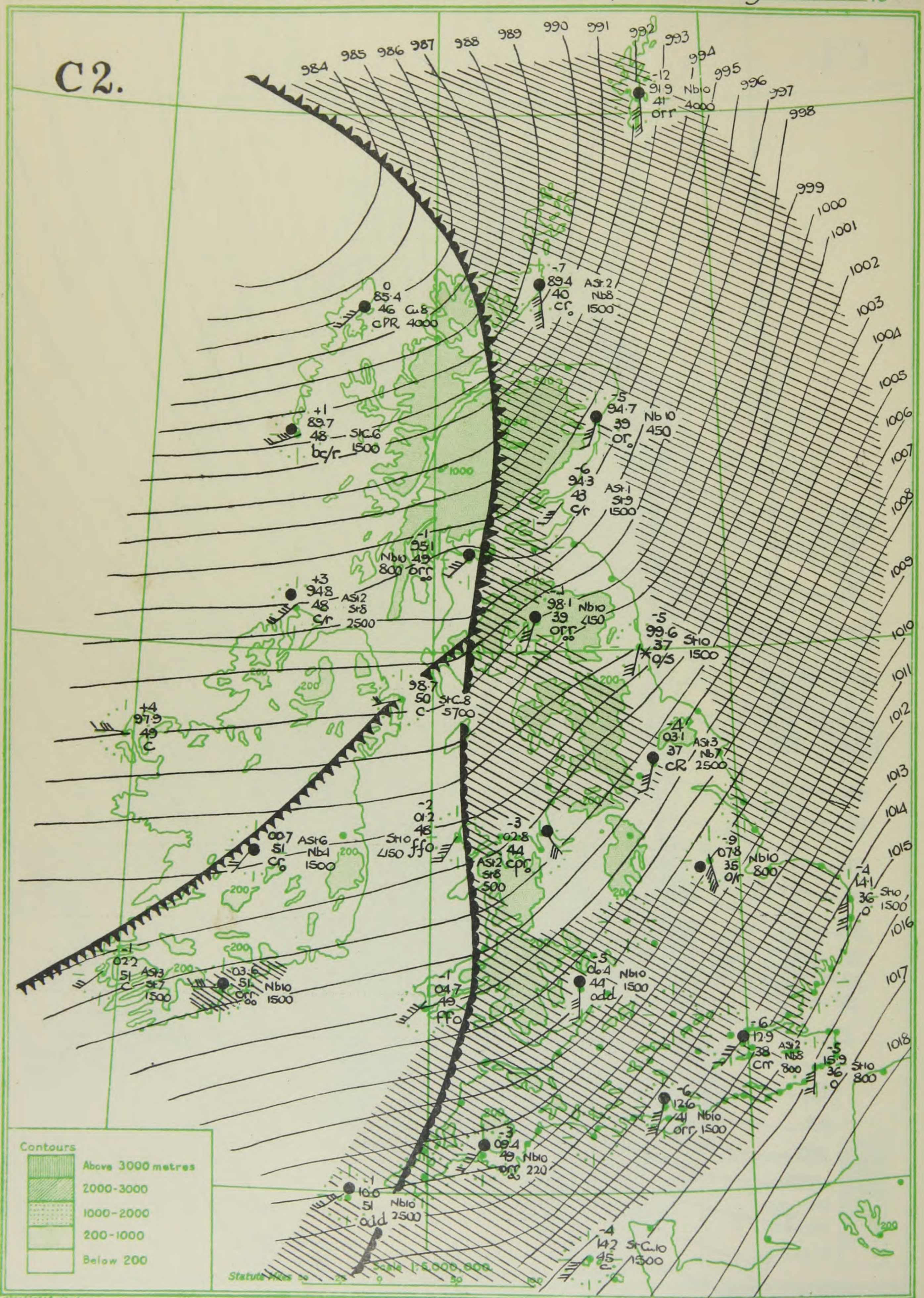
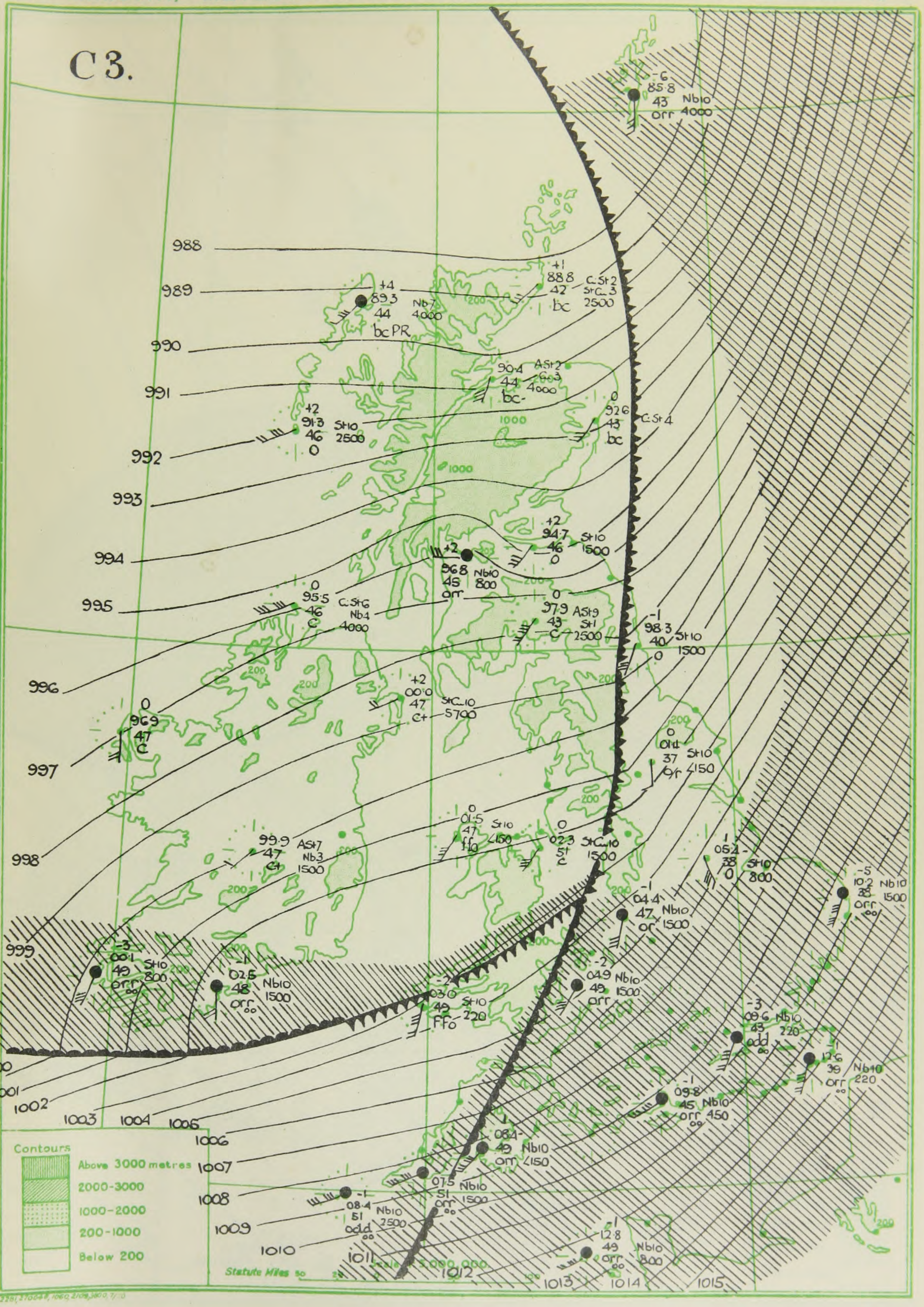
1017
1018
1019

AIR MINISTRY, METEOROLOGICAL OFFICE. 13h., January 22 1926



AIR MINISTRY, METEOROLOGICAL OFFICE. 18h., January 22 1926

C3.



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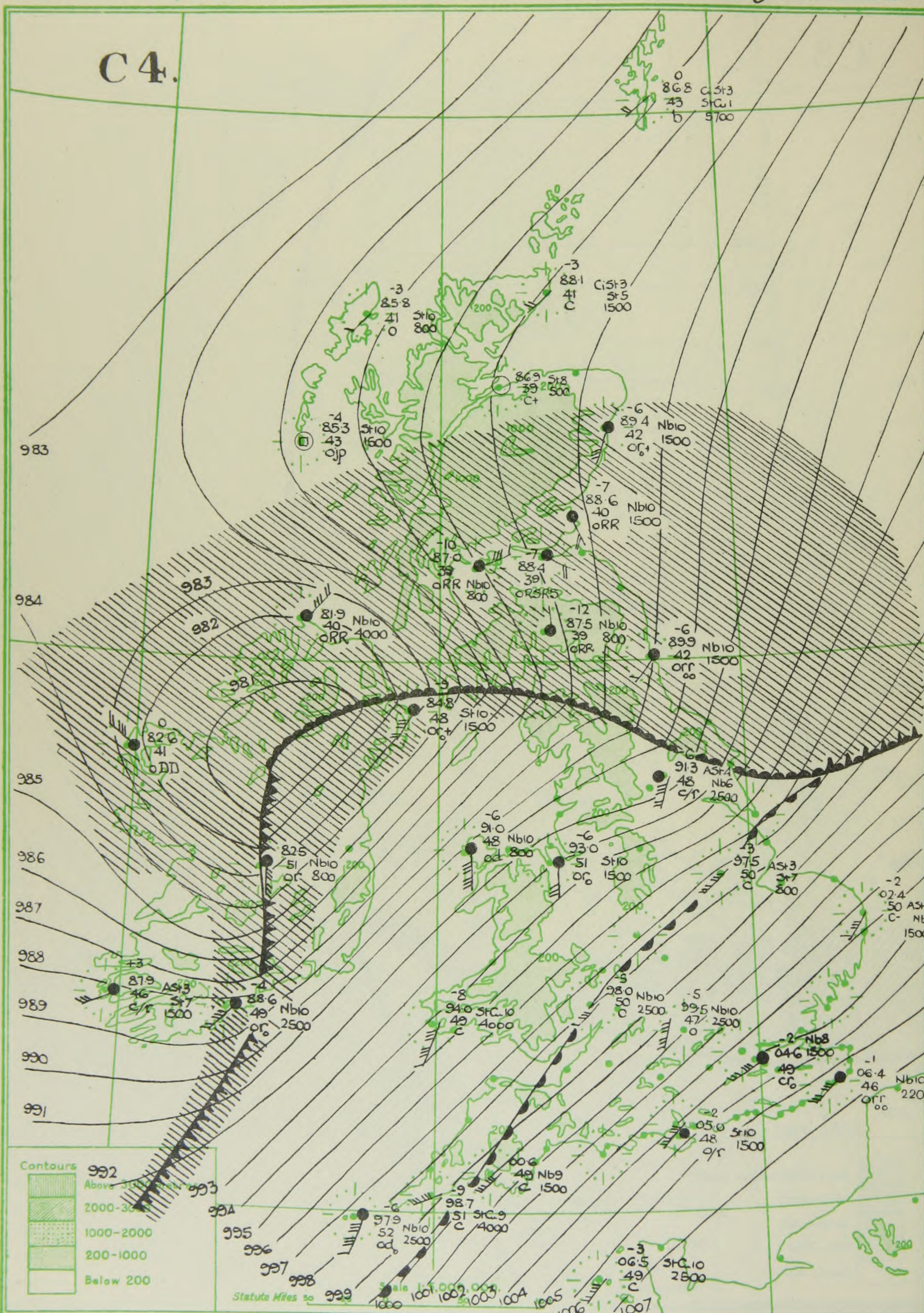

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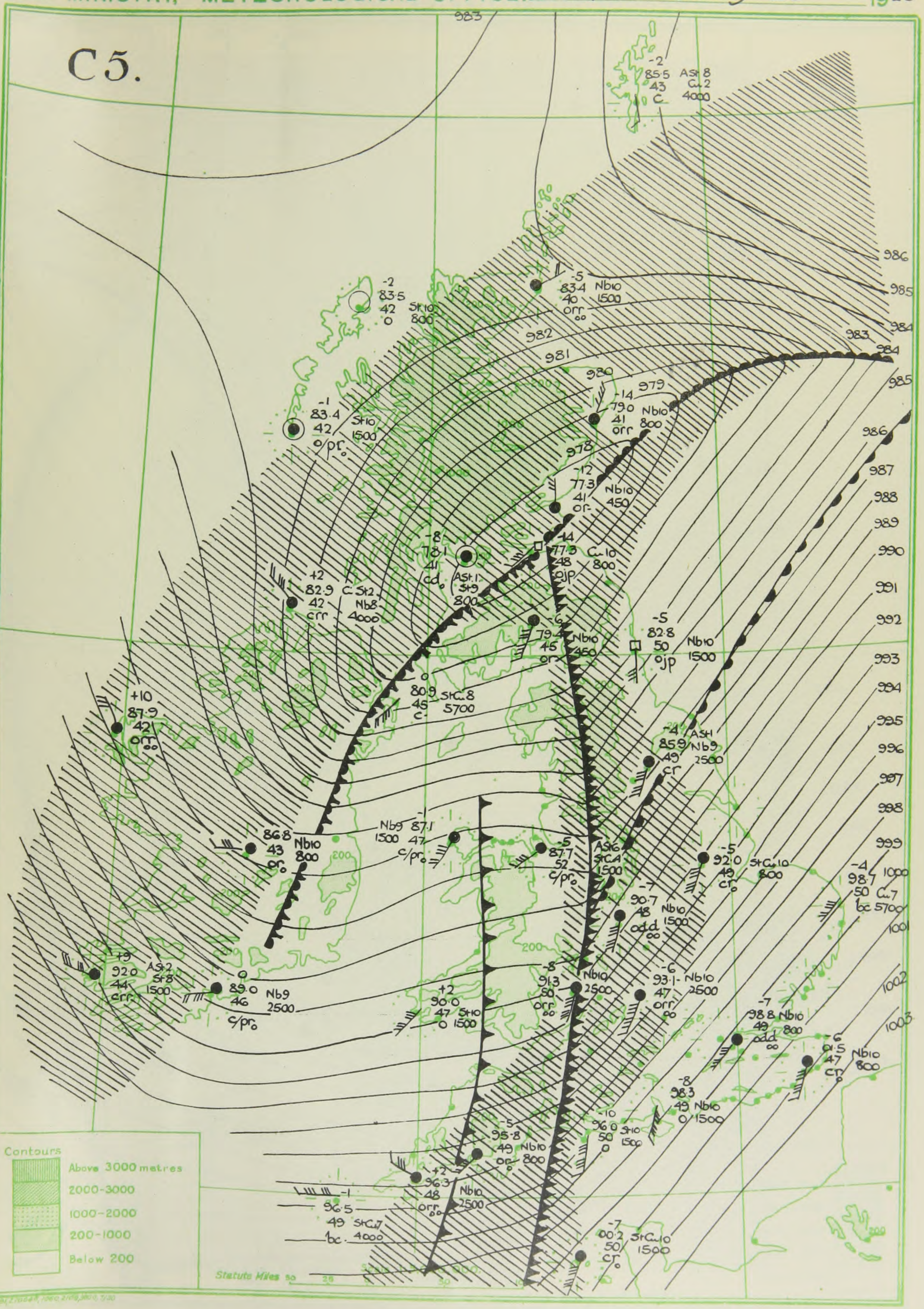

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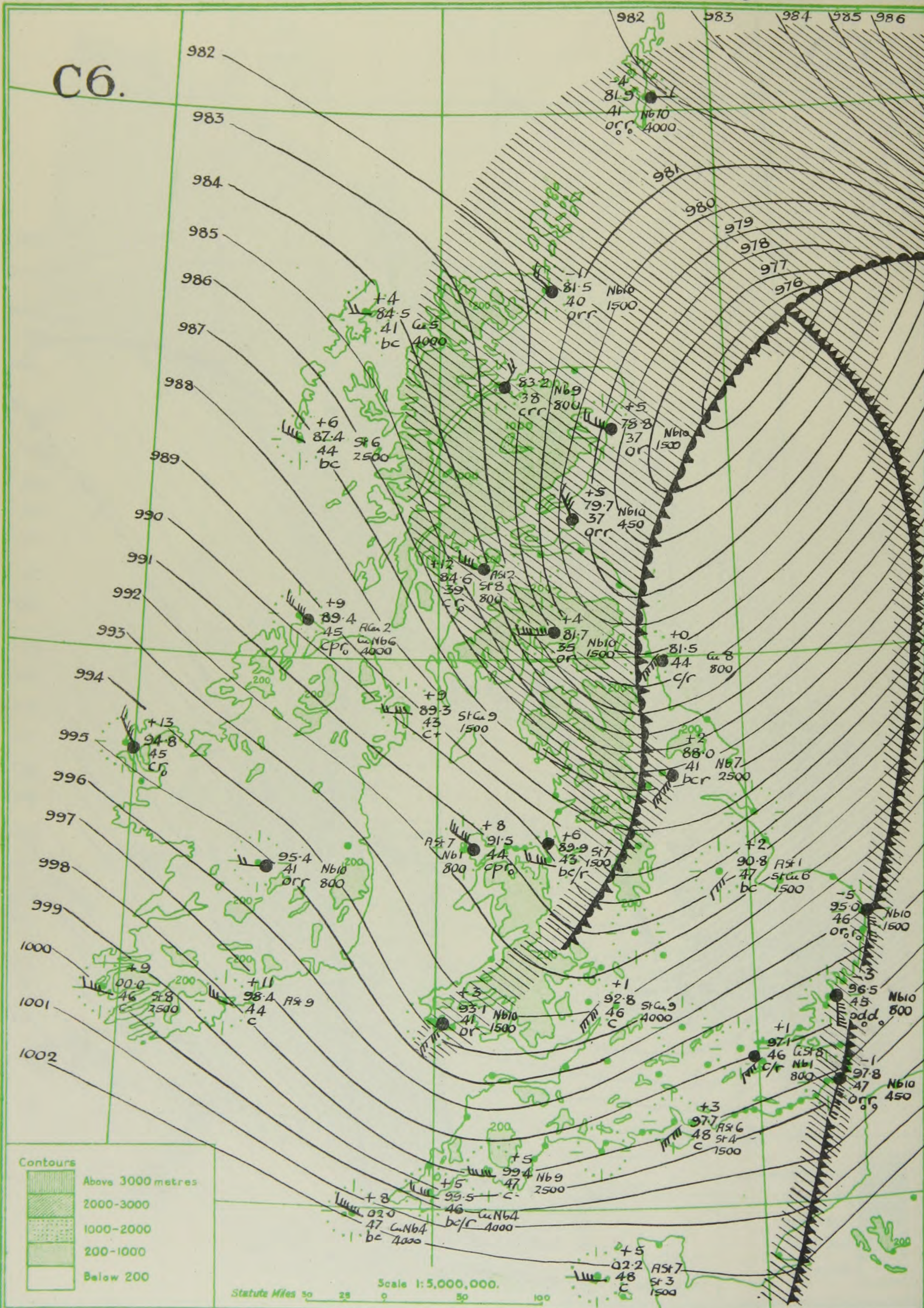
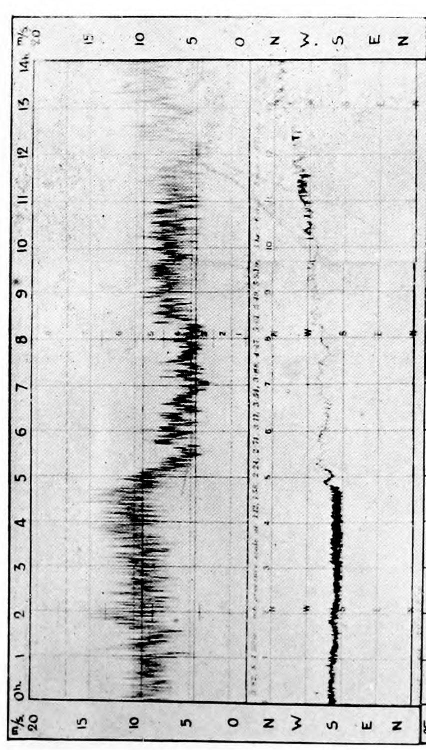
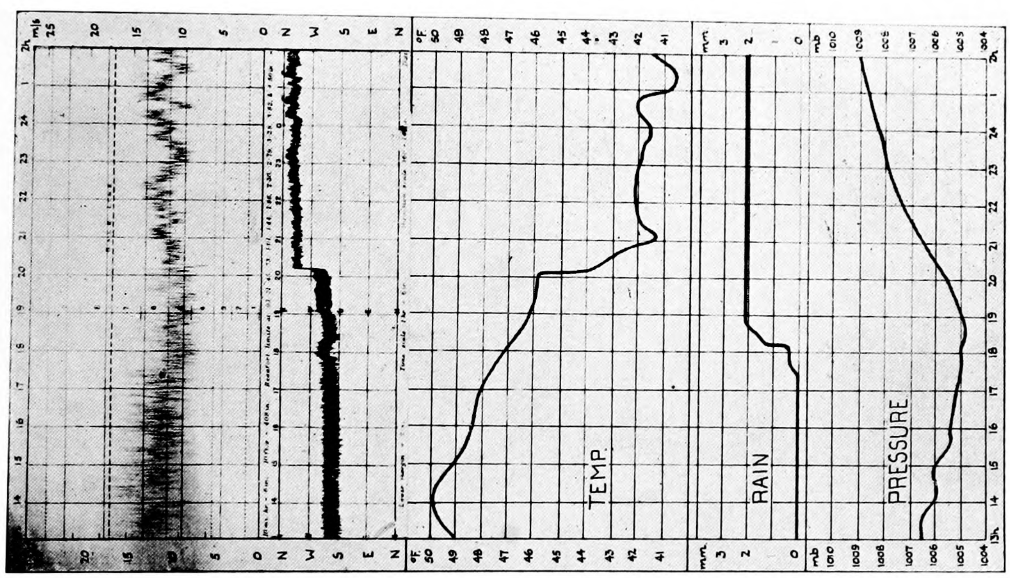
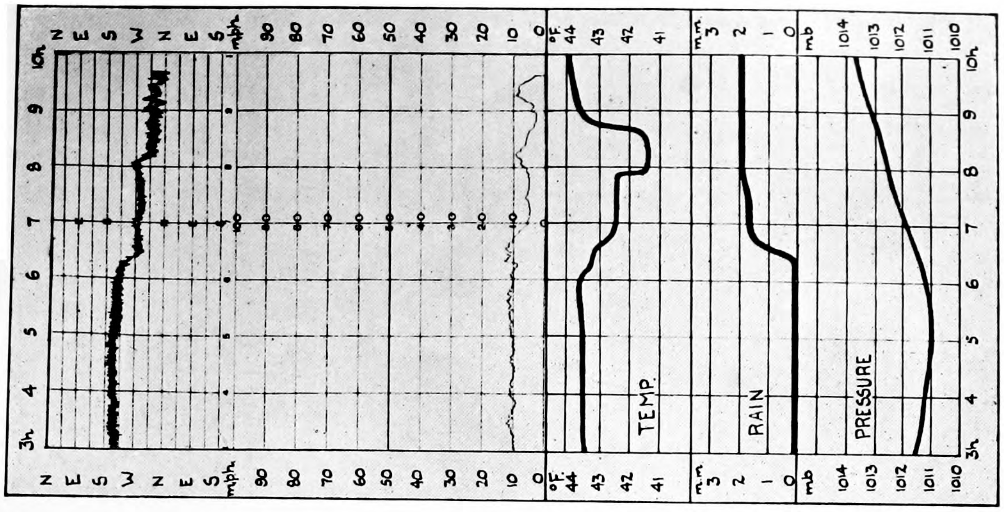




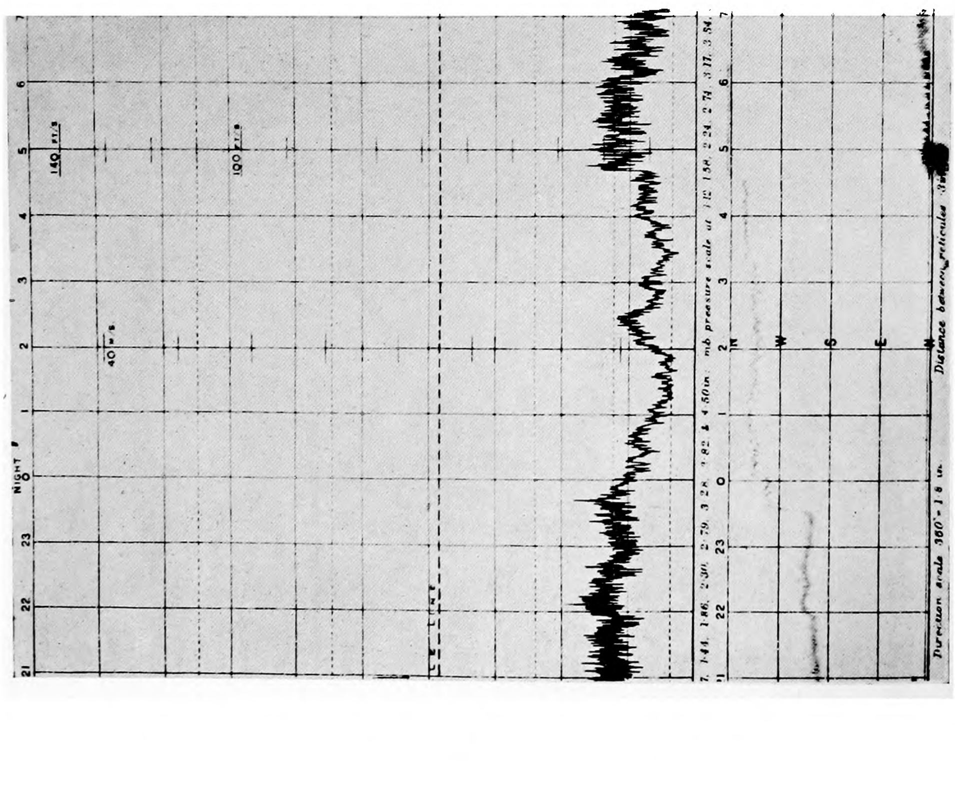
RECORD A1.—Valentia, March 31, 1925.



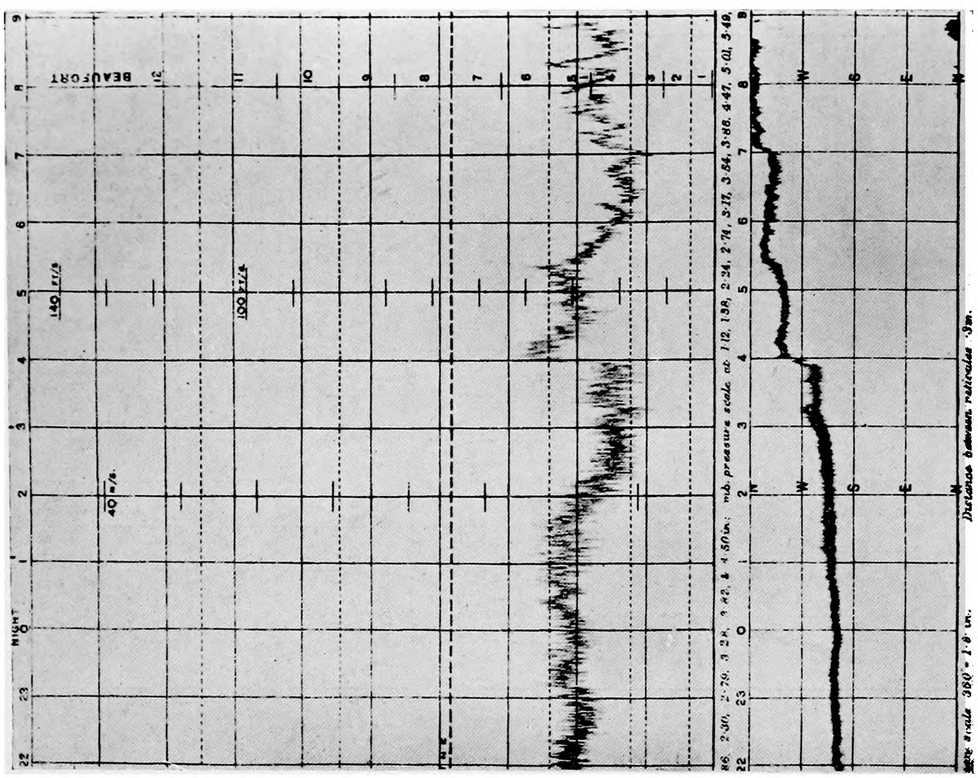
RECORD A2.—Holyhead, March 31 to April 1, 1925.



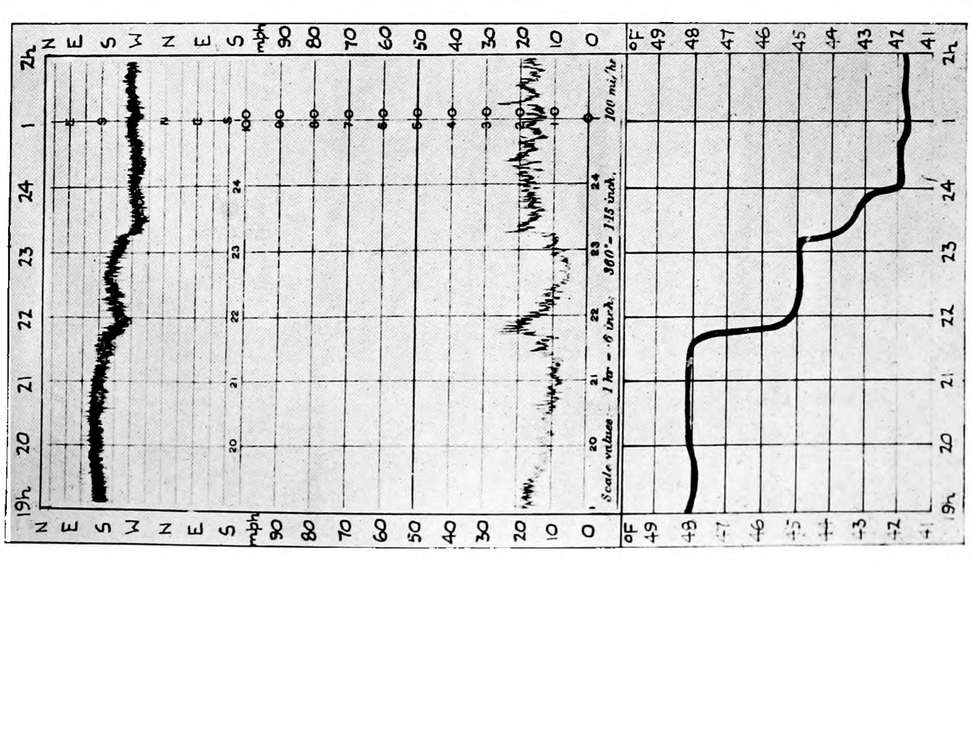
RECORD A3.—Andover, April 1, 1925.



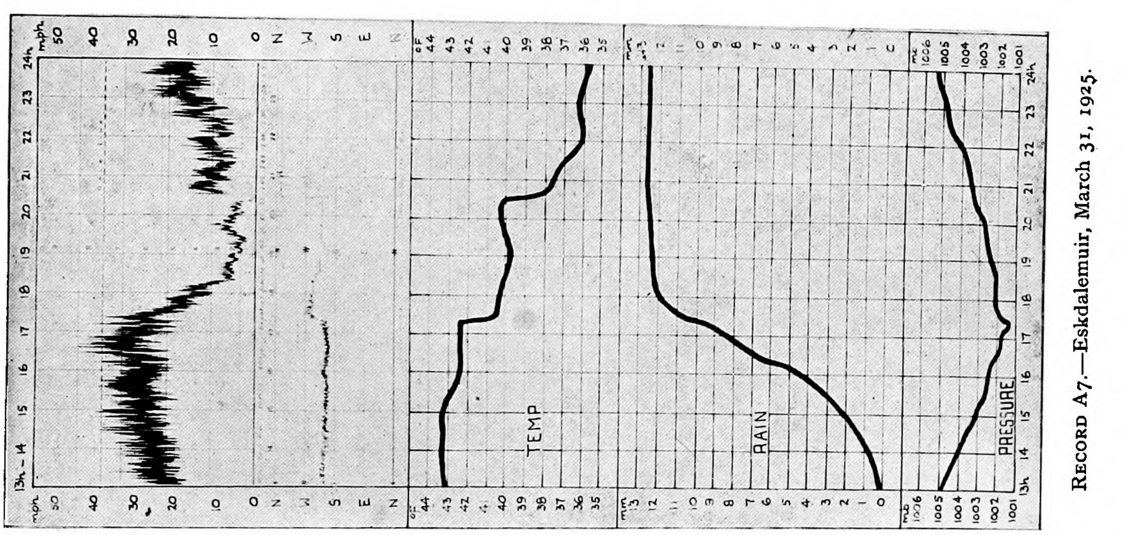
RECORD A4.—Scilly, March 31 to April 1, 1925.



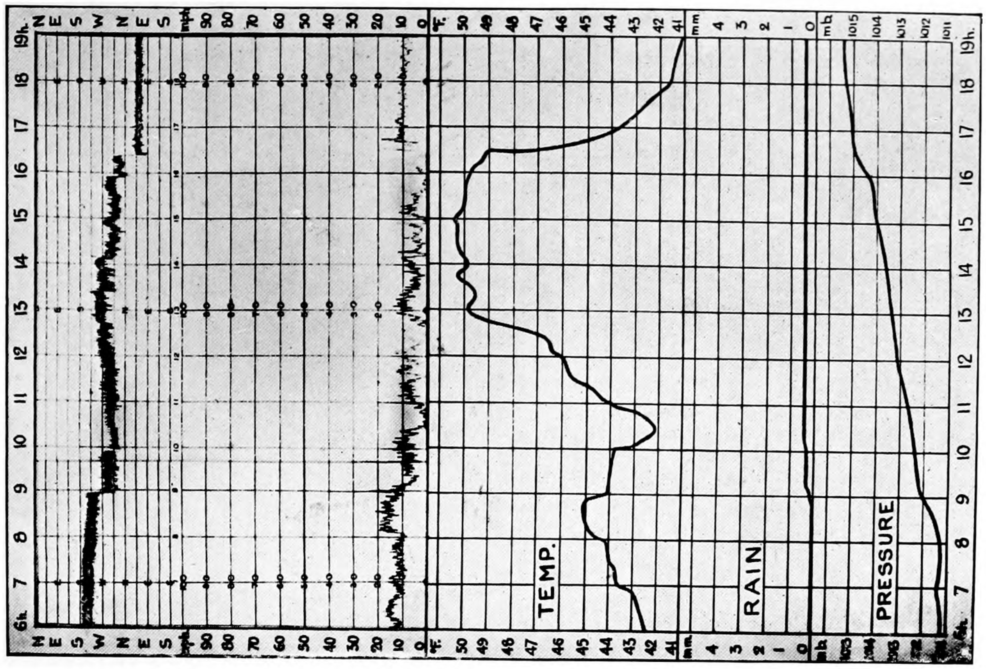
RECORD A6.—Spurn Head, March 31 to April 1, 1925.



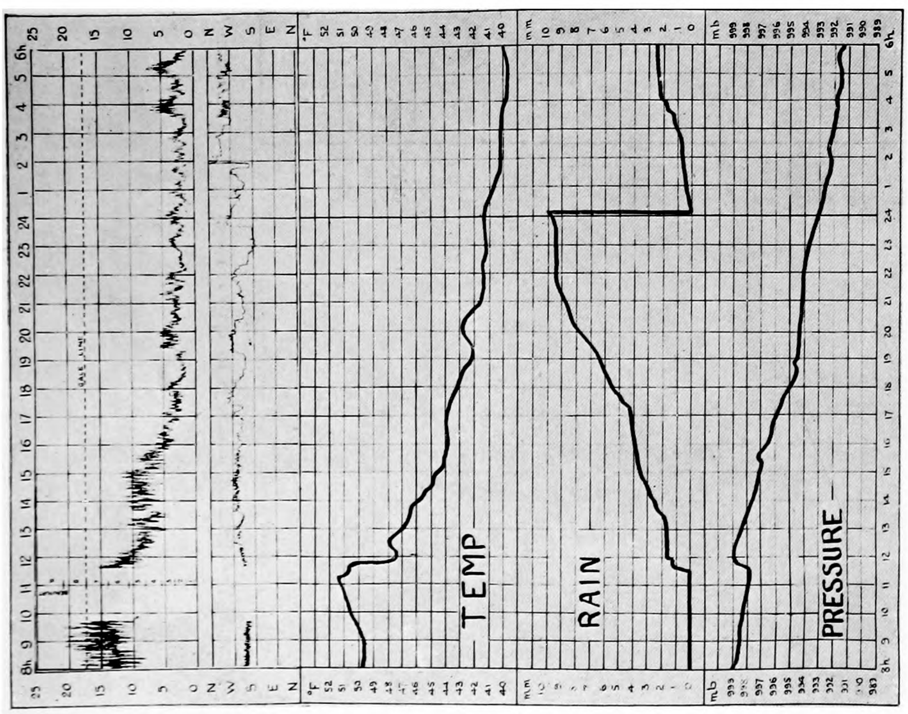
RECORD A5.—Sealand, March 31 to April 1, 1925.



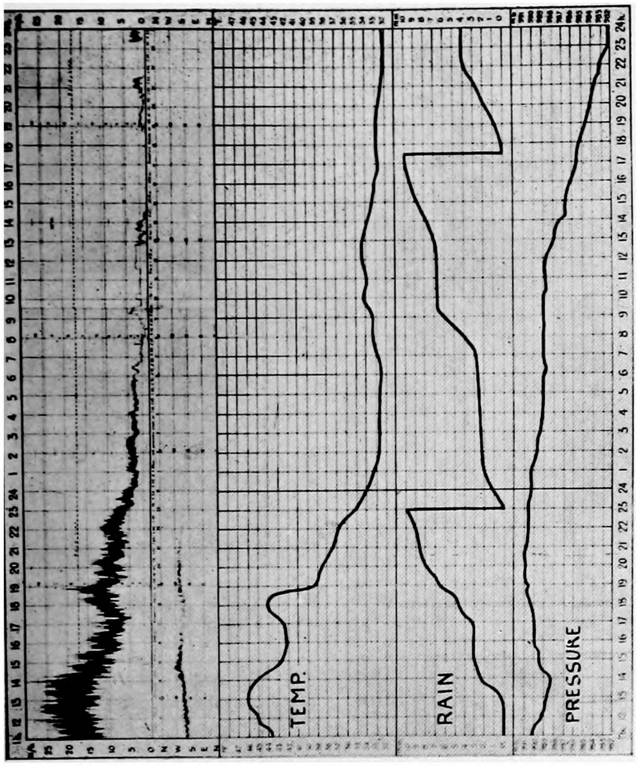
RECORD A7.—Eskdalemuir, March 31, 1925.



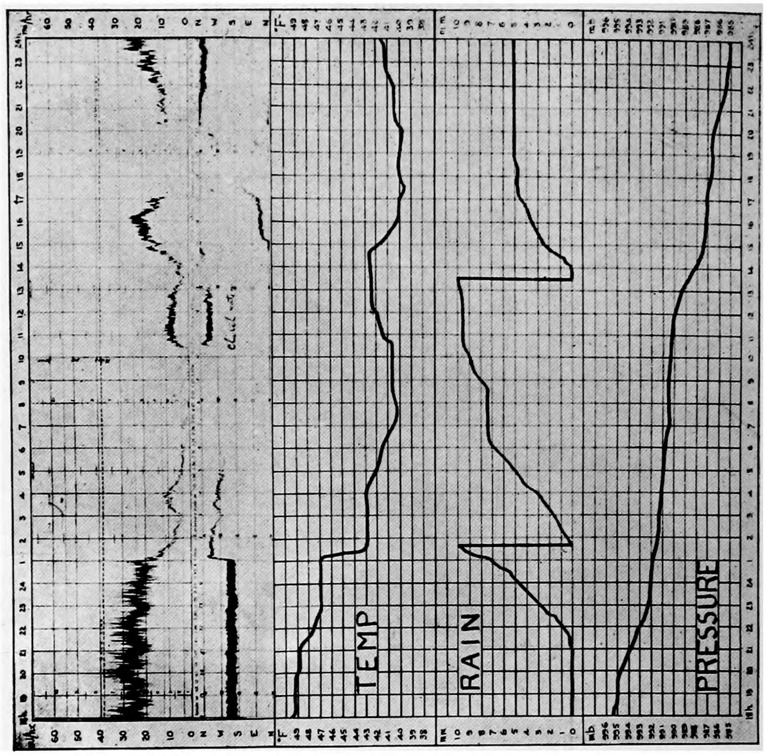
RECORD A8.—Felixstowe, April 1, 1925.



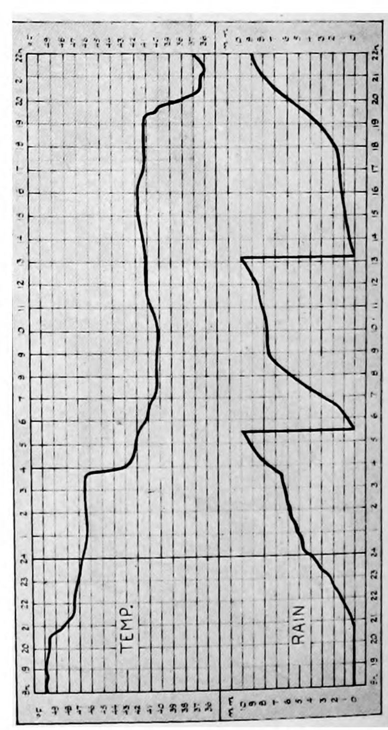
RECORD B1.—Valentia, February 10 to 11, 1925.



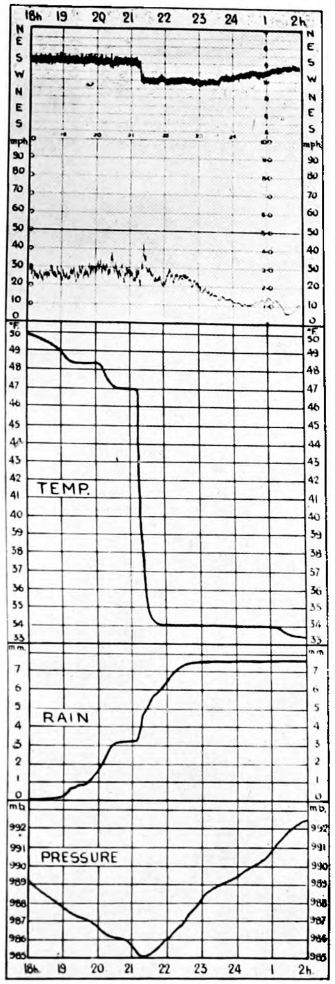
RECORD B2.—Eskdalemuir, February 10 to 11, 1925.



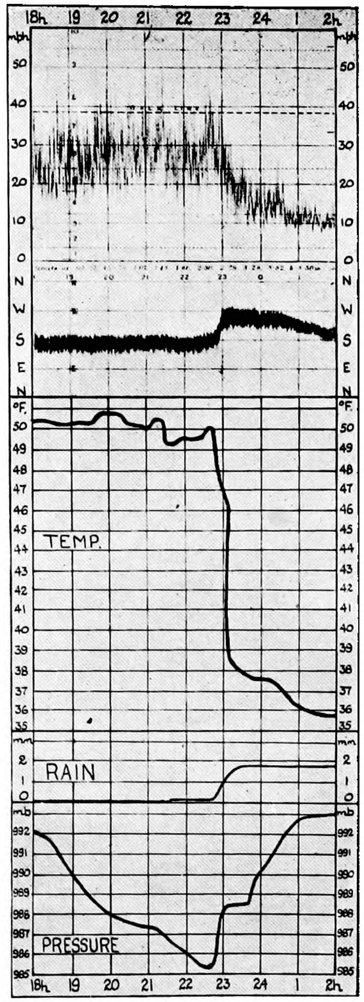
RECORD B3.—Holyhead, February 10 to 11, 1925.



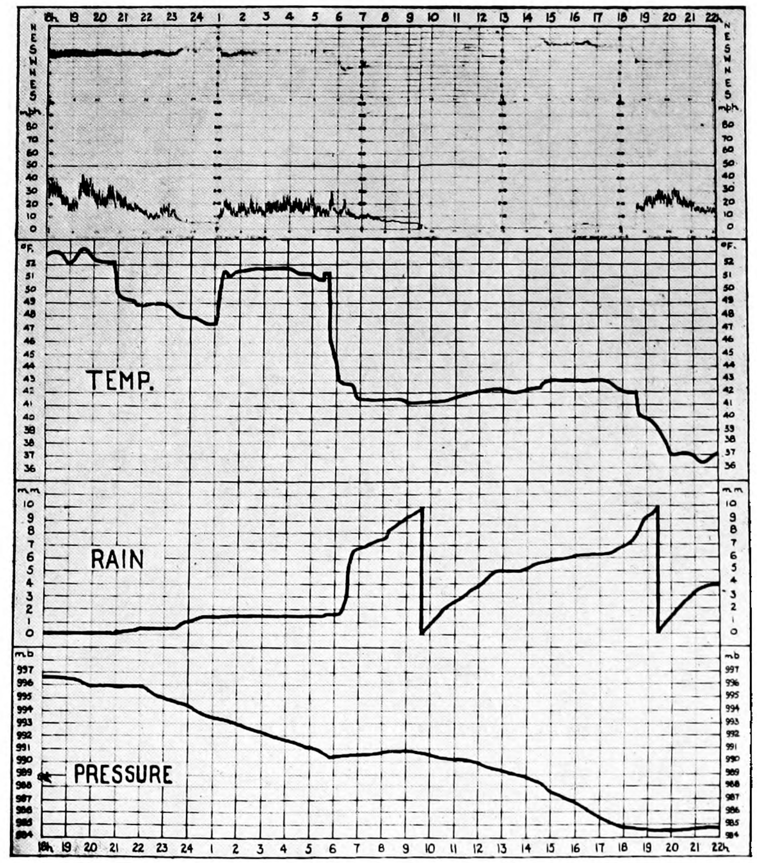
RECORD B4.—Southport, February 10 to 11, 1925.



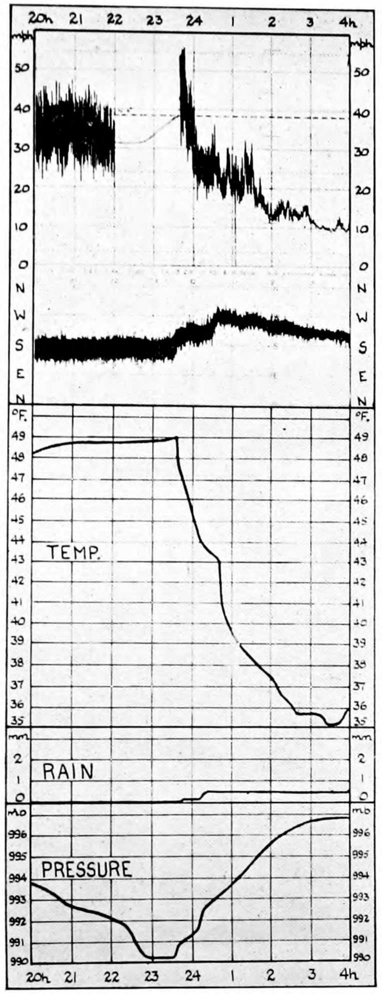
Record B5.—
Andover, February 11 to 12, 1925.



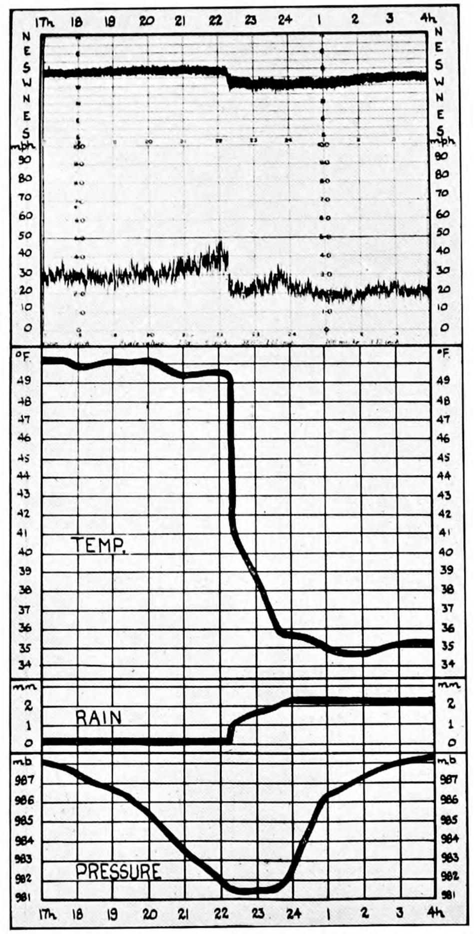
Record B6.—
Croydon, February 11 to 12, 1925.



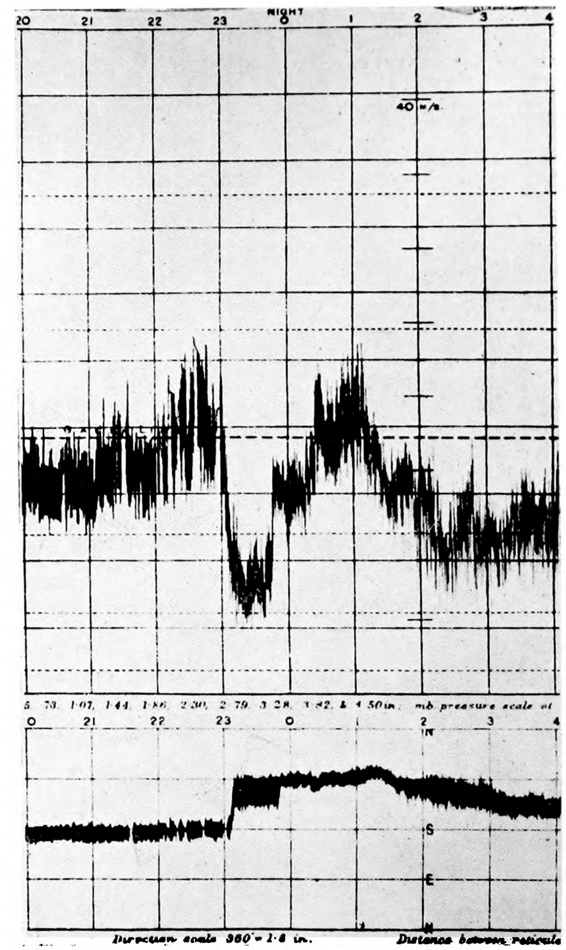
Record B7.—Sealand, February 10 to 11, 1925.



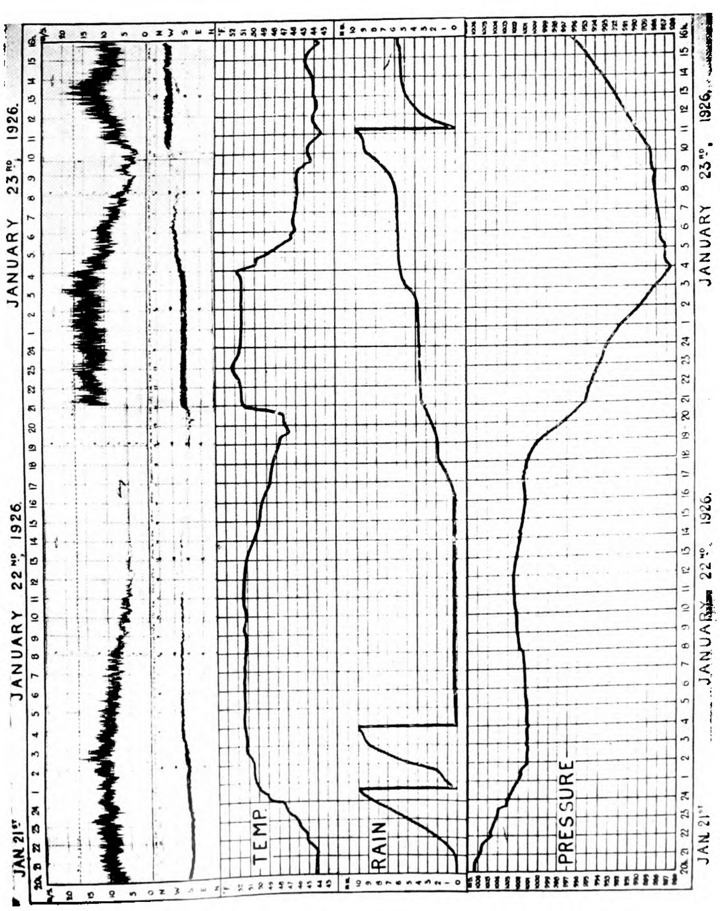
Record B8.—
Lympne, February 11 to 12, 1925.



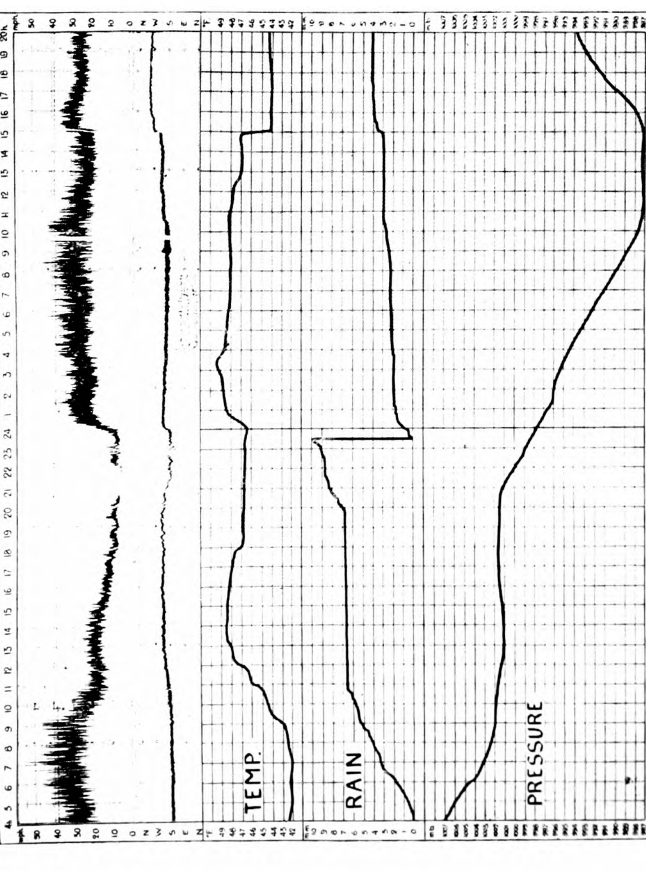
Record B9.—Cranwell, February 11 to 12, 1925.



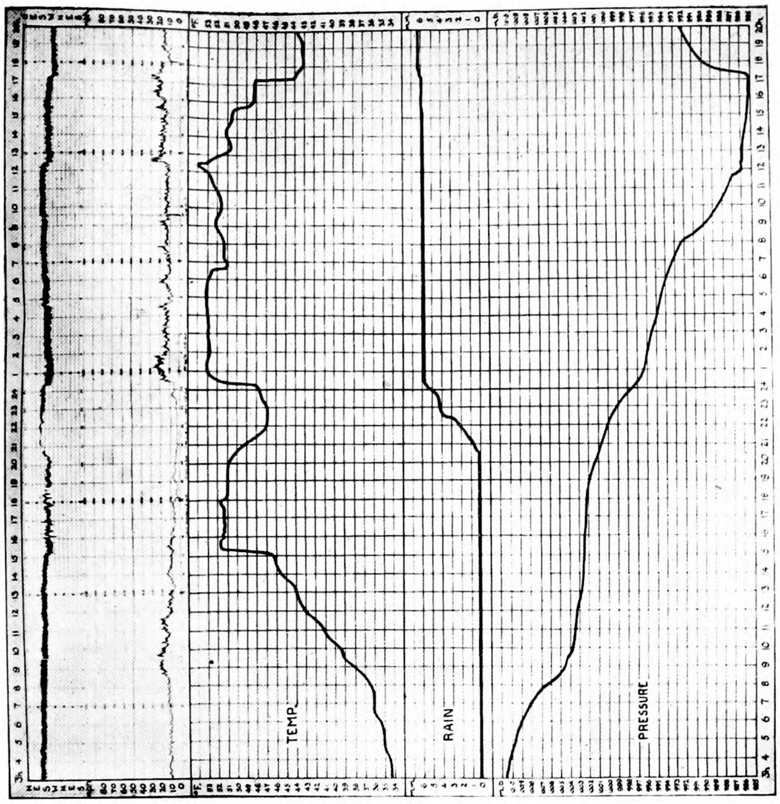
Record B10.—Spurn Head, February 11 to 12, 1925.



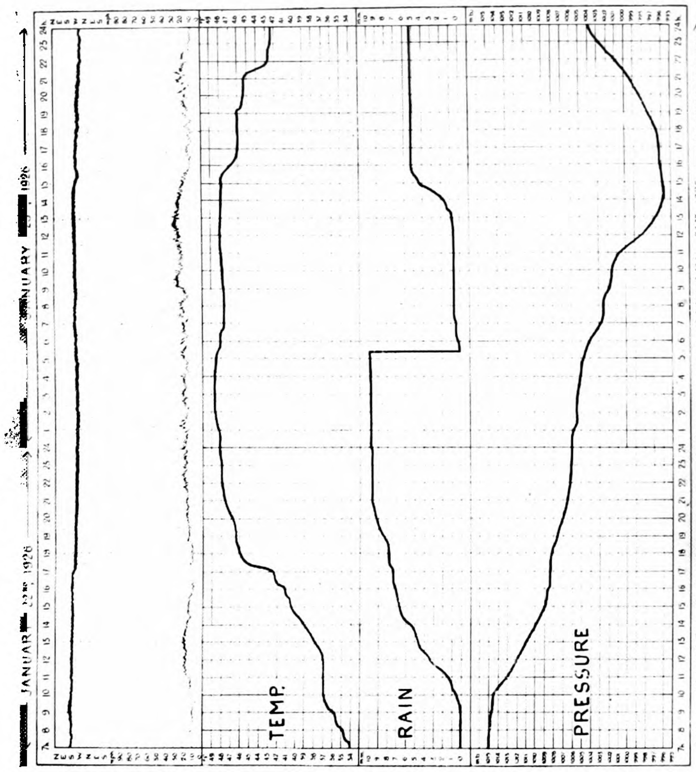
RECORD C1.—Valentia, January 22 to 23, 1926.



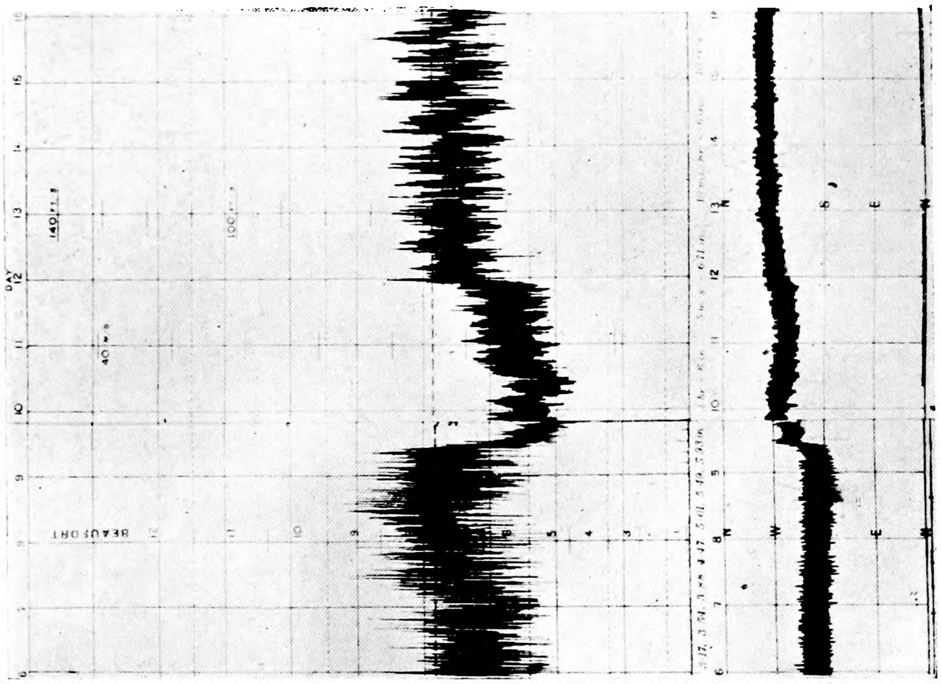
RECORD C2.—Holyhead, January 22 to 23, 1926.



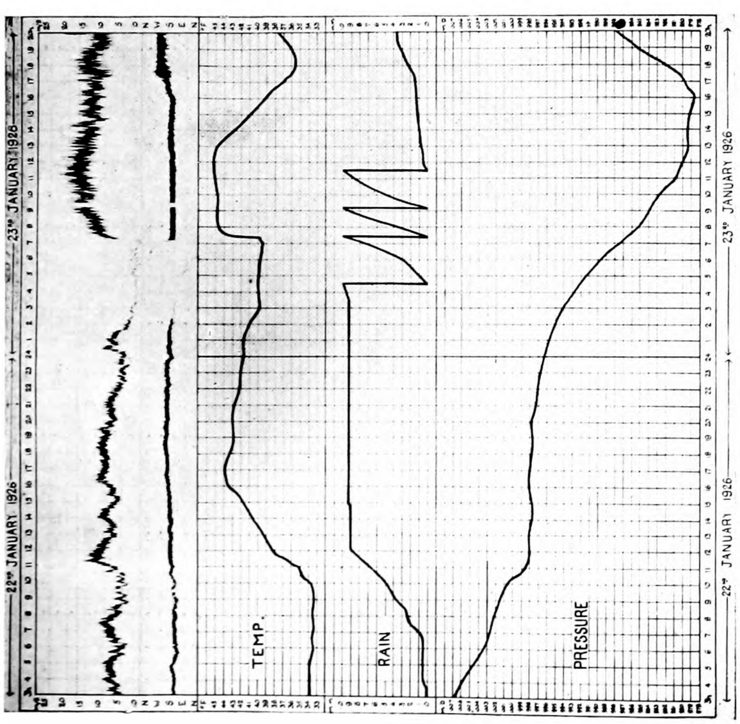
RECORD C3.—Sealand, January 22 to 23, 1926.



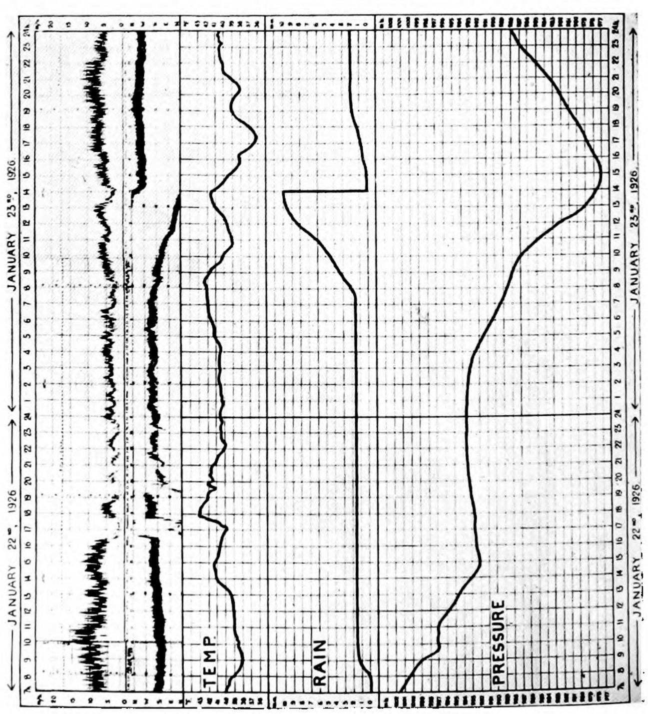
RECORD C4.—Andover, January 22 to 23, 1926.



Record C7.—Scilly, January 23, 1926.



Record C5.—Eskdalemuir, January 22 to 23, 1926.



Record C6.—Aberdeen, January 22 to 23, 1926.