QUARTERLY JOURNAL

OF THE

ROYAL METEOROLOGICAL SOCIETY

VOL. XLVI.] JULY 1920 [No. 195

# CLOUDS AS SEEN FROM AN AEROPLANE.

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[Synopsis of a Lecture delivered before the Royal Meteorological Society, March 17, 1920.]

A SERIES of photographs will be shown on the screen this afternoon which will illustrate, firstly, the appearance of the clouds from above; and, secondly, the relation of the forms of the clouds to the distribution of temperature and humidity in the upper air, and to the local weather and general meteorological conditions. The photographs were taken in conjunction with observations of temperature and humidity at different heights, from fully exposed dry and wet bulb thermometers on the wing strut of the aeroplane, and also from self-recording instruments.

It is not generally realised that when the sky is covered with a gloomy canopy of cloud, with the inevitable smoky haze over towns and for a considerable distance to leeward, one has only to ascend about a mile in order to enter a region with clear blue sky above, and a sea of white billowy cloud underneath, which stretches in all directions to a distant horizon which stands out sharply owing to the perfect visibility.

Until recently almost the only method of getting above the clouds was by the slow and laborious process of climbing a mountain, and from the mountains of this country a view of the upper surface of the clouds is comparatively rare. A fair number of instances were recorded at the Ben Nevis Observatory, but most of them were in winter or in the early morning. In many cases when the level of the cloud-sheet is just below the top of the mountain, the sheet rises to cross the mountain and covers up the top.

The aeroplane now provides a much simpler means of getting above the clouds. A modern high-powered machine will climb up through several thousand feet of cloud in a very few minutes. In the cloud one is surrounded by thick fog which covers the machine with water, or with ice if the temperature is below the freezing-point and the cloud consists of super-cooled water-drops. Very soon, however, it grows lighter up above, and shortly afterwards one breaks out into clear sunshine. On some occasions there are other layers of cloud up above, but in anticyclones at any rate there is usually only a single sheet.

I carried out observations of clouds from aeroplanes since 1915, but got very few opportunities of taking photographs. It was impossible to carry out cloud photography when flying on the line. But in the summer of 1918 I took over the flight which was obtaining upper air data for the meteorological section R.E. at G.H.Q. There was then a unique opportunity of obtaining cloud photographs. The necessary apparatus was already available, having been issued to the flight at the request of Lt.-Col. Gold. The camera used was one of the older patterns of R.A.F. hand cameras which proved suitable for the purpose. The plates available were the very fast panchromatic used for trench photographs and slow process plates used chiefly for copying. We found it difficult to avoid over-exposure with the fast panchromatics, and also found that they tended to get fogged as they had no paper on their backs, not being meant for taking bright objects. We found the process plates very suitable for bold cumulus clouds or rippled sheets of cloud. Some types, however, we never photographed successfully. We had no opportunity of carrying the photography to a fine art, as has been done by Capt. C. J. P. Cave and by Mr. G. A. Clarke of Aberdeen Observatory. It is possible to obtain quite good cloud photographs from an aeroplane by using Kodak films. The author obtained some photographs with Kodak films in England in the autumn of 1917, which were reproduced in the *Journal* of the Scottish Meteorological Society.[1] The best of these photographs illustrates the capabilities of a Kodak camera for cloud photography, when the lens is well stopped down and the right exposure given.

The flights were carried out twice daily in all types of weather in order to obtain upper air temperature for the artillery and forecasting. There were thus fairly frequent opportunities of taking photographs of clouds from above, but the photography was merely an extra. If ascents were made primarily to obtain cloud photographs, they would not be made at fixed hours, but when the clouds looked suitable for photography. In summer the clouds are usually most striking about the middle of the day, or early in the afternoon.

The photography was started in the middle of July 1918, and within ten weeks nearly a hundred good negatives had been obtained. Some further photographs were taken in the winter, but the clouds then have less variety than in summer. The majority of the photographs were taken by the author, but a number of good ones were also obtained by Lieut. R. V. Sessions, R.A.F., including Figs. 7 and 14 of those which are being reproduced. The photographs were taken from the pilot's seat, as we did not as a rule take up passengers. They were all obtained over or near Berck, on the French coast about twenty miles south of Boulogne. The locality is of interest from the meteorological point of view, and also because the area under observation included the Channel, which is important for commercial aviation. The coast-line runs from north to south from Cape Grisnez to the mouth of the Somme, a distance of fifty miles.

In winter the sky is very frequently overcast with a single sheet of low cloud varying in thickness from 500 to 2000 feet. This type of cloud is very characteristic of anticyclonic weather. There may be

[1] Vol. 17, ser. 3, 1917, pp. 133-147.

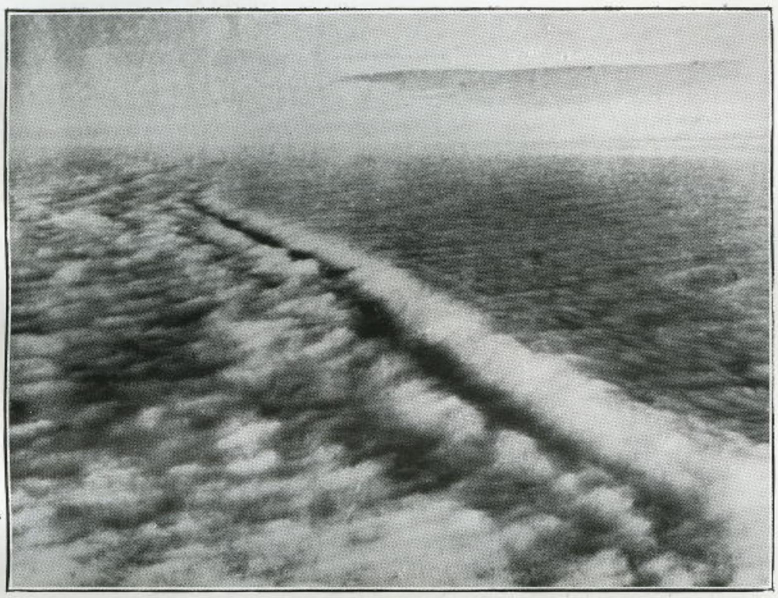

Fig. 1.—February 2, 1919, 15 h. A bank from SE to NW in a sheet of strato-cumulus cloud at about 4000 feet, moving from ENE.

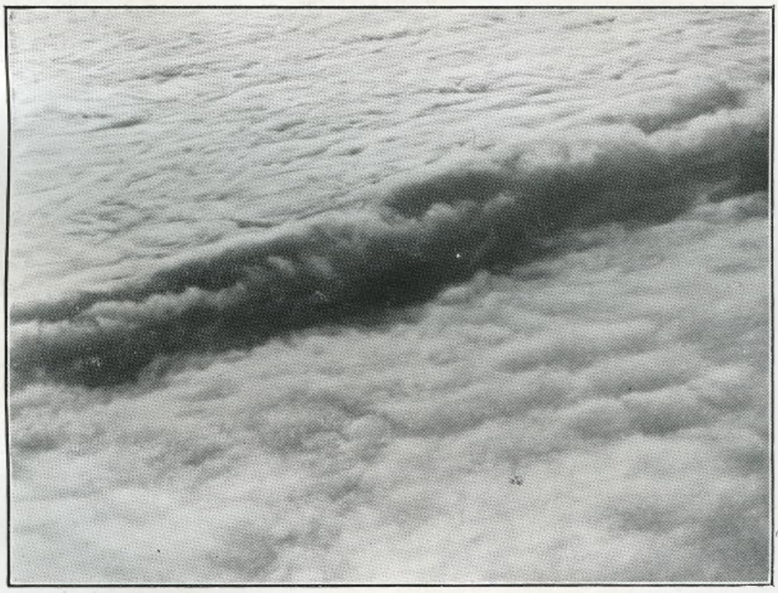

Fig. 2.—Another bank a few miles away at about the same time, in line ESE to WNW.

FIG. 3.—February 3, 1919, 15 h. A typical rippled sheet of strato-cumulus cloud, with its upper surface 2500 feet.

FIG. 4.—February 20, 1919, 10 h. Strato-cumulus below at 3000 feet, and other clouds above.

several days or a week of overcast sky, a state of affairs described by Mr. W. H. Dines as "anticyclonic gloom." The same type of cloud is characteristic of Easterly winds in winter, with an anticyclone to the north. There was a spell of gloomy weather with East winds from January 29 to February 3, 1919. On January 29 there was a belt of high pressure from the Atlantic to the southward of Iceland, across Scandinavia to the Baltic. This belt moved south and decreased in intensity, and on February 3 the remnant of the anticyclone lay across England. The photographs reproduced in Figs. 1 and 2 were obtained on the afternoon of February 2, and that in Fig. 3 on the following afternoon. The first two photographs show parts of two separate banks in the cloud-sheet, each about 700 feet high, and with hollows underneath them, with some spaces through which narrow strips of the ground could be seen. The clouds were moving from ENE, and their base was at 3000 feet. The upper surface of the portion of the cloud-sheet seen on the right of the first photograph was at 5000 feet, but that on the extreme left was as low as 3800 feet, as though the cloud level rose somewhat immediately to the south-west (the left as seen in the picture) of the hollow below the bank, it sloped down again still further to the south-west. Some miles to the south-west there was a rather similar but more vertical bank, facing NNW and 700 feet high, and the cloud level was at 4500 feet on the south side of it, and at about that level to the horizon. Fig. 2 shows a portion of this bank. The total length of each bank was over twenty miles; the portion seen in Fig. 1 was over ten miles long. They were not quite parallel but formed an angle with its apex towards the south-east. Neither bank could be traced as far as the apex. The cause of the banks is not clear; their formation may have been connected with the fact that the current carrying the cloud-sheet had crossed a ridge of high ground and then descended to the coast. When the photographs were taken the banks were over the sea, moving along with the cloud. Mr. G. A. Clarke at Aberdeen Observatory is familiar with long narrow strips of blue sky in the middle of the clouds, and with banks of cloud with straight edges such as would be visible from the ground if the lower part of the clouds shown in Figs. 1 and 2 were absent.

Fig. 3 shows a very typical rippled sheet t[illegible]n on the following day. The clouds were from 1000 to 2500 feet, lower than on the previous day. The ripples were across the North-east current, but not necessarily exactly at right angles to it. The photograph was taken from about a thousand feet above the clouds, looking towards the south-west. A photograph, taken from higher up and looking west, reproduced in *Symons' Meteorological Magazine* (January 1920) shows a very long ridge in the background not unlike those on the previous day, though only two or three hundred feet high.

The wind was measured above the clouds on February 2 by flying through a line of smoke shells burst at given intervals at the same place. No other upper wind observations were obtained on either the 2nd or the 3rd, even below the clouds, as there was a very thick haze, owing to smoke which had drifted from Germany and Belgium during the preceding few days. On the 3rd the upper wind had certainly backed somewhat towards North. The following are the observations of temperature and wind in the upper air corresponding to Figs. 1 to 4. The heights refer to the true height above the ground, the altimeter readings being corrected for temperature.

| Date and Time. | Height (feet). | 0. | 1,000. | 2,000. | 4,000. | 6,000. | 8,000. | 10,000. |
|---|---|---|---|---|---|---|---|---|
| Feb. 2, 15 hr. | Temp. ° F. | 32 | 29 | 25 | 23 | 23 | 19 | 13 |
| | Wind (Dir.) | ... | ... | ... | ... | ENE | ... | ENE |
| | ,, (Vel. m.p.h.) | ... | ... | ... | ... | 18 | ... | 17 |
| Feb. 3, 15 hr. | Temp. ° F. | 29 | 25 | 24 | 27 | 20 | ... | ... |
| Feb. 20, 10 hr. | Temp. ° F. | 51 | 49 | 45 | 40 | 35 | 26 | 20 |
| | Wind (Dir.) | S by E | S | S | ... | ... | ... | ... |
| | ,, (Vel. m.p.h.) | 10 | 32 | 36 | ... | ... | ... | ... |

There was a rise of temperature above the clouds on February 2 and 3, as is usually the case. On February 2 temperature rose 2° as the machine climbed out of the thin part of the cloud at 3700 feet, and a further 2° at 4500 feet. Five hours earlier there was an inversion of 10° F. above the cloud-sheet, the temperature rising from 16° at the top of the clouds at 4300 feet to 26° at 4800 feet. On February 3 there was an inversion of 4° immediately above the clouds at 2500 feet, but on the 20th there was no inversion. On this occasion there was a warm Southerly current and low pressure, a deep depression being centred off SW Ireland. The photograph was taken towards the east, and the ripples lie along the direction of the wind rather than across it. It was quite a thin sheet at 3000 feet, and was not perfectly level. Up above there were other clouds at 8000 feet, the shadows of which are seen on the lower sheet. Thicker clouds from 6000 to above 12,000 feet came over soon after and caused showers. It will be noted that although there was no inversion above the lower clouds, the lapse-rate of temperature above them was stable even for saturated air. Unless this condition is fulfilled, the clouds are unlikely to remain long in the form of a horizontal sheet. These horizontal sheets may be met with in most types of weather, but are commonest in quiet anticyclonic weather.

A description of the method of development of these cloud-sheets is given by Sir Napier Shaw in the *Manual of Meteorology*, Part IV.[1] There is a system of eddies up to the top of the cloud-sheet which keeps up a supply of moisture from underneath, which is cooled as it is diffused upwards and condenses into cloud. A note from Mr. W. H. Dines is also included which emphasises the importance of radiation first from the damp layer where the clouds form, and later from the cloud itself. In a period of overcast weather in winter it is plain that there must be a good deal of radiation from the cloud. Even in quiet weather slight bumps are met with below and in the cloud, so that eddy motion is probably the most important factor in maintaining the cloud-sheet. Both eddy motion and radiation no doubt play a part in the development of inversions, but the chief factor in the production of large inversions would appear to be the presence of air above the clouds which

[1] Chapter v. p. 48.

has descended *en masse* and been dynamically warmed. The relative humidity at the top of the inversion is usually below 40 per cent, occasionally below 20 per cent. Except close to the surface, large inversions are limited to anticyclones and to the regions just outside their boundaries. Inversions of as much as 15° F. in 500 or 1000 feet may exist at about 4000 to 6000 feet in winter, when air has descended down to the inversion, and the lower air was drawn originally from a cold source. If the lower cold air passes over a relatively warm sea clouds are particularly certain to develop under the inversion. In spells of cold East wind it frequently happens that the weather is overcast in the east of Great Britain but fine on the Continent. During the period January 29 to February 3, 1919, the weather was overcast over a large area on the Continent also.

The theory that the inversions of anticyclones are due to the upper air having been dynamically warmed by descent was put forward by Mr. W. H. Dines in 1911.[1] The air descending does not usually reach the ground, but may travel horizontally at 4000 feet or higher. In Southerly currents the descending air reaches a low level and much of it probably reaches the ground, being mixed up with the lowest layer by mechanical eddy motion and by convection in summer. In Northerly currents the inversion is usually above 5000 feet. Near the east and north-east boundary of an anticyclone it is often above 8000 feet, occasionally above 10,000 feet. The highest cloud layer shown in Fig. 5 was up to 9800 feet, and there was an inversion of 3° in 500 feet above it. This layer was only 100 to 200 feet thick, but another thicker layer from 7000 up to 9000 feet may be seen in the foreground through a gap in the top layer. There was another gap in the distance, but the upper layer was renewed towards the horizon, and in places clouds had broken through from below and exceeded 11,000 feet, which may be seen in the photograph. Note the folds in the cloud in two directions, crossing in the middle of the picture. The camera was pointing towards the north-west. Of the upper wind observations given below, those from 6000 to 15,000 feet were obtained from anti-aircraft shell bursts (single mirror method) about two hours earlier, before the sky was overcast. There were some cumulus clouds at 1500 feet which grew up to the upper layer locally inland, reaching 11,000 feet or so, and some local showers.

There were depressions over the North Sea and Iceland, a shoulder of high pressure over Ireland, and an extensive anticyclone to the south-west. The relatively warm and drier air above 10,000 feet had probably been carried forward from the shoulder of high pressure by the upper wind at those heights, which was stronger than the wind at 6000 feet. Next morning, when the shoulder of high pressure lay over northern France and southern England, about 300 miles further east, the inversion was at 5000 feet, and the relative humidity was about 30 per cent from 7000 to 8000 feet.

The upper air temperatures, humidities, and winds for August 26 and 28, corresponding to Figs. 5 and 7, are given below. The humidity figures in italics were obtained from the hygrograph records, the wet

[1] W. H. Dines. "The vertical temperature distribution in the atmosphere over England, and some remarks on the general and local circulation." *London, Phil. Trans. R. Soc.*, **211**, (ser. A.), 1911, pp. 253–278.

bulb having dried up. The other humidities were obtained from the wet bulb readings, and gave good agreement with the hygrograph readings, making some allowance for the lag of the latter instrument.

| Date and Time. | Height (feet). | 0. | 1,000. | 2,000. | 4,000. | 6,000. | 8,000. | 10,000. | 11,000. | 12,000. | 13,500. | 15,000. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| August 26, 1918, 18 hr. | Temp. ° F. | 62 | 56 | 54 | 47 | 38 | 30 | 26 | ... | 23 | 19 | ... |
| | R.H. % | 82 | 93 | 86 | 73 | 91 | 100 | 76 | *75* | *70* | *60* | ... |
| | Wind (Dir.) | ... | W by S | W by S | ... | WNW | ... | WbyN | ... | ... | ... | WNW |
| | ,, (Vel., m.p.h.) | ... | 39 | 37 | ... | 22 | ... | 32 | ... | ... | ... | 34 |
| August 28, 1918, 8 hr. | Temp. ° F. | ... | 56 | 52 | 48 | 40 | 34 | 28 | 29 | ... | ... | ... |
| | R.H. % | ... | 93 | 86 | 79 | 92 | 89 | 50 | 22 | ... | ... | ... |
| | Wind (Dir.) | ... | WbyN | WbyN | ... | ... | ... | ... | ... | ... | ... | ... |
| | ,, (Vel., m.p.h.) | ... | 30 | 30 | ... | ... | ... | ... | ... | ... | ... | ... |

Fig. 7 shows the top of a large cumulus protruding rather more than 2000 feet through a cloud-sheet with its upper surface at 8000 feet. The base of the cumulus was at 2000 feet, and that of the cloud-sheet at 6000 feet. This protrusion of the tops of cumuli above cloud-sheets is very common inland on summer days, but if there is an inversion above the clouds the cumuli do not stand out so boldly above as in the example shown in the photograph. Nevertheless large cumuli may ultimately grow a thousand feet or even more above clouds with an inversion of 3° or 4° F. above them, the top of the cumulus being wider and flatter than that of Fig. 7. The cumulus had reached an inversion at 10,500 feet and did not grow much higher. The inversion was unusual considering that there was a well-marked depression centred over the North Sea with the trough right over NE France. An inversion at that level or higher is occasionally met with just behind the trough of a depression, due to a cold current flowing under a warm damp current, but it does not persist long, the cold current soon prevailing up above also. In this instance the air was dry above the inversion, which still persisted in the evening and amounted to 4° F., though the actual temperatures were rather lower. Next morning, when Berck was at the boundary of a large anticyclone to the south-west, the inversion amounted to 6° at about 11,000 feet. In the evening the inversion was at 8000 feet, but on the following day (Aug. 30) it was again at 11,000 feet.

There were some showers in NE France on August 28, and a little local thunder. No thunderstorm of any intensity will develop unless the clouds can grow up to a considerably greater height than 11,000 feet.

The forms assumed by the clouds over the land on summer days present a more complex problem than the cloud-sheets in winter or over the sea, which tend to drift for great distances without much change of form. If the temperature is low at 6000 to 8000 feet and there is plenty of moisture in the lower layers, cumulus clouds are sure to form, and if there is an inversion above the cold layer they spread out into strato-cumulus, so that the clouds are thicker over the land than over the sea. Sometimes it is cloudy over the land during the day and fine over the sea. On the other hand, if there are low clouds and very dry air above them at 3000 or 4000 feet, the clouds over the land during

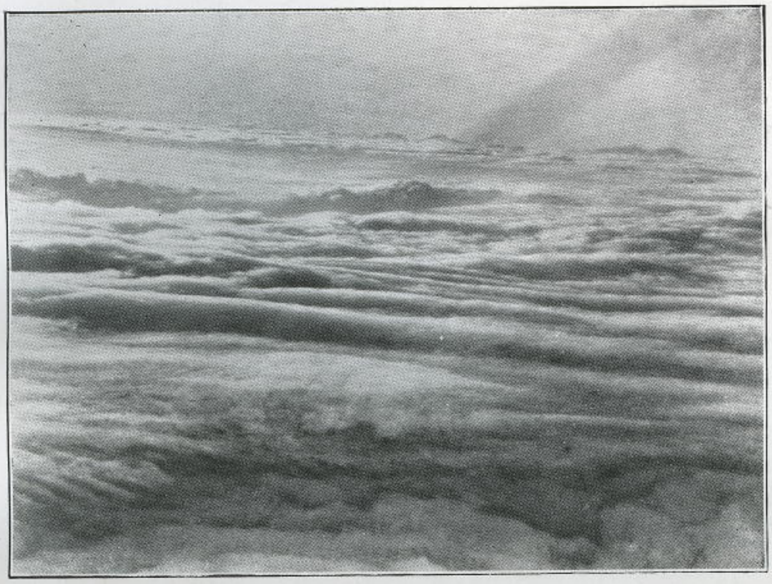

FIG. 5.—August 26, 1918, 18 h. Cloud-sheet at 10,000 feet, with ripples in two directions.

FIG. 6.—September 15, 1918, 10 h. A rippled strip of cloud at 4000 feet. Detached clouds below at 1000 to 1500 feet.

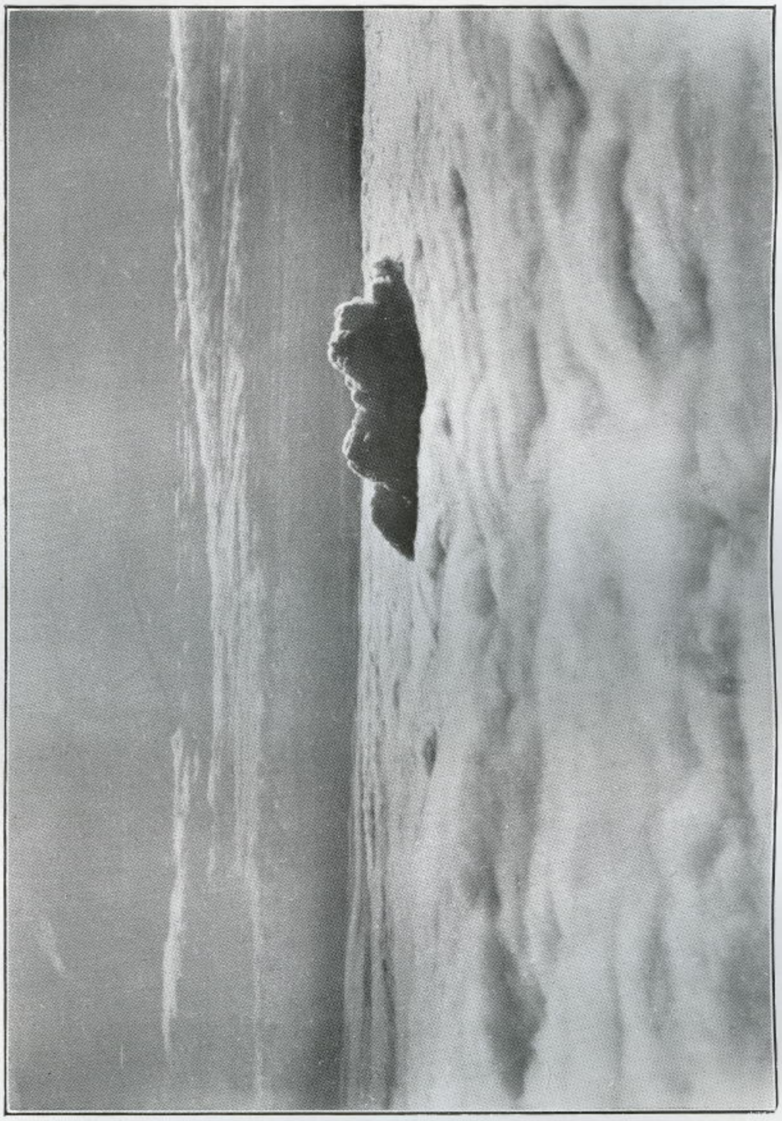

FIG. 7.—August 28, 1918, 8 h. Top of cumulus protruding over 2000 feet through cloud-sheet, with upper surface at 8000 feet.

Fig. 7.—August 28, 1918, 8 h. Top of cumulus protruding over 2000 feet through cloud-sheet, with upper surface at 8000 feet.

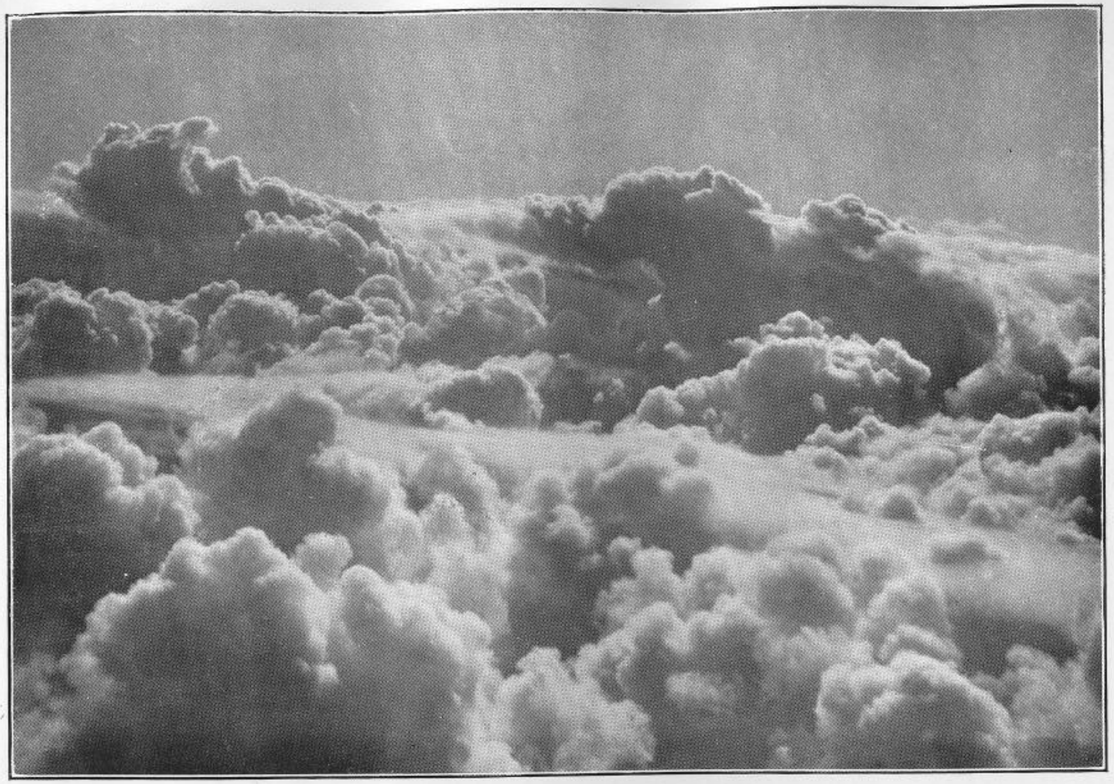

Fig. 8.—September 13, 1918, 9 h. Tops of cumulus and strato-cumulus clouds up to 7500 feet in background. Strip of cloud at about 5000 feet in foreground.

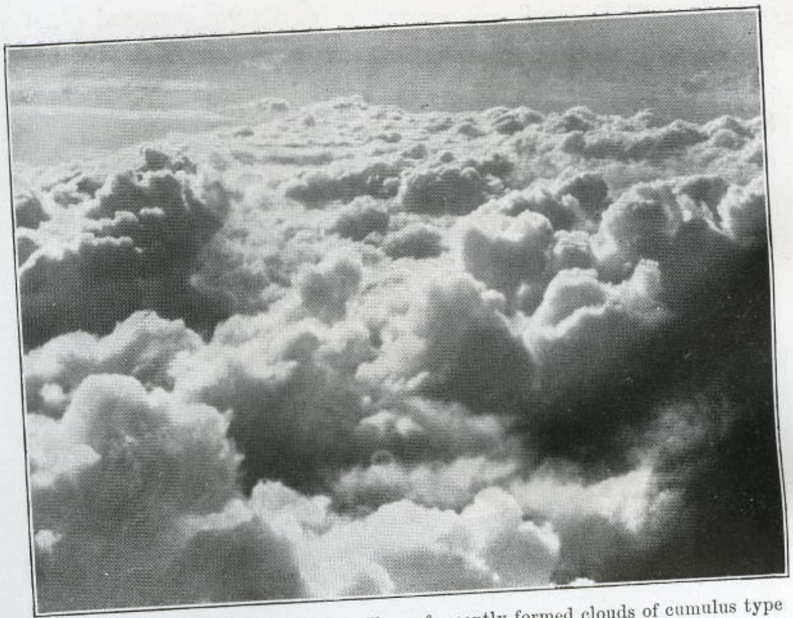

FIG. 9.—September 24, 1918, 7 h. Tops of recently formed clouds of cumulus type up to 5000 feet, extending about ten miles inland. Note haze horizon.

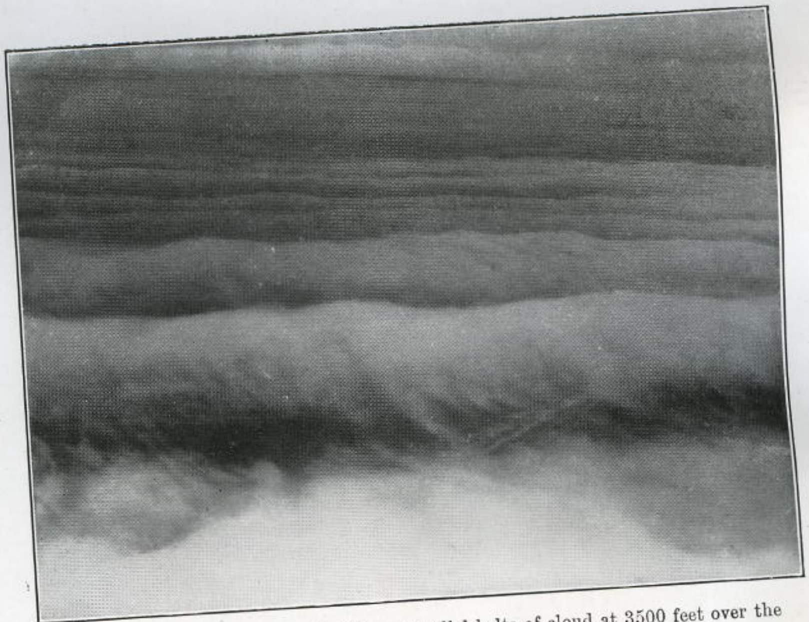

FIG. 10.—September 26, 1918, 18 h. Parallel belts of cloud at 3500 feet over the Channel. The distance between successive crests was about two miles.

*Face p.* 239.

mulus type
zon.

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miles.

*Face p. 239.*



the day tend to get mixed with the dry air and dissolve away entirely. A thick low cloud-sheet with a large inversion above it may persist over the land for a day or two even in midsummer, but in time it nearly always gets dissolved away. There is a well-marked diurnal variation in the height of all types of clouds in summer over the land, the level of the base rising during the day, owing to the lower air being mixed with drier air above. The same process causes the level of the base of the clouds to rise as they drift inland from the coast, except in rainy weather.

Various types of summer clouds are illustrated by Figs. 8, 9, and 11 to 13. Fig. 8 (September 13, 1918) shows the tops of cumulus and strato-cumulus clouds which reached an inversion of 3° at 7500 feet. In the foreground the cumuli had only reached 5000 or 6000 feet, and a long strip of cloud had formed just above the tops of the growing cumuli, some of which were beginning to pass up through it. Such flat strips or patches of cloud frequently form above growing cumuli when the humidity is high, and ultimately become absorbed into the cumuli. The upward current within the cumulus cloud appears to cause the layer above it to bulge upwards.

Two days later the photograph reproduced in Fig. 6 was obtained in different meteorological conditions, an anticyclone having moved east from the Bay of Biscay to Switzerland. The lower clouds were the remains of a fog layer which drifted in from the Channel on the previous evening, and which persisted most of the day over the Channel and the coast near Boulogne. Over the land the clouds broke into cumulus, which ultimately reached 4000 feet, though those shown in Fig. 6 were at 1000 to 1500 feet, with an inversion of 2° above them. The rippled strip was at 4000 feet, and there was an inversion of 3° above it. The upper winds given below were observed nearly fifty miles away in an ESE direction, no observations being available locally. As the temperature at 4000 feet was 2° F. warmer a few miles to the south-east than in the neighbourhood of the cloud strip, it seems probable that in that locality the SW wind was stronger just above 4000 feet than just below it, and this increase of wind, together with the slight decrease of density, probably accounted for the ripples. The strip was approximately parallel to the wind and the ripples at right angles to it. There was much cloud at 4000 feet to the north-west, but little to the south-east, except the strips shown in the background in the photograph.

Fig. 9 shows clouds of cumulus type with their tops at about 5000 feet, looking east from the coast at Berck on the morning of September 24, 1918. The base of the clouds was at about 1500 feet, and they were nearly continuous, presenting the form of strato-cumulus as seen from the ground. The clouds formed over the sea and became larger and more continuous over the land. At the time that the photograph was taken they had only extended about ten miles inland, and further east there were only a few clouds. This may be seen from the photograph, which also shows a haze horizon at 5000 feet. There was no inversion at that height, but there was no fall in the temperature between 5000 and 6000 feet. The humidity was fairly low above 5000 feet, and during the day the dry air became mixed to some extent with the damper air below, with the result that the day was fair, with only detached clouds covering less than half the sky for the most part. In the evening the base of the lower clouds was at 3000 feet.

The cumulus clouds on the morning of September 27 (Figs. 11 to 13) assumed a rather peculiar form. The base of the clouds was at 2000 feet, and most of them had not yet penetrated above 3000 feet. Some of them, however, entered a layer between 4000 and 7000 feet where the lapse-rate of temperature was decidedly above the adiabatic for saturated air, and towered vertically upwards till they reached an inversion at 7700 feet. The photograph reproduced in Fig. 12 was taken two or three minutes after that in Fig. 11, and shows the tops of the cumuli broken away. They soon dissolved away altogether, as is seen in Fig. 13 taken a few minutes later, from rather higher up and from a slightly different position. Other detached fragments may be seen at a distance in the background. The tops of narrow columns of cloud of this sort nearly always break away and dissolve, whether or not they reach an inversion. Near the coast they are most often seen in late summer or autumn, when the sea is warm, but inland they may occasionally be observed as early as April. It requires a very much broader column to produce a shower. The photographs show the edge of a layer of strato-cumulus which had moved east, at about 7000 to 7700 feet just under the inversion. Later in the day most of the cumuli grew up to the inversion, and as a result there was a good deal of strato-cumulus cloud inland, though as usual the level of the base of the clouds increased. The inversion amounted to 8° during the ascent, but during the descent half an hour later it only amounted to 3°, the temperature having fallen at 8000 feet, just above the inversion.

On the following page are given the upper air data for the dates corresponding to Figs. 8 to 14, and Fig. 6.

The humidities in italics refer to the hygrograph readings. On September 13 the temperature was 27° at 7500 feet, and on September 27 it was 25° at 7700 feet.

The upper winds were observed by pilot balloons at Montreuil or by anti-aircraft shells near Berck, except those on September 15 and 26 when there were no observations above 2000 feet available except far inland. On the evening of the 26th the low clouds over the Channel were arranged in waves nearly two miles in width, as shown in Fig. 10. The low clouds were between 3000 and 3800 feet, and were accompanied by very little turbulence, which accounts for their smooth appearance; the lapse-rate of temperature within and just under the clouds was of a stable type. The banks were roughly from south-west to north-east, very nearly along the wind current at their level, though not quite along it. The waves had a very slow lateral motion towards the south-east. Note the coast-line through the nearest gap, and also the small ripples across the cloud strips. The upper wind observation fifty miles inland two hours previously showed a Westerly current at 4000 feet and upwards, above the South-west current. The waves of Fig. 10 may have been set up by a West wind crossing a South-west wind. Half an hour later the wave clouds were replaced by a continuous sheet. There were other clouds above in a succession of thin layers near together from 6000 to 12,000 feet. There was a gradual inversion of 3° at about 7000 feet, but nevertheless there was rain during the night, which amounted to 7 mm. at Calais, and 4 mm. at Montreuil. The temperature may have fallen somewhat at 10,000 feet by the time

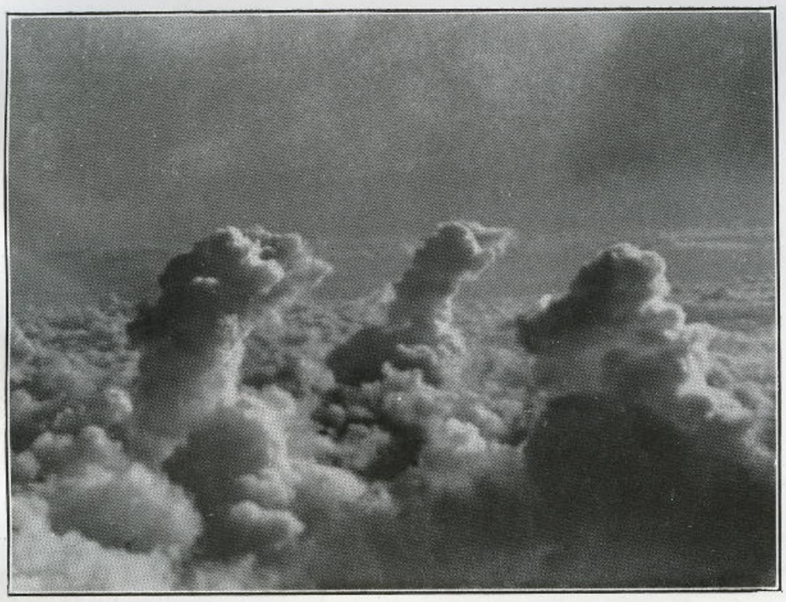

Fig. 11.—September 27, 1918, 7 h. Towering cumuli up to 7700 feet. Lower clouds about 1500 feet.

Fig. 12.—The tops of the same cumuli broken away, a few minutes later.

FIG. 13.—The same clouds as those of Fig. 12, dissolving away a few minutes later. Note other detached fragments in the distance, and the edge of a distant strato-cumulus sheet at 7700 feet.

FIG. 14.—September 5, 1918, 18 h. The edge of a thunderstorm beyond the left of the picture, with clouds underneath and false cirrus on top left-hand corner. Top of the large cumulus on the right at 14,000 feet. Taken from 10,000 feet.

the rain set in, but it cannot have fallen very much. Even if the lapse-rate of temperature is below the adiabatic for saturated air, it is possible for steady rain to fall if a thick saturated layer ascends on a gradual slope in the manner indicated by Bjerknes.[1] It will be noted that colder air had arrived next morning, behind a trough of low pressure.

| Date and Time. | Height (feet) | 0. | 1,000. | 2,000. | 4,000. | 6,000. | 8,000. | 10,000. | 12,000. | 14,000. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1918. Sept. 5, 18 hr. | Temp. °F. | ... | 66 | 62 | 53 | 45 | 40 | 32 | 25 | 18 |
| | R.H. % | ... | 66 | 66 | 76 | 74 | 72 | 64 | *75* | *75* |
| | Wind Dir. | Calm | WNW | WSW | SW by W | WSW | W by S | WSW | WSW | ... |
| | „ Vel. (m.p.h.) | ... | 4 | 7 | 12 | 28 | 26 | 21 | 26 | ... |
| Sept. 13, 9 hr. | Temp. °F. | 58 | 53 | 49 | 40 | 34 | 30 | 24 | 17 | ... |
| | R.H. % | 76 | 88 | 69 | 94 | 87 | 93 | 73 | *32* | ... |
| | Wind Dir. | WNW | NW by W | WNW | WNW | W by N | W by N | W by N | ... | ... |
| | „ Vel. (m.p.h.) | 8 | 18 | 19 | 30 | 31 | 36 | 38 | ... | ... |
| Sept. 15, 10 hr. | Temp. °F. | 62 | 56 | 58 | 50 | 48 | 46 | 38 | 32* | ... |
| | R.H. % | 88 | 100 | 86 | 95 | 62 | 32 | 46 | 73* | ... |
| | Wind Dir. | SE | S by W | SW by S | SSW | SW by W | WSW | WSW | W by S | ... |
| | „ Vel. (m.p.h.) | 4 | 12 | 18 | 19 | 23 | 28 | 26 | 28 | ... |
| Sept. 24, 7 hr. | Temp. °F. | 53 | 49 | 45 | 38 | 35 | 31 | 24 | 17 | ... |
| | R.H. % | 86 | 88 | 81 | 81 | 47 | 40 | *35* | *26* | ... |
| | Wind Dir. | Calm | WNW | WNW | NW by W | NNW | NW by N | ... | ... | ... |
| | „ Vel. (m.p.h.) | ... | 8 | 14 | 21 | 15 | 12 | ... | ... | ... |
| Sept. 26, 18 hr. | Temp. °F. | 59 | 55 | 51 | 47 | 40 | 41 | 36 | 30* | ... |
| | R.H. % | 71 | 74 | 66 | 100 | 100 | 94 | 93 | 93* | ... |
| | Wind Dir. | ... | SW by W | SW by W | W by N | W by S | WNW | WSW | W | ... |
| | „ Vel. (m.p.h.) | ... | 18 | 21 | 30 | 41 | 43 | 34 | 34 | ... |
| Sept. 27, 8 hr. | Temp. °F. (up) | 55 | 51 | 46 | 40 | 30 | 33 | 28 | 20 | ... |
| | „ (down) | 56 | 51 | 46 | 39 | 30 | 27 | 27 | 20 | ... |
| | R.H. % (up) | 93 | 89 | 94 | 75 | 92 | 40 | *20* | *12* | ... |
| | Wind Dir. | NW by W | NW by W | NW by W | WNW | W by N | ... | W by N | ... | ... |
| | „ Vel. (m.p.h.) | 8 | 20 | 18 | 24 | 39† | ... | 45† | ... | ... |

* Refers to 11,500 feet. † From shell-bursts.

The last illustration of the series shows thunder-clouds viewed from about 10,000 feet. The large cumulus on the left was joined to a thunderstorm, and the false cirrus seen in the left-hand top corner was at the edge of the "anvil" whose top exceeded 20,000 feet. The top of the cumulus on the right was at about 14,000 feet, and in the distance in the middle of the picture the false cirrus of another thunderstorm

[1] J. Bjerknes. "The structure of moving cylones." *Washington, D.C., U.S. Dept. Agric., Monthly Weath. Rev.*, **47**, 1919, pp. 95-99.

may be observed, perhaps 100 miles away. The base of the clouds was at about 4000 feet, rather lower in places. The sharply defined clouds, of which an example is seen on the right of the photograph, consist of water-drops, which may be much super-cooled. On the other hand, the false cirrus consists of ice-crystals or snow-flakes which are usually developed from the water-drops, but may continue to ascend. The "anvils" on the tops of severe thunderstorms on hot summer days commonly reach the cirrus level, and the towering clouds with sharply defined tops consisting of super-cooled water-drops may exceed 20,000 feet before false cirrus forms. Even slight thunderstorms in cool weather, or heavy showers at any season of the year, may develop "anvils" up to or above 20,000 feet. In order that a thunderstorm of any intensity may develop, there must in the first place be enough moisture in the lower air for clouds to form as the result of the initial upward movement, which may either be a powerful convection current or a gradual lifting of the strata by converging currents of different temperature at the surface. In the second place, there must be a lapse-rate of temperature for rather more than 10,000 feet above the clouds which averages greater than the adiabatic for saturated air, with no inversion, and no nearly isothermal layer of greater thickness than a few hundred feet. Slight thunder is occasionally noted (as we have seen in the case of August 28, 1918), with an inversion at about 11,000 feet. The clouds probably reached 13,000 or 14,000 feet, as the tops of clouds are frequently observed to be considerably colder than the air surrounding them.

On the evening of September 5, 1918, there were several other thunderstorms visible in France and England besides the one whose boundary is seen in Fig. 14. A thunderstorm 100 miles away is a conspicuous object from the air, and the tops of "anvils" may sometimes be seen from 10,000 feet at a distance of about 200 miles. Thunderstorms can nearly always be avoided without difficulty by aeroplane pilots engaged in ordinary peace-time flying. The higher the pilot flies the more conspicuous the tops of the thunder-clouds become, and the more easily can they be avoided. Sometimes there are extensive clouds at about the level of the base of the thunder-clouds, and it is necessary to climb above them in order to see the thunderstorms at a distance, and to judge the best course to fly in order to avoid them.

The results obtained at Berck illustrate the value of the aeroplane as an instrument for meteorological research. In addition to the photographs, a large number of observations of clouds and visibility were made, showing their relations to the upper air conditions and the general meteorological situation. There were 550 ascents up to at least 10,000 feet, most of them up to 14,000 feet. Meteorological research by means of aeroplanes can be carried out more effectively by a pilot than by an observer going up as a passenger. A pilot who specialises in the work can fly up through any thickness of cloud, while a pilot without experience in cloud-flying is liable to get into difficulties if he attempts to do so.

The photographs only show a small sector of the clouds and convey little impression of the grandeur of the view all round. Very fine cloud scenery may often be seen from within a couple of miles of the ground. As civil aviation develops and becomes cheaper, increasing opportunities of viewing this cloud scenery will present themselves.