CLOUD STUDY

A Pictorial Guide

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and
R. S. SCORER, M.A., Ph.D., F.R.Met.S

Prepared under the auspices of the Royal Meteorological Society

L. Larsson

Cumulonimbus cloud is one of the main sources of the earth's rainfall. It is produced by convection currents rising into cool air from hot land or sea and begins as small cumulus clouds with swelling, cauliflower-shaped outlines, as in the foreground. With vigorous enough convection, the clouds soon grow big enough to produce some rain-sized droplets; and once a few drops in a cloud have frozen, others become infected and in a short time most of the supercooled part of the cloud turns to ice [see no. **11**]. This ice cloud evaporates much more slowly than a water cloud and so it begins to accumulate and spread out at the top in the form of an 'anvil' [see no. **14**]. The parts of the cloud composed of ice crystals have a diffuse outline, clearly distinguishing them from those composed of water droplets. The frozen part is often observed to appear at about the same time as the rain shower begins to reach the ground.

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We are also indebted to Messrs. John Wyeth & Brother Ltd. for the loan of the blocks of four colour pictures (jacket, frontispiece, and nos. **38** and **48**).

F.H.L.

R.S.S.

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FOREWORD

by R. C. SUTCLIFFE, O.B.E., Ph.D., F.R.S.

President, Royal Meteorological Society

The Royal Meteorological Society is justifiably proud of its remarkable collections of cloud photographs left to the Society by enthusiasts of former years —the famous Clarke and Cave collections. From these and many other pictures used as illustrations in the Society's monthly magazine WEATHER, it has been possible to make a selection which is the basis of this book. The photographs are a never ending source of interest, being continually called upon by authors and lecturers; some indeed are 'classics', known the world over, and have been reproduced in printed works in many countries. It was nevertheless the feeling of the Council of the Society that more could still be done and they counted themselves particularly fortunate in finding in F. H. Ludlam and R. S. Scorer, two Fellows with all the attributes required to make Cloud Study attractive to both layman and specialist. Being themselves enthusiasts in cloud photography with some remarkable pictures available in their private collections, and being privileged also to draw upon other sources for special treasures known to them, they have put together what is undoubtedly the most interesting work of its kind. Their explanatory notes, although simply worded, are completely up-to-date, as would be expected from scientists who have contributed much to our present understanding of clouds and rainfall and who are still in the heart of the battle of research.

I would therefore like to express the thanks of the Council of the Society to the contributors and authors and to wish their volume the success which it undoubtedly deserves.

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INTRODUCTION

WATER IN THE ATMOSPHERE

Everyone knows that the clouds we see floating in the sky are made of water. If we are to learn more about them we must first understand how water behaves in the atmosphere.

DRY, MOIST AND SATURATED AIR

The amount of moisture in the air changes noticeably from day to day. Sometimes there is very little and we say the air is 'dry'; on other days it is very moist and we say the weather is 'close' or 'muggy'.

Suppose that on a dry day we take a tin, pour a little water into it, and close the lid. Gradually the water evaporates into the air above it: rapidly at first, but then ever more slowly, until after a time the evaporation stops. We say that the air in the tin is now *saturated* with water vapour. If the contents of the tin are warmed, more water evaporates until the air again becomes saturated: the warmer air is, the more vapour it holds when saturated.

THE FORMATION OF DEW AND CLOUD

If after this warming the tin is allowed to cool a dew forms on the inside, where the air is chilled. As the chilling progresses the dew becomes more copious, and at last, when the air has been restored to its original temperature, as much water as had evaporated during its warming has been deposited out of the vapour as dew.

The air could have been cooled more rapidly by suddenly opening the lid, for during the warming its pressure in the confined volume of the tin rose above the atmospheric pressure. The rapid expansion as the lid flies open causes a chilling throughout the whole of the air, and not just near the sides of the tin as formerly. Consequently this time the condensing vapour forms, not a dew, but a cloud of tiny droplets distributed throughout the volume of the air.

The cooling of expanding air masses is a process of vital importance in the atmosphere. Such a cooling can be noticed in the rush of air escaping from a deflating tyre. It occurs only when the air loses some of its internal, molecular energy—which we sense as temperature—in expanding against a resistance. In the atmosphere a resistance is always provided by the pressure of the surrounding air.

For a cloud to be formed by chilling moist air it is not necessary for the air to be quite saturated originally: if the cooling is prolonged sufficiently the air will eventually become saturated and a condensation will ensue.

ATMOSPHERIC CLOUD FORMATION

In the atmosphere air is chilled on a vast scale in rising currents. As air ascends, the weight of the atmosphere above it decreases, and so the pressure upon it diminishes and it expands. There are some other ways in which the air may be cooled sufficiently to produce clouds, but they play a relatively minor part in cloud formation.

THE CHANGE OF ATMOSPHERIC TEMPERATURE WITH HEIGHT

The atmosphere loses heat into outer space by invisible infra-red radiation, at a rate sufficient to cool it by about ten Centigrade degrees every week. This drastic loss is balanced by the stirring upwards of air from the sun-warmed ground. The upward movements occur in many ways and on a variety of scales, from the tiny shimmerings over hot roads to the tremendous heavings of cyclonic storms. They are accompanied by horizontal movements which similarly range from little puffs of wind to winter gales and hurricanes.

While ascending air remains cloud-free it cools by ten Centigrade degrees for each thousand metres of rise (if it becomes saturated and produces a cloud the liberation of latent heat during condensation somewhat reduces this rate of cooling). Consequently, even the stirring upwards of air heated over the tropical deserts cannot bring the atmosphere a few thousand metres above the ground to temperatures above freezing point. Everywhere over the globe it becomes colder with height until we reach the stratosphere, where the temperature is less dependent upon stirring from the ground (Fig. 1). The air below the stratosphere lies in the troposphere, a name which means that the air is well stirred. Over the British Isles the temperature usually falls below freezing point at a height of about one or two thousand metres in winter, and three or four thousand metres in summer. At the base of the stratosphere, some ten thousand metres above the ground, the temperature is likely to have fallen to about fifty Centigrade degrees below the freezing point. At all levels in the troposphere there are large variations of temperature from day to day as well as season to season.

ICE CLOUDS IN THE ATMOSPHERE

THE FREEZING OF CLOUD DROPLETS

In the upper part of the troposphere, where the temperature is below freezing point, we might expect to encounter clouds of ice crystals. It is surprising, and important, that we also find clouds containing droplets which have not frozen. These droplets are said to be *supercooled.*

It seems that, except at very low temperatures, freezing of water commences only in the presence of minute impurities, whose action is imperfectly understood and is at present the subject of intensive study. Large volumes of water, such as lakes and even puddles, contain multitudes of motes amongst which there are sure to be a few especially effective ones which promote freezing when

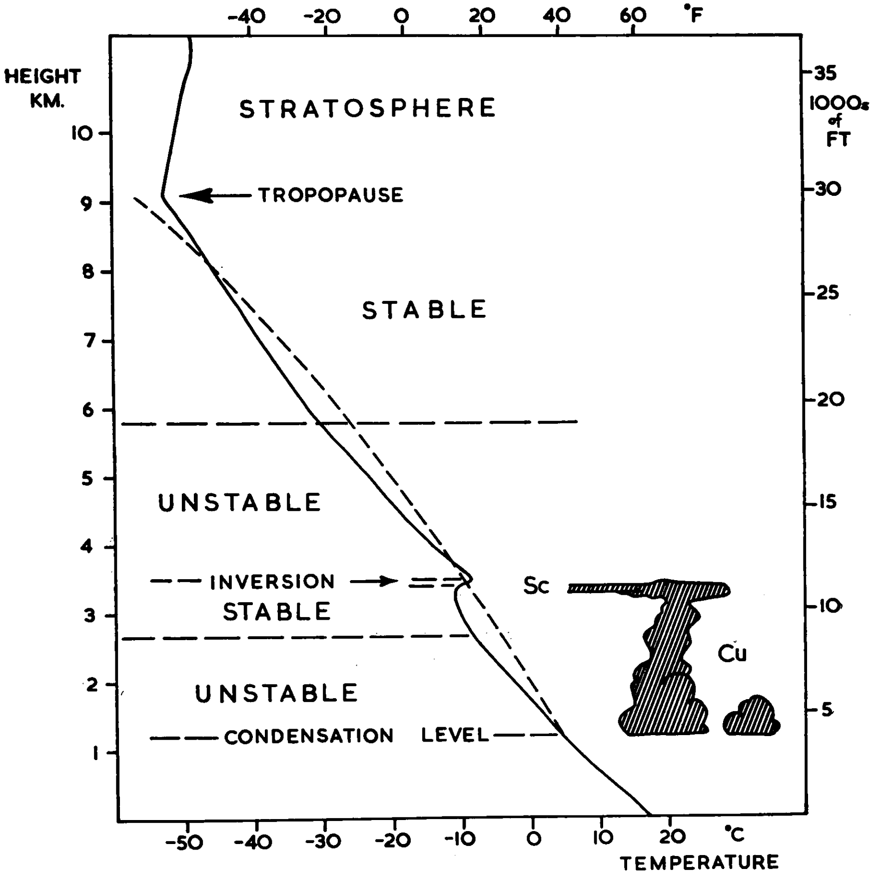

Fig. 1. Variation of temperature with height.

This diagram represents the occasion of no. 5 (p. 25). The solid line shows that the temperature in the clear air falls with height, except in a shallow *inversion* at about 3,500 metres above the ground, and in the stratosphere. In the lower part of the layer occupied by the cumulus (Cu) the temperature decreased more quickly than in ascending cloud air (as shown by the pecked line), and this part is said to be unstable. The cloud air spread out into a stratocumulus (Sc) just below the inversion, where its buoyancy disappeared. There was another unstable layer above, and if the cloud air had become a little warmer, then the clouds could have risen beyond the inversion and reached up to 8 or 9 kilometres. This actually happened later in the afternoon [no. 6], when the stronger sunshine raised the temperature near the ground and at the condensation level.

the temperature falls only a little below 0° C (it is better to call this temperature the melting-point rather than the freezing-point). Small volumes of water, such as cloud droplets, are far less likely to contain very effective impurities, and consequently they may cool to much lower temperatures before freezing.

In the atmosphere it is found that out of every million cloud droplets only one is likely to be frozen at a temperature of −10° C, and only a few hundred at −30° C. However, all droplets rapidly freeze if they are cooled to temperatures below −40° C.

The most effective freezing agent is a particle of ice itself and a supercooled droplet which is touched by an ice crystal freezes at once.

THE GROWTH OF ICE CRYSTALS

As far as we know, condensing vapour rarely, if ever, produces ice crystals directly. Rather, droplets are always formed, of which a very small proportion (except at temperatures near and below $-40°$ C) subsequently produce crystals by freezing. As a result, ice crystals usually appear only amongst overwhelming numbers of supercooled droplets. In these circumstances the vapour condenses more readily upon the crystals than upon the droplets, and they soon become much bigger than the droplets, perhaps attaining the size of snow crystals within an hour. The large crystals sprout slender, branching arms which shed small splinters as the crystals flutter down through the air, and in this way their numbers multiply to a stage at which the crystals absorb so much vapour that the droplets actually evaporate.

Consequently a cloud which is formed predominantly of supercooled droplets may soon release trails of snow crystals and eventually become transformed into a pure ice cloud.

Another aspect of the readiness of vapour to condense upon crystals is seen in the ability of crystals to grow in air which is not saturated (with respect to liquid water). Throughout a layer, sometimes two or three thousand metres deep, beneath a cloud in which crystals form by the freezing of droplets, the air is not saturated but is moist enough to support the growth of crystals which fall from the cloud. It is therefore common for very shallow supercooled clouds to become transformed into deep and dense trails of snow crystals [no. **27**].

It is characteristic of all ice clouds that they evaporate more slowly than droplet clouds: at the edges of droplet clouds mixing with the clear, unsaturated air causes a rapid evaporation, and the cloud edge is well defined. On the other hand, the clear air between ice clouds, which have originally formed as droplet clouds, is usually sufficiently moist to promote the growth of crystals or at least to preserve them, and mixing merely spreads the clouds, which thereby often acquire diffuse edges.

THE FORMS OF CLOUDS

We can see all kinds of likenesses in the ever-changing outlines of clouds, but these are accidental shapes which teach us nothing of the clouds themselves. On the other hand, all clouds appear in one or another of a number of forms, according to the manner in which they have been made. Of the three basic forms one, the trail or *streak*, is characteristic of ice clouds, as we have just described. The other two are the *sheet* and the *heap*, and these correspond respectively to clouds produced by a slow widespread lifting of air, and to those formed in a local, and more rapid, convective upcurrent. In addition to these principal forms we distinguish many modifications, some of which are caused by special kinds of air motion within the clouds, and others of which are due to the behaviour of the cloud particles.

THE NAMES OF CLOUDS

Certain kinds of clouds have very appropriate popular names, but each language has its own incomplete list. Consequently meteorologists use an internationally agreed classification with names based on Latin words. In all essentials it is that proposed by a London pharmacist, Luke Howard, in 1803. He called a sheet cloud *stratus* (a layer), a heap cloud *cumulus* (a pile), and a streak cloud *cirrus* (a hair). With these was *nimbus*, the rain cloud, but this word is now used only in the composite names *nimbostratus*, a raining cloud sheet, and *cumulonimbus*, a raining heap cloud (shower cloud). By further combination we have *cirrostratus*, a layer of streak clouds, and *stratocumulus*, a lumpy or patterned layer cloud (*stratus* is reserved for featureless layers). Similarly we have *cirrocumulus*, which are lumpy or billowy clouds amongst streak clouds. Two more recent additions are *altostratus*, a diffuse sheet cloud in the middle troposphere, and *altocumulus*, a dappled or billowy cloud at similar levels. Some varieties of these cloud species are recognized, of which the most important are *lenticularis*, clouds in oval or lens shapes, and *castellanus*, miniature heap clouds in the middle troposphere. Small, fragmentary clouds amongst cumulus are called *cumulus fractus*, and similar, very low clouds which occur in rain and on the fringes of storms ('scud' clouds) are called *stratus fractus*.

The classification is not perfect; it is unfortunate, for example, that 'cumulus' now refers to lumpy or billowy, as well as to heaped clouds. However, the classification is in widespread use and there is no better one, so we have included its names in our list describing the cloud pictures. They are not essential to our main purpose of relating the visible forms of clouds to the processes which have fashioned them.

PROCESSES OF CLOUD FORMATION

1. CONVECTION

Convection occurs in the atmosphere when it is heated at the earth's surface, as when the ground is warmed in sunshine or when cool air flows into warmer regions. Large volumes of air rise from the surface layers and penetrate into and mix with the cooler air above.

Above the level at which the air becomes saturated, the condensation level (Fig. 2), these volumes become visible as cumulus clouds [nos. **1**, **2**, **4**]. In the lower part of the layer occupied by these clouds the decrease of temperature with height in the clear air is usually more rapid than inside the clouds; consequently the ascending volumes remain warmer, less dense, and more buoyant than the surrounding air. Such a part of the atmosphere is said to be convectively unstable if it contains cloud, for the slightest upward movement of the cloud gives it buoyancy and it continues to rise (Fig. 1).

In the upper part of the layer occupied by cumulus clouds the decrease of temperature upwards is usually less in the clear air than in rising cloudy masses, so that their excess temperature and buoyancy steadily diminish. The tops of the biggest clouds lie near the level where the buoyancy disappears altogether.

A part of the atmosphere with this kind of temperature distribution is said to be stable: a cloud formed in it has no tendency to sprout convective towers.

2. FORCED ASCENT

Some external agency may force air to rise locally. For example, air immediately above a rising cumulus is lifted a little, and may produce a cap cloud (*pileus*) (Fig. 2) [nos. **9**, **10**]. More important is the ascent of air currents which

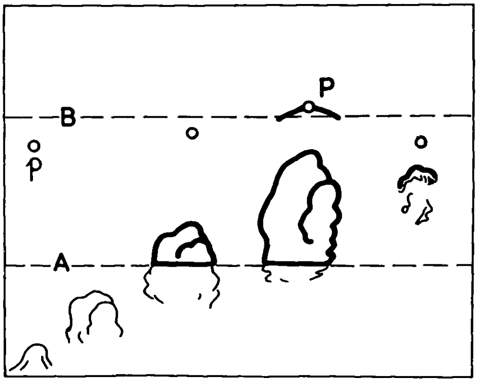

Fig. 2. The formation and evaporation of cumulus and pileus clouds [no. **9**].

A volume of air which has been heated near the ground ascends through the atmosphere. As it rises mixing with surrounding air increases its size. At the condensation level (A) the mixture becomes saturated and a cumulus forms; the bulging upper surface of the cloud shows the position of the rising air, but the base of the cloud is defined by the condensation level, and is strikingly flat. Mixing with outside air causes evaporation and shrinking of the cloud, and soon dissolves the cloud if it is not sustained by the rise of further volumes of warmed air. At some height above the cloud base the air, such as that at p, may be rather damp, so that it will become saturated if lifted to the level B. The upheaval which occurs ahead of the rising cumulus may be pronounced enough to cause this lifting, so that a cap cloud forms (P). Often the cumulus grows into this cap. When the cumulus subsides or dissolves, the air in the cap sinks to its original level, and the cloud evaporates.

pass over hills, and which often produces lenticular clouds, or mountain wave clouds (Fig. 3) [nos. **44, 45**]. Where the air descends in the lee of a wave the cloud droplets evaporate, but they are continuously replaced at the up-wind side of the cloud, which therefore remains poised or slowly wavering above the hills.

3. LARGE-SCALE ASCENT

In cyclonic storms and other bad-weather systems the air throughout the troposphere rises slowly over regions hundreds of miles across. This ascent produces layer clouds at several levels (cirrostratus, altostratus, nimbostratus) [nos. **40-42**].

4. PASSAGE OVER A COLD SURFACE

When air rests on a cooling surface, for example the ground on a clear calm night, dew may be deposited. However, even in hardly perceptible winds there

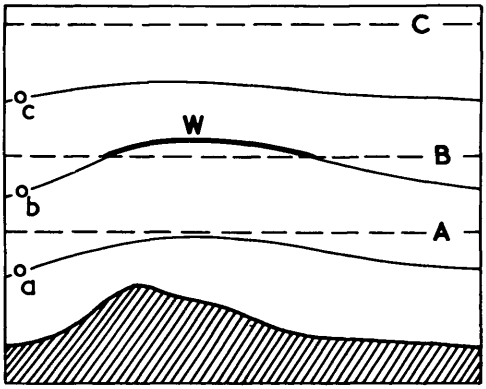

Fig. 3. The formation of a wave cloud over a hill [no. **45**].

A, B, C are the condensation (or saturation) levels of small volumes of air at a, b, c, whose paths in a wind blowing over a hill are shown by the thin lines. Where the path of air takes it above its condensation level a wave cloud (W) forms. This cloud remains stationary as successive volumes of air move through it (commonly small variations in the moisture content and paths of successive volumes cause the position and height of the cloud to waver).

is enough stirring to spread the cooling upwards over a layer of air, and a fog may form [no. **36**]. Extensive sea fogs [no. **38**] are produced in a similar way when tropical air moves northwards over the cool ocean in temperate latitudes.

In strong winds the vigorous stirring spreads the cooling upwards over a layer a few hundred metres deep and the greatest chilling may occur near the top of this layer, so that a low layer cloud (stratus) forms above the ground [no. **37**].

Fragmentary clouds ('scud') are often produced by stirring motions in air near the ground which has been moistened by evaporation of rain falling through it.

5. MIXING OF AIR AT DIFFERENT TEMPERATURES

If damp air masses at different temperatures are mixed, the mixture may become saturated and produce cloud. In this way a cloud forms in the breath on frosty mornings.

In the atmosphere this process is rarely important in the formation of natural clouds, for the temperature differences between neighbouring air masses are too small unless both air masses have been brought almost to saturation by some other process. It is responsible, however, for the wispy clouds which form in shallow layers of cold air which are strongly heated when flowing across warm water. These clouds are encountered mainly near the ice-sheets and cold shores of polar seas, where they are known as *'arctic sea-smoke'* [no. **62**], but may also be noticed inland when strong sunshine heats the ground wetted by a recent shower, or when air which overnight has been chilled close to the ground flows down slopes and across the warmer waters of lakes and streams.

The process frequently causes artificial cloud formation when the exhaust from an aircraft engine (which contains a large proportion of water vapour) mixes into air with a temperature below about $-38°$ C. High-flying aircraft are therefore often seen making *condensation trails* [no. **69**, **70**].

6. RAPID LOCAL REDUCTION OF PRESSURE

A rapid local reduction of pressure, with a consequent expansion and chilling, can occur in violent rotating motion, and causes the *funnel* clouds of tornadoes [nos. **64**, **65**] and water-spouts [no. **66**]. Clouds can also be seen occasionally in the vortices which trail from aircraft wings [no. **67**] or airscrew tips.

PROCESSES WHICH MODIFY CLOUD FORMS

1. SPREADING BENEATH A STRONGLY STABLE LAYER

Occasionally the tops of large cumulus clouds reach the base of the stratosphere. Here their rise is very quickly halted: in the stratosphere the temperature hardly changes or may even increase with height, whereas at these levels rising clouds cool at very nearly ten Centigrade degrees for each thousand metres of ascent. Since clouds have temperature-excesses of only a few degrees they lose their buoyancy after ascending only a few hundred metres into the stratosphere, which behaves almost like a lid to the convection, forcing the clouds to spread out beneath it [no. **24**].

Sometimes shallow layers within which the temperature increases with height are found in the middle troposphere. These layers similarly restrict the growth of cumulus clouds, and cause their tops to spread into oval patches [no. **5**] which sometimes fuse into a complete layer [no. **7**] and persist long after the cumulus have disappeared (Fig. 4).

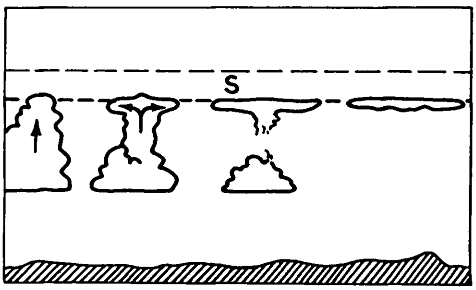

Fig. 4. The spreading of cumulus tops [no. **5**].
When cumulus clouds reach a very stable layer (S) their growth is suddenly halted, and the up-currents spread out at the base of the layer to form oval patches of cloud which often survive the parent cumulus.

2. RELEASE OF CONVECTION IN UNSTABLE LAYERS

Occasionally clouds produced by forced or widespread ascent form in layers of air which are stable while dry but which become unstable when condensation occurs, and these clouds therefore sprout convective towers. If the unstable layer is deep, big cumuliform clouds may develop, and all traces of the lenticular or layer form of the original clouds may be lost.

3. SMALL-SCALE CONVECTION PRODUCED IN A RISING OR DESCENDING CLOUD

When a layer of cloud is lifted it cools less rapidly than the clear air immediately above it. The upper parts of the cloud, thus becoming relatively warm, penetrate a little distance into the clear air in a dappled pattern. A similar process occurs at the lower surface of a layer which is depressed, and causes lumps of the cloud to sink into the clear air below (the protuberances are called *mamma*) [nos. **18, 19**]. The sinking elements mix with the clear air and usually evaporate, but if they contain rain or snow the evaporation is slow and very large pendulous blobs may develop [no. **20**].

4. SMALL-SCALE CONVECTION PRODUCED IN A CLOUD BY RADIATION

The radiation of heat into space from the top of a cloud layer tends to cool it, while the interception of the earth's radiation at the base of the layer tends to warm it. After some time a slow convection is produced in the layer, giving it a dappled structure. All shallow layer clouds soon assume this structure, unless they are shielded from this process by a further layer of cloud at a higher level.

Most of the sunshine which falls upon a cloud is reflected or passes through the cloud, and the slight warming due to the little which is absorbed is appreciable only in thick clouds, whose behaviour, however, is dominated by other processes.

5. GLACIATION

The progressive freezing of the droplets of a supercooled cloud leads to the production of diffuse-edged trails of snow crystals, as already described. The process causes a rapid change in the appearance of the tops of large cumulus clouds which give showers, a transformation which is known as the *glaciation* of the summits [frontispiece]. The fall of trails of crystals from spreading shower-cloud tops produces a mass of ice cloud which often has a characteristic anvil shape [no. **14**] (Fig. 5). The residues of this cloud often persist many hours after the lower cumuliform parts of the shower cloud have evaporated or dissolved in rain: they are called *anvil cirrus*.

6. DISTORTION BY WIND

The wind practically always changes with height; in middle latitudes it commonly increases aloft, without much change in direction. Clouds which extend over a considerable height are often distorted by the varying winds. For example, the lower parts of crystal trails usually lag behind their heads in graceful curves [no. **31**], and the tops of cumulus clouds are often carried away from their bases, so that the cloud towers are tilted [no. **3**] (Fig. 5).

When the direction of the wind changes with height the clouds are stretched in the direction, usually different from that of the wind at any level, of the wind shear (Fig. 6).

7. ARRANGEMENT BY WIND

When clouds form continually over some particular ground feature they tend to form in long lines leading away down-wind. For example, lines of cumulus ('cloud streets') are generated over hills or especially warmed localities [no. **8**]. Occasionally parallel lines of such clouds are seen, but these are shortlived. Sometimes in strong winds great bands of ice clouds stretch for hundreds of miles from stationary wave clouds in which the crystals are formed [no. **49**].

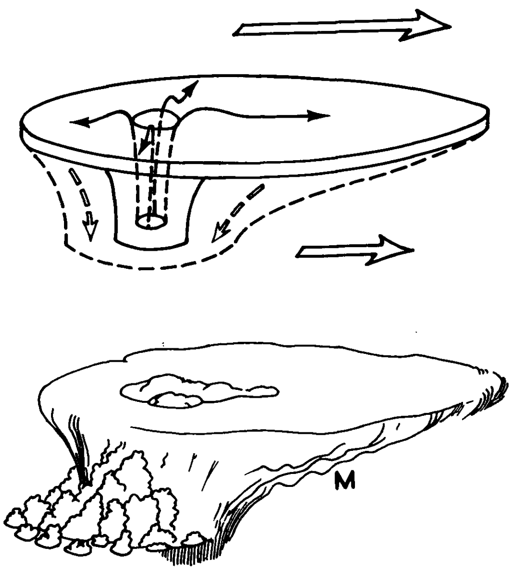

Fig. 5. The formation of anvil clouds [nos. **14**, **24**].

Very large convective clouds which reach the base of the stratosphere begin to spread out in the manner shown in Fig. 4. Frequently the wind at high levels is stronger than lower down (as indicated by the large arrows on the right of Fig. 5), and the cloud tops then spread mainly in the direction of the upper wind, as shown by the principal lines of flow in the upper diagram.

Trails of ice and snow crystals, with hailstones in places, fall from the spreading tops, so that the spreading produces not the upper disc shown by the solid lines, but the anvil shape shown by the pecked lines. The appearance of the mature anvil cloud (which is usually a thundercloud) is sketched in the lower diagram. Often mamma (M) form on the underside of the anvil [no. **19**].

The nature of the change of wind with height is also thought to influence the patterns of globules or rolls of altocumulus and similar layer clouds. Uniformly spread dapples [no. **58**] occur when the wind is almost the same throughout the layer, whereas billows [nos. **57**, **60**] are formed when there is a small change. Billows lie across the direction of the wind shear. In the common circumstance that the wind increases strongly with height without much change

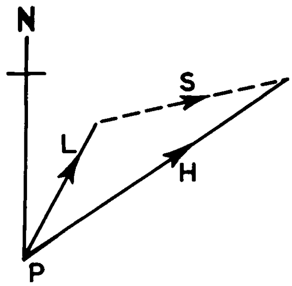

Fig. 6. The meaning of wind 'shear'.

Arrows are drawn from a point P to represent the directions of the wind at a low level (L) and at a higher level (H), and their lengths are made proportional to the wind speeds. The arrow S represents the vector difference between these winds and is referred to as the wind 'shear'; it is specified by a direction and a speed, as if it were a real wind. In this example the wind is SSW 20 knots at the lower level and SW 40 knots at the higher level; the wind shear between the levels is WSW 25 knots. A tall cloud extending between these levels would become stretched so that it leant towards ENE.

in direction, the billows lie nearly across their direction of motion in all parts of the sky; on the other hand, when there is little change of wind with height small local variations have a great effect on the direction of the shear (Fig. 7), and may cause the billows to have different orientations in various parts of the sky [no. **44**], or to be sinuous.

THE DISSIPATION OF CLOUDS AND THE WATER CYCLE

At the earth's surface water evaporates into the atmosphere. The lowest layers would soon become saturated and the ground shrouded in perpetual mist if it were not for the stirrings which carry vapour higher into the atmosphere. The upward transport occurs on a vast scale in the great organized ascent of

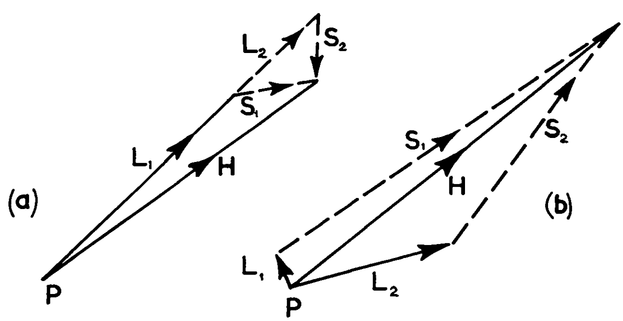

Fig. 7. The variability of wind shear.

When there is only a small wind shear (Fig. 7*a*), a change in the wind at one level (for example from L_1 to L_2) can cause a big change in the direction of the shear (in this example from WSW to N). When there is strong wind shear (Fig. 7*b*) the direction of the shear is not so sensitive to fluctuations in the winds.

air in cyclonic storms and other bad-weather systems. In storms the air becomes saturated a few hundred metres above the surface, and at higher levels the ascent produces dense clouds. Inside the clouds snow forms and descends, usually melting into rain near the ground, or the tiny droplets in some other way become aggregated into large drops and subsequently fall out. In the descending branches of the storm circulations the air is compressed and warmed, and the remaining cloud particles are evaporated. Because much of the cloud water has been lost, the air becomes drier than before. Gradually evaporation from the earth's surface replaces the vapour, and the cycle is repeated as new storms develop.

In the regions between the great layer cloud systems of the storms the other kinds of clouds are formed by the more local upward motions: the wave clouds, the fogs and low-level layer clouds, and the convection clouds which play the principal role in returning surface waters into the atmosphere. Compensating sinking motions in the vicinity of the cloud-forming up-currents are here also the powerful agencies for evaporating clouds, but we can distinguish other processes which help.

EVAPORATION BY MIXING WITH CLEAR AIR

At the edges of clouds evaporation occurs by the mixing of cloud air with clear air. The evaporation of the cloud particles chills the mixture and so increases its density and causes it to sink. Paradoxically, the sinking now produces a warming which assists the evaporation of the remaining cloud. The descent of evaporating cloud masses is easily seen during the dissolution of cumulus towers [no. **4**].

EVAPORATION BY DIRECT WARMING

When the convection above strongly heated ground is restricted to low levels by very stable air aloft, it may warm the entire layer sufficiently to evaporate any clouds within it. In this way small cumulus formed early on summer days sometimes disappear in the afternoon: as time goes on the level of the cloud bases rises, and eventually reaches the level of the tops, which has been prevented from rising by the very stable air at that height. Fogs are evaporated similarly by a convective warming if the ground is sufficiently heated by that part of the sunshine which penetrates them; the convection often also acts by stirring the fog into drier air at higher levels.

It has been mentioned that under a clear sky a layer of cloud is warmed by radiation from the ground, and cools at its upper surface by radiation into the sky, and that consequently a small-scale convection is maintained in the cloud. This stirring distributes a net cooling throughout the cloud layer, which tends to maintain it. If, however, the sky becomes overcast at a higher level, the radiative transports change and the cloud layer is subject to a small net warming, which after a time may be sufficient to evaporate it. Such a process is thought to play a part in dissolving low clouds beneath the canopy of high clouds which spreads ahead of cyclonic storms.

THE COMPLEXITY OF ATMOSPHERIC PROCESSES

It is very rare to encounter a cloud which is formed, maintained, or evaporated by only one of the processes described above. More commonly two or three processes operate together. Consequently a cloud selected as typical of a particular process may be uncommon in its pure form; however, it presents features which can be recognized in other clouds. The skill of observing lies in detecting these features and correctly inferring all the important processes which are forming or moulding everyday clouds.

NAMES OF CLOUDS ILLUSTRATED

The names given below of the principal natural clouds in each picture are according to the International Classification. This classification is based on appearance and does not emphasize the process of formation which is the basis of our arrangement. We have not tried to find pictures which best illustrate the particular types mentioned.

Frontispiece	Cumulonimbus incus
1	Cumulus mediocris
2	Cumulus congestus
3	Cumulus congestus and mediocris
4	Cumulus congestus
5	Stratocumulus stratiformis, stratocumulus cumulogenitus, cumulus congestus
6	Stratocumulus stratiformis, cumulonimbus incus
7	Stratocumulus cumulogenitus, cumulus congestus
8	Cumulus congestus, distant cumulonimbus incus
9, 10	Cumulus congestus pileus
11	Cumulonimbus calvus
12	Cumulonimbus capillatus, altocumulus lenticularis
13	Cumulonimbus capillatus
14	Cumulonimbus incus
15	Cumulus congestus—cumulonimbus incus—cirrus spissatus
16	Cumulonimbus arcus
17	Cumulonimbus pannus
18	Stratocumulus cumulogenitus mamma
19	Cumulonimbus incus mamma
20	Mamma
21	Altocumulus castellanus
22	Altocumulus floccus
23	Stratocumulus castellanus
24	Cumulonimbus incus
25	Cumulonimbus capillatus
26	Rainbow
27	Altocumulus floccus virga
28	Cirrocumulus undulatus
29	Altocumulus floccus virga, cirrostratus fibratus
30, 31	Cirrus uncinus

32	Cirrus spissatus
33	Cirrus mamma
34	Noctilucent clouds
35	Stratus (hill fog), glory
36	Fog
37	Stratus fractus
38	Stratus fractus, cumulus mediocris, stratocumulus cumulogenitus
39	Stratocumulus stratiformis
40	Cirrostratus fibratus
41	Altostratus, altocumulus
42	Altostratus, altocumulus, stratocumulus
43	Cumulus fractus
44	Altocumulus lenticularis, altocumulus undulatus
45	Altocumulus lenticularis
46	Altocumulus lenticularis duplicatus
47	Stratus fractus
48	Stratocumulus lenticularis
49	Cirrus radiatus, altocumulus lenticularis
50	Stratocumulus
51	Stratocumulus castellanus
52	Stratocumulus lenticularis
53	Cirrocumulus lenticularis, altocumulus lenticularis, cumulus fractus
54	Nacreous cloud, cirrus fibratus
55	Altocumulus lenticularis, altocumulus stratiformis perlucidus
56	Altocumulus floccus, altocumulus undulatus
57	Altocumulus lenticularis, altocumulus undulatus, stratocumulus
58	Altocumulus stratiformis perlucidus
59, 60	Altocumulus undulatus
61	Cirrus radiatus, altocumulus undulatus, stratocumulus
62	Arctic sea-smoke
63	Eye of typhoon
64, 65, 66	Cumulonimbus tuba
67	Wingtip trails
68	Dissipation trail
69	Condensation trail
70	Condensation trails
71	Altocumulus stratiformis perlucidus lenticularis, dissipation trail, condensation trail
72	Condensation trail
73	Cirrostratus nebulosus, cumulus fractus, halo, condensation trails

1 *Clarke Collection*

This picture shows small cumulus of the kind which form overland on sunny mornings. Individual clouds appear where great buoyant bubbles ('thermals'), rising from the warm surface, reach their condensation level. When the convection has been in progress for some time the stirring of the atmosphere by these bubbles, which mix into their surroundings as they rise, causes the water vapour to be uniformly distributed, so that there is remarkably little variation in the height of the cloud bases. On the other hand, when the convection has only recently begun over terrain of variable character, the base-levels of clouds not far apart may differ by several hundred metres. Such variations are often noticeable in hilly country on mornings of light winds.

The bases of the individual clouds are usually flat, marking the condensation level, except where the clouds are dissolving and have become fragmentary (cumulus fractus). The level bases are particularly noticeable when the clouds are seen at a distance, and then they appear as dark horizontal lines beneath the sunlit upper parts of the clouds. When the tops of the clouds are domed and peaked without any sign of flattening, as in the picture, the clouds can be expected to grow taller as the surface temperature rises.

Cumulus in the early morning overland. Although the heating of the ground by sunshine has been in progress only three or four hours, the clouds in the middle distance have grown to a substantial size.

Especially when the wind is light the largest clouds tend to grow above 'thermal sources'. These sources may be high ground or areas, such as towns, where the ground becomes hotter in the sunshine than where it is wet or covered with green vegetation.

2

Milan Koldovsky

Purely as a spectacle, clouds are fascinating to watch. This book enables the watcher to increase his enjoyment and wonder by understanding what he sees in the sky.

The expert—meteorologist, airman, geographer, scientist—will welcome this authoritative work, and the layman will find that it opens to him a new and engrossing open-air interest.

The introduction explains simply and clearly how clouds are formed and the 74 photographs of cloud formations, some in colour, each have a detailed caption.

The authors have taken a leading part in postwar research on clouds, and their book has been produced with the active co-operation and support of the Royal Meteorological Society.

Of the superb photographs many are here published for the first time. The selection has been made from the files of *Weather*, the great collections of the Royal Meteorological Society and the Royal Air Force, and private sources.

JOHN MURRAY