FOGS AND CLOUDS.*

BY

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EVAPORATION AND PRECIPITATION.

WHERE FROM AND WHERE TO.

EVERYONE knows that rain and snow come out of the clouds, and that every cloud and fog particle is either a water droplet or an ice crystal. Naturally, therefore, one asks where all this endless supply of water comes from; endless, because year after year, century after century, and age after age, rain and snow have descended as they now descend. And where, too, does it all go, this world average of sixteen million tons a second? The answers are: It comes from the soil and its vegetation, from rivers, lakes and the oceans; and to them it returns—an endless cycle of evaporation and condensation.

“The mist and cloud will turn to rain,
The rain to mist and cloud again.”

—*Longfellow.*

EVAPORATION.

The first of these processes, namely, evaporation, consists in the change of water (water in this case, though many substances behave similarly) from the liquid, or even solid, state to that of an invisible gas, in which condition it becomes an important, though always relatively small, part of the air we breathe.

The rate of this evaporation depends on a number of things, the more important of which are:

a. The area of the evaporating surface. The larger the surface the more rapid the total evaporation. It is in recognition of this law that we spread out a drop or even a puddle of water to hasten its disappearance.

b. The temperature of the evaporating water. The higher

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this temperature the more rapid the evaporation. That is why heating things hastens their drying.

c. The velocity of the wind to which the water is exposed. This explains why roads, for instance, dry so much quicker when the winds are strong than when they are light.

d. The amount of moisture already in the atmosphere. The wash on the clothes-line, as every housewife knows, dries provokingly slowly during cloudy, muggy weather.

All the other factors that affect the rate of evaporation, such as density of the air, saltiness of the water, *et cetera*, generally are small in comparison with the above, and need not here be considered since it is only intended to make perfectly clear, through our everyday experiences, the wide occurrence and great importance of evaporation.

SATURATION.

Although evaporation, as just stated, is so very general there are conditions under which things will not dry, nor bodies of water any longer decrease. Thus even a rather small amount of water in a tightly closed bottle, or other impervious vessel, remains there indefinitely. The space above the water becomes saturated, we say, by which we mean that it gets so charged with water vapor that, under the existing conditions, it can contain no more. At this stage the net evaporation is zero. That is, the amount of the invisible water vapor that now goes back, or condenses, into the liquid stage is exactly equal to that which, in the same time, leaves the liquid surface and becomes invisible vapor. In other words, at this stage, however rapid the interchange between liquid and vapor, the amount of each remains constant.

Numerous careful experiments have determined very closely the exact weight of water vapor per cubic foot, say, when the space in question is saturated at any given temperature, from the boiling point to far below that of freezing. And these experiments show two facts of paramount importance in the formation and dissipation of clouds, namely:

1. The amount of moisture necessary to produce saturation increases rapidly with increase of temperature.

2. The amount of water vapor essential to saturation is not appreciably affected by the presence or absence of the other gases of the normal atmosphere.

It is true that even in technical language we often say that the *air* contains such or such an amount of moisture, as though the presence of the air was essential to the existence of the vapor, or as though the air acted somehow like a sponge in taking up water. But, as explained, this idea is wholly wrong. The only appreciable effect of the presence of the other gases of the atmosphere on the moisture is that of slowing the rate of its spread or diffusion. Temperature and temperature alone, to within a negligible amount, determines the quantity of vapor per any given volume necessary to produce saturation, or, of course, any definite percentage or fraction of saturation.

CONDENSATION.

The percentage of saturation produced by a given amount of water vapor may, therefore, as is obvious from the above discussion, be varied by altering the volume it occupies or its temperature, or both; and as rapidly as saturation tends to be exceeded moisture condenses out onto any water surface or solid that may be present. Thus, the deposition of dew, the formation of hoar-frost, and the sweating of ice pitchers, all are examples of condensation owing to passing the saturation point, or dew-point, as it commonly is called. In these cases just mentioned the temperature of the water vapor, and, of course, of the other constituents of the atmosphere, which, however, play no part in the condensation, is lowered through contact with cold objects, and the volume of this vapor as well as that of the accompanying chilled gases, decreased—decreased because in the open air the pressure remains constant, or nearly so, whatever the degree of cooling.

Similarly, whenever the temperature of the open air passes below the dew-point condensation occurs in the form of innumerable water droplets or tiny ice crystals throughout the chilled volume, and thereby produces a fog or a cloud, as determined by location—a fog if on the surface, a cloud if only in mid-air.

The natural processes by which a given body of the atmosphere may be sufficiently cooled to lose a portion of its water vapor by condensation are: (1) Contact with objects colder than itself; (2) mixing with colder air; (3) radiation; (4) expansion.

Condensation as a result of contact cooling is well illustrated, as already explained, by the deposition of dew—the bedewed

objects having been cooled by radiation; by the formation of hoar-frost, which occurs under the same conditions, except at a lower temperature, as does dew; and by the sweating, during warm humid weather, of all cold objects. It is further illustrated by the formation of fog, generally light, when relatively warm humid air drifts over a snow bank or other cold surface.

The second of the above processes of inducing condensation, that is, the mixing of masses of humid air of different temperatures, is not very effective. Indeed an accurate calculation, based on the temperature and volume changes and other factors of the problem, shows that while a fog or cloud may be obtained by this process no appreciable amount of rain or snow is likely to result. Layer or stratus clouds at the boundary between relatively warm air above and cold beneath, a phenomenon of occasional occurrence, are at least partially due to mixing, as are also the fogs that so frequently occur over adjacent warm and cold ocean currents.

The third process by which air loses heat, namely, by radiation, probably is of little importance in the production of clouds since the most chilled portions of free air sink to lower levels and thereby become even warmer and drier than they were at first. Near the surface, however, where descent and the consequent dynamical warming, as it is called, are impossible, radiation often is very effective in the production of fog.

The last of the cooling processes mentioned above, that is, expansion, is exceedingly effective, and to it is due the great bulk of cloud formation. Now, expansion of the air may be produced either by heating it or by reducing the pressure to which it is subjected. It is the latter process, obviously, and not the former, even though heating generally is the initial cause, that produces the cooling of free air and the formation of cloud. To make these points clear, consider the results when a given mass of humid air is heated, as it may be, over a region warmed by sunshine or otherwise. With increase of temperature it expands and thereby becomes lighter, volume for volume, than the surrounding cooler air. The surrounding denser air then underruns the lighter and lifts it up to higher levels just as hot air is driven up a chimney. As the warmed air is thus forced up (rises, as we generally say) the pressure to which it is subjected obviously decreases in proportion to the weight of the air left below. It therefore gradually expands as it rises and thereby does work, and since the only

energy available for this work is the heat of the ascending air it follows that as its height increases its temperature must correspondingly decrease. As a matter of fact, for air of average humidity, the rate of this decrease is approximately 1° F. per 187 feet increase of elevation up to the base of the cloud, if there be one, in the rising air, and then much less through the cloud. In any event the ascending air attains equilibrium only when it has cooled by expansion to the temperature of the air that finally surrounds it. Hence when it comes to rest it is colder, often much colder, than it was before it was heated.

Of course the expansion of the rising air correspondingly increases the vapor capacity, but it is easy to show, both theoretically and experimentally, that this increase of vapor capacity by volume expansion is small in comparison with its simultaneous decrease through the lowering of the temperature, and that convectional expansion therefore, whether incident to the blowing of wind up and over mountains, or to local heating, is a most effective means of inducing condensation and the formation of clouds.

CONDENSATION NUCLEI.

Whenever ordinary air, kept humid by the presence of water, is suddenly expanded in a closed vessel, it instantly becomes filled throughout with a miniature cloud, precisely as occurs on an incomparably larger scale in nature. Subsequent expansions of the same air, otherwise undisturbed, induce less and less cloud and presently none at all. If filtered air, that is, air drawn through several inches of cotton wool, or other substances of similar texture, is used, condensation by moderate expansion is impossible from the first. The admission, however, of a little smoke restores to the exhausted air, and endows the filtered air with, full powers of condensation. There are, therefore, condensation nuclei in the atmosphere—hundreds and often thousands of them per cubic inch—which can be filtered out; and microscopic examination shows that they consist essentially of dust particles. Hence, dust, moisture and some cooling process are the three essential factors in all natural fog and cloud formation.

It is true that a few substances other than dust, such as the oxides of nitrogen, act as condensation nuclei, but they seem generally to be negligible in quantity. Furthermore, condensation can be obtained in air wholly free from any such nuclei provided it

is ionized and forced to at least a fourfold supersaturation, a degree of humidity that probably never occurs in nature. Indeed under very great supersaturation, eight- or ninefold, condensation occurs even in perfectly clean non-ionized air. But this, too, is only a laboratory experiment, and not a process by which clouds are formed in nature.

FOGS.

DISTINCTION BETWEEN FOG AND CLOUD.

As already explained, whenever the air is cooled, by any means whatever, below its dew-point, a portion of the water vapor present separates out on such dust particles or other condensation nuclei as may happen to be present. If this process occurs only at a considerable distance above the surface of the earth, leaving the lower air clear, the result is some form of cloud. If, on the other hand, it extends quite to, or occurs at, the surface of the earth it is then called a fog no matter how shallow nor how deep it may be. The distinction, therefore, between fog and cloud is that of position. Fog is a cloud on the earth; cloud, a fog in the sky.

In some cases the only basis of distinction between fog and cloud is that of viewpoint. For example, the mist that sometimes covers only the crest of a mountain generally is called fog by those actually in it, and cloud, at the same time, by those in the valley below.

WHERE AND HOW FORMED.

Fogs are likely to form along rivers and large creeks and in the mountain valleys of all but arid regions in the latter part of any still cloudless night of summer or autumn. During these seasons the streams and the humid soil are warm, especially when exposed to sunshine, and hence evaporate much moisture into the lower atmosphere, where, in great measure, it remains when there are no winds to blow it away.

Throughout the night, however, the surface of the soil and the adjacent humid air, by virtue of its humidity, lose heat rapidly by radiation to the colder atmosphere above and to the sky, or empty space, beyond. This loss of heat by radiation is no greater, of course, by night than in the daytime, but when there is no sunshine to make good such loss, or do better—as generally is the case through the forenoon—the inevitable consequence is a lowering of

the temperature. Hence, during calm, clear nights the temperature of the humid surface air often falls below the dew-point and a fog of corresponding depth and density is formed.

If the sky is overcast there commonly is enough radiation from the clouds back to the earth, especially if they happen to be low (hence warm), to prevent the cooling of the surface air to the dew-point and the consequent formation of fog. Neither does fog form when there is considerable wind, partly because the more humid lower air is then mixed with the drier upper air and the surface dew-point thereby lowered, and partly because this mixing prevents much fall in the surface temperature by distributing the loss of heat through a relatively large amount of air instead of leaving it confined essentially to that near the ground. Hence fogs of the kind under consideration—radiation fogs, summer fogs, land fogs, valley fogs—seldom occur either when the sky is cloudy or the night windy.

Another source of numerous fogs is the drifting of relatively warm humid air over places much colder, such as the drifting of on-shore winds over snow-banks. In this way the humid air frequently is cooled below its dew-point and fog—"winter fog" or "sea fog"—produced. Likewise, heavy fogs often are formed when the wind is from warm to cold water—from the Gulf Stream to the Labrador Current, for instance.

Fogs also frequently occur when cold air slowly flows in over warm water. This explains the "frost smokes" of polar seas, and the "steaming" of rivers and lakes on cold frosty mornings. In these cases the relatively warm water goes on evaporating into the cold air even after it becomes saturated and thereby produces a water droplet or a minute ice crystal about every one of the myriad millions of nuclei present. If, however, the cold air comes in with a rush, that is, if it enters as a strong wind, no fog is produced, simply because the vapor is distributed by the accompanying turbulence through too large a volume to produce saturation.

KINDS.

In respect to the ways in which they are formed, fogs may be divided into two classes:

1. *Radiation fog* (Fig. 66, *Physics of the Air*¹), due to the cooling of the lower air below the dew-point, partly by its own

¹ Book published by The Franklin Institute, 1920.

radiation and partly by contact with the surface which itself had cooled by radiation. This type of fog is common, as already

FIG. 1.

Advection fog, seen from Mount Wilson, Cal. (F. Ellerman, photo.)

explained, along streams and in valleys where, through the summer and autumn, it is apt to occur on any calm, clear night.

2. *Advection fog* (Figs. 1, 2), produced by the advection, or horizontal movement of air from one place to another, such as the drifting of relatively mild air from the ocean inland over snow-

banks, or from a warm current to a cold one; and the flow of frosty air over open water. Furthermore, any fog, when shifted to a new position may then be called advection fog. Usually, too, the

FIG. 2.

Advection fog, seen from Mount Wilson, Cal. (F. Ellerman, photo.)

shifted fog, like that so common on many leeward coasts, is advective also in origin.

There also are several other classifications of fogs, less scientific perhaps, but often very convenient. Thus we speak of

dry fog, meaning a fog which, because of the small amount of water content, does not wet our clothing—evaporates as fast as caught up—or else meaning, as we often do, a haze caused by a forest fire, dust storm, or volcanic explosion; *wet fog*, meaning one containing so much water that, like a Scotch mist, it makes at least the surface of one's clothing distinctly damp; *sea fog*, fog originating on the ocean, whether remaining there or drifting on shore; *land fog*, one occurring in the country and which, as its nuclei are but slightly hygroscopic, quickly evaporates; *city fog*, one occurring over a city, especially a city that uses a large amount of soft coal and has but few smoke consumers, generally slow to evaporate, owing jointly, presumably, to the hygroscopic nature of the nuclei and to the oil in the unburned sooty smoke; *black fog*, one containing a great amount of soot, such as occasionally forms over large, smoky cities; *pea-soup fog*, a local name given to those London fogs that contain only a moderate amount of smoke particles—just enough to give the fog a distinctly yellowish cast; *ice fog*, or “frost smoke,” the fog of polar seas, caused by the drifting over them of very cold air; and many others, mostly of less interest and of small importance.

QUANTITY OF WATER CONTAINED.

It might seem, on first thought, that it would be a very easy thing to measure the amount of liquid water in a given volume of fog, but this amount is so small that even tolerably accurate measurements of it require much care. Nevertheless, it has been reliably measured. Thus, in the course of an official Ice Patrol cruise in the *Seneca* about the southern edge of the Grand Banks of Newfoundland, that is, in the region of one of the most frequented of the steamer lanes, Wells and Thurs measured the water content of a dense fog that occurred on the evening of May 9, 1915. In this fog there were about 20,000 droplets per cubic inch. In their report they say: “To gain some idea of the order of magnitude of the quantities involved in this dense fog, assume that one can not see beyond 100 feet. A block of fog 3 feet wide, 6 feet high and 100 feet long contains less than one-seventh of a glass of liquid water. This water is distributed among 60 billion drops.”

Barely one good swallow!

SIZE AND NUMBER OF PARTICLES.

The size of fog particles is easily and accurately determined by looking through the fog at a point (pin-hole) source of bright light and noting the difference in direction toward centre and circumference of any definite one of the rings of colored light seen around this source—rings of precisely the same nature as the coronæ produced by thin clouds around the sun and moon. This angular size, or difference in direction between centre and circumference of any one of these rings, increases as the diameter of the fog particles decreases, and in such known and definite manner that when either is given the other can at once be accurately calculated.

If, then, we know the size of the fog particle and if, in addition, we know the amount of liquid water in a given volume of fog, which, as explained above, can be measured, it obviously is only a matter of easy arithmetic to find the number of such particles per cubic inch, say, or any other given volume.

The numbers, however, so obtained are surprising. Everyone knows, of course, that a fog droplet is small, but not many, perhaps, realize that 2500 of them, of the average size, placed side by side in a single row would extend only one inch, or, in other words, that it would take half an hour to count a string of them an inch long!

Nor is the number of fog particles in a definite volume any less amazing. It is but a light fog that has only 1000 droplets per cubic inch; a heavy fog has around 20,000. Indeed, vastly greater numbers have often been found, even up to nearly a million per cubic inch.

But these droplets, as explained, are so excessively minute that the very maximum density of a million per cubic inch would still leave the empty space 4000 times greater than the volume actually occupied by all the liquid present.

IMPRESSIONS.

If one would thrill his soul with beauty let him, on a brilliant, moonlit night, view from the mountain's crest a far flung fog over all the piedmont region beyond, with foothills and knolls rising here and there as so many enchanted islands in an enchanted sea. Let him, as the dawn breaks clear, gaze from a mountain top on an incipient, fibrous fog, covering a neighboring valley with a fabric more gauzy and delicate than ever Arachne spun. Let him

stand on the topmost peak of rugged Tamalpais and watch in wonder the mighty fog billows crowd through the Golden Gate, break over the barrier mountain crests, and rush down their sides in an all engulfing flood. Let him view from afar the snow-crowned crest of incomparable Fuji, floating without visible support, in a clean, clear sky while all its base and the region around is lost in deep fog and delicate mist.

These are but some, and typical, of the most beautiful and fascinating of fog effects; so impressive, indeed, that we could not forget them if we would, and so charming that certainly we would not forget them if we could.

But the impressions produced by fog are not always so charming and entrancing. If one would go quite to the opposite extreme and experience its terrors let him get lost in London's darkest and densest fog. Let him be alone at night in an unfamiliar forest and have settle down upon him so thick a fog that literally he can not see his hand before him. Let him, on the ocean in the dead of night, between the shrieks of his own ship's siren hear from somewhere, just somewhere, within the encircling gloom, the same dread warning. Let him, when flying over strange territory, be forced to land in a deep, dense fog!

All these, and many others, are horrors one longs to forget, but can not.

And so it is that, from extreme to extreme, from fascination to fear, from delights we fondly cherish to dreads we would fain forget, fog in all its moods and circumstances plays compellingly upon the whole gamut of human emotions.

CLOUD FORMS.

It is passing strange that the ancient Arabs, Greeks and others should have given a name to every portion of the heavens, and to numerous individual stars—names still in current use throughout the civilized world—and yet have failed to name any one of the many kinds of clouds that are even more conspicuous in the sky than the stars themselves or their constellations. Perhaps giving them names long seemed both useless and impracticable owing to their infinite variety and ceaseless changes, for indeed, as Shakespeare puts it:

Sometimes we see a cloud that's dragonish,
A vapour sometimes like a bear or lion,
A towered citadel, a pendent rock,
A forked mountain, a blue promontory
With trees upon't that nod unto the world
And mock our eyes with air.
That which is now a horse, even with a thought,
The rack dislimns and makes it indistinct
As water is in water.

But whatever the cause, there was not, down the ages, until the very modern year 1801, any attempt whatever to classify the clouds, although from the beginning everybody everywhere talked about the weather and many wrote about it. This first attempt, made in 1801, as just stated, was by the French naturalist, Lamarck. It received little attention, however, and no general acceptance; owing in part, presumably, to the fact that it was expressed in the words and phrases of a distinctly local or national language unfamiliar to the world at large.

But the time for a practical classification of the clouds was ripe. The need for it was felt by the large number of educated and cultured people who were then taking an active and inquisitive interest in the weather and its ways. Hence in a little while another classification was proposed, this time, 1803, by the Englishman, Luke Howard. Like that of Lamarck's it too was based on the *appearance* of the clouds, but the names, instead of being only locally understood, were all in tolerably familiar Latin—the Esperanto of the day. At any rate, whether this universal language had much to do with it or not, Howard's classification soon became well known and extensively used; so much so indeed that all subsequent practical classifications have been but extensions of this original one published in 1803, with the addition, perhaps, of a few unusual and, commonly, unimportant types, some of which Howard probably never saw.

To obtain uniformity in the cloud reports of professional meteorologists, and of all others who wished to be clearly understood, the International Meteorological Committee published in 1910, with illustrations, the following definitions and descriptions of cloud forms. The enclosed letters next after each type name are its customary abbreviation. The illustrations are new (the original ones are not available) but quite as good and typical, it is hoped, as those selected by the committee.

The wording here followed of these international definitions and descriptions is not exactly that of the original publication, but that given in the second edition of "Cloud Forms," 1921, by the British Meteorological Office.

This latest classification of the clouds, a modification and extension of Howard's, is also, like it, based on mere *appearance* and not on anything really fundamental, such as cause or mode of formation. But however superficial such a classification may be it nevertheless is the best, perhaps, that can be made, and altogether the most practical. For instance, the mode of origin is not a practical basis for cloud classification, however desirable, because several types of cloud are formed in different ways and frequently one cannot be certain just what the actual way really was.

The supplementary remarks, after each of the following quoted definitions and descriptions, while intrusive in position, may, it is hoped, be of some service to those who are not yet cloud experts.

(To be continued)

Lost Lake in Nevada. (*U. S. Geological Survey Press Bulletin No. 481.*)—During comparatively recent geologic time a great lake flooded a number of the valleys in northwestern Nevada. This lake has now almost completely disappeared, but geologists have named it, in its entirety, Lake Lahontan, in honor of Baron La Hontan, one of the early explorers of the headwaters of the Mississippi. At the time of its greatest expansion, according to the Geological Survey, this ancient lake covered 8400 square miles. The deepest part of Lake Lahontan, which was 880 feet deep, was the site of the present Pyramid Lake, one of its remnants, so that its surface stood about 500 feet above the surface of Pyramid Lake. The ancient lake had no outlet except the one that led straight up, its waters being dissipated entirely by evaporation.

A large area a few miles north of Winnemucca, Nevada, is covered with sand dunes that were formed since Lake Lahontan disappeared. These dunes are fully 75 feet thick, and their steeper slopes are on the east side, indicating that the whole vast field of sand is slowly traveling eastward. The march of this sand is irresistible, and its progress has necessitated a number of changes in the roads in the southern part of Little Humboldt Valley during recent years. In some places in this region the telegraph poles have been buried so deep that they have had to be spliced in order to keep the wires above the crests of the sand dunes. The sand is of a light creamy-yellow color and forms beautifully curved ridges and waves that are covered with an artistic fretwork of wind ripples.