TYPES OF MAMMATO-CUMULUS CLOUDS.

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SYNOPSIS.—The appearance of mammato-cumulus clouds, whether formed at high or low levels, shows that they are formed by local downward thrusts of air. Those associated with overflow sheets of thunderstorms are obviously formed of snow, which accounts for the slowness with which they change shape. While minor developments are not uncommon, the large, well-developed festoons of this class are associated only with the most severe thunderstorms.

On the boundary between two general winds, interference and initial condensation of moisture as a result of the projection of masses of the upper mammato-cumulus into the lower wind, occasionally form. If the upper wind is the colder, convection quickly destroys the mammato formation. If the lower current is already cloudy, cold air from above, especially if dry, may blow "cheese holes" through it.

The most impressive mammato-cumulus is the low, downward boiling cloud surface which marks the top of a cool, squall wind.

INTRODUCTION.

A mammato-cumulus cloud is one with downward bulges rather similar to a cumulo-form cloud upside down. "Mammato-cumulus" has been adopted internationally as the term designating this cloud type. Many other descriptive names for it are in use. In view of the fact that mammato-cumulus forms occur on the undersurfaces (1) of the spreading top sheets of cumulo-nimbus and remnant "false" cirrus, (2) stratus or alto-stratus, and (3) strato-cumulus or cumulus, some observers have sought to name the quiescent, high, snowy mammato-cumulus associated with false cirrus, "globo-cumulus,"[1] or "mammato-cirrus,"[2] and the low types, "mammato-cumulus," or if in violent commotion, like downward boiling, "mammillated squall cloud."[3] Durand Gréville has proposed "mammatus" as a generic term to designate clouds of downward motion, just as "cumulus" designates clouds of upward motion.[4]

MAMMATO-CUMULUS FORMED ON OVERFLOW CLOUDS.

The figures on the plate facing page 396 and figs. 1a and 1b (facing p. 397) are photographs of the mammato-cumulus on the undersides of overflow sheets from the tops of intense thunderstorms, and figure 5 shows diagrammatically the positions of the festoons relative to other parts of the overflow sheet and the probable air movements as indicated by observations of the development of the cloud form illustrated. (Figure 4 shows much the same movements in some strato-cumulus.) Many observers have independently arrived at the conclusion that these festoons are of falling snow (or ice spicules) and that the downward bulges are formed by the downthrust (or settling) of the cold, snow-filled air which is spreading out laterally at the tops of the cumulo-nimbus. It is colder than the clear air at the same level, and so settles into it, because the inertia of the rising air in the cumulo-nimbus carries it beyond the level of equilibrium. On going this additional amount higher it is cooled still more by expansion, but on descending again evaporation of the snow probably prevents any appreciable warming by compression. Occasionally the festoons may be formed by descent of cold air through an already-existing cloud sheet.

Where the downward movement is stronger, i. e., in the center of the festoon, the snow will evaporate most rapidly, and may disappear entirely, as described by Mr. Weeks (p. 397 above). The down-thrusting cold air may by mixture produce a filmy cloud, which gives the festoons a smoother aspect while they still look solid, and which preserves the outline even after the interior has evaporated.

The air between the down bulges must be rising as it is displaced. At times well-defined curls may be seen developing as the middle comes down and the sides go up. Ultimately the festooned false cirrus presents a ragged appearance, with snow still falling apparently only from the parts which were between the festoons. Such snowfall may be intensified by the expansional cooling of the rising air around the festoons; and even before the festoons themselves have begun to break up by evaporation this new snow may begin to veil them.

FIGS. 4 and 5.—Mammato formation in overflow sheets.

The snowy mammato-cumulus is strikingly developed only in the neighborhood of an intense thunderstorm and then more frequently in the rear than in front. When in front it is an ominous sign of the coming storm, which is likely to have tornadoes associated with it. Prof. H. C. Frankenfield states that shortly before the tornado at St. Louis, May 27, 1896:[5]

> The clouds slowly increased in density, and at 3:35 p. m. the sun was obscured. The character of the clouds changed about this time to cumulus, but of a very peculiar formation. The whole sky was compactly covered with small cumuli of almost perfect hemispherical shape, but with the rounded portions underneath. Their color was a dark gray with deep shadows on the sides farthest from the sun. By 4:30 p. m. these clouds had settled into a uniform covering of stratus, which commenced to assume a light green color. * * * [Rain began at 5:43 p. m. The tornado went by at 6:18.]

Also in the case of the clouds (figs. 1a and 1b, plate facing p. 397), photographed by Mr. L. C. Twiford, at Bartlesville, Okla., June 15, 1912, 6:30 p. m., possibly 45 minutes before the clouds were seen a tornado did great damage about 20 miles away, and in the direction from which the clouds came.[6]

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[1] Poey. Classification des Nuages, Paris, 1873, p. 97.
[2] E. Durand Gréville. Le Mammatus, Bull. Soc. Astr. de France, Jan., 1901, 8 p. 6 figs.
[3] G. A. Clarke [British] Met'l Off. Circ. 29, Oct. 23, 1918.
[4] Loc. cit.
[5] MONTHLY WEATHER REVIEW, 1896, 34:77.
[6] From short article, "Mammato-cumulus clouds," by W. J. Humphreys, MONTHLY WEATHER REVIEW, 1912, 40:967-968.

The more common formation of mammato-cumulus in the rear of a thunderstorm may be due to the more favorable conditions for downward air movement there than in front. In front, the upper wind generally removes rapidly the overflow air and so stretches it out that the downward currents have little chance to become localized and well-defined.

Small snow-festoons seem to be formed locally under almost all cumulo-nimbus overflow sheets,* and are seen nearly as often as the sun shines under thunderstorm top (false cirrus) remnants at sunset tipping the festoons with light yellow and pink. Their not infrequent presence in summer adds great beauty to our warm-season sunsets.

MAMMATO-CUMULUS ON WIND BOUNDARIES.[7]

Mammato-cumulus formations on wind boundaries are usually ephemeral sights. They seem to mark the first stage of interference when the contrast between the two over- and under-running currents is strongest. Then if at least the warmer of the winds is saturated, or nearly so, projections of the upper wind into the current below will form mammato-cumulus by mixture.

When the upper current is colder than the lower, convection attends the mixing. The centers of the down-bulges may soon evaporate as the descending

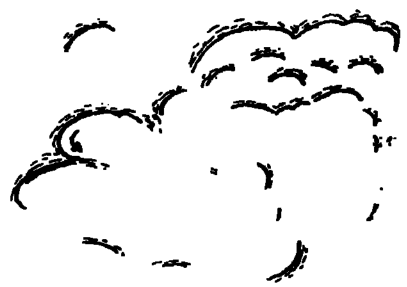
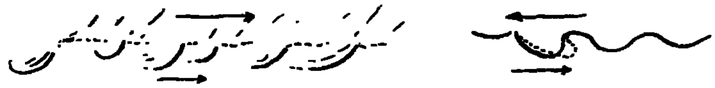


FIG. 6.—"Cheese holes" in St.Cu. overhead, Washington, D. C., Apr. 14, 1919.

air warms by compression; and the inter-bulge portions of the cloud thicken with condensation as the rising air cools by expansion. Thus, in the course of a few minutes the sky may have changed from a smooth rounded mammato condition to the ragged semblance of an inverted choppy sea, and shortly this ragged condition may fade behind a haze of rain or snow beginning to fall from the convectional clouds formed between the original festoons. All three stages are sometimes visible at the same time in different parts of the sky (e. g., 7 p. m., July 9, 1919, at Greenwich, Conn., lower wind, south, upper, west).

At times when the lower wind is already cloudy, down-thrusts of a cooler wind above tend to drive "blow holes" through the cloud. Large groups of slowly downward moving and spreading light spots (see fig. 6) develop and fade away in perhaps 20 minutes moving with the alto-stratus or stra.-cumulus covering across the sky. Here and there slowly forming curls, all anticyclonic, confirm the other impressions of downward movement. On April 14, 1919, snow (apparently) could be seen falling from between the light spots and two hours later light rain fell at the surface. When the cloud sheet is thin the down currents may make clear holes through it. Such a formation resembling exquisitely a thin lenticular slice of large-holed Swiss cheese was observed at 1:30 p. m., October 25, 1918, at College Station, Tex.

On March 27, 1919, at Washington, D. C., about 1½ hours before the arrival of a well-defined squall-line (wind-shift line) the festoons diagramatically shown in figure 7 were seen bulging from the base of a nimbus sheet and silhouetted against the northwestern sky. Here the process of active convection which was forming the nimbus was visible. Small festoons would grow downward, slowly trail behind in the slower-moving air below, and evaporate before being carried back to the cloud by the compensatory upward currents.



FIGS. 7 and 8.—Mammato formation on boundaries of warm currents, Washington, D. C., Mar. 27 and Feb. 28, 1919 (see fig. 2).

The formation of mammato-cumulus seems to be more common when the under current is the colder, for then convection does not set in and destroy the formation.

Gaston Tissandier[8] gives the following interesting account of observations made in a balloon ascent on August 16, 1868 (Observations Météorologiques en Ballon, p. 5):

> Two very distinct currents were superposed in the air. The lower current prevailed from the surface of the earth and the sea up to an altitude of 600 meters. It had a temperature of 13° C. It was directed from the northwest toward the southeast. At its upper part, white and flocculent clouds, isolated from each other by small intervals, were situated in the same horizontal plane in considerable numbers. They floated at the upper surface of the aerial current and in the same direction. These cumulus were rounded and mammillated; their thickness was slight, and did not exceed ten meters. The upper surface of these clouds was uniform and situated exactly in one plane. It is probable that they were arrested or dissolved by the upper current, which glided above them in an opposite direction; that is, from the southeast to the northwest. By a singular effect of perspective, this succession of mammillated clouds, viewed from an altitude of 1,600 meters, appeared to originate on one side of the horizon and disappear on the other.

Figures 2 and 8 give some idea of the outline of the underside of a mammillated stratus sheet which covered the sky at 7 a. m., February 28, 1919, at Washington, D.C. The larger festoons would gradually bend backward (see dotted outline) as they were dragged forward from the southwest over the northeast undercurrent. The clouds did not last long, though after they had evaporated heavy alto-cumulus formed higher in the southwest wind; and rain began to fall from them at 10:30 a. m.

The most marked mammato-cumulus formation which results from a warm current overrunning a cool one is the boiling "mammillated squall cloud," illustrated in figure 3, of the plate facing page 397, and shown diagramatically front view and cross-section in figures 9 and 10. This heavy, low festoon formation is on the underside of a cumulus cloud in a belt miles long and a few miles wide. The description of the occurrence between 6:30 and 7:30 p. m., July 15, 1919, at Washington, D. C. (figs. 9 and 10), applies as well to the occurrences of October 26, 1918, on the front of a Texas "norther" at College Station, Tex., and March 27 and May 17, 1919, at Washington, D. C. The conditions July 15 were exceptionally favorable for a study of the movements involved, for the parent thunder-

* An extensive mammato-cumulus formation was observed on the under side of the A.St overflow sheet of an intense coastal cyclone, east and norteast of Washington, at 3-4 p. m., Aug. 13, 1919.

[7] H. Osthoff has described 67 observations of mammato-cumulus, many of which may be ascribed to mixture on wind boundaries. There are numerous drawings in his article. See Met. Zeitschrift, 1906, pp. 401-408, 6 figs.

[8] From H. H. Clayton, Results of cloud observations, etc., Annals Astr. Obs. Harv. Coll., v. 30, pt. 4, p. 397.

FIGS. 9 and 10.—Lower clouds on side of thunderstorm, Washington, D. C., July 15, 1919. A, St.Cu. cloud over squall; B, Fr.St. squall cloud; C, rain front in background; D, A.Cu.; E, squall front cloud curtain; F, G, H, "mammilated squall cloud" (see fig. 3 on pl.). All arrows indicate movements seen.

storm passed on the north, and so, produced a moderate squall wind which lasted for a considerable time before rain (except occasional drops) fell at Washington. Before the squall the wind was moderate southwest, and alto-cumulus clouds were moving from the west-southwest. At about 6:30 p. m. a heavy, gray cumulus roll was seen forming in the northwest-north against a dark, rainy background. Its top was moving from the southwest. Flecks of cloud appearing just under the base rose and grew rapidly into the cumulus. Still lower were rising pieces of cloud which seemed to be beyond the cloud front, and which did not join it (see fig. 9). Just as the front edge of the heavy strato-cumulus cloud passed overhead a light air movement and then a moderate northwest wind sprang up. Just behind the low, heavy curtain-like front of the strato-cumulus (E, fig. 10) was a downward boiling sky of black-tipped great festoons and rolls (F, G, H, fig. 10). Up through ragged holes the interior of the strato-cumulus could be seen traveling from the southwest as before. A point would be seen slowly beginning to descend, then it would become a part of a small knobby festoon, which would grow downward and expand, then begin moving from the north and finally northwest, becoming overgrown and ragged. Finally, just as parts were beginning to rise again it would have broken into irregular pieces, the inside having been evaporated by the compressional heating as it descended. Here was strong mixture on a turbulent boundary where a northwest squall was driving into a southwest wind.

CONCLUSION.

Since "mammato-cumulus" clouds may be formed in such a variety of ways, a simple record of the fact of their occurrence will tell but little concerning the atmospheric processes involved except that there were either warm or cool local down-thrust currents made visible by saturated moisture.

CLOUD SHADOWS.

Mr. H. H. Martin of the Columbus office of the Weather Bureau has sent us a description of a rather unusual projection of the shadow of the top of one cumulo-nimbus cloud on the underside of the overflow top sheet of another. The accompanying line drawing by Mr. Martin illustrates the relative positions of the clouds and shows that the shadow projected was from a portion of the cloud not visible to the observer. In this respect the conditions are somewhat like those on a previous occasion when a pronounced protuberance in the top of a cumulo-nimbus cloud made its presence known by the shadow it cast.[1]

"[At about 2 p. m., July 5, 1919], a thunderstorm was forming in the southeast. Although without northwesterly movement, this spread a curtain of alto-stratus northwestward across about three-fourths of the sky, the line of demarkation between cloud and clear sky being well defined, the sun shining brightly. At about 5:30 p. m. (90th Meridian Time) another cloud, forming in the northwest, assumed the characteristics of a thunderstorm and progressed slowly southward. Passing directly before the sun about 6 p. m., the sun's rays could be

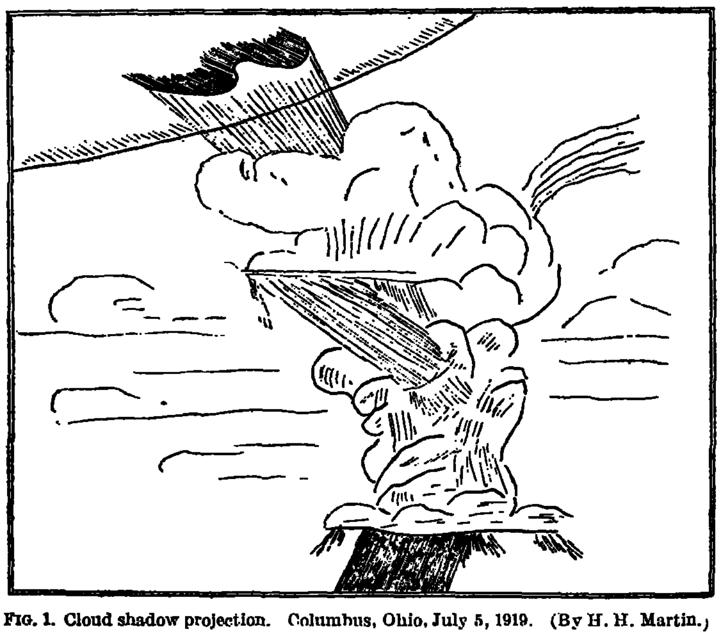


FIG. 1. Cloud shadow projection. Columbus, Ohio, July 5, 1919. (By H. H. Martin.)

seen emanating from all sides and from above. At 6:10 p. m., with the suddenness of the motion-picture projector, the cloud shadow was outlined on the cloud screen above and remained visible until 6:22 p. m."

Close observation of cloud shadows, especially when the sun is low often yields information as to form and relative heights which otherwise are not apparent.—*C. F. B.*

[1] Mo. WEATHER REV., 1913, 41: 599, fig.