A CLOUD CROSS-SECTION OF A WINTER CYCLONE.[1]

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INTRODUCTION.

When closely observed, clouds are remarkable indices of atmospheric processes and movements. Their forms and motions may be used not only directly in determining what general winds and turbulence exist at different levels, but also in surmising the vertical distribution of temperature and humidity. Here, without the expense of apparatus, are the means for discerning what is happening in the atmosphere up to great heights, and therefore the means for determining the causes of certain features of our weather and for forecasting local changes. Also, the effect of cloudiness on the temperature and humidity of the lower air is not to be overlooked.

The cloud transformations and movements during the passage of a strong low-pressure area in winter give a fairly clear picture of the internal dynamics of such a storm. The story may be told in four parts: (1) The early stages of the southerly wind, resting in a stratus cloud below and marked by alto-stratus and alto-cumulus above; (2) the forward movement of great masses of falling snow—dripping cirri—from the stongest belt of converging lower winds; (3) the lateral convergence, forced ascent and rainfall as the lower wind changes direction; and (4) the underthrust of the squall-line wedge of the cold NW. wind, which results first in rainfall from the warm SW. wind aloft, and within which the convection, due to the rapid arrival of cold air at a moderate height, causes snow flurries.

THE SOUTH WIND ARRIVES.

Formation of stratus by mixture and of lower nimbus by forced ascent.—As the crest of a HIGH passes eastward a southerly wind sets in during the night, just above the surface layer of stagnant, cold air, and by mixture with it produces not infrequently a stratus sheet, moving from the south, with a smooth, undulated, and slightly festooned base. (See *A*, fig. 1.) On account of a rapid fall in pressure in the west and southwest the previously nearly calm surface air may for a few hours in the morning move as an increasing light to moderate wind from the east and by crowding from behind quickly form a very low fracto-stratus, which grows to formless stratus and into low nimbus, from which a relatively fine rain may fall for an hour or more. (*B*, fig. 1.) If there is not much of a cloud layer above the mixture stratus, the late morning sun may send enough heat through to aid the descent of the south wind. As mild convection starts, the mixture stratus breaks into strato-cumulus. Soon the thin layer

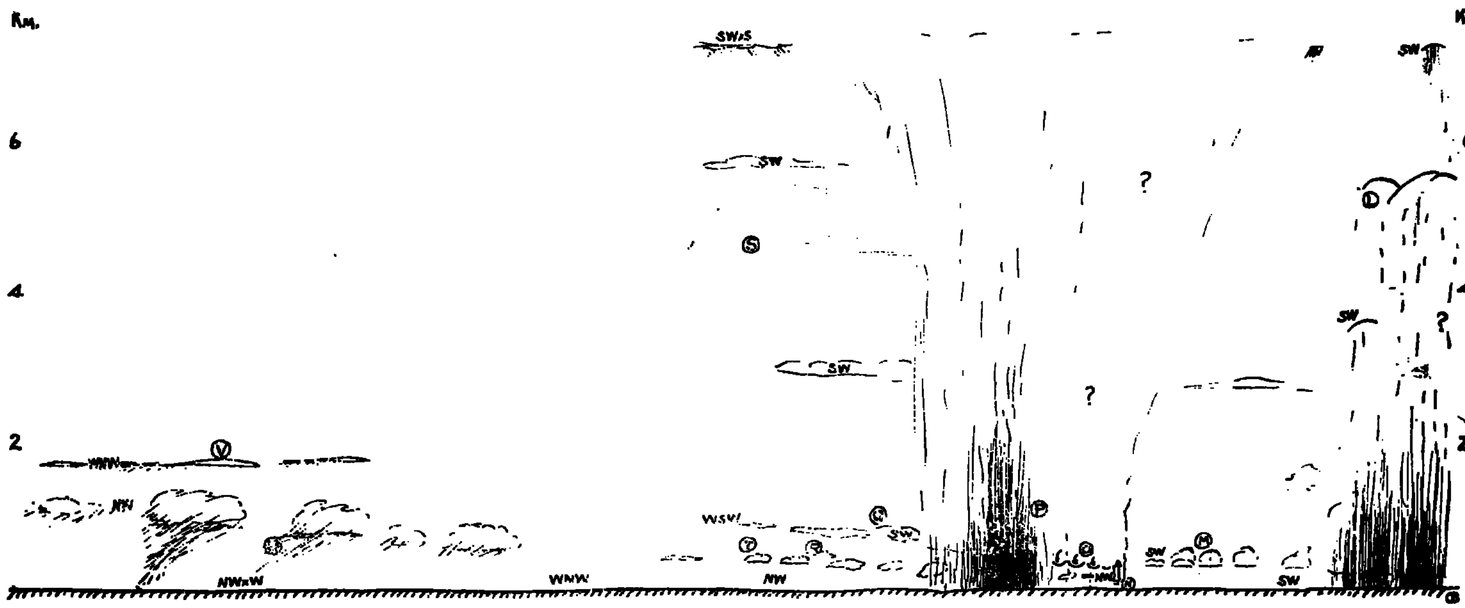

FIG. 2.—A cloud cross section of a winter cyclone.—Second day to third afternoon.

of cold air at the surface may be rolled away with a parting shower due to the converging south and east winds. Shortly, unless the sun is beginning to sink behind the western clouds, the lower clouds have evaporated, and the warmth and moisture of the air at the surface are suggestive of spring weather.

Growth of alto-cumulus by thermal convection from alto-stratus formed by mixture and forced ascent.—Now, some heavily balled alto-cumulus rising from partly broken, smooth-based alto-stratus are visible. (*C*, fig. 1.) Although the temperature gradient between the underrunning southerly wind and colder wind aloft is becoming steeper, the mixture on the boundary so raises the humidity that a slight amount of local forced ascent usually forms lenticular alto-stratus clouds (frequently with two sets of waves) before the vertical temperature gradient becomes adiabatic (1° C. per 100 m.), and therefore before a convectional interchange would begin between the lower and upper winds in contact. Once a cloud is formed, however, convection will take place if the vertical temperature gradient exceeds only the retarded adiabatic rate (say, 0.6° C. per 100 m.); therefore, the alto-cumulus may grow immediately out of the alto-stratus, whereas they could not form directly. Heavy masses of alto-cumulus formed in this way usually

[1] Excerpted from a paper presented before the Philosophical Society of Washington, Dec. 20, 1919, and the American Meteorological Society at St. Louis, Dec. 30, 1919, and at New York, Jan. 3, 1920. Basis—observations at Washington, D. C., 1919.

yield precipitation, a few drops of which may reach the surface. Under such conditions the mixture alto-stratus base tends to be blow-holed by the down-currents between the alto-cumulus units above.[2]

CIRRI COME EAST.

Cirri, streaks of falling snow.—From those parts of the approaching LOW where convection (probably forced, to a large extent) reaches its greatest development the overflowing clouds come east in the rapid winds aloft. First, thin, nearly horizontal lines of cirrus may appear; those which follow carry hooks. (*D*, fig. 1.) Obviously, snow falling from the rounded cirro-cumulus tops descends vertically while in the top current, and then trails off at a sharp angle behind in the differing current below. As large, streaming masses arrive the sky between the most obvious streaks becomes covered with a thin, halo-producing veil of cirro-stratus.

sharp pyramidal pieces of cloud (*H*, fig. 1), due probably to some mixture and the up-movement forced between the large rounded festoons of the falling, snow-filled, air masses. Locally, the cloud pyramids are joined by dark thin streaks (perhaps formed by mixture),—that give the impression that blue sky would give when viewed between rounded nearly contiguous clouds,–essentially the negative of alto-cumulus. The melting of the snow yields raindrops some of which may reach the earth. Thickening low clouds now intervene.

THE WIND-CONVERGENCE NIMBUS.

As the low pressure center draws near to pass on the north, the lower southerly wind makes small shifts in direction. A long north-south line of fracto-stratus (*I*, fig. 1) may mark the line of forced ascent where the wind shifts from SSE. to S. As the wind grows stronger the outlet of the air to windward is not fast enough horizontally, so, as each gust arrives some air is forced up, forming fracto-

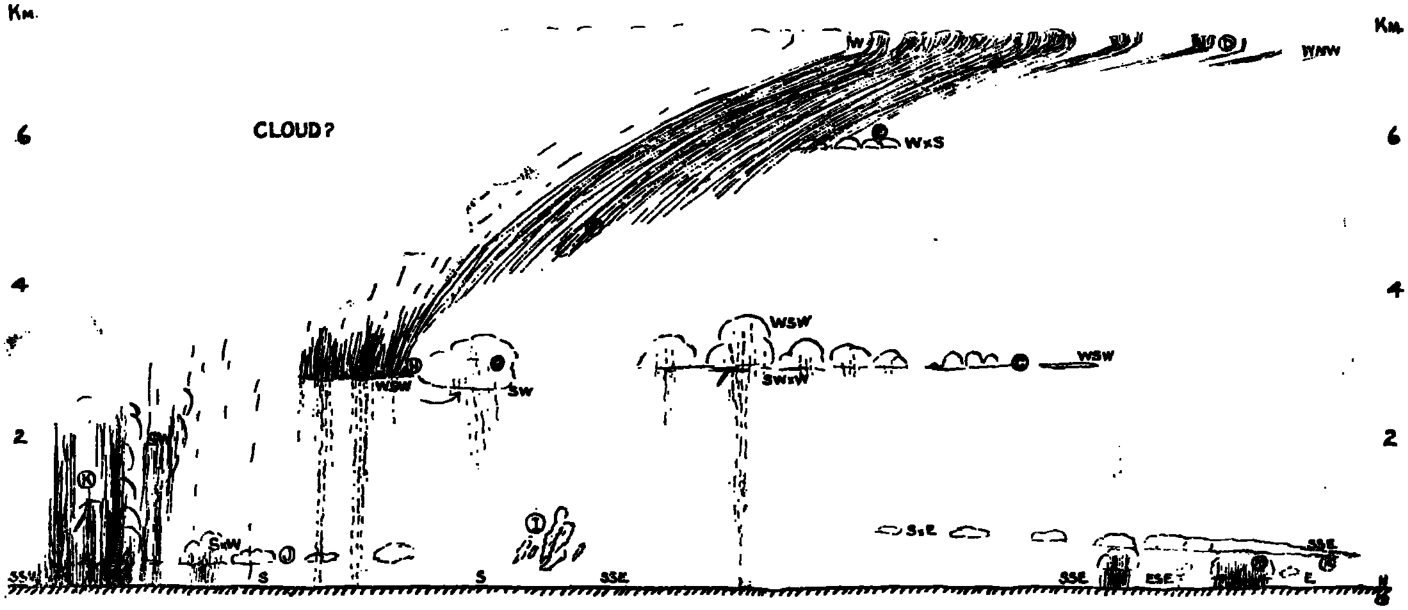

FIG. 1.—A cloud cross section of a winter cyclone.—First day to second morning.

Alto-cumulus formed by thermal convection on account of steepened temperature gradient caused by cooling of the air by evaporating cirrus.—So much snow falling from aloft and evaporating and cooling the air as it descends steepens the vertical temperature gradient near its lower limits to such an extent that cirro-cumulus or alto-cumulus may form at perhaps 2 kilometers below the cirrus tops. (*E*, fig. 1.) But the snow falls ever lower, and engulfs, or, by forced descent, evaporates, the upper, and then the lower, alto-cumulus. The cloud sheet now looks gray and mottled and the sun fades away behind what is called alto-stratus.

A high level squall cloud and cloud pyramids in front of falling snow.—In the west a heavy bank of strato-cumulus, or roll cumulus, approaches as the sun disappears. As it passes overhead the cause of its formation seems obvious—the snow-cooled air descending with a dense snow curtain just in the rear is under-running the warmer air at the upper part of the southerly wind, and by convection along a belt is making a cloud very similar to that which marks a squall front at the earth's surface. The movements are weaker, however. Just behind the roll are

stratus or strato-cumulus clouds having their long axes east-west (*J*, fig. 1), perpendicular to the direction of compression. The wind shifts two points again, from S. to SSW. Winds of higher velocity are now meeting much more rapidly than on the occasion of the first shift and so heavy north-south lines of strato-cumulus grow, in the evening and merge into a belt of nimbus (*K*, fig. 1), from which moderate rain may fall for the hour it may take the shifting belt to pass. If the wind is still increasing the sky is likely to remain covered with low, heavy clouds. A still further shift to SW. is in store, and where the change is most rapid the cooling by forced ascent of considerable masses of warm moist air by the converging strong winds causes moderate to heavy rainfall during the night. Then, the next morning, through the breaks in the clouds in the rear, may be seen the towering summits of the nimbus in the east (*L*, fig. 1); here probably form the cloud masses which pass eastward before the storm, heralding its approach.

THE SQUALL-LINE AND THE NORTHWEST WIND.

Strato-cumulus by forced ascent of air due to lateral compression of SW. wind in front of squall line.—Now the sky is nearly covered with strato-cumulus and

[2] Cf. "Types of mammato-cumulus clouds," MONTHLY WEATHER REVIEW, June, 1919, 47:398-400.

cumulus as the approaching wedge of cold air behind the squall line compresses the SW. wind laterally. (*M*, fig. 2.)

The squall-line cloud curtain and downward-boiling cloud.—In the west or northwest a low arch of dark cloud comes over the horizon; in a few minutes the wind dies down, and scud in the northwest may be seen rapidly approaching. The arch rises rapidly, and as it passes the zenith it stretches as a straight curtain from horizon to horizon; the northwest squall arrives. Soon the ragged foot of the curtain is silhouetted against the light eastern sky. All along the line, but especially at two or three places, little flecks of cloud suddenly appear just below it and rush up into it as if drawn by a magnet. (*N*, fig. 2.) The cold air from the northwest is forcing the warm air immediately in front to rise at a vertical rate of 5, 10, or more, meters per second. Overhead is a downward-boiling, festooned cloud marking the turbulent wind boundary at the top of the squall. (*O*, fig. 2.)[3] An occasional drop of rain reaches the earth.

Heavy rain resulting from strongly forced ascent.—As the light streak in the east becomes a mere line, rain is setting in, perhaps with a thunderstorm. (*P*, fig. 2.) The heaviest shower of the weather cycle falls during the next quarter of an hour or hour, and as this passes off and the clouds begin to break, the surface wind becomes lighter on account of the backward flow of air from the heavily falling rain. Broken clouds at low levels travel from the NW., and, higher up, from the SW. (*Q*, fig. 2.) As the NW. wind strengthens again compression-forced ascent and surface turbulence form low clouds again, which soon become more or less rounded on top (*R*, fig. 2) by thermal convection as colder air quickly arrives just above the slower-moving air dragging over the surface. After a few hours the precipitation finally stops and the breaking alto-stratus, moving rapidly from the SW., reveals several layers of clouds. (*S*, fig. 2.) In long, changing SW. to NE. lines these last indications of the forced ascent of the SW. wind by the underthrust of the NW. wind gradually pass toward the eastern horizon.

The turbulent strato-cumulus caused by thermal convection; snow flurries.—During the afternoon the lower clouds have become well-defined strato-cumulus (*I*, fig. 2), which disappear at sunset. Before daybreak, however, the semi-stagnation of the surface air and the consequent acceleration of the wind just aloft relieved from the surface drag, has allowed the vertical temperature gradient to become adiabatic, whereupon the wind aloft engages the surface wind and with sudden gusts gets under it and raises it, quickly forming strato-cumulus. After sunrise, the heating of the surface air may intensify this convection and make denser and denser strato-cumulus clouds, from which smudges of falling snow cover the sky (*U*, fig. 2) and occasionally reach the surface as light flurries.

Wave-made, lenticular alto-stratus caps.—The relatively slow-moving convectional masses of air from the clouds so interfere with the free sweep of the winds aloft that they are thrown into waves which disturb the upper boundary of the cold, northwest wind, and, not infrequently, force up this moist layer sufficiently to form long lines of lenticular altro-stratus immediately over the strato-cumulus. These lenticular clouds are sometimes remarkably sharp where forming in front (just before the crest of the wave) and often break into detached wave clouds (waved from SW. by warm current above) where evaporating in the rear. (*V*, fig. 2.)

Temperature prognostics from time of occurrence of strato-cumulus.—Unless the strato-cumulus clouds disappear at or before sunset, colder and colder air is still arriving aloft and a colder night is in store. If no strato-cumuli form on the next morning till several hours after sunrise the cold wave is broken, and a new weather cycle is about to begin.

[3] Cf. fig. 10, ibid., p 400.

CONCLUSION.

It is evident from studies of the appearance and transformations of cloud forms that the different types of clouds are very closely interrelated and pass from one to another form without any recognizable dividing line.

Since our weather is largely the result of the interaction of over- and under-running winds, clouds as indices of such are valuable in showing what is going on and what is to be expected. Cloud observations are finely complementary to pilot-balloon observations, for which there must be clear air and a lack of even intermittently intervening clouds. The whole domain of meteorology has no easier, more interesting, or more promising aspect for observation and study than clouds.

ATMOSPHERIC WAVES.

By F. Trey.

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This note presents the results of a study, by means of kites equipped with meteorographs, of the conditions in the neighborhood of cloud strata, on days when there were present well-defined alternating bands of cloud. The observations were carried out at the Aerological Observatory of Pawlowsk, and are summarized in the following table:

1	2	3	4	5	6	7	8	9	10	11	12
Date.	Temperature, lower layer.	Difference, upper-lower layer.		Wave length.			Height above ground.		Clouds—type.	Direction: N=0°, E=90°.	
				Registered.	Measured.	Computed.	Waves.	Clouds.		Observed.	Computed.
1918.	° C.	° C.	m.p.s.	m.	m.	m.	m.	m.		° °	° °
Jan. 17.	−18	+ 4.8	5.5	550	......	550	800	480	Nb.	90-270	85-265
18.	−20	+ 5.1	5.2	......	570	460	800	520	St.	75-250	79-259
18.	−18	+ 1.0	5.0	2,060	......	2,300	1,400	......	......	......	......
21.	− 5	+ 5.4	6.0	660	......	590	300	230	Nb.	......	......
21.	0	− 2.4	5.0	940	......	900	1,000	......	......	......	......
22.	1	+ 5.2	4.5	360	......	350	400	360	St.	......	......
24.	−15	+ 6.3	7.0	720	......	690	130	......	......	......	......
24.	− 9	+ 1.3	2.5	360	......	420	1,300	......	......	......	......
24.	−14	+ 0.8	3.0	990	......	900	2,400	......	......	......	......
25.	−14	+13.4	9.5	700	......	600	200	......	......	140-320	152-332
Feb. 1..	− 1	+ 6.0	8.5	1,000	1,200	1,070	250	150	St.	44-220 48-210	44-224
2 .	− 5	2.7	8.0	......	......	2,200	350	......	......	......	......
3..	......	......	......	......	......	......	......	......	......	48-235	55-235

The observations showed the presence of a more or less sharp surface of discontinuity, above and below which lie several hundred meters of air in which cloud formation takes place. There is then a gradation into a region with the normal temperature gradient. In the disturbed strata occur small but very regular temperature variations which cause waves on the thermogram. It will be noticed that in all but one case a warmer layer is gliding over a colder one.

The data in colums 2, 3, 4 were recorded by the meteorograph; those in columns 6, 8, 9, 10, 11 were obtained by observations from the ground, together with the direction of the wind in each layer of air. Columns 7 and 12 can then be computed. Column 5 was taken from the thermogram. See Wegener, *Thermodynamik der Atmosphäre*, pp. 155-162, 1911.—*E. W. W.*