THUNDERSTORMS,
THEIR CAUSES AND AIDS IN FORECASTING

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Classification of Thunderstorms as to Causes

I. Air Mass Thunderstorms:

(a) From local convection -- Due primarily to insolational heating in lower layers. Found most frequently in Tg air, due to its steep lapse rate and high specific humidity. Valuable local indications of convective thunderstorms are presence and growth of towering separated Cumulonimbus during the day; a warm muggy and often stagnant atmosphere, and a steep pressure fall by afternoon. According to Bjerknes an almost complete covering of the sky by flat Cumulus (Cu. Humilis) is not indicative of thunderstorm activity.

(b) In thermodynamically cold air masses -- With the flow of cold Pc air over a warmer land surface a very steep lapse rate is developed in the lowest layers. This unstable condition will lead to snow flurries in winter; and in spring and early summer to thundershowers, which however are usually of mild intensity because of the low moisture and heat content of the Pc air. In midsummer this type is rare because of the probability of gradual warming of the Pc air as it moves south over continental U. S. Another possible restraining influence on this type of thunderstorm is the presence of a stable layer created by subsidence within the cold air mass, that acts as a lid to stop the upward growth of Cu clouds. Thus, because the surface of subsidence is at its lowest level immediately behind a cold front,

conditions here are least favorable for thunderstorm development. Observations show that air mass thunderstorm activity over the ocean reaches a maximum during the early morning hours and is at a minimum during daylight. The commonly accepted theory explaining this is that the development of instability results from radiational cooling of the upper air, while the surface layers retain their practically constant temperature due to the presence of the water surface, thereby steepening the lapse rate sufficiently to cause convections to be set up from the lower levels.

II. Frontal Thunderstorms:

(a) Associated with a cold front -- With a mass of potentially unstable air in front of a rapidly moving cold front, conditions are ideal for the setting off of a whole line of thunderstorms by the mechanical uplifting of the air to its saturation level. Because of a usual ground inversion at night there is the possibility that a cold front would not cause as many storms at this time; whereas in the afternoon when the same air mass may be characterized by a super-adiabatic lapse rate a thunderstorm is easily produced. Those storms caused by this type condition are generally the most violent and destructive of all, and a series of them is frequently referred to as a "line squall".

(b) Associated with a warm front -- Due to the fact that in this case the vertical velocities are not as great as with a cold front this type thunderstorm is less severe. However, in addition to this upward deflection there is the factor of horizontal convergence or vertical divergence to consider in the warm sector of

of an open wave cyclone. Should the air have b a originally stable then horizontal convergence, which is indicated on a synoptic chart either by an inflection in the isobars in the warm sector or by an isallobaric low, will decrease the stability to possibly the point where it is conditionally unstable. However, on the other hand should the air have been initially unstable then horizontal convergence would decrease its instability.

But there is still another case to consider. There is always some horizontal divergence and subsequent subsidence in the warm air overrunning a warm front, if the front is not associated with a deep low center. In this should the overrunning air be conditionally unstable then this subsidence would tend to increase its instability to a point where thunderstorms would be set off.

From observations it seems that warm front thunderstorms are most active from late in the evening to sunrise and least active in the afternoon. This is explained by the radiational cooling at night from the top of the Altostratus deck formed by the moist air overriding the warm front. This cooling steepens the lapse rate and causes the air to become top-heavy and unstable to the point where strong upward concections develop into thunderstorms, which have their bases above the warm front surface.

(c) Associated with an occluded front -- The usual example cited of this type is a warm front type occlusion in which Tg air is colder than an RTp mass which therefore overrides it; while an RPp mass, warmer at the surface than the Tg due either to adiabatic heating, radiation, or surface heating, overruns the Tg but dis-

places the relatively warmer RTp. This then gives the peculiar situation of the warmest air being pocketed between the Tg wedge and the RPp wedge. With the frontal surface becoming steeper because of the smaller difference in temperature of the two air masses a very unstable relationship becomes possible. Insolational heating in the Tg mass and and adiabatic cooling in the rising in the RPp mass combine their effects to give a lapse rate steep enough to cause convectional activity. This then destroys the unusual situation of a more dense air mass overlying a lighter one, and with the resultant overturning conditions are most favorable for very severe thunderstorms and even tornadoes to result.

III. Orographic Thunderstorms:

These result when unstable air in mountainous country is forced to rise, either by natural wind flow being deflected upward upon striking mountains, or by convections set up because the mountain is heated faster than the surrounding air. This is especially noticeable on mountainous tropical islands where heat convections are more easily formed and the moisture content of the air is high.

Other instances of orographic thunderstorms are when conditionally unstable maritime air masses are forced aloft by a coastal mountain range, such as the Pacific northwest ranges. Even along the southern Gulf coast the gradual land rise combined with land heating is often enough to produce summer thundershowers.

IV. Thunderstorms in Horizontally Converging Air Currents:

Beside the case of convergence in a warm sector caused by an

approaching cold front, there is the possibility of a rapidly moving, deep, bent-back occlusion establishing behind itself a low pressure trough with a resultant convergent field of motion. This convergent zone may be accompanied by a slight wind shift and possibly develop into a secondary cold front. Due to the vertical spreading of the air with a resultant decrease in stability, thunderstorms may be set off even before the secondary front becomes well defined.

Thermodynamic Possibilities for the Development of Cumulus Clouds or Thunderstorms

Case #1: The observed lapse rate is greater than the dry adiabatic, but the ICL is above the resulting cloud of fair weather cumulus type. There will be no precipitation and cloud will be colder than surrounding atmosphere.

Case #2: This type of Cumulus, also without precipitation, results from an original conditional instability situation in which the observed lapse rate was less than the dry adiabatic. However with sufficient surface heating the initial stability is destroyed. In the resulting convections that begin Cumulus clouds form, but due to the fact that the ICL is high enough to remain above the cloud level no precipitation results.

Case #3: An example of showers but no thunderstorms because the maximum vertical velocity below the ICL is less than 8 meters per second. Here the ICL is just within the top portion of the cloud, thus preventing hail formation but giving rain.

Case #4: Should the upward vertical velocity exceed 8 m/s before the ICL is reached then a thunderstorm would result. But there

would still be no hail because the positive area above the ICL is small.

Case #5: If the ICL is sufficiently low in the cloud and a velocity of 8m/s is attained before the ICL is reached, then both hail and a light thunderstorm will result.

Case#6: The ICL is still at a low level in the cloud, but the vertical velocity below it does not exceed 8 m/s. Above the ICL there is increasing positive area which therefore greatly increases the vertical velocity. The result is a Cumulonimbus with large and violent hailstones, some rain, but no lightning.

(Note: In Cases #2-6 the original lapse rates were all conditionally unstable.)

Conclusions that may be drawn from the above:

(1) Precipitation will not begin until the top of the cloud has exceeded the ICL.

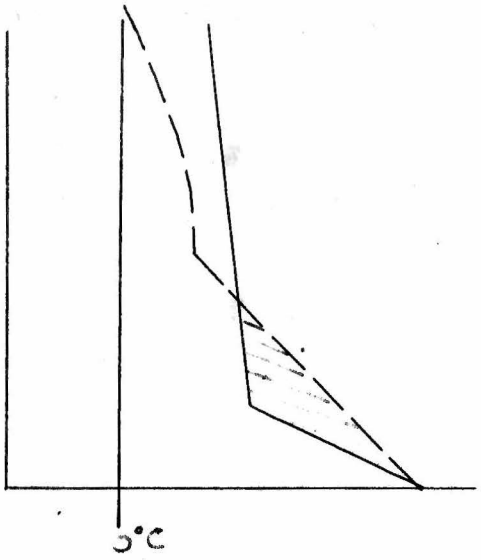
(2) If the ICL falls within the positive area then the size of this area below the ICL determines whether a shower or a thunderstorm will develop from a given situation and is a measure of the intensity of the resulting action. The lower the ICL is in the positive area the greater the chance for hail and the lesser the chance for lightning.

Summary of air mass movements:

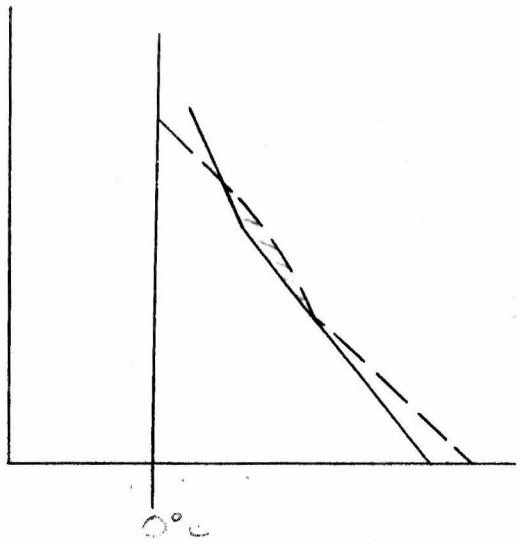
(1) Subsidence, horizontal divergence, or vertical convergence all increase stability of a stable layer; and increase instability of an unstable layer.

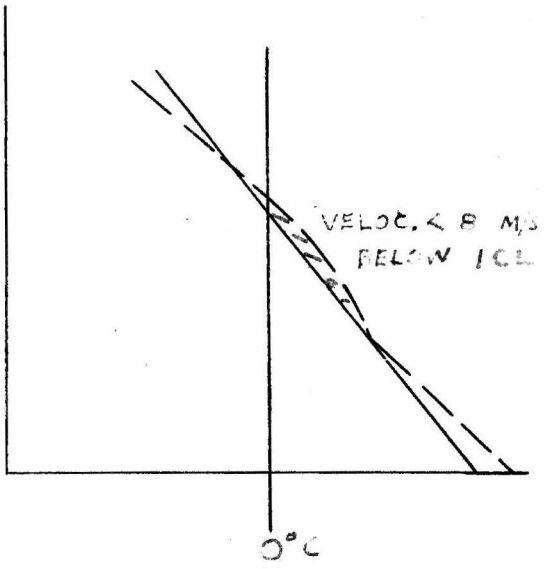
(2) Lifting, horizontal convergence, or vertical divergence all decrease stability of a stable layer, and decrease instability of an unstable layer.

#1

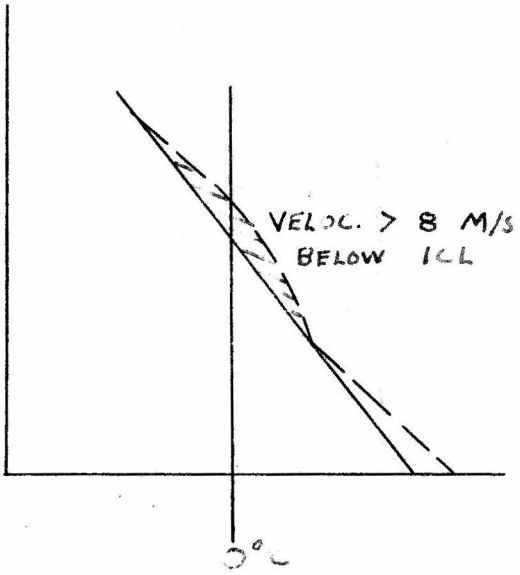

0°C

#2

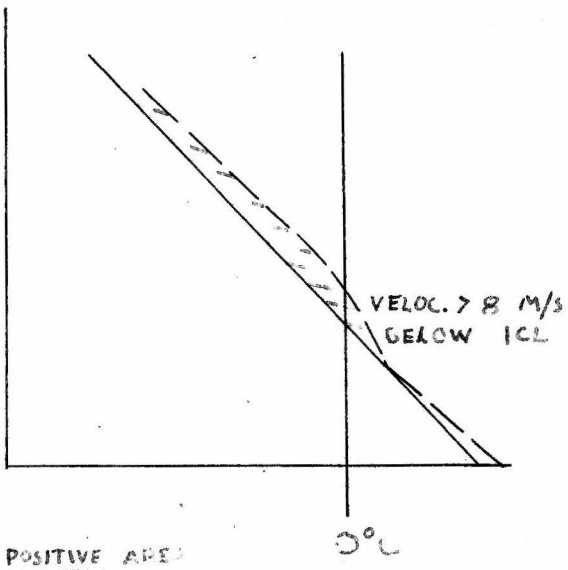

0°C


VELOC. < 8 M/s
BELOW ICL
0°C

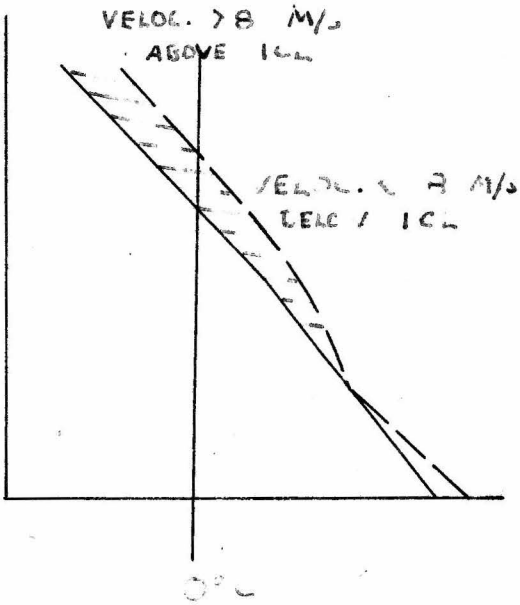
#4


VELOC. > 8 M/s
BELOW ICL
0°C

#5


VELOC. > 8 M/s
BELOW ICL
0°C

#6


VELOC. > 8 M/s
ABOVE ICL
0°C


POSITIVE AREA

Suggested procedure in forecasting of possible thunderstorms:

(1) Referrin to the synoptic chart determine the air masses that will be over the station during forecast period.

(2) Considering the trajectory of the air, plot the sounding which most nearly approximates the air mass expected;and determine the critical temperature required to produce free convections and the lift necessary if orographical lifting is possible. From previously prepared diurnal temperature curves estimate the probable time of the critical temperature being reached.

(3) If any frontal passages are expected during the forecast period, determine the amount of lifting required.to produce instability.

(4) Either from the synoptic map, or from isentropic charts if they have been prepared, determine whether moist or dry tongues of air aloft that might affect the air structure are being transported into the forecast region, and then estimate their probable effect.

(5) If the plotted sounding indicates a thunderstorm then estimate the intensity of it and the type of precipitation to be expected by noting the size of the positive area and its location in regard to the ICL.

(6) Consider the possibility of thunderstorms which might develop in other favorable regions and be carried into the forecast region by the general air drift.

BIBLIOGRAPHY

References used in preparation of this article:

Berry, F. and Maginnis, J., Thunderstorm Forecasting, C.I.T. Thesis, 1937

Namias, J., Air Mass and Isentropic Analysis, Fifth Ed., Am. Met. Soc., 1940., pp 60-68.

War Dept. Technical Manual #1-230, Weather Manual for Pilots, 1940, pp 110-117.

Krick, I. P., Lecture notes, Jan. 1942

Other suggested references:

Thunderstorms associated with a warm fron, by William D. Flower. Met. magazine, London, Mar. 1936, v. 71, no. 842, p. 43

The Thunderstorm as a forerunner of the typhoon, Robert G. Stone, Bull. of the A. M. S., Milton, Mass., Feb. 1936, v. 17, p. 44

Air Mass thunderstorms, by Edward Minser. Bulletin of the A. M. S., Milton, Mass., Mar. 1935, v. 16

Meteorological conditions preceding thunderstorms on the national forests. Part I. Western and Central Oregon, by W. R. Stevens, M. W. R., Washington, Oct. 1934, v. 69, no. 825

Thunderstorms and line s ualls, by P. del Vecchio. Aero Digest, New York, May 1934

Thunderstorms and line squalls. Aero Digest, New York, 1934, v, 24, no. 5.

The Geography of thunderstorms, by Charles Fitzhugh Talman. Bulletin of the A. M. S., June-July 1933, v. 14,

A Contrast in thunde storms, by William Jackson Humphreys, M. W. R. May, July 1932, v. 60,

Thunderstorms and night flying, by Vincent E. Jakl. Science supplement, June 26, 1931, n.s., v. 73

Alto-cumulus castellatus clouds and thunderstorms, by Charles K. M. Douglas. Met. magazine, London, June 1931, v. 68, no. 785.

Mammato-cumulus clouds and thunderstorms, by William H. Pick. Met. magazine, London, June 1931, v. 66, no. 785.

The Occurrence of thunderstorms in New Zealand, by E. Kidson and A. Thomson. Journal of Science and Technology, Wellington, N. Z. 1931, v. 13.

Squall lines in New Mex. by Cleve Hallenbeck. M. W. R., Washington, Oct. 1930, v. 58, pg.402.

Thunderstorms and line squalls, by Martin L. Dobler. Aero digest, July, 1930, v. 17, no. 1.

Ways and means of recognizing and avoiding thunderstorms, byF. A. Carpenter. Aeronautical world, Jan. 1930, p 22.

Aircraft and the thunderstorm, W. J. Humphreys. Aviation, New York, Nov. 16, 1929, v. 27, no. 20.

The hazard of thunderstorms in aviation, by Alexander McAdie. Bulletin of the A. M. S., Feb. 1929, v. 10.

The Relative frequency of thunderstorms throughout the day over the oceans and in the tropics, by G. R. Wait. Terrestrial magnetism, Washington, 1928, v. 34.

Note on pilots' observations of air currents in and near thunderstorms, by Paul A. Miller. M. W. R., Washington, Aug. 1928, v. 56.

Thunderstorms in the Los Angeles district, by Charles C. Conroy. M. W. R., Aug. 1928.

The Mechanism of a thunderstorm, by G. C. Simpson. Proceedings of the Royal Society of London, Apr. 1, 1927, v. 114, no. A768.

Can thunderstorms be classified? by Alfred Jusdon Henry. M. W. R. Mar. 1927, v. 55.

Thunderstorms in San Francisco, by William H. Alexander. Science supplement, Jan.-June 1924, n.s., v. 59.

The local, or heat thunderstorm, by C. F. Brooks. M. W. R., June 1922, v. 12.

Note on thunderstorm breeding spots, by Burton M. Varney. M. W. R. July 1921, v. 49.

Squalls at night on the lee side of a mountainous island. Met. magazine, London, Mar. 1921, v. 56, no. 662.

General meteorlogical aspects of thunderstorm electricity, by H. R. Byers. Bulletin of the A. M. S., May 1939, v. 20.

Thunderstorm forecasting with the aid of isentropic charts, by J. Namias. Bulletin of the A. MS., Jan. 1938, v. 19, no. 1.

Lightning and thunderstorms, by A. Eisler. Bullet. of the A. M. S. June-July 1937, v. 18, no. 6.