STUDY OF UPPER COLD FRONTS

condensed from

Upper - air Cold Fronts in North America - Lichtblau
and
Synoptic Determination and Forecasting Significance
of Cold Fronts Aloft - B. Holzman

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Submitted in Partial Fulfillment
for Seminar Credit

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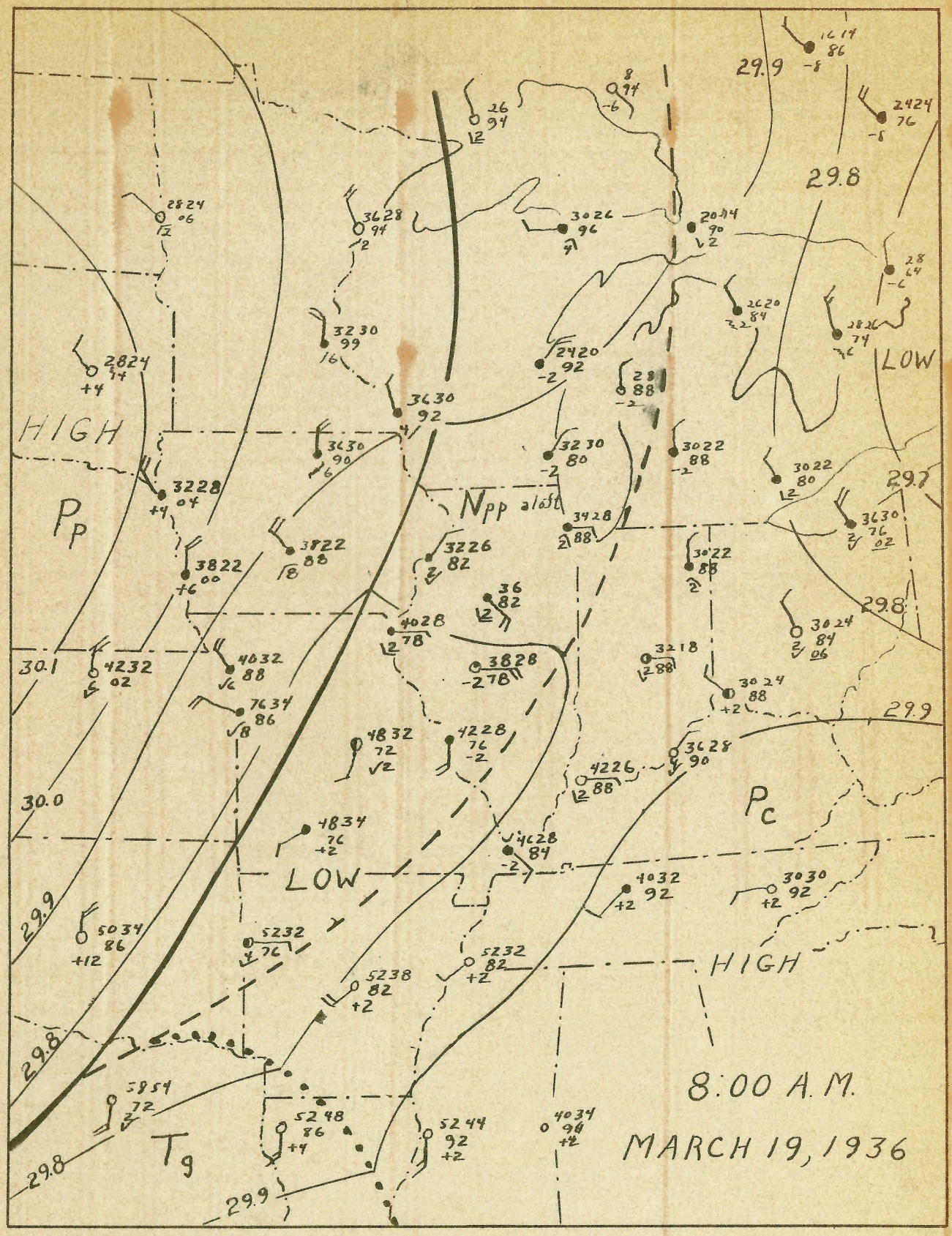

HIGH
LOW
LOW
HIGH
P_P
N_{PP} aloft
P_C
T_g
29.9
29.8
29.7
30.1
30.0
29.9
29.8
29.9
29.8
29.9
8:00 A.M.
MARCH 19, 1936

Figure 1

The density relations for this synoptic situation completely verify the indicated conditions. Figure 2 shows the density curves for Omaha, Scott Field, and Wright Field. The air mass at Omaha on the 19th has a much greater density, level for level, than the air column that was present there on the 18th. This necessarily indicates a surface invasion by a Polar air mass, and is represented by the outbreak of fresh Pp air. The density curves for Scott Field on the 18th and 19th illustrate the singular crossing of curves which is characteristic of the passage of an upper cold front. The upper cold front passed Wright Field between the 19th and 20th; and these curves, similarly, show the peculiar crossing.

The density relations for Omaha, Scott Field, and Wright Field on the 19th are illustrated in Figure 3. It can be seen that in the lower levels that Omaha curve shows a denser air mass than the curve for Wright Field; and one of them must pass through the St. Louis area as a surface invasion. However, the air at Omaha below 800 meters is less dense than at the corresponding levels of the Wright Field curve, and thus illustrates a possibility for the active Pp mass to occlude in the warm front manner by the time the air mass has invaded the Dayton area; but this possibility has to be substantiated by data at some later stage, for it is more than likely that at the time the Pp air is ready to invade the Dayton area, the dense layer of Pc air may have become sufficiently modified to be actually less dense than the advancing Pp air, and thus preclude the possibility of a warm front type of occlusion. The lower levels at Scott Field have a less density than the corresponding levels at Wright Field. This immediately eliminates any possibility of any surface cold front advancing into the Dayton area from the St. Louis area; and necessarily implies that as long as the indicated density relations prevail at these two stations, all air mass invasions must occur aloft.

No significant weather phenomena resulted from the upper cold front on the 19th, but on the 20th, a good deal of precipitation occurred, although the situation was then complicated by the advance of the cold front type of occlusion.

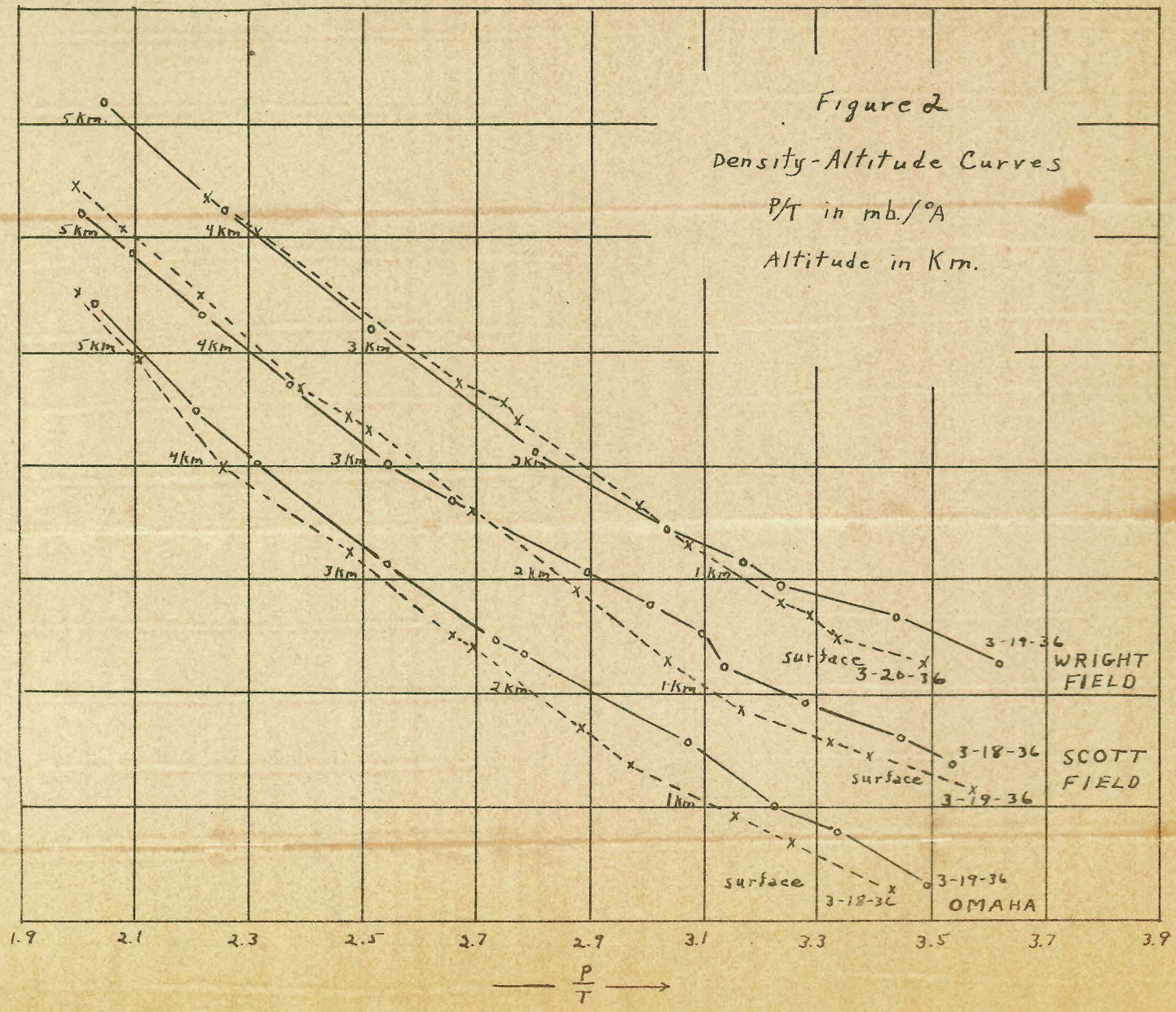


Figure 2

Density-Altitude Curves

P/T in mb./°A

Altitude in Km.

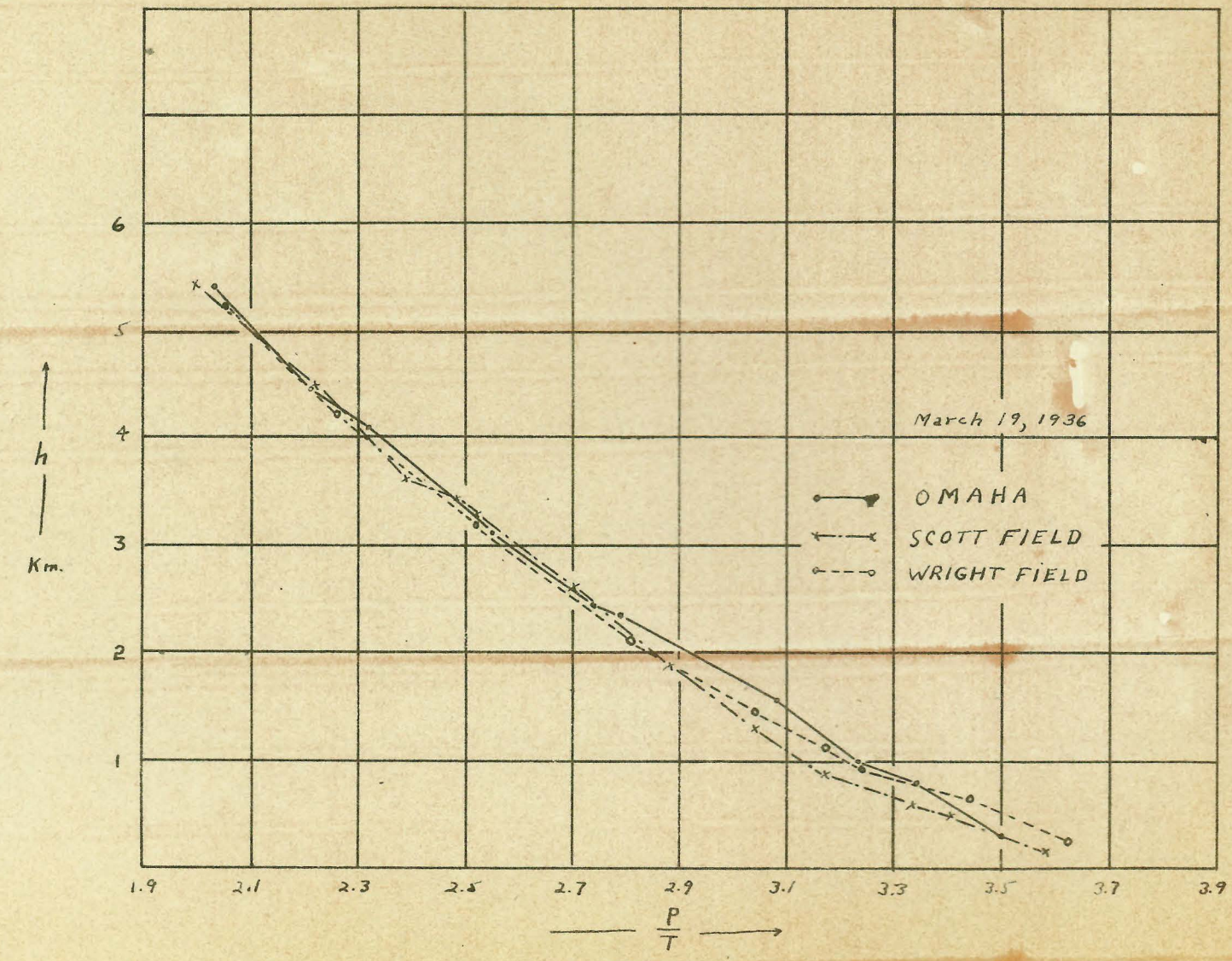


Figure 3 - Density-Altitude Curves

P/T in mb./°A Altitude in Km.

Fronts aloft have long been recognized, but until recently very little attention has been given to them. In the United States much of the weather, especially in the colder months, is governed by such fronts as well as by surface fronts. Although as many different types of fronts may exist aloft as at the surface, we find that of the three types of fronts - namely, cold, warm, and occluded, - only the cold front has much significance aloft, and it is by far the easiest to locate. The following discussion is, therefore, mainly limited to cold fronts in the upper air.

Formation. Cold fronts aloft may, in most cases, be traced back to the surface occlusions of the warm front type. One exception occurs with frontogenesis aloft above a shallow Polar current, usually of continental origin. Another exception of more complicated nature occurs as a development in the advance portion of a deep Polar current, in the form of a steepening of the slope of the Polar wedge at some distance behind the surface front. This implies either a decrease in wind velocity or a change in wind direction above the elevation where the slope changes, in such a manner as to cause the lower portion of the air mass to advance more rapidly than the upper portion. These exceptions, while often important, occur much less frequently than the cold fronts aloft found with warm type occluded fronts.

The two general regions for the formation of occluded fronts of the latter nature, as far as United States weather is concerned, are in the Pacific Ocean at varying distances from our coast (depending principally upon the location of the Aleutian Low) and along the mountain ranges from California to Alaska. When the occlusion of a warm sector of modified Polar Maritime air occurs at some distance from the coast we find, with the warm front type occlusion, that the surface air is warmer to the west than to the east, which permits the air to the west to ascend over the colder wedge as it moves eastward. Aloft, however, in the air to the west we find low temperatures, sometimes exceedingly low with steep lapse rates that often approach the dry adiabatic lapse-rate characteristic of fresh outbreaks of Polar Pacific air. The surface occlusion which was originally the surface warm front may advance slowly or even remain stationary, while the cold front advances rapidly over the shallow Polar wedge. The separation of these may increase quite rapidly to a thousand miles or more. Also, the surface occlusion may have become insignificant from a synoptic viewpoint, remaining near the West Coast, while the upper air front has traversed half the distance or more

across the country, accompanied by considerable precipitation, the amounts, of course, depending upon the air masses encountered.

The other general type of warm front occlusion which forms along the western mountain ranges needs no Low nor even a well-pronounced trough for its formation; east of the mountains is a shallow surface layer of Polar continental air which has been unable to spread westward because of the natural barrier presented by the mountains. This Pc air is usually very cold. Above the Pc is found Pp which has gone through varying stages of modifications, usually by means of subsidence. Fresh Pp air, with steep lapse rate, which comes in behind a surface cold front along the West Coast, is colder than the modified Pp air and displaces it while moving eastward and ascending the mountains. After reaching the Pc air on the other side of the mountains, it continues its movement as a cold front aloft, above and without displacing this Pc air, rather than as a surface front. The movement of such an upper front will often be considerably accelerated after passing over the mountains. Again, the cold front may advance rapidly while the surface front advances slowly or even remains stationary.

Life History. The cold front aloft encountering little resistance usually moves rapidly across the western part of the country, and is usually propogated to the surface only after it is past the Mississippi River. The cold front aloft may come to the surface simply by overtaking the surface cold front and moving down the front of the Pc air mass. As a rule, the two fronts will then proceed as one surface front with the velocity of the cold front aloft. Occasionally, after the cold front aloft overtakes the surface front it will continue to move as a surface front and increase its distance from the Pc front. In comparison with this process of simple descent, the propogation downward to the surface is more complicated. The cold front aloft usually will be propogated to the surface when it comes over a surface pressure trough or field of convergence. When the pressure trough associated with the upper front becomes superimposed upon the surface pressure trough or region favoring frontogenesis, we find that a cold front forms, with well-marked wind shifts and other characteristics of such fronts. If vertical mixing has taken place, the surface cold front may be continuous with the upper front and there will be but one front. If this did not take place, the upper front may continue its advance and outstrip the surface cold

front it generated in the field of convergence. This type of frontogenesis, in contrast with the type that requires no front aloft, may be anticipated much more confidently, because the progress of the front aloft may be followed quite accurately for sometime before it enters the region where frontogenesis is likely.

Cyclogenesis, or intensification of a Low, will take place if the cold front aloft encounters a slow moving or stagnating cyclone. The cyclone will intensify and move rapidly along the upper air front, which then becomes a surface cold front south of the center. Here again, a knowledge of the movement of the cold front aloft is important to the forecaster.

Winds Aloft. Usually, a well-marked discontinuity in the winds aloft separates the encroaching upper wedge and the air mass below. The winds in the surface air may be southwesterly, whereas aloft a vigorous shift to the northwest will be encountered. This type of shift has been observed to accompany the upper front in most of the cases. However, the discontinuity need not be indicated in a directional wind shift, but many times a change in the velocity will be the only clue available. One is to be cautioned against attaching too much significance to a mere change in direction of the winds aloft, and not confuse an overrunning of Tropical air or the gradual deflection of the surface winds up to the gradient wind levels.

Surface Winds. Surface winds are of little synoptic aid in locating an upper front. Since the advancing wedge travels aloft, it usually cannot be expected to extend its influence to surface winds. However, because of a slight deflection of the isobars by the trough accompanying the upper front there will be a slight wind shift of small significance.

Pressure Change Characteristics. The pressure change characteristic offers a very important clue to the presence of an upper front. The barometer trace during the passage of a surface cold front will show falling, and then sharply rising, pressures; but with the passage of an upper cold front the change is usually characterized by a lesser discontinuity - perhaps a slower rate of decrease or only a slight rise in the barometer, followed by a steadily and rapidly rising pressure.

Pressure Trough. In contrast to the generally distinct V-shaped isobars associated with a surface cold front, only minor and poorly defined surface pressure troughs characterize upper cold fronts. Although an upper front may be

evidenced at the surface by a broad pressure trough, aloft it may be accompanied by a pronounced low pressure, and the gradient will be such as to cause a very significant increase in the winds at these levels as the front approaches. However, in the case of the warm-front type of occlusion, a minor surface trough in advance of the trough that accompanies the surface front is generally significant, and is good evidence for the presence of an upper front. Isobars should be drawn carefully, avoiding too great a smoothing, as the minor trough can easily be obscured. Frequently, it will be helpful if the isobars are drawn before attempting to locate the frontal discontinuity.

Cloud Types and Precipitation. A characteristic feature of the warm-front type of occlusion is the frequent absence of cloud forms during the initial occluding process. Usually, a surface wind shift is indicated, and to all appearances it will seem to have all the properties of a cold front type of occlusion except for the fact that a zone of clear skies accompanies the shift. Unfortunately, this evidence in itself is not diagnostic, for many surface cold fronts similarly are attended by the lack of cloud forms. However, well in advance of the surface shift, as much as 100 - 500 miles a zone of alto-cumulus or alto-stratus may lead one to suspect the presence of an upper cold front. When there has been no occlusion and there are no surface wind discontinuities, an anomalous belt of alto-cumulus may likewise indicate an upper cold front. Here again, this evidence needs further substantiation, for a simple warm front may often show a zone of cloudiness separated from the surface wind shift by a zone of clear skies.

Generally, the most complex systems that accompany warm-front type occlusions occur during the Winter. In the initial stage, a belt of alto-cumulus or alto-stratus may be noticed in advance of the surface shift, and the upper front may likewise be present; but as the cold wedge proceeds aloft, there is a sudden thickening of alto-stratus and within one or two hours without any evidence whatsoever from westward-lying stations a moderate snow condition may develop. A strato-cumulus layer generally will form beneath the lowering and thickening alto-stratus; and as precipitation continues a low stratus deck eventually develops within the surface cold air mass, limiting ceilings to 500-1, 500 feet. In the zone below the upper front, the cloud systems may merge into one thi ck cloud system.

The situation just described represents probably the most complex of the cloud systems that accompany the upper cold front, and will probably occur only in Winter. Usually, a zone of alto-cumulus with little or no precipitation will mark the advance of an upper cold front in Spring or Autumn. In Summer, a series of high level thunderstorms, caused by the release of the convective instability of the Tropical air mass which the upper wedge most commonly displaces, or in a few cases caused by the release of the instability of the air in the advancing itself, will serve to locate the boundary of the active air mass.

Surface Temperatures: To ascertain whether a warm front or cold front type occlusion will take place, it is some times sufficient to compare the surface temperatures of the active and passive air masses, and to presume that if the temperatures are high in the active air mass it will flow aloft; but this procedure should be used with reservation. The real reason an air mass ascends is because its density, level for level, is less than that of the wedge with which it comes in contact. Of course, within the narrow limits of the frontal zone the pressure is essentially the same in the cold and the warm mass, and the relative density is thus determined by temperature and to a slight extent also by the water vapor content. However, the distribution of meteorological stations does not allow a determination of density from alone, especially when comparisons for 12 or 24 hours are desirable. Likewise, surface temperatures are easily influenced by insolation, radiation, evaporation, and condensation; and when employed for comparative purposes, in establishing the lesser or greater density of an air mass, should always be used in conjunction with the pressures.

Forecasting Significance. In late Spring, Summer, and Autumn, the weather phenomena resulting from upper cold fronts are relatively unimportant as far as airline transportation is concerned. Almost invariably, one can forecast that all ceilings and visibilities will remain ample. Frequently, a variable broken-overcast alto-cumulus with little or no precipitation will accompany the front.

During Summer and early Autumn when the advancing upper wedge comes in contact with a Tm (Tropical Maritime) air mass characterized by conditional or convective instability, high level thunderstorms are usually developed. The cumulus clouds that accompany the high level thunderstorms

have bases generally between eight to twelve thousand feet, with the maximum convective activity probably occurring well above 18,000 feet. These thunderstorms offer little or no difficulties to aircraft travel.

The weather resulting from an upper cold front situation in Winter occasionally presents a serious icing hazard to aircraft. This condition can best be illustrated by contrasting it with the icing hazards during a surface warm front situation. In the Winter case of a simple warm front, where relatively warm moist southwesterly winds are advancing aloft over a wedge of very cold Polar air, the precipitation usually begins as snowfall. During this incipient stage, aircraft will experience no great difficulties other than the loss of power occasioned by the use of heat to prevent icing in the carburetor. As the warm front action continues, with the consequent modification of the Polar air to higher temperatures, a serious icing stage is reached when the precipitation from the alto-stratus begins as rain and on descent proceeds as a freezing rain. This hazardous stage may continue for from eight to twelve hours, and by then the Polar wedge either has receded sufficiently or has become so modified that the temperature of precipitation is well above the freezing point. Moreover, in this warm front condition it is quite likely that in spite of the fact that the precipitation is freezing in the Polar wedge, a sufficient temperature inversion prevails aloft in the Tropical air for a rapid through the Polar current to permit only a very slight accumulation of ice.

On the other hand, the icing hazard that accompanies an upper cold front may cause considerable doubt as to the safety of the navigation through the frontal zones. The advancing wedge aloft is generally warmer than the surface Polar mass, but will have only a small modifying effect upon the wedge below. This is because the air mass aloft is generally of Polar origin itself. It is also unlikely that any significant inversion is present above the surface Polar current. In addition, an "on the top" flight is generally excluded because of the extreme thickness of the alto-stratus that merges with the lower cloud systems in advance of the upper front. Once the temperature conditions are such as to permit a mixed snow and rain to fall from the alto-stratus, the icing hazard can become indeed serious.

When the upper wedge interacts with Tropical Maritime air, icing conditions seem to be confined to the

cloud sys tem within the Tropical current. This conclusion is based upon evidence furnished by a number of pilots of American Airlines, Inc.

Example. March 19, 1936. The most frequent type of upper cold front appears as a Pp front aloft in the Middle West when the central and eastern portions of the country are occupied by fresh Polar Canadian air. An interesting situation of this type, illustrating both an upper cold front and a cold front type occlusion, occurred on March 19, 1936.

An upper cold front, outlining the boundary of a transitional type of Polar Pacific air, is present between Scott Field and Wright Field, and is advancing over a shallow wedge of Polar Canadian air. A fresher surge of Polar Pacific air is indicated by the cold front between Omaha and Scott Field. This front is proceeding eastward and is displacing the shallow layer of returning Polar Canadian air as a cold front type of occlusion, because the active Polar Pacific air mass is of greater density.