I. FOEHN WINDS OF SOUTHERN CALIFORNIA.

II. FOEHN WIND CYCLO-GENESIS.

III. WEATHER CONDITIONS ASSOCIATED WITH THE AKRON DISASTER.

IV. THE LOS ANGELES STORM OF DECEMBER 30, 1933 TO JANUARY 1, 1934.

Thesis By

Irving P. Krick.

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SUMMARY.

I. FOEHN WINDS OF SOUTHERN CALIFORNIA.

An investigation of the hot, dry and dust laden winds occurring in the late fall and early winter in the Los Angeles Basin and attributed in the past to the influences of the desert regions to the north revealed that these currents were of a foehn nature. Their properties were found to be entirely due to dynamical heating produced in the descent from the high level areas in the interior to the lower Los Angeles Basin. Any dust associated with the phenomenon was found to be acquired from the Los Angeles area rather than transported from the desert. It was found that the frequency of occurrence of a mild type foehn of this nature during this season was sufficient to warrant its classification as a winter monsoon. This results from the topography of the Los Angeles region which allows an easy entrance to the air from the interior by virtue of the low level mountain passes north of the area. This monsoon provides the mild winter climate of southern California since temperatures associated with the foehn currents are far higher than those experienced when maritime air from the adjacent Pacific Ocean occupies the region.

II. FOEHN WIND CYCLO-GENESIS.

Intense anticyclones frequently build up over the high level regions of the Great Basin and Columbia Plateau which lie between the Sierra Nevada and Cascade Mountains to the west and the Rocky Mountains to the east. The outflow from these anticyclones produce extensive foehns east of the Rockies in the comparatively low level areas of the middle west and the Canadian provinces of Alberta and Saskatchewan. Normally at this season of the year very cold polar continental air masses are present over this territory and with the occurrence of these foehns marked discontinuity surfaces arise between the warm foehn current, which is obliged to slide over a colder mass, and the Pc air to the east. Cyclones are easily produced from this phenomenon and take the form of unstable waves which propagate along the discontinuity surface between the two dissimilar masses. A continual series of such cyclones was found to occur as long as the Great Basin anticyclone is maintained with undiminished intensity.

III. WEATHER CONDITIONS ASSOCIATED WITH THE AKRON DISASTER.

This situation illustrates the speedy development and propagation of young disturbances in the eastern United States during the spring of the year under the influence of the conditionally unstable tropical maritime air masses which characterise the region. It also furnishes an excellent example of the superiority of air mass and frontal methods of weather prediction for aircraft operation over the older methods based upon pressure distribution.

IV. THE LOS ANGELES STORM OF DECEMBER 30, 1933 TO JANUARY 1, 1934.

This discussion points out some of the fundamental interactions occurring between air masses of the North Pacific Ocean in connection with Pacific Coast storms and the value of topographic and aerological considerations in predicting them. Estimates of rainfall intensity and duration from analyses of this type may be made and would prove very valuable in the Los Angeles area in connection with flood control problems.

I. FOEHN WINDS OF SOUTHERN CALIFORNIA.

by

Irving P. Krick.

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FOEHN WINDS OF SOUTHERN CALIFORNIA.

By

Irving P. Krick,

California Institute of Technology, Pasadena (Calif.).

(With 3 figures.)

Zusammenfassung: Föhnwinde treten in Südkalifornien häufig während des Winters auf, und zwar machen sie sich besonders im „Los Angeles Basin" bemerkbar, das sich vom Pazifischen Ozean im Westen zu den San Bernardino-Mountains im Osten erstreckt und im Norden durch die vielfach über 2000 m hohen San Gabriel Mountains von den kalifornischen Steppen (desert) getrennt ist. Die Föhnwinde werden durch Luftmassen gespeist, die durch den im Nordosten des Gebietes in nordsüdlicher Richtung in etwa 1300 m Höhe verlaufenden Cajon-Paß [Profil in Fig. 1[1]] aus der Steppe abfließen und in das Bassin gelangen. Diese Föhnwinde wurden seit jeher als Wüstenwinde angesprochen, da sie sehr warm und trocken sind. Sie entstehen, wenn das Luftdruckgefälle von den „Great Basin"-Gebieten in den Staaten Utah und Nevada (mittlere Höhe etwa 1500 m) gegen die höchstens einige hundert Meter über Meereshöhe gelegenen Tiefländer in Südkalifornien gerichtet ist. Die ursprünglich schon trockene und ziemlich stabile Luft gelangt dann auf ihrem Wege aus den ariden Gebieten von Utah und Nevada in immer geringere Meereshöhe. Hierbei entstehen sowohl durch adiabatische Erwärmung wie durch nächtliche Ausstrahlung Temperaturinversionen in Höhen von der Größenordnung 100 m über dem Boden. Die stabilen Luftmassen, und zwar nicht die kältere Bodenluft, sondern die darüberliegende warme Luft strömt nun an der tiefsten Stelle des Gebirgswalls durch den Cajon-Paß in das Los Angeles Basin ab, wobei sie bereits die ganze auf dem Wege erzeugte adiabatische Wärme mit sich führt. Schon vorher war sie so trocken, daß selbst beim Aufsteigen kein Niederschlag fällt. Bei außergewöhnlich steilen Gradienten überquert sie sogar die Gebirge und erzeugt dann in der genannten Ebene Sandstürme, bei denen gelegentlich Luftfeuchtigkeiten bis zu 3% gemessen wurden.

Die Untersuchungen, von denen hier zunächst nur ein kleines Teilergebnis veröffentlicht wird, zeigen, daß der hier behandelte Föhn so häufig auftritt, daß er als Winter-Monsun angesprochen werden kann. Er bewirkt die milden Winter in Südkalifornien, durch die sich dieses von den entsprechend gelegenen Tälern in Nordkalifornien unterscheidet.

One of the characteristic weather phenomena of southern California is a wind of the foehn type known locally as the Santa Ana. Unseasonably

[1]) Eine Karte des Gebietes befindet sich in dieser Zeitschrift, Bd. 35, S. 11, 1932. Der Cajon-Paß liegt etwa 30 km nördlich von Riverside.

high temperatures and very low humidities are associated with its occurence. The maximum effects of this wind are felt in the region south of Cajon Pass at the eastern extremity of the Los Angeles Basin. The latter area, extending eastward from the sea to the San Bernardino Mountains, is ordinarily protected from continental influences by the rather high San Gabriel Mountains to the north. Cajon Pass, trending roughly north and south between the San Gabriel Mountains to the west and the San Bernardino Mountains to the east, opens to the north upon the Mohave Desert and to the south upon the alluvial plain of the Los Angeles Basin.

These winds, originating in the desert regions to the north, blow out upon the Los Angeles Basin from the southern entrance to Cajon Pass. In previous descriptions the writers have used such titles as "The Santa Ana or Desert Winds"[1]) and "Desert Winds in Southern California"[2]). Such titles lead the reader to believe that the desiccating effect of these winds and their high temperatures are entirely due to the fact that they blow off the desert to the north. This idea has also become prevalent among the residents of southern California; descriptions having heretofore stressed the fact that the winds are of desert origin and only mentioning in a general way that the air in passing down from the Great Basin regions to the north is dynamically heated during its journey from these high level areas to the lowlands of southern California.

It is interesting to note that in other regions of the earth also where the Foehn has been observed it usually has been attributed first to the heat of some adjacent desert, as in the present case, and later recognized as a Foehn. Indeed, foehn winds as initially observed years ago in the Swiss Alps were first thought to be air currents originating in the Sahara Desert far to the south, but then the same phenomenon was observed on the west coast of Greenland, a region obviously too far removed from any desert areas to be effected by them. HANN in 1885 first gave a comprehensive explanation of the phenomenon in terms of the compressional heating of an air current as it rapidly descends the leeward slopes of a mountain. This explains the dryness of the wind, as well as the high temperature, since the dynamical heating in raising

[1]) ARCHIBALD CAMPBELL, The Santa Ana or Desert Winds, Monthly Weather Review, Vol. 34, p. 465. 1906.

[2]) D. YOUNG, Desert Winds in Southern California, Monthly Weather Review, Vol. 59, No. 11. Nov. 1931.

the temperature increases the capacity of the air for water vapor which it, however, does not receive. This remains today the generally accepted explanation. Even farther from the truth was the early explanation of the Zonda, a hot, dry wind of the Argentine Republic occurring at the eastern base of the Andes. This wind was attributed to volcanic activity in the lofty Andes to the west until shown to be a foehn type wind by DAVIS[1]). Thus it is not unnatural that many people in southern California still believe the Santa Ana to be merely a hot wind blowing off the desert to the north.

It is the object of this paper to show that these Santa Ana winds owe their properties to compressional heating rather than to the fact that they originate in desert areas, and are therefore truly foehn type winds. It is further to be pointed out that the foehn characteristics of this air current do not become apparent at the surface during its long journey from the high level regions of Utah and Nevada to the lowlands of southern California until with a final rush down Cajon Pass it reaches the Los Angeles Basin. It will be shown also that the temperatures prevailing in the desert during the occurrence of a Foehn are actually lower than those ordinarily recorded.

The U. S. Department of Commerce maintains throughout the country a network of weather reporting stations placed at intervals along the principal airways. The records from two of these stations located in southern California will be used in the present discussion, since these stations are admirably located for such a study. One station, Baldy Mesa, is located on the desert side of Cajon Pass about 2 miles north of the summit at an elevation of about 3700 feet and the other station, Fontana, is located on the western side of the southern entrance to the pass at an elevation of approximately 1700 feet. Fig. 1 represents a profile through Cajon Pass between these two stations. Hourly observations of temperatures, dew points, wind directions and velocities are available from these two stations. Of the many examples of Santa Ana winds noted while examining the records from these stations a typical one of recent date has been chosen for discussion here.

The Santa Ana winds occur almost exclusively during the fall and winter seasons when the barometric gradients are frequently directed across the San Gabriel Mountains causing a flow of air southward from the desert down into the Los Angeles Basin. The air has come

[1]) W. M. DAVIS, The Foehn in the Andes. The American Meteorological Journal. March 1887.

down from the high level areas of the Great Basin. It is a transitional type of air mass which has obtained its initial properties in the polar regions of the Pacific Ocean. It passes over the mountains of Washington and Oregon in the lee of a cyclonic disturbance and in so doing loses a part of its moisture before reaching the Great Basin region. If the barometric gradients are favorable, as is frequently the case, this air will then begin its journey southward over the arid regions of Utah, Nevada and eastern California. As it travels southward a very stable lapse rate ordinarily with marked temperature inversions near the surface will be established in this air mass both by active nocturnal

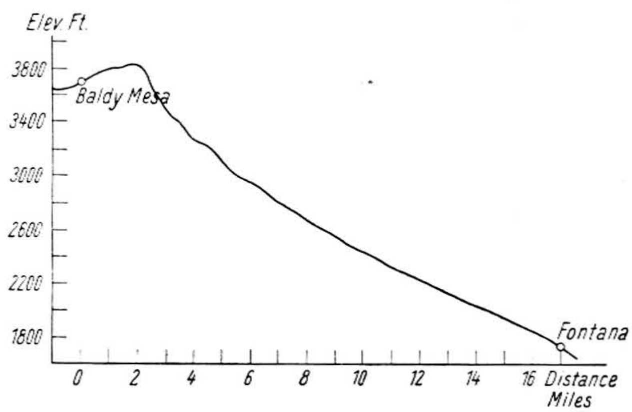

Fig. 1. Profile through Cajon Pass between Baldy Mesa and Fontana. 1 mile = 1.61 km., 1000 feet = 305 m.

radiation and by compressional heating as it passes progressively to lower levels. The stability of this air upon its arrival at the northern slopes of the San Gabriel Mountains accounts for the fact that its passage over the mountains under moderate pressure gradients is limited to the passes, notably Cajon Pass. Due to the crowding of the stream-lines as it flows through Cajon Pass high velocities are attained by the current.

It is worth noting at this point that under similar conditions in summer intense heating of the surface layers of this air as it passes over these arid regions north of the San Gabriel Mountains renders it unstable and it usually passes out over the San Gabriel Mountains without reaching the surface of the Los Angeles Basin below. It is further prevented from reaching the surface due to the fact that during the summer months the Los Angeles Basin is continually occupied by cool, moist, stable air which moves in from the Pacific Ocean a short distance to the west. The warm air aloft is thus obliged to merely slide out over the cooler air below, not being able to displace it at the surface.

In order to show that the Santa Ana is a foehn type wind and does not owe its characteristic properties to desert influences it will be shown that for the duration of the phenomenon the same air mass is present both at Baldy Mesa, the desert station, and at Fontana, the station to the south of the San Gabriel Mountains, and that the relative humidity at the former station is higher and the temperature lower than the relative humidity and temperature at the latter.

The Foehn which I have chosen for discussion here occurred during

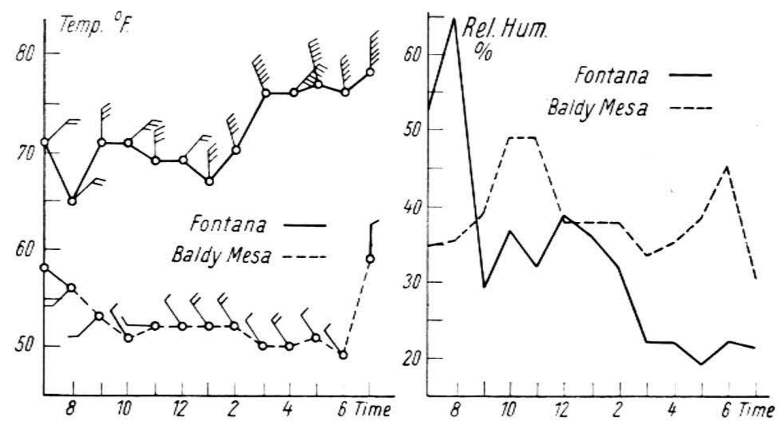

Fig. 2. Temperature, relative humidity and wind (see text) at Baldy Mesa and Fontana (profile in Fig. 1) during the night of October 10—11, 1932.

the night of October 10—11, 1932, and was initiated by conditions similar to those described above as necessary for its genesis. We shall examine here the records of the two stations, Baldy Mesa and Fontana, for that night using the observations from 7.00 PM., October 10th, to 7.00 AM., October 11th. Fig. 2 shows a plot of the temperatures and relative humidities recorded at the two stations for this period with the wind directions and velocities indicated for each hour during the period, each barb representing a wind velocity of 4 miles per hour.

In order to determine the identity of air masses present at the wo stations some conservative property of an air mass must be used tasa criterion. One of the most conservative properties of any air mass when no precipitation or evaporation is involved is the specific humidity. In computing the specific humidities of the air masses present at Baldy Mesa and at Fontana at the beginning of the period under consideration it is found that the specific humidity at Fontana is 9 g./kg. while that at Baldy Mesa is only 4 g./kg., a fact which indicates that the same air mass is not present at both stations at this time. A specific humidity of 9 g./kg. at Fontana indicates that the moist air from the adjacent Pacific Ocean usually occupying the Los Angeles Basin is still present at Fontana since this value of the specific humidity closely approximates the characteristic value for this air mass at this time of year. On the other hand the air at Baldy Mesa is the Transitional Polar Pacific air referred to above which has made its way southward from the Great Basin, because the specific humidity of this air mass is known to have a value of about 4 g./kg. at this season. At 9.00 PM. the specific humidity of the air at Fontana is 5 g./kg. which shows that the same air is now present at both stations, the moist air formerly occupying Fontana having moved out in response to the prevailing pressure gradient allowing the dryer Transitional Polar Pacific air air to replace it. The difference in the values of the specific humidities at Baldy Mesa and Fontana is due to the difference in elevation of the two stations. For the remainder of the period under discussion these values remain the same respectively for the two stations.

The temperature difference between the two stations during the first hour of the period is due to the difference in the air masses present. The dry Transitional Polar Pacific air present at Baldy Mesa being intrinsically a colder air mass at the surface than the moist air at Fontana and subject to wider diurnal variations in temperature by virtue of its dryness. At 8.00 PM. the difference in temperature between the two stations amounts to 9° F. while at 9.00 PM. after the moist air at Fontana has been replaced by the drier air this difference amounts to 18° F. The same air mass is now present at both stations, however, the air now at Fontana could not have come from the surface at Baldy Mesa. If the surface air at Baldy Mesa were to rush down Cajon Pass to Fontana losing no heat by radiation cooling and being heated by compression during the descent it could only gain an increase in temperature of 11° F. since the difference in elevation between the two stations is 2000 feet. Furthermore in this case there is opportunity for radiation cooling during the descent from Baldy Mesa to Fontana as indicated by the low wind velocities at Fontana at this time. It is seen from Fig. 2 that with similar wind velocities radiation cooling continues at Fontana between 9.00 PM. and 1.00 AM. We can therefore not infer that the increase in temperature between 8.00 PM. and 9.00 PM.

is due primarily to a foehn effect, since during the Foehn velocities of the current are high enough to prevent radiation cooling, thus bringing out the maximum effect of the compressional heating undergone during the descent. The temperature increase during this period is then due almost entirely to the change of air that takes place at Fontana during this interval and since we have shown that the new air could not possibly have come from the surface at Baldy Mesa we are obliged to look to the temperature inversions known to exist in this air mass at levels short distances above the surface as the source of this new warm air at Fontana. This warmer air aloft at Baldy Mesa slides out over the cool surface air below at elevations approximating the altitude of the summit of Cajon Pass and flows down the pass toward Fontana.

After 1.00 AM. the true Foehn begins, the wind velocities having been increased sufficiently to overcome radiation cooling as the air descends the Cajon Pass. Between 1.00 AM. and 3.00 AM. the wind velocities at Fontana increase from 12 miles per hour to 25 miles per hour with a temperature increase of 9° F. in the interval. During this time the temperatures at Baldy Mesa are continually decreasing by radiation cooling. From 3.00 AM. until sunrise the temperatures and wind velocities at Fontana remain practically constant the wind having a direction which parallels the longitudinal axis of Cajon Pass since, due to its stability, the current is restricted to the pass. Just before sunrise the temperature at Fontana is 76° F. while at Baldy Mesa it is 49° F., a difference of 27° F. Normally the temperature at both stations at this time of the morning during this season is around 53° F., as will be shown below. During the Foehn the relative humidity at Fontana dropped to 19% while at Baldy Mesa values as high as 45% were recorded. This is the more remarkable when one considers the difference in elevation between the two stations.

A significant result of the Foehn was that the day of its occurrence was the only day for a period of 42 days on which the Los Angeles Basin was entirely free from fog. During the Foehn the maritime air, in which the fog of the Los Angeles Basin forms, withdrew; the entire area being occupied by the warm dry air of the Foehn.

In order to further bring out the contrasting conditions at Baldy Mesa and Fontana during the Foehn let us look at records for a similar interval during an average day for this time of year. Fig. 3 shows a plot analagous to Fig. 2 with respect to the meteorological elements involved, compiled for the night of October 2—3, 1932. The wind velocities and directions have been omitted in this case as they are not significant. The specific humidities at Baldy Mesa and at Fontana for this period are 9 g./kg. and 10 g./kg. respectively indicating the presence at both stations of the moist air which we noted to be present the evening of October 10th at Fontana before being replaced by the drier air from the region to the north. The discrepancy between the two values is again due to the difference in altitude between the two stations. We see that during the night the temperatures at the two stations remain practically the same, indeed, within the limit of error

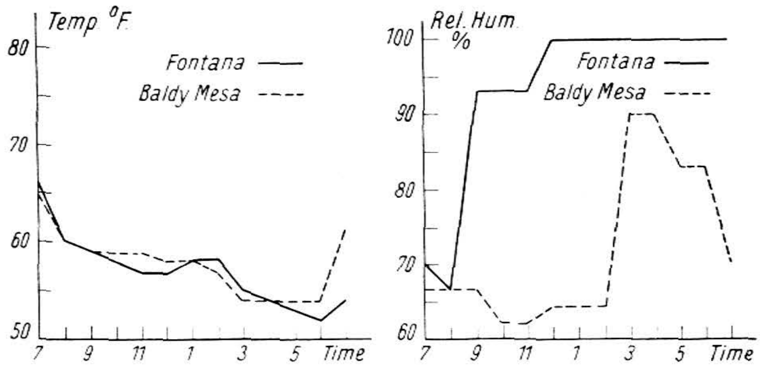

Fig. 3. Temperature and relative humidity at Baldy Mesa and Fontana (profile in fig. 1) during the night of October 2—3, 1932.

of the observations except in the case of the final reading at 7.00 AM. In this case the difference is due to the fact that at Fontana there is fog while at Baldy Mesa it is clear. The trend of the relative humidity curves would have been similar had not the relative humidity at Fontana reached 100% by midnight and remained at that value for the remainder of the period. It will be noted that in this case the relative humidities at Baldy Mesa are lower than those at Fontana while in the case of the Foehn they were higher. It will be seen in comparing Figs. 2 and 3 that temperatures at Baldy Mesa are consistently lower during the Foehn than under ordinary conditions, due to the dryness of the air mass present at the station in the former case.

When excessive pressure gradients exist over the San Gabriel Mountains the current may come directly over the mountains. In this case great clouds of dust are raised as the current strikes the surface of the Los Angeles Basin a few miles south of the mountains, and the air reaching the surface is from even higher levels than in the ordinary cases; relative humidities as low as 3 and 4 percent have been recorded. These extreme cases are, however, rather rare.

Foehn winds occur very often during fall and winter in southern California and influence the climate considerably. The mild winter of southern California is usually attributed to the proximity of the Pacific Ocean only, but during the foehn winds the temperatures are raised far above those prevalent when air from the Pacific is present, especially in the late fall and early winter before the Great Basin region becomes extremely cold. A glance at Figs. 2 and 3 shows this very clearly. These winds really represent a winter monsoon in southern California and will be treated in more detail in a later paper. They do not occur in northern California nearly as frequently due to the great barrier set up by the Sierra Nevada Mountains.

Hot dry winds occuring about 100 miles north of the Los Angeles area in the vicinity of Santa Barbara probably have the same origin since any air which reaches the California coast after passing down from the Great Basin area must be dynamically heated. In other regions true desert winds may occur occasionally, but probably at no point along the coast.

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II. FOEHN WIND CYCLO-GENESIS.

by

Irving P. Krick.

II. FOEHN WIND CYCLO-GENESIS.

By Irving P. Krick.

Zusammenfassung: Im Herbst und Winter bilden sich häufig in den Kanadischen Provinzen Saskatchewan und Alberta, östlich der Kanadischen Rocky-Mountains, primäre Tiefdruckgebiete aus, sobald die in weiterer Ausdehnung vom Osthang der Gebirge in die Ebene hinabströmenden Föhnwinde dort auf die kalte kontinentale Polarluft treffen, die sich während der genannten Jahreszeiten dort gewöhnlich befindet. Die erwähnten Föhnwinde entströmen den kräftigen Hochdruckgebieten, die sich über den Hochebenen des Great Basin (Fig. 1) und des Columbia Plateaus bilden. Diese werden im Westen von der Sierra Nevada und den Cascade Mountains, im Osten von den Rocky Mountains begrenzt. Der Luftkörper, welcher die Föhnwinde bildet, entstammt ursprünglich dem nördlichsten Teil des Pazifischen Ozeans. Bei seiner Wanderung über die hohen Gebirge gibt er seine Feuchtigkeit ab und gelangt als trockene, warme Luft in die Ebene, wo er auf die trockene, sehr kalte kontinentale Polarluft trifft. Er bildet dann den warmen Sektor der Tiefdruckgebiete, die sich an der Granze zwischen den beiden Luftkörpern ausbilden end durch die grossen Temperaturgegensätze sehr kräftig werden können. Trotzdem sind die Niederschläge in ihrem Bereiche infolge der grossen Trockenheit der beiden Luftkörper gewöhnlich unbedeutend. Solange das Hochdruckgebiet über den Hochebenen die Föhnwinde östlich der Rocky Mountains unterhält, bilden sich immer wieder Tiefdruckgebiete der erwähnten Art aus und wandern südöstlich längs der Grenze zwischen der warmen Föhnluft and dem ausserordentlich kalten Luftkörper nördlich and östlich davon. Die mehrfache Wiederholung des ganzen Vorganges wird dadurch begünstigt, dass

im Rücken jedes Tiefdruckgebietes ein kräftiger Strom kalter kontinentaler Polarluft einsetzt, der wieder auf den warmen Föhnluftstrom trifft. Als Beispiel wird die Entwicklung einer Serie von drei Tiefdruckgebieten dieser Art zwischen dem 9. und 15. November 1933 gegeben.

According to modern theories regions of cyclo-genesis arise where convergent flow occurs between air masses of different characteristics, provided significant temperature differences exist. Such a flow tends to form a discontinuity surface or front between the masses and to produce large amounts of potential energy of mass distribution along the frontal zone. If the conditions for stable equilibrium are not rigidly maintained along the front, the colder mass may move forward into the warmer current or vice versa. In any case there occurs a compensating flow in the adjacent mass, the whole process giving rise to the genesis of a cyclonic disturbance in the form of an unstable wave on the discontinuity surface between the masses. The kinetic energy of the resulting cyclone is provided to a large measure by the initial potential energy of mass distribution; although, of course, the kinetic energy of the initial flow and the heat of condensation liberated in the event that the warm mass is particularly moist furnish minor portions. A detailed discussion of the formation, maintenance, occlusion and final death of the cyclone is beyond the scope of the present paper. I merely wish to emphasize at this point the importance of convergent flow in contrasting air masses for furnishing large amounts of potential energy in connection with the genesis and subsequent maintenance of the extra-tropical cyclone.

In the descending motion associated with foehn phenomena relatively high temperatures are frequently attained by the air mass involved. Often the dynamical heating of a column of air in this manner is capable of creating extreme temperature differences between the foehn current and adjacent masses. If the foehn reaches large proportions, that is effects sufficient mass transport, enough potential energy of mass distribution, arising from the contrast between this air and adjacent masses, may become available to initiate the formation and maintenance of a cyclone of major importance. Secondary cyclones of foehn origin are not uncommon and have been treated in some detail in the past. Schneider[1)] has discussed a particularly interesting type occurring off the west coast of Greenland during the southeast foehns of that region. We are concerned here not with the formation of secondary cyclones but with the foehn genesis of primary cyclones, a situation requiring rather unique meteorological and topographic conditions.

During the late fall and early winter rather intense anticyclones frequently build up over the high level regions of the Great Basin and Columbia Plateau in the northwestern United States (Fig. 1). They are usually the result of an influx of Polar Pacific (Pp) air to the lee of an occlusion occurring off the Washington and Oregon coasts. The outflow from such an anticyclone causes a steepening of the pressure gradients over the Rocky Mountains to the east and the Sierra Nevada Mountains to the west, due to the damming effect of these great natural barriers upon the stable air masses always associated with such anticyclones. If the HIGH is maintained with undiminished intensity, there will occur eventually

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1) Schnieder, Leonard R., Greenland West-coast Foehns. M.W.R. April 1930.


ALBERTA
SASKA-
TCHEWAN
COLUMBIA
PLATEAU
GREAT
BASIN
SIERRA NEVADA MTNS.
ROCKY MTNS.
BLACK
HILLS
APPALACHIAN MTNS.
BERRY'S RELIEF MAP OF
UNITED STATES
A base for charting geography
and history facts
SCALE

Fig. 1.

an outflow from the region, causing foehn phenomena east and north of the Rockies and west and south of the Sierras. In southern California these winds occur with only moderate pressure gradients over the mountains to the north and/east due to the low level passes in the region which offer and easy entrance to the air from the Great Basin. They are so persistent in late fall and early winter as to be classified as a winter monsoon bringing unseasonably high temperatures and low humidities to the area, and thus providing the mild winter climate of the district[1]. This foehn, however, is not flowing into a region which is normally exceedingly cold and therefore great contrasts in temperature between this air and the masses to the south and west do not readily arise. Occasionally a cold front lies just off the California coast under such circumstances and the outflow of foehn air from southern California forms a weak secondary cyclone along this front, usually giving rise to little precipitation due to the dryness of the air forming the warm sector of the disturbance.

More important for the present discussion is the extensive foehn resulting from an outflow from the Columbia Plateau anticyclone into the comparatively low level provinces of Alberta and Saskatchewan east of the Canadian Rockies. These regions are normally occupied at this season by very cold Polar Continental (Pc) air masses and during the marked foehn which occurs when the pressure gradients over the Rockies are strong, large temperature differences arise between the foehn current and the air to the east and northeast. Temperature differences in a few hundred miles not

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1) Krick, Irving P., Foehn Winds of Southern California. Gerl. Beitr. Geophys. 39 (1933) 399--407.

infrequently exceed 60° F. under such conditions. This is not purely a surface phenomenon since in the foehn an entire column of air has undergone compressional heating, thus producing in the region between this air and the Pc air to the northeast a tremendous density of solenoids, which indicates, of course, vast amounts of available potential energy of mass distribution. The movement of the foehn air into regions formerly occupied by Pc masses constitutes a breakdown of any stability which might have existed at the initial formation of the discontinuity between the air masses, and a cyclone is quickly generated along the great warm front which first appears on the synoptic chart as the boundary between the foehn air and the very cold Pc air to the northeast. There is, of course, active overrunning of the Pc current by the foehn xxxx air as indicated by three hourly pressure decreases in advance of the front which often exceed 0.2 inch. The foehn current which now constitutes the warm sector of the disturbance has a southward component and the whole disturbance moves off to the southeast along the discontinuity rather than to the east or northeast as is usually the case with the high-level cyclones of this region.

The foehn air of these disturbances is usually a Transitional Polar Pacific mass (Npp). It is initially quite dry regardless of its maritime origin, since air moving into the Great Basin or Columbia Plateau from the Pacific Ocean must lose a good deal of its moisture in crossing the mountains to the west or even in accomplishing the 4000 to 6000 ft. ascent to this region. The descent of this air east of the Rockies further reduces the relative humidities and usually the specific humidities will be lower than those at the surface in the Great Basin due to the fact that the air forming the foehn usually originates at levels approximating the altitudes of the summits of the passes or crests over which it pours into the lower areas to the east. This sliding out of the air at high levels is assisted by the intensification of low level temperature inversions by subsidence and radiation effects and is entirely analogous to the situation in the foehns of the Los Angeles Basin described in a previous paper[1].

It is interesting to note that as long as the Columbia Plateau anticyclone is maintained with undiminished intensity a continual series of such cyclones will be generated. This is readily understood when one considers the fact that these disturbances move off to the southeast along the Pc--Npp front in accordance with the general direction of the current in the warm sector, and cause to their north a fresh movement of Pc air into the region southwest of Hudson Bay. The convergence of this southward moving cold mass with the warm foehn air descending the eastern slopes of the Canadian Rockies will result in the genesis of a new cyclone with an intensity proportional to the temperature differences arising between the air masses.

Disturbances of this nature may become very intense due to the sharp contrasts in temperature which have been occasioned. Practically the entire kinetic energy of such a disturbance is provided by the initial potential energy of the system and the kinetic energy provided by the initial flow in the warm and cold currents since the air forming the warm sector is extremely dry and no appreciable condensation takes place within the disturbance until after the air has crossed the Great Lakes and picked up small amounts of moisture. Even then the heat of condensation released is negligible

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1) Krick, op. cit. in fn. 1) p. 4.

This type of cyclone has its maximum intensity at the ground and in the lower levels since the greatest temperature contrasts arise here. For this reason, strong surface winds occur within the cyclone which may blow dust or snow rendering the passage of the disturbance rather disagreeable, regardless of the lack of precipitation associated with it. These disturbances propagate quite rapidly whereas the normal cyclone passing eastward along the International Boundary is a slow moving affair being usually no more than an occluded front which has passed over the mountains east of the Gulf of Alaska. In such a case no large temperature contrasts are to be noted at the surface and the maximum activity of the disturbance remains at high levels unless a source of warm air is encountered and regeneration takes place.

A typical situation of this kind occurred during the period November 9 to November 15, 1933. Three such cyclones were generated during this period due to a continual foehn maintained east of the Canadian Rockies by a well developed anticyclone centered over the Great Basin and Columbia Plateau. At the beginning of the period the anticyclone was not the usual eastward extension of the Pacific anticyclone, but a westward extension of a large anticyclone consisting of Pc air which had moved southward from its source region and subsided over the central United States. At least at low levels the air in the Great Basin anticyclone was Transitional Polar Continental (Npc) with characteristically low specific humidities; about 2 g./kg. in this case. Subsequently Transitional Polar Pacific air (Nppc) played a role of increasing importance, forming the major portion of the foehn air. However, for the present discussion this is of little importance since both of these air masses are characterized by low specific humidities and a stable stratification whenever they appear at this season in the regions under discussion.

For the sake of clarifying the discussion, daily synoptic charts for the period under consideration have been included. The charts are constructed from synchronous data compiled at 5;00 AM Pacific Standard Time. Each full barb on the wind arrows represents approximately one unit on the Beaufort scale. The pressure field is indicated by isobars drawn for each tenth of an inch. The principal fronts have been represented as follows: cold fronts by heavy solid lines, warm fronts by double lines, cold front type occlusions by broken lines and warm front type occlusions by dotted lines. The symbols adjacent to the fronts indicate the recent life history of the air masses involved. In this connection the local classification of American air masses developed at the Massachusetts Institute of Technology has been closely followed. The elementary symbol represents the type and source region of the mass, for example, Pc (Polar Continental of Polar Canadian). To denote transitional types the letter "N" precedes the elementary symbol. Occasionally this latter portion is followed by a "c" or an "m" to indicate that the modification of the air mass has been due to continental or maritime influences respectively. For a complete classification and description of the American air masses the reader is referred to a Paper on the subject by H. C. Willett[1)].

On the synoptic chart of November 9, (Fig. 2), we observe an anticyclone centered over the Columbia Plateau and the plains of South Dakota east of the Rockies. The portion of this anticyclone west of the Rockies is what remains of the previous outbreak of Pc air mentioned above. The eastern portion of this anticyclone is the result of a southward flow of fresh Pc air to the rear of the cyclone

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1). Willett, H. C., American Air Mass Properties. M. I. T. Met. Pub. Vol. II, No. 2.

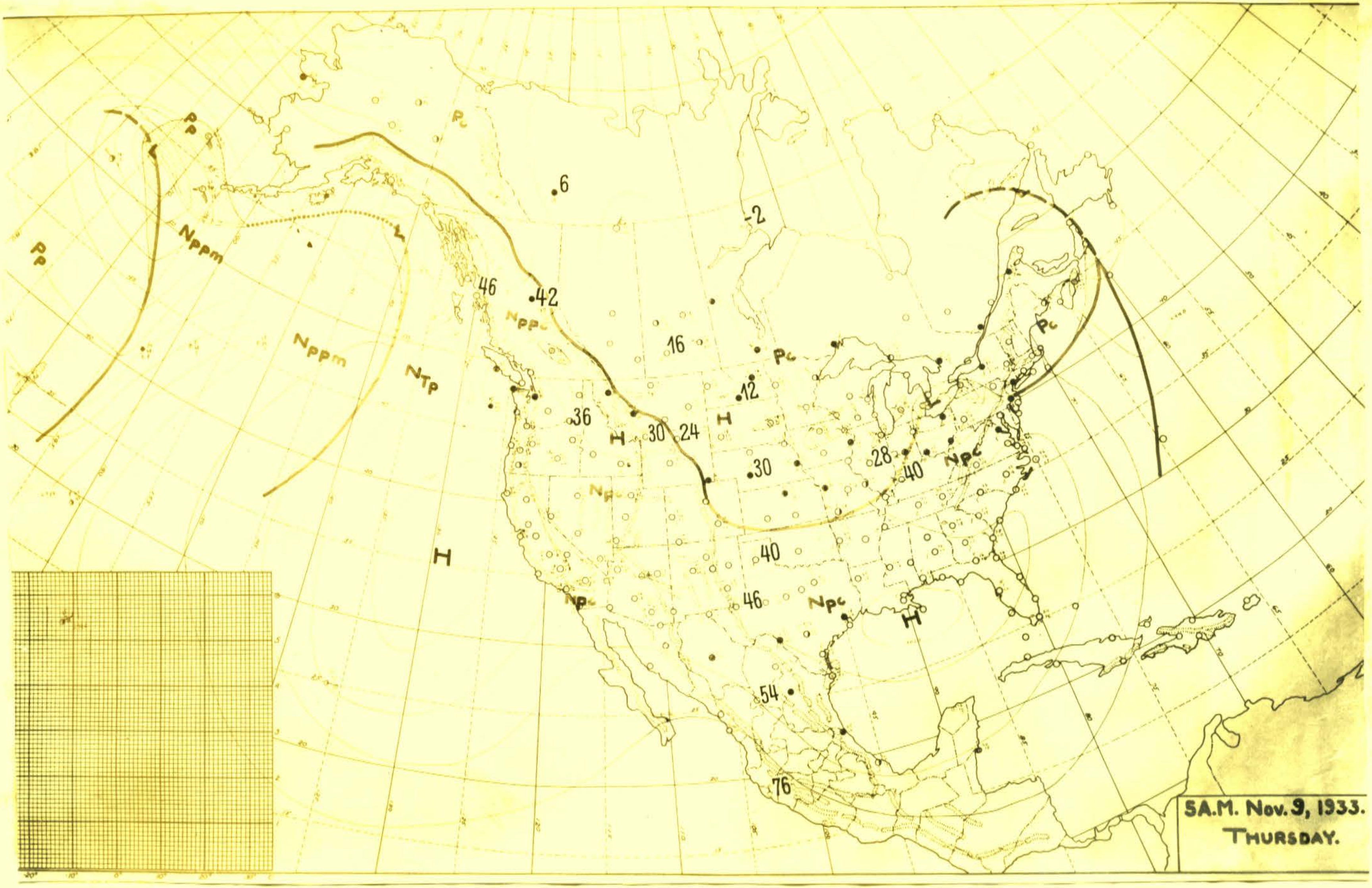

Fig. 2.

centered over the Great Lakes and will simply move south and east as the migratory anticyclone associated with it. This difference between the air masses in the anticyclone is indicated by the cold front paralleling the eastern slopes of the Rockies and the symbols adjacent to it denoting the air masses involved. A cyclone centered in the Gulf of Alaska is occluding along the coast of British Columbia. The progress of the warm front is blocked by the lofty mountain ranges paralleling the coast thus facilitating the occlusion by the cold front to the west. At this time of the year the occlusions in this region are usually of a warm front type, the abnormally high ocean temperatures in these latitudes causing the air behind the cold front to be warmer than the air lying along the coast of British Columbia east of the warm front. Normally the eastward progress of even the portion of the warm front surface lying above the crest of the mountains ceases during occlusion and only the upper front of the occlusion finally passes over the mountains and proceeds eastward as a rather weak high level disturbance. However, in the first foehn cyclone of our series the anticyclone to the south assists the upper front of the above mentioned occlusion over the Canadian Rockies, giving rise at the same time to foehn phenomena east of the mountains which in turn produce considerable amounts of available potential energy of mass distribution between this air and the cold Pc air to the northeast. This activity results in the regeneration of the dying cyclone and transports the level of maximum activity from high levels to the surface. This cannot be considered as the genesis of a primary cyclone since an upper front would probably have passed over the region anyway; however, subsequent disturbances appear to owe their origin entirely to the convergence of the foehn air with that to the northeast.

On the November 10 map (Fig. 3) we note that only an occluded

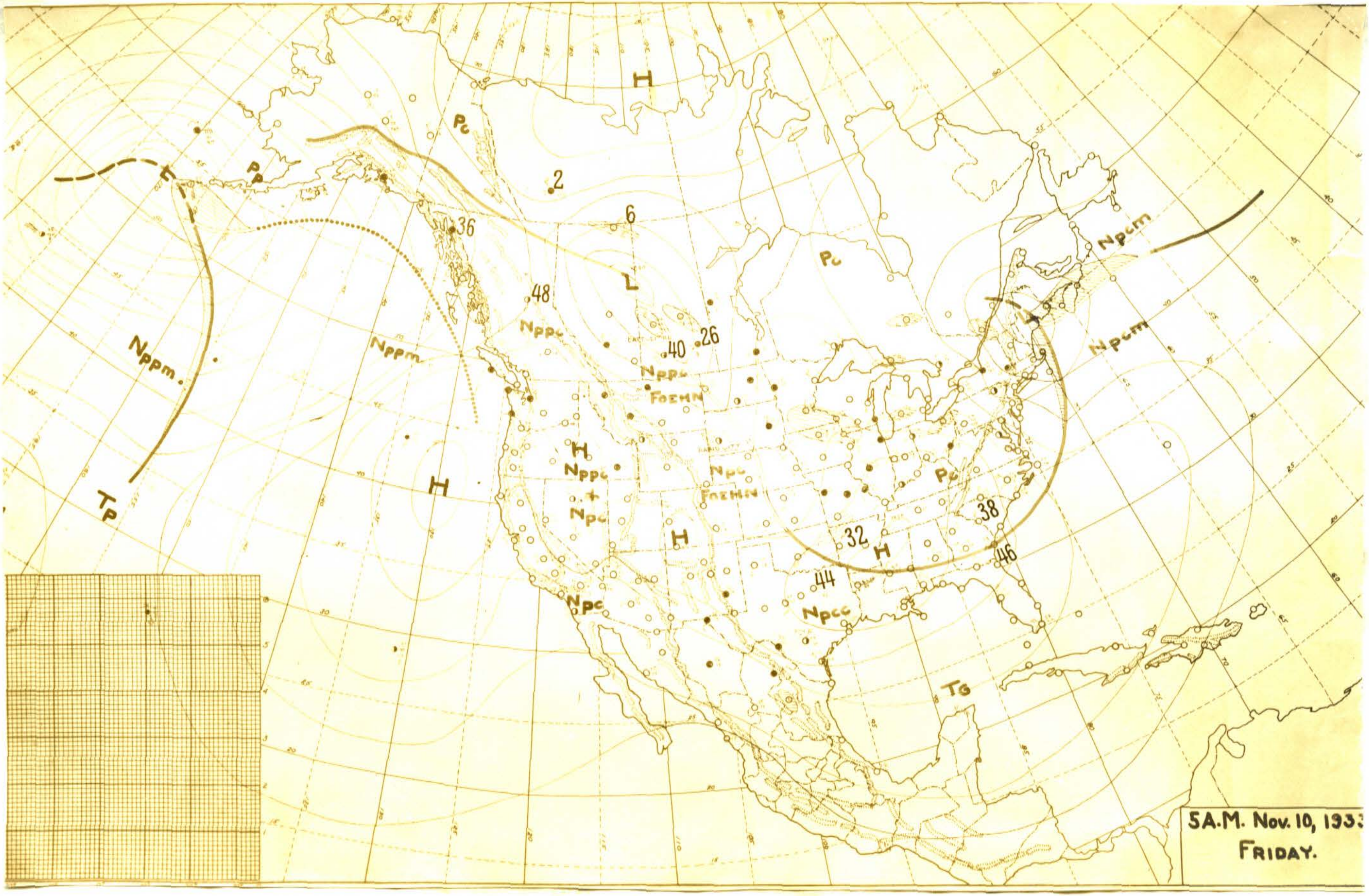
5 A.M. Nov. 10, 1933
FRIDAY.
H
Pc
Pp
2
6
36
48
L
40
26
Nppm
Nppc
Npcm
H
Nppc
+
Npc
Npc
Npc
H
Pc
38
32
H
46
44
Npcc
Npc
Tp
Tg

Fig. 3.

front off the coast of British Columbia marks the cyclone which was centered over the Gulf of Alaska the previous day. Foehn phenomena are observed east of the Rockies as far south as Colorado as indicated by the warm front extending southward into this area. The upper front of the disturbance has been omitted since the maximum intensity is now at lower levels. The foehn in this case is perhaps not as pronounced as subsequently, but it is nevertheless quite apparent when one compares the temperatures of the foehn area with those of the preceding map. For example, at Battleford, Saskatchewan, the temperature increase during the period is 36°F., while farther south at Rapid City, South Dakota, just east of the Black Hills, the increase has been 28° F. The foehn air in Canada has been indicated on the chart as Transitional Polar Pacific (Nppc) and the subsequent increasing pressures in the Columbia Plateau anticyclone are no doubt due to an inflow of this type of air over the region resulting in the usual eastward extension of the Pacific anticyclone.

On November 11, (Fig. 4), we note a steepening of the pressure gradients over the Rockies, a condition favoring an intensification of the foehn. The cyclone of the previous day is now centered just west of the Great Lakes region and is feeding cold Pc air into the region southwest of Hudson Bay. The temperature at the Pas, Manitoba, for example, has dropped 10°F. since the previous map. The convergence of this cold current with the warm foehn air about to descend the eastern slopes of the Rockies will favor the genesis of a new cyclone having an intensity proportional to the temperature difference between these two air masses. This tendency is already apparent in the distribution of the isobars east of the Rockies. The cyclone off the Aleutian Islands in the North Pacific in this case is too far removed to effect the formation of this cyclone,

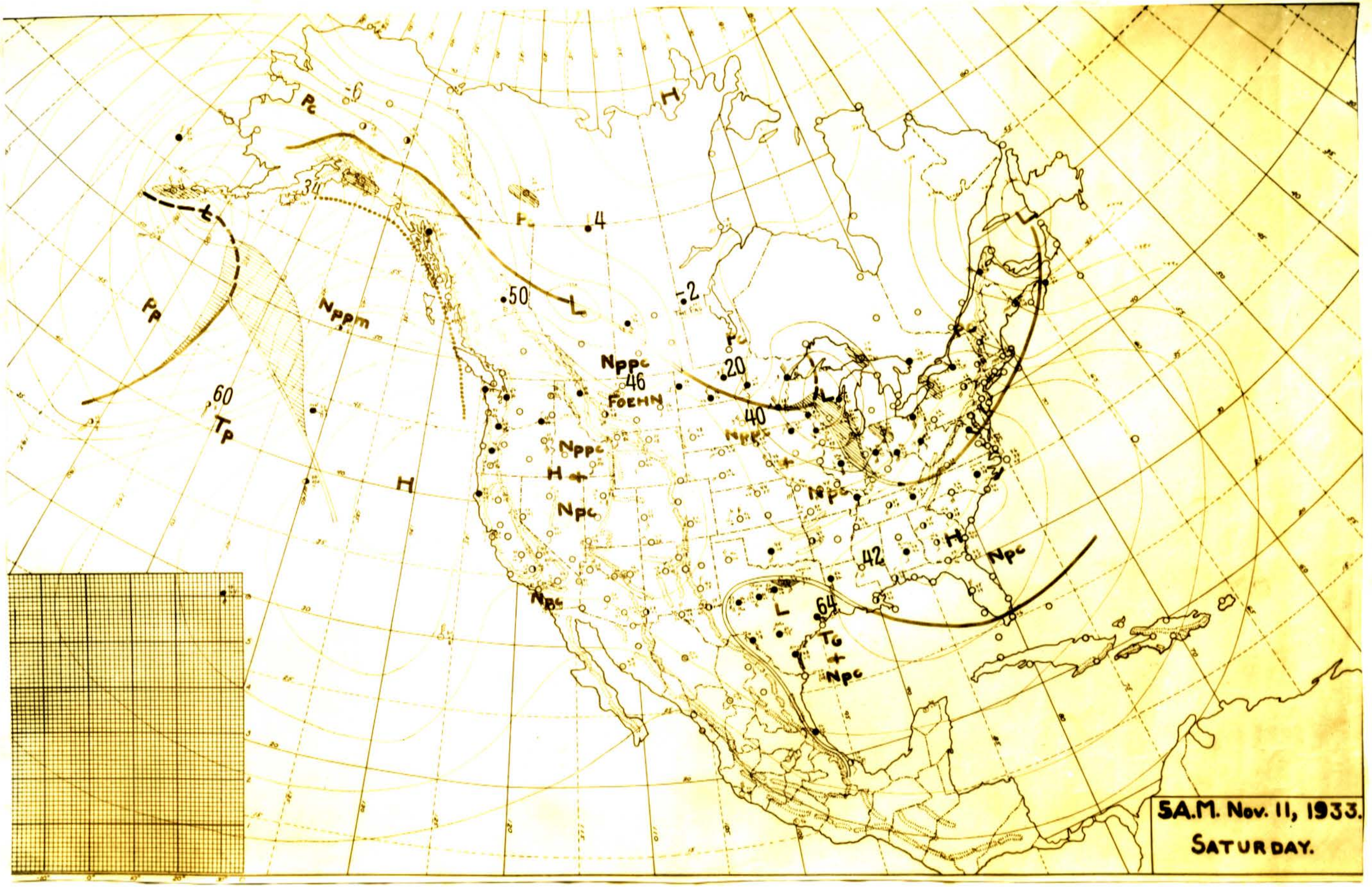
5A.M. Nov. 11, 1933.
SATURDAY.
Pc
-6
H
34
4
Pp
Nppm
50
L
-2
Nppc
46
FOEHN
20
40
60
Tp
H
Nppc
H
Npc
Npc
Npc
42
H
Npc
L
64
TG
Npc

Fig. 4.

therefore we must regard this case as the genesis of a primary rather than of a secondary disturbance. The formation of subsequent cyclones in the region results from an entirely analogous process since no fronts from the Gulf of Alaska are observed to cross the mountains before November 16, by which time the Columbia Plateau anticyclone has subsided and moved eastward.

The synoptic chart of November 12, (Fig. 5), shows the intense disturbance which has developed from the contrast between the foehn which forms its warm sector and the surrounding Pc air. It is interesting to note the almost complete lack of precipitation accompanying the phenomenon due to the low moisture content of the air masses involved. The absence of precipitation is certainly not due to a lack of active overrunning on the part of the warm air since very sharp temperature contrasts and marked convergence in the flow may be noted along the warm front, as well as marked pressure drops during the three hours prior to the observations at all stations in advance of this front. Duluth, Minnesota, for example, records a pressure drop of 0.24 inch. The only precipitation occurring in advance of the warm front is north of Lake Superior and Lake Michigan, the air moving up rapidly from the south having picked up sufficient moisture in crossing the lakes to produce a miniature warm front precipitation in overrunning the colder air to the north.

The great contrasts in temperature between the foehn air of the warm sector and the surrounding cold mass amounting in most cases to about 20°F., are apparent at a glance. The high wind velocities associated with the passage of this cyclone caused violent dust storms all through the middle western states, tying up air transport operations as far south as Kansas City, Mo. The situation favors the genesis of another such cyclone since the pressure continues

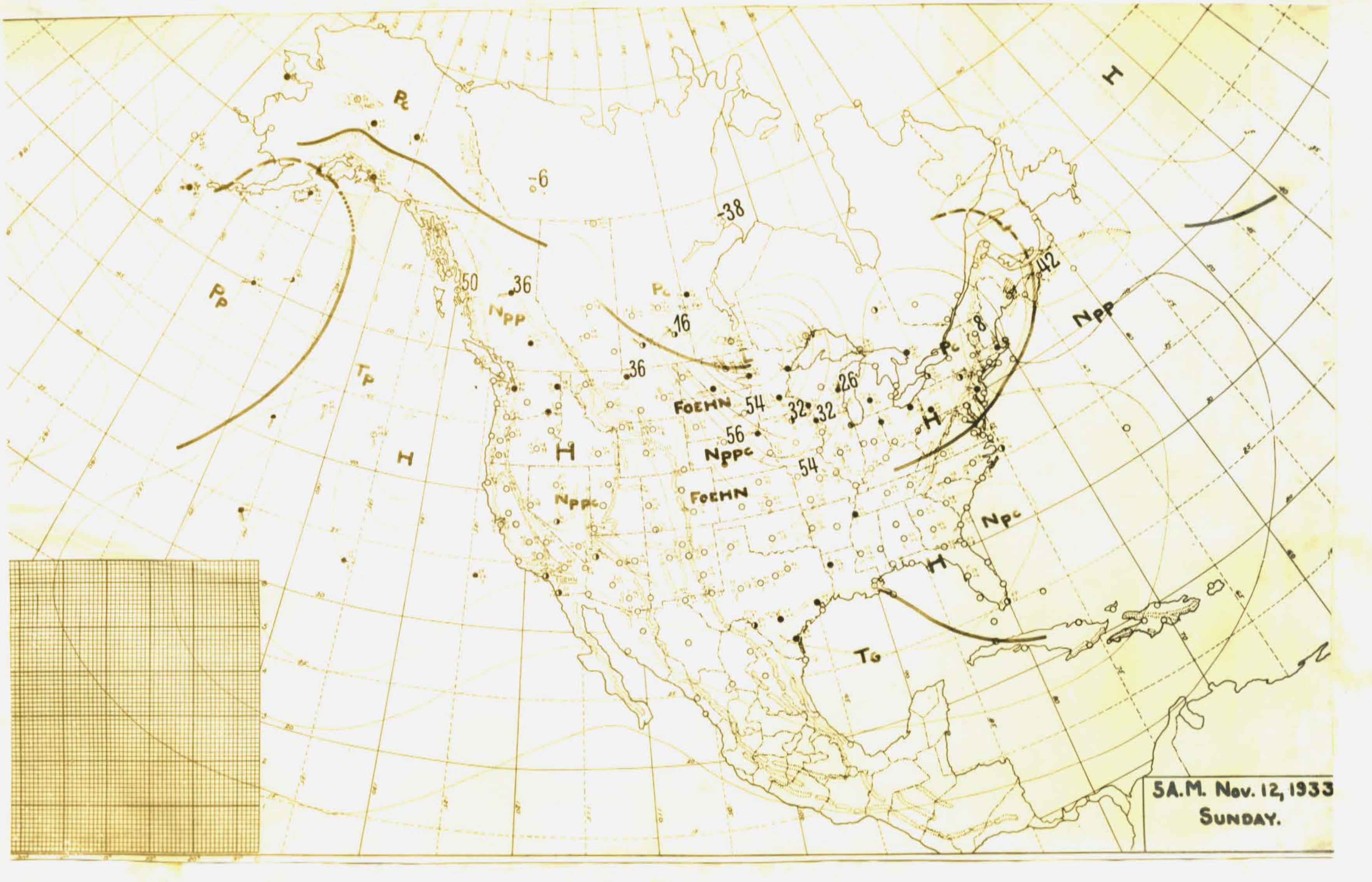
Pc
-6
-38
Pp
50
36
Npp
Pc
16
36
Tp
H
H
Foehn
54
32
32
26
56
Nppc
54
Nppc
Foehn
8
Pc
42
Npp
H
H
Npc
H
Tg
5 A.M. Nov. 12, 1933
Sunday.

Fig. 5.

to build up in the Columbia Plateau anticyclone and very cold Pc air is again being brought into the area east of the Canadian Rockies in the lee of the present disturbance as indicated by the very large three hourly pressure increases behind the cold front. An increase of 0.40 inch may be noted at the Pas.

The synoptic chart for November 13, (Fig. 6), shows the initial stage in the development of the final cyclone of this series. The intensity of the foehn and the tremendous horizontal temperature gradients produced between this air and the Pc to the northeast may perhaps be better appreciated by a comparison with temperatures elsewhere on the map. At Calgary, Alberta, in the foehn air just east of the mountains we note a temperature of 56°F.; the temperature at Tampa, Florida, on that morning. The comparison is even more significant when one considers the fact that at Tampa the sun has been shining for several hours while at Calgary the sun is still below the horizon. Thus we have contrasts between the foehn and the Pc air to the northeast of the order of those which would arise if the Pc air were transported southward adiabatically and in the absence of subsidence affects to the Gulf of Mexico. In such a case we should certainly anticipate the development of a violent disturbance.

We note the intensification of the foehn of southern California on this day due to the steepening of the pressure gradients over the mountains to the north. This results in foehn phenomena at various points along the coast as far north as San Francisco. Ordinarily only southern California benefits by the mild foehn weather in such a situation, since the lofty Sierras prevent the air from reaching the surface farther north when only moderate pressure gradients exist.

The chart of November 14, (Fig. 7), indicates that sub-

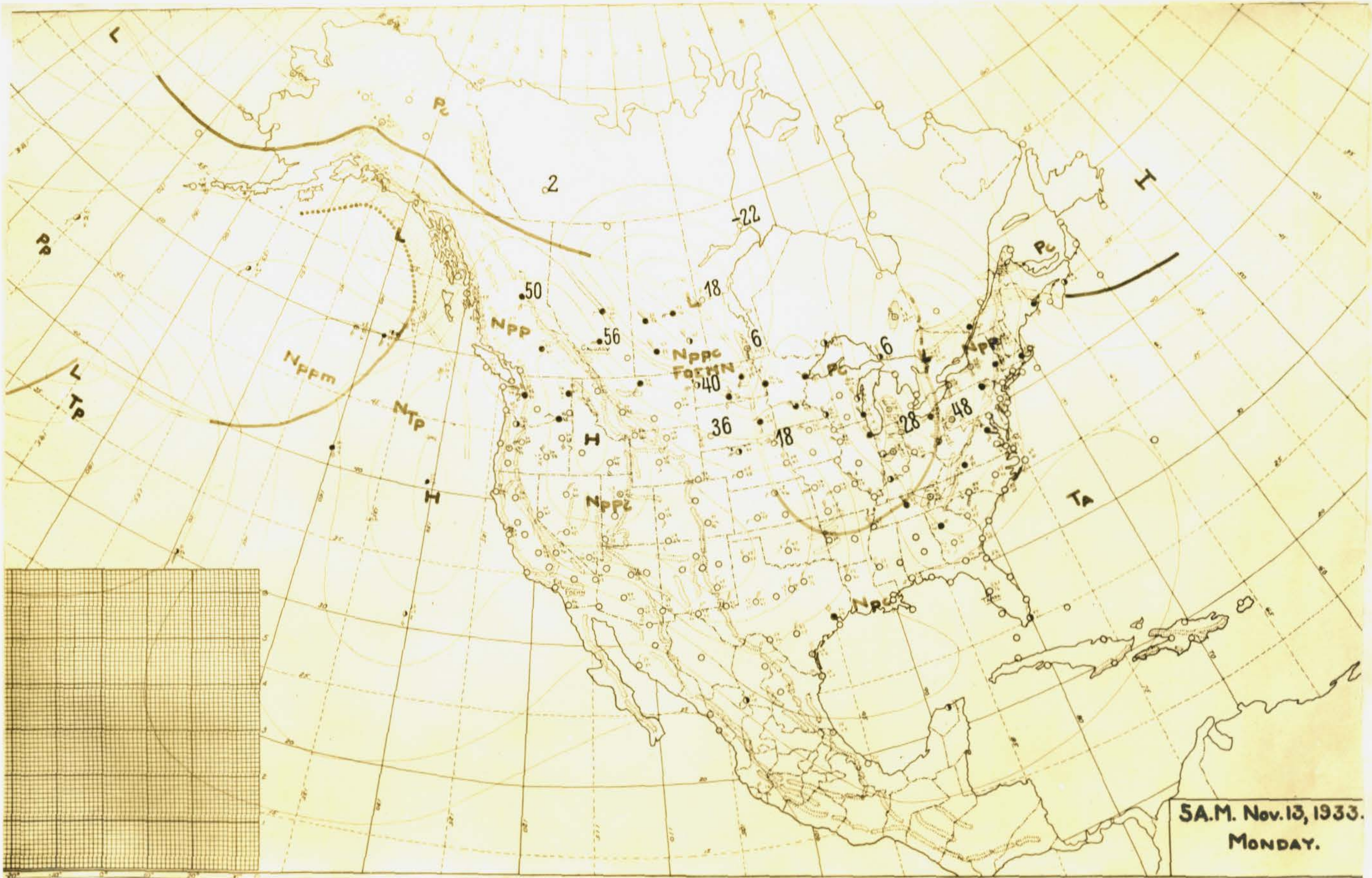

Fig. 6.

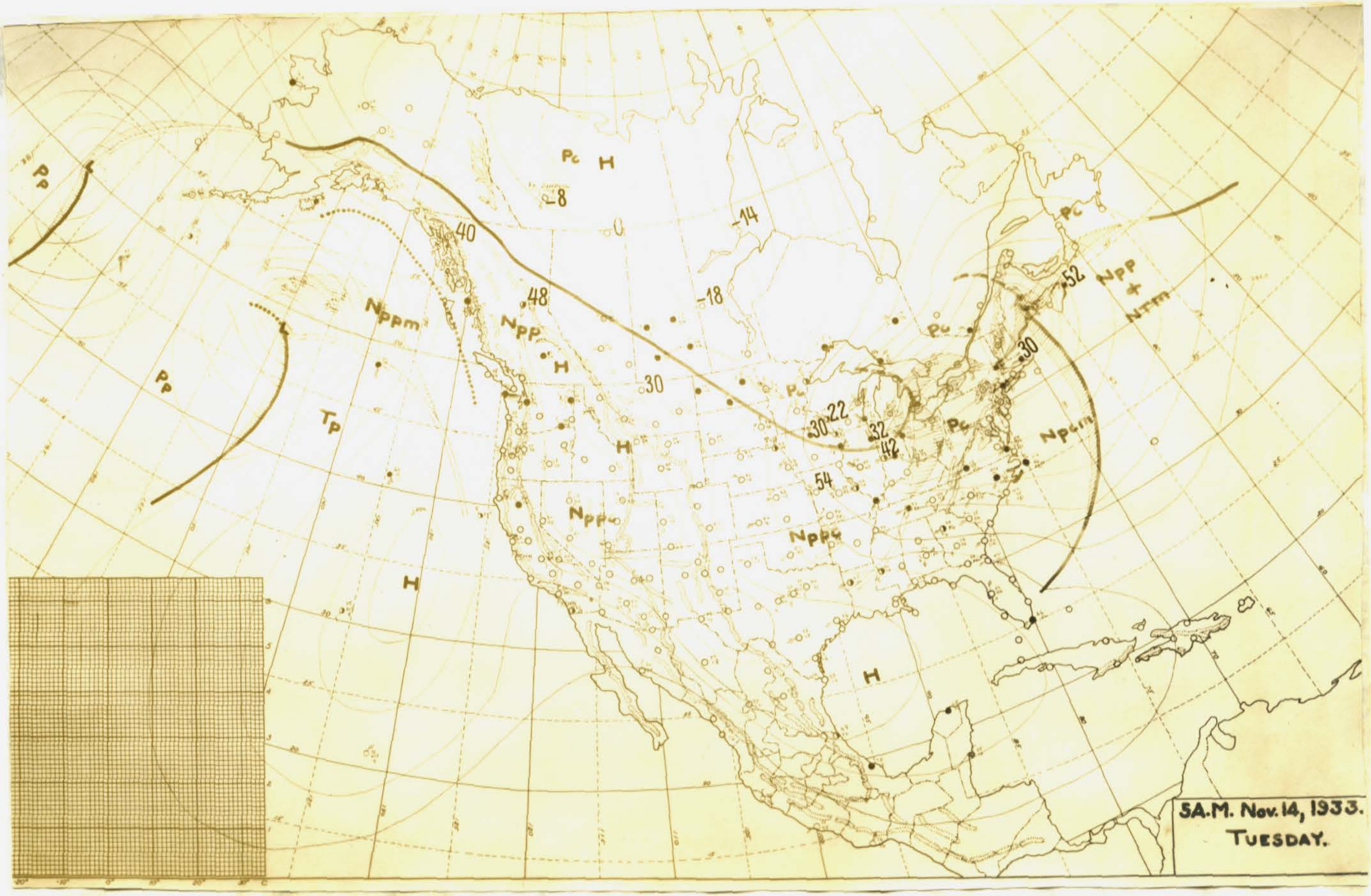
Pp
Pc
H
-8
-14
-18
40
48
Nppm
Npp
H
30
Pp
Tp
H
Npp
Nppq
H
Pc
22
30
32
42
54
Pc
Pc
Pc
52
Npp
+
Ntm
30
Npcm
H
H
5A.M. Nov. 14, 1933.
TUESDAY.

Fig. 7.

sidence has begun in the Columbia Plateau anticyclone. Another anticyclone has put in an appearance to the north apparently due to a fresh movement southward of Pc air, the temperature at Ft. Simpson, British Northwest Territory, having dropped 10° F. during the past 24 hours. The presence of this anticyclone together with the subsidence of the Columbia Plateau anticyclone will put an end to the foehns east of the Rockies by destroying the pressure gradients necessary for their genesis. We note that the cyclone of the day before has deepened and moved southward in accordance with the southward component in the foehn air of the warm sector. This unusual wind direction in the warm portion of the cyclone accounts for the peculiar position of the warm front in the disturbance. This is rather significant in this case since we note that the front parallels the Appalachians to the east. Usually the warm fronts of cyclones in this region lie normal to these ranges and encounter no particular difficulty in negotiating them, but in our present case the progressof the portion of the front lying below the crest of the mountains will be stopped, causing an occlusion of the cold front type to take place along the western slopes. This prevents the increasing temperatures along the central and south Atlantic coast which occur at a warm front passage. This may be noted by a comparison with the previous cases where the warm fronts are roughly normal to the Applachians.

The chart of November 15, (Fig. 8), indicates an increase in the intensity of the anticyclone moving south over Canada and a further subsidence in the Columbia Plateau anticyclone together with a slow eastward movement. This situation excludes the possibility of further genesis of foehn cyclones in the region for the present. The warm sector of the cyclone in the east has

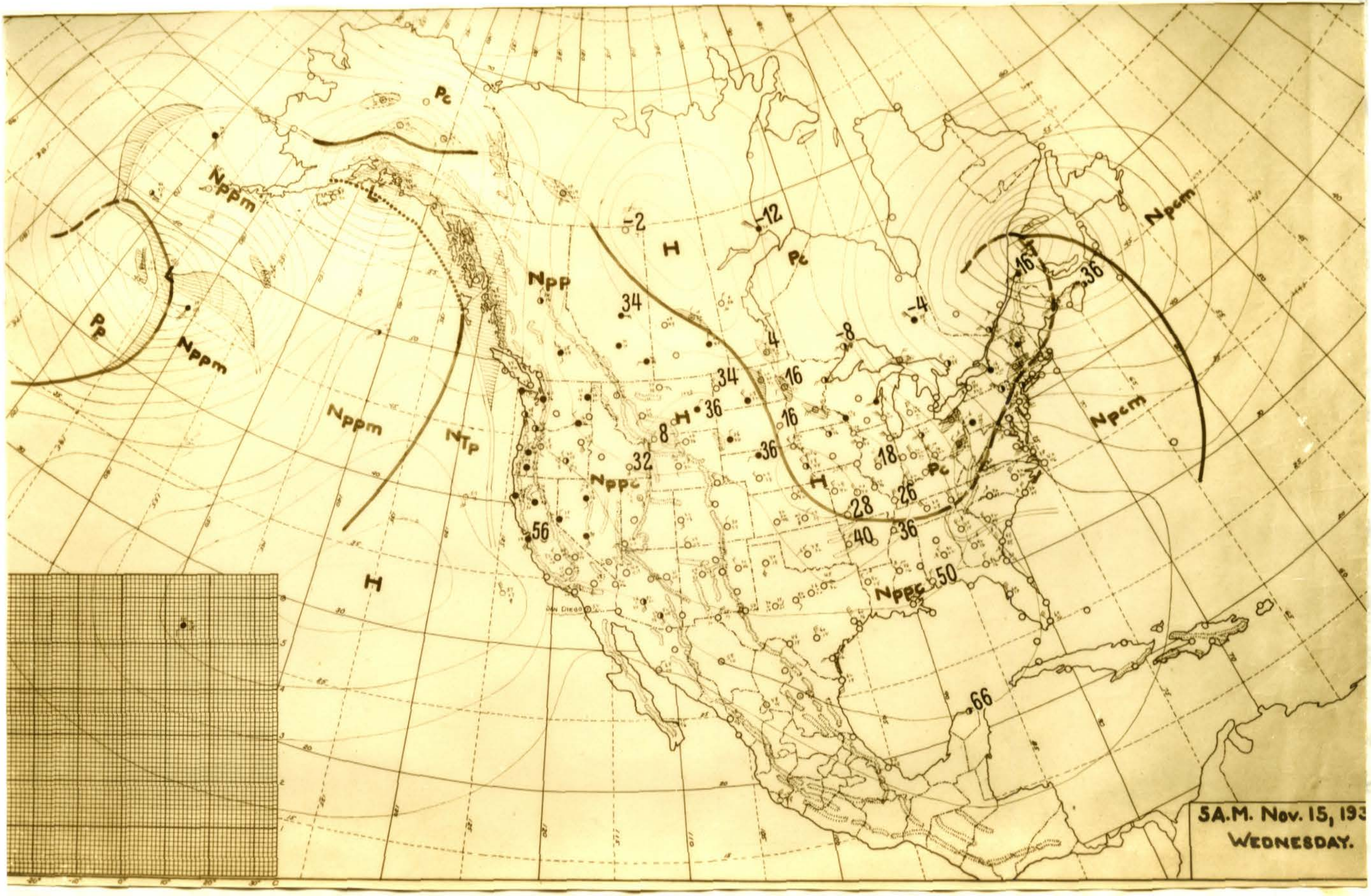
Pc
Nppm
L
Pp
Nppm
Npp
Nppm
NTp
H
-2
H
-12
Pc
34
4
-8
-4
16
34
36
H
16
8
32
36
Nppc
18
Pc
H
28
26
56
40
36
Nppc
50
66
16
36
Npcm
Npcm
San Diego
5A.M. Nov. 15, 193
WEDNESDAY.

Fig. 8.

disappeared due to occlusion west of the Appalachians, with the exception of some of the warm air which found its way around the southern extremity of the ranges. Since the occlusion is of the cold front type the mountains will not prevent its ultimate passage, indeed, near the center of the cyclone where the pressure gradients are very marked a portion of the occluded front has passed over the mountains as indicated. A warm front type occlusion has occurred in the disturbance centered over the Gulf of Alaska and it is the upper front of this occlusion which appears over Alberta, Canada, the following day as mentioned above. This is the normal high level disturbance usually observed moving eastward over the Canadian Rockies at this time of year and need not be considered here. The foehn has ceased now even in southern California as indicated by the temperatures along the coast and the formation of a ground fog at San Diego. The foehn air returning from the Pacific Ocean having picked up a shallow layer of moisture produced a dense ground fog in all coastal areas the following morning, aided by intensive nocturnal radiation through the transparent upper layers.

III. WEATHER CONDITIONS ASSOCIATED WITH THE AKRON DISASTER

by

Irving P. Krick

WEATHER CONDITIONS ASSOCIATED WITH THE AKRON DISASTER

by Irving P. Krick

The charts presented herewith are constructed from synchronous data compiled every four hours from 0800 EST April 3, 1933, to 0800 EST April 4, 1933. Each full barb on the wind arrows represents approximately one unit on the Beaufort scale. The principal fronts have been indicated as follows: cold fronts by heavy solid lines, warm fronts by double lines, and cold front type occlusions by dotted lines. The symbols adjacent to the fronts indicate the recent life history of the air masses involved. The elementary symbol represents the type and source region of the mass, for example, Pc would point out the polar origin of the mass and the continental (Canadian) nature of its source region. To denote the transitional types, the letter N precedes the elementary symbol. Occasionally this latter portion is followed by a c or an m to indicate that the modification of the air mass has been due to continental or maritime influences respectively. For a complete classification and description of the American air masses the reader is referred to a paper on the subject by H. C. Willett[1)].

On the first synoptic chart of the series (0800 EST April 3, 1933), there is an occluded front extending from Canada southward to Ohio with the cyclone associated with it centered over the Great Lakes. To the west and north of this occlusion there appears a fresh southward movement of Polar Continental (Pc) air mixing with the original Transitional Polar Pacific (Nppc) air formerly occupying the region to the west of the front. The southern limit of this outbreak is indicated by the cold front lying across Kentucky, northwestern Tennessee, and Arkansas. The air behind this front is characterized by low temperatures, low specific humidities and a stable stratification. The interactions occurring along this front are at present not violent because the air to the north is underrunning

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1) Willett, H. C.: "American Air Mass Properties", M.I.T. Met. Papers, Vol. II, No. 2.

an air mass having a vertical structure very similar to its own. The higher temperatures and slightly higher moisture content of the Nppc air to the south of the front form the essential differences between this air and the mixture to the north. The cold front extending across the Carolinas, Georgia and Florida is no longer an active front, but serves to indicate that the Tropical Gulf (Tg) and the Tropical Atlantic (Ta) air to the southeast does not extend inland over the south Atlantic coast. These tropical maritime masses are very warm and moist in the lower levels and are characterized by potential instability; i.e. if they be lifted sufficiently either by active overrunning of a warm front surface or by an underrunning cold mass free convection may occur with attendant heavy precipitation and thunder storms. The fresh outbreak of Pc air mentioned above will induce a compensating northward flow of the air to the east and south with a tendency toward the formation of a secondary cyclone between the currents. This will not become very intense until the southward moving current of Pc air reaches the Tg and Ta air to the southeast. When this occurs marked activity may be expected along the cold front separating the masses due to the tremendous contrasts arising along the frontal zone. The warm front between the Ta air along the south Atlantic coast and the Nppc air over the region to the north is at present inactive but will not remain so with a northward movement of the Ta current in the anticipated secondary.

Of prime importance is the Polar Atlantic (Pa) air lying off the New England coast. The cold front indicated on the map is not at present particularly active, but if a rapid flow of this air southward along the coast is induced it will become so, particularly if it reaches a region occupied by tropical maritime air either at the surface or at low levels.

On the chart for 1200 EST the occluded front mentioned above is seen to have moved slowly eastward since the previous map accompanied by scattered light showers and snow flurries along the frontal zone. By far the most interesting feature of this map is the rapidity with which the cold front marking the southern limit of the Pc and Nppc mixture is moving. The cold front to the east lying between the Nppc air to the west and Tg and Ta to the east has apparently remained practically stationary as might be expected from the parallel or even divergent flow adjacent to it. The secondary cyclone mentioned above has begun to form as indicated by the configuration of the isobars and the increase in wind velocities over the region, the latter indicating the tendency for the potential energy of the mass distribution of the system to become transformed into kinetic energy of motion. The Ta air south of the warm front on the map has begun its northward journey by this time as shown by the shift of the wind at Wilmington, N.C., from a light westerly current on the previous map to a moderate southerly one on the present chart. The Pa cold front to the northeast at present remains almost stationary.

The chart for 1600 EST is one of the most important of the series since the commander of the AKRON saw this map and based his decision to take off upon it. Our secondary cyclone is now well established and the active cold front of the disturbance is still moving rapidly southward and eastward. The mixture behind the front has now been designated Npc in accordance with the major importance of the Pc air involved. The Nppc air which separated this mass from the tropical maritime air to the southeast on the previous map has been displaced and for the first time the active cold front reaches a source of moist air essentially different in vertical structure from the air behind the front. The activity resulting is evidenced by the prefrontal thunder show at Thomasville, Georgia, which is at present situated practically in the frontal zone. The progress of the front since the previous chart is readily followed by comparing the dew-points (indicated by upper figure to left of stations) at the various stations before and after the frontal passage. This is possible because the dew-point is a fairly conservative air mass property. Particularly striking is the drop from 62° F. to 34° F. at Mobile, Alabama.

From the contrast in wind velocities adjacent to the warm front it is apparent that there must be active overrunning of Ta air at the front. This means that Ta air will be present aloft for considerable distances in advance of the frontal position at the ground and a regeneration of the occluded front to the west will probably occur due to the potential energy of mass distribution thus provided. The Nppc air north of the warm front is a rather shallow current and will probably not provoke appreciable warm front precipitation from the overrunning Ta current.

Particularly important is the fact that the primary disturbance to the north is filling up and the secondary has not yet reached its maximum intensity, the combination giving rise to a "flat" pressure distribution which is practically meaningless in the absence of proper consideration of the air masses involved. It is unfortunate that the cold front of the secondary had not yet reached the coast line where severe thunder showers would result and give at least a warning of the tremendous energies stored up in the mass distribution of the system. We can now expect a deepening of the disturbance and a movement northnortheastward along the principal frontal system of the cyclone. The importance of the Pa cold front may now be more fully appreciated since the direction of motion of the secondary cyclone to the south will be directly toward the tongue of Pa air projecting southward along the New England coast. This movement of the LOW will establish the pressure gradients necessary for a southward movement of the Pa mass bringing about a convergence between this mass and the Ta current to the south, not only aloft in advance of the warm front but eventually even at the surface in the warm sector of the disturbance. Thus the Pa cold front will become active and be characterized by the attendant cold front phenomena.

On the 2000 EST chart may be noted the northward movement and the intensification of the secondary cyclone together with the southward movement of the Pa front induced by the resulting gradients. This southward movement of Pa air is also suggested by the positive pressure changes (third figure in column to right of stations) which have occurred in the three hourly period prior to the time of observation at stations within the current. These increases are hardly to be accounted for by the diurnal pressure wave (having a maximum at 2200 EST in the region) in view of the frontal systems approaching from the west and south with their accompanying low pressures. Active overrunning of Ta air along the warm front is apparent from a comparison of the pressure changes within the warm sector of the disturbance and in advance of the front. As a result of this overrunning the occluded front to the west has now become regenerated as indicated by a thunder storm at Washington, D.C. The Ta air has apparently made its way aloft far enough to the north so that activity may soon be expected along the Pa front now lying in the vicinity of New Jersey. It is interesting to note that a thunder storm began at Lakehurst, N.J., at 2200 EST following a two hour period of falling pressure which would seem to indicate an influx of Ta air over the region leading to activity along the Pa front as it moved southward. The thunder storm was accompanied by high winds from the eastnortheast and increasing pressure which began to fall again several hours later with the approach of the center of the secondary. The thunder storms along the Pa front had extended as far north as New York by midnight. It is possible that thunder storms occurring during the night far to the north, for example at Boston, were due not to frontal activity on the part of the Pa air, but to the "realization" of the characteristic conditional instability of the Ta air in overrunning the Pa air from the warm front lying out over the ocean to the east. I believe, however, that we may be certain that the thunder storms at the southern extremity of the Pa front are pure cold front type phenomena, and it was, of course, in this region that the AKRON was lost.

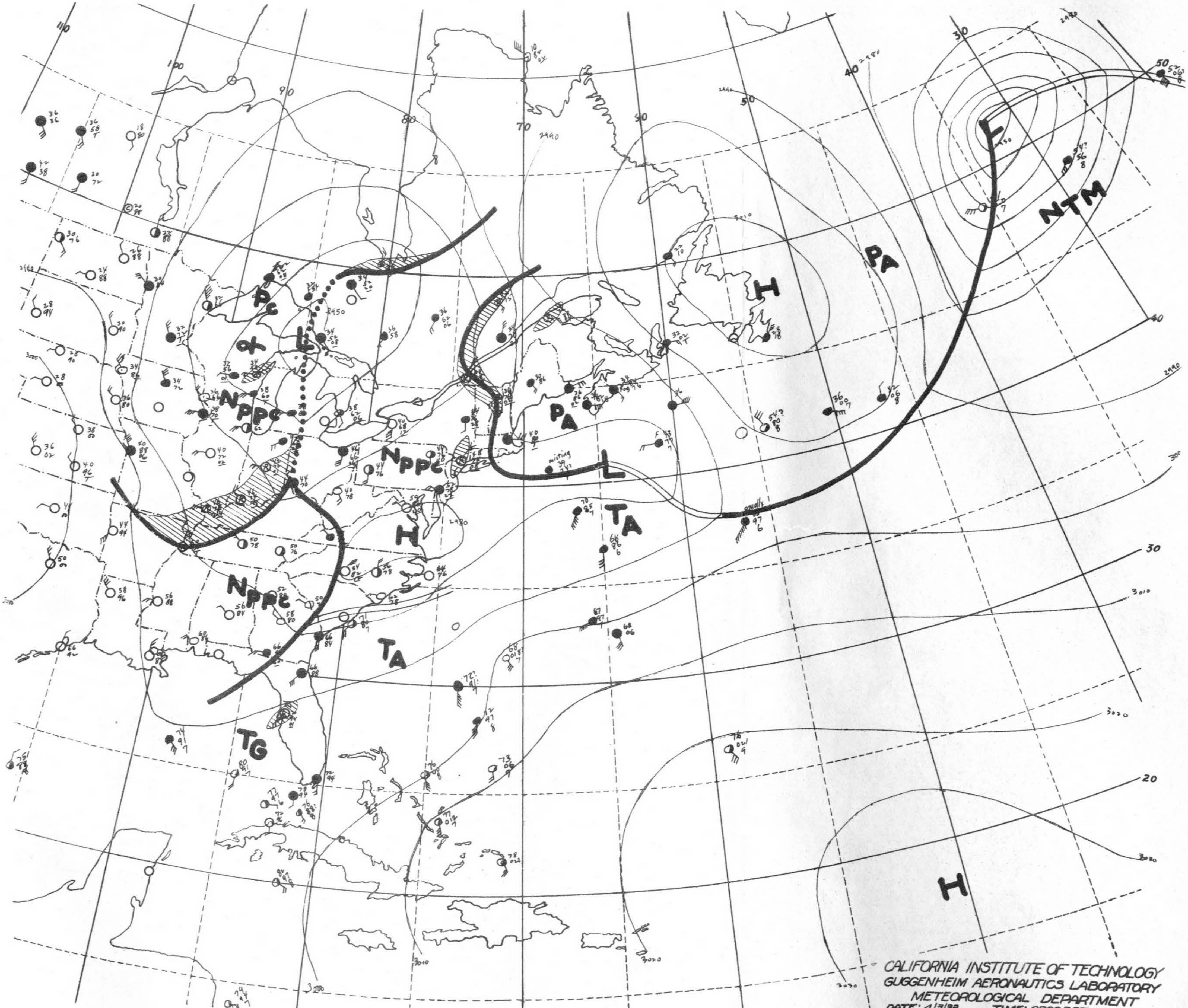
The midnight map merely shows an intensification of the 2000 EST situation in that the secondary has moved northeastward, the Pa front southward and a general convergence of the frontal system of the cyclone with the Pa front to the north and east is imminent. Since this map illustrates the situation very close to the time of the disaster, it seems evident that the AKRON was forced into the sea in the Pa frontal zone rather than in that of the regenerated occlusion to the west. The activity along the fronts under consideration is apparent from the thunder storms extending along the Atlantic coast from New York to Florida. The tendency of the two cold masses behind the Pa front and the occluded front to the west to crowd out the tongue of Ta air aloft between them is aiding in the intensification of both frontal zones north of the center of the distunbance.

The situation at 0400 EST on April 4 shows that the cold air behind the Pa front and that behind the occluded front have united. The fact that Pa air has probably penetrated into the warm sector of the cyclone is indicated by the occluded portion of what would normally be the warm front. This is not an occlusion in the ordinary sense but will serve to illustrate the fact that the Pa front has pushed into the Ta current.

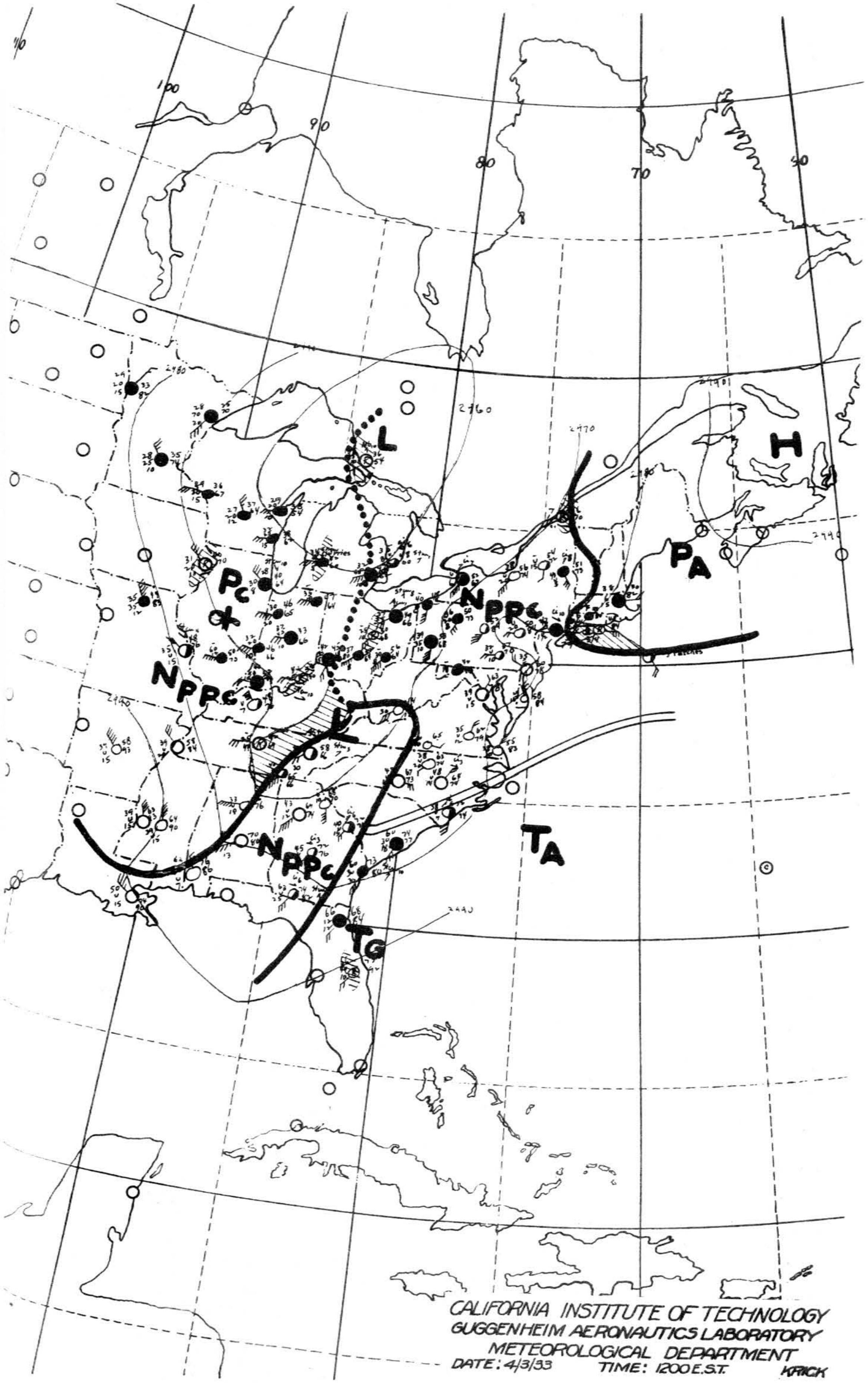
The final map of the series drawn for 0800 EST differs little from that for 0400 EST except for the additional stations over the Atlantic. The occluded section of the warm front will undoubtedly disappear and again become the normal warm front of an occluding cyclone as the disturbance moves eastward.

I believe that this series of maps is an excellent illustration of the superiority of air mass and frontal methods of weather analysis over the older ones based upon the movement of HIGHS and LOWS, particularly in the case of aircraft operation where a three-dimensional picture of atmospheric conditions is so essential. Severe conditions such as those experienced in the present case do not arise instantaneously in the atmosphere, but may be anticipated with a good deal of confidence by anyone familiar with these methods of analysis by watching the trajectories of the various air masses and determining where frontal zones will develop and how violent the interactions along them will be. To a meteorologist who has become proficient in the use of these methods of analysis for airways weather forecasting the situation represented on the first map of the series would provide a warning as to what was to follow. The afternoon map (1600 EST) would certainly leave no doubt as to the situation and all flights along the south Atlantic coast would be suspended until the Npc cold front passage.

It is needless to say that this would also apply to the region to the north which would be overrun by Ta air subsequently to be displaced by the collision of the Pa air from the northeast and the Npc air from the west. The above condlusions are based upon actual experiments carried out by the writer for the region west of the Rockies through the facilities of the Western Air Express, one of the pioneer air transport operators of the country. Here the analyses are more difficult than in the central and eastern parts of the country since the distinctions between air masses are more difficult to ascertain and the effects of the topography upon the air mass properties and upon the movements of the fronts play a major role. Nevertheless, satisfactory analyses of this type have proved practicable and following the inauguration of these methods, marked increases in operation efficiency have been effected without sacrificing the remarkable record of safe operation maintained by this line.



CALIFORNIA INSTITUTE OF TECHNOLOGY
GUGGENHEIM AERONAUTICS LABORATORY
METEOROLOGICAL DEPARTMENT
DATE: 4/3/33 TIME: 0800 E.S.T. KRICK


L
H
PA
Pc
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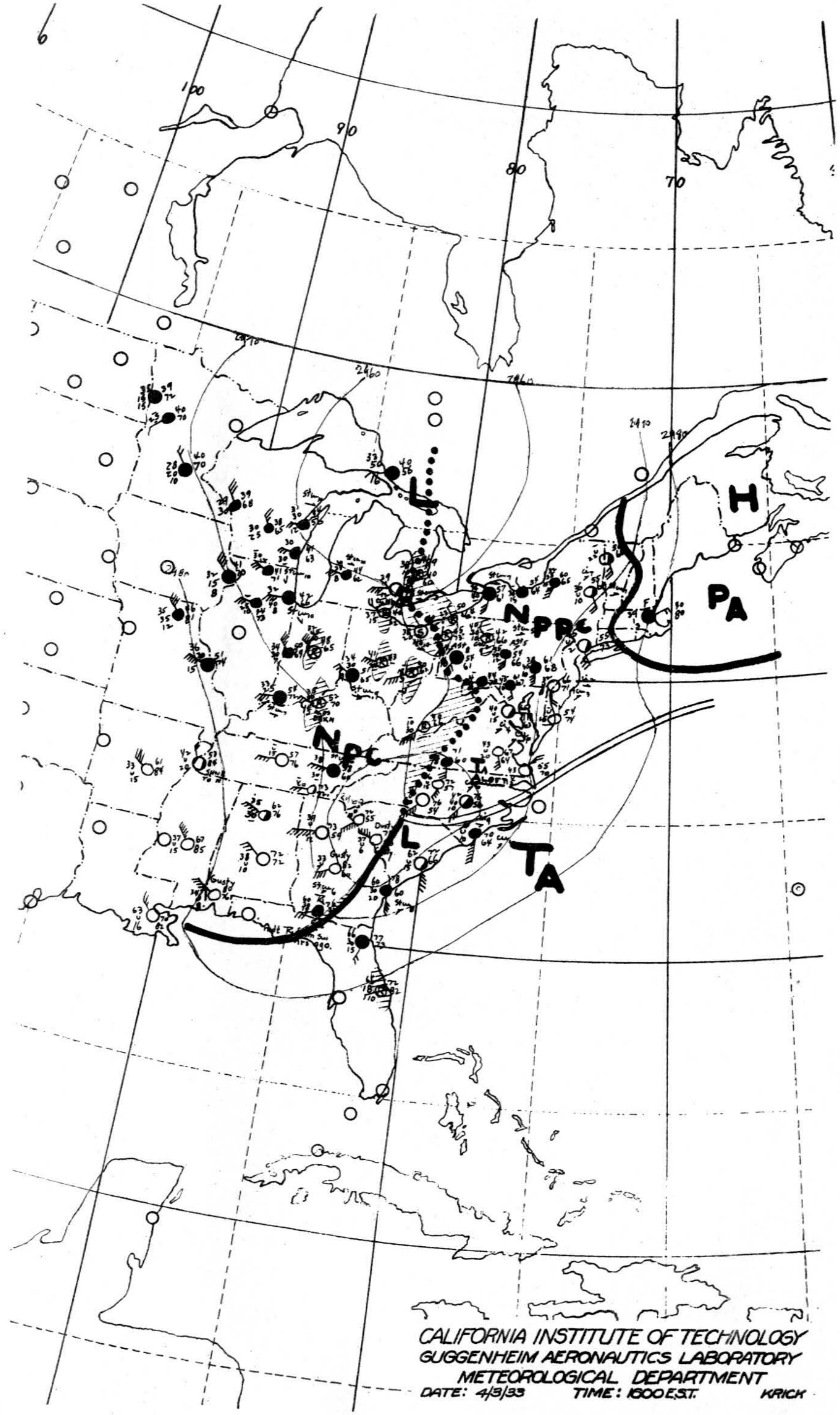
NPPc
TA
TG
CALIFORNIA INSTITUTE OF TECHNOLOGY
GUGGENHEIM AERONAUTICS LABORATORY
METEOROLOGICAL DEPARTMENT
DATE: 4/3/33 TIME: 1200 E.S.T. KRICK


L
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NPc
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CALIFORNIA INSTITUTE OF TECHNOLOGY
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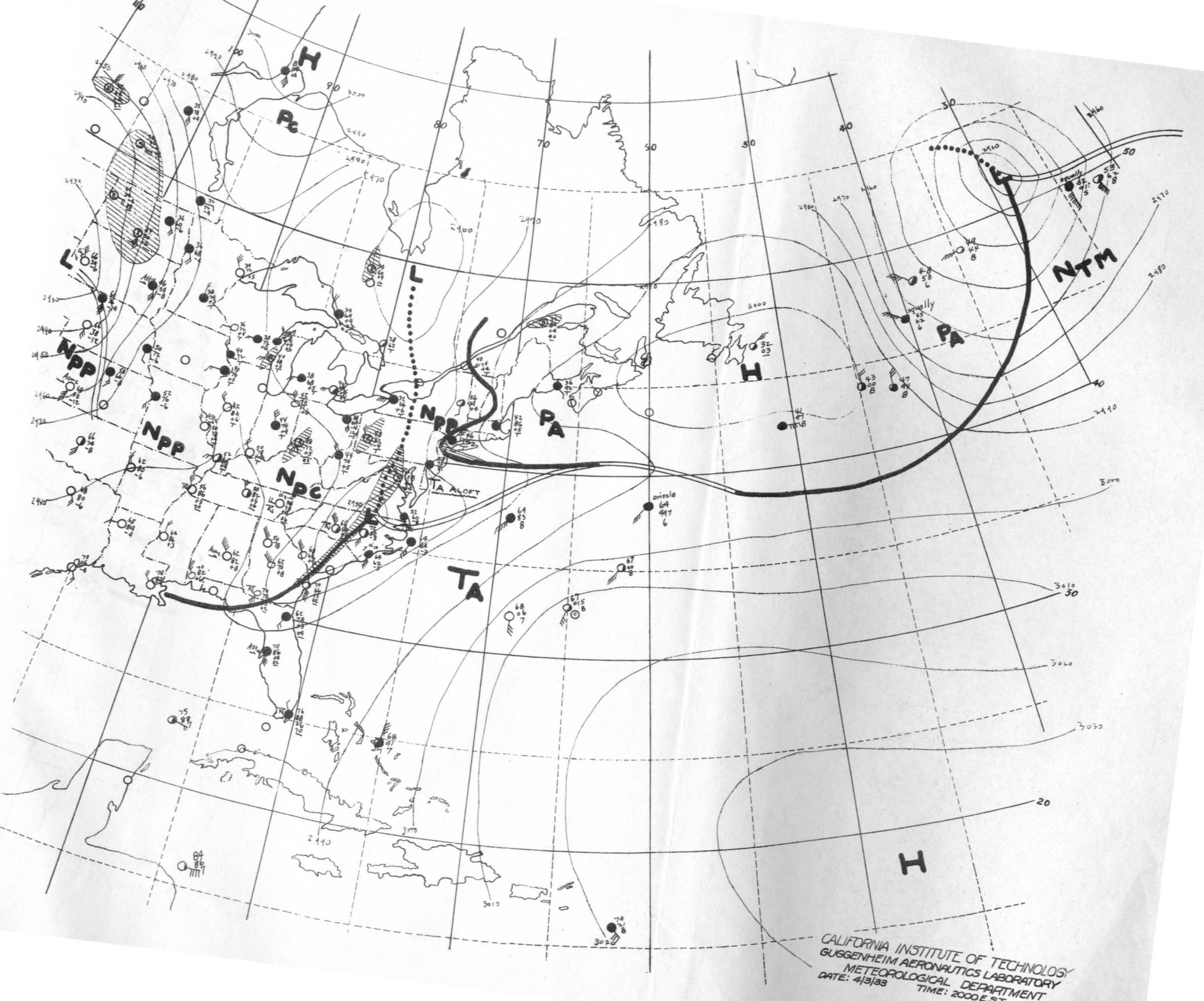
METEOROLOGICAL DEPARTMENT
DATE: 4/3/33 TIME: 1800 E.S.T. KRICK


H
Pc
L
NPP
NPP
Npc
NPP
PA
TA
TA ALOFT
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PA
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CALIFORNIA INSTITUTE OF TECHNOLOGY
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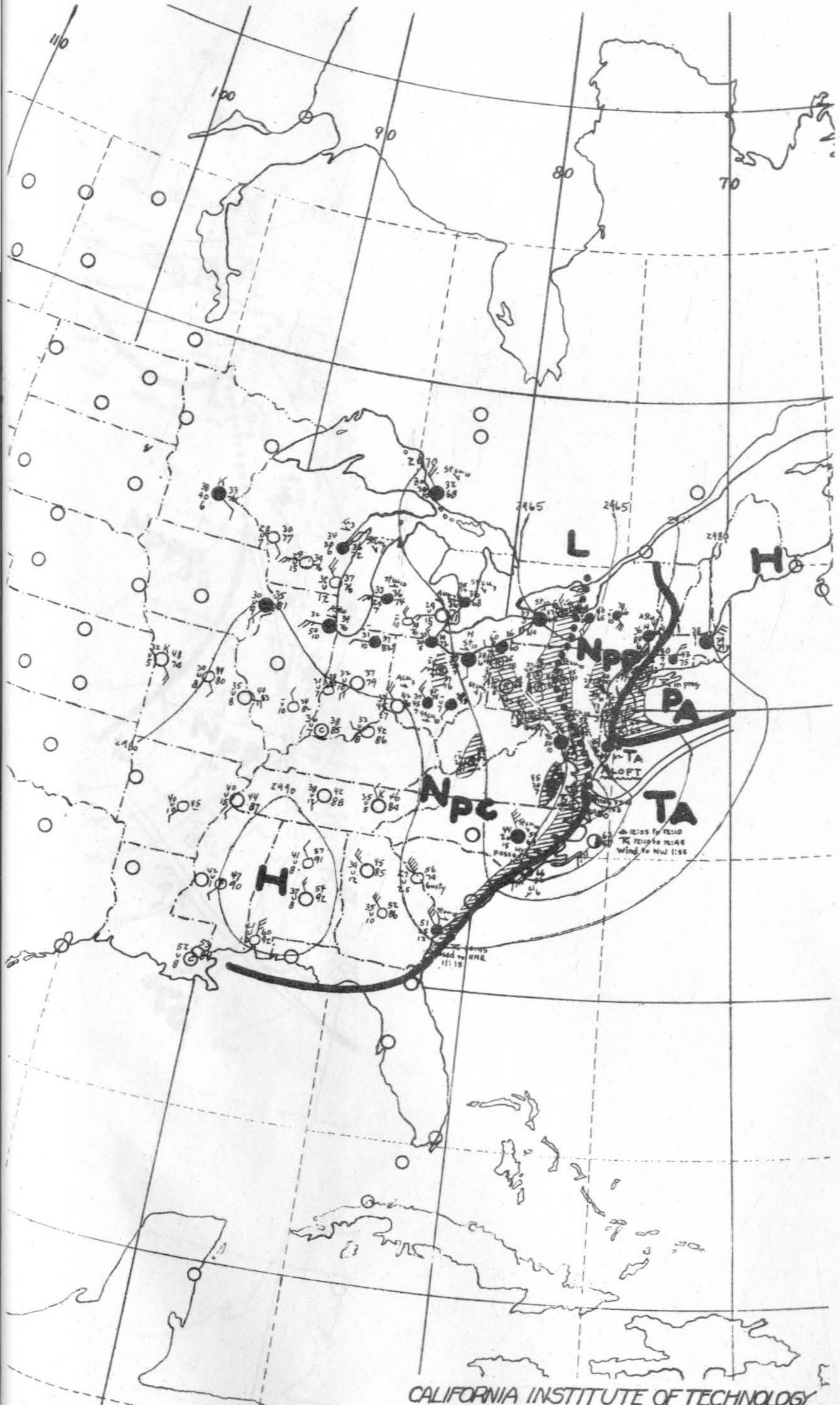
DATE: 4/3/33
TIME: 2000 E.ST.



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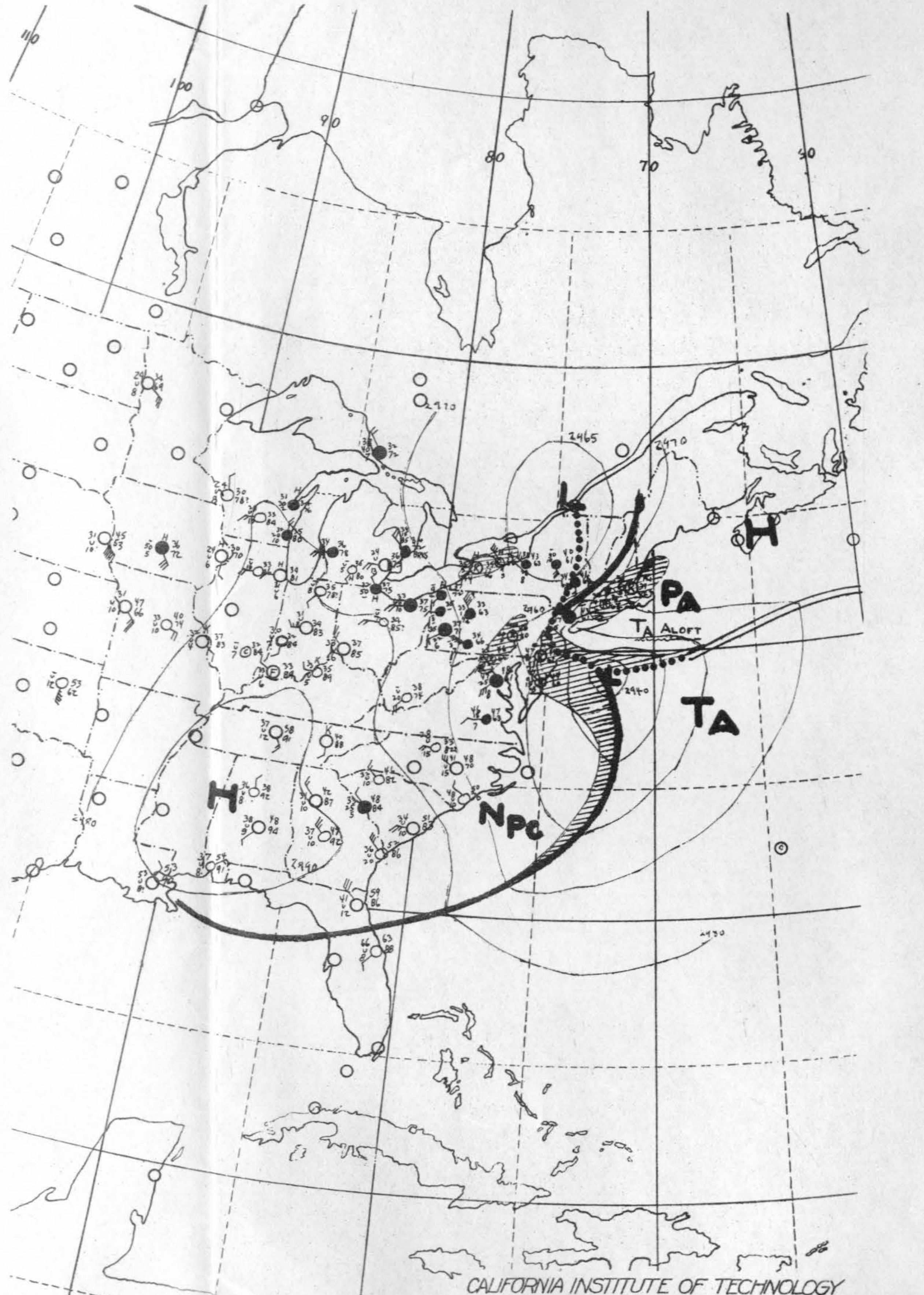
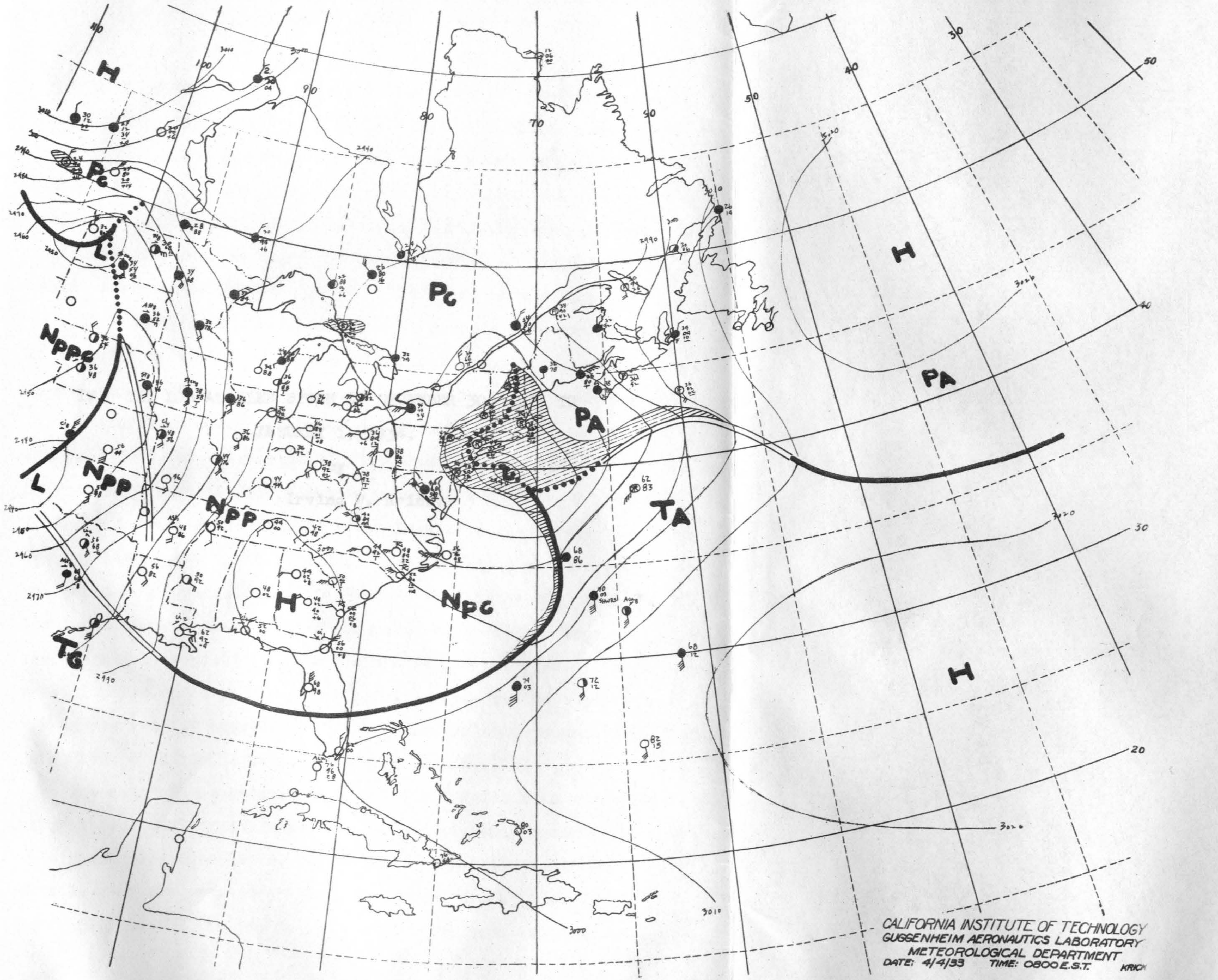
METEOROLOGICAL DEPARTMENT
DATE: 4/4/33 TIME: 0000 E.S.T. KRICK



CALIFORNIA INSTITUTE OF TECHNOLOGY
GUGGENHEIM AERONAUTICS LABORATORY
METEOROLOGICAL DEPARTMENT
DATE: 4/4/33 TIME: 0400 E.S.T. KRICK



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KRICK

IV. THE LOS ANGELES STORM OF DECEMBER 30, 1933 TO JANUARY 1, 1934.

by

Irving P. Krick.

THE LOS ANGELES STORM OF DECEMBER 30, 1933 TO JANUARY 1, 1934.

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The synoptic situation during heavy rains in the Los Angeles Basin during the period Dec. 30, 1933 to Jan 1, 1934 lends itself admirably to a discussion of certain fundamental interactions between the air masses of the North Pacific Ocean which ordinarily yield copious rainfall to the southern California coast. In view of the recent adoption by the U.S. Weather Bureau of the recommendations of the President's Science Advisory Board urging a more general use in this country of air mass and frontal methods of weather analysis it is believed that discussions of various synoptic situations of this nature may prove valuable to those engaged in the reorganisation program.

The present paper also attempts to bring out the value of such analyses from the standpoint of flood control. An accurate anticipation of rainfall intensity and duration prior to a storm would prove invaluable for the adjustment of water levels in reservoirs to provide for expected run-off. The run-off from the storm considered herein was particularly significant in certain localities due to the fact that considerable areas in the mountains north of Los Angeles had been burned over previous to the storm by a brush fire. Although the precipitation which followed was not a maximum in these areas the tremendous run-off experienced at the base of these mountains led to a large loss of life and property in the district.

The rainfall associated with the storm was not an excessive intermittent instability type, but rather a steady moderate to heavy warm front type produced by the continuous active over-running of a cold mass of air present in the Los Angeles Basin by warm moist currents from the Pacific Ocean. As will be seen it is important to consider the fact that more than one mass of air from the Pacific partook of this over-running. The rising waters in the canyons in the mountains north of Los Angeles which finally swept out over the Los Angeles and San Fernando Basins causing the loss of approximately forty lives and the destruction of many homes were thus not due to scattered cloud-bursts in the mountains but to a steady moderate rain over the entire area. The precipitation endured for about forty eight hours and on the average amounted to something over ten inches most of which fell during the last twenty four hour period (see Fig. 1). It is interesting to note that areas outside of the Los Angeles and San Fernando Basins and their adjacent mountains escaped with relatively small amounts.

To appreciate the apparent local nature of the storm one must be familiar with the topographic features of the Los Angeles area. The topography of the Pacific Coast plays a major role in all frontal and air mass movements in the region and therefore forms an integral part of any weather analysis for the district. Most significant for the present discussion are the San Gabriel and Sierra Madre Mountains which rise abruptly to the north of the Los Angeles Basin to an elevation of approximately 1600 meters with peaks exceeding 2800 meters. They parallel the entire basin and run roughly from east to west (see Fig. 2). This huge mountain mass is capable of limiting the advance of any warm front approaching from the south to the portion lying above the crest of the ranges by preventing the escape of the cold air below. This results in a stationary frontal surface extending from the divide southward out over the adjacent Pacific Ocean. If the warm current passing up over the frontal surface remains active large amounts of precipitation are apt to be recorded in the regions south of the mountains below the discontinuity surface, namely in the

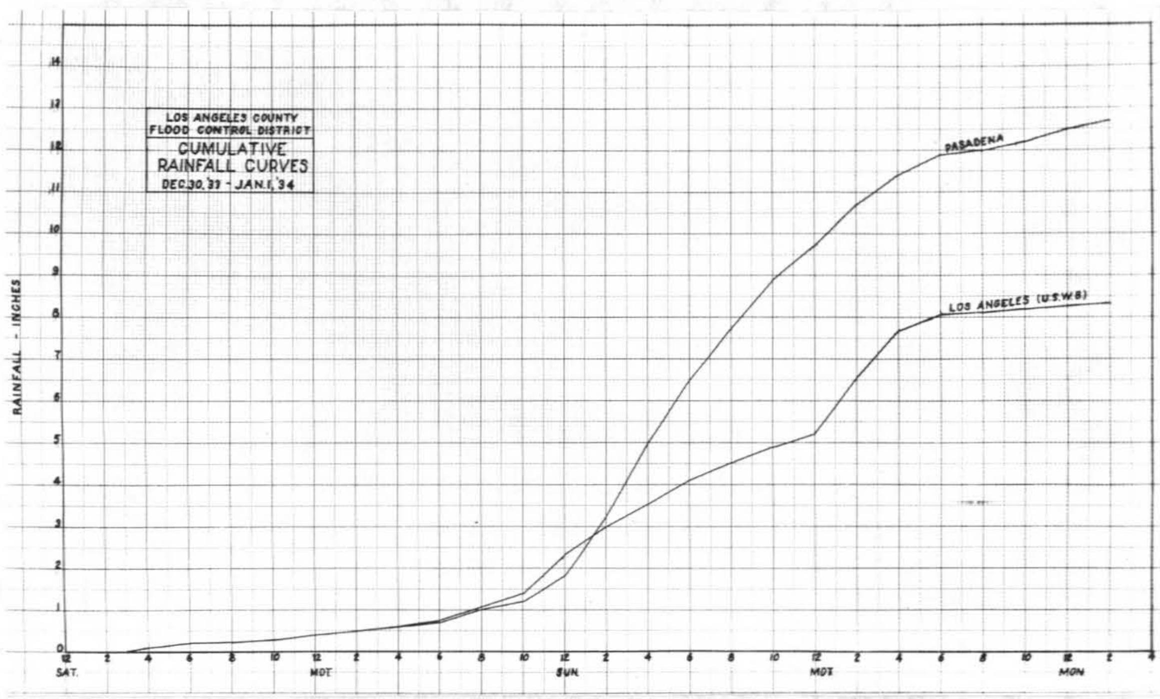
LOS ANGELES COUNTY
FLOOD CONTROL DISTRICT
CUMULATIVE
RAINFALL CURVES
DEC.30,'33 - JAN.1,'34
PASADENA
LOS ANGELES (U.S.W.B.)
RAINFALL - INCHES
SAT.
MDT
SUN.
MDT
MON

Fig. 1.


PLATE I.
GEOMORPHIC MAP
OF
CALIFORNIA AND NEVADA
WITH PORTIONS OF
OREGON AND IDAHO
PUBLISHED BY THE STANFORD BOOKSTORE
STANFORD UNIVERSITY, CALIFORNIA
ORIGINALLY ISSUED BY THE CALIFORNIA STATE EARTHQUAKE
INVESTIGATION COMMISSION OF 1906 TO DEMONSTRATE
THE FAULTED CHARACTER OF THE RELIEF
SAN FRANCISCO
Santa Barbara Channel
San Pedro Channel
M E X I C O

Fig. 2.

Los Angeles Basin. Such a situation occurs occasionally during the winter season, but normally lasts only a short time as most stationary warm fronts of this nature are quickly occluded by cold air moving in from the west. The large amounts of precipitation recorded during the storm treated in this paper were due to the extended period occupied by the over-running of such a stationary front before a mass of air moved into the region which was cold enough to displace the mass initially lying below the warm front surface. The precipitation was not all produced by the over-running of one air mass, but by two types, namely Tropical Pacific (Tp) air in the primary phases of the development and later by Transitional Polar Pacific (Nppm) air. The latter was by far the more important of the two yielding much greater amounts of precipitation at considerably higher intensities. An examination of the vertical structure of these two over-running masses will be necessary to understand why more precipitation was received from the mass of polar origin than from the tropical mass which had a much higher moisture content.

The duration of the storm was caused largely by the warm front nature of the initial occlusion which occurred along the southern California coast. Occlusions of this nature are infrequent as far south as Los Angeles and in the present case resulted from the very long trajectory of the Nppm air behind the front over the low latitudes of the North Pacific Ocean. This extended journey far to the south rendered the air as warm and moist as Tp in its lowest levels. The occurence of this type occlusion meant a continued warm front precipitation in the Los Angeles area which was only finally dissipated by the arrival of rather fresh Polar Pacific (Pp) air from the north, a mass cold enough to displace the air originally below the stationary warm front surface. It is interesting to note that most of the rainfall accompanying the storm occurred after this initial occlusion, or in other words from over-running Nppm air rather than from Tp. The transition from a light rain associated with the passage of Tp air over the warm front surface prior to the occlusion to a moderate or heavy rain from over-running Nppm air after occlusion was quite distinct. This may be noted as an inflection occurring on the morning of Dec. 31 on the cumulative rainfall curves marking an increase in the intensity of the precipitation. The difference in vertical structure of the two over-running air masses is almost entirely responsible for this transition. Further investigation has shown that most of the heavy warm front type rains occurring in the region are due to the presence of Nppm air above warm front surfaces rather than true Tp. From surface observations alone the two masses appear to be entirely analogous, however upper air data indicate significant differences, both in moisture and temperature distribution which affect the relative stability of the two masses. These variations may be best appreciated perhaps by the use of an equivalent potential temperature diagram. The curves shown in Fig. 3 were plotted from all upper air data available from San Diego during the winter 1933-1934 in which flights in Nppm and Tp masses analagous to those considered herein were made. San Diego is located on the coast about one hundred and twenty miles southeast of Los Angeles. In this short distance no appreciable differences in similar air masses would appear so we may consider these data as representative of these masses in the vicinity of Los Angeles.

The base chart is a modification of the equivalent potential temperature diagram developed by Rossby[1)] and provides a means of determining the degree of instability of an air mass from the standpoint of moisture as well as temperature distribution. Ordinates represent

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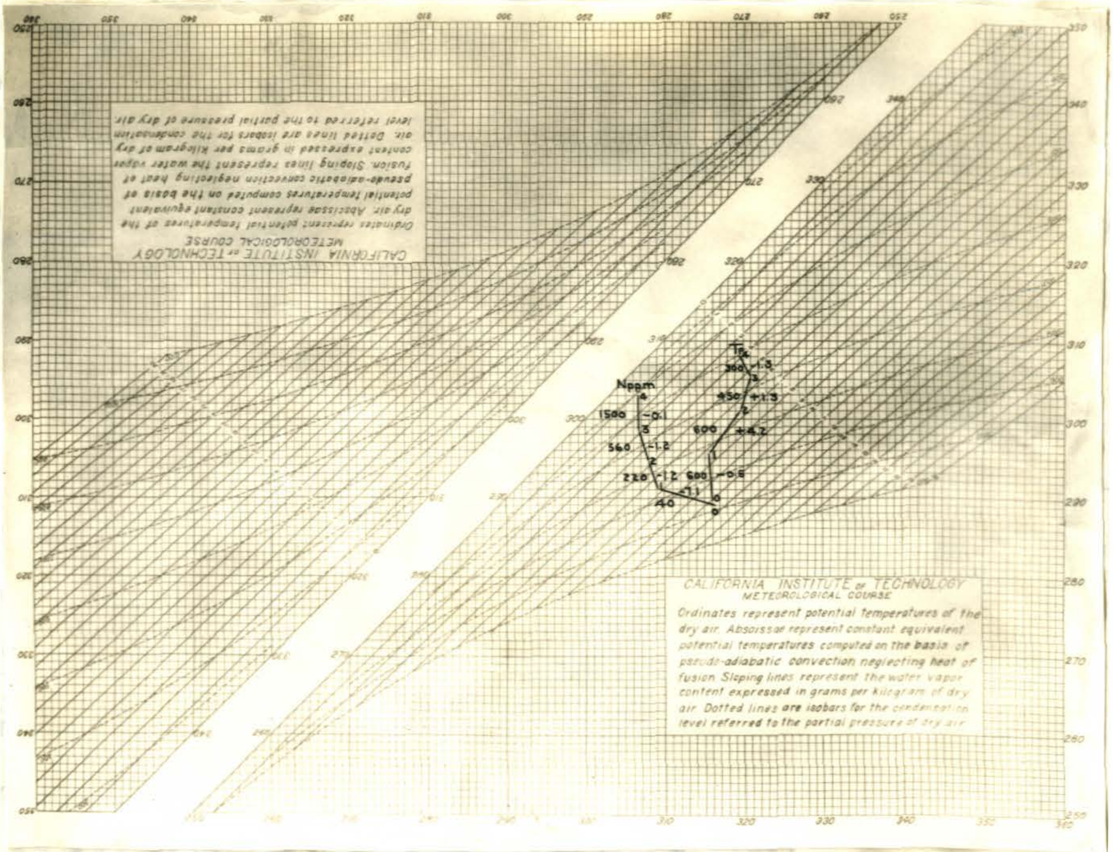
1) Rossby, C. G. Thermodynamics applied to air mass analysis. Mass. Inst. of Tech. Met. Papers, Vol. I, No. 3.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Ordinates represent potential temperatures of the dry air. Abscissae represent constant equivalent potential temperatures computed on the basis of pseudo-adiabatic convection neglecting heat of fusion. Sloping lines represent the water vapor content expressed in grams per kilogram of dry air. Dotted lines are isobars for the condensation level referred to the partial pressure of dry air.
Nppm
Tp

Fig. 3.

potential temperatures of the dry air, usually termed the partial potential temperature, Θ_d, a conservative air mass property in the absence of condensation or evaporation. It may be expressed by the formula: $\Theta_d = T\left(\frac{1000}{p_d}\right)^{0.288}$ where T is the air temperature in absolute degrees and p_d is the partial pressure of the dry air. Abscissae represent constant equivalent potential temperatures, Θ_E, a conservative air mass property for pseudo-adiabatic convection. It may be written: $\Theta_E = \Theta_d e^{\frac{rW}{c_p T_o} \cdot 10^{-3}}$ where e is the base of the natural logarithms, r is the latent heat of condensation , W is the mixing ratio expressed in grams per kilogram, c_p is the specific heat of air at constant pressure and T_o is the temperature at the condensation level. The solid sloping lines represent water vapor content, W, expressed in grams per kilogram of dry air. This is also a conservative air mass property in the absence of condensation or evaporation. It may be expressed as: $W = 622 \frac{p_w}{p_d}$ where p_w is the water vapor pressure and p_d the partial pressure of the dry air. The dotted lines on the diagram are isobars representing partial pressures of dry air at condensation levels and facilitate the calculation of the amount of lifting necessary to saturate any given layer within the mass. In cases of conditional instability, as we shall find exists in the Nppm air of the present case, this is the lifting necessary to produce absolute instability within the layer brought to saturation, and provides a valuable aid to the forecaster in anticipating the amount of precipitation to expect from warm front rain produced by such a mass. Curves on the diagram sloping upward toward the left show a decrease with elevation of Θ_E an indication of conditional instability. Those sloping upward toward the right denote absolute stability while curves with constant Θ_E represent air masses which will remain in equilibrium under pseudo-adiabatic convection. One can readily see from Fig. 3 that the Nppm is characterised by a marked potential instability while the Tp is quite stable. This means that free convection will never begin in the Tp air, but will tend to take place in the Nppm air as soon as saturation is reached. The curves in each case represent a layer of air four kilometers in thickness. The numbers to the left of the various portions of the curves denote the amount of lifting in meters necessary to saturate the entire portion of the curve in question. In this case strata one kilometer in thickness have been chosen. The numbers to the right indicate the change in Θ_E between the extremities of the various layers, a positive value being an increase and a negative value a decrease. The higher the negative value the greater the degree of conditional instability and vice versa. In layers having significant decreases of Θ_E we need only to lift the layer to saturation and free convection may begin. In the case of the Nppm air we can see that the lower kilometer is practically saturated only a few meters lifting being necessary to saturate it throughout. This is the result of a steep lapse rate throughout the layer. This condition coupled with the instability indicated by a decrease of 7°C. in Θ_E for the layer points to a high degree of potential instability. In fact with a rise of 560 meters a layer 3 kms in thickness will become absolutely unstable and free convection is easily provoked within the mass. This lifting is easily accomplished in the over-running of the stationary warm front surface above the Los Angeles Basin. Consequently large amounts of precipitation may be expected from the continued passage of this unstable mass up over this discontinuity surface.

In the Tp air we find high water vapor content throughout and see that a rise of 600 meters will saturate the entire four km. layer. However, the layer from the one km. to the three km. level is absolutely stable and only slight conditional instability may be noted in the remaining layers. This condition prevents any free convection within the mass even after saturation and leads only to light rain in the event of lifting by passage up the warm front surface.

As may be noted from the diagram θ_E is about the same for the two masses at the surface. This causes difficulty in differentiating between them from surface observations except when the trajectories of the two are known. It is this difference in the life history of the masses which is responsible for their totally dissimilar vertical structure. At the four kilometer level there is a difference in θ_E of about 13° C. between the masses which is due both to the higher moisture content and the higher temperature of the Tp air at that level. The trajectory of the Nppm air has carried it far south over the North Pacific, as mentioned above, causing it to absorb large amounts of heat and moisture and giving to it the appearance of true Tp air at the surface. However, its movement has been sufficiently rapid to prevent much transport of heat and moisture to the upper levels leaving them characteristically cold and dry, but establishing steep lapse rates in the lower levels. The difference in moisture content at the four kilometer level is particularly noticeable amounting to about 3 g/kg. The Tp air has had a long sojourn over the warm waters of the lower latitudes of the North Pacific and has therefore practically reached equilibrium with respect to the surface becoming quite moist throughout and acquiring a stable lapse rate, particularly in the lower levels, under the influence of subsidence affects in the Pacific anticyclone.

In order to follow the development of the storm in question synoptic charts have been included for the period 5:00 AM PST Dec. 29, 1933 to 5:00 AM PST Jan 2, 1934. Each barb on the wind arrows represents approximately one unit on the Beaufort scale. The principal fronts are indicated as follows; warm fronts by solid red lines, cold fronts by solid white lines, warm front type occlusions by dotted red lines and cold front type occlusions by dotted white lines. The symbols adjacent to the fronts indicate the recent life history of the various air masses involved. The symbol consists of a two letter element indicating the polar of tropical origin of the mass and the local source region, thus Pp indicates polar air originating over the high latitudes of the North Pacific Ocean. An air mass symbol preceded by the letter "N" denotes a mass which has been appreciably modified since migrating from its source region. The continental or maritime nature of this transition is usually included in the symbol by following the original two letter element with a "c" or an "m". Shaded areas on the charts represent regions where precipitation is occurring at the time of observation.

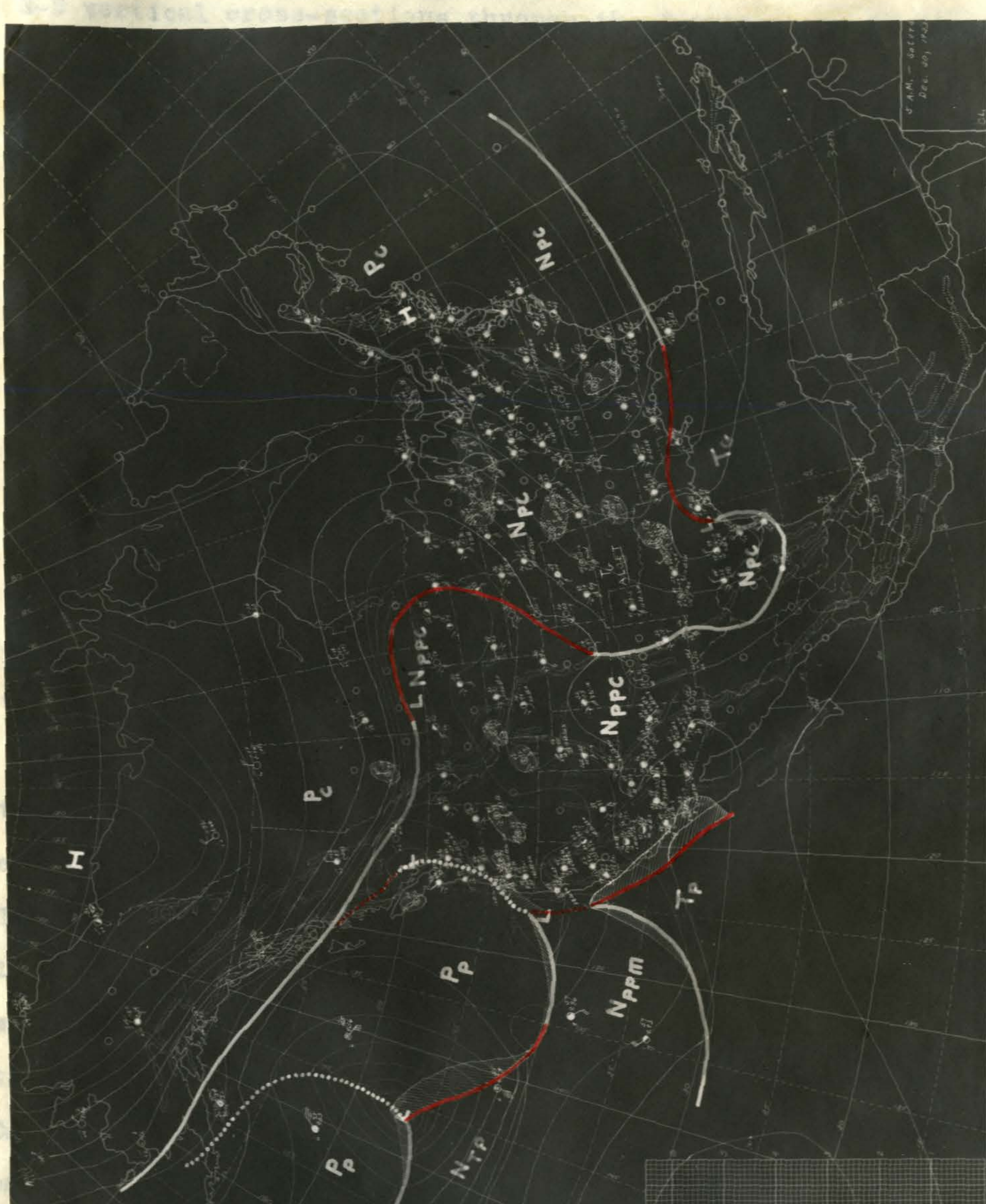
The presence of Tp air off the California coast is shown on the first map of the series depicting conditions at 5:00 AM on Friday Dec. 29, 1933 (Fig. 4). A warm front can be noted extending roughly parallel to the coast and separating the Tp air from the colder Npp air occupying the continental areas to the east. To the west lies an Nppm cold front which has caused a warm front type occlusion along the coast north of the Tp air by virtue of its greater warmth than the Npp air over the land areas. The front extending northeastward over Oregon and Washington from the northern tip of the Tp air is the upper front associated with the warm front type occlusion lying off-shore and has no particular significance in the further development of the situation. It is therefore dropped from subsequent charts. The Pp cold front farther west will displace the warm front type occlusion upon moving eastward transforming it into a cold front type which will move in over Oregon and Washington.

H
NPPM
PP
NTP
PP
PC
NPPC
NPPM
TP
NPPC H
H
PC
PC
H
NPC
NPC
TG
5AM - FRIDAY
12/29/33

Fig. 4.

The progress of the Tp warm front is being effectively blocked by the high mountain ranges paralleling the coast and it is producing considerable precipitation over northern California. The Nppm cold front to the west will continue to move eastward causing a southward extension of the warm front type occlusion along the California coast. The air behind this front has the structure of the Nppm air described above owing to a migration far south over the Pacific Ocean. The instability of this mass is responsible for the large amounts of precipitation recorded in the Los Angeles area for upon reaching the region it is obliged to over-run the colder Npp air occupying the Los Angeles Basin.

By 5:00 AM the following morning (Fig. 5) the Tp warm front had extended its influence to southern California, occasional light rain already being reported at some of the mountain stations in the vicinity of Los Angeles. The Nppm cold front to the west is moving rather slowly owing to the weak gradients existing over the ocean. Of considerable importance is the rather open wave disturbance about one thousand miles off-shore occurring between Ntp air to the south and Pp air to the north. The eastward propagation of this system will cause considerable alteration in the form of the fronts lying off the Pacific Coast and will strengthen the pressure gradients in the region causing a more active over-running of the Tp warm front surface and a much more rapid movement of the Nppm cold front. The Pp air behind the cold front of this wave disturbance is of particular significance since it is this air which finally reaches the Los Angeles Basin and is capable of displacing the rather cold Npp air which now occupies it. The effect of the mountains of southern California upon the frontal system of the storm is perhaps made clearer by the approximately



SAM - SATURDAY
12/30/33

Fig. 5.

N-S vertical cross-sections through the fronts shown in Fig. 11. The upper diagram illustrates the present stage in the development with cold Npp air below the frontal surface, warm Tp air above it and the discontinuity itself resting upon the crest of the Sierra Madre Mountains. The warm front at the surface lies about 160 kms. south of the crest of the ranges since the divide is approximately 1.6 kms. in height and the slope of the frontal surface of the order of 1/100. The rainfall recorded in the Los Angeles Basin during the next twenty-four hours amounted to only about 0.6 in. although it was of the steady warm front type. This is due in part to the weak pressure gradients forcing the Tp air up over the warm front surface, but more to the stability of the Tp mass itself since no free convection can take place within the mass even after saturation has been attained.

The synoptic chart for 5:00 AM Sunday Dec. 31,(Fig. 6) shows the changes wrought in the frontal system lying off the California coast provoked by the approach of the disturbance from the west. The most significant affect which it has produced is the increase in the pressure gradients in coastal areas. This will cause a more active over-running of the Tp warm front and will accelerate the formation of a warm front type occlusion along the southern California coast with the more rapid movement eastward and north-eastward of the Nppm front. After occlusion the movement of the Nppm air over the initial warm front surface will give rise to an increase in the intensity of the rainfall in the regions below this discontinuity by virtue of the instability produced within this mass by resultant lifting. Shortly before noon an inflection in the cumulative rainfall curves for the storm (Fig. 1) indicates the presence of the Nppm air over the Los Angeles area producing

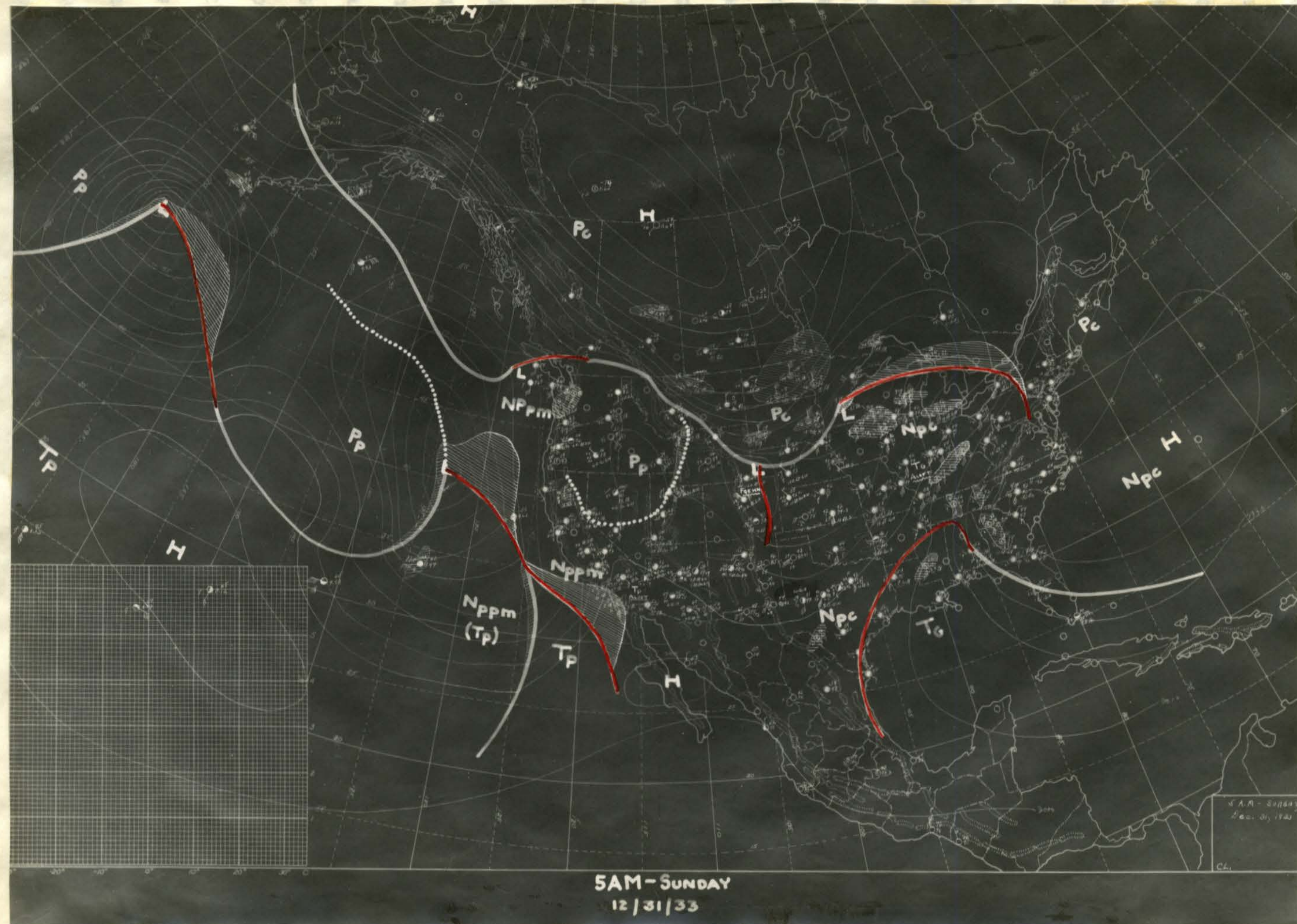

Pp
Tp
H
Pp
Pc
H
NPpm
L
Pp
Nppm
Nppm
(Tp)
Tp
H
Pc
L
Npc
Npc
TG
Pc
H
Npc
5AM-SUNDAY
12/31/33

Fig. 6.

an increase in the intensity of the rainfall. The center cross-section in Fig. 11 illustrates the influx of the Nppm air over the Los Angeles Basin on Sunday morning. It is obliged to slide up over the colder air occupying the region thus producing the warm front type occlusion which continues to lie off-shore as shown in the figure. A glance at the 5:00 AM map (Fig. 6) shows that the isobars in the vicinity of southern California are roughly normal to the Sierra Madre ranges. This fact coupled with the orientation of the warm front parallel to the ranges causes a maximum lifting of the air to occur over the Los Angeles Basin. Farther south in the vicinity of San Diego very little precipitation was recorded because the motion of the air above the warm front surface was practically parallel to the front or showed very small components normal to it. The Pp air is now in a position to move down the California coast in accordance with the pressure gradients established by the present configuration.

Due to the greater activity now present subsequent maps are drawn for twelve hour intervals rather than twenty four. The 5:00 PM map for Dec. 31 (Fig. 7) shows the warm front type occlusion which has taken place along the southern California coast as explained above. The situation indicates a continuation of the rainfall in the Los Angeles area. Rather interesting is the appearance of a precipitation area over southern Utah indicating regeneration of the portion of the warm front surface which passed above the crest of the Sierra Madres. This also verifies the assumption that maximum over-running of the warm front by the Nppm air is taking place in that direction. The pressure gradients favor a continued rapid movement of the cold Pp air lying to the northwest which by the formation of a cold front type occlusion upon moving down the

H
H
P_C
P_P
T_P
N_{PPC}
N_{PPC}
N_{PPC} Aloft
P_C
P_C
L
N_{PC} & T_G
P_C
N_{PC}
H
P_P
H
H
N_{PPM} & T_P
N_{PPM}
T_P
T_G
H
5PM - SUNDAY
12/31/33

Fig. 7.

California coast will finally arrive at the surface in the Los Angeles area breaking up the steady rain.

On the following morning (Fig. 8) the Pp air is seen to lie only a short distance to the north of the area. It has actually moved in over portions of northern California near the coast. This is possible on account of the cold front nature of the occlusion and indicates that a similar condition may be expected upon the arrival of the Pp current over southern California. It will soon fill the Los Angeles Basin displacing the air present there which is now largely a mixture of the unstable Nppm and the original colder Npp thus bring to a close the heavy precipitation. During the morning the steady rain broke up into showers denoting the approach of the Pp air. The bottom cross-section on Fig. 11 indicates the nature of the conditions leading to the dissipation of the storm. The Pp air may be seen moving into the Los Angeles area at the surface and displacing the old Npp air which has occupied it for so long.

The chart constructed for 5:00 PM of this day (Fig. 9) shows the spreading of the Pp current over the Great Basin region as well as its continued movement down the California Coast. Los Angeles by this time is only partly cloudy and all rain has ceased. The only appreciable precipitation recorded at San Diego for the storm occurred during the night at the Pp frontal passage.

The final map of the series based upon 5:00 AM observations Tuesday Jan 2, 1934 (Fig. 10) shows a remnant of the Pp front over Arizona and Utah with clear weather everywhere to the west in the Pp current which has been quickly stabilised by radiation affects over the continent during the night.


H
Pc
Pc
Pp
L
Nppm
Pp
L
Tp
Nppc
Nppc
Tp
Pp
Tp
Nppm
H
Pc
Npc
Npc
Tg
H
H
5AM - Monday
Jan 1, 1934
5AM-MONDAY
1/1/34

Fig. 8.


Pp
Nppm
Pc
H
Npc
L
Npcm
Pc
Pp
Nppc
Nppc
Tp
Npc
TG
H
Pp
H
Tp
H
5 P.M. - Jan. 1,
5PM - MONDAY
1/1/34

Fig. 9.

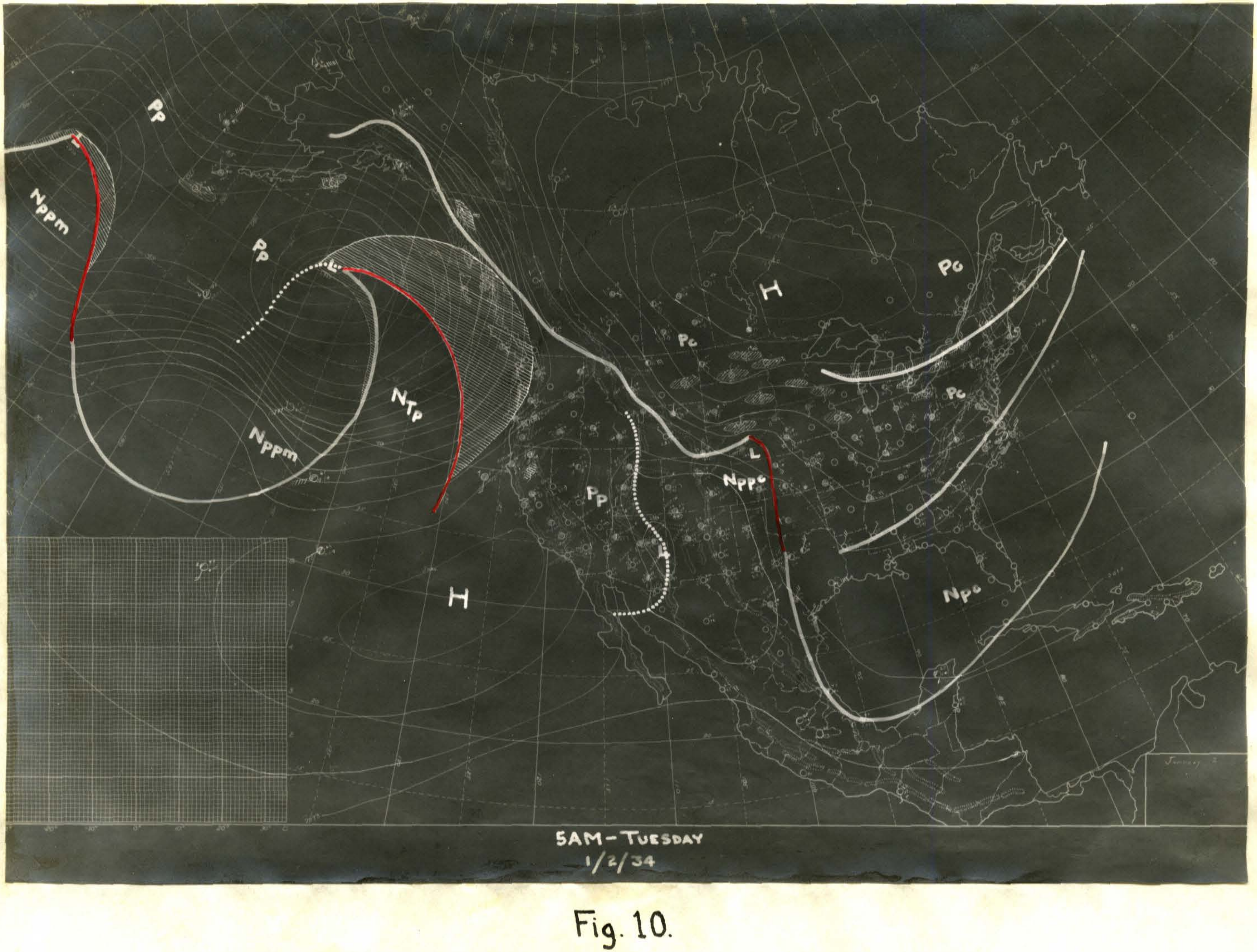


Fig. 10.

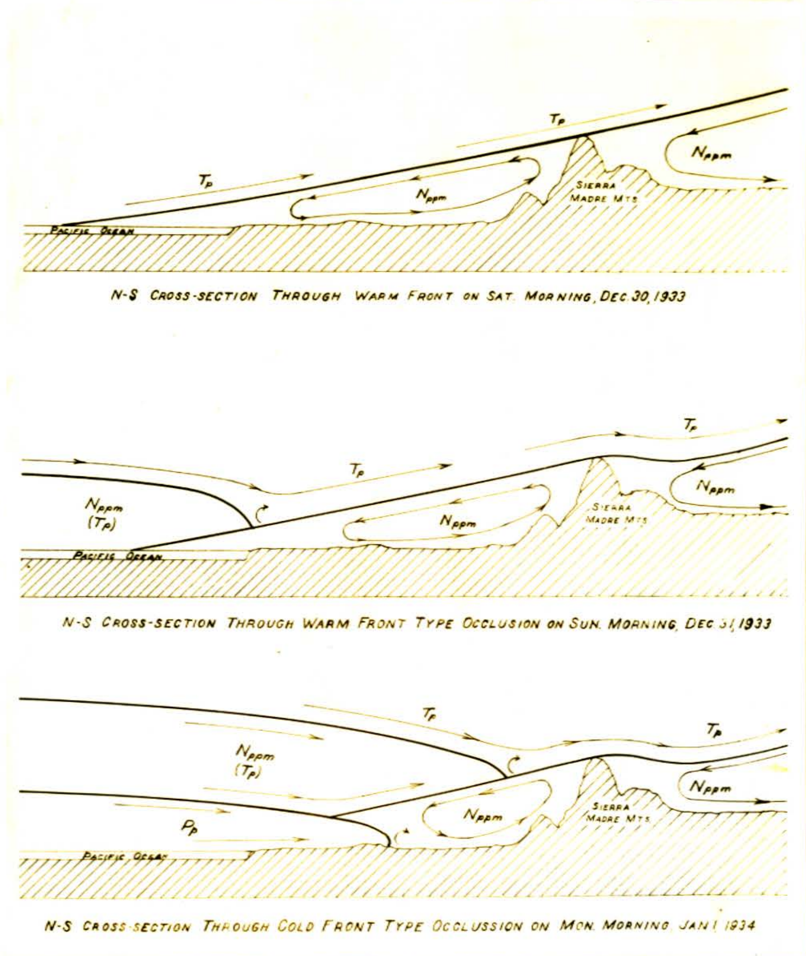

T_p
N_{ppm}
SIERRA MADRE MTS
PACIFIC OCEAN
N-S CROSS-SECTION THROUGH WARM FRONT ON SAT. MORNING, DEC. 30, 1933
T_p
N_{ppm} (T_p)
N_{ppm}
SIERRA MADRE MTS
PACIFIC OCEAN
N-S CROSS-SECTION THROUGH WARM FRONT TYPE OCCLUSION ON SUN. MORNING, DEC. 31, 1933
T_p
N_{ppm} (T_p)
P_p
N_{ppm}
SIERRA MADRE MTS
PACIFIC OCEAN
N-S CROSS-SECTION THROUGH COLD FRONT TYPE OCCLUSSION ON MON. MORNING JAN 1 1934

Fig. 11.

NS
P_p →

Perhaps the most important point brought out by the present study is the value of reliable upper air information in determining the structure of interacting air masses. This enables the forecaster to not only anticipate weather changes with a high degree of accuracy, but also makes it possible to predict in most cases duration and intensity of rainfall. This latter element is of particular importance in the Los Angeles area where considerable run-off accompanies any storm of major consequence. Water is very precious in the region and lowering the levels in reservoirs in anticipation of a severe storm is a rather dubious procedure unless the expected rainfall is forthcoming. However if accurate knowledge of rainfall duration and intensity is known prior to a storm such precautions may be taken to reduce the flood hazard to a minimum. In the present case such advance information would have undoubtedly prevented considerable loss of life and property.