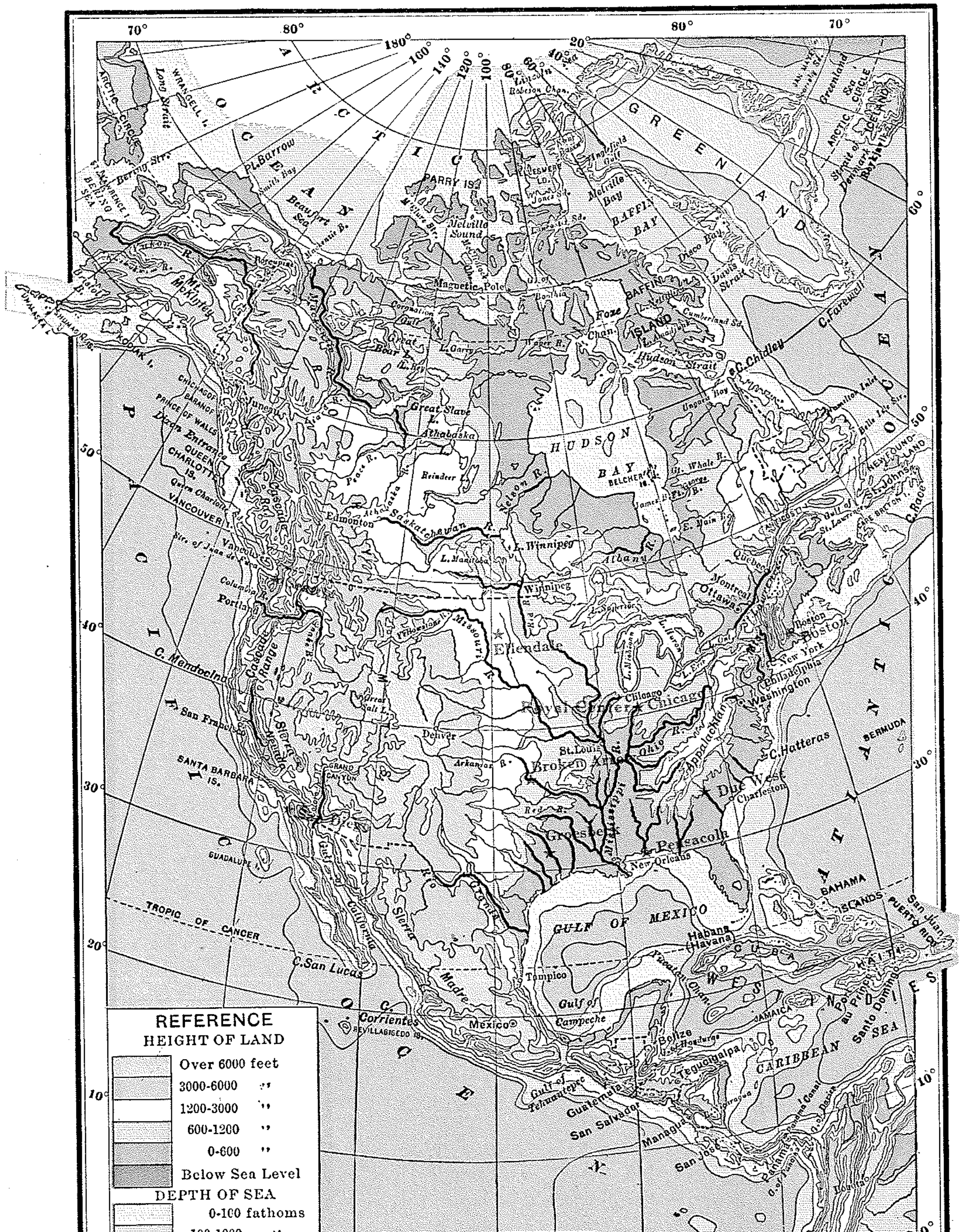
PHYSICAL MAP OF NORTH AMERICA
SCALE OF MILES
0 100 200 400 600 800 1000
Hammond's Physical Map of North America
Copyright by C.S. Hammond & Co., N.Y.
REFERENCE
HEIGHT OF LAND
Over 6000 feet
3000-6000 "
1200-3000 "
600-1200 "
0-600 "
Below Sea Level
DEPTH OF SEA
0-100 fathoms
100-1000 "
1000-2000 "
★ Aerological Stations
110° Longitude West 100° from Greenwich 90°
ARCTIC OCEAN
GREENLAND
BAFFIN BAY
HUDSON BAY
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
CARIBBEAN SEA
TROPIC OF CANCER
EQUATOR
GALAPAGOS IS.
BERMUDA
BAHAMA ISLANDS
PUERTO RICO
CUBA
Habana (Havana)
Chicago
New York
Boston
Washington
Philadelphia
New Orleans
St. Louis
Denver
Mexico
Tampico
Charleston
C. Hatteras
C. San Lucas
C. Mendocino
Great Salt L.
Great Slave L.
Athabaska
L. Winnipeg
Edmonton
Winnipeg
Montreal
Ottawa
Quebec
Juneau
Vancouver
Portland
San Francisco
Ellendale
Royal Center
Broken Arrow
Groesbeck
Pensacola
Due West
Quito
Panama
San Salvador
Guatemala
Tegucigalpa
Managua
San José
Belize
Santo Domingo
JAMAICA
HAITI
NEWFOUNDLAND
St. Johns
C. Race
C. Farewell
C. Chidley
Hudson Strait
Davis Strait
BAFFIN ISLAND
Magnetic Pole
Melville Sound
Beaufort Sea
Pt. Barrow
Bering Str.
KODIAK I.
VANCOUVER I.
QUEEN CHARLOTTE IS.
SANTA BARBARA IS.
GUADALUPE I.
REVILLAGIGEDO IS.
C. Corrientes
Gulf of Campeche
Gulf of California
Yucatan Chan.
Gulf of Tehuantepec
Gulf of Honduras
133

PAPERS IN PHYSICAL OCEANOGRAPHY AND METEOROLOGY

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AMERICAN AIR MASS PROPERTIES

BY

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CAMBRIDGE, MASSACHUSETTS

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CONTENTS

LIST OF TABLES OF AIR MASS PROPERTIES AND PLATES SHOWING CORRESPONDING CHARACTERISTIC CURVES

I. INTRODUCTION

A. Preliminary Remarks on Air Masses

1. *Definition and Use of the Term "Air Mass"*

In this paper the term Air Mass is applied to an extensive portion of the earth's atmosphere which approximates horizontal homogeneity. The formation of an air mass in this sense takes place on the earth's surface wherever the atmosphere remains at rest over an extensive area of uniform surface properties for a sufficiently long time so that the properties of the atmosphere (vertical distribution of temperature and moisture) reach equilibrium with respect to the surface beneath. Such a region on the earth's surface is referred to as a *source region* of air masses. As examples of source regions we might cite the uniformly snow and ice covered northern portion of the continent of North America in winter, or the uniformly warm waters of the Gulf of Mexico and Caribbean Sea. Obviously the properties of an air mass in the source region will depend entirely upon the nature of the source region.

The concept of the air mass is of importance not only in the source regions. Sooner or later a general movement of the air mass from the source region is certain to occur, as one of the large-scale air currents which we find continually moving across the synoptic charts. Because of the great extent of such currents and the conservatism of the air mass properties, it is usually easy to trace the movement of the air mass from day to day, while at the same time any modification of its properties by its new environment can be carefully noted.

Since this modification is not likely to be uniform throughout the entire air mass, it may to a certain degree destroy the horizontal homogeneity of the mass. However, the horizontal differences produced within an air mass in this manner are small and continuous in comparison to the abrupt and discontinuous transition zones, or *fronts,* which mark the boundaries between air masses. Frontal discontinuities are intensified wherever there is found in the atmosphere convergent movement of air masses of different properties.

Since the air masses from particular sources are found to possess at any season certain characteristic properties which undergo rather definite modification depending upon the trajectory of the air mass after leaving its source region, the investigation of the characteristic properties of the principal air mass types can be of great assistance to the synoptic meteorologist and forecaster. We owe this method of attack on the problems of synoptic meteorology to the Norwegian school of meteorologists, notably to T. Bergeron.[1][6] Investigation of the properties of the principal air masses appearing in western Europe has been made in particular by O. Moese and G. Schinze.[2][3][4] The purpose of this paper is to give the results of a similar investigation of the properties of the principal air masses of North America, and to comment on some of the striking differences which appear between conditions here and in Europe.

2. *Classification of Air Masses*

The study of synoptic weather maps indicates that air masses are entities having such definite characteristic properties that they may be classified and studied as distinct types. Since the characteristic properties of an air mass at any point depend primarily upon the nature of its source region, and secondarily upon the modifications of the source properties which the air mass has undergone en route to the point of observation, any classification of air mass types must be based essentially on the air mass source regions, with perhaps a sub-classification based on later modifications of the source properties.

The air mass sources fall naturally into two groups, the tropical or sub-tropical, and the polar or sub-polar. The large areas on the earth of uniform surface conditions and comparatively light atmospheric movement lie almost entirely at high latitudes or at low latitudes. In middle latitudes, generally speaking, we find the zone of greatest atmospheric circulation, or of most intense interaction between the warm and cold air currents, *i.e.*, air masses, from the tropical and polar regions. Consequently in middle latitudes the uniformity of conditions and light air movement which must characterize a source region is generally lacking. Rather than the development of horizontally homogeneous air masses, we find here the rapid modification, in varied forms, with changing environment, of the characteristic polar and tropical air mass types. Thus the basis of any comprehensive air mass classification must be the distinction between the polar and tropical source types, with a further distinction between the modified forms which these principal types acquire in middle latitudes during their later life history.

Assuming that the principal air masses which appear in any definite region, such as North America, have been classified according to their source properties and later modifications, the actual designation of the air mass types may be made either local or general in its connotation. If the typical air masses are designated according to the particular local geographical source region in which they originate, then the classification is entirely local in its significance. If, on the other hand, the typical air masses are designated according to the general type of source region in which they originate, without restriction to any one particular source region, the classification is then general in its significance, and may be applied to the air masses of any locality. For local synoptic weather map work and local forecasting, the local system of air mass classification has the very considerable advantage of being more definite and precise in its significance to the local meteorologist. He is thoroughly familiar with the individual source regions affecting his locality, with all the peculiarities of the air masses coming from these sources, and with the usual modifications which these air masses undergo while en route from their source regions. But for purposes of comparison of the properties of similar air masses in widely separated localities, for climatological or statistical treatment of air masses, or for the study of synoptic charts covering a whole hemisphere, an air mass classification capable of general application is obviously desirable.

In the present discussion of the American air masses a local classification of the air masses is employed. This course is followed because the entire study is based upon the series of North American synoptic maps analyzed at the Massachusetts Institute of Technology during the past three years. This local air mass classification has been employed in the analysis of these maps, and will doubtless be more readily followed by American meteorologists. At the same time the corresponding designations in the general air mass classification suggested by Bergeron[(1)] are given, wherever practicable, to facilitate comparison of the typical American air masses with the corresponding European types.

In the local air mass classification followed in synoptic analysis at the Massachusetts Institute of Technology, three principal groups of air masses are recognized, the group of those whose properties typify their tropical origin (T), the group of those whose properties typify their polar origin (P), and the group of those whose properties are of the transitional type (N). The transitional air masses are those originally of tropical or polar origin, but so much modified since leaving their source regions that their distinction from the newly arrived air masses from the same sources is of synoptic significance. The individual polar and tropical source regions are indicated by subscripts, so that the principal source air mass designations for North America are the following:

(1) P_C (Polar Canadian), from the northern continental area
(2) P_P (Polar Pacific), from the north Pacific area
(3) P_A (Polar Atlantic), from the north Atlantic area
(4) T_G (Tropical Gulf), from the Gulf of Mexico and Caribbean Sea area
(5) T_A (Tropical Atlantic), from the Sargasso Sea area
(6) T_C (Tropical continental), from the southwestern continental area.

The Transitional air masses are classified only according to the original source of the modified air mass, this source being indicated by a two letter subscript. Thus for each of the above source air masses there is the Transitional air mass, N_{PC} (Transitional Polar Canadian), N_{PP} (Transitional Polar Pacific) and so forth. In the actual synoptic practice N_{TC} does not appear, and usually no attempt is made to distinguish between N_{TG} and N_{TA}, which are so similar in properties that they are combined into N_{TM} (Transitional Tropical Maritime). It will be noticed at once that this transitional classification takes no account whatsoever of the nature of the modification of the original air mass properties. The synoptic meteorologist using this system of classification must, from experience, be familiar both with the source properties of these air masses and the typical transformation of each source type to the transitional form. The determination and explanation of these source properties and typical transformations constitutes the main subject of discussion in this paper. But it is with the purpose of making this discussion intelligible to meteorologists who are not familiar with our local classification, and of making the American air mass data more directly comparable with the European data, that the general air mass classification outlined by Bergeron is also introduced in this paper.

In the general air mass classification which Bergeron[1] has suggested for climatological and comparative purposes, and which, at least in its broader features, Moese[2] and Schinze[3] [4] follow in their discussions of European air masses, the essential distinction is still that between the Tropical or the Polar source of each air mass. However, Bergeron carries this zonal distinction one step further, distinguishing between real Arctic (A) and sub-Arctic, or Polar (P) air mass sources in the north, and between sub-tropical (T) and real Equatorial (E) or Trade wind zone air mass sources in the south. Bergeron points out, however, that in northwestern Europe the Equatorial air masses play a negligible rôle, appearing only at high levels in the atmosphere, if at all. As is explained in the discussion following the table on page 7, in the case of the North American air masses the distinction between Polar and Arctic air masses and that between Tropical and Equatorial air masses are both difficult to make and of little significance.

The general air mass classification is carried further by the subdivision of the Arctic, Polar, Tropical and Equatorial air masses into continental or maritime groups, according as the source in each case is a continental or an oceanic region. Since the uniform source regions are always entirely continental or entirely maritime, and since this is *the* essential difference between source regions in the same latitude, this distinction furnishes a satisfactory basis for a general grouping of the air masses from each latitudinal zone corresponding to that gained by indicating by name the individual source region in the local classification. Thus the principal source air masses in Bergeron's classification are the continental Arctic (cA), maritime Arctic (mA), continental Polar (cP), and so on through the mP, cT, mT, cE, and mE groups. Of course such a designation of air masses, while indicating very definitely the type of each air mass, is of necessity less precise in the information it gives to one thoroughly *familiar with the particular sources* in question than is the local classification by direct specification of the source of each individual air mass.

Air masses of Tropical and Polar origin are modified during their later history in either of two essentially different ways. If the air mass moves over a surface warmer than its own temperature at the ground, the tendency is then towards a warming of the lower strata of the air mass, *i.e.*, an increasing thermal instability, and towards an increasing moisture content of the lower strata of the air mass, caused by evaporation from the warm surface. If, on the other hand, the air mass moves over a surface colder than its own temperature at the ground, the tendency is towards a cooling of the lower strata of the air mass, *i.e.*, an increasing thermal stability, and towards a decreasing moisture content of the mass, caused by condensation from the cooled air strata. Evidently Polar air masses must normally undergo the first type of change when modified after leaving the source region, and Tropical air masses the second type. However, there may be exceptions in both cases, and any air mass may for a time be subjected first to the one and afterwards to the other type of influence.

In Bergeron's general air mass classification, modification of the source properties of the air mass, which in the local classification is indicated by the N (Transitional) group, is indicated by a W (warm) or a K (cold, kalt) distinction according as the recent modification of the air mass has been of the second or the first type mentioned above. The warm (W) designation indicates that the air mass is warm relative to the surface it is moving over, the cold (K) designation indicates that it is cold relative to the surface it is moving over. Thus in the general classification of air masses the source designations cP, mP, cT, and so forth, when applied to air masses which have left their source regions, appear in the modified forms cPW (continental Polar Warm), cPK (continental Polar Cold), mPW (maritime Polar Warm) and so forth, depending upon the type of modification which the air mass has undergone during its recent history. It should be stressed that this warm and cold designation has nothing to do with the evidence by the air mass of a high or a low temperature, but only as to the evidence of a temperature near the ground higher or lower than that of the surface beneath. This warm and cold distinction is not always easy to make, as the passage of the air mass from ocean to continent or the transition from day to night may reverse the sign of the difference of the air temperature from that of the surface beneath. In the present discussion the policy will be to consider only the general tendency in the change of properties from one day to the next in the history of the air mass when determining the warm or cold designation. Continued or increasing surface stability from day to day indicates a warm air mass (W), continued or increasing instability from day to day a cold air mass (K). This thermodynamic classification of air masses into warm and cold groups is essentially differential in nature, depending as it does upon changes produced in the air mass properties by boundary surface temperature differences. In contrast to the significance of the source classification which depends upon the conservatism of certain of the air mass properties, the significance of the W and K classification lies in the modification of the non-conservative air mass properties.

This is the essence of Bergeron's general air mass classification which is followed as an alternative system in this paper. It should be noted that in their discussion of the typical air masses of northwestern Europe, Moese and Schinze, while they follow Bergeron's air mass notation, do *not* make the warm and cold distinction in the way that Bergeron does. In their practice, apparently, W and K, instead of indicating the thermal state of the air mass relative to the surface beneath, indicate whether it is warm or cold at the ground relative to adjacent air masses. This seems a less satisfactory method of classification than Bergeron's, for it indicates nothing definite as to the vertical structure of the air mass and is dependent upon the arbitrary choice of the adjacent air mass with which the comparison is made.

The following table (Table I) presents the complete local classification of the principal North American air masses, together with the parallel designations in Bergeron's general classification, which is found in the last column. It will be noticed that the W or K modification appears in the notation of Bergeron's general classification long before the transitional symbol N is used in the local American classification. This follows from the fact that the warm or cold designation is applicable the moment that the air mass leaves the source region, whereas it is the arbitrary practice at M. I. T. to apply the transitional designation only after the air mass properties are significantly modified from the source values. It will also be noticed that no

TABLE I

CLASSIFICATION OF AMERICAN AIR MASSES

Classification by Local Source Regions					General Classification, after Bergeron
Source by		Local Source Regions	Corresponding Air Mass Symbols	Season of Frequent Occurrence	
Latitude	Nature				
P	Continental	Alaska, Canada, and the Arctic	P_C	Entire year	cP or cPW, winter cPK, summer
		Modified in southern and central U. S.	N_{PC}	Entire year	cPK
	Maritime	North Pacific Ocean	P_P	Entire year	mPK, winter mP or mPK, summer
		Modified in western and central U. S.	N_{PP}	Entire year	cPW, winter cPK, summer
		Colder portions of the North Atlantic Ocean	P_A	Entire year	mPK, winter mPW, spring and summer
		Modified over warmer portions of the North Atlantic Ocean	N_{PA}	Spring and summer	mPK
T	Continental	Southwestern U. S. and northern Mexico	T_C	Warmer half of year	cTK
			N_{TC}	Negligible	
	Maritime	Gulf of Mexico and Caribbean Sea	T_G	Entire year	mTW, winter mTW or mTK, summer
		Modified in the U. S. or over the North Atlantic Ocean	$N_{TM}(N_{TG})$	Entire year	mTW
		Sargasso Sea (Middle Atlantic)	T_A	Entire year	mTW, winter mTW or mTK, summer
		Modified in the U. S. or over the North Atlantic Ocean	$N_{TM}(N_{TA})$	Entire year	mTW

attempt is made in Table I to distinguish between Arctic and Polar or between Tropical and Equatorial sources, nor to introduce this distinction in giving the parallel general classification. In order to explain this omission it is necessary to sum up rather carefully certain features of the physical geography of North America. The writer has already had occasion to mention briefly(5) some of the essential differences between the geography of the continent of Europe and that of North America and the significance of these differences for the prevailing air mass types. Further study and comparison of the typical air masses of the two continents adds greatly to the apparent significance of these geographical differences.

There are four essential facts concerning the geography (see Plate I) of the North American continent which are of fundamental importance in explaining the characteristic differences between the American and European air masses:

(1) The U. S. proper, within whose boundaries are located all of the aerological stations whose data are used in this discussion, lies roughly between the 30th and 49th parallels of latitude. Three of the eight aerological stations referred to, Groesbeck, Pensacola, and Due West, lie between the 30th and 35th latitude circles, and the northernmost stations, Ellendale and Seattle, lie at about 47°. The German aerological stations, on the other hand, whose data were used by Schinze, lie roughly between 48°N. (Munich) and 53°N. (Hamburg). Bergeron likewise, who really initiated this type of air mass investigation(6), was originally concerned primarily with the properties of the principal European air masses north of latitude 50°. The significance of this difference lies in the proximity of the European stations to the Arctic air mass sources, and the proximity of the American stations to the Tropical sources.

(2) With respect to the U. S., the land areas (North American continent) broaden out to the north, and are sharply contracted to the south. This means that for the eastern and central U. S. the direct Polar and Arctic air mass sources are essentially continental, while the direct Tropical air mass sources are essentially maritime. With respect to Germany, on the other hand, the great land areas lie to the east (Eurasia) and south (Africa). Thus her direct Polar and Arctic air mass sources are maritime (though continental cold air from the northeast or east is of frequent occurrence) and her direct Tropical air mass sources are continental (though the Mediterranean doubtless importantly modifies at least the lower strata of the dry hot air masses which move northward from the great desert regions of northern Africa).

(3) The entire western third of the North American continent from Mexico to the Alaskan Peninsula is high land with numerous towering mountain ranges. So effective is this orographical barrier that little if any air from the Pacific Ocean can reach the eastern or central U. S. without having ascended to at least 2000 m. elevation. On the other hand, the entire eastern and central U. S. lies completely open to Tropical maritime air from the south or southeast (Gulf of Mexico, Caribbean, and Sargasso Sea). In Germany again the condition is reversed. The mountains lie to the south and southeast. Thus the Mediterranean Sea as a source of Tropical maritime air is largely cut off. Tropical air currents from the south lose most of the moisture they may have acquired over the Mediterranean Sea, reaching central Germany with the typical dry Föhn characteristics which probably closely resemble the properties with which they left the African deserts. On the other hand, Germany lies completely exposed to maritime air masses from the Atlantic advancing from any direction between southwest and north.

(4) The surface temperatures of the Gulf of Mexico, Caribbean Sea, and eastern Sargasso Sea (principal sources of Tropical maritime air in the eastern and central U. S.) are abnormally high even for the low latitudes. The ocean surface temperatures along the Pacific coast, broadly speaking, run parallel to those along the western coast of Europe. In the south these surface temperatures are rather low for the latitude, especially in summer. This effect is more marked

along the coast of California than along the corresponding coast of Portugal in Europe. Further north the ocean surface temperatures become relatively warmer for the latitude, until in the region of the Aleutian Islands (south coast of Alaska) as off the Scandinavian west coast of Europe, there are found two of the most abnormally warm ocean regions known.

From a consideration of these facts may be drawn certain conclusions about the prevailing air mass types of the eastern and central U. S. in contrast to the prevailing European types. And we shall see presently that these conclusions are justified further by the detailed study of the typical air mass properties.

In the first place, the distinction between Arctic and Polar air masses seems scarcely to be justified in the U. S. Either the majority of our winter air masses from the north are of Arctic origin, or else the Arctic-Polar distinction cannot be made. The entire North American continent from 50° northward is almost equally effective in winter in producing continental cold air masses. The characteristics of these cold air masses resemble those of the continental Arctic air which reaches Germany by way of Russia; they are very cold but apparently very shallow. I shall return later to the question of the justification of referring to any such air masses as Arctic. On the other hand, the North American Polar maritime air masses, as indicated by Seattle aerological ascents, do not even approximate in coldness Schinze's Arctic maritime air masses, which are of great depth and very cold aloft. But at upper levels, above $3\frac{1}{2}$ or 4 km., they approximate both in temperature and in moisture the condition of the American Polar continental air masses as shown by ascents at Ellendale in the same latitude. For these reasons it has seemed best to eliminate the term "Arctic" in the discussion of American air masses, though it is by no means proved that real Arctic air may not on occasion advance as far south as the U. S. proper. It can be stated only that during the winter investigated it did not appear with sufficient definiteness to be distinguishable from the Polar air masses. To conclusively prove its appearance observations extending to above 4 km. are desirable.

Just as we find the Arctic-Polar distinction scarcely justifiable in the case of the American air masses, so is the Tropical-Equatorial distinction equally difficult. Practically all Tropical air in the eastern and central U. S. comes directly from the warm waters lying to the south and east. Tropical continental air is of little significance owing to the lack of large land areas to the south, and Tropical maritime air from the south Pacific Ocean plays an almost negligible rôle in consequence of the mountain barriers to the west. But this predominating source of our Tropical air masses is actually equatorial in its characteristics, and nearly so in latitude. Furthermore, as we shall see later, a great part of the time the air currents reaching the eastern U. S. from these regions are probably of true Equatorial origin. But whether they have their actual origin in the Equatorial Trade wind system or not, their properties are not to be distinguished from the Equatorial, owing to the Equatorial warmth of the waters at their source. Consequently the term "Tropical" as applied to our maritime air masses from the south indicates properties which Bergeron or Schinze would correctly designate "Equatorial." Therefore in the present discussion of the characteristic properties of American air masses, only two principal classes are considered, Polar and Tropical, instead of the four possible ones. The immediate juxtaposition in winter of Polar continental air masses of Arctic coldness and Tropical maritime masses of Equatorial warmth accounts for the excessive local temperature fluctuations which frequently occur in the U. S. in winter within 24 hours. Such changes have been known to exceed 40°C., the entire effect being caused simply by the change of air mass.

There are a number of conditions which are more or less frequently met with in the synoptic study of air masses which may locally or temporarily render difficult the proper classification of an air mass. In particular the disturbing effect on the air mass properties of the surface over which the mass is moving and the consequent formation of a ground layer with its own peculiar properties cannot be overlooked. When this influence is regular and continuous, it gradually affects the entire mass until it becomes characteristic for the properties of the mass. On just such influences depend the thermodynamic "warm" and "cold" classification of air masses already mentioned. But mechanical turbulence produced by surface irregularities, and the radiational effects of a single night and insolational heating of a single day often produce ground layers with properties which may be neither permanent nor characteristic of the air mass, and which consequently must be allowed for in the discussion of the air mass properties in particular cases. Especially troublesome are the large radiational-insolational effects at the surface in dry continental air masses during the warm season. In the central U. S. this diurnal surface temperature change may amount to more than 20°C., may produce an afternoon unstable layer more than 2 km. thick, and may change the air mass from the warm to the cold type. Föhn and subsidence effects are also frequently to be noted, but they are usually definitely characteristic of certain air masses under certain conditions, and belong as such to the characteristic air mass properties, not being to any great extent diurnally variable.

One additional difficulty which must be recognized in defining characteristic air mass properties is the frequently non-discontinuous transition of these properties at the front between masses. In summer, when movements are slow, this is particularly noticeable. In one or two instances the front passage, as indicated by wind shift and pressure change, at whatever level the seat of this pressure change may have been located, preceded by some hundreds of miles the appearance at any level in the lower troposphere of any noticeably colder or drier air. This began to make its appearance at upper levels first, some 24 hours after the front passage, causing instability thundershowers. Although such extreme cases are rare, it was found preferable even in winter to wait 24 hours after the front passage if it was desired to determine the true characteristics of the incoming air mass, as there is usually some mixing and a more rapid transformation of the air mass properties in its forward portion.

A somewhat similar difficulty occasionally occurs when a warm air mass overruns a shallow layer of colder air. It frequently happens in the central U. S. that such a warm front becomes almost horizontal over a very large area, practically without the formation of any precipitation. When this happens the thin surface layer of cold air becomes slowly transformed and eventually lost, probably by slow mixing with the warm air current. But at the surface there is a gradual transformation of the meteorological elements from the values characteristic of one mass to those of the other, during which they truly represent neither one. In the early stages of such a transition a cold air layer only 300 or 400 meters thick, yet 10°C. colder than, and with less than half the specific humidity of, the warm air above, may extend for many hundreds of miles, and persist in modified form for more than 24 hours. In such cases of air mass mixing or of failure of the meteorological front to coincide with any air mass boundary, it is not permissible to classify the air masses concerned as of any one type.

B. Discussion of Observational Material Used

For the present investigation of American air masses the winter period, December 1929–March 1930, inclusive, and the summer period July–August 1930, were chosen. In spite of the restriction of the investigation to winter and midsummer conditions, and the shortness of the periods selected, the amount of routine work involved was almost prohibitive. For these periods the synoptic maps were based on the regular a.m. and p.m. U. S. Weather Bureau broadcasts for North America, and a good scattering of pilot balloon observations. Material is a little scanty, however, in the far West, and especially unfortunate is the absence of ship reports from the

Pacific Ocean. Consequently the discussion of conditions on the Pacific coast is always more uncertain and less thorough than for the eastern and central U. S. The mountainous topography of the western third of the country adds to the uncertainty resulting from insufficient observations in this region.

The aerological material, which forms the real basis of this study, is from nine stations, five of them being Weather Bureau kite stations, three of them Navy aeroplane stations, and one private aeroplane station. The material from the Weather Bureau stations has the advantage of being regular for each station through both periods, but the disadvantage so common with kite and captive balloon ascents, that the average height reached is rather low. Recently aeroplanes have largely taken the place of kites in the Weather Bureau aerological soundings, but that change had not been made when this study was begun. The five kite stations which have been used are Ellendale, N. D., Broken Arrow, Okla., Groesbeck, Tex., Royal Center, Ind., and Due West, S. C. The aeroplane ascents at the three Navy stations are rather irregular in distribution, and average about 3½ or 4 km. in height. From Pensacola, Fla., there are observations for part of the summer period only; from San Diego, Cal., for part of the winter period only; and from Seattle, Wash., for part of the summer period and part of the winter period. Part of this material had been evaluated in the course of some thesis work at M. I. T. by Lieutenants Raftery and Graesser, who were obliging enough to turn over to me their computed data.

The private station is that of M. I. T. at East Boston Airport. Here regular daily aeroplane ascents are made with particular care in the calibration of the meteorograph and the evaluation of the record. Unfortunately this M. I. T. station was not established until the autumn of 1931, and does not operate during the summer, but since no other aerological material was available for the northeastern part of the country, it seemed advisable to use Boston ascents from the winter of 1931-32 in order to determine the typical air mass properties in New England for comparison with the results obtained in other parts of the country in the winter of 1929-30. Apart from the fact that the Boston ascents averaged higher than those of any other station, there were some very interesting differences found between the typical air mass properties in New England and in other parts of the country.

Unfortunately no sounding balloon ascents were available for the period of this investigation, and as a general rule the aerological ascents do not extend high enough so that any conclusions may be drawn as to the vertical extent of the typical American air masses. For the most part the 3 or the 4 km. level is as high as any statistical treatment of the air mass properties can be extended.

C. Treatment of Observational Material

The careful analysis of the synoptic charts for 8 a.m. and 8 p.m. during the two periods, one winter and one summer, covered by this investigation, furnished the basis of the identification and classification of the air masses investigated. Each individual aerological ascent was carefully evaluated and plotted on the Rossby diagram. The actual procedure in the evalution of these ascents was to compute the water vapor-dry air ratio w, the potential temperature for the partial pressure of the dry air, θ_D, and the equivalent potential temperature, θ_E, for each significant point. A detailed discussion of these computations cannot be given in this paper. They were accurately made by the method and tables recently developed by C.-G. Rossby(7).* The quantity w, expressed in grams of water vapor per kg. of dry air, is for all practical purposes the same as the specific humidity q, expressed in grams of water vapor per kg.

* The definition of the equivalent potential temperature concept in its present form and its first application to the identification of air masses was made by C. W. B. Normand in a paper which appeared in the *Indian Meteorological Memoirs* in 1921, Vol. XXIII.

of moist air. The quantity θ_D differs seldom by much more than one degree C. from the ordinary potential temperature θ. The quantities w and θ_D, instead of q and θ, are used in order to facilitate the computation of the equivalent potential temperature, θ_E.

With the aid of the synoptic charts a number of good aerological soundings characteristic of each principal air mass type were selected, when possible, from all of those worked up for each station. From these selected air mass soundings there were computed for each station tables showing the average value of temperature T, of w, and of θ_E for each air mass type, for the summer and for the winter, at the ground and at each km. level above ground. These tables furnish the basis of the discussion of the characteristic properties of the air masses. The source properties of each air mass type are discussed first in terms of the nature of the particular source region. Usually the properties shown by the aerological station nearest the source region are accepted as typical of the source properties. Then an attempt is made to explain the modifications of the source properties of the air mass which are found at the more distant aerological stations, in terms of the influences to which the air mass has been subjected during its later history. Finally, a comparison is usually made of the air mass properties with those of the corresponding European air mass, as reported by Schinze.

For the graphical representation of the typical air mass properties the characteristic curves of the Rossby diagram are relied upon entirely. These curves were plotted for all of the more than 1500 soundings evaluated. This method of graphical representation of air mass properties was chosen, after careful consideration, as presenting more clearly than any other type of curve the significant features of air mass vertical structure. On this diagram the coördinates are w (plotted linearly as abscissæ) and θ_D (plotted logarithmically as ordinates). The θ_E isotherms then appear as almost straight sloping lines. (See for example Plates II–V). If the successive significant points of an aerological sounding for which the values of w and θ_D have been computed are plotted on this diagram, the line joining these plotted points is the "characteristic curve" for the ascent. These curves have been found[7] to be a markedly conservative and characteristic air mass property. A few of the significant properties of the characteristic curve may be summarized very briefly at this point.

(1) If the significant points lie close together, the air mass is vertically homogeneous, or well "mixed." If the air mass is unsaturated and perfectly mixed, the curve contracts to a single point. If it is saturated and perfectly mixed, the curve runs parallel to the θ_E isotherms.

(2) If the significant points lie widely scattered, the air mass is markedly stratified. If the spread of the points is vertically upward, the stratification is thermal; if it is horizontal, the stratification is one of moisture.

(3) A negative slope of the curve with increasing elevation indicates a superadiabatic lapse rate. A slope closer to the horizontal than that of the θ_E isotherms indicates a condition of potential instability, a condition which will supply convective energy if sufficient vertical lifting of the air stratum takes place. The amount of lifting necessary before this energy source can be drawn upon depends upon the relative humidity of the potentially unstable stratum. This condition is usually referred to in this paper as one of *conditional instability*.

(4) A subsidence inversion is indicated by a vertical elongation of the curve with a slope to the left, a warm front inversion by a vertical elongation of the curve with a slope to the right. In order to judge the elongation of the curve effectively, it is necessary to indicate by a number the elevation above the ground at each significant point.

For the graphical representation of air mass properties Schinze uses the thetagram (θ_E plotted against elevation). Although this type of curve has the advantage of representing directly vertical depth, it has also the great disadvantage of not distinguishing between the temperature and the moisture distribution. A moderate warm front inversion and a sharp subsidence inversion may well be indistinguishable in this type of curve.

In the discussion of air mass types in this paper characteristic curves for each type are presented, curves which are based on the average values of θ_D and w found for the different km. levels at each station. (See for example Plates II-A, III-A, IV-A, and V-A). In the case of these average curves the aerological station is indicated by an initial at the base of the curve, and the elevation of each significant point is indicated in km. by a small number placed beside it. The stations whose initials may appear are the nine listed on p. 11. In the case of the curves for individual ascents, the height of the significant points in decameters is placed beside each point, and wherever the data were available, a small arrow is drawn from each of these points indicating the wind direction and an attached small number gives the velocity in m.p.s. The station is again indicated by its initials, a small subscript on the initial indicating the month and a small superscript the day of the ascent. The type of air mass in these cases is indicated by the usual air mass symbols immediately after the initial of the station. Type air mass curves for individual ascents appear in this form in Plates II-B, II-C, III-B, IV-B, and V-B. There are also individual characteristic curves presented for two short periods of detailed analysis (Plates XIX-C, XX, and XXX) which differ from the air mass type individual ascents only in that the station initial subscript indicates the day of the month, and the superscript the hour of the day at which the ascent was begun.

The last part of this paper presents a brief discussion of an interesting winter synoptic situation and a corresponding discussion of a summer situation. For these periods there are presented analyzed synoptic charts, charts of winds at upper levels, and all aerological ascents in the form of characteristic curves on the Rossby diagram. The presentation of this material is explained at the beginning of the discussion (p. 71). This discussion is intended to illustrate the application of the methods followed throughout the period of this investigation to a definite situation of interest and to demonstrate the practical usefulness of this method of attack on the problems of synoptic meteorology, both for winter and for summer conditions.

At this point I want to acknowledge my indebtedness to Professor Rossby, in charge of the M. I. T. Meteorological Course, for valuable suggestions and coöperation in the preparation of this paper, to Mr. Emmons and Mr. Lichtblau of the Meteorological Course for assistance in the evaluation of aerological data, and to my father for suggestions and assistance in the revision of the manuscript.

II. AMERICAN AIR MASS PROPERTIES

A. The Polar Continental Air Masses — Winter

1. *Source Properties of the P_C Air Masses in Winter*

For the U. S. proper, the one prime source of Polar continental air masses is the North American continent from Canada northward over Alaska and the neighboring Arctic. This entire region is protected from invasion by the warm maritime air of the north Pacific by the lofty mountain ranges which extend the entire length of the continent in the west. Occasionally a general flow of maritime air from the north Atlantic far to the east may penetrate into this region in winter by way of northern Labrador and Hudson Bay, but this maritime air is cold to start with, and after such a long passage over Arctic regions it is characterized by a dryness and coldness exceeded only by the continental air it is displacing. Furthermore, this entire vast region from southern Canada northward over Hudson Bay and the Arctic Ocean is uniformly covered with ice and snow throughout the winter season. The high latitude, snow cover and protection, at least at low levels, against the warm maritime westerly winds of the North Pacific make this region ideally suited to a general stagnation of the atmospheric circulation and to extreme radiational cooling of the lower strata of the atmosphere. In other words, it is ideally suited to the formation of uniformly cold dry air masses of great extent. The markedly characteristic properties of our Polar continental air masses in winter, then, are to be explained in terms of the properties acquired in this source region and the later modification of these source properties in the course of the passage of the air masses to other regions. In summer this source region is radically different in nature, so that the observations here made do not apply at all to summer conditions.

From the nature of the source of the American Polar continental air masses in winter quite definite conclusions may be drawn as to their properties at the source. In the first place, they should be extremely cold at the ground, probably with a large temperature inversion extending from the ground to a considerable elevation. This marked stability is the result of extreme radiational cooling of the snow surface through the dry clear air above, with consequent cooling of the superincumbent air strata from beneath, and the general lack of air movement and of any form of turbulence tending to effect mixing. Hence the Polar continental masses must definitely be classed as thermodynamically warm air masses, and designated as cPW. In our local notation they are referred to as P_C (Polar Canadian, continental). Furthermore, due to the extreme coldness of this cPW air, its moisture content is of necessity very small. Since the temperature increases from the ground up to a considerable elevation, a parallel distribution of moisture may be looked for, if it is assumed that the very low surface temperatures are the result of radiational cooling of originally somewhat warmer air. In the coldest ground stratum the specific humidity will be that representing saturation at the existing low temperatures. In the course of the radiational cooling of the lower strata the specific humidity has been reduced by heavy frost deposits and by the formation of Arctic haze or frost smoke, which sometimes assumes the proportions of a dense ice crystal fog. In fact, it is by no means unusual in the coldest cPW air even as far south as the U. S. to have a dead calm or very light wind and dense fog reported with a temperature lower than −30°C. An instance will be found on the map for January 17, 8 a.m., for Lander, Wyoming, with a temperature of −38°F. (See Plate XV.) If the vertical distribution of moisture in cPW air is explained in this way, we should expect the relative humidity (f) to remain near 100% well up into the inversion, with a corresponding increase in the specific humidity (q), or the moisture dry-air ratio w. At higher levels, towards the top of the radiationally cooled stratum and above, we should expect the relative humidity as well as q and w to decrease steadily to lower values. But at all levels the coldness of this air will be such that w will remain below 1 g. per kg., and consequently the difference between the potential temperature θ and equivalent potential temperature θ_E will be negligibly small. Each will increase very rapidly to the top of the temperature inversion, and more moderately beyond. Apart from heavy frost deposits and possible frost haze or even ice crystal fogs near the ground, the cPW air masses at the source will be lacking in condensation forms. The skies should be characteristically cloudless at upper levels, at least to the top of the air mass.

Unfortunately we have no station furnishing upper air data from within this source region by which to verify the correctness of our assumptions as to the source properties of our winter P_C air masses at upper levels. However, the station of Ellendale, N. D. (see Plate I) is located not far south of this region, and lies freely exposed to all direct air mass movements southward from the source. Probably Ellendale, with one or two minor modifications, may be considered then as giving fairly representative values of the source properties of our winter P_C air masses. The possible modifications which should not be forgotten in considering the Ellendale data are the undetermined amount of subsidence which may have occurred in the P_C mass en route to this point, and the frequently unquestionable appearance of a shallow turbulence layer next to the ground in consequence of the appreciable wind velocity pertaining to the southward movement of the mass. The formation of a surface turbulence layer has the effect of raising the temperature and specific humidity at the ground and lowering the relative humidity from the values originally belonging to the air mass. This effect is always very definitely to be observed at Ellendale in fresh outbreaks of P_C air when good wind velocities prevail. Later, when the wind has become light, temperature and specific humidity always fall at the ground, while the temperature tends to increase aloft. Since the mean values given in Table II for Ellendale are based on averages of both types of ascents, the surface temperature and specific humidity found there are doubtless somewhat higher than those characterizing the P_C air at its source, but not enough so to disguise the true source characteristics of the air mass. The mean values of temperature, water vapor ratio w, and equivalent potential temperature θ_E aloft, as given by 10 typical P_C air ascents at Ellendale during January, 1930, will be found in Table II. The θ-w characteristic curve for these same mean values will be found in Plate II-A, and a typical individual curve in Plate II-B. The weather map of the morning on which this typical flight was made is shown in Plate XV.

The mean values of T and w at Ellendale shown in Table II verify in every particular the expected source properties of our P_C air in winter. In particular will be noted the marked temperature inversion amounting to more than 6°C., the top of which is somewhere above the 2 km. level. The reason for the smallness of the inversion and of the moisture increase in the first km. is to be found in the frequent presence of the turbulence layer. In those ascents with very light winds, the inversion is marked from the ground up, and the relative humidity at the ground is usually more than 90% instead of the 82% found for the average.

There is another question which naturally presents itself in connection with the explanation which has been offered for the marked temperature inversion prevailing in the P_C air masses, namely: How far is this inversion the result of the original radiational cooling of this air at its source, as already suggested; or how far may it be attributed to subsidence within the cold air mass either at the source or in the course of its progress to Ellendale; or finally, to what extent may it be due to the presence aloft of an air mass of different source and properties? The possible explanation of the inversion as primarily the result of subsidence is at once eliminated by consideration of the moisture distribution. If the warmth of the upper strata in this case were the result of subsidence within an air mass originally of normal lapse rate or even isothermal,

TABLE II

P_C AIR MASSES—WINTER (cP, cPW, AND cPK)

ELEVATION ABOVE SEA LEVEL (km)	STATION																			
	ELLENDALE				ROYAL CENTER				BROKEN ARROW				GROESBECK				BOSTON			
	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A
Surface	−26.1	0.32	82	250	−22.5	0.45	91	251.5	−14.8	0.95	86	260.5	−13.0	0.9	70	261.0	−6.3	0.9	43	267.0
1	−25.3	0.35		256	−19.5	0.48		262.0	−8.8	1.15		275.3	−9.3	0.9		274.0	−14.3	0.6		268.0
2	−20.1	0.60		272	−15.8	0.48		276.5	−8.0	1.20		285.7	−1.3	1.2		293.7	−18.0	0.5		274.3
3	−21.5	0.50		280	−18.0	0.85		286.0	−10.3	1.03		294.3					−23.0	0.3		279.0
4	−25.4	0.45		288													−29.0	0.2		283.3

the w values would have to show a decrease, or at most constancy, with increasing elevation. The observed values, indicating a relative humidity of approximately 80% throughout the air mass, would have required originally a considerable degree of supersaturation of the air stratum now at the 2 km. level if subsidence alone is to account for its present high temperature. Hence the indications of the water vapor are that comparatively little subsidence has occurred in the air mass by the time it has reached Ellendale, N. D. On the other hand, there is another possibility which must be borne in mind in the case of these very cold P_C air conditions. The hair hygrometer (humidity element of the standard meteorographs) is unreliable at very low temperatures. It is comparatively insensitive, showing a large lag, it is not known exactly how much. Thus there is a possibility that the constant high relative humidity and consequent increase of specific humidity with increasing elevation observed generally in the very cold P_C air masses may be due entirely to consistent instrumental errors. It is hoped that investigations now being carried on at M. I. T. will clear up this question. If it should be found to be the case that the relative and specific humidities at upper levels in the P_C air masses are really lower than indicated, then the principal objection to an explanation of the formation of the temperature inversion by subsidence would be removed, and it could be assumed that even in the source region the subsidence factor is to be considered in explaining the stability of the P_C air at upper levels.

To prove that the upper warmer and moister portion of our P_C masses may not really be air of a different source and history is not so easy. But at least this much can be said, that the P_C outbreaks at Ellendale always show marked uniformity of movement at all levels. The wind velocity between the one and three km. levels in these outflows usually remains almost constant. If the upper strata of such an outflow are of another source, there is no indication of it to be found in the vertical wind distribution at Ellendale.* This fact together with the apparent approximate coincidence of the vertical moisture distribution with the saturation values at all levels seem to indicate a homogeneous air mass which has been cooled at all levels, principally from below. The extremely low temperatures at the ground are purely the result of radiational cooling and in themselves are no justification for assuming that the air mass is of true Arctic origin, though it may frequently be so. This point of view is in opposition to that of Schinze[3] regarding the air masses which he classifies as continental Arctic (cA). The principal European source of continental cold air extends from western Russia eastward into Siberia and northward into the Arctic. The winter air masses from this source are presumably (Schinze gives no figures for them) very similar in their properties to our winter P_C masses, but probably not quite so cold and not quite so dry, in Germany. However, Schinze chooses to designate such air masses as cA, but to consider the Arctic air as only some $1\frac{1}{2}$ or 2 km. thick, and to assume that the warmer air above is of Polar instead of Arctic origin, because it is not so cold at high levels as the deep outflows of air reaching Europe directly from the Arctic after traversing the north Atlantic Ocean. But the relative coldness of the surface air does not necessarily stamp it as of Arctic origin, as we have already seen, nor does the relative warmth and greater moisture of the upper strata of the cold continental air necessarily exclude the possibility of its Arctic origin. An increase of temperature and moisture with elevation is a normally prevalent condition in the Arctic in winter, probably the result of radiational cooling of the lower strata, and the frequent influx

*Of course, it may occasionally happen that we do find another air mass above the P_C at only 2 or 3 km. elevation. But this happens rarely, and when it does the transition is so obvious that the conditions cannot be confused with those of the typical P_C ascents. The Ellendale ascent for March 4 (Plate II-B) shows a typical early spring N_{PC} condition at Ellendale to $2\frac{1}{2}$ km., and typical Polar maritime air from the Pacific above that. In the N_{PC} mass the specific humidity decreases steadily from the ground to the very low values characterizing P_C air in winter at 2400 m., while above that level there is an increase of w to values markedly above the winter limits for P_C air, together with a shift of wind from NW to WNW, two facts which seem indisputably to establish the Pacific Origin of the upper air strata.

aloft of warmer air, possibly of maritime origin, which cannot displace the colder air at the ground. In the particular case of our P_C air source, which is Arctic in its properties, the high mountain ranges extending along the entire Pacific coast constitute a further effective barrier to the inflow of warmer maritime air at low levels. In fact, when this region does warm up in winter, the warmer air comes in by either of two indirect routes. Sometimes it circles around the Alaskan Peninsula and moves up the McKenzie Valley from the north. This is the more frequent route. The first evidence of the coming change which is to be observed on the weather map is a rapidly falling barometer and rising temperature at Point Barrow, Alaska, then some 12 to 24 hours later at Aklavik and on down through the British Northwest Territory. The temperatures at Point Barrow and Aklavik often become surprisingly high with this type of warm air inflow, the rise sometimes exceeding 30°C., but a gradual cooling of the warm air current takes place as it moves southward. The region just behind the coastal mountain ranges is the last to be affected by the warm air, so that a narrow ridge of high pressure is likely to persist in this region. The other route by which warm air may occasionally enter our P_C source region is from Davis Strait west northwestward around Hudson Bay, and then southward. This happens rarely, when a deep stationary depression lies east of Hudson Bay, but it may be very effective. An excellent example of this development is shown on the weather maps in Plates VI through XVI. Here again the warming-up effect gradually diminishes as the warm current passes through the cold continental region. It is quite probable, however, that relatively warm air frequently moves into the P_C source region at high levels above the mountains from the west without making its influence much felt at the ground. If this is the case, then the warm upper strata of the P_C air masses, although coming from the same source region as the cold lower strata, nevertheless would not have been exposed to the same extreme conditions for the same length of time that the surface strata have been.

The Rossby diagrams for P_C air (cPW) at Ellendale (Plate II, A and B) show the typical extremely characteristic form of the θ-w curve for this type of air at its source.(7) And this type form is characteristically conservative at least as long as the air mass remains over a snow-covered surface. The curve is nearly vertical, showing a small increase of w at intermediate levels, but with w values less than a gram at all levels. The potential and equivalent potential temperatures increase some 40°C. in 4 km.; consequently the existence of any mechanically produced turbulence effects rapid transfer of heat downward in the turbulent layer.

There is nothing very distinctive about the synoptic situation which leads to the outflow southward of P_C air from the source region in North America. Usually the outbreak is preceded by a gradual building up of high pressure and low temperatures in the source region, often without any very obvious atmospheric movements. Sometimes the cold air outbreak follows quickly on the first appearance of the cold anticyclonic circulation in the north, but often there is an extended delay, during which cold air surges in the north seem on the point of breaking out, only to recede again. Sometimes the final outbreak follows on the passage inland from the Pacific Ocean of a disturbance usually already occluded in the Aleutian Island region. Other times the cold air suddenly advances without any very obvious disturbance to start it moving. Usually, however, when this happens, one or more disturbances are likely to form along the cold front as it advances southward. This is especially likely to happen as the cold air pushes southward to a point where it begins to come in contact with warm moist air from the south, particularly Tropical maritime air from the Gulf (T_G). The disturbances usually appear first as flat wave formations on the cold front, but are likely to develop rapidly into intense occluding cyclones which greatly accelerate the movement of the P_C air behind them to more southerly latitudes. In such a development the advance of the P_C air mass and cold front is likely to be checked at first by the warm air current. Then very quickly an extensive overrunning of the P_C air by the T_G current takes place. The overrunning circulation tends to develop cyclonically or counter clockwise, with heaviest precipitation extending far back of the cold front. As J. Bjerknes[8] has recently pointed out, this type of overrunning is to be expected only when the warm current is unstable; but as we shall see presently marked conditional instability is always characteristic of our Tropical air from the Gulf. Refsdal[13] was the first to call attention to the importance of the rôle which conditional instability in the atmosphere may play in the development of frontal disturbances and in the regeneration of old occluded disturbances. The writer is inclined to the belief that the conditional instability of our T_G air masses (Feuchtlabilität) is a very important factor in the control of the interaction between the warm and cold air masses and the stability or the tendency to occlusion shown by wave disturbances on the cold front between such air masses. An excellent instance of the weather sequence with the gradual advance of a cold front followed by an extensive P_C air mass may be found on the weather maps and upper air data reproduced in Plates VI to XI, inclusive. Following the first sweep of the cold air southeastward to the Gulf of Mexico, the whole frontal system followed by the P_C outflow advances steadily eastward until the whole eastern and central U. S. is covered by the cold air. On the other hand, it sometimes happens that the cold air outflow from the source region takes place in one sudden abrupt outbreak, without the development of any well-marked disturbance. In this case the cold air sweeps everything before it, apparently too rapidly for any localized disturbance to develop on the cold front. Furthermore, these very fast moving cold air outflows usually occur only on the heels of a preceding outbreak which has as it were paved the way for it by displacing the warm maritime air masses, so that we find the fresh P_C mass displacing only moderately cold and dry continental Polar air masses (N_{PC}) as it moves southward towards the Gulf. At this point it is necessary to inquire a little further as to what happens to the original P_C or cPW air mass properties in the course of the later history of the mass.

2. *Modification of the Winter Source Properties of the P_C Air Masses*

Following the first outflow of the P_C mass from the source region, where its properties are essentially those shown by the Ellendale data, there are three principal influences which may be at work to change these properties. Observed changes of the properties are to be explained then in terms of one or more of the following modifying influences:

(1) Supply of heat by contact with and radiation from the surface beneath, and supply of moisture by evaporation from this surface. This influence tends to make the lower strata of the P_C mass increasingly warm and moist, or to change its properties from cPW to cPK.

(2) The effect of subsidence, which tends to intensify the temperature inversion at a low level and to effect a general warming of all the upper strata.

(3) The effect of turbulence occasioned by a rough undersurface in developing a thoroughly mixed lower stratum in the air mass. This is important in hilly or mountainous regions.

As the cold P_C air mass moves southeastward from the Canadian border west of the Great Lakes across the Plains states and down through the Mississippi Valley towards the Gulf of Mexico, the modification of its properties depends principally upon the extent of the snow cover, for on this depends the effectiveness of the first and most important of the above three influences. The path of the cold air advance is over flat country all the way to the Gulf of Mexico, so that turbulence effects become no more pronounced than they are at Ellendale. As long as the air mass continues moving over snow cover, there is only a very slight warming and increase of moisture to be observed. The air mass retains the characteristic coldness of the surface stratum, though the cold layer becomes shallower, and the temperature inversion sharper. This is doubtless due to subsidence, *i.e.*, the sinking and spreading of the cold air mass. The P_C values of the air mass properties given in Table II for Royal Center, Ind., Broken Arrow, Okla., and Groesbeck, Tex., are averages of ascents for the same period as those at Ellendale, January, 1930, in cases of minimum modification of the original P_C properties, *i.e.*, in cases of the maximum coldness and dryness of the P_C air. Such cases are those where the trajectory of the air mass the entire distance to the point of observation has been over snow-covered ground. And this will be the case only for the rapid outbreaks of cold air mentioned above (see p. 19), where the freshly outflowing cold air is displacing only slightly less cold air of the same source. Otherwise the modification of the P_C properties takes place much more rapidly. The number of P_C ascents averaged to give the mean values of the elements recorded in Table II grows rapidly less, in passing southward from Ellendale to Groesbeck, because in comparatively few cases were the conditions of snow cover and preceding cold air to be met with so far south. This may help to account for certain discrepancies which appear when one station is compared with another.

We notice in passing southward from Ellendale to Groesbeck that the surface temperature of the P_C air becomes somewhat warmer, as would be expected, but remains extremely cold considering that Groesbeck is at only 32°N. At Royal Center and Broken Arrow the surface relative humidity remains very high, and the temperature inversion increases slightly and becomes lower in elevation. The water vapor ratio w still increases with elevation at all stations. These changes are just what we should expect from a moderate degree of subsidence and a slight increase of heating by terrestrial radiation, and as a result of evaporation from a snow surface which is no longer so cold as it was further north in the source region. Especially during the daytime is the sun much more effective at the lower latitudes in raising the temperature of the snow surface, and doubtless more heat is transmitted from the ground beneath, which is warmer, through a snow cover which is thinner. At Groesbeck, surprisingly enough, we find the relative humidity at the surface considerably reduced, and the amount of the inversion greatly increased and centered somewhat higher than at Broken Arrow. This is probably to be explained by the fact that only the three strongest cold air outbreaks during January, 1930, reached Groesbeck sufficiently directly so that they could be taken as typical of real P_C air at that station. Furthermore, in those cases the winds were so high that the turbulence effects were more marked than on the average in P_C air. This fact probably explains the comparatively low surface relative humidity and the high level of the temperature inversion relative to Broken Arrow. The temperature at the 2 km. level is surprisingly high at Groesbeck, but the Polar continental source of the air is definitely established by the low value of w, 1.2 g., which is not approached at this station by any other air mass at the 2 km. level. It is unfortunate that at the more southerly stations the height to which the kite ascents extend falls off so much. This may be taken as an indication that the upper boundary of the P_C air mass, probably marked by a wind discontinuity through which the kite cannot penetrate, is becoming steadily lower. It will be noticed that the equivalent potential temperature θ_E marking this upper limit of ascent remains much more constant from station to station than it does at any fixed elevation, another fact which is indicative of continued subsidence.

The characteristic curves for these stations representing their average P_C properties on the Rossby diagram will be found on Plate II-A. Their striking similarity will be noted at once. And equally uniform is the clear, dry, cloudless weather attending the passage of the P_C air mass, as long as it retains this characteristic temperature and moisture distribution. In the later stages of the P_C outbreak, if the cold air outflow weakens and the conditions become stagnant, the gradually lowering and intensifying subsidence inversion is naturally attended by markedly decreased visibilities below the inversion, particularly in industrial regions where smoke pollution of the atmosphere is pronounced. It is, however, the exception rather than the rule for such stagnation to follow in the case of a strong outbreak of P_C air. The stagnant anticyclonic condition with low subsidence inversion and poor visibility usually occurs in the U. S. in the southeastern states, and only with mild outbreaks of P_C air. And it seldom leads to fog formation, because the cold air, being continental, is usually too dry. In Europe, on the other hand, where the stagnation of the cold air masses is more frequent and prolonged, and where the Polar and Arctic air masses are frequently of maritime origin and comparatively moist, this condition often leads to the widespread formation of fog or low stratus cloud, with practically zero visibility below the temperature inversion. Above the inversion visibilities are always excellent. Of course, active overrunning of the P_C mass by a warmer moister air current completely changes the type of weather. Such overrunning by warm Pacific air in the Rocky Mountain region or by warm Gulf air in the Plains states produces the typical blizzard conditions for these respective regions.

As soon as a typical P_C air mass leaves snow-covered territory, the modification of its characteristic properties becomes very rapid. Heating of the lower strata by contact with and radiation from the ground, and increase of moisture by evaporation from the ground surface, effect a rapid transformation of its properties, most marked near the ground and diminishing aloft. At the same time that the lower strata of the air mass are being rapidly warmed and moistened from the ground, there is doubtless also some direct radiational heating of the upper strata in response to the increased terrestrial radiation from the warmer ground surface. The initial heating of the upper strata does not have to wait on the establishment of thermal convection. The ground heating of the air mass is especially rapid during the daytime in southerly latitudes, where the clear skies characteristic of P_C weather favor marked insolational heating of the ground, and in particular when the P_C mass is displacing a Tropical maritime air current, in which case the ground will be particularly warm and moist and the cold air mixes with remnants of the warm moist air. In this way under ordinary conditions the southern portion of an advancing P_C mass becomes rapidly transformed as it moves southeastward across the U. S. from the typical source cPW properties of the air mass to a cPK or unstable air mass, in which the water vapor falls off rapidly with elevation to the low values aloft initially characteristic of the P_C mass. This modified cPK form of the P_C mass is designated as N_{PC} on the M. I. T. maps. Characteristic curves on the Rossby diagram for ascents in such N_{PC} or cPK air masses are shown on Plate II-B by the ascents for Groesbeck and Broken Arrow on January 2, and that for Groesbeck on January 31. The comparative potential instability of the N_{PC} air at these southern stations, the result as much of increased moisture as of heating, is indicated by the much closer coincidence of these three curves with the θ_E isotherms than is shown by the N_{PC} ascent at Ellendale or the P_C ascents at Boston and Ellendale on the same Plate. In contrast to the increasing instability of the P_C air mass as it is transformed to N_{PC}, should be noted the increasing stability of the P_P air mass as it is transformed to N_{PP} (Plate II-C). In the extreme case the N_{PC} mass, or part of it, may be turned northward again, become a return flow over a colder surface, and tend to a reëstablishment of cPW stability. In general, this rapid modification of the properties of the southern portion of the P_C air mass relative to the northern portion means that the initial horizontal homogeneity of the air mass is destroyed, or, in other words, the isentropic surfaces do not remain in their initial horizontal position. This fact has long since been remarked by Bergeron[9] as characterizing all Polar air masses, and offered as the explanation of the readiness of the Polar air masses to form secondary fronts within themselves. Any wind discontinuity quickly produces a discontinuity of the other elements under these conditions.

Generally speaking, the transformation over land of the cPW to cPK air mass has little significance for the general weather conditions. Visibility at the ground is improved, and apart from the possibility of the formation of a few cumulus clouds during the day, the skies remain clear. But the effect of open water on the cPW air mass in winter is immediate and pronounced, the mass becomes cPK forthwith. The addition of moisture and heat to the cold dry air mass takes place very rapidly from any water surface. In surprisingly quick time the lower strata of the air mass are rendered convectively unstable, and heat and moisture are carried to successively higher levels by active convection. The quantitative effect of this influence on the vertical distribution of temperature and specific humidity will of course depend upon the P_C air mass properties, the warmth of the water surface, and the length of the sojourn of the cold air over the open water. The extreme degree to which such a modification may go is indicated by a comparison of the properties of our Polar maritime air masses at Seattle (see Table III) with our Polar continental masses at Ellendale. Originally these two air masses have about the same properties, but the P_P is modified during its passage over the ocean. A still more extreme case is that of our P_C air which may reach the Gulf of Mexico, under favorable winter conditions, still as a very cold, dry and essentially stable mass. But the winter northers in the Central American countries, which are invariably continuations of our P_C outbreaks across the Gulf of Mexico southward into the sub-Tropical circulation, are typically only moderately cool at the surface and attended by extremely heavy convective precipitation. This change which takes place in only 36 to 48 hours over the warm waters of the Gulf amounts often to a warming of the surface stratum of the P_C mass by 25° or even 30°C., and an increase of w from perhaps 1 to about 15 g. Unfortunately no soundings from these regions are available, but there is no question but that they would show extreme convective instability under these conditions.

For the north-central and northeastern U. S. the modification of the P_C air mass properties by the Great Lakes is very important. During the late fall and early winter, while the Lakes are still free of ice, this effect is particularly well marked. In the coldest P_C outflows with a northwest wind blowing across Lake Michigan, for example, which is less than a hundred miles wide, the temperature may be 10°C., or even more, higher at Ludington on the east shore than at Green Bay on the west shore. And whereas the sky will be cloudless at Green Bay, at Ludington there will be low ceiling and constant snow flurries. And this difference is characteristic of all the Lake stations; passage of the cold air across the Lakes produces always a low nb or cu nb cloud with almost continuous snow flurries. Apparently the instability layer produced over the Lakes is rather shallow, as evidenced by the characteristic lightness of the precipitation and the amount of the temperature increase in the ground stratum of the air mass. However, it is marked enough so that considerable cloudiness with snow flurries characterizes the P_C current from the Lake region eastward up the moderate slopes to the Appalachian Divide. The surface values of w are found to have increased in passing over the Lakes from a normal value of about 0.5 g. to perhaps 2.0 g., and the temperature to have been raised by some 10°C. This modification is a maximum at the ground, disappearing at some $2\frac{1}{2}$ km. elevation. In fact, the thermal influence of the Great Lakes favors very markedly the formation of more or less stationary secondary cold fronts in this region, which are indicated at the ground by a well-marked wind-shift from southwest to northwest and a corresponding trough in the isobars. But observations of winds aloft show always that at as low as 2 km. elevation this discontinuity has completely disappeared, the wind at that level being uniformly northwest. This means that from the Lake Region eastward to the Appalachians the tendency is to a continuous overrunning of the somewhat modified P_C air at the ground by colder P_C air aloft coming more directly from the source. This doubtless favors the appearance of the instability snow flurries which characterize the P_C weather in this entire region.

Along the Atlantic coast, east of the Appalachian Mountains, the characteristic P_C air mass properties are quite distinctive. The Appalachians, though for the most part not very lofty mountains, are high enough, at least in the northeast, to effect a rather thorough mixing of the P_C air current through the lower 2 or 3 km. The results of this mixing are a marked warming of the ground layers of the P_C air masses, the establishment of a steep lapse rate, and the precipitation of most of the moisture acquired in the Lake Region. Hence the showers and snow flurries, cloudiness, and relatively high w found to characterize the P_C air masses between the Great Lakes and the Appalachian Divide might be expected to have disappeared. We should expect to find clear skies, or at most high cu clouds, a steep lapse rate from the ground up with much higher temperatures at the ground than in the west, a fairly constant low value of the water vapor ratio w, and a low value of the relative humidity at the ground increasing with elevation. The condensation of the water vapor in the lower 2 km. of the P_C air mass while crossing the mountains will have contributed somewhat to a uniform heating of the lower strata of the air mass.

Probably the coldest P_C air reaching New England, however, comes direct from the northwest, without having passed over the Great Lakes, which lie more to the west. In this case the heating and moistening effect of the Great Lakes and the subsequent precipitation of this moisture on the western slopes of the Appalachian ranges is eliminated, but turbulent mixing of the air mass is doubtless at a maximum, for some of the highest ranges of the Appalachians lie in New England. The Boston P_C data, taken as typical for the North Atlantic coast, probably represent just this type of cold air outflow without the Great Lakes influence. At the only other Atlantic coast aerological station, Due West, S. C., not a single good ascent was available in a fresh P_C air mass during the period of this investigation. That is due partly to the fact that Due West is so sheltered from north and northwest winds that good kite ascents are few with such winds, and partly to the southern location of the station, as a consequence of which comparatively few of our cold waves reach there with undiminished vigor.

A comparison of the mean values shown by the Boston data for P_C air masses (Table II) with the corresponding values for Ellendale and Royal Center (Broken Arrow and Groesbeck lie much further south) shows perfectly the expected differences. The surface temperature at Boston is some 16°C. warmer than at Royal Center, which lies slightly further south, while the lapse rate through the first km. is 0.8 of the dry adiabatic, and the relative humidity at the ground only 43%, in contrast to a temperature inversion and relative humidities of 80% or 90% at the western stations. This low value of the relative humidity is the more remarkable when it is considered that the Boston ascents were taken before 8 a.m. During the warmer part of the day relative humidities as low as 20% or even lower are observed at Boston in P_C air. Of course, the Boston data were obtained during quite another winter than the data for the other stations, but the differences shown here are characteristic for cold wave conditions (P_C outbreaks) along the Atlantic coast and in the west. However, it probably is true that the Boston data do not represent to the same degree as those of the western stations the most extreme cold which may be found in P_C air. January, 1930, was a period of severe cold in the middle west, whereas the winter of 1931-32 was noted for the absence of extreme cold in the eastern U. S. The characteristic curve (Plate II-B) given for a typical Boston ascent shows by its vertical compactness in comparison with Ellendale's curve the relative instability of the P_C air at Boston.

But in spite of the fact that the Boston P_C data probably represent the extreme properties of the P_C air mass in the northeast less than do the Ellendale and Royal Center data in the middle west, we find as low as at 3 km. and still more markedly at 4 km. both lower temperatures and less moisture at Boston than at either Ellendale or Royal Center, and correspondingly a greater lapse rate at all elevations. Neither turbulence nor surface heating can be made to explain the increasing lapse rate at Boston from 2 to 4 km., nor the fact that it exceeds the rate of the other stations at these levels.

In fact, from the effect of turbulence alone we should expect to find a temperature inversion at the top of the turbulent layer of the P_C mass. It is true that we find a much smaller lapse rate (less than half as steep) at Boston in the second kilometer than in the first. This difference probably indicates the turbulence effect. But the data indicate a fundamental difference in the vertical structure of the P_C mass at Boston from that found at Ellendale far beyond the turbulence effect and any small part of the Lake effect which may appear there. There is, however, one striking difference between the P_C outflow in the west and that at Boston, which suggests an explanation of the excessive coldness aloft of this air mass in New England. And that is in the vertical distribution of wind velocities. We have seen that at Ellendale in the typical P_C outflow the wind velocity is notably constant with elevation at values which are never excessively large. This indicates a distinctly ordered movement of the air mass as a whole in which every stratum partakes equally, the air mass movement apparently depending upon the thermally caused pressure gradient from warm to cold regions, an effect which is at a maximum near the ground. The movement seems very little dependent upon cyclonic pressure gradients or even upon the existence of cyclonic circulations at all. But in New England the typical P_C outbreak occurs in the rear of an actively developing cyclone, and usually the more intense the cyclonic circulation the more marked is the cold air outflow. Disturbances which have developed on the P_C cold front in the middle west, the Gulf region, or along the south Atlantic coast all tend to move towards New England. Usually they are rapidly occluding, increasing in intensity, and probably extending their influence to high levels. They bring the cold air southward in a sweep behind them, not as an independently moving cold air mass vertically homogeneous in velocity, but in a current belonging to the cyclonic circulation whose velocity at every level depends upon the cyclonic pressure gradient at that level. This will explain the fact of observation that in the typical P_C outflow at Boston the wind velocities which are quite high at the ground usually increase markedly with elevation to values which are excessively high between 2 and 4 km. Probably first at about 2 km. does one get above the turbulence effect of the mountains northwest of Boston. This effect is especially pronounced due to the high wind velocity, and explains the great increase in this velocity with elevation. And the high wind velocities found at 3 and 4 km. elevation explain the extreme coldness and dryness of the air at those levels. Under these conditions we have a rapid overrunning of the lower strata of the P_C outflow by the upper strata, the air aloft having been brought southward more rapidly from higher latitudes than the surface air. Since the vast cyclonic circulations developing in these situations often extend their influence well into the Arctic by the time they are centered in the Newfoundland region, it is not surprising if at upper levels the direct transport of Arctic air even to the latitude of Boston is taking place. Probably further south along the Atlantic coast the moisture from the Great Lakes becomes increasingly noticeable in the P_C air masses, while the overrunning of the surface strata by colder air aloft becomes decreasingly noticeable. Hence the steep lapse rate found at Boston at upper levels probably will not be found to the same degree along the middle and south Atlantic coast. Even at Boston it is very short lived. Whereas the second and sometimes even the third day of a marked P_C outflow brings the lowest surface temperatures at Boston, usually above 2 km. a marked warming-up has set in by the second day, so that above the turbulence layer the tendency is already to increasing stability or the formation of an inversion. This takes place while the winds are still strong northwest aloft, and the air very dry, which points conclusively to active subsidence in the P_C air current. Exactly the same thing is shown by the observations from Mt. Washington (150 miles north of Boston, elevation 2000 m.). The marked P_C outflows invariably bring hurricane winds and extreme cold to this station, but the warming-up begins while the wind is still blowing from the same quarter with almost undiminished velocity, and long before the lowest temperatures are reached at the base of the mountain.

Probably this type of P_C outflow corresponds fairly closely to the typical invasion of northwestern Europe by mA air masses. Certainly the properties of the P_C air masses at Boston at the 3 and 4 km. elevations resemble more closely those found by Schinze for the mAK air masses in northwestern Europe (see Table II) than do the properties observed at any other American station for any of the Polar air masses. It must be remembered, too, that Boston is some 8° further south than central Germany. No further direct comparison between the winter properties of the American P_C air masses and the European cP or cA masses can be made, for Schinze has not tabulated mean values of their properties. However, from what he has said it is evident that our source P_C properties, as shown by Ellendale aerological data, correspond to those of the cold continental air masses of small vertical extent which Schinze describes as coming from Russia. And this should obviously be so, for the sources are similar, and the advance of cold continental air from the east or northeast into Germany takes place easily and at the ground. The violent cyclonic transportation of cold air, with increasing intensity at upper levels, is found in Europe only in the case of mP and mA inflows, behind the deep disturbances moving in from the Atlantic.

B. The Polar Continental Air Masses — Summer

During the warm season the source properties of the American P_C air masses are very different from those characteristic of the cold season. The snow cover which is always present over this source region during the colder half of the year completely disappears, and the bare ground surface becomes much warmed during the long summer days. Consequently instead of being cooled from beneath as in winter, the P_C air masses are heated from the ground. Even though the air mass may originate over the cold waters of the Arctic, it quickly loses the coldness and stability of its lower strata over the warm land. It is usually impossible to tell from its properties whether the air mass came initially from the ocean or not. This holds for the Pacific as well as for the Arctic Ocean, for in any case by the time the air mass has crossed the western mountain ranges or moved southward from the Arctic Ocean to the field of observation it has acquired about the same characteristics. These characteristics are typically as follows:

(1) A fairly low moisture content (low compared with that of summertime air masses of more southerly origin). The values of w at the ground usually are near 5 or 6 grams, and decrease steadily with elevation. Relative humidity is also low, especially during the warmer time of day, so that conditions are favorable for the steady supply of moisture by evaporation from the warm ground and its transport upwards by convection. It is probably in this way that the observed moisture distribution has been established. With increasing age and displacement southward of the air mass the w values increase steadily at all levels from the ground up.

(2) A moderately low temperature. The P_C air mass in summer is characteristically cool, compared with masses of southern origin, but hardly to be distinguished in temperature from the mP (P_P) masses of the Pacific. The dryness of the P_C mass favors a large daily temperature fluctuation in its lower strata near the ground, for this condition is conducive to radiational cooling by night and insolational heating by day. In general, as it proceeds southward, the air mass tends to become increasingly unstable, hence is always designated as cPK. However, since nearly all the upper air data available are for the early morning hours, this instability is not apparent in the data shown in Table III. In the middle west a diurnal temperature range at the

ground of approximately 15°C. is typical for this cool dry air mass, a range which is usually sufficient to establish a dry adiabatic or superadiabatic lapse rate up to 2 or 2½ km. by early afternoon. See for example the P_C ascents for Ellendale and Royal Center on Plate III-B. These show the typical mid-day instability of the P_C air mass in summer. It is interesting to note how the Royal Center ascent for 10 a.m. shows already at that hour a markedly unstable layer to a height of 800 m. above the ground with a decreasing lapse rate above, but a rather uniform decrease of moisture through the first 3 km. On the other hand, the Ellendale ascent taken at 6 p.m. shows very little change in potential temperature or w through the first 2200 m. above the ground, the closeness to one another of the significant points up to this elevation indicating the effect of a day of active convection which has extended to this height. The changes in the next 200 m. elevation are greater than those in the first 2200 m.

(3) A lack of condensation forms. Due to the dryness of the summer P_C air mass, it is typically cloudless. In spite of the marked daytime instability of the mass, the condensation level is so high that only a few scattered high cu clouds at most are likely to be observed. In the later portion of its life history, however, the conditions favoring rapid evaporation of moisture from the ground to the P_C air mass may so increase its moisture that eventually even thundershowers may develop locally. This is, however, unusual, occurring only in cases of marked stagnation of the air mass movement.

TABLE III

THE P_C AIR MASSES—SUMMER (cPK)

Elevation above Sea Level (km)	Station: Ellendale T °C	w g	θ_E °A	Royal Center T °C	w g	θ_E °A	Broken Arrow T °C	w g	θ_E °A	Pensacola T °C	w g	θ_E °A	Due West T °C	w g	θ_E °A
Surface	19.0	6.3	312	17.0	8.3	314	15.0	8.3	312	22.8	13.4	332	22.2	10.0	324
1	16.2	5.6	313	12.8	5.8	311	17.0	5.8	315	19.5	9.8	330	17.2	7.3	320
2	9.8	3.9	312	5.8	4.5	310	12.0	2.9	312	12.2	7.2	325	9.0	4.8	315
3	4.0	3.1	314	2.0	2.6	311	6.0	1.7	314	7.0	5.0	324	4.0	3.0	315
4	−2.5	2.9	318	−1.8	1.4	314	1.0	1.2	317						
5				−7.2	1.0	318									
6				−15.5	1.3	320									

Table III gives the vertical distribution of T, w, and θ_E for summer P_C air masses at five stations in the central and eastern U. S. These values are the averages of ascents made during the months of July and August, 1930. Unfortunately we have no summer data for Boston, and not a single ascent at Groesbeck in P_C air during this period. We have, however, data from another Gulf coast station, Pensacola, Fla. The characteristic curves plotted for these mean station values on the Rossby diagram will be found on Plate III-A. The contrast between the type form of these curves and that of the winter P_C curves is striking. Instead of being almost vertical with a w value throughout less than a gram, these curves have approximately the slope of the θ_E isotherms and show a large moisture decrease with elevation. This slope of the curves shows the effect of heating and evaporation from the ground, and so to an extreme degree the sort of modification which even in winter appears in P_C masses which have passed far southward from the source region and snow-covered territory (Plate II-B, N_{PC}).

When we consider the stations in Table III individually, Ellendale may again be assumed to show the P_C properties of the air masses which have moved southeastward across western Canada, as they first enter the U. S. We observe here the expected moderate lapse rate showing distinct stability near the ground, which later in the day will probably approximate the dry adiabatic rate up to 2 or $2\frac{1}{2}$ km., often distinctly exceeding it through the first km. The surface temperature of 19° probably already in the early morning represents an increase of 4° or 5° from the night's minimum. We also find the expected steady decrease in w up to at least 3 km., and up to this point a fairly constant value of θ_E which will increase steadily at higher elevations.

At Royal Center the general trend of the vertical distribution of these elements is the same as at Ellendale, but there are certain definite differences which are rather interesting and at first sight surprising. In the first place, we find the temperatures at lower levels definitely colder at Royal Center than at Ellendale. The difference reaches the quite significant amount of 4°C. at the 2 km. level, and its sign is first reversed at the 4 km. elevation. This is especially noteworthy in view of the fact that Royal Center is located 6° south of Ellendale. In the second place, in spite of the lower temperatures at Royal Center through the first 3 km., the values of w through the first 2 km. are actually higher than at Ellendale at the corresponding levels. And finally, at higher levels where the sign of the Ellendale-Royal Center temperature differences seems to be reversed, the sign of the w differences also seems to be, the lower values of w being found at Royal Center, which has the higher temperatures. All these differences, which are much too pronounced to be accidental, require explanation.

Before any explanation can be offered, one feature of the summer P_C outflows must be mentioned, namely, that the cool air current itself, instead of showing the characteristics of a rather discrete mass of cold air moving rapidly, an outbreak from some cold air reservoir in the north, as the winter cold waves appear to do, is more in the nature of an almost stationary deep northerly current, like the winter P_C outflows over New England. In winter we find normally a rapid movement of the cold air mass, or the cold wave, directly from Ellendale southeastward over Royal Center in short time and with little change in properties. The summer P_C ascents on the other hand are made usually in steady deep northerly currents which may remain in almost the same longitudinal zone for several days. Thus the Royal Center P_C ascents in summer do not represent at all, as they do in winter, the same air mass which is previously observed at Ellendale. They represent rather an outflow of cool air from the Hudson Bay region southward across the Great Lakes, while the Ellendale ascents typify conditions in a similar current which has been moving southward for a considerable distance across the British Northwest Territory. Usually in summer these two stations are very unequally influenced by one and the same cool air outflow. When it does happen that the cool air current which has affected Ellendale eventually reaches Royal Center with undiminished vigor, then the displacement of this current eastward is usually so slow that the stream lines or isobars show much more accurately the trajectory of the air reaching the latter station than does the trajectory of the cool air mass as a whole, which is indicated by the displacement of the entire anticyclonic circulation.

Obviously, then, the differences between the summer P_C properties at these two stations must be explained in terms of the influence of either the Great Lakes, or Hudson Bay, or both. But a moment's consideration will show that it is the Hudson Bay influence rather than the Great Lakes influence. In the first place, the maximum effect is found at 2 km. elevation, whereas the nearness of Royal Center to the Great Lakes, and their comparatively small area, would lead one to expect their maximum effect to show at lower elevations. But much more significant is the fact that in July and August the Great Lakes surface temperatures are so high that it is doubtful if these water bodies can lower even the surface temperature of the P_C air mass, except to check the daytime warming of the lower strata. It is utterly out of the question to explain the temperature of 6°C. found at 2 km. at Royal Center in terms of the effect of the Great Lakes. On the other hand, Hudson Bay is a vast area of water so cold that only for a few months in the late summer does the ice clear up sufficiently to permit navigation, the water temperature remaining close to freezing. The extreme effect of this cold water on summer air temperatures in the Hudson Bay region is shown by a comparison of stations on the Bay with those further inland in the British Northwest Territory. As the Hudson Bay air mass moves southward, it is heated from the ground, acquiring gradually an unstable surface layer, but this heating has been of short duration compared with that of the heated P_C currents further west which reach Ellendale. Hence at 2 km. elevation we find the coldness and moisture which characterized the air mass over Hudson Bay. And through the next 2 km. we find the stability which the air mass possessed over Hudson Bay, and the rapid decrease of moisture which follows from the impossibility of the convective penetration of the upper strata of the air mass by the moist cold surface strata. This explains the fact that the values of w at Royal Center are markedly less above 3 km. than those at Ellendale. The comparatively high value of w at the ground at Royal Center may be attributed to the acquisition of moisture from the moderately warm surface of the Great Lakes.

The vertical distribution of T, w, and θ_E at Broken Arrow as shown by Table III, has little significance, as the data are based on a single ascent. As already mentioned, during July and August, 1930, the P_C outbreaks failed to get very far south, especially in the west, so that there was only one good ascent in P_C air for Broken Arrow, and none for Groesbeck. The temperature distribution shown by this one ascent is about as would be expected, running a little higher than at Ellendale, except at the ground, where we obviously have a well-marked early morning inversion. The ascent was started at 6 a.m. The moisture runs surprisingly low, especially in the upper levels, but in this respect the humidity observations from this ascent were certainly faulty or this is an exceptional case.

At Pensacola, Fla. (Gulf coast), the southernmost of the stations, we find the maximum modification of the original P_C coolness and dryness shown by any of the stations. The value of θ_E found at the surface, 332°, is not far from the lower limit of θ_E for Tropical maritime air in summer, which at the ground at Pensacola is about 340°. We notice also that now for the first time in the history of the P_C air mass there is quite an appreciable decrease in θ_E apparent through the first 3 km., in spite of the continued presence of a small lapse rate in the first km. This indicates a state of conditional instability which in the afternoon must become quite marked, and in which the greatly increased water vapor content compared with that of the more northern stations plays the important rôle. In other words, it represents a close approach to a condition of convective instability such that local thundershowers may develop, which has already been pointed out as a possible eventuality in the modification of the dry P_C air mass moving slowly southward in the U. S. in summer. By the time P_C air has been modified to this extent it is indicated on the map as N_{PC}, signifying that it is on the way to losing the distinguishing P_C characteristics, in this case coolness and dryness. Obviously N_{PC} in the U. S. in summer always appears with cPK properties. A typical individual ascent of this type at Pensacola is shown on the Rossby diagram on Plate III-B. The slope of the curve is shown to be equal to or greater than that of the θ_E isotherms all the way from the ground to $3\frac{1}{2}$ km. However, as it was an early morning ascent we do not find the superadiabatic lapse rate in the first km. which characterizes the late morning and late afternoon ascents at Royal Center and Ellendale, which also appear on this Plate. We note, however, the much greater moisture content at Pensacola, especially near the ground, which accounts for the conditional instability of the air mass. At Due West we find the same degree of conditional instability as at Pensacola, but considerably smaller values of w, as might be expected. It is a steeper lapse rate in the first 2 km., and especially the lowest km., which is responsible for a θ_E lapse rate as steep as that at Pensacola, but the θ_E values run about 10°C. lower at all elevations than at Pensacola. The steeper lapse rate at Due West is probably to be explained by the fact that the time of the ascent is usually later there than at the other stations. Probably the turbulence effects of the mountains have not much importance for the comparatively light summer P_C air currents.

As in the case of P_C air masses in winter, no direct comparison of the summer properties of the American Polar continental air masses with the European can be made, for Schinze gives no separate tabulation of the Polar continental air masses in Europe. Presumably, however, the differences would be much less than they are in the case of the Tropical air masses in summer. Polar continental air can reach central Europe (Germany) only indirectly by way of Russia, which means that it becomes rather thoroughly heated in summer before reaching Germany, just as do our P_C air masses in summer which reach the U. S. via the British Northwest Territory. Probably our summer Polar air from the Hudson Bay region is cooler than air reaching Germany in summer from Russia.

C. The Polar Maritime Air Masses — Winter

1. *Source Properties of the P_P Air Masses in Winter*

There are two distinct and markedly different Polar maritime (mP) air masses which make their influence felt in the U. S. in winter, those having a north Atlantic trajectory (P_A) and those having a north Pacific trajectory (P_P). Of these two, the P_A masses are comparatively unimportant, affecting as they do only a narrow coastal strip in the east, and that rather infrequently. The P_P masses, on the other hand, play a dominant rôle in the weather of the Pacific coast region of the U. S., and in winter frequently extend their influence across the entire U. S., as we shall see presently. It is extremely regrettable, however, that for this study only incomplete aerological material from two Pacific coast Navy stations (Seattle, Wash., and San Diego, Cal.) exists, and that no analyzed maps or complete observations from the Pacific Ocean were available. This means that frequently the exact source and trajectory of the air masses observed on the Pacific coast cannot be determined with the desired accuracy. Furthermore, there are no aerological stations between the two above mentioned coast stations and Ellendale and Broken Arrow in the middle west. All the western mountain ranges and the Plateau region lie in between, so that it is impossible to get any continuous picture of the modification of the vertical structure of the Pacific air masses while they are passing from the ocean to the interior of the continent. Nevertheless, a good many interesting conclusions may be drawn from the material obtainable.

In the first place, the P_P air masses reaching the western coast of the U. S. are probably of about the same Arctic or sub-Arctic origin as our P_C air masses. The difference in their properties is caused by a more or less extended sojourn over a warm ocean surface in the course of their progress southward. Consequently they have quite a range in properties, from the coldest and driest, which have advanced directly and rapidly from the northwest, to the warmest and moistest, which have passed far around to the south over the ocean and finally reach the Pacific coast as an air flow returning northward. Air masses having such a trajectory are only with difficulty distinguished from air of tropical Pacific origin. But the characteristic P_P air mass properties are taken in this discussion to be those of the coldest maritime air flows coming directly from the northwest. The properties of these masses should correspond more closely to those of

Schinze's mAK masses than will those of any of the other American air masses. Their original source region is probably very similar in nature to the source region of the P_C masses, except that it is further removed and more definitely Arctic in latitude. They are apparently drawn either from the interior of Alaska or the ice-covered Bering Sea region and northeastern Asia following the pronounced development and movement southeastward of the Aleutian Low. In their original source region these air masses must resemble very closely in their surface properties and their vertical structure the characteristic source properties of the P_C masses, with their coldness, dryness, and stability. But instead of remaining over a cold snow or ice surface, they move southward over the warm waters of the north Pacific, where they are rapidly modified to the condition in which they arrive on the north Pacific coast of the U. S., as shown by aerological data from Seattle. We should expect to find in the P_P air masses at Seattle, then, a rather high surface temperature, only slightly colder than the ocean surface temperature off the coast, and a steep lapse rate with a rapid decrease of moisture with elevation to a coldness and dryness at upper levels comparable with that found in the P_C air masses. However, in making a comparison with Ellendale ascents it must be remembered the amount of our Seattle material is very small, covering as it does only the last half of February for the winter period of investigation. Consequently the choice of ascents was very restricted, and it so happens that none of the Seattle ascents represented in Table IV shows the greatest degree of coldness which may be found in P_P air at this station, whereas the Ellendale ascents show the extreme condition for P_C air at that station. Thus we find an average surface temperature at Seattle of only 8.3°C., which is scarcely 1°C. colder than the ocean surface off the Washington coast. Yet surface temperatures as much as 4° or 5°C. colder than this have been observed in P_P air masses at this station, and since these masses have been heated from below, the temperature differences are probably still greater aloft. However, the mean values given in Table IV for Seattle indicate just the vertical distribution of elements to be expected. Through the first 2 km. we find a very steep lapse rate, averaging 0.83 of the dry adiabatic rate, and a very rapid decrease in w. The decrease in w is so marked, that even θ_E becomes less up to this elevation, showing that the changes have been too rapid for a condition of convective equilibrium to have been reached. This is brought out very clearly by the characteristic curve on the Rossby diagram for this Seattle data (see Plate II-A). It will be noticed that the numerical value of w at the ground is more than ten times the value found in P_C air at Ellendale, and the temperature is some 34°C. warmer (see Table II). This difference represents the influence of the warm water on the Pacific air masses after they leave their original Arctic source.

Above 2 km. the lapse rate becomes less steep and w falls off less rapidly, as would be expected. At 4 km. we find a value of w quite as low as that for P_C air at the same level at Ellendale, and a temperature only 6° warmer than the corresponding Ellendale P_C value. The above mentioned failure of these Seattle observations to show the same extreme of coldness of the P_P air masses as the Ellendale observations show for the P_C masses seems to indicate rather definitely that the source properties of the P_P mass and the P_C mass are the same. The individual ascent for Seattle for February 24 (see Plate II-B for the characteristic curve), although indicating a high surface temperature of 8°C., shows a lapse rate of 0.90 of the dry adiabatic rate through the first 2 km. and 0.60 through the next three, the temperature at 4 km. being only 3° above the Ellendale P_C average at that level, and at 5 km. about the same as that which Ellendale would probably show at this level. For the stronger and colder outflows of P_P air, when the Seattle surface temperature is only 3° or 4°C., the values of w and T above 3 km. would certainly be as low as the Ellendale P_C values or even lower. Hence it seems that as far as the source is concerned, there is no justification for making any distinction between the direct outflows of P_P

TABLE IV
THE POLAR MARITIME AIR MASSES—WINTER

Elevation above Sea Level (km)	Air Mass Type—Station																					
	P_P (mPK)						N_{PP} (cPW)															mAK
	Seattle			San Diego			Ellendale			Broken Arrow			Groesbeck			Royal Center			Due West			Germany (Schinze)
	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C
Surface	8.3	4.4	292	13.5	6.1	301	−1.2	3.0	284	3.7	3.9	288	6.3	4.7	292	−0.4	3.1	282	4.5	3.2	287	−2 3
1	0.0	2.7	289	7.5	5.3	302	+7.0	3.0	299	7.7	3.3	300	9.5	2.2	297	+3.0	2.3	292	8.5	1.7	296	−10.1
2	−8.3	1.5	288	0.5	2.8	300	0.8	2.2	300	3.7	2.4	302	4.3	1.2	300	+0.9	1.4	297	7.2	1.4	304	−17.9
3	−14.3	0.8	289	−6.0	1.3	299	−6.5	1.5	301	−2.3	1.8	305	2.5	0.4	305	−3.5	1.0	302	2.0	0.7	306	−25.6
4	−19.3	0.4	294				−14.0	1.1	302													−33.4

and of P_C air. The only difference lies in the modification of the lower 3 km. caused by their different trajectories, the P_C masses remaining cPW in their properties, the P_P being transformed to mPK. If the P_P outflow is slow or indirect, the modification extends still higher. If there is justification for using the term Arctic rather than Polar in designating any of the American air masses, then it applies even more to the P_P than to the P_C masses, for the former must have come originally from sub-Arctic latitudes, while the latter may have originated well south of the Arctic Circle.

The P_P air masses at Seattle show the typical mPK condensation forms and visibility. The condensation level is usually rather low, and the cloud forms typically cu nb, indicating the instability of the air mass. Showers normally continue along the entire Pacific coast of the U. S. long after the front passage which is followed by a fresh P_P air mass. No doubt the effect of the coast line is to accentuate the convective overturning of this conditionally unstable type of air mass, which fact probably explains the almost continuous sequence of showers with rather heavy rainfall frequently found under these conditions. Occasionally the convective activity is sufficient to cause brief thundershowers with small hailstones. The P_P air is not in itself cold enough to cause snow at the ground on the Pacific coast. Snow does occur along the Pacific coast occasionally, however, even southward to the latitude of south-central California. This occurrence is usually associated with the southward movement along the coast of cold P_C air which has arrived at the coast in the region of Washington or British Columbia from the interior of the continent. According to Byers[11] this type of cold air is markedly unstable when it reaches California, the characteristic cu nb cloud forms indicating the convective nature of the precipitation. As far as the fresh unstable P_P air masses are concerned, however, the surface visibilities are always very good. This is generally characteristic of all mPK air masses, apart from the local obscuring effect of falling precipitation.

For the P_P air masses which have completed a broad swing southward over the ocean, and approach the coast from the west or southwest instead of from the northwest, or in cases where the movement has been slow and the sojourn over the ocean long, the above mentioned P_P properties are considerably modified. In general, the further south these masses have extended in their swing, the warmer and moister they become, especially at upper levels, and the less is the lapse rate. Consequently they tend to show st cu or st clouds instead of the convective types, and the instability showers disappear. At the same time surface visibility becomes poorer, until in an extreme case an air mass originally of Polar origin may show complete modification from the mPK to the mPW type, even to the point of fog formation.

At San Diego, which lies 15° south of Seattle, we find, as shown by Table IV, that the fresh P_P air mass is still characterized by a fairly steep lapse rate, but the temperature and moisture at every level have increased. Furthermore, we find that now the temperature and moisture decrease is more rapid between the 1 and 3 km. levels than it is in the lowest km., a fact which probably indicates that the lowest km. of the air mass has come to an equilibrium temperature with respect to the water surface beneath. We now find conditional instability between 1 and 3 km. instead of between the ground and 2 km., so that the characteristic curve on the Rossby diagram (Plate II-A) runs in general parallel to the Seattle curve, but tends to approach closer to the Seattle curve at higher levels where the Polar characteristics of the air mass have been less modified. We notice also the same tendency in the individual P_P ascent from each of these stations found in Plate II-C. Probably if San Diego's ascent extended to a higher level the curve would approach much more closely to the one for Seattle.

It is interesting to compare the temperature of our maritime Polar air at Seattle with the values Schinze gives for Germany for mAK. His mean values for January are given in the last column of Table IV, but unfortunately he gives no mean values of the humidity. We see at once that Schinze's air masses are much colder, the difference being about 10°C. up to $2\frac{1}{2}$ km., increasing above that level. The lapse rate at Seattle is found to be a little steeper through the first 2 km. than in Germany (perhaps due to Seattle's proximity to the ocean) whereas above this level the relative instability of Schinze's Arctic air becomes increasingly pronounced. Probably the relative warmth of the Seattle P_P air at lower levels is to be explained in part by the lower latitude of Seattle (5° south of Germany's North Sea coast), in part by the higher ocean surface temperature than that of the North Sea, which is somewhat sheltered from the warm Atlantic current by the British Isles, and in part by the fact that Schinze has picked instances of the most extreme cold (Arctic outflows) while the Seattle data do not represent such cases. The relative coldness of the European mAK outflow at high levels is probably, as already suggested (see p. 25), the result of the fact that an intense current extends much higher in the atmosphere than our cold air outflows in the west. Boston was found to be the only one of the American aerological stations showing anything comparable at upper levels (see Table II). This is probably associated with the deepening, occlusion, and transformation of low cyclones to the high type, with their maximum intensity aloft. Such intense occluded disturbances occasionally come as far south as Seattle on the Pacific coast, but there was no instance of this during the short winter period for which Seattle data were available. At Boston the low temperatures aloft appear in continental instead of maritime air masses, but at the elevations which are being considered here, above 3 km., this distinction is of little significance. The occasional occurrence at Boston of temperatures at the 3 and 4 km. levels in P_C outbreaks which are as low as those observed at Hamburg, located 10° further north, in Arctic air outflows, attests to the extreme intensity at upper levels of our winter cyclones in the northeastern U. S. The lowest temperatures under these conditions occur in connection with the intense disturbances of the latter part of February or the first part of March.

2. *Modification of the Winter Source Properties of the P_P Air Masses*

In the course of their movement from the Pacific coast to the interior of the U. S. the P_P air masses are very greatly modified. Between the coastal stations of Seattle and San Diego and the interior stations of Ellendale and Broken Arrow there lies a region of high plateaus and lofty mountain ranges which is a thousand miles wide, from within which no upper air soundings are available. Probably all air currents crossing this region from the Pacific Ocean are forced to ascend to an elevation of at least 2000 m. above sea level. Yet in spite of this formidable barrier to air mass movements from the Pacific, the prevailing tendency to west-east air movement in middle latitudes is so pronounced that for considerable periods of time the greater part of the U. S. may be covered by air masses from the Pacific, usually of Polar origin. This occurs when the Aleutian center of action is particularly well developed, and when the successive fronts and barometric minima advancing from or around this center follow a northerly course into northwestern Canada and thence southeastward toward the Lake Region. This path of the barometric minima coincides with the front between the cold P_C air on the north and the relatively mild P_P current on the south. The P_P air masses come in successive surges following the successive disturbances on the maritime-continental front. They usually represent a rather mild type of P_P air mass with a long maritime history, a mass which has more recently been moving from the west southwest. Occasionally real tropical air from the southwest (source region the Pacific High) may appear in such a current, but usually it is air of Polar origin. This general situation is attended by a rather definite type of winter weather over the greater part of the U. S., consequently the properties of the P_P air masses after crossing the mountains are of considerable significance for the central and even the eastern part of the country. However, it must be borne in mind, when the P_P characteristics of Seattle and San Diego as indicated in Table IV are compared with those of the other stations, that they represent a distinctly fresher, drier and colder type of P_P air on the Pacific coast than the Ellendale P_P air masses were even when they were on the coast. An outflow of fresh P_P air from the northwest approaching the coast at Seattle never reaches Ellendale, but rather Broken Arrow or Groesbeck. Under such conditions Ellendale must be in dry cold P_C air from the northwest, which has come southward on the inside of the mountains. The only P_P air flow which can reach Ellendale is one which approaches Seattle from the west or southwest. Such an air mass has the greatly modified properties found in P_P air at San Diego, rather than the properties typical of fresh P_P air reaching Seattle directly from the northwest. Hence it is not permissible to try to trace the P_P air mass properties of each of the inland stations in Table IV back to the P_P properties of the coastal station at the same latitude. In the same way, when an inflow of Pacific air from the west or west southwest takes place, the more southerly stations in the U. S., such as Groesbeck and Due West, are certain to be considerably influenced by warm air from the Gulf of Mexico. Quite generally, when the whole U. S. is swept by Pacific air, there is bound to be on either the north or the south, and sometimes on both sides, a contiguous current of P_C or T_M air. Furthermore, under these conditions, when there is no appreciable wind discontinuity at the front between the contiguous air currents, the front itself becomes very diffuse, so that there is a very definite tendency toward the development of a broad transition zone of mixing between the two air masses. On the north side of the Pacific current there seems often to be a marked change in the pressure gradient with elevation, so that when the isobars are east and west at the surface, there appears at higher levels a strong northwest current of cold dry air of P_C properties. The effect of this overrunning by cold air is to produce convective instability, turbulent overturning sometimes with light showers (the surface P_P air is usually rather dry), and consequently a gradual cooling and drying of all the northern portion of the P_P air mass, due to the convective mixing with the P_C air. It is quite impossible to place any definite front between the two air masses, yet of course it is equally impossible to refer to this mixed air as typical P_P air. Correspondingly in the south warm moist air works gradually northward in the surface winds from the Gulf region, probably largely due to departure from gradient wind velocity near the ground. During the daytime this warm moist air becomes thoroughly mixed with the dry current from the west, gradually imparting to it a specific humidity which is excessive for the P_P air current. In choosing the ascents from which the mean values of Table IV were computed, special pains were taken to eliminate all cases in which these influences were present. The result is that for the more eastern stations the number of usable P_P ascents was very small. In fact, for Boston not a single ascent typifying pure P_P air at this station could be found. There was nearly always considerable P_C influence indicated at Boston, both in the air mass properties and in the wind direction aloft.

In a general way the modifications which the P_P air masses undergo in crossing the western mountain ranges are as follows:

(1) Effect on moisture content.

In the course of the ascent and movement of the P_P current across the mountains, a considerable amount of condensation takes place, particularly from the moist lower strata of the mass. Because of the initial conditional instability or near-instability of the mass, there is little or no resistance to the ascent of the P_P current up the western slopes of the mountains, the precipitation is heavy and convective, and the air mass becomes thoroughly mixed by both convective and mechanical turbulence. We expect then to find a marked decrease of the w values of the mass, the decrease being at a maximum near the ground.

(2) Effect on temperature and lapse rate.

The active convective mixing and considerable precipitation of moisture in the ascending saturated P_P current would lead us to expect the maintenance of a saturation adiabatic lapse rate, and the liberation of a considerable amount of latent heat. Upon the descent of this air current on the east slope of the Rockies these effects should become evident in the increased temperature and decreased values of w (Föhn effect) relative to the initial values on the Pacific coast, θ_E remaining constant. But with respect to the ground temperatures in this air mass there are other influences to be considered. The P_P current is usually displacing colder continental air over a snow-covered surface. Frequently in the lee of the mountains a layer of cold air remains at the ground, and is but slowly displaced, the overrunning warm current only gradually mixing with it and carrying it off. Besides this mixing with cold air at the ground, radiational cooling of the lower strata of the warm, fairly dry P_P current takes place rapidly over the Plains States, especially if the ground is snow-covered.

We should expect to find then east of the Rockies the P_P air mass to be rather dry for its temperature at all levels. Its temperature will be high for a winter air mass of continental dryness, with a fair lapse rate above the lowest km. There will be a marked tendency to the occurrence of a cold ground layer with a low temperature inversion, but because of the dryness of these air masses and the southerly course followed by them, conditions are favorable for considerable insolational heating during the warmer part of the day. Thus they show a rather large diurnal temperature fluctuation near the ground, with a complete disappearance normally during the afternoon of the surface temperature inversion. Also because of the dryness of the P_P mass, condensation forms are usually absent, skies are clear, and visibilities good. The surface inversion is not usually persistent enough to depress the visibility to any marked extent. It is when such Pacific air is flowing eastward across the continent that the pleasantest winter weather is experienced east of the Rocky Mountains, with clear skies and moderate temperatures. Exception must be made, however, of the situation where a persistent southward advance of cold P_C air is taking place east of the Rockies, at the same time that an active inflow of P_P air into the Plateau and Rocky Mountain region is occurring. Under these conditions the Rockies may be high enough to serve as a barrier to the westward spread of the cold P_C air, while the Pacific air continues to flow across the mountains without being able to displace the cold air mass to the east. We may then have a stationary front along the eastern ridges of the Rockies and a continuous overflow of the P_C air mass by the Pacific current. This gives rise to widespread snow and blizzard conditions over the western portion of the Great Plains, with severe cold. The intensity of the snowfall depends principally on the warmth and moisture of the Pacific current.

In general, however, we find the P_P air mass changed from a moist unstable typically Polar maritime condition on the coast to a fairly dry and much more stable condition in the interior. For this reason the P_P designation is changed on our maps to N_{PP} as the mass moves inland, and occasionally the N_{PP} designation appears even on the coast when the air mass is returning northward and seems to be markedly warm aloft and stable at lower levels. For the same reason the mPK designation is changed in the interior of the continent to either cPK or cPW, according to the apparent effect of the ground surface on the particular mass in question. The "c" designation implies that the mountains have removed so much moisture from the P_P mass that it has become more typically continental than maritime.

Table IV shows that at Ellendale the cold air layer at the ground is very well pronounced, the average ground inversion being greater than 8 °C. To what extent this may be due to remnants of P_C air at the ground, and to what extent to radiational cooling of the P_P mass cannot be stated with certainty, but the constancy of w through this first km. would suggest the presence of well-mixed air with a radiational ground inversion, and the known large diurnal temperature variation in this type of air mass would strengthen the probability of the correctness of this interpretation. From 1 km. up we have just the vertical distribution of T and w which we have been led to expect, a lapse rate around the saturation adiabatic rate, a specific humidity moderately low for the temperature and decreasing with elevation (relative humidity about 50%), and an almost constant value of θ_E averaging nearly the same as that for fresh P_P air at San Diego. The Ellendale N_{PP} mass is distinctly warmer and moister than fresh P_P air from Seattle would be after crossing the mountains. It evidently came from further south, presumably from the middle Pacific coast of the U. S.

As we go southward from Ellendale, we find that at Broken Arrow the general properties are similar to those at Ellendale, but the surface inversion is much less marked, perhaps because of the comparative infrequency of a snow cover on the ground. Also the air aloft is distinctly warmer, but more markedly so at high levels, a fact which would seem to indicate a disappearance of the turbulent condition acquired by the air current in crossing the mountains, and perhaps the appearance of a certain amount of subsidence. At Groesbeck all these same tendencies have progressed still further; the surface inversion is still smaller, and the surface value of w larger. This condition indicates the comparative infrequency of a snow cover on the ground. The air mass is also warmer throughout, but most markedly so at the top, while w shows a decrease aloft at the same time that it has increased below. This indicates definitely a continuation of the subsidence already apparent at Broken Arrow. It is probable that in comparison with the Ellendale P_P air masses those reaching Broken Arrow, and still more those reaching Groesbeck, passed inland over the Pacific coast further north towards Seattle, as a flow of fresh P_P air, for most such inflows after passing inland move southward toward the Gulf of Mexico. This may account for the marked dryness found at high levels at Groesbeck.

Further east at Royal Center, and still more at Due West, the N_{PP} air mass properties are hardly to be compared directly with those of any of the western stations, though the general type has remained unchanged. We find at both stations an air mass fairly warm, dry, and stable throughout. The surface inversion remains about as in the middle west, Royal Center having at all levels a temperature about 5° colder than that of Due West, in accordance with its more northerly latitude. The stability of the air mass at upper levels shows a slight further increase as we go eastward. Probably these air masses in their eastward progress across the country approach gradually a vertical structure representing an approximate mean winter condition for light air movement over a land surface under radiational and convective equilibrium in the latitude where they are found. They become what Bergeron[1] has called neutral in their character with respect to the surface beneath, probably alternating between cPK characteristics by day and cPW characteristics by night.

The characteristic curves for the average P_P and N_{PP} air mass properties (Plate II-A) show clearly by their closer approximation to a vertical course at the eastern stations the normal transformation of the unstable P_P air mass as found at Seattle and San Diego on the Pacific coast to the stable N_{PP} air mass indicated at Ellendale, Groesbeck, Royal Center, and Due West in the interior of the continent. The individual N_{PP} ascents for Ellendale and Due West (Plate II-C) show the same contrast with the individual P_P ascents for Seattle and San Diego. Plate II-C should be compared with Plate II-B, which contains individual P_C and N_{PC} ascents. For the Polar continental air the transformation is clearly shown to be just the reverse of what it is for the Polar maritime air, the N_{PC} curves being more nearly horizontal, and the P_C curves more nearly vertical. These curves present graphically the characteristic differences between the two principal Polar air masses, and their normal modifications, as they appear over the continent of North America.

3. *The Polar Atlantic Air Masses*

Since the prevailing atmospheric movement in north-temperate latitudes is from west to east, the north Atlantic Ocean plays in comparison with the north Pacific a very minor rôle as a source of air masses affecting the continent of North America. Because this movement is much stronger during the colder half of the year than during the warmer half, the importance of the north Atlantic Ocean as a source of air masses affecting the U. S. is much greater in summer than in winter. Owing to the coldness of the water surface in part of the north Atlantic area in summer, it becomes at that season a true source region of some consequence, whereas in winter it effects only a moderate modification of the Polar continental air masses which move eastward from the continent. It is only when we find a retrograde westward movement of these modified Polar air masses over the east coast of the U. S. that they appear on our synoptic charts or are of significance for our weather. Nevertheless, when this occurs, their characteristic properties are significant enough to require an individual designation.

Accordingly the source region of the P_A air mass is that portion of the North Atlantic Ocean adjacent to the continent of North America, and north of the warm Gulf Stream current, or essentially the area from the Gulf of Maine northeastward. It must be remembered that this is a region for which the ocean surface temperature is abnormally low for the latitude during the entire year. In winter this temperature is not far from 0°C. Furthermore the normal condition in winter is one in which cold P_C air is moving out from the continent over this region along the coast of New England and off the Canadian Maritime Provinces. It usually happens with an outbreak of cold P_C air in this region that with the movement of the cold air mass out over the ocean the coextensive anticyclonic circulation is displaced slowly off the coast, so that in this circulation the very same P_C air which a short time previously was moving from the land to the water returns over the north Atlantic coast as a northeast backing to southeast wind. This return flow is strengthened by the approach of a disturbance from the south or southwest (associated with a warm current from the Gulf of Mexico or south Atlantic Ocean). This is the normal sequence under these conditions. This onshore flow of modified P_C air, which seldom extends its influence west of the Appalachian Mountains, yet is of real significance on the north Atlantic coast of the U. S., is the typical P_A air mass in winter. Its importance lies in the sudden change of weather along the coast which accompanies the usually rather abrupt transition from the P_C outflow to the P_A inflow as the center of the anticyclone passes slowly to the eastward.

In explaining the properties of this characteristic winter P_A air mass, as it appears on the north Atlantic coast of the U. S., several facts must be borne in mind. In the first place, since the water is much colder than along the north Pacific coast of the U. S., the P_A air masses are considerably colder and drier at low levels than the P_P masses and consequently less markedly unstable, with a comparatively shallower layer of instability. Greater stability of the P_A than of the P_P air mass is to be expected also from the fact that the distance through which the P_A air mass has passed over the water, and the period of time during which the maritime influence has affected it, are both much less than in the case of the P_P mass. Equally important in respect to the stability of the P_A air mass at upper levels, however, is the fact that the initial cold air outflow no longer continues where this air mass is found on the coast. The vertical structure of the P_A air mass is that characteristic of the rear side of a quasi-stationary anticyclonic circulation with cold air at the ground. Observation shows that normally in the P_C outbreaks at Boston, on the first day of the outbreak the lapse rate is steep, and the temperatures above 3 km. reach their lowest level. On the second day the temperature at the ground reaches its lowest value, but already a pronounced warming (subsidence) is found to have taken place since the first day, above the 2 km. level. On the third day there is only a thin layer of cold air near the ground remaining. This is the condition of that part of the P_C air mass which returns over the north Atlantic coast as P_A air. Consequently there is a very definite upper limit set to the thickness of the layer of convective equilibrium, or of the height to which the maritime influence extends, that of the subsidence inversion, which is not very high. Very often at a somewhat higher elevation, usually near 3 km., we find the warm front inversion belonging to the next approaching disturbance, and frequently above this inversion the overrunning air is found to be of tropical origin.

In view of these facts we should expect the P_A mass on the north Atlantic coast in winter to show a surface temperature near freezing or a little below, with a good lapse rate through the first km. or thereabouts. The relative humidity should be high, increasing to near saturation at the top of the convective stratum, the values of w lying mostly between 2 and 3 g. At the top of this convective layer should be a deck of thickening st cu clouds, but the growth of cu nb forms and showers should be prevented by a marked inversion above the cloud deck. Above this inversion the air should be dry, moderate in temperature and clear, except perhaps for a warm front cloud layer at higher levels.

Unfortunately there is no aerological material to confirm by direct observation the correctness of these assumed P_A air mass properties. Boston is the only station properly located for this purpose (Due West is too far from the coast and too far south). Furthermore the conditions at such a time are distinctly bad for flying. The ceiling is usually low and the visibility poor. In fact, we find very frequently light snow flurries, or when the air is a little warmer, passing showers of light misting rain falling from low thick st clouds along the coast. The precipitation during a whole day of this type of weather seldom amounts to a mm., yet the effect of such misting rain on the visibility is very depressing. The stability aloft is too marked to permit of sufficient convection to cause any appreciable amount of instability precipitation. The principal significance of this P_A air mass in winter time is the sudden and complete change of weather which accompanies the onshore movement of the mass. The change usually takes place rather suddenly. With the change a moderate northwest wind at the ground usually backs to northeast in the course of an hour or two, and almost at once a rapidly thickening deck of st cu clouds advances from the east. It is not uncommon to find within a few hours a light mist or snow flurries falling, a temperature increase of as much as 10°C., and the reduction of excellent visibility to very poor. Subsequently the maritime influence works steadily inland, terminating abruptly conditions of extreme cold, but seldom extending its influence beyond the eastern ranges of the Appalachians. Along the south Atlantic coast this type of onshore air flow is usually much warmer than on the north Atlantic coast, because of the proximity of the Gulf Stream, but it is seldom possible to prove definitely the P_C origin of the advancing air mass. It can be said, however, that it has had a longer maritime history than the P_A mass further north, that it is unstable to higher levels, and that it occasionally yields rather heavy local convective rains along the coast. If there is real proof, either in the coldness of this southerly Atlantic air mass or in its instability, that it is of moderately recent Polar origin, it is classified as P_A or N_{PA} air, otherwise it is classified as T_A or N_{TA}. The N_{PA} classification indicates an air mass heated and unstable beyond the typical P_A condition, and the N_{TA} an air mass cooled and stable beyond the typical T_A condition (see Table VII for Tropical maritime air mass properties). It frequently happens that available ship reports from the region off the south Atlantic coast are too few to make possible any satisfactory analysis of this portion of the map, a fact which adds to the difficulty of a proper designation of the air masses appearing over this area.

D. The Polar Maritime Air Masses — Summer

1. *The Polar Pacific Air Masses*

Generally speaking, we expect to find in summer all maritime air masses relatively stable, and continental masses relatively unstable, compared with their winter vertical structure, because of the seasonal reversal of the normal temperature difference between land and water surfaces. We have seen that for the P_C air masses this difference is very pronounced, that the condition of extreme stability of the winter continental Polar air is changed in summer to a condition of moderate instability, especially marked during the daytime. But a glance at the summer properties of the P_P air mass at Seattle at upper levels (Table V) shows the presence of a surprisingly good lapse rate. Especially through the first km. do we find a steep lapse rate. Since all the Seattle ascents were made during the early morning hours, this surface instability cannot be explained as the result of insolational heating during the short interval that the air has been moving inland from the sea. It must be explained rather as the result of turbulent mixing effected in an air mass initially moderately stable by its passage over the mountainous promontories or along the devious water route to the head of the fjord where Seattle is located. The constancy of w, and the increase of the relative humidity from an average surface value of 62% to an average of 91% at 1 km. is further evidence of the correctness of this assumption. St cu clouds are nearly always present with a base elevation between 8 and 14 hundred meters under these conditions. But the cu nb clouds and showers characteristic of the P_P air mass in winter are definitely absent. The reason is obvious when we note a lapse rate between the 1 and 3 km. levels of only four-tenths of the dry adiabatic rate, whereas in winter between these levels we found (Table IV) a lapse rate of more than seven-tenths of the dry adiabatic rate. The large decrease of w to be noted in the P_P air mass in summer between the 1 and 2 km. levels is noteworthy as indicating definitely that between these levels must lie the upper limit of the turbulence layer and doubtless therefore of the st cu cloud layer also.

Table V

The Polar Maritime Air Masses—Summer (mPK)

Seattle P_P

Elevation above Sea Level (km)	T °C	w g	RH %	θ_E °A
Surface	16.5	7.1	62	308
1	8.5	6.3	91	308
2	4.5	3.9		307
3	0.5	2.3		308.5
3½	–2.5	1.7		310

Seattle is the only station for which summer ascents in Polar maritime air are available. At San Diego and Boston summer data are entirely lacking. Due West is too far south and too far inland to be of any use in the investigation of the P_A air mass properties, and in the summer the P_P air masses cannot be distinguished from the P_C masses after they have crossed the western mountain ranges to the interior of the United States.

In the accompanying table a top elevation of 3½ instead of 4 km. was chosen for representation because most of the few summer ascents which were available from Seattle terminated between these two elevations.

In general, however, in spite of the fact that fresh P_P air at Seattle is characterized by greater stability between 1 and 3 km. than is summer P_C air at the inland stations, nevertheless, no condition approaching isothermalcy is found at any level in the P_P air masses, but rather quite an appreciable lapse rate at all levels. Furthermore, we find that from 1 km. upwards the P_P air mass is markedly colder than the P_C mass at any of the inland stations. The temperature found at $3\frac{1}{2}$ km. in fresh P_P air at Seattle is the same as that observed at 4 km. in P_C air at Ellendale, where this air mass is colder aloft than at any of the other inland stations. Furthermore, the values of w at Seattle are slightly less than those in the P_C air masses at Ellendale and Royal Center. A comparison of the characteristic curve on the Rossby diagram for the Seattle data in Table V with the summer P_C curves for Ellendale, Royal Center, and Broken Arrow (Plate III-A) shows very clearly the parallel structure of the two air masses, and the consistently lower temperature in the P_P air at Seattle. Rather noteworthy is the marked constancy of equivalent potential temperature in the P_P air at Seattle. This constancy of θ_E indicates the absence of potential instability at any level of the P_P air mass, but on the other hand it definitely does not represent the stable structure of an air mass cooled from below. For this reason I have designated fresh P_P air even in summer as mPK rather than mPW. A typical individual summer ascent in P_P air at Seattle is shown in Plate III-B. The curve does not differ markedly from the mean curve in Plate III-A.

The coldness and dryness of the summer P_P air masses at Seattle indicate almost conclusively the correctness of the assumption, based on the study of the winter properties of this air mass type, that the source of the air mass is the same as that of the P_C mass, or at least that it is as truly Polar or Arctic in character. In winter we found that although the lower strata of the P_P air mass were greatly warmed and moistened by the warm ocean, the upper strata were quite as dry and only a little warmer than the same strata of the P_C air mass at Ellendale. In summer we find the P_P air mass cooler than the P_C mass at all levels, and above the first km. just as dry. The relative coolness of the maritime Polar air mass in summer depends primarily upon the coolness of the ocean surface relative to the land surface. Not only are the lower strata of the maritime air mass less heated by their contact with the earth's surface than are the same strata of the P_C mass, but there is also less terrestrial radiation from the cool water surface to the upper layers of the maritime air mass. The absence of the marked heating by contact which occurs in winter at the warm ocean surface is reflected also in the low elevation to which the dampness of the summer P_P air mass extends, *i.e.*, the small vertical extent of the penetration of mechanical or convective turbulence. Nevertheless, the lapse rate in the summer P_P air masses at Seattle is steep enough to indicate that the air flow has been from colder to warmer surfaces. Probably the heating is rather gradual during the progress of the air mass from the cold Polar seas southward. This heating probably becomes effective at upper levels only by means of direct radiation from the surface beneath without mechanical or convective turbulence having played any rôle above an elevation of about 1 km., which we found to be a normal depth of the turbulence layer at Seattle.

But there is besides the relative coolness of the water surface in summer another fact which should not be overlooked in the explanation of the coolness of the P_P air masses at this season. This fact has to do with the change in the normal atmospheric pressure distribution along the north Pacific coast from winter to summer. In summer the pressure is relatively low over the continent, and relatively high over the ocean, especially over the northern area, so that in summer the middle Pacific anticyclone extends far northward into the region normally occupied in winter by the so-called Aleutian Low, which tends to be displaced inland from its winter position with greatly diminished intensity. Consequently in summer there is normally prevalent a well-marked pressure gradient directed from ocean to continent along the entire Pacific coast from California northward, a condition which favors a steady transport of Polar maritime air southeastward along the entire Pacific coast. This condition is so persistent in summer that warm maritime air from the south seldom if ever reaches the north Pacific coast at the surface directly, as it frequently does in winter. Occasionally there occurs a temporary cessation of the maritime Polar outflow on the north Pacific coast during the passage further north of a disturbance following a more southerly course than is usual in summer. Furthermore, the ocean surface temperature along the California coast is so low in summer, because of the upwelling of cold water, that Tropical maritime air masses must pass a great distance northward from their source region to reach the latitude of Seattle. Owing to the small number of flights available at Seattle for the summer period, and the prevalence of st cu clouds on the days of marked P_P outflow, it was impossible to check up by pilot balloon runs on the depth of this outflow, and on the wind velocities aloft. However, the marked coldness of the P_P air masses up to at least $3\frac{1}{2}$ km. seems to indicate that the pressure gradient bringing the cold air southward does not weaken appreciably up to this level.

Unfortunately the lack of any aerological ascents from San Diego or from any other point on the California coast during the summer period of investigation makes the discussion of the vertical structure of the P_P air masses in summer in that region purely hypothetical. However, it seems very probable that the change at San Diego from the Seattle values of the P_P air mass properties would be in the direction of a marked increase in stability, especially at the surface. Probably even in the prevailing air flow from the northwest we would find a pronounced low turbulence inversion (the wind velocities are usually too great to permit of the formation of a surface temperature inversion) with dense st or st cu clouds, which may at times approximate surface fog in their low elevation in the upper portion of the turbulence layer. The extreme local coldness of the ocean surface along the California coast is sufficient to cool the lower strata of even the coolest P_P air masses from the northwest. H. R. Byers[10] has discussed in detail the normal distribution of ocean surface temperatures, the mean atmospheric stratification, and fog formation in this region in summer.

It is quite impossible in summer to distinguish air of Polar Pacific origin from that of Polar continental origin after the former has reached the aerological stations in the interior of the U. S. In summer most outflows of Polar air over North America first become evident in a strengthening of the normal pressure gradient along the Pacific coast, and consequently in an intensification of the P_P air flow. This northerly current gradually works inland, with an accompanying general rise of pressure in the coastal region, and a gradual displacement eastward of the zone of strongest north or northwest winds. Consequently the Polar air current becomes increasingly continental in its composition as the Polar source region from which the outflow takes place is displaced continually inland, or eastward. Under these conditions it becomes almost impossible to determine a boundary between the air current of maritime and that of continental origin. In winter this distinction is easier to make, because of the very much greater coldness and dryness of the continental air. But in summer when the initial differences between the P_P and P_C air mass properties are so slight, by the time that the P_P mass has crossed the mountains, usually rather slowly, and come probably into radiation equilibrium with the continental surface beneath, all differences between these air masses are so completely obliterated that it is neither possible nor of any advantage to distinguish between them. Consequently the designation P_C can be used indifferently, in summer, for Polar continental air masses or Polar air masses of Pacific origin after they have reached the interior of the U. S. In the tables of the air mass properties included in this discussion, no separate values are given for the P_P air masses in summer at the inland stations. Both air masses must be designated in the differential notation as cPK, and may in their later history reach the transitional N_{PC} condition. When it remains fairly obvious that the air mass in a certain inland region is definitely from the maritime or from the continental source, its distinctive designation is retained. A typical summer outflow of Polar air, beginning on the Pacific coast and working eastward, is shown in Plates XXI through XXX.

2. *The Polar Atlantic Air Masses*

The Polar Atlantic (P_A) air masses are more important in the late spring and early summer than at any other time of the year. At this season the ocean surface in their source region, from Cape Cod northeastward to Newfoundland, is at its maximum of abnormal coldness for the latitude and at its coldest in comparison with the continental region to the west. This relative coldness is a consequence of the slowness of the cold continental ocean current from the north in warming up in the spring, and of the transport of icebergs into this region by the Labrador current. It follows that this ocean region in late spring and early summer becomes a real cold air source. Whenever the normal eastward movement of air over this region ceases, as it frequently does in the spring and summer, the tendency is towards the immediate development of a stationary anticyclone thermally maintained by the cooling of the stagnant air mass present in the region. Such developments frequently manifest surprising persistence over the cold water, and usually lead eventually to an overrunning of the north Atlantic coastal region by the cold P_A air of the anticyclonic circulation. Occasionally it happens that a general southward movement of the cold air follows down the entire Atlantic coast as far south as northern Florida, bringing with it a decided drop in temperature. The difference in temperature between this cold maritime air and the hot continental air may amount to as much as 20° or 25°C. Usually, however, the P_A air masses in summer do not make their influence felt south of Cape Hatteras, and the greater part of the time only on the north Atlantic and especially the New England coast.

For the determination of the summer P_A air mass properties, only surface observations and indirect indications as to the vertical structure of the air mass are available. This lack of data is caused partly by the discontinuance of the M. I. T. aerological station during the summer months, and partly by the fact that Due West is too far south and too far inland to be affected by the P_A air masses. The term P_A, in summer as in winter, is applied to those air masses which were originally P_C, but which have remained long enough over the cold waters of the north Atlantic to have become appreciably modified. We have seen that in winter very little time is required to effect such a modification because of the marked initial coldness of the air mass. In late spring and early summer, however, the water surface is colder than the surface strata of the P_C air, so that the modification takes place slowly. On the other hand, the general stagnation of the air movement over this north Atlantic area is frequently so persistent at this time of year, that the air mass may have days in which to reach a condition of equilibrium with respect to the surface beneath. As the stationary maritime anticyclone develops under these conditions, the cold air usually reaches the coastal stations at first as not much more than a sea breeze, but on the following days the cold air mass usually invades the whole coastal area east of the Appalachian Mountains, and occasionally advances far to the south. The properties of the cold air mass are shown best by the New England coast stations, although in the case of a southward displacement of the air mass the characteristic coldness is retained to a surprising degree. The surface air temperature of the mass, as indicated by an outlying station like Nantucket, is probably very close to that of the cold ocean surface from which it is moving. This temperature is likely to be about 5°C. at the beginning of May, about 10°C. at the beginning of June and 12° to 15°C. later in the summer. There is almost no daily period in these temperatures. In spite of the fact that these temperatures indicate a cooling of the air mass from the temperature which it originally possessed over the continent as P_C air, the P_A air mass is found to have just as in winter a rather unstable structure up to about 1 km. Since this lapse rate cannot be explained in this case as caused by heating from below, mechanical turbulence remains as the only obvious explanation of the instability of the lower km. of the P_A air mass. Stratiform cloud forms indicate a marked inversion at the top of the turbulence layer. It is very probable, in view of the prevailingly stagnant anticyclonic condition associated with this air mass, that the inversion is intensified by continual subsidence of the upper strata of the mass. The wind velocity is usually strong enough in the cool maritime anticyclone to justify the turbulence explanation of the unstable ground layer of the P_A air mass, and the long exposure of the mass over the cold water could account for the loss of much heat from this stratum by turbulent transfer downward to the cold surface. Two April ascents at Boston in this type of air mass showed a lapse rate nearly nine-tenths of the dry adiabatic rate up to 1 km., where there was a thin st cu cloud layer, with a temperature inversion immediately above of 5 °C. We find typically in the P_A air mass in summer some st or st cu or fr st clouds at the top of the instability layer, though they are usually much thinner than in the same mass in winter, seldom covering the entire sky, and frequently appearing as only a few scattered fr cu or completely disappearing. Precipitation never falls from these clouds in summer. This follows from the initial dryness of the P_C air mass, and the very small amount of evaporation which takes place from the cold water in summer. There is very little difference between the specific humidity of the P_C and that of the P_A air mass at this season. The cooling of the air mass at the cold water surface, an effect which we assume to be carried upward by turbulence, produces usually a thin saturated stratum at the top of the turbulence layer (as indicated by the cloud formations mentioned above), but seldom more than about 70% relative humidity at the surface. Hence the real P_A air mass does not become foggy over the water, but is on the contrary usually characterized by excellent horizontal visibility, apart from the occasional thin cloud layer mentioned above. There is, however, occasionally visible over the ocean on a clear afternoon in this air mass a very noticeable whitish haze, even when the relative humidity is much below saturation, and the condition is far from being one of real fog. This may be due to the presence of tiny water droplets on salt nuclei.

It is obvious that the general effect of the underlying cold water surface in the source region of the P_A mass in summer is to effect a cooling of the air mass from beneath making it essentially stable, though this is apparently counteracted close to the ground by turbulence. Since the underlying surface is usually colder than the air above it, the P_A mass in summer is designated in the differential notation as mPW. As soon as this air mass moves inland, however, the temperature difference is reversed, so that the mass becomes mPK.

It should be mentioned at this point that warm, moist, continental air in summer, and even more Tropical maritime air masses from the Gulf Stream, which move into the P_A source region, are very quickly cooled over the cold water to such an extent that dense fog is immediately formed. Partly because of their greater initial warmth and moisture, and perhaps partly also because of less wind and mechanical turbulence, the dense fog appears almost immediately at the surface and grows deeper with prolonged cooling. It is this condition which gives to this region its reputation for spring and summer fogginess. These air masses of Tropical origin, cooled in the P_A source region, are designated on the M. I. T. maps as N_{TM} or rarely N_{TC}. The symbol N_{PA} may appear on the summer weather maps for P_A air which has moved far south over warmer water, or been brought to a considerable distance inland. In either case the air mass will have lost its coldness, and will have the mPK characteristic properties.

E. The Tropical Continental Air Masses — Winter

The Tropical continental air masses in North America play a very insignificant rôle. This is because the land areas to the south contract very rapidly, so that the possible source regions for such air masses are very restricted. Not only is the land area small, but it is not suitable for the origin of heated continental air masses. Apart from the coastal regions which are damp and hot, most of Mexico and Central America is high plateau or mountain country, with a comfortably cool climate. Especially in winter is this region quite cold. Thus we find that about the only possible source of T_C air in North America is the area covering the semi-arid portion of the Great Plains in the southwest, and extending westward and southwestward from Oklahoma and western Texas into the plateau and mountain districts of New Mexico, Arizona, and northern Mexico. This region is dry, but it is too elevated and too far north to be an effective warm air source in winter. It is usually occupied in winter by old P_C or old P_P air masses, which are cool and dry, and which, under conditions so favorable to radiational cooling, remain cool. The air mass lying in this area acquires no distinguishing warmth by which it may be traced from the source region, nor any properties by which it may be distinguished from similar continental air masses further north. Thus in winter there is no justification for using the term Tropical continental in referring to any air masses which appear on the North American weather maps. In summer, however, an air mass coming from this source region has distinctive properties which are of real significance for the weather in the central U. S.

F. The Tropical Continental Air Masses — Summer

In the summer the arid region in the southwestern U. S. and northern Mexico is greatly heated by the sun. The dryness of the air favors the insolational heating of the dry ground surface, which in turn heats the air above it. The heat and low relative humidity become most extreme over the less elevated portions of this region, but when the warm air from the higher plateaus moves eastward or northeastward over the lower Plains, Föhn effects quickly bring it to as high a degree of warmth and dryness as the air which is already present at the lower elevations. During the daytime especially, when the ground becomes excessively heated, the overlying atmosphere must be markedly unstable, but its dryness is such that the resultant convection seldom reaches the condensation level, consequently condensation forms are characteristically missing in the T_C air mass. This mass must, of course, be classified as cTK air in the differential notation, although during the night the tendency is towards a very rapid radiational cooling of the ground and of the lower strata of the air mass. Thus marked dryness, clear skies, and a large diurnal temperature range with notably high surface temperature and convective instability in the afternoon characterize the T_C air mass in summer near the source region. The importance of the T_C properties to the synoptic meteorologist lies in their contrast to the properties of the moisture-laden Tropical maritime air which moves northward from the Gulf of Mexico, accompanied by humid oppressive conditions, frequent heat thunderstorms, and a small diurnal temperature range. The line of demarcation or front between these air masses usually sets off very definitely the limit of the region within which heat thunderstorms and the attendant oppressive conditions are likely to prevail.

Generally speaking, the hot dry T_C air is brought northeastward into the central part of the country when relatively low pressure prevails over the northern Plains, especially the Dakotas, and thence northward into Canada. When there exists a moderate pressure gradient over Texas and Oklahoma towards the north, this region is likely to be invaded by hot dry air from the west southwest, but if the gradient is directed towards the northwest, then the warm moist air from the Gulf moves northward at the ground. Usually it is a rather fine problem to decide just how far the moist T_G air is going to extend its influence, and to what depth. Normally in summer the pressure distribution at the ground over the interior of the North American continent is such that there is a marked tendency towards a prevalence of southerly winds at low levels over the Plains states for considerable periods of time. As we shall note presently in discussing the T_G air masses, the consequence of this normal pressure and wind distribution is that moisture-laden winds from the Gulf of Mexico prevail at the ground a great deal of the time in summer even as far north as southern Canada. Under these conditions the dry T_C air moves directly northward along the eastern slope of the Rockies. For this reason it is the exception rather than the rule to find the dry T_C air at the ground at Broken Arrow or Ellendale. However, when the general air movement becomes more eastward, as occasionally happens, then the T_C influence at these stations becomes very pronounced. Under these conditions the T_G air mass is found further to the east or southeast. An excellent illustration of this type of air flow, and of air mass distribution, will be found on the maps for July 26-29, in Plates XXII-XXVIII. In this instance the characteristic warmth, dryness, and clear skies of the T_C mass as it moved slowly eastward persisted for two days in sharp contrast to the thunderstorms and lower daytime temperatures of the T_G air masses which almost surrounded it.

Groesbeck, in east central Texas, is so near the Gulf that the dry T_C air is very seldom found at the ground at that station. But we do find very frequently at Groesbeck, which is near the edge of the T_C source region, a comparatively shallow layer of moist T_G air at the ground, with a very pronounced layer of extremely dry T_C air overrunning the moist air at an elevation between 1 and 2 km. Usually we observe under these conditions light southerly winds at the ground and fresh southwest or south southwest winds in the dry layer. Frequently the moist T_G air is observed again at higher levels above the dry T_C stratum. A pronounced stratification of this sort is found in some 40% of the Groesbeck summer ascents. The same stratification is found in a much less marked degree, and more rarely, at Broken Arrow. At Pensacola, Fla., and Ellendale it is never observed. Such extreme stratification as is indicated between the T_G and T_C currents at Groesbeck certainly cannot survive a summer afternoon's convective mixing. It is found at Groesbeck in the early morning ascents, when it is obviously the result of nocturnal thermal stratification and undisturbed air flow. The thin dry stratum is usually almost effaced by mixing, by the time that the air flow reaches Broken Arrow, and completely so by the time that Ellendale is reached. The T_C air is never found at the ground as far southeast as Pensacola and probably not at any elevation. It is seldom that the T_C air mass can be traced at the ground far east of the Mississippi River, for by the time that this mass has moved so far eastward from its source it is usually being mixed with the moist T_G air from the south, or being moistened by evaporation from the warm surface beneath, which takes place very rapidly in summer, or being displaced by cold Polar air from the north. The gradual displacement of the T_C air mass at the ground between P_C air on the north and T_G air on the south and east, as it occurs during the period from July 27-29, 1930 (See Plates XXIII-XXVIII) is very typical for the final history of this air mass. For that reason no T_C air mass properties can be given for the eastern stations. For the summer of 1930, aerological ascents made in T_C air from the ground up were available only from Broken Arrow and Ellendale, and in T_C air at upper levels from Groesbeck. The source region of the American T_C air is not extensive enough to make possible very large scale currents of this origin, a fact which helps to explain why these air masses disappear so quickly at the ground.

The properties of the T_C air masses at Broken Arrow and Ellendale are shown in Table VI. These figures are based on very few ascents, for this air mass is found surprisingly seldom without T_G contamination in this region. For Groesbeck it is impossible to give an average vertical distribution of the air mass properties that will show the dry T_C air layer which occurs there so often at intermediate levels, for the exact elevation of the dry stratum is seldom twice the same. Hence an average of the conditions at fixed levels when the dry T_C layer is pronounced does not present at all a true picture of the properties of the dry air itself. Consequently two typical individual ascents at Groesbeck showing the dry layer well pronounced are entered in Table VI instead of the mean values from a number of such ascents. Furthermore, the intermediate elevation of 600 m. is entered for these two ascents, in order to present a clearer picture of the abruptness of the transition from the T_G air to the T_C.

TABLE VI

THE T_C AIR MASSES—SUMMER (cTK)

ELEVATION ABOVE SEA LEVEL (km)	STATION															
	BROKEN ARROW				ELLENDALE				GROESBECK				GROESBECK			
	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A
Surface	27.3	9.5	40	329	27	11.3	48	335	23	14.5	80	337	24	17.1	80	346
0.6									27	3.5	16	316	22	17.0	80	348
1	26.7	7.9	32	332	28	8.0	30	333	24	6.0	35	323	23	4.3	18	316
2	19.0	6.5		330	22	6.1		332	16	8.1	60	331	16	9.4	65	337
3	10.0	5.0		327	15	4.6		332								
4					6	3.3		329								

If we note the values of T tabulated for Broken Arrow and Ellendale in Table VI, we find that above the first km., where the stabilizing effect of the nocturnal radiational cooling is obvious, the lapse rates are steep, and increasingly so above 2 km. The insolational heating during the day doubtless eliminates any comparative stability which may be observed during the early morning hours below the 2 km. level. Mid-afternoon surface temperatures in this region in T_C air frequently exceed 35° and may reach even 40°C. The early morning temperature distribution, however, does not differ markedly from that observed in T_G air at the same stations (see Table VIII), but the specific humidity differences, on the other hand, are very marked, running from about 6 g. at the ground to about 3 g. at upper levels. Correspondingly we find at the ground relative humidities of less than 50% in the T_C air, in spite of the early morning coolness. The equivalent potential temperatures lie characteristically between 325° and 335°, whereas in T_G air 335° represents a lower limit which in the lowest 2 km. is seldom reached. At high levels, where the moisture differences are smaller, there is no such characteristic distinction in the values of θ_E which are observed in the T_G and T_C air masses. It will be noticed also that q at the ground is a little greater at Ellendale than at Broken Arrow, probably because of the greater distance of the former station from the source region. This greater distance of travel offers more opportunity for the increase of q in the dry T_C air mass by evaporation from the ground and perhaps also by some mixing with T_G air.

At Groesbeck the two typical ascents given in Table VI indicate near the ground the large moisture content and the temperature typical of the T_G air mass. The coolness of the air is explained by the fact that the ascents are from an earlier hour in the morning than those at the other stations. We find the characteristic extremely dry T_C air stratum, in one case at 600 m., in the other at 1 km. This air stratum is observed to have a relative humidity and a specific humidity markedly lower than T_C air found at any other station. The equivalent potential temperature, 316°, is about that characteristic of summer P_C air at Broken Arrow. This low value of θ_E, however, is due to the extreme dryness of the air, and not to its coolness. The possible explanation of this extreme dryness as being an error of observation introduced by a failure on the part of the humidity element of the meteorograph is excluded by the frequency of its appearance and the close check which is found on the ascent and descent through the dry stratum. Apparently it must be explained as the result of markedly stratified air flow with a penetration at intermediate levels of a stratum of dry T_C air from the west. Usually a small increase of the W component of the wind velocity is detectable in the dry stratum. The extreme dryness may be accentuated locally at Groesbeck by the Föhn effect of the mountains lying to the west, but their distance is so great and the rate of descent so gradual that it seems difficult to explain the entire phenomenon as a Föhn effect. But it is noteworthy that the T_C air does not retain such extreme dryness far from its source. The marked increase in the moisture indicated by the increasing values of w and the relative humidity above the level of maximum dryness is also typical of nearly all the Groesbeck ascents in which dry air is found aloft, although the recovery of the moisture is not always so pronounced at the uppermost levels as it is in these two cases. Usually a small decrease in the W component of the wind velocity is detectable at those levels where the increase of moisture takes place.

The characteristic curves on the Rossby diagram for Broken Arrow and Ellendale plotted from the mean values of the T_C properties as tabulated in Table VI will be found on Plate V-A. The slope of these curves is roughly that of the θ_E isotherms, while point for point they lie decidedly to the left of the T_G curves, because of the much lower values of W in the T_C air. Although the vertical spread of the T_C and T_G curves is numerically about the same, the T_G curves are much more extended horizontally than the T_C, which establishes clearly the importance of the moisture distribution as the cause of the potential instability of the former mass. In contrast to the approximate constancy of θ_E with elevation found in the T_C air masses, the T_G masses show a marked decrease. Individual T_C ascents at Ellendale and Broken Arrow made on July 27, 1930 (for weather map of this date see Plate XXIII), will be found in Plate V-D. The typical constancy of equivalent potential temperature stands out very clearly in these curves, and should be compared with the decrease of this element shown by the individual T_G ascents in the same plate. There will be found also on this plate a typical Groesbeck ascent in which the dry T_C layer is very pronounced. The extremely moist T_G stratum at the ground is found to extend to an elevation of 580 m., while in the next 400 m. we find the abrupt transition to the very dry T_C layer. In the second km. we find that the moisture increases again to a value at 2 km. which is typical of T_G air at this elevation. It is interesting to notice that in the surface T_G stratum the wind increases from light south southeast at the ground to fresh south at the top of the stratum, and that the change in wind velocity at the transition from the moist to the dry air stratum is the very slight one from fresh south to fresh south southwest. Above the driest level the wind velocity changes from fresh south southwest back to light south with the passage into the upper moist air stratum. This decrease in wind velocity in the transition from the dry to the upper moist air stratum is very typical of this stratified condition of the atmosphere at Groesbeck, although the change in wind direction is not always detectable. But the dry layer is a rapidly moving stratum, always so relative to the surface air and usually so relative to the upper air strata.

The T_C air masses even in summer do not keep their identity long enough, or at least cannot be traced far enough at the ground, to make the use of the N_{TC} designation of any significance. This symbol has been used on the M. I. T. weather maps in the past in a few doubtful cases, but its use will probably be avoided in the future. Obviously in the differential notation the T_C air mass must be prevailingly of the cTK type.

G. The Tropical Maritime Air Masses — Winter

1. *The Tropical Pacific Air Masses*

There are three sources of tropical maritime air which must be considered in any discussion of North American air masses. The principal distinction, however, lies between the maritime Tropical air which originates on the Atlantic side, and that which originates on the Pacific side of the continent. On the Atlantic side the distinction is made between the air masses which originate over the Caribbean Sea and Gulf of Mexico to the south of the U. S. (T_G), and those which originate over the Sargasso Sea to the southeast (T_A). These two air masses really constitute the Tropical maritime group for the eastern and central U. S. The distinction between these two air masses is purely geographical, and is scarcely detectable in their properties. On the Pacific coast and in the Rocky Mountain region, on the other hand, the only Tropical maritime air mass which plays any rôle is the one which comes from the sub-Tropical zone of the north Pacific Ocean (T_P). This Tropical Pacific air, as we shall see presently, is quite distinct in its properties from the T_A and T_G air masses. We will consider the T_P air masses first, and of necessity rather briefly, owing to the lack of upper air data and of properly analyzed weather maps for the Pacific coast region.

The source of the T_P air masses is that portion of the Pacific Ocean lying west and southwest of southern California, roughly between latitudes 25° and 35°N. During the cold season this region is one of markedly steady weather conditions, as it is normally the winter seat of the stationary Pacific anticyclone. Over the Pacific Ocean north of latitude 30° we find normally in winter a pressure gradient directed northward towards the Gulf of Alaska and the Aleutian Island region, which is the winter seat of the north Pacific low pressure area, usually referred to as the Aleutian Low. From or around the Aleutian area move most of the winter frontal systems and disturbances which approach the north and central Pacific coast. When these disturbances follow an unusually southerly path, or develop secondary centers which move further south than the usual Pacific depression, or develop in themselves to an unusual intensity, then the Tropical maritime air lying in the northern portion of the Pacific anticyclone is set in motion towards the northeast in response to the intensified pressure gradient toward the north or northwest. Occasionally an extension of the anticyclone northeastward towards the California coast occurs, causing the establishment of a pressure gradient which brings a general flow of T_P air northward along the entire length of the middle Pacific coast even beyond Seattle. Thus in advance of the southern portion of the cold front or the occluded front which marks the southward advance of fresh P_P air behind the depression approaching from the northwest, we may find a broad open warm sector of T_P air moving northeastward or even northward along the coast with rather high wind velocities. Frequently this warm sector is occluded before the warm air reaches the coast, especially when the coastal region is covered with cold continental air. Under these conditions California gets its heaviest winter rain, caused by condensation from the overrunning the T_P air, but the coastal stations from San Diego northward usually remain in the cold air. The occasional winter development of a marked depression inland as far as the Great Basin or the southern Plateau region of Nevada and Utah, accompanied by widespread heavy precipitation, is apparently associated with marked overrunning at high levels by T_P air from the south. On the other hand, the T_P air frequently sweeps northward along the Pacific coast with little or no resistance by colder air masses, consequently without appreciable overrunning at the warm front and with little or no rain before the approach of the cold front. It is equally true along the Gulf coast and along the Atlantic coast that the advance of the warm front and the Tropical maritime air at the ground is accompanied by very little precipitation unless a markedly colder air mass resists the advance of the warm current and forces its vertical ascent at the warm front.

The properties of the T_P air mass may be anticipated to some extent from the nature of the source region. The ocean surface in this region is rather cool for the latitude, ranging in temperature during the coldest season from about 14°C. at latitude 35°N. to about 19°C. at latitude 25°N. The weather condition is prevailingly anticyclonic, which suggests the probability that more or less subsidence is taking place aloft. Thus we should expect to find that the air masses which come from this region are only moderately warm, or even cool for Tropical maritime air, at least near the ground. We should expect to find these air masses also relatively stable, perhaps with indications of a subsidence inversion which should be marked by an abrupt decrease of the water vapor ratio w. W should be moderately high near the ground, but definitely not high for a Tropical maritime air mass. Finally, we should expect to observe an absence of condensation forms in this air until it has moved some distance northward from its source and has been appreciably cooled from below.

In its principal features we find that the T_P air mass data at San Diego, the aerological station nearest to this source region, verify the anticipated T_P properties. It should be noted, however, that San Diego is a rather unsatisfactory station for aerological investigation, because it lies south of the main zone of meteorological activity on the Pacific coast. Consequently conditions are so stagnant at this station a large part of the time that we observe little else than the daily interchange with the land and sea breeze of stagnating continental and maritime air, which become rather thoroughly mixed. However, the data for San Diego in Table VII probably give a fairly good picture of the T_P properties in this region.

The temperatures we notice are rather high at all levels, though not markedly so considering the proximity of the maritime Tropical source and the southerly latitude. The surface temperature is about 2°C. higher than the water temperature off the coast at San Diego, a fact which indicates a moderate recent movement of the air from a warmer region. We notice also the marked stability of the lowest km. of the air mass, as well as the large decrease in w, both facts which indicate either a low subsidence inversion or a low turbulence inversion. The rather surprising frequency of low st or st cu clouds in the T_P air mass at San Diego seems to favor the second possibility. If the air mass was originally characterized by marked stability and a rapid decrease of w with elevation at low levels, then the decrease of w at an inversion produced by turbulence might be as large as the difference observed at San Diego between the value at the ground and that at 1 km., otherwise the decrease would not be so large. Above 1 km. we note a stable lapse rate, but one which increases somewhat with elevation. The decrease of moisture noted in the first km. continues at higher elevations, but especially markedly at the 3 km. level. It is generally characteristic of the American Tropical maritime air masses that their moisture shows a rapid decrease at either the 2 or the 3 km. level. This moisture distribution is probably the result of the stability of these air masses which is such that the moisture acquired at the surface can make its way only very slowly to upper levels. If this explanation is correct, then the condition of stability of the air mass must be assumed to exist not only during its later history as it moves northward and is cooled in the lower strata by contact with a cold surface, but also in the source region, and even in those cases where the ocean surface in the source region is warm. However the vertical temperature distribution may be established in an air mass at rest over a warm water surface, it is a fact that when equilibrium is reached the lapse rate is always found to be rather conservative, and the moisture to be concentrated in the lower 2 or 3 km. of the mass. This concentration of moisture near the ground may establish a condition of marked con-

TABLE VII

THE TROPICAL MARITIME AIR MASSES—WINTER (mTW)

Elevation above Sea Level (km)	Air Mass and Station																														
	T_P (February 1930)										T_G and T_A (Winter 1929–30)													T_G and T_A Winter 1931–32				mTW (February)			
	San Diego				Seattle			Ellendale			Groesbeck				Broken Arrow			Royal Center			Due West			Boston				Germany (Schinze)			
	T °C	w g	RH %	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A
Surface	18.5	9.1	68	316	13.3	7.4	305	−3.3	2.8	281	18.8	12.6	90	327	20.2	11.8	328	17.5	11.3	324	17.3	10.5	320	14.0	8.8	82	310	13.6	7.8	73	307
1	16.5	6.1		315	8.0	5.7	308	+5.3	2.8	297	14.0	10.4	95	326	14.4	9.7	324	12.5	9.6	322	12.8	9.1	320	13.7	6.5	60	314	7.4			
2	11.0	5.3		319	1.7	4.3	308	+1.3	3.7	305	13.0	4.1	40	318	12.2	4.8	318	8.0	4.5	314	8.4	5.3	315	8.7	6.2	86	319	1.2			
3	4.5	3.7		318	−2.3	2.9	309	−4.7	2.8	307	7.5	1.2	15	312	7.3	3.1	318				3.0	4.0	316	2.0	4.6	84	318	−5.0			
4																								−3.7	2.9	85	319	−11.2			

ditional instability, which we shall find to be the case in the T_G air masses, but considerable vertical displacement is always necessary under these conditions before the potential instability can be converted into convective energy. In case the water surface in the source region is rather cool for the latitude, as is true for the source region of the T_P air masses, then the air mass does not become even conditionally unstable. Thus we note that at San Diego in the T_P air mass there is a slight increase of θ_E with elevation, and the same thing is found to be true for this air mass at Seattle. This fact explains why the T_P air flow along the Pacific coast gives quantitative precipitation only at an active front. It is too stable for the coast line to be effective in forcing much ascent of the warm current. And even at an active warm front the amount of precipitation from T_P air is considerably less than the amount at an active warm front where the more unstable T_G or T_A air is overrunning.

At Seattle the general properties of the T_P air mass are found to be similar to those observed at San Diego. The air mass has become cooler throughout, but the difference is not very great in view of the 15° difference in the latitude of the two stations. The surface temperature at Seattle in the T_P air is approximately 5°C. warmer than the lowest average ocean surface temperature which is found during the winter off the coast from this station. The relative warmth of the T_P air indicates the rapidity with which this air mass has moved from the south. At San Diego, where the air mass movement is much more sluggish, the difference was found to be only 2°C. But in spite of the warmth of the T_P air at Seattle relative to the ocean surface, a fair lapse rate from the ground up is observed in this air mass. The decrease with elevation both of T and of q is much more uniform than it is at San Diego. In particular has the marked stratification of temperature and moisture, which was noted in the first km. of this air mass at San Diego, disappeared at Seattle. This is a change which would scarcely have been expected, considering the increasing relative coolness of the underlying water surface with the progress of the air mass northward. It seems to indicate a large degree of turbulent mixing up to a considerable elevation in the T_P current. This marked turbulence probably is a consequence of the high wind velocity which must characterize any winter air current of Tropical origin reaching Seattle, and of the ruggedness of the north Pacific coast. But in its general characteristics the air mass is found to be at Seattle as it was at San Diego, warm, moist, and relatively stable. As at San Diego, we note that θ_E increases slightly with elevation, a fact which indicates the absolute convective stability of the mass. Consequently as at San Diego the air mass is characterized by stratiform clouds, and by the restriction of any considerable amount of precipitation to the frontal zones. The characteristic curves on the Rossby diagram for T_P air at these two stations will be found on Plate IV-A. The close parallelism of the two curves and their approximate coincidence with the θ_E isotherms are striking. A comparison of these curves with the characteristic curves of the T_G and T_A air masses which appear on the same plate, will call to attention at once the comparative instability of the latter air masses, which is indicated by their more nearly horizontal course on the diagram.

It is interesting to compare the properties of the T_P air at Seattle with the properties of the Tropical maritime air masses found by Schinze over northern Germany. The data for Seattle in Table VII apply to February, and in the last column of Table VII will be found Schinze's mean values of the properties of the European mTW air masses for the same month. We note that except for a slightly lower temperature at the 3 km. level found by Schinze, the temperature distribution in the two air masses at Seattle and in Germany is almost identical, at least up to this level. And even the surface value of q is found to be almost the same. Unfortunately, Schinze gives no humidity data above the ground. But this approximate identity, as far as the comparison can be made, of the T_P properties in winter at Seattle and of the properties of the

Tropical maritime air masses over Germany at the same season, might be anticipated from the general geographical and meteorological similarity of the two regions. West of Europe the Azores high over the cool ocean surface in the south, and the Icelandic low over the warm ocean surface in the north play exactly the same rôle in determining the normal meteorological conditions in western Europe that are played off the west coast of North America by the Pacific high over the cool ocean surface in the south, and the Aleutian low over the warm ocean surface in the north in determining the normal meteorological conditions on our west coast. The Tropical maritime air masses in both regions originate over the cool waters in the southern anticyclone, and move northeastward toward the continents under the influence of the same sort of cyclonic activity of the disturbances in the north. But whereas northwestern Europe lies open to invasion by this type of Tropical maritime air, the western mountain ranges of North America offer a very real obstacle to the movement of the T_P air masses to the interior of the continent, so that in general east of the Rockies this air mass plays an almost negligible rôle. In the mountains it becomes very difficult to trace with certainty the T_P air mass. Probably the majority of the stations in this region lie sufficiently in the shelter of the mountains so that they are unlikely to come into the warm T_P air flow which must overrun the cold continental air in the valleys. Furthermore, there is no aerological station in this region by which to establish with certainty the presence of the warm air aloft. Ellendale, however, has shown very definitely on a few occasions the presence of the T_P air at high levels. I have been unable to trace it further than Ellendale with any certainty, but there its presence aloft was unmistakable.

In Table VII is given the average of a few ascents at Ellendale when both the synoptic situation and the observed air mass properties aloft indicated the presence of T_P air at high levels. The presence of the T_P air at the 2 km. and 3 km. elevations is shown unmistakably by a comparison of the values of T, w, and θ_E at these levels with those shown by Seattle at the same levels. The temperature is slightly lower at Ellendale at the upper level, the value of w slightly lower at the lower level, and the difference in θ_E at the two stations is only some 2°C. At the surface at Ellendale we observe the lower temperature and moisture content belonging to N_{PC} or N_{PP} air. At 1 km. we note at Ellendale the high temperature indicative of air descending from the mountains in the west, but not until the 2 km. elevation do we observe a specific humidity directly comparable with that at Seattle.

A comparison of the characteristic curves on the Rossby diagram for these data from Ellendale and Seattle (see Plate IV-A) is very interesting. The Seattle curve shows throughout its course the slope to the left and the approximate constancy of θ_E which are characteristic of T_P air. The Ellendale curve, on the other hand, follows in the first km. the vertical course which is characteristic of Polar continental air in winter. In the second km. the slope of the curve to the right is caused by the increase of w in the transition from N_{PC} to T_P air. In the third km. are found the same slope of the curve to the left and the approximate constancy of θ_E which are characteristic of the Seattle curve throughout its course. On Plate IV-B are found the characteristic curves for two individual ascents at these stations. The Seattle ascent for February 4 is taken in a very rapidly moving current of T_P air, as is shown by the high wind velocities aloft, and by the st cu clouds at 1890 m. which are moving from the southwest with a velocity of 70 miles per hour. The light wind at the ground and the unusual stability in the first 600 m. indicate that the station in the fjord is sheltered from the full force of the warm air current. The Ellendale ascent is taken one day later, on February 5, showing the same T_P current aloft, between 2 and 3 km., after it has passed 1500 miles over the mountains from Seattle. The wind velocities are no longer as high as they were at Seattle on the previous day, but they still reach gale velocity from the west southwest and west. The specific humidity of

4 g. which is observed at the 2 km. elevation is never found at this elevation in winter at Ellendale except in T_P air, for the T_G and T_A air masses never move far enough northwestward during the winter season to be observed at Ellendale at any elevation.

For the other inland stations than Ellendale no values of the properties of T_P air can be tabulated. These warm maritime currents from the Pacific become weaker as they move eastward, and gradually mix with and lose their identity in the colder and drier continental air masses.

2. *The Tropical Gulf and Tropical Atlantic Air Masses*

a. Source Properties of the T_G and T_A Air Masses.

The Tropical maritime air masses which are of prime importance for the eastern and central U. S. are those originating over the Gulf of Mexico, the Caribbean Sea, or the Sargasso Sea. The essential characteristic of this entire region is the marked warmth of the water surface throughout the year. Except perhaps for a narrow strip along the coast of the U. S., the temperature of the ocean surface over this entire region remains well above 20°C. even when it is coldest. In the Caribbean Sea the lowest surface water temperature in winter is about 26°. In the Gulf of Mexico the water temperature at its lowest shades off from about 25° in the south to about 22° in the north central portion and somewhat lower along the immediate coast. In the Florida Straits the surface Gulf Stream temperature at the coldest season averages about 23° or 24°, and even off Cape Hatteras this current has a surface temperature of about 21° at its coldest. Southeast of the Gulf Stream the Sargasso Sea, only a degree or two cooler in its surface temperature, extends for a thousand miles. From these facts it is obvious that all air currents reaching the eastern U. S. from the southeast or south must come from uniformly warm maritime regions. The water temperature differences in these regions are too small to have any great significance for the properties of the air masses originating there. Consequently no attempt is made in the following discussion to distinguish between the properties of the different Tropical maritime air masses from these regions, but the two symbols T_G and T_A are used simply as an indication of the general trajectory of the air mass, to distinguish between the Gulf and Caribbean Sea source region on the one hand, and the Sargasso Sea on the other hand. As a matter of fact, the T_A (Tropical Atlantic) air masses are likely to be of distinctly less equatorial source than the T_G (Tropical Gulf). They usually have come more recently from the north and have had a shorter sojourn over the warm tropical waters than the T_G masses, and they seldom come from truly equatorial latitudes. Their immediate origin is normally the west-central portion of the middle Atlantic belt of high pressure. These T_A air masses advance into the U. S. only when a general movement of air occurs from their source region westward or northwestward towards our Atlantic coast. Such a movement is likely to take place when the western portion of the middle Atlantic high pressure belt becomes particularly well developed, *i.e.*, when the Bermuda high is well pronounced and centered far enough west so that the anticyclonic circulation extends its influence over the southeastern U. S. This development occurs usually during the three or four days following a major outbreak of Polar air southward over the Atlantic Ocean. Consequently the T_A air mass apparently represents in its properties the ultimate or equilibrium condition with respect to the underlying surface which a P_A air mass attains in a scant week's sojourn over tropical waters. The T_G air masses, on the other hand, have usually moved northwestward from the Caribbean Sea or the West Indies before they appear over the Gulf. They represent real equatorial air from the Trade wind circulation, air which probably has moved around the southern periphery of the Atlantic high pressure belt and has reached the Gulf coast of the U. S. only after an equatorial sojourn of some weeks. The astonishing fact is that these two Tropical air masses, the T_A and T_G, in spite of such different life histories, should be so similar in their properties both at the surface and aloft that they can scarcely be distinguished from each other. Both air masses are characterized by the same marked warmth and high specific humidity at the ground, the same stability in lapse rate, and the same surprisingly low specific and relative humidity at high levels. One would expect to find the T_A masses markedly cooler aloft and more unstable than the T_G, because of their shorter Tropical sojourn. The absence of this expected difference justifies further the conclusion already indicated in the discussion of the Tropical Pacific air masses, — that an air mass over water acquires very quickly a vertical temperature distribution which represents an equilibrium condition with respect to the surface beneath. Both the vertical moisture distribution and the lapse rate in all the American maritime air masses indicate that at upper levels (above 2½ or 3 km.) the equilibrium has been reached not by convection from the surface but apparently rather by radiation processes, and probably in the case of the Tropical maritime air masses with the superposed effect of an appreciable amount of subsidence. Only the very rapid movement of very cold air over a water surface in the direction of increasing water temperature is capable of maintaining a condition of convective instability or even of convective equilibrium in a maritime air mass, a condition such as is found in fresh Polar Pacific air masses. As soon as the rapid southward movement ceases, the air mass becomes markedly stable. Similarly, we found that the T_P air mass moving rapidly northward cools equally at all levels, yet the lapse rate is too stable to allow much turbulent mixing. But, however the rapid maritime modification of air masses at upper levels is to be explained, the fact remains that in the case of the T_G and T_A air masses the similarity of their properties is too close to justify a separate discussion of the masses. Hence from this point all discussion of the properties of the Tropical maritime air masses in the eastern U. S. is meant to apply to both the T_G and T_A masses, unless otherwise specified, and they will be referred to either as mT (Tropical maritime) or simply T_G. The uniformity of the water temperature in the mT source regions has thus proved to be of more importance in fixing the properties of the mT masses at all levels than has the previous life history of the individual air masses. This would, of course, cease to be true if the air masses remained too short a time in the source region, but in that case the use of the term "source region" would not be justified, for by definition the term source when applied to an air mass implies a condition of equilibrium of the air mass with respect to the surface beneath.

The surface temperature of the mT air mass at its source is very close to that of the water surface temperature at the same point, hence it is likely to range from 20° to 26°C. The temperature is normally a little lower along the Gulf or south Atlantic coast, because of the somewhat lower water temperatures along the immediate coast. The specific humidity of the mT air mass at its source is very high near the surface, a condition which must follow from the warmth of the air mass and the high relative humidity which always characterizes an air stratum which has remained long in contact with a water surface. Unfortunately, we have no data on the vertical distribution of temperature or moisture in the T_G or T_A masses in the source region, but the marked decrease of specific humidity between the 1 and the 3 km. levels which is found over the U. S. in these air masses seems to be generally characteristic of Tropical and Equatorial maritime air. This decrease was found in the Tropical Pacific air in the source region, and it first received comment in the Atlantic Trade wind region from Sverdrup[(12)]. Robitzsch's analysis of upper air data from Batavia, on Java (at lat. 6°S.), shows that even in the real equatorial zone a similar moisture distribution prevails, though there is not found at Batavia quite such an abrupt decrease of moisture with elevation as is found in the sub-Tropics. This characteristic of the sub-Tropical maritime air masses is probably to be explained by the fact, first pointed out by Sverdrup for the Atlantic Trade winds, that all of these air masses originate in the anticyclonic centers of the sub-Tropical high pressure belt, where gradual subsidence is doubtless continually taking place. The mT air masses which have moved far northward from their sub-Tropical source regions are found to acquire gradually an increasingly uniform vertical moisture distribution, which is caused probably by the cessation of the subsidence and by a slow turbulent mixing in the air mass. The marked stability of the mT air mass at the level in which the moisture decrease occurs is also indicative of the subsidence process. At any rate, as far as the T_G and T_A air masses are concerned, in spite of their very high moisture content at the surface, their stability is such that when the air current is moving freely over the ocean in the source region convection is conspicuously missing. Either insolational heating of this air over a land surface or a considerable forced ascent of the air at a coast line or active front is required before its potential instability becomes effective in producing free convection. The skies are characteristically clear or partially overcast with broken st cu clouds, and the visibility is very good in the mT air mass in the source region. It is the exception rather than the rule, even in winter when the water is relatively warm compared with the land, for the low Gulf and south Atlantic coast line to effect enough vertical displacement of the T_G air current to initiate convective showers, though when sufficient lifting does occur the showers are likely to be heavy. It is the active overrunning of cold continental air by the mT air current at the warm front which is the prime liberator of the potential convective instability of the T_G and T_A air masses.

Probably the best station in Table VII by which to judge the properties of the T_G air mass in winter as it first leaves the source region is Groesbeck, Tex., for it is the closest to the Gulf of the stations in this table. The surface temperature at Groesbeck of 18.8°C. is doubtless slightly too low to indicate the true source temperature of the air mass, for the Groesbeck temperature reflects probably both the influence of the cool coastal water, and the effect of a small amount of early morning radiational cooling over the land. It will be found, however, as the T_G air mass is followed northward, that radiational cooling effects are extremely small in this air mass. The extremely high value of w at Groesbeck, of 12.6 g., corresponding to a relative humidity of about 90% at the observed temperature and pressure, and the correspondingly high value of θ_E of 327°, both indicate the truly equatorial characteristics of this air mass. If we observe the distribution of these elements at higher levels above Groesbeck, we find marked homogeneity of the air mass through the first km. The lapse rate is rather small, only half of the dry adiabatic rate, but this small lapse rate is slightly in excess of the saturation adiabatic rate at such high temperatures. Furthermore, the value of w at 1 km., although somewhat less than at the ground, corresponds to a relative humidity of between 95% and 100% at the given temperature and at the pressure normally prevailing at this level. These facts indicate at Groesbeck the existence of a rather well-mixed stratum of the T_G air mass up to 1 km., the small lapse rate of the turbulent or mixed stratum being due to its saturation. This condition is indicated also by the constancy of θ_E. The normal prevalence of low st or st cu clouds in the T_G air mass at Groesbeck during the early morning hours (the time at which the Groesbeck ascents were made from which the data of Table VII are taken), is further evidence of the correctness of the explanation of the lower stratum of the air mass as the result of turbulent mixing of saturated air.

Between the 1 km. and the 2 km. level there is evidence of a very marked stratification of the T_G mass at Groesbeck. The temperature is almost isothermal, but w is reduced by 3/5 of its value, corresponding to a reduction of the relative humidity from close to 100% at 1 km.

to less than 40% at 2 km. This moisture distribution probably represents more than just the effect of the surface turbulent stratum. The surprising dryness of the T_G air mass above 2 km. must be ascribed to the general subsidence at upper levels which was suggested above as probably characteristic of the source region of the mT air masses. In spite of the large decrease in θ_E of 8°C. between the 1 km. and 2 km. levels at Groesbeck, a decrease which is associated with the great change in w, the condition of the air mass between these levels is to all practical purposes one of very stable stratification, for a large vertical displacement is necessary before any of the potential convective energy of the water vapor can be realized. This condition explains the observed fact that in winter extensive convective overturning of the T_G air current is usually restricted to a well-developed frontal zone. It explains also the fact that during the day with the movement inland of the T_G air mass the st cloud deck is frequently dissipated by the action of the sun through the clear dry air above and the surface moist air considerably warmed without the development of convective showers. The same stratification of the T_G air mass between 1 and 2 km. is shown also at Broken Arrow, Royal Center, and Due West, although it is notably absent at Boston, and not quite so extreme at the other stations as it is at Groesbeck. But this condition is general enough to show that it is characteristic of T_G air, and not restricted to the west Gulf coast. Furthermore, although the tendency is for the wind direction to shift slightly toward the west with increasing elevation in the T_G air current, there is no reason to attribute any importance to this fact in explaining the T_G stratification between the 1 km. and 2 km. levels, for the amount of the change is small and is normally restricted to the lower km. of the air current, where the adjustment to the gradient direction takes place. Usually there is *no change* of wind direction associated with the transition from the moist to the dry air strata of the T_G masses in winter.

The value of w observed at the 3 km. level at Groesbeck cannot be accepted as typical of the source properties of T_G air at this elevation. In the first place, it is based on only two observations, for the T_G current at Groesbeck seems usually to weaken so much above the 2 km. level that very few kite ascents in this air mass extend much higher. The probability is that on these two occasions the air at 3 km. was continental Föhn air, for the pilot balloons on both occasions showed a wind velocity of 6 m.p.s. from the southwest. The indicated relative humidity is only 15%. On no other occasion at any level or at any station in the U. S. has such extreme dryness been observed in T_G air.

b. Modification of the T_G and T_A Source Properties.

Except when the continent is snow-covered, the T_G air masses show surprisingly little modification as they move northward and eastward from the Gulf coast. The data for each station in Table VII are obtained by averaging ascents made in typical T_G (or T_A) air masses, and consequently, of course, they are based on ascents made when the ground is free of snow and the air mass retains its full warmth. The T_G warm air currents do not usually reach very high latitudes in winter before they are forced to ascend over the cold continental air masses which they are displacing in their northward advance. This ascent of the warm air current occurs frequently before it reaches the north coast of the Gulf of Mexico. Chicago and the southern shores of the Great Lakes lie at approximately the extreme northern limit reached by T_G warm fronts at the ground in winter. Since at this season the T_G air never advances further northwest at the ground than Iowa, Ellendale does not appear in the list of stations for which the winter properties of the T_G air masses are tabulated. The values appearing in Table VII for Royal Center are the average of only two T_G ascents, neither of which reached the 3 km. level.

We note at once how little the properties of the T_G current are modified in its northward progress from the Gulf. Conservatism of their properties, at least in the absence of an underlying surface of ice and snow, or cold water, characterizes the mT air masses above all others. This conservatism applies to progressive changes from one day to the next, and to periodic diurnal changes. It is probably the result of the high moisture content of the air mass together with the prevalence of low st clouds, a condition which interferes with both the diurnal insolational and radiational influences, and with the normal winter radiational cooling over a continental area. This marked conservatism of the T_G air mass properties during the northward progress of the air mass, a characteristic of all mT air masses, stands out in sharp contrast to the rapid modification by surface heating of the southward moving Polar currents. This difference between the Polar and the Tropical maritime air masses explains the relative slope of the isentropic surfaces and the consequent tendency to the formation of secondary fronts in the Polar air masses. The P_C air masses, however, are rapidly modified only after they have left the snow- and ice-covered source region, as has already been pointed out.

There is no doubt that in winter the mT air masses are continually moving in their northward progress from the source region over ground surfaces which are somewhat cooler than the lower strata of the air masses, and consequently that they are continuously subjected to some degree of cooling from below. Hence in winter these air masses are always classified as mTW in the differential notation. This slight surface cooling effect and the accompanying small decrease of w is indicated in Table VII by the progressive changes from Groesbeck to Broken Arrow and Royal Center, with the exception of the surprisingly high temperatures at the ground and the 1 km. elevation at Broken Arrow. These high temperatures are the result of the inclusion of a few afternoon ascents in the computation of Broken Arrow's averages, with the further result that the table indicates slightly lower relative humidity at this station than at Groesbeck. At Royal Center we find a relative humidity of almost 100% at the ground and at 1 km., a high value which is suggested by the general tendency of the st cloud deck to thicken and grow downward at the base with the northward movement of the air mass. But active convection remains conspicuously absent, for the most part, from the T_G air current, a fact which is to be expected in view of the continued warmth and dryness of the T_G air mass at 2 km. However, the stability of the second km. of the air mass becomes noticeably less with increasing distance northward and eastward from Groesbeck. The indications, both of the temperature and of the moisture, are that somewhat less subsidence has occurred in this portion of the T_G current. It at once becomes evident, however, from an inspection of individual ascents, that the height and the amount of the temperature inversion, and the moisture decrease in the transition from the dampness of the T_G air at the ground to its dryness aloft vary much more from one ascent to another than might be supposed from the uniformity of the mean values in Table VII. Such differences are to be observed between the individual ascents in Plate IV-B. These differences between individual T_G currents probably are very significant with regard to the readiness of the warm air masses to interact with the cold Polar air masses in the active development of intense occluding cyclonic disturbances (see p. 19). Nevertheless, in general it can be said of the T_G air masses between the Gulf of Mexico and the Great Lakes, west of the Appalachian Mountains, that because of their high moisture content at low levels and their dryness aloft, they are marked by potential instability, but that because of their pronounced thermal stability considerable vertical displacement of the T_G current must be effected before their potential instability can become effective in producing active convection. As a rule, at the ground and the 1 km. level in this region characteristic values of θ_E between 320° and 330° are observed, at the 2 and 3 km. levels values of about 315°. Generally speaking, any winter observation in the eastern or central U. S. at less than 4 km. elevation from which is computed a value of θ_E greater than 310° may safely be assumed to have been taken in T_G or T_A air, while any observation within these limits marked by a value of θ_E markedly less than 310° cannot be considered as typifying T_G or T_A air.

In this connection Plate XIX, A and B, shows an interesting use of the Rossby diagram. On these two figures are plotted every significant point observation for the month of January, 1930, from the kite soundings at Ellendale and at Groesbeck. The small circles represent points in P_C air, the small crosses points in T_G air, and the transitional or somewhat mixed air mass points are represented by other symbols as indicated on the charts. We note at once the predominance at Ellendale during this month of P_C air, in which no observation was marked by a value of w greater than 2 g. or a value of θ_E greater than 294°. Even the N_{PC} points lie within these limits. A few points only, in N_{PP} air, lie outside the limits by a small amount. Hence Ellendale's observations are all crowded into the lower left-hand corner of the diagram. At Groesbeck, on the other hand, we observe a large number of T_G points, all of which are grouped above the θ_E isotherm of 308°, and mostly above that of 310°, and a large number of P_C points which are grouped below the 300° isotherm. In the region between 300° and 310° there lie only a few scattered points belonging to transitional or more or less mixed air masses. Also noticeable at Groesbeck is the scattering of the P_C points to the right compared with their distribution at Ellendale, a fact which indicates the tendency towards the transformation of the dry stable P_C air mass to a moister and less stable condition as it moves southward. The high moisture content at low levels and the conditional instability of the T_G air mass are clearly indicated by the horizontal distribution on the Rossby diagram of the T_G points. Air mass point diagrams of this type present in a very clear form a picture of the climatic condition prevailing at any station during any period of time, indicating as they do the prevailing air mass types at all elevations and the characteristic thermal stability and moisture distribution in these air masses.

Plate IV-A presents the characteristic curves for the mean values of Table VII plotted on the Rossby diagram. The parallelism of these curves at Groesbeck, Broken Arrow, Royal Center, and Due West is striking. Also we notice at once the horizontal course of these curves compared with the θ_E isotherms and compared with the T_P curves for San Diego and Seattle, a characteristic which indicates directly the comparative potential instability of the T_G air masses. The characteristic curve for one individual T_G ascent each from Groesbeck, Broken Arrow, and Due West will be found in Plate IV-B. These three ascents were made during the same widespread T_G air flow which invaded the southern and eastern U. S. from February 21-26, 1930. The ascent at Broken Arrow on February 22 shows two definite strata in the T_G air mass, each potentially unstable, but with an increase in w and θ_E in the transition from the lower to the upper stratum, between 1360 and 1810 m. Except for this transition layer, the specific humidity decreases steadily from the ground up, but no very marked dryness of the air mass is found at any level below the top of the flight at 2830 m., where w has the very characteristic value of 3.2 g. The ascent at Groesbeck on February 23 is marked by a moist homogeneous layer of air at the ground to a depth of 1 km. with a small surface inversion, but above this homogeneous layer the specific humidity falls off very rapidly with elevation, so much so that w reaches the low value of 1.7 g. at 2250 m., at the same time that the air remains very warm. The winds are southwest, diminishing with elevation and backing to southerly in the layer in which w decreases. The next day this dry stratum makes itself felt at Broken Arrow, where on February 24 the ascent shows that w in the lowest km. has increased roughly from 10 to 12 g. since the ascent of the 22nd, while at the 2 km. level this quantity has fallen from 6.1 g. to 3.5 g. at the same time that the temperature has increased by 1°C. Even as far east as Due West this dryness aloft is indicated in the ascent for the 24th (see Plate IV-B) since w remains quite high up to 1380 m., but in the next 320 m. falls off from 7.9 to 3.4 g., and remains low throughout the rest of the ascent up to 3 km. At Due West also there occurs an increase of moisture at the ground and a decrease at high levels from February 23 to 24. Since all of these stations report light winds from between south and southwest during the period of the inflow of the dry air aloft, this air appears really to belong to the T_G current and to have come direct from the T_G source region. At Royal Center also there was observed during the inflow of T_G air between February 22 and 24, an increase of w at the ground from 6 to 12 g., and a decrease at 2 km. from 4 to 2 g., yet the temperature rose nearly 10°C. at all levels during this period. The relative humidity at the 2 km. elevation on February 24, apparently in T_G air, was only 21%. Such extreme dryness is by no means always to be observed in the upper levels of the T_G air mass, yet normally at 3 km. elevation the relative humidity in this air mass in winter is found to be below 40% throughout the Mississippi Valley region.

Along the north Atlantic coast, as typified by Boston, the mT air mass is strikingly different from the T_G mass of the Mississippi Valley. It really does not come from the Gulf source, either. Boston seldom feels at the ground in winter the full effect of the T_G air current, for that current usually moves either northeastward toward the Great Lakes, remaining at the ground only on the west side of the Appalachian Mountains, or it moves eastward over the southeastern states to the Atlantic coast, in such a way that Boston remains just north of the warm front at the ground, while the island of Nantucket, only a hundred miles southeast of Boston, frequently comes into the warm sector. In the first case the warm air frequently passes eastward over the mountains and is observed at upper levels over Boston, but at the ground there is found only the cold air wedge beneath the warm front. This cold air wedge is usually displaced only with the passage of the cold front or occluded front of the disturbance in which the T_G air mass initially formed the warm sector. Real mT air reaches Boston at the ground in winter only under the condition that a slowly moving trough of low pressure in the Lake Region and the Ohio or Mississippi Valley is accompanied by markedly high pressure off the entire Atlantic coast. This condition causes strong northward air movement along the entire Atlantic coast from the Sargasso Sea region, so that Boston may remain for days at a time in a rapidly moving current of T_A air from the northern portion of the Sargasso Sea. This situation was unusually well developed on several occasions during the winter of 1931-32, so that it was from T_A currents of this type that the data for Boston in Table VII were obtained.

We notice from the first glance at these data a number of interesting facts, some of which are difficult of explanation. In the first place, the surface temperature and specific humidity are markedly lower than are the same quantities at the Mississippi Valley stations. This is probably to be explained by the fact that the T_A air which reaches Boston comes from the northern border of the mT source region, and to the fact that this air has moved northward over the markedly cold water along the north Atlantic coast. A cold water surface is much more effective than a land surface (in the absence of snow cover) in cooling the lower strata of mT air, probably in part because the high moisture content and low stratus cloud deck of the mT air prevent the radiational cooling of the land surface, and in part because of the great heat capacity and mobility of the water surface. A snow or ice surface, however, cools the mT air mass very rapidly at the ground by its melting. The cooling effect of the cold north Atlantic coastal water is indicated very clearly at Boston also by the stability of the mT air mass in the first km. The contrast in this respect between the slight lapse rate observed in the lowest km. of the mT air at Boston and the much greater rate found in T_P air at Seattle is probably caused by the greater coldness of the water on the north Atlantic coast. At Boston the mT air current is usually marked very definitely by a low turbulence inversion at less than 1 km. elevation. This elevation indicates the height to which the surface cooling of the air current has been carried by turbulence. St or st cu clouds are nearly always present at the top of the turbulence layer. These clouds, whose base is sometimes only two or three hundred m. above the surface, constitute a high fog caused by the surface cooling and turbulent mixing of the lowest mT air stratum. With further progress of the mT air current over the cold ocean surface northeastward from Boston towards Newfoundland, this cooling and stratification of the mT air mass continues at an accelerated rate. Consequently at the coastal and island stations of the Canadian maritime provinces this air mass is likely to be characterized by dense fog of great depth (Tropical Air Fog) which frequently develops, after sufficient cooling of the air mass, into a fine mist or drizzle rain from low st clouds. Under these conditions the surface temperature of the air mass normally has been reduced to approximately 8° or 10°C. When the modification of the original properties of the mT air mass has been carried to this extent, this mass is designated on the M. I. T. maps by the symbol N_{TM} (transitional air of Tropical maritime origin). The N_{TM} air mass is, of course, abnormally warm for the latitude at which it is found and warm relative to the surface beneath, therefore it is designated as mTW in the differential notation. The marked cooling of the mT air mass to the N_{TM} condition occurs in North America only over the cold waters off the north Atlantic coast, or occasionally locally along the Great Lakes, and over snow- or ice-covered ground. When the continent is snow-covered, the foremost portion of the advancing mT current, by the warmth of which the rapid melting of snow is effected, is quickly cooled to the typical N_{TM} condition, but otherwise in the U. S. the mT air mass is only slightly cooled over the continent, so that it retains fair to good horizontal visibility at the ground with a st ceiling at a moderate elevation.

At Boston the outstanding fact brought out by Table VII about the mT air mass above 1 km. is that of the high moisture content, together with the disappearance of the marked stability between 1 and 2 km. which characterizes the T_G air in the west. In other words, indication of subsidence at upper levels is completely lacking in both the temperature and the moisture distribution. At all levels above 1 km. the mT air mass at Boston is marked by a specific humidity considerably higher than that found in Tropical maritime air at any other station in the U. S. This is all the more surprising when the comparatively high latitude of Boston is considered. Of the stations in Table VII only Seattle and Ellendale lie further north than Boston. The temperatures observed at Boston at these upper levels are distinctly lower than those found at San Diego, Groesbeck, and Broken Arrow. Thus it is obvious that the relative humidity in the mT air masses must be very much higher aloft at Boston than it is at the other stations. No very obvious explanation of this high moisture content of the mT air at high levels at Boston suggests itself. In fact, until we have average values of the air mass properties which are based on a much longer series of observations than the present ones, it might be questioned whether this characteristic difference is permanent, or whether it is in some way connected with the marked differences in the general circulation between the winters of 1929-30 and 1931-32. The latter winter, during which Boston's data were obtained, was one of abnormal warmth and persistence of mT air currents in the eastern U. S. However, there is one plausible explanation of the reality of the moisture difference between Boston and the other stations which seems rather acceptable. That rests on the fact that the source of Boston's mT air is probably the northernmost edge of the whole mT source region. The mT air drawn from this area is of comparatively recent Polar extraction, and has been neither far enough nor long enough south to have partaken very actively in the general subsidence movement of the Atlantic sub-Tropical high pressure zone. The moisture was probably carried aloft in the active convection which was caused by the initial heating of the Polar air current over the Tropical waters. Although the gradual establishment of a condition of radiational equilibrium between the moist air mass and the warm water surface beneath gradually destroyed the steep lapse rate and established in the air mass the typical mT stability, no opportunity has been given for the development of a subsidence inversion and moisture discontinuity in the upper strata of the air mass.

But whatever the truth may be as to the reality and the correct explanation of the relative moisture of the mT air mass at Boston at upper levels, the fact of its existence in these data, together with the relative coolness and dryness of the surface km. of the air mass, has one very obvious manifestation. That is found in the marked absolute stability of the air mass, as indicated by the vertical distribution of θ_E. θ_E increases 9°C. in the first 2 km., and above that level remains constant. This is approximately the magnitude of the decrease of θ_E found in the first 2 km. at the stations in the middle West and South. This increase of θ_E indicates a condition markedly more stable even than that found in the T_P air on the Pacific coast. Although this stability of the mT air at Boston rules out all possibility of convective precipitation, the significance for frontal precipitation of the difference between the conditional instability of the T_G air in the Mississippi Valley and the absolute stability of the T_A air at Boston is not nearly so great as the first glance would indicate. We have already noted that because of the thermal stability aloft of the T_G air in the West considerable vertical displacement of the moist stratum with condensation must occur before the potential convective energy present in this air mass becomes available, and the dry layers aloft will contribute little or nothing to the precipitation. At Boston, on the other hand, because of the high relative humidity of the upper strata of the mT air mass, condensation must begin aloft with very little vertical displacement, and though there is no potential convective energy available to further an overturning of the air mass, at least above the 2 km. level there is no stability present to resist vertical movements in the almost saturated upper strata of the air mass. Consequently we find that the frontal precipitation associated with mT air on the north Atlantic coast, although it is not quite as heavy as the locally extreme amounts associated with T_G frontal activity in the Mississippi Valley, is nevertheless comparable in amount and more uniform in distribution.

The characteristic curve on the Rossby diagram for mT air at Boston (averages from Table VII) is shown in Plate IV-A. The general mT type of the curve is obvious, but the much greater slope of this curve compared with the slope of the mT curves for the data of the other stations in the eastern U. S. indicates the relative stability of this air mass at Boston. Its stability relative even to the T_P air masses at Seattle and San Diego is shown in the same way.

From a comparison of the T_G and T_A air mass properties as summarized in Table VII with the properties of the mTW air masses in Germany in February, as tabulated by Schinze, we notice at once the much greater moisture near the ground and the much greater warmth at all levels of the American mT air masses. This difference may be attributed in part to the difference in latitude between Germany and the U. S., by assuming that in the course of a longer journey from the source region the European mTW air masses are more cooled than the American. But if this were the correct explanation of the large difference in the surface properties of the two air masses, then we should expect to find the European mT air mass characterized by the same thermal stratification and warmth and high moisture content aloft which is found at Boston. At Boston we find at the ground mT air mass properties very similar to those reported in Germany by Schinze, but at higher levels Schinze's observations indicate much lower temperatures and presumably markedly lower moisture content than we find at Boston. Hence the European mT air mass in winter apparently has had at no stage in its history either the warmth or the high moisture content indicative of the Equatorial origin of our T_G air. Presumably it lacks also the potential instability which characterizes our mT air masses of Equatorial origin. In its later history, however, as is indicated by its properties along the Scandinavian coast, the European mT air mass gives some evidence of a vertical structure approximating that of our N_{TM} air mass on the coast of the Canadian Maritime Provinces.

There are two points in connection with the T_G air mass properties which should be mentioned here. One of these has to do with the way in which the potentially unstable T_G current tends to overrun an adjacent cold air mass. J. Bjerknes[(8)] has recently indicated that, depending upon the stability or instability of the overrunning warm current, the tendency is toward the development of an anticyclonic or a cyclonic circulation (deflection) in the overrunning warm current. This difference in the direction of deflection of the warm current depends upon the resistance to the vertical displacement of the warm air current by the cold air mass in case of a markedly stable stratification of the warm air current, and on the acceleration of the same vertical displacement in case of a convectively unstable stratification of the warm air current. The frequently observed tendency towards the establishment of active overrunning of the cold air along a slowly moving cold front between P_C and T_G air masses in the Mississippi Valley may depend to a large extent upon the potential instability of the T_G air mass. The direction of the spread of the precipitation area behind the cold front in such cases frequently clearly indicates a counterclockwise (cyclonic) deflection of the overrunning warm air current above the cold air mass. (See pp. 19, 57.)

The second point mentioned above has to do with the occasional difficulty in the proper designation of the surface air mass type in the Mississippi Valley under the rather frequent condition in which an extensive thin layer of old continental cold air is being actively overrun by T_G air. The cold air stratum is often only a few hundred m. thick, and yet it extends with almost horizontal upper surface for a thousand miles or more. The T_G air current aloft gradually warms and moistens the cold air stratum, until eventually it makes its full effect felt at the ground, but the transition takes place slowly and irregularly, so that the warm air displaces the cold air at the ground at some points before others. The forced ascent of the overrunning warm air is not sufficient to cause an appreciable amount of precipitation. This condition is characterized by low st clouds, possibly with some light drizzle rain, and by poor visibility and even extensive fogginess in the thin cold air stratum. During this transition period the air mass at the ground is usually designated as N_{PC}, because it does not have the warmth or specific humidity of T_G air. At the same time it must be remembered that the N_{PC} layer is very thin, that it has a warmth and moisture content which really are greater than those characteristic of N_{PC} air, and that at a comparatively low elevation normal T_G air mass properties will be found.

H. The Tropical Maritime Air Masses — Summer

1. *The Tropical Pacific Air Masses*

During the warm season the Tropical Pacific air masses play a negligible rôle on the Pacific coast. It was remarked in the discussion of the P_P air masses in summer that the pressure distribution at this season along the entire middle and north Pacific coast of North America is such that there is found a persistent on-shore gradient, and a correspondingly persistent movement of air at least to a considerable elevation from the north and northwest. This pressure gradient may temporarily disappear to such an extent that the air movement for a time is almost stagnant, the winds becoming light variable. At such times the aerological ascents at Seattle indicate the presence of higher temperatures at all levels, and usually of somewhat higher specific humidity at the ground, than occur in the P_P current when it is well developed. But at upper levels one usually finds a dryness indicative either of subsidence or of a light continental outflow of air with some Föhn effect from the mountains inland. During the summer of 1930 there was not found a single instance either of marked southerly air movement or of a moisture distribution indicative of T_P air at Seattle at the ground. Probably this particular summer was quite typical of the average summer in this respect, so that it may be concluded that real T_P air does not appear on the Pacific coast of the U. S. in summer, at least at low levels. This can certainly be said of Seattle. At San Diego the situation is much more uncertain, as the condition there is normally one of comparative stagnation. No summer ascents from San Diego were available for this particular investigation, however. Consequently no attempt is made in this paper to discuss at length the possible properties of the T_P air mass in summer. Probably it would be somewhat warmer and somewhat moister in summer than in winter, corresponding to the higher temperature of the ocean surface in the source region. On the California coast this air mass, if it appears at all, should be definitely cool at low levels and foggy, because of the extreme local coldness of the water along the coast.

It seems quite probable, however, that in the Plateau and Rocky Mountain regions the T_P air is of real importance in summer. Temperatures in the Plateau region are rather high at this season, and the pressure normally rather low. Under these conditions rather steady southerly winds frequently are observed in this region for rather prolonged periods, with the result that the moisture thus brought inland establishes a specific humidity high enough so that considerable cloudiness and widespread thundershowers develop throughout the low pressure trough. If the air thus brought into the Plateau region had its source in the comparatively cool and dry P_P current prevailing along the coast, an extremely low relative humidity would prevail in the air in this heated inland Plateau which is normally too dry to furnish much moisture by evaporation. We have found that P_P air in summer is characterized by a specific humidity on the order of 7 g. at the ground, decreasing to only slightly over 2 g. at 3 km. elevation. Warm air which reaches Ellendale from the northern Plateau low pressure region is observed to have a specific humidity of from 10 to 12 g. at 1 km. elevation, a value which definitely suggests that the air is of T_P origin. On the other hand, under these conditions the synoptic situation is too indefinite, the air movement too stagnant, and observational data especially from upper levels are too scanty, to make possible any attempt to prove conclusively the Tropical Pacific origin of the warm moist air. Although this origin seems plausible in view of the general pressure distribution, it is too uncertain to justify the attempt to investigate the properties of these rather infrequent Plateau air masses at Ellendale on the assumption that they are really T_P. Consequently it is impossible at this time to present any tabulation of the T_P air mass properties in summer.

2. *The Tropical Gulf and Tropical Atlantic Air Masses*

a. Source Properties of the T_G and T_A Air Masses.

For the T_G and T_A air masses the normal summer conditions are much more favorable than they are for the T_P air masses. The combination of the tendency toward the development of low pressure over the interior of North America and the tendency toward the development of a well-marked center of high pressure over the western Atlantic Ocean (Bermuda High) results much of the time in summer in a pressure distribution which brings mT air northward over most of the eastern U. S. and even into Canada. Consequently the mT air masses in the eastern and central U. S. are present a much greater part of the time and extend over much wider areas in summer than they do in winter. They are responsible for the oppressive heat with high humidity which more than anything else characterizes our summer weather in the eastern and central U. S. The map of July 26, 1930, 8 a.m. (Plate XXII) represents almost in ideal type form the general condition which leads to the widespread prevalence of mT air in the U. S. in summer. We notice a weak trough of low pressure over the northern Plains states, and a broad extension of the Bermuda High westward over the southeastern U. S. The resulting general air movement consists of a light flow from the West Indies and Caribbean Sea northwestward into the Gulf of Mexico, thence northward over the southeastern and south central U. S., and thence northeastward into the Lake Region and towards New England. In other words, we observe a slow steady flow of Equatorial air which originated in the Tradewind zone over the entire eastern and central U. S. As this condition is usually very stationary, the stream lines on this map as indicated by the isobars may be taken as typical trajectories of the mT air masses in summer, the air masses to which the following discussion applies.

The general difference between the normal winter and the normal summer condition as regards the distribution and prevalence of the mT air masses may be expressed in another way by saying that the zone of maximum frontal activity between the mT and cP air masses, or the sub-Polar front, is displaced in summer from its normal winter position somewhere over the northern Gulf of Mexico, northward into the U. S. almost to the region of the Great Lakes.

In general the properties of the mT (T_G and T_A) air masses in summer as they leave their source region are similar to their properties in winter in the same region. The ocean surface temperatures during the warmest season average over the entire Gulf and Caribbean Sea region close to 28° or 29°C. In the Caribbean Sea this is only 3°C. warmer than the temperature during the coldest season, a difference which increases probably to nearly 10°C. on the immediate Gulf coast. Thus we should expect the mT air mass in summer to leave the source region somewhat warmer and somewhat moister than it does in winter, but quite similar to its winter condition in its general vertical structure. We should also expect to find that as the mT air mass passes inland from the source region the general tendency of the effect of the continent will be towards a raising of the air mass temperature, instead of towards a lowering, as it is in winter.

Of the stations in Table VIII, Pensacola, Fla., doubtless gives the best indication of the source properties of T_G air in summer. This station lies directly on the shore, and far enough east not to be subject to the same continental influence which we have found at Groesbeck. Unfortunately there were available no winter data from Pensacola with which to compare the summer data on the T_G air mass properties. We note at Pensacola a surface temperature in the T_G air which is almost identical with the water surface temperature of the source region. Above the surface we find a moderate lapse rate, about 0.6 of the dry adiabatic rate, which indicates a condition of thermal stability in the air mass. Afternoon ascents would doubtless indicate a steeper lapse rate near the ground. The relative humidity is surprisingly high, in view of the warmth of the air mass, so that the specific humidity exceeds slightly the large value of 20 g. Probably this value is as great as would be found as an average in any maritime location in Equatorial regions. Not only is w extremely high at the ground at Pensacola, but the values found up to at least the 3 km. level indicate very high relative humidities at the prevailing temperatures. There is no indication at this station of the apparent subsidence effect which is found at upper levels in the T_G air mass in winter. At the same time the values of w observed at Pensacola at all levels in the T_G air are higher than those found at any other station. In spite of the high moisture content found at the 3 km. level, the excessive amount of water vapor present in this air mass at low levels gives rise to a condition of marked potential instability. Up to the 3 km. level a decrease of 18° in θ_E is noted, while the high value of w at this level

TABLE VIII
THE TROPICAL MARITIME AIR MASSES—SUMMER (mTW AND mTK)

Elevation above Sea Level (km)	Air Mass and Station																							
	T_G (July–August 1930)																				T_G and T_A				mTW (July–August)			
	Groesbeck				Pensacola				Broken Arrow				Ellendale				Royal Center				Due West				Germany (Schinze)			
	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A	T °C	w g	RH %	θ_E °A
Surface	28.0	17.5	72	350	28.5	20.7	85	359	29.5	15.4	58	348	28.5	16.5	66	351	29.0	15.9	61	349	28.8	18.4	72	356	20.8	11.5	73	325
1	20.8	13.0		340	23.2	15.6		350	26.5	12.3		345	27.0	13.3		346	25.2	13.9		348	25.2	12.8		345	15.2			
2	15.8	6.4		326	17.0	12.5		345	20.2	9.9		342	21.8	8.7		339	18.5	11.5		344	18.0	10.3		340	9.3			
3	9.0	4.9		325	10.8	9.5		341	12.8	8.2		339	12.8	5.7		332	10.8	8.6		339	10.0	8.1		336	3.9			
4									7.0	5.4		336									3.5	5.9		333	−1.7			
5									1.5	3.5		336													−7.4			

would indicate that the decrease in θ_E should continue for at least 2 km. further. This condition implies that all convective or mechanical turbulence up to at least 5 km. elevation must effect an upward transport of latent heat, and the high values of the relative humidity indicate that very little vertical displacement is necessary in order to initiate active convection which should extend well beyond this level. This same marked potential instability which we observe in the T_G air masses coming from the Gulf of Mexico and the Caribbean Sea in summer, and which we shall find presently to be characteristic of all maritime Equatorial air masses, is the source of the great amounts of energy consumed in the genesis and maintenance of the Tropical hurricane. When we consider the added effect of insolational heating of the T_G air mass near the ground during the daytime as it moves inland from the Gulf coast, it is obvious why cu clouds which develop during the afternoon into cu nb and heavy local thundershowers are so characteristic of this air mass.

The only other Gulf coast station in Table VIII is Groesbeck, Tex., but this station, lying as it does definitely to the west of the Gulf and in close proximity to an arid continental region, shows probably much less typically the source properties of T_G air than does Pensacola. We observe at Groesbeck in the first km. slightly lower temperatures, and somewhat lower relative humidity and specific humidity than at Pensacola, and consequently values of θ_E about 10°C. lower than at Pensacola. These differences are approximately those which might be expected from the location of the station. But at the 2 and 3 km. levels at Groesbeck, although the temperatures observed continue to be only slightly lower than those observed at Pensacola at the same levels, the values of w are found to decrease very abruptly to amounts approximately only half of the Pensacola values. This decrease reflects very clearly the continental influence at Groesbeck. The lapse rate (0.6 of the dry adiabatic rate) makes impossible any explanation of this dryness as a subsidence effect, so that it is scarcely justifiable to speak of the 2 and 3 km. observations at Groesbeck as really representing the properties of T_G air at these levels. One consequence of the marked dryness aloft in the obvious presence of moist T_G air at the ground at Groesbeck is the indication by the θ_E lapse rate of very marked potential instability at this station, where θ_E decreases 24° in 2 km., as compared with 18° in 3 km. at Pensacola. But once more it must be emphasized that this indicated potential instability at Groesbeck requires, because of the comparatively low relative humidities, very much greater vertical displacements of the potentially unstable air strata than are necessary at Pensacola before the convective energy can become available. Consequently active thermal convection and thunderstorms are much less likely to occur in T_G air at Groesbeck than they are further east along the Gulf coast. At Groesbeck their occurrence is restricted much more to the passage of cold fronts than is the case further east.

b. Modification of the T_G and T_A Source Properties.

As the T_G air mass moves northward from the Gulf of Mexico in summer we should not expect as a rule any very great changes in its properties. During the late spring and the summer the North American Continent is insolationally warmed even at rather high latitudes. Only in the region of the Great Lakes and off the north Atlantic coast is there any possibility of a marked cooling of the T_G air mass from the surface beneath. Apart from these water areas the ground is normally warmer, especially during the daytime, than is the water surface in the source region of the air mass, so that the general tendency must be towards a warming of the air mass from the warmer surface beneath as the T_G current moves northward from the Gulf of Mexico. Consequently, the designation in the differential notation of the T_G air mass in the interior of the U. S. in summer must be mTK, for this air mass keeps its maritime dampness and at the same time moves over a surface essentially warmer than its own lower strata. Near the source region, on the other hand, the T_G air mass is indicated in summer as it is in winter with the mTW designation, for it is moving northward over a water surface which in winter definitely becomes colder with increasing latitude and which in summer also is probably found to be slightly colder over the north portion. At greater distances from the source region we would expect to find a small decrease in the moisture content of the T_G air mass as the result of the precipitation of some of the excessive moisture in widely scattered thundershowers. Especially in the west and at upper levels we should expect to find the influence of the gradual infiltration and overrunning of dry continental air from the far west. But in general, a condition of oppressive warmth and moisture with afternoon thunderstorms should characterize mT air over the entire eastern and central U. S.

A survey of the T_G air mass properties as set forth in Table VIII for the U. S. stations other than Groesbeck and Pensacola indicates that broadly speaking their mean values correspond very closely to those which might be expected. It is at once evident that the temperatures at all levels tend to run a little higher than at the Gulf coast stations. This difference is, perhaps rather surprisingly, a maximum at the 1 and 2 km. levels. This is to be explained by the early morning hour of the majority of the ascents, a fact which is indicated by the stability of the lowest km. of the air mass at the inland stations, the consequence of nocturnal radiational cooling. The heating of the upper strata of the air mass takes place during the afternoon thermal convection, but during the night the temperatures near the ground fall. It is especially interesting to note that the very highest T_G temperatures aloft occur at Ellendale, the northernmost station in the list and the one furthest from the Gulf. This fact proves quite definitely the heating effect of the continent. We also notice that at all the stations located inland from the Gulf lower values of w at all levels are observed than those found at Pensacola, and that with the exception of Due West, which is near the south Atlantic coast and rather directly exposed to the T_A air masses, all the inland stations report lower values of w at the ground even than Groesbeck does. Another noteworthy detail is that at Broken Arrow, which lies some 300 miles due north of Groesbeck, lower values of w are found at the ground and at 1 km. than are found at Groesbeck at these levels, whereas higher values are found aloft than at Groesbeck. This fact indicates that the moist and the dry air strata at Groesbeck have become convectively mixed by the time that the T_G current reaches Broken Arrow. This effect is indicated also by the fact that at Groesbeck θ_E is found to decrease 24°C. in the lowest 2 km., reaching a constant value at this level, whereas at Broken Arrow the decrease is only 6°C. in the first 2 km., and a further decrease of 6° occurs in the next 2 km. At Ellendale, which is approximately 700 miles due north of Broken Arrow, we find continental air indicated again by the dryness at high levels, but high specific humidity is found near the ground. Up to the 3 km. level is found a uniformly decreasing value of θ_E, the decrease amounting to about 20°C. At Royal Center, which is approximately 600 miles due north of Pensacola, we find vertical distributions of temperature and moisture corresponding to those at Pensacola. The temperatures are slightly higher, and the w-values slightly lower than at Pensacola, as would be expected, but from the 1 km. level upward the temperatures are lower and the w-values definitely higher than those at the western stations. This indicates the disappearance of the influence of the dry continental air aloft. At Due West also there are found the slightly lower temperatures and higher specific humidities which characterize the fresh mT air in the absence of the T_C influence. As in the winter, it is difficult to distinguish between the T_A and T_G air masses. At Due West is evident about the same degree of conditional instability as at Pensacola, indicated by a 20° decrease of θ_E in the first 3 km., and a further decrease of 3° in the fourth km.

And also as at Pensacola the relative humidity is high enough so that thunderstorm convection to well above 5 km. should be of frequent occurrence in the T_G air mass. This condition is generally characteristic of mT air in summer to a considerable distance inland, but especially so near the source region where its moisture content is greatest. A glance at Table VIII shows that the decrease in θ_E in the lowest 3 km. of the mT air mass ranges from 25°C. at Groesbeck to 9°C. at Broken Arrow, where the moist and dry strata appearing at Groesbeck seem to be well mixed. The 18° and 20° decreases of θ_E at Pensacola and Due West are much the most significant for thunderstorm convection, because of the comparatively high relative humidities of these stations. In the first km., as we see from Table VIII, we may set a value of θ_E of approximately 340°A. as a lower limit for mT air, and in the next 2 km. a value of approximately 335°. θ_E values in summer below these limits indicate definitely the influence of dry cT air. We have already noted (Table VII) the marked dryness and vertical constancy of θ_E at values below 335° in the cT air masses. The dryness and stability of the cT compared with the mT air masses in summer is responsible for the clear skies, good visibility, and large diurnal temperature range at the ground which are observed in the former air masses in contrast to the convective cloud forms and heavy local thundershowers, the high humidity, the haziness, and the constant oppressive heat which are characteristic of the latter air masses. This characteristic air mass difference is very strikingly illustrated on the synoptic weather maps for July 26-28, 1930, which are reproduced in Plates XXI-XXVII.

The conditional instability of the mT air masses in summer is to be seen very clearly in the characteristic curves on the Rossby diagram (see Plate V-A). The course of these curves in the lower 3 km. is in every case much more nearly horizontal than are the θ_E isotherms. Above 3 km. the slope of the characteristic curves, at those stations where there are data above this level, approaches the slope of the θ_E isotherms, and consequently the curves become parallel to the characteristic curves for the cT air masses, curves which follow closely these isotherms throughout their course. The difference in the two sets of curves in their lower course is caused by the much greater moisture content of the mT air masses at low levels. The remarkable similarity of the mT curves for Broken Arrow, Royal Center, Ellendale, Due West, and Pensacola is very striking. The only noticeable differences among these stations are the somewhat higher values of w near the ground at Pensacola and Due West. Otherwise the curves almost coincide. The curve for Groesbeck, on the other hand, lies distinctly below those for the other stations. This difference is a result of the comparatively low temperatures found at this station at low levels, and the markedly low specific humidities aloft, relative to the other stations.

The true Equatorial nature of the mT air masses in summer is proved by the close resemblance of these characteristic curves to that for Batavia, on the island of Java. This station lies 6° south of the equator, and its climate is entirely maritime. Consequently the prevailing air masses there are Equatorial maritime, and practically without seasonal change. The curve for Batavia is taken from a paper of H. R. Byers,[(11)] as yet unpublished, and is based on Robitzsch's tabulation of aerological soundings made at this station over a considerable period of time. The characteristic curve for this truly Equatorial station parallels very closely our mT curves. We find that the annual temperatures at Batavia average a trifle lower than the summer mT air temperatures at our American stations, with the exception of Groesbeck, where there is almost no difference, and that the water vapor distribution at Batavia is almost exactly the same as the mean distribution found at our stations. At the surface the value of w at Batavia lies between the high values found at Pensacola and Due West, and the slightly lower values found at the inland stations. At upper levels w is found to be almost identical with the average value at the American stations. The decrease in θ_E is 16°C. in the first 3 km., which is approximately the same as that at Pensacola and Due West, while above this level θ_E remains almost constant to 5 km., then begins slowly to increase. Thus we find in every detail approximate identity between the properties of real Equatorial air at Batavia and the mT air masses of the eastern and central U. S. in summer, a fact which proves the real Equatorial nature of the American mT air masses.

The contrast between the properties of the mT air masses of the U. S. in July and August and the properties of the European mT air masses for the same months is to be seen at once from Table VIII, in the last column of which are given Schinze's values of the mT air masses as determined in Germany. The temperatures, level for level, found by Schinze, average from 6° to 12°C. lower than at the American stations, the maximum differences occurring at the 1 and 2 km. levels. Unfortunately figures for the moisture content of the air masses are reported by Schinze only at the ground level, but from the surface value it appears that the relative humidity is approximately the same as that found at the more southerly of the American stations, but because of the much lower temperature the specific humidity at the German stations is very much lower. In fact, as far as can be judged from the data given by Schinze, the western European mT air mass properties in July and August are identical with those found by an afternoon ascent in T_G air at Broken Arrow, Okla., in January or February. Concerning the conditional instability of Schinze's mT air nothing definite can be said without more humidity data, but presumably θ_E remains practically constant with elevation. Such constancy is indicated by the typical individual mT ascents for which he has published thetagrams (θ_E plotted against elevation). At any rate it can be assumed with certainty that the marked conditional instability so characteristic of the American mT air masses is not found in western Europe. The value of θ_E at the surface is from 25° to 35°C. less than at the American stations, or approximately the characteristic value of θ_E for N_{PC} or very dry T_C air in the U. S. in summer. Probably if T_P air reached Seattle in summer it would bear some resemblance to the European mT air. The great difference between the western European and the American mT air masses is a result of the difference in latitude of the two regions and of the nature and proximity of the respective source regions. (See pp. 8-9.)

The characteristic curves on the Rossby diagram for a few individual mT ascents will be found in Plate V-B. In general they correspond to the type curves, but of especial interest are the curves for Groesbeck on August 17 (early morning) and for Ellendale on July 11 (mid-afternoon). At Groesbeck we find between 580 m. and 1000 m., a transition from moist T_G air to very dry T_C air, with a wind shift from south to south southwest, and at 2000 m. a return to the moist T_G air mass with south wind. This stratification with a layer of dry air between two moist air layers is a typical summer condition at Groesbeck. At Ellendale we have a typical afternoon T_G ascent, with a marked degree of convective instability. The lapse rate is almost dry adiabatic, the potential temperature for dry air increasing only 3°C. in 2800 m. At the same time the specific humidity at the ground is so high that θ_E decreases 26°C. in less than 3 km., yet because of the very high surface temperature the surface relative humidity is not excessive in spite of the high value of w. It is also striking again in the case of these individual Tropical air ascents, as it was in the case of the average curves, how the mT and cT curves, which diverge widely at the base, converge at high levels. This is, of course, the result of the water vapor distribution in the Tropical air masses.

In summer the modification of the typical T_G or T_A air mass to the N_{TM} condition by cooling from below occurs only in rather restricted regions, for over the continent proper such cooling does not take place. It occurs only over a cold water surface. On the Canadian side of the Great Lakes this effect is sometimes noticeable, especially in the early summer when the

Lakes are still cold. At this season the mT air from the south may arrive on the northern shores of the Great Lakes definitely cooled and even foggy or with low st clouds. But this cooling effect is most important over the cold water off the north Atlantic coast. In only a day or two of slow movement of the warm moist mT air mass over this cold ocean surface, the lower strata are cooled almost to the water surface temperature, and the cooling effect is carried upward, presumably by mechanical turbulence, with surprising swiftness. The resulting condition is one of stable stratification with the rapid formation of dense fog of considerable depth. This is the cause of the high frequency of summer fog on the north Atlantic coast. It is principally in this region that the N_{TM} designation is used on the synoptic charts in summer. In the differential notation this air mass must, of course, be designated as mTW. The M. I. T. aerological station at Boston is the only American aerological station situated in the region directly affected by the summer N_{TM} air masses, but since the aerological work at M. I. T. is not carried through the summer months, no soundings from this air mass type are available. It is doubtful whether aerological flights in this air mass could be made even if the station were in operation, on account of the typically poor visibility and fog which characterize the air mass.

The completion of this discussion of the mT air masses in summer finishes the general analysis of the American air mass properties. There is much more detail which might be given concerning the modifications of the typical air mass properties in particular situations and under varying conditions, but it does not pay to go into too many refinements in a general discussion of this kind. Such details can be really appreciated only after long experience with the daily synoptic maps. There follow now discussions of a typical winter and of a typical summer synoptic situation, with analyzed weather maps, in illustration of some of the more important facts brought out in the foregoing discussion.

III. ILLUSTRATIVE SYNOPTIC MATERIAL

A. The Synoptic Situation from January 13-18, 1930

On the synoptic charts presented in Plates VI-XXX, the temperature, wind direction and velocity, state of weather, and cloud forms as reported are entered at each station. The pressure distribution is represented by the isobars, and 2-hour pressure changes in hundredths of an inch are entered when they are greater than .04 as a number at the left of the station. The word fog indicates that dense fog was reported at the current observation, and the occurrence of a thunderstorm during the 12 hours preceding the observation is indicated by the usual symbol. The air masses are indicated where practicable both in the local notation and in the differential notation. Cold fronts are indicated as heavy black lines, occluded fronts as broken heavy black lines, warm fronts as double light lines, and uncertain or upper level warm fronts as broken double light lines. For each analyzed synoptic chart two small maps are added on which are entered the winds aloft at two significant elevations. The wind velocities are indicated in the same way as on the surface maps, by small barbs on the wind arrow. Each full-length barb indicates two on the Beaufort scale, each half-length barb, one. Also on these upper air charts will be found the temperature, water vapor ratio w, and equivalent potential temperature θ_E, entered in this order in figures at the few stations for which aerological ascents were available. The elevation above sea level for which these maps are chosen varies from one synoptic chart to the next, according to the seat of the most significant wind action aloft. Generally speaking, higher levels must be chosen in order to represent action in the Rocky Mountain region than in the eastern U. S. Finally, all of the individual aerological ascents for this period, plotted on the Rossby diagram, appear in Plates XIX-C and XX.

The synoptic map for January 13, 1930, 8 p.m. (Plate VI) indicates the presence over southern Canada and the northern and central U. S. of an extensive P_C air mass which has become almost stagnant, with a nearly stationary cold front extending across the entire country. On this front are centered several weak centers of low pressure. In the far west we find that P_P air has advanced inland against the colder P_C air mass which lies east of the Rocky Mountains. An extensive area of falling snow appears east of this portion of the front along which the P_P air is advancing. Unfortunately it is impossible by means of pilot balloons to investigate the winds aloft in this blizzard area, but the indication of the winds at the 3 km. and 4 km. levels at Denver points very definitely to the conclusion that this extensive area of falling precipitation lying just east of the Rockies belongs in this instance to the overrunning current of air from the Pacific Ocean. In the southeastern U. S. we find a typical mT current from the south and southeast which has moved northward to a point where the warm T_G air is almost in contact with the P_C air mass. As yet there has fallen only scattered convective precipitation behind this portion of the stationary cold front, but the impulse of the warm current together with its conditional instability as evidenced by the occurrence of scattered thundershowers may be counted on to start interaction between the warm and cold air masses, with active cyclogenesis and occlusion. In the far northwest there appears a vigorous fresh outbreak of P_C air which is destined to become the cold wave which is the keynote of the synoptic situation during the following days.

On the map for the next morning (January 14, 8 a.m.), we find that the approach of the conditionally unstable T_G current to the P_C cold front has had the expected effect, so that the weak disturbance which had appeared on the cold front over Arkansas has moved rapidly northeastward along the cold front towards Lake Michigan, where it now appears with considerably increased intensity and with a well-marked warm sector obviously ready to occlude rapidly. The widespread occurrence of thunderstorms indicates the continued convective instability of the T_G air mass. The T_G warm current has not yet reached the original cold front at the ground, so that we find a double warm front, with a continuous zone of falling precipitation extending from the T_G front to and along the advanced warm front, which was originally the cold front. The extent and distribution of the falling precipitation indicate that at upper levels the T_G current is overrunning the cold air with a cyclonic circulation. The rapid spread of this precipitation area with the spread of the T_G current aloft and the cessation of precipitation over the western Plains states behind the almost stationary P_P warm front, indicate definitely that it is now the Gulf air current and no longer the Pacific air current which is producing the precipitation. The intensification of the disturbance which developed between the cold P_C air mass and the unstable T_G current has imparted to the cold air behind the disturbance a renewed southward movement, with the consequence that the fresh P_C outbreak in the north is advancing more rapidly southward. Because of the widespread bad weather (note the extensive Tropical air fog in the warm sector), upper wind reports are few. We see very clearly at the 500 and 1000 m. levels the general outline of the warm sector. The temperature contrast, reaching 16°C. at 1000 m., between Broken Arrow in the P_C air mass and Groesbeck in the N_{PP} mass, indicates well this air mass contrast. Also it is worth noting how above Royal Center, which lies just in advance of the T_G warm front at the ground, the warm T_G current is found to be present above the 1 km. level. The ascents for Ellendale and Broken Arrow (see Plate XIX-C) are typical for P_C conditions at these stations, with the usual increase of T and w at intermediate levels in the air mass. Royal Center's ascent indicates clearly penetration of the warm front by the kite, but the contrast between conditions above and below the front is much less marked than it would be if the station were in the real P_C air at the ground. The overrunning warm air shows somewhat modified T_G properties, but the upper portion of the characteristic curve has the typical, almost horizontal slope characteristic of T_G air, a fact which indicates the convective instability of the present T_G current.

Twenty-four hours later, as we see from the map for January 15, 8 a.m. (Plate IX), the principal disturbance has moved slowly northeastward, increased in intensity, and completely occluded in the central portion. The occluded front remains over the Great Lakes, appearing at the ground as a noticeable wind discontinuity with a considerable area of falling precipitation, which may indicate either the presence of considerable warm air aloft, or the marked thermal effect of the Great Lakes on the cold air at the ground. Otherwise the precipitation is scattered along the foremost warm front and along the T_G warm front to the south, which still remains quite distinct at the ground and on which lies a secondary disturbance centered just off the coast. The increasing intensity of the Bermuda High indicates a strengthening of the mT current such that only a very slow advance of the cold air mass toward the southeast may be looked for. Extensive prefrontal fog is in evidence just in advance of the T_G warm front. In the west the P_C air has advanced rapidly southward in typical severe cold wave form, with the usual sharp discontinuity along the eastern slope of the Rocky Mountains between the cold P_C air and the comparatively mild stagnant N_{PP} air mass. The wind discontinuity aloft between the Pacific and cold continental air currents is clearly indicated on the wind charts at the 2000 and 2500 m. levels (Plate XI). Especially significant is the indication at the 2500 m. level of an active overrunning of the P_C air by the N_{PP} current, a development which is indicated also in the north by the Ci and A St cloud forms. The aerological ascents at Ellendale and Broken Arrow on this day (Plate XIX-C) indicate typical P_C conditions, *i.e.,* stability, coldness, and dryness of the air, while at Groesbeck we find clearly marked, both in temperature and in wind direction, the transition, between 670 and 980 m. elevation, from P_C air to N_{PP} air, indicating the shallowness of the P_C air mass at that station. At Royal Center the ascent shows in the lower km. the comparative instability of P_C air somewhat heated by the Great Lakes. At Due West the ascent taken at 11 a.m. is very typical for T_G air. The parallelism of the upper portion of this curve with the upper portion of the curve at Royal Center in the same air mass on the preceding day is striking. The cold front advances very little over the southeastern U. S. during the day, a fact which might be anticipated from the shallowness of the cold air mass observed at Groesbeck, and the prevalence of west or west southwest winds east of the Mississippi River above the 1500 m. level. The marked conditional instability of the Due West ascent stands out in clear contrast to the marked stability of the typical P_C ascents on the same day. This ascent is further proof that on this occasion the T_G current is marked by its usual convective instability, the fact which probably accounts for the considerable amount of scattered convective precipitation appearing in the T_G air mass both in the warm sector and behind the cold front during this period, and which probably explains the marked tendency towards the development of a counterclockwise movement (against the cold air) in the T_G current during the overrunning of the P_C air mass. This potential instability of the T_G current may well be the most significant factor determining the nature of the interaction between our mT and P_C air masses in general. (See pp. 19, 57, 62.)

The synoptic chart for January 15, 8 p.m. (Plate X) doesn't differ very markedly from the 8 a.m. map. The cold air has advanced southward but has made little progress towards the southeast in displacing the warm T_G current. It has moved eastward into the Lake region, with a gradual displacement and filling of the occluded depression centered there. We now find in the northwest that the overrunning of the P_C air mass by the N_{PP} air has led to the development of a broad warm front zone of falling precipitation over the northern Rocky Mountain region, which is a typical development leading to blizzard conditions in this region. In this case there can be no doubt but that it is Pacific air and not Gulf air which is supplying the moisture for precipitation. A comparison of the winds at the 1500 and 3000 m. levels (Plate XI) indicates very clearly this overrunning. We notice also that falling precipitation and decreasing pressure along the California coast indicate the approach of a front, probably an occluded or cold front, in connection with the disturbance centered on the Oregon coast.

On the synoptic chart for January 16, 8 a.m. (Plate XII) we find the cold P_C air advancing slowly southward and eastward, but the cold front has not yet moved off the south Atlantic coast. The occluded front discontinuity in the Lake region has almost disappeared, yet snow is falling generally from the Great Lakes southward and eastward to the easternmost ridges of the Appalachian Mountains. This condition is typical of the combination of lake effect and orographical effect on extremely cold P_C air currents advancing from directions between west and north. (See p. 22.) Royal Center is a little too far west to show much of this lake effect, yet even at that station the upper air sounding shows a lapse rate in the first 2 km. averaging half of the dry adiabatic rate, instead of the isothermalcy or inversion found at the more western aerological stations in the P_C air mass. At Due West, where the cold air is advancing only very slowly, we find the rather high temperature and high moisture content at low levels which characterize P_C air which has been modified to N_{PC}. The characteristic curve is typical for N_{PC} air at that station. The ascents at Ellendale, Broken Arrow and Groesbeck (Plate XX-A) give typical P_C characteristic curves, but they throw light on an interesting difference in the vertical structure of the P_C air mass near its center at Ellendale and in the tongue of cold air extending southward to the Gulf. The upper winds (Plate XIV) indicate above all these stations the presence of a uniform rapidly moving current of air from the northwest or north northwest extending to at least the 3 km. level, but at Ellendale we find almost perfect isothermalcy from the ground up to the top of the flight at 2280 m. (no marked subsidence inversion), at Broken Arrow there is an inversion of 11°C. between 500 and 2000 m., and at Groesbeck, farthest south in the cold air, there is an inversion of 16°C. between 500 and 1500 m. This illustrates perfectly the tendency of the subsidence effect to become more pronounced as the P_C current advances southward from the source. The rapid southward advance of the cold air mass during the next 24 hours increases the height of the inversion at the southern stations.

The synoptic chart indicates that the area of falling precipitation situated the previous evening over the northern Rocky Mountain region and attributed to the overrunning of the P_C air by the N_{PP} current is tending to move southeastward, while with the movement inland of a rather weak cold front along the California coast the precipitation there has ceased. The upper winds at the 2000 and 2500 m. levels (Plate XIV) show a change in direction between these levels from northwest to south at the stations just east of the Rocky Mountains, a shift which marks the position of the N_{PP} warm front. At the 3 and 4 km. levels the winds became west southwest and west with velocities increasing up to force 11. This should indicate a rapid advance of the N_{PP} current eastward in this region above the P_C air mass, and presumably a correspondingly rapid spread of precipitation eastward.

One other feature of interest on this map is the rapid sweep of a warm air current southward from the region directly north of Hudson Bay, bringing to a sudden termination the extreme cold in the area over which it is advancing. The source of this warm air is rather hypothetical, but apparently it comes from the North Atlantic Ocean by way of Davis Strait. The advance of a warm front in this manner, accompanied by rapidly falling pressure and rapidly rising temperature, is a phenomenon which not infrequently terminates our coldest P_C outflows from the northwest (see p. 18). In this case the warm current has brought a rise of temperature of 30°F. at Ft. Smith since the previous morning. Usually the decided warmth of such an air mass is gradually lost as it moves southward, but it is frequently traced to the middle of the U. S. before its identity is lost.

The synoptic chart for January 16, 8 p.m. (Plate XIII) shows the continued slow southeastward progress of the cold air mass in the east to a point such that the cold front has finally moved off the Atlantic coast, and the air mass following the front is no longer really cold. In the far west there has been a renewal of the southward movement of the extremely cold P_C air mass centered along the Canadian border, a movement which has caused the development of a secondary cold front on the forward or southeastern edge of the new cold air advance. At the same time the active overrunning of this extremely cold P_C air by the N_{PP} current from the west has given rise to the expected rapid eastward advance of a broad area of falling precipitation accompanied by blizzard conditions with extreme cold over the Plains states. The winds at the 1500 and 2500 m. levels (Plate XIV) indicate very clearly the eastward progress made by this overrunning warm air since morning, as well as the rapid advance inland of the new P_P air mass accompanied by rising pressure over California, and the southward advance over the northern Rocky Mountain region of the extremely cold P_C air mass. In the far north the warm N_{PM} air mass from the northeast continues to advance rapidly southward, terminating the cold wave as it advances.

On the synoptic map of the next morning (January 17, 8 a.m., Plate XV) we find that the new advance of extremely cold P_C air has continued steadily southward in the Rocky Mountain region and southeastward into the Mississippi Valley. Blizzard conditions are now restricted entirely to the area behind this new advancing cold front, probably because only there is found active underrunning and lifting of the N_{PP} current at higher levels by the cold P_C air. The winds at the 2 and 3 km. levels (Plate XVII) indicate that the N_{PP} current has advanced above the southeastern and east central states as far as to the Atlantic coast, for in this entire region the winds at these levels have shifted from northwest to west southwest since morning (cf. Plate XIV). But except over the rapidly advancing wedge of fresh P_C air this overrunning has led to no precipitation, only to general cloudiness. This restriction of falling precipitation to the area behind the new cold front may be explained by assuming that the old P_C air mass has settled and spread out to such an extent that there is no longer any forced ascent of the overrunning N_{PP} current.

The warm air current from the north has swept rapidly southward over the Canadian prairie region, bringing cloudiness and temperature rises of from 30° to 50°F. since the previous morning to those stations which it has reached. Along the Canadian Rockies there still remains a belt of the cold P_C air with a ridge of high pressure. The aerological ascent at Ellendale which on this morning lies in the northern portion of the extremely cold P_C air mass gives a typical P_C characteristic curve (Plate XX-B). Since the previous morning the P_C air mass has become colder at the ground and warmer aloft (the typical combination of radiational cooling and subsidence aloft) so that we now find a temperature inversion of 6°C. between the ground and the 2 km. level, and approximate isothermalcy above this level. The winds are uniform fresh northwest at elevations between 1 and 4 km. The ascent at Broken Arrow, which lies in the forward portion of the cold air mass, shows approximate isothermalcy at this station from the ground to the top of the ascent at 1750 m., exactly the condition which was found at Ellendale in the foremost portion of the cold air mass on the previous morning, although the entire air mass has become warmer by nearly 10°C. in the meantime. Groesbeck's ascent, which extends to only a little over a thousand meters elevation, and which was made in the old P_C air mass just ahead of the advancing cold front, indicates the comparative warmth and moisture of the old P_C air mass. The conditions are perfect, however, for the advance of the fresh P_C air with almost undiminished coldness quite to the Gulf coast, for the preceding cold air outbreaks and general snowfall have established winter conditions and a snow cover almost to the coast. Hence a severe cold wave extending to the Gulf may be anticipated on this occasion. The ascent at Due West shows the presence of typical N_{PC} or old P_C air conditions up to 1200 m., but between 1200 m. and 1850 m. there occurs a small inversion in temperature and almost a tripling of the water vapor ratio w. This increase of T and w, together with a wind shift from northeast to southwest, indicates clearly the penetration by the kite of the warm front between the old P_C air at the ground and the overrunning N_{PP} current.

By 8 p.m. of January 17 (Chart XVI) the cold wave has advanced rapidly southward over Texas, but there has been very little progress of the cold front eastward. An extensive area of falling snow is still found behind the cold front which extends from Texas to the Lake region, where a weak center has developed on the front, apparently caused by interaction between the warm N_{PP} and the cold P_C currents aloft. Pilot balloon observations at the 1500 and 2500 m. levels (Plate XVII) indicate that a strong southwest current is now well established over the whole eastern U. S., a condition which is direct evidence that the new disturbance developing in the Lake region must be more intense at upper levels than at the ground. This southwest current aloft has caused general cloudiness from Florida to New England, but precipitation remains restricted to the cold front region. The reëstablishment of a southwest air movement aloft over the southeastern U. S. has apparently initiated a northward movement of the warm T_G air which is found at the ground further south over the Gulf of Mexico. As a result of this renewed northward advance of the T_G air mass the cold front which passed southward over Florida on the preceding day is now transformed into a T_G warm front. Precipitation has set in as yet at only two or three scattered stations, but if this northward movement of the warm air becomes well established, general heavy precipitation is to be expected in the southeast. In the far northwest the warm front of the N_{TM} air mass has advanced rapidly southward from Canada, bringing with it cloudiness and a termination of the cold wave to the northern Plains states, but the cold air barrier remains along the eastern slope of the northern Rocky Mountains. In the far north the indications are that cold P_C air is beginning to move southward again behind the warm N_{PM} current which made its first appearance coming from the northeast.

On the map of January 18, 8 a.m. (Plate XVIII), we find that the extremely cold P_C air mass is now centered over Texas, and that it has advanced generally eastward to the western slopes of the Appalachian Mountains. The depression which formed on this cold front at upper levels in the Lake region has moved to the upper St. Lawrence valley, with an occluding loop or fold in the cold front, but without the appearance of any real warm air at the ground, yet with the continuance of general precipitation. At the same time the T_G warm front which was indicated on the preceding map as advancing from the southeast now lies over northern Florida and just off the south and middle Atlantic coast, accompanied by a broad warm front zone of heavy falling precipitation extending from northern Florida to southern New England. The overrunning along the northern portion of this warm front seems to extend northward quite to the depression northeast of the Great Lakes, at least according to the indication of the advance of the zone of falling precipitation in this direction. The reality of the warm sector indicated as lying just off the middle Atlantic coast is proved by the observation from Cape Hatteras, which station reports clear skies, temperature of 68°F., and a wind of force 8 from the south, while Cape Henry, situated about one hundred miles to the north northwest, reports heavy rain, a temperature of 34°F., and a wind of force 7 from the north. Owing to the lack of data in the region of bad weather along the Atlantic coast, in just the area which is of particular interest on this morning, no maps of winds at upper levels are included for January 18. There are insufficient wind observations to prove how far inland the overrunning T_G air has extended, but its presence at Due West at the 2 km. level is definitely proved by the aerograph record. Up to 1 km. at this station (Plate XX-C) we find moderate northwest winds and conditions which are typical of N_{PC} air behind a precipitating warm front, but between 880 m. and 1950 m. the wind shifts to southwest and increases to a force of 8, the temperature shows a small inversion, w increases markedly, and θ_E increases from 290° to 310°, which is a value characteristic of T_G air at this level. The characteristic curve is an ideal type curve for a thin layer of old P_C air and above this a gradual transition to an overrunning T_G current.

In the northwest the warm N_{PM} air mass from the north has begun to lose its effectiveness. Its warm front is losing its sharpness and ceasing to advance southeastward, and it is being rapidly displaced from behind by a renewed outbreak of cold P_C air from the north. Usually warm waves of this type fade out in just this manner at approximately this location. At Ellendale on this morning the winds are found to be increasing northwest up to 3 km., while the kite ascent shows that a warming up has occurred from the temperatures of the previous morning amounting to 12°C. at the ground and decreasing to 4°C. at 2 km. elevation. The specific humidity has also increased considerably from the values of the previous day, but the air mass properties observed at this station may still be classified as P_C. At Broken Arrow the isothermalcy of the previous morning has given way to a marked subsidence inversion amounting to 13°C., the same sequence as that occurring at Ellendale in the same P_C air mass on the previous two days. Also at Groesbeck, with prevailing strong northerly winds, we find a subsidence inversion of 12°C. between the 500 and 1500 m. levels. At Royal Center likewise is found a typical P_C ascent, with a subsidence inversion of 7°C. between the 500 and 1500 m. levels, and isothermalcy in the next km. The winds at this station are increasing westerly aloft. It will be noticed (see Plate XX-C) that apart from Due West, which has not yet been reached by the cold air, that no station shows at any level on this day specific humidity in excess of 1 g. We have here really a group of four perfect P_C air type characteristic curves, indicating the predominance over the entire country between the Rocky Mountains and the Appalachian Mountains of practically unmodified P_C air. The evening map for January 18 shows the cold air mass in the central portion of the country to be advancing eastward along the entire Atlantic coast. The warm front secondary disturbance which was centered on the middle Atlantic coast in the morning has advanced rapidly northeastward with increasing intensity and is occluding rapidly as the cold air sweeps around behind it. Falling precipitation is found only in the far northeast where the T_G warm front is still advancing and active overrunning by the warm air current continues. In the northwest the new cold wave has advanced rapidly southward into the border states of the U. S., and the warm N_{PM} air mass is rapidly disappearing at the ground.

B. Synoptic Situation from July 25-30, 1930

In the summer situation to which the brief discussion of the following pages applies we find very marked the general sluggishness of movement of the fronts and air masses, and lack of sharp contrasts which typifies summer weather conditions in the U. S. On the map for July 25, 8 p.m. (Plate XXI), there appears a very typical summer condition. The Bermuda High is rather well developed, and extends westward to the southeastern U. S. with a very flat secondary center on the Gulf coast. A weak slowly moving cold front and low pressure trough extend from western Texas to Hudson Bay. This almost stationary pressure distribution has brought a slow steady movement of mT air northward over most of the eastern U. S., the T_G warm front now lying over the upper Lake region. North of the Great Lakes a typical summer P_C air mass is advancing slowly eastward. Along the Atlantic coast there lies an old occluded front remnant which is rapidly disappearing, but which probably indicates at the ground an approximate boundary between T_G and T_A air masses. We find that scattered thunderstorms have occurred generally in the T_G air mass from the Gulf coast to the Great Lakes, with especial concentration along the Great Lakes warm front and the coastal occluded front.

Behind the weak cold front in the west, there is advancing in the north a slowly moving P_C air mass, while in the south there lies an old Pacific Polar air mass (N_{PP}) which is being rapidly heated. Although in this air mass scattered thundershowers occur at a few of the high mountain stations, and extreme local irregularities in temperature indicate further mountain effects, its specific humidity is probably rather low, so that as this air mass descends from the western plateaus and mountains and moves eastward over the Plains states it is not surprising to find that it becomes a typical hot dry T_C air mass. The T_C masses usually originate as old N_{PP} or N_{PC} air masses which are heated adiabatically and insolationally in the dry southwestern Plains states. On the Pacific coast we find indications of the advance of a well-marked cool current of fresh P_P air, in which we note the mostly clear skies which are typical of this air mass on the north Pacific coast in summer. The morning airplane ascent at Seattle (Plate XXX-A) verifies the presence aloft of the typical summer P_P air mass properties, which are a rather low specific humidity decreasing with elevation, marked coldness, and a low equivalent potential temperature remaining almost constant at all levels. This ascent is entered on the upper air maps (Plate XXI-B) for 8 p.m. of July 25, in spite of the fact that it is a morning report, because it is the only available observation of the conditions aloft in this P_P current on the Pacific coast, and the eastward advance of this air flow during the following days is one of the outstanding features of this series of synoptic charts. The winds at the 750 m. level show essentially the same air current distribution as at the ground, but at 1500 m. we notice very definitely an area of prevailingly northerly winds over the southeastern states which is doubtless associated with the old occluded front lying in that region. At the 3 km. level these northerly winds are somewhat stronger. This northerly current may be partly responsible for the concentration of thundershowers behind the occluded front, although the morning ascent at Due West did not show the current to be either cold or dry. In fact, the air at the 2 km. level was found to have typical T_G properties. The lapse rate was equal to the dry adiabatic rate through the first km., and only 0.6 of the dry adiabatic rate in the second km. This temperature distribution represents a typical mid-morning condition in T_G air insolationally heated at the ground.

On the synoptic chart of the next morning, July 26 (Plate XXII), the general situation has changed but little. The P_C air mass in the northeast is advancing off the coast, the one in the northwest has moved very little southward, and the P_P current on the Pacific coast has advanced slightly inland. The weak cold front in the west remains almost unchanged in position, while the T_G warm front has moved slightly northward in the Lake region. Thunderstorms have continued during the night in the T_G air over the north central portion of the country, and are still active in the morning in the Great Lakes region. In the southeast the old occlusion seems to have filled completely, and showers have ceased. In the southwest, over western Texas, a rather questionable warm front appears which indicates the advance of a dry T_C current with a westerly component into the southerly T_G current. We will find that this T_C front becomes more pronounced on the following maps, and that it marks the advance of a dry heat wave with extremely high temperatures, although in the early morning the T_C air is frequently cooler at the ground than is the T_G air.

The winds at the 500 m. level correspond to the sea level isobars and the surface fronts. At all five aerological stations we find at this level the high values of w and θ_E which are characteristic of T_G air. At 1500 m. the wind distribution is almost unchanged, but we find very definitely between Groesbeck and Broken Arrow the T_C front, which is indicated by a specific humidity at the former station only one-half of that at the latter. The aerological data from this morning's ascents (Plate XXX-A) show typical T_G conditions at Broken Arrow and Royal Center, with a high moisture content at all levels and marked potential instability. Groesbeck's ascent shows the presence of the typical shallow moist T_G current at the ground, the greatest value of w being found as usual at this station in the morning at the gradient wind level. Between 470 and 700 m. elevation occurs the abrupt transition from T_G to T_C air, marked by a shift of wind from south southwest to southwest. Between the 1600 and 2000 m. levels the moisture increases somewhat, with the wind back in the south southwest. Ellendale's ascent on this morning is not very distinctive. Although the station seems to lie just behind the cold front, the temperatures at intermediate levels are very high, and the moisture moderately high, enough so to indicate that there is still T_G influence. Between 1700 and 3300 m., however, the lapse rate is nearly the dry adiabatic rate, and the moisture decreases steadily. This may be N_{PP} air or even P_C air adiabatically heated by active descending movement in the foremost portion of the cool air wedge.

By the morning of July 27 (Plate XXIII) we notice how the P_P current in the northwest has advanced across the mountains, bringing with it clear skies and a marked drop in temperature. The cold front has just passed Ellendale at the ground, but even as low as at 750 m. (Plate XXIII-B) the warm dry T_C air current from the southwest is found at this station. The 750 m. level is only 300 m. above the ground at Ellendale. Especially noticeable is the eastward advance of the dry T_C current in the Mississippi Valley. The T_C front has become quite well marked as a discontinuity in wind and pressure as well as in the prevailing type of weather. The stations in the T_C air report without exception clear skies, while in the T_G air mass the stations report general cloudiness and thundershowers over a wide area. The T_C front is still clearly marked in the wind distribution at the 750 m. level. Also at this level will be noticed the contrast between the values of w, all less than 10 g. in the T_C air, and the values of 13 and 14 g. found at Due West and Royal Center in the T_G air. At the 2 km. level we find that at Groesbeck the winds have backed to south southwest again, and that the relatively large moisture content typical of T_G air is again in evidence. On the north Pacific coast we note that at this level the winds are now from the southeast, which indicates that the northerly current now centered further inland has temporarily ceased on the coast. The T_G warm front, on which lie two wave disturbances, one of which has developed a well-marked zone of warm front precipitation, still extends from the upper Lake region to southern New England. The passage of the T_G warm front at Boston was marked by an increase in w of 6 g. from the value of the preceding P_C air mass. Of the aerological ascents for this morning (Plate XXX-B) those at Due West and Royal Center prove the existence of the typical T_G condition of potential instability. Those at Broken Arrow and Ellendale give typical T_C curves, in which w, especially at lower levels, is markedly lower than it is in the curves from the stations in the T_G air, with the consequence that θ_E is nearly constant at all elevations. At Groesbeck the characteristic curve indicates clearly the usual T_G stratum at the ground, a very dry T_C layer at about 700 m., and moist T_G air again between 1400 and 1900 m. At Broken Arrow the T_C air is not nearly so dry as is the dry layer at Groesbeck, but conditions are much more uniform throughout the ascent, a fact which indicates that Groesbeck's moist and dry air layers have become well mixed. Furthermore, at Broken Arrow there is no indication of a moist current from the south above the dry southwest current, which continues uniformly to the top of the ascent just above 3 km.

On the evening synoptic map of July 27 (Plate XXIV-A) the position of the T_C warm front has advanced very little since morning. On this map we notice especially the extremely high temperatures which are observed during the day in the dry T_C air compared with those observed in the moist T_G air mass. Even at this evening hour we find a large area in the Mississippi Valley reporting temperatures between 38° and 40°C. Thunderstorms continue widely distributed in the T_G air mass. The upper wind charts (Plate XXIV) show the T_C front well marked at the 500 m. level, and fairly well so at the 2 km. level. Over the north and middle Atlantic coast the further development of a wave disturbance on the T_G front which lies just off the coast has brought cool maritime Polar air (P_A) inland and southward. At the 2 km. level this development is indicated by the freshening northwest winds which appear over the eastern states. Also at this level the winds over the south Pacific coast region indicate a general movement of air from the southwest, probably of T_P origin, into the southern Plateau region. This is represented at the ground by a broken warm front. In the northwest the N_{PP} current advances steadily southeastward, bringing with it cooler weather.

On the morning of July 28 the synoptic map (Plate XXV-A) indicates the continued rapid advance southeastward of the cool N_{PP} current in the northwest with the result that the warm dry T_C air mass in the middle Mississippi Valley is being displaced at the ground between this cold air current and the warm moist T_G air mass in the south, which is again advancing northward. The coastal disturbance on the T_G front is centered near Cape Hatteras, so that P_A air continues to be brought over the middle and north Atlantic coast by the circulation around this center. We notice on the New England coast the uniform cloudiness (low st or st cu clouds) which normally characterizes the P_A air masses in summer. The specific humidity observed at Boston in the P_A air mass is found to have decreased by 4.5 g. from the value found on the T_G warm front the previous morning. The eastward advance of the disturbance north of the Great Lakes, which is followed by the cold air outflow from the northwest, is bringing the T_G air in the Lake region northeastward into the St. Lawrence Valley as a warm sector.

On the Pacific coast the map indicates at the ground a condition of general stagnation of all air movement, but the movement of the high clouds indicates a southerly current, probably of T_P air, at higher elevations. The existence of this southerly current is verified by the winds at the 2 km. level (Plate XXV-B), while at the 4 km. level the southerly current is found to extend uniformly from southern California to the Canadian border. The aerological ascent at Seattle this morning (Plate XXX-B) shows up to 1 km. a condition of marked stability and sharp decrease of w, together with light east winds, which indicate clearly a Föhn wind of continental air (N_{PP}) from the interior. But from 1 up to 4 km. we find the wind shifting slowly to the south, and the specific humidity increasing slowly but steadily to a value of 5 g. with a value of θ_E slightly over 326° at 4 km. This is the highest equivalent potential temperature which was found at Seattle at any level during the period of this investigation. This high value of θ_E confirms the T_P origin of the upper level air current, corresponding closely as it does to the properties of Schinze's mT air in Europe.

In general on this morning the winds at the 750 m. level correspond to the surface fronts and the sea level isobars. We notice at this level w values of 15 to 16 g. in the T_G air, of 8 or 9 g. in the T_C air in the southwest, and of 7 g. in the P_C air at Ellendale. The temperature at Ellendale at this level is from 10° to 14°C. colder than that at the stations in the Tropical air. At the 2 km. level is to be noted the increasing intensity of the circulation behind the Cape Hatteras disturbance. The aerological ascent at Ellendale on this morning indicates that the air mass properties at that station are typical of summer P_C air. These properties are scarcely to be distinguished from the P_P air mass properties at this season. Thus this Ellendale ascent corresponds very closely to the Seattle ascent of July 25 which was made in the same air current (Plate XXX-A). We find at Ellendale the same practical constancy of θ_E as at Seattle in the same air mass three days previously, but w, T, and θ_E all have slightly higher values at all levels than they did at Seattle. From the values found in the T_C air mass by the ascent of the previous day at Ellendale, w has decreased by from 25%-30%, and the temperature by from 11° to 14°C. at all levels. Broken Arrow's ascent remains fairly typical of T_C air, but at Groesbeck the advance of the T_G moisture is making itself evident at all levels. The very dry intermediate layer of the previous day has disappeared, while at the ground and at the top of the flight, at 1840 m., the properties observed are typical of T_G air. At Royal Center and Due West the ascents continue to show conditions typical of T_G air at all levels, but with unusually high values of w at Royal Center in intermediate levels, so that the potential instability at that station first appears above the 1600 m. level.

Because the ascent at Due West on this morning is so typical of T_G air conditions in the southeastern U. S., and because the occurrence of thunderstorms in the T_G air mass was so widespread during this day, it was decided to plot the tephigram for this ascent. The result is shown in Plate XXXI-B. The ascent was made at ten o'clock in the morning. The remains of the nocturnal radiation inversion are evident below 719 m., while insolational heating at the ground has established a superadiabatic lapse rate in the lowest 200 m. We see that for a particle of surface air there is a small positive area of available convective energy near the ground, then a negative area extending through more than a km., and finally a large positive area extending to the top of the ascent and doubtless much higher. For a particle of air starting from the top of the inversion, energy would have to be supplied through the first 2 km. of ascent, but the negative area is small. At higher levels again there appears a positive area of available convective energy which promises to extend considerably above the top of the ascent. From the appearance of this tephigram it seems justifiable to assume that by late afternoon practically all areas of negative convective energy will have been wiped out by insolational heating, so that a continuous supply of energy will be available to accelerate the convection of air particles from any of the lower levels up to a great height. This is the condition which we should expect to find in this T_G air mass in the afternoon, in view of the widespread occurrence of afternoon thunderstorms which has characterized its entire history.

The 8 p.m. map of July 28 (Plate XXVI-A) shows little significant change in the general situation. Thunderstorms continue throughout the T_G air mass, while the T_C air continues hot and dry, with clear skies. The T_G air is now clearly advancing northward from the Gulf, while the advance of the N_{PP} air mass continues eastward and southeastward, so that the area covered by the T_C air mass is continually being reduced. The P_A air mass on the north and middle Atlantic coast is resisting displacement, so that with the continued eastward advance of the northern disturbance and the cold front, the T_G warm sector in the St. Lawrence Valley is being occluded slowly between the two Polar air masses. In the far west a general fall in pressure and rise in temperature have taken place over a large area. From the wind distribution at the 3 km. level we see that the extent of this area coincides with the region into which the southerly current of T_P air has been moving aloft. At no time, however, has this T_P current made itself felt at the surface along the Pacific coast, and even at the upper levels the movement has not become very rapid. The present fall of pressure inland from the coast may be expected to terminate this movement of T_P air northward along the Pacific coast at high levels.

On the map of July 29, 8 a.m. (Plate XXVII-A), we find that the dry T_C air mass in the Mississippi Valley has almost disappeared at the ground between the slow southward advance of the cool N_{PP} air mass, and the northward movement of the moist T_G air mass. It is noticeable the extent to which the southern portion of this N_{PP} air mass has become warmed, and the extent to which cloudiness is appearing in the western portion of the air mass, a development which indicates probable overrunning by Tropical air from the south. Along the middle Atlantic coast a narrow warm sector of T_G air still remains between the advancing P_C air mass and the P_A air mass which lies just off the coast. In the far west little change has taken place, and the winds aloft are found to be rather light variable up at least to the 3 km. level. If we compare the wind distribution at the 750 m. level with that at the 2000 m. level (Plate XXVII-B) we notice that the cold front, which lies close to Broken Arrow at the lower elevation, is found 200 miles further north, in the neighborhood of Omaha, at the upper level. This proves the shallowness of the cold air mass in this region, while the winds at the 2 km. level indicate probable overrunning by T_G air, a development which would explain the st cu clouds from the south reported at Omaha and the general cloudiness appearing in the region.

The northward advance of the T_G air since the previous morning is clearly indicated by the aerological ascents at Groesbeck and Broken Arrow (Plate XXX-C). At both of these stations there are now found typical T_G air mass properties at all levels. The contrast is especially striking at Broken Arrow, where on the previous morning typical T_C air mass properties were reported. The increase in w at this station since the previous day ranges from over 6 g. at the ground to 3 g. at the 2 km. level, while an increase on the first day of 9°C. in θ_E between these two levels has been converted into a decrease of the same amount. At Due West the ascent, which extends to only 1250 m. elevation, shows a typical T_G condition of extreme conditional instability from the ground up. At Royal Center we find a great contrast between the ascent of the previous day in very moist T_G air and that of the present day in N_{PC} air. Between the 500 m. and 2 km. levels θ_E has been reduced by between 30° and 35°C., yet the value is still markedly above that typical of P_C air. At the top of the ascent, at 3500 m., the indications are that the top of the N_{PP} air mass has been reached, so that a rapid transition to T_G air must occur at this level. The N_{PP} or N_{PC} air mass shows now the effect of much warming and evaporation at the ground since its first appearance at Seattle and Ellendale. Up to the 1600 m. level this effect has raised its θ_E by approximately 20°C.; above the 2 km. level the effect has been only about half as great, so that the air mass now shows definite potential instability. The Ellendale ascent of this morning shows typical P_C (or N_{PP}) air conditions still persisting at that station, as evidenced by the constancy of θ_E with elevation. The aerological ascent at Seattle shows that a marked increase in w has occurred between the 500 and 1500 m. levels since the previous morning, caused doubtless by the cessation of the continental Föhn outflow between these levels. At the 3 km. level, on the other hand, w has decreased appreciably, probably a result of the disappearance of the T_P current at high levels.

On the evening map of July 29 (Plate XXVIII-A) it appears that the cold front is now advancing only slowly eastward and southeastward towards the Atlantic coast, where the P_A air mass is slowly receding. Boston, which now lies in the T_G warm sector, reports a specific humidity 6.5 g. higher than was reported there the previous morning in the P_A air mass. Thunderstorms continue scattered throughout the T_G air mass from the New England coast to western Texas, but in the cool dry air mass they are reported only from the stations in the narrow strip of territory which was passed by the cold front during the day. In the far west conditions remain stagnant both at the surface and at upper levels, although thundershowers are beginning to appear in the eastern part of the region into which during the previous two days the movement of T_P air was found to be taking place aloft. The wind chart for the 750 m. level (Plate XXVIII-B) shows very clearly at that level the wind discontinuity of the principal cold front, but this discontinuity is not to be seen at the 2 km. level, owing to the continuance of northerly winds at this level along the south Atlantic coast. However, the aerological ascents at Due West have proved conclusively that the air taking part in this movement from the northwest at upper levels along the coast is very decidedly T_G in its properties. The wind distribution at the 2 km. level also indicates that the northward advance of T_G air from Oklahoma towards Iowa and Nebraska, an advance which was noted at this level on the morning map, has ceased, with the result that the cloudiness present in this region in the morning has disappeared. On the other hand, cloud movements just west of this region indicate that a similar overrunning of the N_{PP} air mass by the N_{TP} air from the Pacific may be developing.

On the synoptic map for July 30, 8 a.m. (Plate XXIX-A) we find that the N_{PP} (or N_{PC}) cold front has finally advanced beyond the north and middle Atlantic coast. In spite of the warmth which now characterizes this air mass, Boston reports a decrease of $7\frac{1}{2}$ g. in specific humidity from the T_G value of the previous evening, although the temperature during the intervening 12 hours has fallen only 2°C. In the south the cold front has practically ceased to advance, while it is marked this morning by two distinct wave disturbances, one of which is located just south of Broken Arrow. The winds aloft are rather irregular and indecisive in their indications, so that no attempt was made to locate fronts at the 750 m. and 1500 m. levels (Plate XXIX-B). However, at both of these levels there is some indication of a tendency toward the renewal of an advance of air at low levels from Oklahoma northward. This tendency is also suggested by the unsettled conditions in the N_{PP} air mass in this region, and by the aerological ascent at Broken Arrow (Plate XXX-C). This ascent shows for the first 700 m. a shallow air stratum whose properties are those of T_G air mixed with N_{PC} air. Between 710 and 970 m. the wind shifts from east southeast to south southeast and w increases by a small amount. From this point up to at least 4 km. elevation the air mass properties are typical T_G, without any Polar influence to be detected. On this morning the ascent at Royal Center shows the P_C influence more markedly than on the previous morning, but the air mass properties are still N_{PC} rather than typical P_C at this station. At Ellendale the ascent indicates again the ideal P_C air mass properties, *i.e.*, low values of w and almost constant θ_E from the ground up to the top of the flight at 4330 m. The winds at this station are strong northwest above 2 km., a fact which indicates a renewal of the P_C outflow. On the north Pacific coast we notice the apparent passage inland of a cold front, a development which should be followed by the reëstablishment of the P_P current along this coast. Such a current is indicated by the Seattle ascent of July 31, but there is available no ascent for the current date from this station.

This completes the discussion of the present summer synoptic situation. A more detailed discussion could not be included in this paper, so that many interesting features of the situation were left unmentioned. Yet enough has been pointed out to indicate the value, even in our typically sluggish summer weather conditions, of a thorough and correct air mass analysis in forecasting, and of a careful consideration of the air mass properties in this work.

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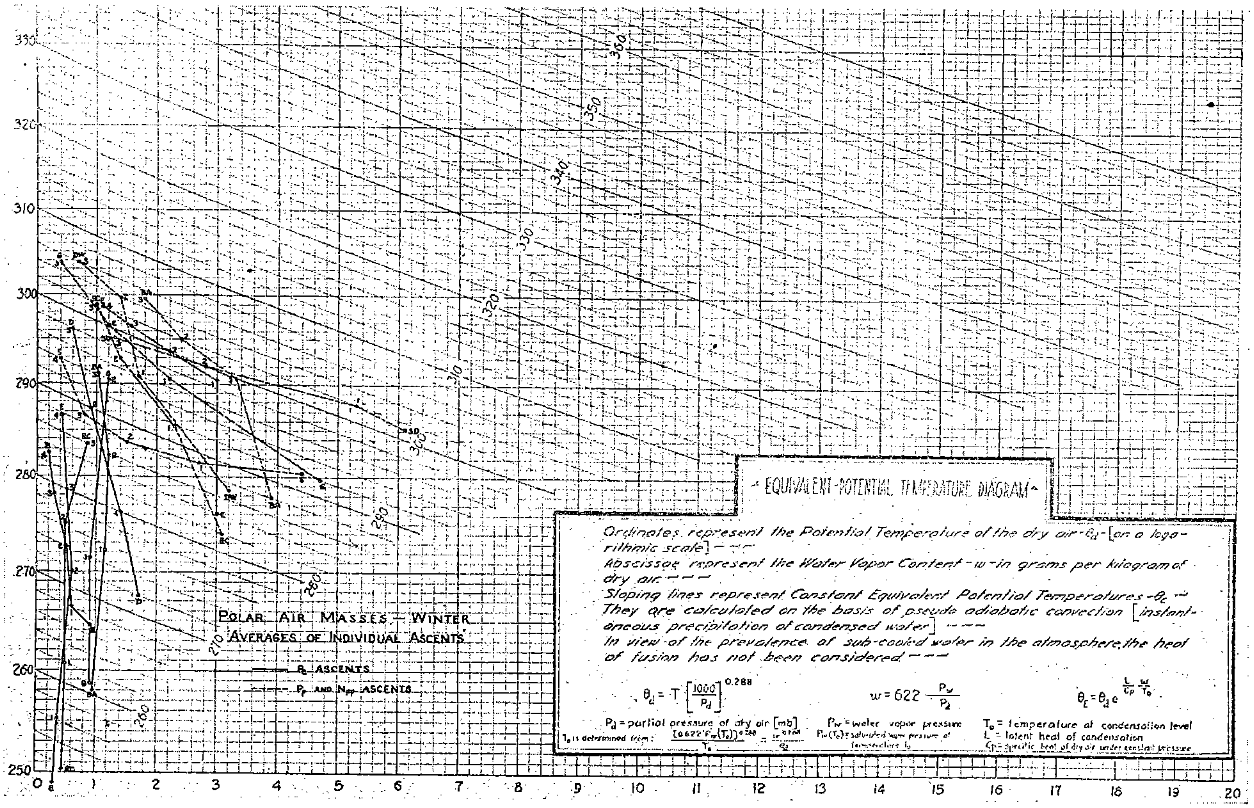
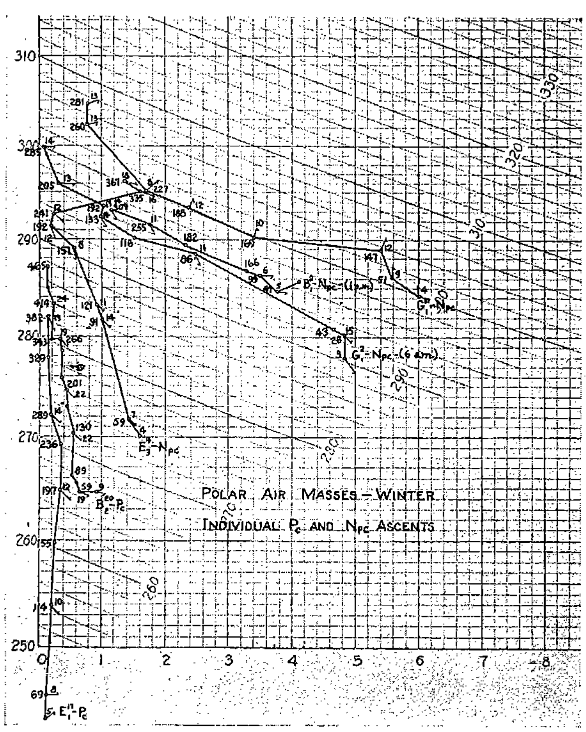
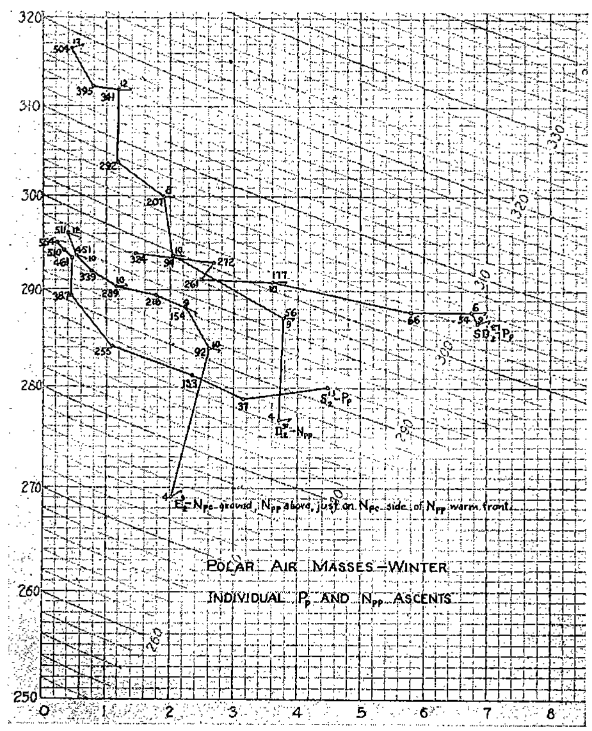
PLATES


EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air - θ_d - [on a logarithmic scale]
Abscissae represent the Water Vapor Content - w - in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures - θ_E
They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
$\theta_d = T\left[\frac{1000}{P_d}\right]^{0.288}$
$w = 622\,\frac{P_w}{P_d}$
$\theta_E = \theta_d\, e^{\frac{L}{c_p}\frac{w}{T_0}}$
P_d = partial pressure of dry air [mb]
P_w = water vapor pressure
T_0 = temperature at condensation level
L = latent heat of condensation
C_p = specific heat of dry air under constant pressure
POLAR AIR MASSES – WINTER
AVERAGES OF INDIVIDUAL ASCENTS
P_c ASCENTS
P_p AND N_{pp} ASCENTS

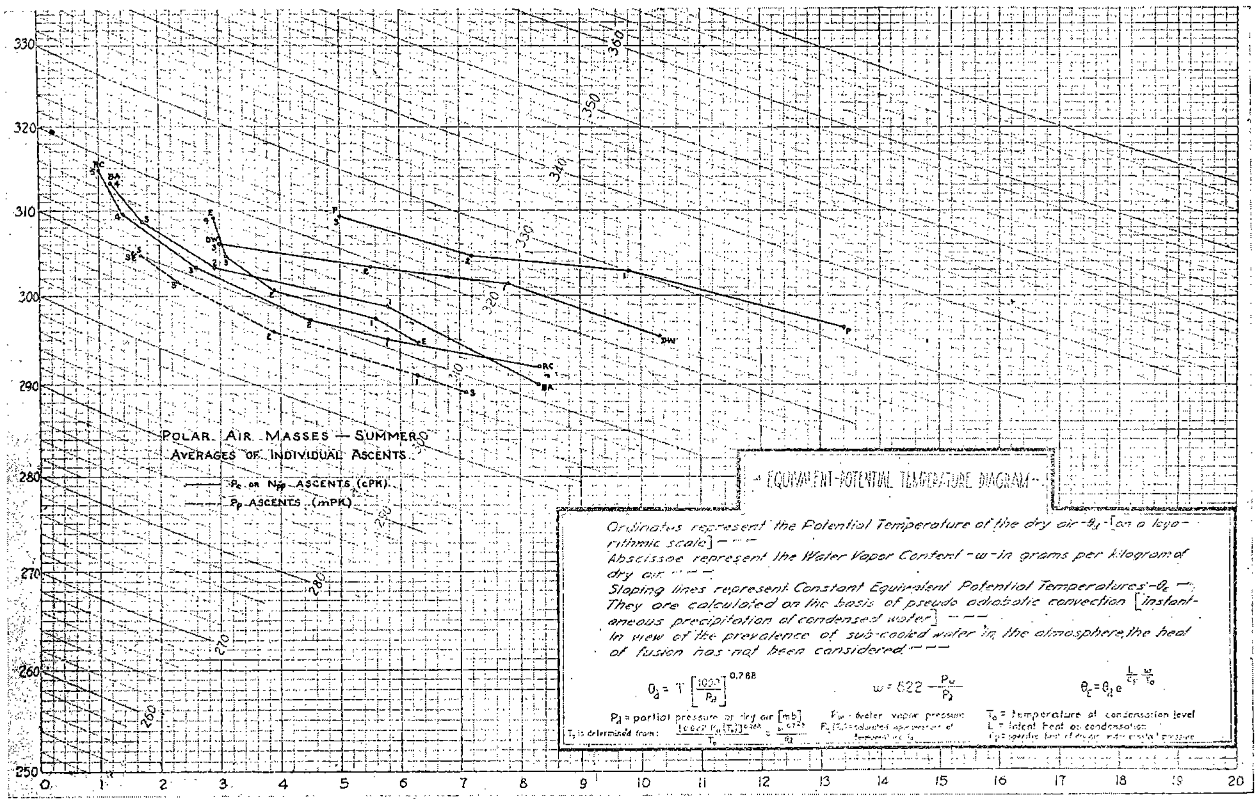
A


POLAR AIR MASSES – WINTER
INDIVIDUAL P_c AND N_{pc} ASCENTS

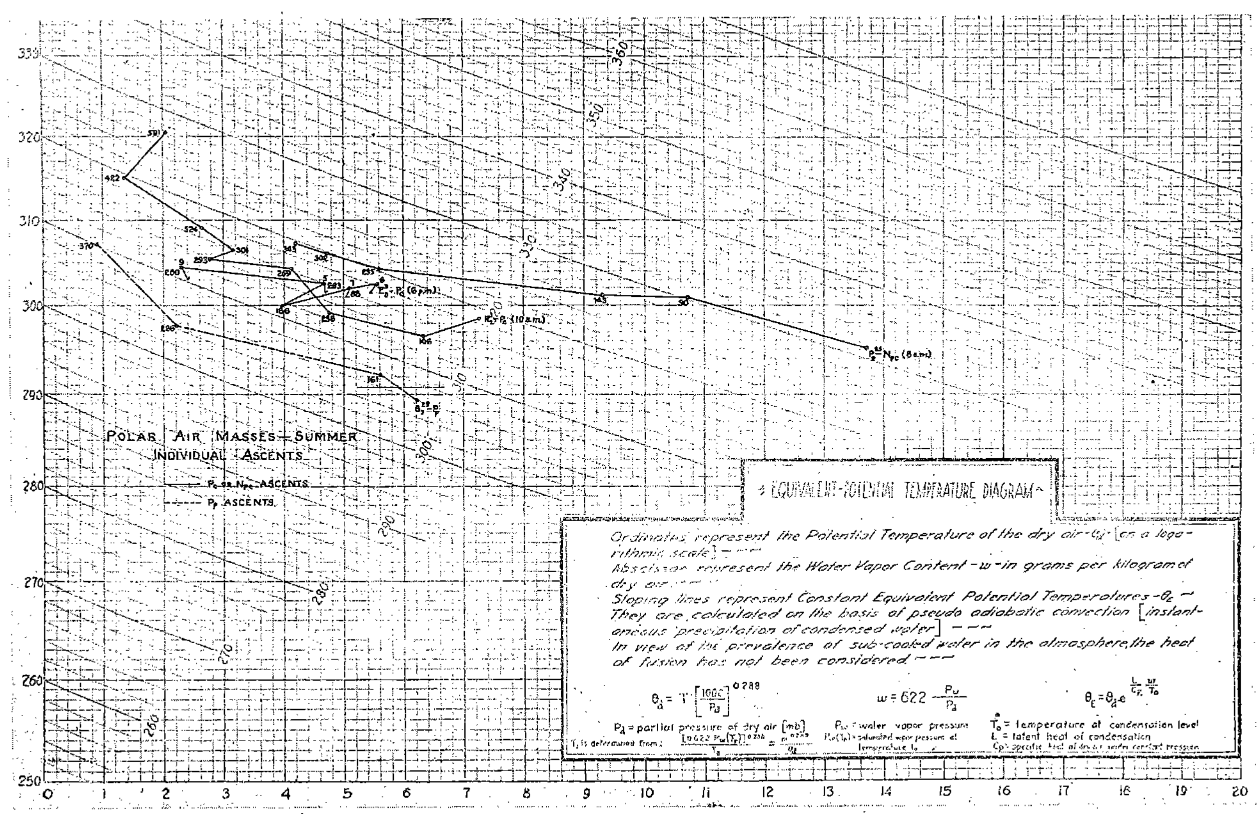
B


POLAR AIR MASSES – WINTER
INDIVIDUAL P_p AND N_{pp} ASCENTS

C


POLAR AIR MASSES — SUMMER
AVERAGES OF INDIVIDUAL ASCENTS
Pc or Npc ASCENTS (cPK)
Pp ASCENTS (mPK)
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air - θd - [on a logarithmic scale]
Abscissae represent the Water Vapor Content - w - in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures - θE
They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
Pd = partial pressure of dry air [mb]
To = Temperature at condensation level
L = latent heat of condensation

A


POLAR AIR MASSES — SUMMER
INDIVIDUAL ASCENTS
Pc or Npc ASCENTS
Pp ASCENTS
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air - θd - [on a logarithmic scale]
Abscissae represent the Water Vapor Content - w - in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures - θE
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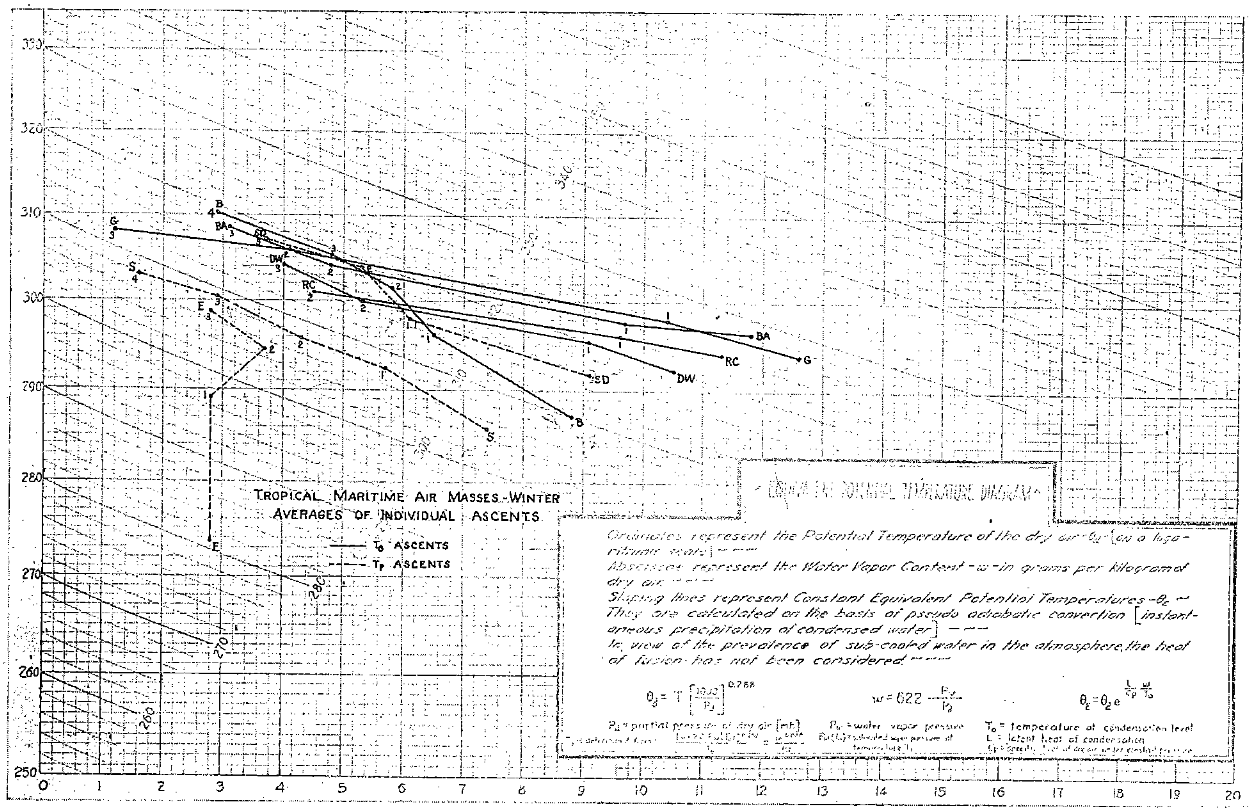
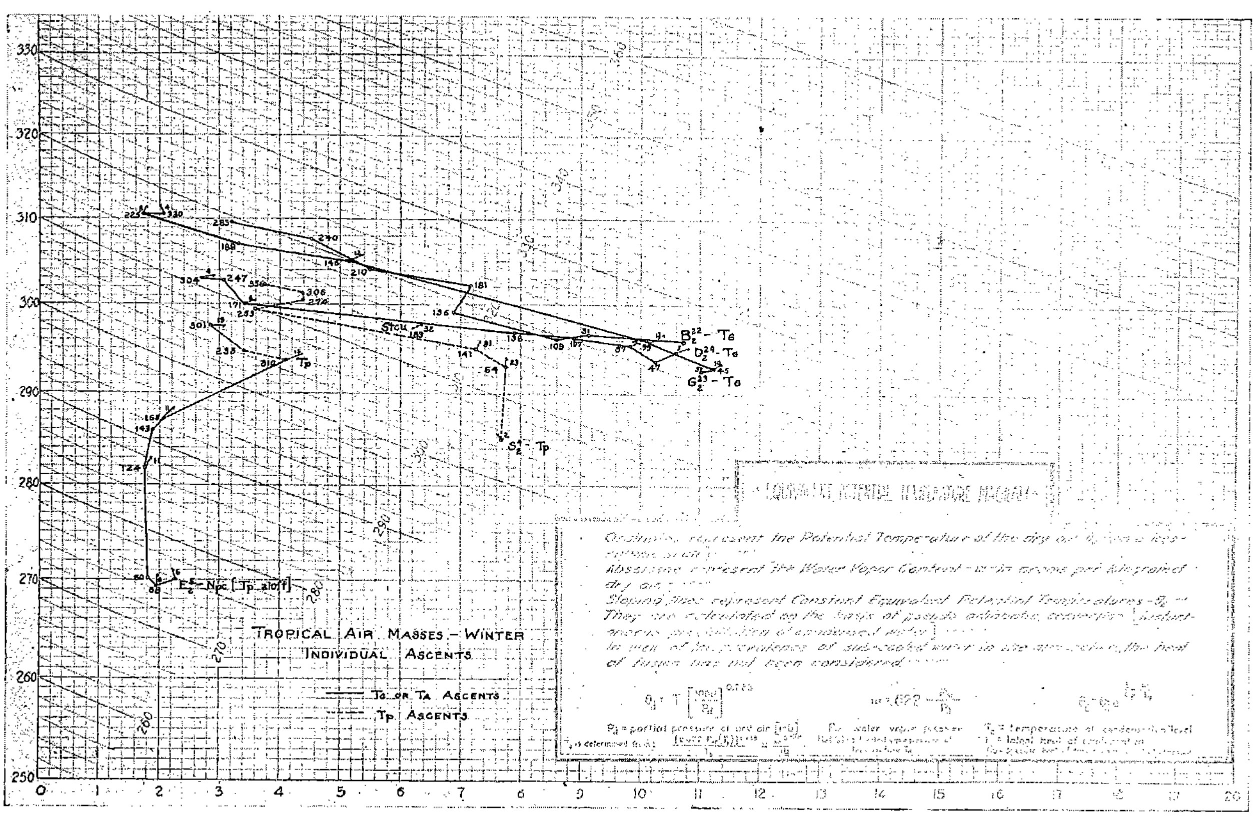
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
Pd = partial pressure of dry air [mb]
To = Temperature at condensation level
L = latent heat of condensation

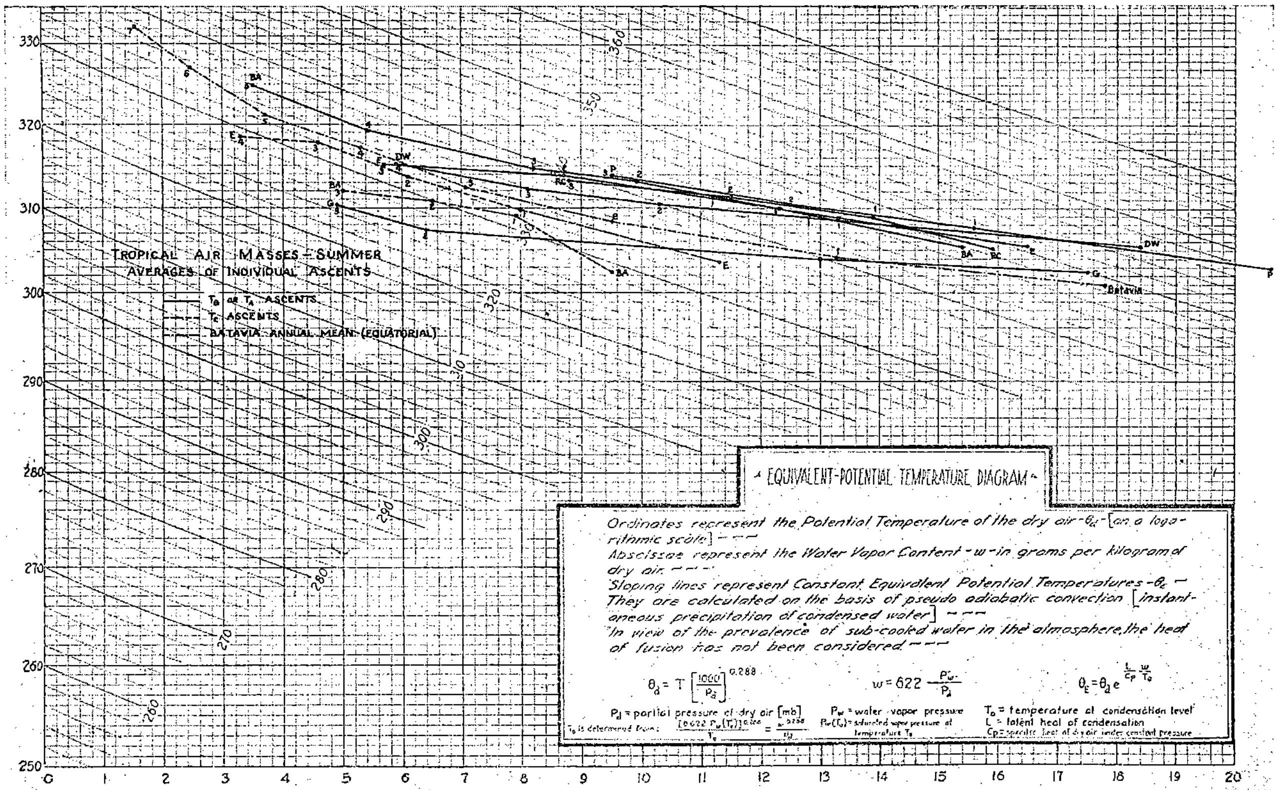
B


TROPICAL MARITIME AIR MASSES-WINTER
AVERAGES OF INDIVIDUAL ASCENTS
T0 ASCENTS
Tp ASCENTS
Ordinates represent the Potential Temperature of the dry air
Abscissae represent the Water Vapor Content - w - in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures
They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered.

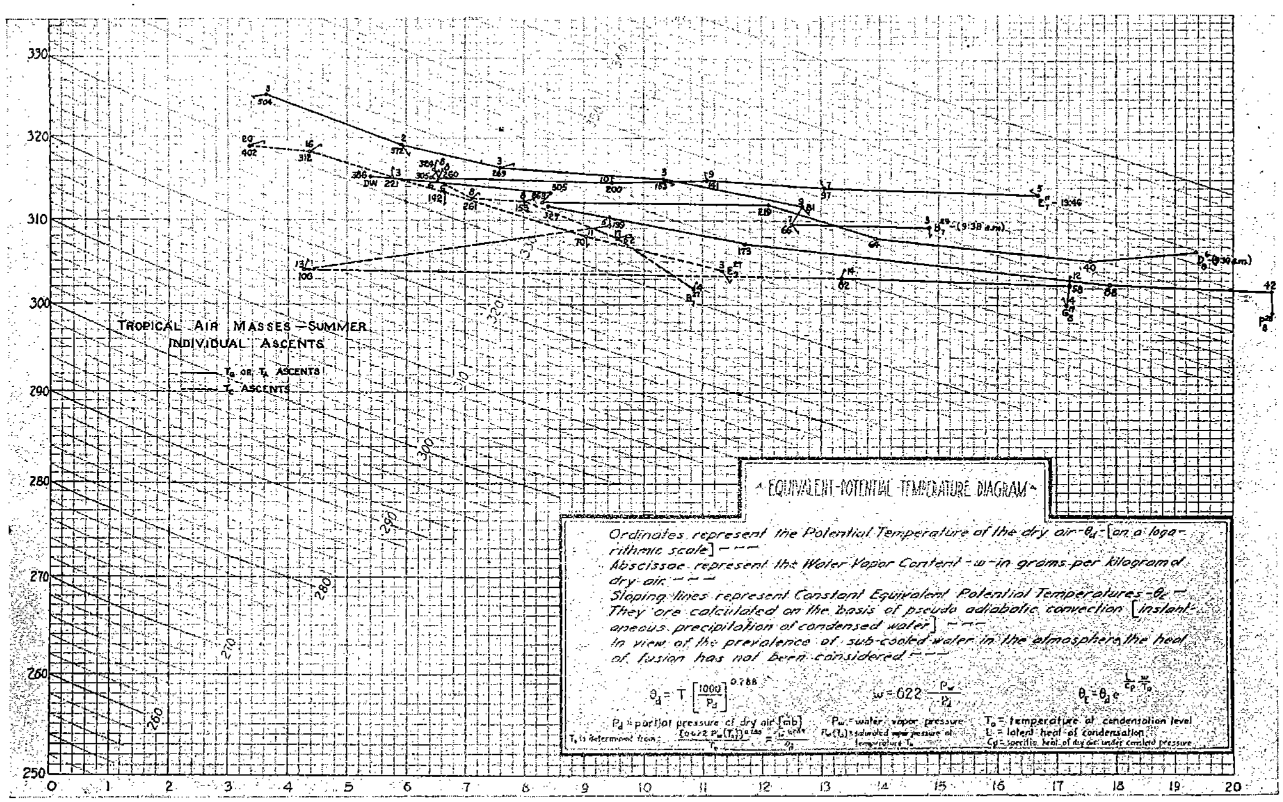
A


TROPICAL AIR MASSES - WINTER
INDIVIDUAL ASCENTS
T0 OR TA ASCENTS
Tp ASCENTS

B


TROPICAL AIR MASSES – SUMMER
AVERAGES OF INDIVIDUAL ASCENTS
T_B or T_A ASCENTS
T_c ASCENTS
BATAVIA ANNUAL MEAN (EQUATORIAL)
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air – θ_d – [on a logarithmic scale]
Abscissae represent the Water Vapor Content – w – in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures – θ_E – They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
$\theta_d = T\left[\frac{1000}{P_d}\right]^{0.288}$
$w = 622\,\frac{P_w}{P_d}$
$\theta_E = \theta_d\, e^{\frac{L}{c_p}\frac{w}{T_0}}$
P_d = partial pressure of dry air [mb]
P_w = water vapor pressure
T_0 = temperature at condensation level
L = latent heat of condensation
Batavia

A


TROPICAL AIR MASSES – SUMMER
INDIVIDUAL ASCENTS
T_B or T_A ASCENTS
T_c ASCENTS
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air – θ_d – [on a logarithmic scale]
Abscissae represent the Water Vapor Content – w – in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures – θ_E – They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
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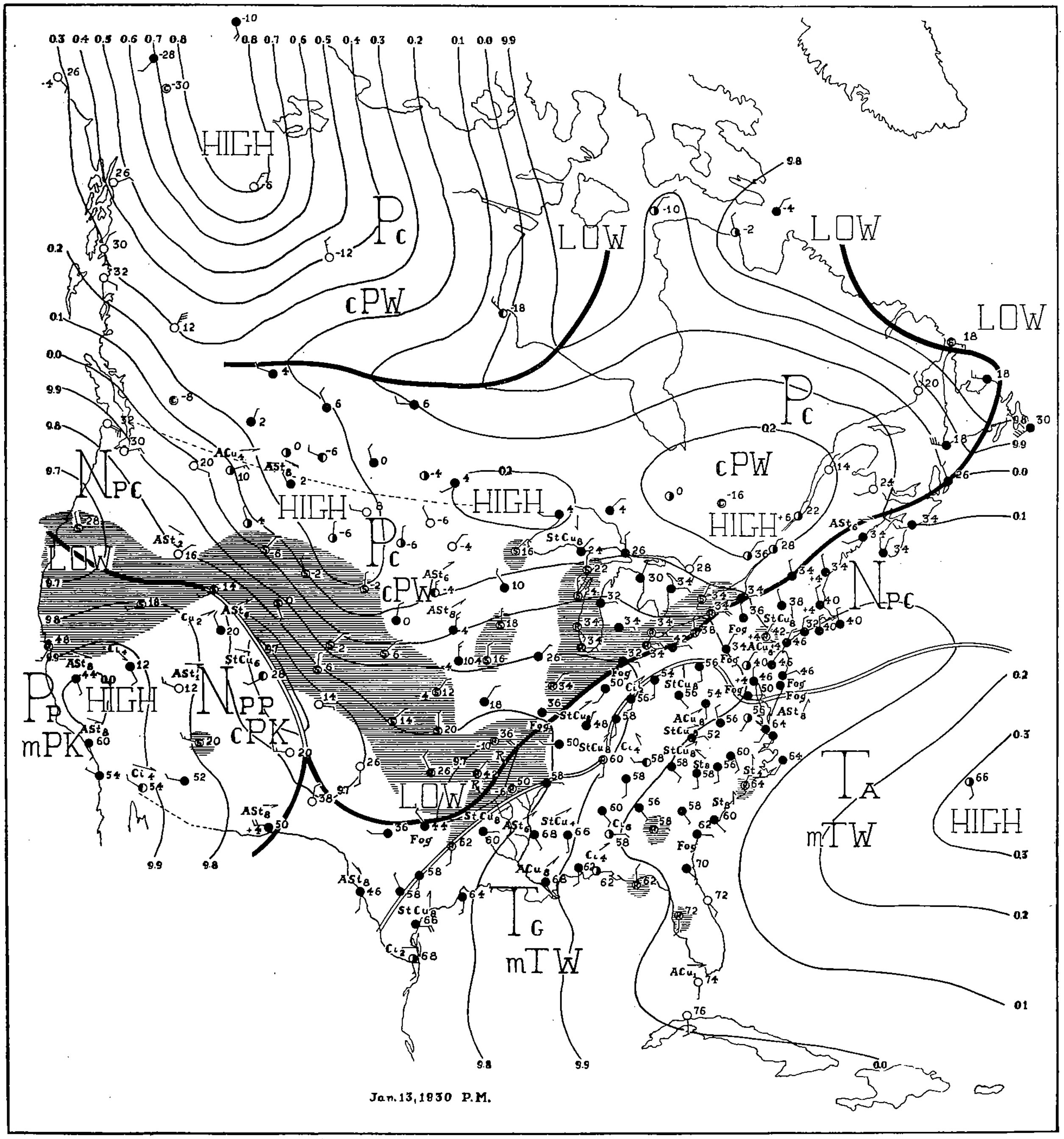
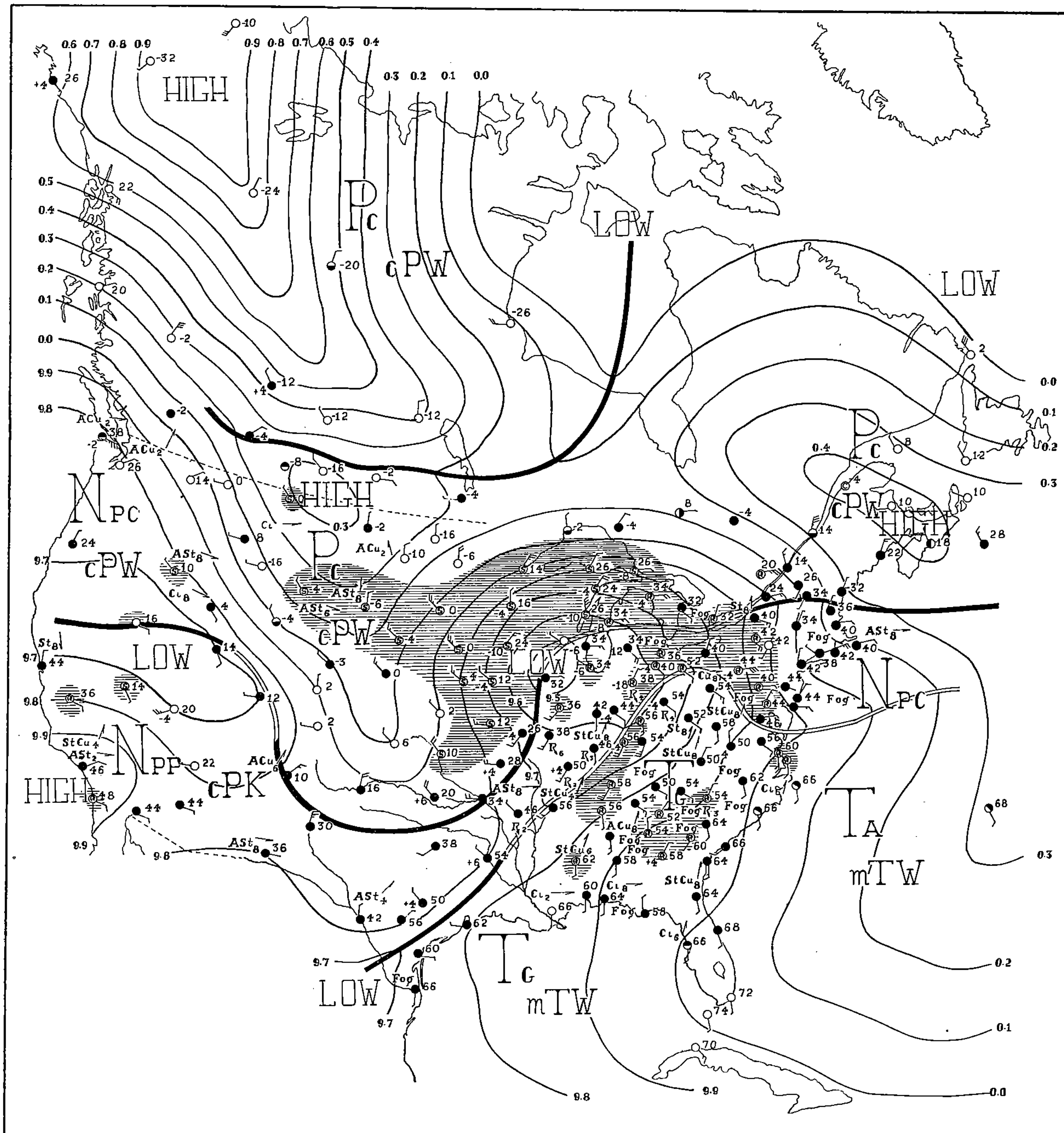
$w = 622\,\frac{P_w}{P_d}$
P_d = partial pressure of dry air [mb]
P_w = water vapor pressure
T_0 = temperature of condensation level
L = latent heat of condensation

B



Jan. 13, 1930 P.M.

VII



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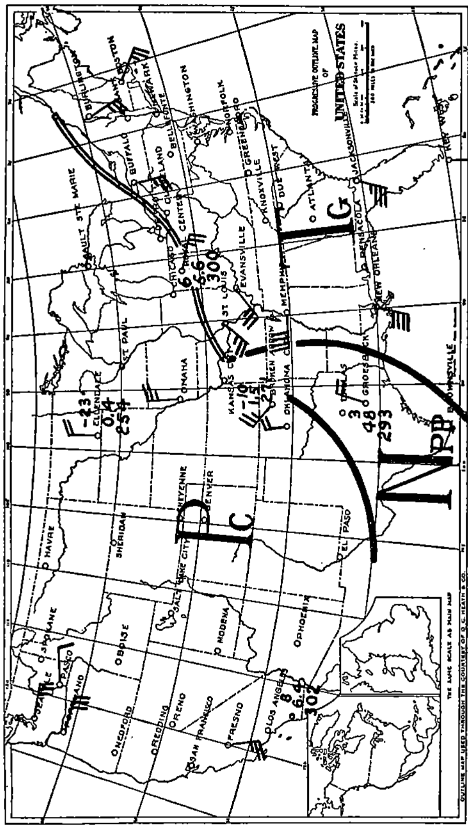
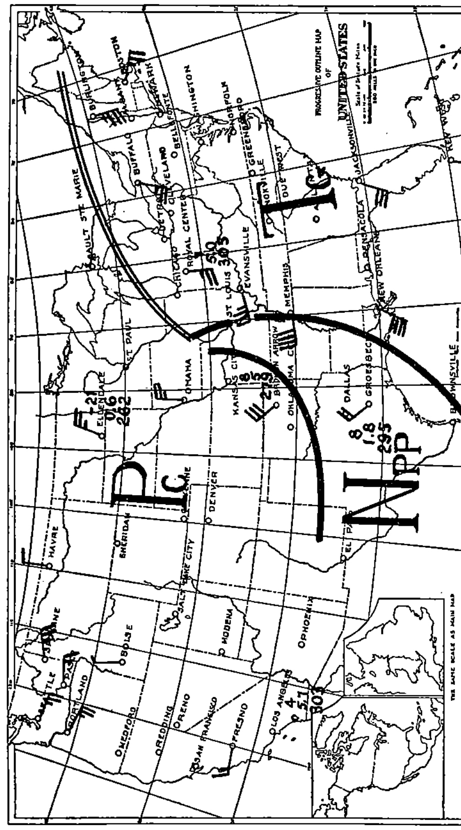


JANUARY 14, 1930, 8:00 A.M.
500 METERS



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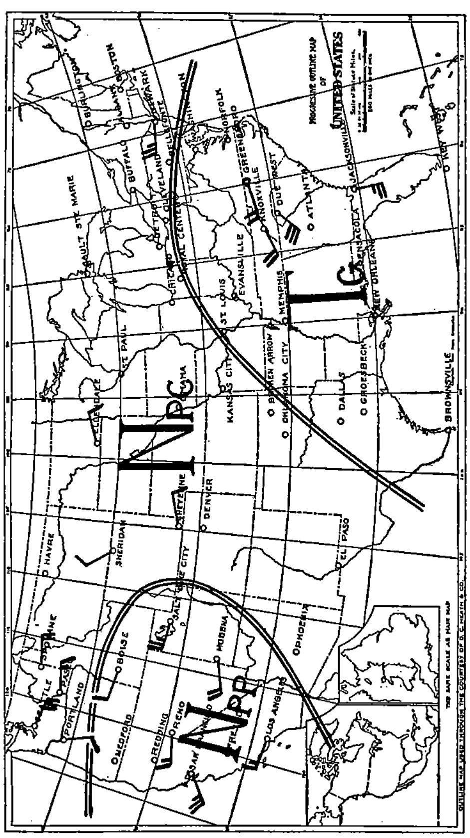

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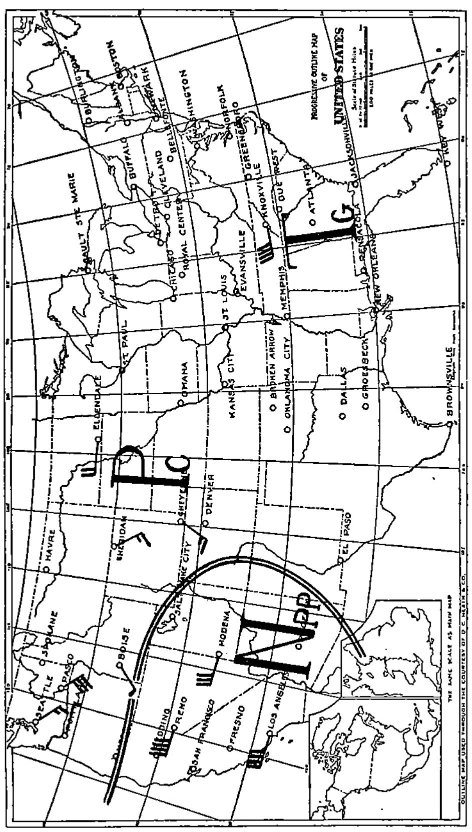

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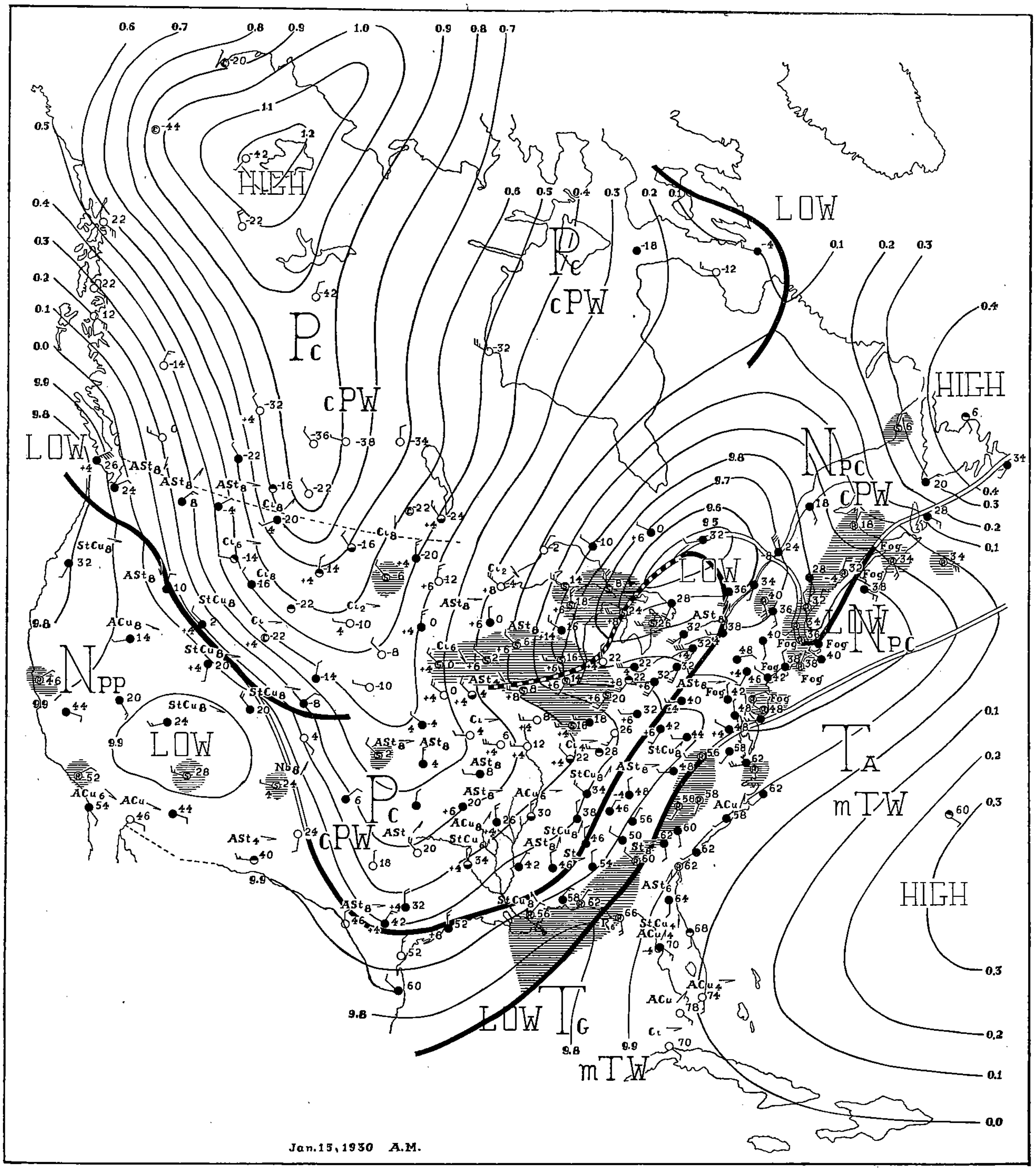

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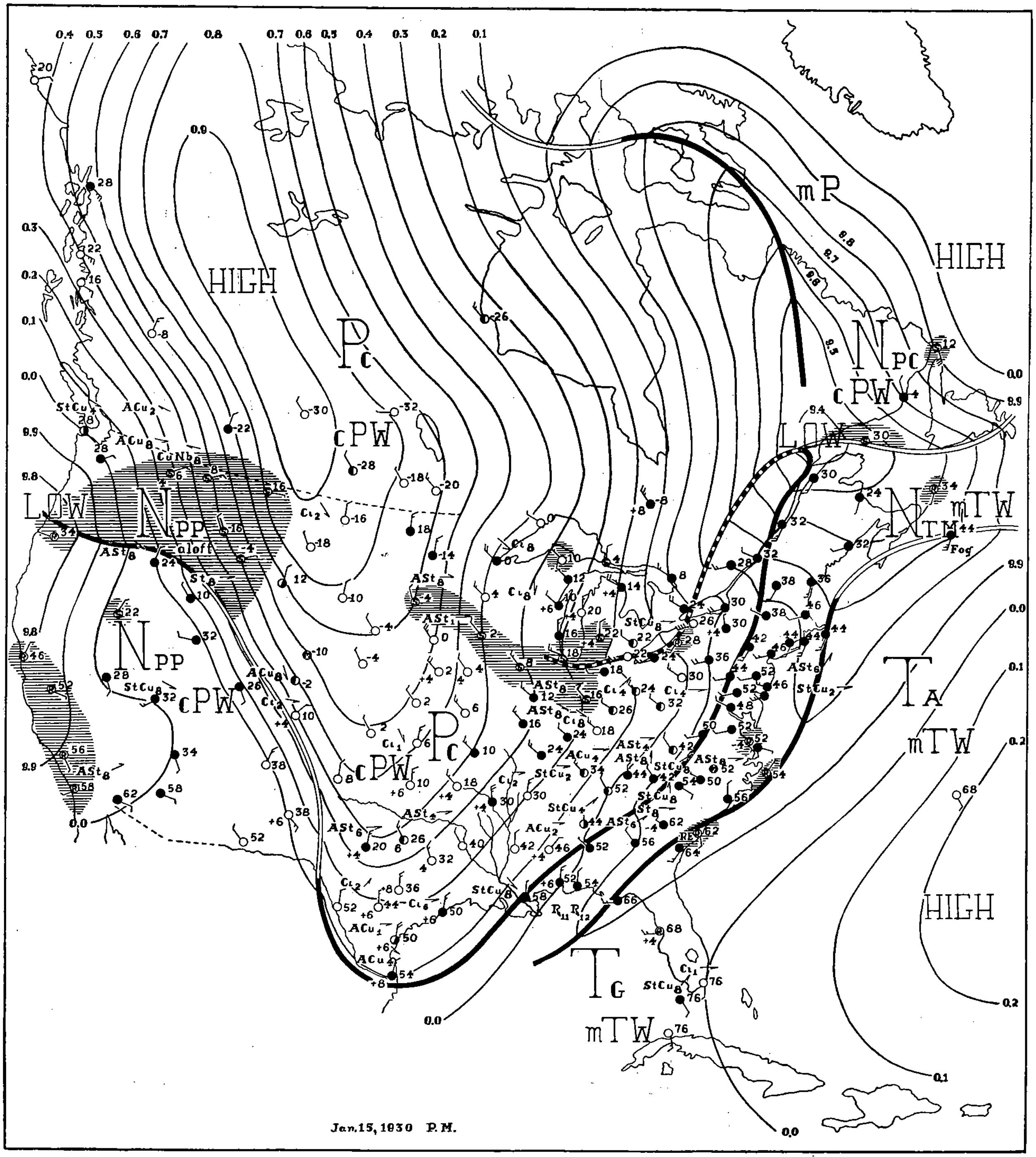
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Pc
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Npp
aloft
cPW
Npp
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Pc
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TG
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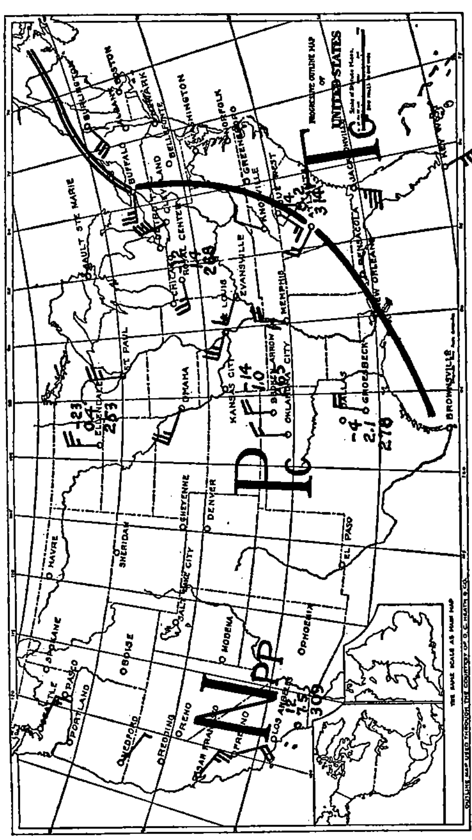
Fog
Jan.15, 1930 P.M.



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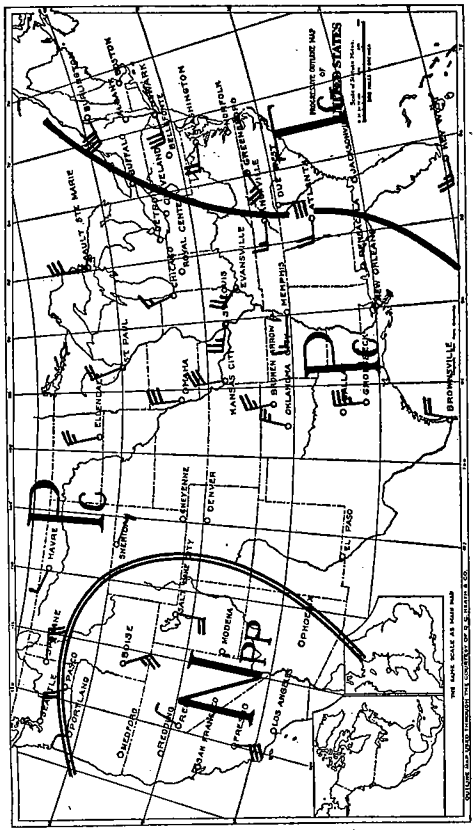

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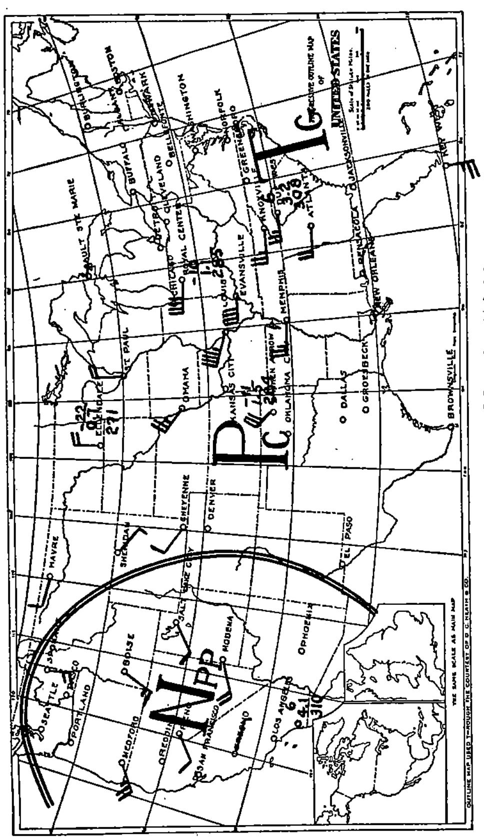
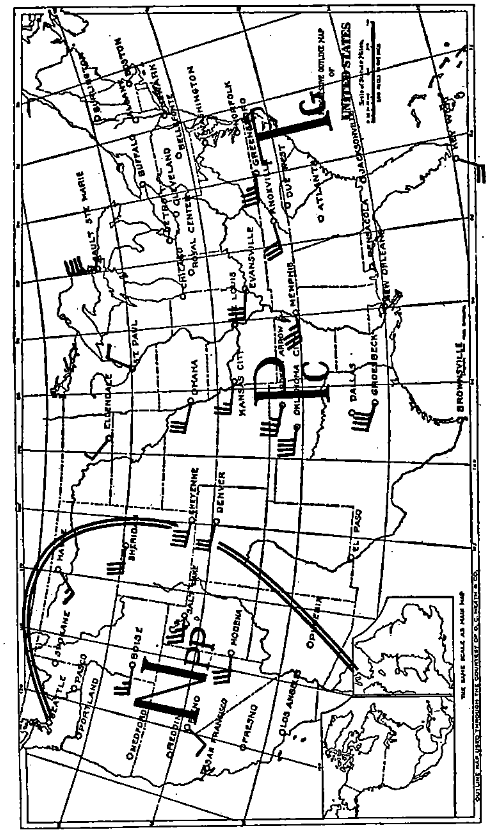
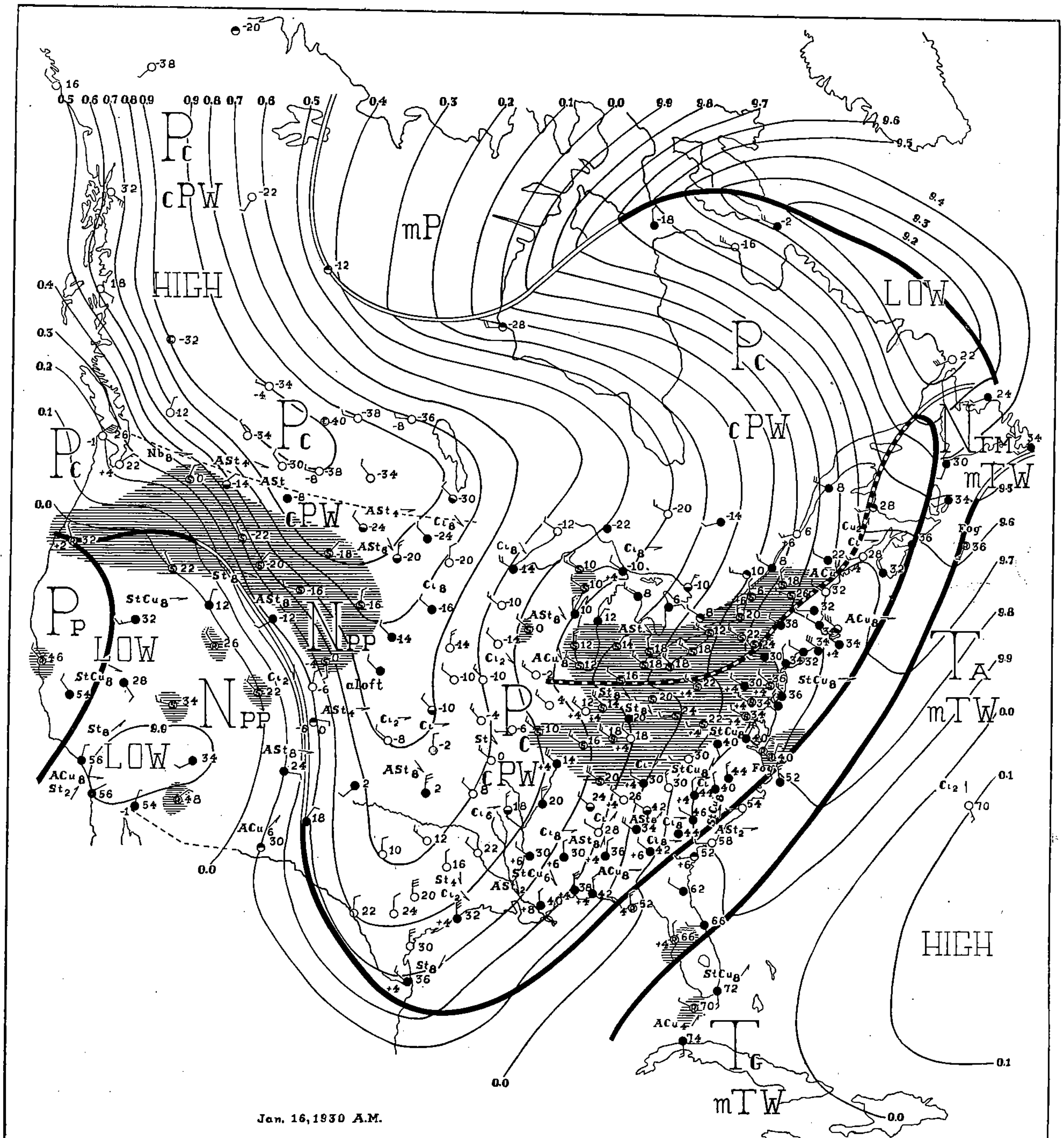
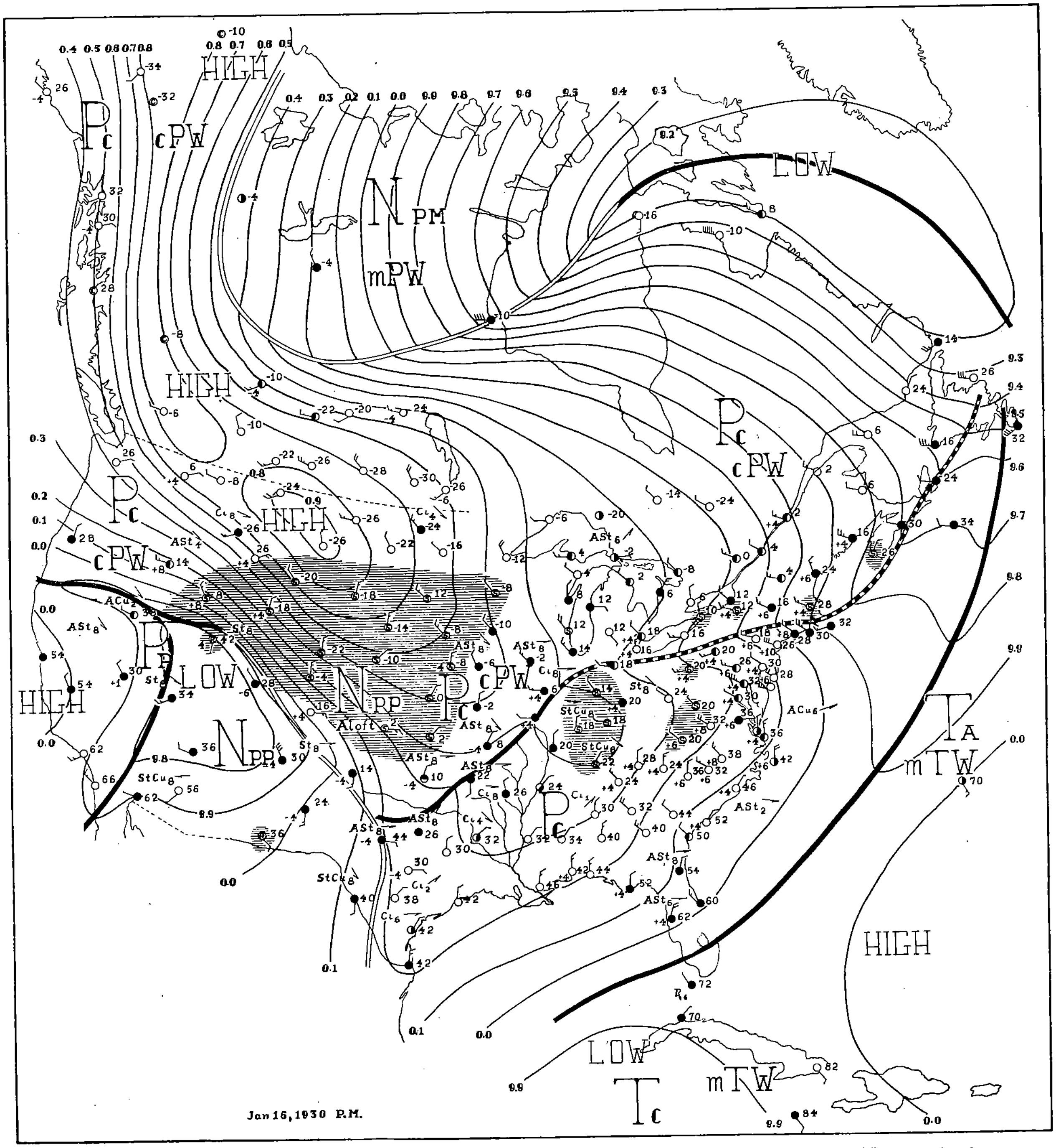


JANUARY 15, 1930, 8:00 A.M.
2000 METERS

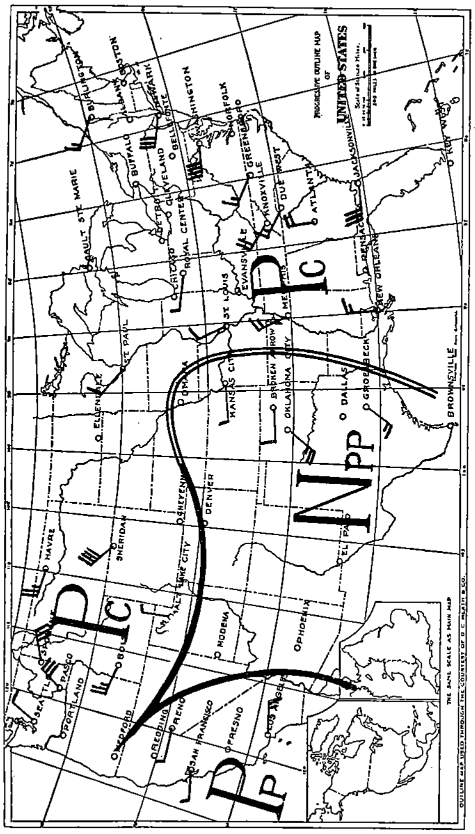


JANUARY 15, 1930, 8:00 P.M.
3000 METERS

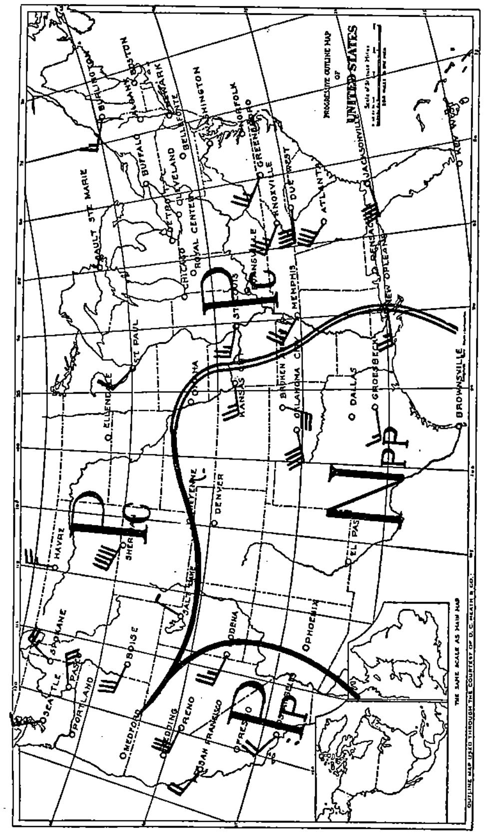

HIGH
LOW
HIGH
LOW
LOW
mP
cPW
mTW
Jan. 16, 1930 A.M.



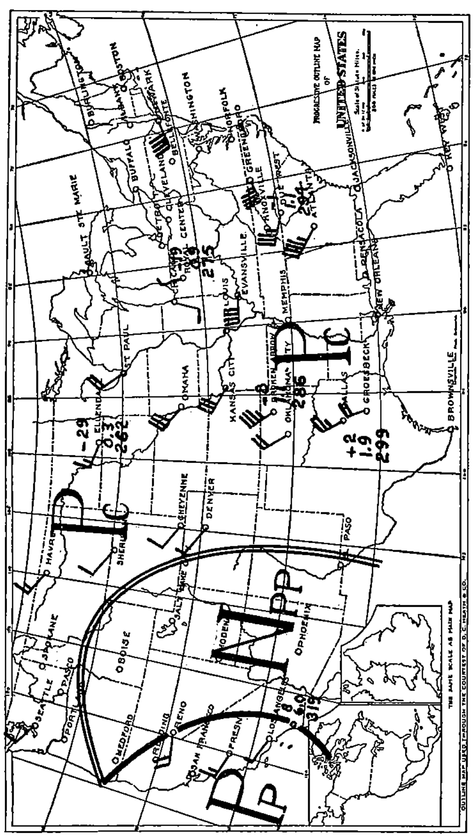
Jan 16, 1930 P.M.



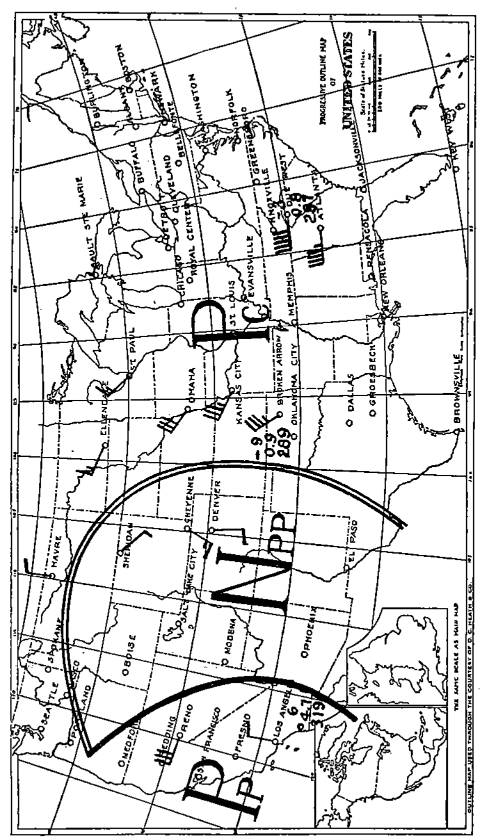
JANUARY 16, 1930, 8:00 P.M.
1500 METERS



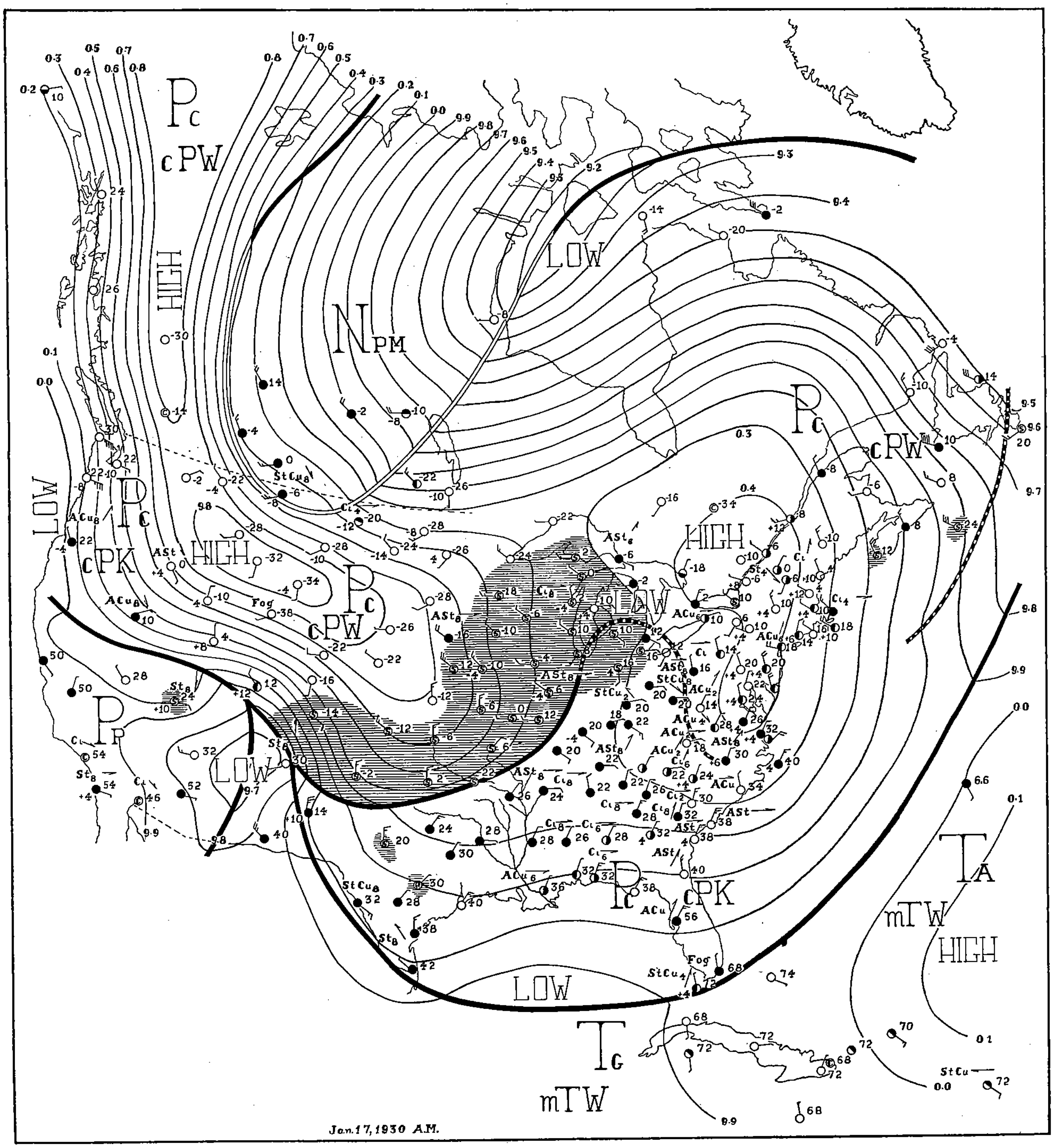
JANUARY 16, 1930, 8:00 P.M.
2500 METERS

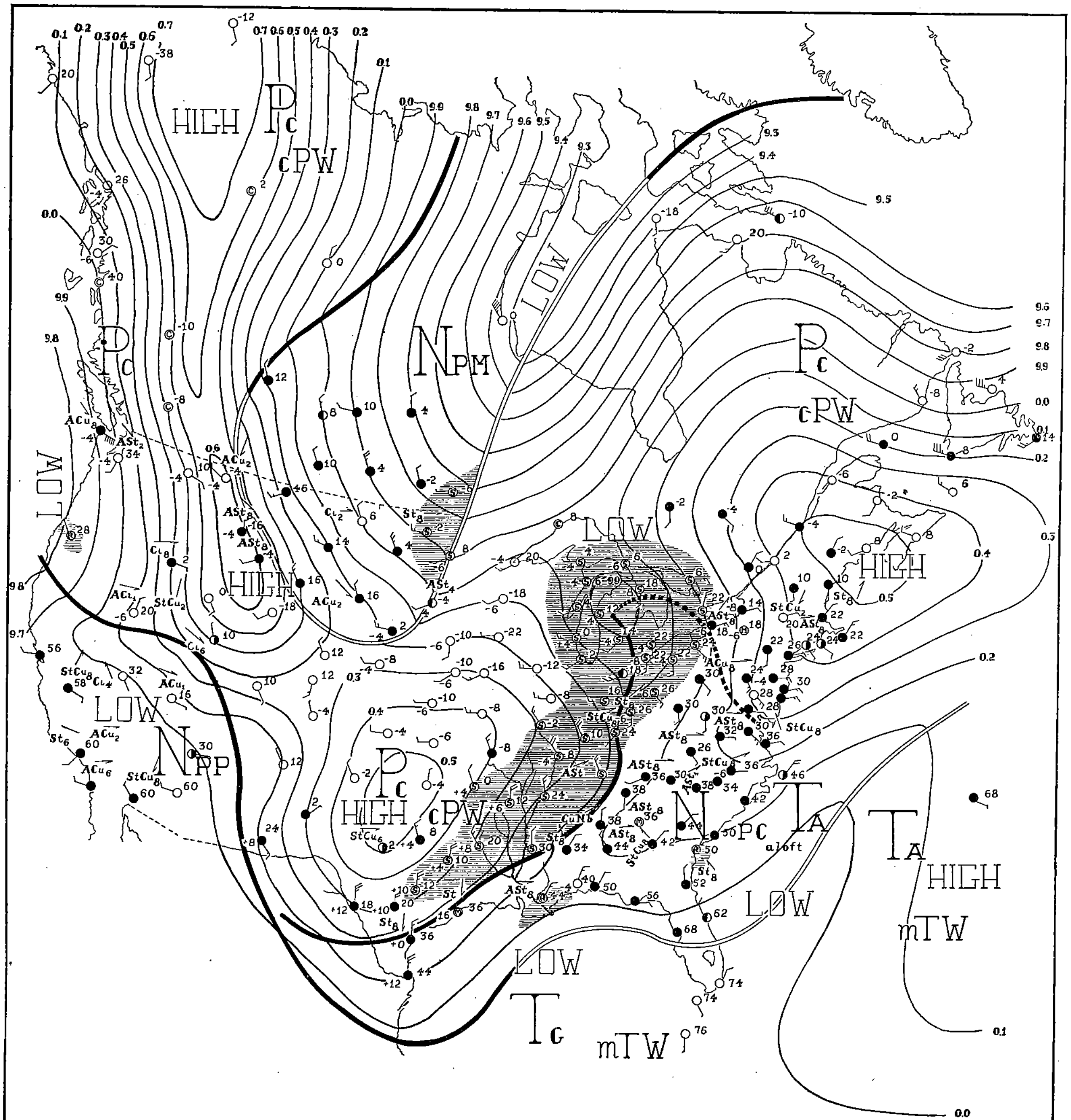


JANUARY 16, 1930, 8:00 A.M.
2000 METERS



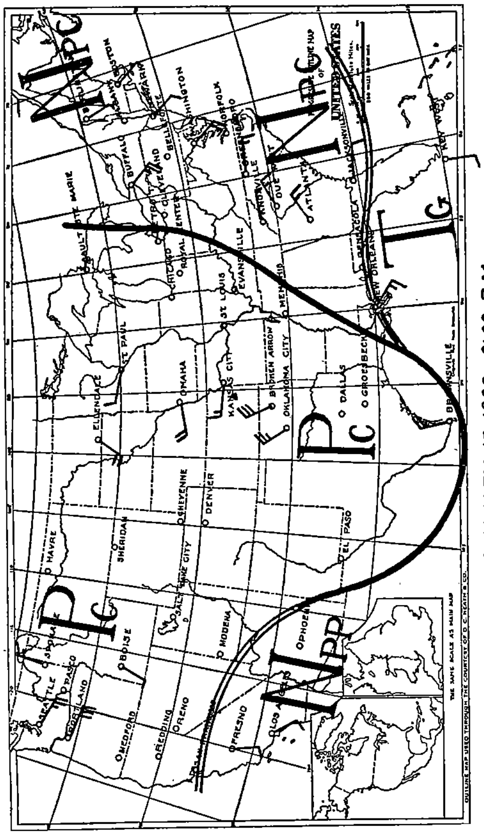
JANUARY 16, 1930, 8:00 A.M.
2500 METERS


Pc
cPW
HIGH
LOW
NPM
LOW
Pc
cPK
HIGH
Pc
cPW
HIGH
LOW
Pc
cPW
Pp
LOW
Pc
cPK
TA
mTW
HIGH
LOW
TG
mTW
Jan. 17, 1930 A.M.

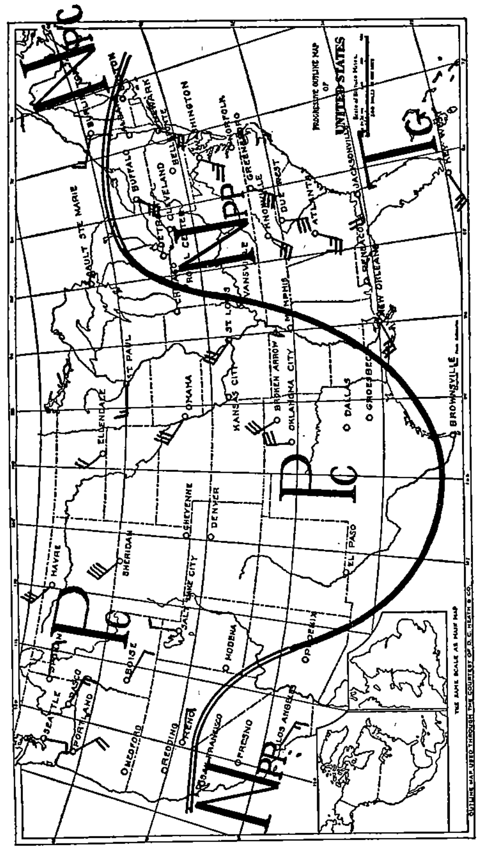


Jan. 17, 1930 P.M.

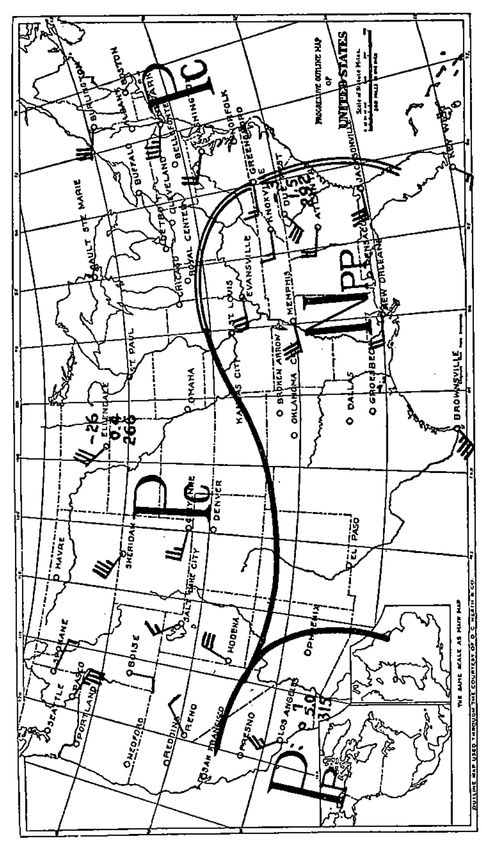
XVII



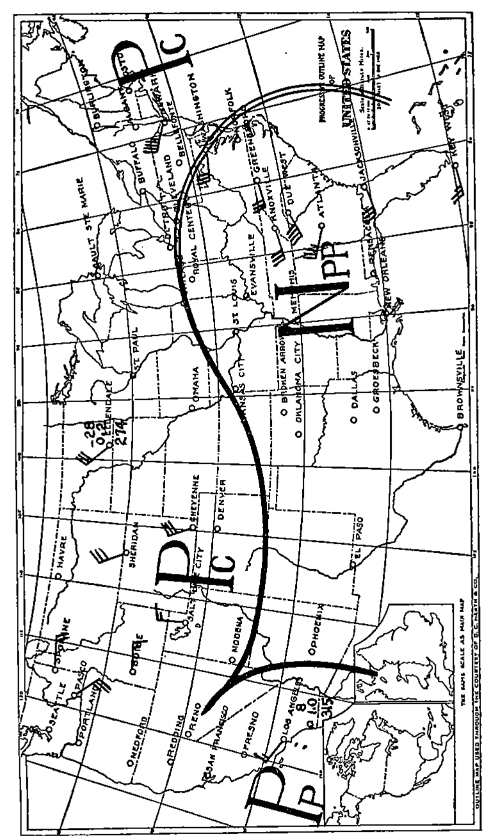
JANUARY 17, 1930, 8:00 P.M.
500 METERS



JANUARY 17, 1930, 8:00 P.M.
1500 METERS

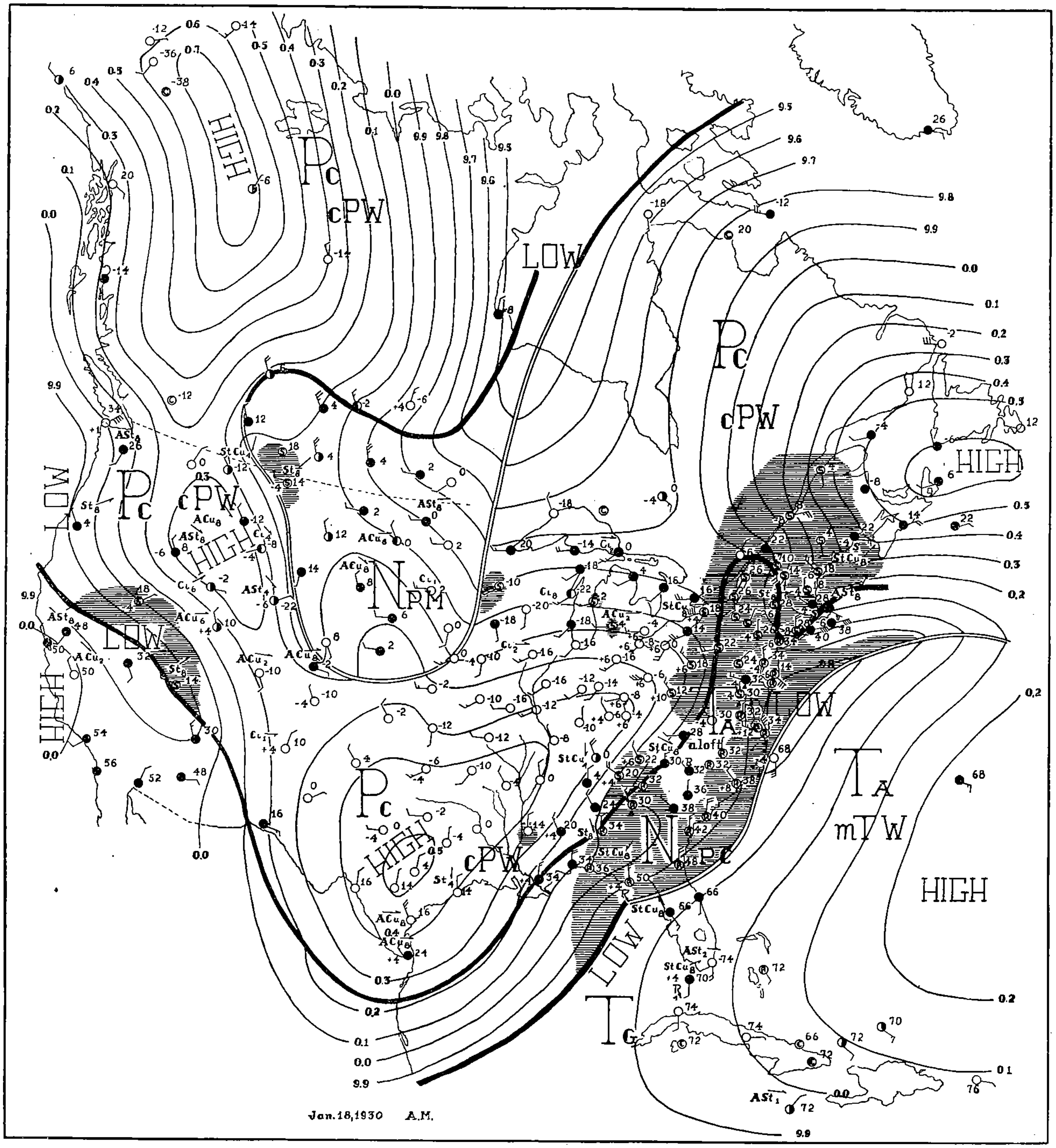


JANUARY 17, 1930, 8:00 A.M.
2000 METERS

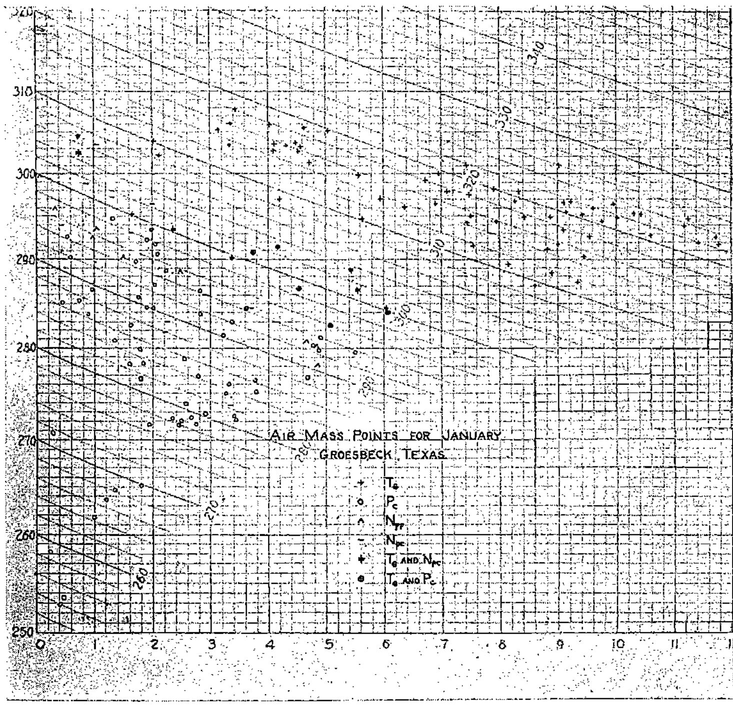


JANUARY 17, 1930, 8:00 A.M.
3000 METERS

XVIII

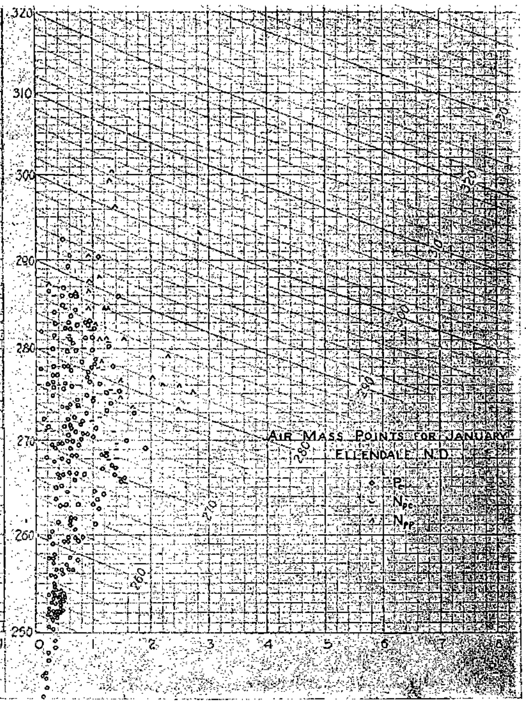


XIX



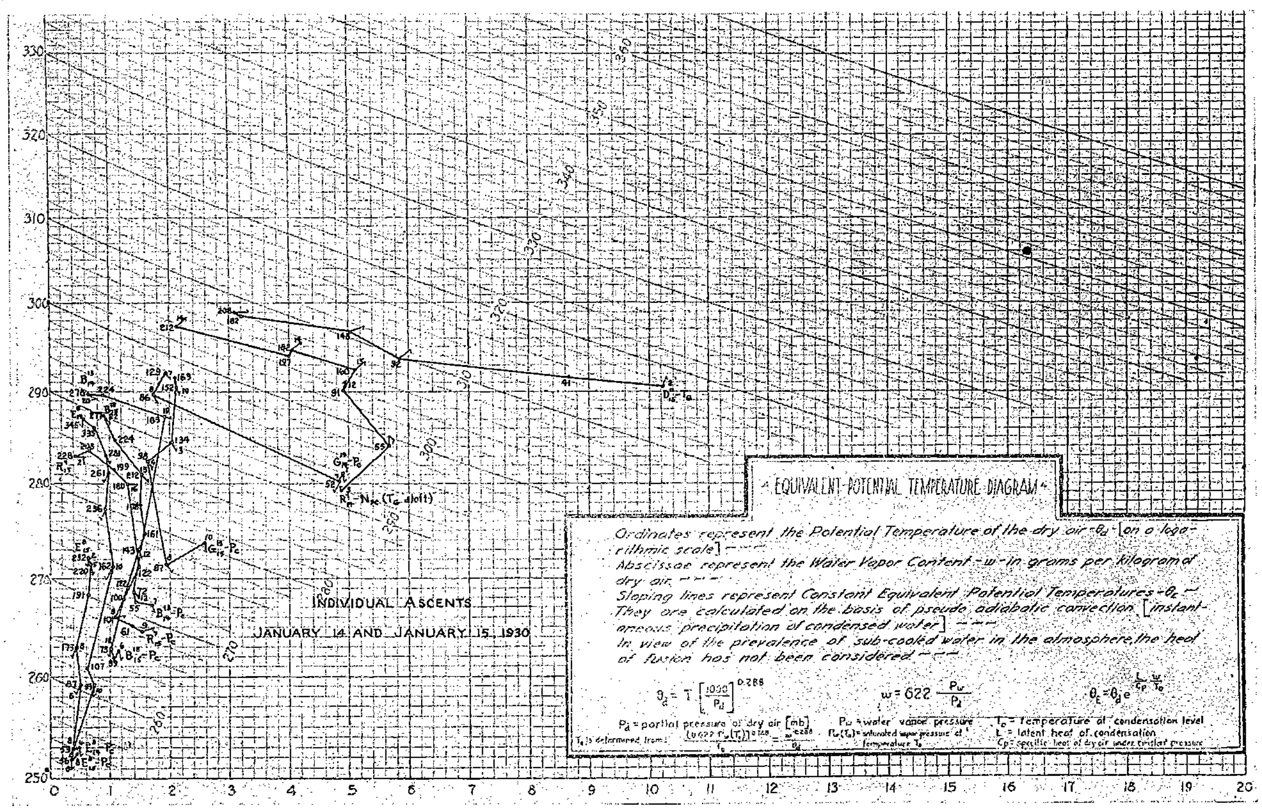
AIR MASS POINTS FOR JANUARY
GROESBECK, TEXAS

A



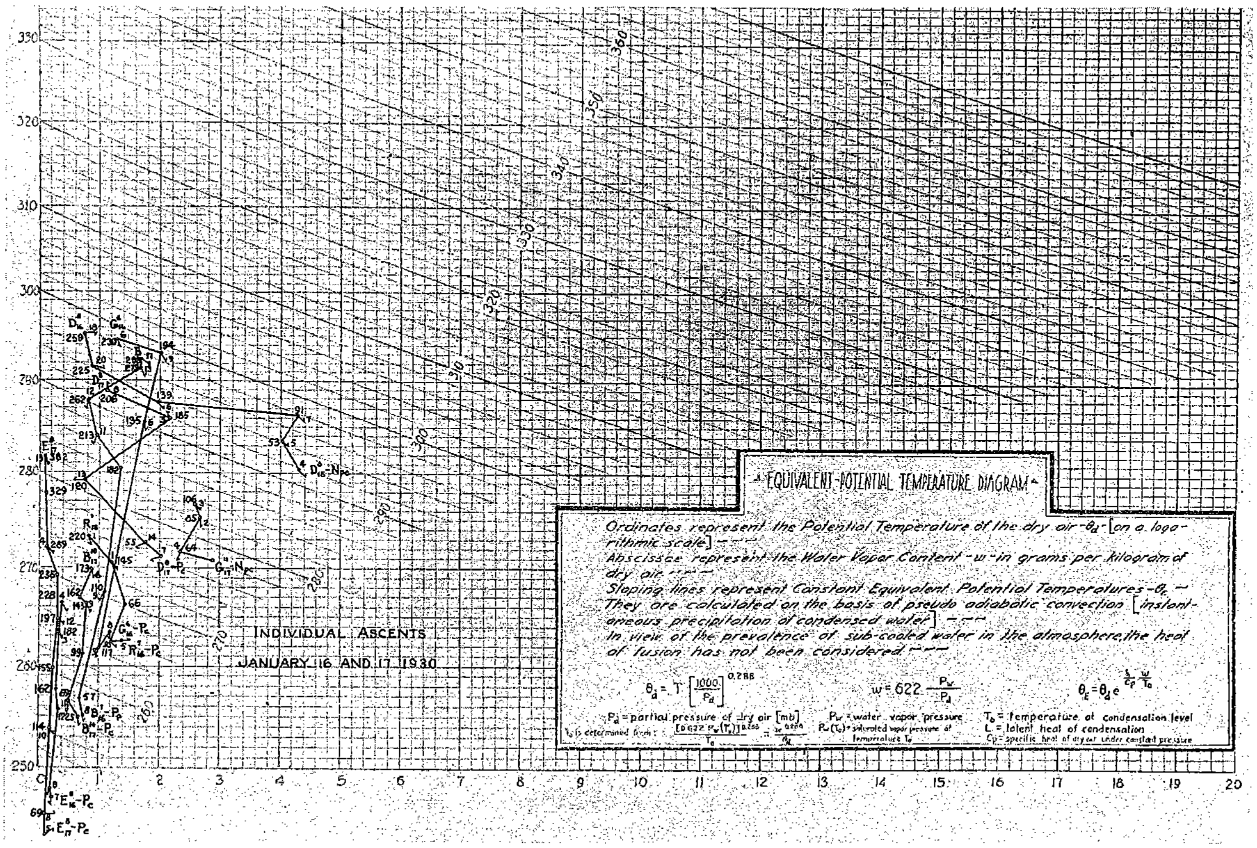
AIR MASS POINTS FOR JANUARY
ELLENDALE, N.D.

B

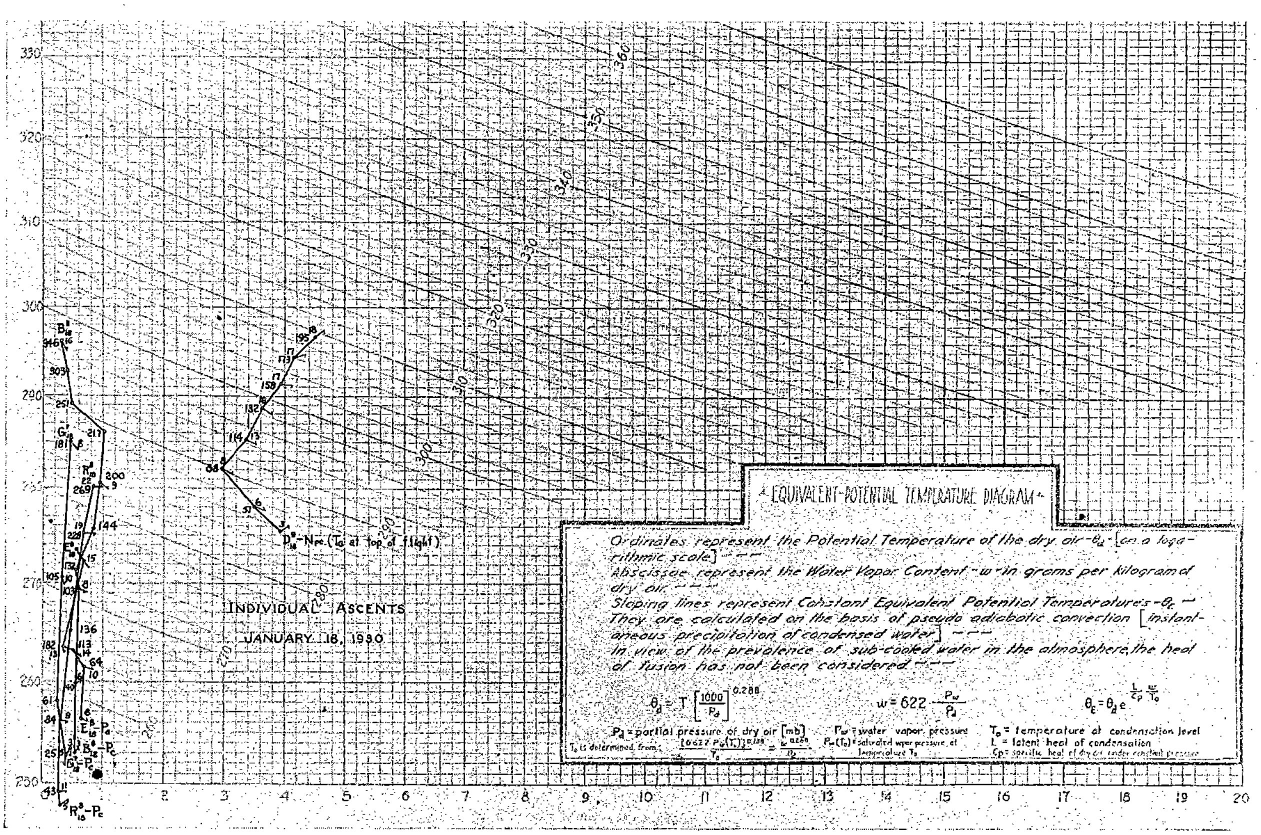


INDIVIDUAL ASCENTS
JANUARY 14 AND JANUARY 15, 1930
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air - θ_d - [on a logarithmic scale]
Abscissae represent the Water Vapor Content - w - in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures - θ_E
They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
$\theta_d = T\left[\frac{1000}{P_d}\right]^{0.288}$
$w = 622\frac{P_w}{P_d}$
$\theta_E = \theta_d e^{\frac{L}{c_p}\frac{w}{T_o}}$
P_d = partial pressure of dry air [mb]
P_w = water vapor pressure
T_o = Temperature of condensation level
L = latent heat of condensation

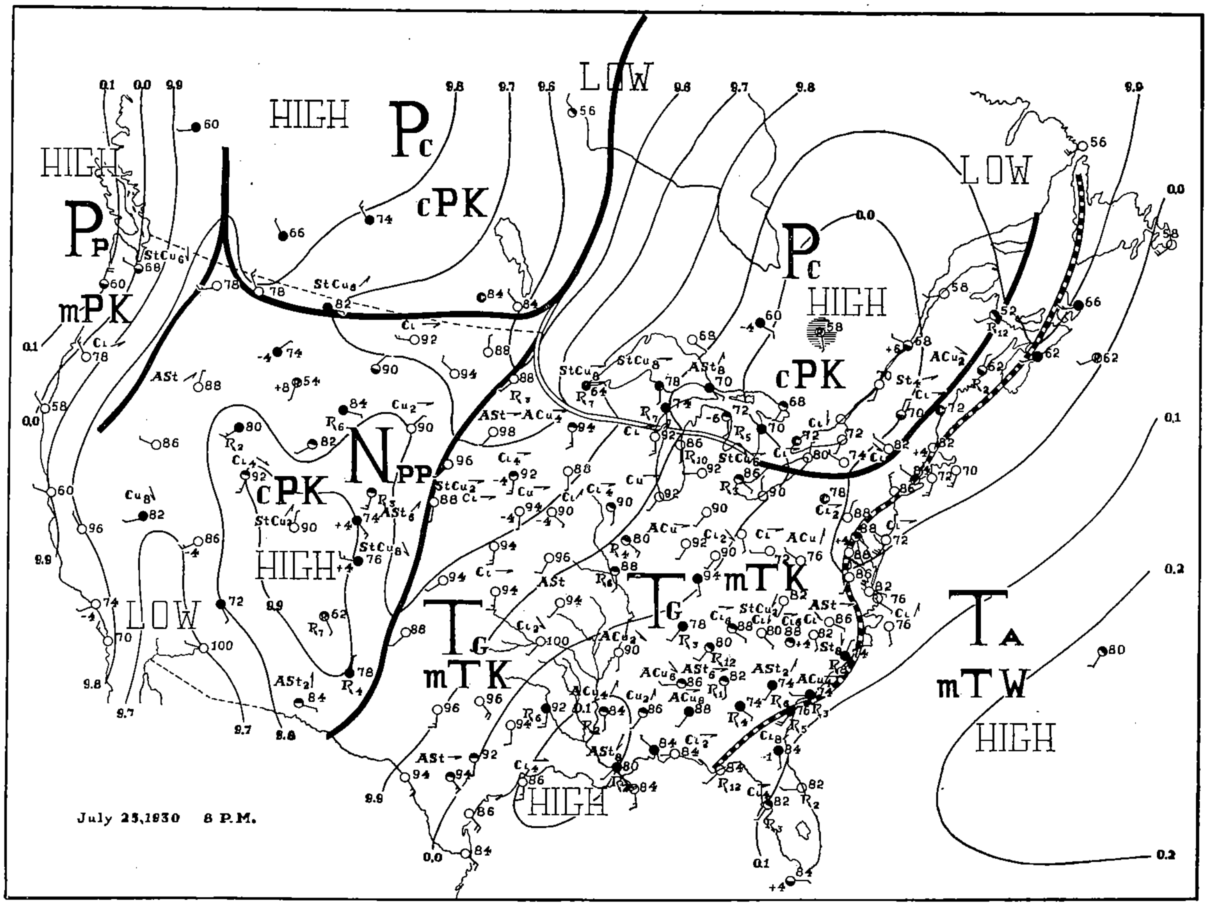
C


EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air $-\theta_d-$ [on a logarithmic scale]
Abscissae represent the Water Vapor Content $-w-$ in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures $-\theta_e-$
They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
INDIVIDUAL ASCENTS
JANUARY 16 AND 17, 1930

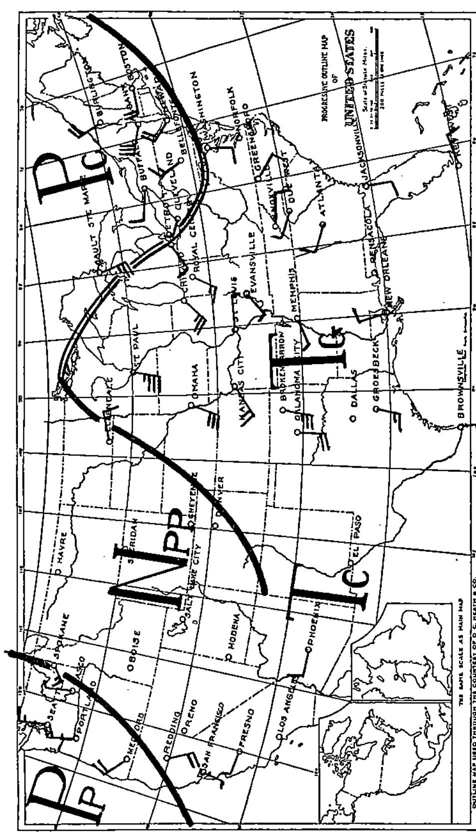
A


EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air $-\theta_d-$ [on a logarithmic scale]
Abscissae represent the Water Vapor Content $-w-$ in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures $-\theta_e-$
They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
INDIVIDUAL ASCENTS
JANUARY 18, 1930

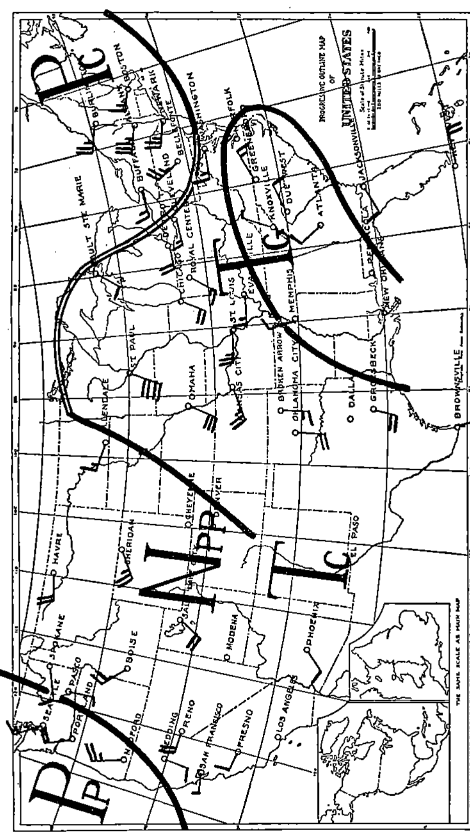
B



A

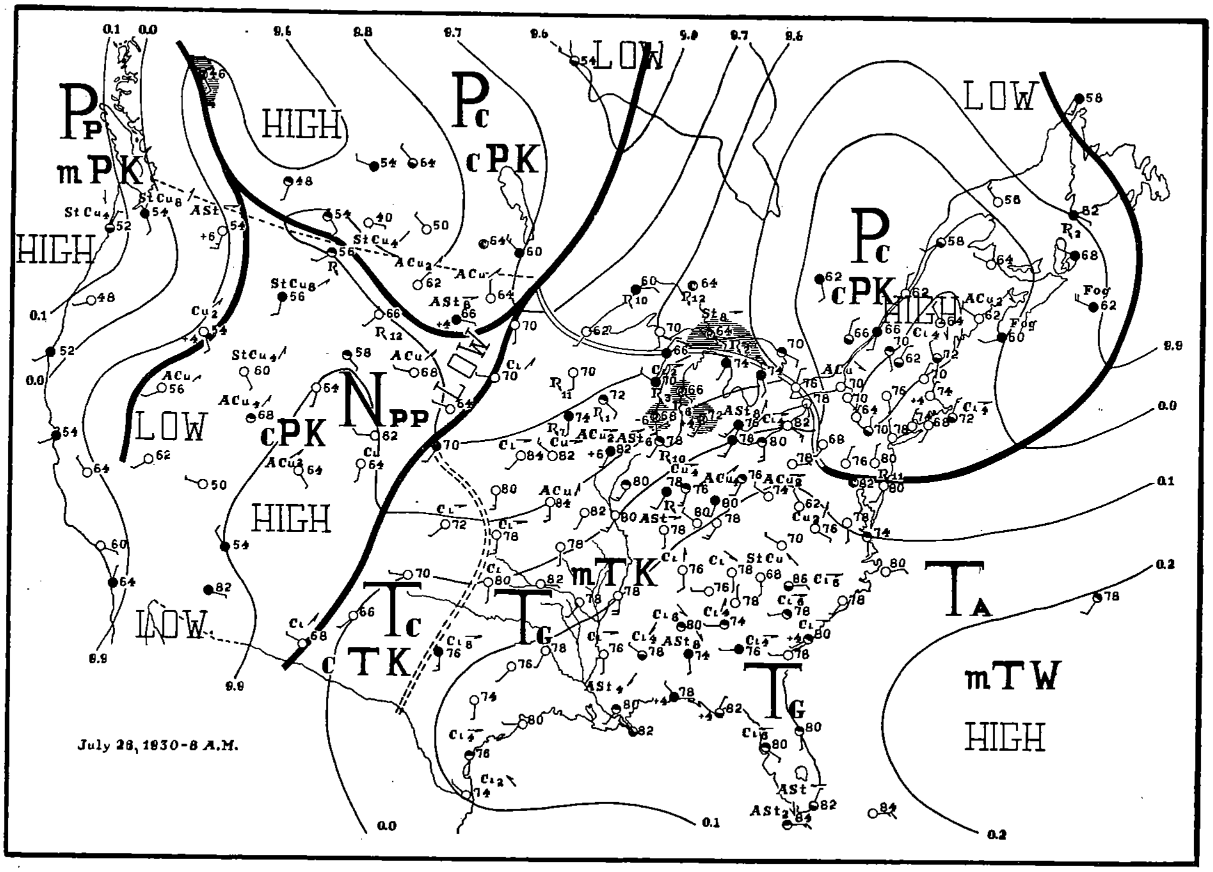


JULY 25, 1930, 8:00 P.M.
750 METERS

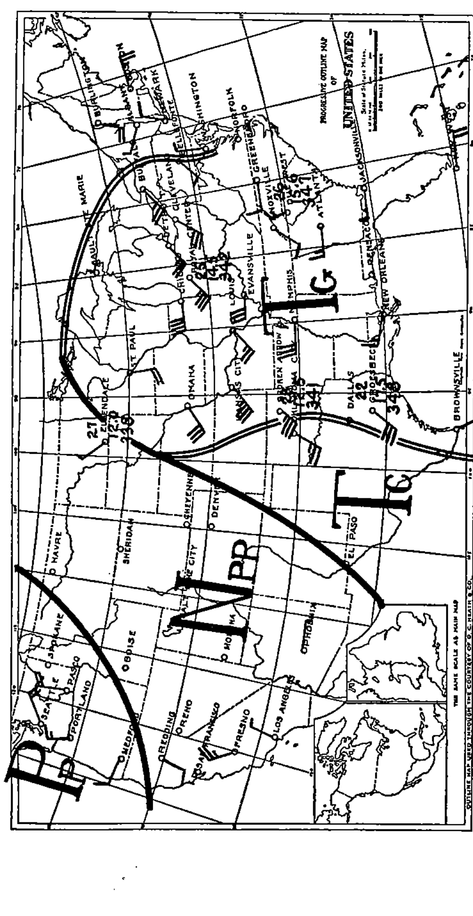


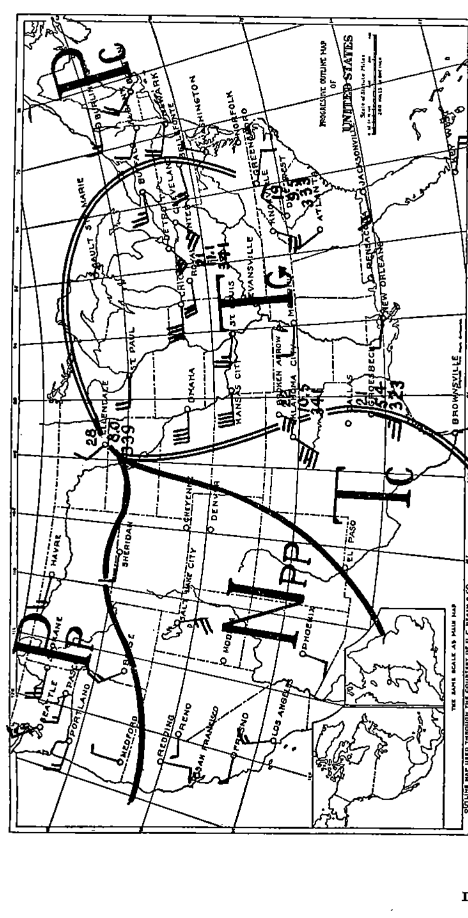
JULY 25, 1930, 8:00 P.M.
1500 METERS

B



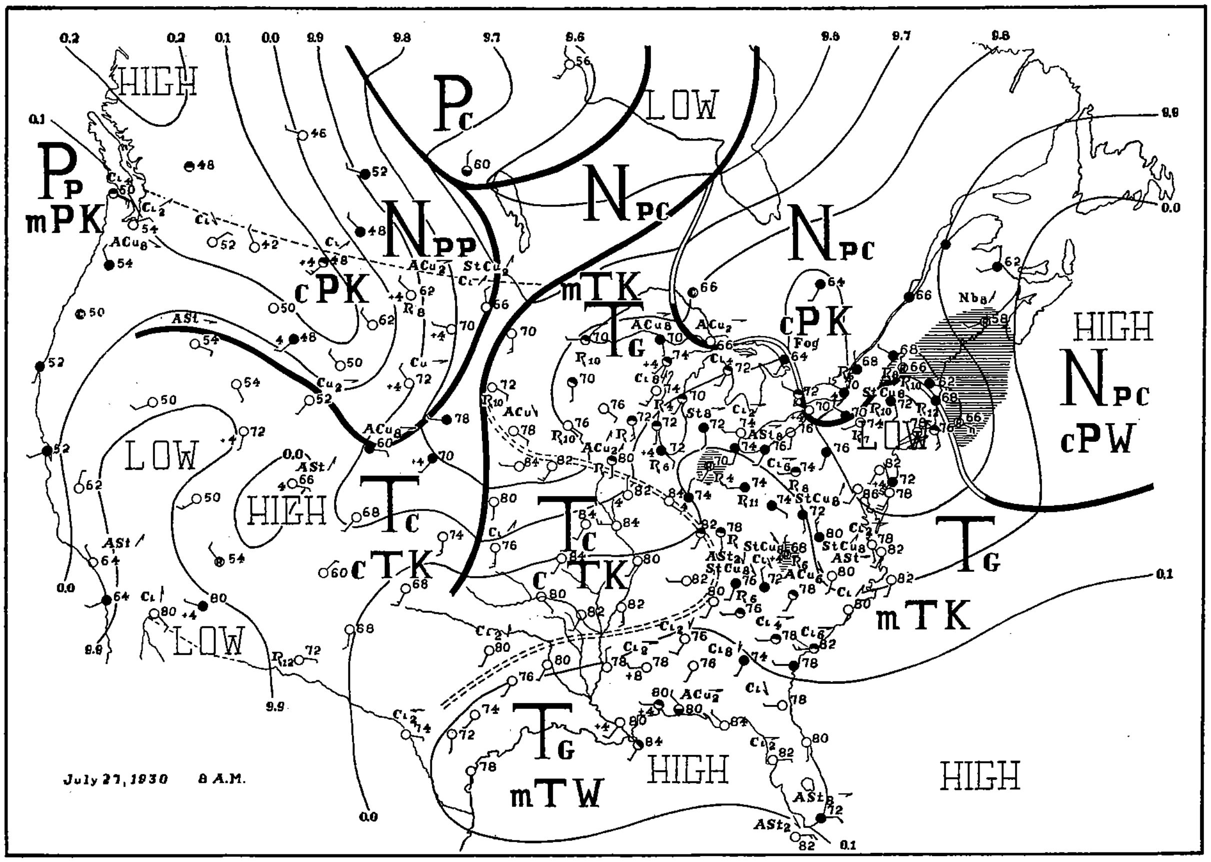
A


JULY 26, 1930, 8:00 A.M.
500 METERS

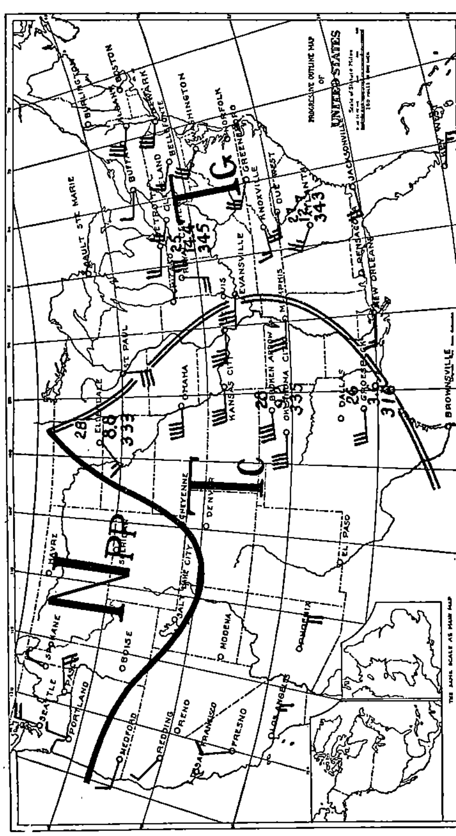

JULY 26, 1930, 8:00 A.M.
1500 METERS

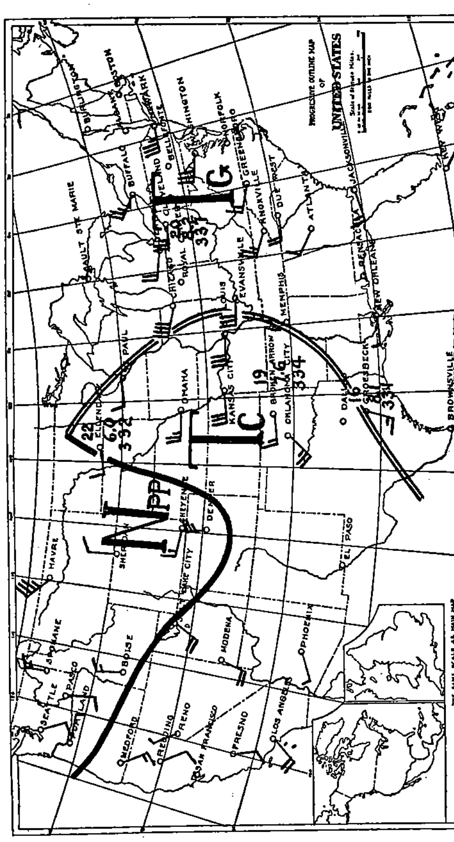
B

XXIII



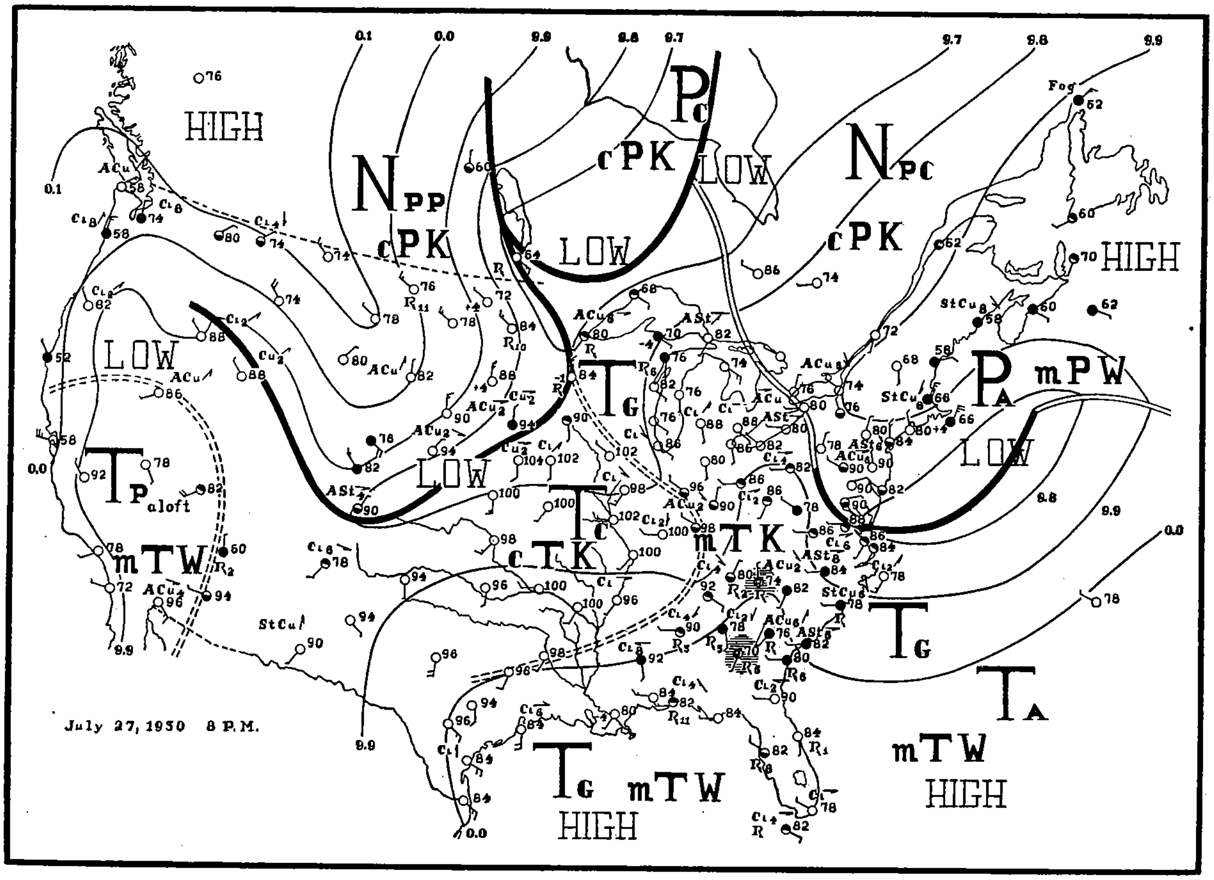
A


JULY 27, 1930, 8:00 A.M.
750 METERS

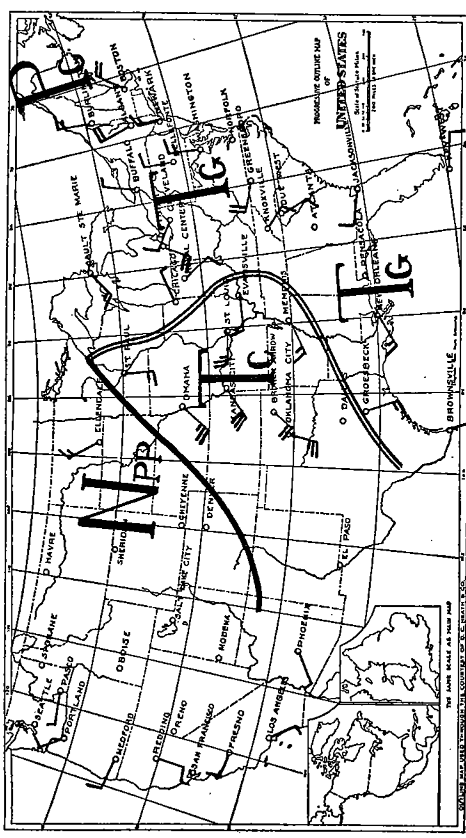

JULY 27, 1930, 8:00 A.M.
2000 METERS

B

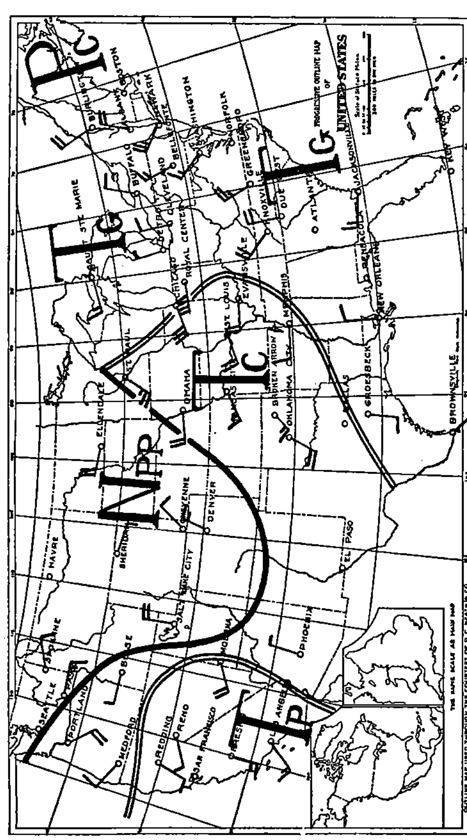
XXIV



A

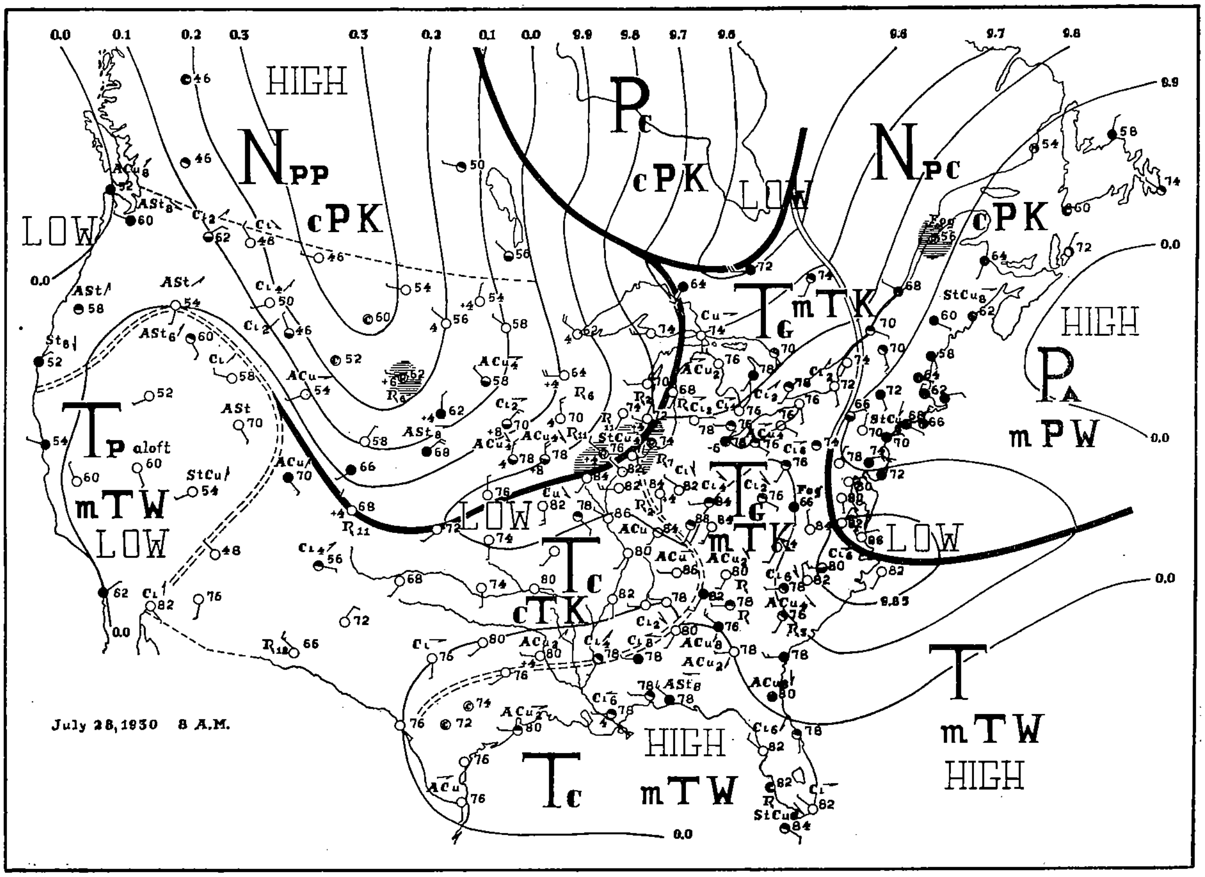


JULY 27, 1930, 8:00 P.M.
500 METERS

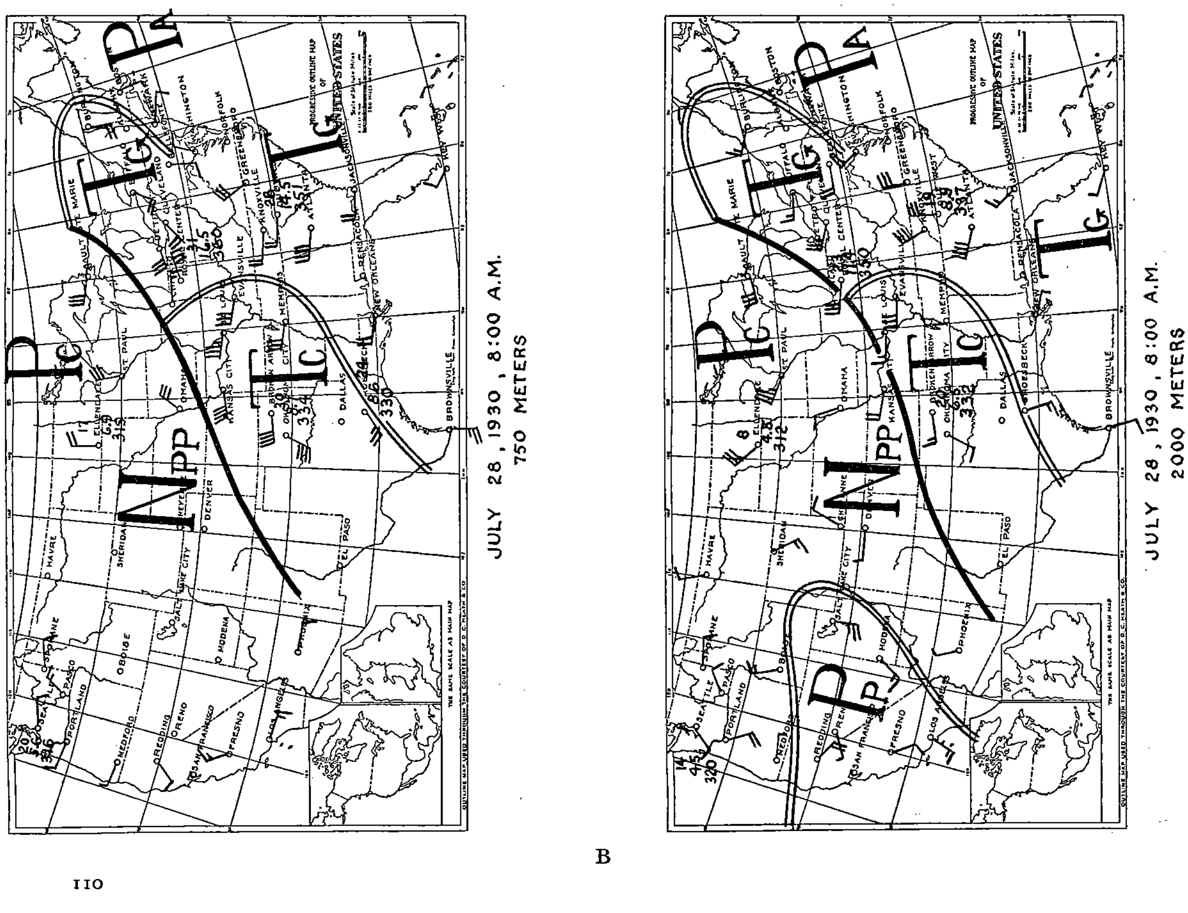


JULY 27, 1930, 8:00 P.M.
2000 METERS

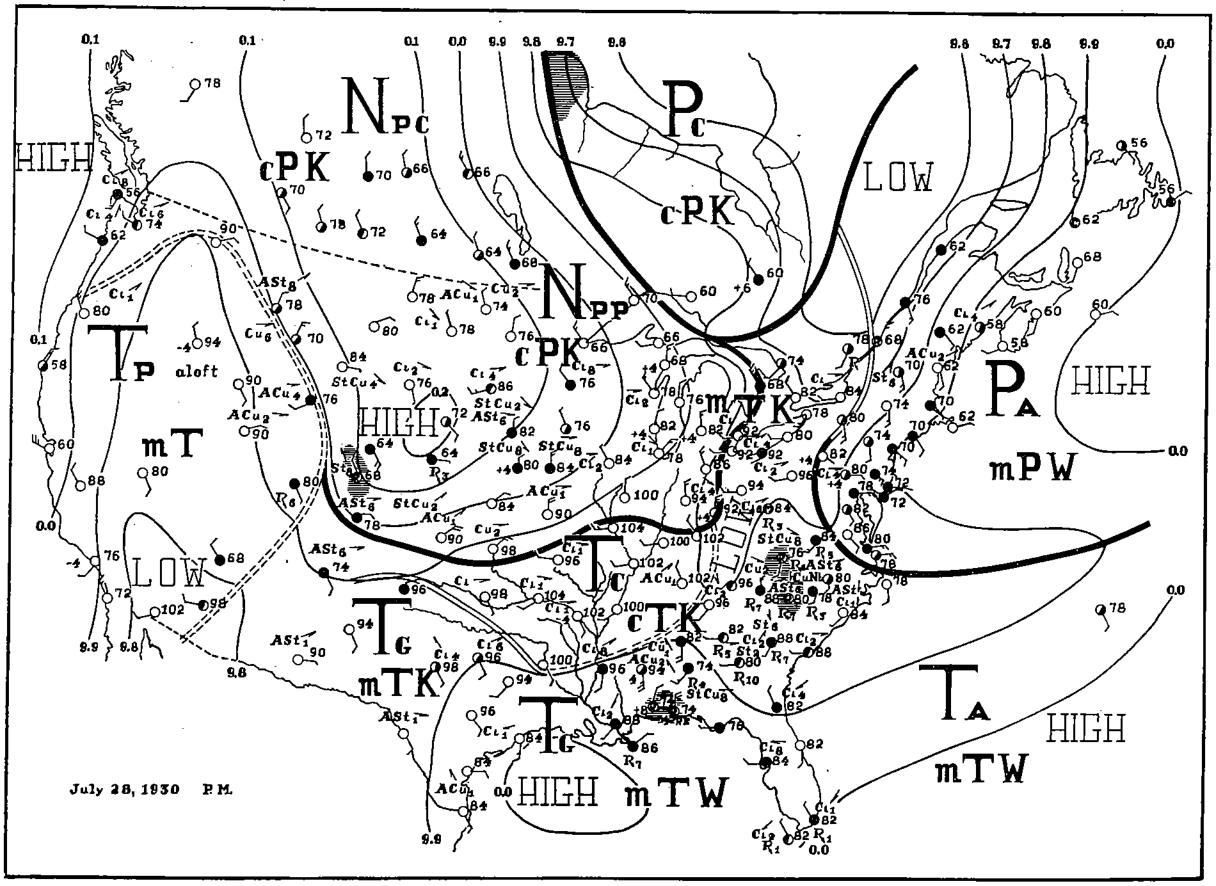
B


HIGH
Npp
cPK
Pc
cPK
LOW
Npc
cPK
LOW
HIGH
Tp aloft
mTW
LOW
TG
mTK
PA
mPW
LOW
TG
mTK
LOW
Tc
cTK
T
mTW
HIGH
HIGH
Tc
mTW
July 28, 1930 8 A.M.

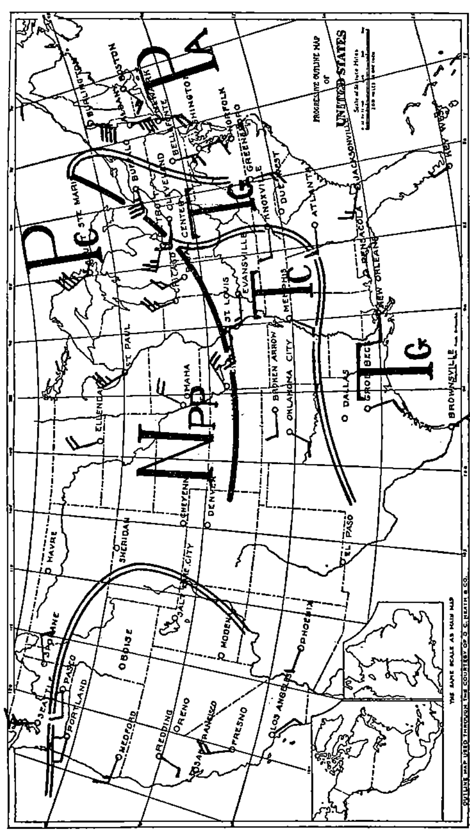
A


JULY 28, 1930, 8:00 A.M.
750 METERS
JULY 28, 1930, 8:00 A.M.
2000 METERS

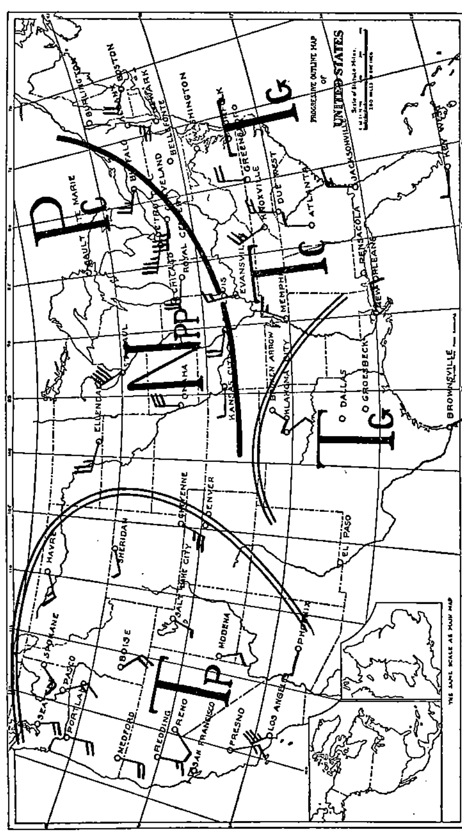
B



A



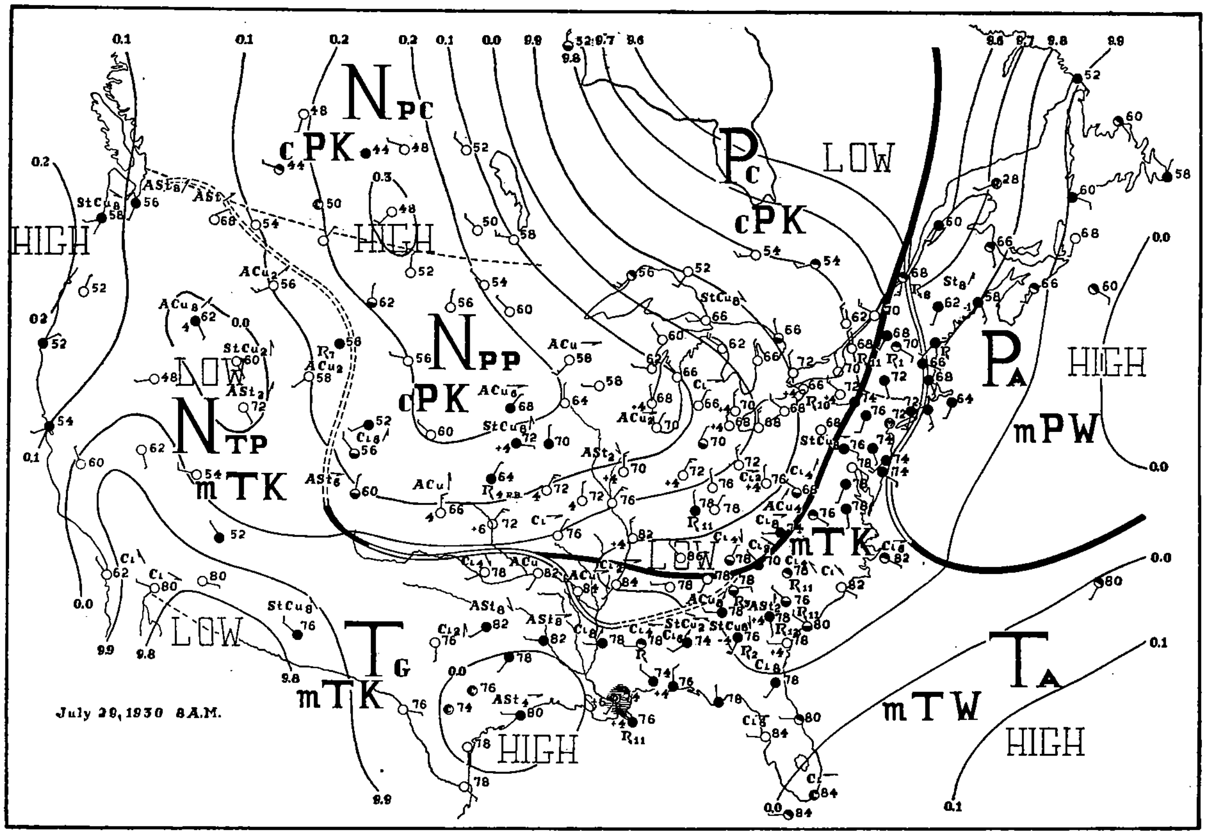
JULY 28, 1930, 8:00 P.M.
750 METERS



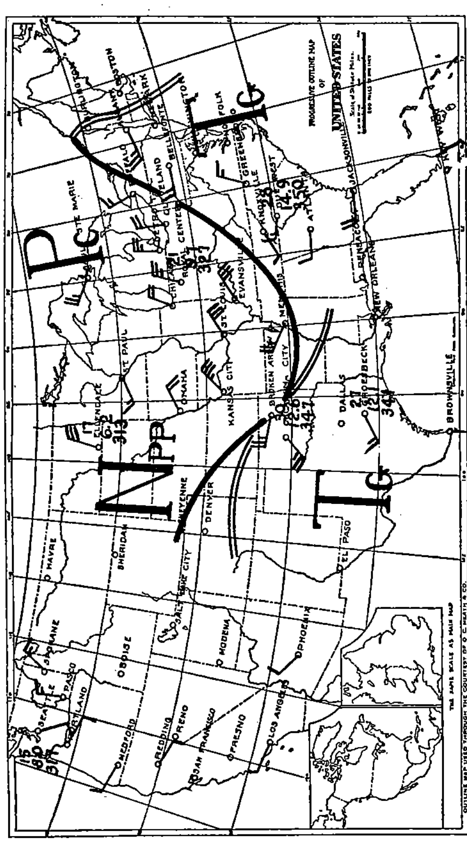
JULY 28, 1930, 8:00 P.M.
3000 METERS

B

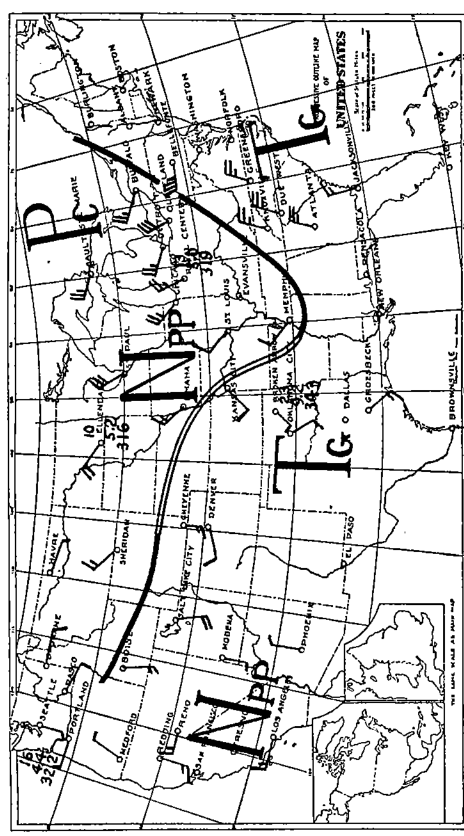
XXVII



A

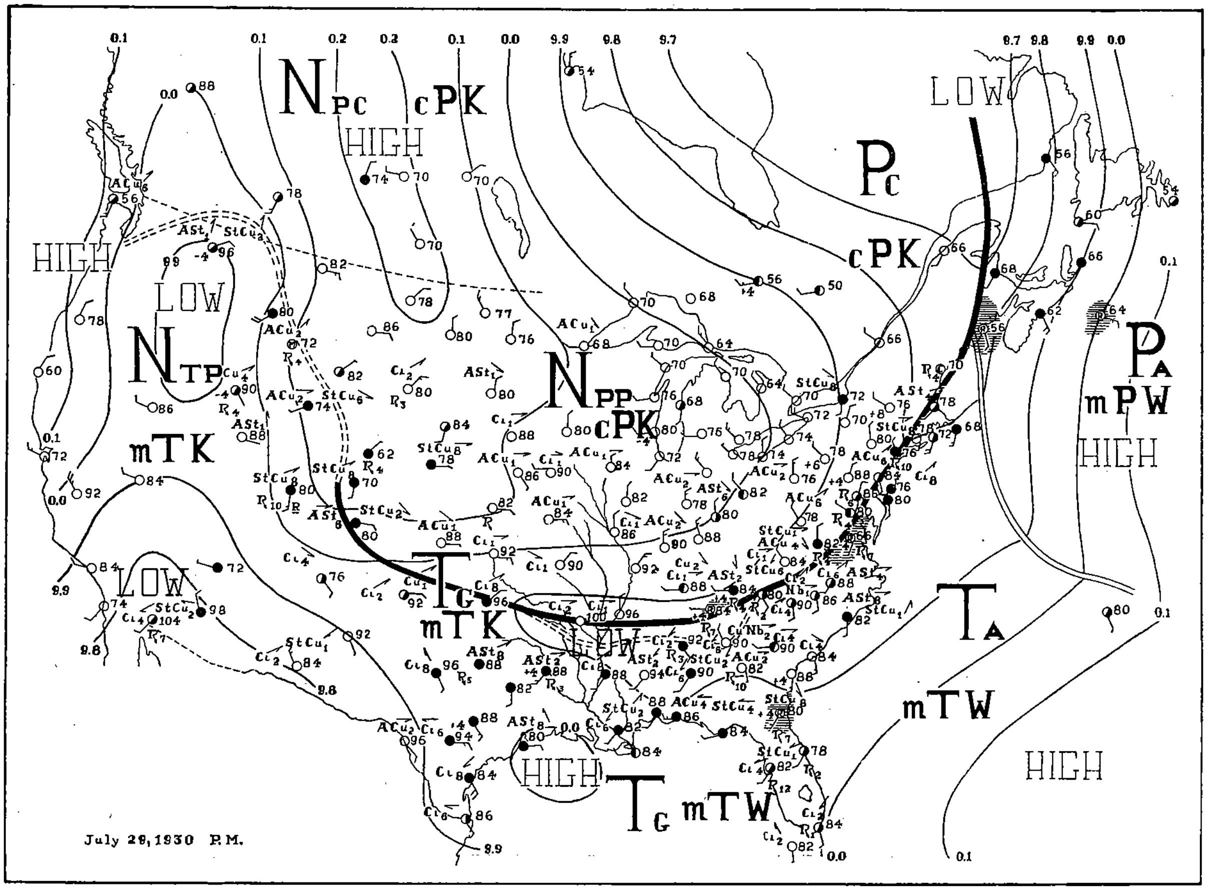


JULY 29, 1930 8:00 A.M.
750 METERS

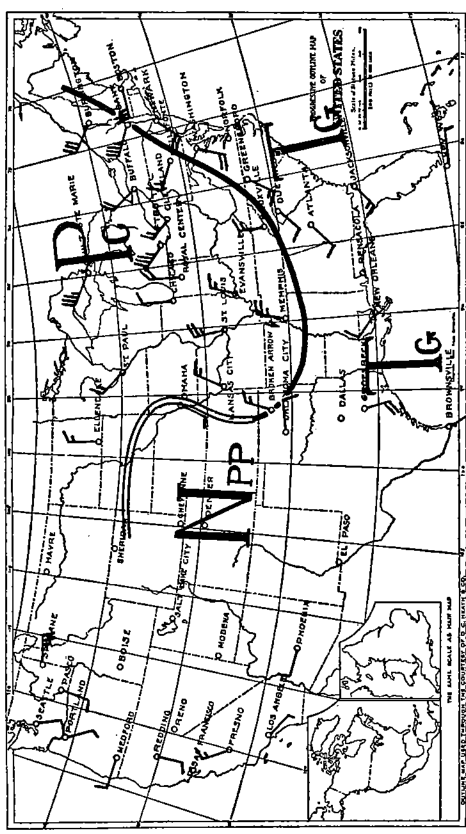


JULY 29, 1930, 8:00 A.M.
2000 METERS

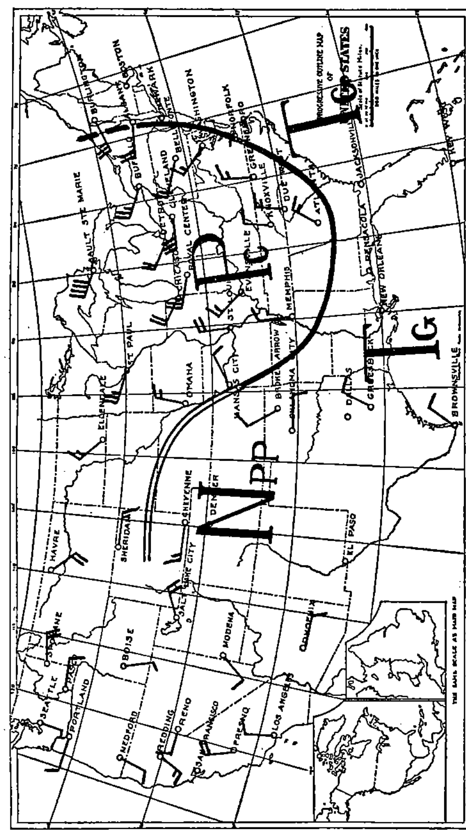
B



A

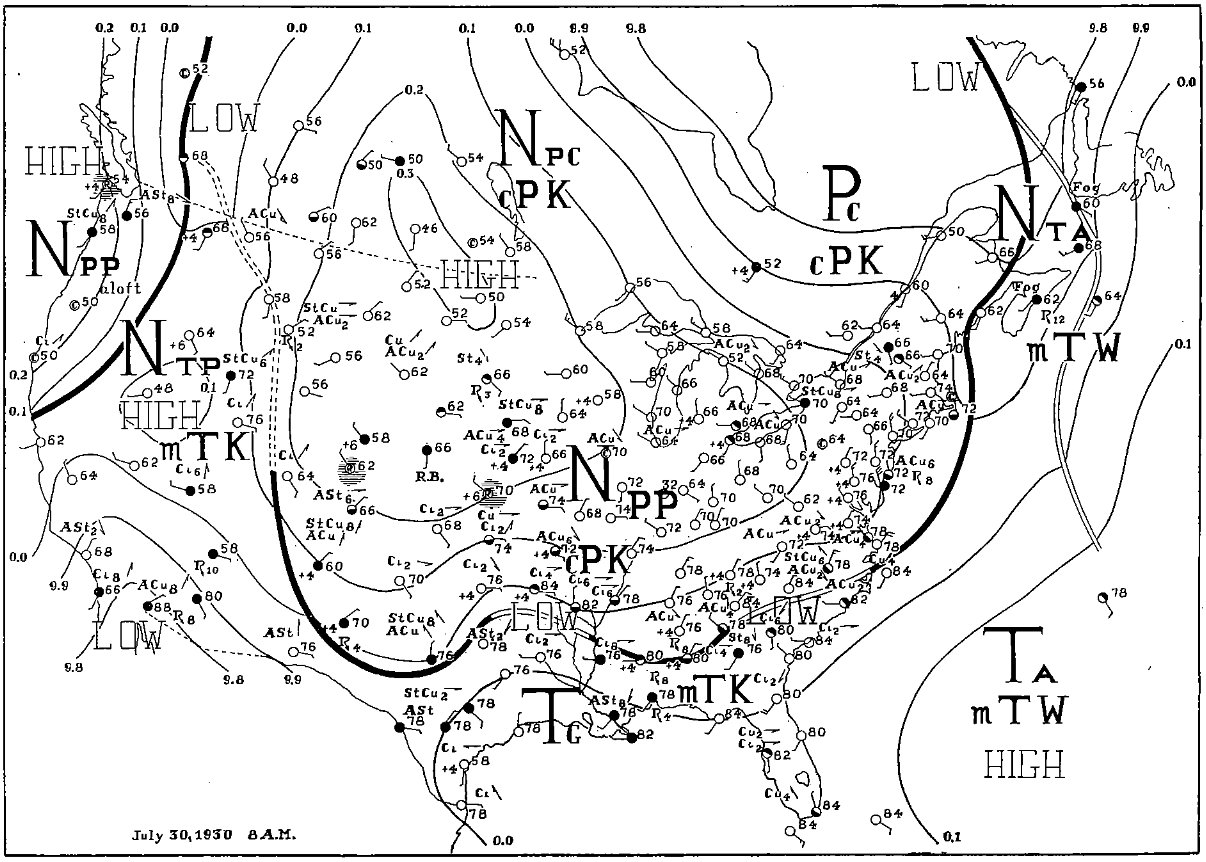


JULY 29, 1930, 8:00 P.M.
750 METERS

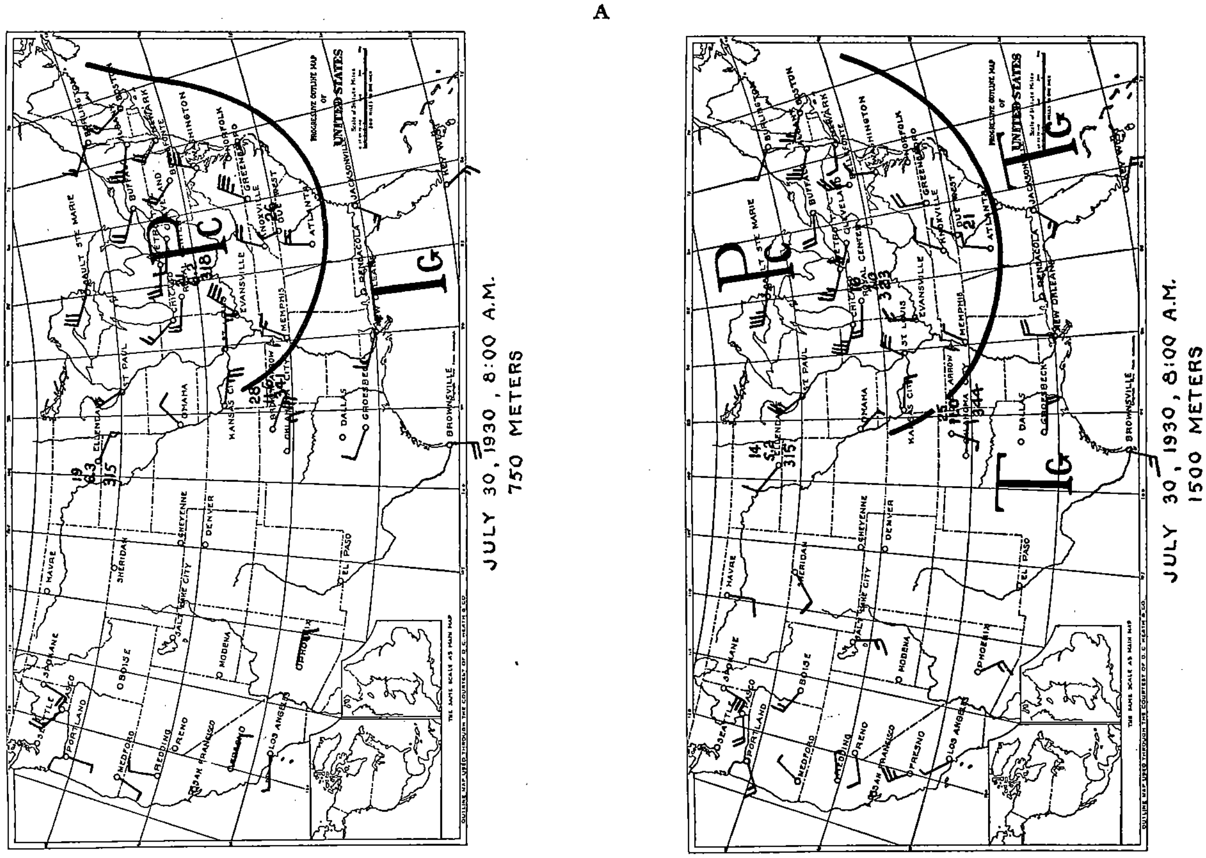


JULY 29, 1930, 8:00 P.M.
2000 METERS

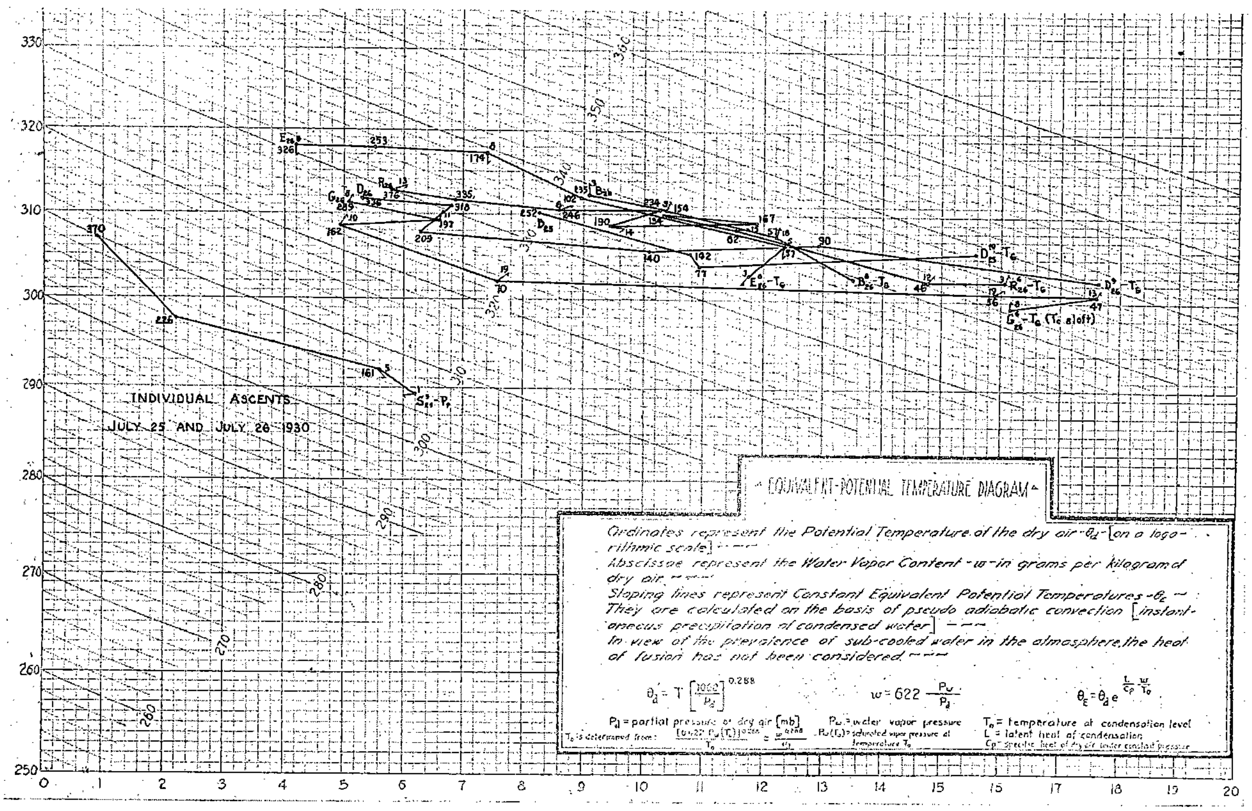
B


LOW
HIGH
NPP
NTP
mTK
NPC
cPK
PC
NTA
mTW
TA
TG
aloft
Fog
July 30, 1930 8 A.M.

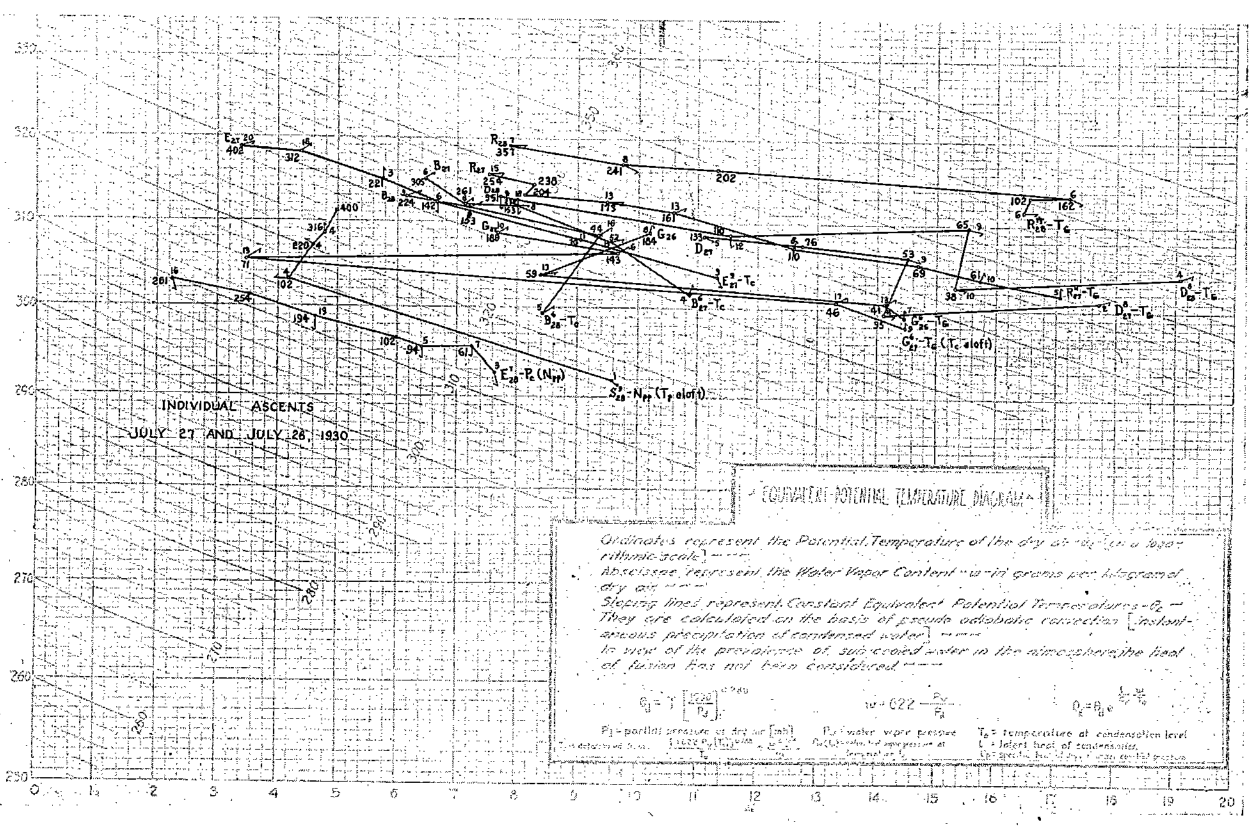
A


JULY 30, 1930, 8:00 A.M.
750 METERS
JULY 30, 1930, 8:00 A.M.
1500 METERS
PC
TG

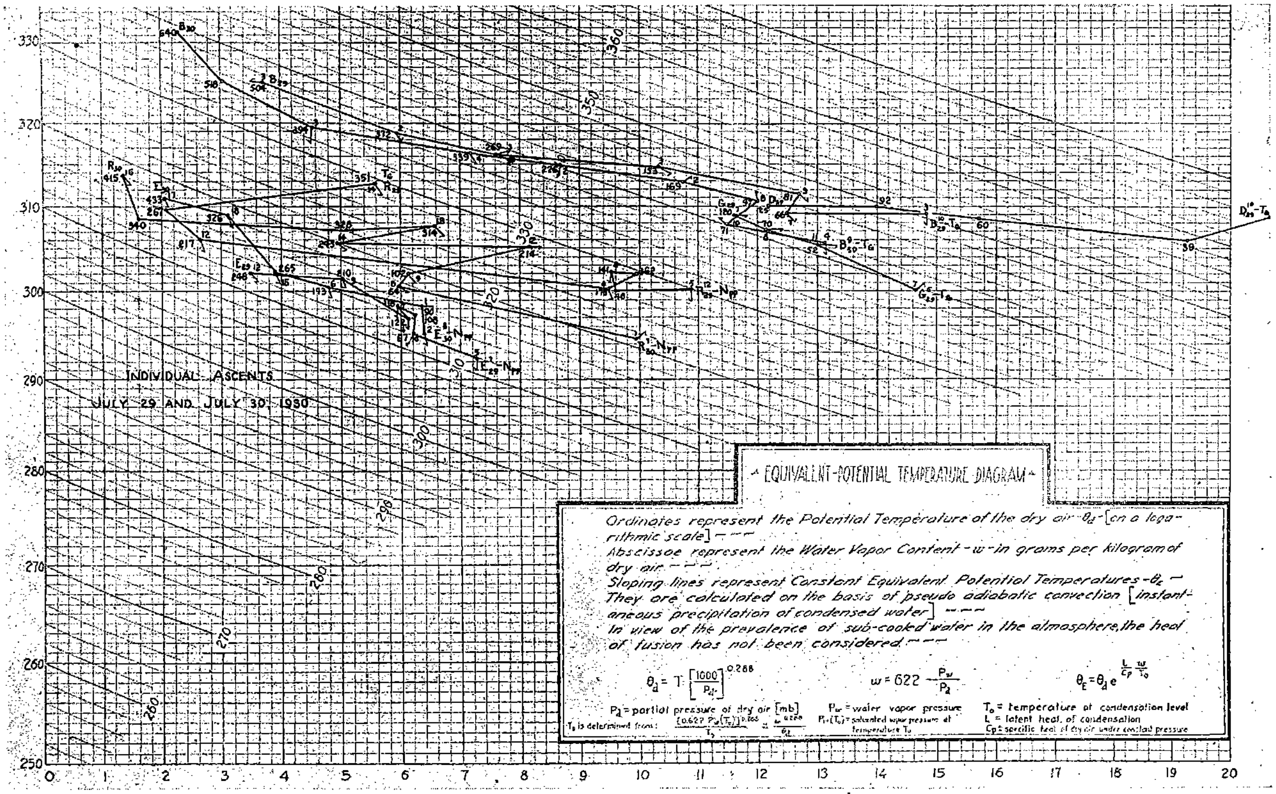
B


INDIVIDUAL ASCENTS
JULY 25 AND JULY 26, 1930
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air $-\theta_d-$ [on a logarithmic scale]
Abscissae represent the Water Vapor Content $-w-$ in grams per kilogram of dry air.
Sloping lines represent Constant Equivalent Potential Temperatures $-\theta_E-$
They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered.
P_d = partial pressure of dry air [mb]
P_v = water vapor pressure
T_c = temperature at condensation level
L = latent heat of condensation

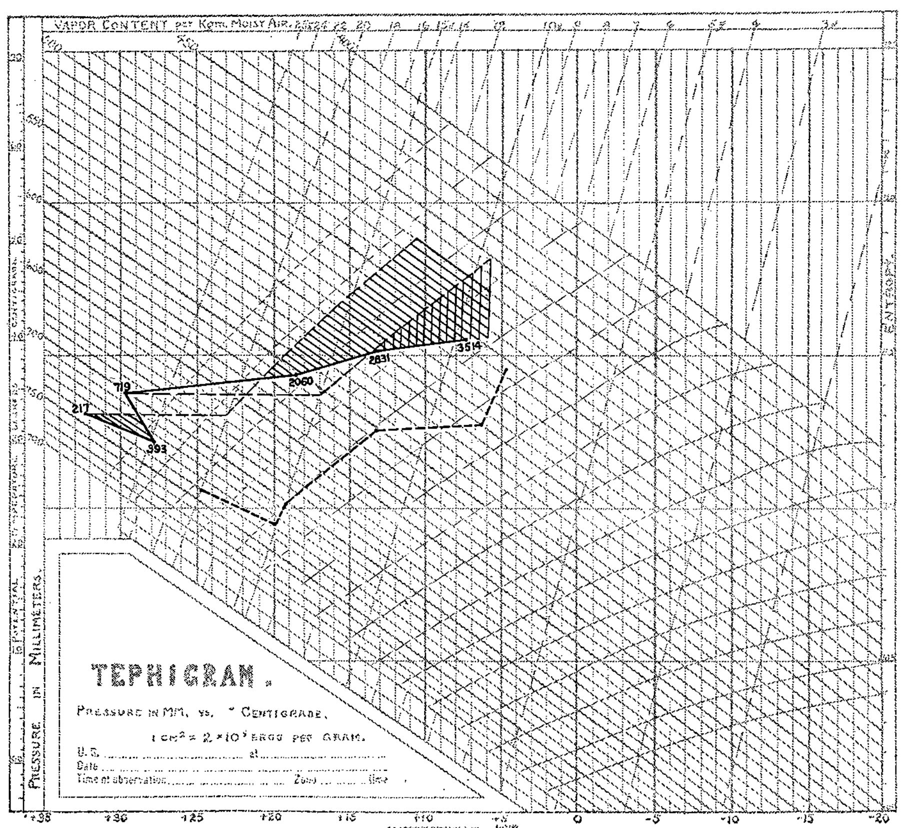
A


INDIVIDUAL ASCENTS
JULY 27 AND JULY 28, 1930
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM

B


INDIVIDUAL ASCENTS
JULY 29 AND JULY 30, 1930
EQUIVALENT-POTENTIAL TEMPERATURE DIAGRAM
Ordinates represent the Potential Temperature of the dry air - θ_d - [on a logarithmic scale]
Abscissae represent the Water Vapor Content - w - in grams per kilogram of dry air
Sloping lines represent Constant Equivalent Potential Temperatures - θ_E - They are calculated on the basis of pseudo adiabatic convection [instantaneous precipitation of condensed water]
In view of the prevalence of sub-cooled water in the atmosphere, the heat of fusion has not been considered
$\theta_d = T\left[\frac{1000}{P_d}\right]^{0.288}$
$w = 622\frac{P_w}{P_d}$
$\theta_E = \theta_d e^{\frac{L}{c_p}\frac{w}{T_0}}$
P_d = partial pressure of dry air [mb]
P_w = water vapor pressure
T_0 = temperature at condensation level
L = latent heat of condensation
Cp = specific heat of dry air under constant pressure

A


VAPOR CONTENT per Kgm. MOIST AIR
TEPHIGRAM.
PRESSURE IN MM. vs. ° CENTIGRADE.
1 cm² = 2 × 10⁵ ergs per gram.
PRESSURE IN MILLIMETERS.
ENTROPY
217
719
393
2060
2831
3514

B