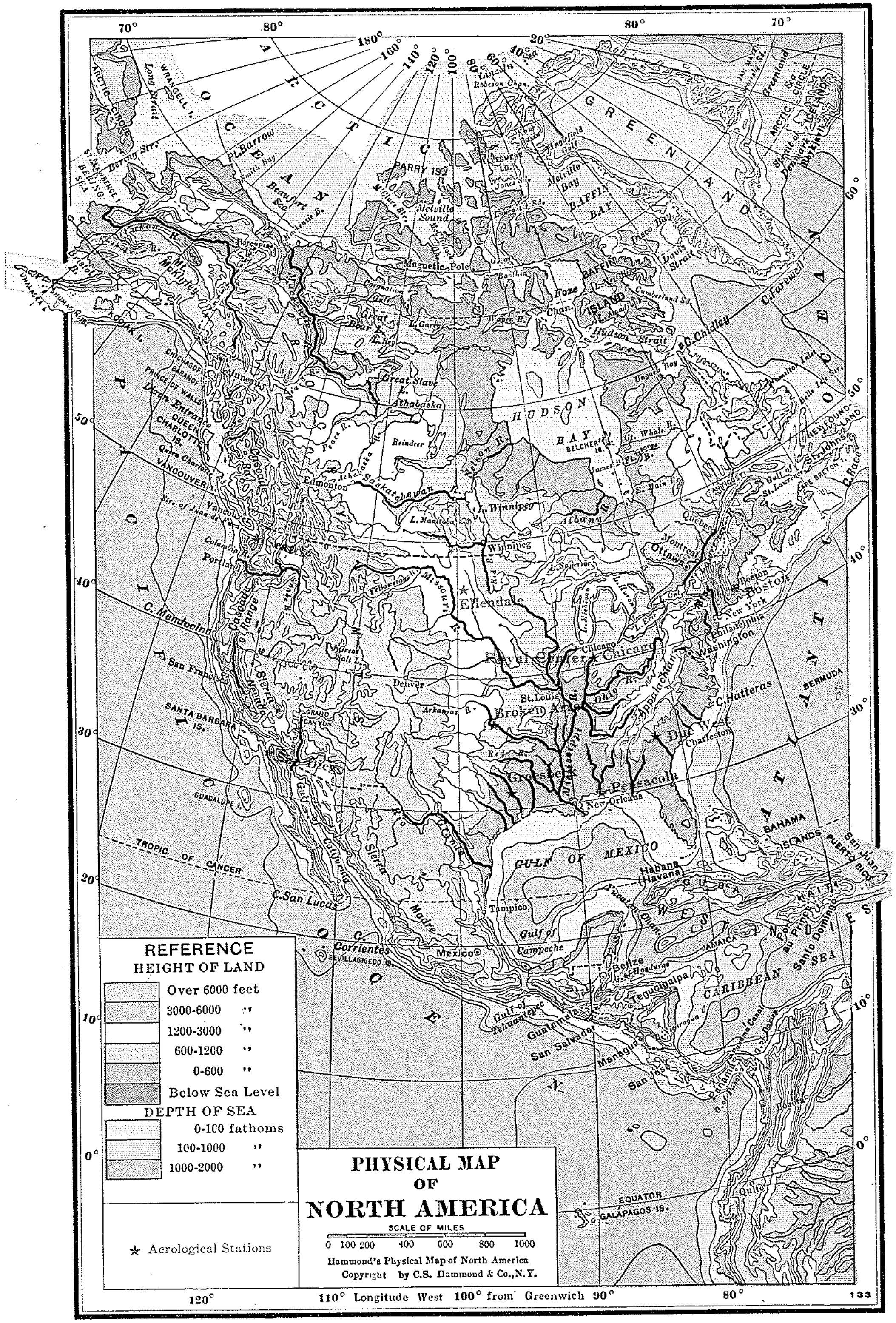
PHYSICAL MAP
OF
NORTH AMERICA
SCALE OF MILES
0 100 200 400 600 800 1000
Hammond's Physical Map of North America
Copyright by C.S. Hammond & Co., N.Y.
REFERENCE
HEIGHT OF LAND
Over 6000 feet
3000-6000 "
1200-3000 "
600-1200 "
0-600 "
Below Sea Level
DEPTH OF SEA
0-100 fathoms
100-1000 "
1000-2000 "
★ Aerological Stations
120° 110° Longitude West 100° from Greenwich 90° 80°
133
ARCTIC OCEAN
GREENLAND
BAFFIN BAY
BAFFIN ISLAND
HUDSON BAY
Hudson Strait
Davis Strait
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
CARIBBEAN SEA
WEST INDIES
BAHAMA ISLANDS
BERMUDA
CUBA
HAITI
JAMAICA
PUERTO RICO
TROPIC OF CANCER
EQUATOR
GALAPAGOS IS.
ARCTIC CIRCLE
Bering Str.
BERING SEA
Pt. Barrow
Beaufort Sea
PARRY IS.
Melville Sound
Magnetic Pole
Great Bear L.
Great Slave L.
L. Athabaska
Reindeer L.
Saskatchewan R.
Nelson R.
L. Winnipeg
L. Manitoba
Winnipeg
Edmonton
Vancouver
VANCOUVER I.
QUEEN CHARLOTTE IS.
Juneau
Mt. McKinley
KODIAK I.
Yukon R.
Columbia R.
Portland
Cascade Range
C. Mendocino
San Francisco
Sierra Nevada
SANTA BARBARA IS.
GUADALUPE I.
Great Salt L.
Denver
Missouri R.
Ellendale
Royal Center
Chicago
St. Louis
Broken Arrow
Arkansas R.
Red R.
Groesbeck
Mississippi R.
Ohio R.
New Orleans
Pensacola
Charleston
Due West
C. Hatteras
Appalachian Mts.
Washington
Philadelphia
New York
Boston
Montreal
Ottawa
Quebec
St. Lawrence R.
NEWFOUNDLAND
St. Johns
C. Race
C. Chidley
C. Farewell
Albany R.
James B.
Rio Grande
Sierra Madre
Gulf of California
C. San Lucas
C. Corrientes
REVILLAGIGEDO IS.
Mexico
Tampico
Gulf of Campeche
Gulf of Tehuantepec
Guatemala
San Salvador
Tegucigalpa
Managua
San José
Belize
Habana (Havana)
Yucatan Chan.
Santo Domingo
Port au Prince
San Juan
Panama
Bogota
Quito

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AMERICAN AIR MASS PROPERTIES

BY
H. C. WILLETT

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