The Geographic Distribution of Air Masses in North America

By

DIETER H. BRUNNSCHWEILER (Madison, Wis./Zürich)

(with 3 figures)

Introduction

The well-known "climatic systems" have, as a rule, in common that they are based upon mean values of main climatic elements such as temperature and precipitation. In spite of the fact that our knowledge of atmospheric conditions has been considerably enlarged since the period of "classical climatology" there was made no attempt to incorporate the results of recent meteorological investigations into climatological research.

The concept of the air mass, for instance, has not yet found its appropriate place in climatology. It is true that the analysis of air masses is entirely involved in the studies of the meteorologists. Nevertheless, since the surface of the earth—the geographer's laboratory—plays a decisive rôle in the formation of air masses it is a matter of first importance to Geography to concern itself with the object.

Recently climate has been defined as the normal succession of weather situations. Weather, however, is a natural sequence of the air mass regime; consequently we may specify the above definition as follows: "Climate is the result of the frequency and the efficiency of individual air masses over a particular region."

With such a definition in mind it should be a worth-while undertaking to set about a task for a new solution of the problem of climatic classification. Therefore, in this study which focuses North America only, regions have been established whose limits represent summations of air mass boundaries and whose core areas have a climate dominated by a specific type of air mass regime. The question is raised whether or not the following investigation might suggest another approach toward a more dynamic climatology.

Method of Investigation

In the preparation of the maps in this paper the following procedure was adopted. The actual daily position of each air mass boundary derived from daily weather maps[1]) was plotted on an outline map of North America. There were considered the three winter months (December, January, February) and the three summer months (June, July, August) over the period 1945—1949. Thus a total of fifteen maps for each season was compiled. From these thirty maps two maps were drawn up (one for each season) indicating the distribution and tendencies of expansion of the various air masses.

It has proved inappropriate to determine one "average" position of the different air mass boundaries, the minimum and maximum expansion lines being 1000 miles apart in places. Therefore, I prefered to set up zones of varying prevalence. The narrower the zones, the more truly they represent, however, normal frontal positions.

The following three zones have been established.

1. Regions dominated by an air mass at least 80 % of the days during the season concerned. (Source Regions in Fig. 1 and 3, encircled by the 80 % isarithm).
2. Regions in which the particular air mass prevails 20—80 % of the period (Conflict Regions, if two or more air masses occur; circumscribed by the 80 % and 20 % isarithms respectively).
3. Regions invaded by the particular air mass only occasionally, i. e. less than 20 % frequency. (The 1 % isarithm has been omitted to avoid confusion.)

So far as the distinction of the air masses is concerned some generalizations were necessary. Thus, designations as N, k and w have been omitted. Moreover, the air masses were considered as having horizontal uniformitiy only, i. e. the upper levels have not been included in plotting the discontinu-

[1]) Sources of data for this study were: The Daily Weather Map of the USWB, The Daily Weather Map of the Weather Bureau in Madison, Wis. and a set of Historical Weather Maps published by the USWB, Washington.

Air Mass Distribution in Winter (Dec., Jan., Feb. 1945–1949)

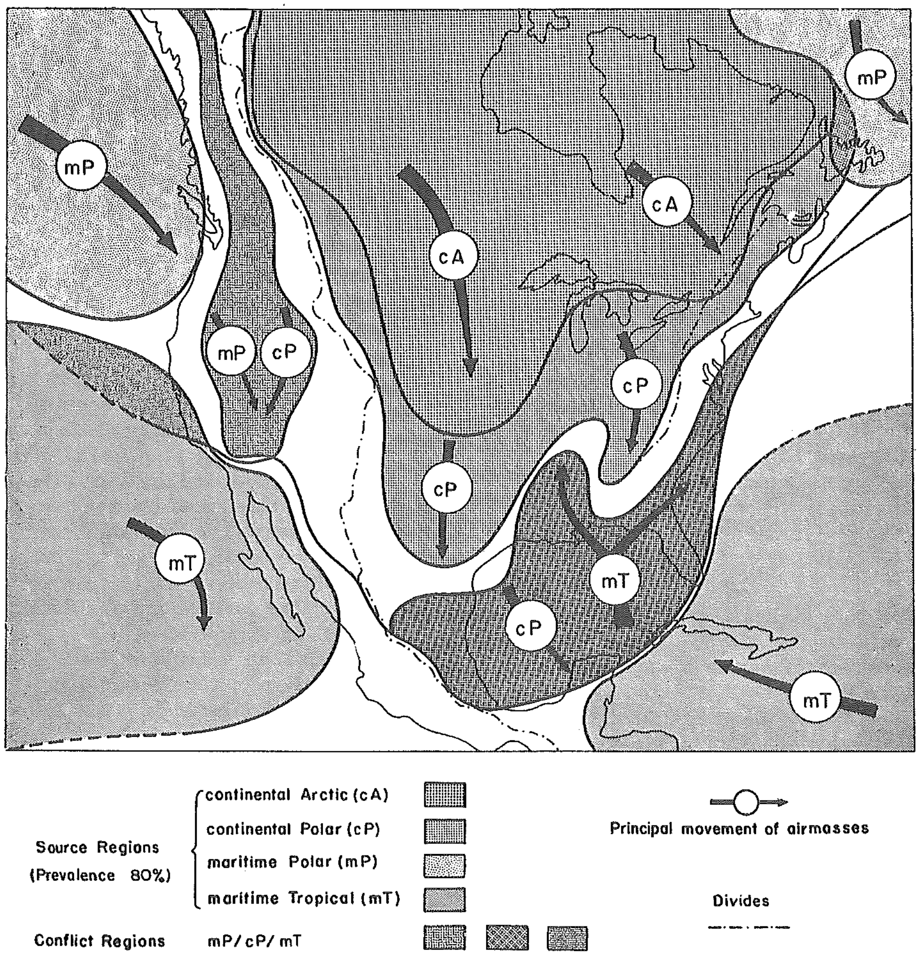

Fig. 1

ity. In Fig. 3, 13 representative stations have been selected which show different air mass regimes in the United States. The percentage of each air mass at these stations is shown for summer and winter.

Air Mass Distribution in Winter (Fig. 1)

The fact that the North American continent lacks a latitudinal mountain barrier seems to induce an unrestrained air mass interchange along a longitudinal axis. Consequently it is to be expected that outbreaks of arctic and polar air will move across the Canadian plains, into the Middle West, and uniformly southward to the Gulf of Mexico. Moreover, the mountain systems in the west and the east may have a funneling effect upon the advance of northern air masses.

The map of winter air mass distribution, however, shows very strikingly that this southward expansion does not take place uniformly.

Instead of paralleling lines of latitude, the 80 % isarithms of both cP and cA air masses extend southward in two large tongues.

These lie very distinctly over the western half of the Mississippi valley as if they represented a cold wave in two phases of its development. A minor southward extension is visible over the southern Appalachians. Thus, a marked indentation is formed over the lower Mississippi valley with northerly flow of mT air masses. This causes the extension of the 20 % isarithm of mT air masses as far north as Memphis (Tennessee) and, east of the Appalachians, approximately to Cape Hatteras.

The "station-models" of Jacksonville and San Antonio indicate the different influence of the two main counteracting air masses in winter (see Fig. 2).

	San Antonio (Texas) (29° 30′ NL)	Jacksonville (Fla.) (30° 30′ NL)
cP	78 % (!)	62 %
mT	12 %	29 %
N	10 %	9 %

For New Orleans, lying at the base of the mT tongue and in the same latitude, the respective numbers are 55 % cP and 36 % mT.

Undoubtedly the most stationary air mass boundary which is not affected by the configuration of the earth's surface lies across the Florida peninsula. Here, the polar front can truly be spoken of as having a position between 25° and 30° NL, stretching from south-west to north-east. In many cases the polar front is even more localized over the central part of the peninsula within a strip of about 100 miles (e. g. in December 1948 the polar front was quasistationary between Fort Meyers and Melbourne on 12 days of the month). Thus it is characteristic that even powerful outbreaks of cP air reach Central America before coming to the Straits of Florida, if indeed they penetrate that far.

As a consequence of the dominance of cP and cA air masses over the land mass of North America in winter, air mass conflict regions (see definition pag. 2) are restricted to two large zones: the "Gulf conflict zone" and the "Great Basin conflict zone". The former is limited on the north side by the previously described 20 % isarithm of mT air, and on the tropical side by the 20 % isarithm of cP air which encircles the Gulf of Mexico. The boundary line of the Great Basin conflict region is formed by the 20 % isarithms of both cP air masses and mP air masses of the Pacific. This latter is a typical orographically influenced air mass boundary representing a marked gradient in air mass frequency. (In several months the mP front lay along the Pacific coast north of 40° NL on 90—95 % of the days.) A sharp decrease in the prevalence of mP air masses can be observed as soon as we reach the continent leeward of the coastal islands. Thus, Seattle lies outside of the source region, having 71 % mP-days, whereas the west side of Vancouver Island is clearly included by the 80 %-mP isarithm. On the other hand, the 20 %-mP isarithm is representative of the steep gradient of invading mP air masses which occurs along the Continental divide. In turn, the Cascades and the Sierra Nevada restrain the cP air masses from penetrating to the Pacific coast. The Wasatch Mountains act in the same sense upon mP air masses. Consequently, the areas shown in white on Fig. 1, coinciding with the mountain ranges, are distinct air mass divides.

With regard to maritime tropical air masses of the Pacific it was found impossible to trace exact expansion lines. It is extremely difficult to identify this air mass on the ground. The 80 % isarithm is drawn arbitrarily coinciding with the average position of the subtropical cell. In a more detailed study keen consideration should be given to upper air mass analysis in this area.

Air Mass Distribution in Summer (Fig. 3)

The interaction of cP and mT air masses is still the dominant factor in air mass distribution in summer. However, the mT air masses of the Pacific and the cT air masses of the south-western part of the continent control large regions of the land mass in summer. The mP air masses of the Atlantic play an important rôle in the summer climate of the north-eastern United States.

Due to an approaching of the source regions—defined as having a frequency of 80 % + domination by a given air mass—and the addition of a new, continental air mass (cT) the picture of the air mass distribution in summer is somewhat more intricate than that on the winter map.

Percentage of Air Mass Types at Selected Stations (Summer and Winter 1945–1949)

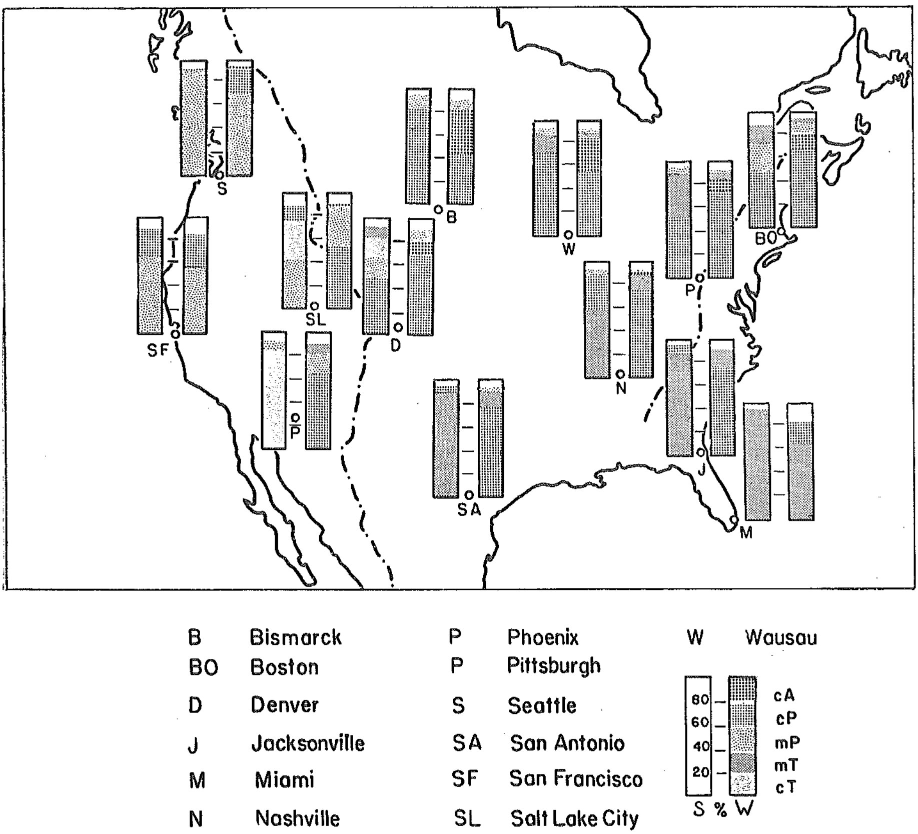

Fig. 2

The recession of cP air masses is accompanied by an expansion of all other air masses toward the interior of the continent: the southern and south-eastern part of North America is dominated by mT air masses, the coastal areas of the Pacific lie within the source region of mP and mT air masses, and extreme north-eastern Canada—is included by the 80 % isarithm of Atlantic mP air masses.

Three main conflict regions appear on the summer map:

1. The cP/mT conflict region forming a belt of varying width and stretching in a south-west/north-east direction from the Texas panhandle through the central states to New England. The southern limit of this conflict region, formed by the 20 %-cP isarithm, shows a marked correlation with the 80 % winter isarithm of the same air mass. This illustrates, again, the characteristic southward protrusion of cP air over the west flank of the Mississippi valley with a minor lobe over the southern Appalachians. The northward flow of mT air masses appears to be slightly displaced toward the west as compared with its winter position. The 20 % isarithm of mT air stretches in a marked diagonal direction through the continent, approximating a line from El Paso–Amarillo–Kansas City–Iowa City-Madison-Muskegon to Toronto, thence

paralleling 44° NL to Fundy Bay. The striking fact revealed by this isarithm is that northern Maine has the same number of mT-days as northern Texas.

2. At either end of this southern conflict region the area is contested by two other air masses: cT in the south-west and mP (Atlantic) in the north-east. Thus, two relatively small regions appear in which three air masses prevail in a frequency exceeding 20 %. Whereas the "Texas triple-conflict" region is somewhat arbitrary due to frequently indistinct air mass boundaries, the New England triple-conflict region is clearly definable. The expansion of Atlantic mP air masses has its 20 % isarithm roughly along the St. Lawrence-Hudson Valley depression, thence along the Appalachian piedmont, turning seaward approximately along the Potomac River. Transgression of mP air over the Appalachians is rare. cP air masses, in turn, are only exceptionally able to reach the Atlantic seaboard. With the mT-20 % isarithm forming the northern limit (in northern Maine), and the 20 % isarithms of cP and mP forming the eastern and southern limits respectively, a region is delineated which has an air mass regime composite of all North American summer air mass types except cT. Since the same combination of air masses prevails in different places on the earth it might be better to label this air mass regime "cP—mP—mT Type" instead of using the term "New England Type".

3. Due to the proximity and extent of the mP Pacific source region in conjunction with the main westerly drift, these mP air masses are able to cross the Rockies and establish a vast conflict area east of the Divide—the usual realm of cP air masses. The summer track of the mP stream is quite comparable to the winter southward swell of a cold wave along the eastern piedmont of the Rockies, but it reaches only as far south as approximately 50° NL, where a sharp gradient occurs in the frequency of mP-days. The peculiar course of the 20 %-mP isarithm, paralleling either side of the Rockies from 50° NL to about 60° NL, is indicating that the transgression occurs north of the international boundary and not in a broad overflow over the entire northern Rocky Mountain system. In other words, a major portion of the invading mP air masses accumulates on the western side of the Rockies and the Wasatch Mountains and is not able to penetrate into the Great Plains. The northern-most parts however, find their way to the interior on a northerly detour.

In comparison with the other air masses cT air masses are rather stationary. However, their influence reaches as far north as southern Idaho. On all sides cT air masses are clearly confined by orographic barriers. Only in exceptional cases is cT discernible in the Great Plains. (Denver 16%, see Fig. 2) and on the Pacific coast.

The exact location of the 80 % and the 20 % isarithms respectively of Pacific mT air can only be determined with the aid of sufficient local and upper air data.

The Significance of Air Mass Distribution in Regional Climatology

If it can be proven that air masses and their boundaries are not fortuitously distributed over the earth, but prefer, by contrast, definite seasonal patterns, then local climates might well be represented in terms of various weather types associated with prevailing air masses. Air mass boundaries if grouped within a definite area—thus representing a sharp climatic gradient—attain the nature of climatic divides.

In the process of this investigation three types of air mass boundaries were distinguished:

1. Geographic boundaries, i. e. separations of air masses due to surface configuration, particularly mountain ranges.

Examples: Continental Divide, Cascades, Sierra Nevada, Wasatch Mountains, Appalachians (!).

2. Air mass boundaries in a proper sense, i. e. fronts, developed due to marked contrast in neighbouring air masses.

Examples: Arctic and polar front, squall lines.

3. Transitional zones, in which no marked change occurs on the surface within relatively short distances.

Examples: Transitions between two air masses due to mixing or modification (particularly between mP and cP).

Emphasis has to be laid on the fact that there exist no linear climatic boundaries at all. Fronts are but representative for relatively rapid transition between two air

Air Mass Distribution in Summer (June, July, August 1945–1949)

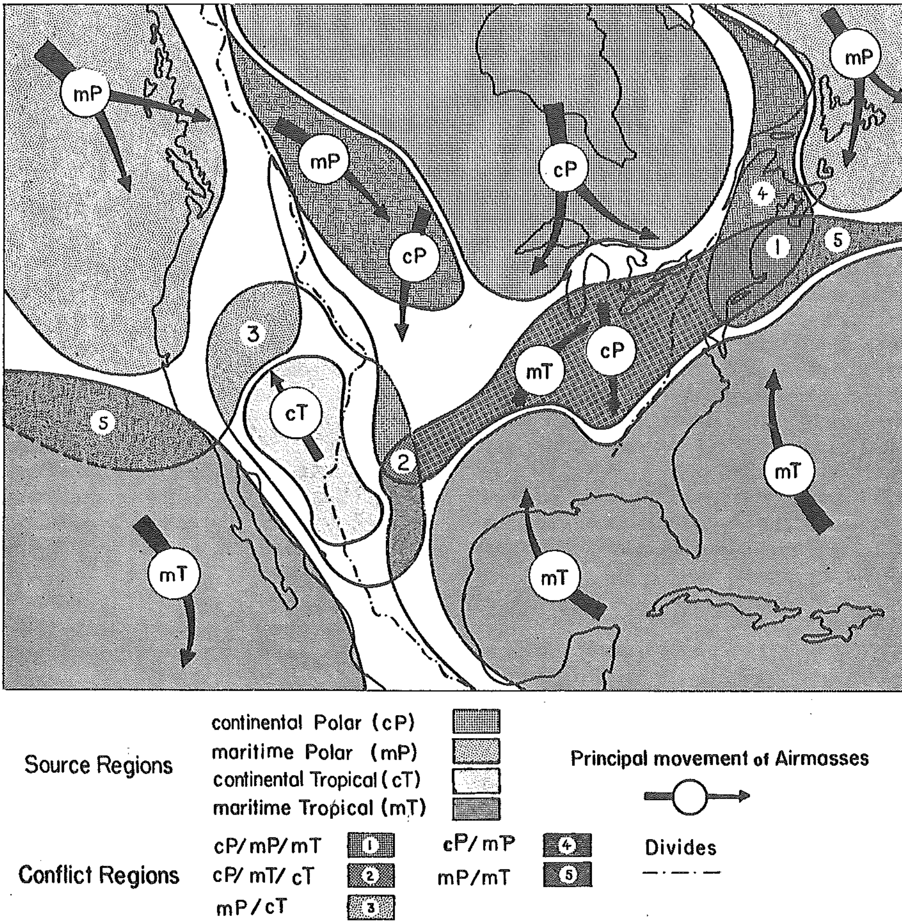

Fig. 3

masses of different character. On the other hand, it is even more unsatisfactory to use single climatic elements such as temperature or rainfall as criteria for the linear delimitation of climatic regions.

It seems, then, that a worth-while goal of a modern regional climatology would be to establish climatic provinces by means of average air mass cycles. Each air mass should be studied as to: season and duration, effect (climatic activity), appearance (association with weather types), relation to topography and other air masses. By superimposition of the separate cycles of all air masses prevailing at the respective stations, a more dynamic representation of the drama of weather could be attained and its complexity would not be distorted by the description of isolated elements.

Summary

By plotting air mass boundaries for both the winter and summer seasons, regions of different prevalence for each of the air masses affecting the North American continent have been delimited. The source regions are circumscribed by isarithms of 80 % prevalence. The 20 % isarithm has been

chosen to determine the limits of the "normal expansion" of the various air masses. If two or more air masses dominate a region in a frequency exceeding 20 %, this region was considered a conflict region.

A distinct dominance of arctic and polar air masses is observed in winter. The 20 %-cP isarithm includes the whole continent save southernmost Florida and a coastal margin along the Pacific. The marked preponderance of polar and arctic air outbreaks over the western Plains is clearly demonstrated by the southward extension of the isarithms in this region. A minor southward convexity lies over the southern Appalachians. The two main conflict regions in winter are to be found over the Gulf of Mexico and over the Great Basin. The former includes the lower Mississippi valley (coincident with the Tennessee-winter rain area?) and Florida.

The summer map exhibits a less uniform air mass regime than that of winter. New conflict regions appear in addition to those of the cold season:

1. A cT-mP conflict region south of the Great Basin conflict region,
2. At either end of the cP-mT conflict region, now occupying a broad belt crossing the United States from northern Texas to Maine, a triple conflict region composite in the northeast of cP, mT and mP air masses and in the southwest of cP, mT and cT air masses.

Acknowledgments

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«Die geographische Verbreitung der Luftmassen über Nordamerika»

Zusammenfassung:

Die statische Betrachtungsweise in der Klimatologie beginnt in den letzten Jahren einer neuartigen, dynamischen zu weichen, welche versucht, das Klima nicht durch Mittlung von Temperatur- und Niederschlagsdata, sondern als Folge charakteristischer Wetter- beziehungsweise Luftmassenlagen darzustellen.

Verstehen wir unter dem Klima das Resultat von Häufigkeit und Wirksamkeit einzelner Luftmassen und gelingt es, diese spezifisch und räumlich zu erfassen, dürfte ein wichtiger Schritt in Richtung einer die bedeutenden meteorologischen Erkenntnisse der letzten Dekade besser verwertenden Klimaklassifikation getan sein.

Diese Arbeit sollte als Versuch aufgefasst werden, auf Grund der Luftmassenverteilung über dem nordamerikanischen Kontinent Klimaprovinzen abzugrenzen, deren Kerngebiete ein von bestimmten Luftmassen beherrschtes Klima aufweisen und deren Grenzen Frontenscharungen darstellen.

Die Untersuchung der täglichen Wetterkarten der Sommer- und Wintermonate über den Zeitraum von 1945 bis 1949 hat in bezug auf die Luftmassenverbreitung folgende Resultate ergeben:
(cf. Karten)

Zu Fig. 1: In den Wintermonaten ist die Vorherrschaft von arktischen und polaren Kontinentalluftmassen über Nordamerika unbestritten. Maritim-polaren beziehungsweise maritim-tropischen Luftmassen gelingt es nur randlich, nämlich im Gebiete des Grossen Beckens und jenem des unteren Mississippitieflandes, die Herrschaft der kontinentalen Luftmassen in über 20 % der untersuchten Tage zu unterbrechen; diese Räume werden zu Kampfgebieten (conflict regions) zweier dominanter Luftmassen und zeichnen sich im Gegensatz zu den Ursprungsgebieten (source regions) durch sehr labilen Witterungscharakter aus. Sehr typisch ist das weite Vordringen der 20 %- sowie der 80 %-cP-Linie über der Westflanke des Mississippitales, die eigentliche Bahn der Kaltluftausbrüche darstellend.

Zu Fig. 2: Die Karte der Sommermonate

zeigt die Einengung der cP-Luftmassen durch solche maritimer Art aus Südosten und Nordwesten und das Hinzutreten einer den Südwesten dominierenden Luftmasse tropisch-kontinentalen Ursprungs. Die Kampfzone zwischen cP- und mT-Luft zieht sich in variierender Breite in SW—NE-Richtung über den Kontinent, wobei besonders das weite nördliche Vordringen der 20 %-mT-Linie ins Auge fällt. Durch den starken Einfluss von maritim-polaren Luftmassen des Atlantik bildet sich im Raume der Neu-Englandstaaten eine durch drei Luftmassen bestimmte Klimaprovinz aus, die sich durch ihren unsteten Witterungsverlauf als eigentlichste Kampfregion des Kontinentes heraushebt. In den Sommermonaten gelingt es auch den maritim-polaren Luftmassen des Nordpazifiks die kontinentale Wasserscheide zu überqueren und jenseits derselben eine Kampfzone mit cP-Luftmassen zu etablieren.

Im Verlaufe dieser Untersuchung hat sich ergeben, dass die Expansionsgebiete der einzelnen Luftmassen einerseits von den geographischen Gegebenheiten, anderseits von den Ausbreitungstendenzen benachbarter Luftmassen abhängig sind; ihre Grenzen scharen sich in den meisten Fällen innerhalb einer Übergangszone, die indessen die Bedeutung einer Klimascheide annimmt, da sich bei der Querung dieser Zone nicht nur ein einzelnes Element wie Temperatur oder Niederschlag, sondern der Gesamtcharakter des Witterungsverlaufes ändert.