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A Synoptic Air Mass Climatology of the Eastern United States

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A SYNOPTIC AIR MASS CLIMATOLOGY OF THE EASTERN UNITED STATES

by

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Robert I. Wittick

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CHAPTER I

INTRODUCTION

Orientation and Objectives

The concept of the air mass was developed by a group of Norwegian meteorologists during World War I. An air mass, they said, was a body of air which was horizontally homogeneous with respect to temperature and humidity. These bodies of air were classified according to their place of origin since the basic character of an air mass is similar to that of its source region.

Since 1932 when the first air mass climatology was written by Dinies[1], the meteorological and geographical journals have published many studies of air mass movements and characteristics. The vast majority of these studies have been concerned with air mass characteristics and modifications, and not

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[1]E. Dinies, Luftkörper-Klimatologie. Dissertation Frankfort 1930, cited by Helmut Landsberg, "Air Mass Climatology for Central Pennsylvania," Gerlands Beiträge zur Geophysik, LI (1937), 285.

with associated local weather. These studies are termed dynamic climatologies because of their primary concern with general circulation patterns.[2]

In contrast to dynamic climatologies, synoptic climatologies attempt to depict local weather conditions as they are related to some aspect of the atmospheric circulation. Synoptic climatologies, then, are descriptive and explanatory methods of studying the atmosphere. Since the geographer is primarily interested in the surface weather and climatic situation of the atmosphere, synoptic climatology with its explanation of these surface weather conditions is of more value to him.

The air mass analysis which is presented in this investigation is a synoptic climatology because it attempts to portray associations between surface temperatures and corresponding air mass types. Hence, a causal relationship is assumed to exist between air masses and surface temperatures.

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[2]For a discussion of the contrasting purpose and methodology of dynamic and synoptic climatologies see Arnold Court, "Climatology: Complex, Dynamic, and Synoptic," Annals of the Association of American Geographers, XLVII (June, 1957), 125-136, and F. Kenneth Hare, "Dynamic and Synoptic Climatology," Annals of the Association of American Geographers, XLV (June, 1955), 152-162.

The purpose of this study is to analyze the frequency of occurrence of air mass types over the eastern United States, and to determine the range and spatial variations of associated surface temperatures. Four specific factors will be investigated: (1) the mean position of the surface polar front during winter and summer seasons; (2) the frequency of occurrence of air mass types at selected stations; (3) the variation of temperatures at selected weather stations while under the influence of contrasting air masses; and (4) the latitudinal variations of temperatures within homogeneous air masses and across frontal zones.

This air mass study is somewhat different because it is a synoptic climatology. Associations between air mass types and surface temperatures are not usually studied in air mass climatologies; therefore, such studies are not synoptic in nature. The reasons these associations are not made are perhaps best explained by Namias[3] who notes that surface temperatures are greatly influenced by four factors: (1) conduction and mixing, (2) expansion and compression,

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[3]Jerome Namias, An Introduction to the Study of Air Mass and Isentropic Anal sis, ed. Robert C. Stone (Milton, Mass.: The American Meteorological Society, 1940), 7.

(3) evaporation and condensation, and (4) insolation and radiation. These factors act to change surface temperatures to such an extent that they may not be representative of the air masses which dominate them. Thus, most of the previous air mass climatologies have used upper air soundings to distinguish the thermal properties since the upper air is not as greatly affected by these temperature-changing processes.

It has never been established, however, to what degree associations exist between surface temperatures and air mass types. Although it is recognized that changes in air mass types will bring about corresponding changes in surface temperatures, the degree of change or the normal range of these temperatures have never been computed. This study will attempt to fill this gap in climatological knowledge.

Research Methods

Data source

The primary data source used for this study was the Daily Weather Map Series of the United States Weather Bureau. These were chosen because of their availability and the inclusion of all the necessary daily information on each map. Although other sources could have been used for temperature data, the weather maps are the only source known which includes the necessary air mass information.

Time period selected

The study period covered five years from 1961 to 1965. This period was chosen because of the availability of the necessary weather maps in the Western Michigan University Map Library. For each day during January and July of this period (these months representing winter and summer for this study), the following information was recorded from the daily weather maps on tally sheets:[4] (1) the position of the polar front, (2) the position of the dominate air mass types, and (3) the various representative temperatures within the different air masses.

The statistical values used in this study should not be construed as long-term averages but only as indicative of trends and frequencies during the investigative period. It should be noted, however, that

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[4]The data extraction techniques and computer programs used in this study are detailed in the appendix.

this five-year period is as long or longer than any other study period chosen by air mass climatologists, and therefore the results should be just as meaningful as in other air mass climatologies.

Weather stations

Twelve weather stations were selected from the daily weather maps from which four different daily temperatures were recorded for each station during the five-year period. These stations were Sault Saint Marie, Michigan; Detroit, Michigan; Cleveland, Ohio; Columbus, Ohio; Cincinatti, Ohio; Louisville, Kentucky; Knoxville, Tennessee; Atlanta, Georgia; Alma, Georgia; Jacksonville, Florida; Orlando, Florida; and Miami, Florida (see Figure 1).

These stations were chosen for two reasons: (1) all are first-order weather stations, and thus the necessary data appear on the weather maps, and (2) together they represent a latitudinal cross-section of the eastern United States extending from the northern border of the country to the tip of Florida.

Correlation of surface temperatures

Four surface temperatures were correlated with the air mass occurrences at the twelve stations.

Fig. 1.--Weather stations used for temperature comparisons

These temperatures were the 1:00 a. m. (E.S.T.) temperature, the dew point for 1:00 a. m. (E.S.T.), the daily maximum temperature, and the daily minimum temperature. These four were selected because they are the only four appearing on the weather maps.

For each of the twelve stations these four daily temperatures were recorded for the months of January and July during the entire five-year study period. The air mass type which was present over each station for each day was also recorded, and these figures served as the basis for the correlations made between the temperatures and the air mass types.

Interpretation of results

Before any results can be presented, however, it must be emphasized that many generalizations are necessary in presenting such a study because of the nature of climatology. That is, there are many atmospheric conditions which do not repeat themselves in the same manner each time they occur. This is due largely to the great number of variables which can affect these atmospheric conditions.

In isolating one or two of these variables, such as air mass types and temperatures, and attempting to show correlations between them, it is often difficult to come to meaningful conclusions without considering the many additional variables that may also interact with the ones being studied. Likewise, the necessary subjectivity of the analyst who compiled the map and the researcher who interprets the map suggest that caution must be exercised in interpreting the statistical results of a study such as that presented here. Nevertheless, there is validity in such a study, provided the generalizations present are understood and accepted.

Organization of Materials

The first section of the study includes a review of the past air mass climatologies that have been written about the United States. This information discussed in Chapter II is included to emphasize the the fact that much research remains to be done in the field of air mass climatologies. The third and fourth chapters present the results of the research, and the last chapter sets forth the conclusions that were reached. The appendix describes the data gathering procedures and the computer operations.

CHAPTER II

REVIEW OF LITERATURE

The first air mass climatology of the United States was written by Willett[1] in 1933. He explained the purpose of his study as an attempt to distinguish air mass source properties and air mass modifications. Willett described the associations that existed between different air mass types and upper air temperatures as they occurred at scattered stations throughout the country. His study focused on these air mass properties for winter and summer using the months of December, 1929 to March, 1930 as his winter study period, and July and August, 1930 for his summer study period. Thus, all of his conclusions were based on one winter and one summer season.

Willett's study was a pioneer in the field in that it was the first attempt made to describe and

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[1] H. C. Willett, "American Airmass Properties," Massachusetts Institute of Technology Papers in Physical Oceanography and Meteorology, II (1933), 116 pp.

explain the characteristics of the air masses that dominate the North American continent. This study, however, was not specifically geographical. It did not analyze the frequencies or areal distributions of these various air masses. Willett's primary interest was in the source regions of the air masses, the modifications that took place as they migrated over the United States, and the associated upper air temperatures and humidity characteristics.

In 1939 a study by Showalter[2] refined and updated the material presented in Willett's paper. Showalter modified Willett's approach in that he explained the American air mass pattern using the differential classification of air masses as adapted from Bergeron.[3] It is this adapted classification system which is used today by the United States Weather Bureau, and which will be employed throughout this paper.

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[2]Albert Showalter, "Further Studies of American Air Mass Properties," Monthly Weather Review, LXVII (July, 1939), 204-218.

[3]This system of air mass classification differs from the absolute classification used by Willett in that Bergeron's includes symbols indicating the stability of the lower air and the degree of thermal modification taking place within the air. Bergeron's system also distinguishes between arctic and sub-arctic or polar air, and sub-tropical and equatorial air.

Showalter followed Willett's basic approach by analyzing the composition of each air mass with respect to the lapse rate, moisture content, and the equivalent potential temperature at various levels in the atmosphere. Showalter also discussed the source regions and the modifications of the air masses as they advanced into the United States. Like Willett, he also used a single year (1936) for his study period.

Between the time of Willett's and Showalter's studies, Landsberg[4] wrote the first regional air mass climatology for North America. His study presented an air mass calendar depicting the frequency of occurrence of the various types of air masses observed over central Pennsylvania. Landsberg chose as his study period a sequence of five years from July, 1932 to July, 1937.

Although air mass frequencies were described by Landsberg, he made no attempt to correlate surface temperatures or other local weather conditions with these frequencies. Thus, Landsberg's study differed from the one presented in this paper in its lack of

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[4]Helmut Landsberg, "Air Mass Climatology for Central Pennsylvania," Gerlands Beiträge zur Geophysik, LI (1937), 278-285.

synoptic application.

At about the same time that Landsberg's study appeared, Gerlach[5] introduced another American air mass climatology. This investigation indicated the frequency of air masses as they occurred at six scattered stations in the western half of the United States. The text of the study was based on two tables and accompanying graphs depicting air mass frequencies. These frequencies were discussed both as percentage of occurrences and as number of air mass changes per month. Like Landsberg's, Gerlach's study was not synoptic because of a lack of consideration of surface conditions. In addition, this study was handicapped by attempting to describe climatically a large region while using only a limited number of stations for reference points.

The most recent geographically oriented air mass climatology was written in 1952 by Brunnschweiler.[6]

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[5]Arch C. Gerlach, "Distribution of Air Mass Types and Frequency of Change in the Western United States during 1937-38," Monthly Weather Review, LXVI (November, 1938), 376-378.

[6]Dieter H. Brunnschweiler, "The Geographic Distribution of Air Masses in North America," Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich, XCVII (1952), 42-49.

He felt that it was incorrect to determine average air mass positions because of the great range possible for such a position. He, therefore, used three zones of varying prevalence. His first zone included all regions which were dominated by an air mass at least 80% of the days during a season. The second included all regions in which an air mass prevailed from 20% to 80% of the days, and the third zone included regions which were dominated by an air mass less than 20% of the time.

While it is agreed that the great range of possible frontal positions limits the validity of a mean frontal position, Brunnschweiler seems to have overlooked the possibility of using modal positions to show frontal and air mass locations. Since the mode indicates only the most frequently occurring position of the front or air mass, it is not influenced by the extreme positions. Thus, this study will present the modal positions of the polar front, thereby also indicating the approximate modal positions of the adjacent mT and cP air masses.

Brunnschweiler plotted the actual daily position of each air mass boundary on outline maps of the continent. These maps were combined into two composite maps, one showing air mass frequencies in the summer, and the other in winter. He considered the months of December, January, and February as the winter season, and June, July, and August as the summer. The study covered the years from 1945 to 1949.

Brunnschweiler's study somewhat parallels the study presented in this paper except that Brunnschweiler was interested only in air mass frequencies and not the associated weather related to the air masses. In addition, his stations were much more scattered than those used in this study. Thus, his results were more general.

These, then, are the major air mass climatologies which pertain to North America. Other climatologies have been written, concerning both air masses of North America and other continents.[7] While there is no purpose served in discussing each one of these, a study

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7Cf. J. E. Belasco, "The Temperature Characteristics of Different Classes of Air over the British Isles in Winter," Quarterly Journal of the Royal Meteorology Society, LXXI (1945), 351-376; Photios P. Karapiperis, "The Climate of Blue Hill According to Air Masses and Winds," Harvard Meteorological Studies, IX (1951), 105 pp.; H. Arakawa, "The Air Masses of Japan," Bulletin of the American Meteorological Society, XVIII (December, 1937), 407-410.

by Belasco[8] is worth mentioning because of certain similarities with the present study.

Among other things, Belasco studied the degree of association between air mass types and the daily mean maximum and minimum surface temperatures over Great Britain. This is the same correlation that is made for this study of the United States. Belasco, however, made no attempt to depict the changes of thermal latitudinal gradients for different degrees of air mass dominance, whereas this problem is discussed in this study.

Belasco included not only the means of his various temperatures but also the standard deviations from the means. This statistical tool was used to describe the degree of temperature variation existing within the different air masses. This technique has much value in the description of temperature variations, and has also been employed in this study.

To conclude this section, it should be noted that only Belasco's study could be considered synoptic

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[8] J. E. Belasco, "Characteristics of Air Masses over the British Isles," Great Britain Monthly Geophysical Memoirs, LXXXVII (1952), 34 pp.

because the other studies did not correlate surface weather with upper air conditions. Even Belasco's study only borders on the synoptic because his primary concern was with the character of the upper air, and his discussion of surface temperatures was rather superficial.

Only two of the studies, Landsberg's and Brunnschweiler's, used research periods longer than one year. The remainder were written from the results of a single year's information. Willett and Showalter were not concerned with air mass frequencies, and Landsberg was concerned with frequencies of only a very limited area. The weakness of Gerlach's study was that it used only six stations as representative of the entire western half of the United States, whereas this study makes use of thirty-nine checkpoints for a much smaller area.

These, then, are some of the weaknesses of the previous air mass climatologies which this study has tried to avoid. Each of these climatologies was a significant addition to the meteorological literature; however, they had their limitations. It is hoped that this study will overcome some of these limitations.

CHAPTER III

POLAR FRONT LOCATION AND AIR MASS FREQUENCIES

Types of Air Masses Distinguished

The eastern United States, as defined in this study, is that portion of the country which is east of the Mississippi River. Within this region four different air masses, following the differential classification system, are known to occur. These are (1) continental arctic (cA), (2) continental polar (cP), (3) maritime polar (mP), and (4) maritime tropical (mT).

The characteristics of these air masses in the eastern United States have been described by Trewartha.[1] He noted that cP air has its source region in the interior of Canada. This air moves in a general southerly direction and usually brings clear cool weather to the United States since its moisture content is slight. cA air is similar to cP air except that it originates farther north within the interior of Canada and hence

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[1]Glenn T. Trewartha, An Introduction to Climate, (New York: McGraw-Hill, 1954), 158-169.

has colder temperatures and less humidity associated with it.

The mP air which affects the eastern United States originates off the coasts of Newfoundland, Labrador, and Greenland. Due to the prevailing west-to-east movement of the weather systems within the study area, mP air masses rarely reach this area. When they do, however, they bring cold and humid weather in winter and cool and clear weather in summer.

The Gulf, Caribbean, and Sargasso Sea regions are the primary sources for the mT air that affects the eastern portion of the United States. This type of air mass produces warm and rainy weather in winter and hot and humid weather in summer.

For the purposes of this study, these four types of air masses were combined to form two categories, cP and mT. The very infrequent occurrence of mP air and its thermal similarity with cP air suggested that this category could be combined with the cP. Willett[2] supported this theory of cP dominance when he noted:

> The North American continent broadens out to the north and is contracted to the south. This means that for the eastern and central

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[2]Willett, op. cit., p. 8.

> United States the direct polar and arctic air mass sources are essentially continental, while the direct tropical air mass sources are essentially maritime.

It was also felt that the cA air could be combined with the cP since it is somewhat similar to the continental polar air, and as Willett[3] noted: "The distinction between arctic and polar air masses seems scarcely to be justified in the United States." He later added: "It has seemed best to eliminate the term 'arctic' in the discussion of American air masses . . . ."[4] A second reason for combining cP and cA air masses together is that it is often difficult to distinguish between them on the weather map since the arctic front separating the two is often not visible at the surface. Thus, two air mass groups will be considered to dominate the eastern United States, cP and mT.

Normal Polar Front Positions

The polar front may be defined simply as the boundary zone which separates polar and tropical air

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[3] *Ibid.*, p. 9.

[4] *Ibid.*

masses. While this definition is quite accurate for the upper air polar front, Byers[5] notes that

> in the lower atmosphere the picture is more complicated for two reasons: (1) the perturbations (cyclones, anticyclones) are more complex and hence are capable of creating transitional air mass types through circuitous passages of air and of forming intermediate, detached fronts; (2) the continents and oceans impart different properties to the overlying atmosphere and thus create contrasting air masses.

Thus, the surface plotting of this front is often more difficult than its definition suggests.

However, once the position of the polar front has been determined, the relative position of the polar and tropical air can also be determined. Since the polar front is a primary region for cyclogenesis and cyclone tracks, this front has a significant effect upon the climatic picture of the study area. In addition, it is being given particular emphasis in this air mass climatology because of its direct connection with mT and cP air mass movements.

As indicated in Chapter II, there has been very little research on the migrations and frequency of occurrence of the surface polar front over the United

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[5]Horace Robert Byers, General Meteorology (New York: McGraw-Hill, 1959), 325.

States. This, then, is the first objective of this study--to determine the normal winter and summer positions of the surface polar front. In order to determine these positions, a grid network was superimposed over each weather map used in the study, and tabulations were made for frontal frequencies within each grid square.[6]

It was found that during the month of January the front commonly had a northeast-southwest alignment whenever it was over the eastern portion of the United States, which was only on about 35% of the days. The remaining 65% of the days found the front situated south of the Florida peninsula. In summer the alignment of the front was more in the expected east-west direction, and it was over the study area on about 93% of the days. During the remaining 7% of the time it was located over southern Canada.

As mentioned in the previous chapter, Brunnschweiler indicated that it was not useful to determine a statistical mean position for the polar front because of the great range of its possible locations.

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[6]See Appendix for details of research methods used in tabulation of grid square data.

Panofsky and Brier[7] confirm this statistical obervation and note that of the measures of central tendency the mode is the least affected by extreme values whereas the mean is greatly affected. They also noted that the median is influenced by the number but not the value of the extreme frequencies.

It therefore seemed that the most significant type of normal frontal position was to be determined by using the mode. This was done for the month of July. The January modal position could not be determined because the necessary data were unavailable for those days when the front was south of the United States--a condition which occurred on the majority of days during the study period. Thus, it can only be stated that the January modal position of the polar front was south of the Florida peninsula.

The July modal position of the polar front was found to bisect approximately the eastern portion of the United States (Figure 2). The unusual feature of this position is the southward tongue of cP air which

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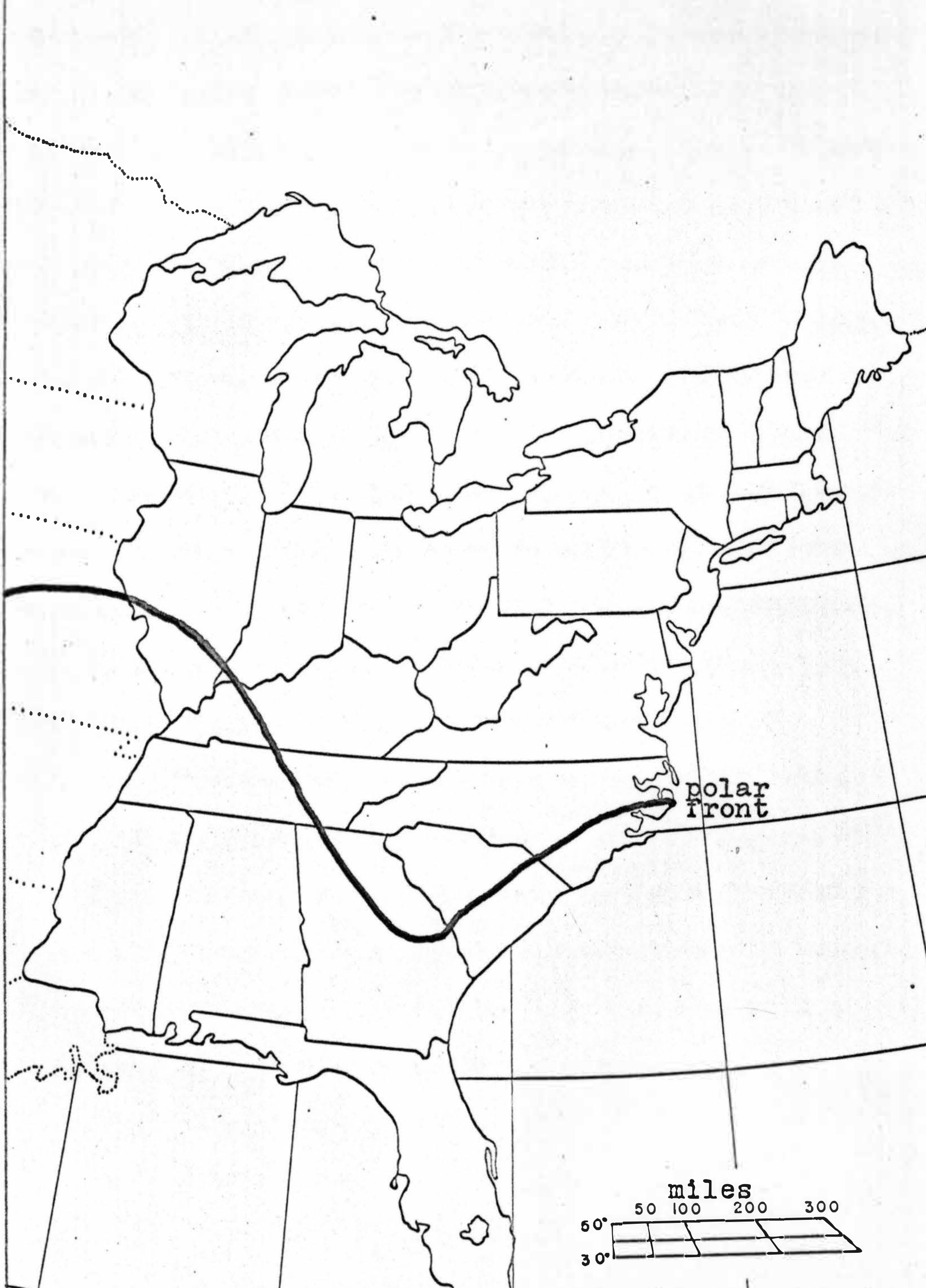
[7] Hans A. Panofsky and Glenn W. Brier, Some Applications of Statistics to Meteorology (University Park, Pennsylvania: Pennsylvania State University Press, 1963), 17.

Fig. 2.--Modal position of polar front in July



pushes down almost to central Georgia before swinging northward again further east. From this map it appears as if the Appalachian Mountains act to retard the northward movement of the front or funnel the cP air further south. However, this may also be explained as a result of subjectivity of the map analyst who in plotting the location of the polar front must rely to some extent upon surface temperatures. Since the mountains have a tendency to lower the surrounding temperatures, the analyst may tend to draw the polar front as dipping occasionally to the south in this Appalachian region because of the lower temperatures.

This July frontal position closely paralleled that found by Willett[8], who indicated:

> The general difference between the normal winter and the normal summer condition as regards the distribution of prevalence of the mT air masses may be expressed . . . by saying that the zone of maximum frontal activity between 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.

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[8]Willett, op. cit., p. 64.

Brunnschweiler's[9] results differed somewhat from those of Willett's, however, because he noted that in winter the polar front usually lies across the Florida peninsula. The difference between Brunnschweiler's results and those obtained in this study may be explained by the fact that Brunnschweiler used a three-month period for his winter season (December through February), whereas this study considered only the month of January.

Willett, however, used a four-month period for his "winter" (December through March), and his frontal positions still coincided with those found in this study. This may be explained by the fact that Willett's study covered only one year, while Brunnschweiler's and the present one covered five-year periods. It is therefore assumed that Willett's study was more responsive to extreme conditions. Since he did not explain his computing methodology, it is not possible to analyze it for possible errors.

This portion of the research, then, has established the fact that the July normal position of the polar front is through the middle of the eastern

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[9]Brunnschweiler, op. cit., p. 44.

portion of the country aligned in an east-west direction. The January position, while not possible to map because of extending beyond the study area, was determined to be south of the Florida peninsula and aligned in a northeast-southwest manner.

These frontal positions reflect the mean positions of the maximum westerly wind component (polar-front jet stream). This is known to be located slightly poleward of the above-mentioned locations for the respective seasons.[10] Since, by definition, the polar-front jet's baroclinic zone extends to the surface, the surface frontal positions which were found in this study are not surprising.

Air Mass Frequencies

By using the same grid square data as were used to determine the normal position of the polar front, it was also possible to determine the frequency of occurrence of the two air mass types. By connecting with isopleths the centers of all grid squares that

[10] J. F. Lahey, et. al., Atlas of 500 mb. Wind Characteristics for the Northern Hemisphere; Scientific Report No. 1, USAF Contract A119(604)-992, (Madison, Wisc.: University of Wisconsin Press, 1958).

had approximately equal percentages of air mass frequencies, four separate maps showing frequencies of both air masses for January and July were compiled.

Since only cP and mT air mass types were considered, it might be expected that the frequency of occurrence of one air mass would complement the other for any particular area; that is, for any point on the map, the per cent of cP air occurrence and the per cent of mT occurrence would equal 100. This is not necessarily true, however, because in addition to air mass occurrences, frontal occurrences were also possible within the grid squares.

January air mass frequencies

In January a great portion of the country had cP air present on 90 to 100 per cent of the days (Figures 3 and 4). In fact, the only major deviation from this pattern occurred over the Florida peninsula where the cP occurrences dropped from 90% in the northern edge of the state to under 70% at the southern tip.

This rapid decrease in cP occurrence over Florida can be explained by Klein's[11] findings that polar air

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[11] Wilbur M. Klein, "Modifications of Polar Air over Water," *Journal of Meteorology*, III (September, 1946), 100.

Fig. 3.--Frequency of occurrence of cP air in January

(figures represent % of days)

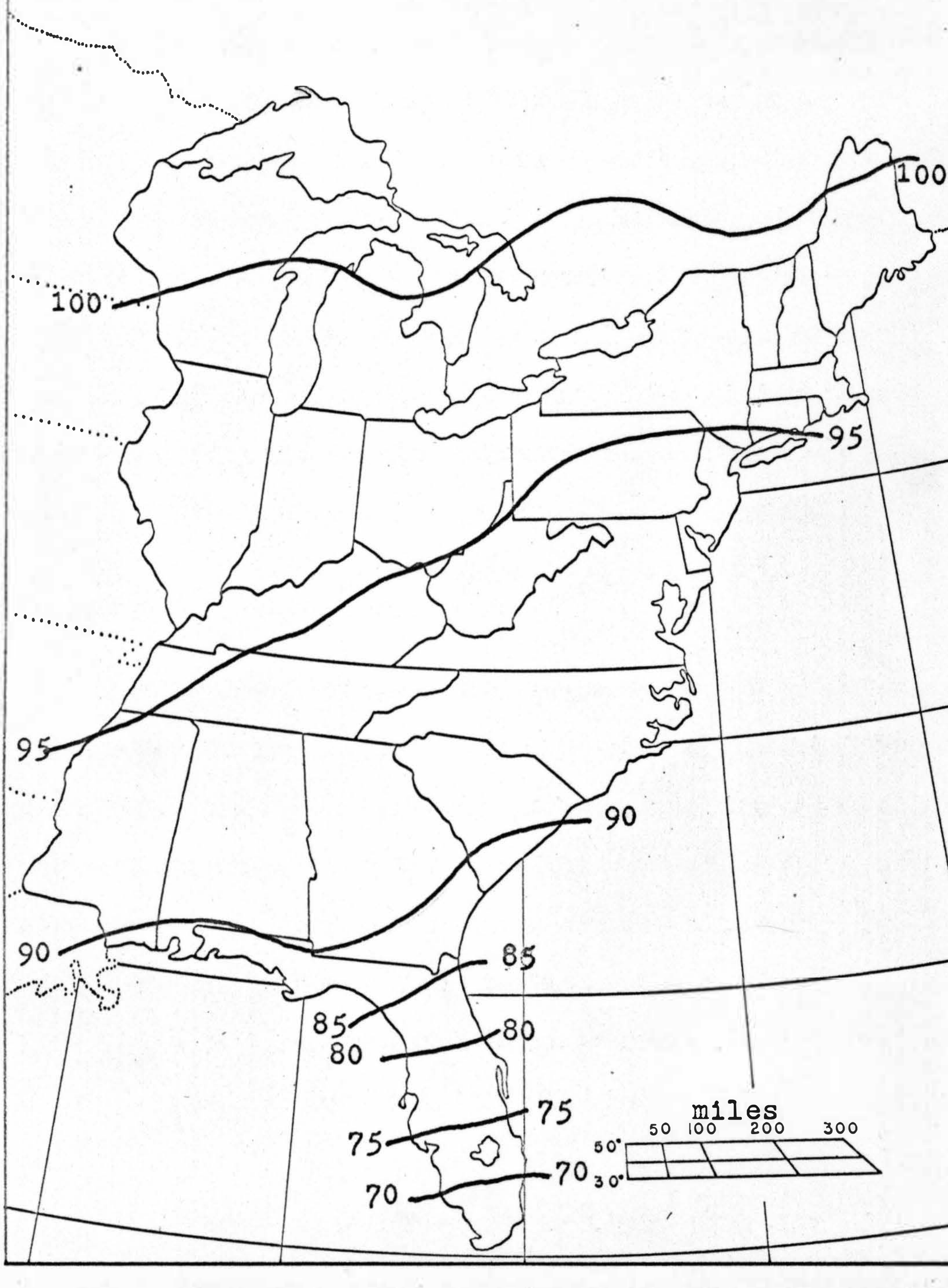
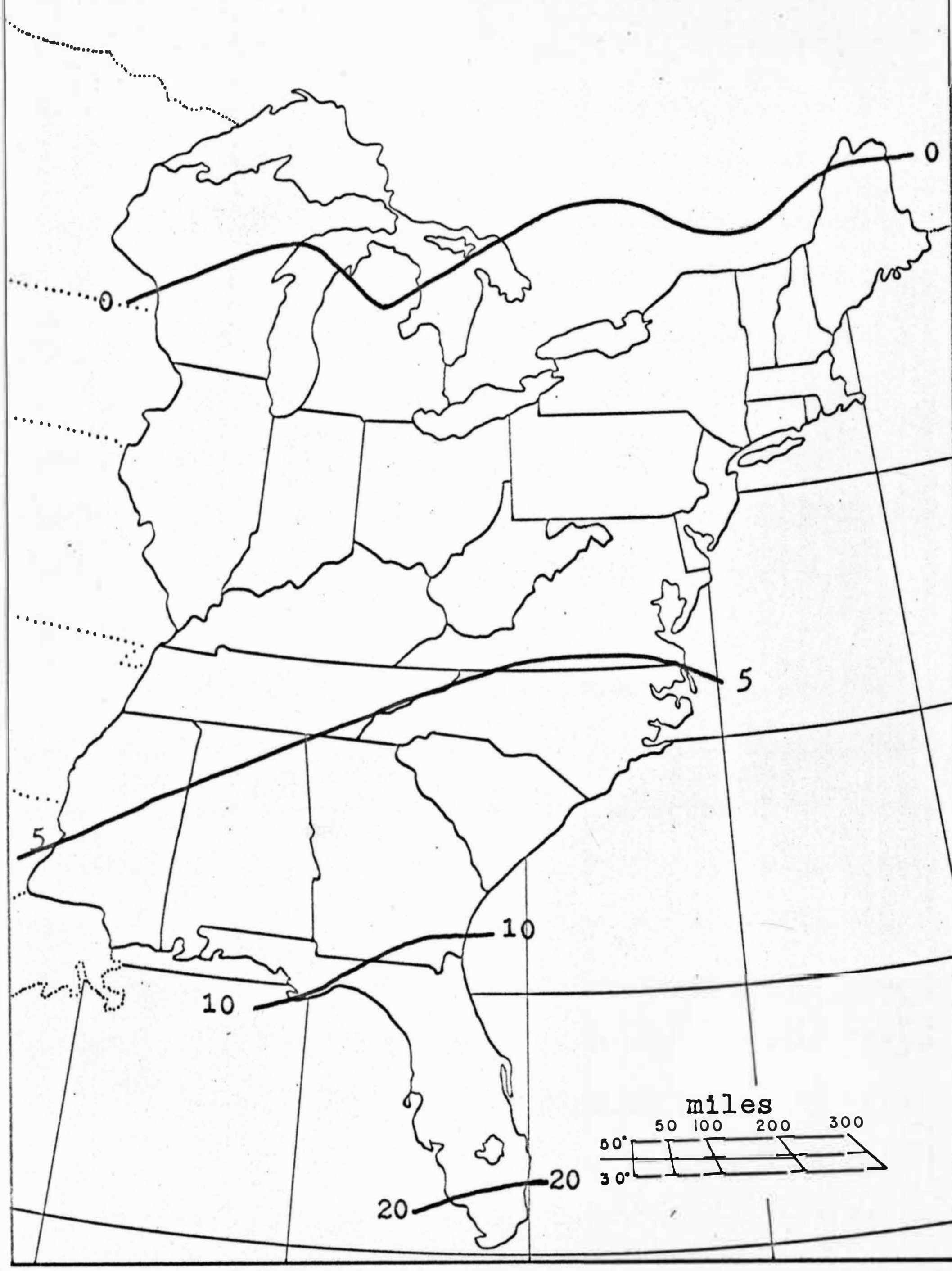


Fig. 4.--Frequency of occurrence of mT air in January

(figures represent % of days)



is greatly modified as it comes in contact with large water bodies. Thus, as the polar air migrates over the Gulf and the Florida Peninsula, it quickly takes on the characteristics of mT air. This explanation may also be used to account for the northeast-southwest alignment of the isopleths. The polar air moving down the eastern seaboard is rapidly modified by the marine conditions, and hence, the cP frequency for any given latitude is less along the coast than it is inland. Therefore, the isopleths bend northward as they approach the coast. This alignment of the isopleths, however, is also due to the orientation of the polar jet axis which has this same general northeast-southwest position during January.

The general dominance of cP air during the winter season may be explained by three factors. First, the mean position of the polar-front jet and its accompanying surface frontal zone is over the extreme southeast portion of the country in the winter. Secondly, the lack of east-west trending physical barriers in the country aids in the southward movement of the polar air into the extreme southeastern portion of the country. This geographic factor also determines, at least partially, the polar-front jet position, and hence these two points are not completely independent.

Thirdly, the subtropical high pressure cell which dominates the source region of the mT air is quite far south in winter. In fact, much of the study area is now dominated by the polar anticyclone and its cP air.[12] This circulation pattern acts to retard entrance of mT air into the country. When it does enter, however, the warm mT air is quickly cooled by the colder land, and thus modified into cP air.

July air mass frequencies

In July the circulation pattern is quite different from January. The polar-front jet stream is located much farther north.[13] In addition,

> A strengthening of the Bermuda High over the western Atlantic Ocean and the tendency toward a thermally maintained low over the warmed continent produces a relatively northward persistent monsoonal indraft that flows even into Canada.[14]

The mT air is now able to migrate much farther north into the continent. Thus, the air mass frequencies

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[12]Trewartha, *op. cit.*, p. 164.

[13]Lahey, et. al., *op. cit.*

[14]Trewartha, *op. cit.*, p. 168.

are quite different at this time of year than they were in January (Figures 5 and 6).

The alignment of the isopleths is now in the more expected east-west direction. It is also apparent that the Florida peninsula is quite homogeneous since it is almost entirely dominated by mT air. Thus, the marine influence which was so important in the northward bending of the isopleths in January appears to have little effect in July. This is understandable because both air masses have thermal characteristics which are more similar to the water than was true in January.

Trewartha[15] noted that in summer the most prevalent type of air mass found at the surface in the eastern United States is mT air. This seems rather generalized according to Figures 5 and 6 which also show frequency of surface occurrence. While the southern portion of the country is definitely dominated by mT air, the northern half is more frequently dominated by cP air.

It can therefore be concluded that cP air is the dominant air mass over the eastern United States. In

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[15] Ibid.

Fig. 5.--Frequency of occurrence of cP air in July

(figures represent % of days)

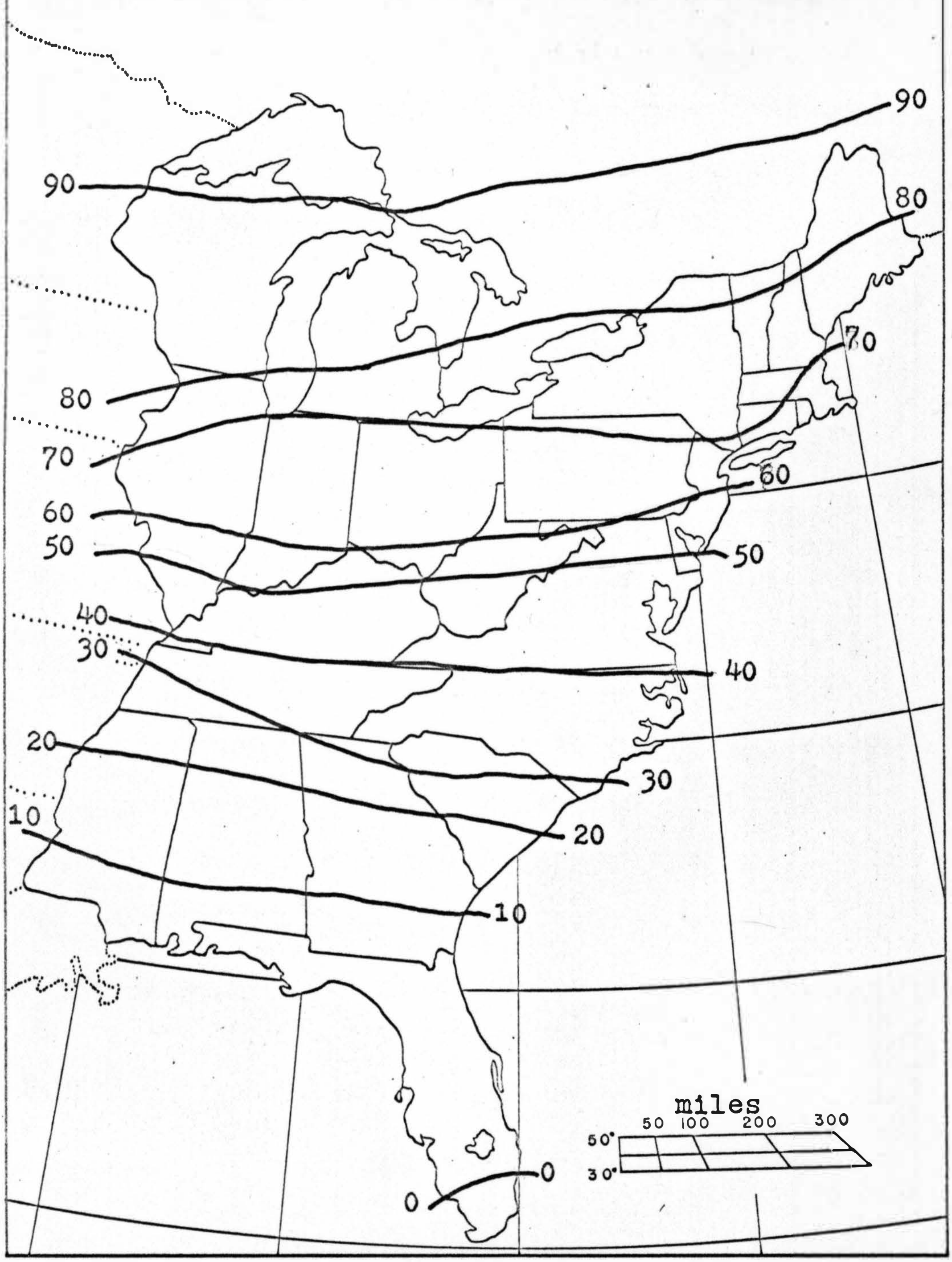
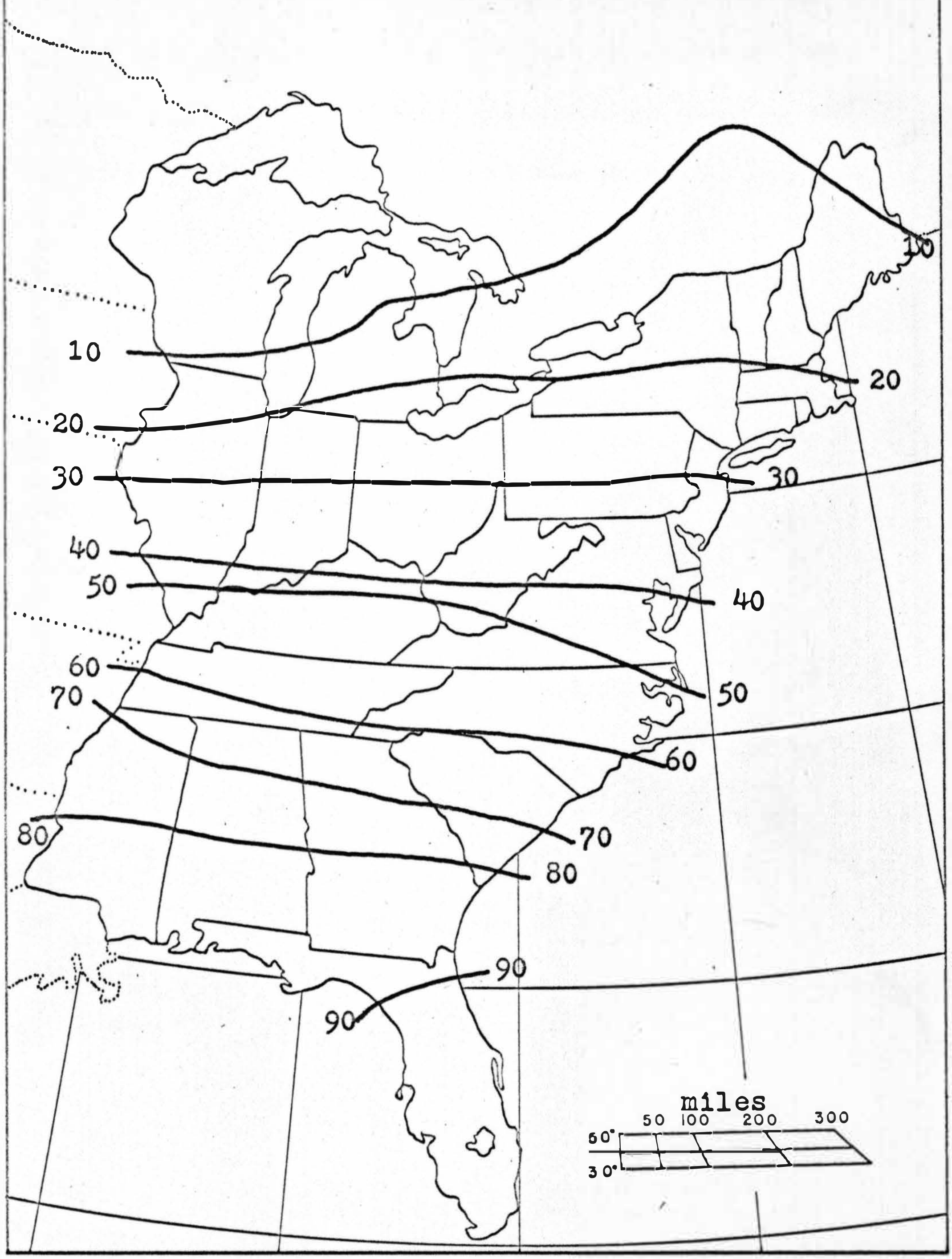


Fig. 6.--Frequency of occurrence of mT air in July

(figures represent % of days)



winter mT air only rarely penetrates into this area, and in summer it only dominates the southern portion of the study area. This cP dominance appears to be the result of the position of the polar-front jet, the location of the dominating pressure cells, and the physiographic structure of the area.

CHAPTER IV

AIR MASS SURFACE TEMPERATURE CHARACTERISTICS

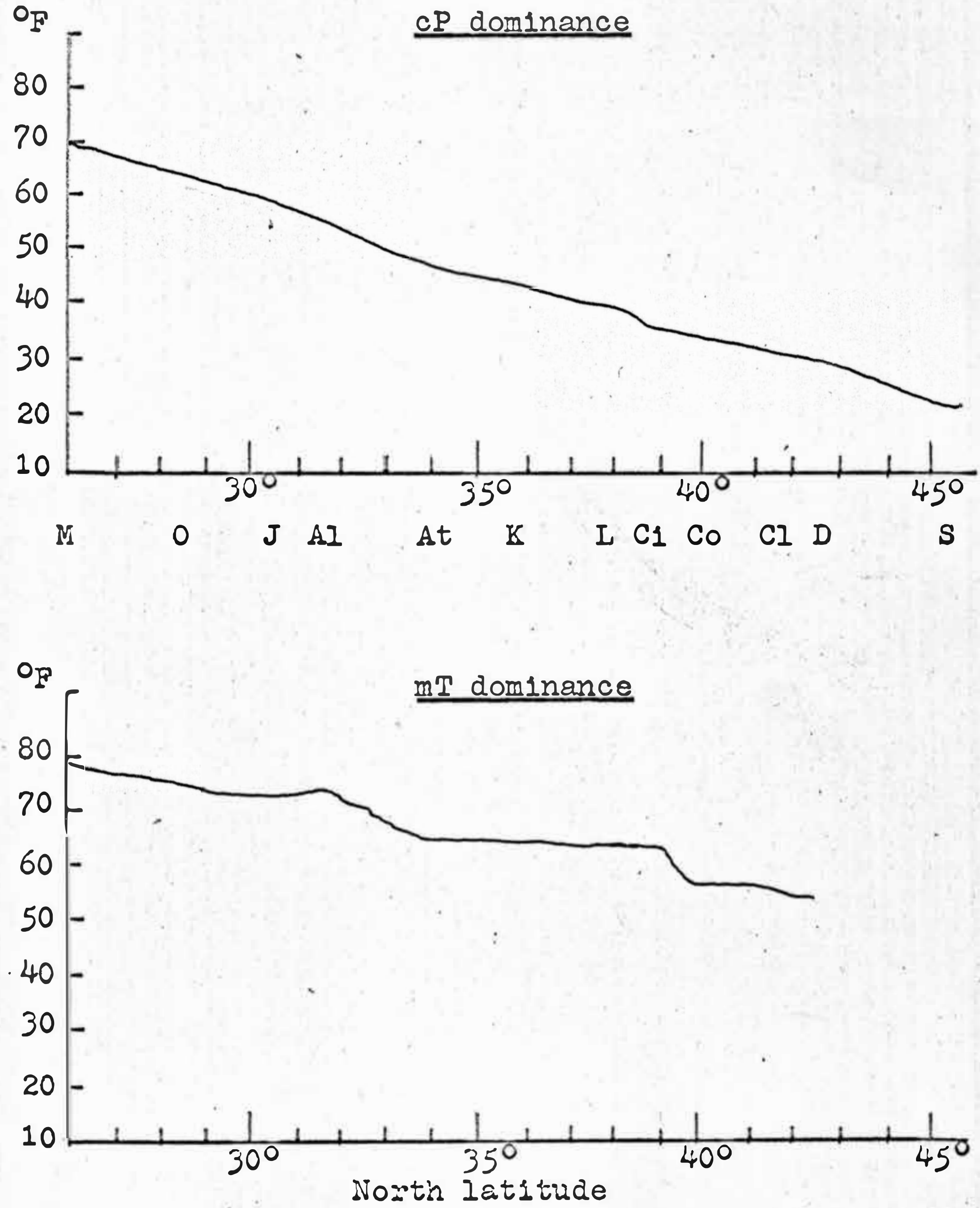
Now that the average positions and frequencies of air masses and the polar front have been established, it is the purpose of this chapter to delve into the surface thermal characteristics of these air masses. Various questions regarding this topic need answering. For example, what are the surface temperature characteristics of cP and mT air masses at various latitudes during different seasons? Are surface temperatures "horizontally homogeneous" within air masses as suggested by the definition of the concept? Is the latitudinal temperature gradient in the eastern United States a response to the theoretical values of insolational control or to air mass control? This chapter will attempt to answer these questions.

Mean Surface Temperatures of cP and mT Air

In order to determine whether there is a significant difference between surface temperatures associated with cP and mT air in the eastern United States, computations were made to find the mean and standard deviation of daily maximum temperatures of the twelve weather stations while under the influence of each air mass. Maximum daily temperatures were used because they are least affected by cloud cover, radiation cooling, and other similar local temperature modifying factors, and hence are most representative of air mass control.

In comparing the temperatures recorded at the various stations while under the influence of the two different air masses, it is first noted that the maximum temperatures were less at all stations when under cP dominance than when under the dominance of mT air (Figures 7 and 8). For example, in January Detroit recorded a mean maximum average of 31 degrees when dominated by cP air and 53 degrees when dominated by mT air. In July Detroit recorded an 81 degree cP average maximum and an 88 degree mT average maximum. This same set of temperatures for Louisville and for Orlando are given in Table 1.

Fig. 7.--January mean maximum temperatures



S -Sault St. Marie
D -Detroit
Cl-Cleveland
Co-Columbus

Ci-Cincinatti
L -Louisville
K -Knoxville
At-Atlanta

Al-Alma
J -Jacksonville
O -Orlando
M -Miami

Fig. 8.--July mean maximum temperatures

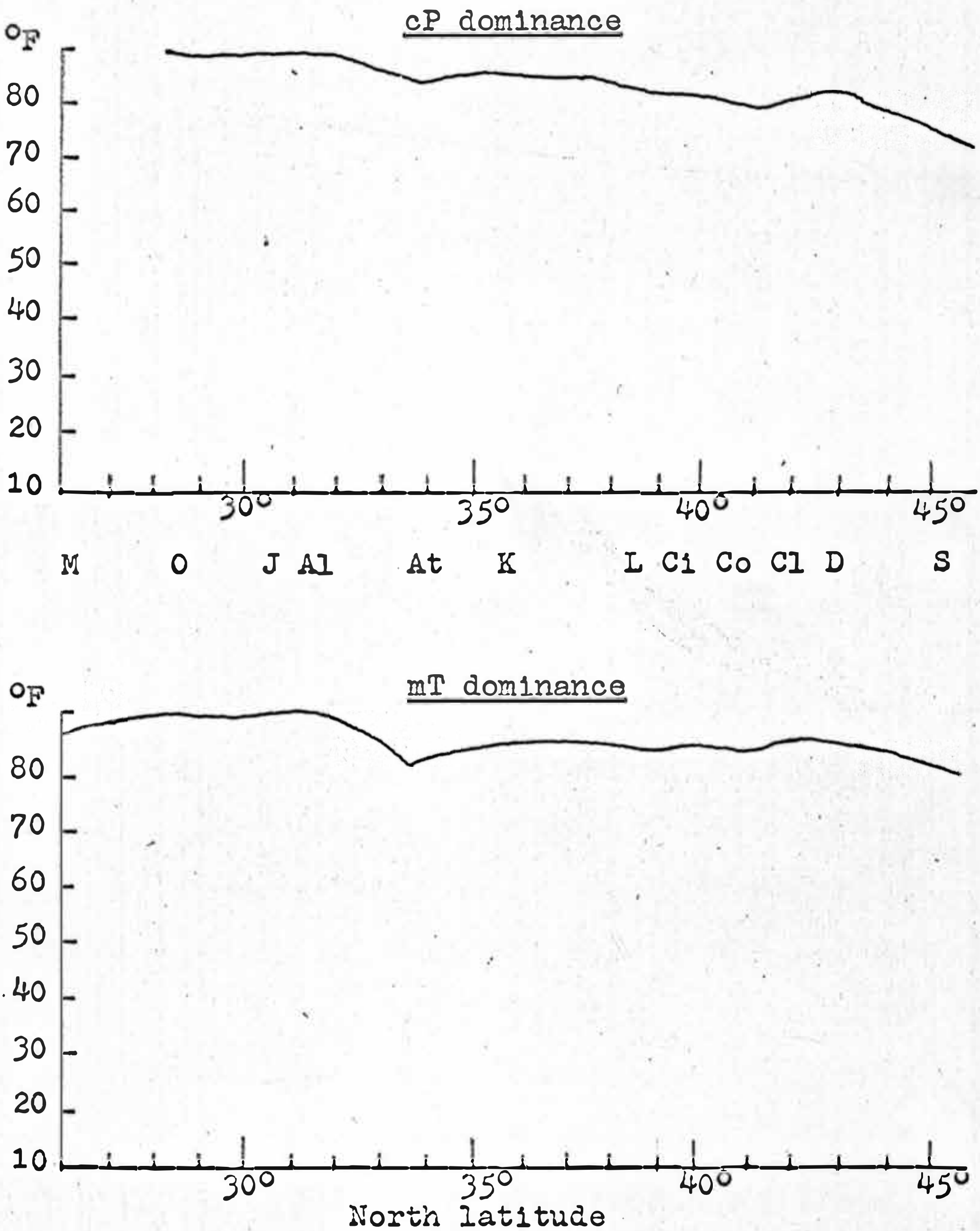


TABLE 1

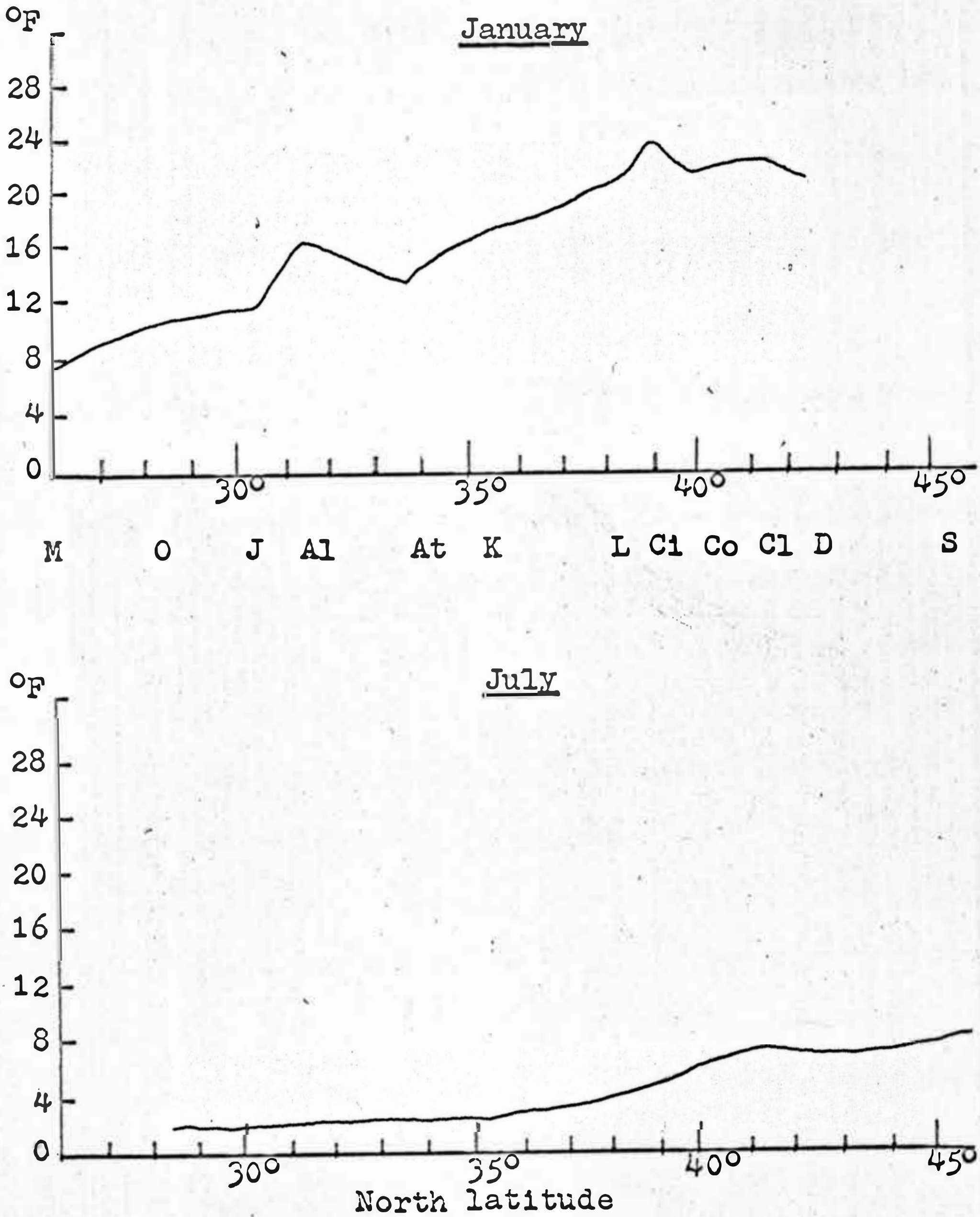
MEAN MAXIMUM TEMPERATURES FOR
LOUISVILLE AND ORLANDO

Station	January		July	
	cP	mT	cP	mT
Louisville	41°	62°	84°	88°
Orlando	65°	76°	90°	92°

<u>Range of temperatures between cP and mT air masses</u>

In general, at each northern station the range between the cP and mT temperatures was about 22 degrees in winter and 6 degrees in summer. However, at the southern stations the range was about 10 degrees in winter and 2 degrees in summer (Figure 9). For instance, Detroit's winter temperature difference was 22 degrees, Cleveland's was 23 degrees, and Cincinatti's was 24 degrees. In summer Detroit's was 6 degrees, Cleveland's was 7 degrees, and Cincinatti's was 5 degrees. Orlando, on the other hand, recorded a January difference of 9 degrees and a July difference of 2 degrees while Atlanta had a 6-degree difference

Fig. 9.--Temperature differences between cP and mT air



in January and a 2-degree difference in July. This general pattern can be explained by the rapid modification of the cP air which dominates the northern areas and the slower modification of mT air which dominates the southern areas.

Latitudinal gradients within homogeneous air masses

From Figures 7 and 8 it is apparent that in January there was a much steeper latitudinal gradient when the cP air dominated than when mT air did. This difference in gradients, however, was not apparent during July. This has been explained by Trewartha[1] who indicates that in winter rapid insolational heating and humidification of cP air takes place when it moves from the snow-covered northern portion of the continent into the southern portion where snow is less common. In summer, however, this cP air advancing into the study area is already relatively warm due to the warmer temperatures of its source region, and thus a steep gradient does not occur. This pattern also reflects the sharp insolational gradient of winter which does not occur in summer.

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[1]Trewartha, op. cit., p. 160.

This difference between the winter and summer gradients is more apparent when discussed in terms of the mean latitudinal temperature gradients (temperature per degree of latitude). Table 2 depicting these mean gradients helps illustrate the relative steepness of the winter gradient.

TABLE 2

MEAN LATITUDINAL TEMPERATURE GRADIENTS
WITHIN HOMOGENEOUS AIR MASSES
(PER DEGREE OF LATITUDE)

Month	cP	mT
January	2.5°	1.6°
July	0.0°	0.4°

These figures appear especially interesting when compared to Trewartha's statement that in the eastern United States the normal winter gradient is 2.5 degrees and the normal summer gradient is 1.0 degree. It can be seen that while the cP gradients closely approximate

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[2] *Ibid.*, p. 328.

Trewartha's normal gradients, the mT gradients are somewhat smaller. Thus, the comparatively small frequency of mT air in the study area helps to account for this difference between the mT gradients and the normal gradients. In addition, the greater frontal activity which is associated with the entrance of mT air into the eastern United States may act to modify the mT gradients found here.

Variability of surface temperatures

It was also found that there was a greater degree of variability of temperatures within the cP air masses than in the mT (Figures 10 and 11); the variability is described here by standard deviations (90 per cent significant). These graphs show that, in general, the higher latitude stations had higher standard deviations than did the lower latitude stations. For example, compare Columbus' winter deviation of 11 degrees with that of Miami's 6-degree winter deviation when both are dominated by cP air.

This pattern is not true for the January mT graph, however, probably because of the very small sample of days which fit this category. In fact, the highest standard deviations in January were at stations in the

Fig. 10.--Standard deviations of January mean maximum temperatures

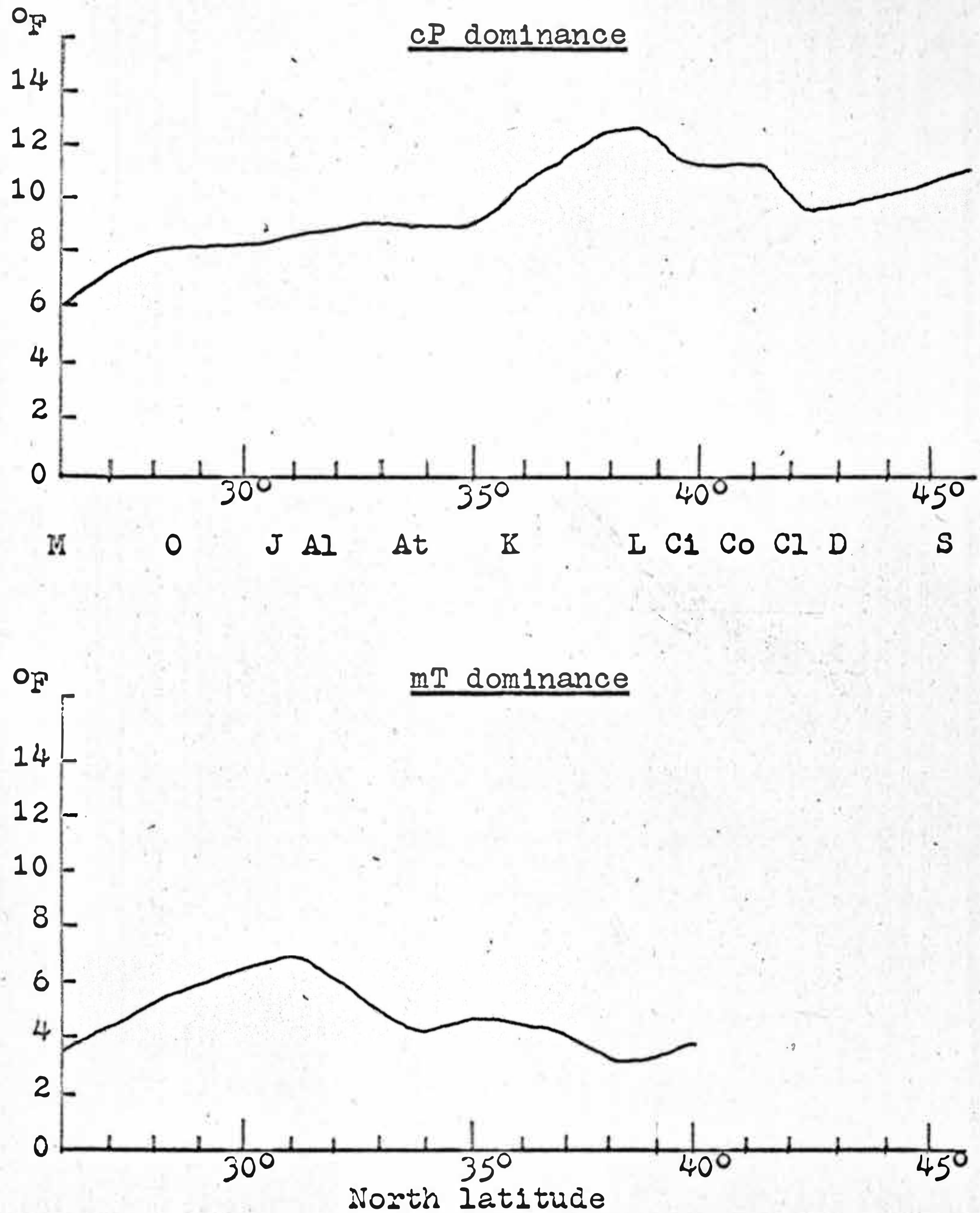
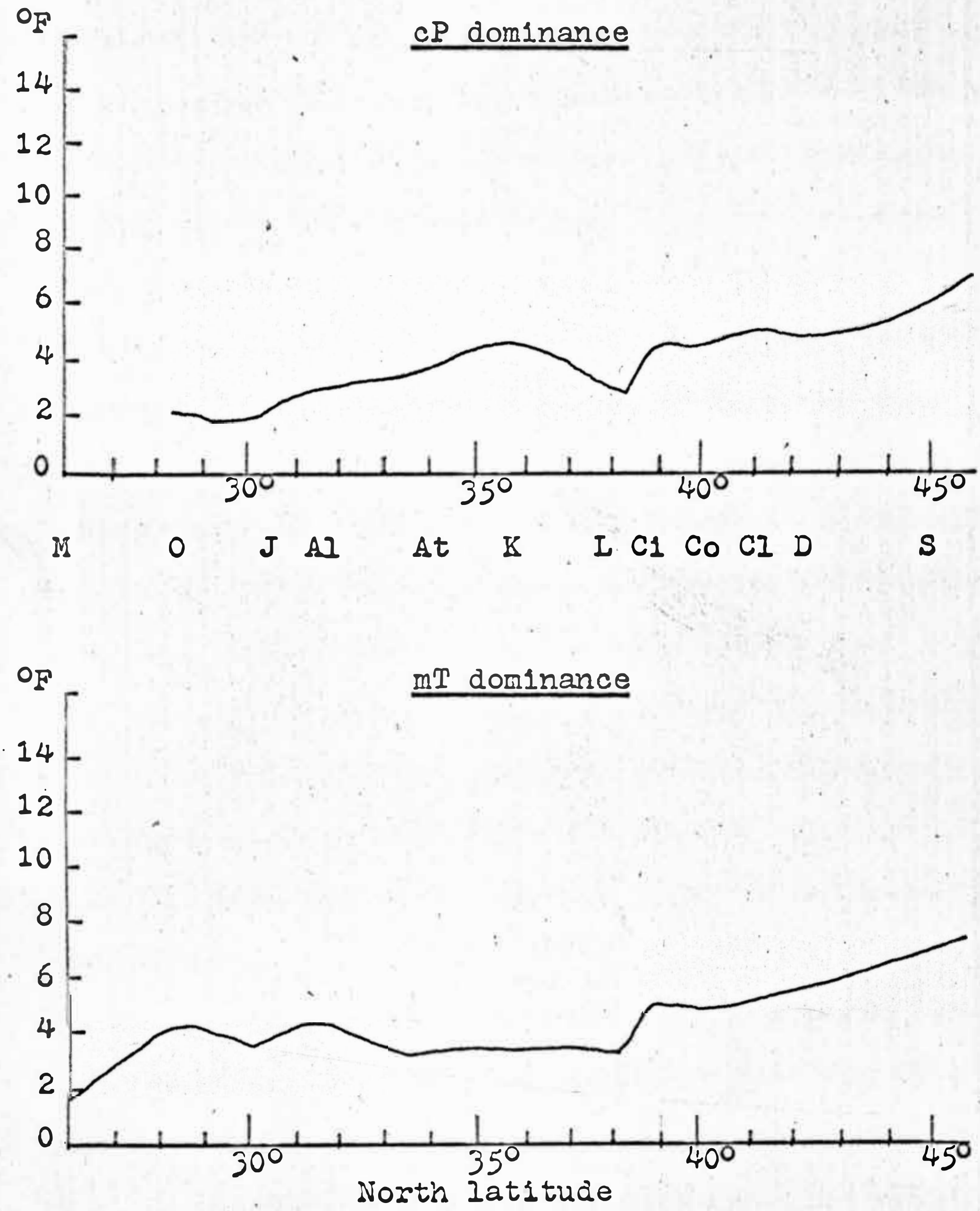


Fig. 11.--Standard deviation of July mean maximum temperatures



middle of the study area. Louisville recorded a deviation of 13 degrees from its mean cP maximum and Cincinatti recorded a 12-degree deviation. In part this may be explained by the continentality of these locations, but also in part by the vigorous and rapid exchange of air masses that takes place in this section of the country during winter.

The marine effect is shown by the lower standard deviations of temperatures for both January and July at Miami. It appears, then, that continentality and latitudinal location have a stronger effect on temperature variability than any inherent air mass characteristics. Thus, the larger winter standard deviations occur regardless of the air masses present. This can be explained by the greater vigor of the weather systems present, fluctuations in cloudiness, the shorter length of days, and other similar temperature changing conditions.

It can thus be concluded that air masses do appear to be important criteria for temperature determination particularly in the more northern areas where insolational control is negligible and advection is more important. This was illustrated by the fact that air masses apparently can change temperatures at these locations more than twenty degrees. However, this change is not consistent as illustrated by the large standard deviation figures.

Temperature Gradients for Various Frontal Positions

In order to answer the remainder of the questions which were posed at the beginning of this chapter, it was necessary to construct latitudinal temperature profiles for various polar-front positions. These gradients were then used to illustrate the temperature characteristics and latitudinal gradients which occur through the polar-front zone and within homogeneous air masses with the polar front in varying positions.

For this purpose thirteen different frontal positions were chosen. These were: (1) north of Sault Saint Marie, (2) south of Miami, and (3) between each pair of adjacent stations. A peculiarity of the computer program used for this portion of the research was that in order for any day to be included in one of the gradients, the polar front had to lie between two adjacent stations, and only those two (see Appendix for details of computer program). Hence days with frontal dominance at any station were excluded from analysis.

January

In considering frontal positions between stations during January, it is seen that the polar front is never north of the Louisville-Knoxville pair except during those days when it dominates a station further north, and such days are not considered for this study.

As can be seen from the January temperature gradient graphs (Figures 12 to 18), the latitudinal gradient in the southern portion of the study area is not as steep as is the northern portion of the area, regardless of air mass locations. For example, in comparing the Knoxville-Atlanta graph (Figure 13) and the Alma-Jacksonville graph (Figure 15) it is obvious that the southern areas have shallower gradients than do the central areas, regardless of polar-front position, even though the mT air has extended into this central section on the Knoxville-Atlanta graph. Likewise, when the study area is entirely dominated by cP air (Figure 18), the southern latitudes still have a shallower gradient than do the middle latitudes. This decrease in the gradient in the southern latitudes can be explained both by the marine influence of the Atlantic Ocean and Gulf of Mexico as described

January Mean Temperatures for Various Frontal Positions

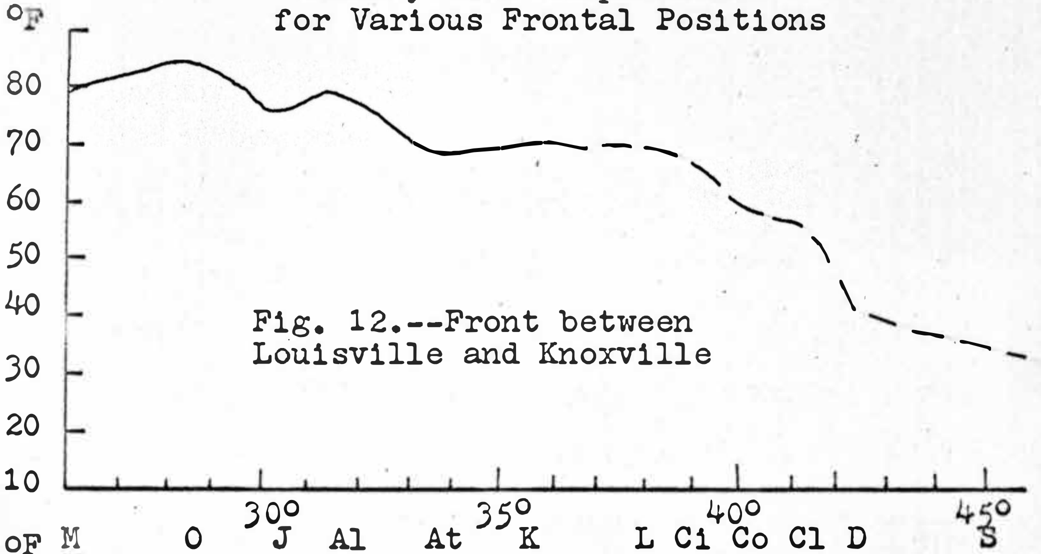


Fig. 12.--Front between Louisville and Knoxville

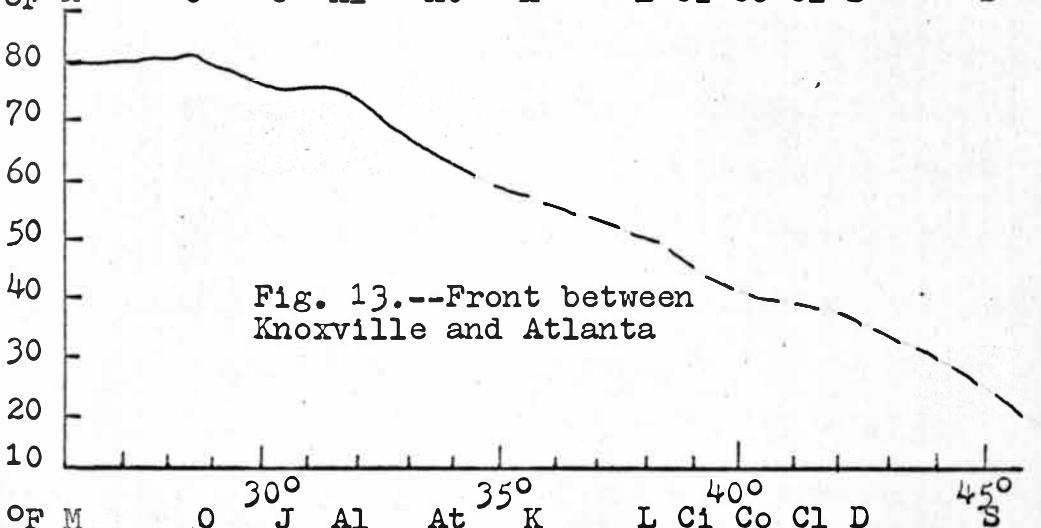


Fig. 13.--Front between Knoxville and Atlanta

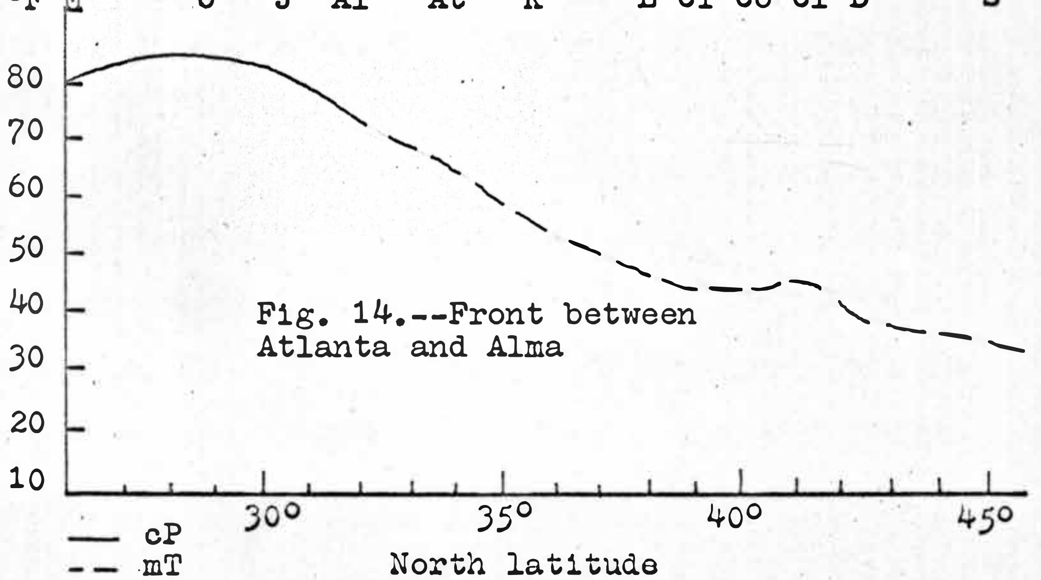


Fig. 14.--Front between Atlanta and Alma

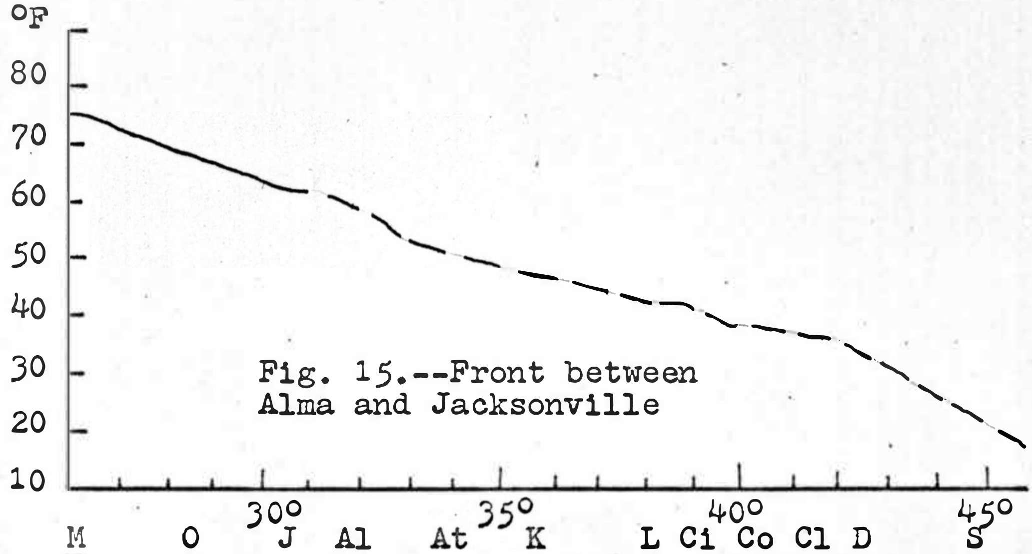


Fig. 15.--Front between Alma and Jacksonville

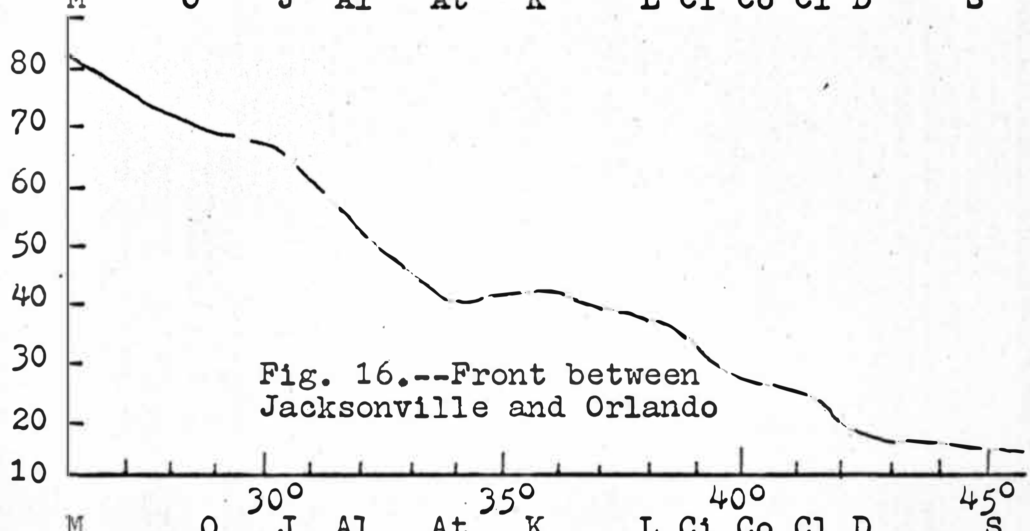


Fig. 16.--Front between Jacksonville and Orlando

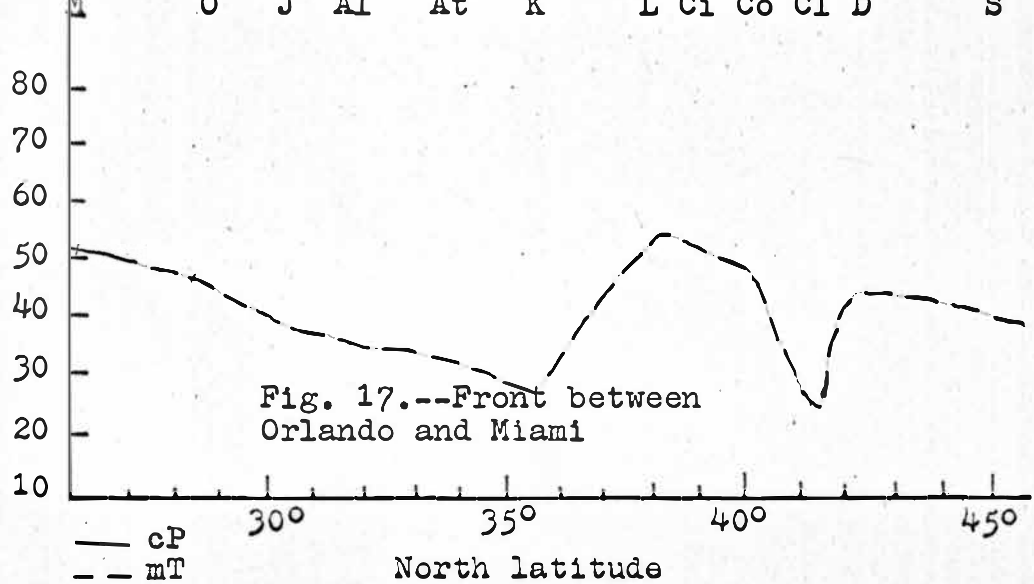


Fig. 17.--Front between Orlando and Miami

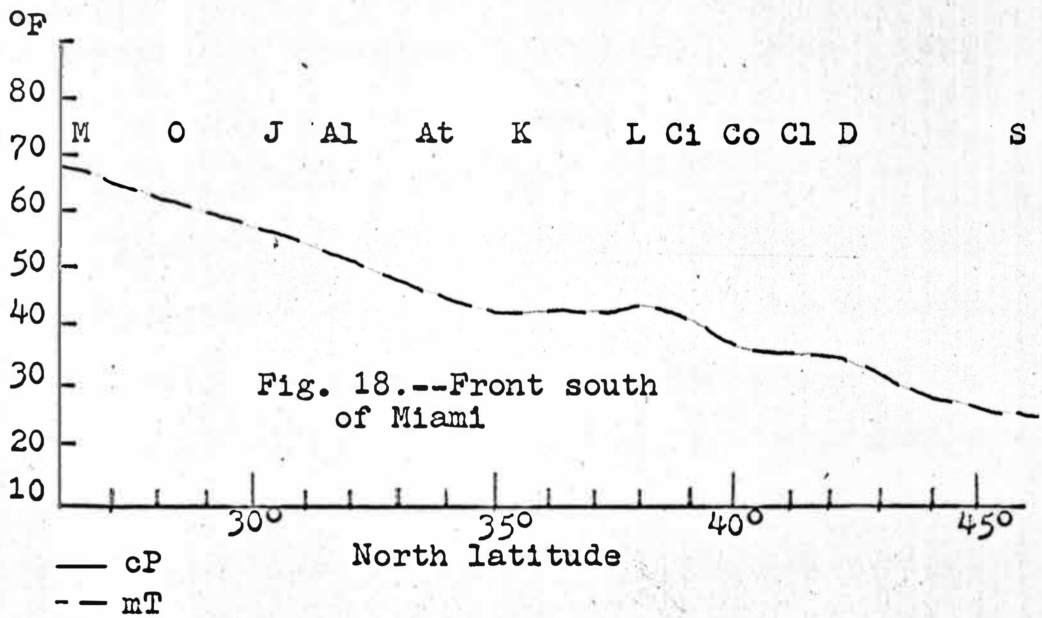


Fig. 18.--Front south of Miami

by Klein[3] and by the insolation gradient.

Although all the gradients are generally similar, there are many irregularities present. Again, these seem best explained by the small samples available for certain frontal positions.

It should be noted, however, that although the different positions of the air mass boundaries do not appear to affect the thermal latitudinal gradients, at least not in the area analysed, the temperatures are usually lower at all locations when under cP influence. Since the slopes of the gradients are not affected but their position in relation to the temperature axis of the graphs is affected, it follows that there should be a rather steep gradient close to the frontal positions. As shown by the graphs, however, this is not usually the case. Instead the steep gradient usually lies several latitudinal degrees north of the front, well within the cP air. This may be attributed to two factors. First, the mixed air that is adjacent to the front tends to take on the thermal characteristics of mT air since the dry cP air is more easily modified to mT air than vice versa.

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[3]Klein, op. cit., p. 100.

Secondly, the time lag between the 1:00 a. m. frontal position and the time of the maximum temperatures which usually occurs around 2:00 p. m. may be enough to cause this pattern to occur since the front can move a considerable distance in thirteen hours.

The continentality of the stations is also apparent from these latitudinal gradient graphs. For instance, when Miami is well within the mT air, it has a lower mean maximum temperature (79 degrees) than does Orlando (84 degrees). This indicates the prevalence of the marine effect upon coastal Miami in comparison to that of the more interior Orlando (Figure 12).

However, such a marine effect does not appear to be present as the cP air advances in Florida (Figure 18). Now Orlando has a mean maximum temperature of 47 degrees compared to Miami's 51 degrees. This suggests that the steeper gradient associated with the cP air acts to hide the presence of any marine effect. This phenomena can also be explained, in part, by the reversal of the wind direction at Miami as the front passes.

A somewhat similar situation exists at Alma and Jacksonville. When Jacksonville is well within the mT air, it records a lower mean temperature (75 degrees) than does the interior location of Alma (79 degrees). However, when the front is south of Tennessee, this marine effect upon Jacksonville does not show up on the graphs since Jacksonville's 56 degrees is warmer than Alma's 53 degrees.

The difference in gradient steepness can also be seen on these graphs. That is, when the front is near the center of the area (Figures 13 and 14), the gradient in the mT air is quite shallow in comparison to the much steeper gradient in the cP air.

July

The thermal gradient graphs for July are quite different in appearance from the January graphs (Figures 19 to 29). There is now a greater degree of homogeneity between the two air masses than was present in January. This is explained in part by Haurwitz and Austin[4] who noted that in summer the continental heating of the cP air causes it to be rapidly modified as it advances southward. However,

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[4] Bernard Haurwitz and James M. Austin, Climatology, (New York: McGraw-Hill, 1944), 184.

July Mean Temperatures for
Various Frontal Positions

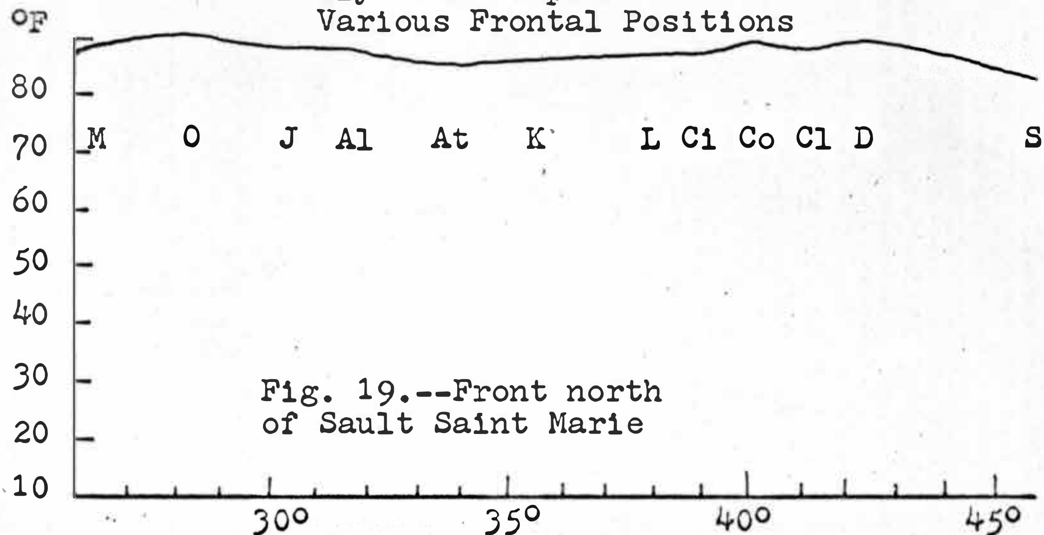

Fig. 19.--Front north
of Sault Saint Marie

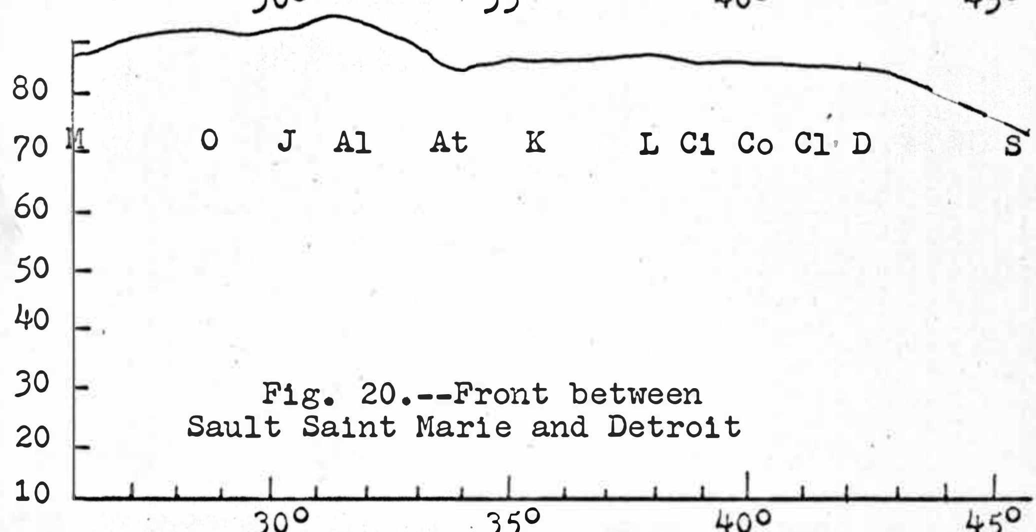

Fig. 20.--Front between
Sault Saint Marie and Detroit

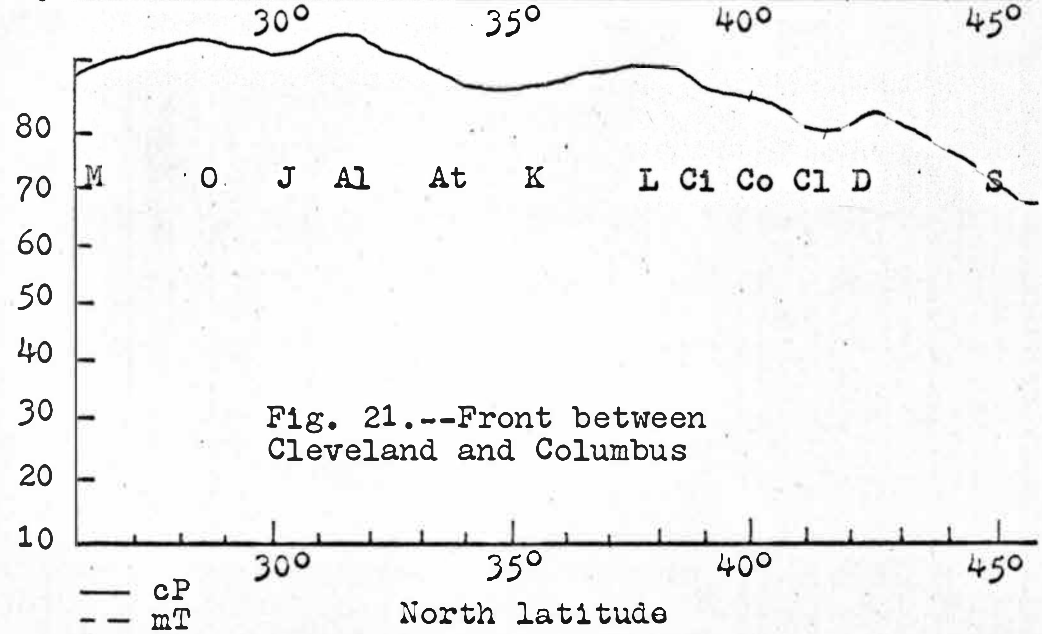

Fig. 21.--Front between
Cleveland and Columbus

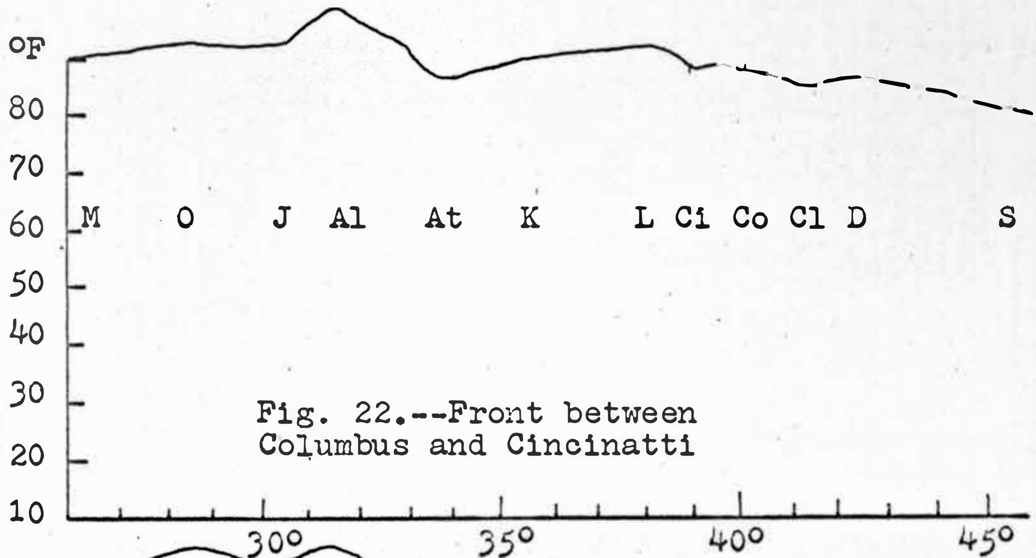

Fig. 22.--Front between Columbus and Cincinatti

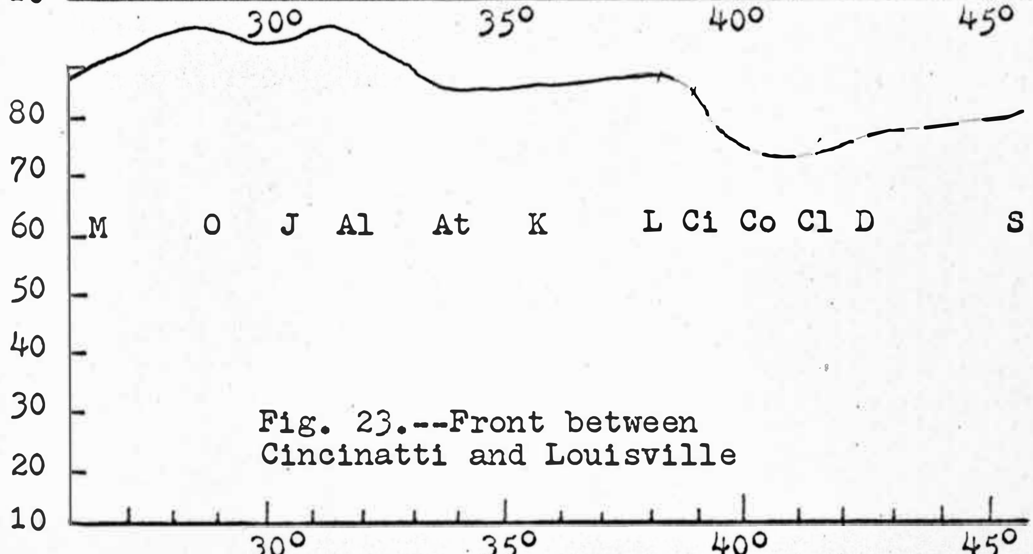

Fig. 23.--Front between Cincinatti and Louisville

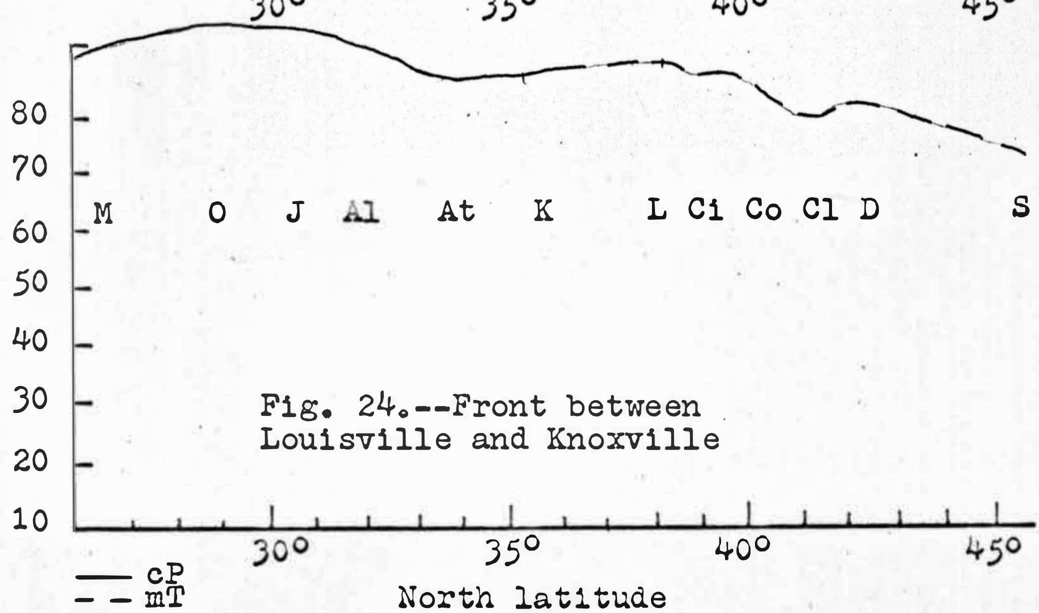

Fig. 24.--Front between Louisville and Knoxville

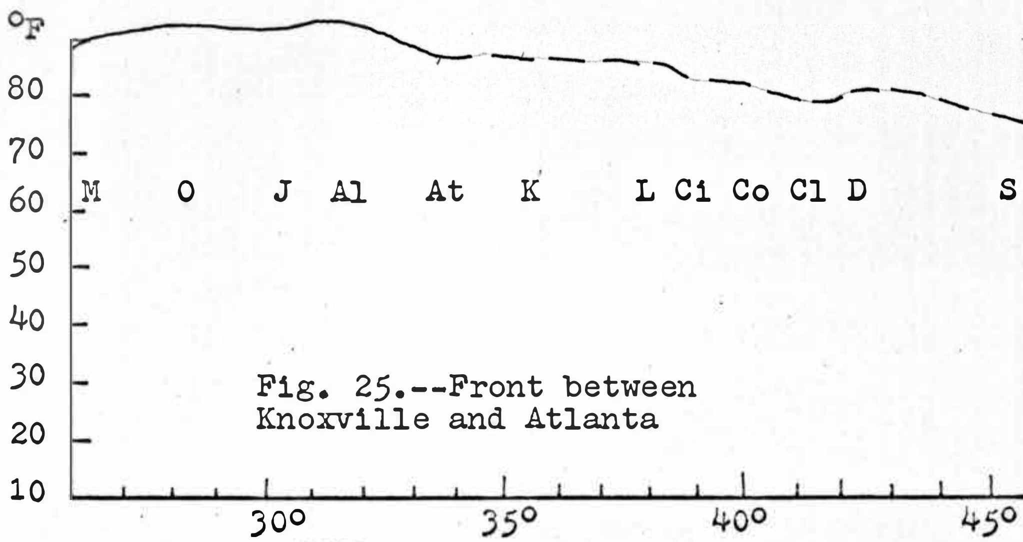

Fig. 25.--Front between Knoxville and Atlanta

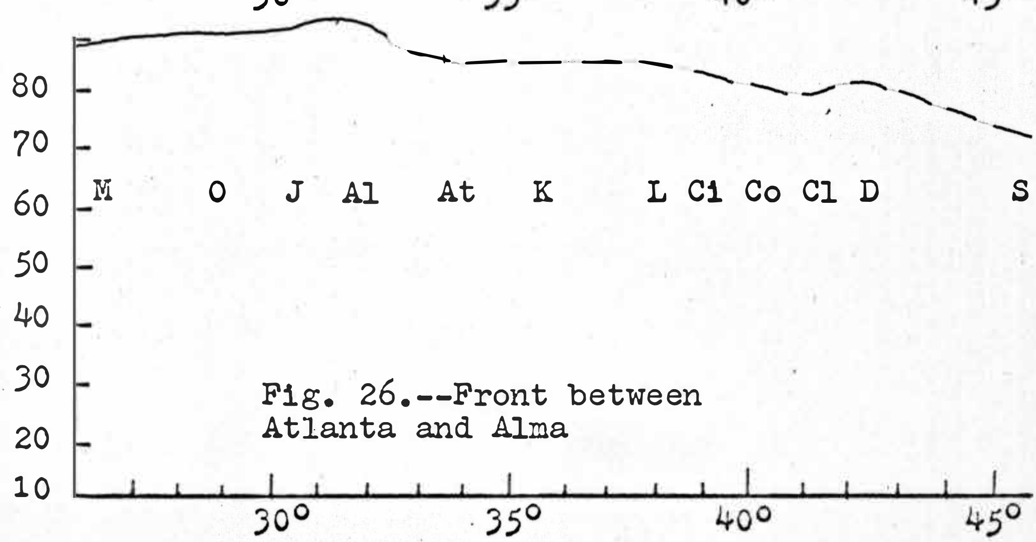

Fig. 26.--Front between Atlanta and Alma

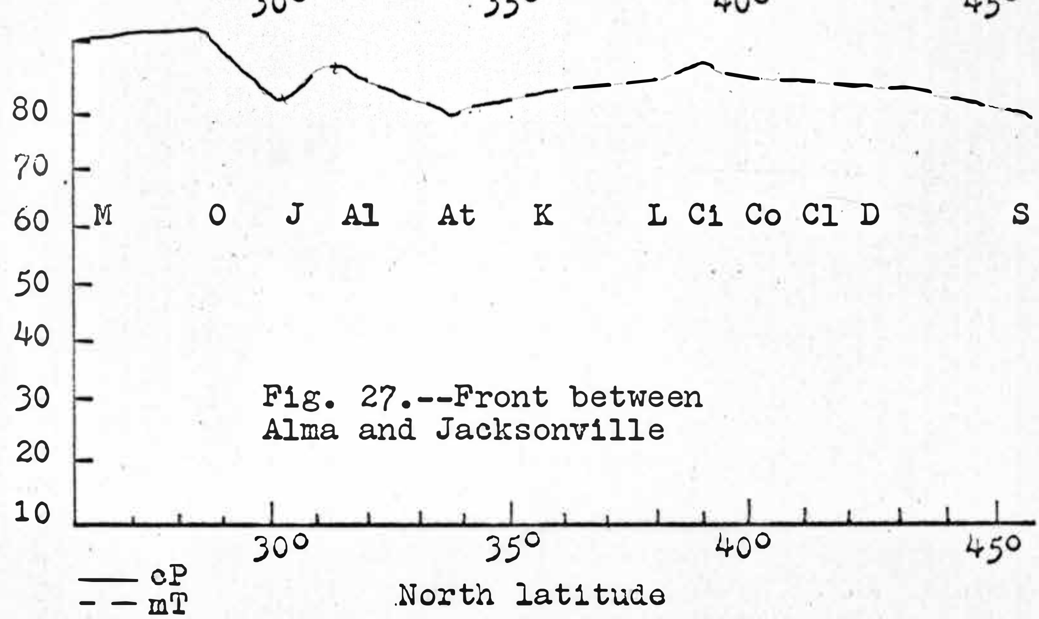

Fig. 27.--Front between Alma and Jacksonville

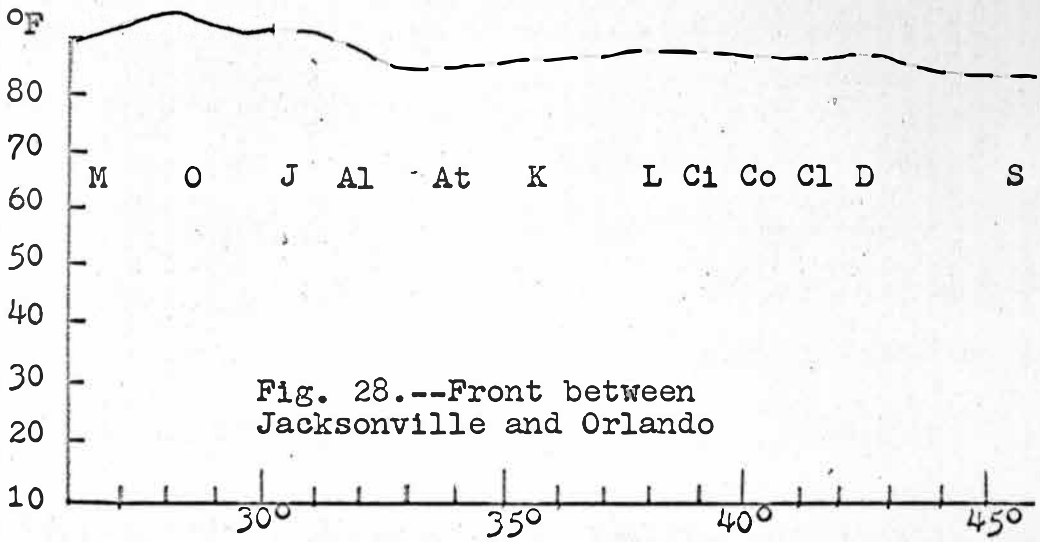

Fig. 28.--Front between Jacksonville and Orlando

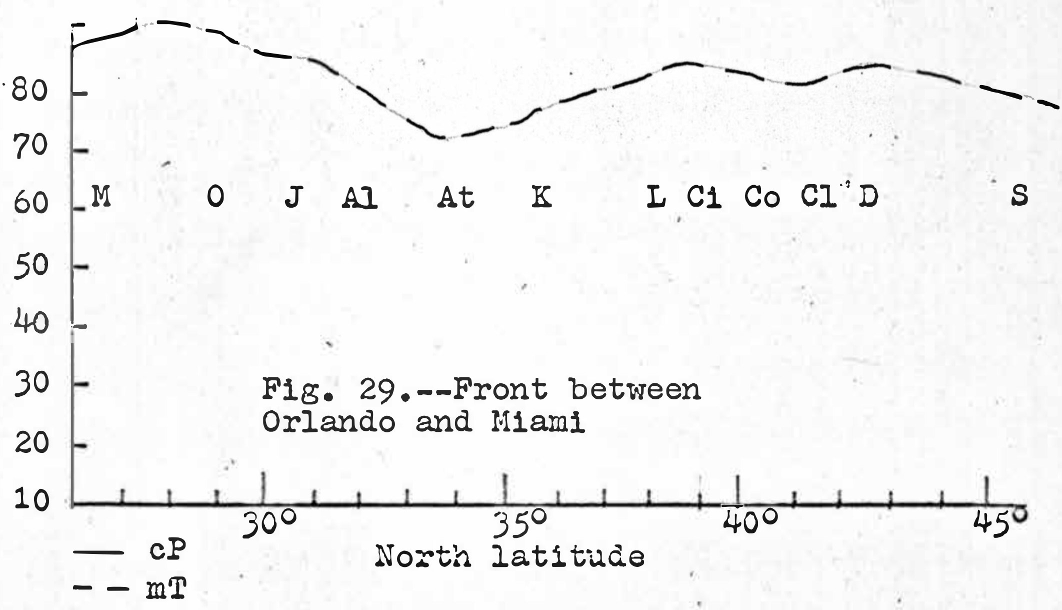

Fig. 29.--Front between Orlando and Miami

also important is the fact that during this time of the year the insolation received in the study area is quite uniform, and thus a steep temperature gradient can not be expected.

These two factors also explain why the polar front does not have the steep gradient associated with it as was true in January. Undoubtedly, a much greater contrast would have appeared between the two air masses had the minimum temperatures been graphed rather than the maximums, since the more continental northern latitudes cool faster at night due to the lower humidity of cP air and thus have greater diurnal ranges of temperatures.

Without exception, the gradient between stations exhibiting different air masses has a southward temperature increase. These frontal gradients seem to be steeper between those stations which have steep gradients regardless of the air masses present. Thus, the steep frontal gradient between Atlanta and Alma (Figure 26) is comparatively meaningless because steep gradients always exist between these two stations regardless of air mass positions. This can be explained by Atlanta's piedmont location which invariably causes cooler temperatures in both winter and summer than those of southern Georgia. This, then, tends to substantiate Namias'[5] statement that there are too many outside factors affecting temperatures to classify them according to air mass or frontal dominance.

In comparing the two extreme frontal positions, during July it is found that when the front is north of the study area (Figure 19) there is a latitudinal range of temperature of 11 degrees (from a low of 81 degrees at Sault Saint Marie to a high of 92 degrees at Orlando). At the other extreme, however, when the front is between Miami and Orlando (Figure 29), its most southern July position, there is an increase of 20 degrees from Atlanta, which recorded the lowest mean maximum of 73 degrees, to Orlando, which although still within the cP sector, recorded the high of 93 degrees.

There are several other peculiarities which appear on the July graphs. For instance, there are depressions in almost all of the latitudinal gradients at Cleveland, Knoxville, and Jacksonville regardless of the air mass or front present. Cleveland's lower temperatures can be explained by its lake-front location, and likewise

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[5]Namias, op. cit., p. 7.

Jacksonville's can be explained by a marine influence. Knoxville's depression, however, is more difficult to explain. Perhaps an increased cloud cover caused by the mountainous surroundings helps to keep Knoxville's temperatures lower. On the other hand, the placement of the station's thermometer or an inaccuracy in the instrument may be the cause of this anomaly.

It is also interesting that Orlando records higher mean maxima when in a cP sector (Figure 28) than it does when deep into mT air--93 degrees in cP air and 90 degrees when the front is in central Georgia. This is probably due to the fewer clouds associated with the cP air permitting greater heating. In addition, Orlando records the highest temperatures in July of any of the stations (95 degrees) even though, in one case, the polar front is between Orlando and Miami (Figure 28), thus putting the latter within the supposedly warmer mT air.

Summary

It has been found that surface temperatures are more homogeneous within mT air than in cP in winter, and that both summer air masses are more homogeneous than their winter counterparts. An appreciable temperature change appears to take place behind the polar front within the cP sector in winter, but in summer any such change is at a minimum.

Air masses appear to have a moderate influence upon surface temperatures, usually by modifying the existing patterns caused by the more dominant surface temperature-changing factors noted by Namias.[6] The surface thermal latitudinal gradient graphs indicate that there is a definite latitudinal increase in temperature as one progresses southward; however, the rate of increase appears to be little influenced by polar front or air mass movements, and the actual surface temperature changes caused by the air masses appear to be only slight.

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[6] Ibid.

CHAPTER V

CONCLUSIONS

One of the objectives of this study has been to emphasize the need for additional geographically-oriented air mass studies. There appears to be a particular need for studies of air mass movements, their frequencies, and their effects upon the environment of man through accompanying surface weather conditions. Only a very few studies of this type have been written, and most of these concerned limited study areas. The investigation presented in this thesis has attempted to fill a small portion of this geographical void.

As noted in the introductory chapter, it is difficult to assess the results of a study such as this due to the nature of climatological phenomena. That is, when isolating a limited number of meteorological factors for analysis, the conclusions of such a study must be qualified according to the factors used. For example, it has been shown in this investigation that air mass thermal modifications are closely related to the humidity present in the air mass.

Thus, although humidity was not one of the factors analyzed, it is nevertheless necessary to consider it in such an investigation.

Subjectivity is also an important consideration in such a study; in this case the subjectivity of both the Weather Bureau's map analysts and the author must be considered. That is, the original plotting of the air mass and frontal boundaries on the weather maps is open to subjective error, and this fact must be considered when working with the weather maps. Likewise, the author's interpretation of the polar front's position on days when it does not appear on the surface maps is quite subjective. It is thus important that the reader interpret the conclusions presented here with an understanding of these qualifications.

The normal positions, alignments, and movements of the surface polar front which were found in this study closely agree with the findings of earlier investigations. Therefore, while no new findings are presented regarding these aspects of the polar front, the agreement with other findings helps to give the rest of the investigation support, and it also suggests the normality of the study period chosen.

The polar front has been shown to be of definite influence in temperature changes, particularly in winter. However, again due to the subjective nature of the investigation, the exact location of change in relation to the front can not be determined. This temperature influence of the polar front has been shown to be much more pronounced in winter primarily because of the more uniform receipt of insolation in summer.

It was also determined that air mass control of surface temperatures appears to be important only in the more northern latitudes of the eastern United States. In the southern latitudes insolational control is the dominant factor. However, the constancy of temperatures in the southern latitudes is also due to the marine influence of the surrounding water bodies. Thus, it appears that the marine influence and insolational control are the dominant temperature-changing processes, whereas the air mass control of surface temperatures is only effective in the absence of the other two.

It has thus been found that the common definition of an air mass which refers to a "horizontally homogeneous" body of air is obviously not applicable to the surface conditions of the air. The only latitudinal homogeneity which does occur can be attributed to either a marine influence or a uniformity in insolation. This study has, therefore, upheld Namias' statement that there are too many outside factors affecting surface temperatures to correlate them with the air masses which supposedly dominate them. However, on the other hand, there was found to be marked contrasts between cP dominated temperatures and mT temperatures, and again this contrast was strongest in the more northern latitudes.

It may therefore be concluded that air masses possess surface temperature characteristics which vary considerably according to latitude, and other temperature-changing factors. The only apparent patterns which appear in these temperatures are caused by local temperature-changing processes; and the most noticeable thermal pattern that can be attributed to air mass control stems from the temperature changes that occur as an area's air mass dominance shifts, and even these temperature changes have been found to be greatly variable.

APPENDIX

METHODS USED IN RESEARCH

Grid Pattern

As noted in the text of the paper, in order to determine the mean position of the polar front a grid system was used in conjunction with the daily weather maps. The Polar Stereographic grid which was drawn on a transparent overlay was placed over each synoptic chart during the study period (see Figure 30), and the type of air mass or front appearing in each grid square was recorded on a tally sheet. If the polar front appeared in a square, a "2" was recorded for that square for that day. If the polar front was south of the square, a "1" was recorded signifying the presence of a cP air mass. If the front was north of the square in question, a "3" was recorded indicating the presence of mT air.

Each square was two-and-a-half degrees in latitude by five degrees in longitude. The entire system extended from 25°N to 50°N, and from 50°W to 90°W. However, since this area covers much more than the

Fig. 30.--Grid pattern used in research
(based on polar stereographic projection)

eastern United States, records were kept only for those squares which were over the study area. The resulting network included a pattern of thirty-nine grid squares.

The records for this part of the research were then transferred from the tally sheets to IBM punch cards, one card for each day of the study period. Hence, this data bank was composed of 310 cards.

Interpretation of Weather Maps

The interpretation of the weather maps was, for the most part, simply a matter of copying temperatures, dates, or air mass types from the charts to tally sheets which were later transferred to the IBM punch cards. The only major chart interpretation difficulty arose in attempting to classify air mass types on days when the polar front was not apparent at the surface. On these days the surface chart gave the impression that there was no boundary line between the air masses, but rather a large boundary zone in which considerable mixing of the different air masses was taking place. Such a condition required a subjective judgment to determine the surface division between the two air masses since a frontal classification would not be appropriate without a front actually being present. While each chart differed in appearance, the boundary line was usually approximated by studying the maps for the two adjacent days and then determining the frontal position of the day in question by interpolation.

A second cause for subjective judgment came in determining the air mass types which dominated the stations each day. Since the frontal position shown on the chart was for 1:00 a. m. only, and two of the temperatures were for a twenty-four hour period, it was necessary to determine whether the air mass type present over a station at 1:00 a. m. dominated the station's weather during the entire day. On the other hand, if the station was crossed by the polar front during the day it had to be determined whether the station was dominated by the first air mass present, the polar front, or the second air mass.

The decision usually depended upon the position of the front for the day in question and the following day. If the front was adjacent to the station on the day in question but several hundred miles away on the following day, the air mass present during the second day was considered dominant. If, on the other hand, the front was far away on the first day but adjacent to the station on the second day, the first day's air mass was considered dominant. On days when the front appeared to remain stationary, or was equally far away on both days, the day was classified as frontal. Thus, a day was not classified as frontal merely because it was passed over by the polar front. The front had to dominate the station's weather that day in order to receive this classification.

Computer Operations

The major computations carried out for this study were accomplished by the IBM 1620 computer of Western Michigan University's Computer Center. In order to use this equipment it was first necessary to record all of the data on punch cards which could then be read by the computer. Thus, two separate data banks were compiled. The primary bank consisted of one card for each station for each day during the study (3720 cards). On each card were recorded the station code, the date, the air mass which dominated that station's day, and the four daily temperatures for that station.

This data bank was fed into the computer behind a program which instructed the computer to find the frequency of each air mass type for both months for each station, the mean and standard deviation of each temperature type according to air mass association for both months for each station, and the mean and standard deviation of each temperature disregarding air mass association for both months for each station.

This same data bank was then put through the computer a second time using a different program. The new program was written to determine the mean and standard deviation of the four temperatures for each station for thirteen different positions of the polar front. From this program thirteen different sets of means and standard deviations were determined for each month for each station for each of the four temperatures.

One peculiarity of this program was that frontal positions were only determined if two adjacent stations had different air masses present. For example, if Detroit was dominated on a particular day by cP air and Cleveland was dominated by mT air that same day, this day was then classified as having the front between Detroit and Cleveland. If, however, any station of the twelve was dominated by the polar front on a particular day, then that day was considered as frontal, and it was not included in these calculations. Likewise, if one station was dominated by cP air, the southern adjacent station was dominated by mT air, and some other station further south was dominated by cP air, that day was put into the category of "north-south alignment of the front," and the mean temperatures were not computed for these days either. In July there was only one day (less than 1% of the days) that had a north-south alignment of the front, whereas in January almost 11% of the days fit into this category.

The second data bank consisted of the records of the grid square notations. Each card in this bank was for one day during the study period. In addition to the date, the type of air mass or front that appeared in each grid square was recorded. This data was then put into the computer and the total number of each type of air mass or frontal occurrence was added for each grid square.

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