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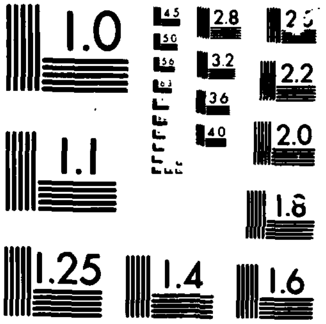

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ABSTRACT

Continentality: Its Estimation and Physical
Significance. (December 1985)
Juan Manuel Yee Fong, B.S., University of New Mexico
Chairman of Advisory Committee: Dr. Dennis M. Driscoll

An attempt has been made to quantify continentality better than exists in current indexes. Conventional indexes of continentality were examined and their deficiencies noted. Several different approaches were taken to develop alternative continentality indexes. These approaches were: dividing annual temperature range by the difference between summer and winter insolation, regressing annual temperature range on latitude and isolating the residuals such that positive ones represent continental locations and negative ones indicate maritime, or less continental, locations; and finding the summer and winter lag of temperature behind radiation with the cubic spline interpolation technique. All three approaches were used to examine the North American continent as a whole. In addition, the Rocky Mountain and Great Lakes-Appalachia regions were chosen for mesoscale analysis in order to determine what effect elevation and large water bodies have on lag.

Isopleth analyses of the plotted values of the proposed alternative indexes were compared with conventional index patterns for North America and with each other. Each newly developed index was evaluated as an appropriate measure of continentality and a physical (meteorological) explanation attempted for the patterns.

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CONTINENTALITY: ITS ESTIMATION AND PHYSICAL SIGNIFICANCE

A Thesis

by

JUAN MANUEL YEE FONG

Submitted to the Graduate College of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 1985

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CONTINENTALITY: ITS ESTIMATION AND PHYSICAL SIGNIFICANCE

A Thesis

by

JUAN MANUEL YEE FONG

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December 1985

DEDICATION

This thesis is dedicated to my parents, Yen Chin Yee and Chi Gu Sin Yee.

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The author would like to express his sincere appreciation to Dr. Dennis M. Driscoll, Professor John F. Griffiths, and Dr. Rudolf J. Freund for their assistance, guidance, and support. I am also grateful to the other members of the meteorology faculty and to my fellow Air Force officers for their support and encouragement. Credit is also due to the United States Air Force for giving me the opportunity to attend graduate school, and to Mrs. Jackie Strong, who typed the manuscript.

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1. INTRODUCTION

Continentality is a comparative measure of the differences between climates controlled by land masses and those controlled by water. It was first used, apparently, by W. Zenker in the 1890's. Continentality reflects the influence of the strength and direction of the general atmospheric circulation, topography, and aridity (Griffiths and Driscoll, 1982). The degree of continentality of a given location is, in general, proportional to its distance from a large body of water, modified by prevailing wind direction and topography. Oceanicity is the opposite of continentality, and characterizes a marine climate.

As a concept, continentality can be useful in helping to explain the similarities and differences in climate between various locations. There is an inherent problem, however, in defining continentality in a detailed and unambiguous manner. Part of the problem is that there is no way of assessing absolute continentality.

There are several ways in which continentality has been defined. One method is from a geographic point of view. The closer a location is to the center of a land mass, the more continental it is. Another definition can be based on a location's distance from the nearest ocean or other large body of water. A third way of describing continentality is in terms of climatic extremes and variability (e.g., temperature). A continental location experiences more climatic extremes and variability, and has more seasons than oceanic locations, where there is often only

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one season due to the uniformity of the climate. These definitions are by their nature relative measures of continentality, since they stress one or more variables, no one of which gives the absolute continentality index.

Of all climatic elements, temperature is probably the one most profoundly influenced by continentality. The most conspicuous difference between regions having continental climates and those with maritime climates is reflected in their daily, seasonal, and annual temperature ranges as well as in their lag times between radiation and temperature. Other meteorological elements affected by continentality are vapor pressure, cloud cover, precipitation, and wind direction and speed. There is more evaporation over water than over land and therefore humidities are lower in continental climates. With less evaporation comes reduced cloudiness and rainfall. Air masses originating over continental interiors form high pressure systems around which wind flow is anticyclonic (clockwise). Greater surface roughness makes wind speeds lower over land areas than over relatively smooth oceans.

The physical basis of continentality is in the different thermal properties of water and the various land substances. Soils have low heat capacities and heat transfer is through molecular conduction. Incoming solar radiation (insolation) penetrates only a very shallow layer. Virtually all heat energy, therefore, is gained and lost at the surface. For this reason, land areas heat and cool quickly. The air above, having a very low heat capacity and very large internal mobility, also changes its temperature rapidly in response to the heating and cooling at the surface. Water, on the other hand, experiences smaller temperature fluctuations due to its high heat capacity and its ability to transport heat via convection. Furthermore, insolation penetrates through a much deeper layer than in soil; not very much energy remains to heat the air above. In addition, evaporation is greater over water than over land surfaces, leaving less insolation available to heat the water. Lower humidities contribute to larger temperature ranges over land. As a consequence, daily and annual temperature ranges are greater over land than over water.

2. BACKGROUND AND LITERATURE REVIEW

Quantitative, or semi-quantitative, measures of continentality have been based on characteristics of radiation, temperature, precipitation, and frequency of air mass types. Continentality is manifested in temperature in three principal ways: range, lag, and variability. Range and lag have been used in the construction of continentality indexes. Indexes based on range have the general form

$$k = (mA/(\sin\emptyset + b)) + n, \qquad (1)$$

where k is the index of continentality, A the average annual temperature range (difference between the mean monthly temperatures of the extreme months, usually July and January in extra-tropical areas), $\emptyset$ the latitude; and b, m, and n are constants. Indexes based on air masses reflect, of course, the frequency of occurrence of air masses originating over continents, as opposed to those originating over large bodies of water.

a. Previous studies

Brunt (1924), following studies of R. Spitaler and G. Swoboda, related continentality to the annual temperature range and the annual range of the average global solar radiation intensity. His equation is:

$$Ne + 0.12 = \Delta t/(130.61\Delta S), \qquad (2)$$

where Ne is the continentality index, Δt is the annual range of mean monthly temperature (July minus January), and ΔS is the difference between the mean global solar radiation accumulated in the months of

January and July. Curiously, Brunt did not include a map of his results, nor did he specify units for temperature or radiation. The quantity Ne + 0.12 is equivalent to the ratio of the observed annual temperature range to a standard range of temperature expected for the location's latitude. It expresses the fraction of a 1° latitude band that would have to be covered by land in order for the entire parallel of latitude to have the same annual temperature range as that observed at a given latitude. For example, a station at 45°N and Ne = 0.5 means that half of the 45° parallel must be covered by land in order that the mean annual temperature range of the entire parallel be the same as the station's observed annual range. This term also measures the response in monthly mean temperature to a unit change in the mean solar radiation intensity. If the response is zero (e.g., an oceanic climate), then the corresponding continentality index is -0.12. Calculated values of Ne ranged from about -0.12 in mid-ocean in the southern hemisphere to approximately 1.3 in Siberia.

Zenker (Conrad, 1946) proposed the following formula for continentality:

$$k = (1.2A/\phi) - 20 \; . \tag{3}$$

Latitude was included to account for generally increasing annual temperature range with increasing latitude. Johansson, Gorczynski, and others modified Zenker's formula by taking the sine of latitude and introducing different constants. The constants for Johansson's formula,

$$k = (1.6A/\sin\phi) - 14 \tag{4}$$

were derived by arbitrarily choosing two stations which seem to represent best a totally continental and a totally oceanic climate (Landsberg, 1958). Stations selected were Thornshavn in the Faroe Islands (k = 0%) and Verkhoyansk in eastern Siberia (k = 100%). At low latitudes, k may far exceed its theoretical maximum of 100%. In some cases k is negative. Temperature ranges are so small in the interval 10°N - 10°S that latitude in this equation becomes the dominant factor in the expression for continentality.

Conrad (1946) introduced a correction factor that yields more reasonable values for the tropics. Ten degrees are added to the latitude to give the following equation:

$$k = (1.7A/\sin(\emptyset + 10)) - 14 \quad . \tag{5}$$

Conrad's formula, however, still produces some negative values. Another disadvantage is that it loses its validity at latitudes greater than 80 degrees. To correct for this, for all latitudes greater than 80 degrees, $(\emptyset + 10)$ is assumed to equal 90.

Several workers have plotted and analyzed continentality according to Conrad's definition for a number of areas. These areas include: New England (Fobes, 1954), the western United States (D'Ooge, 1955), the Great Lakes region (Kopec, 1965), the Texas coastal zone (Jehn, 1977a and 1977b), and Anglo-America (Trewartha, 1981). Using Johansson's formula (Eq. 4), MacKay and Cook (1963) constructed a map of continentality for Canada. Each of these maps shows the moderating influence of upwind bodies of water and distance from that water. Effects of topography also are apparent. In North America, index values are generally lower east of the Great Lakes and Hudson Bay and are higher to the west. Isolines of continentality are more closely spaced along the coastlines of North America than in the interior. In addition, the gradient along the west coast of the continent is tighter than along the eastern seaboard (Fig. 1).

Prescott and Collins (1951) constructed worldwide maps of the lag of air and sea surface temperatures behind radiation by means of elementary Fourier analysis. They calculated the phase angle of the first harmonic of the annual temperature curve, and that of twelve months of solar radiation, and expressed the difference in degrees, which is essentially the same as days. This lag of temperature behind solar radiation in days is in itself an index of continentality. Coastal stations are late in phase while continental stations are early. Lags along the western edge of continents in the middle latitudes are longer than along the eastern edges, due to the influence of the westerly flow.

In a continental climate, spring months and the corresponding autum months have about the same mean temperatures. At coastal stations, months with comparable temperatures occur later in the year. This delay, or lag, in maritime climates was used by F. Kerner to define an index of oceanicity called the thermoisodromic ratio:

$$O = ((To - Ta)/A)100 \qquad (6)$$

where O is the degree of oceanicity in percent, A is the annual temperature range, and To and Ta are the October and April mean temperatures, respectively (Landsberg, 1958). Kerner's results agree fairly well with conventional maps of continentality. A high degree of oceanicity

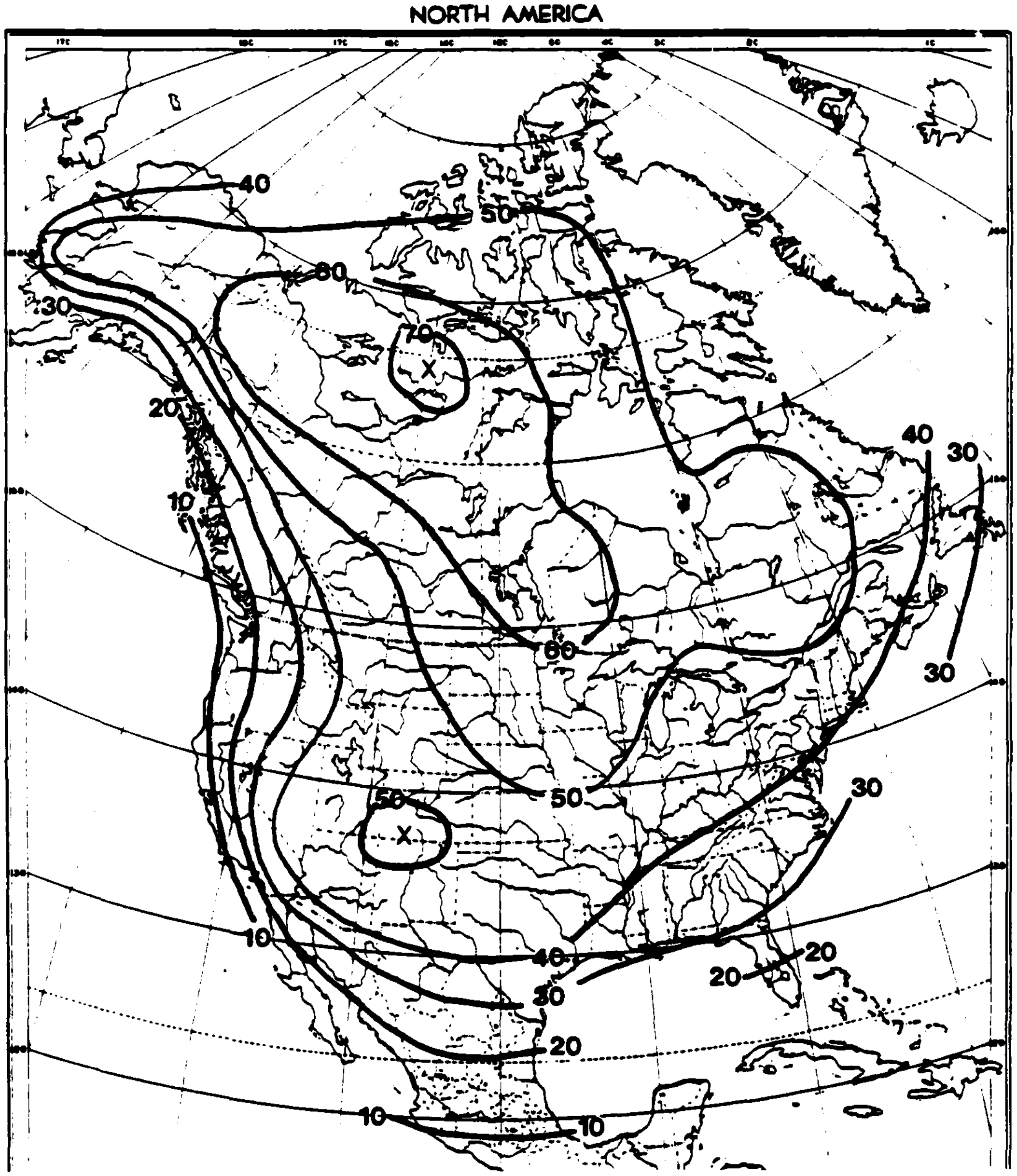

Fig. 1. Continentality of North America according to Conrad. Map of North America adapted from Leppard (1937).

corresponds to low continentality index values.

Sumner (1953) calculated the standard deviation of mean monthly temperatures for a number of stations in Anglo-America. He did not use temperature variation as an index of continentality, but his patterns of mean monthly temperature standard deviations are very similar to those shown by, for example, Conrad's map of continentality for North America.

Oliver (1970) plotted average temperature and precipitation data for all twelve months for a number of stations on a climograph and connected the extreme points with a straight line to obtain the long axis. The longer the axis, the larger is the annual temperature range and the more continental is the station. Also, a small angle (subtended from the vertical) indicates the dominance of continental air masses (those originating in the interior of a continent) throughout the year while a high angle means maritime air masses (those forming over large bodies of water) dominate. Perfect continentality and perfect oceanity are represented by vertical and horizontal lines, respectively. His formula for continentality is:

$$C = L\cos A \tag{7}$$

where L is the comparative length of the long axis and A is the axis' angular deviation from the vertical.

By introducing precipitation, Oliver unnecessarily complicated the elucidation of continentality. Annual precipitation amount should not be used as a measure of continentality, because the occurrence of precipitation is influenced by more important factors such as orography and transitory circulation systems.

Berg (1944) formulated an index based on the relative frequencies of continental and maritime air masses:

$$K = c/(c + m) \tag{8}$$

where c and m are the percentage frequencies of continental and maritime air masses, respectively. Quite often, however, it is difficult to distinguish air mass types. They often have a combination of continental and marine characteristics, and such a distinction is both difficult and arbitrary.

b. Evaluation of existing indexes

Contemporary representations of continentality, such as are found in textbooks of meteorology and climatology, use indexes based on the annual range of temperature as noted above. The fundamental contributor to annual range, however, is not continentality but the variation of insolation over the year. To eliminate this influence, these indexes incorporate a corrective term as noted (ΔS, sine ϕ or sine $(\phi + 10)$), which, when used as the denominator in the expression for continentality, presumable makes the resultant index essentially independent of latitude so that only the effects of continentality remain. As Conrad and Pollak (1962) note, the annual temperature range must be reduced to equality at all latitudes.

This compensation, however, is not adequate. Assuming a reasonable average atmospheric transmission coefficient of 0.7 and taking the difference (ΔS) between summer (June + July) and winter (December + January) insolation, then dividing by $\sin\phi$ or $\sin(\phi + 10)$, yields values that vary considerably with latitude (Table 1). These values should be nearly equal if incorporating latitude properly corrects for the latitudinal differences in insolation. Employing a sine function implies that ΔS is a maximum at 90 degrees, but the highest value occurs at approximately 55 degrees. A better correction could be to divide annual temperature range by the ΔS value corresponding to a location's latitude.

Another deficiency of previous studies, in this case of those using the lag of temperature behind radiation to indicate continentality, is the implication (and perhaps the assumption) that these lags are equal in length throughout the year. In fact, this lag varies. Annual temperature curves for stations outside the tropics are, in general, not symmetrical; the lag of temperature after insolation is not the same for summer maximum and winter minimum (Driscoll, 1984). Thus, the best-fit method of Fourier analysis which Prescott and Collins (1951) attempted, which predicated lag based on the first harmonic only, is misleading. Continentality can thus be seen as a dynamic, not static, climatological indicator.

A more appropriate index of continentality based on lag should therefore be possible. Lags for both winter and summer can be constructed and mapped. The data needed are simply the times, to the nearest day, when mean daily temperatures are a maximum and minimum over the year.

Table 1. Latitudinal variation of ΔS, $\Delta S/\sin Ø$, and $\Delta S/(\sin (Ø + 10))$.

LAT (Ø)	ΔS (Jun + Jul) - (Dec + Jan)	Dividing ΔS by Sin (Ø)	Dividing ΔS by Sin (Ø + 10)
90	791	791	803
85	793	796	796
80	802	814	802
75	823	852	826
70	865	921	878
65	915	1010	947
60	966	1115	1028
55	991	1210	1093
50	981	1281	1133
45	945	1336	1154
40	884	1375	1154
35	803	1400	1136
30	706	1412	1098
25	596	1410	1039
20	477	1395	954
15	348	1345	823
10	215	1238	629
5	77	883	248
0	- 61	--	- 351

3. OBJECTIVES

The objectives of this research are:

(1) To develop an index of continentality based on annual temperature range which compensates for the annual variation of insolation more satisfactorily than existing indexes;

(2) To develop indexes of continentality based on the lag of temperature behind insolation in summer and winter;

(3) To obtain suitable temperature data for an appropriate number of stations in North America and map the indexes developed in (1) and (2) for this continent;

(4) To obtain temperature data sufficient for a mesoscale (regional) analysis of continentality in the Rocky Mountains of the United States and southern Canada, and the area from the Great Lakes southeastward to the Atlantic Ocean, and therewith determine the influence of elevation and the proximity of large water bodies on continentality; and

(5) To compare and contrast the resultant maps of continentality, attempt a physical (meteorological) explanation for them, and evaluate each as an appropriate measure of continentality.

4. DATA AND PROCEDURE

For the purposes of this study an appropriate distribution of stations throughout the three political entities in North America is required. The greatest number of stations with long-term temperature records is in the United States. Some of these U.S. stations were deleted to ensure a more equitable distribution of stations throughout North America. There were 77 U.S. stations, 42 Canadian stations, and 9 Mexican stations for a total of 128 (Fig. 2) for the macroscale (continental) analysis. For the mesoscale analysis of continentality in the Rocky Mountains, 90 stations were selected (Fig. 3). About half of the stations were below 1500 meters elevation. One hundred nineteen stations were used to analyze the Great Lakes-Appalachia region (Fig. 4).

There is a question of whether to use the mean monthly maximum, average, or minimum temperatures for each station. A preliminary analysis showed that there is practically no difference between using maximum, minimum, or average temperature; the ΔT values required to achieve objective (1), and the times of the year at which temperature maximizes and minimizes (objective 2), are virtually identical for all three. Because mean monthly maximum and minimum temperature records are not readily available for all stations in North America, monthly temperature means were used to approximate daily mean temperatures. Information for each station consisted of 30-year values of the mean daily average temperature for each month, as well as latitude and elevation.

Data should be from coincident time periods for all three countries in North America. The normal period 1941-1970 was used for Canada

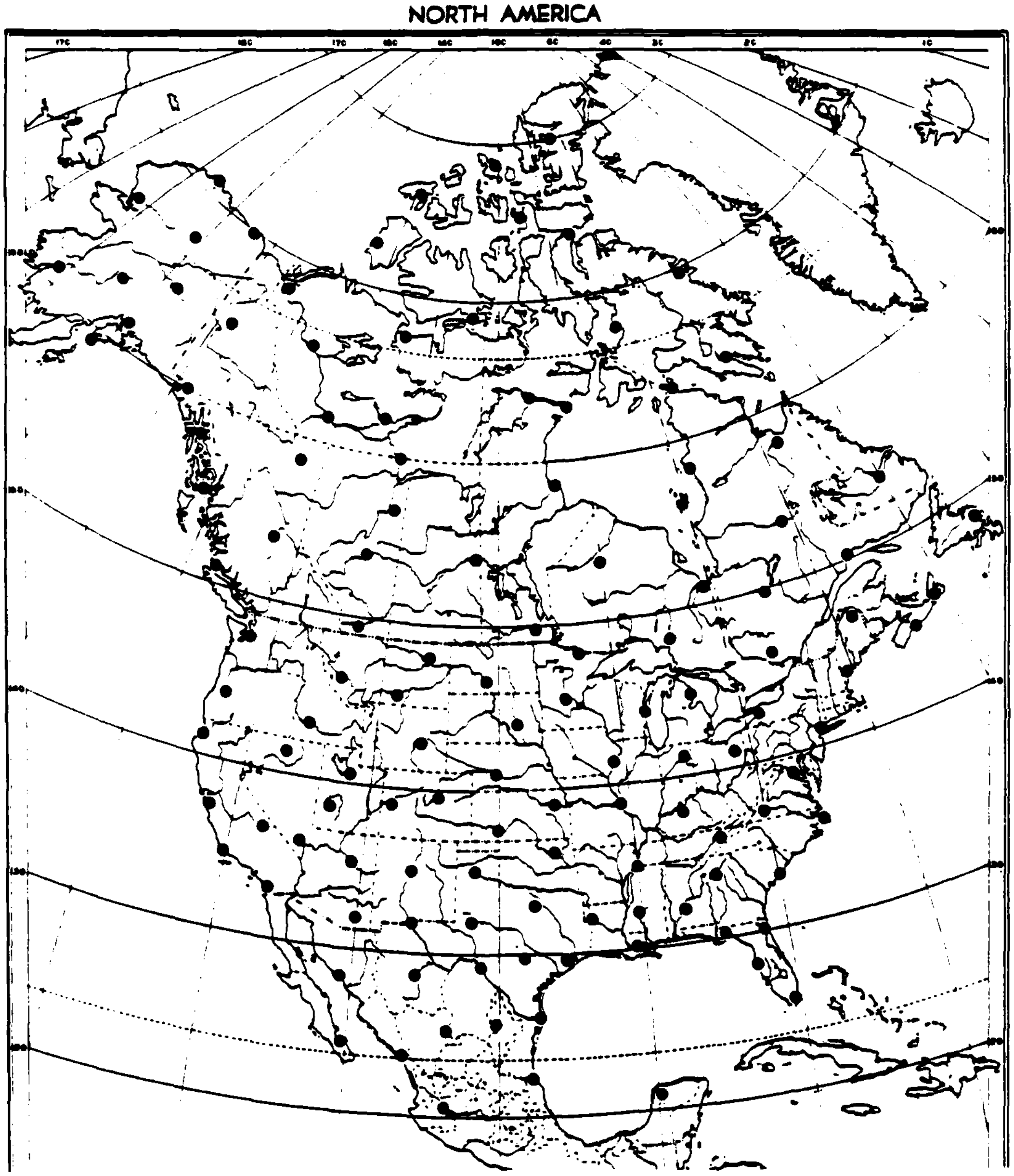

Fig. 2. Stations used for continental scale analysis. Map of North America adapted from Leppard (1937).

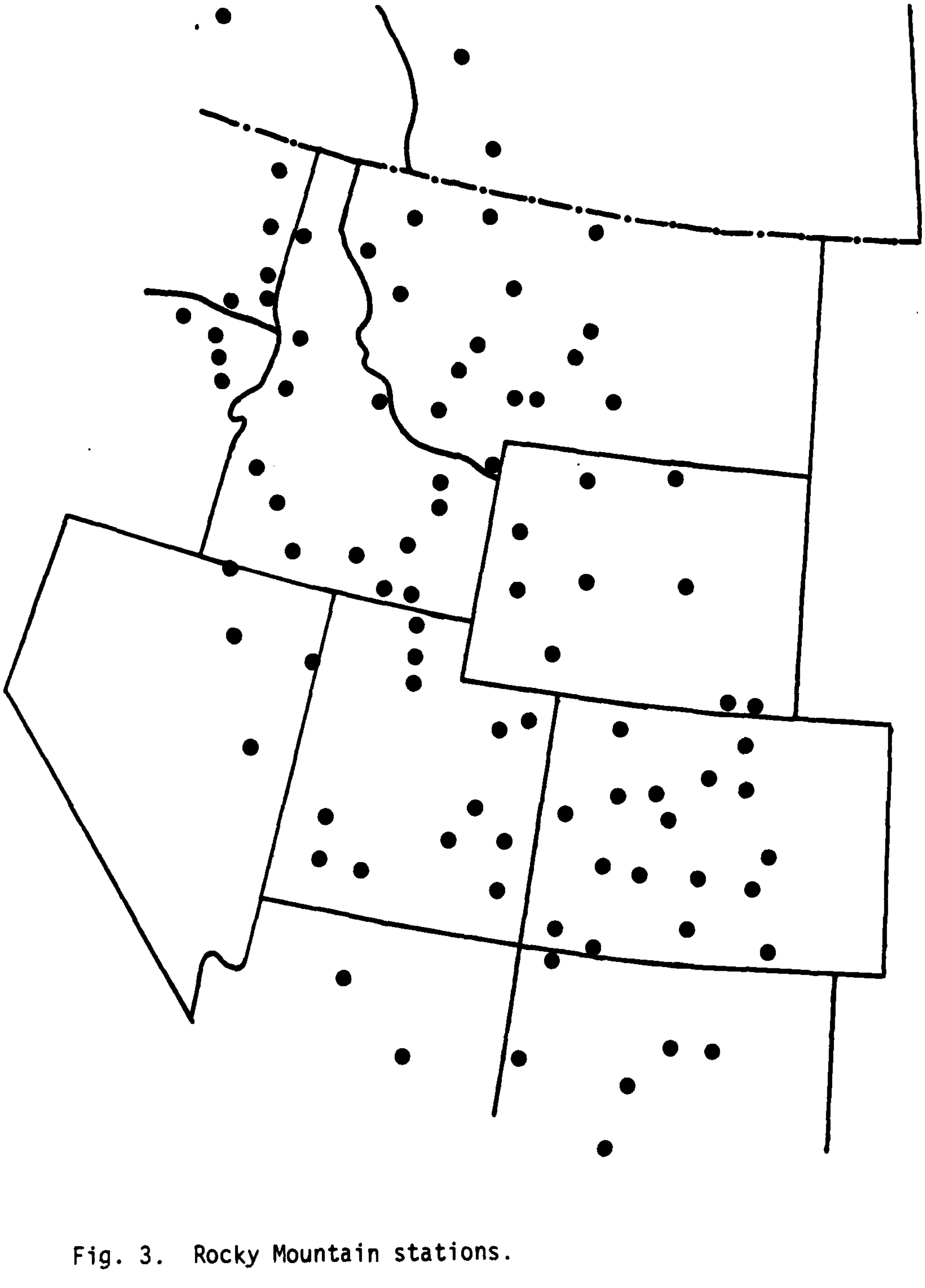

Fig. 3. Rocky Mountain stations.

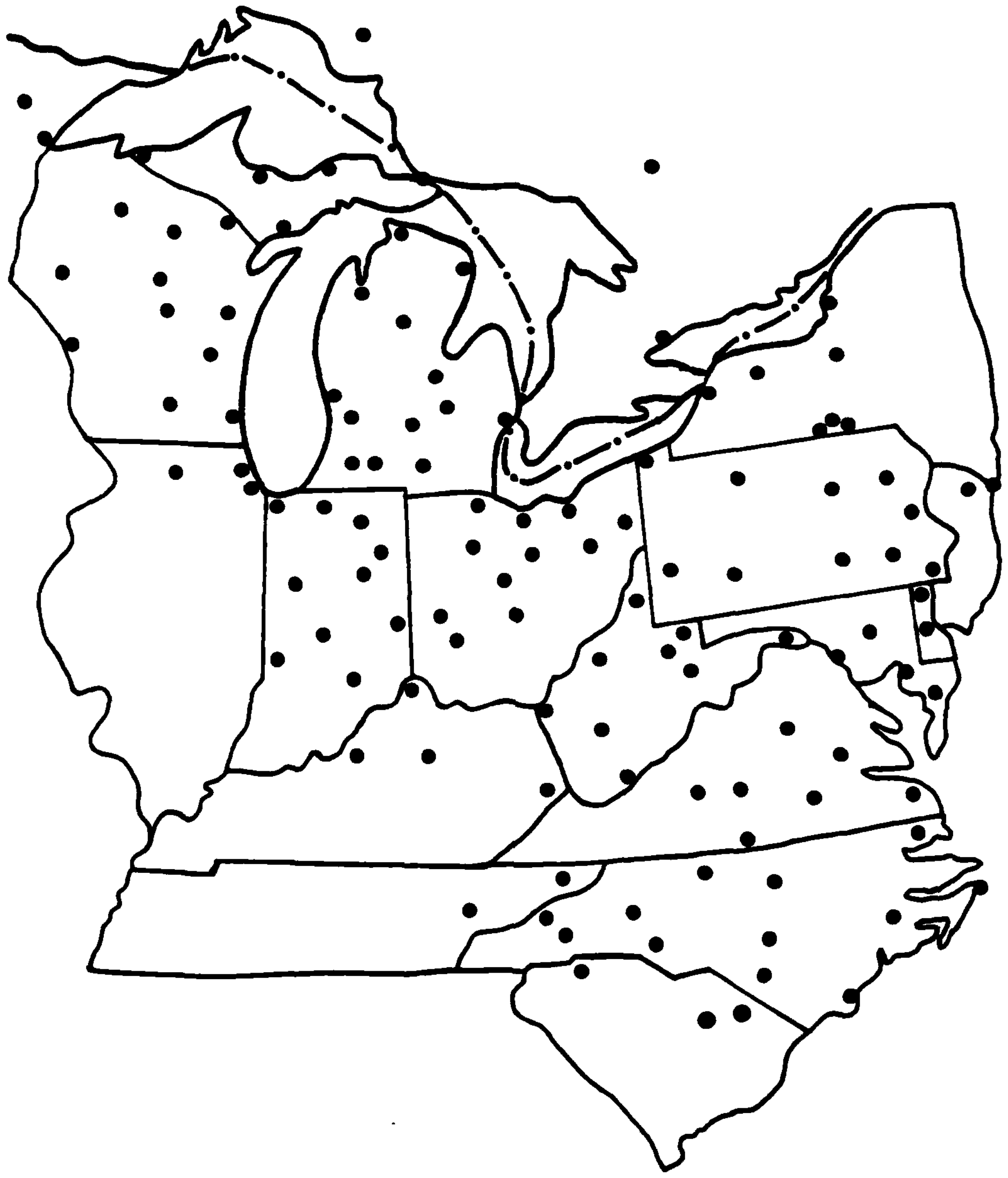

Fig. 4. Great Lakes-Appalachia stations.

because it was the only period for which temperature information was available. The Mexican temperature normals utilized were based on the period 1931-1960. Temperature records from the periods 1941-1970 and 1951-1980 were available for the United States. The period 1941-1970 was chosen for U.S. stations to provide the most overlap (20 years) among the three countries, thereby keeping the data as homogeneous as possible.

The first objective is to develop an index of continentality that compensates for the annual variation of radiation better than existing indexes. The annual temperature range for each station was divided by a seasonal difference in radiation received (ΔS) that corresponds with the whole degree of latitude nearest that station. Values of ΔS were calculated by subtracting the sum of December and January radiation from the sum of June and July radiation. The difference between January and July radiation could have been used, as Brunt (1924) did, but the mean temperature of a particular month is determined, in part, by the radiation received during the preceding, as well as current, month. Since most maximum and minimum temperatures in North America occur in July and January, respectively, radiation received during the months of December and January, and June and July, was used to calculate ΔS. Regardless of how ΔS is calculated, the latitudes of maximum ΔS are almost identical (Fig. 5). Since, when ΔS is in units of W $m^{-2}day^{-1}$ and range is in degrees Celsius, the resultant values are small, they were multiplied by a scaling factor of 1000 to yield integers. These numbers were then plotted and an isopleth analysis performed.

An alternative approach to developing a better continentality index

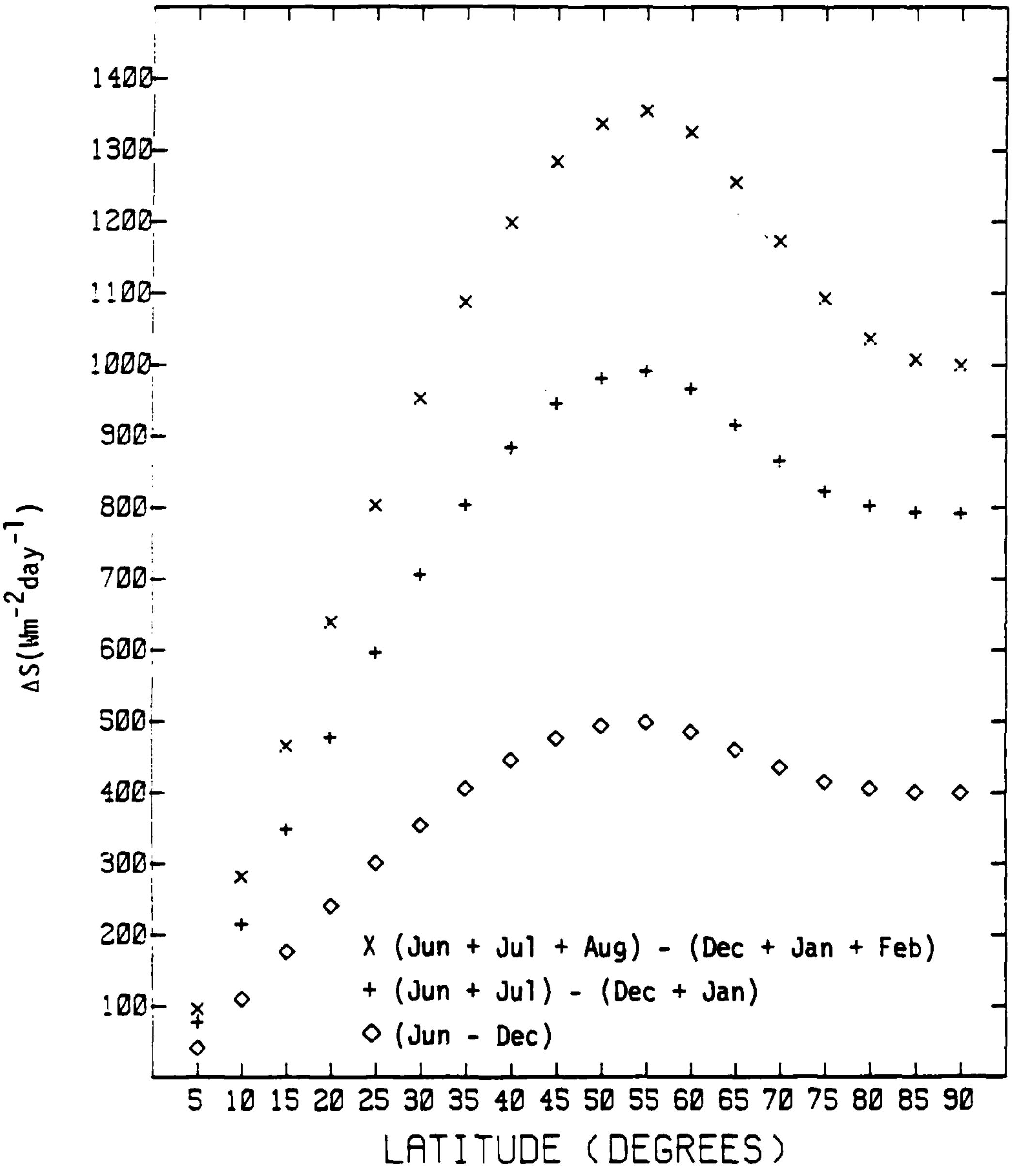

Fig. 5. (Jun + Jul) - (Dec + Jan) radiation versus (Jun + Jul + Aug) - (Dec + Jan + Feb) radiation versus (Jun - Dec) radiation.

based on annual range of temperature is that of regressing the annual temperature range on latitude and isolating the residuals from the regression line. Residuals were plotted and an isopleth analysis performed. Regression results are relative. Positive values can be considered to represent continental stations while negative values indicate oceanic, or less continental, climates.

To calculate the summer and winter lag of temperature behind radiation, a method of determining the dates of maximum and minimum temperature had to be found. It had to be one that can approximate daily temperature values from monthly means because daily means are not available for North American stations during the period 1941-1970.

The technique known as cubic spline interpolation was employed. References to spline functions are found in the mathematical, but not the meteorological, literature. A smooth curve is fitted through a given set of data points on an X-Y plot. From that curve, values of Y lying between the given data points can be calculated. In our case the X-coordinate is time in days, the Y-coordinate is temperature (°C), and the interpolating interval is one day.

Each interpolation interval is connected by a third order, twice differentiable polynomial. Second derivatives are then calculated and joined together to form an interpolating curve called a cubic spline function. Details on cubic splines are found in Appendix A. Mean daily temperatures were generated for the periods December-January-February and June-July-August, and dates of maximum and minimum temperature were determined by inspection.

With the spline technique, a minimum of three initial data points is required to determine dates of maximum or minimum temperature. But three initial data points produced dates that deviated from the "true" dates of maximum or minimum temperature by a week or more. The true dates of maximum and minimum temperature are those dates on which the highest and lowest mean daily temperatures usually occur, based on long-term climatological normal periods (e.g., 30 years). To determine the true dates precisely would entail using the actual recorded daily maximum and minimum temperatures and averaging them over 30 years. Calculating true dates for every station used in this investigation would have taken a considerable length of time. In addition, daily temperature records were not available for all of the stations, in particular those in Canada and Mexico. The actual dates of maximum and minimum temperatures were therefore estimated.

To estimate these true dates using only three data points, smooth curves were drawn manually through the three highest and three lowest mean monthly temperatures of a few selected stations, and the dates of maximum and minimum temperatures determined by inspection. Assuming that the mean temperature of any month occurs on the 15th day, and if the preceding and the following months have the same mean temperature, then the maximum or minimum point of the curve occurs on the 30th day of the 60-day interval. The spline function, however, places the maximum (minimum) temperature eight days later than it should be. For example, if we assume that June and August have the same mean temperature (less than July's), then the maximum temperature of the year occurs on or about July 15, as opposed to the spline date of July 23. After some experimentation, it was found that using five data points (mean monthly temperatures) instead of three yielded much better results. Dates of maxima and minima were consistently closer to true values, differing non-systematically by 3-4 days at the most. It was decided, therefore, to use the mean temperature of the warmest (coldest) month of the year plus the mean temperatures of the two preceding and the two succeeding months, as input to the cubic spline procedure. If, for example, the coldest month is January, then the mean temperatures of November, December, January, February, and March are used to calculate the date of the minimum temperature of the year.

Once the dates of maximum and minimum temperature were known, differences in days were taken between those dates and the dates of the two solstices to find the summer and winter lag of temperature behind radiation. The differences were plotted and analyzed. Lag patterns were also compared with the patterns of other continentality indexes.

5. RESULTS

If we envision a hypothetical circular, flat land mass totally surrounded by water, it is reasonable to assume that the highest continentality is situated at the exact center of that land mass. Prevailing wind currents such as the westerlies would shift the location of the maximum continentality in the direction of the wind flow (downstream). Topographic features affect the wind flow and consequently play a role in determining a particular location's index of continentality.

Considering the North American continent as a whole and taking into account the prevailing westerly wind flow, the topography, and the fact that all of northern Canada is an archipelago, the theoretical center of continentality would likely be located somewhere along the U.S.-Canadian border or just to the north of it, between 50-55°N latitude and 95-100°W longitude. In the absence of the Rocky Mountains, the center would be shifted eastward to an area situated north of the Great Lakes and south of Hudson Bay.

An isopleth analysis of continentality index values derived by dividing annual temperature range by annual variation of insolation for 128 stations in North America is shown in Fig. 6. The patterns exhibit some similarity to Conrad's map of continentality for North America (Fig. 1). An "X" on the map means a maximum value while an "N" signifies a minimum value. Index values are highest in the northern interior of the continent, with a ridge running down the center from north central Canada, through the Great Plains of the United States, into the interior of Mexico; and lowest along the coastlines, with lower values downwind (to the east) of the Great Lakes and Hudson Bay. The tight

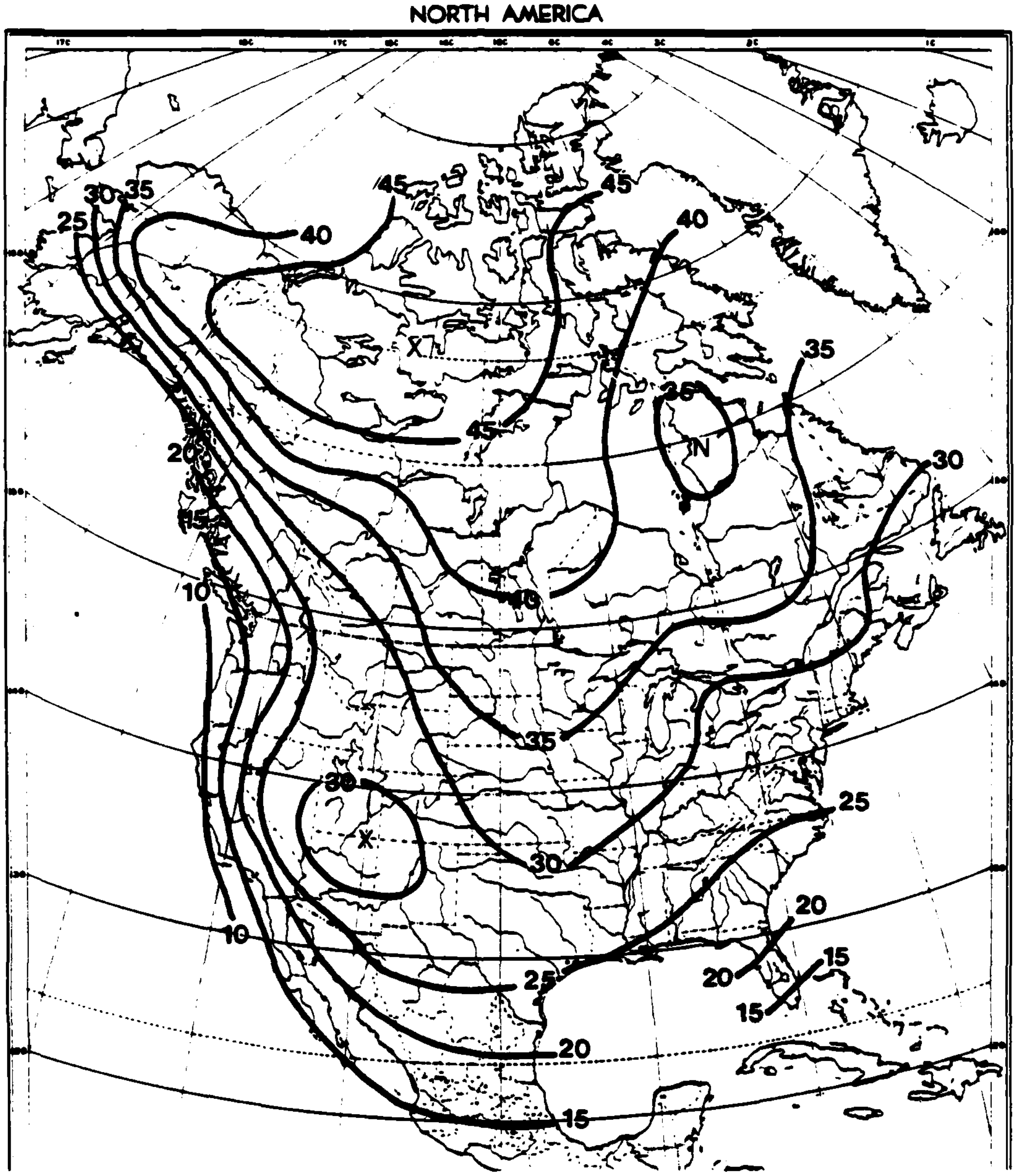

Fig. 6. Continentality of North America using A/ΔS. Map of North America adapted from Leppard (1937).

gradient along the west coast reflects the blocking action of the coastal ranges against the intrusion of maritime air--although to a lesser extent in the Puget Sound and Columbia River Valley areas, where topographic breaks permit a farther eastward penetration of this air.

The maximum continentality index values noted above (A/ΔS) are at 65-70°N, which is also where Conrad's maximum continentality of North America occurs. An index of continentality that compensates for the annual variation of insolation by dividing annual temperature range by ΔS therefore does not show the highest degree of continentality where it is hypothesized to be.

The next approach was to regress annual temperature range on latitude for the same 128 stations in North America (Fig. 7). An isopleth analysis of the residuals (Fig. 8) is similar to Conrad's North American continentality index patterns (Fig. 1) and to Fig. 6 (A/ΔS). In Fig. 8, positive residuals indicate continental climates and negative residuals represent locations with maritime, or less continental, climates. Particularly evident in all three of Figures 6, 7, and 8 is the influence of Hudson Bay and the Great Lakes. Index values are higher to the west and lower on the downwind (east) side of both these water bodies. There is, however, one notable exception to the similarity. While Conrad's maximum continentality and that of A/ΔS are located at 65-70°N, the largest positive residuals in Fig. 8 are located at 50-55°N along the 100th meridan, which is where the highest degree of continentality should theoretically be.

Figures 9 and 10 show the summer and winter lags (in days) of the maximum and minimum temperature behind radiation, respectively. If lag

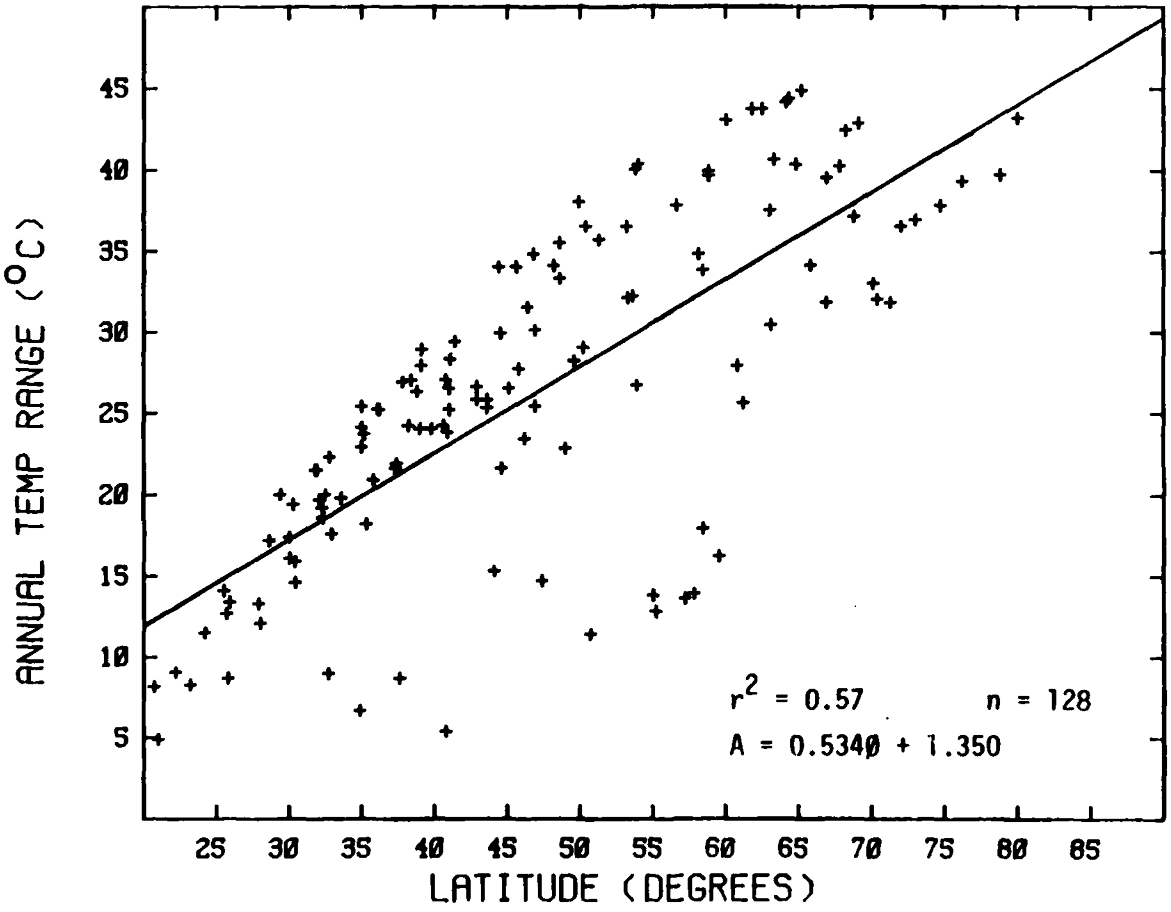

Fig. 7. Annual temperature range (A) as a function of latitude (ϕ) for 128 stations in North America, and the resulting regression line.

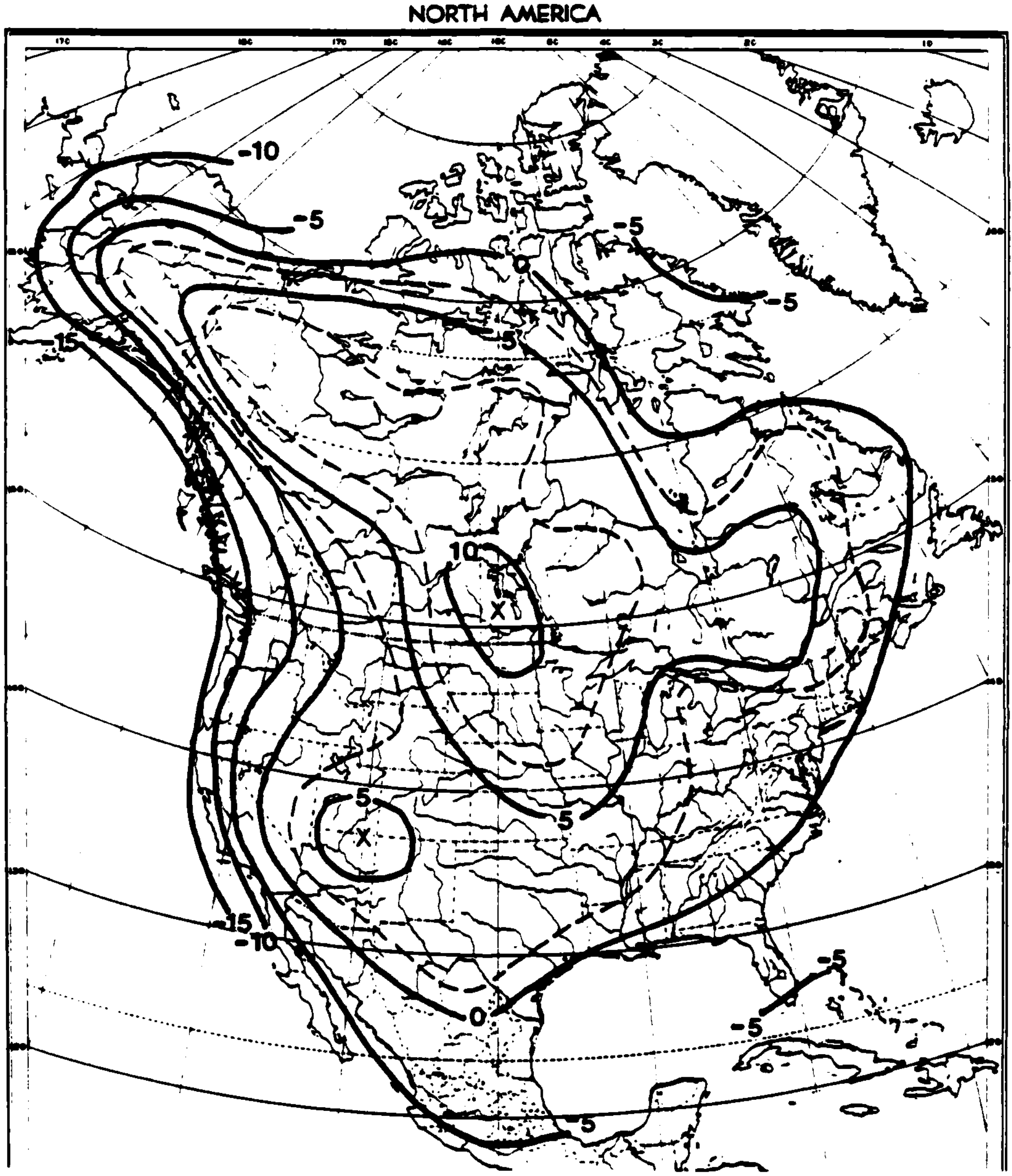

Fig. 8. Regression line residuals for 128 North American stations. Map of North America adapted from Leppard (1937).

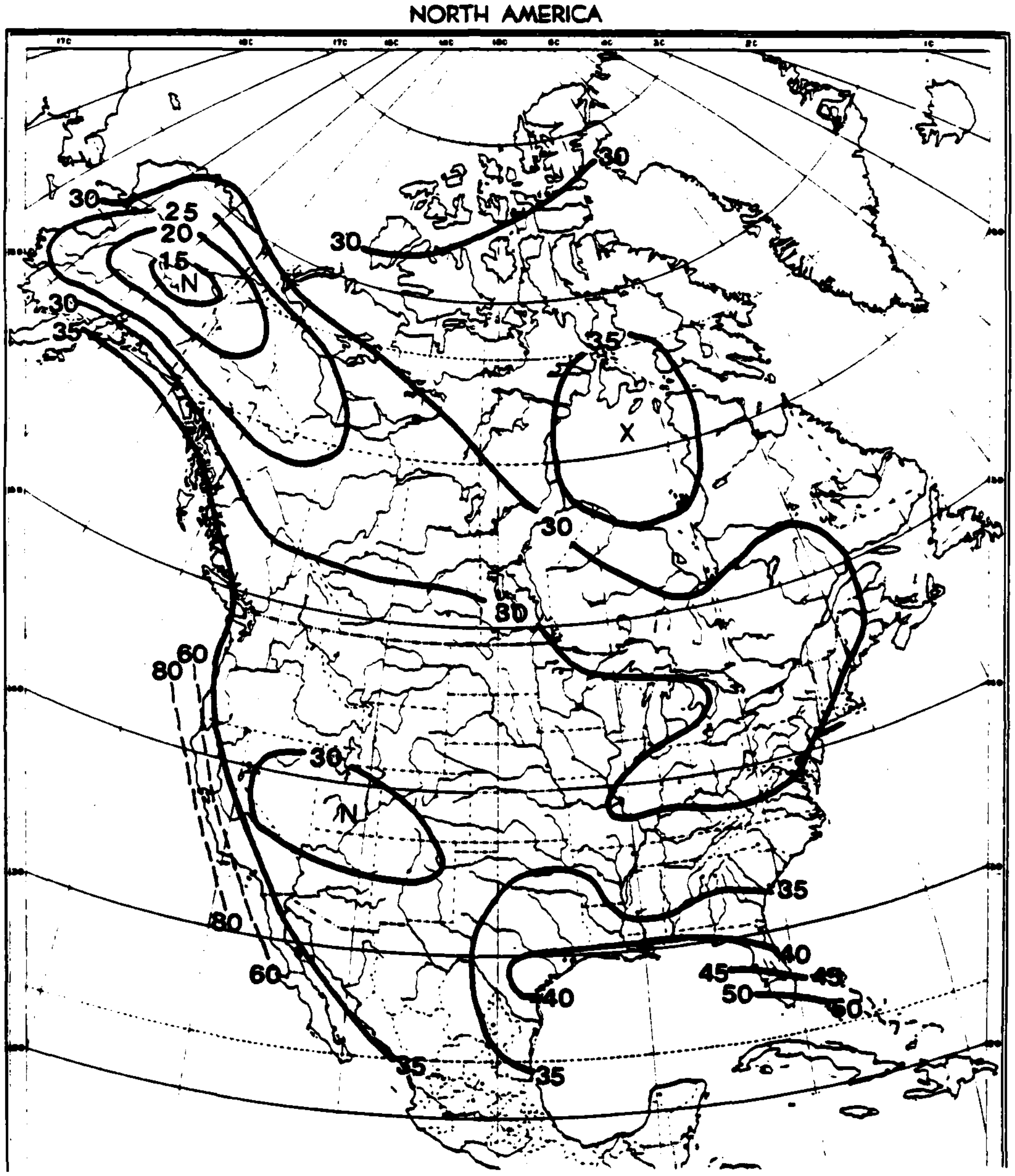

Fig. 9. North American summer lag (days) of temperature maximum behind radiation maximum. Map of North America adapted from Leppard (1937).

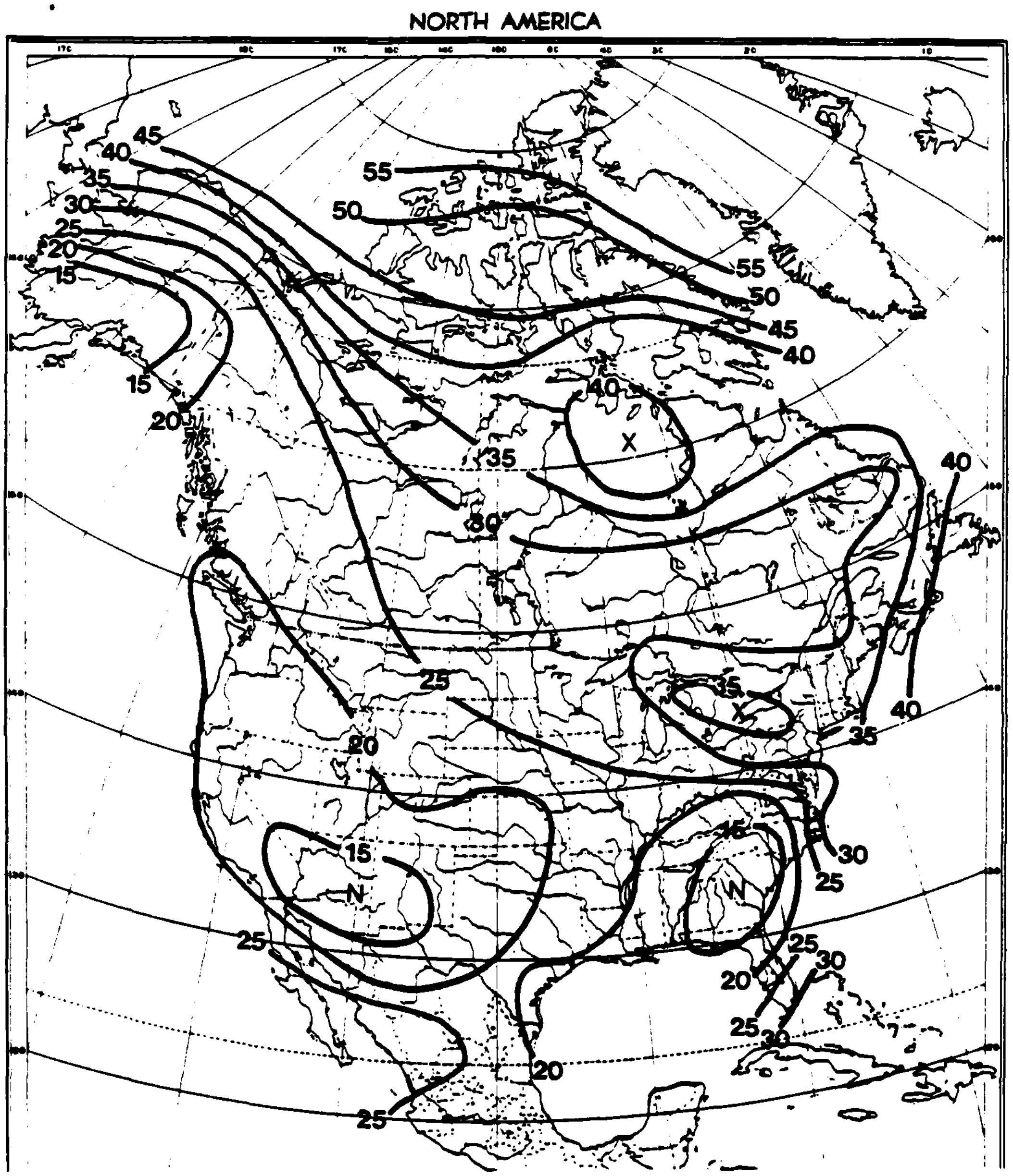

Fig. 10. North American winter lag (days) of temperature minimum behind radiation minimum. Map of North America adapted from Leppard (1937).

were to indicate degree of continentality correctly, it ought to lengthen inversely with continentality (e.g., continental climates would have the shortest lags). The only areas that show the expected results are along the west coast and in Florida, which have relatively long summer lags.

It is quite clear that the summer and winter lag patterns for North America otherwise bear little, if any, resemblance to the corresponding conventional continentality index patterns. That is not to say, however, that conventional indexes are wrong. But they could be, in light of their deficiencies. There are evidently factors other than continentality present. Some of the summer and winter lag patterns can be interpreted with the aid of surface streamline analyses of the mean resultant wind fields for the summer and winter months (Wendland and Bryson, 1981; and Bryson and Hare, 1974). Topography and nearby bodies of water must also be considered.

Summer lag is not well differentiated (Fig. 9). About 95% of the continent has a 25-35 day lag. Exceptions are the west coast, the shore along the Gulf of Mexico, and Alaska. In the summer, the North Pacific anticyclone advects maritime air all along the west coast of the North American continent, where the stations do not reach maximum temperature until September in some places. To the east of the coastal ranges the lag steadily decreases. Clockwise circulation around the North Atlantic anticyclone brings in moist air from the Gulf of Mexico into the central United States, causing the 35-day isoline along the Gulf Coast to protrude northward toward the Great Plains. The moderating influence of the Great Lakes is shown by the bulge or tongue-like pattern over those large bodies of water, with the tongue pointed downwind toward New England. Some surface streamlines of tropical air run parallel to the east coast all the way up to the maritime provinces (Fig. 11). As a result, dates of maximum temperature along the eastern seaboard are somewhat delayed relative to more inland stations, but not delayed as much as west coast stations.

A possible reason for the short lag times in the Yukon Territory and the interior of Alaska is the presence of a warm belt (temperature ridge) at 850 millibars that forms in April and then vanishes in September (Bryson and Hare, 1974). The warm belt is most likely the result of intense radiational heating of the plateau and mountain surfaces. As a consequence of this heating, maximum temperatures occur early with respect to the summer solstice.

The winter lag pattern (Fig. 10) is more varied than the summer pattern. Lag generally increases with latitude, from 25 days in central Mexico to 55 days in the Canadian archipalego. Especially well marked is the gradient in Alaska. The tight gradient is most likely due to the interaction between Alaska's topography, the Pacific Ocean, and the nearby polar ice pack.

Several exceptions to the northward increase in winter lag are present. Minimum values from northern Florida to Virginia could be associated with an anticyclonic eddy (region of divergence) in the southeastern United States (Fig. 12). The eddy is usually the remnant of an outbreak of Arctic or polar air, but occasionally the air is of Pacific origin. Whatever the source, the air that settles over that section of the country is more continental (drier and colder) than the

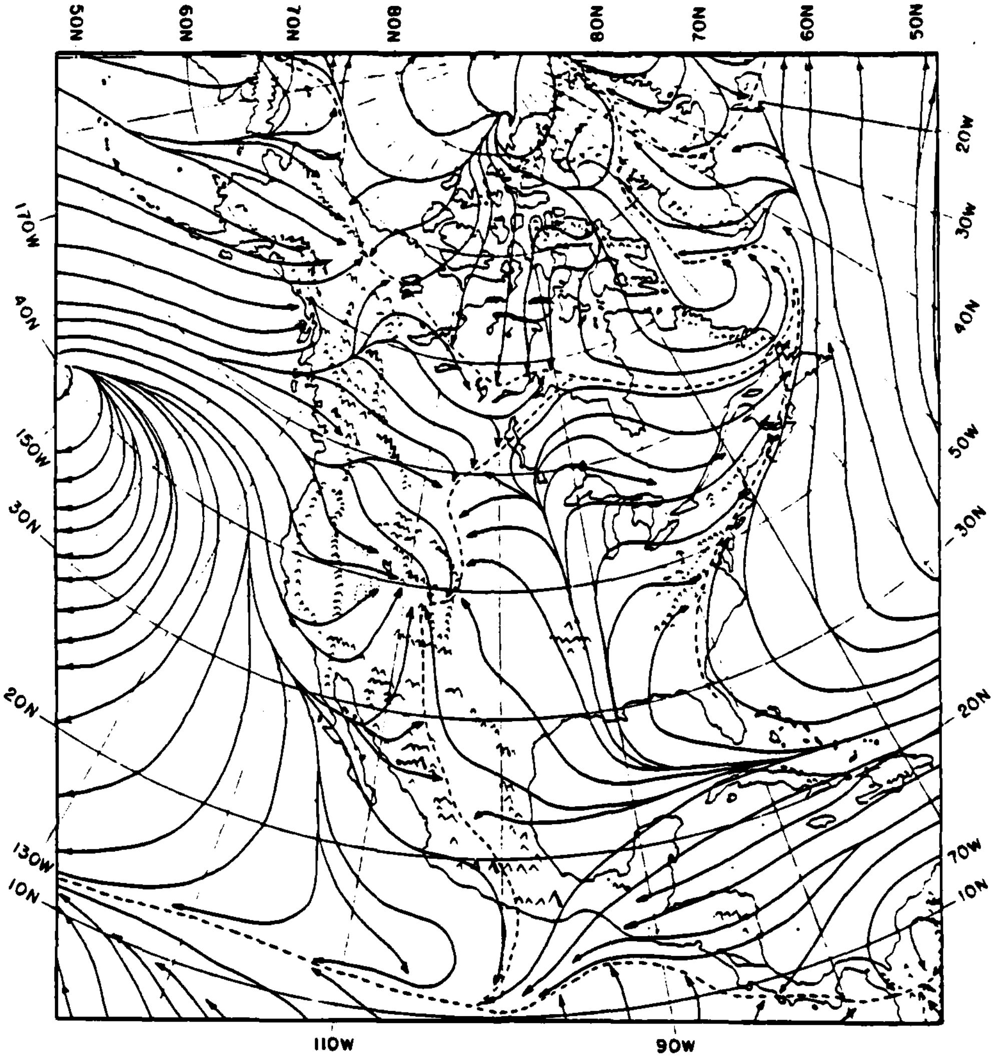

Fig. 11. Streamline analysis of the North American mean July resultant wind field. Adapted from Bryson and Hare (1974).

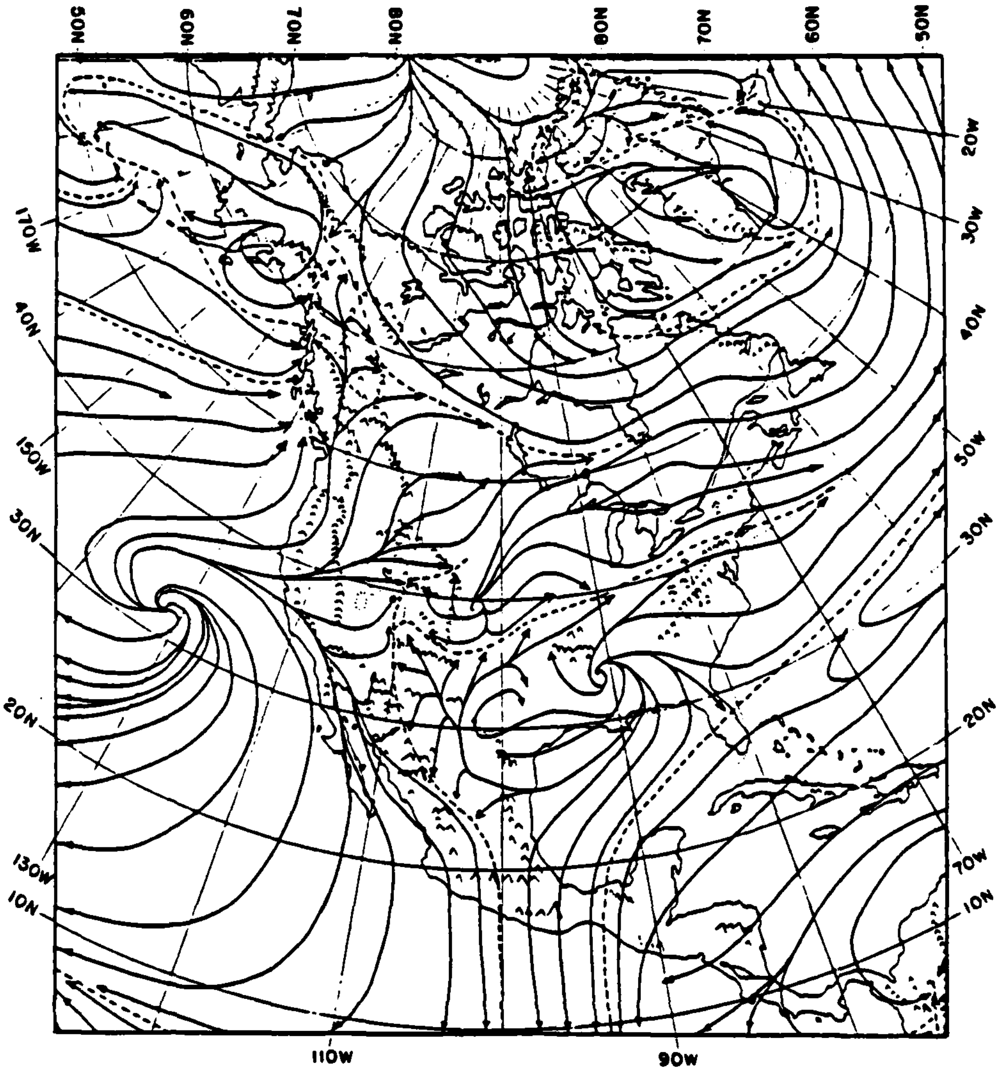

Fig. 12. Streamline analysis of the North American mean January resultant wind field. Adapted from Bryson and Hare (1974).

surrounding air masses, causing minimum temperatures to occur earlier than would otherwise be expected. The aridity of the southwestern United States could be a factor in explaining the short lags in that region. There is less cloud cover to absorb the outgoing terrestrial radiation and consequently the ground and the air immediately above it cool faster than if the air was more humid. Hudson Bay begins to freeze in mid-December, but is not completely frozen over until late January. The delay of the freeze-over is long enough to warm the prevailing northwesterly Arctic airstreams that pass overhead, thereby increasing the lag to late January for stations east and southeast of Hudson Bay. From late January to late June the bay remains frozen over, making it essentially a land surface. Air masses passing overhead are not moderated, as they would be at other times. Occurrence of minimum temperatures are also delayed by a few days in the vicinity of the Great Lakes.

From a mesoscale analysis of stations in the Rocky Mountain region of the United States and southern Canada, there is no apparent influence of elevation on the lag of temperature behind radiation, for both the summer and winter cases (Figs. 13 and 14). The other region to be examined more closely extends from the Great Lakes southeastward to the Atlantic Ocean (Figs. 15 and 16). Areas to the east and southeast of the Great Lakes have lags longer than would be expected in the lakes' absence, with the influence of those lakes being much more pronounced in the winter.

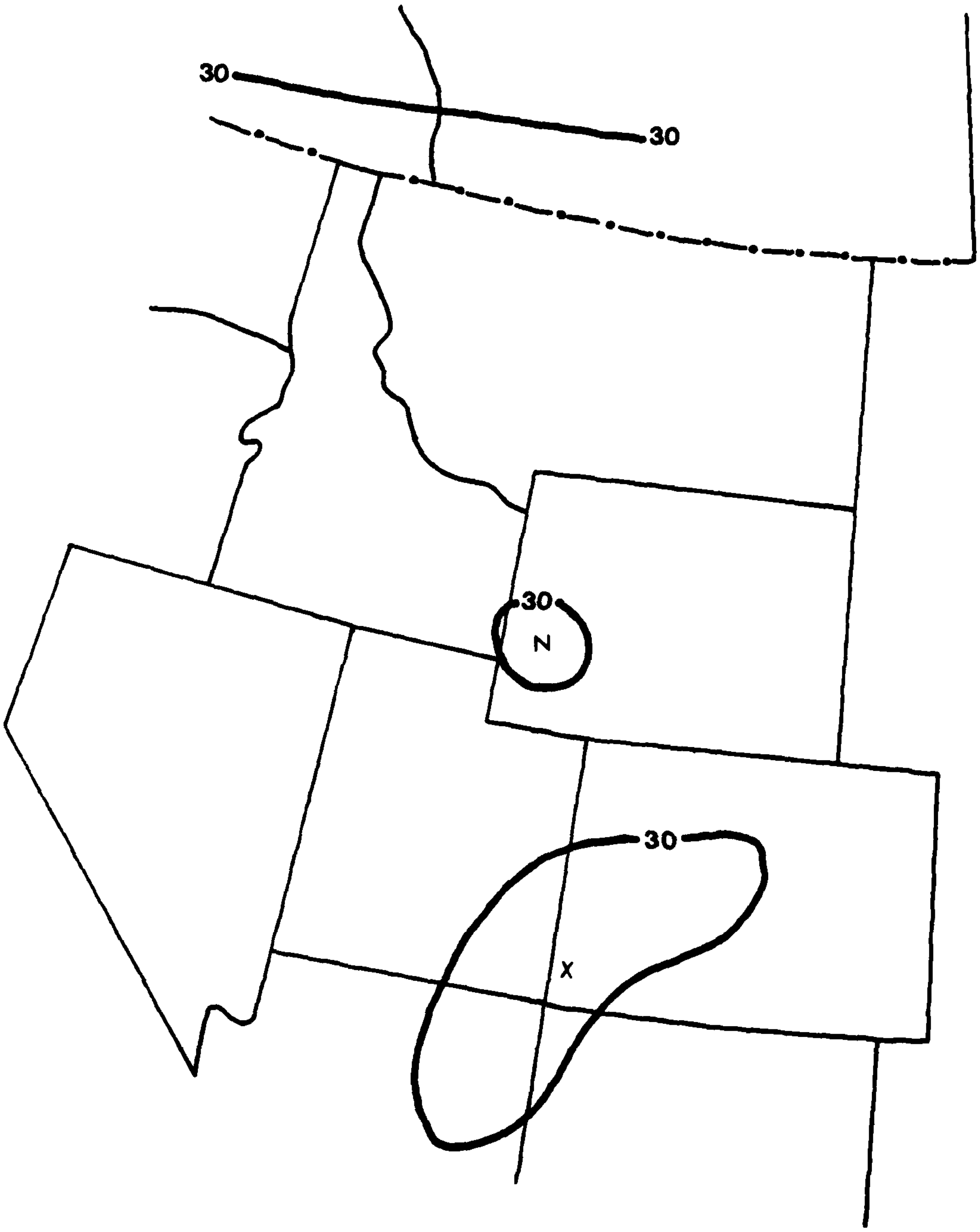

Fig. 13. Rocky Mountain summer lag (days) of temperature maximum behind radiation maximum.

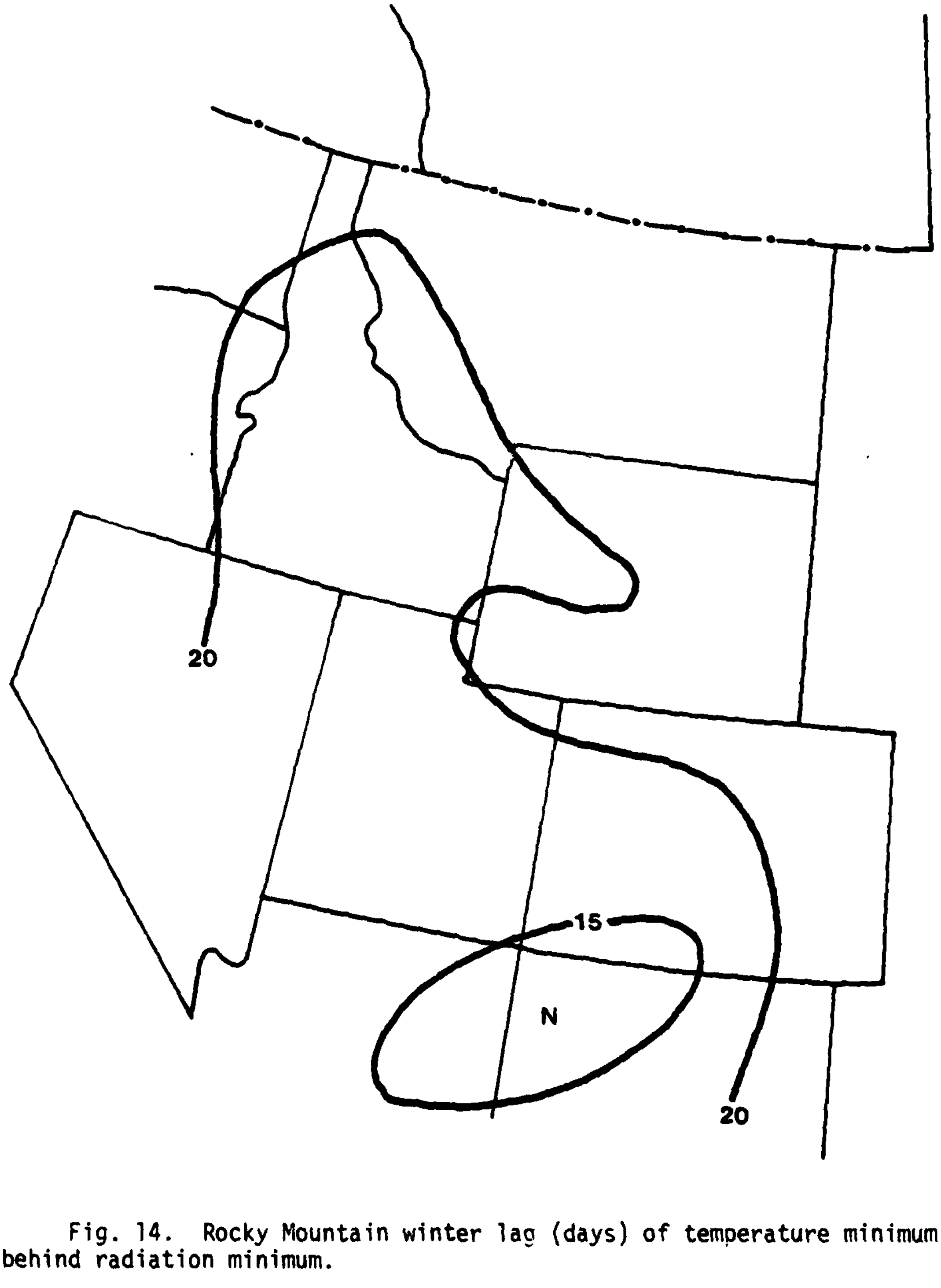

Fig. 14. Rocky Mountain winter lag (days) of temperature minimum behind radiation minimum.

Fig. 15. Great Lakes-Appalachia summer lag (days) of temperature maximum behind radiation maximum.

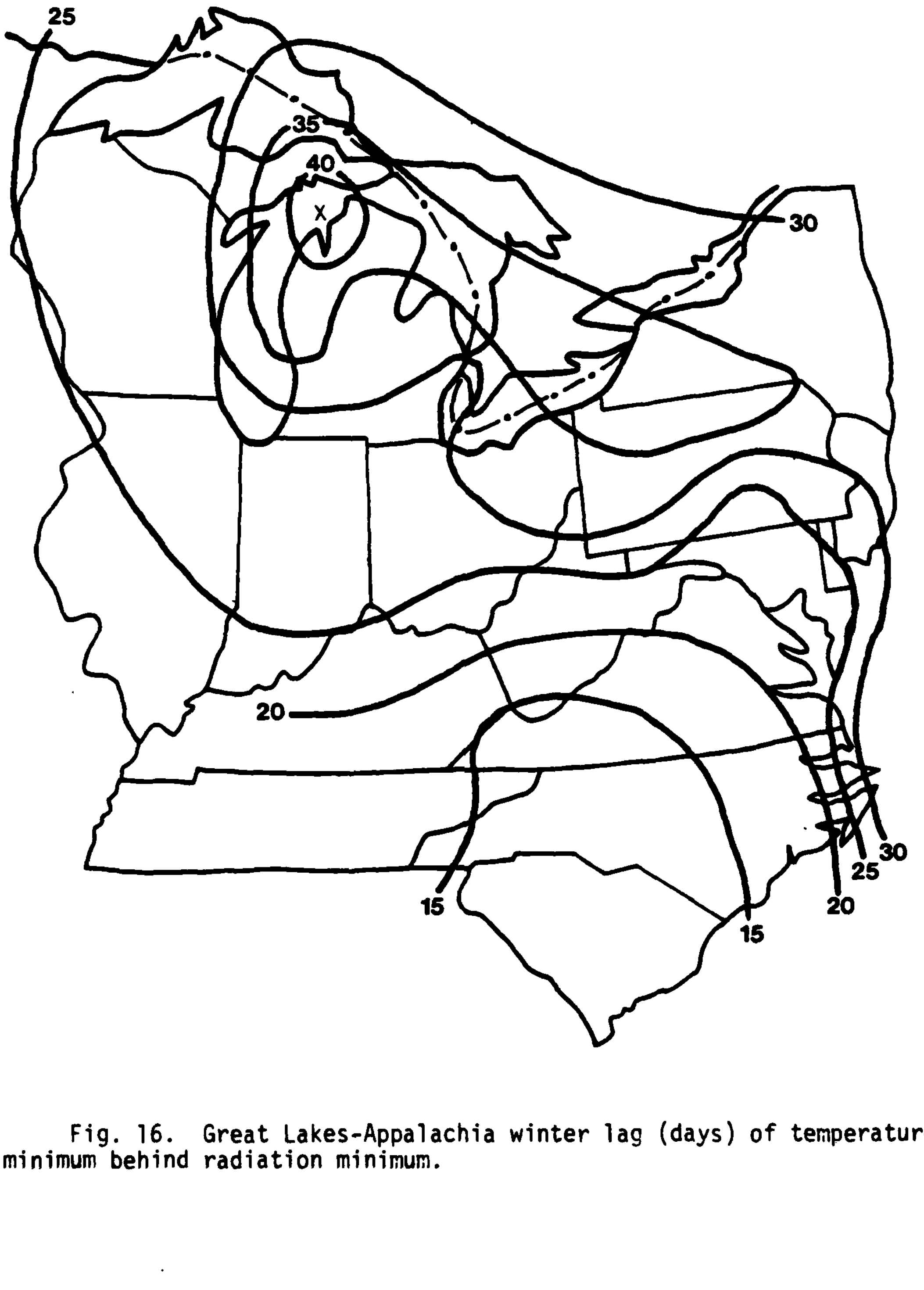

Fig. 16. Great Lakes-Appalachia winter lag (days) of temperature minimum behind radiation minimum.

6. SUMMARY

In this research, an attempt has been made to quantify continentality better than has previously been the case. First, conventional indexes of continentality were examined and their deficiencies noted. Several approaches were then taken to develop alternative continentality indexes. These approaches were: (1) dividing annual temperature range (A) by the summer-winter difference in radiation receipts (ΔS); (2) regressing annual temperature range on latitude, and; (3) determining the summer and winter lag of temperature behind radiation. In the first approach, ΔS was used in place of $\sin\phi$ and $\sin(\phi + 10)$, the conventional correction factors, to produce a continentality ratio which should correct for the differences with latitude of summer-winter differences in radiation receipts. Linear regression was employed to show the relationship between latitude and annual temperature range, and to derive an index of continentality based upon the deviation of annual temperature range from the regression line. Summer and winter lag of temperature behind radiation (the number of days that the maximum/minimum temperature occurs after summer/winter solstice) were determined by the method of cubic spline interpolation.

The resultant maps of the developed continentality indexes were compared with each other and contrasted with maps of conventional indexes. Each of the newly developed indexes was evaluated as an appropriate measure of continentality and a physical (meteorologica) explanation attempted for the patterns.

7. CONCLUSIONS

Dividing annual temperature range by ΔS produces a map of continentality that is similar to maps of existing indexes of continentality. A continentality index with annual temperature range and annual variation of radiation as the parameters therefore appears to be no better than conventional measures of continentality.

An empirical approach is an index of continentality derived by regressing annual temperature range on latitude, and then isolating the residuals from the regression line. The higher above the regression line a point is, the more continental the location; the lower, the more maritime. The region of the highest residual values in North America comes very close to the intuitive center of continentality hypothesized previously. This index comes closest to conforming to the hypothesized distribution of continentality. The regression technique takes into account the annual variation of radiation and apparently compensates for it more adequately than existing indexes of continentality.

North American maps of A/ΔS and regression residuals both have similarities to maps of conventional indexes (e.g., Conrad). Isopleth analyses of the index values reveal the influence of the prevailing westerly wind flow and the topography as well as large water bodies. The A/ΔS patterns bear the closest resemblance to Conrad's patterns. About the only difference between the residual patterns and Conrad's patterns is that the highest residual values are much closer to the center of the continent than are Conrad's highest values.

The continental scale summer and winter lag patterns for North America reveal to a limited extent the influence of the atmospheric and oceanic general circulation, air masses, topography, and large bodies of water. Separate mesoscale analysis of the Rocky Mountain and Great Lakes-Appalachia regions indicate that elevation is not a factor in determining lag. The lag patterns show little resemblance to conventional index patterns or to the patterns of A/ΔS and regression residuals, and thus other factors may be present that were not addressed in this study. An index based on the lag of temperature behind radiation fails to place the maximum continentality of North America where it should theoretically be.

This research has made it apparent that continentality is relative, and is a dynamic, rather than static, phenomenon in that we have shown it varies with time (season) and definition. Of all the indexes proposed in this study, the one developed by regressing annual temperature range on latitude is offered as an alternative to conventional indexes of continentality.

8. RECOMMENDATIONS

There appears to be an upper limit (envelope) to annual temperature range as a function of latitude (Fig. 7). The line containing the maximum values of annual temperature range is curved, suggesting that second-order or higher regression may be a feasible approach to developing an index of continentality. A quadratic solution possibly could provide a better fit through all the points than can a straight line. Examining other areas of the world would be helpful in establishing the validity and usefulness of the continentality indexes developed in this study, compared to existing indexes of continentality. An investigation of the Eurasian land mass would be particularly interesting and revealing, in light of the enormous size of that area. Other avenues of research are to look at temperature variability and to find more satisfactory explanations for the lag patterns.

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APPENDIX A

CUBIC SPLINE INTERPOLATION

The most basic curve-fitting problem is fitting a smooth function through a set of X,Y pairs. There is an infinite set of solutions to this problem, two of which are polynomials and cubic splines (Cline, 1975). Given n data points, a polynomial of degree n-1 can be passed through them. One of the difficulties with conventional polynomial interpolation is that the polynomial may oscillate while the function itself varies smoothly. Another disadvantage is the extreme dependency of the entire curve on each data point. A slight movement of a point at one end can drastically affect the curve all the way to the other end. A way of overcoming these problems is to use piecewise low-order interpolating polynomials on subintervals of the given interval.

Such polynomials are called spline functions, introduced by I. J. Schoenberg in 1946. First order spline functions are the simplest. They are piecewise linear and not very smooth, but very useful if the spacing between nodes or knots (the given X values) is small. Second order splines lack symmetry in their determination with relation to endpoints of the interval. Third order or cubic splines are the most widely used. An interpolating cubic between two adjacent points can be denoted as:

$$F_i(X) = a_0 + a_1X + a_2X^2 + a_3X^3.$$

A smooth spline fit is achieved by connecting each pair of adjacent points with a third degree polynomial, then matching up the sections so that the first and second derivatives (slope and curvature) are continuous at each point X and over the entire region $X_0 \leq X_i \leq X_n$. The approximating function over the whole region is a cubic spline function g(X). Because the second derivative of a cubic is a straight line, the second derivative of g(X) varies linearly over each interval. The second derivative at any point X is given by

$$g''(X) = g''(X_i) + \frac{X - X_i}{X_{i+1} - X_i}\left[g''(X_{i+1}) - g''(X_i)\right] \tag{A.1}$$

where $X_i \leq X \leq X_{i+1}$ (Hornbeck, 1975). Integrating twice and applying the conditions that $g(X_i) = f(X_i)$ and $g(X_{i+1}) = f(X_{i+1})$, it is found that for the interval between X_i and X_{i+1},

$$\begin{aligned} g(X) = F_i(X) = {} & \frac{g''(X_i)}{6}\left[\frac{(X_{i+1} - X)^3}{\Delta X_i} - \Delta X_i(X_{i+1} - X)\right] \\ & + \frac{g''(X_{i+1})}{6}\left[\frac{(X - X_i)^3}{\Delta X_i} - \Delta X_i(X - X_i)\right] \\ & + f(X_i)\left[\frac{X_{i+1} - X}{\Delta X}\right] + f(X_{i+1})\left[\frac{X - X_i}{\Delta X_i}\right] \end{aligned} \tag{A.2}$$

where $\Delta X_i = X_{i+1} - X_i$. Equation A.2 determines the interpolating cubics over each interval for i = 0, 1, . . . , n - 1. The second derivatives are found by using the derivative matching conditions $F_i'(X_i) = F_{i-1}''(X_i)$ and $F_i''(X_i) = F_{i-1}''(X_i)$ to Eq. A.2. These conditions mean that $g'(X_i)$ or $g''(X_i)$ are the same when X is approached from either side. For i = 1, 2, . . . , n - 1 the conditions yield a set of linear simutaneous equations of the form

$$\left[\frac{\Delta X_{i-1}}{\Delta X_i}\right] g''(X_{i-1}) + \left[\frac{2(X_{i+1} - X_{i-1})}{\Delta X_i}\right] g''(X_i) + [1]g''(X_{i+1})$$

$$= 6\left[\frac{f(X_{i+1}) - f(X_i)}{(\Delta X_i)^2} - \frac{f(X_i) - f(X_{i-1})}{(\Delta X_i)(\Delta X_{i-1})}\right] \qquad \text{(A.3)}$$

If the X_i are evenly spaced, then Eq. A.3 simplifies to

$$[1]g''(X_{i-1}) + [4]g''(X_i) + [1]g''(X_{i+1})$$

$$= 6\left[\frac{f(X_{i+1}) - 2f(X_i) + f(X_{i-1})}{(\Delta X_i)^2}\right]. \qquad \text{(A.4)}$$

There are n - 1 equations in n + 1 unknowns $g''(X_0)$, $g''(X_1)$. . . . , $g''(X_n)$. Two other required equations are derived by specifying the boundary conditions at the endpoints $g''(X_0)$ and $g''(X_n)$. A natural cubic spline is obtained if we let $g''(X_0) = g''(X_n) = 0$. The complete set of equations is solved for $g''(X_i)$, i = 1, 2, . . . , n - 1. Substituting $g''(X_i)$ back into Eq. A.2 yields the desired interpolated values of Y.

Five data points provide greater resolution. Since the desired value falls somewhere between the second and fourth month (day 30 to day 60), adding the two outlying months does not significantly affect the maximum/minimum dates. Because of the endpoints, the outer two intervals (day 0 to day 30, and day 90 to day 120) are less reliable than the two inner intervals (days 30 through 90).

Program input was five X,Y pairs (monthly temperatures) and one day as the interpolation interval. Output consisted of 120 daily temperatures.

There is an error term associated with the spline-derived temperature values which could affect the lag results. The spline value of the mean temperature of any month (sum of the daily values divided by the number of days in that month) should equal the actual mean temperature. But as shown in Table A1, the spline and actual values are not identical, as calculated from a sample of ten stations. It is interesting to note that the differences between the actual and spline values are all positive for the summer months while the differences are all negative for the winter months. In addition, the more continental a location is (the greater the amplitude of the annual temperature curve), the larger is the difference.

If the actual maximum and minimum temperatures occur on the same dates as the spline-derived maximum and minimum temperatures, then the error term would not change the lag values at all. On the other hand, if the dates of occurrence are not identical, the effect on the lag results could be significant. Since the differences are proportional to degree of continentality, the lag values may change, but not much. The overall lag patterns would probably remain essentially the same.

Table Al. Actual mean temperature of the warmest/coolest month versus the corresponding spline-derived temperatures for ten selected stations in North America. Actual temperatures are from Bryson and Hare (1974).

Station	Actual Mean Temp (°C) of Warmest/Coolest Month	Spline Mean Temp (°C) of Warmest/Coolest Month	Actual - Spline
Albuquerque, NM	25.94 (July)	25.79	0.15
	1.78 (January)	1.98	- 0.20
Boston, MA	22.94 (July)	22.77	0.17
	- 1.56 (January)	- 1.49	- 0.07
Cape Hatteras, NC	25.56 (July)	25.47	0.09
	7.39 (January)	7.40	- 0.01
Chihuahua, Mexico	26.60 (June)	26.45	0.15
	9.40 (January)	9.58	- 0.18
Fargo, ND	21.50 (July)	21.36	0.14
	- 14.50 (January)	- 14.23	- 0.27
Miami, FL	28.28 (August)	28.23	0.05
	19.56 (January)	19.58	- 0.02
The Pas, Manitoba	17.90 (July)	17.67	0.23
	- 22.40 (January)	- 21.97	- 0.43
San Francisco, CA	17.83 (September)	17.70	0.13
	9.06 (January)	9.20	- 0.14
Seattle, WA	18.06 (July)	17.93	0.13
	3.44 (January)	3.67	- 0.23
Winnepeg, Manitoba	19.70 (July)	19.54	0.16
	- 18.30 (January)	- 18.02	- 0.28

APPENDIX B

Table B1. Data for the continental scale stations.

Station	Latitude (°)	A (°C)	ΔS (W $m^{-2} day^{-1}$)
Aklavik, N.W.T.	68.2	42.4	885
Arctic Bay, N.W.T.	73.0	36.9	838
Baker Lake, N.W.T.	64.3	44.3	924
Cambridge Bay, N.W.T.	69.1	42.8	875
Chesterfield, N.W.T.	63.3	40.6	934
Churchill, Man.	58.8	39.6	975
Clyde, N.W.T.	70.4	32.0	860
Coppermine, N.W.T.	67.8	40.2	885
Dawson, Yukon	64.1	44.1	924
Edmonton, Alta.	53.6	32.2	990
Eureka, N.W.T.	80.0	43.2	802
Ft. Chimo, Que.	58.1	34.8	982
Ft. McMurray, Alta.	56.6	37.8	987
Ft. Nelson, B.C.	58.8	39.9	975
Ft. Simpson, N.W.T.	61.8	43.7	945
Ft. Smith, N.W.T.	60.0	43.0	966
Frobisher, N.W.T.	65.8	34.1	905
Gander, Nfld.	49.0	22.8	975
Goose, Nfld.	53.3	32.1	990
Hall Beach, N.W.T.	68.8	37.1	875
Inducdjouac, Que.	58.4	33.8	979
Isachsen, N.W.T.	78.8	39.7	805
Lethbridge, Alta.	49.6	28.2	981
Maniwaki, Que.	46.4	31.5	954
Mistassini Post, Que.	50.4	36.5	983
Moosonee, Ont.	51.3	35.7	985
Mould Bay, N.W.T.	76.2	39.3	817
Nitchequon, Que.	53.2	36.5	990
Norman Wells, N.W.T.	65.2	44.8	915
Nottingham Is., N.W.T.	63.1	30.4	935
Port Hardy, B.C.	50.7	11.4	985
Prince George, B.C.	53.9	26.7	990

Table B1. Continued.

Station	Latitude (°)	A (°C)	ΔS ($W\ m^{-2} day^{-1}$)
Resolute, N.W.T.	74.7	37.8	823
Sachs Harbour, N.W.T.	72.0	36.5	846
Sept-Isles, Que.	50.2	29.0	981
Shearwater, N.S.	44.6	21.6	945
Sydney, N.S.	46.2	23.4	954
The Pas, Man.	54.0	40.3	990
Trout Lake, Ont.	53.8	40.0	990
White River, Ont.	48.6	33.3	972
Winnepeg, Man.	49.9	38.0	981
Yellowknife, N.W.T.	62.5	43.7	934
Chihuahua, Chihuahua	28.6	17.2	685
Guadalajara, Jalisco	20.7	8.2	501
Guaymas, Sonora	27.9	13.3	663
La Paz, Baja Calif.	24.2	11.5	573
Lerdo, Durango	25.5	14.1	608
Mazatlan, Sinaloa	23.2	8.3	549
Merida, Yucatan	21.0	4.9	501
Monterrey, Nuevo Leon	25.7	12.7	619
Tampico, Tamaulipas	22.2	9.1	525
Montgomery, AL	32.3	18.6	746
Anchorage, AK	61.2	25.6	956
Annette, AK	55.0	13.8	991
Barrow, AK	71.3	31.8	855
Barter Is., AK	70.1	33.0	865
Bethel, AK	60.8	27.9	956
Bettles, AK	66.9	39.5	895
Cold Bay, AK	55.2	12.8	991
Fairbanks, AK	64.8	40.3	915
Juneau, AK	58.4	17.9	982
Kodiak, AK	57.8	13.9	982
Kotzebue, AK	66.9	31.8	895

Table B1. Continued.

Station	Latitude (°)	A (°C)	ΔS (W $m^{-2}day^{-1}$)
McGrath, AK	63.0	37.5	934
St. Paul Is., AK	57.2	13.6	987
Yakutat, AK	59.5	16.2	970
Tucson, AZ	32.1	19.7	746
Winslow, AZ	35.0	25.4	803
Bishop, CA	37.4	21.9	835
Eureka, CA	40.8	5.4	898
San Diego, CA	32.7	9.0	765
San Francisco, CA	37.6	8.7	854
Santa Maria, CA	34.9	6.7	803
Denver, CO	39.8	24.0	884
Grand Junction, CO	39.1	28.9	869
Dulles IAP, D.C.	39.0	24.0	869
Jacksonville, FL	30.4	14.6	716
Miami, FL	25.8	8.7	619
Tallahassee, FL	30.4	15.9	706
Tampa, FL	28.0	12.1	663
Atlanta, GA	33.6	19.8	784
Boise, ID	43.6	25.3	928
Moline, IL	41.4	29.4	904
Ft. Wayne, IN	41.0	26.5	898
Dodge City, KS	37.8	26.9	854
Topeka, KS	39.1	27.9	869
Louisville, KY	38.2	24.2	854
New Orleans, LA	30.0	16.1	706
Shreveport, LA	32.5	20.0	756
Caribou, ME	46.9	30.1	962
Portland, ME	43.6	25.8	934
Alpena, MI	45.1	26.5	945
Int'l Falls, MN	48.6	35.5	972
Saint Cloud, MN	45.6	34.0	950
Jackson, MS	32.3	19.2	746

Table B1. Continued.

Station	Latitude (°)	A (°C)	ΔS (W $m^{-2}day^{-1}$)
Saint Louis, MO	38.8	26.3	869
Billings, MT	45.8	27.7	954
Glasgow, MT	48.2	34.1	969
Missoula, MT	46.9	25.4	962
North Platte, NE	41.1	28.3	898
Las Vegas, NV	36.1	25.2	821
Winnemuca, NV	40.9	23.8	898
Albuquerque, NM	35.0	24.1	803
Buffalo, NY	42.9	25.8	923
Kennedy IAP, NY	40.6	24.2	898
Cape Hatteras, NC	35.3	18.2	803
Bismarck, ND	46.7	34.8	962
Akron, OH	41.0	25.2	898
Tulsa, OK	36.2	25.2	821
Eugene, OR	44.1	15.3	934
Charleston, SC	32.9	17.6	765
Huron, SD	44.4	34.0	934
Knoxville, TN	35.8	20.9	821
Memphis, TN	35.0	22.9	803
Amarillo, TX	35.2	23.7	803
Austin, TX	30.3	19.4	706
Brownsville, TX	25.9	13.4	619
Dallas-Ft. Worth, TX	32.8	22.3	765
Del Rio, TX	29.4	20.0	685
El Paso, TX	31.8	21.5	746
Houston, TX	30.0	17.4	706
Midland-Odessa, TX	31.9	21.5	746
Milford, UT	38.4	27.0	862
Salt Lake City, UT	40.8	27.0	898
Roanoke, VA	37.3	21.6	838
Seattle, WA	47.4	14.7	966
Green Bay, WI	44.5	29.9	940

Table B1. Continued.

Station	Latitude (°)	A (°C)	ΔS (W $m^{-2}day^{-1}$)
Casper, WY	42.9	26.6	923

Table B2. Conventional and proposed continentality index values for the continental scale stations.

Station	Conrad Index	(A/ΔS)1000	Regression Residuals	Summer Lag (days)	Winter Lag (days)
Montgomery, AL	33.0	25	0.0	36	13
Anchorage, AK	32.0	27	- 8.5	27	13
Annette, AK	11.9	14	- 16.9	42	21
Barrow, AK	40.7	37	- 7.7	33	59
Barter Is., AK	42.9	38	- 5.8	33	57
Bethel, AK	50.2	29	- 5.9	23	4
Bettles, AK	54.9	44	2.4	13	12
Cold Bay, AK	10.0	13	- 18.1	46	9
Fairbanks, AK	57.0	44	4.3	13	12
Juneau, AK	32.7	18	- 14.7	27	23
Kodiak, AK	11.5	14	- 18.3	43	3
Kotzebue, AK	41.5	35	- 5.3	32	43
McGrath, AK	52.7	40	2.5	17	6
St. Paul Is., AK	11.1	14	- 18.3	50	65
Yakutat, AK	15.4	17	- 17.0	34	19
Tucson, AZ	36.0	26	1.2	25	15
Winslow, AZ	47.1	32	5.3	30	12
Bishop, CA	36.6	26	0.6	29	16
Eureka, CA	- 2.2	6	- 17.8	61	23
San Diego, CA	8.6	12	- 9.8	55	22

Table B2. Continued.

Station	Conrad Index	(A/ΔS)1000	Regression Residuals	Summer Lag (days)	Winter Lag (days)
San Francisco, CA	6.0	10	- 12.7	80	16
Santa Maria, CA	2.1	8	- 13.3	76	20
Denver, CO	39.4	27	1.4	33	22
Grand Junction, CO	51.0	33	6.7	28	17
Dulles IAP, D.C.	40.1	28	1.8	29	22
Jacksonville, FL	24.3	20	- 3.0	39	16
Miami, FL	11.3	14	6.4	51	30
Tallahassee, FL	27.7	22	- 1.7	41	12
Tampa, FL	19.4	18	- 4.2	48	20
Atlanta, GA	34.8	25	0.5	34	14
Boise, ID	39.4	27	0.7	32	18
Moline, IL	49.9	33	5.9	30	25
Ft. Wayne, IN	44.0	30	3.2	28	26
Dodge City, KS	47.7	31	5.3	34	18
Topeka, KS	48.8	32	5.7	34	20
Louisville, KY	41.2	28	2.4	32	21
New Orleans, LA	28.6	23	- 1.3	40	20
Shreveport, LA	36.3	26	1.3	39	19
Caribou, ME	47.1	31	3.7	28	30
Portland, ME	40.5	28	1.2	31	32

Table B2. Continued.

Station	Conrad Index	$(A/\Delta S)1000$	Regression Residuals	Summer Lag (days)	Winter Lag (days)
Alpena, MI	40.9	28	1.1	32	37
Int'l Falls, MN	56.7	37	8.2	29	26
Saint Cloud, MN	56.0	36	8.3	31	27
Jackson, MS	34.5	26	0.6	34	20
Saint Louis, MO	45.4	30	4.2	30	21
Billings, MT	42.9	29	1.9	33	22
Glasgow, MT	54.2	35	7.0	34	26
Missoula, MT	37.5	26	- 1.0	33	20
North Platte, NE	47.8	32	5.0	34	20
Las Vegas, NV	45.4	31	4.6	30	12
Winnemuca, NV	38.1	26	0.6	30	16
Albuquerque, NM	43.9	30	4.0	27	12
Buffalo, NY	41.0	28	1.5	29	36
Kennedy IAP, NY	39.2	27	1.2	31	34
Cape Hatteras, NC	29.5	23	- 2.0	34	35
Bismarck, ND	56.7	36	8.4	33	26
Akron, OH	41.1	28	1.9	29	31
Tulsa, OK	45.4	31	4.7	35	20
Eugene, OR	18.1	16	- 9.6	33	18
Charleston, SC	30.0	23	- 1.3	33	12

Table B2. Continued.

Station	Conrad Index	$(A/\Delta S)1000$	Regression Residuals	Summer Lag (days)	Winter Lag (days)
Huron, SD	57.1	36	8.9	33	25
Knoxville, TN	35.6	25	0.4	31	13
Memphis, TN	41.1	28	2.8	30	19
Amarillo, TX	42.8	29	3.5	33	19
Austin, TX	37.0	27	1.9	40	20
Brownsville, TX	24.8	22	- 1.8	39	21
Dallas-Ft. Worth, TX	41.8	29	3.4	39	21
Del Rio, TX	39.6	29	2.9	34	15
El Paso, TX	40.8	29	3.2	23	12
Houston, TX	32.0	25	0.0	40	21
Midland-Odessa, TX	40.7	29	3.1	35	18
Milford, UT	47.4	31	5.1	33	18
Salt Lake City, UT	45.2	30	3.8	31	17
Roanoke, VA	36.0	26	0.3	31	13
Seattle, WA	15.7	15	- 12.0	33	19
Green Bay, WI	48.4	32	4.8	31	29
Casper, WY	42.7	29	2.3	34	21
Aklavik, N.W.T.	59.6	48	4.6	32	31
Arctic Bay, N.W.T.	49.2	44	- 3.5	32	49

Table B2. Continued.

Station	Conrad Index	$(A/\Delta S)1000$	Regression Residuals	Summer Lag (days)	Winter Lag (days)
Baker Lake, N.W.T.	64.2	48	8.6	31	35
Cambridge Bay, N.W.T.	60.1	49	4.5	33	45
Chesterfield, N.W.T.	58.1	43	5.4	36	40
Churchill, Man.	58.2	41	6.8	35	35
Clyde, N.W.T.	41.2	37	- 7.0	33	58
Coppermine, N.W.T.	69.9	45	2.6	34	48
Dawson, Yukon	64.0	48	8.5	19	19
Edmonton, Alta.	47.1	32	2.2	27	22
Eureka, N.W.T.	59.4	54	- 0.9	29	65
Ft. Chimo, Que.	49.8	35	2.7	32	36
Ft. McMurray, Alta.	56.0	38	6.2	28	22
Ft. Nelson, B.C.	58.0	41	7.1	25	17
Ft. Simpson, N.W.T.	64.2	46	9.3	24	24
Ft. Smith, N.W.T.	63.8	44	9.6	27	25
Frobisher, N.W.T.	45.8	38	- 2.4	32	33
Gander, Nfld.	31.2	23	- 4.7	33	41
Goose, Nfld.	47.1	32	2.3	31	29
Hall Beach, N.W.T.	50.3	42	- 1.0	35	38
Inducdjouac, Que.	47.8	34	1.2	35	40
Isachsen, N.W.T.	53.7	49	- 3.8	28	56

Table B2. Continued.

Station	Conrad Index	(A/ΔS)1000	Regression Residuals	Summer Lag (days)	Winter Lag (days)
Lethbridge, Alta.	41.6	29	0.3	31	24
Maniwaki, Que.	50.3	33	5.4	27	30
Mistassini Post, Que.	57.4	37	8.2	28	28
Moosonee, Ont.	55.2	36	6.9	31	29
Mould Bay, N.W.T.	53.0	48	- 2.8	28	52
Nitchequon, Que.	55.5	37	6.7	29	29
Norman Wells, N.W.T.	64.8	49	8.6	21	27
Nottingham Is., N.W.T.	40.0	32	- 4.7	36	37
Port Hardy, B.C.	8.2	12	- 17.0	42	20
Prince George, B.C.	36.5	27	- 3.5	27	21
Resolute, N.W.T.	50.5	46	- 3.5	30	49
Sachs Harbour, N.W.T.	48.7	43	- 3.3	29	48
Sept-Isles, Que.	42.8	30	0.8	32	31
Shearwater, N.S.	31.0	23	- 3.6	40	44
Sydney, N.S.	33.9	24	- 2.6	37	48
The Pas, Man.	62.2	41	10.1	29	25
Trout Lake, Ont.	61.8	40	9.9	29	27
White River, Ont.	52.3	34	6.0	28	30
Winnepeg, Man.	60.7	39	10.0	32	28
Yellowknife, N.W.T.	63.9	47	8.9	37	33

Table B2. Continued.

Station	Conrad Index	(A/ΔS)1000	Regression Residuals	Summer Lag (days)	Winter Lag (days)
Chihuahua, Chihuahua	32.9	25	0.6	- 2	19
Guadalajara, Jalisco	13.3	16	- 4.2	- 31	15
Guaymas, Sonora	22.8	15	- 3.0	34	25
La Paz, Baja Calif.	20.8	20	- 2.8	46	29
Lerdo, Durango	27.3	23	- 0.9	- 3	39
Mazatlan, Sinaloa	11.8	15	- 5.4	35	41
Merida, Yucatan	2.8	10	- 7.7	- 32	11
Monterrey, Nuevo Leon	23.0	20	- 2.4	38	11
Tampico, Tamaulipas	15.0	17	- 4.1	1	19

VITA

Juan Manuel Yee Fong was born in Havana, Cuba on 1 January 1955. He immigrated into the United States in 1962 and settled in Albuquerque, NM, where he graduated from Highland High School in 1973 and became a naturalized U.S. citizen in August 1976.

In December 1977, Juan received his Bachelor of Science degree in Biology + Chemistry. He was commissioned into the U.S. Air Force in May 1979, then was assigned to the University of Texas at Austin from June 1979 to May 1980 for the AFIT (Air Force Institute of Technology) Basic Meteorology Program. His next assignment was at Luke AFB, AZ from June 1980 to July 1983, where he served as a forecaster and Wing Weather Officer.

Juan came to Texas A&M University in August 1983 to pursue the degree of Master of Science in Meteorology under the sponsorship of AFIT. Captain Yee Fong is currently assigned to the Air Force Global Weather Central, Offutt AFB, NE. His permanent mailing address is: 516 Georgia SE, Albuquerque, NM 87108.

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