INTERNATIONAL JOURNAL OF CLIMATOLOGY, VOL. 14, 1001-1008 (1994) 551.524.2:551.524.36:551.588.1(7)

SPATIAL VARIATION OF CLIMATIC ASPECTS OF TEMPERATURE: INTERDIURNAL VARIABILITY AND LAG

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Received 16 April 1993
Accepted 20 January 1994

ABSTRACT

Two relatively neglected aspects of climatic temperature variability are mean interdiurnal temperature variability (MITV), and the lag of maximum and minimum temperature behind their respective solstices. After determining the length of record to attain stability for the former, and the dates (of the year) on which temperatures are a maximum and minimum, these parameters are mapped for North America. For MITV there is a general association with continentality and the location of the surface polar front zone; the lag patterns bear only a slight resemblance to continentality.

KEY WORDS Temperature variability Continentality Interdiurnal changes Polar front zone North America

INTRODUCTION

A fundamental tenet of climatology is that the proper description of climate requires not only means, e.g. the so-called normal values in use in the USA, but also some indication of the variability about that mean. For continuous, commonly used variables, such as temperature, standard deviation is the measure of variability commonly used, but others, such as mean deviation and quartile deviation, have been preferred in some cases.

Means and standard deviations of temperature have been calculated routinely for calendar-based periods such as days, months, and years; for example, for all the January firsts, and for all the Januaries in a number of years. This is sequential variability, where order is not taken into account, and in which differences from the mean derive from the variability of iterations of the same period, where the period is all or any part of a year. Consecutive variability, on the other hand, does take order into account, and the interest is in determining the average change from one iteration to the next, and its variability. Examples are interdiurnal, and intermonthly, temperature variability. For the former the mean temperature of each of the days of a month is calculated, as the average either of the maximum and minimum for the 24 h or of all 24-h temperatures, then the mean of the absolute difference of consecutive days' mean temperatures is calculated for each of the 29 day-to-day differences in a 30-day month. Lastly, from all monthly means a long-term mean is formed from several years of that month.

In this paper we examine, for North America, two aspects of temperature which seem to have received little attention, mean interdiurnal temperature variability for each of the 12 months and the year, and the lag of the dates of maximum and minimum temperatures behind the dates of the June and December solstices, respectively. We will also determine if elevation has an effect on this lag. Some explanation of these patterns is attempted.

CCC 0899-8418/94/091001-08

PREVIOUS STUDIES

Mean interdiurnal temperature variability (MITV) in the USA has been shown for January minimum and daily mean temperature, and July maximum temperature (Calef, 1950), and both maximum and minimum for all months (Landsberg, 1968). Their interest was in showing those areas of the country where day-to-day changes of temperature are most pronounced because this parameter indicates the rapidity with which weather changes. Driscoll and Landsberg (1967) suspected that certain biometeorological responses, e.g., mortality and morbidity, are related to this aspect of the weather, and they examined the mortality response to the interdiurnal temperature variability resulting from a pronounced cold front as it traversed the USA from north-west to south-east.

In the studies of Landsberg and Calef no attempt was made to determine the length of record required to obtain stable values for MITV. Calef used a 10-year sample, but also calculated MITV for five of those ten to compare the differences, which he found negligible. Landsberg used 5 years in his 1968 study, but earlier (1958) suggested that this parameter would be quite stable, and that even 3 years might suffice to reveal the main features. However, a comparison of their maps, i.e. of mean daily maximum temperatures in July and mean daily minimum temperatures in January for different periods of record, shows rather pronounced differences, and a lack of spatial consistency—undoubtedly the result of one or two anomalous values—is very apparent. In addition, there appears to be no map of MITV for Canada.

We decided therefore that a more rigorous approach was necessary. In particular, and before mapping this climatic indicator, we need to determine how many years of record are required to obtain stable values of MITV.

The thermal properties of land and water, and atmospheric circulation, produce a lag of temperature behind radiation, which is longer for maritime than for continental locations (Prescott and Collins, 1951). Trenberth (1983) showed that this lag averages 27·5 days for the 48 contiguous States. In both cases, however, the interval was determined by harmonic analysis of mean monthly temperatures, which produces an average annual lag, and disguises any differences that may exist in the separate lags of winter and summer temperatures after their respective radiation maxima and minima. We will show how this characteristic of climate varies over North America in both winter and summer, and attempt to relate it to other climate characteristics.

DATA

The data used in the MITV part of this study consist of the average of daily mean maximum and daily mean minimum temperatures (daily mean temperatures) for the period 1951–1985 for 51 Canadian Stations (from the Canadian Climate Centre), and 40 conterminous USA stations (from the National Climatic Data Center). Data from Alaska were not included, although a study of MITV in Alaska has been made (Cushman, 1953). In the temperature lag part of the study we used data from 128 stations in the United States (including Alaska), Canada, and Mexico north of 20 °N. The Canadian and USA data are for 1941–1970, and the Mexican data for 1931–1960. It is unlikely that having non-identical data sets will appreciably affect the results.

MEAN INTERDIURNAL TEMPERATURE VARIABILITY

Record length

We want to choose a record length which results in a stable value of MITV but is not unnecessarily long. Stability, defined generally as a relatively small change in MITV with the addition of another iteration—in this case a 5-year period—will vary with geography and time of year. By experimenting with three variables, (i) record lengths, (ii) the incremental changes in MITV which resulted, and (iii) percentage of station-months thus defined as stable, it was determined that 91 per cent of the station-months have a stable MITV with a 0·2 °C increment after 20 years. That is, when a period of 20 years is chosen the great majority of the station-months have MITV such that when more 5-year iterations are chosen the resulting decrease in MITV is 0·2 °C or less and stays that way for additional iterations.

This analysis reveals that continental stations, and the winter–spring months, require the longest records by this criterion. For example, at six Canadian stations, for each of the months February–April, the 90 per cent criterion required 25 years. All other station-months required 20 years or less. If this study was restricted to the USA the chosen record length would be 15 years, but including Canada requires an increase to 20 years. The mapping of MITV is thus based on the mean daily temperature for the first 20-year period of the record (1951–1970).

Spatial patterns

Figure 1 shows MITV for four mid-season months, Figure 2 for the year. In January the variation across the continent is larger than in any other month: values range from below 3 °C in the western USA and southern Florida to about 5 °C in a ridge which extends from the Yukon through Alberta into Ontario and Quebec. The moderating effect of the Great Lakes is much in evidence. Strong gradients of MITV are found both in British Columbia, where they extend south-eastward through the Rockies, and in far eastern Canada.

In April the gradients have lessened but the overall pattern is much the same as in January. A northward shift in both the ridge of highest values and the minimum over the Great Lakes is evident. In July the transcontinental variation is least, the maximum is now over southern Hudson Bay and the pattern is quite zonal in the USA. There is no apparent influence of the Great Lakes. In October the area of highest MITV has shifted southward and extends from the Northwest Territories to Montana and then eastward to the Great Lakes, where a moderating effect reverses the pattern. The relatively strong gradient in the extreme east has lessened.

Average annual MITV—a plot of the average MITV for all 12 months at each station—summarizes the principal features. Values range from below 2 °C in southern Florida to a maximum of somewhat above 4 °C in the area just south of Hudson Bay. The ridge of highest values in the center of the continent is still evident, as are the strong gradients in the west and in the extreme east. Throughout the year values in the Canadian archipelago (data from seven stations north of 68 °N were utilized) vary comparatively little, both throughout this area in all months, and from about 2 °C in July to about 3·5 °C in January.

Associations

Two climatological factors appear to be related to the monthly and annual patterns of interdiurnal temperature variability shown in Figures 1 and 2 (all maps in this paper were computer generated, with hand smoothing). The first is continentality, which has been associated with other aspects of temperature variability, such as that of hourly temperatures (Bailey, 1968), of mean monthly temperature (Sumner, 1953), and of winter in the Northern Hemisphere (Barnett, 1978). By this we mean the effects of the various earth-surface substances on fluxes of radiation, heat and moisture at the air–land and air–water interfaces, and their consequences for the elements of weather such as temperature, precipitation, cloudiness, etc. (Driscoll and Yee Fong, 1992). This property of climate is usually defined only with respect to annual values, in particular the mean annual temperature range, so we look for correspondence between continentality and the annual pattern of MITV (Figure 2). Driscoll and Yee Fong (1992) showed that conventional measures of this parameter, which have used the sine of the latitude to correct for the variation of insolation with latitude, are in error. Their reformulation of continentality using a regression-based approach showed that the appropriate 'centre of gravity' of North America—just north of the USA–Canada border in Manitoba—is the most continental, as opposed to earlier, more traditional estimates which placed the maximum farther north.

This is somewhat different than the annual pattern of MITV (Figure 2), which has a maximum—however slight—just south of James Bay (southern Hudson Bay), i.e. somewhat farther east. The other noticeable lack of agreement in the patterns is in the four corners area of the South-west (junction of Utah, Colorado,

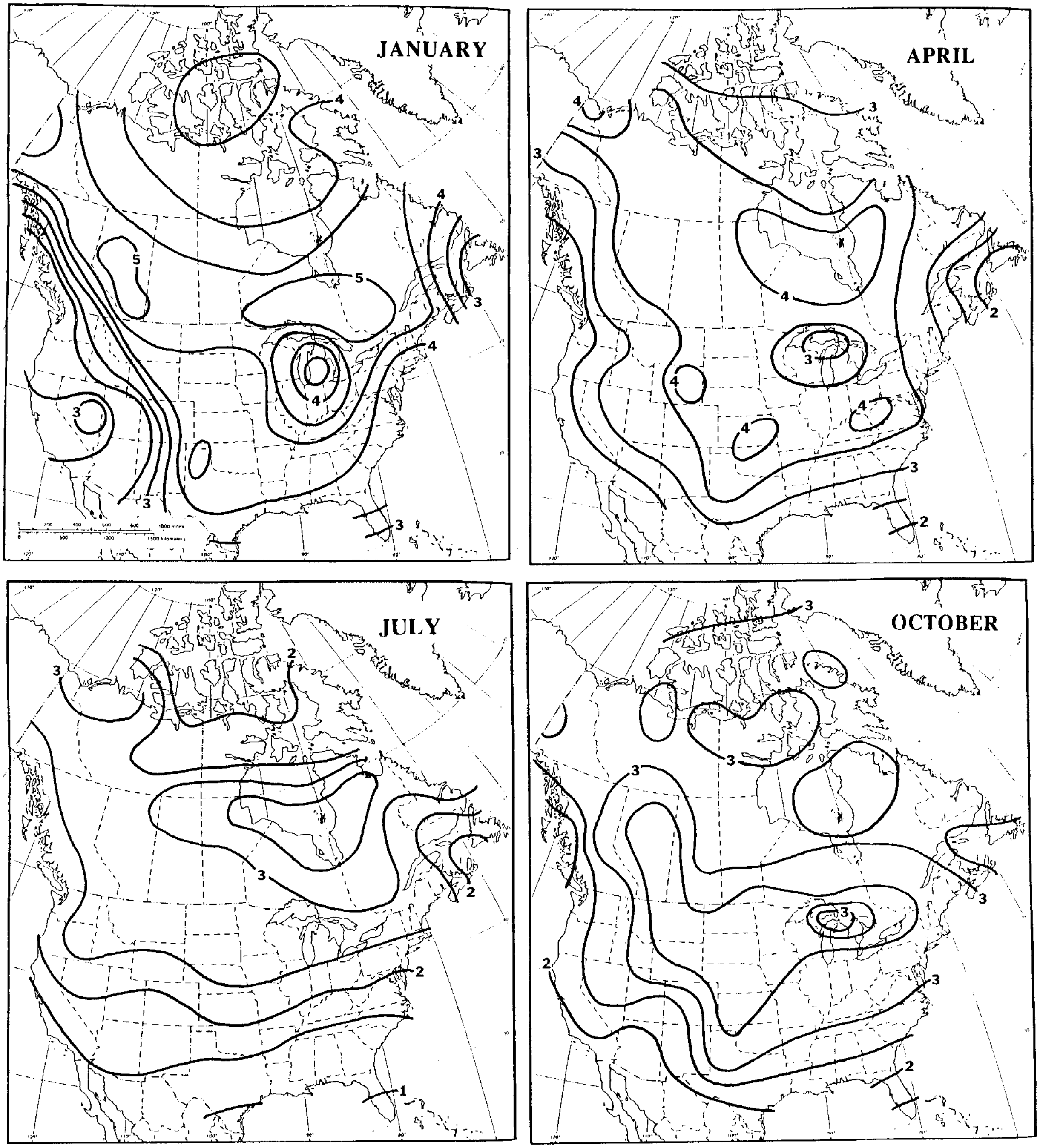

Figure 1. Mean interdiurnal temperature variability (°C) for the mid-season months of January, April, July, and October

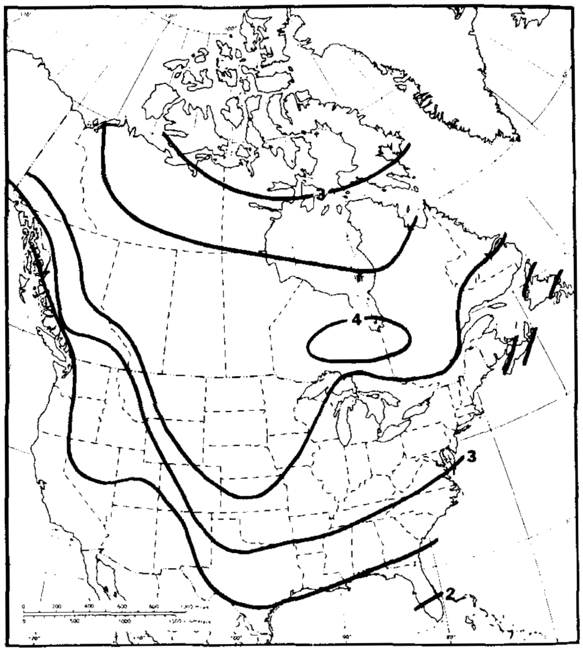

Figure 2. Mean annual interdiurnal temperature variability (°C). Values are the average of the 12 monthly values for each station

Arizona, and New Mexico), which shows a secondary maximum for continentality, but not for MITV. This is likely due to the greater influence of aridity on continentality, based as it is on mean monthly temperature differences, than on MITV, for which the aridity of the climate makes little difference.

The second major influence on MITV, and one which permits differentiation over the year, is the location of the surface polar front zone. Relatively large day-to-day changes in temperature associated with enhanced baroclinicity should occur in its vicinity. The location of this zone at the extremes of the year—in January along the Gulf Coast States and in July at about the USA–Canadian border—does not coincide with the locations of maximum MITV during these months. However, in both patterns there is a seasonal latitudinal variation, and the MITV patterns may simply be a reflection of both the location of the polar front zone at the surface and continentality.

TIME LAG OF TEMPERATURE BEHIND RADIATION

Method

Annual temperature curves for extratropical areas are, in general, not symmetrical; in particular 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, attempted by Prescott and Collins (1951) and Trenberth (1983), which predicates lag based on the first harmonic only, disguises seasonal differences in this lag.

To calculate the summer and winter lags of temperature behind the solstices we needed the dates of temperature maximum and minimum. For this we used the cubic spline interpolation scheme described by Greville (1967) and illustrated for temperature normals by Guttman and Plantico (1987). The input to this procedure was the mean temperature of the month of the day in question, as well as that of the 2 months preceding, and the 2 months succeeding that month.

Spatial patterns

The summer lag, in days, is shown in Figure 3. The least is in central Alaska, about 15 days, and from there a trough extends south-eastward to the Great Lakes. Another slight minimum is in the four corners region of the South-west, and a slight moderating effect (toward increased lag) is evident in the Great Lakes region and over Hudson Bay. Maximum lag is up to 80 days on the west coast, but values drop rapidly inland. A secondary area of high lag extends from Florida across the Gulf States into Texas. Areas of most pronounced gradients are in Alaska, and along the west coast and Gulf Coast.

Winter lag (Figure 4) shows greater variation over the continent, from less than 15 days in the south-west, in Georgia and South Carolina, and coastal areas of Alaska, to about 40 in the eastern Canadian provinces and more than 50 days in the far north. Again, relative maxima are apparent in both Hudson Bay and to a somewhat greater extent in the Great Lakes region.

We were curious to know the extent to which lag is influenced by factors that act on space-scales smaller than those thus far examined; in particular, if there might be mesoscale influences due to elevation. For this purpose we calculated lags from a subnetwork of 90 Rocky Mountain stations extending from southern British Columbia and Alberta to northern New Mexico and Arizona. About one-half of these are above 1500 m elevation. For neither the winter nor summer lags did we find any difference from the macroscale patterns shown in Figures 3 and 4.

Associations

An examination of these patterns for association with causal factors is not as straightforward as it was with mean interdiurnal temperature range. For MITV there is at least one depiction, mean annual, which incorporates data from each of the 12 months, permitting comparison with continentality, which also is an

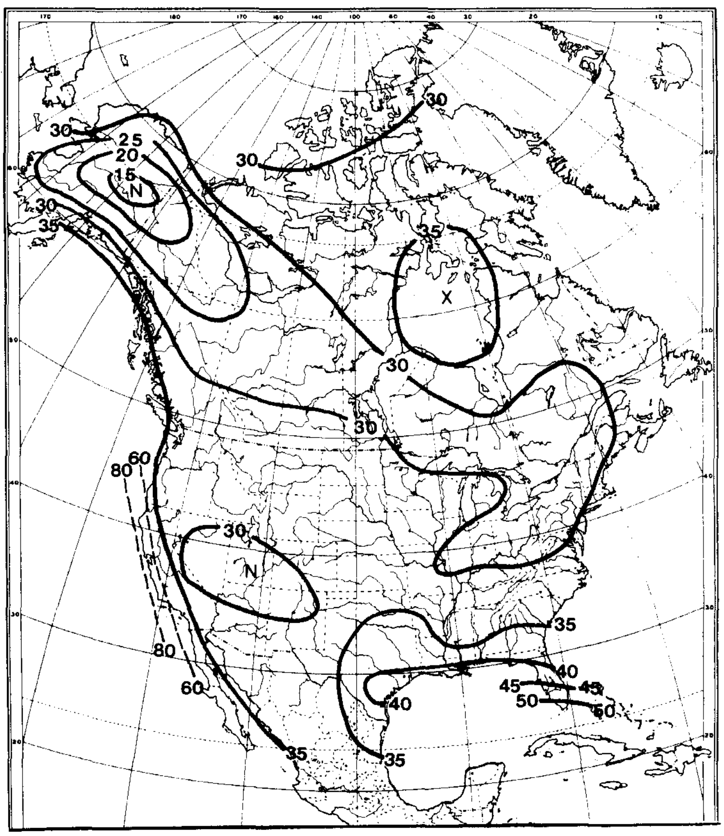

Figure 3. Mean length (days) between the summer solstice and the date of maximum daily mean temperature

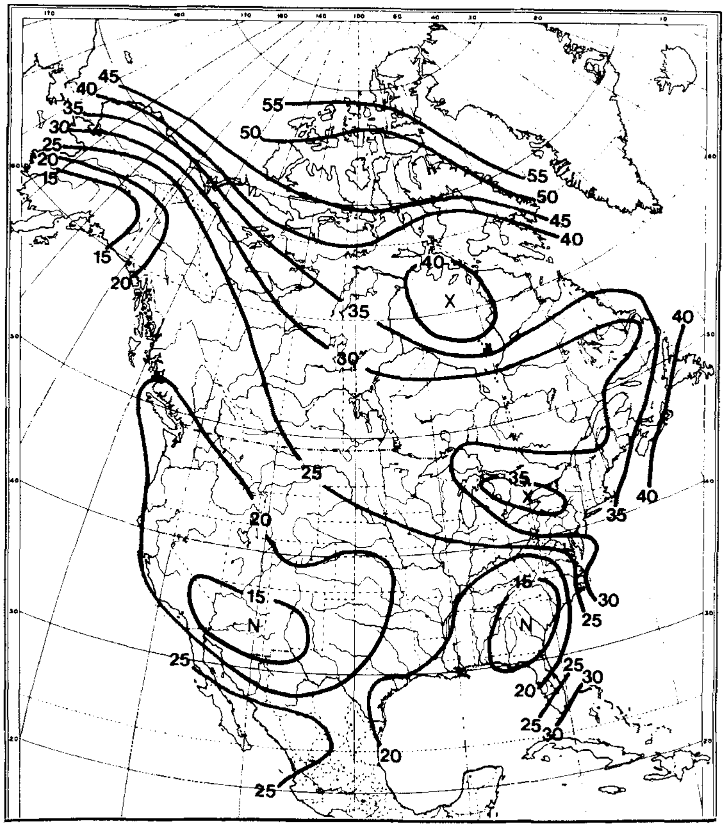

Figure 4. Mean length (days) between the winter solstice and the date of minimum daily mean temperature

annual factor (although only the most extreme of the 12 months are actually used in its computation). Now, however, the lag between the solstices and daily maximum and minimum temperatures depends only on conditions around that interval, e.g. for the summer maximum the period from June through to August, approximately. Nevertheless, a comparison with continentality is possible, and the traditional association has been that the more continental a station, the less the lag.

Figures 3 and 4 show that this is only approximately the case. In summer both the low values in the interior of the continent and the strong gradient along the west coast are consistent with the above association. However, the high values and strong gradient in the Florida–Gulf Coast area are not, although it could be argued that the tempering effect of the Atlantic and Gulf is most pronounced in southern Florida, and decreases rapidly northward. The strong minimum in central Alaska is commensurate with continentality except that the latter (see Driscoll and Yee Fong, 1992) does not have a core of high values in central Alaska.

In winter there is no apparent association with continentality. About the only features of this pattern for which an explanation is reasonable are the very long period in the far north, where low temperatures are prolonged by the retention of ice cover, and the slight maxima over Hudson Bay and the Great Lakes for the same reason. The pattern in Alaska is somewhat deceptive because smoothing in the analysis disguises the fact that the lag inmost of Alaska is quite uniform, with values up to about 20, except north of the Brooks Range, where for Barrow and Barter Island the lag approaches 60 days. Again, ice-cover retention appears to be the explanation. At the same time the very low values in the littoral of the Gulf of Alaska are inexplicable. This is not simply an anomaly resulting from one or two values. Including two nearby stations in Yukon and Northwest Territories, Alaska has 12 stations. Similarly, there is no apparent explanation for the minima in New Mexico–Arizona and in Georgia and South Carolina.

SUMMARY AND CONCLUSIONS

Two climatic aspects of the variability of temperature that have received little emphasis are the spatial and temporal variation of the average day-to-day change of temperature (MITV), and the lag of temperature behind solar radiation maxima and minima. In this paper MITV has been calculated for all months and mapped for January, April, July, and October in North America. The MITV is greatest in winter, especially in January, and least in July (Figures 1 and 2). A core of highest values extends east–west across the northern USA and south-central Canada, being farthest north in July and farthest south in January, when this core is roughly along the border. Tempering effects of both the western mountains, which produce sharp gradients of MITV, and of the Great Lakes and Hudson Bay, are evident. The causes appear to be continentality and the latitudinal migration of surface polar front zone.

The lag of temperature behind radiation maxima and minima is quite different from winter to summer, and explanations of the patterns are not apparent. In summer (Figure 3) minimum lag extends from very low values (as few as 15 days) in south coastal Alaska south-eastward toward the Great Lakes, which act slightly to increase this lag. Maximum values are along the east coast (values up to 80 days) and southern Florida (up to 50 days). Minima in winter are in the south-east and south-west USA, excepting Florida, and in Alaska (Figure 4). Highest values are in the far north, and appear to be related to the retention of ice cover. The tempering effect—toward increased lag—of water bodies (Great Lakes and Hudson Bay) is evident.

To the extent that the spatial and temporal patterns of MITV and lag are not coincident with continentality and the polar front zone, additional research will be necessary to determine the reasons for these patterns.

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