What are the Seasons?

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Abstract

The concept of dividing the year into four seasons is reexamined to appraise critically the relative merit of two commonly used definitions of the seasons: 1) the astronomical definition; and 2) the meteorological breakdown into four three-month periods. These are compared with the definition of winter as the coldest season, summer as the warmest season, and spring and autumn as the transition seasons. Observational data on surface temperatures over the entire globe and, in particular, over the United States, are used to determine what the seasons should be. Presented here is an analysis of the amplitude, and phase of and percentage variance explained by the first harmonic of solar radiation at the top of the atmosphere and surface temperatures.

Annual changes in surface temperature associated with the seasons are much larger over land than over the oceans. Surface temperatures lag the solar cycle by 27½ days over the United States, compared with 32½ days in mid-latitudes over the Northern Hemisphere as a whole, and 44 days in mid-latitudes of the Southern Hemisphere.

The astronomical definition of seasons is appropriate only over the oceanic regions of the Southern Hemisphere. Over the continental regions of the Northern Hemisphere, the "meteorological" seasons in which winter is December, January, and February, etc., agree reasonably well with observed events and are recommended for general usage.

1. Introduction

It is mid-December. A winter storm warning is in effect. A swath of 6–10 inches of snow blankets the midwest region of the United States and, further south, freezing rain is being encountered. While assessing the situation, the weathercaster on television notes that there are 10 more days before winter begins.

Something like this seems to occur every year, the behavior of the atmosphere at odds apparently with our conception of what the seasons are—or is it? What really is winter? When is summer? What are the definitions of the seasons? These are the questions we attempt to address in this article. There are two common definitions of the seasons in widespread use: the astronomical and the meteorological. Here we seek to investigate which of the two reflects the observed temperature variations over various portions of the earth's surface more accurately.

In Section 2, we delve into the origin of the seasons and briefly consider the basis for dividing the year into four parts, at least in mid-latitudes. Here, the astronomical and meteorological seasons are contrasted with each other and with a definition based upon temperatures. Section 3 describes the data and methods used in this study, and Section 4 uses the observed data to explore how these definitions differ from one another. A detailed analysis of each state in the United States is presented. We note that there are big differences between continents and maritime areas and between the Northern and Southern Hemispheres. In addition, the seasons are reversed in the Southern Hemisphere. The results are not really new (although there are some differences from previous studies), but they are presented in a new manner designed to reveal the effects of continentality and illustrate the concept of the season. Section 5 summarizes the results and makes recommendations on the practical usage of the terms "summer" and "winter."

2. Definitions of the seasons

The astronomical definition of the seasons is the one used most widely by the American media. The astronomical and meteorological definitions are compared in Table 1. The astronomical seasons define winter (Northern Hemisphere, or summer Southern Hemisphere) as the period from the winter solstice (22 December on average)[1] to the vernal equinox (21 March). Spring ends at the summer solstice (22 June), summer continues until the autumnal equinox (23 September), and autumn completes the cycle, ending on the winter solstice. Note that the astronomical seasons vary in length from 89 to 93 days, owing to the noncircular orbit of the earth around the sun. Although the sun-earth geometry is clearly the origin of the seasons on earth, these seasons have nothing to do directly with temperature or weather.

In contrast, in meteorology, the most widely used breakdown into seasons is simply the subdivision into four three-month periods. Winter is December, January, and February, the three coldest months in the Northern Hemisphere; spring is March, April, and May; summer is the three warmest months, June, July and August; and autumn is September, October, and November. This breakdown is largely one of convenience for compiling statistics, and does not recognize units of time shorter than a month. Owing to the uneven length of the months, these seasons vary too, ranging from 90 to 92 days in length (Table 1).

The Glossary of Meteorology (Huschke, 1959) defines the seasons, in part, as follows:

> Summer: The warmest season of the year everywhere except in some tropical regions; . . .
> Winter: The coldest season of the year; . . .

Spring and autumn are defined as the transition periods be-

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[1] Variations occur principally because the year is ~365¼ days long but is approximated by 365 days with a leap year every fourth year. In this article, we simplify the statistics by assuming a year of length 365 days.

TABLE 1. Starting and ending dates D and length L of each season for various definitions. The astronomical and meteorological seasons are given along with the corresponding values for seasons if defined based upon observed temperatures for different regions.

Northern Hemisphere Southern Hemisphere		Winter Summer	Spring Autumn	Summer Winter	Autumn Spring
Astronomical	D	22 Dec.-21 Mar.	21 Mar.-22 June	22 June-23 Sept.	23 Sept.-22 Dec.
	L	89	93	93	90
Meteorological	D	1 Dec.-28 Feb.	1 Mar.-31 May	1 June-31 Aug.	1 Sept.-30 Nov.
	L	90	92	92	91
Northern Hemisphere	D	8 Dec.-9 Mar.	9 Mar.-8 June	8 June-8 Sept.	8 Sept.-8 Dec.
(22.5-67.5°N)	L	91.25	91.25	91.25	91.25
Southern Hemisphere	D	19 Dec.-21 Mar.	21 Mar.-20 June	20 June-19 Sept.	19 Sept.-19 Dec.
(22.5-67.5°S)	L	91.25	91.25	91.25	91.25
U.S.A.	D	3 Dec.-4 Mar.	4 Mar.-4 June	4 June-3 Sept.	3 Sept.-3 Dec.
	L	91.25	91.25	91.25	91.25

tween these two seasons. These definitions are qualified in the tropics and high latitudes for reasons given below. The definitions are in terms of temperature and can be readily applied in mid-latitudes to divide the year into four seasons of equal or nearly equal length.

There are many alternative definitions of seasons which relate to certain events, such as the "tornado season," or specific activities, like the "growing season". These divisions of the year are arbitrary in length and although they may be referred to as "seasons", they do not relate to the concept of four seasons of equal length to be considered here.

The breakdown into four seasons is associated most logically with the 365-day period sine wave. For the solar radiation, this is illustrated in Fig. 1, which shows the period and phase of the 365-day period sine wave (the first harmonic) relative to the yearly calendar. Also shown, but discussed in more detail later, is the response in U.S. mean temperatures. It is well known that a pure sine wave has a U-shaped frequency distribution (see Fig. 2) which therefore naturally gives rise to the concept of two extreme and two transitional seasons.

The reason to expect temperatures on the earth to follow, for the most part, a 365-day cycle is directly related to the solar forcing and the astronomical seasons. In mid-latitudes, daily averaged radiation from the sun is dominated by the 365-day period although, as noted previously, the cycle is not a pure sine wave. However, we note that the astronomical seasons are offset by a lag of ½ season or ⅛ of the total period from what the seasons would be if there were an instantaneous temperature response on the earth.

In the tropics, at latitudes less than 23°27′, however, the sun is overhead twice each year and the dominance of a 365-day period is less assured. Rather, a prominent six-month cycle also is evident in temperatures in low latitudes. However, the yearly fluctuations in temperatures are not large, and seasons in the tropics more usually are defined meteorologically, in terms of the wet and dry seasons.

Similarly, inside the Arctic or Antarctic circles, the sun is entirely absent for part of the winter. This, too, leads to a significant six-month cycle in the direct solar heating. The effect

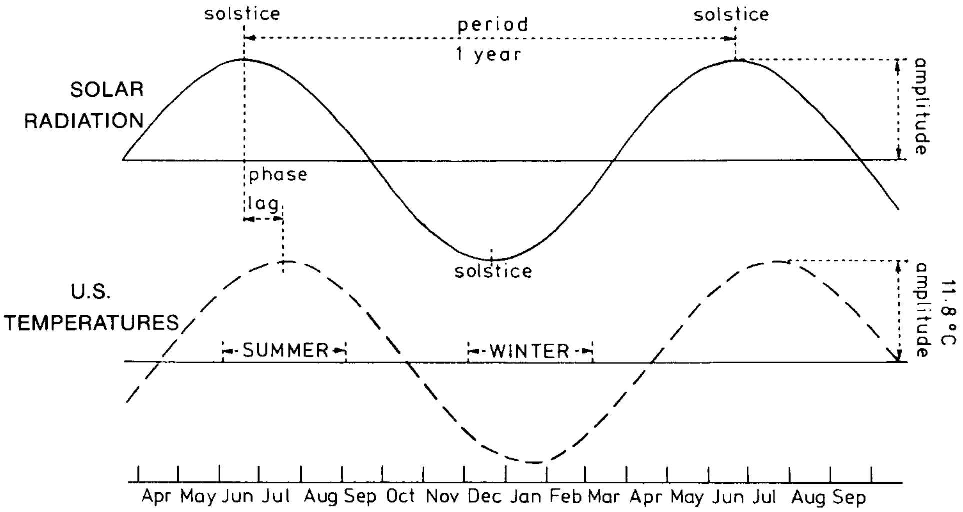

FIG. 1. Two sine curves, each of 365-day period, and amplitude as shown. The solid curve represents the solar radiation and is in arbitrary units (the amplitude varies with latitude). It has a maximum at the summer solstice in June (Northern Hemisphere) and a minimum at the winter solstice in December. The dashed sine curve depicts the response in the mean U.S. surface temperatures. Again the period is 365 days and the amplitude is at right, but there is a phase lag between the two curves of 27½ days.

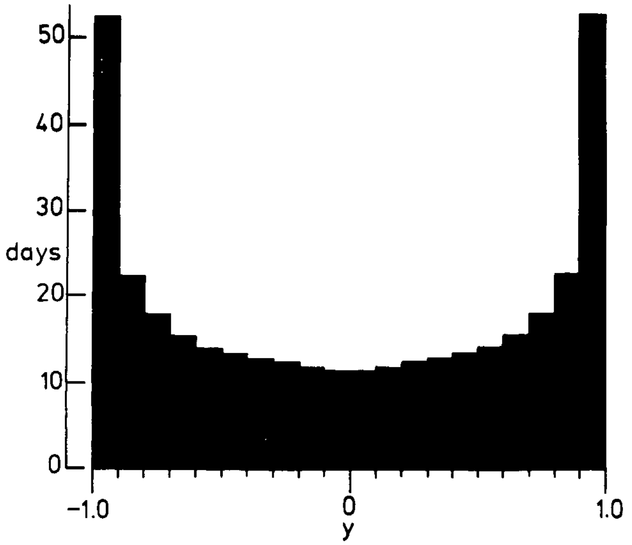

FIG. 2. Histogram of $y_t = \sin(2\pi t/365)$ corresponding to equal class intervals of $\delta y = 0.1$. The ordinate is the number of days y falls into each category. Note that the three categories $.7 \geqslant y \geqslant 1$ account for 92 days or ~25% of the total.

of the semiannual heating component on temperature is really pronounced only over Antarctica, owing to the existence of a continental land mass there. The result is a short summer and long but relatively uniformly cold winter half year that is referred to as the "coreless" winter. However, the lack of a sharp midwinter minimum in temperature is also related to dynamical factors and the "venting" of the polar region by storms in winter (van Loon, 1967).

Consequently, the concept of the four seasons should be applicable mainly in mid-latitudes, and we shall see that this indeed is borne out by observations.

3. Data and methods

We have analyzed several different data sets to explore these aspects in more detail. Mean surface temperatures over the Northern and Southern Hemispheres are available through NCAR[2] (Jenne *et al.*, 1974) and are based upon the analyses by Crutcher and Meserve (1970) for the Northern Hemisphere, and Taljaard *et al.* (1969) for the Southern Hemisphere. We have used mainly the zonal mean surface temperatures from these data sets. For the Southern Hemisphere the latter are given by Jenne *et al.* (1968) and the annual cycle has been analyzed by van Loon *et al.* (1968) and van Loon (1972). North and Coakley (1979) and North *et al.* (1983) also have analyzed the amplitude and phase of the annual cycle in surface temperatures from the same data sets.

In addition, the state, regional, and national monthly mean temperatures for 1931–1979 over the United States of America (U.S. Department of Commerce, 1978) are analyzed. In these cases, a mean temperature for each state is first obtained by weighting the values from different climatic divisions areally. Regional and national values are based upon areal weightings given to each mean state value.

Data on solar radiation are taken from the Smithsonian Meteorological Tables (List, 1968) but adjusted to correspond to a Solar Constant of 1370 W/m^2. Prescott and Collins (1951) previously have presented an analysis of the lag of surface temperatures behind solar radiation both world wide and in more detail over the United States. Although the main features of our results are similar to those of Prescott and Collins, the details differ considerably. Our results are compatible with the other studies noted, but the emphasis in the interpretation and presentation is quite different.

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[2] NCAR is the National Center for Atmospheric Research and is sponsored by the National Science Foundation.

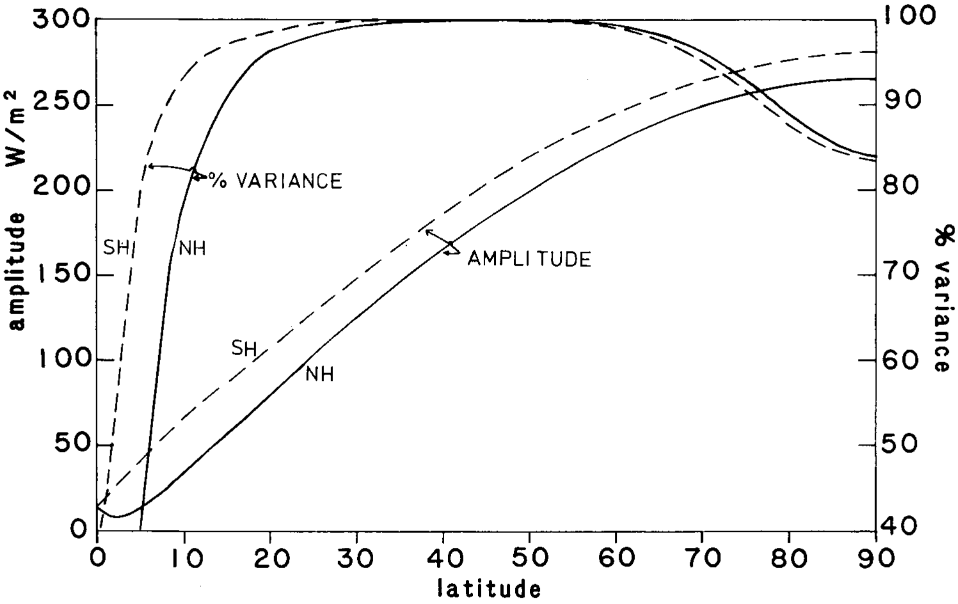

FIG. 3. Amplitude W/m^2 and percentage variance explained of the 365-day cycle in solar radiation at the top of the atmosphere for the Northern (solid) and Southern (dashed) Hemispheres as a function of latitude.

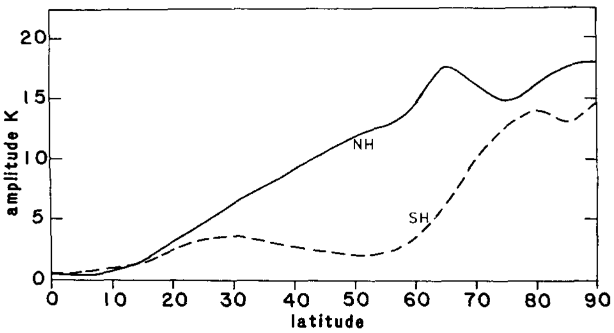

FIG. 4. Amplitude in K of the 365-day period annual cycle in zonal mean surface temperature for the Northern (solid) and the Southern (dashed) Hemispheres as a function of latitude.

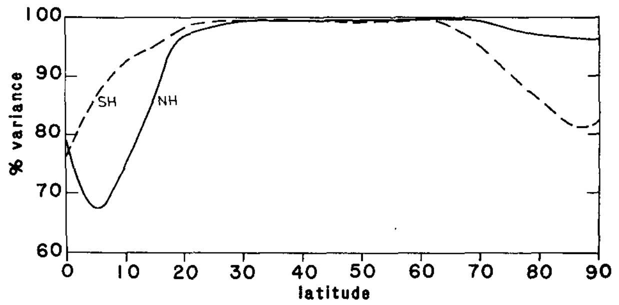

FIG. 5. The percentage variance accounted for by the 365-day period annual cycle of zonal mean surface temperature given in Fig. 4, for the Northern (solid) and Southern (dashed) Hemispheres.

The amplitude, phase, and percentage variance explained by the first three harmonics of the annual cycle have been obtained by Fourier analysis.

Since the concept of four seasons is based upon a simple sine wave, for the purpose of the analysis it is necessary to assume that all four seasons are of equal length. Consequently, small adjustments are needed to fit the solar cycle into four seasons each of 91.25 days duration, and to allow for the unequal length of each month. Accordingly, our model for the solar cycle has the summer solstice at day 173.13 (22 June), the autumnal equinox at day 264.38 (21 September), the winter solstice at day 355.63 (21 December), and the vernal equinox at day 81.88 (22 March). Similarly, in analyzing 12 monthly values we assume months of equal length, 30.42 days, and a small adjustment is necessary to get the correct phase of the annual cycle relative to 1 January. The procedures have been chosen to provide a mean adjustment of zero, thereby eliminating bias.[3]

Comparing the surface temperatures with the solar radiation, another complicating factor emerges. The solar cycle

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[3] The mean temperature of each month is assumed to apply at the central day of the month. The time of year in days, or fraction thereof, is determined for the central day of each month and for each model month where the latter have a length of 30.42 days. The mean difference between these 12 values is the phase adjustment required.

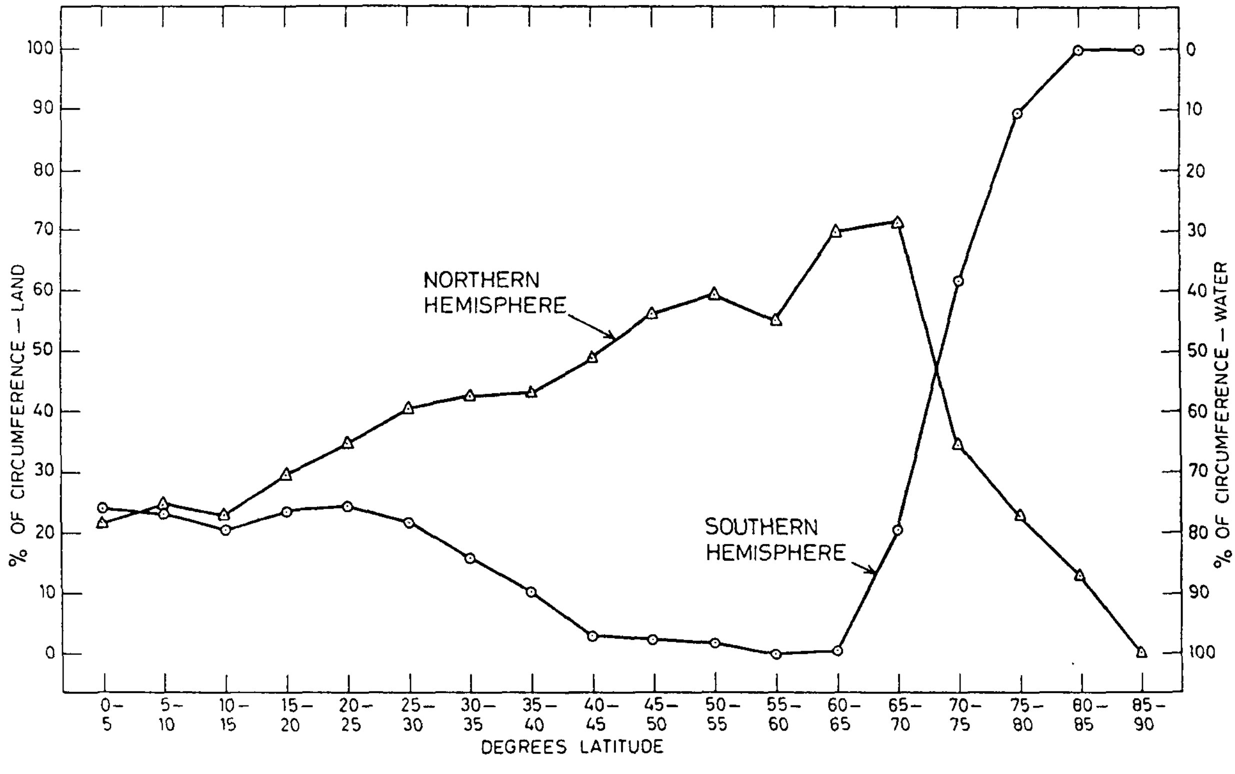

FIG. 6. Percentage of each zonal strip covered by land, scale at left, or water, scale at right.

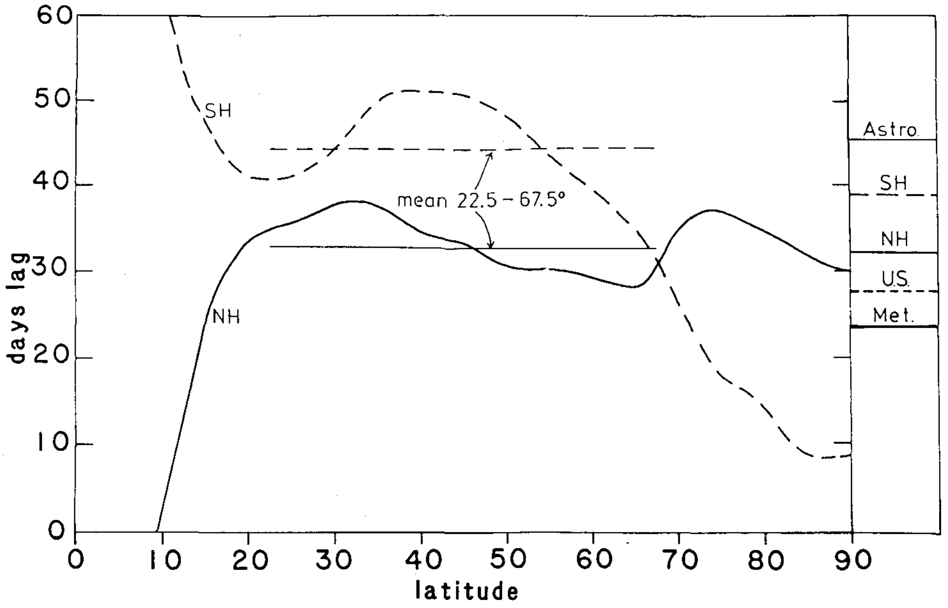

FIG. 7. The phase of the 365-day period annual cycle in zonal mean surface temperature expressed as days lag behind the sun. Profiles, as a function of latitude, are given for the Northern (solid) and Southern (dashed) Hemispheres. Also given is the areally weighted mean for the mid-latitude zone 22.5°–67.5° latitude in each hemisphere. At right, the lags corresponding to (from top) 1) the Astronomical seasons, 2) the mean Southern Hemisphere surface temperatures, 3) the mean Northern Hemisphere surface temperatures, 4) the mean United States surface temperatures, and 5) the meteorological seasons.

given takes no account of the changes in solar heating due to changes in the sun-earth distance associated with the elliptical orbit. The perihelion, the closest point, occurs about 1 January. Consequently, maximum heating in both hemispheres tends to be shifted slightly toward this date. In mid-latitudes, maximum heating occurs about a half day before the summer solstice in the Northern Hemisphere and about a half day after the summer solstice in the Southern Hemisphere. At the equator, maximum heating coincides with the time of perihelion. In polar regions, the effect is small and the shift is less than ±0.2 day polewards of 75° latitudes.

We will still use the model solar cycle previously defined as our reference, since it is applicable on a global basis. It is equivalent to North and Coakley's (1979) symmetricized assumption. They found the phase of the first harmonic of solar radiation relative to the Northern Hemisphere winter solstice to be 0.4 days, which is the same as the adjustment made in setting up our solar cycle. The reader should be aware that our results concerning the phase of the temperature cycle are relative to the above model solar cycle dates.

4. Observed "seasons"

To provide a frame of reference for the subsequent temperature analyses, we first present, in Fig. 3, the amplitude of and percentage variance explained by the first harmonic of the solar radiation at the top of the atmosphere. As noted earlier, the 365-day period cycle accounts for over 95% of the variance only between 20 and 70° latitude. Also of note is the generally larger amplitude in the Southern Hemisphere, the minimum north of the equator, and the general increase in amplitude with increasing latitude in both hemispheres.

The corresponding results for the zonal mean surface temperatures are shown in Figs. 4 and 5. First we compare the percentage variance of the total annual cycle accounted for by the first harmonics, as given in Figs. 3 and 5. The residual variance in each case is nearly all accounted for by the semiannual cycle (the second harmonic). In mid-latitudes of both hemispheres most of the solar heating and most of the temperature response is in the 365-day cycle. However, over the polar regions up to 16% of the variance in the heating field is in the semiannual component. This agrees quite well with the fraction of variance in the semiannual temperature component over Antarctica (Fig. 5) but not over the Arctic. North *et al.* (1983) attribute this discrepancy to the large heat capacity in the Arctic, which suppresses the semiannual response.

However, the amplitude of the response in the two hemispheres (Fig. 4) is not so clearly linked to the solar radiation, although there is a general increase with latitude. The discrepancy is explained mostly by the difference in heat capacity between the land and oceanic regions. Figure 6 shows the percentage of area covered by land and sea in each hemisphere as a function of latitude. Comparing Figs. 4 and 6, we note that the maximum amplitude near 65°N corresponds to the maximum fraction of land, and that the minimum in amplitude from 40°S to 60°S corresponds to the minimum fraction of land.

The differences in heat capacity are revealed further in the lag behind the sun of the temperature response, shown in Fig. 7. Since the concept of seasons as we have defined it, is conceived best outside of the tropics and polar circles, we have

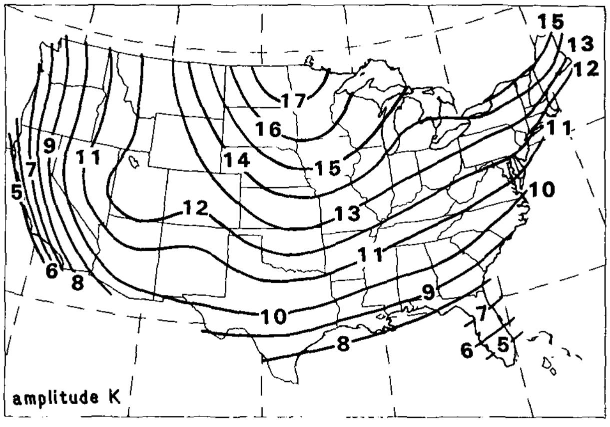

FIG. 8. The amplitude in K of the 365-day period annual cycle in surface temperature over the United States.

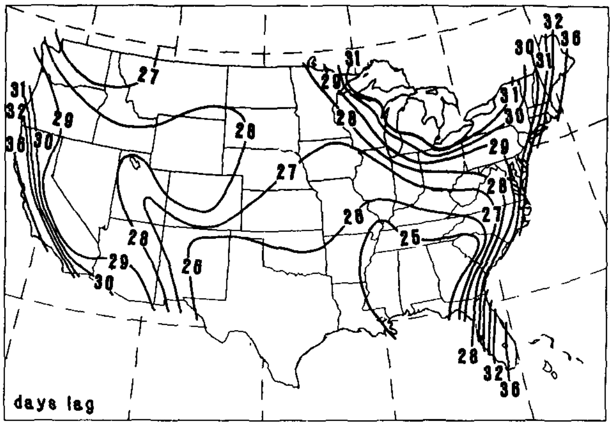

FIG. 9. The phase of the 365-day period annual cycle in surface temperature expressed as days lag behind the sun. The contour interval is one day except along the coast.

weighted the temperatures areally from 22.5 to 67.5° latitude in each hemisphere, and the phase lags for these mid-latitude regions are also shown on Fig. 7. On the right hand side, the phase lag for both hemispheres are also given along with some other values that will be discussed later.

In mid-latitudes, the lag behind the solar cycle is 32.4 days in the Northern Hemisphere, compared with 44.0 days in the Southern Hemisphere. The corresponding lag behind the actual solar radiation in each hemisphere (see section 3) is about 32.9 days in the Northern Hemisphere and 43.5 days in the Southern Hemisphere—a difference of 11.6 days. Together, the differences in amplitude and phase lag between the hemispheres plainly reveal the differences in continentality.

The effects of continentality are further illustrated by considering the surface temperature response over the 48 contiguous United States of America. The amplitude of the first harmonic is given in Fig. 8 and the phase lag behind the solar cycle is given in Fig. 9 (add ½ day to the Fig. 9 values to get the lag relative to the actual heating), see also Fig. 1. These patterns are relatively smoothed since they are constructed from mean values for the individual states which are given along with regional means in Table 2.

In Fig. 8 we note that maximum amplitude occurs almost exactly halfway across the continent although values fall off in magnitude to the south. The range in temperatures from summer to winter, double the values of Fig. 8, are as large as 35 K in North Dakota and Minnesota. This seasonal range in temperature is the main factor entering formulae that define an index or coefficient of continentality (e.g., Huschke, 1959). However, continentality also is reflected in the increase in lag of the temperatures in the coastal regions compared with the interior, as revealed in Fig. 9. Also very noticeable is a roughly five-day increase in lag and a small effect on amplitude associated with the Great Lakes. For the United States as a whole, the lag is 27.5 days, as shown in Fig. 1, and the temperature response occurs a further five days earlier than the mean for the latitude belt (Fig. 7).

One well-known consequence of the much larger amplitude in surface temperatures over the continents compared with the oceans, is that the continents tend to be warmer than the oceans in summer, while they are colder during winter. This seasonal reversal is the driving force behind the monsoon circulations.

5. Summary and recommendations

Based upon the results presented in the previous section, the definition of the summer and winter seasons as being the warmest and coldest quarters of the year results in the seasons given in Table 1. The relationships between the different definitions are graphically depicted in Fig. 7. Shown on the right hand side of Fig. 7 are the lag in days of the astronomical and meteorological seasons and the lag in mean surface temperatures for each hemisphere and the United States. As given in Table 1, rather than the entire hemispheric mean, a more appropriate value is the mean over mid-latitudes which is also shown on Fig. 7.

We see that the seasons defined by the temperature criteria fall between the astronomical and meteorological seasons. In mid-latitudes of the Southern Hemisphere, which is dominated by the ocean, the astronomical seasons are only about one day different and would seem to offer the more appropriate definition. As shown by Prescott and Collins (1951), sea surface temperatures lag the surface air temperatures by up to several weeks more.

For the mid-latitudes of the entire Northern Hemisphere, neither the astronomical nor the meteorological seasons fit very well. However, most people live on land in continental regions of the hemisphere, and for them, the seasons as defined by the mean temperatures over the United States would seem to be more appropriate. From Figs. 1 and 7 and Table 1, this definition of the seasons differs by only three to four days from the meteorological definition. It is, therefore, recommended that, for most practical purposes, the meteorological definition of the seasons should be preferred.

A reconsideration of the scenario depicted in the opening sentences of this article is now appropriate. Provided the seasons are defined along the lines suggested, we see that perhaps the weather situation described is not so much out of line with our concept of the seasons.

TABLE 2. Amplitude K and phase of the first harmonic in temperature by region over the contiguous United States of America. The phase is the lag in days of the temperature behind the sun.

Region	Amplitude	Lag	Region	Amplitude	Lag
U.S.A.	11.8	27.5	S. Atlantic	9.5	26.6
New England	13.7	30.9	Delaware	11.7	30.0
Connecticut	12.5	30.9	Florida	6.5	28.7
Maine	14.2	31.2	Georgia	9.3	25.1
Massachusetts	12.6	31.5	Maryland	11.8	28.7
New Hampshire	13.6	30.0	North Carolina	10.2	26.3
Rhode Island	11.6	33.9	South Carolina	9.8	25.4
Vermont	14.1	30.0	Virginia	11.1	27.2
Mid-Atlantic	12.9	29.9	West Virginia	11.4	27.2
New Jersey	12.1	30.3	E. S. Central	10.5	25.1
New York	13.4	30.9	Alabama	9.7	24.8
Pennsylvania	12.5	29.0	Kentucky	11.7	26.0
E. N. Central	13.8	28.7	Mississippi	9.8	24.8
Illinois	13.6	26.9	Tennessee	11.1	25.4
Indiana	13.1	27.5	W. S. Central	10.5	25.4
Michigan	13.6	31.2	Arkansas	11.2	25.4
Ohio	12.7	28.4	Louisiana	9.0	25.4
Wisconsin	15.3	28.4	Oklahoma	12.2	26.3
W. N. Central	15.1	27.2	Texas	10.2	25.1
Iowa	15.2	26.9	Mountain	10.9	27.8
Kansas	13.6	26.9	Arizona	10.7	29.0
Minnesota	16.8	27.5	Colorado	12.1	28.1
Missouri	13.0	26.6	Idaho	11.8	27.8
Nebraska	14.3	27.2	Montana	13.2	27.5
North Dakota	17.0	27.2	Nevada	11.3	28.4
South Dakota	15.6	27.8	New Mexico	10.9	26.0
			Utah	12.6	27.2
			Wyoming	12.8	28.7
			Pacific	8.9	29.9
			California	8.6	32.1
			Oregon	9.1	29.0
			Washington	9.5	26.9

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