Precipitation and the Lunar Synodic Cycle: Phase Progression across the United States

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ABSTRACT

The question of whether there is significant variation in precipitation in the United States at the lunar synodic period (29.531 days) has been examined, based on daily precipitation data for the period 1900–80. Our results confirm previous studies and indicate by a new method that there is statistically significant variation in precipitation at this lunar frequency. We also show for the first time that there is spatial progression over the United States in the phase of the lunar–precipitation relationship. During spring, a precipitation maximum occurs first when the moon is gibbous in the northwestern United States, progressively later during the lunar cycle in the Midwest, and, finally, about the time of the new moon in the East. The recognition of spatial progression in phase raises questions about the reality of previously proposed global, lunar–precipitation mechanisms. We suggest, instead, the actual cause–effect relationship may involve the long-wave circulation of the atmosphere.

1. Introduction

In the early 1960s, Brier and colleagues (Bradley et al., 1962; Brier and Bradley, 1964) made the remarkable discovery that extreme precipitation events in the United States occurred less frequently a few days prior to full moon, and more frequently a few days after. Their study was based on dates of heaviest 24-h total precipitation, during the period 1900–50, at 1544 stations.

The importance of the analyses by Brier and colleagues was that it established for the first time the statistical credibility of a lunar–weather relationship; this followed a period of time in which research on this cause–effect relationship suffered because of scarcity of data and limited statistical tests to distinguish significant variations from chance occurrence.

Brier and colleagues carried out numerous statistical tests showing that the lunar–precipitation relationship was highly significant; they demonstrated that a "lunar signal" was present in subsets of the total observational period, and they also showed that it was present in both total rainfall and extreme rainfall amounts.

In the interim since this important work, several studies have shown that other tropospheric variables appear to be modulated at the lunar synodic period (29.531 days). The variables studied were thunderstorm frequency (Lethbridge, 1970, 1981; Markson, 1971), cloudiness (sunshine) (Lund, 1965), and ice nuclei (Adderley and Bowen, 1962; Bigg, 1963).

In these studies, there is some consistency in the way lunar position appeared to modulate these variables, in that cloudiness, precipitation, and thunderstorm frequency were less than normal a few days prior to full moon, and greater than normal a few days after. In addition to monthly variations, there were fortnightly variations in precipitation (Brier and Bradley, 1964) and cloudiness (Lund, 1965) over the synodic cycle, with minima prior to new moon and full moon and maxima following them.

Previous authors have suggested two possible mechanisms for the influence of the moon on the troposphere: magnetospheric disturbance (Lethbridge, 1970; Markson, 1971), and meteoric dust (Adderley and Bowen, 1962). In both cases, the presumed cause–effect relationship is such that either a global or broad regional tropospheric response would have been expected. The remarkable similarity in the phase of the lunar-precipitation relationship in both the Northern and Southern Hemispheres—indicated by prior studies—did little to discourage the concept of a global-scale mechanism (Bradley and Brier, 1962; Adderley and Bowen, 1962).

New evidence presented herein raises questions about the reality of cause–effect scenarios previously put forward, in which the moon must affect tropospheric variables simultaneously over all or broad regions of the earth. It suggests, instead, that the actual mechanism involves, in some manner, the long-wave circulation of the troposphere.

2. Data

Because of increased availability of digitized precipitation data since earlier studies of this subject, we have been able to reexamine the question of the precipitation variation in the United States over the lunar synodic cycle. Our study is based on daily precipitation measurements in 34 regional areas with each region com-

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prised of one state, except in a few cases of limited data or limited size, where a region was comprised of a combination of two or three neighboring states (Table 1). California and Arizona were excluded from the study because of inadequate data. Precipitation measurements were obtained by the climatological network of the United States, and data were supplied by the National Climatic Center (NOAA, 1985). For this analysis, a subset of the original dataset was selected. The subset includes only the 12 stations with the longest records in each region. The ending date, 31 December 1980, was common for all regions, but beginning dates differed (Table 1).

For most regions, the period of available precipitation data ranged from the early 1930s to 1980 (about 50 years), with a few regions having a longer record (80 years), and a few shorter (30–35 years). Regions with a 50-yr record and the subset of 12 stations have a database of approximately 220 000 daily observations.

The angular difference between the apparent longitudes of the moon and sun at Greenwich noon was determined for each day and was expressed in 25ths of the synodic month. These time intervals are termed "synodic classes" and are 1.1812 days in length. At the instant of new moon, the longitudes coincide, and the angular difference is 0 deg. We have used convention and defined the beginning of the first synodic class at new moon. It follows that full moon occurs during the 13th synodic class. Synodic class values for each day of the present century were provided by Cotton (personal communication, 1984), using a computer program similar to that by Carpenter et al. (1972).

TABLE 1. States comprising the 34 separate regions employed in this study. All data series began on 1 January for the year and region indicated and they end 31 December 1980.

Region no.	State	Beginning year
1	Ala., Miss.	1930
2	Ark., La.	1937
3	Colo.	1949
4	Fla., Ga.	1931
5	Idaho, Mont.	1936
6	Ill.	1903
7	Ind.	1917
8	Iowa	1900
9	Kans.	1905
10	Ky.	1933
11	Maine, N.H., Vt.	1949
12	Mich.	1948
13	Minn.	1932
14	Mo.	1919
15	Mont.	1930
16	Nebr.	1900
18	N. Mex.	1950
19	N.Y.	1931
20	N.C.	1933
21	N. Dak.	1949
23	Okla.	1948
24	Oreg.	1932
25	Pa.	1942
26	S.C.	1930
27	S. Dak.	1930
28	Tenn.	1935
29	Tex.	1935
30	Utah	1928
31	Va.	1933
32	Wash.	1931
33	Wis.	1949
34	Wyo.	1948

TABLE 2. Precipitation frequency of occurrence for South Dakota during spring in relation to lunar synodic class for precipitation area index values >1 and precipitation of 0.01 inch or greater.

		Frequency of occurrence	
Synodic class no.	Phase	Unsmoothed	Five-point smoothed
1	New moon	0.453	0.477
2		0.521	0.475
3		0.479	0.462
4		0.450	0.459
5		0.408	0.452
6	First quarter	0.438	0.445
7		0.485	0.451
8		0.443	0.459
9		0.479	0.450
10		0.449	0.451
11		0.394	0.468
12		0.489	0.471
13	Full moon	0.527	0.484
14		0.494	0.506
15		0.514	0.515
16		0.508	0.527
17		0.533	0.535
18		0.587	0.530
19	Last quarter	0.532	0.527
20		0.489	0.530
21		0.495	0.515
22		0.548	0.500
23		0.511	0.497
24		0.459	0.489
25	New moon	0.472	0.483
Average		0.486	0.486
Lunar sorting			
Std. dev.		0.0441	—
Ampl. (1)		0.0430	—
Ampl. (2)		0.0108	—
Random sorting (100 times)			
Mean std. dev.		0.0359	—
Std. dev.		0.0055	—
Mean ampl. (1)		0.0118	
Std. dev.		0.0058	—
Mean ampl. (2)		0.0134	—
Std. dev.		0.0067	—

3. Analysis

A daily precipitation-area index [PAI] was calculated for each region. It is defined as the number of stations, out of the 12 with the longest records, where precipitation occurred on a given day. Thus, the range of the daily PAI values is 0–12.

The PAI values were sorted by region, season, and lunar synodic class, in that order. For a 50-yr period,

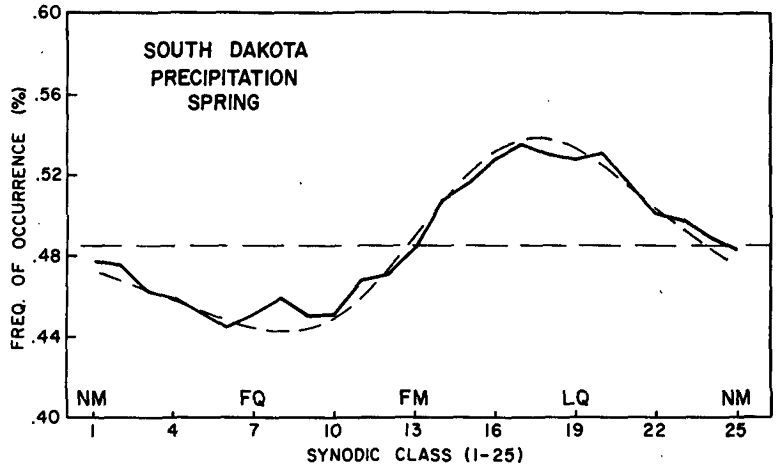

FIG. 1. Frequency of occurrence of precipitation in South Dakota during spring in relation to the synodic period: "smoothed" data of Table 2 (solid curve), and sum of the first and second harmonics (dashed curve). New moon occurs at the beginning of synodic class 1 and at the end of synodic class 25. Full moon occurs during synodic class 13.

this gives approximately 180 PAI values per region, season, and synodic class. Finally, frequency of occurrence values were calculated for each class by finding the number of PAI values greater than 1.0 in that class and dividing it by the total number of PAI values in the class. This calculation gives, essentially, the fraction of time precipitation occurred, covering approximately 8% or more of the region, during a particular portion of the synodic cycle.

An example of a regional–seasonal analysis of precipitation over the synodic period is given in Table 2, for South Dakota during spring. A five-point moving average (equal weight) was applied to these data, and the results are given in both Table 2 and Fig. 1. Clearly, there is systematic variation in precipitation over the lunar cycle, particularly at the first harmonic. The average frequency of occurrence (25 unsmoothed values) is 0.486, the standard deviation is ±0.0441, the amplitude of the first harmonic is 0.0430, and the amplitude of the second harmonic is 0.0108.

The South Dakota-spring PAI dataset was also sorted randomly 100 times and similar standard deviations and amplitudes were obtained for each of the 100 sortings. Means of the standard deviations and of the amplitudes of the first and second harmonics are given in Table 2.

In examining the nature of the variability in the South Dakota data in Table 2, we find the first harmonic accounts for much of the variability. This comes as no surprise in view of the close match in Fig. 1 between the "smoothed" data and the variation of the first and second harmonics. The variance of the first harmonic is 48% of the total variance, ±4%. The average variance obtained through random sorting of the South Dakota spring data is 66% of the lunar sorted variance, ±18%. Thus, these two variability source terms can account for all of the variance in the South Dakota spring data.

However, the total variance is small. The range of the first harmonic, for example, is only 18% of the mean value. Thus, the analysis (sorting) technique has extracted a small "signal" from significant "noise."

From the sorting statistics of Table 2, it is apparent that the amplitude of the first harmonic based on lunar sorting is statistically significant, as its value, 0.0430, departs from the mean amplitude from random sorting, 0.0118, by [(0.0430–0.0118)/0.0058]-5.4 standard deviations. The phase value for that harmonic is 269 deg, indicating maximum precipitation about the time of the last quarter.

Analyses similar to that for South Dakota have been done for all of the 34 regions and all four seasons. A summary of the results of these analyses is given in Table 3. The value presented is the "number of standard deviations" (NSD) for the amplitudes of the first and second harmonics. As previously indicated, this index is the number of standard deviations by which the lunar-based amplitude departs from the mean of the 100 random-based amplitudes for the same dataset. Note that the NSD value for South Dakota for spring is 5.4.

In Table 3, we have not included NSD values < 2.0 as these values are associated with theoretical significance levels of <95%. At the bottom of Table 3, the total number of regions with NSD values of ≥2.0 is given for each season.

From Table 3, the first harmonic appears to be significant in a few more regions during spring and fall than during the other two seasons, whereas the second harmonic is significant in more regions in summer and

TABLE 3. The number of standard deviations (NSD) is determined as the difference between the harmonic amplitude based on sorting at the synodic period, and the mean of 100 amplitudes based on random sorting, scaled in units of standard deviation of the random sorts.

		Number of std. dev. (NSD)*							
		First harmonic				Second harmonic			
Region no.	State	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
1	Ala., Miss.	3.3	—	3.9	—	—	—	—	—
2	Ark., La.	2.2	2.3	—	—	—	—	2.6	—
3	Colo.	—	3.9	—	2.2	3.0	—	—	—
4	Fla., Ga.	2.1	2.8	—	2.5	—	—	—	—
5	Idaho, Mont.	—	3.3	2.2	3.1	3.2	—	4.7	2.3
6	Ill.	—	2.4	—	—	—	—	7.2	2.0
7	Ind.	—	3.2	3.1	3.4	—	3.6	3.0	2.2
8	Iowa	—	2.8	—	—	—	—	2.5	2.2
9	Kans.	—	—	2.0	—	—	2.0	3.2	—
10	Ky.	—	—	—	3.4	—	4.2	2.4	—
11	Maine, N.H., Vt.	3.5	—	—	—	2.2	—	—	2.0
12	Mich.	—	—	3.2	—	2.3	—	—	3.4
13	Minn.	—	—	4.5	—	—	—	—	4.8
14	Mo.	—	2.9	—	—	—	2.1	3.9	2.5
15	Mont.	2.0	3.4	—	2.4	—	2.1	—	3.4
16	Nebr.	—	—	—	—	2.6	2.3	—	—
17	Nev., Utah	3.0	3.2	—	2.0	—	—	2.2	—
18	N. Mex.	2.8	2.5	2.3	3.5	3.6	—	2.1	2.8
19	N.Y.	—	—	—	—	—	2.0	—	3.2
20	N.C.	2.6	—	—	—	—	—	2.6	—
21	N. Dak.	—	—	—	—	—	2.4	—	4.6
22	Ohio	—	—	2.8	2.4	—	4.2	2.2	2.7
23	Okla.	—	3.8	2.9	2.5	—	—	—	3.6
24	Oreg.	—	—	2.1	2.5	5.0	—	—	—
25	Pa.	—	—	—	—	—	—	—	2.8
26	S.C.	—	—	—	2.0	—	—	3.2	—
27	S. Dak.	—	5.4	—	2.7	—	—	—	2.8
28	Tenn.	—	—	—	—	—	2.5	—	—
29	Tex.	—	3.1	—	2.2	—	—	—	—
30	Utah	—	—	—	—	—	—	3.0	2.1
31	Va.	2.6	2.4	—	—	—	2.6	3.4	—
32	Wash.	2.5	4.2	2.1	3.3	4.0	2.5	3.0	—
33	Wis.	3.5	2.4	2.4	—	—	—	2.0	—
34	Wyo.	—	5.6	—	2.5	3.0	—	—	—
	n =	11	18	12	16	9	12	17	17

$$* \text{ NSD} = \frac{(\text{ampl. lunar sort} - \text{ampl. random sort})}{\text{std. dev. of random sort}}.$$

fall than in winter and spring. During spring, approximately two-thirds of the regions have NSD values of ⩾2.0, clearly exceeding the approximately 5% expected by chance. The largest NSD value in Table 3 is 7.2 for Illinois in summer. During spring the largest value is 5.4 for South Dakota, this being the reason for its use as an example in Fig. 1.

Values for the phase of the first harmonic, for spring, are illustrated in Fig. 2. For those regions with NSD values of the first harmonic of <1.0, phase values are not given. For those regions with NSD values between 1.0 and 2.0, phase values are given in parentheses; and for NSD values of ⩾2.0, phase values are given without parenthesis.

It is apparent from Fig. 2 that during spring the phase of the first harmonic is not constant over the United States, but progresses with time from the Northwest to the East. Maximum precipitation appears to start when the moon is gibbous after being full in the Northwest, and progresses eastward to occur when the moon is new in the East. The time difference from west to east is approximately 13 days, which equates to hemispheric wave 3 to 4. There is some scatter in the regional phase values of Fig. 2 relative to the smooth contours; however, the (rms) departure of the regional values from the smooth contour analysis is only ±9 deg over a total change from the West to East Coast of approximately 160 deg, indicating the significance of the coast-to-coast phase change during spring.

During two other seasons (not presented here), there is also a spatial change of phase over the United States. During winter the phase change is similar to that for spring (Fig. 2). During summer there is a north-to-south phase change, but in fall the spatial pattern of phase change is not well defined. The analysis for spring has been presented here because it provides a simple,

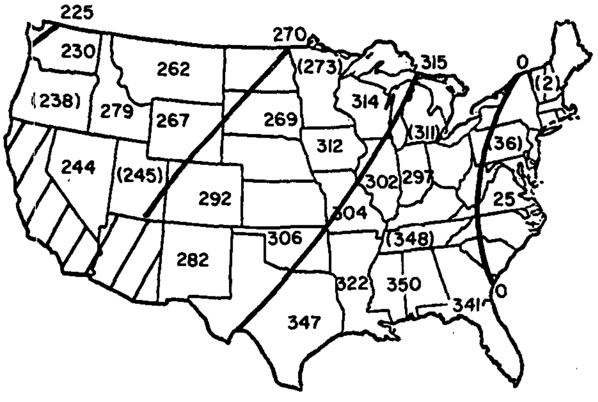

FIG. 2. Phase of the first harmonic of precipitation frequency of occurrence values over the synodic period during spring. For regions with NSD values (Table 3) in the range 1.0 to 2.0, phase values in this illustration are enclosed in parentheses. For regions with NSD values less than 1.0, phase values are not given.

spatially coherent pattern which is adequate to support our conclusions. Analyses for the other three seasons will be presented elsewhere. In the interim, interested readers are encouraged to contact the authors concerning the database or analysis results.

4. Discussion

An important question is whether or not the present results are consistent with those of earlier studies. The most comprehensive prior study of lunar–precipitation association is that of Brier and Bradley (1964). In that study, they indicated that ". . . [the] analysis . . . suggests there may be a seasonal variation in phase and amplitude of the 14.765 day cycle [in precipitation]. . . ." We confirm that result and, indeed, have found it necessary to sort precipitation data seasonally in order to obtain optimum information on precipitation variation over the synodic cycle. They also indicated that ". . . [the] study of phase information does not suggest a regular movement of a wave pattern across the United States. Although some constancy of phase . . . is shown, [the results] indicate that a lot of noise or unexplained variation remains." Our present study of the 29-day cycle does detect a vernal phase progression over the United States, the pattern of which changes from season to season. Thus, an analysis such as that by Brier and Bradley (1964) which looked for a spatial phase pattern for the entire year, would, no doubt, obtain relatively noisy results.

In conclusion, it would appear that the limited amount of precipitation data available prior to this study (mainly dates of extreme precipitation), restricted the ability of earlier investigators to discriminate spatial variation of the phase of the lunar-precipitation relationship. This conclusion in no way detracts from the fact that the analysis of Brier and Bradley (1964) remains an important, impressive, landmark study which established the existence and statistical significance of a lunar-precipitation relationship in the United States.

Of additional interest to us are the implications of these results to previous postulations of the root cause of atmospheric variation at this lunar monthly frequency. Lethbridge (1970) proposed that lunar distortion of the earth's magnetosphere may be the cause of tropospheric anomalies at the synodic period. Adderley and Bowen (1962) indicated the tropospheric phenomenon was "not incompatible with the meteor (dust) hypothesis." Both of these causes, considered with likely associated direct mechanisms, suggest the tropospheric response would occur simultaneously over broad regions of the earth. The results of the present study are not supportive of a causal mechanism that creates tropospheric response simultaneously over global or continental-scale regions.

The present results suggest that the mechanism by which lunar position may modulate precipitation could involve the long wave circulation in the troposphere. The results of the present analysis suggest hemispheric wave 3 or 4 may be involved. But even if such long waves are involved, What is the cause of the apparent synchronism between geographic location and phase of the lunar cycle?

In future studies, an important test will be to determine whether tropospheric variation at this lunar period is statistically different than that at other nearby frequencies, but frequencies unrelated to lunar position. In this regard, our studies do not suggest there is significant variation in precipitation at the lunar anomalistic and nodical periods.

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