HISTORIC RECORDS OF METEORITE FALLS IN CHINA AND THEIR TIME-SERIES ANALYSIS

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***Abstract*:** The time distribution of meteorite falls in China is shown to be uneven on the basis of the historic records compiled in "Table of historic records of ancient astronomical phenomena in China". The time series analysis is made on the frequency of the meteorite falls of 580 records in ancient to recent China. The correlation function is calculated by means of a computer on the frequency of meteorite falls in one year and in 10 years in the two intervals of time; 620–1499, and 1479–1924. The period of meteorite falls is determined from the time intervals between the successive peaks of the correlation function. The presence of two periodicities in meteorite falls is concluded; a long cycle of 240 years and a short cycle of 60 years.

1. Introduction

China has rich historic records of astronomical data. One of the authors had taken part in the work of compiling "Table of historic records of astronomic phenomena in China", headed by Beijing Observatory. This table includes: eclipses of sun and moon, sunspots, comets, nova, polar light, meteorites, meteor, queer sound from heaven, tides, etc.

The earliest record on meteorites appeared in 2133 B.C., but most of the earlier records are not very accurate or systematic. Since 1479 A.D. (the 15th year of Chen Hua' Min dynasty), such records as astronomic phenomena including many local ones (local chronicles), increased considerably and systematically. Besides the vivid and impressive descriptions of the meteorite-falling phenomena in detail; time, place, and the number of falls, and the size and shape of the recovered meteorites had also begun to be recorded in number of ancient books since then.

The meteorite falls of 580 records in 1405 years between 620 and 1924 A.D. are identified in the compiled table. The time distribution of these meteorite falls looks apparently uneven, suggesting a possibility of presence of some periodicity in meteorite falls. Therefore, we have made a study on the temporal variation of these meteorite falls by means of the time series analysis in order to clarify the nature of the meteorite-falling phenomena and also to obtain a clue to the related subjects.

The presence of two cycles, 60 years and 240 years, is indicated in the meteorite falls by the present preliminary analysis. The presence of a 60 year cycle is also pointed out in the meteorite falls witnessed all over the world (1800–1974). The obtained periodicity of meteorite falls is discussed in relation to the commensuration of orbital motion of asteroids with the periods of planetary motions in the solar system. Further it is pointed out that the temporal variation of meteorite falls is resembling to that of the sunspot activity.

2. Methods of Analysis and Computation

Calculation of an autocorrelation function is a useful approach in time series analysis for determination of the periodic components embedded in the sequential data. The data sequence sometimes appears to repeat as shown in Fig. 1. We suppose two sequential data; one is an original sequence named X1, and another, named X2, is the same data sequence as X1, but is shifted by a certain time (step of data point), and we compare them as shown in Fig. 2A. When X1 and X2 are compared very well and fit one to another as shown by the case B in Fig. 2, we can find out the repetition period of the original sequential data from the necessary time shift of X2 relative to X1.

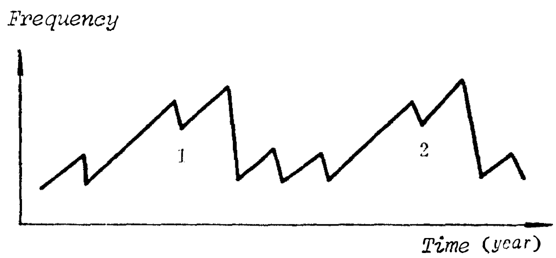

Fig. 1. Frequency of meteorite falls versus time. The repetitive nature (1 and 2) of the meteorite falls is schematically illustrated.

In order to make such a comparison of the sequential data with itself at successive position of shift, we compute a correlation function R by the following formula;

$$R=\frac{N\Sigma(\mathrm{X1}\cdot\mathrm{X2})-(\Sigma\mathrm{X1})(\Sigma\mathrm{X2})}{\sqrt{[N\Sigma(\mathrm{X1})^2-(\Sigma\mathrm{X1})^2]\cdot[N\Sigma(\mathrm{X2})^2-(\Sigma\mathrm{X2})^2]}},$$

where N is the number of overlapped data point in the region of comparison. We calculate one value of R, then the curve X2 is shifted by one step relative to X1, and we make the same calculation. This procedure is repeated on computer until two

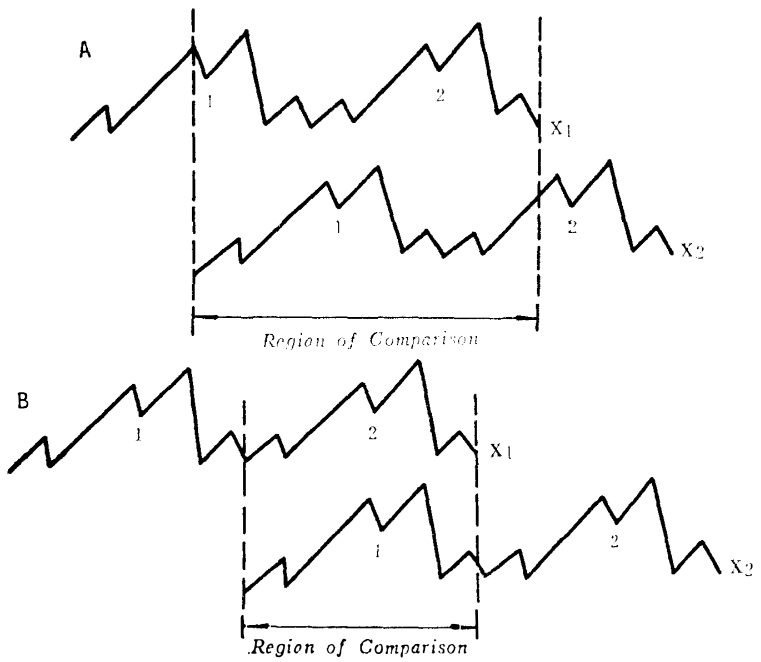

Fig. 2. An explanation of a basic idea how to find out the periodicity in the sequential data by means of auto-correlation function. X1 is a sequential data, and X2 is the same one with a time shift of certain amount. B shows the good correlation, while A is not.

sequential data overlap. Then we obtain an auto-correlation function, or a series of R values as a function of the time shift.

The autocorrelation function R exhibits the following properties:

(1) It is a unit less number, ranging from -1 to $+1$.

(2) When it is close to zero, any sort of correlation is not indicated at all. When R is $+1$, there is a perfect positive correlation between X1 and X2.

(3) The time interval between the adjacent successive positive peaks on curve R is identified with the repetition period in the original data sequence, if statistical structure of the data sequence is simple.

As the first approach, we employed (3) in the above for the present data analysis.

3. Analysis and Result

In the actual application of the autocorrelation analysis to the present data of meteorite falls, we considered the following two:

(1) The analysis is made on the two different time intervals of data; 880 years between 620 and 1499, and 445 years between 1479 to 1924. In the historic records, the number of meteorite falls increased suddenly in 1479, when the systematic recording of the astronomic data has begun as a result of the rises in cultural activity and ancient books in China. The quality of the data before and after 1479 is different, and

the whole data sequence is divided into two segments near 1479, and the analysis is made separately.

(2) The analysis is made on the two cases; data of meteorite falls in one year, and those in ten years. The meteorite falls are rare phenomena, and the frequency of falls in 10 years may raise the statistical reliability, while those in 1 year may be useful to detect the shorter periods.

3.1. Analysis of frequency in one year

3.1.1. 620–1499 (total 880 years)

In this case we have two positions of good correlation on curve R. The time interval between the two adjacent peaks of R is 350—110=240 as shown in Table 1. This means that the frequency of meteorite falls has a repetitive nature with a cycle of 240 years.

Table 1. Peak position of correlation function for the data sequence per one year (620–1449).

Comparison No.	R (Peak)
110	0.2872
350	0.2438

3.1.2. 1479–1924 (total 445 years)

There is one position of good correlation as shown in Table 2. The cyclic period is then calculated as 395—156=239 years.

Table 2. Peak position of correlation function for the data sequence per one year between 1479 and 1924.

Comparison No.	R
156	1.0000 (ordinary)
395	0.2531 (peak)

3.2. Analysis of frequency in ten years

3.2.1. 620–1499 (total 880 years)

The autocorrelation function is shown in Fig. 3, in which a number of positive peaks appear. These peak positions are tabulated in Table 3. This table shows clearly that there is a 60 year cycle, which is also seen obviously on the curve of the autocorrelation function.

3.2.2. 1480–1919 (total 440 years)

The autocorrelation function is shown in Fig. 4. The R curve apparently shows a significant stair at the comparison number below 10. If we take the first peak of the stair as a position of the good correlation for a period of meteorite falls in this case, we have 240 years for the period as shown in Table 4.

Summing up the results obtained in the above, we conclude that the meteorite falls are certainly periodic and that there are two periods; a longer cycle of 240 years and a shorter one of 60 years.

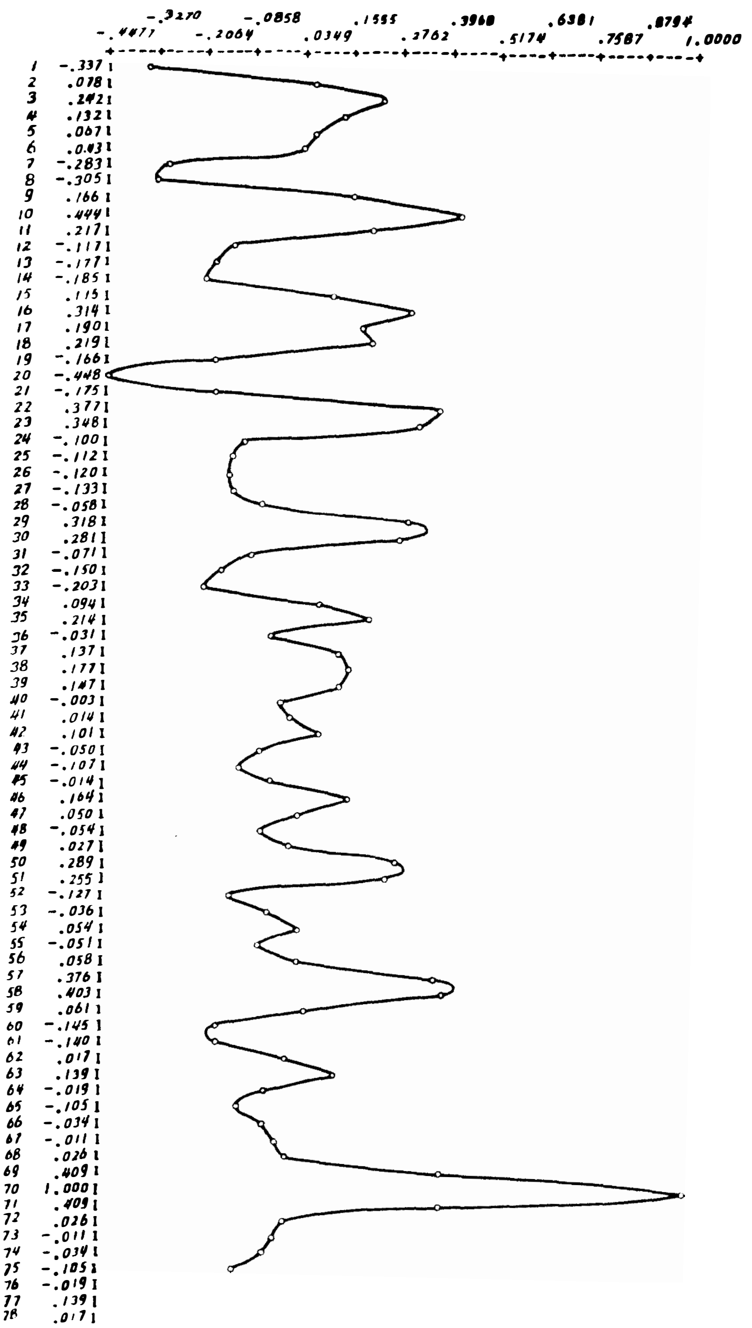

Fig. 3. Autocorrelation function for the number of meteorite falls per one year in 880 years between 620 and 1499.

Table 3. Peak positions and their time interval for the data sequence per ten years (620–1499).

Comparison No.	Position of comparison		Time interval (year) multiple of 60 years and deviation	R (peak)
	X1	X2		
10	620	680	$(680-620)\times 10=600$ $=60\times 10$	0.4439
16	620	674	$(674-620)\times 10=540$ $=60\times 9$	0.3140
22	620	668	$(668-620)\times 10=480$ $=60\times 8$	0.3770
29	620	661	$(661-620)\times 10=410$ $=60\times 7$ $\boxed{-10}$	0.3182
35	620	655	$(655-620)\times 10=350$ $=60\times 6$ $\boxed{-10}$	0.2145
42	620	648	$(648-620)\times 10=280$ $=60\times 5$ $\boxed{-20}$	0.1014
46	620	644	$(644-620)\times 10=240$ $=60\times 4$	0.1640
50	620	640	$(640-620)\times 10=200$ $=60\times 3$ $\boxed{+20}$	0.2890
58	620	632	$(632-620)\times 10=120$ $=60\times 2$	0.4031
63	620	627	$(627-620)\times 10=70$ $=60\times 1$ $\boxed{+10}$	0.1387

4. Discussion

The meteorite falls are the accidental events or the periodic phenomena, that is an important subject for studying the genesis of meteorites and also of solar system.

4.1. Presence of periodicity in meteorite falls

The study of meteorites in general is related to the theory about asteroids, and it may enrich our understanding of asteroids. According to Titius-Bode law, the motion of planets including asteroids is regular. The planets and asteroids are revolving periodically along their orbits around the sun. Since the meteorites are closely related to the asteroids, the meteorite falls on the earth may exhibit some periodicity. As expected, the result of our study shows that there is a periodic nature in the meteorite falls in China. The detected periods are 60 years and 240 years. There is a periodicity in meteorite falls in China, and we can expect the same periodicity in the other areas. It is pointed out that there is the 60 year period in the 791 witnessed meteorite falls in the whole world (LAPEDES, 1978) as shown in Table 5. In this table,

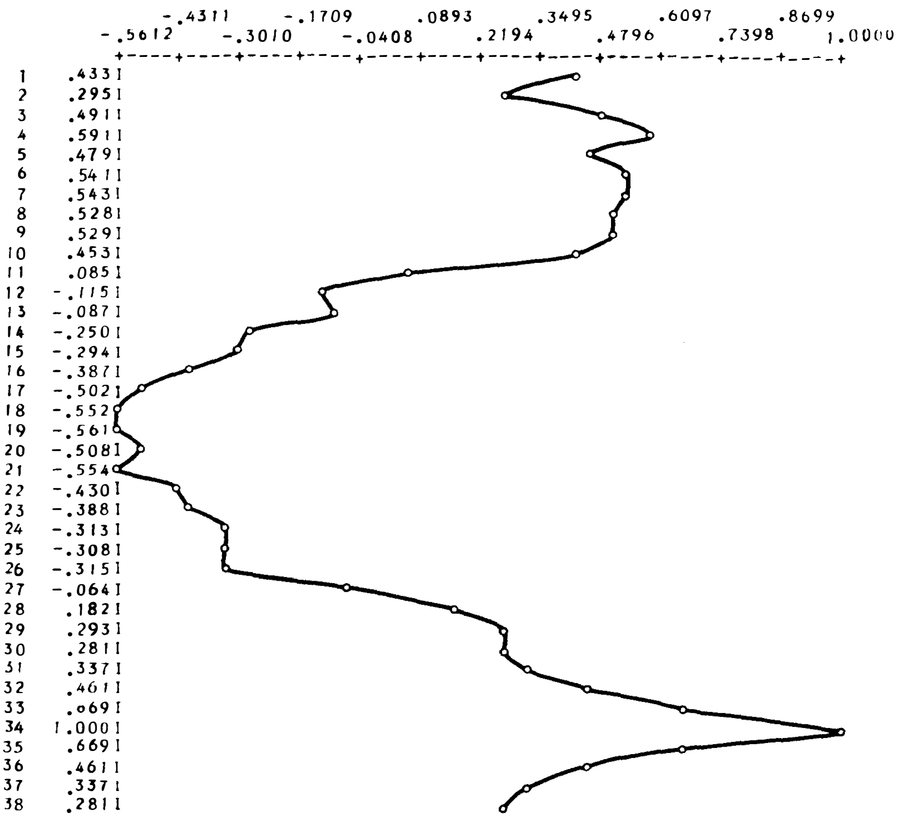

Fig. 4. Autocorrelation function for the number of meteorite falls per ten years in 400 years between 1480 and 1919.

Table 4. Peak positions and their time interval for the data sequence per ten years between 1480 and 1919.

No.	Position		Period (years)	R
	X1	X2		
10	1400	1424	(1424−1400)×10=240	0.4530 (first peak)
34	1400	1400		1.0000 (ordinary position)

three peaks in the number of meteorite falls occurred in the three periods of time; 1810–1814, 1865–1869 and 1930–1934. The time intervals of these three peaks are 55 years and 65 years, which are very close to our 60 years.

4.2. The cause of periodicity

As mentioned above, the genesis of meteorites is closely related with asteroids. The orbits of asteroids lies between those of Mars and Jupiter. The orbital motions of asteroids are disturbed by Mars and mainly by Jupiter, their orbits are altered,

Table 5. Witnessed meteorite falls in the whole world (LAPEDES, 1978).

Interval	Number	Interval	Number
1800–1804	7	1885–1889	21
1805–1809	11	1890–1894	20
1810–1814	14	1895–1899	28
1815–1819	9	1900–1904	29
1820–1824	13	1905–1909	25
1825–1829	13	1910–1914	29
1830–1834	9	1915–1919	32
1835–1839	16	1920–1924	34
1840–1844	19	1925–1929	33
1845–1849	13	1930–1934	50
1850–1854	15	1935–1939	33
1855–1859	25	1940–1944	23
1860–1864	20	1945–1949	29
1865–1869	34	1950–1954	31
1870–1874	19	1955–1959	22
1875–1879	31	1960–1964	26
1880–1884	20	1965–1969	21
		1970–1974	17

and some asteroids may collide with each other. Some of their fragments penetrate into the field of earth's gravitation, and part of them would be meteorites falling on the earth. The periods of 60 and 240 years in the frequency of meteorite falls may be related to the commensurability with the period of orbital motion of Jupiter, which is almost 12 years. Then we suppose that the cyclic meteorite falls may be related with the cyclic disturbing force of Jupiter to the orbital motions of asteroids.

Of course, this is one of the possible explanations and we should not exclude other theories on the periodic falls of meteorites with 60 and 240 year cycles.

4.3. Similarity between meteorite falls and sunspot acticity

It is well known that the sunspot activity possesses a periodic nature. The calculation made by YUNNAN OBSERVATORY (1976) shows the presence of three periods; 11, 62.2+2.8, and about 250 years. The latter two periods, 62 and 250 years, are close to the periods of meteorite falls, which are analyzed in the above. The curves of sunspot activity and of meteorite falls are compared in Fig 5. Both appear to coincide with each other in the time between 1470 and 1920. The Maunder minimum period of sunspot acitivity (EDDY, 1976) is well correlated with the period of minimum frequency of meteorite falls in China.

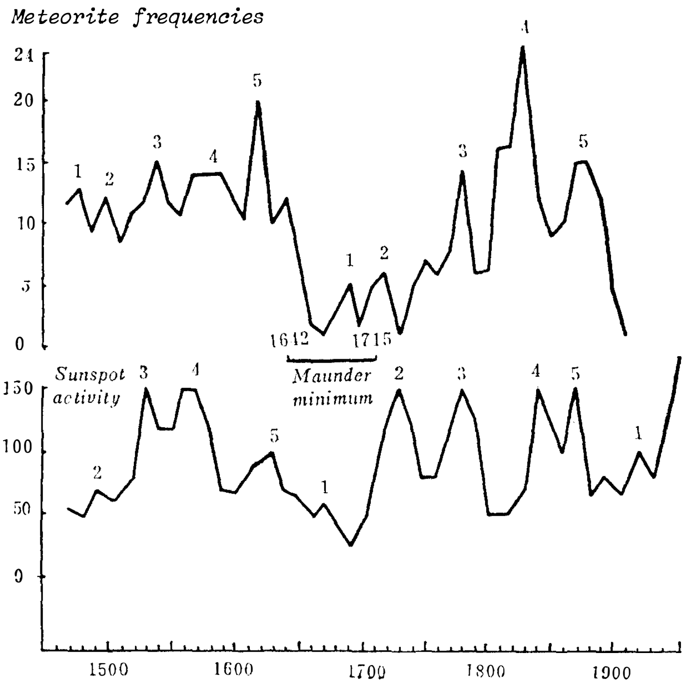

Fig. 5. The comparison of the frequencies of meteorite falls in China and sunspot.

5. Conclusion

To our knowledge, this is the first time to point out the presence of long periodicity, such as 60 years and 240 years, in meteorite falls. Although the actual cause of the periodicity is not clarified yet, it seems to be an important and intersting subject to know the periodicity in detail and also to understand the nature of the whole relations between the meteorite falls and other phenomena in the solar system.

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