ON THE RELATIONSHIP BETWEEN WINTER THUNDER AND THE CLIMATIC CHANGE IN CHINA IN THE PAST 2200 YEARS

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Abstract. An analysis of winter thunder records in China from 250 B.C. to A.D. 1900 shows that there is a relationship between the pattern of winter thunder frequency fluctuation with that of temperature fluctuation. We hypothesized that such a temperature–thunder relationship may possibly be due to the strong frontal movement by cold air masses of well-defined low temperature.

1. Introduction

The climate of the earth is not stable but changes with time. We can detect this change from many natural vestiges such as ancient glacial marks on rocks, tree rings, paleobotanical and paleozoological community distributions, radioactive elements in fossils, etc. On the other hand, this phenomenon can also be traced in historical records, which describe climatic conditions different from what they are today. Sometimes we can even find historical records describing changes which actually took place at the time. When such a change occurred, it often had great social impact. For example, severe droughts and heavy floods caused famine, wide-spread plague and the death of countless people. A sharp change in climate might even have been responsible for the disappearance of whole civilizations (Bryson and Murray, 1977).

Many investigators have used historical records to study the climatic change in the past and have come to some significant conclusions (e.g. Brooks, 1943; Lamb, 1972; Manley, 1959; Bryson and Hare, 1973). Since most of these ancient records are not instrumental measurements but just observations of the eye, we cannot, in general, using only these records, establish any quantitative conclusions about climate. A common way to quantify these observations is to select certain indicators such as the frequency of floods and droughts, the time of the first snow, the freezing of lakes, or even the blossoming dates of certain flowers. These phenomena appear in old records, which indicates that they might have been affected by climatic changes so that, by studying the temporal variation of these climatic indicators, we can infer changes in climate.

Thunderstorms, one of the most dramatic weather phenomena, may conceivably be related to climate as well. However, rarely is it taken to be an indicator of climatic change. There are only a few studies linking thunderstorms to solar activity and these are not readily related to climatic change (e.g. Myrbach, 1935; Lethbridge, 1969; Lamb, 1972; Markson, 1978).

Recently, Changnon (1977) carried out a study on the direct relationships between thunderstorm frequency and climate. He analyzed thunderstorm data at various places

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between 1901 and 1970 and found some relation between thunderstorm frequencies and rainfall rates. However, as Changnon himself pointed out, a 70-year period is not long enough to consider these relations as being conclusive. Still, the relation between thunderstorms and climate over a longer time-scale has up to now not been discussed.

It is the purpose of the present study to determine whether or not such relations exist. In this attempt, ancient Chinese chronicles have been consulted for thunder and lightning records. These records were analyzed and temporal variations were determined. This variation was then compared with the air temperature fluctuation over the same period in China. This study is limited to thunder and lightning events in winter for reasons which we shall discuss in the next section.

2. Winter Thunder Records in Ancient Chinese Chronicles

Ancient Chinese chronicles contain a great wealth of various kinds of meteorological records (Needham, 1959; Wang, 1979). Many of these records are related to thunder and lightning. As we said above, only those events which occurred in winter were investigated. An example of a thunder and lightning record from Sung Dynasty is shown in Figure 1 (from Sung Shih, 1345 edition).

There are two reasons why we will only consider winter events. The first is on account of the completeness of data. Thunderstorms in spring, summer, and autumn were long regarded as normal phenomena, and, as such, they were usually not reported, except for some extraordinary ones which caused fires or death. Consequently, the data for these seasons are rather incomplete. On the other hand, winter thunderstorms were regarded as abnormal or even evil. Some ancient astrologers interpreted winter thunderstorms as bad omens (see, for example, *Jin-Fan-I-Chaun*, by Jin Fan, 77–37 B.C.). Due to their abnormality winter thunders became important events for chroniclers to record and, as a result, a rather complete data set was compiled.

The second reason is related to the uniformity of weather patterns. In summer, the weather pattern in China is complicated and far from being regionally uniform, due to the strong influence of monsoons. It is very difficult to see any connection between different meteorological variables under such complicated conditions. On the other hand, winter weather is largely dominated by the Siberian anticylone and the pattern is usually very simple and uniform over the whole of China. It is therefore much easier to find relationships in this situation.

In this study all events involving thunder and lightning in winter are considered. Therefore, the scope of investigation is broader than if we were only concerned with winter 'thunderstorms', since in many cases no storms were involved. The content of these ancient records vary from time to time. Some are very simple and others more detailed. One of the simplest versions reads: "Emperor Shih-Huang, fifth year, thunder in winter." A slightly more detailed version reads: "Emperor An, Yuan-Ch'u period, first year, tenth month, (the day) Kuei-Chi, winter thunders occurred in three states." One of the records in Nan-Chi-Shu is quite elaborate: "Emperor Wu, tenth year, tenth month, (the day) Gen-Tzu, thunder and lightning occurred in the northwest. Eleventh month, (the day)

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年十月辛卯十二月甲寅雷十六年溫州大雷雷震
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二年十二月戊寅己卯雷二十六年十二月甲子雷
二十七年九月癸未雷三十一年正月丁丑雷乾道

宋史志卷十五 九

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元年九月辛酉雷十一月壬午日南至郊祀風雨大
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年十月乙酉雷景定二年十月戊戌雷電己亥雷電
咸淳四年閏月丁巳九月庚申雷九年十月癸亥十
二月丙辰壬戌雷建炎七年五月汴京無雲而雷紹
興三十年十月壬戌晝漏半無雲而雷癸亥日過中
無雲而雷淳熙十四年六月甲申昧爽禱雨太乙宮
乘輿未駕有大聲自內發及和寧門人馬辟易相踐

Fig. 1. Thunder records in the Sung Dynasty (960–A.D. 1279) (from Sung-Shih, A.D. 1345 Edition).

Ding-Ts'o, lightning occurred in the southwest. Then thunders were heard twice. Twelfth month, (the day) Chia-Shen, it was raining and lightning was seen. The thunder was heard three times in the northwest and southwest. (The day) Bin-Shen thunder was heard twice in the night. (The day) Hsin Hai, thunderstorms."

The ancient Chinese calendar is one kind of lunar calendar. The traditional winter period lasted from the tenth to the twelfth month. We shall take all the thunder and lightning events occurring during these three months as our definition of 'winter thunder'. Slight complications may arise from intercalary months in some particular years, but on the whole we believe that whatever errors due to this effect will be small.

All records taken for this study are taken from 'Official Histories' in China. These are the histories written by royal court historians. In general, should Dynasty B succeed Dynasty A, then the 'Official History of Dynasty A' would be written by royal historians of Dynasty B, although there may be some exceptions. Despite the fact that they are written by so many different authors who lived in times so far apart, all these historical books have a common structure which was first set by Ban Ku (A.D. 32–93) who wrote the famous *Han-Shu* (History of the Han Dynasty). Usually, the winter thunder events are recorded in the chapter 'Wu-Hsing-Chih' (Records of five elements). It was formerly the duty of royal court astronomers to observe and to report these events. The sites of observation usually took place in the capital cities but the reports from other cities were also frequently included.

3. Results

From the above-mentioned histories we found in total 202 years in the period from 250 B.C. to A.D. 1900 which saw winter thunder events. Before 250 B.C. only very few records exist. We then determined the number of *record years* in an interval of n years, and designated this number as f_n. Thus f_{30} represents the number of record years in a 30-year interval.

The variations of f_{30} and f_{50} with time are shown in Figure 2. Obviously the distribution of f_{50} and f_{30} is not uniform. In some periods there are many winter thunder events while in other periods very few. The periods of high winter thunder frequency are A.D. 100–150, 300–500, 1100–1300, 1350–1400, 1450–1550, and 1600–1900. Between A.D. 600–800 there is no report of winter thunder, indicating a period of electrically quiet winters.

It is interesting to note that the period A.D. 600–800 was that of the Tang Dynasty which was also one of the more stable periods in Chinese history. Once could assume that under such a politically stable government the observation records are fairly complete. Thus the lack of winter thunder reporting in this period probably reflects the true climatic situation. On the other hand, during the periods A.D. 300–500, 1100–1300, and 1600–1700, China was torn by war, which leads one to believe that any records were vulnerable to destruction. Yet even during these periods numerous occurrences of winter thunder were recorded. These two facts may suggest that our data are quite homogeneous.

The next step is to find the climatic implication of non-uniform distributions of f_{30}

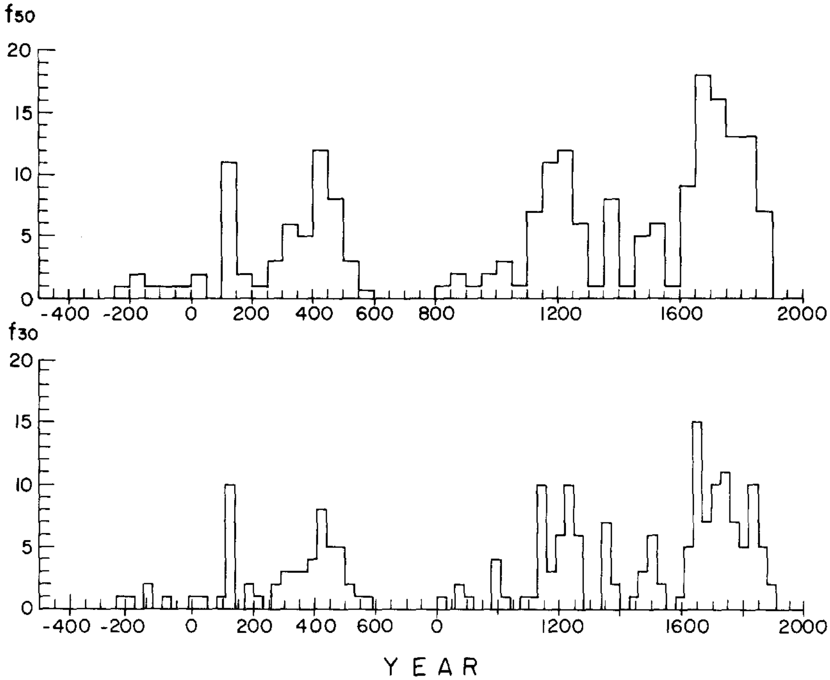

Fig. 2. Secular variation of (a) f_{50} and (b) f_{30}.

and f_{50}. For this purpose we compared our winter thunder distributions to the temperature fluctuations over the same period. Temperature fluctuation was studied by Chu (1973) who inferred the changes in air temperature from phenological phenomena. For example, the late arrival of certain migrating birds might indicate a colder period while the early blossoming of certain flowers might indicate a warmer period. According to Hopkins (1924) one can obtain the changes in air temperature by the time lag of these phenomena. In this manner Chu established a rough picture of the temperature fluctuation in China for the last 5000 years. His data source is rather diverse, ranging from ancient poems, private travel diaries to ancient agricultural books. Despite such diversity in source material we shall see that the distribution of f_n and the fluctuation of air temperature does show a close relationship which in turn strengthens the reliability of our data.

In Figure 3 we compare f_{30} with the temperature fluctuation δT of Chu (1973). The value of δT denotes the deviation of *winter* air temperature from that of the current mean. Unfortunately Chu does not clarify in his article what he means by 'current mean'. However, judging from his Figure 2 it is probably the mean temperature from 1950 to 1972. Thus $\delta T = -2°$ means an air temperature *colder* than the current mean by 2°C. In Figure 3 the T curve is plotted in reverse so that high peaks indicate cold temperatures.

It is obvious from Figure 3 that the two curves are somewhat parallel, with almost every peak of δT also corresponding to a peak of f_{30}. Thus if Chu's results are valid, this parallelism says that, in general, the *colder* the winter, the higher the probability of having

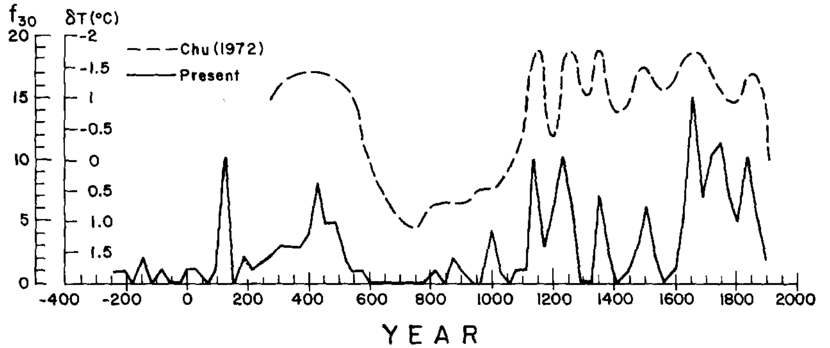

Fig. 3 Comparison between f_{30} and the δT of Chu (1973).

thunder and lightning. It is surprising to find that this simple relation exists since the phenomena being compared are so different in nature.

Since the above conclusion depends on Chu's study we have tried to evaluate the validity of his results. We found that although his absolute values of δT may be only a rough estimate, considering the complicated nature of phenological phenomena, his determination of warm and cold periods at least is on firm ground. Apart from many historical facts, the division of warm and cold periods by Chu is also consistent with the blossoming dates of cherry trees and the freezing years of Lake Suwa in Japan (for details, see Arakawa, 1954; Wadachi, 1958). We will also supply some historical facts in the next section which characterize warm and cold periods.

Taking Chu's δT values we found a correlation coefficient $r = -0.68 \pm 0.05$ between δT and f_{30}. Although the value of this correlation coefficient is not particularly high, it does indicate some relation between the two. Since the generation of thunder is a fairly complicated process, any further correlation between the two without other supporting data is probably not very meaningful.

Simple empirical relations between f_n and the temperature fluctuation can be found. For simplicity we have only chosen to establish such a relation between f_{100} and DT,

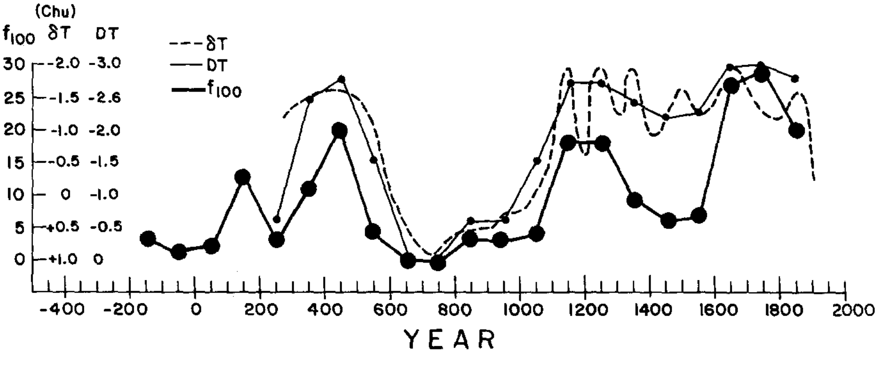

Fig. 4. f_{100}, δT of Chu, and DT computed from Equations (1) and (2).

where DT is the temperature depression from that of the warmest period at A.D. 750 (i.e. the lowest point in δT in Figure 3). These relations are:

$$DT = -1.52\,(f_{100})^{0.2} \quad \text{for} \quad f_{100} > 4 \tag{1}$$

$$DT = -0.018\,(f_{100})^{3.185} \quad \text{for} \quad f_{100} \leqslant 4 \tag{2}$$

where DT is in °C. Figure 4 shows a plot of these two relations together with f_{100} and δT.

4. Some Historical Facts

It may be helpful to have some descriptions from historical sources which characterize the warm and cold periods. Thus, in the following section we supply a short summary. Since the written records in China can be traced back to the period of the Shang Dynasty, it may be pertinent to start our summary from this period. All dates given below are taken from Tung (1960).

4.1. Shang Dynasty (1751–1111 B.C.)

The Shang was a relatively warm and humid period. Archaeological findings at ancient Shang sites include many subtropical animal skeletons such as elephants, tapirs, and roebucks which may possibly indicate a warm climate. In addition, there are several-hundred-thousand pieces of Shang oracle bones which contain information about climate. It is found that during this period continuous rain was common and could occur at any month of the year. This would also indicate a humid climate (Wittfogel, 1940; Hu, 1944).

4.2. Chou and Han Dynasties (1111 B.C. ~ A.D. 220)

In this long period, the climate of China became cooler. In some cold years even rivers became frozen (see Wang, 1979). In general, however, the climate was still warmer that it is today. At that time bamboo and plum trees were widely distributed over northern China. Today these two species are rare due to the colder climate in this area. Towards the end of the Han dynasty the climate became increasingly colder (Chu, 1973).

4.3. Epochs of the Three Kingdoms and South-North Dynasties (A.D. 220–581)

This was a relatively cold period. The Huai river became frozen for the first time in history in A.D. 225 which resulted in the cancellation of naval maneuvers (*San-Kuo-Chih*, by Chen Shou, A.D. 233–297). Another evidence of cold climate is the establishment of imperial ice houses (for storing food) at Nanking (~32°N) during this period. In present days, the winters in Nanking are too warm to support the growth of thick ice chunks (Chu, 1973).

4.4 Sui and Tang Dynasties (589–907)

The climate of China became warmer during this period. Plum and citrus trees were again popular in northern China, indicating a warmer climate. Many winters in Si'an passed without snow and ice (see *Tang Shuh*, The History of the Tang Dynasty).

4.5. Sung and Yuan Dynasties (960–1367)

This was a cold period. Plum trees disappeared again in northern China. Lake Tai was frozen for the first time in history in 1111. When frozen the lake was rigid enough for carriages to ride over (Yen-Pei-Tza-Chi, by Lu Yu-Jen of the Yuan Dynasty). Citrus trees in this region were killed by the cold weather. The freezing of rivers seems to have been quite usual during this period.

4.6. Ming and Ching Dynasties (1368–1900)

The cold climate continued. Not only was the freezing of lakes and rivers a common occurrence but there were also snowfalls in subtropical provinces such as Kwangtung and Kwangsi. A study on the freezing of Lake Suwa in Japan during this period suggests that a similar cold climate also pervaded Japan (Arakawa, 1954).

5. A Hypothesis for the Cause of Winter Thunder–Cold Climate Relationship

From previous discussions it appears that in China the high frequency of winter thunders tends to be associated with colder climates. The exact cause for this is not known. Without the knowledge of the physics of winter thunderstorms in China such a cause is not easy to find. In this section we propose a theory which may partially explain this phenomenon. The question of whether it is true or not will need further study.

It is well known that winter thunderstorms are predominantly frontal thunderstorms in nature (Byers and Braham, 1949; Takeuti and Nakano, 1977). Thus we expect that most of the winter thunder events studied here also occur in frontal regions. As we mentioned earlier, the winter weather in China is largely dominated by the Siberian High. Figure 5 shows such an example. We see here that a cold front, which is also the edge of a cold air mass, is advancing towards southern China and Japan.

But having a cold front alone does not guarantee that thunderstorms will occur. One would need moisture and instability of the air to precede the cold front. In the case of winter thunderstorms in Japan the cold air would pass over the warm water surface of the the Sea of Japan, picking up moisture and becoming unstable, resulting in thunderstorms over coastal regions (Takeuti and Nakano, 1977). In China, however, the situation was slightly different. Most capital cities where winter thunders have been reported in the past are located well inland rather than along the coast. The moisture must therefore have come from rivers. Indeed, these cities are near rivers; for example, Si'an (the national capital of West Chou, West Han, and Han Dynasties) is near the Wei River, and Lo-Yang (capital of East Chou and East Han Dynasties) is near the Lo and Yellow Rivers. These rivers could very well have supplied the moisture.

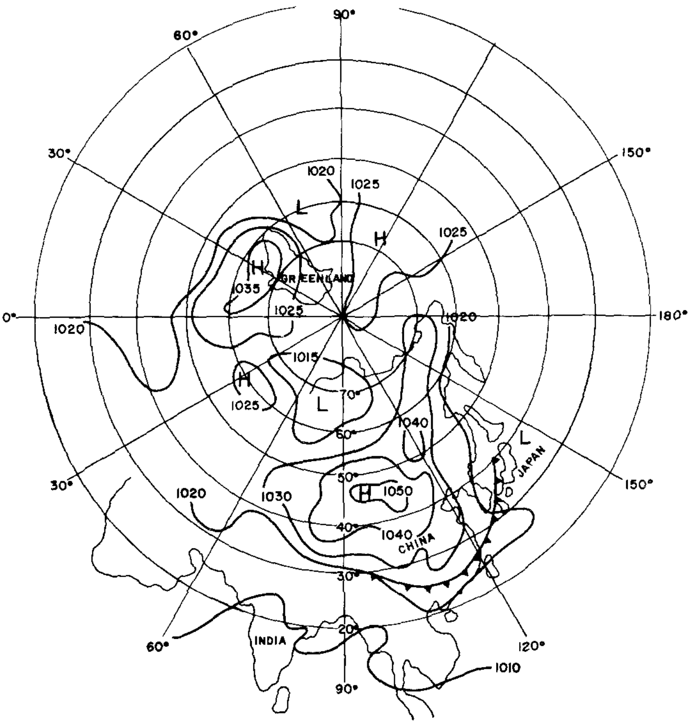

Fig. 5. Weather pattern of East Asia on January 10, 1963.

But why is it that, at the same location, the chances of winter thunder occurring should be different from period to period? This might have been associated with the movement of cold fronts. Conceivably a strong, fast-moving cold front may cause a rapid, uplift motion of the warm air ahead of it which, in turn, may result in higher convective instability. If so, then a stronger cold front will probably have a higher chance of producing thunderstorms. But in order to have a strong cold front we most likely need a cold air mass of well-defined low temperatures. For this to be verified, will, of course, require further study. If it were true, then when this cold air mass of well defined low temperature moves into one area, thunderstorms may occur. The overlying area would suffer cold weather. If such events were quite frequent in a certain period, a cold climate would be the result. Therefore the *colder* climate should correspond to a *higher* frequency of winter thunderstorms.

We want to emphasize, however, that the above discussion is only a hypothesis. Without further investigation it cannot be regarded as conclusive.

6. Conclusion

In the present study we have analyzed winter thunder records in China from 250 B.C. to A.D. 1900. We have found that a higher frequency of winter thunders appears to be associated with a colder climate. The exact cause for this phenomenon is not known, but we have hypothesized that it is probably due to the strong frontal movement caused by an advancing cold air mass of well-defined low temperatures.

It has to be stressed that the relationships found here may only be true for China. For different regions where both weather patterns and geography are different, this relationship may not be applicable. Furthermore, this relationship has been established by composing long-term temperature fluctuations with long-term winter thunder frequency variations. This does not guarantee year-to-year correspondence; but for a time scale greater than two or three decades, such a relationship will most likely hold.

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