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What is This?
Temporal and spatial variations of climate in China during the last 10 000 years

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Abstract: Archaeological, geological, historical, tree-ring and instrumental data indicate that the last 10 000 years were characterized in China by climatic variations at various temporal and spatial scales. The period from 10 000 to 9000 BP was one of increasing temperature. The Holocene ‘Optimal Period’ occurred approximately between 9000 and 3000 BP, within which there were two major cool episodes around 7300 and 5700 BP and one minor cool episode around 4500 BP. During the cool period from 3000 BP to AD 1900 (Neoglacialization) three warm episodes occurred about 2700–2000, 1400–1000 and 800–700 BP. The last millennium was characterized by warming in the first half and cooling in the second half. During the most recent 500 years (‘Little Ice Age’), relatively warm episodes occurred about AD 1520–1650, 1720–1840, and 1890–1945. Over the long term, climate appears to have changed synchronously from the east to the west and from the south to the north, but it has changed asynchronously over the shorter term.

Key words: climatic change, proxy evidence, periodicity, spatial variation, Holocene, China.

Introduction

The study of climatic change on prehistorical and historical timescales provides a valuable perspective for interpreting the natural trend of climatic variability of the past, and a database for assessing present and future climates under intensive and extensive human impacts. Because only a 100–150-year instrumental record is available, it is necessary to resort to various climatic proxies (e.g., geological and archaeological data, tree rings, personal diaries, official documentation, family genealogical records, etc.) to reconstruct past climates. In this review paper, the climates of the past 150 years are based on instrumental records which were presented in the proceedings of the 1977 Conference on Prediction of Long Term Climate Changes (see Meteorological Bureaux, 1977). The climates of the past 500 years are derived from detailed historic records and tree ring data. Historic records and archaeological data are the sources for reconstructing the climates of the past 5000 years. Archaeological and geological data are used as climatic proxies to extend the climatic curve from 5000 to 10 000 BP.

The climate of China is characterized by three major features (Zhao, 1981). First, the monsoon dominates with a significant change or reversal of wind direction between winter and summer, as well as seasonal variation of precipitation according to whether the maritime monsoon advances or retreats. Secondly, climatic continentality is rather pronounced, with high summer temperatures, low winter temperatures, and a large annual range. Thirdly, there are many climatic types in China, ranging from a subpolar climate on the Tibet Plateau to a subtropical climate along the southern coasts. All these climatic characteristics are a product of the interaction of major physical factors, including the vast land area, a middle latitudinal and eastern coastal location, and mountainous topography (the physiographic provinces and the data sites mentioned in the text are shown in Figure 1).

Climate during the last 150 years

Instrumental records in Guanzi Province of southwestern China (Meteorological Bureau of Guanxi, 1977) indicate that solar activity may be the main factor in determining varia-
tions of temperature and precipitation. Temperature and precipitation values appear to oscillate during the twentieth century, i.e.: 1901-1920, cold and wet; 1921-1940, warm and wet; 1941-1950, warm and dry; and 1951-1970, cold and dry (Figure 2-1). In Fujian Province of southeastern China (Meteorological Bureau of Fujian, 1977), the temperature curve has a trend similar to that of precipitation, but with greater variability (Figure 2-2). The precipitation deviation (variation relative to the mean) in Shanghai (Figure 2-3; Yang and Xie, 1984) is approximately the same as that of Fujian, both being located at the Pacific Coast, but different from that of Guanxi, which is more influenced by the Indian Ocean. According to Yang and Xie (1984) and Office of the Yangtze River (1977), the temperature oscillations of the Northern Hemisphere (Figure 2-4) correspond with the precipitation deviation and the sea-level deviation in Shanghai (Figure 2-5), and to the deviation of water level of the Yangtze River at Hankou of Hubei Province which is in phase with solar activity variations (Figure 2-6).

In Jilin Province of northeastern China, Ding (1977) shows that precipitation deviation has the same periodicity (about 11 years) as solar activity cycles. The research indicates that the periods 1940-1950 and 1962-1973 were the two driest, while 1844-1897 and 1903-1918 were the wettest of the past 150 years (Figure 2-7). Both the instrumental record and its relationship to tree rings (Meteorologic Bureau of Jilin, 1977) indicate that each temperature cycle (20-23 or 33-34 years) is associated with two or three precipitation cycles with a 9-11 year periodicity (Figure 2-8), and a long warm period consists of two humid and one dry period (Table 1). Overall, the temperature of China appears to be influenced by the position of the Mongolian High (Figure 2-9), whereas the precipitation is closely related to the position of the Southern Pacific High (Figure 2-10). When the strong Mongolian High moves southward and reduces the strength of the Southern Pacific High, the temperature in China is relatively low and so is the precipitation (Wang and Zhao, 1979a; 1979b).

In conclusion, during the last 150 years, warm and humid periods occurred in AD 1840-1850, 1870-1885, 1920-1940, and around 1960; whereas cold and dry periods occurred in 1830-1840, 1860-1870, 1890-1920, 1940-1950, and 1963-1973. Through comparison, it can be seen that major warm and cold events in Jilin, northeastern China, correspond well with major humid and dry events in the Tianshan Mountains of northwestern China (Zhang, 1984; Kang, 1983; 1985); however, there is some time lag (Table 2).

Climate during the last 500 years

Using the historic data for central and northern China, Zhang and Xu (1977) designed a dryness index: number of flood counties minus number of drought counties for a specified time interval. The reconstructed index (Figure 3-1) demonstrates two extremely dry periods around AD 1625 and 1800...
Table 1 Dry, wet, cold and warm intervals in Jilin, northeastern China, during the last 150 years (H = humid, D = dry, C = cold, W = warm, duration in years; data from Meteorological Bureau of Jilin, 1977).

<table>
<thead>
<tr>
<th>Interval (AD)</th>
<th>D/H</th>
<th>Duration</th>
<th>Interval (AD)</th>
<th>C/W</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1826-1835</td>
<td>H</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1836-1843</td>
<td>D</td>
<td>9</td>
<td>1821-1841</td>
<td>W</td>
<td>21</td>
</tr>
<tr>
<td>1844-1856</td>
<td>H</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1857-1865</td>
<td>D</td>
<td>9</td>
<td>1842-1861</td>
<td>C</td>
<td>20</td>
</tr>
<tr>
<td>1866-1874</td>
<td>H</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1875-1883</td>
<td>D</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1884-1897</td>
<td>H</td>
<td>14</td>
<td>1862-1895</td>
<td>W</td>
<td>34</td>
</tr>
<tr>
<td>1898-1908</td>
<td>D</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1909-1918</td>
<td>D</td>
<td>10</td>
<td>1896-1918</td>
<td>C</td>
<td>23</td>
</tr>
<tr>
<td>1919-1929</td>
<td>D</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1930-1939</td>
<td>H</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1940-1950</td>
<td>D</td>
<td>11</td>
<td>1919-1952</td>
<td>W</td>
<td>34</td>
</tr>
<tr>
<td>1951-1961</td>
<td>H</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Zhang and Xu, 1977; Zhang, 1980; Zhang, 1988a; 1988b). The applicability of the dryness index to estimating rainfall deviation is generally supported by a moisture index (Gong, 1983): \( I = \frac{2F}{F + D} \), where \( F \) is the number of flood records in certain areas during a certain interval of time, and \( D \) is the corresponding drought number (Zhang and Crowley, 1989; Yan et al., 1992). Based on historical descriptions of winter severity, a curve of winter temperature in southeastern China is shown in Figure 3-2 (Zhang, 1980). The variations in length of the Plum Rain (continuous rainfall in late summer) in the lower reach of the Yangtze River are reconstructed from historic agricultural records (solid line in Figure 3-2; Wu, 1983). Comparing Figure 3-1 with Figure 3-2 shows that the dryness of central and northern China corresponds with the length of the Plum Rain and winter temperature in the lower reach of the Yangtze River. Trends varied over the 500-year period: 1470-1522 was wet to dry; 1522-1560, dry to wet; 1560-1624 was wet to dry but typified by frequent wet spells; while 1625-1650 was very dry. No significant variation occurred from 1651 to 1724 in the length of the Plum Rain. A dry period extended from 1725 to 1786; a wet period from 1787 to 1851; and from 1852 to 1932, rainfall was generally low. Periods of cooling were 1470-1520, 1620-1720 (particularly 1650-1700), 1840-1890 and after 1945 (Zhang et al., 1974; Climate Research Group of Nanking University, 1977).

Tree rings have been used as an indicator of precipitation in Hunan Province of southern China. The tree-ring data indicate that the periods of high precipitation from 1780 to 1900 in southern China (Figure 3-3; Meteorologic Bureau of Hunan, 1977) corresponded roughly with the dry periods in central and northern China. The deviation of freezing duration in Poyang Lake of Jianxi Province (adjacent to Hunan Province) appears to correspond with both the length of the Plum Rain and winter temperature in southeastern China (Figure 3-4; Meteorologic Bureau of Jianxi, 1977).

The best-documented and well-preserved historic records in Beijing, then capital city for several Dynasties, show that there were more floods in the first half and more droughts in the second half of the last 500 years (Figure 3-5; Meteorologic Bureau of Beijing, 1977; Wang and Zhao, 1981; 1984; Zhang, 1984; Wang, 1989). The data also indicate that wet periods became shorter (56-24-16 years), and drought periods longer (42-45-54 years). The same studies also show that in eastern and northeastern China the first half of the last 500 years (Zhang and Xu, 1977; Zhang, 1980; Zhang, 1988a; 1988b).
years was characterized by a relatively dry west and humid east; whereas the second half saw a humid west and a dry east (Figure 3-6). Historic records in Henan Province and elsewhere in central China (Wang and Zhao, 1979a; 1979b; 1984; Zheng and Feng, 1985) confirm that climatic conditions in central China were opposite those of the east coast; i.e., the first half was moist and the second half dry (Figure 3-7). Tree rings in the adjacent Shaanxi Province, used as an indicator of precipitation, demonstrate a similar dryness trend as in Henan (Figure 3-8; Meteorological Bureau of Shaanxi, 1977).

Historic dustfall records from China indicate that dustfall primarily occurred during cold periods (Figure 3-9; Zhang, 1980; 1984). For example, 1621-1700 and 1811-1900 were two cold periods, coupled with a high frequency of dustfall (3.7 year/decade), whereas 1511-1620 and 1721-1780 were two warm periods, accompanied by a low frequency of dustfall (2.1 year/decade). To the west, the Tibet Plateau is an ideal place for tree-ring study as temperature is the controlling factor of tree growth at the upper limit of forest while precipitation is the controlling factor at the lower limit. The tree-ring data (Lin and Wu, 1977) show that 1520-1650 and 1916-1950 were two warm and wet periods. The precipitation of the last 200 years was below average from 1750 to 1870, above average from 1870 to 1960, and below again since 1960. The 'Little Ice Age' appears pronounced from 1730 to 1916 in the tree-ring spectrum (Figure 3-10; Wu and Lin, 1981a; 1981b).

In summary, during the last 500 years the climate was predominantly cold or cool and the frequencies of flood and drought increased toward the present (Wang and Wang, 1990). Based upon the historic data, four cycles can be distinguished: 1470-1520, 1650-1720, 1840-1890, and 1945-1960 were relatively cold. All these cold episodes are well recorded by dust- and oxygen-isotope variations in the ice core of the Dunde Ice Cap, Qilianshan Mountains (Yao et al., 1991). Besides the comparability of temperature changes in Jilin, northeastern China, with precipitation changes in the Tian- Shan Mountains of northwestern China (Table 2), dryness or moistness in Beijing (eastern China) is comparable with that in the Qilianshan Mountains of western China (Wang and Zhang, 1984) with a time-lag in the northwest and with the exception of a short wet period from 1644 to 1652 (Table 3).

In China, Chu’s temperature curve was independently con- firmed by Zhu (1977). Four temperature cycles were recog- nized during the past 5000 years (Figure 4-2): 1st warm: 5000-3000 BP 1st cold: 3000-2800 BP 2nd warm: 2700-2000 BP 2nd cold: 2000-1400 BP 3rd warm: 1400-1000 BP 3rd cold: 1000-800 BP 4th warm: 800-700 BP 4th cold: 600-100 BP

Based on pollen assemblages from southeastern China (Wu, 1983; Xu, 1983; Xu and Shen, 1990; Liu et al., 1992), the 5000-year temperature curve of Chu (1973) has been ex- tended to 10 000 BP in Figure 4-1 (but note that 8000–10 000 BP is not shown on Figure 4-1 due to a limited space). This extension is generally supported by pollen assemblages from eastern China (Kong, 1980; Zhao, 1982; Li, 1985; Kong and Du, 1990) and geological evidence from the deltaic sediments of the Yangtze River (Yang and Xie, 1984). The extended temperature curve indicates that the period between 10 000 and 9000 BP was one of increasing temperature and that 9000–3000 BP was the ‘Optimal Period’ of the past 10 000 years. The so-called ‘Optimal Period’ was about 2–3°C warmer than the average from AD 1900–70. Two minor cold intervals around 7300 and 5700 BP divided the ‘Optimal Period’ into three warm subperiods: 9000–7800; 7500–5800 and 5300–3000 BP, with a slight cool interval around 4500 BP. It is interesting to note that the four periods of brilliant Chinese Culture (7800–7300, around 6000, 5900–5600 and 5500–4900 BP) were within the ‘Optimal Period’ (Feng, 1985; Editing Group of Chinese Historic Mapping, 1974).

At Chongqing of Sichuan Province, Three Gorges of the Yangtze River, many monuments were established about 800 years ago to record extreme water levels. The water-level

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**Table 2** Comparison of the temperature in Jilin, northeastern China, with precipitation in the Tianshan Mountains of northwestern China (H = humid, D = dry, C = cold, W = warm, the data from Meteorological Bureau of Jilin, 1977; Zhang, 1984; and Kang, 1983; 1985).

<table>
<thead>
<tr>
<th>Interval (AD)</th>
<th>C/W</th>
<th>Interval (AD)</th>
<th>D/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jilin</td>
<td>Tianshan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1807-1841</td>
<td>W</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1842-1861</td>
<td>C</td>
<td>1841-1854</td>
<td>H</td>
</tr>
<tr>
<td>1862-1895</td>
<td>W</td>
<td>1855-1868</td>
<td>D</td>
</tr>
<tr>
<td>1896-1918</td>
<td>C</td>
<td>1869-1877</td>
<td>H</td>
</tr>
<tr>
<td>1919-1952</td>
<td>W</td>
<td>1878-1904</td>
<td>D</td>
</tr>
<tr>
<td>1952-1980</td>
<td>C</td>
<td>1905-1941</td>
<td>H</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>1942-1980</td>
<td>D</td>
</tr>
</tbody>
</table>

---

**Table 3** Comparison of the dry and wet intervals in Beijing, eastern China, with those in the Qilian Mountains of western China during the last 500 years (H = humid, D = dry, the data from Meteorological Bureau of Beijing, 1977; Wang and Zhao, 1984; and Wang and Zhang, 1984).

<table>
<thead>
<tr>
<th>Interval (AD)</th>
<th>D/H</th>
<th>Interval (AD)</th>
<th>D/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td></td>
<td>Qilian Mountains</td>
<td></td>
</tr>
<tr>
<td>1440-1482</td>
<td>H</td>
<td>1420-1460</td>
<td>H</td>
</tr>
<tr>
<td>1483-1535</td>
<td>D</td>
<td>1461-1560</td>
<td>D</td>
</tr>
<tr>
<td>1536-1580</td>
<td>H</td>
<td>1561-1630</td>
<td>H</td>
</tr>
<tr>
<td>1581-1643</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1644-1657</td>
<td>H</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1658-1694</td>
<td>D</td>
<td>1631-1697</td>
<td>D</td>
</tr>
<tr>
<td>1695-1724</td>
<td>H</td>
<td>1688-1715</td>
<td>H</td>
</tr>
<tr>
<td>1725-1769</td>
<td>D</td>
<td>1716-1770</td>
<td>D</td>
</tr>
<tr>
<td>1770-1825</td>
<td>H</td>
<td>1771-1845</td>
<td>H</td>
</tr>
<tr>
<td>1826-1870</td>
<td>D</td>
<td>1846-1867</td>
<td>D</td>
</tr>
<tr>
<td>1871-1894</td>
<td>H</td>
<td>1868-1882</td>
<td>H</td>
</tr>
<tr>
<td>1895-1948</td>
<td>D</td>
<td>1883-1910</td>
<td>D</td>
</tr>
<tr>
<td>1949-1964</td>
<td>H</td>
<td>1911-1922</td>
<td>H</td>
</tr>
<tr>
<td>1965-1980</td>
<td>D</td>
<td>1922-1980</td>
<td>D</td>
</tr>
</tbody>
</table>
The index of humidity has increased during dry spells, while level deviations in Shanghai during the last 2000 years have decreased during the wet spells. Sea-levelly toward the present, similar to the Yellow River area. That the frequencies of drought and flood increased dramatically around twelfth century (Figure 4-3; Office of the Yangtze River, 1977). Zheng and Feng identified 10 dry periods since the seventeenth century. The driest period occurred in AD 1051-1270 (Figure 4-4). They also showed that the number of flood records in certain areas for a certain period of time and the corresponding drought records (Zheng and Feng, 1975, 1985); (5) sea-level deviation from the present (m) in Shanghai (Yang and Xie, 1984; Yang, 1979); (6) temperature oscillation in southern Liaoning, based on geological evidence (Guiyang Institute of Geochemistry, 1977; Qu, 1981); (7) temperature oscillation in southern China, I = 2F/(F + D) where F is the number of flood records in certain areas for a certain period of time and D is the corresponding drought records (Zheng and Feng, 1975, 1985); (5) sea-level deviation from the present (m) in Shanghai (Yang and Xie, 1984; Yang, 1979); (6) temperature oscillation in southern Liaoning, based on geological evidence (Guiyang Institute of Geochemistry, 1977; Qu, 1981); (7) frequency of dustfall (per decade) on the Loess Plateau (Zhang, 1984). Each cycle is approximately 90 years in length (Figure 4-7). Comparing Figures 4-6 and 4-7 suggests that the cold spell of AD 1000-1200 corresponded with the high frequency of dustfall of 1100-1300 with a 100-year delay, and the cold spell of 1400-1900 with frequent dustfall of the same time. More interestingly, the historically documented frequency of flooding and channel migration in the Yellow River (Figure 4-8; Feng, 1987) roughly reflects the temperature oscillations in China. The first channel migration of the Yellow River occurred before 3000 BP, and there was almost no flooding from 3000 to 2800 BP. More flooding and the second channel migration occurred from 2700 to 2000 BP, and no flooding was recorded from AD 0-800. A low frequency of floods occurred in the cold spell of AD 1000-1300 and many more floods were recorded after AD 1400. Disastrous famine events due to crop failure in Lanzhou (Gansu Province), which have been carefully documented by the governments at all times in this agriculturally vulnerable region, were caused by persistent droughts during cold periods (Feng, 1987). In the adjacent Qilianshans Mountains, east of the Tibet Plateau, where tree rings are temperature sensitive, the tree-ring index (i.e., width of the ring) exhibits two distinct cold periods: AD 1060-1154, relating to the old episode of eleventh and twelfth centuries, and around the seventeenth century, corresponding with the peak of the ‘Little Ice Age’ (Figure 4-9). Each cycle is approximately 90 years in length (Figure 4-7). Comparing Figures 4-6 and 4-7 suggests that the cold spell of AD 1000-1200 corresponded with the high frequency of dustfall of 1100-1300 with a 100-year delay, and the cold spell of 1400-1900 with frequent dustfall of the same time. 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In the adjacent Qilianshans Mountains, east of the Tibet Plateau, where tree rings are temperature sensitive, the tree-ring index (i.e., width of the ring) exhibits two distinct cold periods: AD 1060-1154, relating to the old episode of eleventh and twelfth centuries, and around the seventeenth century, corresponding with the peak of the ‘Little Ice Age’ (Figure 4-9; Wang and Zhang, 1984). In the Tibet Plateau, tree rings have recorded the variations in temperature of the past 3000 years, which are also reflected by glacial advance and retreat (Lin and Wu, 1975; Wu and Lin, 1981a, Li and Feng, 1984). The glaciers in the southern and eastern Tibet Plateau advanced around 2800, 2000, 1900, 1500 BP, and in the seventeenth-nineteenth centuries, and retreated from the mid-sixth to late-twelfth centuries. The limited data suggest that the warm spells may have been longer and the cold spells shorter on the plateau than in other parts of China. On the basis of permafrost evidence in the northern Tibet Plateau, the following sequences are reconstructed (Wang and Zhang, 1985; Wang, 1985; Pan and Xu, 1989): increasing temperature (10 000-8500 BP), warm extremes were also traced on Buddhist statues in the river walls which were sculptured at different times. Archaeological studies of these records confirm that the water level at the middle reach of the Yangtze River has fluctuated more since the seventeenth century. The driest period occurred in the sixteenth century. The water level was more-or-less stable since the seventeenth century. The driest period occurred in AD 1051-1270 (Figure 4-3; Office of the Yangtze River, 1977). The curve of discharge at the middle reach of the Yangtze River, I = [2F/(F + D)] where F is the number of flood records in certain areas for a certain period of time and D is the corresponding drought records (Zheng and Feng, 1975, 1985); (5) sea-level deviation from the present (m) in Shanghai (Yang and Xie, 1984; Yang, 1979); (6) temperature oscillation in southern Liaoning, based on geological evidence (Guiyang Institute of Geochemistry, 1977; Qu, 1981); (7) frequency of dustfall (per decade) on the Loess Plateau (Zhang, 1984); (8) frequency of flood (per century) in the middle reach of the Yellow River (Feng, 1987); (9) tree-ring width (mm) in Qilianshan Mountains (Wang and Zhang, 1984); (10) temperature oscillation estimated from tree-ring data (Wu and Lin, 1981a; 1981b).
Summary

Geological, tree-ring and archaeological data, and an almost 5000-year historic record supplement one another to provide a detailed picture of climate change in China over the past 10,000 years. The last 10,000 years were characterized by climatic oscillations with varying periodicities. 10,000–9000 BP was a period of increasing temperature. 9000–3000 BP was the ‘Optimal Period’ (moist and warm) within which there were two major cool episodes around 7300 and 5700 BP, and a minor cool episode around 4500 BP. After the ‘Optimal Period’, i.e., during the Neoglacialiation, three warm episodes occurred about 2700–2000, 1400–1000 and 800–700 BP. The last 1000 years was typified by warming in the first half and cooling in the second half. During the second half, AD 1520–1650, 1720–1840, and 1890–1945 were warm intervals. The warm and wet regimes were characterized by denser and higher vegetation and fewer occurrences of less intense dustfall on the Loess Plateau of northern China, more floods in the Yellow River and Yangtze River Valleys, a higher growth rate of tree in northern China, and a shorter duration of lake freezing in southern China. Over the long term, climate in China has changed synchronously from the east to the west and from the south to the north. But, it has changed asynchronously over the shorter term. For example, during the last 500 years, the first half was dry in the west and wet in the east but the second half was marked by drying in the east and increasing humidity in the west.

Acknowledgements

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