Differential effects of global and local climate data in assessing environmental drivers of epidemic outbreaks

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This Commentary is the response of a China historian to the paper by the team of biologists headed by Huidong Tian (1) on the differential effects of using long-term or short-term data to reconstruct climatic drivers of human epidemics. The Tian et al. paper is a response to an anomaly they encountered tracking environmental conditions for historical outbreaks of epidemics over two millennia. This anomaly is that disease outbreaks, when charted in relation to long-term climate data, correlate with lower temperatures and decreased precipitation, whereas when observed in relation to short-term climate data, outbreaks are likely to become more prevalent under warm, wet conditions (exemplified in refs. 2 and 3). Tian et al. (1) tentatively conclude that the effect of climate on epidemics is scale-dependent and that the long- and short-term climatic conditions of epidemics yield different findings.

As a historian without science training, I cannot comment on how Tian et al. (1) have analyzed their data, but I can bring to bear the methods that a historian employs to provide a perspective on using such data to develop the argument of scale dependency. Historians usually reconstruct the past by identifying a problem, positing several competing hypotheses in the course of accumulating documentary data, then moving inductively upward from the data toward what we judge to be the most reasonable resolution. Our methodology demands close attention to how sources were originally constructed and for what purposes, and to factor out the downstream effects that these purposes may have on the conclusions we draw. We can do this in part because we usually work with small datasets, but we are strict about not generalizing our data to the extent of overriding the particularities of a historical place and time.

My data for this Commentary comes from the chronological lists of disasters in two types of official published sources for the period from the elevation of Khubilai Khan to Great Khan of the Mongols in 1260 to the Manchu invasion and occupation of China in 1644. Most comprehensive are the lists compiled at the national level and copied into the two official histories of the Yuan (1271–1368) and Ming (1368–1644) dynasties. These I have supplemented with similar lists of climate and human anomalies in 14 regional gazetteers, 8 at the provincial level and 6 at the prefectural level for provinces for which provincial gazetteers were not available [see Brook (4) for a discussion of these sources]. The data I have extracted furnish proxies indicating deviation from normal temperatures and precipitation, as well as record the incidence of famines, floods, locust infestations, and epidemics. A benefit of working with sources from higher administrative levels of the Chinese state is that the compilers have already filtered the data to distinguish between regular disasters and "major" disasters, such as "major epidemics" (*dayi* in Chinese) involving mortality in the high thousands to the hundreds of thousands. Since compiling my data, a more complete list of natural disasters became available, on which Tian et al. (1) rely [see Zhang (5)]. Although the Zhang compendium includes more data than I use, it relies for its core data on mostly the same sources I have used, which were compiled at the upper levels of state administration. The data Zhang draws from local-level sources, while considerable, adds almost nothing to what we know of major epidemics.

Whether any of these disease entities is *Yersinia pestis* is impossible to determine from the documentary evidence alone. They could be plague, but they could be the diseases we know as cholera, measles, dysentery, or smallpox, although smallpox was separately designated in traditional Chinese medical terminology as *dou*. Historians are cautious about retrospective diagnosis, lest this approach predetermine what we are trying to determine (6, 7). However, recent advances in bioarchaeology now make it possible to identify relationships between aDNA and the disease entities we know today (8). Particularly persuasive for this historian is the recent research reconstructing a

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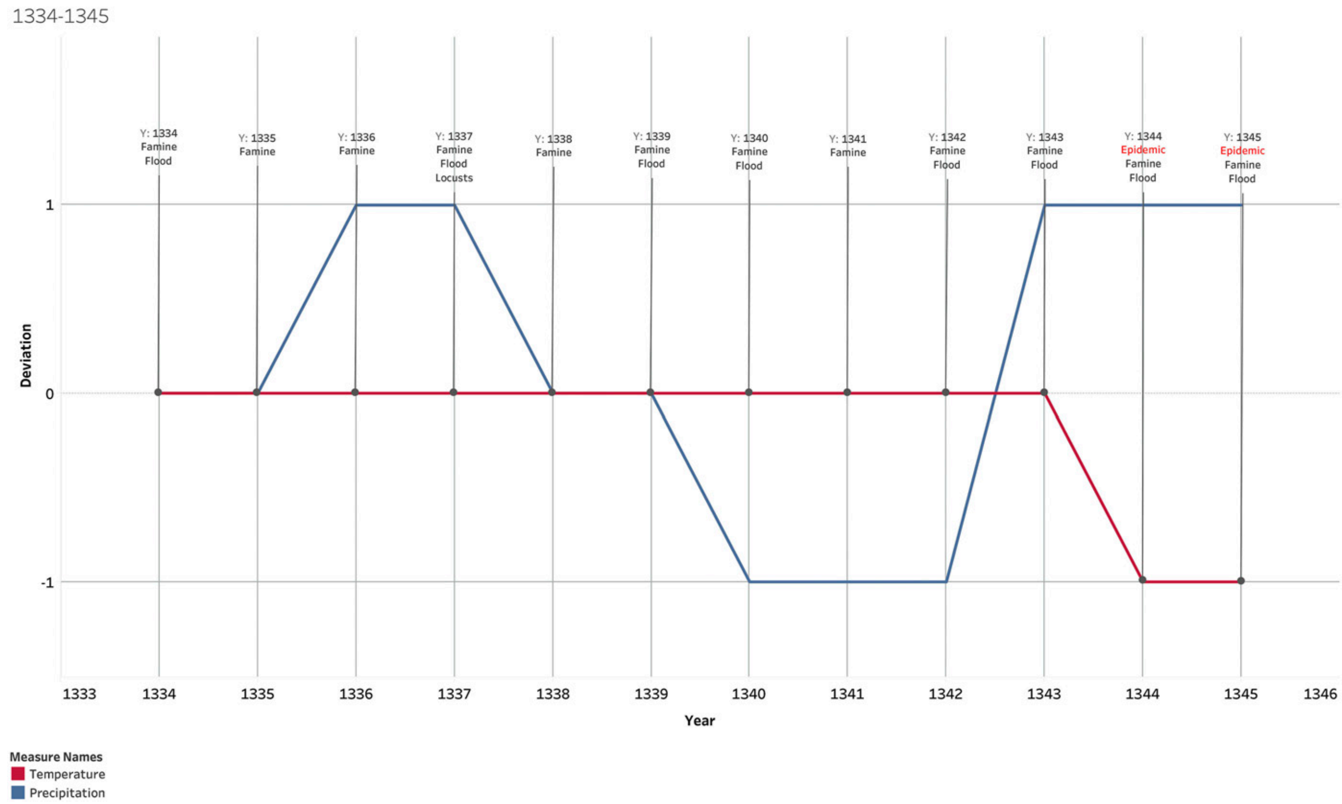

Fig. 1. Annual instances of major epidemics, famines, floods, and locust infestations in relation to deviations in annual temperature in red (+1 warm, −1 cold) and precipitation in blue (+1 wet, −1 dry) for the second of the eight 12-y episodes discussed in this report. Where the blue line disappears, it has been overlapped by the red line and should be taken as indicating normal precipitation levels.

genealogy for strains of *Y. pestis* based on core genome analysis (9). That research has identified a polytomy or "big bang" in the branching of genomic mutation and dated it to 1268, with a 95% confidence interval between 1142 and 1339 [see Green (10) for discussion]. The dating is striking, as it just predates the eruption of the Black Death in Europe in 1346. The findings also strongly indicate that the original plague reservoir was in the Kokonor region along the northeastern edge of the Tibetan massif, which places the disease adjacent to transport routes along the Silk Road.

Even if we cannot yet determine whether all the epidemics Tian et al. (1) reconstruct were plague, we can still test the hypothesis of scale dependency by looking closely at the main epidemics in their data for 1260–1644. From my sources for these 384 y, I have identified 56 y of major epidemics, in addition to 88 y of major locust plagues, 103 y of major floods, and 146 y of major famines. This period was characterized by colder temperatures and lower precipitation. Temperatures reconstructed from documentary proxies were abnormally cold for 121 y and abnormally warm for 45 y. Precipitation deviation was more volatile, although less one-sidedly so: drier than normal for 124 y and wetter than normal for 78 y. Although dendrochronology and other physical proxies attest to an overall absolute decline in temperatures across Inner and East Asia over this period (11), my data reveal only a rise or fall relative to what was considered normal at the time.

To examine the data in relation to the question of possible climatic drivers of epidemics, I have scrutinized eight 12-year periods leading up to major outbreaks [for earlier epidemics, see Hymes (12)]. The first episode (1302–1313) includes the first well-attested major epidemic of the Yuan period in 1308, when over a quarter of a million people died in the coastal prefectures of northern Zhejiang province, possibly suggesting an infection arriving by sea. The outbreak was preceded by 7 y of colder-than-normal temperatures. Precipitation fluctuated but rose to higher-than-normal levels for 2 y before the epidemic.

The second episode (1334–1345) ends with outbreaks in 1344 and 1345, just 1 y before the outbreak of plague in Europe (Fig. 1). The first outbreak was in coastal Fujian south of Zhejiang, the second on the North China Plain in the economic heartland of the Yuan regime. No abnormal temperatures preceded these epidemic years, although it was cold during those 2 y. Precipitation fluctuated in a 7-y cycle, and the epidemics occurred in the second and third years of the second cycle. The North China Plain experienced excessive rainfall, causing severe famine followed by the epidemic that spring. By contrast, Fujian received no rain from April through September, and epidemic seemed to follow the drought through summer and autumn.

During the third episode (1351–1362), China suffered six epidemics in 12 y: in various zones of the North China Plain in 1356, 1358, and 1359; up the Yellow River Valley in 1357; and twice in coastal Zhejiang in 1360 and 1362. This was a period of mostly normal temperatures but sustained drought, which gave rise to widespread famine. During the fourth episode (1400–1411), temperatures were again mostly normal but 9 y were wet, in effect reversing the distortion of the third episode. These epidemics too came in the wake of famines, but famines caused by flooding and waterlogging rather than drought.

In the fifth episode (1450–1461), epidemics broke out in the fifth and sixth years at the end of the harshest half-decade of the 15th century. Cold was the base line, reaching a nadir in 1455, when lakes on the Yangzi Delta froze. Drought compounded cold to produce famines, although the epidemics of 1454–1455, both on the Yangzi Delta, occurred as drought shifted to abnormally heavy rainfall. The 1461 epidemic further up the Yangzi Valley occurred 2 y after China reverted to drought.

During the sixth episode (1519–1530), temperature and precipitation were mostly normal, providing no real evidence of how climate might have spurred the epidemics in 1521–1523 and 1528–1530. The same indeterminacy applies to the seventh episode (1577–1588), when four spectacular epidemics in 1579–1582 occurred in years of cold and normal rainfall, and two even more devastating epidemics in 1587–1588 occurred under reverse conditions of drought and normal precipitation. The final episode (1633–1644) marks the nadir of the Little Ice Age in China: 11 unrelieved years of cold and drought producing annual famines, followed after 6 y by fierce epidemics (1639–1641, 1643–1644) producing 80–90% mortality on parts of the North China Plain. The weather continued cold and dry through to the final year of the dynasty, when temperatures and precipitation returned to normal.

These eight episodes exhibit no common pattern, but do offer some insights regarding the hypothesis of scale-dependent relationships between climate and epidemics. The widely shared view that cooling increases the prevalence of epidemics via harvest failure and sometimes locusts and flight (1, 13) is roughly confirmed by the first, second, fifth, and eighth episodes, and partially confirmed by the seventh. Tian et al. (1) also observe that flood can positively affect epidemics, and the first and second episodes may support this finding. None of the episodes, however, confirms the otherwise logically reasonable finding from short-term data that warming temperatures, by favoring the reproduction of vectors, increase the likelihood of epidemic.

If there is a conclusion to be drawn solely from these eight episodes, it is the fairly modest one that epidemics are least likely to occur during periods of warmer than normal temperatures. Among the four alternatives of excessive warmth, cold, wetness, and drought, warmth is the only climatic anomaly that consistently delivers a boost against the threat of famine, other than when it is coupled with drought, which is the deadliest combination for producing famine. Precipitation deviation, on the other hand, can go either way without making a consistent difference, as the contradictory second and fourth episodes demonstrate. The documentary sources suggest that famine, regardless of origin, is the key middle term in the equation between climate and epidemics [as could be argued from the evidence for Beijing (14)].

Does this finding cast doubt on the scale-dependency hypothesis of Tian et al. (1)? By no means. What I would propose by way of adjustment is that time is not the only scale on which our findings are dependent. Of equal importance is space. The usual practice in long-term climate history is to work from geographically generalized data: that is, data collected on the scale of a subcontinent (such as China) or continent, or even the globe, to model the effects of climate on epidemics. The thinness of historical data encourages this practice, but it means that local variations in climate anomaly, or in human responses to climate stress, can be lost in the aggregation of data over a much broader geographical zone. We need to bear in mind that, however much the global environment matters, a disease outbreak always begins as a local event arising from local conditions. The global environment, exemplified for example by the Little Ice Age, sets the larger terms within which regional climate works its effects. The 1633–1644 episode is powerful testimony to this. But a pathogen jumps to human hosts only under conditions that are highly specific to the locality in which this event happens. If we build our models solely on macrolevel climate data without factoring in geographically localized data, we may fail to detect stresses peculiar to the place and time in which the epidemic broke out. The second episode demonstrated this best: national documentary data indicate that the year 1344 was cold and wet, yet in Fujian a severe regional drought appears to have prompted the epidemic. The generalized data indicate that 1345, too, was cold and wet, and yet the epidemic on the North China Plain occurred in the wake of a famine induced by drought. Without the local data, these epidemics could be marshalled to demonstrate a pattern to which they do not actually conform.

To the extent that climate drives epidemics, whether in the short or long term, it does so in the context of local conditions. Continental- and global-level climate may be a necessary condition for inducing the outbreak of an epidemic, but it is not sufficient to explain why it happens. For that fuller explanation, the local microenvironment, as well as human networks, are essential for grounding and modifying the effects of global climate (9). This is what historians provide.

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