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A probe into the different fates of locust swarms in the plains of North America and East Asia

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Abstract

Locust swarms had periodically raged in both North American Plains (NAP) and East Asian Plains (EAP) before 1880 AD. After this period, the locust outbreaks almost never recurred in NAP but have continued to occur in EAP. Since large quantities of pesticides were used in the major agriculture regions of NAP in the late 1870s; this has been suggested as a possible major cause of the disappearing of locust outbreaks. Extensive applications of more effective chemical pesticides were also used in the granary regions of EAP in the 1950s in an effort to kill the pests at a much higher intensity. However, locust swarms came back again in many areas of China in the 1960s. Therefore, NAP locust extinction still remains a puzzle. Frequent locust outbreaks in EAP over the past 130 yr may offer clues to probe key control elements in the disappearing of locust outbreaks in NAP.

This paper analyzes the climate extremes and monthly temperature-precipitation combines of NAP and EAP, and found the differences in their frequencies of these climate combines caused different locust fates in the two regions: restrained the locust outbreak in NAP but induced such events in EAP. Validation shows that severer EAP locust outbreak years were coincided with the climate extreme combines years. Thus we suggest that climate changes in frequency, extremes and trends can explain why the fate of the locust plague in EAP was different from that in NAP. The study also points out that, under the present global warming, cautions should be taken to make sure the pest hazard being nipped in the-bud.

1 Introduction

To North Americans, locust plagues during the late 19th century are of historical interest only. Rocky Mountain locust, *Melanopolus spretus*, referred to as *Caloptenus spretus* in the reports of the time was a swarming species that periodically produced plague results in the NAP from at least 1800 AD (Riley et al., 1880; Riegert, 1977).

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Typically between 1873 AD and 1877 AD the vast infestations from Canadian Prairies to Missouri devastated crops, starved herds of cattle, ruined state budgets, and drove homesteaders from the land (Hudson Bay Company Archives, 1891; Criddle, 1920). In fact locust swarms were not only plagued in NAP but also in the EAP (Chen, 1935; Ma, 1958). The worst locust plague were concentrated in 1874–1878 AD, with records in history books describing the events as “locust swarms darkened the sky and cleared off grain seedling in the drought summer” in 1876 AD in lower reaches of Yangtze River, and “locust shadowed sunshine; people were starving to death and the bodies on the roads” in 1875 and 1877 AD in lower reaches of Yellow River (Zhang, 2004).

It is fascinating that locust plagues gradually disappeared and almost never recurred in NAP (Lockwood and DeBrey, 1990; Lockwood, 2004; Chapco and Litzenger, 2004) while in EAP locust swarms have outbroken continuously to the 21st century (Chen, 2000; Wu et al., 2006). The locust outbreaks in western and eastern plains of the Pacific have shown very different outcomes (Fig. 1a). Since chemistry industry in North America developed early, large quantities of pesticides were used in the major agriculture regions of NAP in the late 1870s, which has been suggested as a possible major cause of the disappearing of locust outbreaks (Lockwood, 2004). Comparatively, as chemistry industry developed much later in EAP than NAP, extensive applications of more effective chemical pesticide to kill the pest were conducted at higher intensity in the granary region of China in EAP in the 1950s (Chen, 2000). However, locust swarms in many areas of China came back again in the 1960s (Ma, 1965; Wu et al., 1990). Thus we feel that the uneven treatment of the grassland regions with the arsenic baits available at the time would be unlikely to drive the Rocky Mountain locust to extinction, although population densities and reproduction could be reduced. Frequent outbreaks in the EAP over the past 130 yr offer an important evidence to probe key control elements of the disappearing in the NAP.

The major species caused the locust outbreaks in NAP was *Melanopolus spretus* (Melanoplinae subfamily of Acrididae family) (Criddle, 1920; Lockwood, 2004), although non-swarming species of grasshoppers also exhibited extreme fluctuations in

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abundance and widespread damage to vegetation. The historically important locust species in EAP has been *Locusta migratoria manilensis* (Oedipodidae subfamily of Acrididae family) (Ma, 1958; Zhang, 1999; Zhang and Kang, 2005). Although locusts in the two regions are from different subfamilies and may differ in endocrinological characteristics related to locust development, both species are herbivorous insects with high rates of reproduction, swarming behavior, tendency to migrate long distances, and severe cereal-devastation. There were at least 12.5 trillion insects with a total weight of 27.5 million tons in 1874 AD (Garcia, 2000), covered an area of 250 million acres (~ 1.01 million km^2) in the Central US, by entomologists record (Bomar, 2008); which is similar to a fact in EAP that the locust outbreak had a density of more than 2000 locust m^{-2} and covered an area of 1.07 million km^2 in summer of 2001 AD (Huang and Zhu, 2001; Ren and Tang, 2007). These facts enable us to compare both in swarm density and endangering extent.

In terms of the locust ecology and outbreak preconditions, climate strongly influenced the onset and persistence of locust outbreaks, which severe cold winter would kill overwintering eggs, low temperature at growing seasons suppress the insect breeding and reproducing, and higher rainfall and wet condition in spring-summer halt the pest dispersing and migrating (Chen, 1935; Ma, 1958, 1965; Wu et al., 1990, 2006). Combined effects of climate conditions and the extremes may induce or restrain locust outbreaks. Although it is generally believed that changes in pesticide use and land use triggered the demise of the Rocky Mountain locust in NAP (Lockwood, 2004), we feel that it is important to view such hypotheses within the background of climate variability and trends because of their suspected interactions and influence on locust outbreaks in EAP and NAP. Indeed, climates have changed significantly on both sides of the Pacific over the past 130 yr, with extended cooling and warming trends (varying by regions) and increasing in the frequency of extreme weather and climate (IPCC, 2007).

Thus our study took two regions of NAP and EAP together to probe what differences of climate changes have lead to different endings of locust outbreaks during the past 130 yr, by the following approaches: (1) general climate conditions that are

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hypothesized, based on biology and previous studies, to be locust inducing (warm-dry) or restraining (cold-wet and warm-wet), which are summarized and examined for matches with historical locust outbreak years; (2) restraining combinations of unfavorable climate conditions that likely impacted locust outbreaks biologically and ecologically during the past 130 yr are hypothesized as contributing to locust population decline; and (3) the histories and trends of locust hazards in North America and East Asia are compared with regard to the timing of locust decline and extinction in North America and continued periodic locust population eruptions in China.

2 Data and methods

We took two regions of the Northern American Plains (NAP: 35–55° N and 95–110° W) and the Eastern Asian Plains (EAP: 35–55° N and 110–125° E) in the present study (Fig. 1). The NAP study area includes the provinces of Alberta, Saskatchewan and Manitoba in Canada, and the states of North Dakota, South Dakota, Wyoming, Nebraska, and Kansas in the USA. These key locations have good long-term meteorology station data coverage, and had major locust outbreaks during the 19th century. The EAP study area includes the Northeast China Plain, Northern China Plain, and Middle-low Reaches Plains of the Yangtze River, where locust outbreaks have been documented in historical records and monitored by modern observations. Time series of monthly temperature/precipitation changes were carried out by regional means from 30 meteorology stations in NAP (Environment Canada Canadian, 2005; Vose et al., 2008) and 26 meteorology stations in EAP (National Climate Center of China, 2010) during 1880–2009 AD (Fig. 1). In this paper, we abbreviated the 12 months as 1, 2, . . . 12 and the 4 seasons as djf (winter), mam (spring), jja (summer) and son (fall).

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2.1 Compilation of NAP locust data

Locust index has been compiled based on historical reports and summaries of the locust hazards of the time (Riley et al., 1880; Riegert, 1977; Hudson Bay Company Archives, 1891; Criddle, 1920; Conte, 1877; Dawson, 1876; Packard, 1878; Pillsbury et al., 1876; Riley, 1877), and subsequent reviews and commentaries on the locust in NAP (Criddle et al., 1920; Dempsey, 1973; Riegert, 1980). Severe infestations were noted in Canada from at least 1800 AD, when explorer Alexander Henry reported “grasshoppers piled on the shore of Lake Winnipeg” (Riegert, 1980). In 1818 AD, migrant grasshoppers (primarily the Rocky Mountain locust, *M. spretus*), attacked Lord Selkirk’s colony, “on the 18th of July, 1818 AD, clouds of grasshoppers settled down on the colony and ate up every green thing” and in 1819 AD, the colony was “threatened with starvation” indicated by other reports. Some reports also included the damage caused by non-swarmling species of grasshoppers, mainly *Melanoplus sanguinipes* and *Camnula pellucida*, which are still common outbreak pests in the region (Johnson, 1989). Wide-spread damage by Rocky Mountain locust swarms was confirmed and reported in Western Canada in 1800, 1818–1819, 1848, 1857–1858, 1864–1865, 1867, 1869–1870 and 1872 AD, and especially in 1874–1877 AD (Dawson, 1876); similar events were also noted in abundance from Missouri to the Canadian border during the same years (Dawson, 1876; Packard, 1878; Pillsbury et al., 1878). The swarms devastated both agriculture and natural ecosystems. Journalist Henri Julien, accompanying the Northwest Mounted Police (NWMP) in the western territories, documented infestations of 16 July 1874, and noted in his diary: “seeing them at work, as I did, with the modes of attack and the clean sweep of devastation which they carry on, I can form some idea of the locust plagues of ancient Egypt” (Julien, 1989). Private Fred Bagley, accompanying Major James Macleod of the NWMP, recorded seeing at dawn on 12 July 1874 AD that the grasshoppers (Rocky Mountain locusts) covered the landscape, where he also saw the shape of a sleeping sentry, entirely covered with grasshoppers and holding a carbine that was a thick mat of the insects (Cruise and Griffiths, 1997).

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climate change put them at a low and vulnerable state, making way for extinction, as opposed to events in the EAP.

Existing studies indicate that winter temperatures in both North America and East Asia have increased over the past century (Zhao, 2005; IPCC, 2007). However, the temperature increase in Eastern China was particularly significant and reached +0.49 °C/10 yr (Ren and Guo, 2005). Studies also show the frequency of storms has increased, while weak precipitation is significantly decreasing in North America and many regions of the world (Thomas et al., 1998; Gutowski et al., 2007). By contrast, the frequency of weak precipitation has increased in China since the beginning of the 20th century; hence drought has also increased (Ma et al., 1996; Liu and Ding, 2010). The characteristics of large-scale changes in regional temperature and precipitation coincide with the results regarding extreme climate and their characteristic assemblages, and could help to explain the different fates of the locust outbreaks in the two regions.

Differences between EAP and NAP in changes in precipitation and temperature in the current century could be related to the adjustment and reorganizing of atmospheric circulation of the two continents (Allan and Soden, 2008). Precipitation and temperature changes in Northern China were implicated as an explanation for recent Oriental migratory locust outbreaks in the Huanghe River and Huaihe River regions, which have occurred mostly 1 to 2 yr after El Niño events (Zhang and Li, 1999), while combination changes in temperature and precipitation did impact on the locust swarms for thousand years in China (Stige et al., 2007; Yu et al., 2009). Although the locust in North America is now extinct, the threat of related grasshoppers to rangeland and cropland still exists (Lockwood et al., 1995), though many grasshopper species are not agricultural pests (Johnson, 2008). Current and future warming trends are expected to increase the frequency, severity and duration of outbreaks of some of the species remaining in NAP, and cautions should be taken to make sure the pest hazard being nipped in the-bud.

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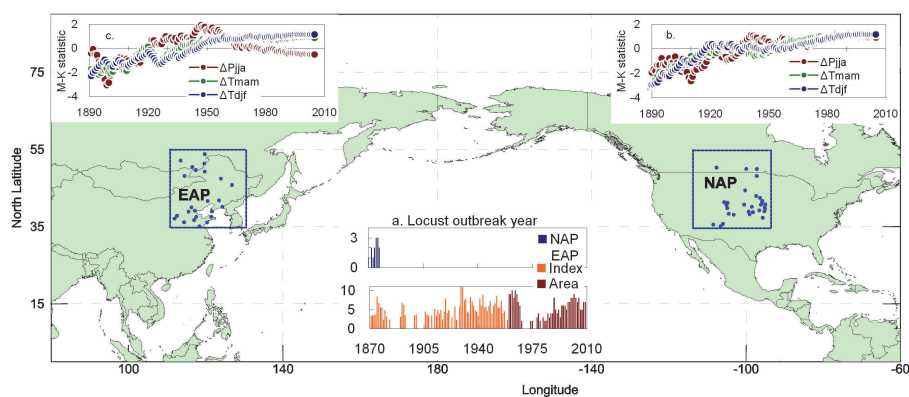


Fig. 1. Maps of study areas with meteorology station locations, information of locust outbreaks (a) and climate changes in NAP (b) and EAP (c). All codes of climate variables are the same as text.

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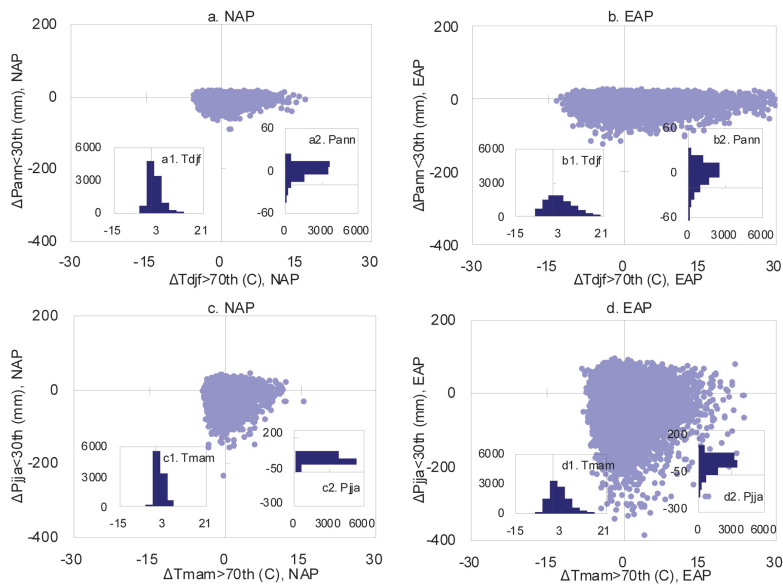


Fig. 4. 2-D-scatter diagrams of Gumbel-distribution climate extremes in NAP and EAP. Combinations $\Delta T > 70$ th and $\Delta P < 30$ th percentiles (**a, b**) and $\Delta T < 30$ th and $\Delta P > 70$ th percentiles (**c, d**) for NAP (**a, c**) and EAP (**b, d**) respectively. Frequency diagrams at 8 panels of a1, a2, b1, b2, c1, c2, d1 and d2 were plotted for 10 000 samples of ΔT (along x-axis, unit in Celsius degree) and ΔP (along y-axis, unit in mm). All codes of climate variables are the same as text.

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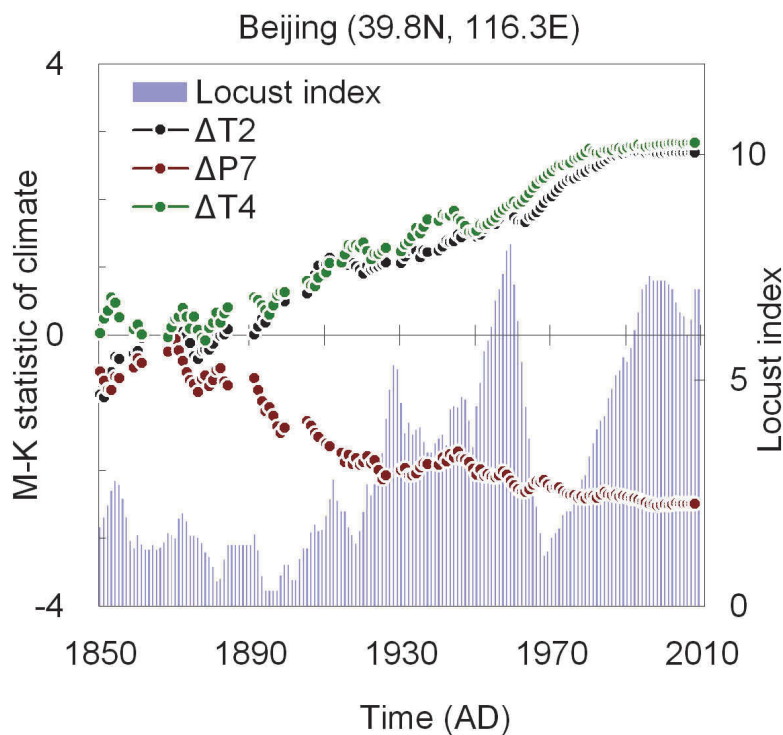


Fig. 5. Comparisons of locust outbreaks with trends of climate changes in Beijing by using M-K trend test ($p < 0.05$). P7, T2 and T4 represent July precipitation, February and April temperatures respectively.

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