Biogeosciences, 10, 1441–1449, 2013
www.biogeosciences.net/10/1441/2013/
doi:10.5194/bg-10-1441-2013

Biogeosciences
Open Access

An analysis of the contrasting fates of locust swarms on the plains of North America and East Asia

G. Yu[1], X. Ke[2], H. D. Shen[1], and Y. F. Li[1]

[1]State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China
[2]Saskatchewan Ministry of the Economy, SK S7N 2X8, Canada

Correspondence to: G. Yu (geyu@niglas.ac.cn)

Received: 31 March 2012 – Published in Biogeosciences Discuss.: 20 August 2012
Revised: 21 January 2013 – Accepted: 31 January 2013 – Published: 4 March 2013

Abstract. Prior to ∼1880 AD locust swarms periodically raged across both the North American Plains (NAP) and East Asian Plains (EAP). After this date, locust outbreaks almost never recurred on the NAP but have continued to cause problems on the EAP. The large quantities of pesticides used in the major agriculture regions of the NAP in the late 1870s have been suggested as a possible reason for the disappearance of locust outbreaks in this area. Extensive applications of modern, i.e. more effective, chemical pesticides were also used in the granary regions of the EAP in the 1950s in an effort to reduce pest outbreaks. However, locust swarms returned again in many areas of China in the 1960s. Therefore, locust extinction on the NAP still remains a puzzle. Frequent locust outbreaks on the EAP over the past 130 yr may offer clues to the key factors that control the disappearance of locust outbreaks on the NAP.

This study analysed the climate extremes and monthly temperature–precipitation combinations for the NAP and EAP, and found that differences in the frequencies of these climate combinations resulted in the contrasting locust fates in the two regions: restricting locust outbreaks in the NAP but inducing such events in the EAP. Validation shows that severe EAP locust outbreak years were coincidental with extreme climate-combination years. Therefore, we suggest that changes in frequency, extremes and trends in climate can explain why the fate of locust outbreaks in the EAP was different from that in the NAP. The results also suggest that, with present global warming trends, precautionary measures should be taken to make sure other similar pest infestations do not occur in either region.

1 Introduction

To North Americans, the locust outbreaks that occurred during the late 19th century are now of historical interest only. The Rocky Mountain locust, *Melanoplus spretus*, referred to as *Caloptenus spretus* in the reports of that time, was a swarming species that periodically reached severe proportions in the North American Plains (NAP) from around 1800 AD (Riley et al., 1880; Riegert, 1977). For example, between 1873 AD and 1877 AD vast infestations from the Canadian Prairies to Missouri devastated crops and grazing land, the later resulting in cattle starving, ruined state budgets and drove homesteaders from the land (Hudson Bay Company Archives, 1891; Criddle, 1920). However, locust swarms were not only a problem on the NAP but also on the East Asian Plains (EAP) (Chen, 1935; Ma, 1958). The worst locust outbreaks were concentrated in the period 1874–1878 AD, with historical records describing the events: "locust swarms darkened the sky and consuming grain seedling in the drought summer" in 1876 AD in lower reaches of Yangtze River, and "locusts caused shadowed sunshine; people starving to death with the bodies lying in the roads" in 1875 and 1877 AD in the lower reaches of Yellow River (Zhang, 2004).

It is fascinating that locust plagues gradually disappeared and almost never recurred in the NAP (Lockwood and DeBrey, 1990; Lockwood, 2004; Chapco and Litzenberger, 2004), while on the EAP locust swarms have occurred continuously up until present (Chen, 2000; Wu et al., 2006). The locust outbreaks on the western and eastern plains of the Pacific have exhibited very different outcomes (Fig. 1a).

Since the chemical industry in North America developed relatively 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 decline of locust outbreaks (Lockwood, 2004). Comparatively, the chemical industry developed much later in Asia than in North America, and extensive applications of pesticides were applied at higher rates in the granary regions of China in the 1950s (Chen, 2000). The pesticides used in the China were mainly organochlorines, such as hexachlorocyclohexane sporicide, which were more effective chemical pesticides (Xue and Qin, 2000). However, locust swarms came back again in the 1960s in many areas of China (Ma, 1965; Wu et al., 1990), although the use of hexachlorocyclohexane pesticides ceased in China in the late 1970s (production was completely prohibited in 1983 and replaced by the less toxic but longer-acting pesticides, which have been used until present day) (Xue and Qin, 2000). There are different locust species in NAP and EAP, and species from different subfamilies may have different responses to the pesticides applied. However, the responses of locust in both regions to the pesticides are similar. Therefore, it is unlikely that the uneven treatment of the NAP grassland regions with the arsenic baits available at the time would have driven the Rocky Mountain locust to extinction, although population densities and reproduction may have been reduced. Frequent locust outbreaks on the EAP over the past 130 yr offer an important means to critically analyse the key elements controlling the disappearance of locusts on the NAP.

The main species that resulted in the locust swarms on NAP was *Melanoplus spretus* (Acrididae, subfamily Melanoplinae) (Criddle, 1920; Lockwood, 2004), although non-swarming species of grasshoppers also exhibited extreme fluctuations in abundance and caused widespread damage to vegetation. Historically, the important locust species in East Asia has been *Locusta migratoria manilensis* (Acrididae, subfamily Oedipodinae) (Ma, 1958; Zhang and Li, 1999; Zhang and Kang, 2005). Although locusts in the two regions are from different subfamilies and may differ in endocrinological characteristics related to their development, both species are herbivorous insects with high rates of reproduction, exhibit swarming behaviour, have a tendency to migrate long distances and cause severe cereal devastation. Entomologists estimated that there were at least 12.5 trillion insects with a total weight of 27.5 million tons in 1874 AD (Garcia, 2000), covering an area of 250 million acres (~ 1.01 million km^2) in the central US (Bomar, 2008), which is similar to a locust outbreak in the EAP with a density of > 2000 locust m^{-2} and covered an area of 1.07 million km^2 in the summer of 2001 AD (Huang and Zhu, 2001; Ren and Tang, 2003). These facts enable us to compare both the swarm density and their environmental impact.

In terms of locust ecology and the environmental preconditions required for an outbreak, climate strongly influences the onset and persistence of locust plagues: severe winters can kill overwintering eggs; low temperature during growing seasons suppresses breeding and reproduction, while higher rainfall and wet conditions in the spring–summer restrict dispersal and migration (Chen, 1935; Ma, 1958, 1965; Wu et al., 1990, 2006). The combined effects of climate conditions and their extremes may induce or restrict locust outbreaks. Although it is generally believed that changes in pesticide use and land-cover change triggered the demise of the Rocky Mountain locust in North America (Lockwood, 2004), it is important to view such hypotheses against the background of climate variability and climate trends because of the possibility of their interactions influencing locust outbreaks in both the EAP and NAP. Indeed, climate has changed significantly on both sides of the Pacific over the past 130 yr, with extended cooling and warming periods (varying by regions) and an increase in the frequency of extreme weather and climate conditions (IPCC, 2007).

In this study, two regions within each of the NAP and EAP (see below) were analysed using a standard methodology to address the possible role climate change played in determining the contrasting nature of locust outbreaks over the last 130 yr on the two continents. The following approaches were used: (1) the general climate conditions that are hypothesized, based on locust biology and previous studies, to induce (warm–dry) or restrict (cold–wet and warm–wet) locust swarming were identified; these data were then summarized and examined for matches with historical locust outbreak years; (2) the identification of combinations of unfavourable climate conditions that probably negatively impacted locust outbreaks during the past 130 yr and that were hypothesized as contributing to locust population decline; and (3) the histories and trends of locust swarms in North America and East Asia were 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

The present study focused on two regions of the North American Plains (NAP: 35–55° N and 95–110° W) and the Eastern Asian Plains (EAP: 35–55° N and 110–125° E) (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 locations have good long-term meteorological data coverage, and had major locust outbreaks during the 19th century. The EAP study area includes the Northeast China Plain, Northern China Plain, and the plains of the middle–low reaches 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 constructed using regional means from 30 meteorological stations in the NAP (Environment Canada Canadian, 2005; Vose

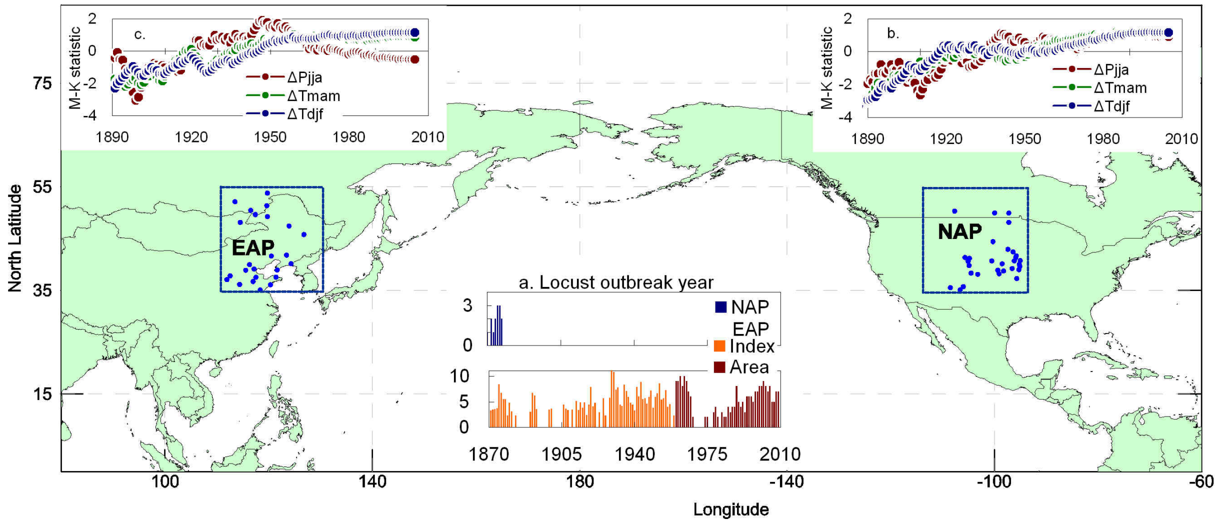

Fig. 1. Maps of study areas with location of meteorological stations, information of locust outbreaks **(a)**, climate changes in the North American Plains (NAP) **(c)**, and the Eastern Asian Plains (EAP) **(b)**. All abbreviations of climate variables are the same as used in the text.

et al., 2008) and 26 stations in the EAP (National Climate Center of China, 2012) 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 (autumn).

2.1 Compilation of NAP locust data

A 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 the 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 18 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" as indicated by other reports. Some reports also referred to the damage caused by non-swarming species of grasshoppers, mainly *Melanoplus sanguinipes* and *Camnula pellucida*, which are still common pests in the region today (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 the USA from Missouri to the Canadian border during the same period (Dawson, 1876; Packard, 1878; Pillsbury et al., 1878). The swarms devastated both agriculture and natural ecosystems. The journalist Henri Julien, accompanying the Northwest Mounted Police (NWMP) in the western territories, documented infestations on 16 July 1874 and noted the following 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, 2012). Private Fred Bagley, accompanying Major James Macleod of the NWMP, recorded seeing at dawn on 12 July 1874 AD that grasshoppers (i.e. Rocky Mountain locusts) covered the landscape, and 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). His diary for that day notes "Grasshoppers so numerous that they darken the sun. Every step we take through the grass disturbs thousands of them". Vitalin Grandin, the Oblate Bishop of St. Albert, travelling with the NWMP to visit missions in southern Prairie Canada wrote that in 1876 the "soil looked rich and fertile, but the grasshoppers destroy everything growing on the soil. Beginning at the Red Deer River, down to this place and even as far as Benton, there reigns real devastation" (Dempsey, 1973). The swarms often also extended into the eastern portion of the Canadian Prairies, not only swarming, but also breeding.

Therefore, based on these historical reports and summaries of the locust hazards of the time, the NAP locust outbreak index was rated on a 0–3 scale, with 0 indicating no reports of major infestations, and 3 being the most severe with widespread devastation (Fig. 1a).

2.2 Compilation of EAP yearly locust series

Annual records of EAP locust outbreaks (Fig. 1a) were derived from two data sources. For the period 1850–1958 AD, an annual locust index was used; this was sourced from Chinese historical documents compiled by Ma (1958) and edited by Yu et al. (2009). This annual locust index was scaled in relative severity from 0 (no locust outbreak) to 10 (most severe). Locust data were derived from contemporary observations of areas with locust outbreaks in China after 1958 AD. The 1949–1999 data were compiled by Wu et al. (2006), while the data for years after 1999 were compiled as part of the present study using details of locust-impacted areas recorded in the *Statistics Annals of Agriculture in China* (China Ministry of Agriculture, 2009). The original annual locust-impacted area data were in km^2 units. To be consistent with Ma's (1958) 10-class locust index, the 1949–2009 AD series were placed into 10 classes by using each 10 percentile with a cut-off at the 5th, 15th,...95th of the area values (Fig. 2a). Cross validation for the time period with overlapping data from both sources (i.e. 1949–1958 AD) shows that the two series are significantly correlated (Fig. 2b).

2.3 Comparative analysis of the two regions

2.3.1 Analysis for frequency differences

Extremes of temperature and precipitation were combined into four models and referred to here as warm–wet, warm–dry, cold–wet and cold–dry combinations. A cut-off of $>$ 50th, 60th,...90th percentiles was applied to temperature or precipitation to derive the extremes of warm or wet climates, and a cut-off $<$ 10th, 20th,...50th percentiles in temperature or precipitation to derive the extremes of cold or dry climate. Frequency analysis of the climate extremes was carried out by establishing two-directional models of "climate-controlled" vs. "climate-induced" locust outbreaks. According to the ecology and biology underlying locust outbreaks (e.g. reviews in Ma, 1965; Wu et al., 1990, 2006; Chen, 2000; and a compilation in Yu et al., 2009), the control model seeks to identify combinations of cold–wet extremes and the induced mode focuses on warm–dry combinations, although two other models of cold–dry and warm–wet combinations were also examined. Significant differences in the frequencies between NAP and EAP were considered, by running the models for each of the two regions 7225 times, i.e. $(17 \times 5) \times (17 \times 5)$ by 17 climate variables (12 months, 4 seasons and 1 annual) and 5 percentile series ($>$50th or $<$50th percentiles with a 10 percentile interval), both for changes of temperature (ΔT) and precipitation (ΔP).

2.3.2 Analysis of the trend and probability

To examine the different climate trends in the NAP and EAP, Mann–Kendall trend tests (Kendall, 1975; Hirsch and Slack, 1984; Gilbert, 1987), the two regional climate series of NAP and EAP, were undertaken. Initially, the climate trends of the two regions were compared, and then the EAP climate trends were checked with EAP locust years.

Finally, in order to check if extreme climate combinations increased their occurrences on the EAP more than those on the NAP, an extreme probability analysis was undertaken. Gumbel probability represents well extreme values and estimates the probability distribution in a population (Gumbel, 1954; Nadarajah, 2006). To estimate the location (μ) and scale (σ) parameters in a Gumbel (X, μ, σ) distribution, the observations of time series of monthly temperature and precipitation ($X = \Delta T_i$ or ΔP_i , where i is month from January to December) for the NAP and EAP for the period 1880–2009 AD were calculated using maximum likelihood estimation methods (Ritzema, 1994). To reduce sampling uncertainty, variate ΔT and ΔP were generated by 10 000-random sampling, following the Gumbel distribution. The patterns of the temperature and precipitation extremes were checked using 2-D scatter diagrams. The data processing and matrix manipulation were undertaken using FORTRAN programs.

3 Results

3.1 Difference of frequencies

Frequency analysis detected the most significant differences of temperature/precipitation between NAP and EAP: the cold–wet extremes at combinations of $\Delta T < 30$th and $\Delta P > 80$th percentiles were $\sim$4.5–6.5 times higher in the NAP than in the EAP, focused on colder spring–summer months with wetter spring–summer months (Fig. 3a). This observation suggests that, during the climate-controlled years for locust outbreaks, lower winter temperatures with higher summer or higher annual precipitations were more likely to occur in the NAP than in the EAP. In fact, among the severe pest outbreak years (defined as the >4 class on the 0–10 scale) since 1850 AD in the EAP, of a total of 26 yr cold–wet combinations, there were only 3 yr with locust outbreaks; i.e. there were 23 yr with no locust outbreaks (brown dots in Fig. 3b). The 88.5 % chance suggests that such extreme climate combination years did restrict most of the locust swarms.

In contrast, the most significant differences of temperature/precipitation between the NAP and EAP occurred in the dry–warm extremes at $\Delta T > 70$th and $\Delta P < 30$th combinations: $\sim$1.8–3.1 times higher in the EAP than in NAP, emphasis on warm winter and warm spring–summers with drier growing seasons (Fig. 3c). Actually, of the total 37 warm–dry extreme years in the EAP, the locust outbreaks occurred in 26 yr (red dots in Fig. 3d), indicating positive impacts with 70 % chance. This result suggests that locust outbreaks caused by higher winter and spring–summer temperatures, together with drier than normal spring–summers, were more likely to occur in the EAP than in NAP. The frequency and matches of warm and wet conditions in both areas were also calculated, using the combination of $T > 30$th and $P > 80$th percentiles. This combination was hypothesized

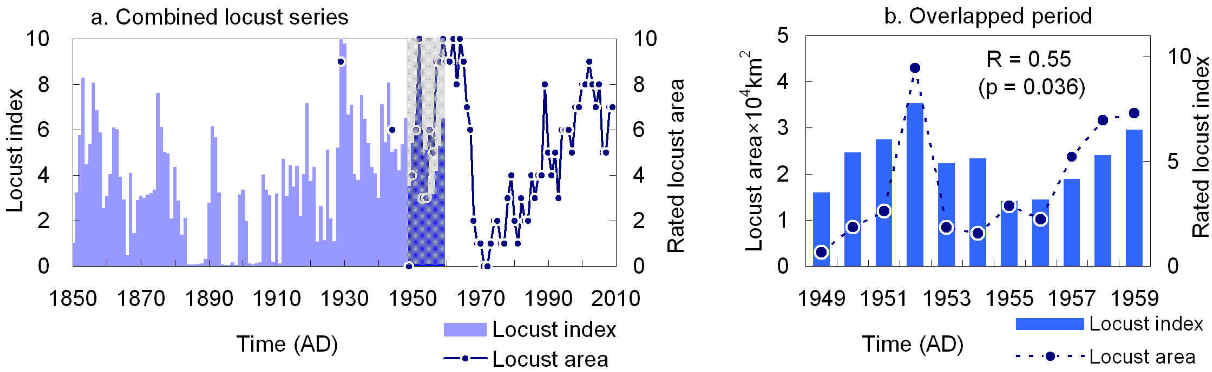

Fig. 2. Combined series of locust outbreak data for the EAP, including the severity index based on historical literature (blue bar) and the area index based on observed locust affected area (blue dotted line) (see main text for further details) **(a)**. The grey box in plot 2a enlarged to show the overlapping period 1949–1958 AD, demonstrating that the two data series are significantly correlated **(b)**.

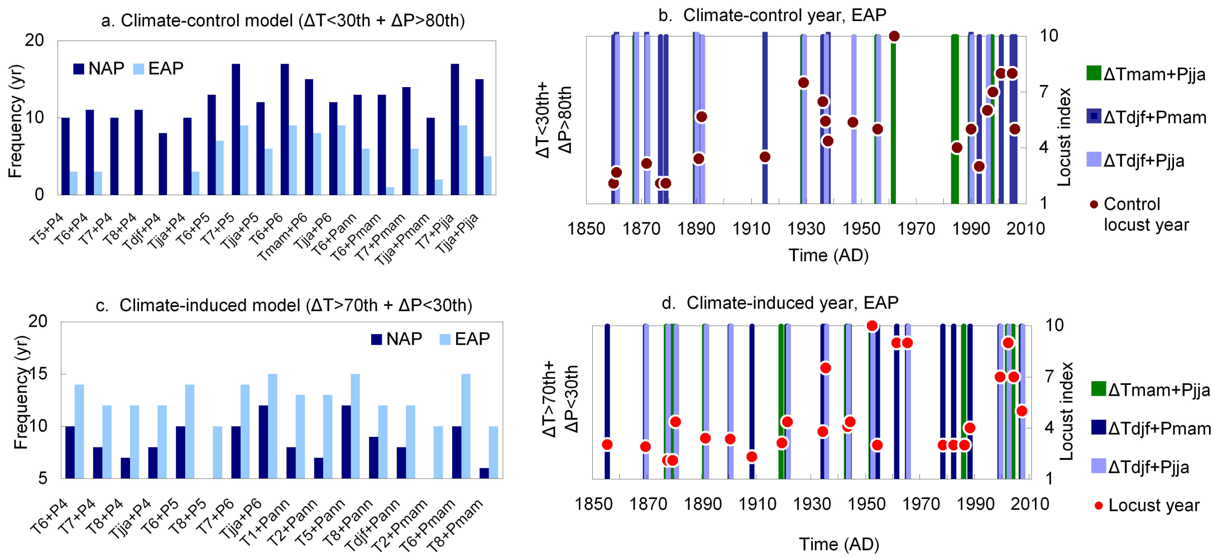

Fig. 3. Frequency comparisons of extreme climatic combinations between the NAP and EAP **(a, c)** and validation with EAP locust outbreak years **(b, d)**, including the climate-controlled model with $\Delta T < 30$th and $\Delta P > 70$th percentiles **(a)**, climate-induced model with $\Delta T > 70$th and $\Delta P < 30$th percentiles **(c)**, year comparisons of locust outbreak with warm–dry extremes ($\Delta T > 70$th and $\Delta P > 30$th) **(d)**, and cold–wet extremes ($\Delta T < 30$th and $\Delta P > 80$th) **(b)**. All climate variable abbreviations are the same as in the text.

to be conducive to natural control by pathogens, although other mechanisms, such as slowed development and feeding rates, may also operate under wet conditions. The ratio of the warm–wet years with locusts (i.e. matching years) to warm–wet years without locusts (non-matching years) in the EAP was 6 : 50 during a total of 56 yr with severe locust outbreaks. This suggests that although there was a higher frequency of warm and wet years in the EAP than in the NAP, the warm–wet years did not favour locust outbreaks in the EAP.

3.2 Probability analysis

Examination of extremes of climate series was performed by Gumbel probability analysis, which showed significant differences in the patterns of extreme values of the NAP compared to the EAP, by plotting 2-D scatter diagrams of Gumbel-distributed temperature/precipitation extremes for 1880–2009 AD series (Fig. 4).

In diagrams of extreme patterns of higher winter temperature changes (ΔTdjf $>$ 70th percentiles) with lower annual precipitation changes (ΔPann $<$ 30th percentiles), positive extreme values of ΔTdjf and negative extreme values of ΔPann in the NAP (Fig. 4a) were observed to be much lower than those in the EAP (Fig. 4b) ($p < 0.01$). The critical values of ΔTdjf $>$ 90th percentiles in NAP and EAP were +4 °C and +6 °C respectively, and ΔTmam $>$ 6 °C in the two regions are 13.0 % and 35.9 %, respectively (Fig. 4a1, b1). The critical values of ΔPjja $<$ 10th percentiles in the NAP and EAP were −17 mm and −303 mm, respectively,

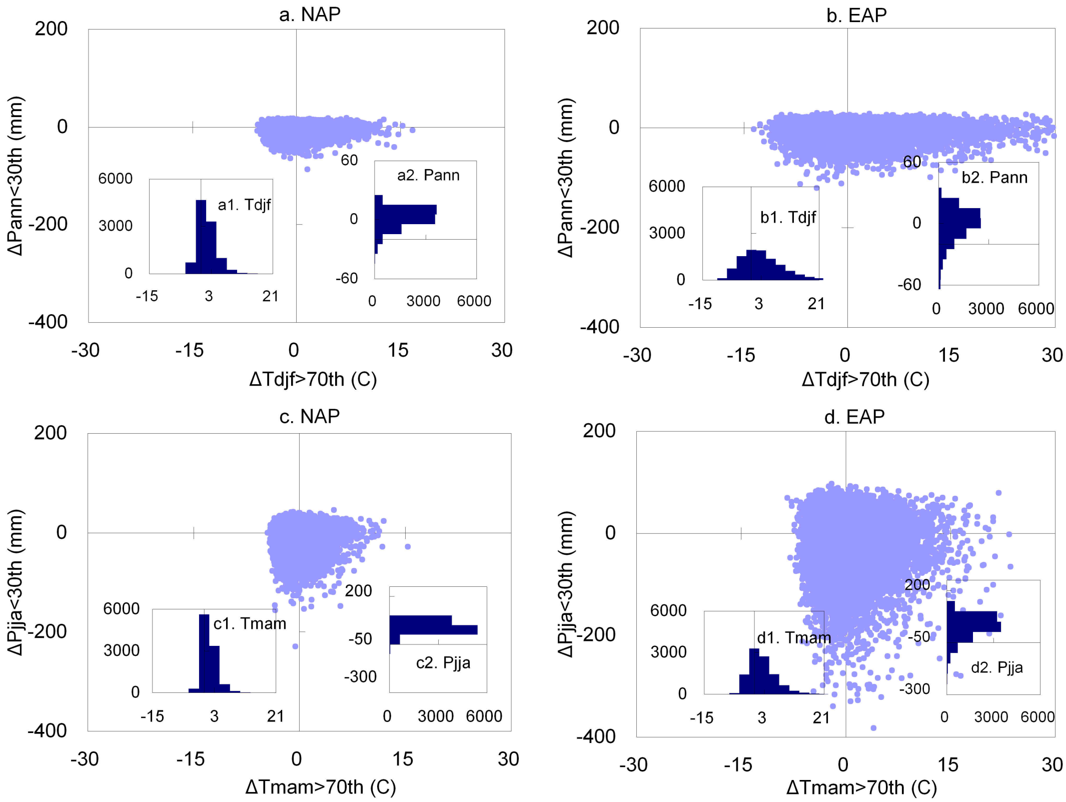

Fig. 4. 2-D scatter diagrams of Gumbel distribution climate extremes in the NAP **(a, c)** and EAP **(b, d)**. Combinations ΔTdjf > 70th and ΔPann < 30th percentiles **(a, b)** and ΔTmam > 70th and ΔPjja < 30th percentiles **(c, d)** respectively. Frequency diagrams (insert panels – a1, a2, b1, b2, c1, c2, d1 and d2) are plotted for 10 000 samples of ΔT (along x-axis, units in degrees Celsius) and ΔP (along y-axis, units in mm). All climate variable abbreviations are the same as in the text.

and ΔPjja < -20 mm in the two regions were 7.20 % and 19.15 %, respectively (Fig. 4a2, b2). This observation suggests that years with warm winter and annual dry extremes, a climate which favours overwintering locust eggs, occurred with a probability of ∼ 2–3 times higher in the EAP than that in NAP.

The extreme patterns in different seasons were also checked: higher spring temperature changed (ΔTmam > 70th) with lower summer precipitation changes (ΔPjja < 30th) (Fig. 4c and d). This showed that positive extreme values of ΔT mam and negative extreme values of ΔPjja in NAP (Fig. 4c) were much lower in the NAP than those in EAP (Fig. 4d) ($p < 0.01$). The critical values of ΔTmam > 90th percentiles in NAP and EAP were +2 °C and +6 °C, respectively, and ΔTmam > 6 °C in the two regions are 7.3 % and 24.9 %, respectively (Fig. 4c1, d1). The critical values of ΔPjja < 10th percentiles in NAP and EAP were −43 mm and −103 mm, respectively, and ΔPjja < -50 mm in the two regions were 7.0 % and 27.5 %, respectively (Fig. 4c2, d2). This analysis indicated that results of extreme climate change differentiated the EAP from the NAP: years with spring and warm summer dry extremes that favour locust multiplying and swarm dispersal occurred with a probability of ∼ 3.5–4 times higher in the EAP than that in NAP.

3.3 Trend analysis

The Mann–Kendall trend analyses indicated that, for the period 1880–2009 AD, the temperatures in January–February, July, winter, spring and summer, and precipitation in spring in NAP all increased significantly ($p < 0.05$) (Fig. 1b). For the same period, the EAP temperatures in January–February, April–May, winter, spring and summer, and precipitations in May and spring in EAP also have increased significantly ($p < 0.05$), with general trends of increased winter and spring temperature and decreased summer precipitation since 1950 (Fig. 1c).

Climate data since 1840 AD from the Beijing meteorological station, one of the longest climate records in the EAP, were used to determine if the locust outbreaks responded positively to climate change trends. The Mann–Kendall trend test for the time series showed that the trend change was significant ($p < 0.05$) for temperatures of January–February, April, winter and spring, and precipitations of July and summer. The climatic trend in Beijing was almost the same as that of the EAP, generally showing increasing temperature in spring but precipitation decreasing in summer (Fig. 5). Correlation analyses showed significantly positive correlations of the EAP locust index with the temperature changes in January, February, April, winter and spring (R +0.37, 0.42, 0.46, 0.44 and 0.36 respectively, $p < 0.05$), and negative correlations with the precipitation changes in July and summer (R −0.38 and −0.3, $p < 0.05$). The results confirmed that both localized and regional trends of climate change favoured locust plagues in the 20th century on the EAP.

4 Discussion

As discussed above, there have been a number of alternative explanations proposed for the disappearance of the Rocky Mountain locust in North America, including large-scale pesticide application and conversion of natural grassland to industrialized agro-systems, often including a change from grass to alfalfa (see the summary by Lookwood, 2004). However, climatic trends and variability were significantly different in the NAP and EAP during the past hundred years and could be a critical component of the different factors causing the loss of this species. In this study the frequency of the combination of lower temperatures in January and February (the overwintering season for locust eggs) and higher precipitation in summer and January–December in the NAP was found to be ∼ 4.5–5.0 times higher than that in the EAP. Also, the frequency of the combination of lower temperatures in March–August (the locust growing season) and higher precipitation in summer and January–December in the NAP was ∼ 5.5–6.0 times higher than that of EAP. In contrast, the frequency of climate combinations of higher temperature in January–February and lower precipitation in April–June and January–December in the EAP was ∼ 2.3–3.1 times higher than that in the NAP. The combination of cold winters and low temperatures during the growing season and higher precipitation in spring and summer in the NAP greatly restricted locust outbreaks and may have contributed to their decline and extinction after 1900 AD. Since there are few if any records of locust swarms in the NAP in the 20th century, it is hard to do statistical analyses of the climate pattern "warm in winter and dry in spring and summer" vs. abundant locust swarms. In contrast, robust statistical relationships during the 20th century are observed for the EAP, which shows that warm–dry conditions (warm in winter and dry in spring and summer) have contributed positively to locust swarming (Fig. 3b). As noted by Lockwood (2004), habitat modification and agricultural changes in vegetation may have been the final blow to locusts on the NAP; it seems likely, however, that a series of years of unfavourable climate conditions put them under considerable ecological stress, preconditioning the populations for extinction, contrasting with events on the EAP.

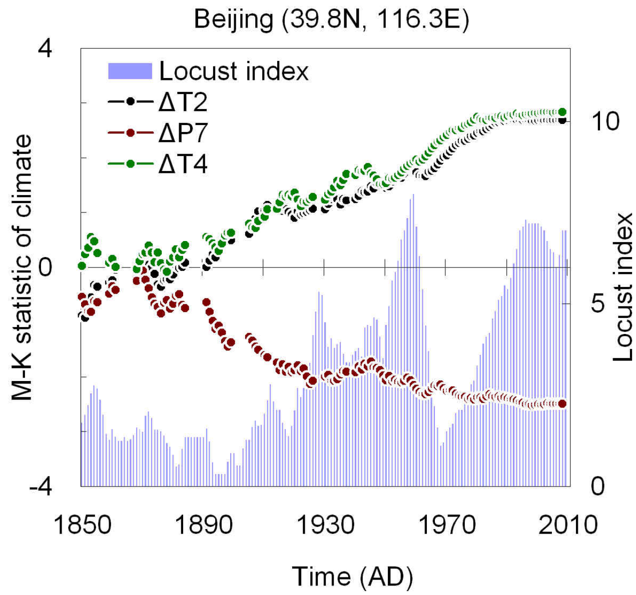

Fig. 5. Comparisons of locust outbreaks with trends of climate changes in Beijing by using Mann–Kendall trend test ($p < 0.05$). P7, T2 and T4 represent July precipitation, February and April temperatures respectively.

Recent 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 et al., 2005). Studies also show that the frequency of storms has increased, while no or light rainfall days have decreased; i.e. heavy rainfall days are increasing significantly in North America and many regions of the world (Thomas et al., 1998; Gutowski et al., 2007). In contrast, in China the frequency of no or light rainfall days has increased; i.e. total precipitation has decreased significantly since the beginning of the 20th century with the result that drought frequency 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 climate extremes and their characteristic assemblages and could help to explain the different fates of the locust outbreaks in the two regions. Differences between the EAP and NAP in terms of precipitation and temperature in the current century could be related to the adjustment and reorganization of atmospheric circulation over the two continents (Allan and Soden, 2008). Precipitation and temperature changes in Northern China were implicated as an explanation for recent outbreaks of the oriental migratory locust 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 changes in combinations of temperature and precipitation have affected locust swarming for a 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 grasshopper species to range- and cropland still exists (Lockwood and Schell, 1995). Even though many grasshopper species are not presently agricultural pests (Johnson, 2008), current and future climate warming trends are expected to increase the frequency, severity and duration of outbreaks of some of those species remaining in the NAP area, and precautions should be taken to make sure that they do not reach plague proportions.

As well as climate aspects influencing locust population dynamics, human activities in 1880s in the NAP, for example cattle grazing and cultivation on the insects' permanent breeding grounds, during a locust population recession may have irreversibly disrupted their reproductive ability. Other studies have shown that the eggs fail to hatch if the soil, they are deposited in is disturbed by ploughing or other means (Lockwood, 2004). Human activity since the end of 19th century could also explain the distinct pattern of local locust population trends in the NAP. In contrast, in the EAP locusts hatch, multiply and grow mostly on river floodplains, lake overbanks, swamps, and coastal lowlands, i.e. areas that are naturally dry during low water levels and/or seasons with below average rainfall but are submerged during high water level and periods of heavy rainfall, whereas locust impacts on cultivated land were due primarily to migration of the locust swarms, not in situ reproduction and growth (Wu et al., 1990). Thus, although farmlands in the EAP have been cultivated for a thousand years, and locusts outbreaks have occurred over the same period (Ma, 1958) they were primarily influenced by changes in flooding or drying of their natural breeding grounds, i.e. uncultivated land; population cycles therefore have been closely linked with natural climate changes for a thousand years (Stige et al., 2008; Yu et al., 2009).

Acknowledgements. Financial support for this research was provided by Key Programs of Ministry of Science and Technology of China (2012CB956103-5, 2013CB956501) and International Partnership Program and External Cooperation Program of Chinese Academy of Sciences (KZZD-EW-TZ-08, GJHZ1214). Many thanks to Dan Johnson (Lethbridge University, Canada) for providing help on the data collection and to John Anderson (Loughborough University, UK) for improving the English language.

Edited by: F. X. Meixner

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