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Impact of Land Use Changes on Surface Warming in China

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ABSTRACT

Land use changes such as urbanization, agriculture, pasturing, deforestation, desertification and irrigation can change the land surface heat flux directly, and also change the atmospheric circulation indirectly, and therefore affect the local temperature. But it is difficult to separate their effects from climate trends such as greenhouse-gas effects. Comparing the decadal trends of the observation station data with those of the NCEP/NCAR Reanalysis (NNR) data provides a good method to separate the effects because the NNR is insensitive to land surface changes. The effects of urbanization and other land use changes over China are estimated by using the difference between the station and the NNR surface temperature trends. Our results show that urbanization and other land use changes may contribute to the observed 0.12°C $(10\,\mathrm{yr})^{-1}$ increase for daily mean surface temperature, and the 0.20°C $(10\,\mathrm{yr})^{-1}$ and 0.03°C $(10\,\mathrm{yr})^{-1}$ increases for the daily minimum and maximum surface temperatures, respectively. The urban heat island effect and the effects of other land-use changes may also play an important role in the diurnal temperature range change. The spatial pattern of the differences in trends shows a marked heterogeneity. The land surface degradation such as deforestation and desertification due to human activities over northern China, and rapidly-developed urbanization over southern China, may have mostly contributed to the increases at stations north of about 38°N and in Southeast China, respectively. Furthermore, the vegetation cover increase due to irrigation and fertilization may have contributed to the decreasing trend of surface temperature over the lower Yellow River Basin. The study illustrates the possible impacts of land use changes on surface temperature over China.

Key words: land use change, temperature, surface warming

1. Introduction

There is a rapidly increasing concern that anthropogenic changes in the land surface condition, such as urbanization and agricultural and pasture practices, may affect local, regional and global climate at diurnal, seasonal, and long-term scales by changing the surface physical properties. The problem has been extensively investigated by model studies (e.g., Charney, 1975; Dickinson and Kennedy, 1992; Zeng et al., 1999; Gao et al., 2003), dynamical and theoretical analyses (e.g., Charney, 1975; Zhou and Wang, 1999; Wu et al., 2003) and data analyses (e.g., Zhang et al., 2003b, 2003c) over the past few decades. Among all kinds of impacts that anthropogenic land cover changes have on climate variables, the contribution to surface warming may have not received enough attention, but the global radiative forcing by surface albedo change may be compared with that due to anthropogenic aerosols, solar radiation and several major greenhouse gases, and the land-use changes can modify the surface heat

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fluxes directly and indirectly, and hence significantly affect the surface warming.

Compared with the impact of greenhouse-gas emissions, it is more difficult to fully quantify the land-use impacts on surface warming. The effects of urbanization have been estimated by classifying meteorological stations as urban or rural depending on population data (Easterling et al., 1997), satellite measurements of night-light (Gallo et al., 1999; Hansen et al., 2001) and other methods (Wu et al., 1994). The urban heat island effects on the global temperature are no more than about 0.05°C from 1900 to 1990, and linearly increasing to 0.06°C in 2000 (IPCC, 2001). Urban heat island studies over China have mainly focused on large cities such as Beijing, Shanghai and Lanzhou (e.g., Johns et al., 1990; Zhou and Shu, 1994; Li et al., 2003; Song and Zhang, 2003), finding that the annual mean surface air temperature in the large cities is significantly higher than that in the suburbs, so the urban heat island effects should not be neglected when considering the local warming of the climate. Compared with the development of urbanization, other land use changes such as agriculture, pasturing, and deforestation occur over larger areas and even increase more rapidly, and China has been considered as one of the most obvious land use change regions. As much as 17630 km^2 of forest was converted into cropland by deforestation from the 1980s to 1990s, and it mostly took place in Northeast China (Zhang et al., 2003a). The developing rate of desertification land over northern China increased to 3600 km^2 per year during the 1990s, and the total desertification land area increased to 385760 km^2 in 2000 from 338950 km^2 in 1987 (Wang et al., 2003). The expansion of built-up and residential areas was obvious during the 1990s, with 5330 km^2 in total from 1995 to 2000, among which most of the land was converted from arable land (Liu et al., 2003). It may be difficult to accurately compare the effects of different local land-use changes with each other and with the effects of increasing greenhouse gases. However, neglecting the impacts of other land-use changes may lead to an inaccurate quantification of contributions to surface warming. It is therefore important to explore the possible impacts of urbanization and other land-use changes.

Kalnay and Cai (2003) introduced a new method to assess the impacts of the urban heat island and other land-use changes on surface climate by comparing the decadal trends of station data with those of the NCEP/NCAR Reanalysis (NNR, Kalnay et al., 1996; Kistler et al., 2000). Very recently, Zhou et al. (2004) used Kalnay and Cai's method to estimate the impact of urbanization over Southeast China, and compared it with the urbanization characterized by changes in the population and the normalized difference vegetation index (NDVI). Here, we focus on the region east of 110°E in China using the same method. Zhou et al. (2004) gave more detail on urban heat island effects, whereas we pay more attention to all kinds of land use changes in China.

2. Data and method

The surface station data that we have used are the daily surface mean, maximum and minimum temperature data for 688 climatic stations across China from the China Meteorological Administration for 1960–1999. These station data have not been adjusted for some non-climatic changes such as station relocation and urbanization. There are 431 stations that have a complete set of observations for the period from January 1960 to December 1999. For the NNR, the global daily surface air maximum and minimum temperature and 6-hour mean temperature data are used for the same period. We followed the same recipes and procedures put forward by Kalnay and Cai (2003) in analyzing the data, and more detail can be found in their study. For decadal trends we subtract the ten years of 1980–1989 from the ten years of 1990–1999.

In the time series, we added a constant to make the 1960s station temperature mean the same as that in the NNR for each of the 431 stations, and this does not affect the correlation or trend results.

3. Results

Figure 1 shows the annual average surface temperature anomalies for both the station and NRR data for the city of Shanghai, located in Southeast China, as one example of the 431 stations. The correlation coefficient between observation and NNR is about 0.8, and there is a good correspondence between the two time series. The differences between the observation and the NNR in the 1960s, 1970s, 1980s and 1990s demonstrate that there is a big shift over the 1980s–1990s due to the urban heat island effect. Yu and Luo (1995) assesed the urbanization effects on surface warming by comparing the Shanghai city station and surrounding stations, and they found that the temperature in January for Shanghai increases by about 1.2°C during 1960–1986, which is more than that of the surrounding stations. The monthly mean urban island intensity is greater than 0.8°C (Deng et al., 2001). The comparisons between the observed and analyzed data at other stations such as Beijing have seen similar results.

In general, the correlation coefficients are much larger for the stations east of 110°E than for those in the west (not shown), and the averaged values for

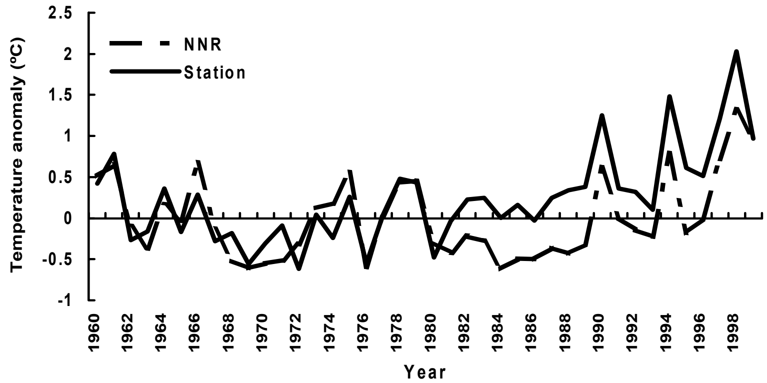

Fig. 1. Comparison of annual average surface temperature anomalies for both the station and NNR data for the city of Shanghai (31.24°N, 121.29°E), where the NNR temperature is linearly interpolated to the location of the station.

the stations east of 110°E over China for mean, maximum and minimum surface temperature are 0.80, 0.64 and 0.70, respectively. So, in the trend study, only the stations east of 110°E are used, giving us 259 stations. This number is still valuable for this study because the urbanization and other land-use changes such as agriculture, pasturing, deforestation, desertification, fertilization and irrigation mostly occur in eastern China.

As indicated by Figs. 2a, 3a and 4a, the decadal trends of the daily mean, maximum and minimum temperature, respectively, are increasing for nearly all 259 stations east of 110°E over China, and the mean values for these stations are 0.66, 0.65 and 0.69°C $(10\ \mathrm{yr})^{-1}$. Compared with the two studies of Wang et al. (1998) based on 1880-1996 data and Zhai and Ren (1997) using the maximum and minimum temperature data for the period of 1951–1990, our calculated decadal trends of mean and minimum temperature are consistent with their studies, but the trends are higher. The maximum temperature trends are different from the earlier study in which decreasing trends were observed in eastern China south of the Yellow River. The differences can be due to the different time series used, and our results of surface temperature are larger partly because of the rapid warming that occurred in the 1990s (Gong and Wang, 1999), and it may also be due to the removed urban heat island effects of the big cities in Zhai and Ren's study.

The NNR trends of daily mean, maximum and minimum temperature (Figs. 2b, 3b and 4b respectively) are increasing at nearly every station east of 110°E in China too, but the trends are less than those of the observations. These results show that both station data and NNR data show a substantial warming, reflecting global warming signals, whereas the differences in decadal trends perhaps provide observational evidence for the local warming due to land use changes.

Figures 2c, 3c and 4c compare the difference between the station and the NNR for the mean, maximum and minimum temperature trends and show the effects of urbanization and other land-use changes. The trends for the mean and minimum temperatures averaged over the region east of 110°E are significantly increasing at rates of 0.12°C $(10\ \mathrm{yr})^{-1}$ and 0.20°C $(10\ \mathrm{yr})^{-1}$, respectively, and the trend for the maximum temperature is slightly increasing at a rate of 0.03°C $(10\ \mathrm{yr})^{-1}$. These show, at least in part, that the urbanization and other land-use changes in China may explain about 18% of the observed increase in mean temperature, and about 29% of the observed increase in the minimum temperature and slight increase in maximum temperature. The trends are very different over different areas of China: strongly increasing at sites north of about 38°N including Northeast China, the northern part of North China and the climatic and ecological transitional zone in northern China; increasing at most sites in southern China; and decreasing at sites in the lower Yellow River Basin. The rapidly expanding population and increase in human activities in northern China have led to environmental degradation. Large areas of arable land have been reclaimed in Northeast China and North China. The desertification area expanded at a rate of 3600 km^2 per year in the 1990s due to over-cultivation, overgrazing, and deforestation. About 17630 km^2 of forest areas were deforested and replaced by cropland, and the most significant deforestation occurred in Northeast China in the 1990s. Both desertification and deforestation tend to increase surface temperature, and land surface degradation may mostly contribute to surface warming over the region north of about 38°N. A multi-year simulation by a regional climate model also showed that the desertification over northern China obviously increases

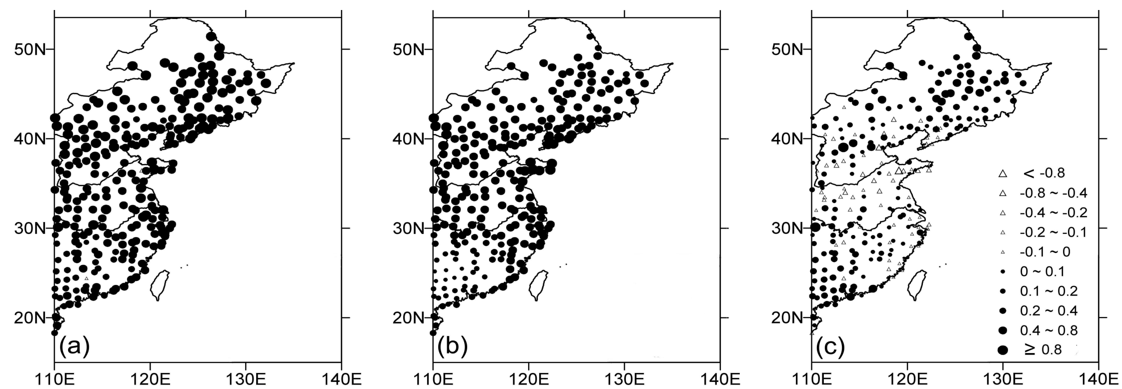

Fig. 2. Decadal trends of mean temperature averaged over every station east of 110°E in China. (a) station (observed) mean temperature trends; (b) NNR (analyzed) mean temperature trends; (c) observed minus NNR mean temperature trends.

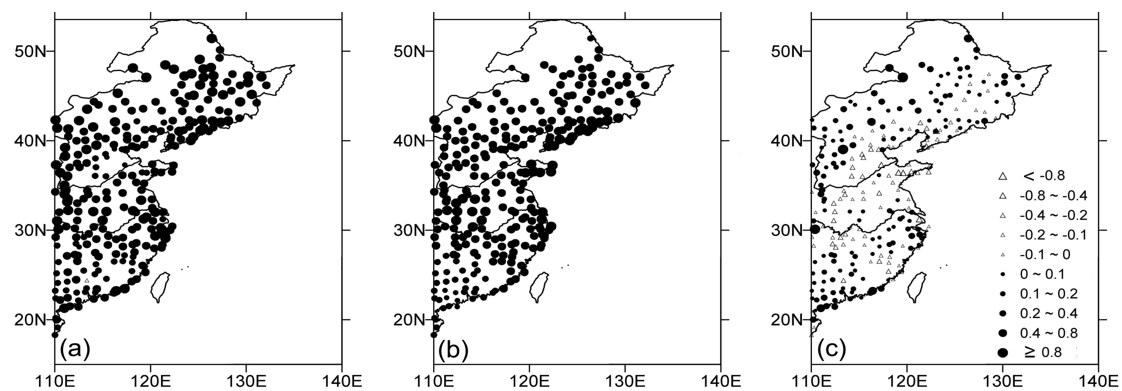

Fig. 3. Same as Fig. 2 except for the maximum temperature

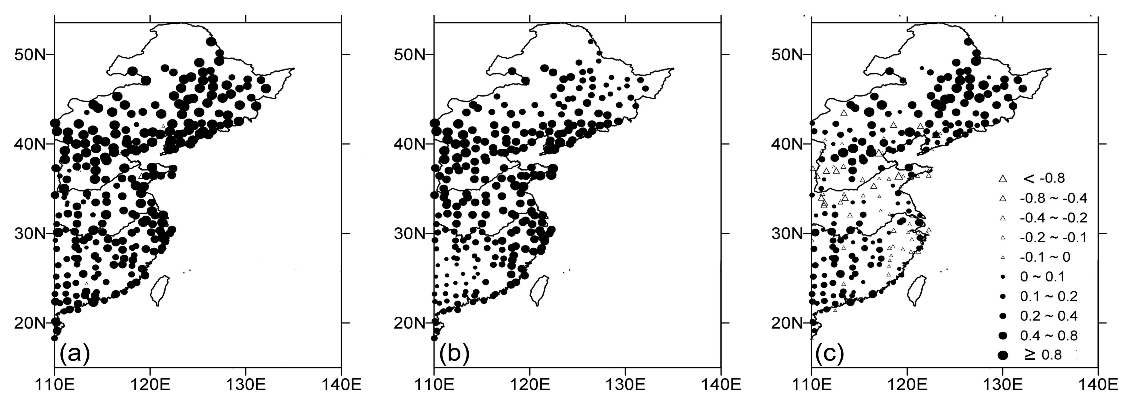

Fig. 4. Same as Fig. 2 except for the minimum temperature.

the local surface temperature with a mean value of about 1°C (Zhang et al., 2005). Rapid urbanization has taken place in southern China and caused a sharp decrease in NDVI in the Yangtze River and Pearl River deltas, and the irrigation and fertilizer use have probably increased plant growth in the North China Plain according to Piao et al.'s (2003) result. These urban heat islands result in rapid increase in surface temperature over southern China, and the increased vegetation cover rate may explain the decrease in surface temperature over the lower Yellow River Basin.

Earlier estimates performed using the differences of decadal trends between NNR and station data over Southeast China reported a warming of the surface temperature of 0.05°C $(10\ \mathrm{yr})^{-1}$ due to urbanization (Zhou et al., 2004). The increase in mean surface temperature is larger than this previous estimate possibly because our calculation includes northern China where warming trends due to land-use changes are stronger.

The observed diurnal temperature range is generally decreased by a mean of about 0.04°C (10 yr)$^{-1}$, and most land-use changes such as urbanization tend to decrease the daily temperature range, and the effects of some land-use changes like desertification may be of opposing sign. Our results also show that land-use changes play an important role in the diurnal temperature range change.

4. Conclusion and discussion

Over the last few decades, the land surface over a number of areas has been rapidly modified by human activities, and China has been considered as one of the major land-use change regions in the globe. Vast areas of forest and grass lands over northern China have already been desertified and deforested, and rapid urbanization has occurred in Southeast China. Earlier simulation studies (Xue, 1996; Zheng et al., 2002; Zhang et al., 2005) have found that desertification and deforestation over northern China can warm the local surface temperature by changing the surface fluxes, and hence the hydrological cycle and surface energy balance. Urban heat islands tend to increase the local surface temperature, and warm the nighttime more than the daytime compared to non-urban areas. These land-use changes such as agriculture, pasturing, deforestation, desertification and irrigation are not included in the estimation of surface warming, implying that the total effects of land-use changes may have been underestimated.

By comparing the decadal trends of the station and NNR surface temperature data, we quantify the total effects of land-use changes on surface warming in China. Generally, our results suggest that land-use changes may explain about 18% (0.12°C (10 yr)$^{-1}$) of the observed daily mean temperature increase, 29% (0.20°C (10 yr)$^{-1}$) of the observed daily minimum temperature increase and slight daily maximum temperature increase, and that they may play an important role in the diurnal temperature range changes.

The land surface degradation such as deforestation and desertification due to over-cultivation, overgrazing, full wood cutting and other human activities in northern China, and the rapid development of urbanization in southern China, may have mostly contributed to surface temperature increases in the region north of about 38°N and in Southeast China, respectively. Furthermore, the plant growth promotion in the lower Yellow River Basin due to irrigation and fertilization may play an important role in the decreasing trend of surface temperature over this region.

As Kalnay and Cai (2003), and Zhou et al. (2004) have noted, some uncertainties such as non-climatic effects occur in the method employed here, and therefore these results should be considered as illustrative rather than definitive. However, the comparison is still a good estimate, and our recent simulation results also show that land surface degradation over northern China and southern Mongolia leads to significant increases in local temperature and has less influence on remote regions except for the adjacent area to the south (Zhang et al., 2005). Furthermore, an integrated study using a few kinds of analyzed data should be carried out to decrease the uncertainties brought about by data deficiencies, and a more realistic treatment of the land surface and vegetation-climate interaction in climate models would be helpful for improving our understanding of the effects of land use and cover changes on the surface climate.

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