Observed Surface Warming Induced by Urbanization in East China

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Abstract: Monthly mean temperature data from 463 meteorological stations in a range of urban and rural settings between 1981 and 2007 were analyzed. Using both raw and NCEP/NCAR reanalyzed (NNR) data, we found that urbanization is responsible for roughly 24 percent of the warming in eastern China in recent decades, thanks to the urban heat island (UHI) effect. In metropolitan areas, UHI contributed up to 44 percent (nearly 0.4℃ decade^{-1}) of the temperature increase. The largest increase in the UHI effect came after 2000, coinciding with a period of rapid industrialization in China.

Introduction: China's rapid urbanization in the past three decades led to a quick transition of stations from rural into urban in a very short period. Note, however, that almost all of the previous studies did not consider this factor in their UMR (urban minus rural) analysis. The type of station remained fixed throughout an entire analysis period once it was identified as rural or urban. Thus, disregarding the effect of the conversion of stations from rural to urban on temperature records may give rise to a considerable underestimation of the UHI effect.

Data and methods:

- Monthly mean surface air temperature data during 1981-2007 from 463 weather and climate stations at elevations below 500 m (Fig.1)
- NNR 2m air temperature data for the same period
- DMSP/OLS V4 stable nighttime light products (1992–2007) with 1 km spatial resolution downloaded from NGDC
- Statistical data of the administrative unit-based urban land area
- Non-agricultural population census data from China City Statistical Yearbook
- DMSP/OLS nighttime light data from 1992 to 2007 were employed to **dynamically** categorize urban and rural stations. Then urban stations were grouped into four types using non-agricultural population data.
- The temperature anomalies were averaged over six station categories to create a six-time series according to the **dynamic** classification for 1992–2007.
- Observation minus reanalysis (OMR)
- Urban minus rural (UMR)

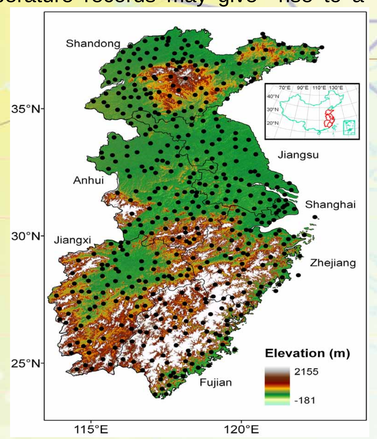

Fig. 1. Terrain of the study area and locations of the stations.

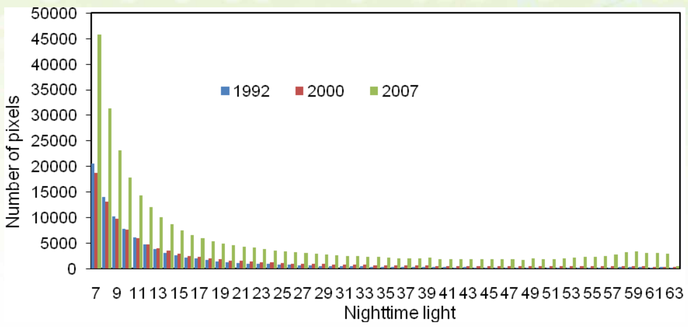

Fig. 2. Number of pixels of nighttime lights with values larger than 6 for 1992, 2000, and 2007 in east China.

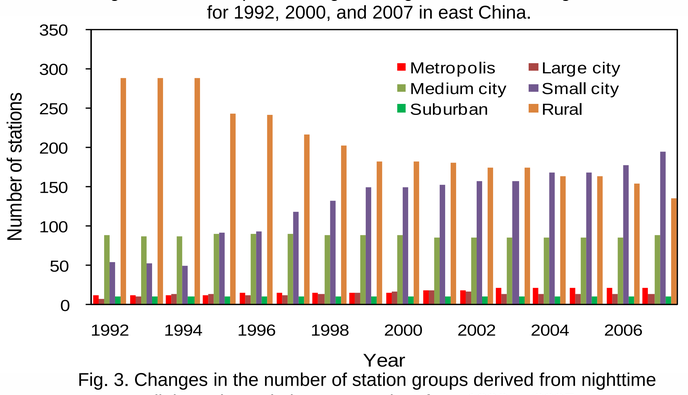

Fig. 3. Changes in the number of station groups derived from nighttime light and population census data from 1992 to 2007.

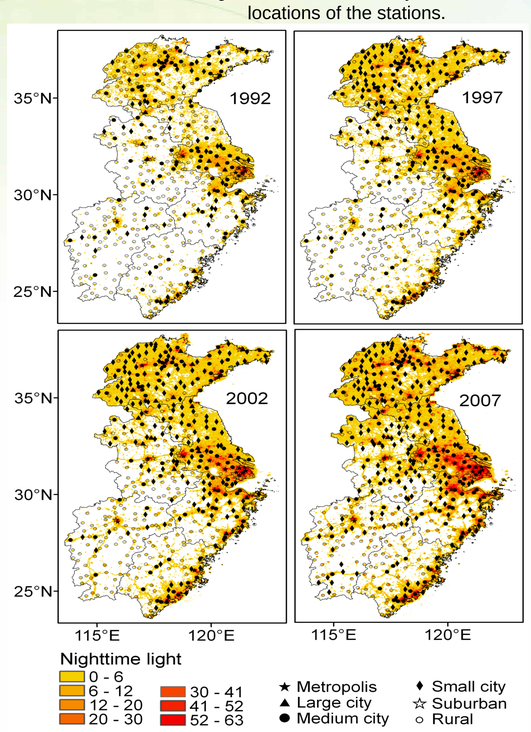

Fig. 4. DMSP/OLS nighttime light and distribution of stations for six categories in 1992, 1997, 2002, and 2007 in east China.

The urbanization process was intensive after 2000 (Fig. 2). Rural stations accounted for more than 60% of the total number of stations in 1992. During the rapid urbanization in east China in the past two decades, many rural stations were converted into small cities in a very short period. The number of small cities exceeded the number of rural stations in 2004. In 2007, the number of rural stations accounted for only about 30% (Fig. 3).

Results:

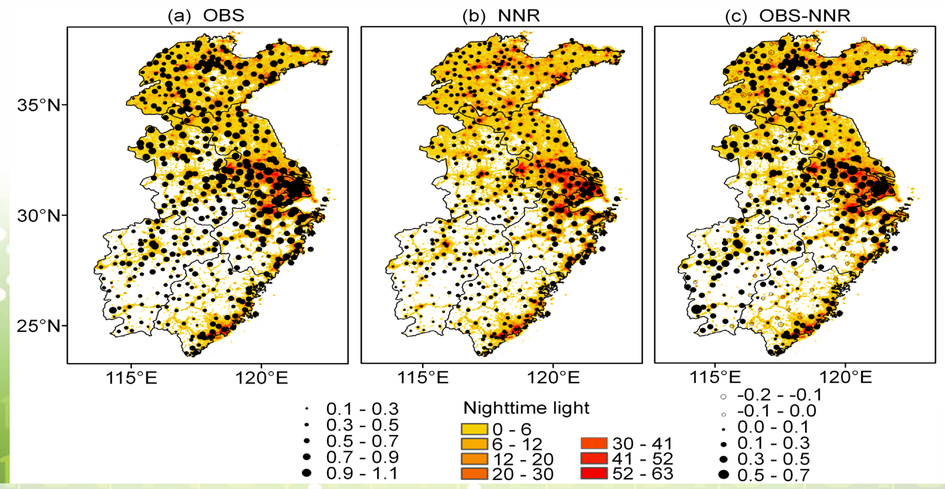

Fig. 5. DMSP/OLS nighttime light imagery of 2007 and annual mean temperature trends from (a) station observations, (b) the NNR, (c) the OMR [℃ decade^{-1}] at sites located below 500 m in east China; 0.578, 0.438, and 0.140 ℃ decade^{-1} are the mean trends of all station observations, NNR, and OMR, respectively.

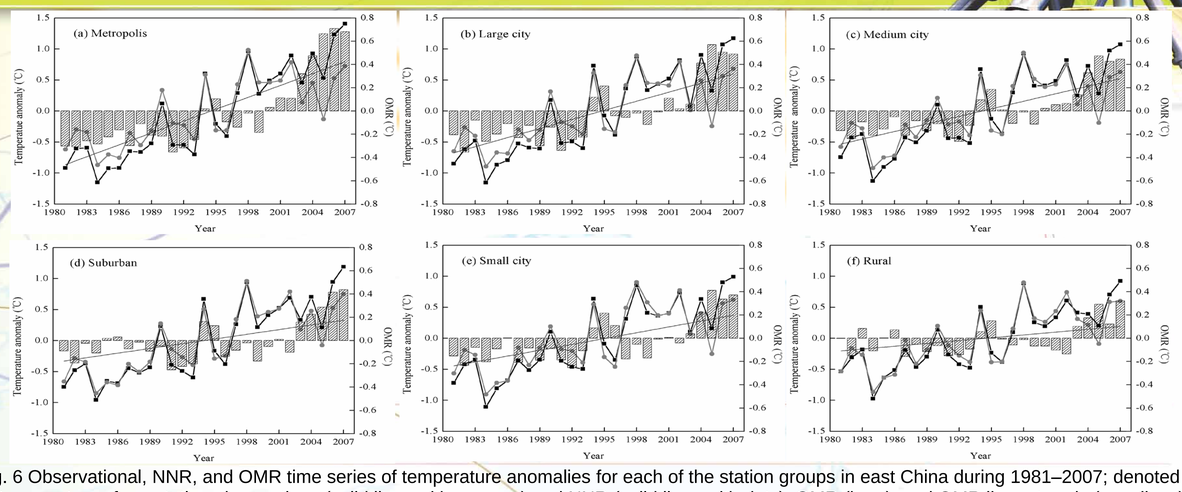

Fig. 6 Observational, NNR, and OMR time series of temperature anomalies for each of the station groups in east China during 1981–2007; denoted are temperatures from station observations (solid lines with squares) and NNR (solid lines with dots), OMR (bars), and OMR linear trends (gray lines).

The warming pattern closely related to the intensity of the nighttime lights. Stations in the urban agglomeration of the Yangtze River Delta, where the nighttime light values are highest, show the most significant warming trends. The distribution of the OMR trends(Fig. 5c) are quite similar to that of the observational temperature change in Fig. 5a, indicating a significant contribution of urbanization on surface warming in east China in the past 27years.

The station observations exhibit a stronger warming trend than does the NNR. As a result, the OMR shows a positive trend, with the strongest being in the metropolis group. The most substantial increase in OMR value occurred after the early 2000s (Fig. 6). Good regional background temperature change was captured for both observations and the NNR over rural areas (Fig. 6f).

Table 1 Temperature trends from station observations and NNR, and the differences between the observations and NNR (i.e., OMR) [unit: ℃ decade^{-1}] for different station groups in east China during 1981–2007

		Annual	Spring(MAM)	Summer(JJA)	Autumn(SON)	Winter(DJF)
Rural						
	OBS	0.502**	0.556**	0.255*	0.446**	0.757**
	NNR	0.421**	0.435**	0.252**	0.386*	0.610*
	OMR	0.081	0.121	0.003	0.060	0.147
Suburban						
	OBS	0.651**	0.745**	0.464**	0.614**	0.780**
	NNR	0.513**	0.562**	0.350**	0.516**	0.623**
	OMR	0.138	0.183	0.114	0.098	0.157
Small city						
	OBS	0.614**	0.646**	0.356**	0.594**	0.854**
	NNR	0.447**	0.467**	0.295**	0.413*	0.612*
	OMR	0.167	0.179	0.061	0.181	0.242
Medium city						
	OBS	0.674**	0.722**	0.424**	0.644**	0.900**
	NNR	0.460**	0.471**	0.306**	0.436*	0.627*
	OMR	0.214	0.251	0.118	0.208	0.273
Large city						
	OBS	0.742**	0.836**	0.527**	0.721**	0.883**
	NNR	0.482**	0.576**	0.328**	0.448**	0.576*
	OMR	0.260	0.260	0.199	0.273	0.307
Metropolis						
	OBS	0.904**	1.010**	0.689**	0.841**	1.077**
	NNR	0.506**	0.525**	0.377**	0.513**	0.611*
	OMR	0.398	0.485	0.312	0.328	0.466

* 0.05 significance level ** 0.01 significance level

Table 2. Urban minus rural (UMR) results for station observations [unit: ℃ decade^{-1}].

	Annual	Spring(MAM)	Summer(JJA)	Autumn(SON)	Winter(DJF)
Suburban					
Urban	0.651**	0.745**	0.464**	0.614**	0.780**
Rural	0.551**	0.652**	0.355**	0.520**	0.759**
UMR	0.100	0.093	0.109	0.094	0.021
Small city					
Urban	0.611**	0.646**	0.363**	0.588**	0.840**
Rural	0.534**	0.571**	0.299*	0.495**	0.773**
UMR	0.077	0.075	0.064	0.083	0.067
Medium city					
Urban	0.670**	0.714**	0.432**	0.633**	0.878**
Rural	0.535**	0.562**	0.319*	0.507**	0.767**
UMR	0.135	0.152	0.113	0.126	0.111
Large city					
Urban	0.802**	0.897**	0.605**	0.772**	0.884**
Rural	0.595**	0.693**	0.372**	0.549**	0.759**
UMR	0.207	0.204	0.233	0.223	0.125
Metropolis					
Urban	0.870**	0.925**	0.637**	0.823**	1.011**
Rural	0.585**	0.653**	0.358*	0.550**	0.781**
UMR	0.285	0.272	0.279	0.273	0.230

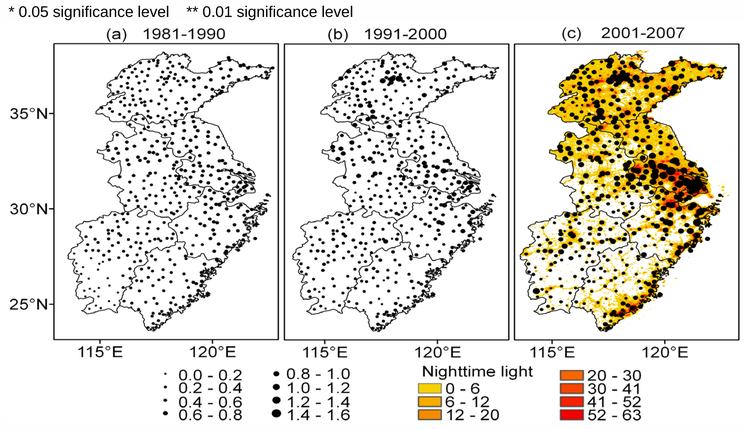

Fig. 7. Decadal mean OMR [℃ decade^{-1}] at different time slices. The DMSP/OLS nighttime light imagery of 2007 is shown in c.

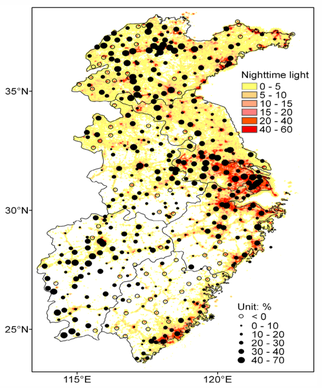

Fig. 8. Percentage of contribution from urbanization to the surface air temperature change during 1981–2007 and the difference in DMSP/OLS nighttime lights between 2007 and 1992.

The mean OMR value during 2001-2007 (Fig. 7c) shows a spatial pattern highly similar to the linear trends of the observational surface air temperature in Figure 5a and the OMR trends in Fig. 5c. The OMR and the linear observational temperature trend both show significant surface warming induced by urbanization in east China, especially in the Yangtze River Delta and coastal areas, with the most intensive UHI effect occurring in the 2000s. In the urban agglomeration in the Yangtze River Delta, urbanization has contributed more than 40% to climate warming since 1981 (Fig. 8).

Conclusions:

- *With objective and dynamic station classification, the observed and reanalyzed temperature changes over rural areas show good agreement, indicating that the reanalysis can effectively capture regional rural temperature trends.*
- *The trends of UHI effects, determined using OMR and UMR approaches, are generally consistent and indicate that rapid urbanization has a significant influence on surface warming over east China.*
- *Overall, UHI effects contribute 24.2% to regional average warming trends. The strongest effect of urbanization on annual mean surface air temperature trends occurs over the metropolis and large city stations, with corresponding contributions of about 44%and 35% to total warming, respectively.*
- *The most substantial UHI effect occurred after the early 2000s, implying a significant effect of rapid urbanization on surface air temperature change during this period.*

Acknowledgments:

This work was supported by the Climate Change Special Foundation of the China Meteorological Administration (Grant CCSF-09-10), National Natural Science Foundation of China (Grant 41001023).

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More information can be obtained at http://www.agu.org/pubs/crossref/2011/2010JD015452.shtml; See also "Hot cities heat up China", Nature research highlights http://www.nature.com/nature/journal/v476/n7359/full/476129e.html