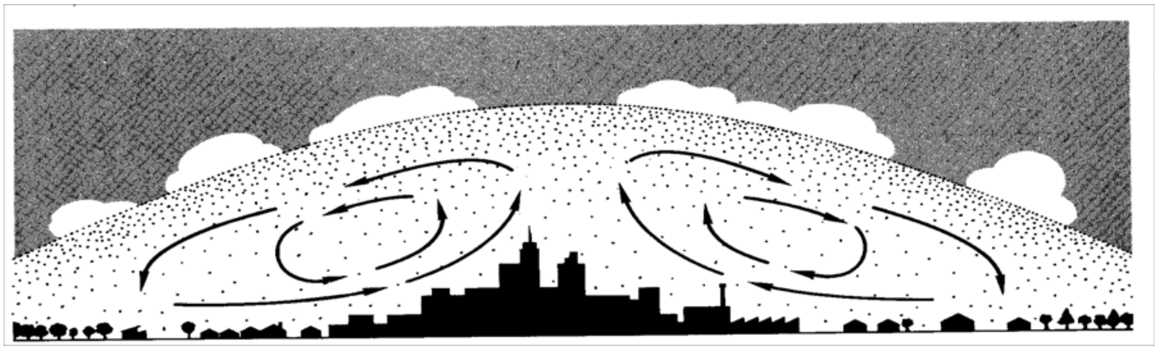
URBAN HEAT ISLAND

We are all familiar with the fact that cities are generally warmer than the surrounding, more rural areas. We see it referenced most nights in our television weather reports. It is especially significant on nights with clear skies and light winds which favor radiational cooling. This is most significant in the rural areas but in the city, the excess heat absorbed during the day and the local heat sources maintain higher nighttime readings. During the days or nights with strong winds and clouds the differences are minimized due to mixing and the advective cooling of the city by the winds.

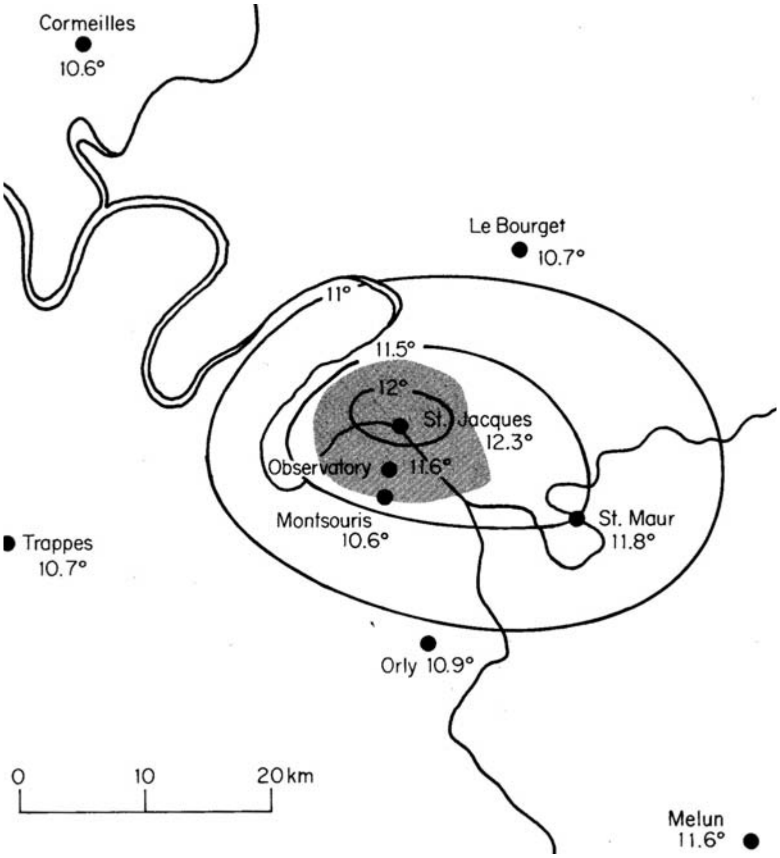
Because of this relative warmth, a city may be referred to as an ***urban heat island.***

The reason the city is warmer than the country comes down to a difference between the energy gains and losses of each region. There are a number of factors that contribute to the relative warmth of cities according to Ackerman:

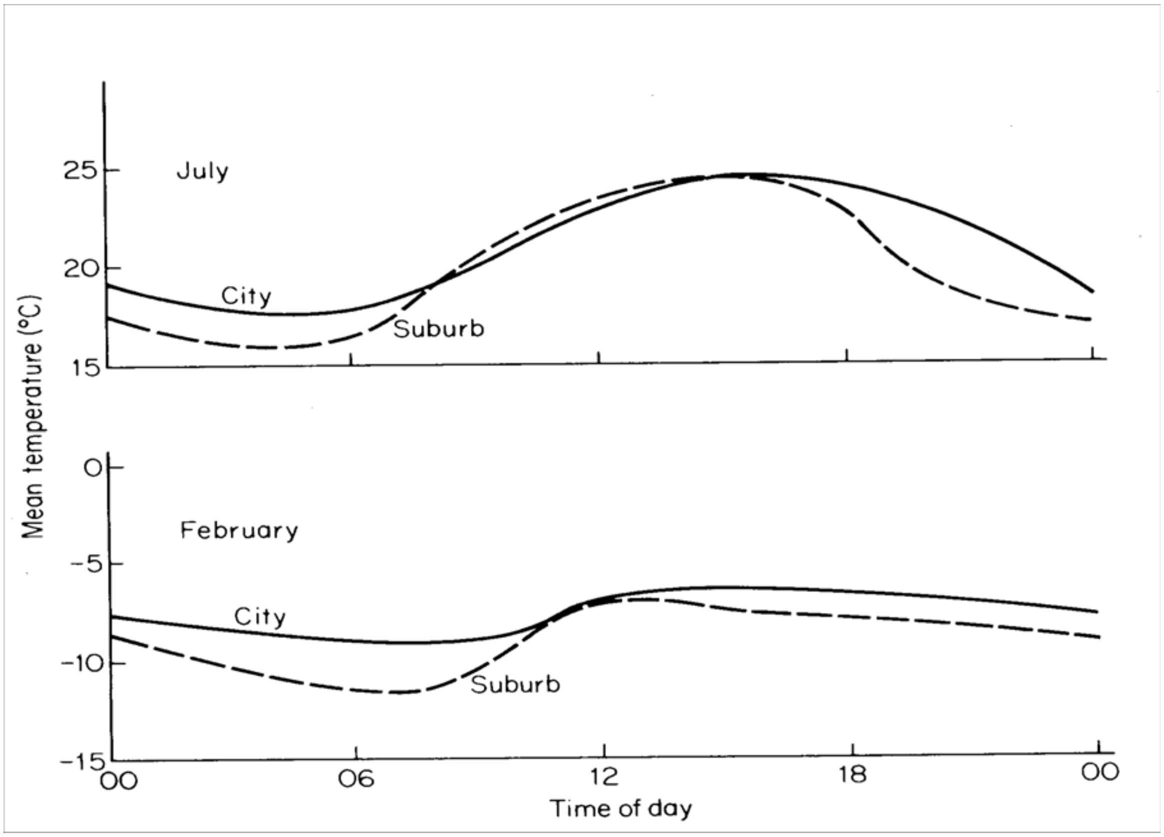
- During the day in rural areas, the solar energy absorbed near the ground evaporates water from the vegetation and soil. Thus, while there is a net solar energy gain, this is compensated to some degree by evaporative cooling. In cities, where there is less vegetation, the buildings, streets and sidewalks absorb the majority of solar energy input.
- Because the city has less water, runoff is greater in the cities because the pavements are largely nonporous (except by the pot holes). Thus, evaporative cooling is less which contributes to the higher air temperatures.
- Waste heat from city buildings, cars and trains is another factor contributing to the warm cities. Heat generated by these objects eventually makes its way into the atmosphere. This heat contribution can be as much as one-third of that received from solar energy.
- The thermal properties of buildings add heat to the air by conduction. Tar, asphalt, brick and concrete are better conductors of heat than the vegetation of the rural area.
- The canyon structure that tall buildings create enhances the warming. During the day, solar energy is trapped by multiple reflections off the buildings while the infrared heat losses are reduced by absorption.
- The urban heat island effects can also be reduced by weather phenomona. The temperature difference between the city and surrounding areas is also a function of winds. Strong winds reduce the temperature contrast by mixing together the city and rural air.
- The urban heat island may also increase cloudiness and precipitation in the city, as a thermal circulation sets up between the city and surrounding region.



The urban heat island is clearly evident in numerous statistical studies of surface air temperatures over the years including Woolum, 1964 and in the depictions below from Critchfield 1983).

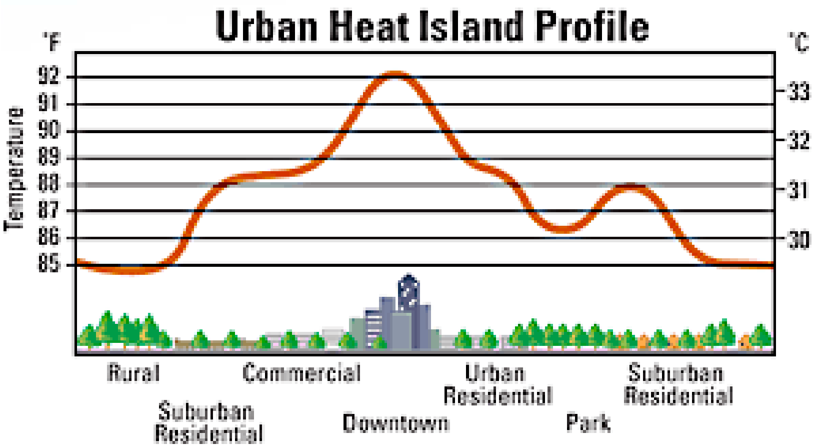


Mean annual surface temperatures for Paris and Surroundings (Crtitchfield 1983)

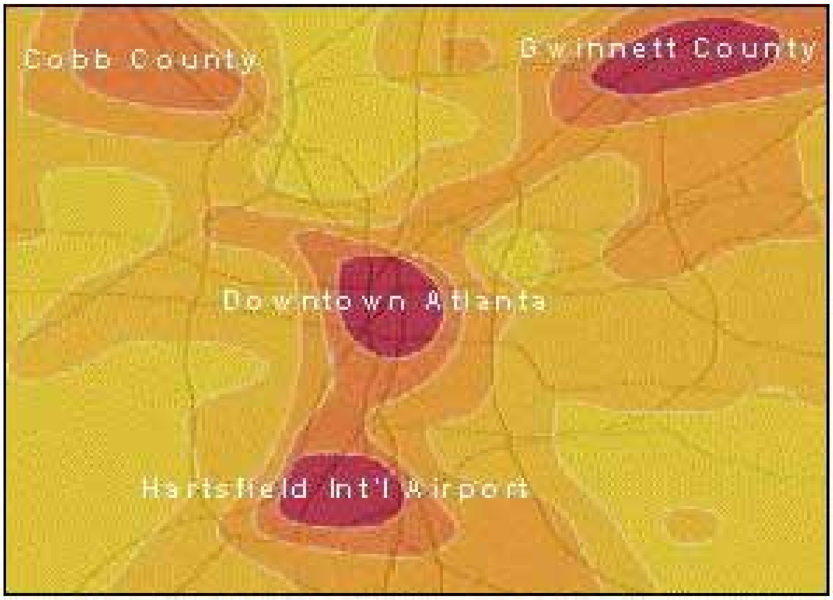


Diurnal temperature variations for Urban Vienna and suburban Hohe Warte for July and February (Critchfield 1983)

The variance across a city and surroundings is shown in the following courtesy of the EPA.

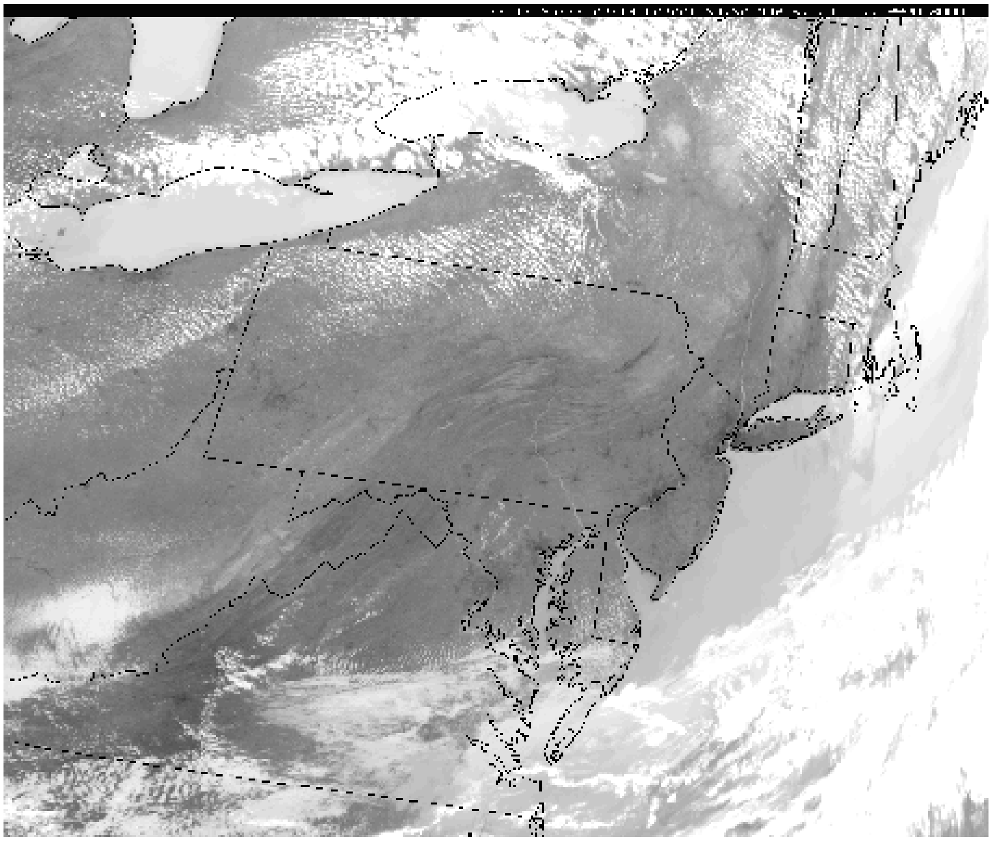


Remote sensing from satellite radiometers show this urban warming effect. The satellite image of Atlanta, GA is an example of a surface-based measurement, which records radiant emissions, or energy reflected and emitted from the land, including roofs, pavements, vegetation, bare ground, and water. ‘’



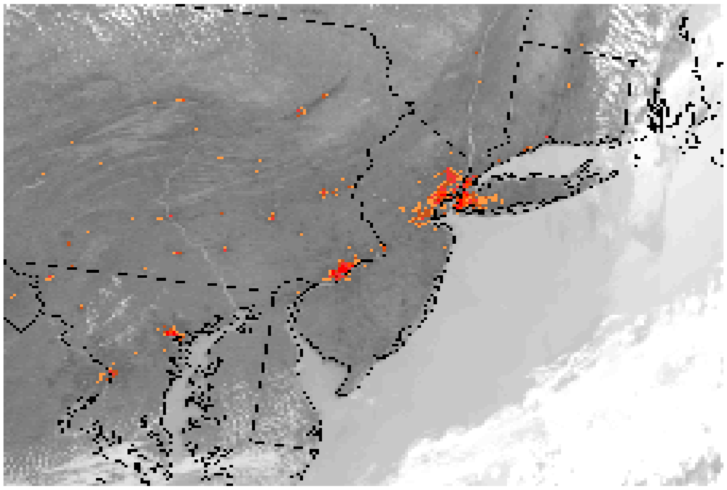
Satellite (Lands at TM) image of multi-nodal heat island in Atlanta, GA. Darker

It is also apparent on cloud-free satellite images, as the 11 micron image below produced with the Advanced Very High Resolution Radiometer (AVHRR) shows.



The image has a spatial resolution of approximately 1 km. At this wavelength, the AVHRR measures the amount of radiant energy emitted by the surface and the tops of clouds, which is proportional to the temperature of the emitting body. The warmer the body, the greater the amount of radiant energy it emits. White portions of the image represent cold objects (e.g., cloud tops) and dark regions are warm areas.

A close up with warmer temperatures shown in red is below



Urbanization and Land Surface Changes

As the CCSP (2006) report notes "Over land, "near-surface" air temperatures are those commonly measured about 1.5 to 2.0 meters above the ground level at official weather stations". One of the most significant features in the observed surface data set is the asymmetric warming between maximum and minimum temperatures. Minimum temperatures have risen about 50% faster than maximum temperatures in the observed surface data set since 1950 (*Vose et al.,* 2005).

In Pielke et.al. (2007), it is shown the minimum temperature is very sensitive to the height of the actual measurement, and to wind speed. In addition, the nighttime boundary readings are especially sensitive to changes in land-surface characteristics, such as heat capacity (*Carlson*, 1986, *McNider et al.,* 2005) and to external forcing such as downward longwave radiation from greenhouse gas forcing, water vapor, clouds or aerosols, moreso than the daytime boundary layer (*Eastman et al*., 2001, *Pielke and Matsui*, 2005). Given the lack of observational robustness of minimum temperatures, the fact that the shallow nocturnal boundary layer does not reflect the heat content of the deeper atmosphere, and problems global models have in replicating nocturnal boundary layers, Pielke suggests that measures of large-scale climate change should only use maximum temperature trends.

There is no real dispute that weather data from cities, as collected by meteorological stations, is contaminated by urban heat island (UHI) bias, and that this has to be removed to identify climatic trends (e.g. Peterson 2003). The dispute centers on whether corrections applied by the researchers on whom the IPCC relies for generating its climatic data are adequate for removing the contamination. The aim is to convert weather data into climate data, i.e. to show what the temperature trends would have been in a region had no cities or farms ever appeared, and had the weather station network been constant and comprehensive across the entire sampling period. The resulting data products are called ‘gridded data’ and are disseminated by the IPCC through its own web site.

Peterson (2003) considers a town with a population of less than 10,000 people to be rural and not to require any adjustment for urbanization. Oke (1973), and Torok et al (2001) show that even towns with populations of 1000 people have urban heating of about 2.2 C compared to the nearby rural countryside. Oke (1973) finds evidence that the UHI (in ^{o}C) increases according to the formula

$$UHI = 0.73 \log_{10}(pop)$$

where *pop* denotes population. This means that a village with a population of 10 has a warm bias of 0.73 ^{o}C, a village with 100 has a warm bias of 1.46 ^{o}C, a town with a population of 1000 people has a warm bias of 2.2 ^{o}C, and a large city with a million people has a warm bias of 4.4 ^{o}C (Oke, 1973).

The IPCC refers to Jones et al. (1990) for its claim that the non-climatic bias due to urbanization is less than one-tenth of the global trend. Aside from being a very old reference, this paper does not settle the issue because of numerous inherent limitations. For one thing it is not a global analysis. It ran comparisons of urban and rural (or rural-urban) composites only for three regions: Eastern Australia, Eastern China and Western USSR. It used inconsistent definitions for urban areas (i.e. allowing communities up to 100,000 people to be classified as ‘rural’ in China), yet they still found warming biases in urban records in almost all locations. They found strong urban warming in China relative to the rural and pooled series, and in the USSR they found stronger relative cooling post-1930 in the rural stations. Eastern Australia yielded no differences. (The China findings in particular contradict those of Li et al (2004) as cited by the IPCC in AR4 Section 3.2.2.2). They also cited earlier results finding strong relative urban warming in the contiguous USA. Their concluding claim that urbanization represents “at most” one-tenth of the global trend is not derived or proved in the paper, it simply appears in the conclusion as an unsupported conjecture. Yet this conjecture has been repeated in several IPCC reports since then, including the new Fourth Assessment Report, as if it were a proven result. Consequently the IPCC’s appeal to Jones et al. (1990) to support the claim that the global data are free of substantial bias is unpersuasive.

The IPCC also relies on Parker (2004) to argue that Urban Heat Island (UHI) effects are not global. Parker’s study compared temperature trends between urban samples taken on calm nights versus windy nights. He found the trends were visually similar and concluded that UHI effects were unlikely to influence the global average. However, the maintained hypothesis is that elevated windspeed reliably reduces UHI effects. This idea has been disputed (see discussion in McKendry 2003), so the similarity in trends may simply indicate that the non-climatic effects exert a similar influence under both conditions (on this see also Pielke Sr. and Matsui 2006).

While the IPCC was alert for the (notably few) studies that support their optimism concerning the lack of non-climatic biases in global surface temperature averages, they ignored some recent studies that showed the opposite. de Laat and Maurellis (2004, 2006) used local carbon dioxide emission estimates as a proxy for local industrial activity, and thereby as an index of possible local non-climatic warming influences on atmospheric temperature trends. This interpretation, along with the assumption that local industrial activity creates a warming bias in the surface temperature network, leads to the prediction that there will be a spatial pattern of enhanced warming trends correlated with local industrial density. The authors found this correlation is indeed present in global temperature data collected both at the surface and the lower atmosphere. They also pointed out that climate models do not predict this spatial pattern of warming in response to greenhouse gas increases. On this basis they argue that surface temperature data reflect non-climatic trends that are attributable to pervasive local patterns of land-use change and industrial activity rather than the influence of greenhouse gas emissions on the general climate system.

McKitrick and Michaels (2004) gathered weather station records from 93 countries and regressed the spatial pattern of trends on a matrix of local climatic variables and socioeconomic indicators such as income, education, and energy use. As expected, some of the non-climatic variables yielded significant coefficients, indicating a significant contamination by non-climatic effects, including indicators of data quality. They then repeated the analysis on the IPCC gridded data covering the same locations. They found approximately the same coefficients emerged, albeit diminished in size, with many individual indicators remaining significant. On this basis they were able to rule out the hypothesis that there are no significant non-climatic biases in the data. Both de Laat and Maurellis and McKitrick and Michaels concluded that the non-climatic effects add up to a substantial warming bias at the global level in the measured data trends.

Ren et al (2007) in the abstract of their GRL paper noted that “Annual and seasonal urbanization-induced warming for the two periods at Beijing and Wuhan stations is also generally significant, with the annual urban warming accounting for about 65−80% of the overall warming in 1961−2000 and about 40−61% of the overall warming in 1981−2000. This result along with the previous researches indicates a need to pay more attention to the urbanization-induced bias probably existing in the current surface air temperature records of the national basic stations.“

Numerous recent studies show the effects of urban anthropogenic warming on local and regional temperatures in many diverse, even remote, locations. Block et al., (2004) showed effects across central Europe, Zhou et al. (2004) and He et al. (2005) across China, Velazquez-Lozada et al. (2006) across San Juan, Puerto Rico and Hinkel et el., (2003) even in the village of Barrow, Alaska. In all cases, the warming was greatest at night and in higher latitudes, mainly in winter.

Kalnay and Cai (2003) found regional differences in US data, but overall very little change (if anything a slight decrease) in daily maximum temperatures for two separate 20 year periods (1980-1999 and 1960-1979), and a slight increase in night-time readings. They found these changes consistent with both urbanization and land use changes (irrigation and agriculture).

Runnalls and Oke (2006) concluded that "Gradual changes in the immediate environment over time, such as vegetation growth, or encroachment by built features such as paths, roads, runways, fences, parking lots, and buildings into the vicinity of the instrument site typically lead to trends in the cooling ratio series. Distinct régime transitions can be caused by seemingly minor instrument relocations (such as from one side of the airport to another, or even within the same instrument enclosure) or due to vegetation clearance. This contradicts the view that only substantial station moves, involving significant changes in elevation and/or exposure are detectable in temperature data."

As Pielke (2007) also notes "Changnon and Kunkel (2006) examined discontinuities in the weather records for Urbana, Illinois; a site with exceptional metadata and concurrent records when important changes occurred. They identified a cooling of 0.17ºC caused by a non-standard height shelter of 3 m from 1898 to 1948, a gradual warming of 0.9ºC as the University of Illinois campus grew around the site from 1900 to 1983, an immediate 0.8ºC cooling when the site moved 2.2 km to a more rural setting in 1984, and a 0.3ºC cooling in a shift to MMTS (Maximum-Minimum Temperature systems, which now represent over 60% of all USHCN stations) in 1988. The experience at the Urbana site reflects the kind of subtle changes described by *Runnalls and Oke* (2006) and underscores the challenge of making adjustments to a gradually changing site."

Christy et al. (2006) showed that temperature trends in California's Central Valley had significant nocturnal warming and daytime cooling over the period of record. The conclusion is that as a result of increases in irrigated land, daytime temperatures are suppressed due to evaporative cooling and nighttime temperatures are warmed in part due to increased heat capacity from water in soils and vegetation. Mahmood *et al.* (2006b) also found similar results for irrigated and non-irrigated areas of the Northern Great Plains.

IPCC AND NCDC VIEW OF URBANIZATION

Peterson and others support the IPCC viewpoint at towns with less than 10,000 populations are towns without the need for adjustment for urbanization. Oke (1973 and Torok et al (2001) show that even towns with populations of 1000 people have urban heating of about 2.2 C compared to the nearby rural countryside. Since the UHI increases as the logarithm of the population or as about 0.73 log (pop), a village with a population of 10 has an urban warming of 0.73 C, a village with 100 has a warming of 1.46 C, a town with a population of 1000 people already has an urban warming of 2.2 C, and a large city with a million people has a warming of 4.4 C (Oke, 1973).

As Doug Hoyt has noted, in 1900, world population is 1 billion and in 2000, it is 6 billion for an increase of a factor of six. If the surface measuring stations are randomly distributed and respond to this population increase, it would equal 2.2 log (6) or 1.7 C, a number already greater than the observed warming of 0.6 C. If however we note that UHIs occur only on land or 29% of the Earth's surface, than the net global warming would be 0.29*1.7 or 0.49 C which is close the observed warming. It is not out of the realm of possibility that most of the twentieth century warming was urban heat islands.

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EXPERTS/LINKS:

Roger Pielke Sr';s Climate Science web log
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