THE CONUNRUM OF IMPACTS OF CLIMATE CHANGE ON URBANIZATION AND THE URBAN HEAT ISLAND EFFECT

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The twenty-first century is the first "urban century" according to the United Nations Development Program. The focus on cities reflects awareness of the growing percentage of the world's population that lives in urban areas. In 2000, approximately 3 billion people representing about 40% of the global population resided in urban areas. The United Nations estimates that by 2025, 60% of the world's population will live in urban areas. As a consequence, the number of "megacities" (those cities with populations of 10 million inhabitants or more) will increase by 100 by 2025. Thus, there is a critical need to understand the spatial growth of urban areas and what the impacts are on the environment. Moreover, there is a critical need to assess how under global climate change, cities will affect the local, regional, and even global climate. As urban areas increase in size, it is anticipated there will be a concomitant growth of the Urban Heat Island effect (UHI), and the attributes that are related to its spatial and temporal dynamics. Therefore, how climate change, including the dynamics of the UHI, will affect the urban environment, must be explored to help mitigate potential impacts on the environment (e.g., air quality, heat stress, vector-borne disease) and on human health and well being, to develop adaptation schemes to cope with these impacts.

2011 International Symposium for Remote Sensing of the Environment
Sydney, Australia
April 10 - 15, 2011

The Conundrum of Impacts of Climate Change on Urbanization and the Urban Heat Island Effect

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Impacts of Climate Change on Urbanization

THE CONUNDRUM:

- The 21st century is the first "urban century"
- In 2000, approximately 3 billion people (40% of global population) resided in urban areas
- The United Nations estimates that by 2025, 60% of the world's population will live in cities
- As a consequence, the number of "megacities" – those cities with populations of 10 million or more – will increase to 100 by 2025

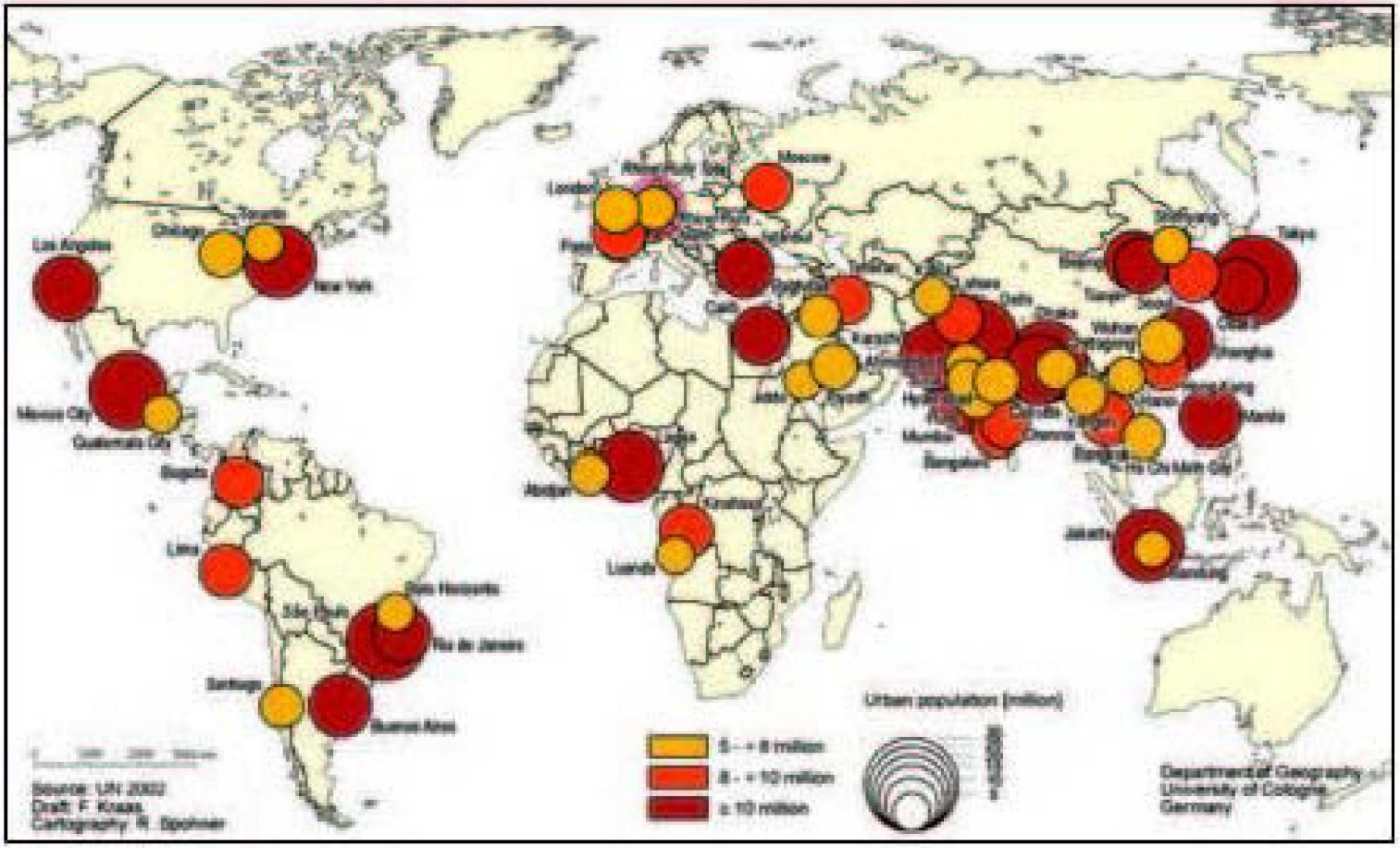
Impacts of Climate Change on Urbanization

Urbanization is one of the most profound examples of human modification of the Earth's surface

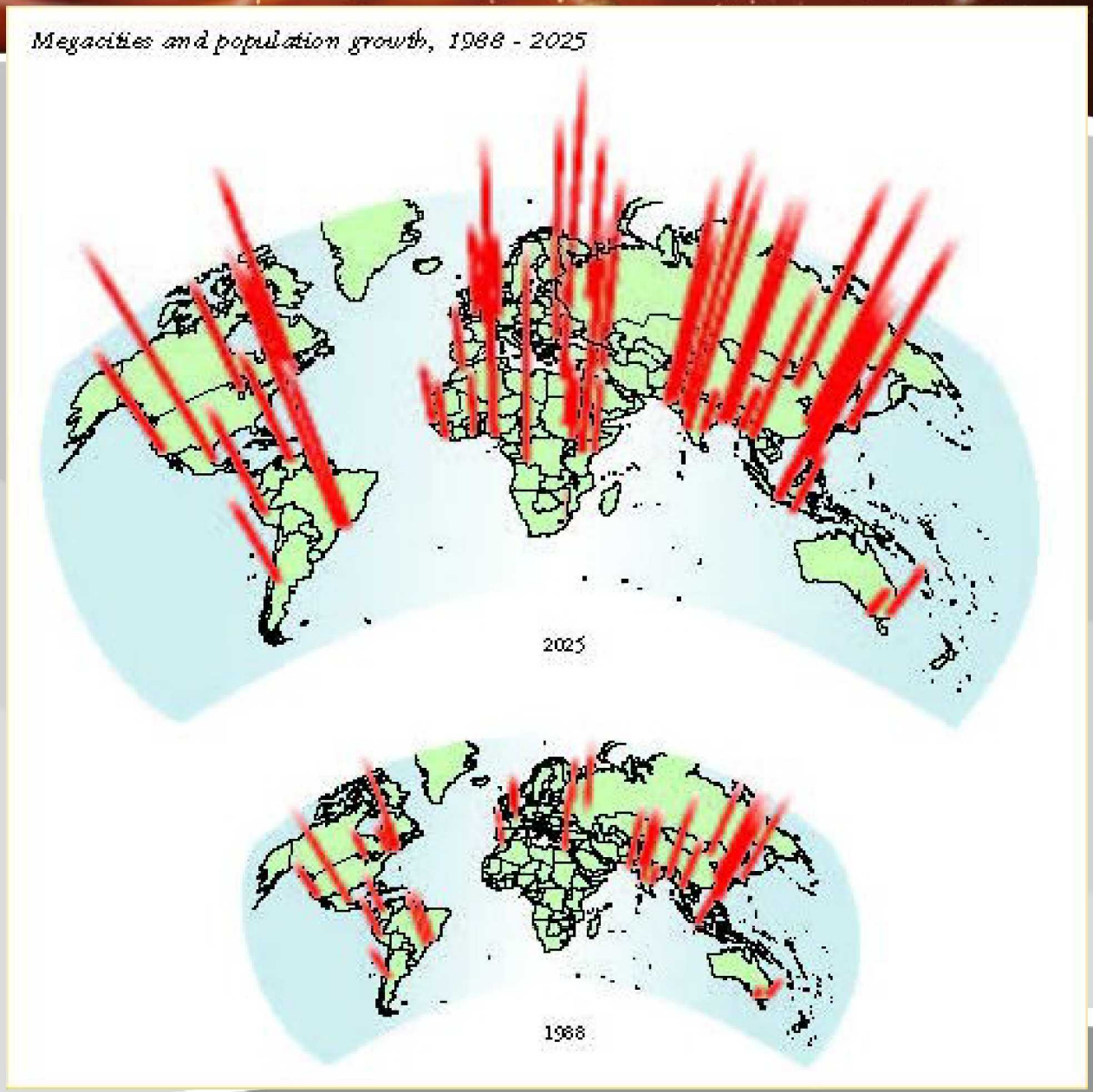
- Impacts on local energy, water and carbon exchanges
- These impacts affect climate, ecosystems, human health, and human systems in the short- and long-term
- The impacts of climate change may be of local, regional, or global scale depending on the size and geographic location of cities

Impacts of Climate Change on Urbanization

Map of Megacities worldwide in the year 2015.

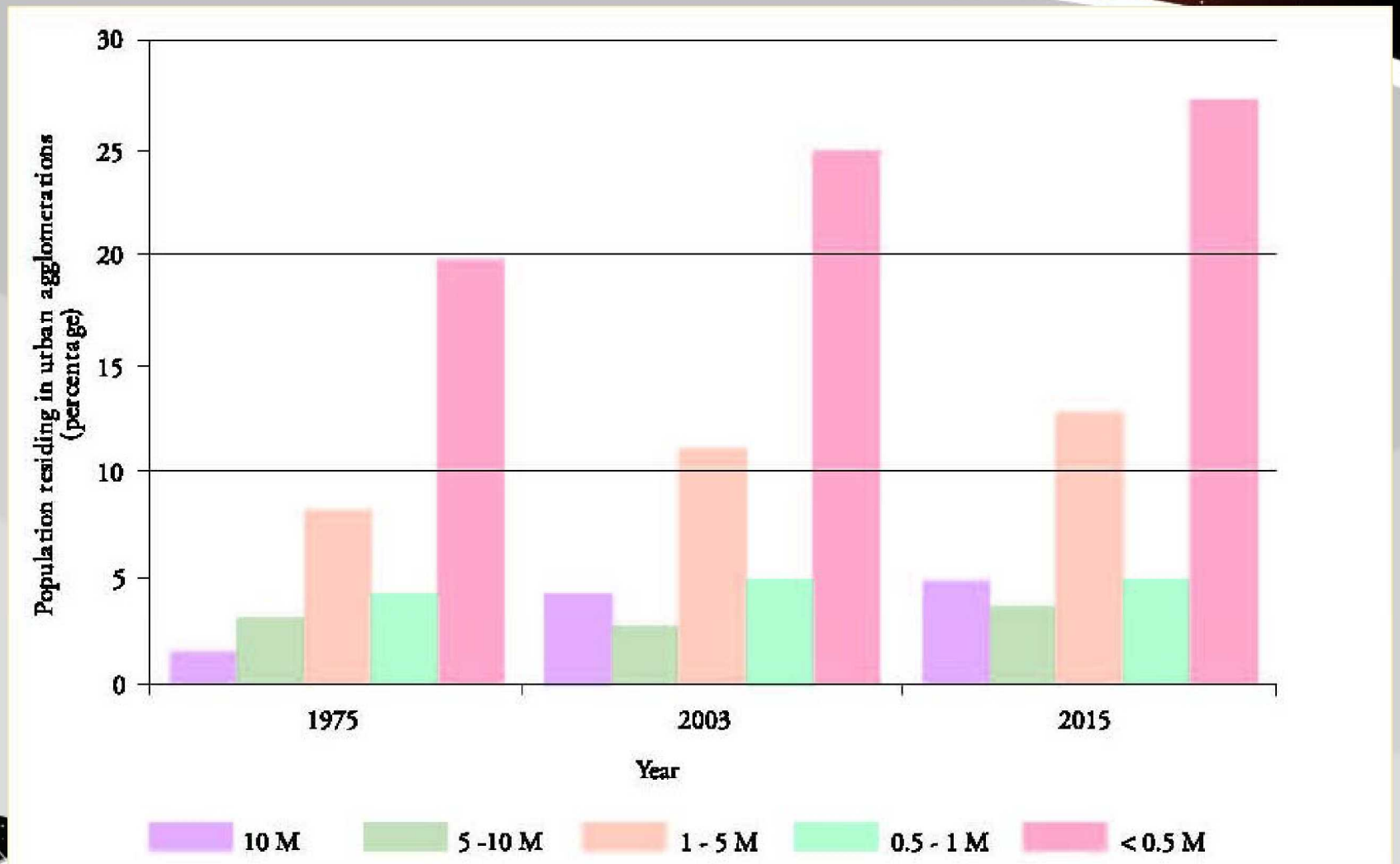


Impacts of Climate Change on Urbanization



Planet Earth, 2005.
Megacities – our global urban future.

Impacts of Climate Change on Urbanization



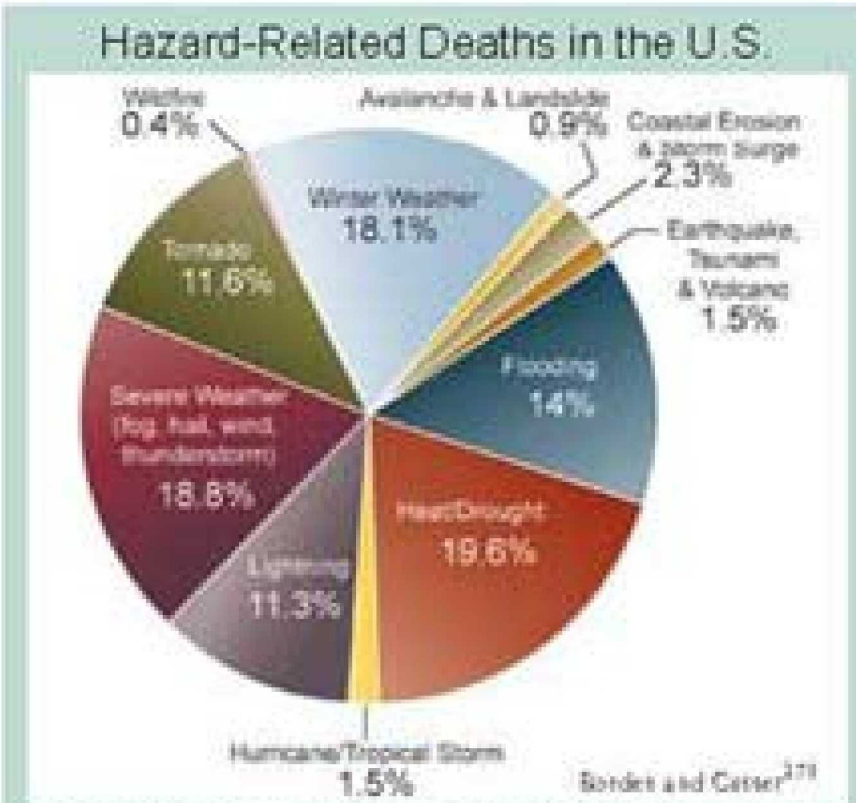
Planet Earth, 2005. *Megacities – our global urban future.*

Impacts of Climate Change on Urbanization

Key Question Regarding Urbanization and the Impacts of Climate Change on Urbanization

- *How does urbanization affect the local, regional, and global environment and how will climate change impact the overall effects that urban areas have on the environment?*
- *What changes can be observed and measured in albedos of urban surfaces and how do albedos change for different cities around the world as they impact urban heat island and dynamics as they impact the local, regional, and even global climate?*

Impacts of Climate Change on Urbanization

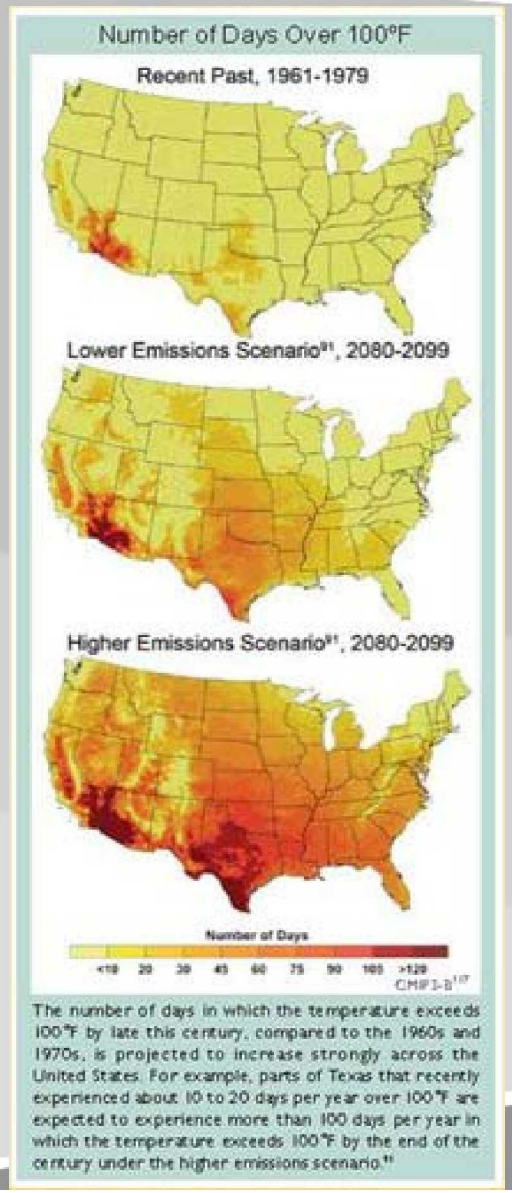


The pie chart shows the distribution of deaths for 11 hazard categories as a percent of the total 19,958 deaths due to these hazards from 1970 to 2004. Heat/drought ranks highest, followed by severe weather, which includes events with multiple causes such as lightning, wind, and rain.[313] This analysis ended prior to the 2005 hurricane season which resulted in approximately 2,000 deaths.[339]

USGCRP, 2009. *Global Climate Change Impacts in the United States*. www.globalchange.gov

Impacts of Climate Change on Urbanization

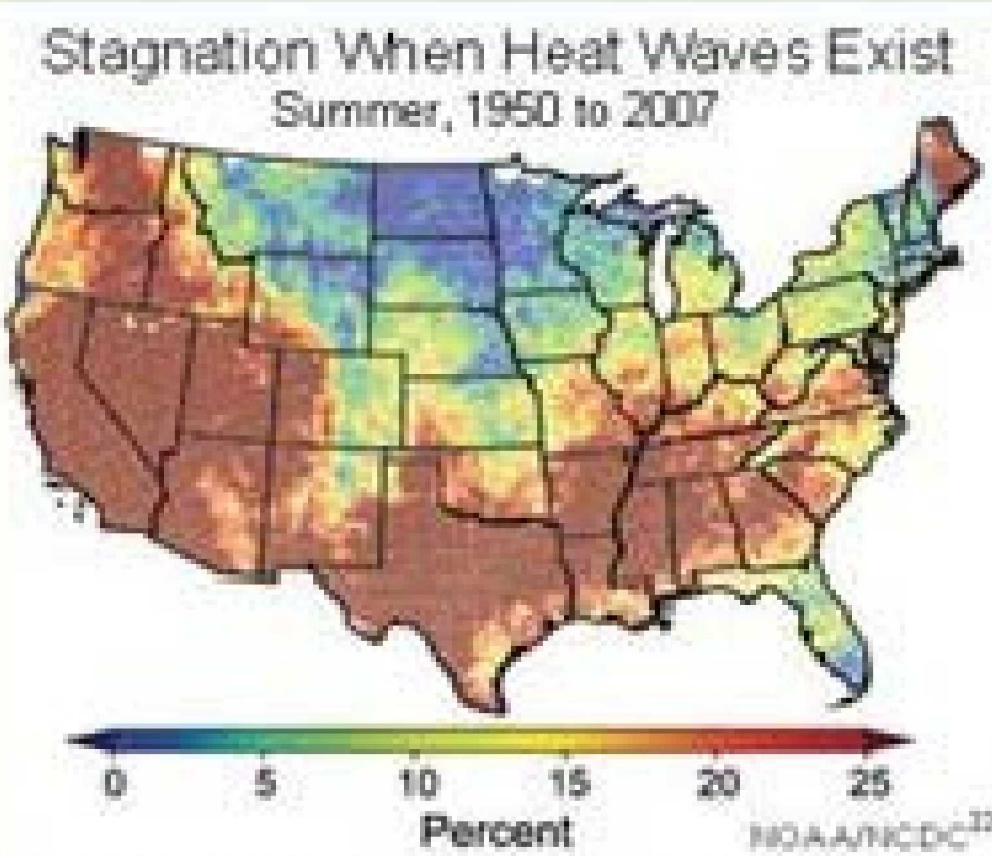
Heat is already the leading cause of weather-related deaths in the United States and a significant factor in deaths around the world



The number of days in which the temperature exceeds 100°F by late this century, compared to the 1960s and 1970s, is projected to increase strongly across the United States. For example, parts of Texas that recently experienced about 10 to 20 days per year over 100°F are expected to experience more than 100 days per year in which the temperature exceeds 100°F by the end of the century under the higher emissions scenario.[11]

USGCRP, 2009. *Global Climate Change Impacts in the United States*. www.globalchange.gov

Impacts of Climate Change on Urbanization



The map shows the frequency of occurrence of stagnant air conditions when heat wave conditions were also present. Since 1950, across the Southeast, southern Great Plains, and most of the West, the air was stagnant more than 25 percent of the time during heat waves.

USGCRP, 2009. *Global Climate Change Impacts in the United States.* www.globalchange.gov

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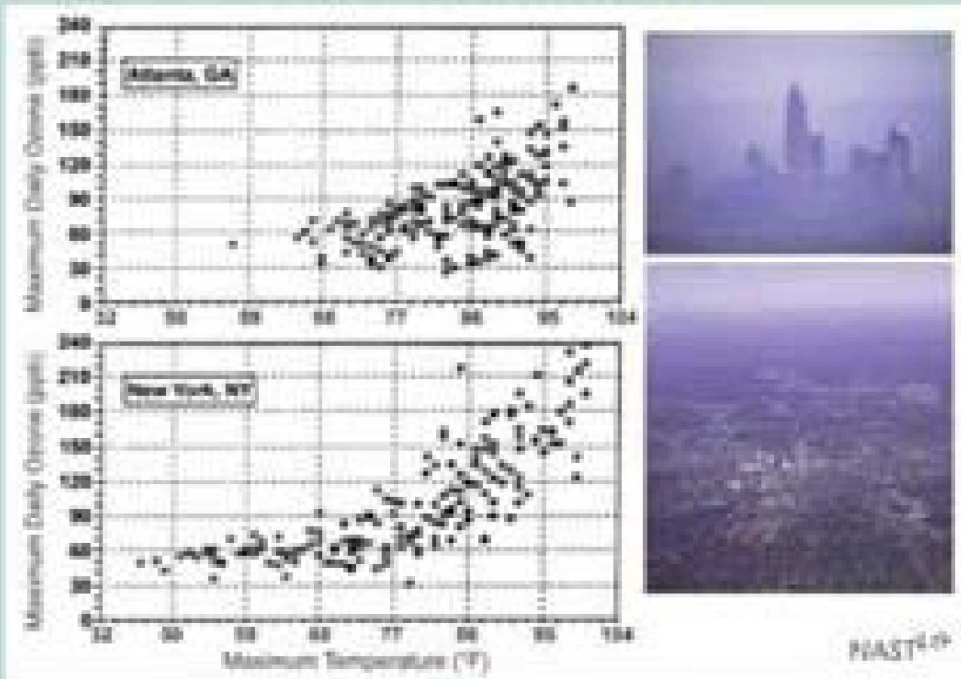
Temperature and Ozone



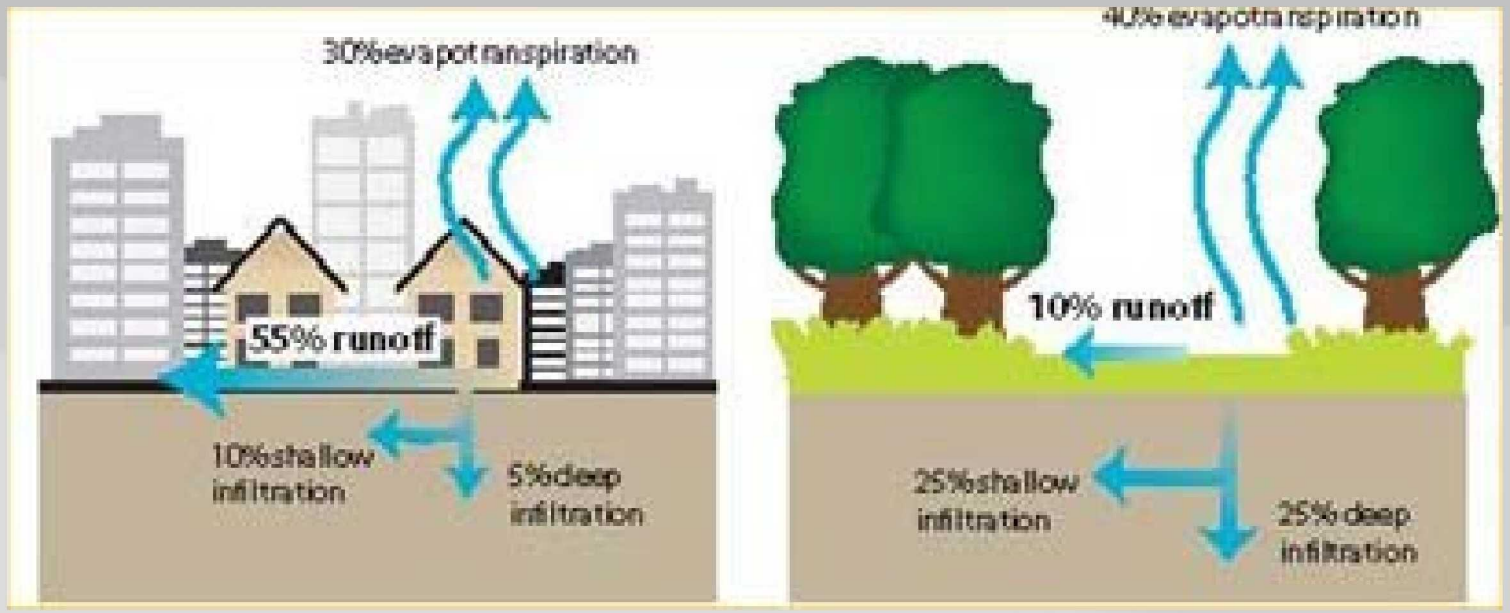
The graphs illustrate the observed association between ground-level ozone (a component of smog) concentration in parts per billion (ppb) and temperature in Atlanta and New York City (May to October 1988 to 1990).[2,3] The projected higher temperatures across the United States in this century are likely to increase the occurrence of high ozone concentrations, although this will also depend on emissions of ozone precursors and meteorological factors. Ground-level ozone can exacerbate respiratory diseases and cause short-term reductions in lung function.

USGCRP, 2009. *Global Climate Change Impacts in the United States.* www.globalchange.gov


Hong Kong 2008

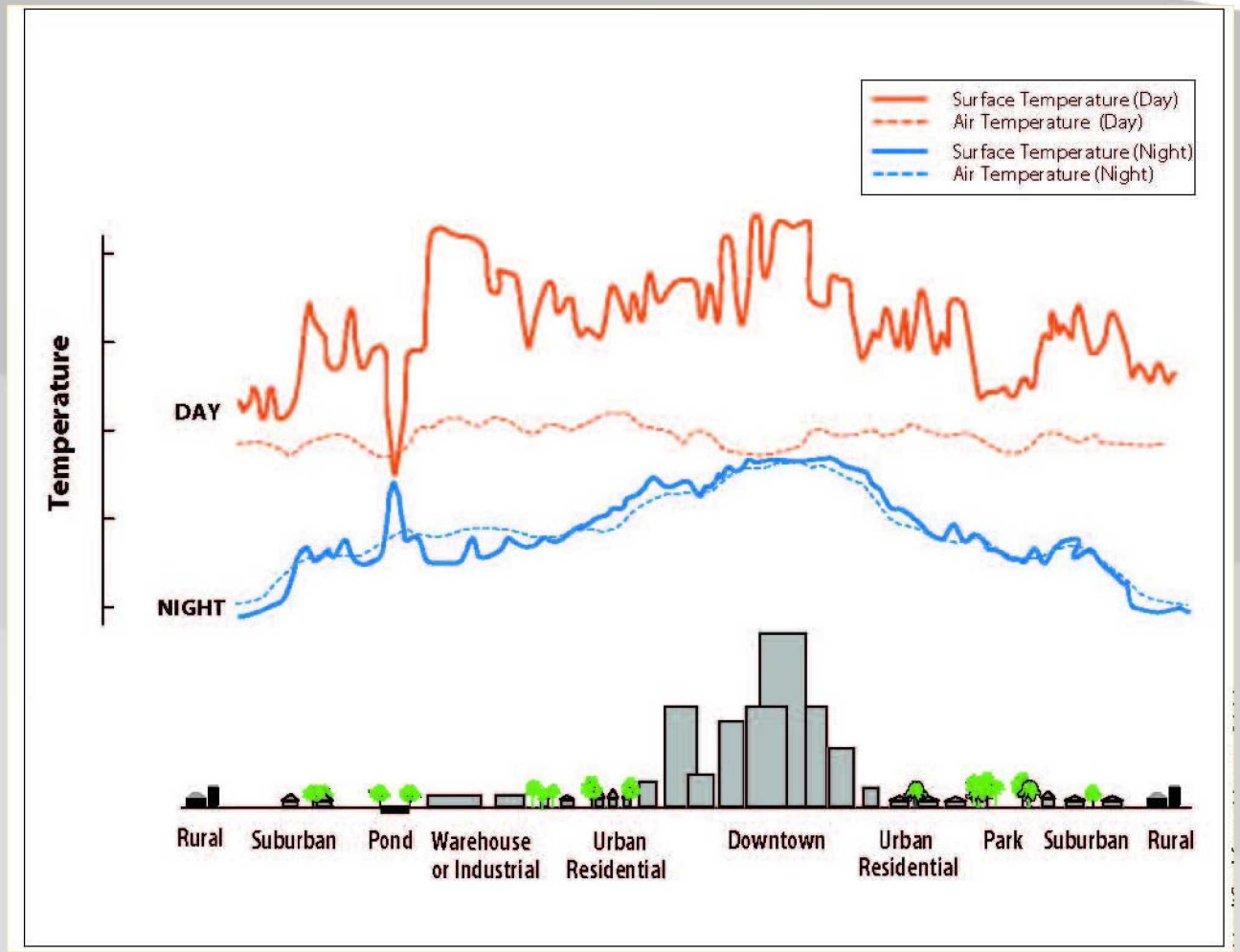
Impacts of Climate Change on Urbanization

Impacts of Climate Change on Urbanization



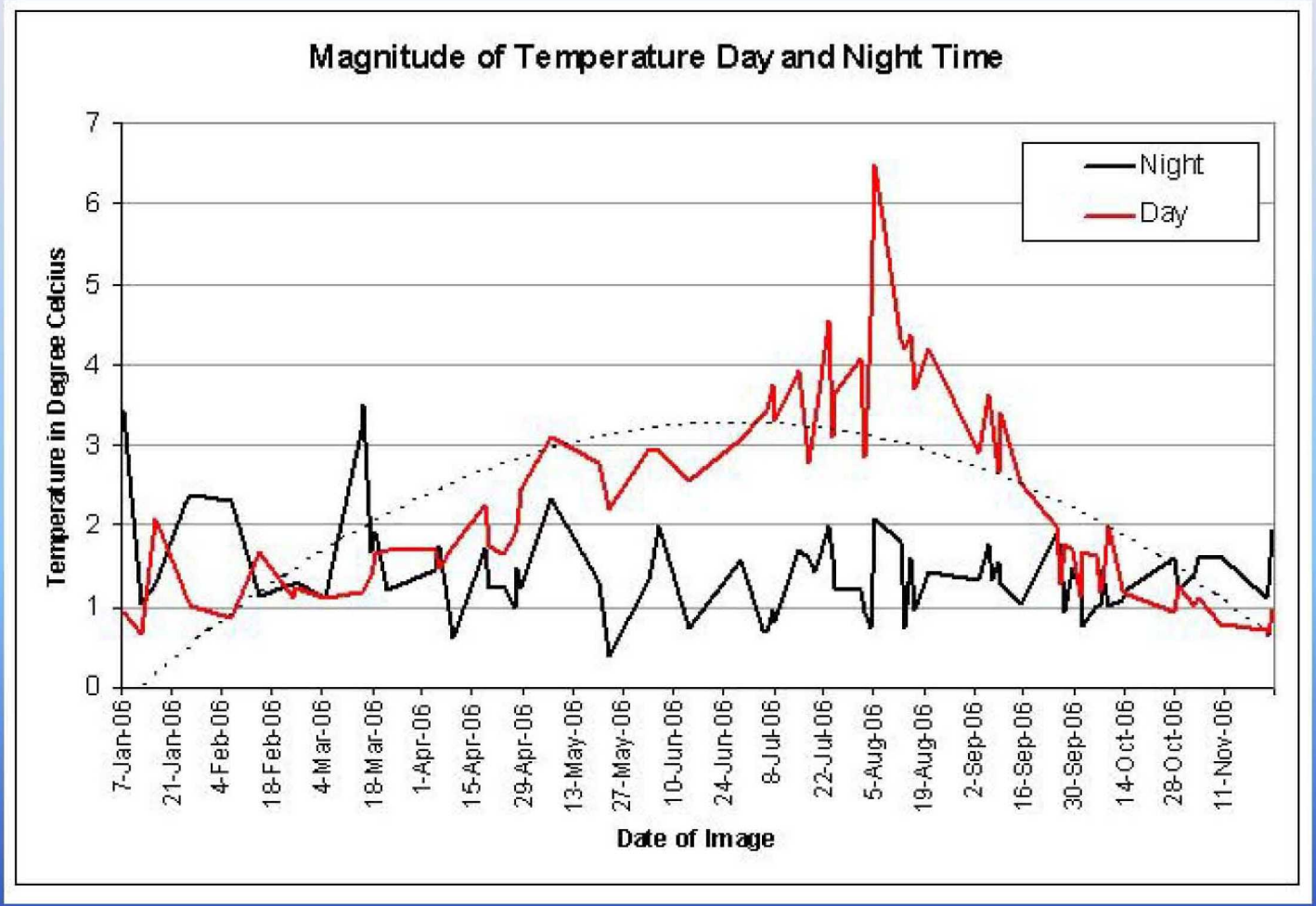
U.S. EPA. *Reducing Urban Heat Islands: Compendium of Strategies*. http://www.epa.gov/heatisland/resources/pdf/BasicsCompendium.pdf.

Impacts of Climate Change on Urbanization



http://www.epa.gov/heatisland/resources/pdf/BasicsCompendium.pdf

UHI Magnitude/Intensity in 2006



Day Mean: 2.28C (Std Dev: 1.22); Night Mean: 1.47C (Std Dev: 0.59)

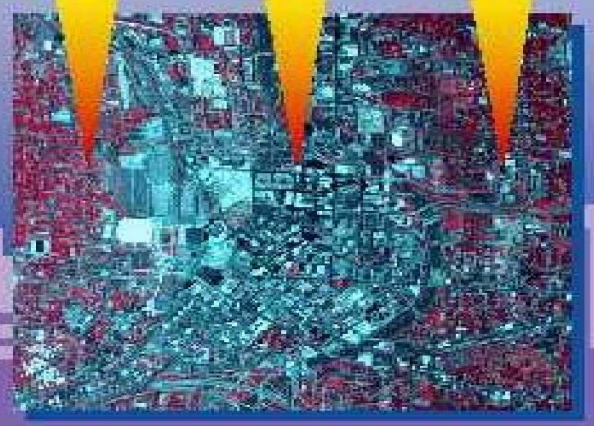
(Rajasekar and Weng, 2009, *ISPRS J.*)

Impacts of Climate Change on Urbanization

Mission to Planet Earth
National Aeronautics and Space Administration

Urban Remote Sensing and Air Quality Models

Volatile Organic Compounds
+ Nitrogen Oxides
+ Sunlight
→ Ozone



- Air pollution remains a National issue.
- Temperature increases the ozone levels.
- Urban heat island has major effect on temperature and height of mixing layer.
- Measurement program is defining land use patterns and relationship to heat production.
- Remote sensing data are being used to improve air quality modeling.

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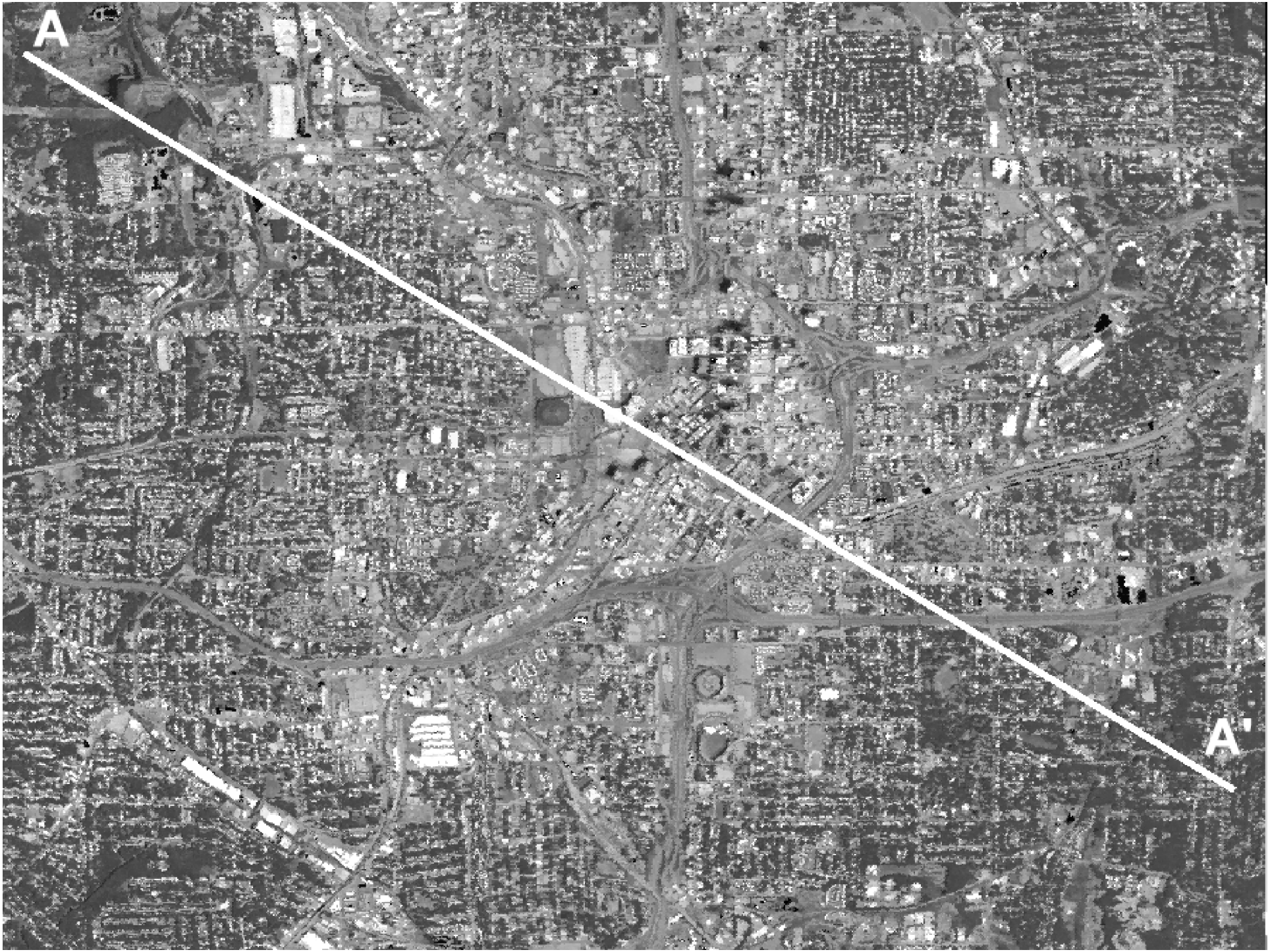
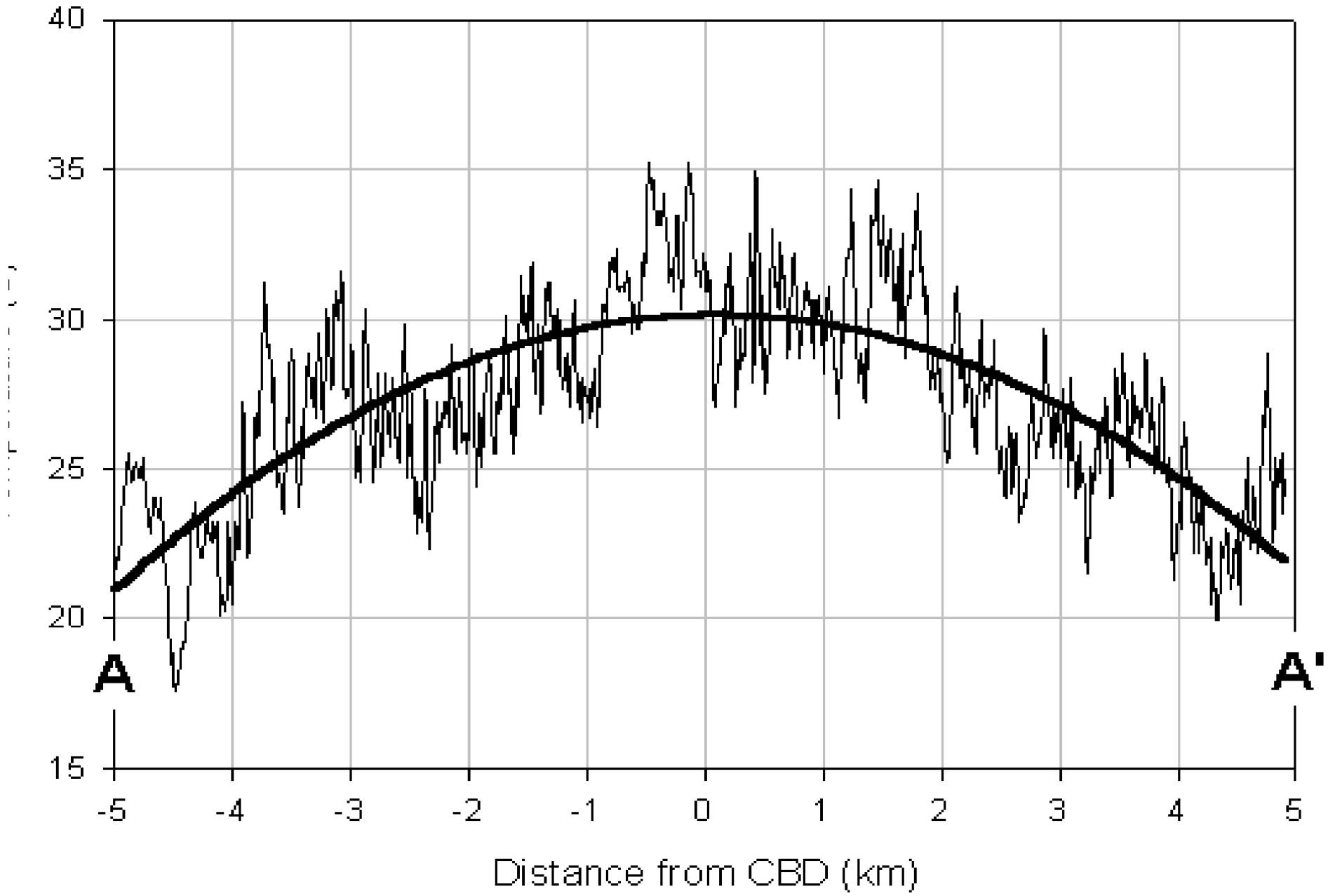
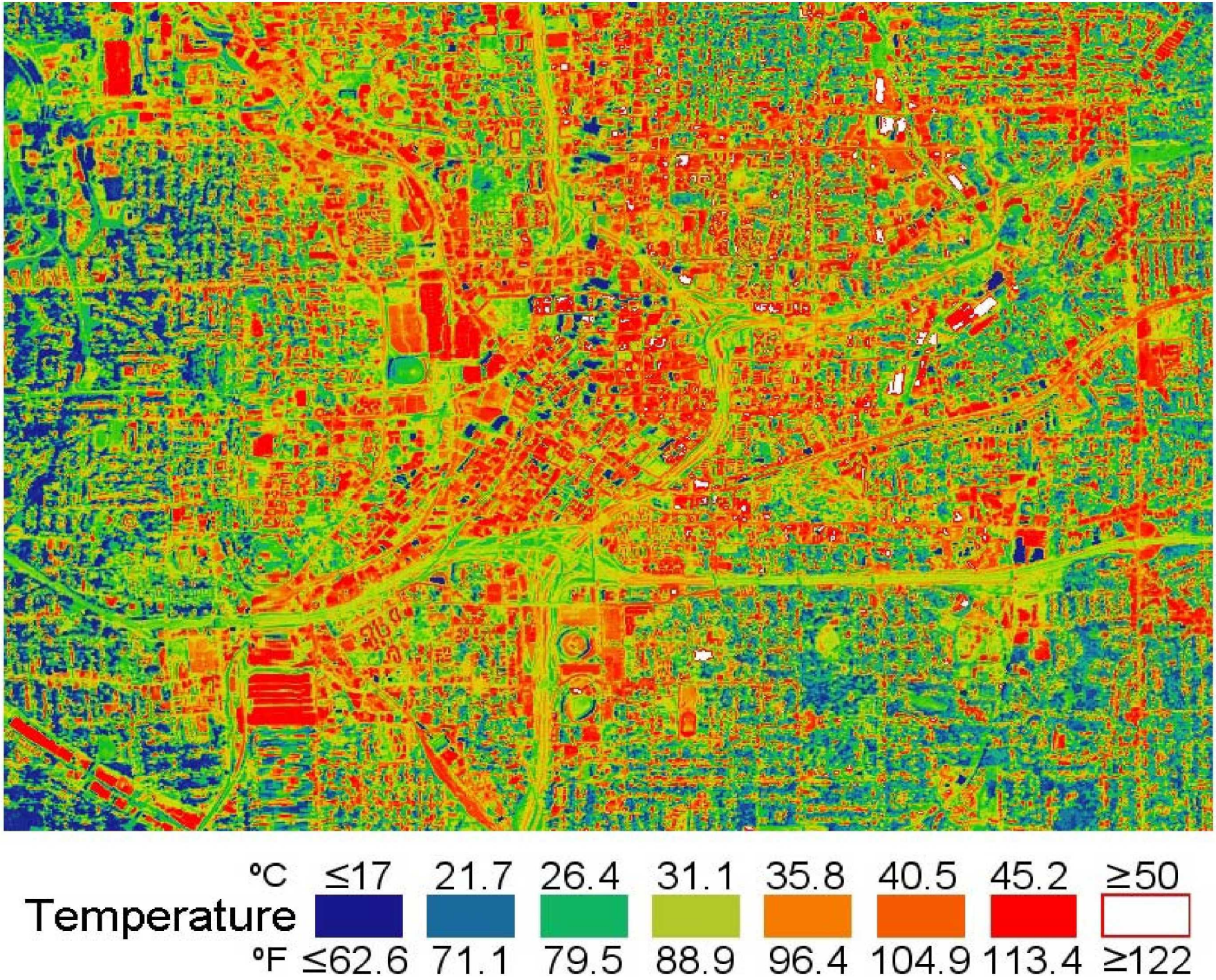
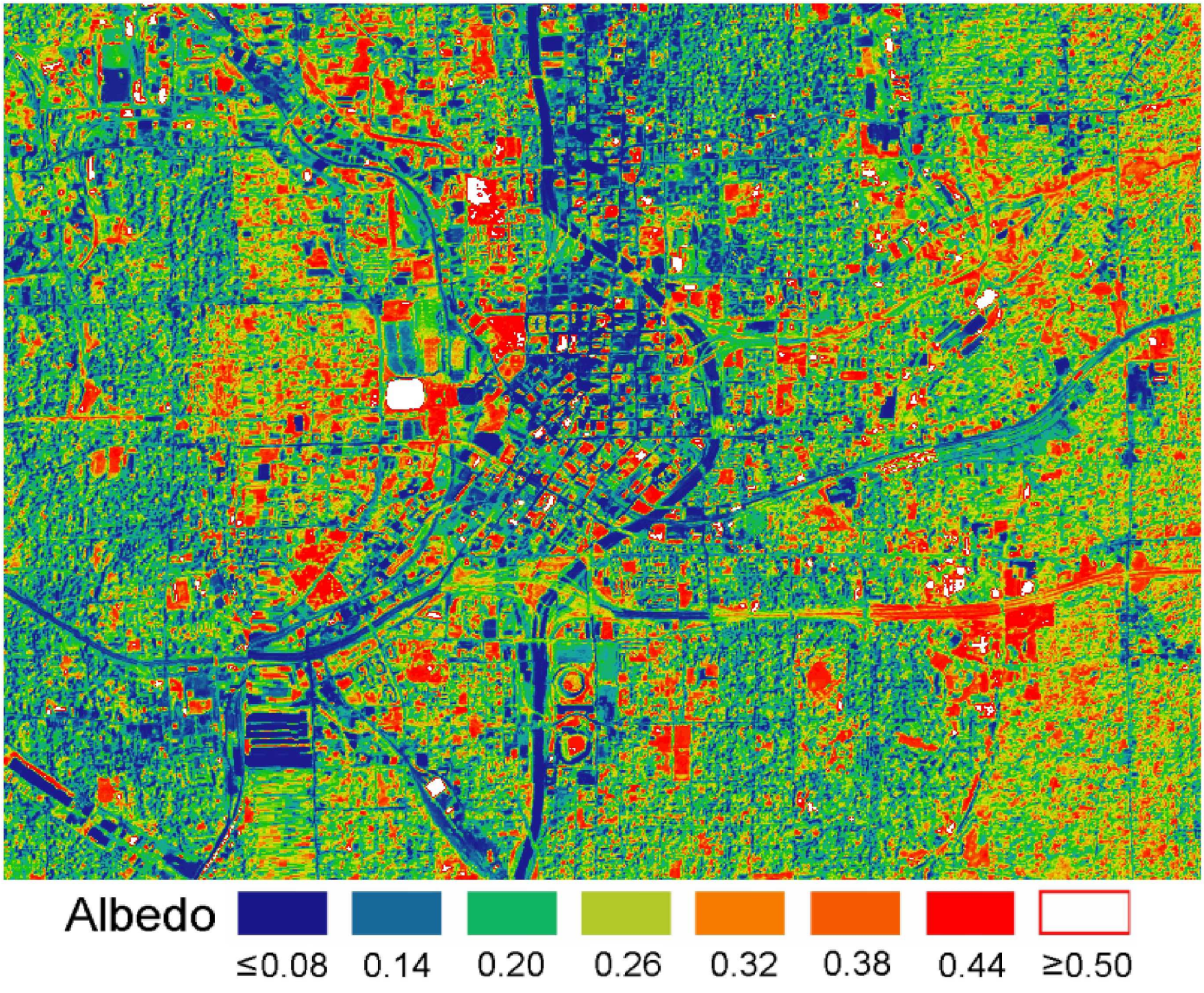
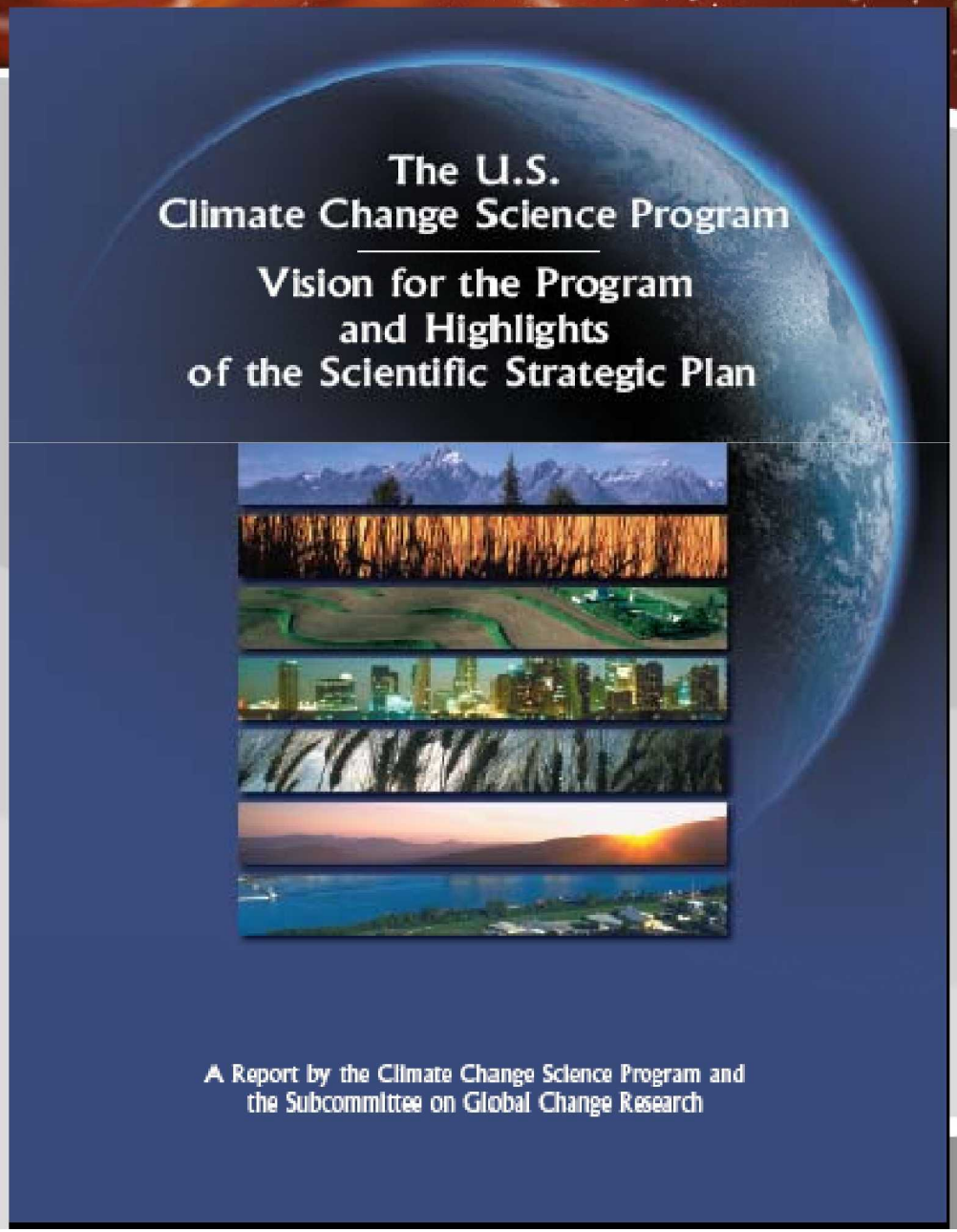

A
A'


40
35
30
25
20
15
A
A'
-5
-4
-3
-2
-1
0
1
2
3
4
5
Distance from CBD (km)


Temperature
°C ≤17 21.7 26.4 31.1 35.8 40.5 45.2 ≥50
°F ≤62.6 71.1 79.5 88.9 96.4 104.9 113.4 ≥122


Albedo
≤0.08
0.14
0.20
0.26
0.32
0.38
0.44
≥0.50

Impacts of Climate Change on Urbanization



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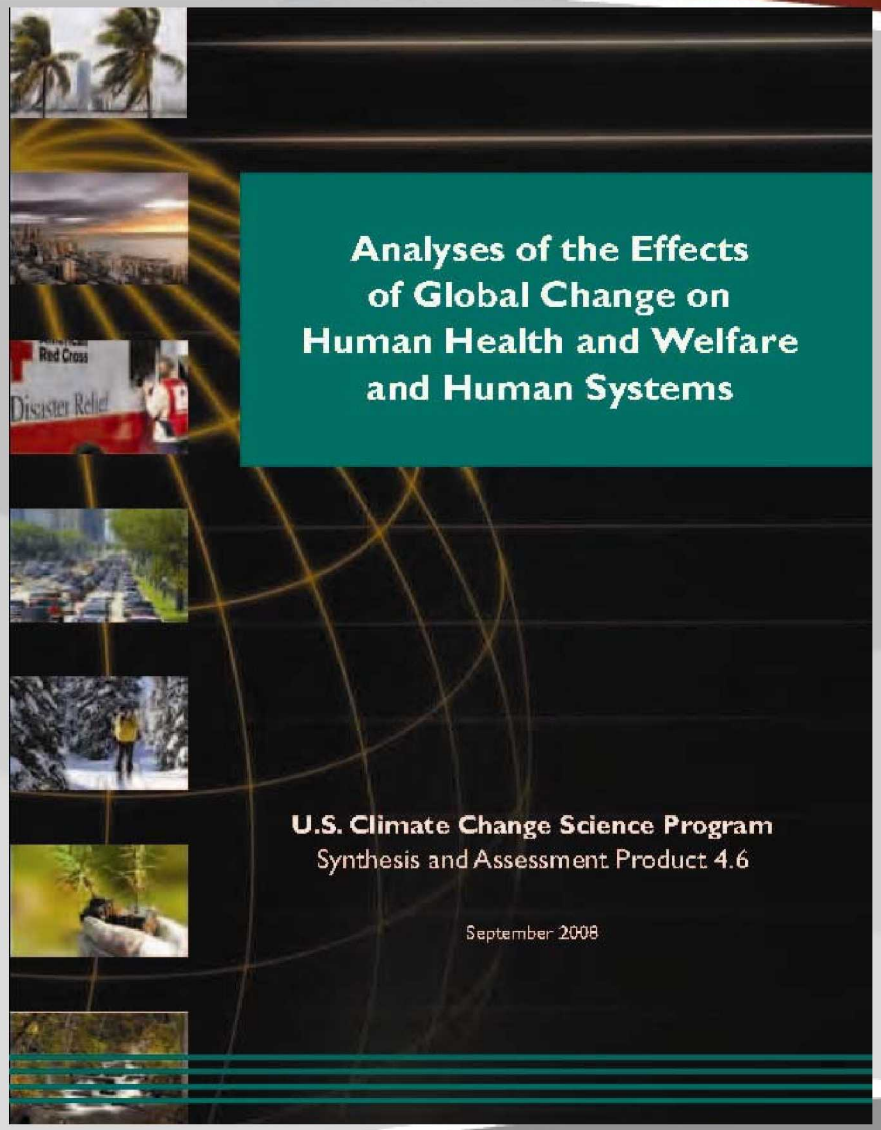


Impacts of Climate Change on Urbanization

CLIMATE CHANGE VULNERABILITIES AND IMPACTS IN HUMAN SETTLEMENTS

Determinants of Vulnerabilities/Impacts

In many cases, it has been it has been difficult to project Impacts of climate

Climate change forecasts are not specific enough for decision-making at the human settlement/urban level

- **Perhaps more profoundly, climate change is not the only change confronted by settlements**
- **More often, attention is paid to vulnerabilities to climate change**
- **At the current state of knowledge, vulnerabilities to possible impacts are easier**
- **to project than actual impacts**

Impacts of Climate Change on Urbanization

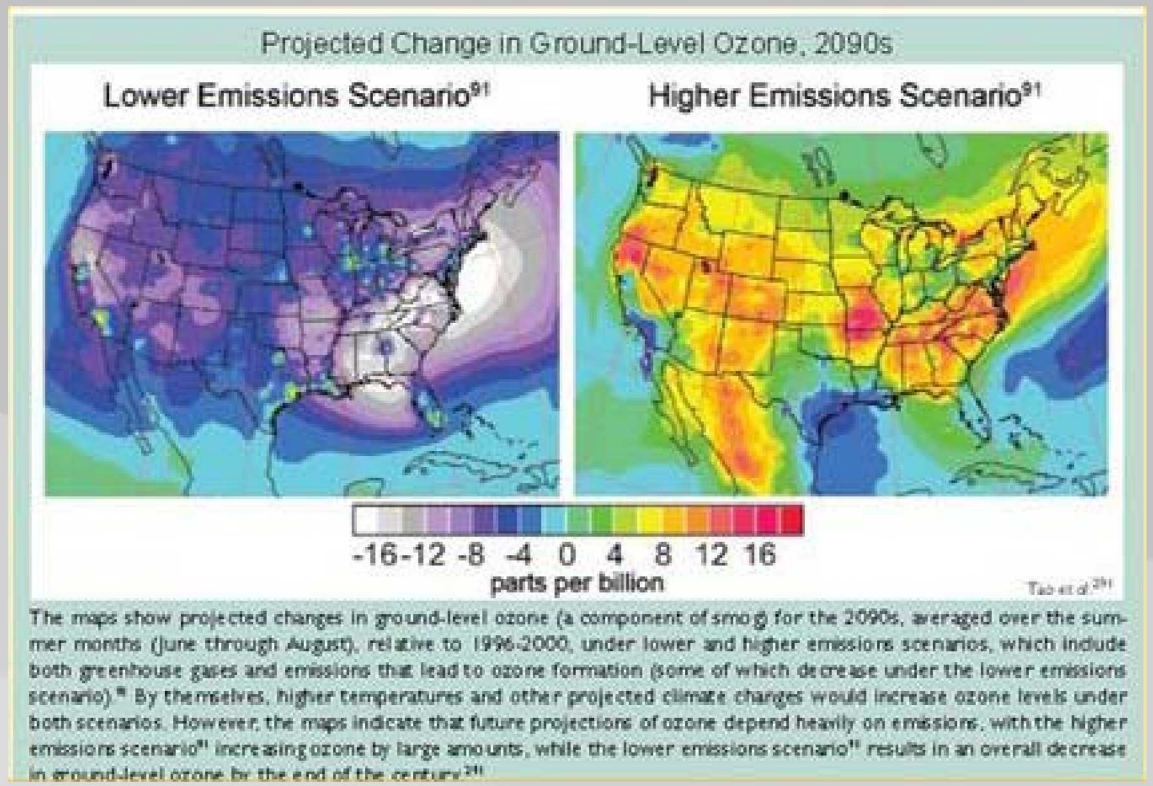
Effects on energy requirements:

- Warming is virtually certain to increase energy demand for cooling

Effects on urban metabolism:

- Climate change will impact a host of inputs, transformations, and outputs such as heat, energy, materials
- An example is the Urban Heat Island (UHI) effect is expected to greatly Increase over cities as a function of urban growth and increased solar radiation and warmer surface temperatures

Impacts of Climate Change on Urbanization



The maps show projected changes in ground-level ozone (a component of smog) for the 2090s, averaged over the summer months (June through August), relative to 1996-2000, under lower and higher emissions scenarios, which include both greenhouse gases and emissions that lead to ozone formation (some of which decrease under the lower emissions scenario).[91] By themselves, higher temperatures and other projected climate changes would increase ozone levels under both scenarios. However, the maps indicate that future projections of ozone depend heavily on emissions, with the higher emissions scenario[91] increasing ozone by large amounts, while the lower emissions scenario[91] results in an overall decrease in ground-level ozone by the end of the century.[91]

USGCRP, 2009. *Global Climate Change Impacts in the United States.* www.globalchange.gov

Impacts of Climate Change on Urbanization

Mitigation Measures

- Green roofs

Mitigation Measures

- Less impervious land cover

Impacts of Climate Change on Urbanization

Mitigation Measures

- Shade trees

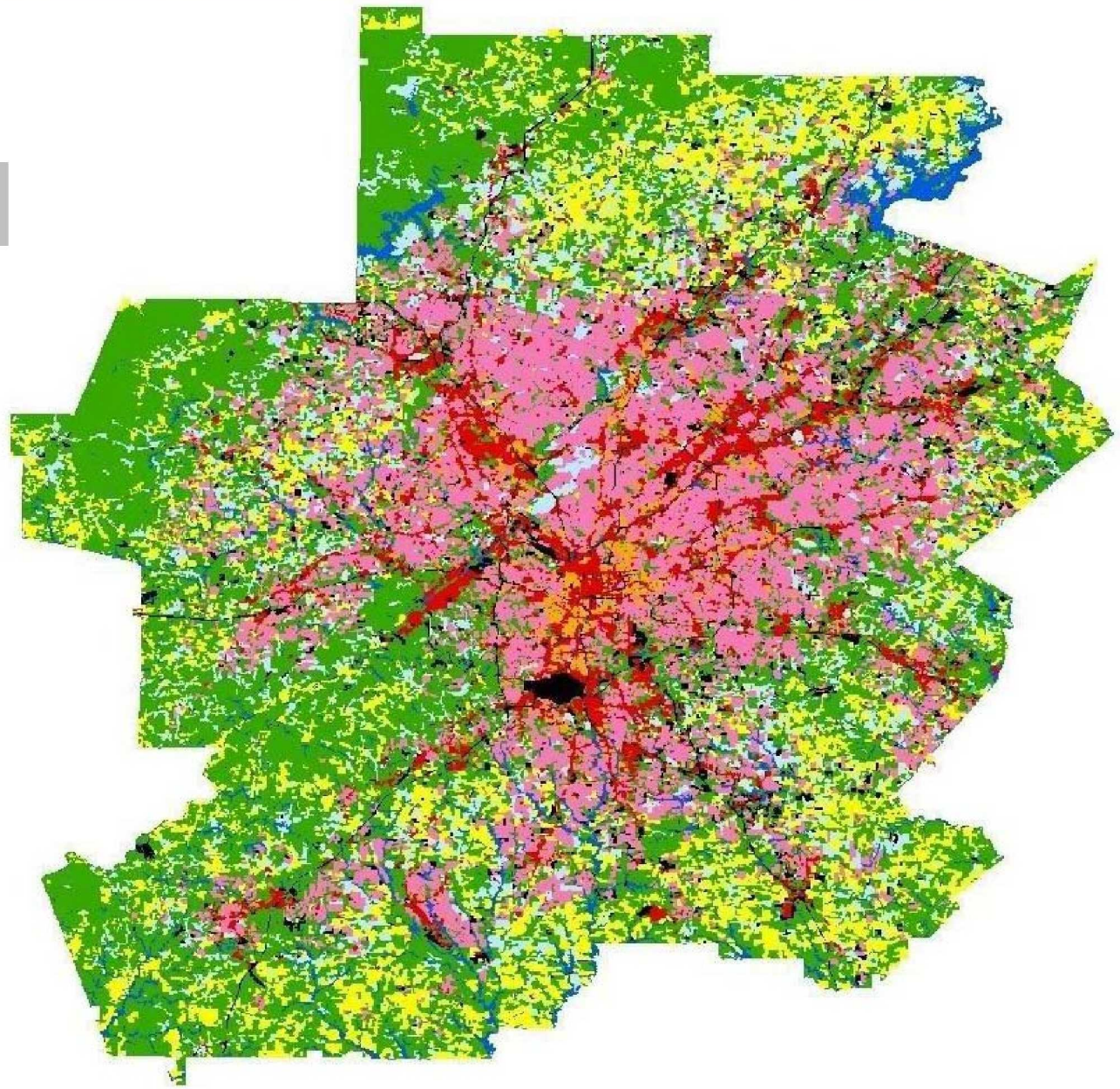
Impacts of Climate Change on Urbanization

Mitigation Strategies

Impacts of Climate Change on Urbanization

Spatial Variability

Land Use in 1999

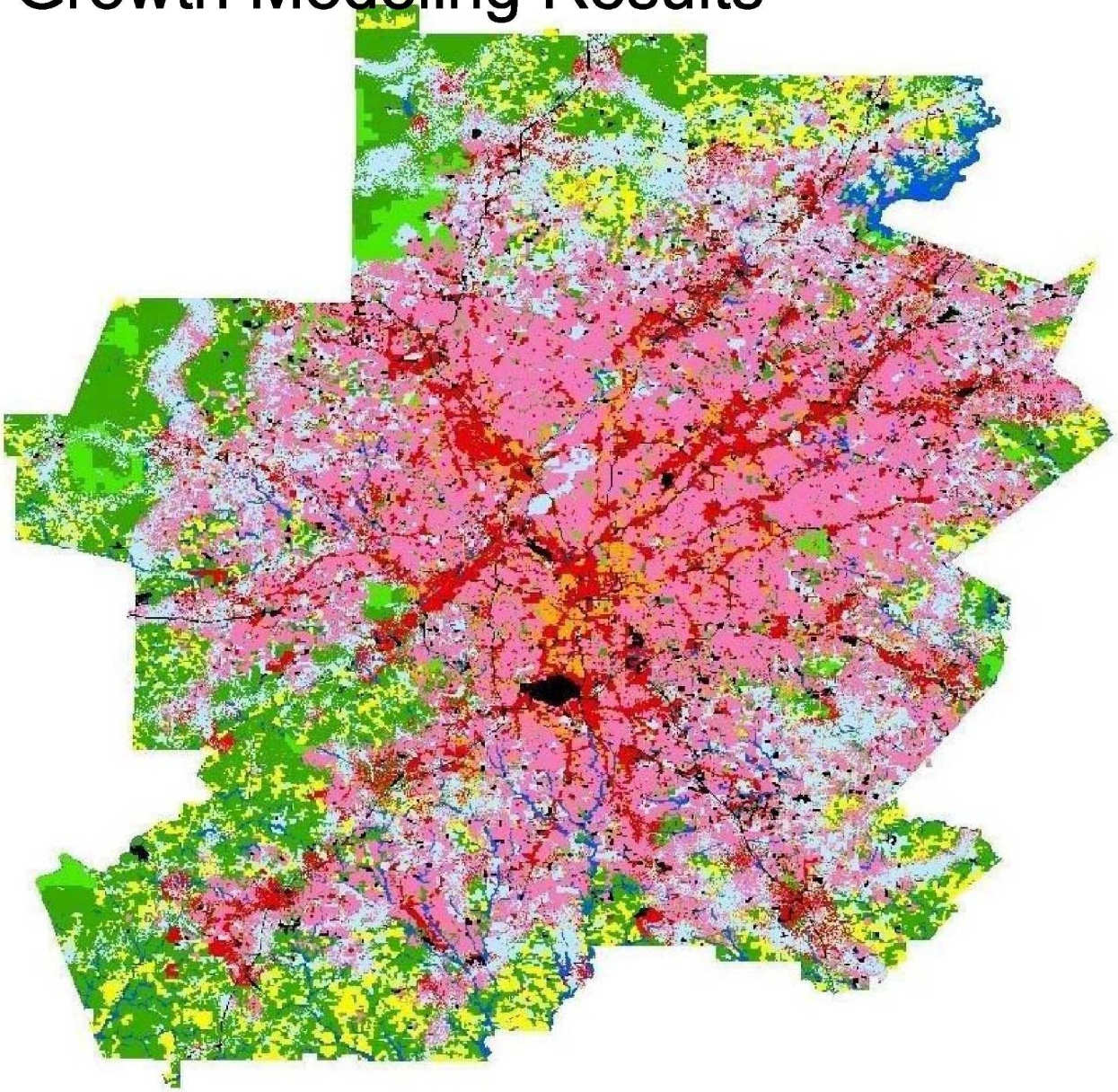


- Low Density Residential
- Med. Density Residential
- High Density Residential
- Commercial/Services
- Institutional
- TCU
- Industrial/Commercial
- Water
- Crops/Pasture
- Row Crops
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Woody Wetlands
- Quarries/Mines/Gravel Pits
- Transitional

Impacts of Climate Change on Urbanization

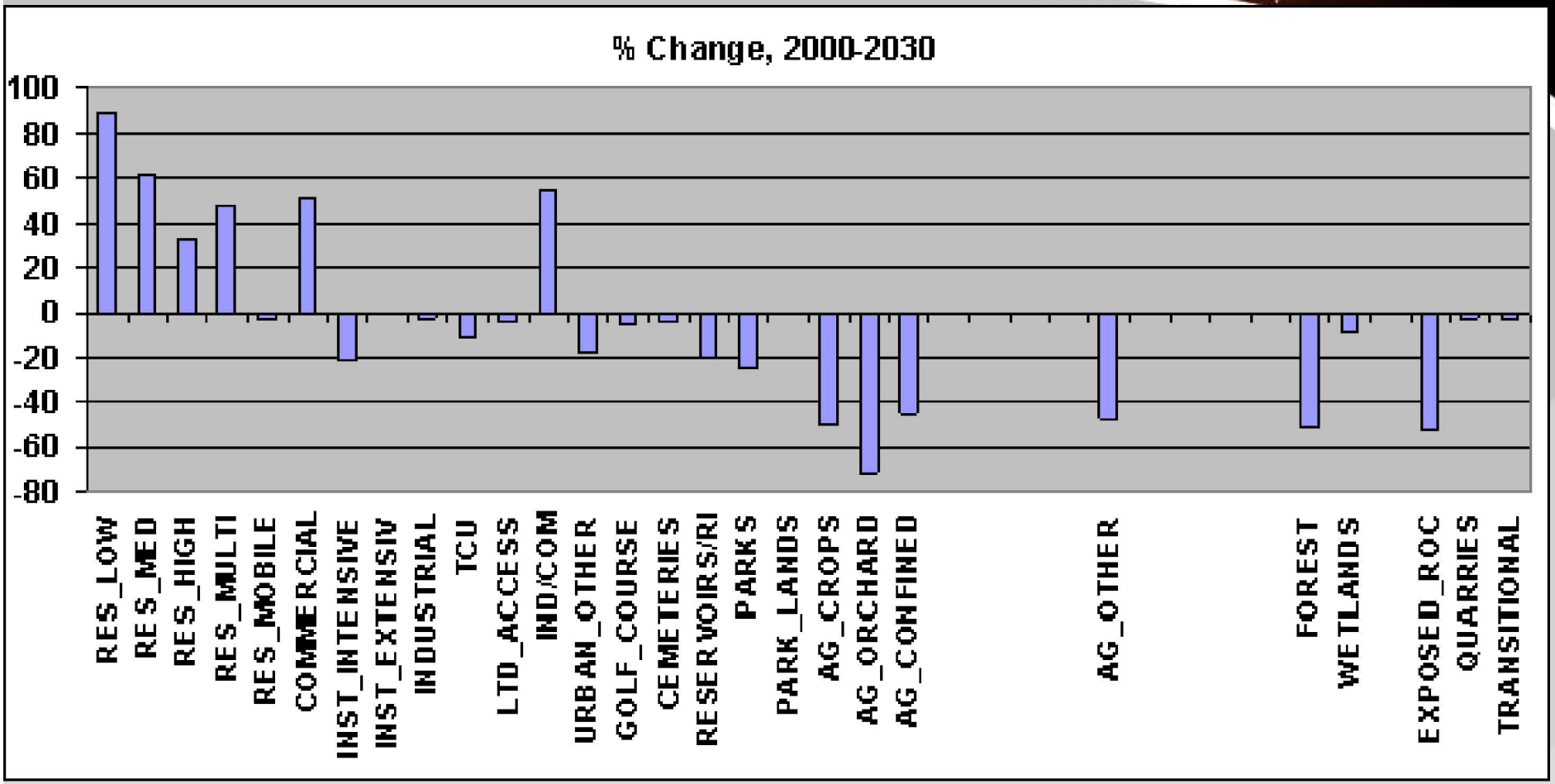
Spatial Growth Modeling Results

Projected Land Use in 2030



Impacts of Climate Change on Urbanization

Land Use Projections

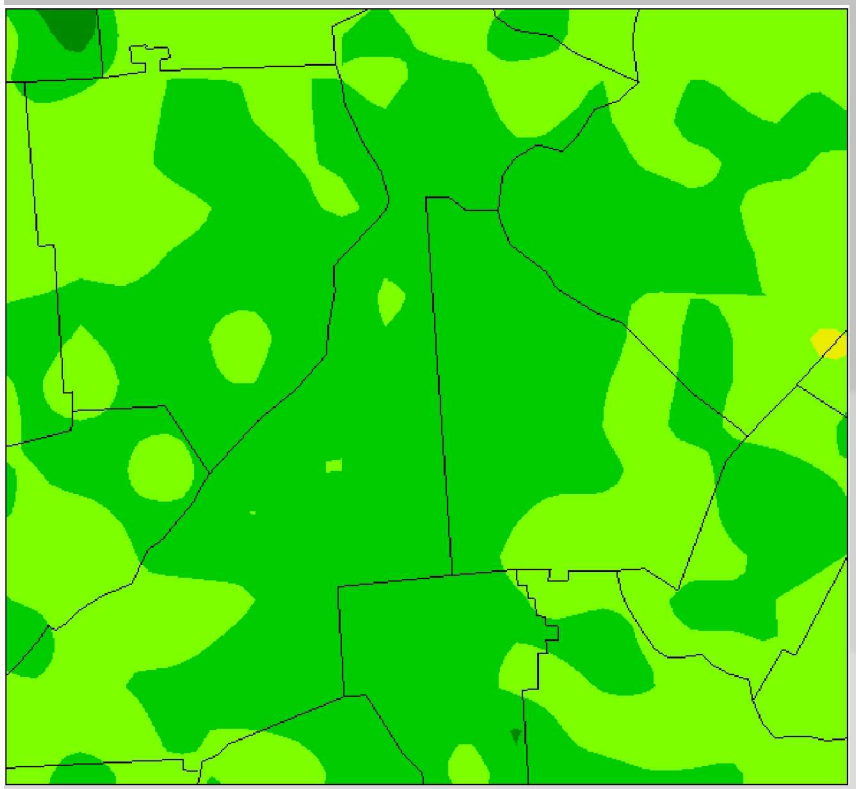


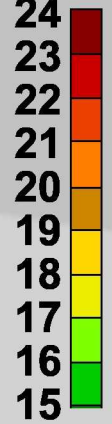
Source: Prescott College Spatial Growth Model

Impacts of Climate Change on Urbanization

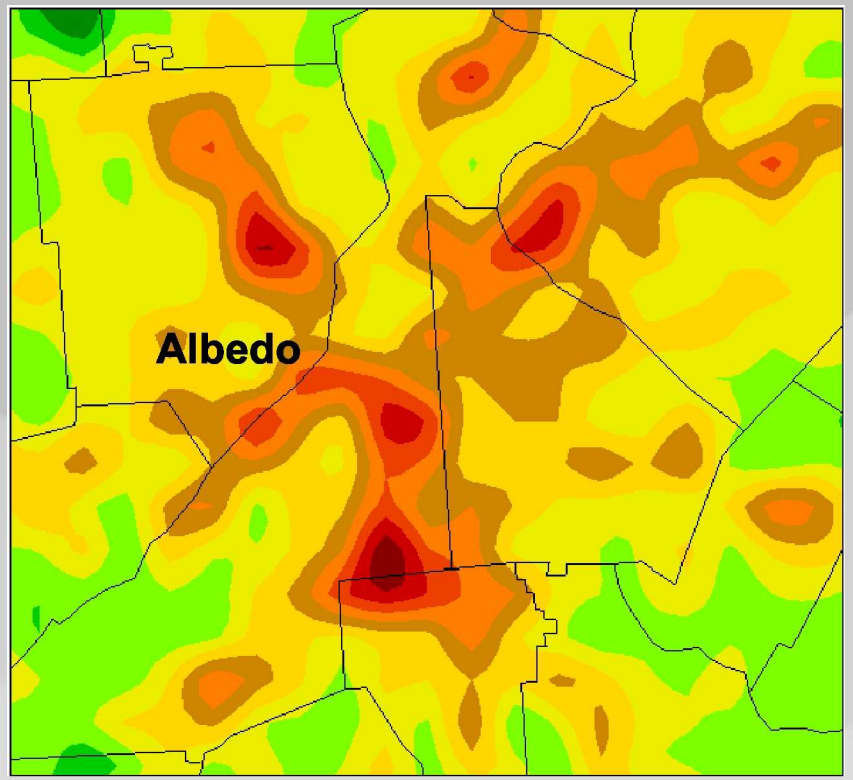
Albedo Mitigation Simulation - 2030

2030 Business As Usual





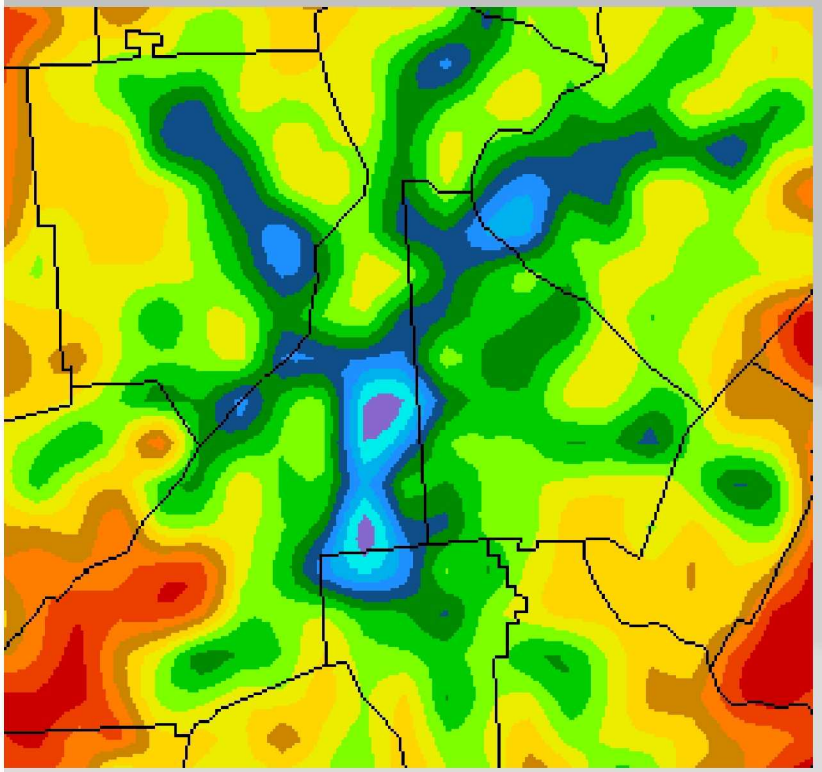
High Albedo

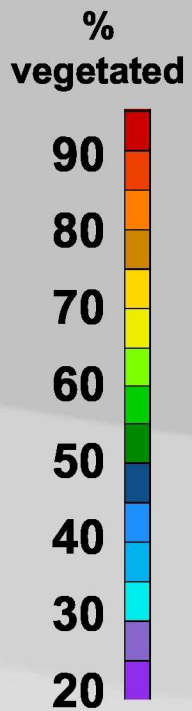


Impacts of Climate Change on Urbanization

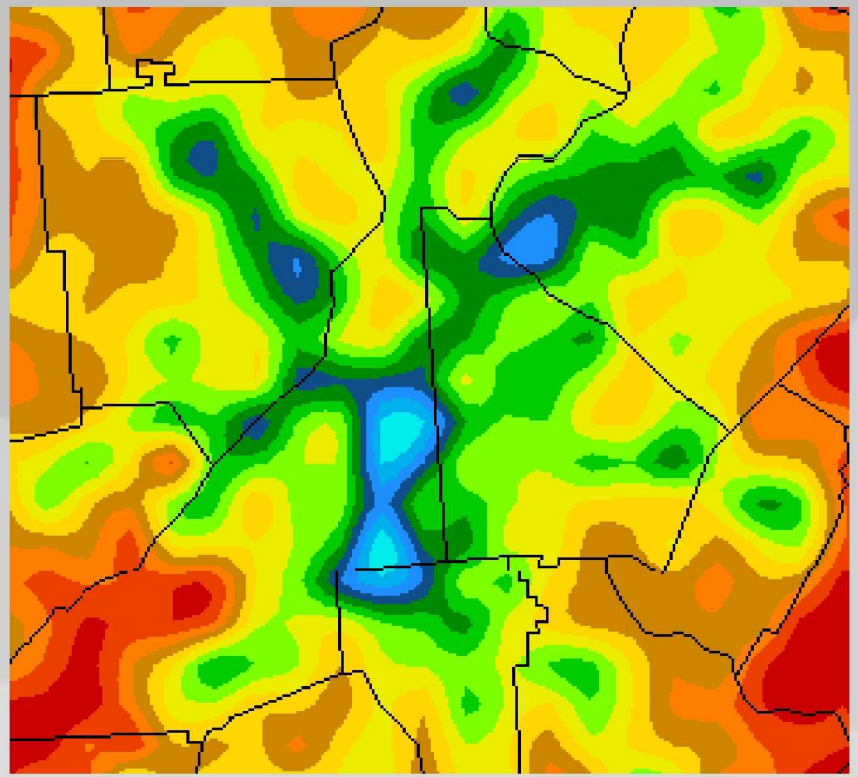
Vegetation Mitigation Simulation - 2030

2030 Business As Usual





2030 Mitigation Scenario



Impacts of Climate Change on Urbanization

Projected Impacts of Climate Change on Settlements in the U.S.

Possible impacts of climate change on settlements in the U.S. are usually assessed by projecting climate change at a regional scale

Vulnerabilities of settlements to impacts of climate change vary regionally, but they generally include some or many of the following impact concerns:

Effects on health:

- **Higher temperatures in urban areas related to higher levels of ozone**
- **Evidence shows combined effects of heat stress and air pollution may be greater than simple additive effects**
- **Other health concerns include vector-borne diseases, allergens, exposure to weather events such as storms floods and fires**

Impacts of Climate Change on Urbanization

Projected Impacts of Climate Change on Settlements in the U.S.

Effects on social and political structures:

- Climate change can add stress on social and political structures
- Increasing management and budget requirements for public services such as public health care, disaster risk reduction, and public security
- Climate change will be especially problematic to vulnerable and disadvantaged parts of the population; e.g., poor, elderly, and those in poor health

Impacts of Climate Change on Urbanization

CLIMATE CHANGE VULNERABILITIES AND IMPACTS IN HUMAN SETTLEMENTS

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Impacts of Climate Change on Urbanization

Conclusions

Even from a current knowledge base that is very limited, it is possible to conclude several things about effects of climate change on human settlements in the United States and around the world:

1. Climate change will seldom be a primary factor in an area's development compared with other driving forces for development. It is likely to be a secondary factor, except in the case of major abrupt climate change

2. Effects of climate change will vary considerably according to location-specific vulnerabilities

Impacts of Climate Change on Urbanization

Conclusions (Cont'd.)

5. While uncertainties are very large about specific impacts, there is a higher level of confidence about the vulnerabilities to impacts for most settlements in most parts of the U.S. and the world

6. Developing a better understanding of these vulnerabilities and reducing uncertainties about impacts will benefit from a higher level research on impact assessment

7. Promoting climate change mitigation and adaptation discussions at an urban/settlement scale will benefit from involvement of stakeholders

Impacts of Climate Change on Urbanization

Potentials for Adaptation to Climate Change in Human Settlements

Where climate change might present risks of adverse impacts for settlements and their populations, there are two basic alternatives to respond to such concerns:

1. **Mitigation strategies (i.e., by taking actions to reduce their greenhouse gas emissions and by showing leadership in encouraging others to support such actions)**
2. **Adaptation strategies (i.e., finding ways either to reduce sensitivity to Projected changes or to increase the settlement's coping capacities)**
3. **Combining both mitigation and adaptation strategies**

Impacts of Climate Change on Urbanization

Potentials for Adaptation to Climate Change in Human Settlements

4. Experiences with urban/settlement climate change responses need to be documented to provide this information to the decision-making, research, and stakeholder communities

Impacts of Climate Change on Urbanization

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THE CHALLENGE:

Remote Sensing Data in Combination with the Modeling of Potential Climate Impacts on Urban Areas is a Critical Aspect in the Assessment, Adaptation, Mitigation Modeling Process

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