Urban Climate and Atmospheric Interactions

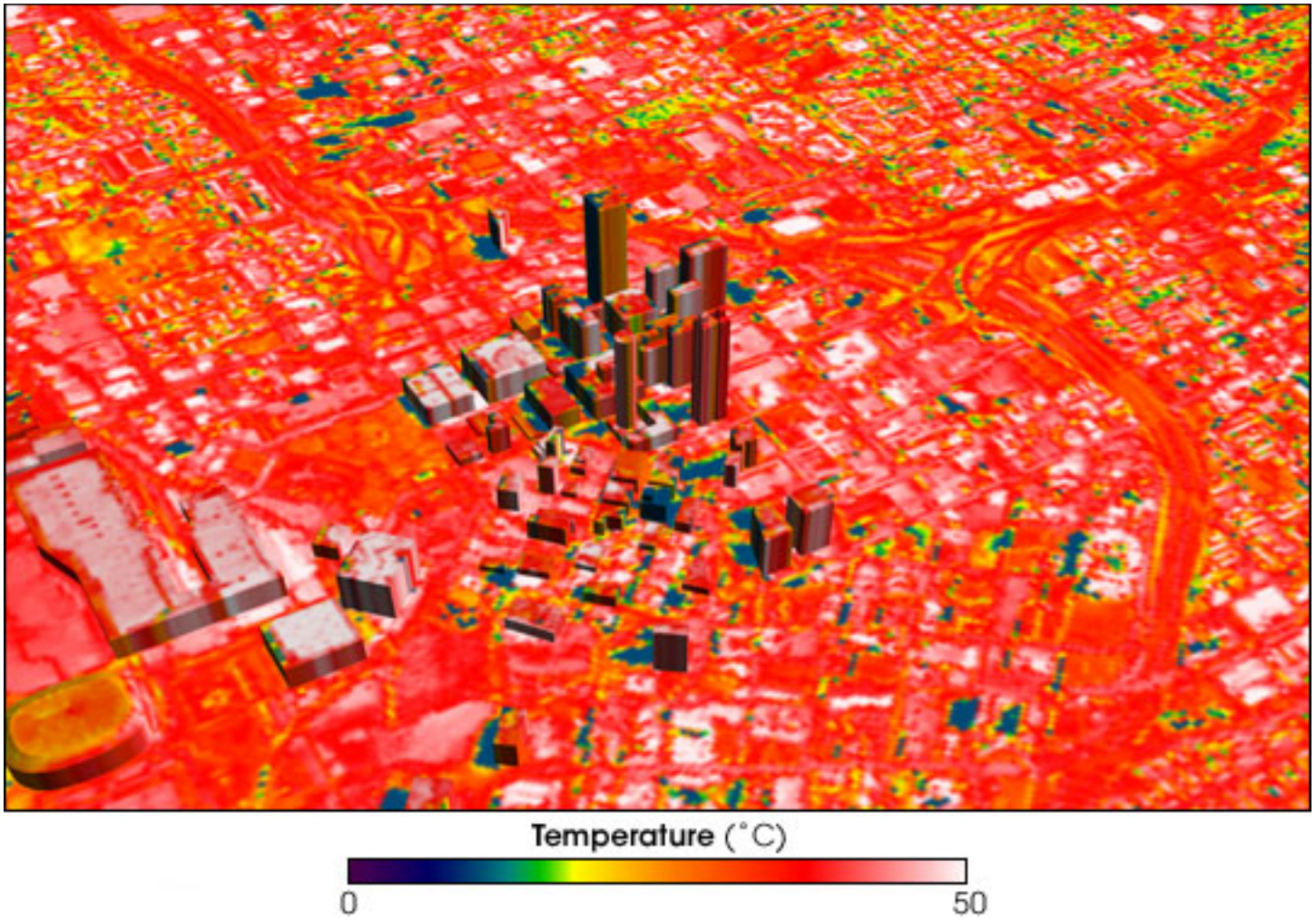


Figure courtesy of NASA: http://earthobservatory.nasa.gov/Features/GreenRoof/Images/atlanta_thermal.jpg

We are increasingly an urban society

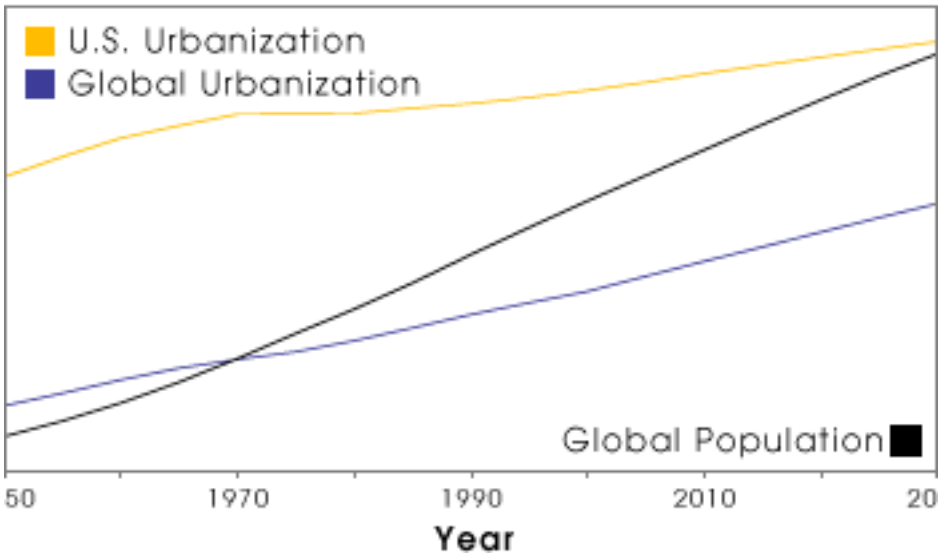


Figure and caption from NASA Earth Observatory website: http://earthobservatory.nasa.gov/Features/Lights3/

Although the majority of the U. S. population lived in cities by 1950, the country continues to urbanize [yellow line (left axis)]. Worldwide, the percentage of people living in cities is expected to increase 15 to 20 percent from 2000 to 2030 (blue line (left axis)]. At the same time, global population levels are steadily climbing [black line (right axis)]. As a result, cities are continually growing and consuming green space. (Graph by Robert Simmon, based on data from the UN Population Information Network)

2016 Blizzard and Urban Lights of the U.S. East Coast

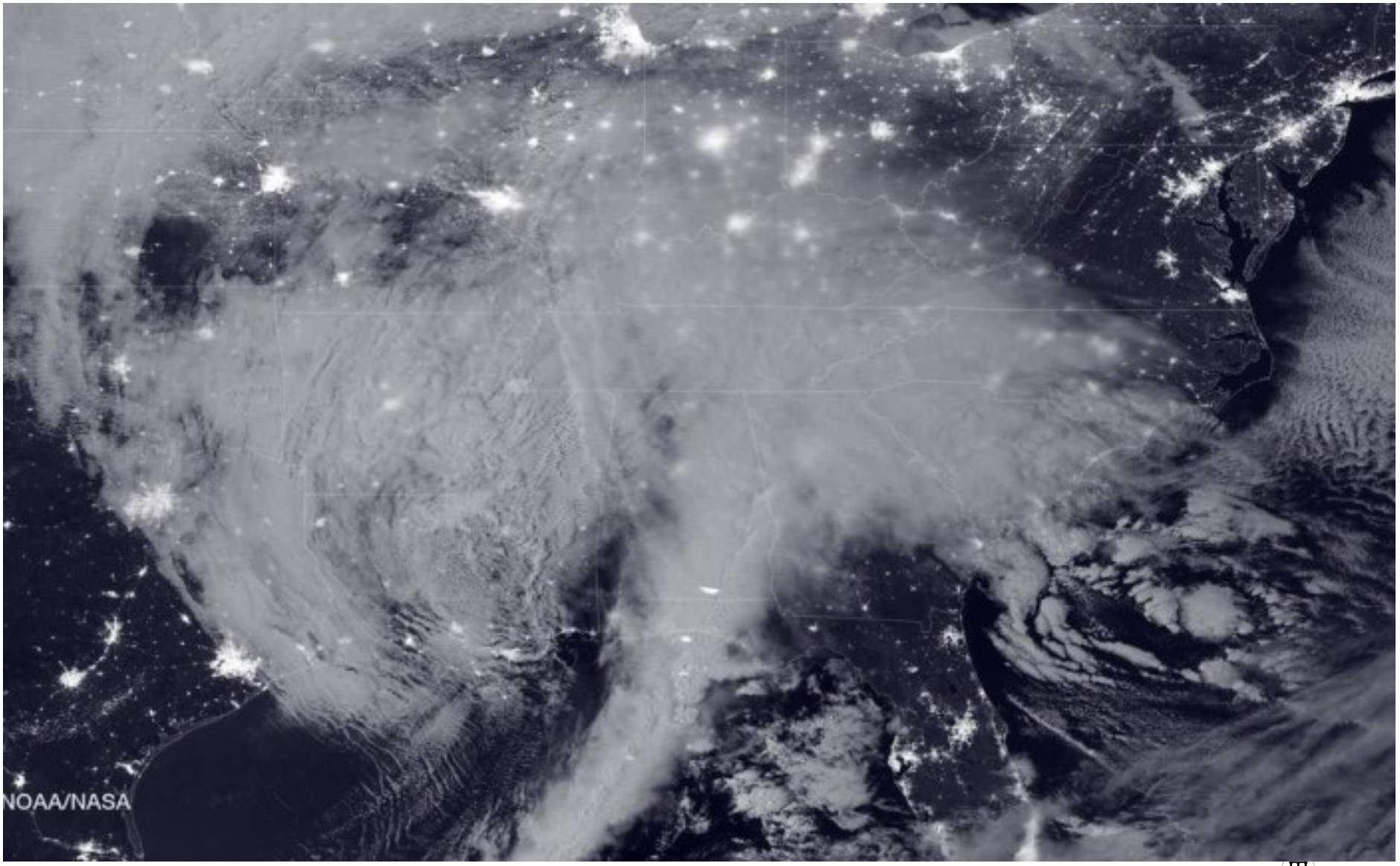


Figure courtesy of NOAA/NASA

What is Climate?

- **Climate** is the long-term statistical properties of the atmosphere for an area. (years to decades)
  - Clouds, temperature, precipitation, wind, barometric pressure, etc
- **Weather** describes these on short time scales (days to weeks)

- *Weather is your Mood, Climate is your personality*

How Does Urbanization Affect Climate? It's Way more than UHI!

Available online at www.sciencedirect.com
ScienceDirect
Current Opinion in Environmental Sustainability
ELSEVIER

Global urban land-use trends and climate impacts

Karen C Seto[1] and J Marshall Shepherd[2]

Table 1

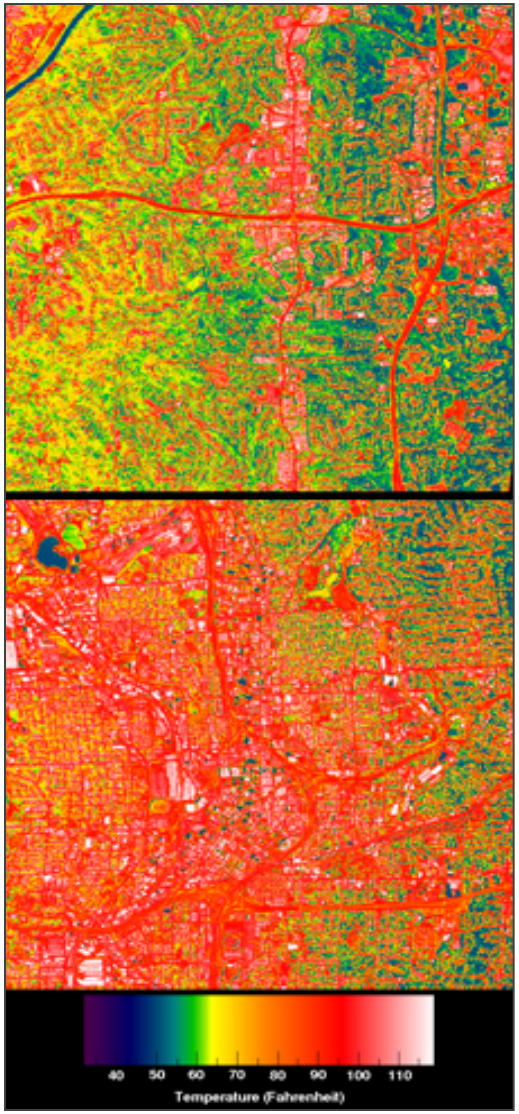
Various pathways for urbanization to impact the climate system (see text for references)

	Urban land-cover	Urban aerosols	Anthropogenic greenhouse gas (GHG) emissions
Urban heat island and mean surface temperature record	Surface energy budget	Insolation, direct aerosol effect	Radiative warming and feedbacks
Wind flow and turbulence	Surface energy budget, urban morphological parameters, mechanical turbulence, bifurcated flow	Direct and indirect aerosol effects and related dynamic/ thermodynamic response	Radiative warming and feedbacks
Clouds and precipitation	Surface energy budget, UHI-destabilization, UHI meso-circulations, UHI-induced convergence zones	Aerosol indirect effects on cloud-precipitation microphysics, insolation effects	Radiative warming and feedbacks
Land surface hydrology	Surface runoff, reduced infiltration, less evapotranspiration	Aerosol indirect effects on cloud-microphysical and precipitation processes	Radiative warming and feedbacks
Carbon cycle	Replacement of high net primary productivity (NPP) land with impervious surface	Black carbon aerosols	Radiative warming and feedbacks, fluxes of carbon dioxide
Nitrogen cycle	Combustion, fertilization, sewage release, and runoff	Acid rain, nitrates	Radiative warming and feedback, NOx emissions

Let’s take a quick look at some ways urbanization interacts with the atmosphere…….

Urban Heat Islands ("UHIs") are the most common manifestation of urban-atmosphere interactions:

NASA website (also source of the images, http://www.nasa.gov/mission_pages/terra/news/heat-islands.html) notes: "Scientists first discovered the heat island effect in the 1800s when they observed cities growing warmer than surrounding rural areas, particularly in summer. Urban surfaces of asphalt, concrete, and other materials -- also referred to as "impervious surfaces" -- absorb more solar radiation by day. At night, much of that heat is given up to the urban air, creating a warm bubble over a city that can be as much as 1 to 3°C (2 to 5°F) higher than temperatures in surrounding rural areas."

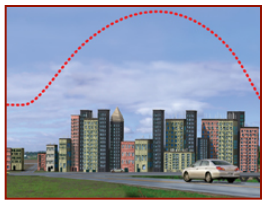


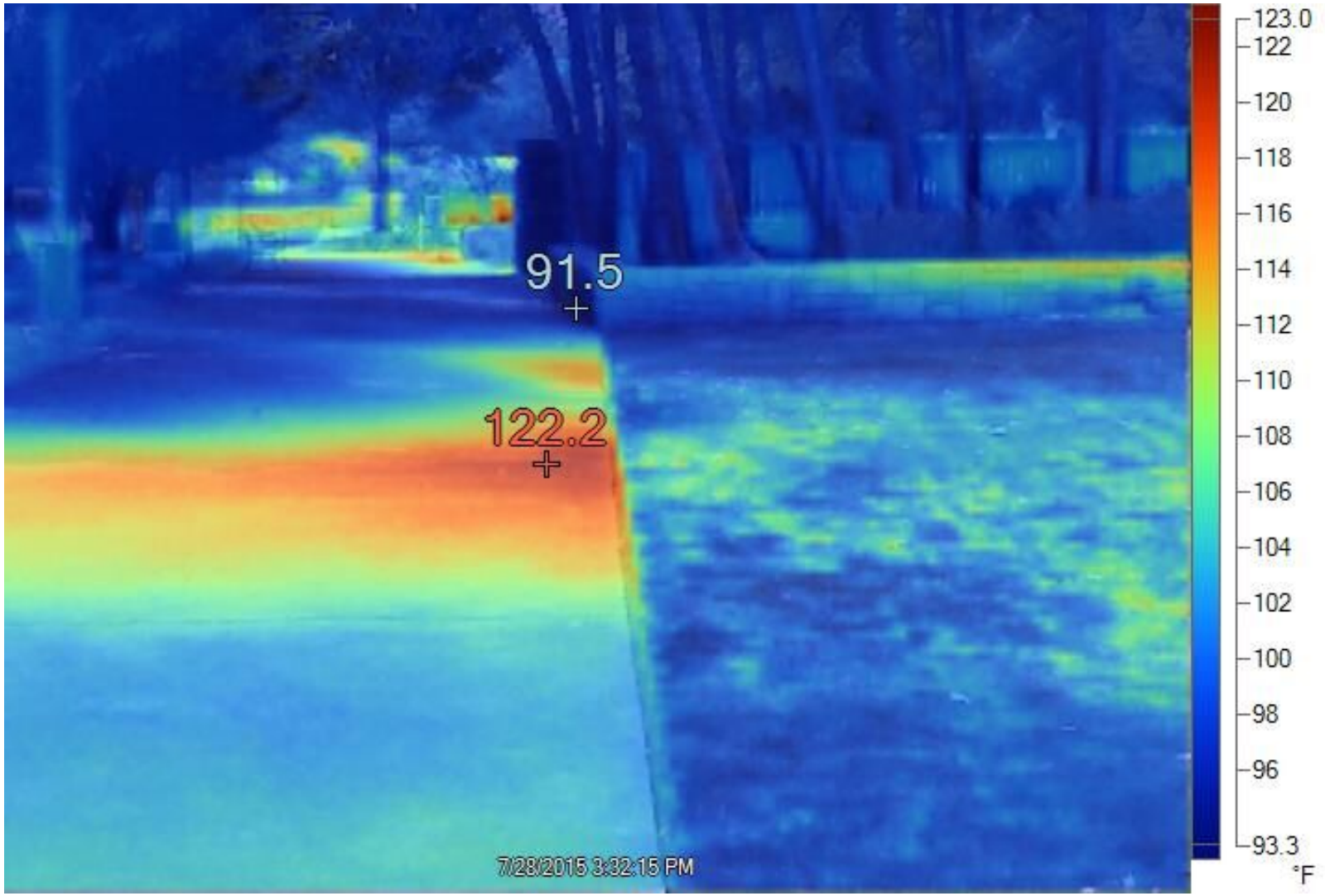
Caused by:

1.Heat-absorbing urban surfaces like asphalt and rooftoops.
2.Lack of vegetation in cities so less cooling from evapotranspiration.
3.Waste heat from engines, HVAC units, and other anthropogenic activities

For a comprehensive discussion of The Science of UHIs read 2015 Article in Forbes by Dr. Marshall Shepherd:

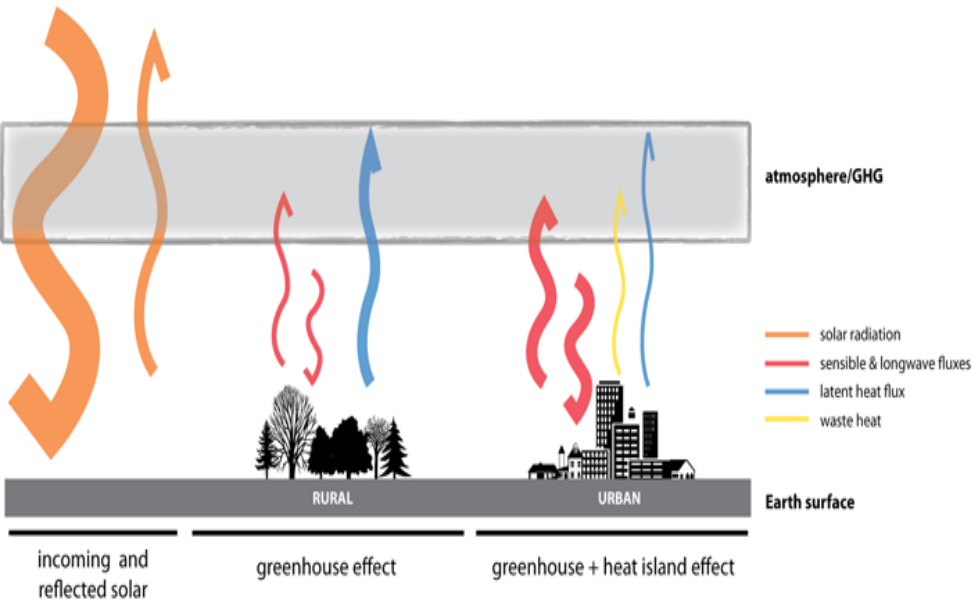
http://www.forbes.com/sites/marshallshepherd/2015/09/25/the-science-of-why-cities-are-warmer-than-rural-areas/#213ab19c745b

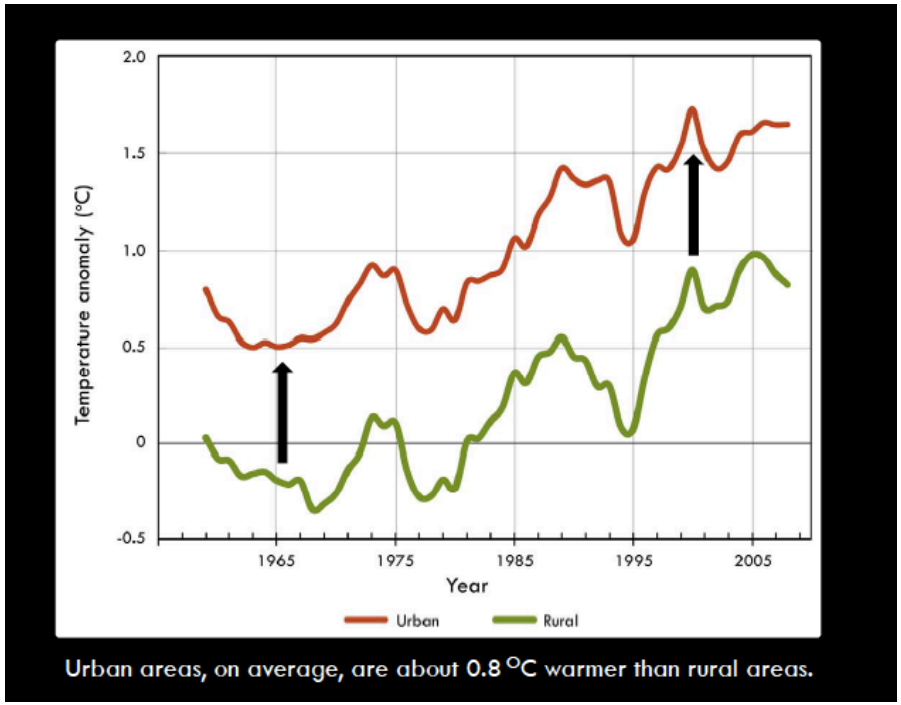




This figure provided by Dr. Marshall Shepherd shows the differences in temperature on paved and natural surfaces at the University of Georgia using a Forward Looking Infrared Gun.

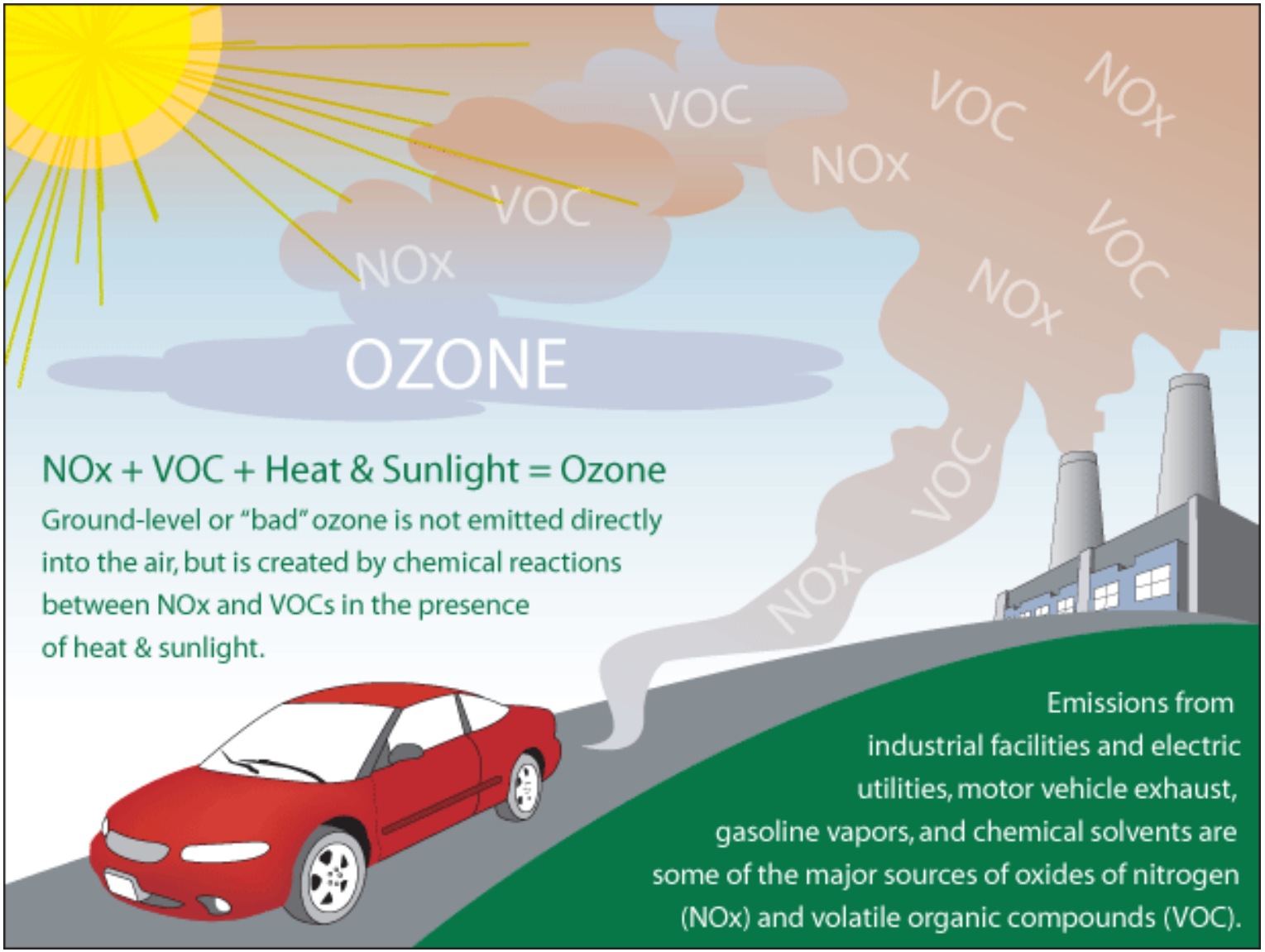
Urban warming outpacing rural warming





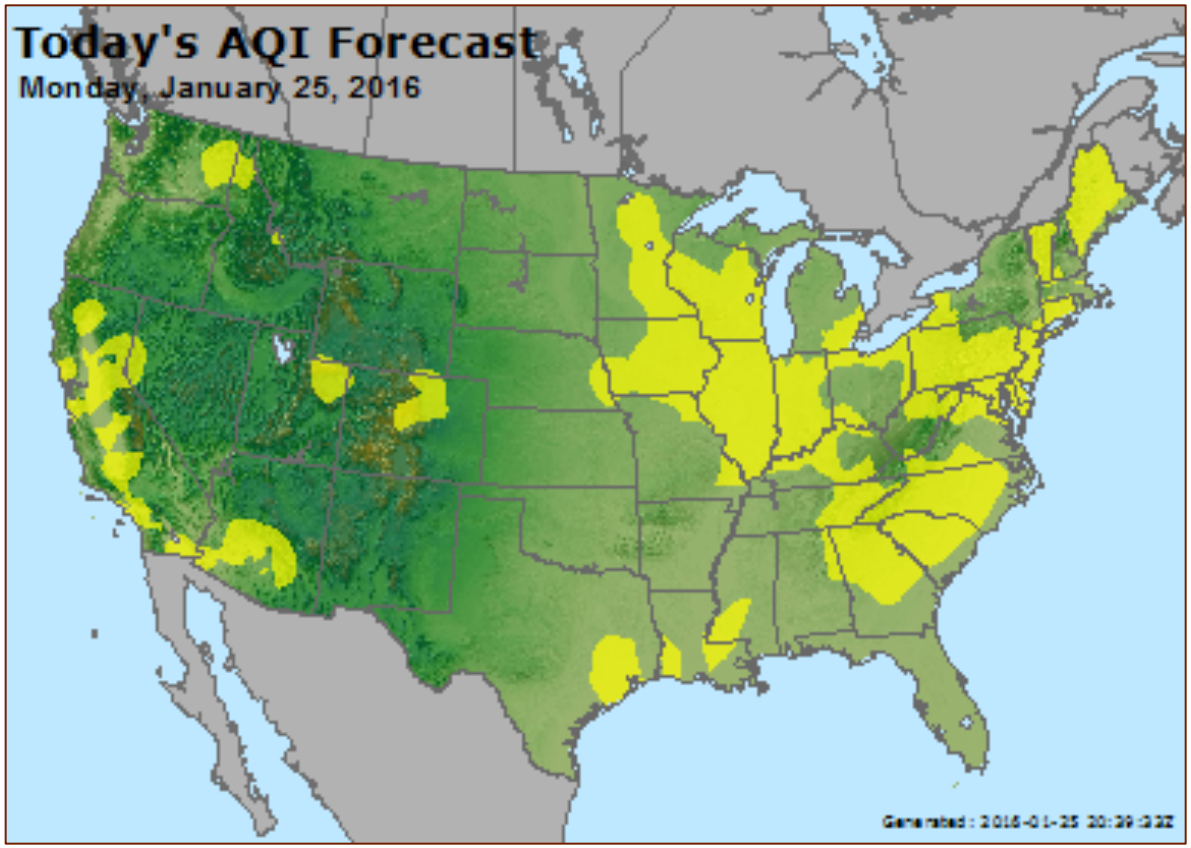
Courtesy of Dr. Brian Stone/Ga. Tech and http://www.urbanclimate.gatech.edu

Pollution and Ozone



Courtesy of EPA Airnow: http://www.airnow.gov/images/ozoneform.gif

Pollution and Ozone



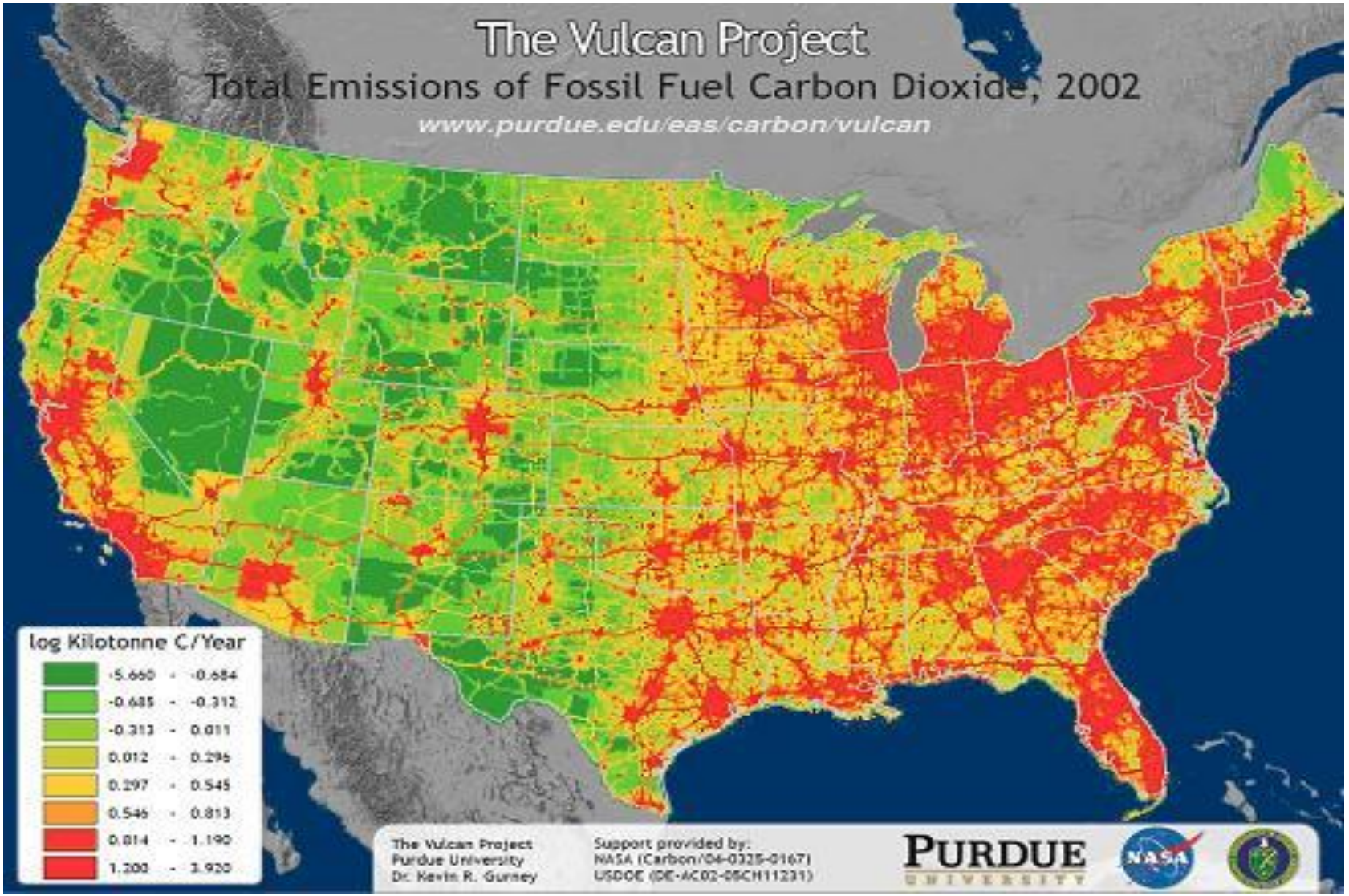
From EPA Website

Particulate matter," also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles.
The size of particles is directly linked to their potential for causing health problems. EPA is concerned about particles that are 10 micrometers in diameter or smaller because those are the particles that generally pass through the throat and nose and enter the lungs. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. EPA groups particle pollution into two categories: "Inhalable coarse particles," such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter.

"Fine particles," such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller. These particles can be directly emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

Courtesy of EPA http://www3.epa.gov/pm/

Cities are regions of excess Carbon Dioxide



Courtesy: Vulcan Project, NASA, and Department of Energy

Urbanization and Nitrogen Cycle

- Urban and industrial processes affect the natural Nitrogen cycle

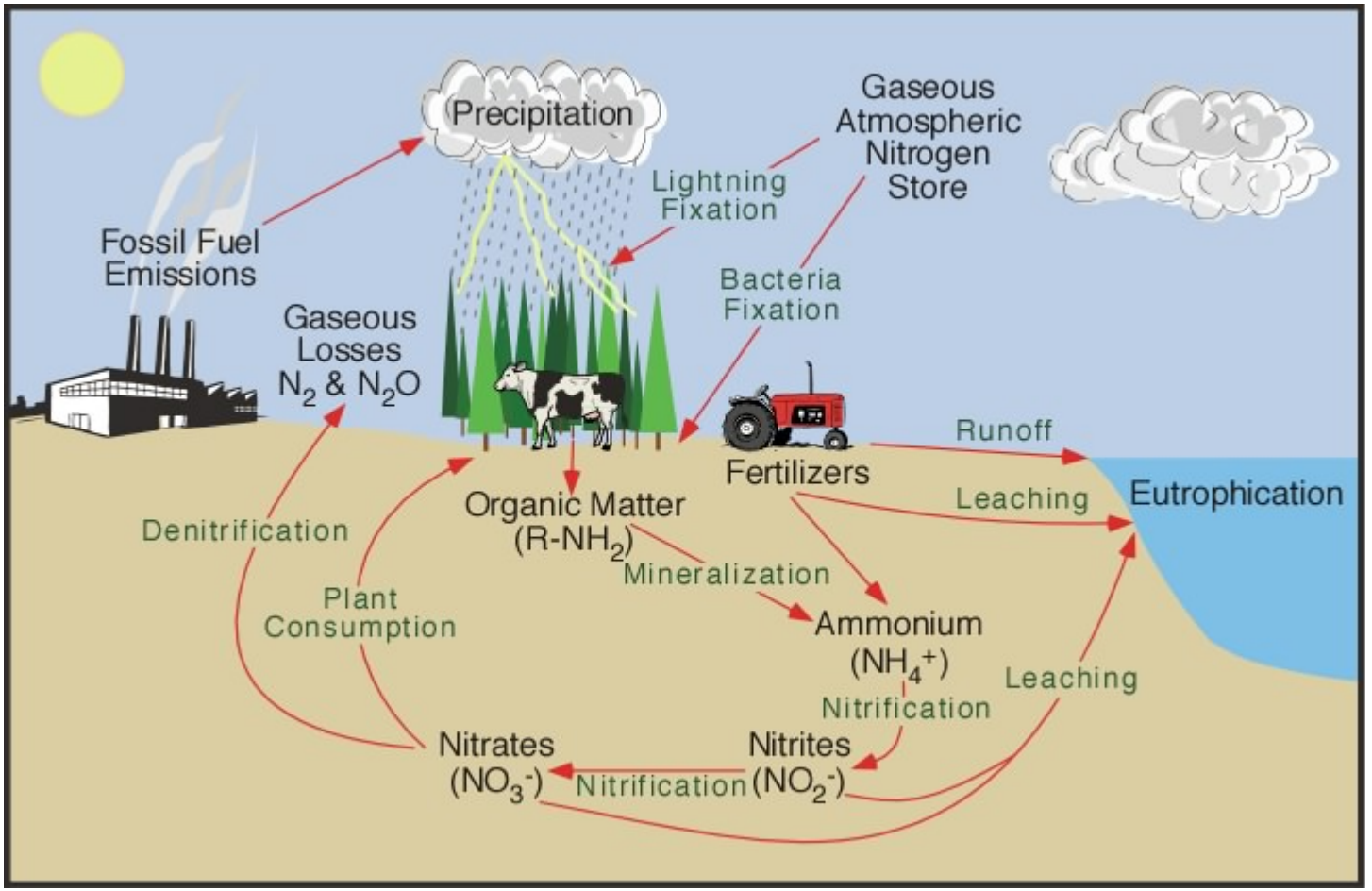
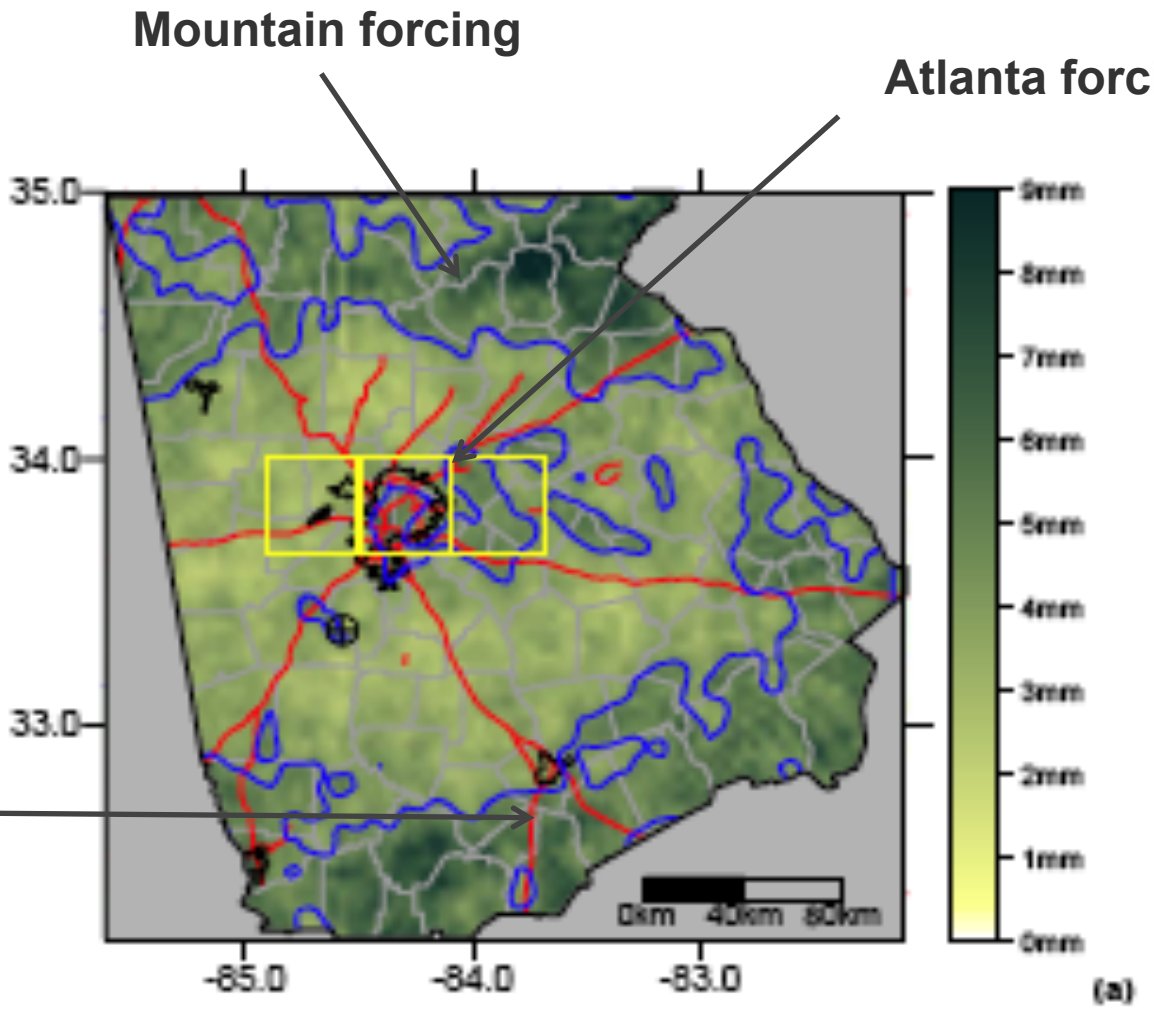


Figure courtesy of NOAA Climate Program Office: http://cpo.noaa.gov/sites/cpo/About_CPO/ac4_nitrogencycle.jpg

Cities Affect Rainfall Distribution. But How?



Inland penetration of Sea Breeze, irrigation (?)

Courtesy of Marshall Shepherd

So How Does A City Create or Modify Rain or Storms?

Previous research (see Shepherd 2013, Shepherd et al. 2010, Shepherd 2005 for reviews)

a. Atmospheric destabilization through the enhanced thermal mixing due to low-level heating (i.e., Urban Heat Island (UHI))
b. Increased turbulence and mechanical mixing due to increased aerodynamic roughness created by tall buildings
c. Modified microphysical and dynamic processes caused by the addition of aerosols from automobiles and industry
d. Bifurcation of pre-existing precipitating systems by physical or thermodynamic processes

Are urban floods increasing?

Picture courtesy of NWS Atlanta: http://www.srh.noaa.gov/images/ffc/downtown_flooding_sep09.jpg

Extreme Events

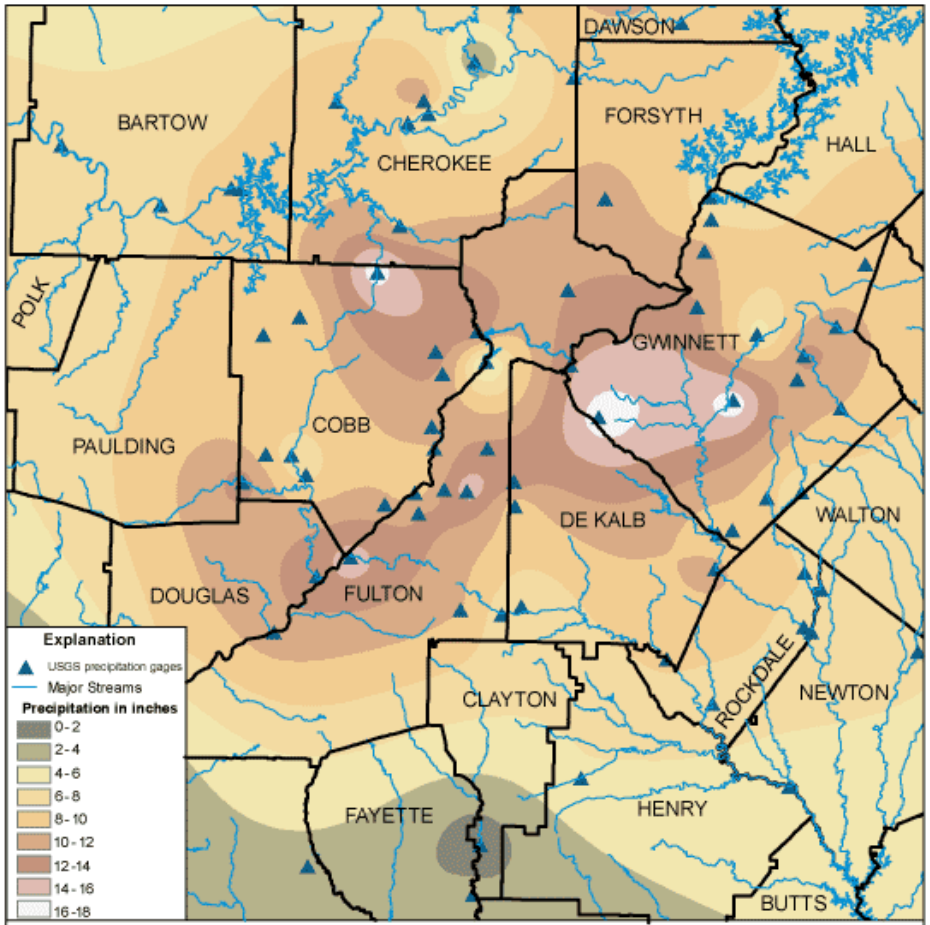
- Extreme events are defined as "most unusual" climatic events at a given place (natural and anthropogenic causes)
- "Most unusual" can be categorized as occurring less than 10 percent of the time based on historical observations
- Climatic events:
  - Flooding
  - Droughts/heat waves
  - Tropical cyclones
  - Severe local storms (tornado, hail, wildfires, crop freeze, winter storms, straight-line wind damage, etc.)
- Can cause severe socio-economic and environmental damage

Atlanta Sept. 2009: Extreme Event Case Study

- September 2009 (227.0 mm) was *219% above normal and 5th wettest in Atlanta's history and the 4th wettest for Athens, Georgia.*
- Parts of Metro Atlanta were inundated to levels exceeding the estimated 500-year flood. 100 to 200-year flood levels common**. Belanger (AMS, 2011) suggests 10,000 yr event
- 10 fatalities, 16000 injured/federal aid requests, $500m +damages,~1500 evacuated, ~20,000 homes/businesses flooded , ~1500 schools closed, ~300 roads/ interstates closed/destroyed ,

Sources: NWS (Nelson, GEMA, AJC)

**100-yr flood used by FEMA to set flood insurance rates



Rainfall in inches, measured at USGS gages, September 11 through 22, 2009 in the Atlanta, Georgia Area - Provisional data

Increasing Urban Flood Risk =

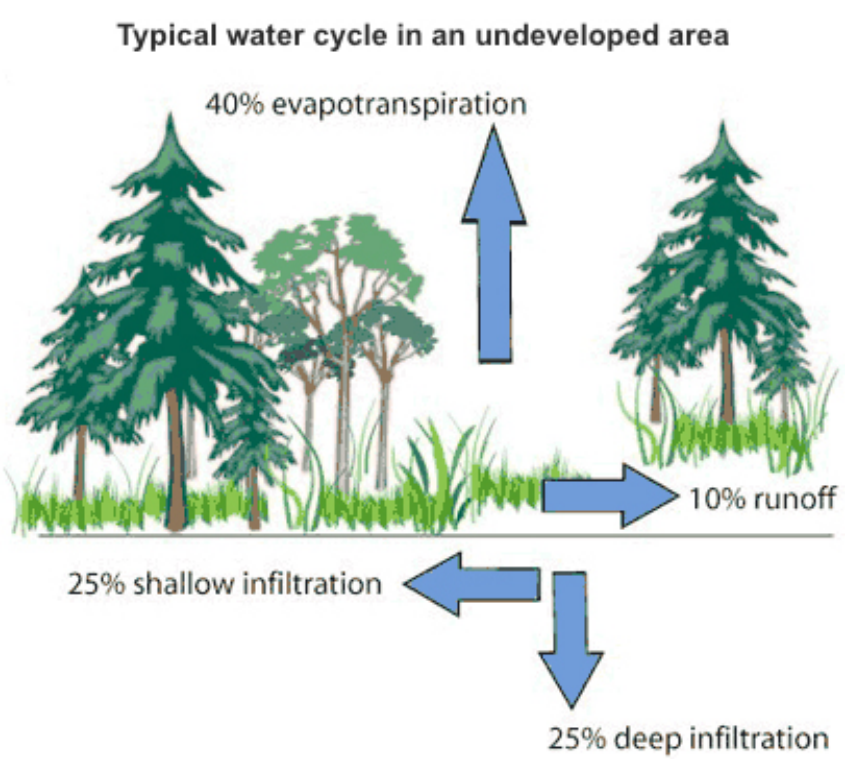
Increase in intensity of top 1% rain events + expanding urban impervious land cover + storm water management engineered for rainstorms of "last century"

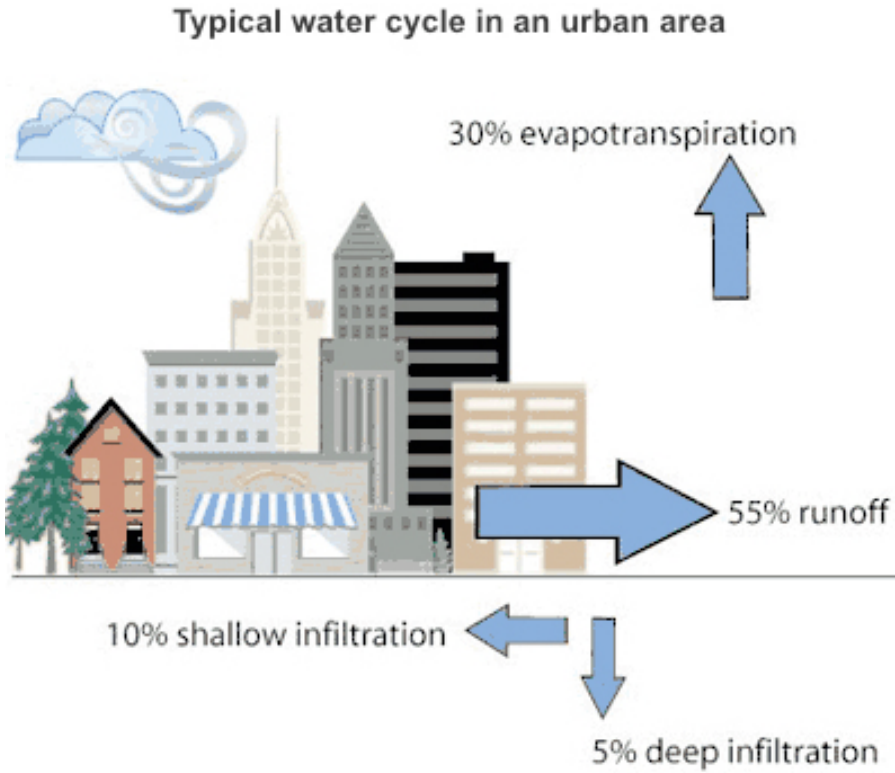
Picture courtesy of NOAA: http://www.floodsafety.noaa.gov/state-images/TX-02-2.jpg

For additional reading on this equation, read Dr. Marshall Shepherd's Blog —Urban Floods: A Simple Equation.

http://www.wunderground.com/blog/DrShepherdWxGeeks/recent-urban-floods-a-simple-equation

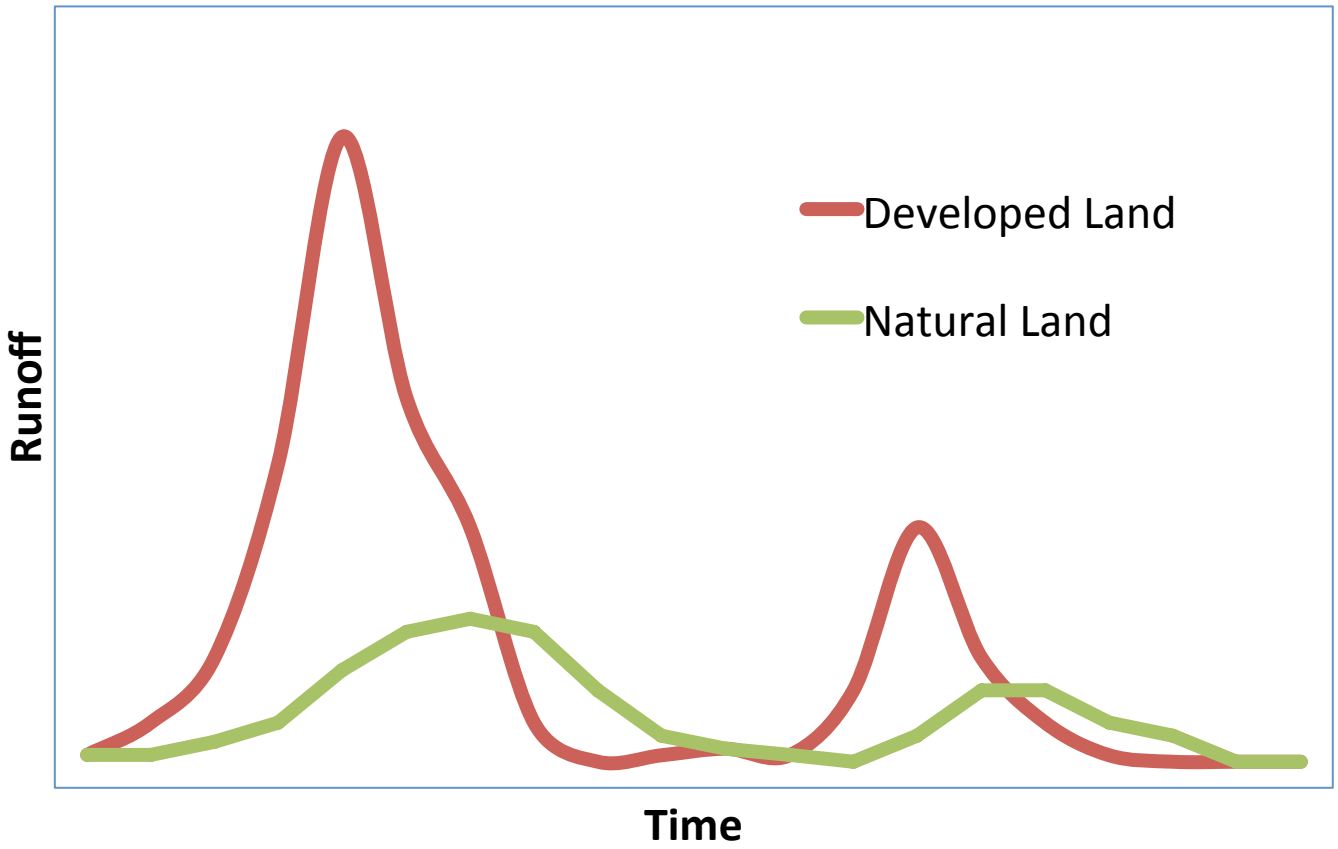
Urban Water Cycle





Source: http://www.teamleaf.org/aqua/ourraingarden.html

Impact of Urbanization on Runoff



- Change of hydrograph (runoff vs. time) shape due to urbanization
- Increase in peak flow with potential to flood nearby streams/rivers
- Water pathways and retention potential

Source: This Integrate Project

Stormwater Management for 1970s Rainstorms

- **Return Period (T)** - The average length of time in years for an event (e.g. flood or river level) of given magnitude to be equaled or exceeded.
- A fundamental relationship is that between flood return period (T) and probability of occurrence (p). *These two variables are inversely related to each other. That is p = 1/T and T = 1/p. For example, the probability of a 50 year storm occurring in a one year period is 1/50 or 0.02.*

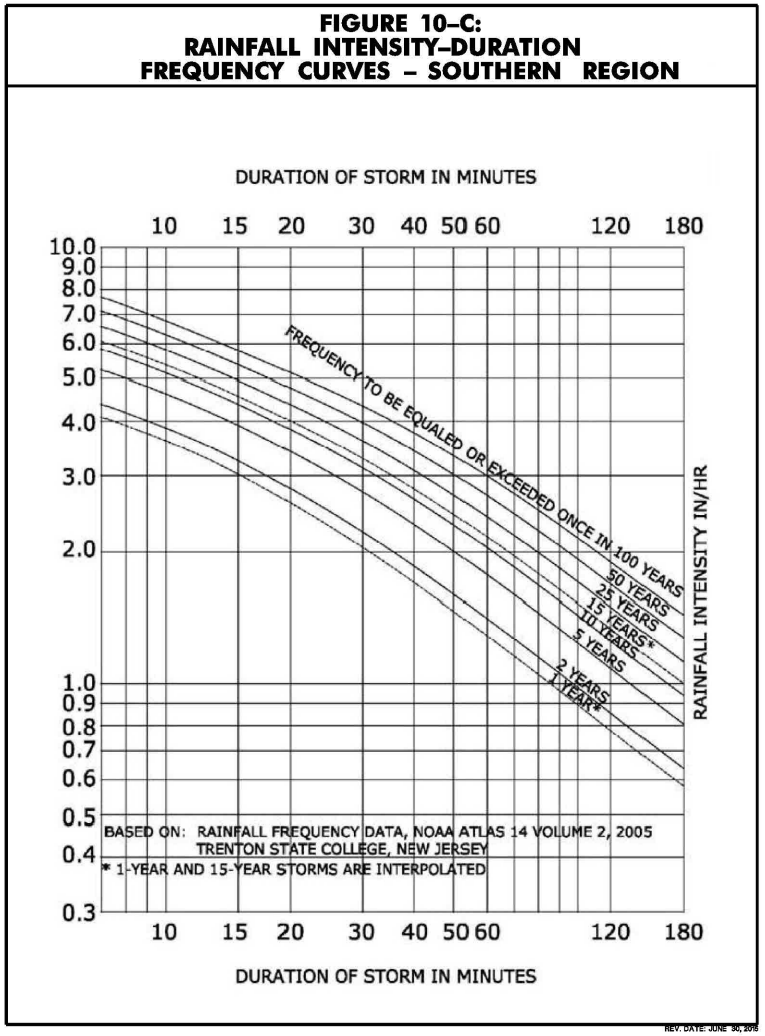
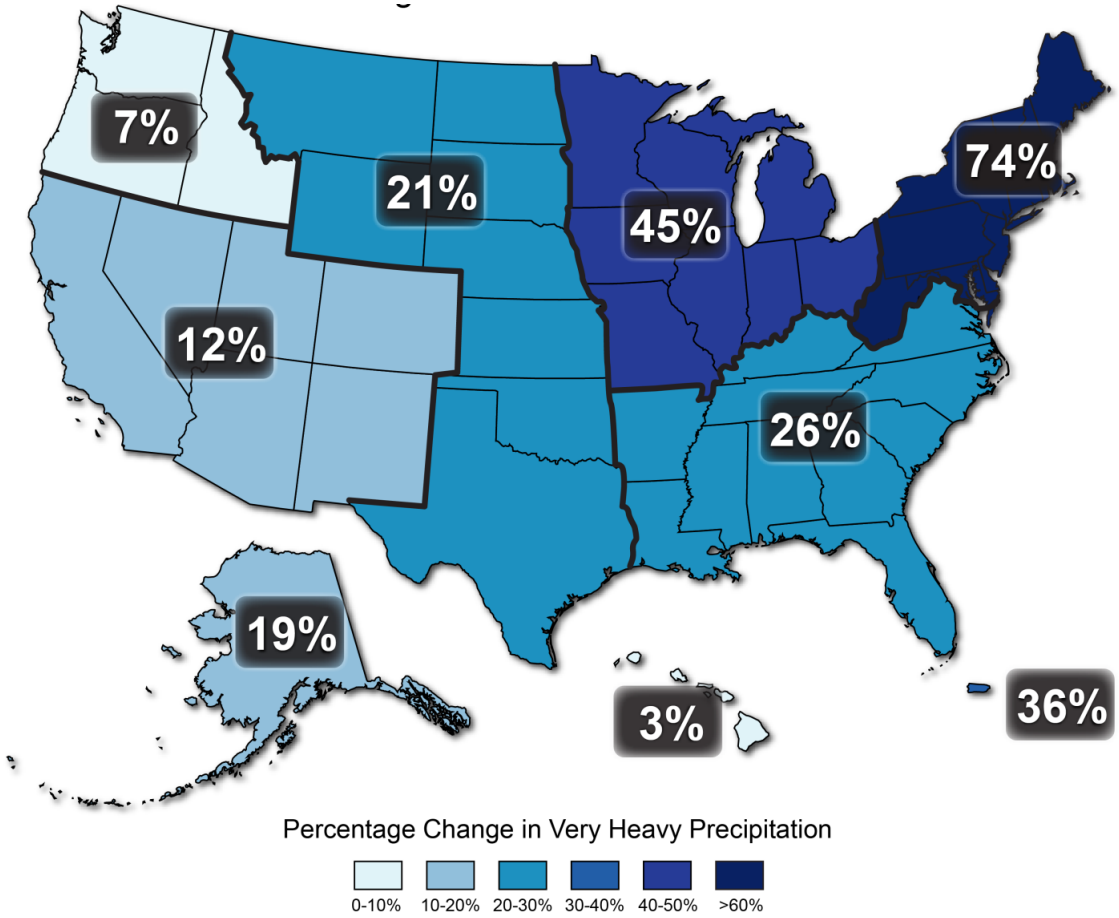


Image Source: http://www.state.nj.us/transportation/eng/documents/RDM/images/figure10c.jpg

Increasing Flood Risks (FEMA 2013, Andersen and Shepherd 2013, Shepherd et al. 2011)



% Change since 1950 in Top 1% Heaviest Rainfall Evets (NCA, 2013)

THE MAP ROOM

An Overview of Synoptic and Mesoscale Factors Contributing to the Disastrous Atlanta Flood of 2009

BY MARSHALL SHEPHERD, THOMAS MOTE, JOHN DOWD, MIKE RODEN, PAMELA KNOX, STEVEN C. MCCUTCHEON, AND STEVEN E. NELSON

Recent literature suggests that damage, loss of life, and costs from flooding have risen in recent decades (Ashley and Ashley 2008; Brissette et al. 2003). In a 2009 *Journal of Climate* article, Seager et al. noted that regions of the southeastern United States face increasing vulnerability to hydroclimatic extremes because of population growth and increasing population density. In 2008, a majority of the population lived in urban areas, and by 2030 this number is expected to reach 81%. The unsustainable, modified water cycle will affect the ecosystem, infrastructure, and societal activities, thereby requiring revolutionary designs, management, and policies. Burian and Shepherd (2005) and Reynolds et al. (2008) represent a sample of recent literature that has reconsidered implications of precipitation on urban drainage and hydrological processes.

In September 2009, the metropolitan area of Atlanta and surrounding areas in northern Georgia experienced disastrous urban flooding that inundated major transportation arteries, closed several major school systems, submerged the popular Six Flags theme park, and contributed to at least 10 deaths as of October 2009 (Fig. 1). The United States Geological Survey (USGS) measured the largest flow ever recorded on Sweetwater Creek near Austell, which has a streamflow record dating back to August 1904. Parts of Cobb and Douglas Counties were inundated to levels exceeding the estimated 500-yr flood. The Yellow River stream gauges in Gwinnett, DeKalb, and Rockdale Counties measured flows that submerged the 100-yr floodplains but failed to reach the 200-yr flood level, which has a 0.5% chance of occurring in any given year (www.usgs.gov/newsroom/article.asp?ID=2316). The 100-yr flood level with a 1% chance of occurrence in any given year is one of the standards that the Federal Emergency Management Agency (FEMA) uses to set flood insurance rates and prevent flood plain development. The USGS recorded 100-yr flood levels on the Chattahoochee River at Vinings in Atlanta (Fig. 2), where stage heights

AFFILIATIONS: Shepherd, Mote, Dowd, and Roden—University of Georgia, Athens, Georgia; Knox—Office of the State Climatologist, Athens, Georgia; McCutcheon—U.S. Environmental Protection Agency, Athens, Georgia; Nelson—National Weather Service, Peachtree City, Georgia
CORRESPONDING AUTHOR: Dr. J. Marshall Shepherd, University of Georgia, Climatological Research Laboratory, Department of Geography, Athens, Georgia 30602
E-mail: marshgeo@uga.edu
DOI:10.1175/2010BAMS3002.1

FIG. 1. (top) Flooding on U.S. Interstate 285 loop around Atlanta and (bottom) Six Flags theme park.

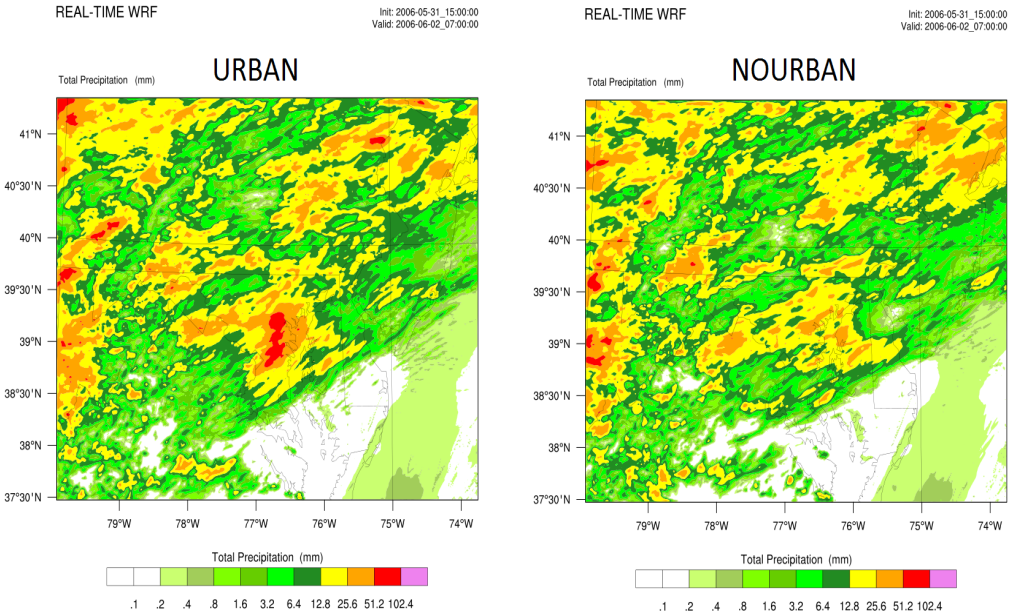
Megalopolis Revisited

- French geographer Jean Guttman's book ***Megalopolis*** described the urbanized region from Boston to Washington, D.C.. Derived from the Greeks, *Megalopolis* means "very large city."
- In contemporary times, the Oxford Dictionary of Geography describes a Megalopolis as "*any many-centered, multi-city, urban area of more than 10 million inhabitants, generally dominated by low-density settlement/complex networks of economic specialization."*
- **How many Megalopoli can you find in the next slide?**


Source: NASA

What is an Urban Climate Archipelago?

- a chain of distinct urban entities with discernible aggregate impacts on at least one segment of the climate system.
- Weather model experiments show that more rain falls when weather models include urban land. This region (on the right) is Washington DC to Philadelphia area.
- Review the reasons in the previous slides why a city can create or enhance rain.



From Shepherd et al 2013, http://earthzine.org/2013/11/29/urban-climate-archipelagos-a-new-framework-for-urban-impacts-on-climate/