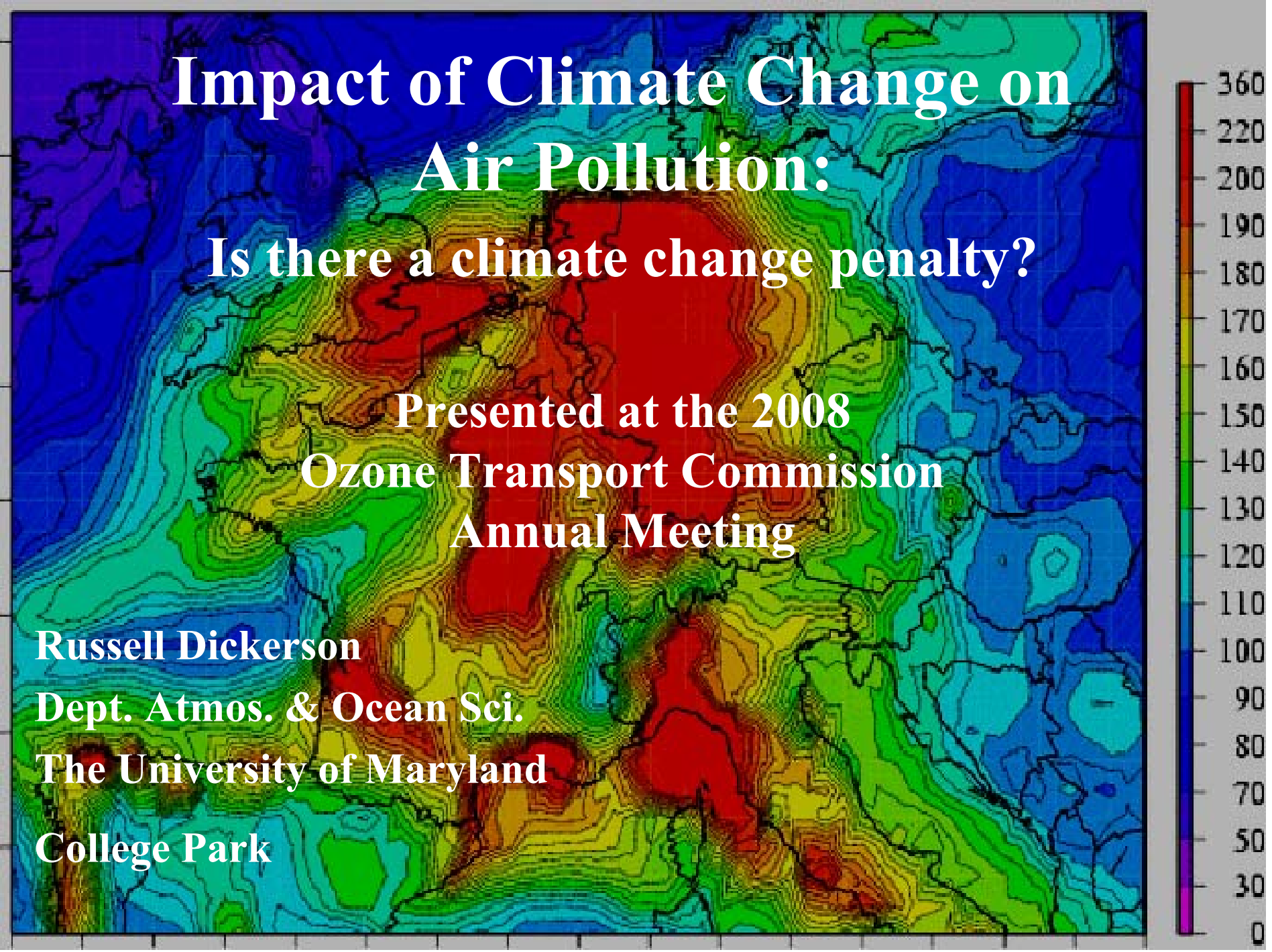
Impact of Climate Change on Air Pollution:

Is there a climate change penalty?

Presented at the 2008
Ozone Transport Commission
Annual Meeting

Russell Dickerson
Dept. Atmos. & Ocean Sci.
The University of Maryland
College Park



August 2003
Heat Wave Strikes Europe.

- Hottest summer on record for western Europe.
- Temperatures exceed 100°f.
- Ozone approaches 300 μg m^{-3} (150 ppb).
- Death attributed (*Science News*, Oct. 2003)
  - 14,800 France
  - 7,000 Germany
  - 4,200 Italy
  - 4,200 Spain
- Europeans go to work on the impact of climate change on air quality; see www.accent-network.org

Outline

- What do models predict about climate change and air quality?
- Has the Eastern US gotten warmer?
- Is more warming in store for us?
- What are the numbers? (ppb/°C)
  - What do models say?
  - What do measurements say?
- What can we do about it?

“Essentially, all models are wrong, some are useful.”

George Edward Pelham Box

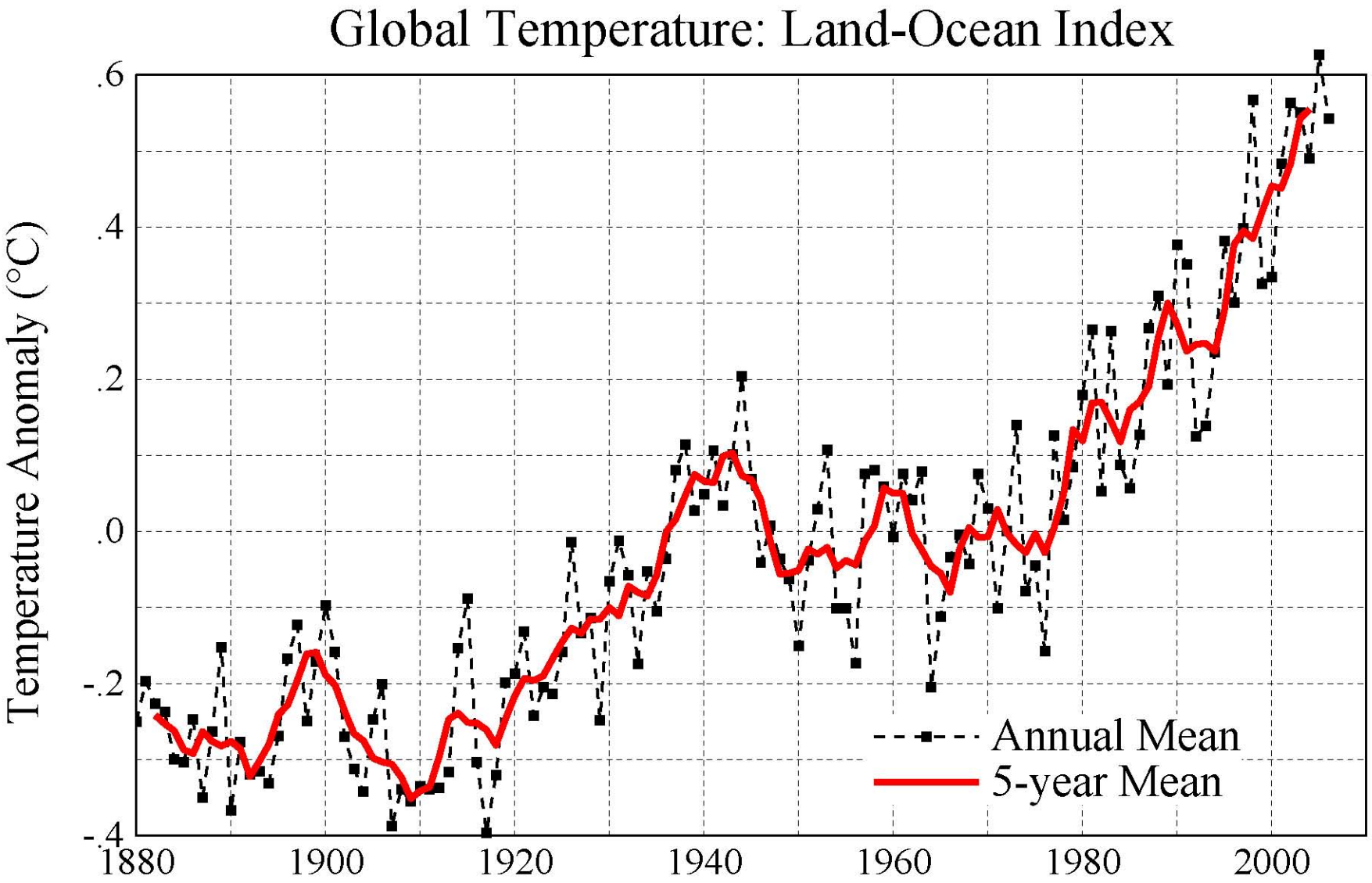
(1919 -)

English chemist and statistician.

Box and Draper (1987). Empirical Model-Building and Response Surfaces, p. 424.

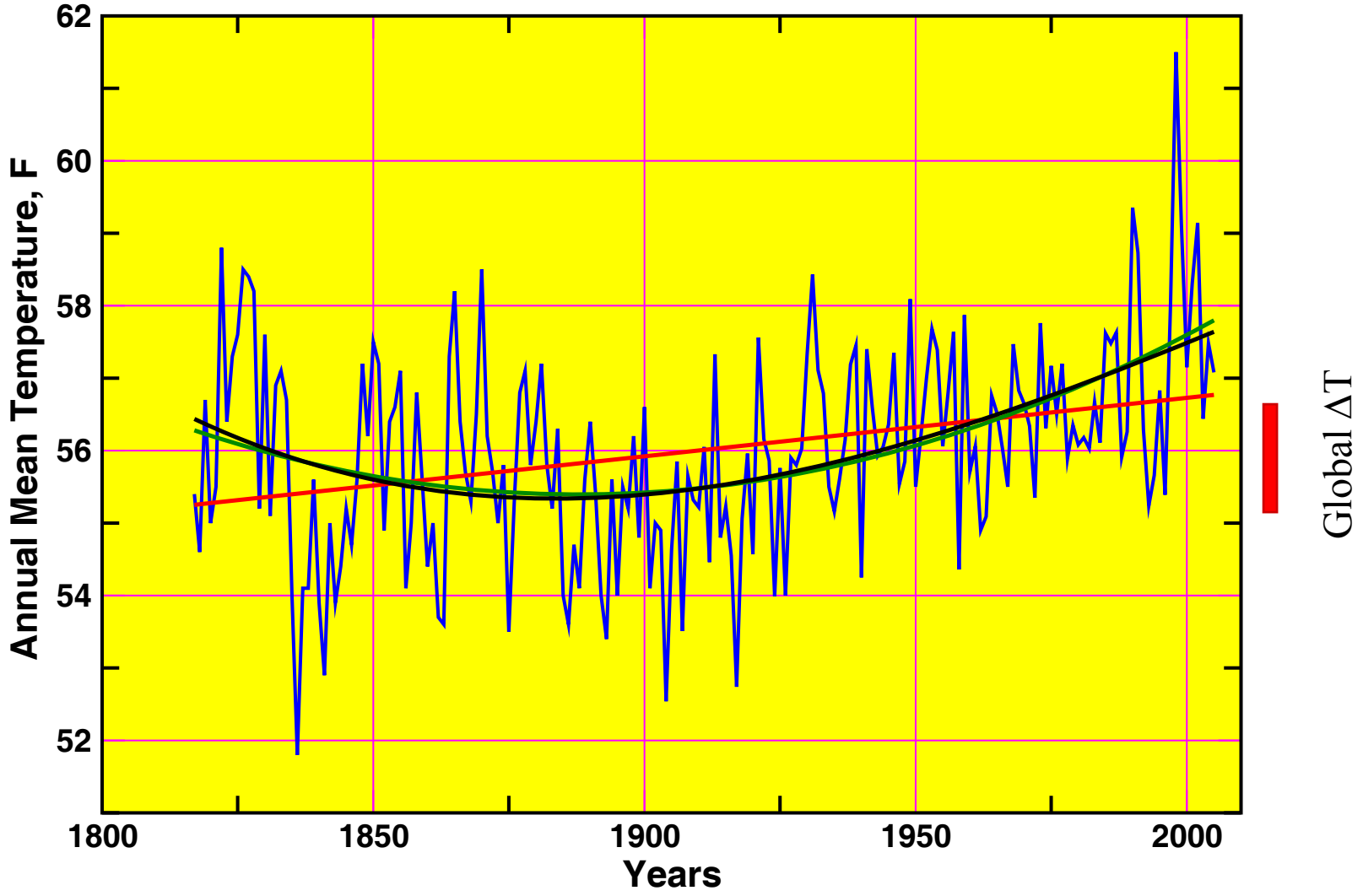
Climate Impact on Air Pollution

- "Climate change penalty" (Shiliang et al., 2008) of 2-8 ppb [O_3] by 2050 says Harvard's model.
- Photochemical smog events generally arrive with heat waves, and the IPCC (2007) predicts more frequent heat waves.
- Slower cyclonic waves and more high pressure events [Mickley et al., *GRL*, 2004].


Global Temperature: Land-Ocean Index
Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000
Annual Mean
5-year Mean

BALTIMORE, MD. ANNUAL TEMPERATURE 1817-2005

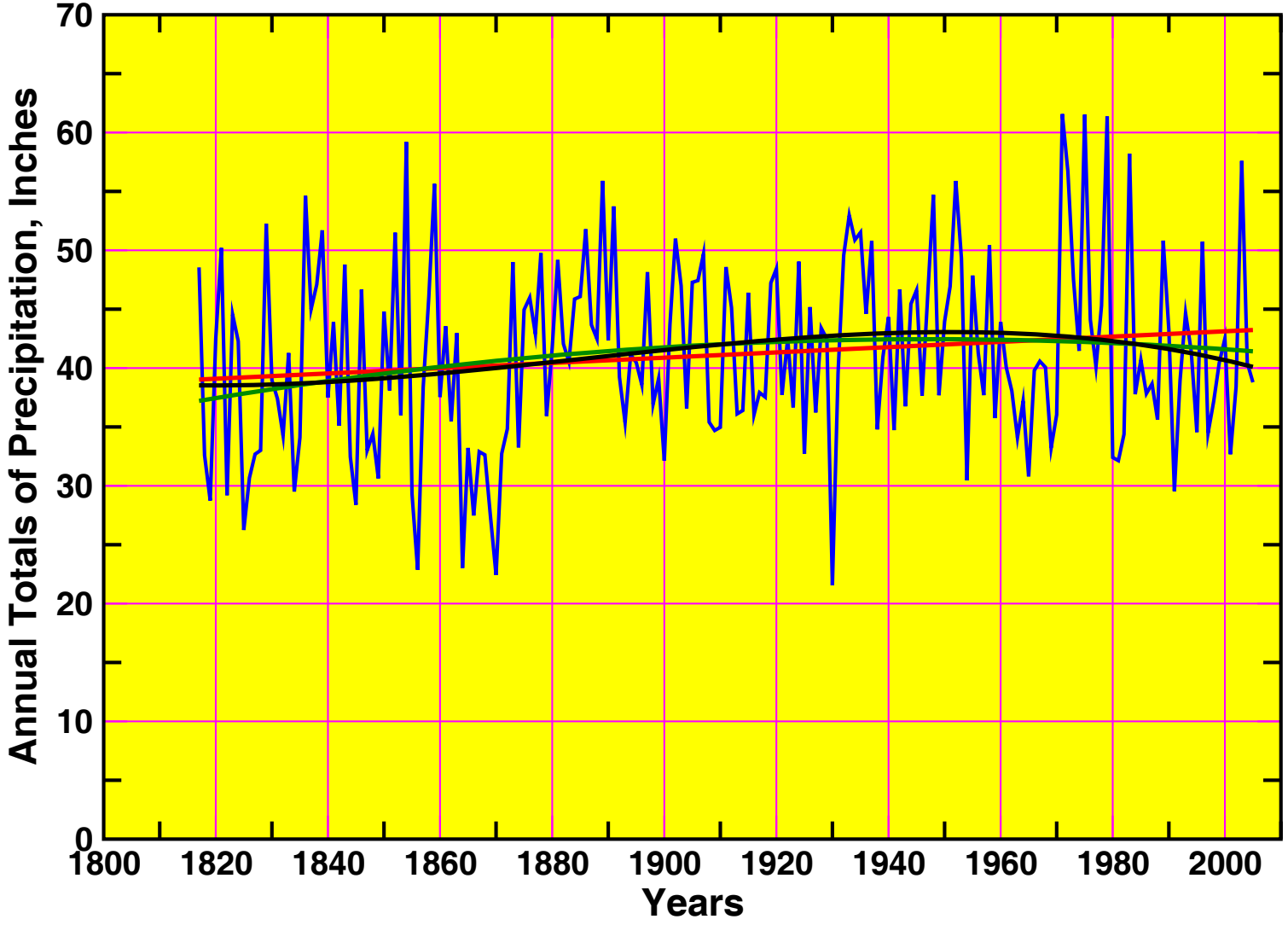
Observed Data and Trend Estimates (Linear, Quadratic, Cubic)



1817-1903: Maryland Weather Service Report, Vol. 2, pp.93-94. 1907.
1904-2005: US Historical Climatology Network. Baltimore WSO City. Observed data are corrected to remove local urbanization effect.

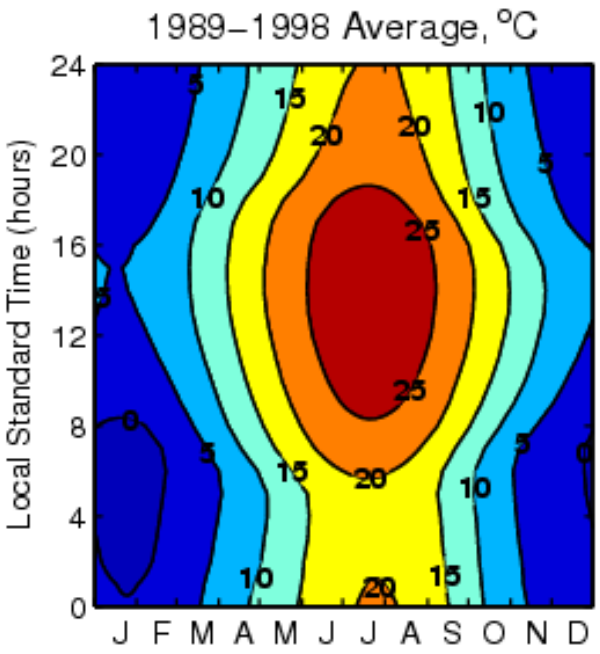
BALTIMORE, MD. ANNUAL PRECIPITATION 1817-2005

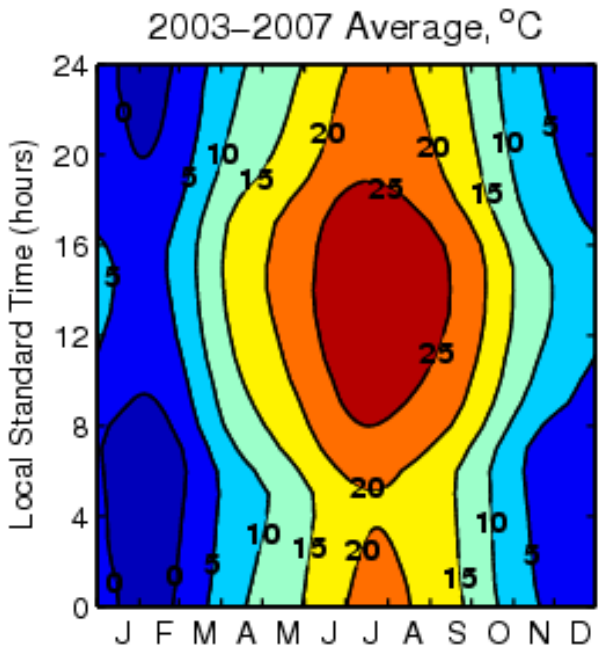
Observed Data and Trend Estimates (Linear, Quadratic, Cubic)

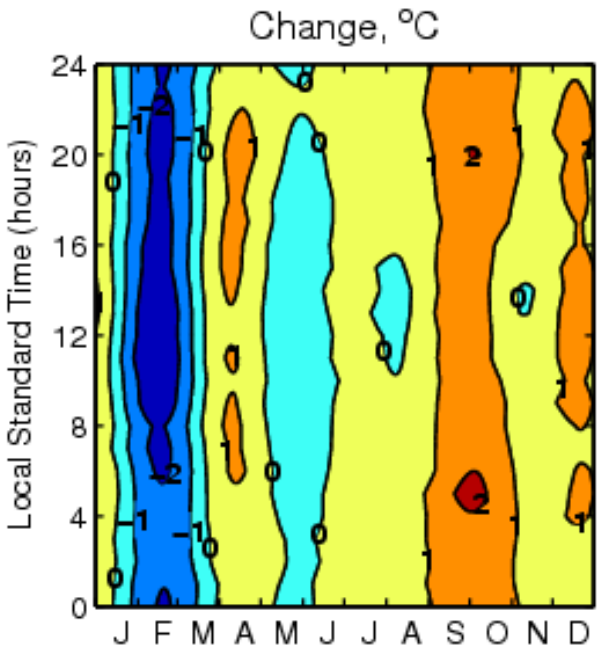


1817-1871 & 1895-1896: Maryland Weather Service Report, Vol. 2, pp.186-187. 1907.
1872-1894 & 1897-2005: US Historical Climatology Network. Baltimore WSO City.

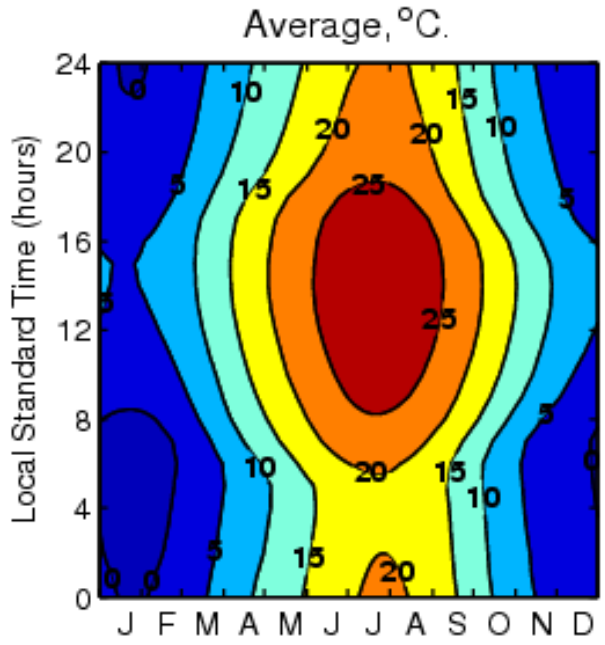
CHANGE of AIR TEMPERATURE AVERAGES from 1989–1998 to 2003–2007. BELTSVILLE, MD

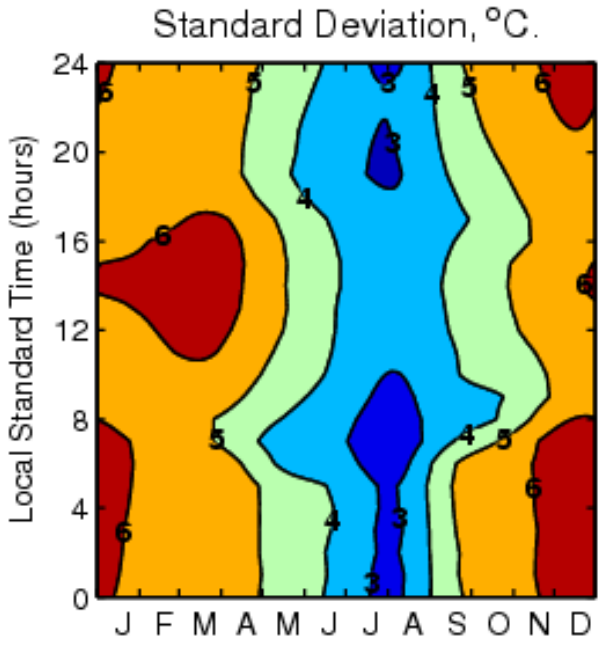


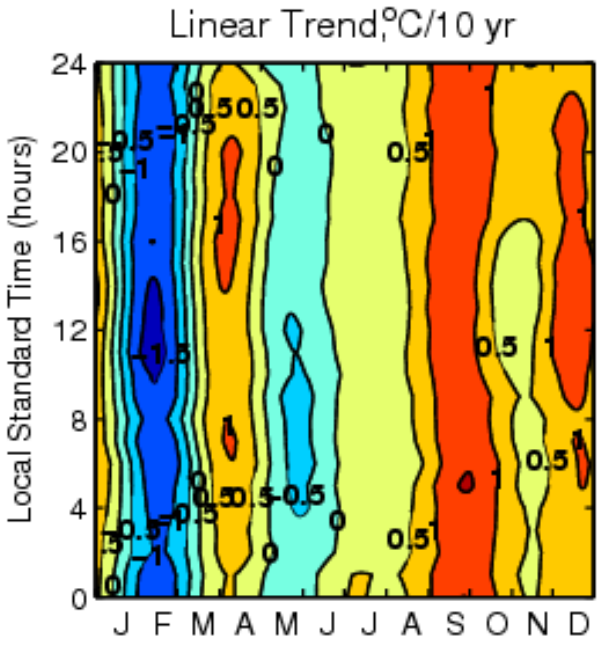




Air Temperature 1989–2007, BELTSVILLE, MD

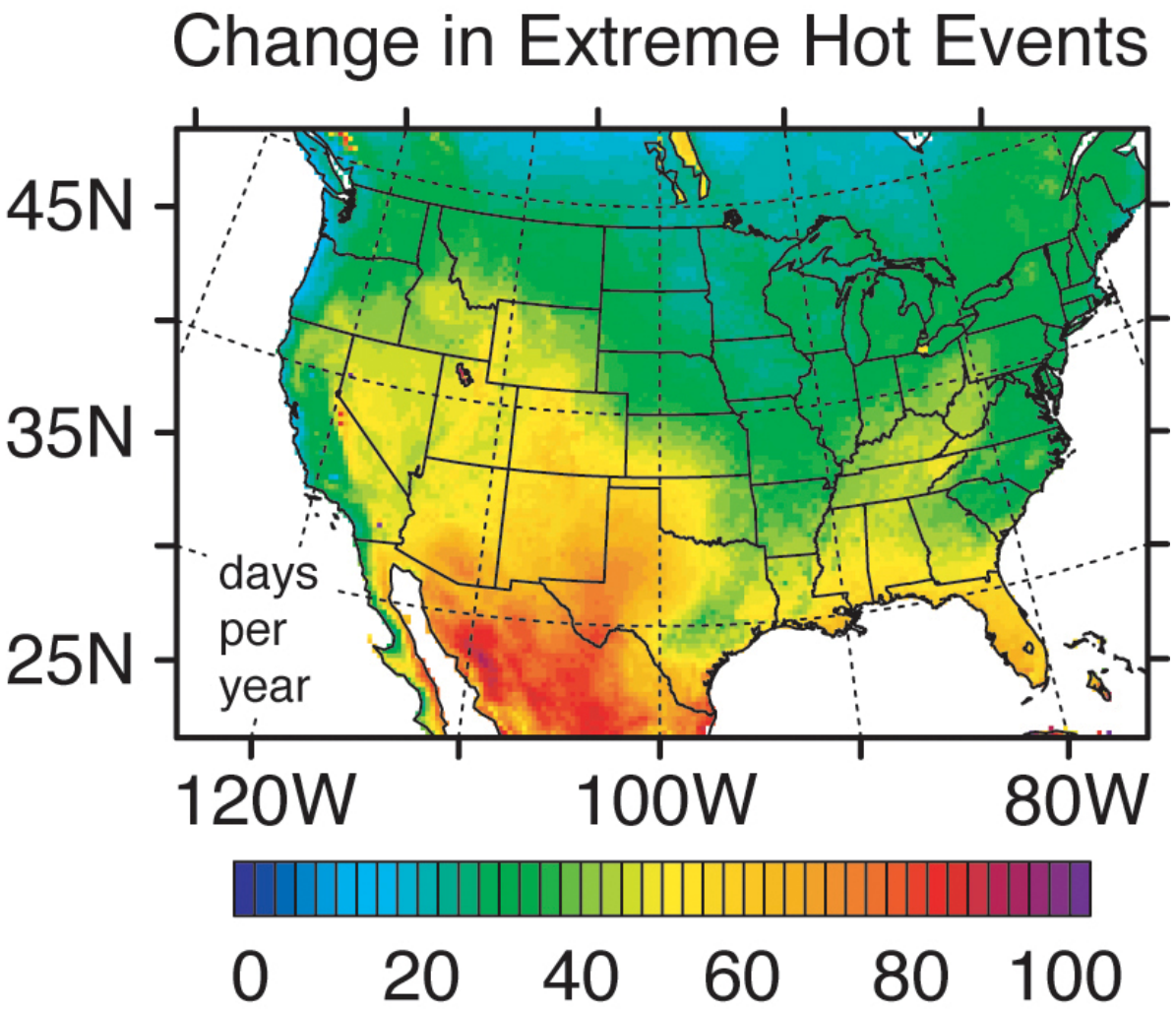






The observed increase in summer temperatures (more than 1°C/decade) exceeds that attributable to global change.

Thanks to Dr. Vinnikov,
Acting (unfunded) State Climatologist

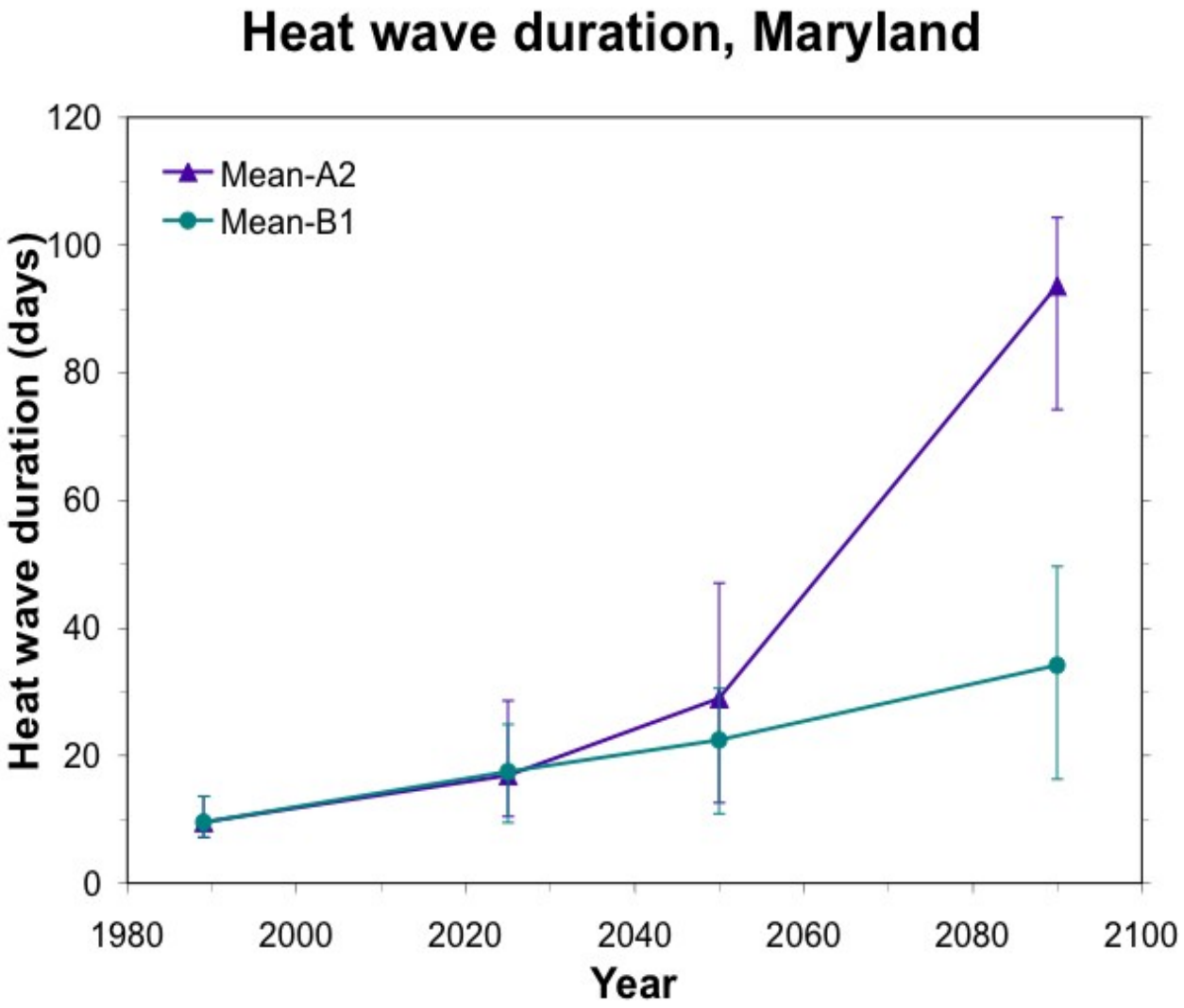


Heat waves:

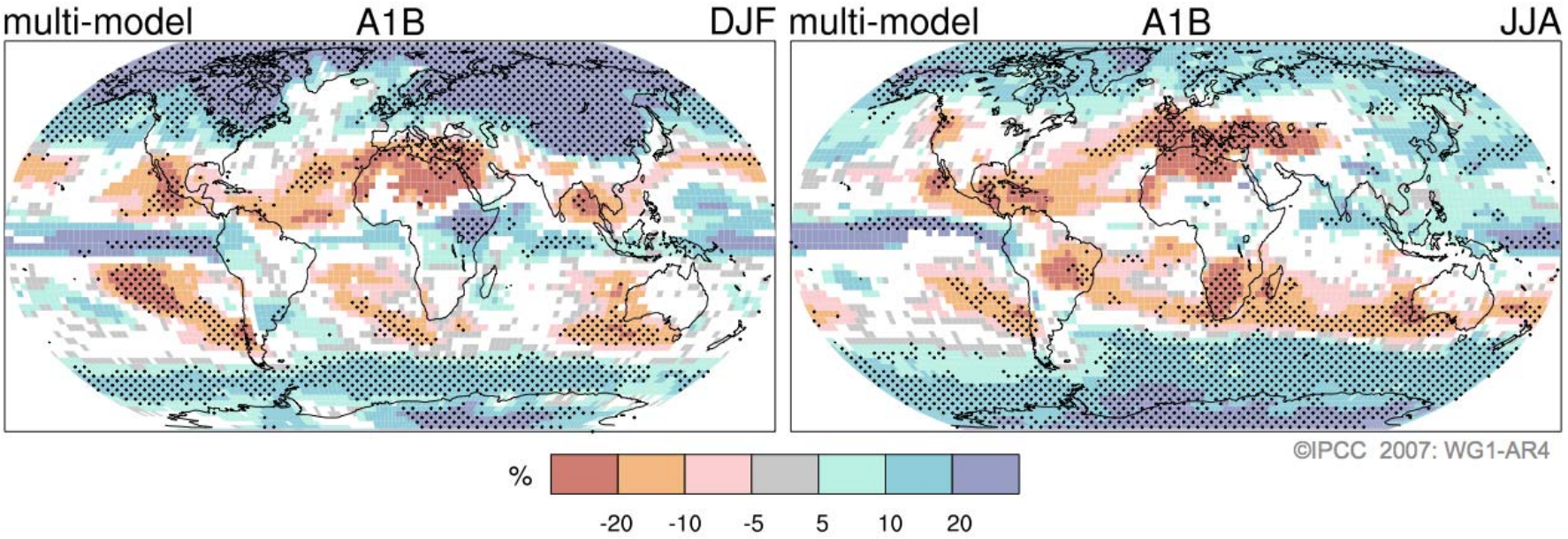
"Rare events, like the 2003 heat wave in Europe, will become much more common…" said Noah Diffenbaugh, the Purdue professor who led the study. "The frequency at which this scale of event occurs at high greenhouse gas concentrations is staggering. Rare events become the norm, and the extreme events of the future are unprecedented in their severity."

Consensus IPCC Predictions From V. Coles, CBL

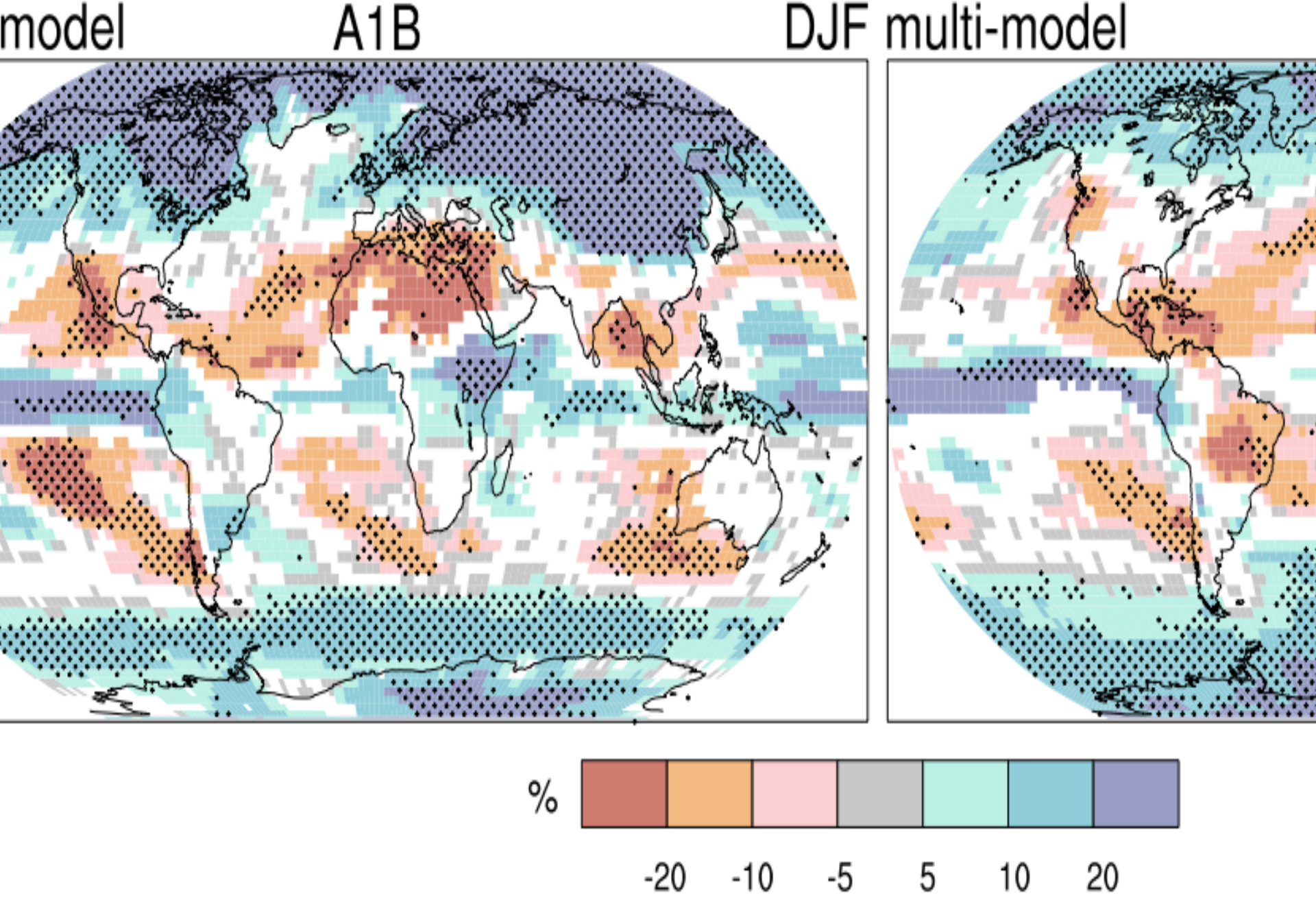
Climate Change Comm. Draft Rpt.



Projected Patterns of Precipitation Changes



- Small increase in winter precipitation predicted for Mid Atlantic.


model
A1B
DJF multi-model
%
-20
-10
-5
5
10
20

Recent Model Predictions

• **Increase** of 3-5 ppb in 8-hr average ozone over the eastern US [*Hogrefe et al.*, *JGR*, 2004].

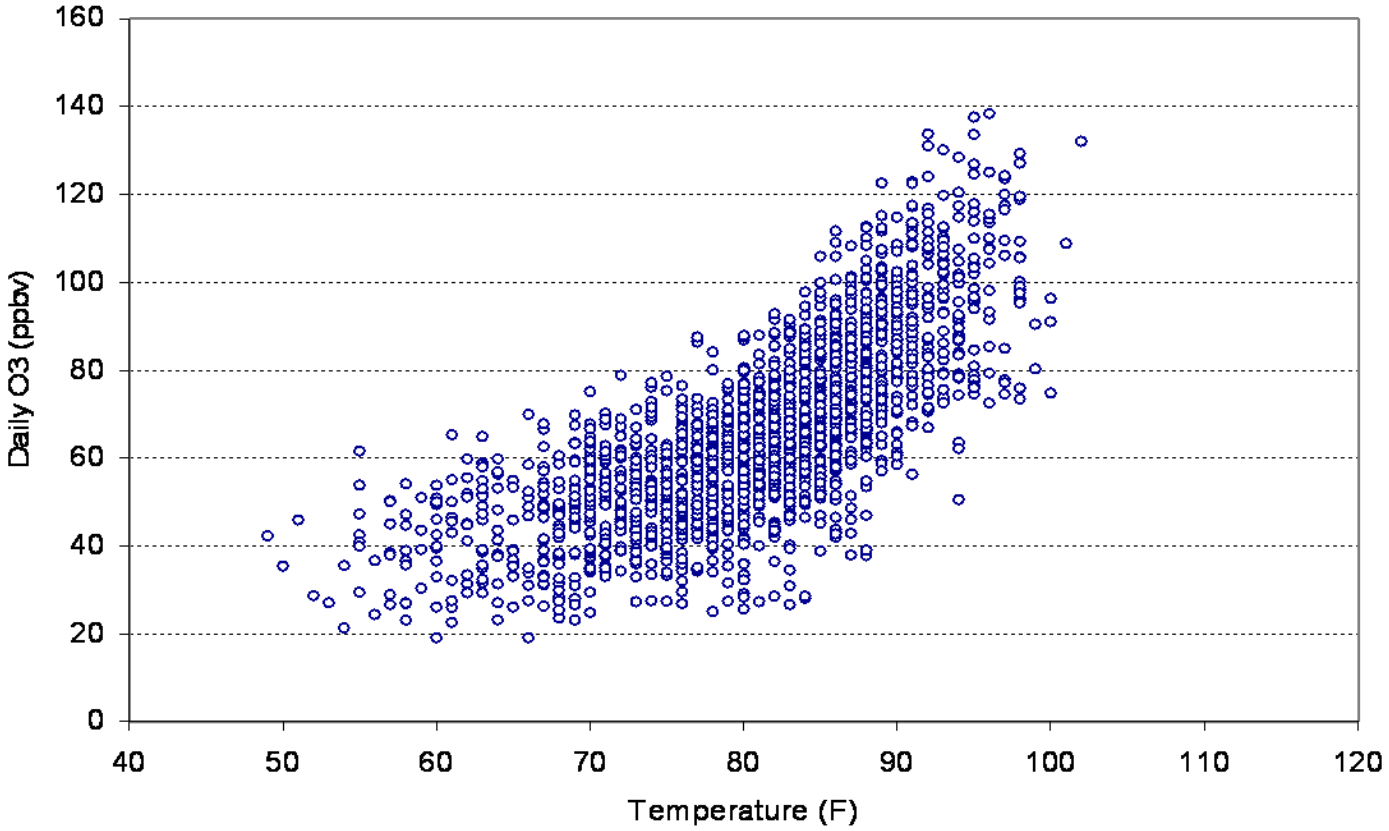
• **Increase** of 10-20 ppb in 8-hr average ozone over the eastern US by 2100 [*Pyle et al.*, *Phil. Trans.*, 2007].

• Climate change impact on smog and haze **small** compared to emissions effects [*Tagaris et al.*, *JGR*, 2007].

• Increasing temperatures will **decrease PM2.5** due to dissociation of ammonium nitrate [*Dawson et al.*, ACP, 2007].

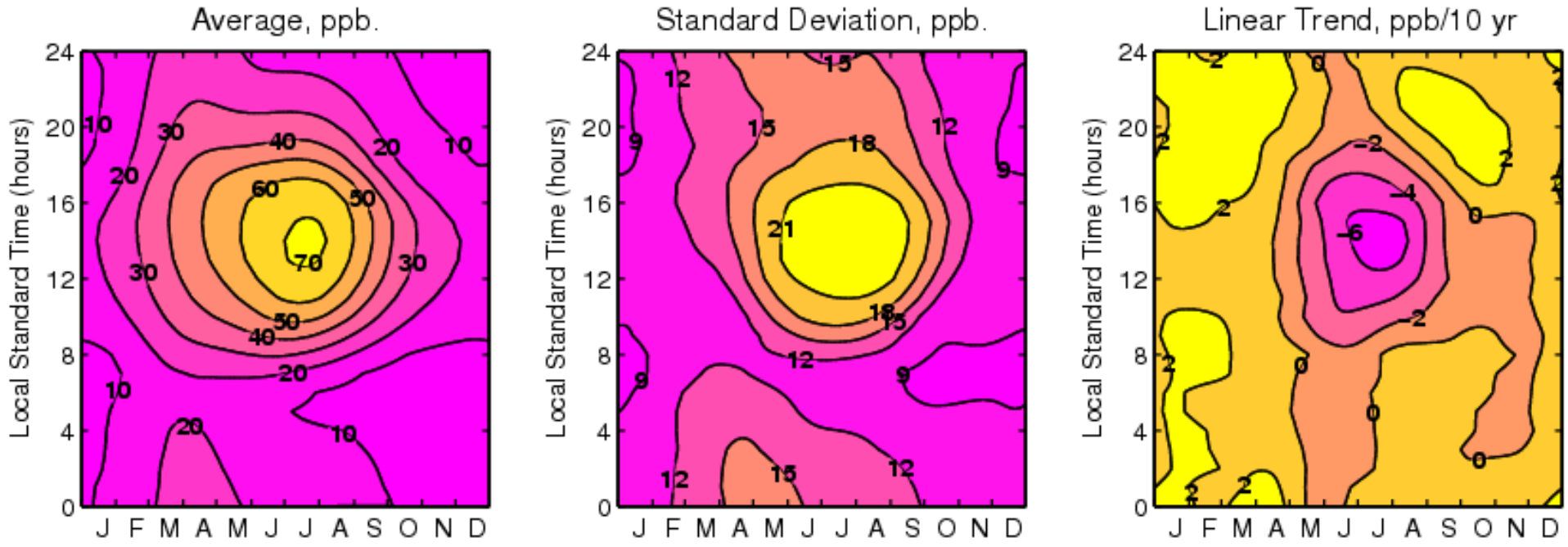
• Increasing temperatures and increasing precipitation will **increase** N deposition [*Civerolo et al.*, *Atmos. Environ.* , 2008].

- Mid Atlantic air quality (ozone and $PM_{2.5}$) has improved, but how does it depend on weather?

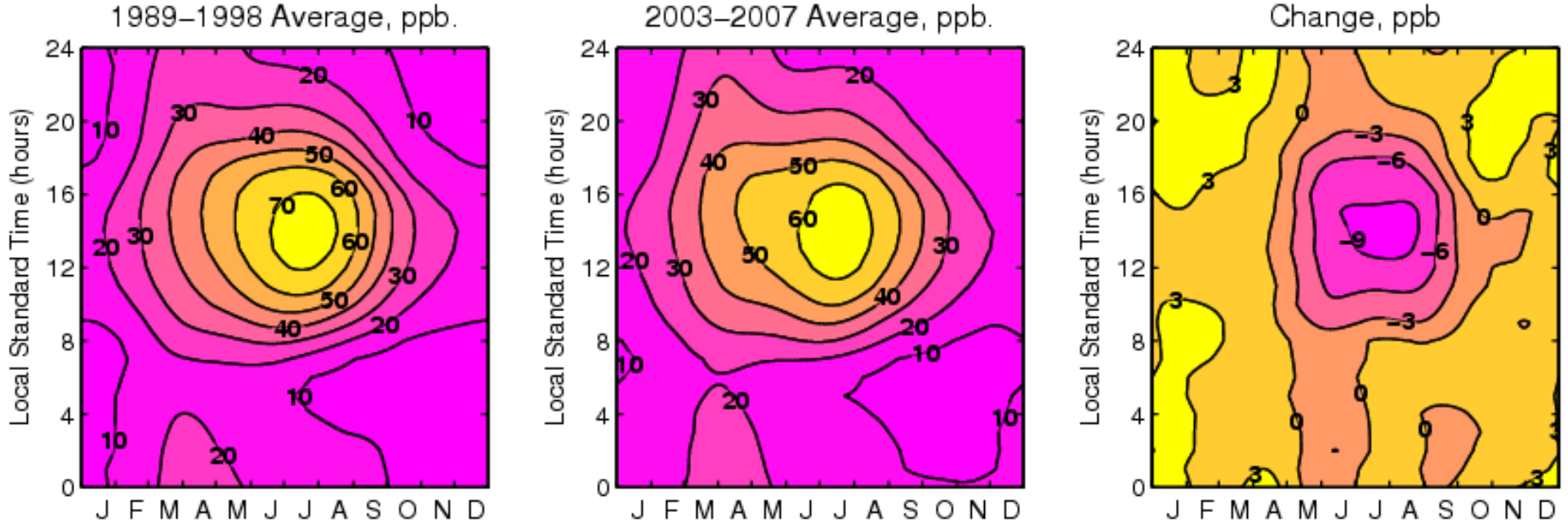


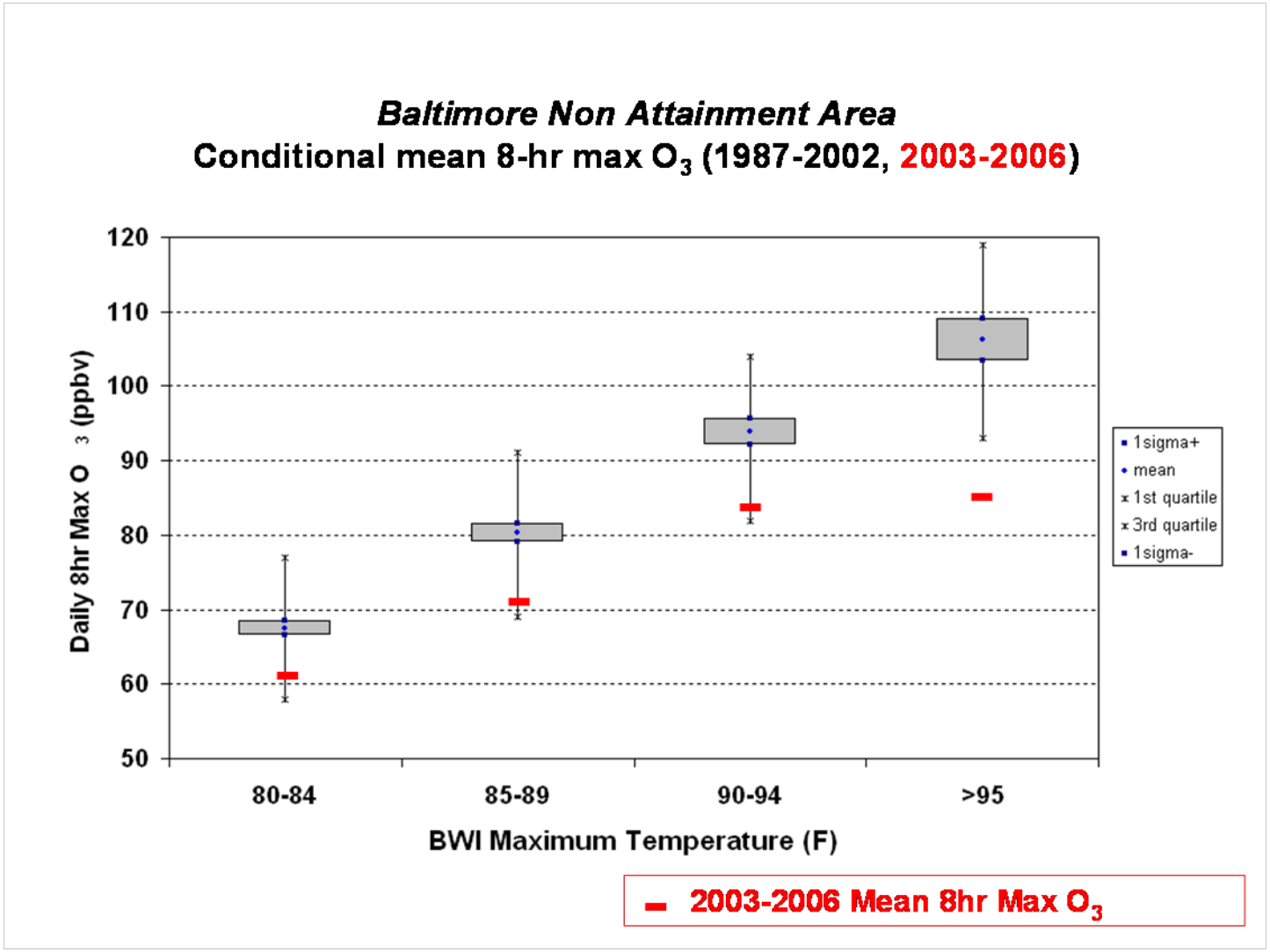
Response of ozone to Maximum temperature measured in Baltimore. 1994-2004

OZONE 1989–2007, BELTSVILLE, MD

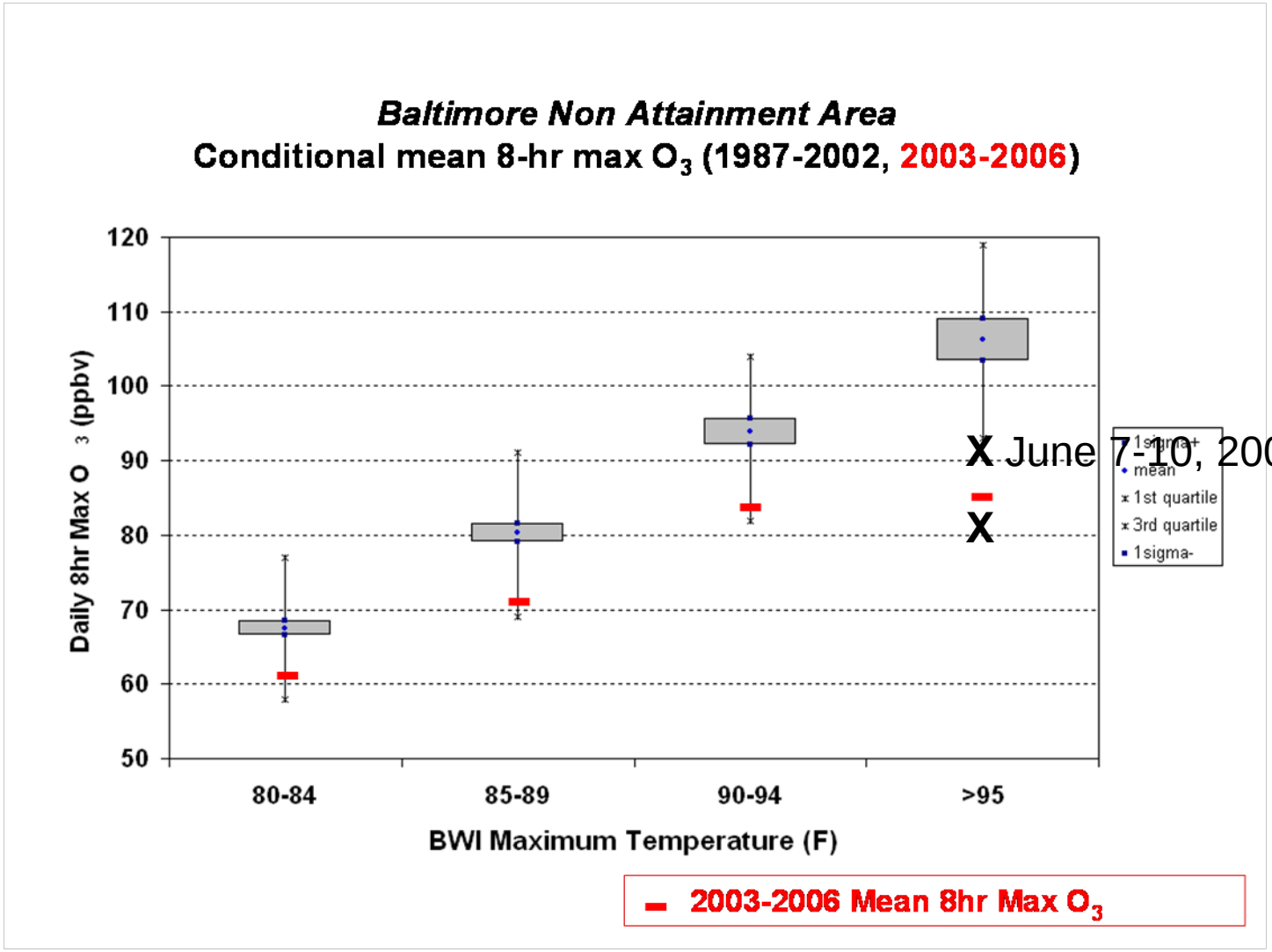


CHANGE of OZONE AVERAGES from 1989–1998 to 2003–2007. BELTSVILLE, MD





Demonstration of the success of the NOx emissions reduction associated with the SIP Call. Prior to the decrease in emissions (large gray boxes), ozone was higher in all temperature categories. After power plants were cleaned up in 2003 and 2004 (small red marks), ozone was reduced substantially.



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Look at all CASTNET sites in the eastern US*

Temperature and ozone records since 1987.
(> 1,000,000 obs)

What impact did the NOx SIP Call have on ozone?

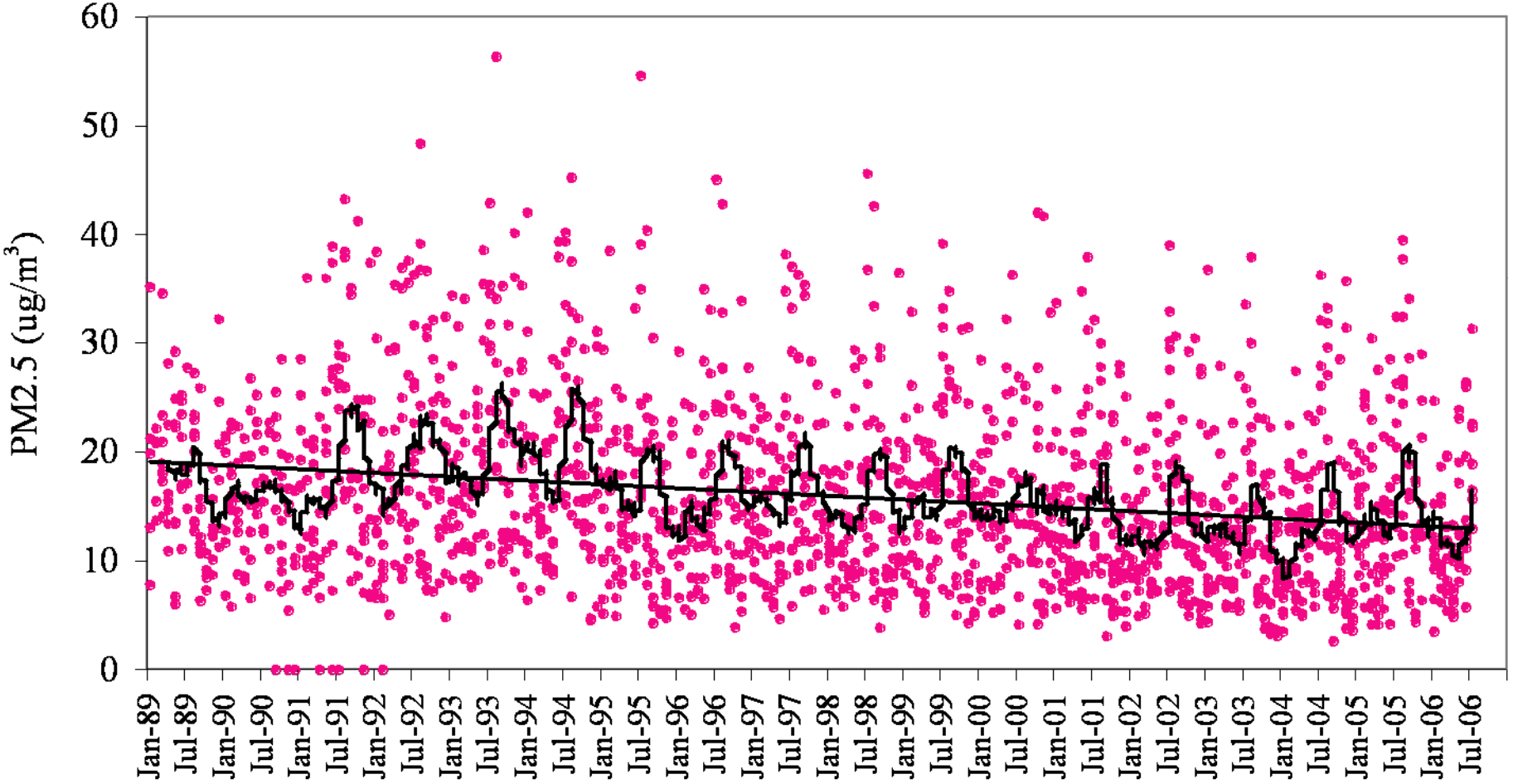
Overall Median: 41 → 38 ppb
Median of 8-hr max: 74 → 70 ppb
95 percentile for hot days: 111 → 86 ppb

Slope ~ 2-4 ppb/◦C.

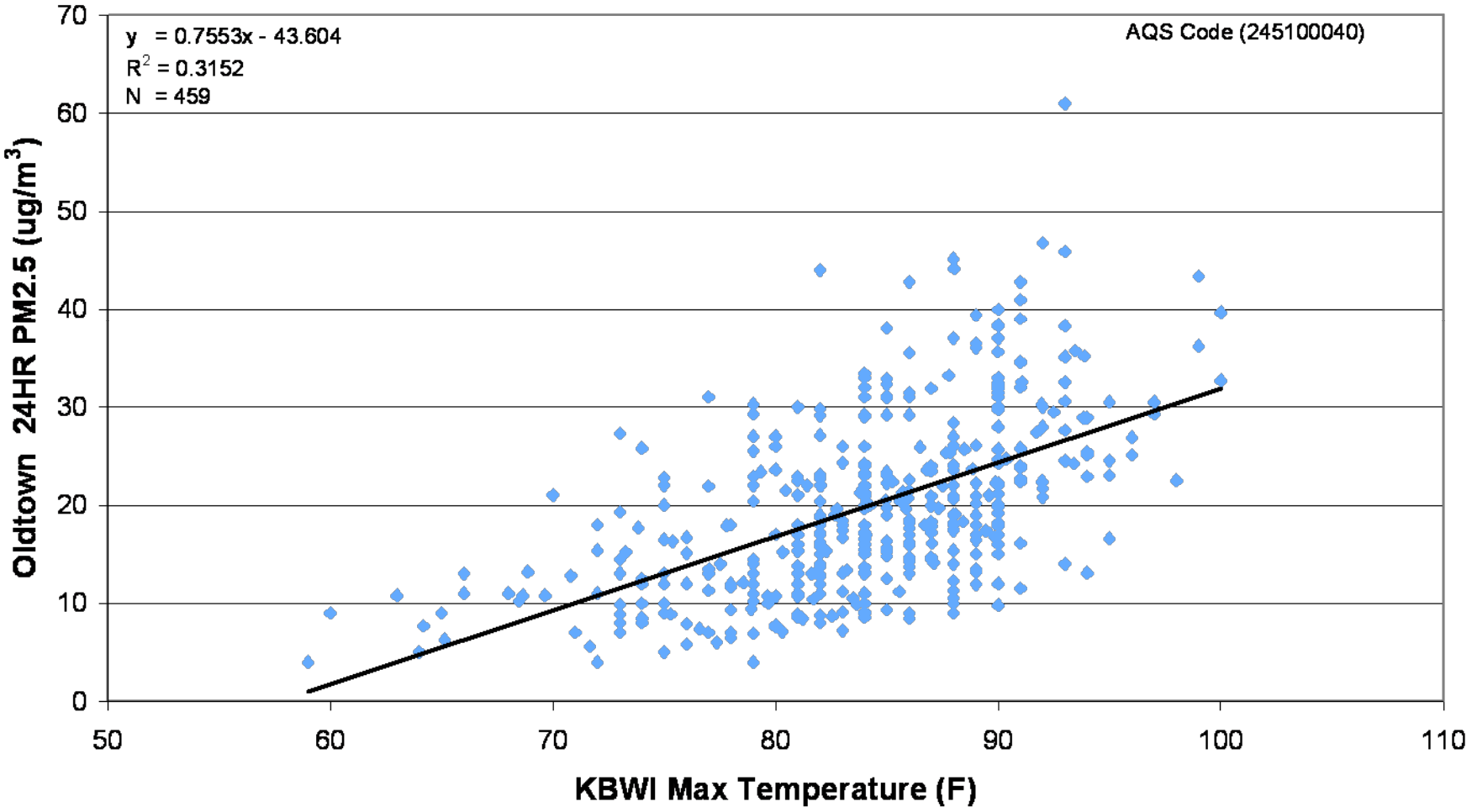
***Bloomer et al. in press 2008.**

Is there more PM on hot days?

Washington, DC PM2.5
Improve every 3rd day Observations (1989-2006)
Linear Trend and 30-Point running mean

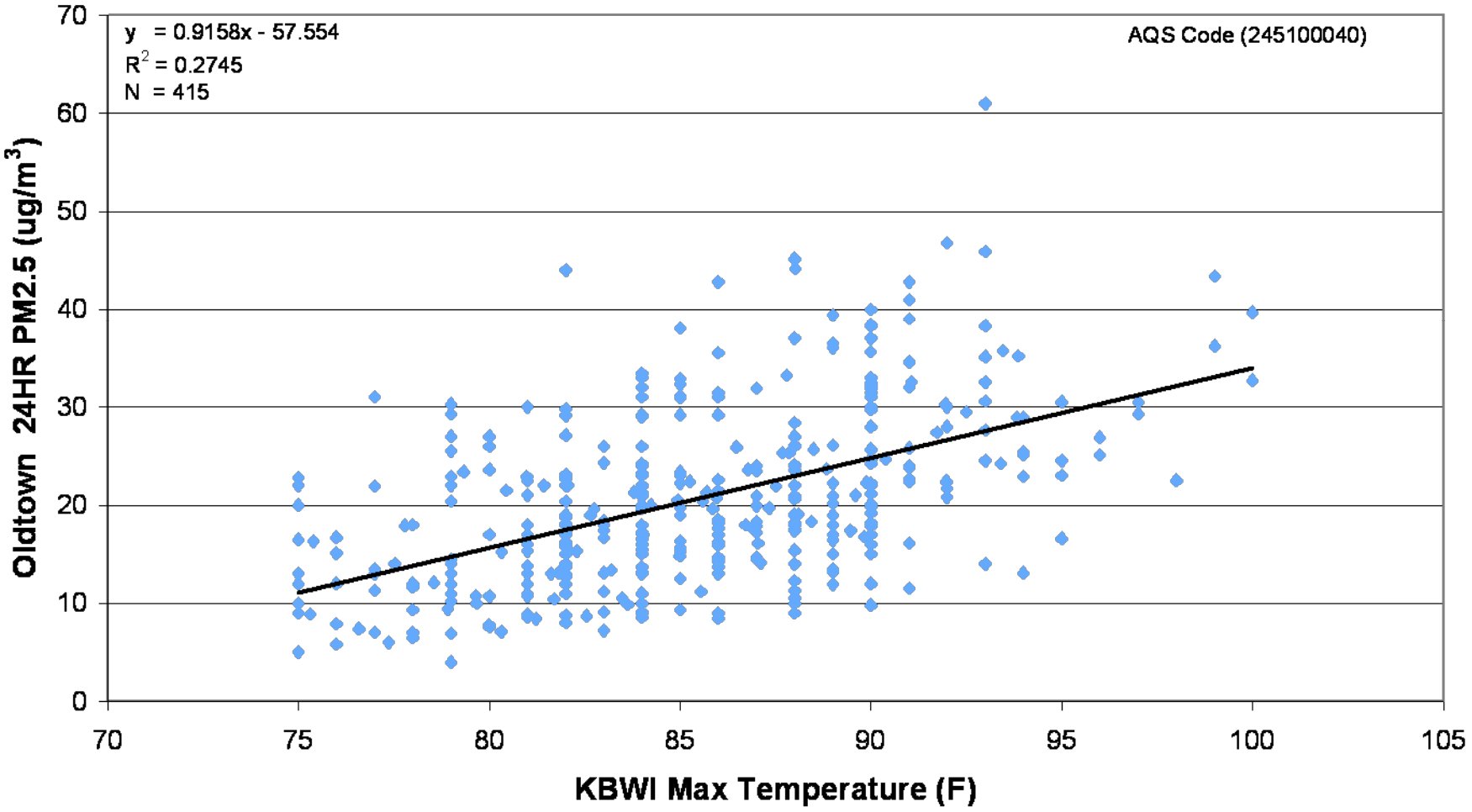


Peak 24HR PM2.5 (Oldtown) vs. Max Temperature (KBWI)
(2003-2007 June-August)



Peak 24HR PM2.5 (Oldtown) vs. Max Temperature (KBWI)

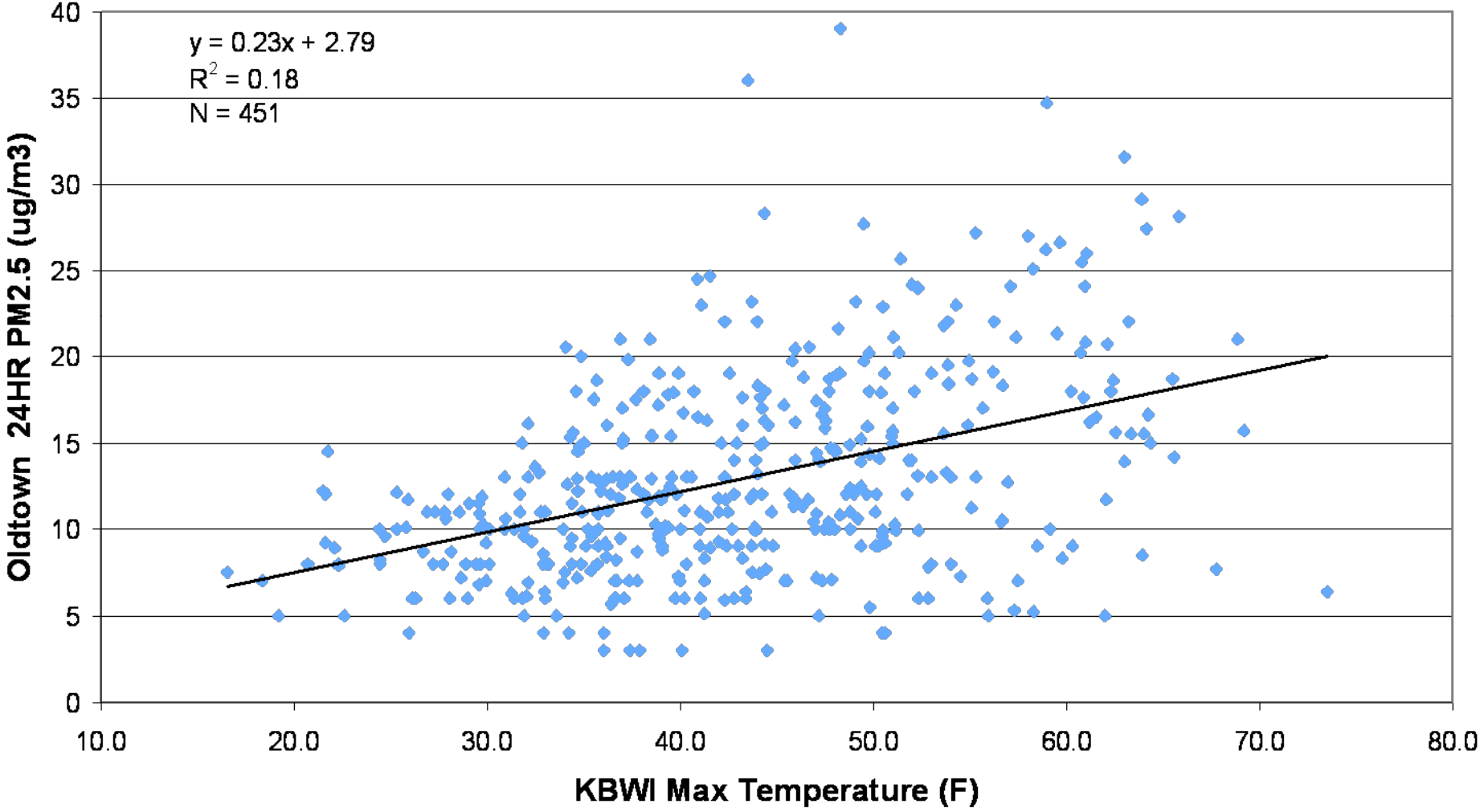
(2003-2007 June, July, August $T \geq 75°F$)



Why is there more PM on hot days?

- In summer hotter weather means faster release of pollutants (e.g., isoprene and evap. emissions) and faster photochemistry for oxidation of SO_2 and organic compounds.
- Does the same apply in winter?

Peak 24HR PM2.5 (Oldtown) vs. Max Temperature (KBWI)
(2003-2007 December-February)



How much can we do to mitigate local climate change?

What would happen if we replaced all of the urban landscape of Baltimore and Washington with forests?

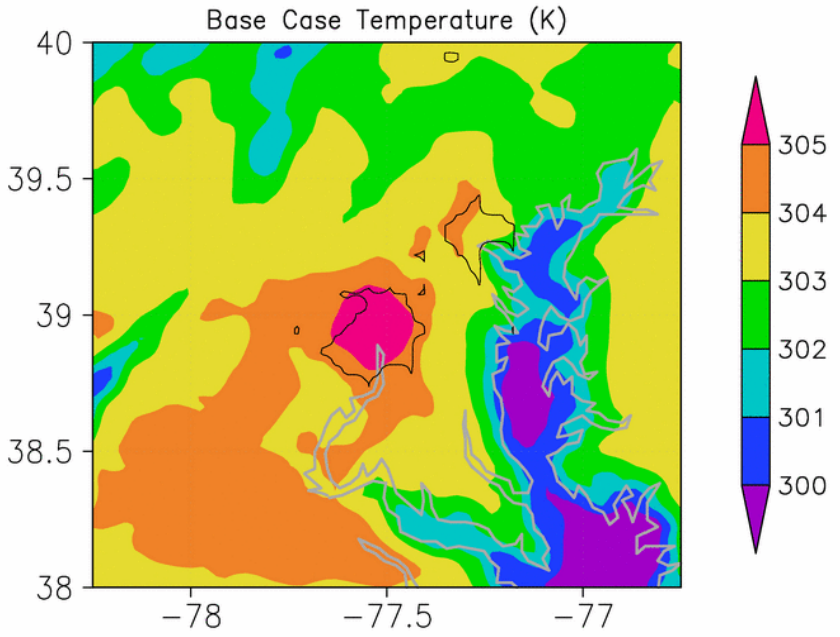
Thanks to Da-Lin Zhang and Chris Loughner.

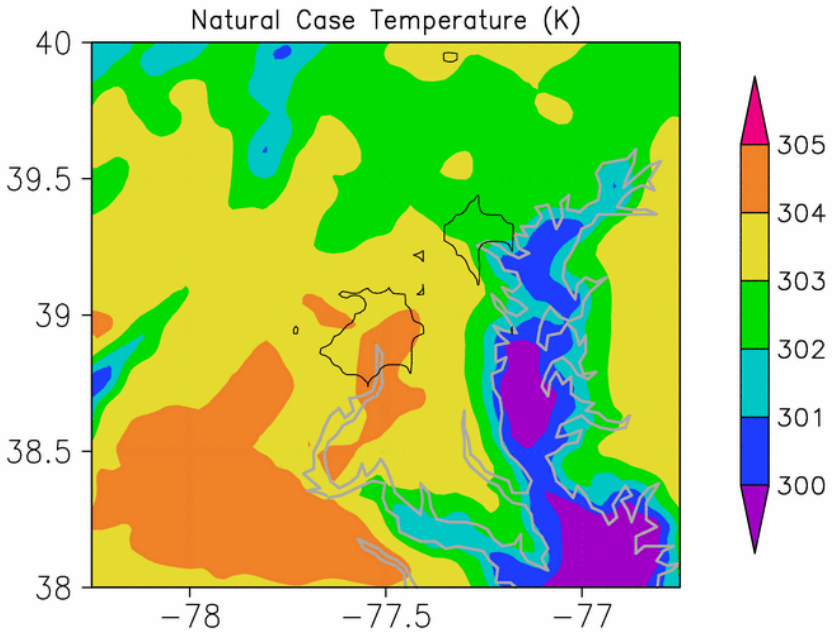
For MM5 Modeling

USGS land-use / land-cover classification for urban and broadleaf deciduous forest surface parameters.

	Urban	Broadleaf Deciduous Forest
albedo (%)	15	16
Moisture availability (%)	10	30
emissivity (% at 9 μm)	88	93
roughness length (cm)	80	50
thermal inertia (cal cm^{-2} K^{-1} $s^{-1/2}$)	0.03	0.04
heat capacity (Jm^{-3} K^{-1})	1.67	2.63

What happens if all urban areas are replaced with forests? Near surface temperature at 3pm EDT August 6, 2006. Urban areas outlined in black and coastline is outlined in gray.

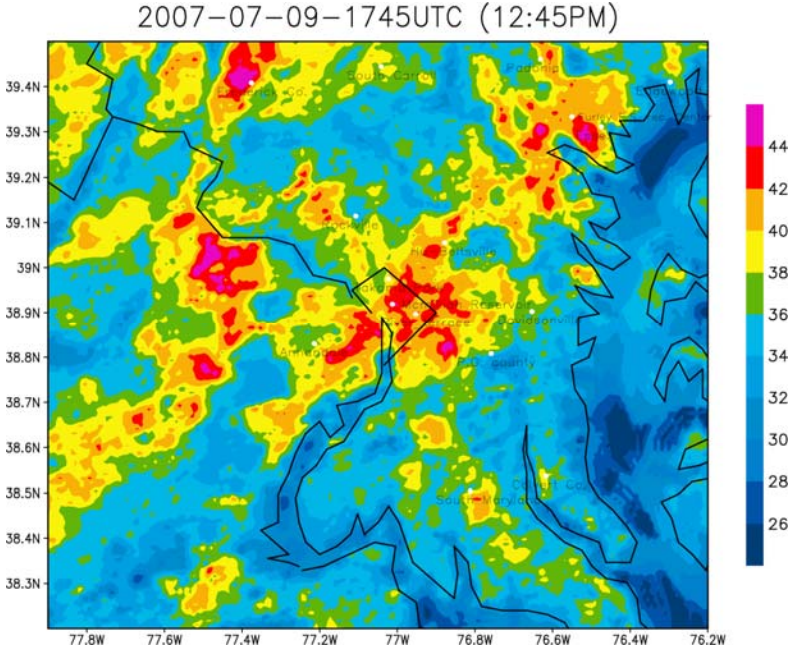




These figures compare near surface temperatures for the base- and natural-cases. Temperatures over urban areas (Baltimore, MD and Washington, DC) are higher by 1-2 K (2-4 f) in the base case confirming the presence of the urban heat island.

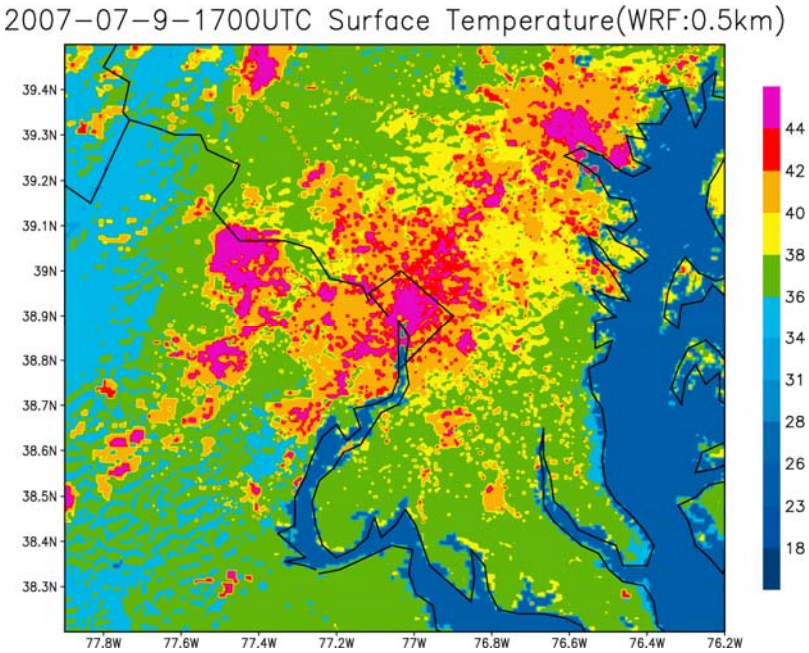
How well can WRF-Urban simulate effect of local land use on skin Temperature?

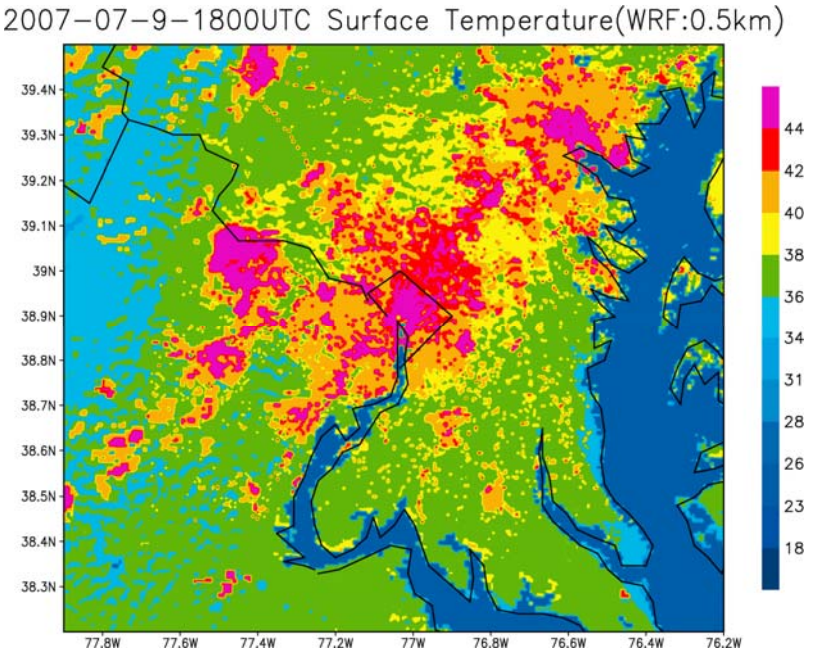
Thanks to Da-Lin Zhang



a

b c



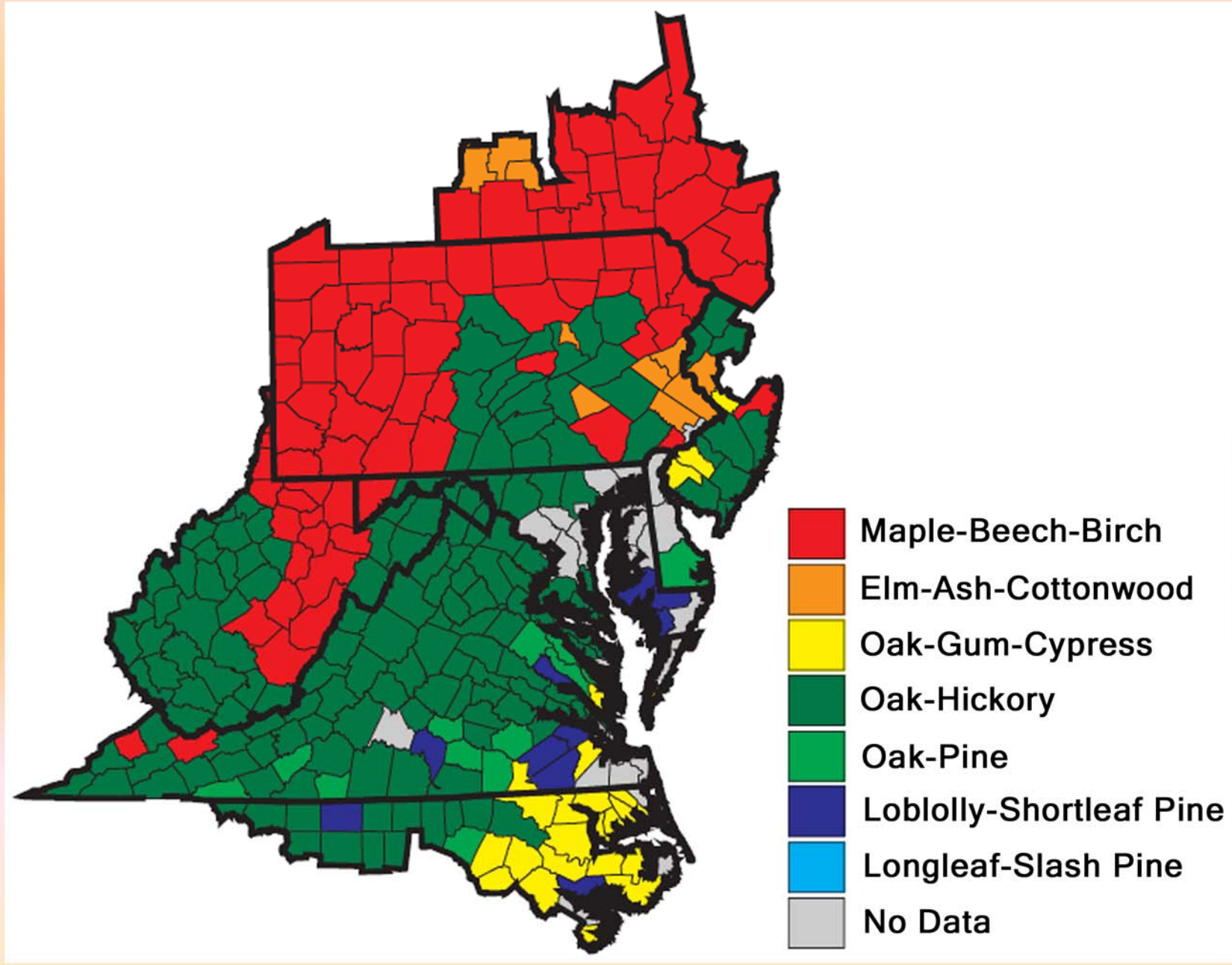


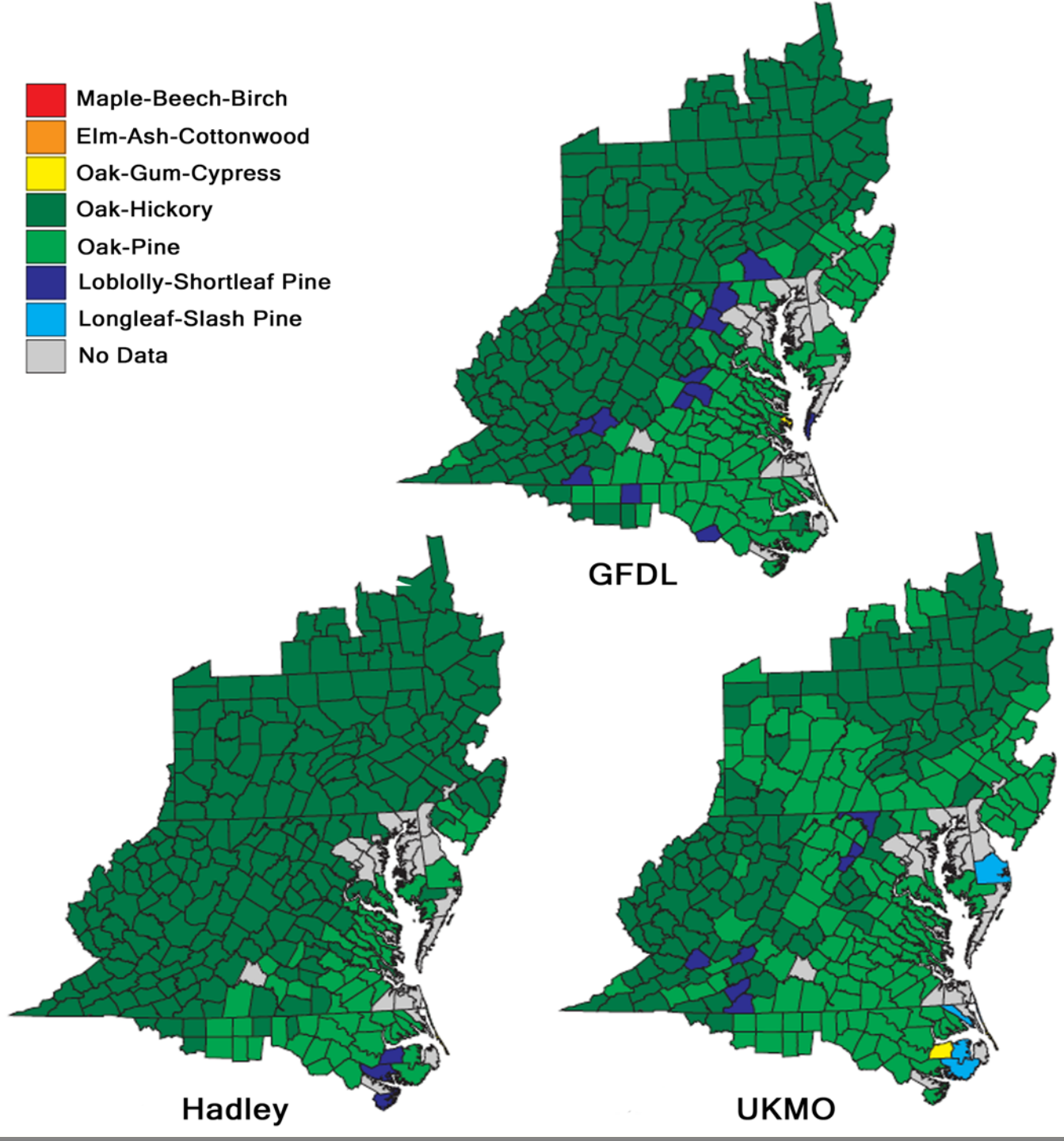
Surface skin temperature (Unit:C) a) MODIS observation at 17:45UTC Jul 9 2007

b) WRF simulation TSK at 17:00UTC c) WRF simulation TSK at 18:00UTC Jul 9 2007 (Resolution :500m)

How might local ecosystems change and what impact might this have on air quality?

Current distribution of major forest types in the Mid-Atlantic Region (McKenney-Easterling et al. 2004).





Predicted dominant forest type distribution for GFDL, Hadley, and UKMO 2 X CO_2 equilibrium scenarios (McKenney-Easterling et al. 2004).

Conclusions

- The Mid-Atlantic appears to have gotten warmer already and to be headed for more heat waves.
- Heat waves are associated with smog and haze events. **Observed climate change penalty 2-4 ppb/°C.**
- Natural forest cover could shift northward.
- Land use (more trees) could help avoid 2-4 F of the warming.

Conclusions continued

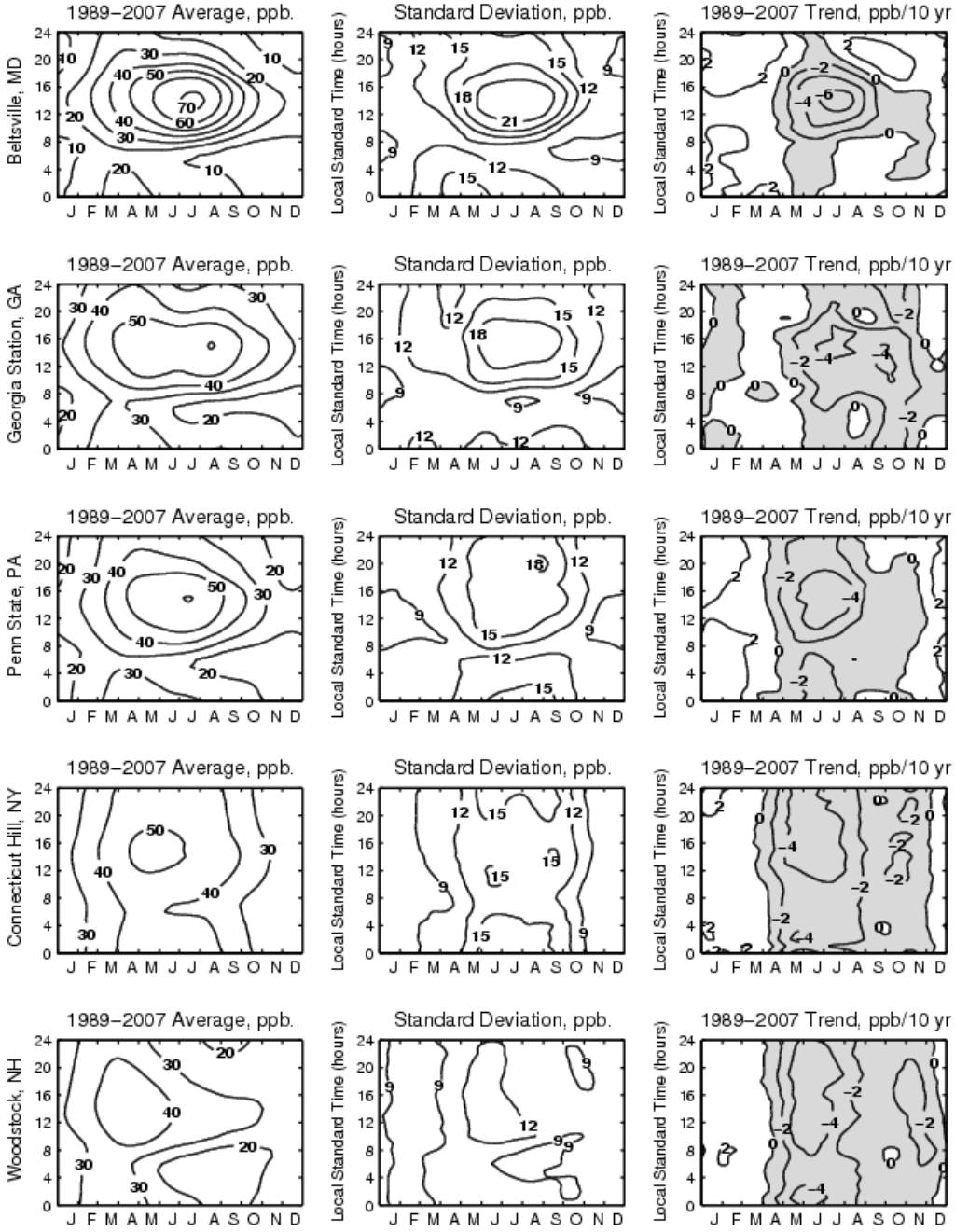
- Changing climate could undo America's progress on smog and haze.
- More severe weather could increase flooding and ironically also increase drought.
- The right changes in land use could mitigate the impacts of climate change, the wrong changes could amplify it.

Recommendations

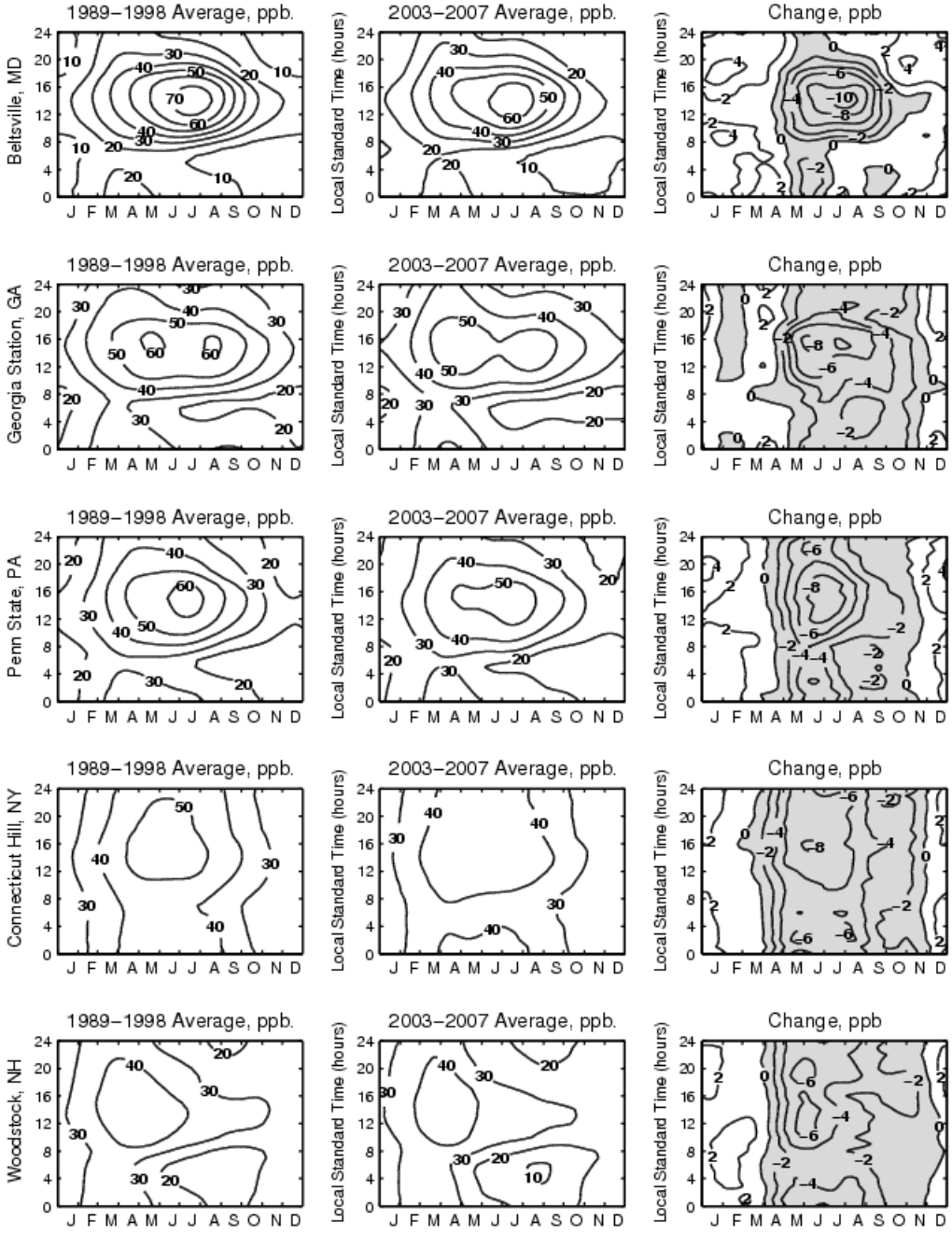
- Low hanging fruit:
  - black carbon (soot)
  - tropospheric ozone
  - N_2O
- Examine past climate (Data analysis).
- Evaluate CMAQ for weather impacts.
- Forecast future climate & pollution (Models).
- Start monitoring CO_2, CH_4, N_2O etc.

The End

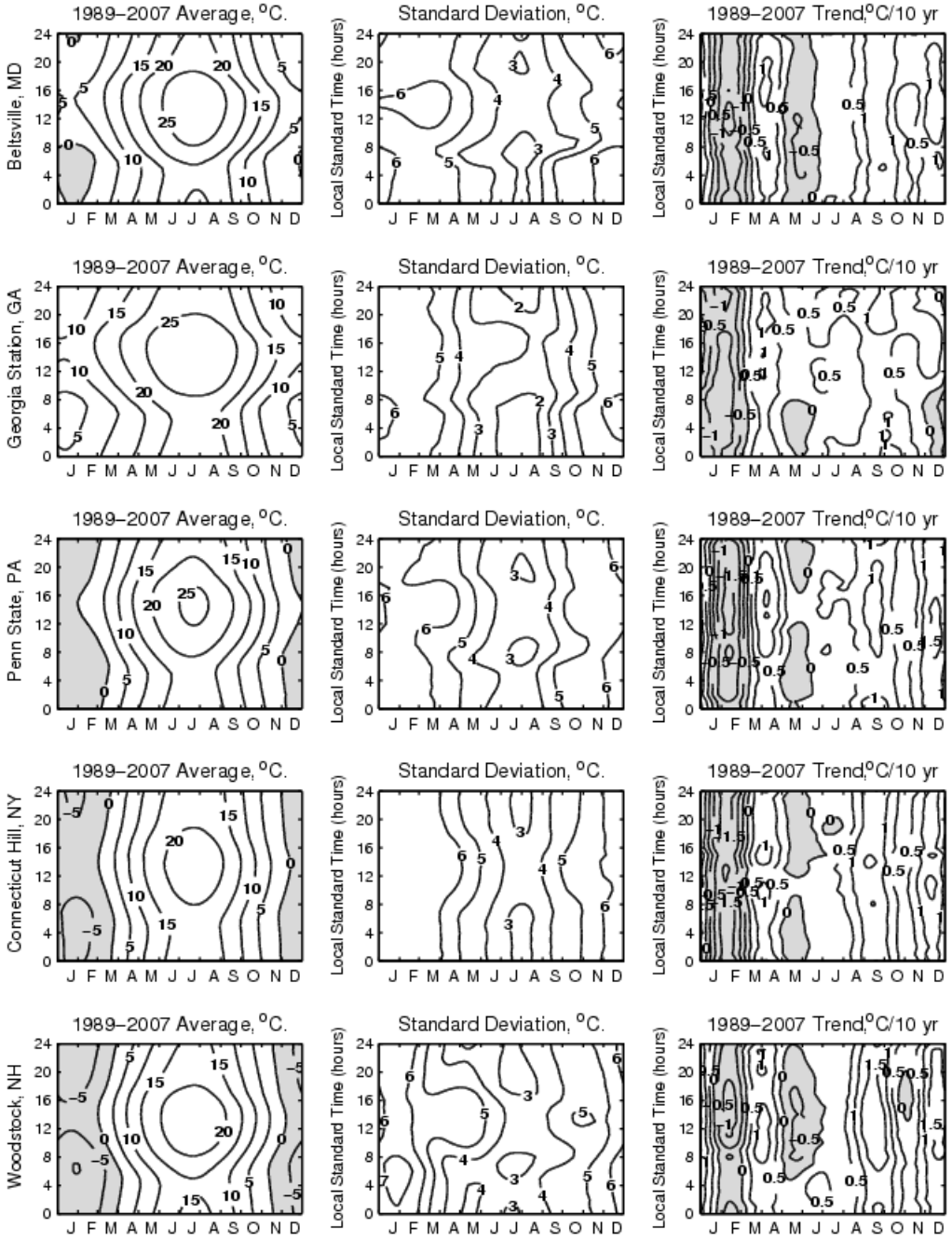
OZONE MONITORING, EPA CASTNET STATIONS



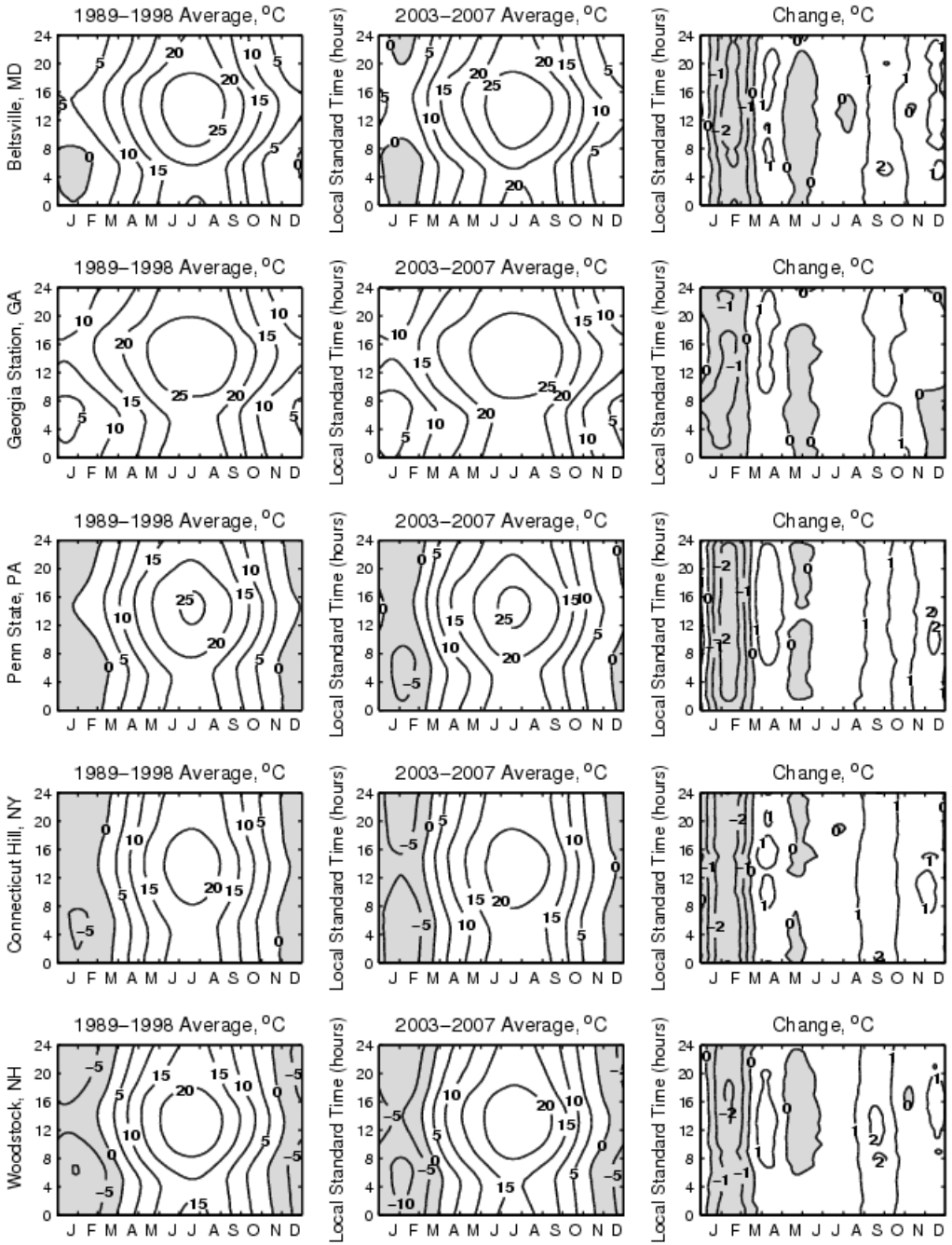
OZONE MONITORING, EPA CASTNET STATIONS



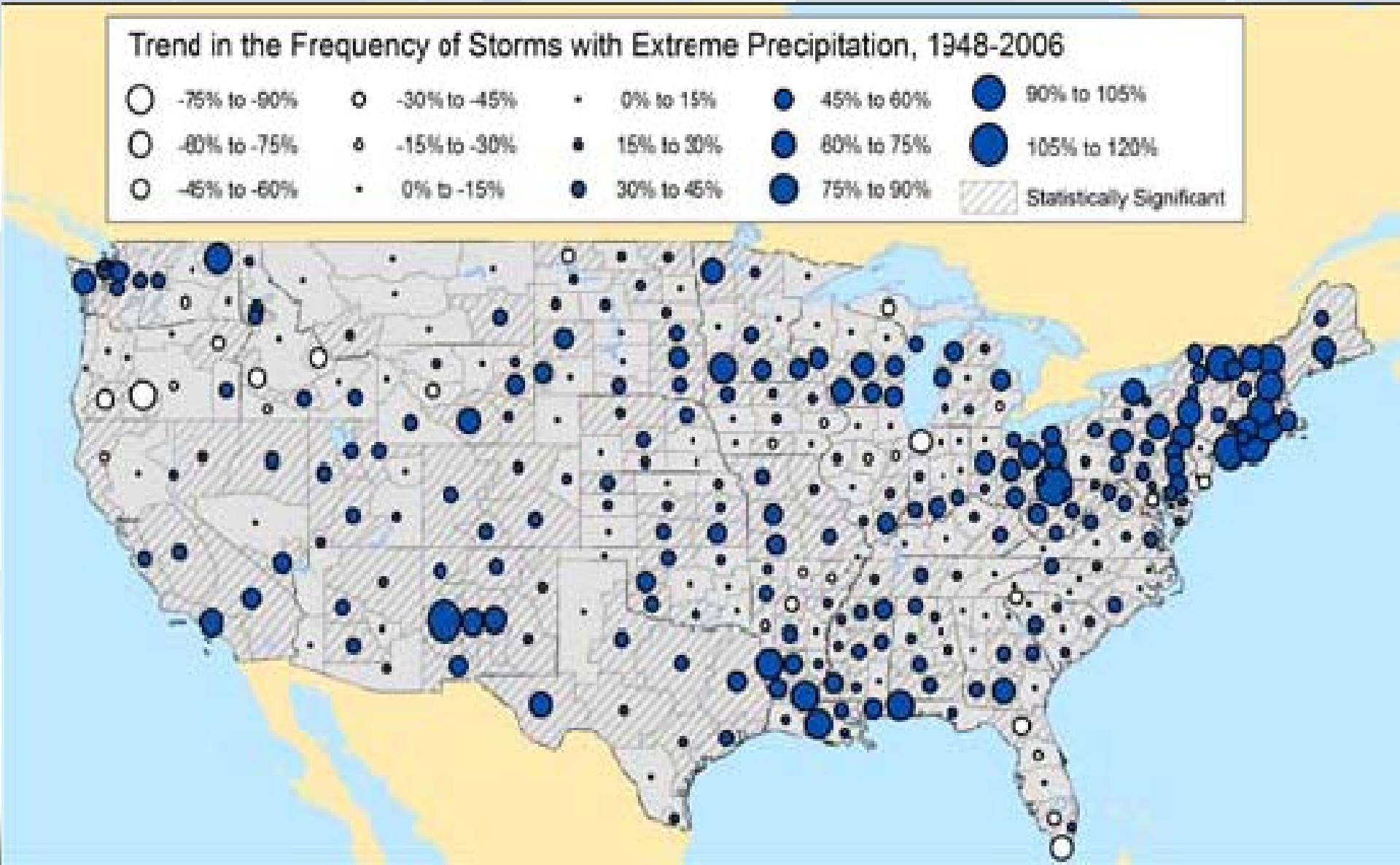
AIR TEMPERATURE MONITORING, EPA CASTNET STATIONS



AIR TEMPERATURE MONITORING, EPA CASTNET STATIONS



Madsen and Figdor, Environment America, Report December 2007.

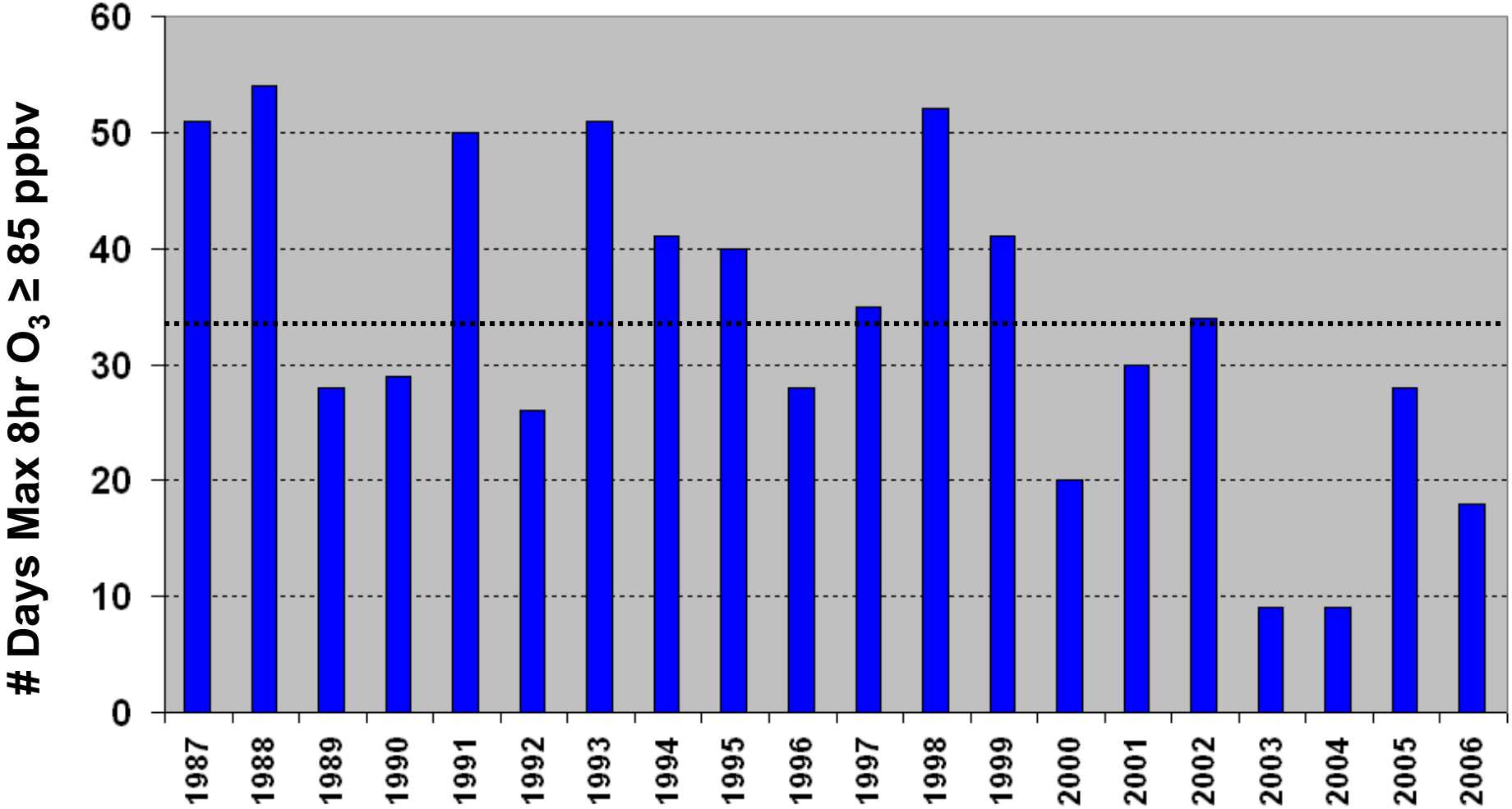


Extreme precipitation events Environment America says:

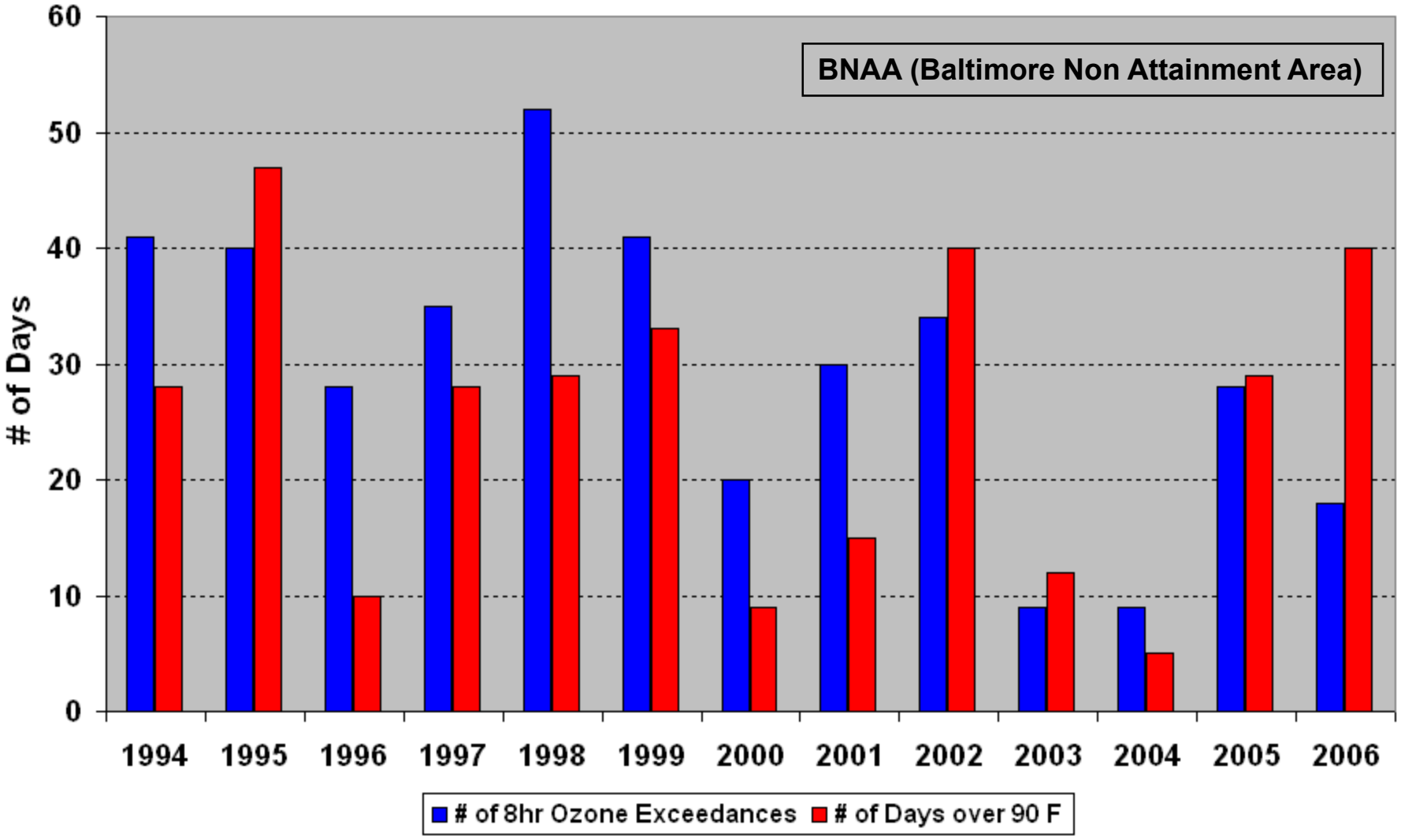
- Weather records show that storms with extreme precipitation have become more frequent over the last 60 years.
- New England and the Mid-Atlantic experienced the largest increase in extreme precipitation frequency.

This report has not appeared in the reviewed literature.

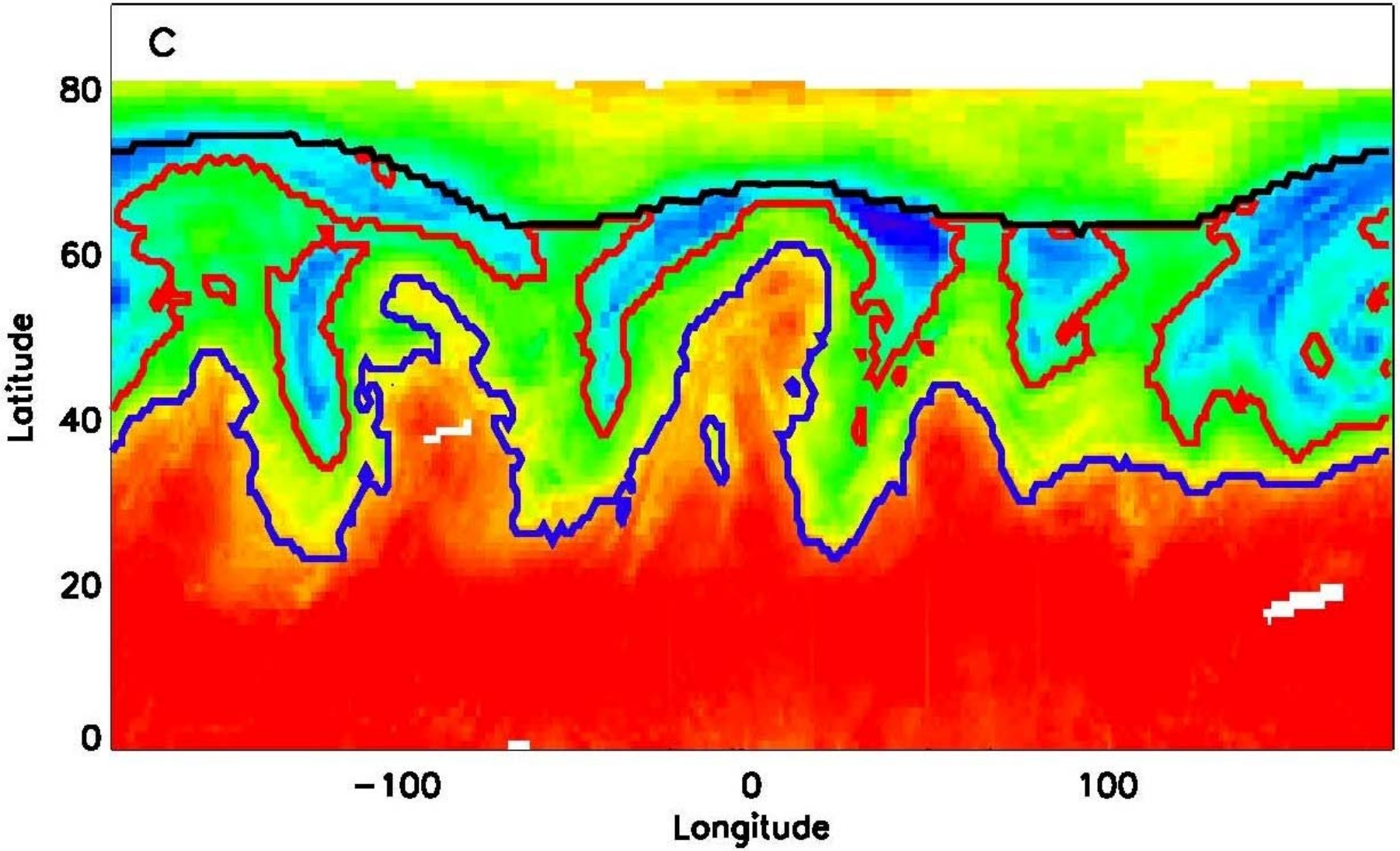
Ozone Violations Over the Baltimore Nonattainment Area



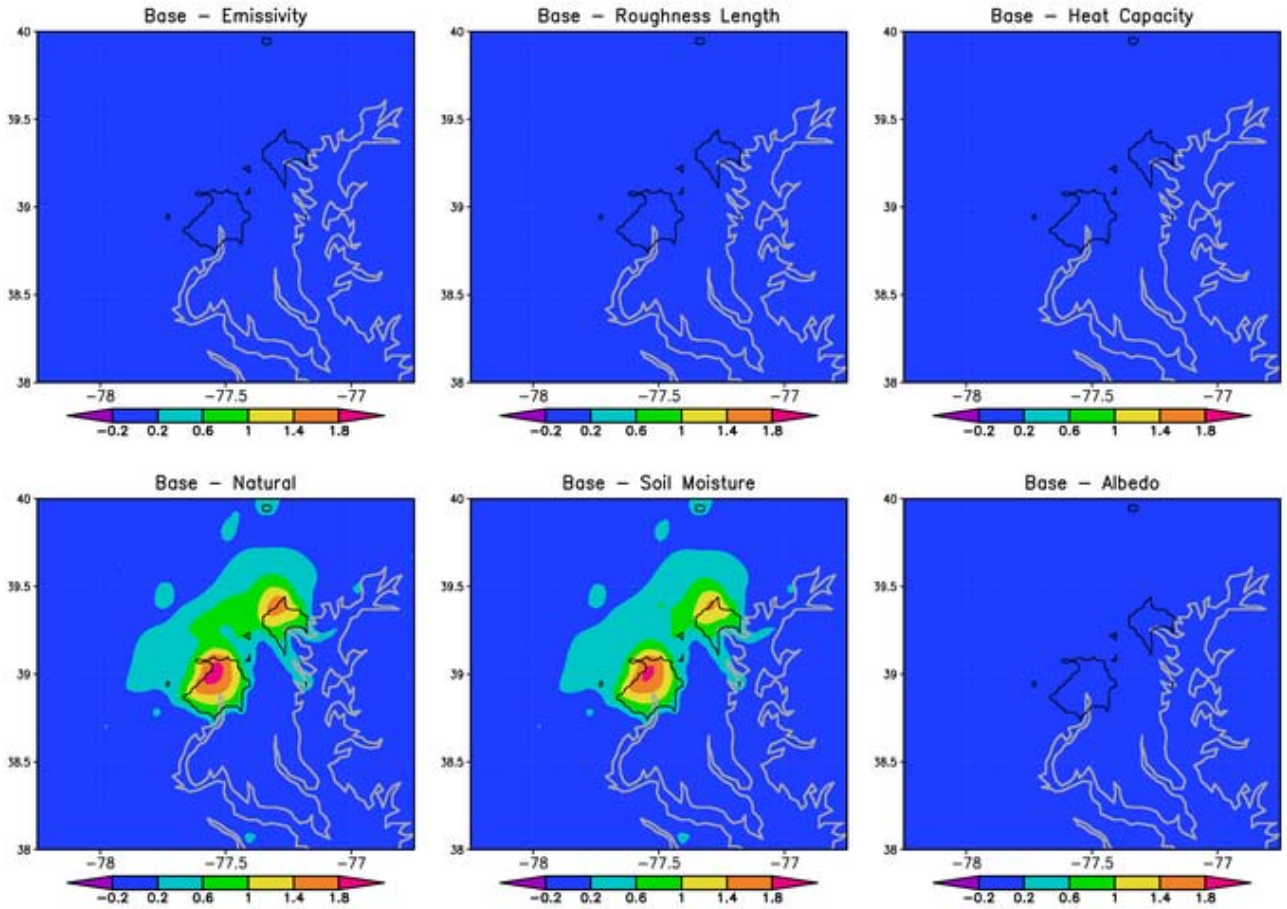
Climatology of Code Orange O_3 and 90 F in BNAA



Jet Streams on March 11, 1990

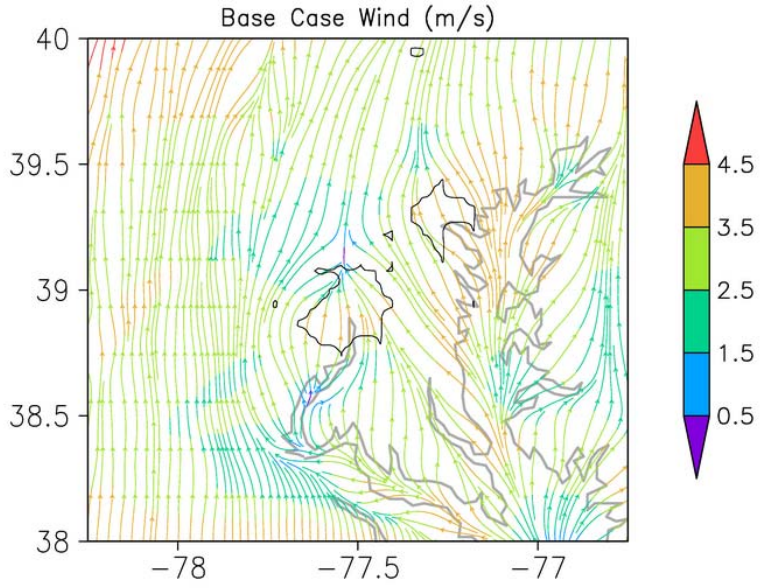


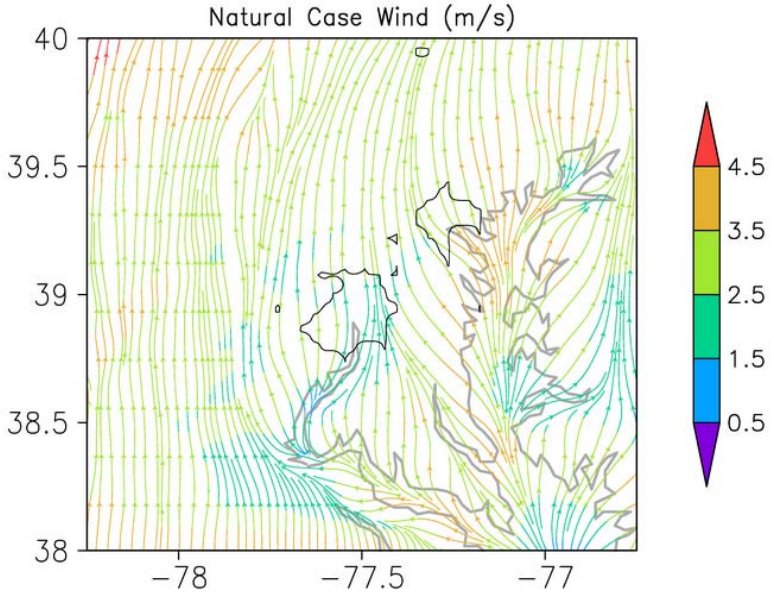
Base case minus emissivity, roughness length, heat capacity, natural, moisture availability, and albedo cases near surface temperature at 3pm EDT August 6, 2006. Urban areas are outlined in black and coastline is outlined in gray.



These figures show that on this particular day a lack of soil moisture in urban areas was the predominant cause of the urban heat island.

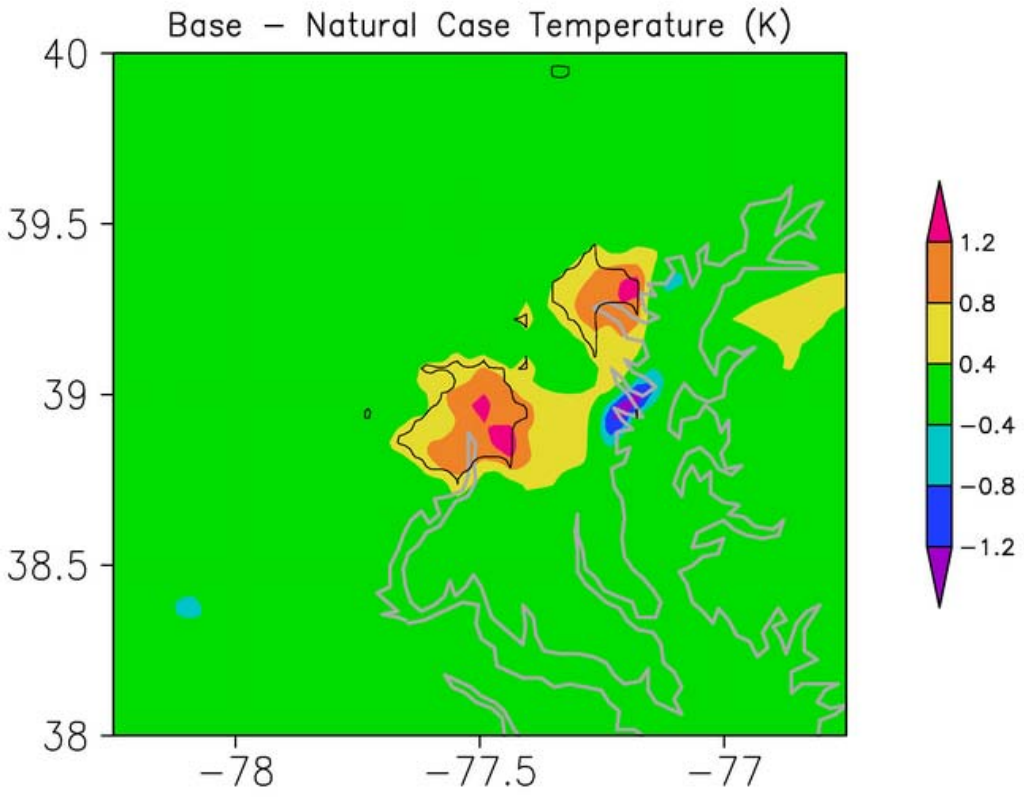
Wind fields for base and natural cases at 3pm EDT August 6, 2006. Urban areas are outlined in black and coastline is outlined in gray.





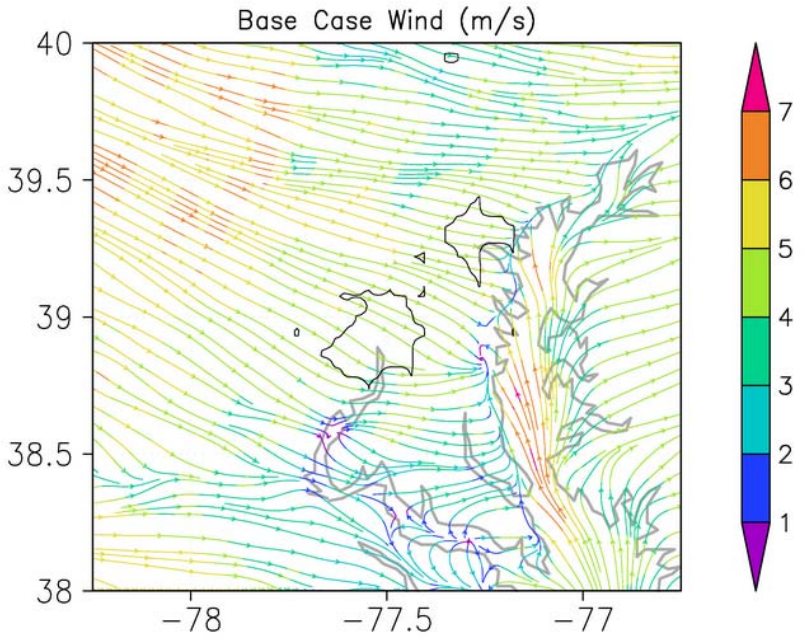
The urban heat island caused a circulation to take place similar to the circulation over a warm lake during the nighttime hours by increasing convergence over the warm air in an urban area. More surface convergence and updrafts were present in an urban heat island and more surface divergence and downdrafts were present in areas adjacent to urban areas.

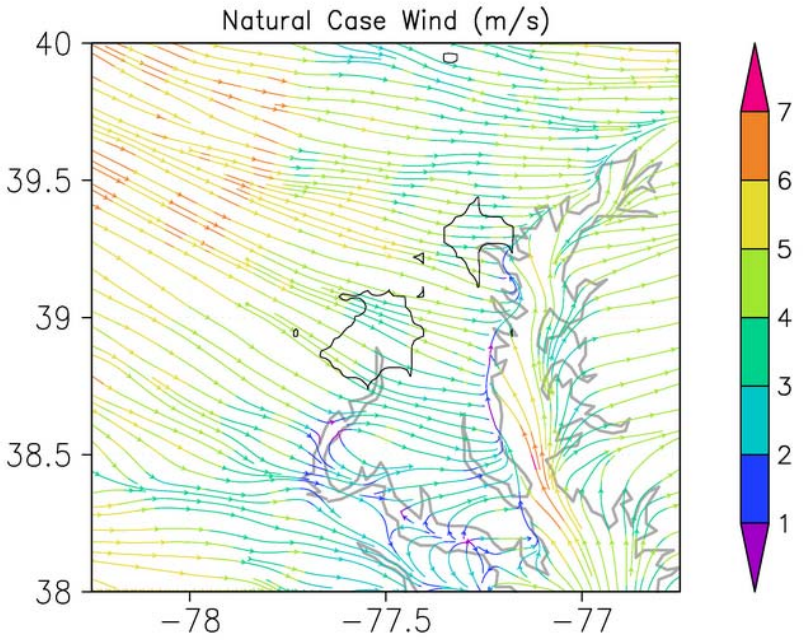
Base minus natural case near surface temperature at 3pm EDT August 7, 2006. Urban areas are outlined in black and coastline is outlined in gray.



In addition, the Washington, DC urban heat island influenced the Chesapeake Bay breeze. This figure shows the base case minus natural case near surface temperature when westerlies were advecting warm air due to the urban heat island toward the Chesapeake Bay.

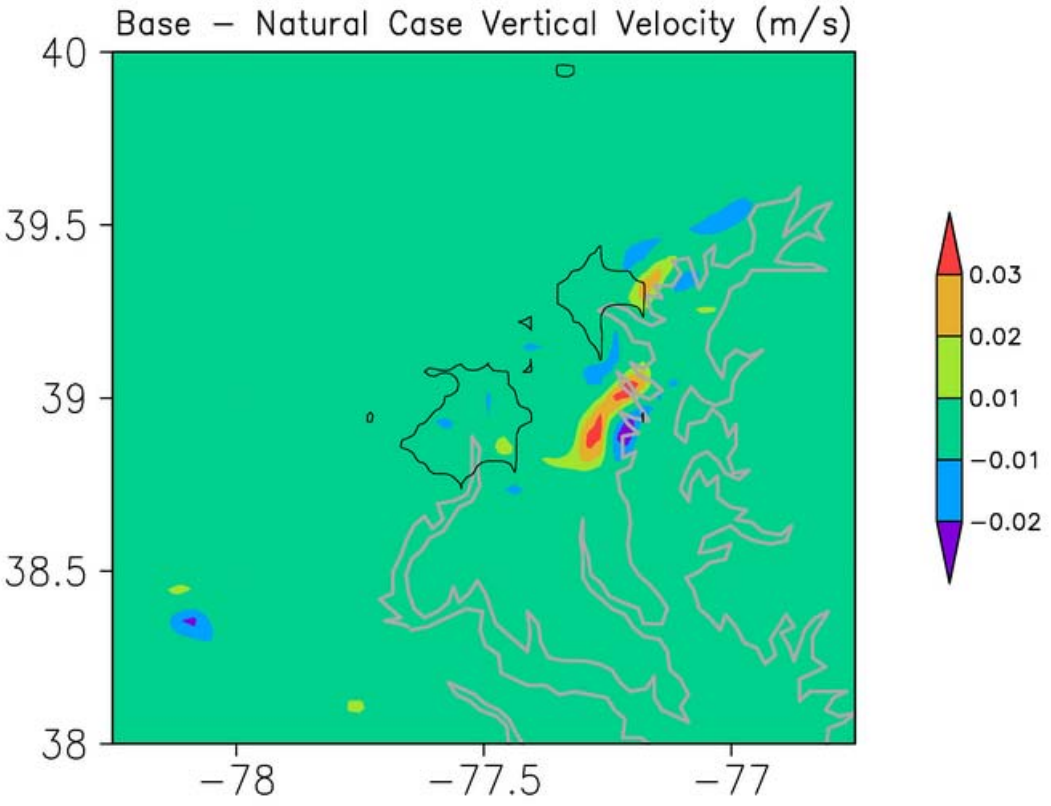
Base and natural case wind at 3pm EDT August 7, 2006. Urban areas are outlined in black and coastline is outlined in gray.





The magnified temperature gradient acted to strengthen the bay breeze so there was more surface convergence

Base minus natural case vertical velocity at 3pm EDT August 7, 2006. Urban areas are outlined in black and coastline is outlined in gray.



The increased convergence due to the urban heat island resulted in more rising air over the land and more surface divergence and downdrafts over the cool water during the daytime hours.

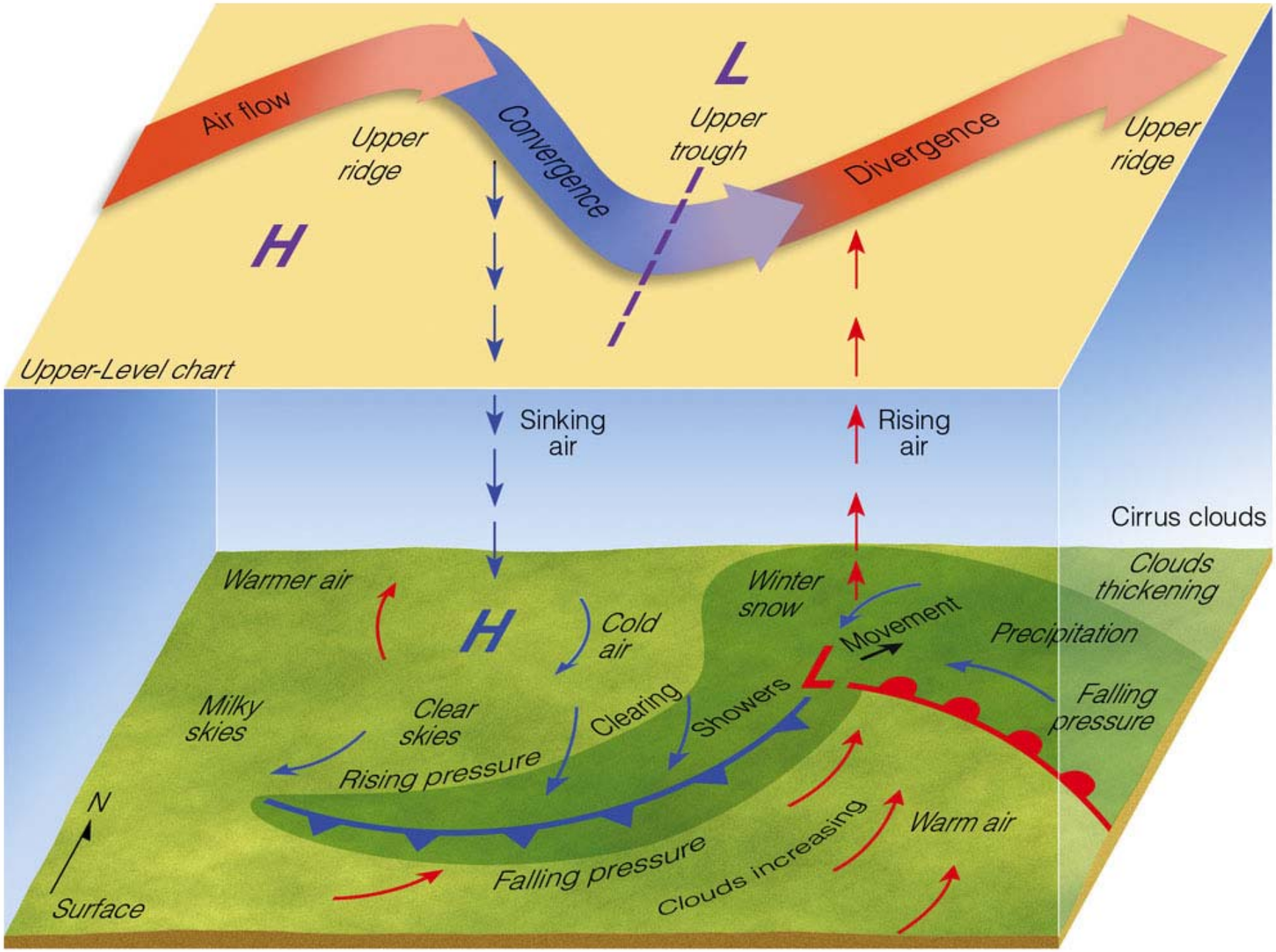


Fig. 8-30, p. 231

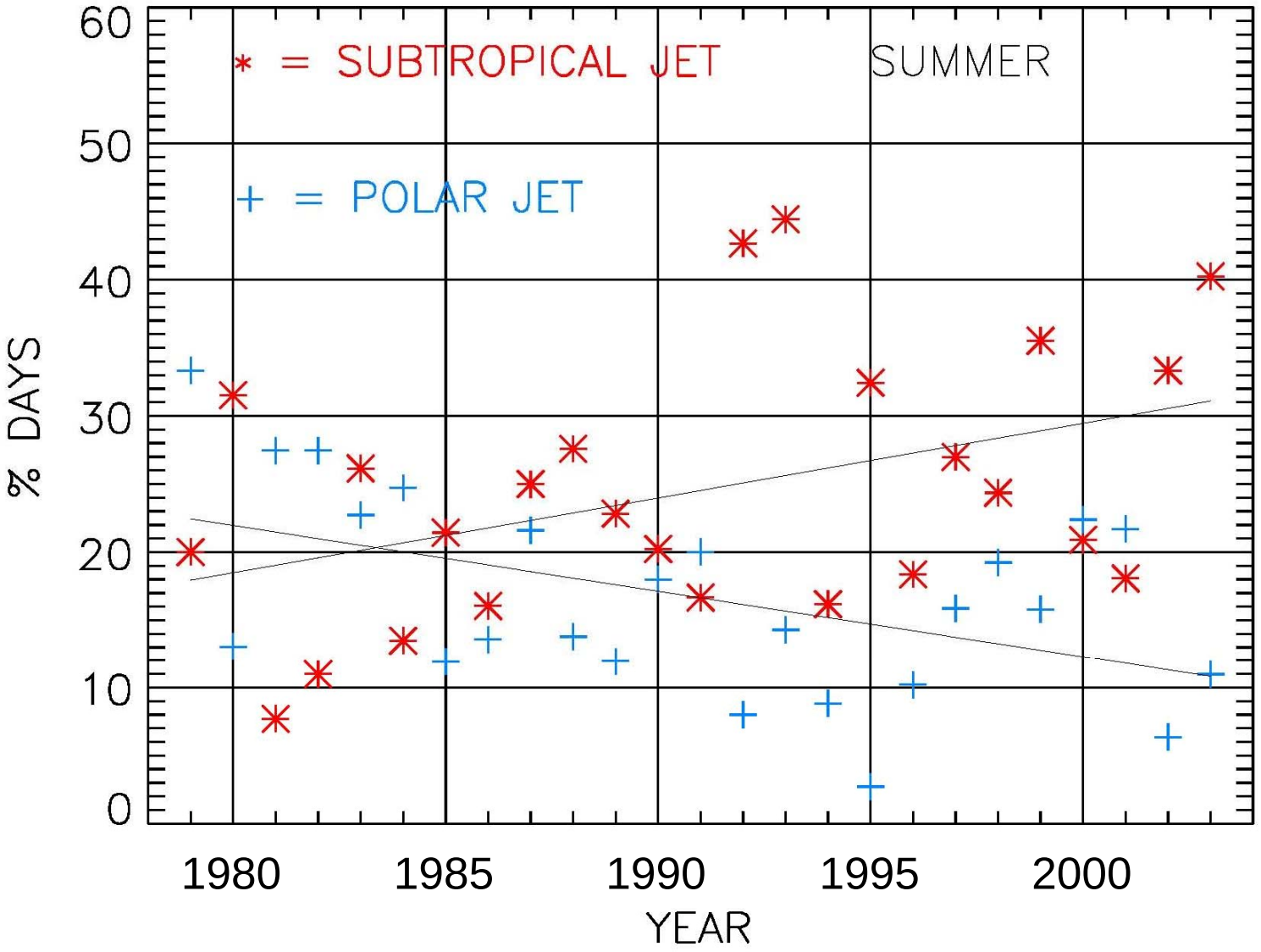
Jet Stream

- Hudson et al. (2003 and 2006) have used satellite data to show that the position of the Subtropical and Polar Jets has moved northward; could this be making the climate of MD more subtropical?

- Polar Jet near or S of Baltimore – cool and dry.

- Subtropical Jet near or N of Baltimore – warm and stagnant (Bermuda High)

Frequency of days when Jet stream within 200 km or beyond Baltimore.



Maryland Susceptible to Climate Change

Maryland: **6 m Sea Level Rise**

- **more coastline than California !**
- **more susceptible to sea level rise than all but 2 other states**