

Impact of Climate Change on Air Pollution:

Is there a climate change penalty?

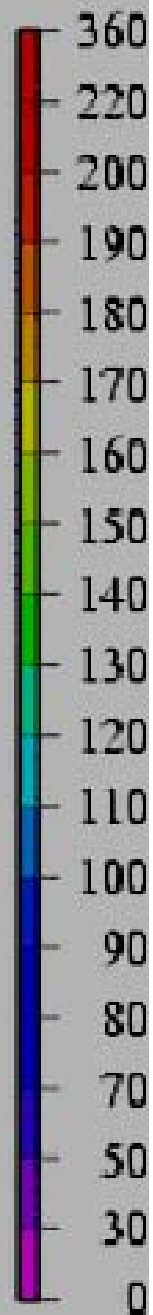
Presented to the
MWWCOG
Technical Advisory Committee (TAC)

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Supported by MDE



August 2003

Heat Wave Strikes Europe.

- Hottest summer on record for western Europe.
- Temperatures exceed 100°f.
- Ozone approaches $300 \mu\text{g m}^{-3}$ (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 -)

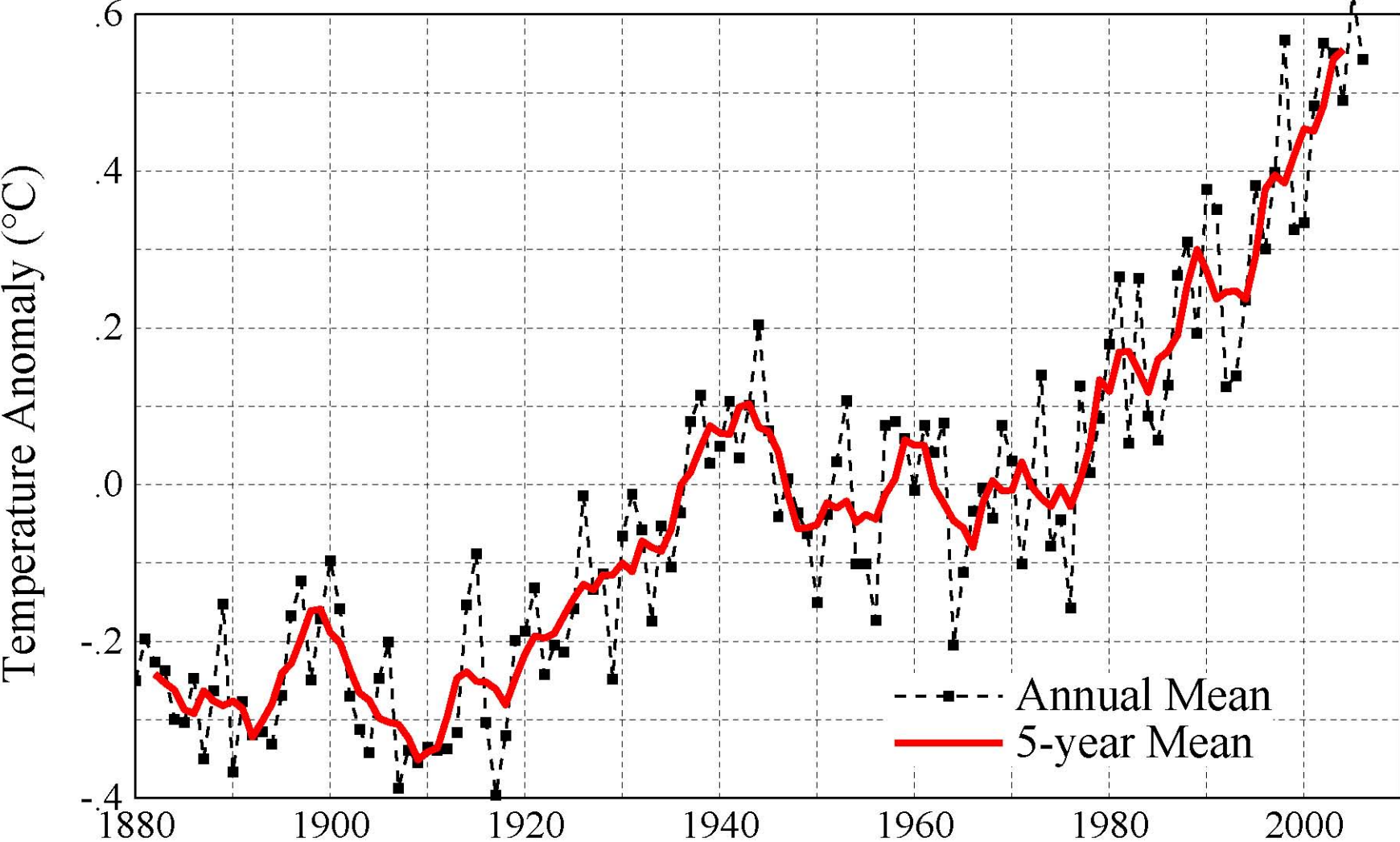
English chemist and statistician.

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

Climate Impact on Air Pollution

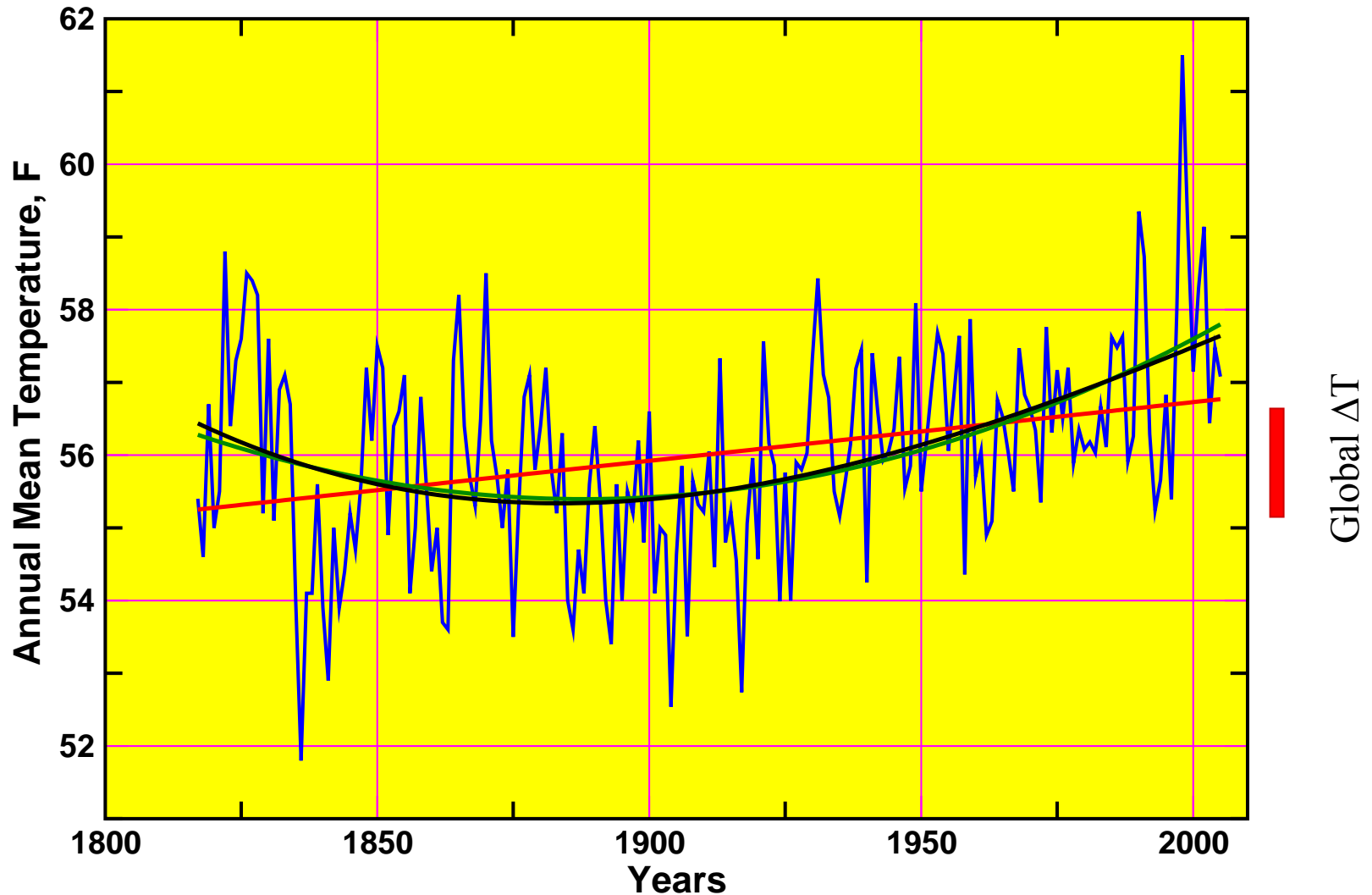
- “Climate change penalty” (Shiliang et al., 2008) of 2-8 ppb [O₃] by 2050 says Harvard’s model.
- Photochemical smog events generally arrive with heat waves, and the IPCC (2007) predicts more frequent heat waves.
- Slower cyclonic waves and more high pressure events [Mickley et al., *GRL*, 2004].

Global Temperature: Land-Ocean Index



BALTIMORE, MD. ANNUAL TEMPERATURE 1817-2005

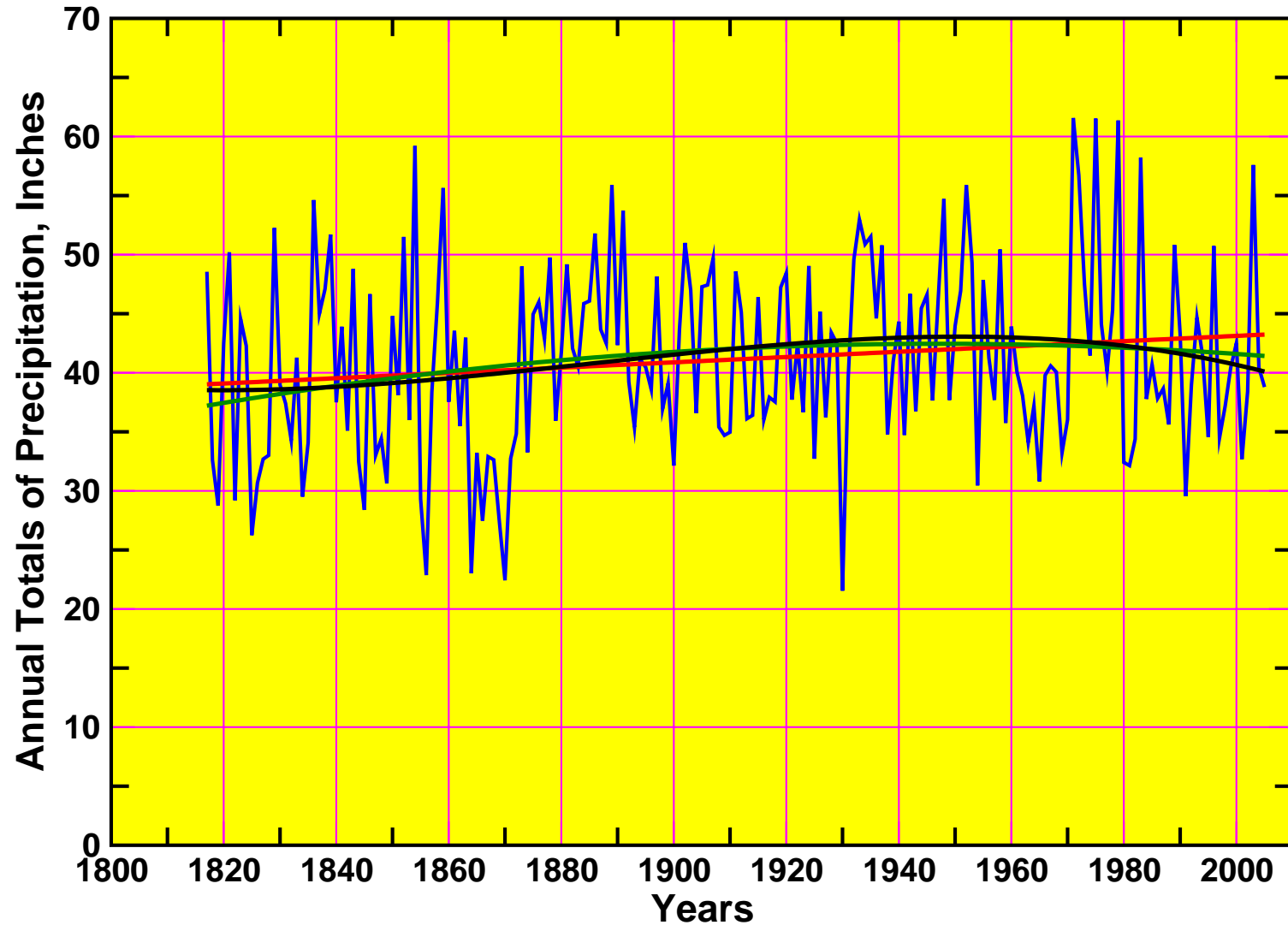
Observed Data and Trend Estimates (Linear, Quadratic, Cubic)



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.

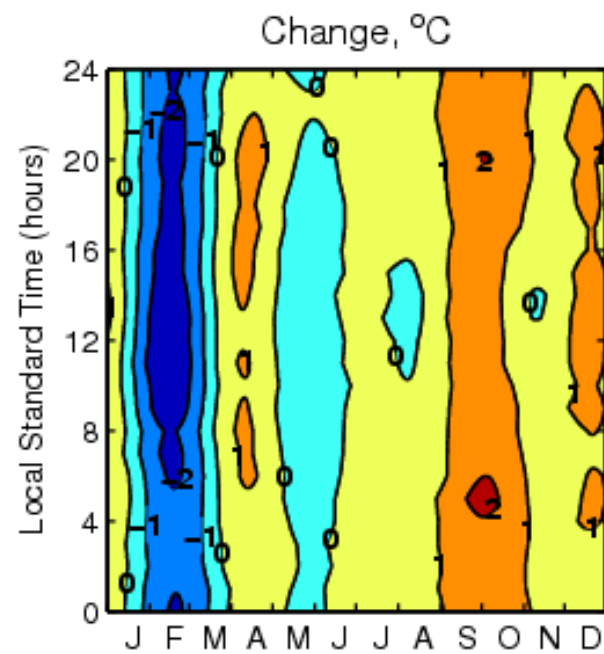
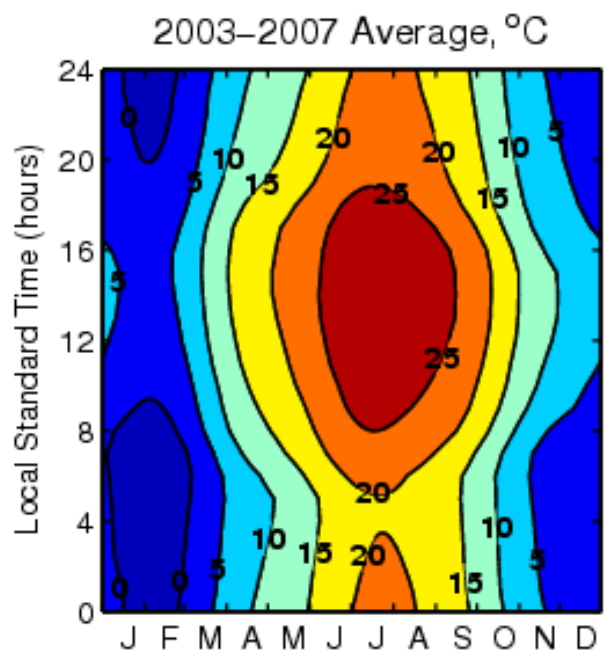
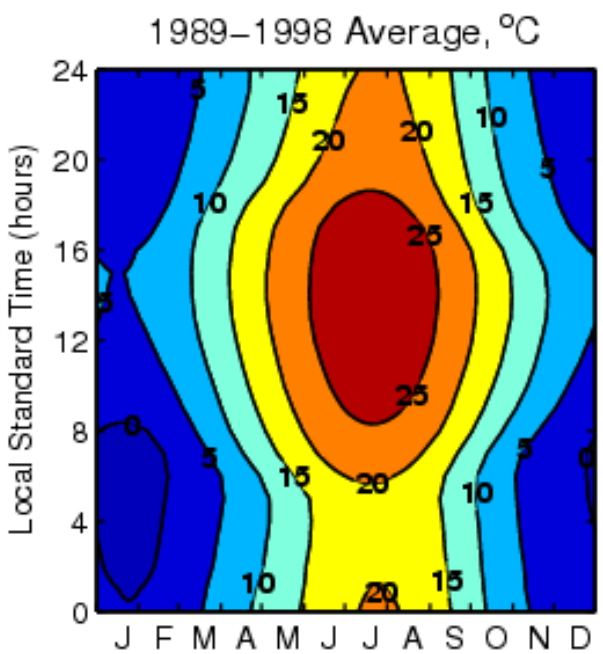
BALTIMORE, MD. ANNUAL PRECIPITATION 1817-2005

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

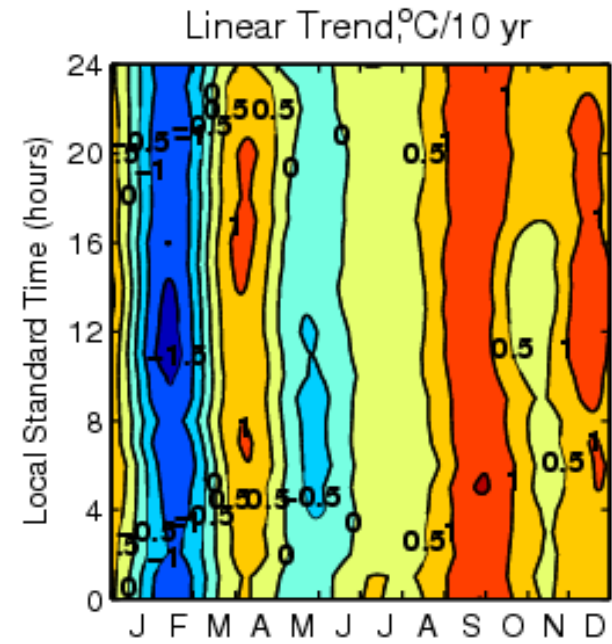
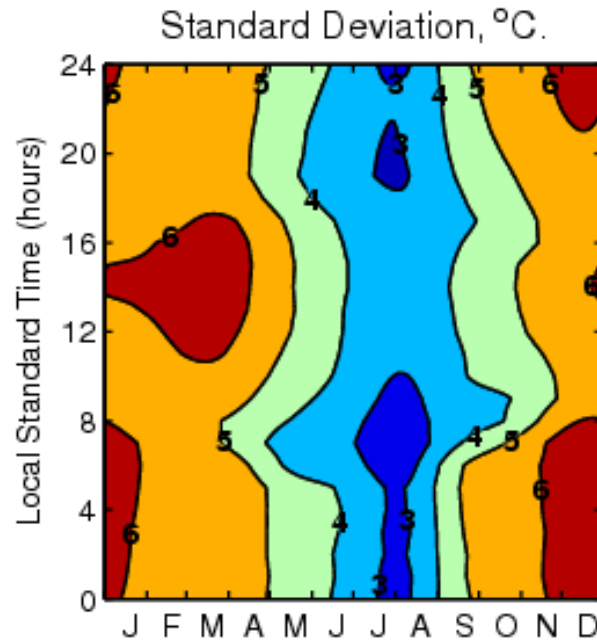
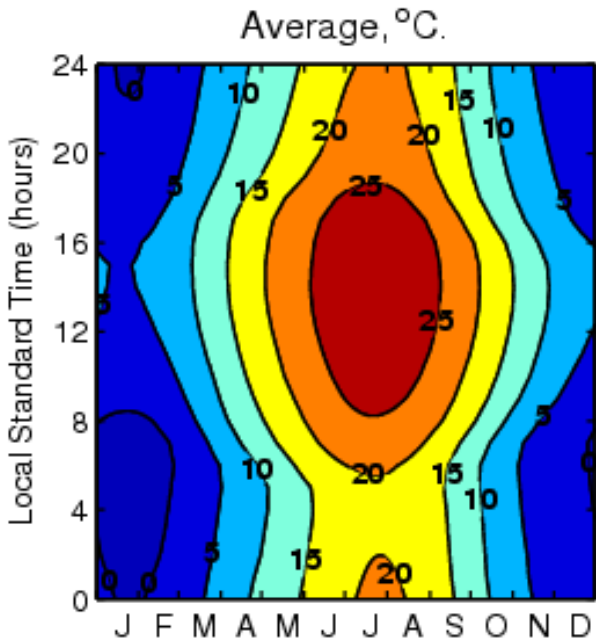


1817-1871 & 1895-1896: Maryland Weather Service Report, Vol. 2, pp.186-187. 1907.
1872-1894 & 1897-2005: US Historical Climatology Network. Baltimore WSO City.

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



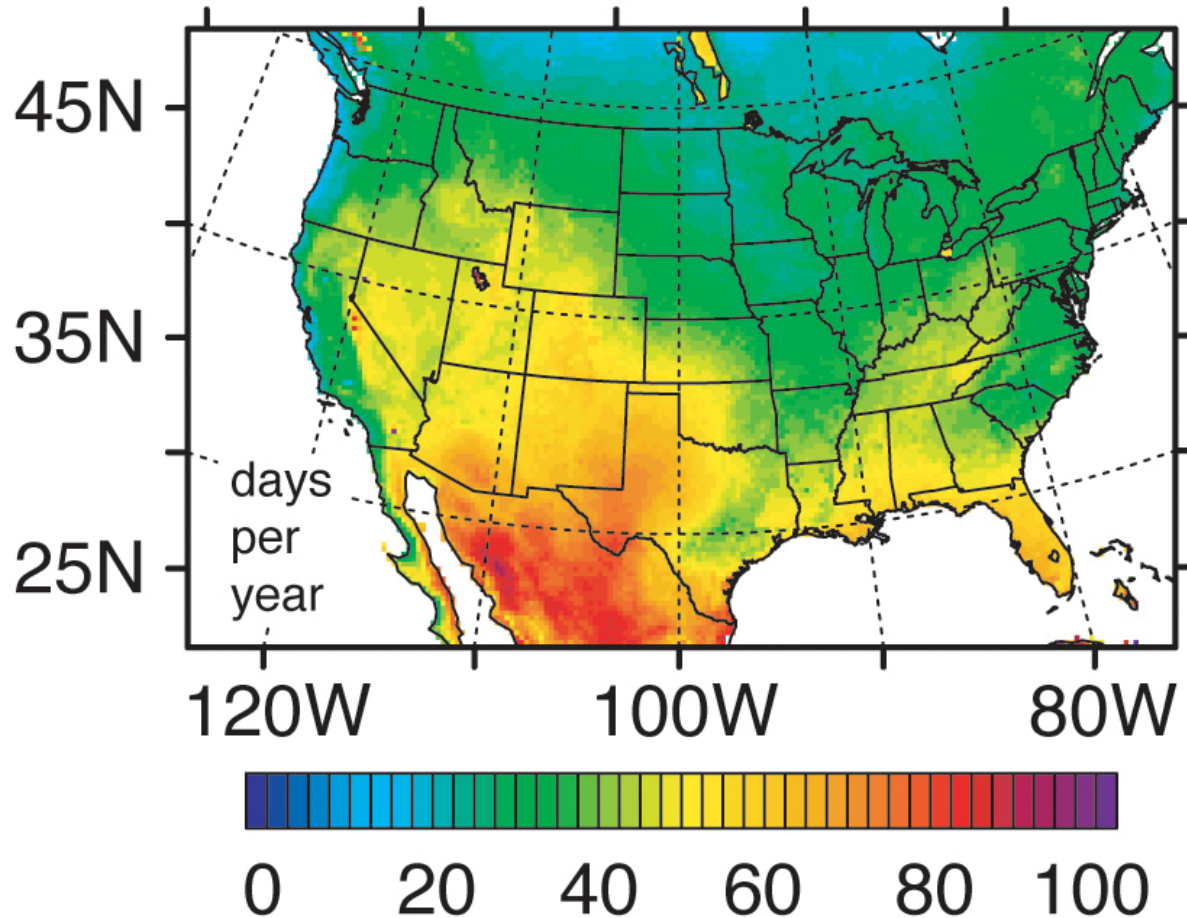
Air Temperature 1989–2007, BELTSVILLE, MD



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

Change in Extreme Hot Events



Heat waves:

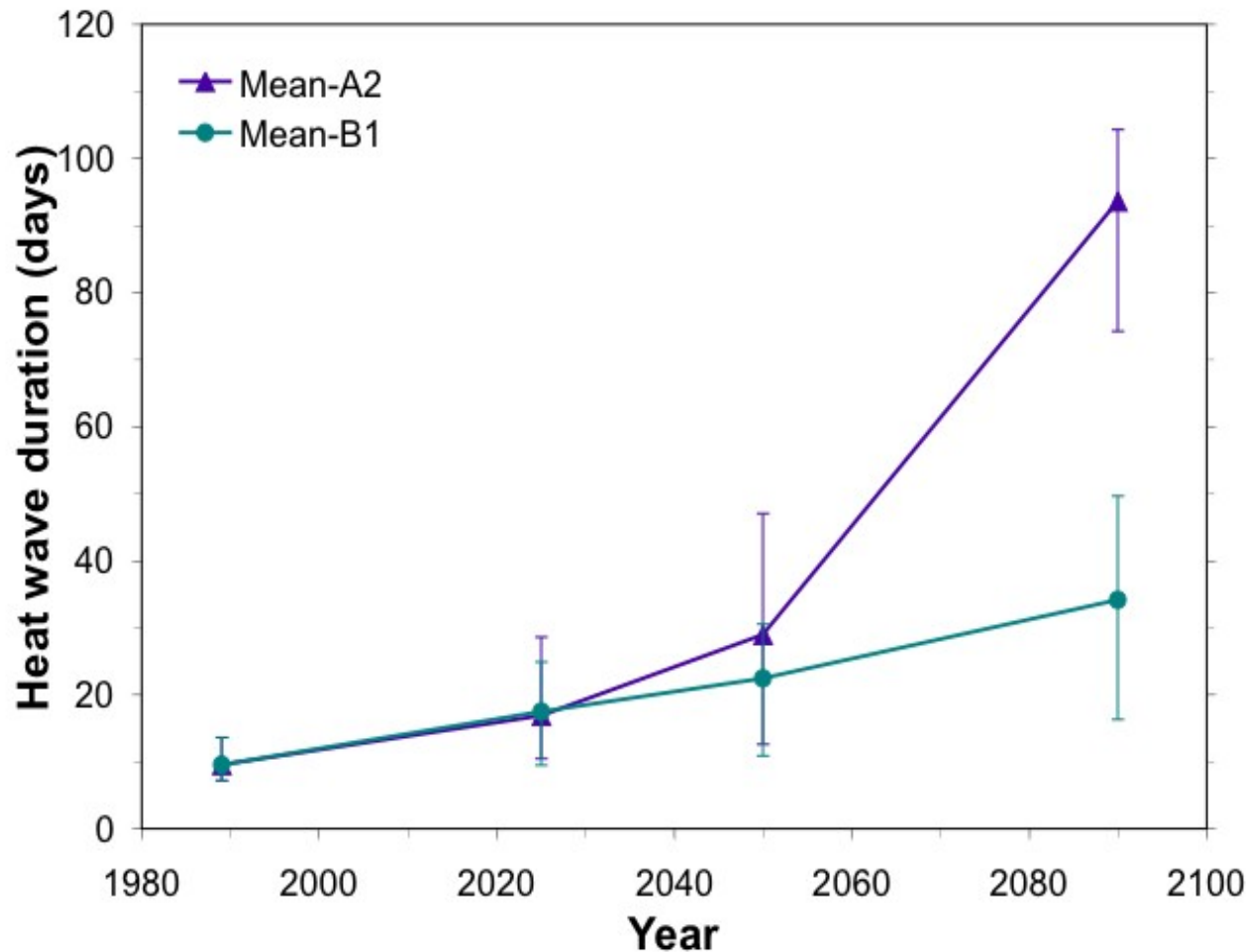
"Rare events, like the 2003 heat wave in Europe, will become much more common..." said Noah Diffenbaugh, the Purdue professor who led the study. "The frequency at which this scale of event occurs at high greenhouse gas concentrations is staggering. Rare events become the norm, and the extreme events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

Consensus IPCC Predictions

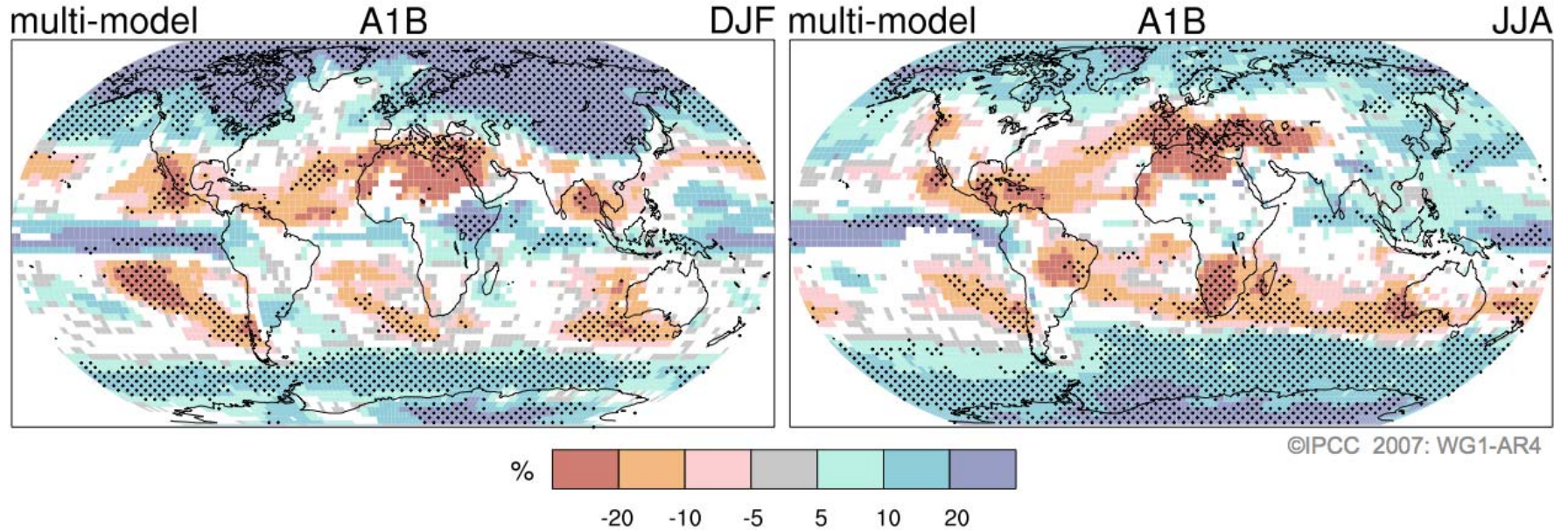
From V. Coles, CBL

Climate Change Comm. Draft Rpt.

Heat wave duration, Maryland



Projected Patterns of Precipitation Changes

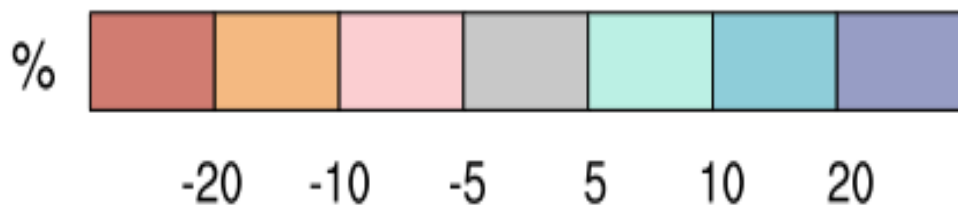
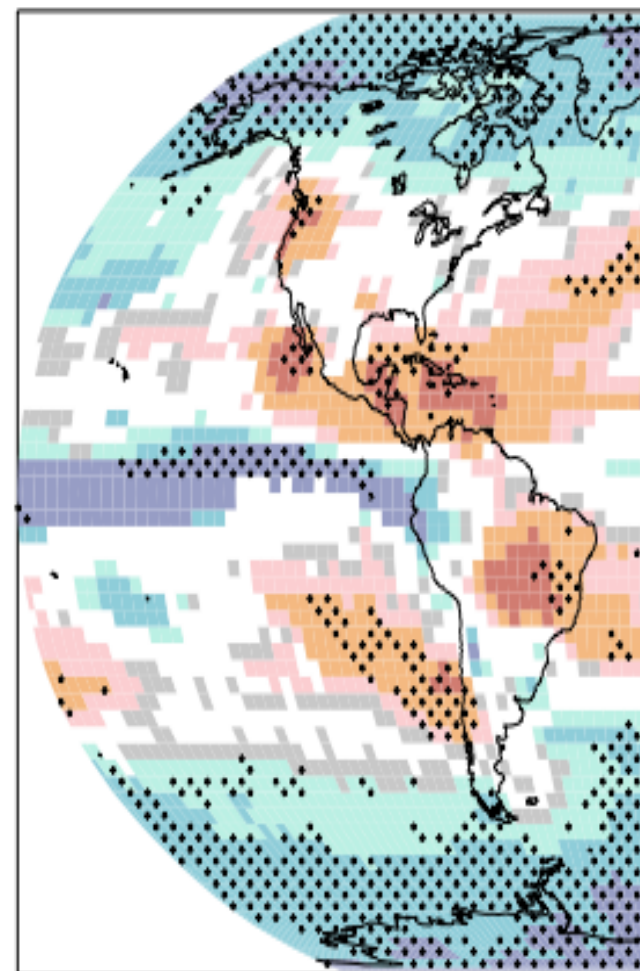
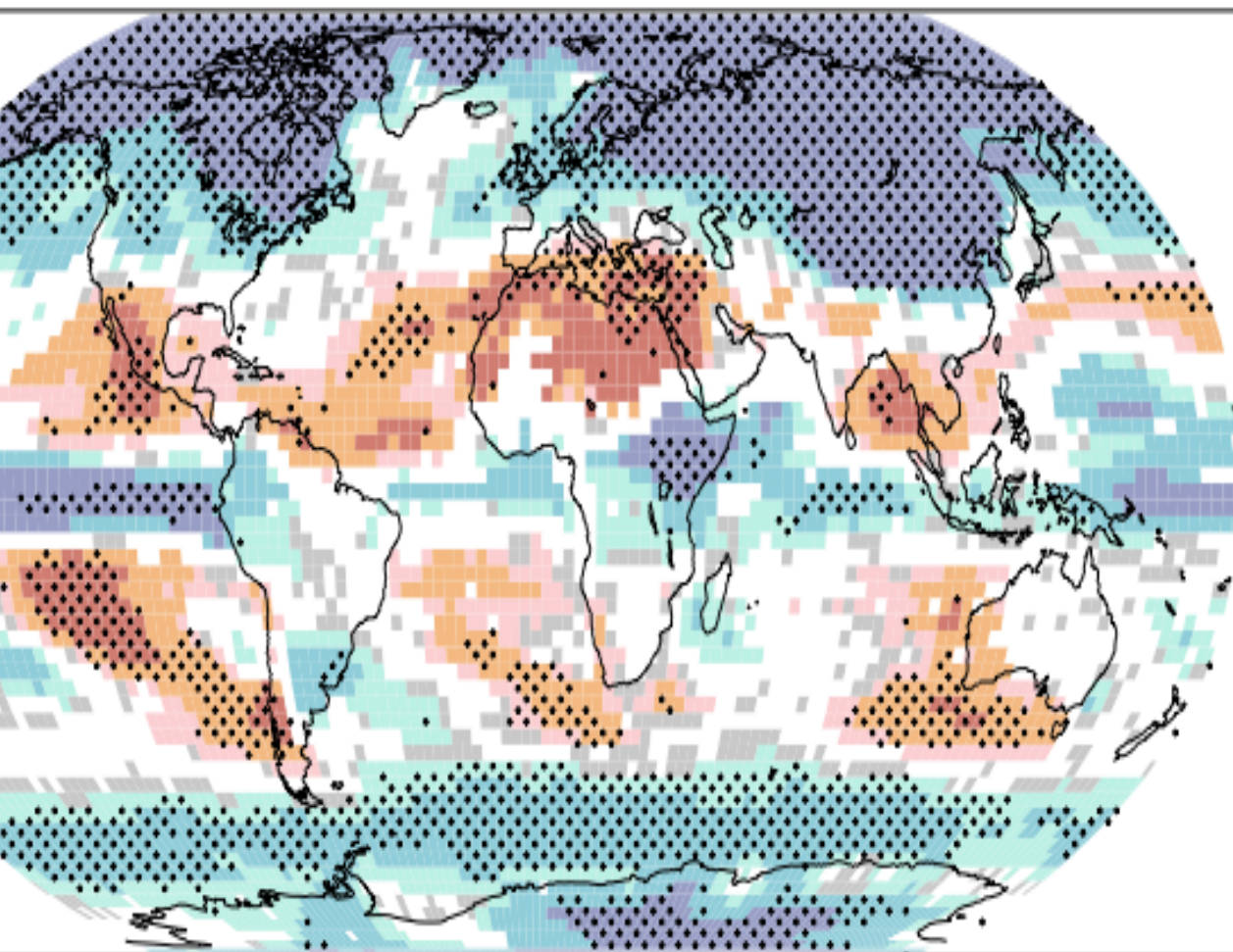


- Small increase in winter precipitation predicted for Mid Atlantic.

model

A1B

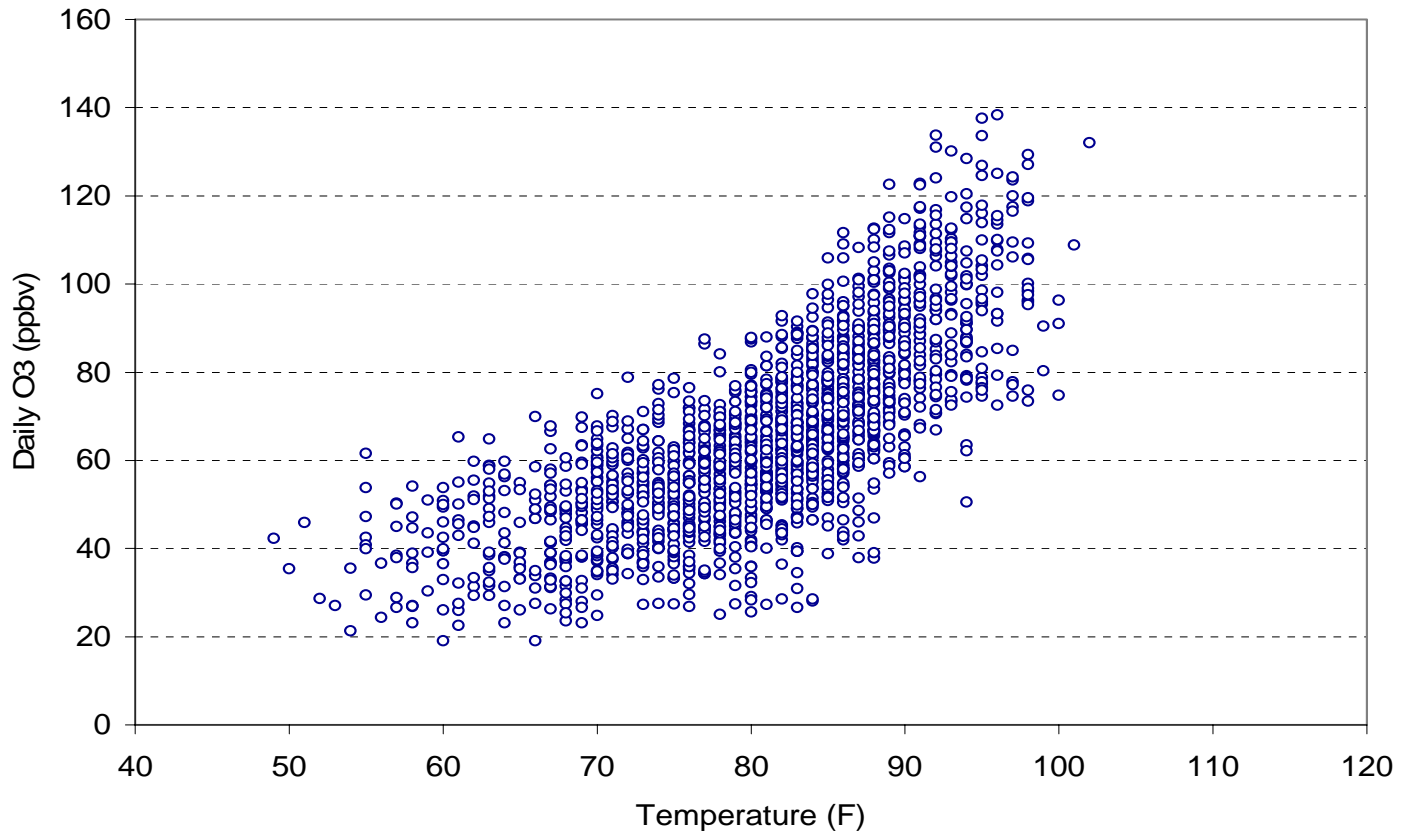
DJF multi-model



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*].

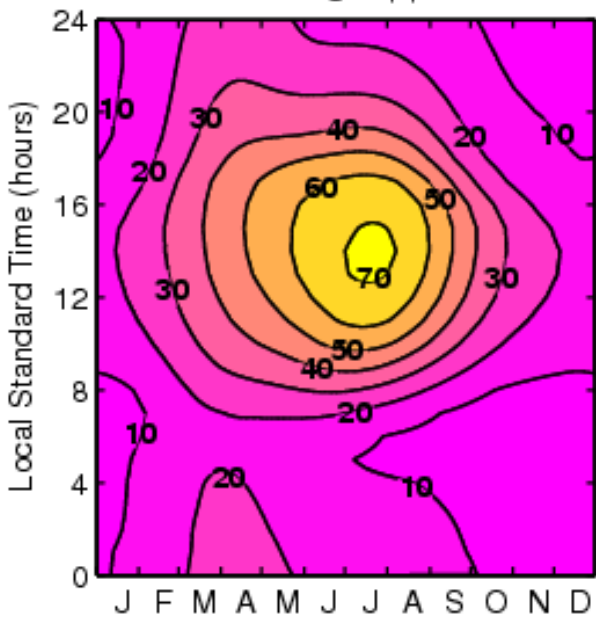
- Mid Atlantic air quality (ozone and PM_{2.5}) has improved, but how does it depend on weather?



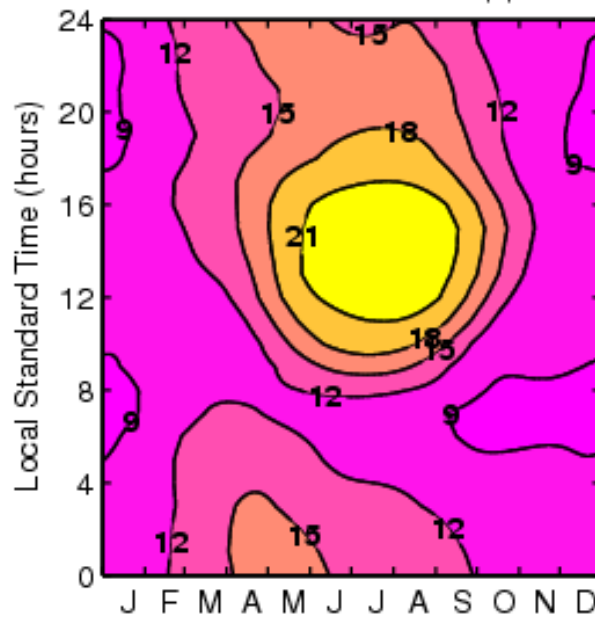
Response of ozone to Maximum temperature measured in Baltimore. 1994-2004

OZONE 1989–2007, BELTSVILLE, MD

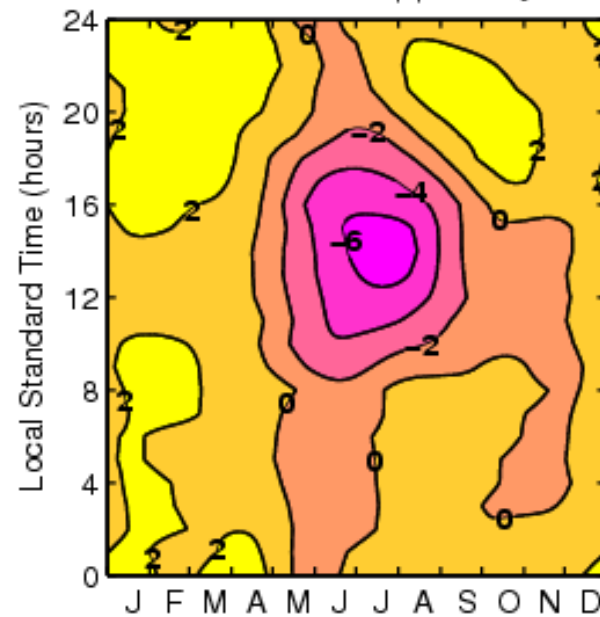
Average, ppb.



Standard Deviation, ppb.

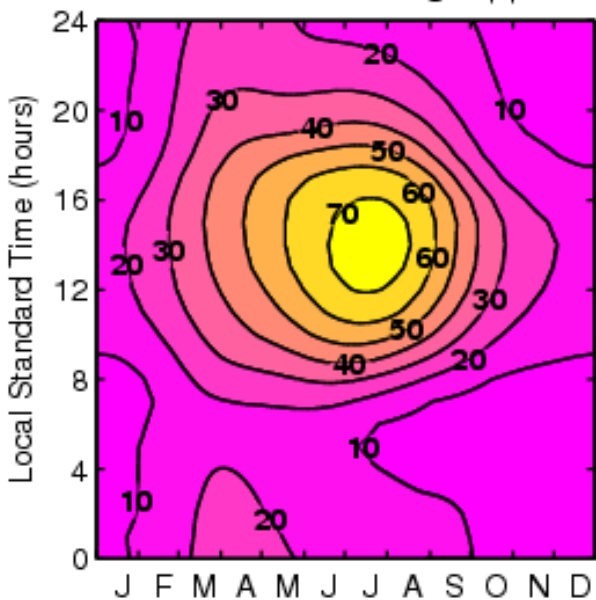


Linear Trend, ppb/10 yr

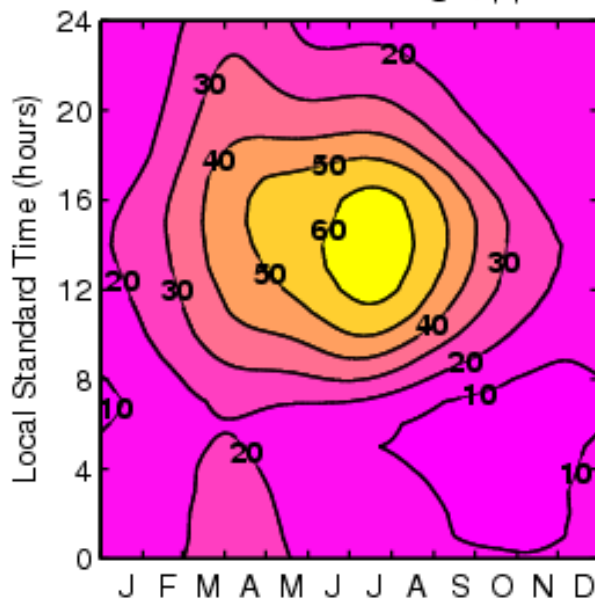


CHANGE of OZONE AVERAGES from 1989–1998 to 2003–2007. BELTSVILLE, MD

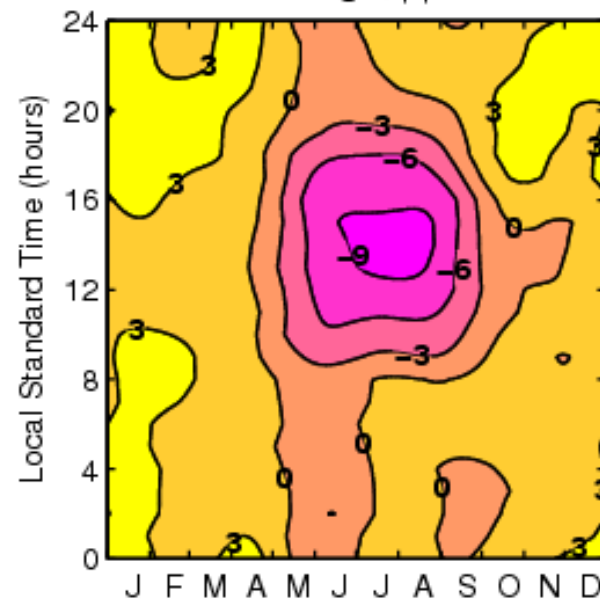
1989–1998 Average, ppb.



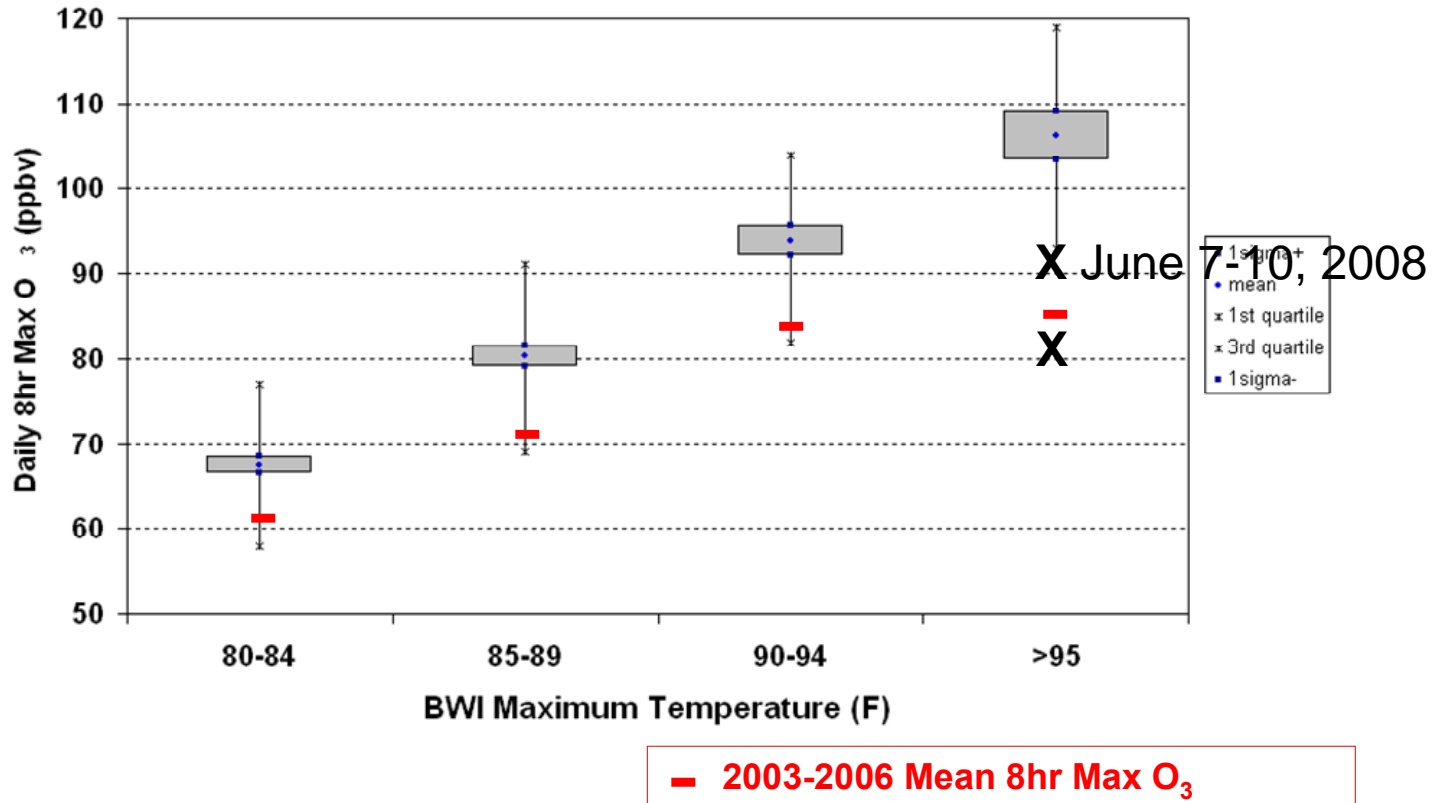
2003–2007 Average, ppb.



Change, ppb



Baltimore Non Attainment Area
Conditional mean 8-hr max O₃ (1987-2002, 2003-2006)



Demonstration of the success of the NO_x 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.

Look at all CASTNET sites in the eastern US*

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

What impact did the NO_x SIP Call have on ozone?

Overall Median: 41 → 38 ppb

Median of 8-hr max: 74 → 70 ppb

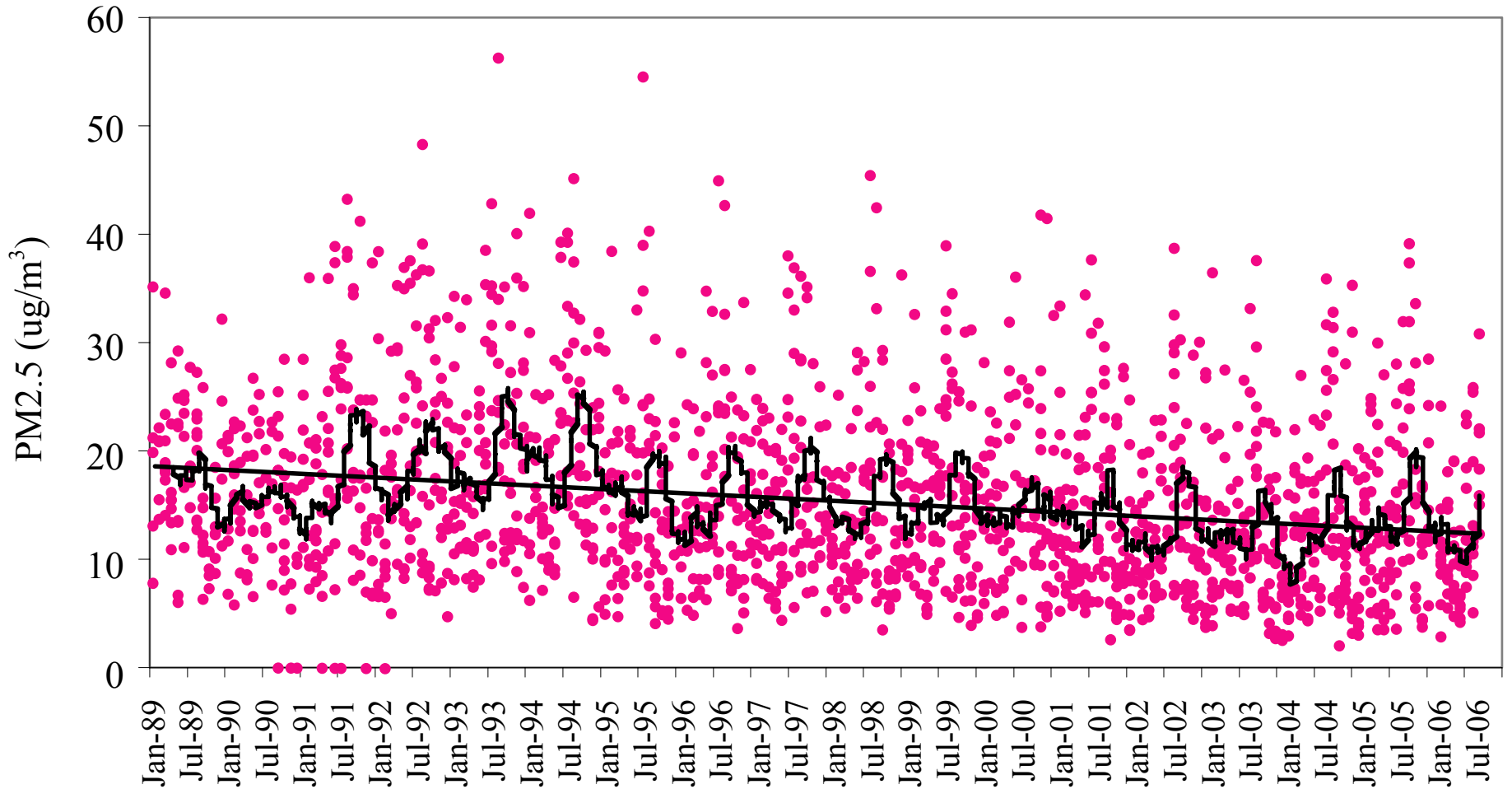
95 percentile for hot days: 111 → 86 ppb

Slope ~ 2-4 ppb/°C.

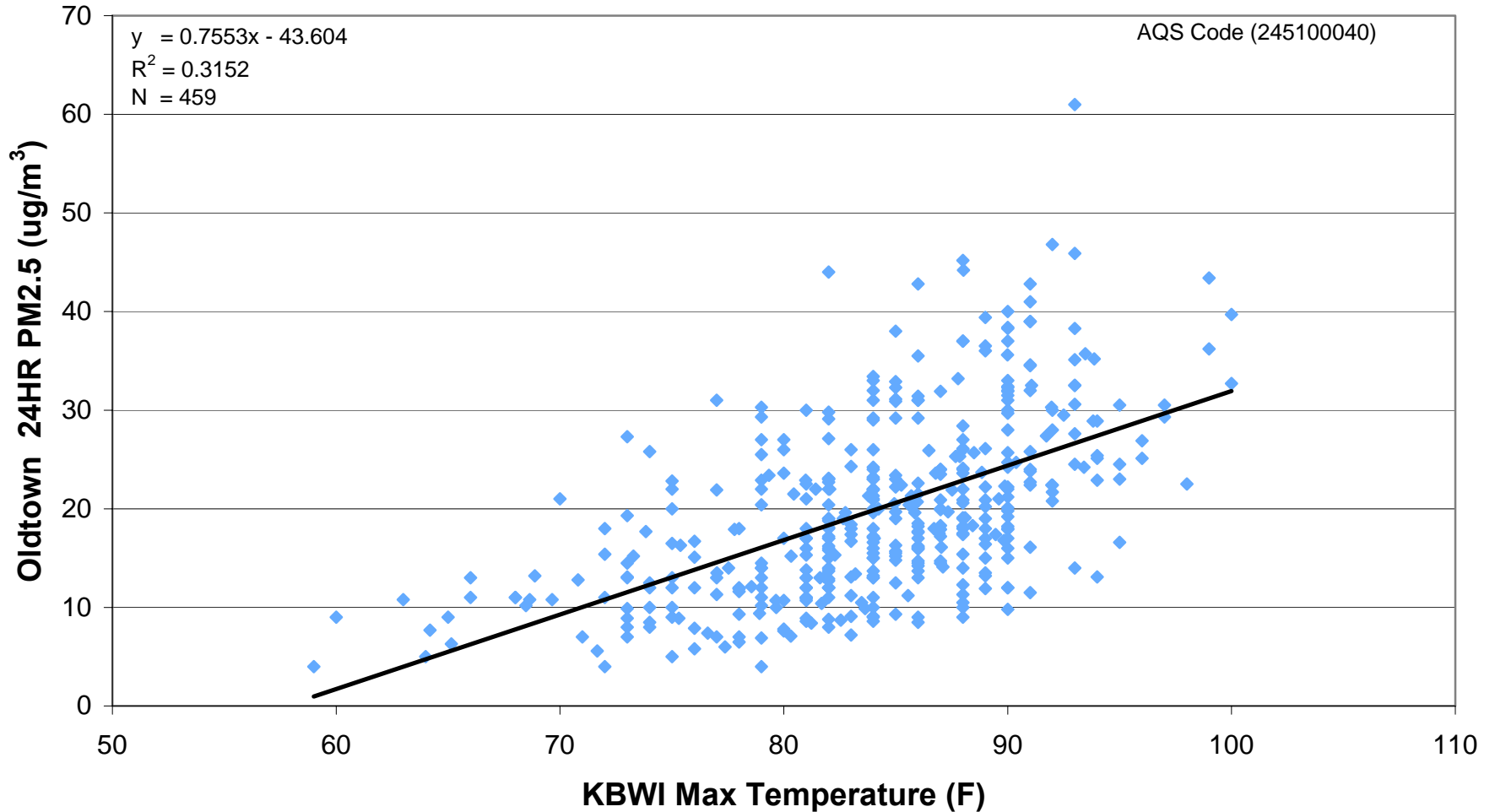
***Bloomer et al. in press 2008.**

Is there more PM on hot days?

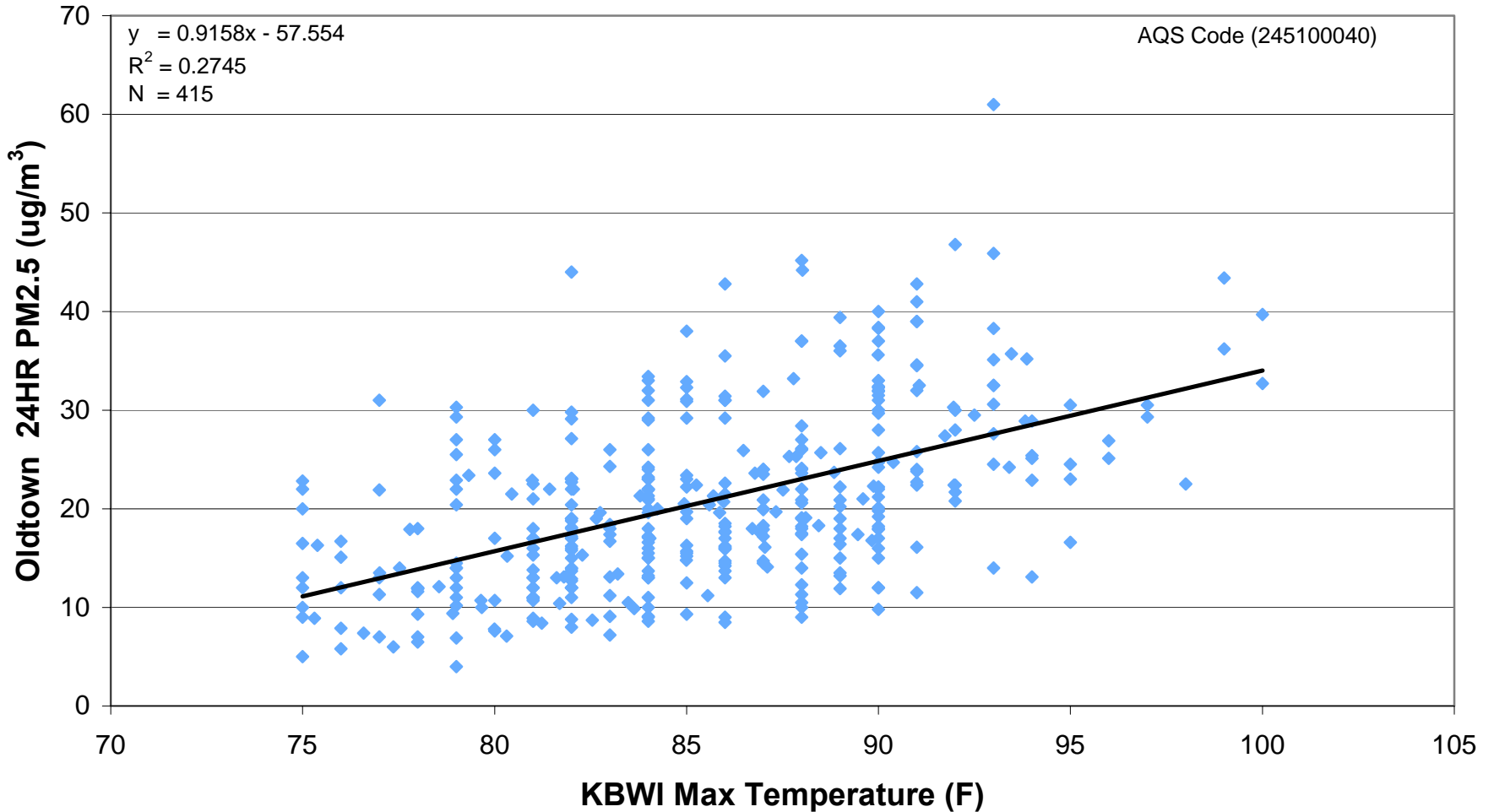
Washington, DC PM2.5
Improve every 3rd day Observations (1989-2006)
Linear Trend and 30-Point running mean



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



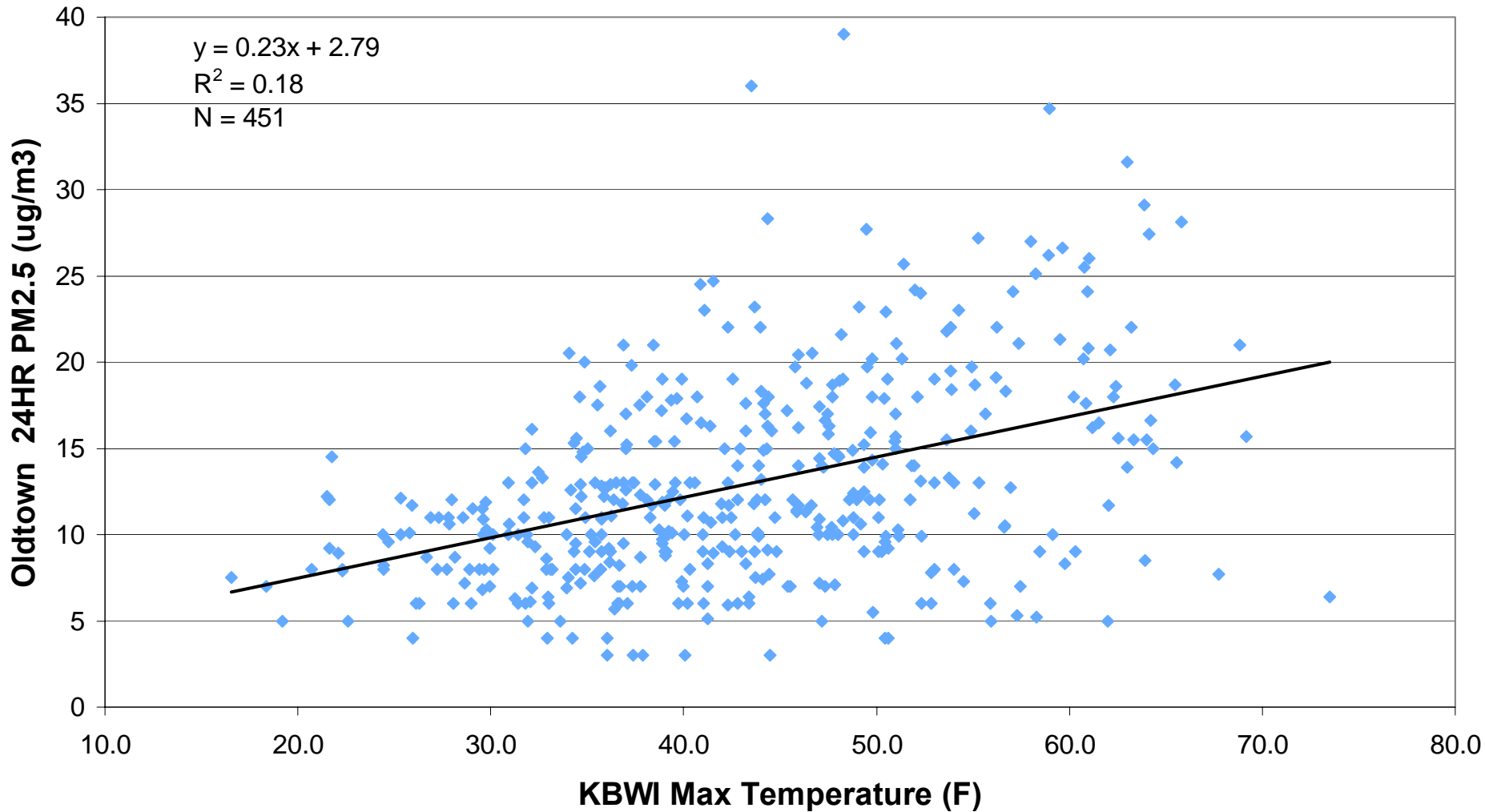
Peak 24HR PM2.5 (Oldtown) vs. Max Temperature (KBWI) (2003-2007 June, July, August $T \geq 75^\circ\text{F}$)



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.

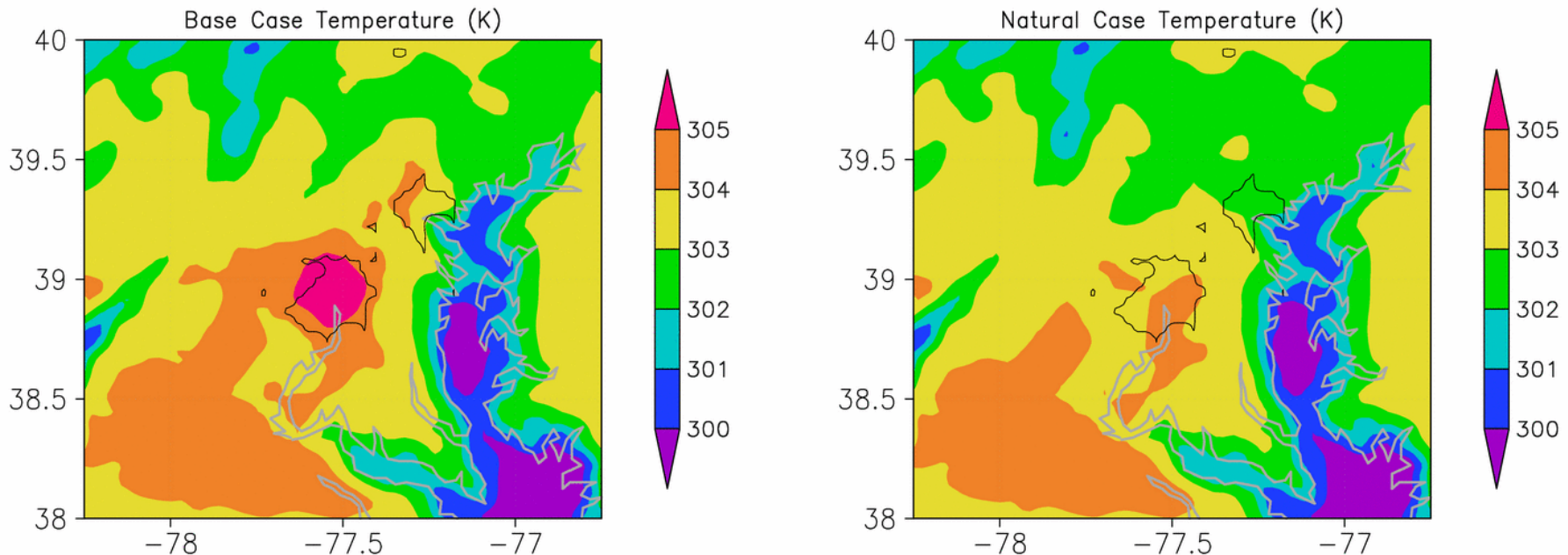
For MM5 Modeling

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 ($\text{cal cm}^{-2} \text{K}^{-1} \text{s}^{-1/2}$)	0.03	0.04
heat capacity ($\text{Jm}^{-3} \text{K}^{-1}$)	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.



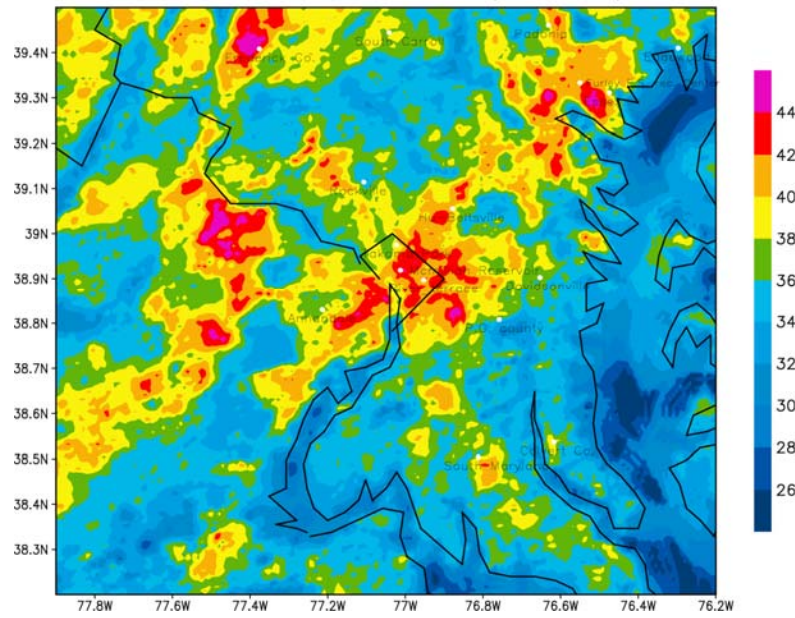
These figures compare near surface temperatures for the base- and natural-cases. Temperatures over urban areas (Baltimore, MD and Washington, DC) are higher by 1-2 K (2-4°f) in the base case confirming the presence of the urban heat island.



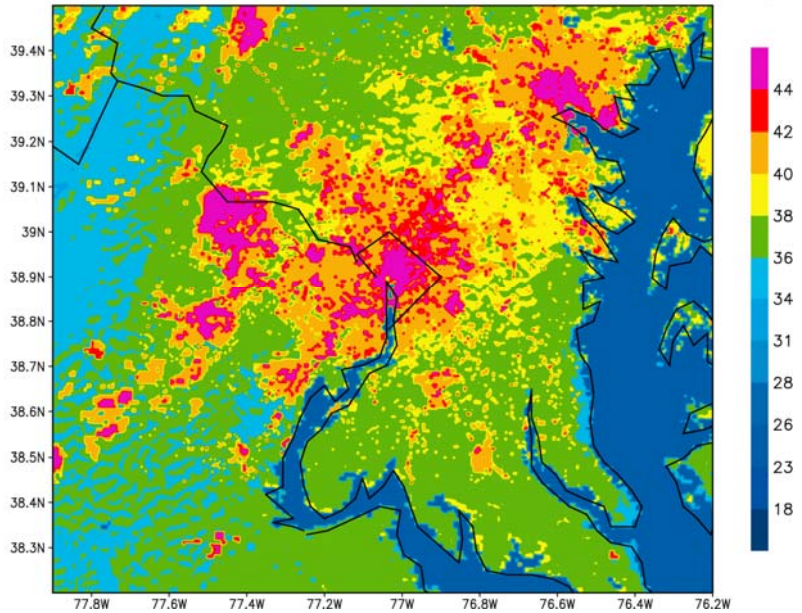
How well can WRF-Urban simulate effect of local land use on skin Temperature?

Thanks to Da-Lin Zhang

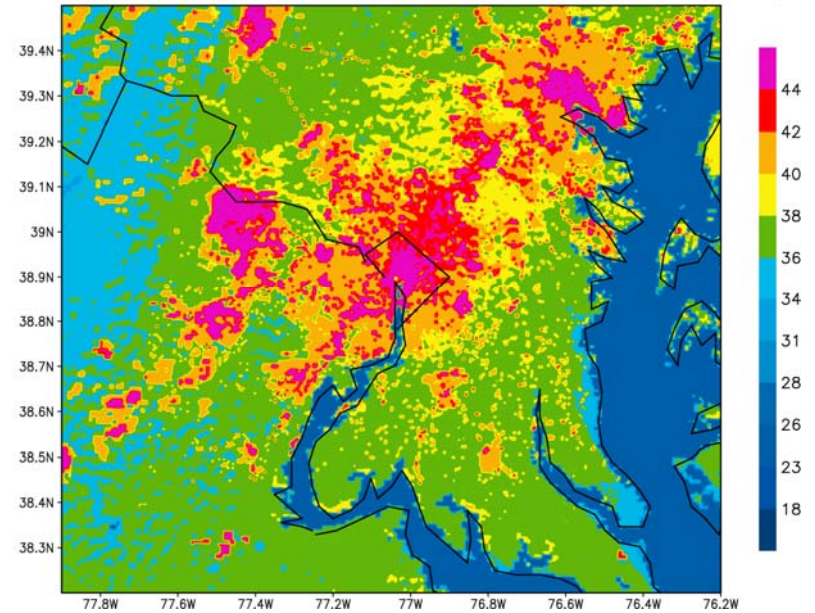
2007-07-09-1745UTC (12:45PM)



2007-07-9-1700UTC Surface Temperature(WRF:0.5km)



2007-07-9-1800UTC Surface Temperature(WRF:0.5km)



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

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

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
 - N₂O
- Examine past climate (Data analysis).
- Evaluate CMAQ for weather impacts.
- Forecast future climate & pollution (Models).
- Start monitoring CO₂, CH₄, N₂O etc.

The End



Fear the Turtle!