Global Change and Air Pollution (EPA-STAR GCAP)

…and some more recent work on climate-AQ interactions

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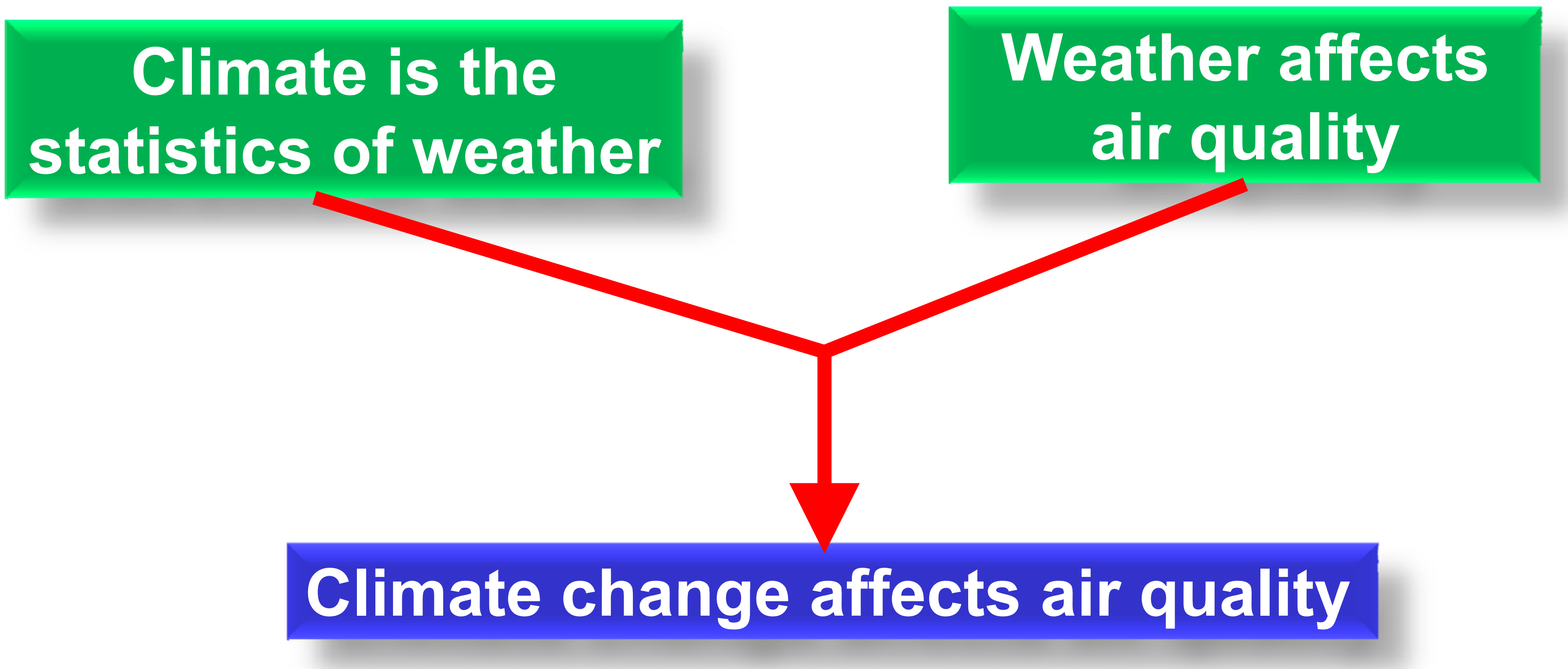
A simple syllogism:



Effect of climate change on air quality

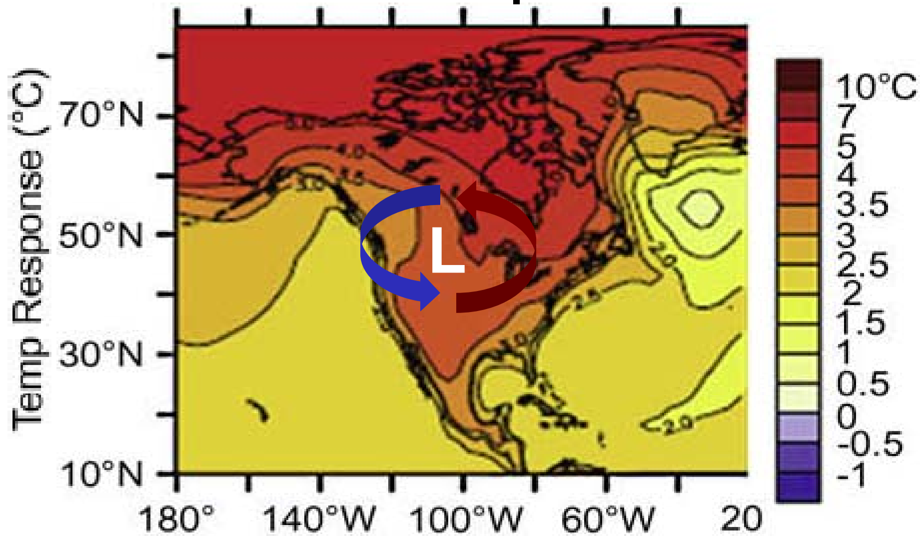
Expected effect of 21st-century climate change		Observed dependences on meteorological variables (polluted air): Ozone	PM
↑	**Stagnation**	↑	↑
↑	**Temperature**	↑	↑↓
?	**Mixing depth**	=	↓
?	**Precipitation**	=	↓
?	**Cloud cover**	↓	↓
?	**Relative humidity**	=	↑

Climate change is expected to degrade ozone air quality; effect on PM uncertain

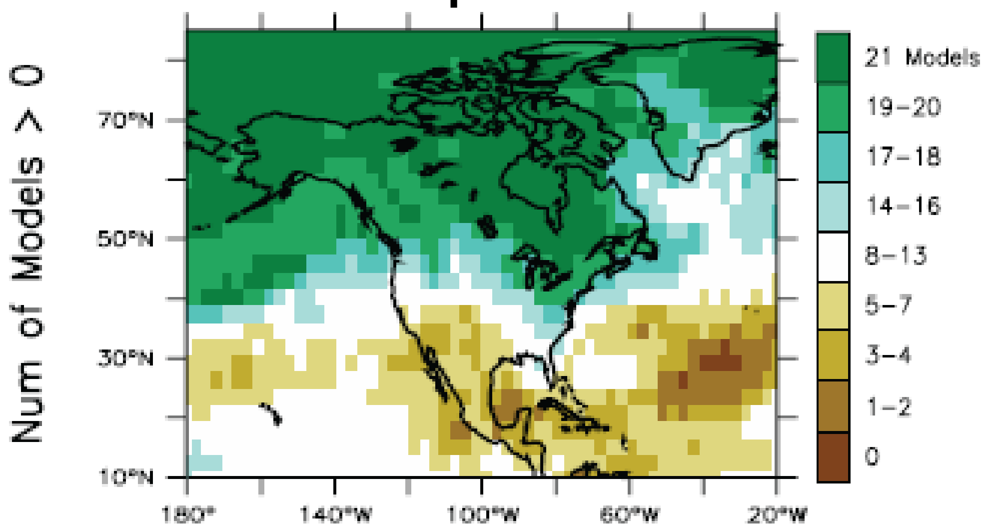
Jacob and Winner [2009]

IPCC projections of 21st-century climate change in N. America

Surface temperature



Precipitation

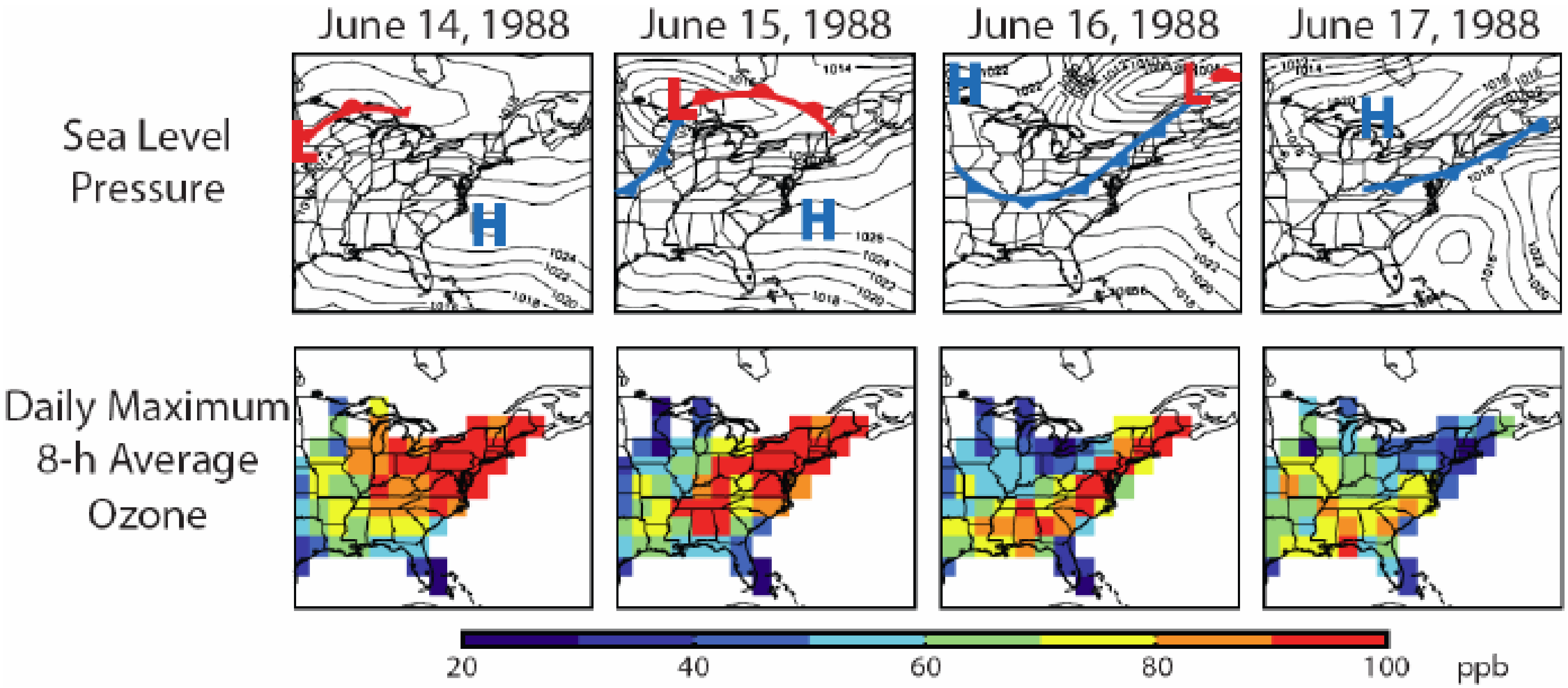


2080-2099 vs. 1980-1999 changes for ensemble of 21 general circulation models (GCMs) in A1B scenario

- **Increasing temperature everywhere, largest at high latitudes**
- **Frequency of heat waves expected to increase**
- **Increasing precipitation at high latitudes, decrease in subtropics but with large uncertainty**
- **Decrease in meridional temperature gradient expected to weaken winds, decrease frequency of mid-latitude cyclones and associated cold fronts**

IPCC [2007]

Importance of mid-latitudes cyclones for ventilation of eastern US

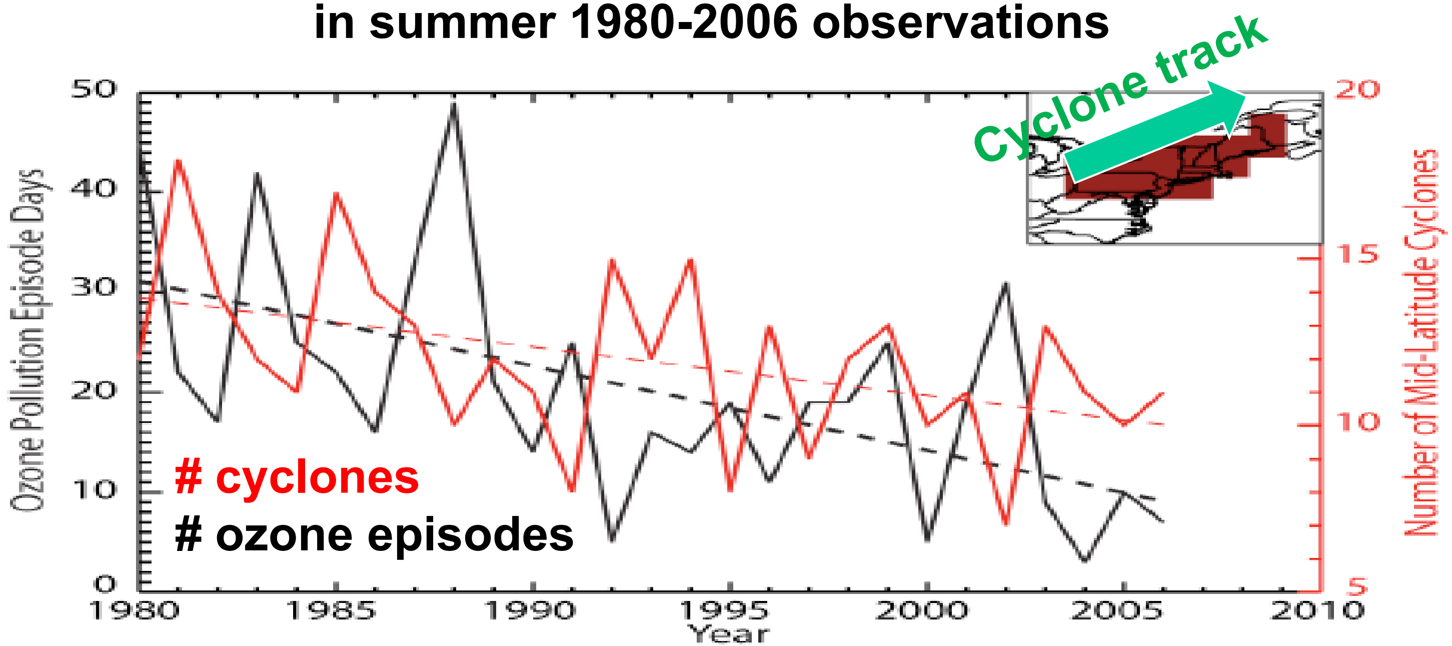


- Cold fronts associated with cyclones tracking across southern Canada are the principal ventilation mechanism for the Midwest and East
- The frequency of these cyclones has decreased in past 50 years, likely due to greenhouse warming

Leibensperger et al. [2008]

Observed trends of ozone pollution and cyclones in Northeast US

 # ozone episode days (O_3>80 ppb) and # cyclones tracking across SE Canada in summer 1980-2006 observations

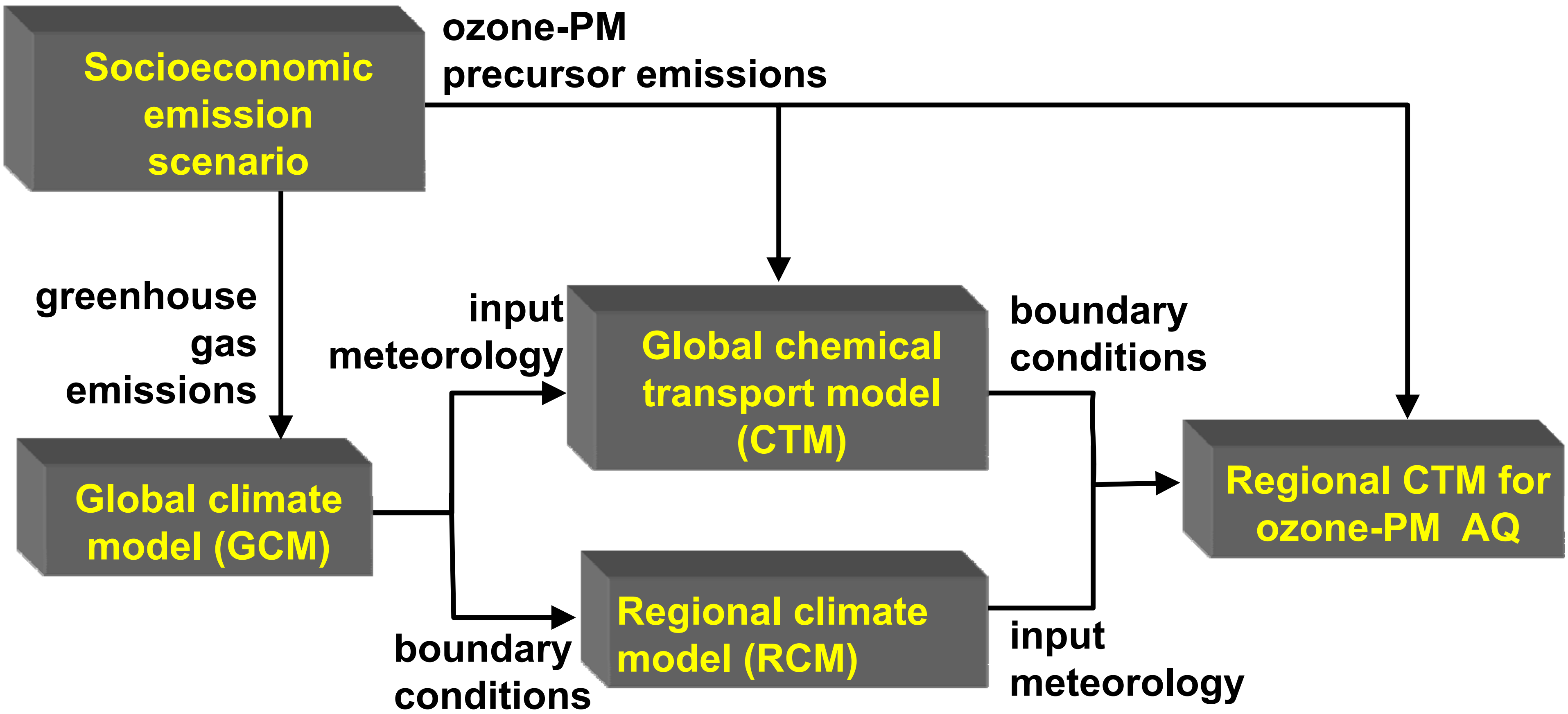


- **Cyclone frequency is predictor of interannual pollution variability**
- **Observed 1980-2006 decrease in cyclone frequency would imply a corresponding degradation of air quality if emissions had remained constant**
- **Expected # of 80 ppb exceedance days for Northeast average ozone dropped from 30 in 1980 to 10 in 2006, but would have dropped to zero in absence of cyclone trend**

This demonstrates impact of climate change on AQ policy over decadal scale

Leibensperger et al. [2008]

GCM-CTM approach to quantify effects of climate change on air quality

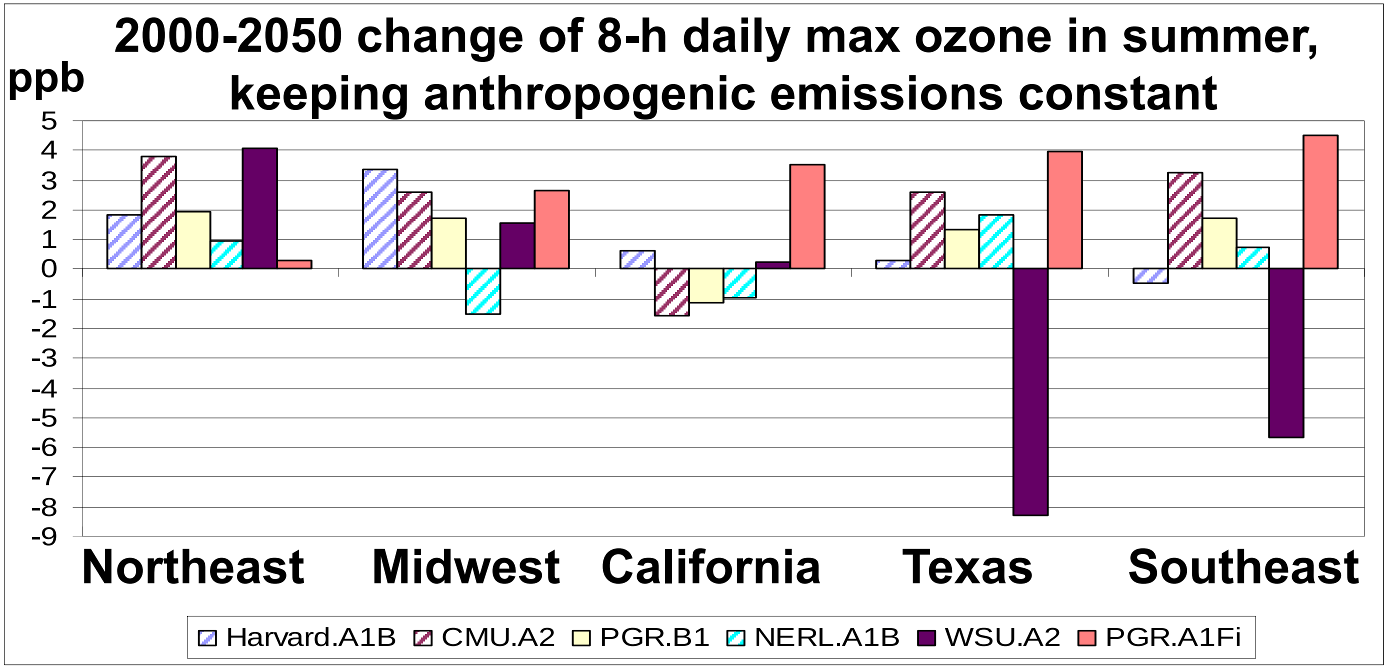


- Computationally expensive machinery, need a number of simulation years for robust statistics
- Five projects funded by EPA-STAR using different GCM-CTMs

Jacob and Winner [2009]

Ensemble model analysis of the effect of 2000-2050 climate change on ozone air quality in the US

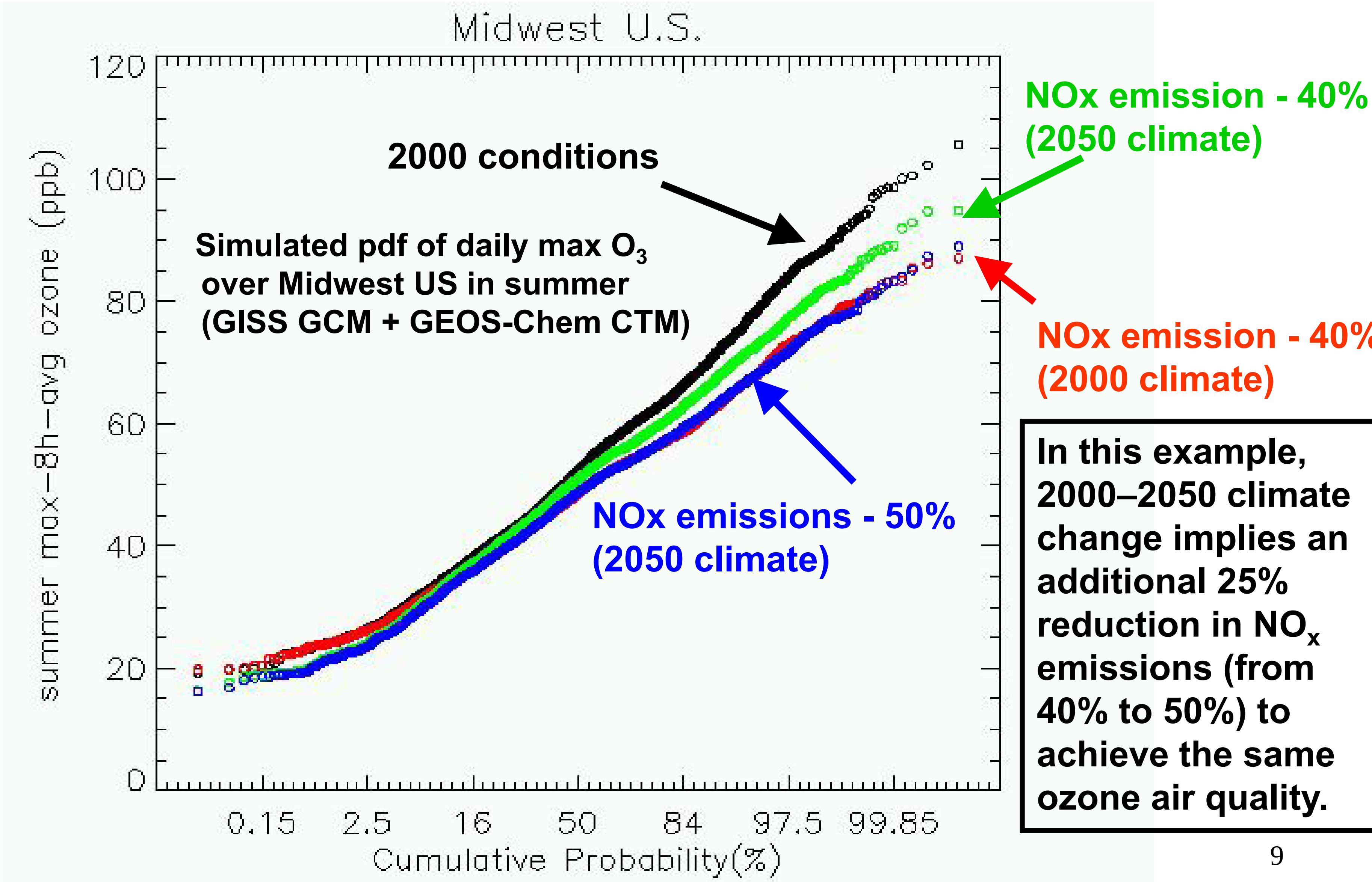
Results from six coupled GCM-CTM simulations



- Models show consistent projection of ozone increase over most of US
- Typical mean increase is 1-4 ppb, up to 10 ppb for ozone pollution episodes
- Increase is largest in urban areas with high ozone

Weaver et al. [2010]

Climate change penalty: meeting a given ozone air quality goal will require larger emission reductions in future climate

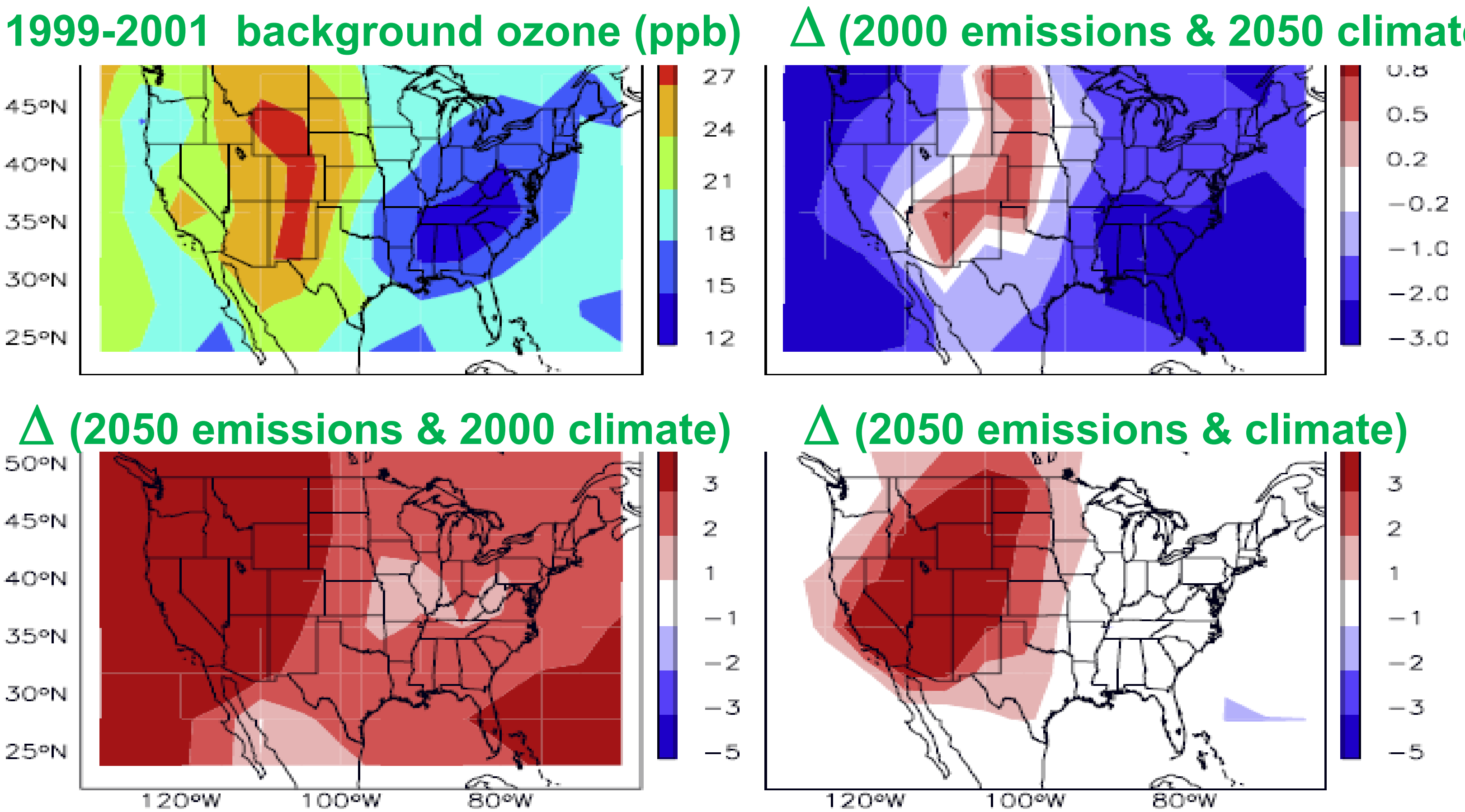


In this example, 2000–2050 climate change implies an additional 25% reduction in NO_x emissions (from 40% to 50%) to achieve the same ozone air quality.

Wu et al. [2008a]

Effect of climate change on background ozone

Background ozone is defined as the surface air concentration in absence of North American anthropogenic emissions



GISS GCM + GEOS-Chem CTM

Jun-Aug 1-5 pm

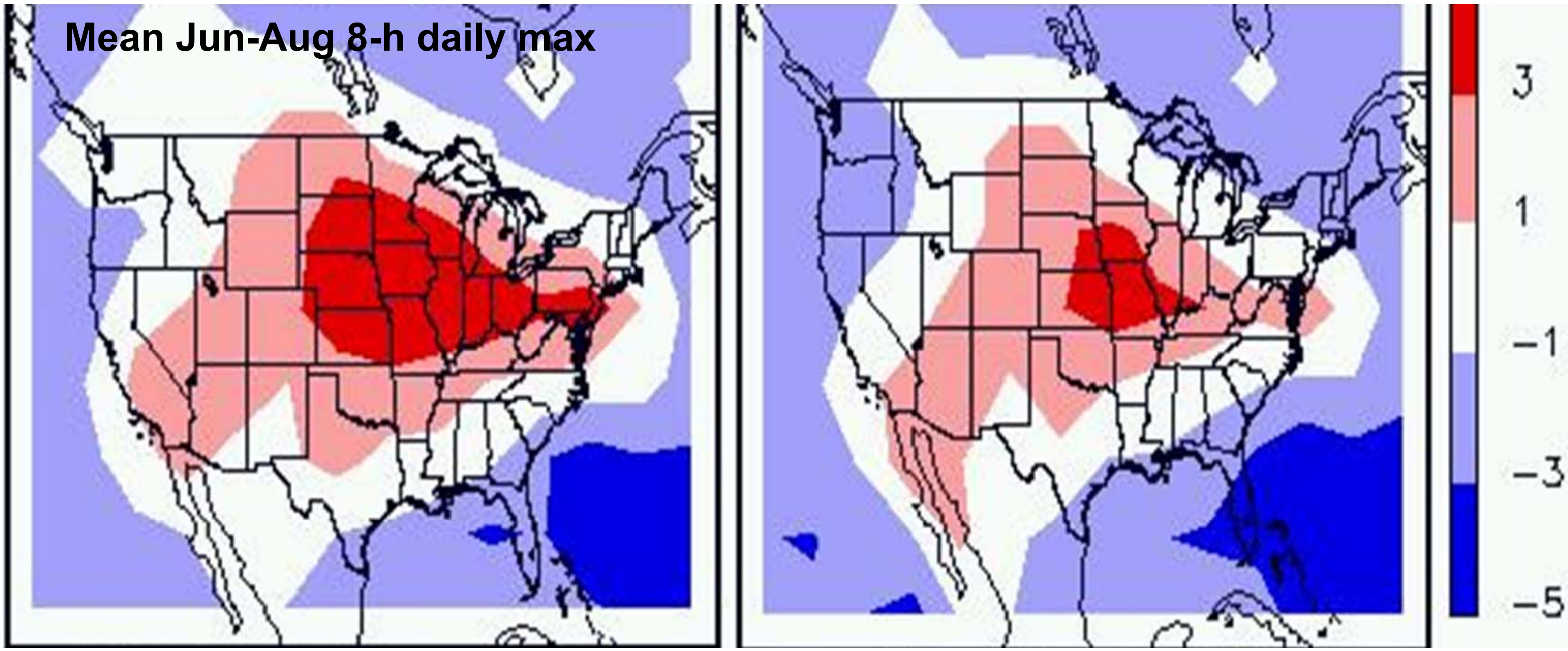
- **2050 emissions increase background due to rising methane, Asian sources**
- **2050 climate decreases background due to higher water vapor, except in inner West due to subsidence and drying**
- **The two effects cancel in the East; residual increase in intermountain West**

[Wu et al., 2008b]

Reducing emissions reduces climate change penalty …and can turn it into a climate benefit

Δ ozone from 2000-2050 climate change

GISS GCM + GEOS-Chem CTM



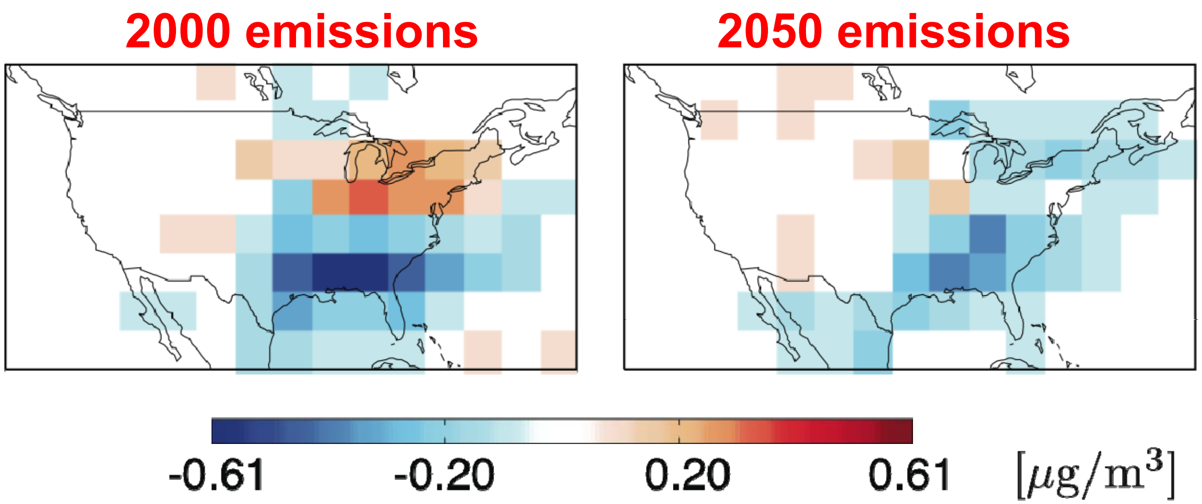
A warmer climate will make ozone pollution worse but ozone background better!
This result is very consistent across models

Wu et al. [2008a]

Effect of 2000-2050 climate change on annual mean $PM_{2.5}$

Different models show ± 0.1-1 μg m^{-3} effects of climate change on $PM_{2.5}$ with no consistency across models including in the sign of the effect

GISS GCM + GEOS-Chem CTM



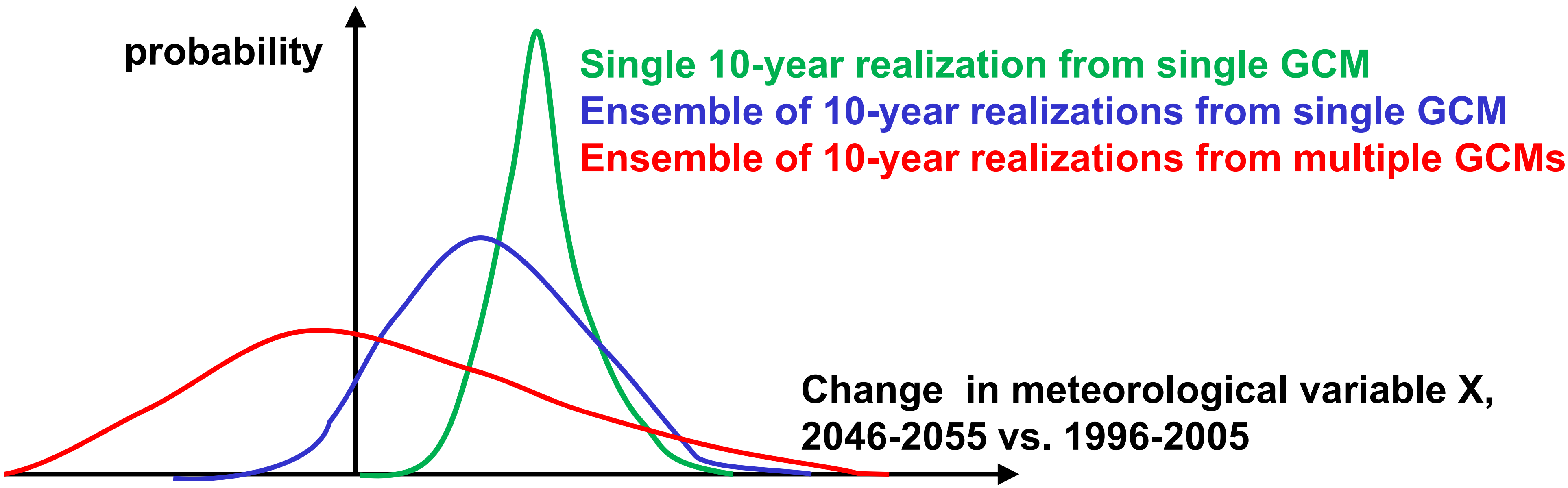
CMAQ model nested in GEOS-Chem

$\Delta PM_{2.5}$ (μg m^{-3})	Midwest	Northeast	Southeast
2000 emissions	+0.5	+0.1	-0.1
2050 emissions	+0.3	-0.4	-0.7

Decrease of SO_2 emissions improves climate effect on PM by changing speciation from sulfate to nitrate

Pye et al. [2009]; Lam et al. [2010]

GCM uncertainty in simulating regional climate change limits ability of GCM-CTMs to project changes in $PM_{2.5}$



- **Standard IPCC approach is to use multi-GCM ensemble statistics to diagnose regional climate change and corresponding confidence intervals**
- **BUT all GCM-CTM studies of ozone and $PM_{2.5}$ so far have used a single realization from a single GCM**
- **OK for ozone (qualitatively) because of dominant dependence on temperature**
- **Not OK for $PM_{2.5}$ because dependence on meteorological variables is far more complicated**

Correlation of $PM_{2.5}$ components with temperature

Deseasonalized annual data

Coefficient from multivariate regression

Simulated direct dependence: GEOS-Chem +1K perturbation

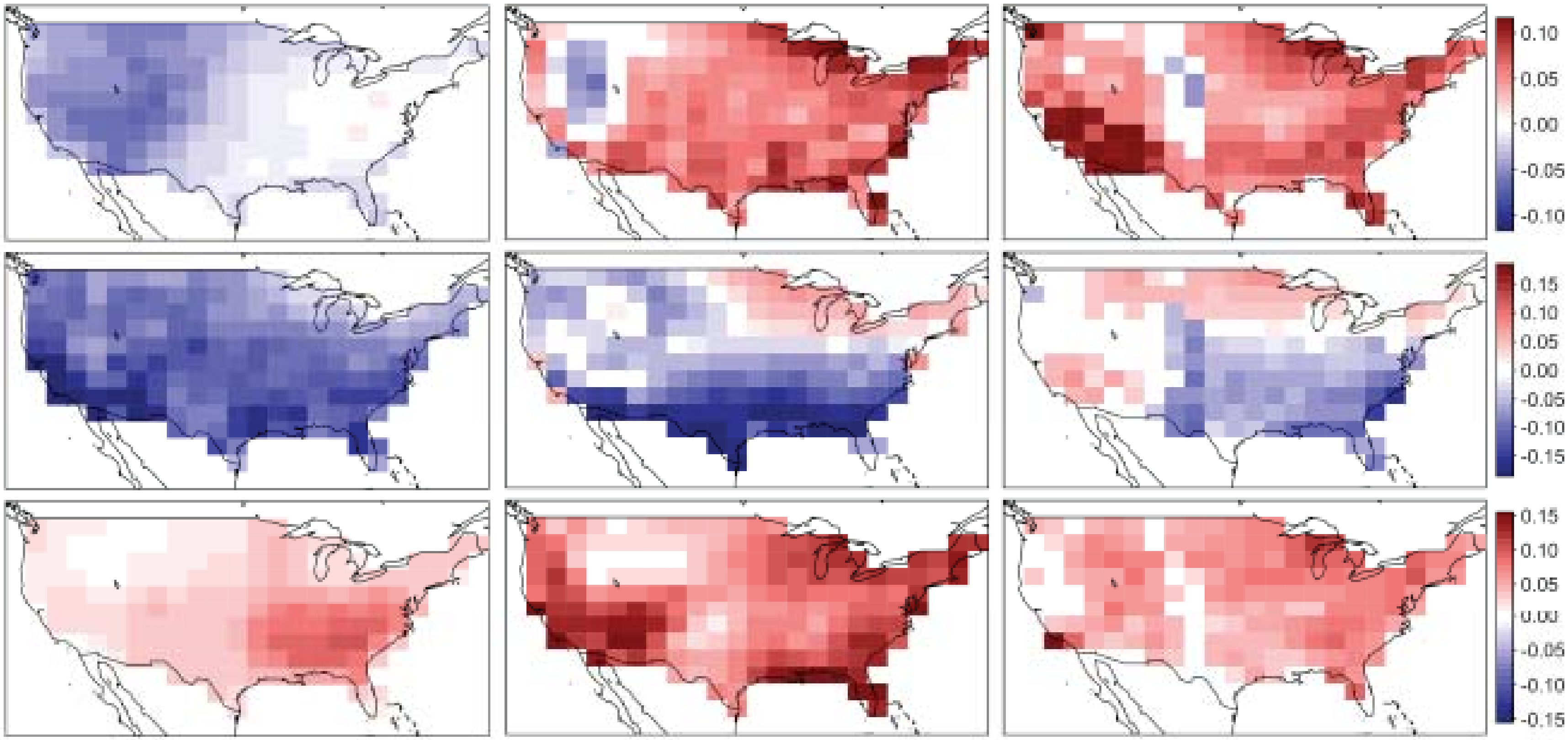
GEOS-Chem 2005-2007

EPA-AQS observations 2004-2008

Sulfate

Nitrate

OC



Correlations with *T* reflect direct dependences for nitrate (volatilization) and OC (vegetation, fires) but also indirect associations with transport

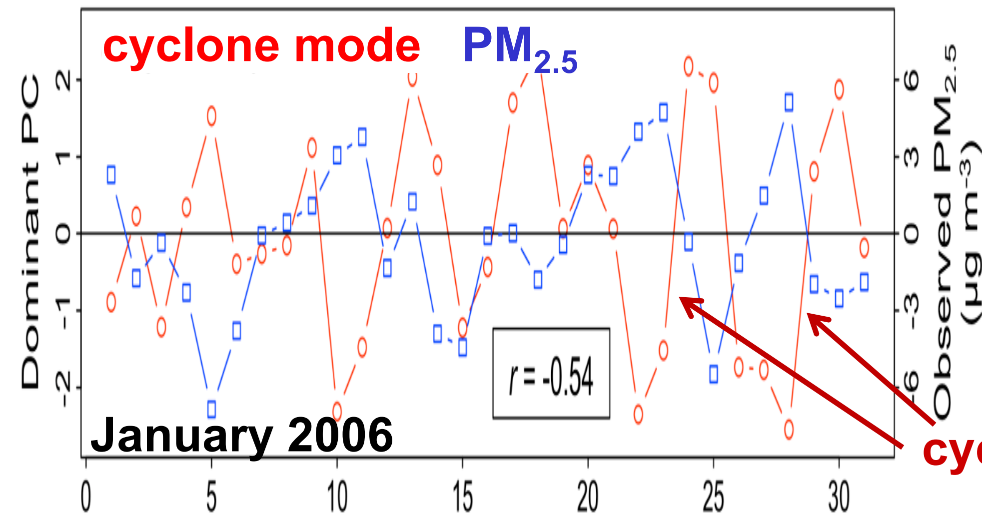
Tai et al. [2012]

Dominant meteorological modes for $PM_{2.5}$ variability in US

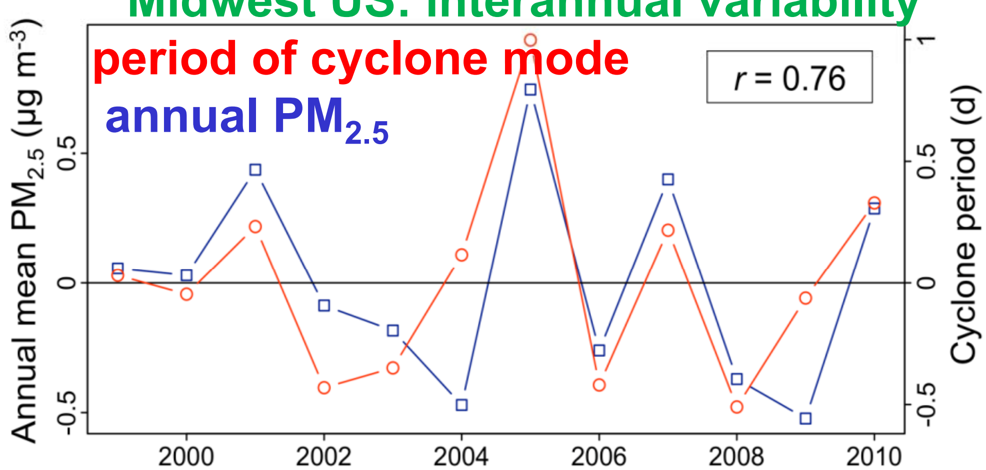
Principal component (PC) analysis of nine meteorological variables by region, and correlation of $PM_{2.5}$ with the corresponding PC modes

Independent Variable	Meteorological Parameter [a]
x_1	Surface temperature (K)
x_2	Surface relative humidity (%)
x_3	Daily total precipitation (in/d)
x_4	Total cloud cover (%)
x_5	Geopotential height at 850 mb (m)
x_6	Local rate of change of sea level pressure ($dSLP/dt$) (Pa/d)
x_7	Surface wind speed (m/s), calculated from u and v wind vectors
x_8	E-W wind direction indicator ($\cos\theta$) [b]
x_9	N-S wind direction indicator ($\sin\theta$) [b]

Midwest US: day-to-day variability



Midwest US: interannual variability

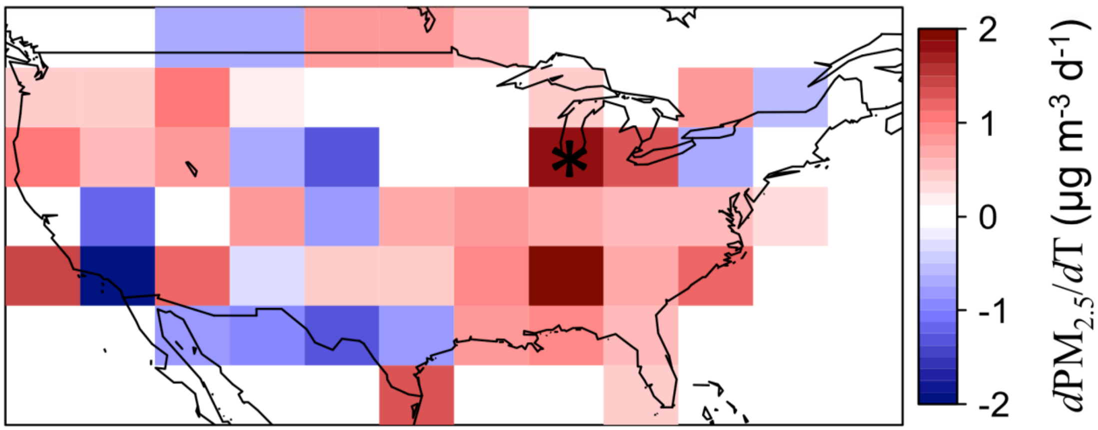


Transport modes for $PM_{2.5}$ variability

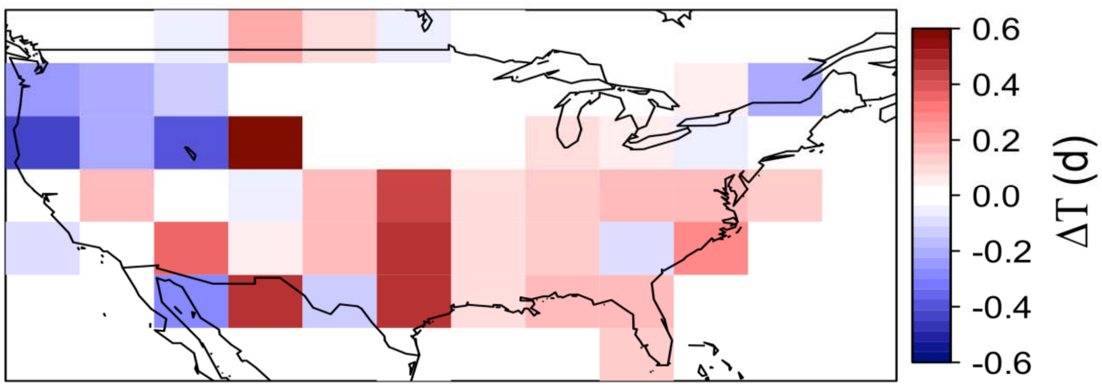
- **East, Midwest: fronts**
- **West Coast: marine inflow**

Tai et al. [2012, in prep]

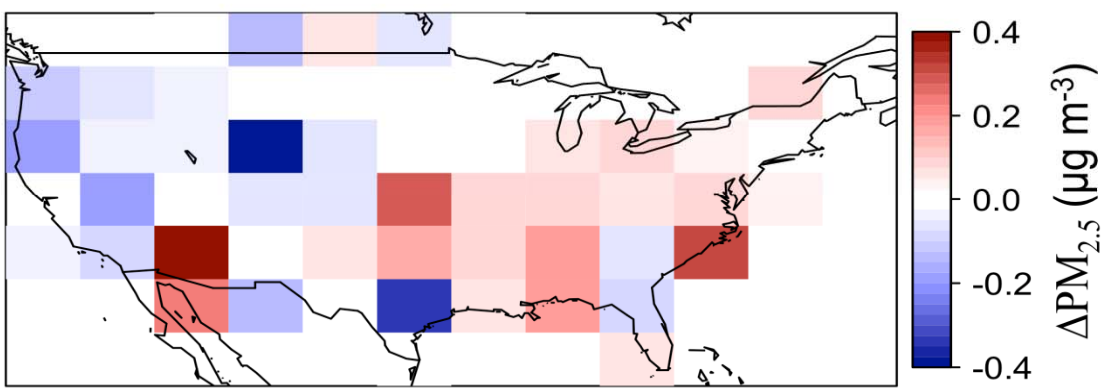
Interannual dependence of annual $PM_{2.5}$ on period T of dominant meteorological mode of variability



Climatological observations of $dPM_{2.5}/dT$ (1999-2010)



Projected change in T, 2000-2050 (fifteen IPCC AR4 GCMs)

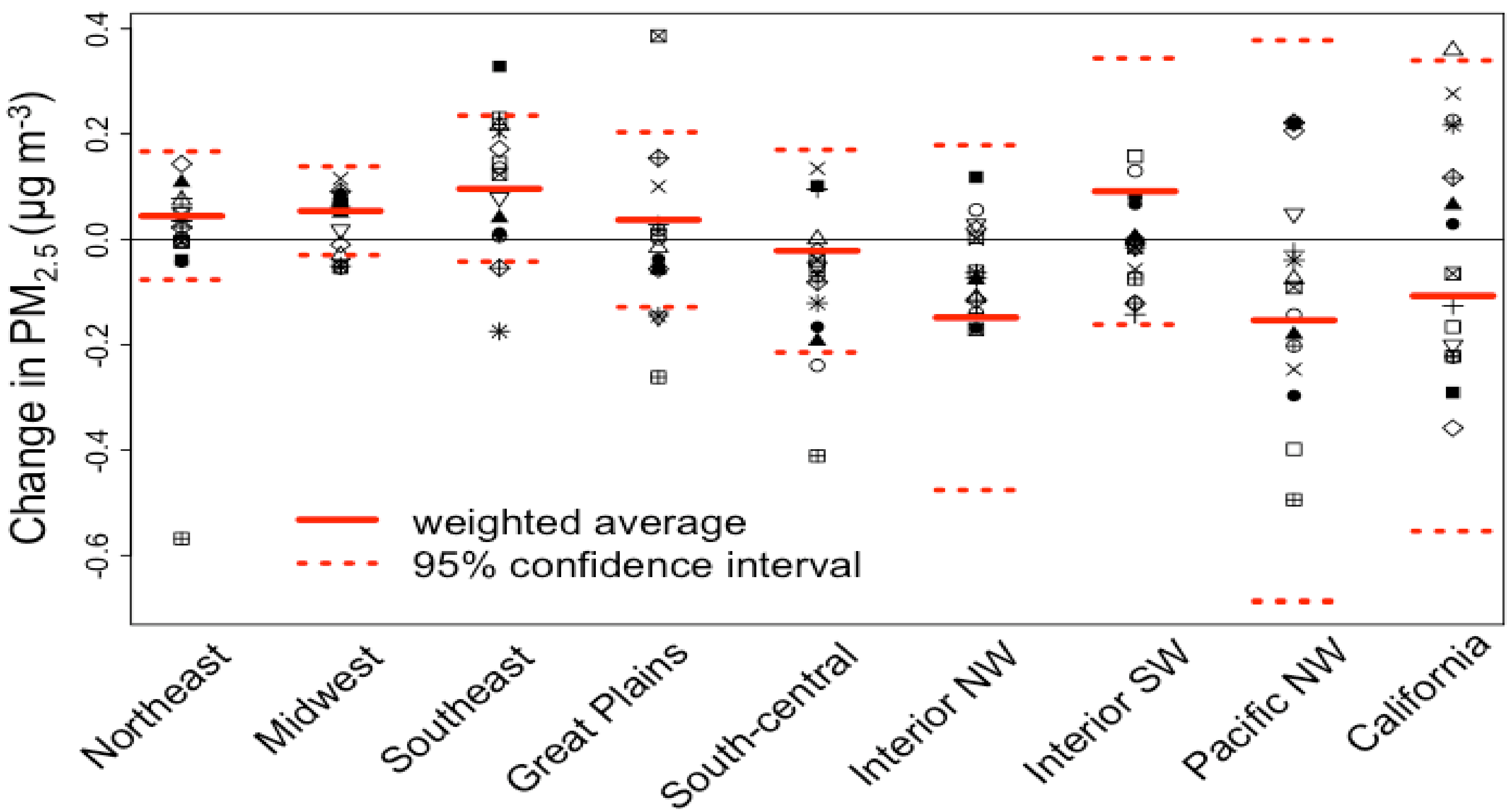


Resulting change in $PM_{2.5}$, 2000-2050

Tai et al. [in prep]

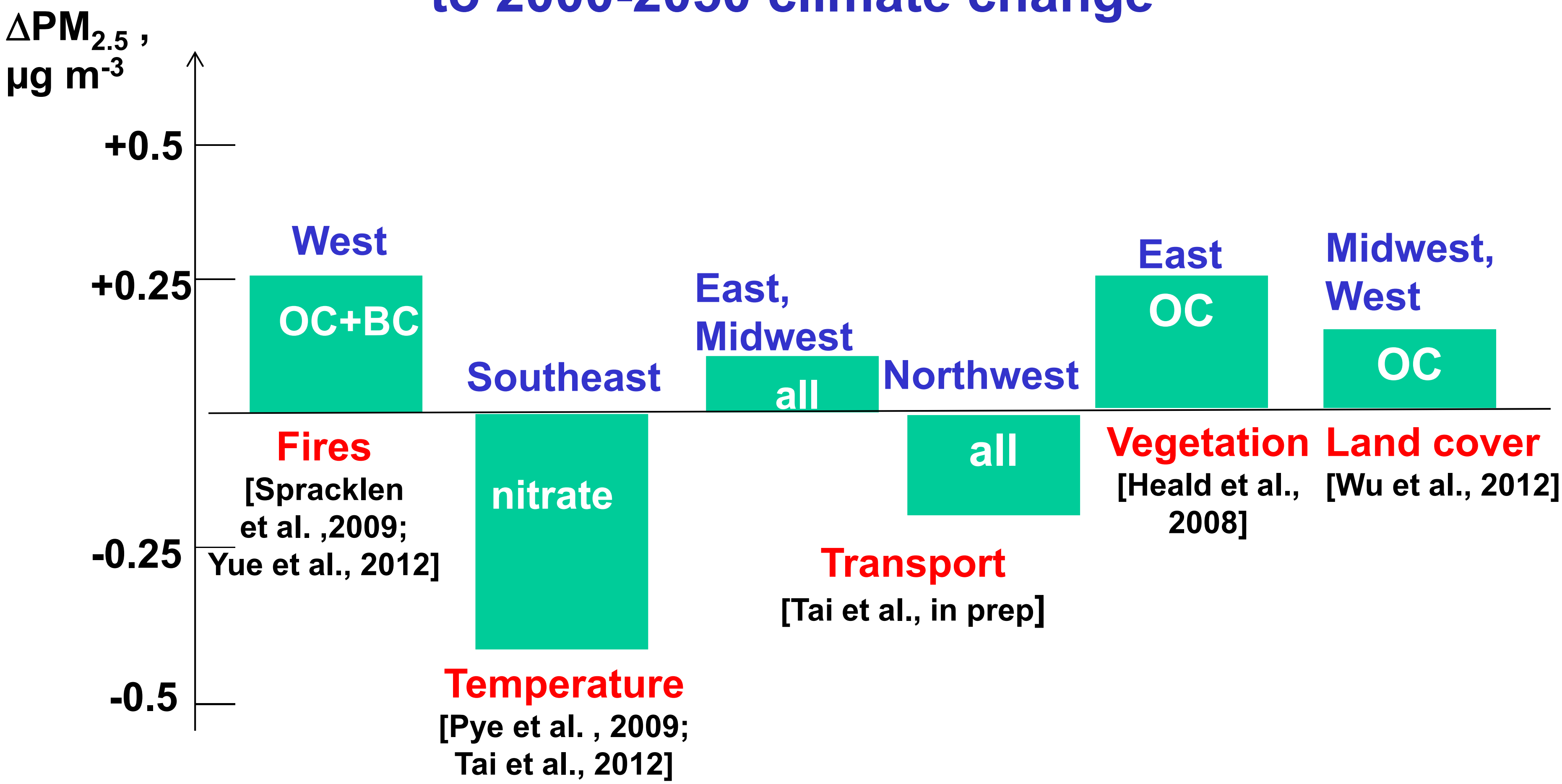
Variability across 15 IPCC GCMs in annual $PM_{2.5}$ response to 2000-2050 change in meteorological transport modes

Symbols are inividual GCMs; statistics use reality ensemble average (REA)



Statistically significant increases of ~0.1 μg m^{-3} in East and Midwest, decrease of ~0.2 μg m^{-3} in Pacific NW

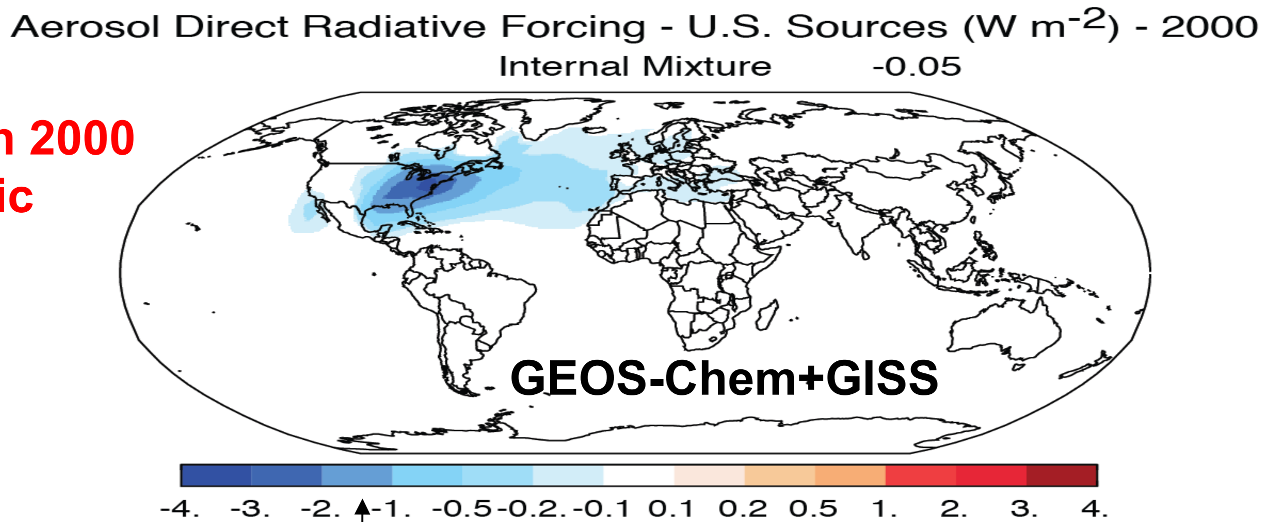
Overall assessment of response of annual $PM_{2.5}$ to 2000-2050 climate change



- Overall effect of climate change on annual $PM_{2.5}$ unlikely to exceed 0.5 $\mu g\ m^{-3}$
- Impact of western fires on daily $PM_{2.5}$ may be the most important issue

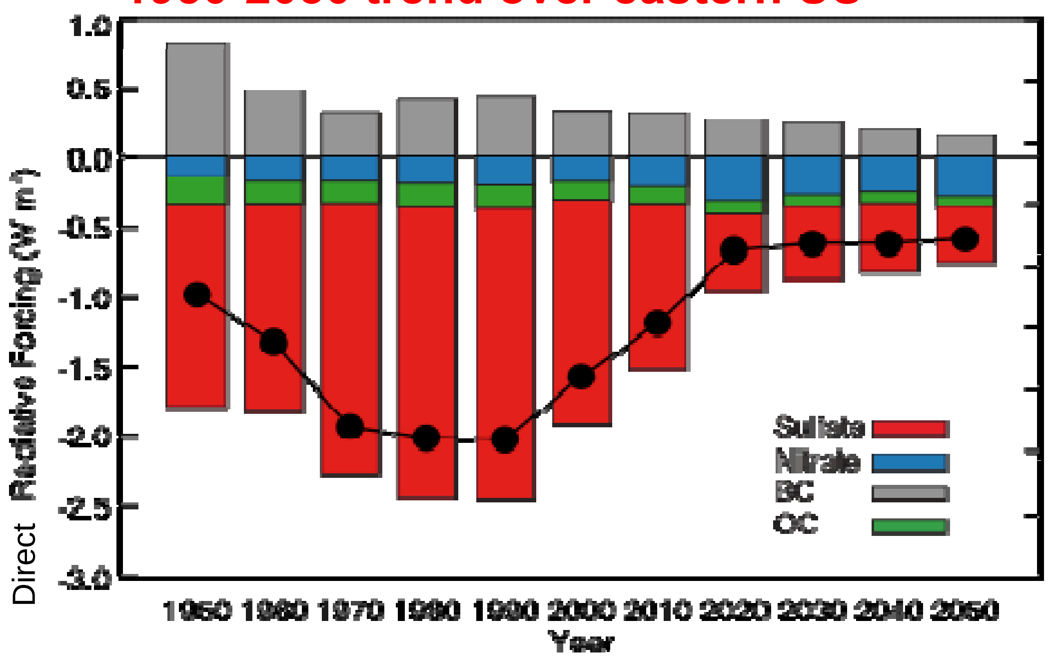
Climate response to 1950-2050 change in US PM sources

PM radiative forcing in 2000 from US anthropogenic sources



global radiative forcing from CO_2

1950-2050 trend over eastern US

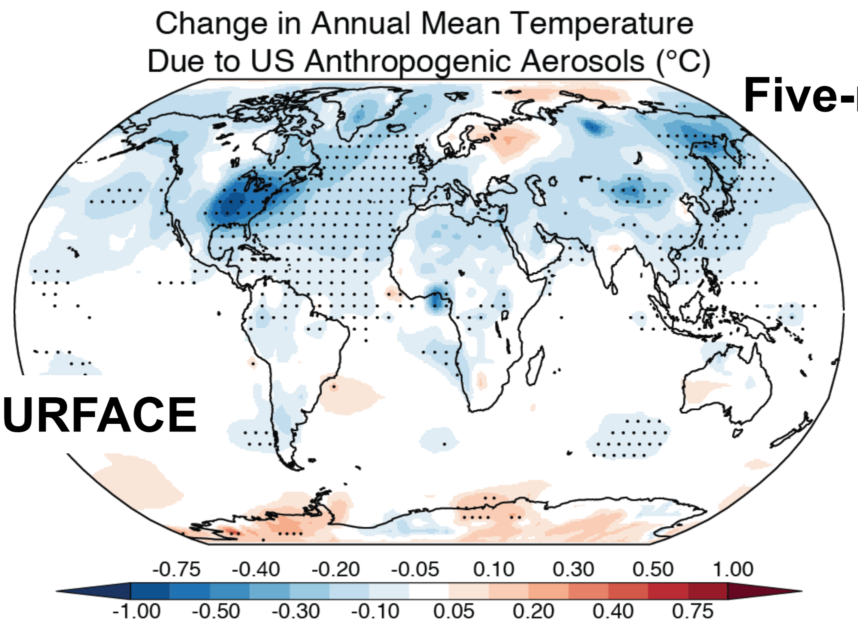


- **Forcing is mostly from sulfate, peaked in 1970-1990**
- **Forcing from OC is very uncertain**
- **Little leverage to be had from BC control**
- **Indirect (cloud) forcing is of similar magnitude to direct forcing**

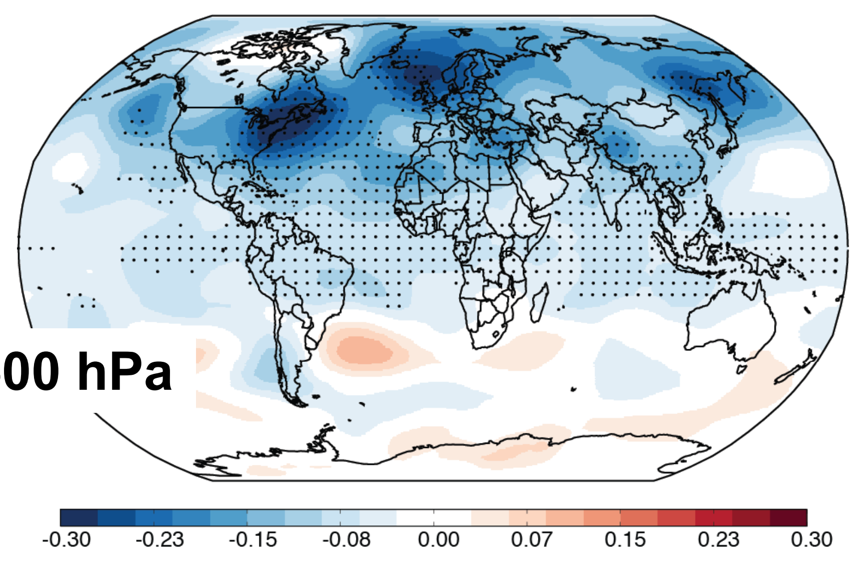
Leibensperger et al., [2012a]

Cooling from US anthropogenic PM (1980)

From difference of GISS GCM simulations with vs. without US aerosol sources (GEOS-Chem), and including direct and cloud (albedo and lifetime) effects



SURFACE



500 hPa

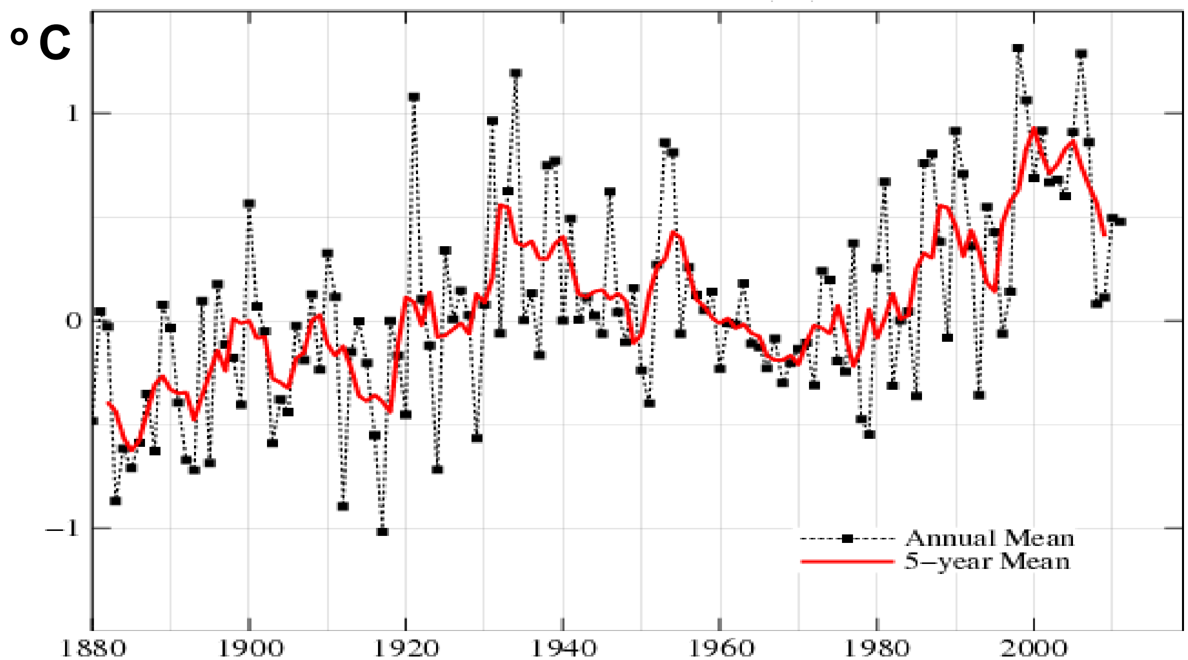
Five-member realizations of 1970-1990 statistics; dots indicate statistical significance

- **Surface cooling (up to 1° C) is strongly localized over eastern US**
- **Cooling at 500 hPa (5 km) is more diffuse because of heat transport**

Leibensperger et al. [2012b]

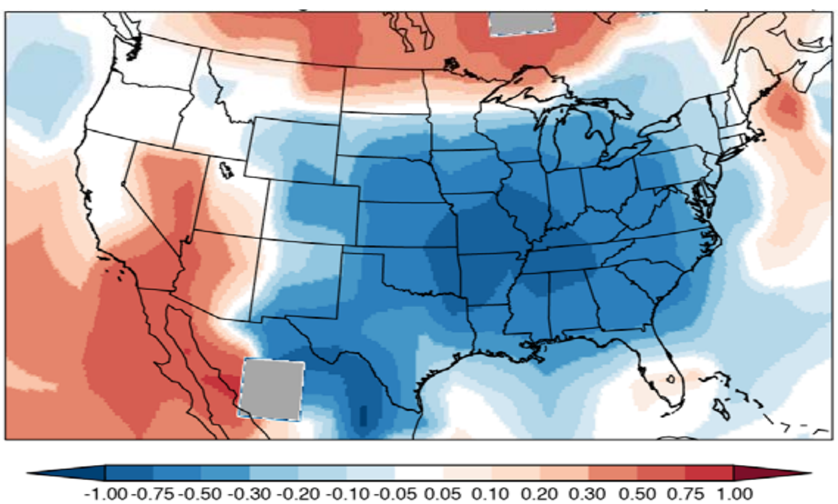
Observed “warming hole” over eastern US

Surface temperature trend, contiguous US



- US has warmed faster than global mean, as expected in general for mid-latitudes land
- But there has been no warming between 1930 and 1980, followed by sharp warming after 1980

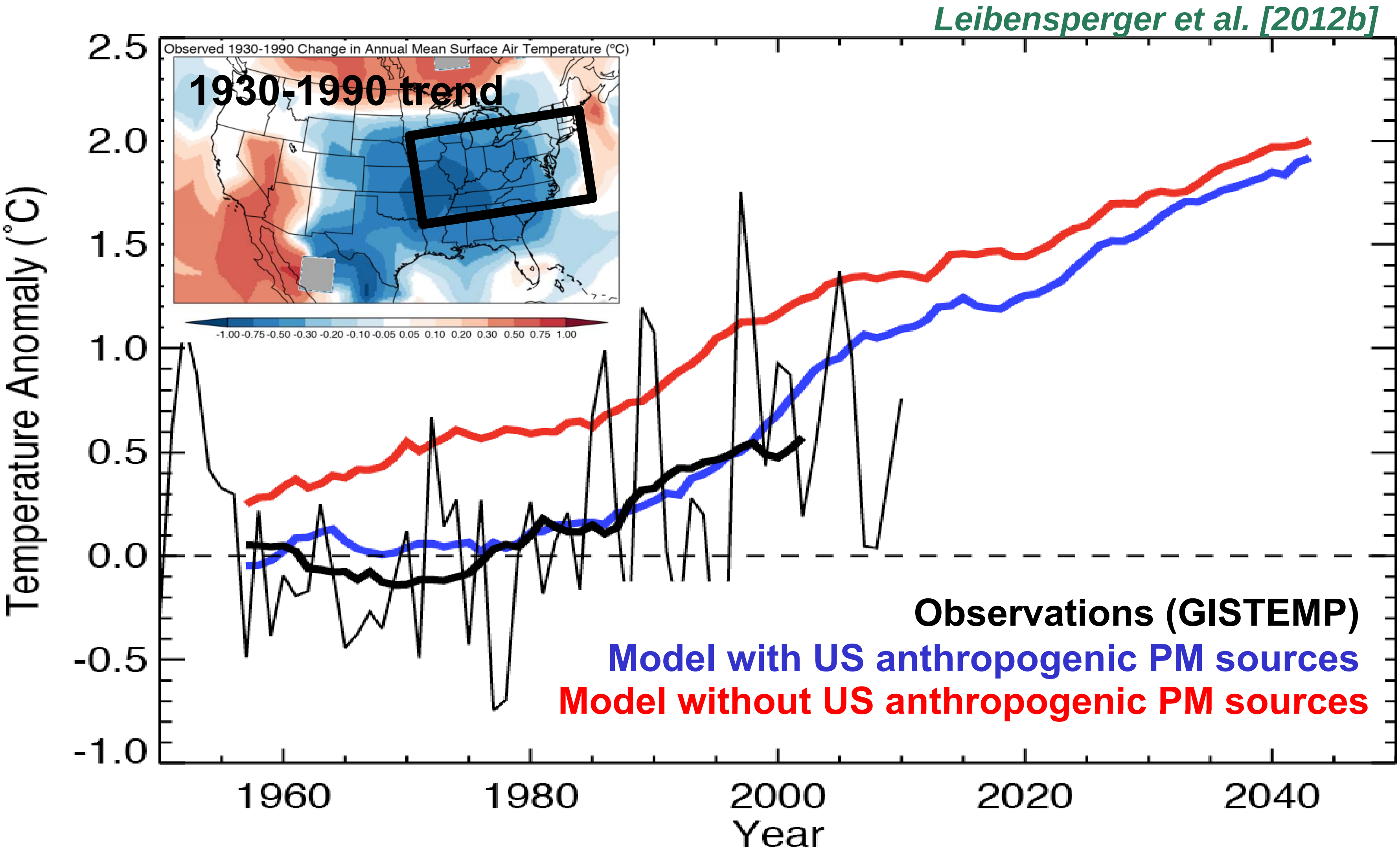
Spatial distribution of 1930-1990 trend



“warming hole” over eastern US

GISTEMP [2010]

1950-2050 surface temperature trend in eastern US



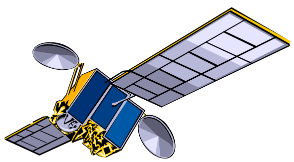
- US anthropogenic PM sources can explain the "warming hole"
- Rapid warming has taken place since 1990s that we attribute to PM reduction
- Most of the warming from PM source reduction will have been realized by 2020

Air Quality Applied Sciences Team (AQAST)

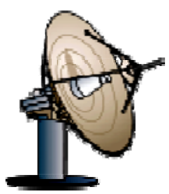
EARTH SCIENCE SERVING AIR QUALITY MANAGEMENT NEEDS

http://acmg.seas.harvard.edu/aqast

Earth science resources



satellites



suborbital platforms

models

AQAST →

Air Quality Management Needs

- **Pollution monitoring**
- **Exposure assessment**
- **AQ forecasting**
- **Source attribution of events**
- **Quantifying emissions**
- **Assessment of natural and international influences**
- **Understanding of transport, chemistry, aerosol processes**
- **Understanding of climate-AQ interactions**

For more information on how AQAST can help you please ask me!