GLOBAL CHANGE AND AIR POLLUTION (GCAP):
Work to date and future plans

an EPA-STAR project

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David G. Streets, ANL
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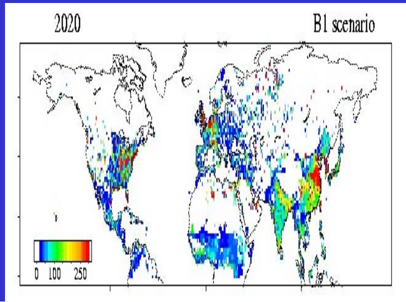
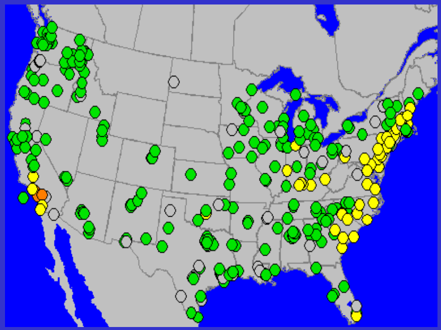
2000-2050 change in climate

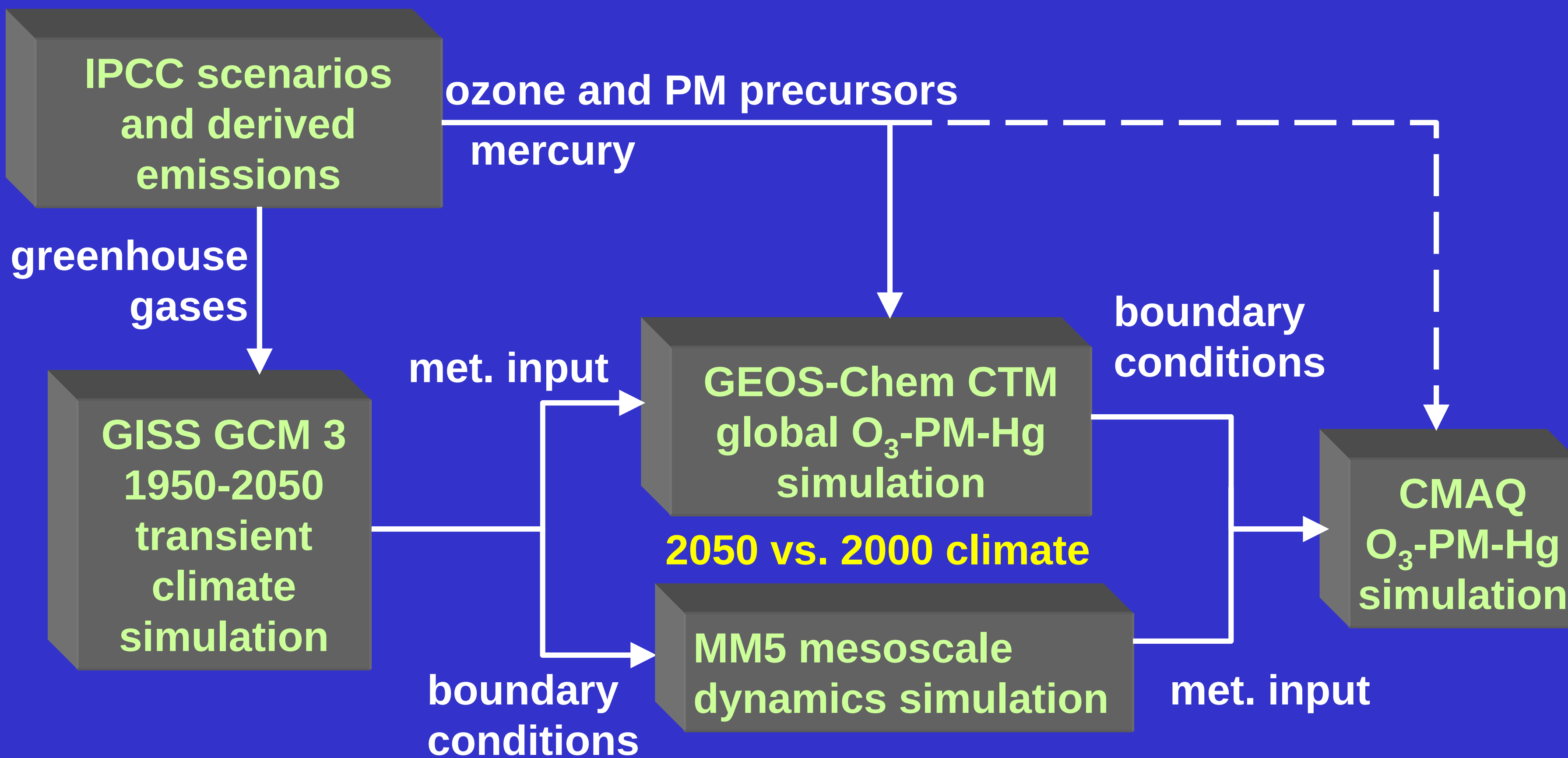
2000-2050 change in pollutant emissions



2000-2050 change in U.S. air quality



THE GCAP STRATEGY



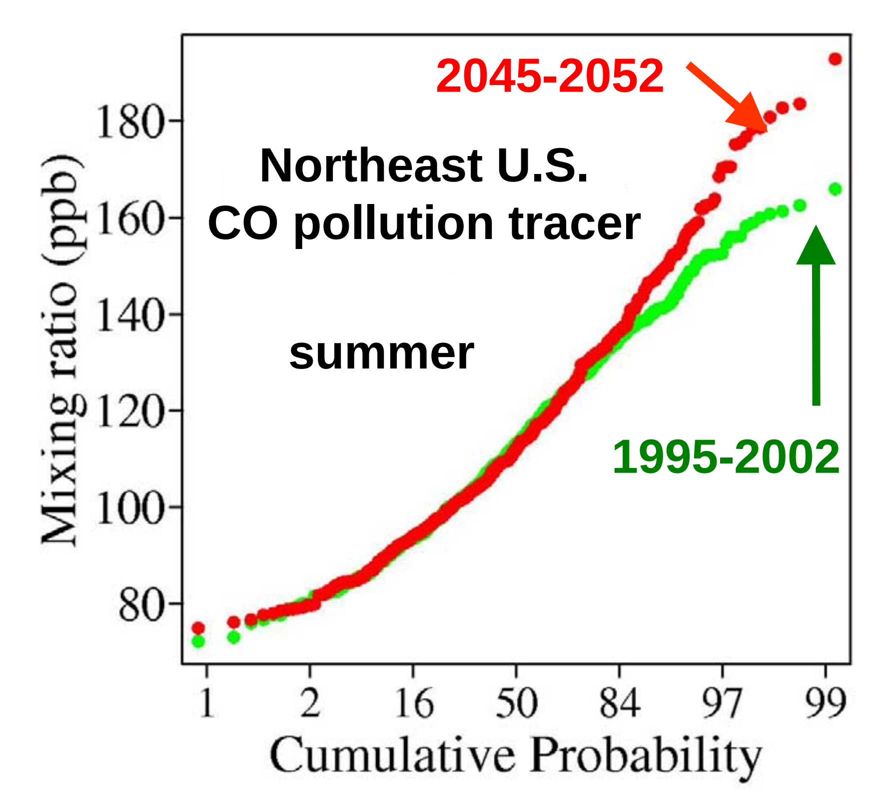
GCAP WORK TO DATE

- Analysis of 2000-2050 trends in air pollution meteorology
- Development of GISS/GEOS-Chem interface
- Development of GISS/MM5 interface
- Development of future emission inventories for carbonaceous aerosols
- Application of GISS/GEOS-Chem to 2000-2050 trends in ozone and PM (IPCC A1 scenario)
- Statistical projection of 2000-2100 ozone trends

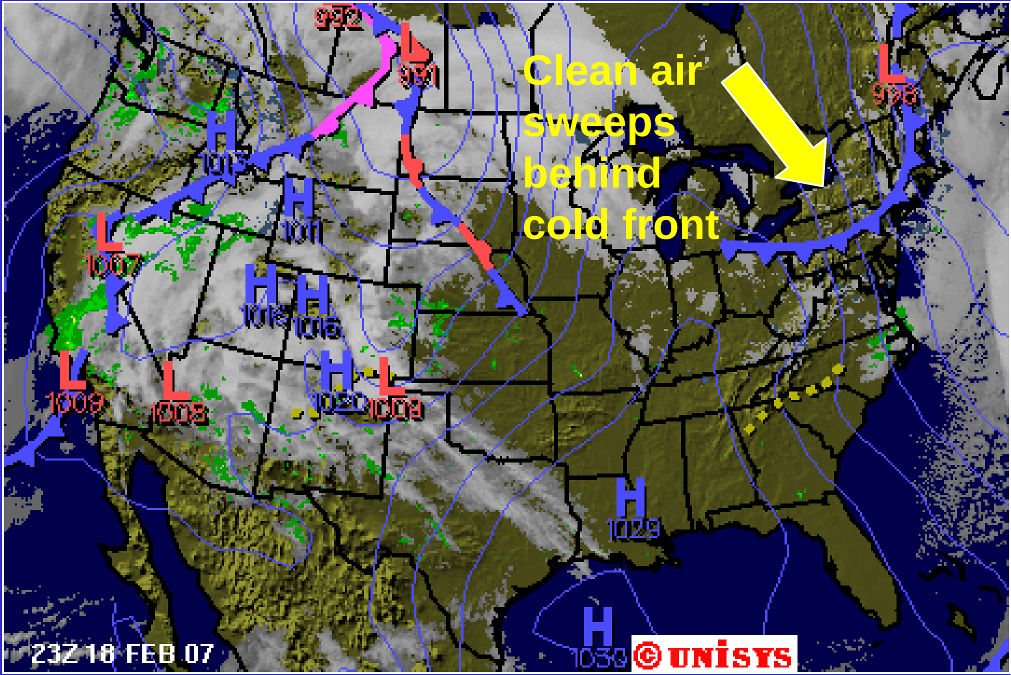
EFFECT OF CLIMATE CHANGE ON REGIONAL STAGNATION

GISS GCM 2' simulations for 2050 vs. present-day climate using pollution tracers with constant emissions

Mid-latitudes cyclones tracking across southern Canada are the main drivers of northern U.S. ventilation



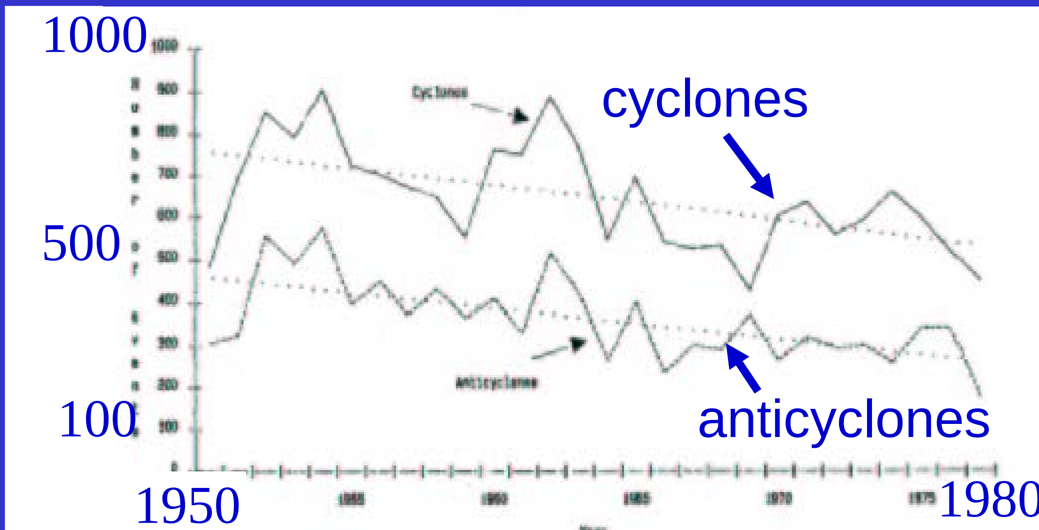
Sunday night's weather map



Pollution episodes double in duration in 2050 climate due to decreasing frequency of cyclones ventilating the eastern U.S; this decrease is an expected consequence of greenhouse warming.

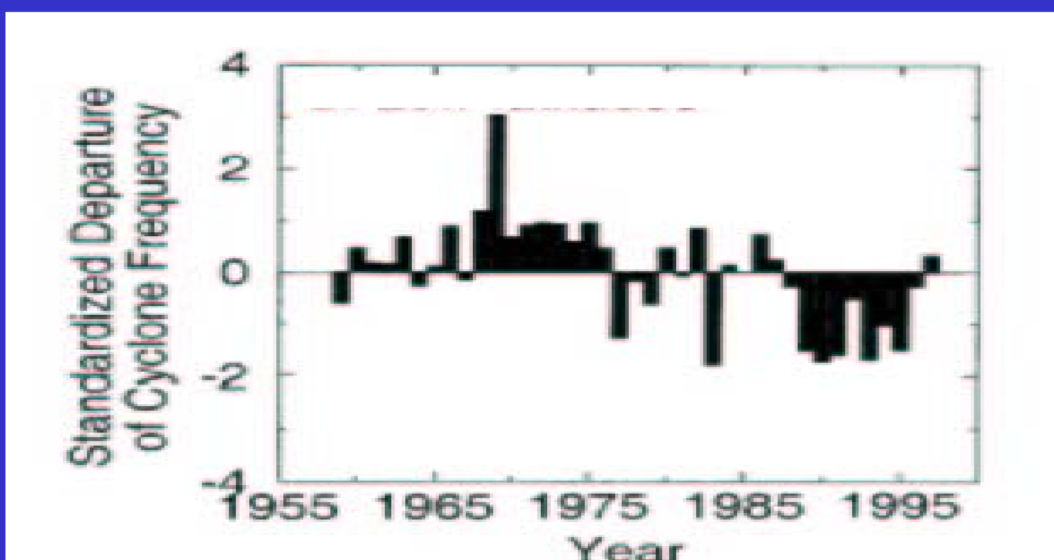
Mickley et al. [2004]

CLIMATOLOGICAL DATA SHOW DECREASE IN FREQUENCY OF MID-LATITUDE CYCLONESOVER PAST 50 YEARS



Annual number of surface cyclones and anticylones over North America

Agee [1991]



Cyclone frequency at 30^o-60^{o}N

McCabe et al. [2001]

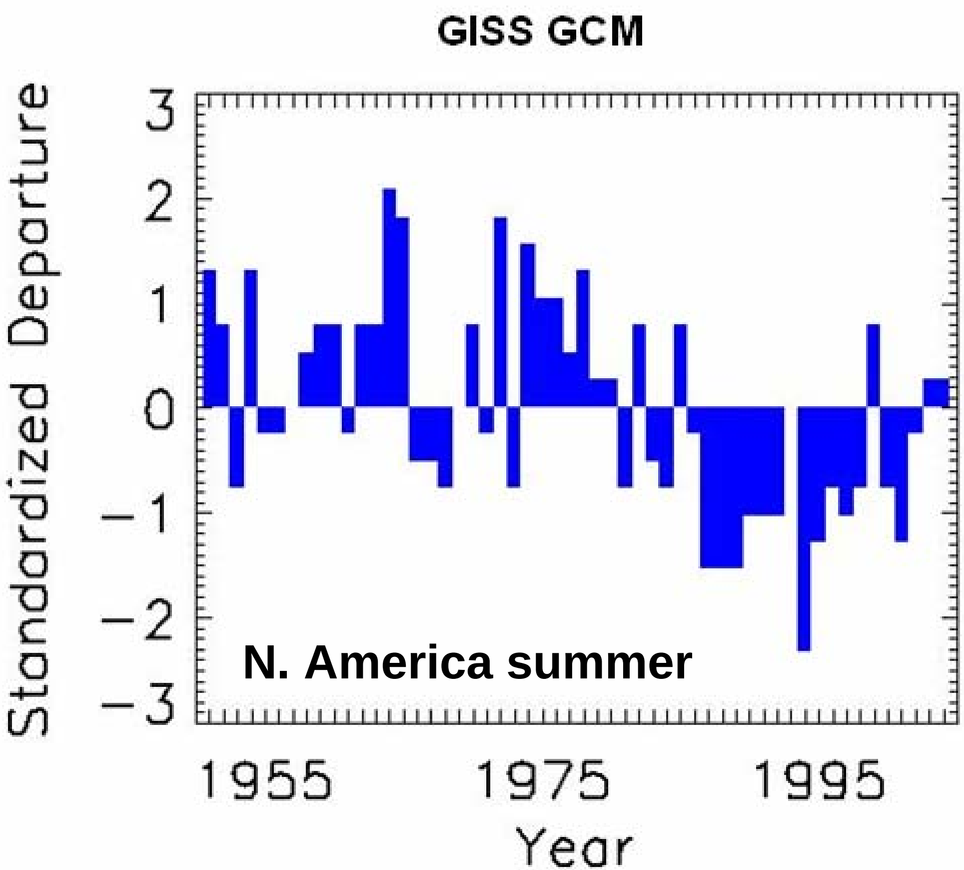
GCM vs. OBSERVED 1950-2000 TRENDS IN CYCLONE FREQUENCIES

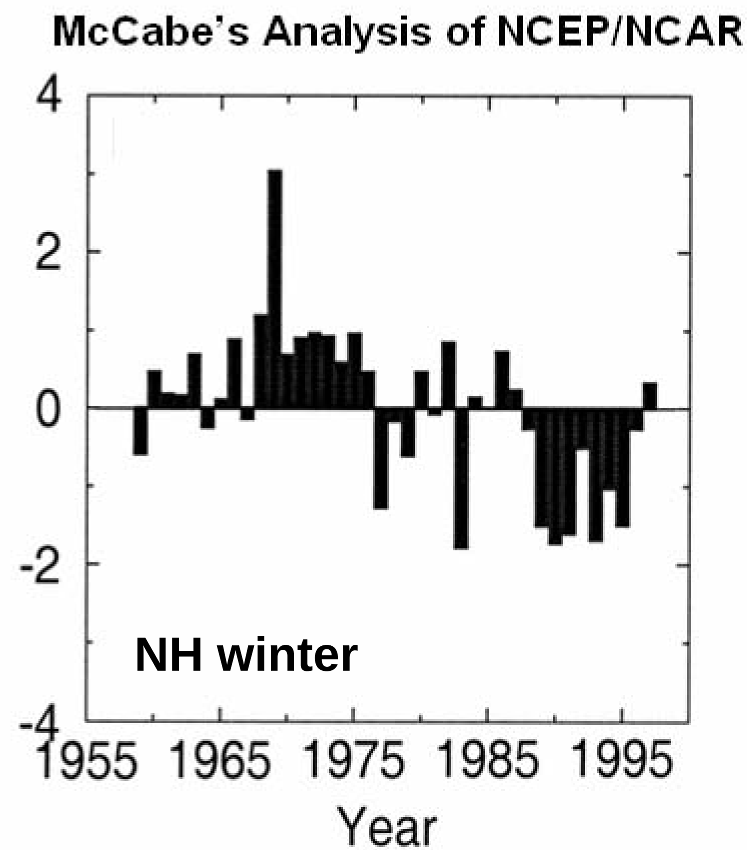
$$\text{Standardized departure} = \frac{n - \bar{n}}{\sigma}$$

n = # cyclones per year

$\bar{n}$ = long-term av. (9 for N.America summer)

σ = std dev (3 for N. America summer)





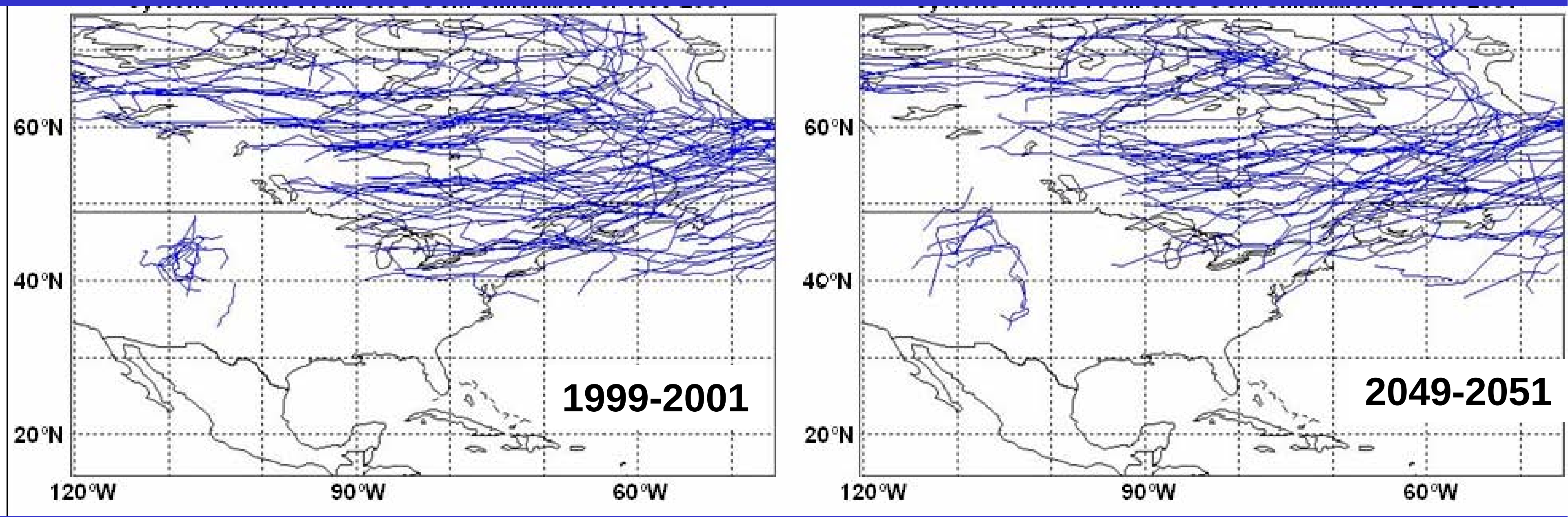
40% simulated decrease in cyclone frequency for N. America for 1950-2000, consistent with observations

Eric M. Leibensperger, Harvard

REDUCED VENTILATION OF CENTRAL/EASTERN U.S. IN FUTURE CLIMATE DU TO LOWER CYCLONE FREQUENCY

Summertime cyclone tracks for three years of GISS GCM climate show 14 % decrease in number of cyclones as well as a poleward shift.

2000 climate | **2050 climate**



Consistent with IPCC [2007] analysis of output from 20 GCMs [Lambert et al., 2006]

Eric M. Leibensperger, Harvard

DRIVING GEOS-Chem WITH GISS GCM 3 OUTPUT

GISS GCM 3 transient climate simulation 4°x5°, 23L

→

6-hour archive:
winds, convective mass fluxes, temperature, humidity, cloud optical depths, precipitation…
3-hour archive:
mixing depths, surface properties

replicates structure of NASA/GEOS assimilated data archive (0.5°x0.625°) used to drive standard GEOS-Chem

→

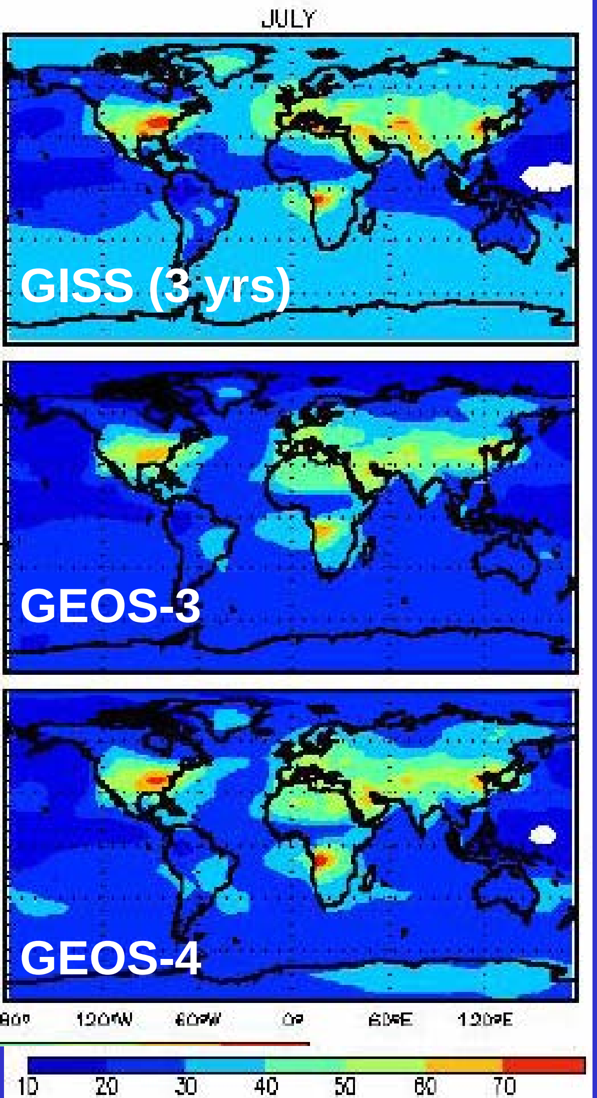
GEOS-Chem O_3-PM-Hg simulation 4°x5°, 23L

Option of using GISS GCM met. fields is now part of the standard GEOS-Chem

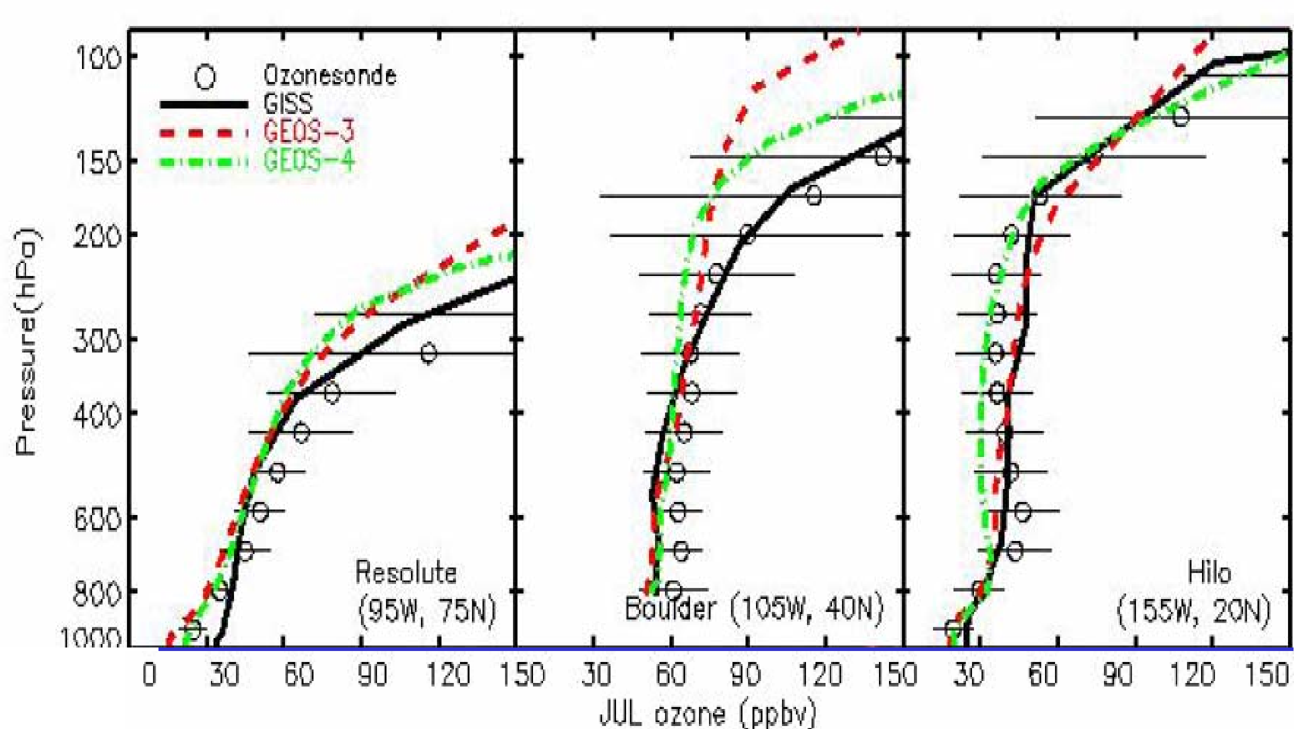
Wu et al. [2007a]

EVALUATION OF GISS/GEOS-Chem OZONE SIMULATION

Present-climate simulation (3 yrs) vs. GEOS-3 (2001), GEOS-4 (2001). ozonesondes



July surface afternoon ozone (ppbv)



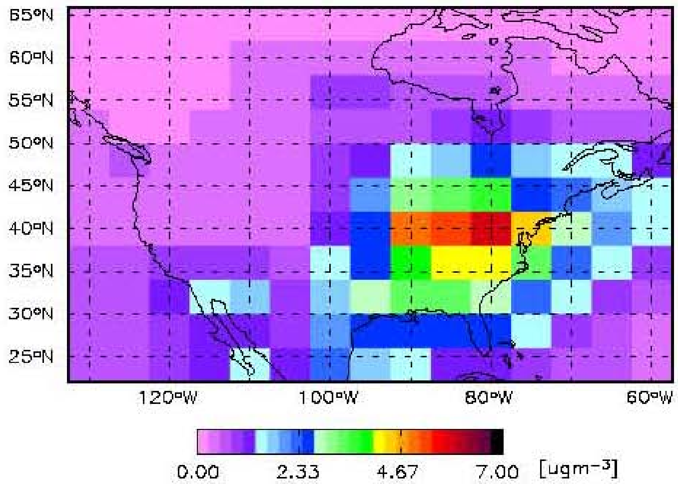
Global ozone budgets:

	$P(O_3)$, Tg y^{-1}	STE, Tg y^{-1}	$L(O_3)$, Tg y^{-1}	$D(O_3)$, Tg y^{-1}	Burden, Tg
GISS	4470	510	3990	990	320
GEOS-3	4250	540	3710	1080	300
GEOS-4	4700	520	4130	1090	300

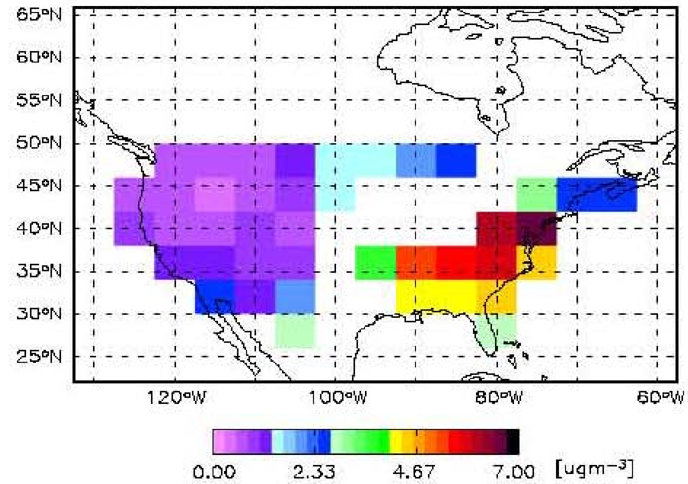
Wu et al. [2007a]

Evaluation of Present-day Sulfate:
Measurements Averaged over 2001-2003

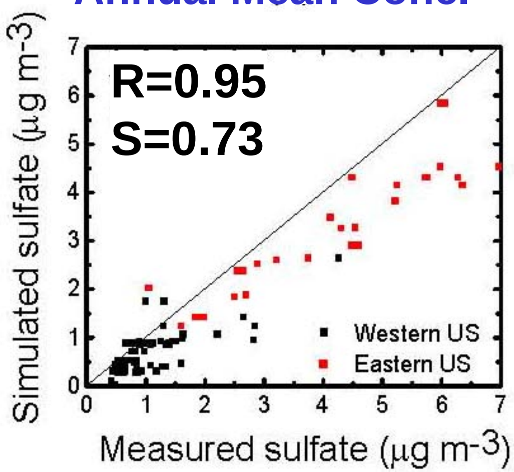
GISS/GEOS-Chem



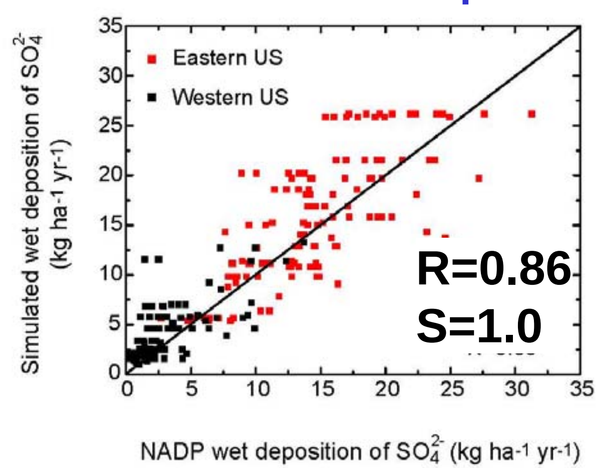
IMPROVE



Simulated vs. IMPROVE Annual Mean Conc.



Simulated vs. NADP Annual Mean Wet Deposition



Liao et al. [2007]

Evaluation of Present-day Nitrate, BC, and OC

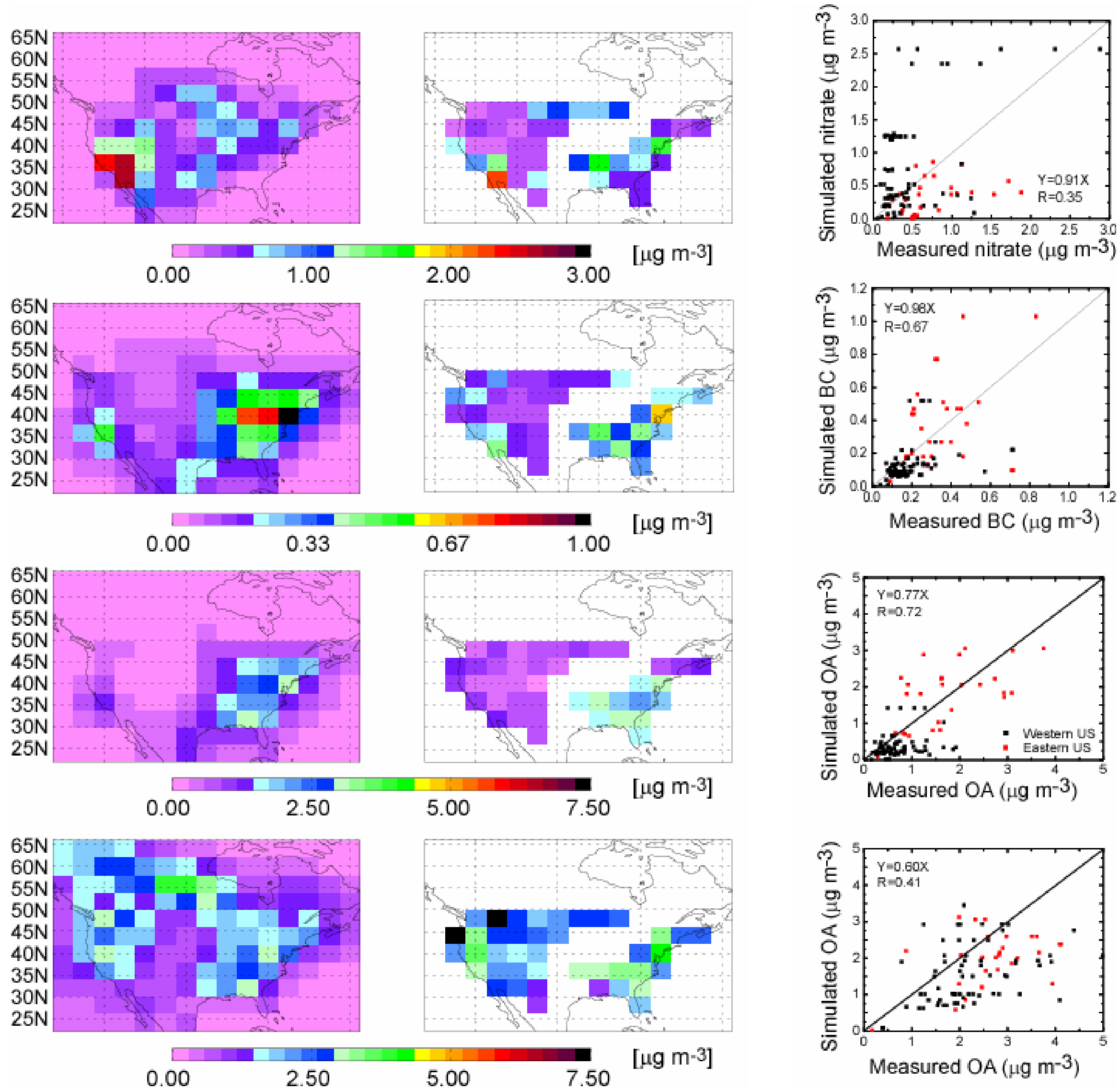
GCAP | IMPROVE | Simulated vs. IMPROVE

Annual Mean Nitrate — R=0.35, S=0.91

Annual Mean BC — R=0.67, S=0.98

Seasonal Mean OC DJF — R=0.72, S=0.77

Seasonal Mean OC JJA — R=0.41, S=0.60

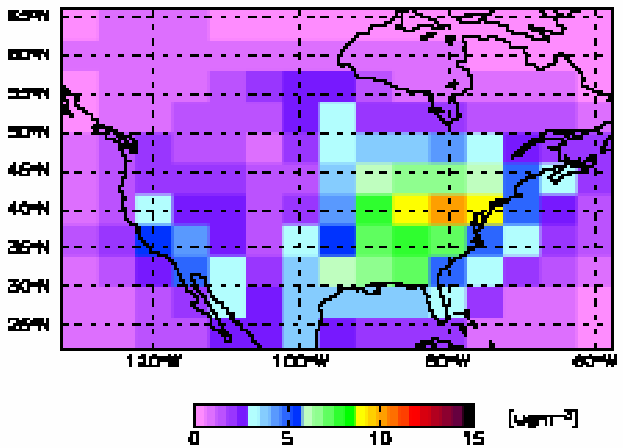


Liao et al. [2007]

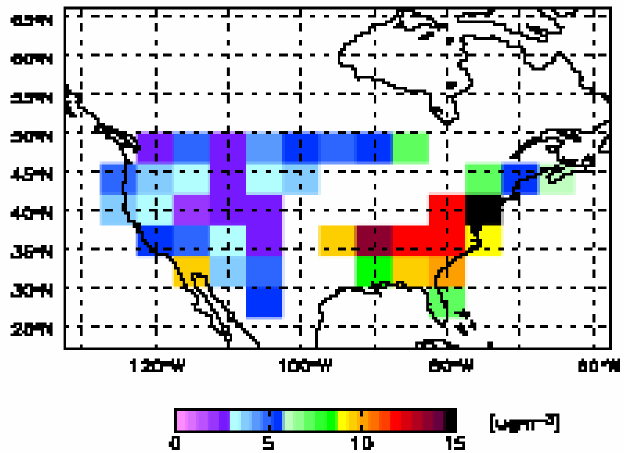
SIMULATED vs. OBSERVED $PM_{2.5}$ AT IMPROVE SITES

Annual mean 2001-2003 values

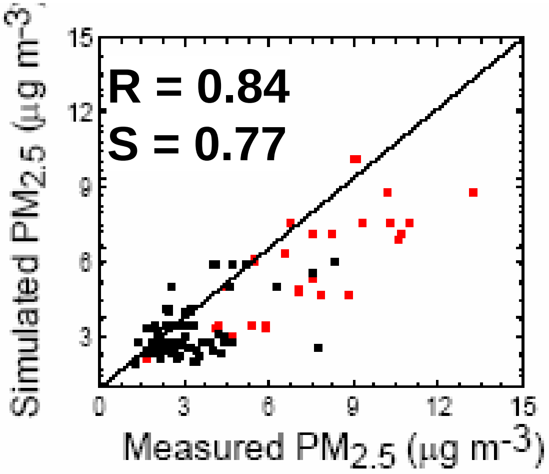
simulated

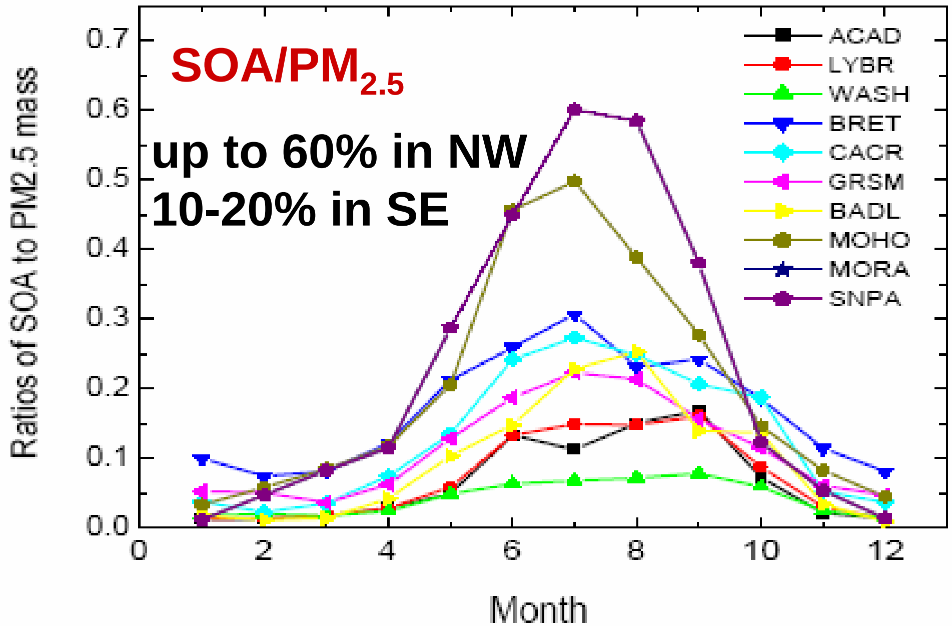


observed



correlation





50% of simulated SOA Is from isoprene

Liao et al. [2007]

2000-2050 CHANGES IN EMISSIONS OF OZONE PRECURSORS

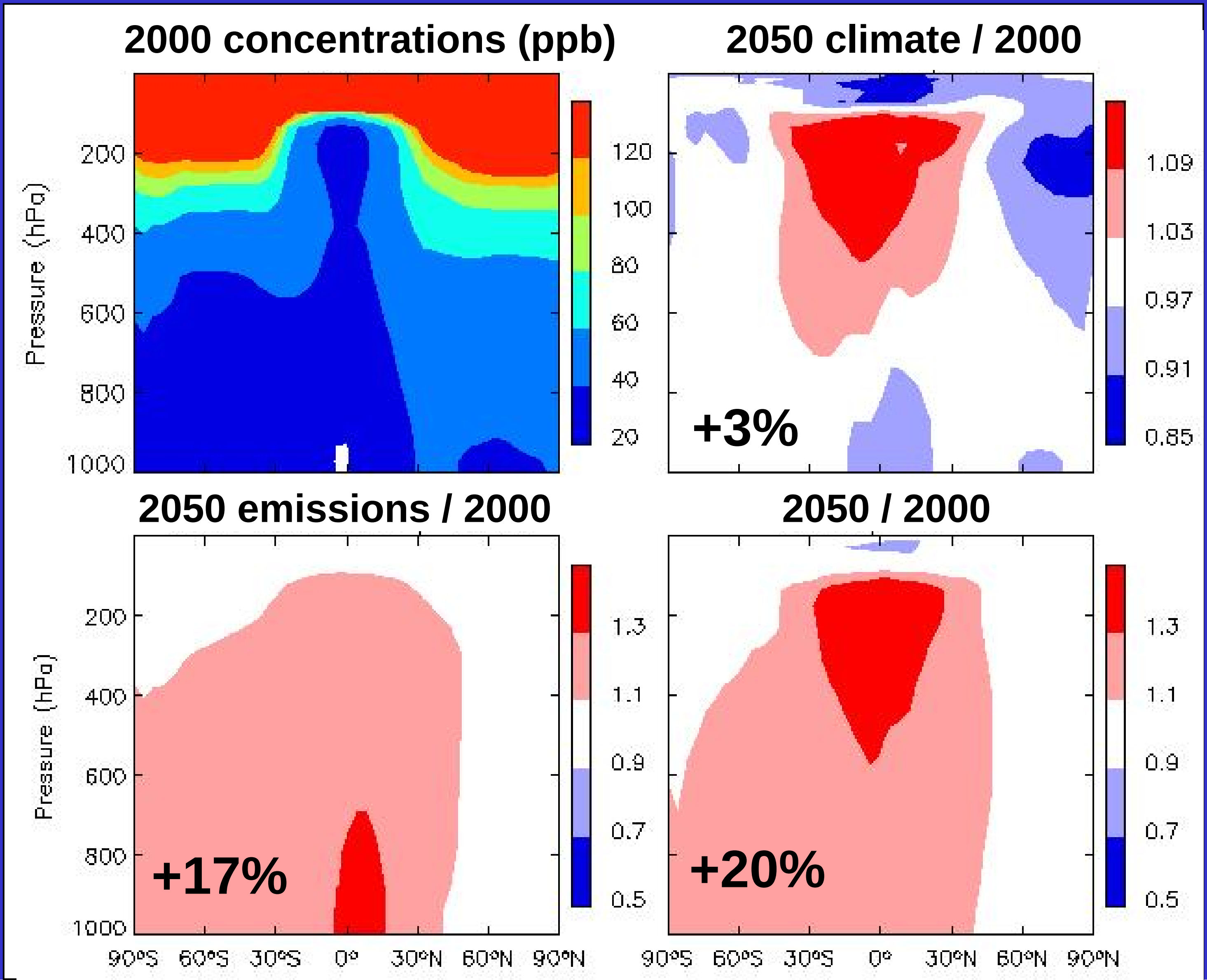
2000 emissions: GEOS-Chem, including NEI 99 for United States
2000-2050 % change, anthropogenic: SRES A1B scenario
2000-2050 % change, natural: GISS/GEOS-Chem

	Global		United States	
	2000 emissions	% change, 2000-2050	2000 emissions	% change, 2000-2050
NO_x, Tg N y^{-1}				
Anthropogenic	34	+71%	6.0	-39%
Lightning	4.9	+18%	0.14	+21%
Soils (natural)	6.1	+8%	0.35	+11%
NMVOCs, Tg C y^{-1}				
Anthropogenic	46	+150%	9.3	-52%
Biogenic	610	+23%	40	+23%
CO, Tg y^{-1}	1020	+25%	87	-47%
Methane, ppbv	1750	2400 (+37%)		

Wu et al. [2007b]

2000-2050 CHANGE IN GLOBAL TROPOSPHERIC OZONE

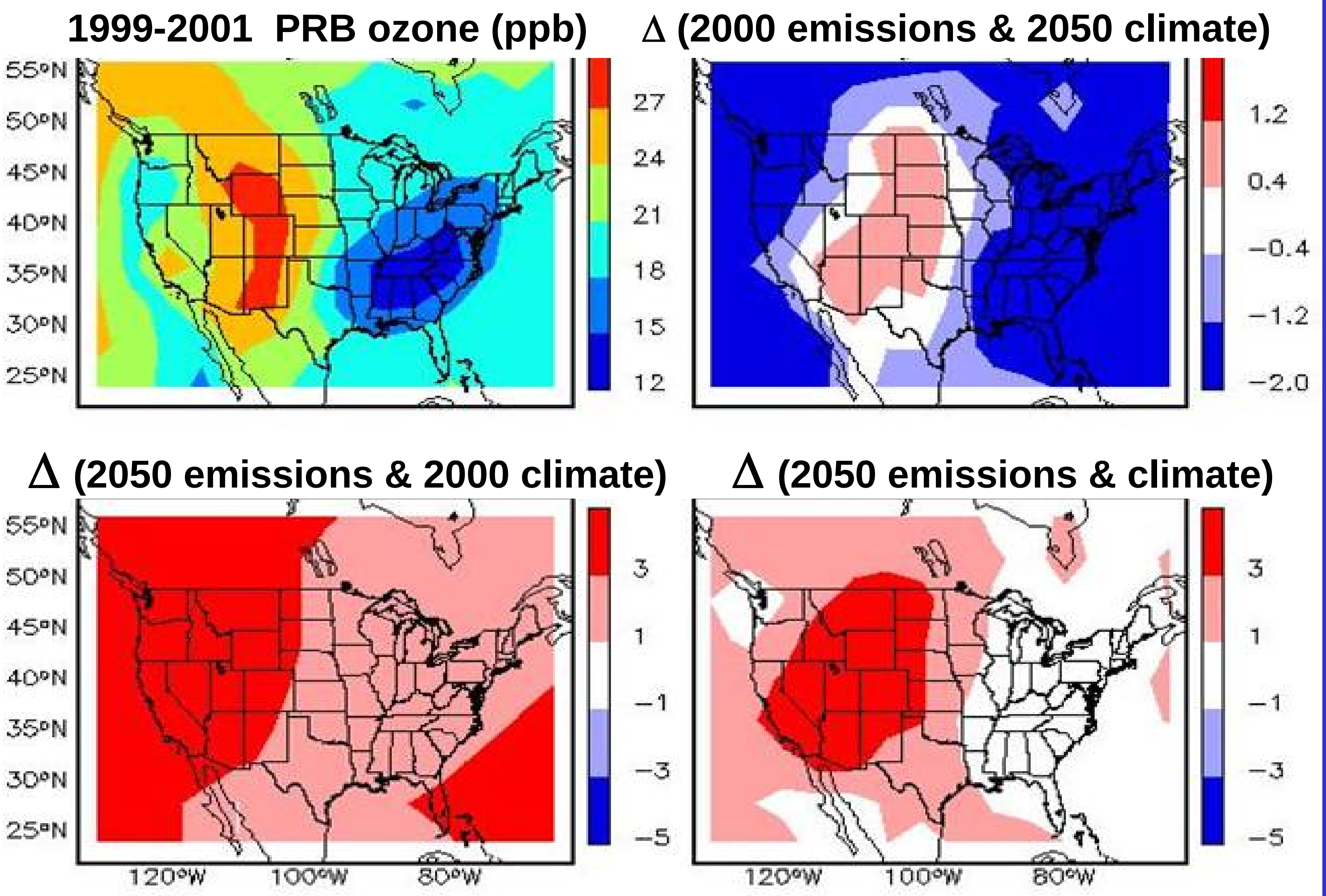
Climate change increases global tropospheric ozone (mostly from lightning) but generally decreases surface ozone (mostly because of water vapor)



Wu et al. [2007b]

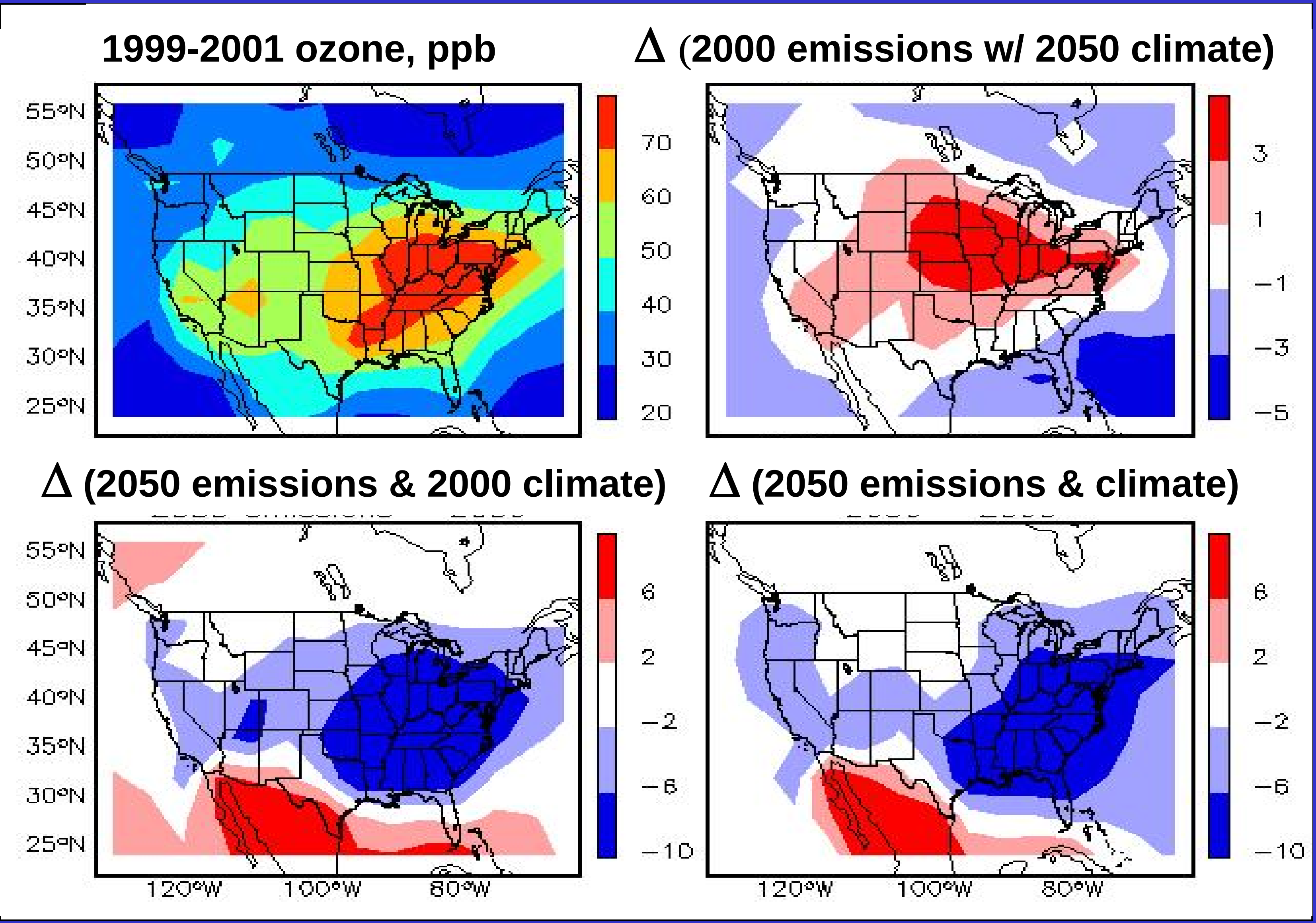
CHANGE IN POLICY-RELEVANT BACKGROUND (PRB) OZONE

2050 climate decreases PRB in subsiding regions, increases in upwelling regions
2050 emissions increases PRB due to rising methane, Asian emissions
The two effects cancel in the eastern U.S.



Wu et al. [2007b]

EFFECTS OF 2000-2050 CHANGES IN CLIMATE AND GLOBALEMISSIONS ON MEAN 8-h AVG. DAILY MAXMUM OZONE IN SUMMER

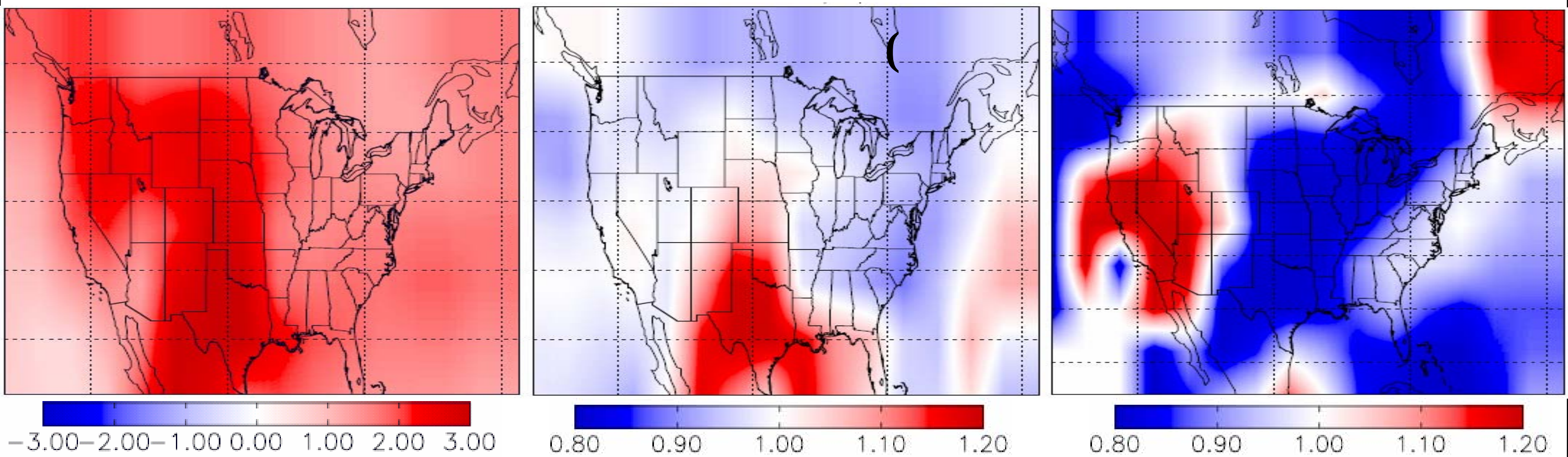


Wu et al. [2007b]

METEOROLOGICAL FACTORS DRIVING 2000-2050 CLIMATE CHANGE SENSITIVITY

Summer afternoon differences in mean values for 2050 vs. 2000 climates

Temperature (K) | **Mixing depth (2050/2000 ratio)** | **850 hPa convective flux (2050/2000 ratio)**

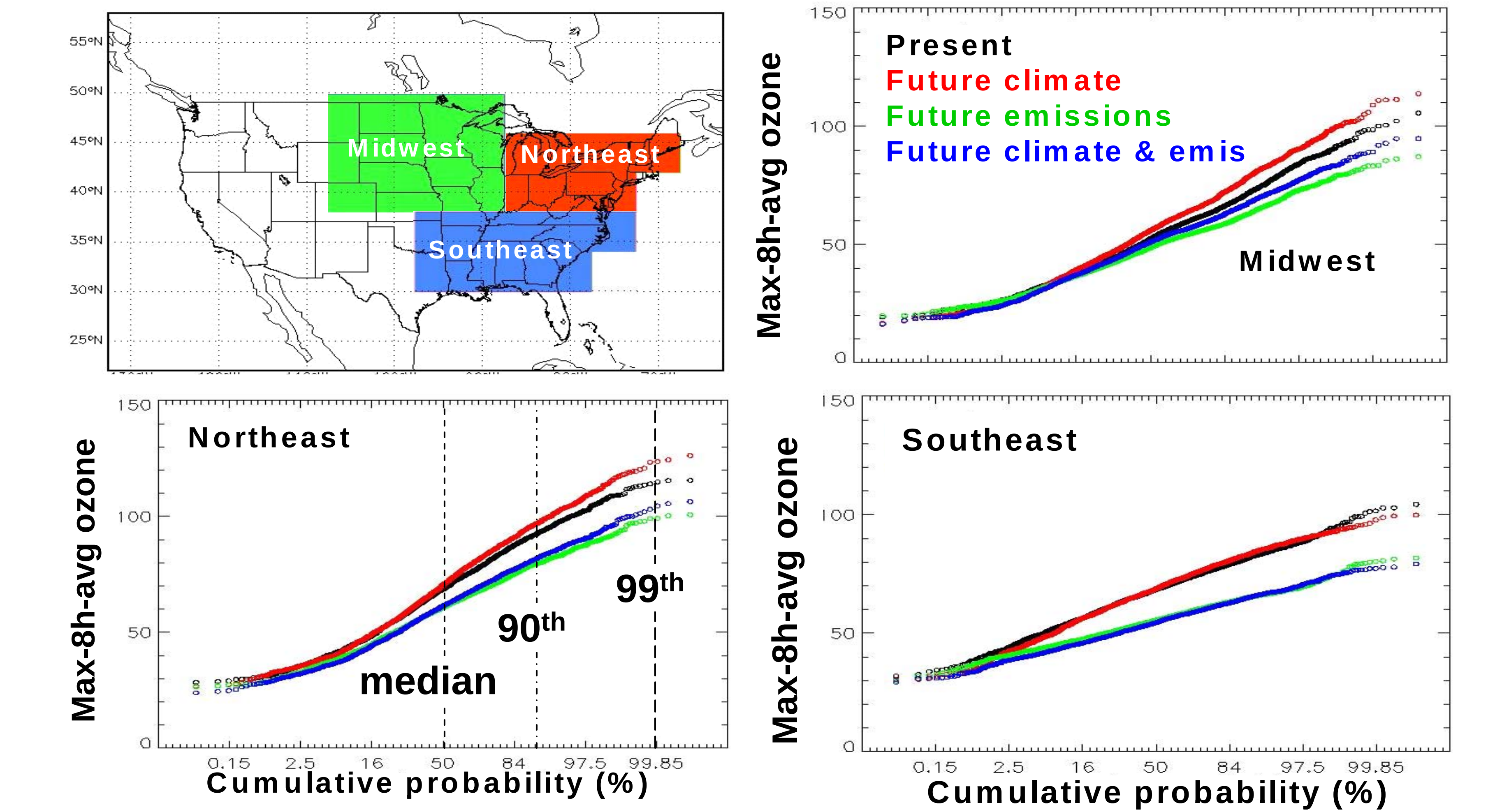


Mixing depths may decrease in a warmer greenhouse climate depending on soil moisture, vertical distribution of greenhouse heating

Wu et al. [2007b]

SENSITIVITY OF POLLUTION EPISODES TO GLOBAL CHANGE

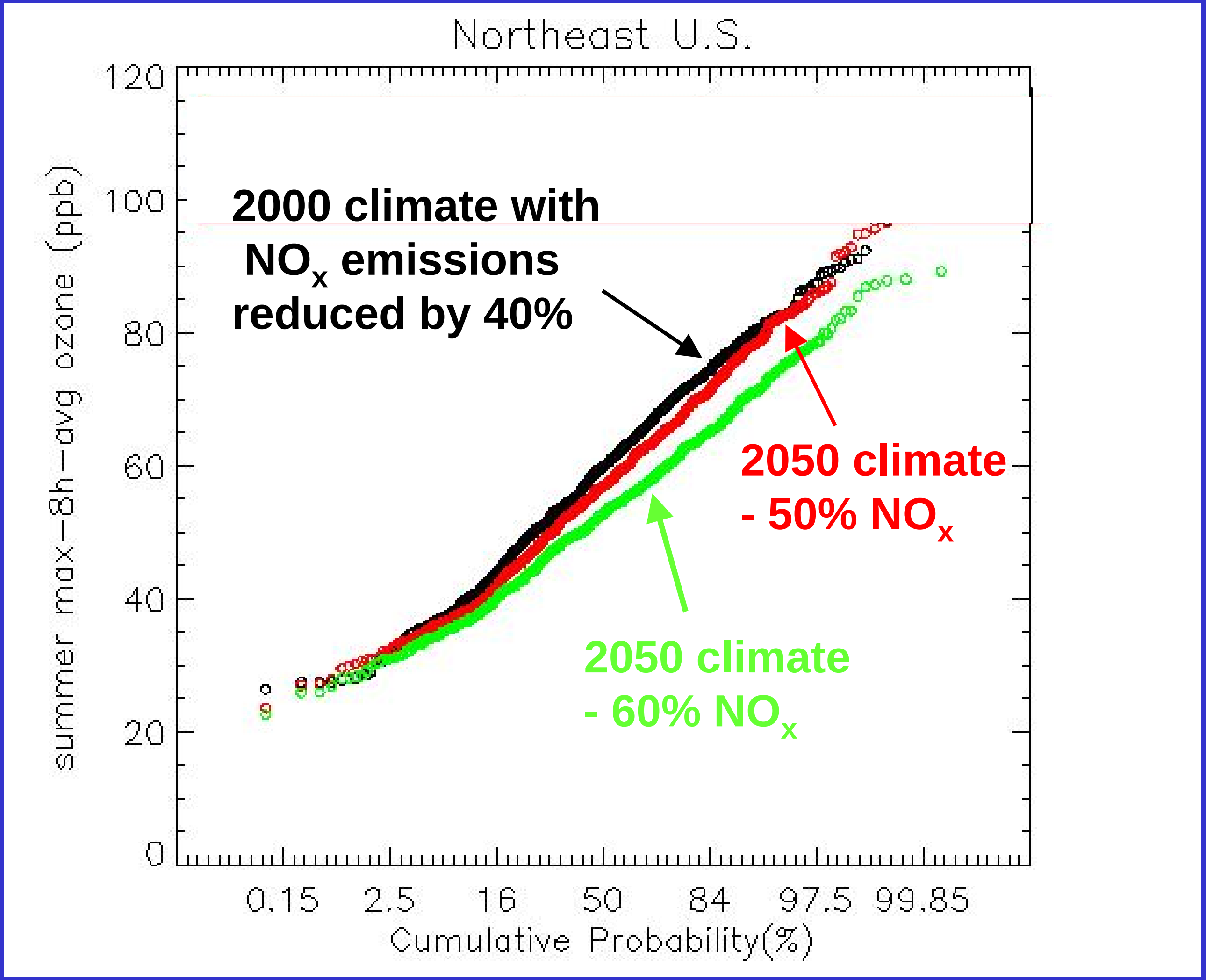
Summer probability distribution of daily 8-h max ozone



- In northeast and midwest, climate change effect reaches 10 ppbv for high-O_3 events; longer and more frequent stagnation episodes
- near-zero effect In southeast

Wu et al. [2007b]

WHAT IS THE CLIMATE CHANGE PENALTY IN TERMS OF ADDED REQUIREMENTS ON EMISSION REDUCTIONS?



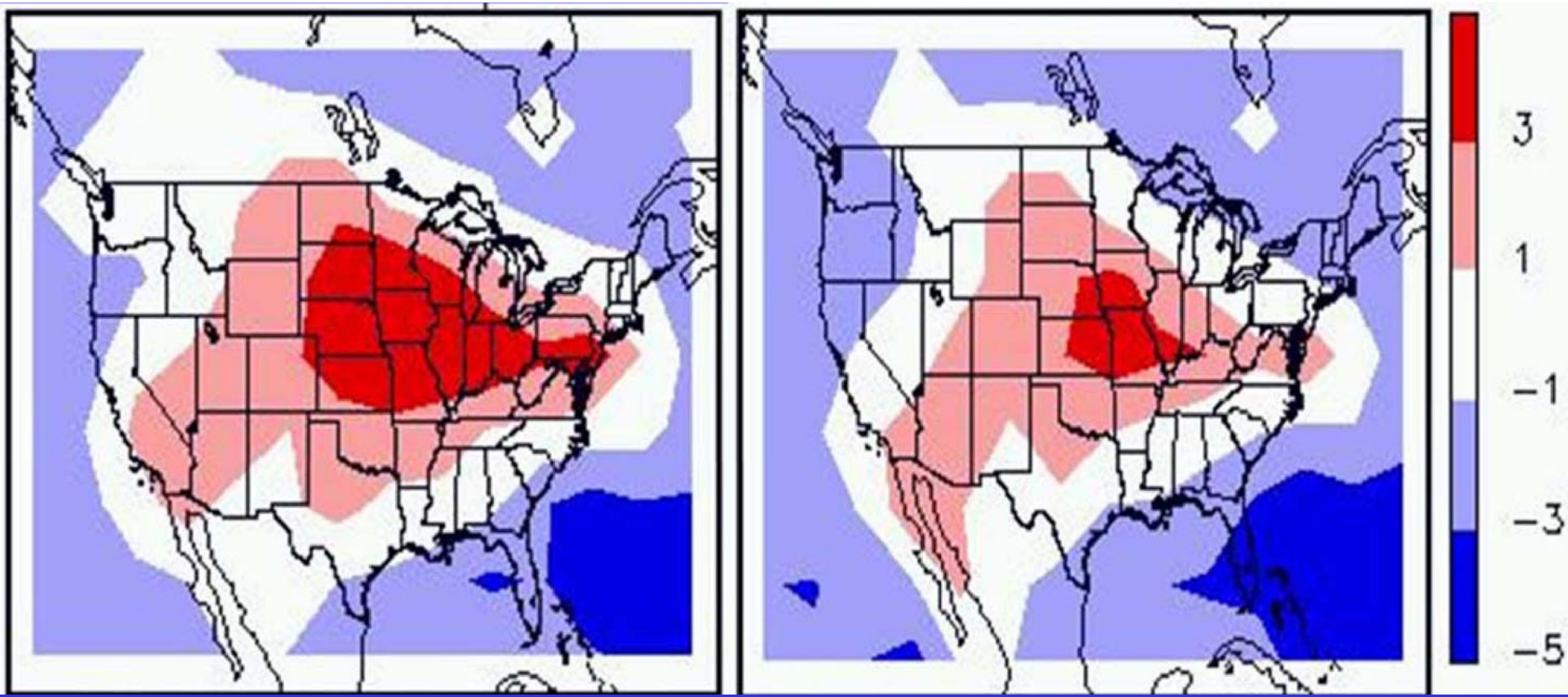
2000-2050 climate change means that we will need to reduce NO_x emissions by 50% instead of 40% to achieve the same ozone air quality goals in the northeast

Wu et al. [2007b]

OZONE CLIMATE CHANGE PENALTY WILL BE HIGHER IF WE DON'T REDUCE EMISSIONS

Change in mean 8-h daily max ozone (ppb) from 2000-2050 climate change

with 2000 emissions **with 2050 emissions**



Reducing U.S. anthropogenic emissions significantly mitigates the climate change penalty

Wu et al. [2007b]

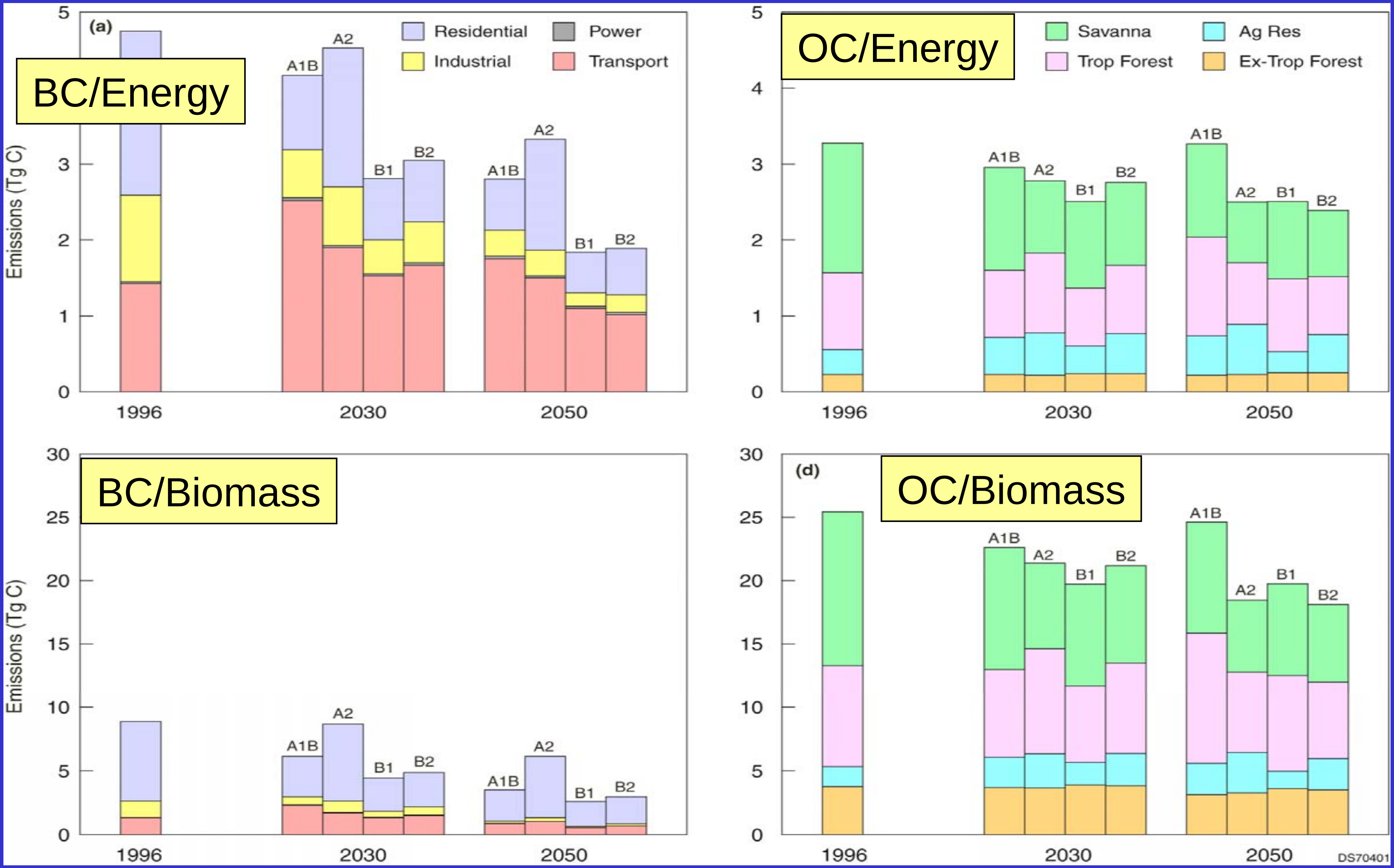
2000-2050 EMISSIONS OF $PM_{2.5}$ PRECURSORS (A1)

	Global		United States	
	2000 emissions	% change, 2000-2050	2000 emissions	% change, 2000-2050
SO_x, Tg S y^{-1}				
Anthropogenic	59	+ 38%	9	- 80%
Natural	21	0%	-	
NO_x, Tg N y^{-1}				
Combustion	34	+ 71%	6.0	- 39%
Lightning	4.9	+ 18%	0.14	+21%
Soils (natural)	6.1	+ 8%	0.35	+11%
NH_3, Tg N y^{-1}				
Anthropogenic	40	+ 43%	2.2	+ 40%
Natural	17	+ 0%	0.8	+ 0%
BC, Tg C y^{-1}	7.9	- 27%	0.6	- 56%
OC, Tg C y^{-1}				
Combustion	33	- 17%	1.5	- 34%
Biogenic (SOA)				

David Streets, ANL and Shiliang Wu, Harvard

CONSTRUCTION OF SRES-BASED EMISSION PROJECTIONS FOR BC AND OC AEROSOL

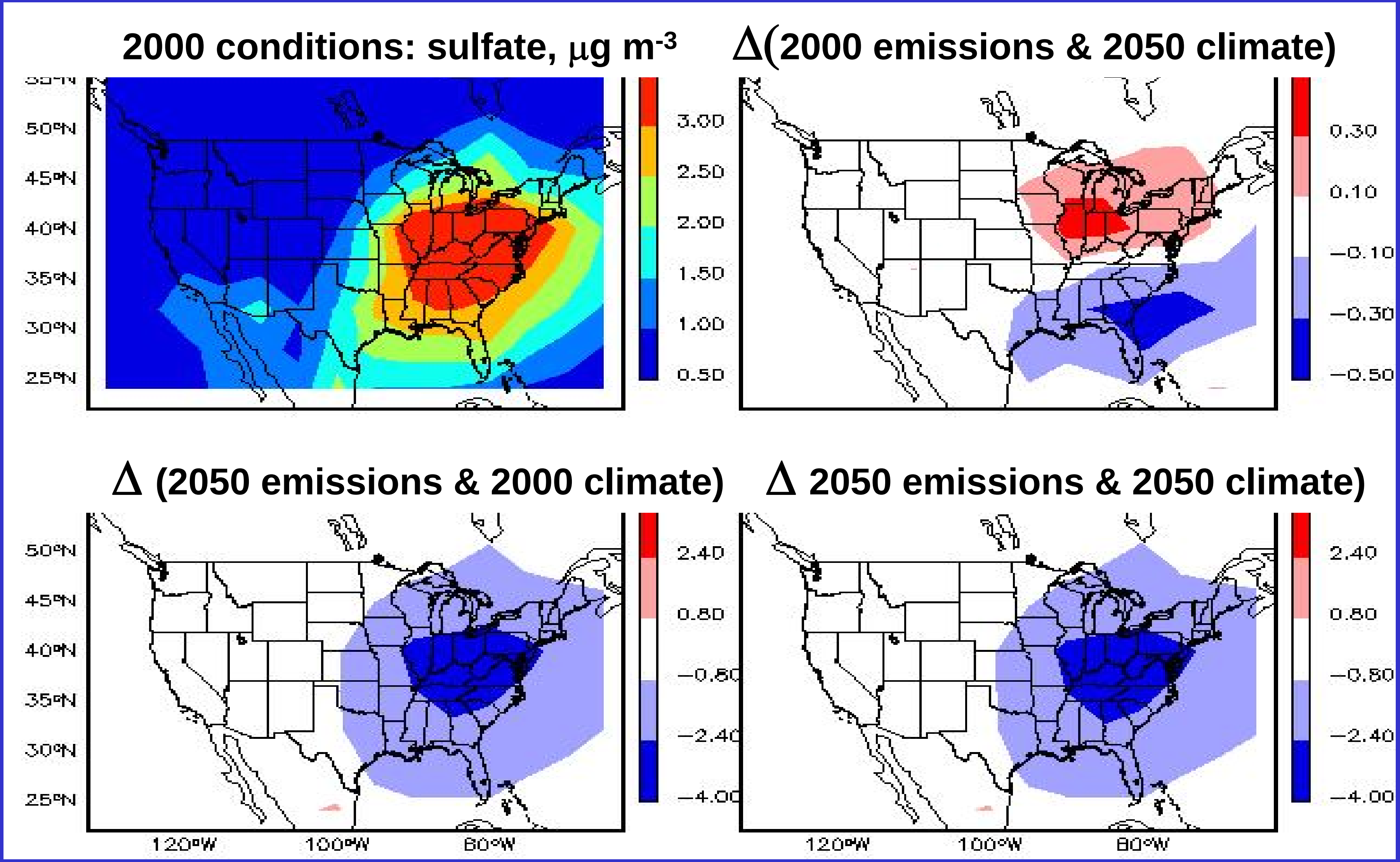
Global and U.S. decreases in emissions (higher energy efficiency)



Streets et al. [2004]

EFFECT OF 2000-2050 GLOBAL CHANGE ON ANNUAL MEAN SULFATE CONCENTRATIONS ($\mu g\ m^{-3}$)

Climate change increases sulfate by up to 0.5 $\mu g\ m^{-3}$ in midwest (more stagnation), decreases sulfate in southeast (more precipitation)

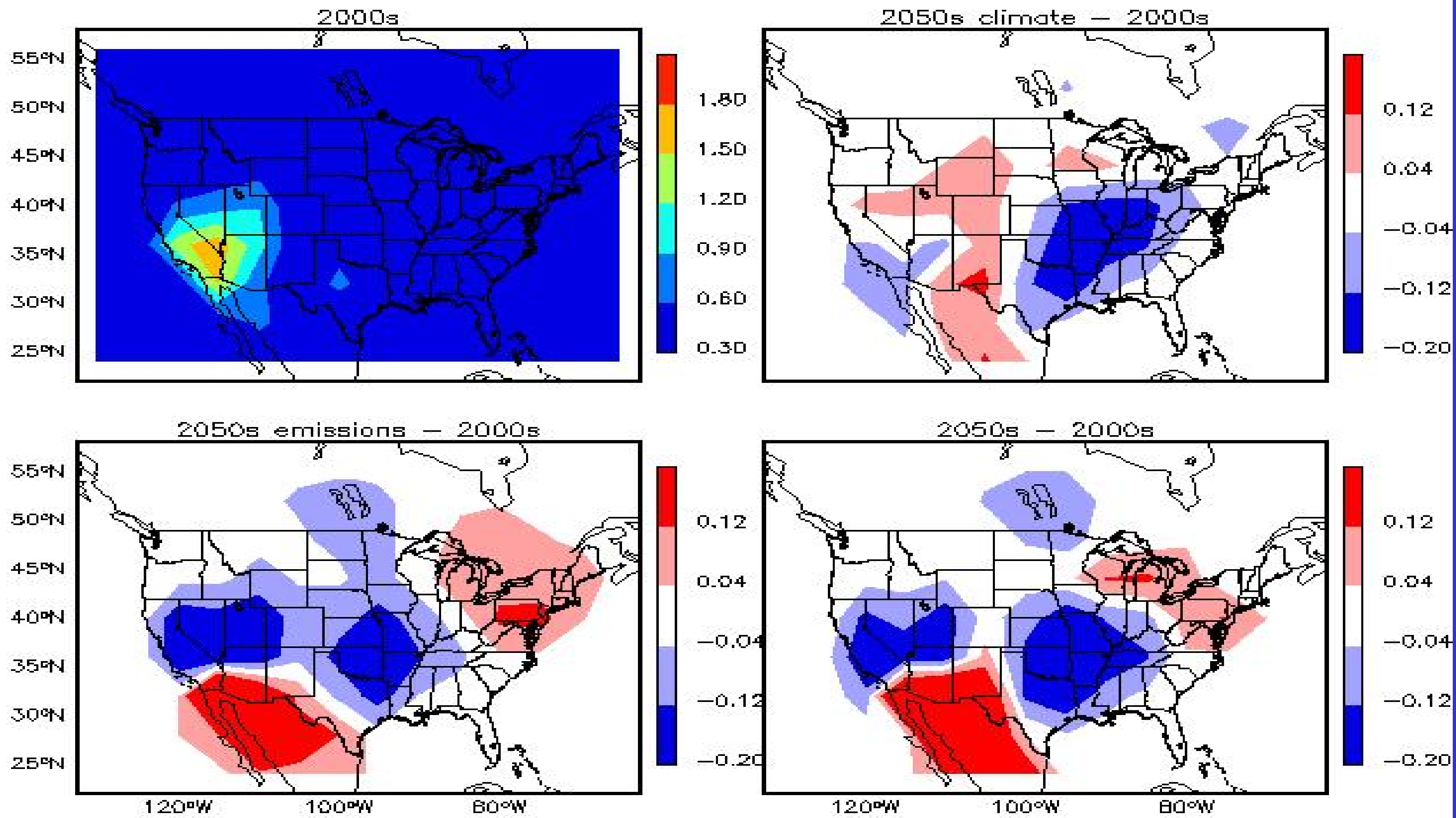


Shiliang Wu, Harvard

EFFECT OF 2000-2050 GLOBAL CHANGE ON ANNUAL MEAN NITRATE CONCENTRATIONS (μg m^{-3})

Climate change decreases nitrate by up to 0.2 μg m^{-3} (higher temperature)

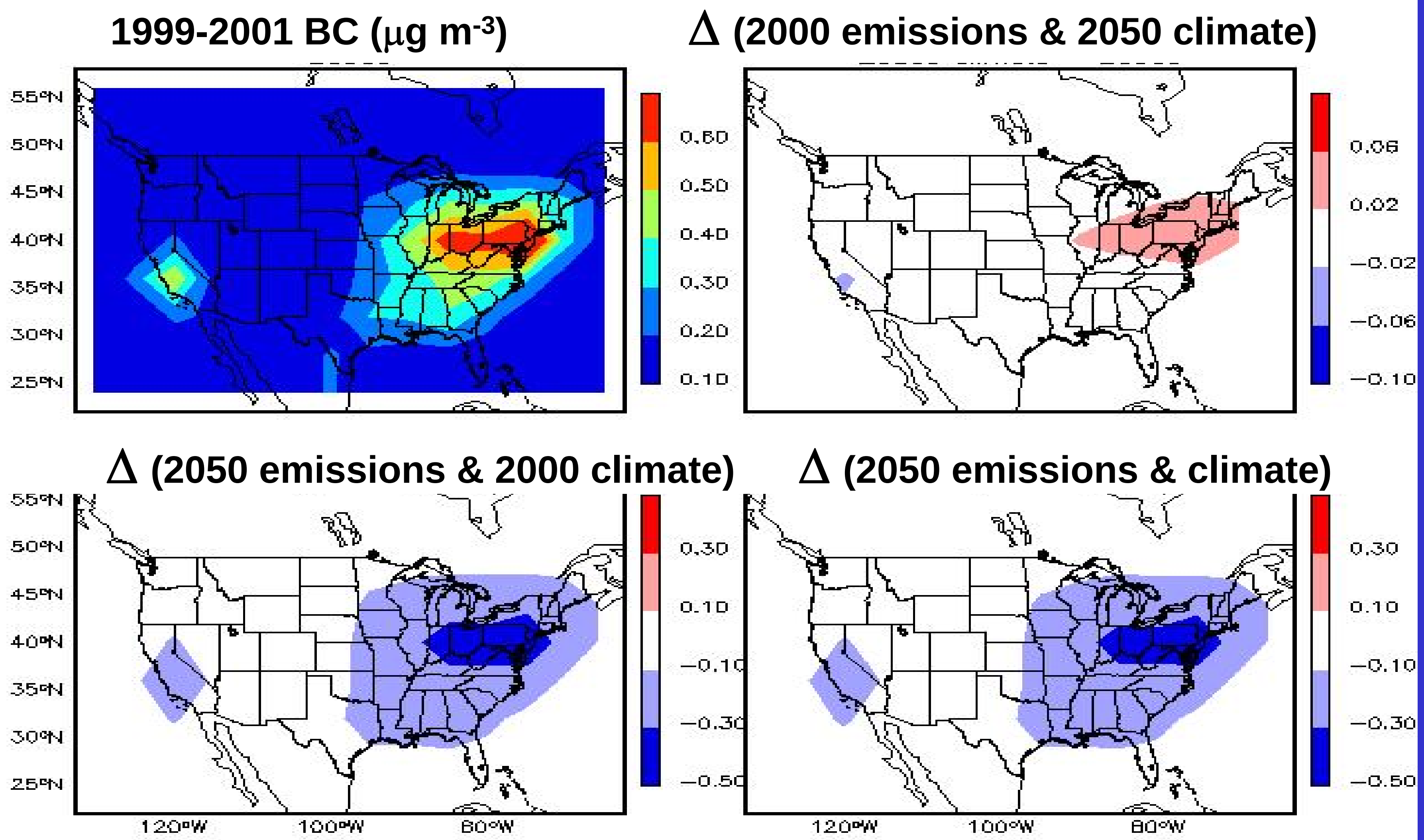
1999-2001 nitrate (μg m^{-3}) | **Δ (2000 emissions & 2050 climate)**



Shiliang Wu, Harvard

EFFECT OF 2000-2050 GLOBAL CHANGE ON ANNUAL MEAN BC AEROSOL CONCENTRATIONS ($\mu g\ m^{-3}$)

Climate change increases BC by up to 0.05 μg C m^{-3} in northeast

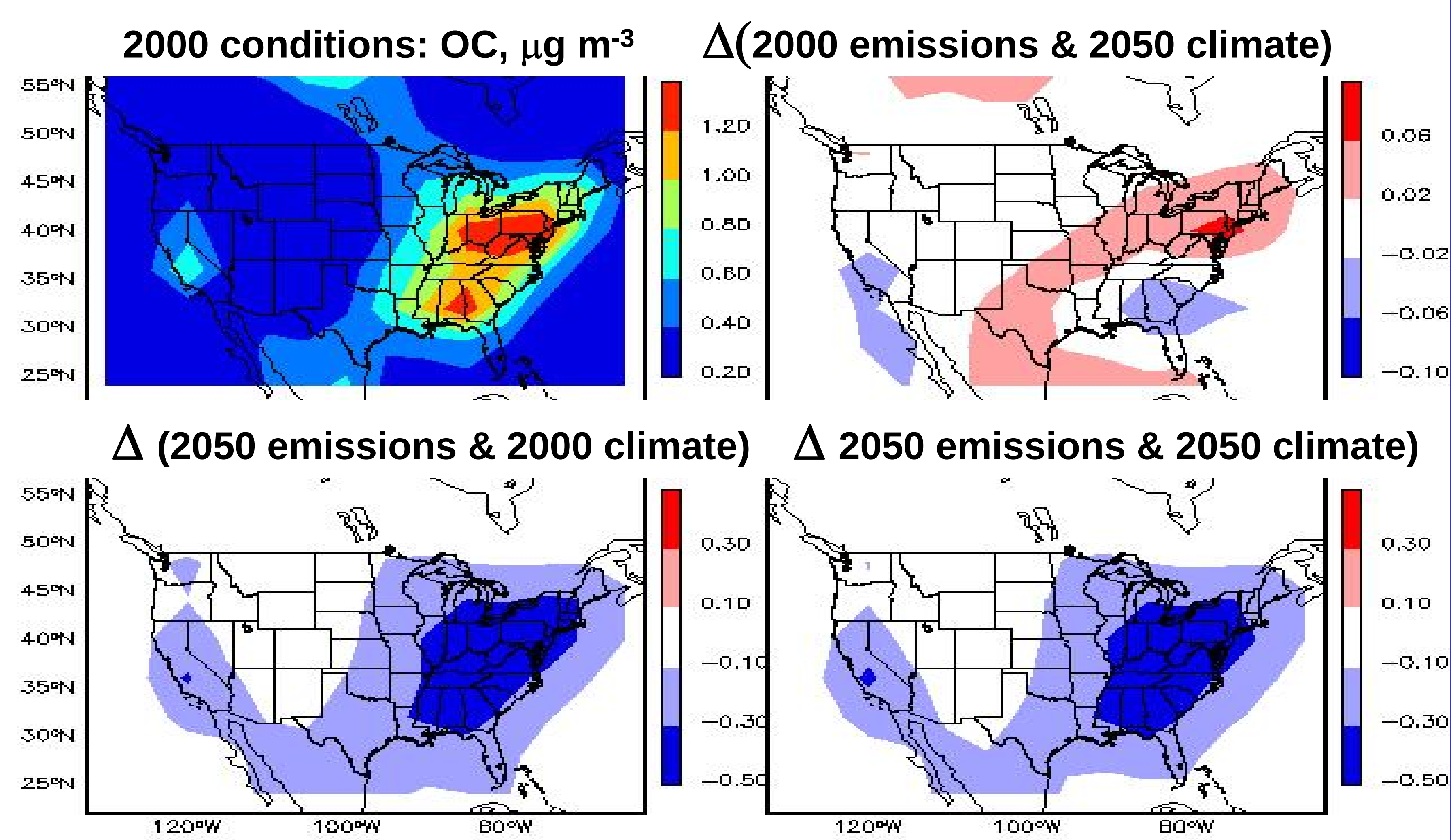


Shiliang Wu, Harvard

EFFECT OF 2000-2050 GLOBAL CHANGE ON ANNUAL MEAN ORGANIC CARBON (OC) AEROSOL CONCENTRATIONS ($\mu g\ m^{-3}$)

Climate change effect is mainly through biogenic SOA and is small because of compensating factors (higher biogenic VOCs, higher volatility)

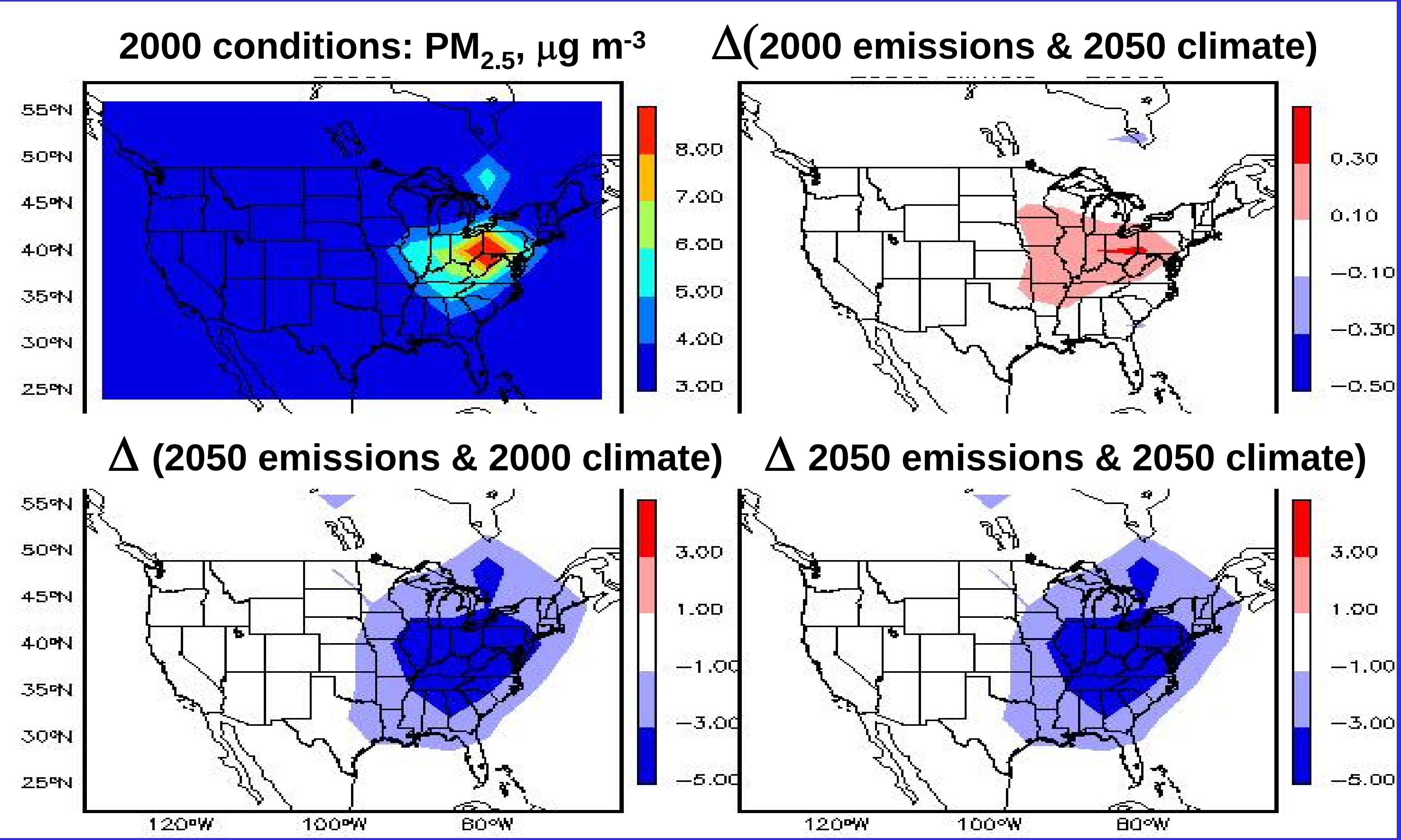
Expect larger effects from increases in wildfires (not included here)



Shiliang Wu, Harvard

EFFECT OF 2000-2050 GLOBAL CHANGE ON ANNUAL MEAN $PM_{2.5}$ CONCENTRATIONS ($\mu g\ m^{-3}$)

Effect of climate change is positive but small (at most 0.3 $\mu g\ m^{-3}$), due to canceling effects

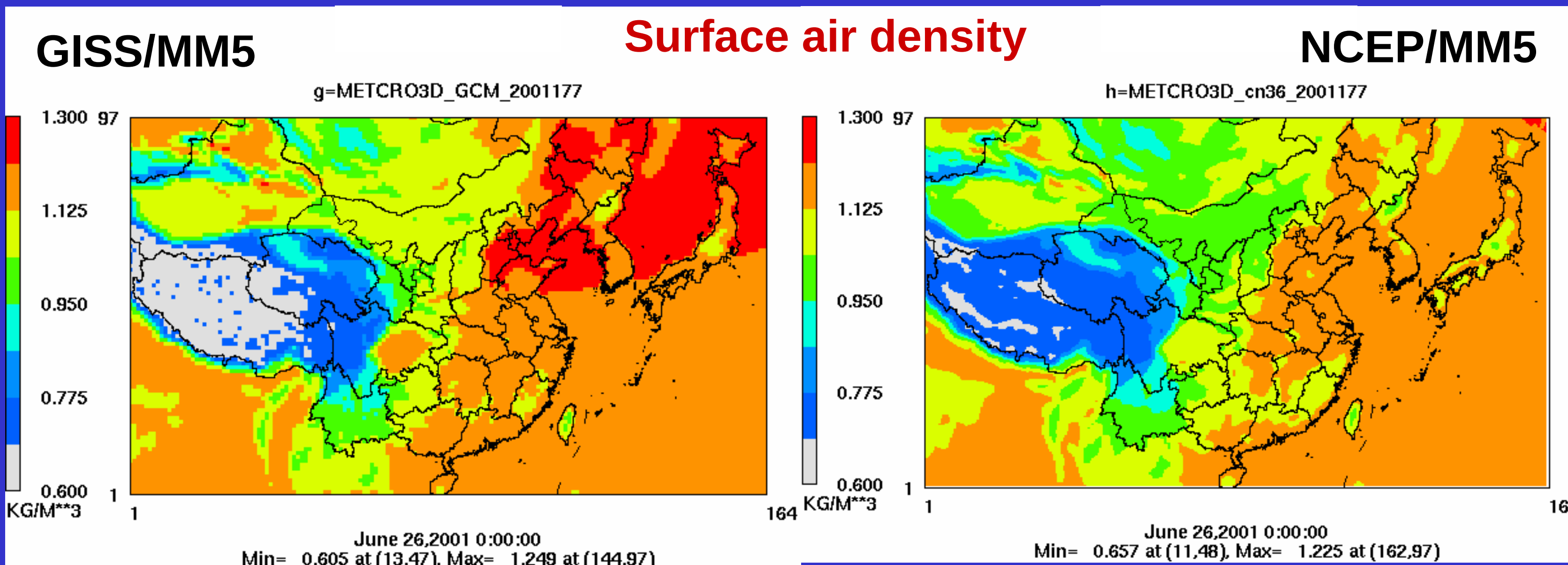


Shiliang Wu, Harvard

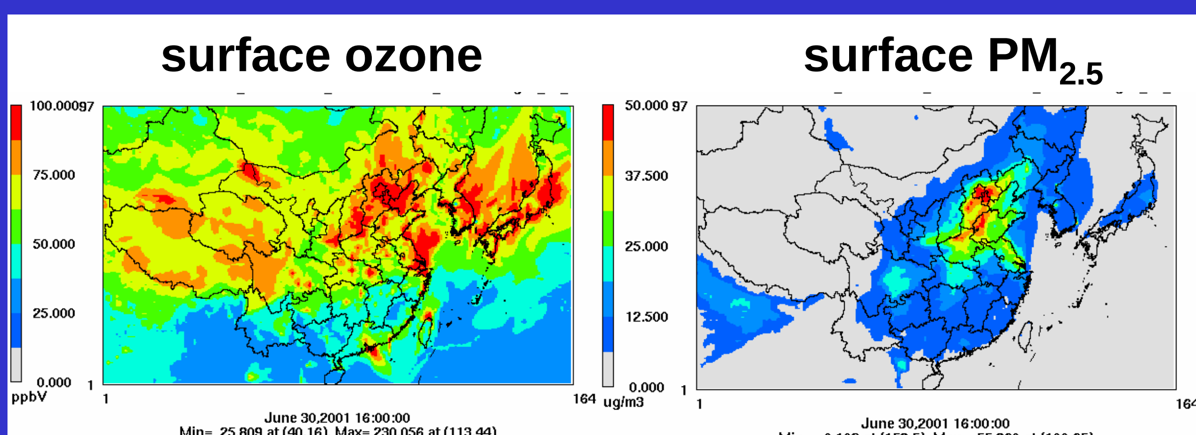
INTERFACING GISS/GEOS-Chem WITH MM5/CMAQ

test application for East Asia

Driving MM5 with GISS vs. NCEP: interface is completed, being tested

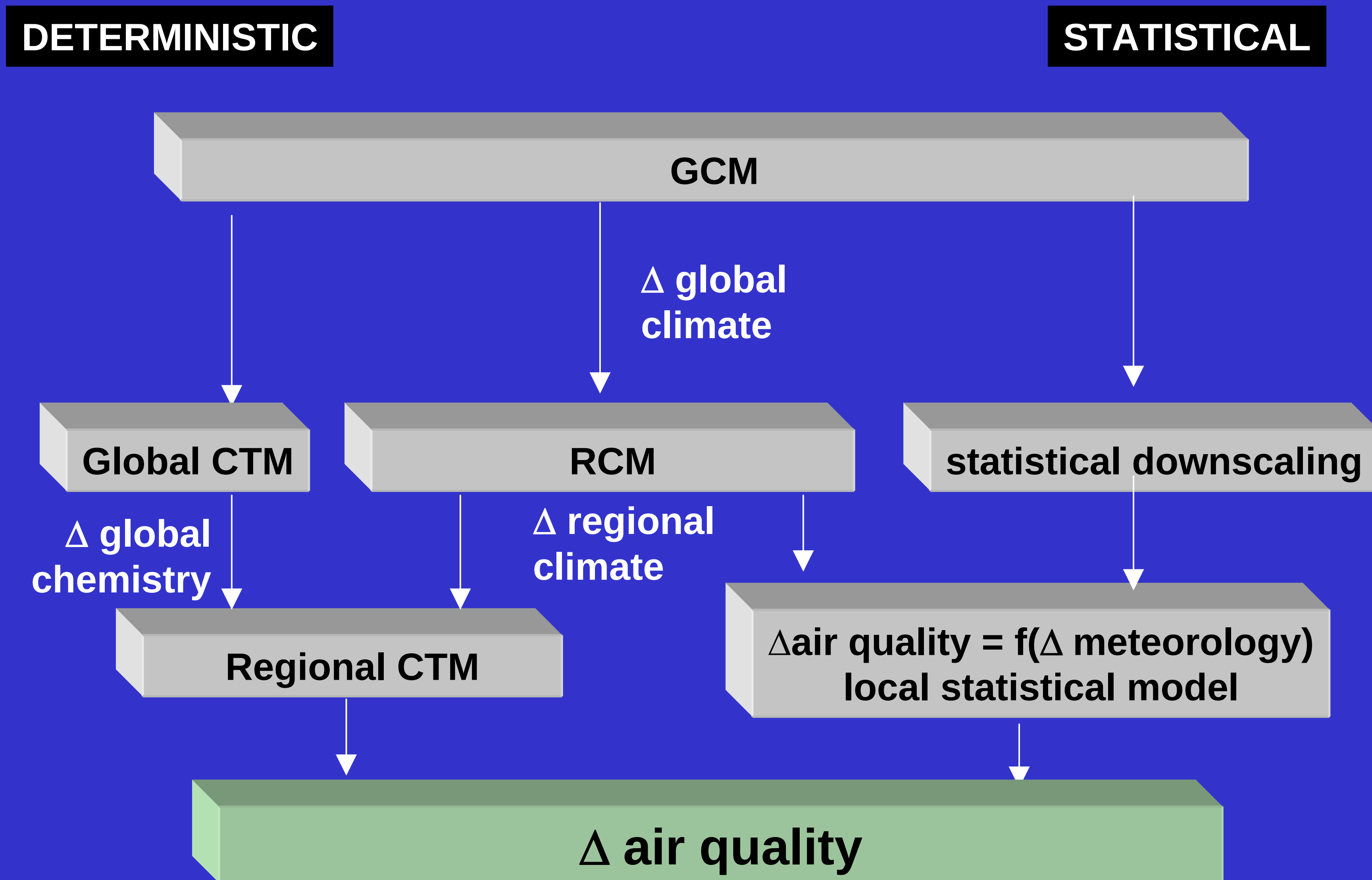


Driving CMAQ with GEOS-Chem BCs: interface is mature



Joshua Fu, UT

DETERMINISTIC vs. STATISTICAL MODELING APPROACHES FOR DIAGNOSING EFFECT OF CLIMATE CHANGE ON AIR QUALITY



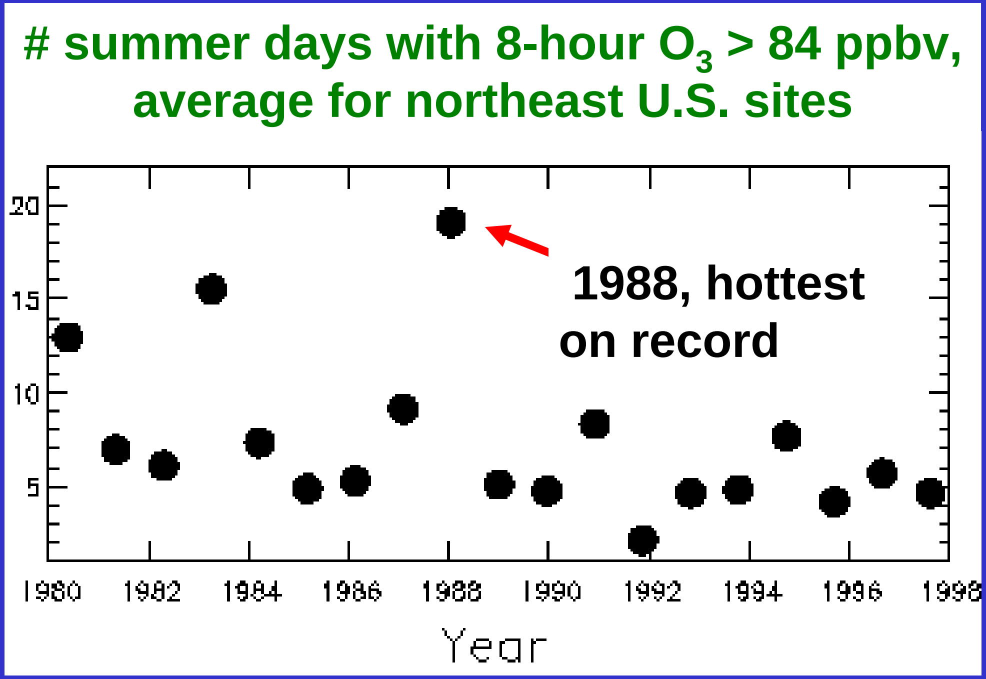
USE OBSERVED OZONE-TEMPERATURE RELATIONSHIP TO DIAGNOSE SENSITIVITY OF OZONE TO CLIMATE CHANGE

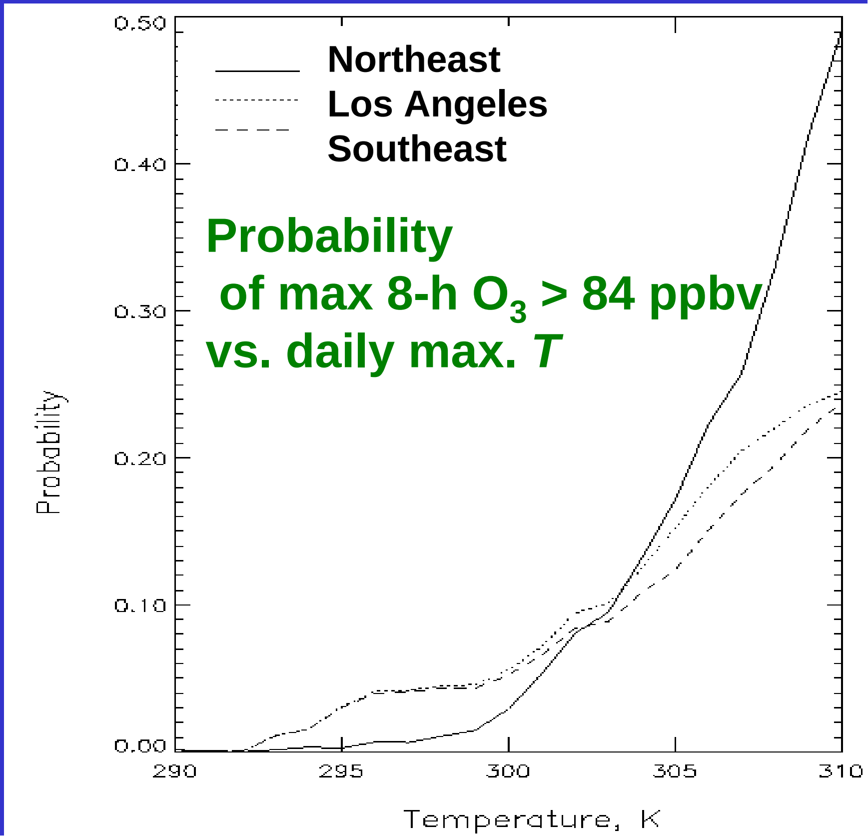
Observed relationship of ozone vs. *T* characterizes the total derivative:

$$\frac{d[O_3]}{dT} = \frac{\partial[O_3]}{\partial T} + \sum_i \frac{\partial[O_3]}{\partial x_i}\frac{\partial x_i}{\partial T}$$

where x_i is the ensemble of *T*-dependent variables affecting ozone;

… and can diagnose effect of climate change as characterized by ΔT from a GCM





Lin et al. [2001]

STATISTICAL METHOD TO PROJECT NAAQS EXCEEDANCES FOR A GIVEN LOCATION OR REGION IN A FUTURE CLIMATE

Apply ensemble of GCMs to simulate future climate

↓

Obtain daily max *T* for individual grid squares

↓

Apply subgrid variability to *T* from present-day climatology

↓

Obtain daily max *T* for individual locations

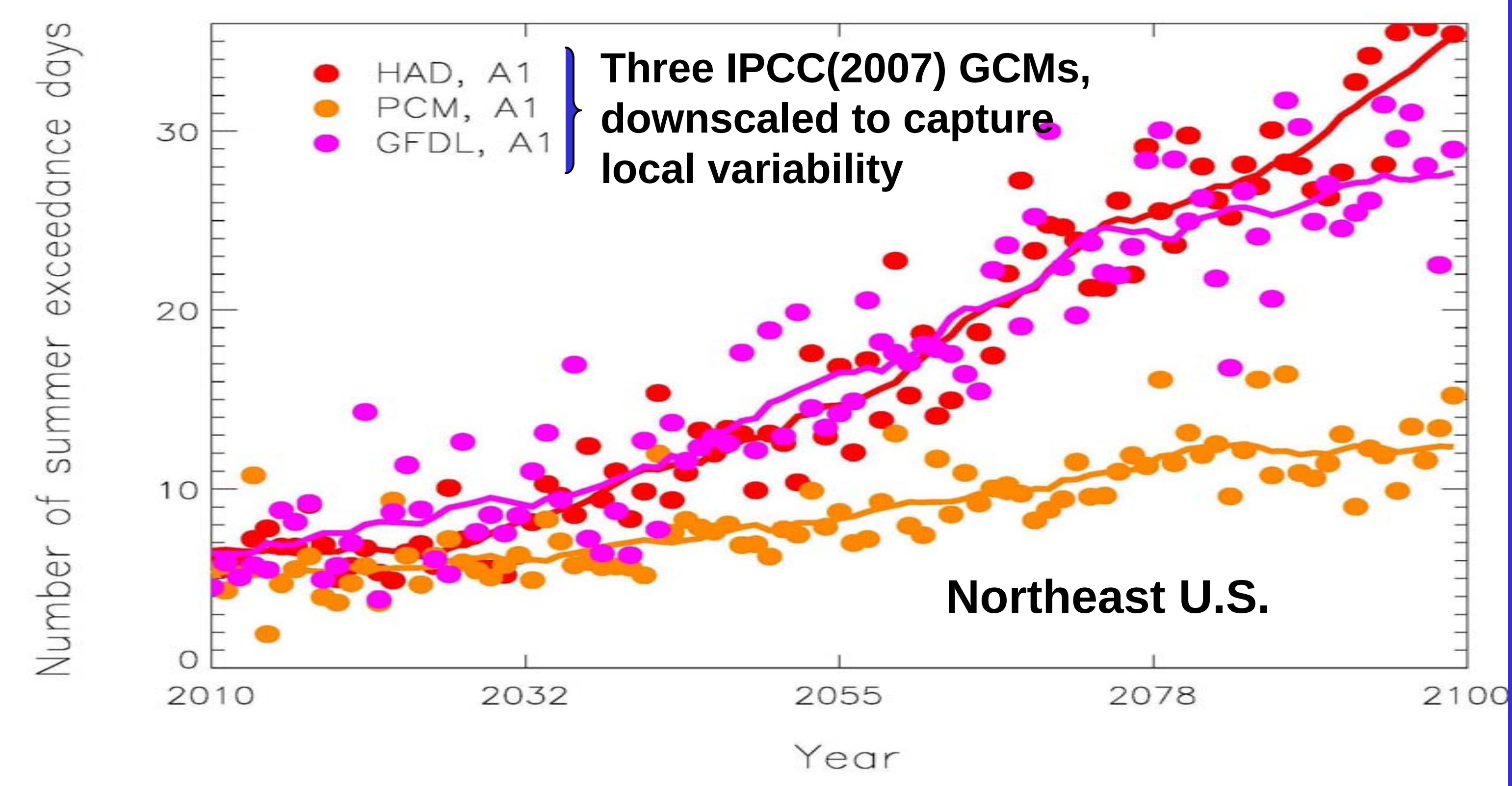
↓

Apply local or regional probability of NAAQS exceedance = f(*T*)

↓

Obtain probability of NAAQS exceedance in future climate assuming constant emissions

APPLICATION TO PROJECT FUTURE EXCEEDANCES OF OZONE NAAQS IN THE NORTHEAST UNITED STATES



Statistical method allows quick local assessment of the effect of climate change, but it has limitations:

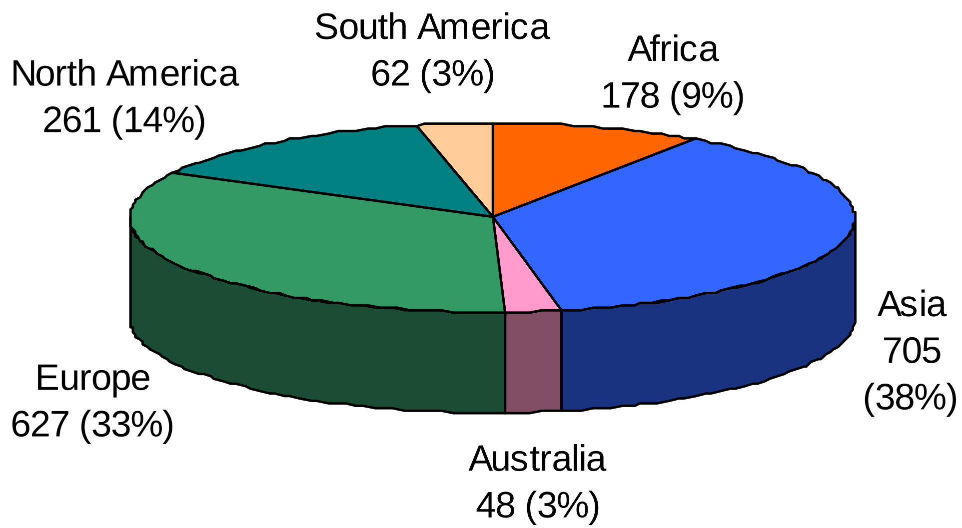
- **gives no insight into the coupled effect of changing emissions**
- **some fraction of variance unresolved by statistical model**
- **no good statistical relationships for PM developed so far**

Loretta Mickley (Harvard) and Cynthia Lin (UC Davis)

GCAP FUTURE PLANS

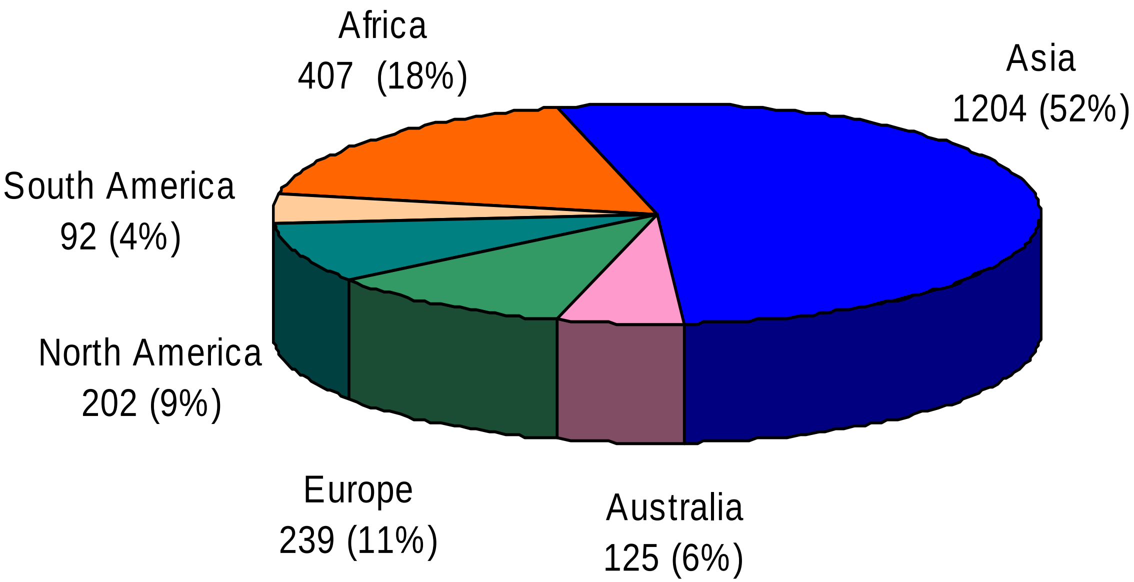
- Downscale GEOS-Chem future-climate simulations to CMAQ
- Improve GCM (GISS)- RCM (MM5) meteorological interface
- Apply additional scenarios for global change in climate and emissions
- Diagnose intercontinental transport in the future atmosphere
- Study effects of 2000-2050 climate and emission changes on mercury, including construction of future mercury emission inventories
- Explore correlations of $PM_{2.5}$ with meteorological variables for future-climate statistical projections

RAPIDLY CHANGING ANTHROPOGENIC EMISSIONS OF MERCURY: recent shift from N.America/Europe to Asia



1990

Total: 1.88 Gg yr^{-1}



2000

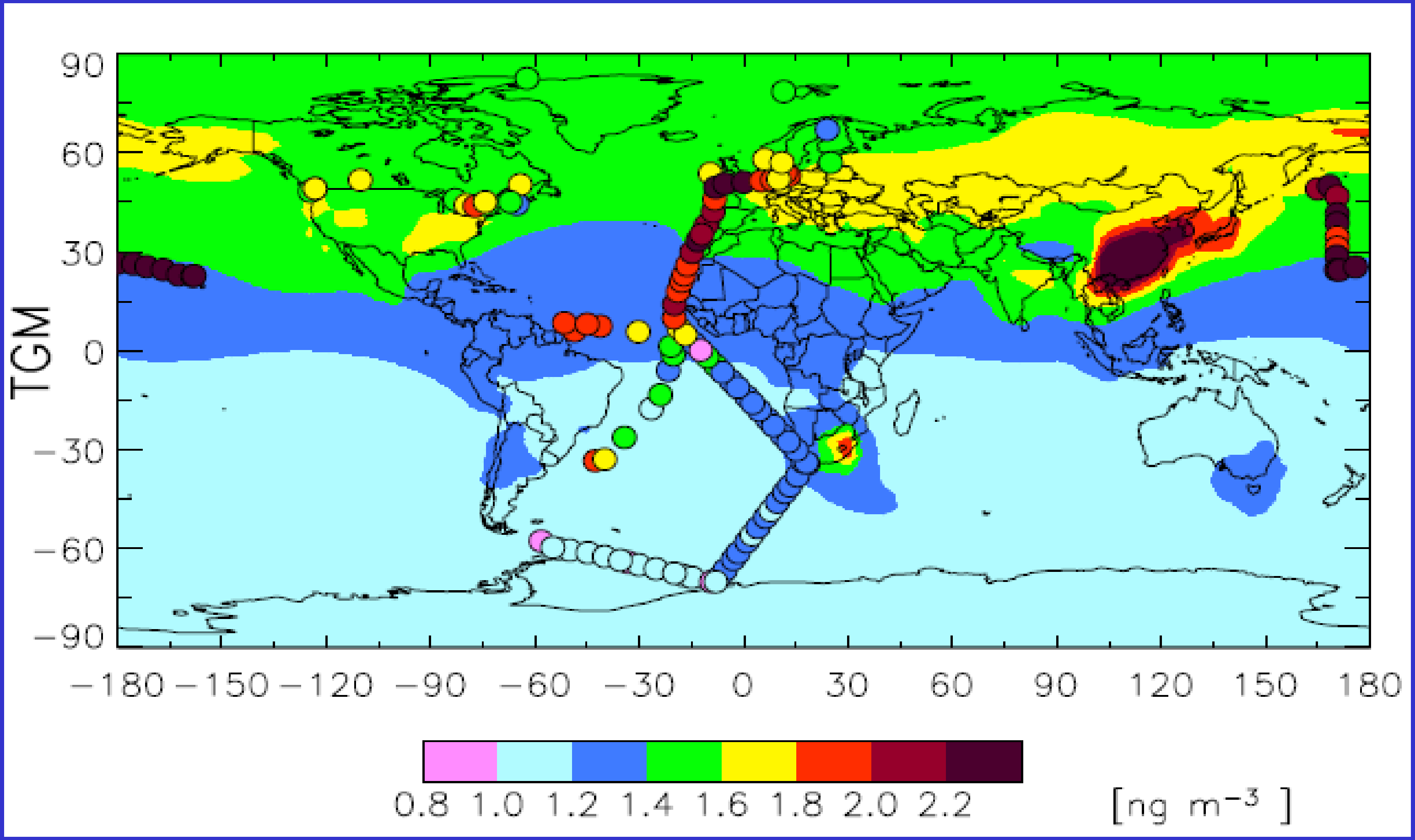
Total: 2.27 Gg yr^{-1}

Pacyna and Pacyna, 2005

GEOS-Chem SIMULATION OF TOTAL GASEOUS MERCURY (TGM)

Annual mean surface air concentrations and ship cruise data

Circles are observations; background is model



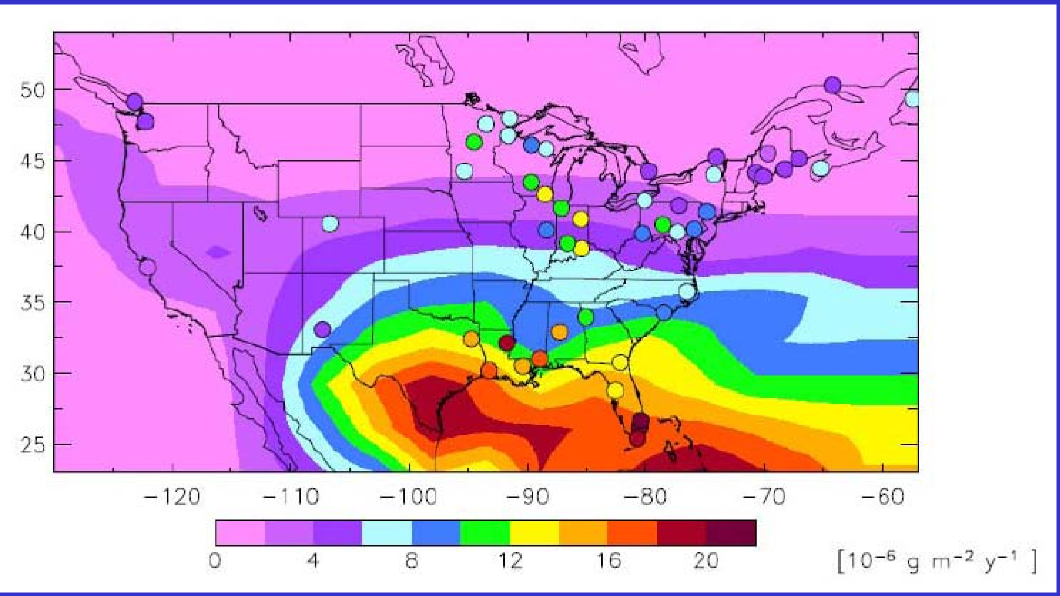
Land-based sites

R^2=0.51 { **observed: 1.58 ± 0.19 ng m^{-3}**
model: 1.60 ± 0.10 ng m^{-3} }

Large underestimate of NH cruise data: legacy of past emissions stored in ocean?

Selin et al., 2007

Hg DEPOSITION OVER U.S. : LOCAL VS. GLOBAL SOURCES



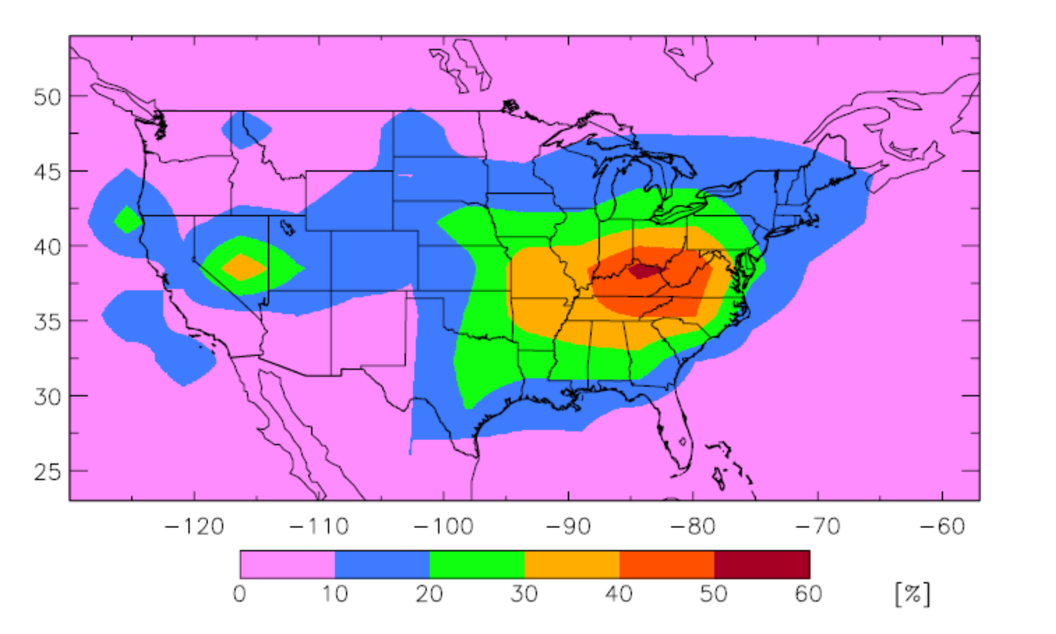
Wet deposition fluxes, 2003-2004

Model: contours Obs: dots

max in southeast U.S. from oxidation of global Hg pool

2nd max in midwest from regional sources (mostly dry deposition in GEOS-Chem)

2/3 of Hg deposition over U.S. in model is dry, not wet!

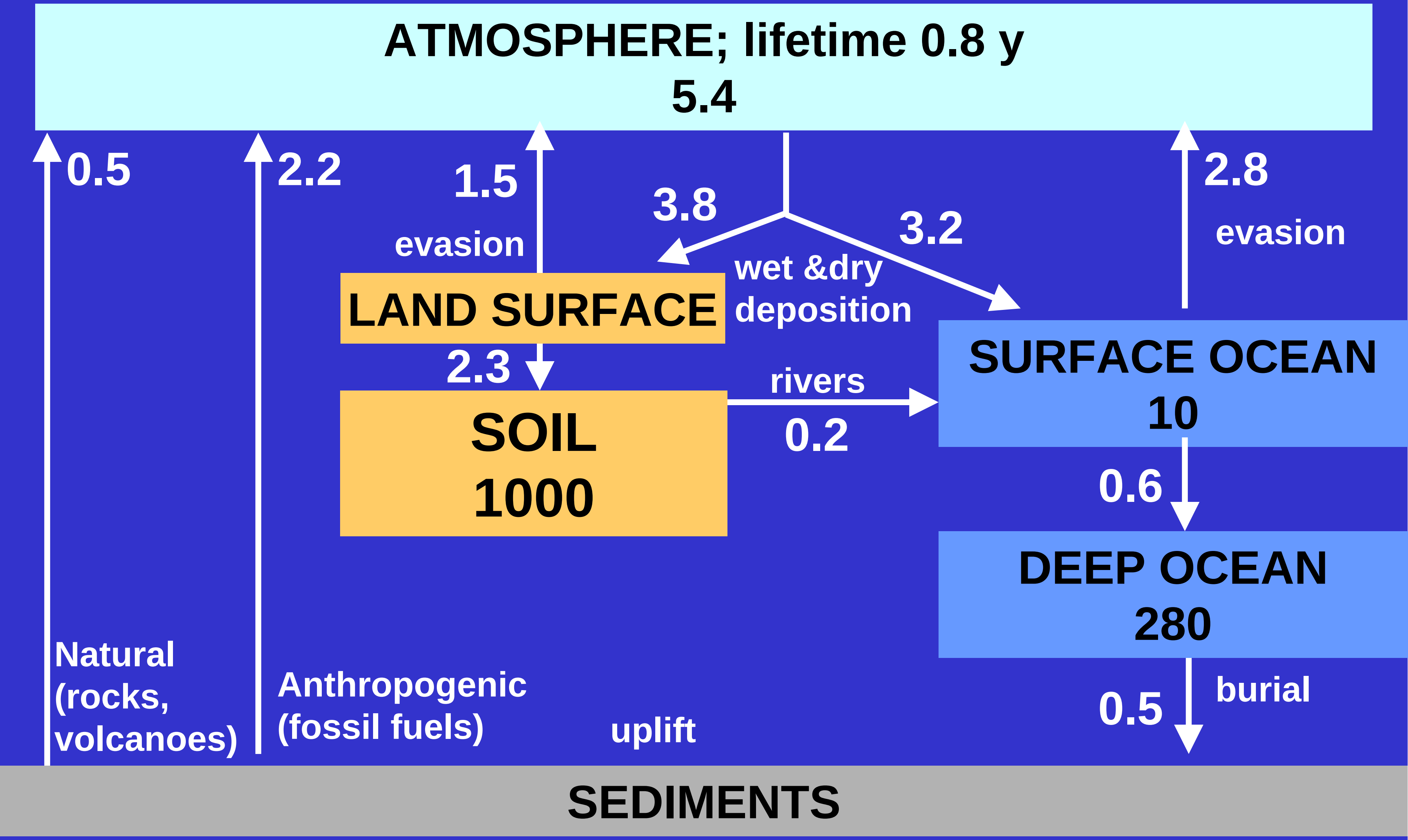


Simulated % contribution of North American sources to total Hg deposition

U.S. mean: 20%

Selin et al. [2007]

GEOS-Chem GLOBAL GEOCHEMICAL CYCLE OF MERCURY (present); exchanges with ocean and land are climate-dependent



Inventories in Gg, fluxes in Gg yr^{-1}

Selin et al. [2007], Strode et al. [2007]

EXTRA SLIDES

WU et al. [2007a] ANALYZE LARGE DIFFERENCES AND TRENDS IN MODELS OF GLOBAL TROPOSPHERIC OZONE

	STE Tg y^{-1}	Production Tg y^{-1}	Loss Tg y^{-1}	Deposition Tg y^{-1}	Burden Tg	Lifetime days
IPCC TAR	770 ± 400	3420 ± 770	3470 ± 520	770 ± 180	300 ± 30	24 ± 2
Wang98	400	4100	3680	820	310	25
IPCC 4AR	520± 100	4570 ± 680	4150 ± 550	1020 ± 220	330 ± 30	25 ± 4
GEOS-Chem	470	4900	4300	1070	320	22
ACCENT	520± 200	5060 ± 570	4560 ± 720	1010 ± 220	340 ± 40	22 ± 2
GEOS-Chem	510	4490	3770	1020	290	22
Wu et al. GEOS-Chem*	510-540	4250-4700	3710-4130	1000-1090	300-320	21-23

* Driven by GISS, GEOS-3, and GEOS-4 met. fields

2/3 of variance in production across models is explainable by NO_x emission, STE, and inclusion of NMVOCs

$$P(O_x) = 94E_{NOx} - 0.83STE + 440\delta(NMVOC) + 160$$

$R^2 = 0.68$ ($n = 19$)