Impact of Potential Future Climate Change on Regional Ozone and Fine Particulate Matter Levels in the USA

(A Joint Research Project of Georgia Tech, NESCAUM, and MIT)

Chair's Air Pollution Seminar
California Air Resources Board
Sacramento, CA, January 10, 2007

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Acknowledgements

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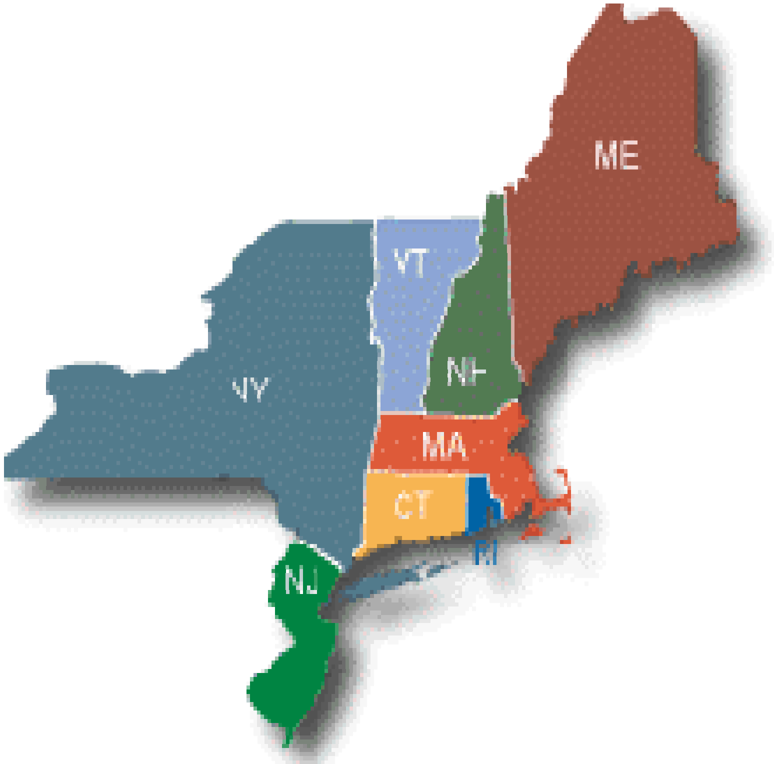
Pacific Northwest National Laboratory (PNNL)

Who we are

- NESCAUM (Northeast States for Coordinated Air Use Management)
- The Clean Air Association of the Northeast States
- A nonprofit organization founded in 1967 to assist the New England states in developing air pollution policy, technical, and management programs.

Who we are (cont.)

- **Our Members include:**
  - **ME, NH, VT, MA, RI, CT, NY and NJ**



NESCAUM

www.nescaum.org

The Clean Air Association of the Northeast States

101 Merrimac Street, 10th Floor   Boston, MA 02114
Phone 617-259-2000   Fax 617-742-9162
Arthur N. Marin, Executive Director

NESCAUM Mission

- **The five elements:**
  - Provide technical assistance to the member States
  - Provide policy guidance and strategic advice to the States
  - Represent States in various national forums
  - Identify and explore emerging issues and programs that will be important to the States in the coming years
  - Provide a forum for the States to work together to resolve regional problems

An Example of NESCAUM's Role: Climate Change Programs with Regional and National Scope

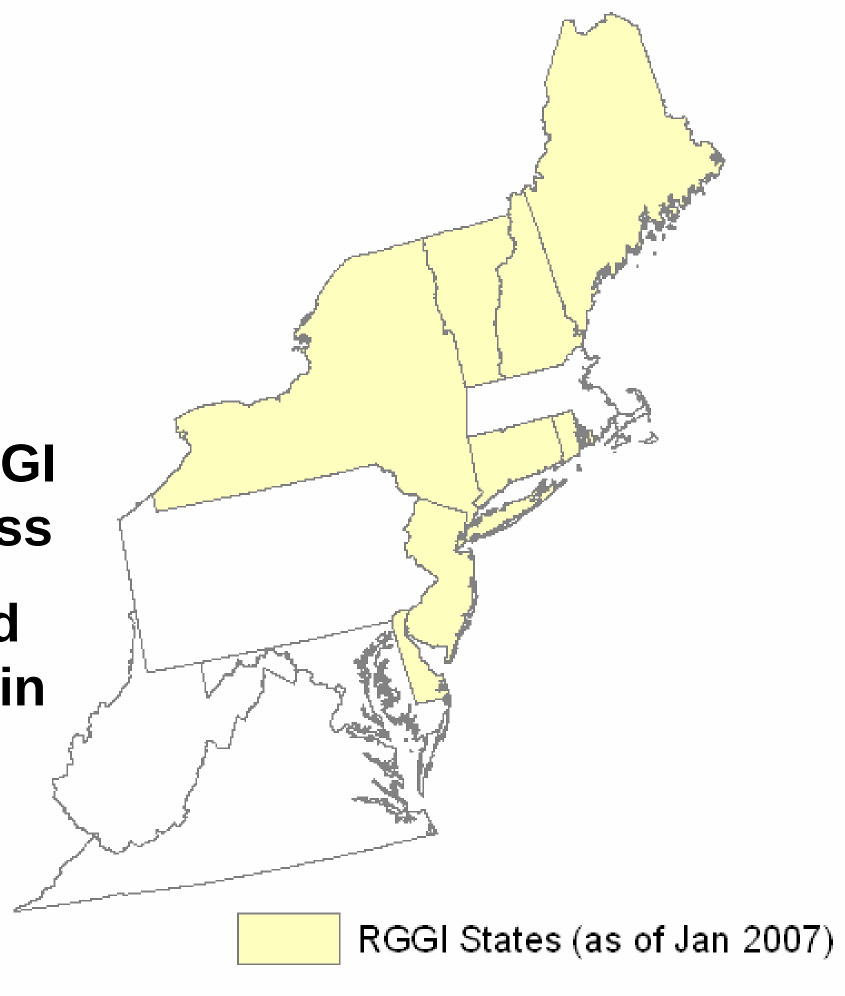
Multi-State Climate Registry

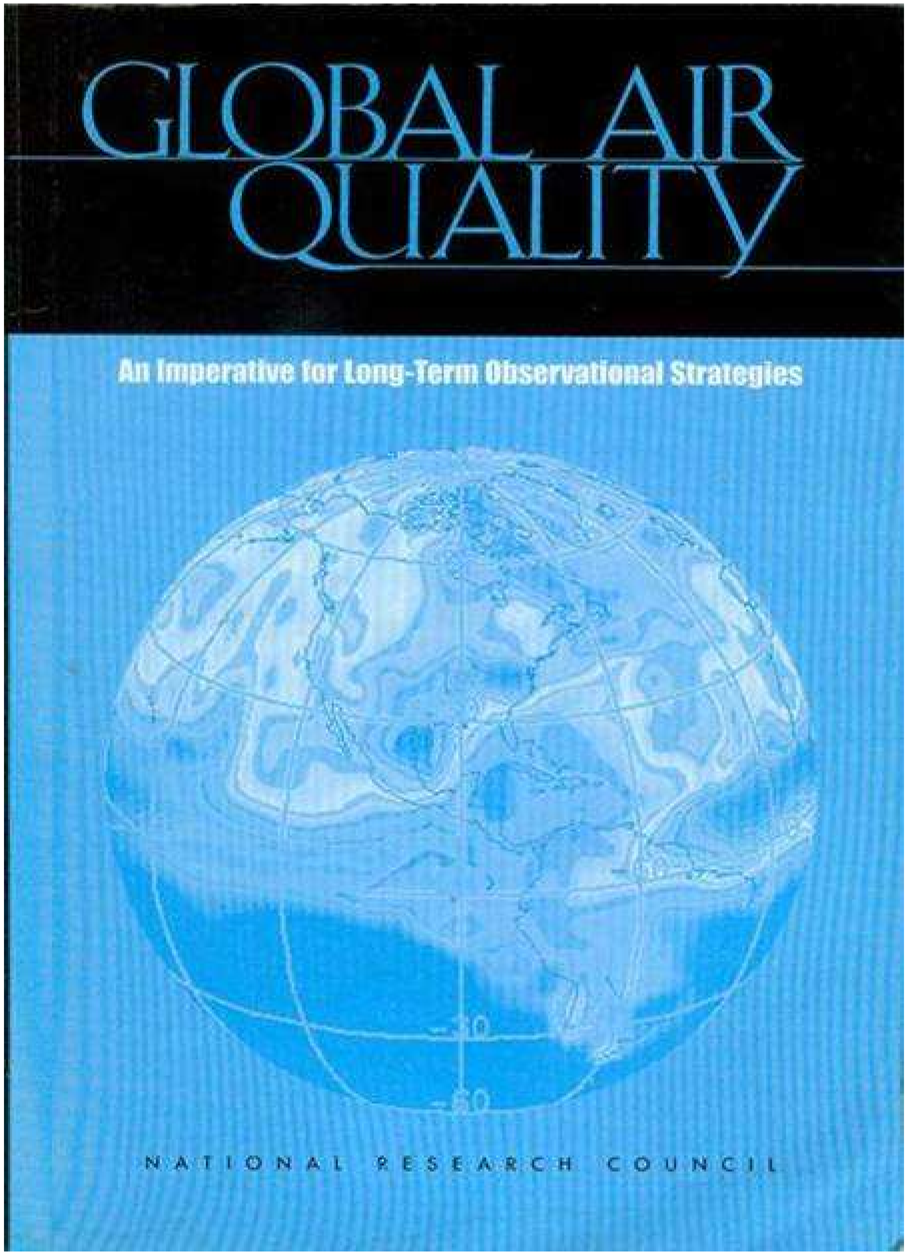
- NESCAUM is helping to coordinate efforts to develop high-quality GHG emissions data and information systems:
  - **Mission:** Provide companies and organizations with opportunity to document early action, demonstrate environmental leadership, and identify GHG risks and opportunities
  - **Benefits:** Program will support multiple state/regional climate policy goals (mandatory and voluntary), leverage state resources, facilitate linkages between programs, and promote transparency and accountability
  - **Goals:** Registry will ensure consistency between reporting programs, help establish common currency, and establish high level of environmental integrity in emissions accounting and reporting
  - **Participating States:** More than 30 eastern, midwestern, and western states engaged in registry development process

Contact: Heather Kaplan, Climate Policy Analyst, hkaplan@nescaum.org

Regional GHG Initiative (RGGI)

- •NESCAUM served as Resource Panelist to RGGI State Working Group
- •Supported analysis on potential economic impacts of RGGI in the northeast (REMI)
- •Supported states through the RGGI model rule public comment process
- •Currently providing analytical and other support to individual states in implementing RGGI





GLOBAL AIR QUALITY

An Imperative for Long-Term Observational Strategies

NATIONAL RESEARCH COUNCIL

Published 2001

The 2001 NRC Report Notes:

- **Our ability to understand observed changes in global air quality and to accurately predict future changes will depend strongly on answering two important questions:**
    - **How can global air quality change affect, and in turn be affected by, global climate change?**
    - **How is global air quality affected by the international and intercontinental transport of air pollutants?**

“Scientific” Scales of Air Pollution

- **Air Pollution is a “Mixture” of Scales**
  - **Local** (CO, ozone, SO_2, PM, mercury);
  - **Regional** (ozone, PM, NOx, mercury, acid deposition, regional haze)
  - **Global** (CFCs, CO_2, mercury, methane, “background” ozone)
- CO_2 is global, but has local and regional impacts

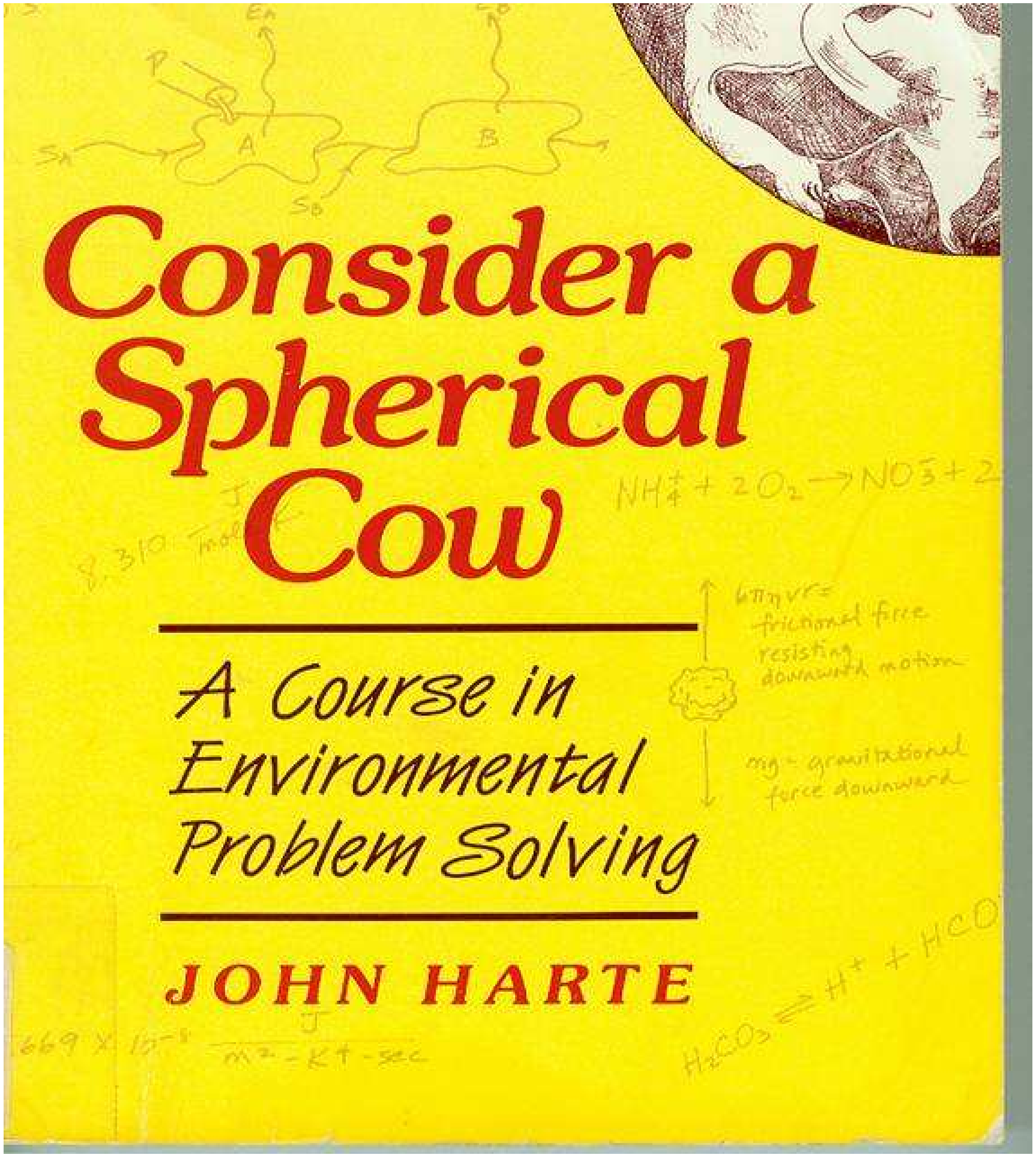
Recent Events

- **November 29, 2006: In the US Supreme Court (Oral Arguments): Massachusetts, et al., v. EPA, et al.**
- The key questions: Is CO_2 a pollutant under the Clean Air Act and does EPA have the authority to regulate it? Does the State of Massachusetts have "standing"?
- Justice Scalia: I thought that the standing requires imminent harm. If you have not been harmed already, you have to show the harm is imminent. Is this harm imminent?
- Mr. Milkey (attorney for Mass.): It is, Your Honor. We have shown that the sea levels are already occurring ("rising") from the current amounts of greenhouse gases in the air, and that it means it is only going to get worse as the ---
- Justice Scalia: When? I mean when is the predicted cataclysm?
- Mr. Milkey: Your Honor, it is not so much a cataclysm as ongoing harm. The harm does not suddenly spring up in the Year 2100, it plays out continuously over time. And even to the extent you focus on harms that occur in the future, there is nothing conjectural about that. Once these gases are emitted into the air, and they stay a long time, the laws of physics take over.

Recent Events (Cont.)

- Later on, Mr. Milkey: Your Honor, first of all, I do think we have special standing. For example, here it is uncontested that greenhouse gases are going to make [the] **ozone** problem worse, which makes it harder for us to comply with our existing Clean Air Act responsibilities.
- A Point to Note: The word “Uncertainty” appears twenty three times in the oral arguments. As in: “the studies that are being developed to reduce the uncertainty,” in the area of global warming (Chief Justice Roberts); “there will always be scientific uncertainty,” (Mr. Milkey); “ those are two very different levels of uncertainty,” (Chief Justice Roberts), referring to lead emissions from vehicles and impact of CO_2 on global warming; “..now is not the time [for EPA to] to exercise such authority, in light of the substantial scientific uncertainty surrounding global climate change and the ongoing studies designed to address those uncertainties,” (Mr. Garre, U.S. Department of Justice), and so on.

It is the mark of an instructed mind to rest satisfied with the degree of precision which the nature of the subject permits and not to seek an exactness where only an approximation of the truth is possible -- Aristotle

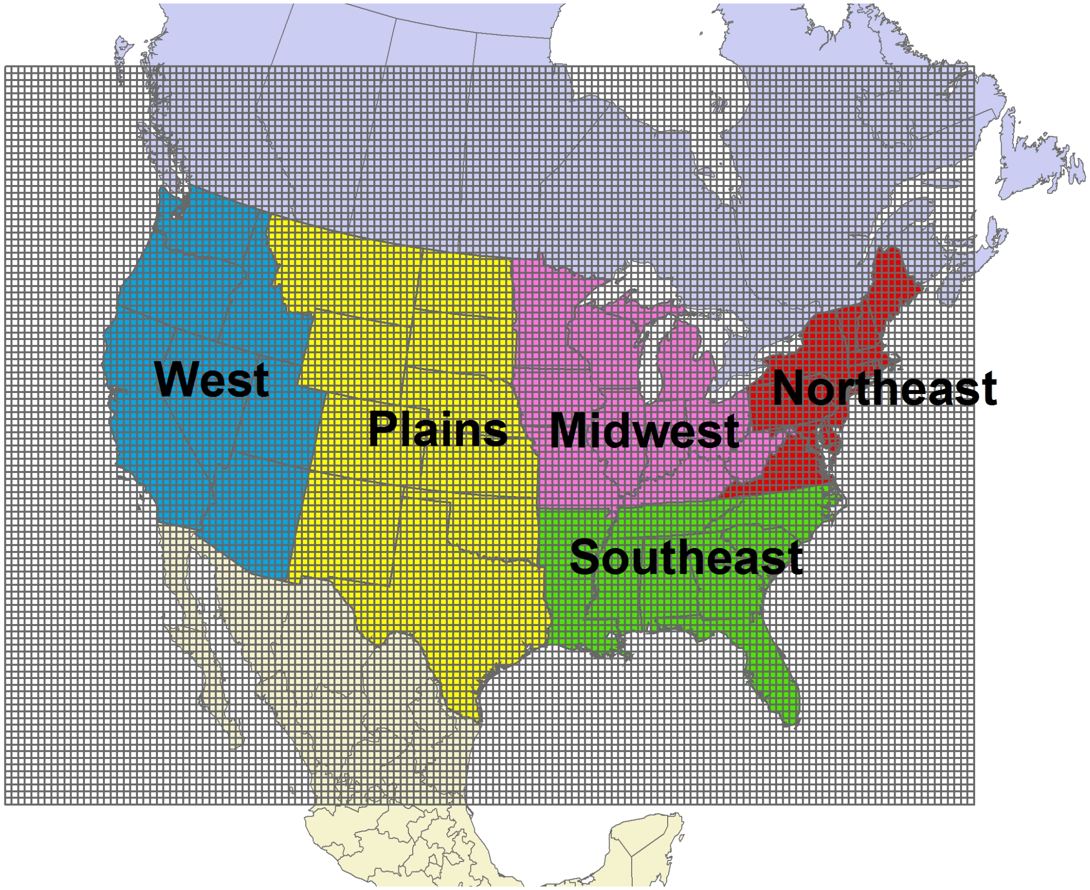


Consider a Spherical Cow

A Course in Environmental Problem Solving

JOHN HARTE

Regional future O_3 and $PM_{2.5}$ levels & components over US



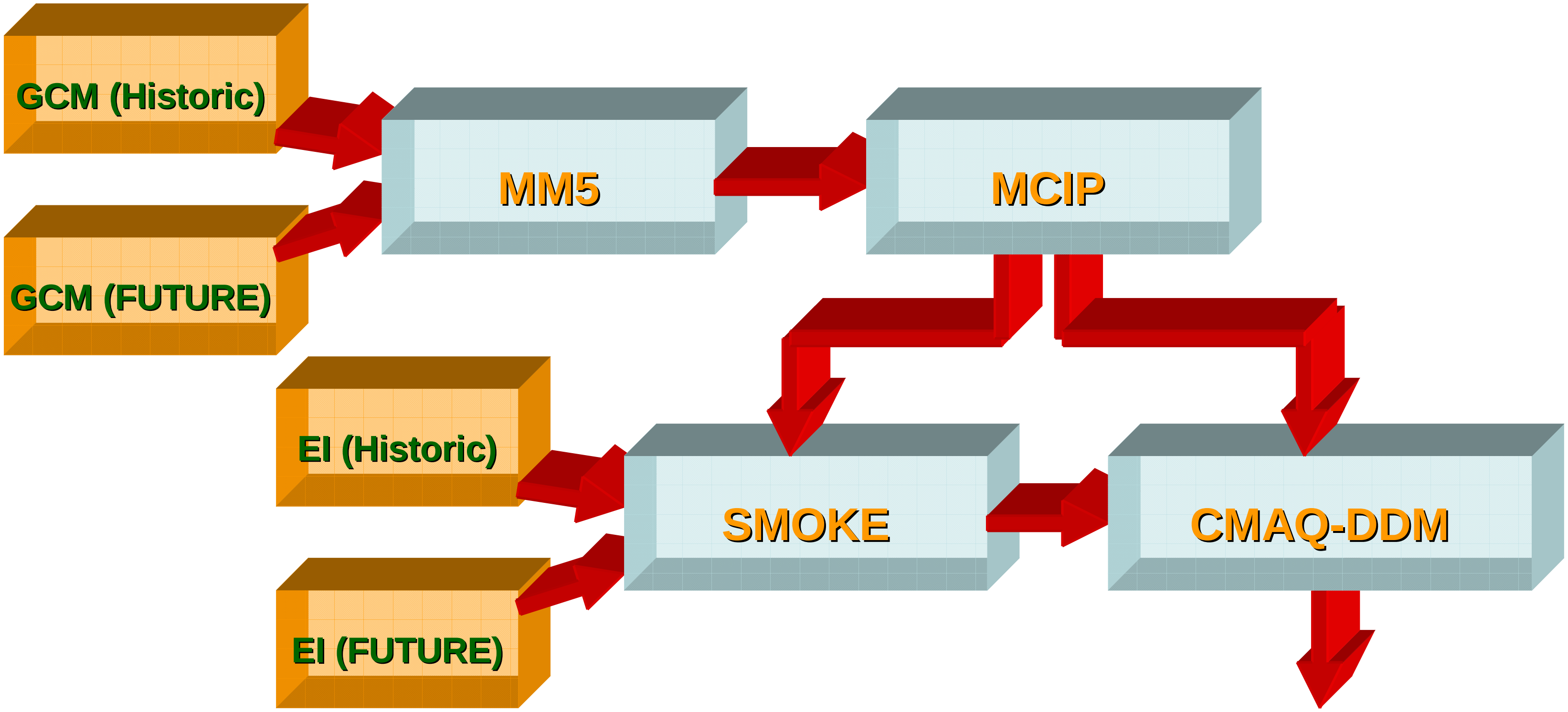
grids: 147 x 111

resolution: 36 x 36 km

Historic period: summer 2000, 2001 (full year), summer 2002

Future climate: summer 2049, 2050 (full year), summer 2051

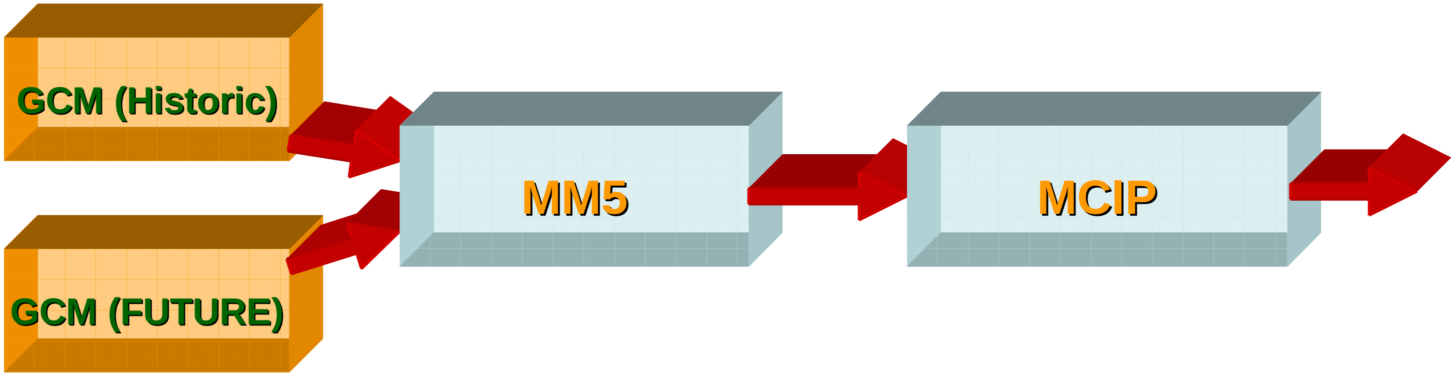
Modeling approach



GCM: Global Climate Model

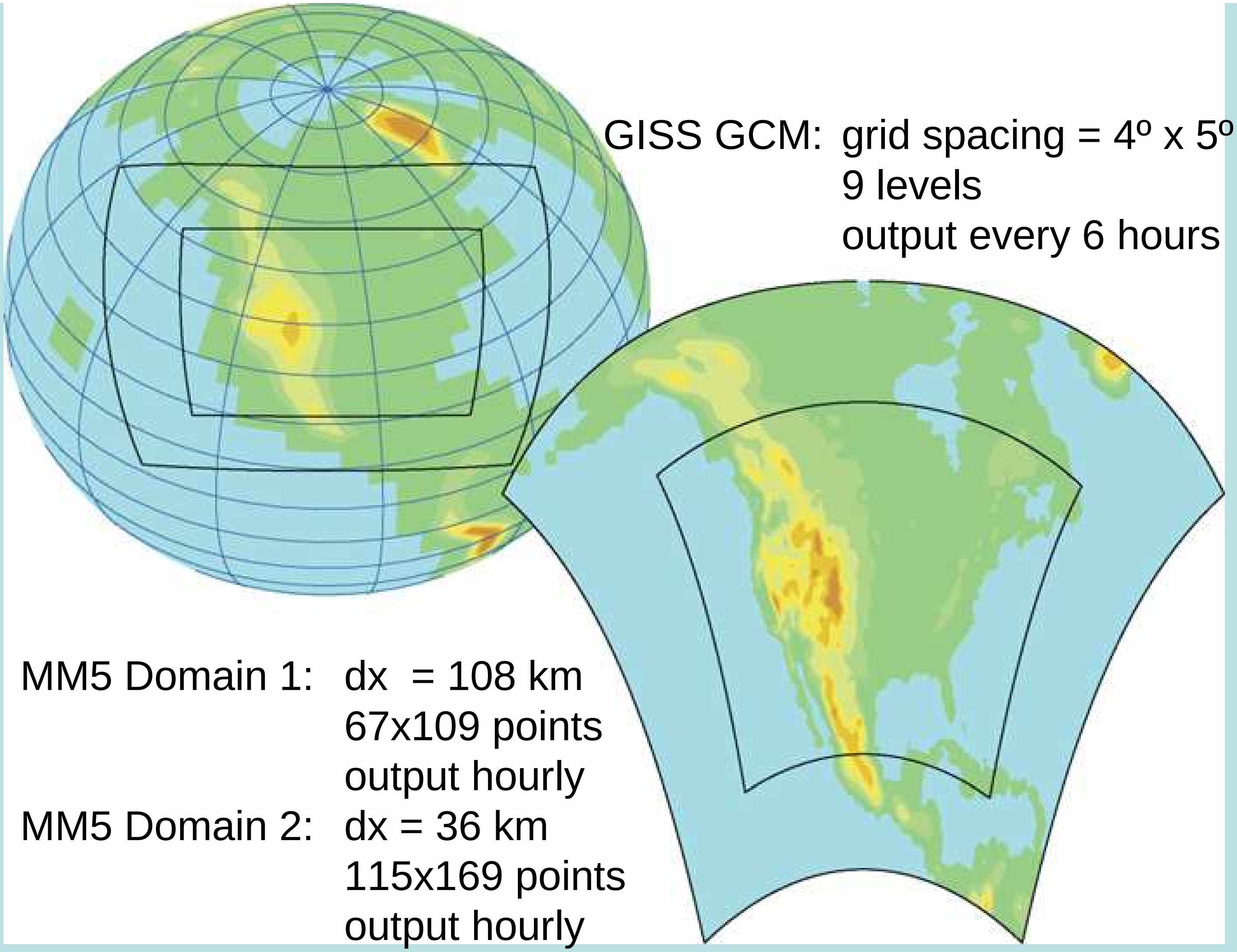
EI: Emission Inventory

Meteorology



Downscaling meteorology (GISS-GCM) using MM5

Global and Regional Climate Models*



GISS GCM: grid spacing = 4º x 5º
9 levels
output every 6 hours

MM5 Domain 1: dx = 108 km
67x109 points
output hourly

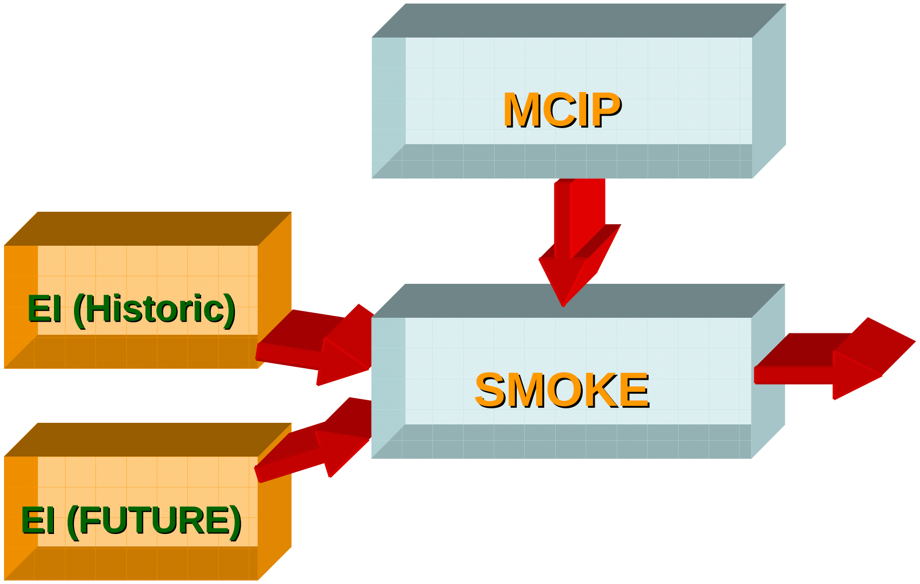
MM5 Domain 2: dx = 36 km
115x169 points
output hourly

Leung and Gustafson (2005),
Geophys. Res. Lett., *32*, L16711

Numerical Experiments

- **Global climate simulations**
  - A transient simulation was performed for 1950 - 2052
  - The A1B SRES scenario for greenhouse gases was assumed for the future (2000 – 2052) and observed greenhouse gas concentrations were used for 1950-2000
- **Regional climate simulations**
  - One simulation driven by NCEP/NCAR reanalysis for 1990-2000 for model evaluation
  - The base case driven by GISS: 1995-2005 (includes 2000-02)
  - A future case driven by GISS: 2045-2055 (includes 2049-51)

Emissions



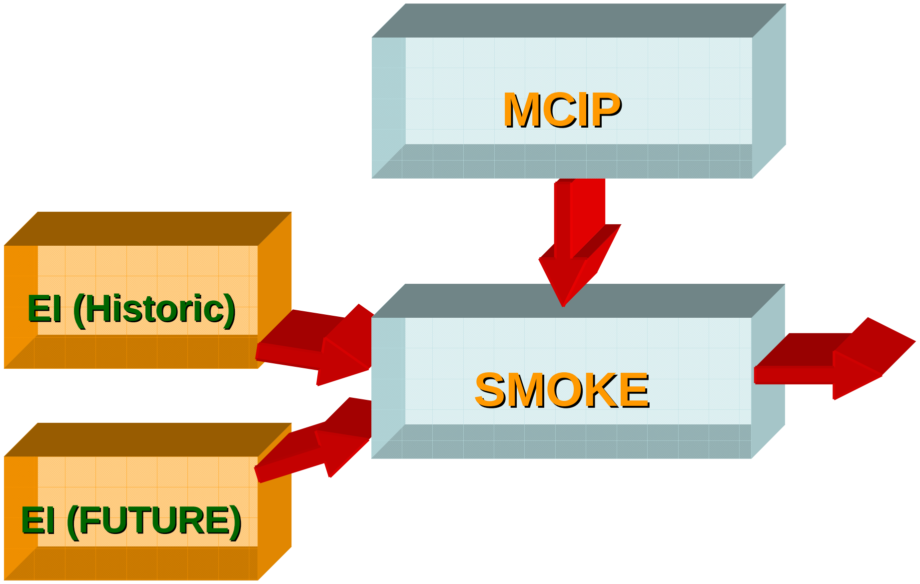
MCIP

EI (Historic)

SMOKE

EI (FUTURE)

Emissions



Emissions inventories:

2001:	U.S.: Clean Air Interstate Rule (CAIR) 2001 Canada: Environment Canada 2000 Mexico: U.S. EPA's 1999 BRAVO
2050:	IPCC-A1B emissions scenario and CAIR 2020

Projection of Future Emissions

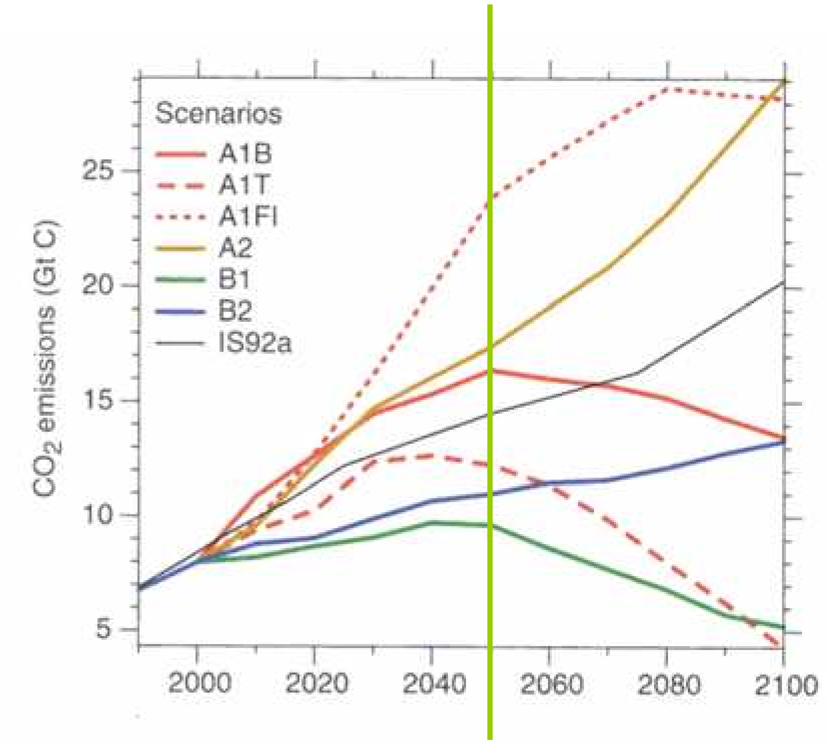
*** Develop 2050 Emission Inventory**

- Target year: Year 2050, Annual
- Format: SMOKE-ready
- Sector: Anthropogenic only
- Geographical domain: US/CAN/MX
- Projection approach:
  Two-stage approach when national projections are available

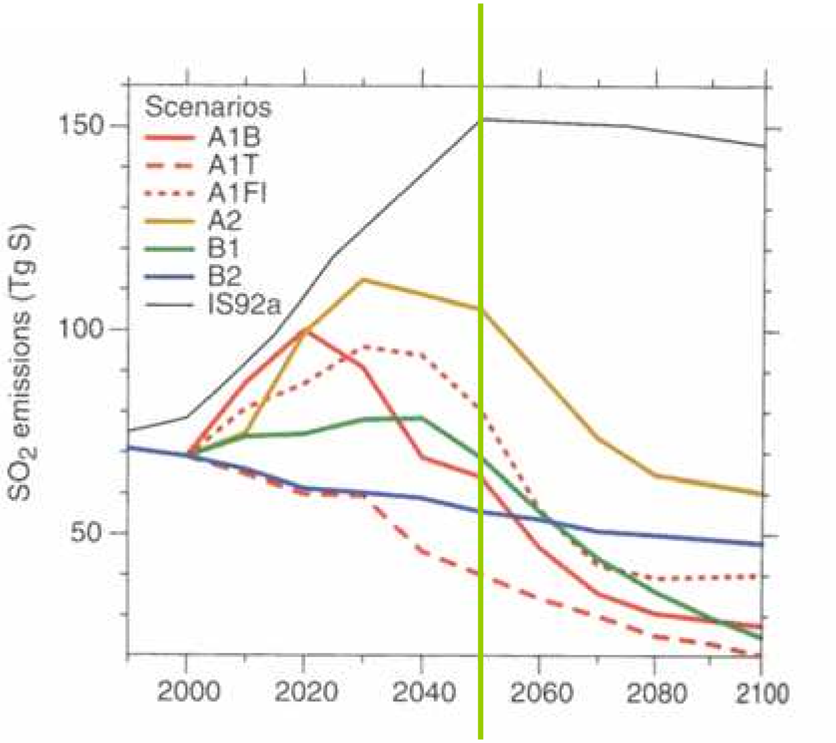
*** In support of modeling**

- Did not create new future energy/emissions scenarios

IPCC SRES Scenarios (Global CO2 & SO2)



2050



2050

Source : IPCC

Basic Strategy

Future-year EI development

- Obtain the best available future EI data possible
- Fill-up gaps from near/certain future to distant/uncertain future

Example : Use EPA projection until 2020 and use IPCC scenario from 2020-2050

Comparison of existing "future-EI" development approaches

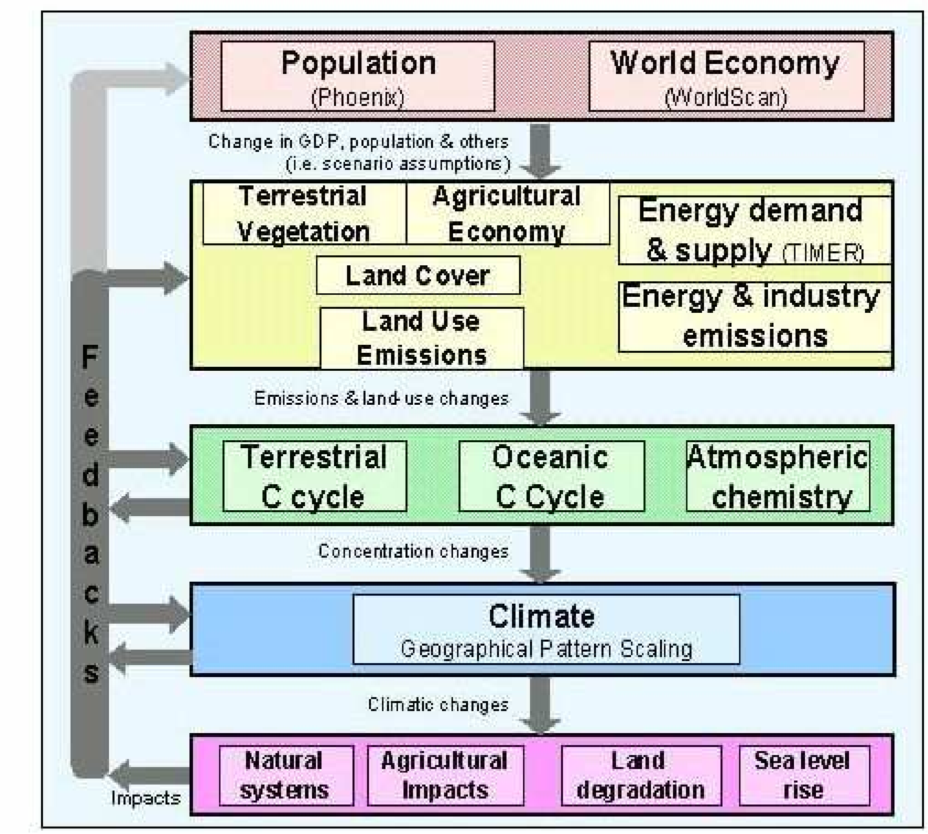
Name	Base Year	Future Years	Geographical Domain	Scenario	Source sectors	Chemical species	Model	Availability
EPA CAIR	2001	2010 /2015 /2020	Continental US	EPA BASE /CAIR	EGUs, non-EGUs	NOx, VOCs, CO, NH3, SO2, PM	IPM /EGAS/NMIM	Yes
EPA CSI	1996	2010 /2020	Continental US	EPA BASE /CSI	EGUs, Non-EGUs	NOx, VOCs, CO, NH3, SO2, PM	IPM /EGAS	Yes
RPOs	2002	2009 /2018	Continental US	OTB/OTW	EGUs & non-EGUs	NOx, VOCs, CO, NH3, SO2, PM	IPM /EGAS	Partly
SAMI	1990	2040 (/10yrs)	38 States + DC	OTB/OTW/BWC/BB	EGUs & non-EGUs	NOx, VOCs, CO, NH3, SO2, PM	SAMI	No
RIVM*	1995	~2100 (/yr)	World (17 regions)	IPCC SRES(A1, B1, A2, B2)	Energy sector/fuel combination	CO2, CH4, N2O, CO, NOx, SO2, NMVOC	IMAGE	Yes
NESCAUM /EPA	1999	~2029+ (/3yrs)	Units(EGUs), States(NE), Country	BAU, RGGI	Energy sector/fuel combination	NOx, VOCs, CO, NH3, SO2, PM	MARKAL	2007

🟦 Pros 🟥 Cons 🟨 Both

- RIVM : Netherlands's National Institute for Public Health and the Environment
- IMAGE : Integrated Model to Assess the Global Environment

RIVM IMAGE

IMAGE: A dynamic integrated assessment modeling framework for global change



Population (Phoenix)

World Economy (WorldScan)

Change in GDP, population & others (i.e. scenario assumptions)

Terrestrial Vegetation

Agricultural Economy

Land Cover

Land Use Emissions

Energy demand & supply (TIMER)

Energy & industry emissions

Emissions & land-use changes

Terrestrial C cycle

Oceanic C Cycle

Atmospheric chemistry

Concentration changes

Climate
Geographical Pattern Scaling

Climatic changes

Natural systems

Agricultural Impacts

Land degradation

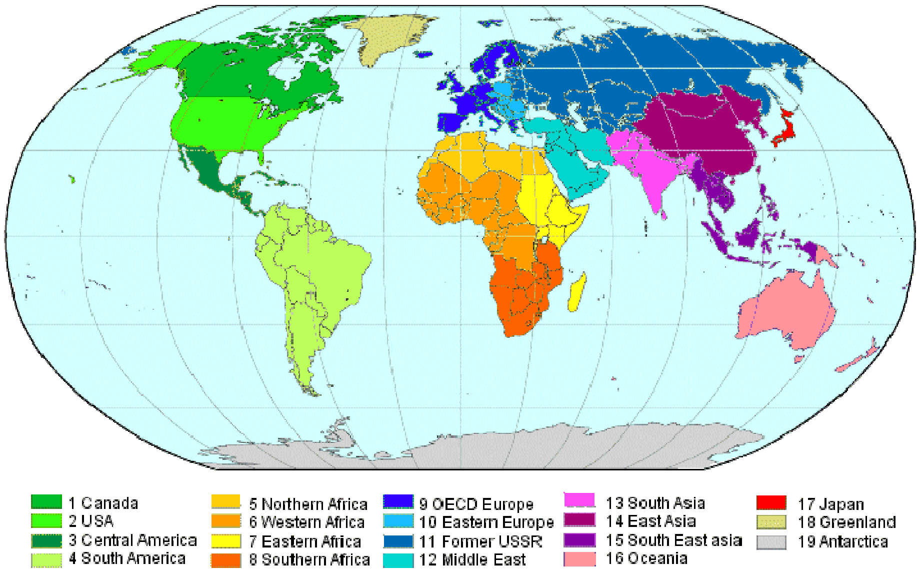
Sea level rise

Impacts

Feedbacks

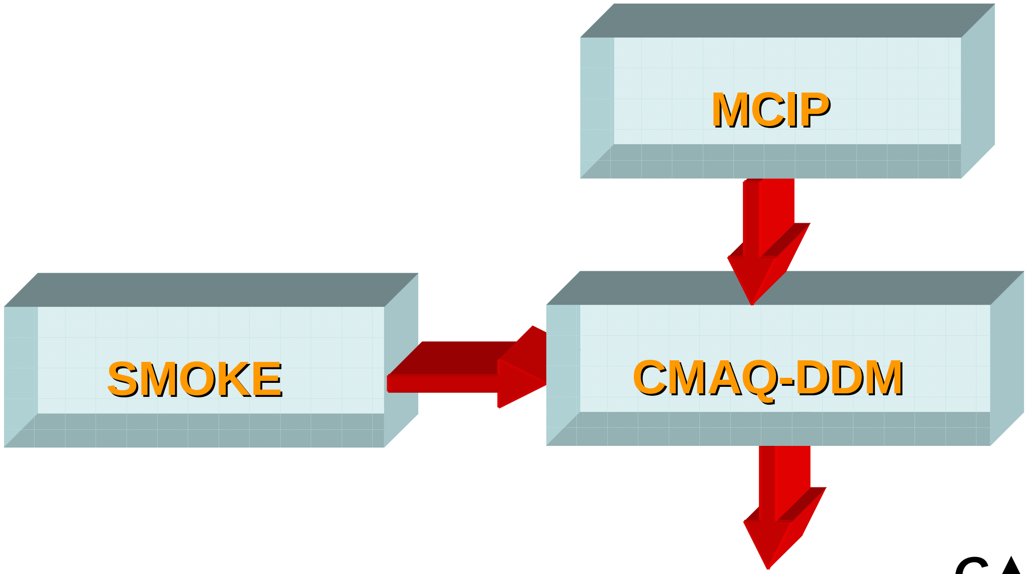
WorldScan(economy model), and PHOENIX (population model) feed the basic information on economic and demographic developments for 17 world regions into three linked subsystems (EIS, TES, and AOS*)

RIVM Environmental Research -1998 World Regions and Subregions



*EIS (Energy-Industry System), TES(Terrestrial Environment System), AOS (Atmospheric Ocean System)

Air Quality



MCIP

SMOKE

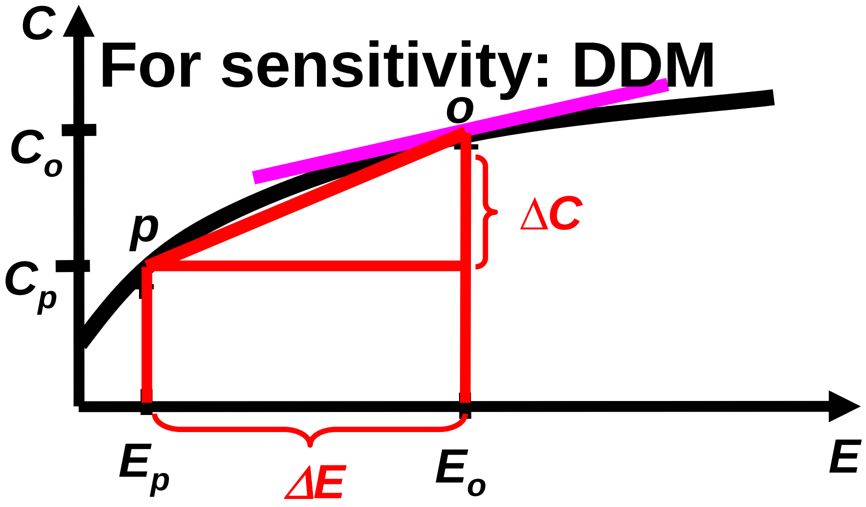
CMAQ-DDM

Brute Force (BF):

$S = \Delta C / \Delta E$

Decoupled Direct Method (DDM):

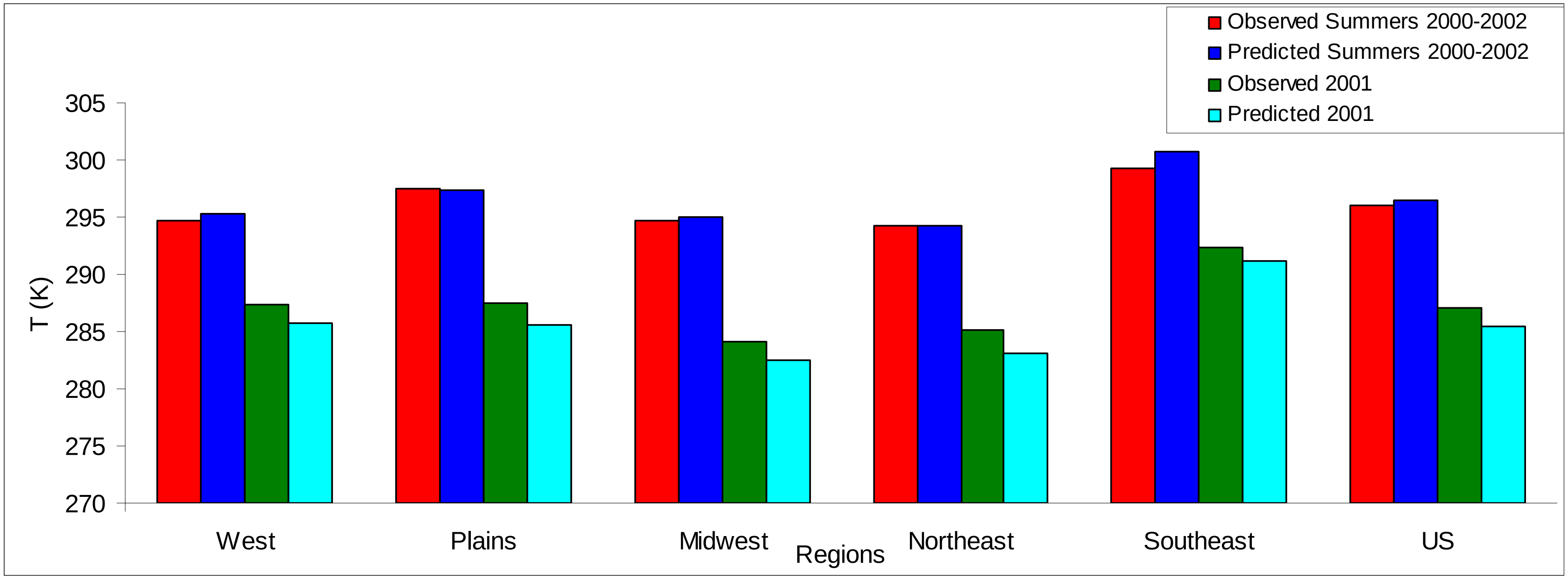
$S = \partial C / \partial E$



For sensitivity: DDM

Baseline Evaluation

Temperature

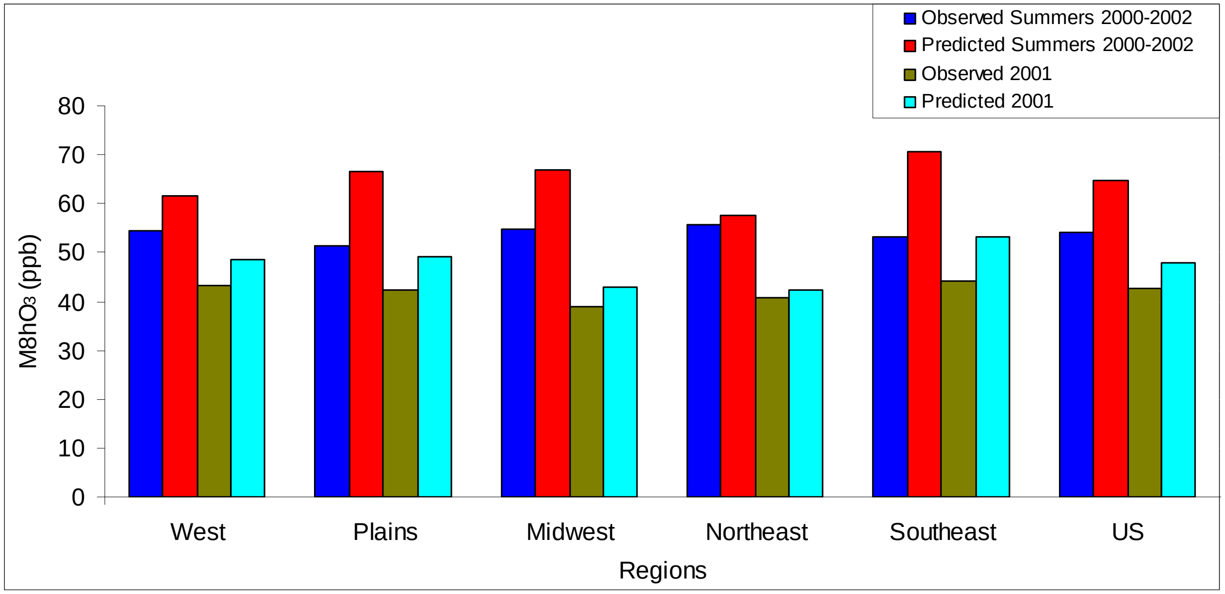


A general under prediction in temperatures

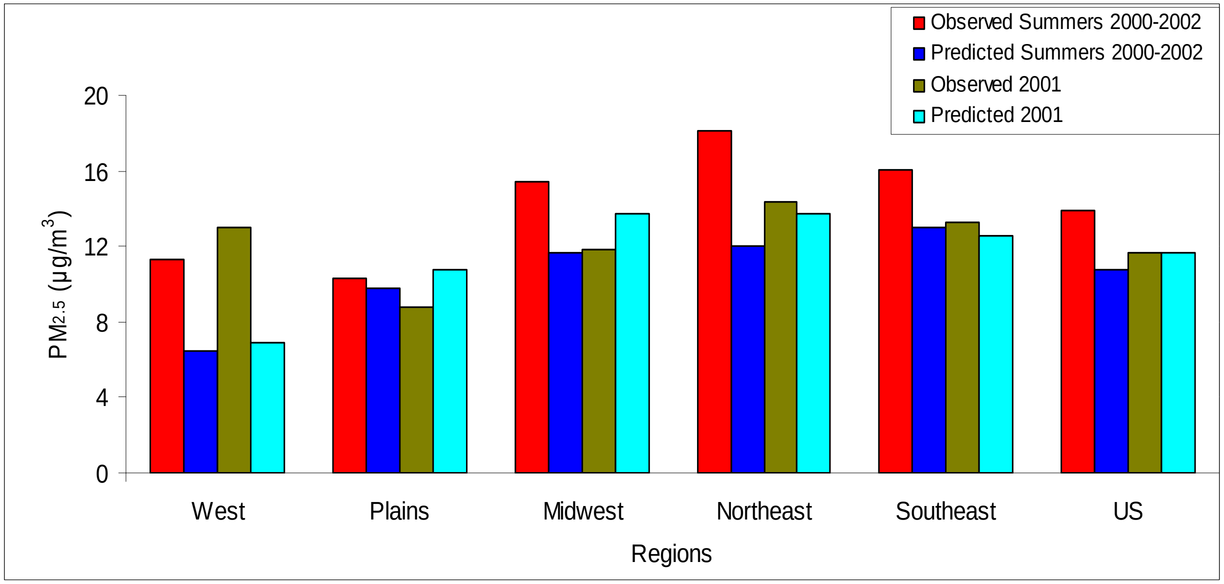
Better performance during summer months and worst during fall, caused by the high mesoscale variability during seasonal transition.

Baseline Evaluation

O_3



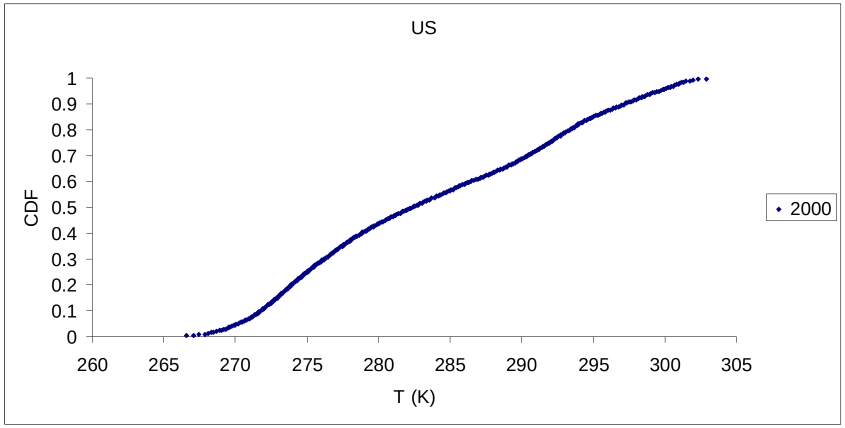
$PM_{2.5}$

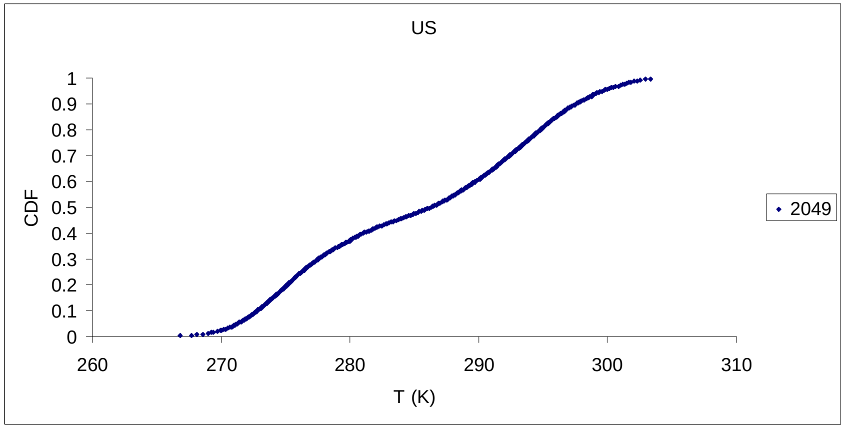


METEOROLOGY

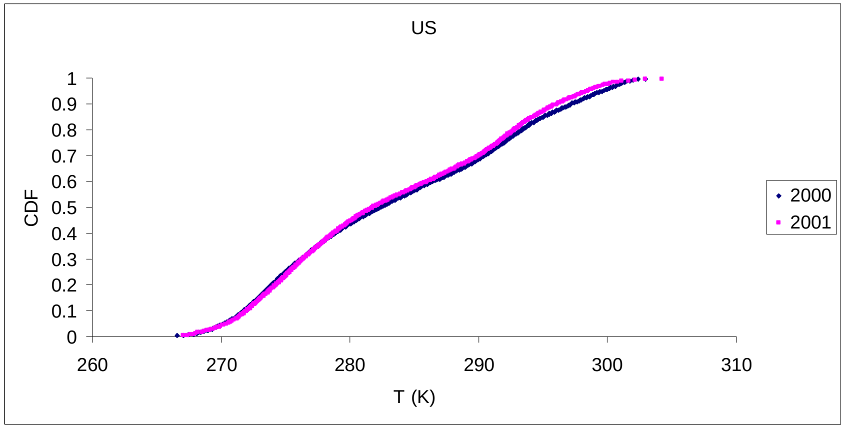
Are historic and future years representative?

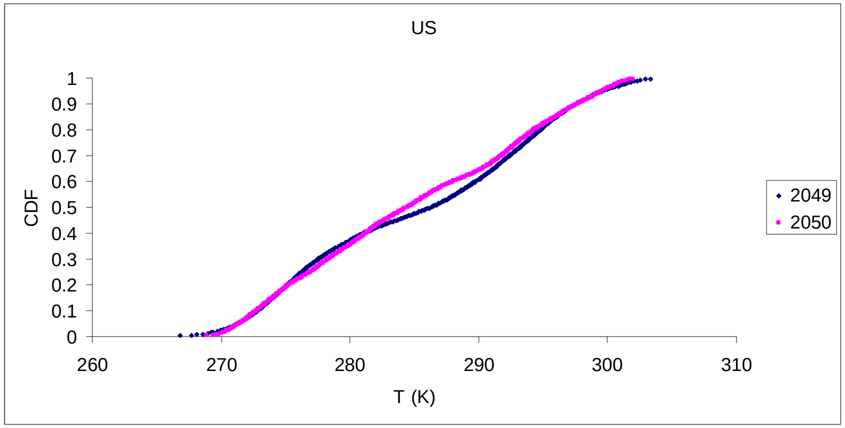
Surface Temperature Distribution



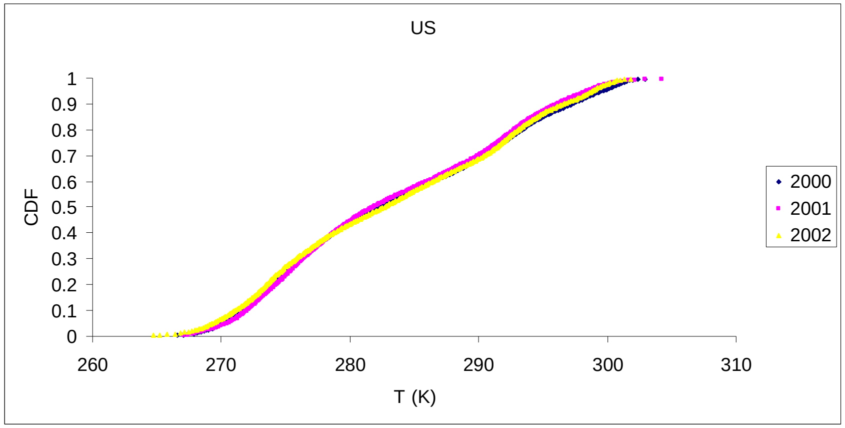


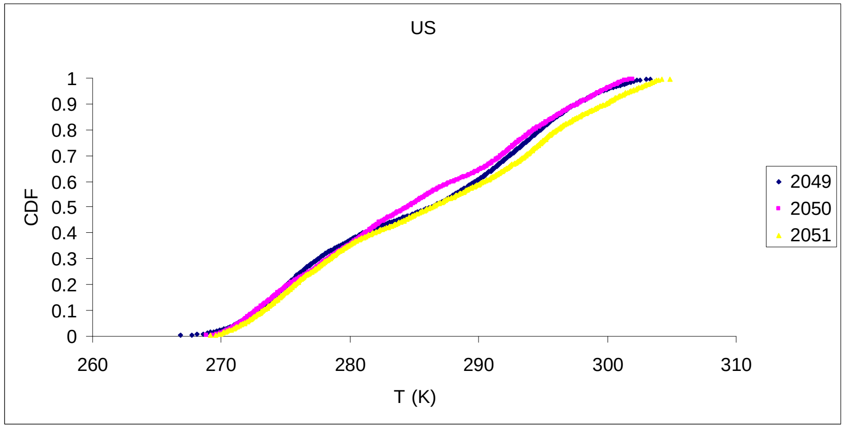
Surface Temperature Distribution



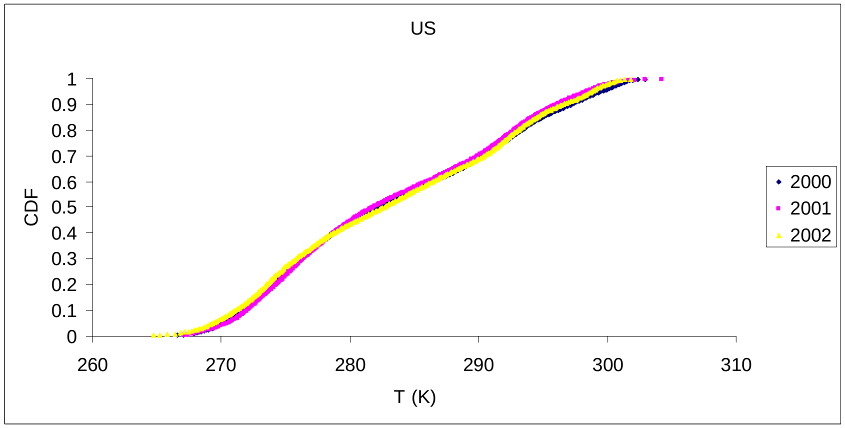


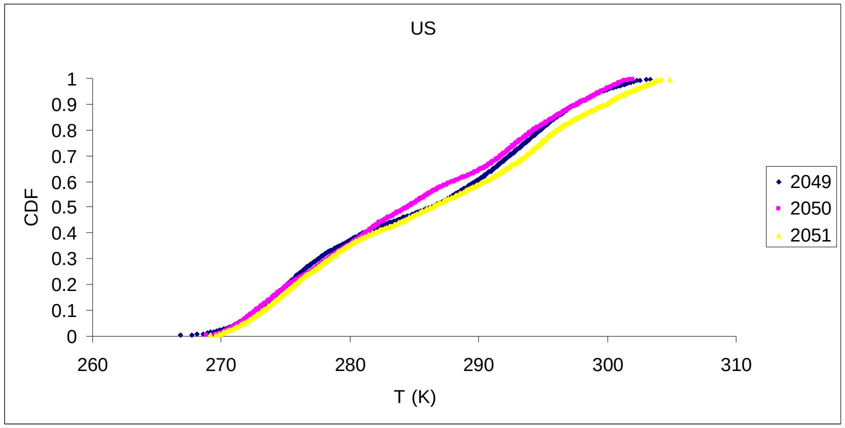
Surface Temperature Distribution

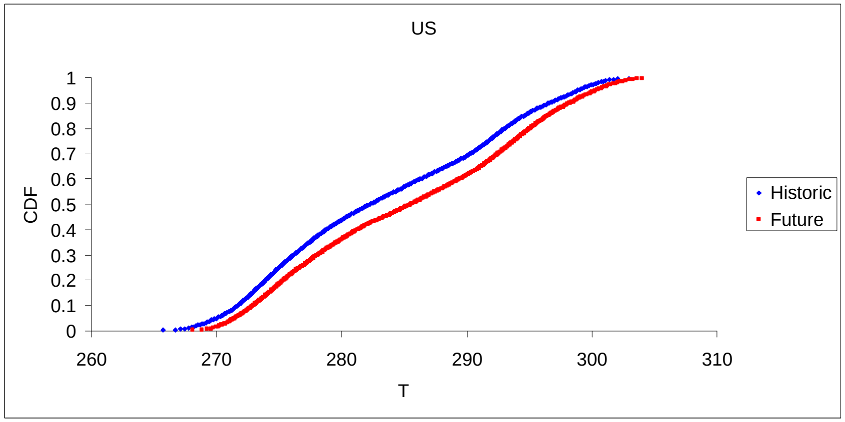




Combined Temperature Distribution

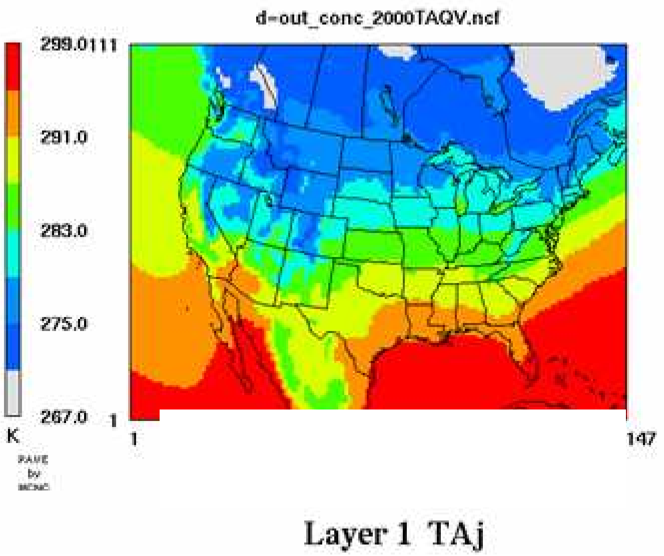




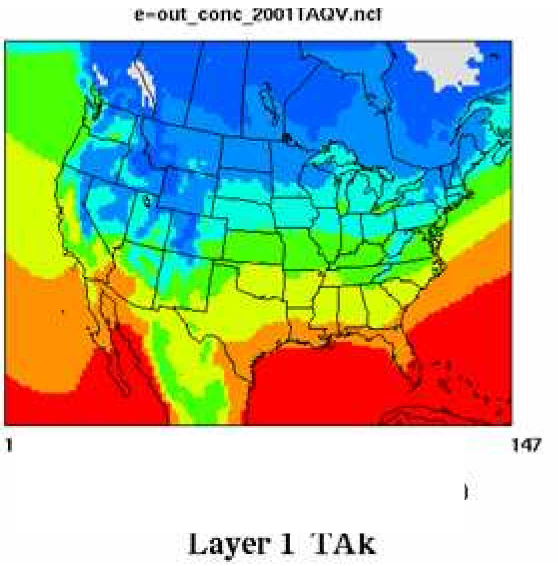


Temperature (Spatial Distribution)

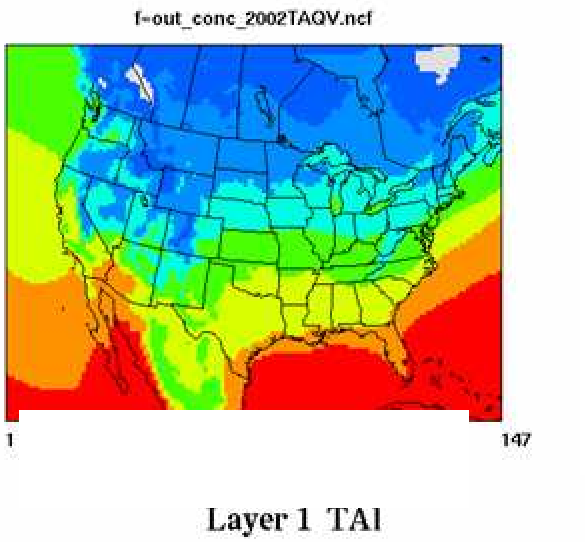
2000



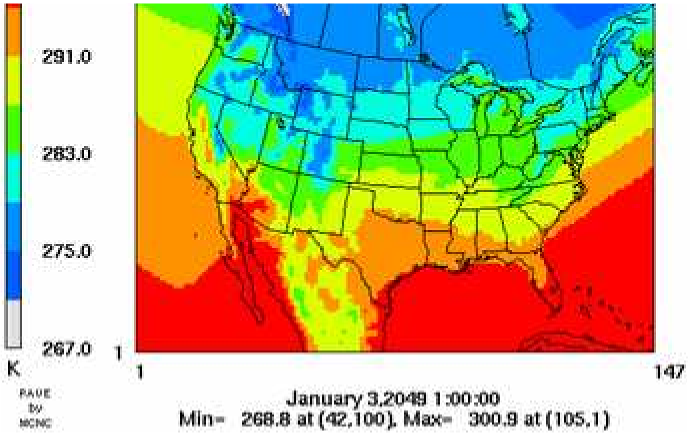
2001



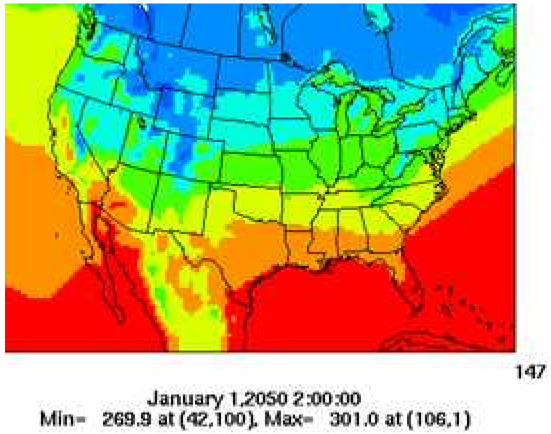
2002



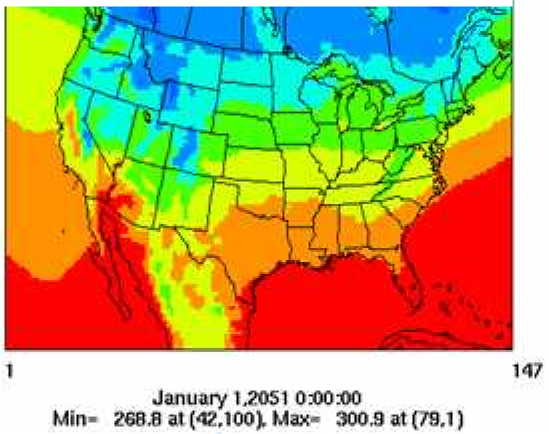
2049



2050



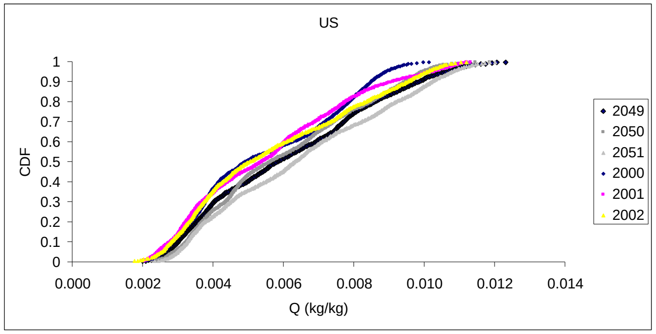
2051

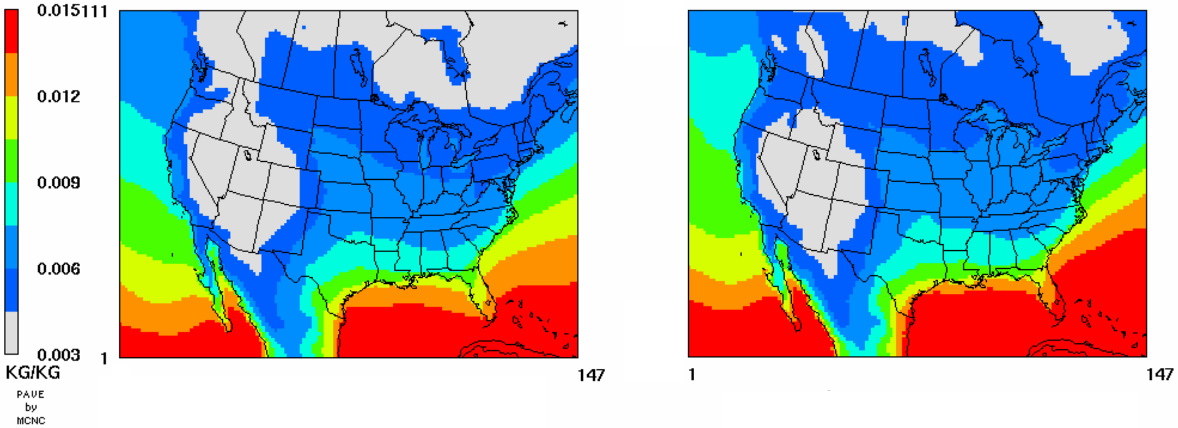


Georgia Institute of Technology

NESCAUM

Humidity

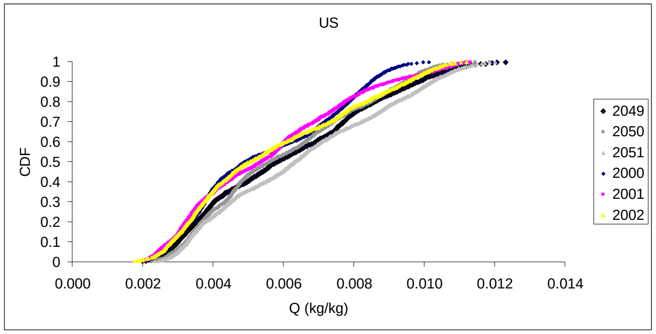




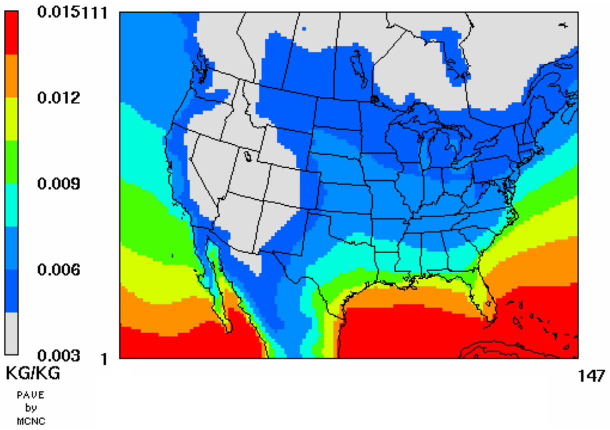
2001

2050

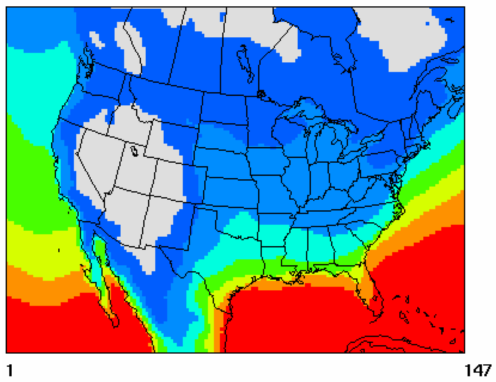
Humidity



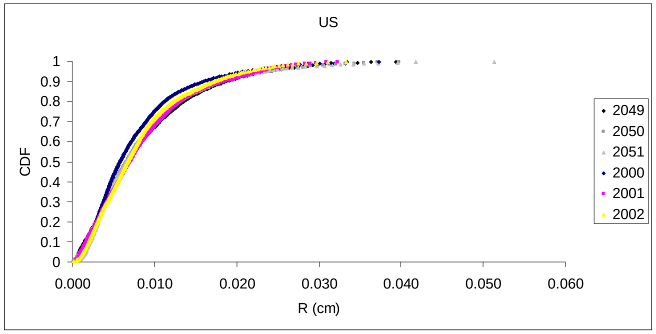
2001



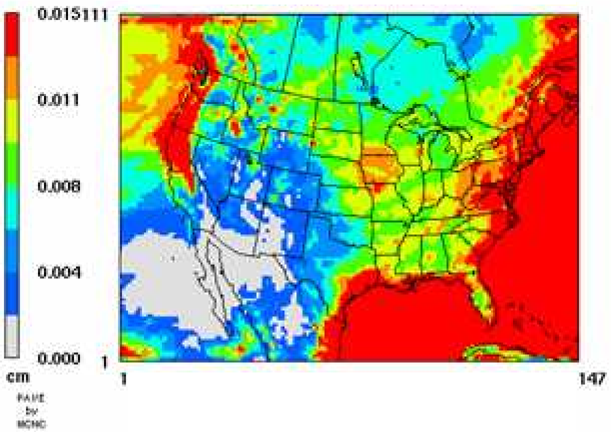
2050



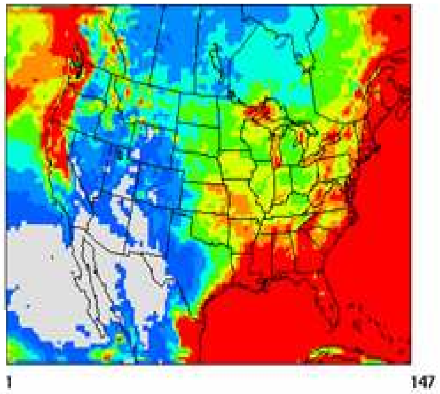
Rain



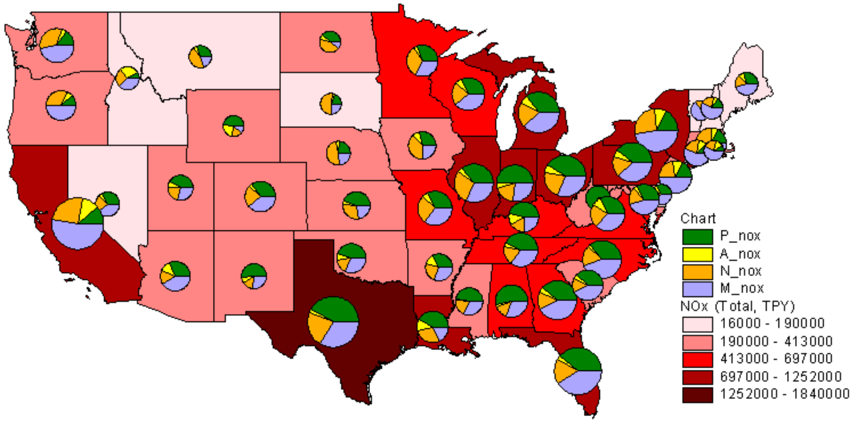
2001



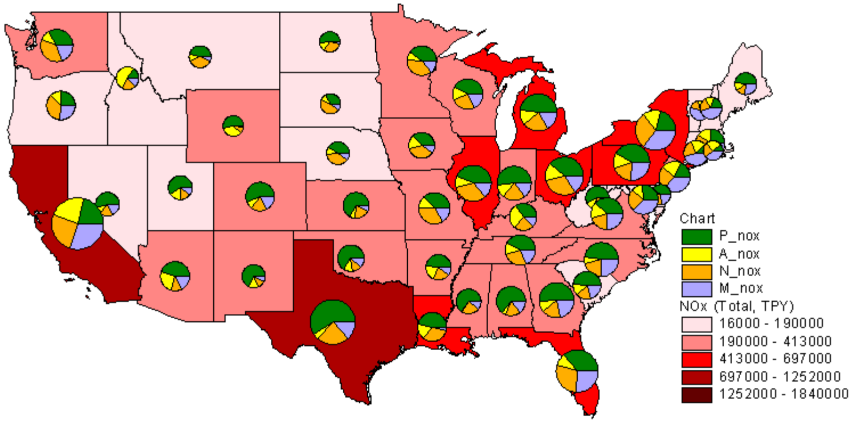
2050



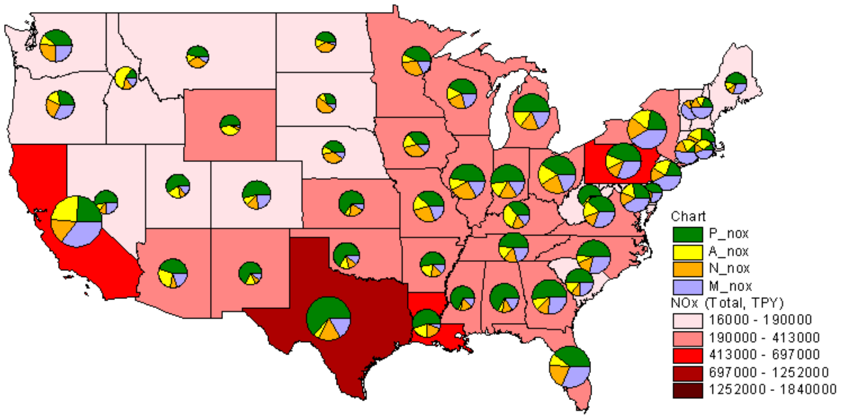
Regional Emissions: Projections



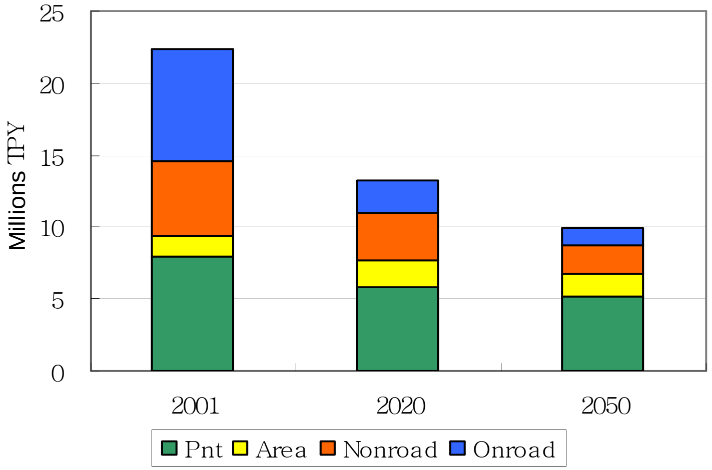
Year 2001



Year 2020

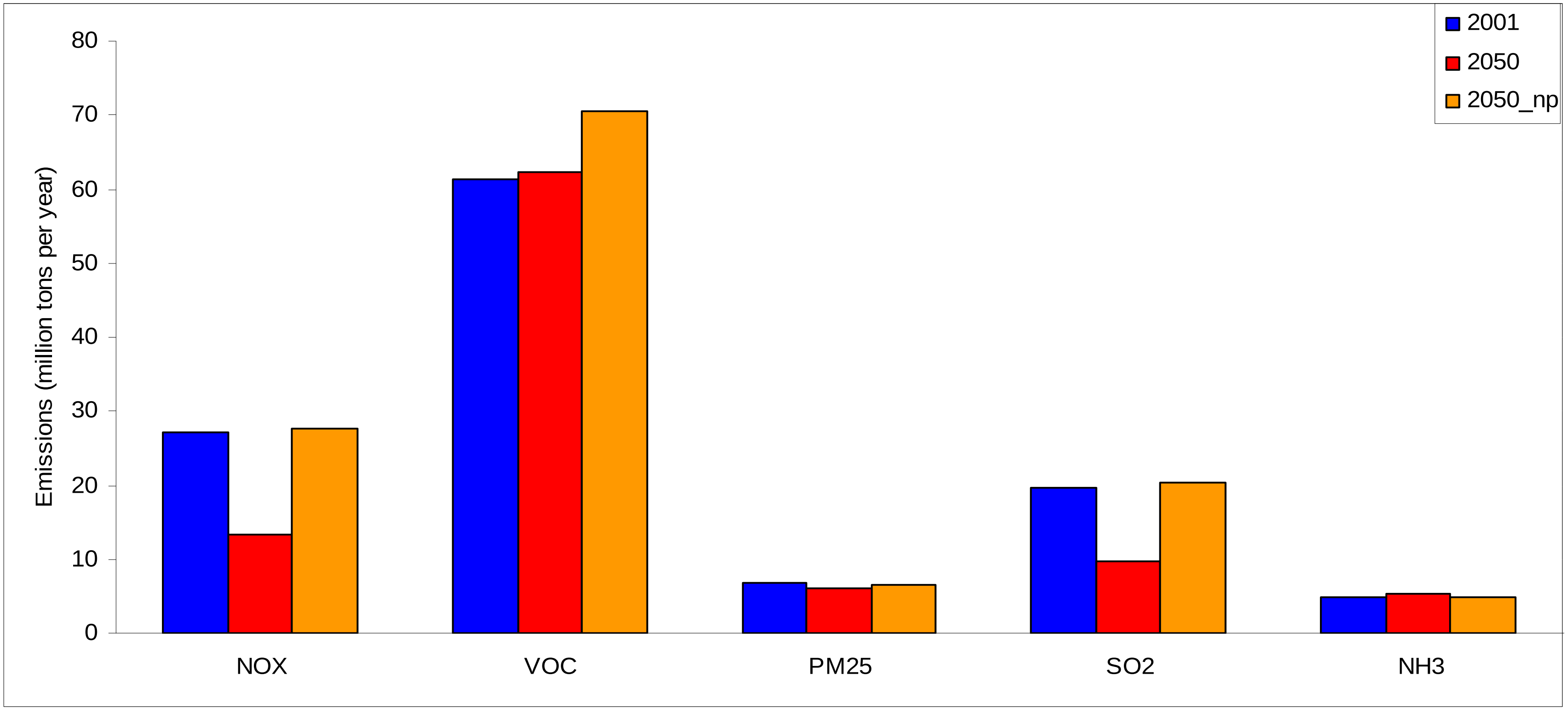


Year 2050



Present and future years NOx emissions by state and by source types

Emissions Projections



2050 – 2001:

NOx: -50% VOC's: +2% PM$_{2.5}$: -10% SO$_2$: -50% NH$_3$: +7%

2050np – 2001: VOC's: +15%

np (non-projected): Emission Inventory 2001, Climate 2050

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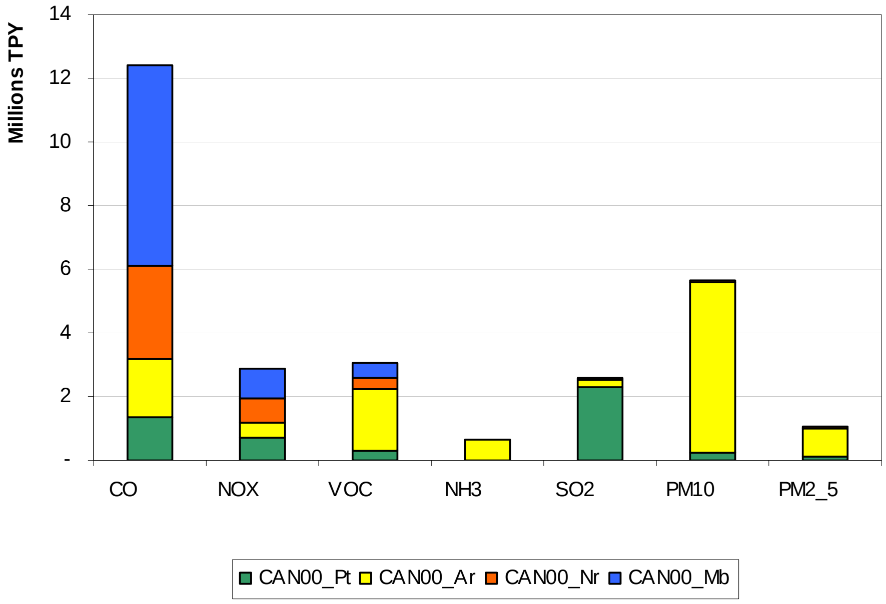
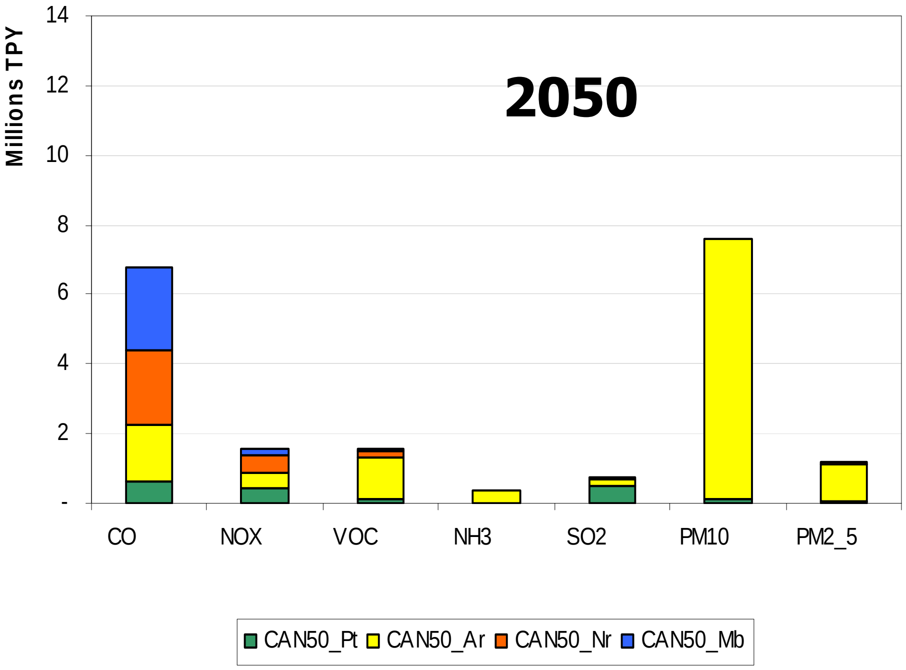
Future Emissions (CANADA)

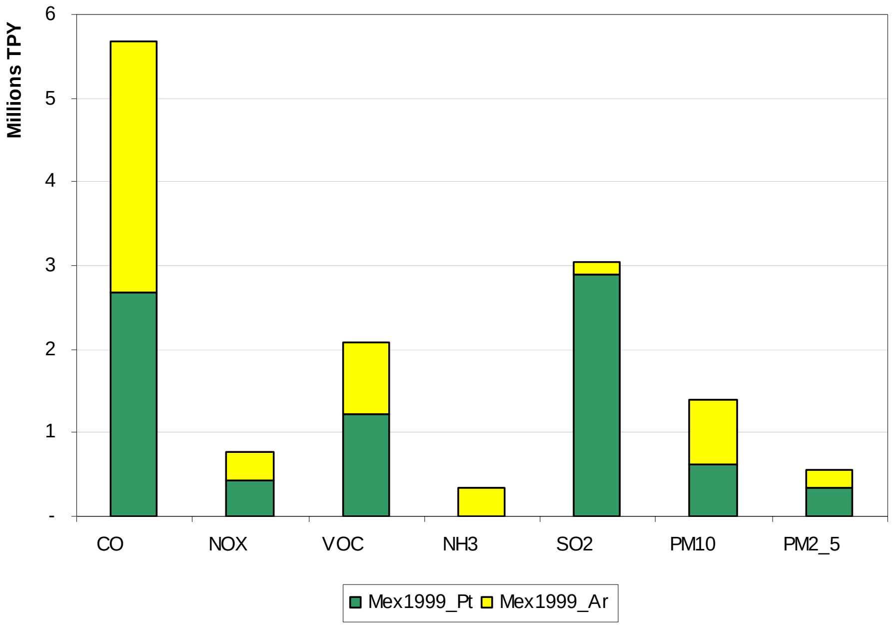


2000

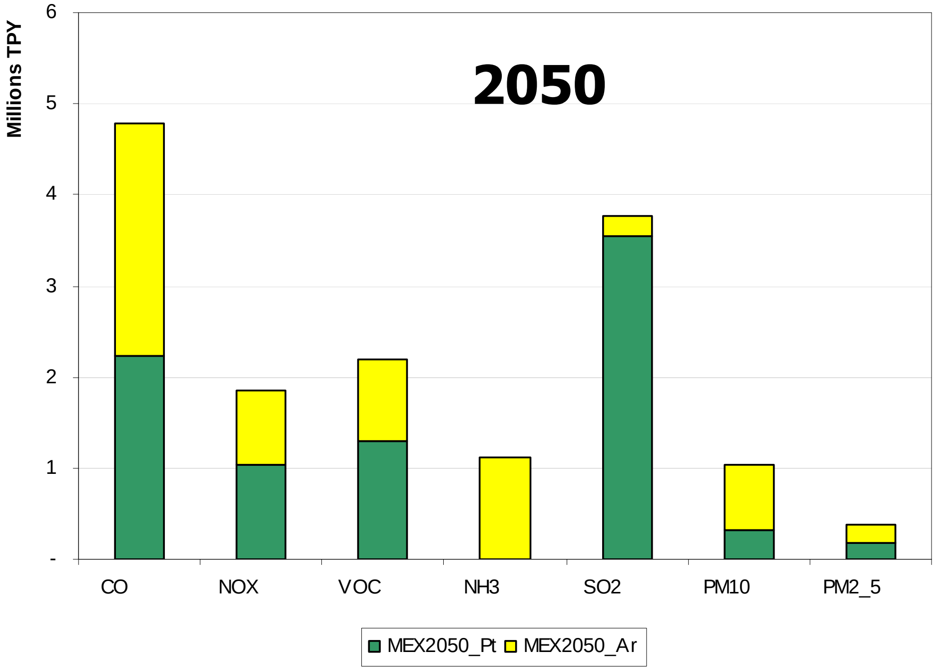


2050

Future Emissions (Mexico)



1999



Changes (in percent) in pollutants concentrations for future compared to historic values

	$M8hO_3$ (%)		$PM_{2.5}$ (%)		SO_4 (%)		NO_3 (%)		NH_4 (%)		OC (%)	
Summer	Summers	Summers _np	Summers	Summers _np	Summers	Summers _np	Summers	Summers _np	Summers	Summers _np	Summers	Summers _np
West	-11.6	0.9	-15.7	-2.0	-32.2	-3.7	-72.8	-42.8	-33.0	-6.9	-6.7	0.7
Plains	-15.8	-0.1	-34.3	-12.1	-48.7	-16.4	-46.4	-15.2	-41.8	-14.1	-16.2	-7.7
Midwest	-24.4	-2.5	-37.1	-18.4	-52.6	-22.4	-68.5	-24.1	-45.7	-21.9	-19.1	-11.7
Northeast	-20.2	2.8	-41.2	-1.7	-56.7	-2.2	-79.3	-28.8	-44.5	-0.8	-25.2	-0.4
Southeast	**-27.9**	0.3	**-45.2**	-14.3	**-60.5**	-16.5	**-77.1**	-37.1	**-47.9**	-13.3	**-27.5**	-14.8
US	-18.9	0.0	-35.9	-9.9	-52.6	-13.9	-65.6	-22.6	-43.9	-12.2	-17.2	-5.5
Annual	2050	2050np	2050	2050np	2050	2050np	2050	2050np	2050	2050np	2050	2050np
West	-6.5	0.2	-9.2	2.9	-20.2	4.8	-41.4	-17.6	-24.9	-3.4	4.0	8.9
Plains	-7.9	1.4	-22.0	-0.8	-29.2	5.5	-45.3	-17.9	-31.7	-3.2	-3.4	4.7
Midwest	-10.5	-0.2	-22.7	4.2	-22.2	12.6	-48.5	-7.7	-28.7	4.2	-9.3	6.6
Northeast	-10.0	-0.5	-28.5	6.5	-37.4	10.3	-45.6	-4.3	-32.6	5.9	-13.0	10.7
Southeast	**-14.8**	2.3	**-31.4**	-2.4	**-41.5**	0.5	**-54.9**	-12.4	**-37.0**	-1.7	**-14.9**	-3.6
US	-9.2	0.9	-23.4	1.1	-30.8	6.2	-47.8	-12.4	-31.6	-0.2	-6.4	4.4

np: Emission Inventory 2001, Climate 2050

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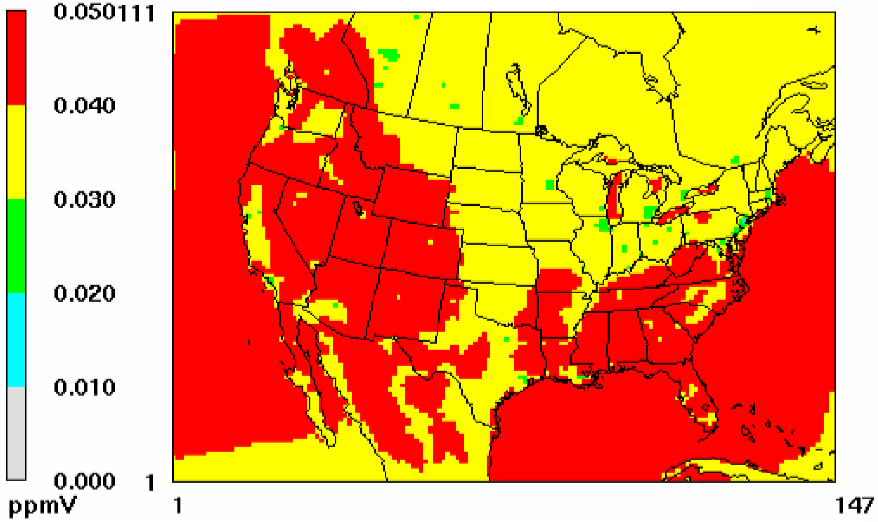
Regional and local (cities) predicted maximum eight-hour O_3 ($M8hO_3$) concentration characteristics

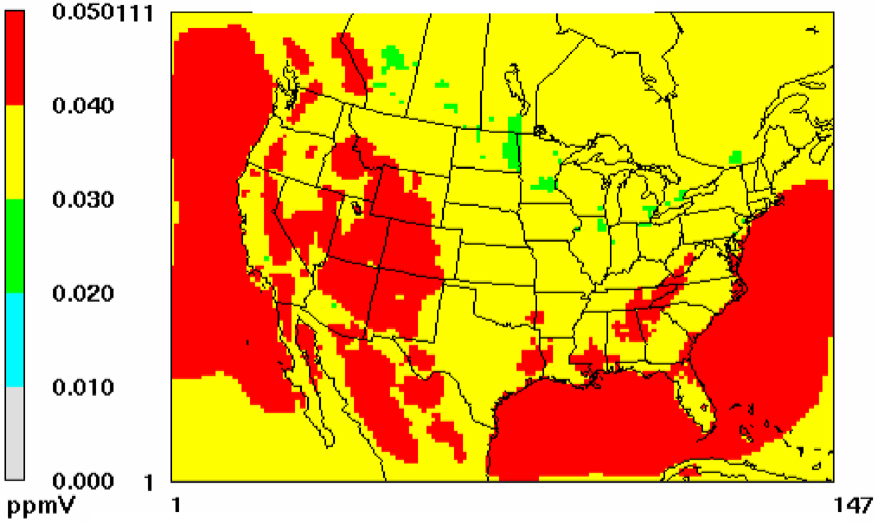
	$M8hO_3$ (ppb)								
	summers 2000-2002			summers 2049-2051			summers 2049-2051_np		
Region / City	Region	City		Region	City		Region	City	
	99.5%	# of days over 80 ppb	Peak value	99.5%	# of days over 80 ppb	Peak value	99.5%	# of days over 80 ppb	Peak value
West / Los Angeles	65	149	119	55	31	97	67	221	146
Plains / Houston	72	127	127	59	29	94	73	165	143
Midwest / Chicago	89	78	138	73	19	106	101	59	152
NorthEast / New York	84	51	112	65	1	81	91	82	121
SouthEast / Atlanta	94	199	124	64	0	78	94	195	131

np: Emission Inventory 2001, Climate 2050

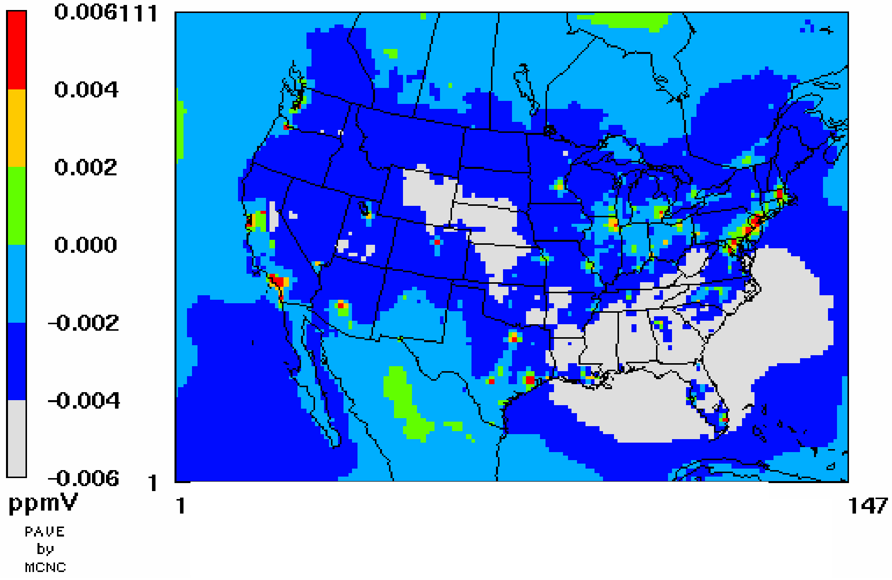
O_3_2001



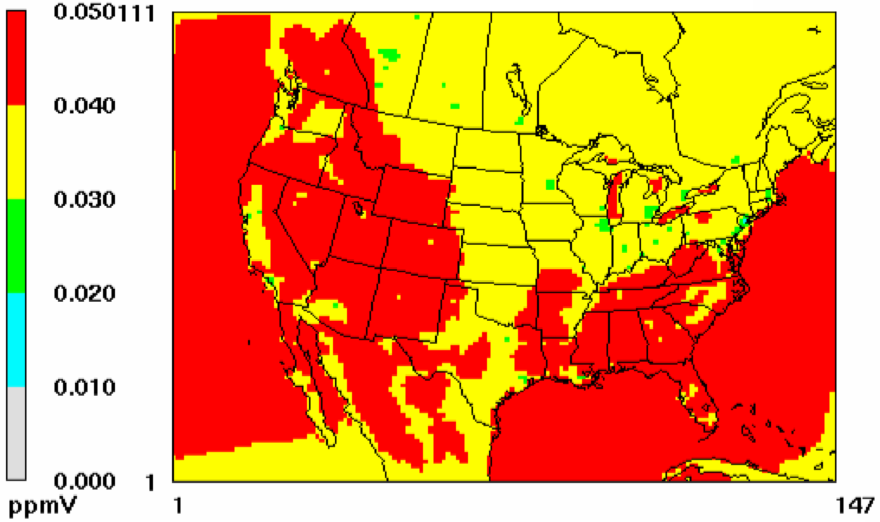
O_3_2050



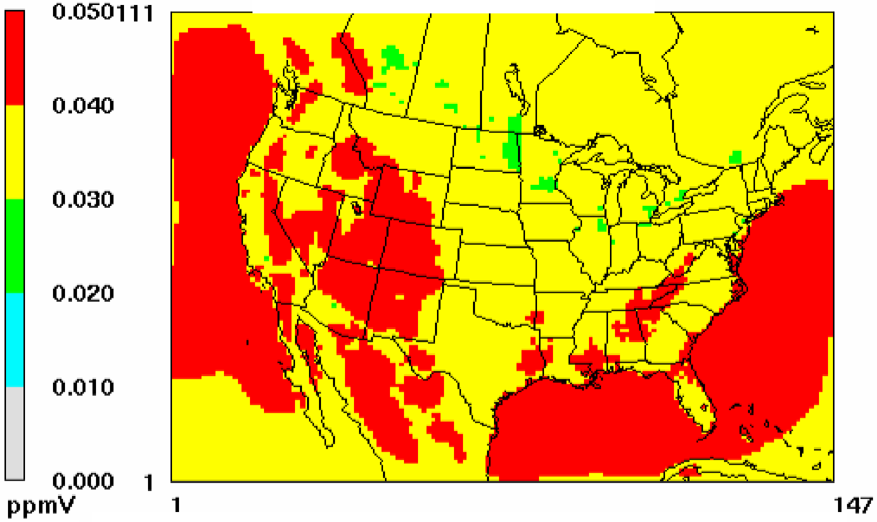
O_3_2050 - O_3_2001



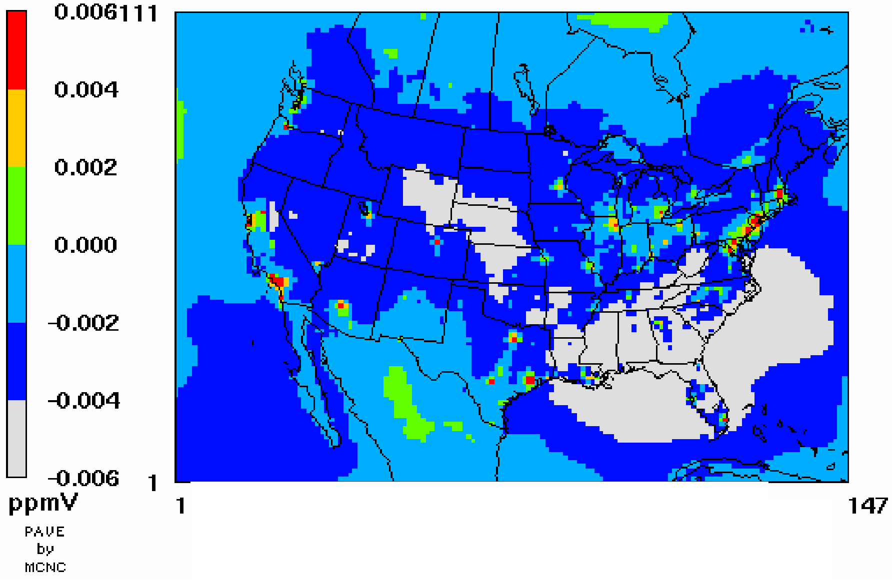
O_3_2001



O_3_2050

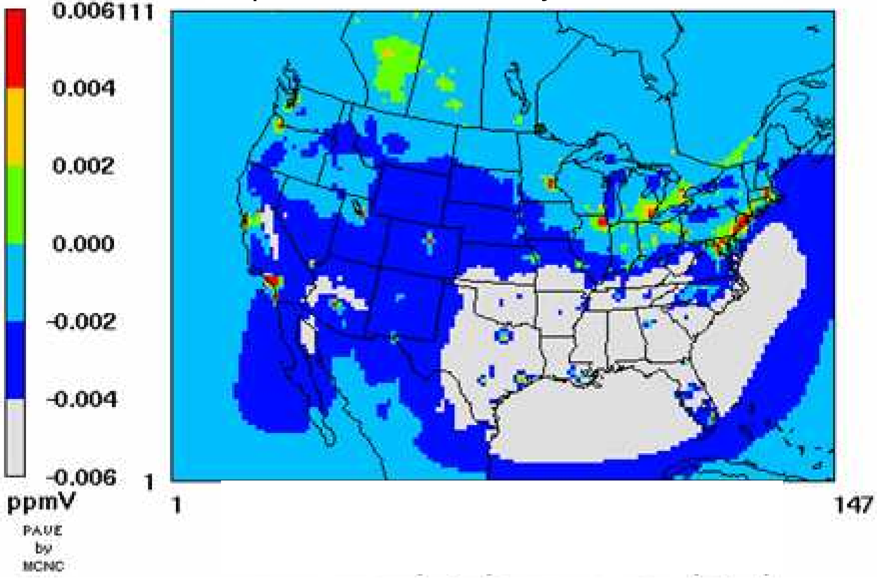


O_3_2050 - O_3_2001

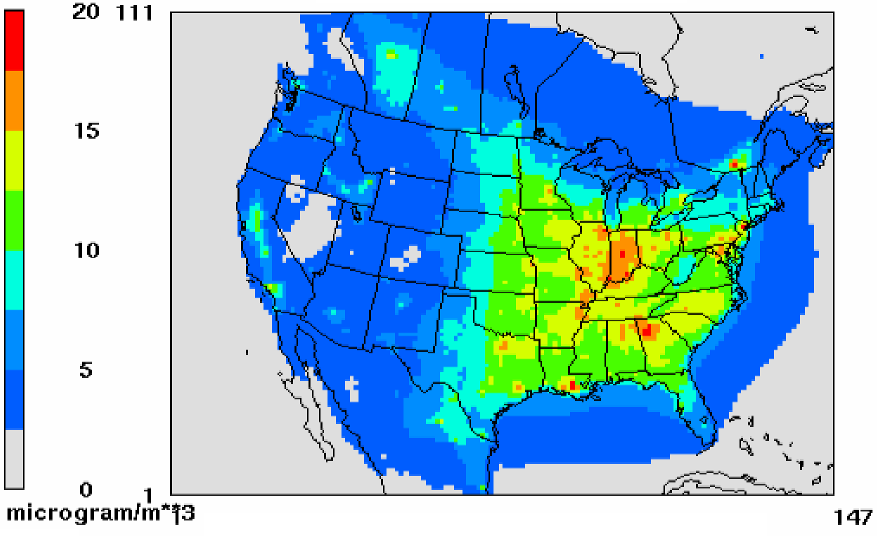


O_3_2050 - O_3_2050np

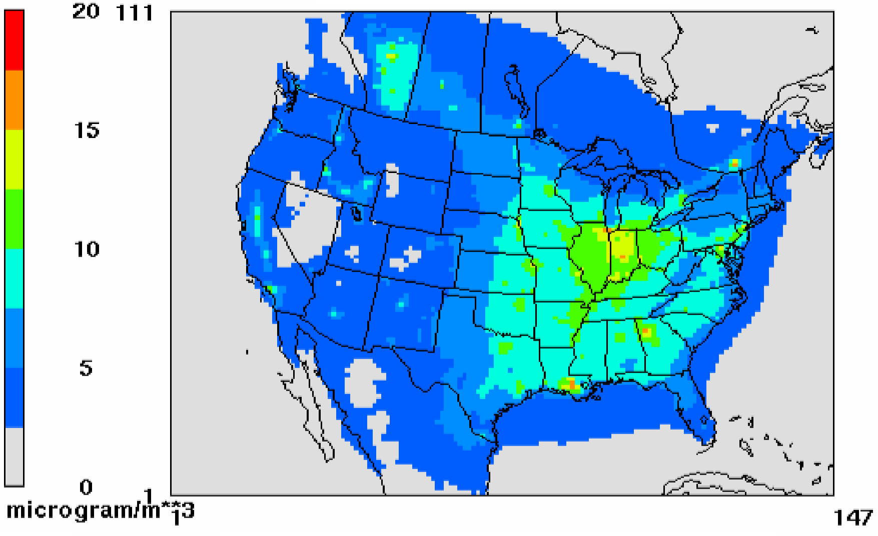
np: Emission Inventory 2001, Climate 2050



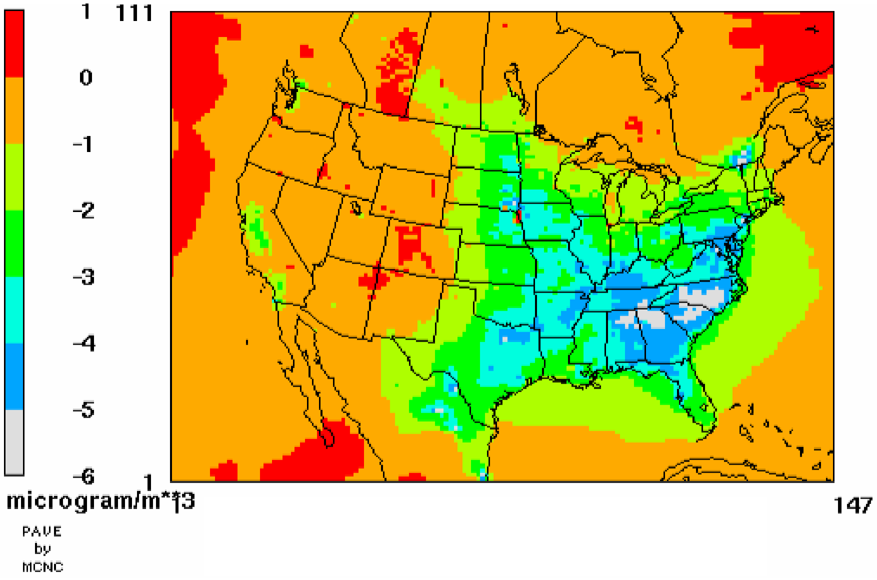
PM$_{2.5}$_2001



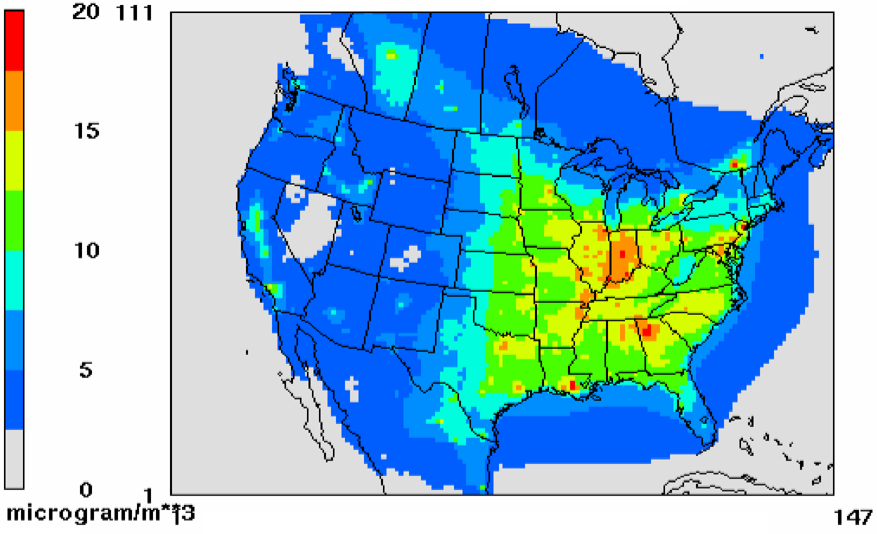
PM$_{2.5}$_2050



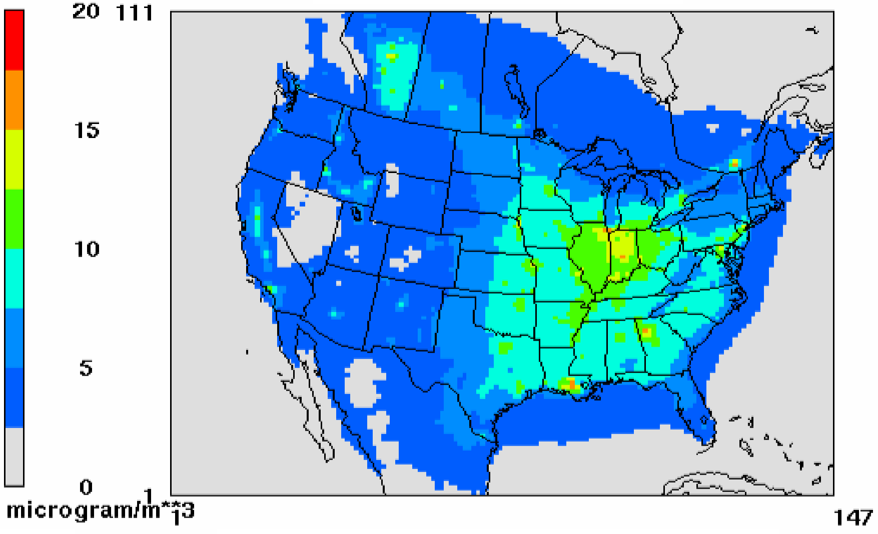
PM$_{2.5}$_2050 - PM$_{2.5}$_2001



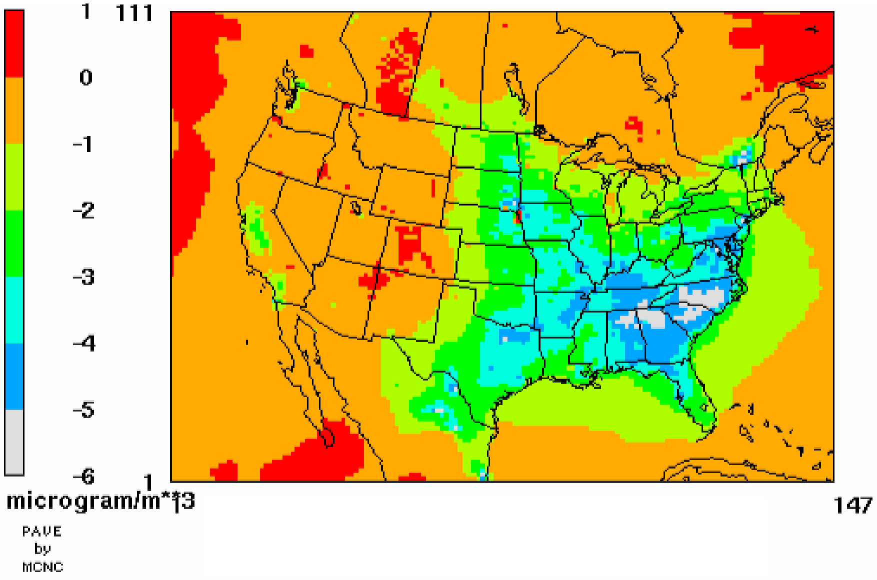
PM$_{2.5}$_2001



PM$_{2.5}$_2050

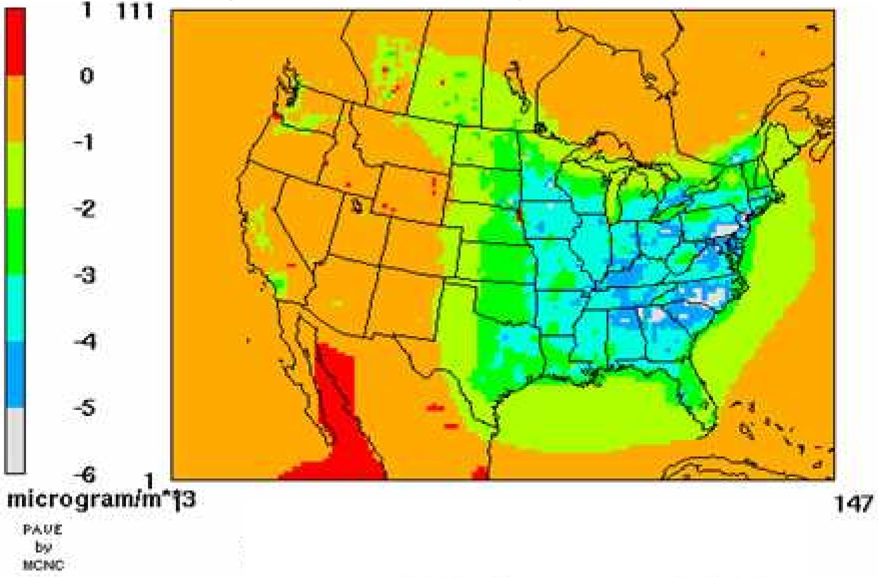


PM$_{2.5}$_2050 - PM$_{2.5}$_2001

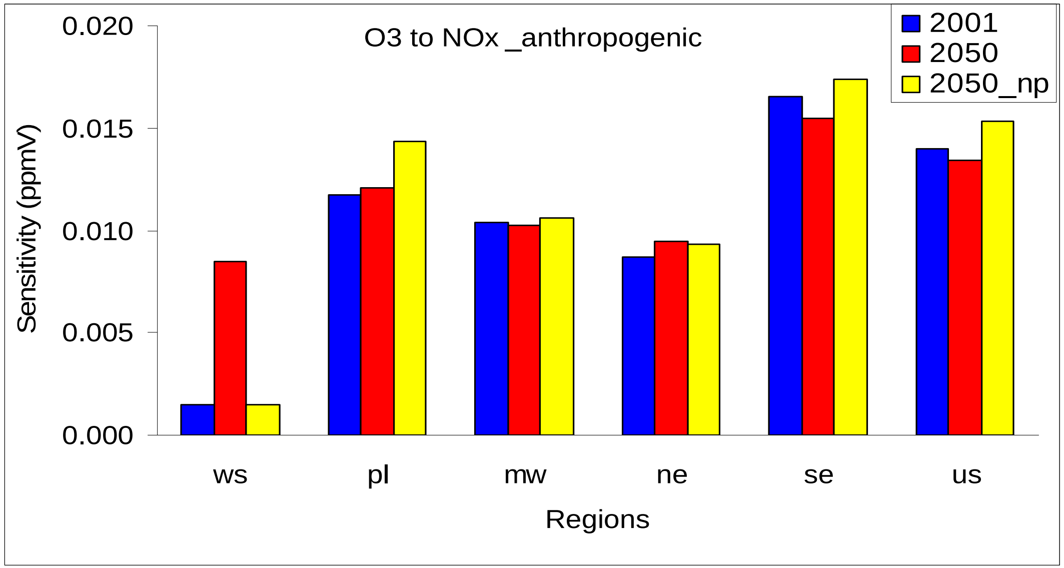


PM$_{2.5}$_2050 - PM$_{2.5}$_2050np

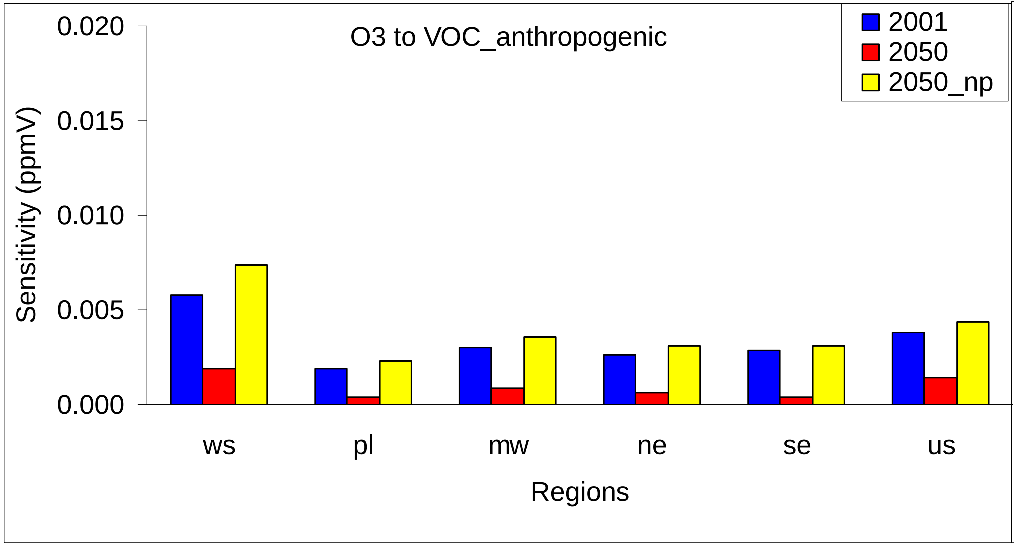
np: Emission Inventory 2001, Climate 2050

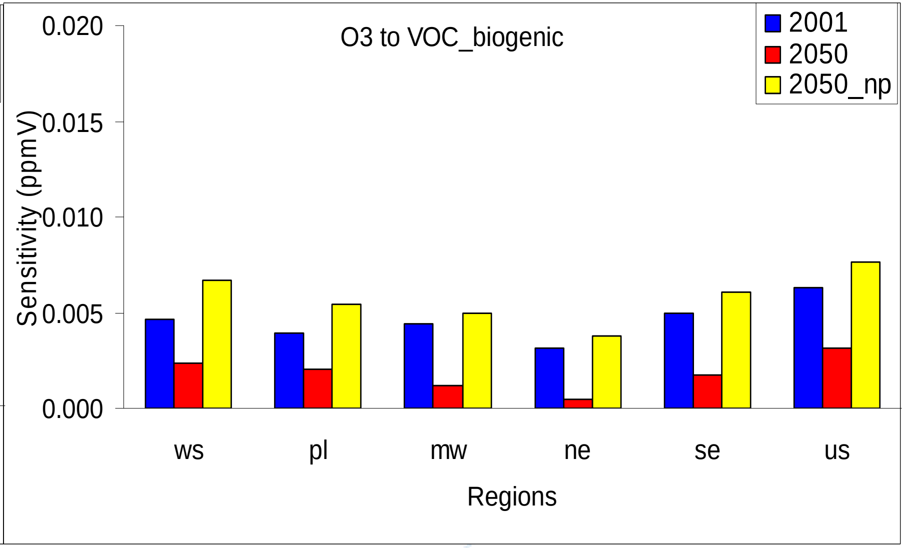


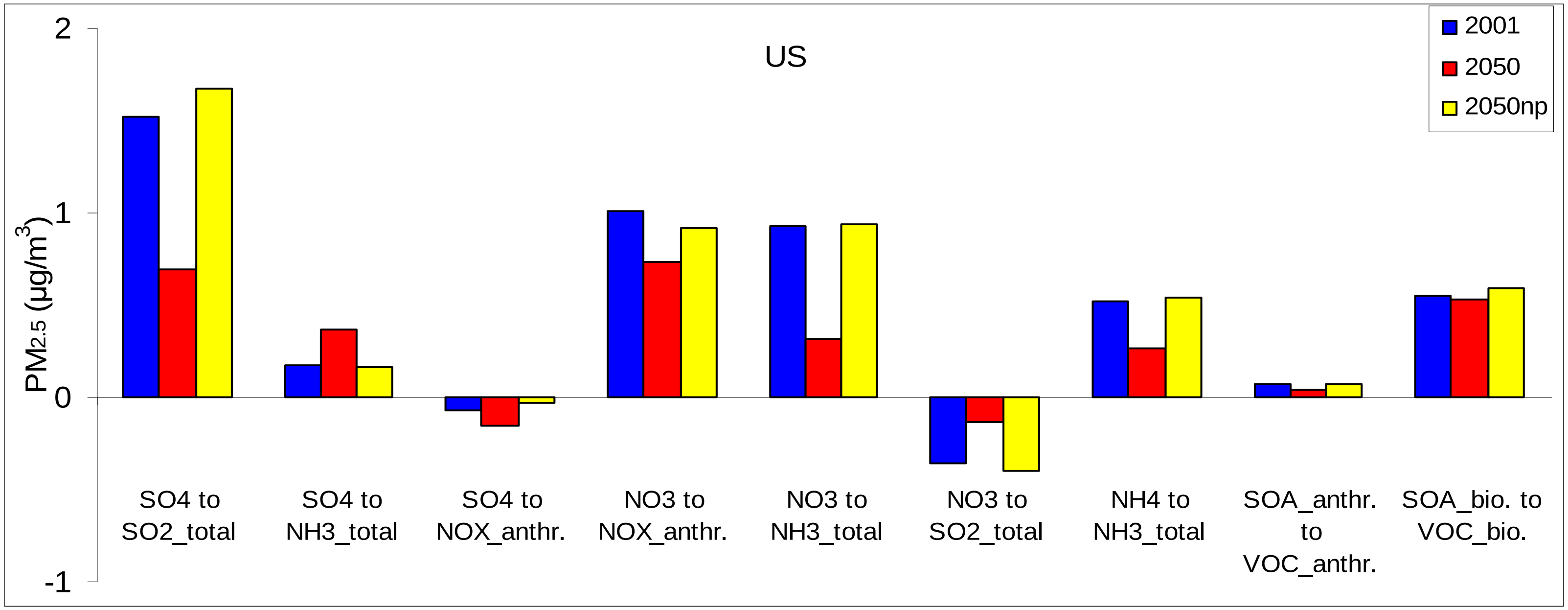
Sensitivity of Ozone to Climate and Emission Controls



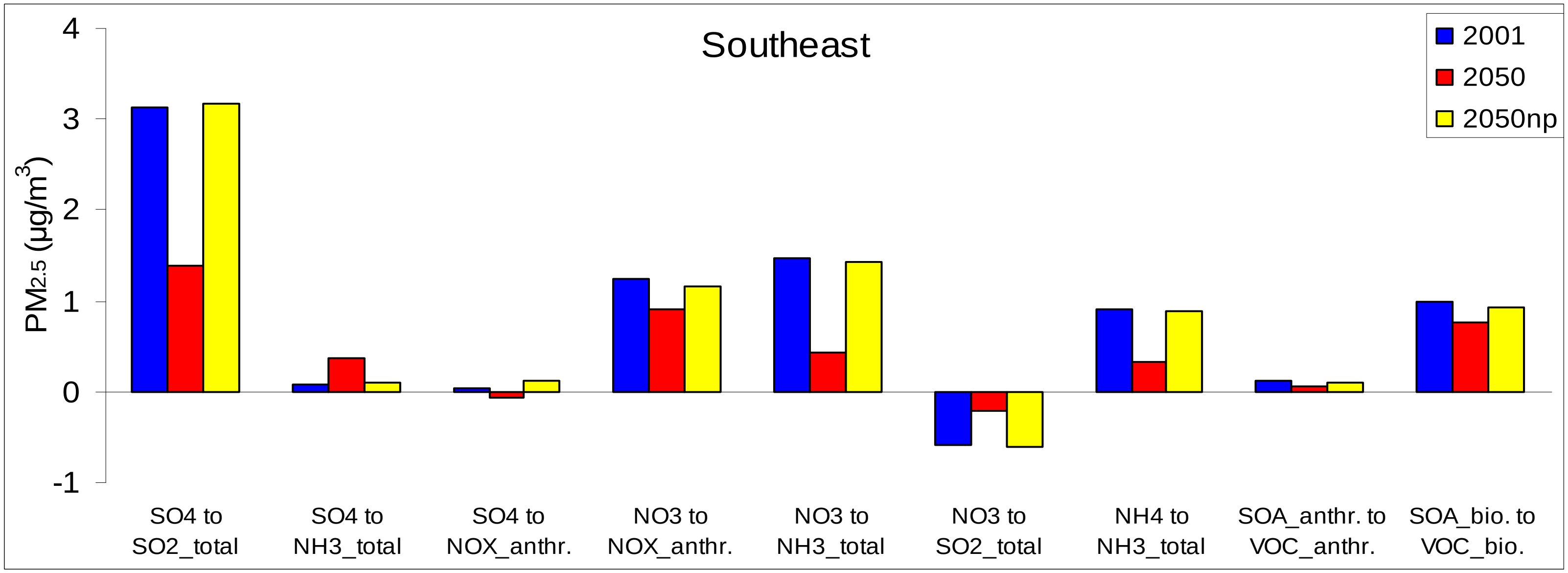
O_3





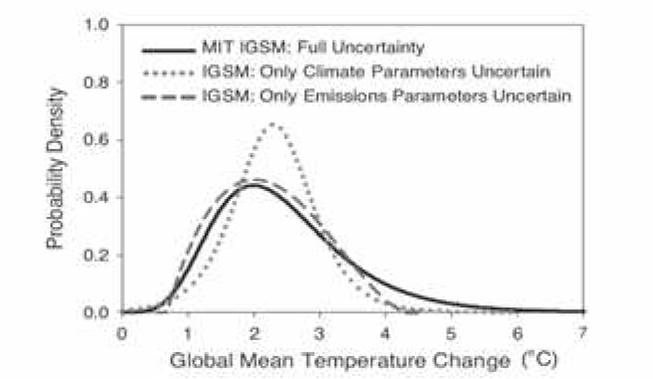

US
2001
2050
2050np
PM2.5 (µg/m3)
2
1
0
-1
SO4 to SO2_total
SO4 to NH3_total
SO4 to NOX_anthr.
NO3 to NOX_anthr.
NO3 to NH3_total
NO3 to SO2_total
NH4 to NH3_total
SOA_anthr. to VOC_anthr.
SOA_bio. to VOC_bio.

PM2.5

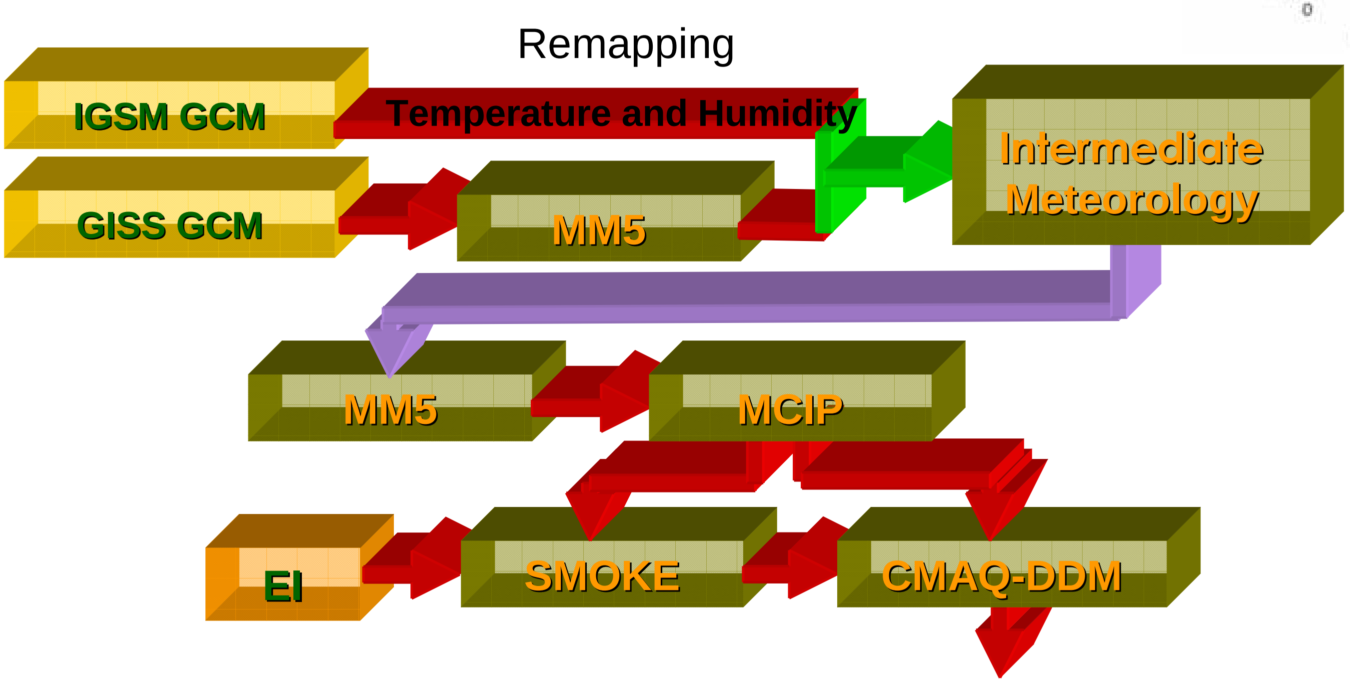

Southeast
2001
2050
2050np
PM2.5 (µg/m3)
4
3
2
1
0
-1
SO4 to SO2_total
SO4 to NH3_total
SO4 to NOX_anthr.
NO3 to NOX_anthr.
NO3 to NH3_total
NO3 to SO2_total
NH4 to NH3_total
SOA_anthr. to VOC_anthr.
SOA_bio. to VOC_bio.

Uncertainty Analysis of Results

Modeling approach

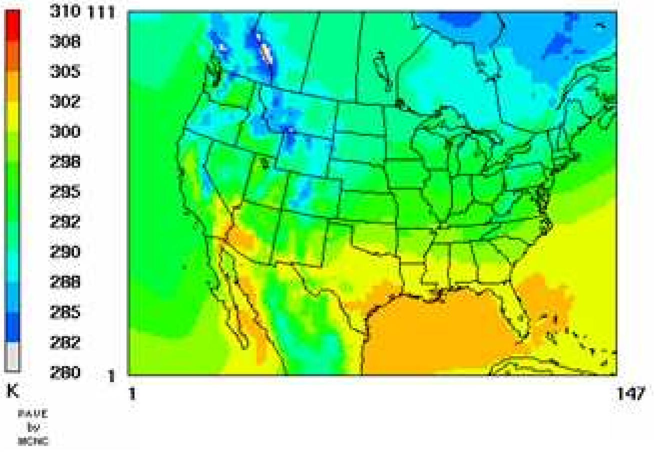


Meteorological data derived based on climatic change runs using MIT's Integrated Global System Model (IGSM) for future years

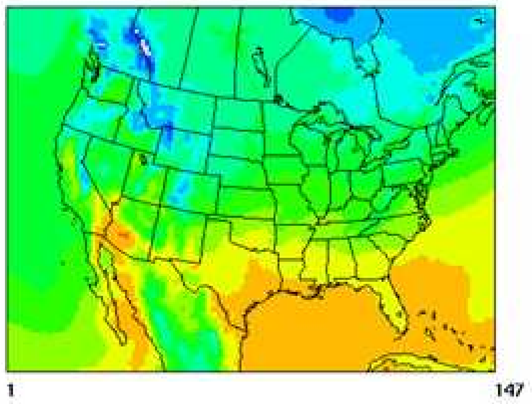


Summer 2050 average temperature

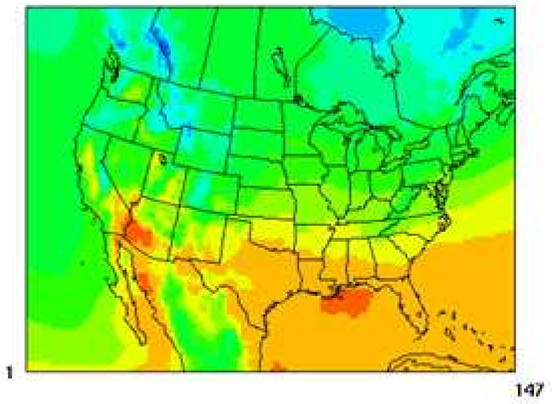
lower



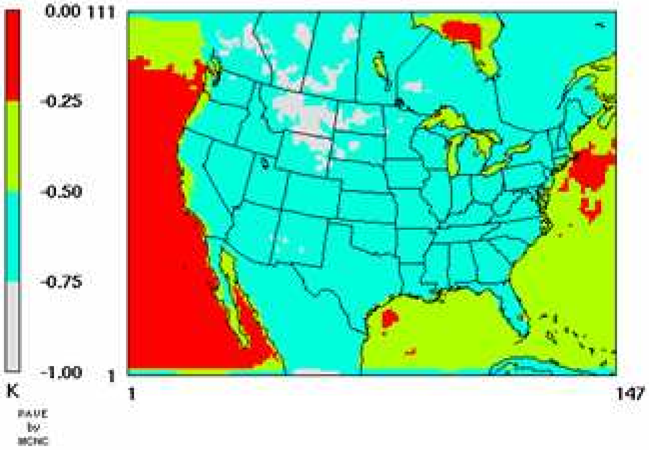
middle



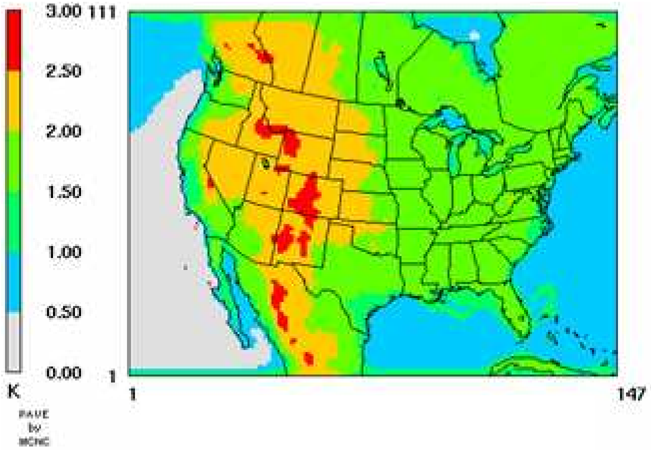
upper



lower - middle

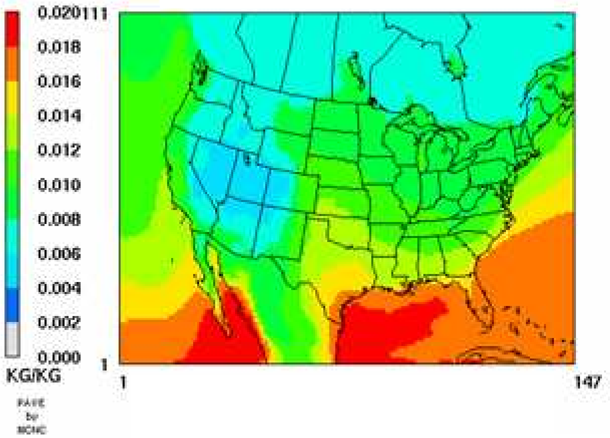


upper - middle

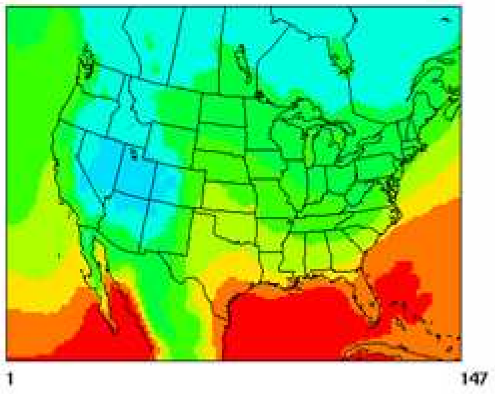


Summer 2050 average humidity

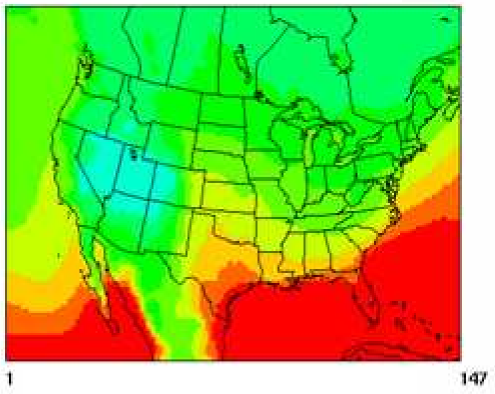
lower



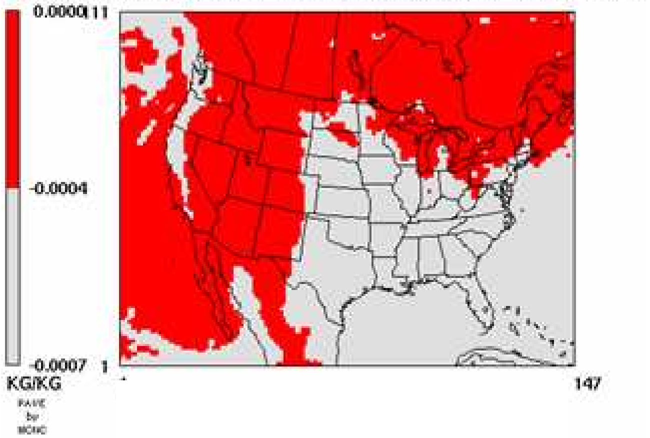
middle



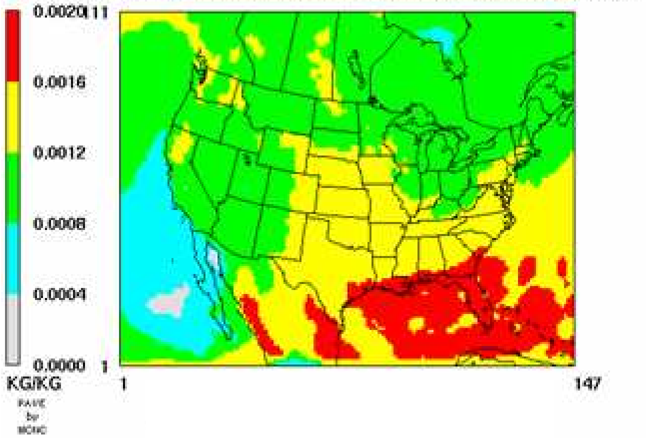
upper



lower - middle

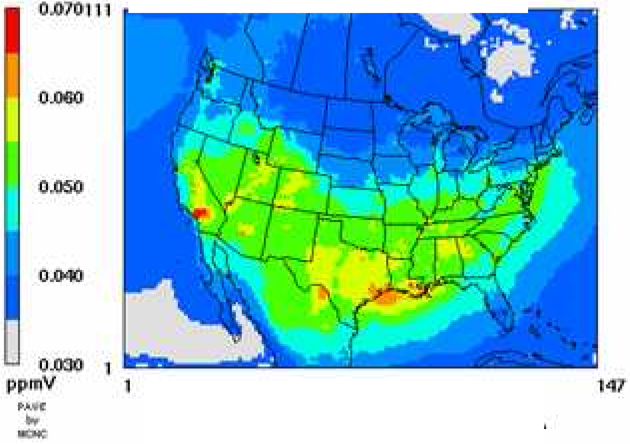


upper- middle

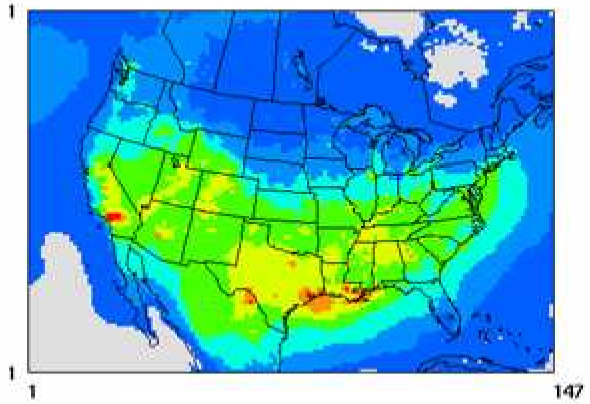


Summer 2050 average max8hrO_3

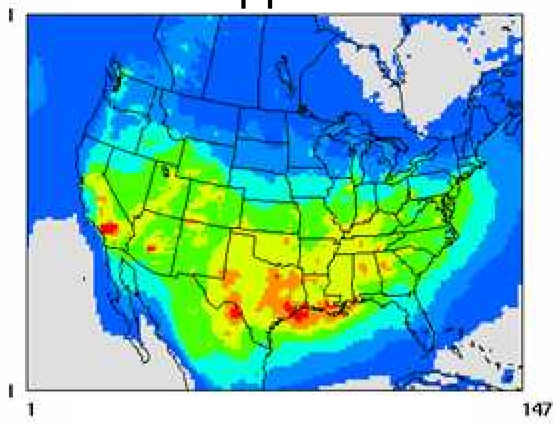
lower



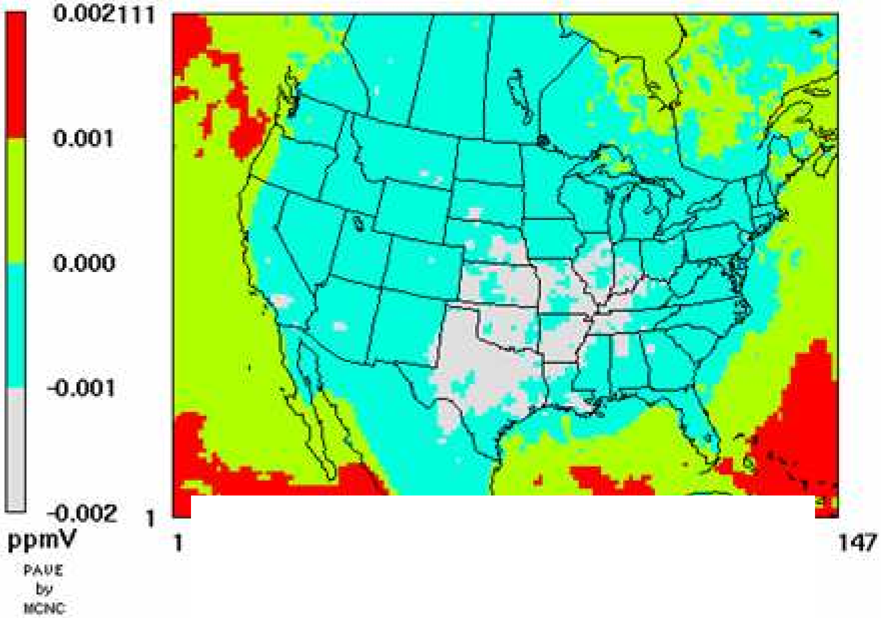
middle



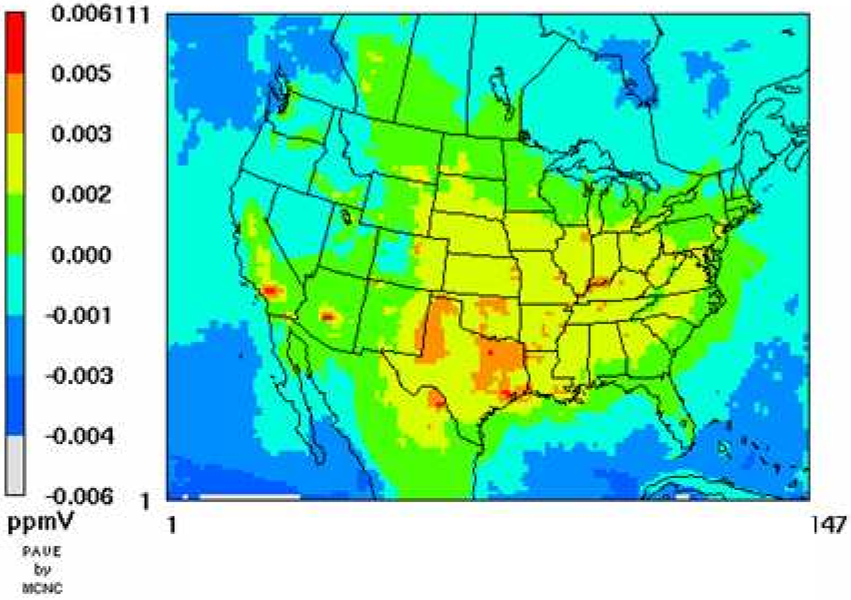
upper



lower – middle

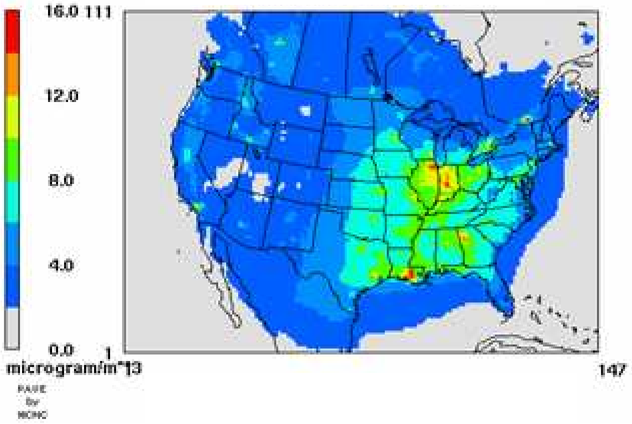


upper – middle



Summer 2050 average $PM_{2.5}$

lower



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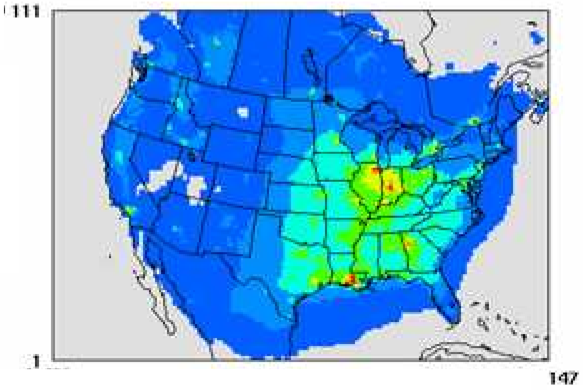
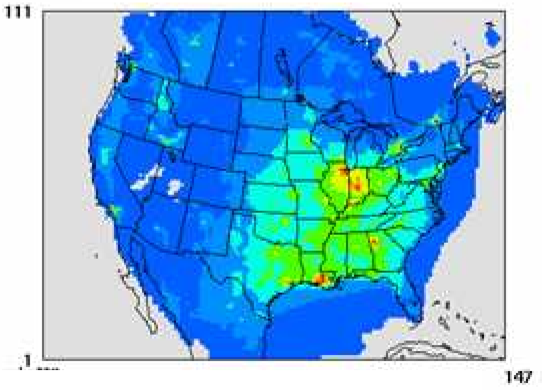
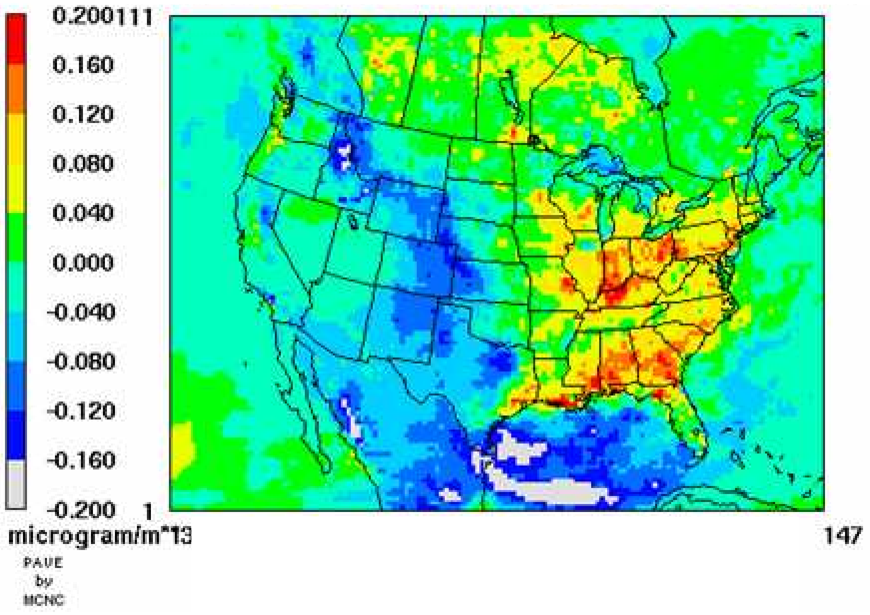


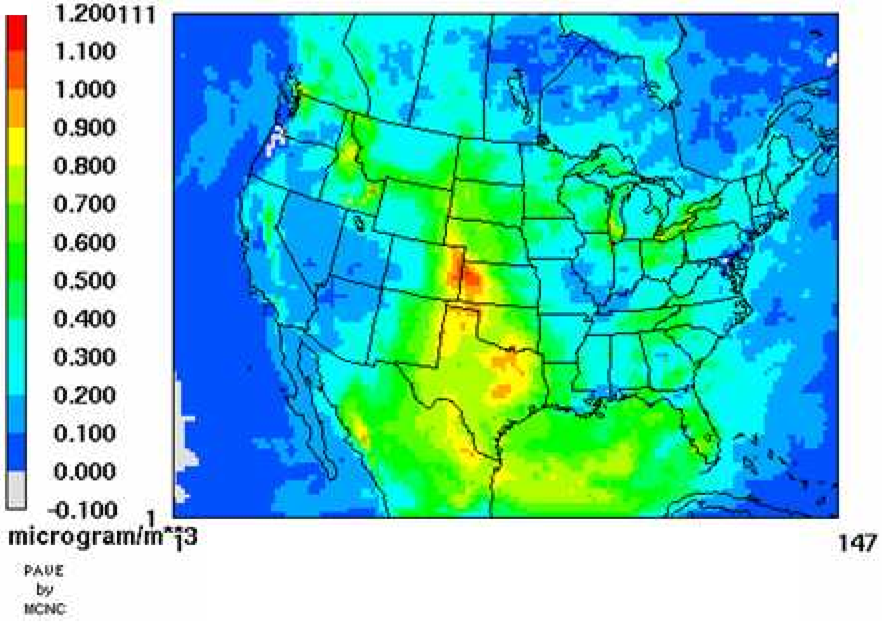
upper



lower – middle



upper – middle



What is the uncertainty in some mega-cities?

Region / City	M8hO$_3$ (ppb)								
	Summer 2050 low			Summer 2050 middle			Summer 2050 up		
	Region	City		Region	City		Region	City	
	99.5%	# of days over 80 ppb	Peak value	99.5%	# of days over 80 ppb	Peak value	99.5%	# of days over 80 ppb	Peak value
West / Los Angeles	82	2	82	82	6	84	82	7	91
Plains / Houston	82	**5**	**87**	82	**10**	**90**	84	**24**	**98**
Midwest / Chicago	84	3	87	84	4	89	86	6	97
Northeast / New York	84	0	68	84	0	70	85	0	74
Southeast / Atlanta	85	0	75	85	0	78	86	2	85

Conclusions

- Combining the effect of emission changes and climate change, future O_3 and $PM_{2.5}$ concentrations over U.S. are expected to be lower *but* the effects are more pronounced for regional $PM_{2.5}$ concentrations
- Organic carbon could become the most important $PM_{2.5}$ component
- Regionally, the Eastern U.S. shows more benefits than the rest of the regions
- The contribution of anthropogenic NOx emissions to O_3 formation is more important than VOCs. Reductions in anthropogenic NO*x* emissions will continue to be effective for reducing regional ozone concentrations
- Uncertainties of predicted O_3 and $PM_{2.5}$ concentrations due to climate change are larger in the “high-extreme” meteorology case
- Uncertainties of predicted O_3 and $PM_{2.5}$ concentrations due to climate change are regional in nature: Plains have higher uncertainties than elsewhere because temperature predictions are more uncertain there
- Emission controls have larger impact than climate change