Utilizing CMAQ Process Analysis in an Attempt to Understand the Impact of Climate Change on O_3 and $PM_{2.5}$

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New York Climate & Health Project

Previously shown at CMAS …

Climate Change and Ozone Air Quality: Applications of a Coupled GCM/MM5/CMAQ Modeling System

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Models-3 Users' Workshop, October 27, 2003, RTP

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Modeling the Air Quality Impacts of Climate and Land Use Change in the New York City Metropolitan Area

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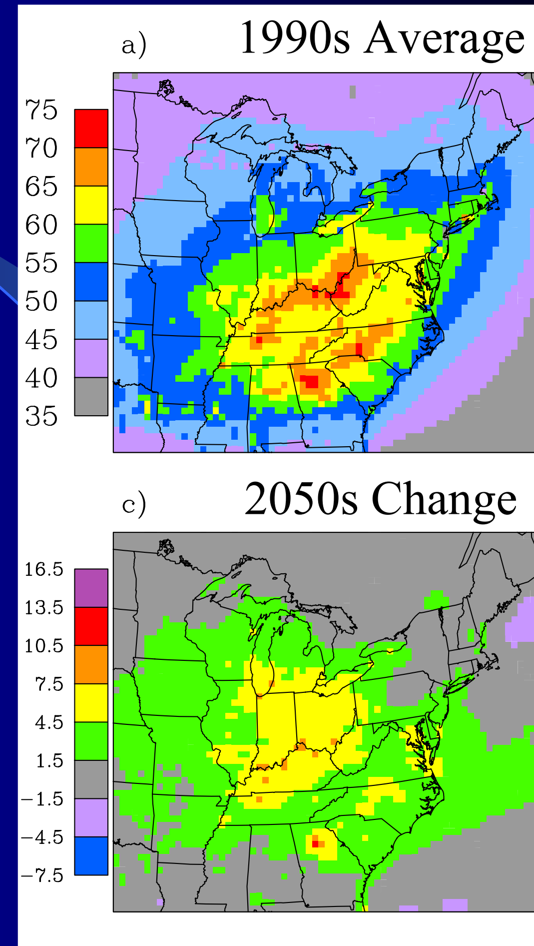
New York Climate & Health Project



- CMAQ simulates an increase in average (~3-5 ppb) and 4th-highest (~5-7 ppb) summertime daily maximum 8-hr ozone concentrations for future decades as a result of climate change alone

And now the Continuation:

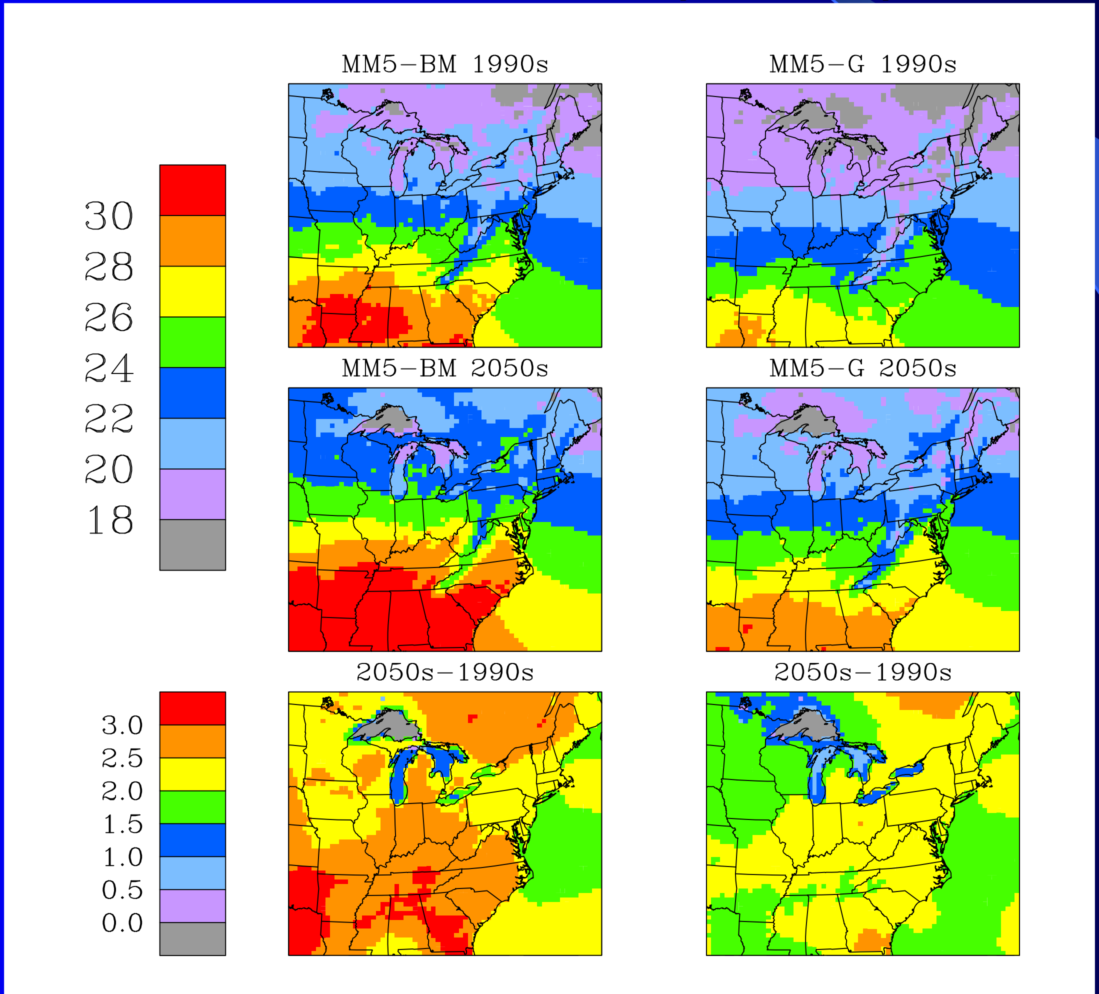
- Include simulation of aerosols
- Utilize regional climate simulations from two configurations of MM5
- Include process analysis

GCM/MM5/CMAQ Model Setup

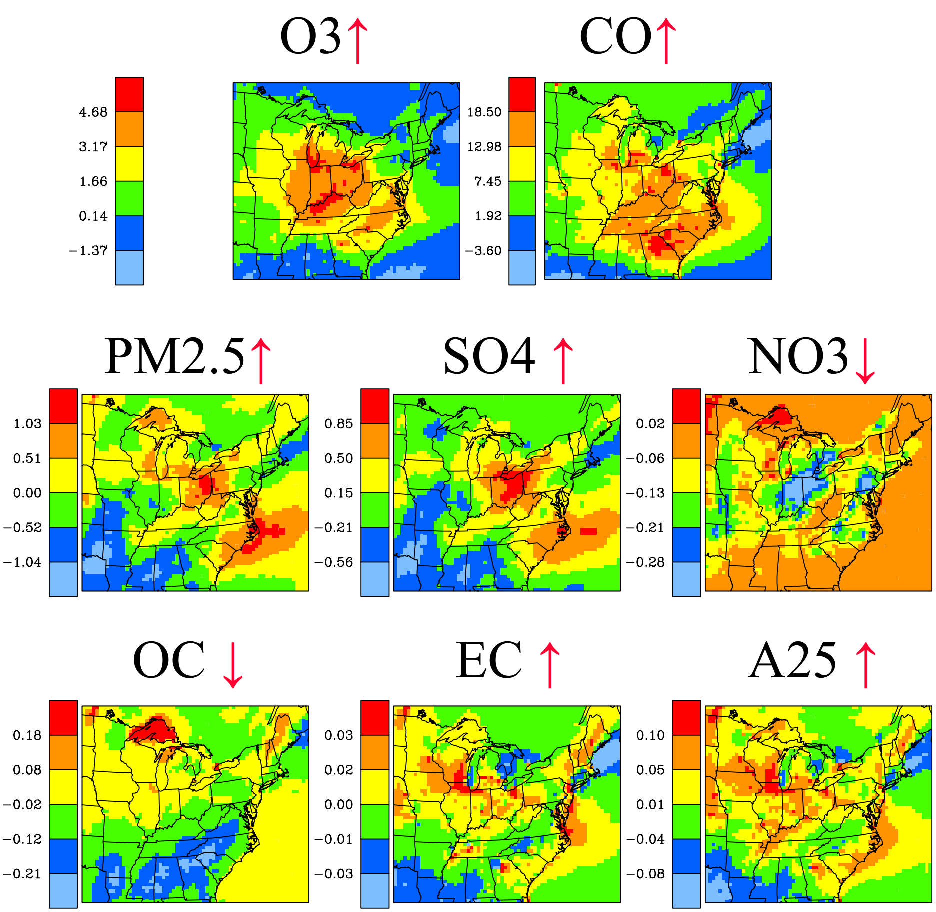
- GISS coupled global ocean/atmosphere model driven by IPCC "A2" greenhouse gas scenario
- MM5 was run on 2 nested domains of 108km and 36km over the U.S. with two cumulus parameterizations:
  - Betts-Miller (MM5-BM)
  - Grell (MM5-G)
- Simulations periods : June – August 1993-1997
  June – August 2053-2057
- 1996 U.S. Emissions processed by SMOKE
- BEIS2 for biogenic emissions and Mobile5b for mobile source emissions
- CMAQ 4.4 was run at 36km to simulate ozone
- CB-IV mechanism, aerosols, process analysis
- Note: No coupling to global chemistry model, no feedback from aerosols to climate simulations

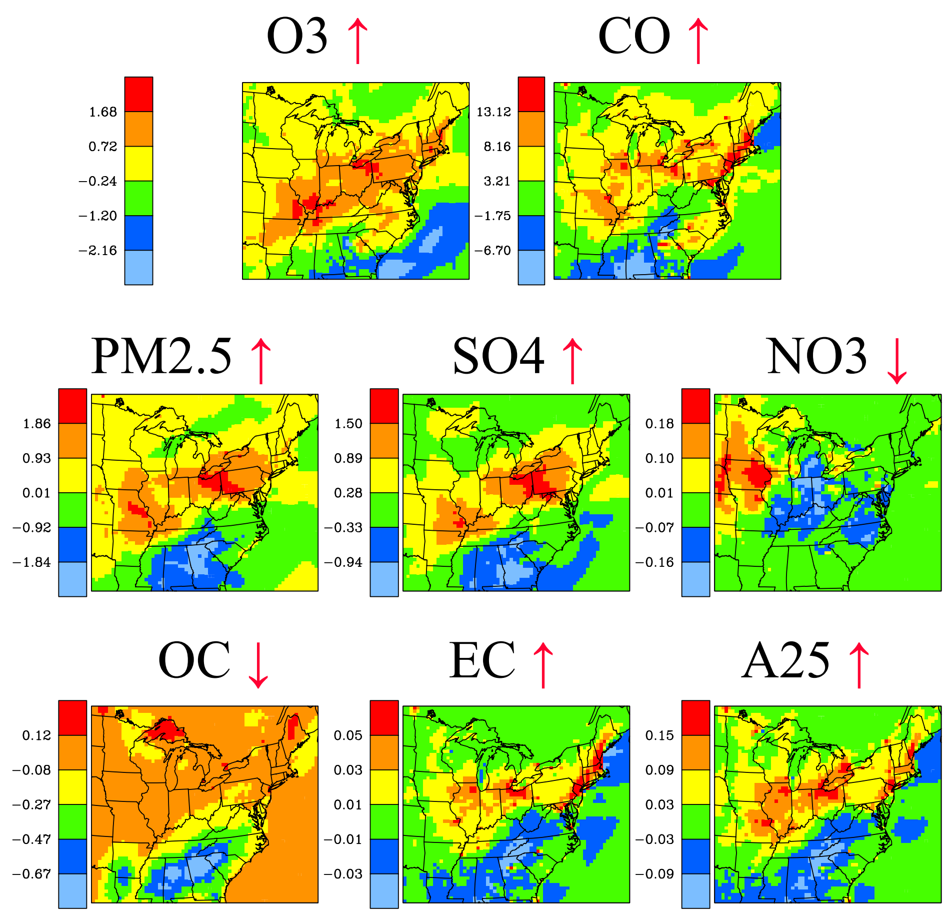
Effect of MM5 Cumulus Parameterization on Regional Climate Fields

Summertime Average Temperatures Simulated by MM5-BM (left) and MM5-G (right) for the 1990s (top), 2050s (center), and 2050s-1990s (bottom)

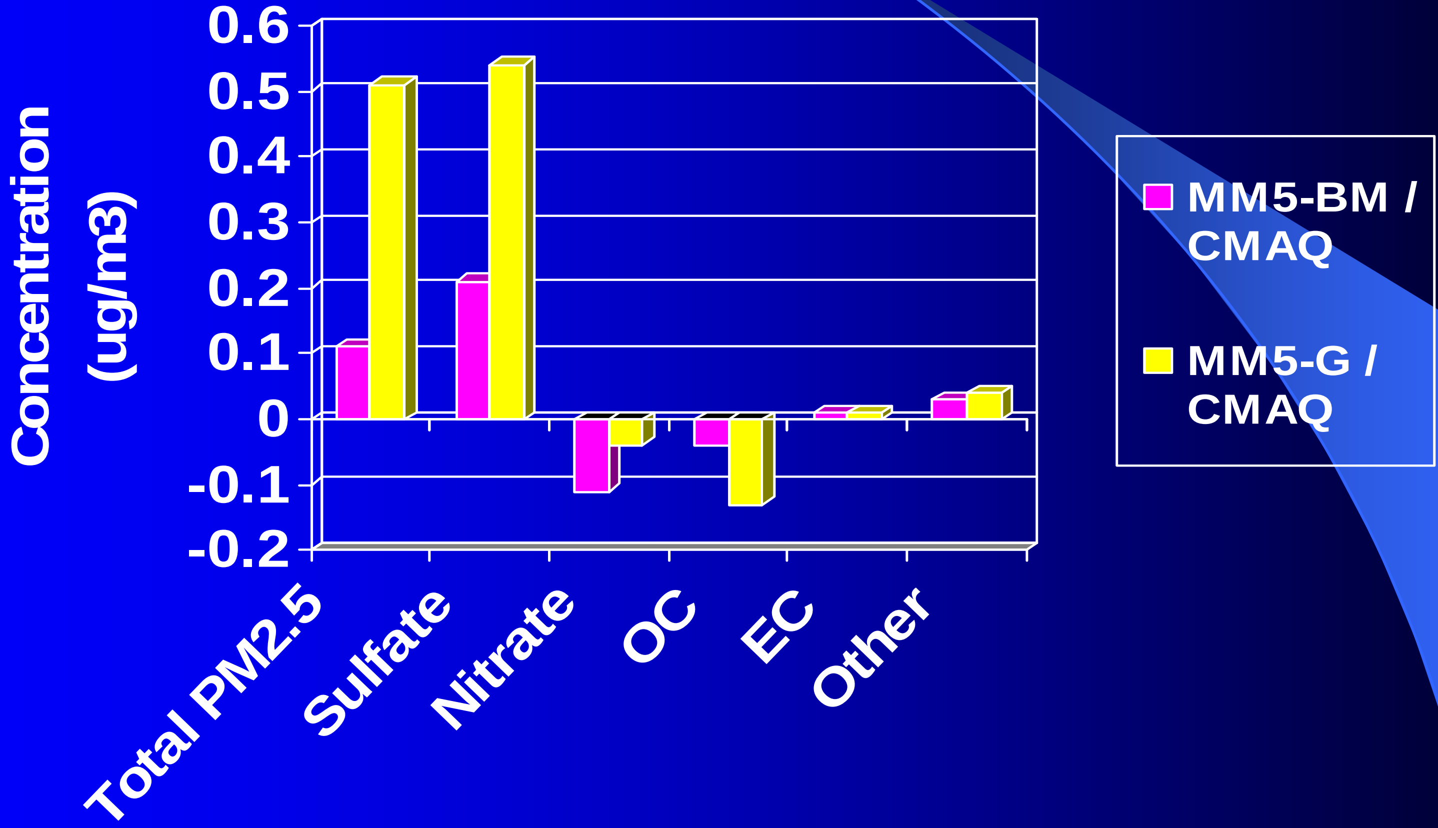


Changes in Summertime Average Species Concentrations, 2050s – 1990s, MM5-BM/CMAQ (left), MM5-G/CMAQ (right)





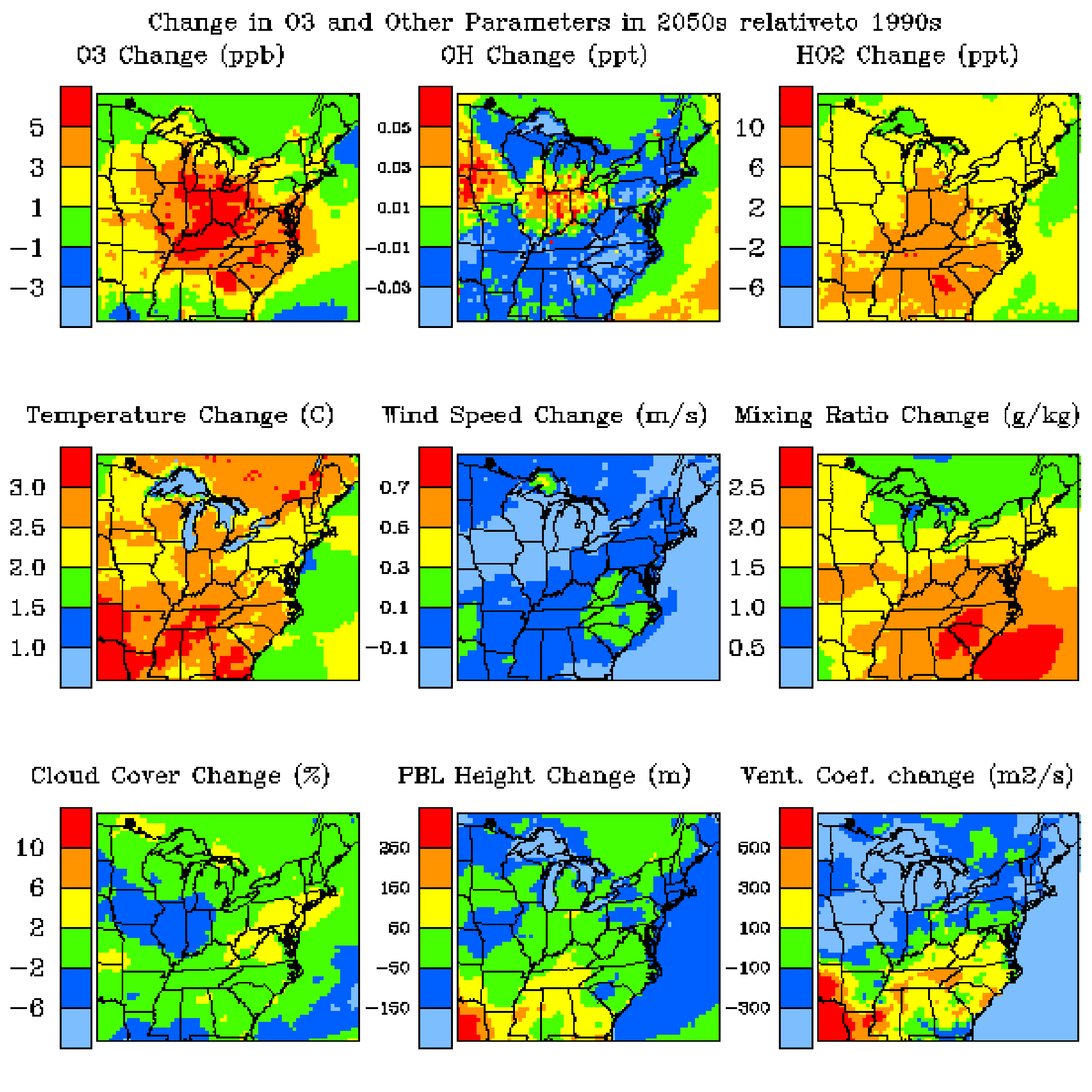
Changes in Summertime Average $PM_{2.5}$ Species Between the 2050s and 1990s for both the MM5-BM / CMAQ and MM5-G / CMAQ Simulations



- Increase in total $PM_{2.5}$, SO_4, EC, and other primary particles, decreases in NO_3 and OC
- Direction of change consistent for both MM5 regional climate scenarios

- Could one parameterize these changes in concentration fields based on the changes in regional climate parameters?

Changes in Summertime Average Ozone, HO_x and Meteorology (2050s – 1990s, MM5-BM / CMAQ)

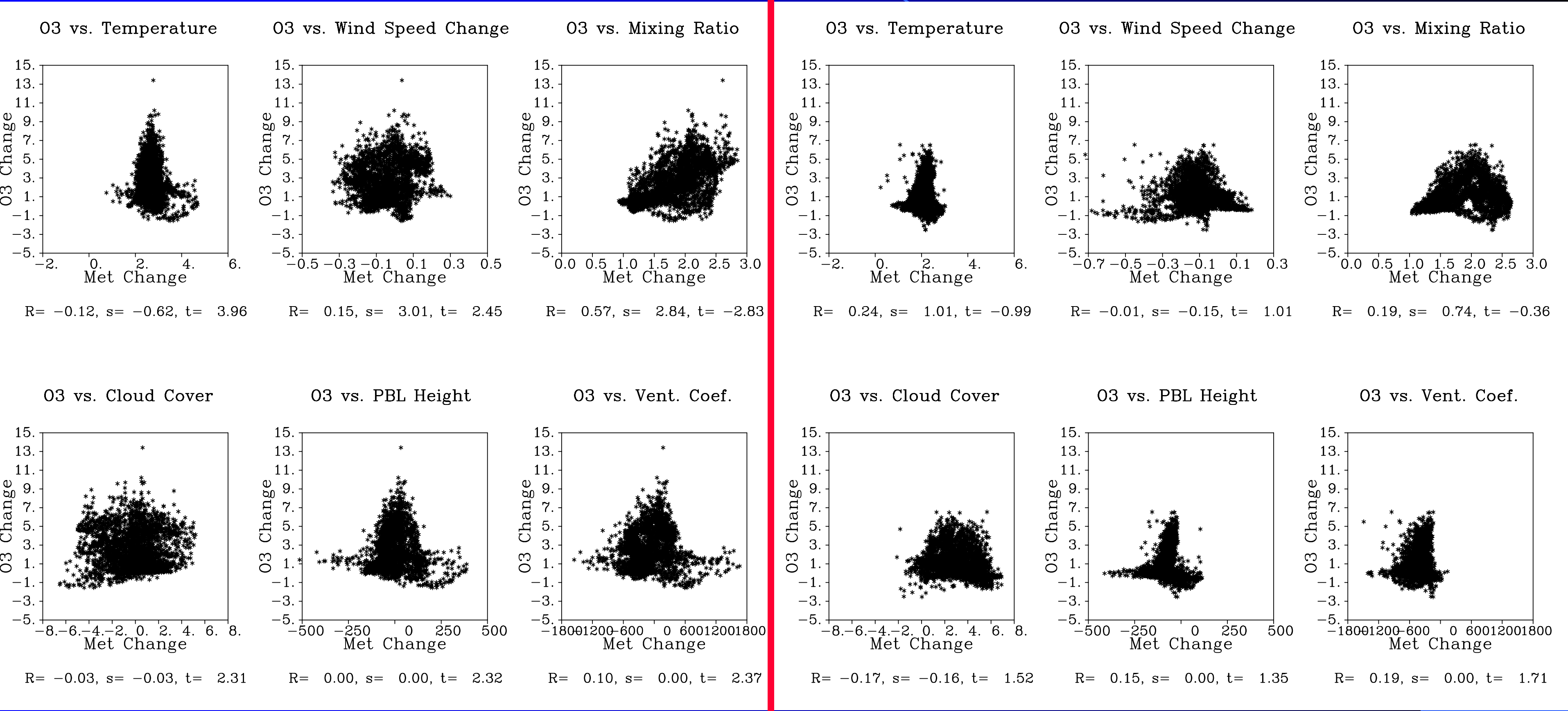


- No strong relationship between patterns of changes in meteorological parameters, summertime average O_3 concentrations, and summertime average HO_x concentrations is evident

How Are Changes In O_3 Related To Changes in Climate Parameters?

MM5-BM / CMAQ

MM5-G / CMAQ



- Little relationship between changes in individual meteorological parameters at a given location and average O_3 changes at the same location for either MM5-BM / CMAQ or MM5-G / CMAQ (2050 A2 scenario)

Correlations Between the Spatial Patterns of Changes in Summertime Average O_3 and Meteorology (MM5-BM)

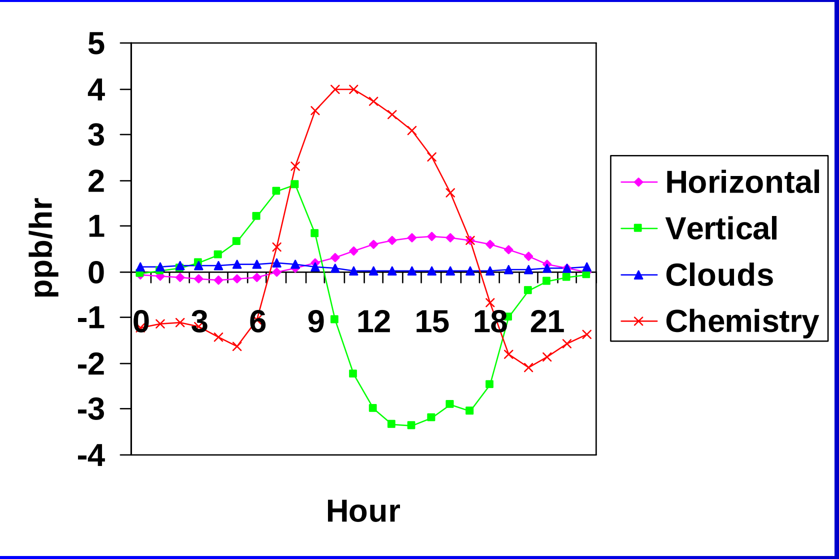
	ΔCloudFr	ΔPBL	ΔWaVap	ΔT	ΔWindsp
ΔCloudFr		-0.06	0.01	0.06	0.33
ΔPBL			0.42	0.83	0.47
ΔWaVap				0.25	0.44
ΔT					0.38
ΔCO	0.12	0.09	0.60	0.08	0.13
ΔO_3	-0.10	0.04	0.48	0.01	0.07
ΔEC	-0.12	-0.32	0.00	-0.35	-0.35
ΔNO_3	0.10	0.01	-0.19	0.00	0.03
ΔOC	-0.08	-0.63	-0.52	-0.53	-0.49
ΔSO_4	0.20	-0.21	0.10	-0.28	-0.02

Process Analysis

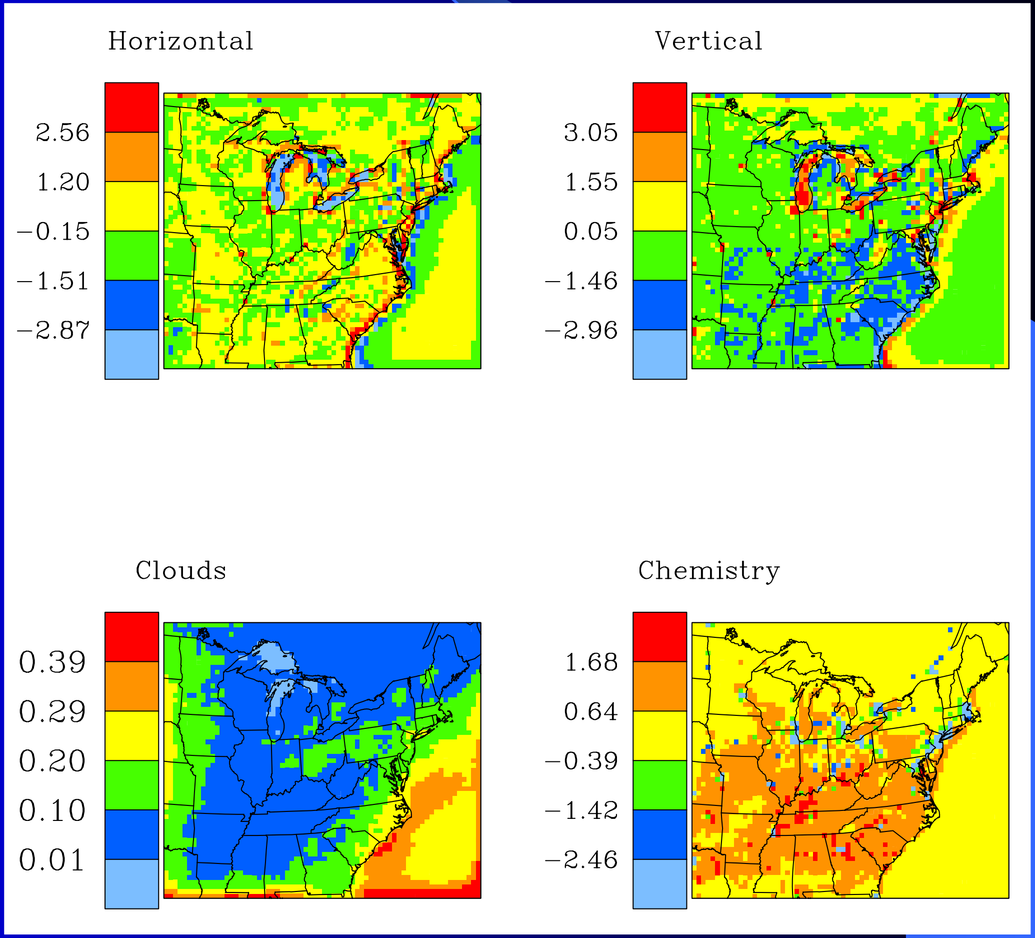
- Goal: Keep track of the contributions of different science processes to the changes in species concentrations
- In this analysis, Integrated Process Rates (IPR) were used and four processes were defined:
  - Vertical: Advection + diffusion + mass adjustment + dry deposition (+ emissions)
  - Horizontal: advection + diffusion
  - Clouds (includes aqueous chemistry, scavenging, cloud vertical mixing)
  - Chemistry/Aerosol Module:
- Analysis is presented for the first model layer and for the MM5-BM / CMAQ simulations only

Temporal and Spatial Patterns of O_3 IPR Factors for the 1990s

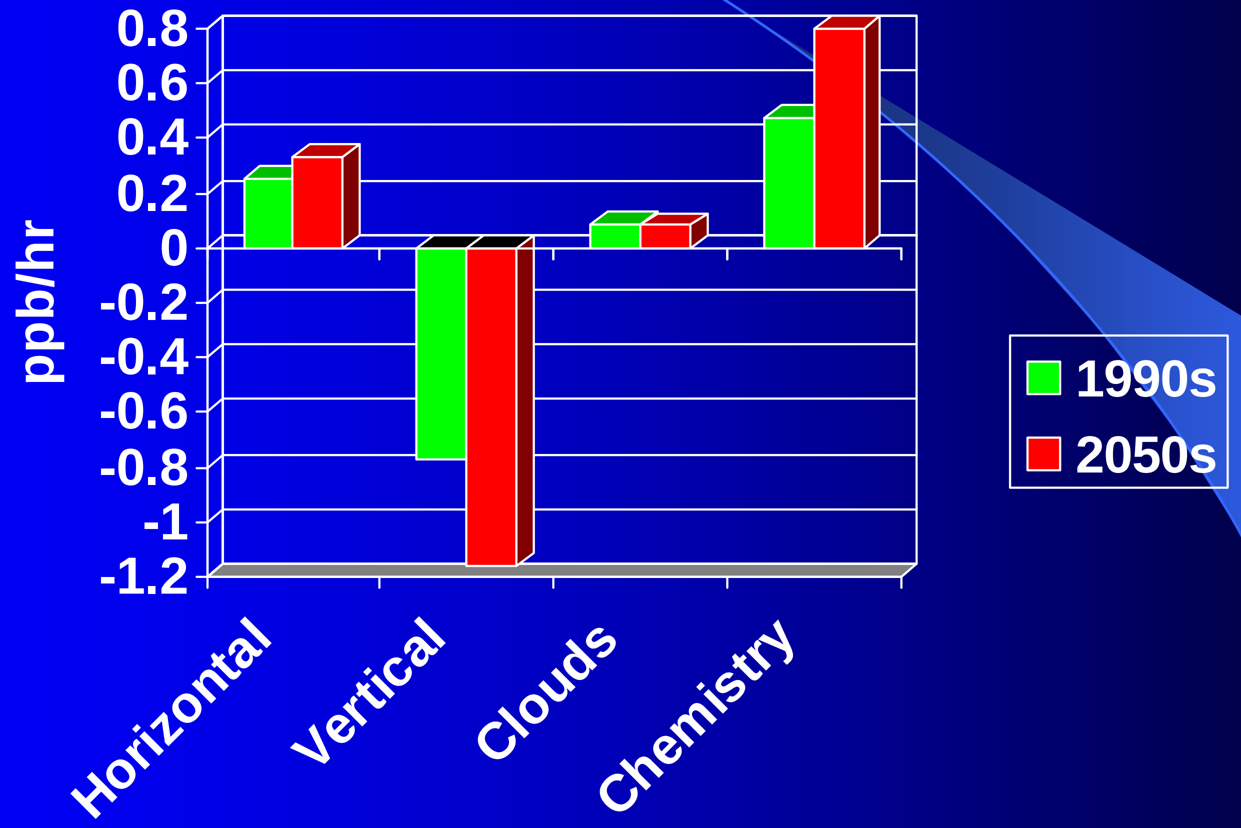
Average Diurnal Cycles of IPR Terms



Summertime Average of IPR Terms

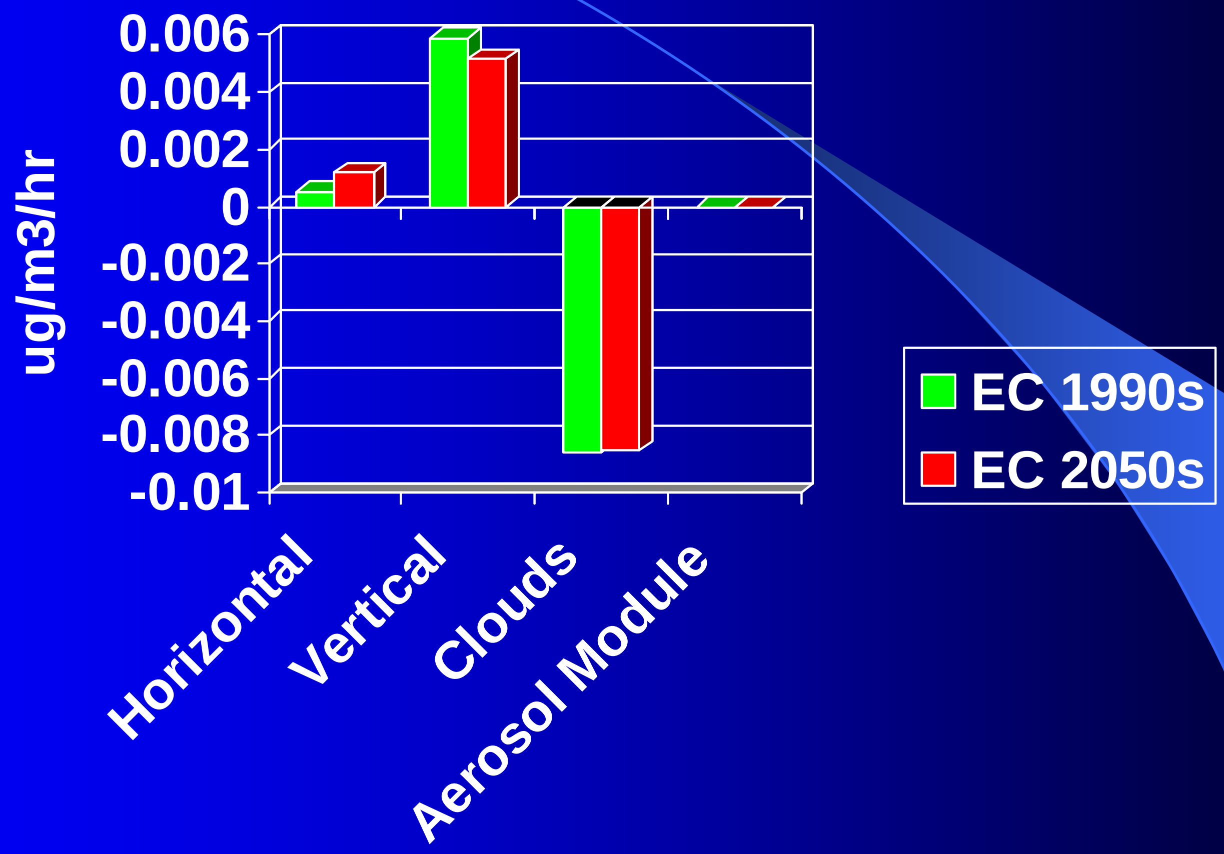


Spatially and Temporally Averaged O_3 Process Rates for the 1990s and 2050s



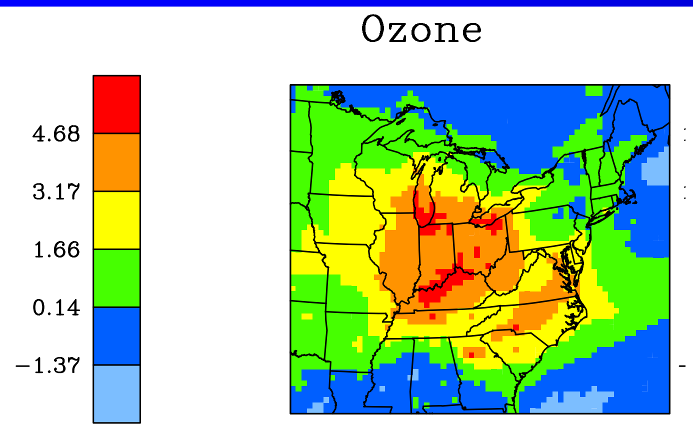
- Increase in the strength of the net chemical production rates for the future climate scenario
- Increase in the net loss due to vertical processes

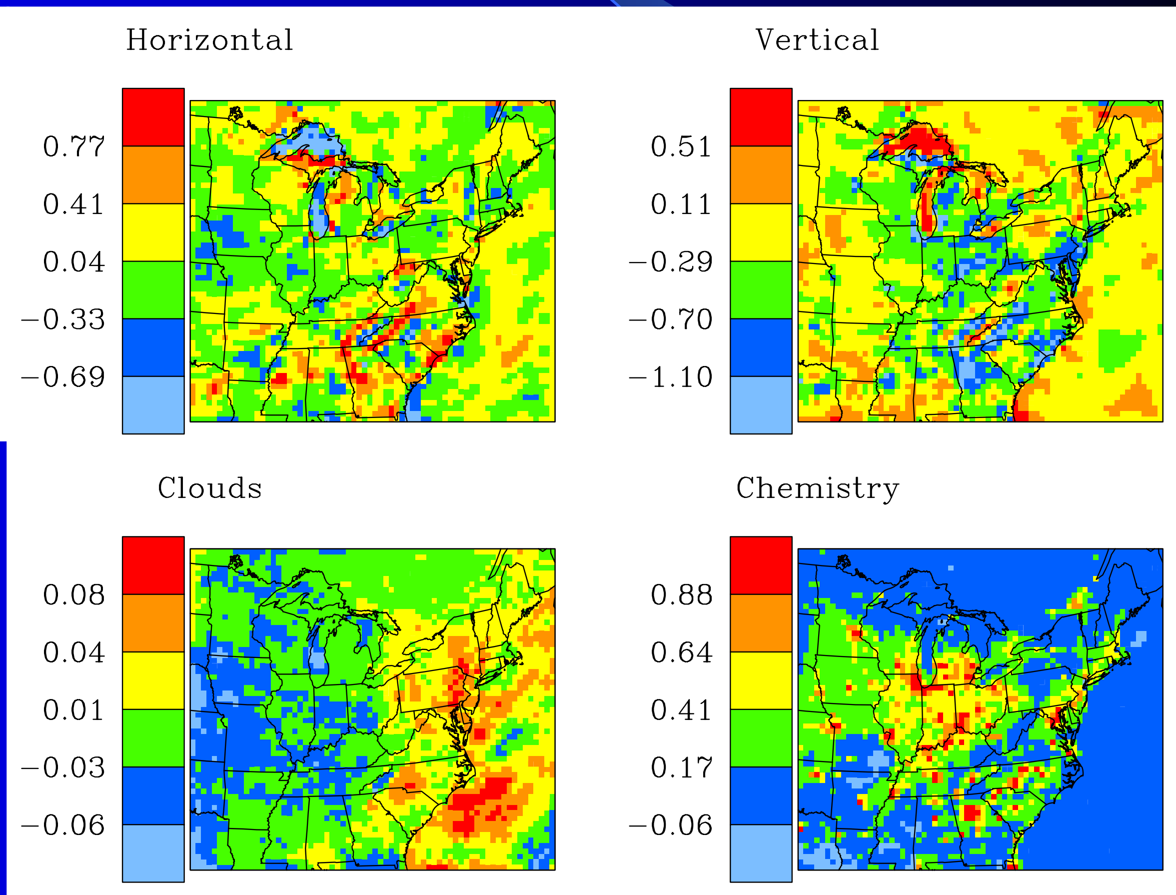
Spatially and Temporally Averaged EC Process Rates for the 1990s and 2050s



- For EC as a primary aerosol, the vertical term (which includes emissions) is the largest net source while cloud processes are the largest net sink in the surface level
- Minor changes in strength between the horizontal and vertical components are seen between the two decades

Changes in Summertime Average O_3(left) and IPR Categories (center, right) 2050s – 1990s, MM5-BM / CMAQ





- With the exception of the chemical term, no strong relationship between patterns of changes in IPR terms and summertime average O_3 concentrations is evident

Correlations Between Spatial Patterns of Changes

	ΔCO	ΔO_3	ΔEC	ΔSO_4
ΔIPR(EC, Clouds)	-0.19	-0.01	0.09	-0.02
ΔIPR(EC, Horizontal)	0.17	0.06	0.17	0.08
ΔIPR(EC, Vertical)	-0.11	-0.10	-0.05	-0.09
ΔIPR(CO, Chemistry)	0.69	0.49	0.00	-0.02
ΔIPR(CO, Clouds)	-0.26	-0.19	-0.18	-0.16
ΔIPR(CO , Horizontal)	0.19	0.08	0.08	0.15
ΔIPR(CO, Vertical)	-0.17	-0.11	0.05	-0.14
ΔIPR(O_3, Chemistry)	0.57	0.70	0.37	0.31
ΔIPR(O_3, Clouds)	0.09	-0.05	0.01	0.35
ΔIPR(O_3 , Horizontal)	0.10	-0.03	-0.10	0.09
ΔIPR(O_3, Vertical)	-0.24	-0.21	-0.01	-0.24

Correlations Between Spatial Patterns of Changes

	ΔCloudFr	ΔPBL	ΔWaVap	ΔT	ΔWindsp
ΔCO	0.12	0.09	0.60	0.08	0.13
ΔEC	-0.12	-0.32	0.00	-0.35	-0.35
ΔNO_3	0.10	0.01	-0.19	0.00	0.03
ΔSO_4	0.20	-0.21	0.10	-0.28	-0.02
ΔIPR(EC, Clouds)	-0.29	0.02	-0.27	0.02	-0.31
ΔIPR(EC, Horizontal)	0.19	0.07	0.11	0.05	0.14
ΔIPR(EC, Vertical)	-0.20	-0.01	-0.14	0.05	-0.11
ΔIPR(O_3, Chemistry)	-0.17	0.05	0.37	-0.02	-0.04
ΔIPR(O_3, Clouds)	0.39	-0.17	0.04	-0.26	0.21
ΔIPR(O_3 , Horizontal)	0.34	0.13	0.00	0.14	0.09
ΔIPR(O_3, Vertical)	-0.19	0.03	-0.25	0.10	-0.08

Summary

- CMAQ simulations with regional climate change under the IPCC A2 scenario for the 2050s shows an increase of up to 1 μg/m^3 in summertime average total $PM_{2.5}$ concentrations, mostly driven by increases in sulfate
  - Decreases in the volatile species nitrate and organic carbon are more than offset by increases in sulfate and primary $PM_{2.5}$ species
  - The directionality of changes is consistent for two different MM5 configurations
  - ⇒ Performing regional climate ensemble modeling studies could help to quantify the uncertainty around simulated pollutant changes as a result of climate change
- Process analysis: strongest link between climate change and changes in pollutant concentrations is through chemical production rates for reactive gas-phase species (via water vapor / radical chemistry?)
- But: Even the strongest linear regression associations explain less than half of the concentration changes simulated by CMAQ
- This implies that the simulated changes in pollutant concentrations stemming from climate change are the result of a complex interaction between changes in transport, mixing and chemistry that cannot be parameterized by spatially uniform linear regression relationships
- Therefore, full-science photochemical modeling systems such as CMAQ are the tool of choice for quantitatively studying the impact of climate change on regional-scale air pollution.
- Need to include global chemistry models and aerosol/climate feedback