OZONE, METHANE AND AIR QUALITY MODELING WITH TRANSPORT/TRANSBOUNDARY

Joshua S. Fu, Ph.D.

[1]Department of Civil and Environmental Engineering
University of Tennessee, Knoxville, TN, USA

[2]UT-ORNL Bredesen Center for Interdisciplinary Research and Graduate Study
Energy Science and Engineering Ph.D. Program

[3]Computer Science and Mathematics Division
Oak Ridge National Laboratory, Oak Ridge, TN, USA

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1: Professor
2: Inaugural Professor
3: Faculty Joint Appointment

Outline

Policy Relevant Background ozone

Transport and transboundary air pollution

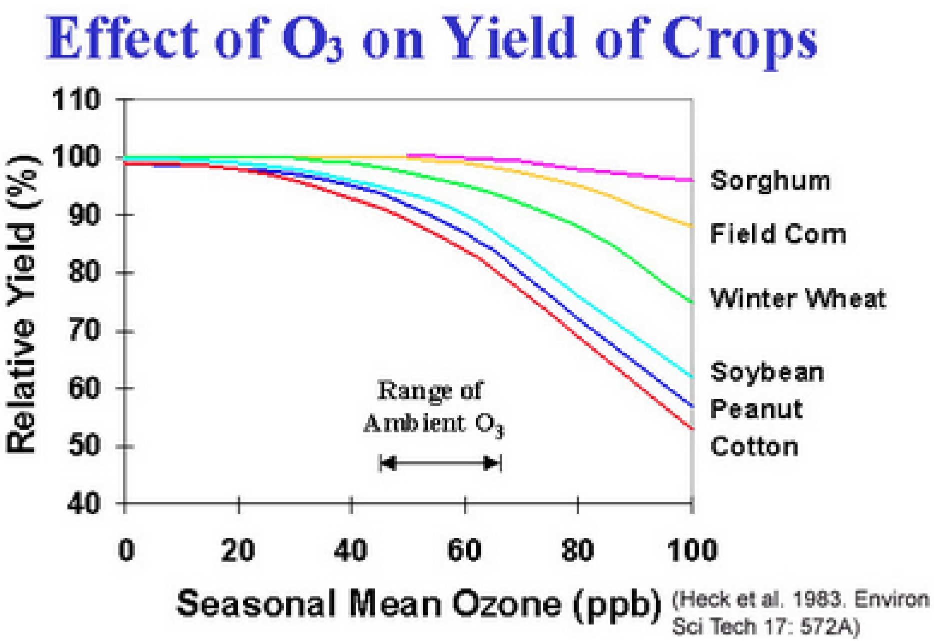
Consequences climate impact on air quality

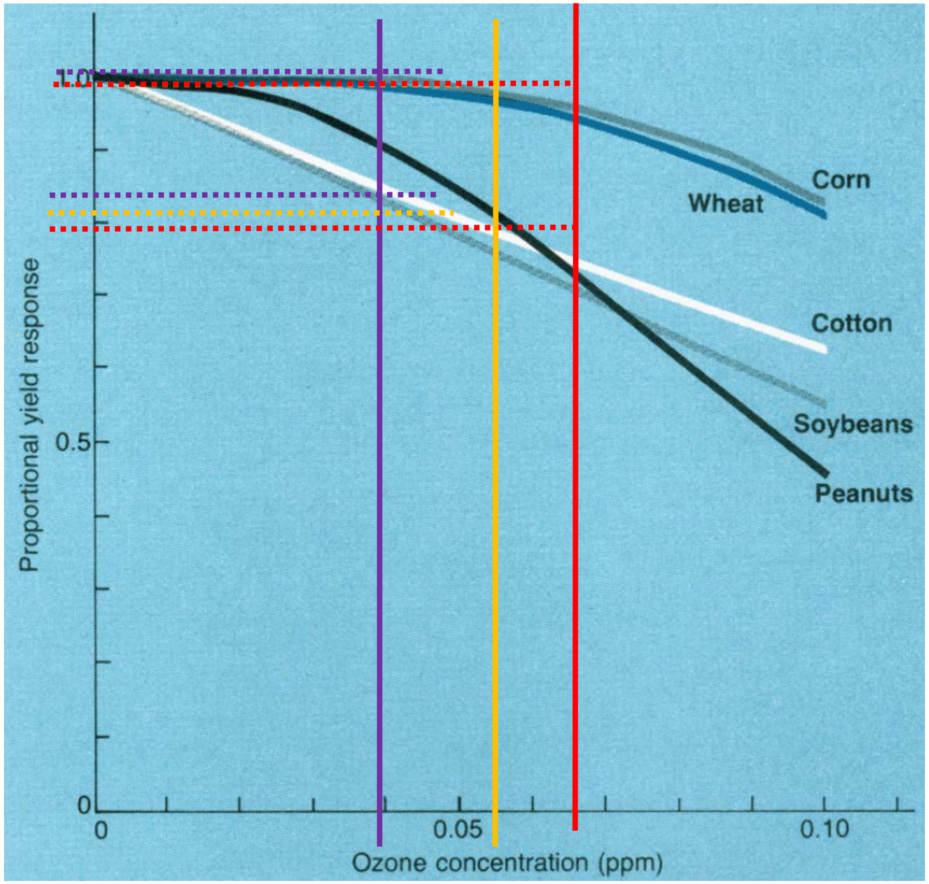
Future air quality – ozone and $PM_{2.5}$

PRB Ozone

Transport and transboundary

Ozone impact on agriculture





A.S. Heagle. 1989. Ozone and crop yield. Annual Review of Phytopathology 27:397-423.

W.W. Heck, R.M. Adams, W.W. Cure, A.S. Heagle, H.E. Heggestad, R.J. Kohut, L.W. Kress, J.O. Rawlings and O.C. 1983. Taylor. A reassessment of crop loss from ozone. *Environ. Sci. Technol.* 17 (12): 572A–581A

Policy Relevant Background ozone

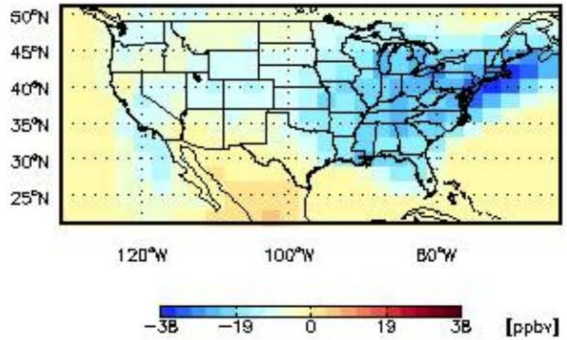
Ozone season: July, Aug and Sept.

"zero-out Asia" contributes : 3.0 to 5.0 ppbv to the background ozone concentration in the United States

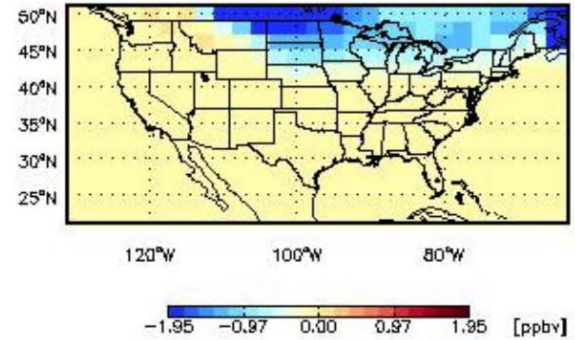
The average ozone impacts are about 2.0 ppbv for the "zero-out Canada" case in northern states, and up to 14.0 ppbv for the "zero-out Mexico" case in California, New Mexico and Texas areas.

"zero-out NA" shows that a large portion of average ozone, up to 38 ppbv, is contributed from the outside of United States

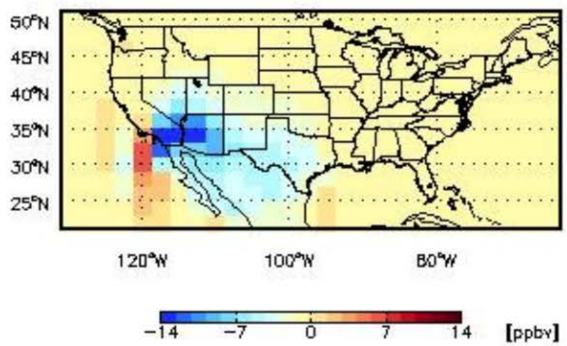
Zero-Out US (Case –Base case)



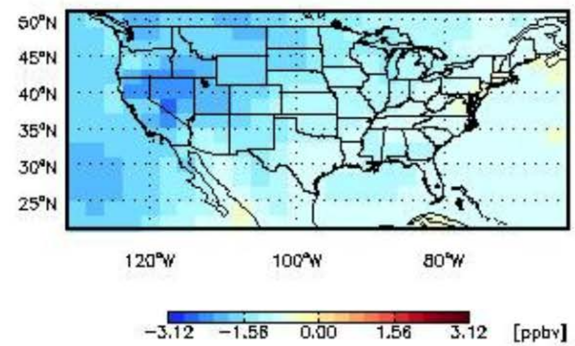
Zero-Out Canada (Case –Base case)



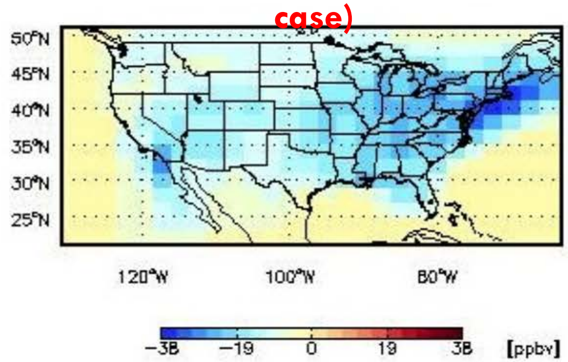
Zero-Out Mexico (Case –Base case)



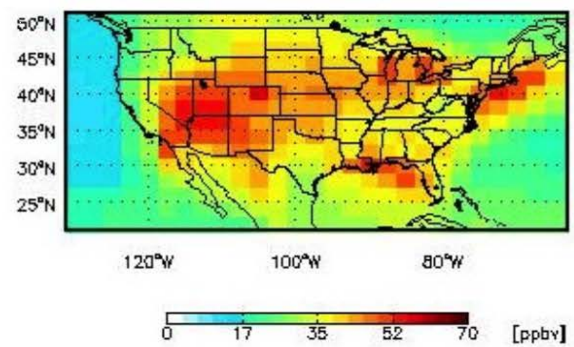
Zero-Out Asia (Case –Base case)



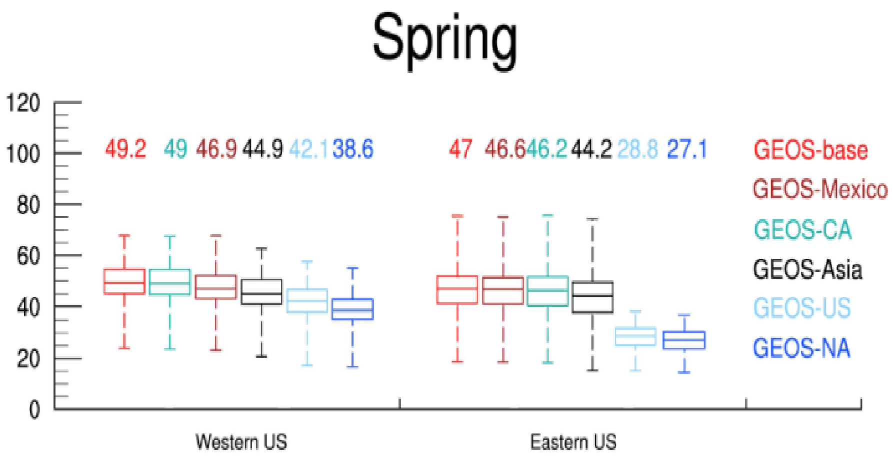
Zero-Out NA (Case –Base case)

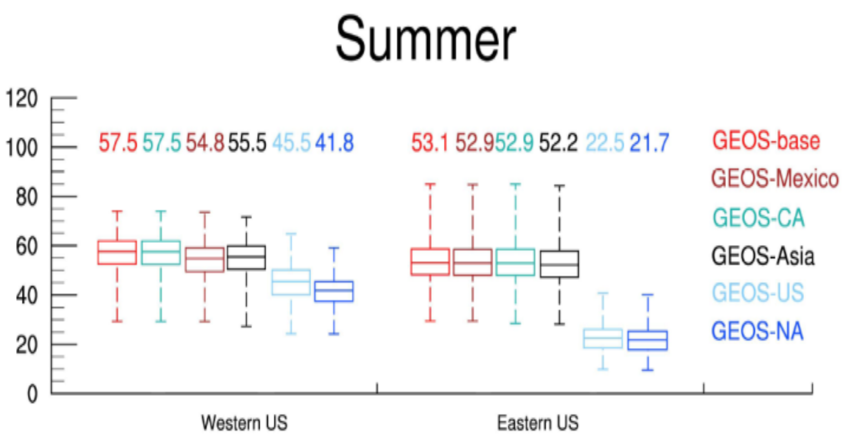


Base case (No change)



Seasonal transport influences on surface ozone concentrations (spring and summer)





The background ozone increases in the Western US due to increase in temperature, while it decreases in the Eastern US due to the rise of the tropopause.

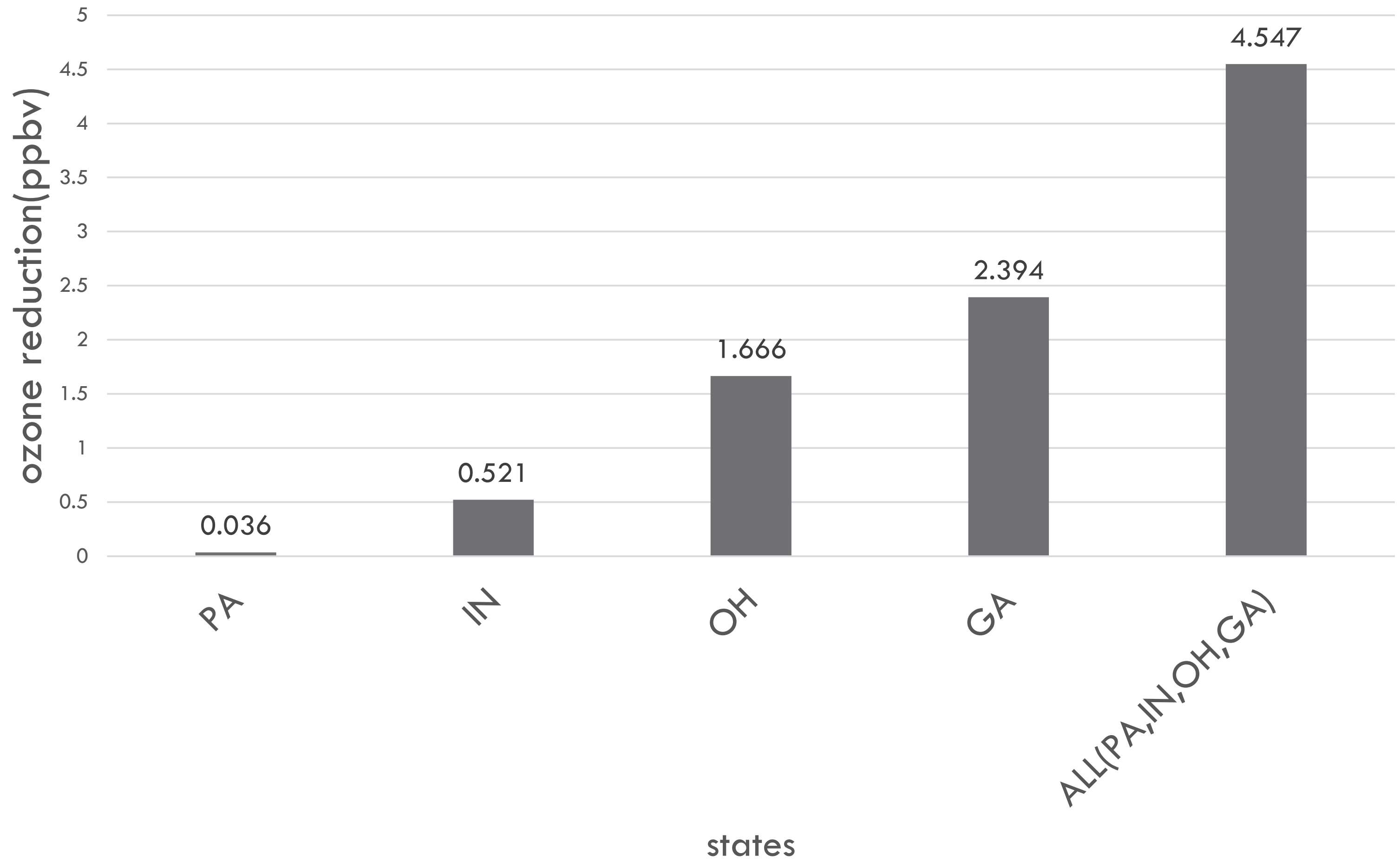
Highlights the impact of transcontinental transport of ozone, namely a 3-5 ppbv increase in MDA8 ozone in both seasons

Air Benefit and Cost and Attainment Assessment System (ABaCAS)

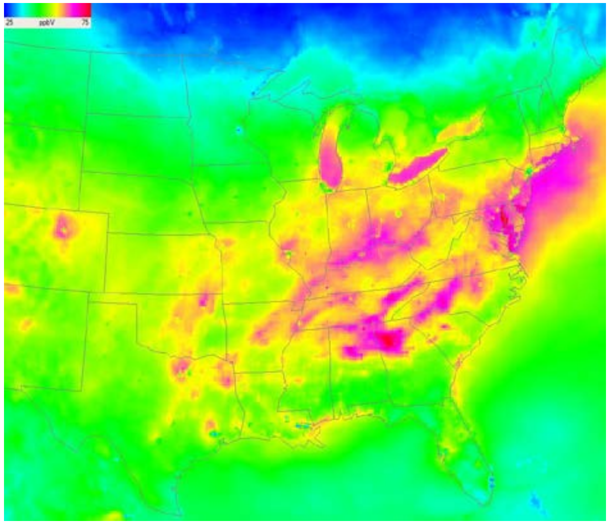
Response Surface Model (RSM)

RSM (Kriging interpolation technique) with Community Multi-scale Air Quality (CMAQ) modelling results. Builds up the connection between pollution and emission reduction control

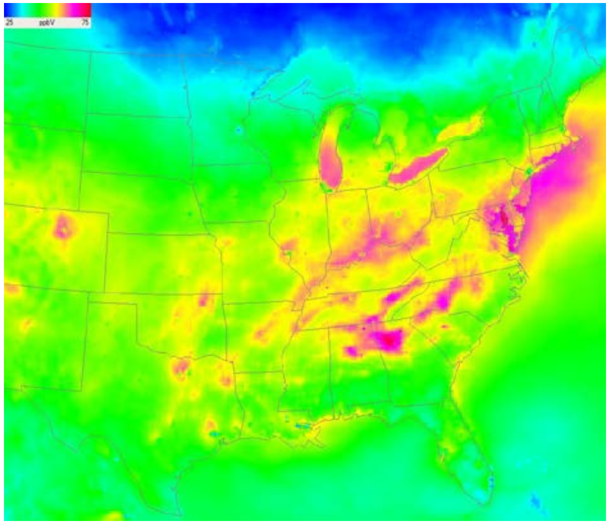
Contributions from PA, IN, OH, IL, GA to GSM individually (RSM results in 2008)



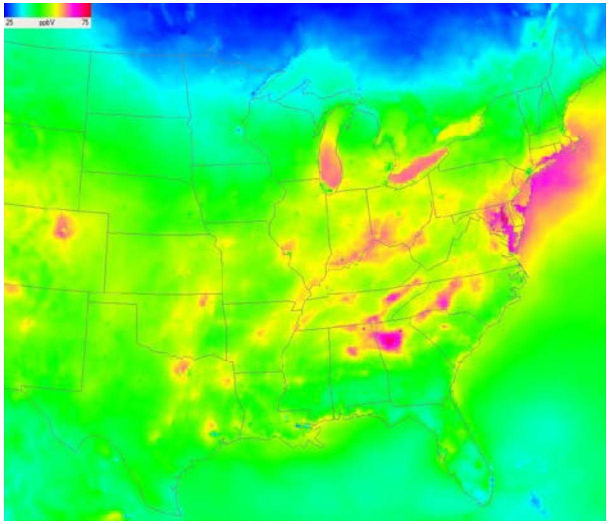
Emission reduction scenarios



Baseline



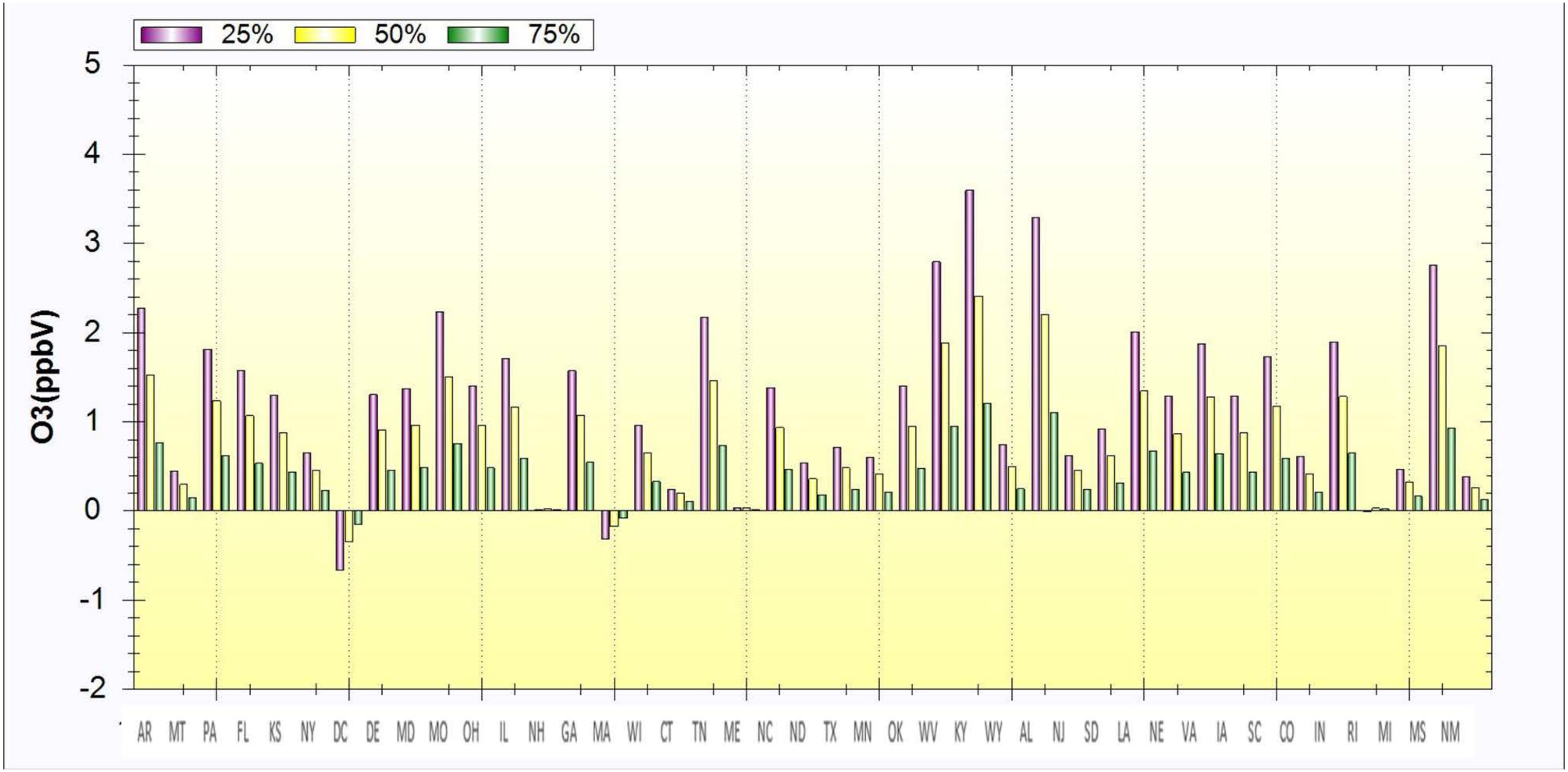
Reduce NOx at EGU, Non-EGU and Mobile at all states by 10%



Reduce NOx at EGU, Non-EGU and Mobile at states by 20%

Power plant NOx emission reduction

O3 reductions at EGU at all states with 25%, 50% and 75% control percentages of NOx



UNECE TF HTAP

- The Task Force on Hemispheric Transport of Air Pollution (TF HTAP) is an international scientific cooperative effort to improve the understanding of the intercontinental transport of air pollution across the Northern Hemisphere. TF HTAP was organized in 2005 under the auspices of the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP Convention) and reports to the Convention's EMEP Steering Body.

UN ECE TF HTAP - Questions

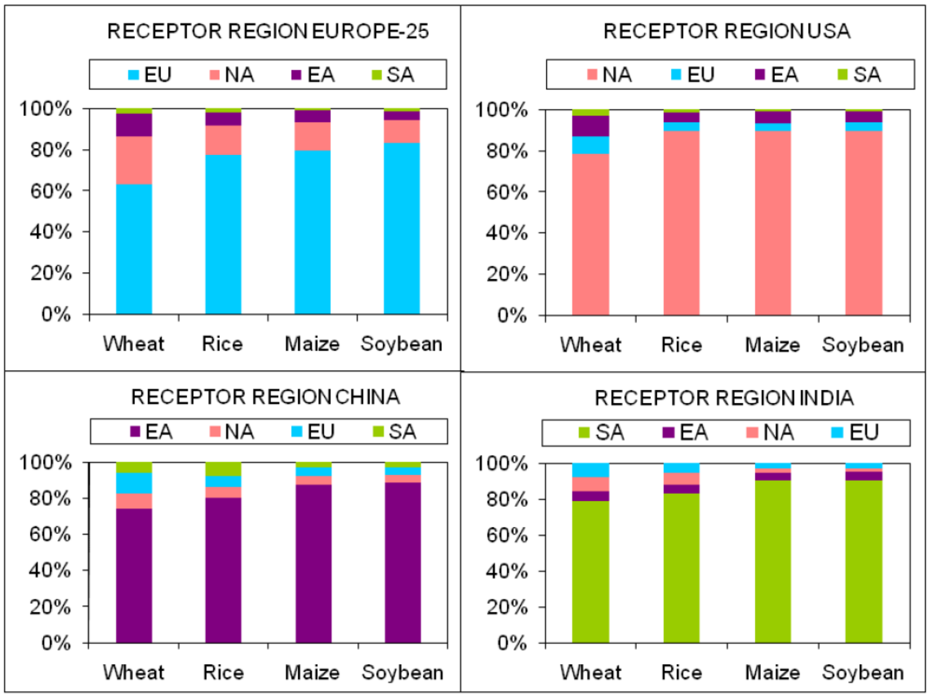
The main questions of interest to the TF HTAP relate to the benefits of international cooperation to decrease air pollution emissions:

- How do air pollution concentrations (or deposition) in one region of the world change as emissions change in other regions or the world?
- How do changes in emissions outside a region affect the health, ecosystem, and climate impacts of air pollution within a given region?
- How does the feasibility of further emissions control differ in different regions of the world?

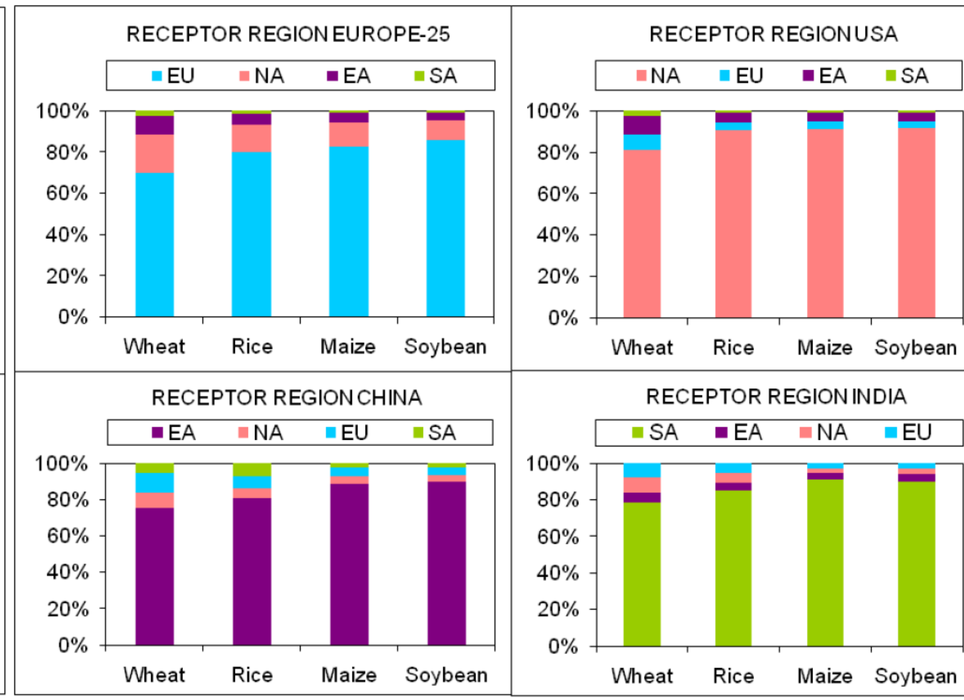
Relative contribution of HTAP region to crop damage

HTAP: UN ECE Task Force Hemispheric Transport of Air Pollution

Mx indices



AOT40 indices



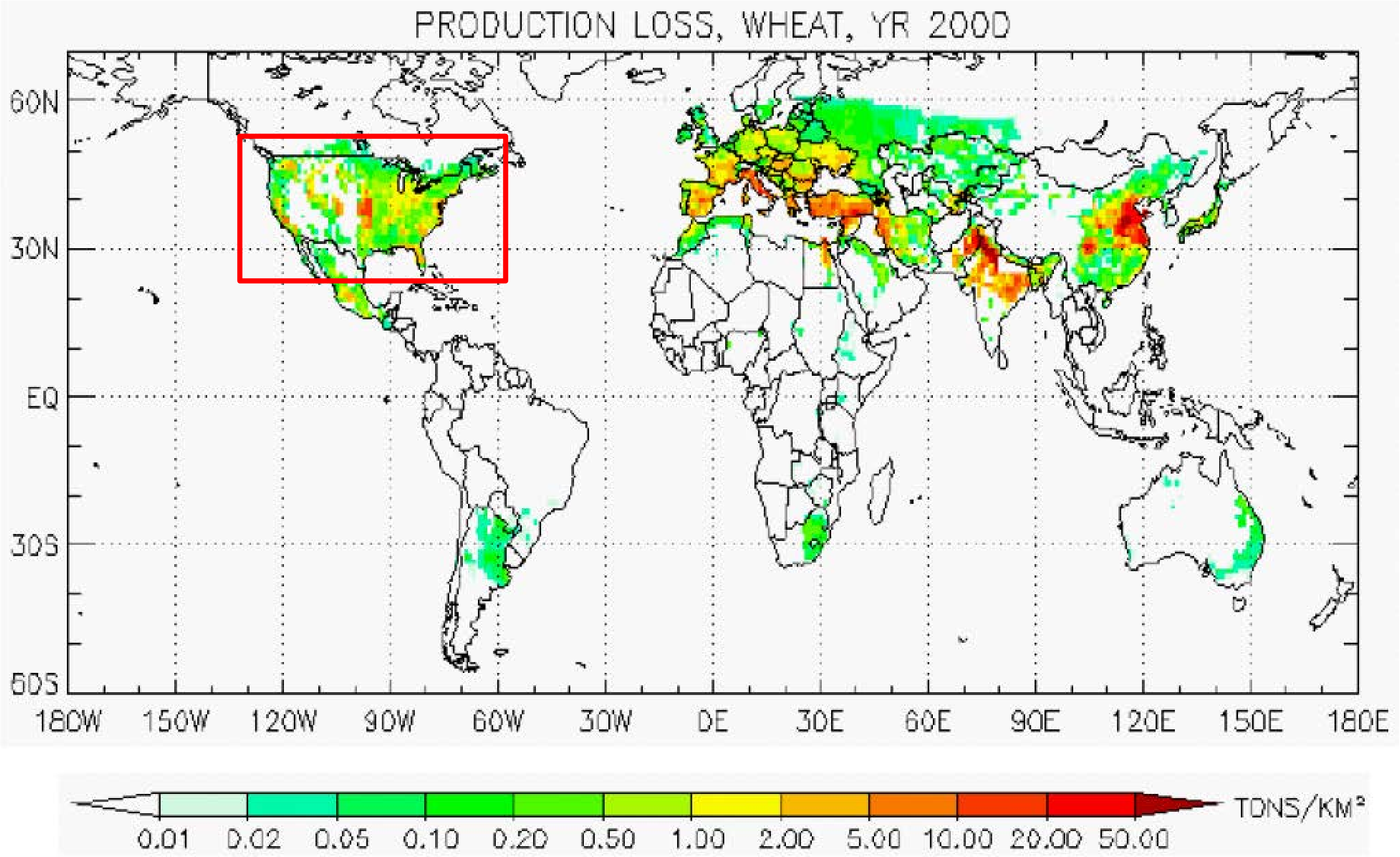
EU: Europe, NA = North America, EA = East Asia, SA = South Asia

Mx(M7 or M12): Daylight (7 or 12 hours) growing season average

AOT40: Accumulated concentration over a threshold of 40 ppb during daylight hours over a growing season

Hemispheric Transport Of Air Pollution. Part A: Ozone And Particulate Matter. 2010.

Average wheat crop production losses due to ozone in 2000



Hemispheric Transport Of Air Pollution. Part A: Ozone And Particulate Matter. 2010.

Climate change consequences

Future air quality

Outline

What is climate change?

Climate change is happening

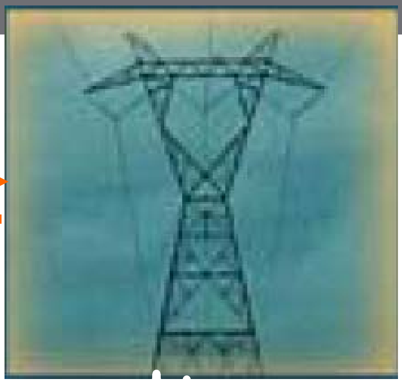
Climate change is no longer a hypothesis;

It is a fact.

We have seen changes in rainfall, resulting in more floods, droughts, or intense rain, acidic, ice caps are melting, and sea levels are rising, as well as more frequent and severe heat waves.

Impacts of Climate Change

Climate Change



Energy

Air Quality

Public Health

Water Resources and
Water Quality

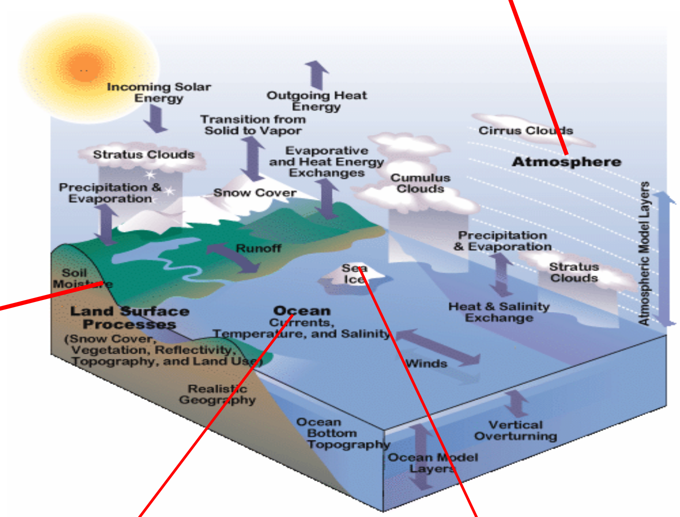
Agriculture and Food

Overview of the study

Community Earth System Model

CESM 1.0

Community Atmosphere Model (CAM-Chem)



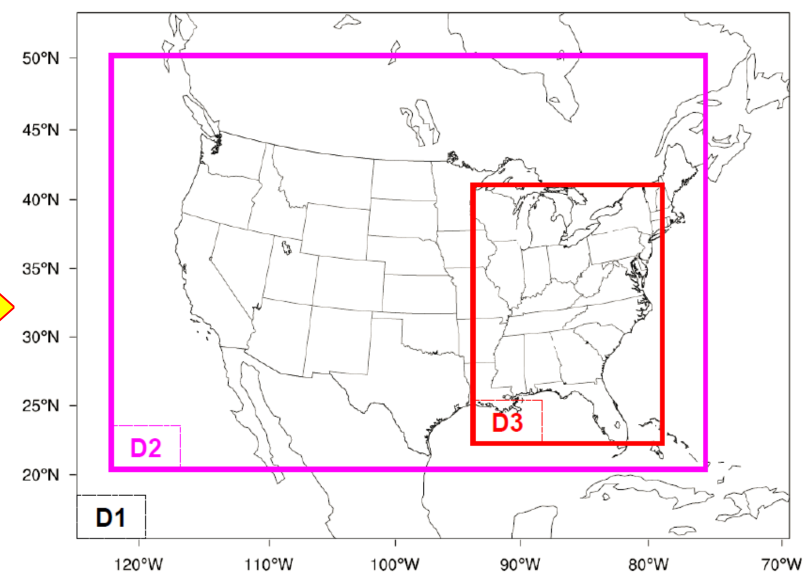
Community Land Model (CLM)

Ocean component (POP)

Community Sea Ice Model (CSIM)

Regional Climate/Chem Model

WRF 3.2.1/CMAQ 5.0



D1/D2/D3: 36-12-4 km

0.9×1.25 deg (~100 × 140km lat/lon)--------> 36-12-4 km

Published papers

Environmental Research Letters > Volume 7 > Number 4

Y Gao *et al* 2012 *Environ. Res. Lett.* **7** 044025 doi:10.1088/1748-9326/7/4/044025

Projected changes of extreme weather events in the eastern United States based on a high resolution climate modeling system

OPEN ACCESS

Y Gao[1], J S Fu[1], J B Drake[1], Y Liu[2] and J-F Lamarque[3]

Hide affiliations

jsfu@utk.edu

[1] Department of Civil and Environmental Engineering, University of Tennessee, Knoxville, TN, USA
[2] Rollins School of Public Health, Emory University, Atlanta, GA, USA
[3] Atmospheric Chemistry and Climate and Global Dynamics Divisions, National Center for Atmospheric Research, Boulder, CO, USA

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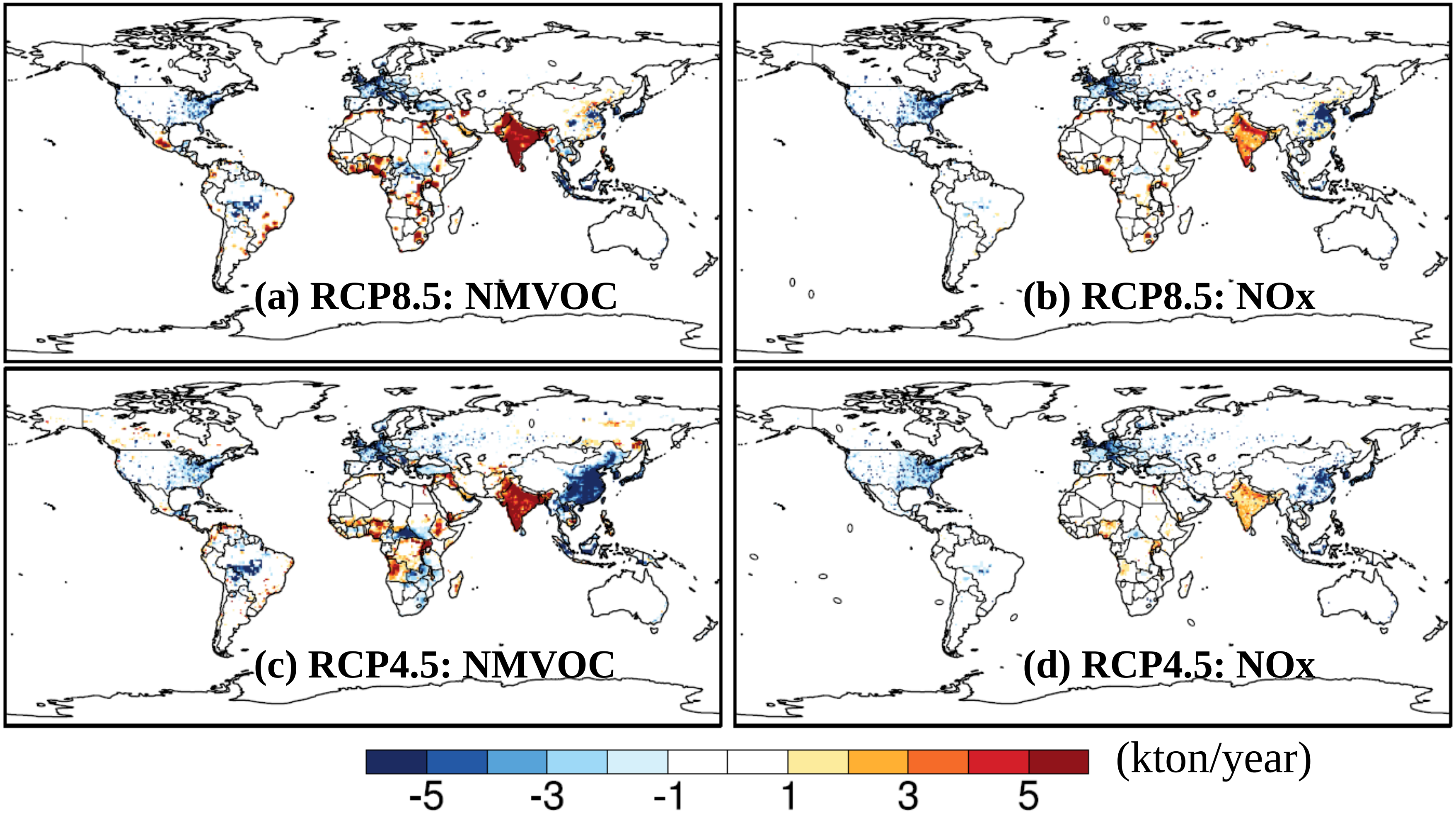
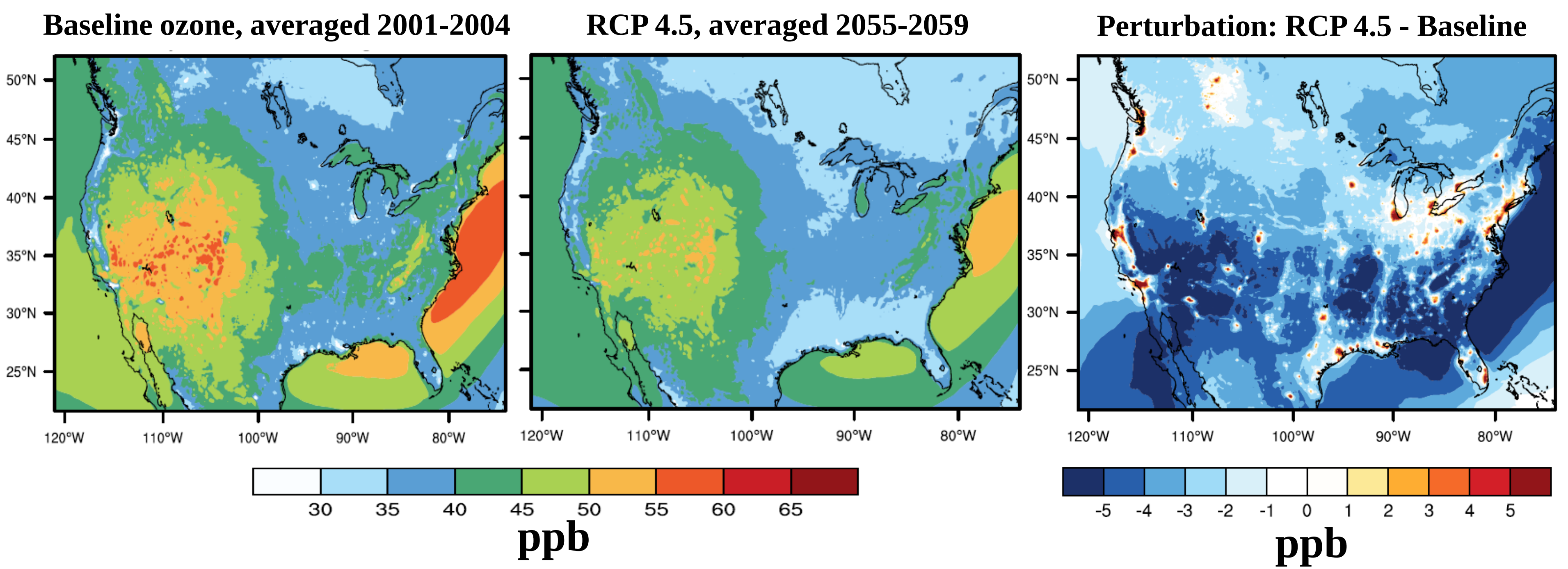
One of top 5 downloads in the last 30 days in the Environmental Research Letters (more than 1000 downloads within 3 months)

Projection of emissions

2060 - 2005

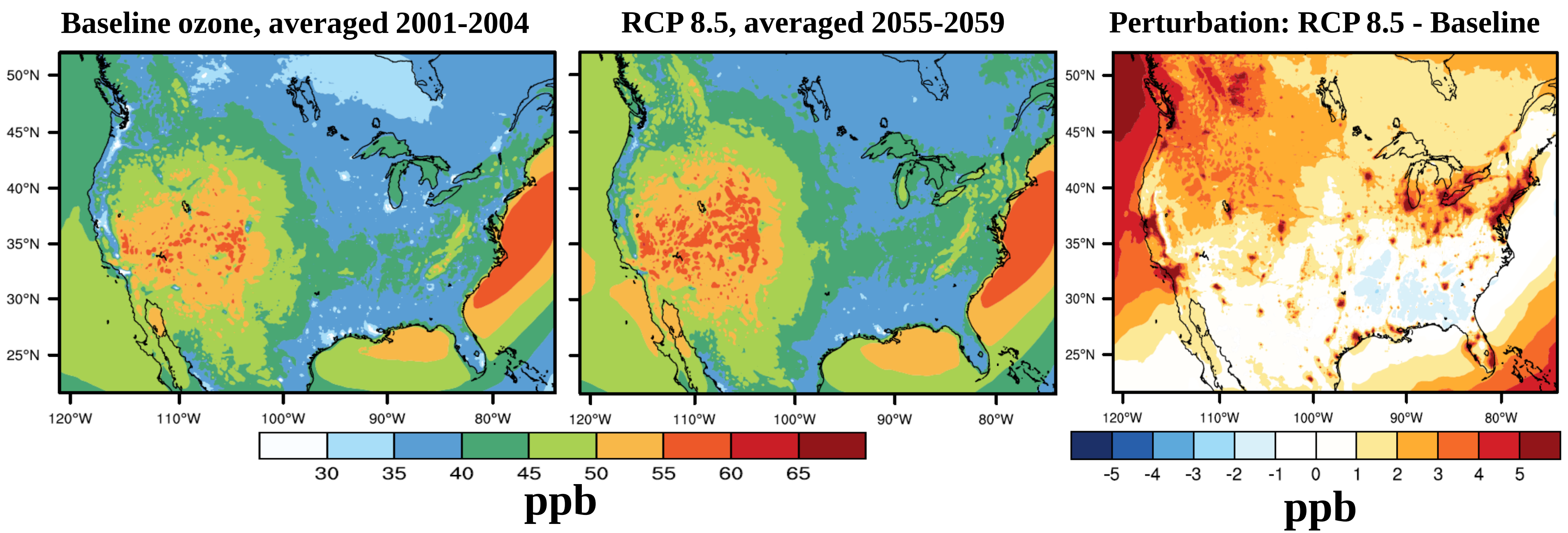


Spatial distribution of annual mean ozone in US (RCP 4.5 scenario)



- 46 out of 48 (95.8%) states show a decreasing trend of ozone trend in the future.
- 26 out of 48 (54.2%) states have ozone decrement > 3 ppb in the future.

Spatial distribution of annual mean ozone in US (RCP 8.5 scenario)



- 43 out of 48 (89.6%) states show a increasing trend of ozone trend in the future.
- 8 out of 48 (16.7%) states have ozone increment > 3 ppb in the future.

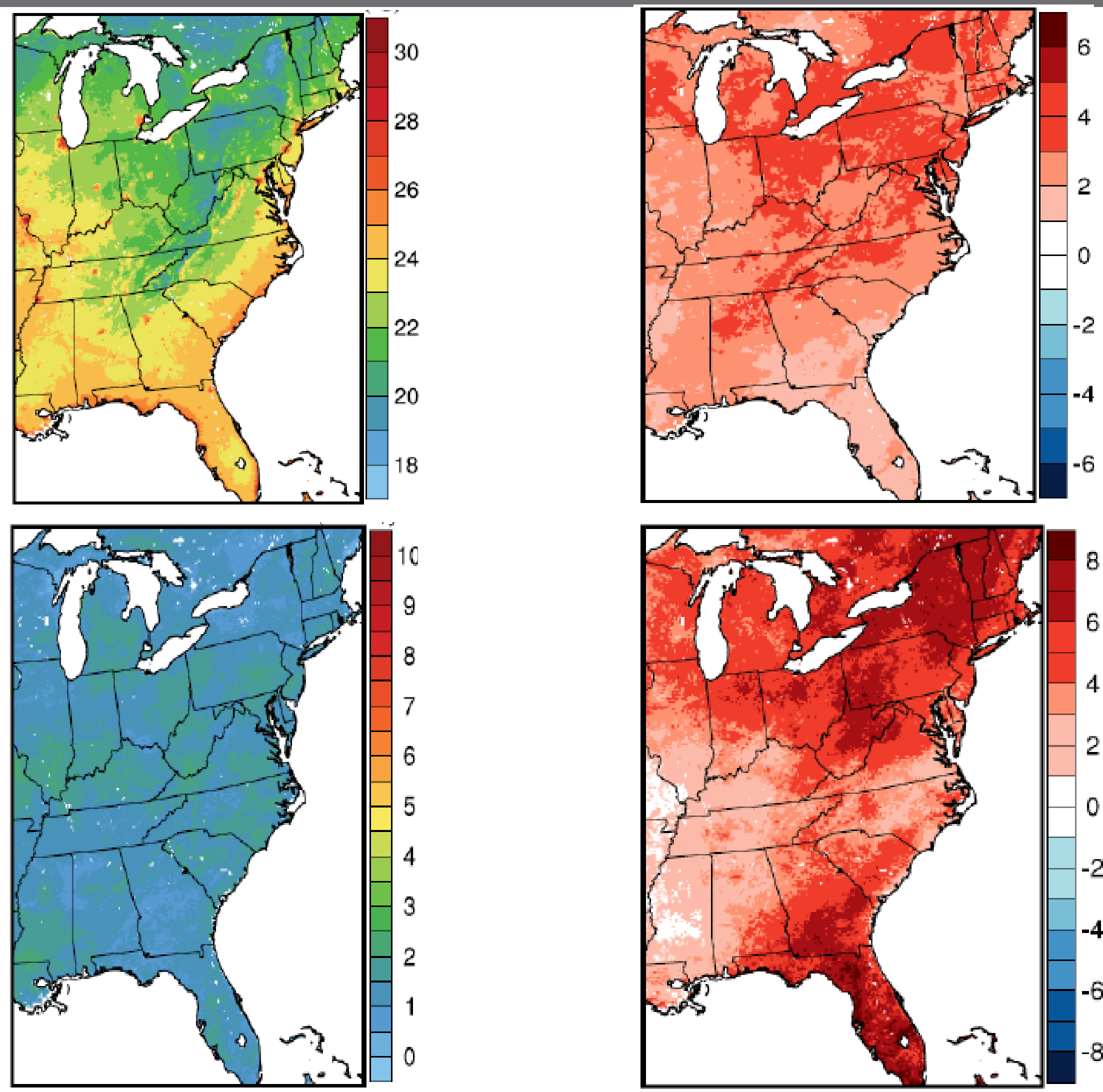
More intense and frequent heat waves in future climate

Present (2001-2004) RCP 8.5 (2057-2059) - P

Heat wave intensity (^oC)

Heat wave frequency (events/year)

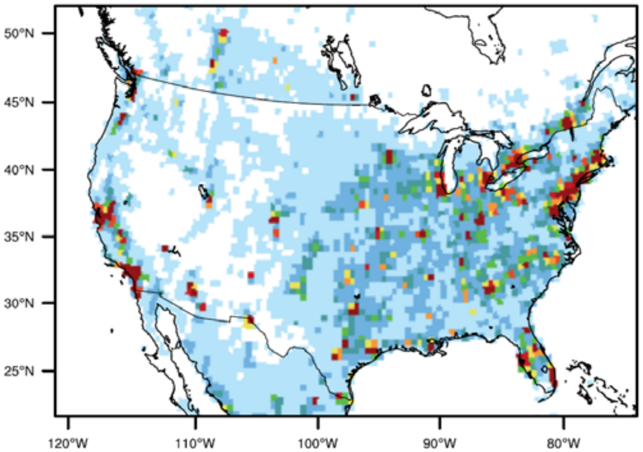
Heat wave duration (days/event)



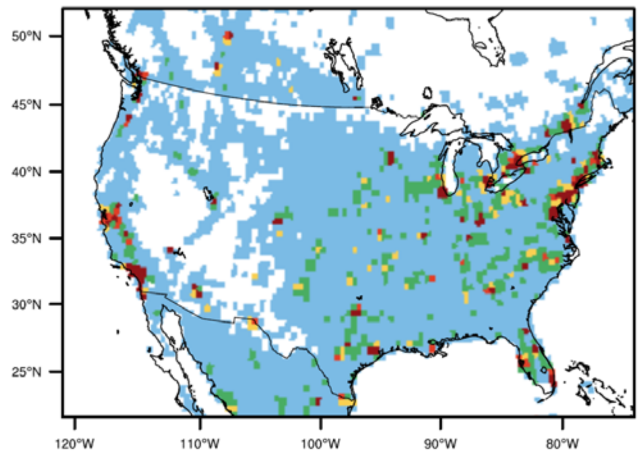
Gao, et al, 2012 ERL

Spatial distribution of methane (CH_4) emission

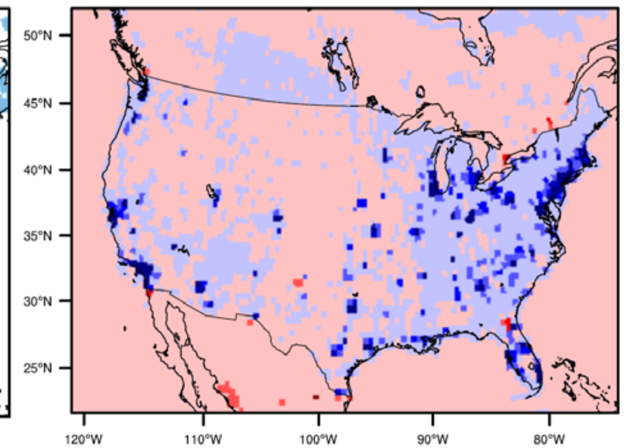
Baseline annual total emission: 2000



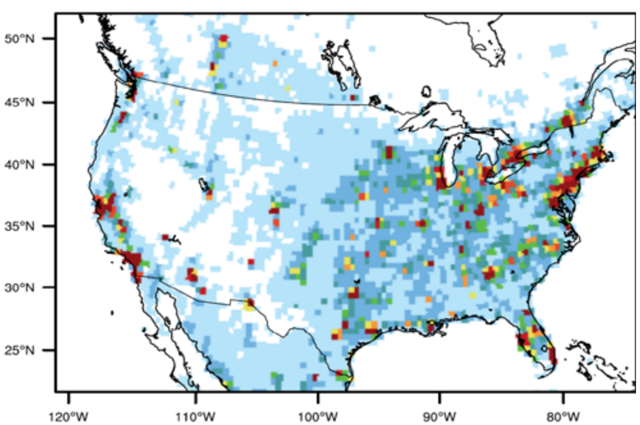
RCP 4.5 annual total emission: 2050



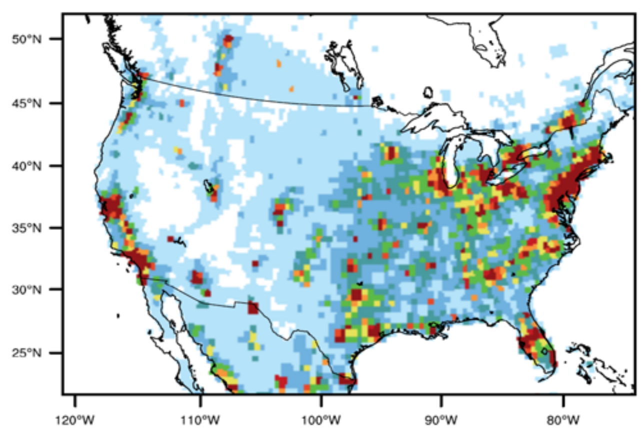
Perturbation: RCP 4.5 - Baseline



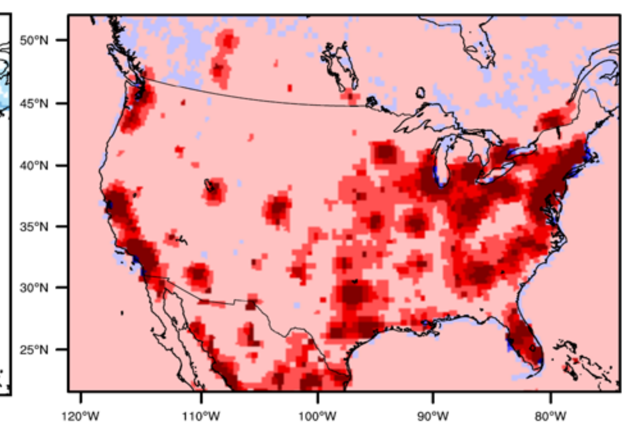
Baseline annual total emission: 2000



RCP 8.5 annual total emission: 2050

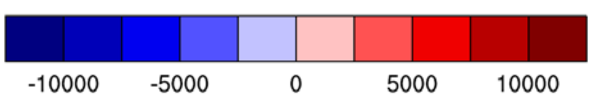


Perturbation: RCP 8.5 - Baseline



Tons/year

Tons/year



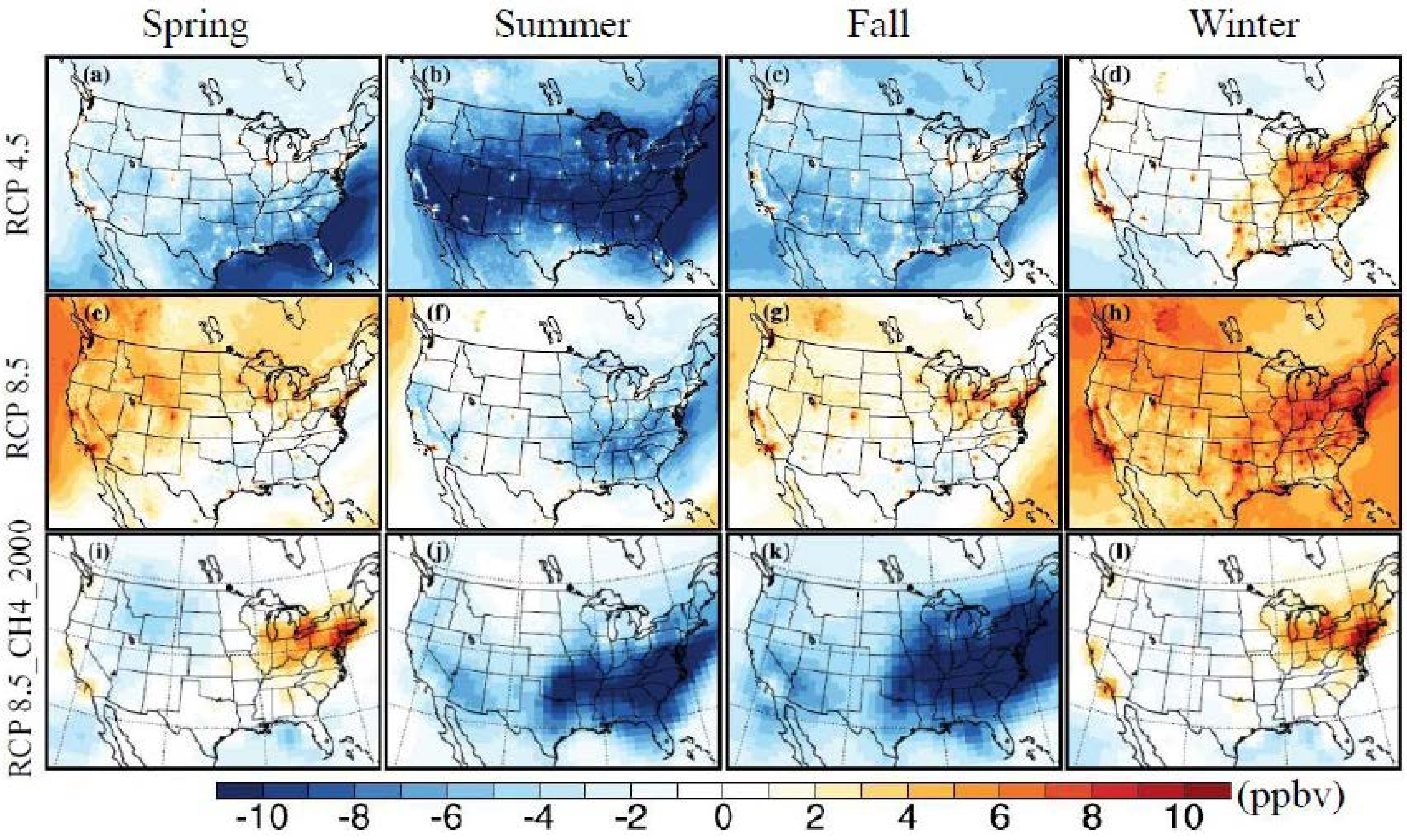
Projection of emissions

	Present climate				2005(Tg)	RCP 4.5			RCP 8.5		
	2001	2002	2003	2004		2057	2058	2059	2057	2058	2059
CO	1.142	1.194	1.129	1.065	93.030	0.272	0.268	0.264	0.246	0.243	0.240
NOX	1.139	1.117	1.078	1.039	18.914	0.342	0.338	0.334	0.493	0.487	0.482
PM10	1.121	1.008	1.006	1.003	21.149	0.552	0.552	0.551	0.542	0.540	0.538
PM2.5	1.282	1.022	1.015	1.007	5.456	0.761	0.754	0.747	0.422	0.417	0.413
SO2	1.092	1.012	1.008	1.004	14.594	0.169	0.166	0.163	0.148	0.137	0.126
VOC	0.929	1.149	1.112	1.074	18.421	0.632	0.630	0.628	0.314	0.310	0.306
NH3	0.904	1.012	1.008	1.004	4.085	1.254	1.253	1.252	1.536	1.544	1.551
CH4	1.202	1.187	1.172	1.156	32.180	0.893	0.888	0.883	1.612	1.626	1.640
BC	1.007	1.005	1.004	1.002	0.394	0.723	0.716	0.709	0.264	0.262	0.260
OC	1.145	1.109	1.073	1.036	1.141	1.060	1.051	1.042	0.609	0.606	0.604

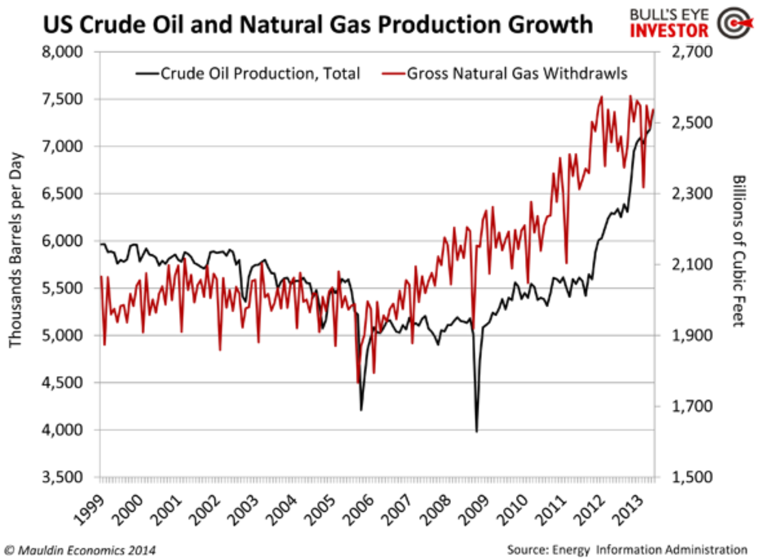
- more than 35% in VOC and 75% in NOx reduction in RCP 4.5
- about 70% in VOC and 50% in NOx in RCP 8.5
- About 25% (RCP 4.5) and 60% (RCP 8.5) reduction in PM2.5
- 10% reduction in RCP 4.5 but **60% increase in methane in RCP 8.5**

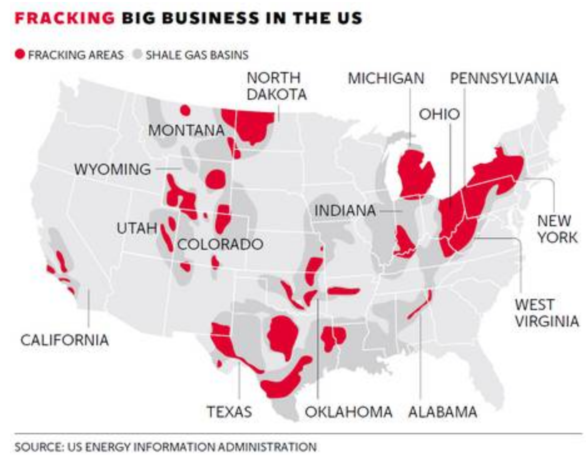
Seasonal variations of ozone changes in future

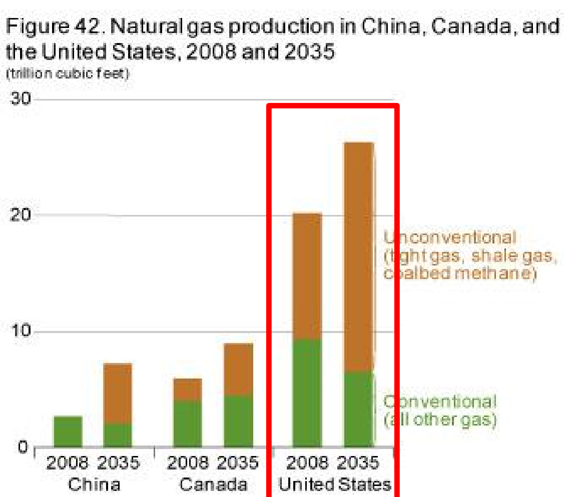
Seasonal mean surface O_3 (2057~2059) – (2001~2004)

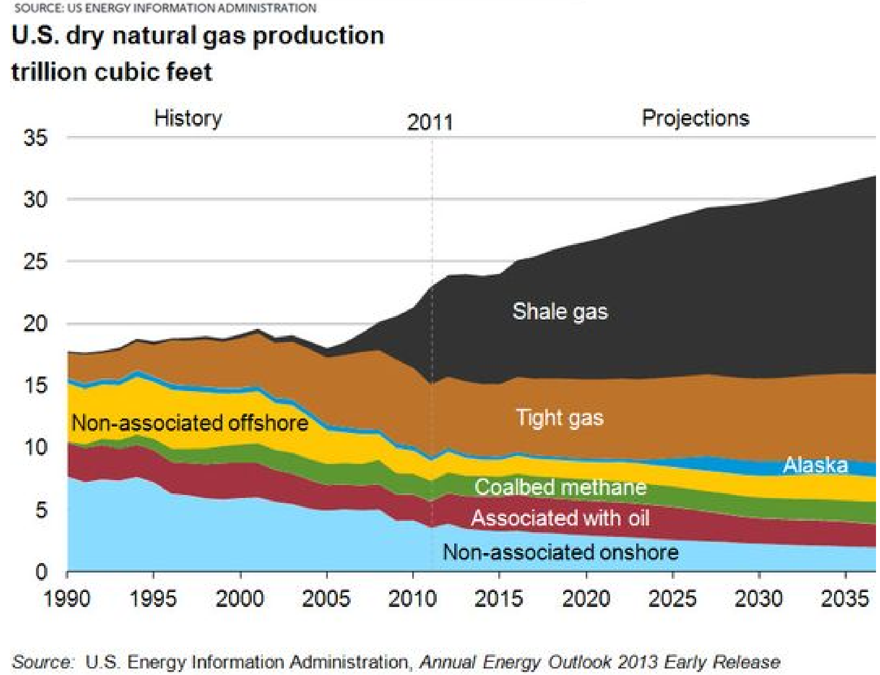


US natural gas/fracking production trend

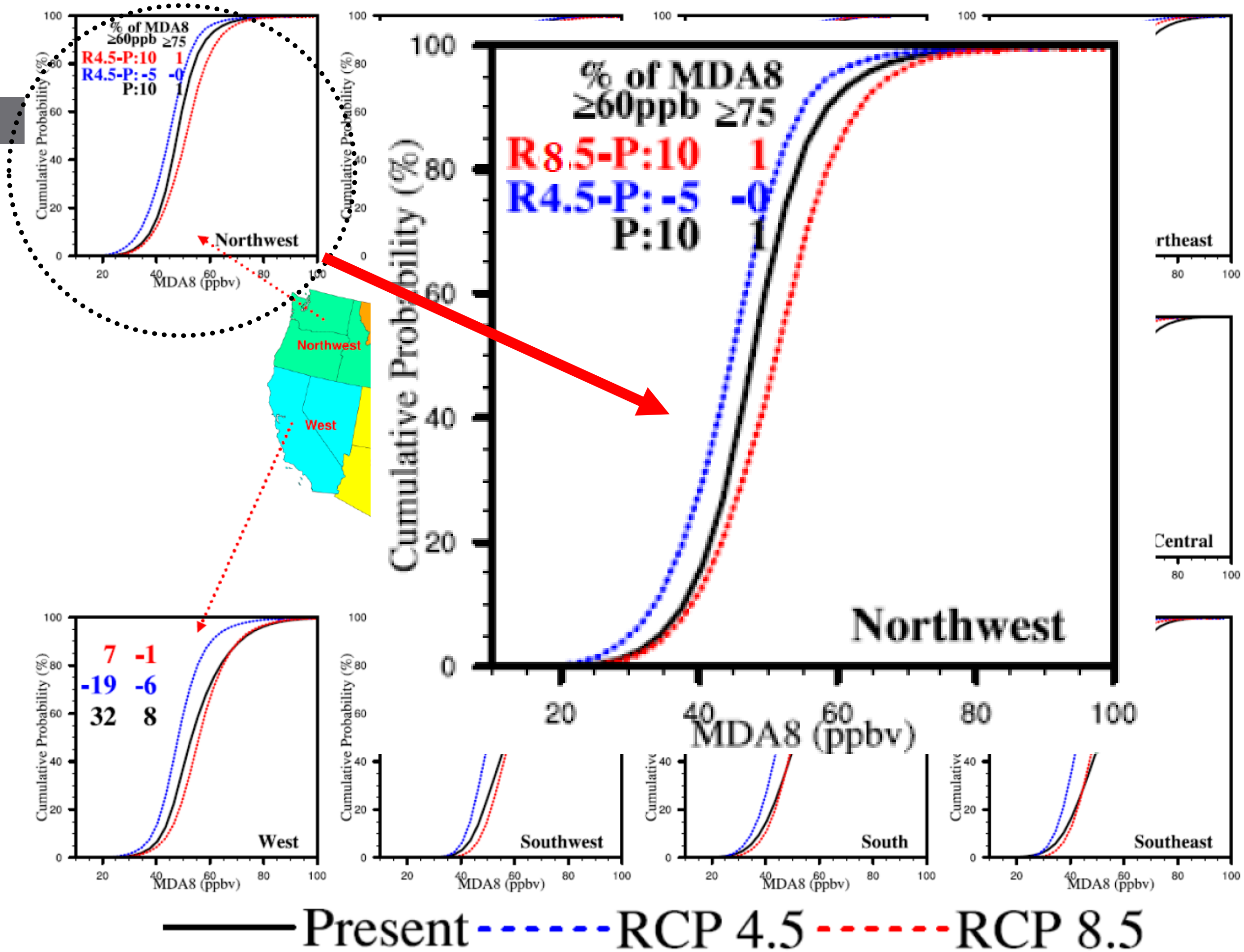








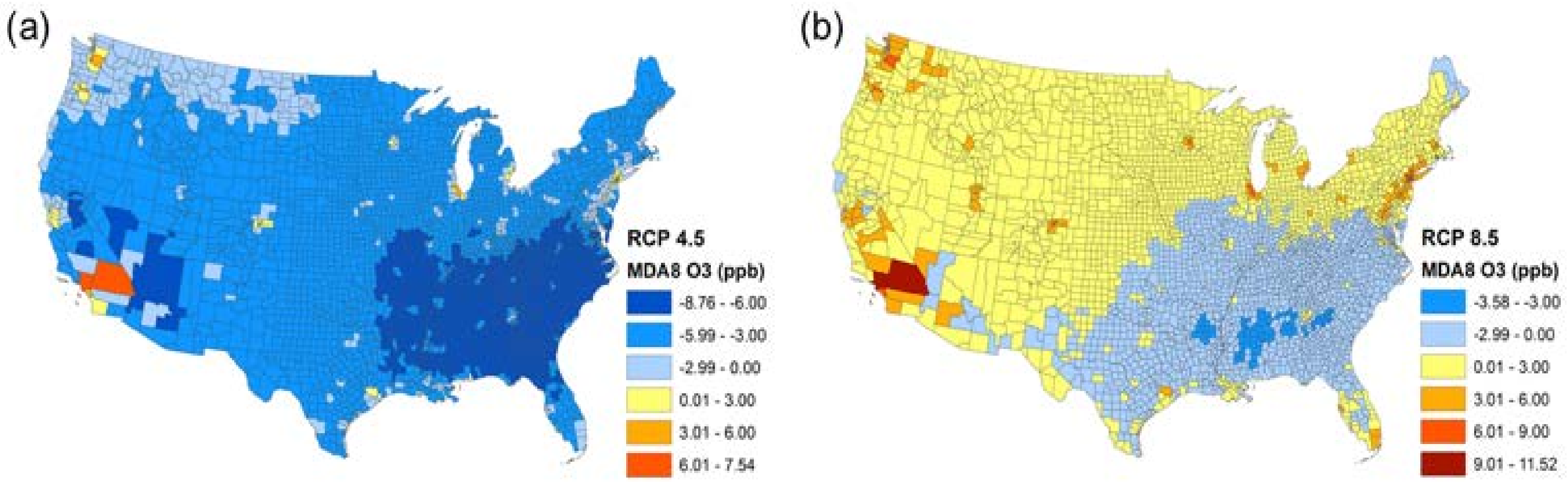
Maximum Daily 8-hr Ozone (MDA8)



➢ The cumulative distribution of RCP 4.5 shifts to the left, indicating reduced ozone concentrations by the end of 2050s

➢ In RCP 8.5, the ozone reduction is smaller than RCP 4.5, and in the western US, the ozone concentration may even increase due to increased methane and stratosphere intrusion

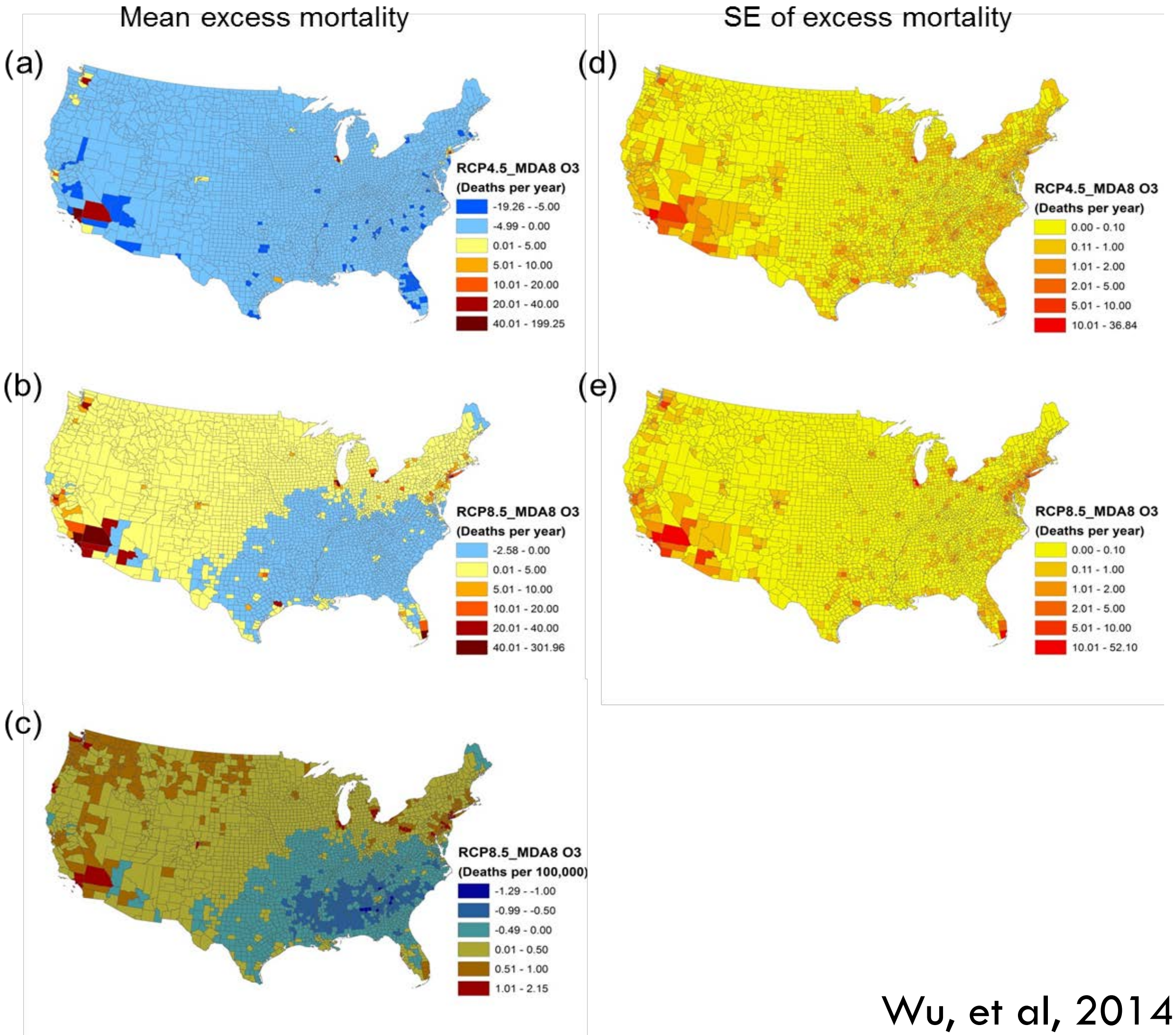
Maximum Daily 8-hr Ozone (MDA8) changes



Spatial distribution of O_3 changes between 2001-2004 and 2057-2059 (a) and (b) are MDA8 O_3 changes for year round under RCP4.5 and 8.5, respectively

Wu, et al., Climatic Change, 2014

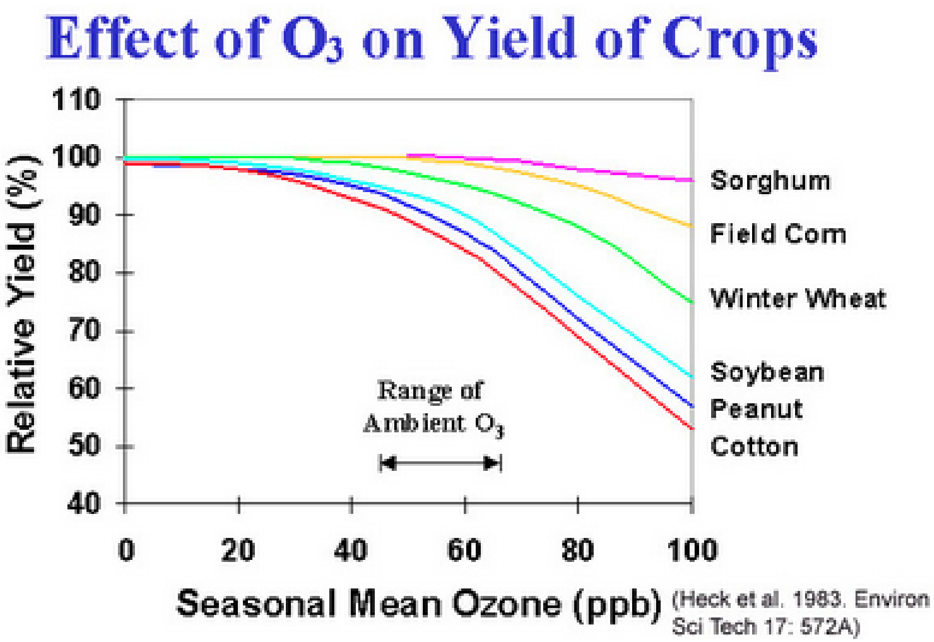
Excess Mortality Changes in 2050s due to O_3

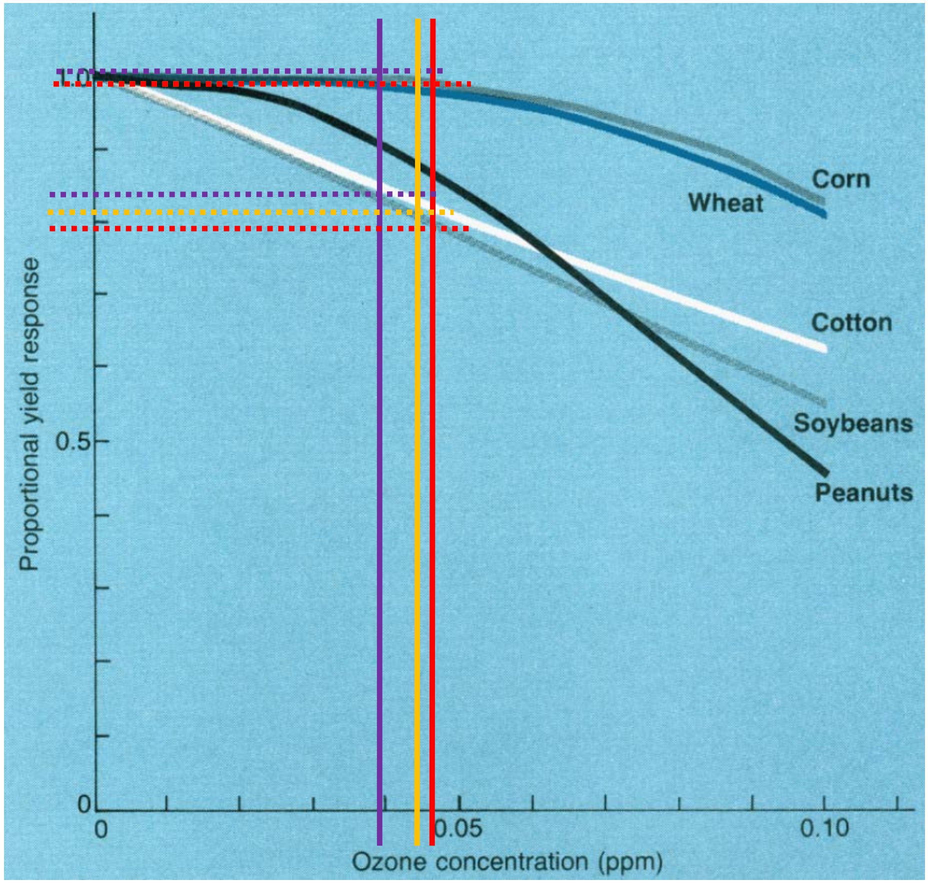


Spatial distribution of excess mortality in 2057-2059 attributable to O_3 changes (a) and (b) indicate annual of MDA8 O_3–related EMs based on mortality risk from Bell et al. (2004) under RCP4.5 and RCP8.5, respectively (c) is EMs per 100,000 persons due to MDA8 O_3 change under RCP8.5 (d) and (e) are the standard errors (SEs) of county-level EM estimates The means and SEs of EMs are derived from 1,000 Monte Carlo simulations of mortality rate, concentration change, and CRF coefficient Each county-level EM is obtained from the average of four EMs from four ICLUS population scenarios

Wu, et al, 2014 EHP; Risk Analysis

Ozone impact on agriculture





Present: 2001-2004, nationally averaged ozone conc. = 43.24 ppb

RCP8.5: 2055-2059, nationally averaged ozone conc. = 45.05 ppb

RCP4.5: 2055-2059, nationally averaged ozone conc. = 39.89 ppb

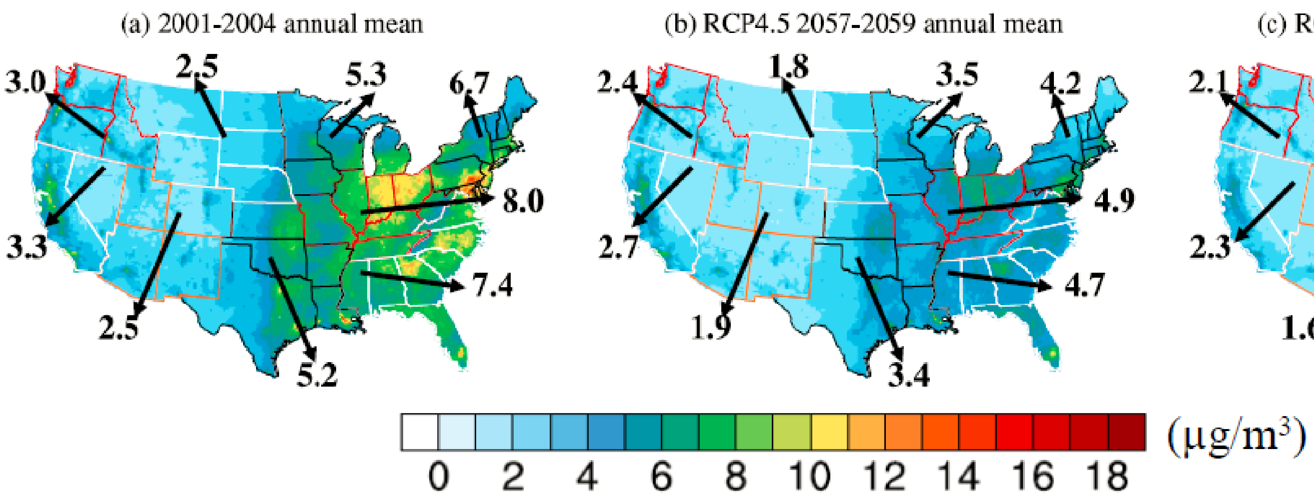
A.S. Heagle. 1989. Ozone and crop yield. Annual Review of Phytopathology 27:397-423.

W.W. Heck, R.M. Adams, W.W. Cure, A.S. Heagle, H.E. Heggestad, R.J. Kohut, L.W. Kress, J.O. Rawlings and O.C. 1983. Taylor. A reassessment of crop loss from ozone. *Environ. Sci. Technol.* 17 (12): 572A–581A

Impact of PM (i.e. dust, black carbon) on crop production

1. Inhibit respiration and photosynthesis
2. Cause chlorosis and death of leaf tissue
3. change soil pH adverse to crop growth

Decreasing trends of $PM_{2.5}$ in future



- Compared to O_3, $PM_{2.5}$ is more related to emission reductions: close to 30% reduction in RCP 4.5 and 60% reduction in RCP 8.5

- By the end of 2050s, the $PM_{2.5}$ in the nine regions is less than 5 ug/m^3, with 16% to 39% reduction in RCP 4.5 and 28% to 44% reduction in RCP 8.5.

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Volume 519, Part A, 27 November 2014, Pages 503–511

Bioretention function under climate change scenarios in North Carolina, USA

J.M. Hathaway[a], , , R.A. Brown[b], J.S. Fu[a], W.F. Hunt[c]

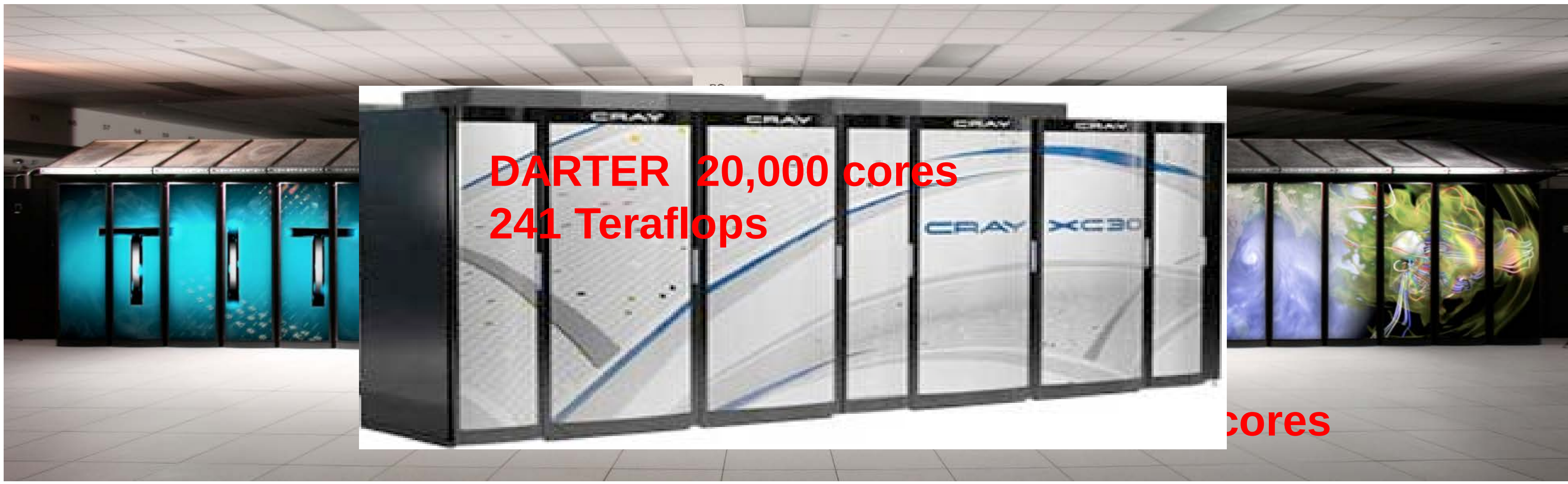
Show more

DOI: 10.1016/j.jhydrol.2014.07.037

Highlights

- Continuous simulation modelling of bioretention with downscaled climate data.
- Examination of effects of projected climate change scenarios on hydrologic function.
- Climate change scenarios result in increased uncontrolled, untreated overflow.
- Substantial additional storage required to ameliorate the effect of climate change.

Peta-scale supercomputer at Oak Ridge National Laboratory **No.2 in the world**



Titan:
18 petaflops

Summit:
150 petaflops
2017

Ted Spiegel / Corbis file

Joshua S. Fu
Professor
Department of Civil and Environmental Engineering
The University of Tennessee

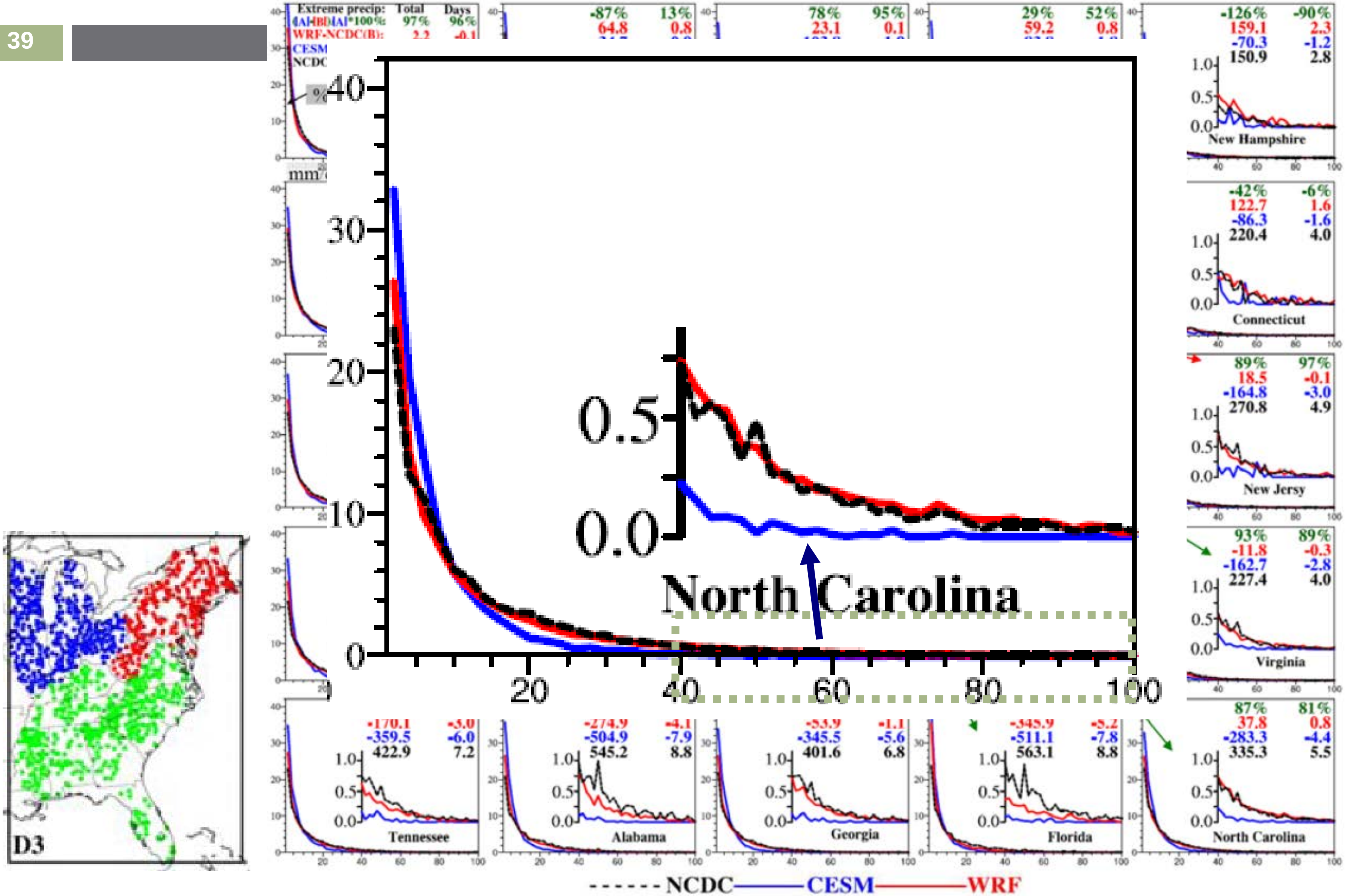
(865) 974-2629

jsfu@utk.edu

Thank you for your attention!

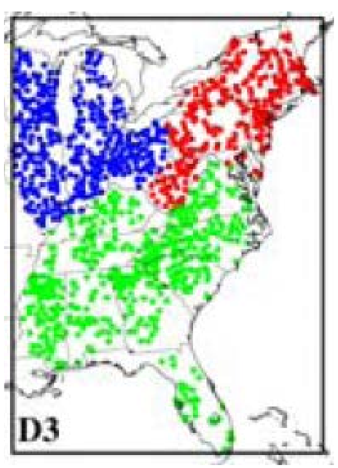
Questions ??????

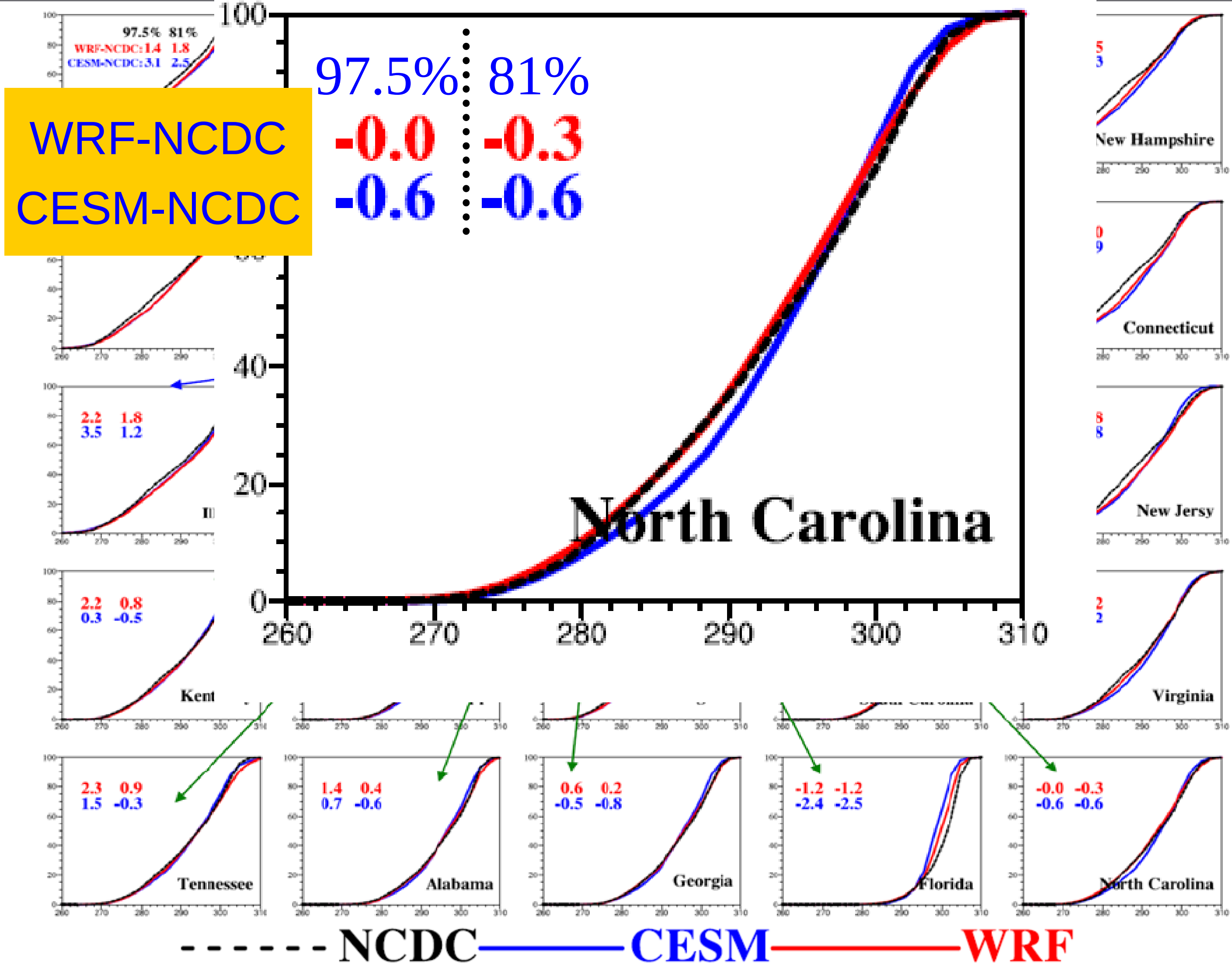
Evaluation of precipitation

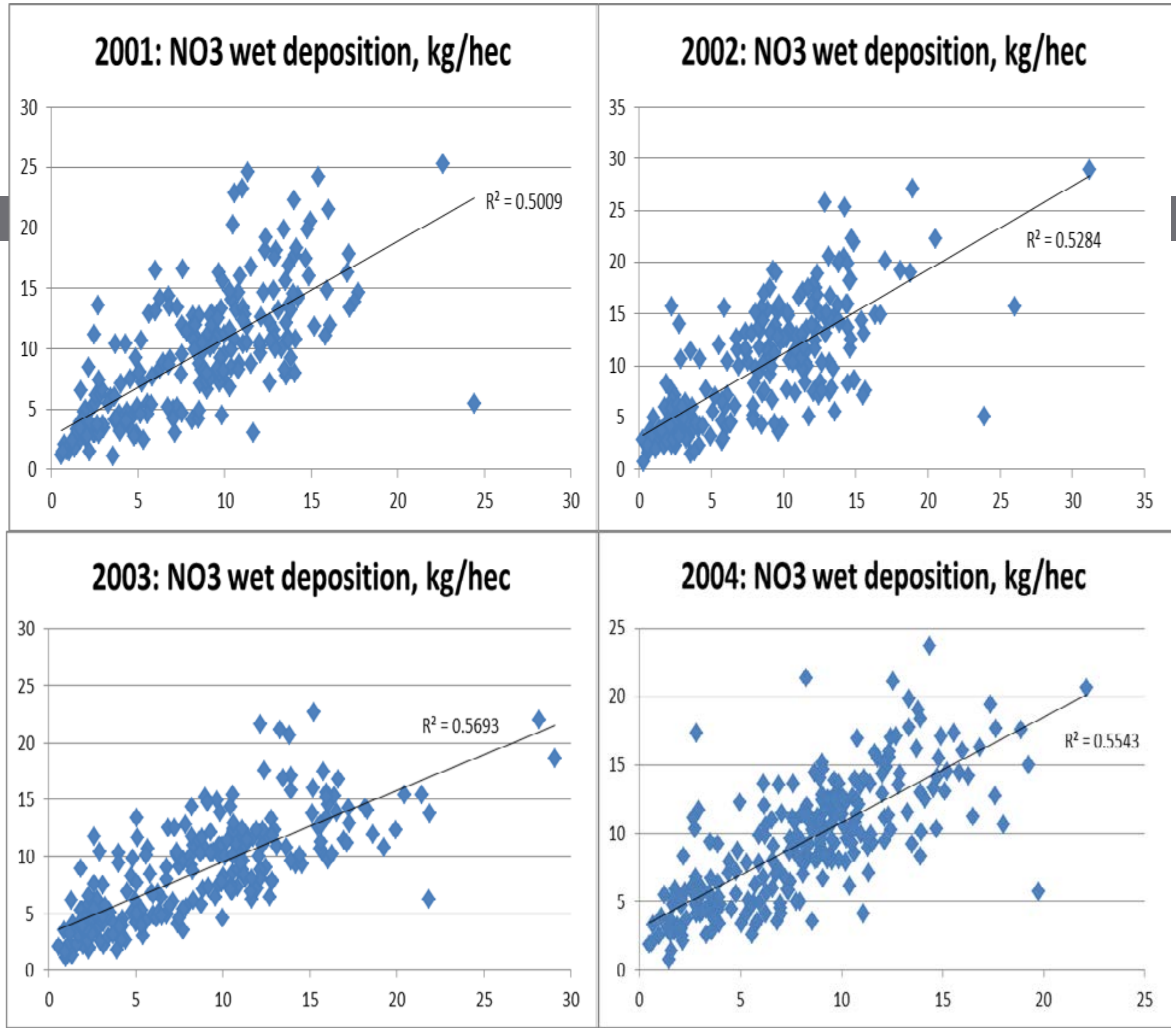


Evaluation of daily maximum temperature (T1/T2)

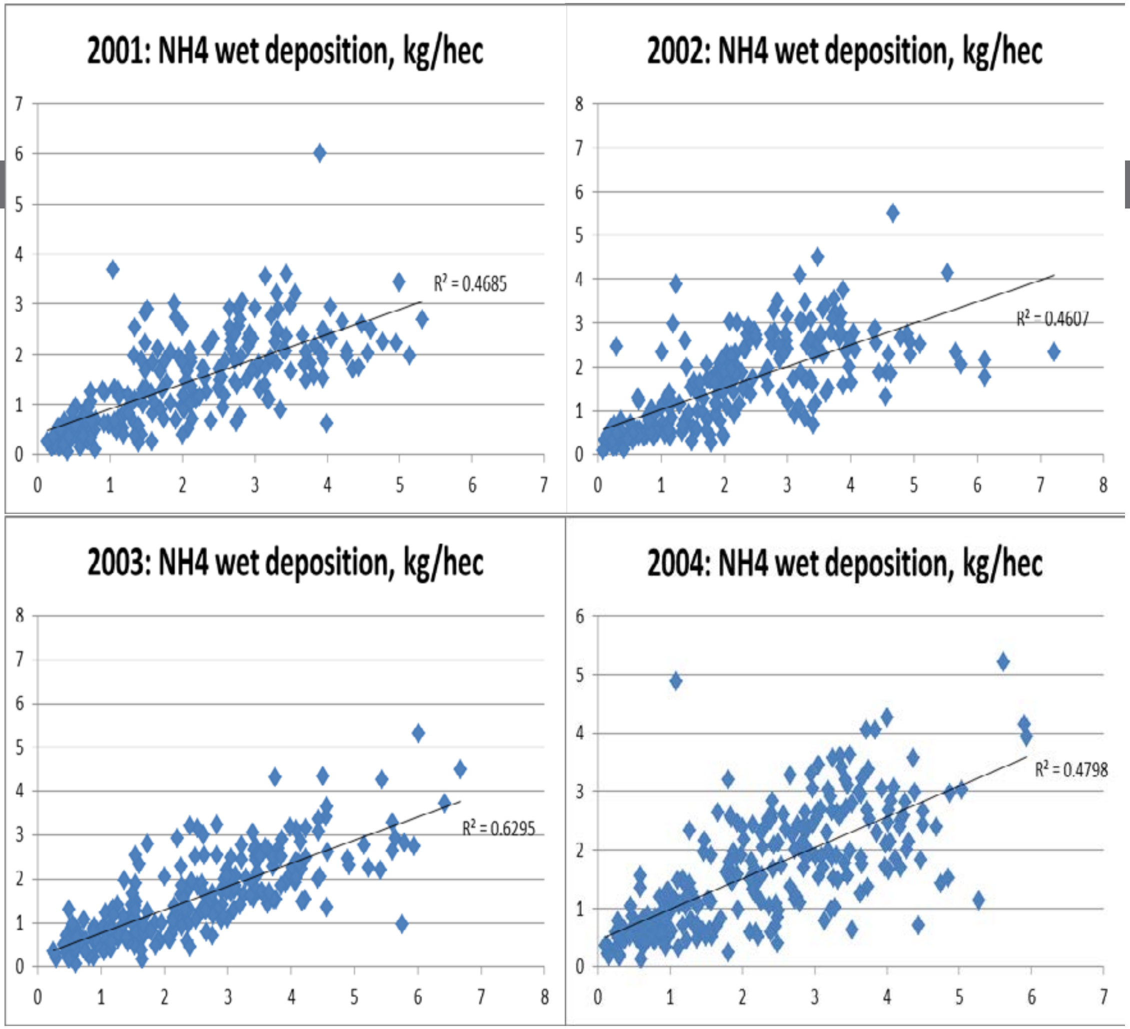
- ❖ 19 states in WRF and 17 states in CESM have bias less than 2 ºC.
- ❖ In WRF, more than half of the states (13 out of 23) shows bias less than 1 ºC





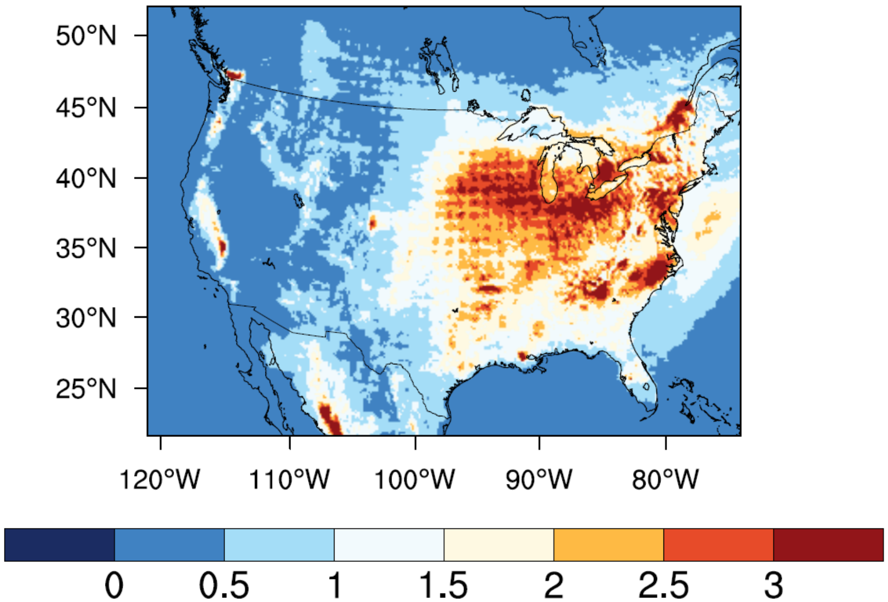


- Annual total NO3 wet deposition, unit: kg/hec
- X-axis: Observation from NADP (National Atmospheric Deposition Program)
- Y-axis: Downscaled CMAQ 12km output

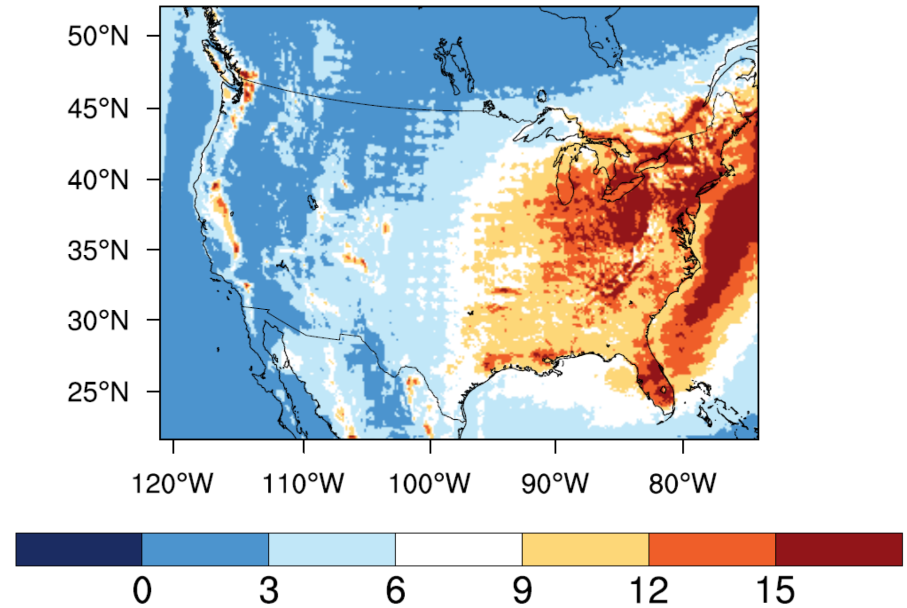


- Annual total NH4 wet deposition, unit: kg/hec
- X-axis: Observation from NADP (National Atmospheric Deposition Program)
- Y-axis: Downscaled CMAQ 12km output

NH4 wet deposition, averaged from 2001 to 2004



NO3 wet deposition, averaged from 2001 to 2004



- Downscaled CMAQ output: Annual total NH4 and NO3 wet deposition, averaged from 2001 to 2004, unit: kg/hec