Modeling the long-term deposition trends in U.S. over 1990—2010 and impacts on ecosystem assessment

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Yuqiang Zhang[1], Rohit Mathur[1], Shawn Roselle[1], Jia Xing[2], Christian Hogrefe[1], Jesse Bash[1], Jonathan Pleim[1], Chuen-Meei Gan[1], David C. Wong[1], Christopher Clark[3]

[1]National Exposure Research Laboratory, U.S. EPA

[2]Tsinghua University, China

[3]National Center for Environmental Assessment, U.S. EPA

Motivation

- Evaluate the model's performance in simulating wet nitrogen deposition and its long-term trends
- Investigate long-term trends in total nitrogen deposition during 1990 to 2010 in U.S., by using air quality simulations with consistent emission inventory in U.S.
- Investigate impacts of nitrogen deposition trends on ecological systems

Model configuration

Coupled WRF-CMAQ two-way model

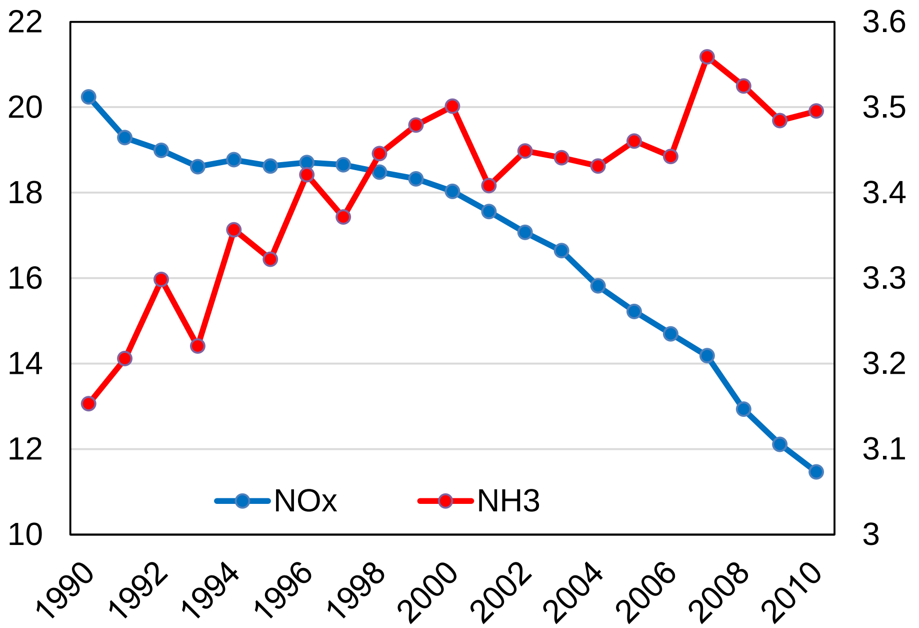
- Horizontal resolution of 36 × 36 km covering the Continental U.S. (CONUS).
- Comprehensive consistent US emission inventory from 1990 to 2010 developed by Xing et al., 2013
- Boundary conditions are obtained from 108 × 108 km WRF-CMAQ hemisphere simulation (Xing et al., 2015)
- Simulation period covering 1990 to 2010

Table 1
List of configurations.

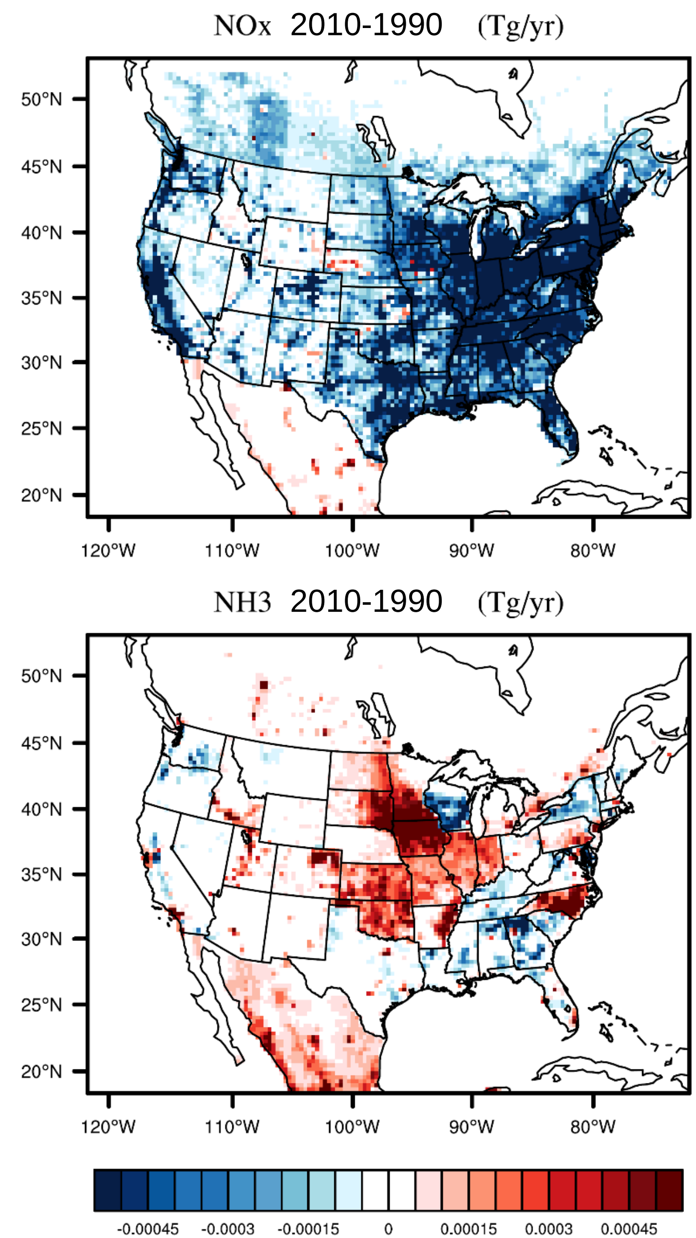
Parameter	Configuration
Emission	Xing et al., (2013)
Planetary Boundary Layer	ACM2 (Pleim, 2007)
Microphysics	Morrison 2-moment
Gas-phase Chemistry	Carbon Bond 05
Aerosol Chemistry	aero6 (Appel et al., 2013)
Land Surface	Pleim-Xiu
Cumulus	Kain-Fritsch 2
Radiation	RRTMG SW & LW
Land use	NLCD 50
Boundary condition	Xing et al., (2015)

Gan et al., 2016

US Emission trends from 1990 to 2010



Jia et al., 2013

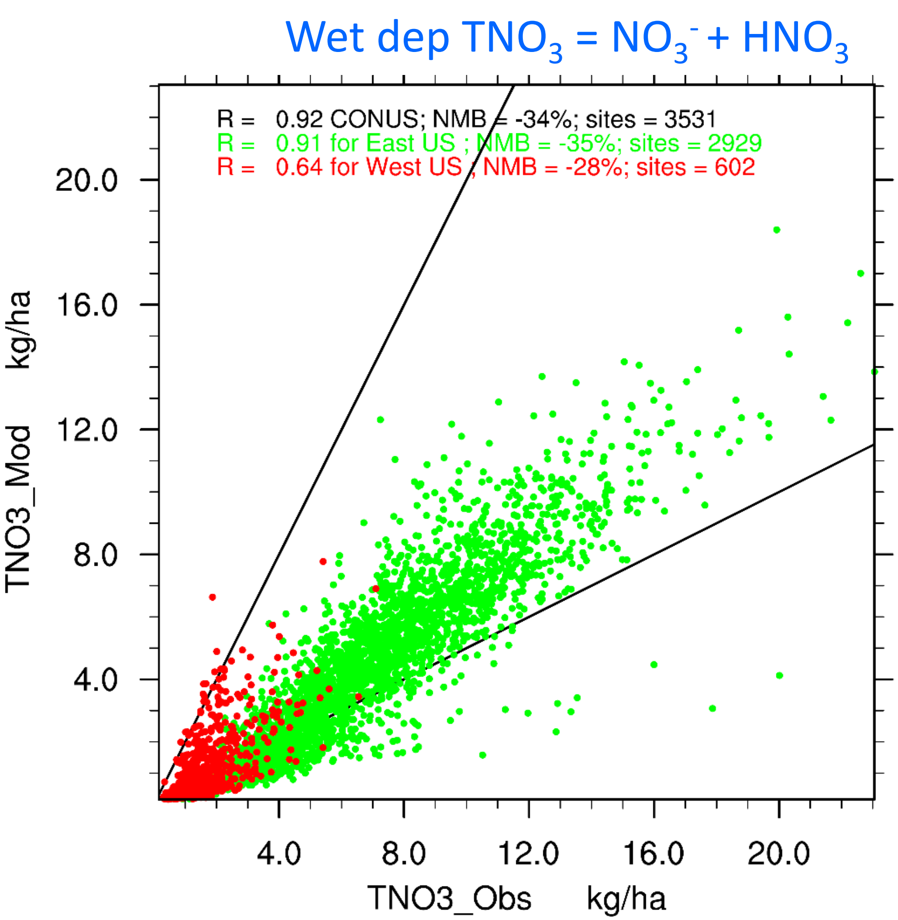


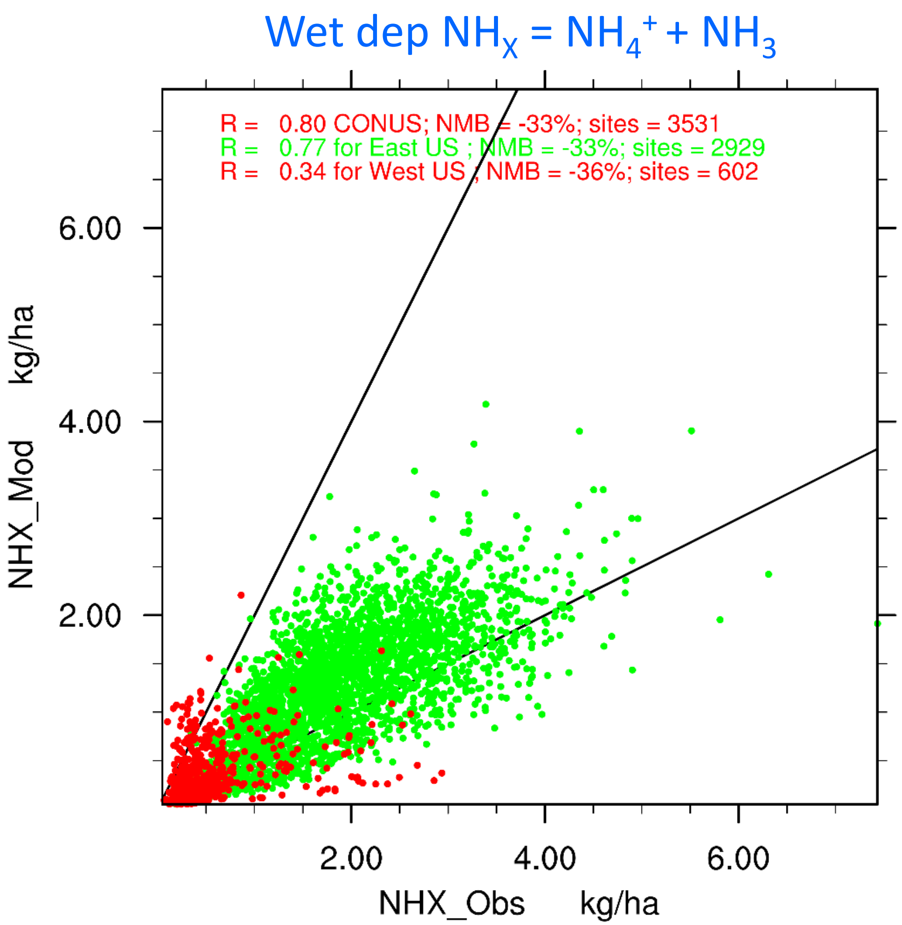
NO_x

NH_3

- Significant decreases for NOx due to the Clean Air Act.
- NH_3 emissions were increased by 11%, particularly in North Carolina and Iowa due to significant increases in the activity of livestock and agriculture.

Model Evaluation

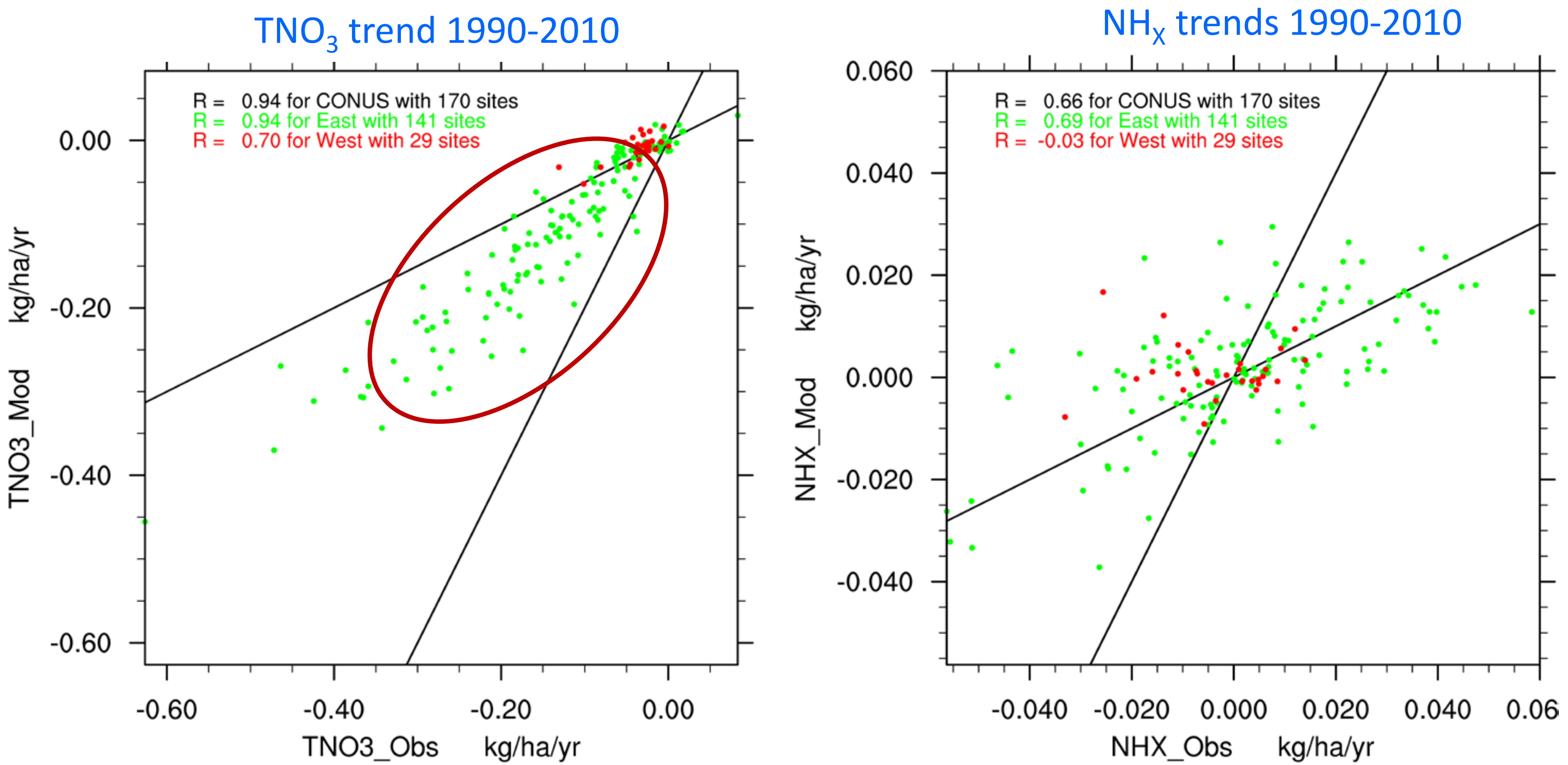




Total 170 valid NADP sites. Data at a location are considered only if at least 18 years of observational data is available for the site, with 75% annual coverage. Precipitation adjustment also considered.

- The model simulates the observed spatial variability
  - The performance is better in Eastern than Western U.S. for both TNO_3 and NH_X
- Model underestimates the nitrogen deposition for both TNO_3 and NH_X

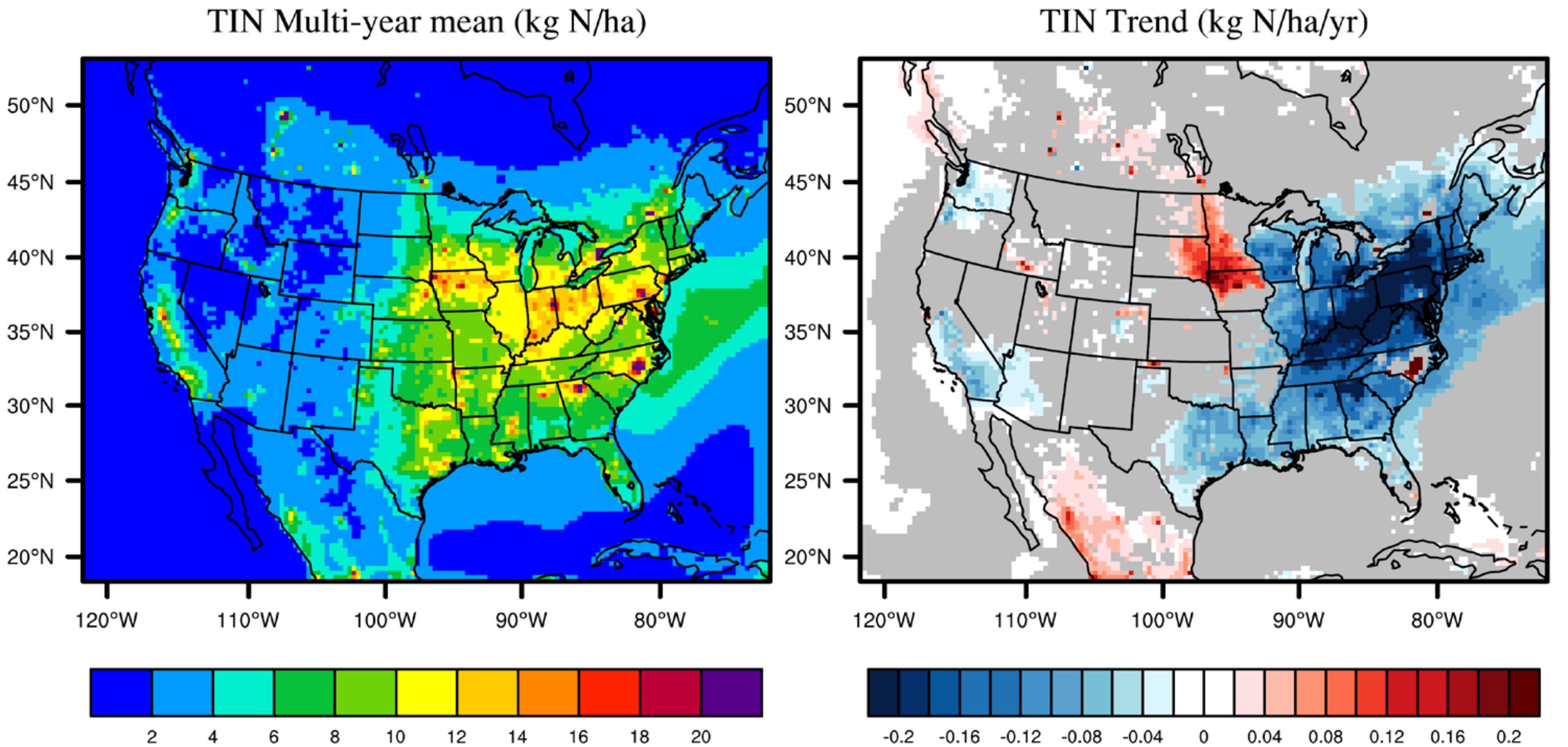
Model Evaluation-cont'd



Total 170 valid NADP sites. Data at a location are considered only if at least 18 years of observational data is available for the site, with 75% annual coverage. Precipitation adjustment also considered. ed. The linear least square fit method was used for the trend analysis.

- For the trend, the performance for TNO_3 is much better than that for NH_X
- East U.S. has a significant decreasing trend in TNO_3 deposition

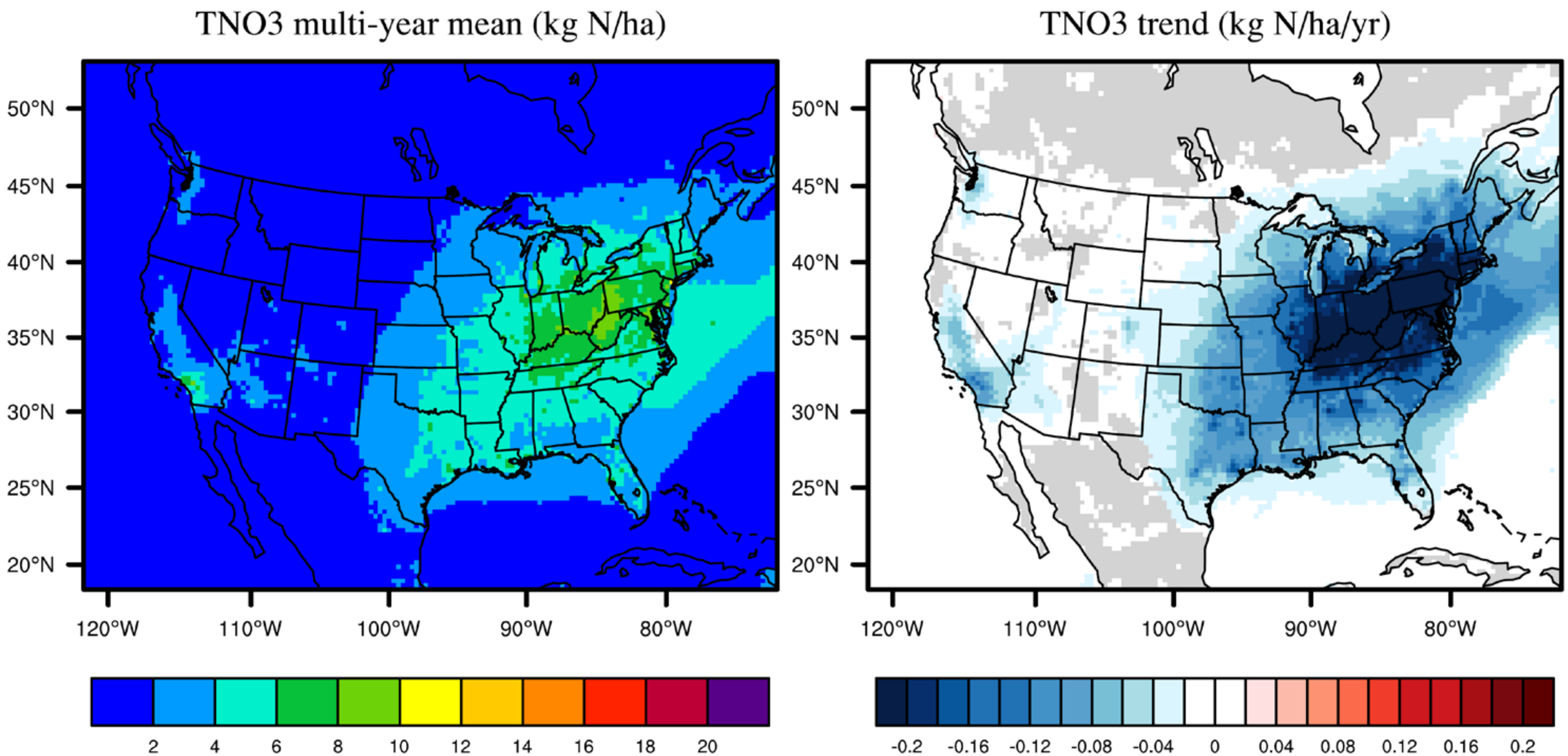
Total Inorganic Nitrogen (TIN) trends



Grey areas in the right panel show regions with the significance of p greater than 0.05 using the Student t test

- For TIN, higher in the East and lower in the West
  - Hot spot of TIN in NC due to high NH_3 emissions
- Significant decrease of the TIN deposition in the East as a result of NOx reductions, and increase over NC, IA, MN and SD.

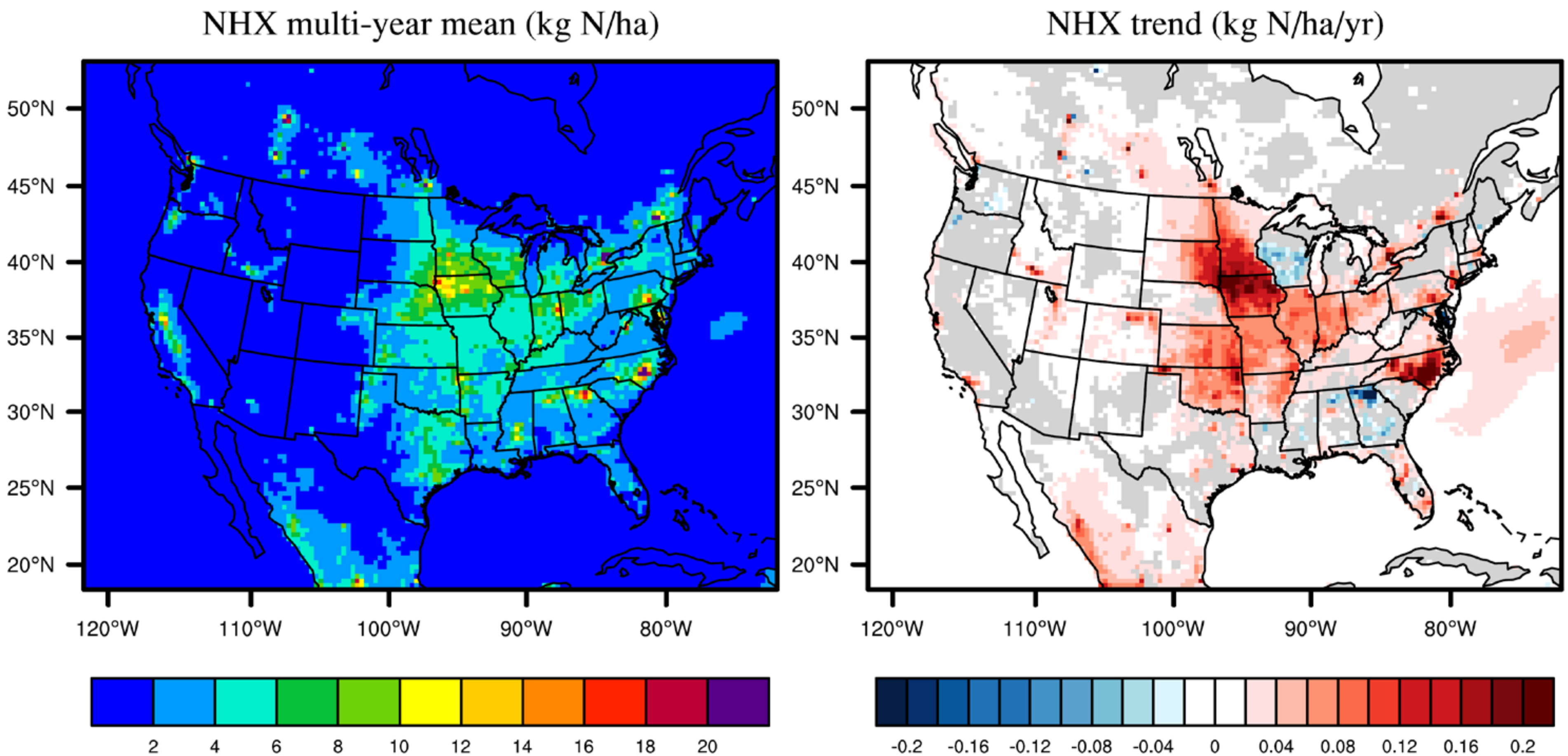
TNO_3 trends (wet + dry)



Grey areas in the right panel show regions with the significance of p greater than 0.05 using the Student t test

- Significant decrease of TNO_3 across the U.S., especially in the East and CA

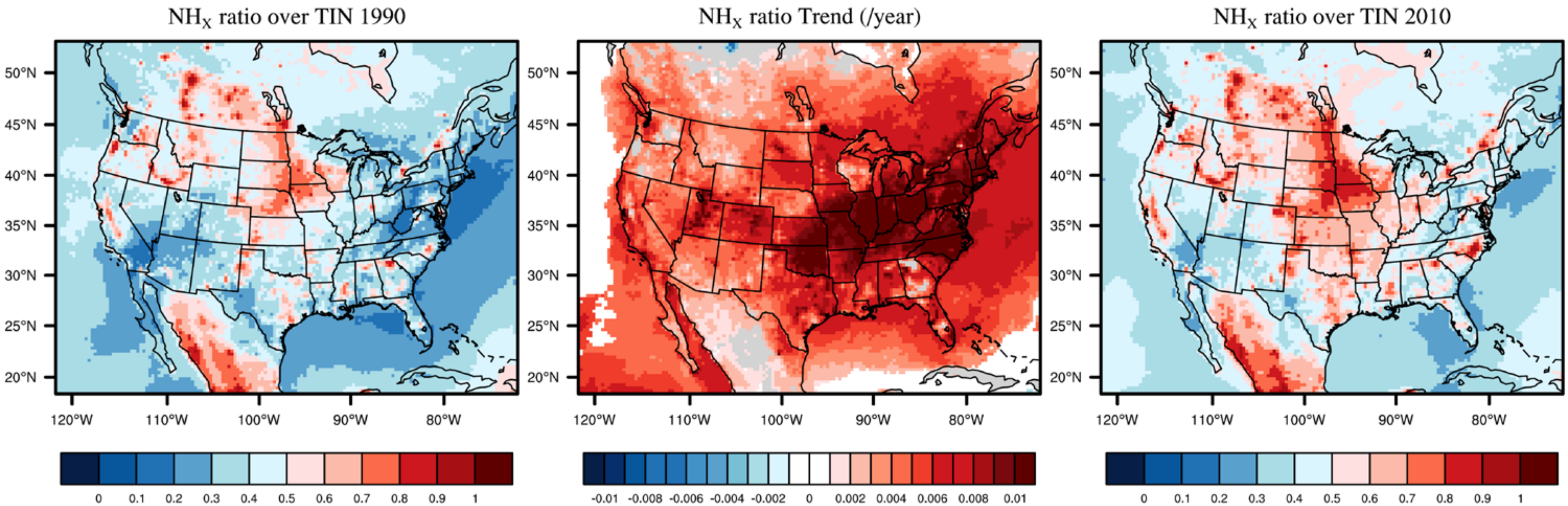
NH_x trends (wet + dry)



Grey areas in the right panel show regions with the significance of p greater than 0.05 using the Student t test

- Significant increase in NH_X in Central U.S., and also over the east coast, especially in NC

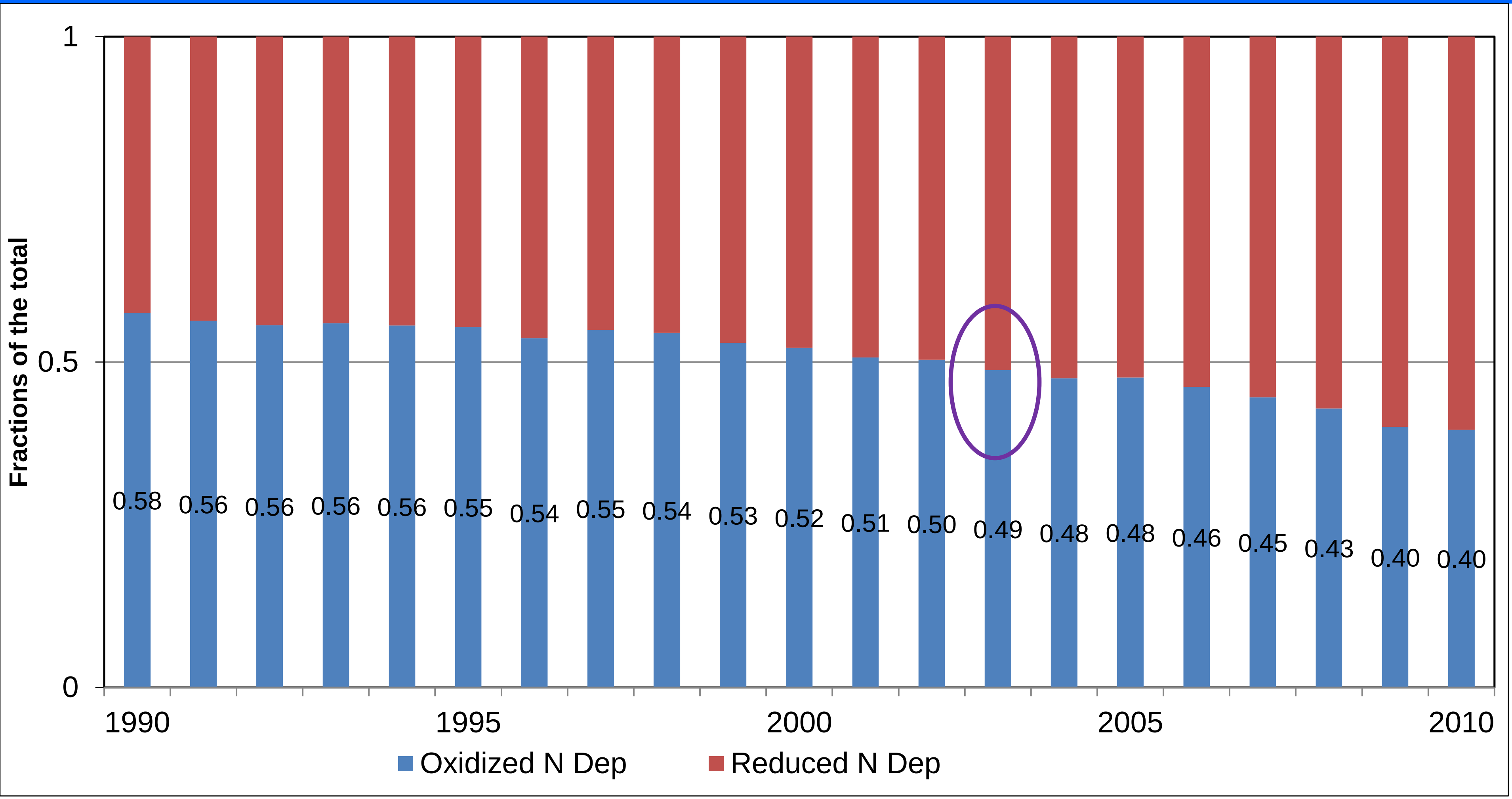
Changing NHx / TIN Ratio



The NHx (wet + dry) ratio over the TIN in 1990 (left), 2010 (right), and the trends (middle). The values shown in the middle are with the significance of p less than 0.05. Red colors means NHx dominates region.

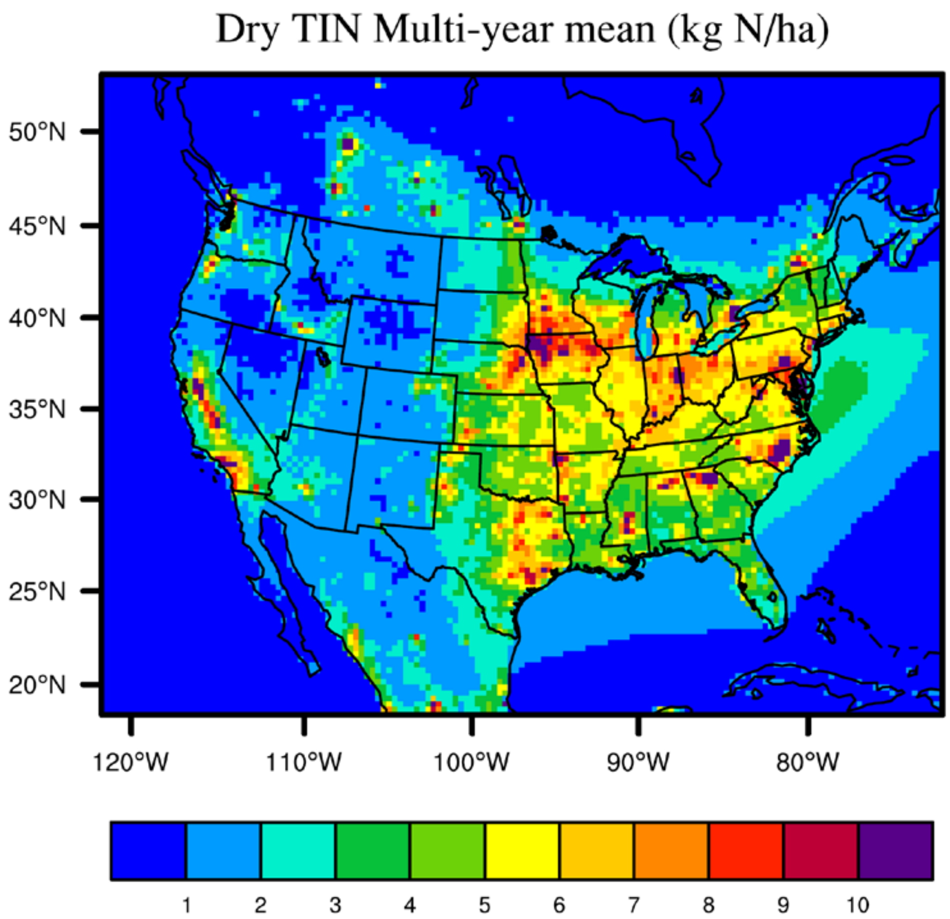
- Larger regions (24% of total grid cells in 1990, and 61% of total in 2010) are shifting from TNO_3–dominated to NH_X–dominated, consistent with Li et al. (2016)
- The fraction of NHx has increased significantly over the past 20 yrs (middle), as a result of NO_x emission decrease and NH_3 increases.

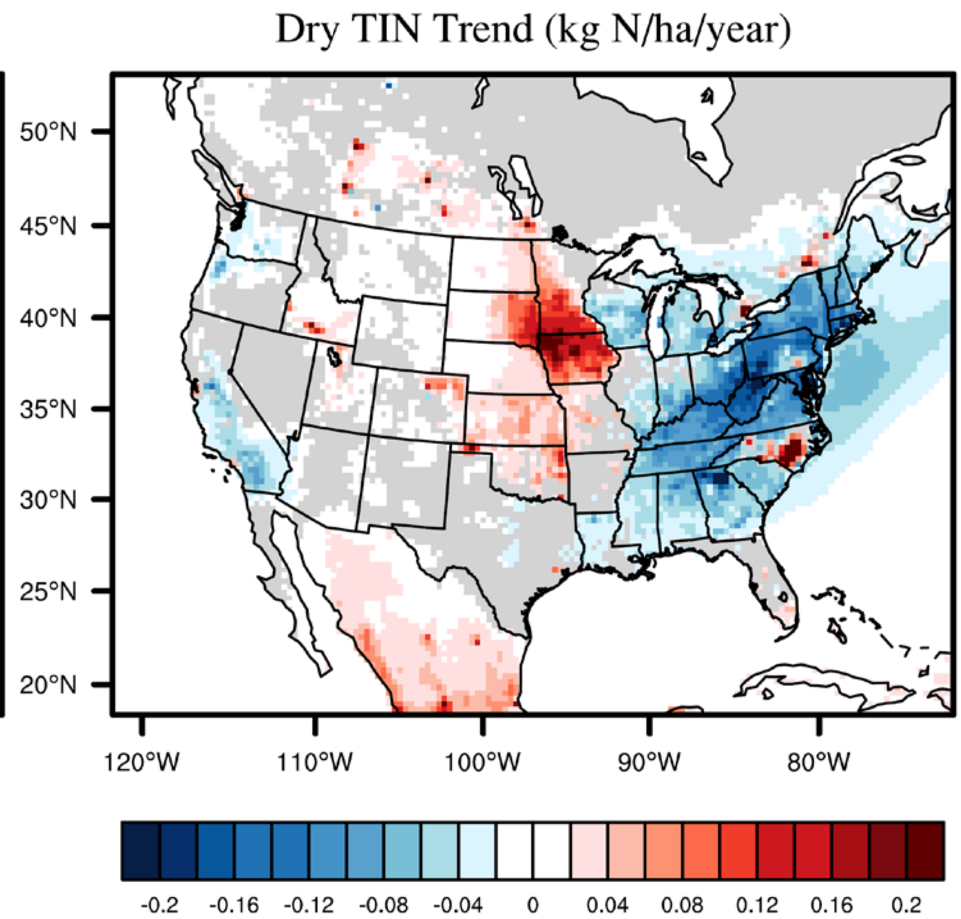
U.S. Total TNO_3 vs. NH_X



- U.S. oxidized nitrogen deposition (TNO_3) is decreasing, and reduced nitrogen deposition (NH_X) is increasing
- The total U.S. N-deposition shifts to ammonium-dominated after 2003

Dry deposition trends ($TNO_3 + NH_x$)

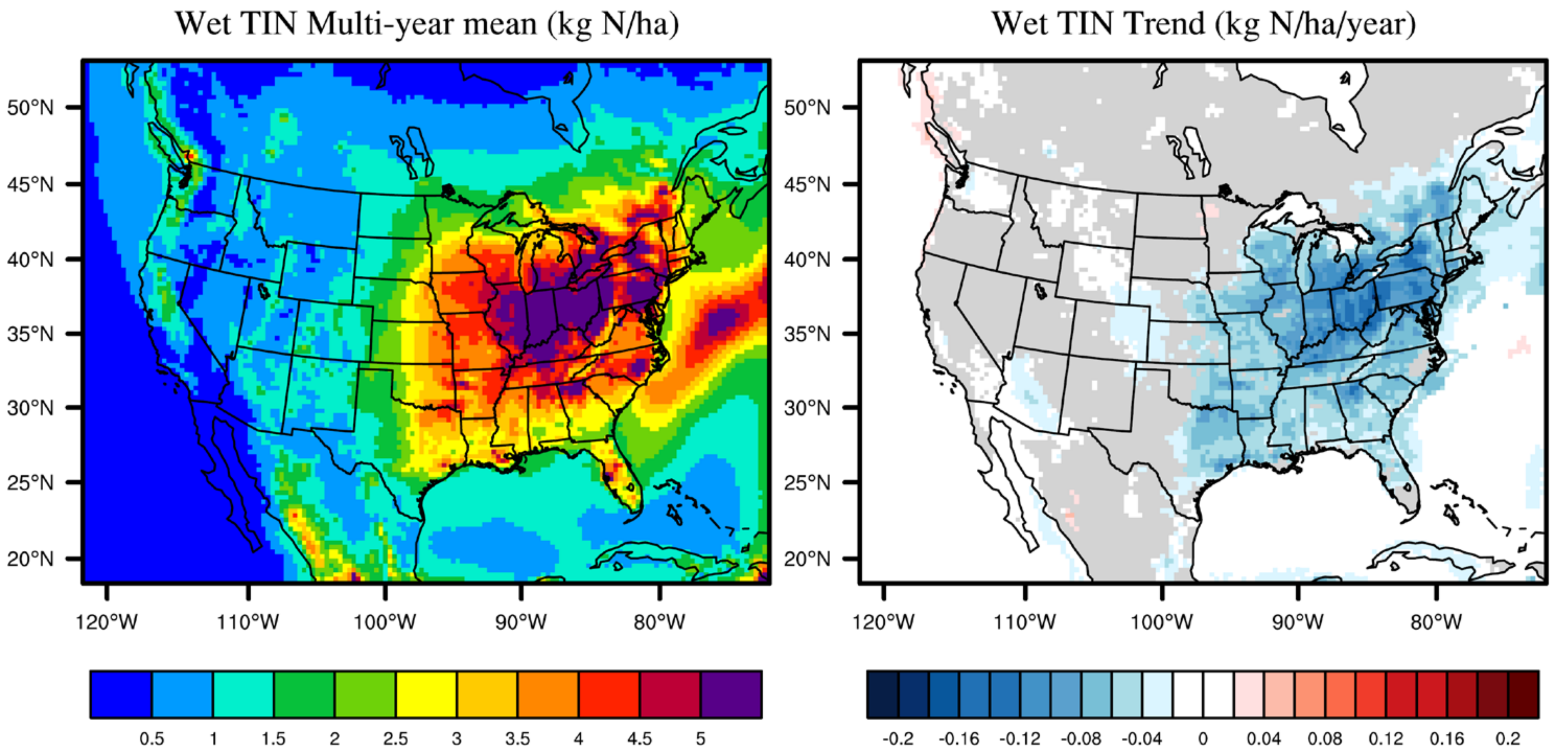




Grey areas in the right panel show regions with the significance of p greater than 0.05 using the Student t test

- Dry deposition decreases in the East and CA, increases in NC, MN, SD and IA.

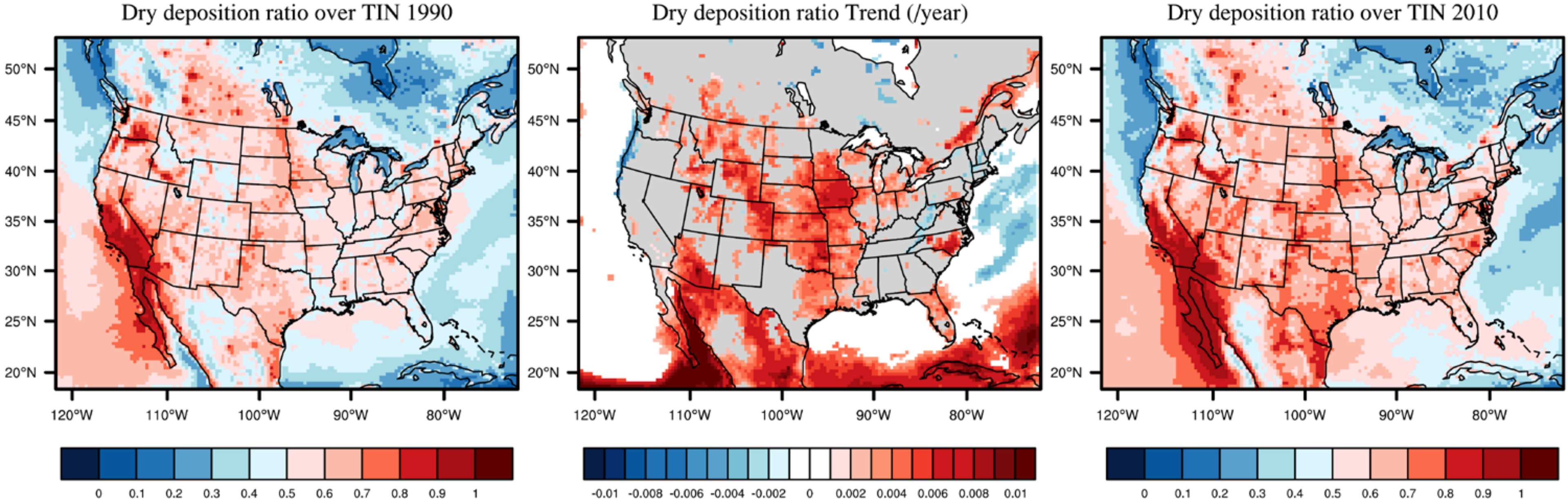
Wet deposition trends ($TNO_3 + NH_x$)



Grey areas in the right panel show regions with the significance of p greater than 0.05 using the Student t test

- Wet deposition decreases all over the domain

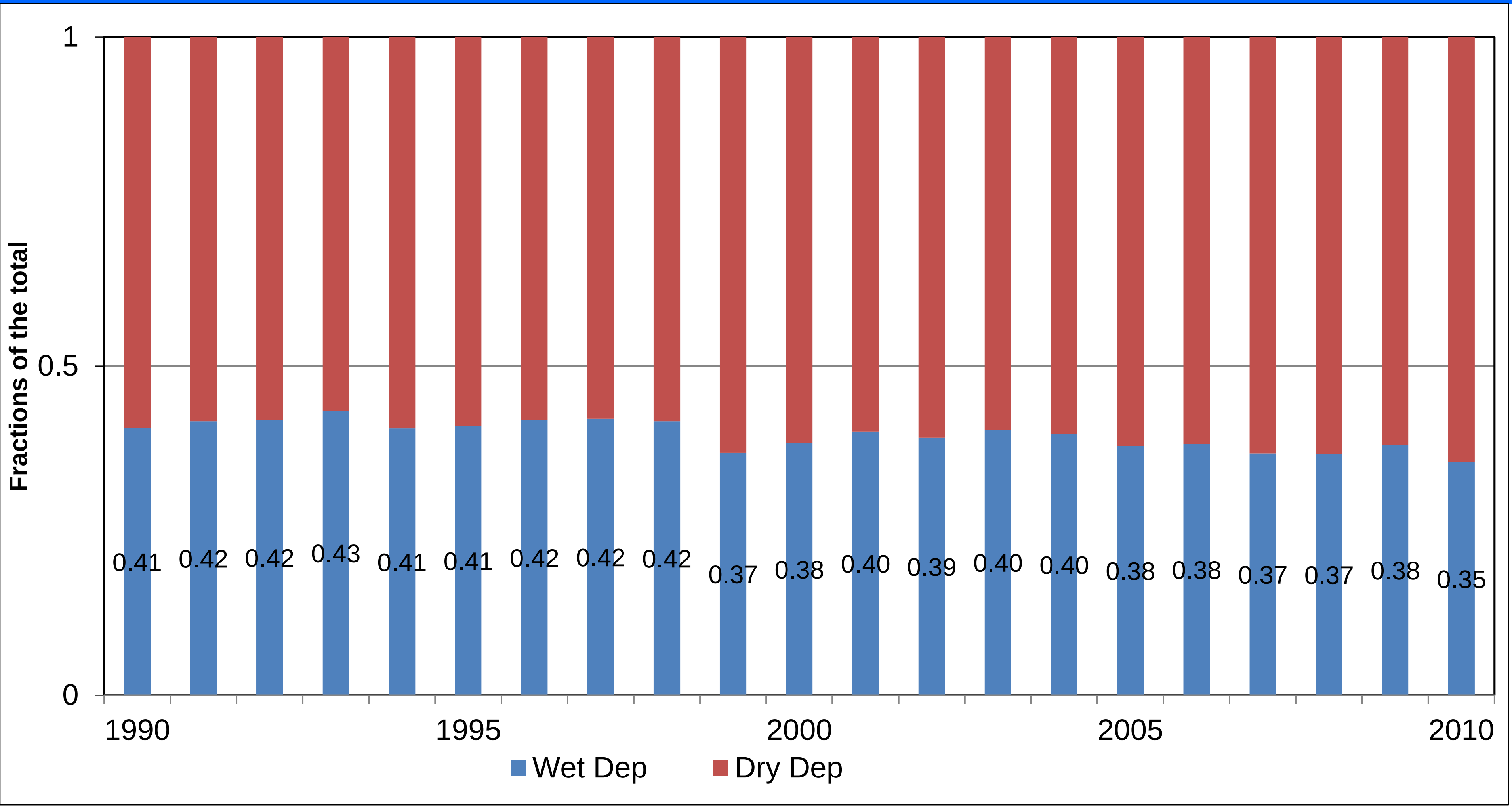
Dry deposition fractions trends



The ratio of dry deposition (TNO_3 + NH_X) over the TIN in 1990 (left), 2010 (right), and the trends (middle). The values shown in the middle are with the significance of p less than 0.05. Red colors means DD dominates.

- More than 80% of U.S. areas are dominated by dry deposition for all the years
- The fractions of dry deposition over the TIN were also increasing during the past 2 decades

U.S. Total Dry vs. Wet deposition



- Dry deposition dominates the total deposition in U.S. all the time

Nitrogen Deposition Effects on Ecosystem

PNAS

Conditional vulnerability of plant diversity to atmospheric nitrogen deposition across the United States

Samuel M. Simkin[a,1], Edith B. Allen[b,c], William D. Bowman[a], Christopher M. Clark[d], Jayne Belnap[e], Matthew L. Brooks[f], Brian S. Cade[g], Scott L. Collins[h], Linda H. Geiser[i], Frank S. Gilliam[j], Sarah E. Jovan[k], Linda H. Pardo[l], Bethany K. Schulz[m], Carly J. Stevens[n], Katharine N. Suding[a], Heather L. Throop[o,p], and Donald M. Waller[q]

[a]Institute of Arctic and Alpine Research and Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO 80309; [b]Department of Botany and Plant Sciences, University of California, Riverside, CA 92521; [c]Center for Conservation Biology, University of California, Riverside, CA 92521; [d]National Center for Environmental Assessment, United States Environmental Protection Agency, Washington, DC 20460; [e]Southwest Biological Science Center, United States Geological Survey, Moab, UT 84532; [f]Western Ecological Research Center, United States Geological Survey, Oakhurst, CA 93644; [g]Fort Collins Science Center, United States Geological Survey, Fort Collins, CO 80226; [h]Department of Biology, University of New Mexico, Albuquerque, NM 87131; [i]Pacific Northwest Region Air Resource Management Program, United States Department of Agriculture Forest Service, Corvallis, OR 97339; [j]Department of Biological Sciences, Marshall University, Huntington, WV 25755; [k]Forest Inventory and Analysis Program, United States Department of Agriculture Forest Service, Portland, OR 97339; [l]Northern Research Station, United States Department of Agriculture Forest Service, Burlington, VT 05405; [m]Forest Inventory and Analysis Program, United States Department of Agriculture Forest Service, Anchorage, AK 99501; [n]Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, United Kingdom; [o]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287; [p]School of Life Sciences, Arizona State University, Tempe, AZ 85287; and [q]Department of Botany, University of Wisconsin, Madison, WI 53706

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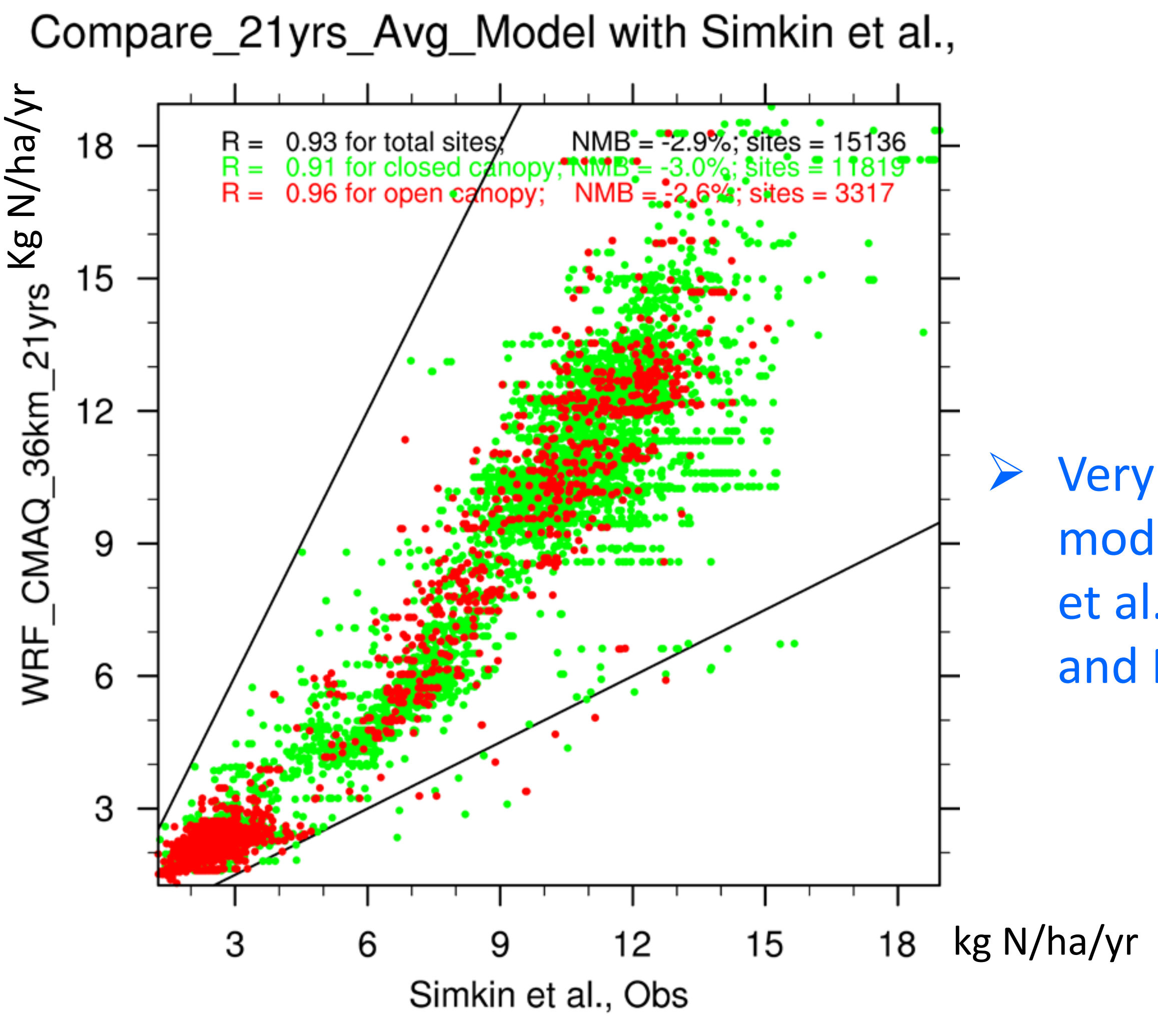
- General response of species richness to N deposition across different vegetation types, soil conditions, and climate variables for 15,136 observation sites, including forest, woodland, shrubland and grassland.

- Derived the latest critical load (CL) for those observation sites

Total N Deposition Evaluation

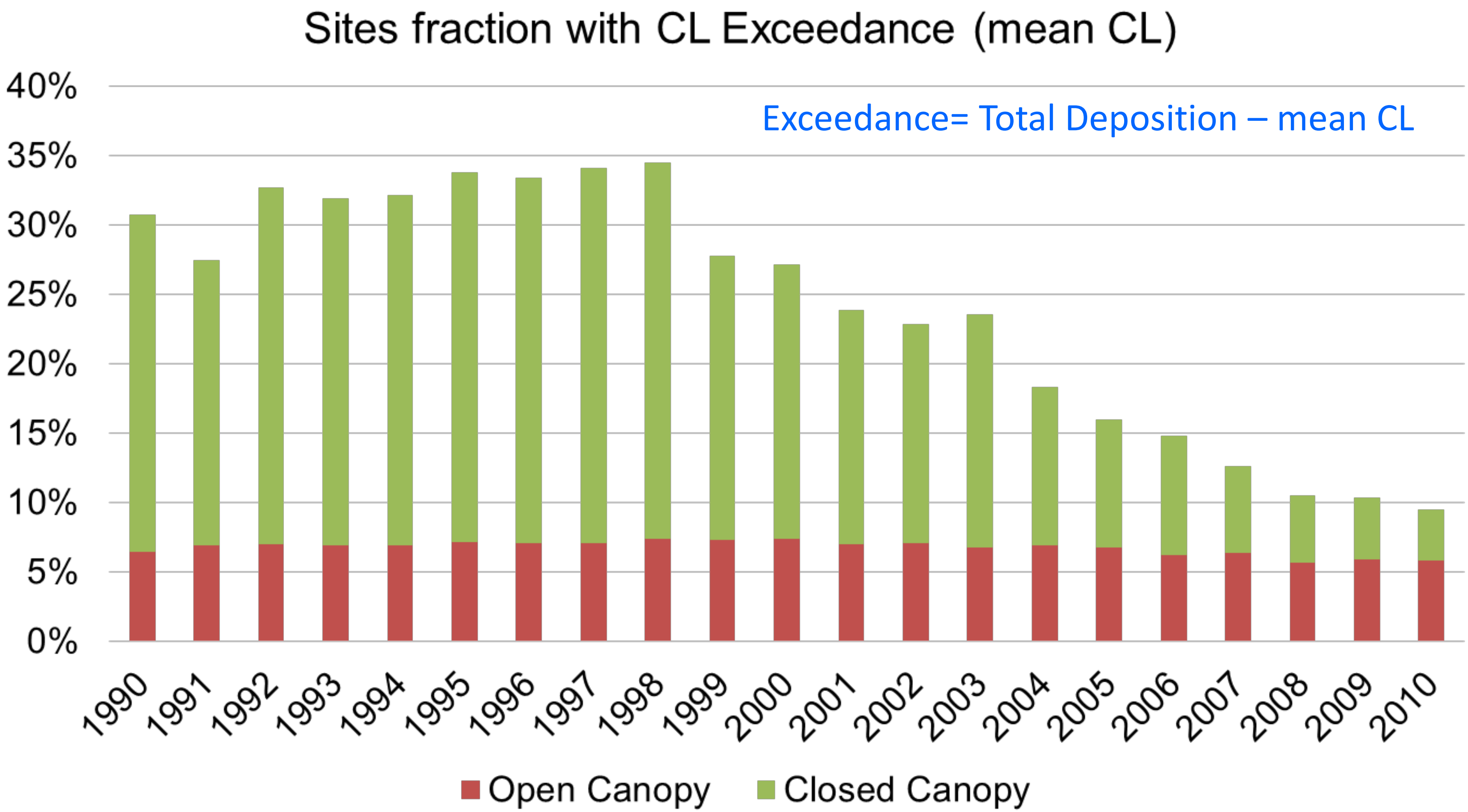


Total: Model = 1.033552 * (Simkin-8.338896) + 8.09399
Close: Model = 1.032598 * (Simkin-8.977433) + 8.707818
Open: Model = 1.06712 * (Simkin-6.063684) + 5.906824

- Very good agreement between our modeled N deposition with Simkin et al., 2016 with R larger than 0.9, and NMB around -3%.

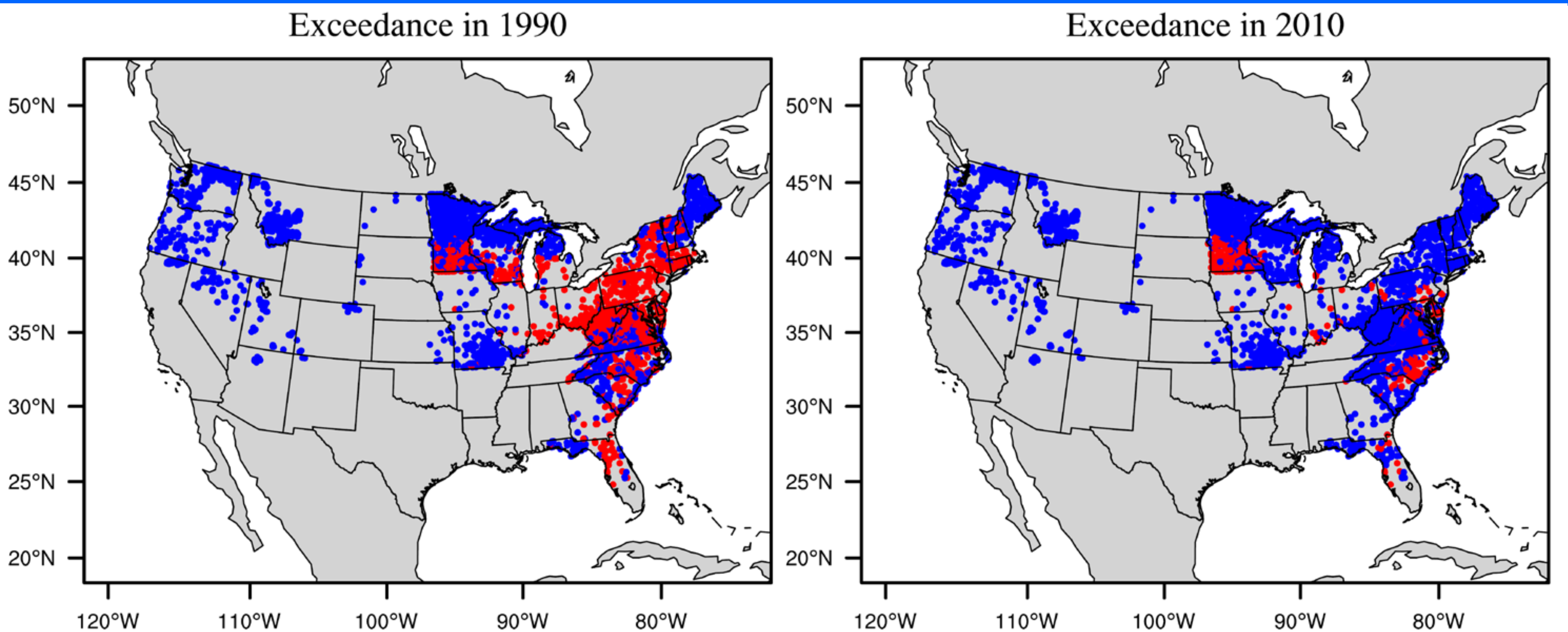
Total depositions in Simkin et al., 2016 are from 27 yrs NADP Wet Dep. + (2002-2011) CMAQ Dry Dep.

Critical Load Exceedance by Canopy Types



- For all the canopy types, the fraction of the total sites with CL exceedances increases till 1998, and then decrease.
- The changes in the closed canopy seems to dominate the total changes, and the exceedances in the open canopy seems to not change at all.

Critical Load Exceedance Spatially and Temporally



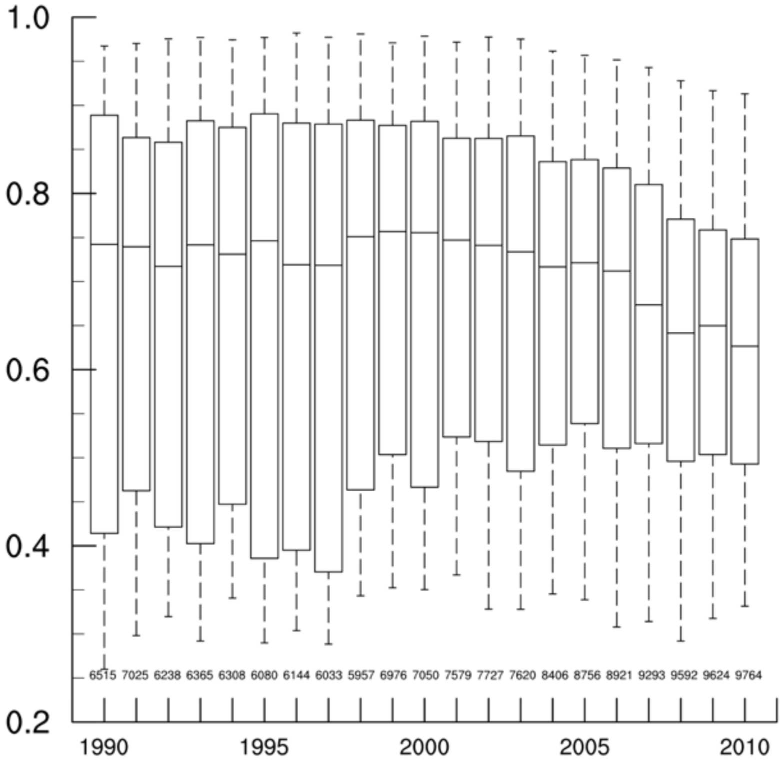
Blue color means the total deposition is below the CL at the site, and red color means there is CL exceedance.

- No exceedance at all in Western U.S. (west of 110°W) from 1990 to 2010 for the 3940 observation sites
- The number of sites exceeding the CL are decreasing in the East (31% of total in 1990, and 9% of total in 2010), as the total deposition is decreasing at these sites

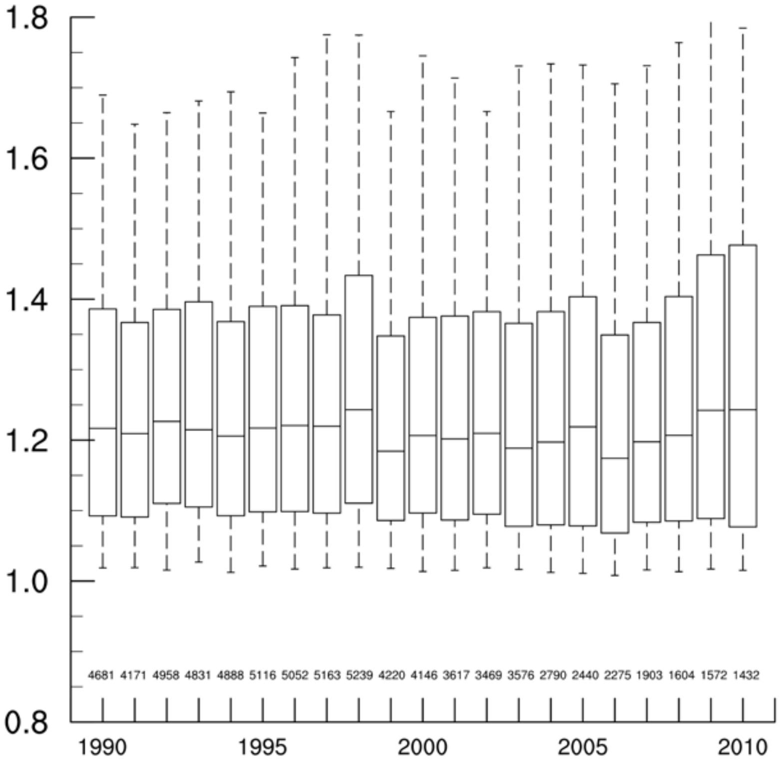
Critical Load Exceedance Spatially and Temporally

Fractions = (total N deposition)/ (critical load) in East U.S.

Sites with total deposition below the CL



Sites with CL exceedances



- The fractions for the sites with total deposition below the CL, decreasing in Eastern U.S.
- The fractions for the sites with CL exceedances not decreasing

Conclusion

- The coupled WRF-CMAQ model can predict the wet nitrogen deposition and its trends very well, compared with the NADP network
- The total deposition are decreasing in most of U.S. as a result of the NOx reductions, except for some states (NC, IA, MN, SD)
- The nitrogen deposition in U.S. are transitioning from nitrate-dominated into ammonium-dominated
- Dry deposition has a larger influence on the total deposition in U.S.
- In general, the exceedances of the critical loads in U.S. sites are decreasing, especially in the Eastern U.S.

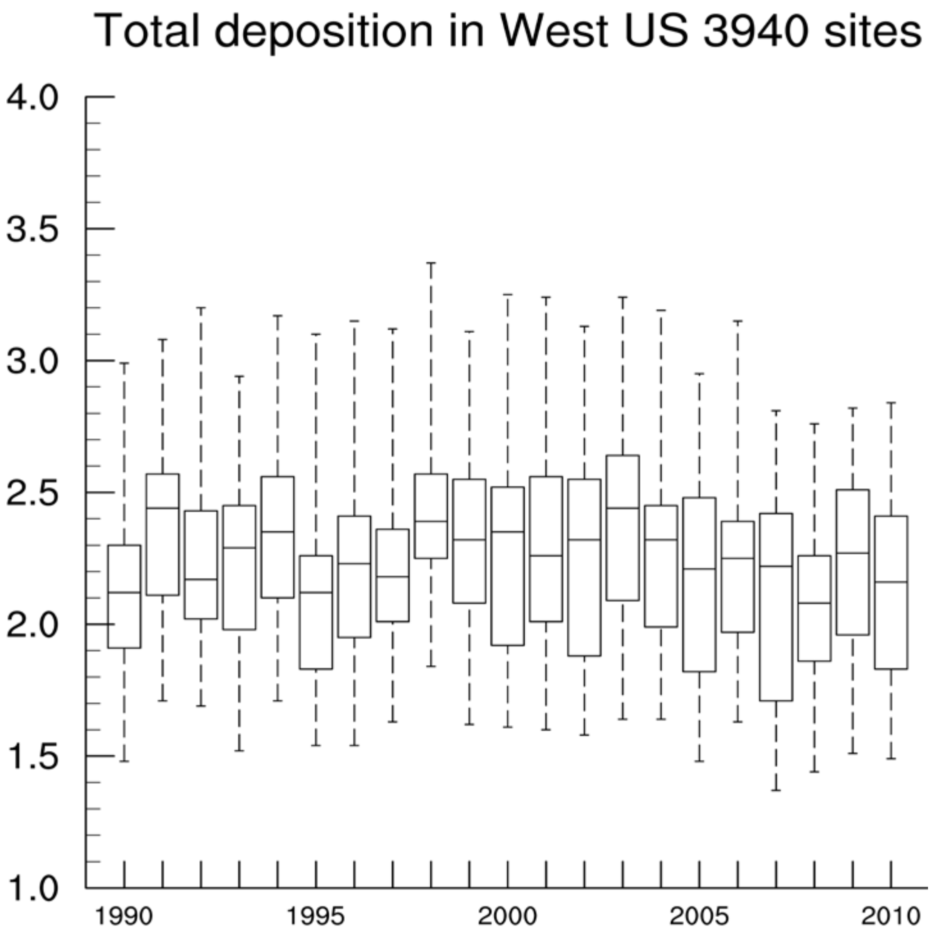
Thank you very much!

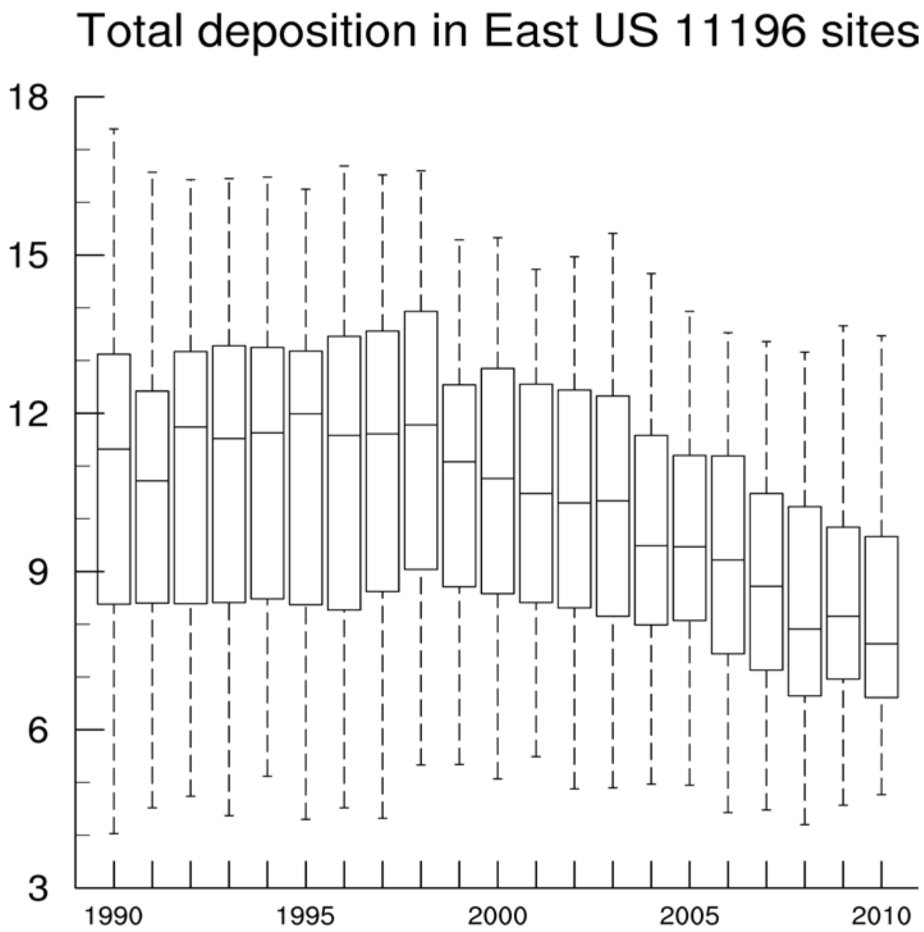
- **Disclaimer**. Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official agency policy.

- **Acknowledgements**. Yuqiang Zhang holds ORISE Postdoctoral fellowship at U.S. EPA.

- Extra slides

CL exceedance spatially and temporally





- The total deposition decreases in east, while not clear for the west.

The fraction of the total deposition over the critical load for the sites in West U.S