Improvements to the Noah Land Surface Model in WRF-CMAQ and its Application to Future Changes in the Chesapeake Bay Region

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Acknowledgments: Chesapeake Bay Program's Lewis Linker, Kyle Hinson, Gary Shenk, and Gopal Bhatt

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Regional Climate and Air Quality

NOAA Technical Report NOS CO-OPS 083

GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES

Sea Level Rise Estimate Grows Alarmingly Higher in Latest Federal Report

Sources: http://www.cbf.org
https://insideclimatenews.org/
https://tidesandcurrents.noaa.gov/

PNAS

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Increasing importance of deposition of reduced nitrogen in the United States

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USGS science for a changing world

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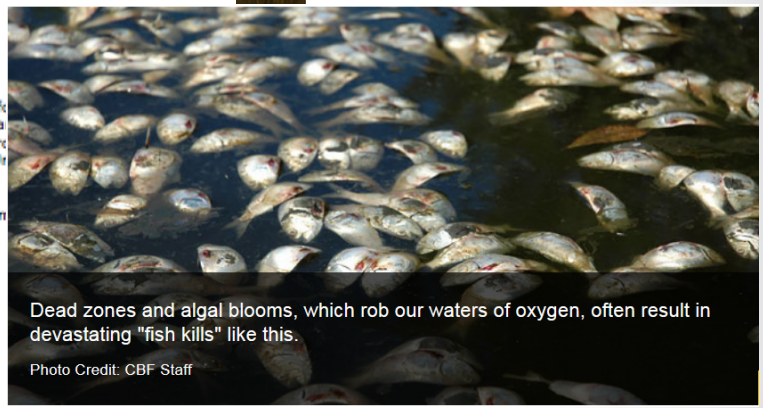
Regional Impacts



- **Consistently study future climate, land use, air quality impacts in the Chesapeake Bay**
- **Apply a "One-atmosphere" modeling system → Towards a "One-biosphere" system**

WRF-CMAQ Simulation Design

"One Atmosphere" Modeling System

Global-to-Regional Emission Projections

RCP (Representative Concentration Pathways)
Greenhouse gas concentration trajectories

EPA Final Rule for Greenhouse Gas Emissions and Fuel Efficiency Phase 2

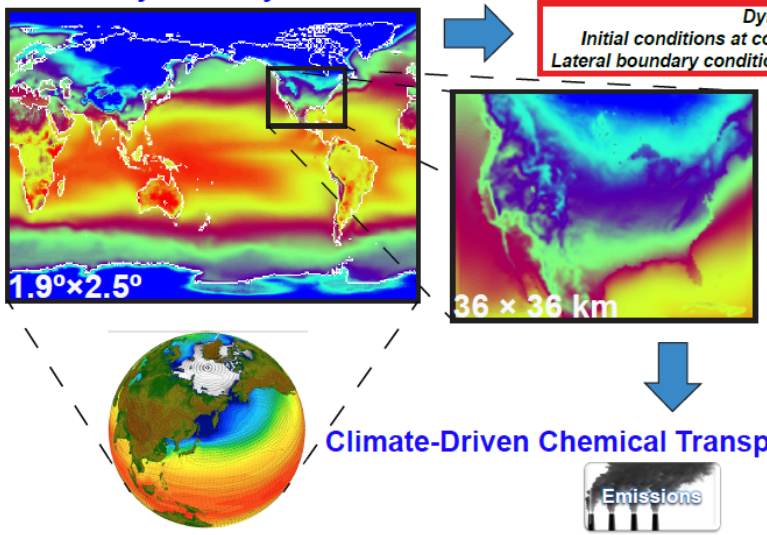
Regional Emission Processing (SMOKE)

Total SMOKE Emissions

- Area
- Point
- Mobile

U.S. EPA 2011 National Emissions Inventory

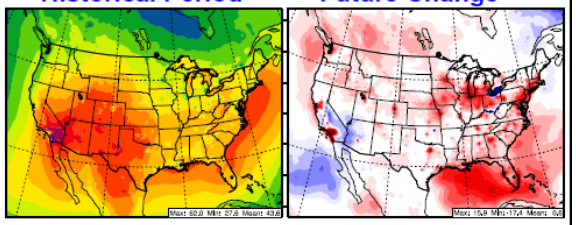
Community Earth System Model



Modified WRF-CMAQ-EPIC Model System

Dynamical Downscaling Technique:
Initial conditions at coarse resolution (soil moisture, temp., SST, sea ice)
Lateral boundary conditions every 6 hours (wind, pressure, temperature, and humidity)

Air Quality Projections



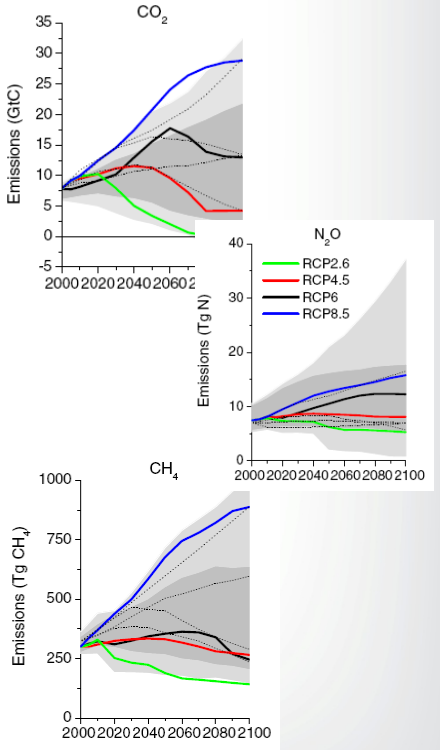
Climate-Driven Chemical Transport, Crop, & Soil Model

Regional Coupled Model Inputs:
High resolution topography
Land/water interfaces
Land use/land cover
Potential physics improvements

Regional Coupled Model Outputs:
Surface fields
Atmospheric fields
Radiation fields
Air quality - climate predictions

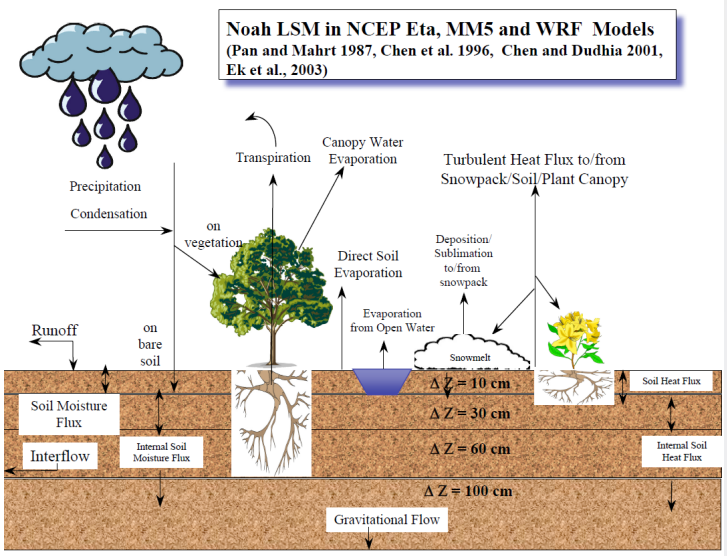
RCP4.5 Scenario

- Historical Period: 1996 - 2005
- Future Period: 2046 - 2055



Noah LSM in WRF-CMAQ

- **Most WRF-CMAQ air quality modeling studies use Pleim-Xiu (P-X) LSM in WRF**
- **P-X is not suitable for future climate applications as it relies on surface moisture and temperature nudging**
- **Thus Noah is widely used in WRF for future climate/air quality applications**
- **The current version of WRF/Noah is limited in its inputs to CMAQ and lacks physical consistency with some parameterizations in CMAQ**
- **Motivation for our work to update WRF/Noah-CMAQ model system →**



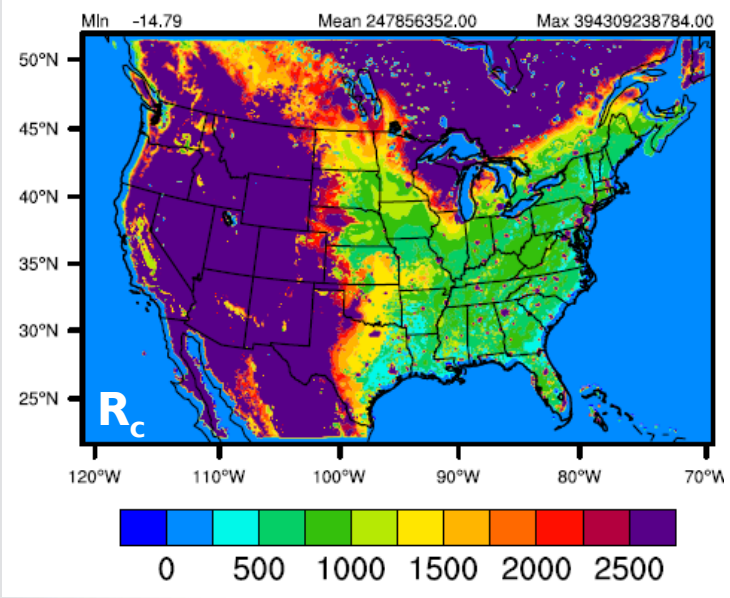
NCAR LSM group meeting (Fei Chen, 2007)

- ✓ Noah stomatal conductance
- ✓ Subgrid-scale land-use (Mosaic)
- ✓ Update soil/vegetation tables
- ✓ Modify top soil layer depth

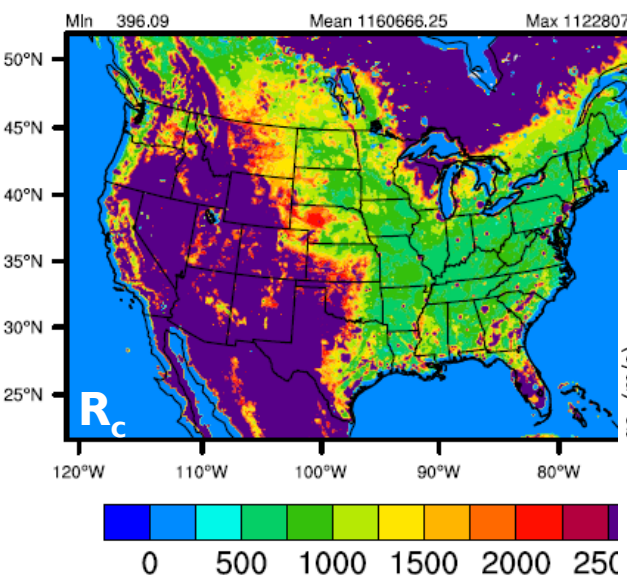
WRF/Noah R_c to CMAQ

WRF/Noah R_c (canopy resistance, i.e., bulk stomatal resistance) used as input into coupled WRF-CMAQ → Key parameter for CMAQ deposition

A. WRF/Noah-CMAQ
Old Stand-alone Calc. (s/m)

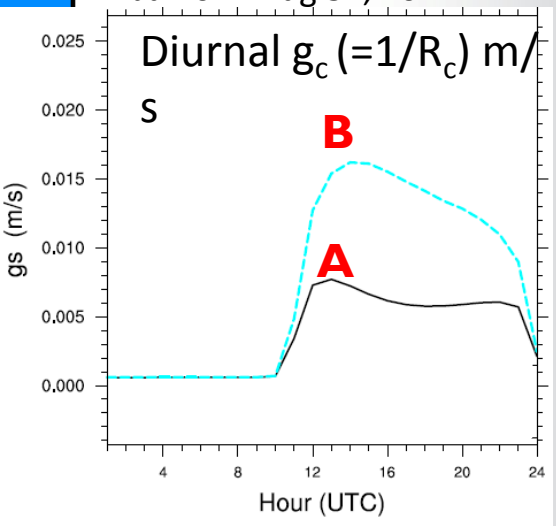


B. WRF/Noah Mosaic-CMAQ
New WRF/Noah Output (s/m)



May 26 – 31, 2011

Jun 01– Aug 31, 2011



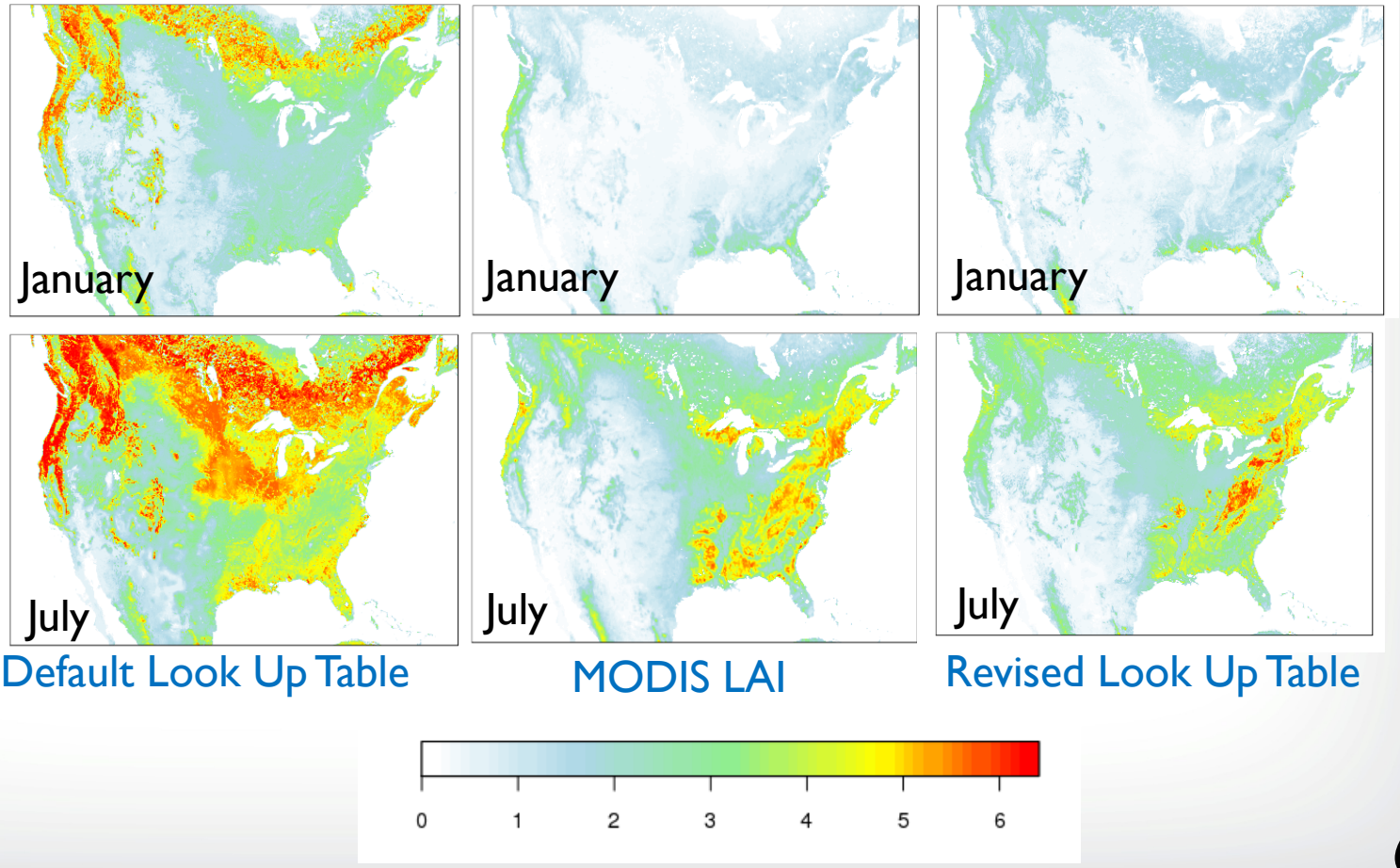
WRF/Noah Vegetation Tables

Default vegetation tables in WRF/Noah show unrealistic Leaf Area Index (LAI) compared to MODIS in many regions of North America

Updated Vegetation Tables:

Based on generalized linear model

Land use types regressed against MODIS LAI

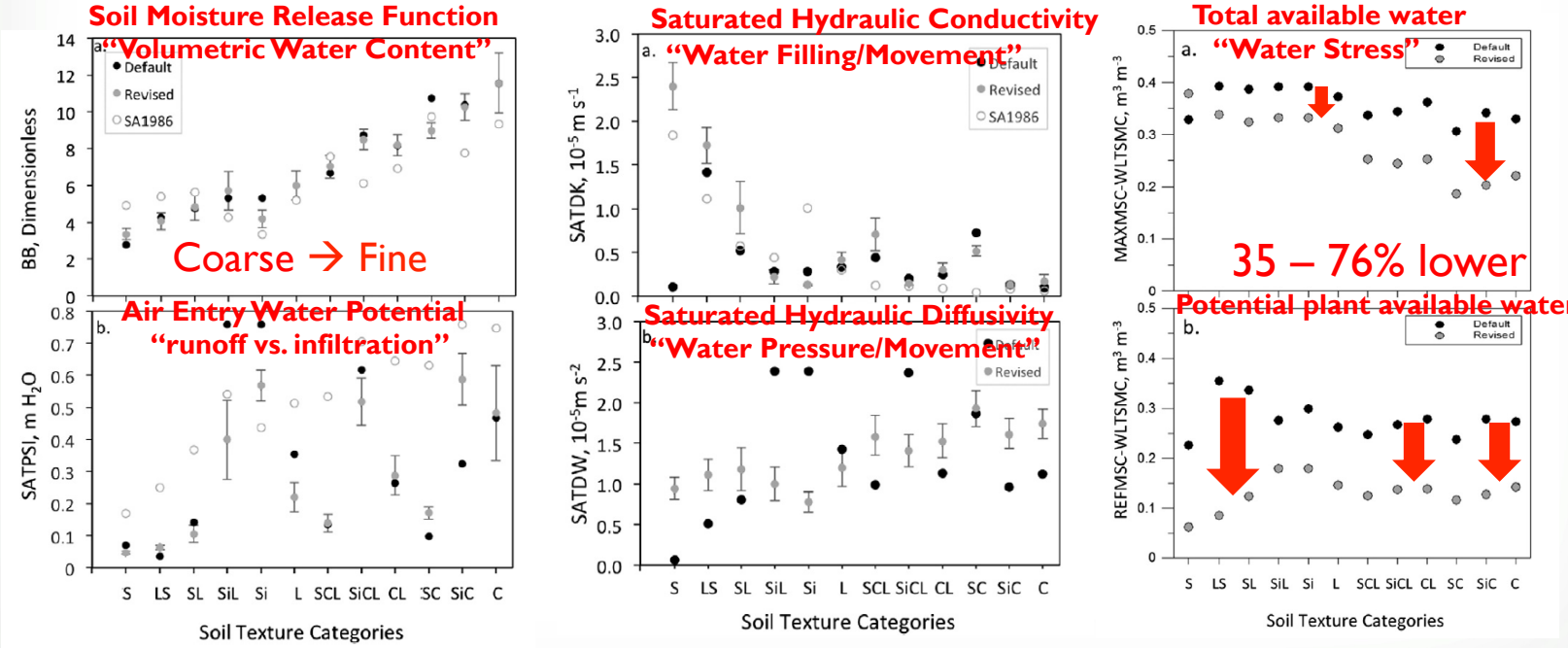


Default Look Up Table | MODIS LAI | Revised Look Up Table

WRF/Noah Soil Tables

Default soil hydraulic tables in WRF/Noah are outdated (> 25 years)

New table values are adapted from Kishne et al. (2017)* → Based on a detailed study using the USDA - National Cooperative Soil Characterization Database (USDA-NRCS)**

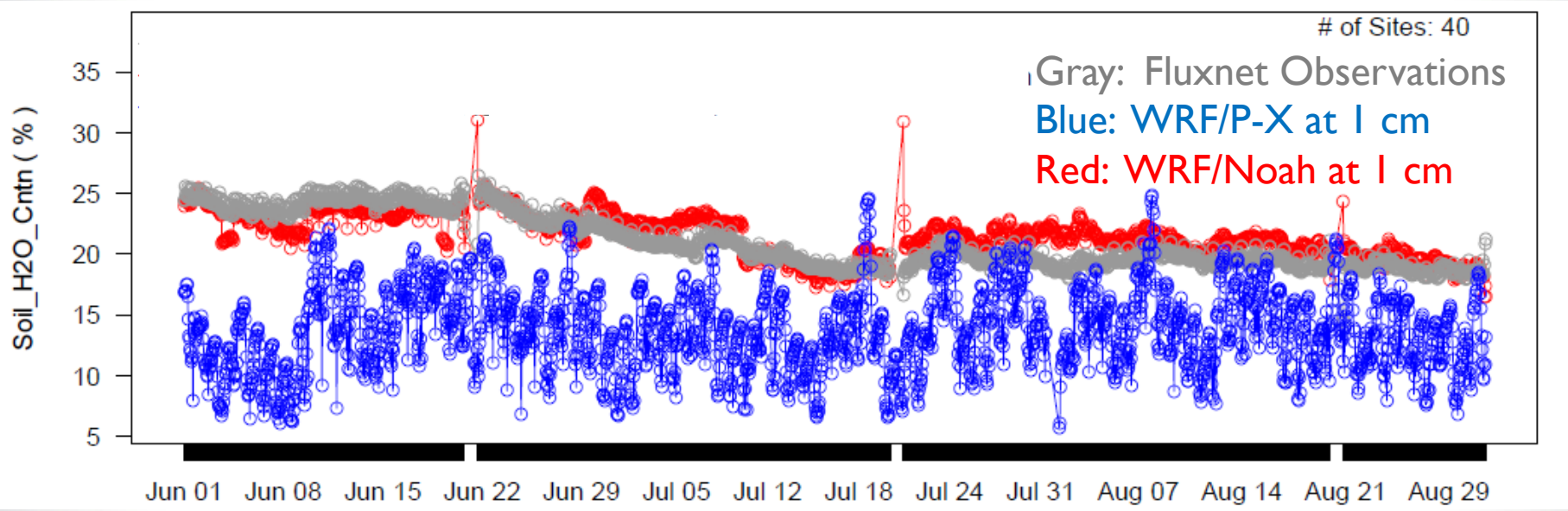


*Kishné, A. S., Y. T. Yimama, C. L. S. Morgan, B. C. Dornblaser (2017), Evaluation and improvement of the default soil hydraulic parameters for the Noah Land Surface Model, Geoderma, 285, 247 – 259, doi: 10.1016/j.geoderma.2016.09.022.

**Data available: http://ncsslabdatamart.sc.egov.usda.gov

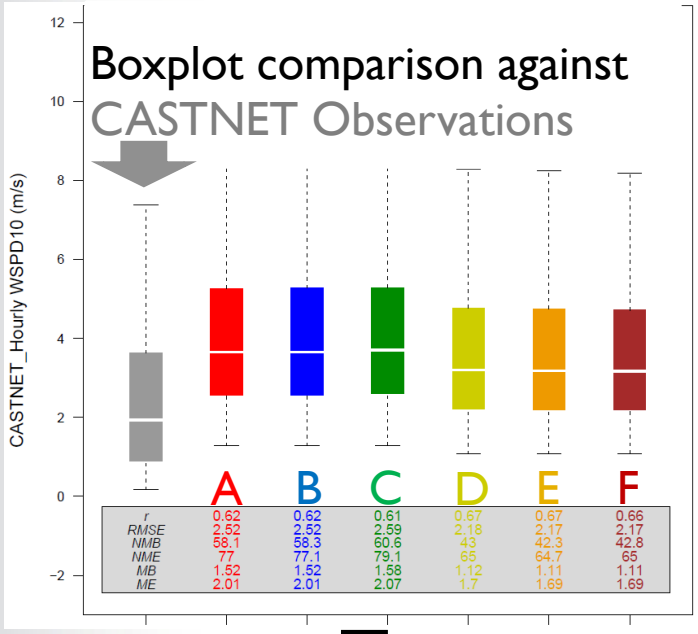
WRF/Noah Top Soil Depth

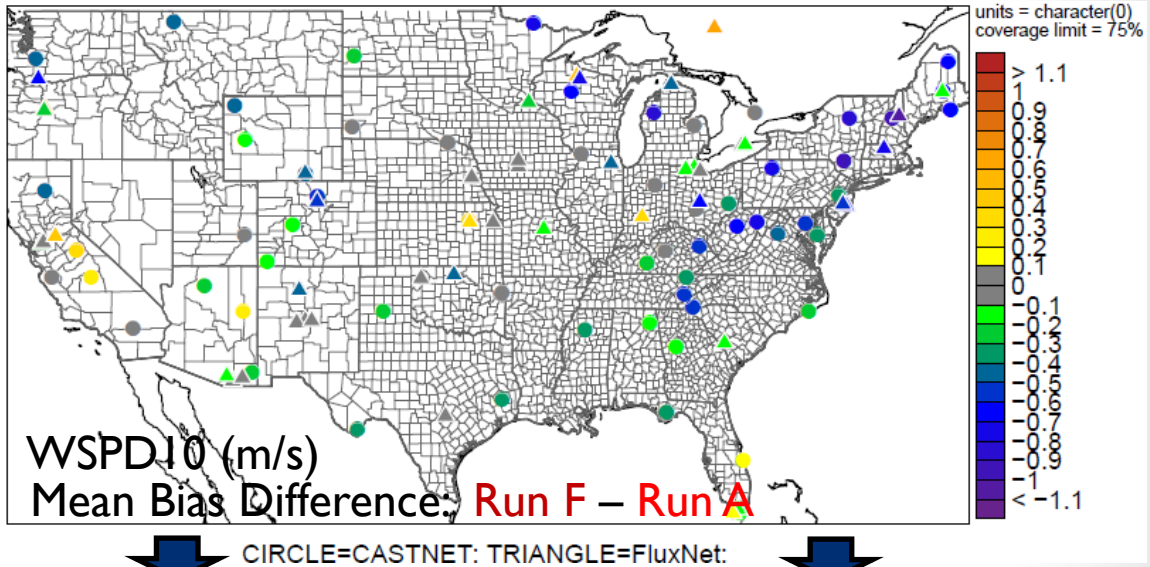
WRF/Noah top soil layer depth is changed from 10 to 1 cm for CMAQ processes (e.g., bi-directional NH_3 exchange and windblown dust)



Impacts on Meteorology

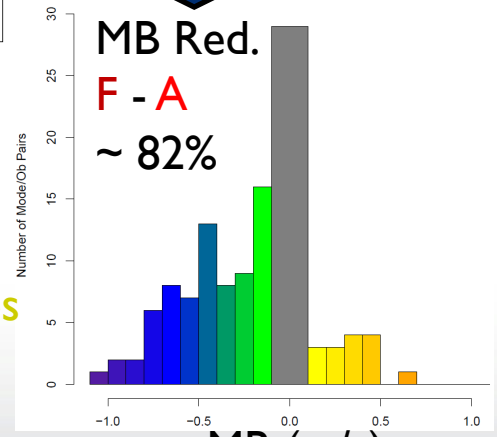
Reductions in 10-m wind speed (WSPD10) bias and error

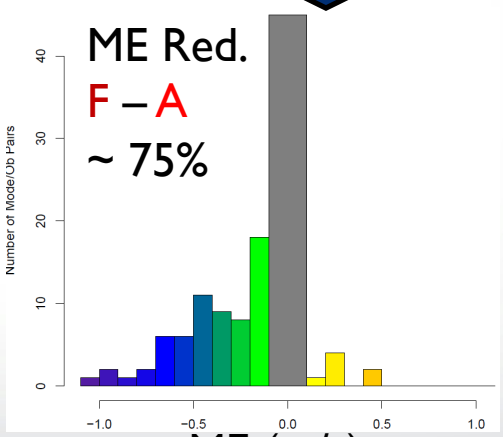




Run A: Base WRF/Noah-CMAQ
Run B: + Resistance (R_c) Updates
Run C: + R_c Mosaic Updates
Run D: + Vegetation Table Updates
Run E: + Soil Table Updates
Run F: + Thin Soil Layer Updates

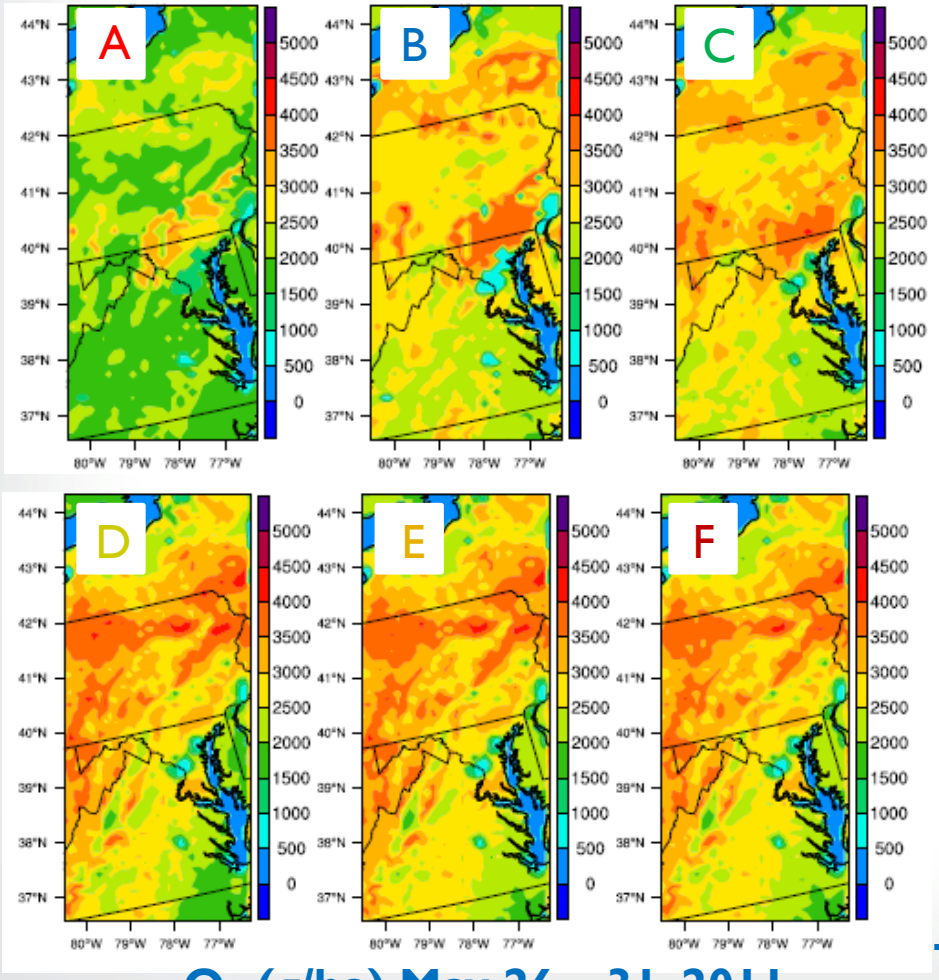
CIRCLE=CASTNET: TRIANGLE=FluxNet:





Impacts on Dry Deposition

Increases in dry deposition of ozone (O_3) and nitrogen (N)



O_3 (g/ha) May 26 – 31, 2011

Chesapeake Bay Watershed

Run A: Base WRF/Noah-CMAQ

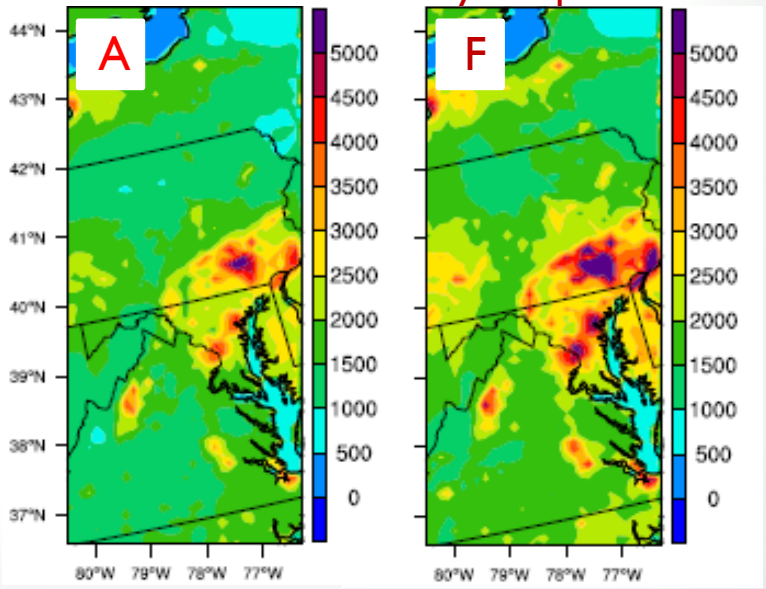
Run B: + Resistance (R_c) Updates

Run C: + R_c Mosaic Updates

Run D: + Vegetation Table Updates

Run E: + Soil Table Updates

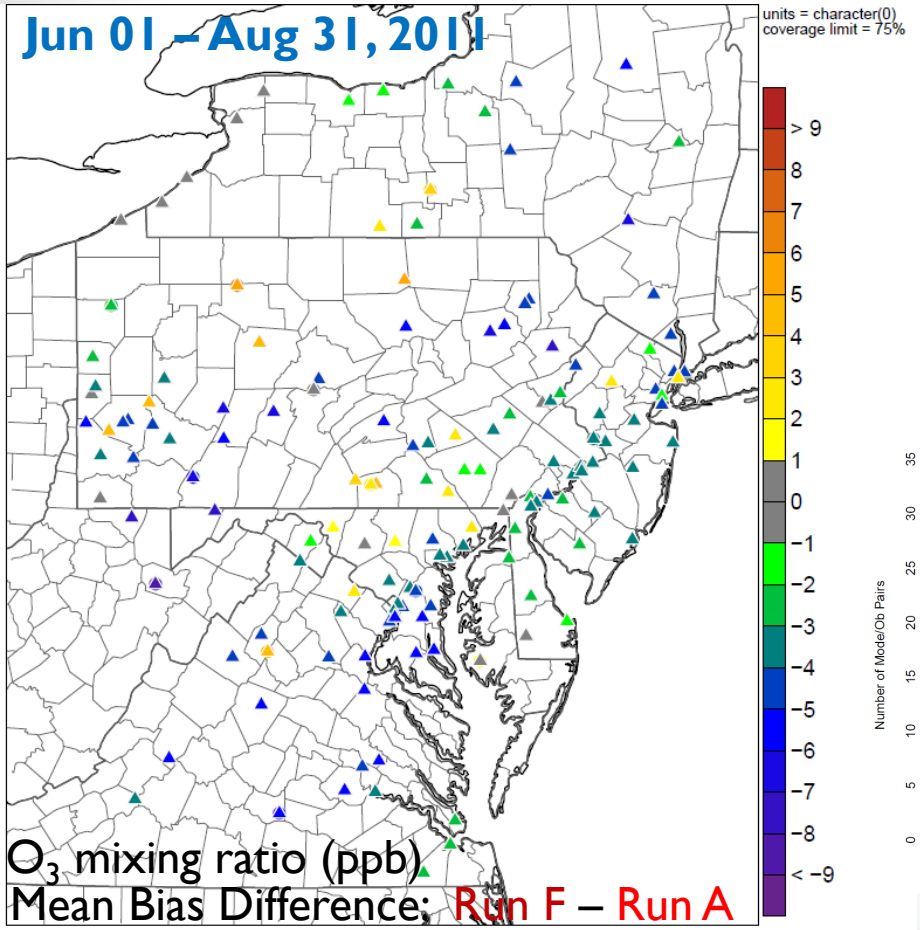
Run F: + Thin Soil Layer Updates



Total N (g/ha) Jun 01 – Aug 31, 2011

Impacts on Air Quality

Widespread reductions in mean bias and error for O_3



Chesapeake Bay Watershed

Run A: Base WRF/Noah-CMAQ
Run B: + Resistance (R_c) Updates
Run C: + R_c Mosaic Updates
Run D: + Vegetation Table Updates
Run E: + Soil Table Updates
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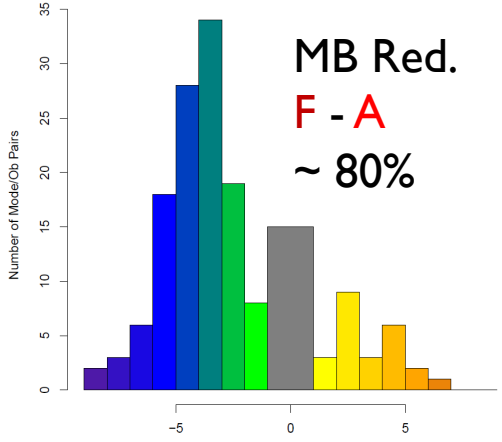
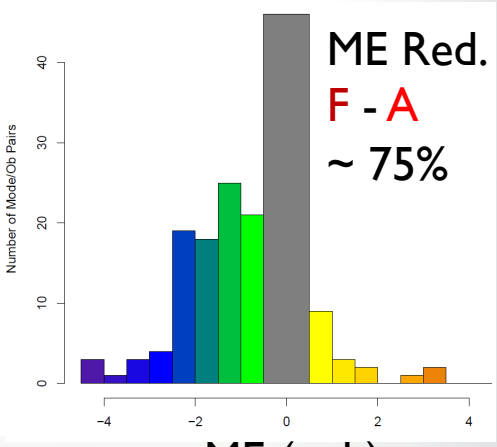
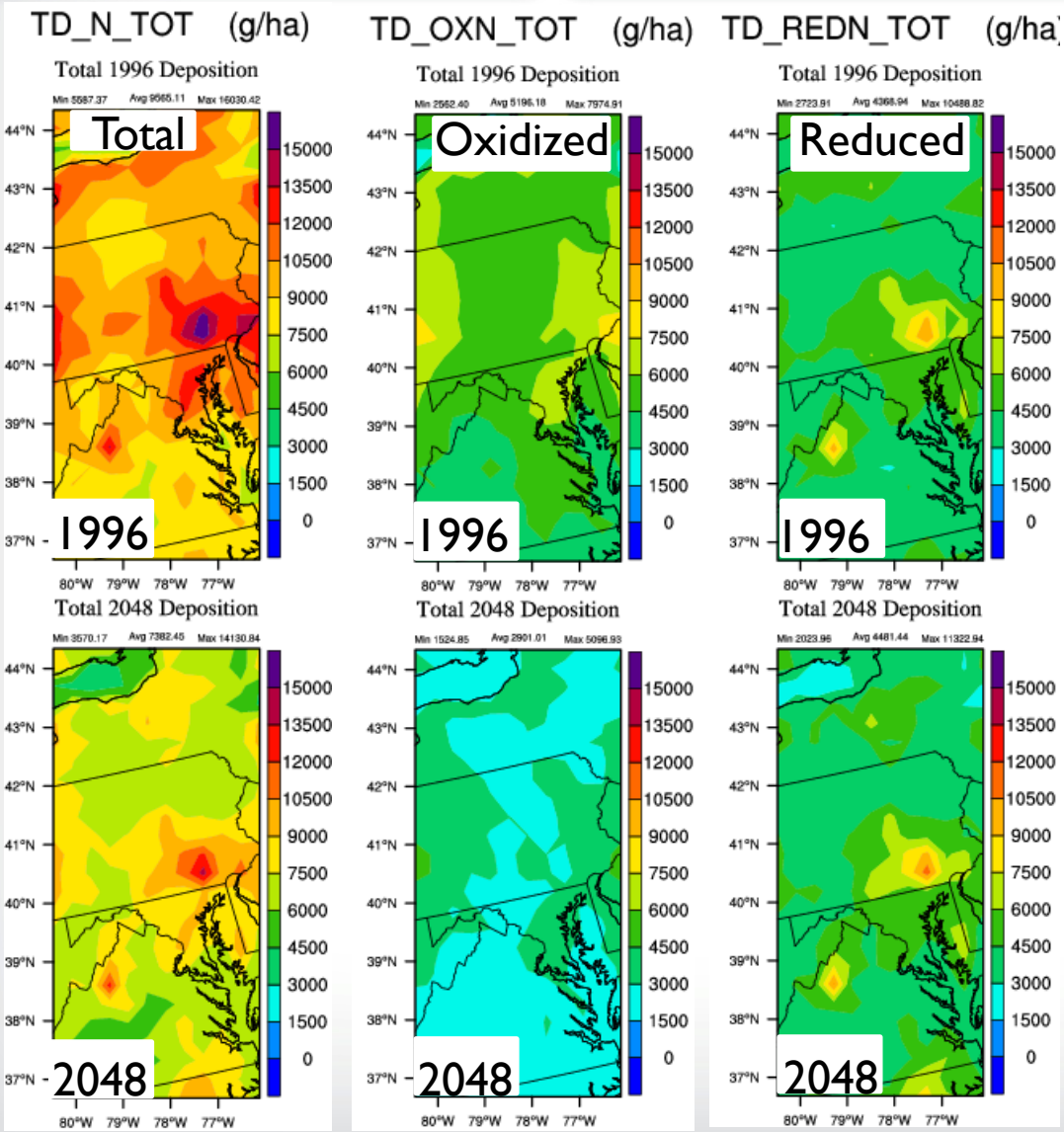




Total Nitrogen Deposition



Preliminary RCP4.5 Climate/ Emission Results
1996 → 2048

Chesapeake Bay Watershed

- 23% reduction in total nitrogen atmospheric deposition
- Clear benefits from air-quality standards
- Largely dominated by reductions in OXN deposition (~ 44%)
- Slight increases in total REDN deposition (3%)

Conclusions

A. Use of Noah R_c, updates to vegetation and soil tables, use of Noah Mosaic R_c, and reducing top soil layer thicknesses for Noah result in:

i. Improved scientific consistency with soil-vegetation-chemistry interactions in CMAQ

ii. Reduced bias and error for meteorology, soil, and air quality variables

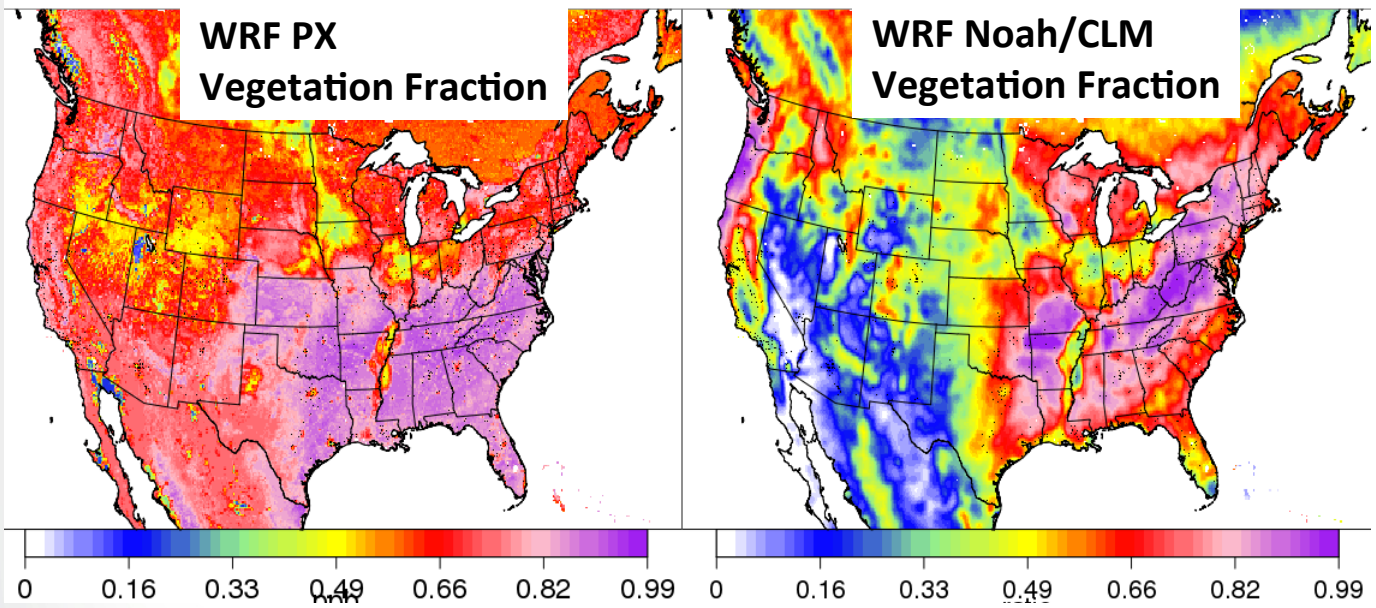
iii. Improved simulation of nitrogen budget in CMAQ—critical for future climate/emission Chesapeake Bay simulations

B. Initial simulations of changes to climate, air quality, and deposition in Chesapeake Bay show:

i. Nutrient deposition changes dominated by emission changes over climate in the future for Chesapeake Bay

CMAQ Soil O_3 Resistance

- **CMAQ underestimates O_3 deposition to soil**
  - **Masked by the exaggerated vegetation fraction in WRF PX**
  - **Results in O3 biases when using Noah, CLM, or PX with MODIS based vegetation fraction (Ran et al. 2016)**



- **Revised soil O_3 resistance based on Meszaros et al. (2009)**

$r_{soil,O_3} = 200 + 300\theta/\theta_{WP}$

Soil moisture content (Θ) from modified WRF/Noah