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Individual and Combined Impacts of Projected Climate and Emission Changes on Future Air Quality over the U.S.

Chinmay Jena[1], Yang Zhang[1], Kai Wang[1], Patrick Campbell[1], Fang Yan[2,3], Zifeng Lu [2,3], David Streets[2, 3]

[1]Department of Marine, Earth, and Atmospheric Sciences, NCSU, Raleigh, NC
[2]Computation Institute, University of Chicago, Chicago, IL
[3]Energy Systems Division, Argonne National Laboratory, Argonne, IL

18th Annual WRF Users' Workshop

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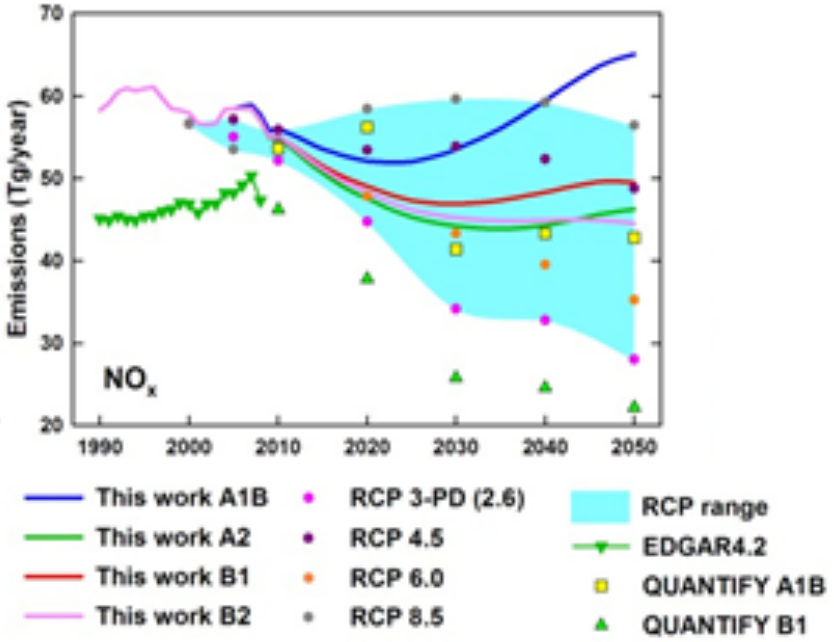
Background and Motivation

- **Emissions Scenarios**
  - Special Report on Emissions Scenarios (SRES, 2000)
  - Special Report on Emissions Scenarios (SRES, AR4, 2007)
  - Representative Concentration Pathways (RCP, AR5, 2014)

- **But both SRES and RCP scenarios neglecting relationship between socioeconomic factors and projected technology change**

- **Dynamic Technology Model: SPEW-Trend Projections**

(Yan et. al., 2014)



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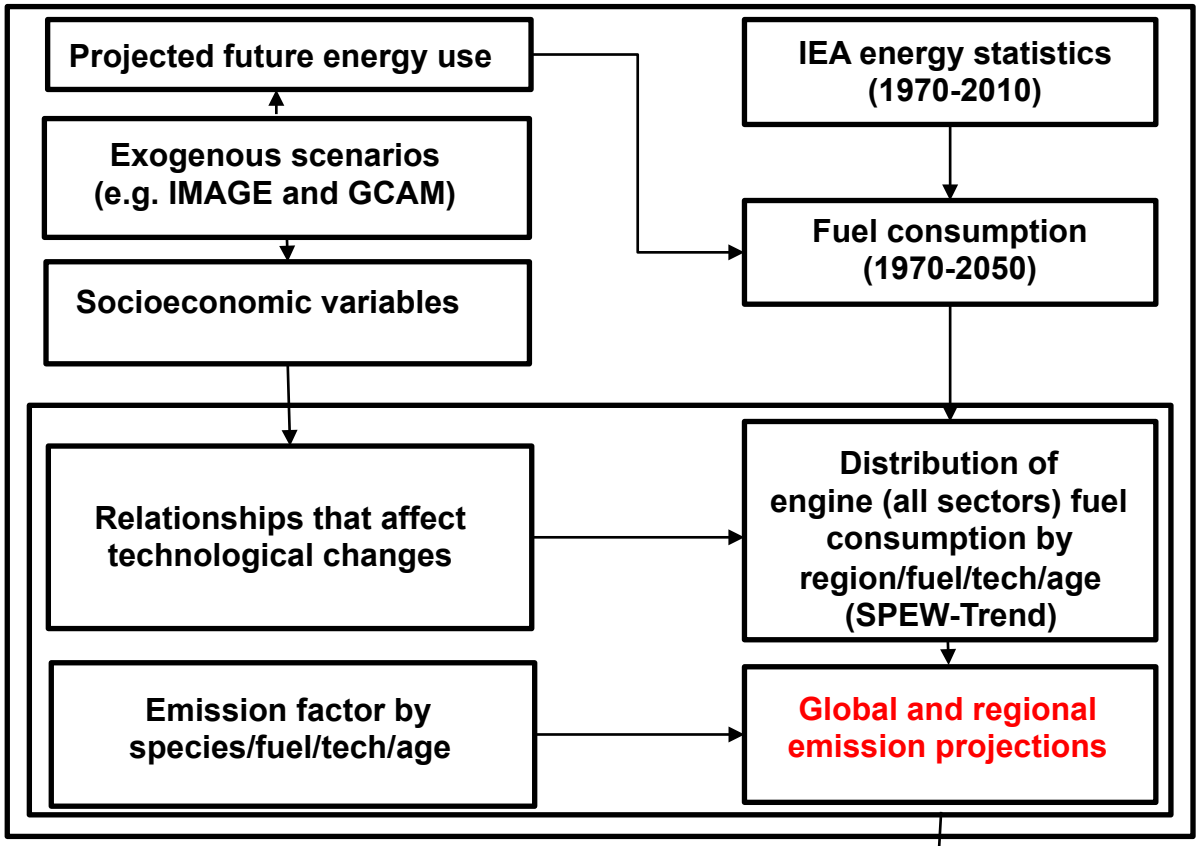
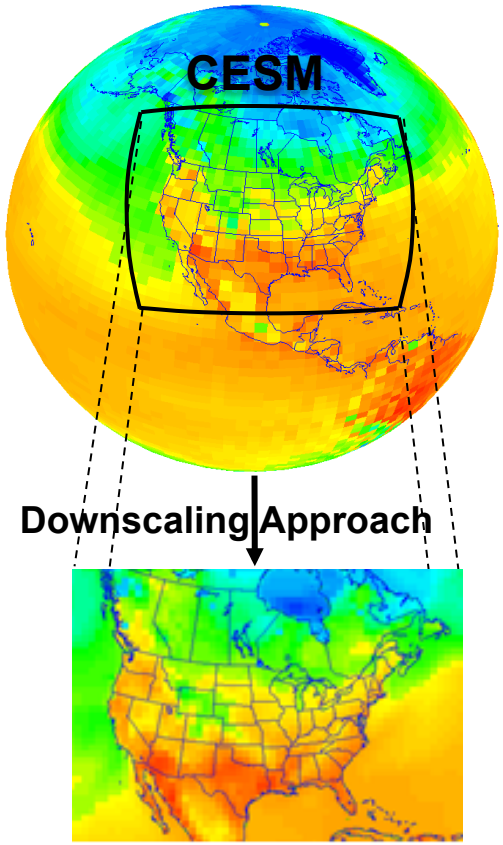
Technology Driver Model (TDM)



Diagrams of TDM Emission Projection Methods (SPEW-Trend, Yan et. al., 2014)



Growth Factors Regions/Sectors/Species

Gridded Emissions (SMOKE Model)

Regional Online Couple Model (WRF-Chem3.7)

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Objectives

- **Impacts on Future Air Quality over the U.S.**
  from
  Emissions Change only
  vs.
  Climate Change only
  vs.
  Emissions & Climate Changes

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Model Configuration

Domain and Period	
• Model	Online-coupled WRF-Chem 3.7
• Period & domain	Current decade 2001-2010 and future decade 2046-2055 over CONUS
• Horiz. & Vert. Resolution	36-km & 34 layers vertically from surface to 100 hPa
WRF-Chem Physics and Chemistry Options	
• Radiation	Rapid and accurate Radiative Transfer Model for GCM (RRTMG)
• Land and PBL	National Center for Environmental Prediction, Oregon State University, Air Force and Hydrologic Research Lab (NOAH) and Yonsei University (YSU)
• Cumulus	Multi-Scale Kain Fritsch (MSKF)
• Microphysics	Morrison 2-moment scheme
• Gas-Phase Chemistry	Modified CB05 with updated chlorine chemistry
• Aqueous-Phase Chemistry	AQ chemistry module (AQCHEM)
• Aerosol Module	Modal Aerosol Dynamics Model/Volatility Basis Set (MADE/VBS)
• Photolysis	Fast Troposphere Ultraviolet Visible (FTUV)
Input	
• Meteorological and Chemical (Initial and Boundary Conditions)	Modified CESM/CAM5 v1.2.2 (Glotfelty et al., 2016 a,b) for both meteorology & chemistry; meteorology ICs/BCs bias corrected with NCEP/FNL.
• Anthropogenic Emissions	U.S. EPA National Emissions Inventory 2002, 2005, 2008 for current decade; TDM-projected growth factor under the IPCC/A1B and B2 scenarios based on 2005 emission;
•Biogenic Emissions	Model of Emissions of Gases and Aerosols from Nature version 2 (MEGAN v2)
•Dust and Sea Salt Emissions	AER/AFWA (Jones et al., 2012) and Gong et al. (1997) parameterization

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Simulation Design

Simulation Details	Impacts on Air Quality
✓Current Climate ✓Current GHG Levels ✓Current emissions	Base Case
✓Future Climate ✓Future GHG Levels ✓Future emissions	Combined emissions and Climate changes
✓Current Climate ✓Current GHG Levels ✓Future emissions	Emissions change only
✓Future Climate ✓Future GHG Levels ✓Future emissions	Climate change only

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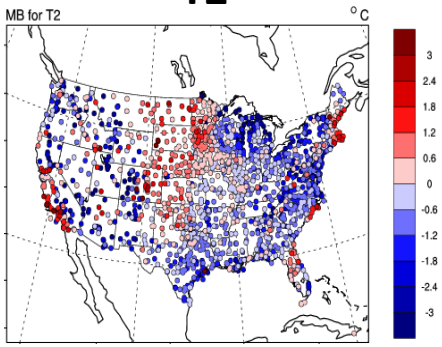
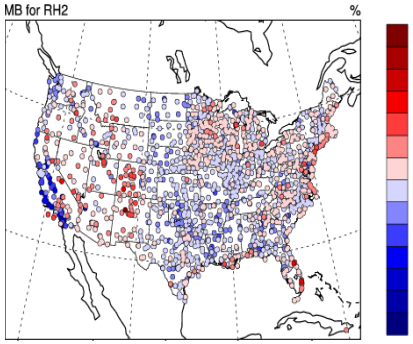
Meteorological Performance

T2



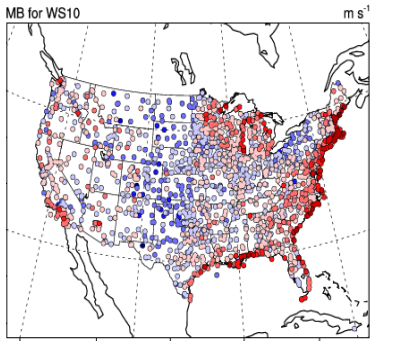
MB: -0.6°C, NMB: -4.9%

RH2



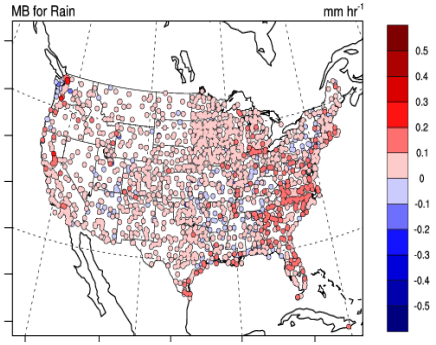
MB: -1.4%, NMB: -2.0%

WS10



MB: 0.23 ms^{-1} , NMB: 6.7%

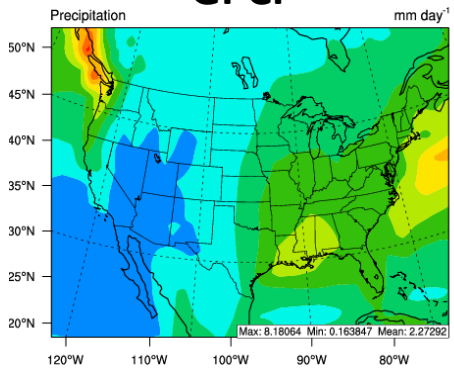
Rain



MB: 0.04 mm hr^{-1}, NMB: 57.5%

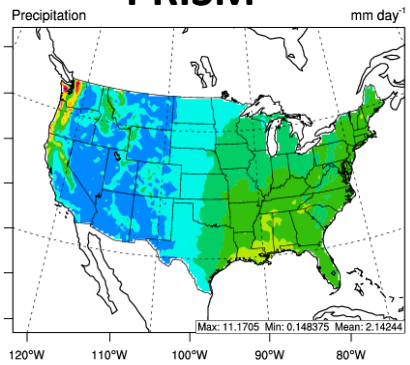
Precipitation Performance against Satellite/Reanalysis Data

GPCP



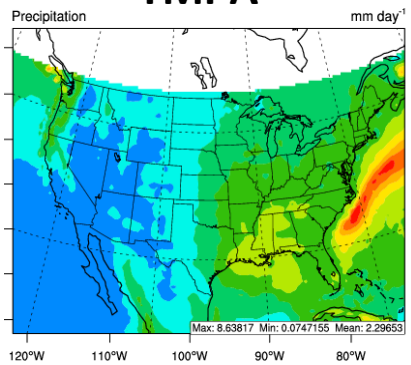
MB:0.34 mm day^{-1} ,NMB: 15%

PRISM



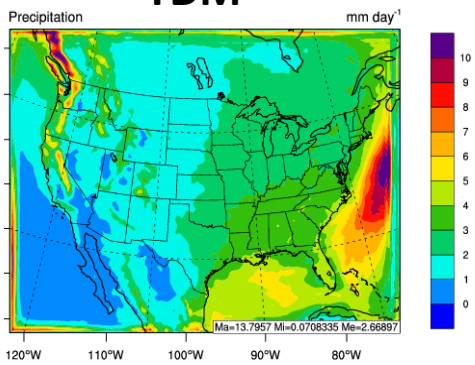
MB: 0.25 mm day, NMB: 11.7%

TMPA



MB: 0.35 mm/day, NMB: 15.5%

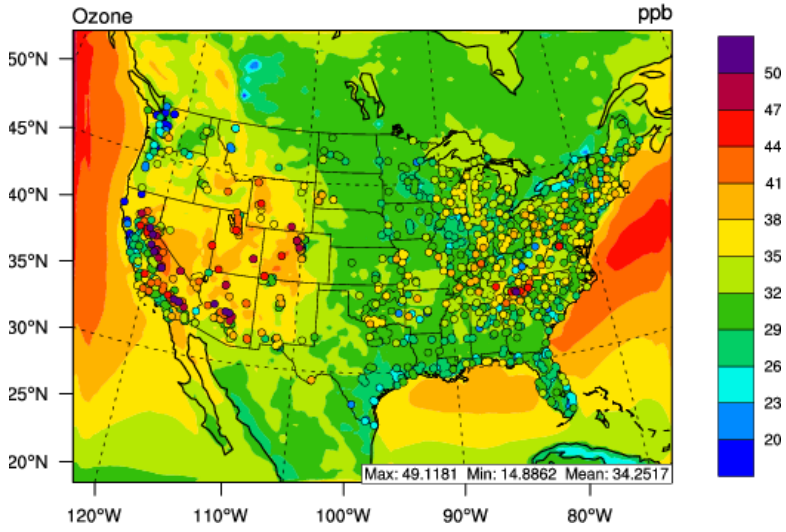
TDM



Generally cold biases for T2, overprediction of WS10 and RH2 in eastern and mountainous areas of U.S., precipitation overpredicted across the domain

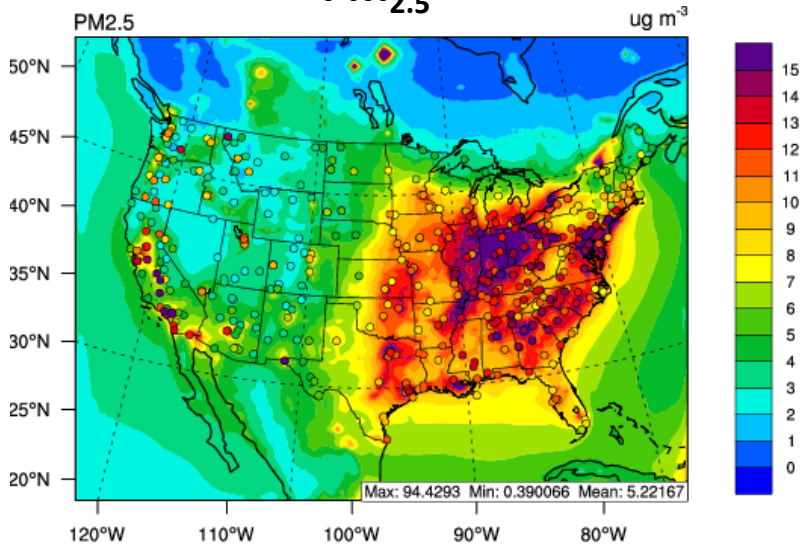
Simulated O_3 and $PM_{2.5}$ Overlaid with Observations

Ozone



CASTNET: NMB=-8.9%; AQS: NMB=2.3%

$PM_{2.5}$



IMPROVE: NMB=12.9%; CSN: NMB=6.2%

Overall good performance for O_3 (NMB < ±10%), but locally large underpredictions exist in both eastern and western U.S.; $PM_{2.5}$ performs well in eastern U.S., but there are larger negative biases in western U.S.

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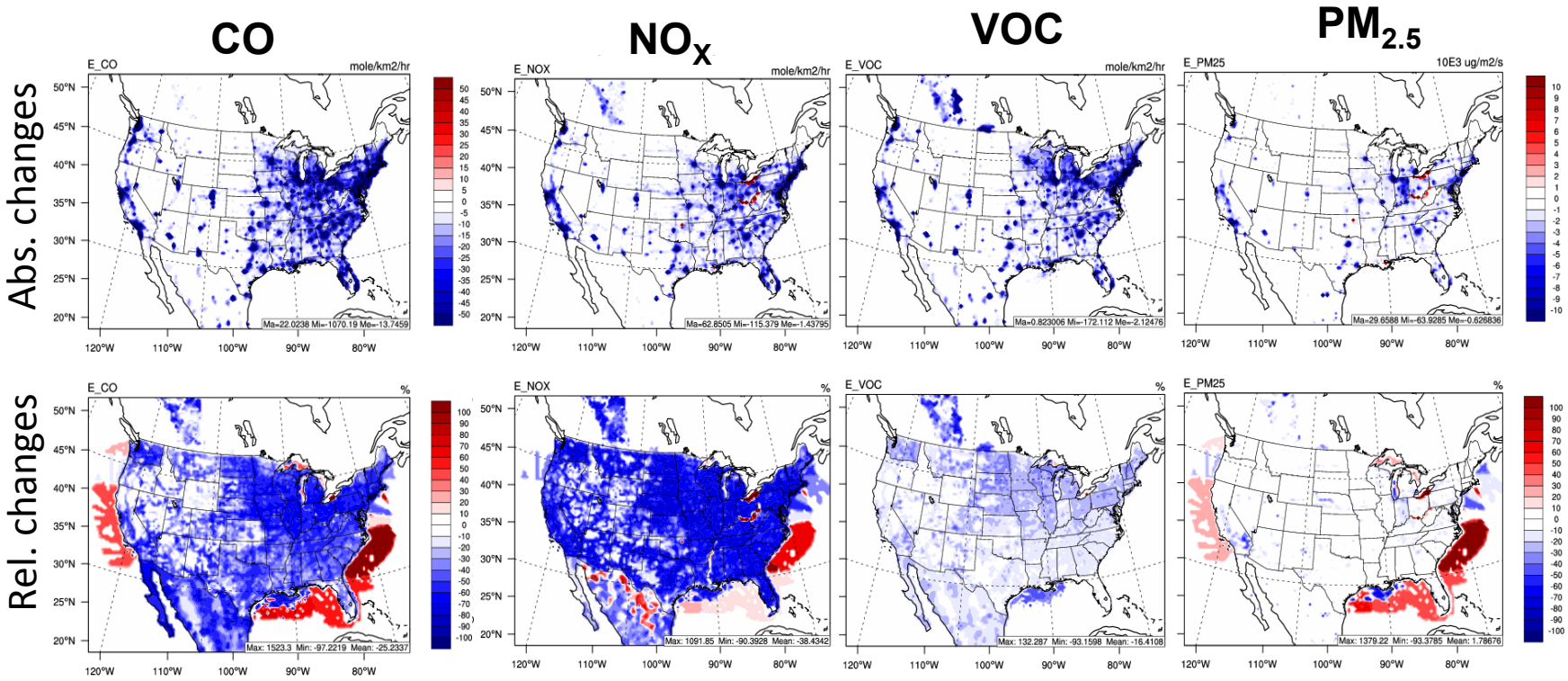
Projected Emission Changes

TDM B2 Scenario



Under the B2 scenario, emissions of CO, NO_x, VOCs, and $PM_{2.5}$ are projected to decrease over large areas of domain with a few exceptions (e.g., Ohio River)

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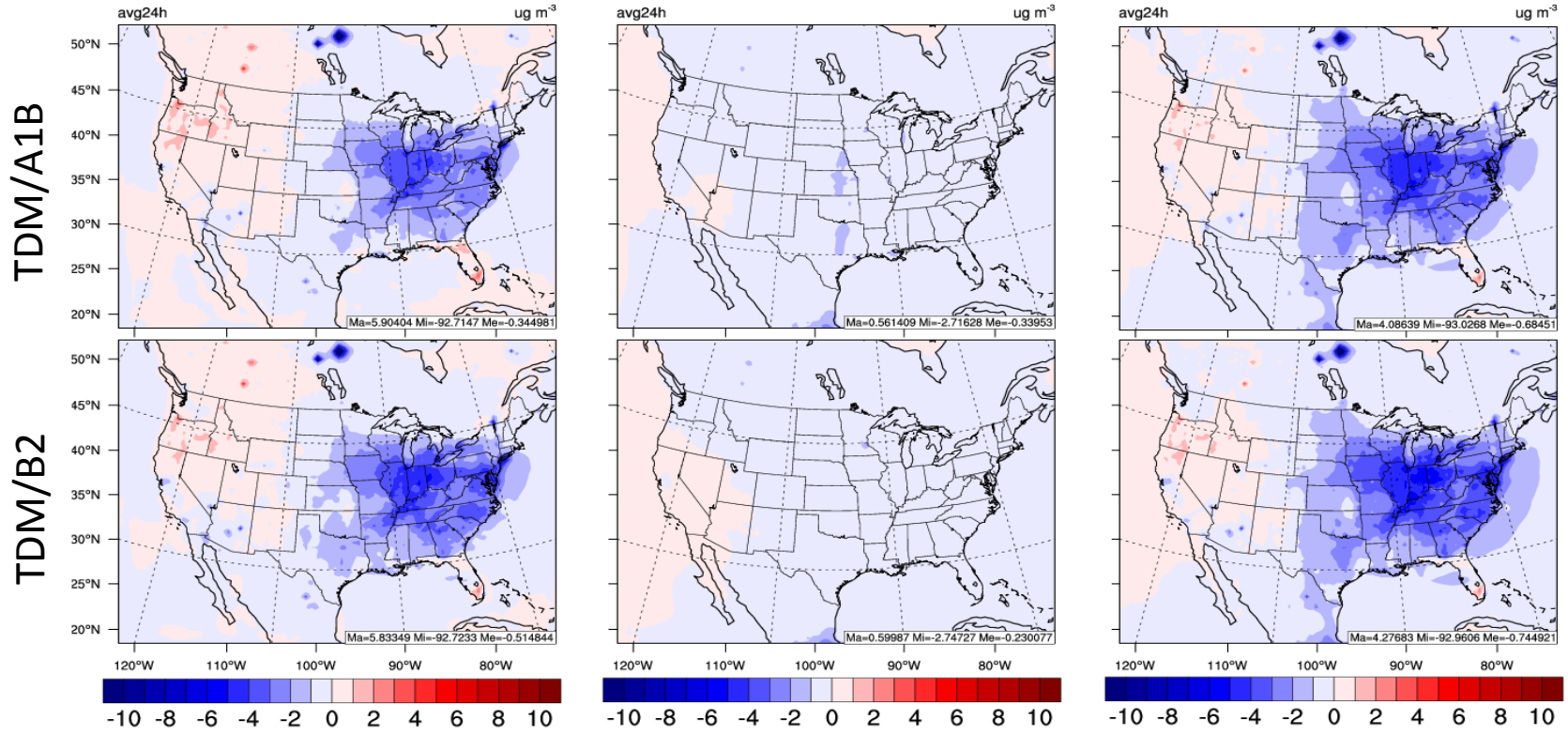
Projected Air Quality Changes

Daily 24-hr Avg. $PM_{2.5}$



Emissions Change only

Climate Change only

Emissions and Climate Changes

The daily 24-h average (DA24h) $PM_{2.5}$ levels are projected to decrease over eastern U.S., mainly due to the decreases in primary anthropogenic emissions of PM species and gaseous precursors and secondary formation of inorganic aerosols as well as increased precipitation

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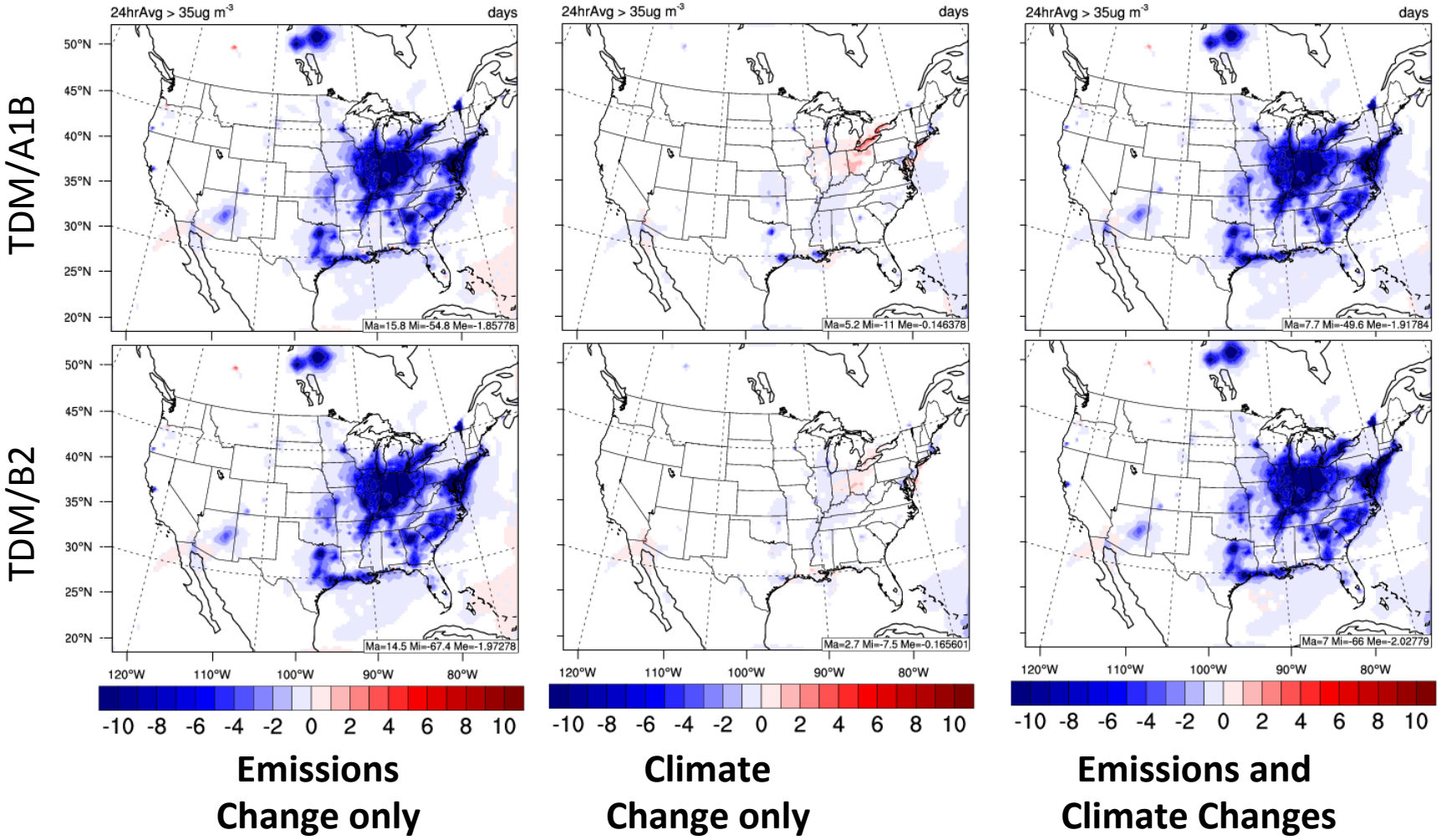
Number of exceedance days for daily 24-hr Avg. $PM_{2.5}$ > 35 µg m^{-3}



Emissions Change only | **Climate Change only** | **Emissions and Climate Changes**

The number of exceedance days DA 24hr $PM_{2.5}$ > 35 µg m^{-3} is significantly reduced over eastern U.S.

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Conclusions

- The model shows overall good performance for meteorological variables, O_3 and $PM_{2.5}$ over CONUS
- The maximum daily 8-h average surface ozone (MDA8h O_3) increases by ~3 ppb across the U.S. The number of exceedance days (MDA8h O_3 > 70 ppb) is significantly reduced but some areas remain non-attainment
- The daily 24-h average (DA24h) $PM_{2.5}$ levels are projected to decrease over eastern U.S. The number of exceedance days (DA24hr $PM_{2.5}$ > 35 μg m^{-3}) is significantly reduced over eastern U.S.
- The climate change dominates the changes in surface O_3 concentration under the TDM A1B scenario across the CONUS, while the changes in anthropogenic emissions dominate surface O_3 levels under the TDM B2 scenario and $PM_{2.5}$ under both TDM A1B and B2 scenarios
- The results will be useful for policy makers to develop integrated strategies to control anthropogenic emissions and mitigate adverse climate change

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Acknowledgments

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