Sensitivity of the US climate penalty to local and global emissions

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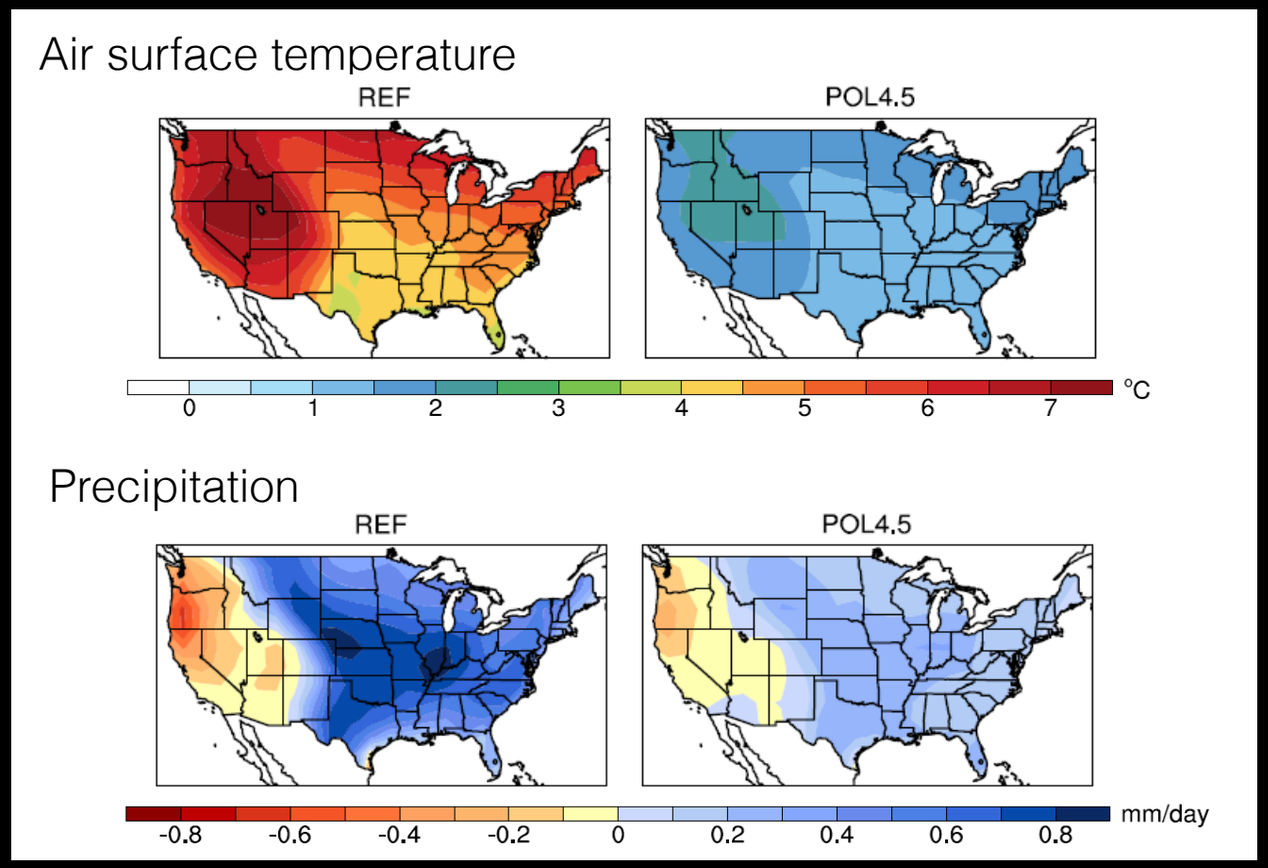
Climate influence on air quality is complex!

Projected changes in 2100 relative to present



Monier et al. (2014)

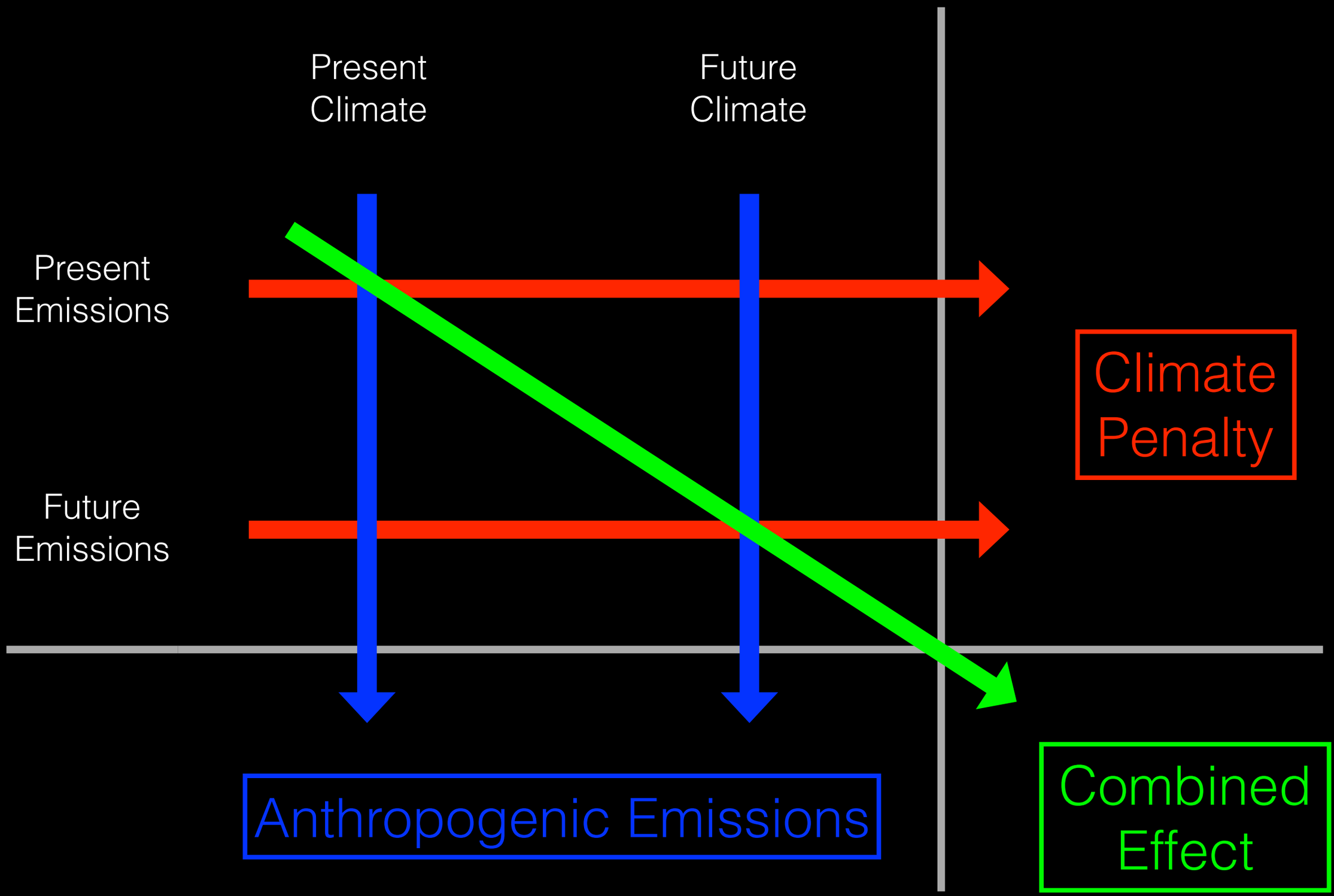
Climate change impacts air quality through a number of mechanisms:

- chemistry
- ventilation and stagnation
- biogenic emissions
- deposition rates

Climate Penalty = degradation of air quality under climate change in the absence of emissions changes

The climate penalty is likely a function of **both** climate and non-GHG emissions. To what extent do non-GHG anthropogenic emissions affect the climate penalty?

Is climate penalty a function of anthropogenic emissions?

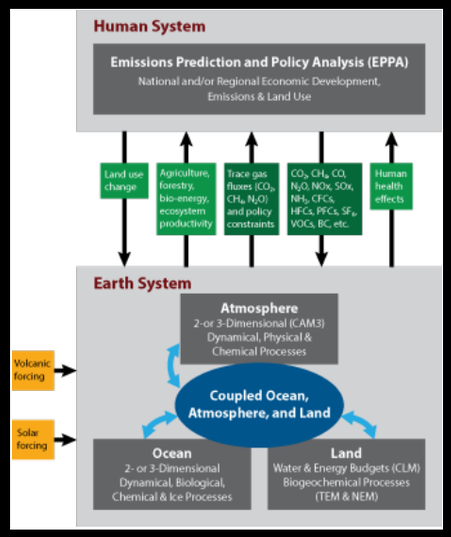


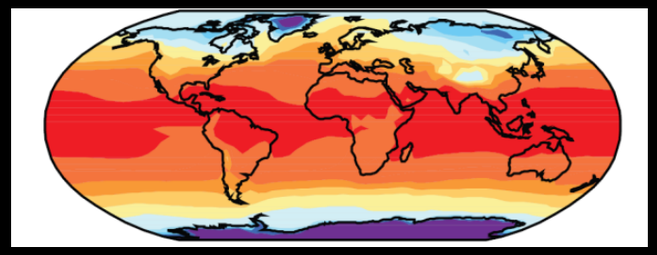
Modeling climate impacts on AQ requires linked models.

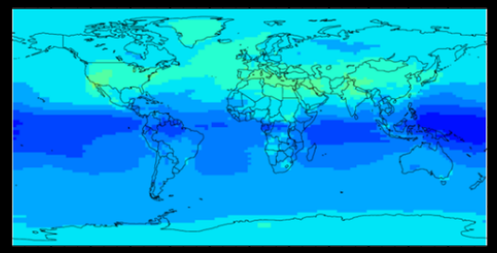
Socioeconomic emissions scenarios

General Circulation Models

Global/regional chemical transport models

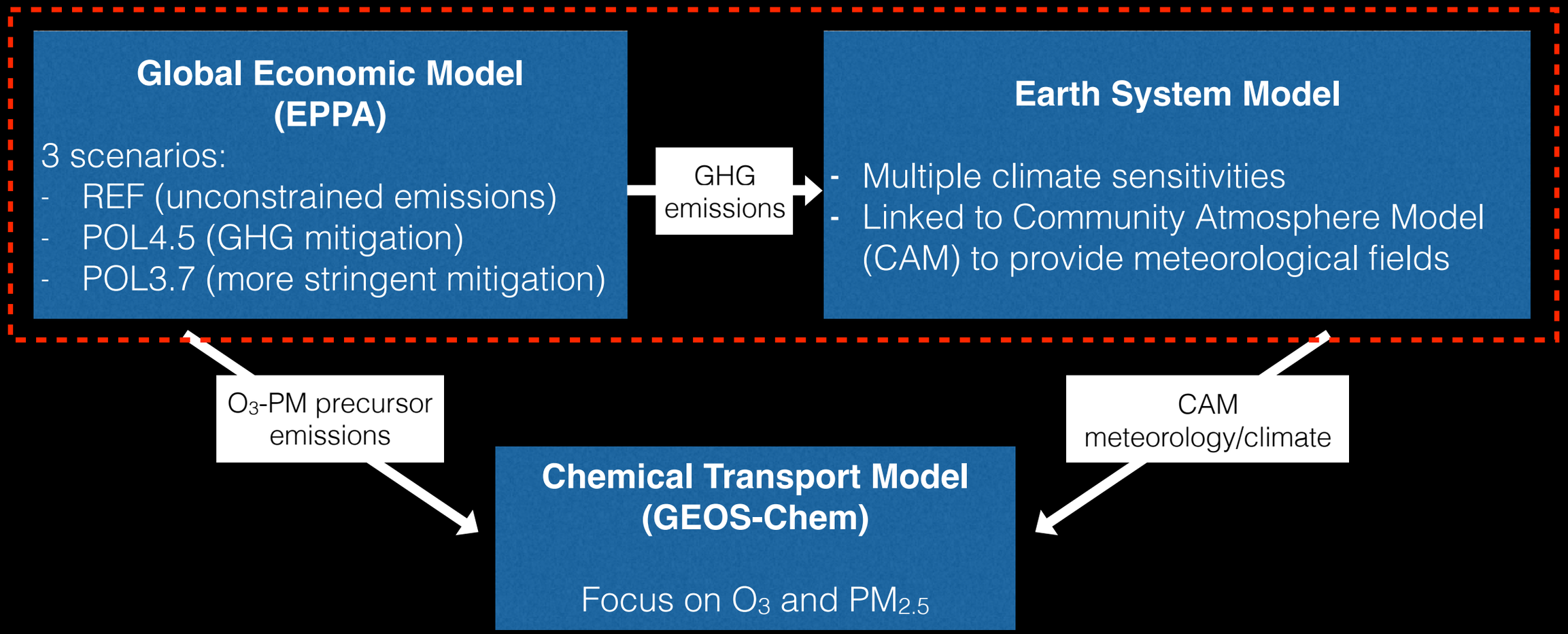






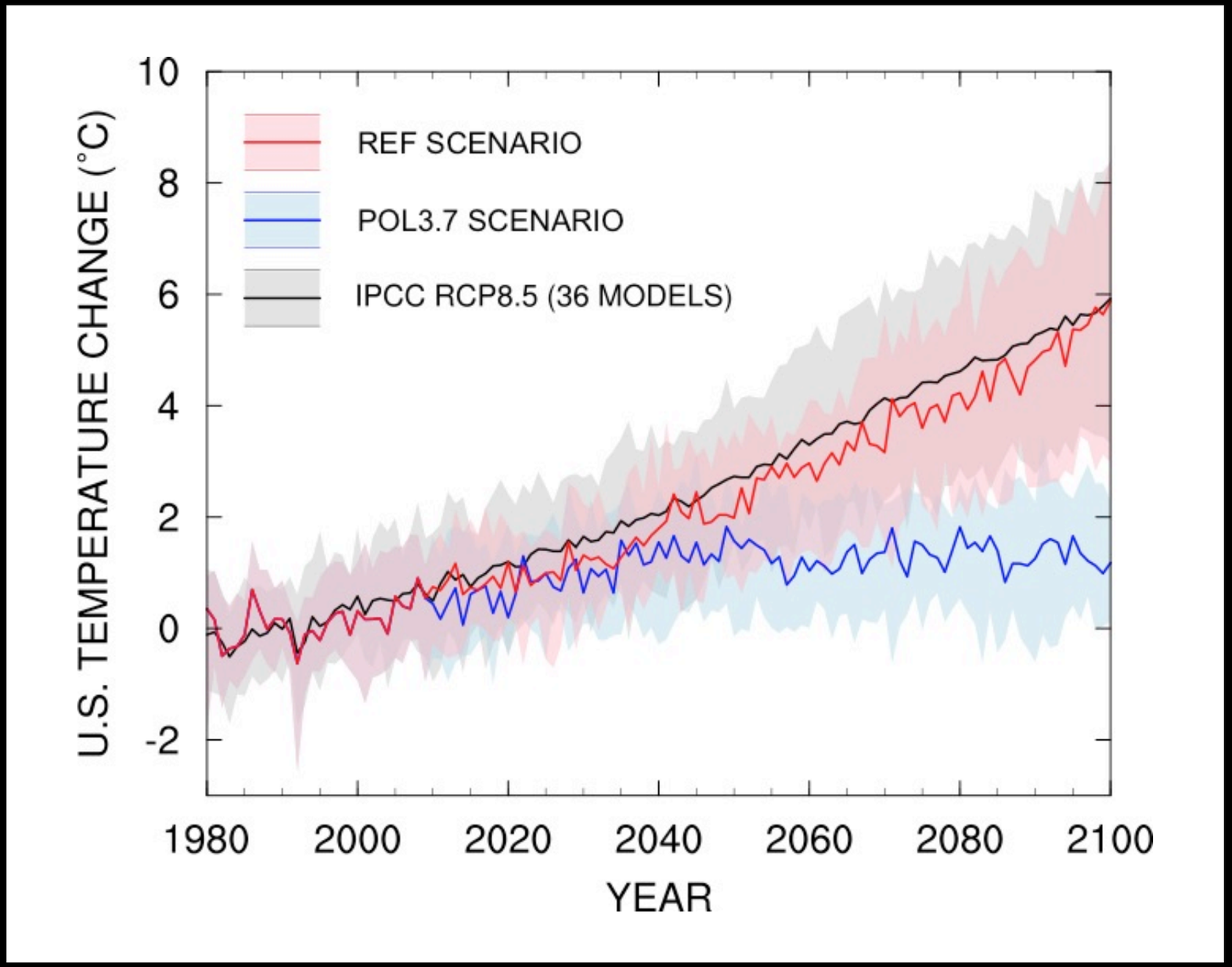
- Large uncertainties are associated with climate simulations and propagate to projections of air quality.
- Characterizing uncertainty across the complete human-climate system is essential to generation policy-relevant insights and guide environmental decision-making.

MIT's Integrated Global System Model is self-consistent.



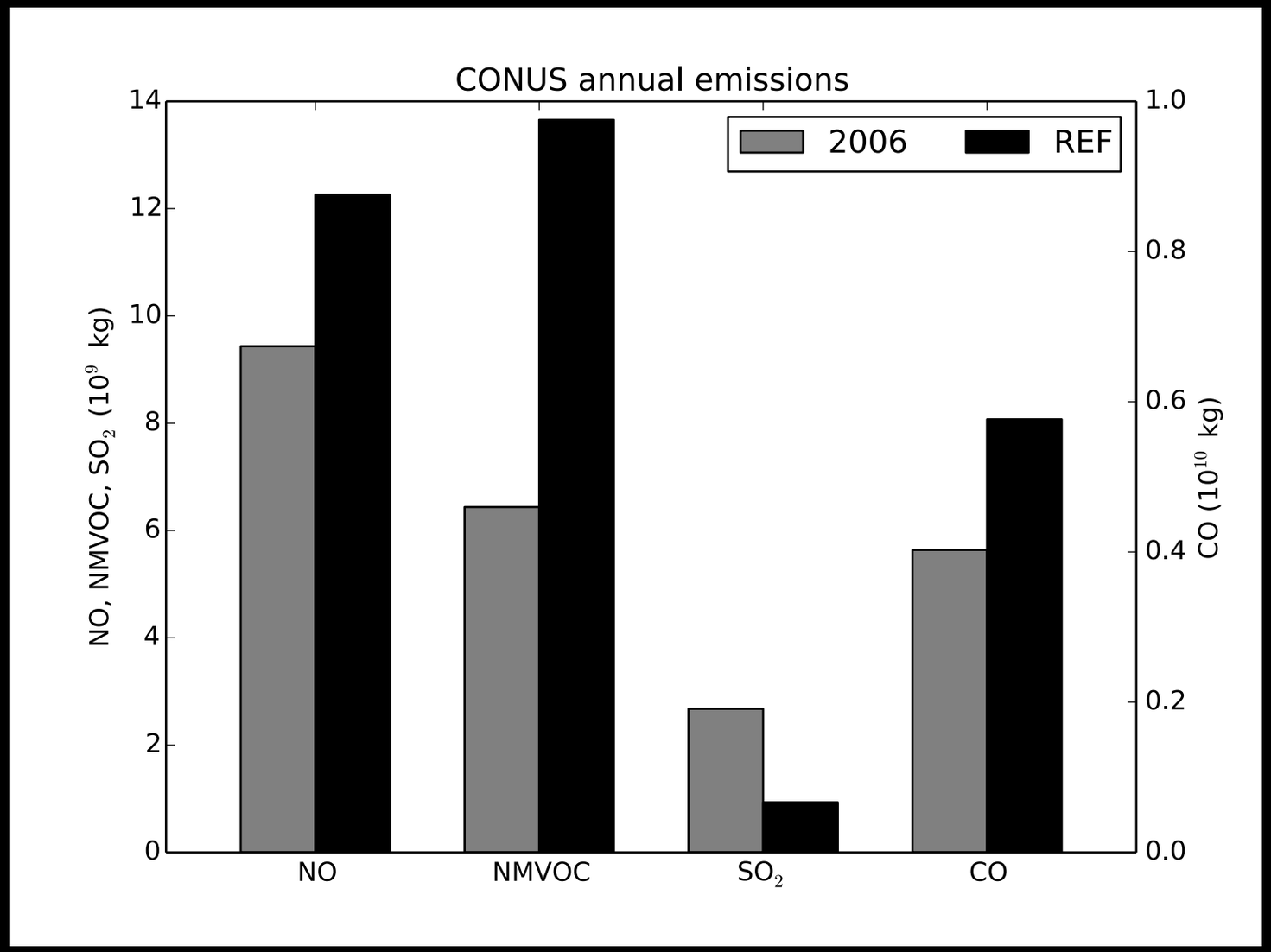
- GEOS-Chem v9.02 with full chemistry
- 2 x 2.5 degrees, 47 vertical layers
- 10-year simulations to capture climate variability
    - 1995-2004 and 2095-2105
- MIT's IGSM used to drive CAM
- GEOS meteorological fields replaced with CAM meteorology
- Base emissions from 2006 projected for a future high emissions "no climate policy" scenario (REF)

REF induces similar temperature increase to RCP 8.5.



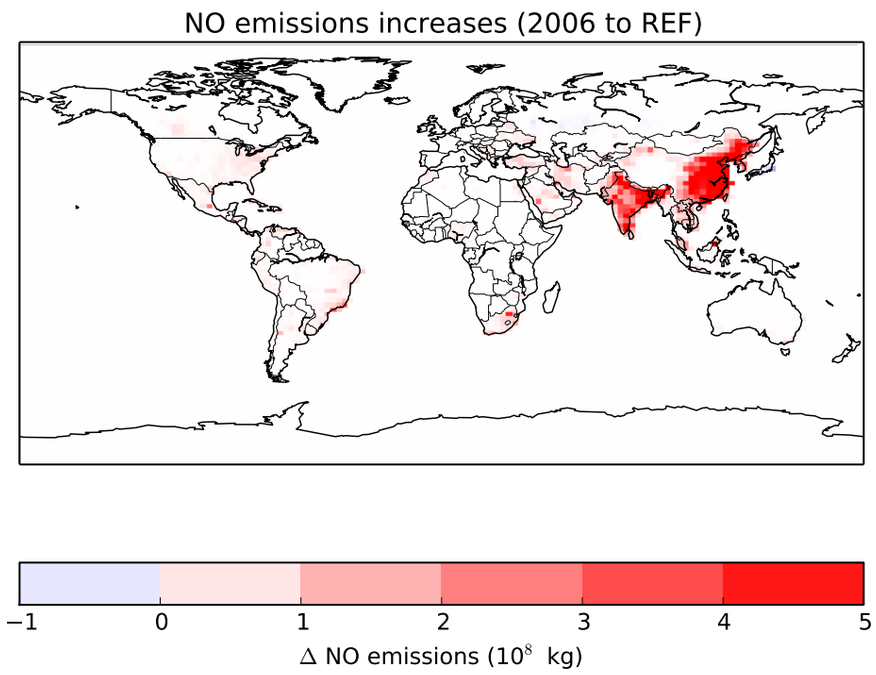
REF is high emissions no-climate policy scenario.

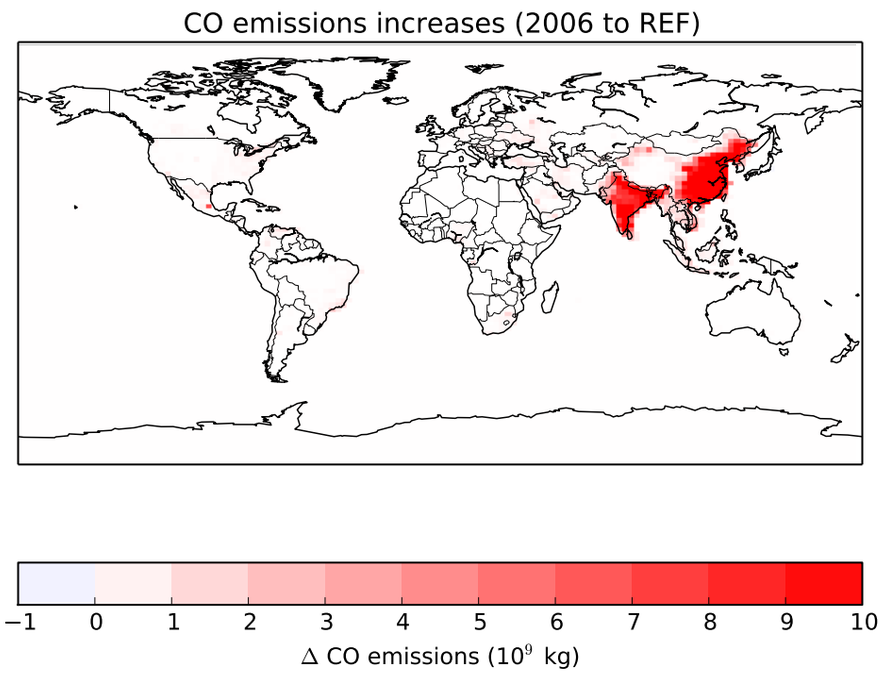
REF US anthropogenic emissions changes from 2006.

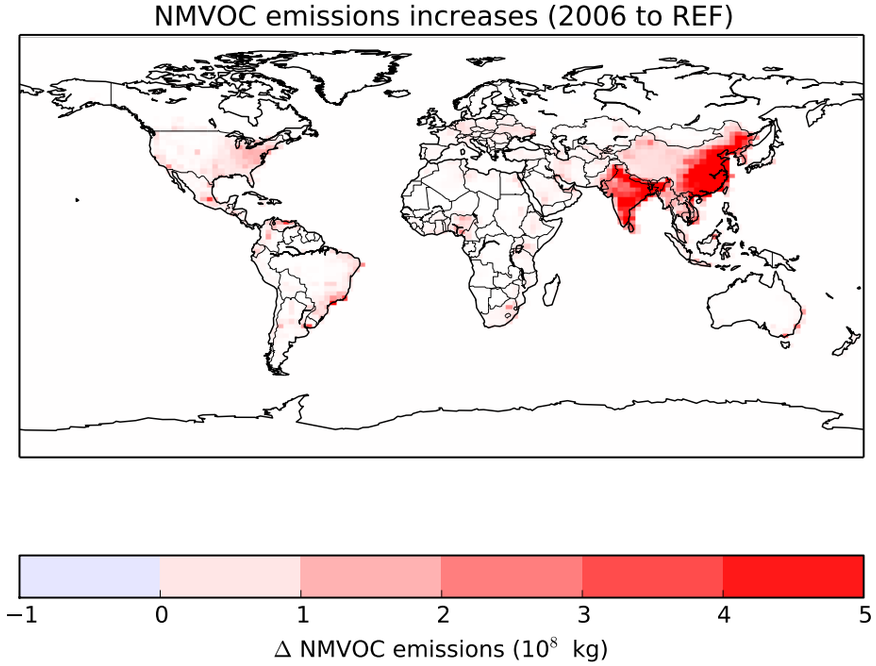


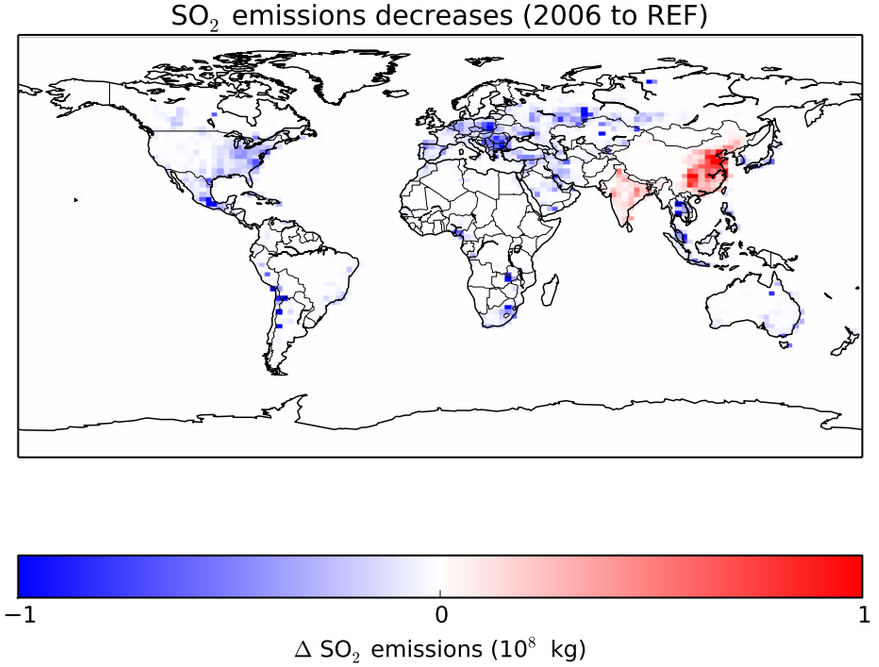
- NO, NMVOC, and CO emissions increase in REF scenario
- SO_2 emissions decrease sharply

REF anthropogenic emissions changes from 2006.

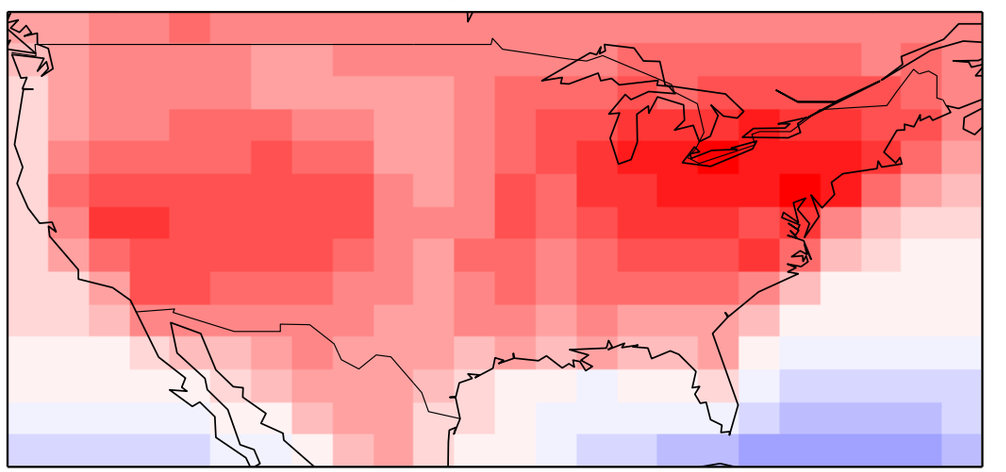


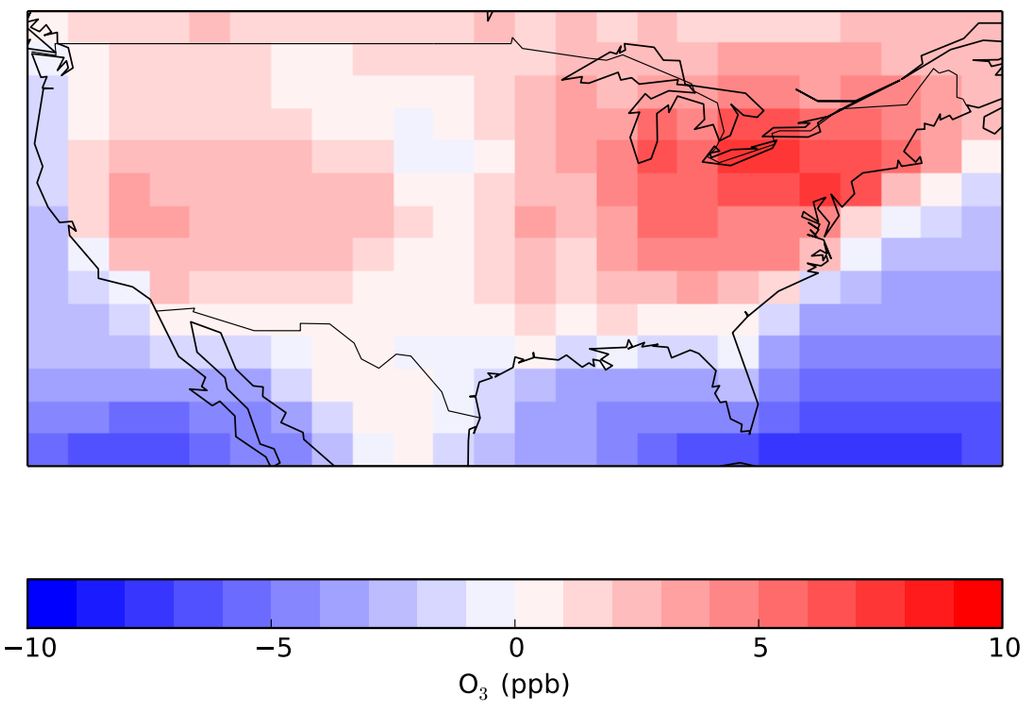




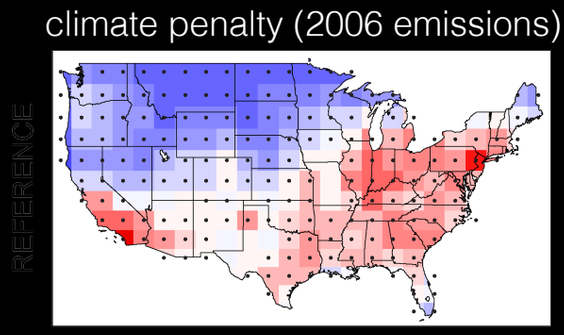


Annual average O_3 climate penalty leads to increases.



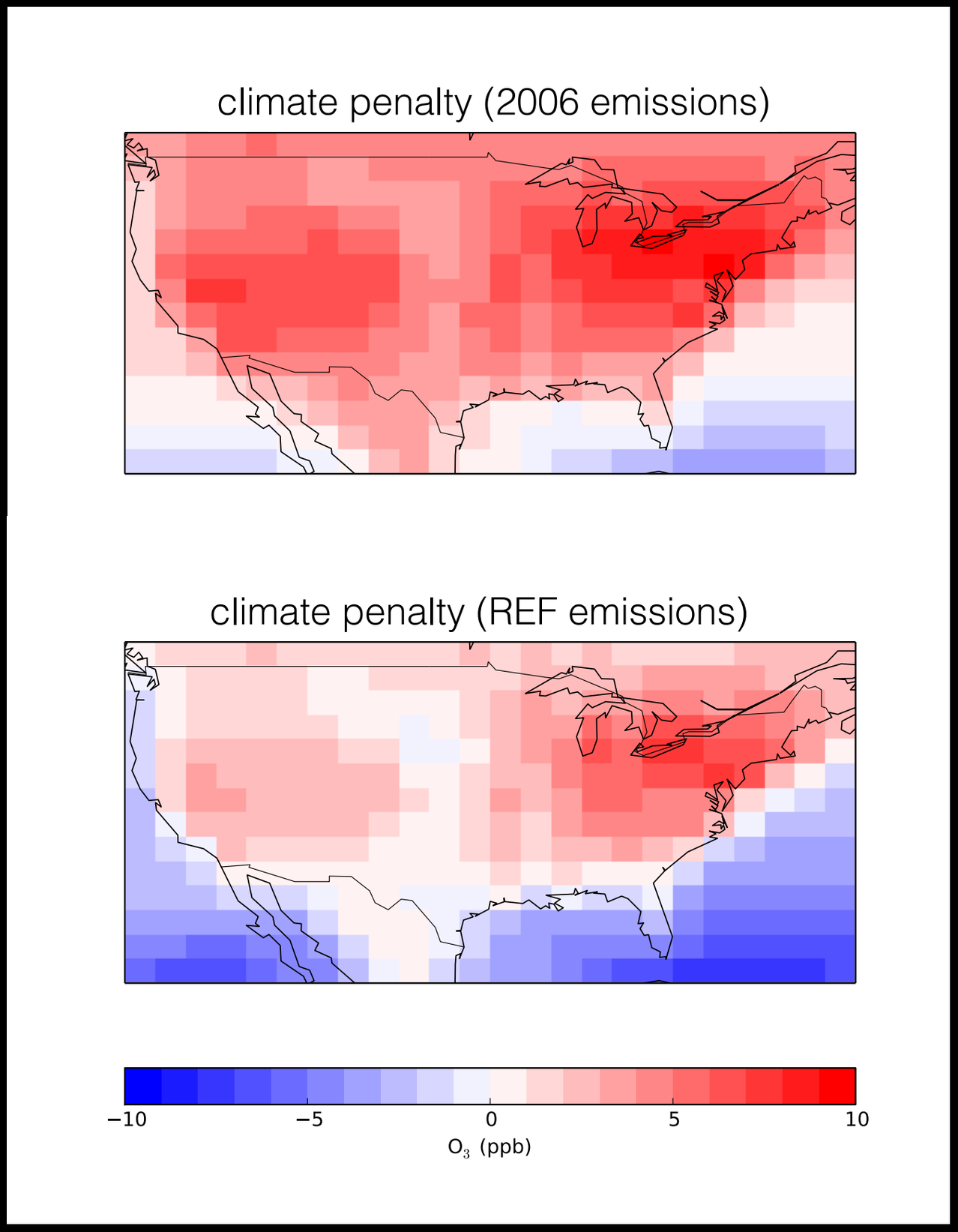


- O_3 Climate penalty is greater when using 2006 emissions.
- Two hot spots: northeast and southwest.
- Climate penalty up to 9.2 ppb with 2006 emissions.
- Garcia-Menendez (2015) showed more regional variation (e.g. north and northwest decreased), but they used annual 8-hr max.

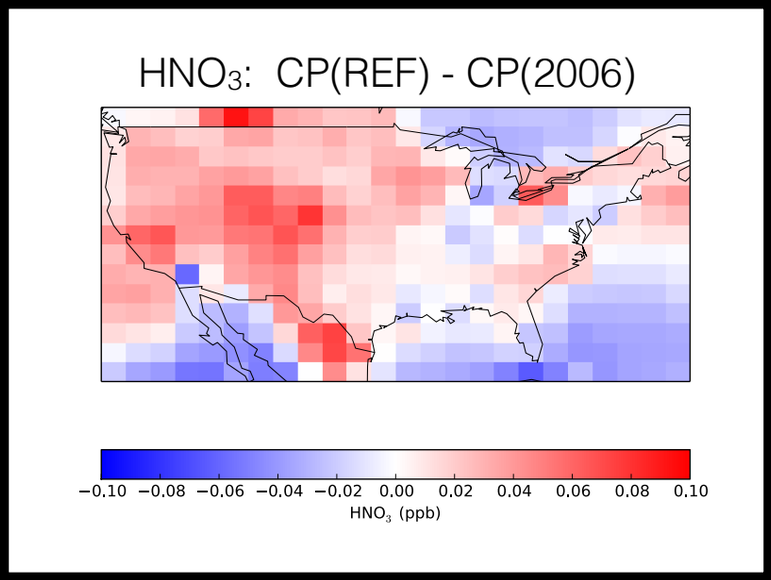


Garcia-Menendez et al. (2015)

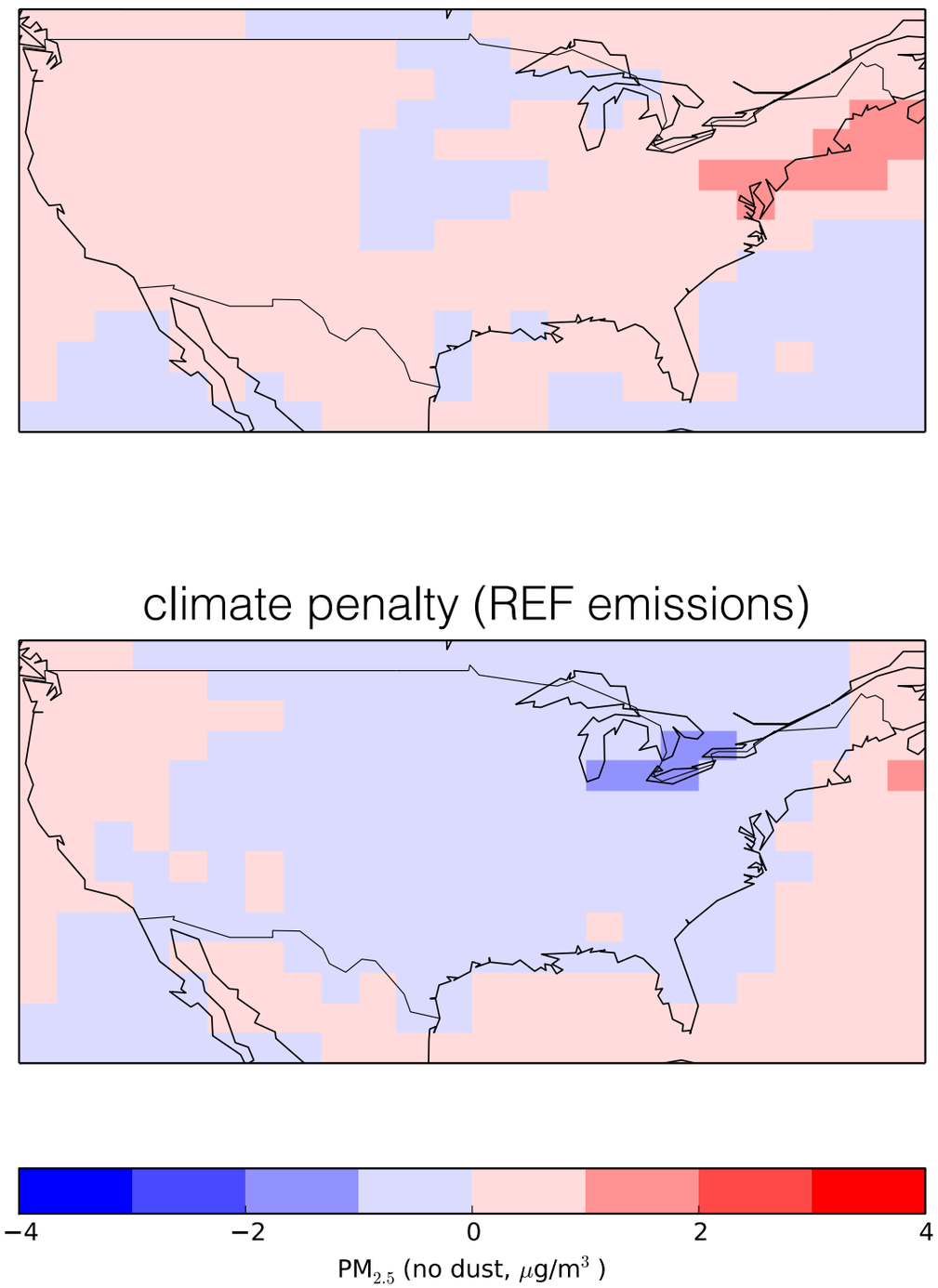
Why is climate penalty smaller with greater emissions?



- Same Δclimate produced more O_3 with 2006 emissions than REF emissions
- Anthropogenic NMVOC increase likely small compared to biogenic NMVOC increase
- Greater NOx efficiency ($\delta O_3/\delta NOx$) with lower NOx emissions, not converting as much NOx to O_3 in REF
- More NOx becoming HNO_3 (surrogate for NOz) as a result of climate with REF emissions.



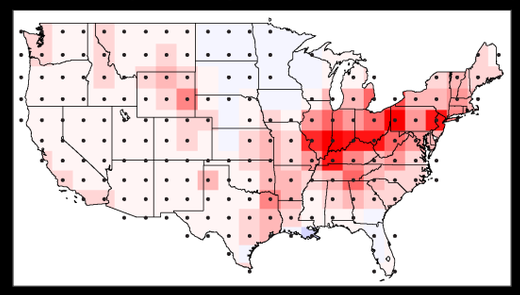
Sign of $PM_{2.5}$ climate penalty dependent on emissions.



$PM_{2.5}$ calculations do not include windblown dust.

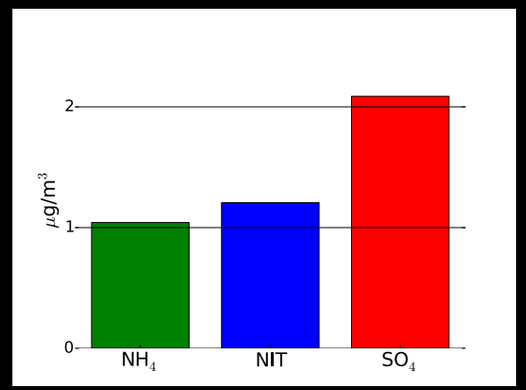
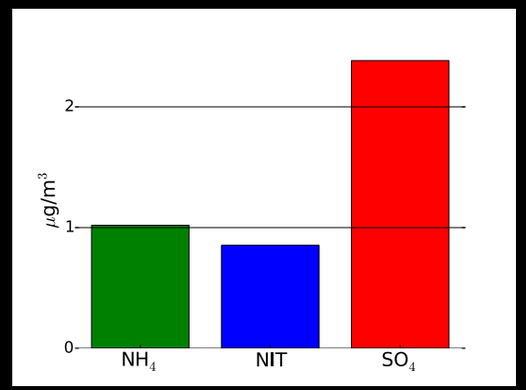
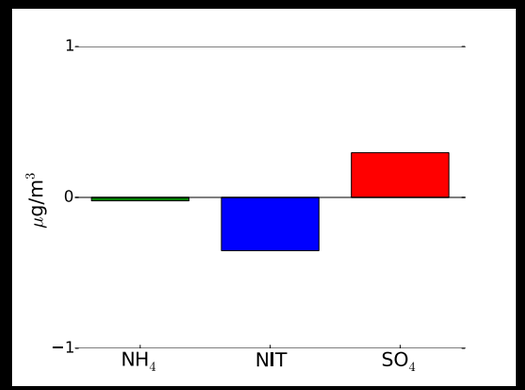
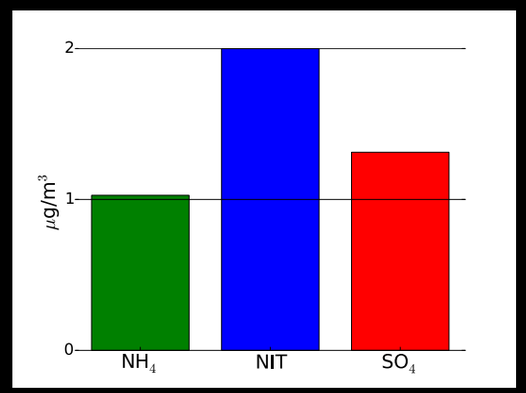
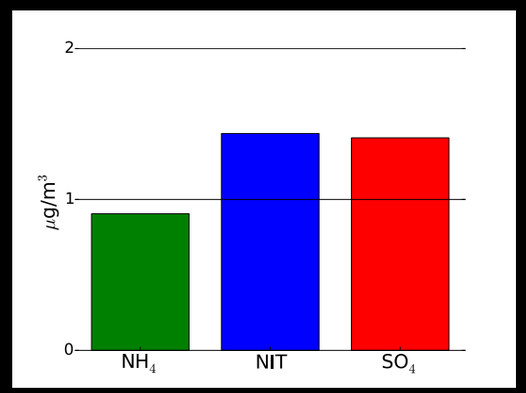
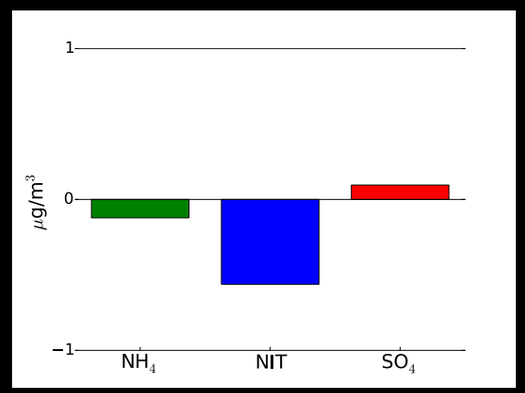
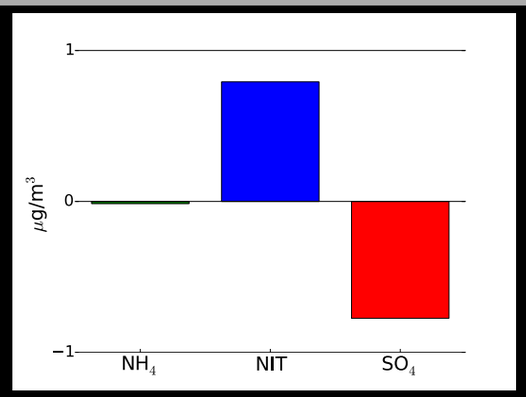
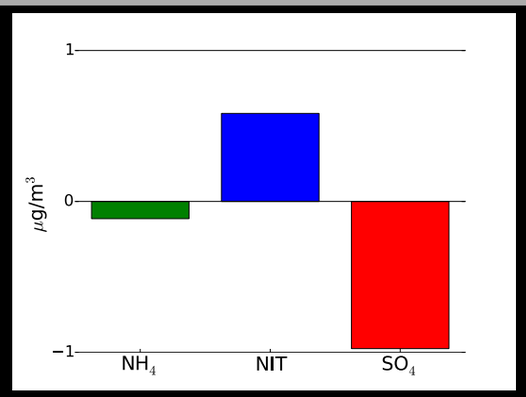
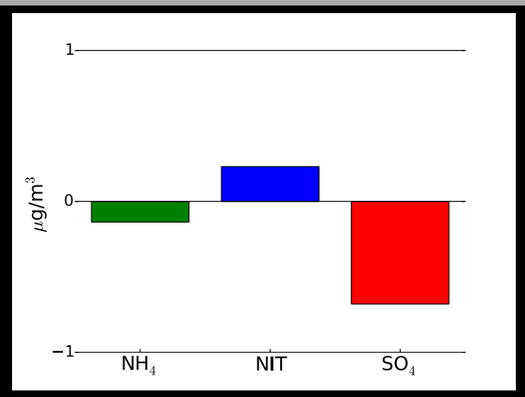
- US-wide increases in climate penalty under 2006 emissions (except for upper midwest).
- Under 2100 emissions, the climate penalty becomes negative (climate benefit) except for northwest.
- Maximum climate penalty increase is 1.3 ug/m^3 using 2006 emissions. Maximum decrease is 1.2 ug/m^3 using 2100 emissions.
- Sign and magnitude of $PM_{2.5}$ climate penalty agrees with Garcia-Melendez (2015) using 2006 emissions.

climate penalty (2006 emissions)



Garcia-Menendez et al. (2015)

Climate and emissions affect $PM_{2.5}$ species differently.

	2000 climate	2100 climate	climate penalty
2006 emis.			
REF emis.			
anthro emissions			

Climate and emissions affect $PM_{2.5}$ species differently.

↑ T = ↑ SO_2 oxidation

↑ T = ↑ gas-phase HNO_3

↑ NOx emissions

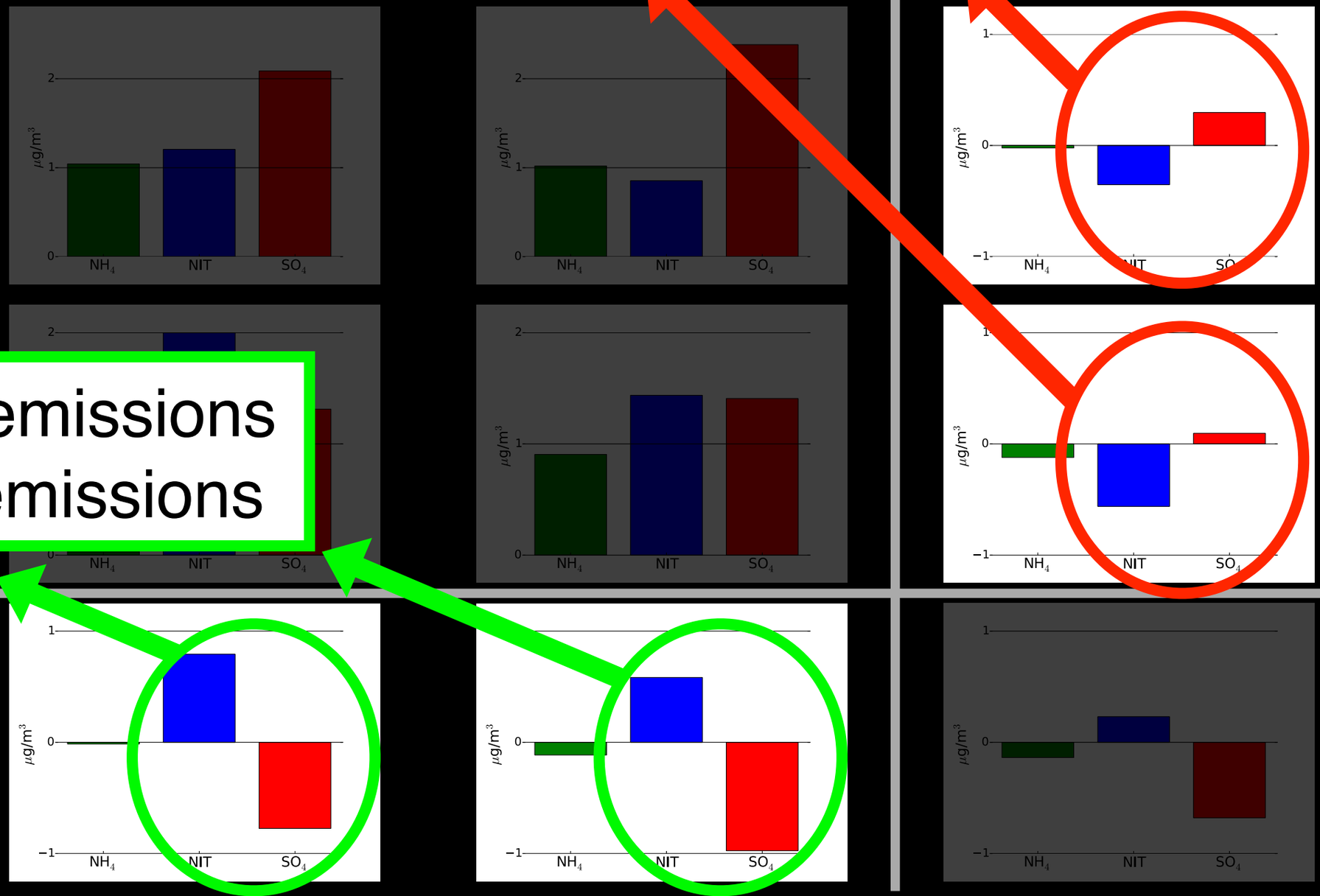
↓ SO_2 emissions

2000 climate

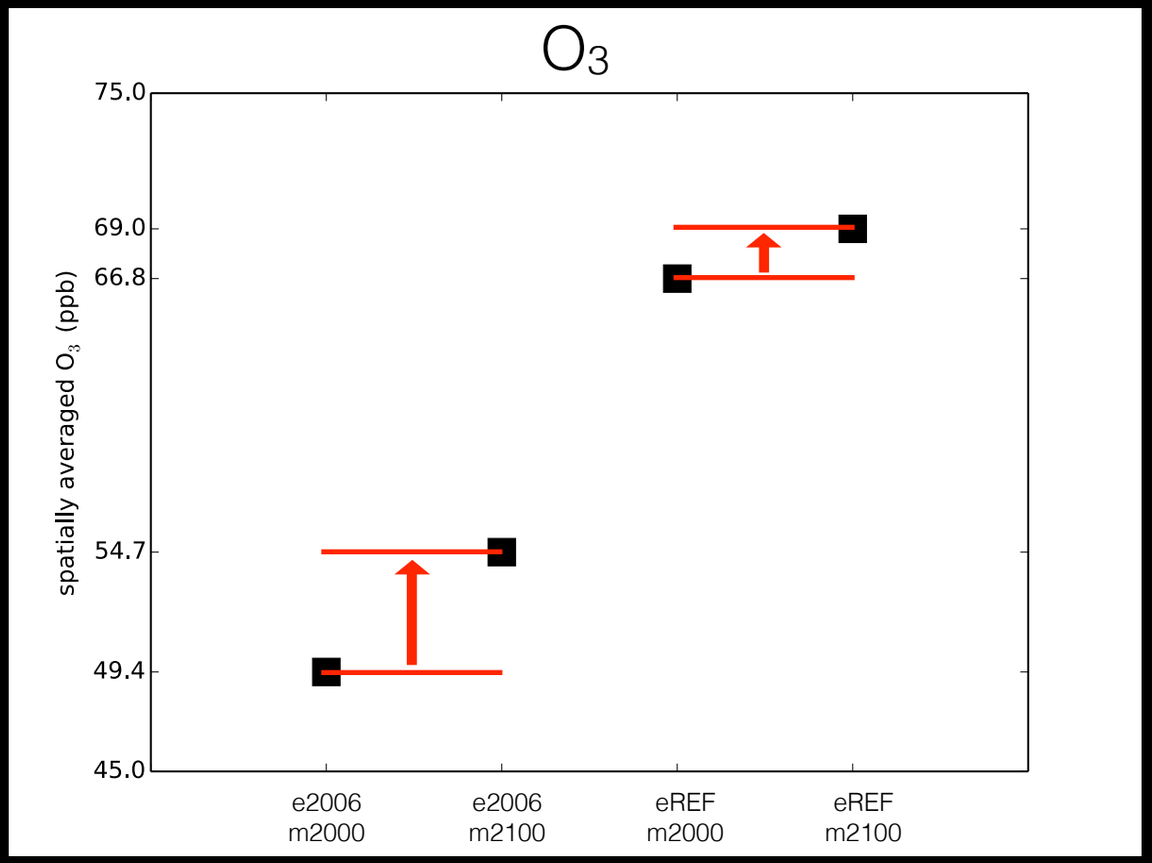
2006 emis.

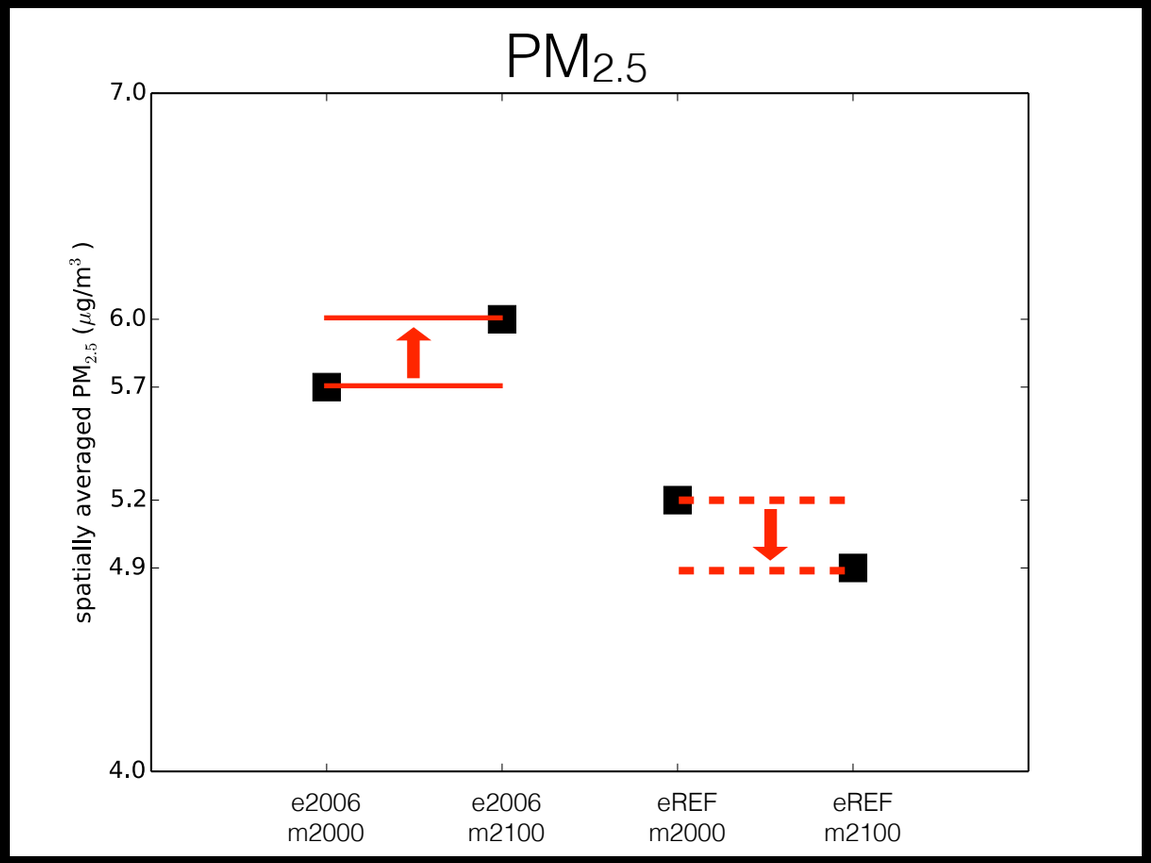
anthro emissions

te penalty



Conclusions





- Climate penalty is reduced under REF emissions scenarios.
- Spatially averaged O_3 penalty is 2.2 ppb (e2100) and 5.3 ppb (e2006). $PM_{2.5}$ penalty is -0.3 ug/m^3 (e2100) and 0.3 ug/m^3 (e2006).
- Climate decreases nitrate and increases sulfate.
- Choice of emissions year determines whether climate causes $PM_{2.5}$ *increase* or *decrease*.

Next steps

- Calculate population-weighted averages (should increase the climate penalty)
- Use longer climate averaging period (20 years or 30 years as in Garcia-Menendez et al. (2015))
- Look at chemical indicators (e.g. $\delta O_3/\delta NO_2$, $\delta O_3/\delta HNO_3$)
- Simulate climate policy/lower emissions scenarios
- Include climate effects on wildfires and dust
- Perform complete benchmarking/model performance evaluation

Thanks.