Source attribution of radiative forcing from short lived climate forcing agents

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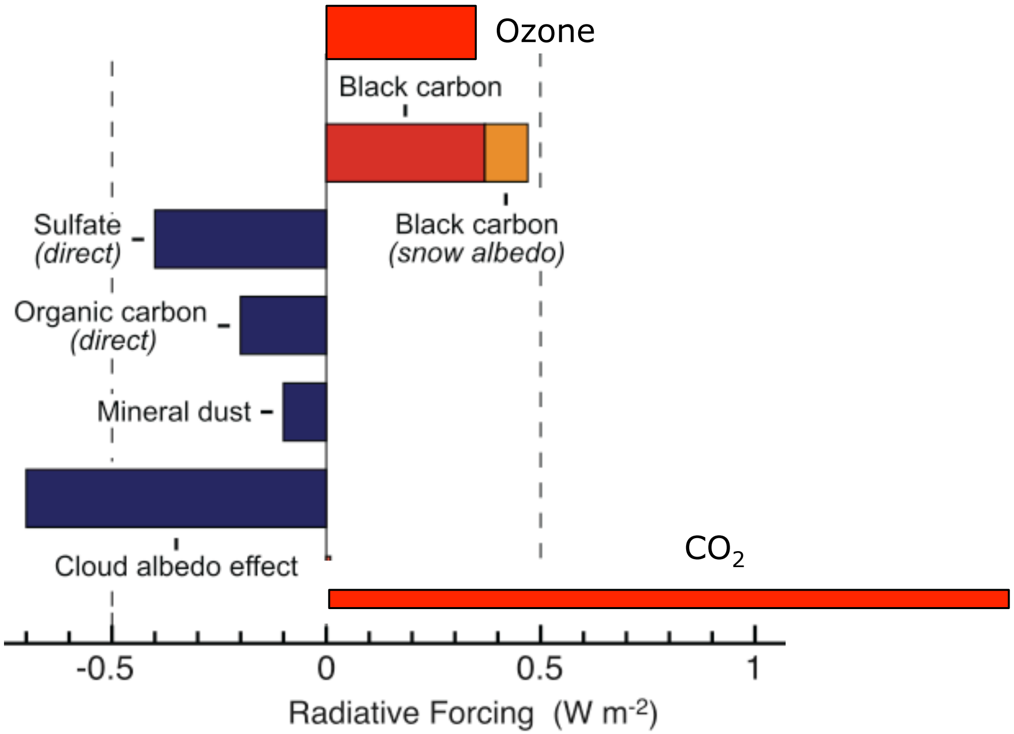
Source attribution of radiative forcing from short lived climate forcing agents

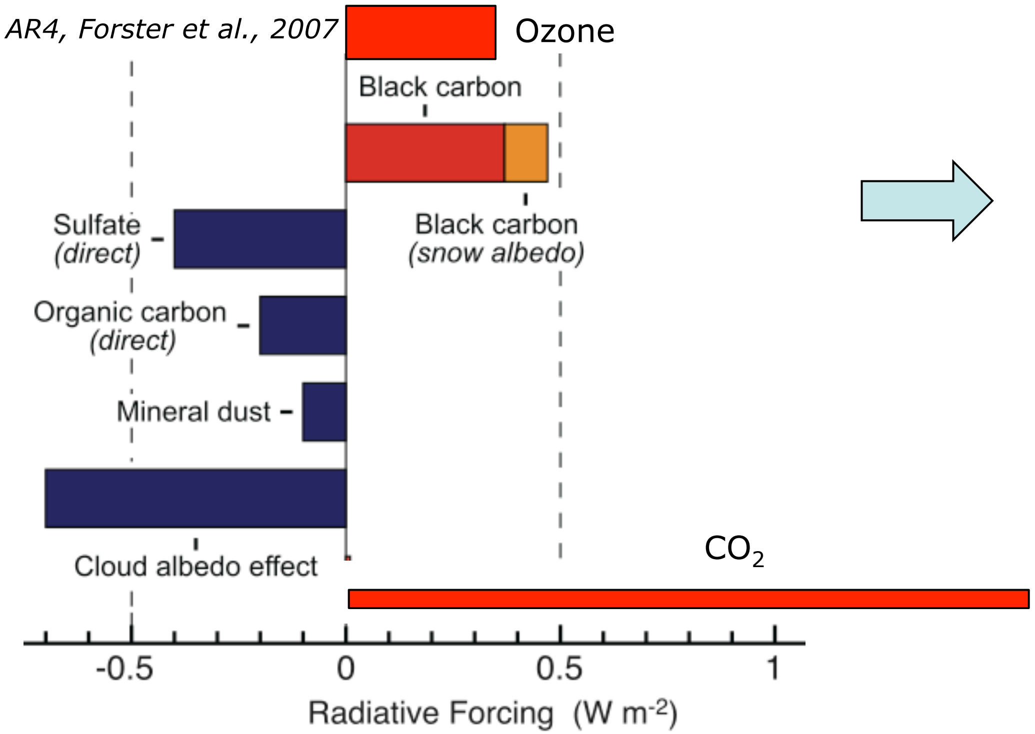
Preindustrial to present radiative forcing *AR4, Forster et al., 2007*



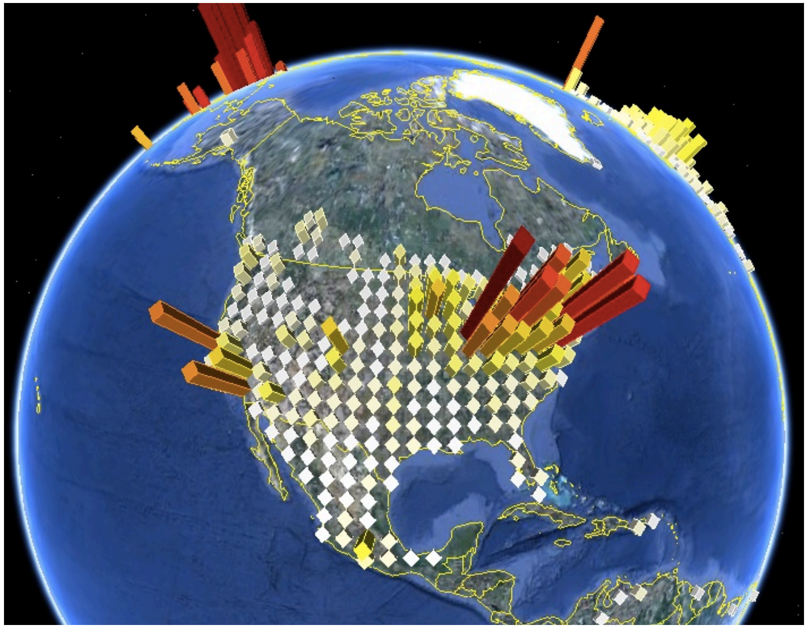
Source attribution of radiative forcing from short lived climate forcing agents

Shift from abundance-based RF to emissions-based RF:

Abundance-based RF



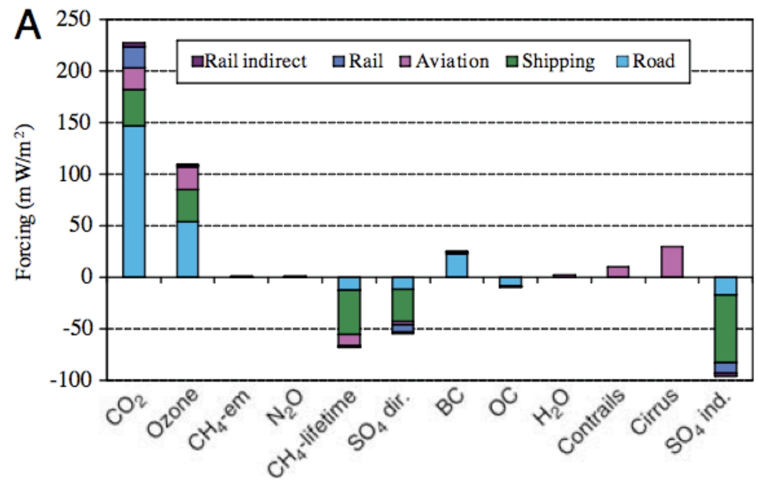
RF of fossil fuel BC emissions



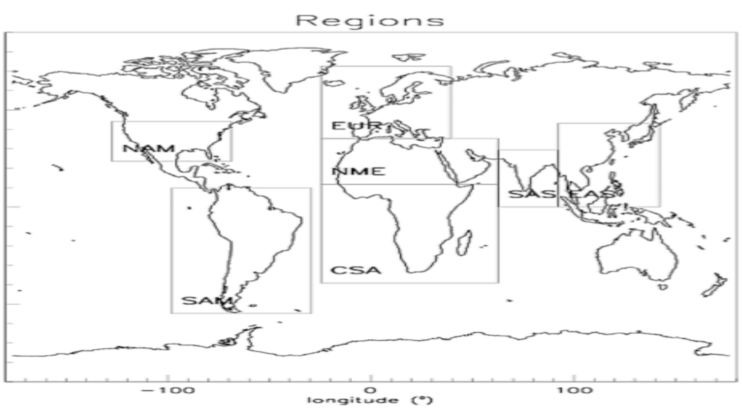
- relevant for policy, exploring co-benefit strategies for AQ and climate
- propagate emissions uncertainty / variability to RF impacts

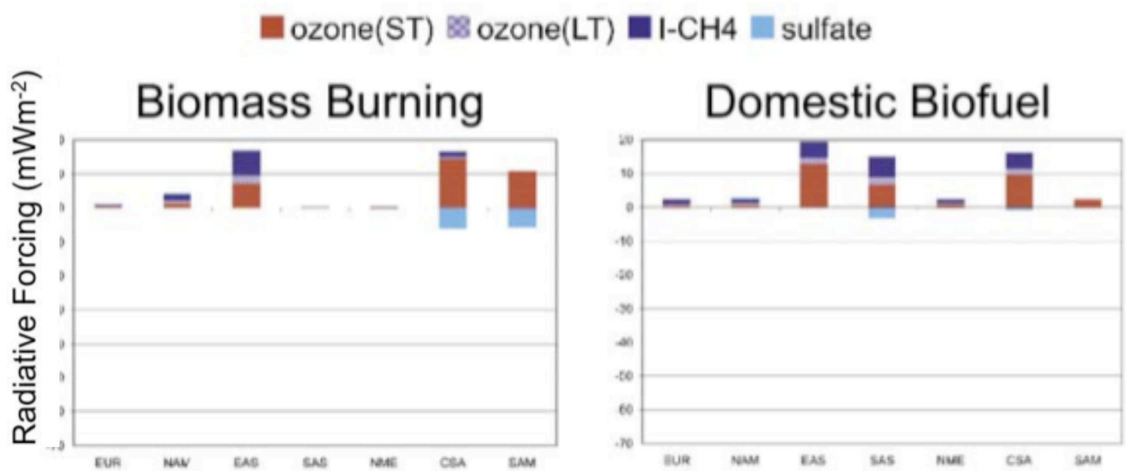
Refining the bar chart: from abundance-based to emissions-based RF

- Sector specific contributions: Fuglestvedt et al., 2008;



- Sector & regional specific contributions: Unger et al., 2008





Koch et al., 2005; Unger et al., 2010; Shindell et al., 2011; 2012; Menon and Bauer, 2012; Yu et al., 2013, Leibensperger et al., 2012, Naik et al., 2005; Fry et al., 2012

Calculating emissions-based RF

Directly: perturb emissions and re-run model (CTM or GCM)

$$RF = F(E') - F(E)$$

E = emissions
E' = perturbed emissions
F = model estimated change in TOA global radiative flux
RF = radiative forcing

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Directly: perturb emissions and re-run model (CTM or GCM)

$$RF = F(E') - F(E)$$

E = emissions
E' = perturbed emissions
F = model estimated change in TOA global radiative flux
RF = radiative forcing

Approximately: use RF sensitivities

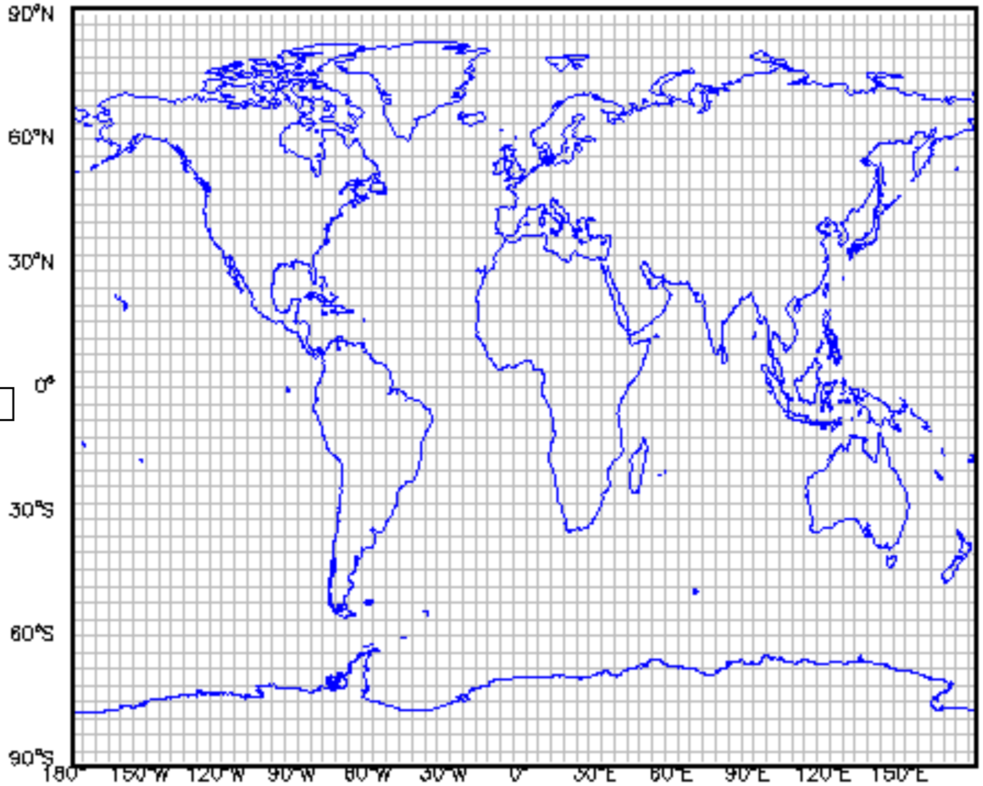
$$RF \approx \left(\frac{\partial F}{\partial E}\right)(E' - E)$$

New approach:
Radiative Forcing Sensitivities

Sensitivities from **every** sector and region:

$$\delta E_1 \quad \delta E_2 \quad \vdots \quad \delta E_{10^5}$$

⇦

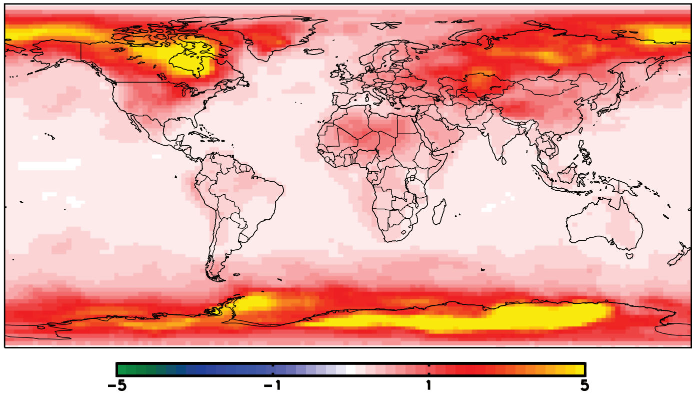


⇦ δRF

Calculated very efficiently using **GEOS-Chem adjoint** (Henze et al., 2007) and **LIDORT** (Spurr, 2002)

Direct Radiative Forcing efficiencies: aerosol

The change in DRF
per change in BC emission



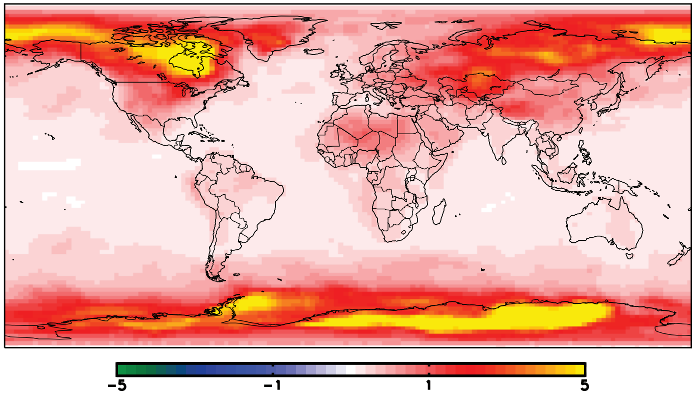
W m^{-2} / (kg m^{-2} yr^{-1})

Henze et al., 2012

Direct Radiative Forcing efficiencies: aerosol

How does variability in DRF efficiency impact DRF for various emissions sources and sectors following future scenarios?

The change in DRF
per change in BC emission



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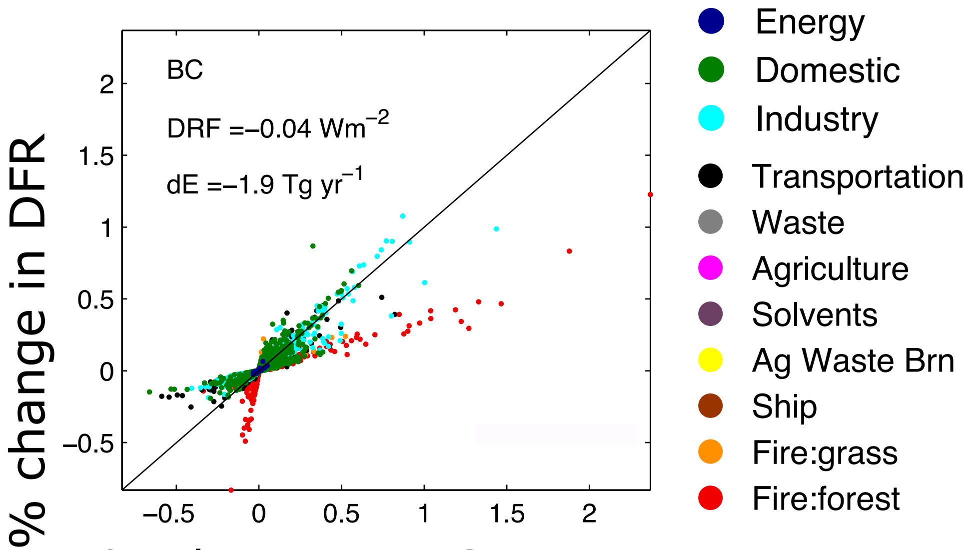


% change in BC emissions
for 2050 – 2000 RCP 4.5

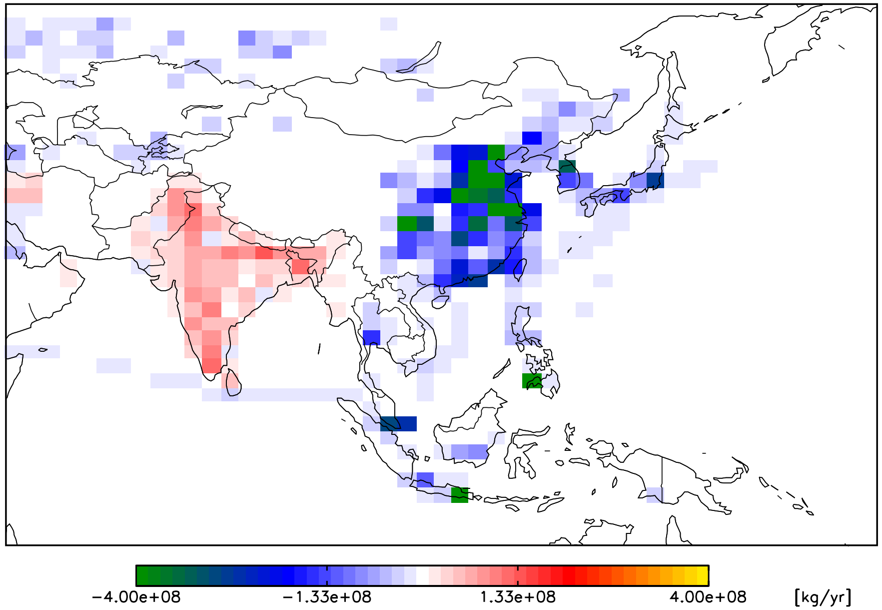
Location matters

Henze et al., 2012

Importance of high-resolution emissions-based RF

Spatial heterogeneity in SO_2 emissions changes following
- a single Representative Concentration Pathway for AR5

RCP 8.5: 2050 - 2000

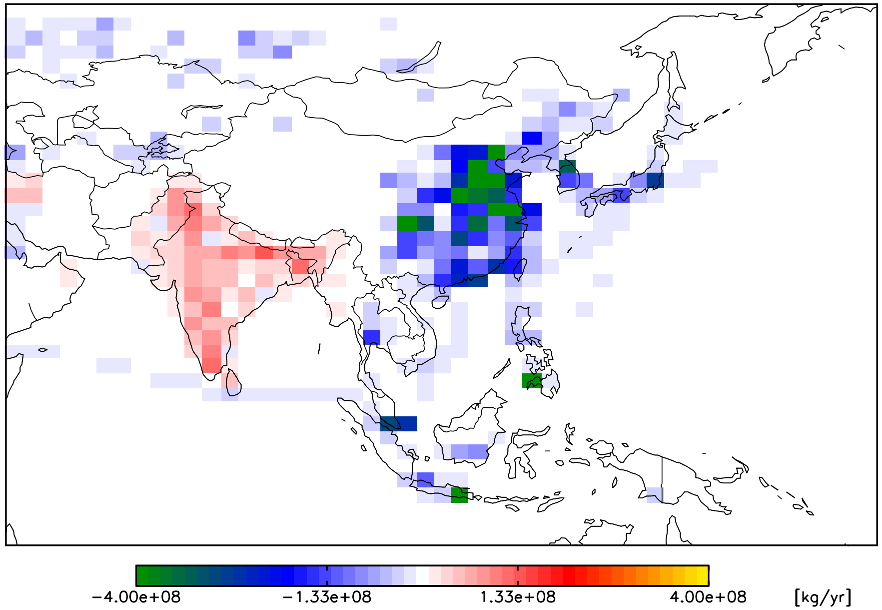


Importance of high-resolution emissions-based RF

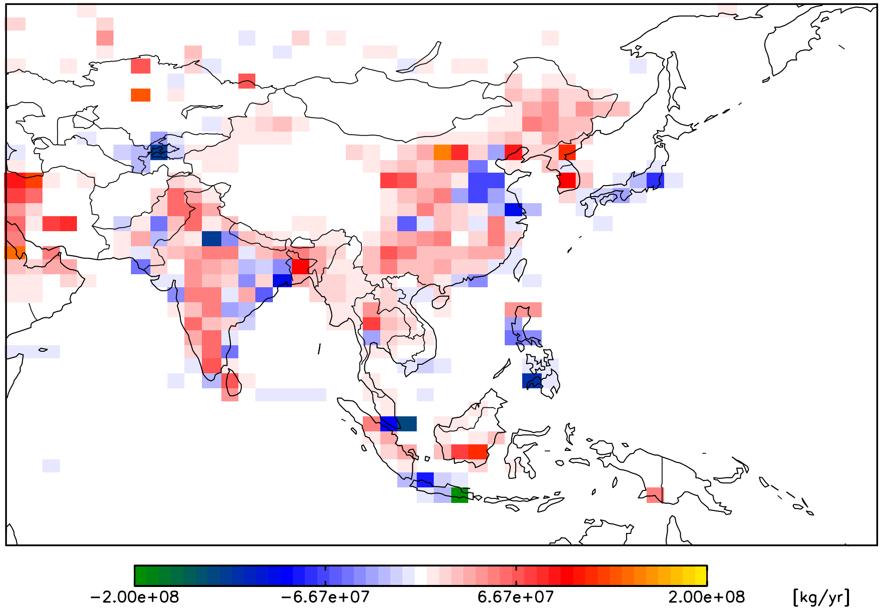
Spatial heterogeneity in SO_2 emissions changes following

- a single Representative Concentration Pathway for AR5
- the difference between two Pathways for AR5

RCP 8.5: 2050 - 2000

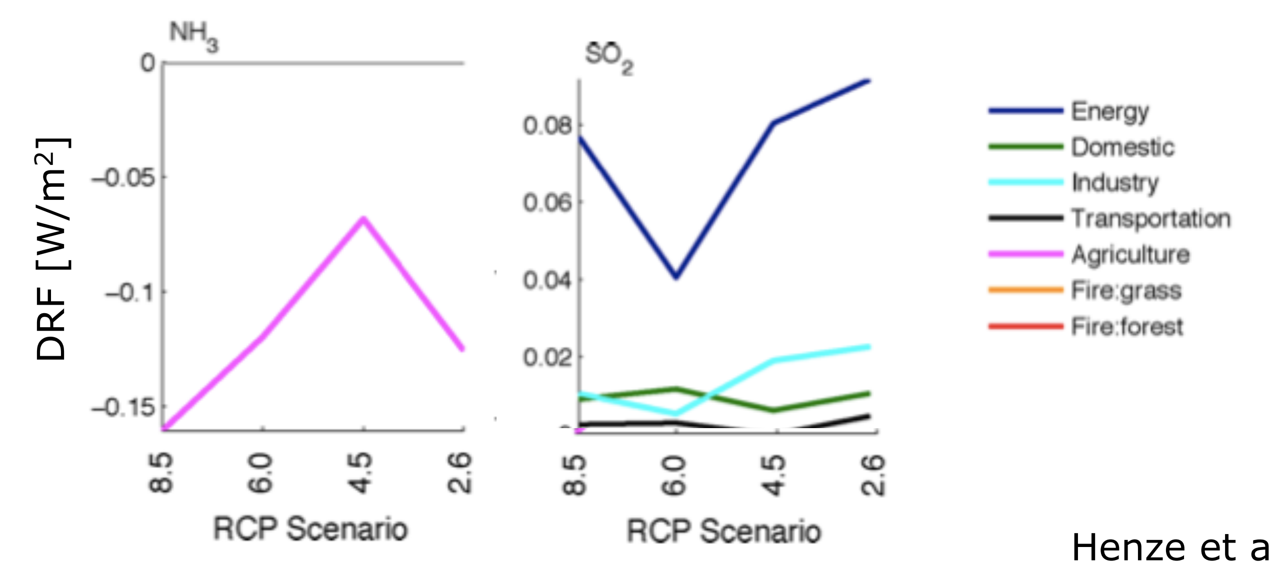


RCP 8.5 2050 – RCP 4.5 2050



Significant intra-regional variability

Comparison of aerosol RF across emissions scenarios: present to 2050



Henze et al., 2012

- NH_3 emissions are projected to increase in all RCP scenarios (Moss et al., 2010)

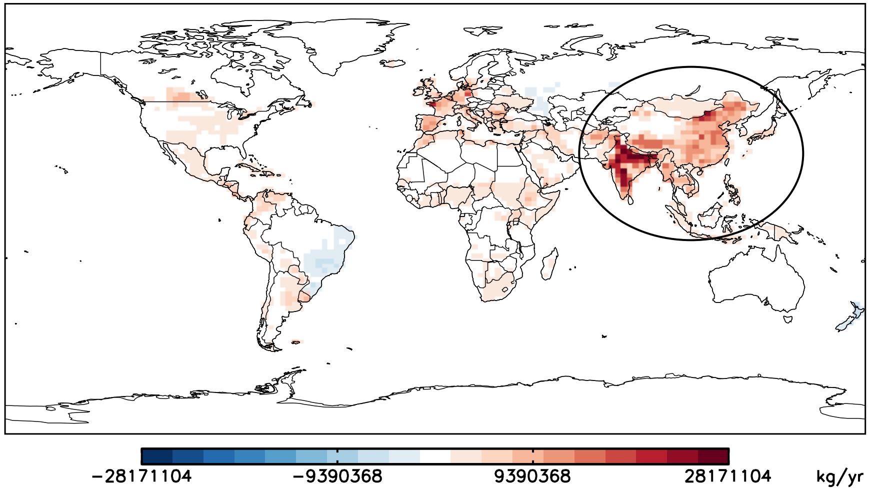
- Looking ahead to 2050, negative DRF of NH_3 increases outweighs positive DRF of SO_2 decreases in many scenarios.

- How sensitive are adjoint model sensitivity calculations to emissions basis?

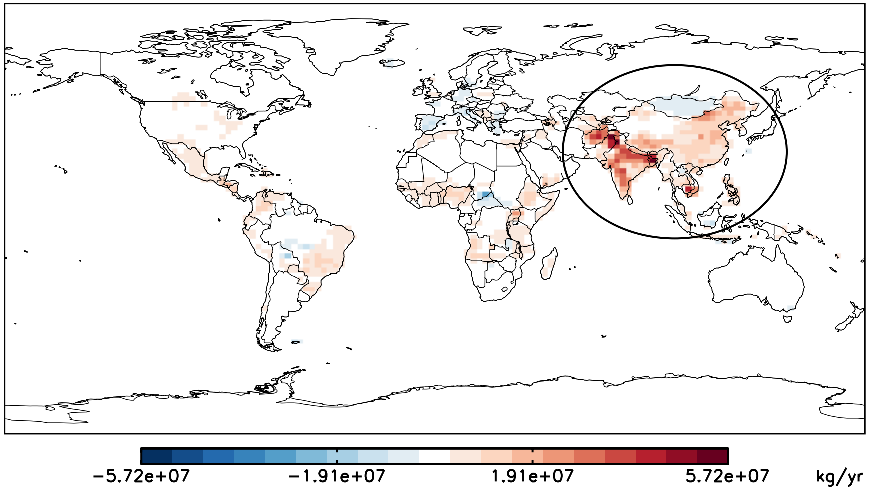
Cross-species impacts on aerosol DRF

NH_3 emissions: 2050 - 2000

RCP 6.0



RCP 2.6



Cross-species impacts on aerosol DRF

NH_3 emissions: 2050 - 2000

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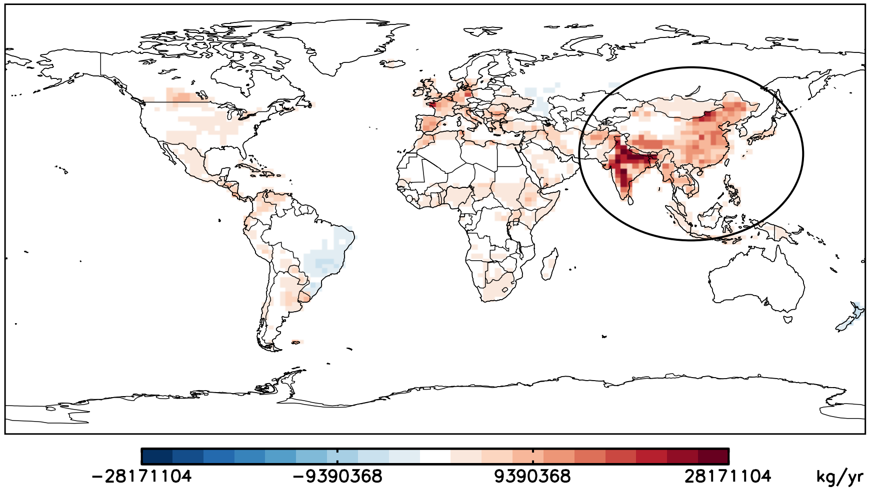

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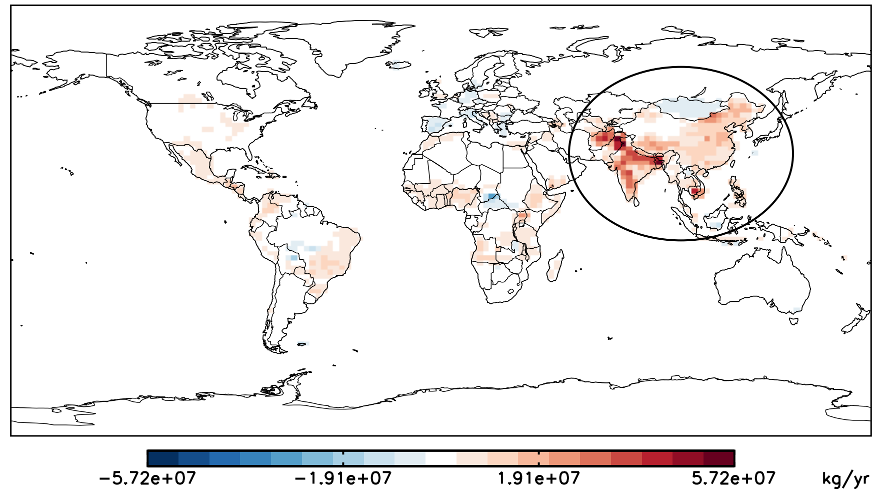
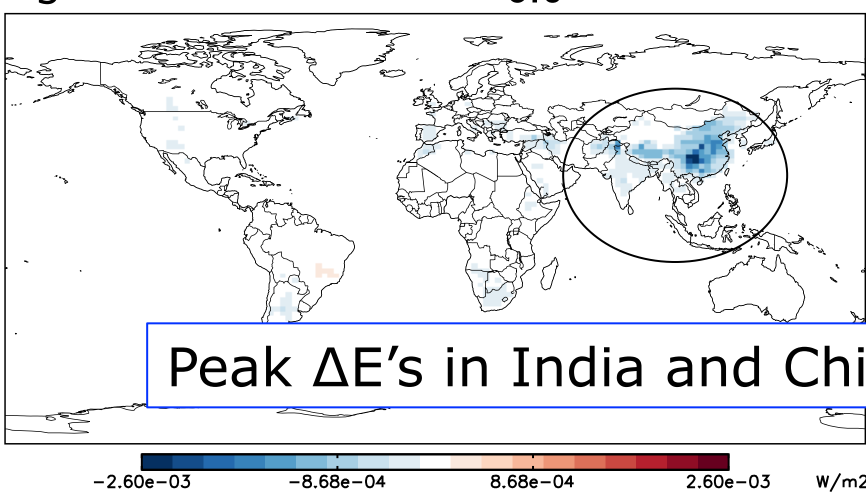
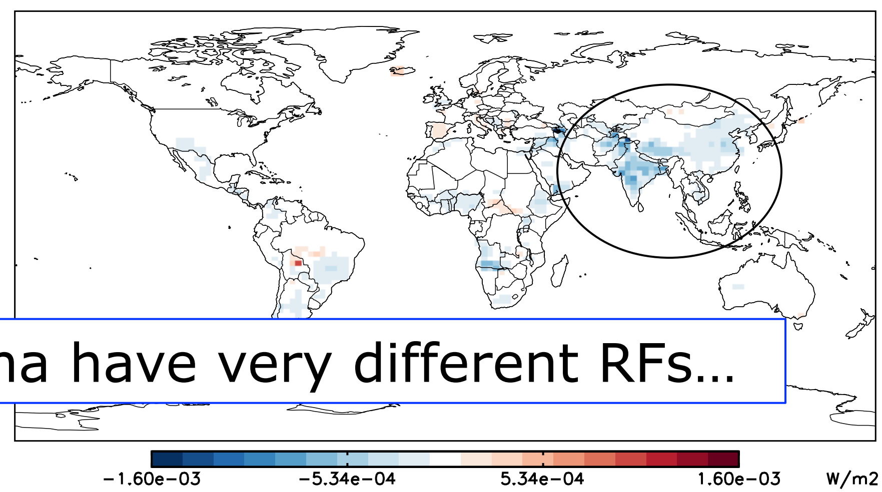


NH_3 DRF: $(dRF/dE)_{6.0} * \Delta E$



$(dRF/dE)_{2.6} * \Delta E$

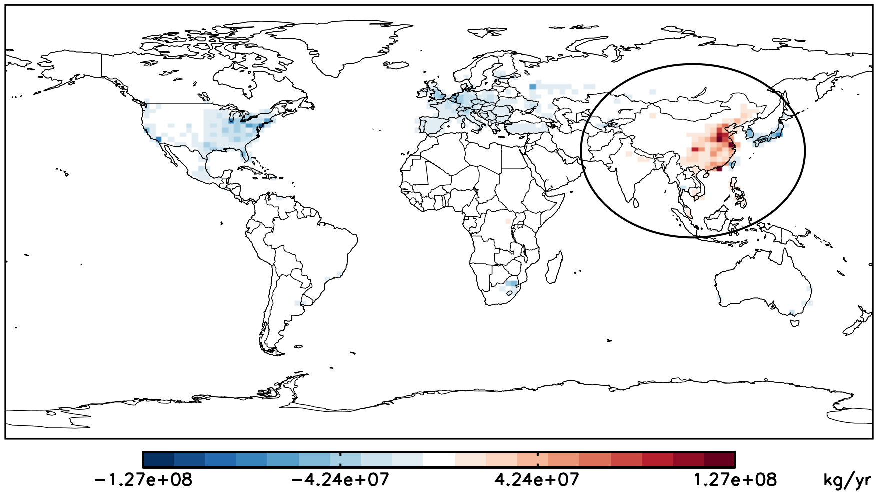


Peak ΔE's in India and China have very different RFs…

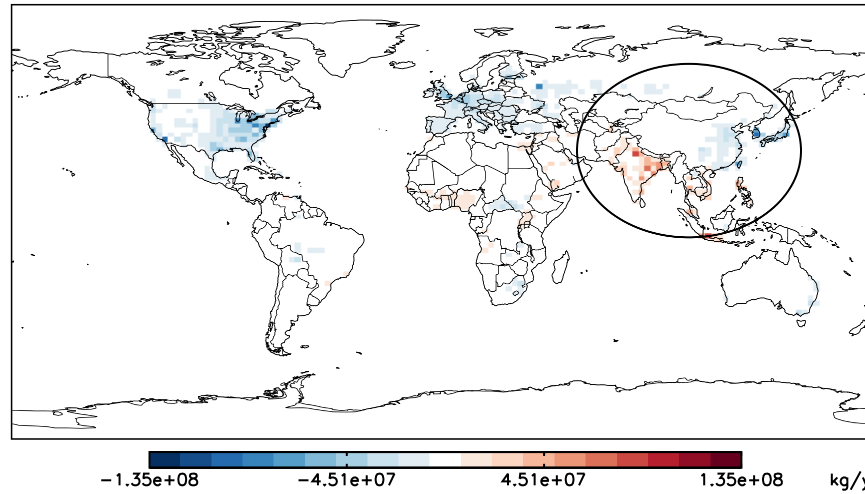
Cross-species impacts on aerosol DRF

NO_x emissions: 2050 - 2000

RCP 6.0



RCP 2.6



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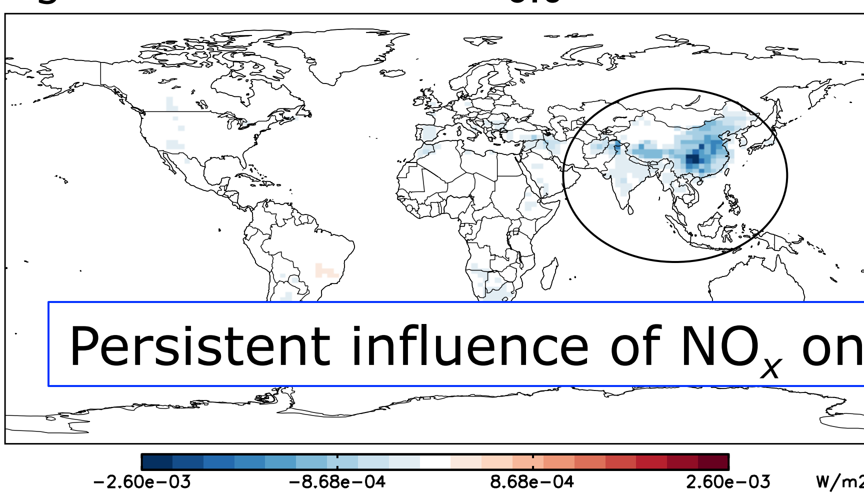
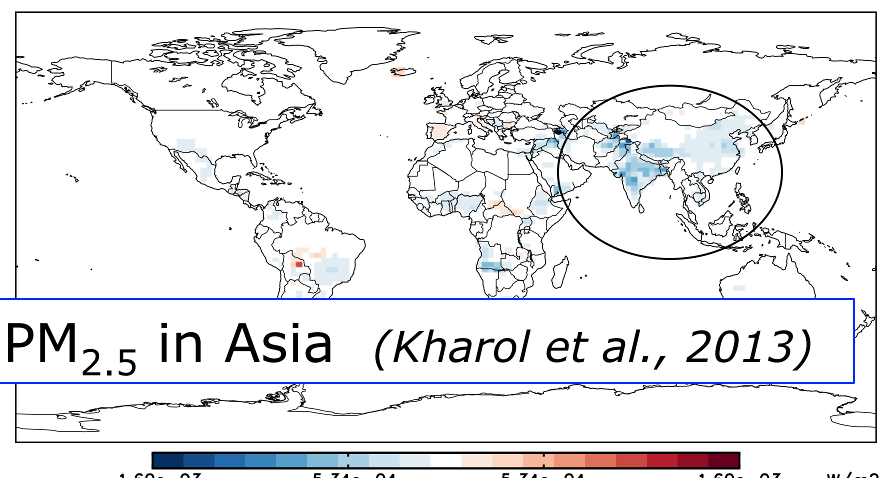


$(dRF/dE)_{2.6} * \Delta E$

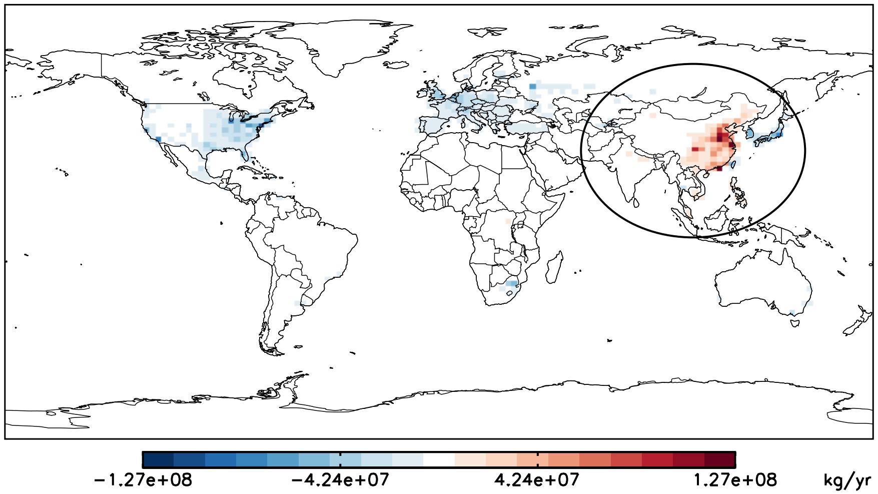


Persistent influence of NO_x on $PM_{2.5}$ in Asia *(Kharol et al., 2013)*

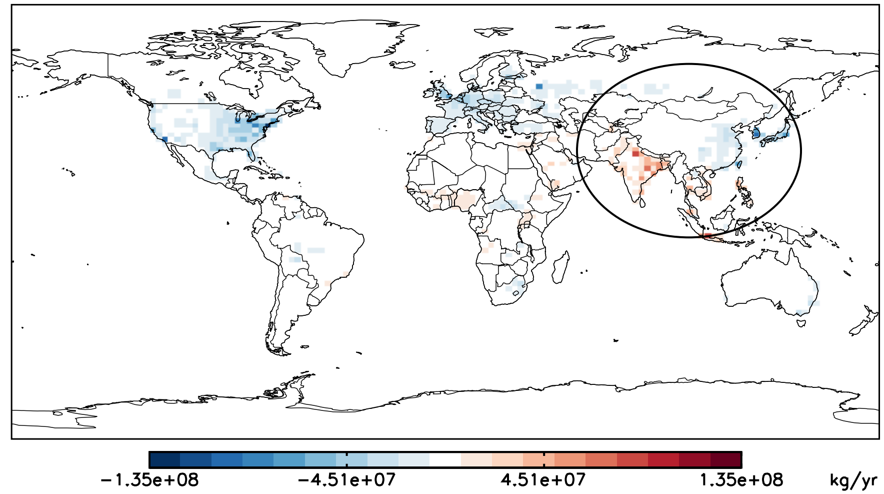
Cross-species impacts on aerosol DRF

NO_x emissions: 2050 - 2000

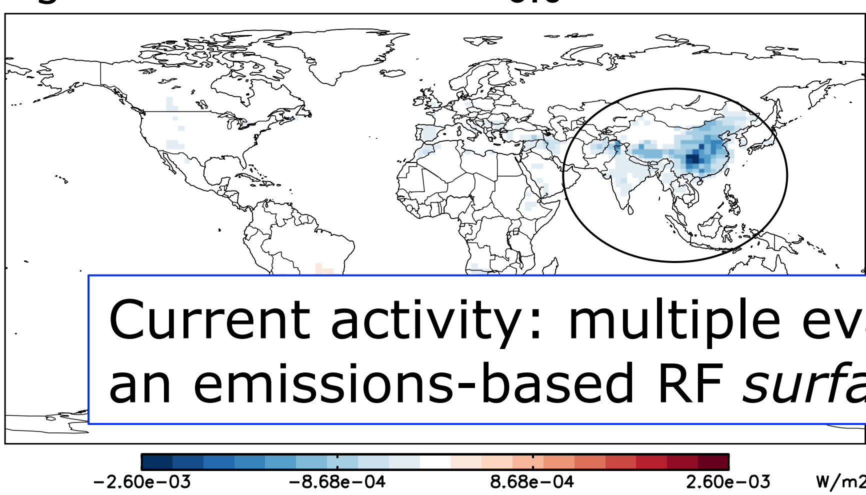
RCP 6.0



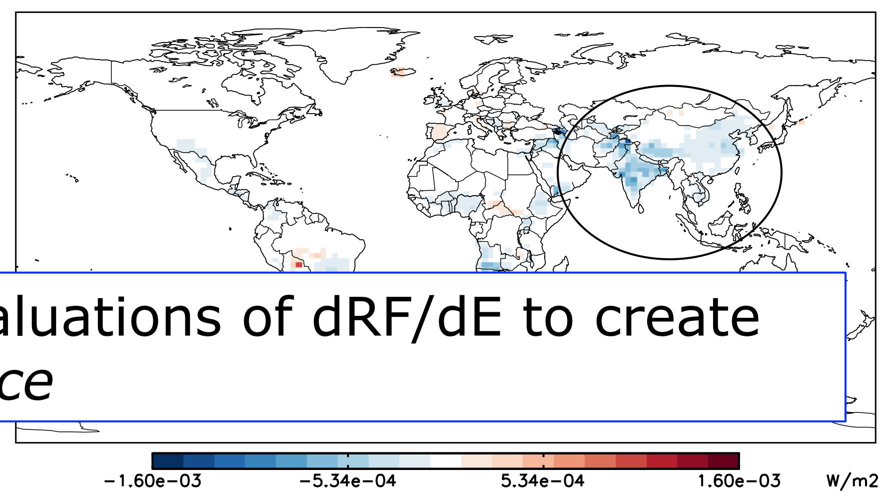
RCP 2.6



NH_3 DRF: $(dRF/dE)_{6.0} * \Delta E$



$(dRF/dE)_{2.6} * \Delta E$

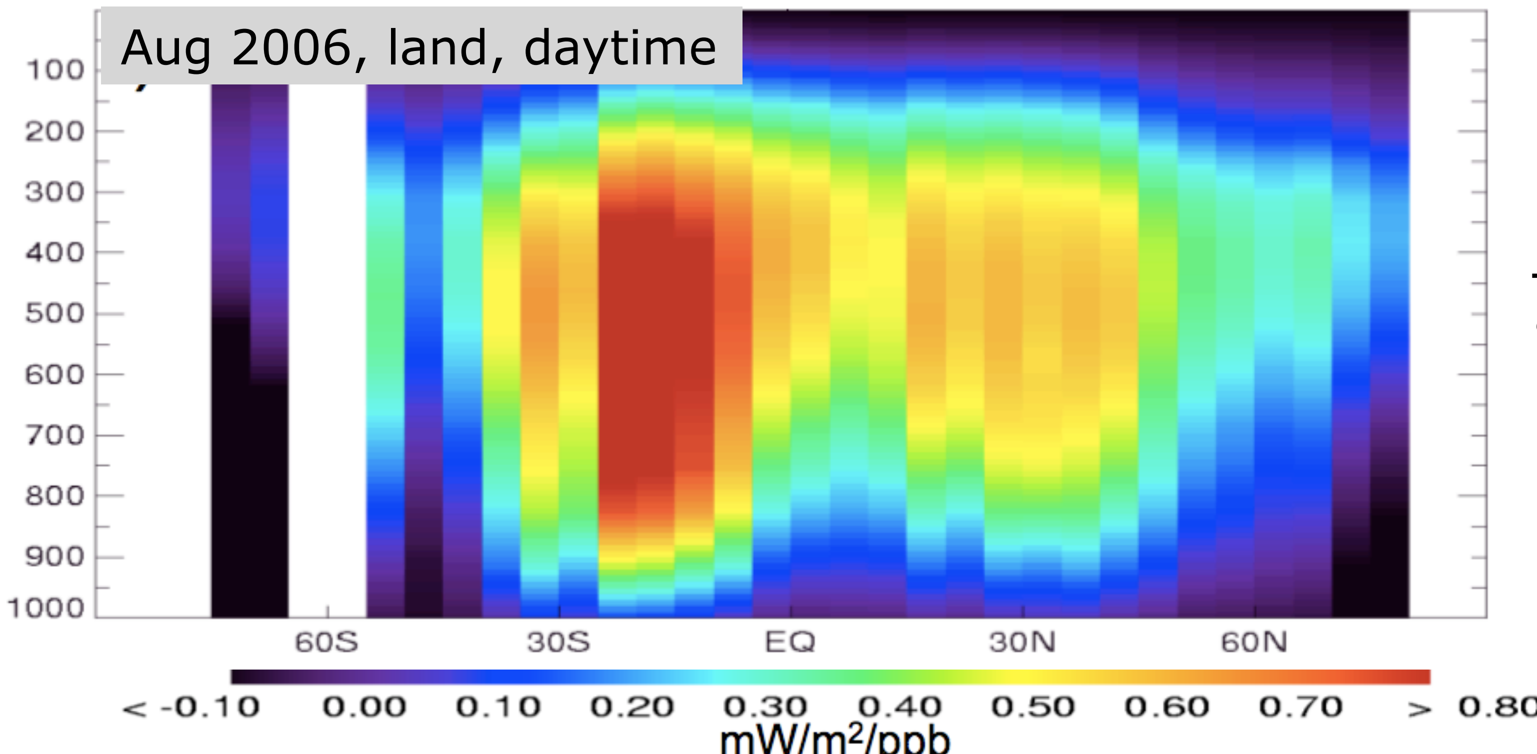


Current activity: multiple evaluations of dRF/dE to create an emissions-based RF *surface*

Tropospheric O_3 radiative forcing

IPCC estimate (model based) of 0.35 [0.25 – 0.65] W/m^2 is 3rd largest preindustrial to present GHG forcing *(Forster et al., 2007)*.

TES Tropospheric Instantaneous Radiative Kernel, IRK, is **remotely observed** change in outgoing radiation (OLR) per change in O_3 [ppb].



$$\frac{\partial OLR}{\partial O_3(z)}$$

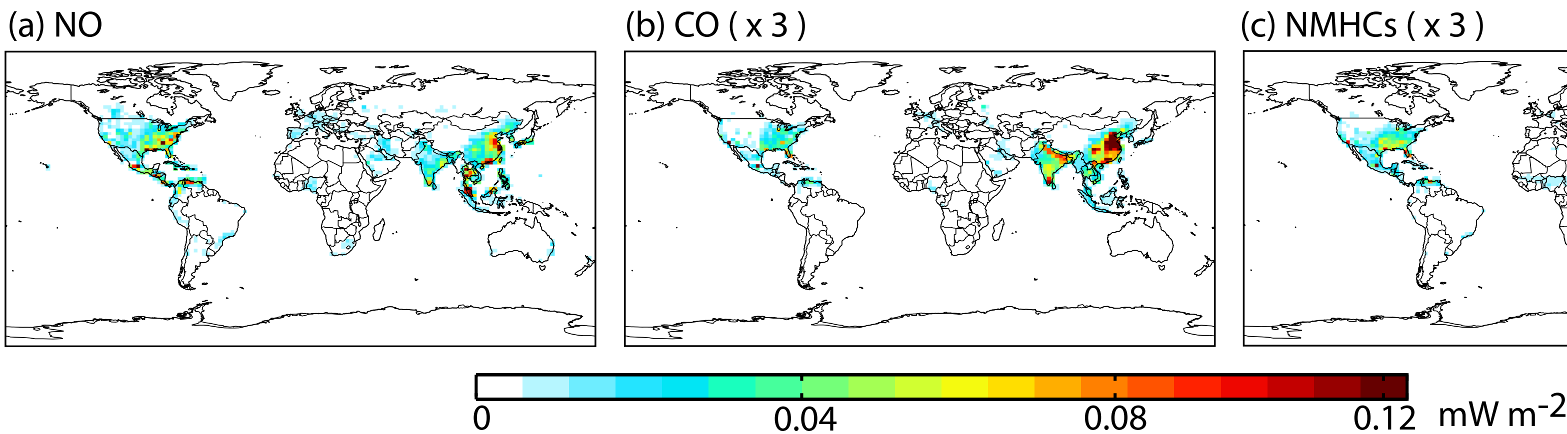
Worden et al., (2008; 2011), Aghedo et al., 2011

Tropospheric O_3 radiative forcing

Combine GEOS-Chem adjoint sensitivities with TES IRKs:

$$\frac{\partial \text{radiative effect}}{\partial E_i(x,y)} = \frac{\partial O_3(x,y,z)}{\partial E_i(x,y)} \times \frac{\partial \text{radiative effect}}{\partial O_3(x,y,z)}$$

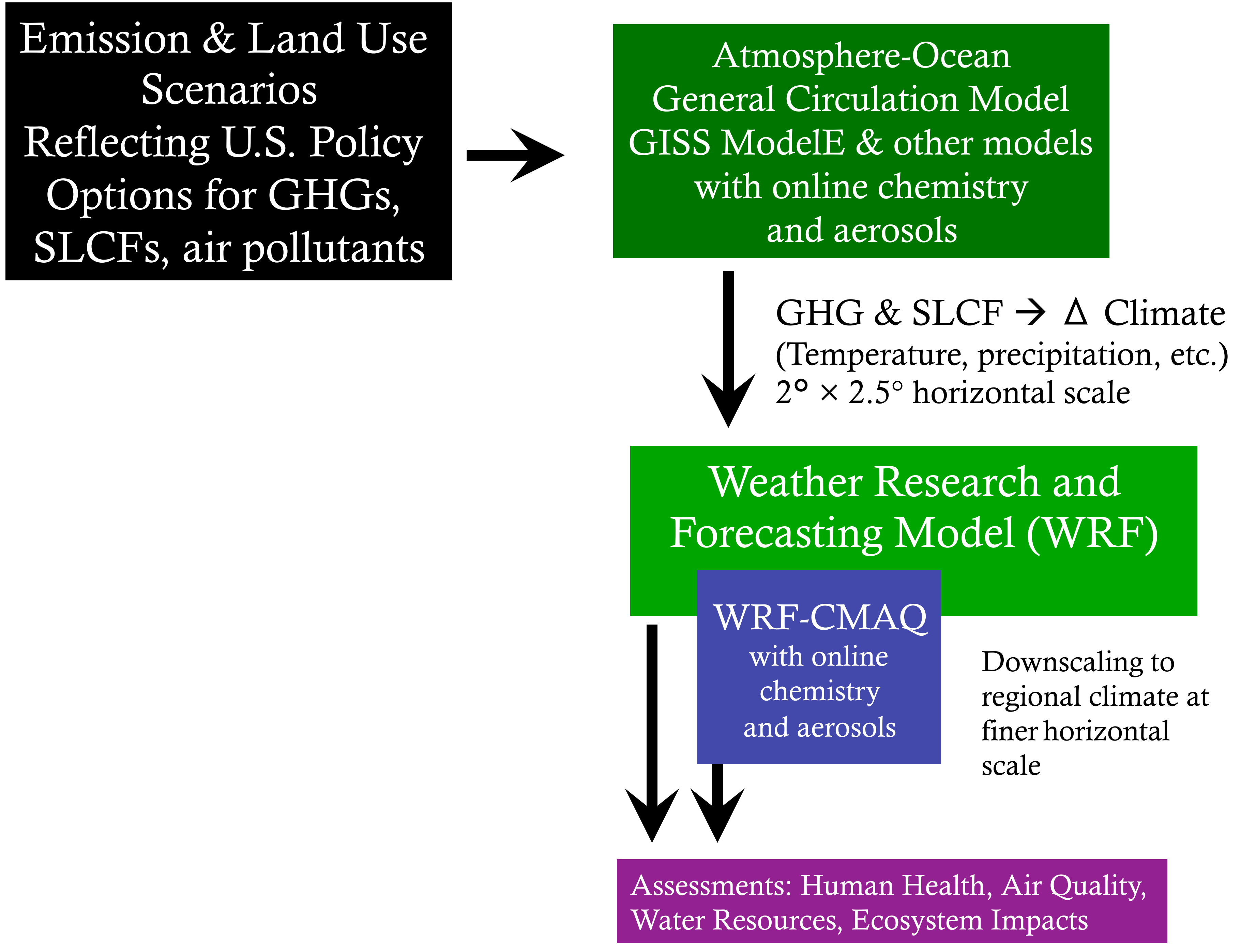
Estimate location-specific RF contributions by species:



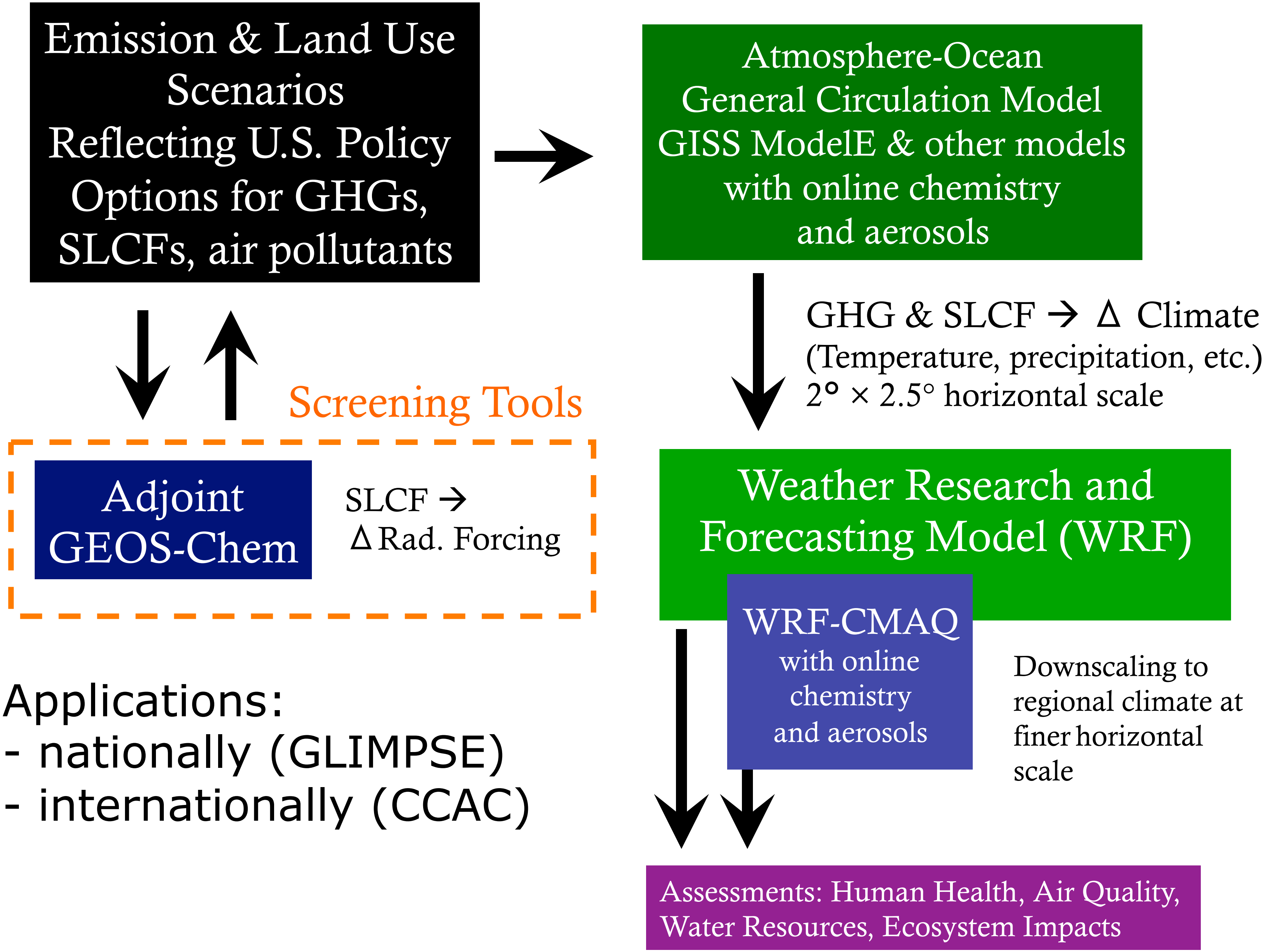
Forcing efficiency:

- varies by latitude by *x*10 *(Naik et al., 2005; Stevenson and Derwent, 2009)*
- varies intra-continentally by *x*3 – *x*10

note: results for August, not including OH/CH_4 feedback *Bowman and Henze, 2012*



Emission & Land Use Scenarios Reflecting U.S. Policy Options for GHGs, SLCFs, air pollutants
Atmosphere-Ocean General Circulation Model GISS ModelE & other models with online chemistry and aerosols
GHG & SLCF → Δ Climate
(Temperature, precipitation, etc.)
2° × 2.5° horizontal scale
Weather Research and Forecasting Model (WRF)
WRF-CMAQ with online chemistry and aerosols
Downscaling to regional climate at finer horizontal scale
Assessments: Human Health, Air Quality, Water Resources, Ecosystem Impacts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GHG & SLCF → Δ Climate
(Temperature, precipitation, etc.)
2° × 2.5° horizontal scale
Screening Tools
Adjoint GEOS-Chem
SLCF → Δ Rad. Forcing
Weather Research and Forecasting Model (WRF)
WRF-CMAQ
with online chemistry and aerosols
Downscaling to regional climate at finer horizontal scale
Applications:
- nationally (GLIMPSE)
- internationally (CCAC)
Assessments: Human Health, Air Quality, Water Resources, Ecosystem Impacts

Summary of project activities and goals

Science goals:

- Estimate uncertainty in RF and estimates of climate impact owing to ranges of possible emissions scenarios
- Determine co-benefits of emissions scenarios for air quality and climate

Activities year 1:

- Second order sensitivity analysis of aerosol DRF
- Regional aerosol DRF (and estimated climate response)
- Extension of O_3 RF attribution to include long-term feedbacks

Activities Year 2:

- Annual ozone RF
- Regional ozone RF (and estimated climate response)
- Assess impacts of range of emissions scenarios

Final comments

- Adjoint model sensitivities provide quick estimates of emissions-based radiative forcing.

- Radiative forcing efficiencies are variable at scales commensurate with those on which emissions control strategies are enacted.

- Second-order sensitivity analysis important for aerosol and ozone RF projections.

- To better understand climate response, need to move beyond the global radiative forcing.

- This is just one model. Factors beyond emissions contribute to diversity of model RFs (e.g., Stier et al., 2012; Myhre et al., 2012).

Questions?