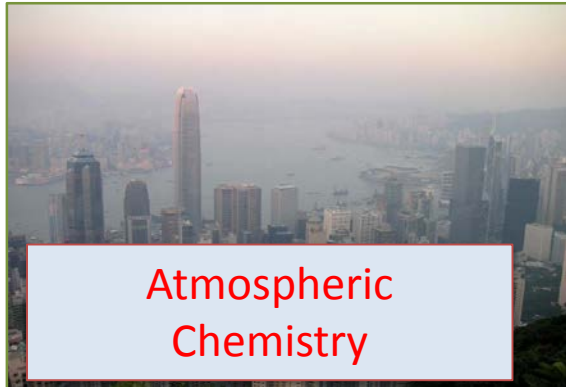


# Chemistry-Ecosystems-Climate Working Group

- Focus on the coupling of atmospheric chemistry with varying components of the broader climate system and the biosphere with GEOS-Chem
- Co-Chairs
  - Jeff Geddes (Boston University; [jgeddes@bu.edu](mailto:jgeddes@bu.edu))
  - Hong Liao (Nanjing University of Information Science & Technology; [hongliao@nuist.edu.cn](mailto:hongliao@nuist.edu.cn))
  - Lee Murray (University of Rochester; [lee.murray@rochester.edu](mailto:lee.murray@rochester.edu))
  - Amos Tai (Chinese University of Hong Kong; [amostai@cuhk.edu.hk](mailto:amostai@cuhk.edu.hk))
- E-mail list: [geos-chem-climate@g.harvard.edu](mailto:geos-chem-climate@g.harvard.edu)
- wiki page / Ongoing project list
  - [http://wiki.seas.harvard.edu/geos-chem/index.php/Chemistry-Ecosystems-Climate\\_Working\\_Group](http://wiki.seas.harvard.edu/geos-chem/index.php/Chemistry-Ecosystems-Climate_Working_Group)

# Chemistry-ecosystems-climate interactions



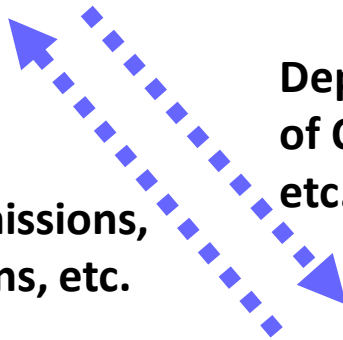
Radiative forcing by GHGs, aerosols



Changes in emissions, transport, chemical reactions, and deposition

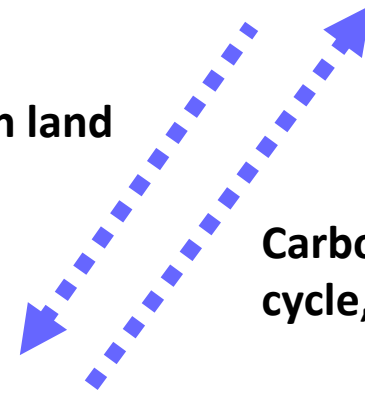


Biogenic emissions, fire emissions, etc.



Deposition of  $O_3$ , N, S, etc.

Impacts on land cover, etc.



Carbon cycle, etc.



# One-way coupling of GEOS-Chem with GCMs and RTMs

- Standard GEOS-Chem driven by historical **meteorological reanalysis products** from NASA GEOS-DAS
- Alternative interfaces exist for driving GEOS-Chem using meteorology archived from other **general circulation models (GCMs)** for a variety of past, present and future climate scenarios

## GCM

### NASA GEOS-DAS FP/MERRA2

Key Contacts:  
Harvard/Dalhousie/GCST

### NASA GISS ModelE

Key Contacts:  
Lee Murray (U. Rochester);  
Eric Leibensperger (SUNY Plattsburgh)

### NCAR CESM

Key Contacts:  
Rokjin Park (Seoul National University);  
Daniel Rothenberg (MIT)

- Tools also exist to convert GEOS-Chem output to input files for **prescribing climate forcings** within these GCMs
- GEOS-Chem also now contains an **online radiative transfer model (RRTMG)** for direct radiative forcing calculations

Archived  
Meteorology

GEOS-Chem

Archived  
Composition

GCM

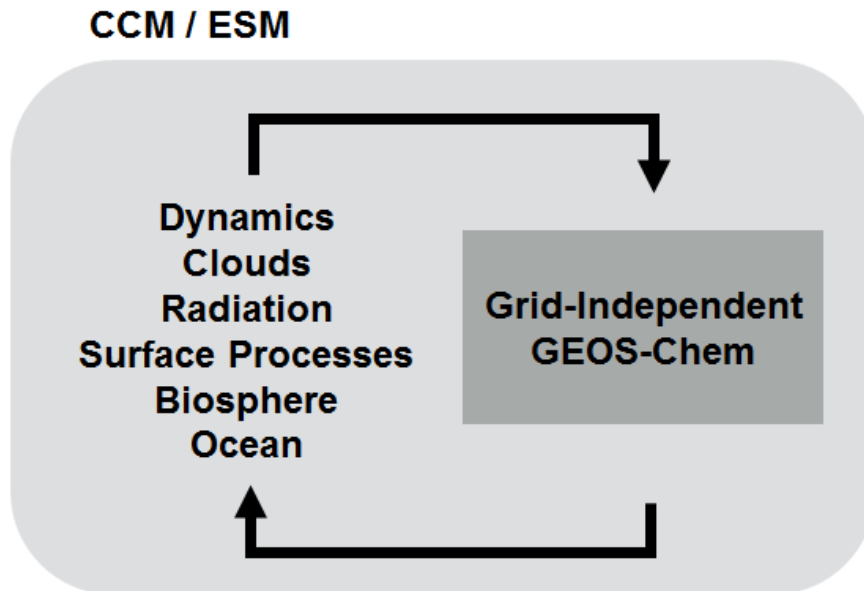
RRTMG

C. Heald; D. Ridley (MIT)

- One-way coupling useful for isolating the first-order impact of **climate variability on chemistry**, or **chemistry on climate**

## Two-way coupling of GEOS-Chem within CCMs and ESMs

- GCHP has facilitated the embedding of GEOS-Chem as an **online interactive atmospheric chemistry module** within Chemistry-Climate Models (CCMs) and Earth-System Models (ESMs)



### Ongoing CCM/ESM Integration Efforts

#### NASA GEOS CCM

Key Contacts:  
Lu Hu (U. Montana)  
Christoph Keller (NASA GSFC)

#### Beijing Climate Center CSM

Key Contacts:  
Xiao Lu, Lin Zhang (PKU); Mike Long (Harvard)

#### NCAR CESM

Key Contacts:  
Sebastian Eastham (MIT)

- Two-way coupling a **more holistic representation** of atmospheric processes and is **necessary to quantify chemistry-climate feedbacks**, but is computationally very expensive

## The standard GEOS-Chem has been used to understand historical changes in atmospheric Chemistry

- To quantify the variations in chemical species on interannual to decadal scales;
- To understand the drivers (meteorological parameters vs. emissions) of the variations of different species;
- To help with the interpretation of year-by-year variations in measurements;
- To assess the effectiveness of short-term air quality control strategies.

Mu and Liao, 2014; Yang et al., 2014, 2015, 2016; Lou et al., 2016; Mao et al., 2016, 2017

# The GCAP model framework can be used to investigate past and future atmospheres

Three versions of GCAP are available:

1. GISS Model 3 + GEOS-Chem (4° x 5°, by Loretta Mickley in year 2003)
2. GISS Model E + GEOS-Chem (2° x 2.5° or 4° x 5°, by L. T. Murray and E. M. Leibensperger in year 2014)
3. CESM + GEOS-Chem (2° x 2.5°, by Rokjin Park in year 2014)

# Lots of research involving chemistry-ecosystems-climate interactions in the context of global change

## Impacts from various factors

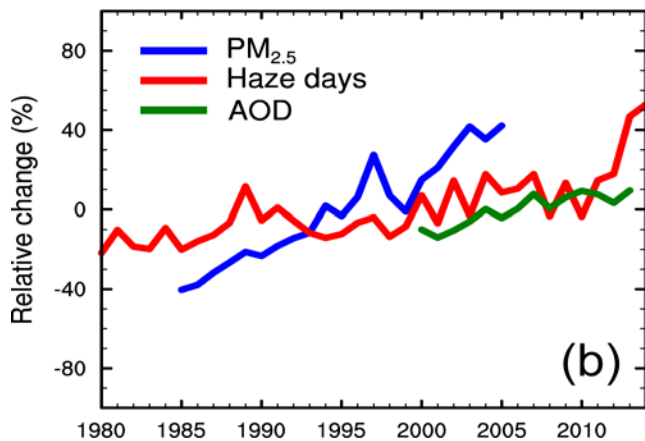
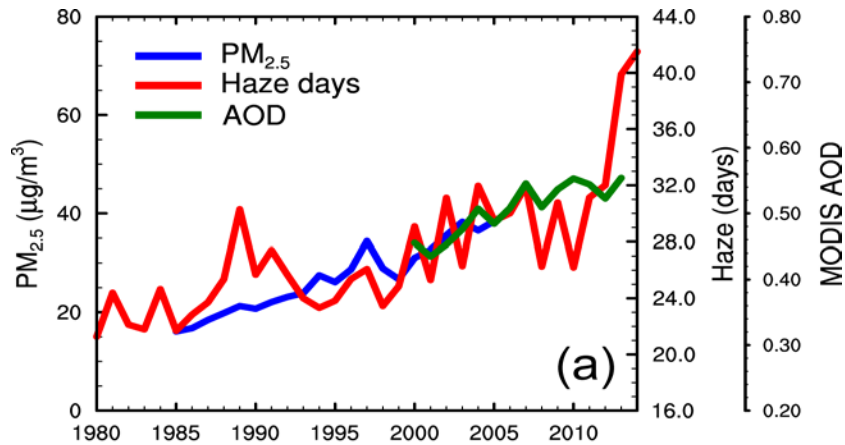
- ❑ **Fossil fuel emissions**  
(e.g., Wu et al., 2008; Pye et al., 2009; Giang et al., 2015; Li et al., 2016)
- ❑ **Climate**  
(e.g., Wang et al., 2013; Jiang et al., 2013)
- ❑ **Land use/Land Cover**  
(e.g., Wu et al., 2012; Tai et al., 2013; Zhang et al., 2016)
- ❑ **Fire/biomass burning emissions**  
(e.g., Yue et al., 2013, 2014; Huang et al., 2014)
- ❑ **Agriculture/Fertilizer-induced emissions**  
(e.g. Hickman et al., 2017)



## Impacts on various species

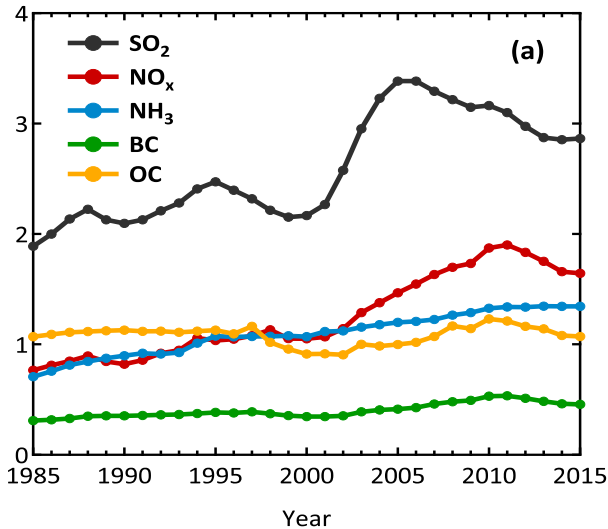
- ❑ **Ozone**  
(too many to list here)
- ❑ **Aerosols**
- ❑ **Polycyclic aromatic hydrocarbons (PAHs)**  
(Friedman et al., 2014)
- ❑ **Polychlorinated biphenyls (PCBs)**  
(Friedman et al., 2016)
- ❑ **Hg**  
(e.g. Corbitt et al., 2011; Giang and Selin, 2016; Zhang et al., 2016; Kumar et al., 2018)

# Simulated vs. observed decadal trend of PM<sub>2.5</sub> in eastern China



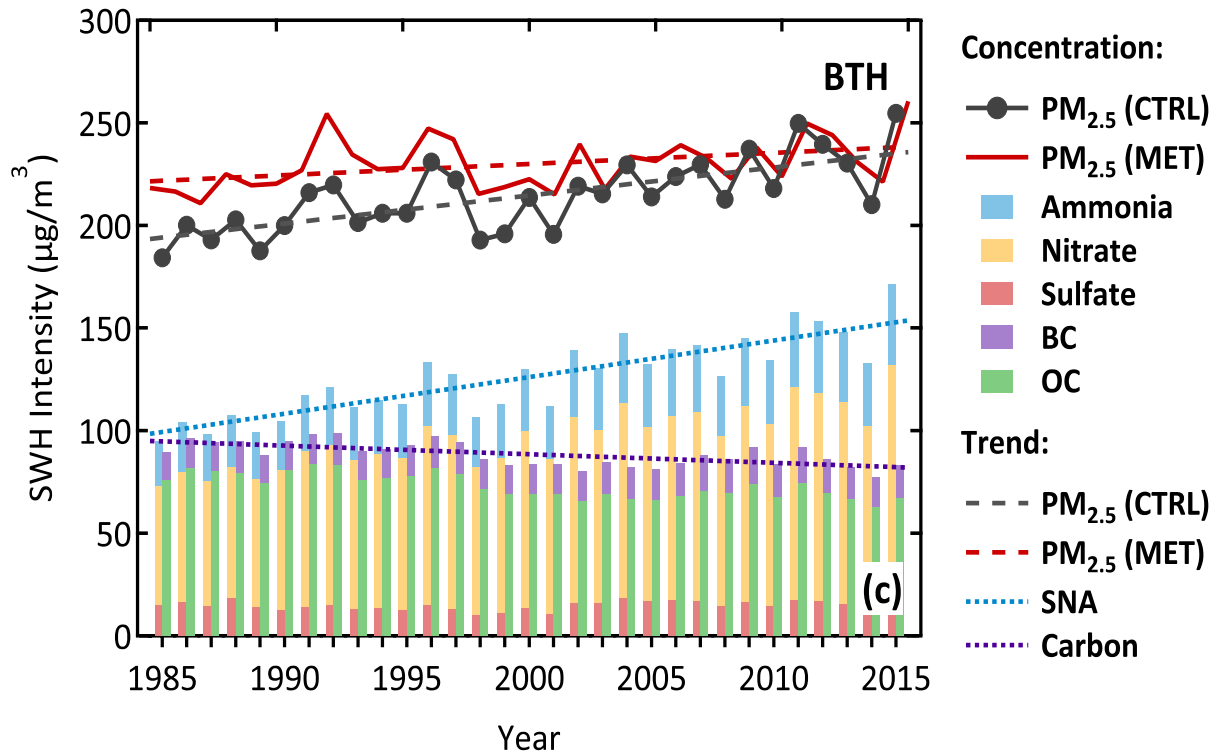
- Simulated PM<sub>2.5</sub> concentrations increased from 16.1  $\mu\text{g}/\text{m}^3$  in 1986 to 38.4  $\mu\text{g}/\text{m}^3$  in 2006, while observed winter haze days increased from 21.7 days in 1986 to 29.5 days in 2006;
- Variations in meteorological parameters alone led to increases in wintertime PM<sub>2.5</sub>, which explained 17 ( $\pm 14$ ) % of the increases in the CTRL simulation.

# Emissions



# Simulated changes in severe haze events in North China Plain over 1985-2015

## Increase in wintertime severe haze intensity

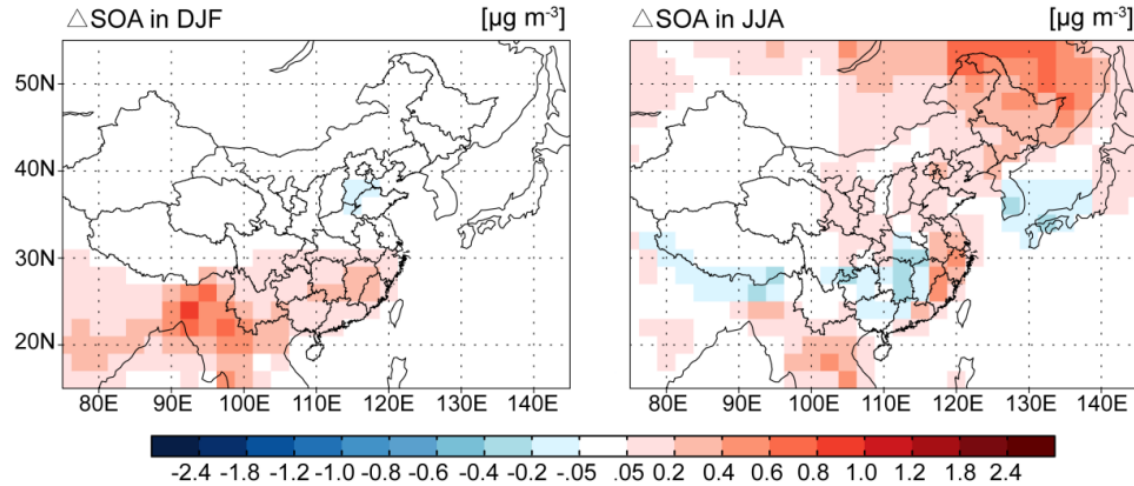


See Dang talk,  
Tues. 9:50 a.m.

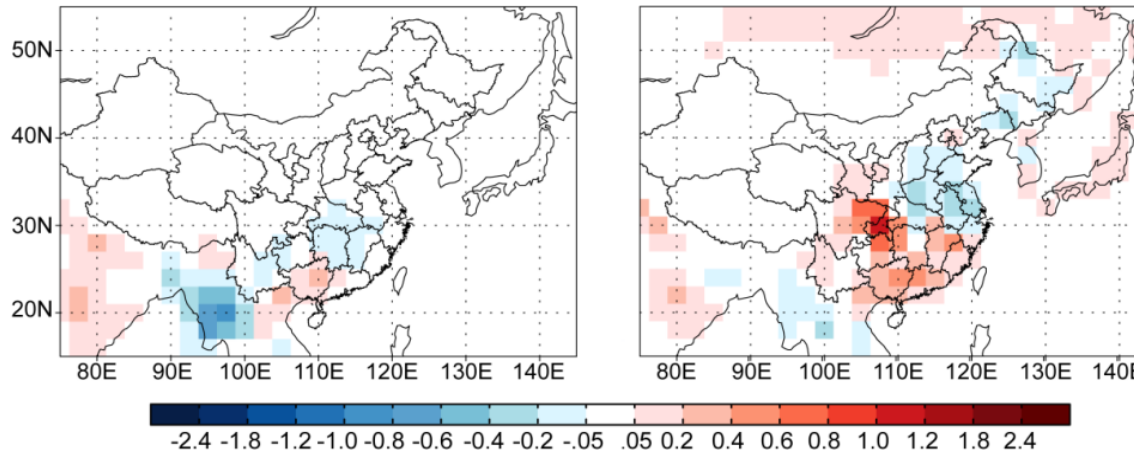
# Impacts of changes in climate and land use/land cover on SOA

Changes in SOA from past (1981-1985) to present (2007-2011)

Climate change

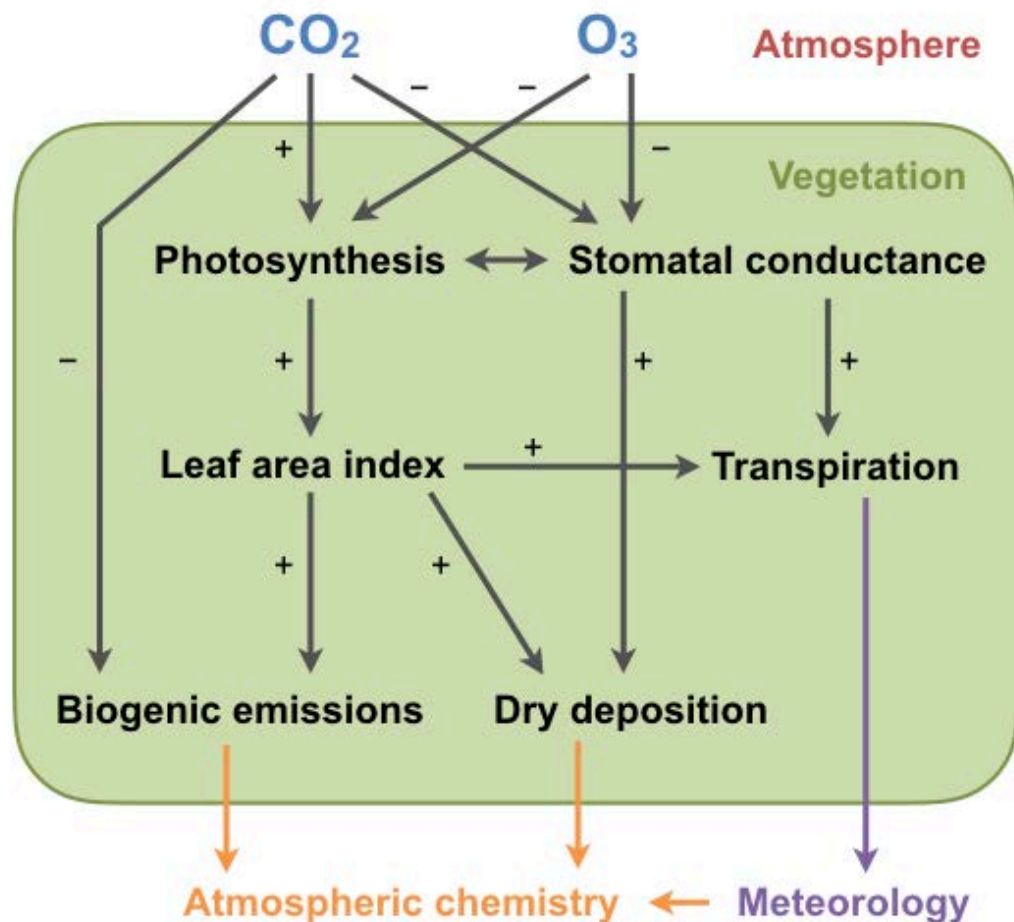


Change in land use and land cover



# Plant Ecophysiology and Plant-Atmosphere Interactions

Plant ecophysiology and responses to meteorological stress, CO<sub>2</sub> and ozone pollution is important in modulating atmospheric chemistry via biogenic emissions, dry deposition, transpiration, etc.



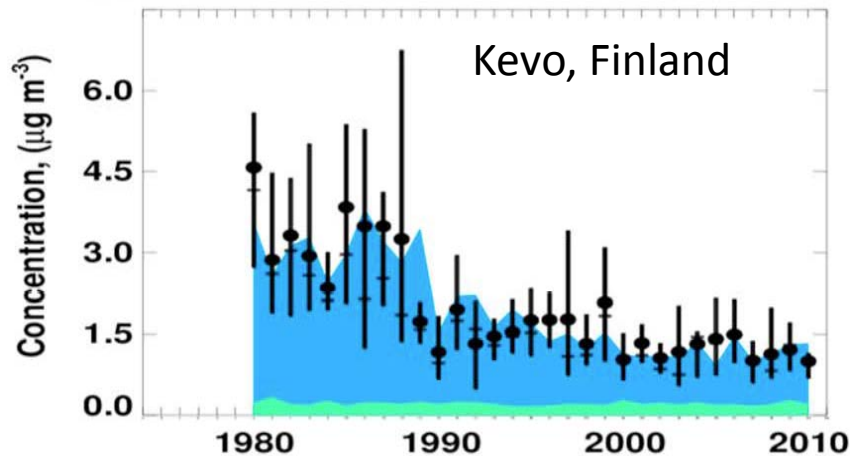
Ongoing work:

- ▶ Plant ecophysiology module in GEOS-Chem to link dry deposition and biogenic emissions to photosynthesis (Tai, Unger)
- ▶ Coupling GEOS-Chem with YIBs to simulate interactions between atmospheric chemistry and carbon cycle (Yue, Unger)
- ▶ Evaluation of different dry deposition schemes (Tai, Geddes, Holmes)

# Harvard project on the effects of aerosol trends on Arctic climate

This project used GEOS-Chem + radiative transfer model to quantify the contribution of trends in sulfate aerosol over the Arctic to observed warming.

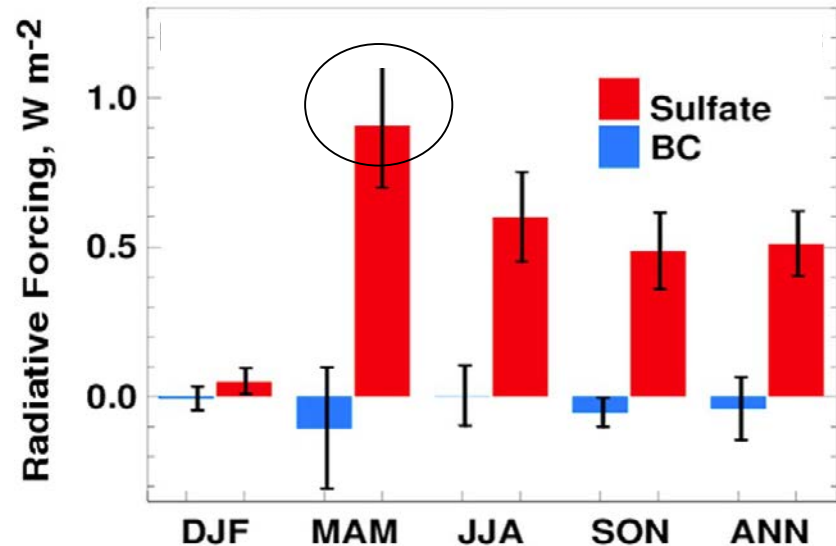
Sulfate concentrations



Observations in the Arctic show significant decreases in sulfate from 1980-2010.

Stacked contours represent GEOS-Chem, with anthropogenic (blue) and natural (green) contributions.

Net TOA radiative forcing, 1980-2010

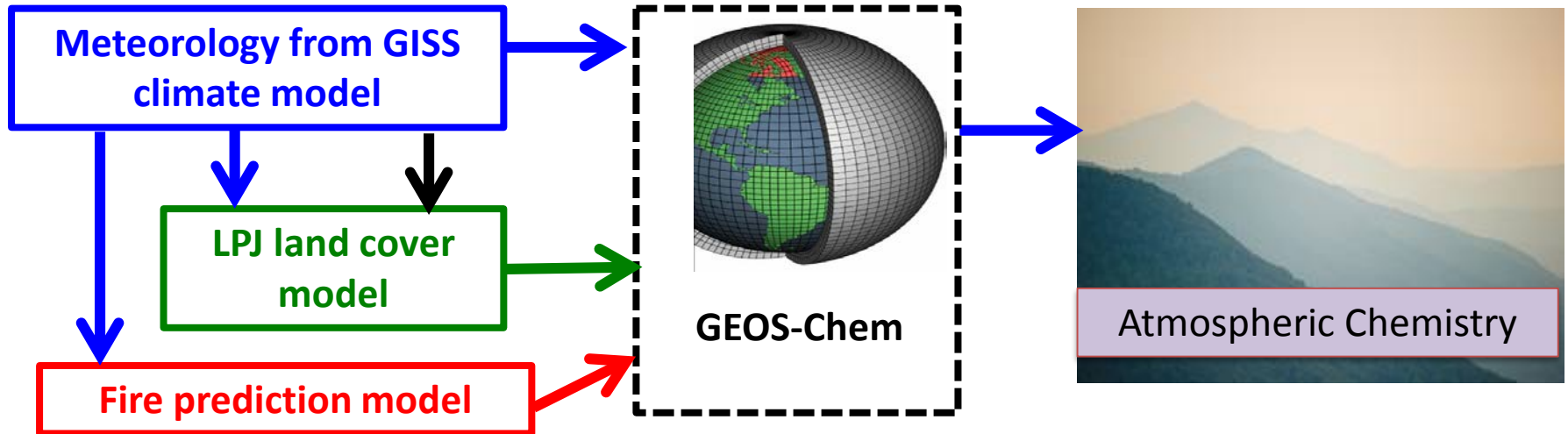


The 1980-2010 trend in sulfate accounts for net TOA RF of  $+0.51 \pm 0.05 \text{ W m}^{-2}$  annually, and nearly  $+1.0 \text{ W m}^{-2}$  in spring.

# EPA project at Harvard: Climate change, land use, and US dust and wildfire particulate matter

The goal of the project is to understand the effects of future climate and land use change on U.S. dust and wildfire PM.

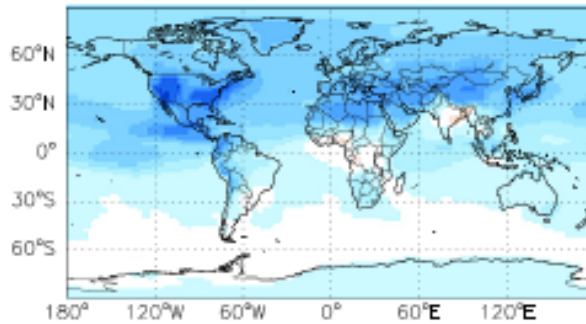
## GCAP model



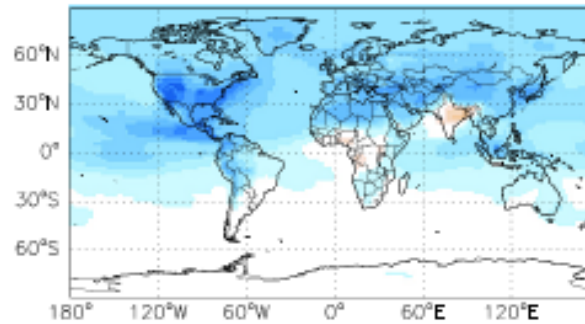
Yue et al., 2013, 2014, 2015  
Liu et al., 2016a, 2016b, 2017

# GEOS-Chem has been used to study future O<sub>3</sub> and aerosols under the RCPs

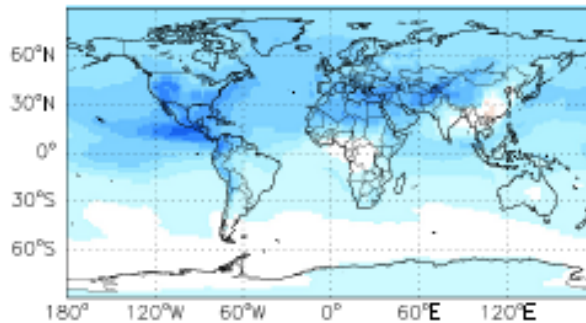
**RCP2.6 O<sub>3</sub> 2050-2000**



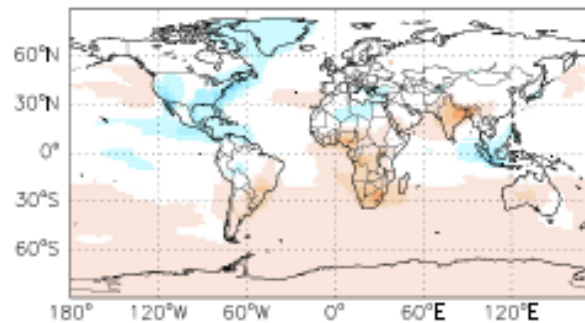
**RCP4.5 O<sub>3</sub> 2050-2000**



**RCP6.0 O<sub>3</sub> 2050-2000**

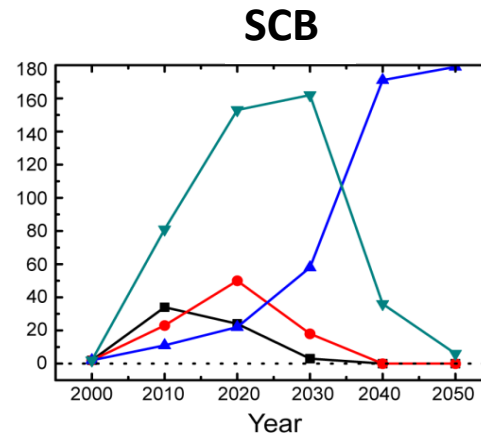
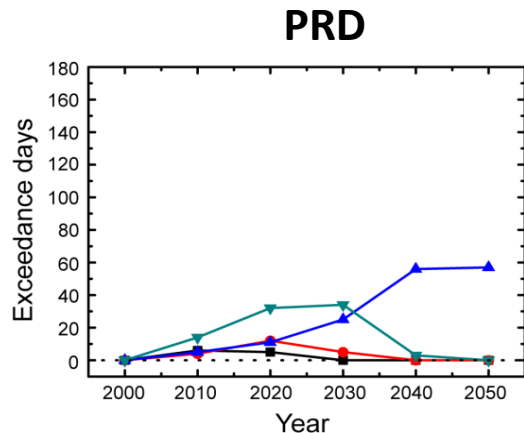
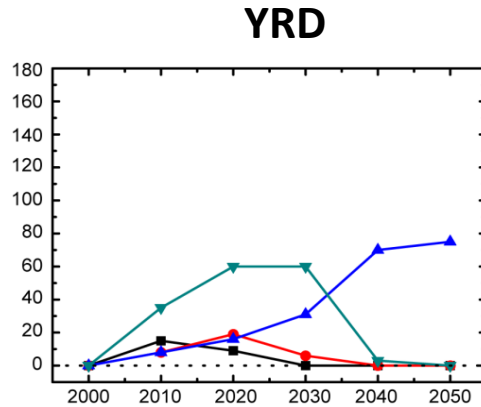
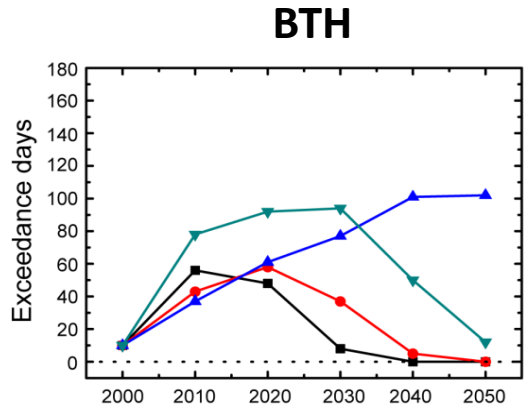


**RCP8.5 O<sub>3</sub> 2050-2000**



Kim et al., 2015; Zhu et al., 2016; Li et al., 2016

# Projected numbers of O<sub>3</sub> exceedance days for the polluted regions in China under RCPs



RCP2.6    
  RCP4.5    
  RCP6.0    
  RCP8.5

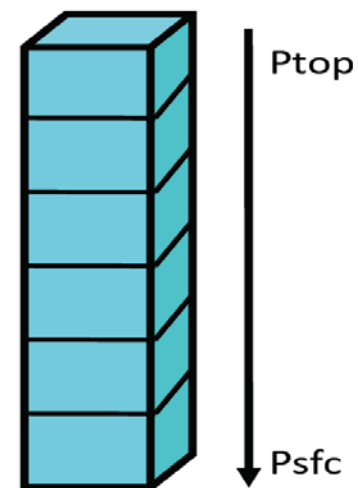
(Maximum daily 8-h average (MDA8) ozone >75 ppbv)

Zhu and Liao, JGR, 2016

## Future directions

1. Coupling of the GEOS-Chem with climate models to allow us to easily link chemistry with climate, vegetation, ocean biology, fire, carbon cycle .
2. The impacts of air pollutants on crops and ecosystems.

*Chemistry on one column*



*With IIPAR\*JJPARG columns in the entire "world" grid*