Representation of CESM CAM4-chem within the Chemistry-Climate Model Initiative (CCMI)

Authors: *Simone Tilmes, Louisa Emmons, Jean-Francois Lamarque, Doug Kinnison, Dan Marsh, Rolando Garcia, Anne Smith, Andrew Conley, Ryan Neely, Maria ValMartin, Francis Vitt, Gary Strand (CMORIZING)*
Contributions: *Sarah Monks, Lili Xia, Claire Granier, Katarina Sindelarova, Thierno Doumbia, Peter Hess, Tracy Sun*

Overview

- CCMI introduction
- CESM model simulations
- Performance of CESM CAM4-chem (WACCM)
- Other ongoing work using the CESM-CCMI version (GeoMIP)

IGAC/SPARC Chemistry-Climate Model Initiative

Evaluation of chemistry and climate in troposphere and stratosphere
Following CCMVal (focused on UTLS and Stratosphere)

CCMI reference experiments:

- REFC1: 1960-2010 (prescribed SSTs), 26L vertical resolution
- REFC1SD: 1980-2010 (specified dynamics), 56L vertical resolution
- climate run RCP6.0: REFC2: 1960-2100, vertical resolution

Various sensitivity experiments

CESM1.1.1. with updates (1.9x2.5deg horiz.res.), FV
CAM4chem and WACCM with full tropospheric and stratospheric chemistry

- Bug fixes
- New volcanic heating rates calculation
- Updated chemical mechanism (JPL2010), 2-step SOA calculation
- New polar stratospheric chemistry (WACCM only)
- Updated dry deposition velocities, and wet deposition (Neu scheme)
- New gravity waves, all run with TMS and prescribed QBO (REFC1/REFC2)

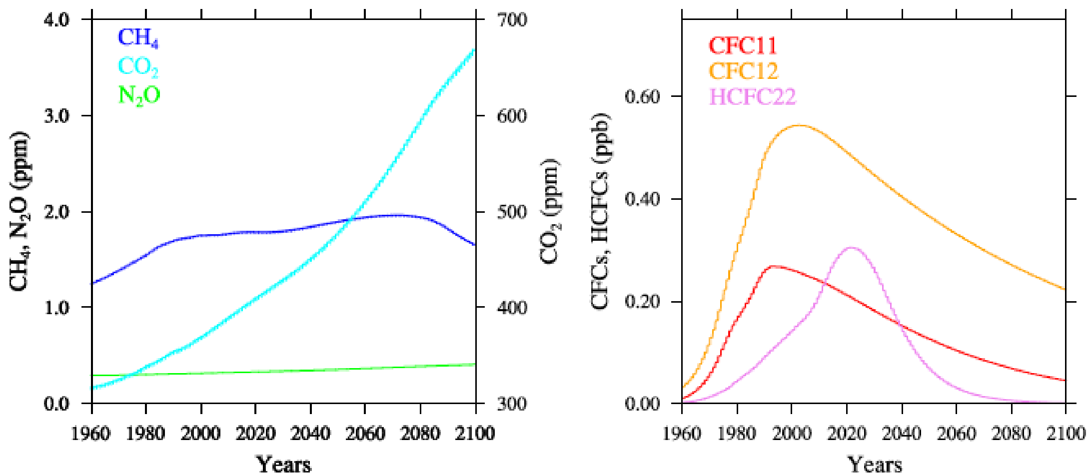
-> updates are going to be all in the next model release

Status of CAM4-chem experiments

Simulation: CESM1.1.1 plus updates, 2deg	Status	How many ensemble members?	Run by:
REF-C1	Finished on ESG	3 members	NCAR
REF-C1SD	Finished, on ESG	1 member	NCAR
REF-C2 (RCP 6.0)	Re-run	3 members	NCAR
SEN-C1SD-fEmis	Finished (glade)	1 member	NCAR
SEN-C1SD-fEmis fCH4	Finished (glade)	1 member	NCAR
SEN-C1SD-fEmis vMEG	Finished (glade)	1 member	NCAR
REF-C2 (RCP 6.0) 1deg	2005-2090	3 members	Rutgers
G4SSA (RCP 6.0) 1deg	2020-2090	3 members	Rutgers
REF-C2 2000fEmis	In progress		Cornell
REF-C2 2100fEmis	In progress		Cornell
REF-C1 SD 0.5deg	In progress (2008)		NCAR
HTAP experiments	In progress		NCAR/IASS/Leeds

Climate Response of CAM4-chem in RCP6.0

Lower Boundary Conditions, RCP6.0

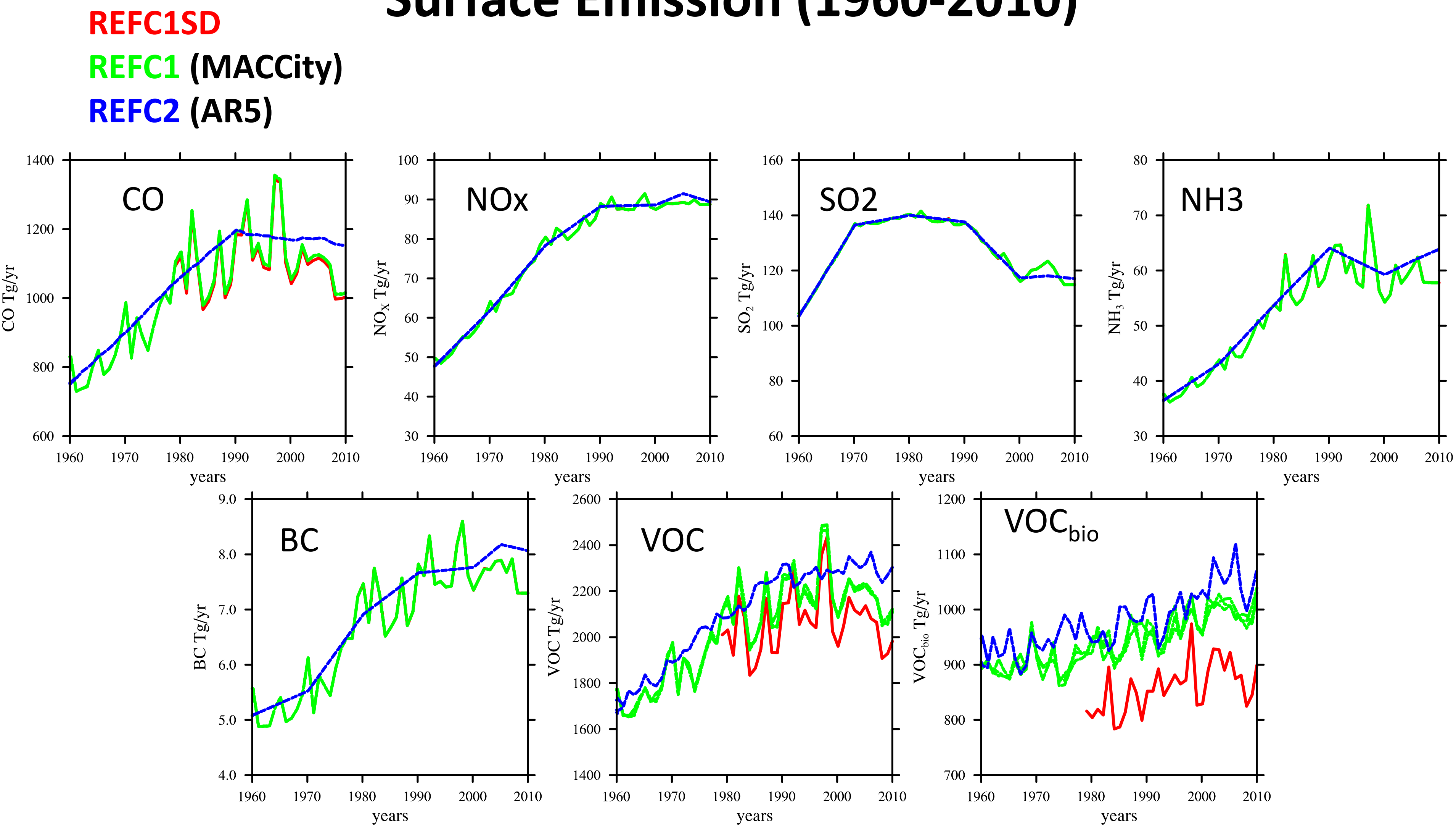


Surface Temperature Change to 1995-2005

REFC1SD
REFC1
REFC2

REFC2 runs will be updated

Surface Emission (1960-2010)



REFC1SD
REFC1
REFC2

General Performance of the Model

Tropical Averages 30S-30N

Column trop. O_3

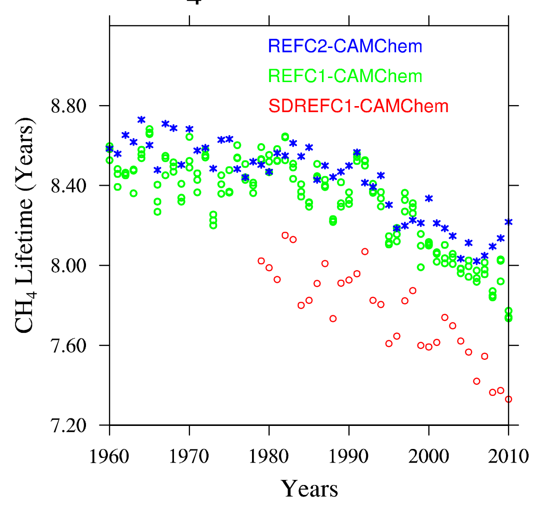
SAD

Column NOx

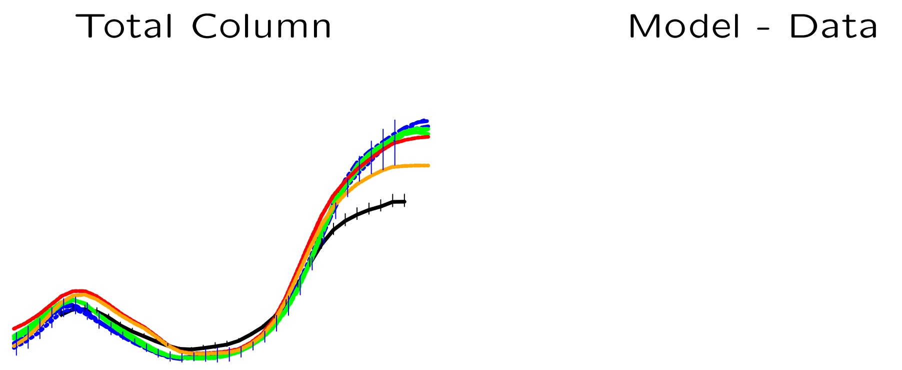
Column CO

Column strat. O_3

CH_4 Lifetime



Present-day (2004-2010) Ozone Comparison to OMI/MLS Observations



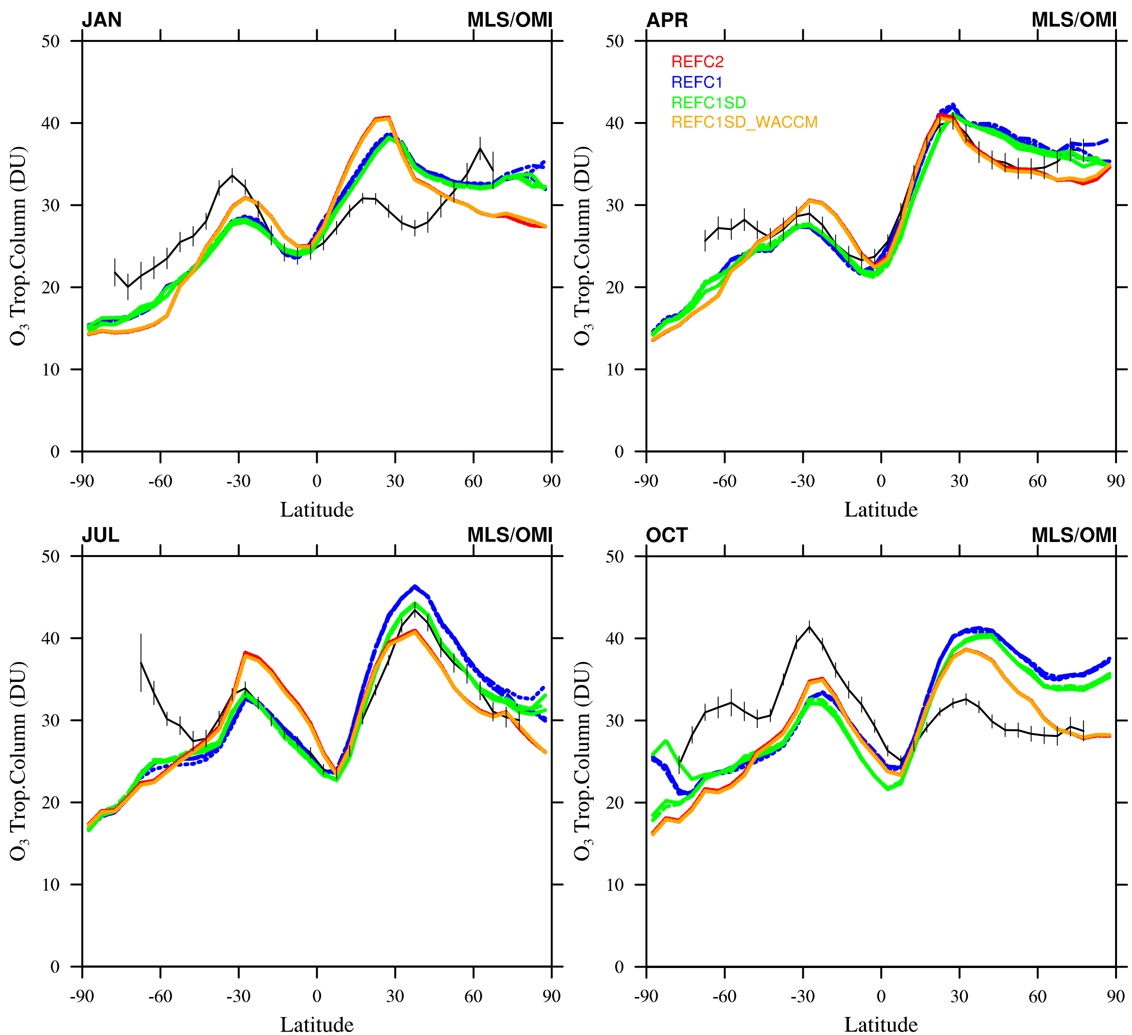
- Total column ozone is represented close to observed values for all the runs.
- Overestimation in high NH latitudes especially in spring.
- Specified Dynamics simulations show a high bias in the mid-latitude UTLS region.
- WACCM nudged to same meteorology but better agreement in high latitudes

-> points to problems in transport and/or mixing

REFC1SD
REFC1
REFC2
WACCM SD

Present-day (2004-2010) Ozone Comparison to OMI/MLS Observations

Tropospheric ozone column



- Very good agreement in spring and summer
- Overestimation in fall/winter in the NH, underestimation in the SH
- More ozone in the SD runs in the Tropics
- More ozone in free running experiments in NH high latitudes

Comparison to Ozonesonde Observations

500hPa

REFC1SD_WACCM
REFC1SD
REFC1
REFC2

Tropics

Mid Latitudes

High Latitudes

1 NH Sub-Tropics
2 W-Pac/E-Indian Ocn.
3 Atlantic/Africa

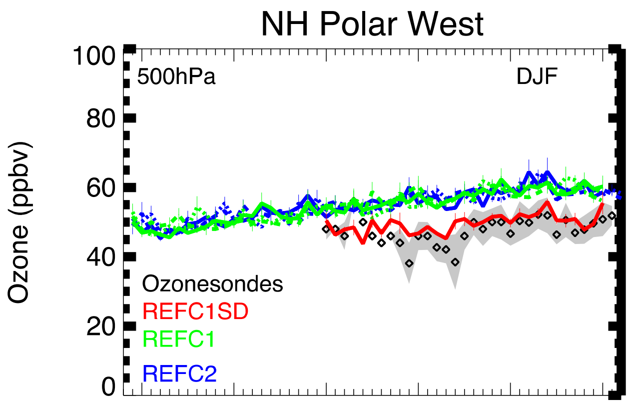
1 West Europe
2 East US
3 Japan
4 SH Mid-lat

1 NH Polar West
2 NH Polar East
3 Canada
4 SH Polar

250hPa

REFC1SD
REFC1
REFC2

Comparison to Ozonesonde Observations



- Very nice agreement with observations for REFC1SD, not quite simulating dips in ozone after volcanic eruptions
- Overestimation in REFC1/REFC2 is linked to too much strat/trop exchange

REFC1SD
REFC1
REFC2

Comparison to Ozonesonde Observations

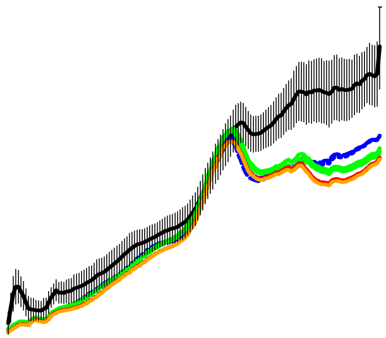
- Some regions, e.g. Japan, show disagreement in magnitude and trend

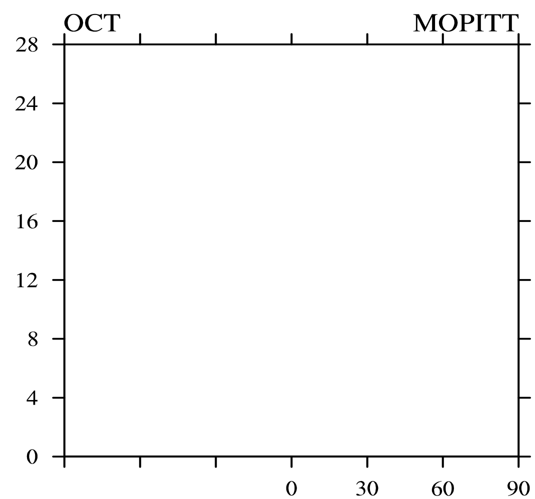
-> possible underestimation of inflow from Asian emissions (chemistry and aerosols)

REFC1SD
REFC1
REFC2
WACCM SD

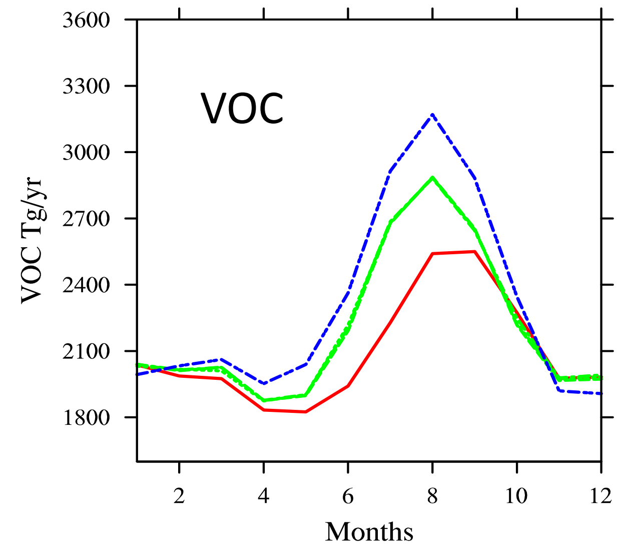
Comparison to MOPITT Carbon Monoxide

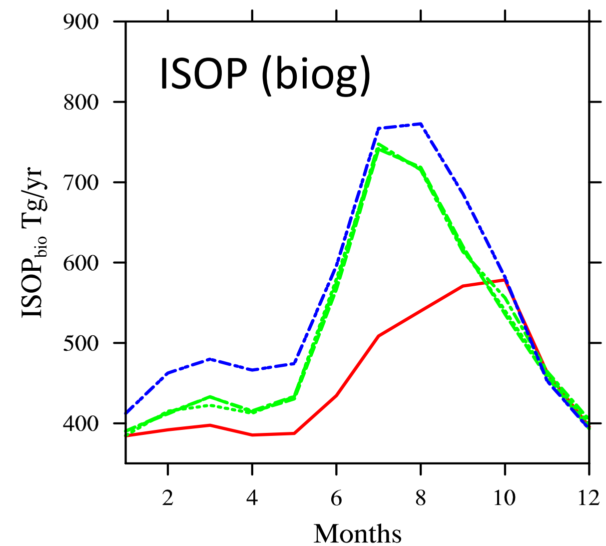
2004-2010 Average





Surface Emissions





-> Underestimation of CO in the NH

-> Importance of biogenic emissions especially in summer and fall

Comparison to HIPPO Carbon Monoxide

2005-2010 Average over the Pacific

REFC1SD

REFC1

1-2km

4-5km

7-8km

1-2km

4-5km

7-8km

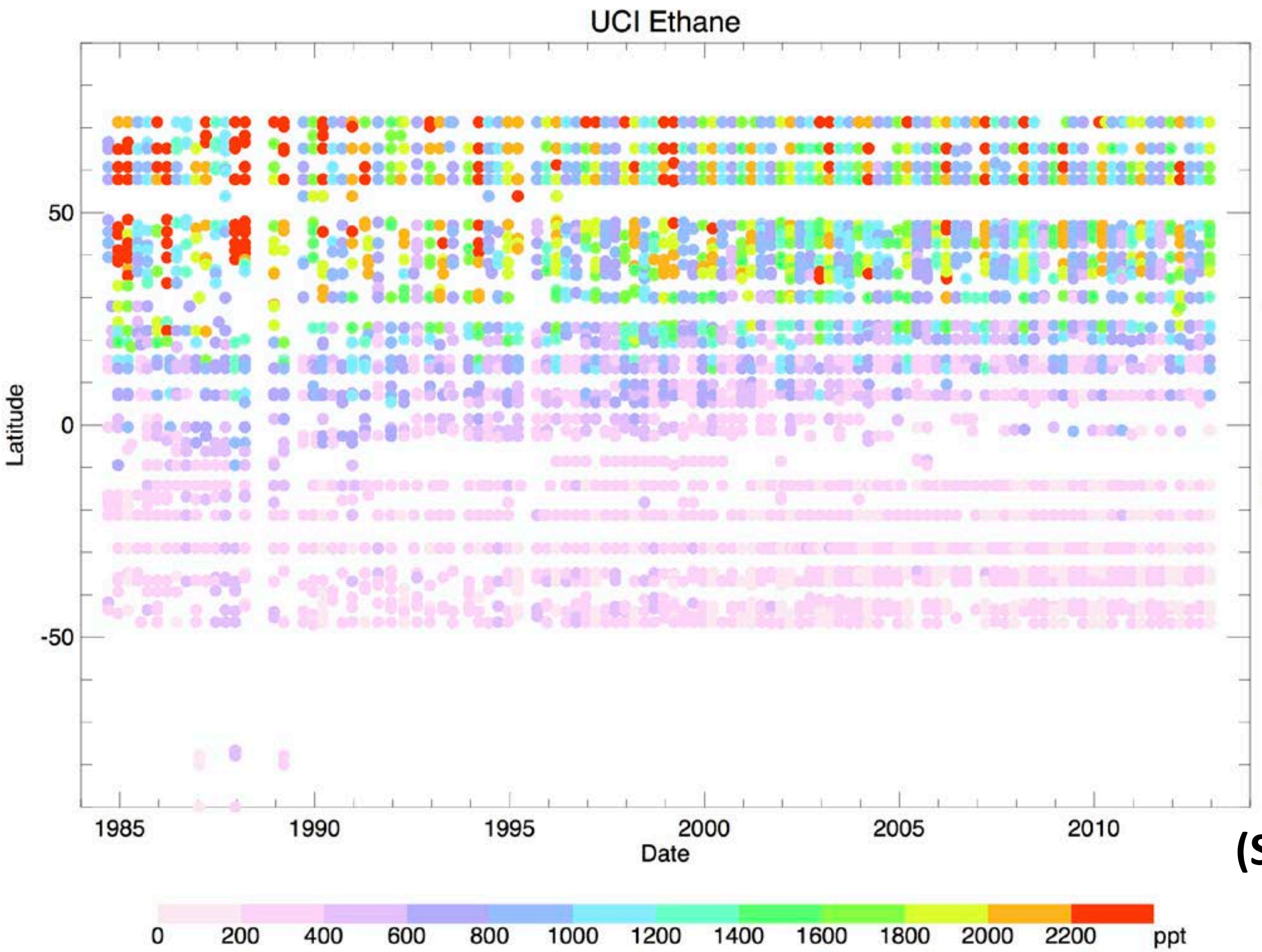
latitude

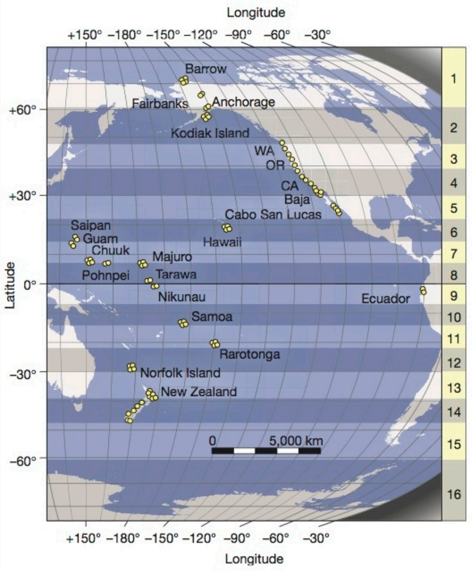
latitude

latitude

Support findings from satellite comparisons for remote regions

Ethane (and other Hydrocarbons) from canister samples at coastal sites around the Pacific





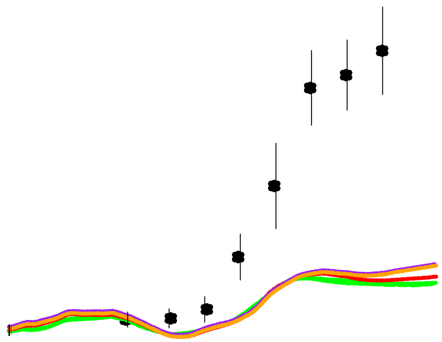
(Simpson et al., Nature, 2012)

UCI samples each March, June, Sept, Dec.

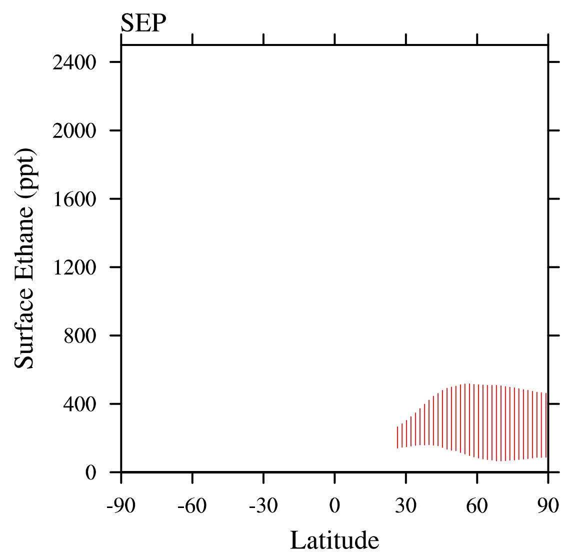
REFC1SD
REFC1
REFC2
REFC1SD_vMEG

Comparison to UCI Surface Ethane

1995-2010 Average



Significant underestimation of Hydrocarbons in the Northern Hemisphere, example Ethane at the surface.
-> strong underestimation of emissions



REFC1SD
REFC1

Comparison to HIPPO Black Carbon

2005-2010 Average over the Pacific

Spring:

- underestimation of BC in high Northern Latitudes (fire plumes)
- overestimation in the SH

Summer:

- good agreement in NH
- overestimation of BC in SH

Fall/Winter:

- overestimation in the NH
- good agreement in the SH
- Overestimation in the Tropics

-> seasonality not captured correctly

Conclusions

- Very good performance of tropospheric ozone in comparison to observations, but
  - REFC1/REFC2 too high in the tropospheric high latitudes

  -> too much Srat/Trop Exchange in REFC1/REFC2 in the NH high latitudes
  - REFC1SD: LMS ozone too high, more ozone in the tropics

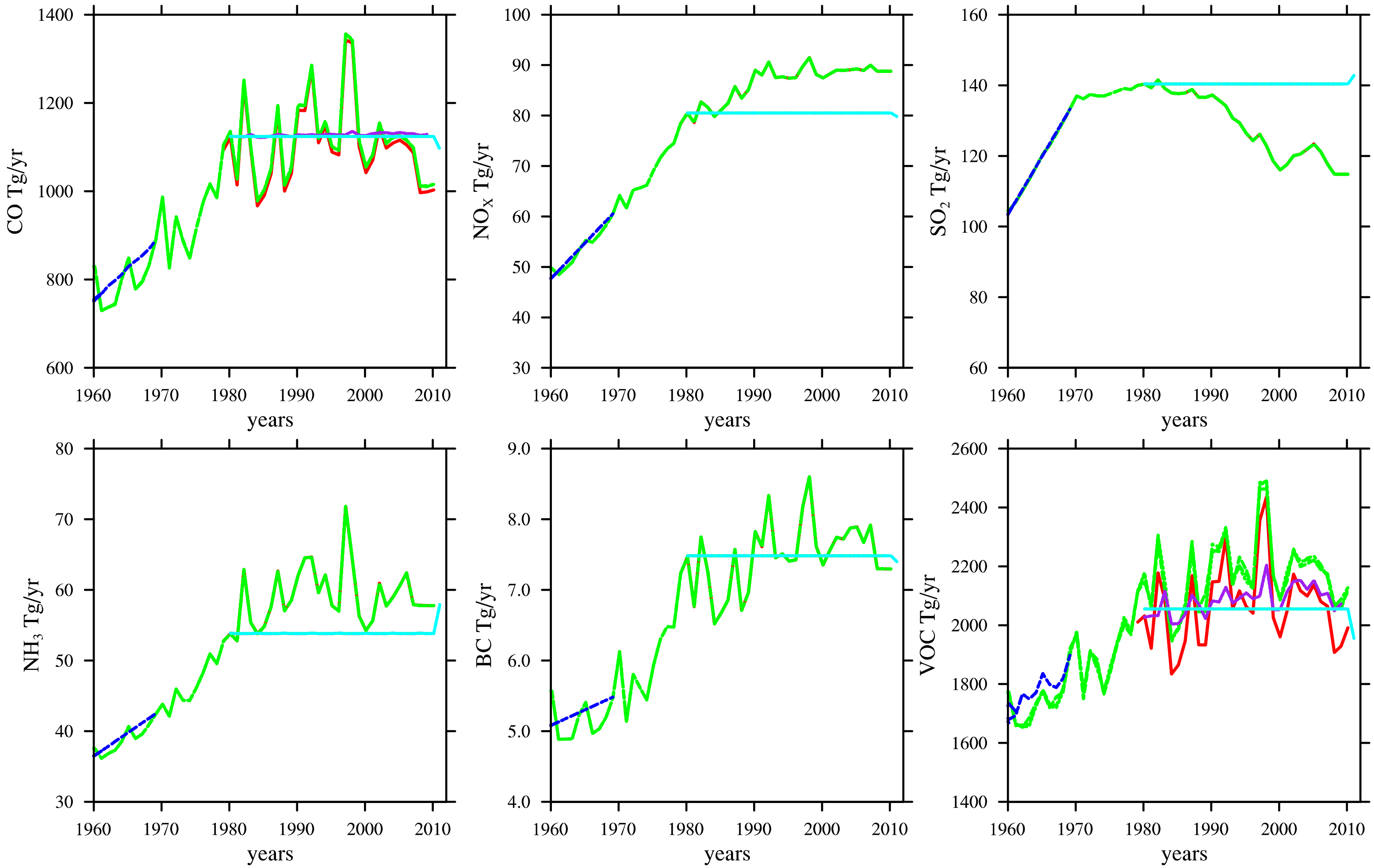
  -> impacts methane lifetime

  -> impact of pollution in Japan not captured

  -> transport and dynamics need to be further investigated
- CO underestimated especially in spring
  - Biogenic emissions in REFC1/REFC2 result in an increase of CO in summer and fall (warmer T and more clouds in REFC1)
- Methane lifetime is rather low in REFC1SD
- HC too low in general, wrong seasonality
- Black Carbon over the Pacific: overestimation in winter NH and SH may point to problems in sources and removal
- PAN still too high, H_2O very good (not shown)

Sensitivity Simulations, REFC1SD
Surface Emission (1960-2010)

REFC1, REFC1SD, REFC1SD_fEmis, REFC1SD_fEmis_vMEG, REFC1SD_fEmis_fCH4



Comparison to MOPITT Carbon Monoxide

2004-2010 Average

Plus Sensitivity Experiments:

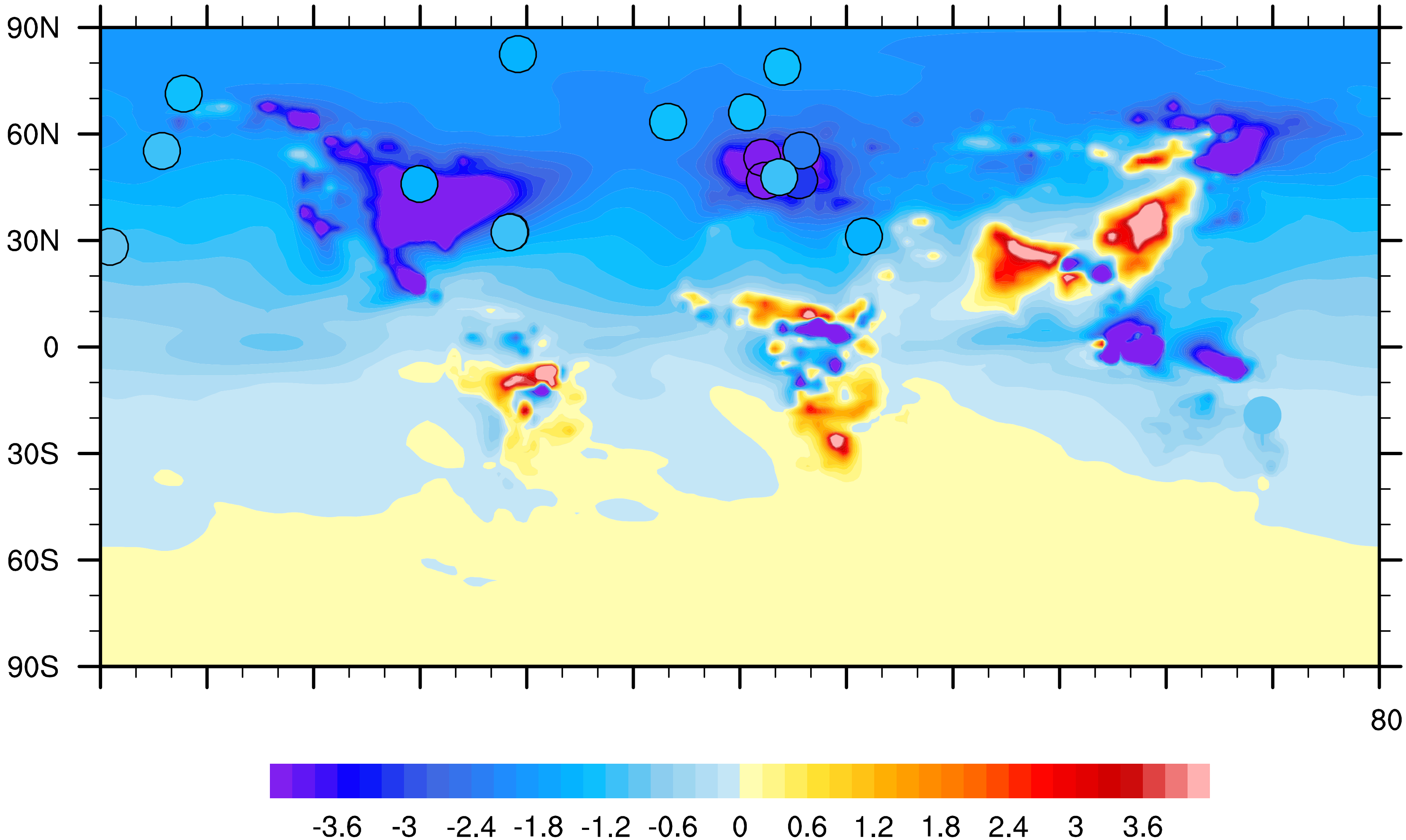
CO emissions about same
NO_x emissions lower
-> Ozone only slightly lower

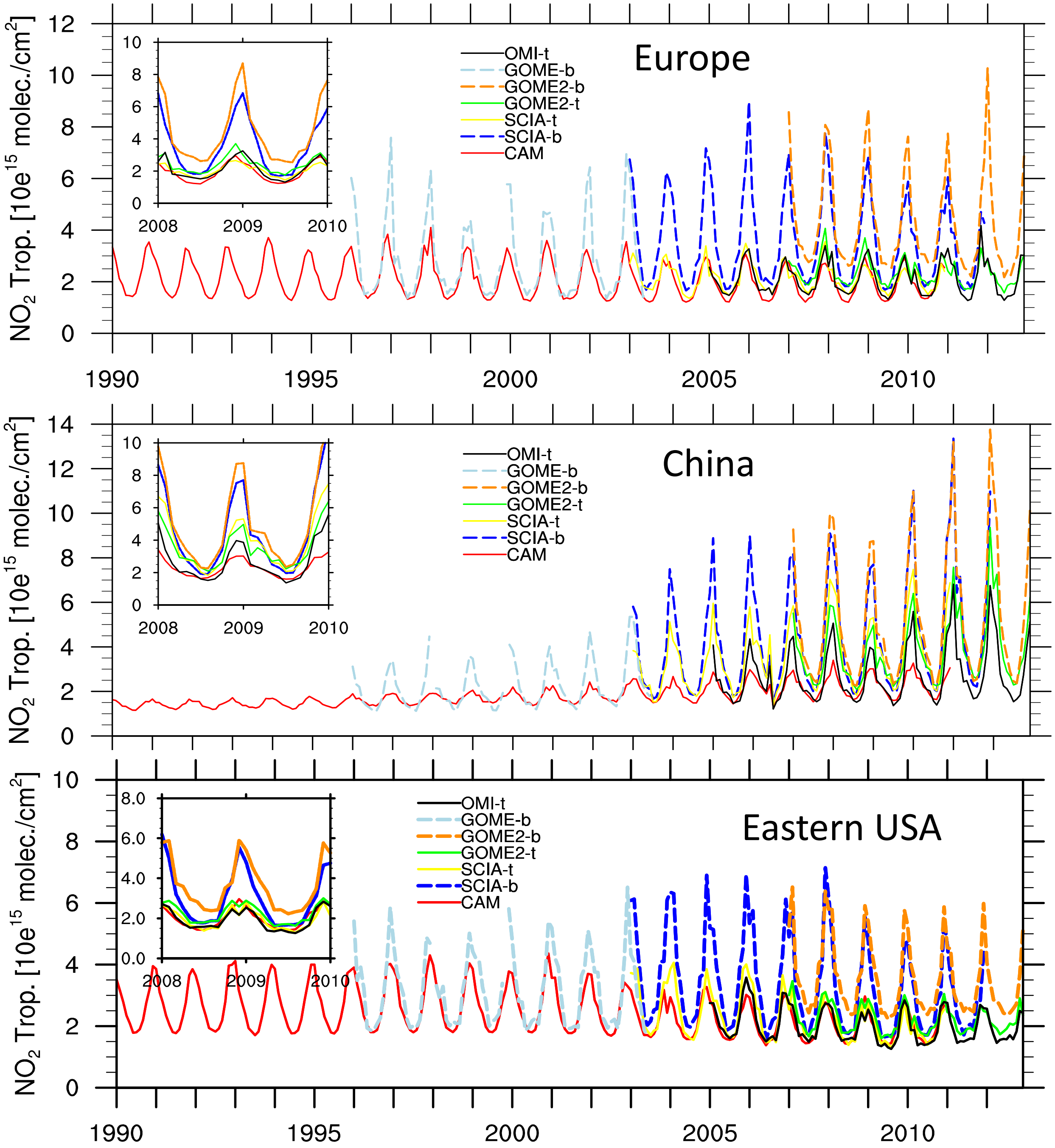
Sulfate higher
-> SAD higher
-> reduced OH,
-> longer CH4-lifetime

Points to the importance of OH burden and the connections to aerosols!

Work by: Claire Granier, Katarina Sindelarova, Thierno Doumbia

Temporal changes of simulations using WDCGG surface CO



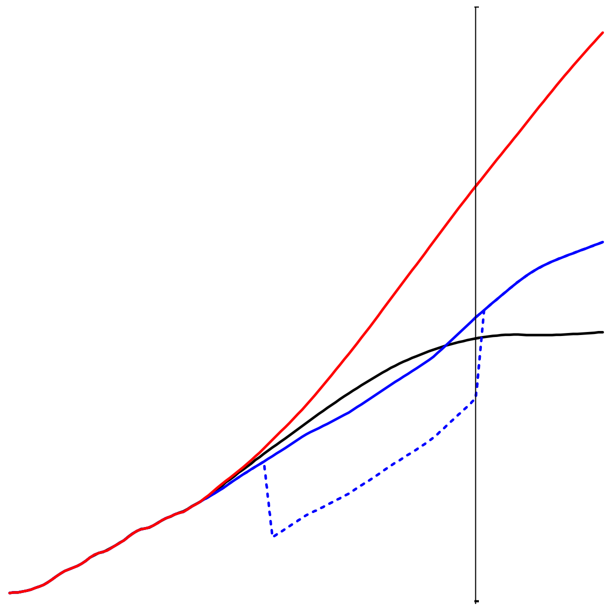


Comparison of CAM4-Chem simulations With several satellite observations of the NO_2 tropospheric column, as well as different retrievals of the same instrument

CAM4-Chem simulations = red line

Additional Studies: GeoMIP G4SSA *by Lili Xia*

Prescribed stratospheric aerosol distribution



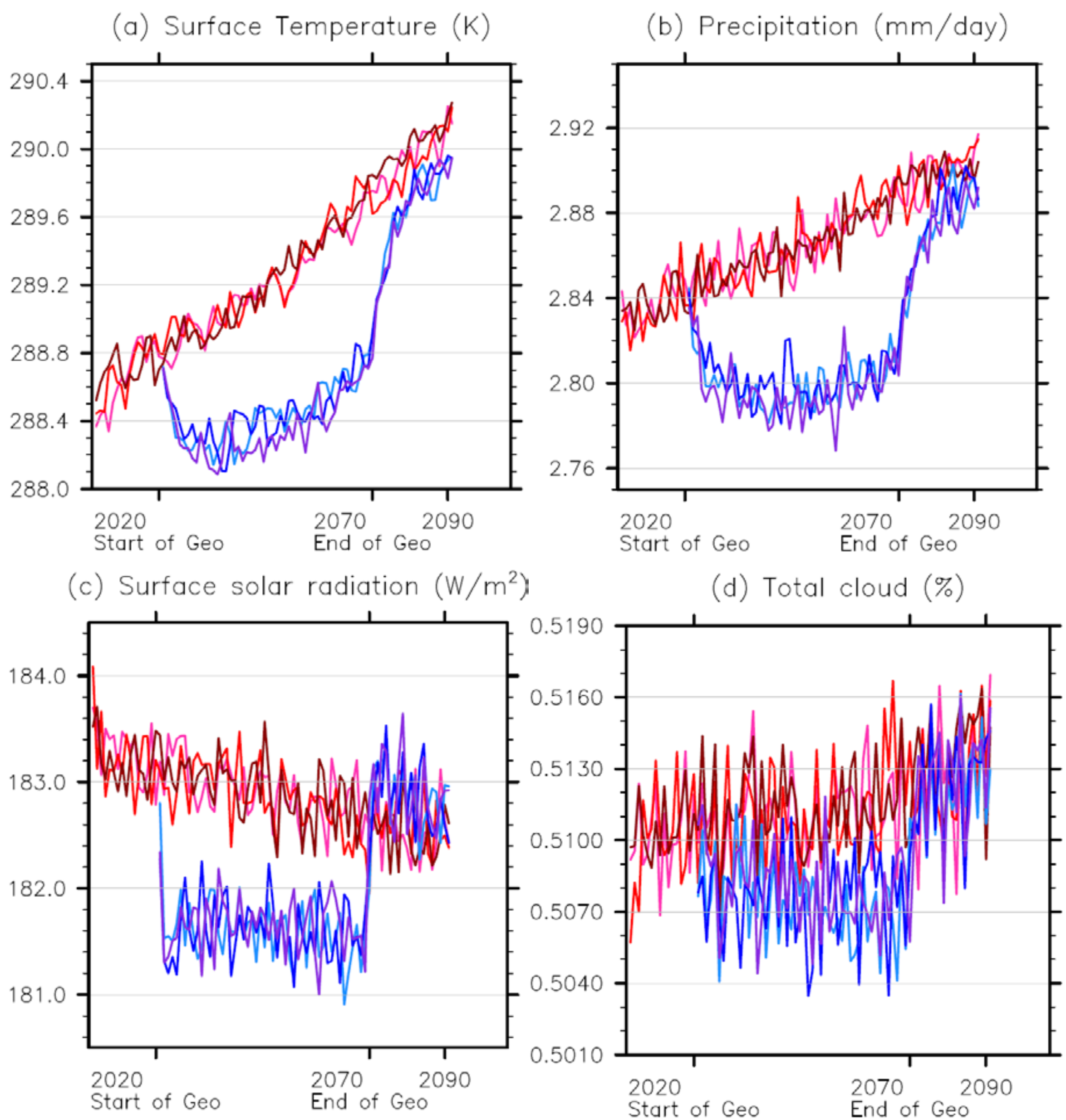
CESM CAM4chem: 1deg

Off-line post4.5CLM-crop, 2deg

- Fixed CO2 (392ppm), fertilizer/irrigation (year 2000)
- CLM-crop control run: AgMERRA reanalysis data 1978-2012
- Climate model control run: RCP6.0 2004-2010
- RCP6.0 monthly anomalies and G4SSA monthly anomalies (2060-2069)
- Perturb 35 years AgMERRA with each year of RCP6.0/G4SSA climate anomalies

Tilmes et al., 2015

GeoMIP G4SSA



CESM-CAM4-chem
1 degree

Global average of annual

(a) Temperature
(b) Precipitation
(c) Solar radiation
(d) Total cloud

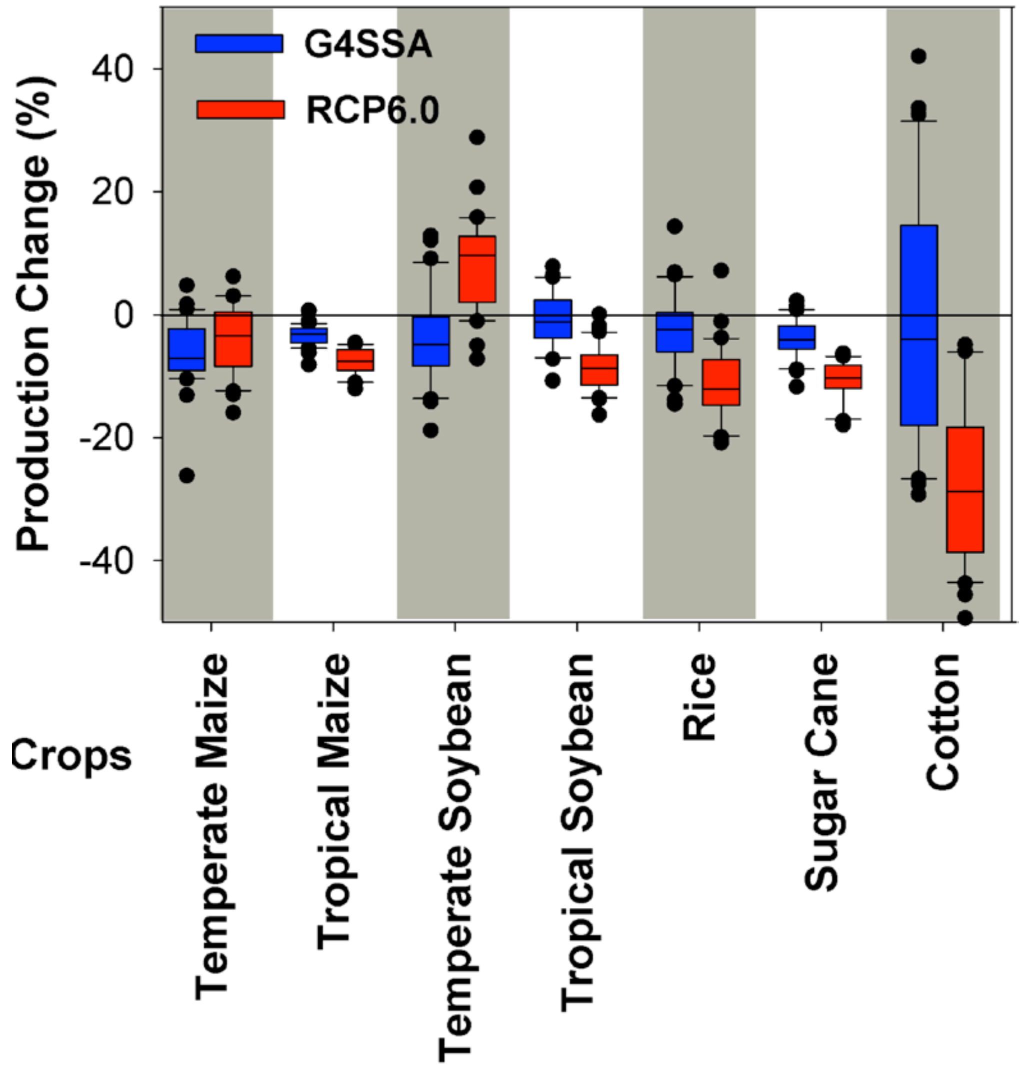
RCP6.0
Three reddish lines
(2004-2089)

G4SSA
Three bluish lines
(2020-2089)

Xia et al., in preparation

Climate Impact of Climate change and Geoengineering on Crops

From one crop model – CLM-crop, G4SSA reduces the damage from RCP6.0 for tropical maize, tropical soybean, rice, sugar cane and cotton. While it decreases the productions of temperate maize and temperate soybean.



Impact of changes in chemistry (CO_2, O_3) are not included here

Xia et al., in preparation