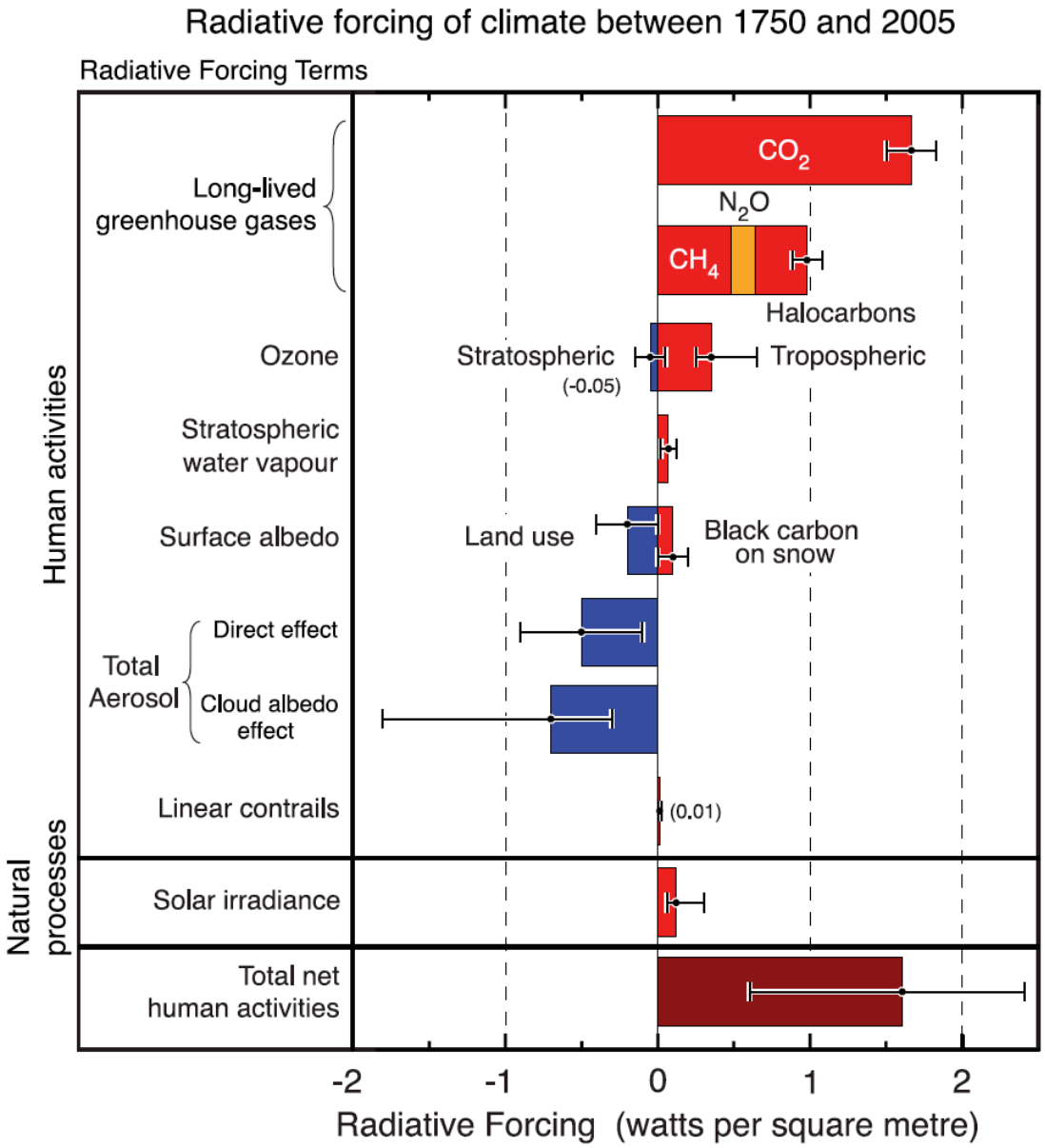
Ozone and chemistry

Jean-François Lamarque

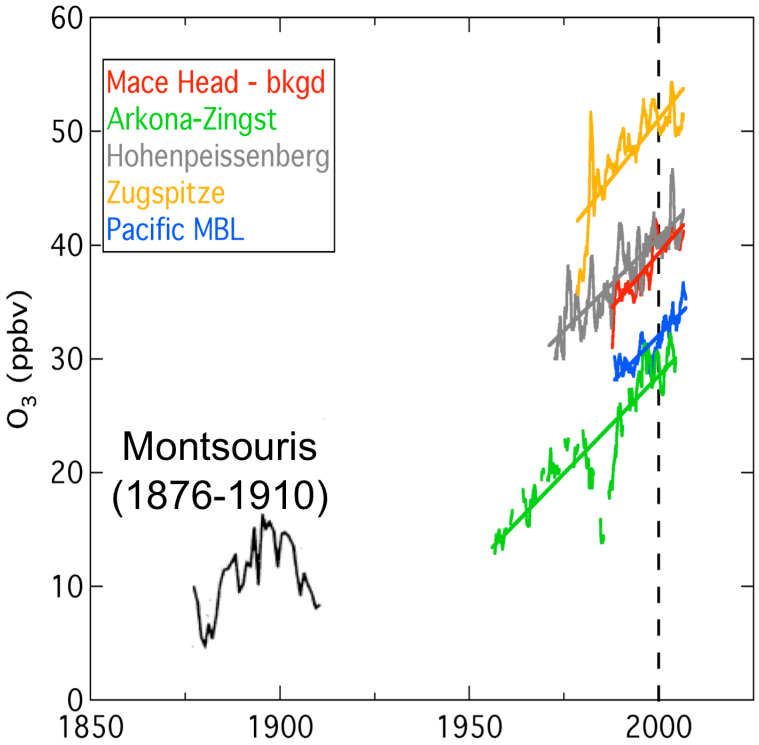
NCAR

Changing composition



Forster and Ramaswamy, AR4 Chapter 2

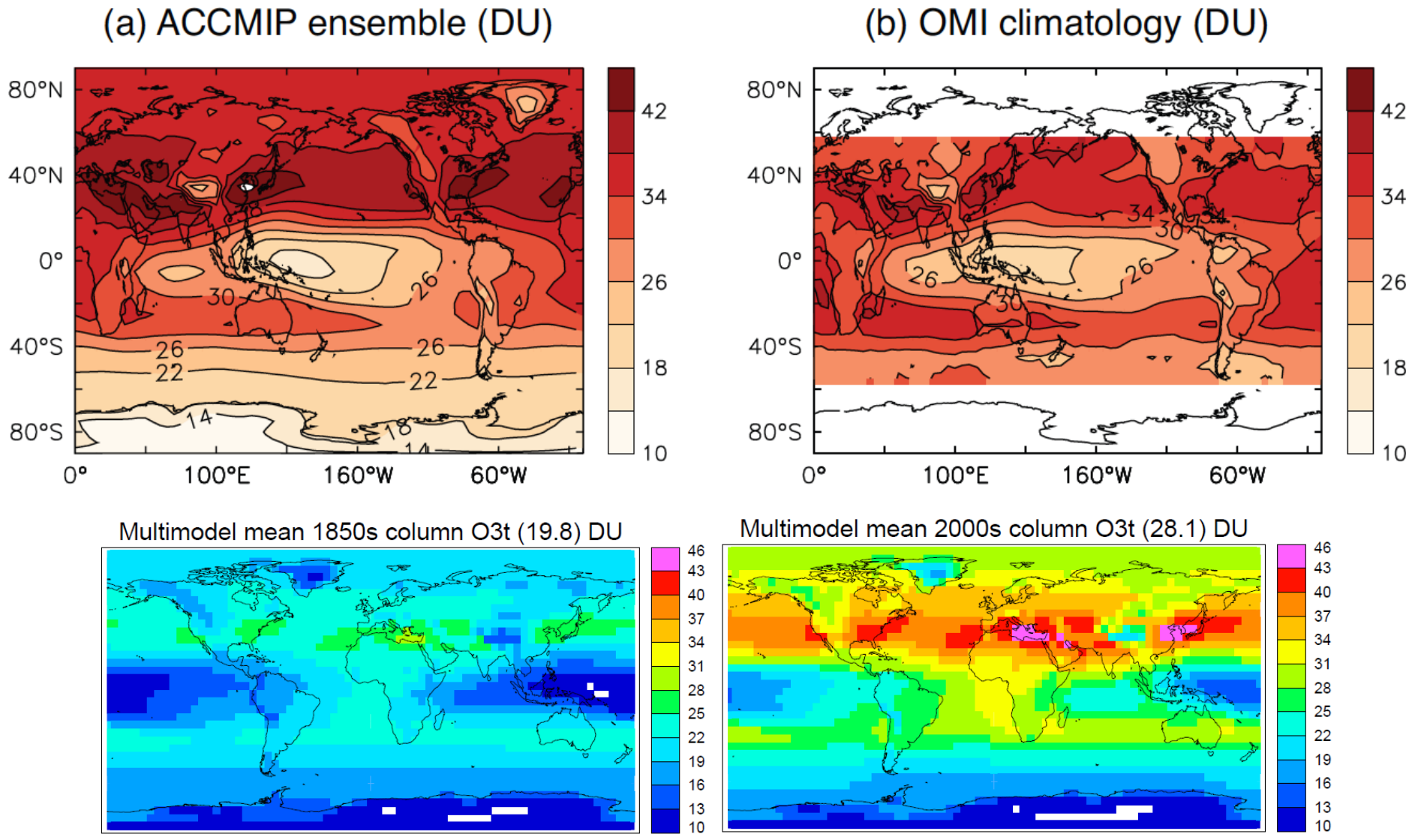
OZONE



Surface ozone 1850-2000 from obs. Slide from D. Parrish.

Tropospheric ozone

Young et al., 2012



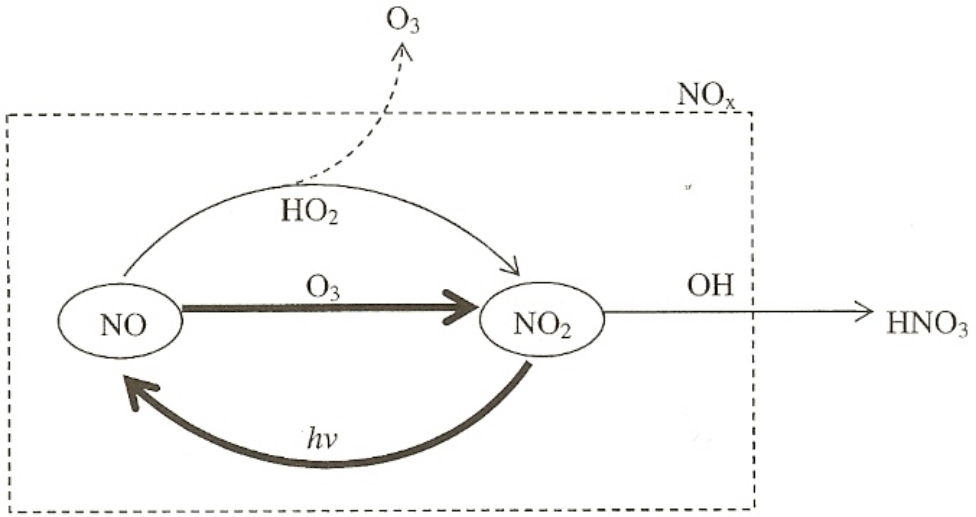
Stevenson et al., 2012

Tropospheric ozone production

$$\mathrm{CO} + \mathrm{OH} \xrightarrow{\mathrm{O_2}} \mathrm{CO_2} + \mathrm{HO_2}$$
$$\mathrm{HO_2} + \mathrm{NO} \longrightarrow \mathrm{NO_2} + \mathrm{OH}$$
$$\mathrm{NO_2} + h\nu \xrightarrow{\mathrm{O_2}} \mathrm{NO} + \mathrm{O_3}$$

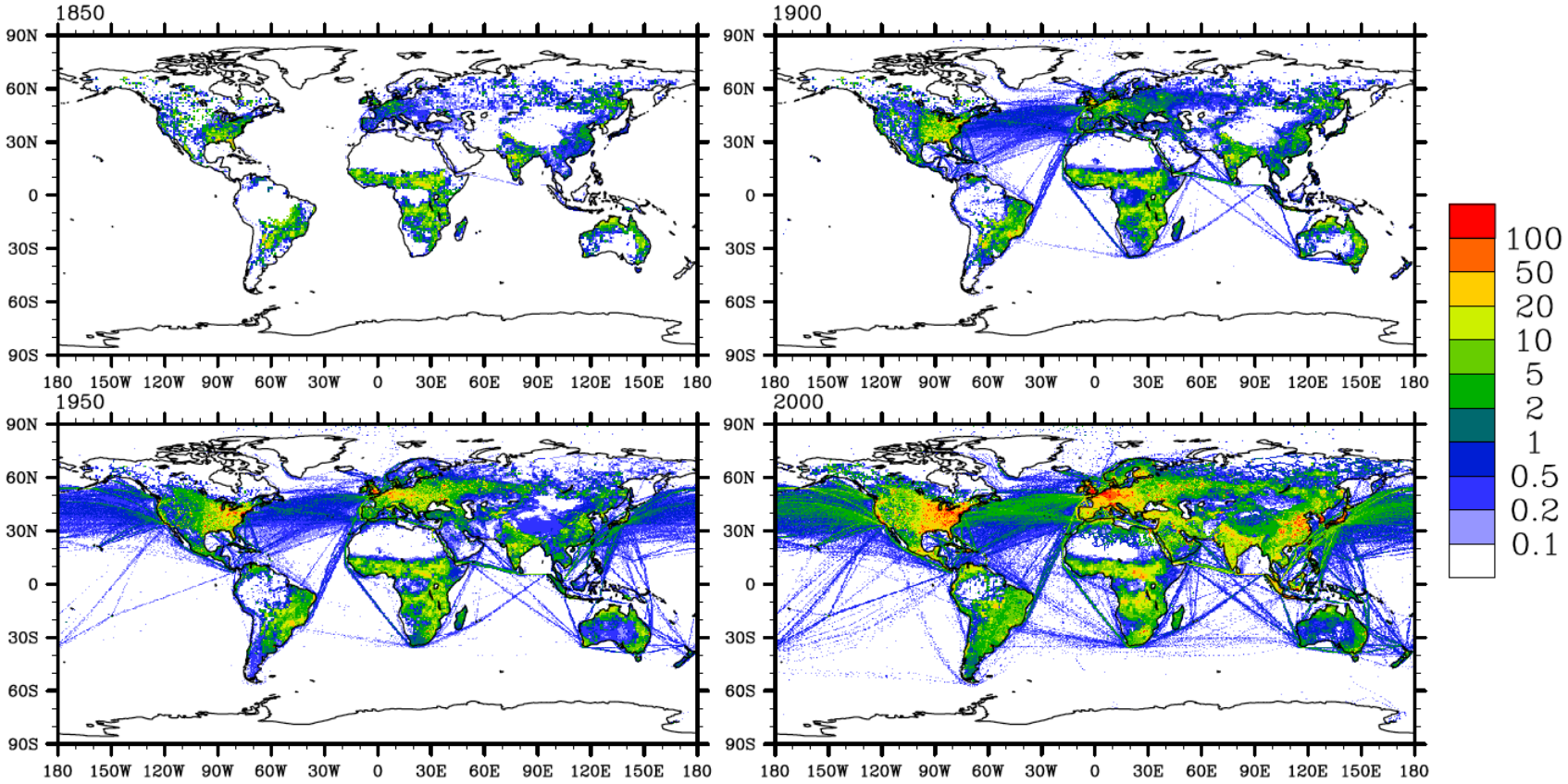
Net: $\mathrm{CO} + 2\mathrm{O_2} + h\nu \longrightarrow \mathrm{CO_2} + \mathrm{O_3}$

$NO_x = NO + NO_2$



From Seinfeld and Pandis, 2007

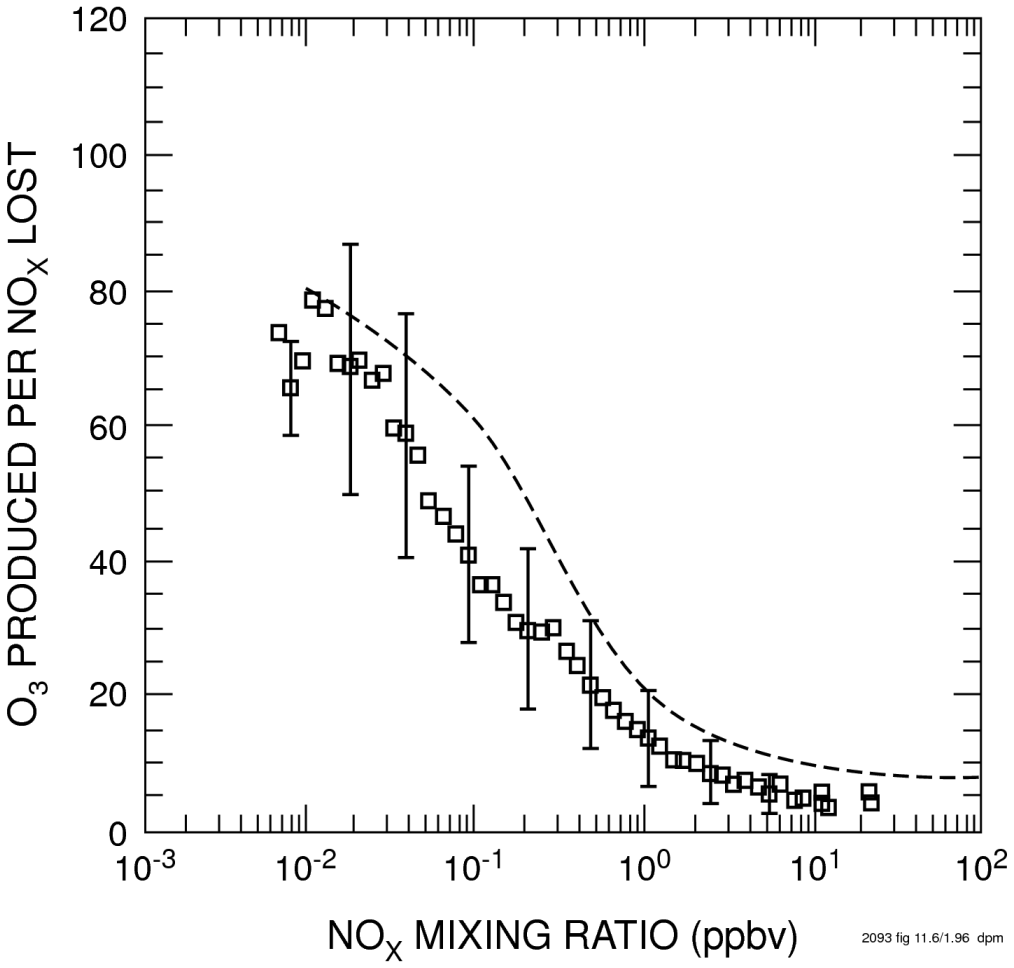
Example: NO_x emissions



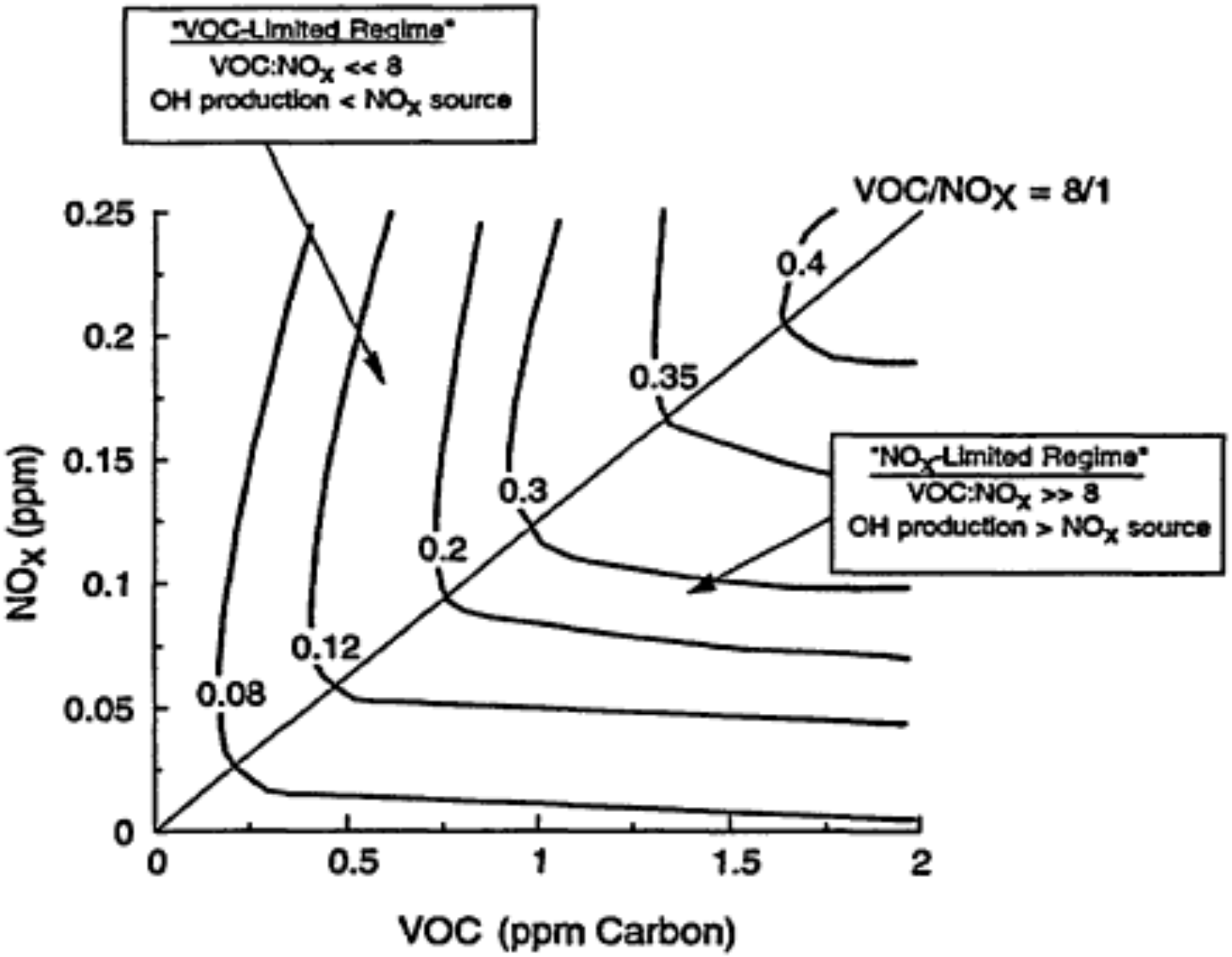
Anthropogenic + biomass burning + ships: kg(N)/year

Lamarque et al., ACP, 2010

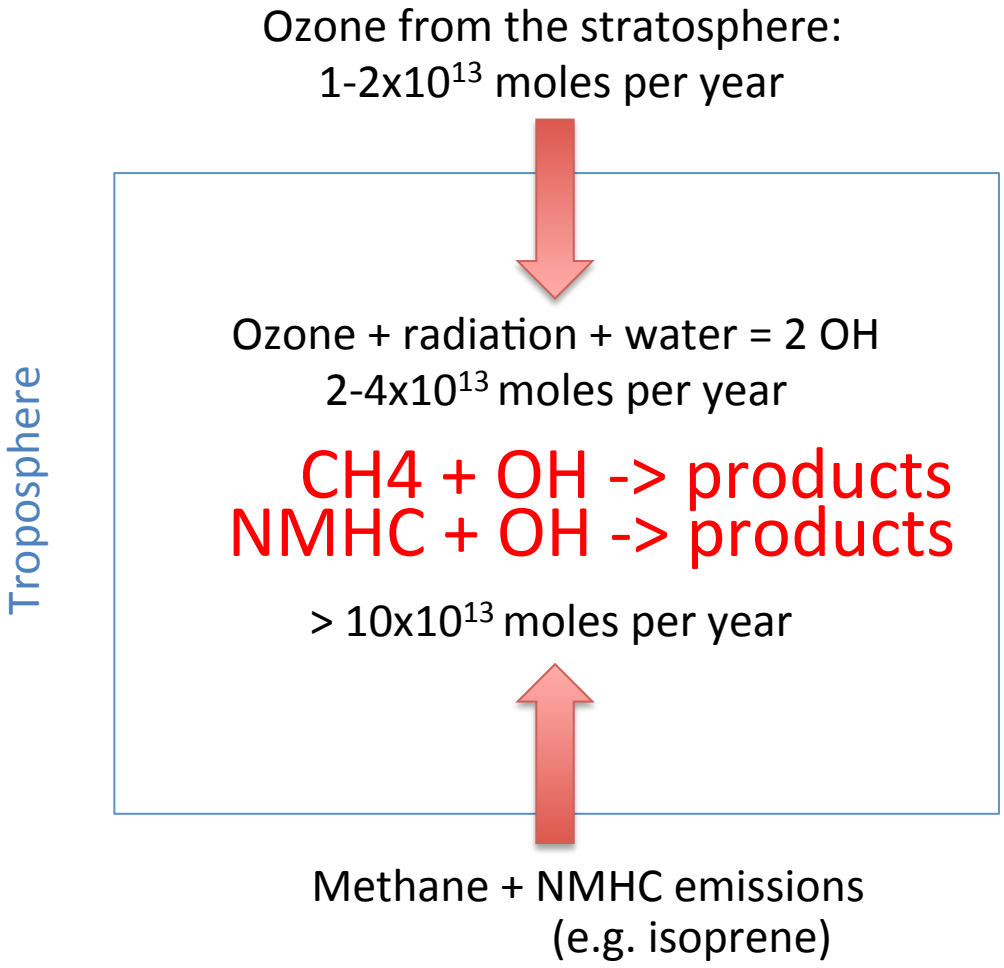
Ozone, NOx and VOCs



Ozone production rate



Is the atmosphere chemically stable?



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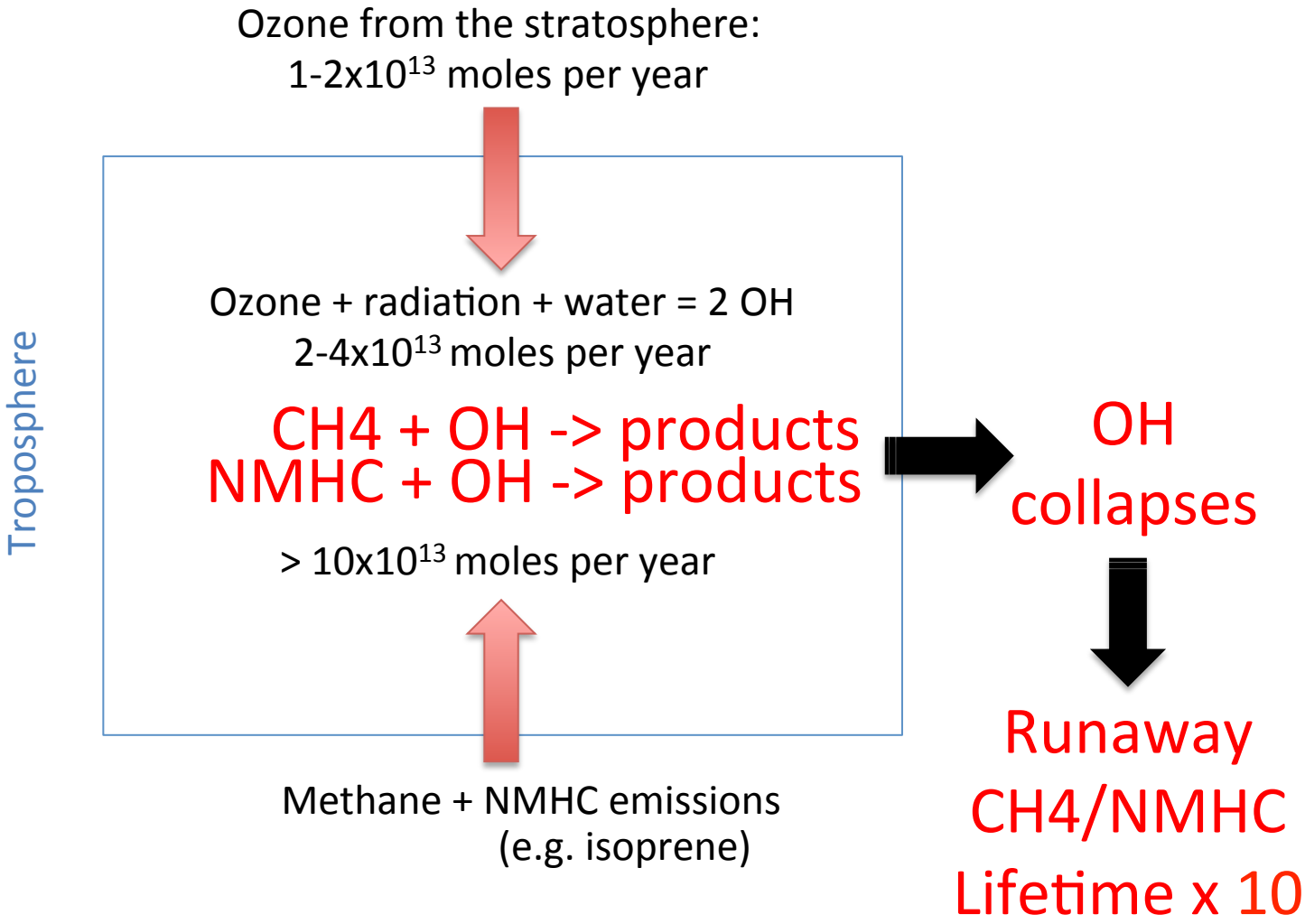

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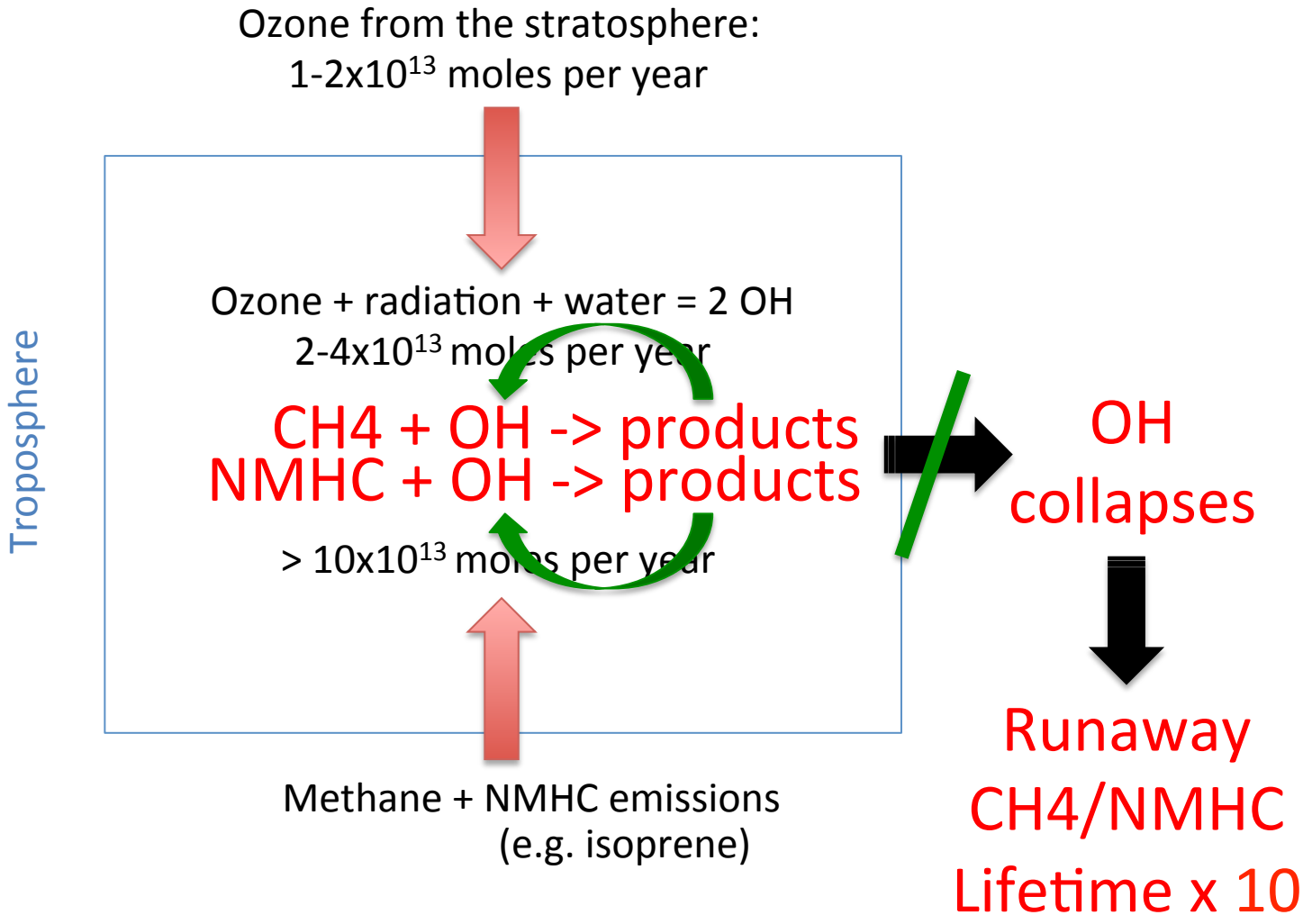


Global modeling of OH in IPCC AR5: wide spread

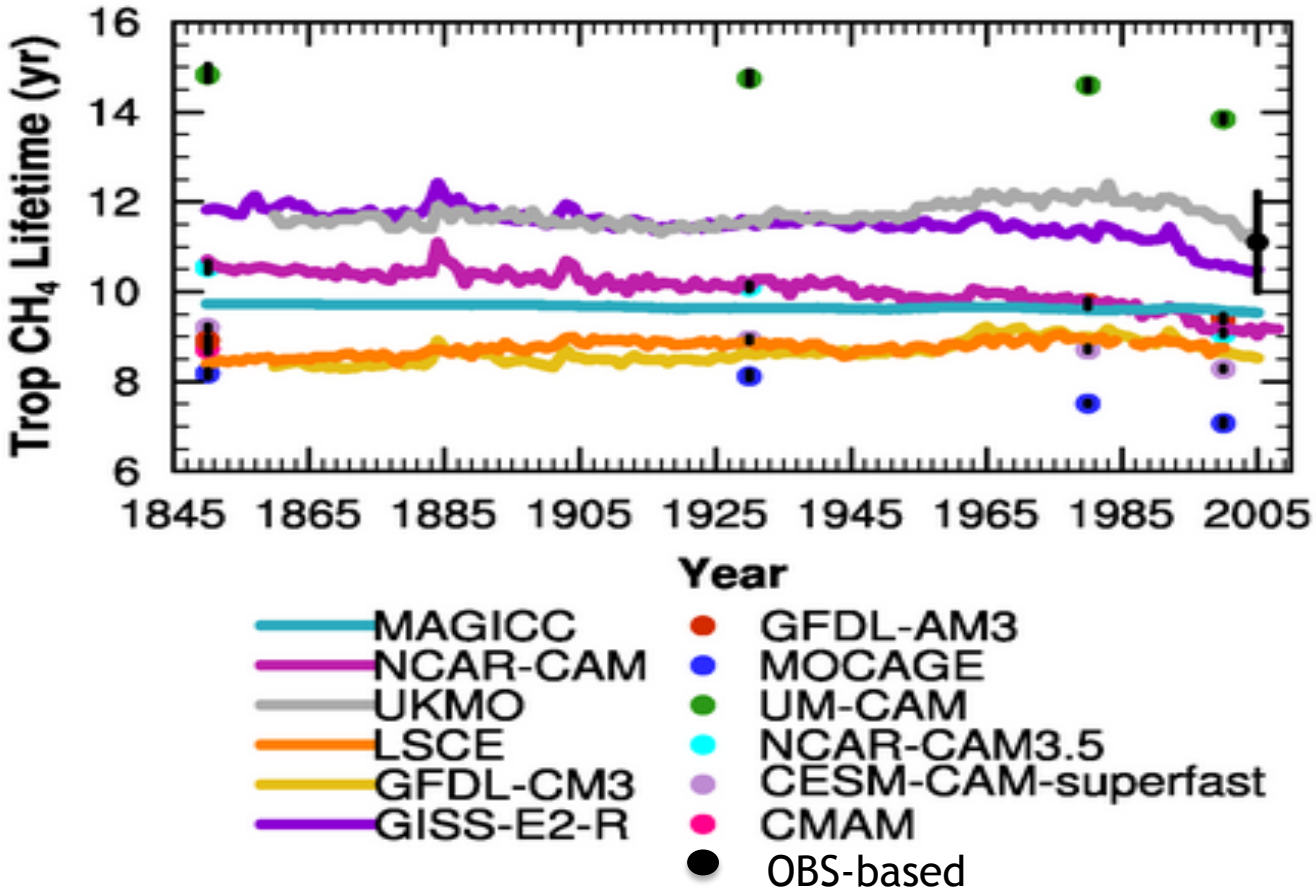
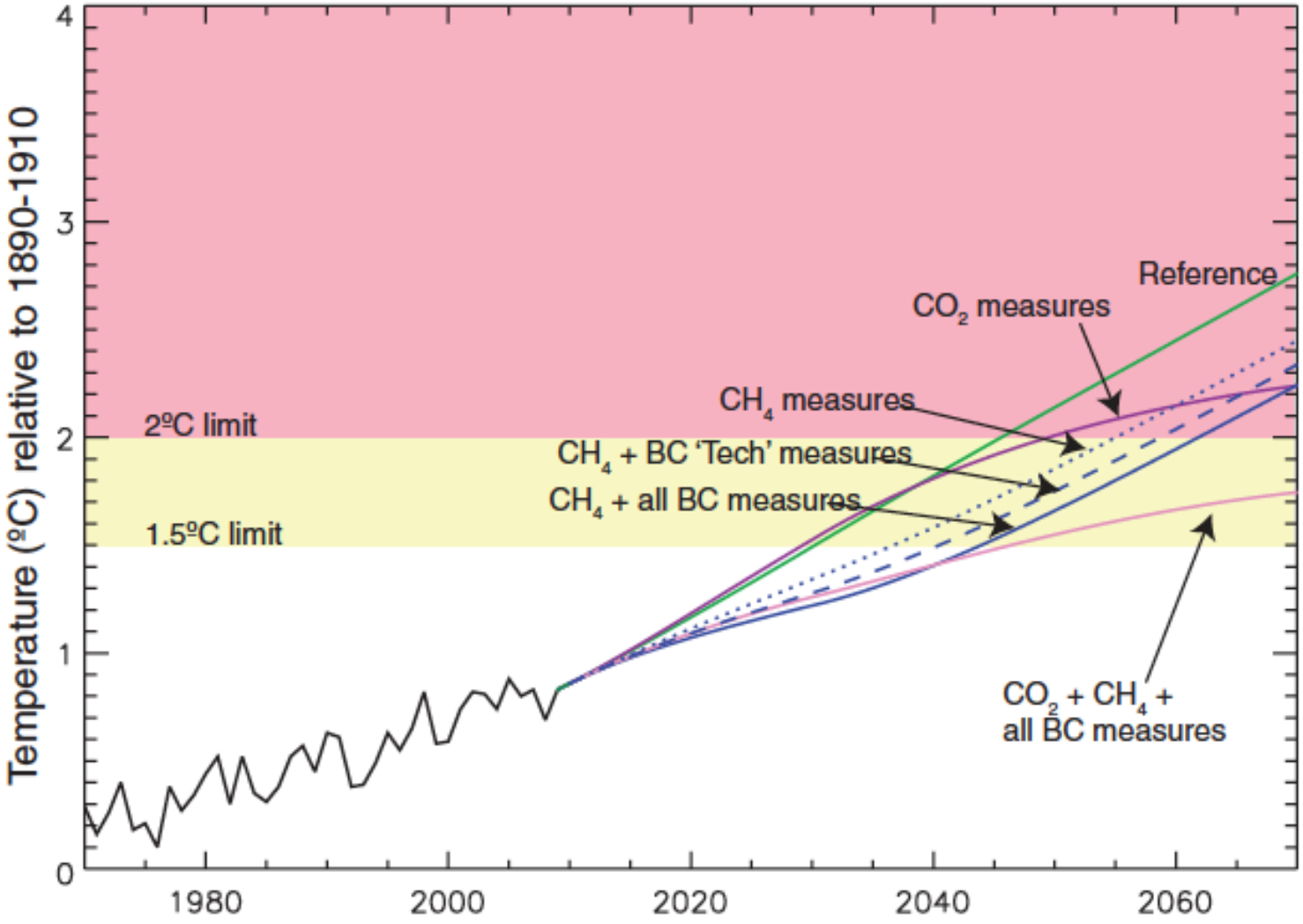


Figure courtesy of V. Naik, GFDL, 2012

Climate benefits from methane reductions



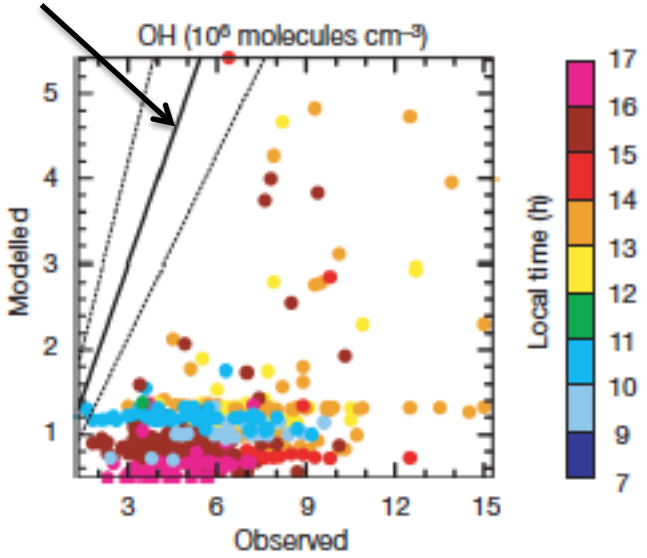
Reference

CH_4 measures

Shindell et al., Science, 2012

OH in the PBL and beyond

One-to-one



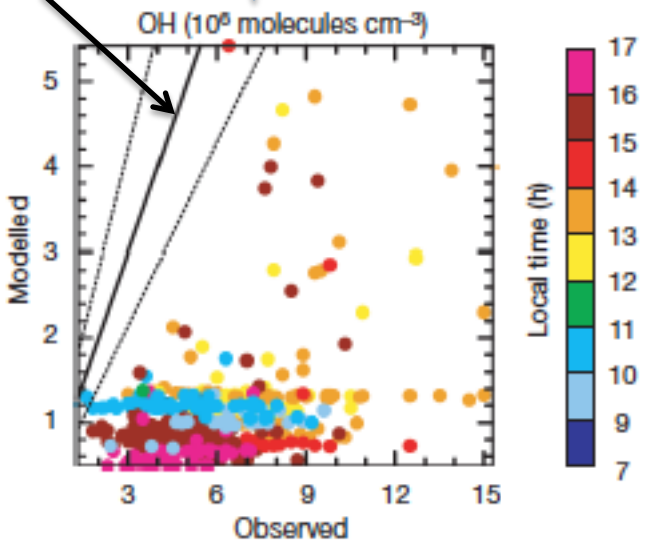
Lelieveld et al., 2008

Isoprene-rich environment
Amazon

OH in the PBL and beyond

Impact of modifying isoprene chemistry to address observed bias

One-to-one



Lelieveld et al., 2008

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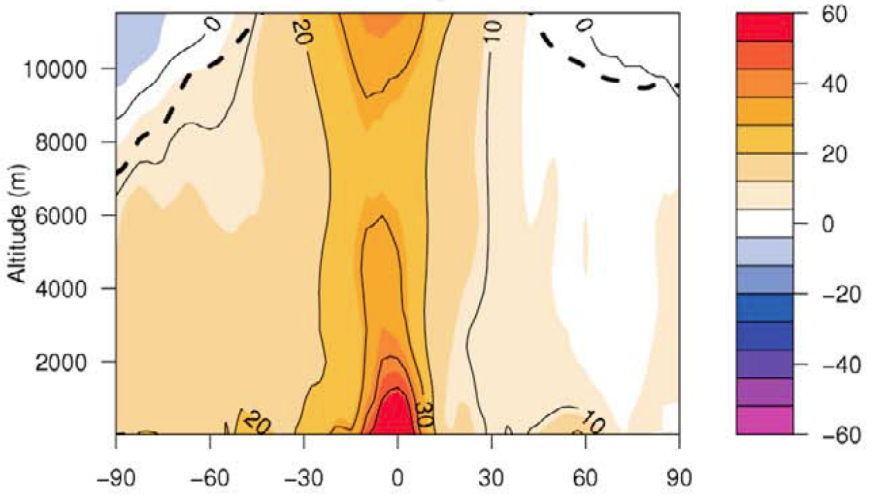
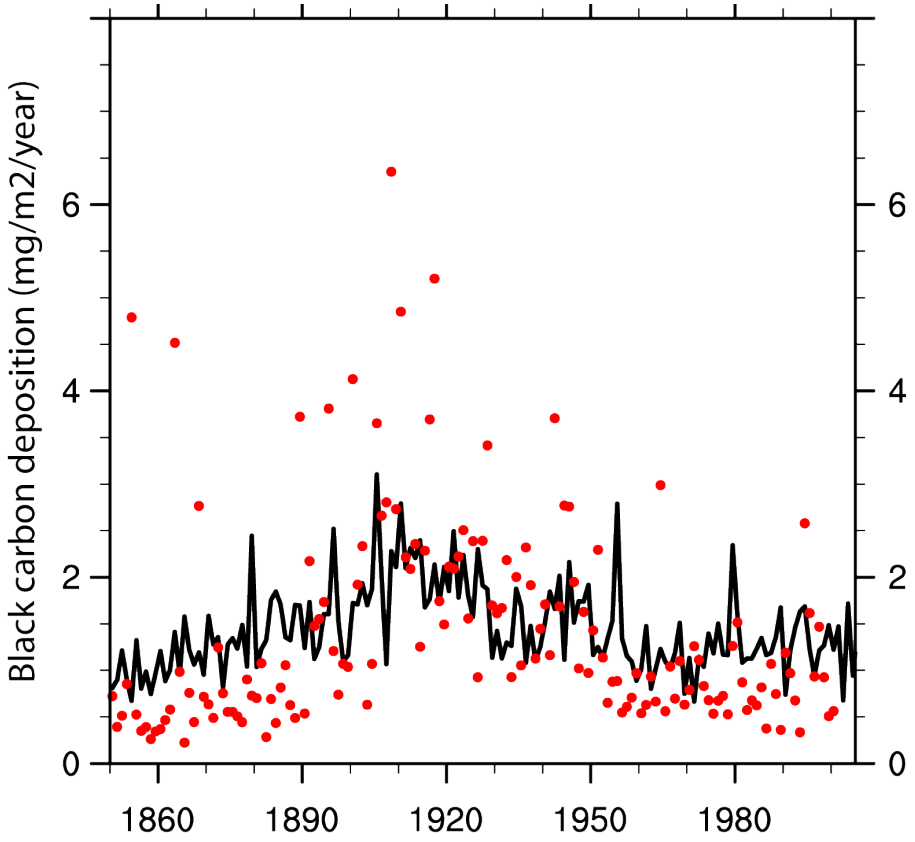
Amazon



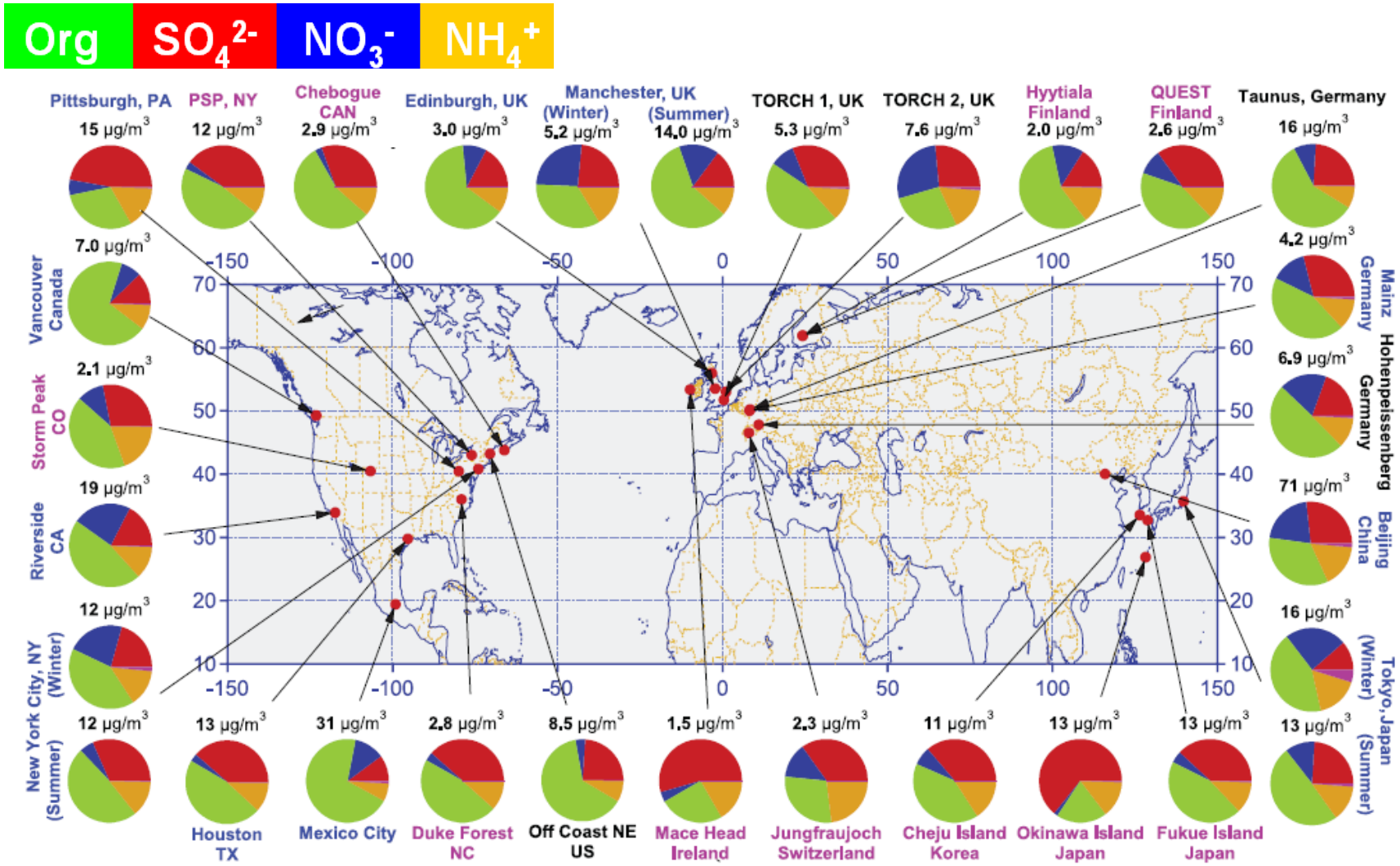
Archibald et al., GRL, 2011

AEROSOLS



Deposition rate (annual average) over Greenland (D4 site) of BC vs. year. Data from J. McConnell (DRI).

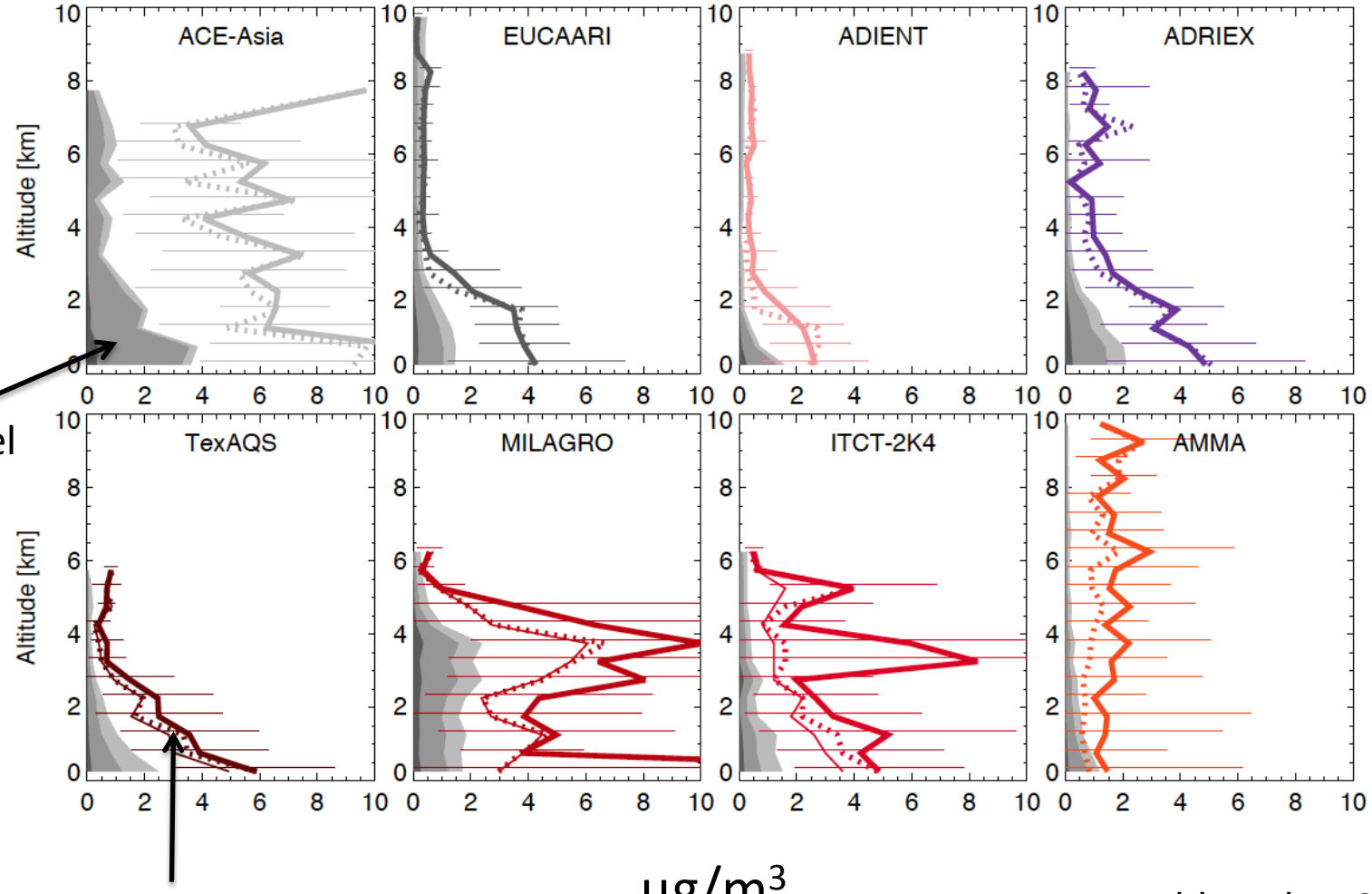
Organic aerosol > Sulfate in most observations



Note: 2/3 OA is of biogenic origin

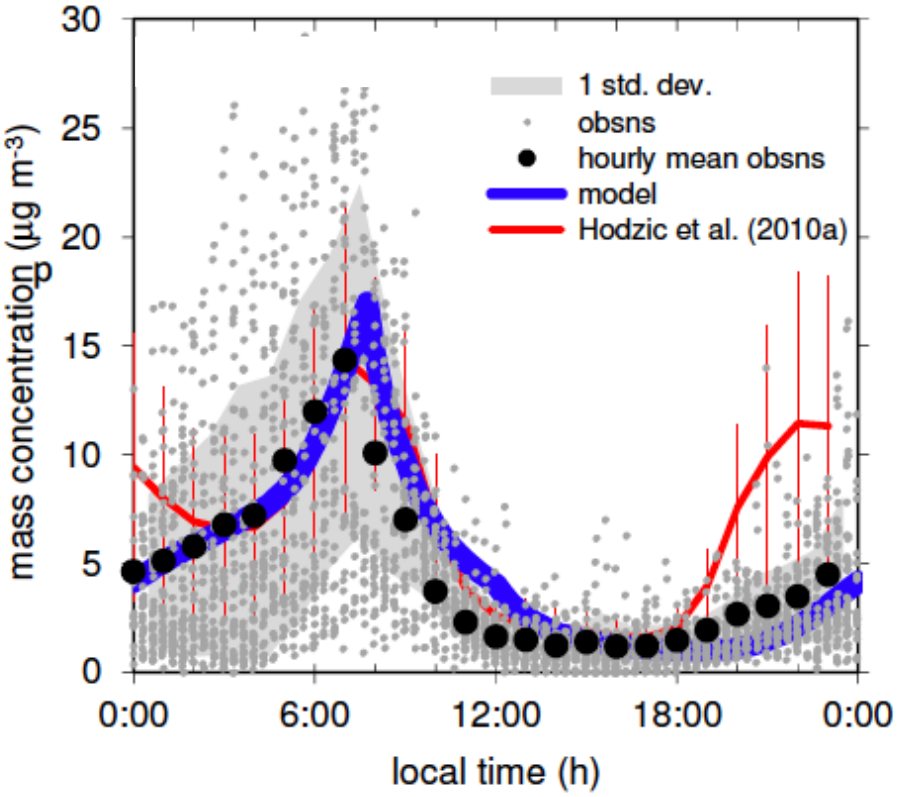
Zhang et al., GRL 2007

OA: not just in the PBL

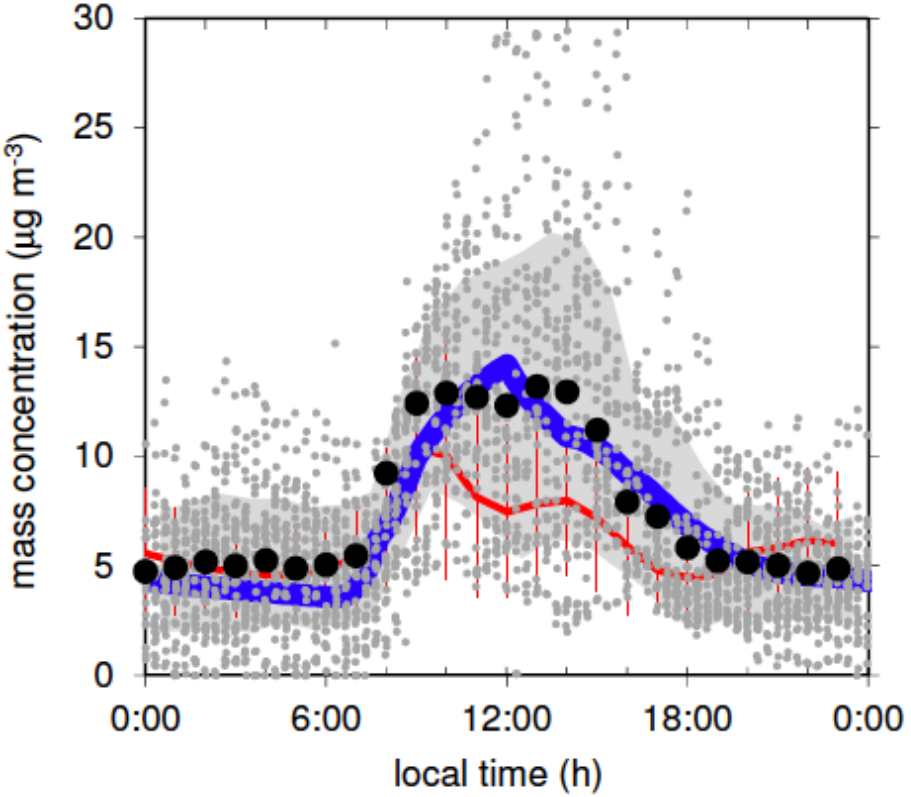


Heald et al., ACP, 2011

Obs. and modeling of SOA: Mexico City March 8-30 2006



Primary organic aerosols



Secondary organic aerosols

Lee-Taylor et al., 2011

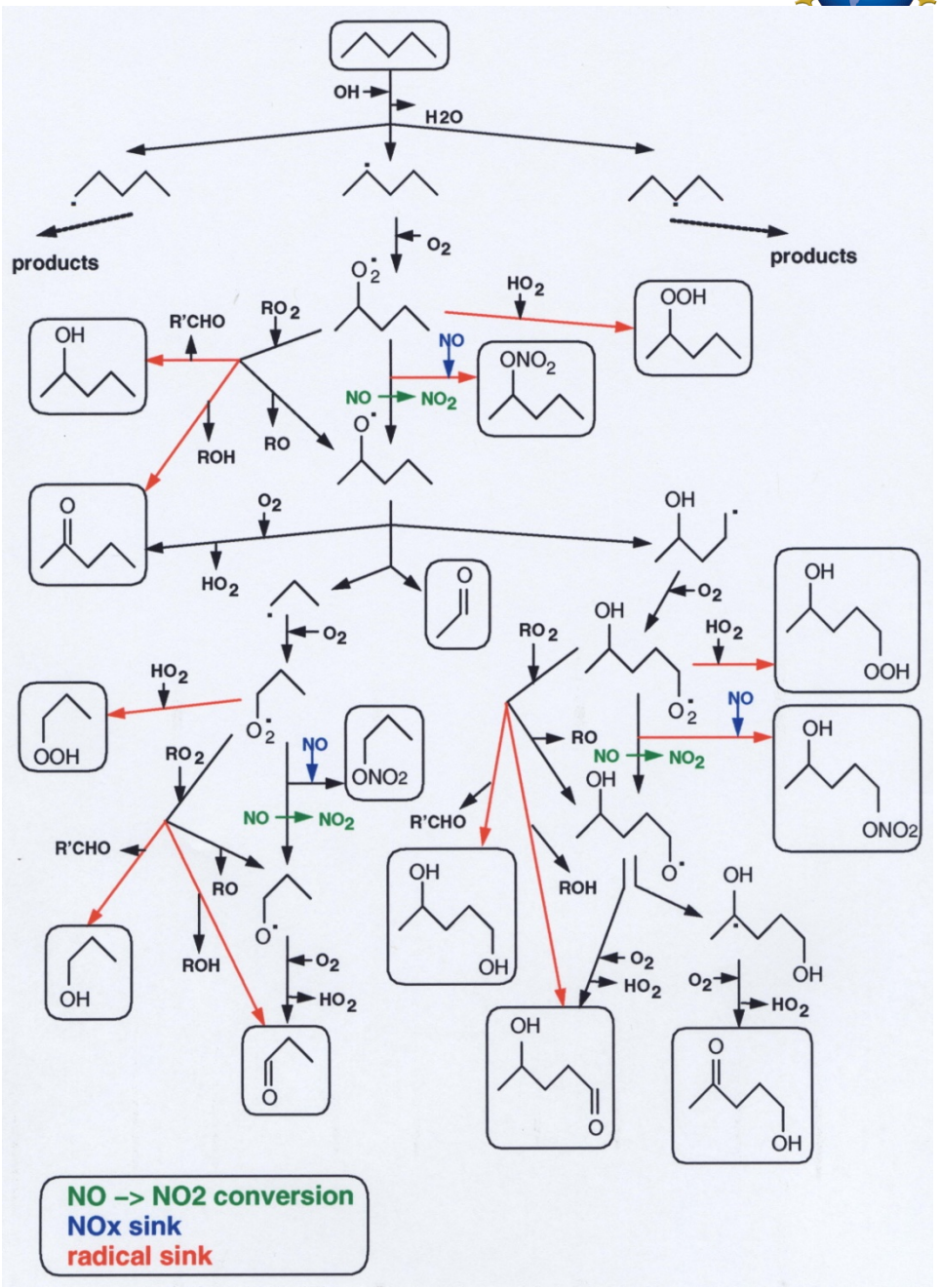
Simplified Mechanism for Pentane (C_5H_{12})

Multiple NO→NO_2 conversions produce O_3

Organic nitrates allow long-range transport of NOx

Radical sinks:
Some are temporary, producing HOx later

Some products have low vapor pressures, can make organic aerosols



Biogenic SOA

- Precursor emissions 10x anthropogenic
- Growing evidence that anthropogenic gases enhance SOA efficiency

➪ Biogenic SOA has contributed to radiative forcing since pre-industrial

➪ Controlling emissions may reduce SOA

Biogenic SOA

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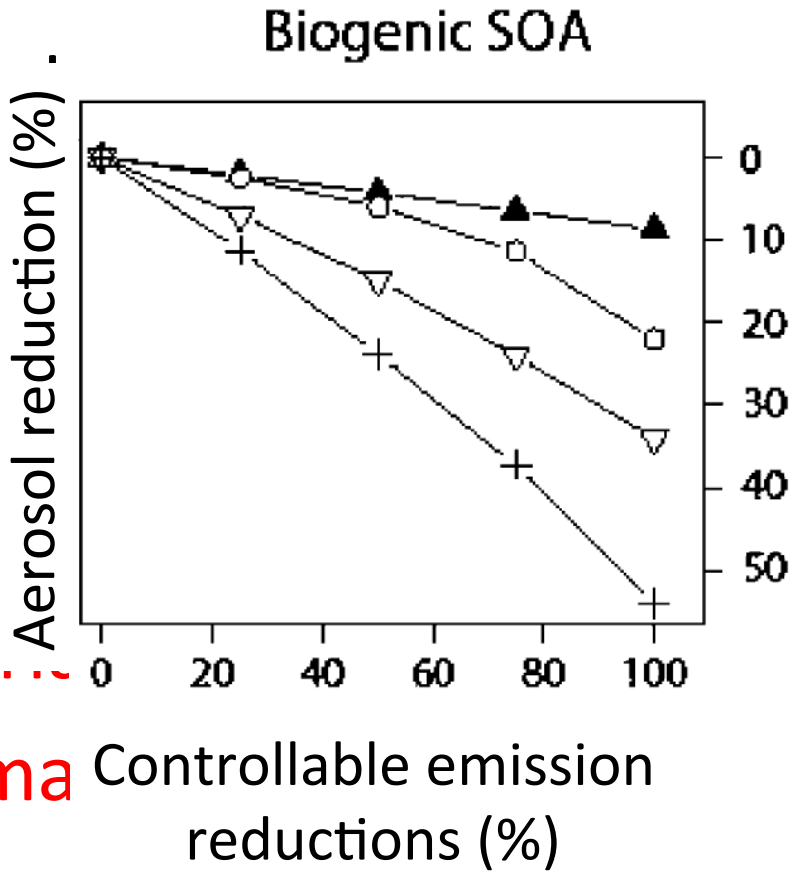
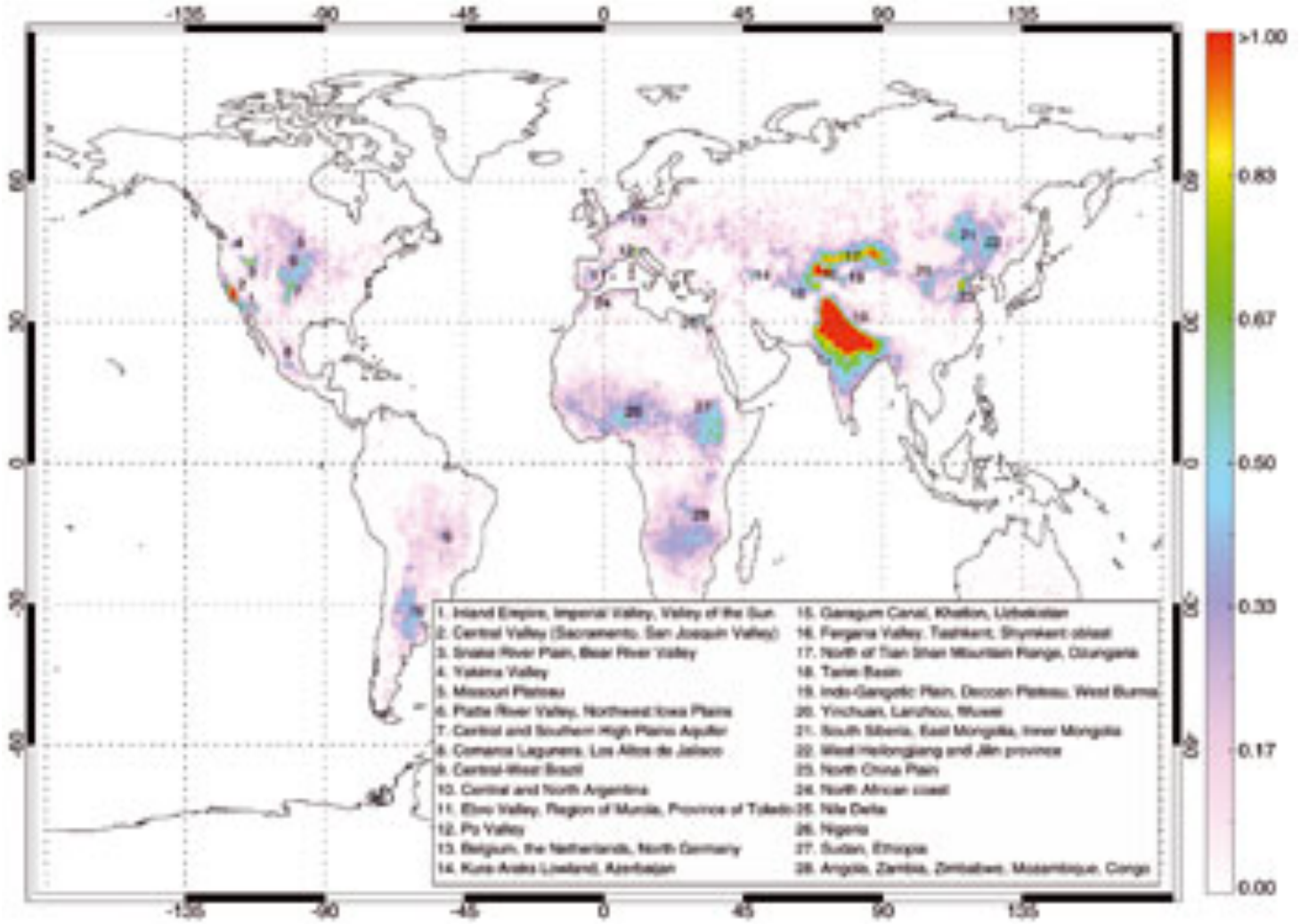
➪ Biogenic SOA has cont forcing since pre-indust…

➪ Controlling emissions ma

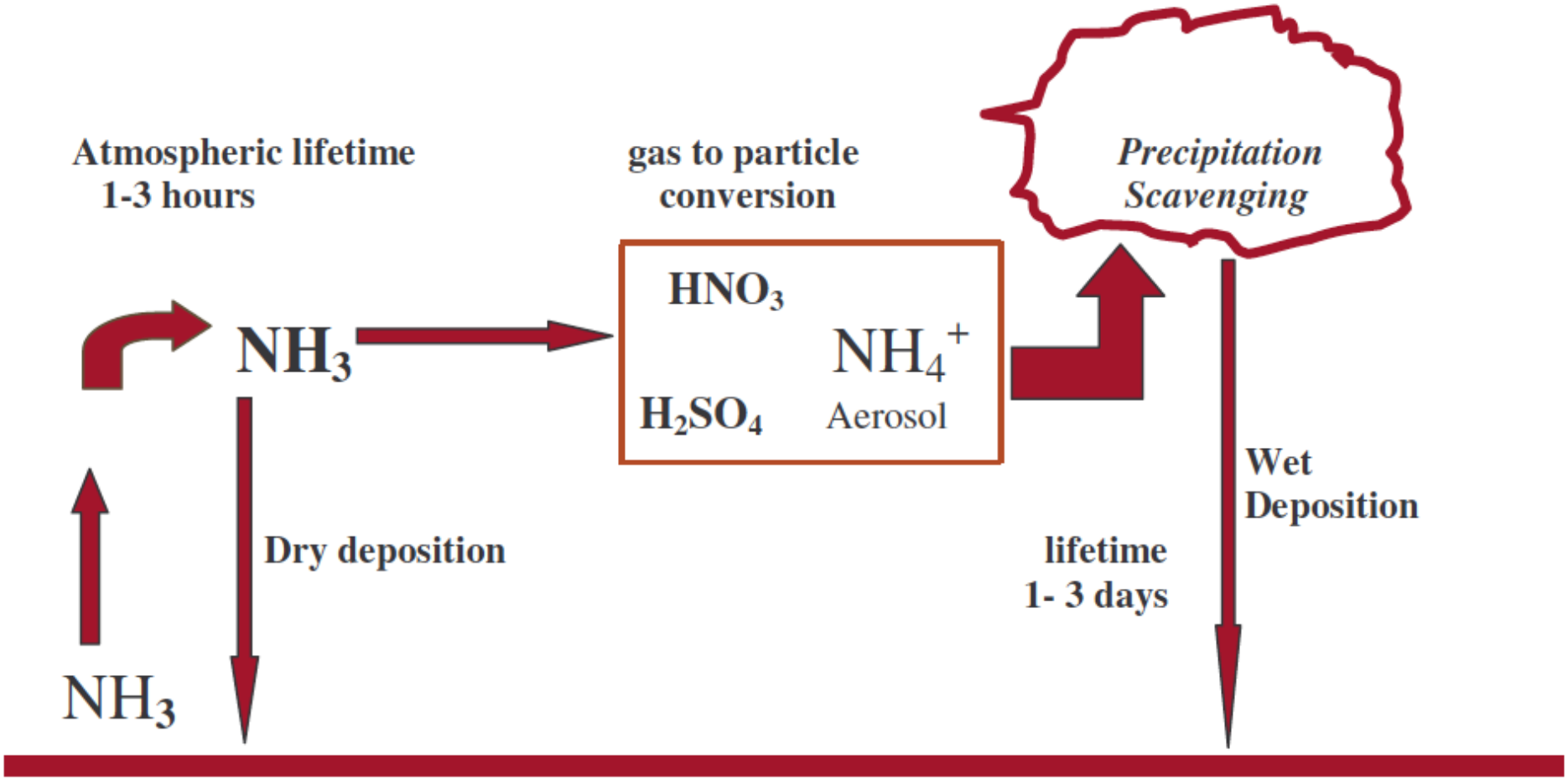


Carlton et al., ES&T, 2010

NH3 distribution

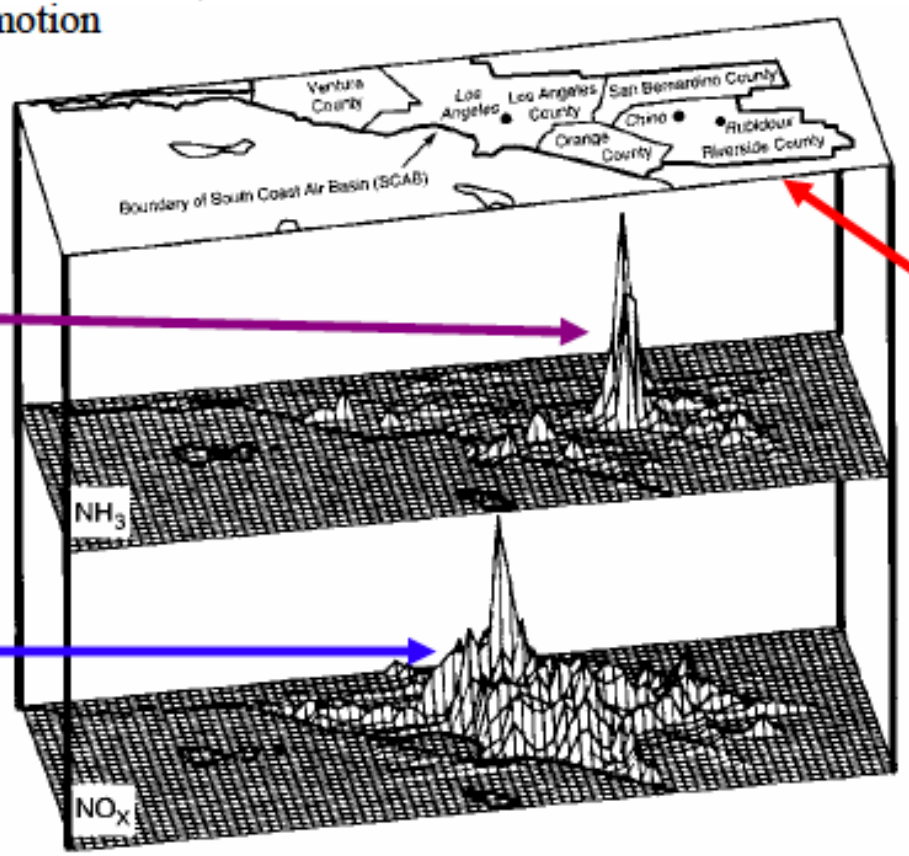


IASI instrument on MetOp satellite (Lieven et al., 2009)


Atmospheric lifetime
1-3 hours
gas to particle
conversion
Precipitation
Scavenging
HNO3
NH4+
H2SO4
Aerosol
NH3
Dry deposition
Wet
Deposition
lifetime
1- 3 days
NH3

NH_4NO_3 Formation: LA Example

General air motion



NH_3 from agriculture to east of LA

NOx from vehicles in LA produces HNO_3

$NH_3 + HNO_3 \rightarrow NH_4NO_3$ enhances particle formation leading to visibility problems in Riverside further inland

FIGURE 7.21 Estimated daily emissions of NH_3 and NO_x in the Los Angeles area in 1982 (adapted from Russell and Cass, 1986).

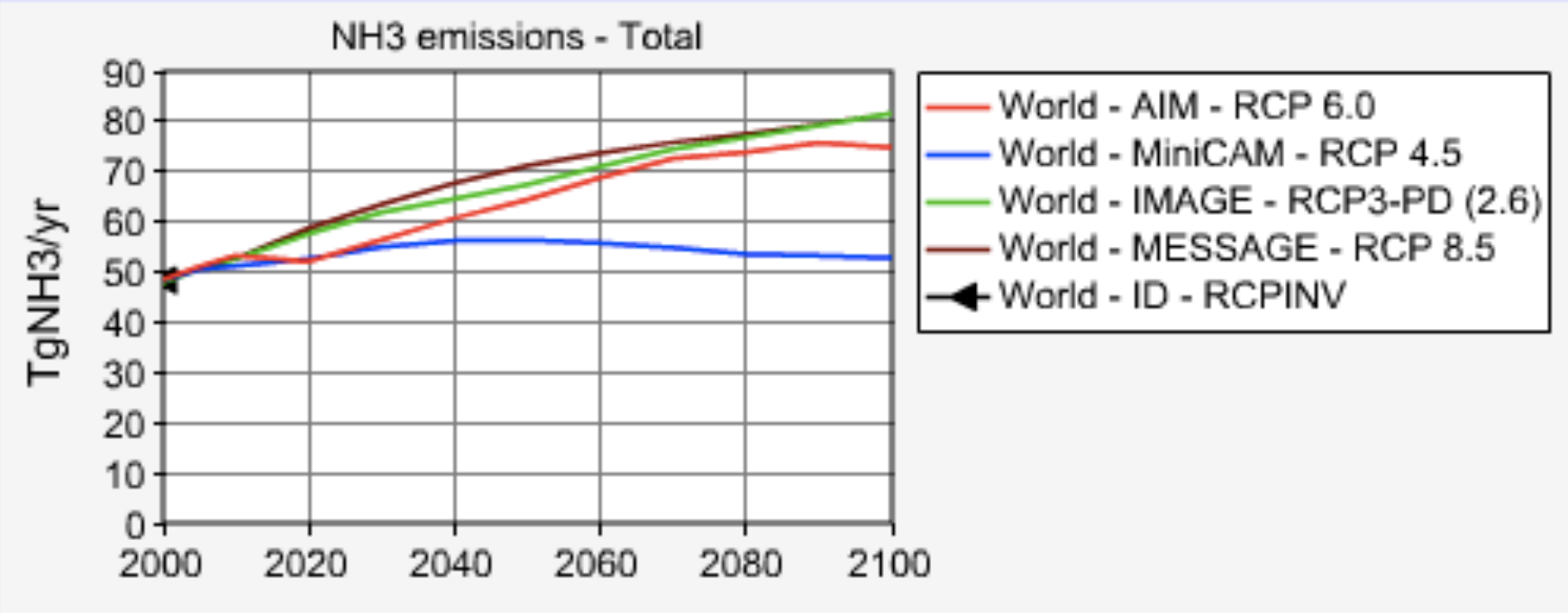
From Finlayson-Pitts and Pitts

E

NH3 Chemistry

- Gas-phase conversion of NH3 -> NH4
- NH4 bonds more readily with sulfate (SO4) than nitrate (NO3)
- But this is a very complicated system characterized by equilibrium between gas-phase, solid-phase and aqueous-phase
- Strong natural sources

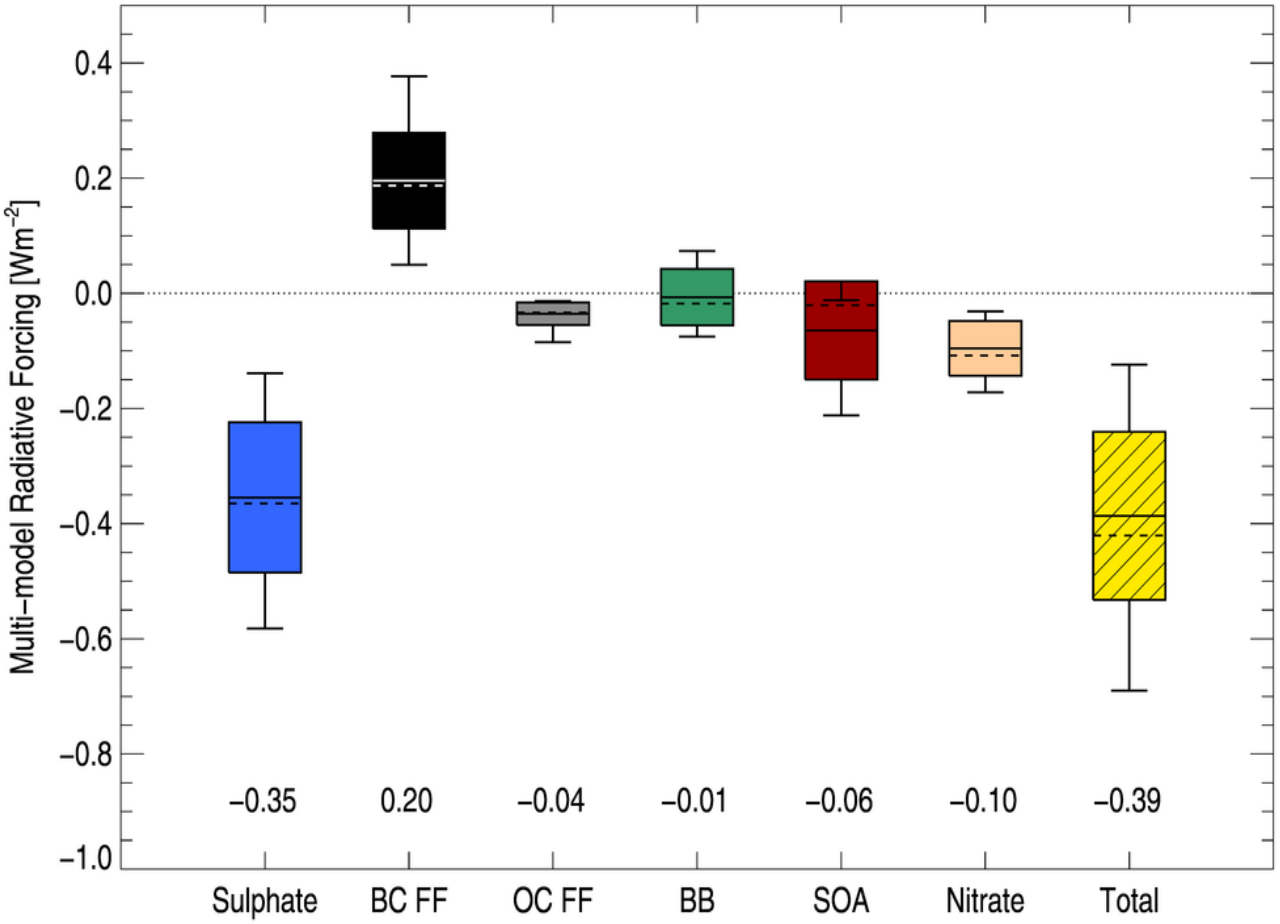
NH3



In the RCPs, anthropogenic emissions of all other aerosols are decreasing

=> increasing role of NH3

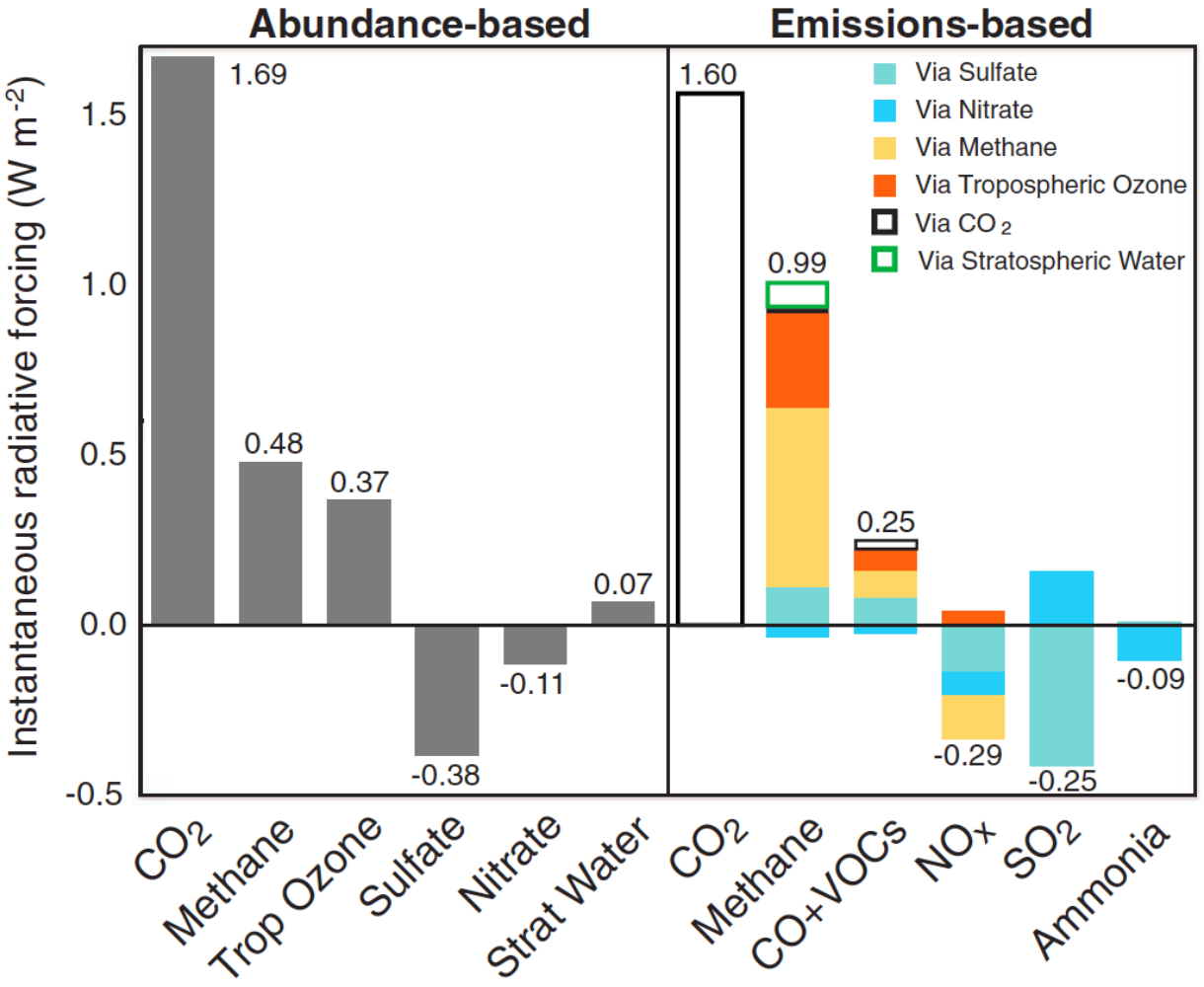
Present-day RF



Myhre et al., to be submitted July 31, 2012

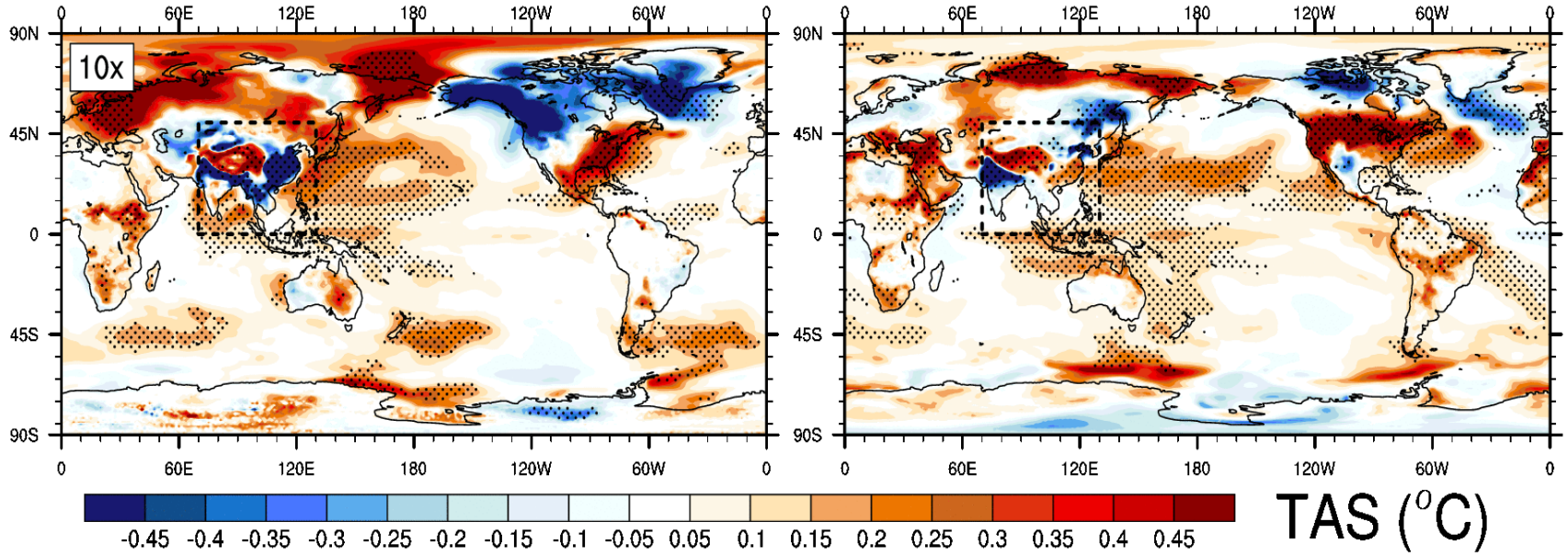
COUPLINGS

Gas-aerosol couplings



Shindell et al., 2009

Remote influence of BC

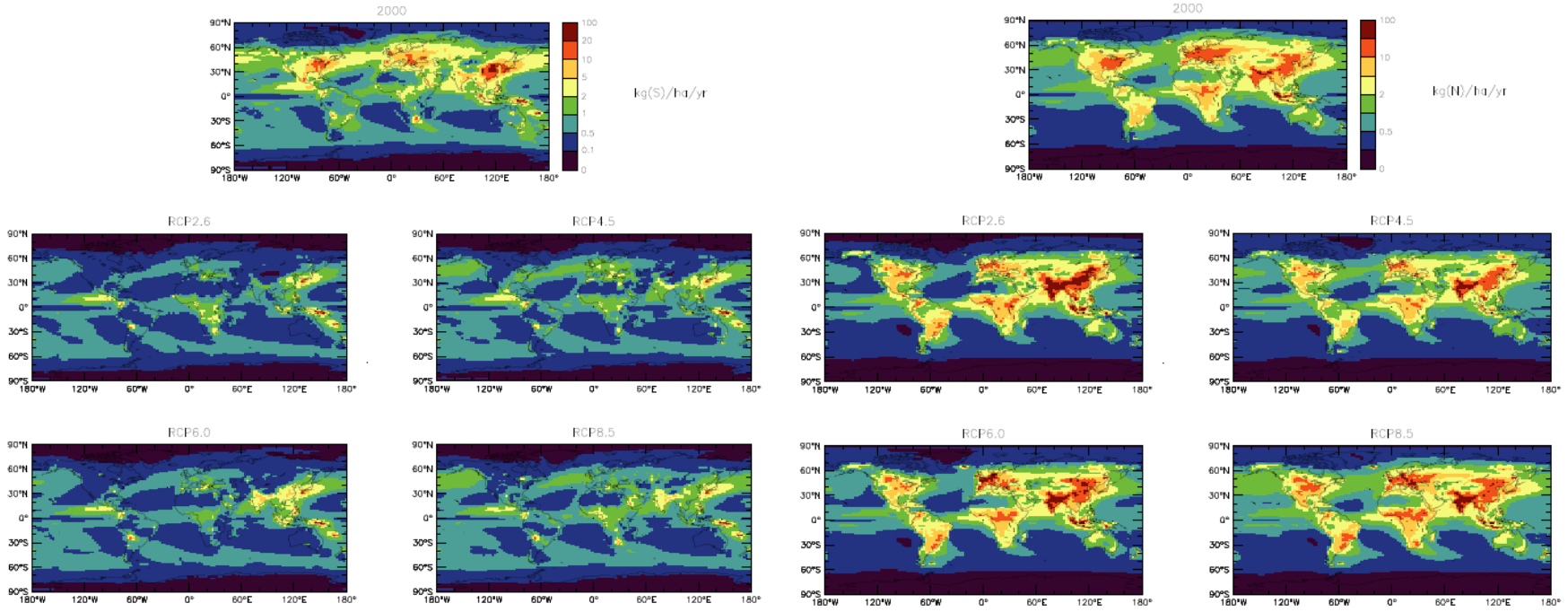


Importance of regional distribution!

From Teng et al., GRL, 2012

Chemistry impacts beyond radiation and clouds

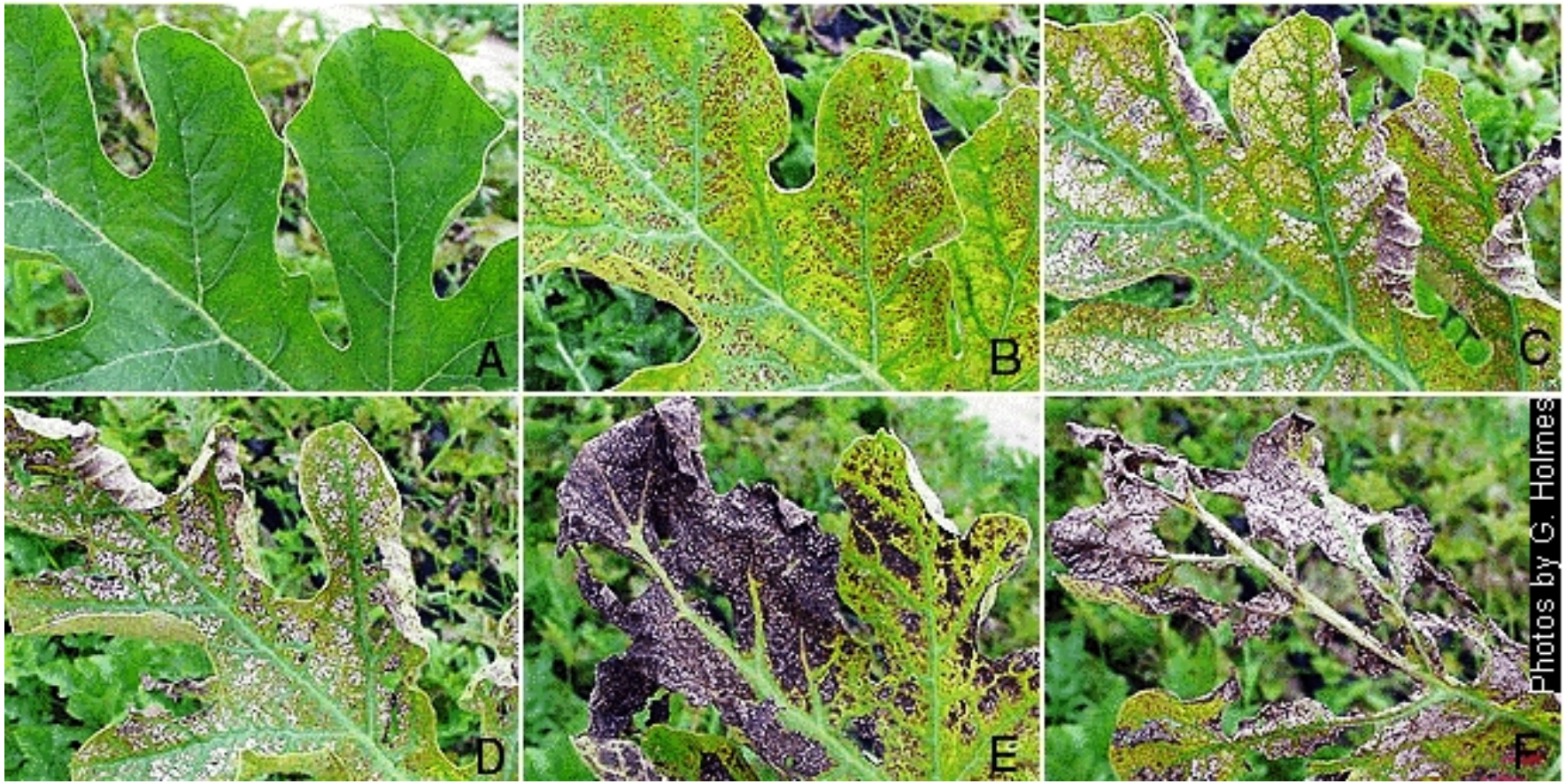
Nitrogen/sulfate deposition => impact on CO2



Nitrogen increase driven by NH3

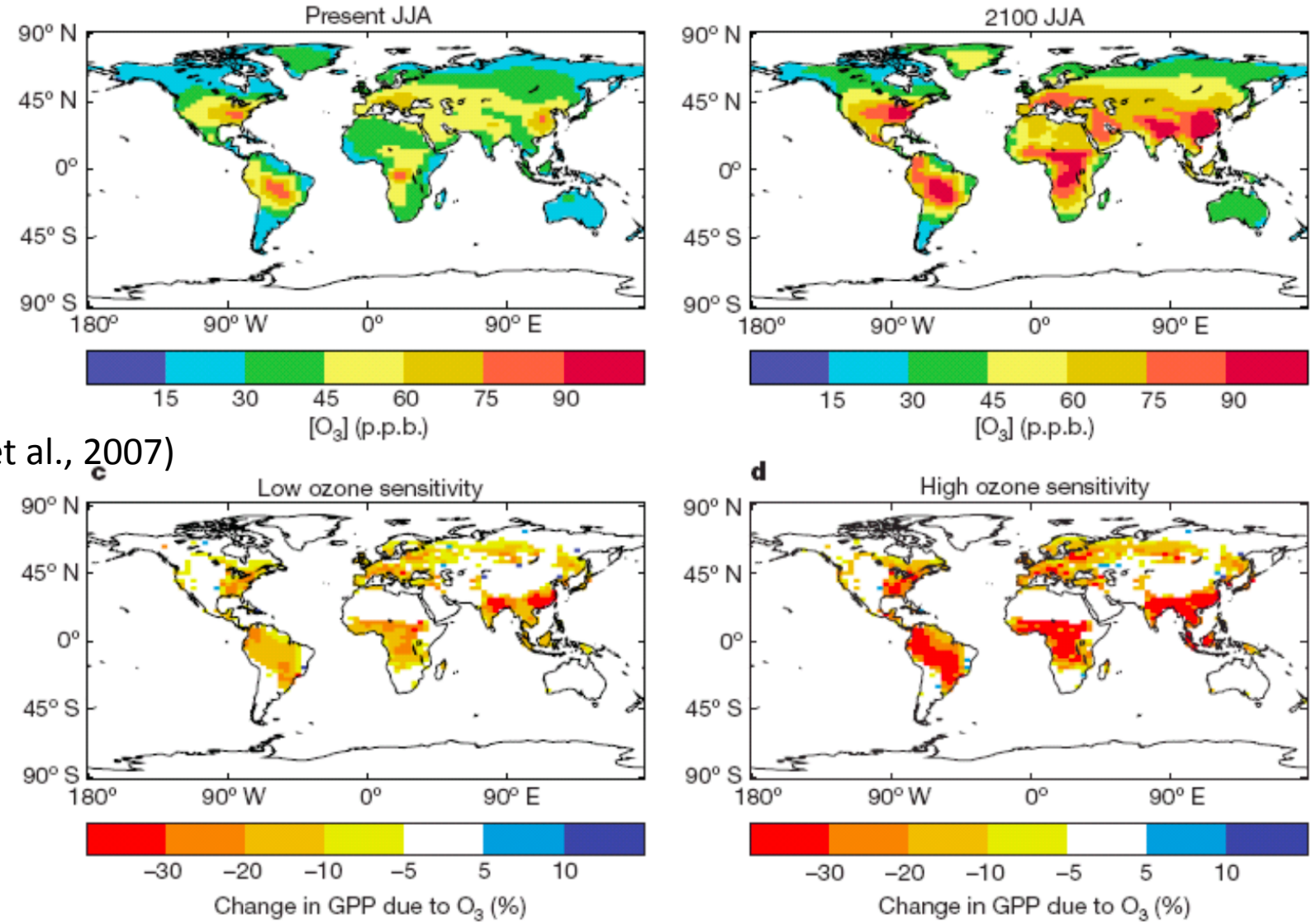
Ecosystem Damage by O_3

$3.5B-6.1B /yr in US for 8 major crops (Murphy, 1999)



http://agdev.anr.udel.edu/weeklycropupdate/wp-content/uploads/2009/07/ozone.jpg

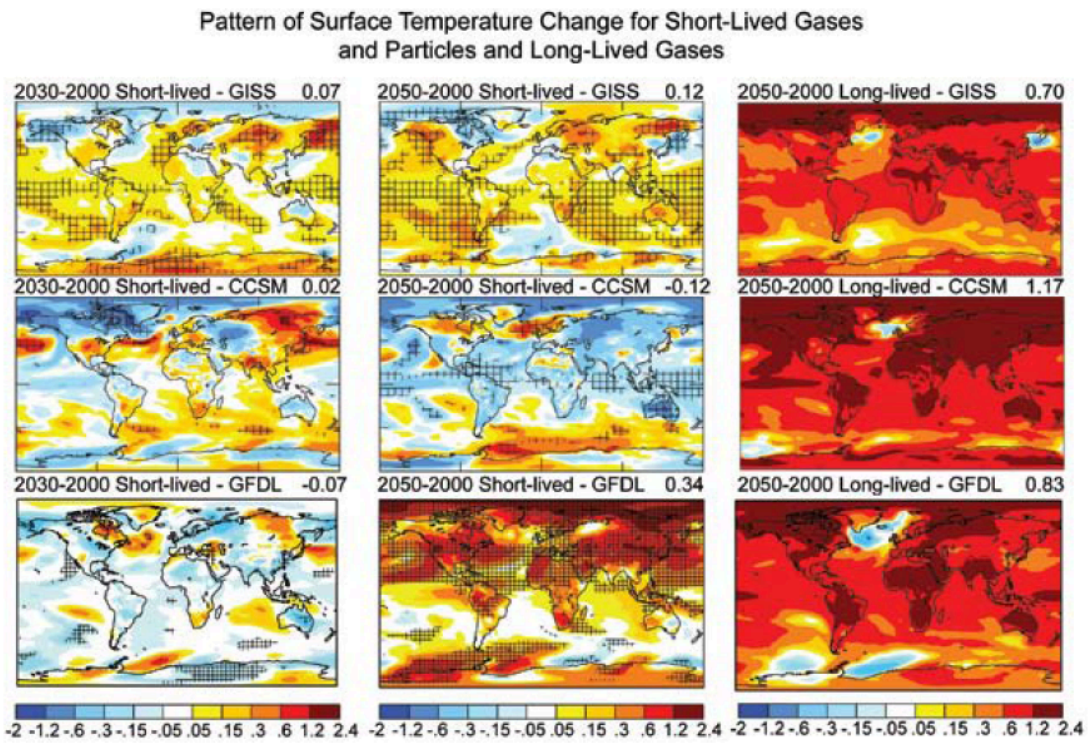
Ozone and vegetation

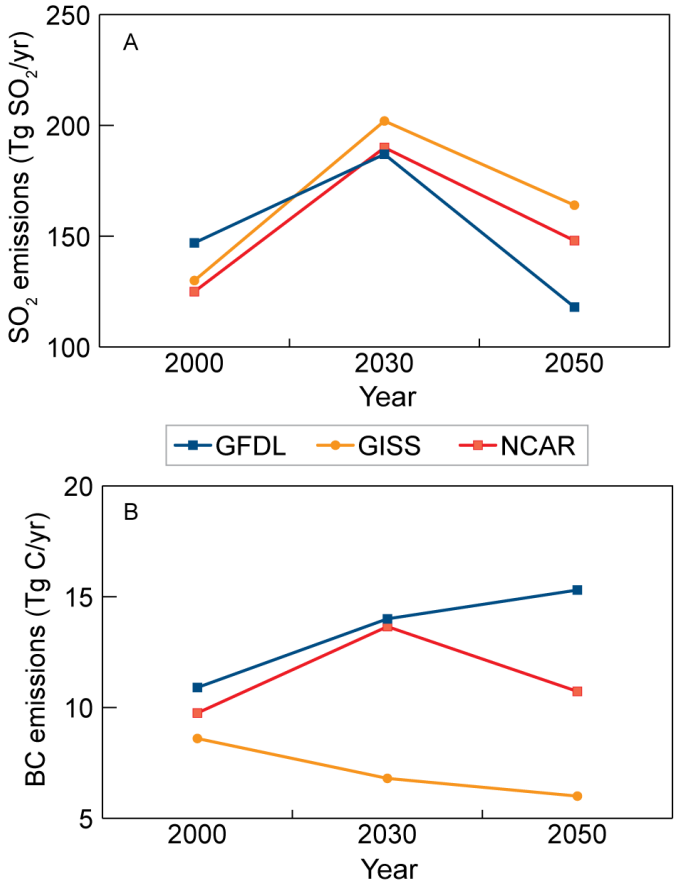


Sitch et al., 2007)

LINK TO IAM

IPCC AR4



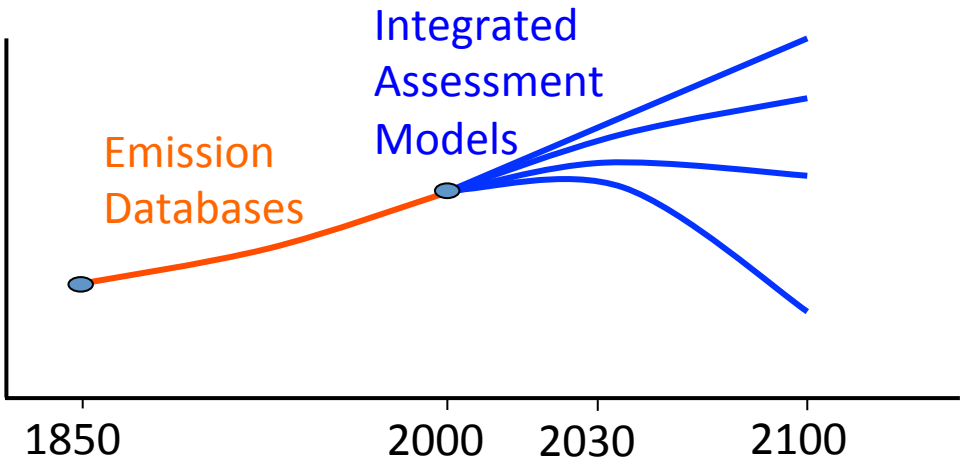


From Shindell et al., 2008

USGCRP SAP3.1, 2007

Air pollutants in RCPs

- Decadal estimates, harmonized for 2000, of anthropogenic (land, ship and aircraft) and biomass burning emissions of ozone precursors, aerosols and ODSs:
  1. 1850-2000 (from available emission estimates)
  2. 2000-2100 for each RCP
- AP emissions output of IAM RCP projections
  - ↳ Concentration of radiatively-active gases and aerosols computed by chemistry-climate models



Weaknesses of RCPs

- Propagation of uncertainty from present-day harmonization
- How do we move harmonization forward?
- Natural sources (big source of spread in model simulations); also critical to define background/pre-industrial conditions (and therefore baseline to RF)
- Missing couplings (dust from land-use, climate change and biomass burning impacts, …)

Steps forward

- For applicability of IAM emissions to climate and chemistry modelling, regionality of emissions is necessary
- Emission factors are very dependent on specific sectors and application of pollution controls
- To represent regional climate impacts, can we build on source-receptor relationships and pattern scaling?

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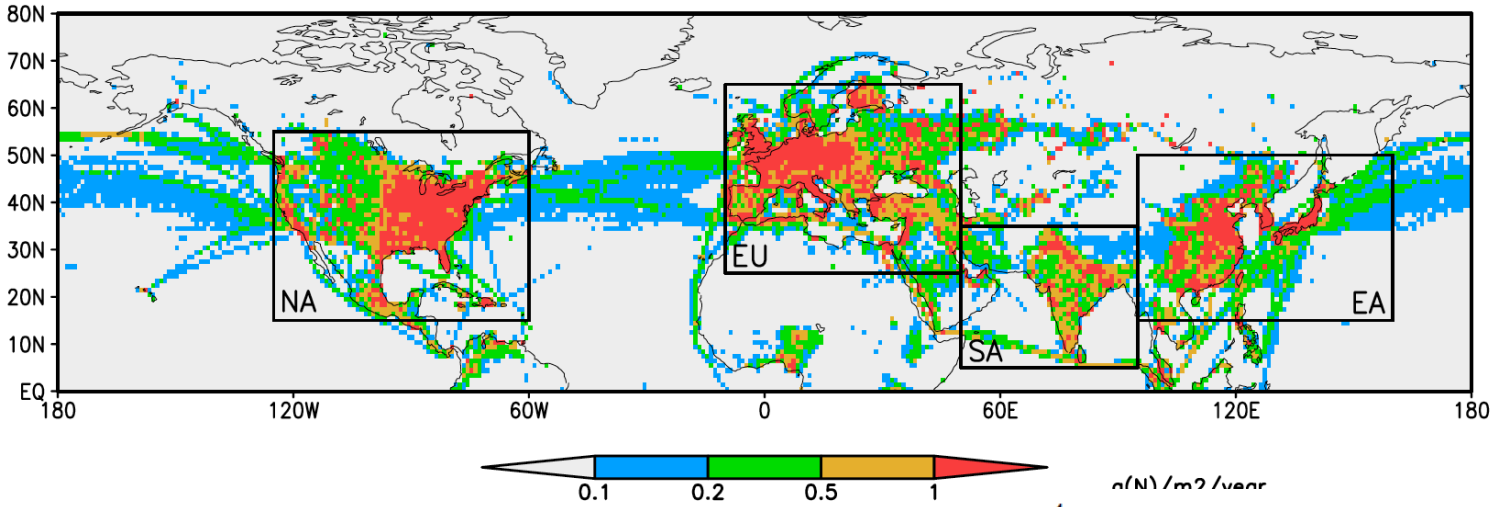
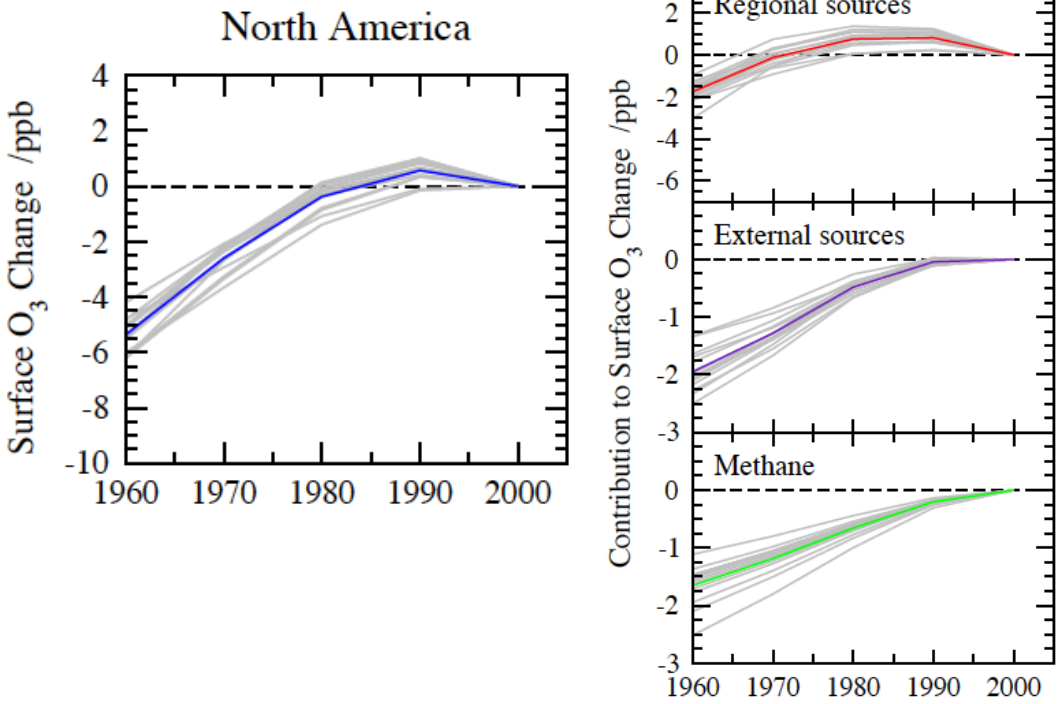
Source-receptor relationships

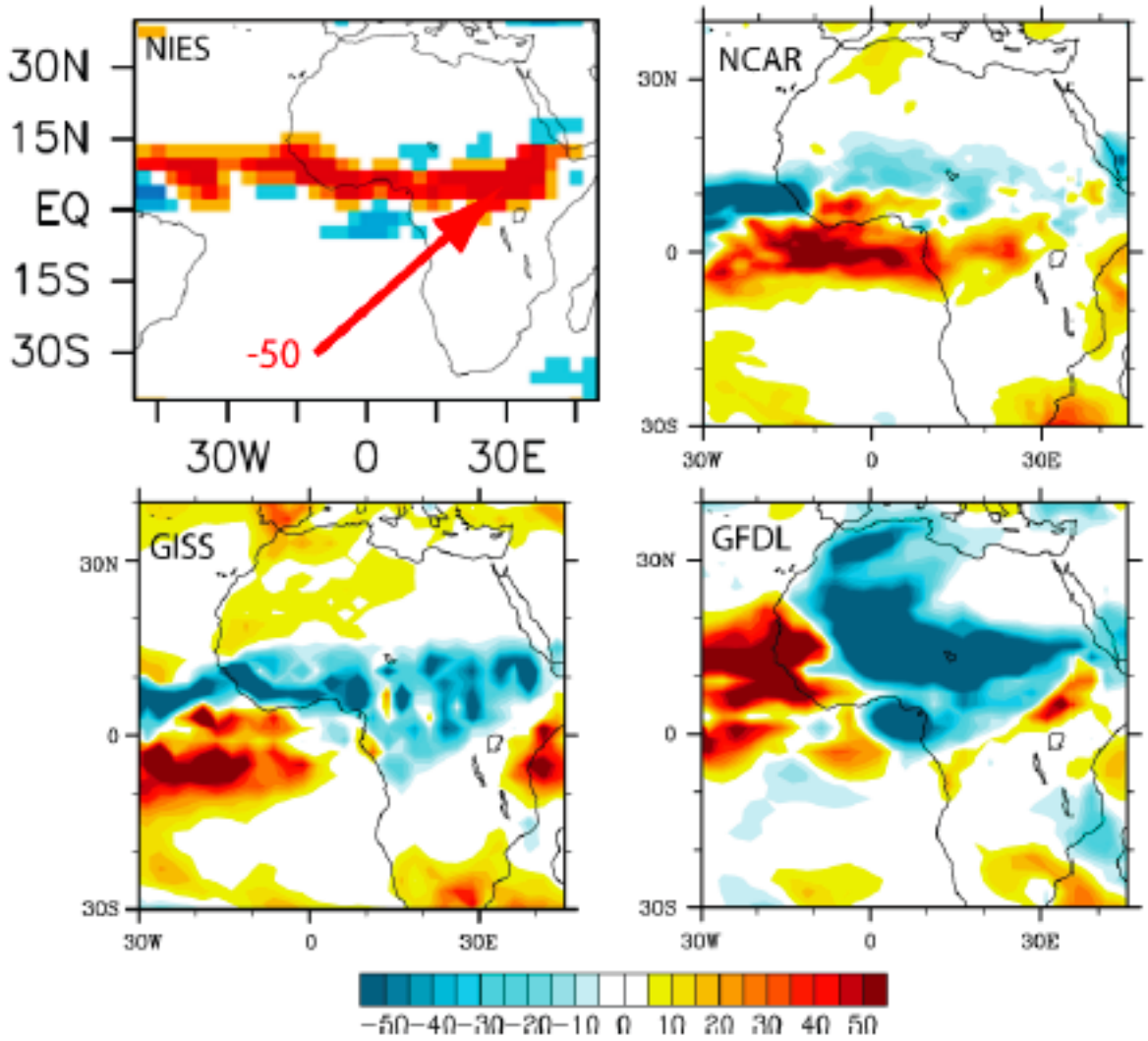


14 models, including CAM-chem

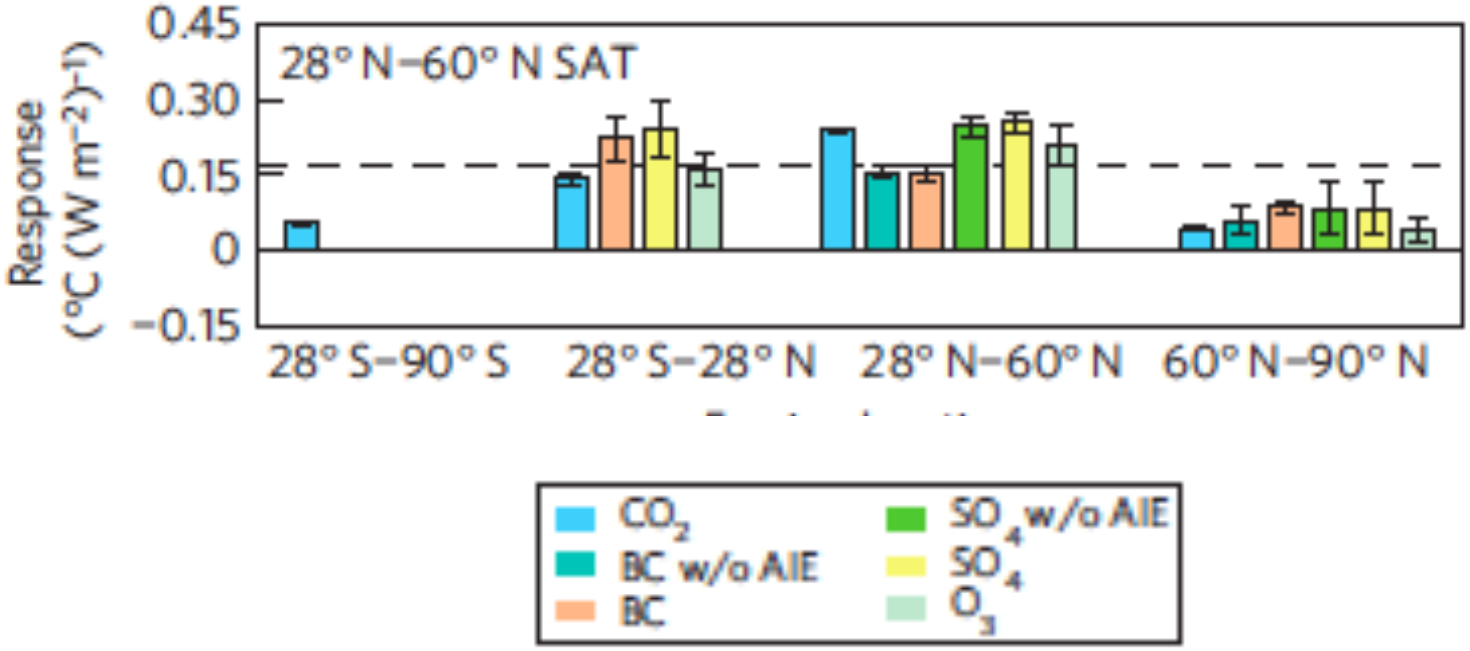


Wild et al., ACP, 2012

Impact of aerosols on precipitation trends



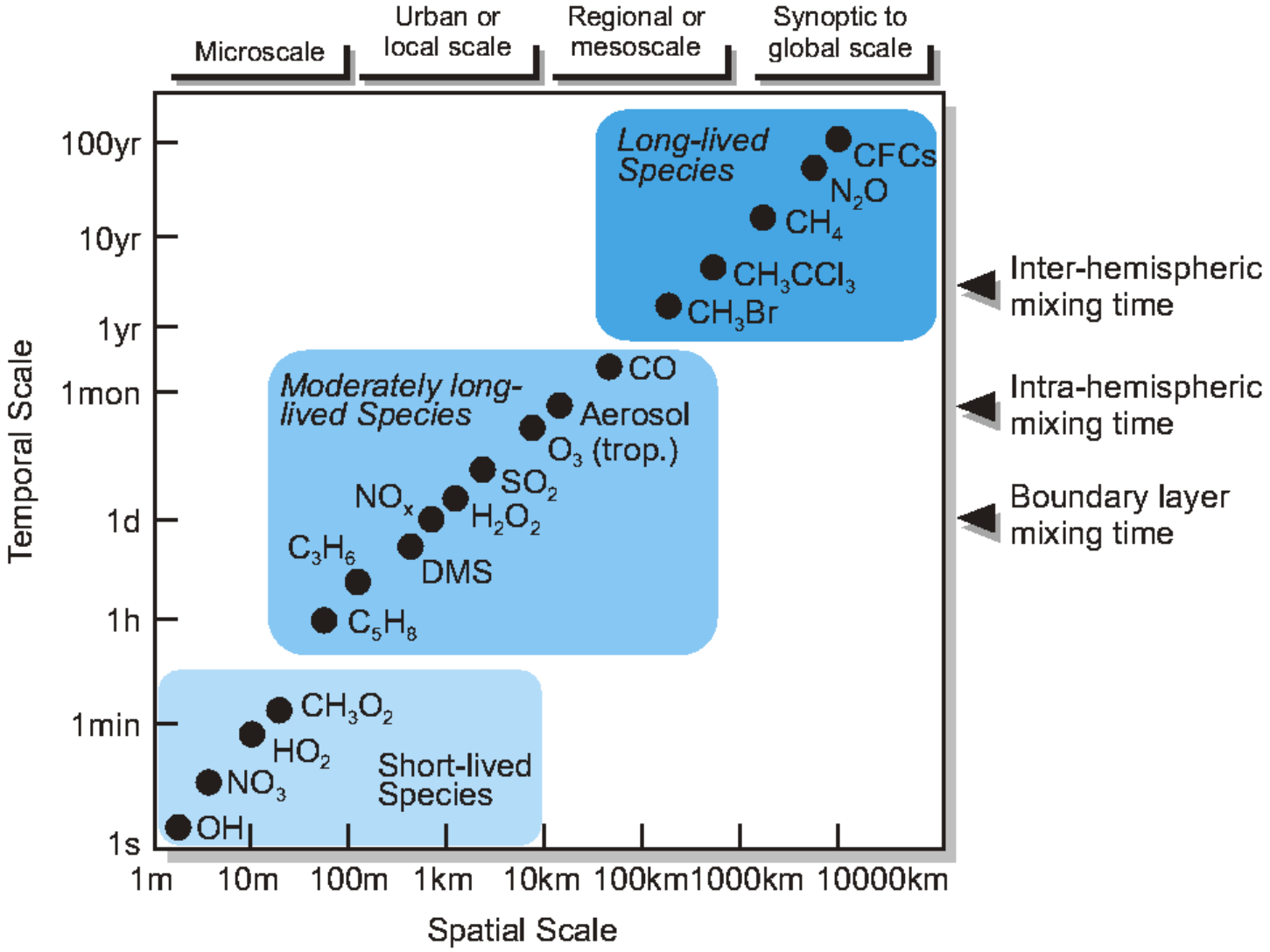
Forcing-response functions



Shindell and Faluvegi, 2009

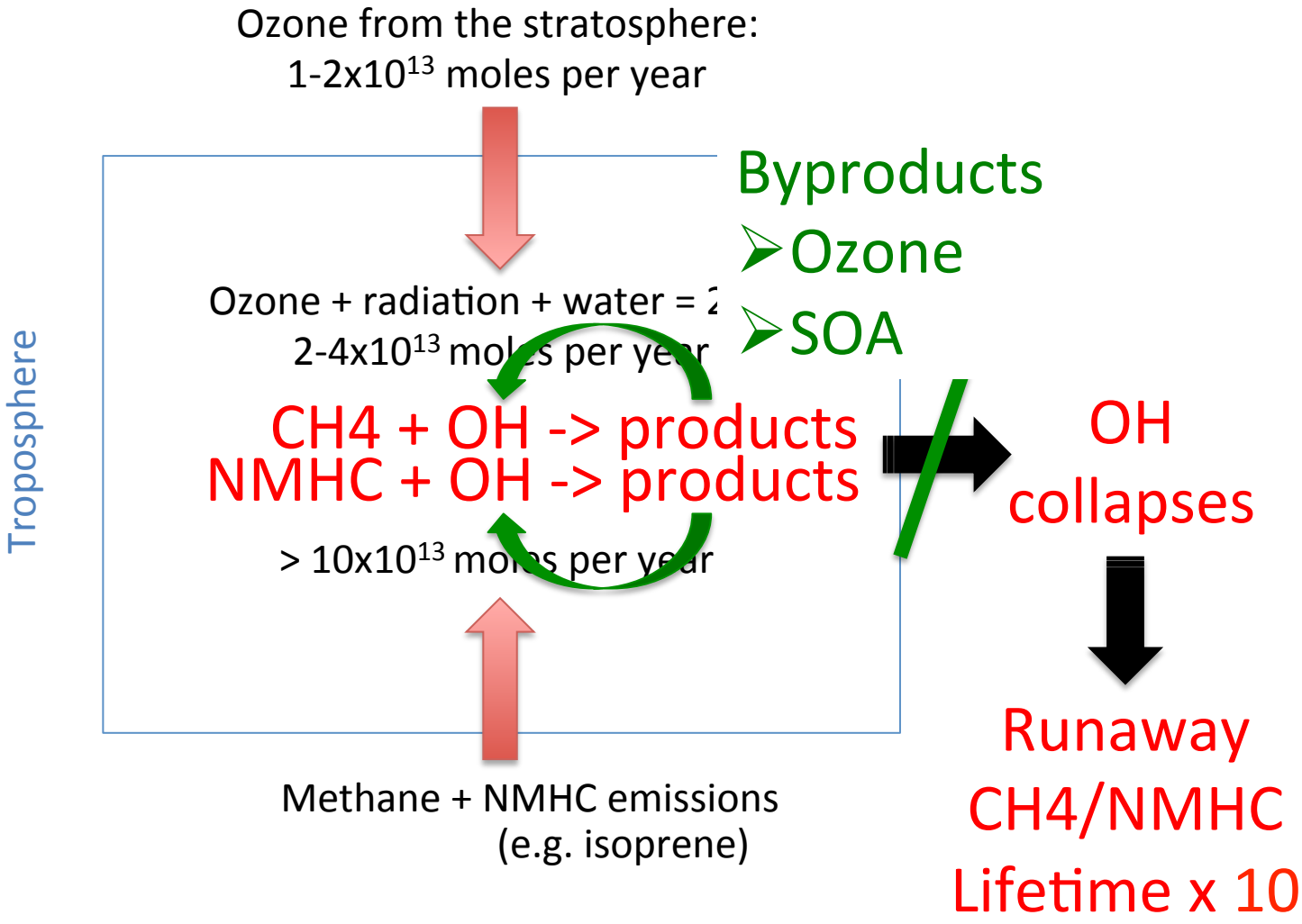
Thank you

Chemical lifetimes

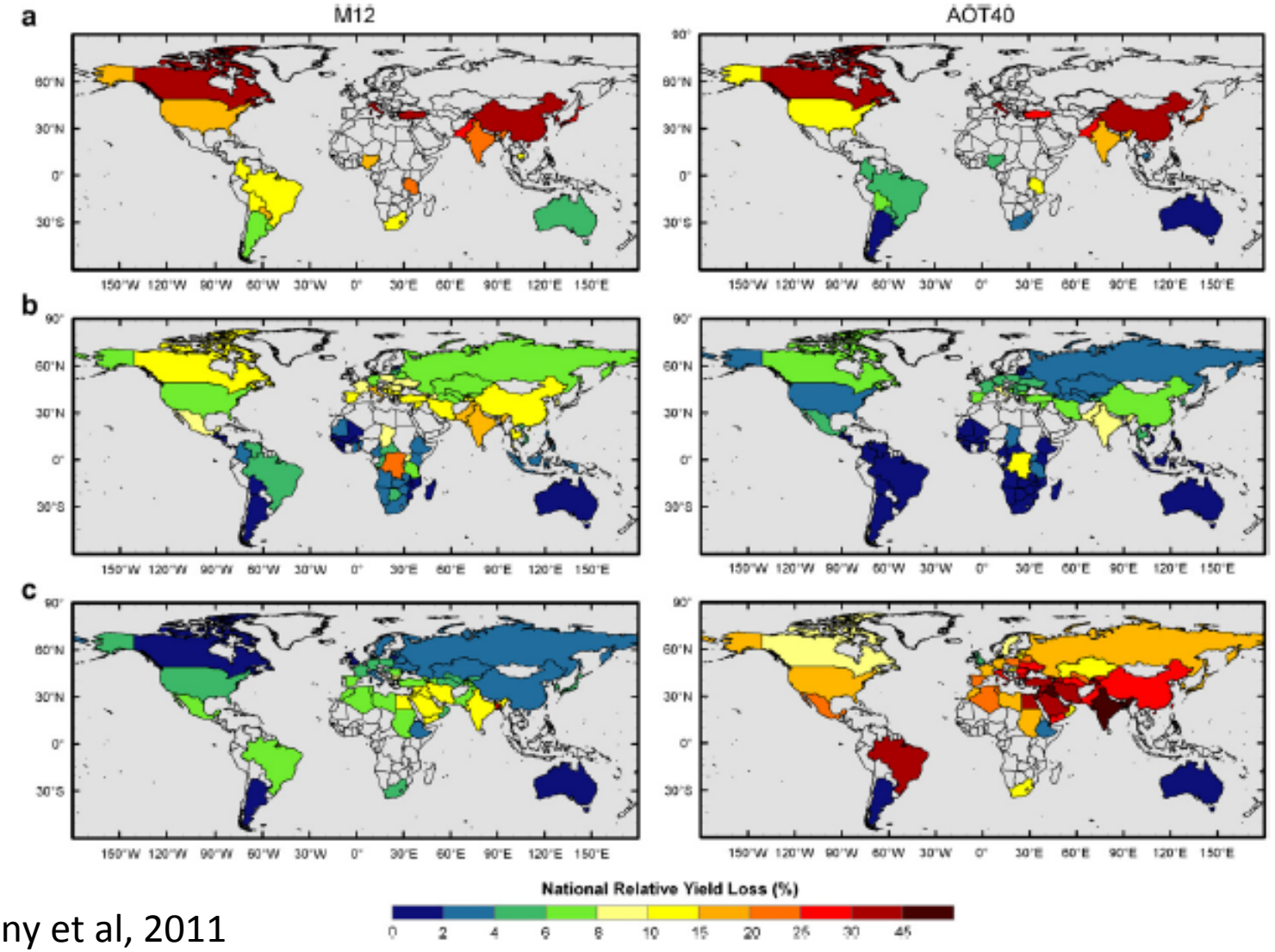


After Seinfeld and Pandis [1998]

Is the atmosphere chemically stable?



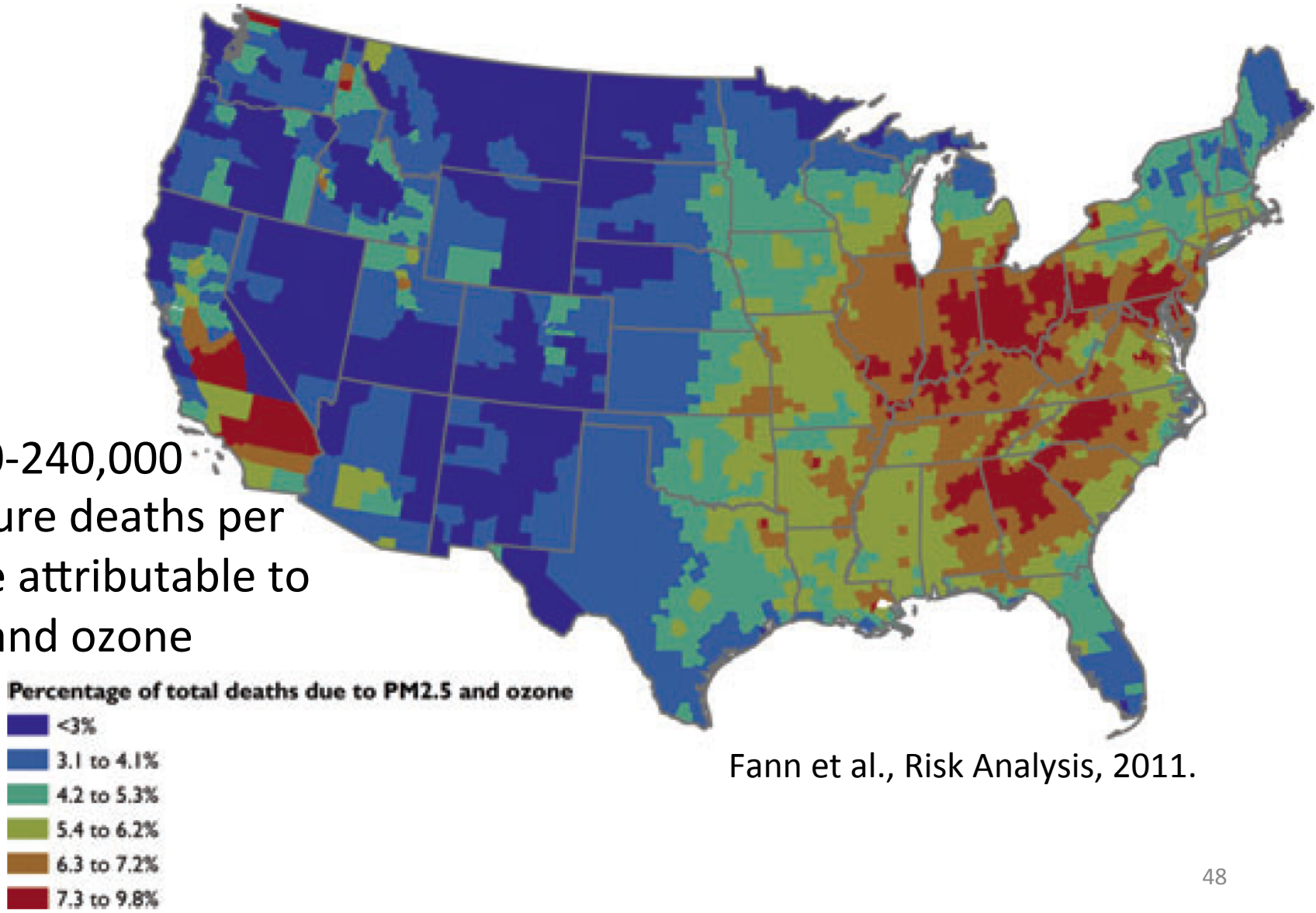
Ozone damage on crops: 2030 A2



Avneny et al, 2011

Not just climate: air quality and mortality

130,000-240,000 premature deaths per year are attributable to PM2.5 and ozone



Fann et al., Risk Analysis, 2011.