Chemistry-climate interactions in CCSM

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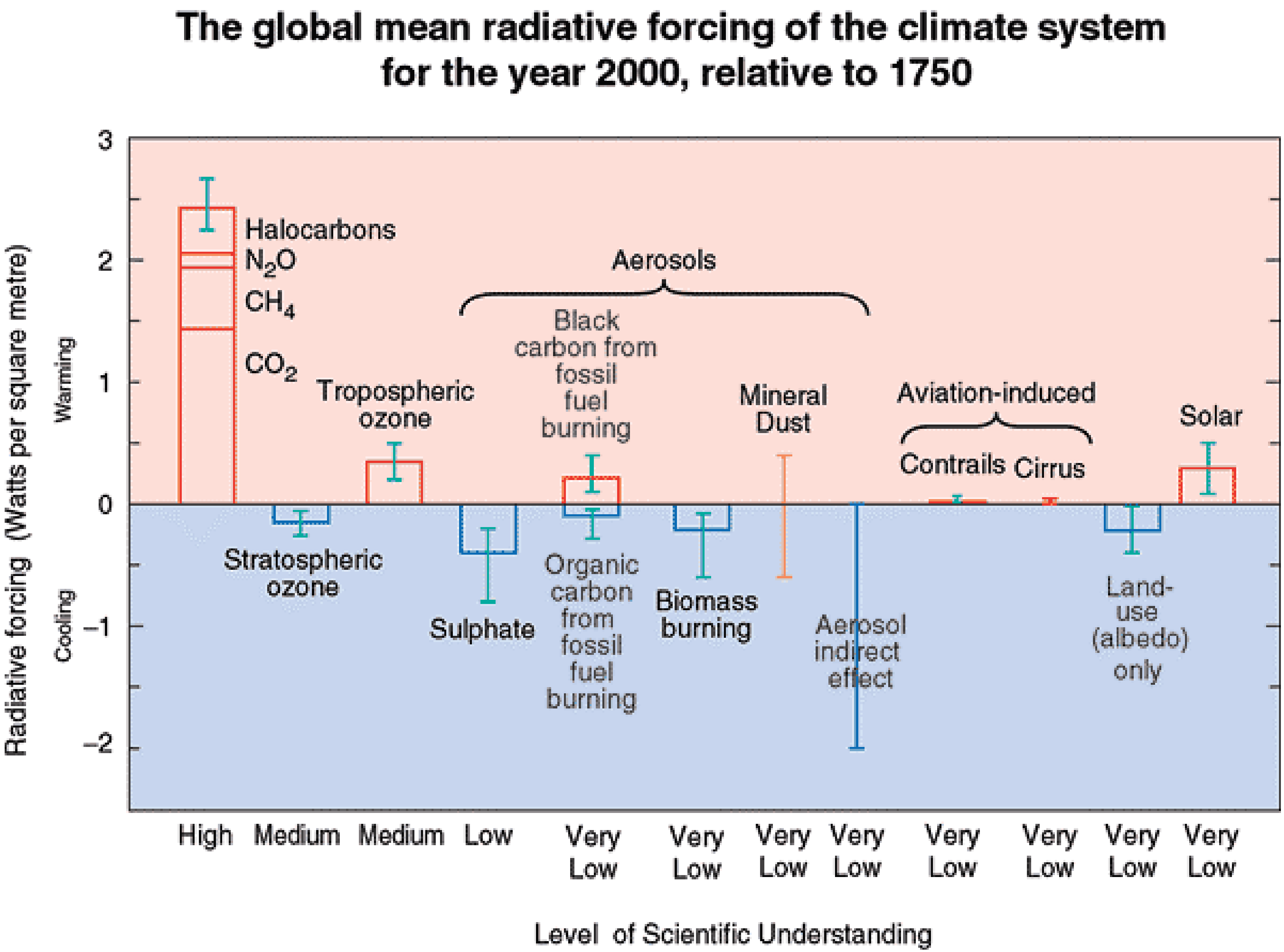
Overall scope

Identify and study interactions and feedbacks between atmospheric chemistry (gas phase/aerosols and biogeochemistry) and climate

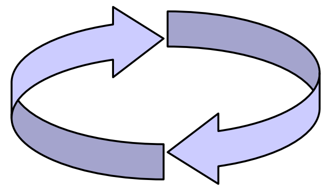


IPCC TAR (2001)

• Radiative forcing by ozone, methane, aerosols, etc.

• CCN dependence on aerosol formation

• Modification of cloud albedo

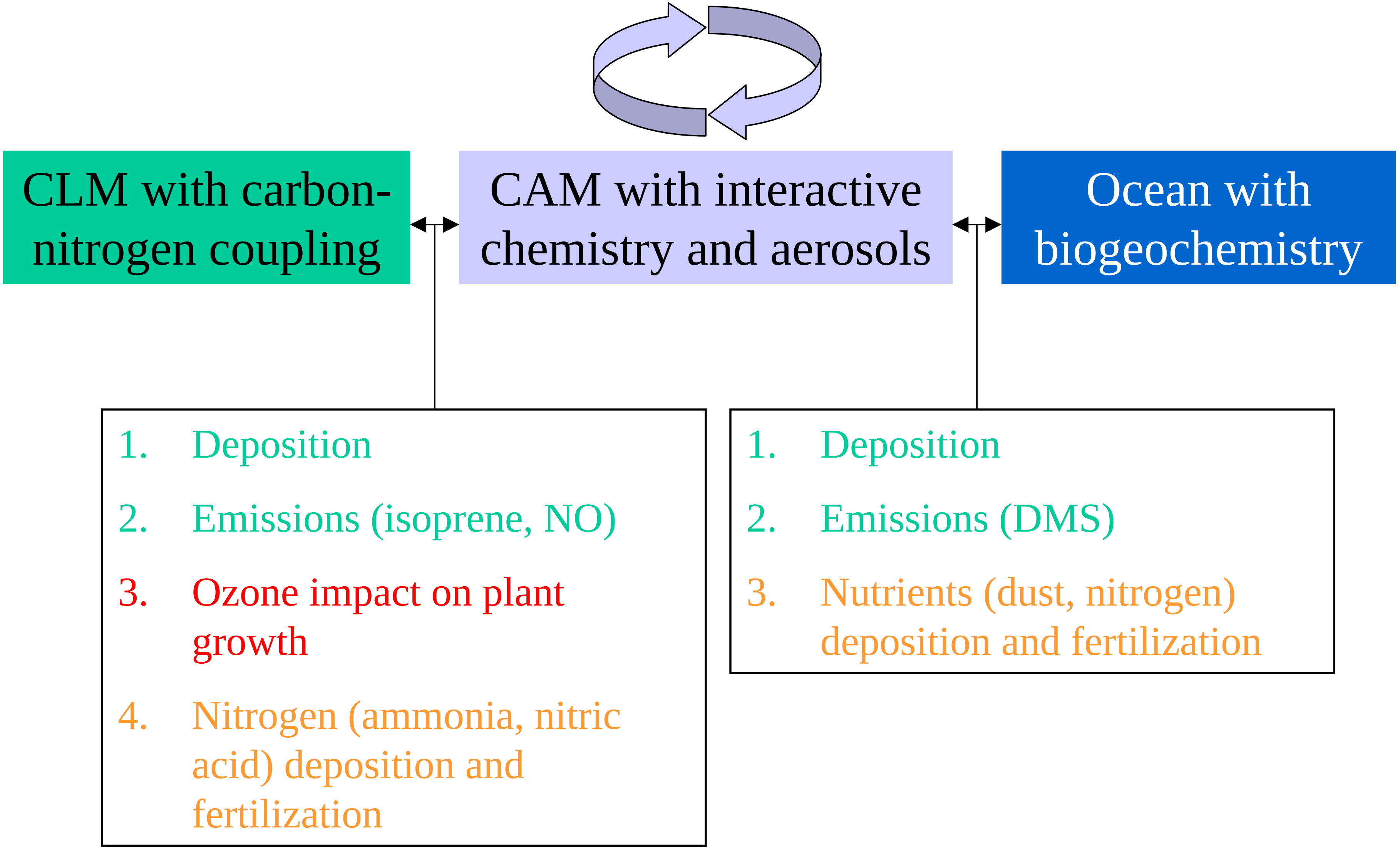


CLM with carbon-nitrogen coupling ⟷ CAM with interactive chemistry and aerosols ⟷ Ocean with biogeochemistry

1. Deposition
2. Emissions (isoprene, NO)
3. Ozone impact on plant growth
4. Nitrogen (ammonia, nitric acid) deposition and fertilization

1. Deposition
2. Emissions (DMS, NMHC)
3. Nutrients (dust, nitrogen) deposition and fertilization

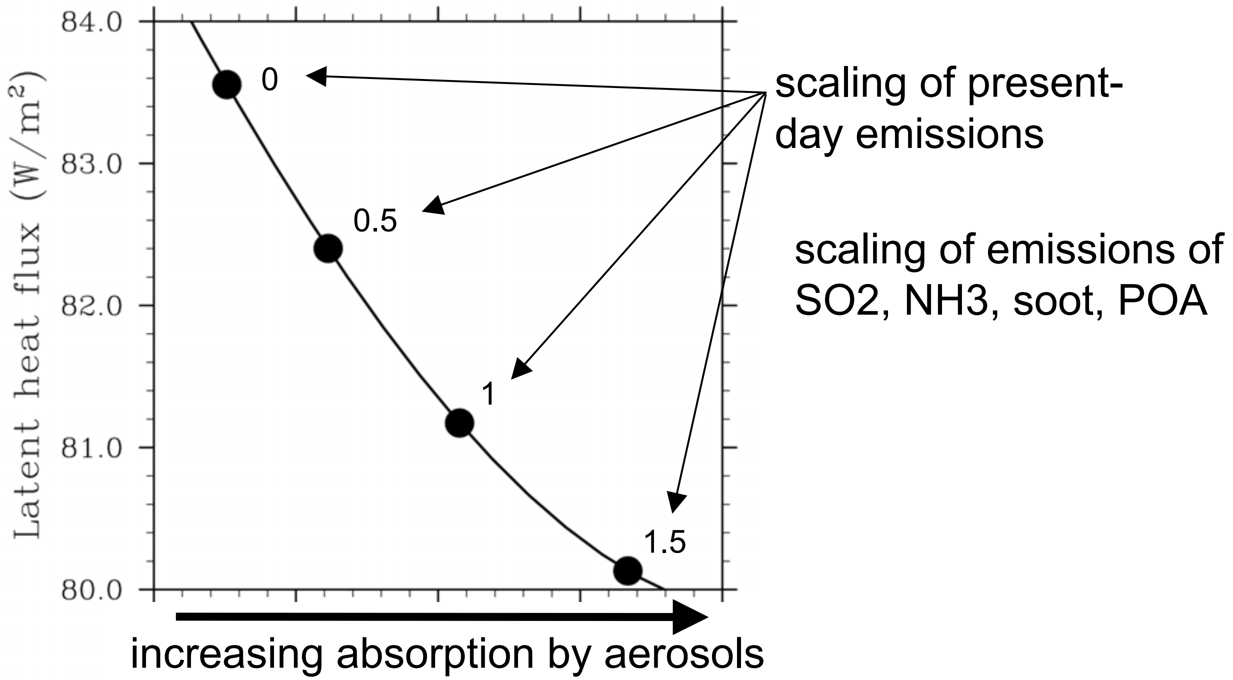
- Radiative forcing by ozone, methane and aerosols
- CCN dependence on aerosol formation
- Modification of cloud albedo



What is in CAM/Chem now?

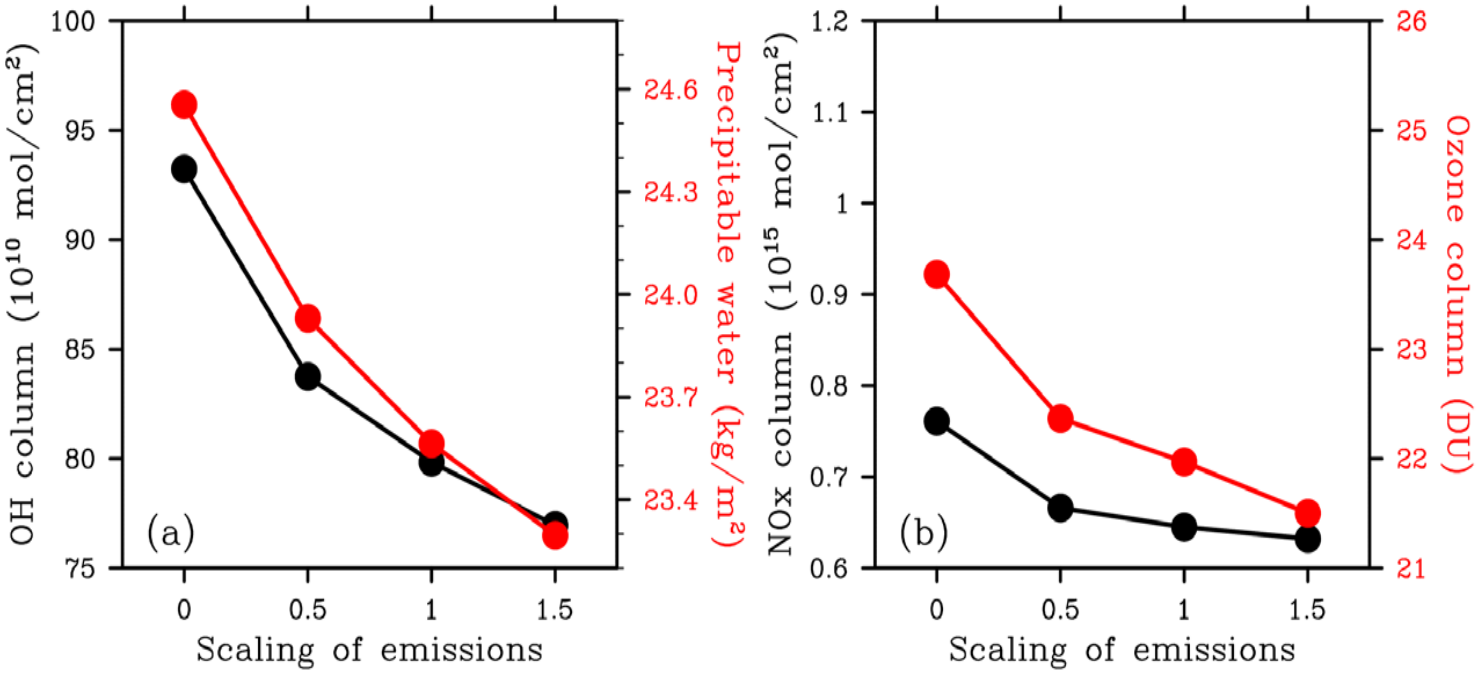
- Ozone chemistry (including hydrocarbons up to isoprene, toluene and terpenes)
- Bulk aerosols: soot, organic aerosols (primary and secondary), sulfate, ammonium nitrate, sea-salt and dust
- Coupling through radiative fluxes
- 3-4 times more expensive than CAM

Response of the chemistry-climate system to changes in aerosols emissions.



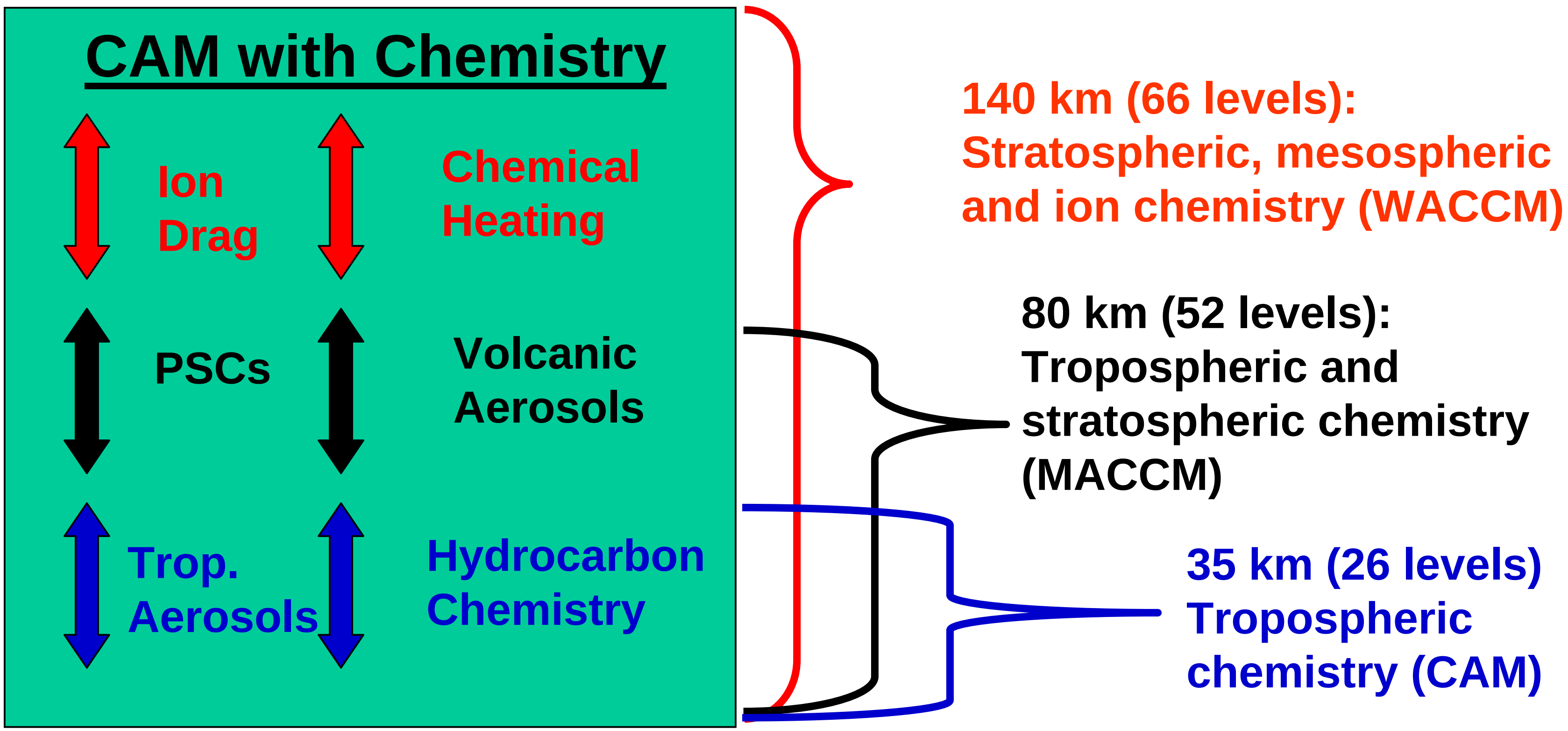
The hydrological cycle (measured by the global integral of the latent heat flux) slows down with increasing aerosol loading

Response of the chemistry-climate system to changes in aerosols emissions.



Without any changes to surface emissions of ozone precursors, the global integrals (surface to 300 hPa) of OH, ozone and NO_x show a large increase from decreasing aerosols. This is due to a combination of an increase in water vapor (shown here by the integrated precipitable water) and reduced chemical uptake on aerosols.

Unified Modeling Framework



WACCM, version 3

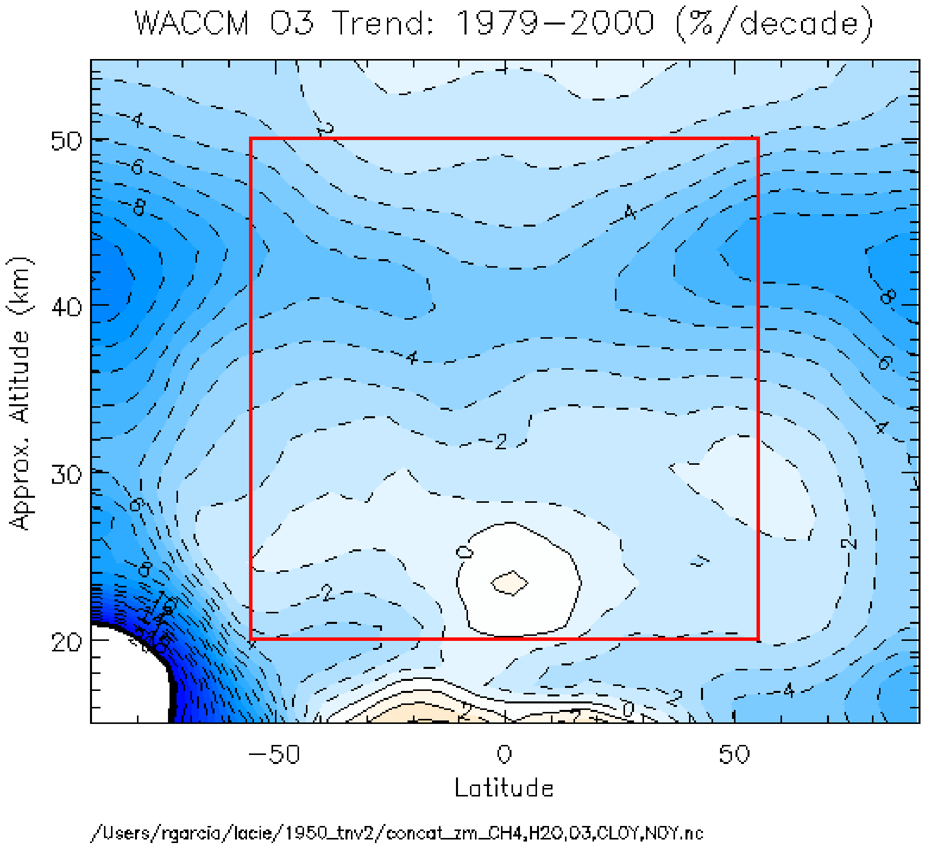
- Fully interactive chemistry, ground to 140 km

- Includes wavelength-resolved solar variability

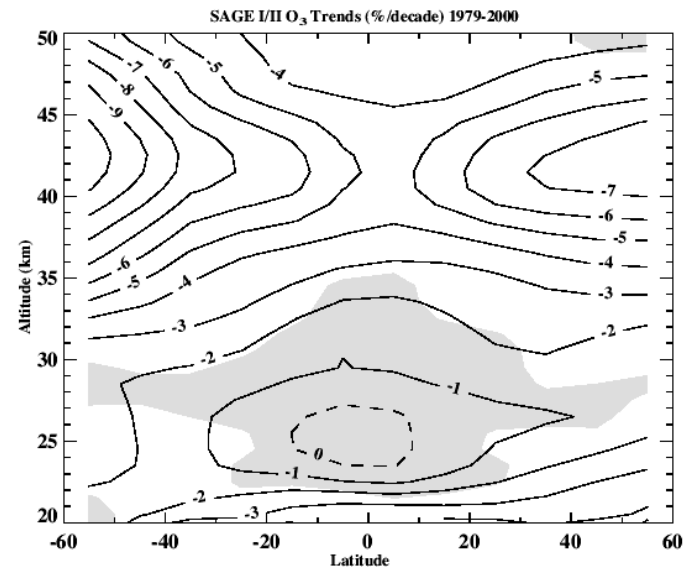
- Results shown next are for a “retrospective run”, 1950-2003, including solar variability, observed SST, observed trends in GHG and halogen species, and observed aerosol surface area densities (for heterogeneous chemistry)

- Note: Calculated trends are shown without correction for solar variability (which becomes large for $z \geq 50$ km)

Calculated and Observed Ozone Trends



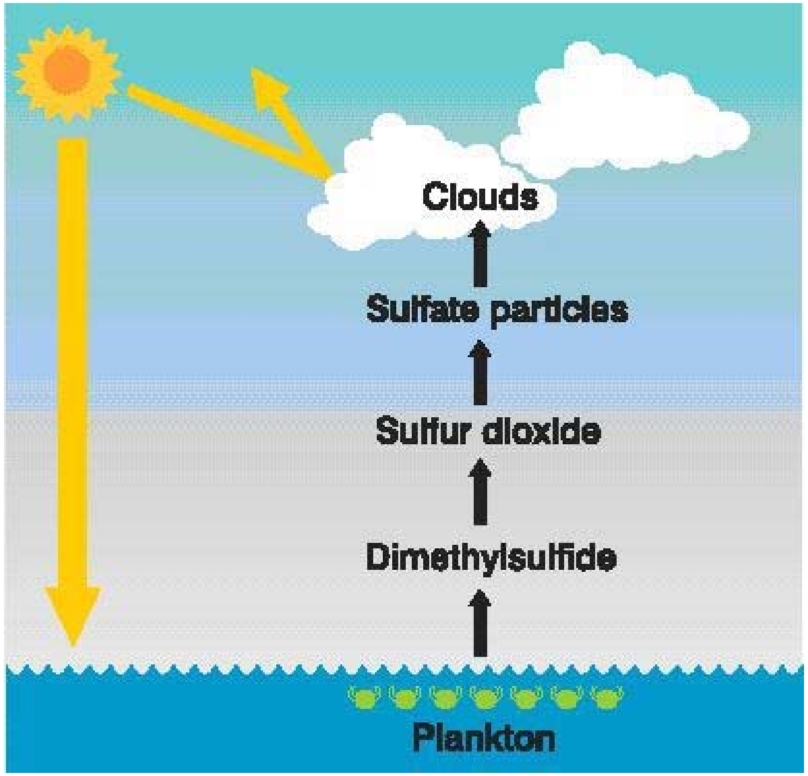
SAGE-I 1979-1981 and
SAGE-II 1984-2000



- Red inset on left covers approximately same region as observations on right
- Agreement is quite good, including region of apparent “self-healing” in lower tropical stratosphere

Future developments

- Coupled DMS fluxes in CCSM

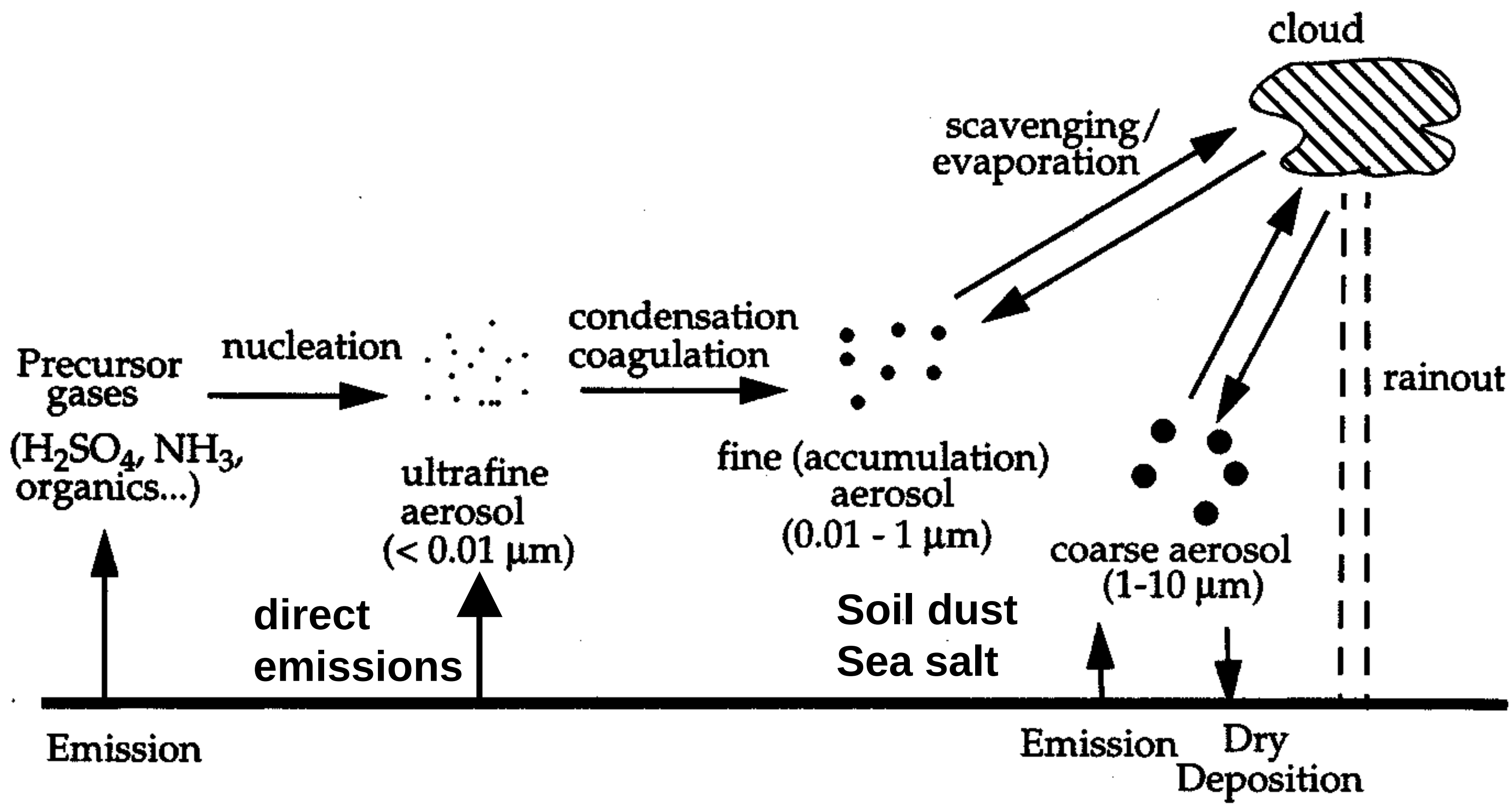


Future developments

- Coupled DMS fluxes in CCSM
- Indirect effect: will require a better description of aerosols (modes or size-resolved)

Physical transformation of aerosols

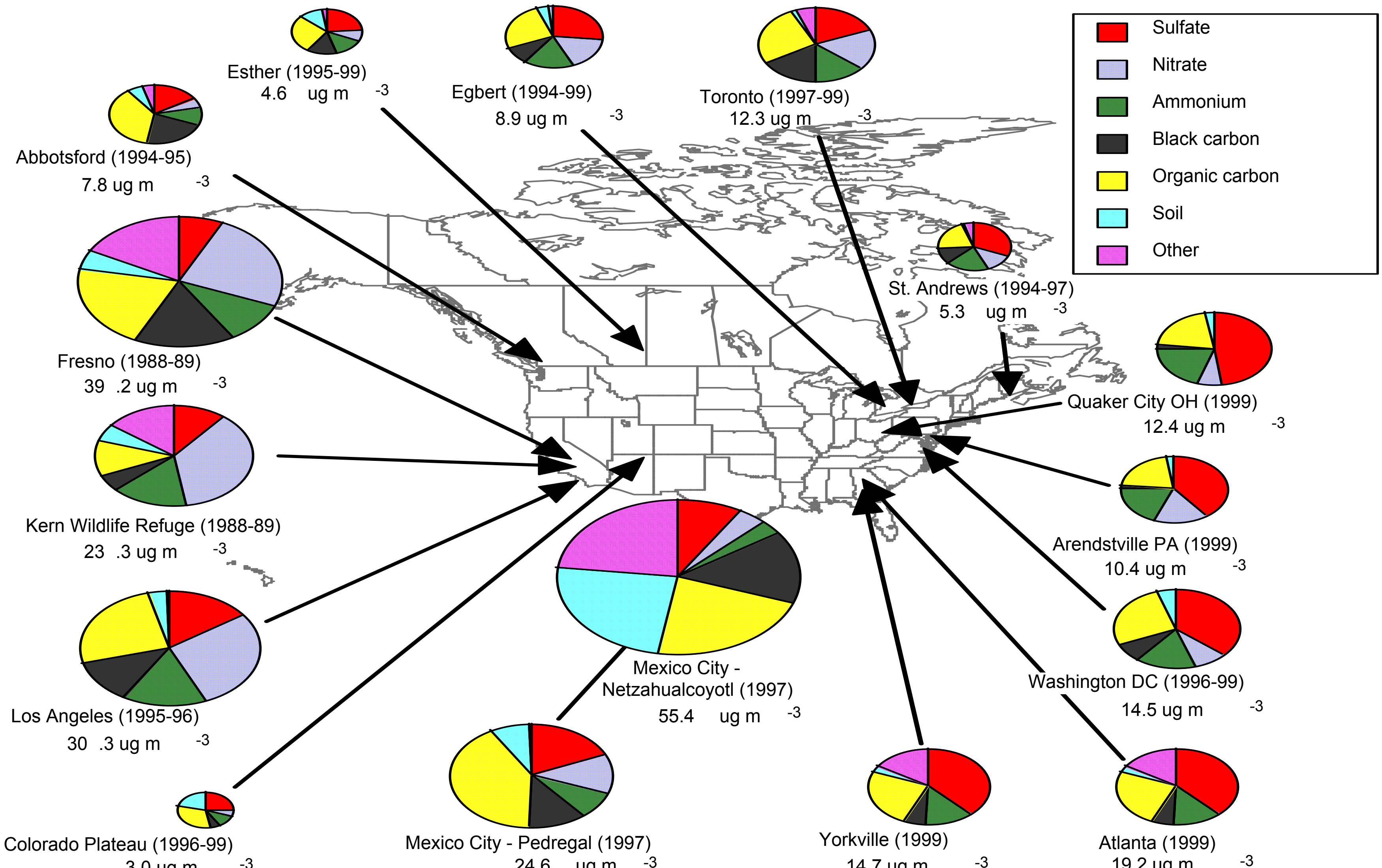
Size range: 0.001 μm (molecular cluster) to 100 μm (small raindrop)

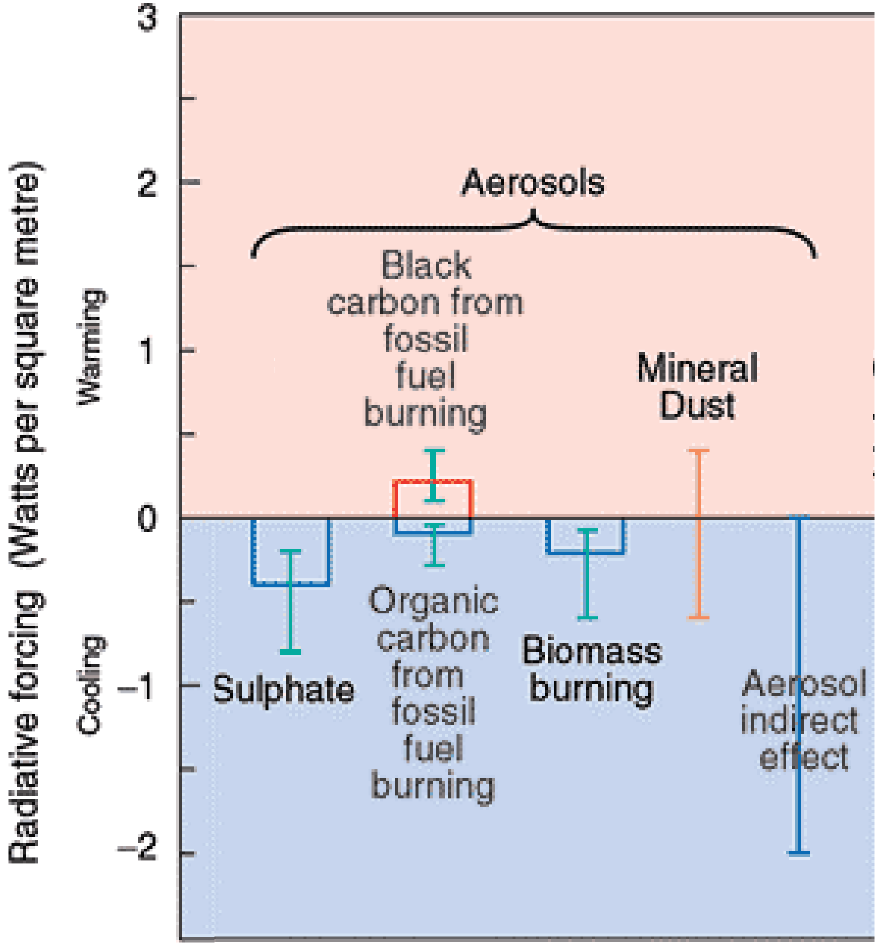


Environmental importance: health (respiration), visibility, radiative balance, cloud formation, heterogeneous reactions, delivery of nutrients…

From D. Jacob

COMPOSITION OF PM2.5
(NARSTO PM ASSESSMENT)





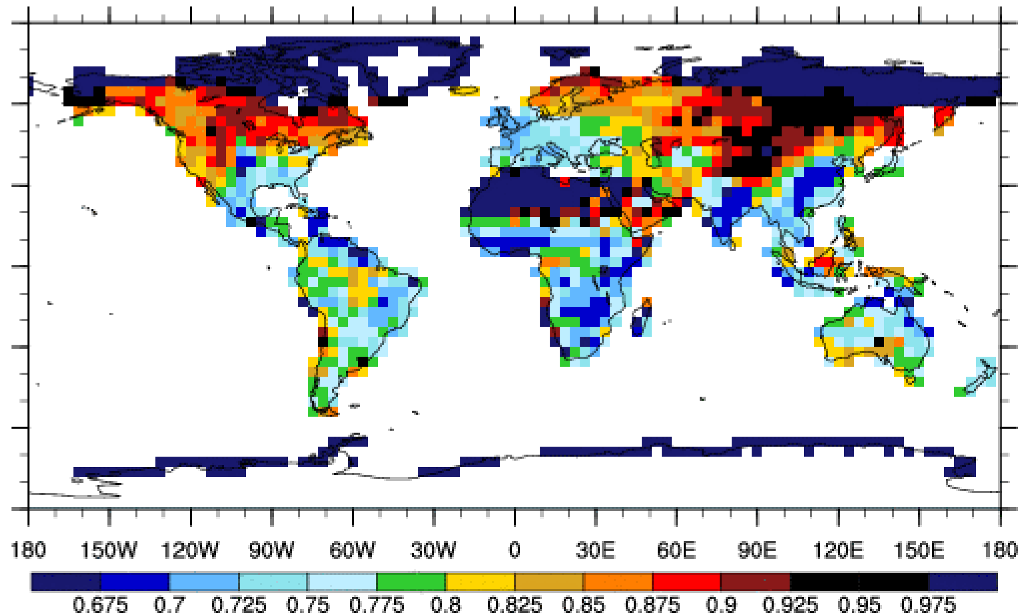
Radiative forcing (Watts per square metre)
Warming
Cooling
3
2
1
0
−1
−2
Aerosols
Black carbon from fossil fuel burning
Mineral Dust
Sulphate
Organic carbon from fossil fuel burning
Biomass burning
Aerosol indirect effect

Future developments

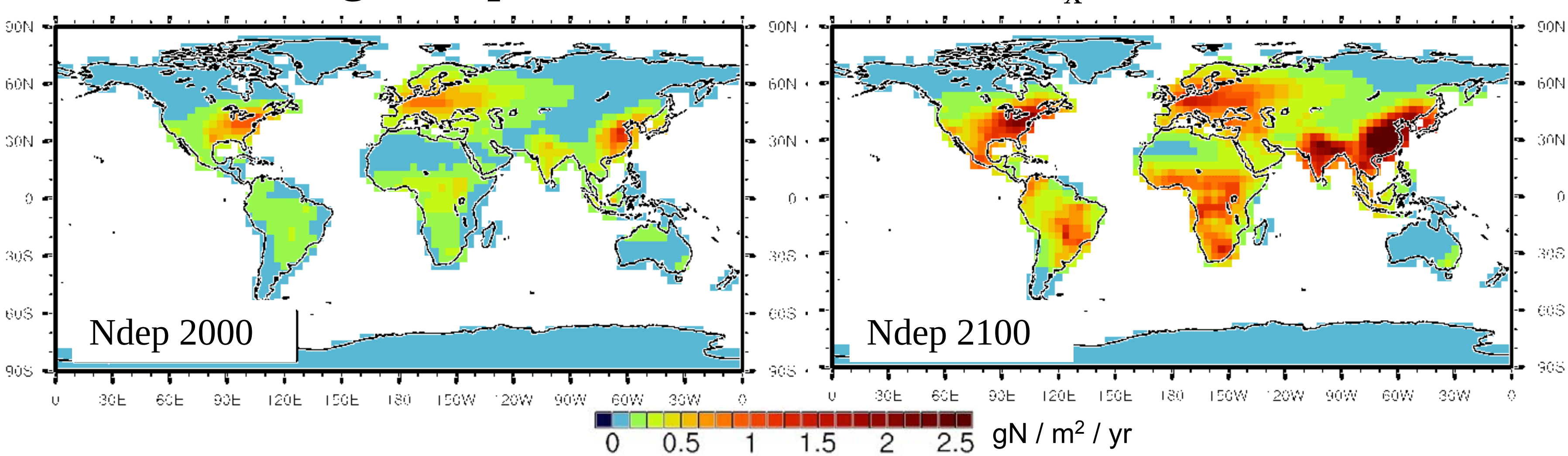
- Coupled DMS fluxes in CCSM
- Indirect effect: will require a better description of aerosols (modes or size-resolved)
- Nitrogen deposition impact on carbon cycle

N availability index (blue: N avail is low, red: N avail is high)

CCSM3-biogeochemistry coupled result

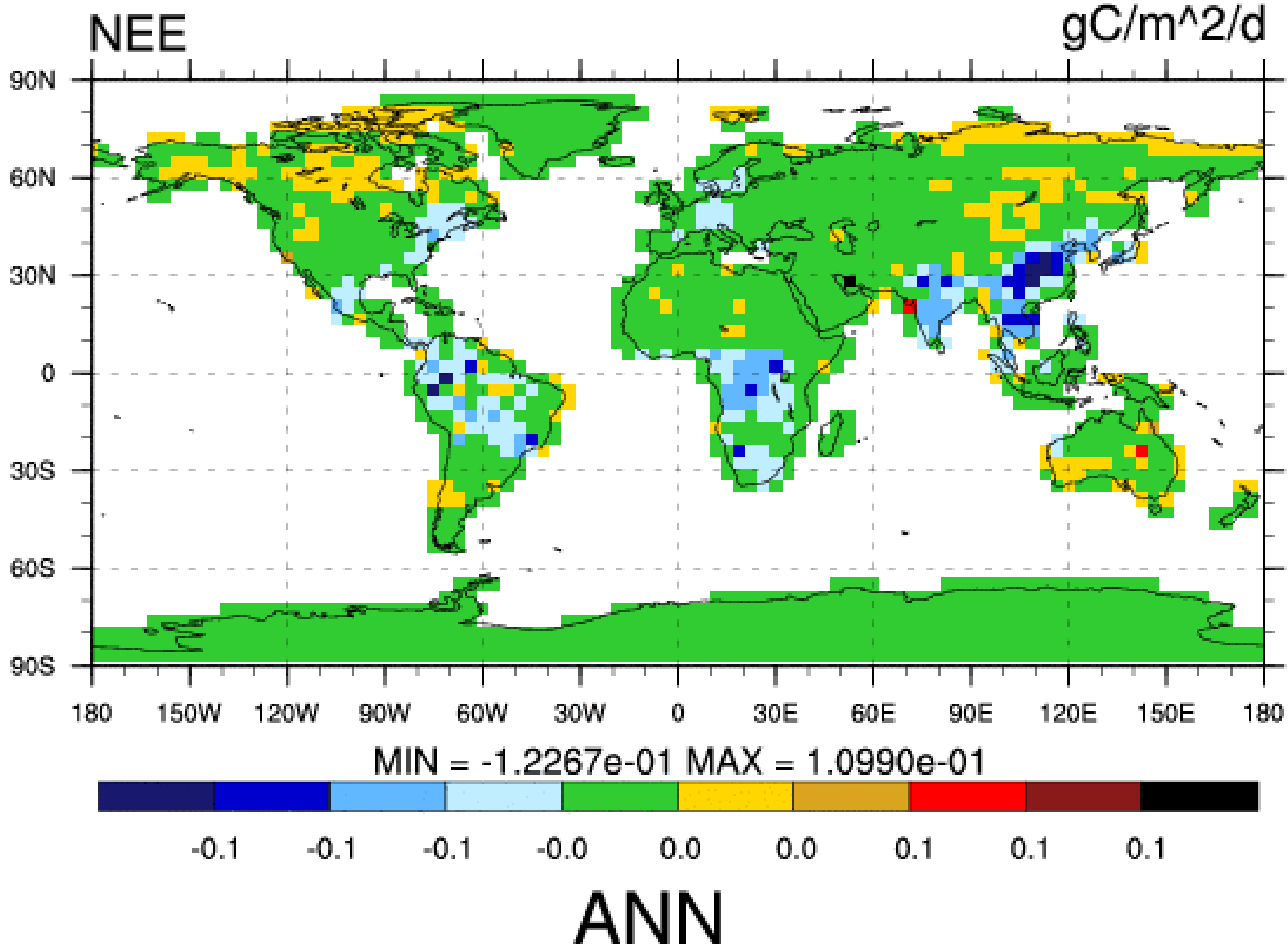


Nitrogen deposition on land from NO_x emissions

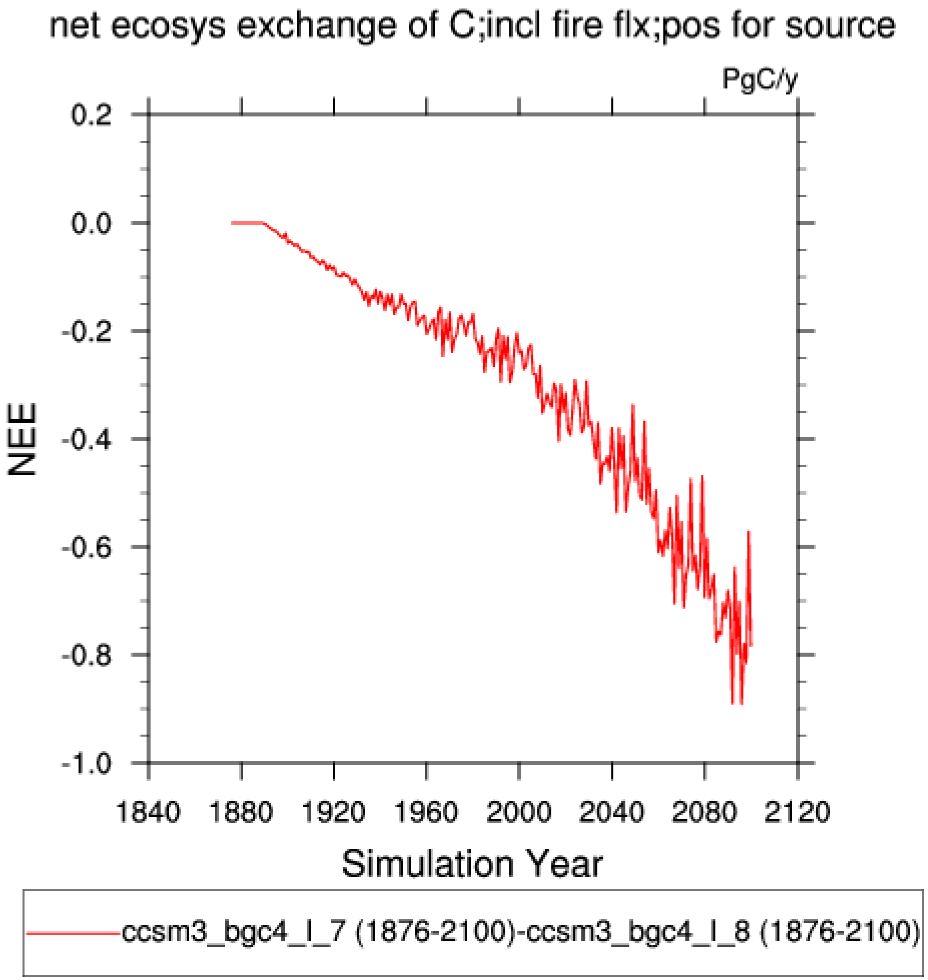


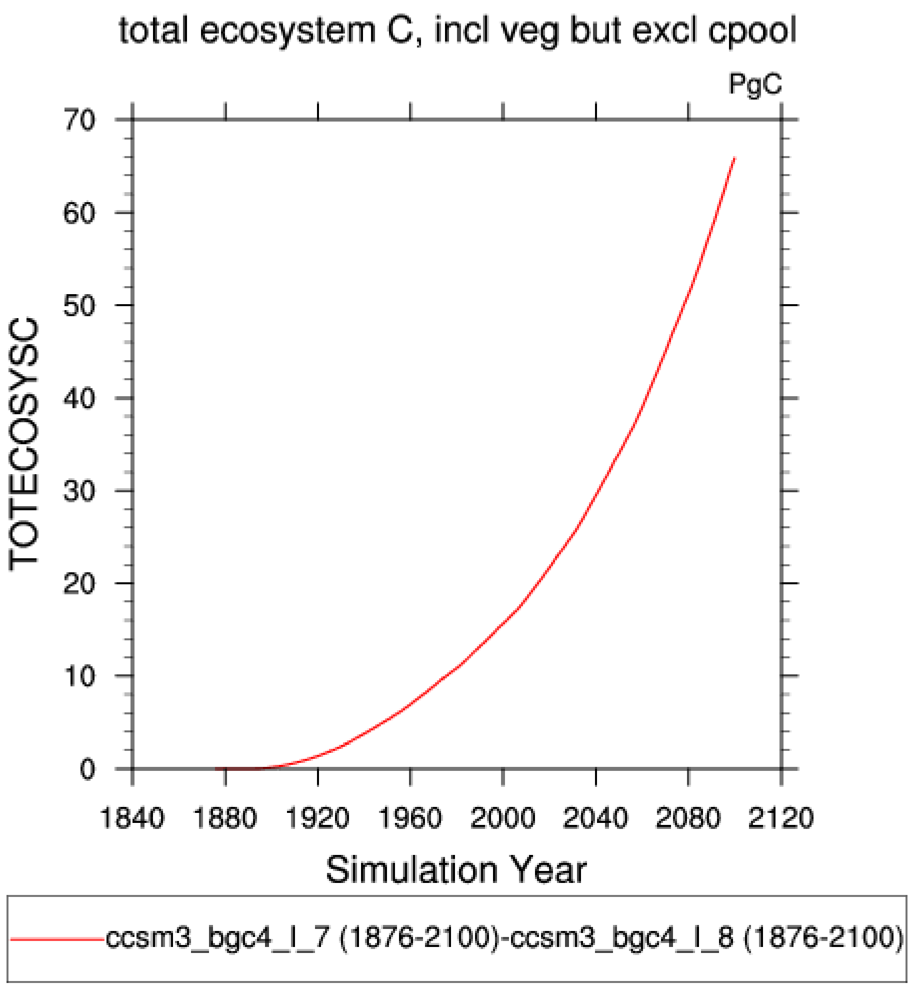
Experiment: Increasing N deposition

Net annual CO_2 flux at year 2100 (neg. is C sink)



impact of nitrogen deposition; NEE at present-day is approx 1.5 PgC/year




total ecosystem C, incl veg but excl cpool
PgC
TOTECOSYSC
70
60
50
40
30
20
10
0
1840
1880
1920
1960
2000
2040
2080
2120
Simulation Year
ccsm3_bgc4_l_7 (1876-2100)-ccsm3_bgc4_l_8 (1876-2100)

Future developments

- Coupled DMS fluxes in CCSM
- Indirect effect: will require a better description of aerosols (modes or size-resolved)
- Nitrogen deposition impact on carbon cycle
- Ability to perform transient CCSM simulations (1850-2100) using emissions by AR5