Current understanding and challenges in stratospheric aerosol modeling for SRM

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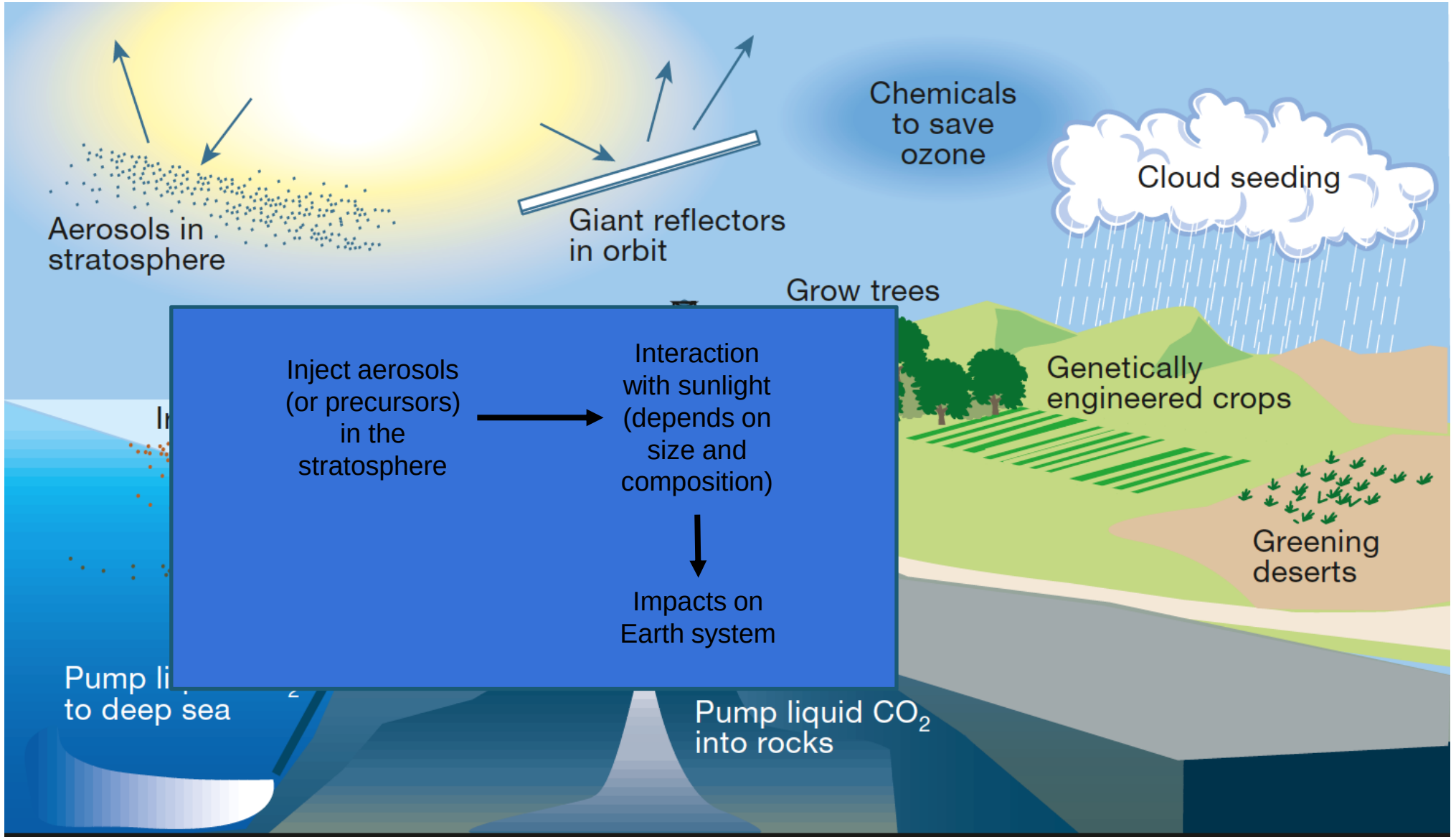
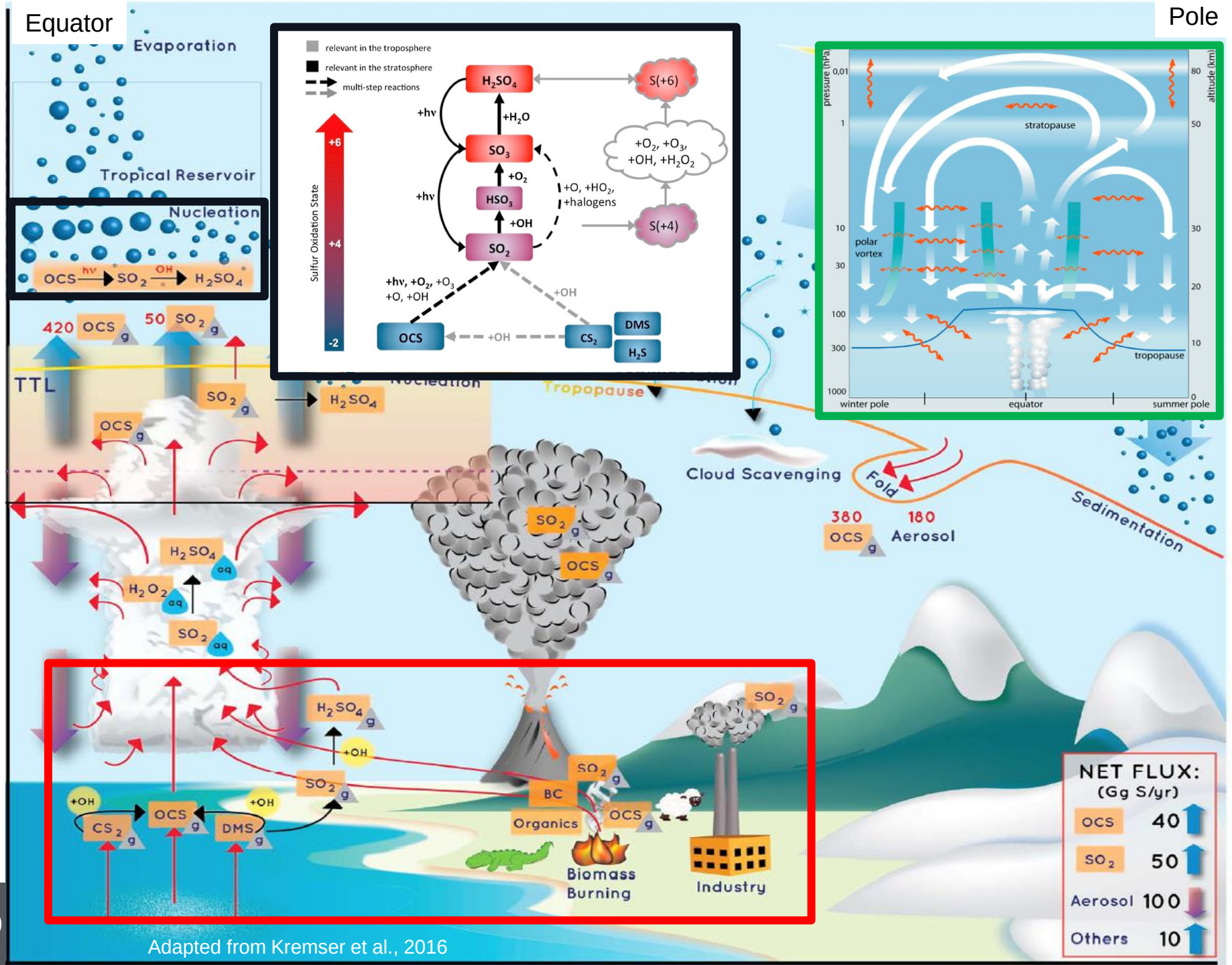


Schematic representation of various climate-engineering proposals (courtesy B. Matthews). Keith, 2001

Chemical transformation
(needs light and oxidants)

Life cycle of Stratospheric Aerosols

Emissions of DMS, OCS and SO_2



Adapted from Kremser et al., 2016

Pinatubo eruption June 1991

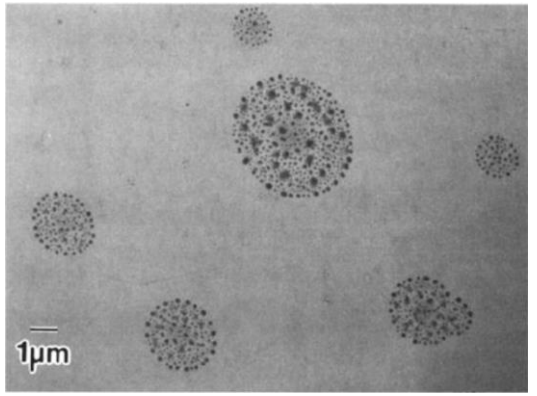
Pinatubo sunset in Australia

Pinatubo aerosols from Space station

August 30, 1984

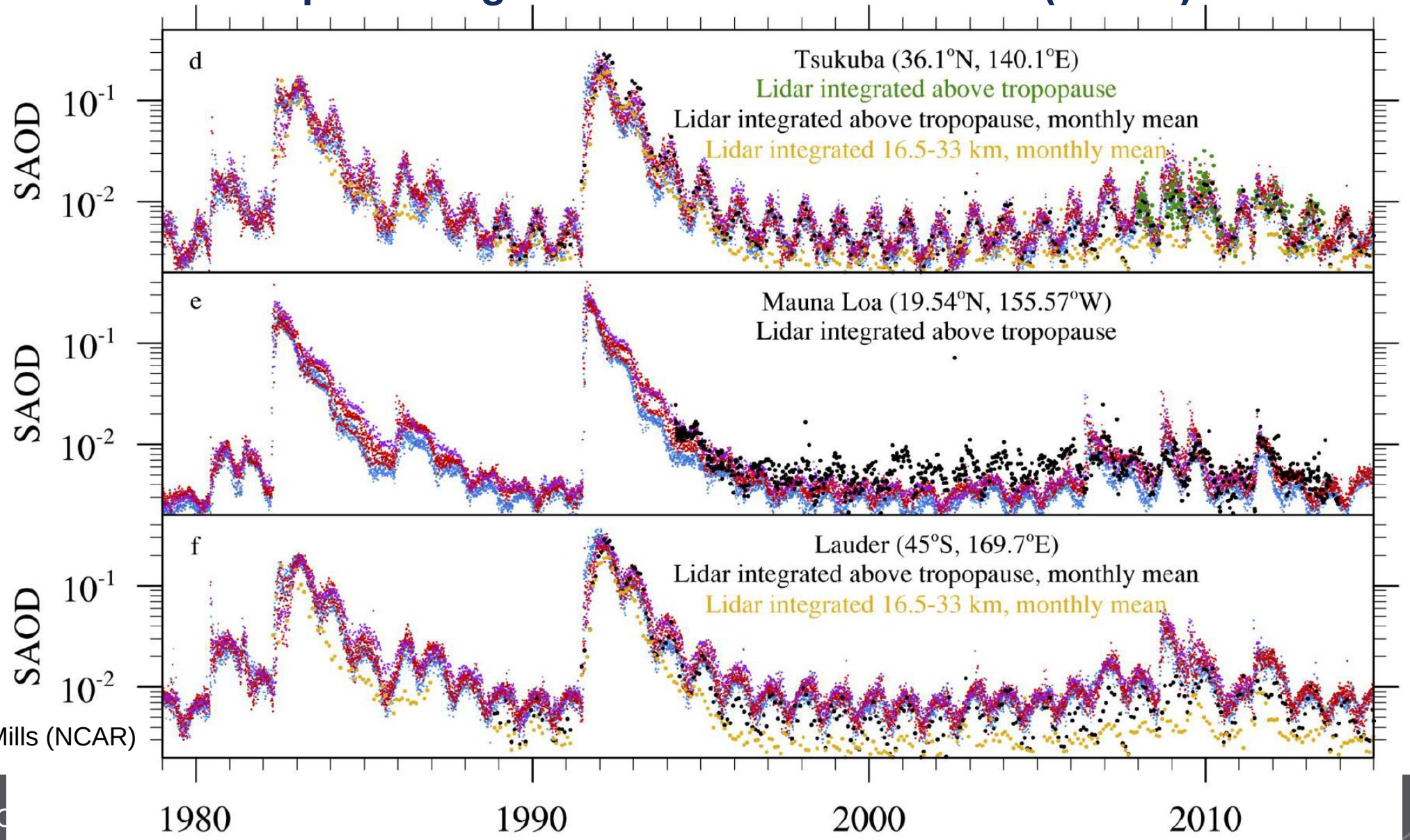
August 8, 1991

Electron microscope picture of stratospheric sulfate aerosol



Sheridan et al., 1994

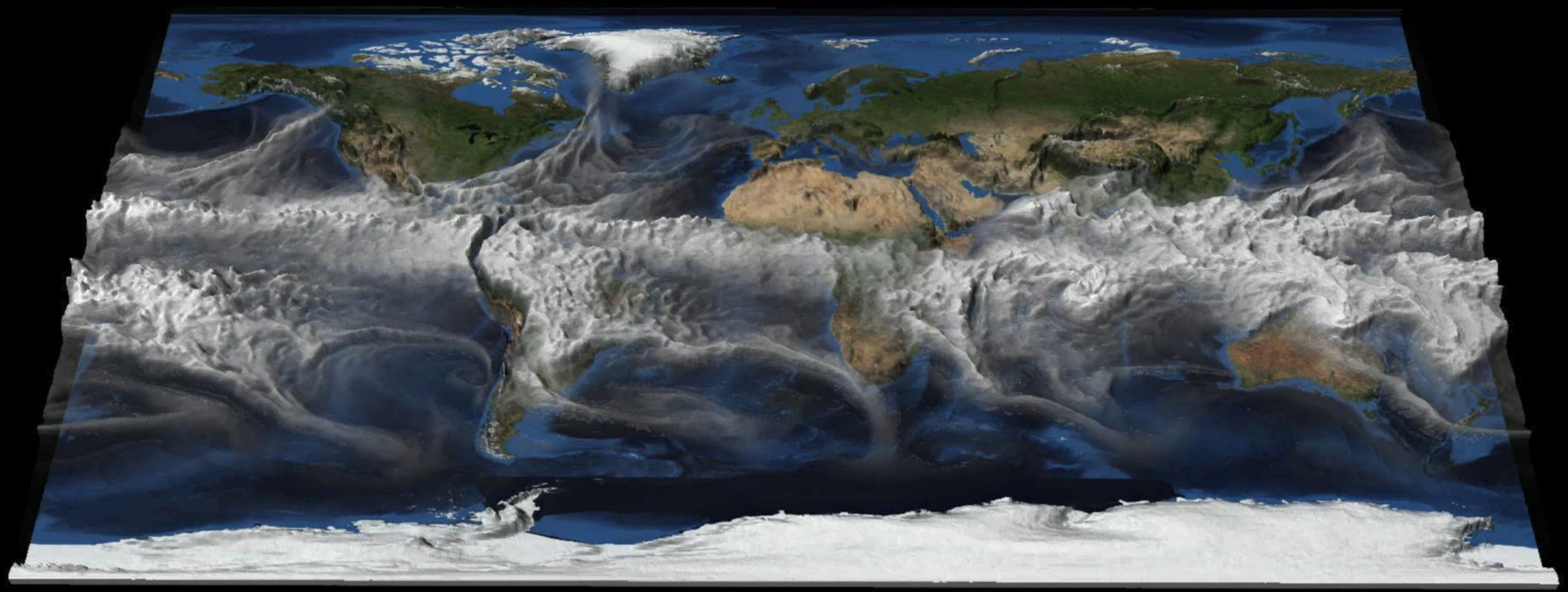
WACCM6 simulation of stratospheric aerosol optical depth compared to ground-based observations (LIDAR)



Slide from M. Mills (NCAR)

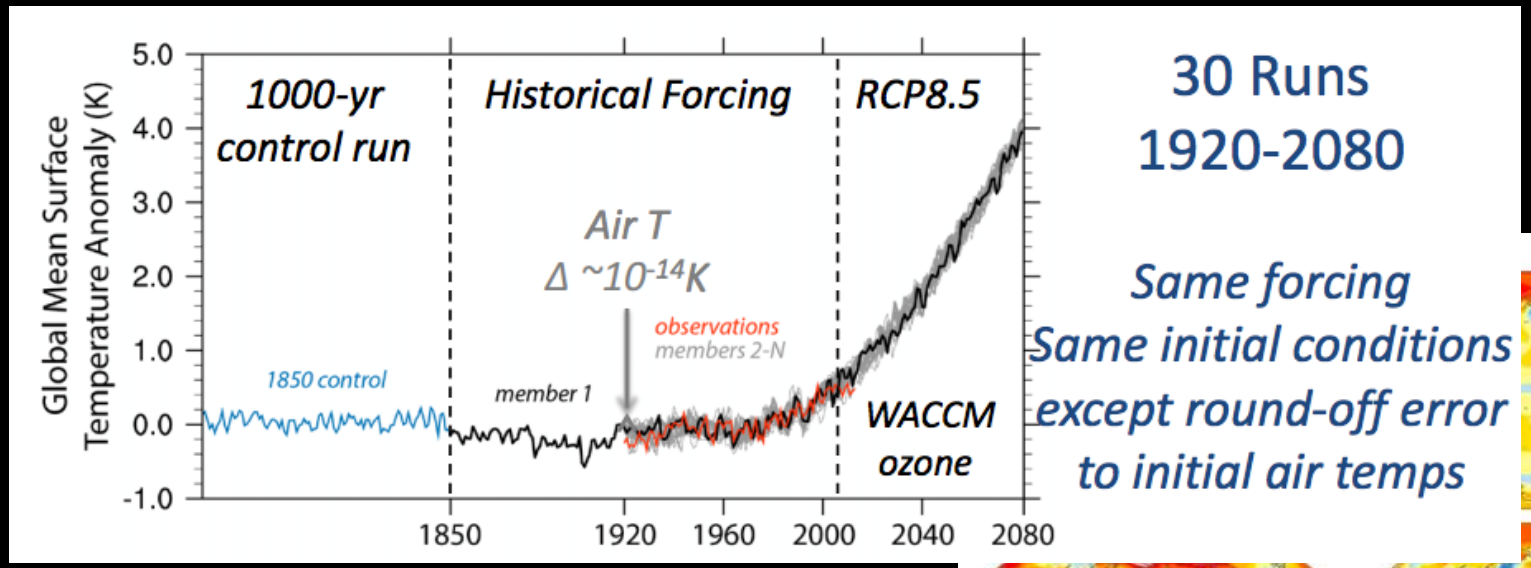
What is a global Earth System Model?

- Software (about 1.5M lines of code) based on fundamental laws of physics and chemistry
- Discretizes the globe in blocks of 25-200 km (grid)
- Requires parameterizations for all sub-grid scale processes and all processes that cannot be directly related to fundamental laws (like biology)
- Computes the state of the atmosphere (and ocean/land/ice) every 30 minutes, from the surface to 40-150km (2M grid points)



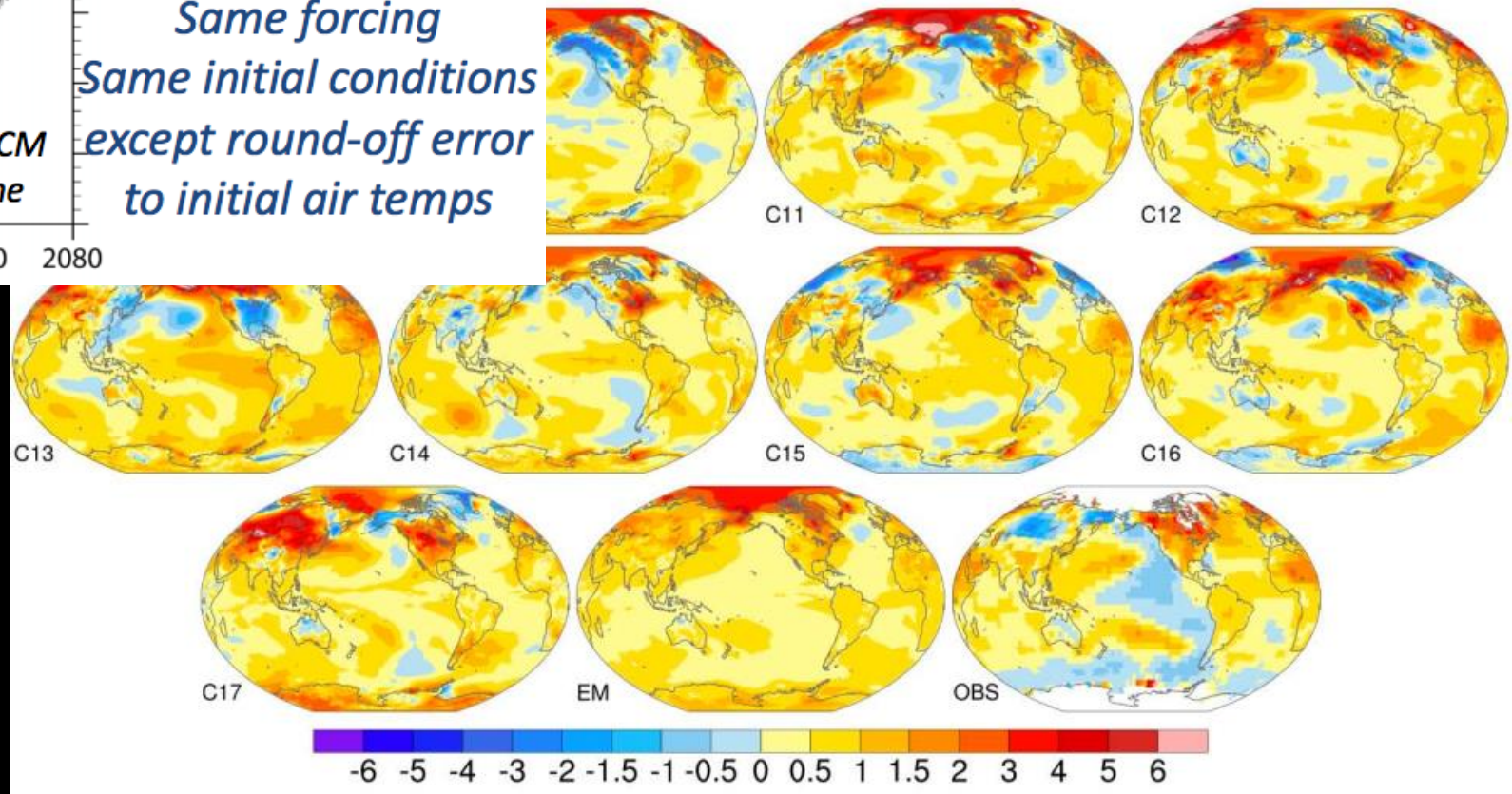
Movie courtesy of J. Small and T. Scheitlin

Internal variability and initial-condition ensemble



30 Runs
1920-2080

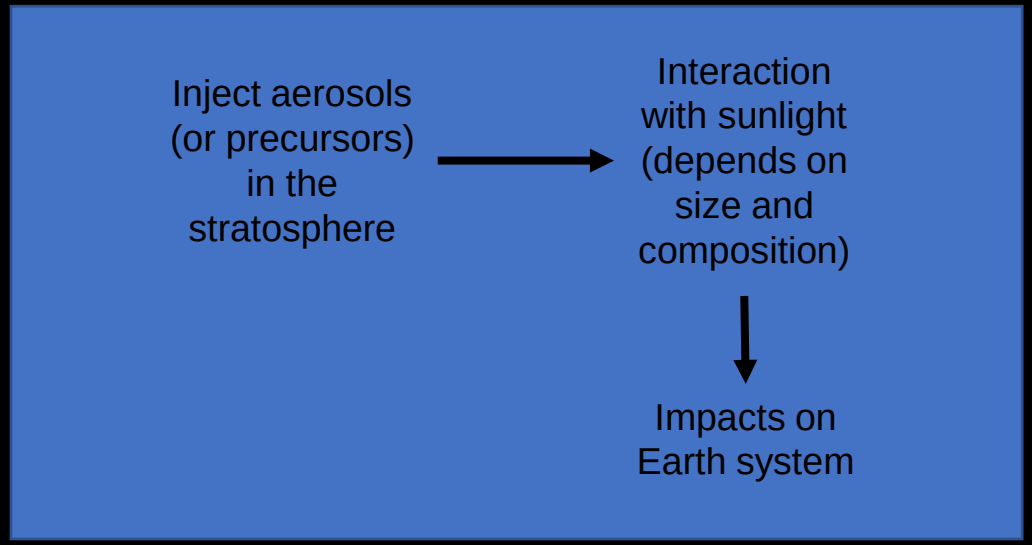
Same forcing
Same initial conditions
except round-off error
to initial air temps



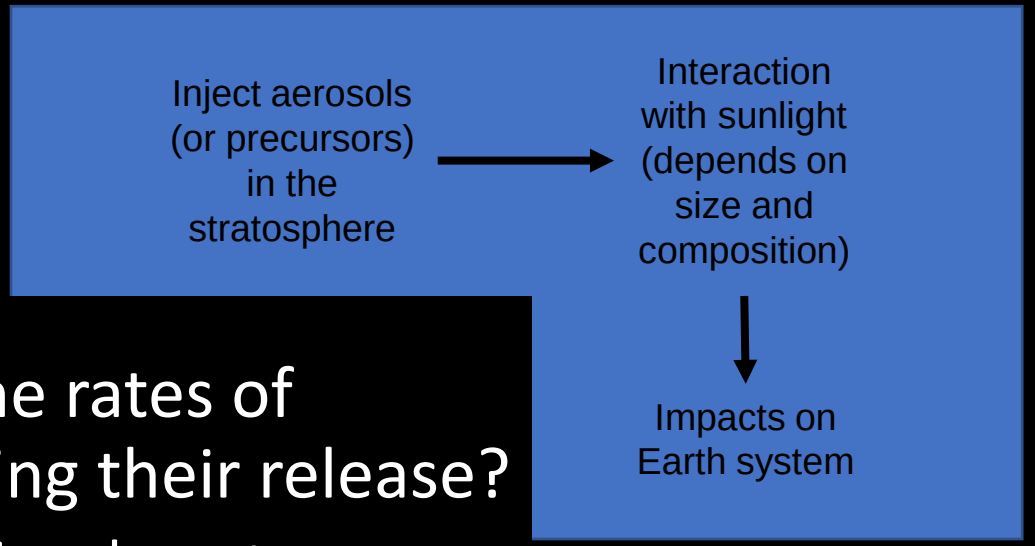
Panels show 1979-2012 DJF surface temperature trends for 9 ensemble members, the ensemble mean, and observations.

Slides from C. Deser (NCAR)

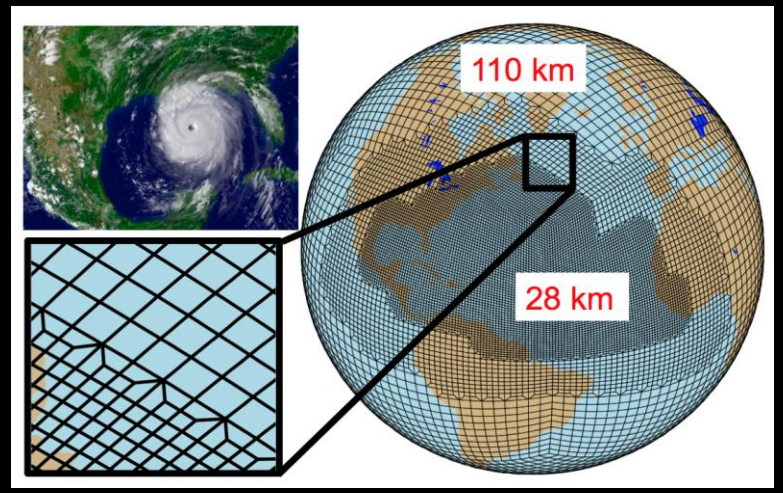
Major challenges



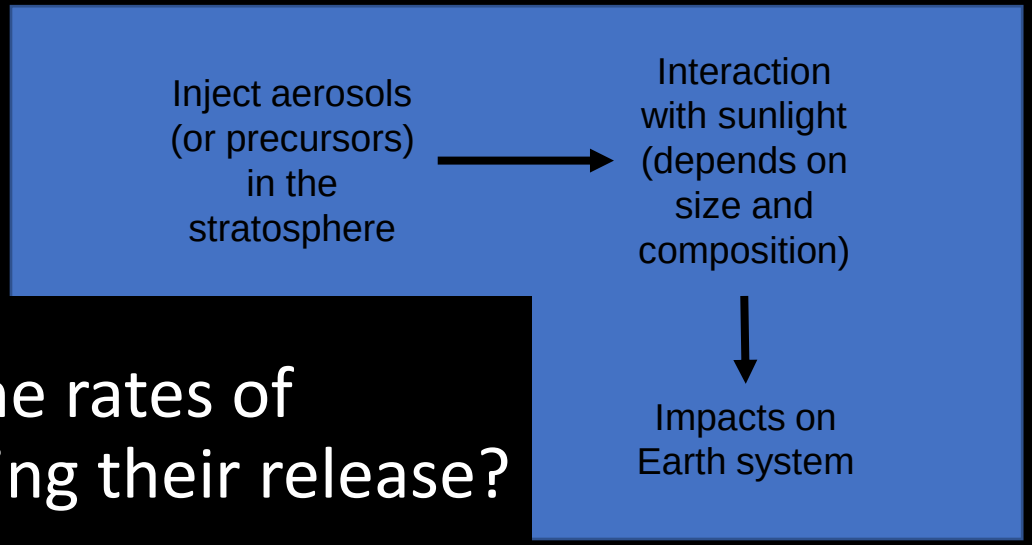
Major challenges



- Model resolution -> how dependent are the rates of formation and dispersal of aerosols following their release?
  - ➢ Need observations of degree of nonlinearity in relevant process
  - ➢ Plume-in-grid model
  - ➢ Regional refinement

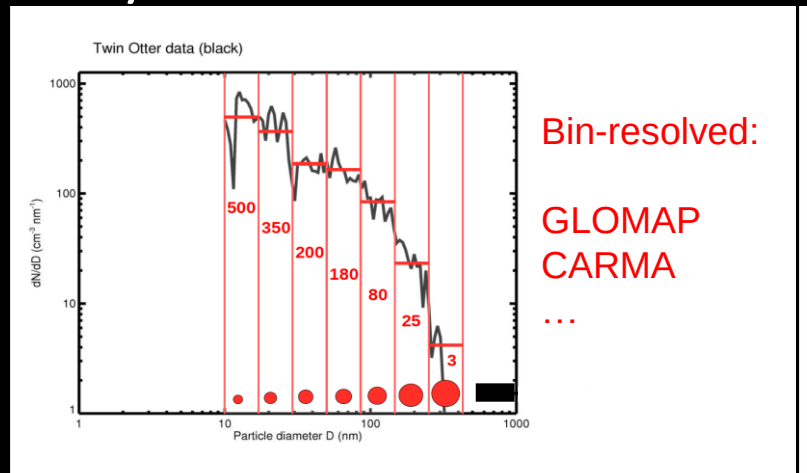


Major challenges



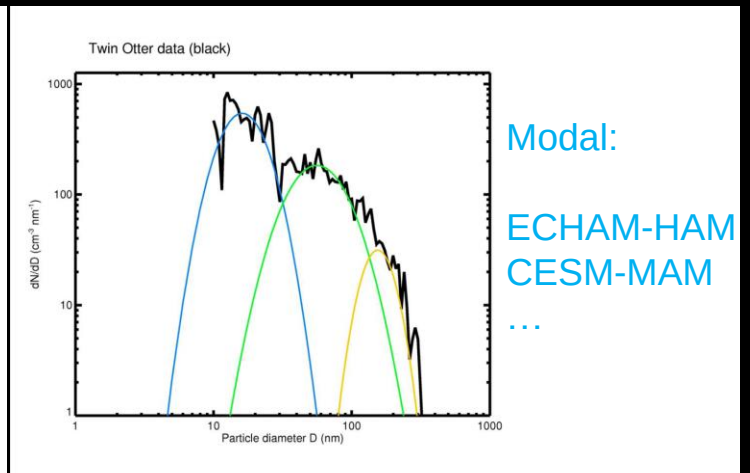
- Model resolution -> how dependent are the rates of formation and dispersal of aerosols following their release?
- Size distribution and composition of the stratospheric aerosols after injection
  - ➢ Need observations of the size distribution and composition <u>before</u> injection (climatology and variability)
  - ➢ Sensitivity of model results to discretization method

Illustration from J. Kazil (NOAA)



Bin-resolved:

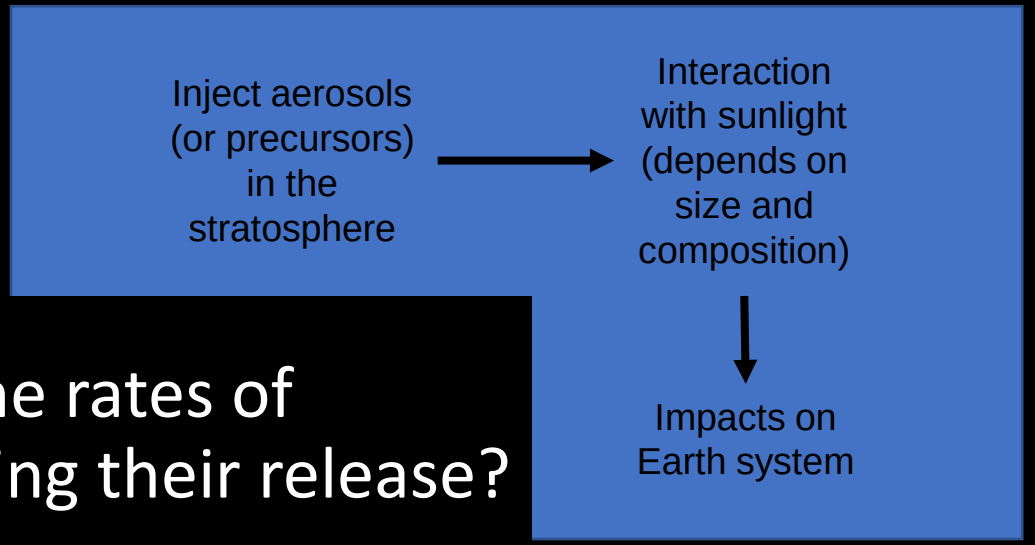
GLOMAP
CARMA
…



Modal:

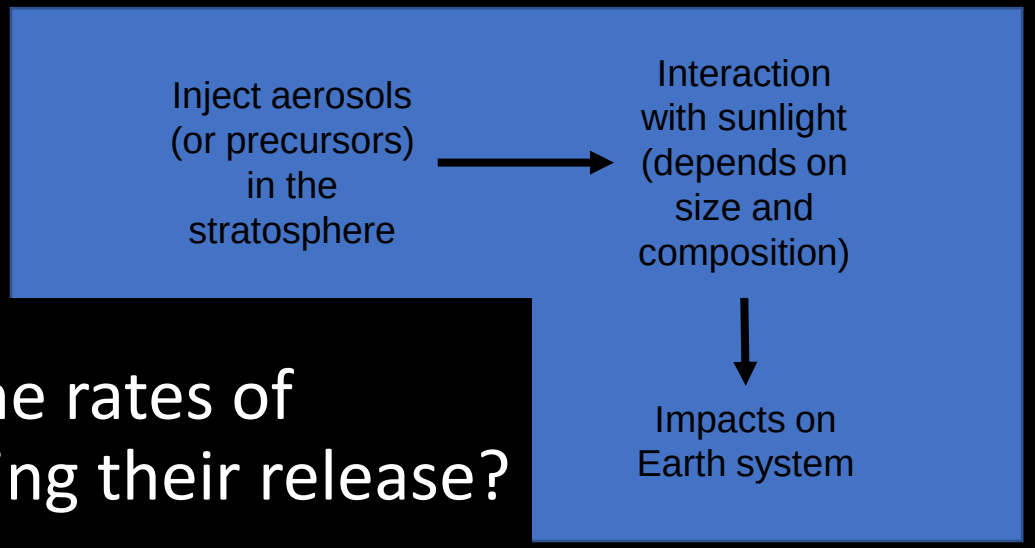
ECHAM-HAM
CESM-MAM
…

Major challenges



- Model resolution -> how dependent are the rates of formation and dispersal of aerosols following their release?
- Size distribution and composition of the stratospheric aerosols after injection?
- Robustness and statistical significance in simulations of impacts
  - Stratospheric ozone loss
  - Stratospheric heating/ Tropospheric cooling
  - Diffuse light and impact on vegetation/agriculture
  - ….
  - ???

Major challenges



- Model resolution -> how dependent are the rates of formation and dispersal of aerosols following their release?
- Size distribution and composition of the stratospheric aerosols after injection?
- Robustness and statistical significance in simulations of impacts
- Any experiment will create a perturbation too small to observe except for concentrations (aerosols and gases)

Main modeling groups

- GeoMIP (http://climate.envsci.rutgers.edu/GeoMIP/)
- Individual research groups (mainly in Germany, UK, US)
- Geoengineering Modeling Research Consortium (http://www.cgd.ucar.edu/projects/gmrc/)

Opportunities

- Ultra-high (sub-km) simulations of lower stratosphere, with simplified chemistry
- Hierarchy (in degrees of complexity) of models (e.g. specified-heating experiments)
- Increased coordination of experiments for multi-model analysis
- Observations of relevant processes in ambient (stratospheric) conditions

Questions?
Comments?