GFDL Contributions to the Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC AR5)

Presented by
RJ Stouffer and L Horowitz

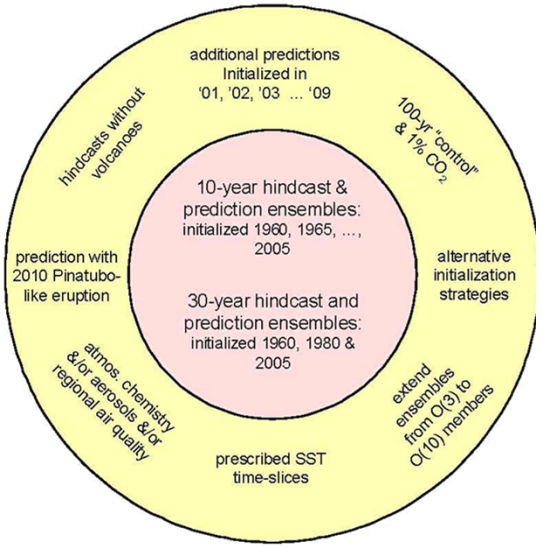
Frontiers in Climate and Earth System Modeling: Advancing the Science

Geophysical Fluid Dynamics Laboratory

May 20, 2013

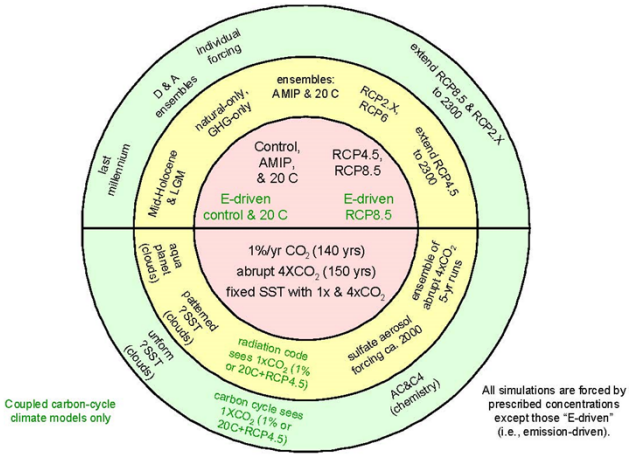
Coupled Model Intercomparison Project (CMIP)

- CMIP5 is an international scientific activity
  - Consists of a set of coordinated experiments
  - Database supports IPCC and other assessments
  - Distributed data system
- CMIP5 goals and new activities
  - Provide data for new science
    - 100s or more peer-reviewed papers
  - Investigate decadal prediction
  - Include carbon response/feedbacks in climate change
  - Include atmospheric chemistry and stratosphere-troposphere interactions



GFDL contributions to CMIP5

- 4 streams or activities with independent models
  - Investigate decadal prediction – (CM2.1)
  - Include carbon response/feedbacks in climate change – Earth System Models (ESM2M and ESM2G)
  - Include atmospheric chemistry and stratosphere-troposphere interactions – Atmosphere-Ocean-GCM (CM3)
  - Understanding changes in weather extremes – High resolution atmosphere-only model (HiRAM)



GFDL contributions to CMIP5: Process

- Model development (4 streams)
  - Lab-wide activity
  - Several Year Activity
- Running models for CMIP5
  - Core people

    B Wyman, W Hurlin, R Gudgel, F Zeng, J Krasting, L Sentman, S Malyshev plus Modeling Services
  - Large fraction of lab computer resources

    Computer time

    Storage (3 Pb internally for ESM alone)
  - About 1 year activity

GFDL Contributions to CMIP5: Process

- Preparing data for public distribution
  - Large activity involving most of lab
    - Lots of data manipulations
    - Meeting standards not easy
  - Quality Control
    - Checking each model variable for correctness
    - Requires high degree of technical and scientific skill
  - Transferring data from servers inside GFDL to servers available from outside GFDL
    - Earth System Grid Federation and distributed data serving
  - About 1 year – completed in summer 2012

GFDL Contributions to CMIP5: Process

- METAFOR
  - Community standard for model documentation
  - Few people involved, few weeks of effort
- Peer reviewed papers
  - Model documentation
    - 1 or 2 for each stream
    - Large number of authors
  - New science papers (focus of this day)
    - Papers describing models and new science
    - Much of the lab involved as authors

GFDL has many contributions to IPCC AR5

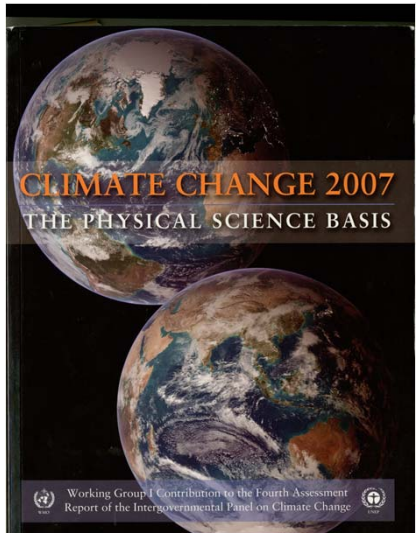
- Science papers
  - Many papers are integral parts of the IPCC reports
- Model data
  - More later
- Chapter Lead Authors (LAs)
  - Gabriel Vecchi, Gabriel Lau, Ram (SPM)
- Review editors
  - Ramaswamy, Held
- Contributors and reviewers
- Other important assessments: e.g. US National Assessment

GFDL's CMIP5 contribution about equal to all modeling groups for CMIP3/AR4

- GFDL data available
  - Decadal Prediction - 10TB
  - Earth System Models – 128TB
  - CM3 – 30TB
  - High Resolution atm-only (HiRam) – 22TB
  - Total = 188TB

    Comparable to whole CMIP3 archive

    used to support IPCC 4th Assessment



Accomplishments: Data actively being used

- GFDL data server - January 1, 2012 to April 22, 2013
  - 800,000+ requests for data
  - 700,000+ different files downloaded
  - 1,200+ different IP addresses accessing the data
  - 300+ TB of data downloaded
  - GFDL model data widely used in IPCC and other new assessments

Accomplishments: Science

- ESM - Stouffer
  - Compare CMIP5 ESMs to IAMs (WG1 and 3 models)
  - Investigate role of ocean formulation

- CM3 - Horowitz
  - Role of aerosols in historical and future climate
  - Stratospheric ozone and temperatures

Important CMIP5/IPCC science question

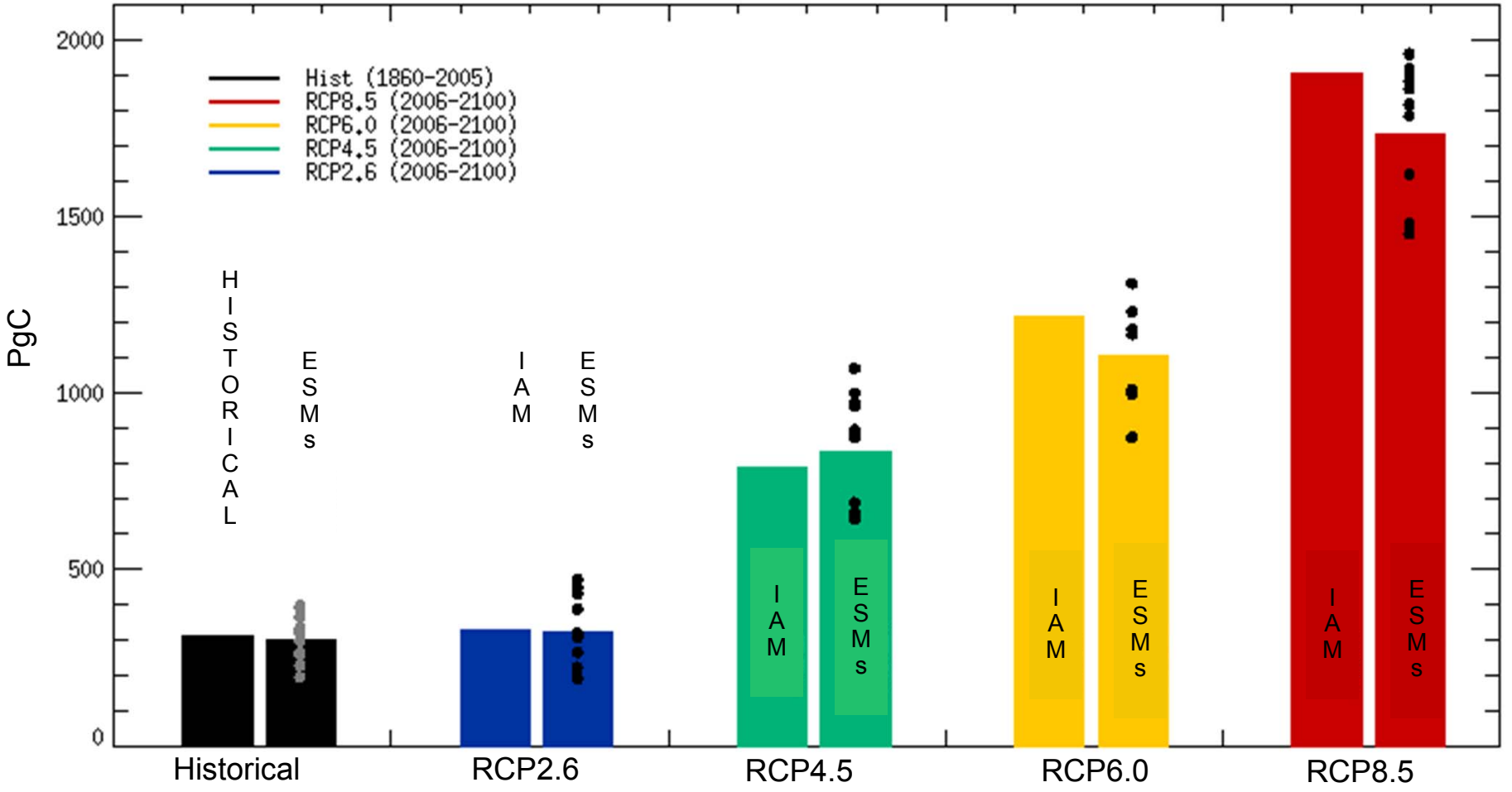
How well do the simple models (IAMs) used by WG3 emulate the complex ESMs used by WG1?

Integrated Assessment Models (IAMs) - Predict own emissions and contain simple climate model which emulates ESM climate and carbon response. The IAM emissions are used as input to the ESMs.

=> Compare ESM allowable cumulative carbon emissions to those found in IAMs (Jones et al. 2013)

ESM results similar to historical estimates and future projections for RCP2.6 and RCP4.5

Allowable Cumulative Carbon Emissions



Jones et al. 2013 (in press)

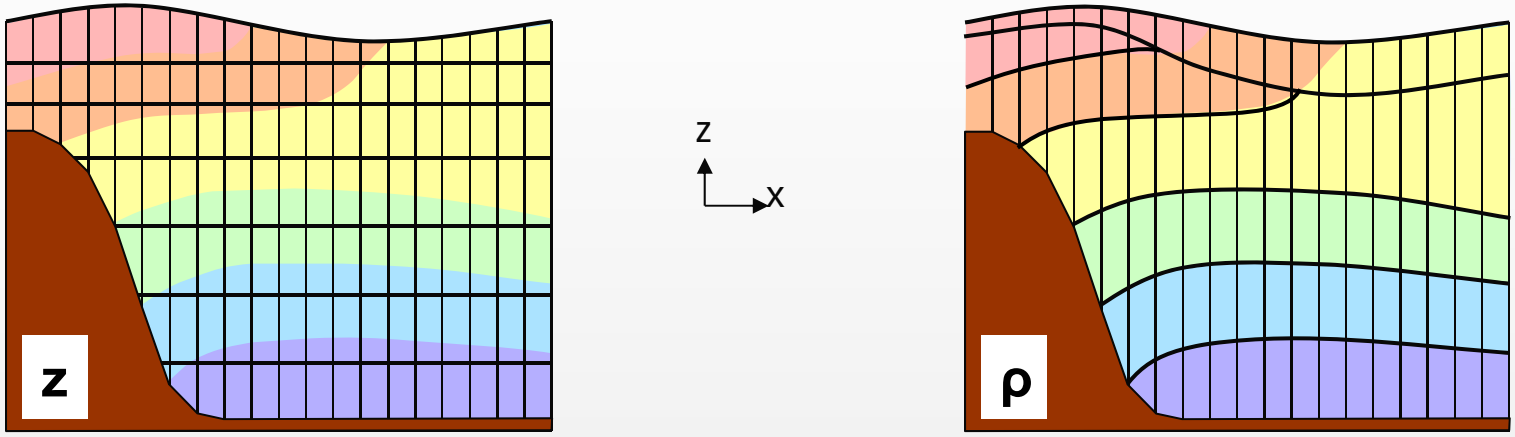
Uncertainty in climate projections

Major uncertainties:

- Clouds
- Carbon Feedbacks
- Oceanic heat uptake
  - Role of oceanic eddies
  - Role of ocean formulation

ESM2M and ESM2G differ only in ocean physics

Goal: Comparison of implications of ocean vertical coordinate choice



z* (MOM4.1):

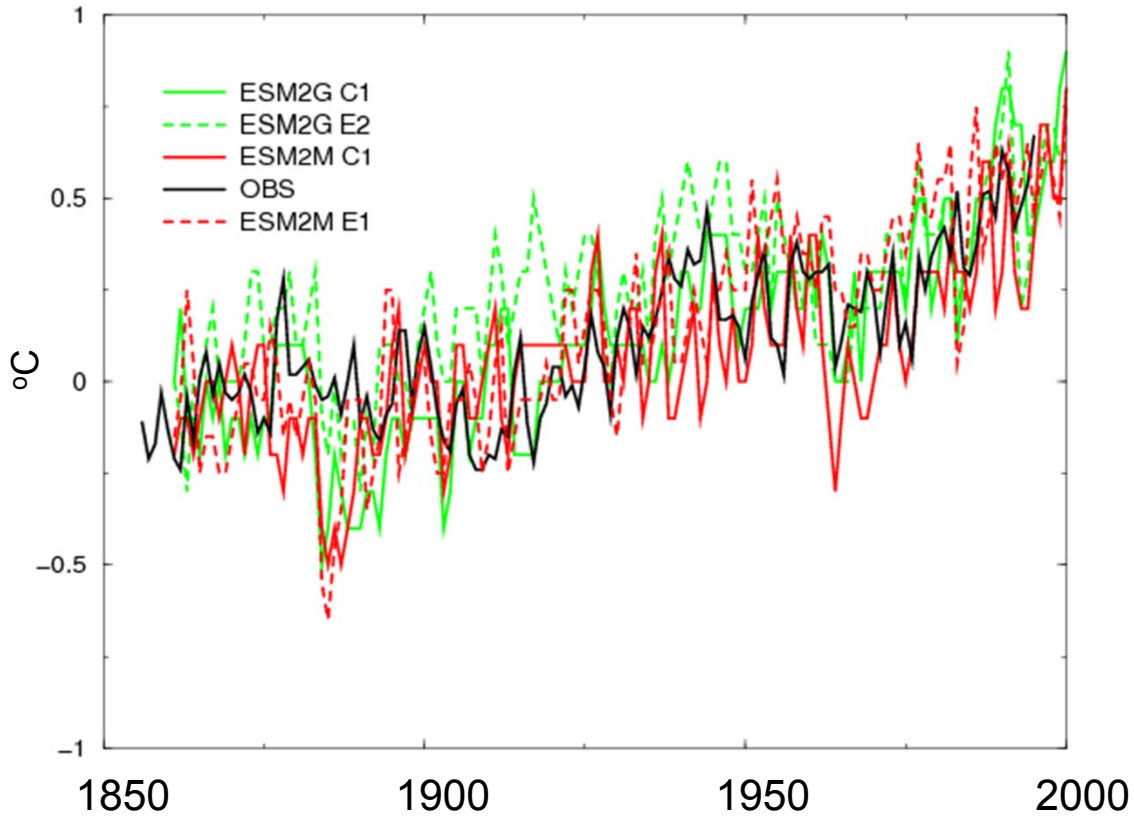
- **Depth-based vertical coordinate**
- **Over 40 years of experience**

ρ (GOLD):

- **Density-based vertical coordinate**
- **Easy to preserve water masses**

ESMs concentration (C1) and emissions (E1) driven runs show similar Global Surface Air Temperature Response

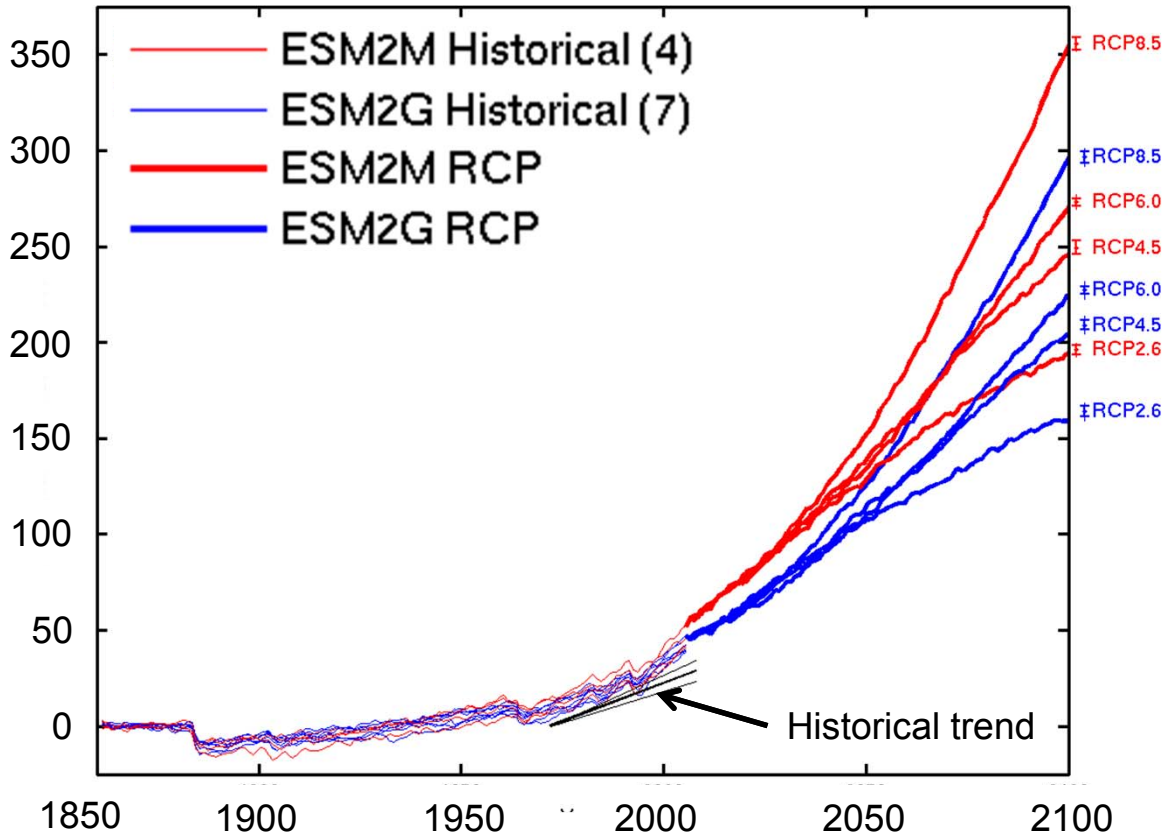
Surface Air Temperature Response



- Two different forcings (C & E) give very similar responses
- Both models (M&G) do good job of simulating observed trend using emissions and concentrations.

ESM2M has larger sea level response compared to ESM2G in future at the global scale

Globally averaged steric sea level rise since 1861-1900 (mm)



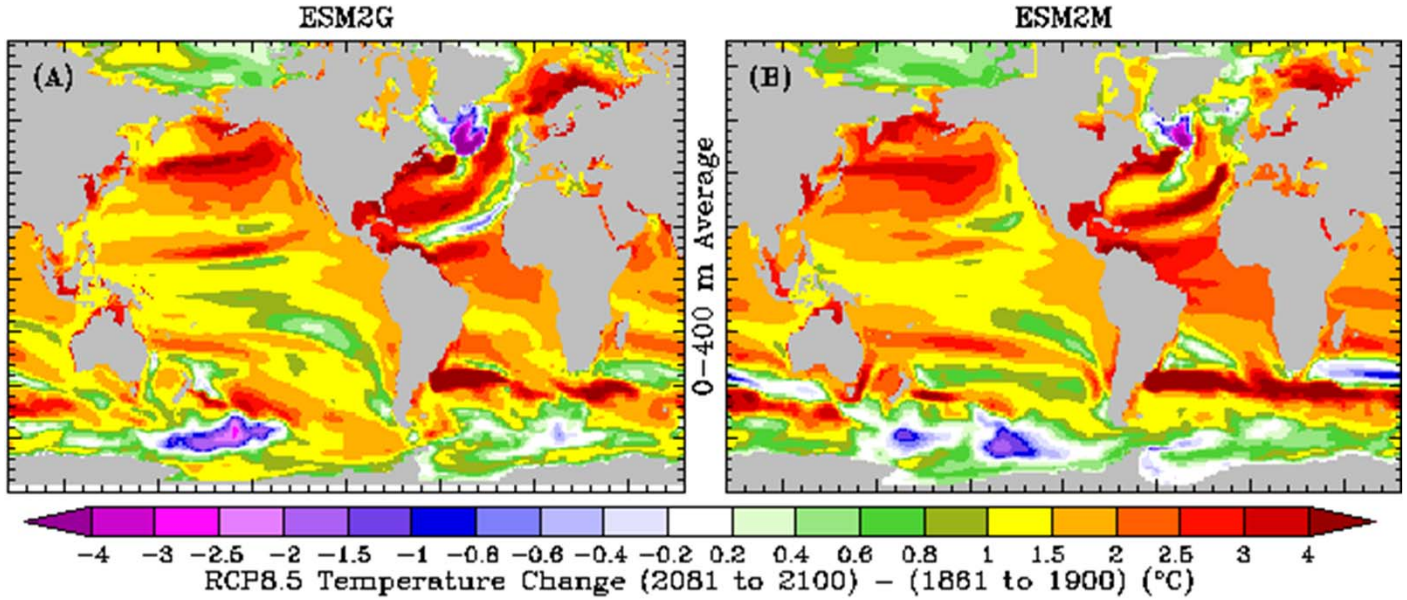
Both models capture historical SLR.

ESM2M has larger SLR than **ESM2G** during this century.

Hallberg et al. 2013

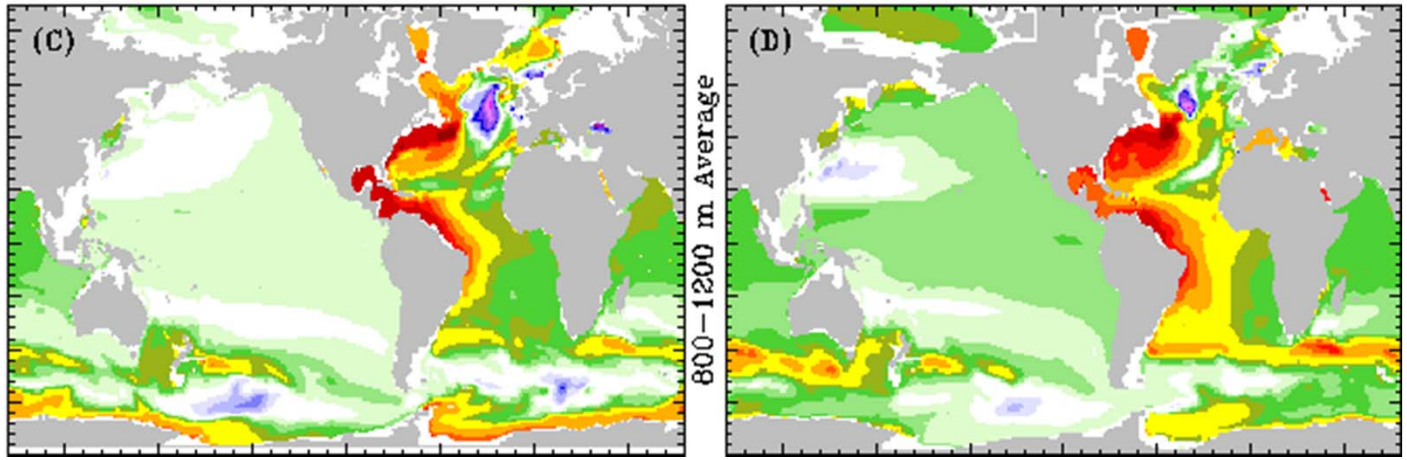
Uncertainty due to the ocean vertical coordinate is relatively small

0-400 m



Temperature response is very similar near the surface

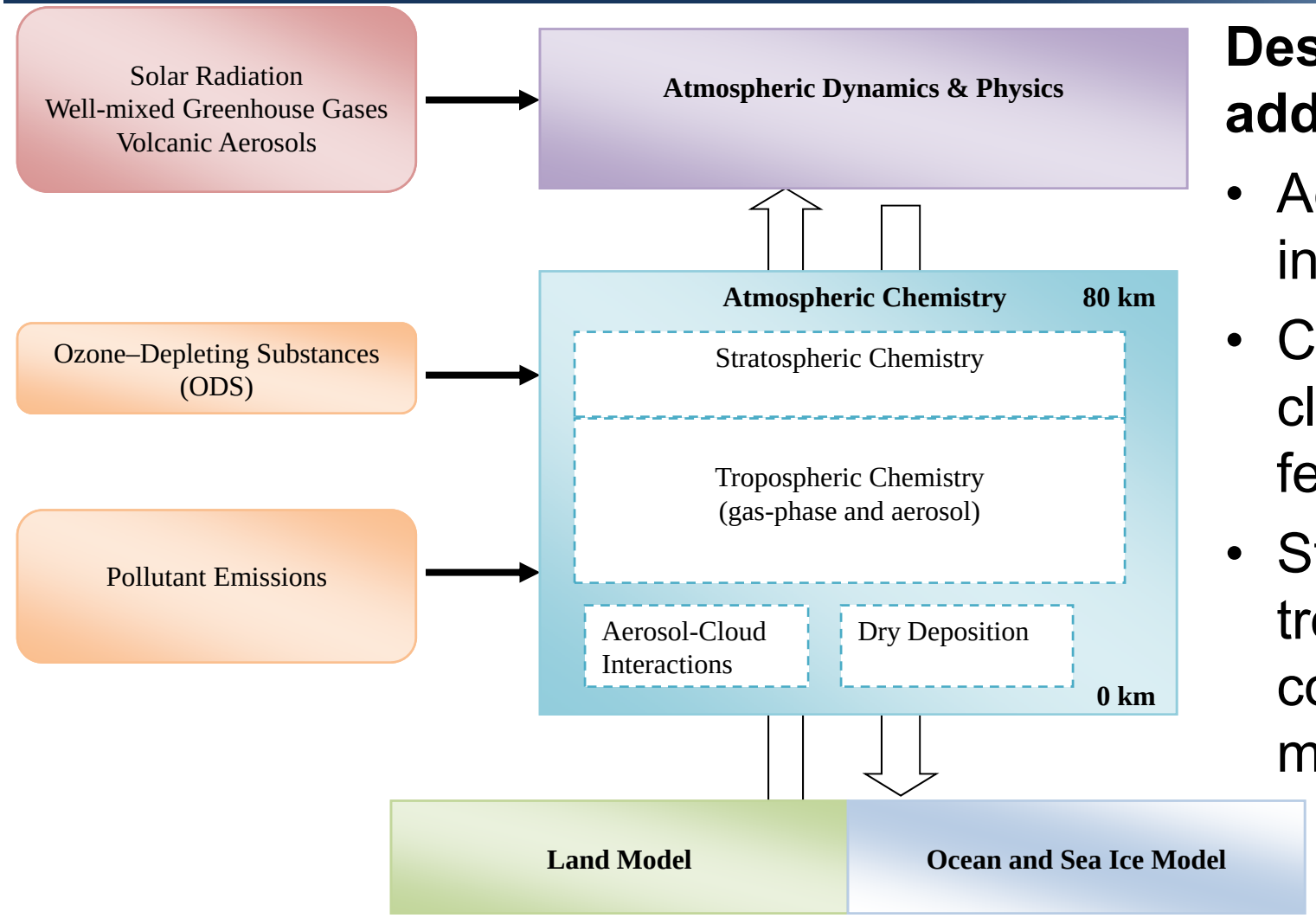
800-1200 m



Temperature response is different at depth

Hallberg et al. 2013

CM3 Coupled Climate Model

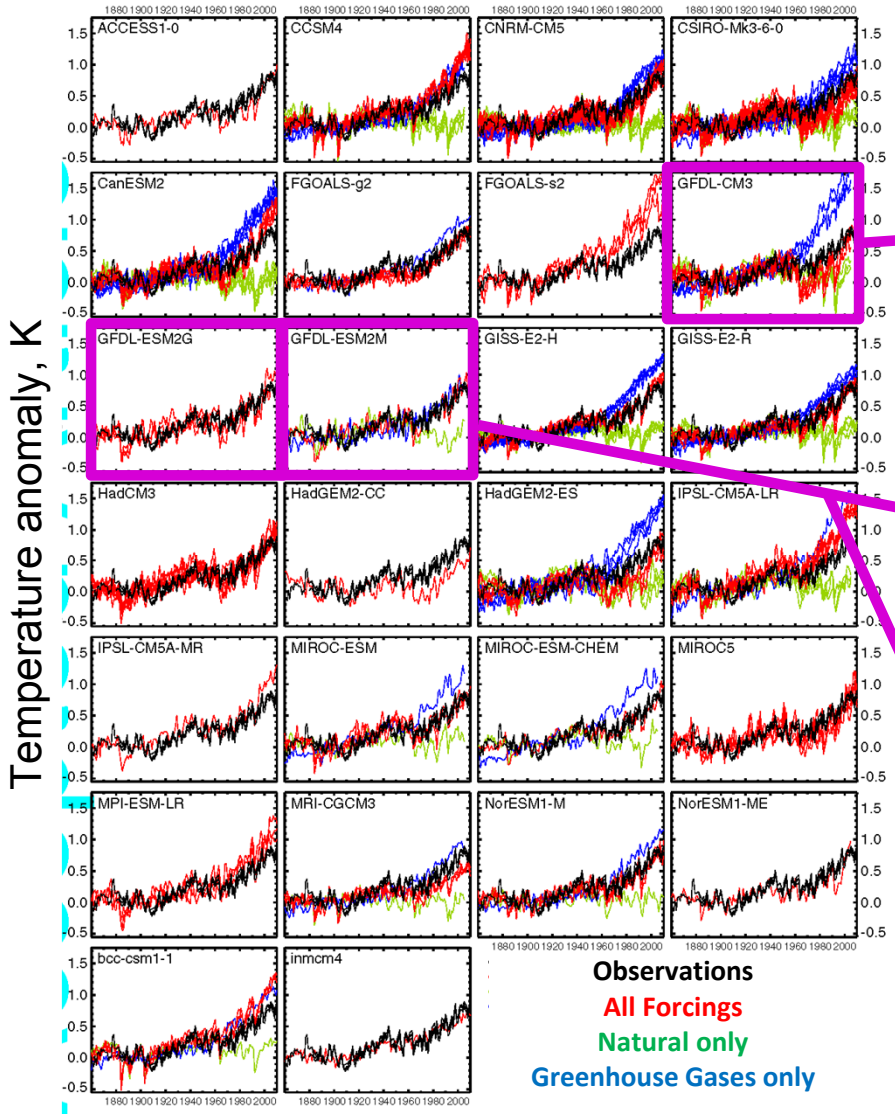


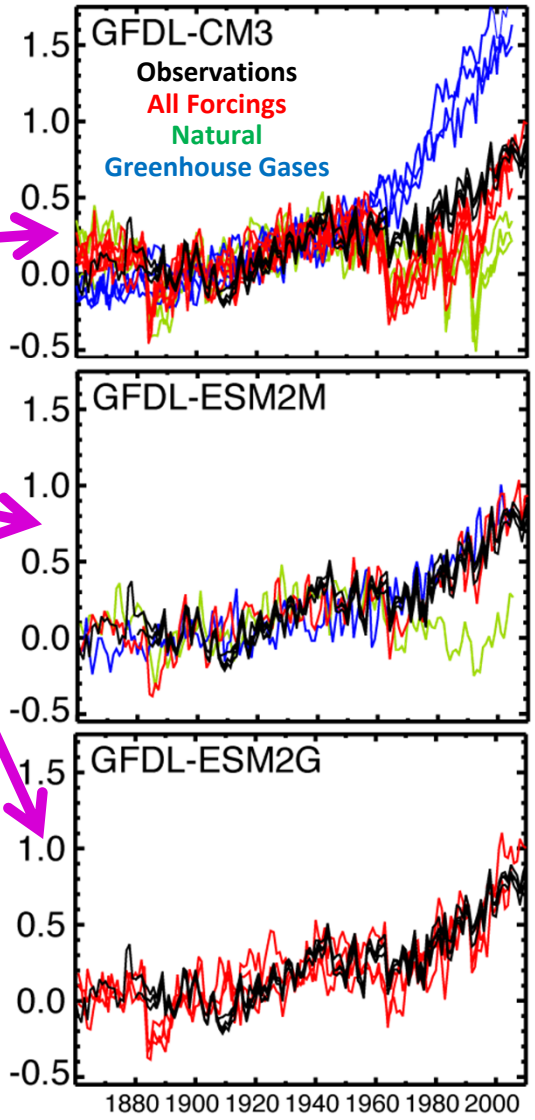
Designed to address:

- Aerosol-cloud interactions
- Chemistry-climate feedbacks
- Stratosphere-troposphere coupling (high model top)

Donner et al. (*J. Climate*, 2011)

CM3 warms more strongly than ESMs in response to greenhouse gases



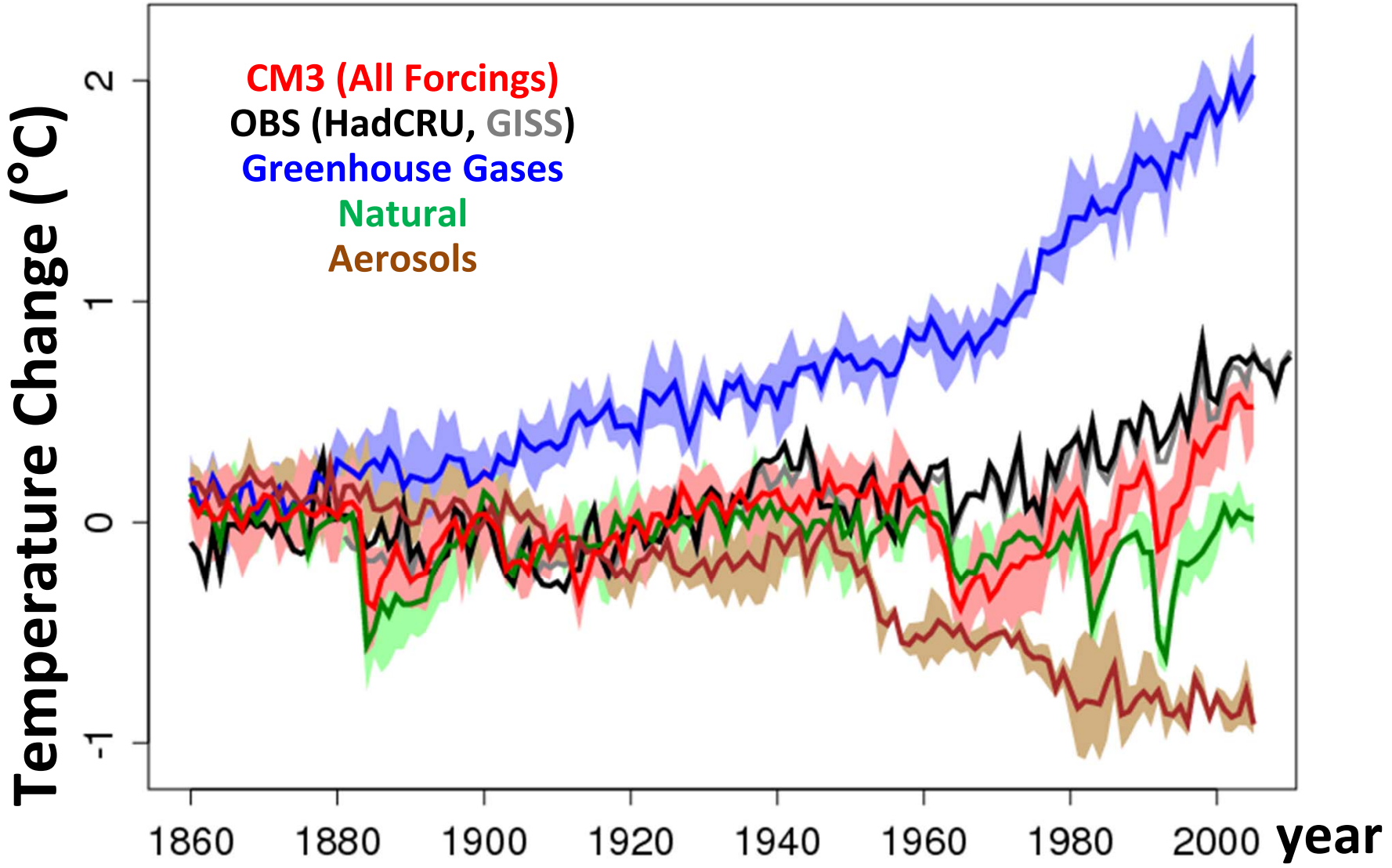


CM3
Strong **GHG** warming offset by **aerosol/volc** cooling

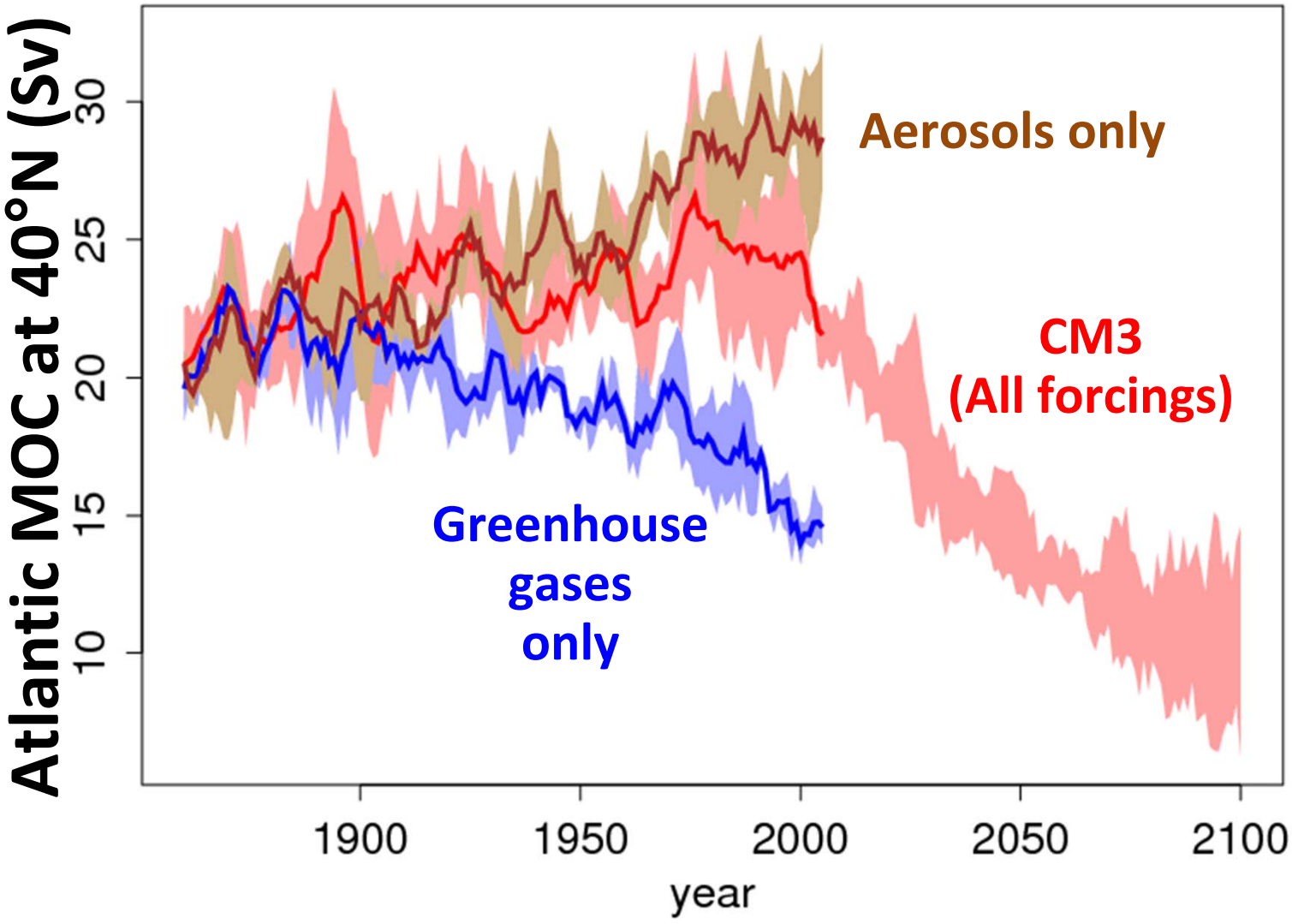
ESM2M/2G
GHG warming similar to **total historical** warming

Gareth Jones et al. (2013)

Late 20th century cooling from aerosols and volcanoes in CM3

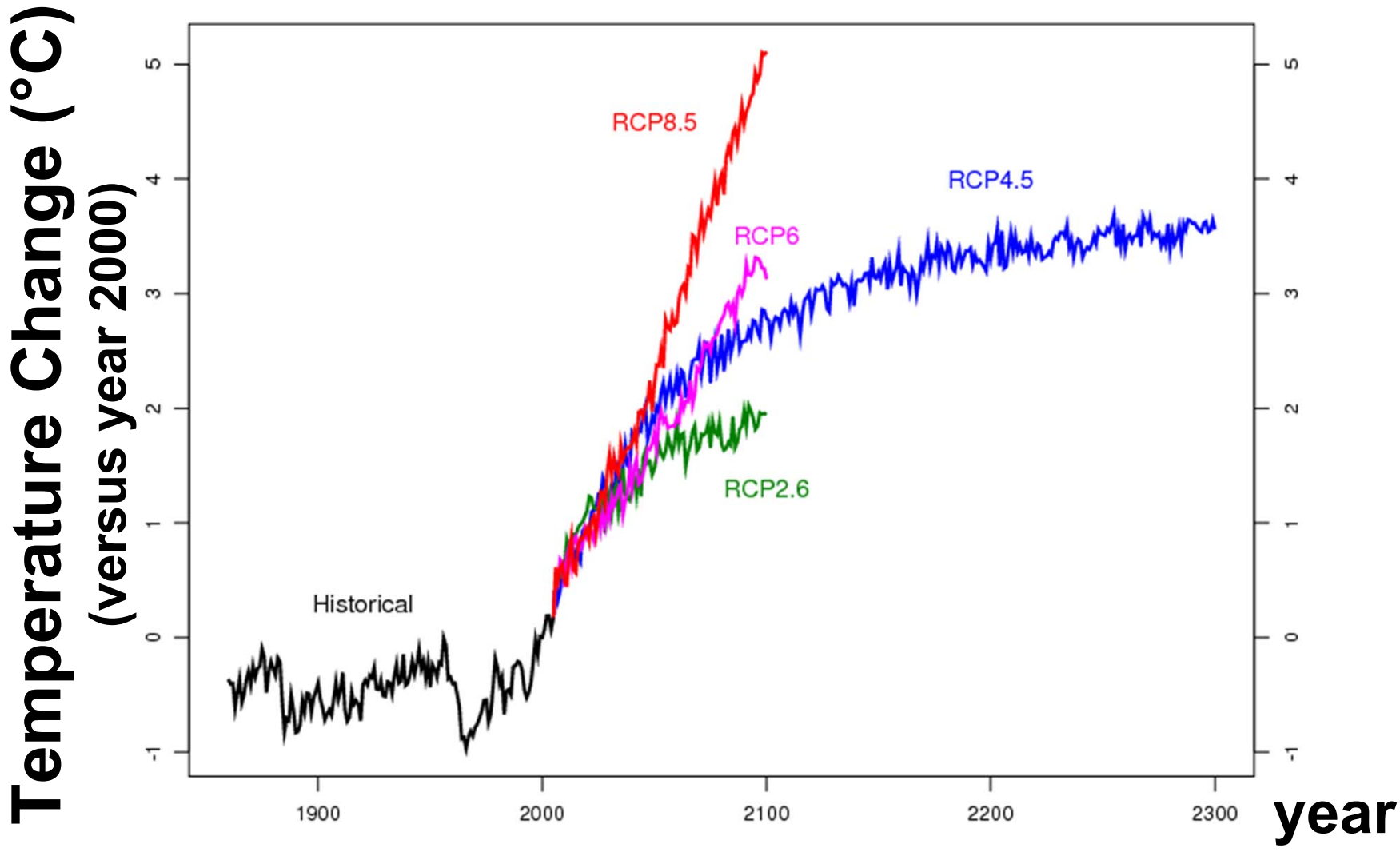


Aerosols and greenhouse gases have competing effects on Atlantic circulation

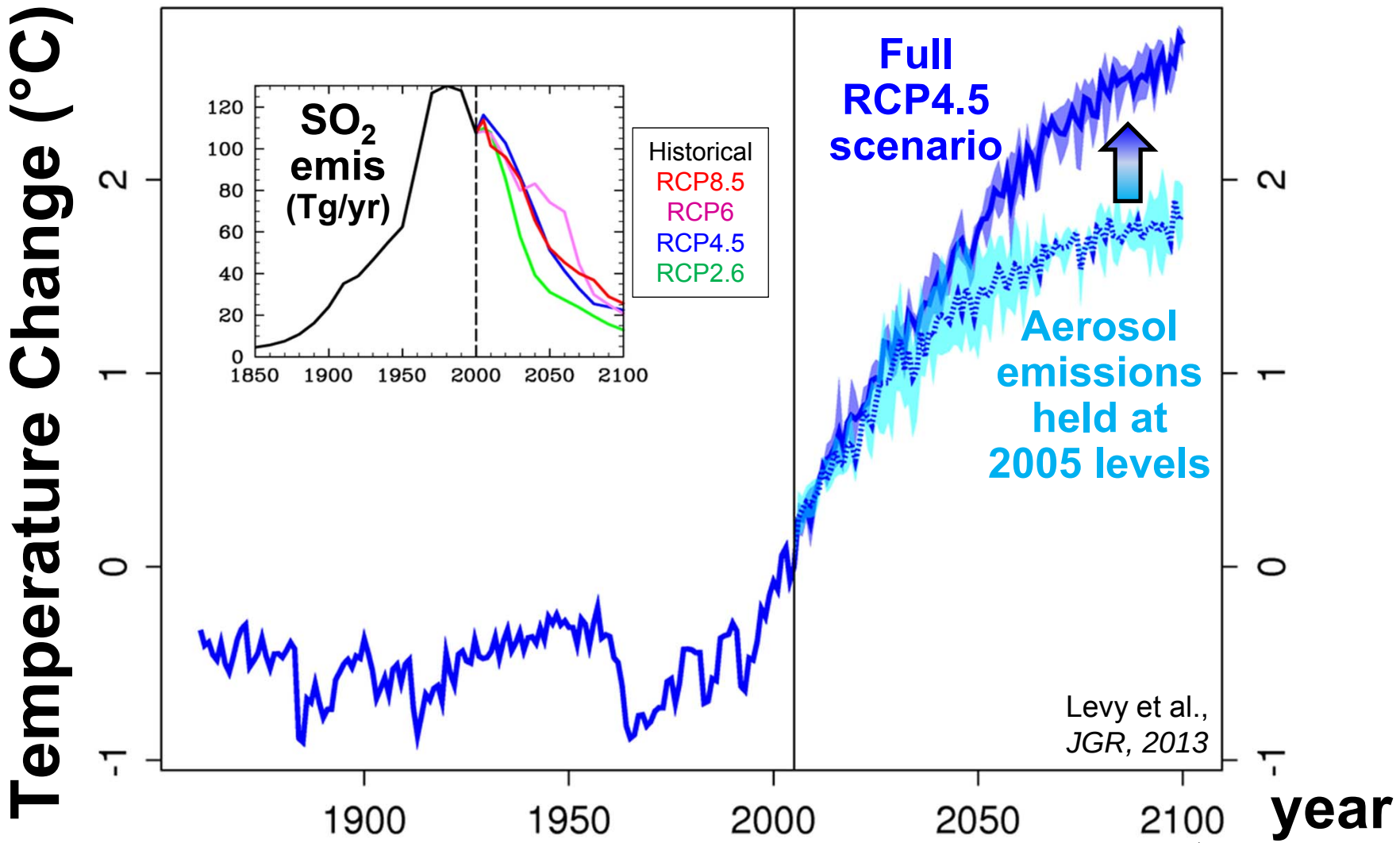


Atlantic meridional overturning (AMOC) in CM3 responds strongly to greenhouse gases (-) and aerosols (+)

Strong warming projected by CM3 following RCP scenarios



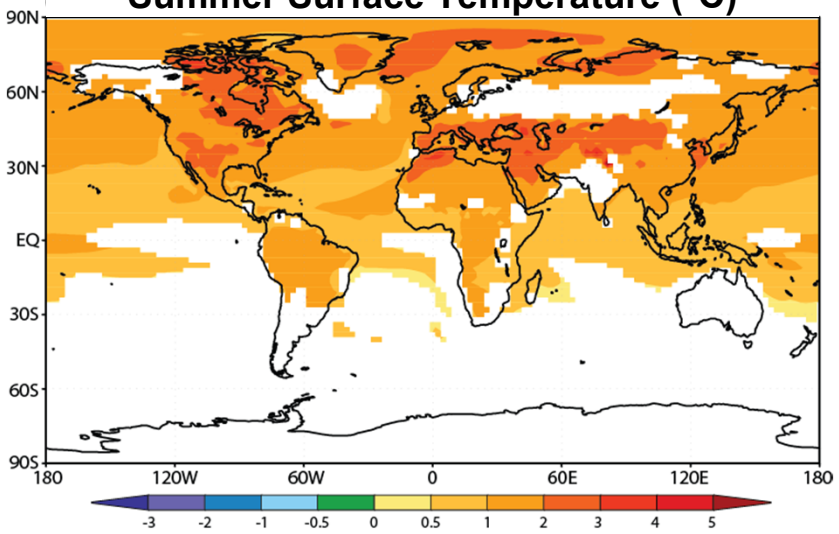
Aerosol reductions warm climate over 21st century



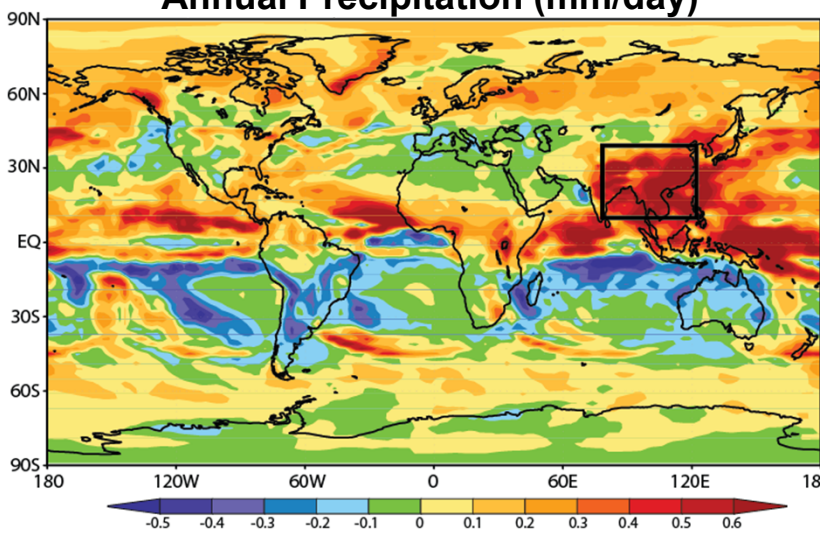
Large additional warming projected from aerosols over 21st century

Projected aerosol changes (RCP4.5) will impact temperature and precipitation

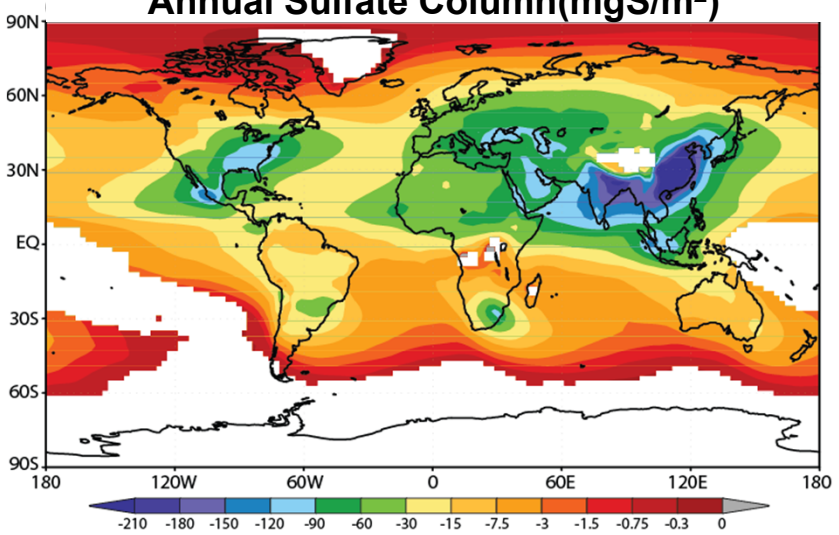
Summer Surface Temperature (°C)



Annual Precipitation (mm/day)



Annual Sulfate Column(mgS/m^2)

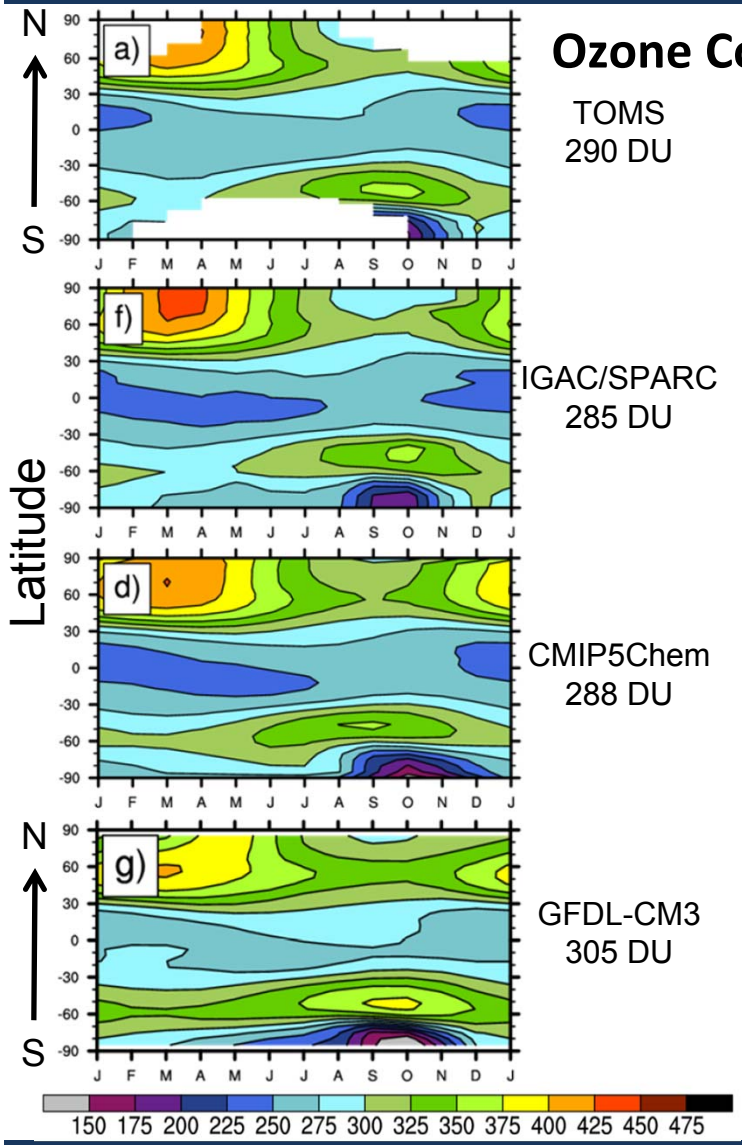


Hemispheric response for temperature, more localized response for precipitation

(2091-2100 versus 2005)

Levy et al., *JGR, 2013*

Stratospheric ozone distributions and trends are well simulated



Ozone Column

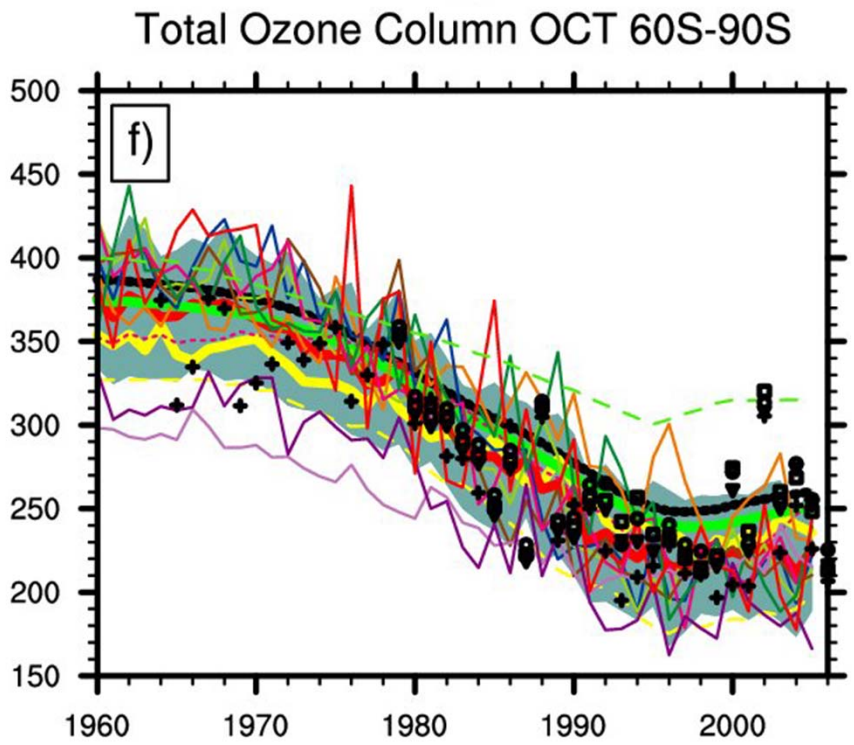
TOMS
290 DU

IGAC/SPARC
285 DU

CMIP5Chem
288 DU

GFDL-CM3
305 DU

Development of Antarctic Ozone Hole



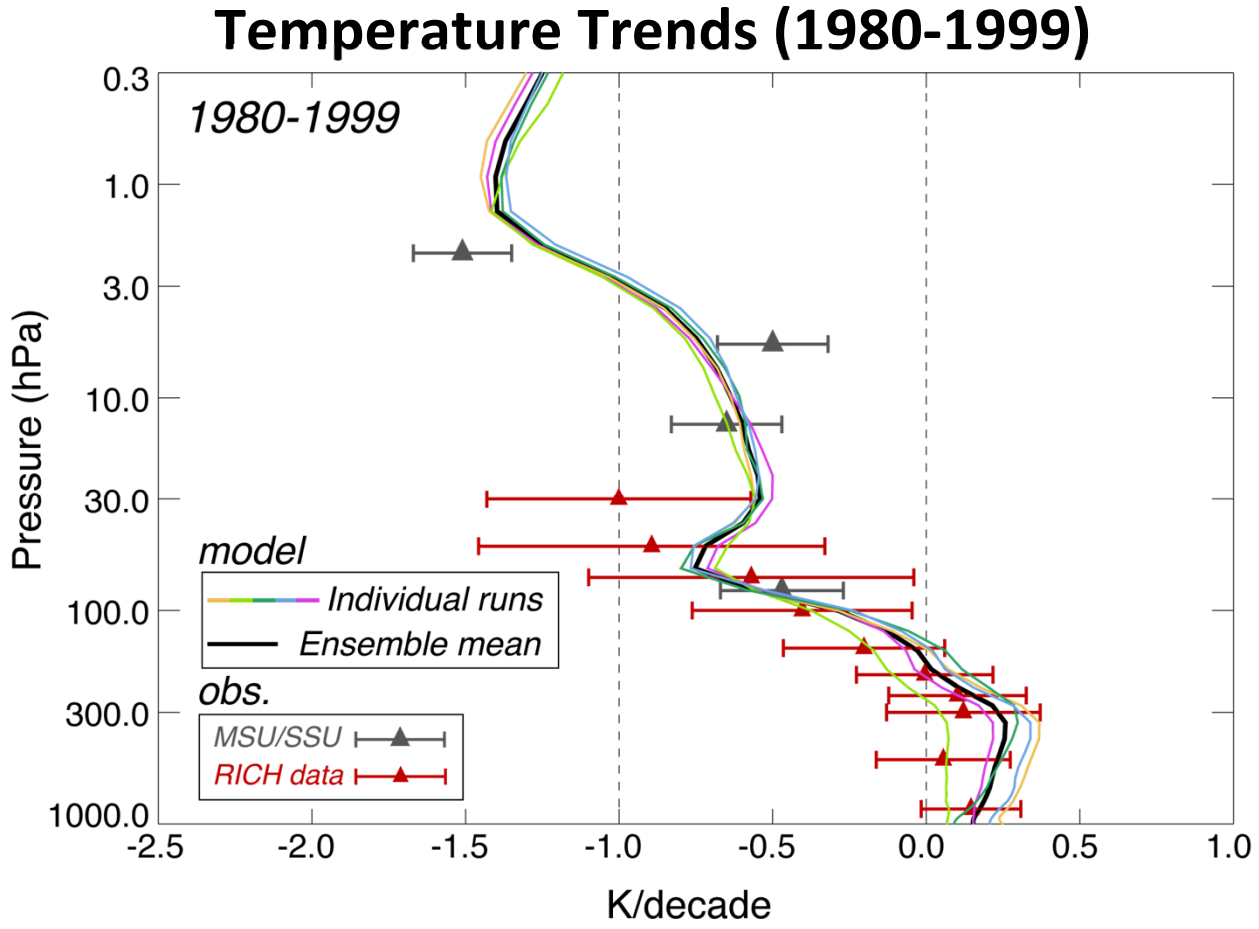
IGAC/SPARC

OBS

CMIP5 models

Eyring et al.
JGR, 2013

Greenhouse gases warm troposphere, but cool stratosphere

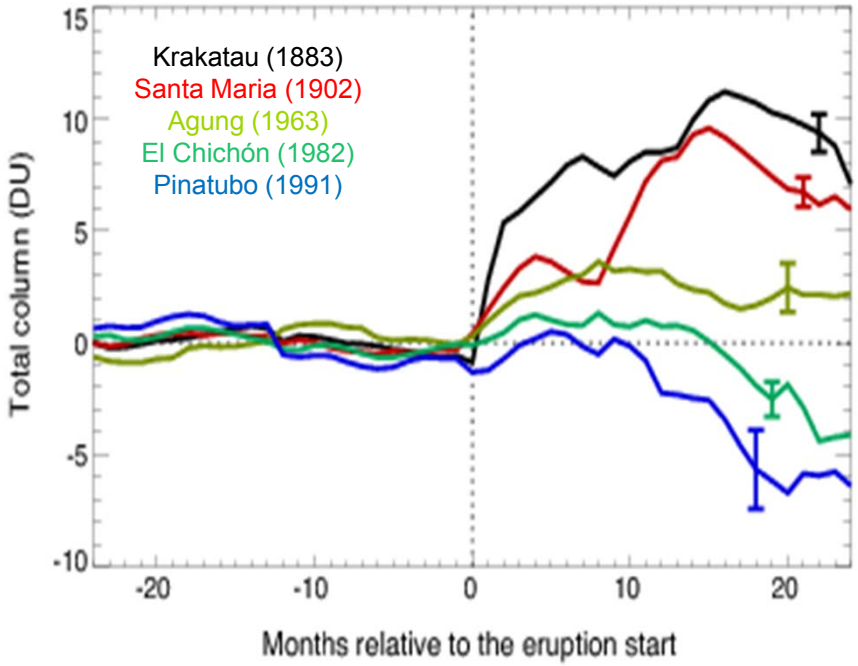


Stratospheric cooling, resulting from **CO_2 increases** and **ozone depletion**, is simulated well by CM3

Austin et al., *J.Clim., 2013*

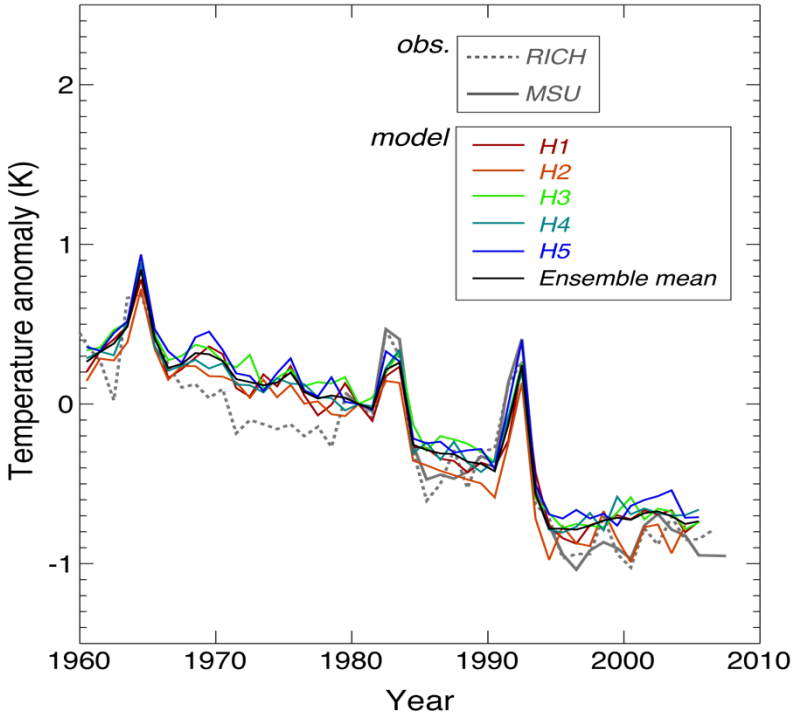
Stratospheric ozone and temperature respond strongly to volcanic eruptions

Ozone Column



Sign of ozone response to volcanic aerosols depends on atmospheric chlorine loading

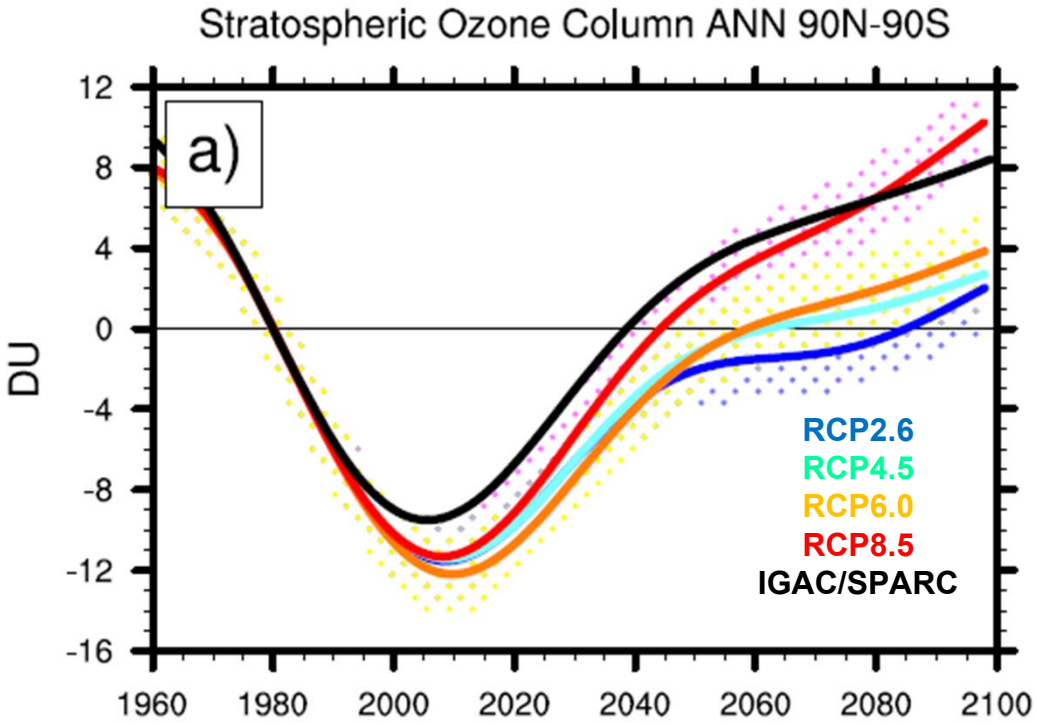
Temperature



Post-volcanic warming and long-term cooling in stratosphere are well simulated by CM3

Austin et al., *J.Clim., 2013*

Stratospheric ozone recovery sensitive to greenhouse gases



Strongest global ozone recovery in high-forcing RCP8.5 scenario:

- increased Brewer-Dobson circulation
  (increases ozone at high latitudes, decreases ozone in tropical lower stratosphere)
- decreased chemical loss
  (increases ozone at high latitudes and high altitudes)

Eyring et al., *JGR, 2013*

Future Directions

- Science results from other streams in later talks
  - Decadal prediction
  - High resolution atmosphere-only
  - and more ESM and CM3

- Model development (CM4) activity starting looking forwards towards AR6/CMIP6
  - Merge ocean models into MOM6
  - Merge atmospheric models into AM4
  - New sea ice model
  - New land surface component
  - New ocean biogeochemistry (COBALT)