Using climate models to address societally-relevant issues: selected examples

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NCAR

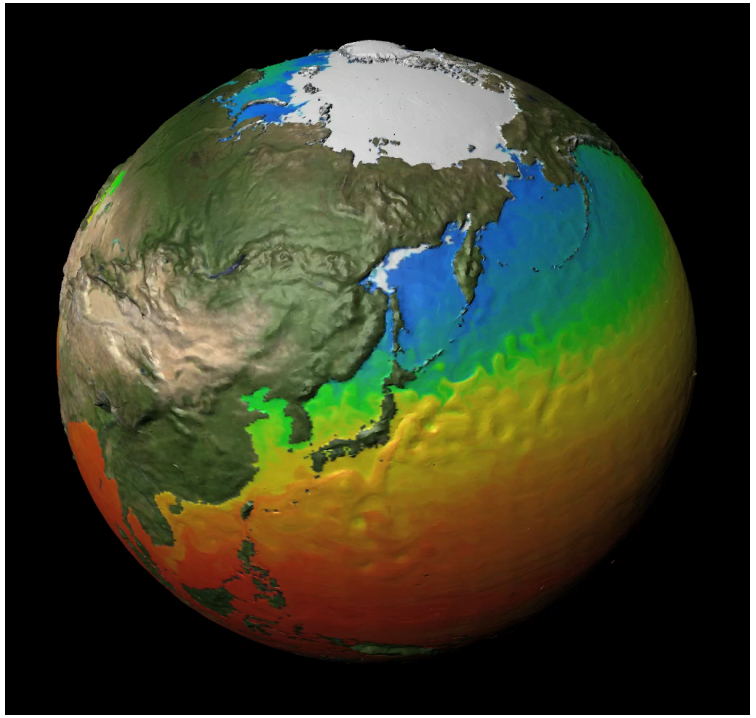
Outline

- Description of CESM
- Climate
- Antarctic ozone hole
- Outlook

CESM description

Purpose of Earth System Modeling

- **To provide scientific understanding of observed climate change (historical, paleo)**
- **To simulate future climate change and its impacts**
- **Builds on our process understanding from observations and highly-detailed models (large-eddy simulations, chemical master mechanism, …)**



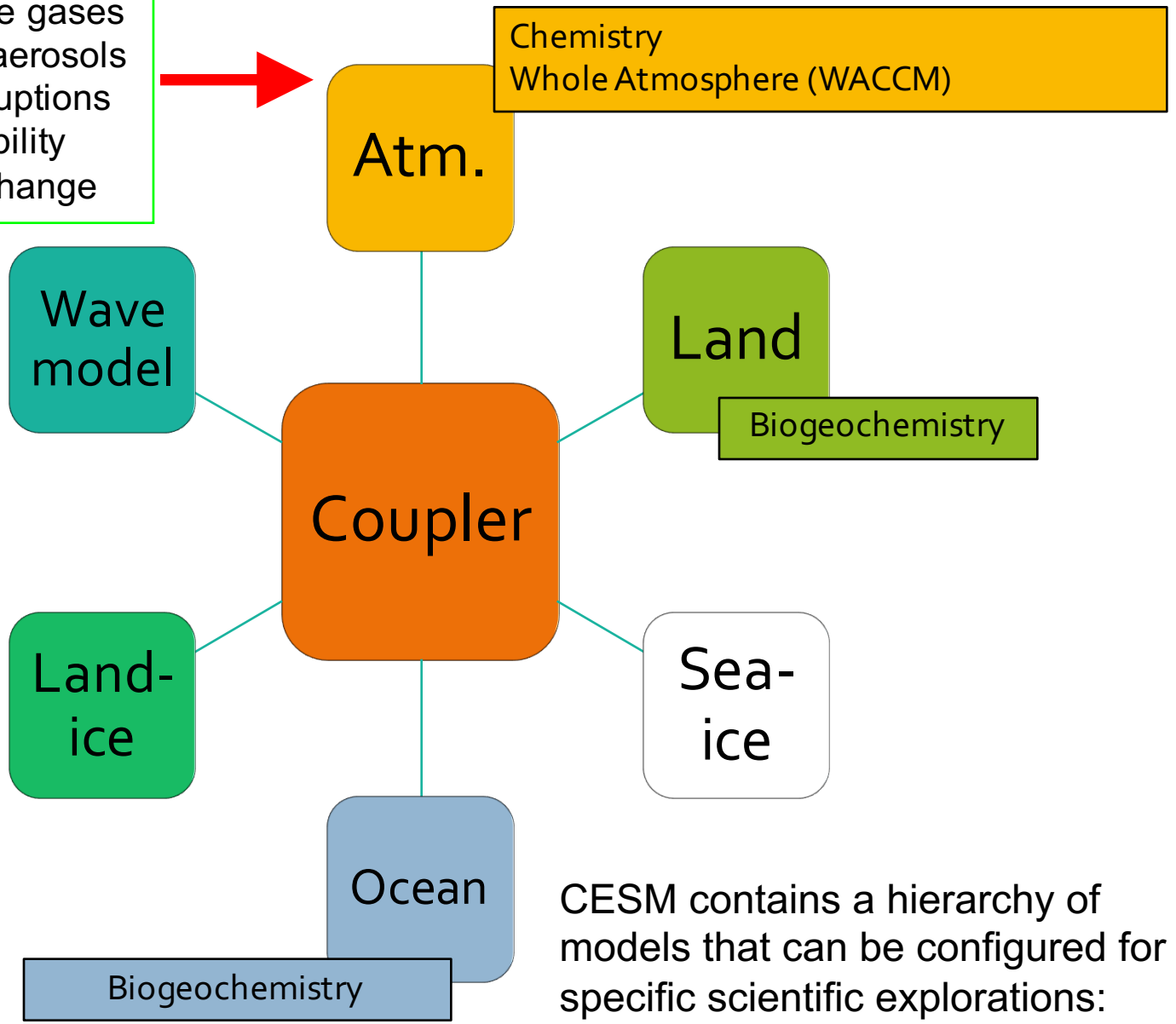
High-resolution (25 km atmosphere, 0.1^{o} ocean) coupled simulation captures short-term variability (hurricanes) and seasonal variations (sea-ice)

From J. Small

Community Earth System Model (CESM)

Forcings:

- Greenhouse gases
- Manmade aerosols
- Volcanic eruptions
- Solar variability
- Land-use change



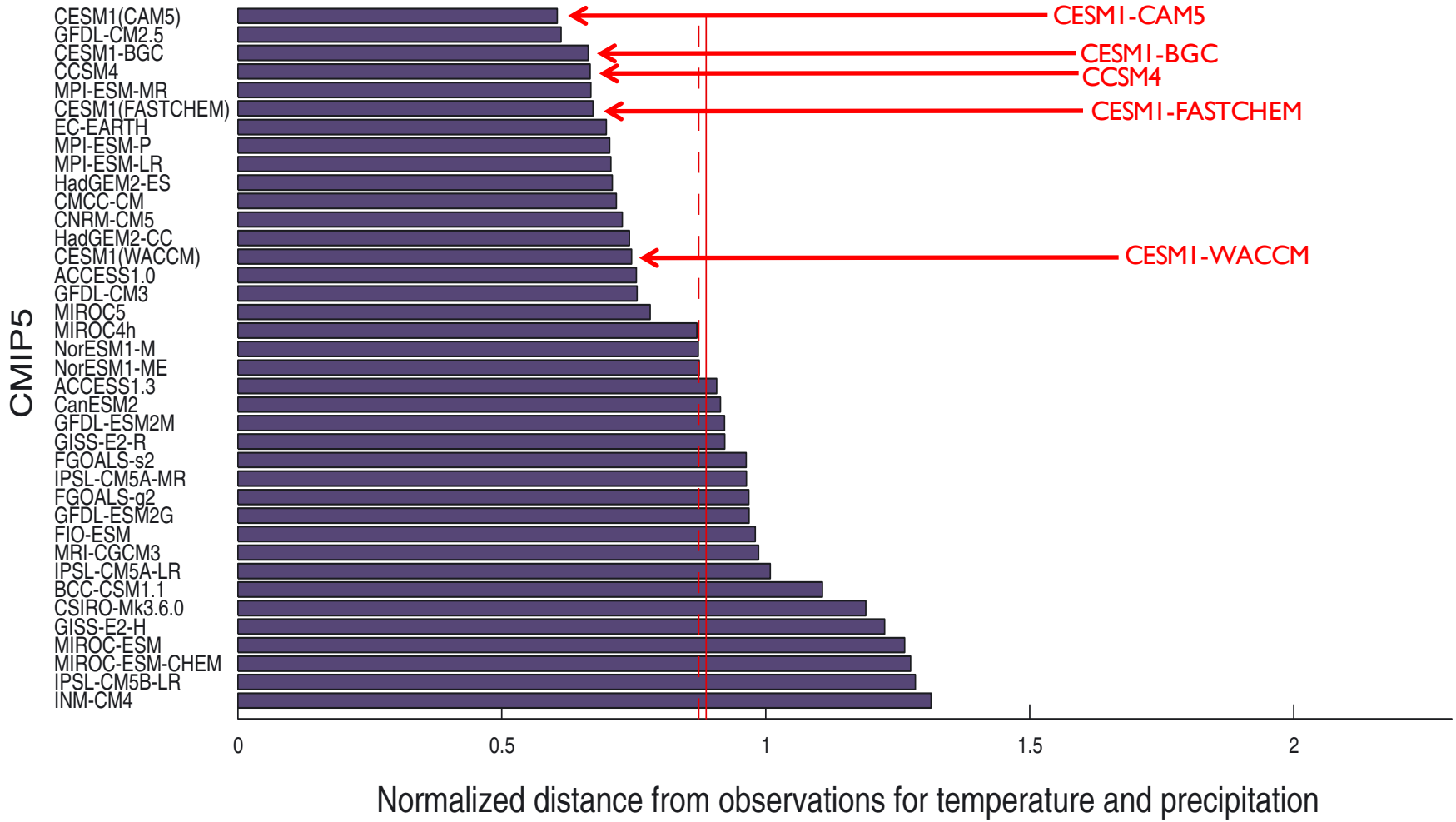
CESM contains a hierarchy of models that can be configured for specific scientific explorations: single column, aquaplanet, dynamical cores, ocean-only, …

Standard configurations for CESM

- Timestep: 30 minutes
- Atmospheric resolution: ¼, 1 or 2 degrees
- Atmospheric vertical extent: 40 (32L) or 150 km (72L)
- Ocean resolution: 1 degree (60L)
- Throughput:
  - 20 sypd for 1-degree model (low top)
  - 8 sypd for 1-degree model (high top) with full chemistry

Evaluation

CMIP5 Model Intercomparison

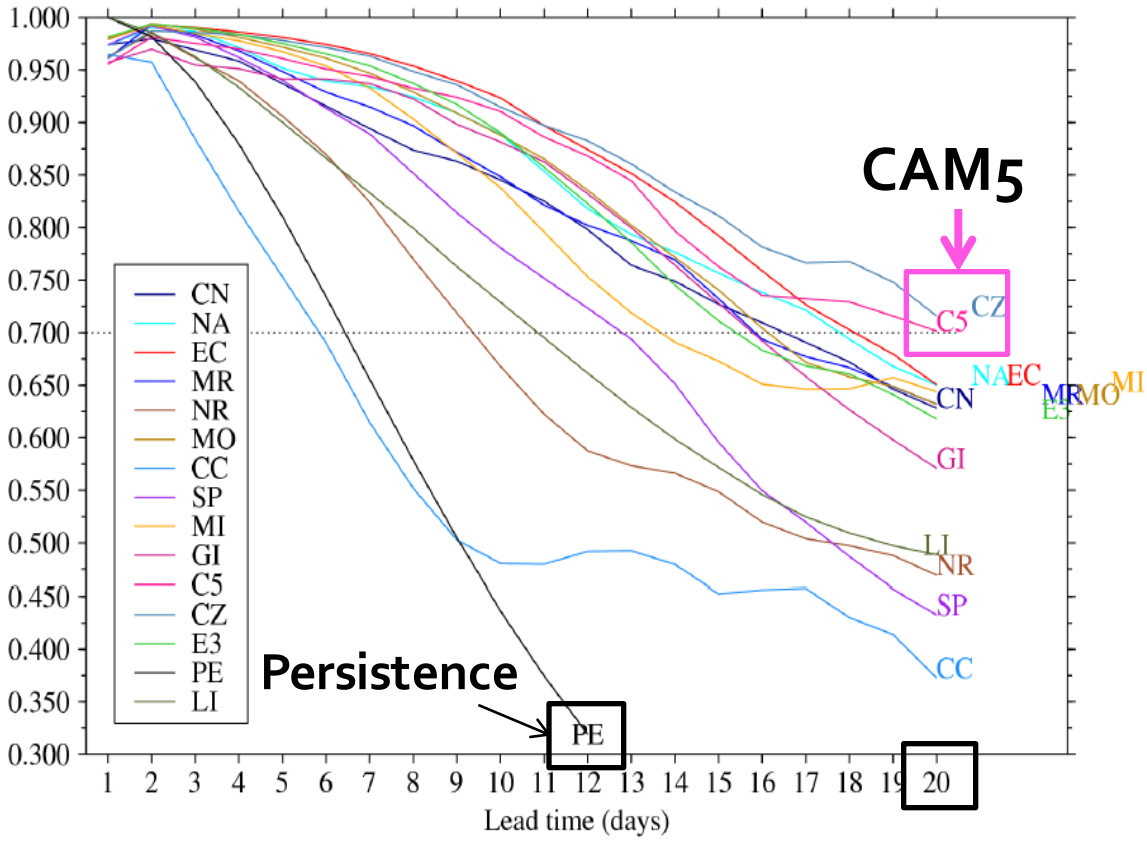


(Knutti, Masson, Gettelman, GRL, 2013)

Getting the weather right

Predictability of Madden Julian Oscillation (MJO)

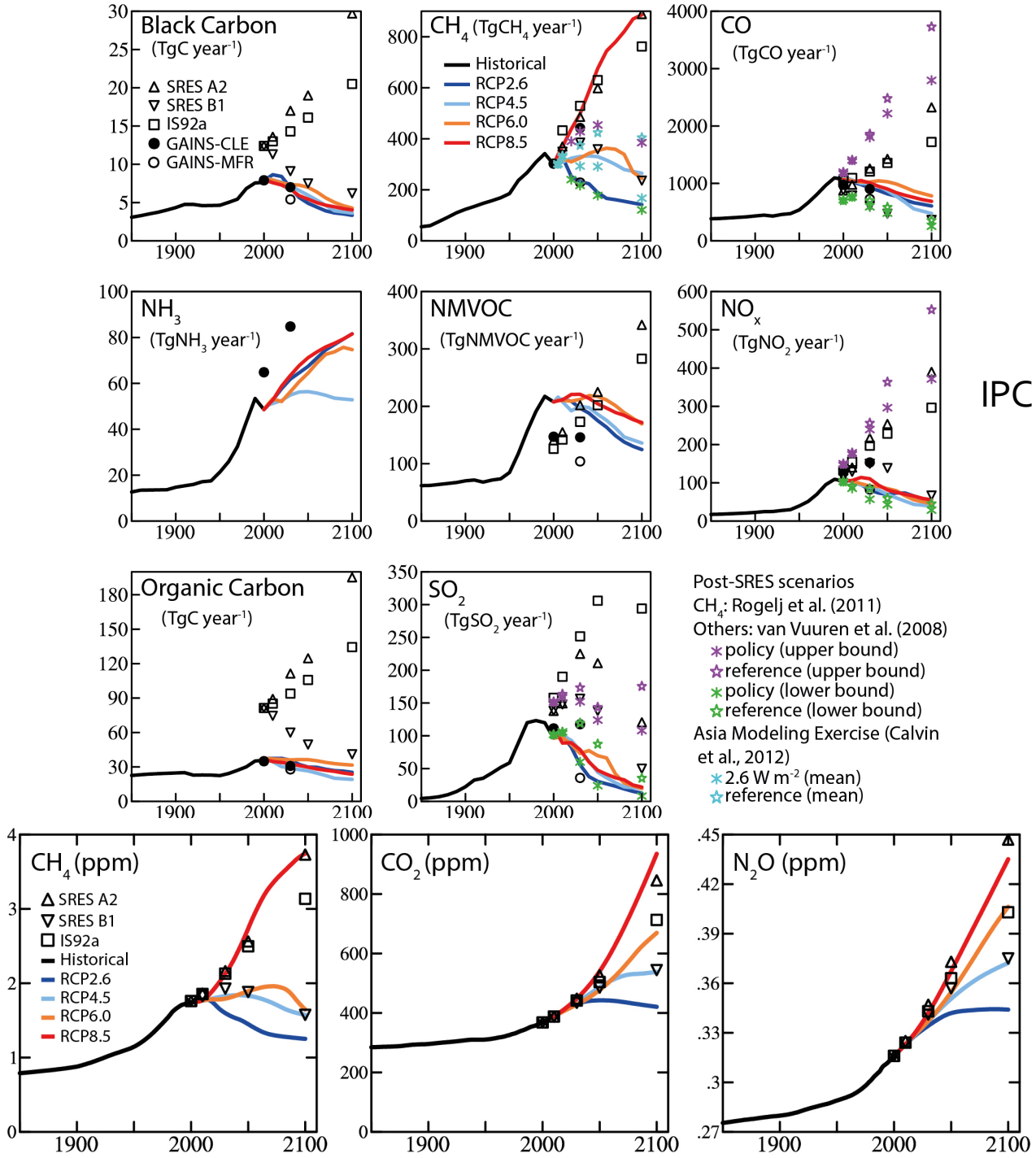
- Intensive obs. campaign DYNAMO-CINDY period 2011-12
- Initialized with ECMWF analyses
- CAM5 only model to retain MJO skill out to 20 days.
- Top performer among participating CMIP5 models



From R. Neale

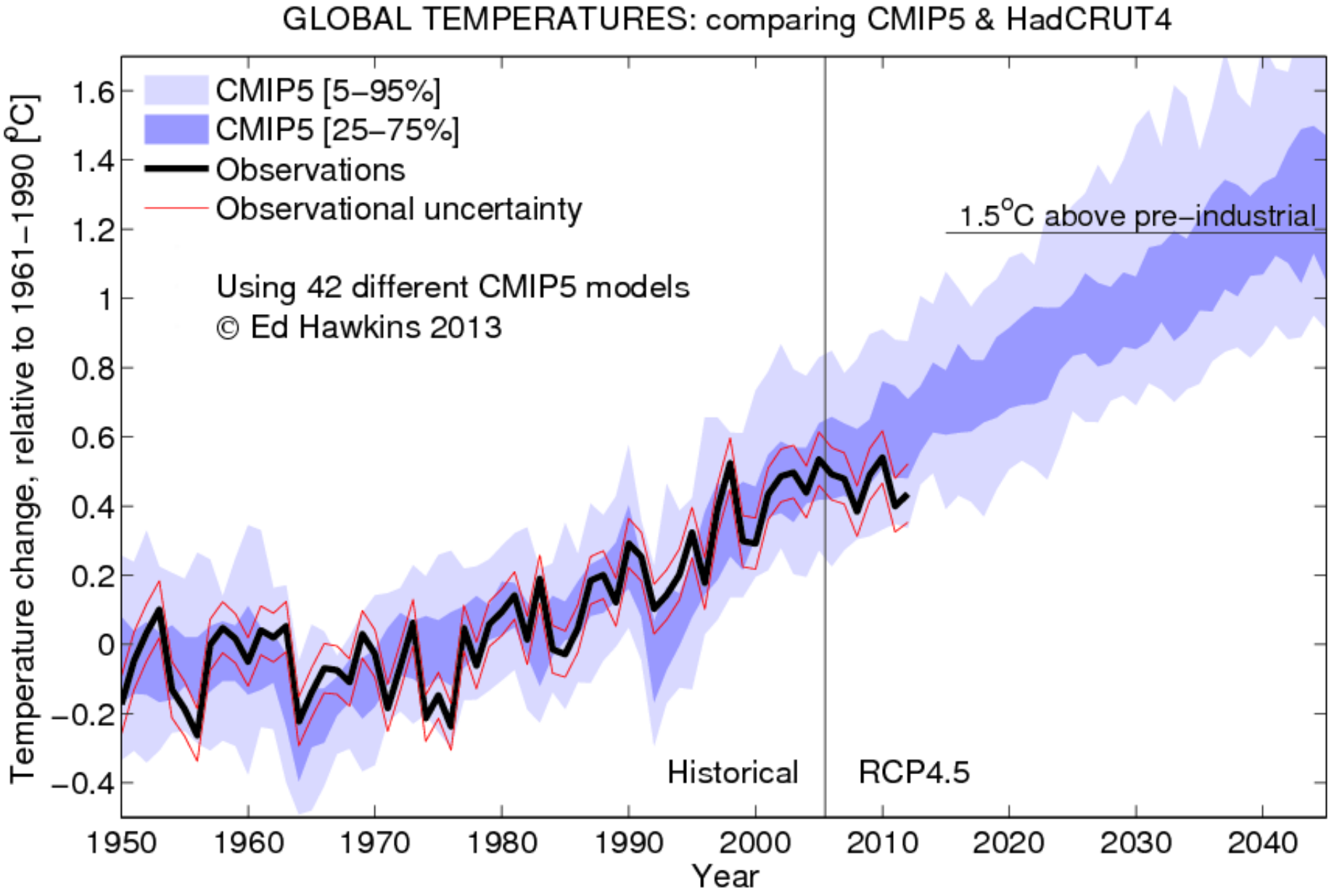
Climate

Emissions and Scenarios

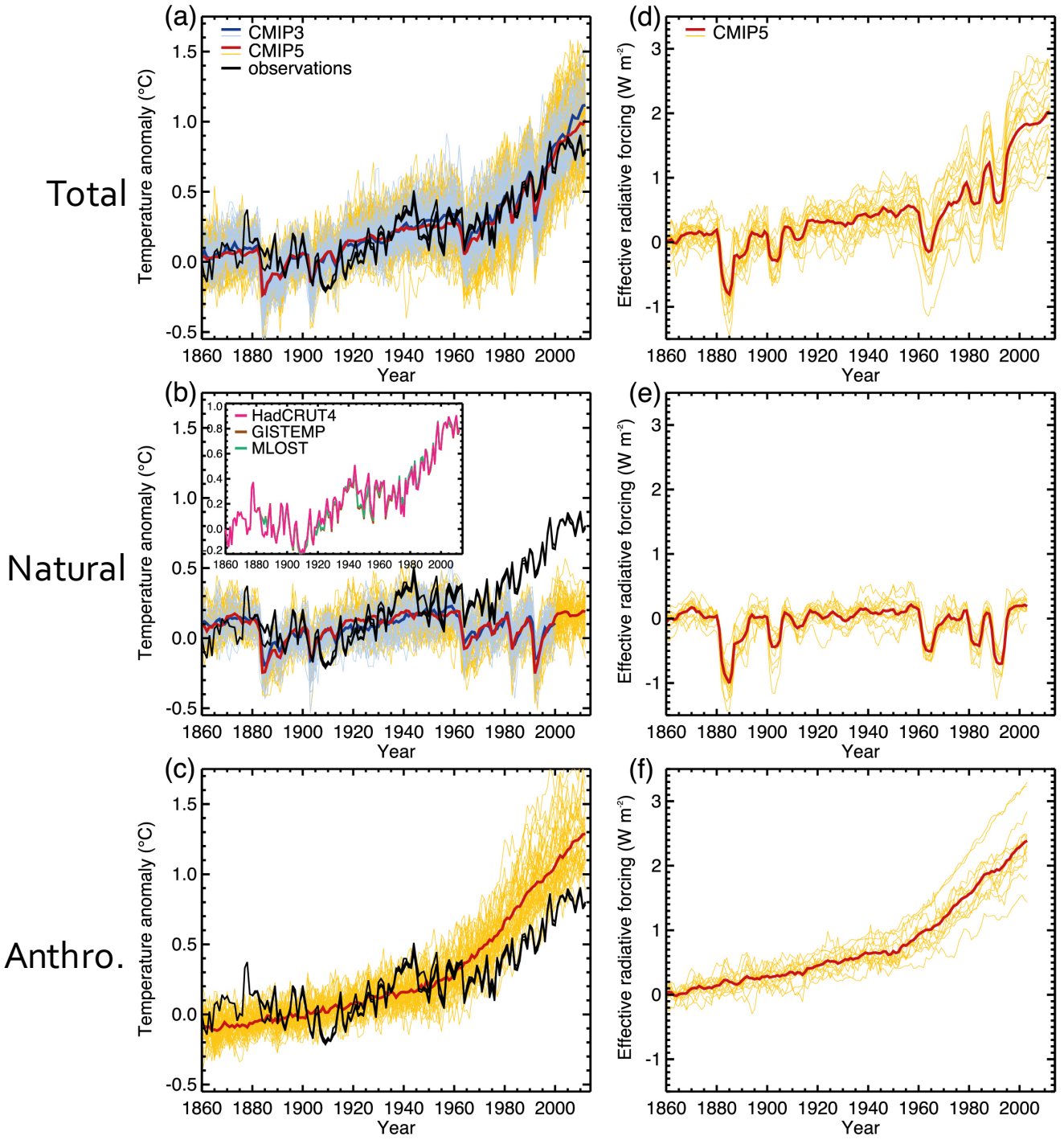


IPCC AR5, Ch. 8

Global surface temperature

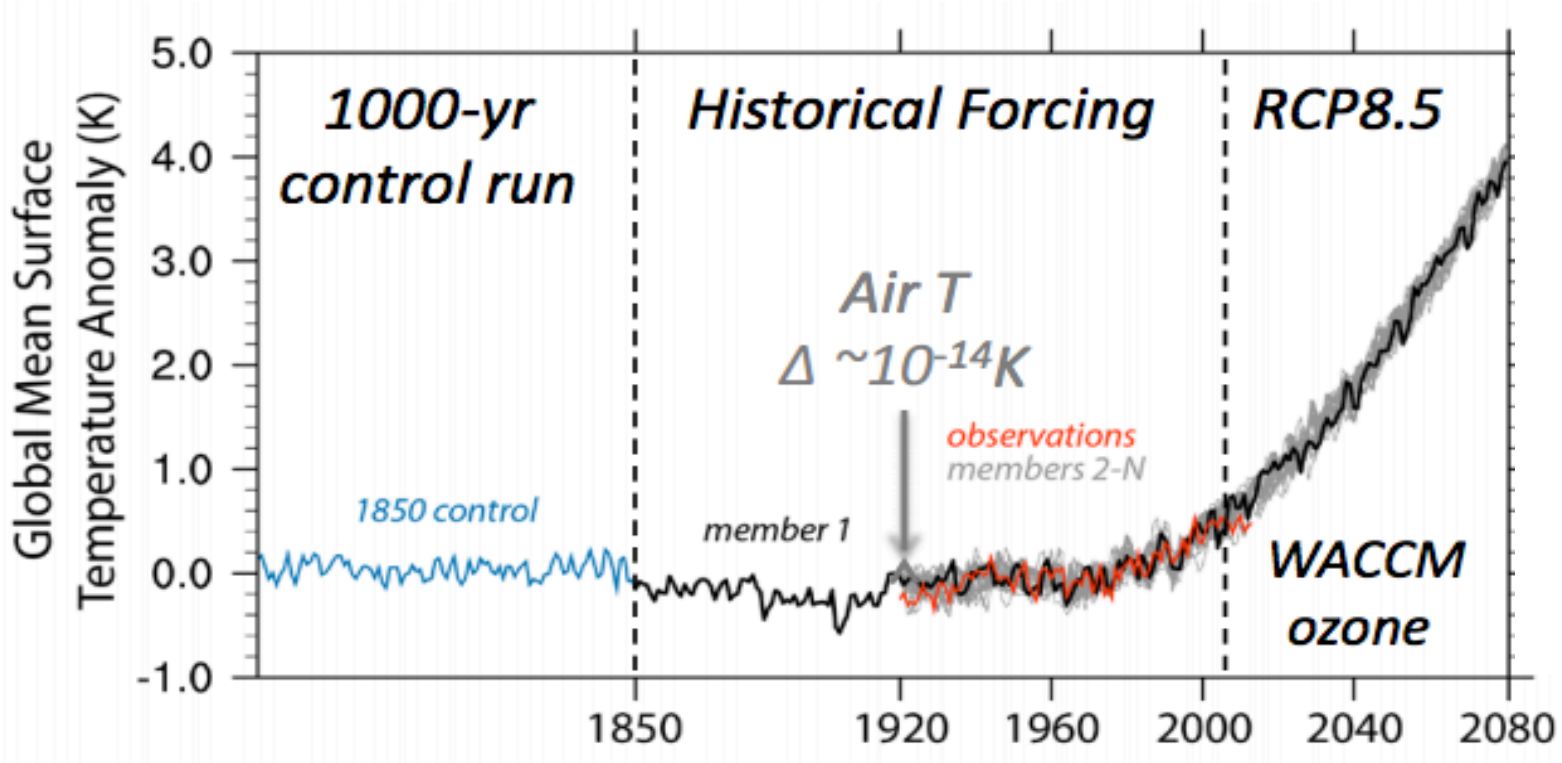


Natural vs anthropogenic historical TS change



IPCC AR5 Ch. 10

Internal variability and ensembles



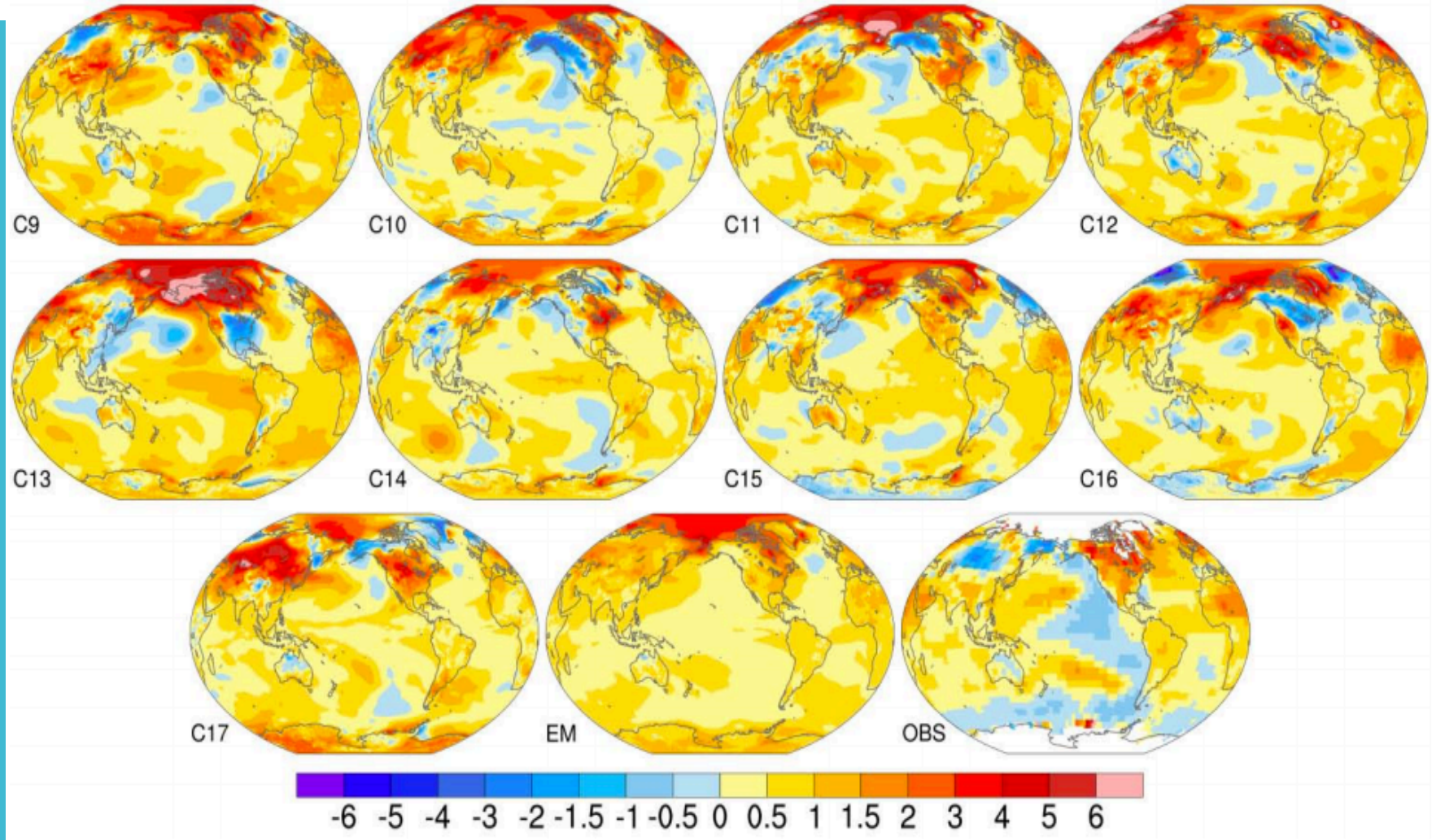
40 runs (NCAR/U. Toronto)

1920-2100

Same forcing

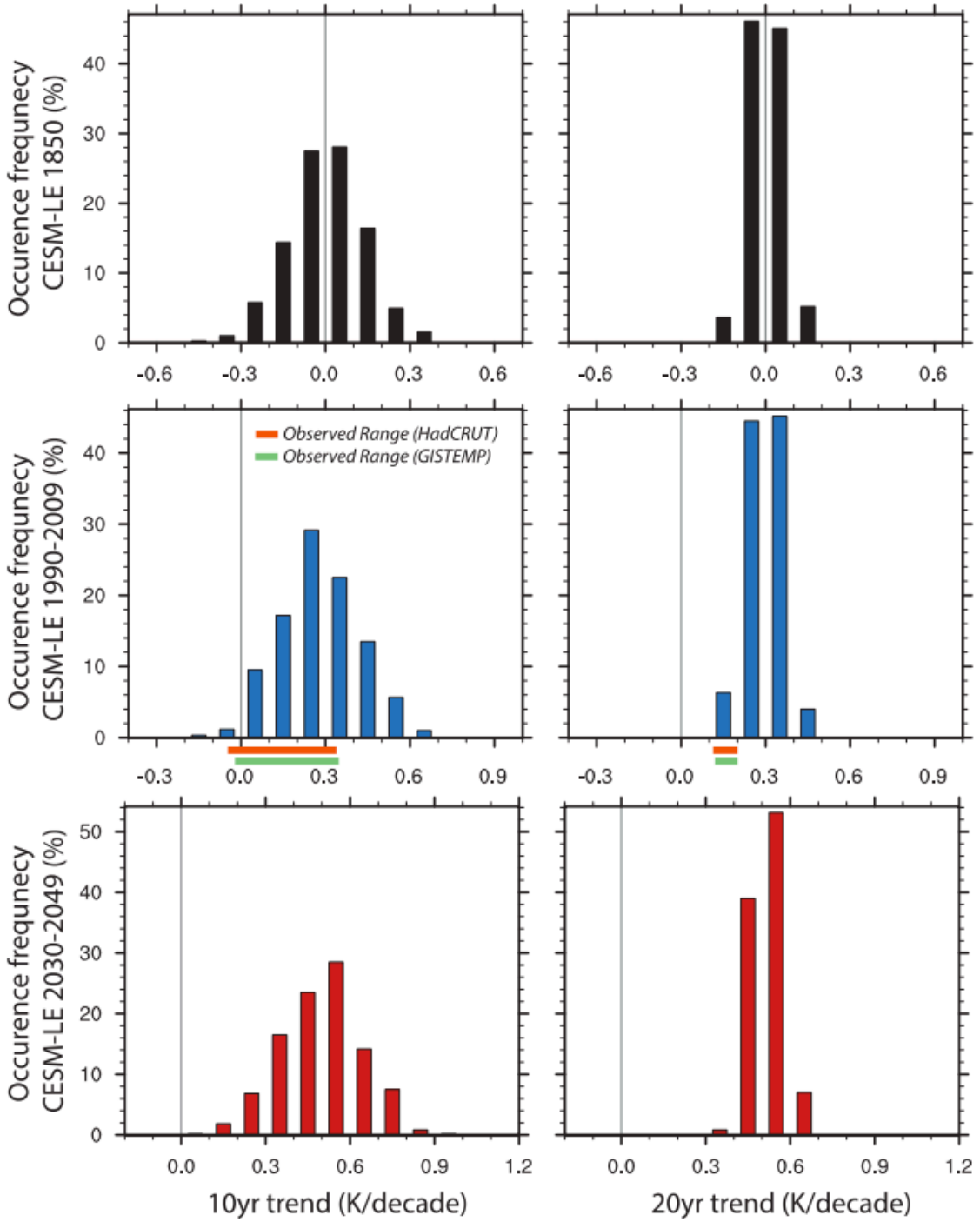
Same initial conditions except for round-off perturbation to initial air temperature

Internal variability and ensembles



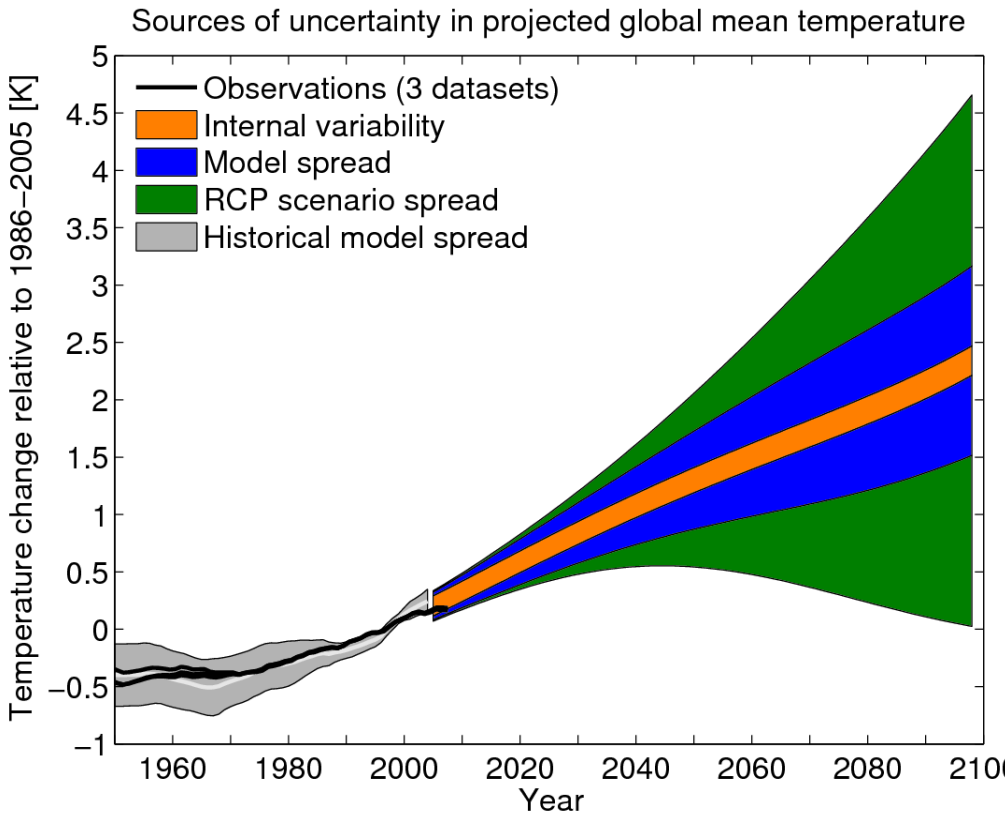
Panels show 1979-2012 DJF surface temperature trends for 9 ensemble members, the ensemble mean, and observations.

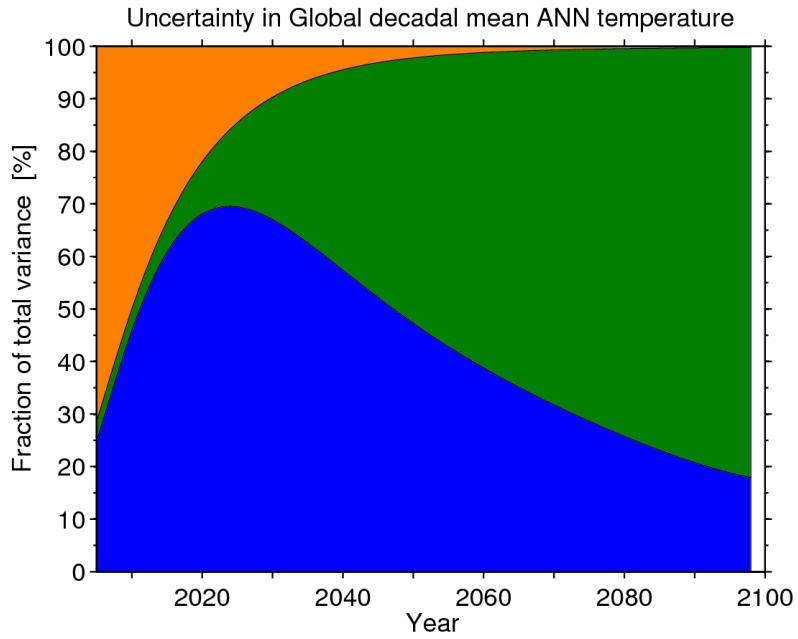
Internal variability and ensembles: T trend distribution

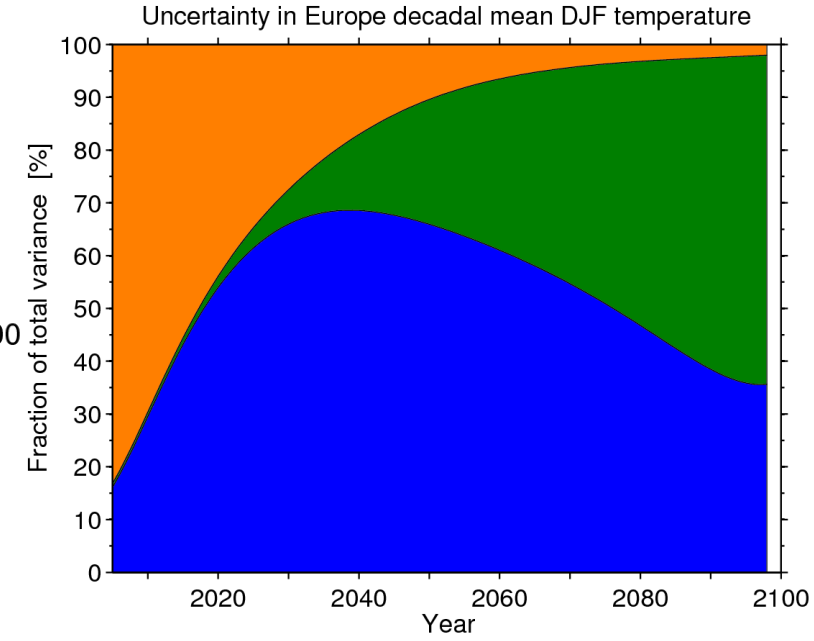


Kay et al., 2015

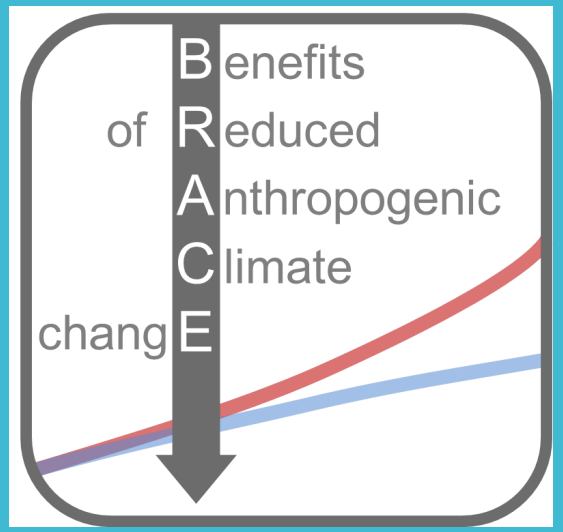
Sources of uncertainty



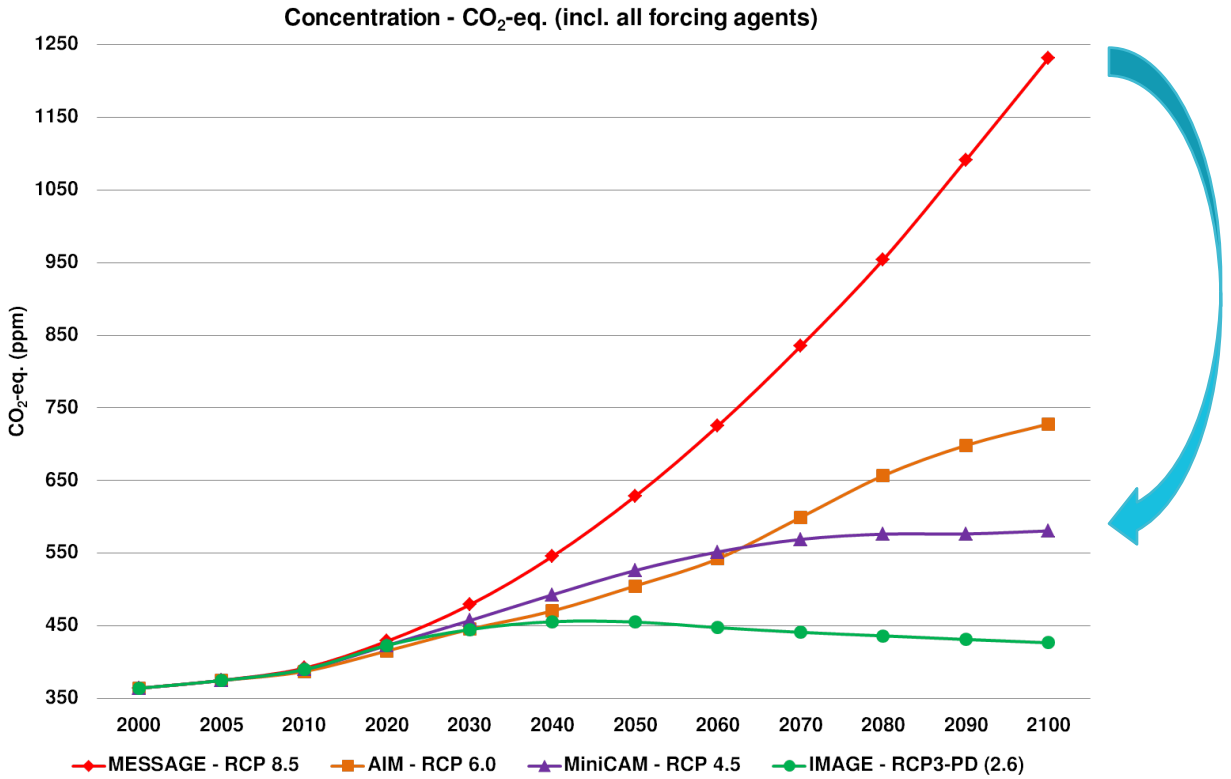




Question we are trying to answer:



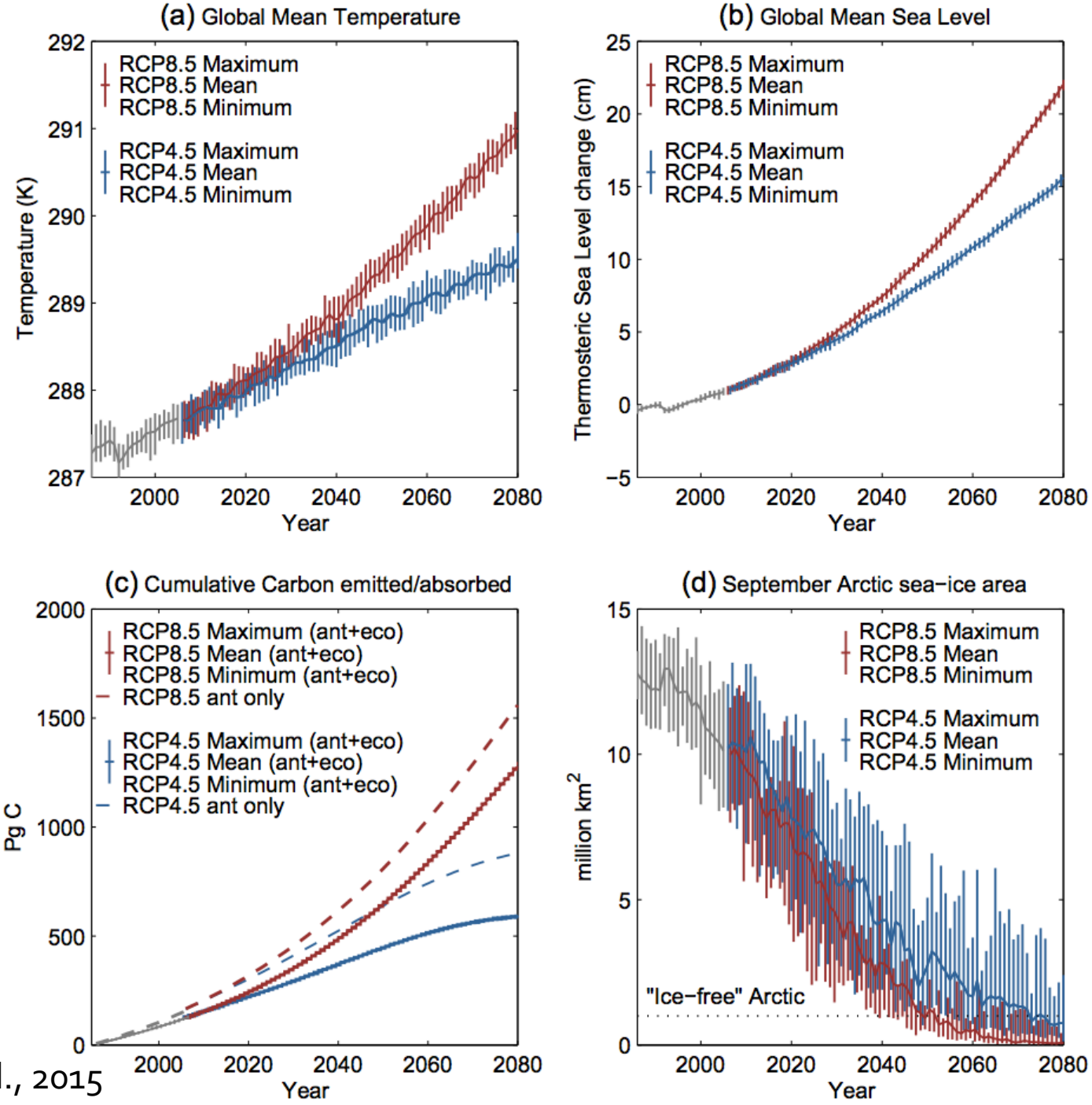
What are the benefits of mitigating from a high-emission scenario (RCP8.5) to a medium-emission scenario (RCP4.5)?



Methodology

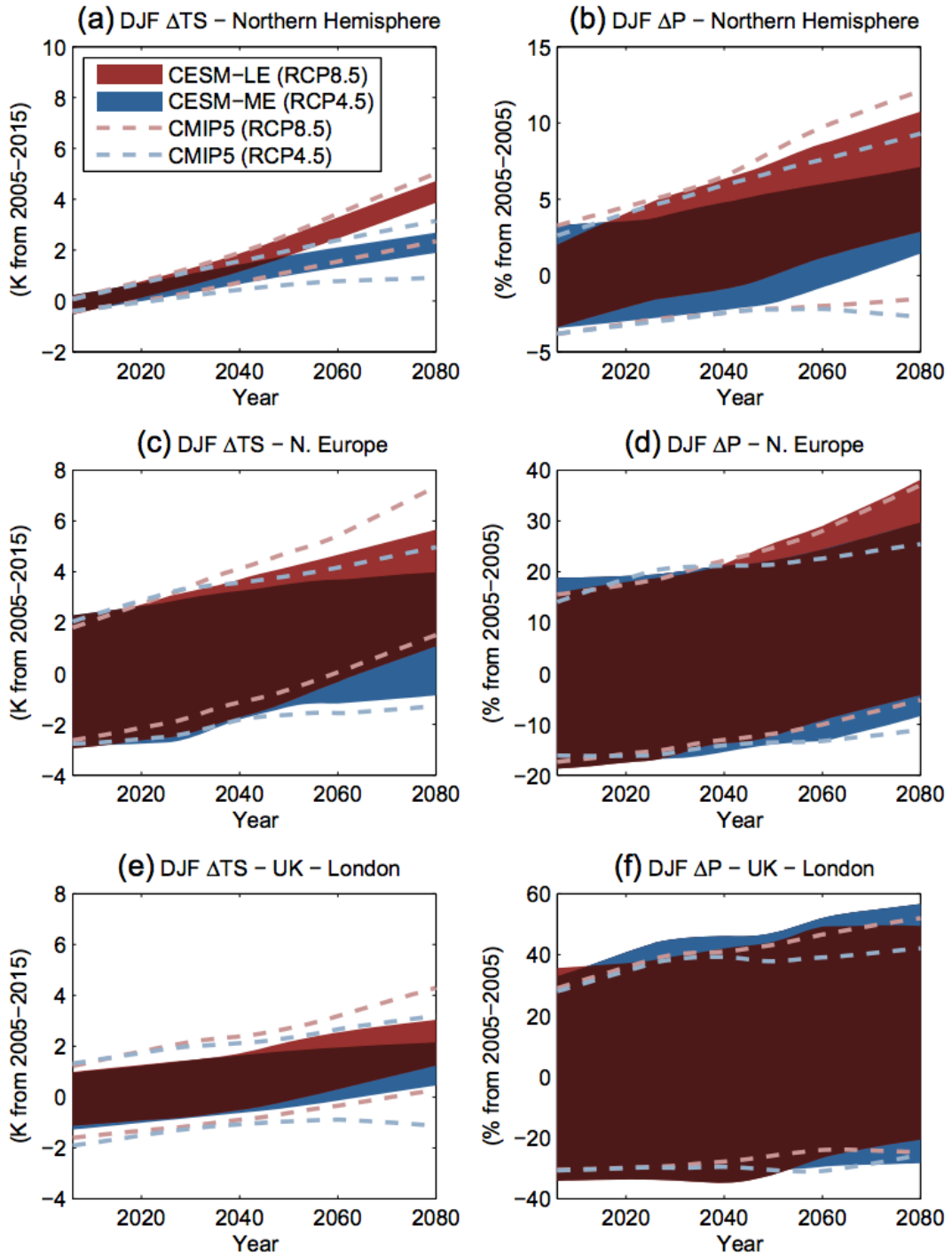
- Builds upon the RCP8.5 Large Ensemble simulations
- Only requires additional RCP4.5 simulations (15)
- Perform enough ensemble members to provide statistical information on differences (e.g. significance of differences), including extremes

Large scale comparison of RCP8.5 and RCP4.5



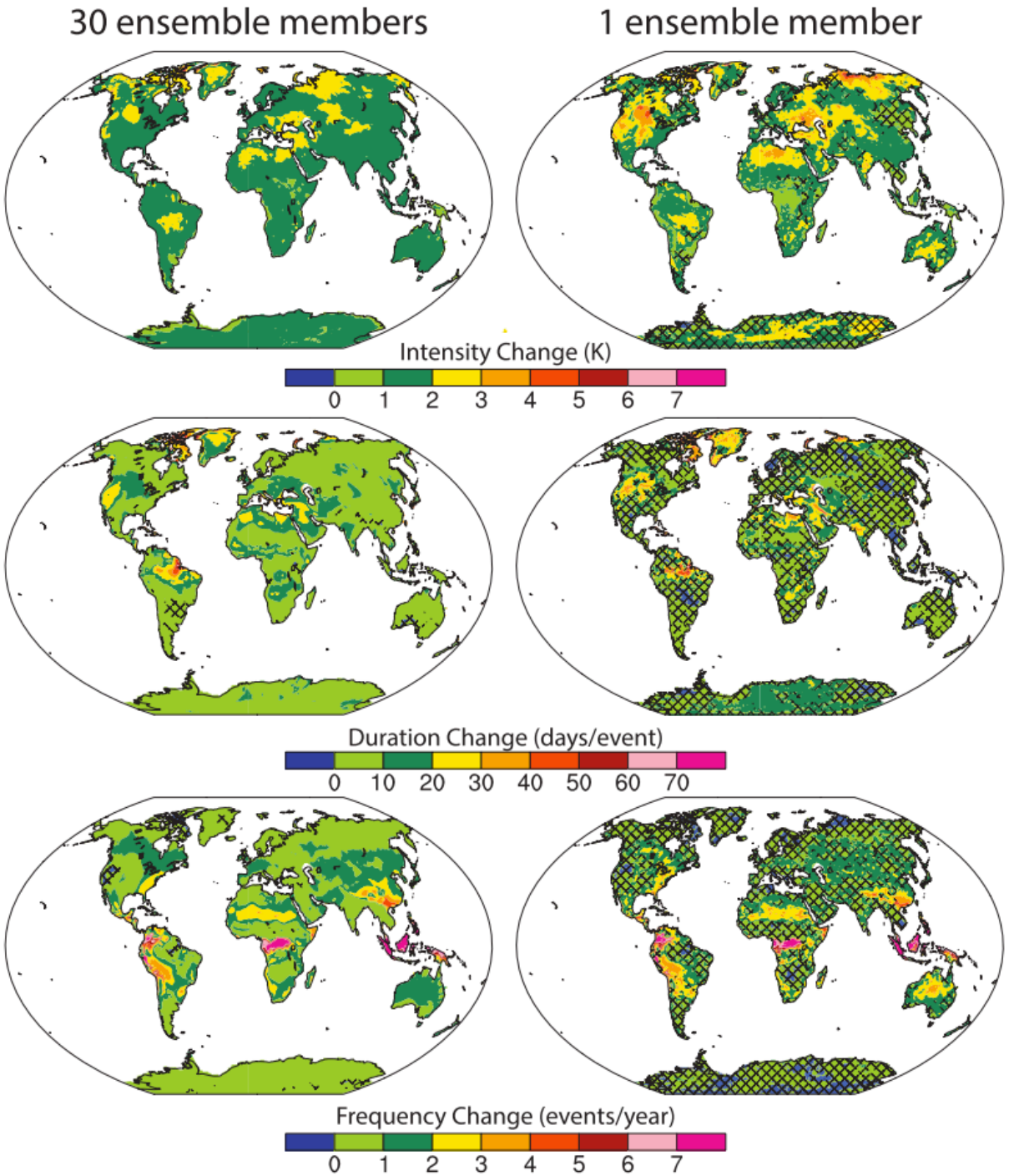
Sanderson et al., 2015

Regional trends: LE and CMIP5



Sanderson et al., 2015

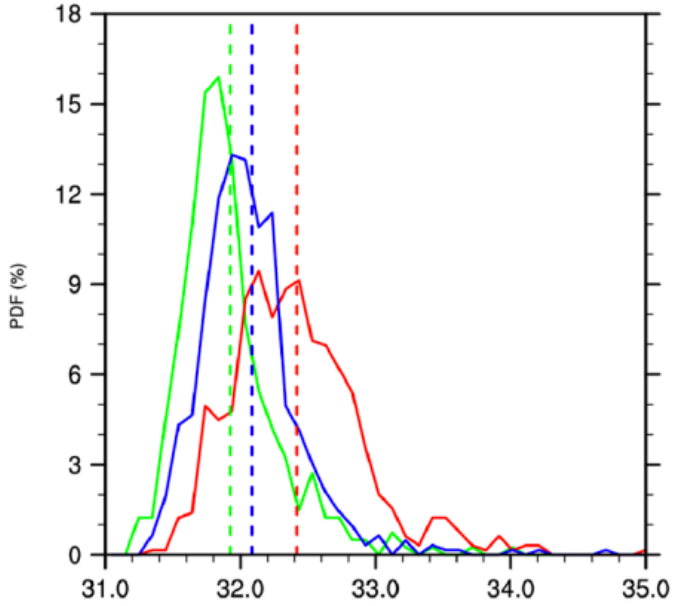
Heat waves and ensemble size



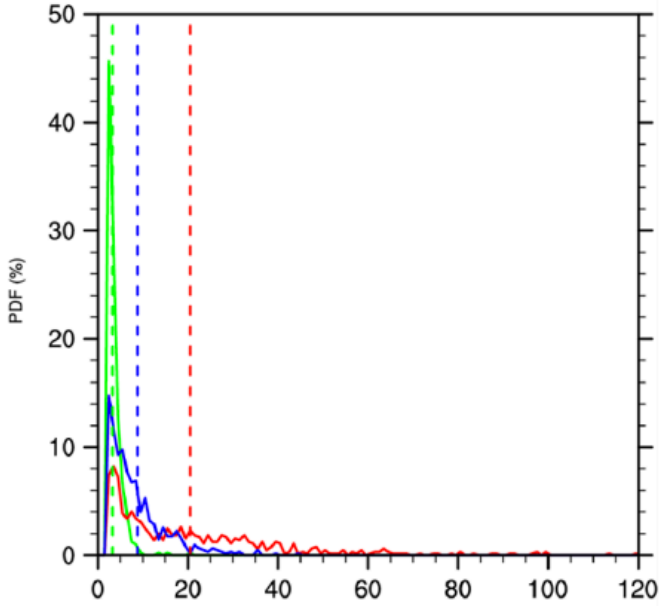
2040s-2010s change in heat wave intensity, duration, and frequency. Hatching indicates differences insignificant at the 95% level using a Student's t-test

Kay et al., 2015

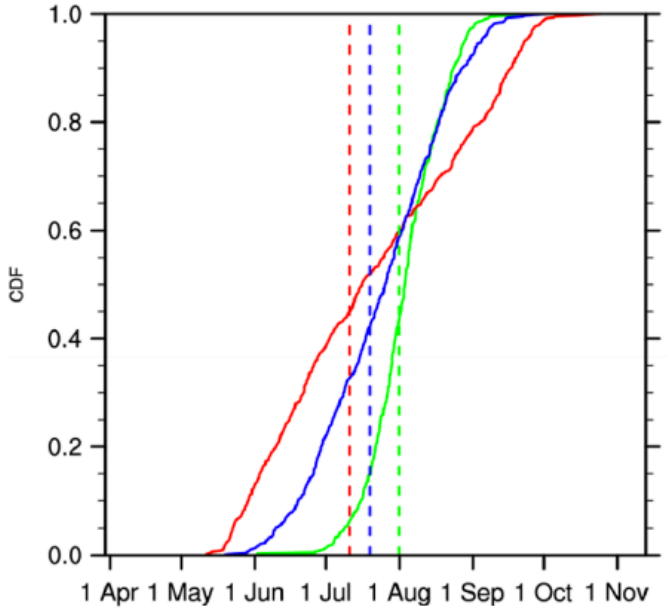
Focusing on extremes in urban areas



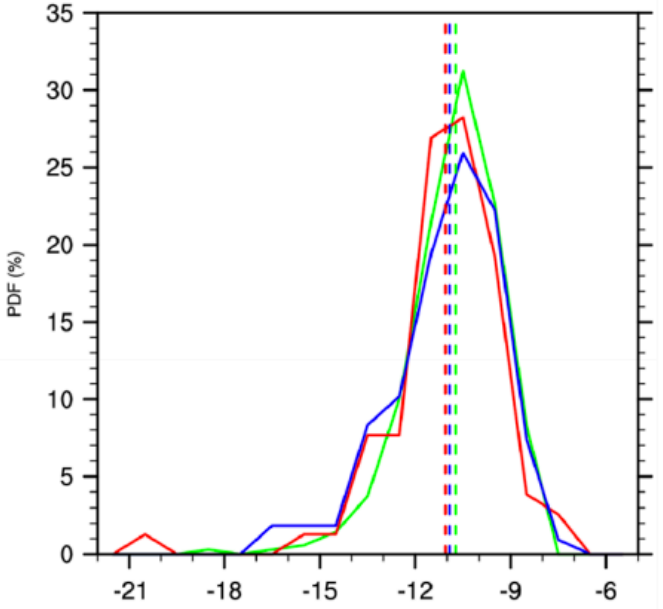
Heat wave intensity



Duration of heat waves



Start day of heat wave



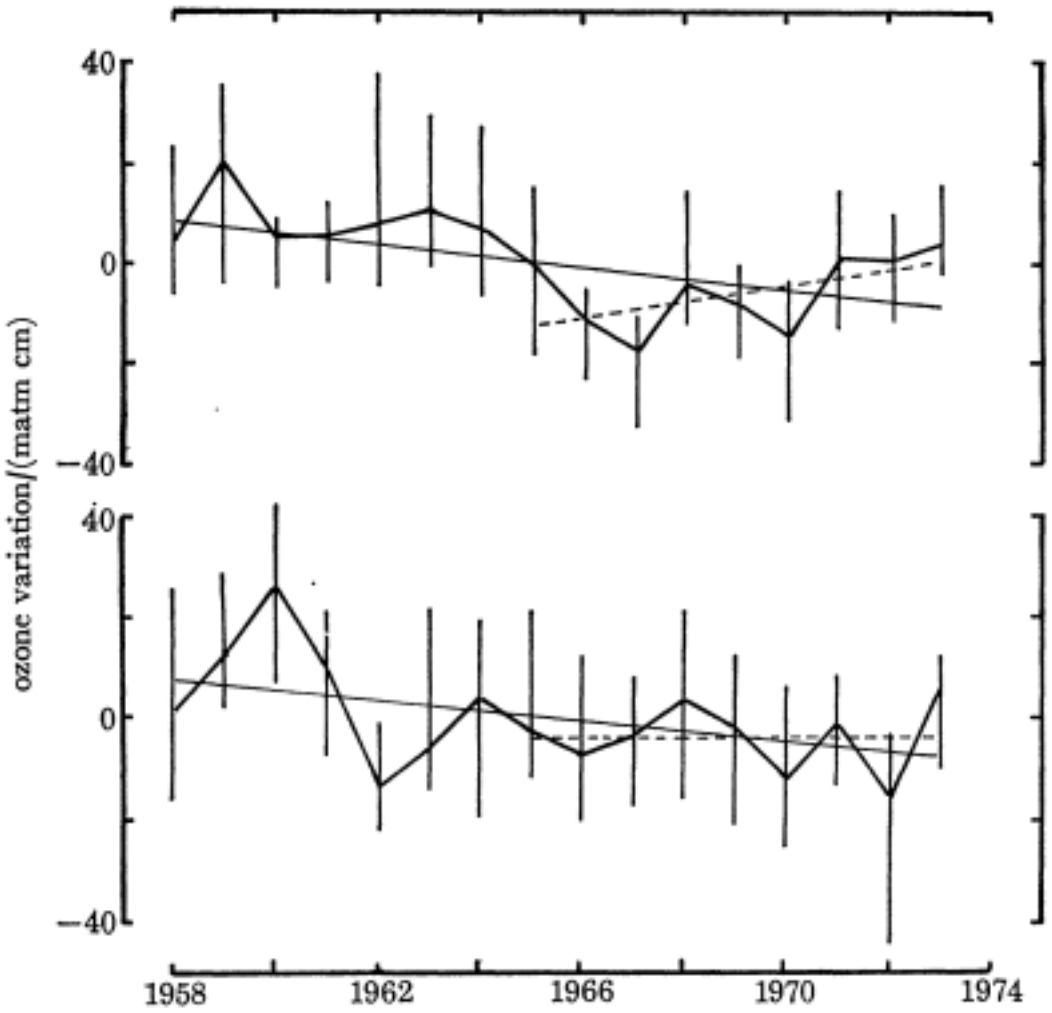
Cold wave intensity

Oleson et al., 2016

Antarctic ozone hole

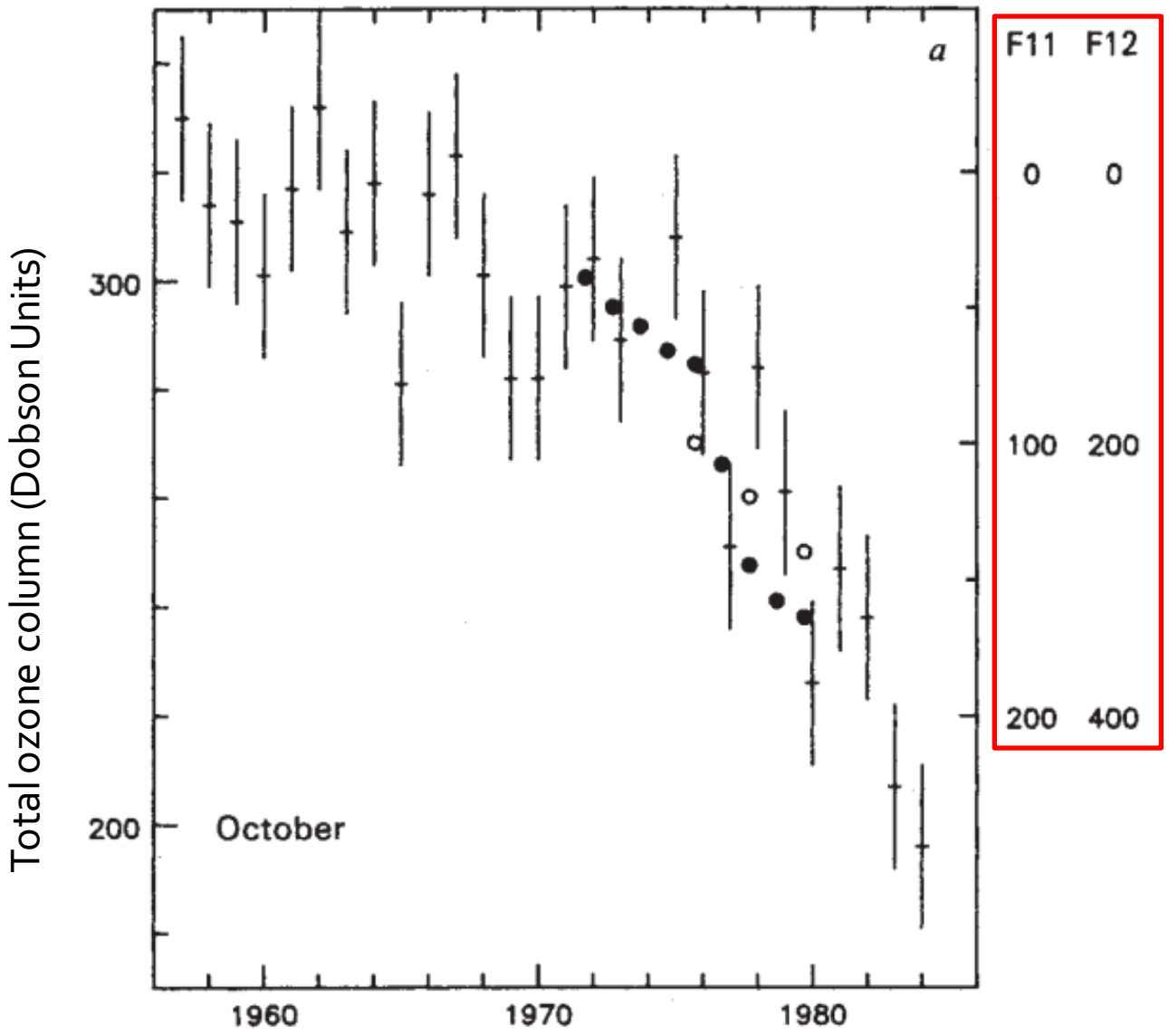
Observations

Total ozone column (Dobson Units)



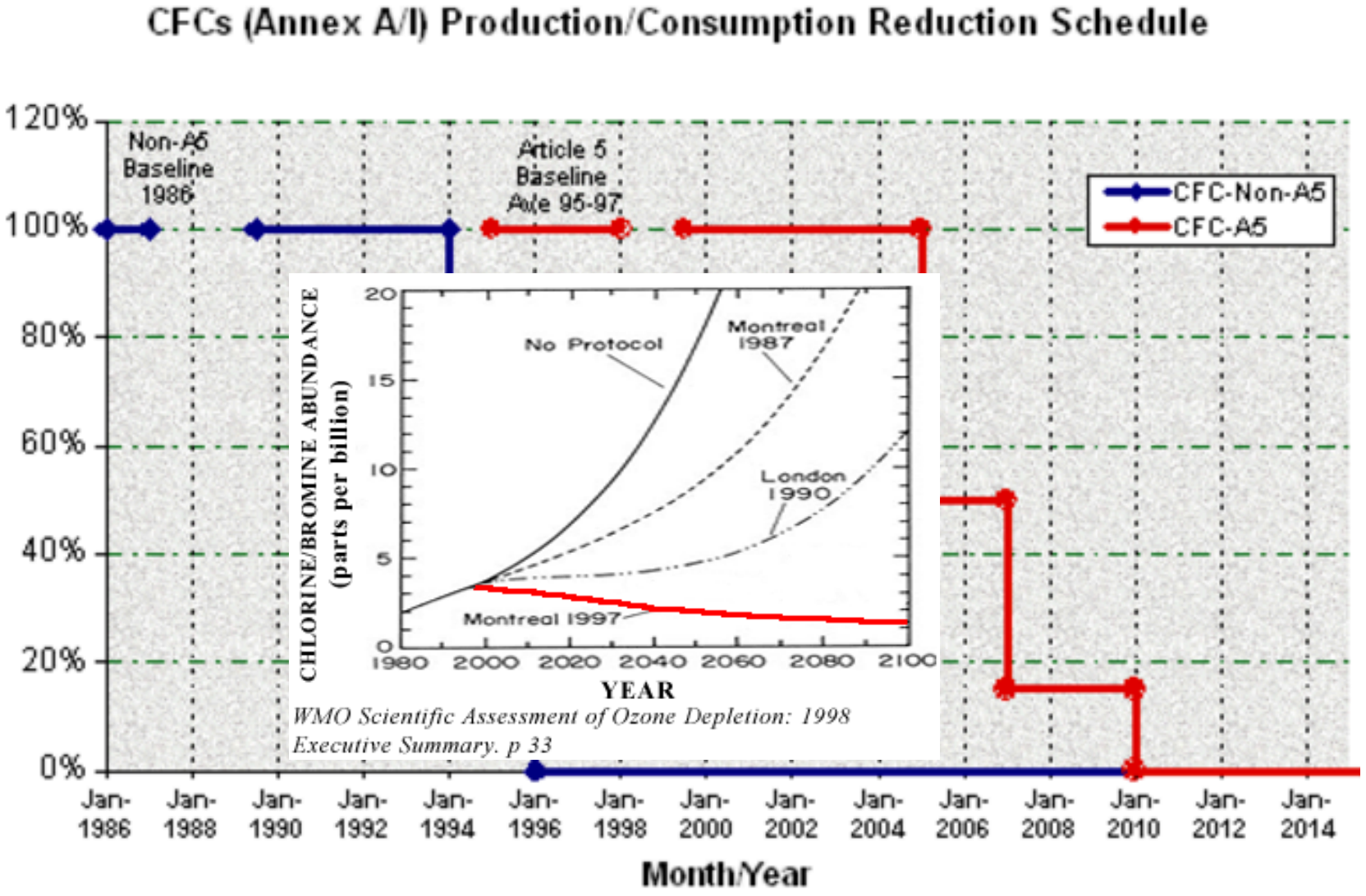
Farman, 1977

Observations

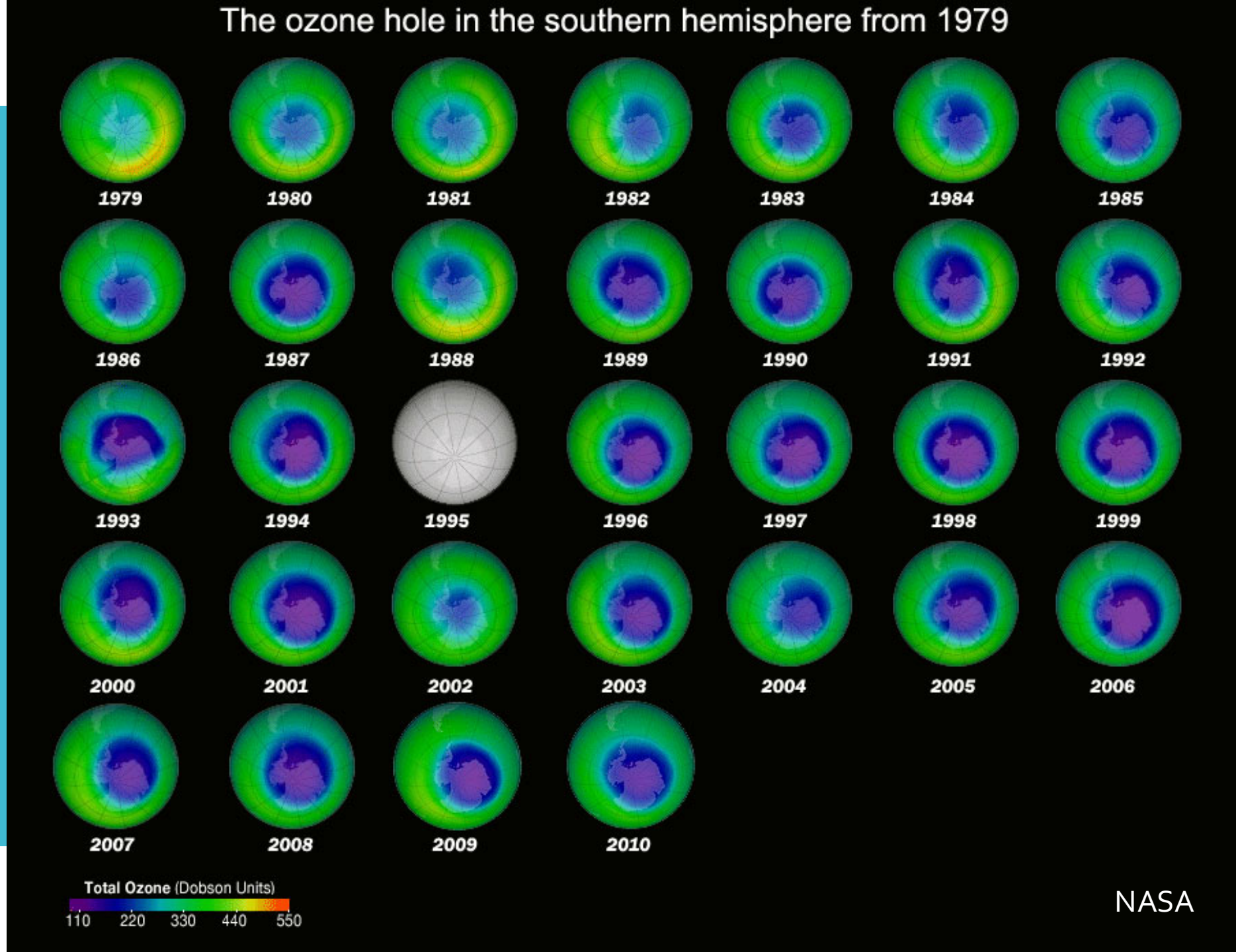


Farman et al., 1985

Montreal Protocol (1987) decisions and impact

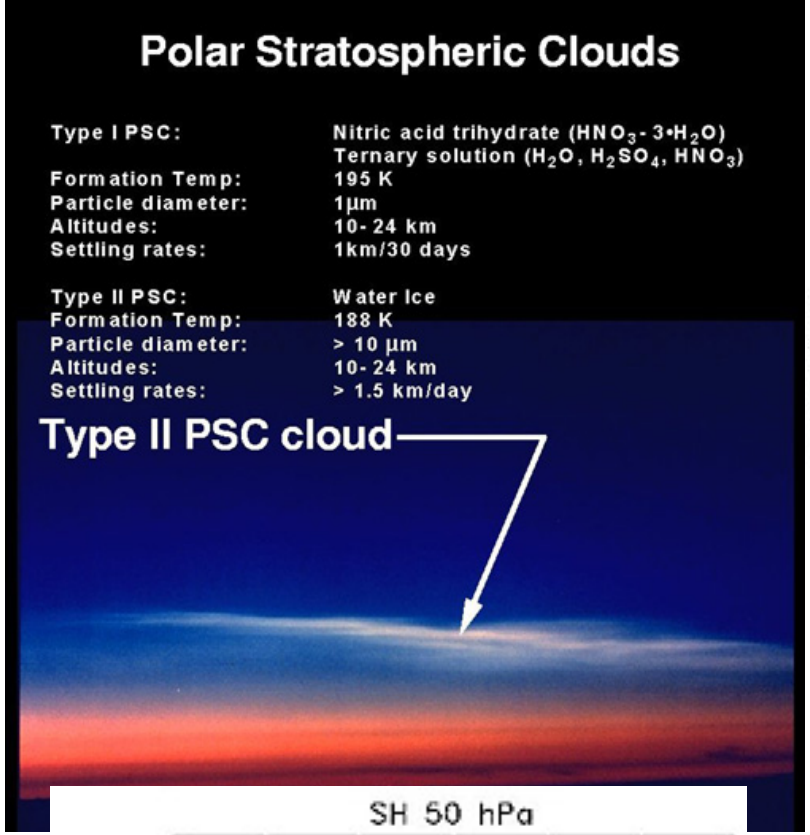


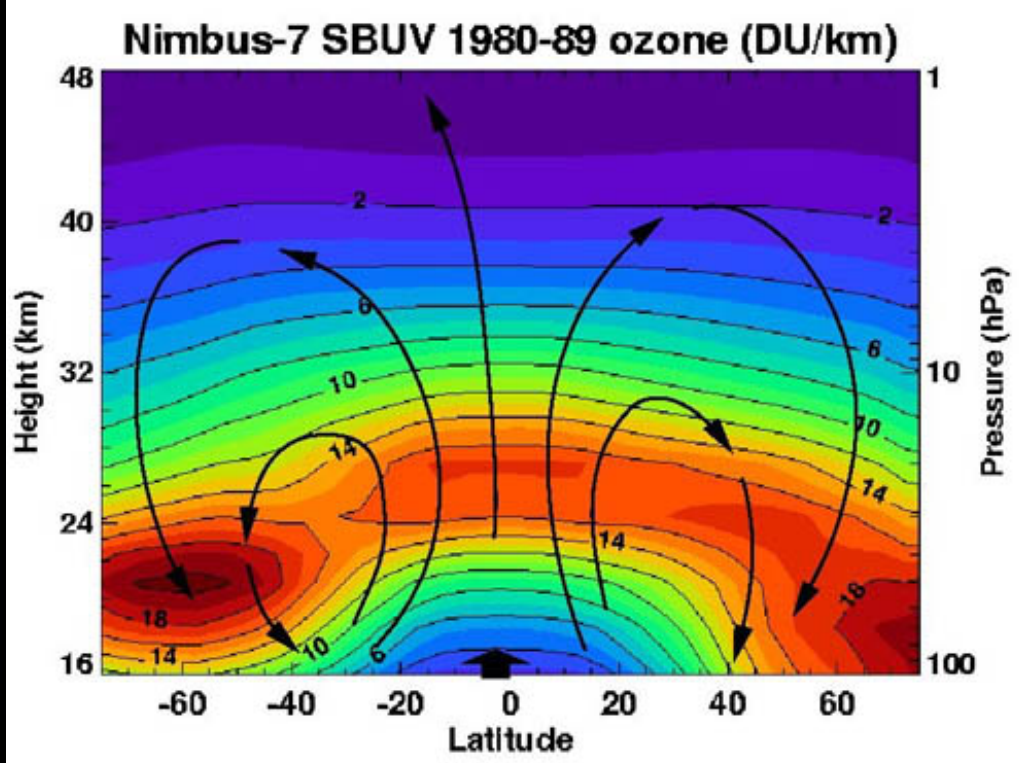
Observations indicate large interannual variability

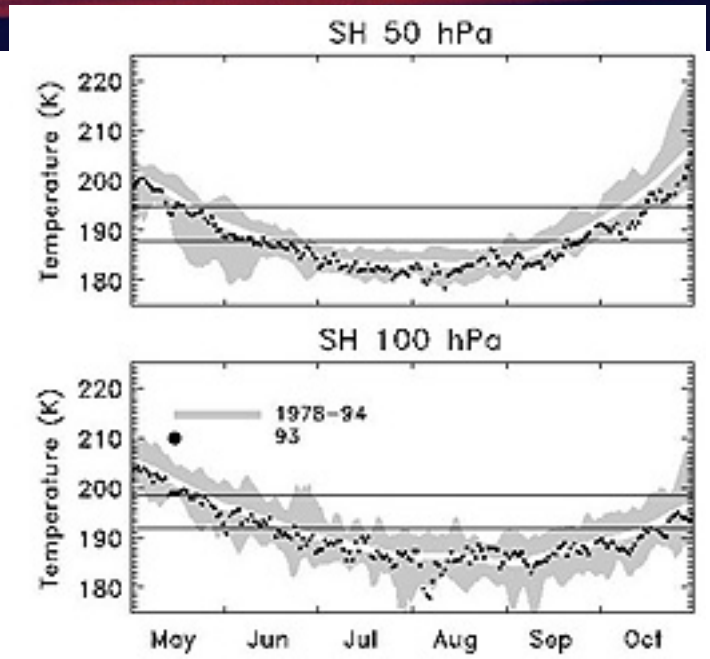


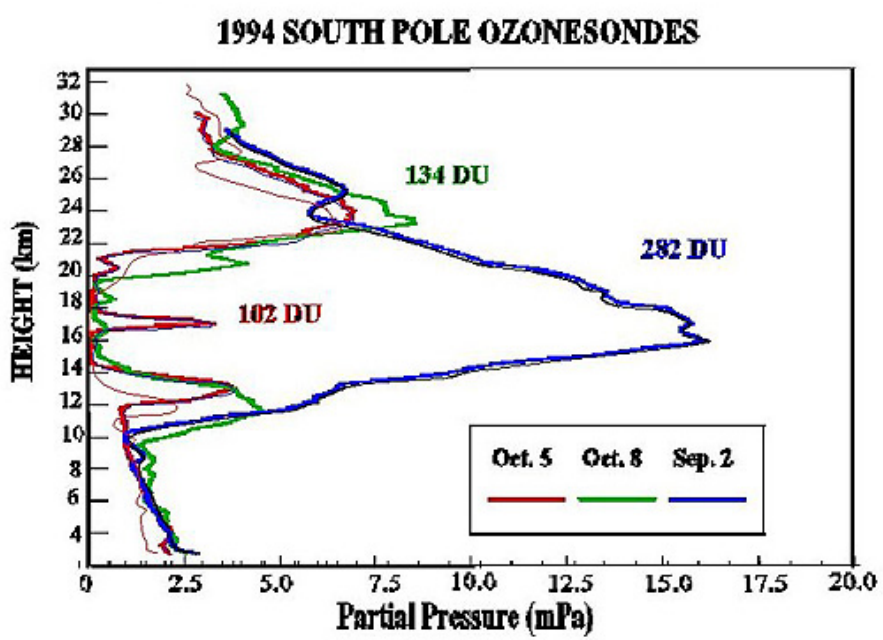
NASA

A combination of dynamics and chemistry

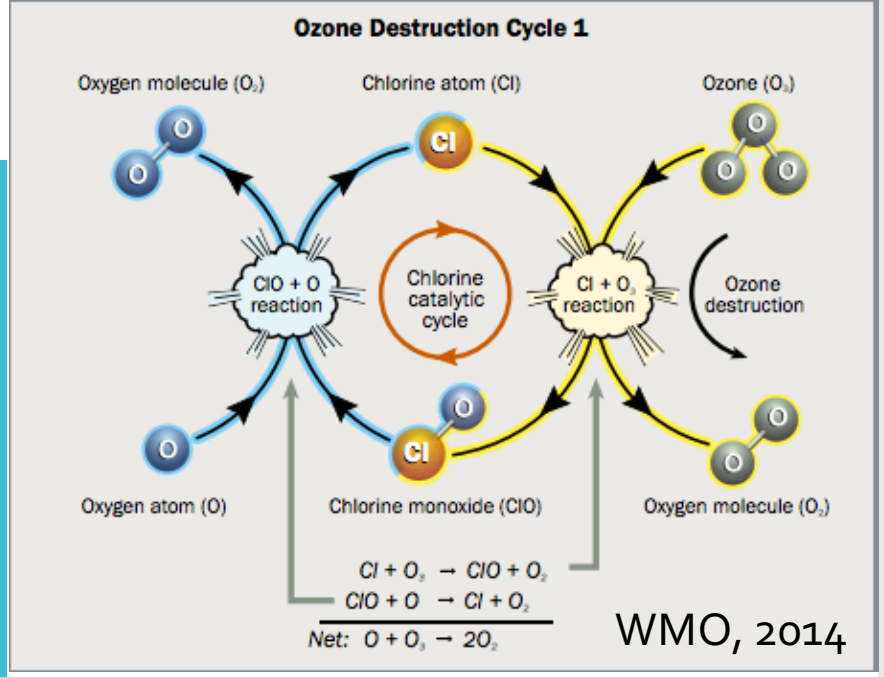








Link to DCMIP!



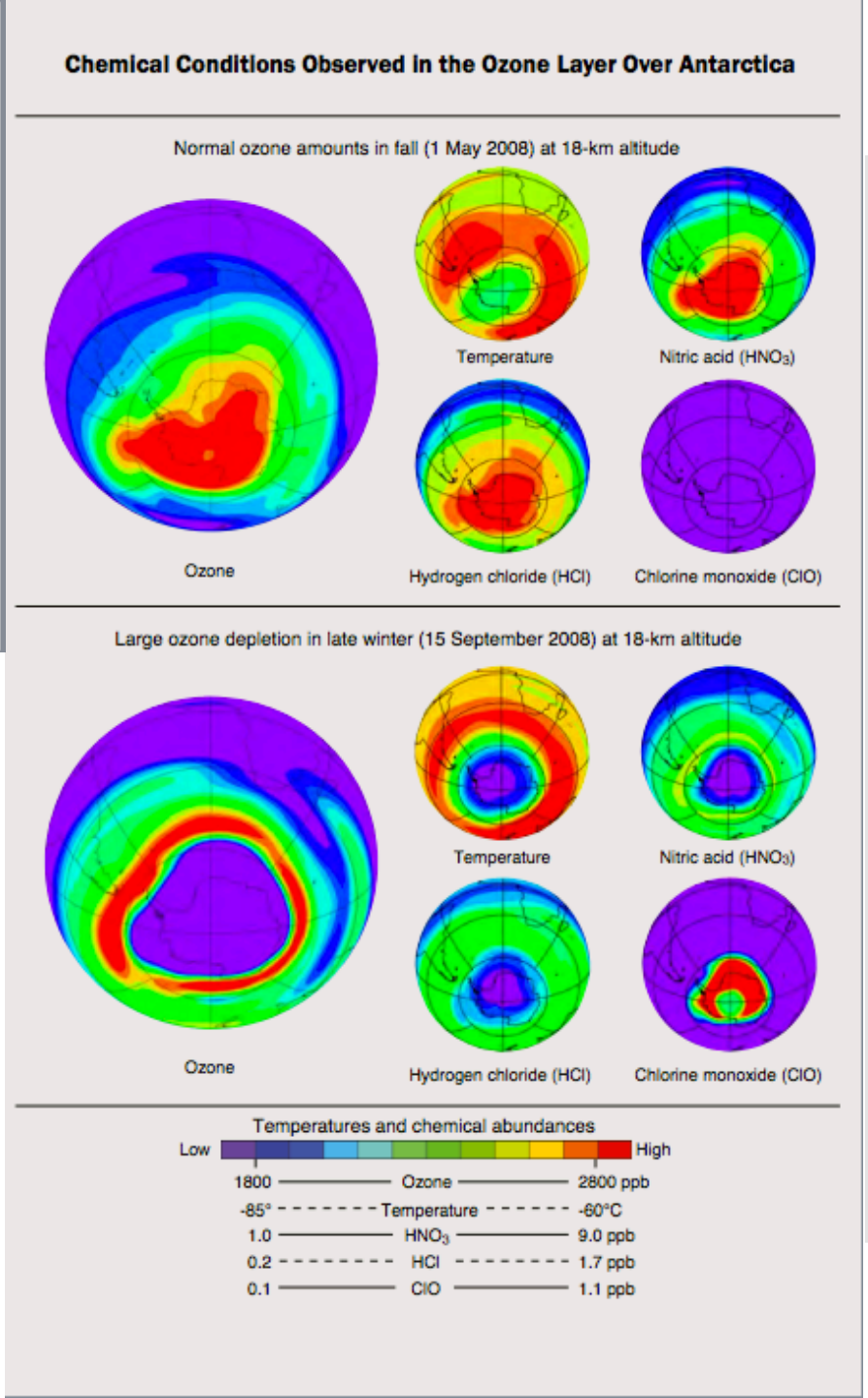
WMO, 2014

$$X_2 \xrightarrow{k_1} 2X, \qquad \frac{dX}{dt} = 2k_1X_2 - 2k_2XX,$$

$$X + X \xrightarrow{k_2} X_2, \qquad \frac{dX_2}{dt} = -k_1X_2 + k_2XX,$$

$$X_T = X + 2X_2.$$

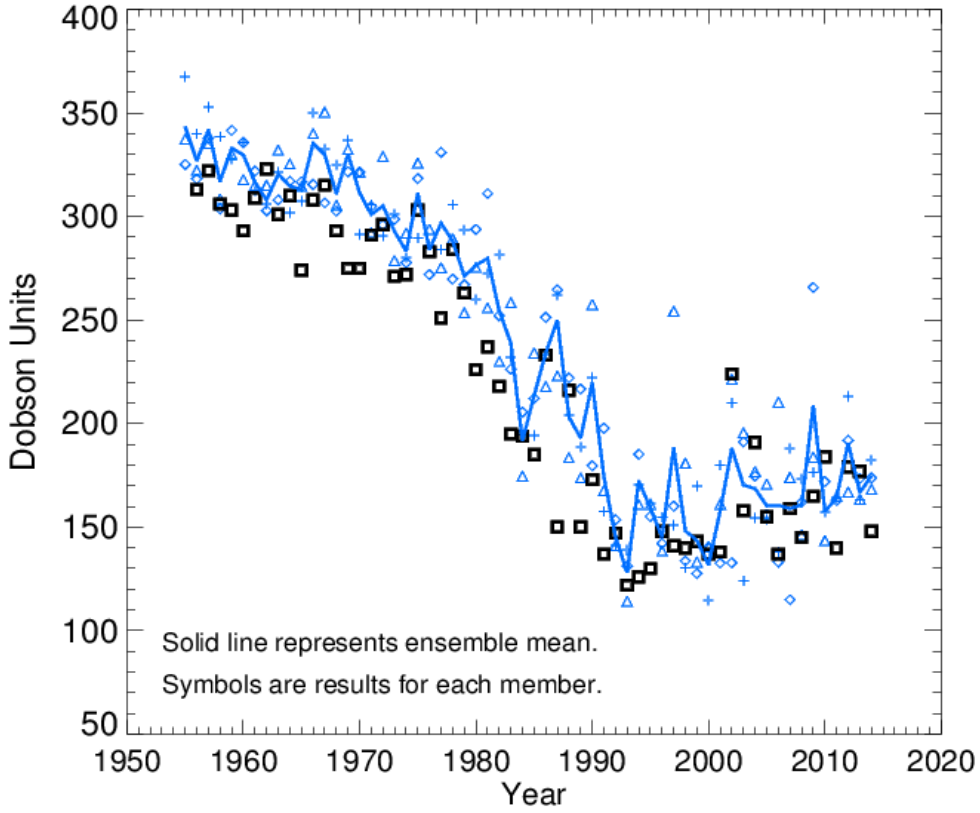
Toy chemistry (Lauritzen et al., 2015)

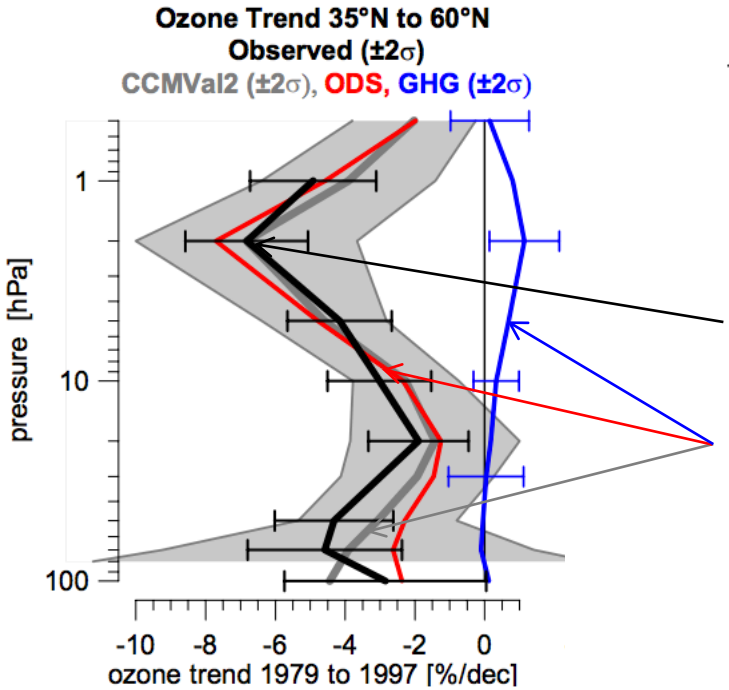


Modeling the separate role of ODS and climate

Observed and WACCM simulated October total ozone column over Halley Bay (Antarctica)

From D. Kinnison



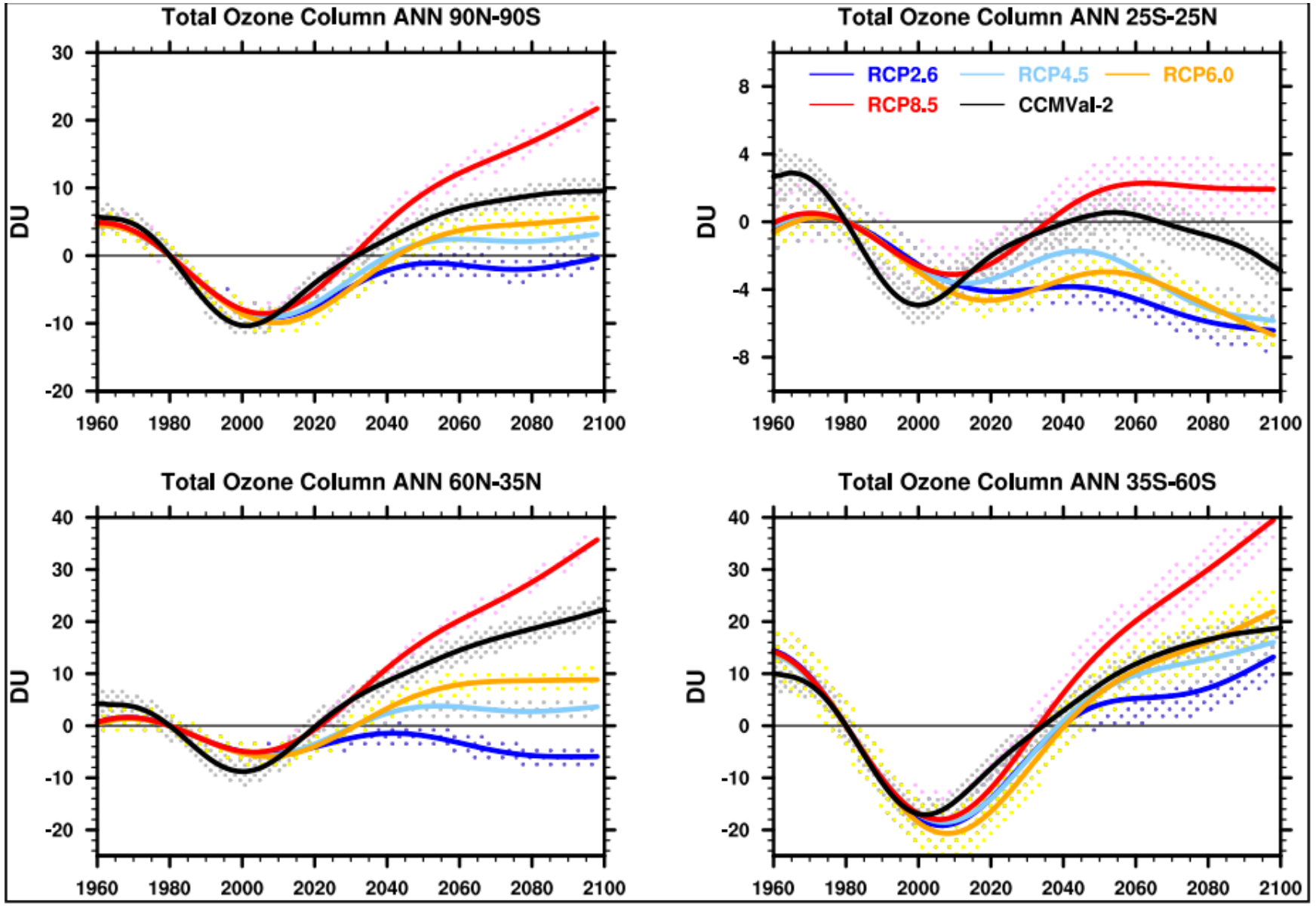


Observations

Model simulations (incl. WACCM above)

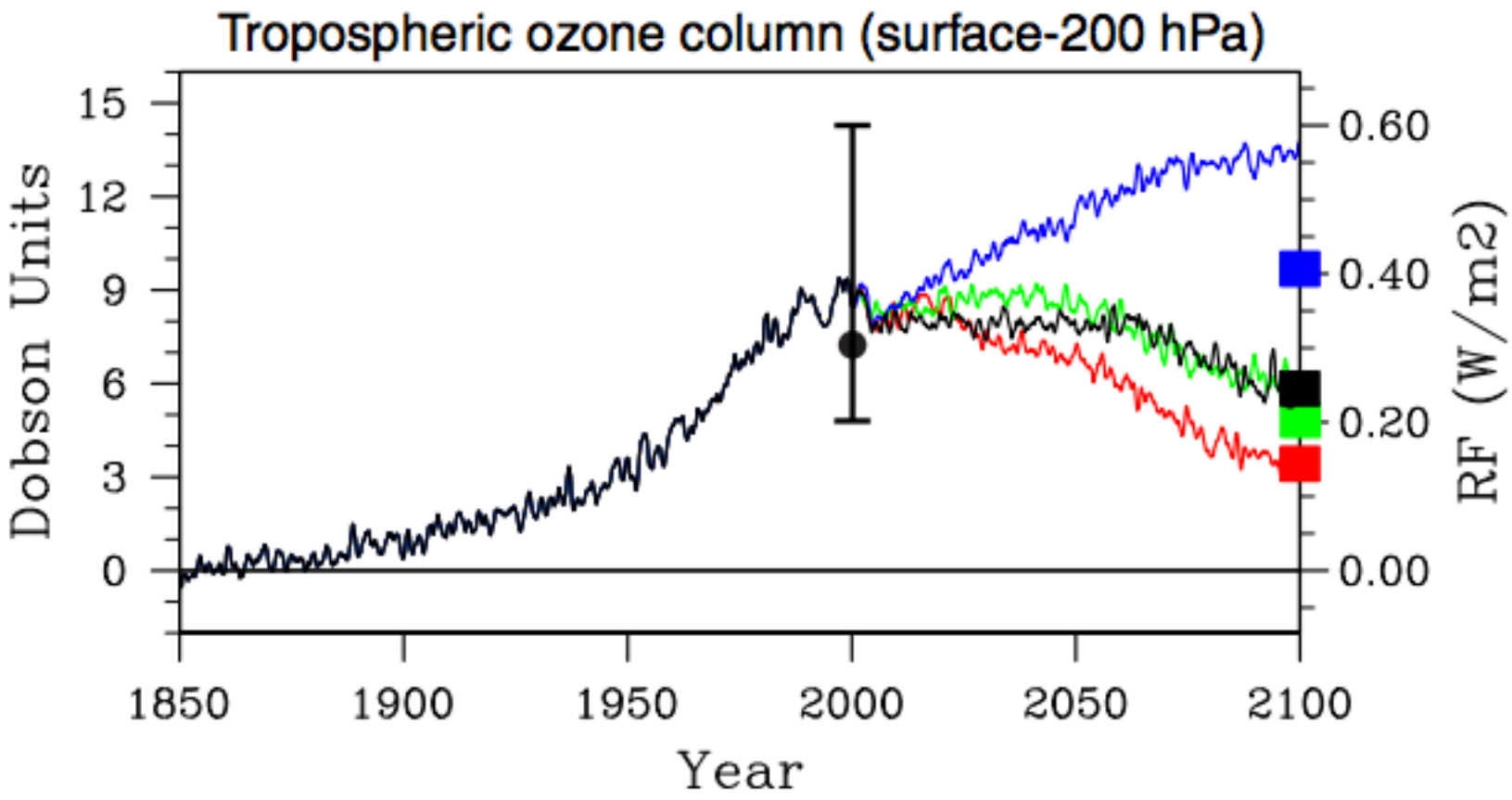
WMO Ozone Assessment, 2014

Projections and return to 1980



WMO, 2014

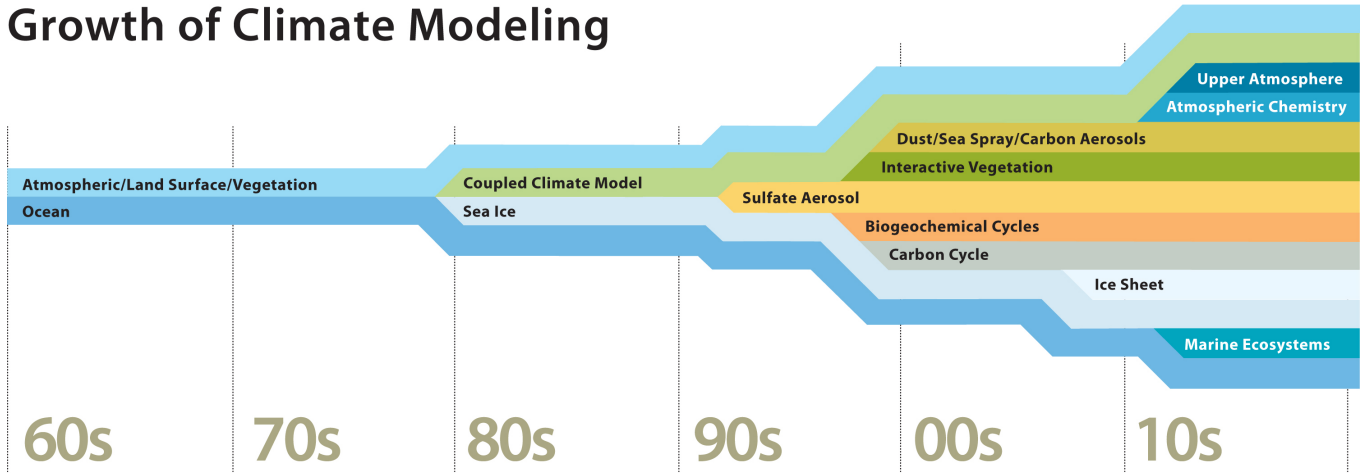
Role of tropospheric ozone

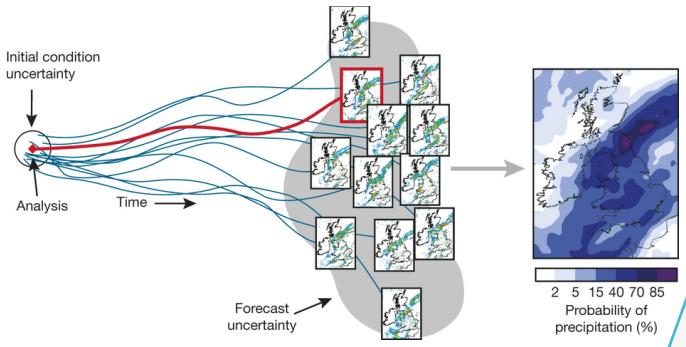


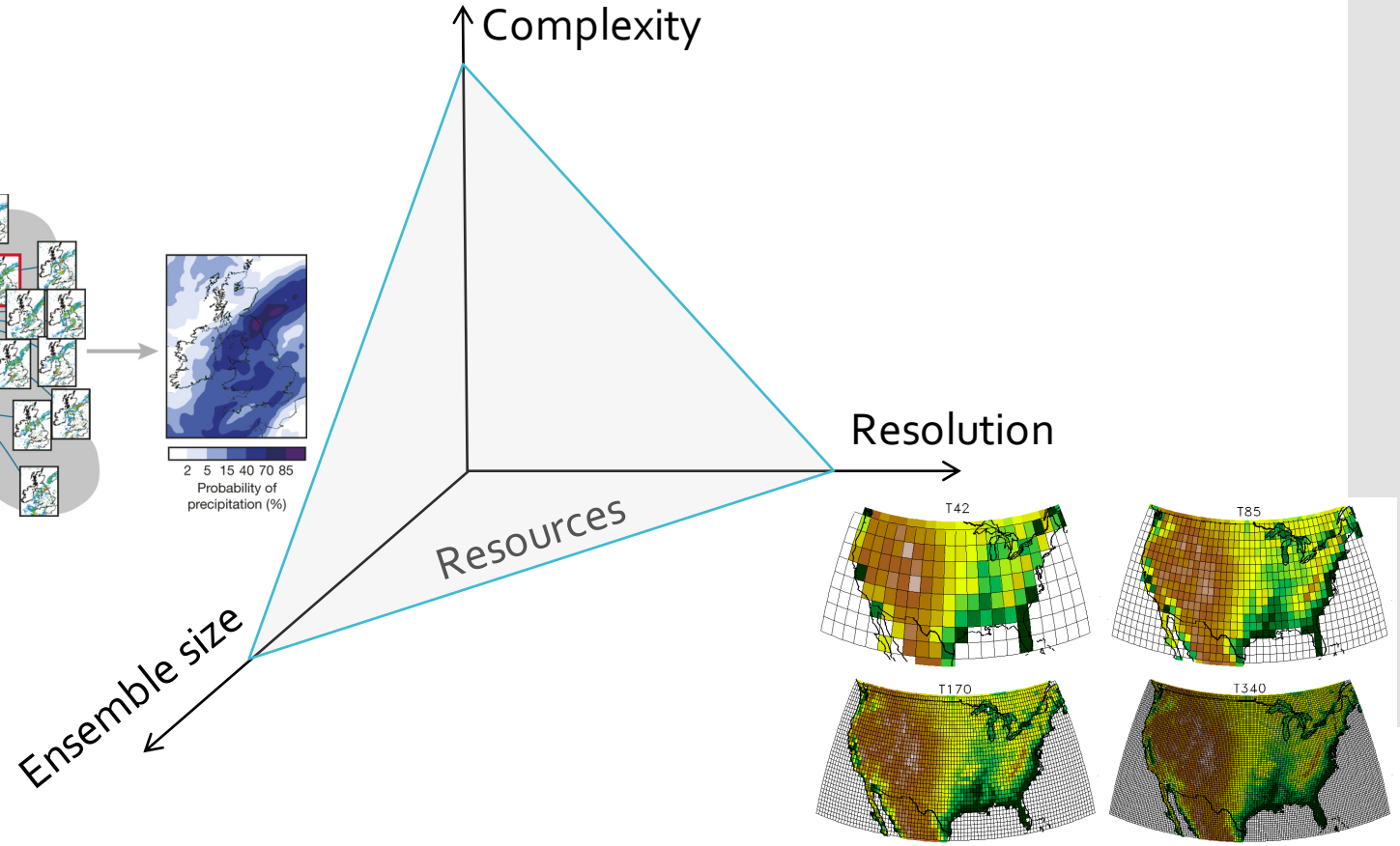
Lamarque et al., 2011

Outlook

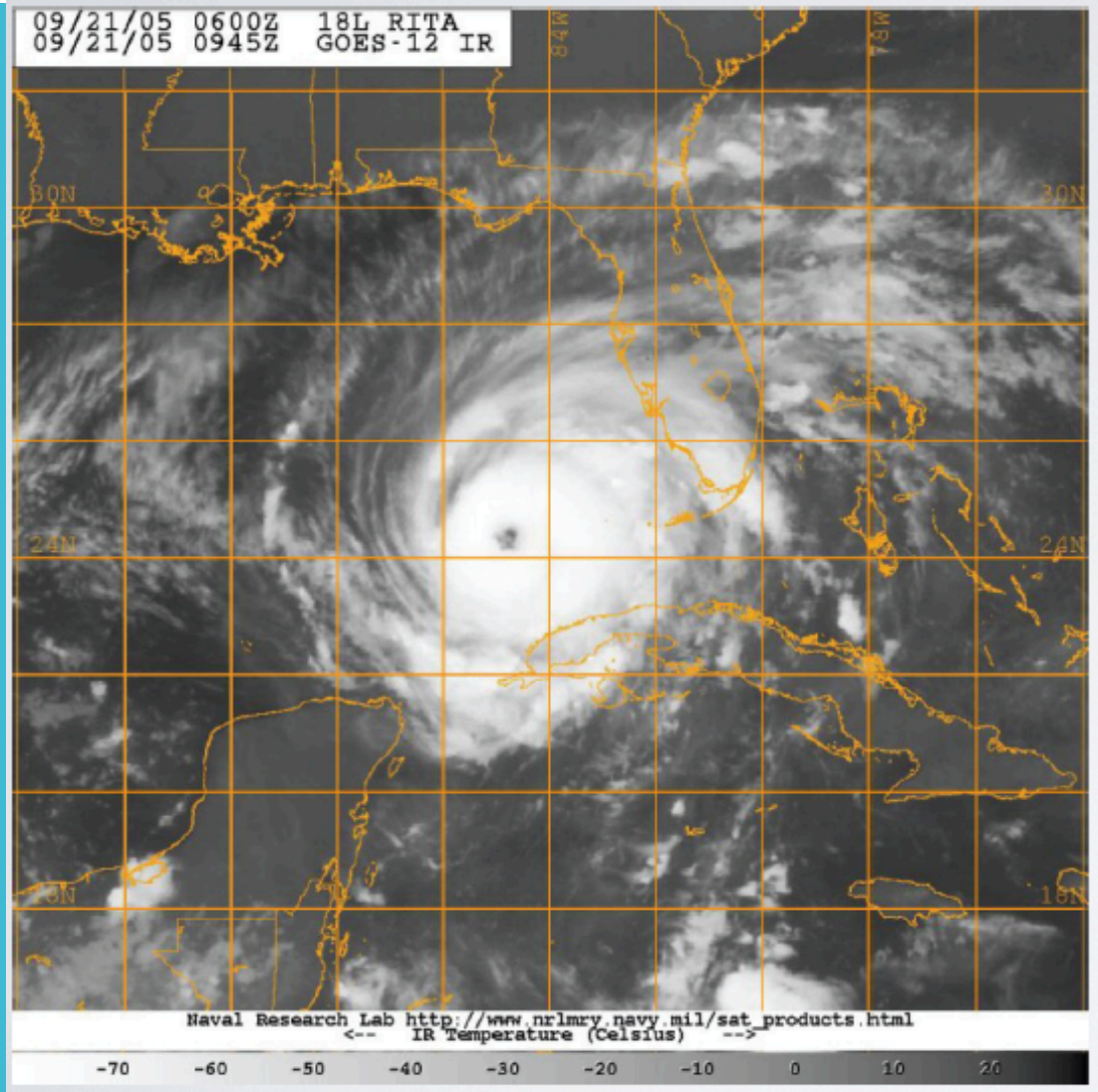
Balancing with constrained resources







Limitation from model resolution



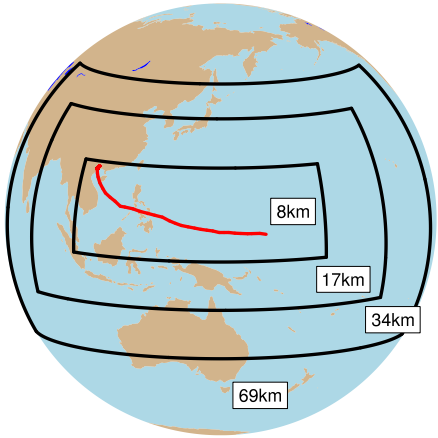
Hurricane Rita (2005): orange grid is representative of most current *coupled* ***global*** climate model resolution.

Size of grid limited by power of computers.

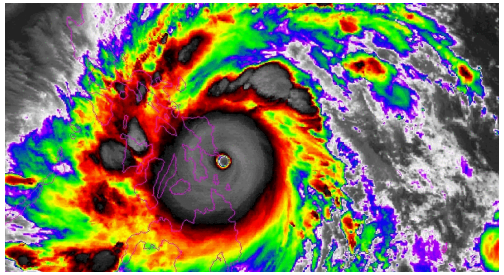
From G. Vecchi

Stretch-grid: getting more science done with lower computational cost

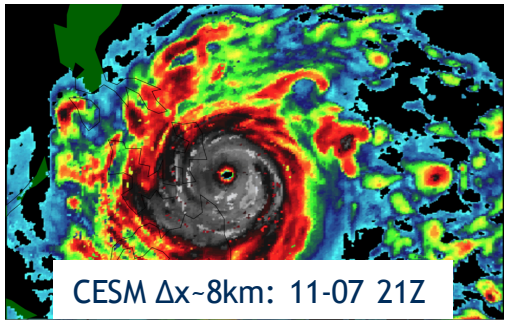
Spectral Element



From C. Zarzycki

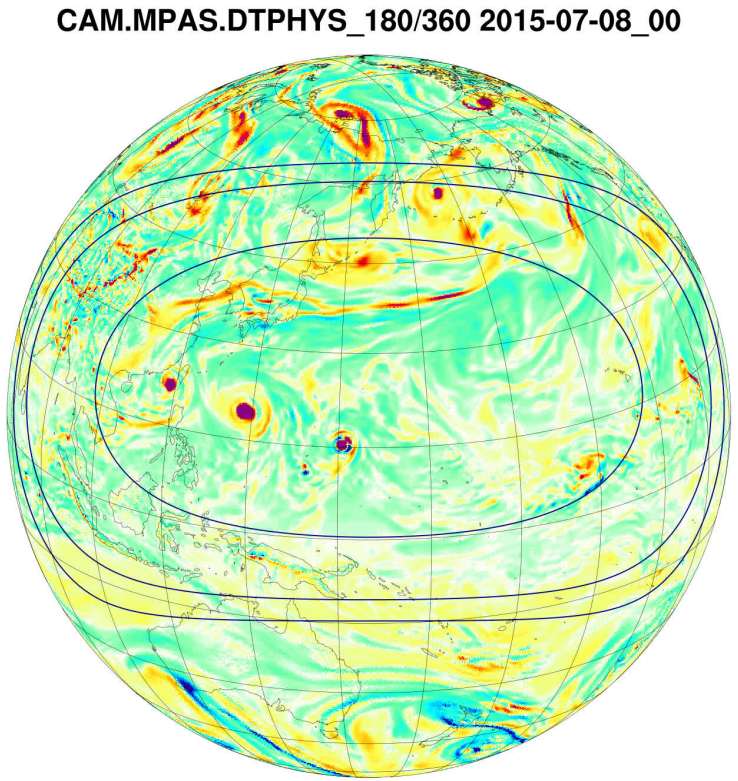


NOAA IR satellite obs: 11-07 21Z



CESM Δx~8km: 11-07 21Z

MPAS



CAM-MPAS coupled with ocean/ice model

500 hPa Vorticity, 15-60 km grid

From B. Skamarock