



U.S. DEPARTMENT OF
ENERGY

Office of Science

Climate Change

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Climate Change Research Section

National Center for Atmospheric
Research

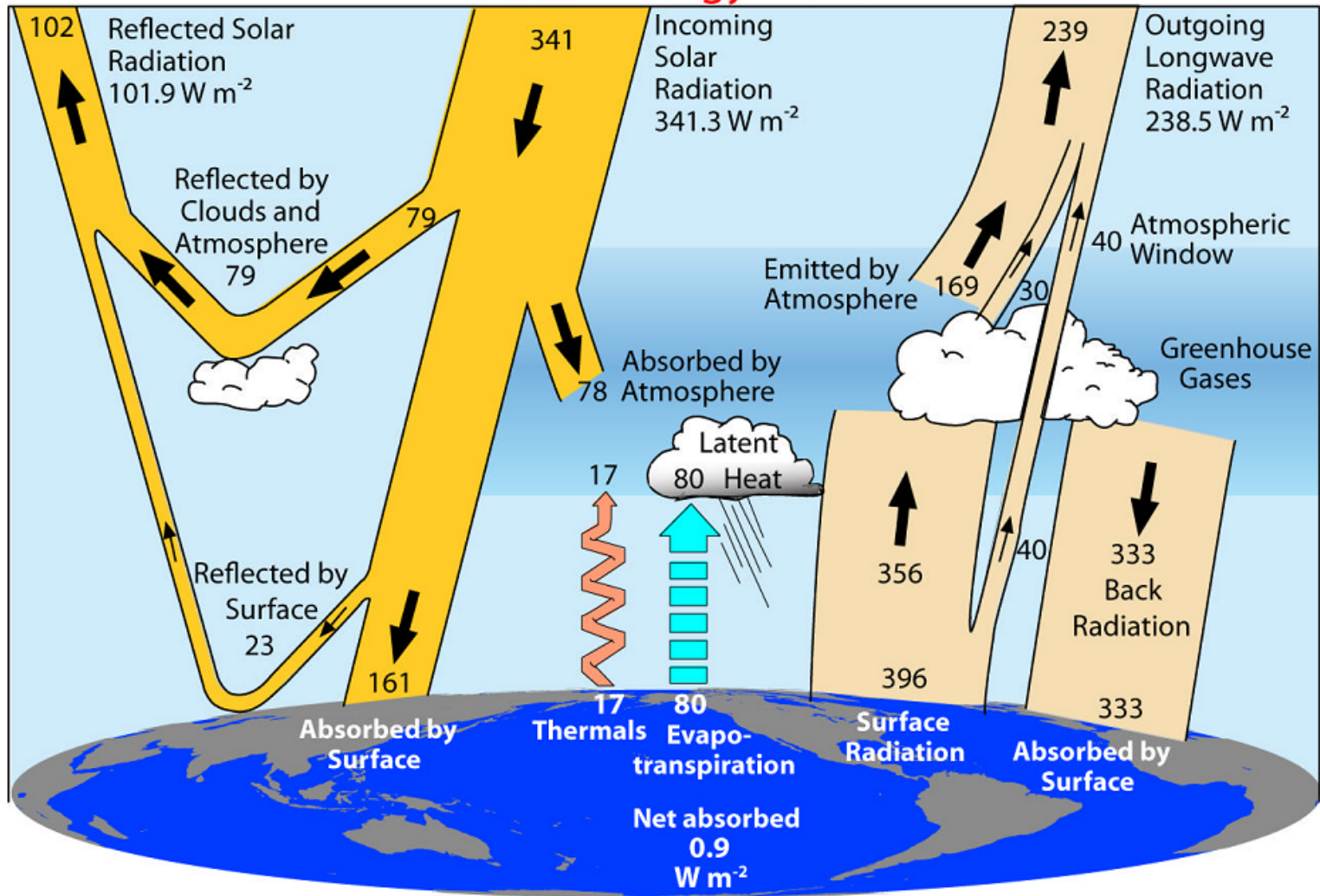
Outline

- Recipe for Climate Change
- The Global Picture
- Uncertainties in Ingredients
- Examples: Past, Present & Future
- Ensembles
- Challenges: Expanding the Menu

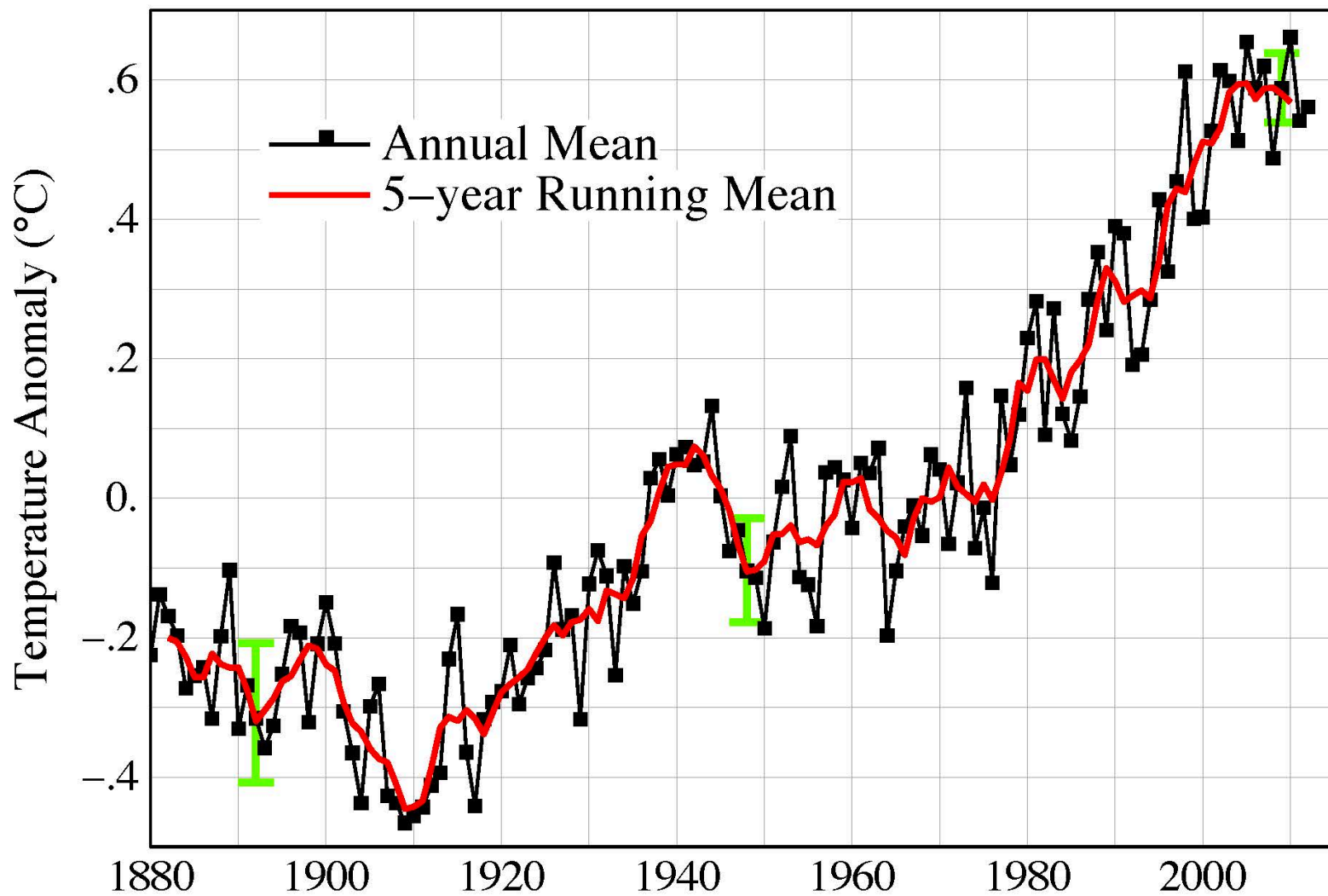
Recipe for Climate Change



Global Energy Flows $W m^{-2}$



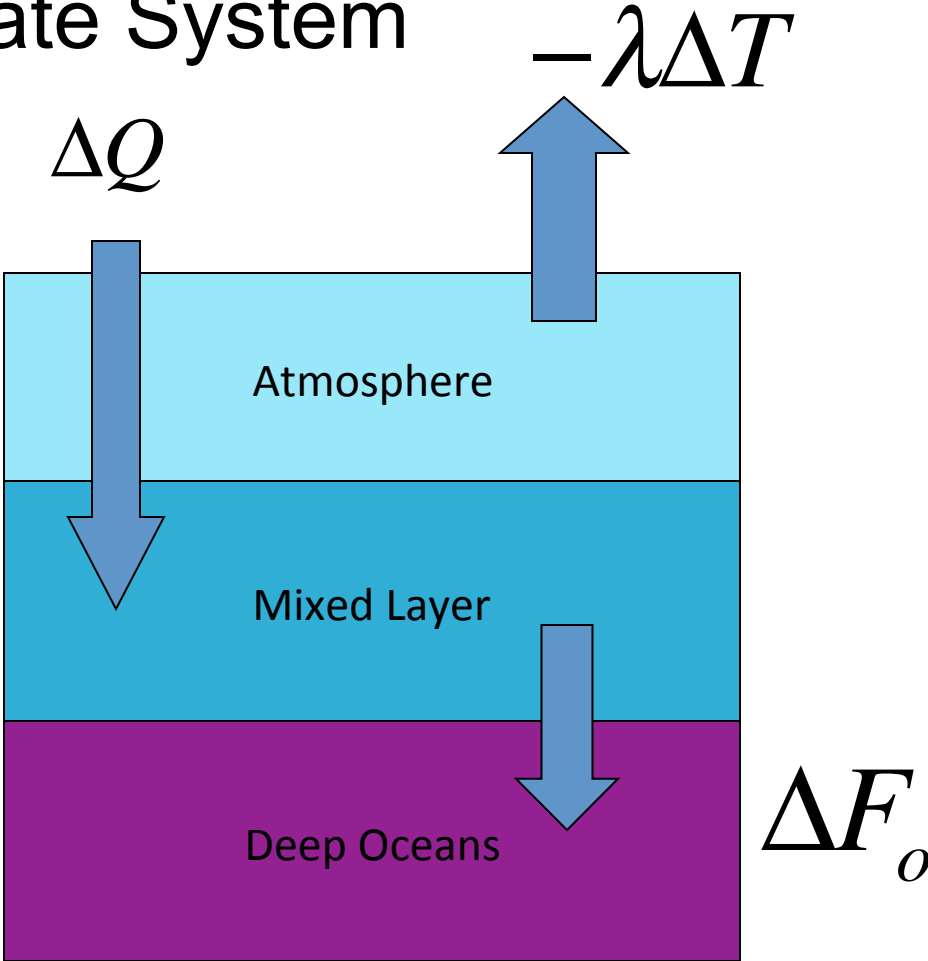
Global Land–Ocean Temperature Index



Ingredients

- Forcing
 - Time scale dependence {When is forcing a feedback?}
 - Shortwave {Solar Variations, Aerosols, ...}
 - Longwave {Greenhouse Gases}
 - Other {Continents, Glacial Distribution, ...}
- Feedbacks
 - Fast (months to years) {WV, Clouds, Snow, Sea-Ice}
 - Slow (decades to millennia) {Veg., Land Ice, CH₄}
- Ocean Mixing
 - Vertical heating of ocean {where & how deep}
- Natural Variability {ENSO, NAO, PDO,...}

Simple Climate System



Simple Climate Model

$$f_o C \frac{d\Delta T_M}{dt} = \Delta Q - \lambda \Delta T_G - f_o \Delta F_o$$

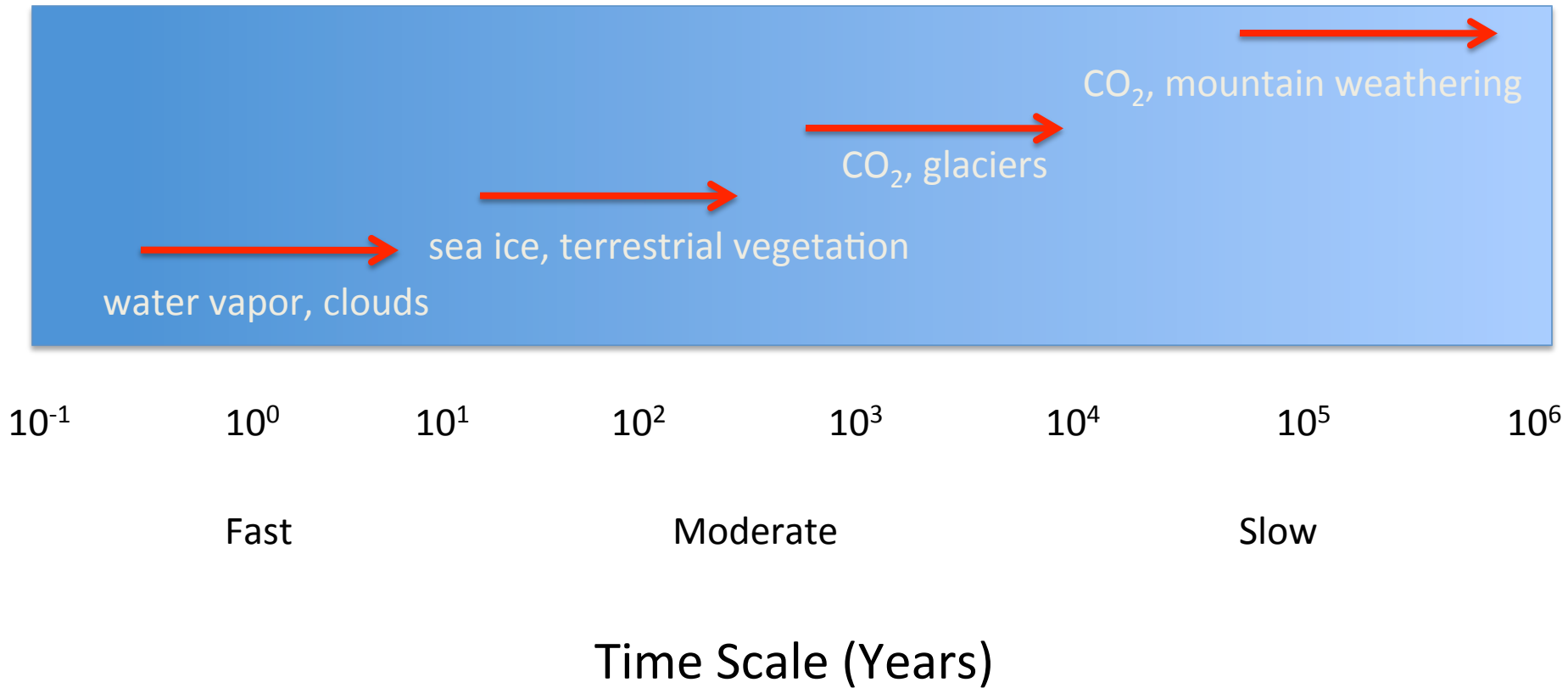
Forcing

Feedback

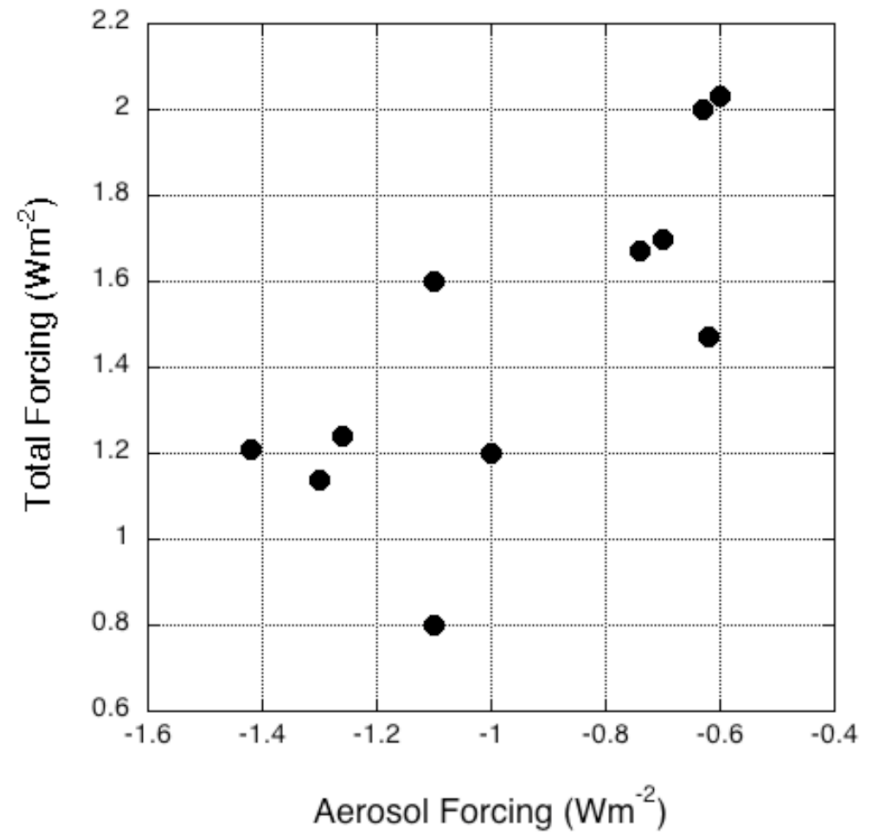
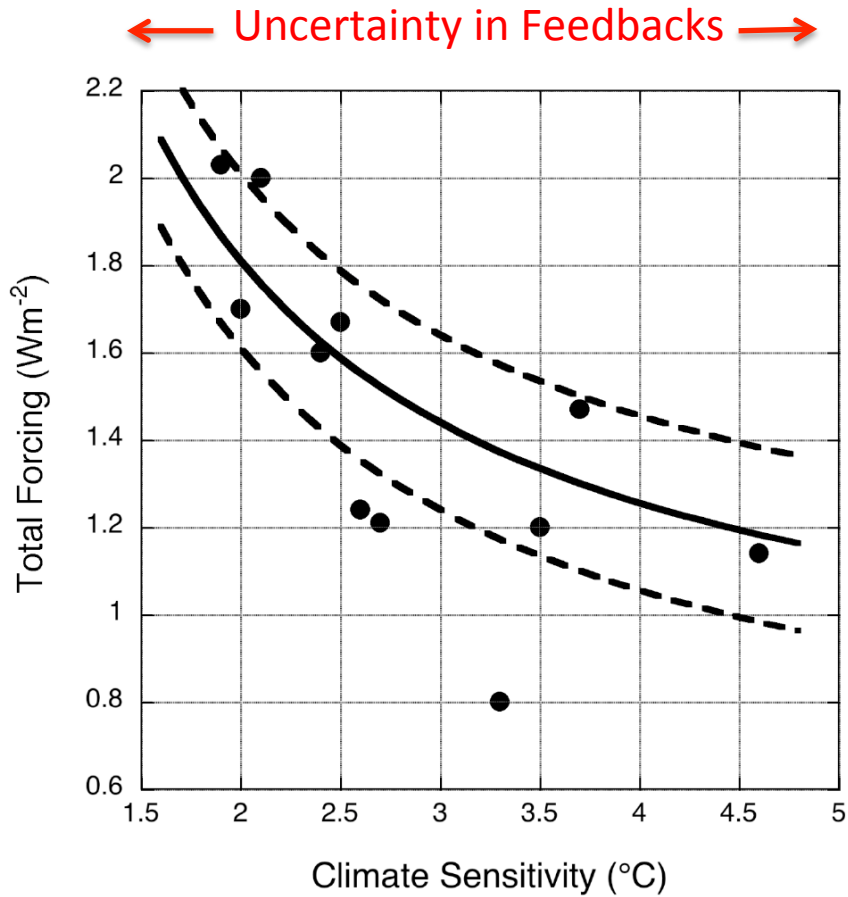
Mixing

$$\Delta F_o = \kappa \Delta T$$

Multi-time Scale Feedbacks in Earth's Climate System

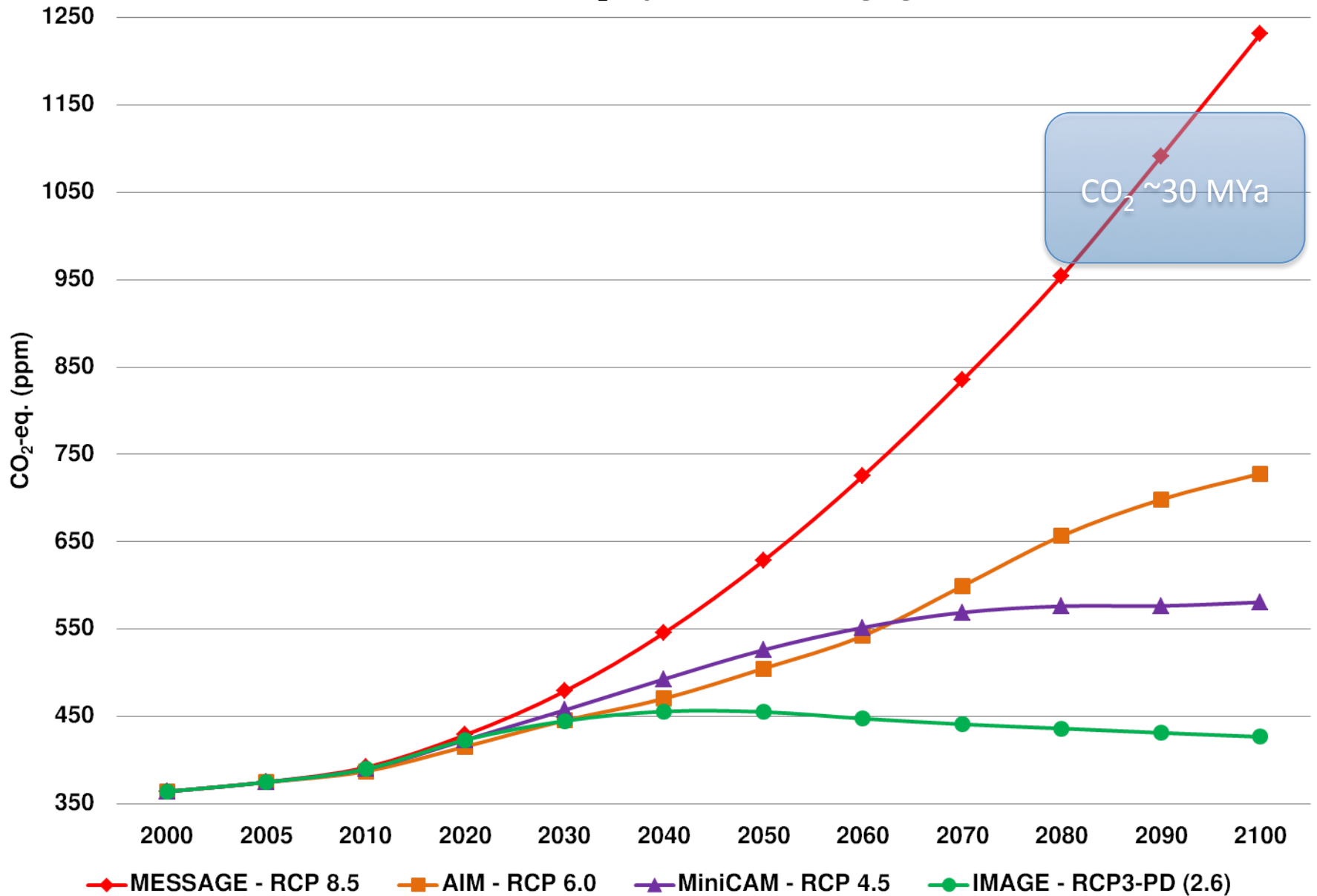


Uncertainties in Ingredients



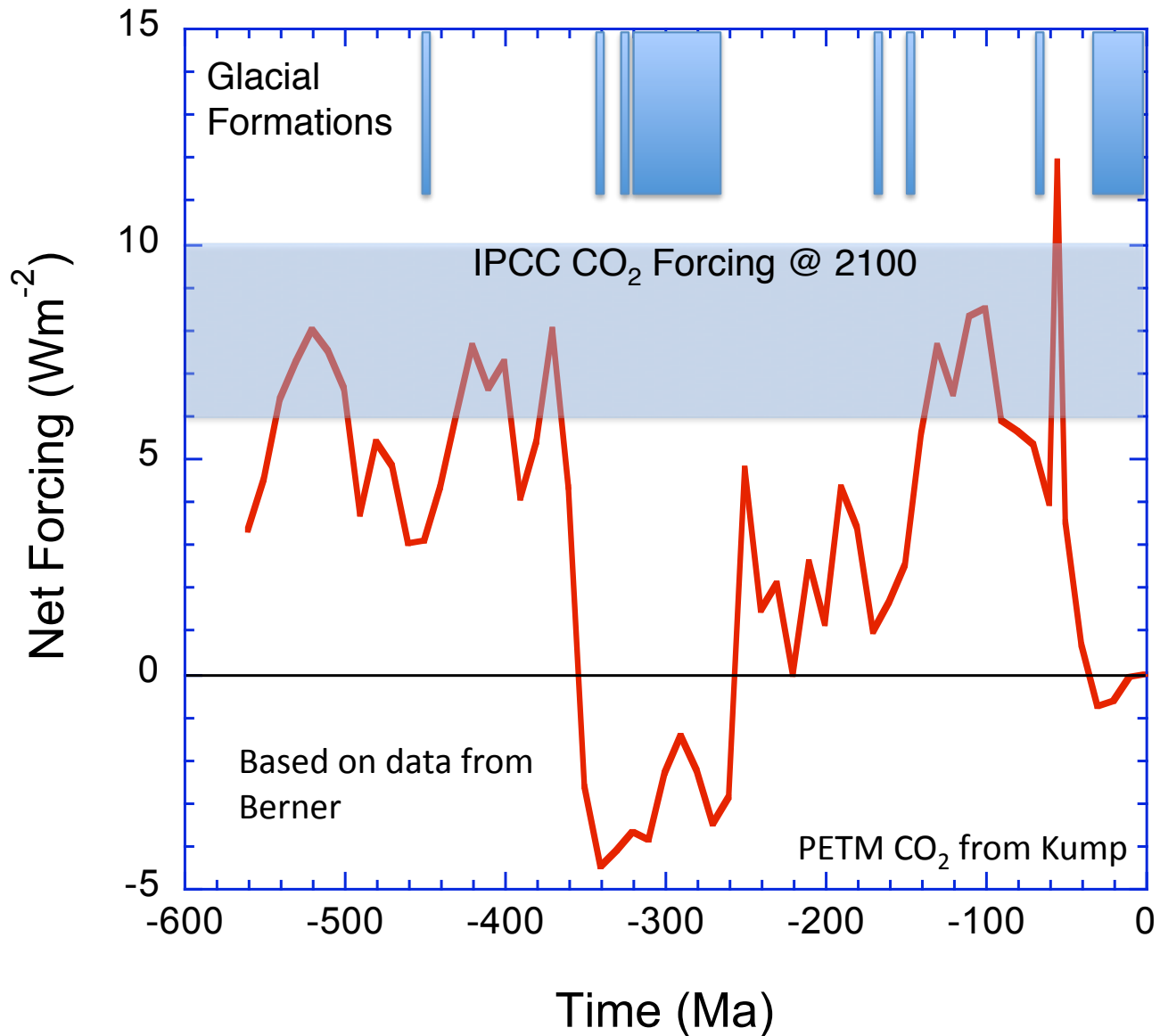
IPCC (AR5) Representative Concentration Pathways

Concentration - CO₂-eq. (incl. all forcing agents)



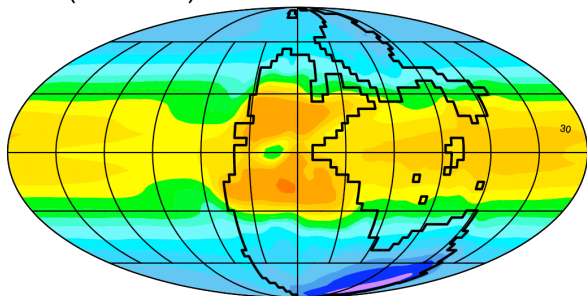
Examples: Past, Present & Future

Forcing of the Past

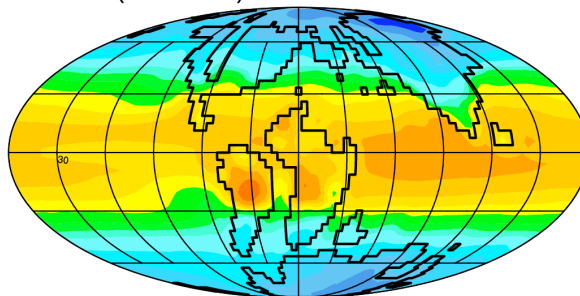


CCSM3 Simulations

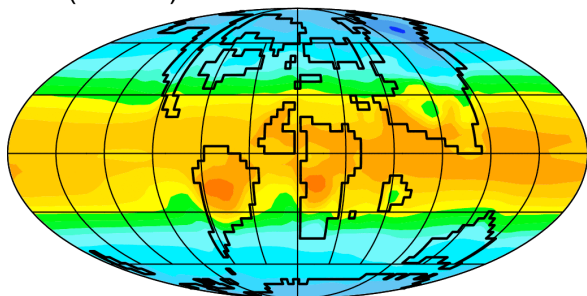
P/T (250 Ma)



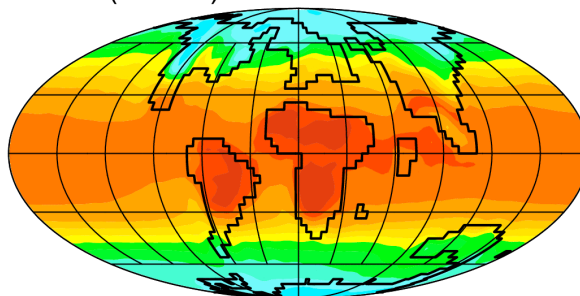
Cretac (100 Ma)



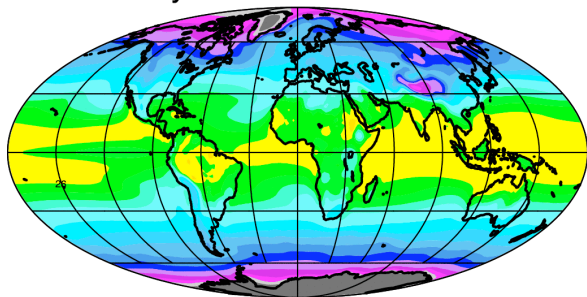
K/T (65 Ma)



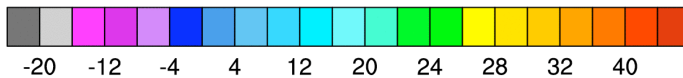
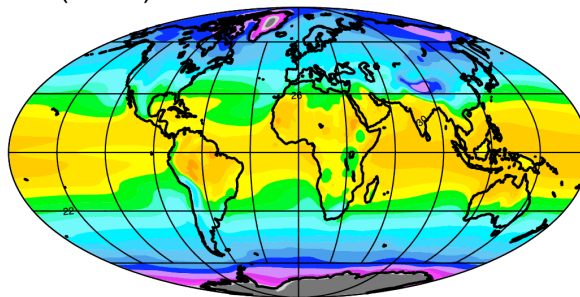
PETM (55 Ma)



Present Day



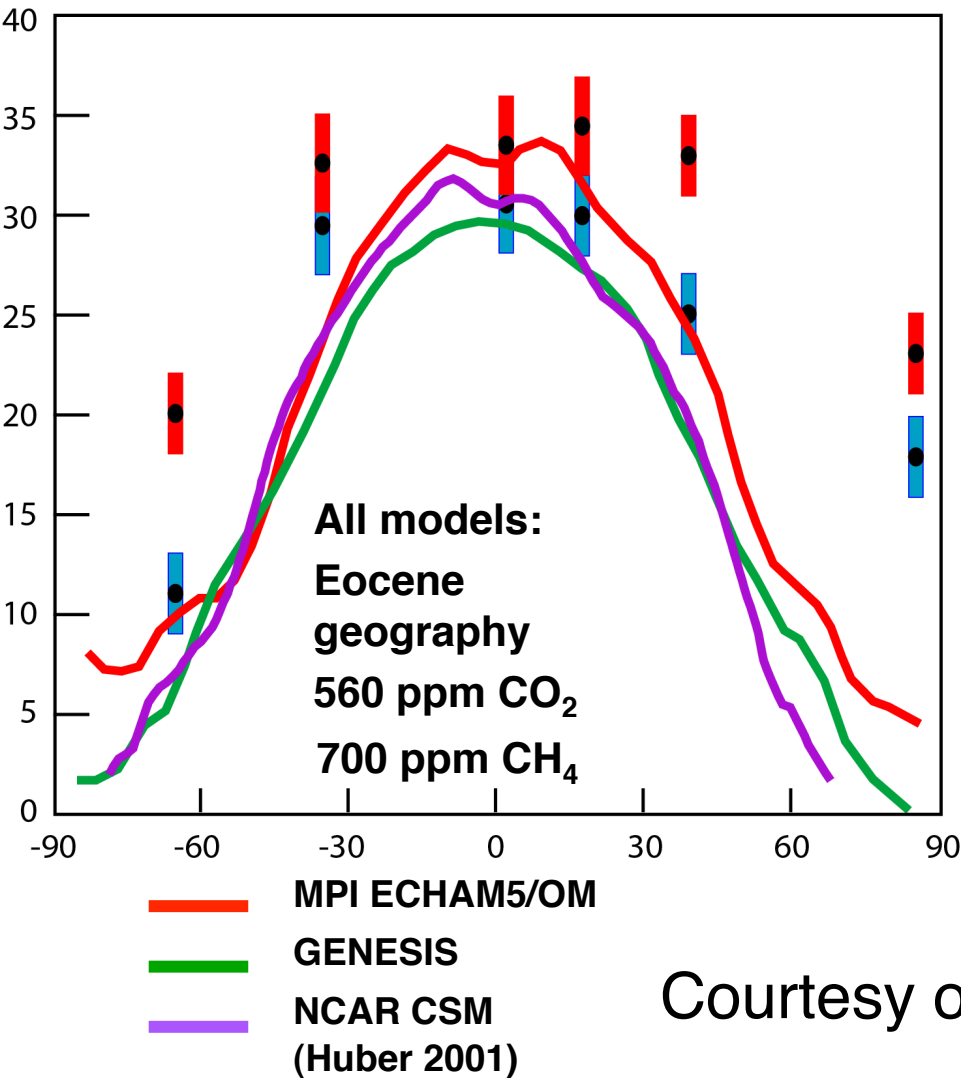
A2 (2100)



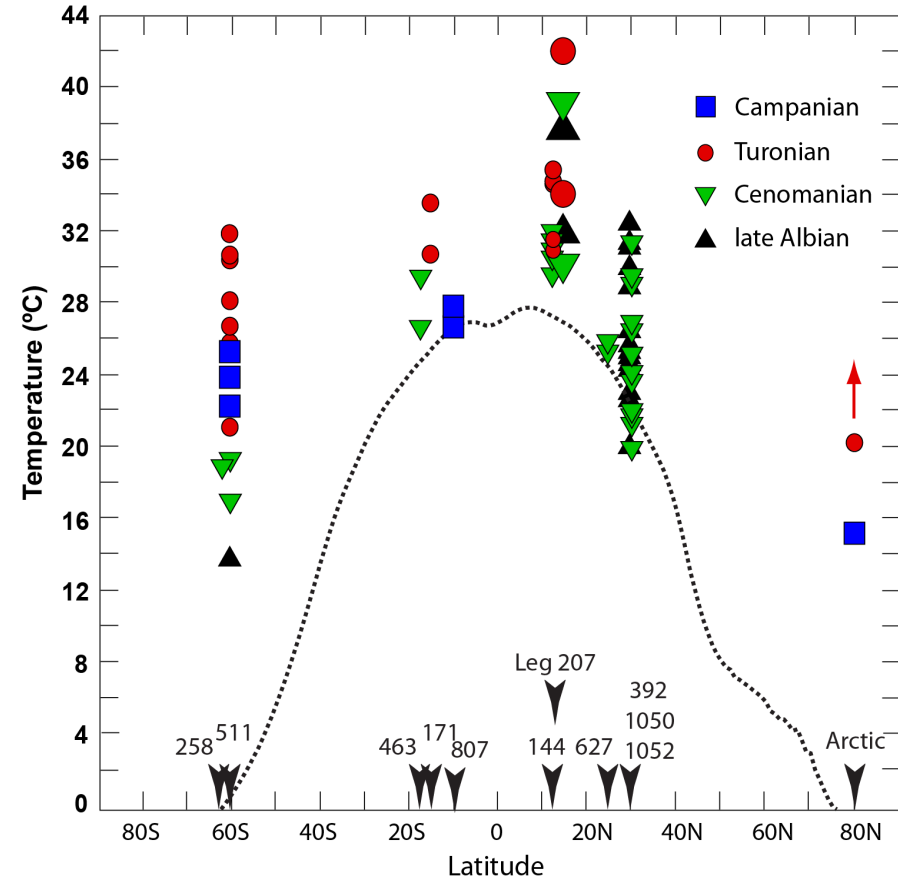
°C Surface Air Temperature

A Warning from Deep Time?

Eocene

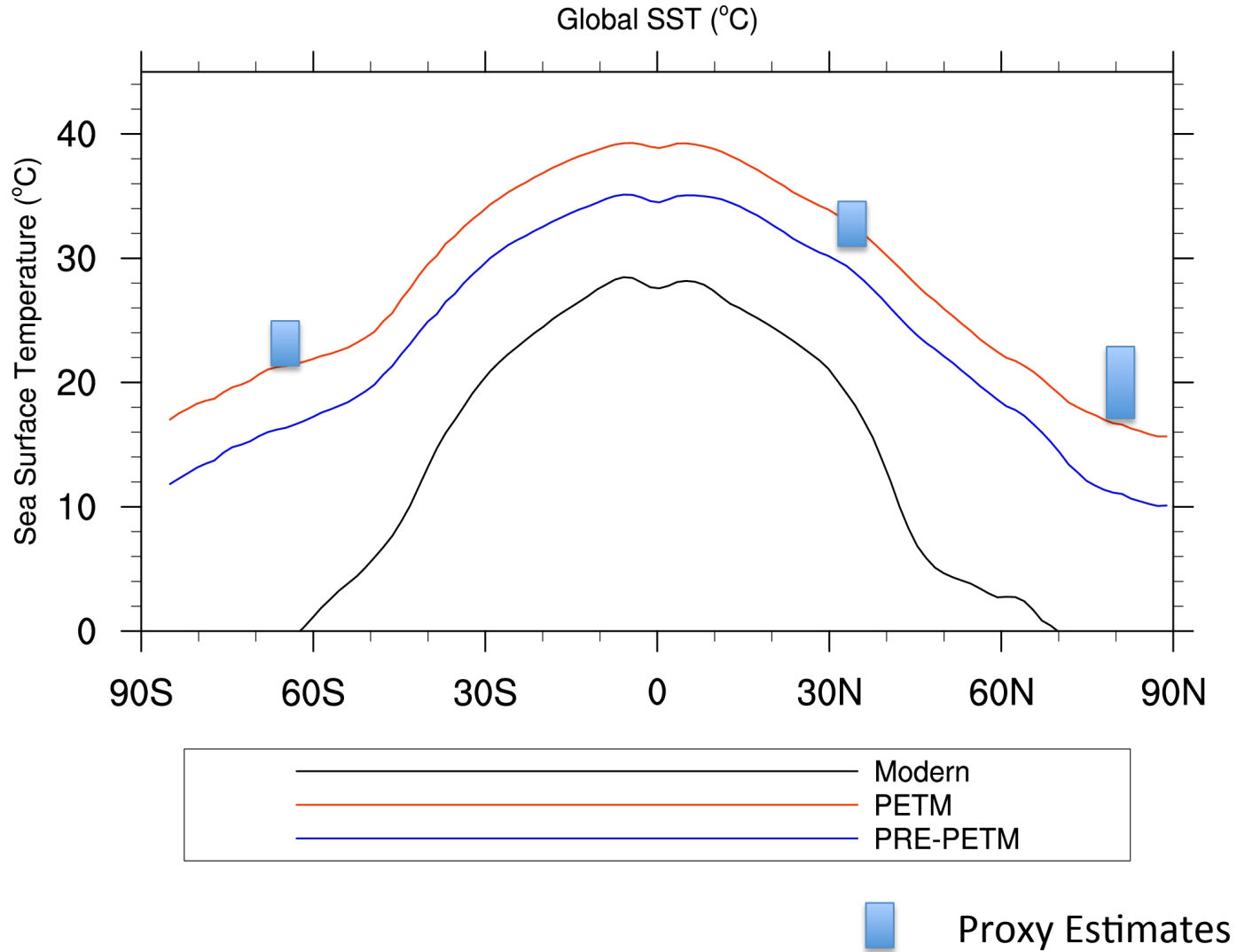


Cretaceous



Courtesy of Karen Bice (2008)

Process Study: Role of Aerosols & Clouds in Deep Time

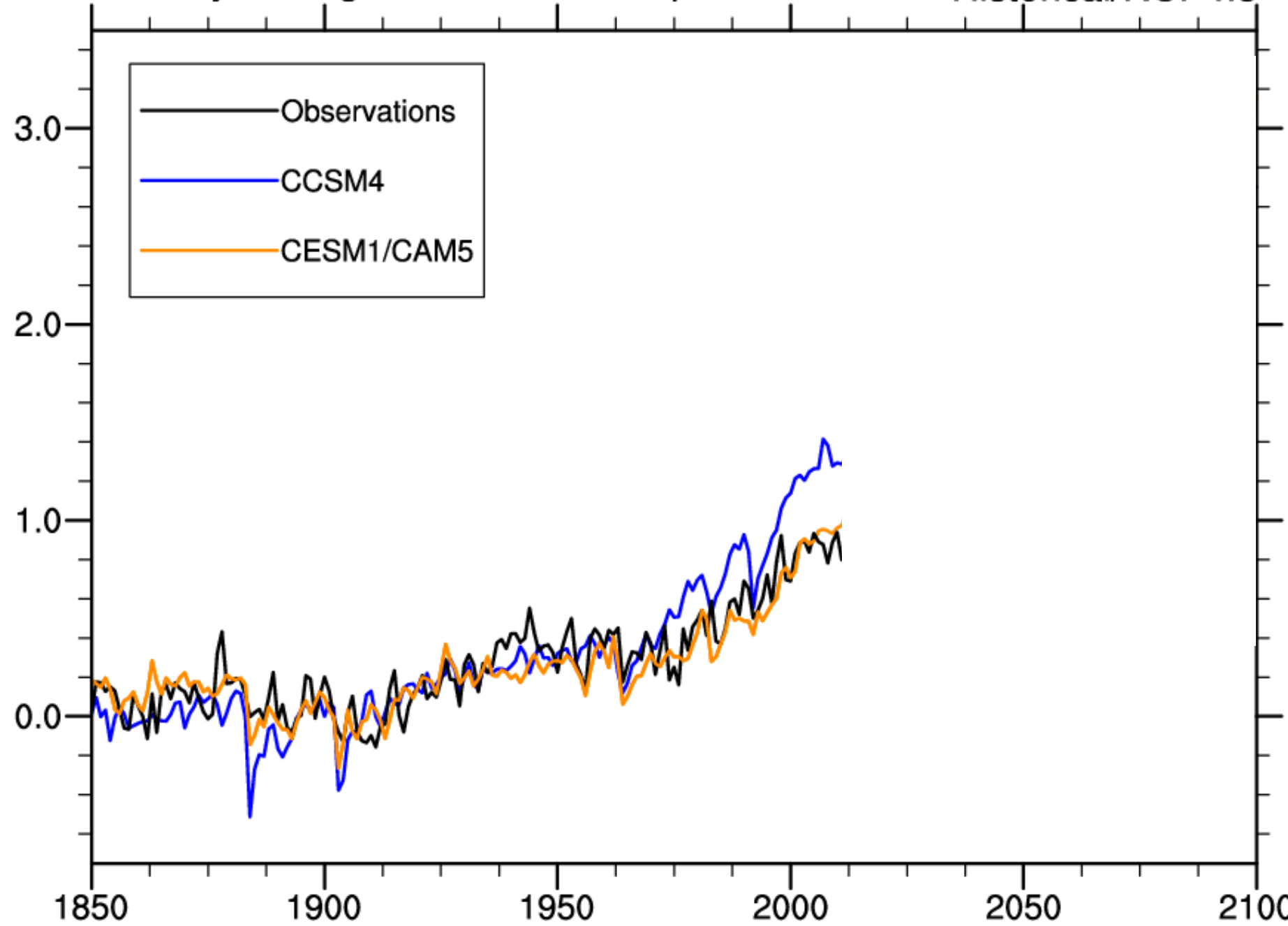


Kiehl & Shields (2013)

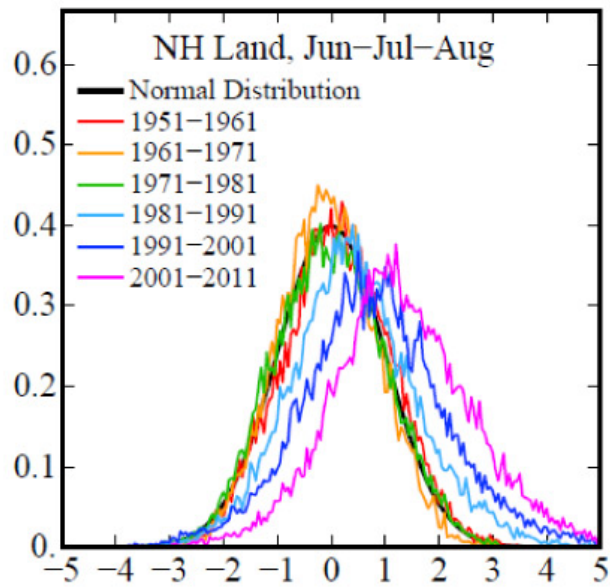
Globally averaged surface air temperature

Historical/RCP4.5

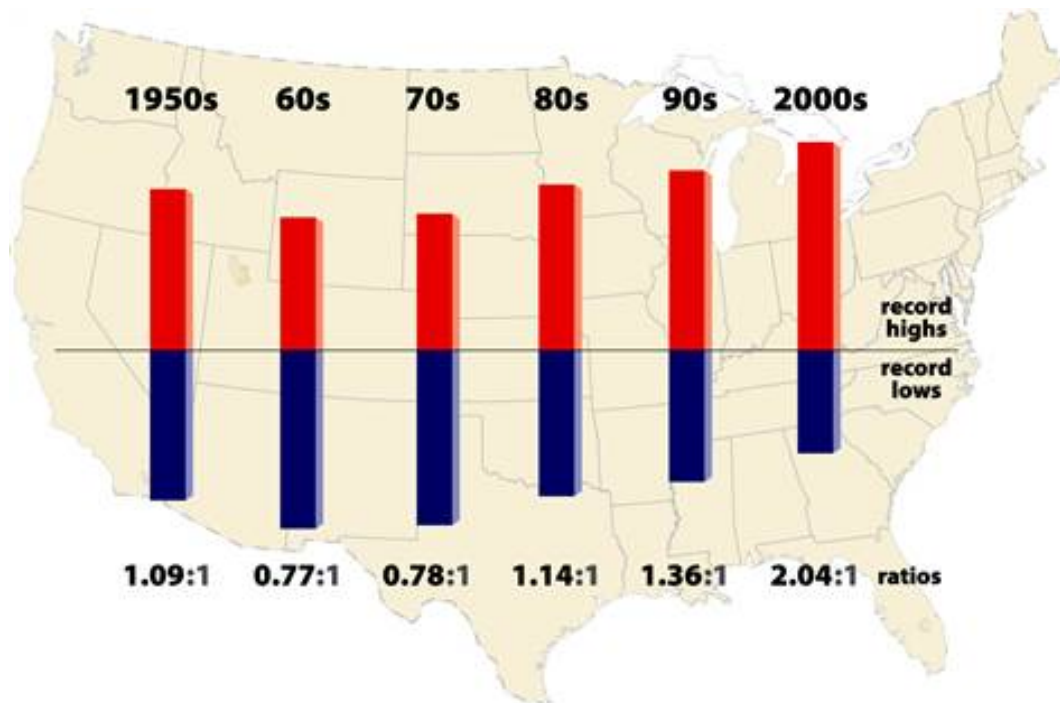
Anomalies from 1900-1919 (°C)



Temperature Anomaly Distribution



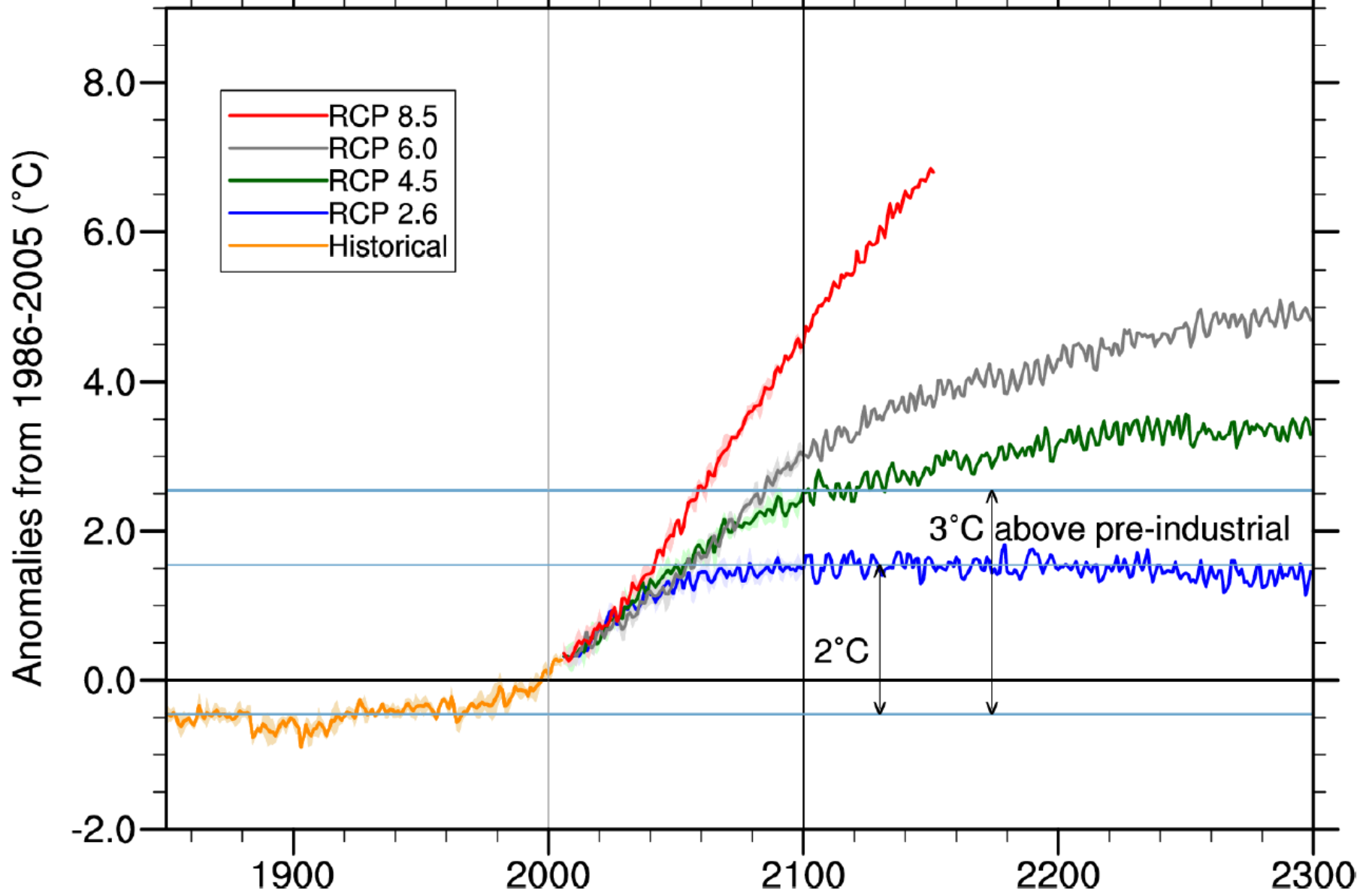
Hansen et al. (2011)



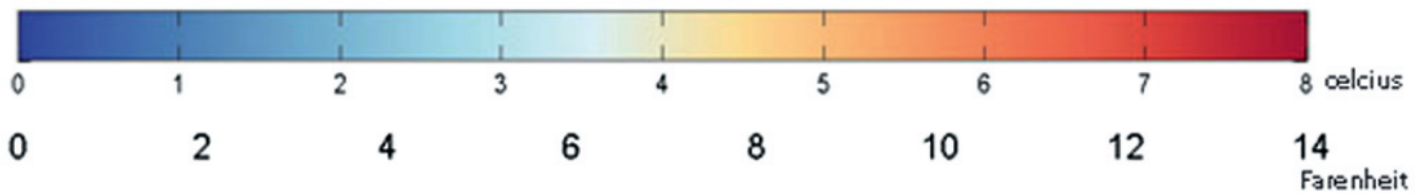
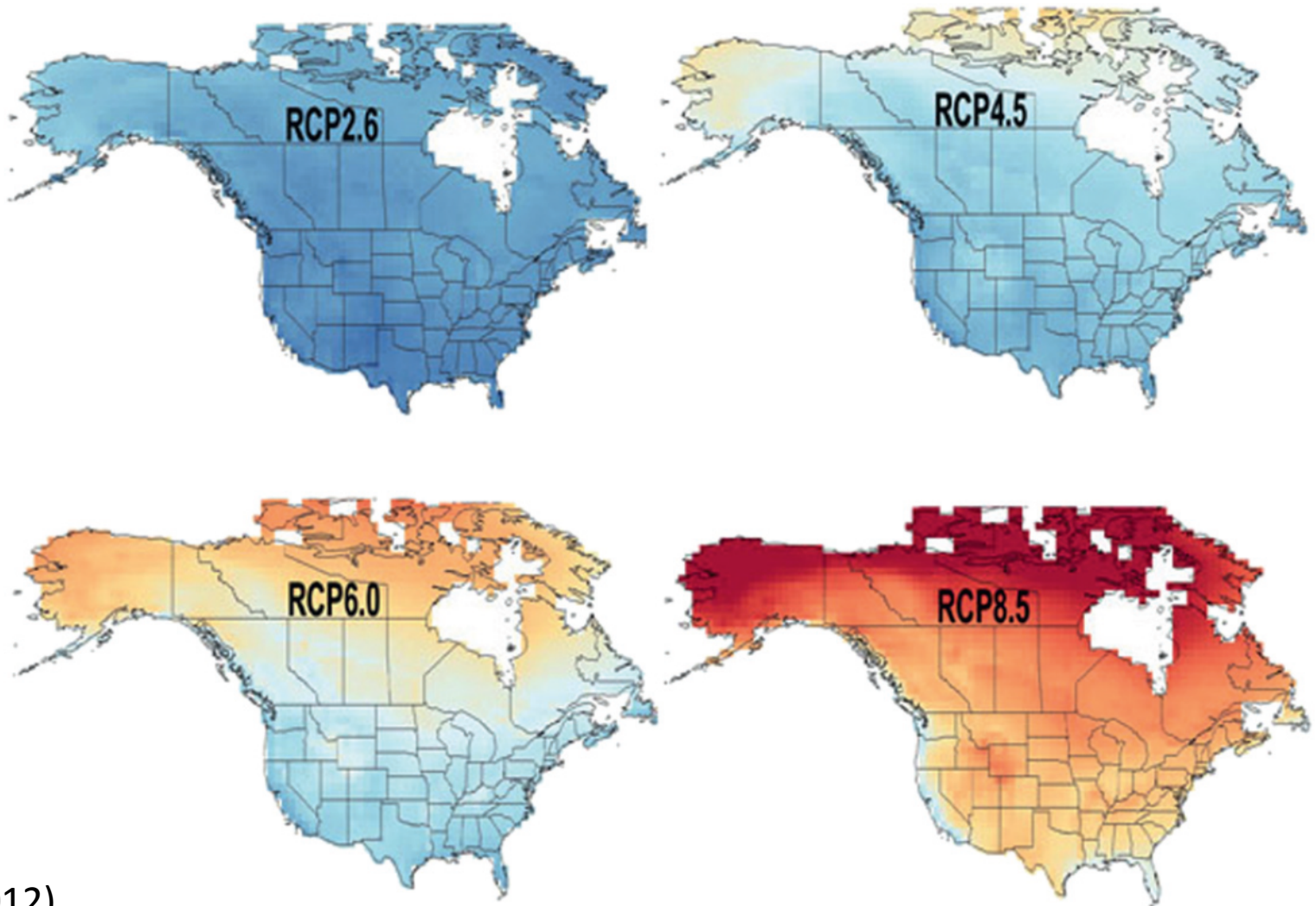
Meehl et al. (2009)

Globally averaged surface air temperature

CESM1-CAM5



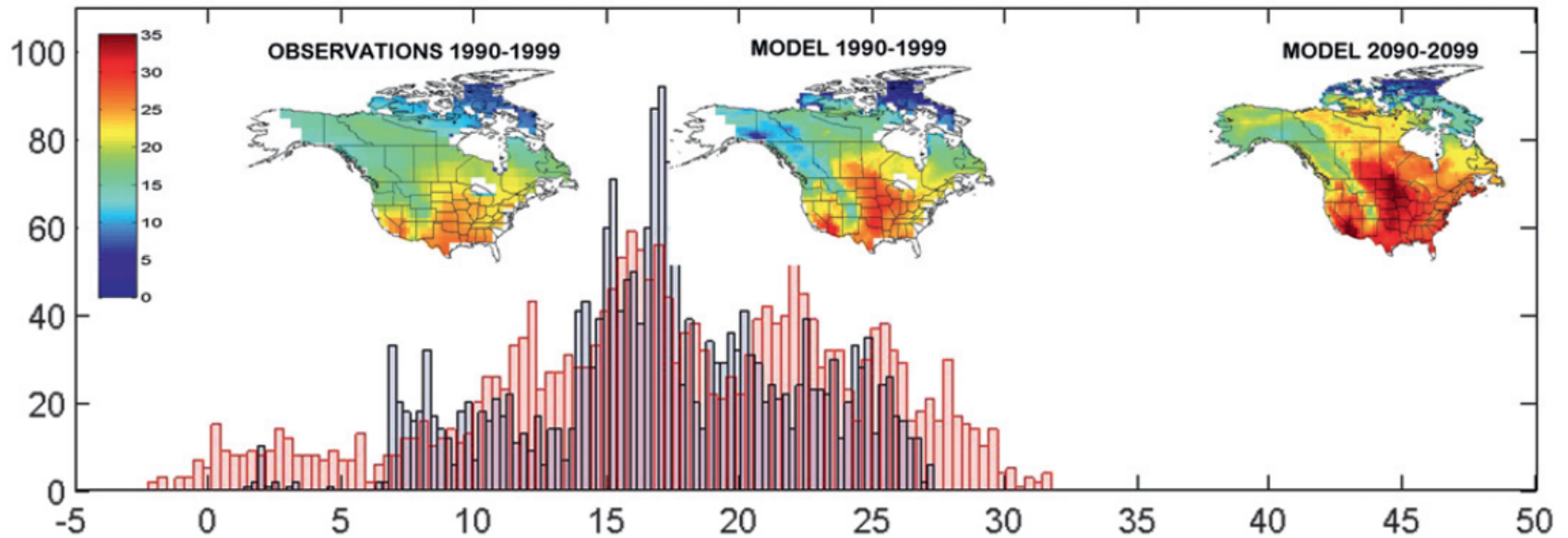
CCSM4 Annual Mean [(2090-2099) – (1990-1999)]



Peacock (2012)

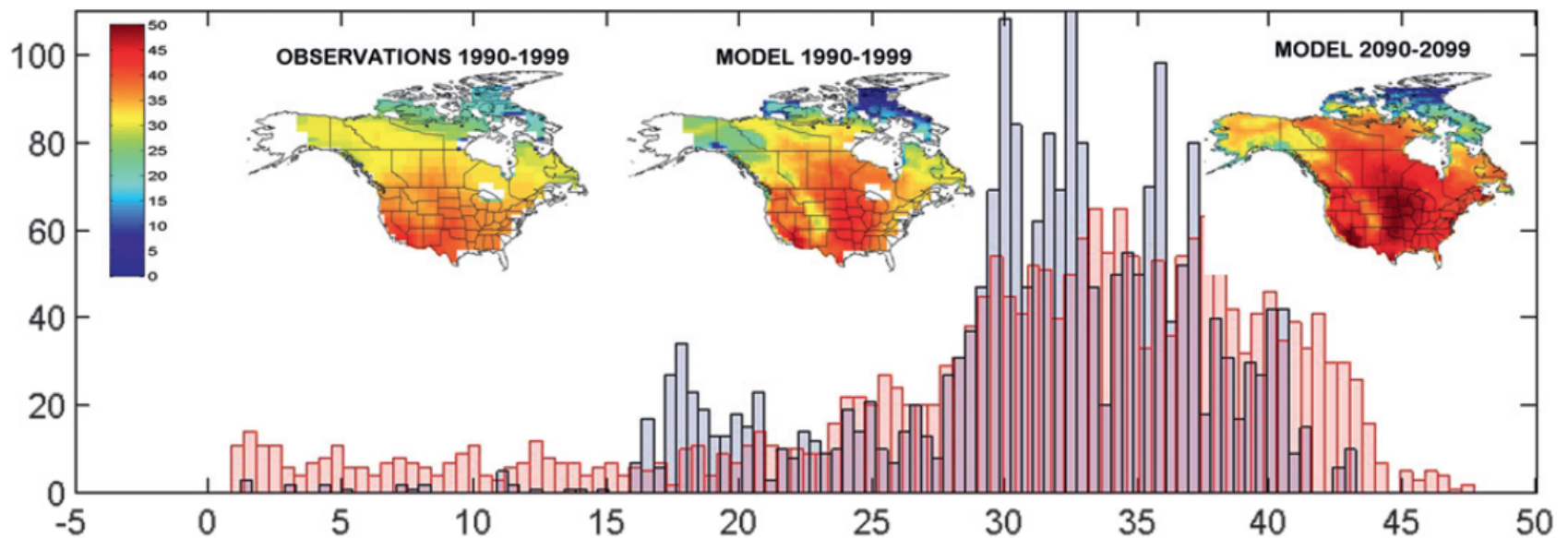
5 member ensemble

Maximum value of daily minimum temperature (deg C); model(red) and observed (blue)



Peacock (2012)

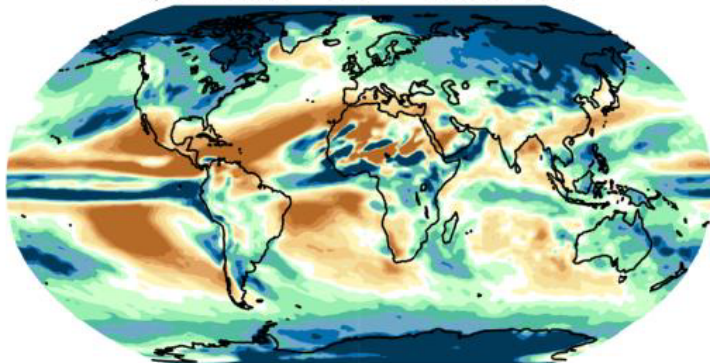
Maximum value of daily maximum temperature (deg C); model(red) and observed (blue)



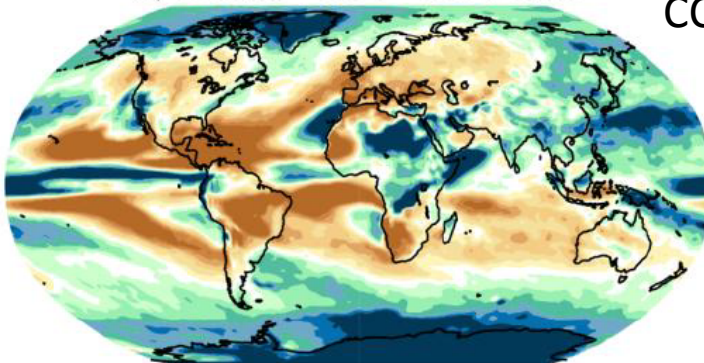
CESM1(CAM5) minus CCSM4 total precipitation changes

CESM1 3-member
CCSM4 5-member

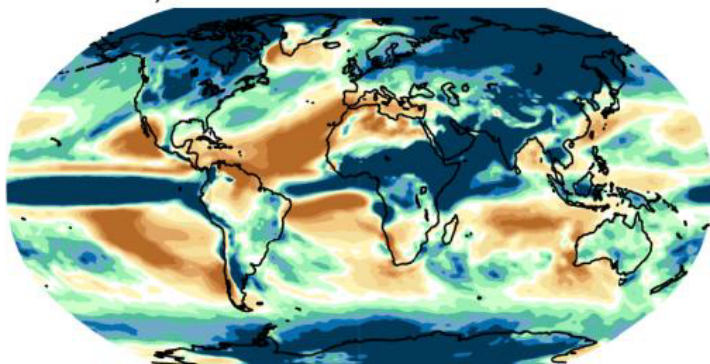
a) CCSM4 DJF 2081-2100



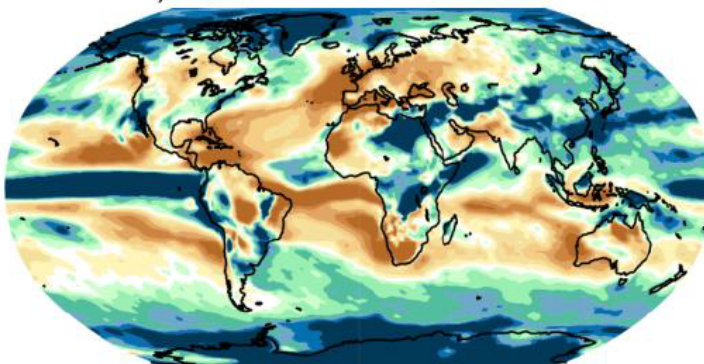
b) CCSM4 JJA 2081-2100



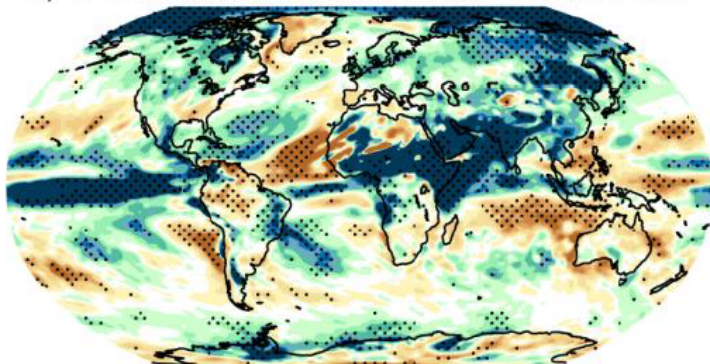
c) CESM1 DJF 2081-2100



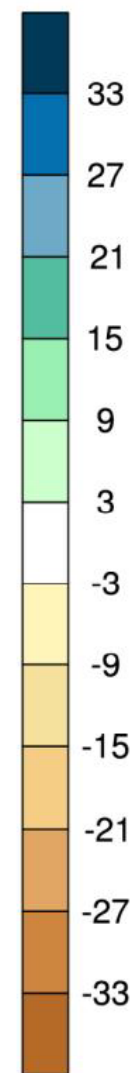
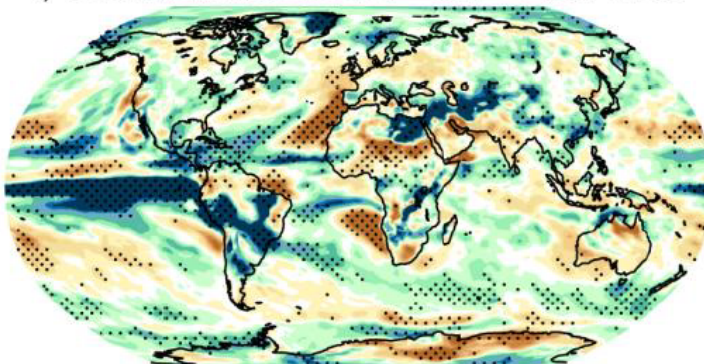
d) CESM1 JJA 2081-2100

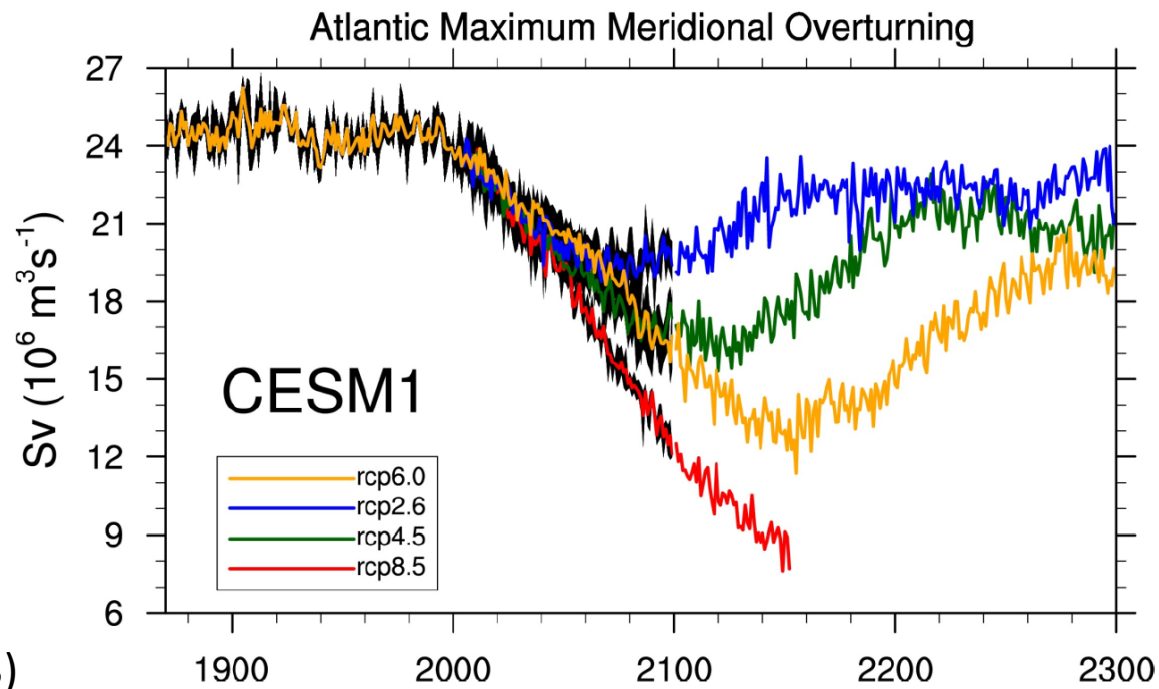
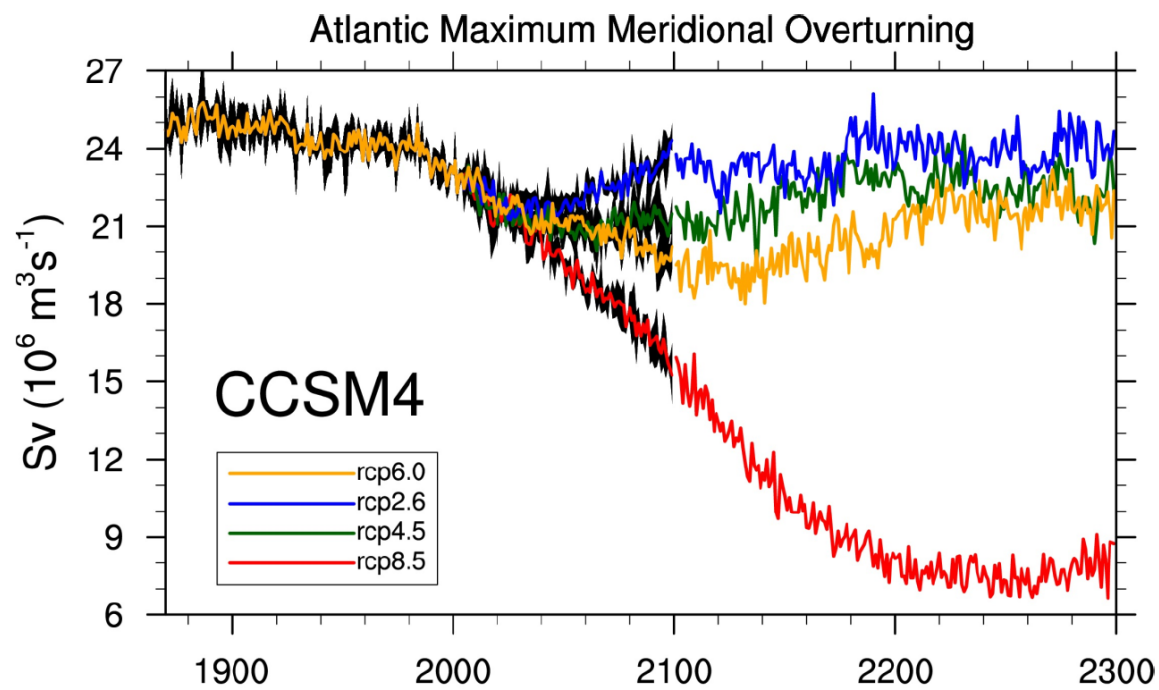


e) CESM1 minus CCSM4 DJF 2081-2100



f) CESM1 minus CCSM4 JJA 2081-2100

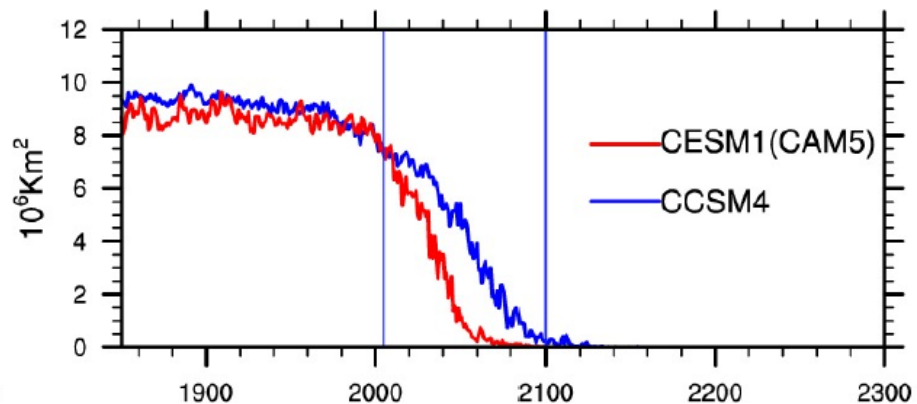
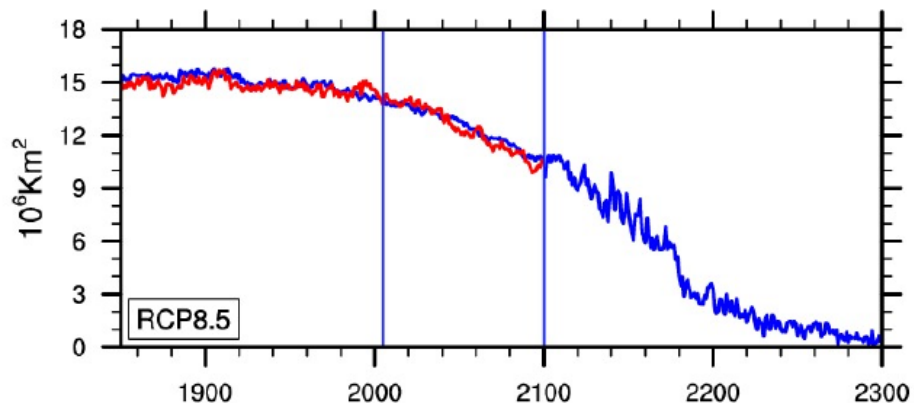




FMA

Arctic Sea Ice Extent

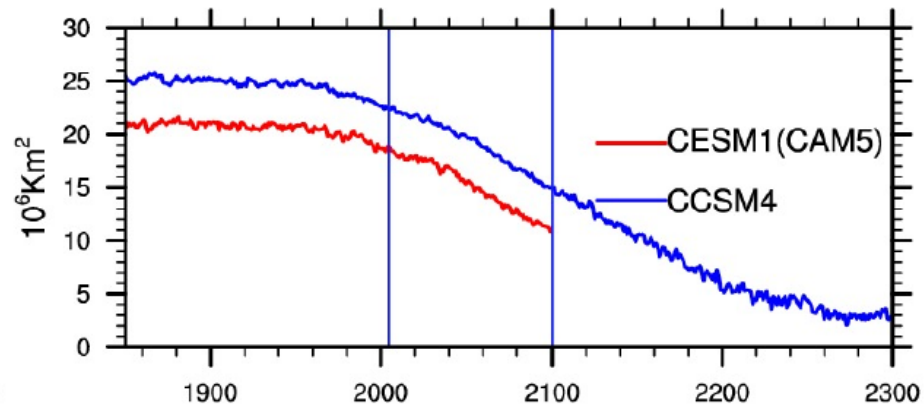
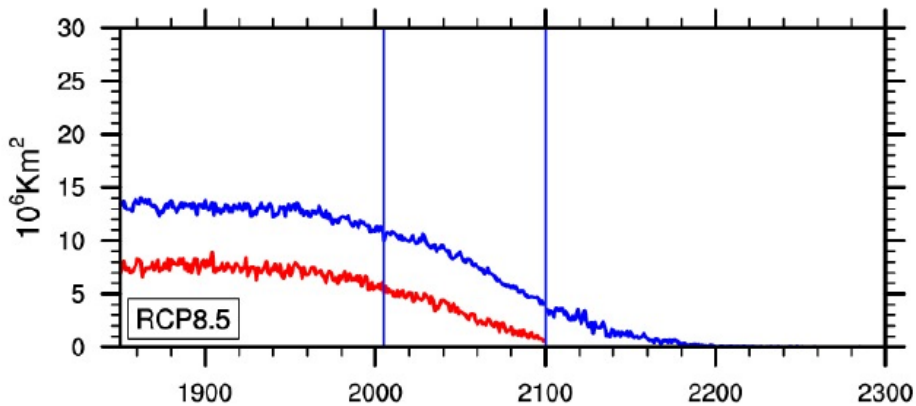
ASO



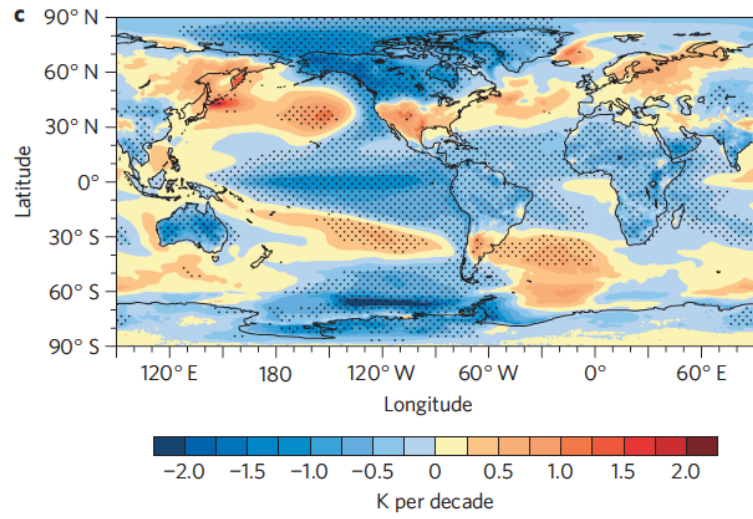
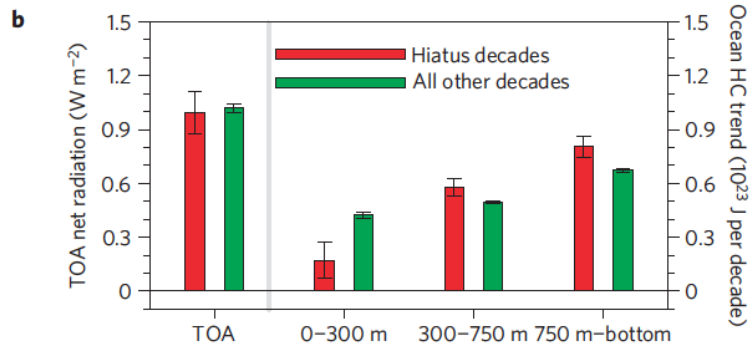
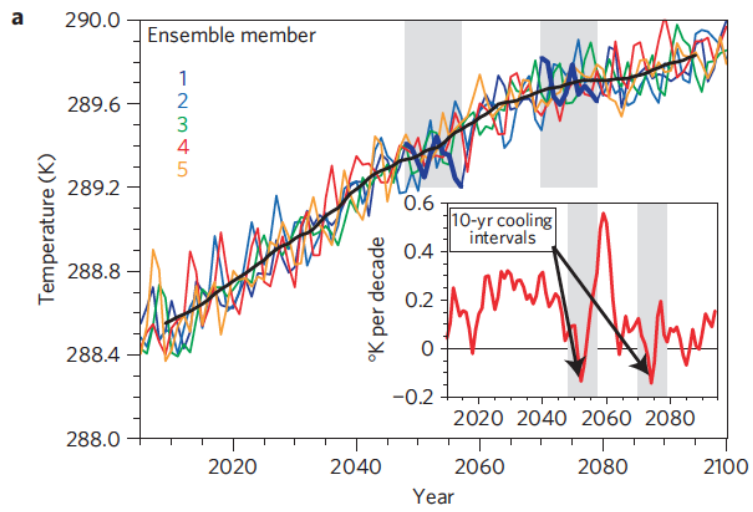
FMA

Antarctic Sea Ice Extent

ASO



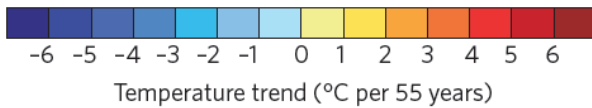
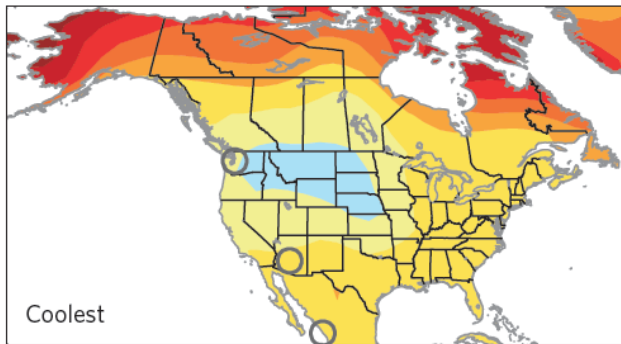
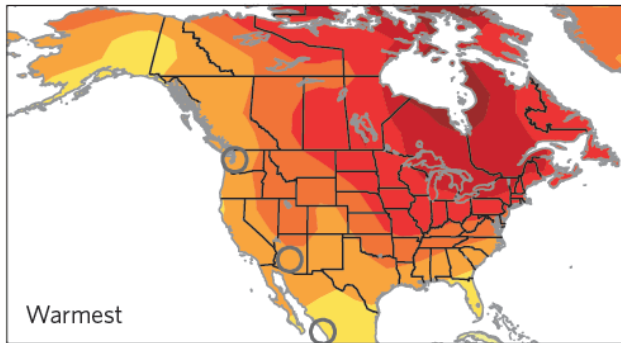
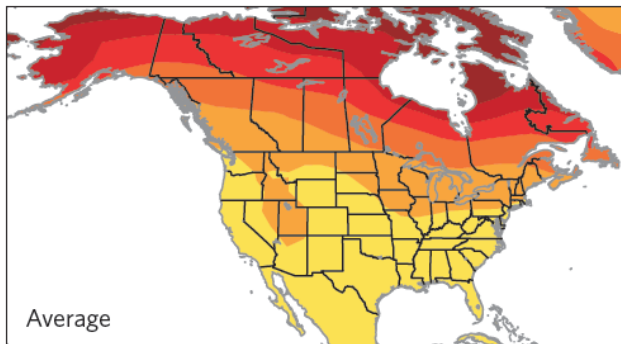
Process Studies to Understand the System



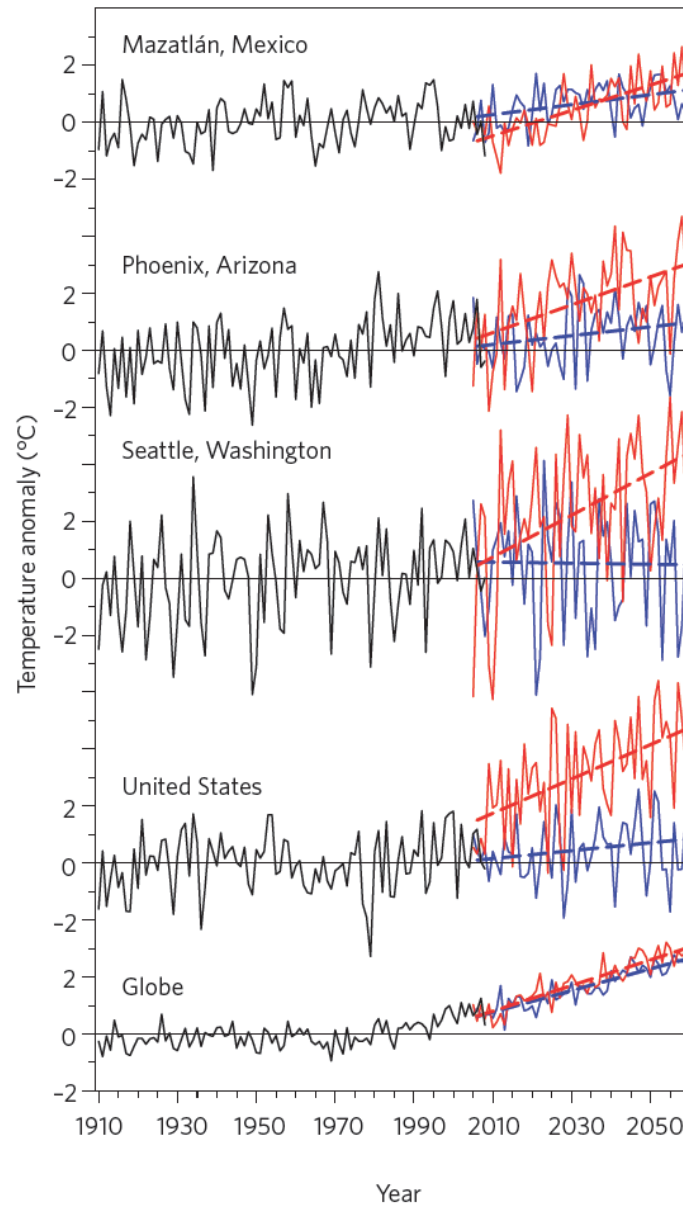
Ensembles

Ensemble of 40 CCSM3 simulations - Temperature

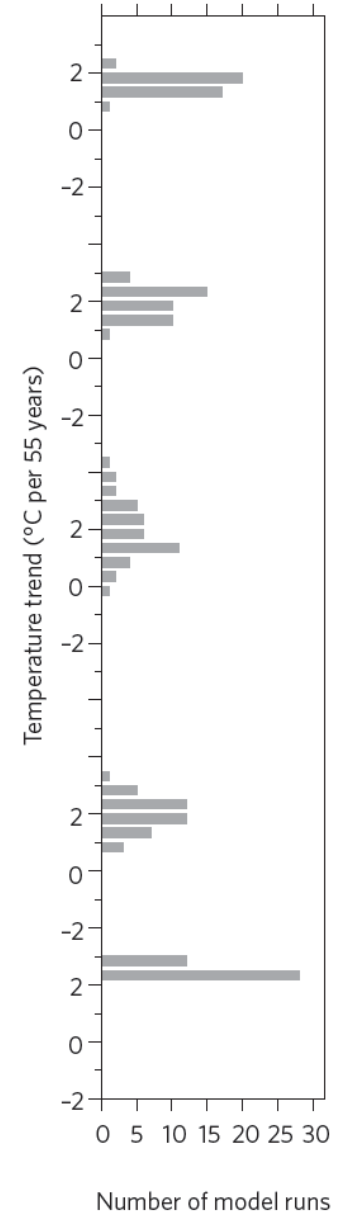
a



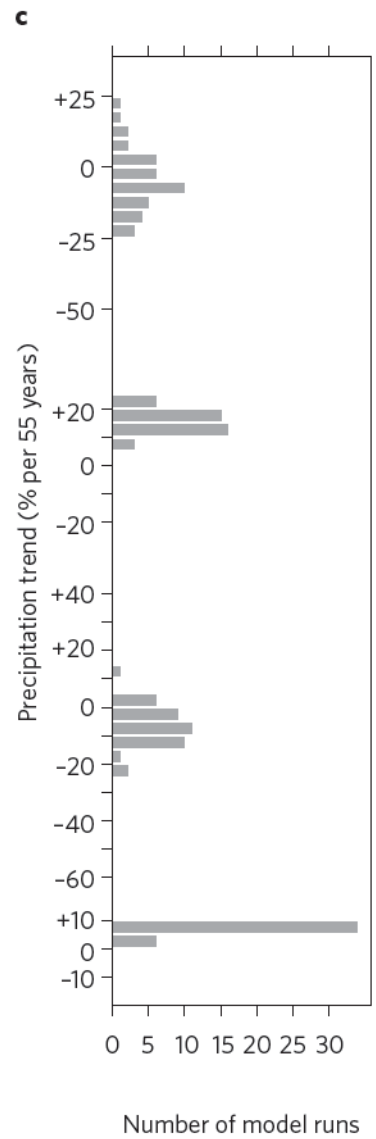
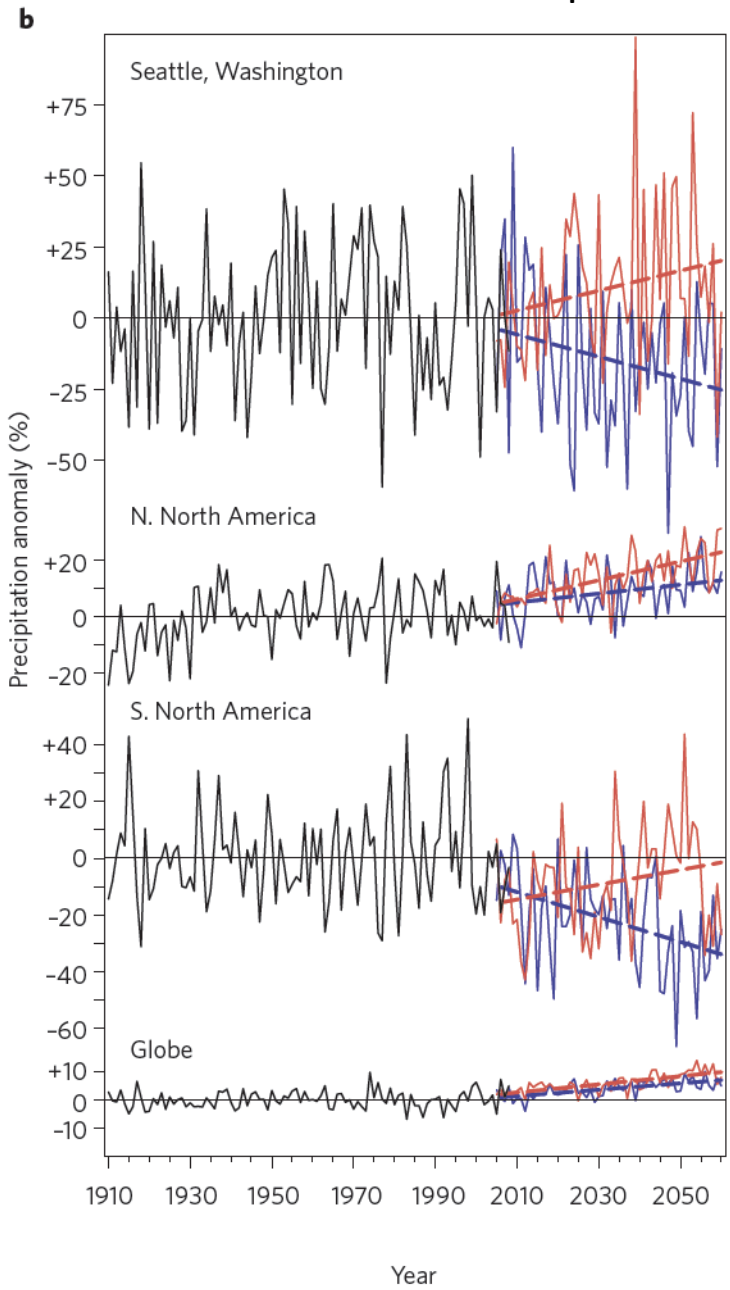
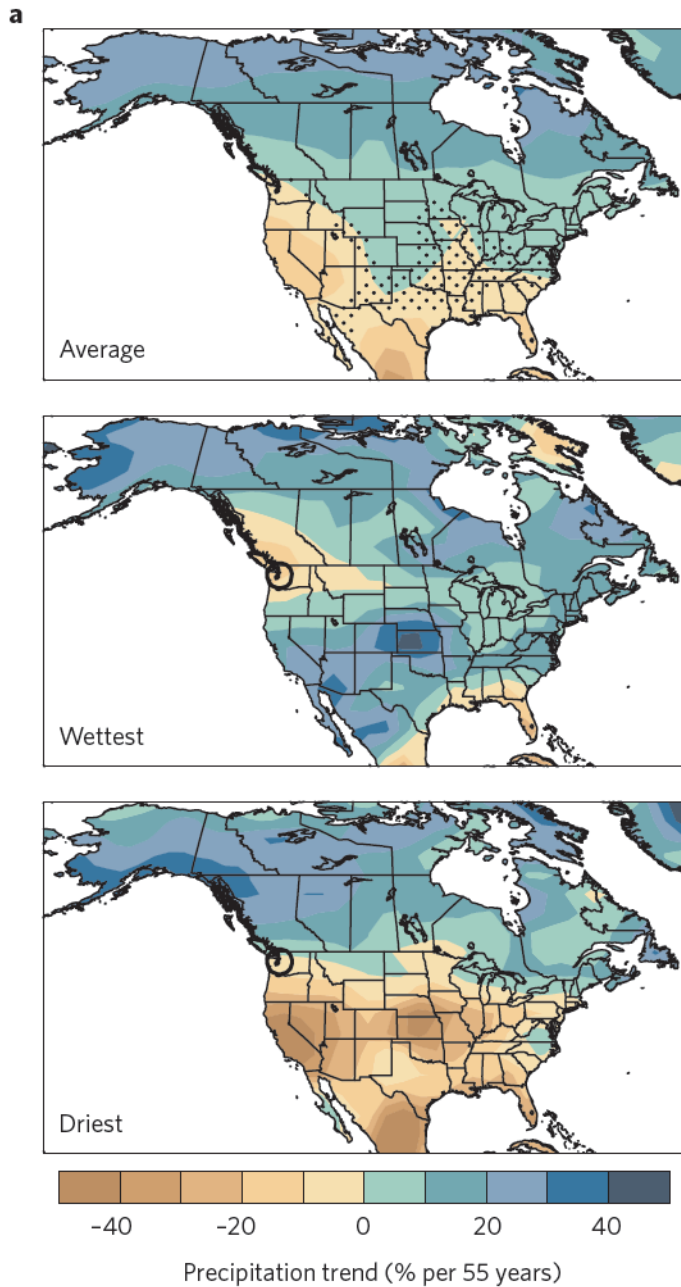
b



c

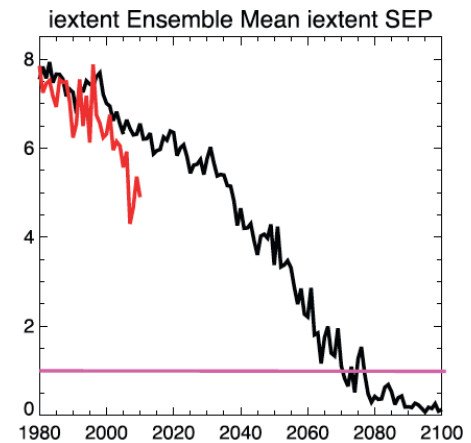


Ensemble of 40 CCSM3 simulations - Precipitation



September sea-ice extent

But ensembles may hide some interesting features!

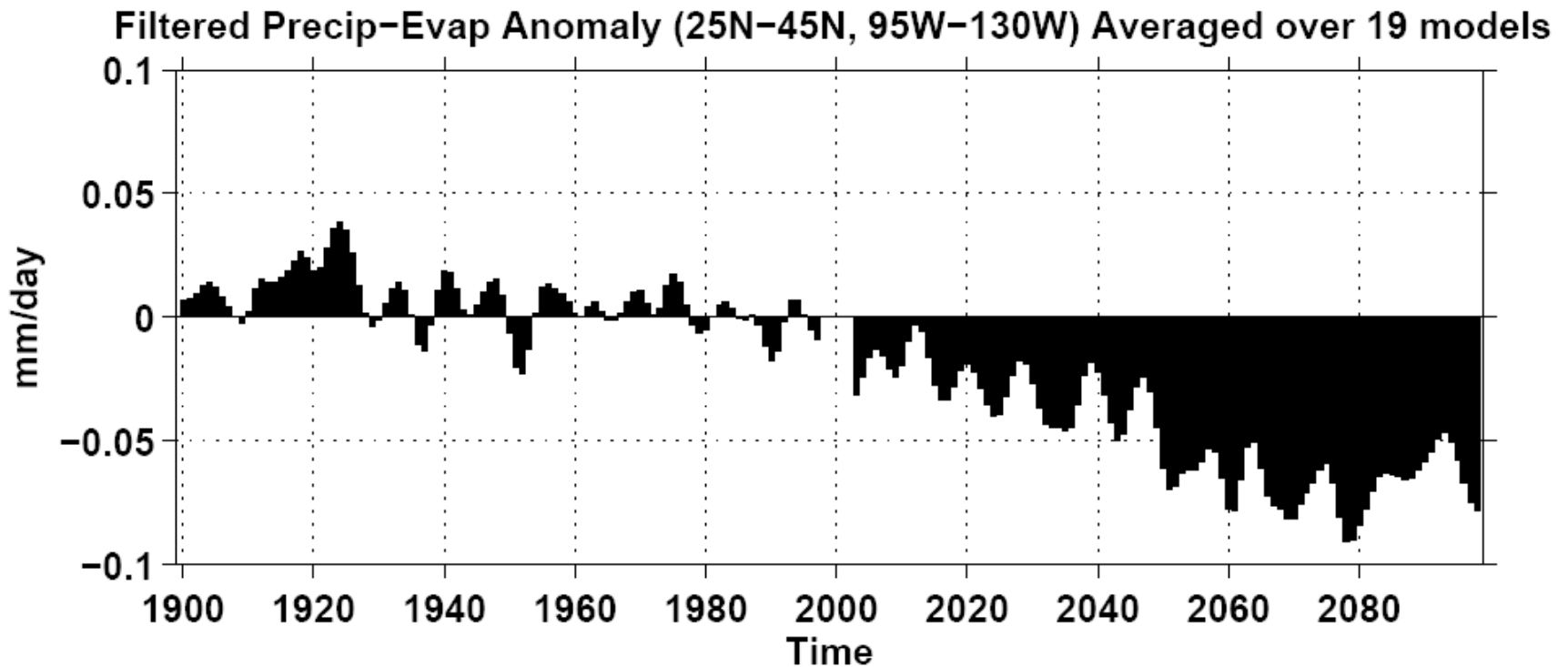


US South West

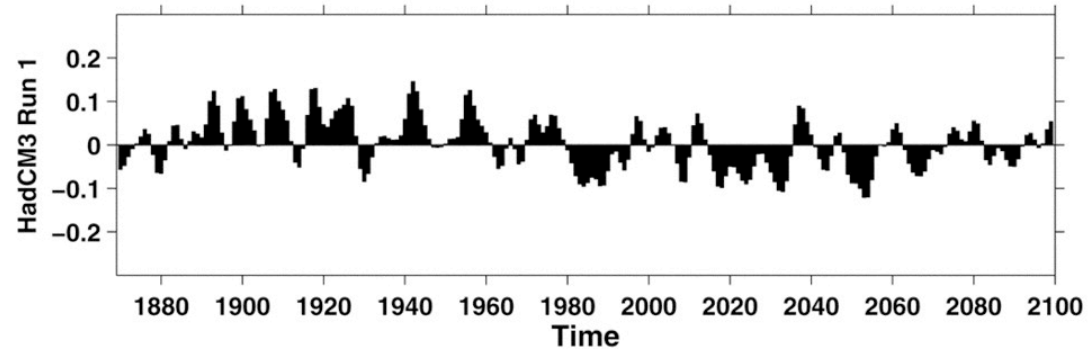
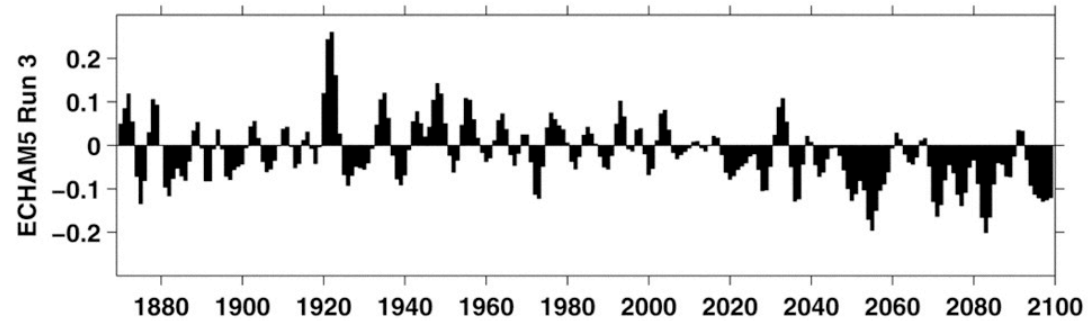
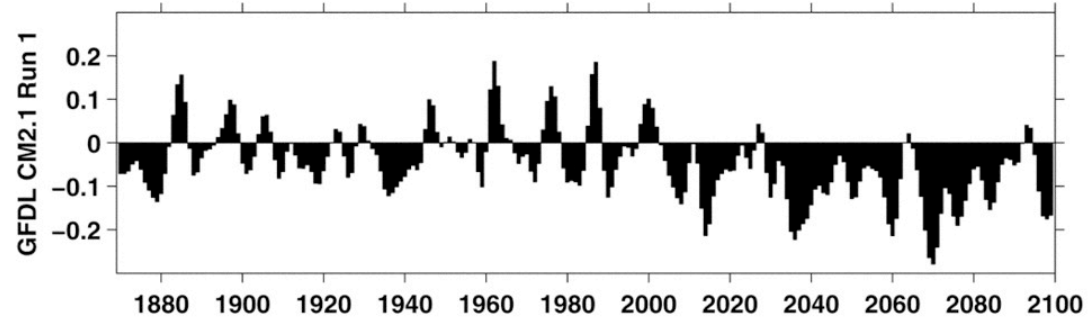
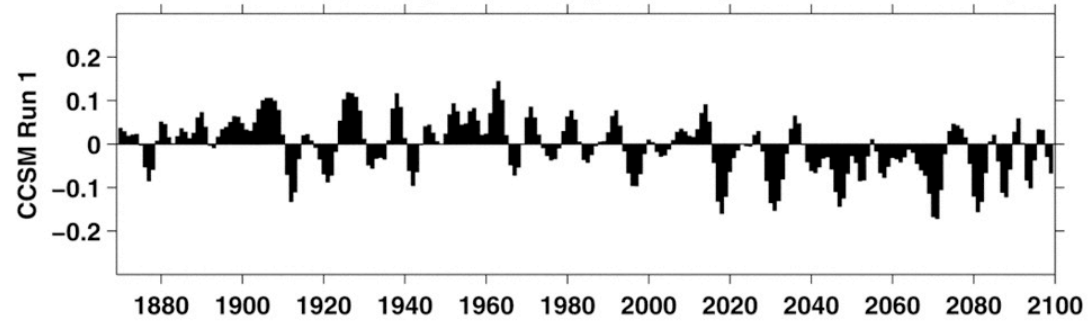
Is the current drought just the start?



IPCC Distribution Multi-Model Outlook:



Filtered Precip-Evap Anomaly (25N-40N, 95W-125W) mm/day



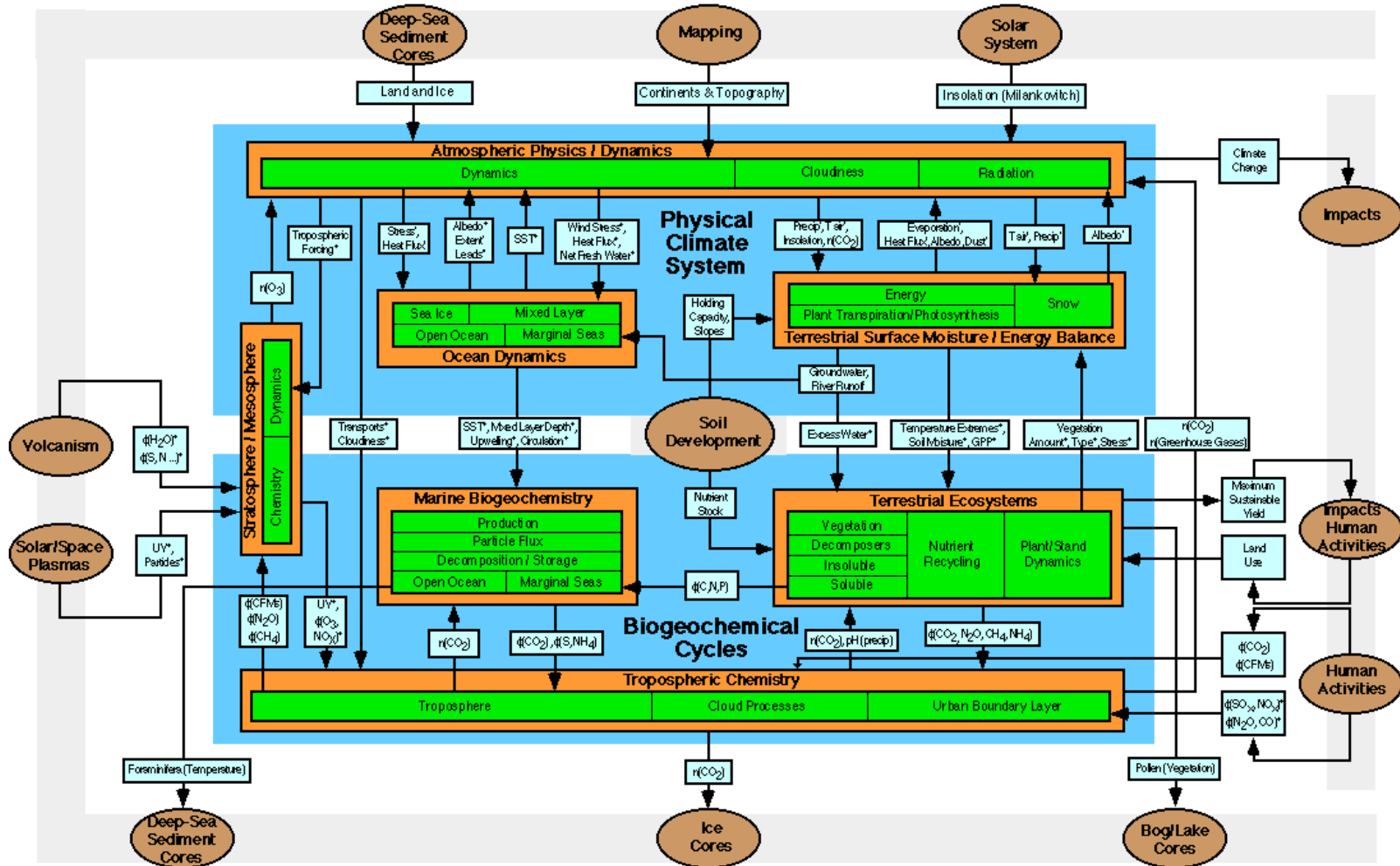
Seager
et al.
(2007)

An Ever Expanding the Menu



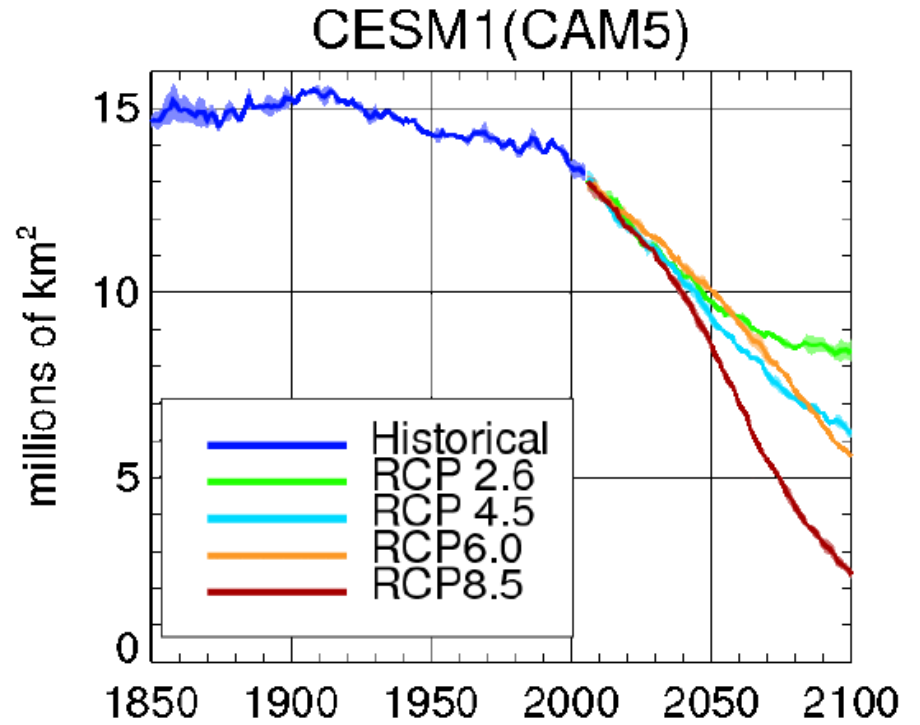
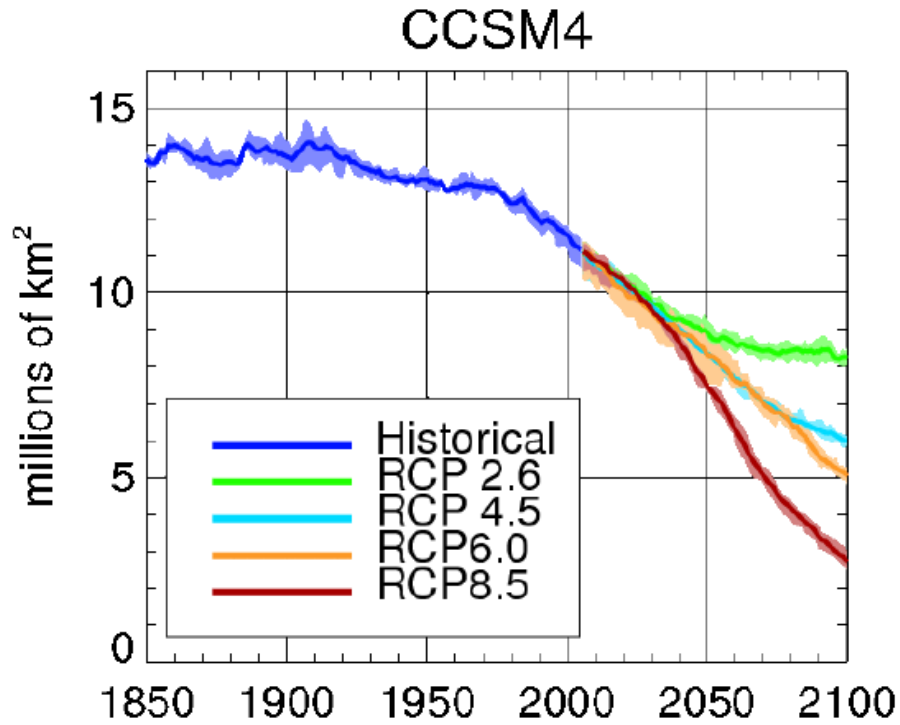
Earth System Modeling

CONCEPTUAL MODEL of Earth System process operating on timescales of decades to centuries

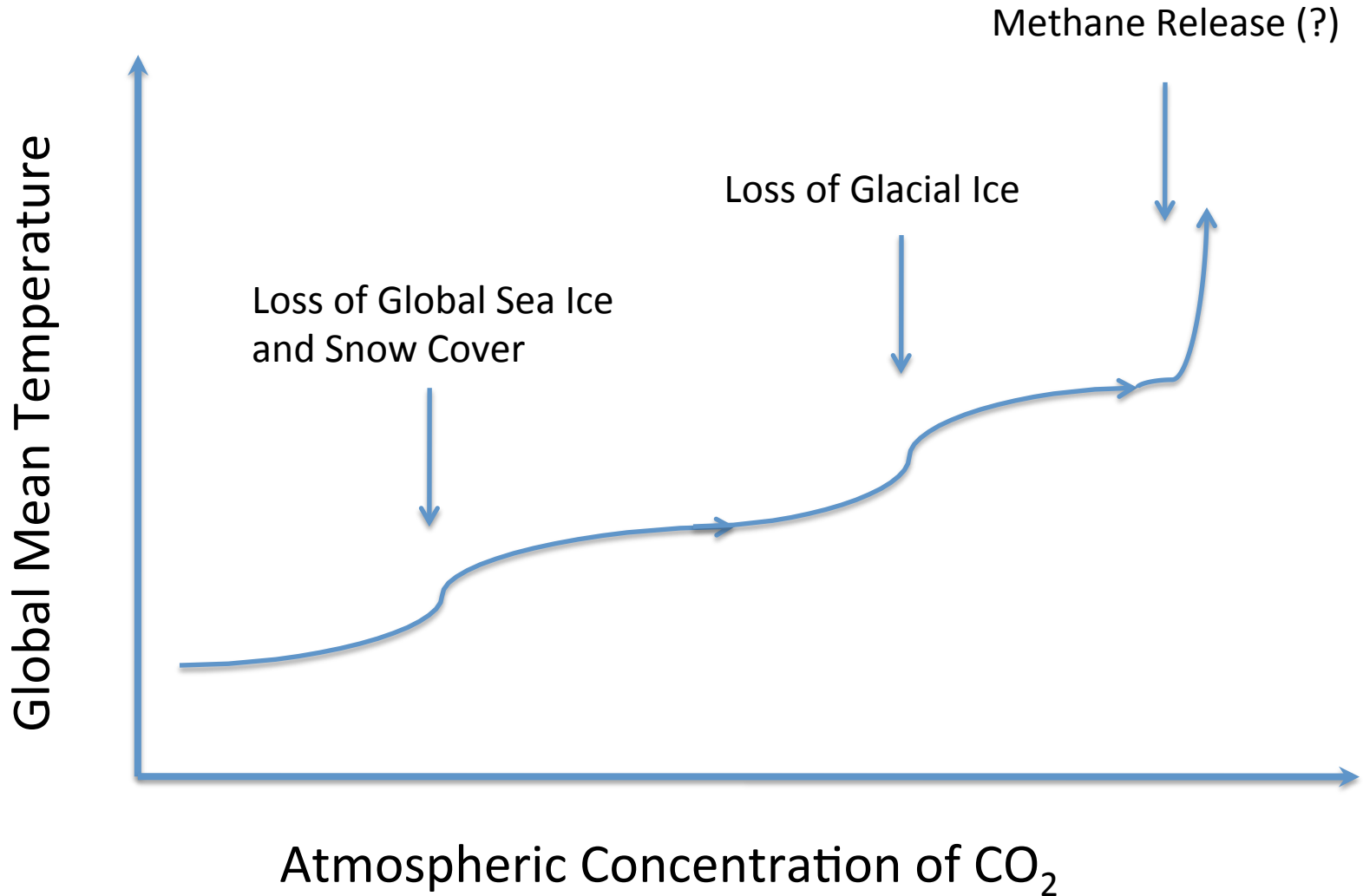


* = on timescale of hours to days * = on timescale of months to seasons ϕ = flux n = concentration

Northern Hemisphere Permafrost Extent



Potential Nonlinear Changes in Global Surface Temperature



May You All Become Good Chefs!

