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Climate Change – Past, Present, and Future

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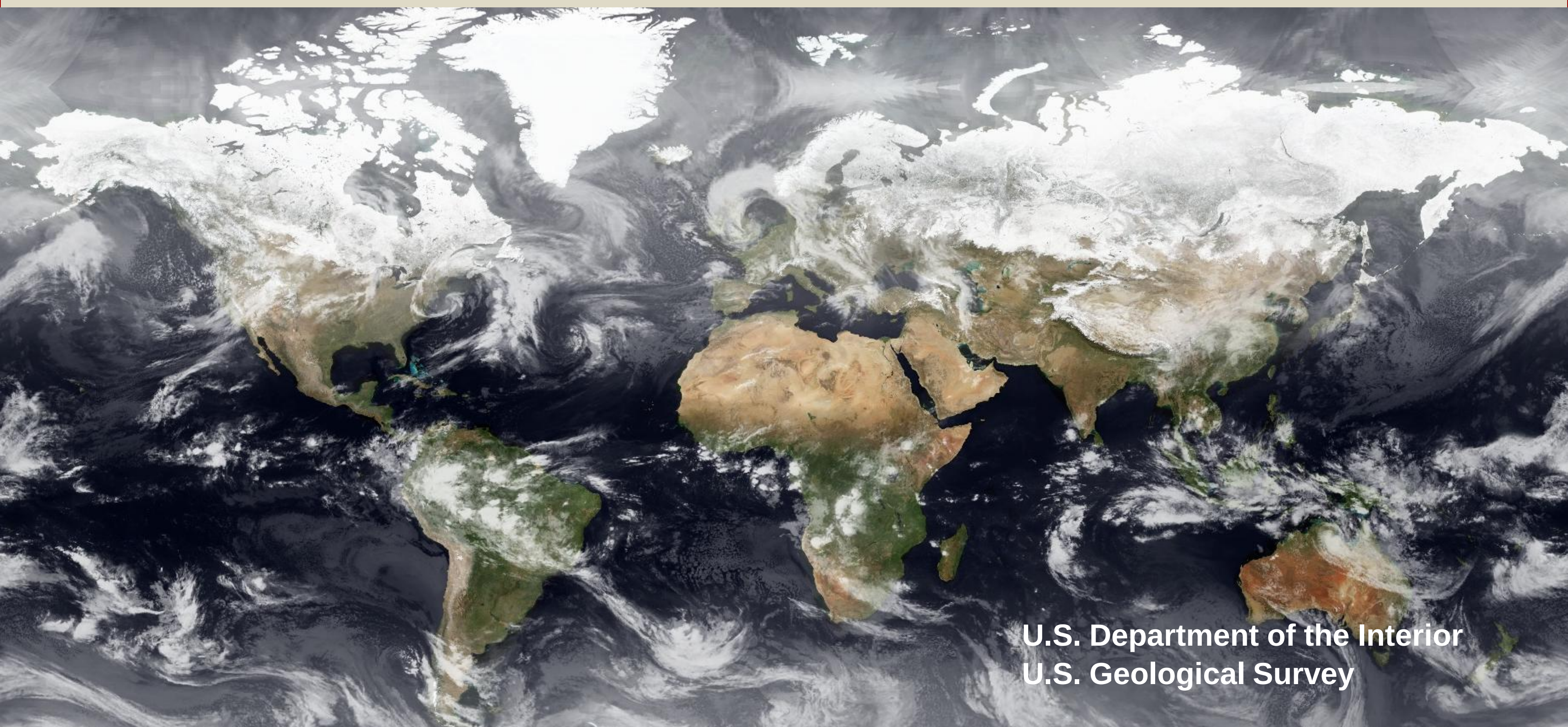
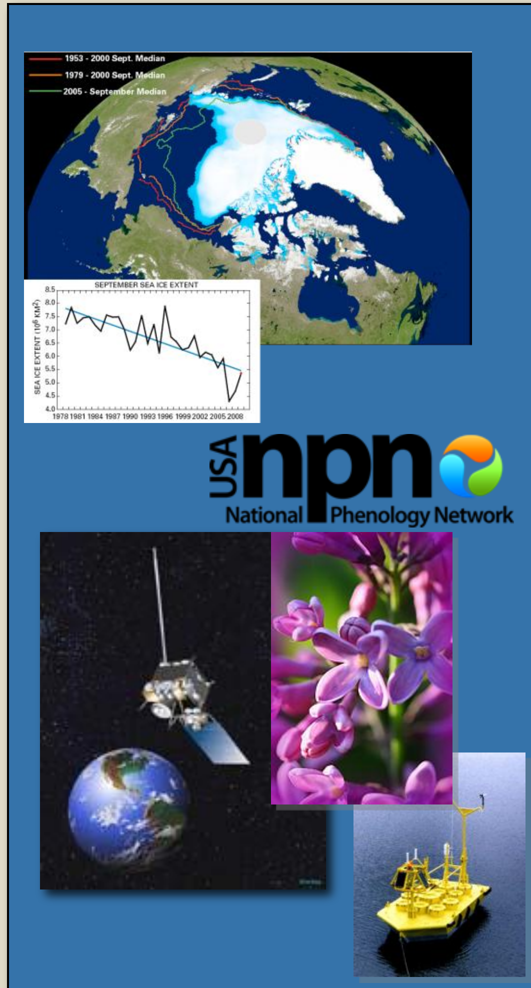
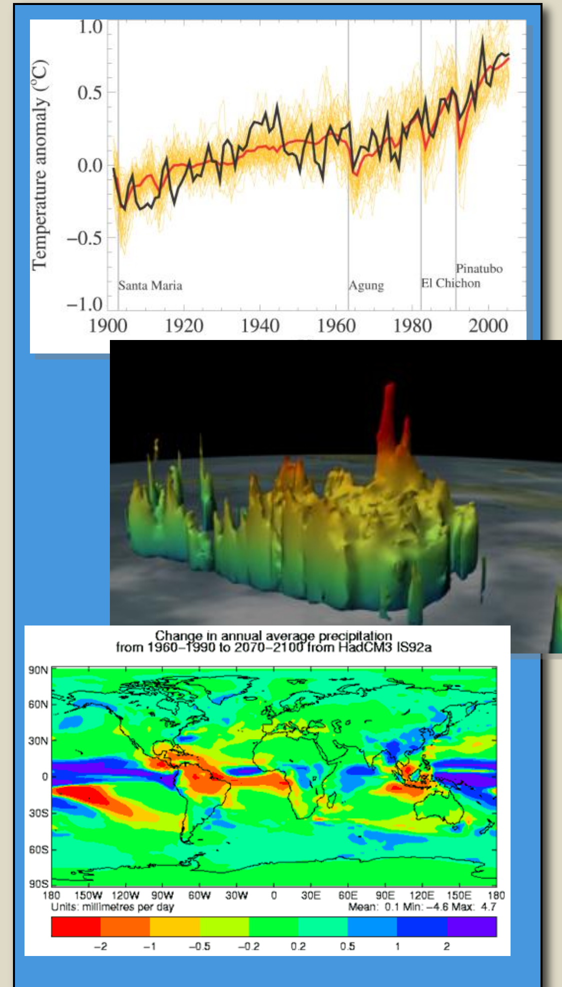
Geology and Environmental Change Science Center



U.S. Department of the Interior
U.S. Geological Survey

Climate – The Future





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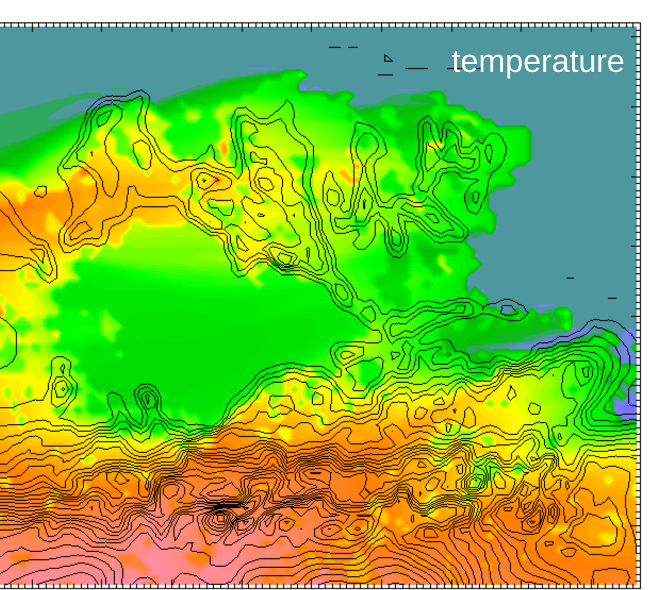
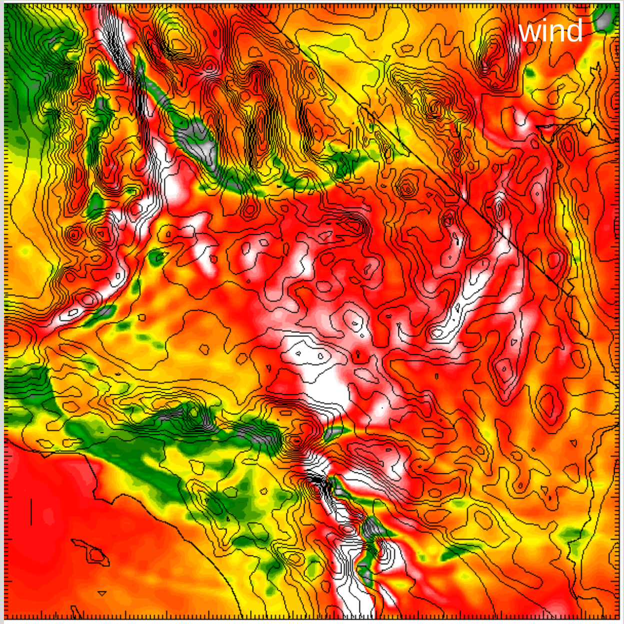
Outline

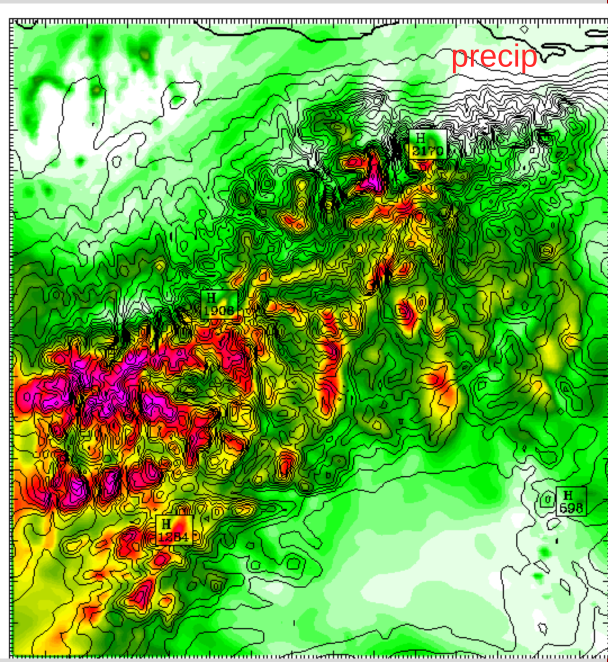
1) Tools – How do we Project what will Happen in the Future?

2) AOGCM (Global) Climate Projections for the 21st Century

3) Regional Climate Projections







1) Tools,

How do we Project what will Happen in the Future?

Climate Models – Two Basic Categories:

- **Statistical or Empirical Models**

  - based on an observed relationship between 2 or more quantities

- **Physically-Based Models**

  - based on laws of physics

Flux-Form Equations in Mass Coordinate

Introduce the perturbation variables: $\phi = \bar{\phi}(z) + \phi', \mu = \bar{\mu}(z) + \mu';$ $p = \bar{p}(z) + p', \alpha = \bar{\alpha}(z) + \alpha'$

Note – $\phi = \bar{\phi}(z) = \bar{\phi}(x, y, \eta),$

likewise $\bar{p}(x, y, \eta), \bar{\alpha}(x, y, \eta)$

Momentum and hydrostatic equations become:

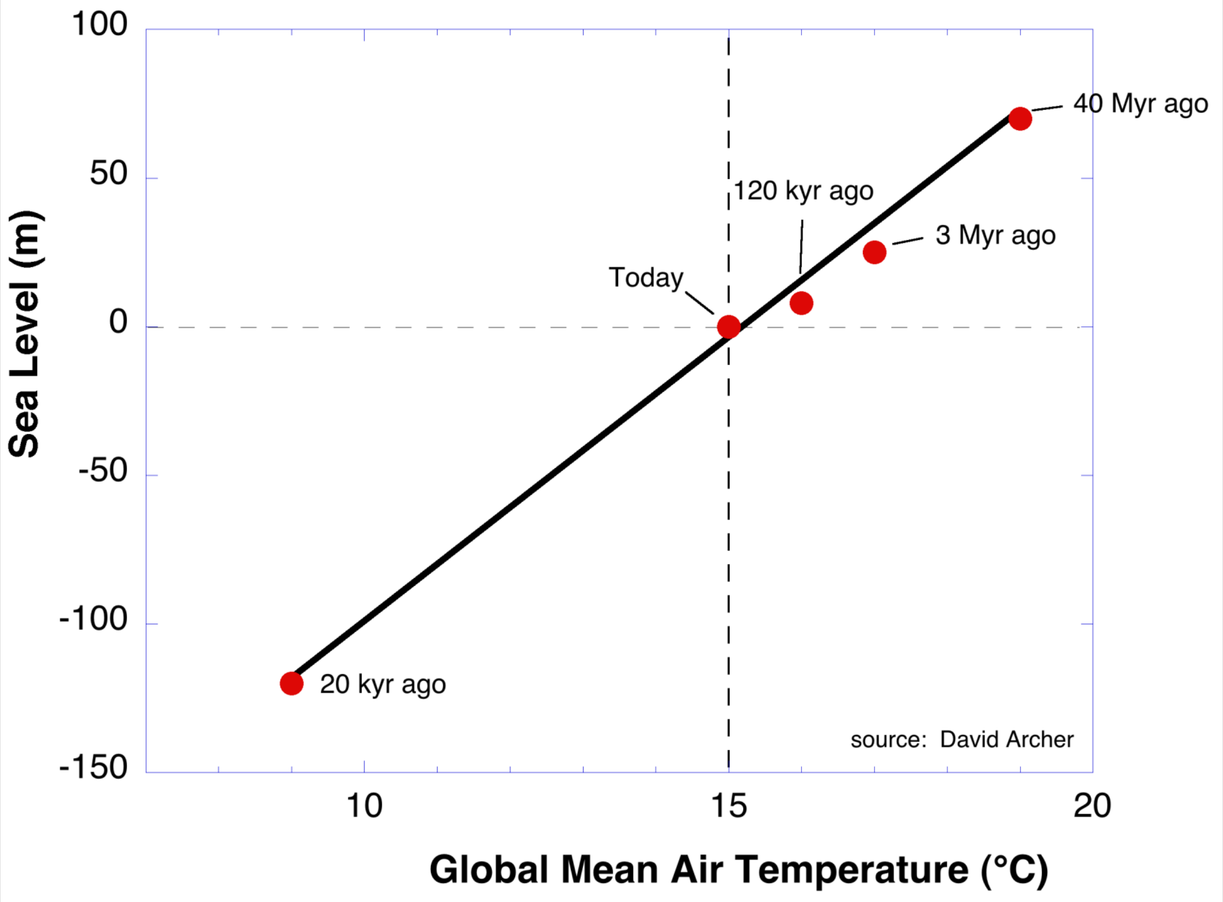
$$\frac{\partial U}{\partial t} + \mu\alpha\frac{\partial p'}{\partial x} + \eta\mu\alpha'\frac{\partial \bar{\mu}}{\partial x} + \mu\frac{\partial \phi'}{\partial x} + \frac{\partial \phi'}{\partial x}\left(\frac{\partial p}{\partial \eta} - \mu'\right) = -\frac{\partial Uu}{\partial x} - \frac{\partial \Omega u}{\partial \eta}$$

$$\frac{\partial W}{\partial t} + g\left(\mu' - \frac{\partial p'}{\partial \eta}\right) = -\frac{\partial Uw}{\partial x} - \frac{\partial \Omega w}{\partial \eta}$$

$$\frac{\partial \phi'}{\partial \eta} = -\bar{\mu}\alpha' - \bar{\alpha}\mu'$$

Tools: Statistical or Empirical Models

A Simple Example,



Tools: Physically-Based Models

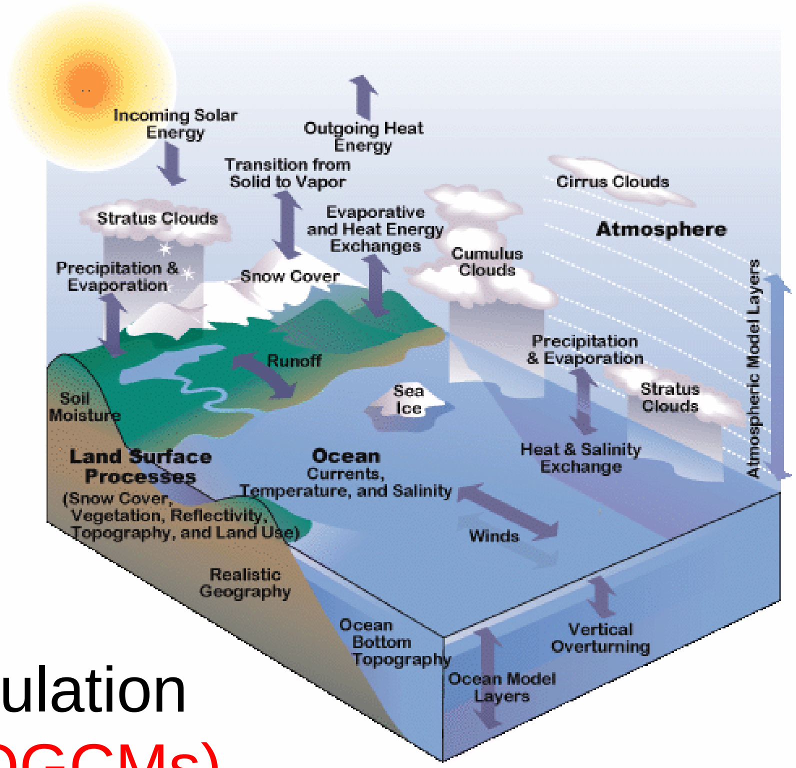
Categories:

- Simple Climate Models

- Earth System Models of Intermediate Complexity

- Atmosphere/Ocean General Circulation Models (AGCMs, OGCMs, AOGCMs)

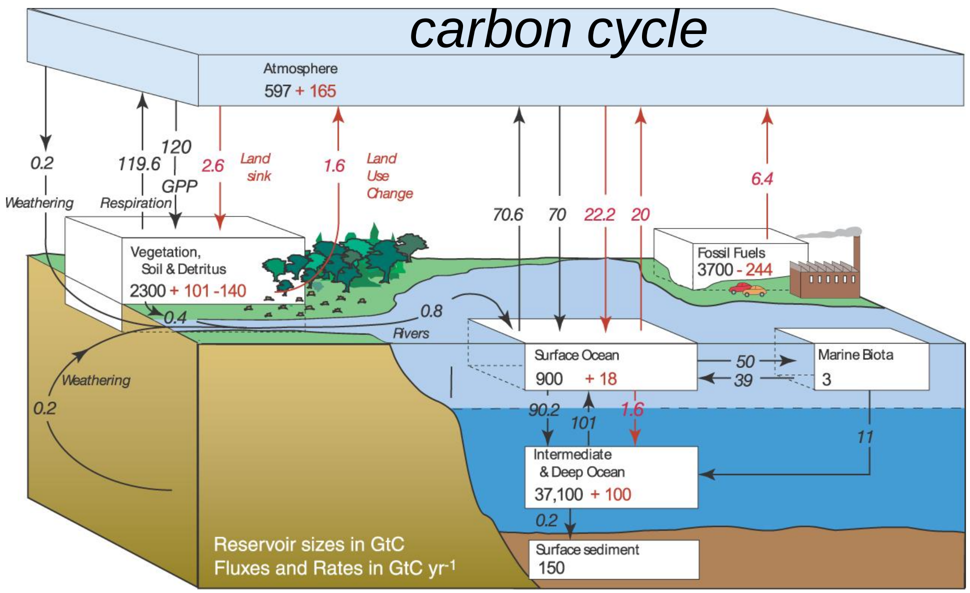
- Regional Climate Models (RCMs)



Tools: Physically-Based Models

Sources of Uncertainty in Future Climate Projections:

- Incomplete understanding of Earth System processes



Tools: Physically-Based Models

Sources of Uncertainty in Future Climate Projections:

- Incomplete understanding of Earth System processes

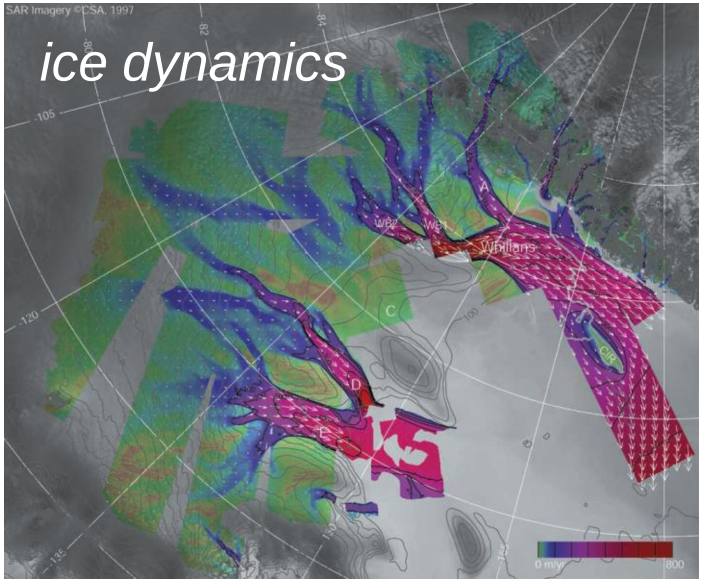
- Missing processes & feedbacks

future volcanic activity

future solar variability

ice sheet dynamics

carbon cycle feedbacks



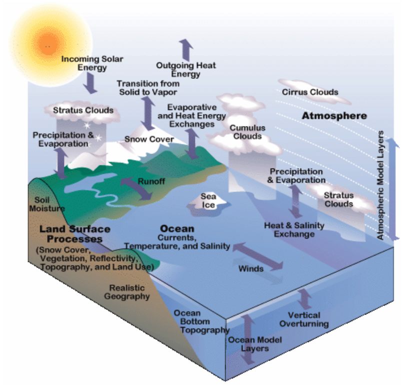
Tools: Physically-Based Models

Sources of Uncertainty in Future Climate Projections:

- Incomplete understanding of Earth System processes

- Missing processes

- Uncertainties in the parameters



Physics

Evaporation Rate = $C_R \left[\frac{\kappa w^{1/2} u_\star^{3/4} \rho_o (q_o - q_d)}{(\nu z_o)^{1/4}} \right]$

What's this?

Tools: Physically-Based Models

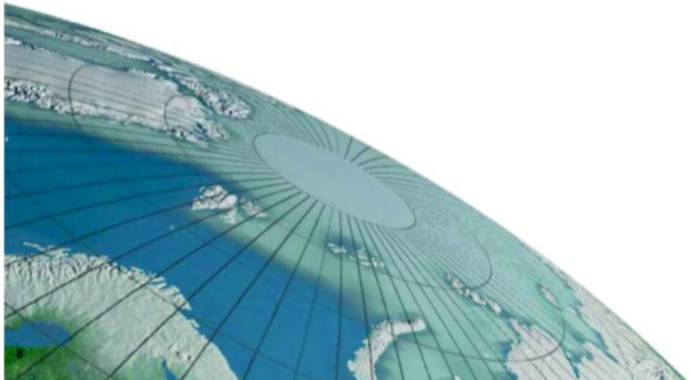
Sources of Uncertainty in Future Climate Projections:

- Incomplete understanding of Earth System processes

- Missing processes

- Uncertainties in the parameters

- Numerical Representation of Processes



Advection in the Height/Mass Coordinate Model

2nd, 3rd, 4th, 5th and 6th order centered and upwind-biased schemes are available in the WRF model.

Example: 5th order scheme

$$\frac{\partial(U\phi)}{\partial x} = \frac{1}{\Delta x}\left(F_{i+\frac{1}{2}}(U\phi) - F_{i-\frac{1}{2}}(U\phi)\right)$$

where

$$F_{i-\frac{1}{2}}(U\phi) = U_{i-\frac{1}{2}}\left\{\frac{37}{60}(\phi_i + \phi_{i-1}) - \frac{2}{15}(\phi_{i+1} + \phi_{i-2}) + \frac{1}{60}(\phi_{i+2} + \phi_{i-3})\right\}$$
$$- sign(1,U)\,\frac{1}{60}\left\{(\phi_{i+2} - \phi_{i-3}) - 5(\phi_{i+1} - \phi_{i-2}) + 10(\phi_i - \phi_{i-1})\right\}$$

Tools: Physically-Based Models

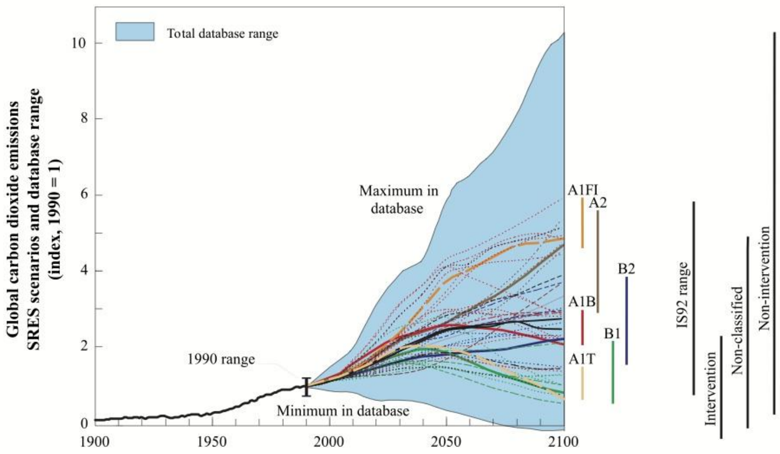
Sources of Uncertainty in Future Climate Projections:

- Incomplete understanding of Earth System processes

- Missing processes

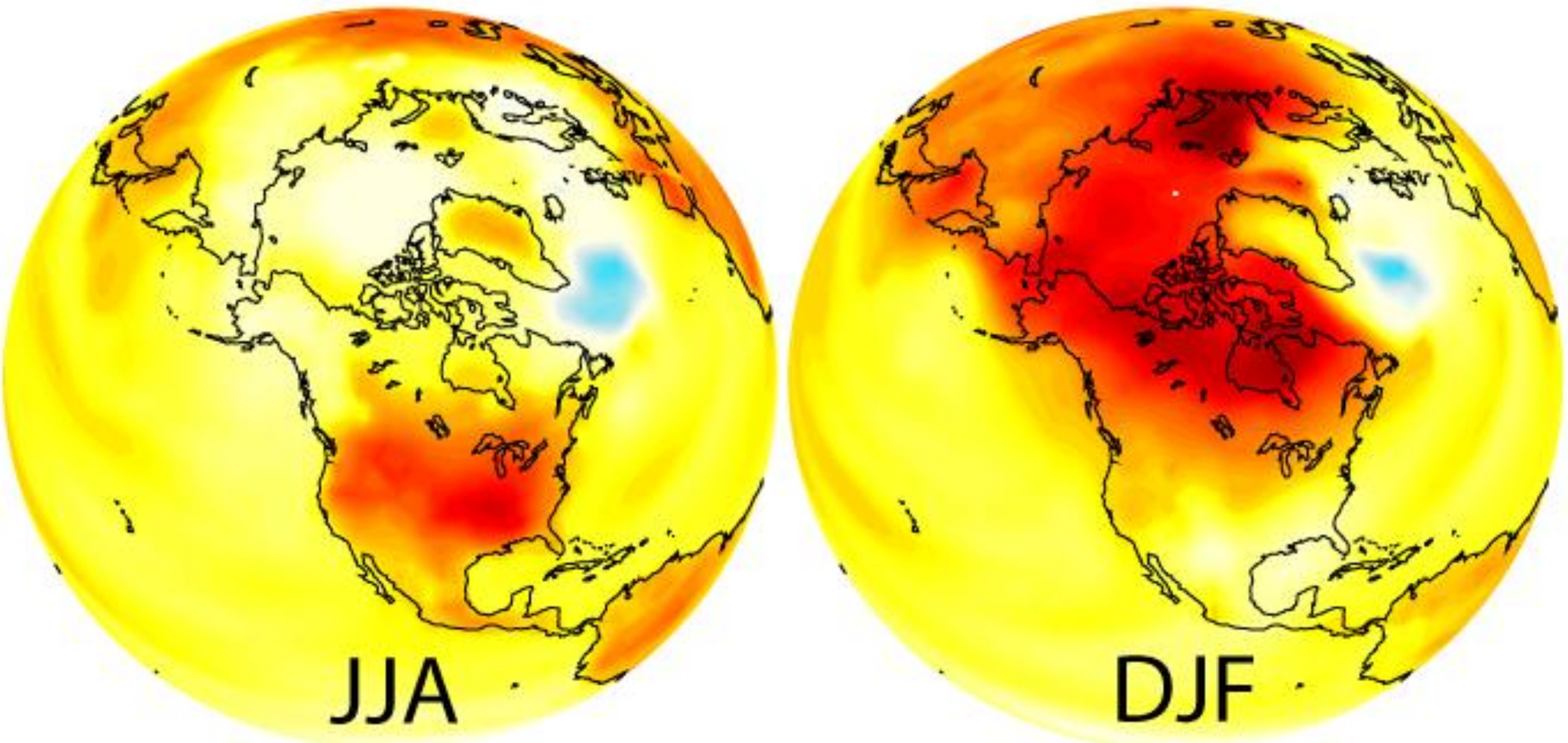
- Uncertainties in the parameters

- Numerical Representation

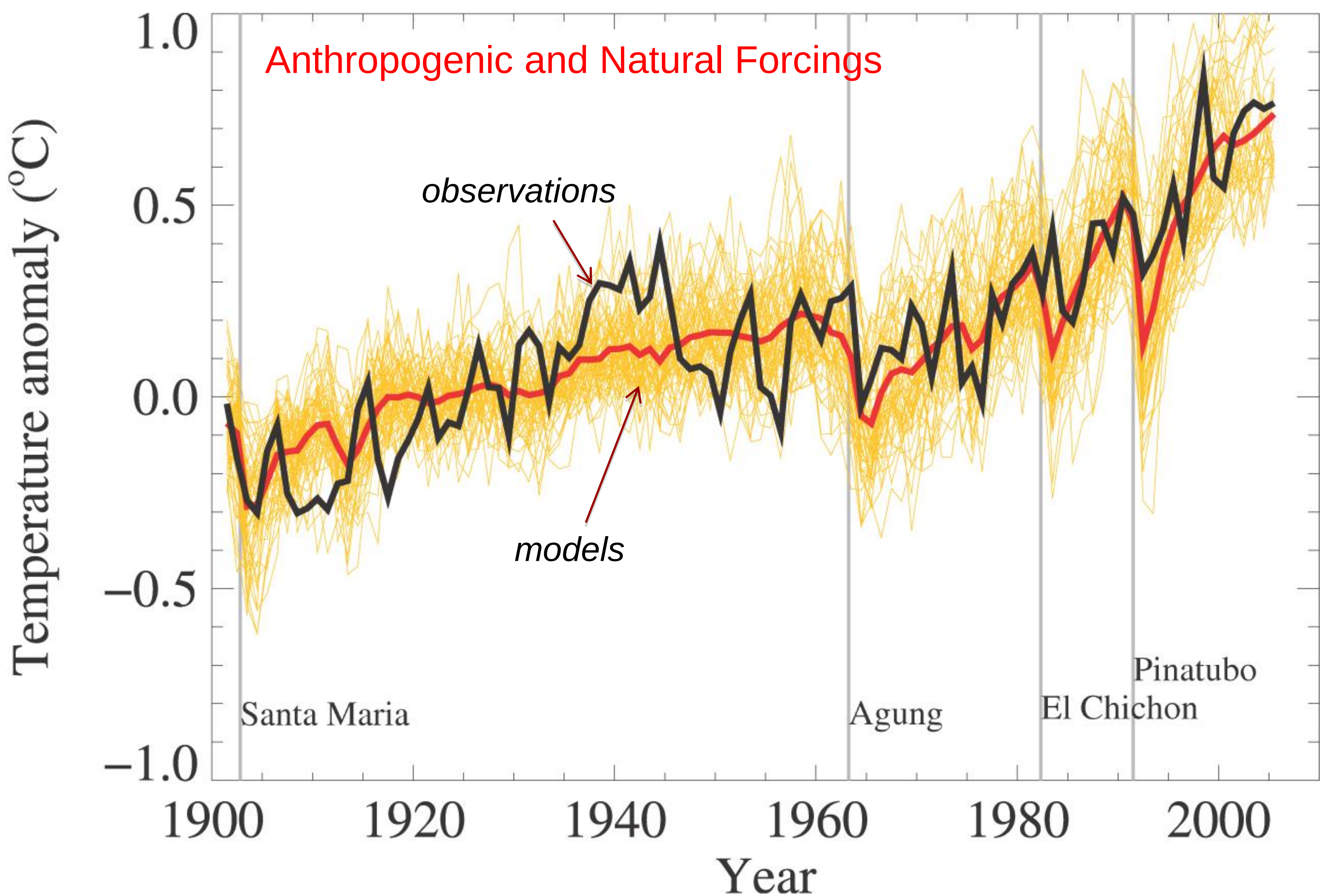


- Humans (GHG emissions, aerosols, landuse change ...)

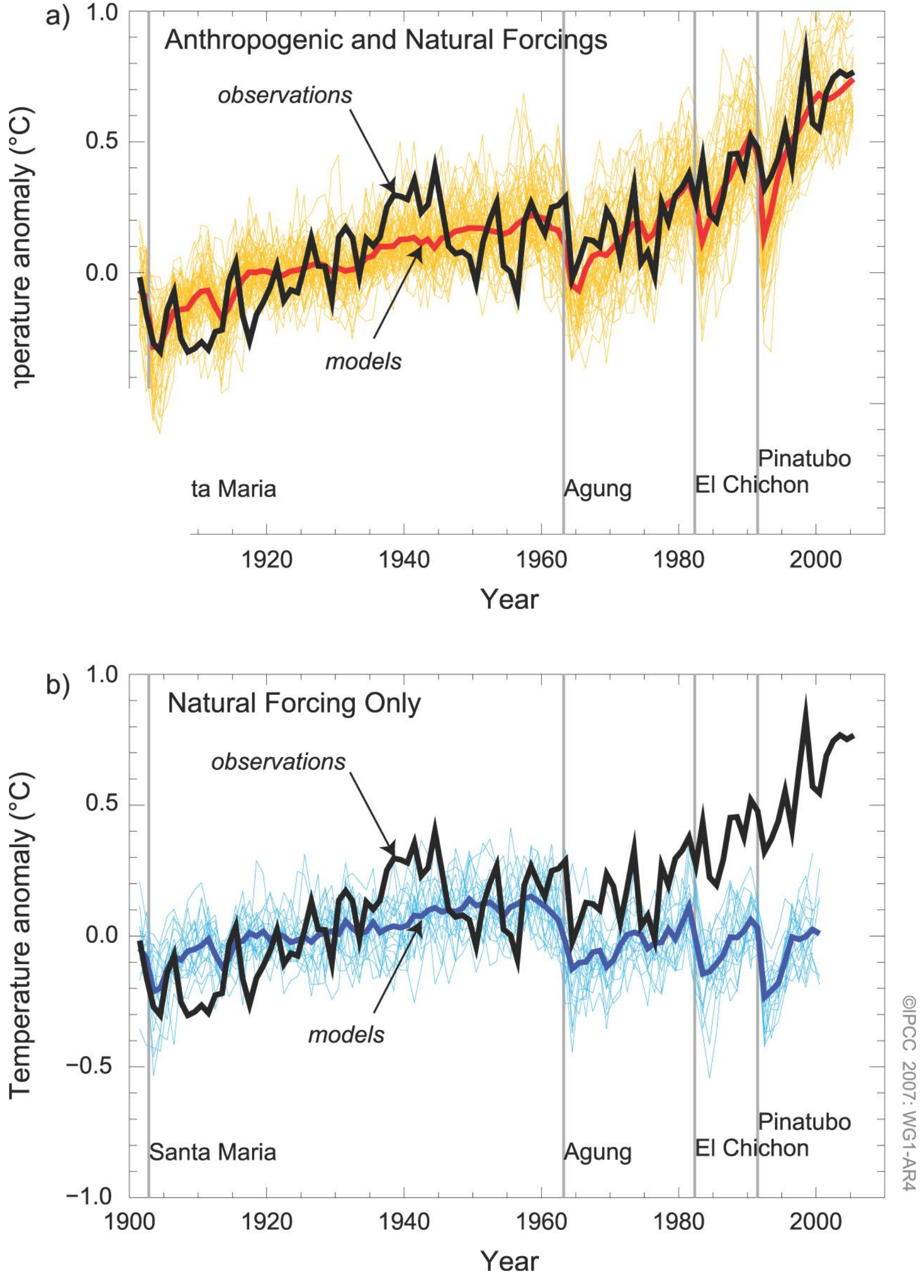
AOGCM Performance – 20th Century Tests



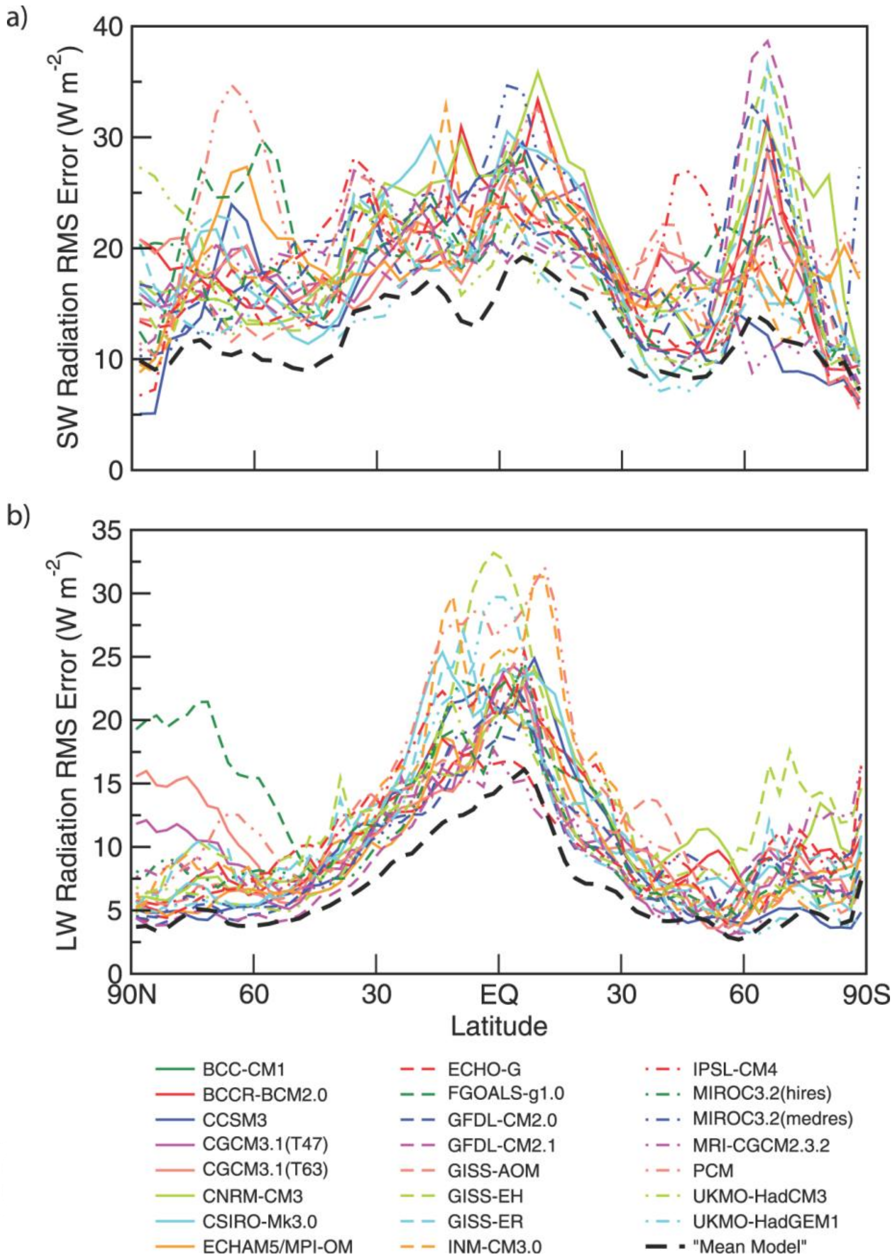
Observed and Simulated 20th-century Global Temperature Change



Observed and Simulated 20th-century Global Temperature Change



Errors in Shortwave and Longwave Radiation Fluxes (TOA)

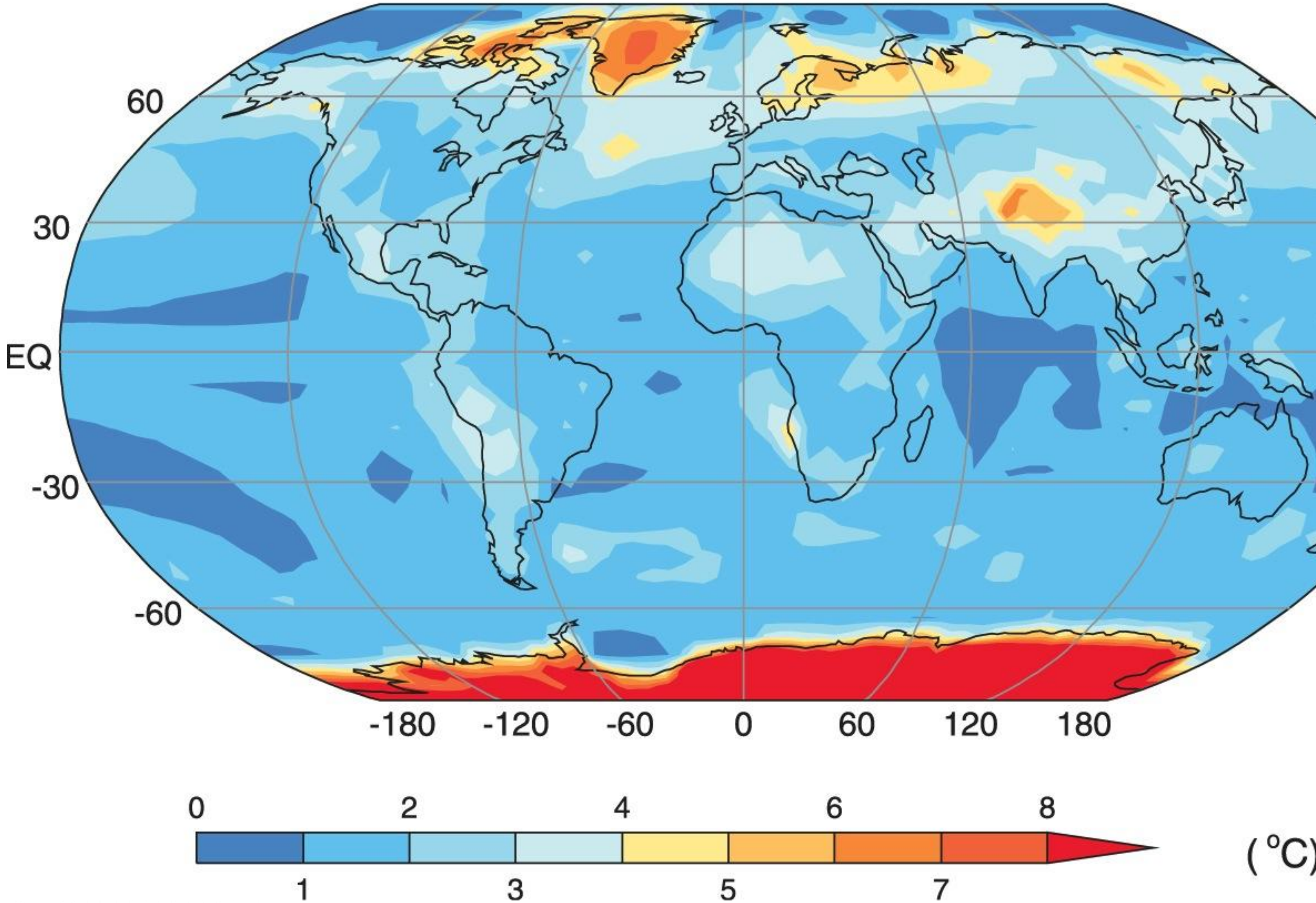


“Ensemble Mean” is better than any individual model

23 AOGCMs

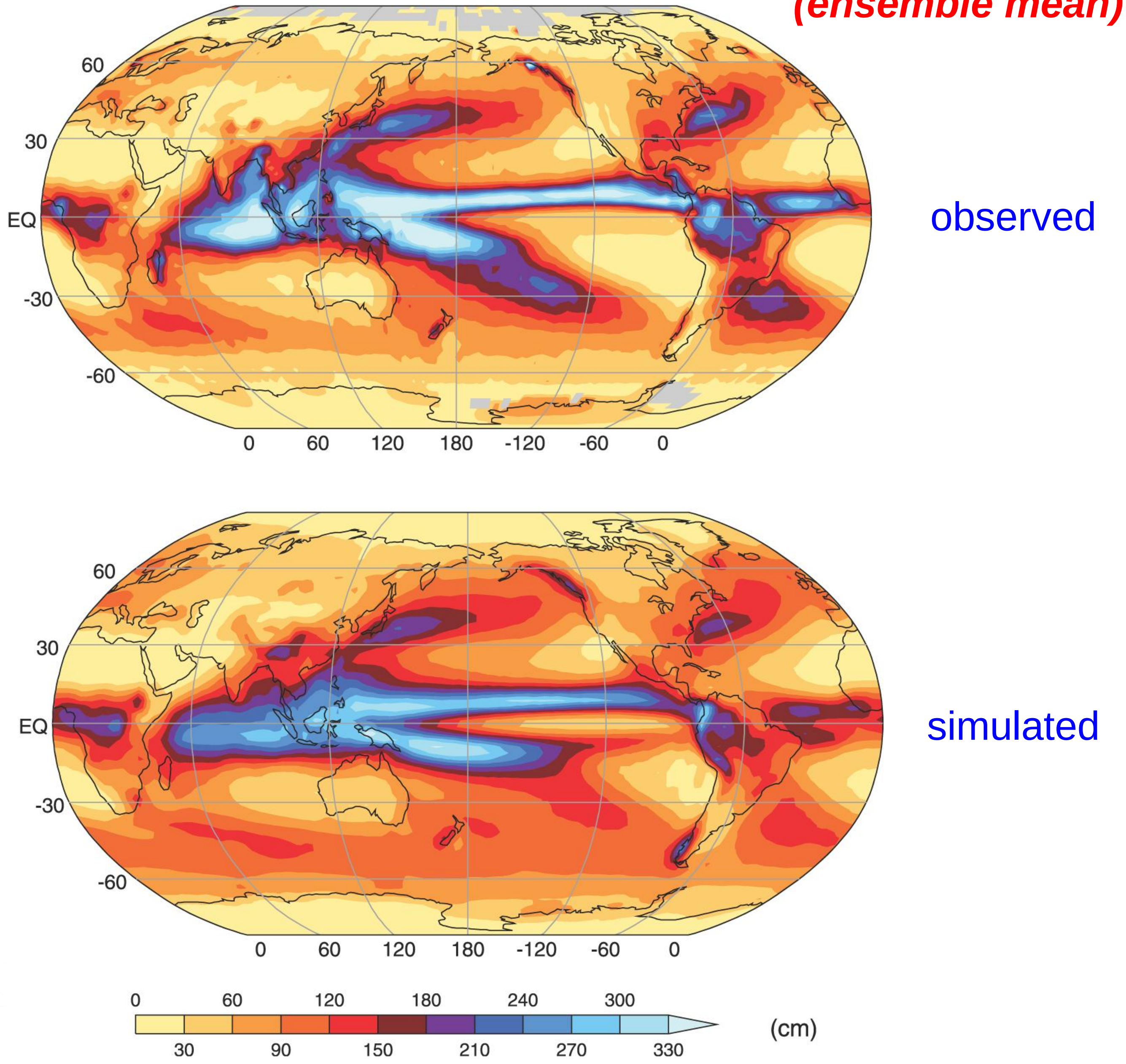
Error in Simulating Contemporary Surface-Temperature Pattern

(ensemble mean)

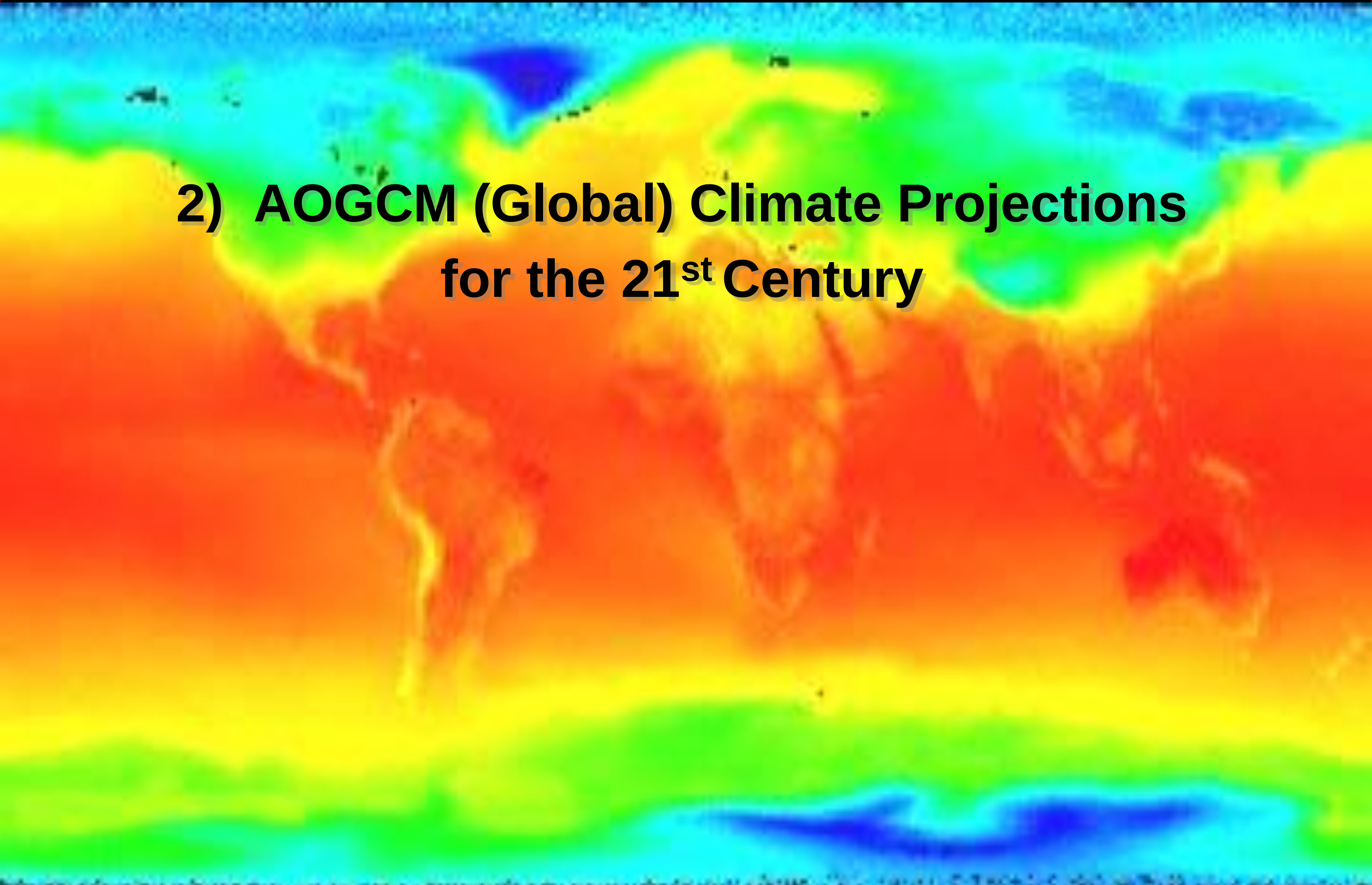


Observed and Simulated Mean-Annual Precipitation Pattern

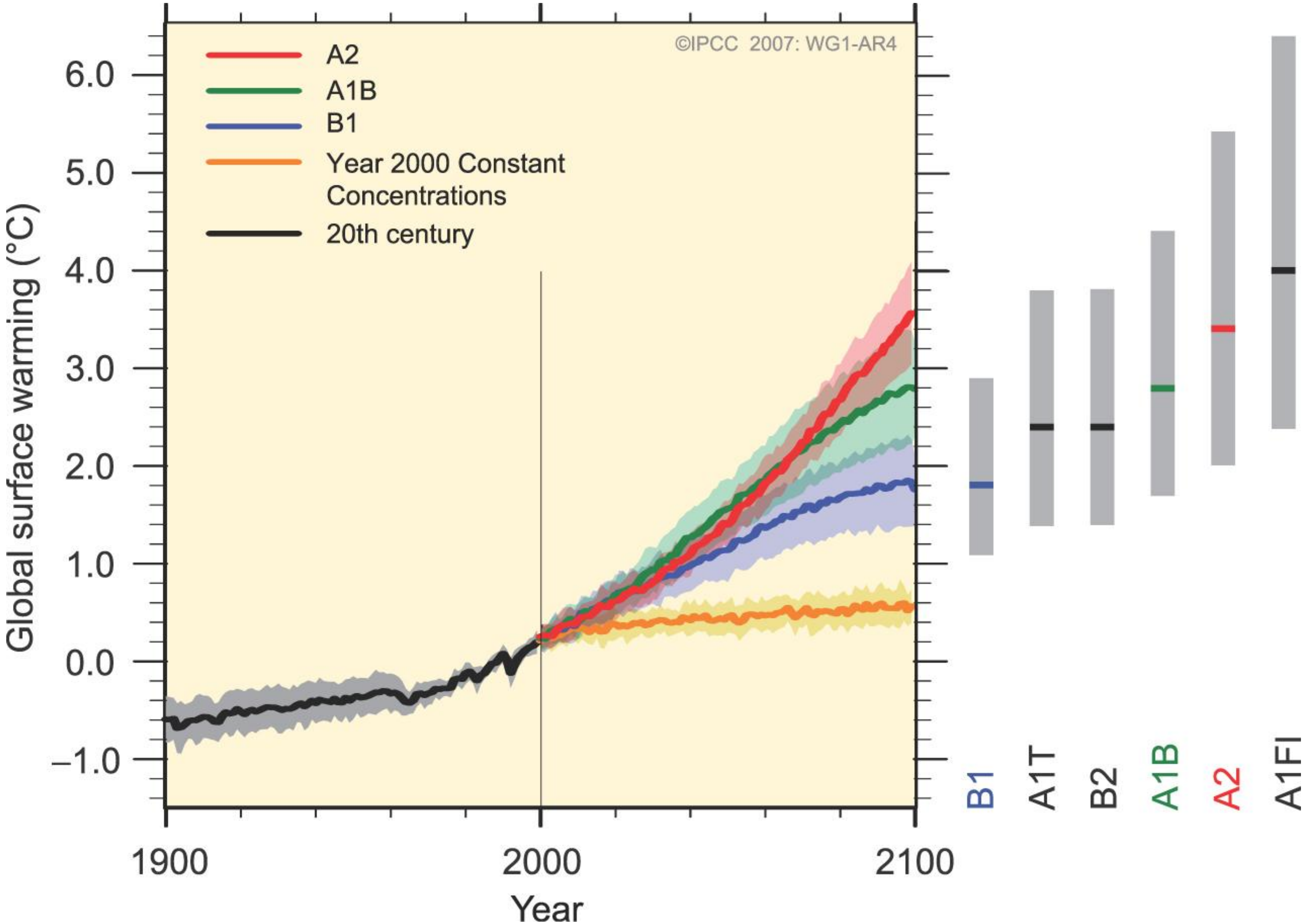
(ensemble mean)



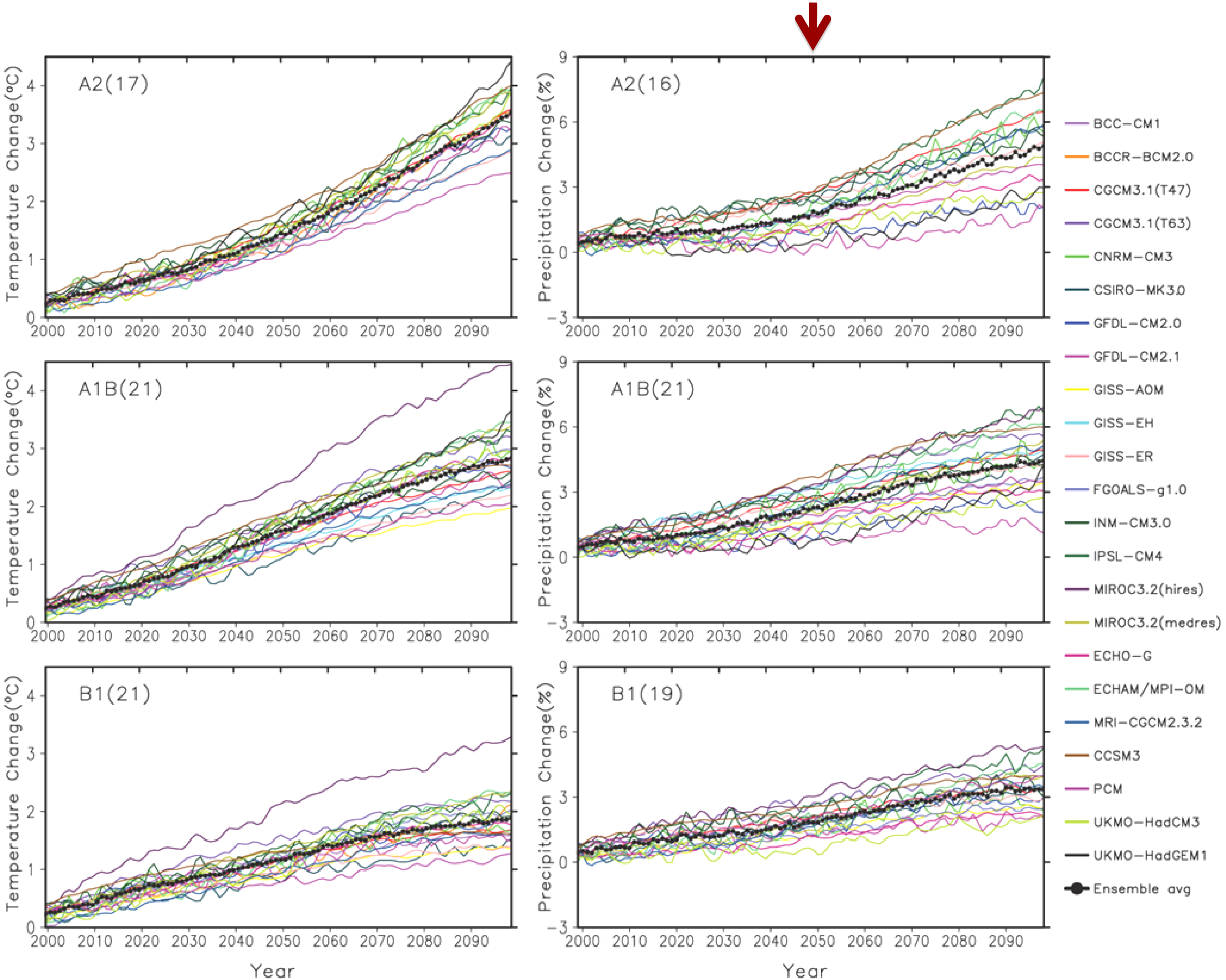
2) AOGCM (Global) Climate Projections for the 21st Century



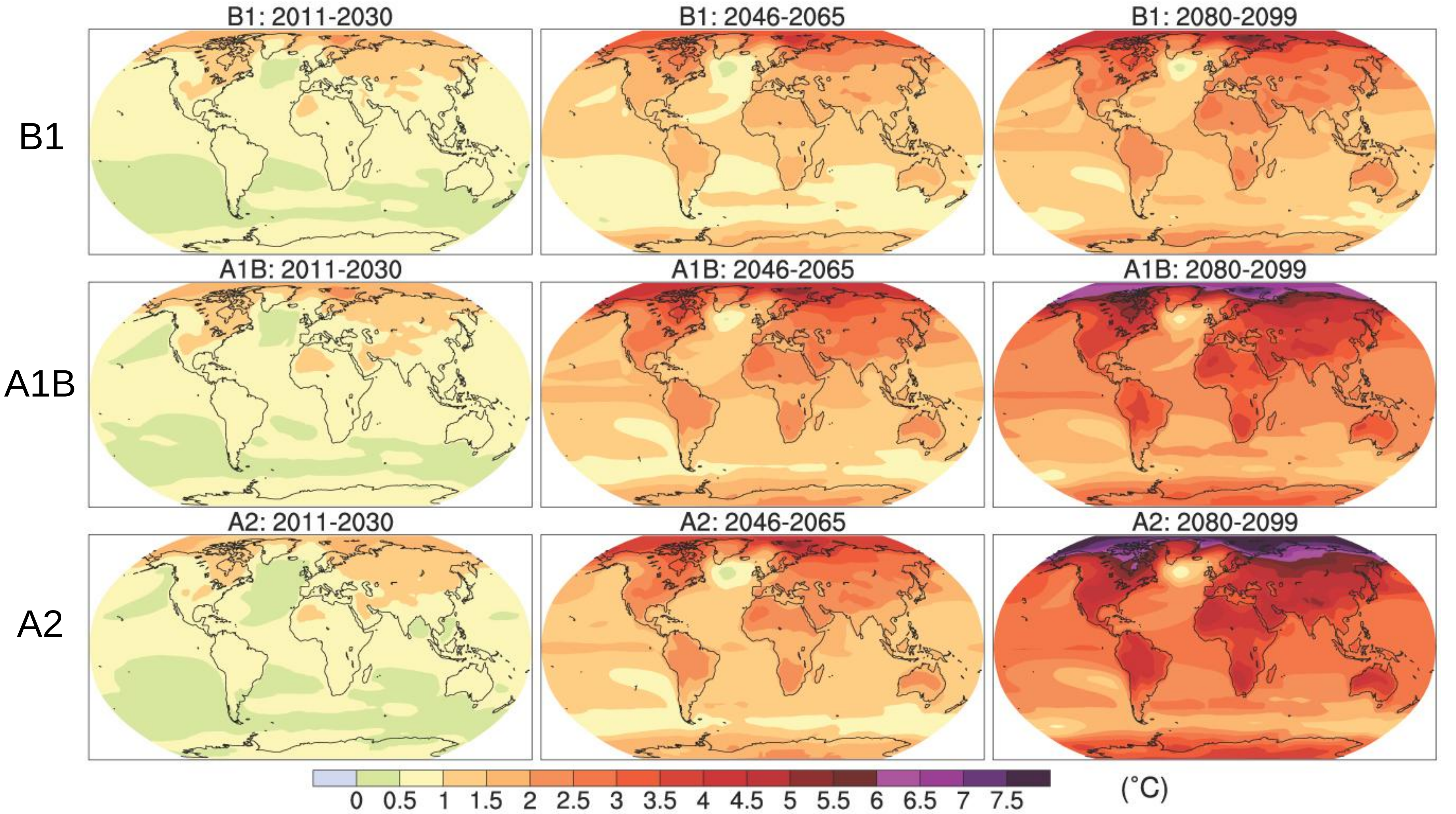
Global Surface-Temperature Projections to 2100



Projected 21st-Century Global Precipitation Changes

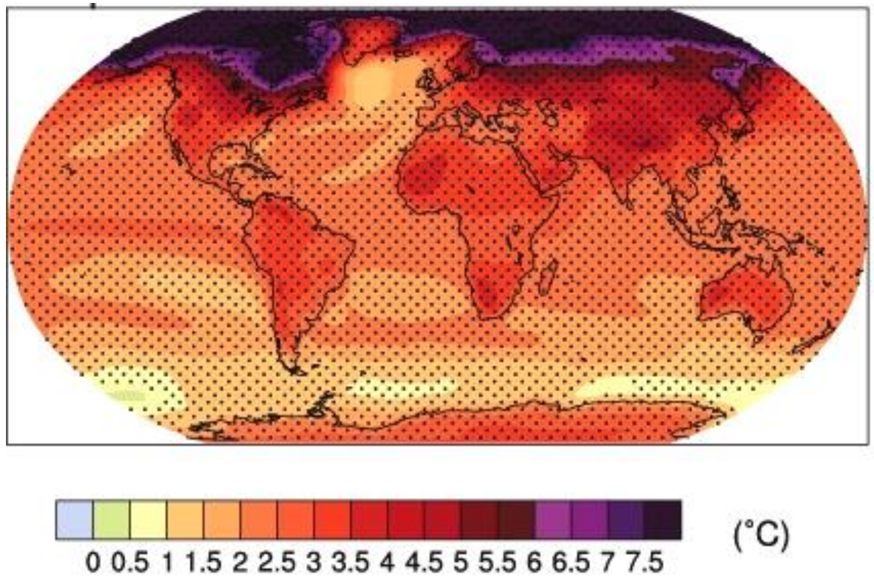


Projected Pattern of Mean-Annual Temperature Change

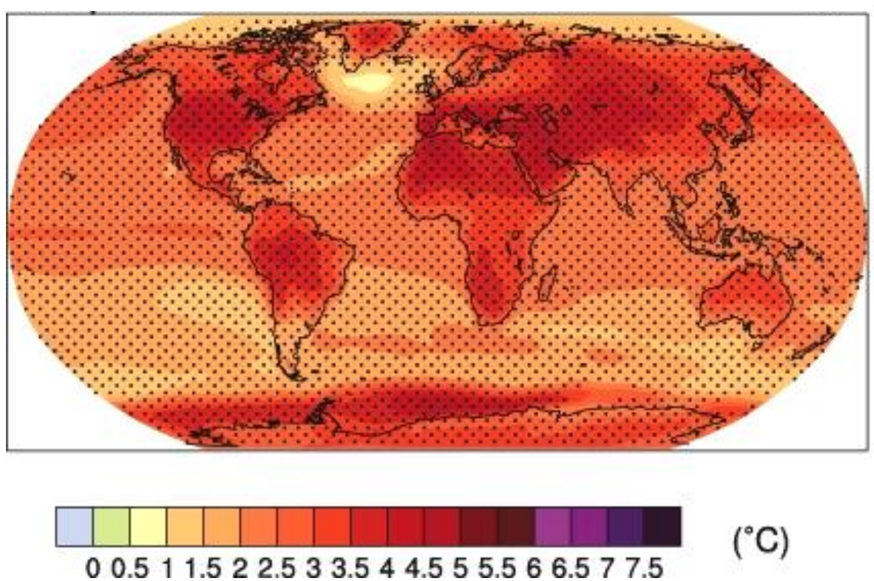


IPCC, 2007

Projected Pattern of Seasonal Temperature Change (A1B, 2080-2099)

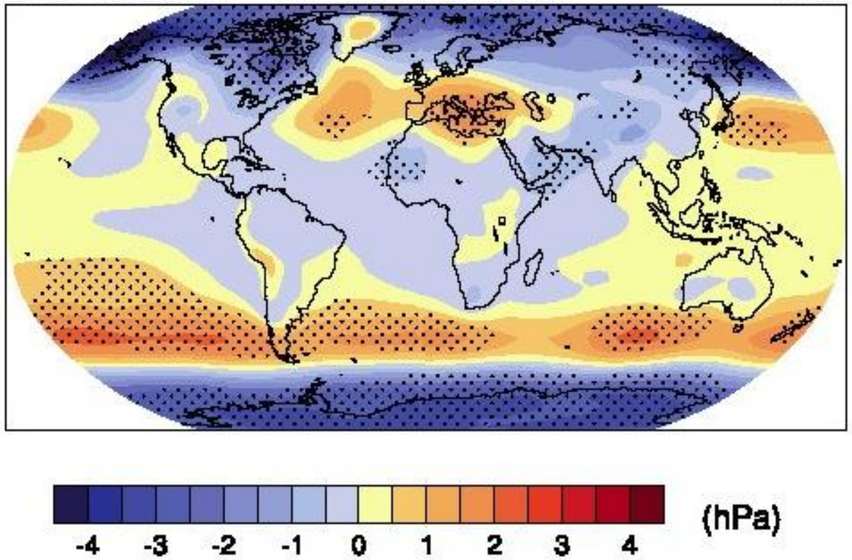


winter

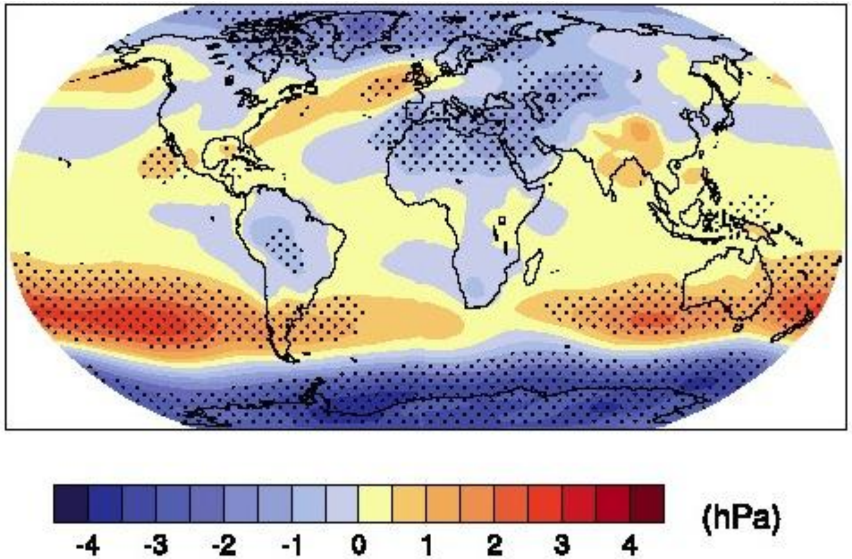


summer

Projected Pattern of Atmospheric Pressure Change (A1B, 2080-2099)

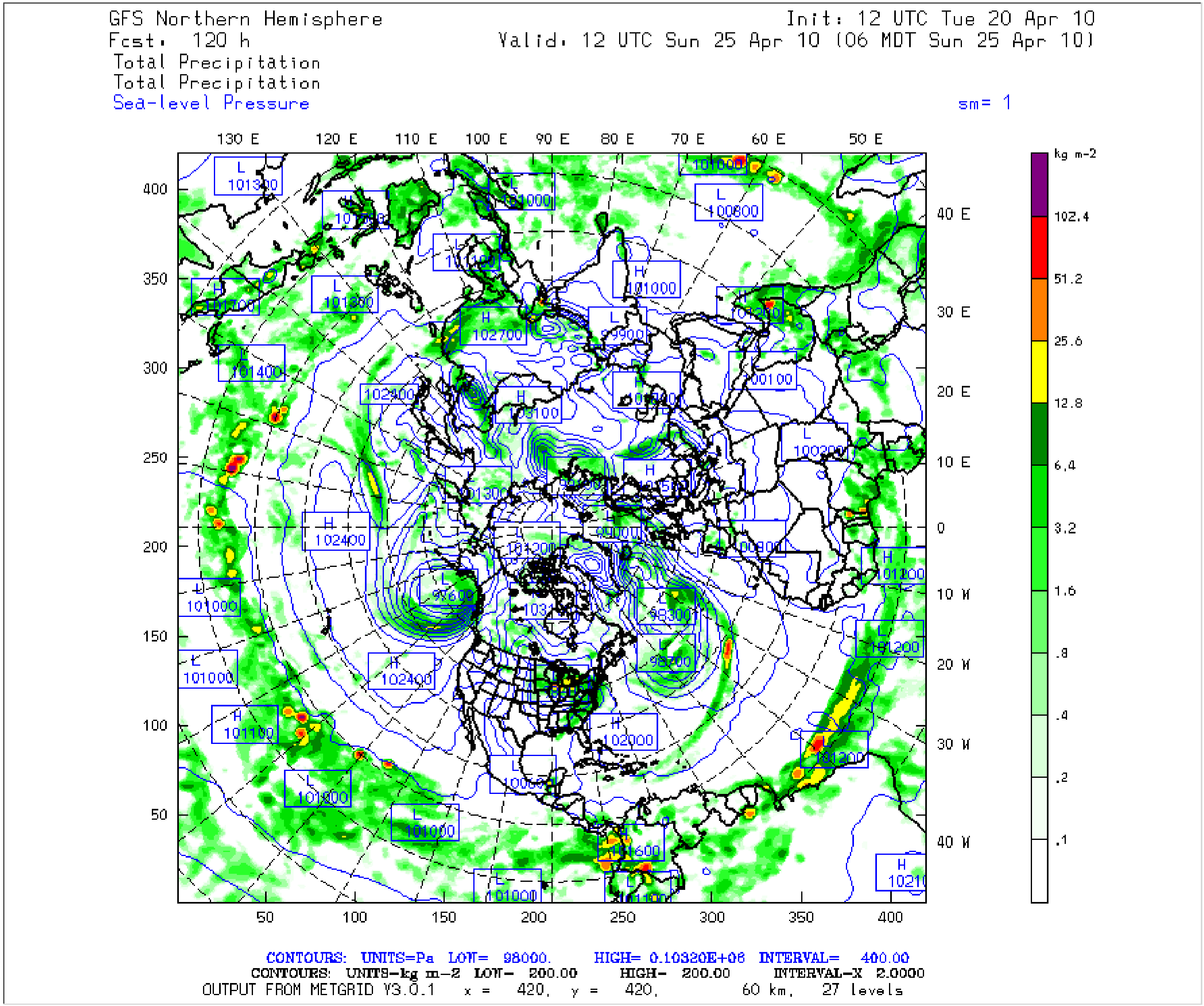


winter

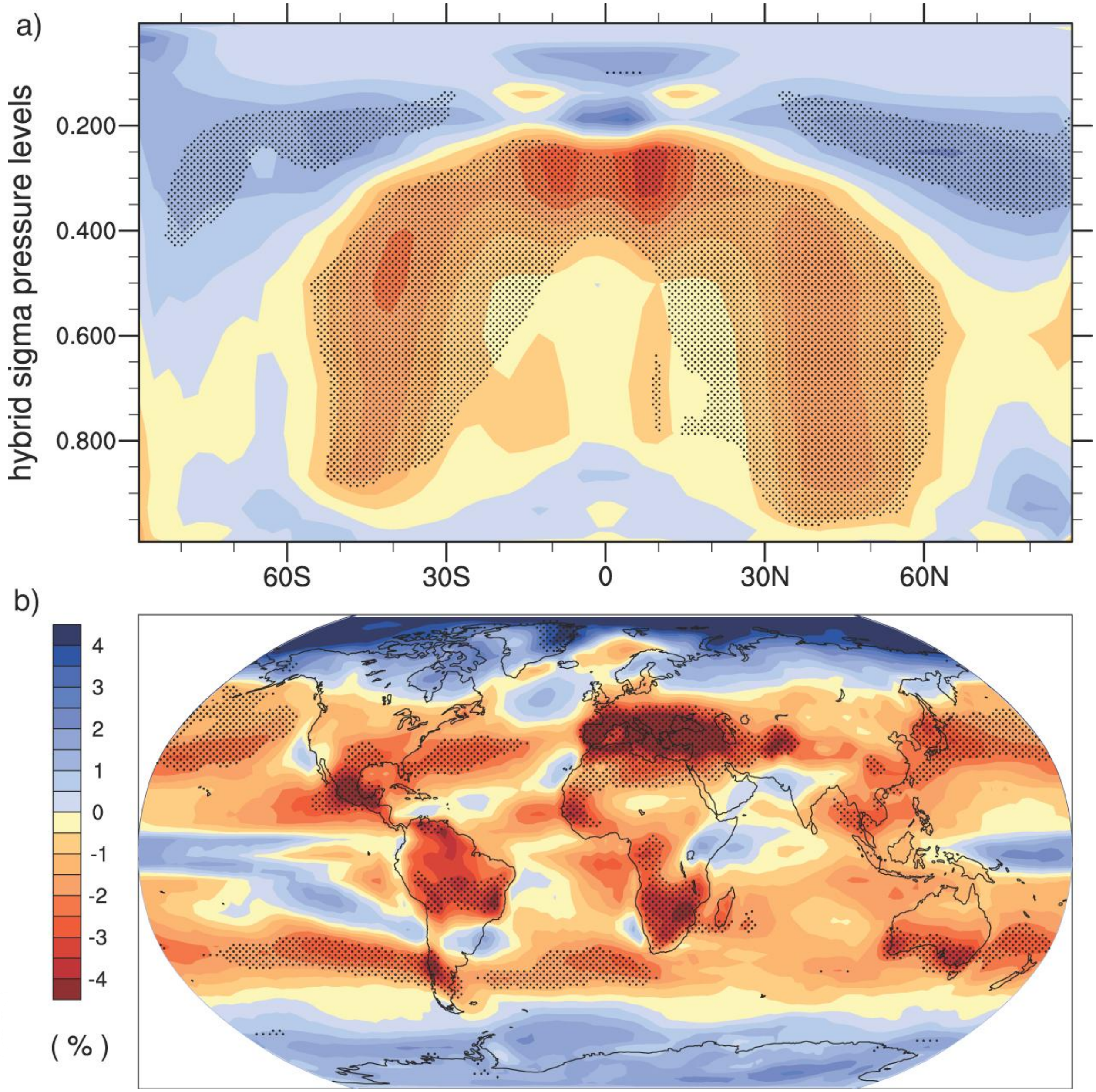


summer

Example: Storms in Northern Hemisphere 2 Days Ago (25 April, 2010)

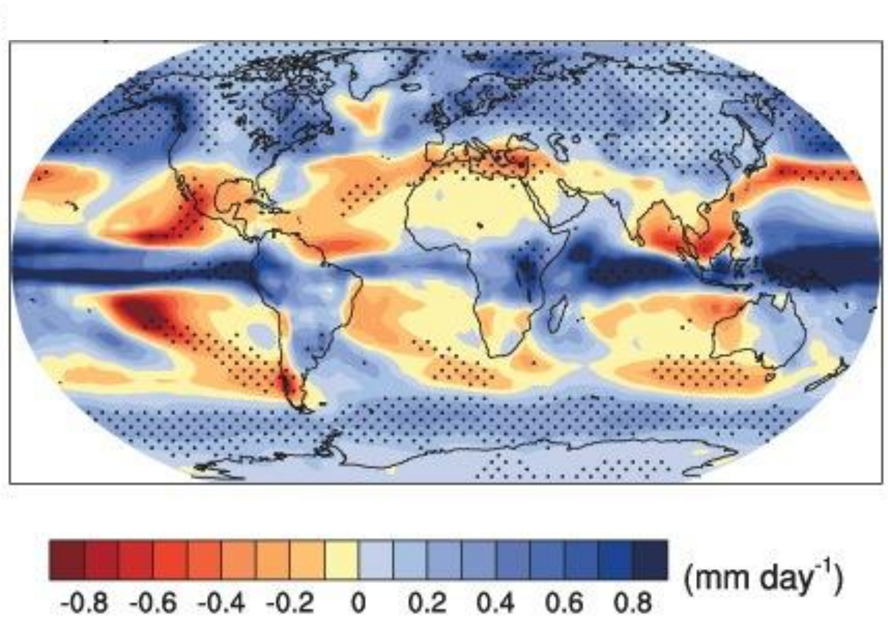


Projected Pattern of Cloud Cover Change (A1B, 2080-2099)

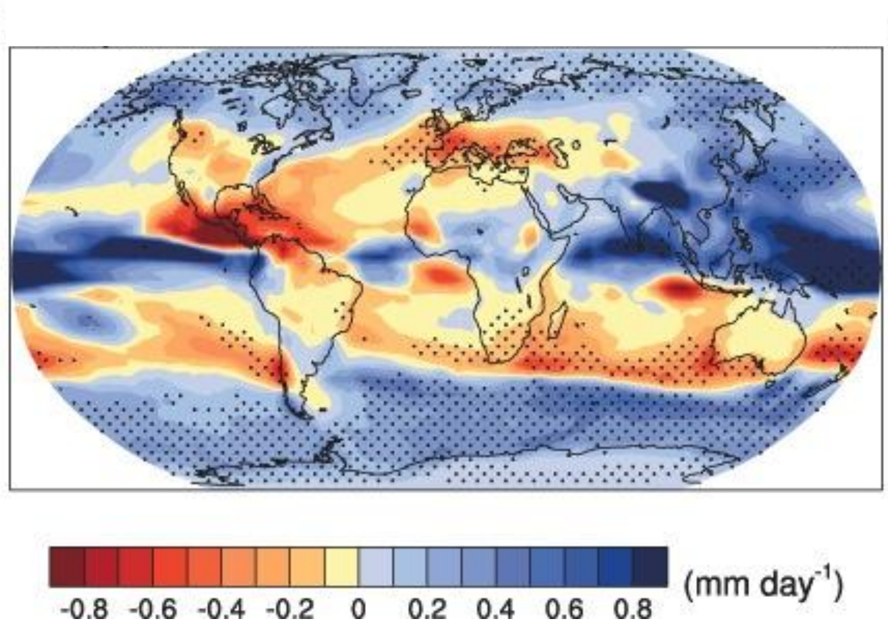


Projected Pattern of Precipitation Change

(A1B, 2080-2099)

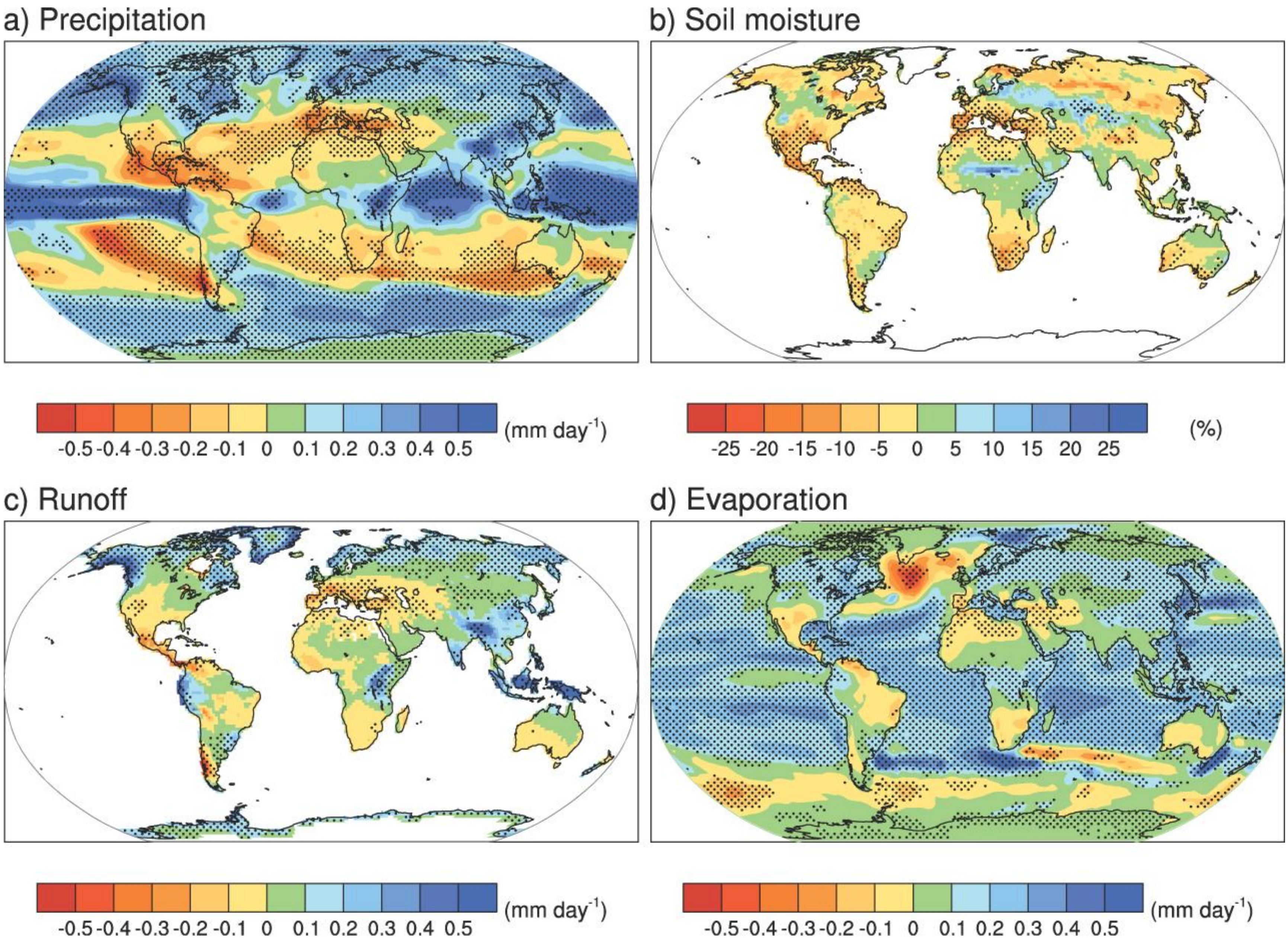


winter

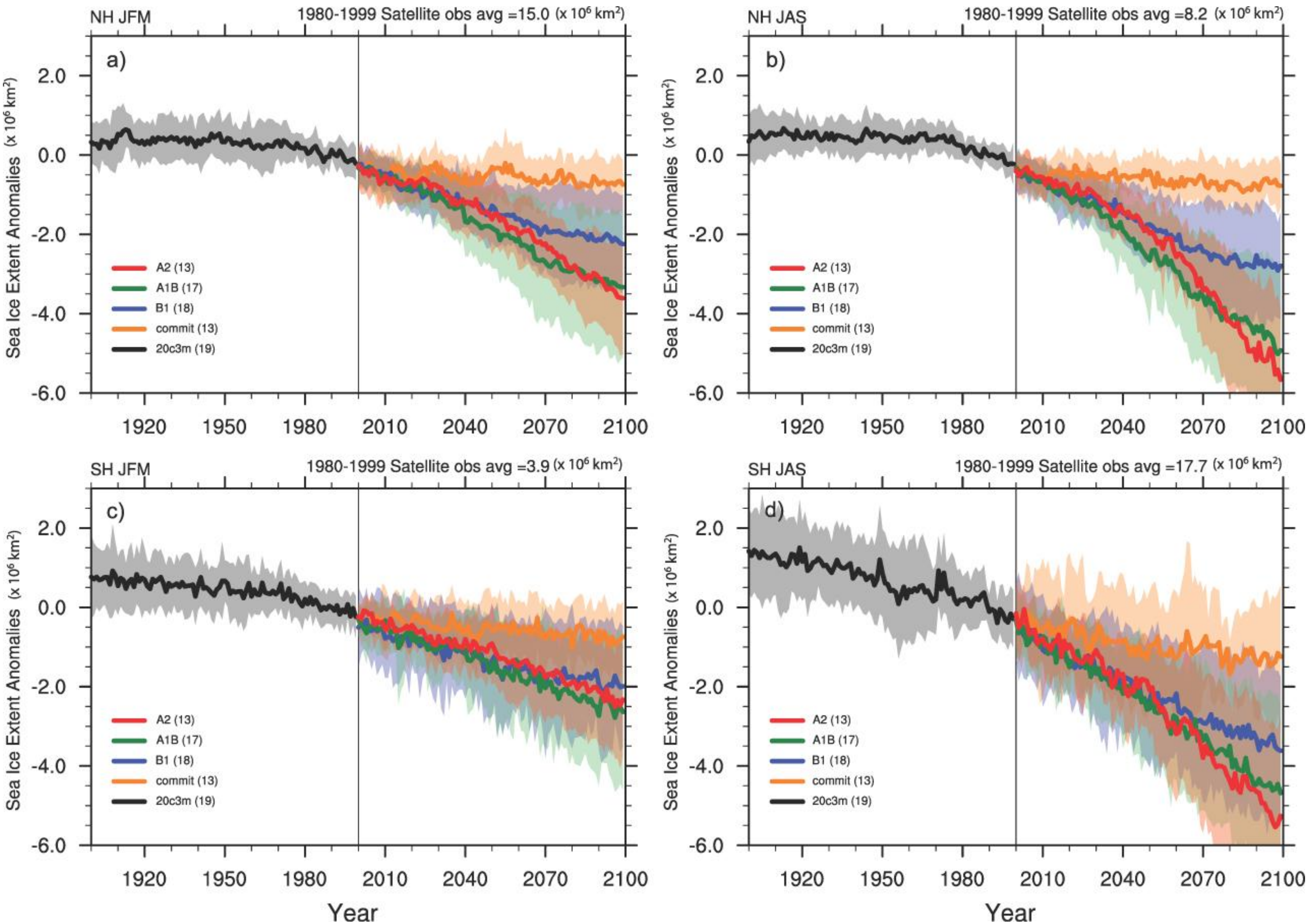


summer

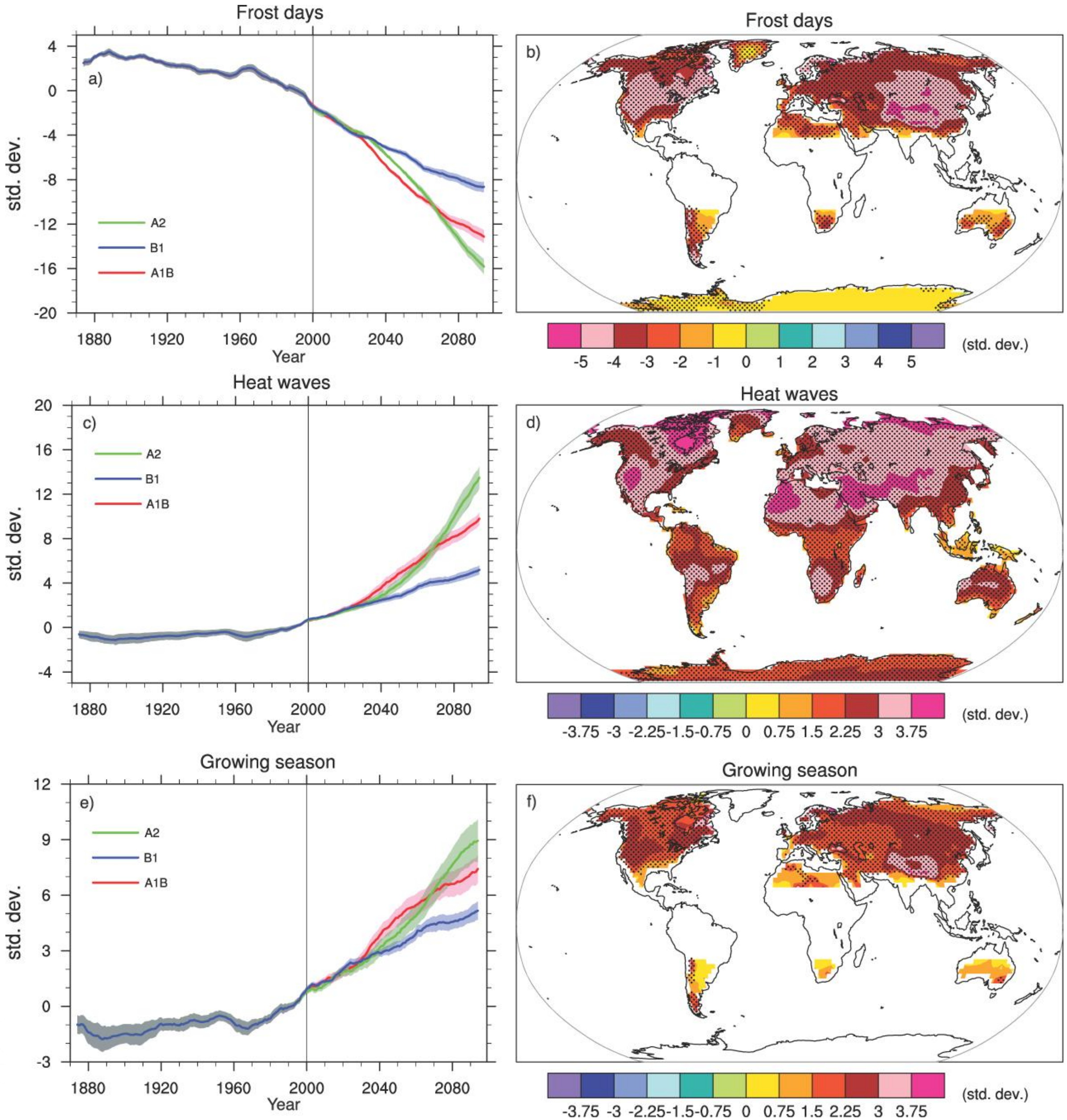
Projected Pattern of Soil Moisture, Runoff, Evaporation Changes



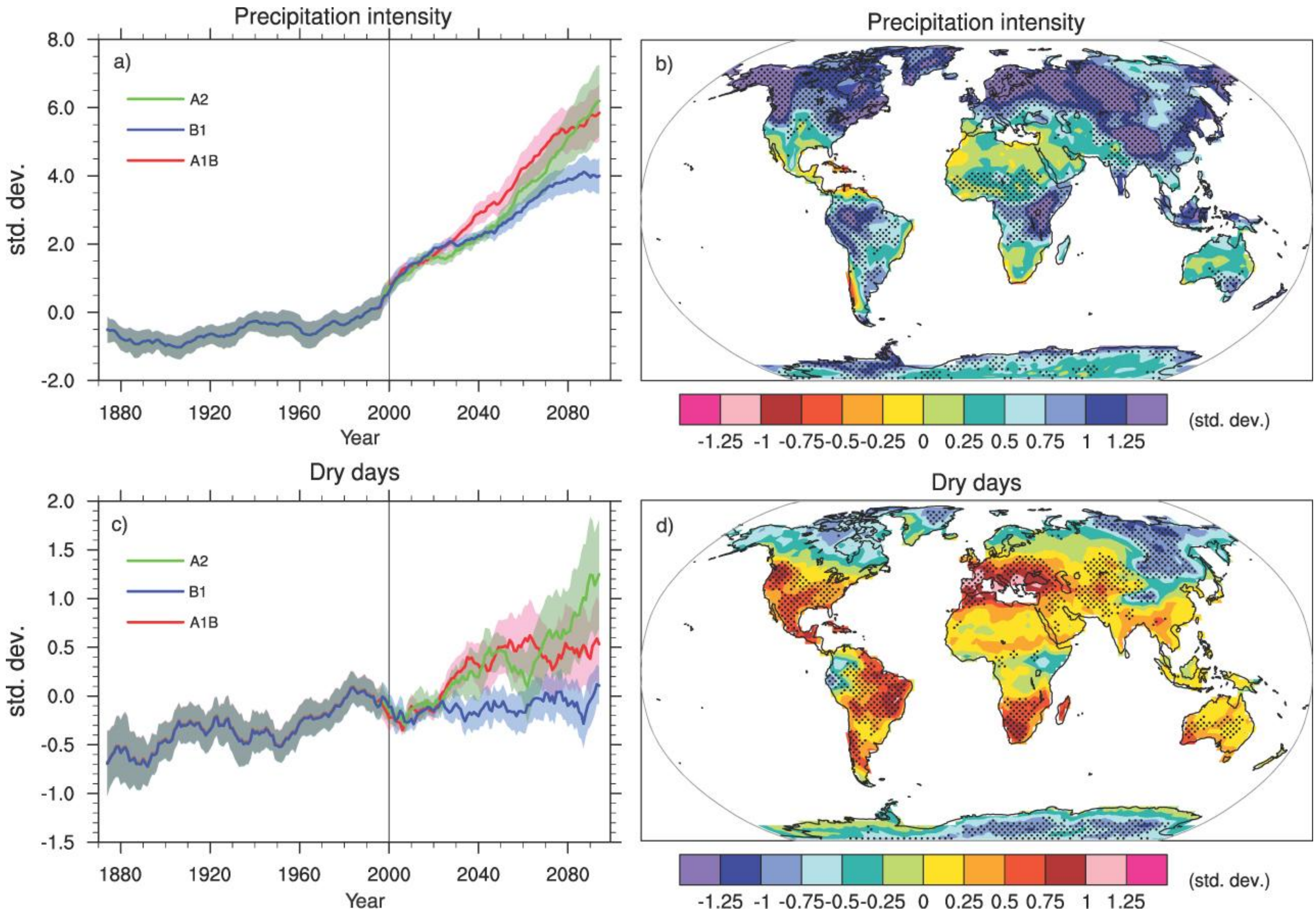
Projected Sea-Ice Extent



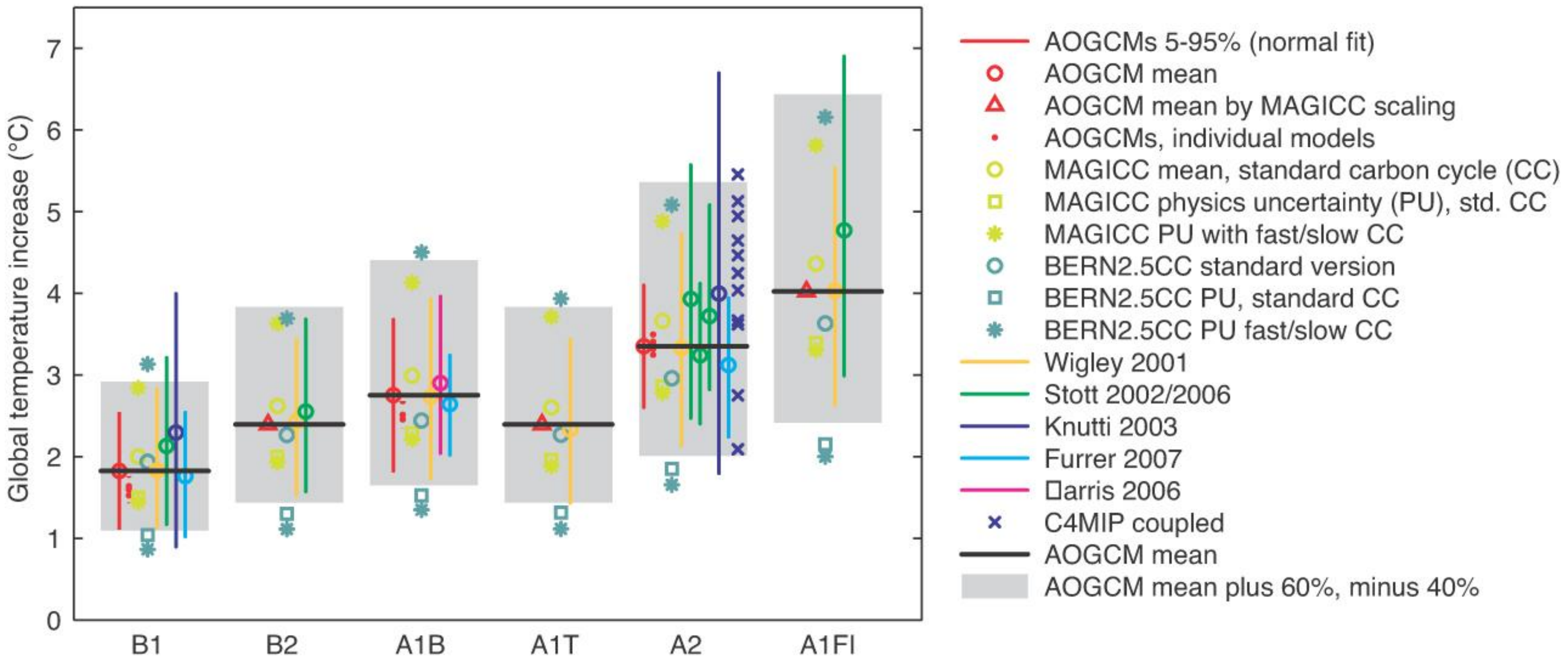
Extremes: Projected Frost Days, Heat Waves, Growing Season Changes



Extremes: Projected Precipitation Intensity, Dry Period Changes

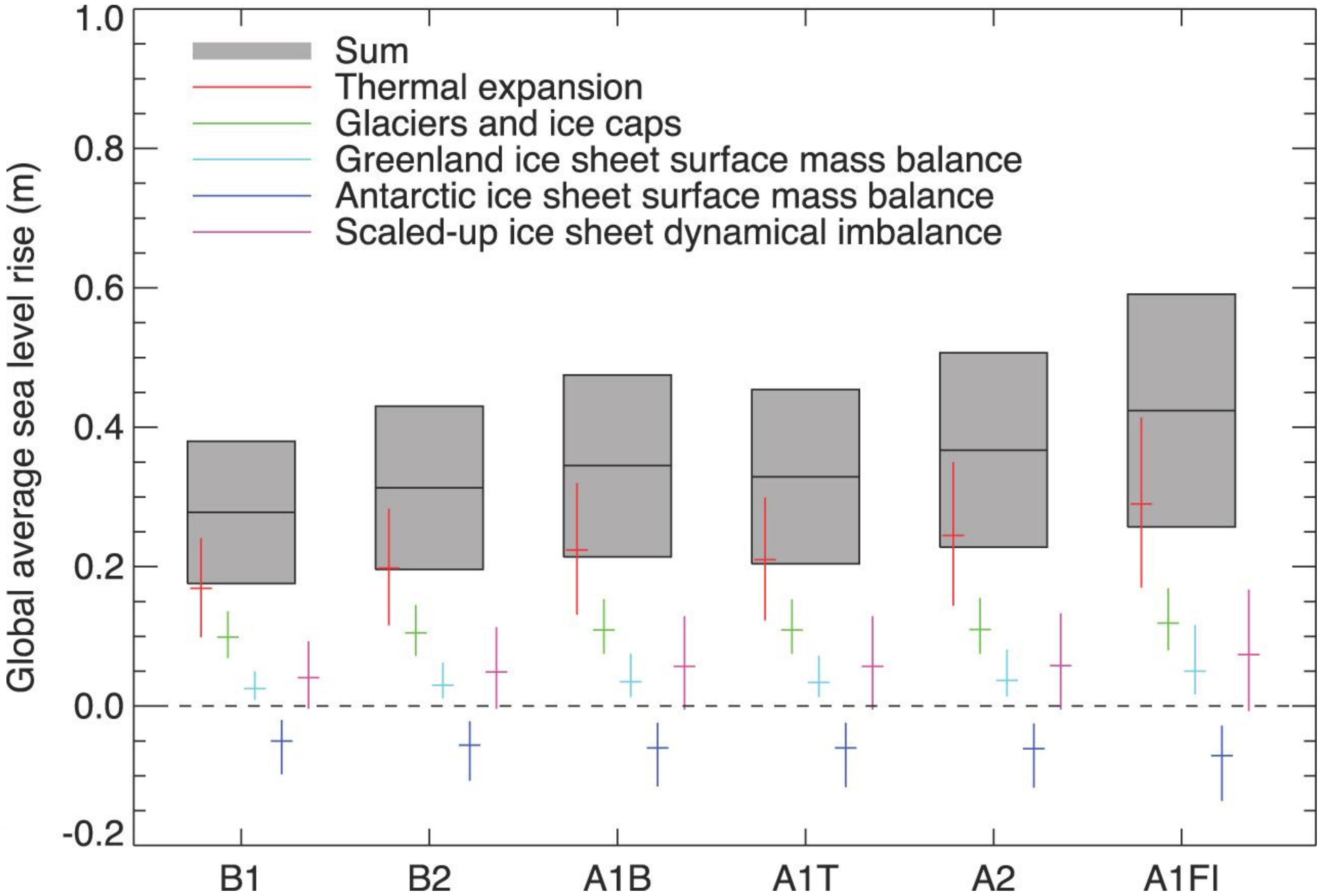


Projections and Uncertainties for Global Mean Temperature Increase by 2090-2099



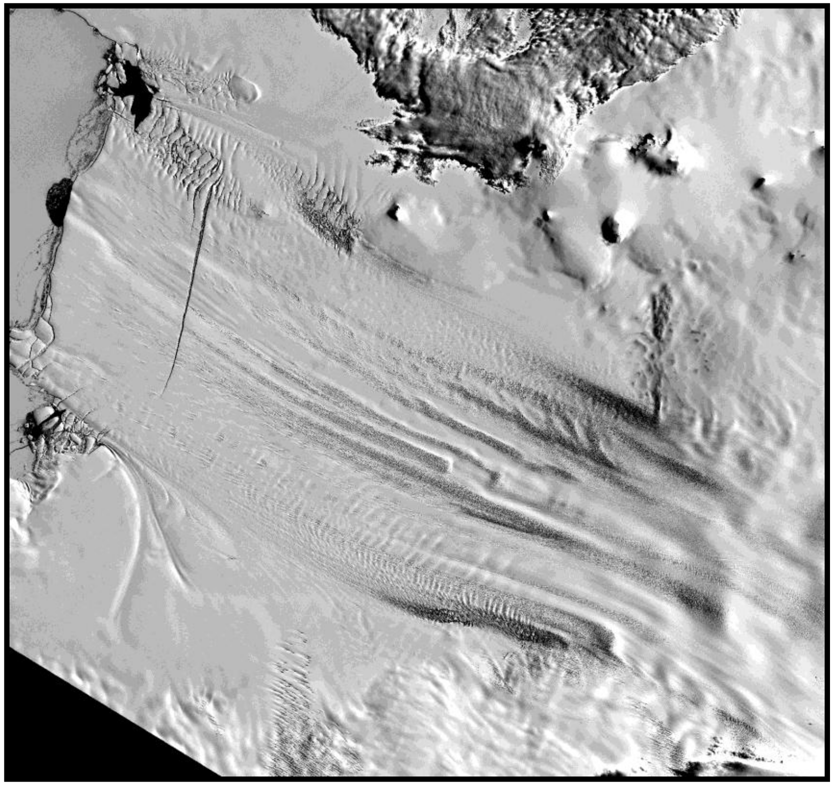
Projected Sea-Level Changes for 2100,

Excluding future rapid dynamic response of the Ice Sheets



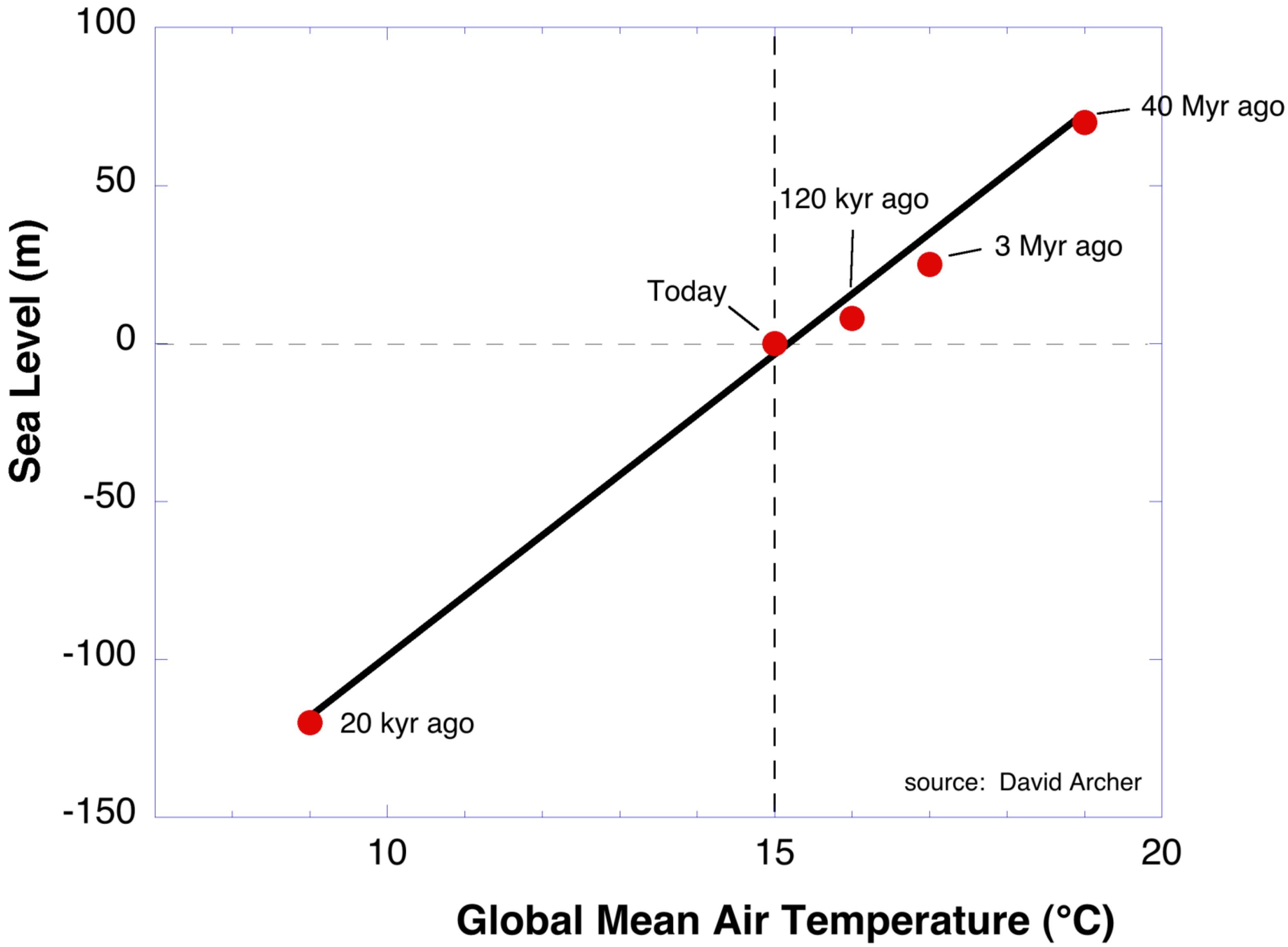
New Evidence indicates a Rapid Dynamic Response of the Ice Sheets to Climate Change May be Possible

Disintegration of Larsen B Ice Shelf, 2002

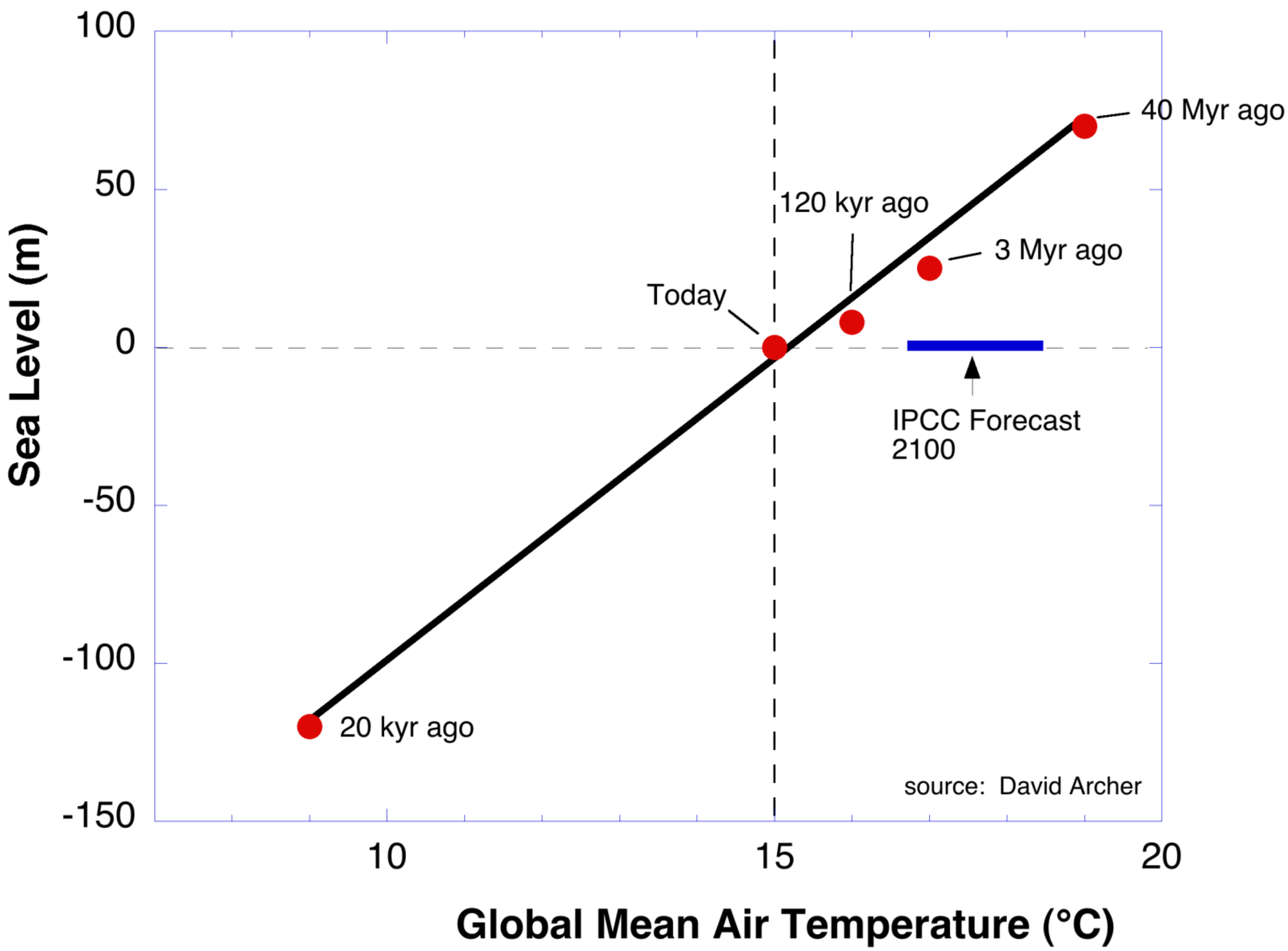


Pine Island Glacier, West Antarctica

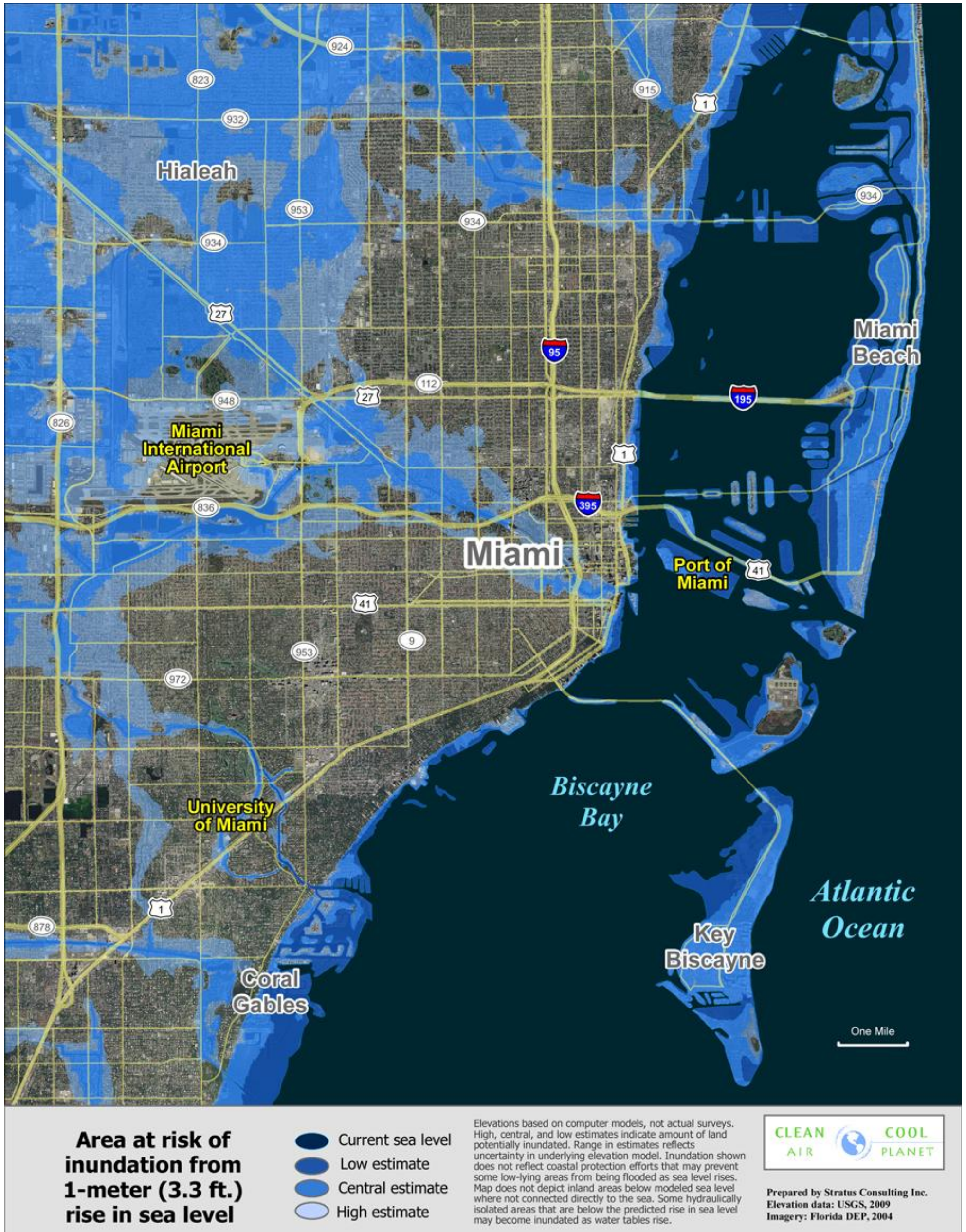
How has Sea-Level Responded in the Past to the Projected 21st Century Temperatures?



How has Sea-Level Responded in the Past to the Projected 21st Century Temperatures?

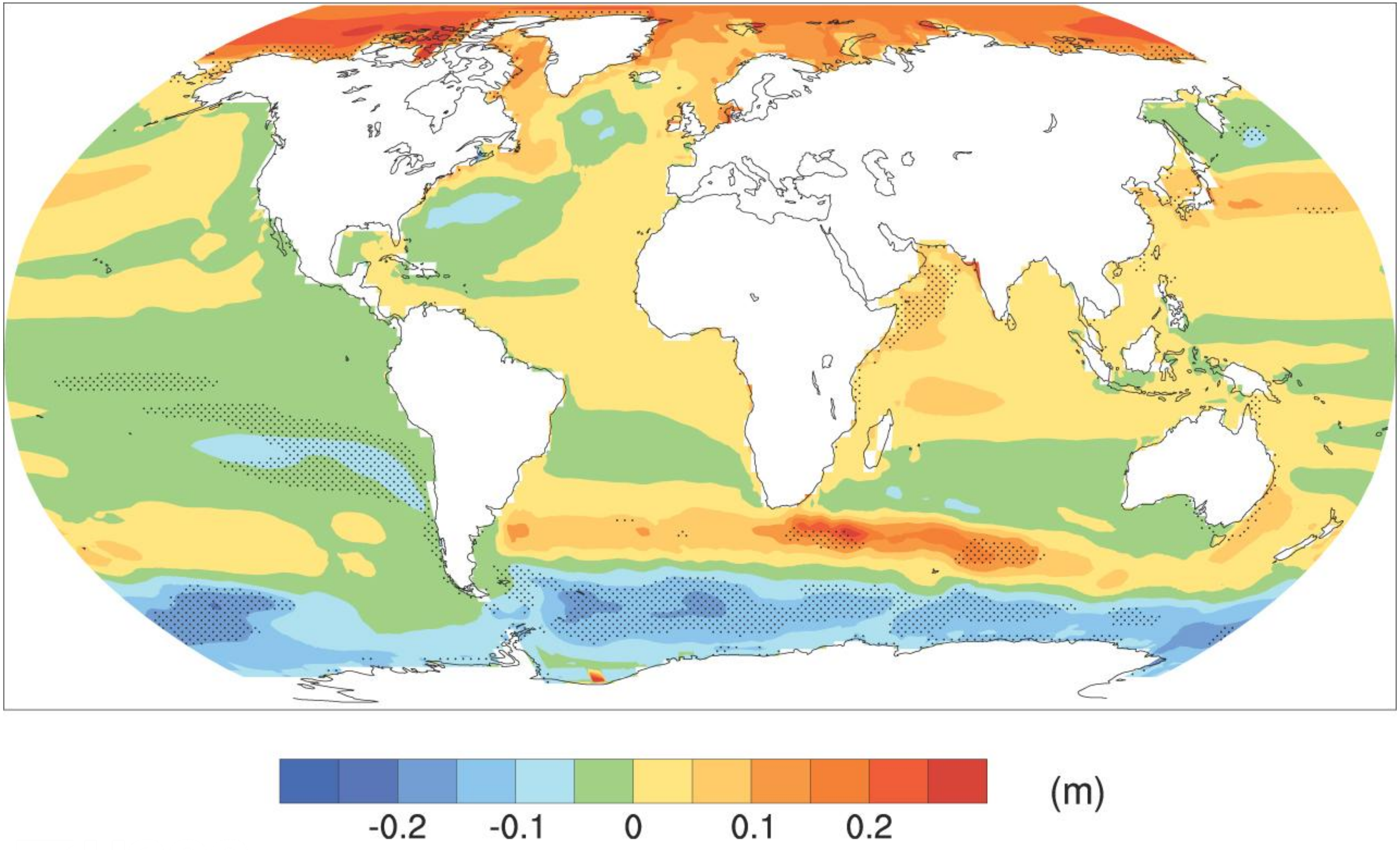


Miami with a 1-meter Rise in Sea Level

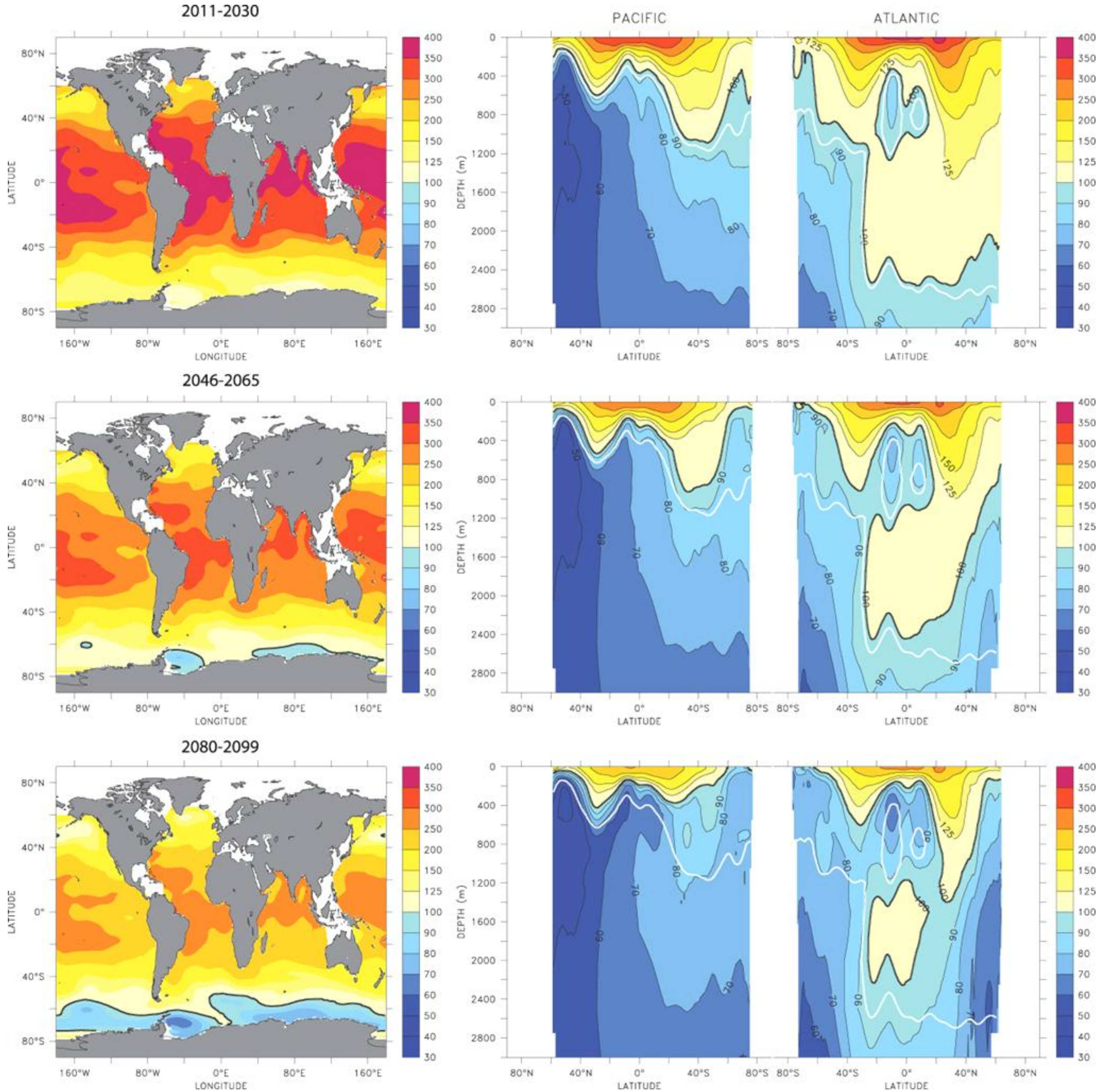


Jim White

Sea-Level Rise Won't be the Same Everywhere

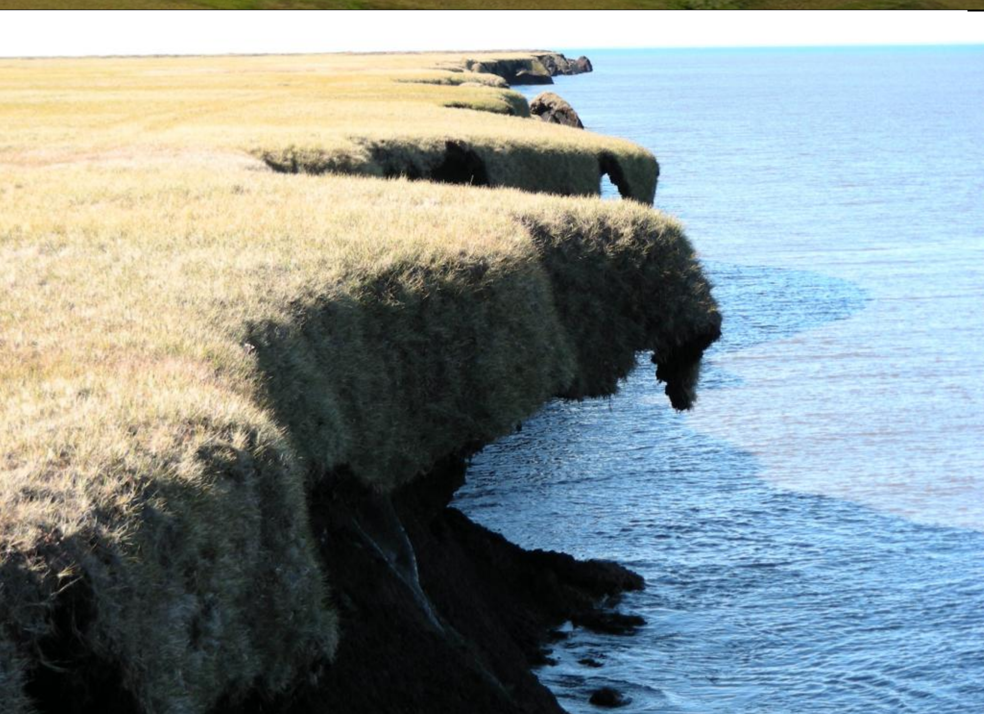
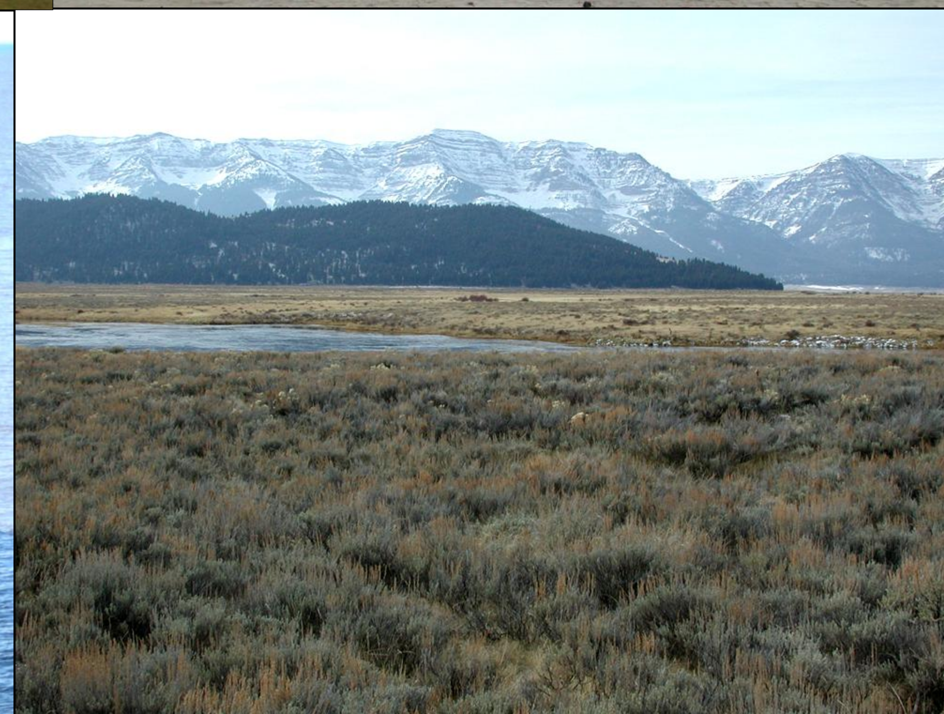


Changes in Ocean Acidification Due to Increasing Atmospheric CO_2

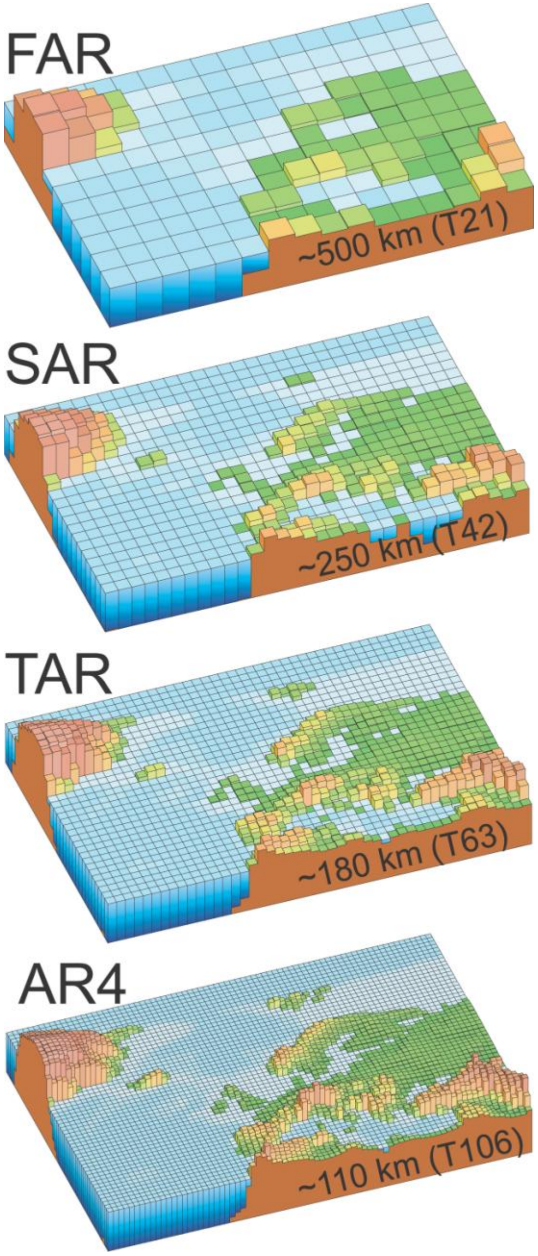


3) Regional Climate Projections for the 21st Century



Evolution of AOGCM Resolution



1990

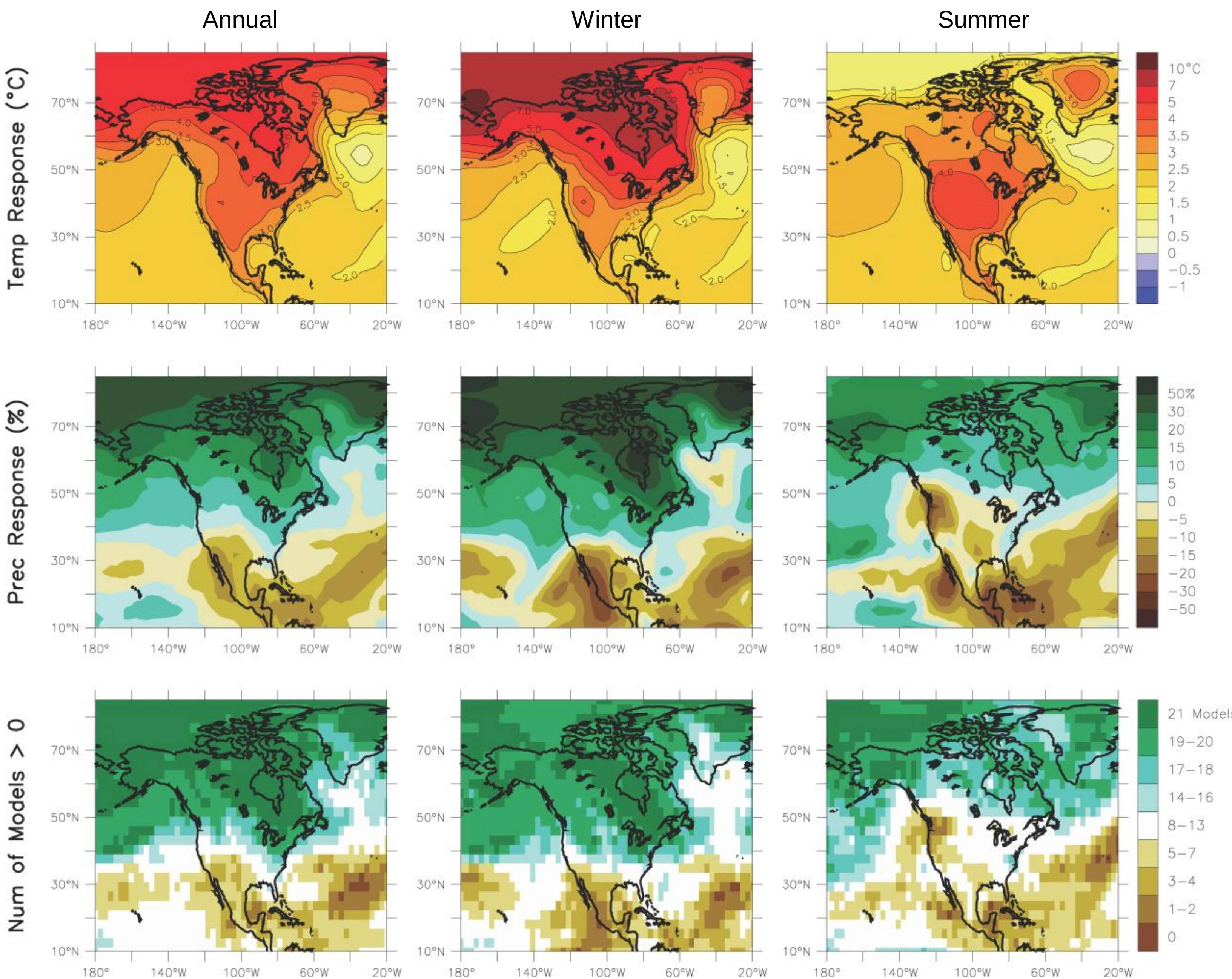
1995

2001

2007

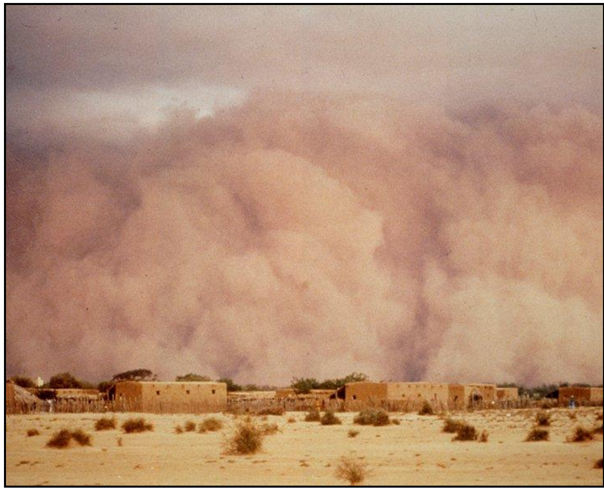
The horizontal scale at which AOGCMs provide useful information is about 4-5 times the horizontal resolution.

Temperature and Precipitation Changes, North America



Other Regional/Local Results:

- Compared to the previous figure, warming is likely to be larger in winter over elevated areas due to snow-albedo feedback which is poorly simulated by AOGCMs.

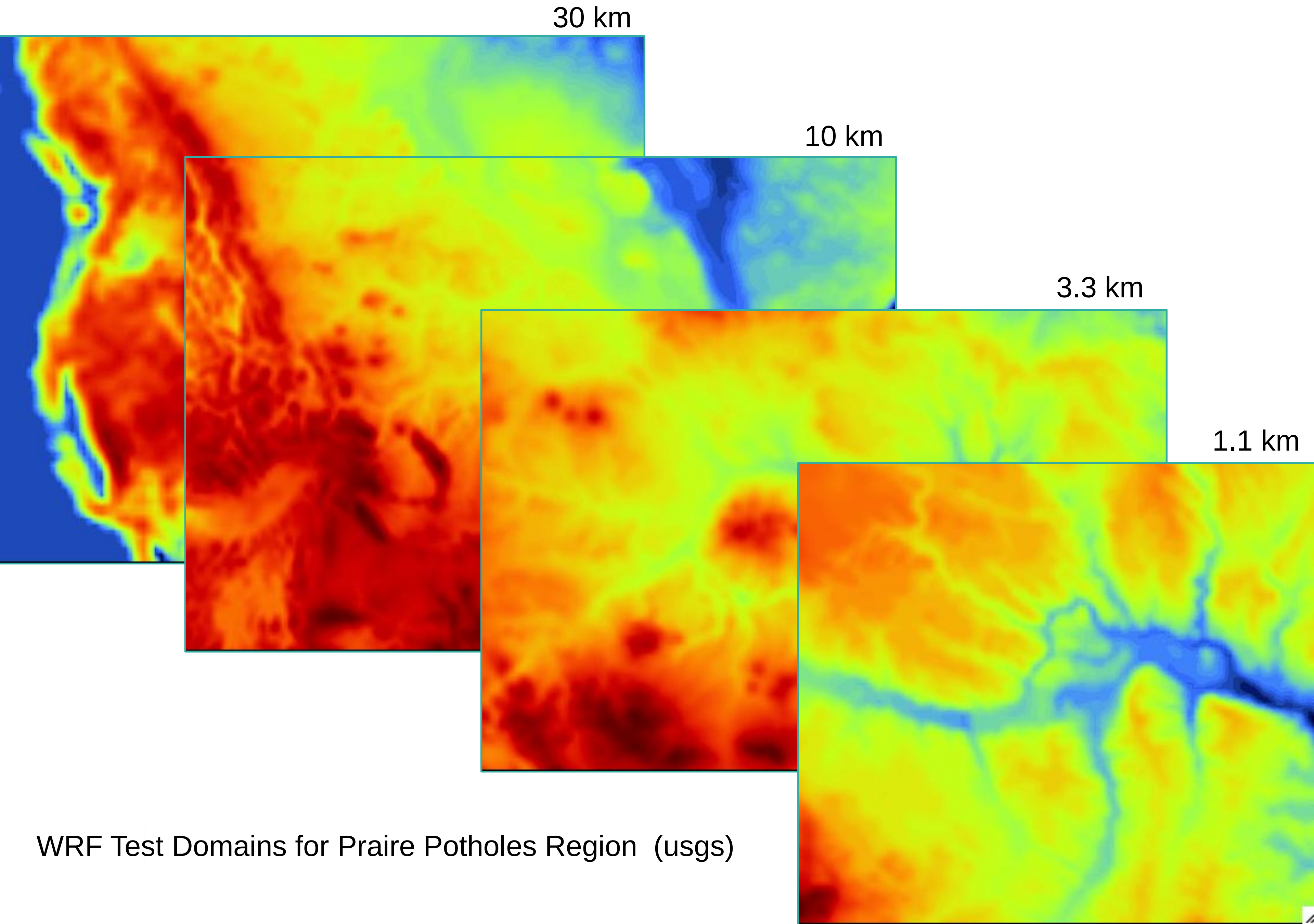


- Compared to the previous figure, precipitation is likely to be greater on the windward slopes of mountains in the west with orographic precipitation.

- The northward displacement and strengthening of the westerly flow will be enhanced during the autumn and winter.

- The East Pacific subtropical high will intensity during the summer, particularly off the coast of California and Baja California (with possible impacts on the North Pacific eastern boundary current, offshore Ekman transport, marine stratus clouds, North American Monsoon System).

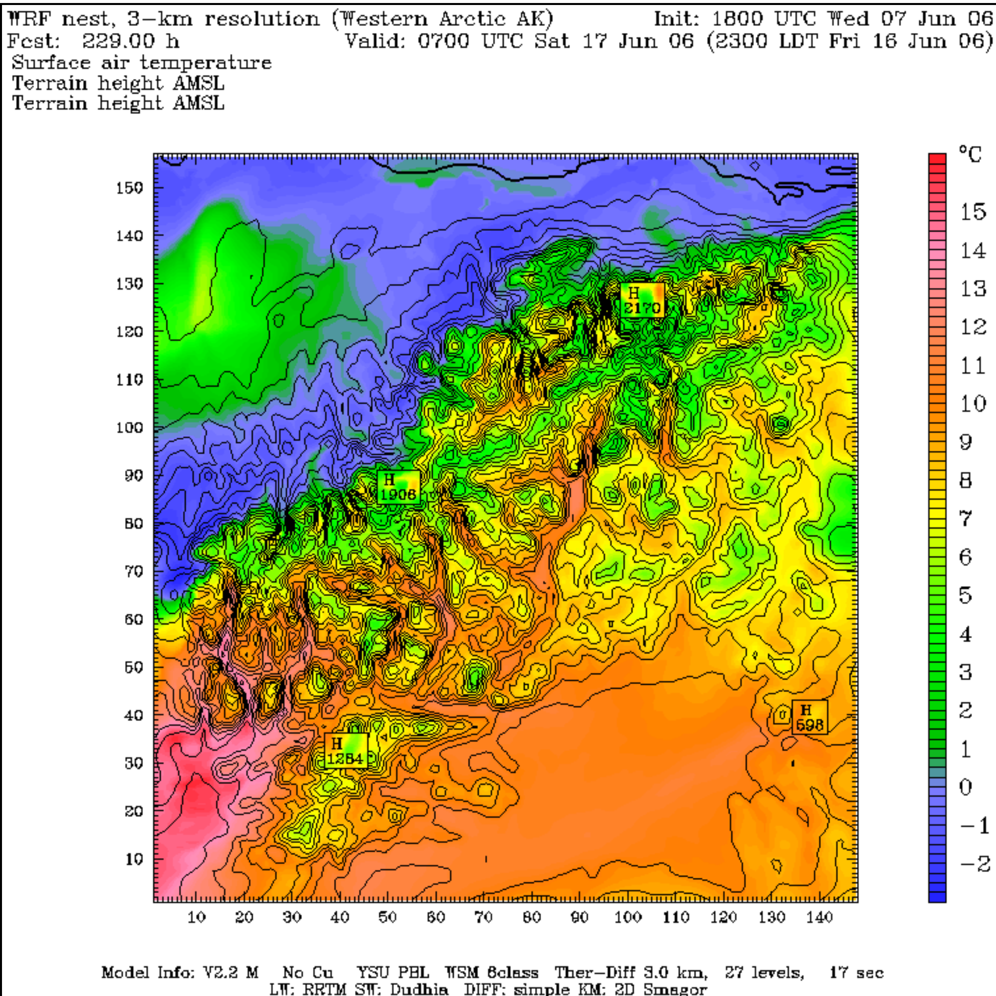
Downscaling to Achieve Higher Resolution



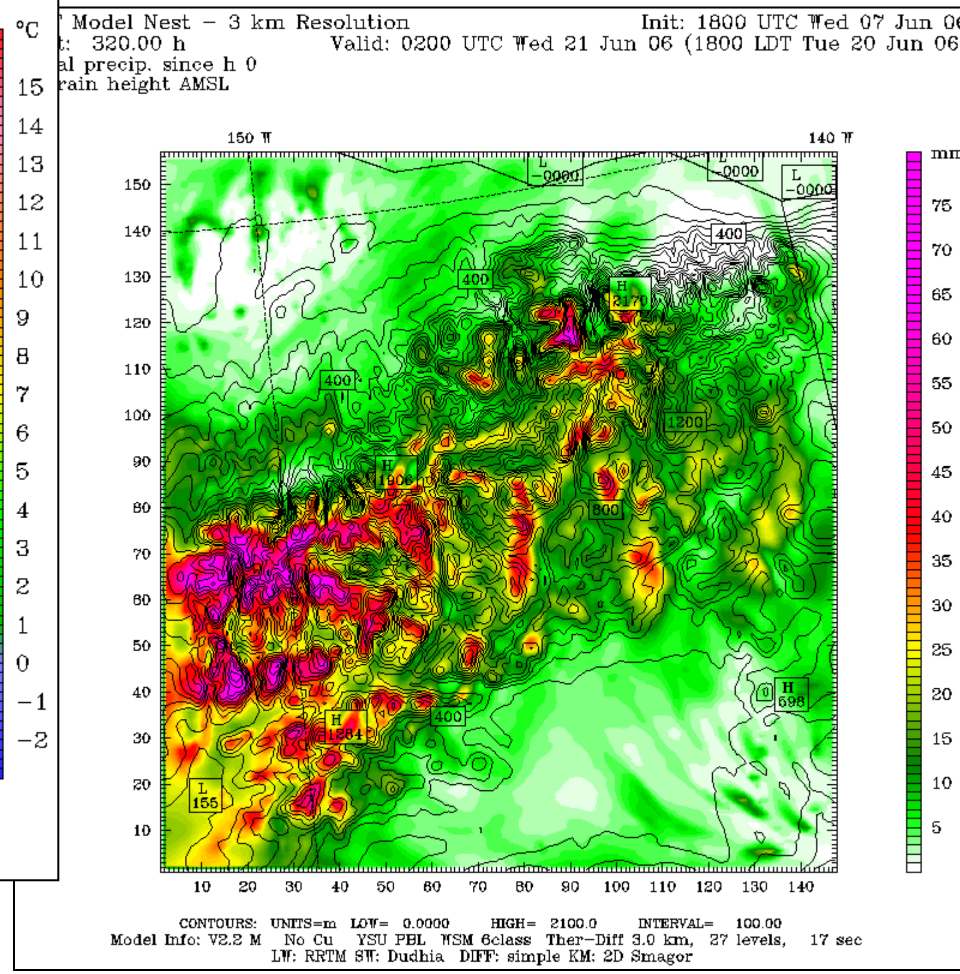
WRF Test Domains for Praire Potholes Region (usgs)

Dynamical Downscaling, Arctic NWR – 3 km Resolution

Temperature

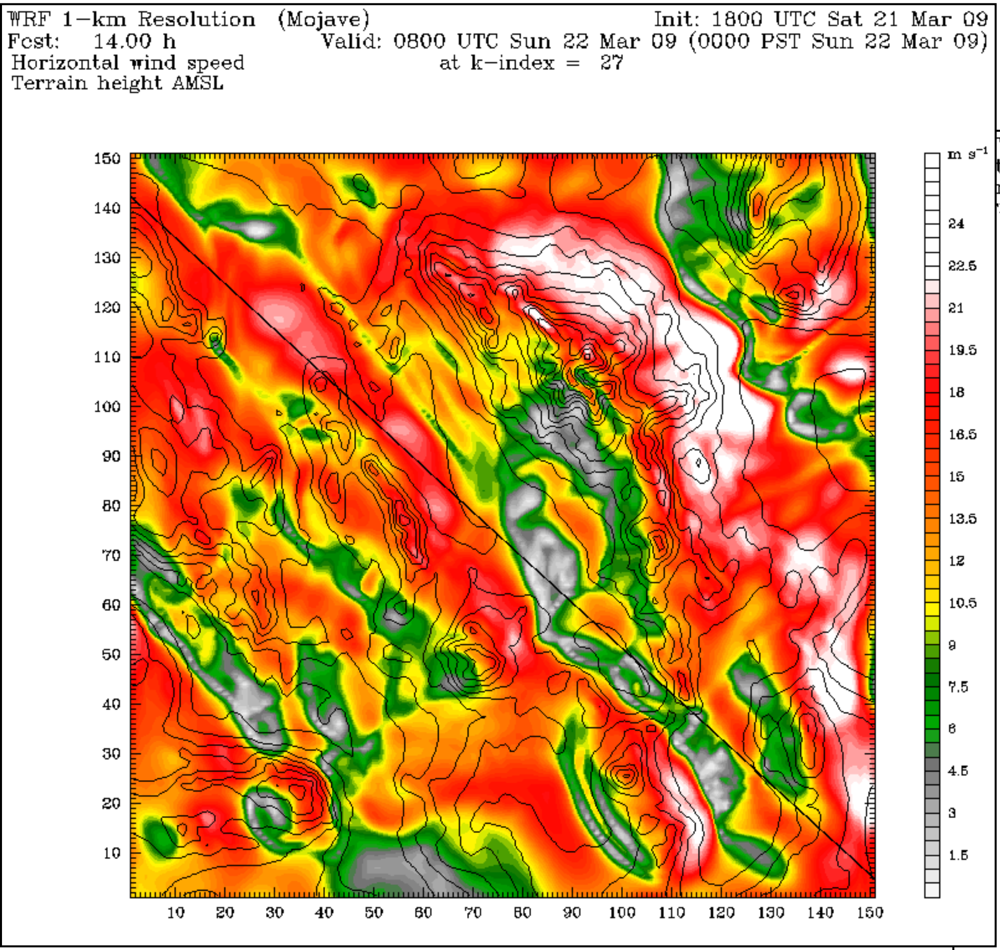


Precipitation



Dynamical Downscaling, Mojave Desert – 1 km Resolution

Wind Speed



Wind Direction