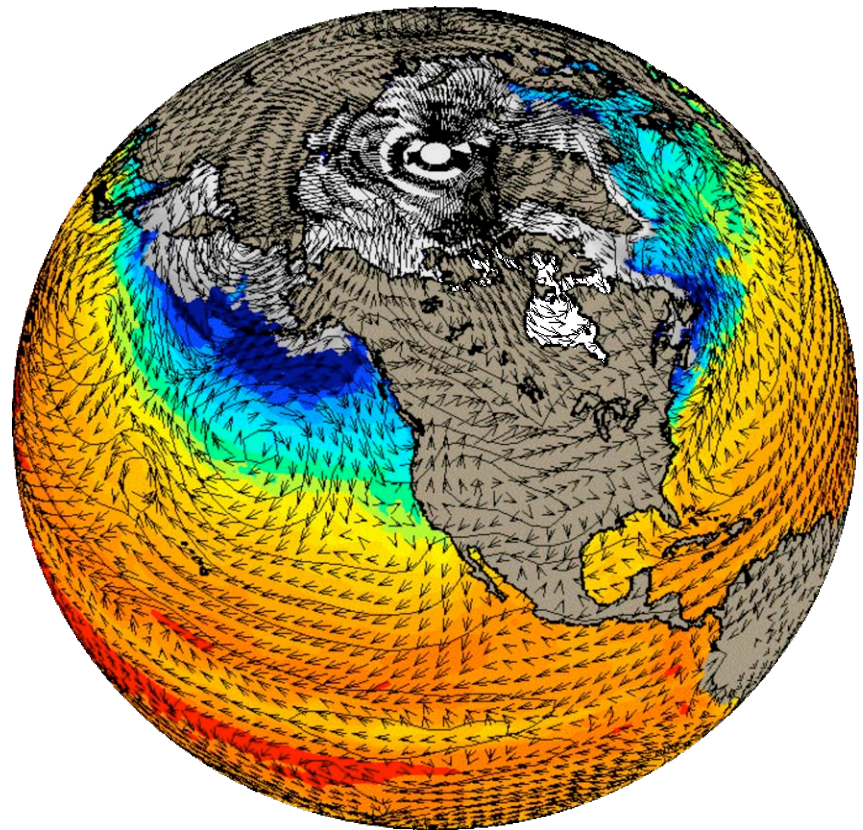


Climate model simulations for the IPCC Fourth Assessment Report (AR4)

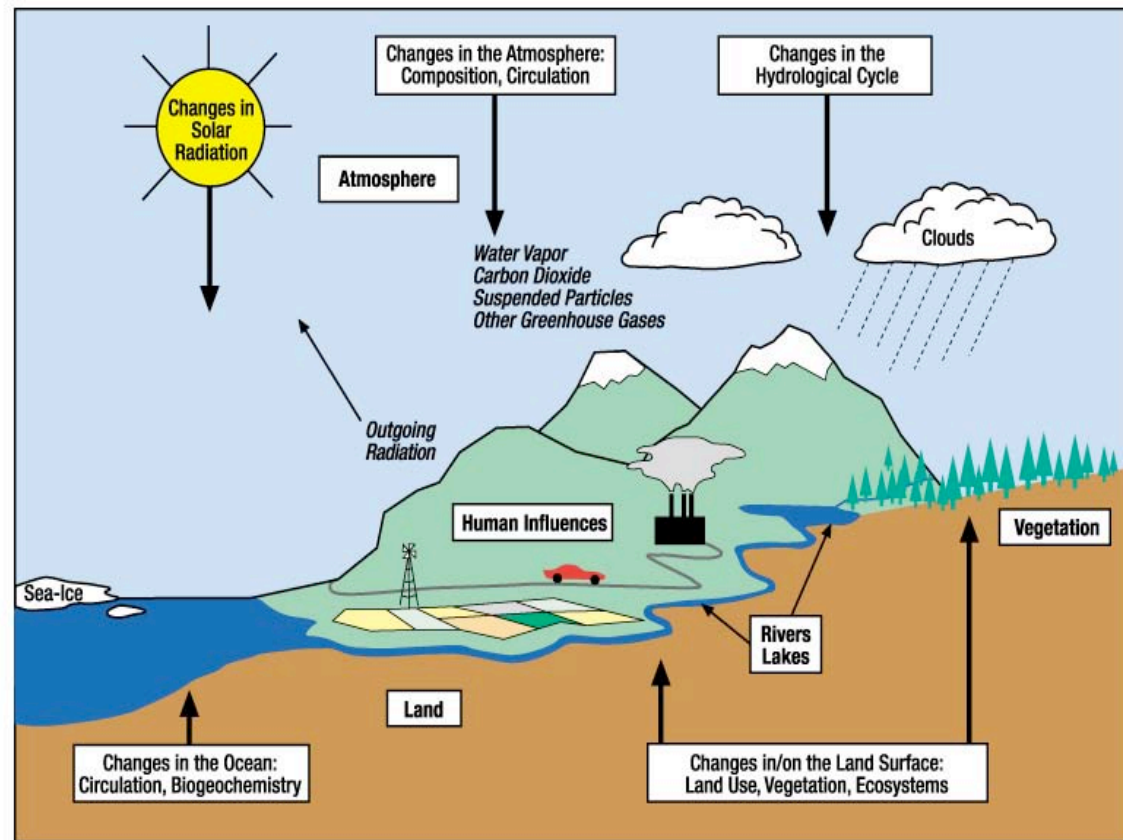
Gerald A. Meehl

NCAR

Boulder, CO



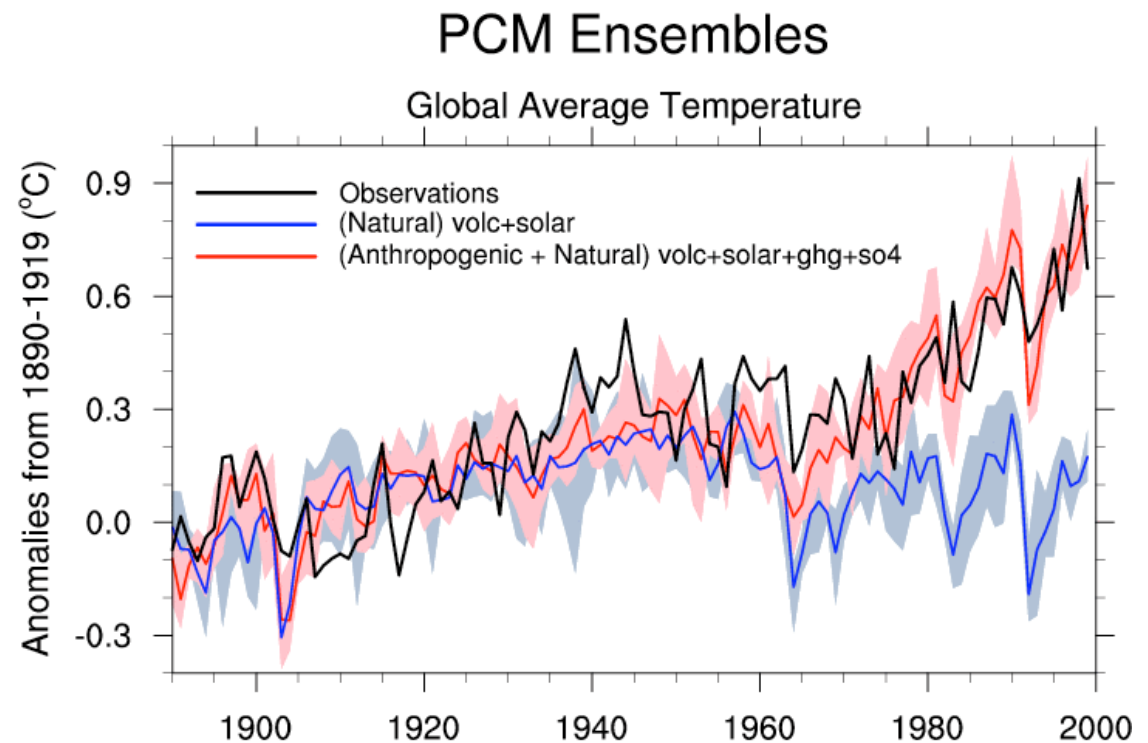
Climate models are a lot like weather forecast models, but include interactive ocean, land surface, and sea ice components, and also account for changes in atmospheric constituents like greenhouse gases (atmospheric and land surface model spatial resolution: $\sim 120 - 300$ km; ocean and sea ice: ~ 100 km); current NCAR model CCSM3: atmosphere 140 km resolution, ocean 100 km, can run about 4 model years per wall clock day, or about a century a month on IBM supercomputers; for IPCC, 8 ensemble members for 20th century, three 21st century scenarios, three commitment experiments on supercomputers at NCAR, ORNL, NERSC and Japan took about 10 months



Natural forcings do not fully explain observed late 20th century warming

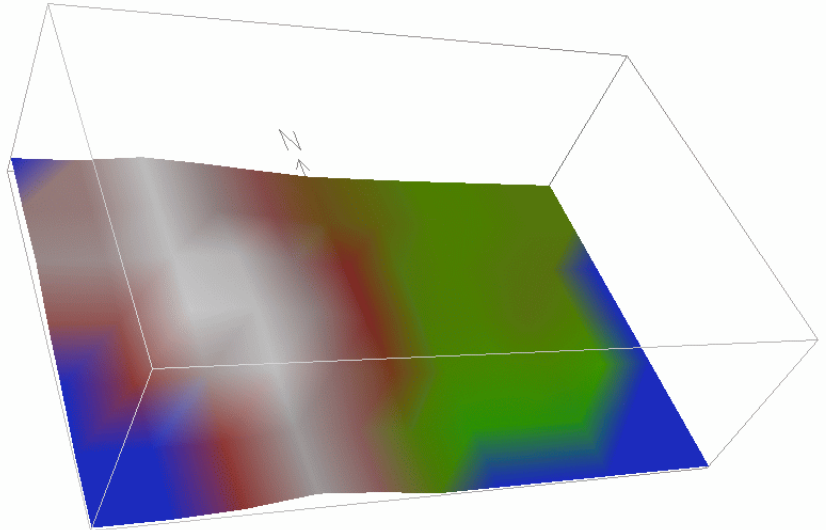
(uncertainty in climate model response is reduced by demonstrating that 20th century temperatures are directly related to the relevant forcings)

- Climate models with only “natural” forcings (volcanic and solar) do not reproduce observed late 20th century warming
- When increases in anthropogenic greenhouse gases and sulfate aerosols are included, models are able to reproduce observed late 20th century warming



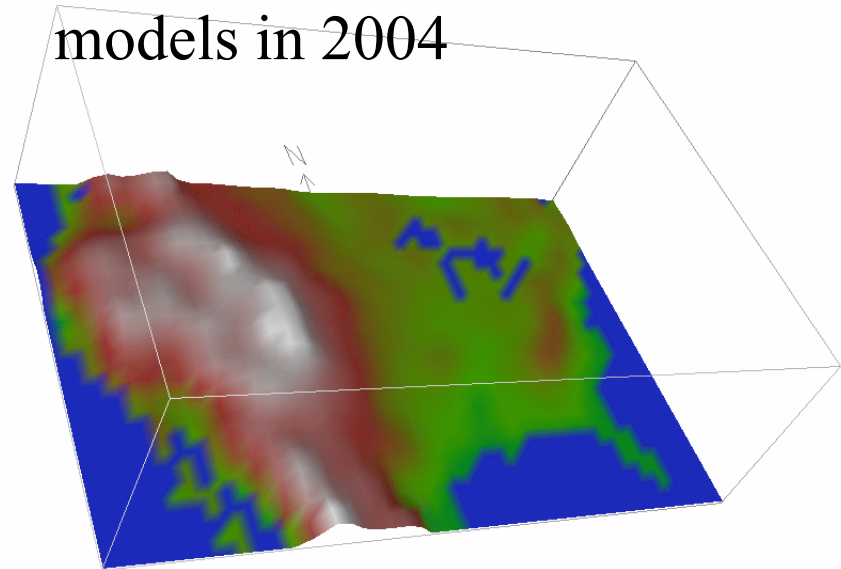
Meehl, G.A., W.M. Washington, C. Ammann, J.M. Arblaster, T.M.L. Wigley, and C. Tebaldi, 2004: Combinations of natural and anthropogenic forcings and 20th century climate. *J. Climate*, 17, 3721-3727.

Climate Models circa early 1990s



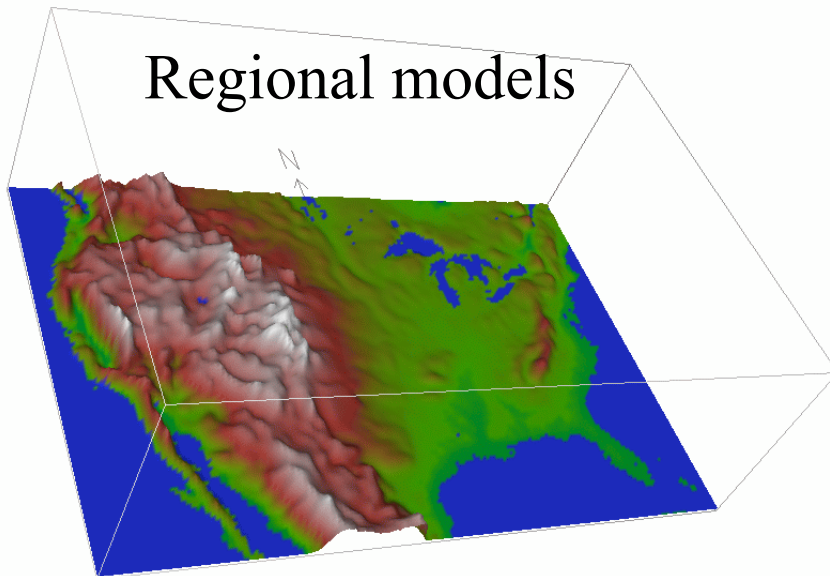
400 km

Global coupled climate models in 2004



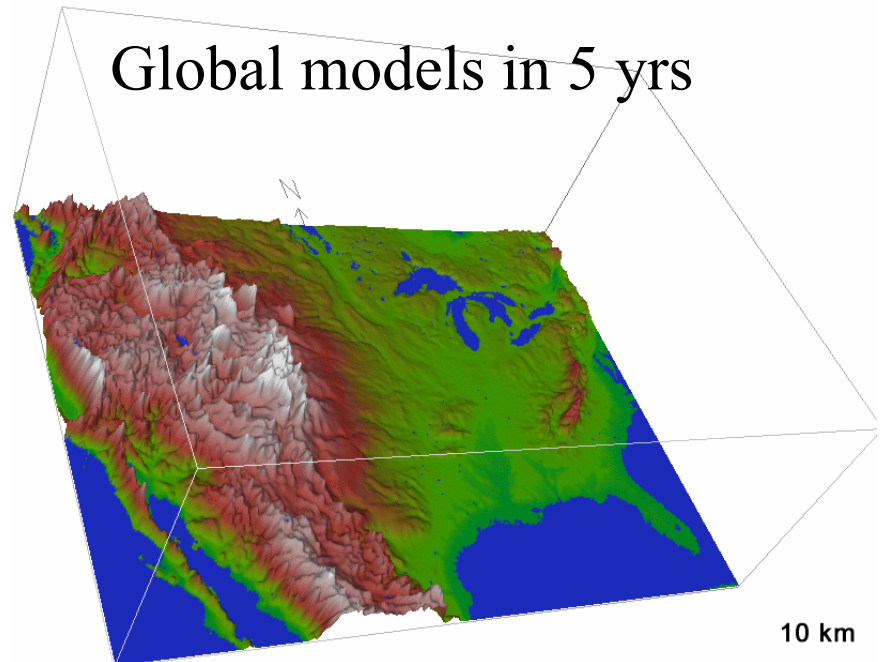
100 km

Regional models



25 km

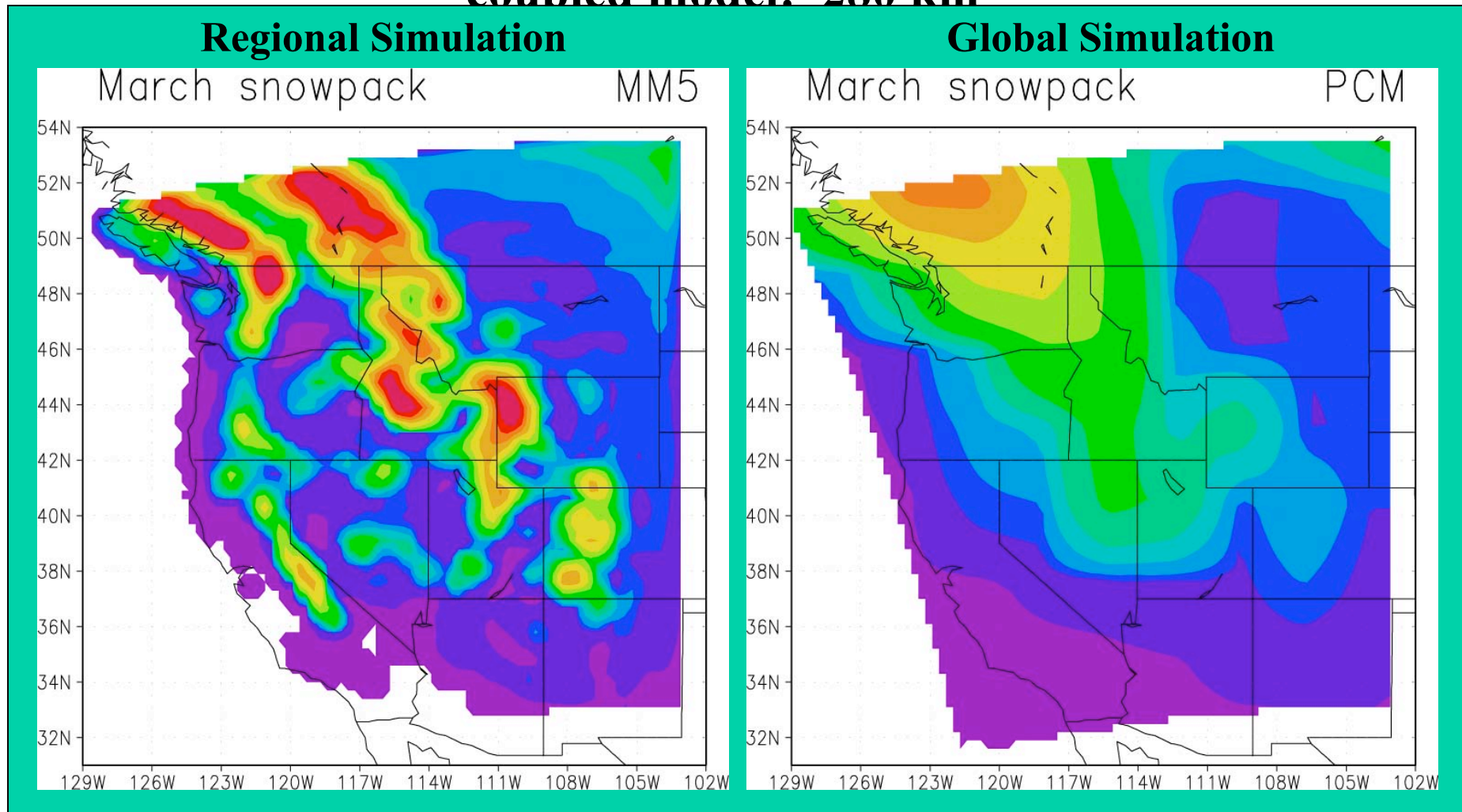
Global models in 5 yrs



10 km

Global and Regional Simulations of Snowpack

MM5 embedded regional model: 50 km (also can use statistical downscaling to smaller scales); PCM global coupled model: 280 km



The IPCC AR4 has motivated the formulation of the largest international global coupled climate model experiment and multi-model analysis effort ever attempted, and is being coordinated by the WGCM Climate Simulation Panel

Fourteen modeling groups from around the world are participating with 21 models; considerable resources have been devoted to this project; PCMDI has archived ~27 TeraBytes of model data so far

From over 60 proposals submitted, funding for 18 analyses of the 20th century climate simulations was provided by NSF-NOAA-NASA-DOE under the Climate Model Evaluation Project (CMEP) and

Results from analyses of the multi-model dataset were presented by 125 scientists at a workshop convened by US CLIVAR and hosted by IPRC (Univ. of Hawaii) March 1-4, 2005, and are feeding directly into the AR4 assessment process

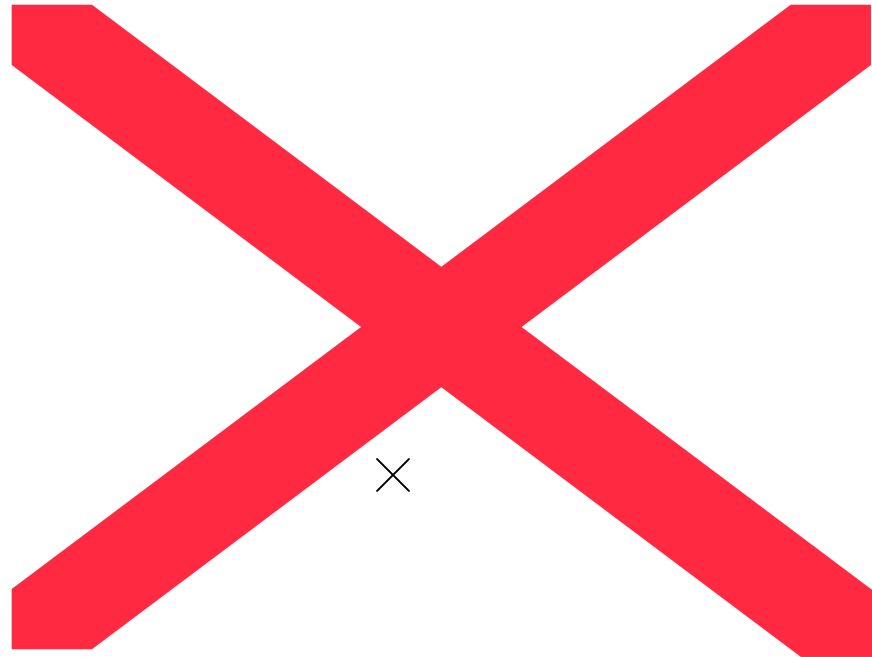
To date, there are 335 analysis projects registered at PCMDI, and over 220 papers have been submitted to peer-reviewed journals with results from multi-model analyses for assessment in the IPCC AR4

Results from analyses of the multi-model dataset were presented by 125 scientists at a workshop convened by US CLIVAR and hosted by IPRC (Univ. of Hawaii) March 1-4, 2005, and are feeding directly into the AR4 assessment process

To date, there are 306 analysis projects registered at PCMDI, and over 220 papers have been submitted to peer-reviewed journals with results from multi-model analyses for assessment in the IPCC AR4

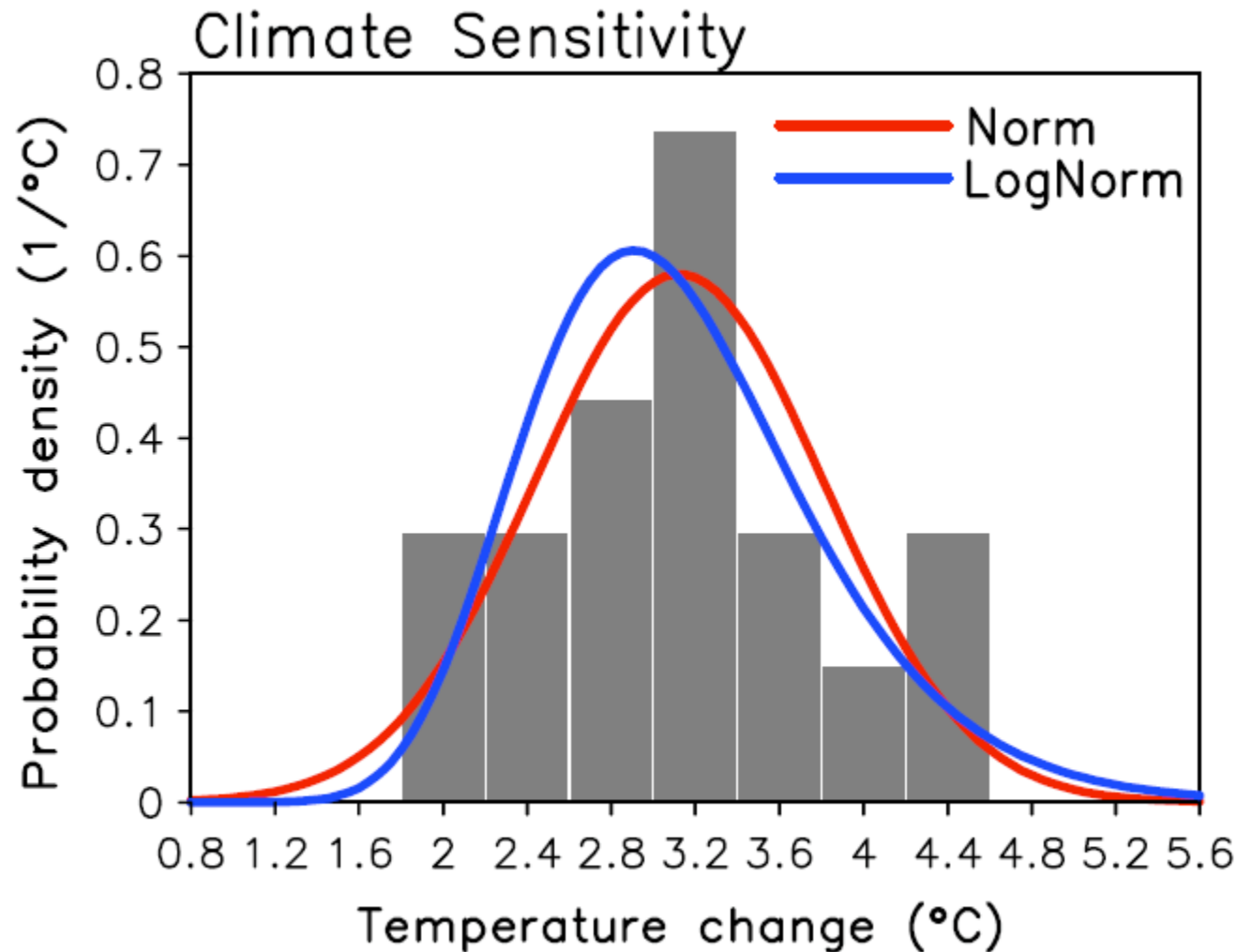
This is more than double our most optimistic estimate for participation

Equilibrium climate sensitivity from
17 models currently in use for the
IPCC AR4 (CCSM3=X)



Based on 17 AOGCMs currently in use for the IPCC AR4:

The 5-95% uncertainty range for equilibrium climate sensitivity is 2.0-4.4_C, with median value of 3.1_C

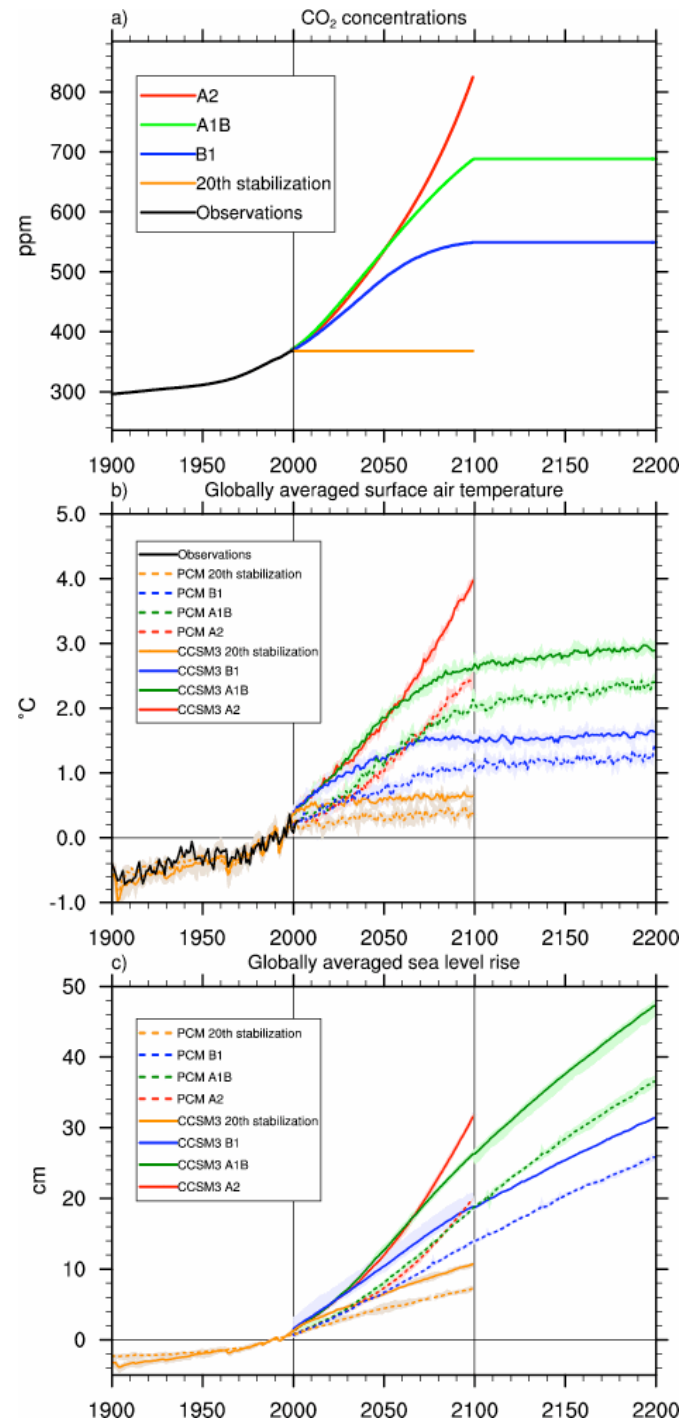


Climate change commitment:

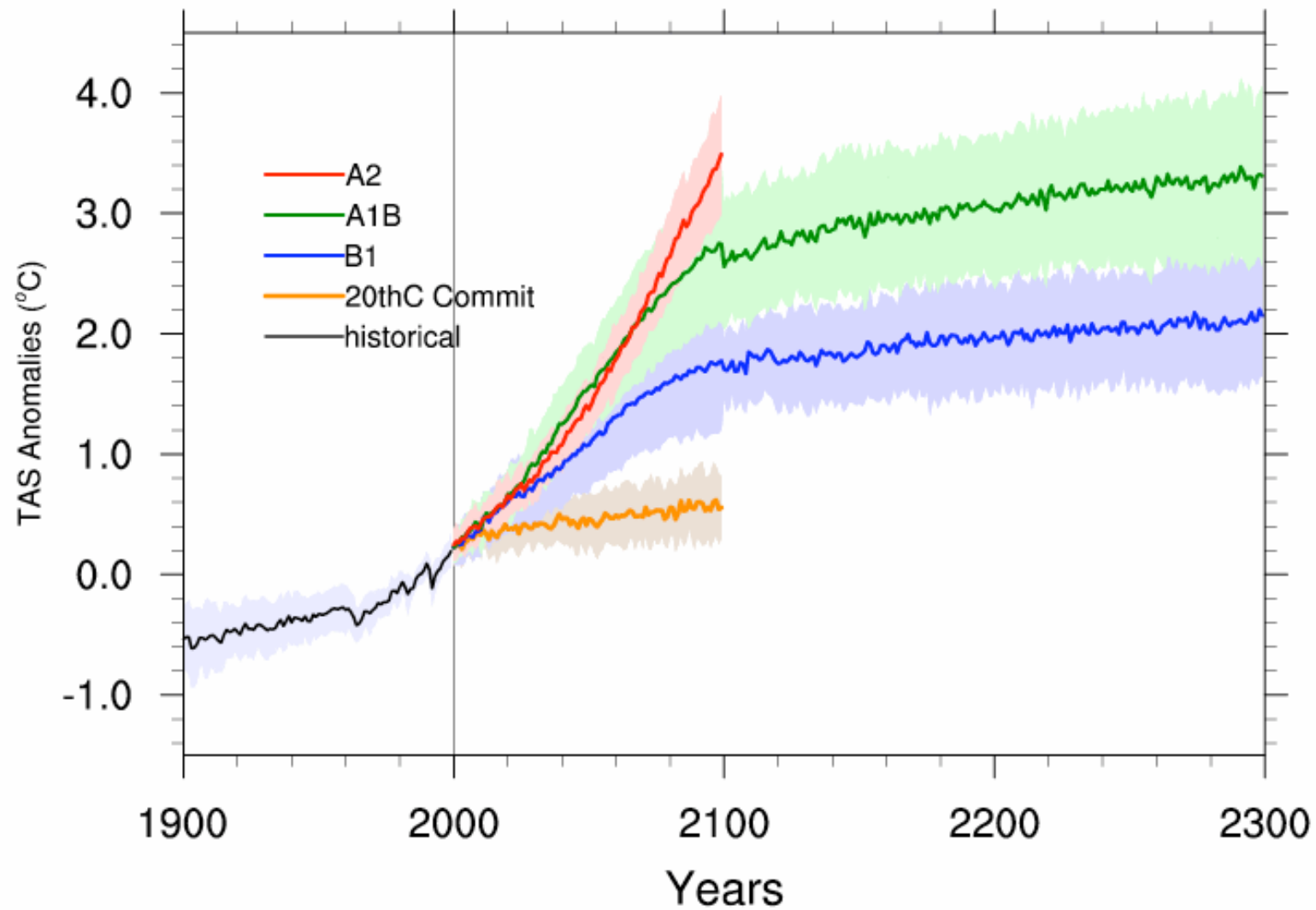
at any point in time, we are committed to additional warming and sea level rise from the radiative forcing already in the system.

Warming stabilizes after several decades, but sea level continues to rise for centuries.

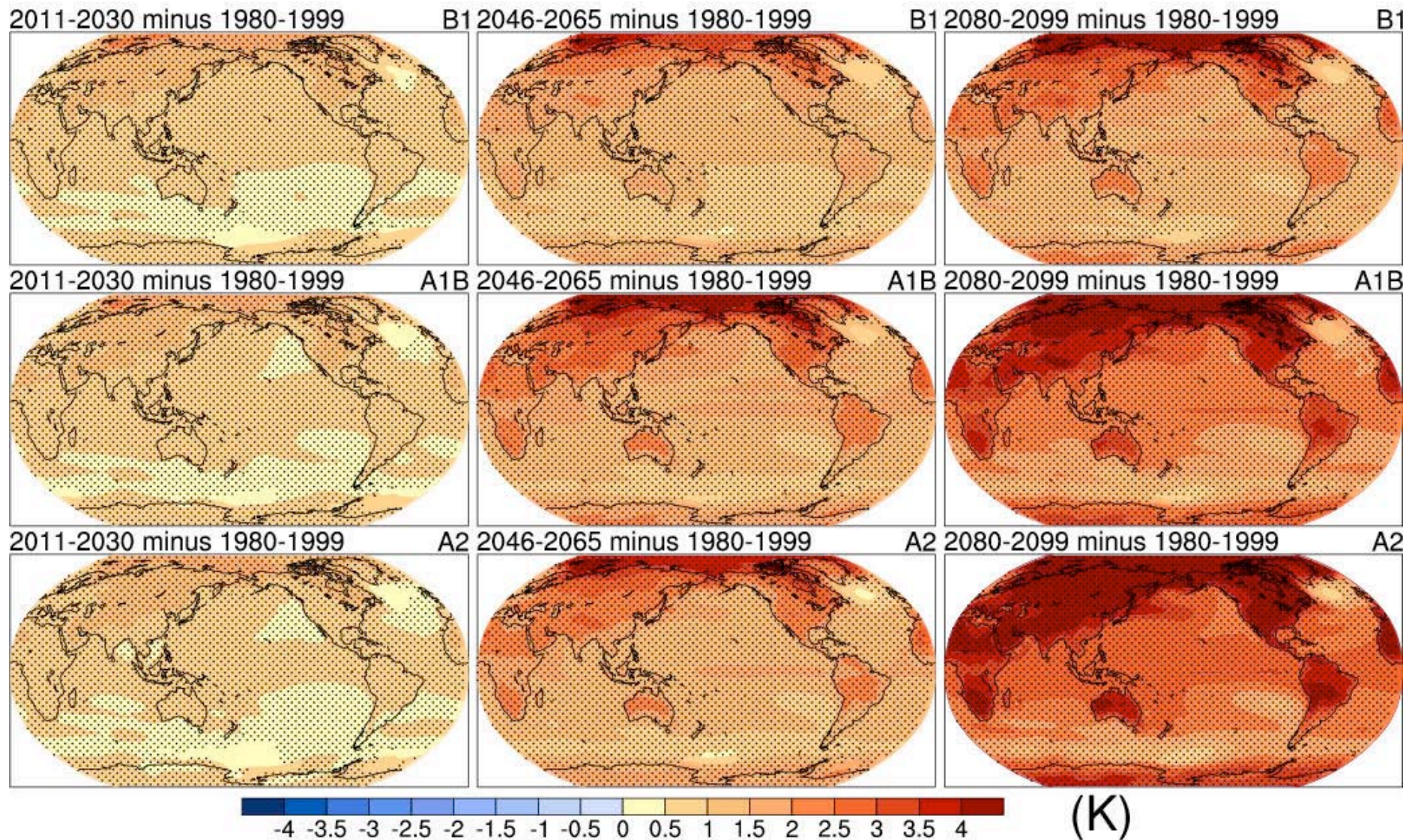
(Meehl et al., 2005: How much more warming and sea level rise? *Science*, **307**, 1769—1772)



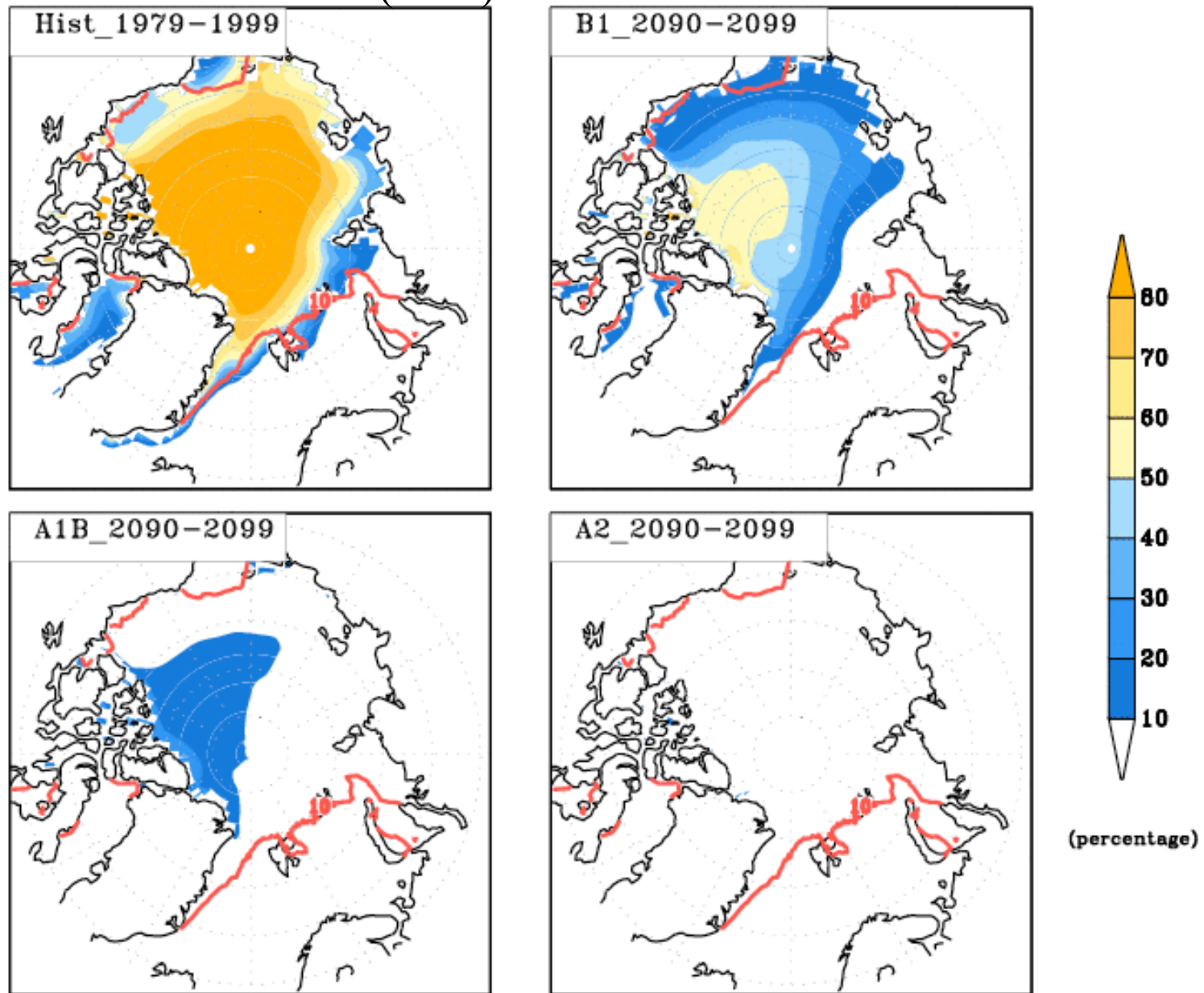
IPCC multi-model Glb Avg



IPCC multi-model mean surface air temperature



CCSM3 SUM(JAS) Sea Ice Concentration



(Teng et al., 2005, *Cli. Dyn.*, submitted)

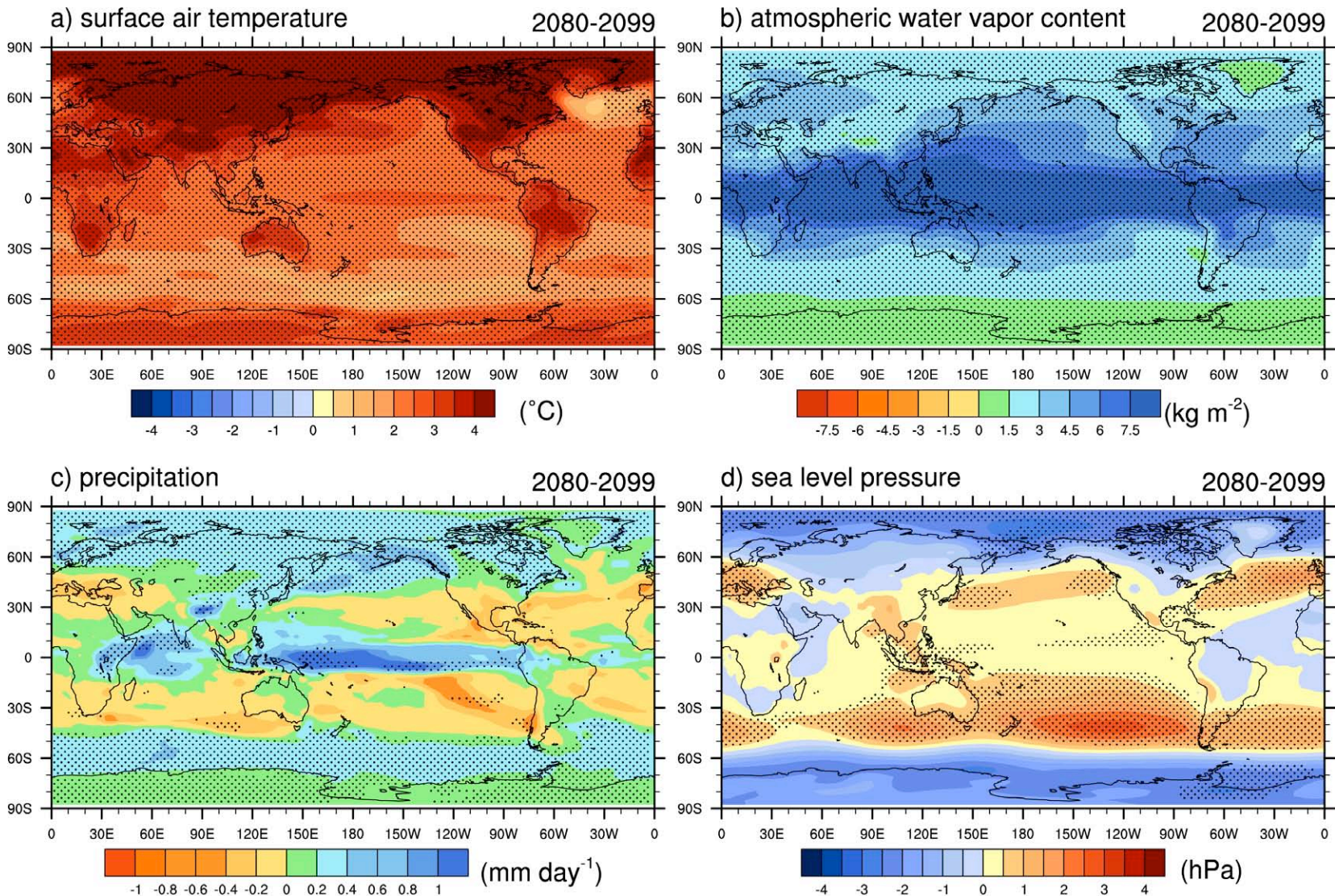
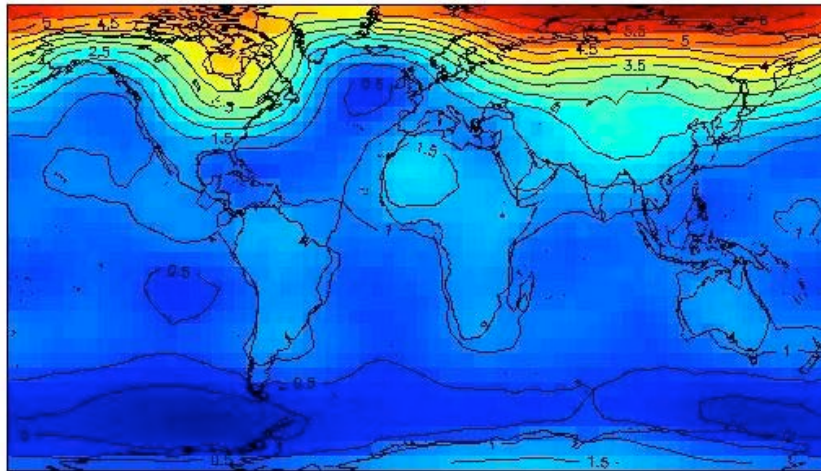


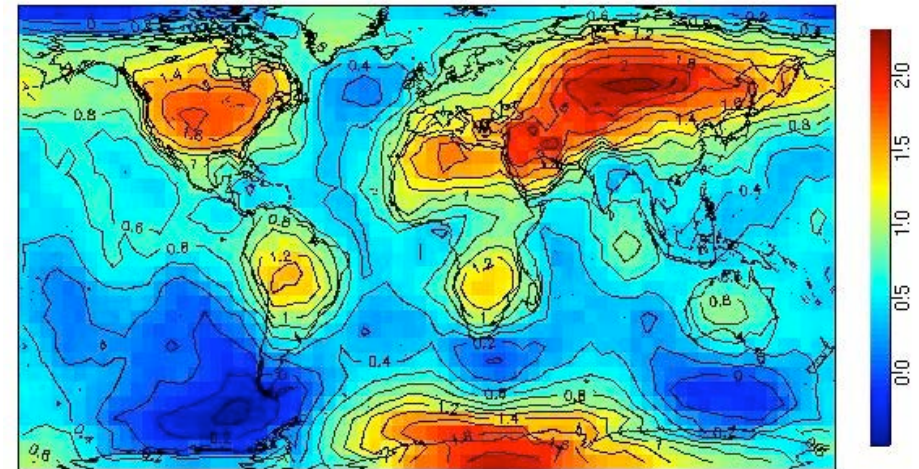
Fig. 2: a) annual mean surface temperature differences ($^{\circ}\text{C}$), 2080-2099 minus 1980-1999, for A1B from the 8 member multi-model ensemble; b) same as (a) except for vertically integrated water vapor differences (kg m^{-2}); c) same as (a) except for precipitation differences (mm day^{-1}); d) same as (a) except for SLP differences (hPa). Dotted regions correspond to areas where the multi-model mean divided by the multi-model standard deviation is greater than 1 (Meehl et al., 2005, GRL, submitted)

80% probability of at least this surface temperature change from 9 models for $2\times\text{CO}_2$:

DJF Temperature change delta such that $P\{X>\text{delta}\}=0.8$

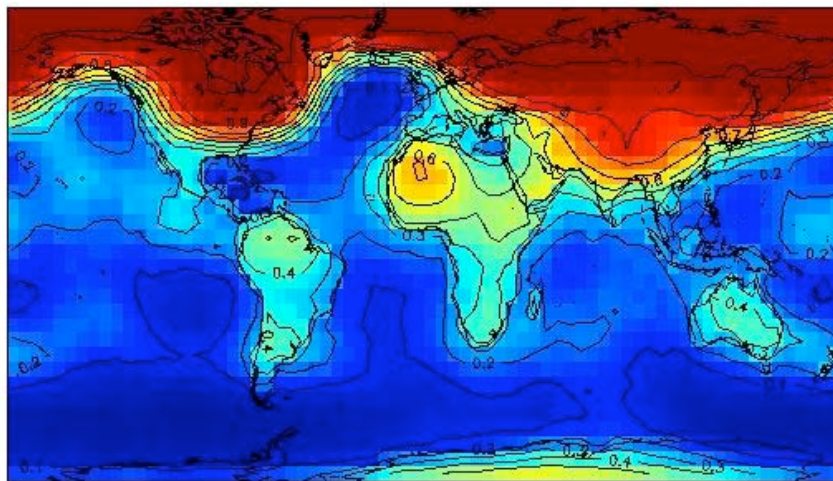


JJA Temperature change delta such that $P\{X>\text{delta}\}=0.8$

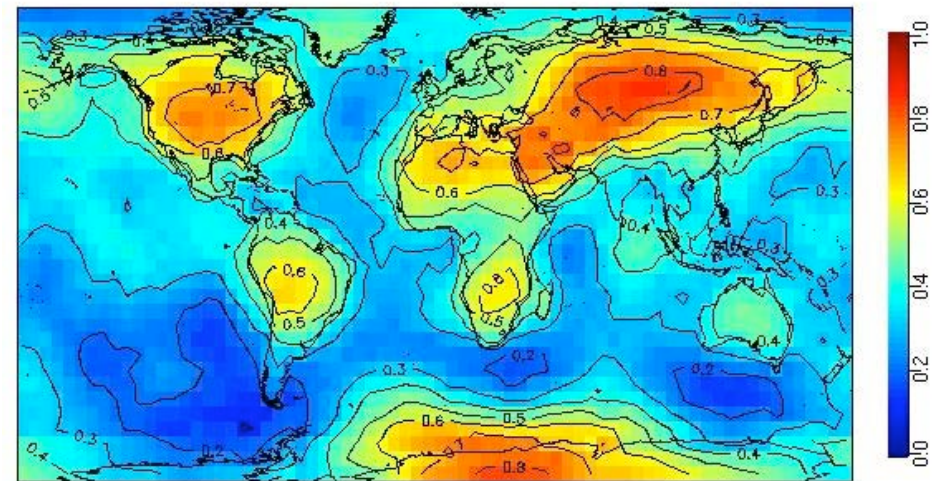


probability of temperature change exceeding 2°C from 9 models for $2\times\text{CO}_2$:

Probability that DJF temperature exceeds 2 degrees C



Probability that JJA temperature exceeds 2 degrees C

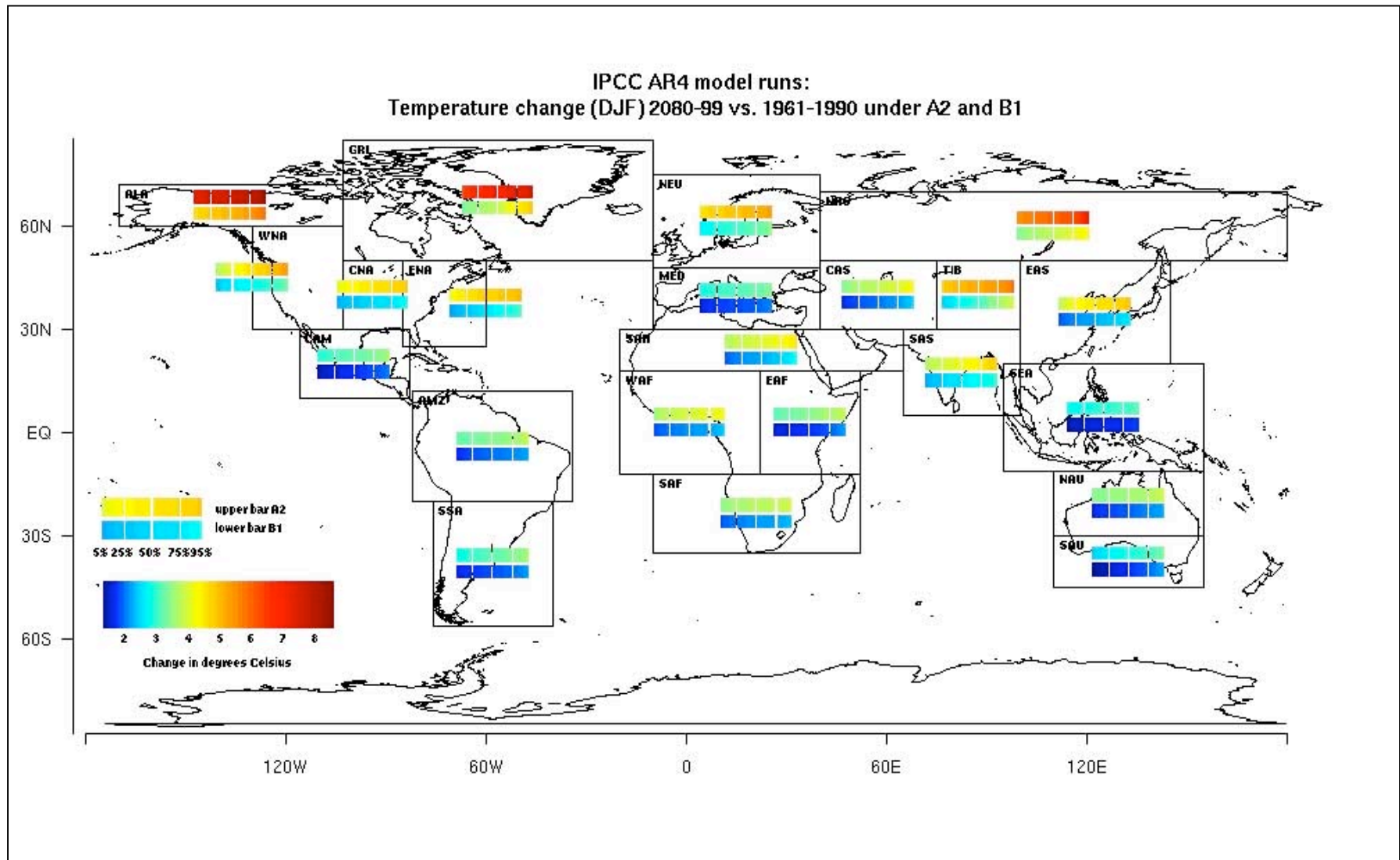


(from Furrer et al., 2005)

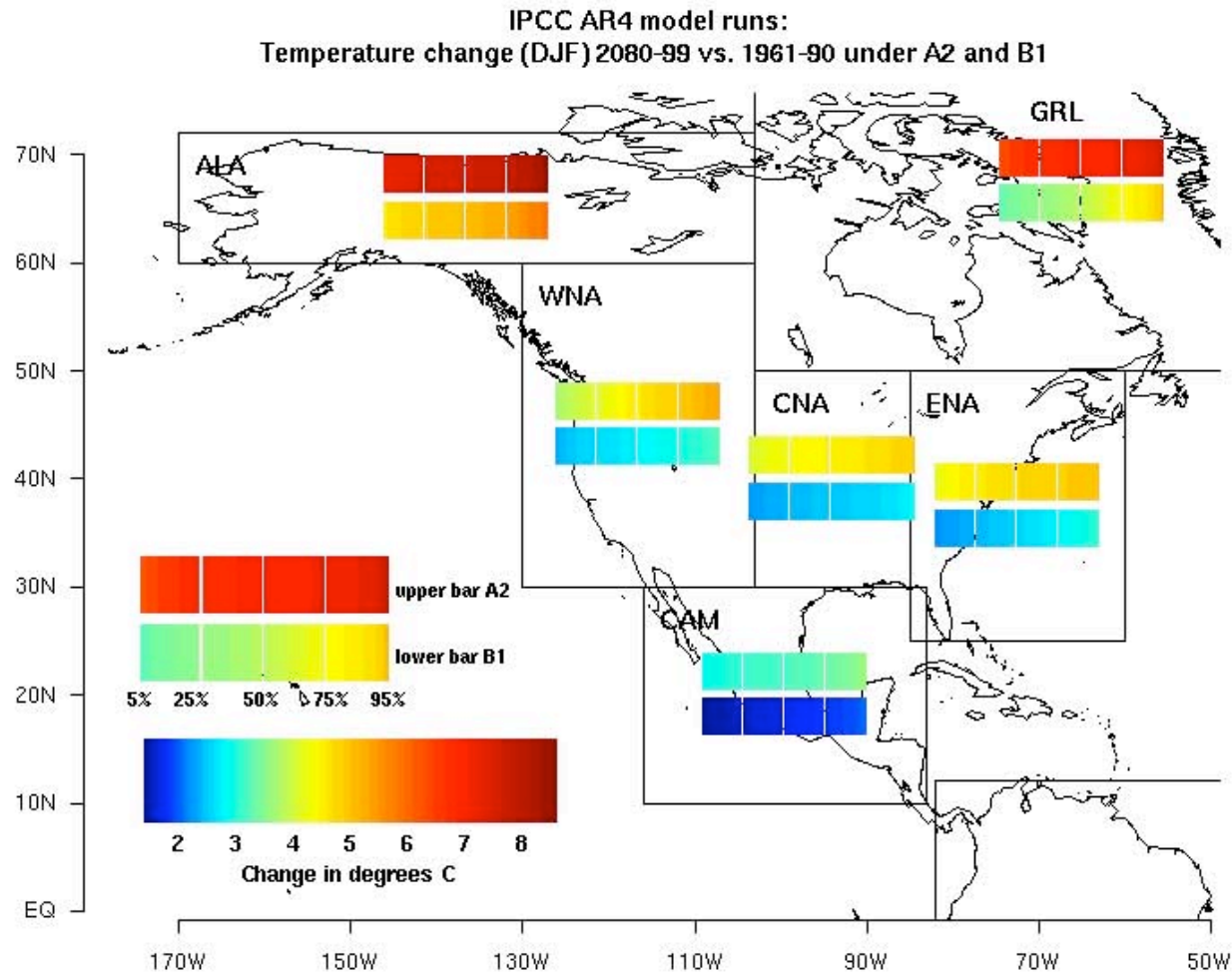
Regional Probabilities of Climate Change

95% Probability Range

Tebaldi et al., 2005



Regional Probabilities of Climate Change



Impacts on Agricultural and Biological Systems related to Frost Days

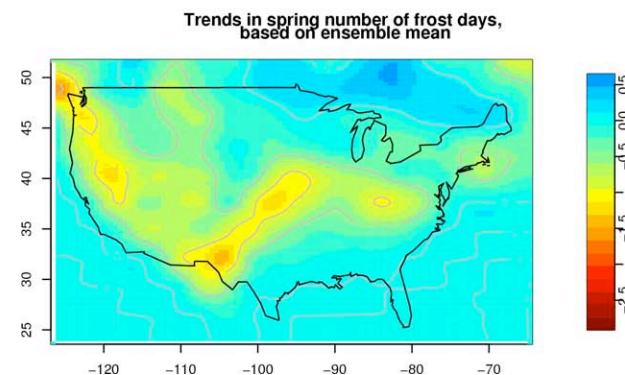
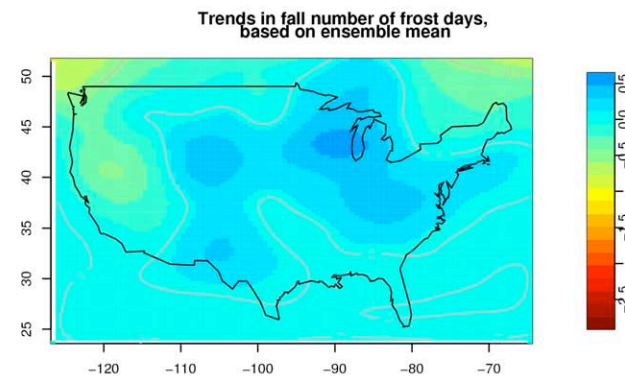
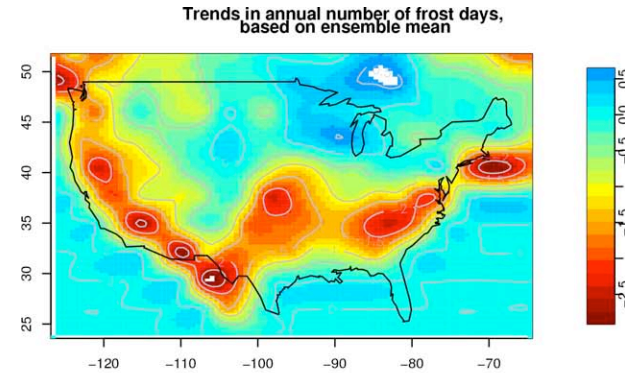
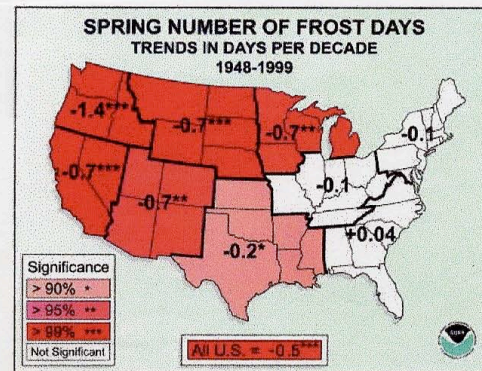
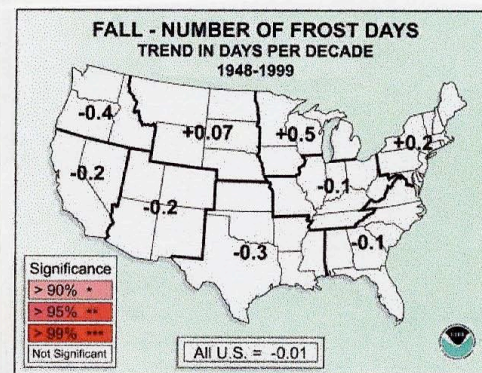
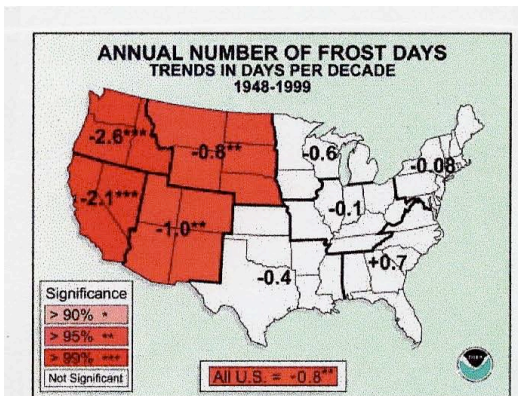
(Meehl, Tebaldi and Nychka, 2004: Changes in frost days in simulations of twentyfirst century climate, *Climate Dynamics*, 23, 495--511)

Changes in frost days affect:

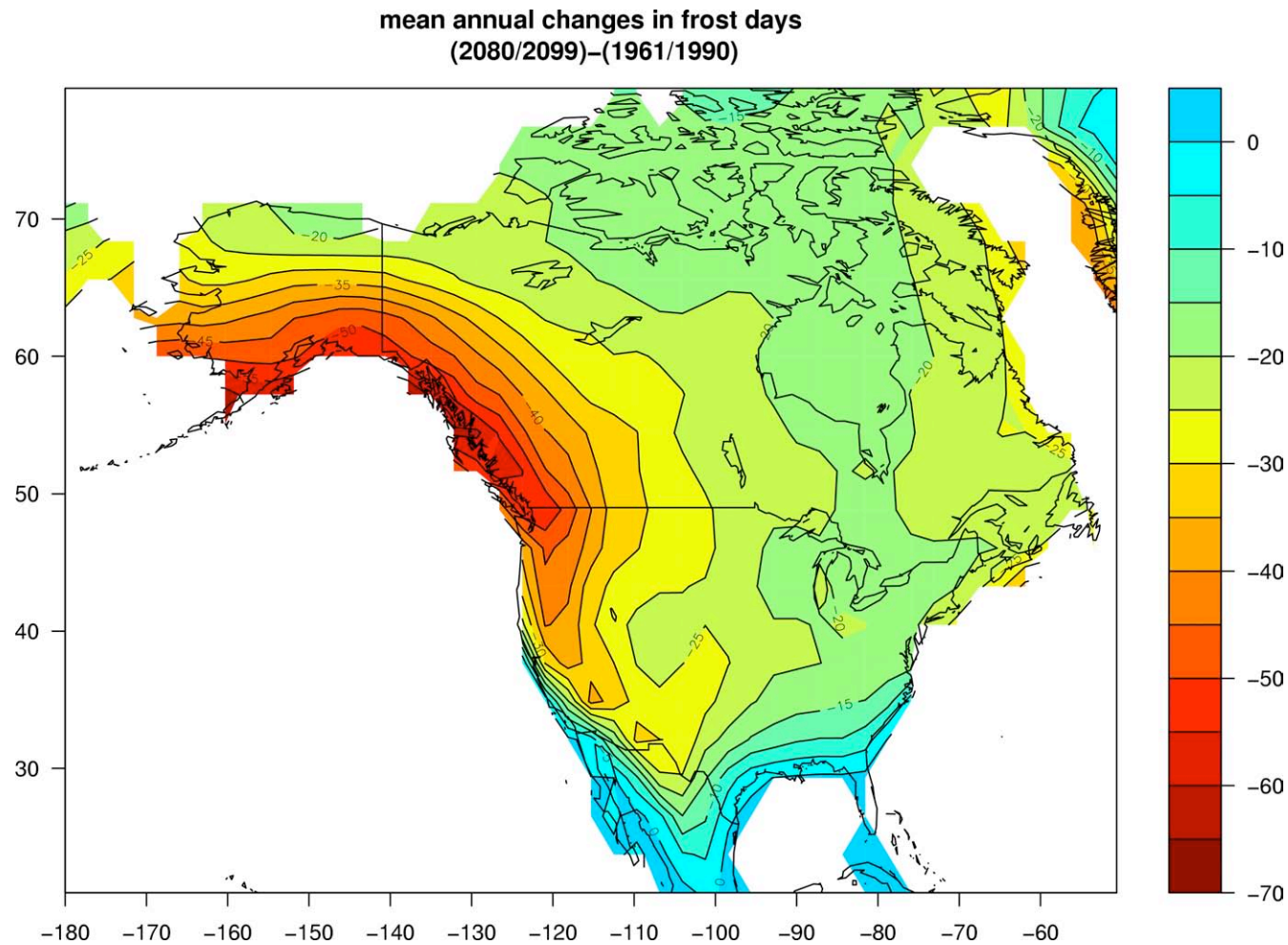
- ◆ Range shifts (latitudinal or altitudinal)
- ◆ Change in growing season length
- ◆ Water resources (change in snow melt season)
- ◆ Earlier flowering; emergence of insects; earlier mating; loss of habitat, shorter hibernation



Changes in frost days in the late 20th century show biggest decreases over the western and southwestern U.S. in observations and the model



Future changes in frost days from the climate model
show greatest decreases in the western and
southwestern U.S., similar to late 20th century



Heat Waves

Impacts on human health and mortality, economic impacts, ecosystem and wildlife impacts

(Meehl and Tebaldi, 2004: More intense, more frequent and longer lasting heat waves in the 21st century, *Science*, 305, 994-997)



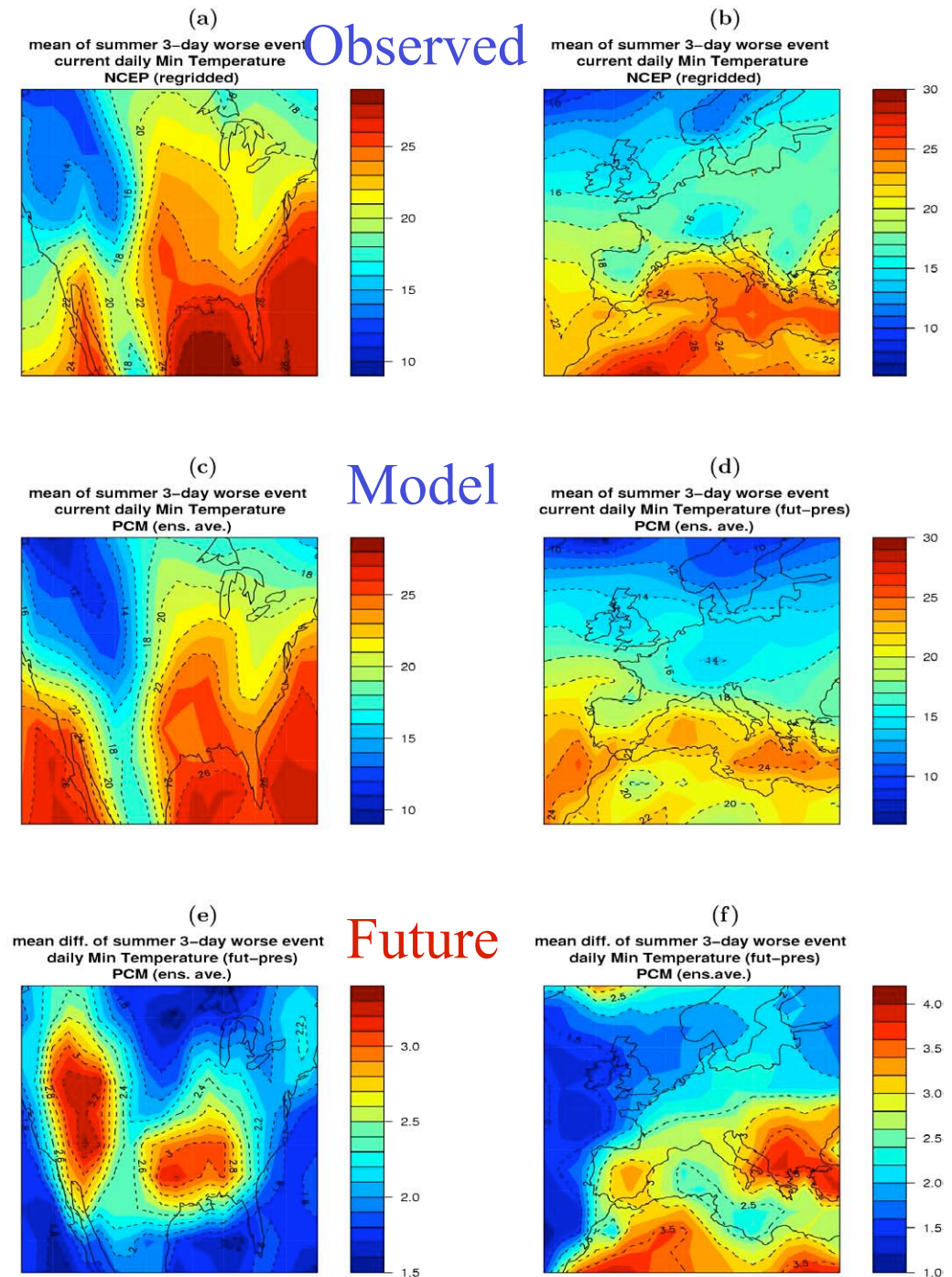
Climate models can be used to provide information on changes in extreme events such as heat waves

Heat wave severity defined as the mean annual 3-day warmest nighttime minima event

Model compares favorably with present-day heat wave severity

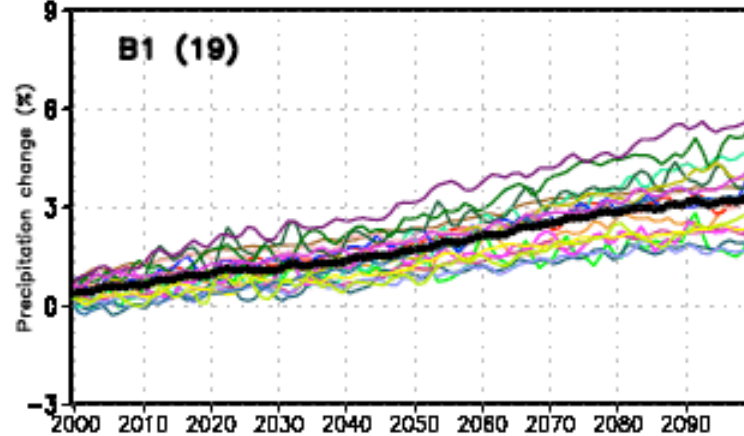
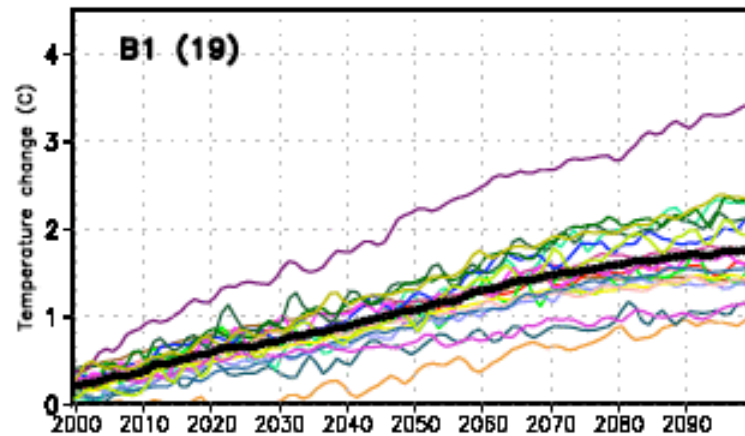
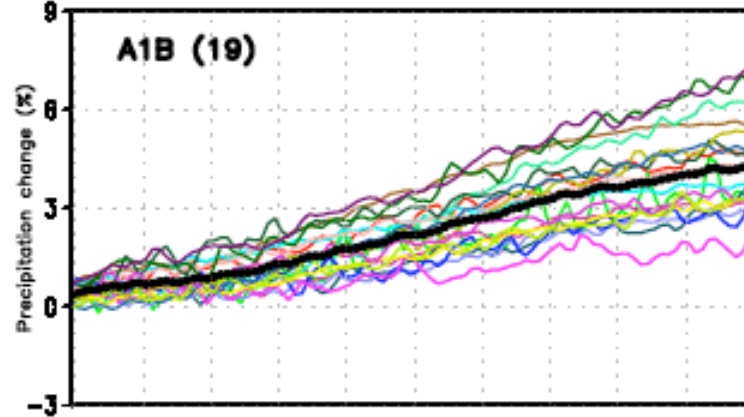
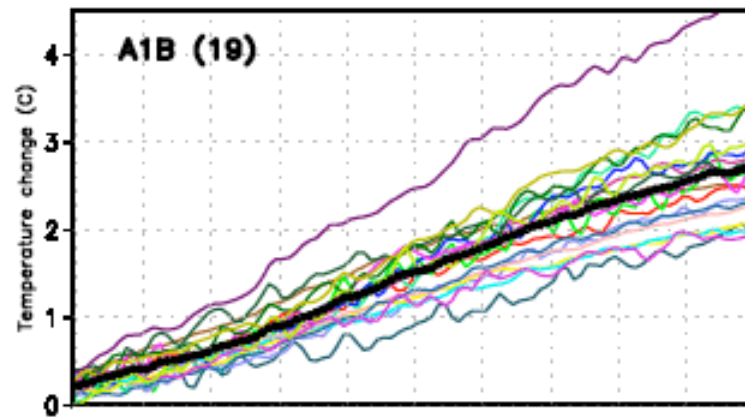
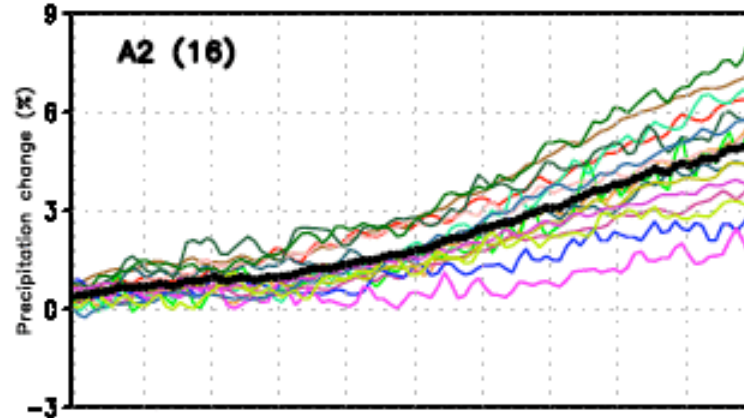
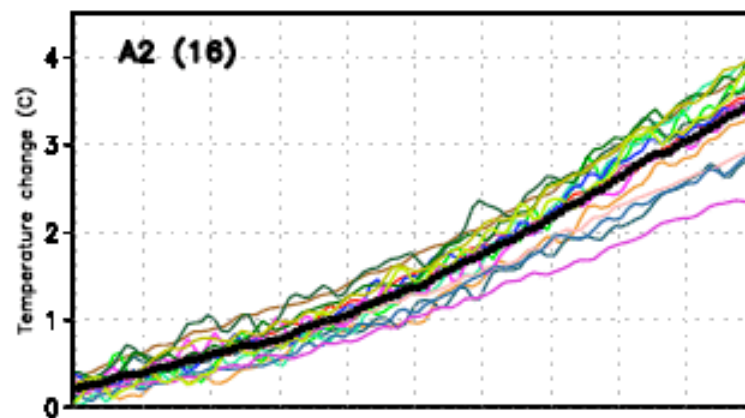
In a future warmer climate, heat waves become more severe in southern and western North America, and in the western European and Mediterranean region

Meehl, G.A., and C. Tebaldi, 2004: More intense, more frequent and longer lasting heat waves in the 21st century. *Science*, **305**, 994--997.



Summary

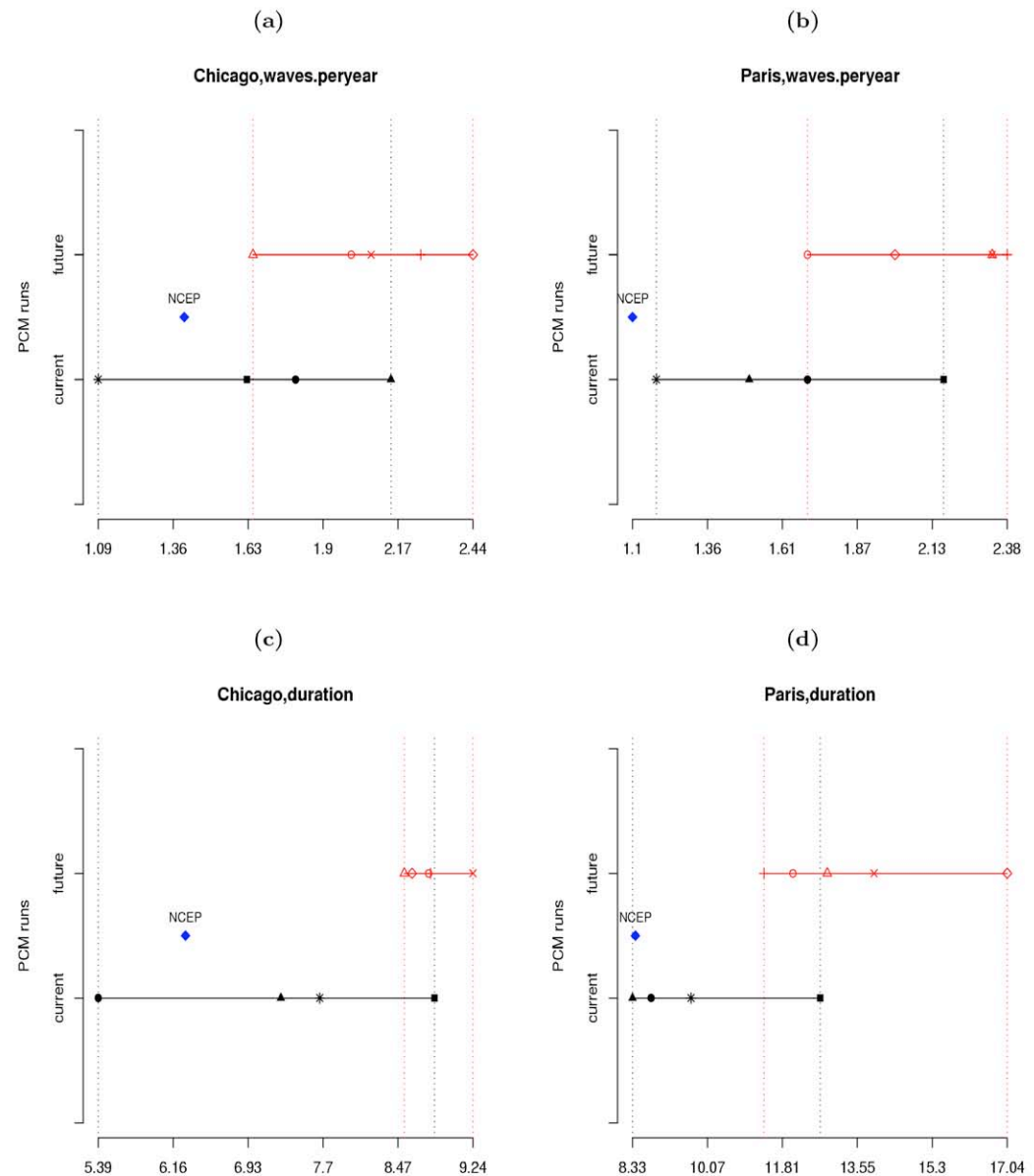
1. An internationally coordinated climate change experiment, the most extensive ever attempted, has resulted in 21 models from 14 groups around the world contributing about 27 Tb of data that is being analyzed by over 300 scientists, and has produced over 220 papers to date for assessment for the IPCC AR4
2. Multi-model climate change results are providing better quantifications and depictions of uncertainty (simple differences with uncertainty ranges and probabilistic climate change estimates)
3. Heat waves are projected to become more intense, more numerous and longer lasting in a future climate warmed by increasing anthropogenic greenhouse gases



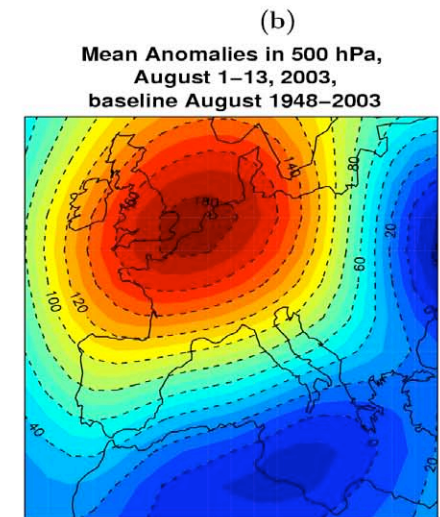
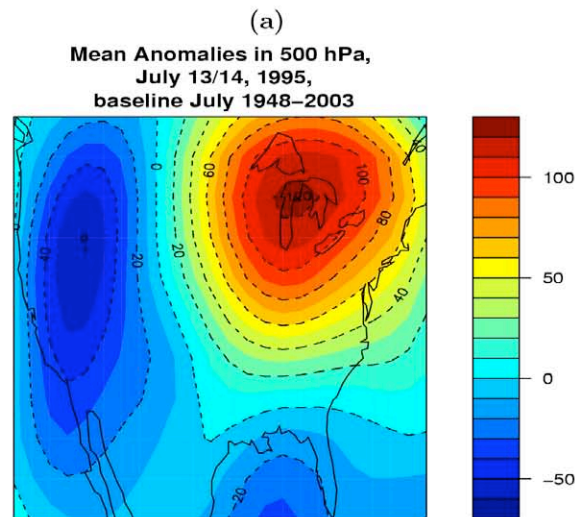
- BCC-CM1
- BCCR-BCM2.0
- CCSM3
- CGCM3.1(T47)
- CGCM3.1(T63)
- CNRM-CM3
- CSIRO-Mk3.0
- ECHAM/MPI-OM
- ECHO-G
- FGOALS-g1.0
- GFDL-CM2.0
- GFDL-CM2.1
- GISS-AOM
- GISS-EH
- GISS-ER
- INM-CM3.0
- IPSL-CM4
- MIROC3.2(hires)
- MIROC3.2(medres)
- MRI-CGCM2.3.2
- PCM
- UKMO-HadCM3
- UKMO-HadGEM1
- Ensemble avg

Climate model shows an increase in the average number of heat waves per year in the future (top) and an increase in heat wave duration (bottom)

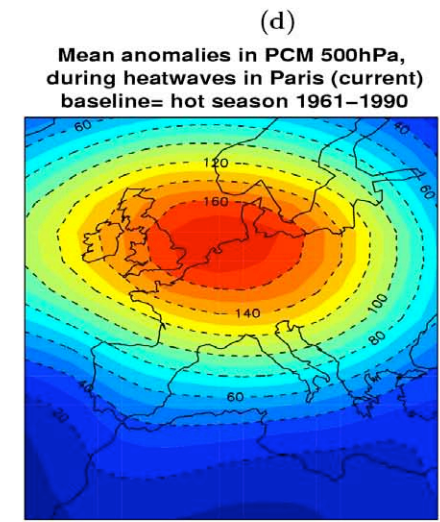
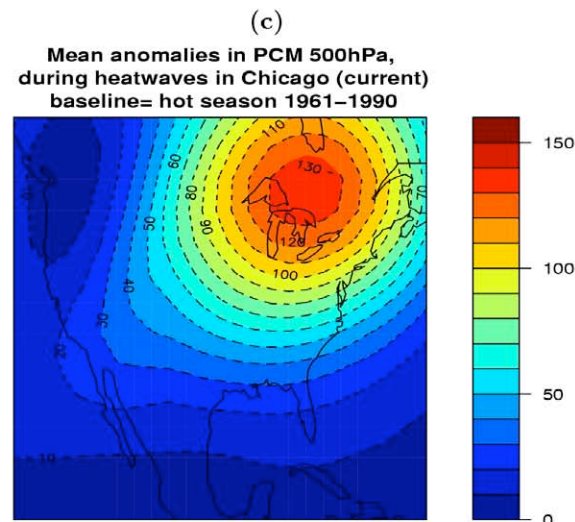
(model grid points near Chicago and Paris)



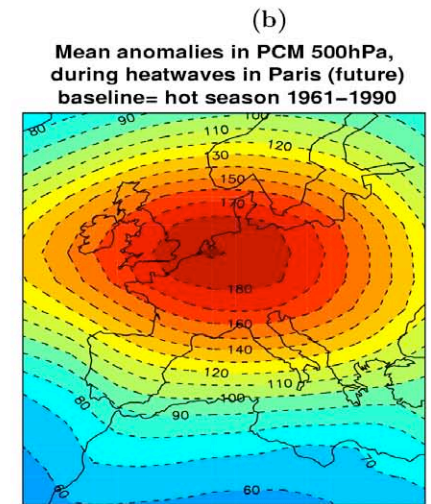
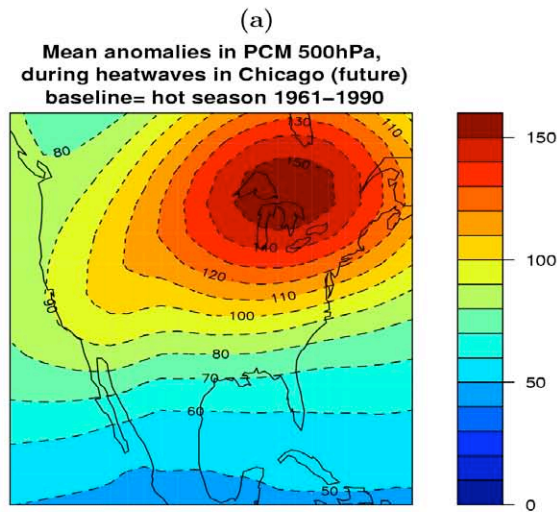
The Chicago (1995)
and Paris (2003) heat
waves show large
positive 500 hPa
height anomalies



For present-day heat
waves near Chicago
and Paris, the climate
model also simulates
large positive 500 hpa
height anomalies

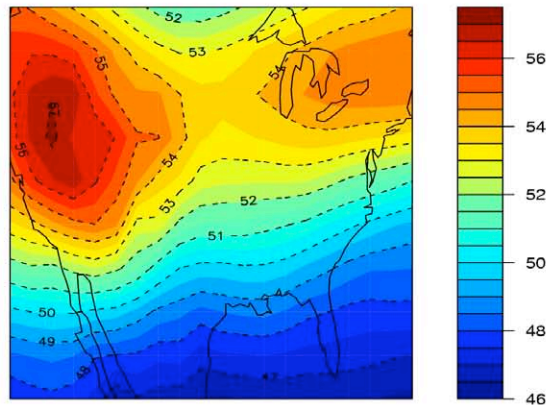


Atmospheric circulation
in heat waves becomes
more intense for future
climate (2080-2099)
compared to present-day
(1961-1990)



Future change in base
state (mean) atmospheric
circulation due to
increased CO2 is
conducive to more
intense heat waves

(c)
mean difference in Z500, future – present,
PCM (ens.ave.)



(d)
mean difference in Z500, future – present,
PCM (ens.ave.)

