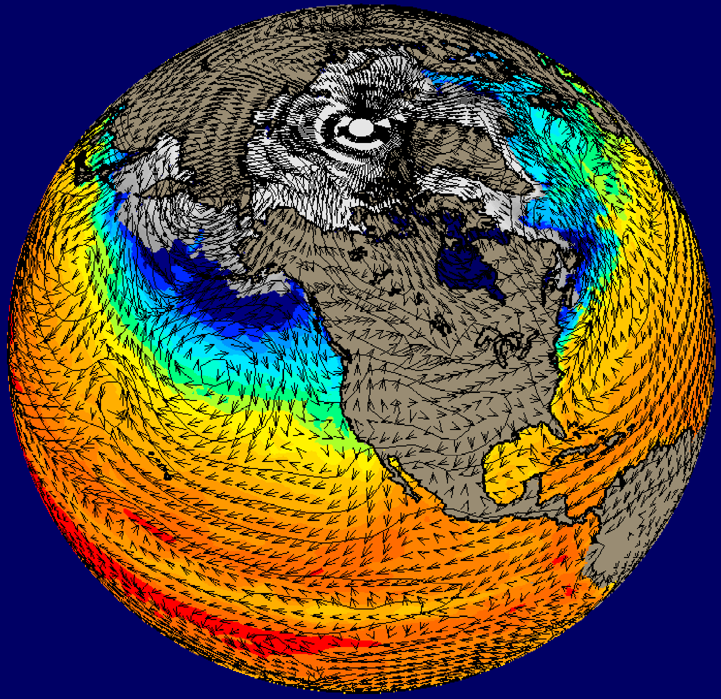
Plans for Projections of Future Climate Change with Global Coupled Models at NCAR

Gerald A. Meehl



Global Coupled Climate Models

CSM atmosphere: CCM3.2, T42 (~2.8 degrees), 18L
ocean: NCOM, 2 degree, 45L, GM, KPP
sea ice: cavitating fluid
land surface: LSM

PCM atmosphere: CCM3.2, T42, 18L
ocean: POP, 2/3 to 1/2 degree in eq. Tropics, 32L, biharmonic diffusion, Pacanowski/Philander mixing
sea ice: dynamic (EVP), thermodynamic
land surface: LSM

CCSM atmosphere: CAM, T42 (and T85, ~1.5 degrees), 26L
ocean: POP, 1 to 1/2 degree in eq. Tropics, 40L, GM, KPP
sea ice: dynamic (EVP), thermodynamic
land: CLM

(T42 class models run 4 years per day on present IBM, 10 years per day on IBM Power4; T85 is more than factor of two slower)

Accelerated Climate Prediction Initiative (ACPI) Demonstration Project

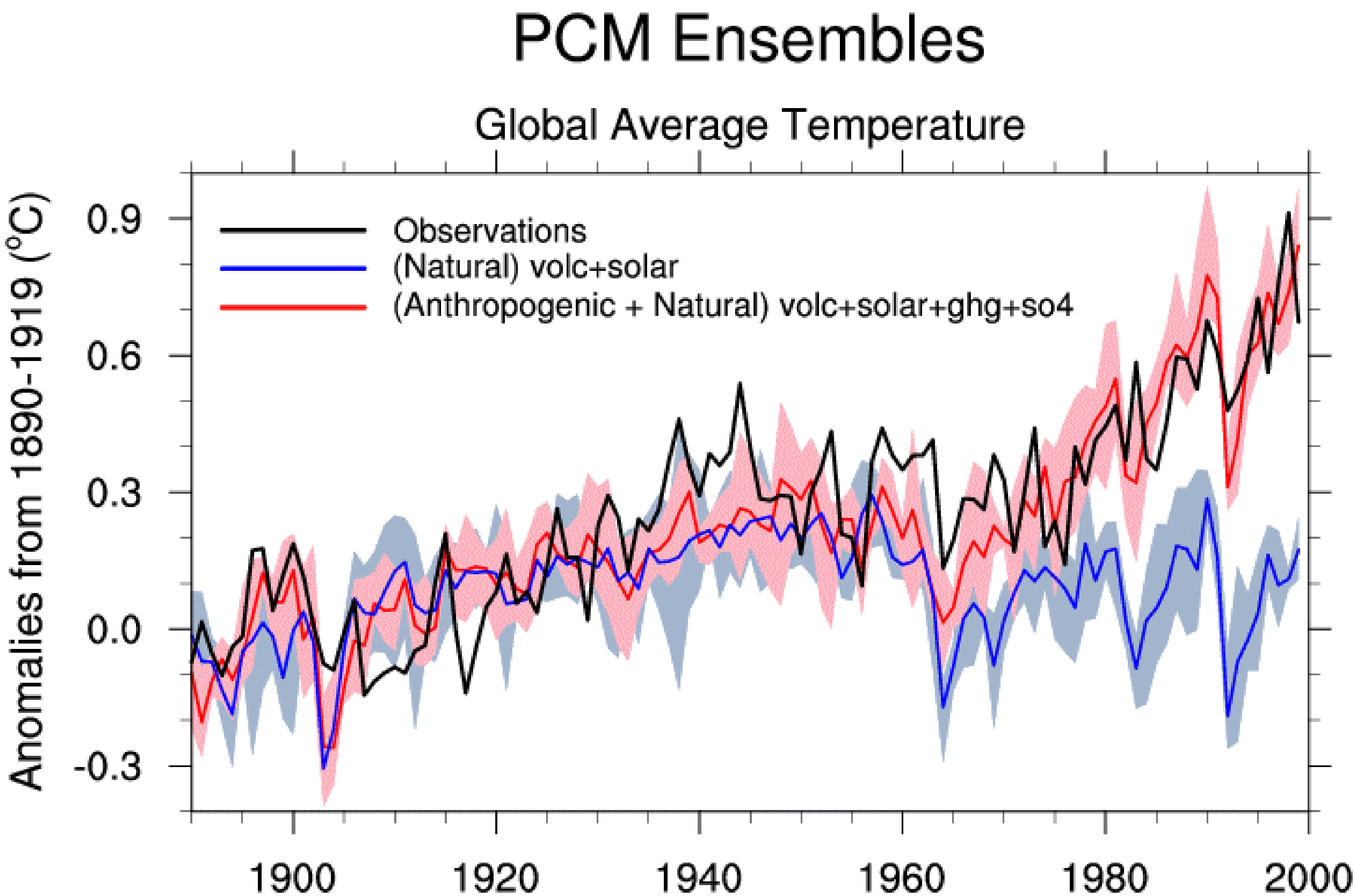
- End to end test of climate prediction. Initialize ocean -> global prediction of climate change -> regional modeling of climate change -> special impacts models such as hydrological models of small regions
- Several (6) special PCM simulations with 6 hour output for regional models
- Special issue of Climatic Change in late 2002

PCM 20th, 21st and 22nd Century Simulations

- GHG+sulfates+ozone, 1870-2000, 10 members
- GHG+sulfates+ozone+solar, 1870-2000, 4 members
- GHG+sulfates+ozone+solar+volcano, 1870-2000, 4 members
- Solar-only, 1870-2000, 4 members
- Volcano-only, 1870-2000, 4 members
- Solar+volcano, 1870-2000, 4 members
- Solar+volcano+ozone, 1870-2000, 4 members
- GHG+sulfates only, 1870-2000, 4 members
- control simulation (1000 years)
- 1% CO2 increase to doubling (5 members), and quadrupling (1 member); 150 years at 2XCO2, 150 years at 4XCO2; (CMIP)
- ACACIA "Business as Usual", 5 members, 2000-2100; 1 member to 2200
- ACACIA "stabilization", 5 members, 2000-2100, 1 member to 2200
- SRES A2 and B2 (completed), A1B, A1FI, and B1 (in progress), 2000-2100, single members; (IPCC DDC)

Ongoing and Planned Climate Change Simulations

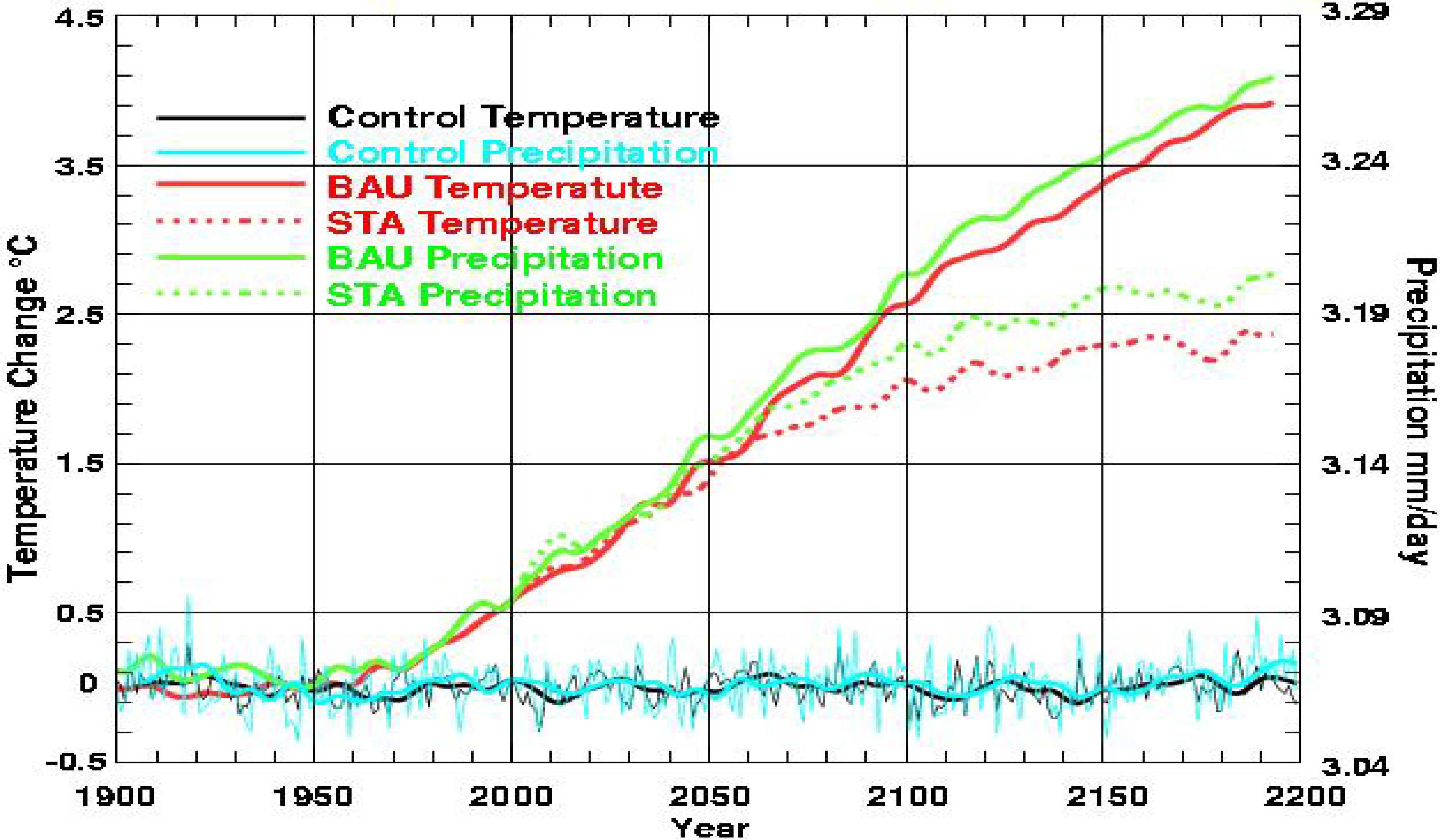
- Simulations with carbon aerosol distributions with the PCM
- Land surface change simulations (urbanization, soil degradation, land use), PCM and CCSM, 20^{th} and 21^{st} century
- Sulfur cycle with varying pattern of SO2 emissions, 20^{th} century, CCSM
- 21^{st} century simulation with statistical solar and volcanic data
- CCSM T42 atmosphere, 20^{th} century all-forcings, 21^{st} century A2, B2, single members
- CCSM T85 atmosphere, 20^{th} century all-forcings, 21^{st} century A2, B2, A1FI, A1B, and B1, 4 member ensembles
- 20^{th} and 21^{st} century climate simulation with interactive carbon cycle, CSM presently, CCSM subsequently



PCM Ensembles
Global Average Temperature
Observations
(Natural) volc+solar
(Anthropogenic + Natural) volc+solar+ghg+so4
Anomalies from 1890-1919 (°C)
0.9
0.6
0.3
0.0
-0.3
1900
1920
1940
1960
1980
2000

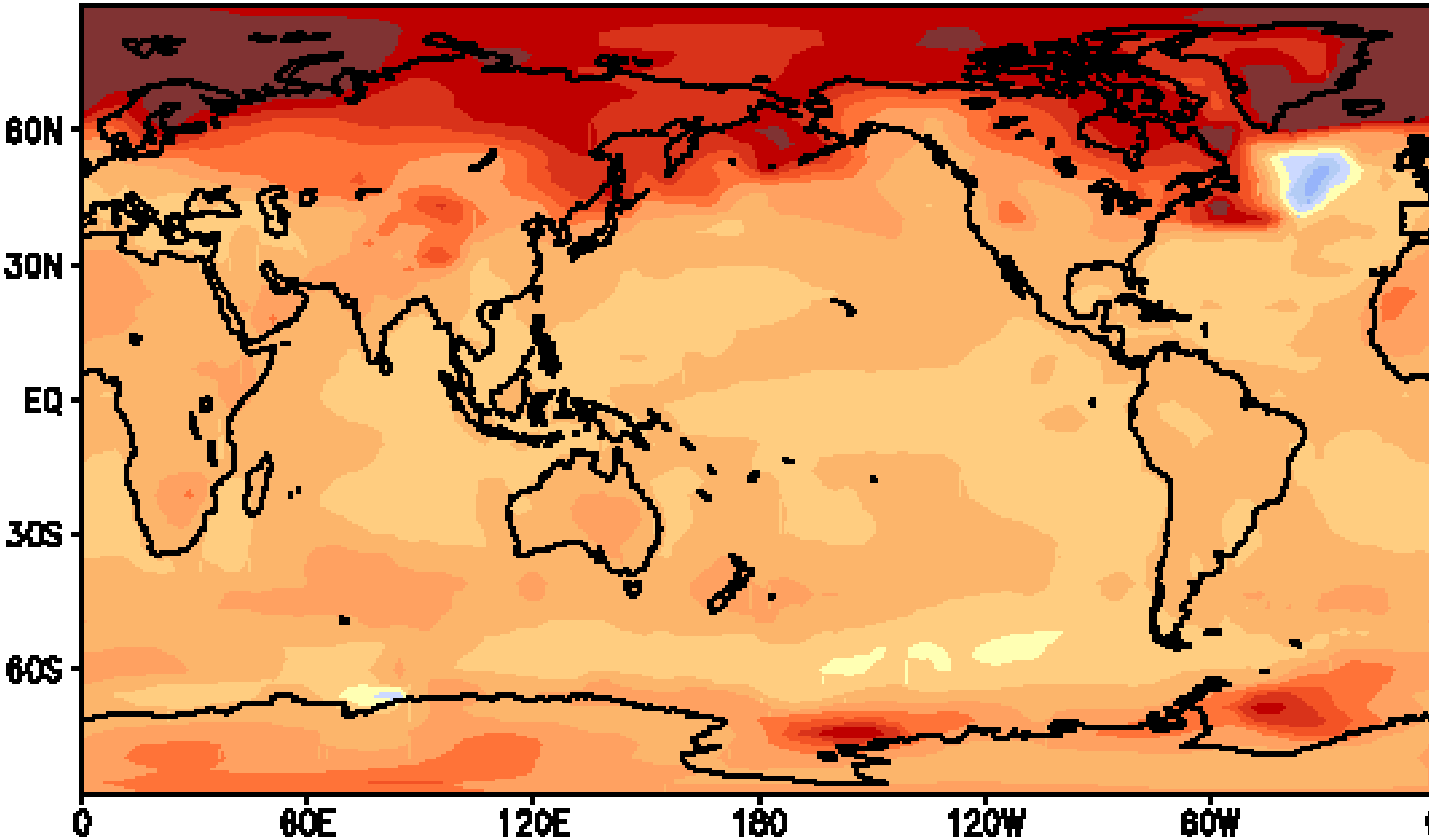
NCAR Climate Model (PCM)

Global Temperature and Precipitation Changes

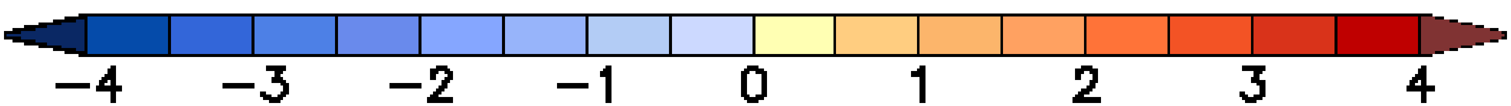


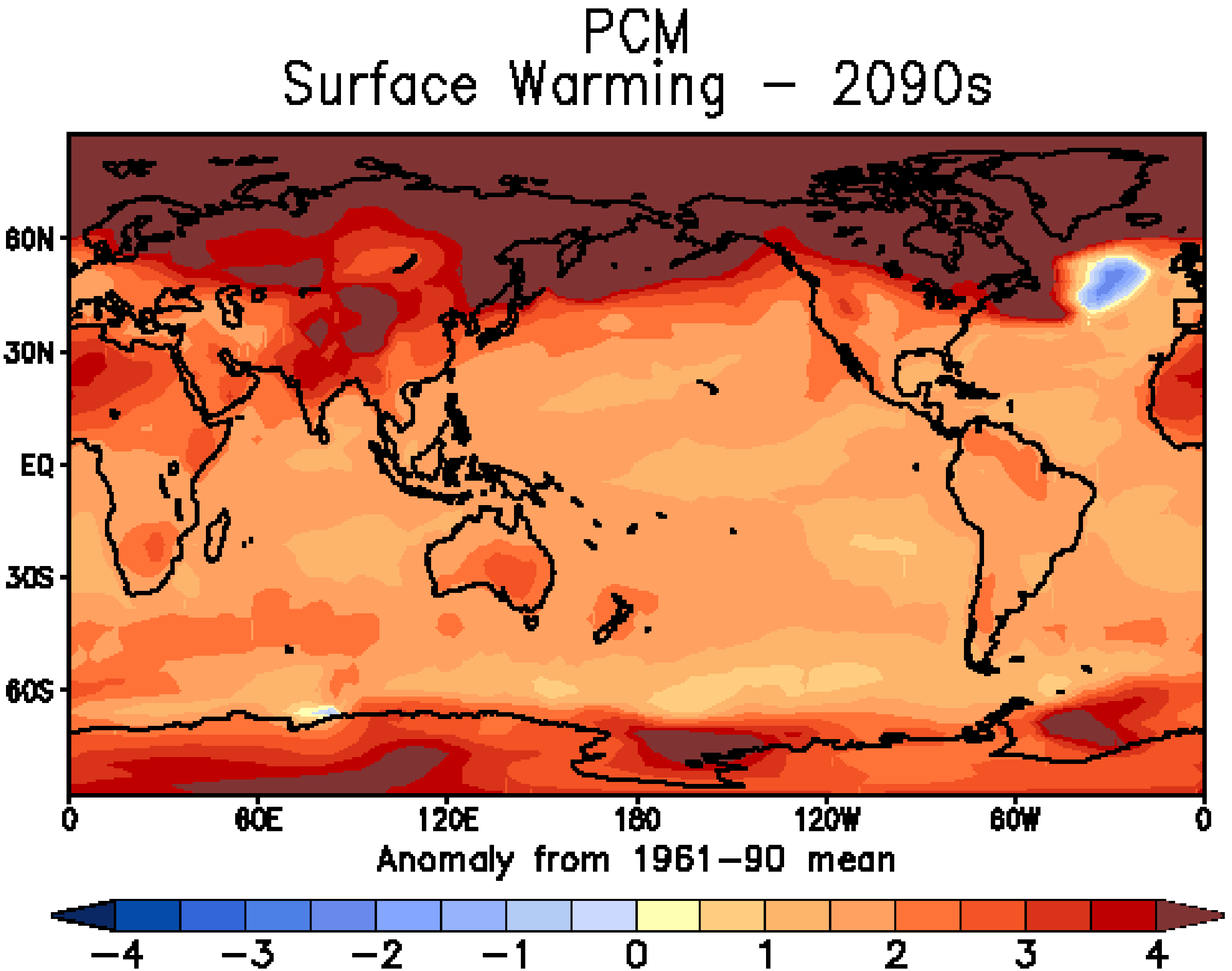
Control run: Annual means (thin lines) and 20 year means
Other runs: 20 year means
Business as Usual (BAU)
Stabilization of Carbon Dioxide concentrations (STA)

PCM
Surface Warming - 2050s



Anomaly from 1961-90 mean




PCM
Surface Warming - 2090s
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
Anomaly from 1961-90 mean
-4
-3
-2
-1
0
1
2
3
4

General Theme for Next Five Years of CCSM Climate Change and Assessment Working Group

- Quantifying uncertainty in climate change projections
- Steps to accomplish this objective:

    1. Improve regional climate simulation and extremes: higher resolution atmospheric component, T85, T170 coupled simulations
    2. Probabilistic projections of climate change: Ensemble simulations with various forcings and emission scenarios
    3. Understand model response and factors that affect sensitivity
        a. single model--sensitivity experiments
        b. coordinated experiments involving other models from different modeling centers in addition to CCSM (CMIP coordinated experiments)

Key issue for this objective: Model data transfer, storage and access

The End

General Theme for Next Five Years of CCSM Climate Change and Assessment Working Group

- Quantifying uncertainty in climate change projections
  - Need “forcing repository” so groups can use same forcings
  - Single forcing experiments still useful
- Steps to accomplish this objective:

Forcing: GHGs, SA, Volcanic, ozone, solar, CA, land, surface, etc.

1. Improve regional climate simulation and extremes: higher resolution atmospheric component, T85, T170 coupled simulations; need more outputs from model in time and space for extremes analyses
2. Probabilistic projections of climate change: Ensemble simulations with various forcings and scenarios
   - Integration from 1500-2000 with volcano and solar to look at variability (work with Paleo WG)
3. Understand model response to changes of forcing; climate sensitivity likely to be main issue for next IPCC
   a. single model--sensitivity experiments with CCSM; atmosphere only or mixed layer slab coupled experiments
   b. coordinated experiments involving other models from different modeling centers in addition to CCSM; analysis of 1000 year runs from PCM and CCSM

Key issue for this objective: Computer time in (2003-2005), model data transfer, storage and access

- New scenarios for IPCC: A1FI, A1B, B1 (in addition to A2 & B2)

Distributed Involvement

DOE and NSF Supported Project with:

- Los Alamos National Laboratory*
- National Center for Atmospheric Research*
- Naval Postgraduate School
- Oak Ridge National Laboratory*
- University of Texas, Austin
- Scripps Oceanographic Institute
- DOE Program on Climate Diagnostics and Intercomparison
- U.S. Army Cold Regions Research and Engineering Laboratory
- National Energy Research Supercomputer Center*
- Lawrence Berkeley National Laboratory
- Argonne National Laboratory

*computing support

Data Users and Collaborators

- Bill Anderson, NCAR
- Jeffrey Annis, Scripps
- Julie Arblaster, NCAR
- Raymond Arritt, Iowa State
- Tim Barnett, Scripps
- Pat Behling, U. Wisconsin
- Cecilia Bitz, U. Washington
- Marcia Branstetter, U. Texas
- James Boyle, LLNL
- Curtis Covey, LLNL
- Ulrich Cubasch, DKRZ
- Aiguo Dai, NCAR
- Clara Deser, NCAR
- Charles Doutriaux, LLNL
- Bob Drach, LLNL
- Wesley Ebisuzaki, NOAA
- Irene Fischer-Burn, DKRZ
- Peter Gleckler, LLNL
- B. Govindasamy, LLNL
- John Gregory, IPCC
- Vadim Guzey, U. Adelaide, Australia
- James Hack, NCAR
- Charles Hakkarinen, EPRI
- Justin Hnilo, LLNL
- Regine Hock, Swedish Royal Institute of Technology
- James Hack, NCAR
- Charles Hakkarinen, EPRI
- Tony Hirst, CSIRO
- Roy Jenne, NCAR
- M. Kanamitsu, U. California
- Vladimir Kattsov, Russian Academy of Science
- Kevin Keay, U. Melbourne
- Chick Keller, LANL
- Helen Kettle, Edinburgh U.
- Jeff Kiehl, NCAR
- Kwang Yul Kim, Florida State
- Tom Knutson, NOAA
- Eric Leuliette, CU
- Hans Luthardt, DKRZ
- Bob Malone, LANL
- Vadim Matyugn, Russian Academy of Science
- Gerald Meehl, NCAR
- Sylvia Murphy, NCAR
- Robert Oglesby, NASA Ames
- Greg Ostermeier, U. Washington
- David Pierce, Scripps
- Wilfred Post, ORNL
- Gerald Potter, LLNL
- Jouni Raisane, Swedish Met. & Hydro. Institute
- Thomas Reichler, U. California
- Alex Sim, LBNL
- Dennis Shea, NCAR
- Scott Smith, LANL
- Ken Sperber, LLNL
- Ronald Stouffer, NOAA
- Youichi Tanimoto, Japan Network Information Center
- John Taylor, Argonne
- Tony Tubbs, Scripps
- Dmitry Vjushin, Bar-Ilan U. Israel
- Warren Washington, NCAR
- John Weatherly, CRREL
- Michael Wehner, LLNL
- Dean Williams, LLNL
- Andrew Wood, U. Washington
- Kao J. Chin Yue, LANL
- Alan Ziegler, Princeton University

DOE and NSF Research Interest

- Develop climate modeling capability that takes advantage of new generation parallel architecture supercomputers
- Develop model components and coupled models that can be used for energy policy, IPCC, and the National Assessments

History
CSM1 and PCM1

- Built for vector Computers
- Atmosphere: CCM3
- Ocean component: NCAR ocean model
- Sea ice simplified dynamics and thermodynamics

- Built for parallel Computer system
- Atmosphere: CCM3
- Ocean component: Parallel Ocean Program (POP)
- Sea ice Model -Naval Postgraduate School model: VP, P&W

Examples of Climate Change Experiments

- Greenhouse gases
- Sulfate aerosols (direct effect)
- Carbon aerosols
- Stratospheric ozone
- Land surface changes
- Volcanic forcing
- Solar change forcing
- Biomass burning
- Various energy/emissions use strategies

Change of Extremes

- Heat waves, cold snaps
- Floods, droughts
- First freeze dates, hard freeze frequency
- Precipitation intensity
- Diurnal temperature

CSM Climate Change Simulations

- 1% CO_2 increase year
- Historical 1870 to present (GHG)
- Historical 1870 to present (GHG+SA)
- Ensemble (4) Historical 1870 to present (GHG+SA+Solar)
- 21st Century Business as Usual (BAU), IPCC A1(5), A2, and B2
- 21st Century with improved ocean features

PCM 1% CO2 Increase/Year

- Control simulation– 300 years
- Ensemble of 5 capped at 2X CO_2
- One simulation capped at 4X CO_2
- One simulation with 0.5% per year capped at 2X CO_2

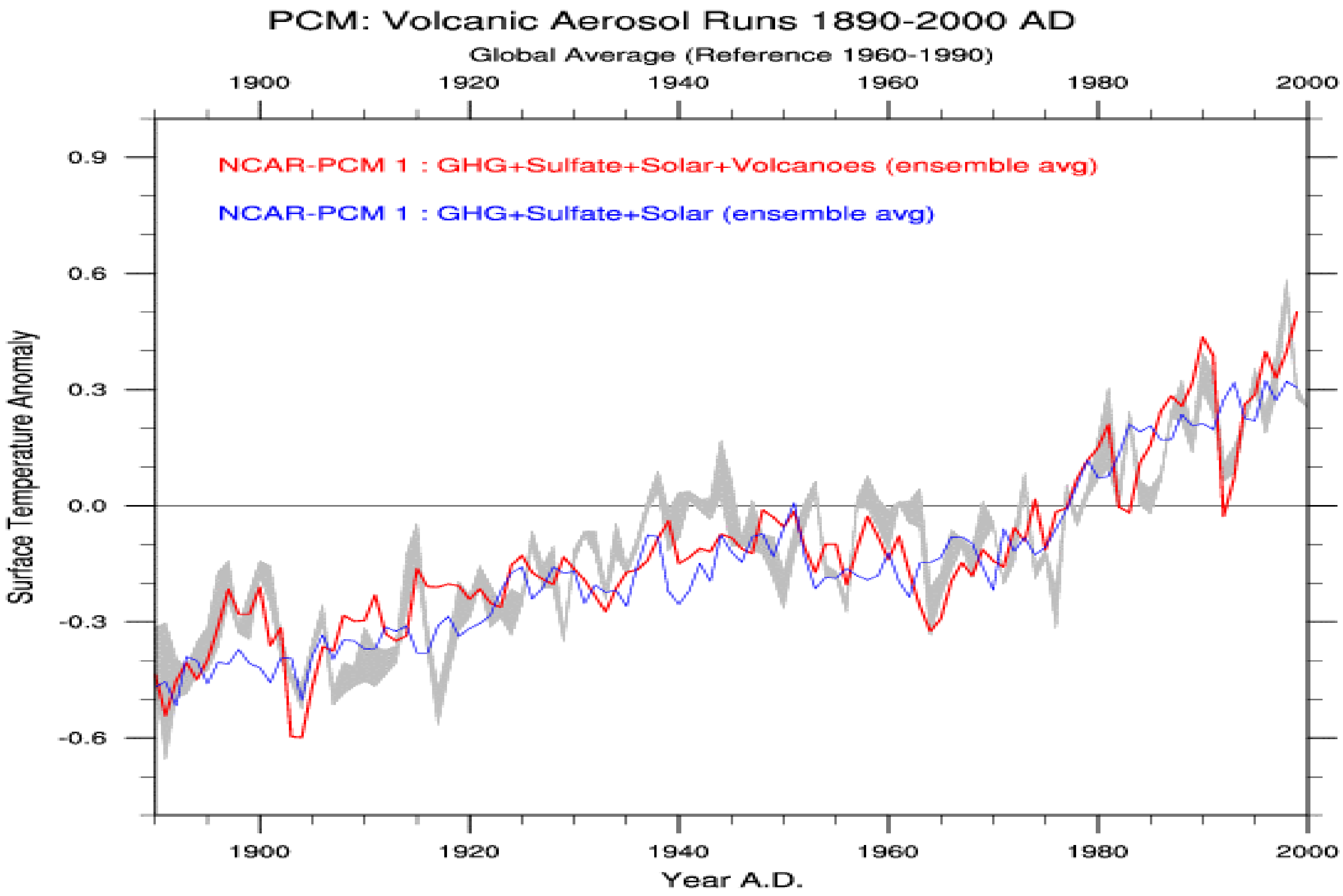
80 Simulations later!

PCM Historical and Future Simulations

- Use of CSM greenhouse gas and sulfate aerosol forcing
- 1870 control simulation (approximately 1000 years)
- Historical 1870 to present
- IPCC “Business as Usual” assumption
- IPCC stabilization assumption
- Ensemble of 10 for Historical, BAU/STAB ensemble 5
- Solar variability simulation-ensemble of 4
- Simulations to year 2200-ensemble BAU/STAB 3
- Additional simulations aimed separation of natural forcing from anthropogenic forcing

Dissect Forcing

- GHS + Sulfate aerosols
- GHS + Sulfate aerosols + Volcanic
- GHS + Sulfate aerosols + Volcanic +Solar
- Above + ozone fixed in time
- Different combinations of the above such as solar only, etc


PCM: Volcanic Aerosol Runs 1890-2000 AD
Global Average (Reference 1960-1990)
NCAR-PCM 1 : GHG+Sulfate+Solar+Volcanoes (ensemble avg)
NCAR-PCM 1 : GHG+Sulfate+Solar (ensemble avg)
Surface Temperature Anomaly
0.9
0.6
0.3
0.0
-0.3
-0.6
1900
1920
1940
1960
1980
2000
Year A.D.

DOE Earth System Grid/ SciDac Development

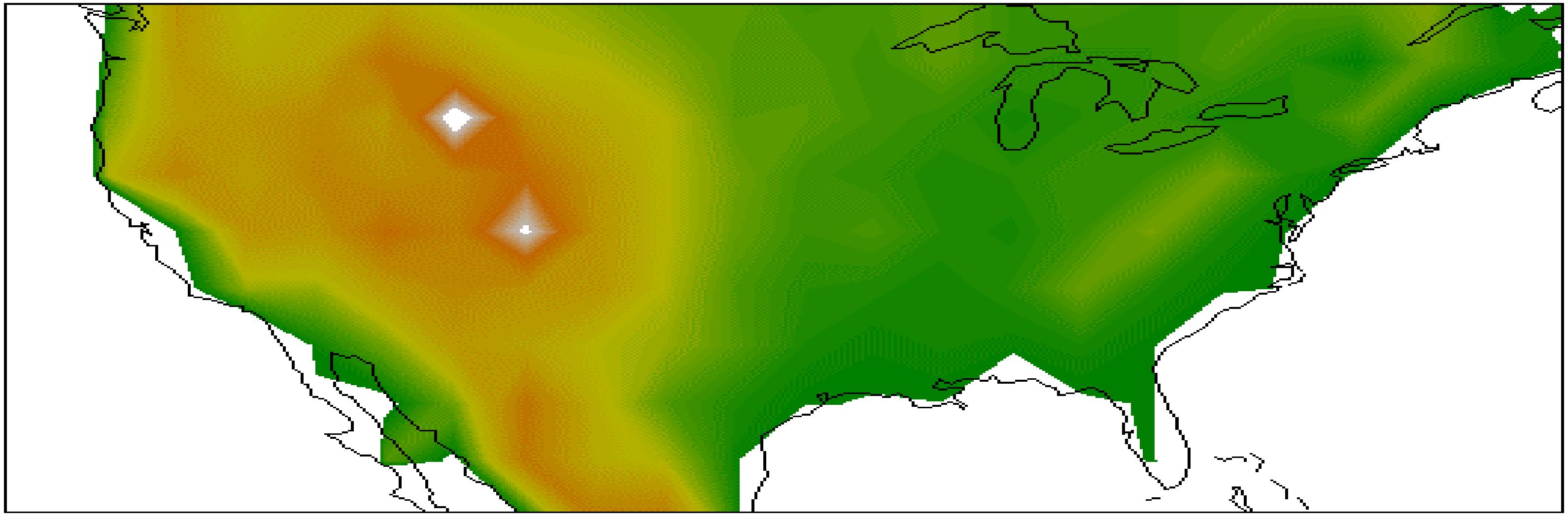
- Simulations at NSF, LANL, NERSC, and ORNL (70 Tbytes of data, 80 simulations already)
- Archives at PCMDI, NERSC, NCAR, ORNL, LANL
- Easy access for transferring large data sets
- Catalog system across distributed system
- Cooperative Program between DOE laboratories and NCAR

Coupled Model Inter-Comparison Program (CMIP) Coordinated Simulations

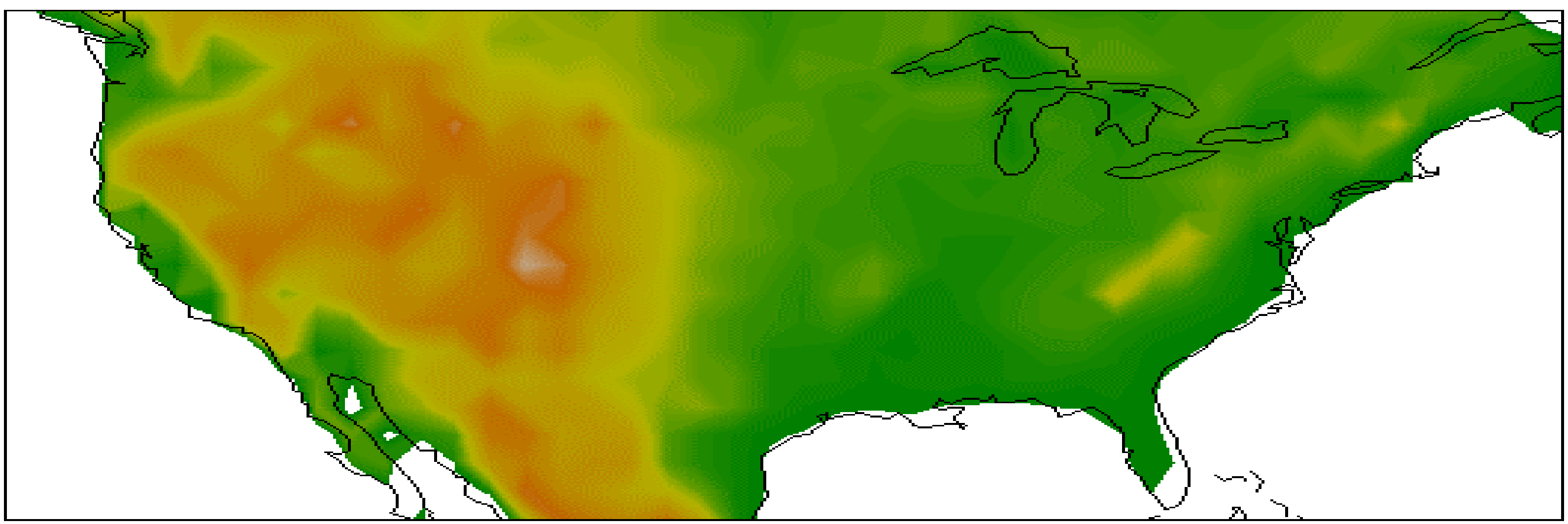
- Testing the effects of weakened thermohaline North Atlantic circulation
- Other simulations expected

Model topography

T42 Resolution



T85 Resolution



Issues

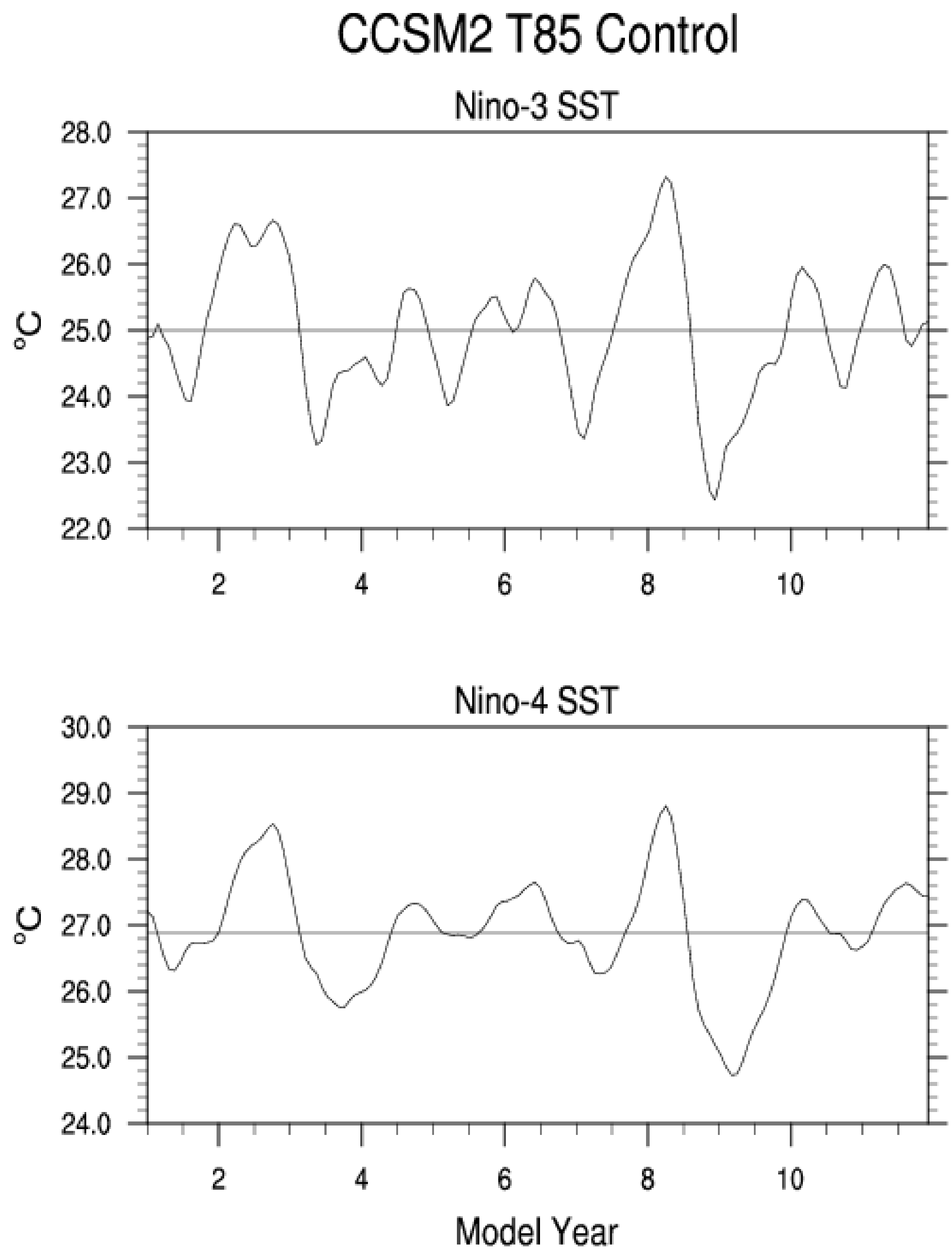
- Need updated climate change scenario forcing: GHGs and sulfur cycle; carbon cycle, land-surface changes (U. of Kansas); volcanic
- Higher resolution for atmospheric component (T85 and T170)
- High computer performance is a very high imperative
- Ensembles are an imperative: Typically 3 to 5
- Continue policy of making simulations openly available soon after completion

CCSM2/CCA Diagnostics

- For quick looks, using component model log files
- Time series of globally-averaged fields
- Generated twice per day
- Can show up to six experiments simultaneously
- Provides instant analysis of model state, and can indicate if the experiment becomes unstable

Recent Highlights

- Currently producing the “first” fully coupled climate simulation using the T85 CAM atmospheric model with CCSM2.0 (all previous simulations have used T42), which will provide more regional climate change detail



CCSM2 T85 Control
Nino-3 SST
28.0
27.0
26.0
25.0
24.0
23.0
22.0
°C
2
4
6
8
10
Nino-4 SST
30.0
29.0
28.0
27.0
26.0
25.0
24.0
°C
2
4
6
8
10
Model Year

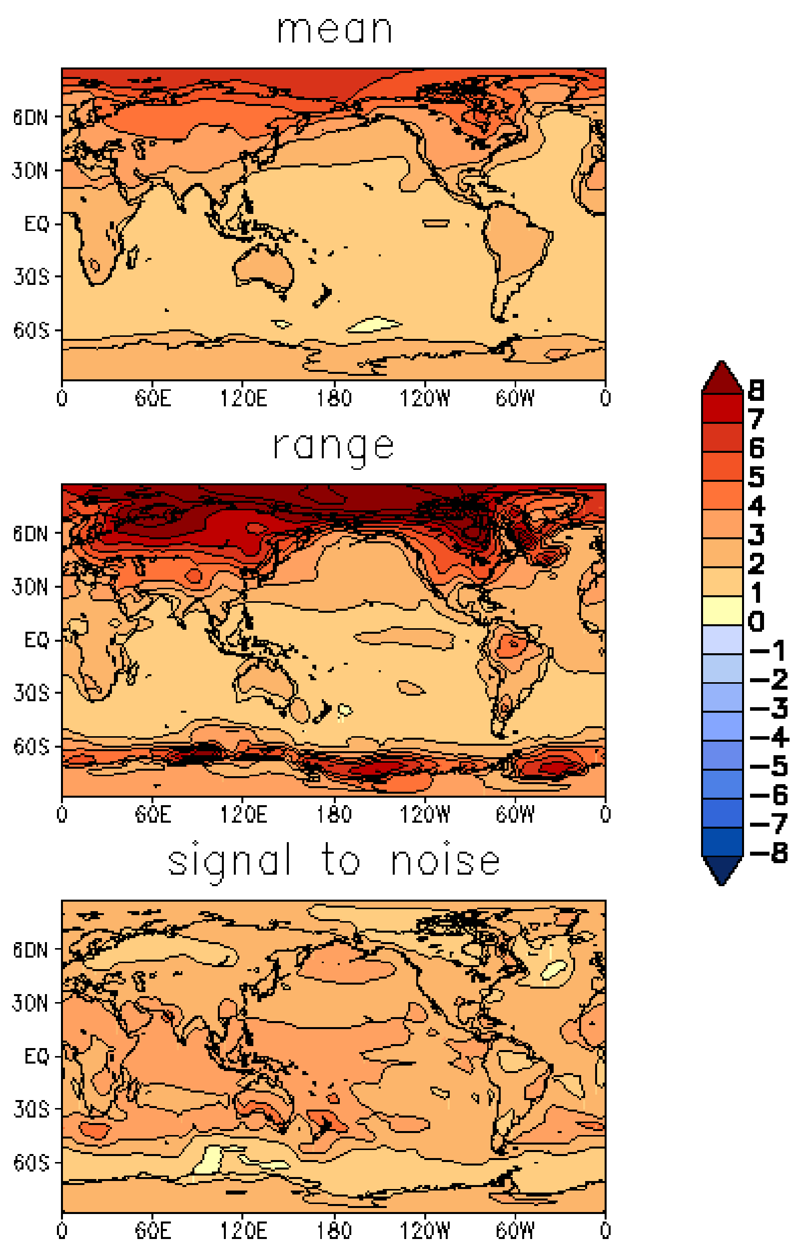
Future Directions (2003)

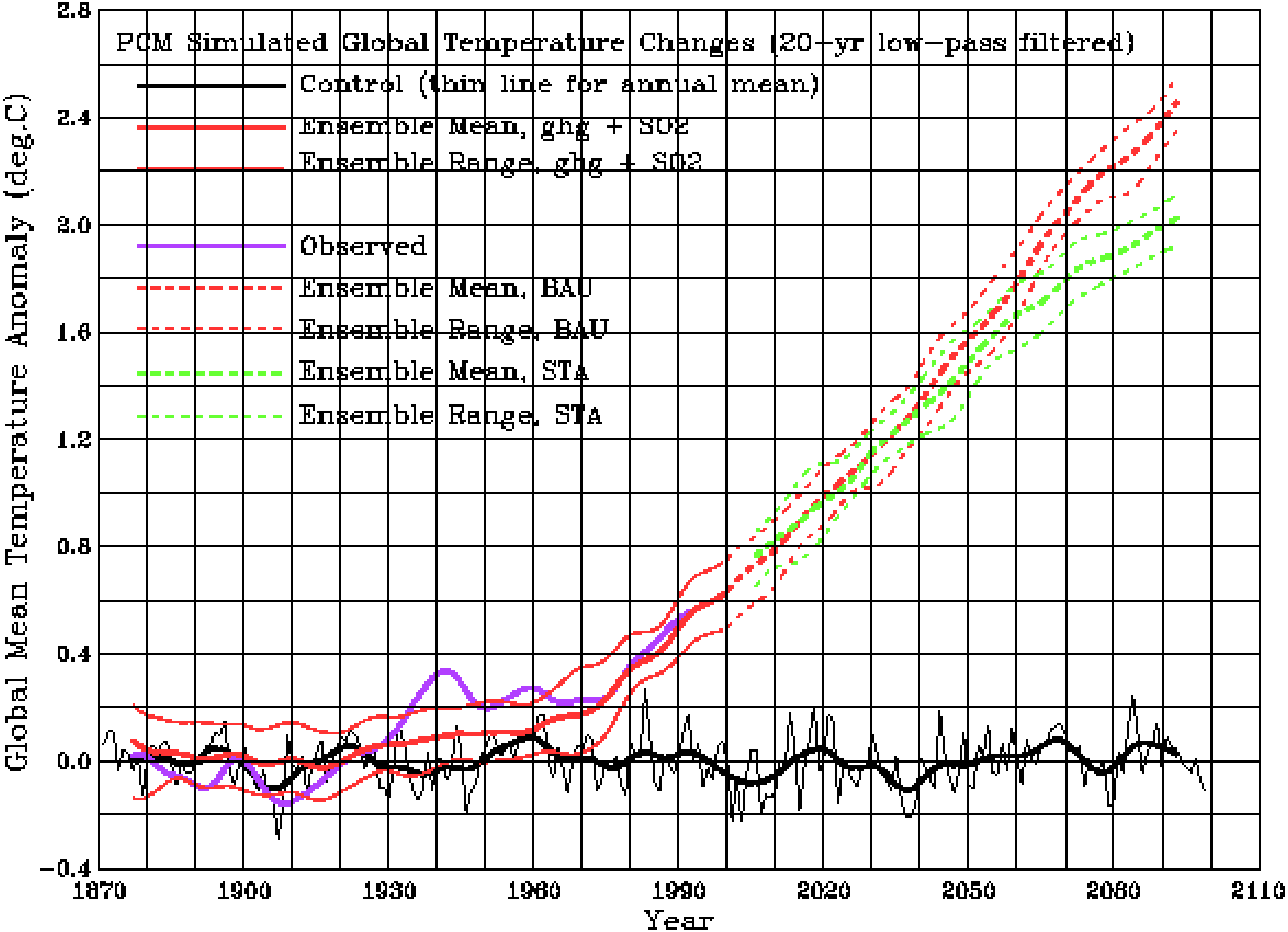
- Use higher CCSM2 atmospheric and ocean/sea ice horizontal model resolution for regional climate change studies
- T42 historical (1870-2100) climate change studies with CCSM2 (sulfur cycle included)
- Use output from July Workshop for the development of future scenarios
- Conduct climate change research on carbon aerosols and land surface changes
- Explore with Biogeochemistry Working Group the carbon cycle

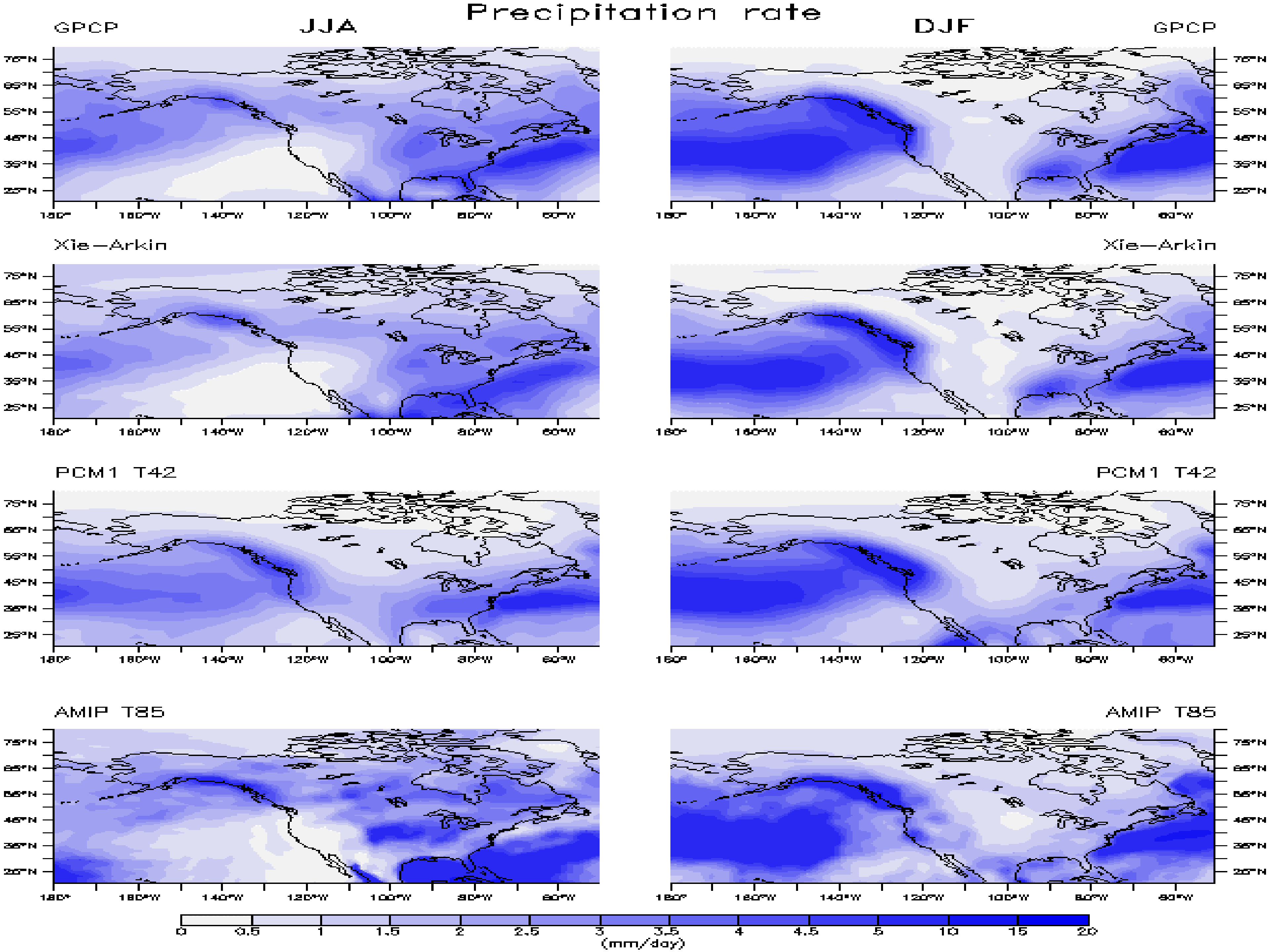
Future Direction (2003-2005)

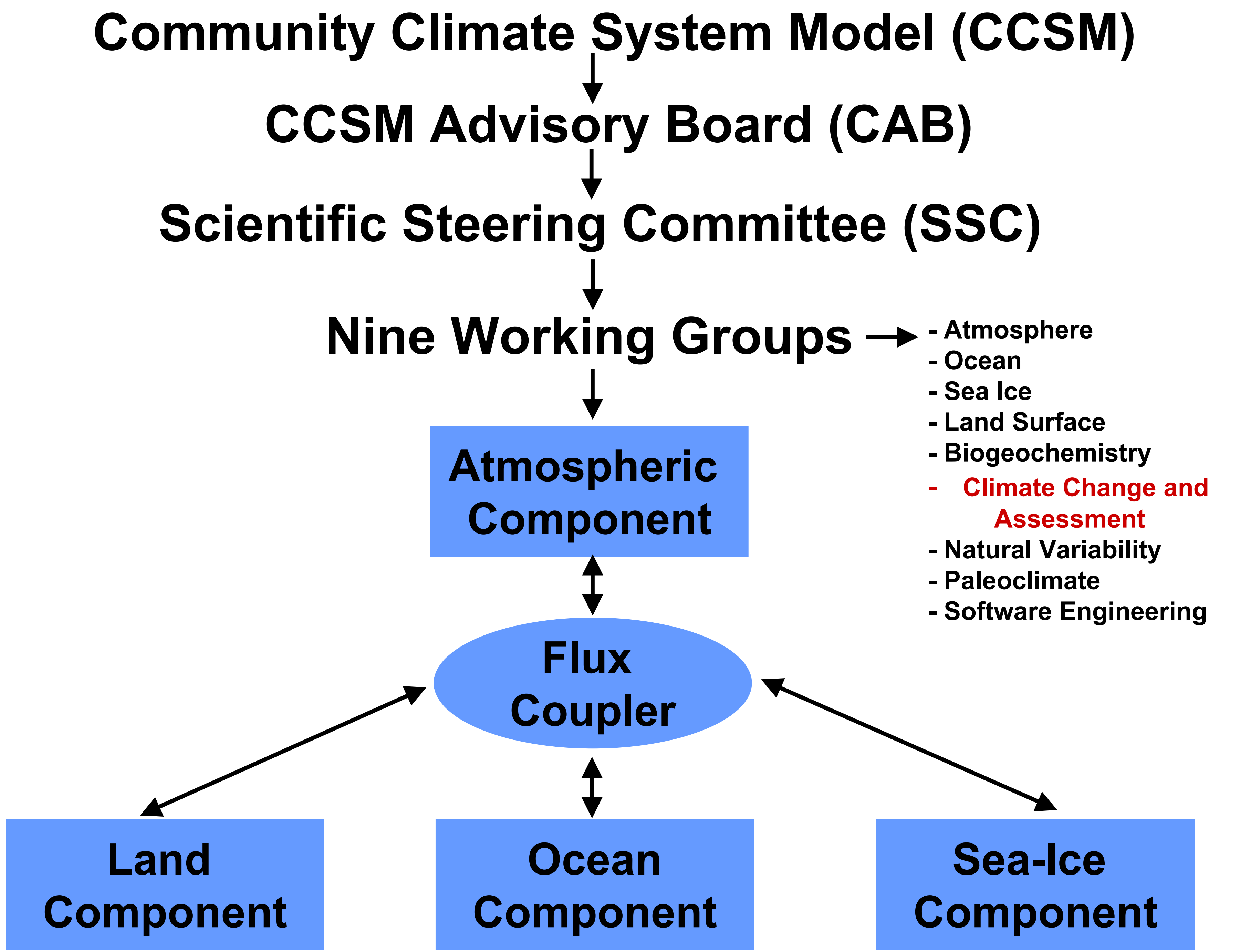
During this time frame it is expected that we will devote much of our resources primarily to IPCC and National Assessments Simulations

IPCC
B2 Scenario




PCM Simulated Global Temperature Changes (20-yr low-pass filtered)
Control (thin line for annual mean)
Ensemble Mean, ghg + SO2
Ensemble Range, ghg + SO2
Observed
Ensemble Mean, BAU
Ensemble Range, BAU
Ensemble Mean, STA
Ensemble Range, STA
Global Mean Temperature Anomaly (deg.C)
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
1870
1900
1930
1960
1990
2020
2050
2080
2110
Year


Precipitation rate
JJA
DJF
GPCP
GPCP
Xie−Arkin
Xie−Arkin
PCM1 T42
PCM1 T42
AMIP T85
AMIP T85
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
10
15
20
(mm/day)

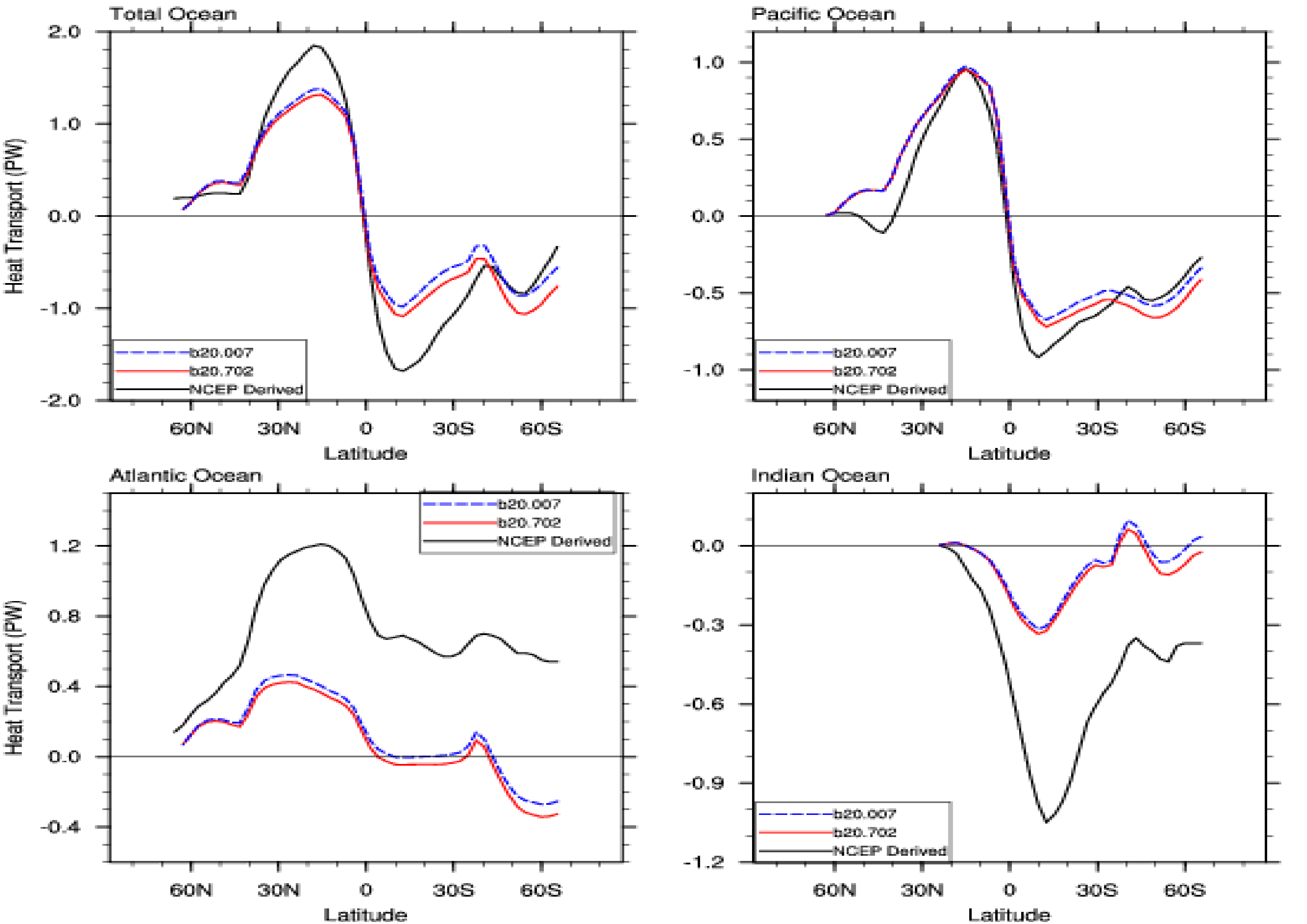

Community Climate System Model (CCSM)
CCSM Advisory Board (CAB)
Scientific Steering Committee (SSC)
Nine Working Groups
- Atmosphere
- Ocean
- Sea Ice
- Land Surface
- Biogeochemistry
- Climate Change and Assessment
- Natural Variability
- Paleoclimate
- Software Engineering
Atmospheric Component
Flux Coupler
Land Component
Ocean Component
Sea-Ice Component

Recent Highlights

- Completed an ensemble of simulations of the global climate during the period 1870-2000 using observed sources of external forcing, including anthropogenic greenhouse gas and sulfate aerosol increases, solar variability and changes in volcanic aerosol input.

- Completed a set of three future (21st century) business-as-usual climate simulations, with high frequency data saves. These climate projections were then used as forcing to a regional climate model to examine potential changes in the water supply to the northwest United States during the next century.

Annual Implied Northward Ocean Heat Transport



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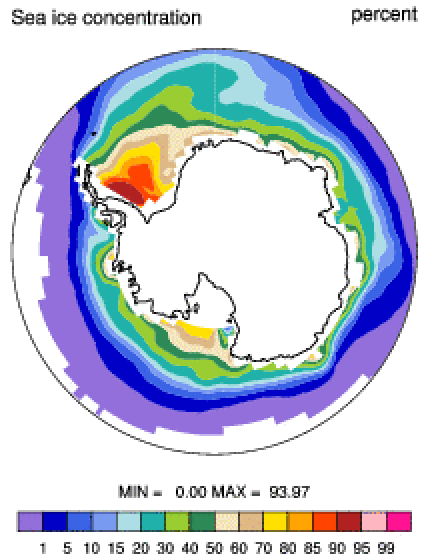
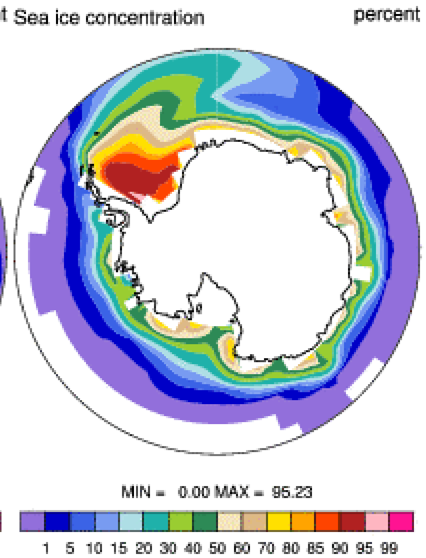
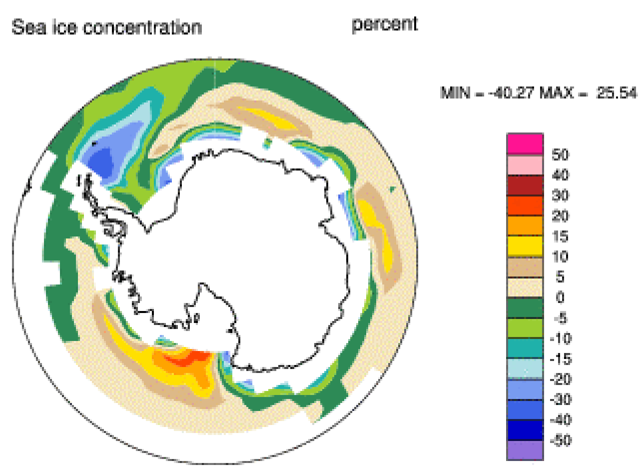
DJF

b20.704 (yrs 3-10) **b20.007 (yrs 561-580)**





b20.704 - b20.007



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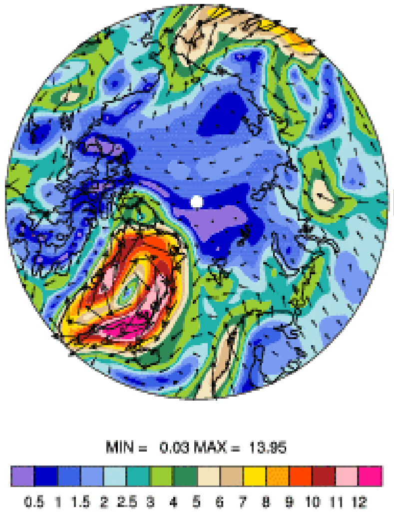
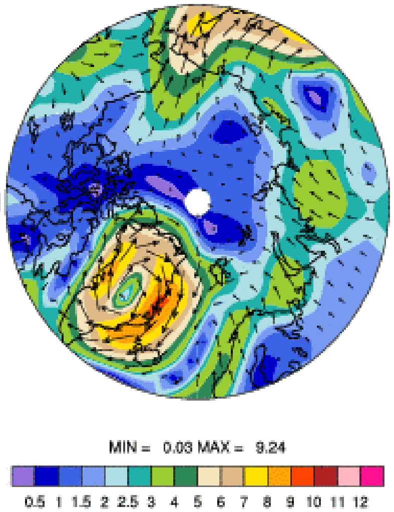
DJF

b20.704 (yrs 3-10) **b20.007 (yrs 561-580)**

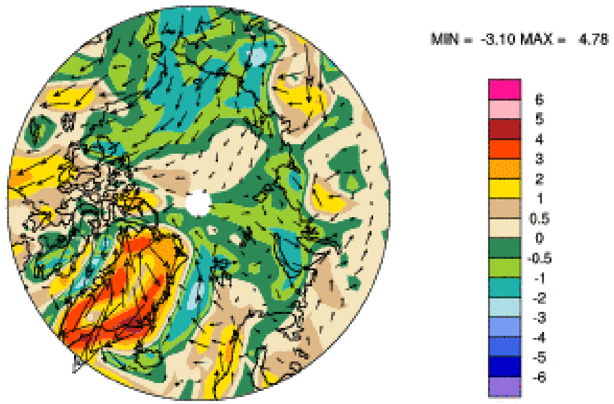
Near surface wind m/s Near surface wind m/s





b20.704 - b20.007

Near surface wind m/s



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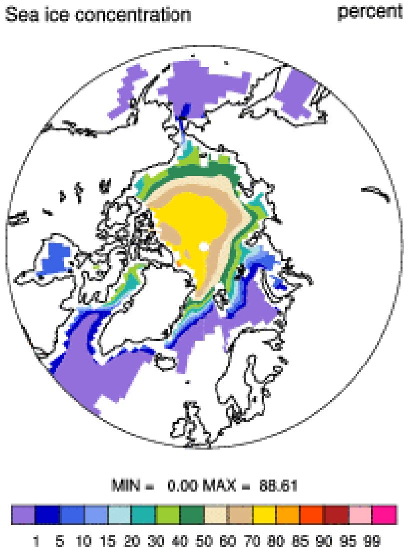
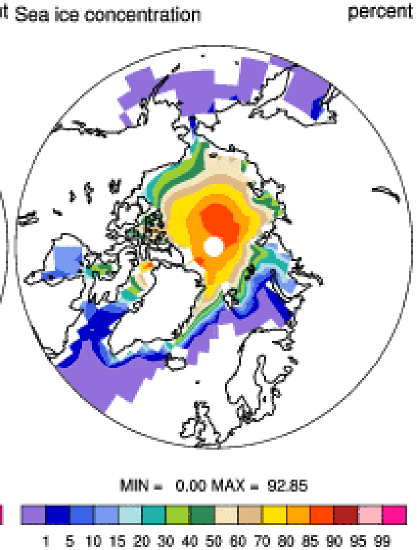
JJA

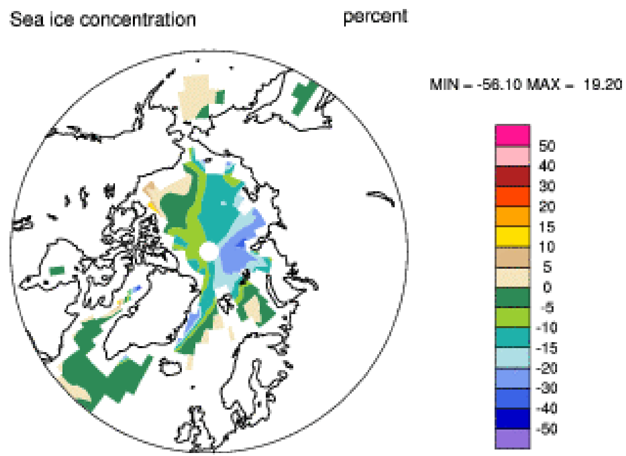
b20.704 (yrs 3-10)



b20.007 (yrs 561-580)



b20.704 - b20.007



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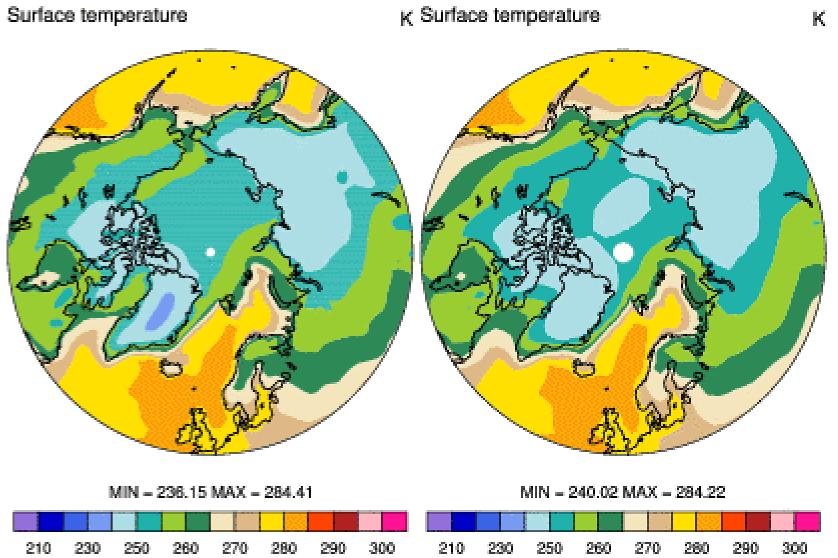
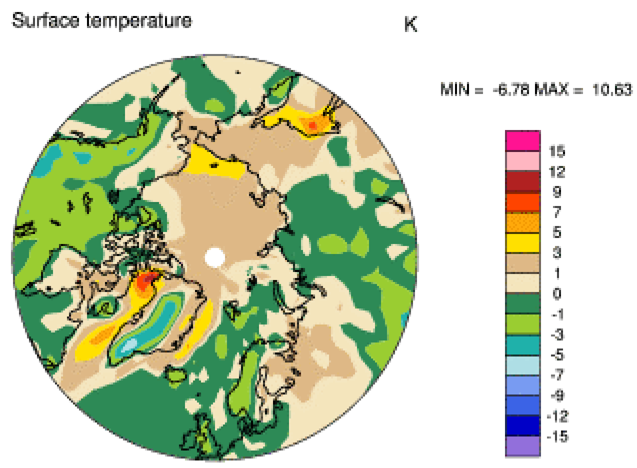
DIAG Version: 020522

DJF

b20.704 (yrs 3-10) **b20.007 (yrs 561-580)**



b20.704 - b20.007



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