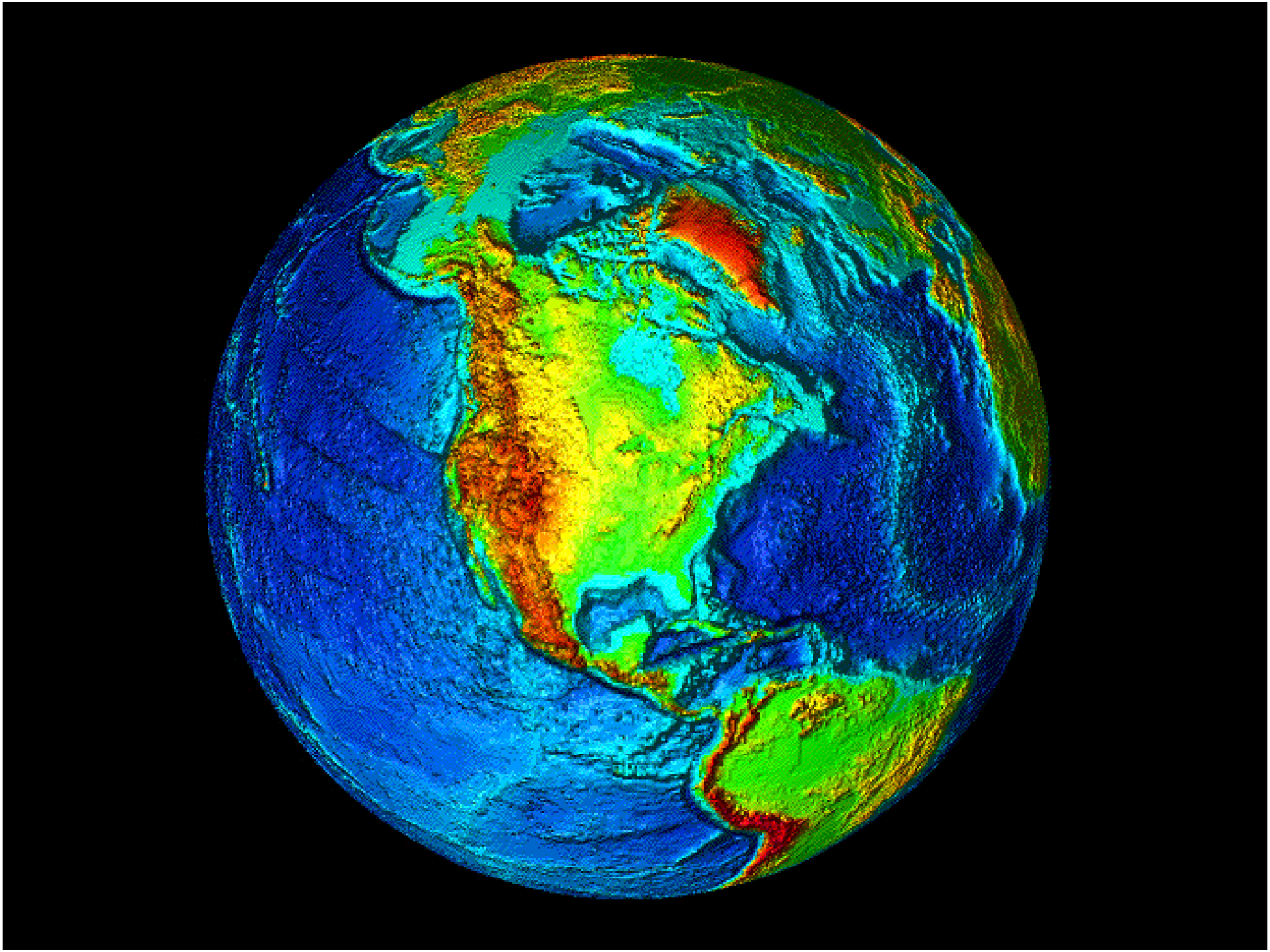
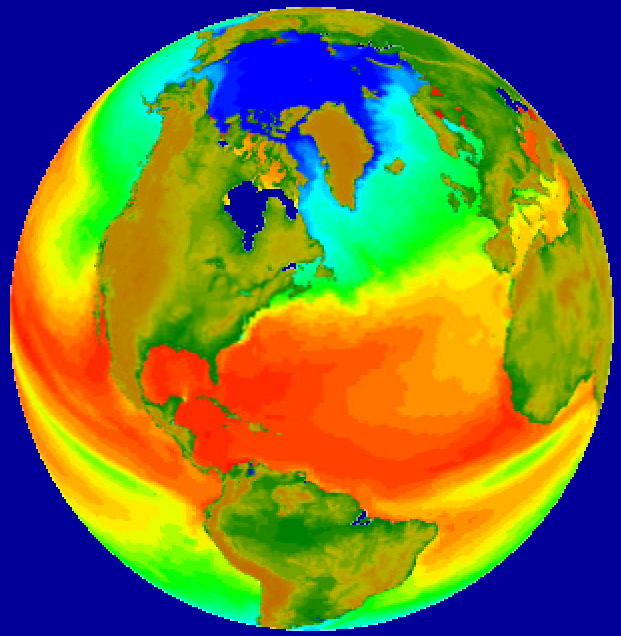
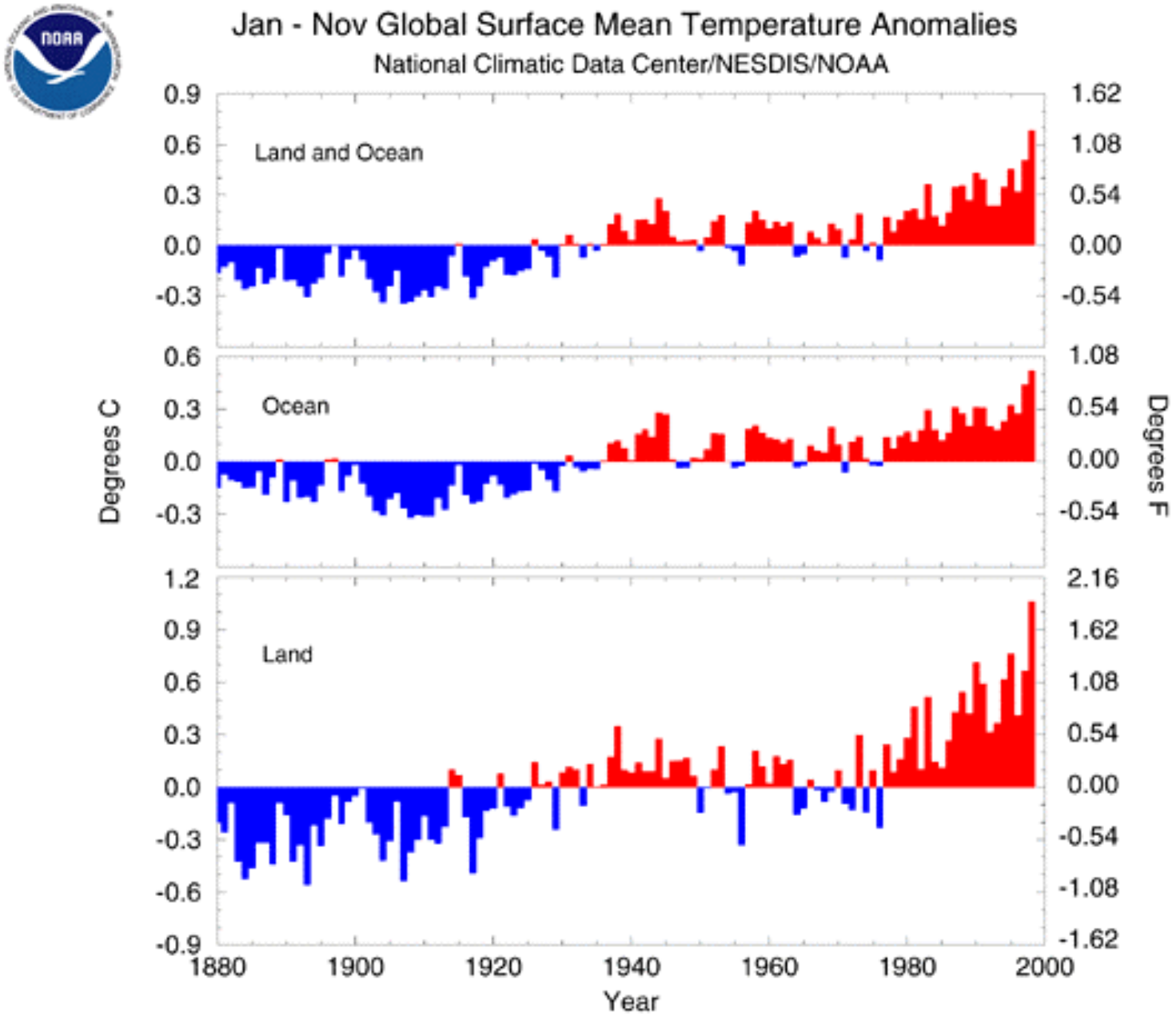
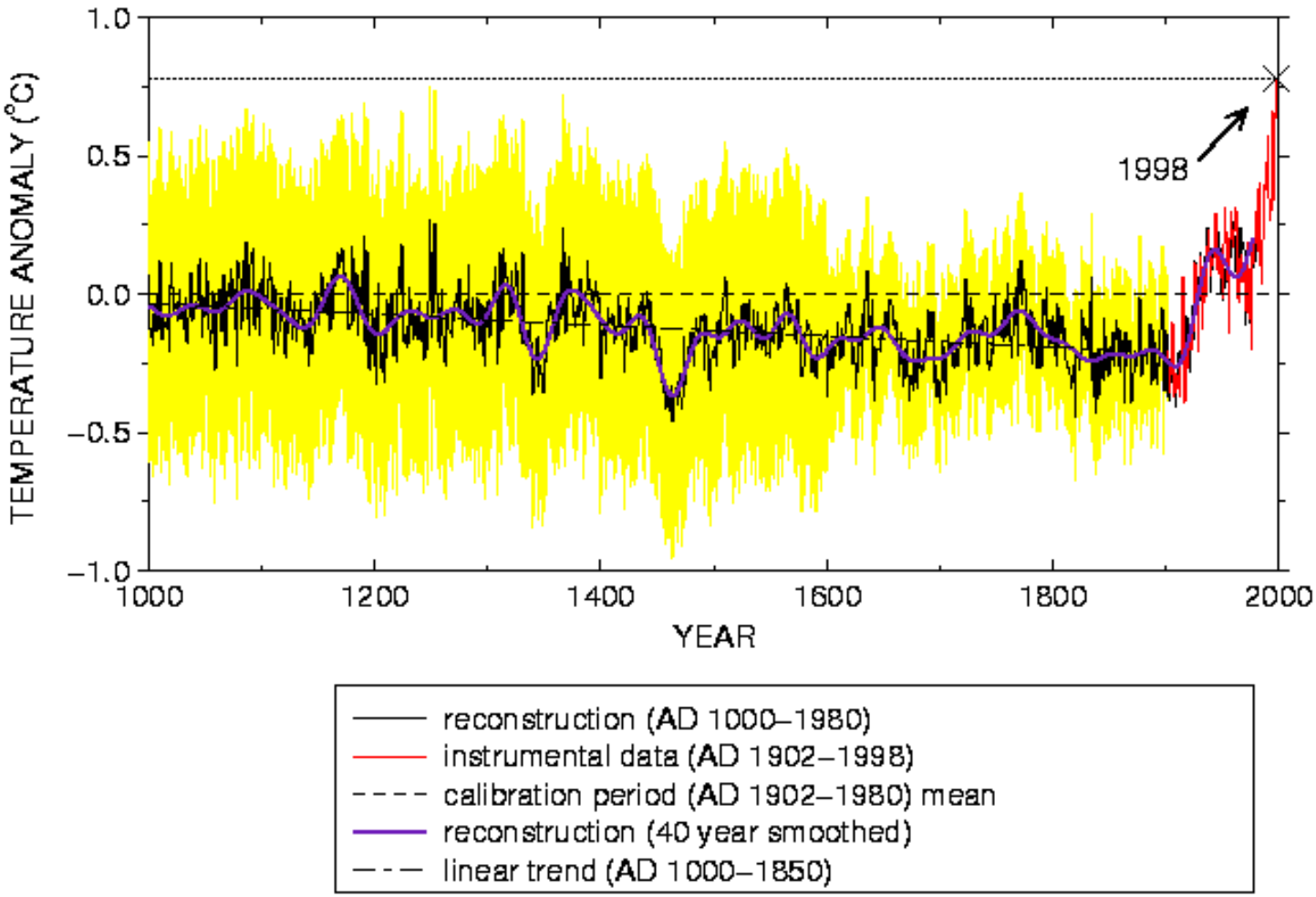


Global Climate Modeling

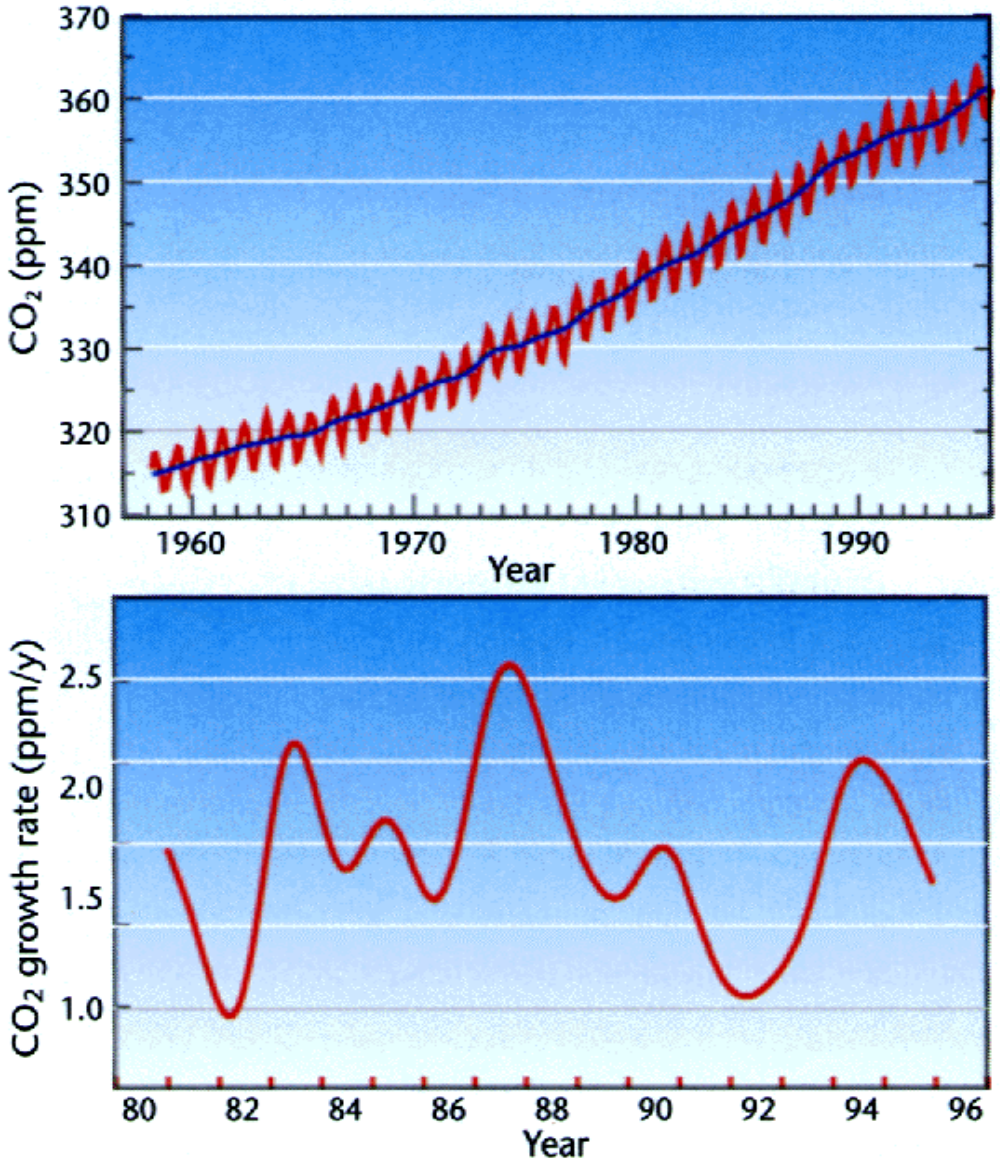
Warren M. Washington
NCAR
April 2000




Jan - Nov Global Surface Mean Temperature Anomalies
National Climatic Data Center/NESDIS/NOAA
Land and Ocean
Ocean
Land
Degrees C
Degrees F
Year
0.9
0.6
0.3
0.0
-0.3
1.62
1.08
0.54
0.00
-0.54
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
2.16
1.62
1.08
0.54
0.00
-0.54
-1.08
-1.62
1880
1900
1920
1940
1960
1980
2000

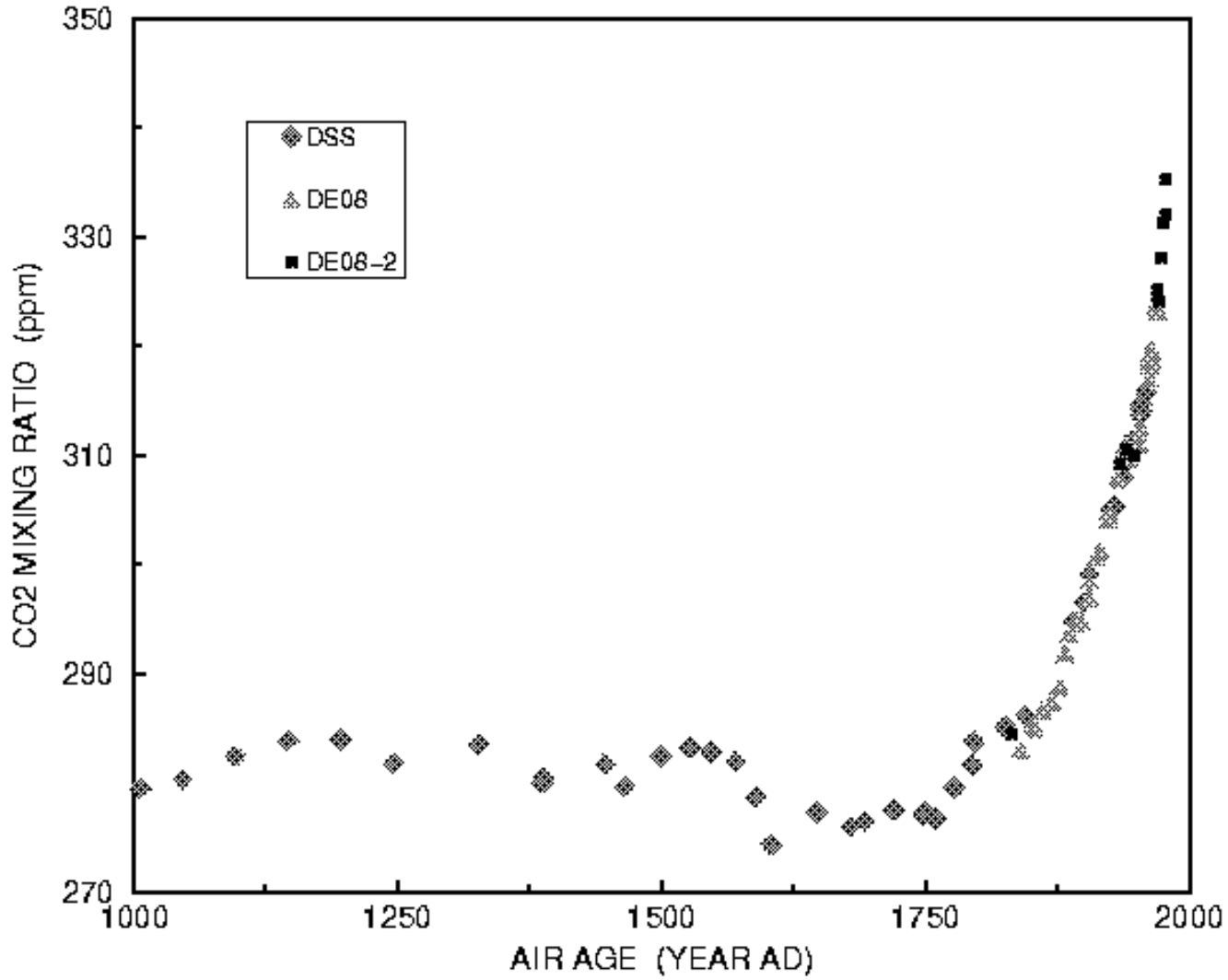

1.0
0.5
0.0
−0.5
−1.0
TEMPERATURE ANOMALY (°C)
1000
1200
1400
1600
1800
2000
YEAR
1998
reconstruction (AD 1000–1980)
instrumental data (AD 1902–1998)
calibration period (AD 1902–1980) mean
reconstruction (40 year smoothed)
linear trend (AD 1000–1850)

Global CO_2 Trend and Rate of Increase

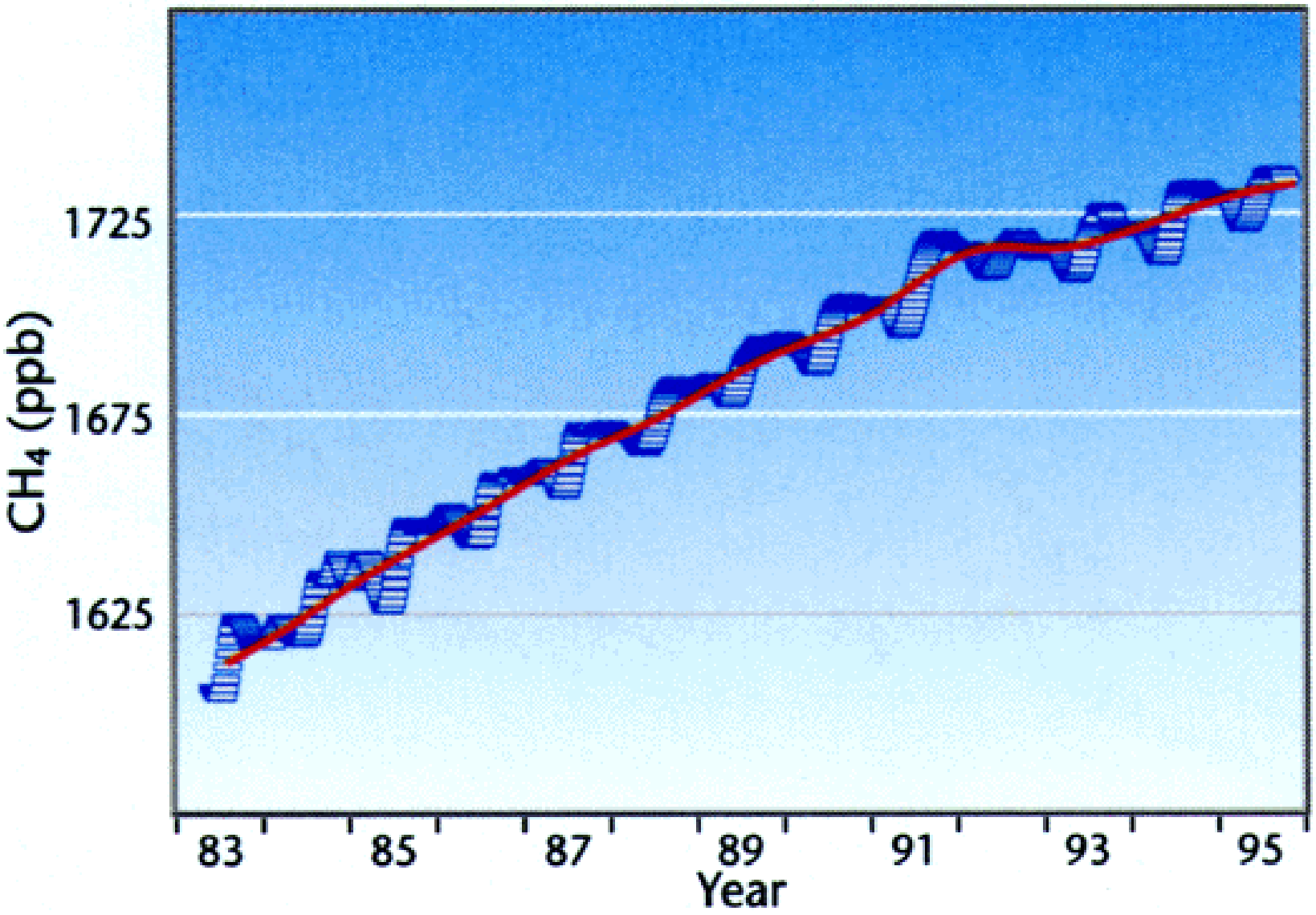


LAW DOME, ANTARCTICA ICE CORES

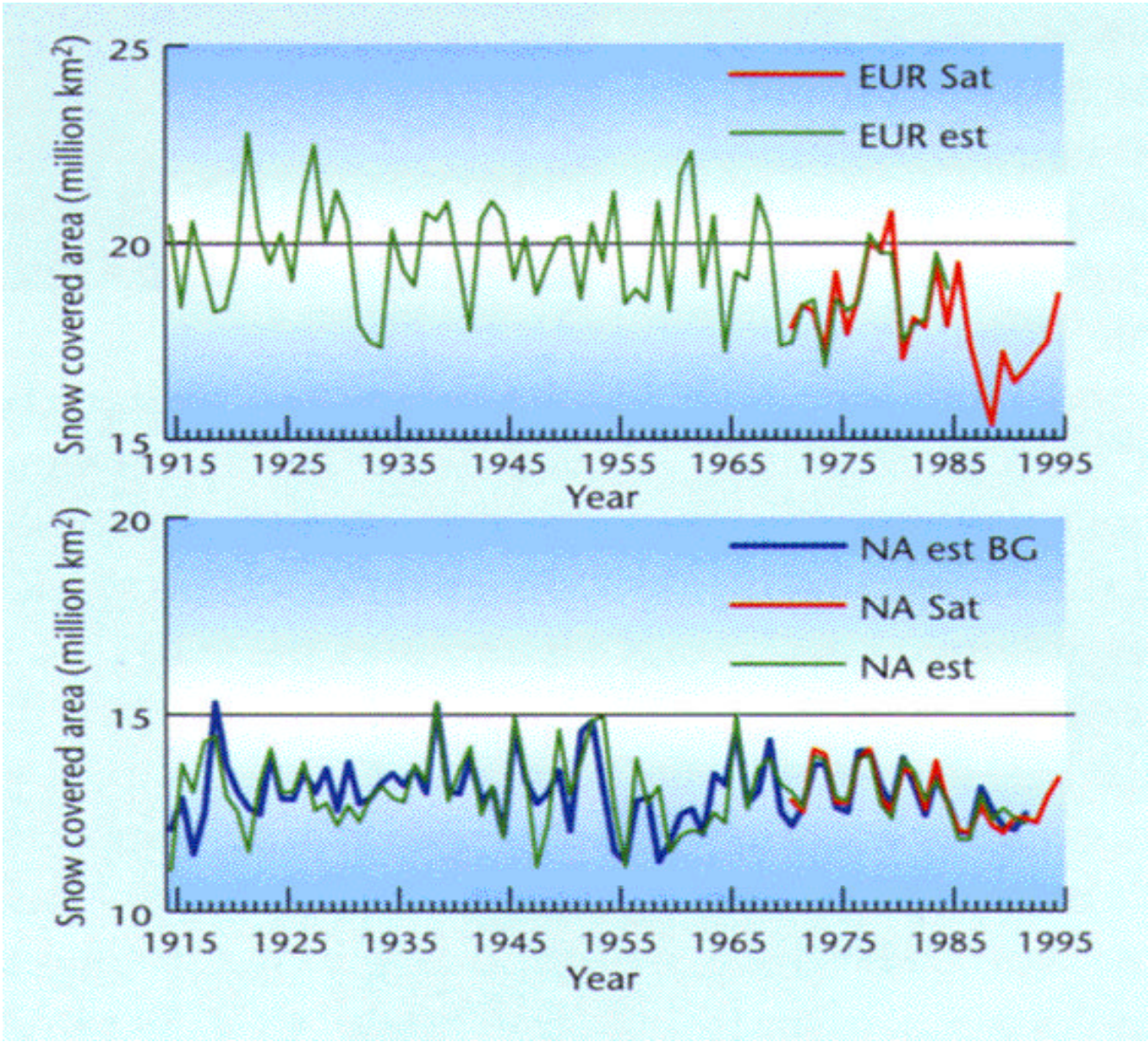
Source: Etheridge et al. (CSIRO)



Global Methane Trends



Snow Cover Trends



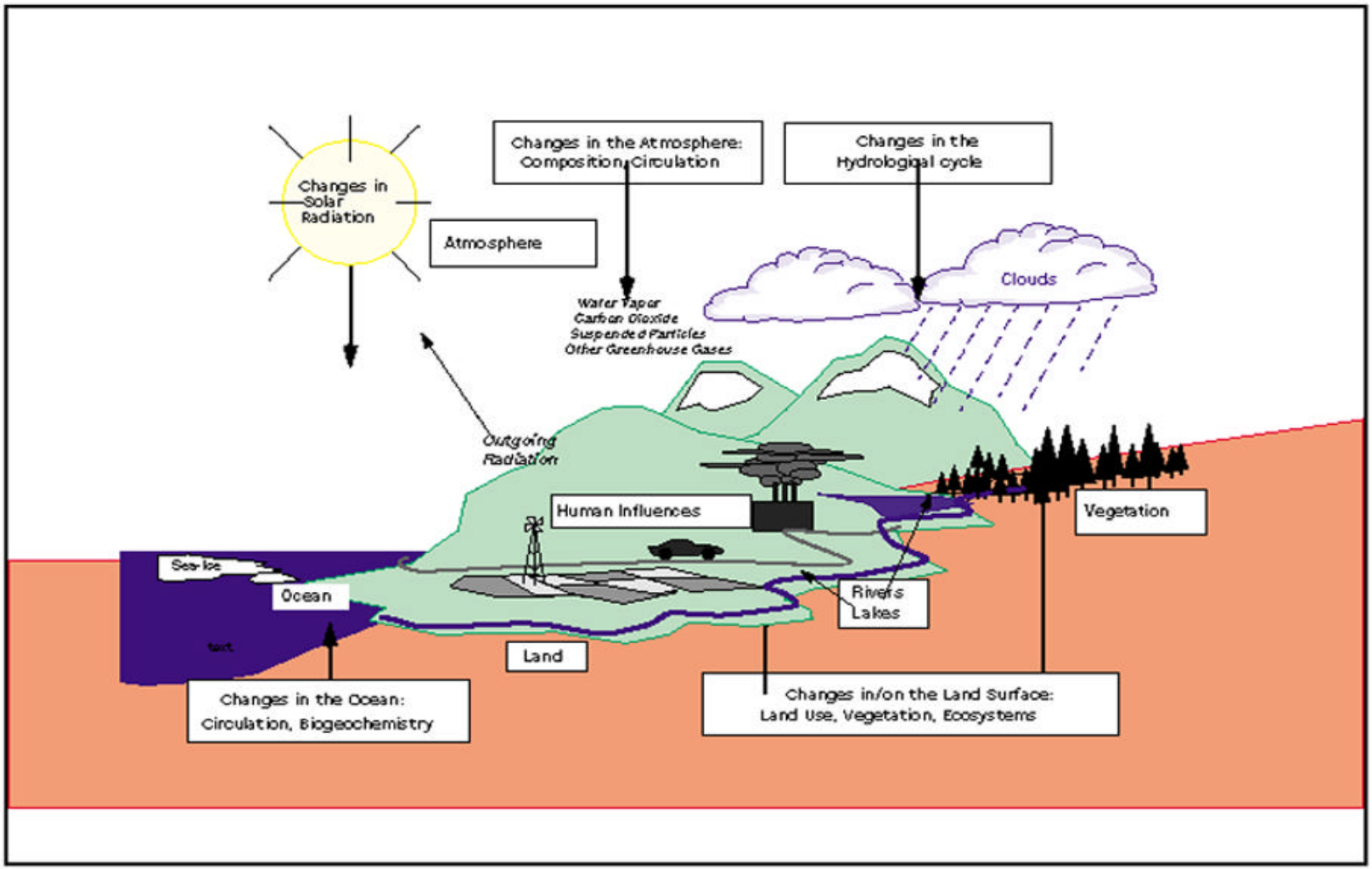
Greenland Ice Thinning

- Melting in low-lying areas is very rapid at about 3 feet per year….Science Magazine
- Most melting on the southern and eastern parts of Greenland
- Snowfall not changed much…..it is the glaciers moving faster and melting

Expected Changes in the Earth's Chemistry

- Increased carbon dioxide, methane, nitrogen oxide, lower atmosphere ozone
- Decreased CFCs
- Increased aerosols from fossil fuel combustion, biomass burning

Parallel Climate Model (PCM)


Changes in Solar Radiation
Changes in the Atmosphere: Composition, Circulation
Changes in the Hydrological cycle
Atmosphere
Clouds
Water Vapor
Carbon Dioxide
Suspended Particles
Other Greenhouse Gases
Outgoing Radiation
Human Influences
Vegetation
Sea-Ice
Ocean
Rivers
Lakes
Land
Changes in the Ocean: Circulation, Biogeochemistry
Changes in/on the Land Surface: Land Use, Vegetation, Ecosystems

Laws of Physics in Climate Models

- Conservation of Momentum
- First Law of Thermodynamics
- Conservation of Mass
- Ideal Gas Law
- Hydrostatic Assumption
- Conservation of Water (Vapor and Liquid)
- Some models have active atmospheric chemistry and aerosol physics

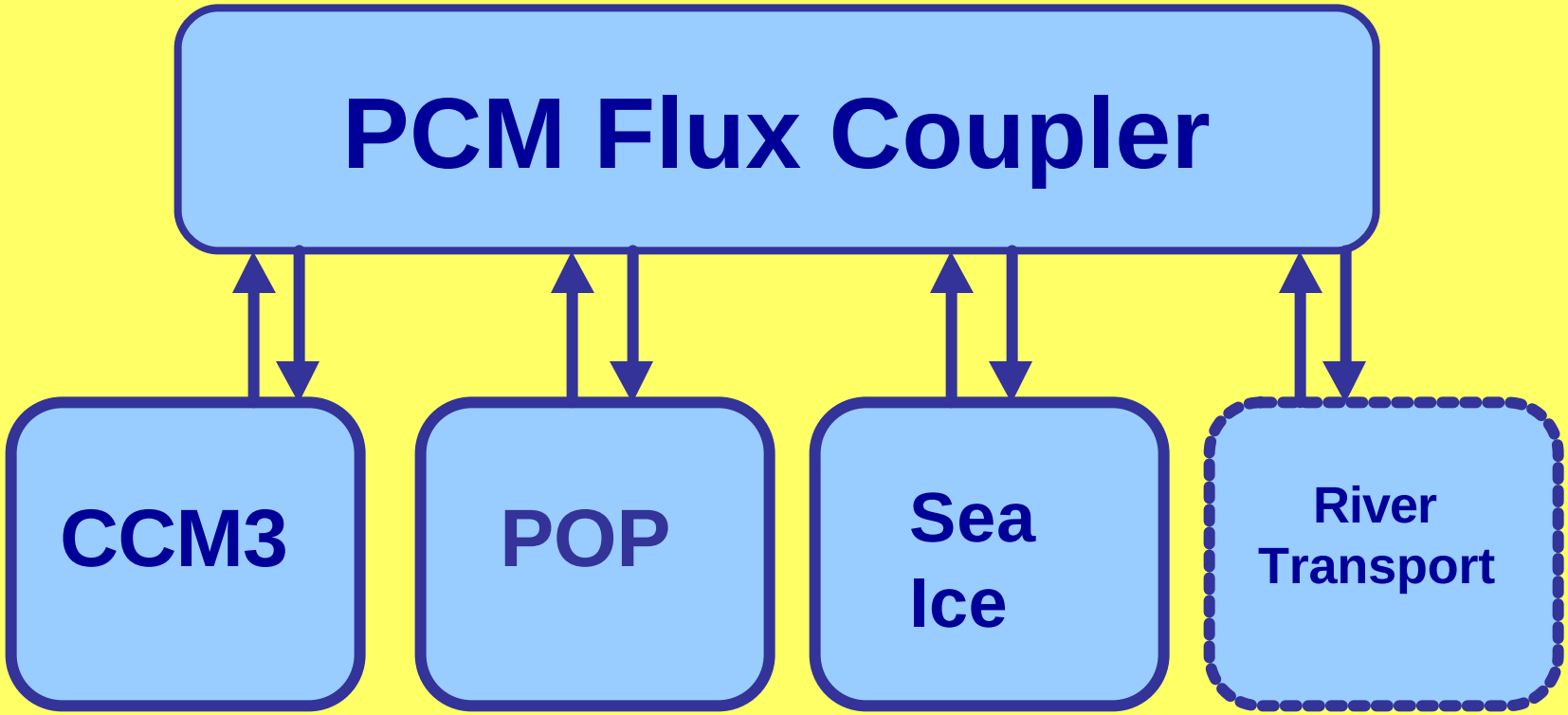
PCM Component Models

- Atmosphere
  - NCAR CCM3.2
  - T42 18 levels
  - land surface model embedded
  - SPMD option: 1-D data decomposition (64pe limit)
- Ocean
  - Parallel Ocean Program (POP)
  - ~2/3 degree horizontal displaced polar grid
  - 32 levels
  - 2-D data decomposition

More Components

- Sea ice-viscous-plastic Hibler dynamics with relaxation, option for elastic-viscous-plastic, 27 km resolution, and Parkinson-Washington thermodynamics (Zhang, Semtner-NPS; Weatherly-CRREL; Craig-NCAR; Hunke, Dukowicz-LANL)
- Parallel flux coupler (Craig, Bettge, Loft, Dennis, James-NCAR; Jones-LANL)
- River Transport Model (Branstetter, Famiglietti-U. Texas, Austin; Craig-NCAR)

Sequential Execution of PCM



Parallel Computers

PCM 1.1

2/3º POP

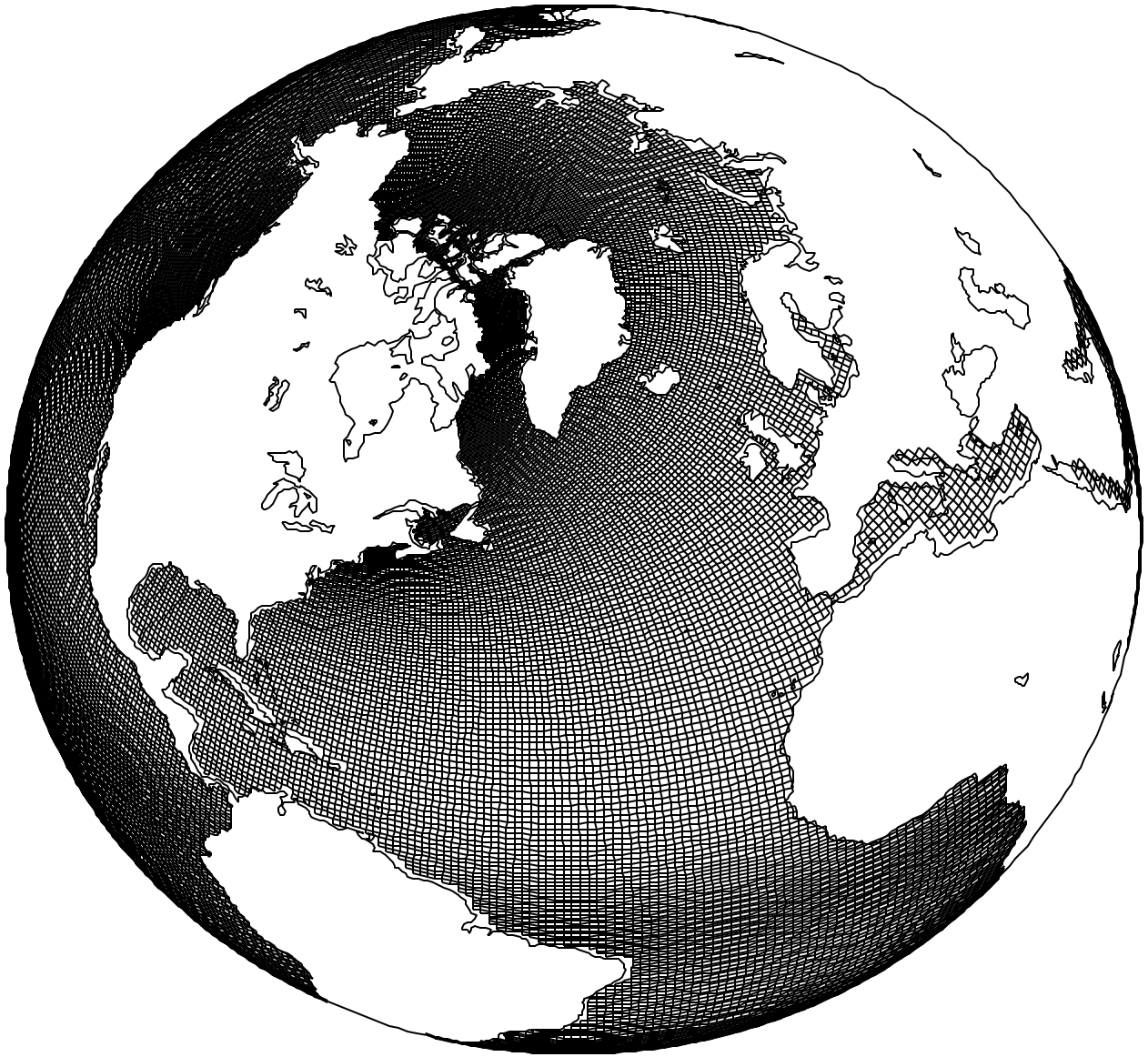
27 km sea ice

T42 CCM3.2

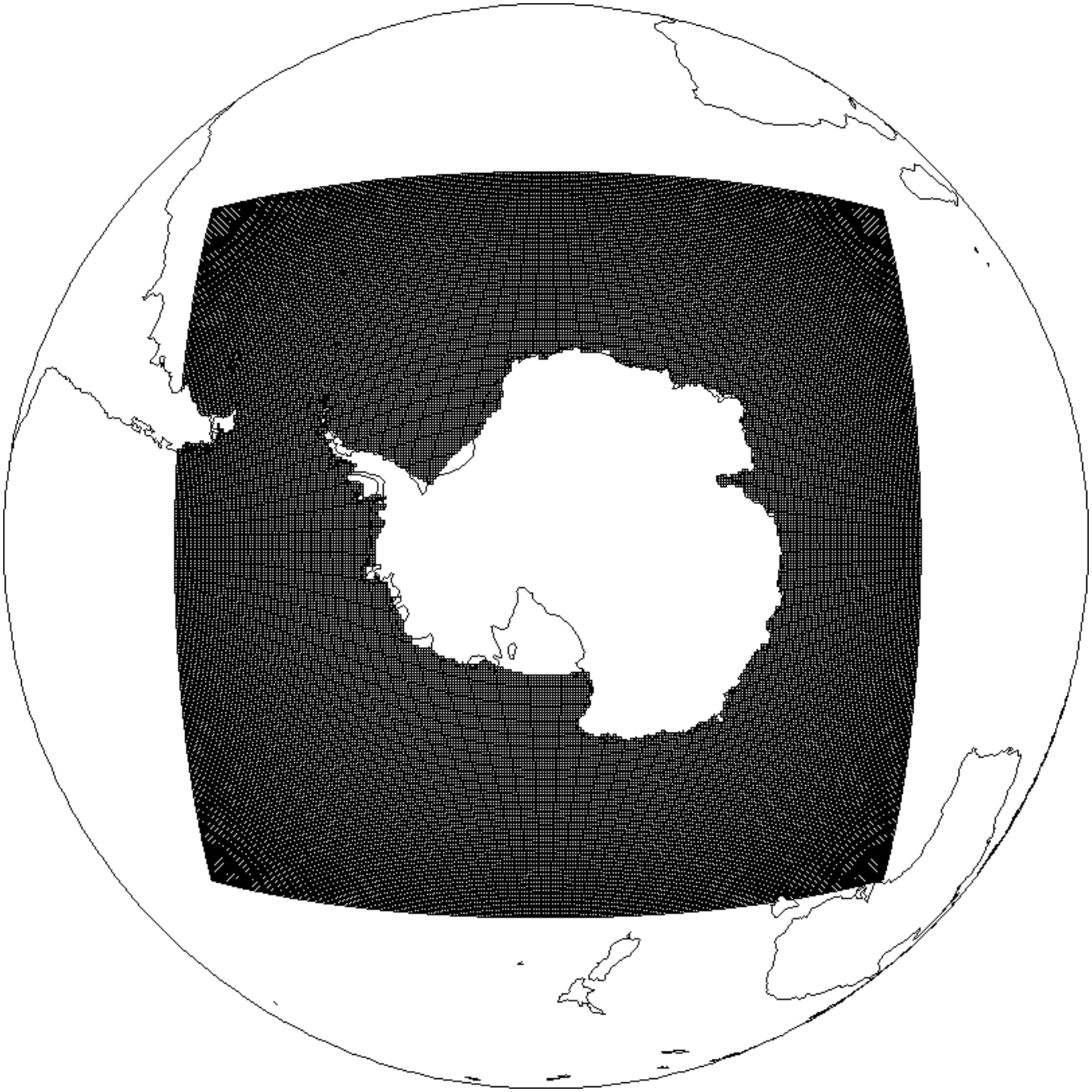
PCM 1.1 has been run on the following distributed and shared memory systems:

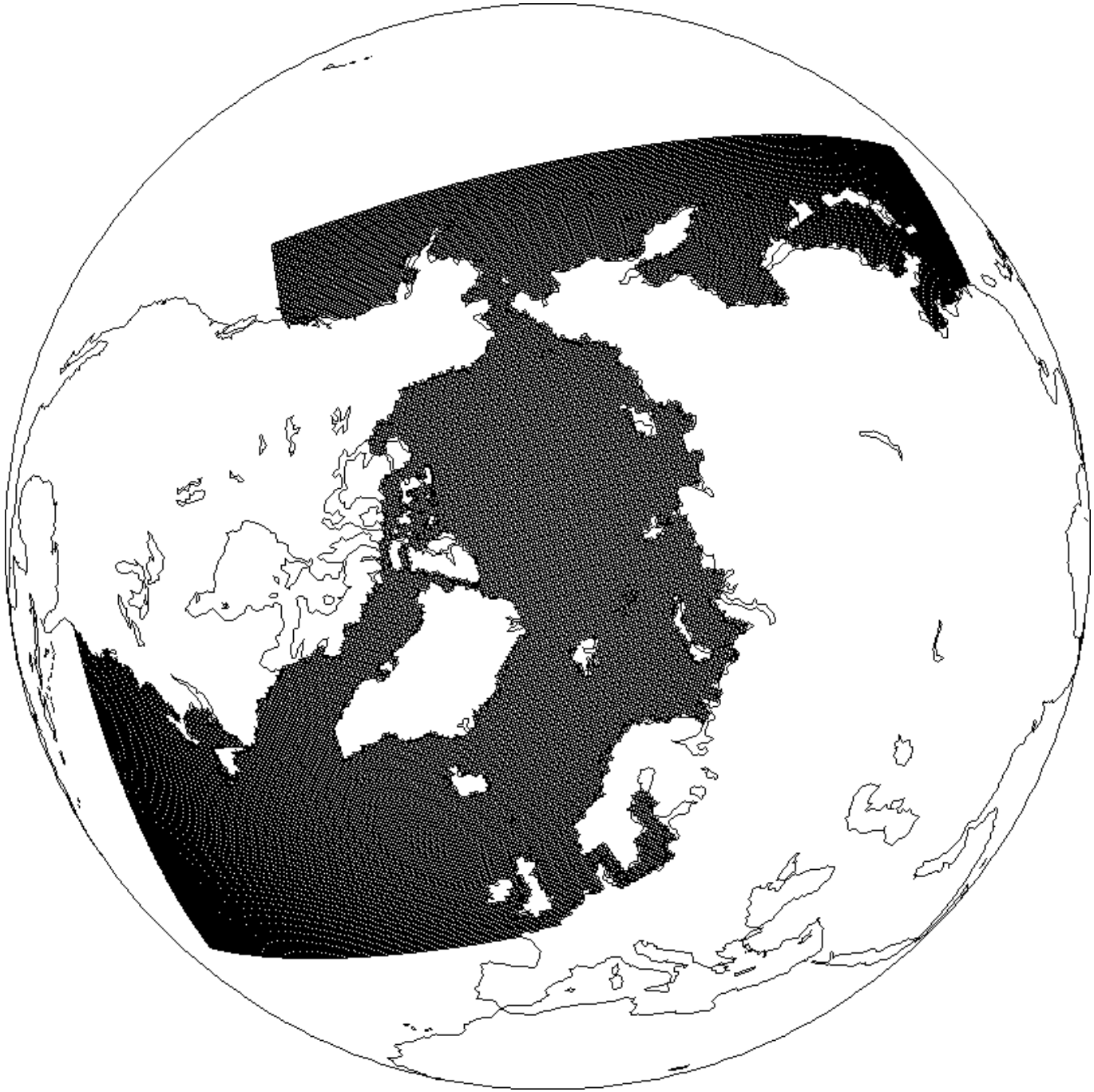
- CRAY T3E900
- SGI Origin 2000/128
- HP SPP2000
- IBM SP2
- Sun Starfire
- DEC/Compaq Alpha Cluster
- Linux Cluster

View of the Parallel Ocean Program (POP) Model Horizontal Grid at 2/3º Resolution



Note high resolution in North Atlantic and near equator.

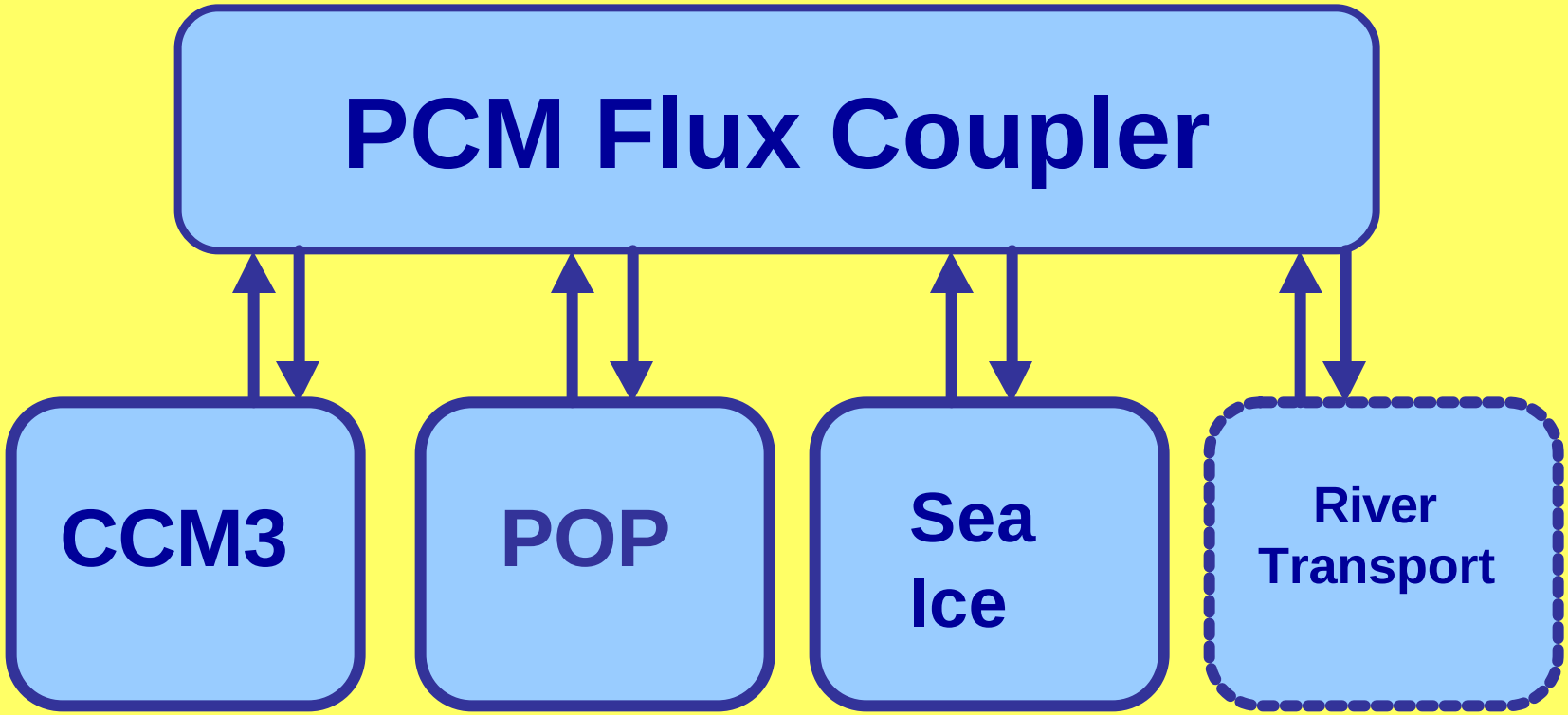




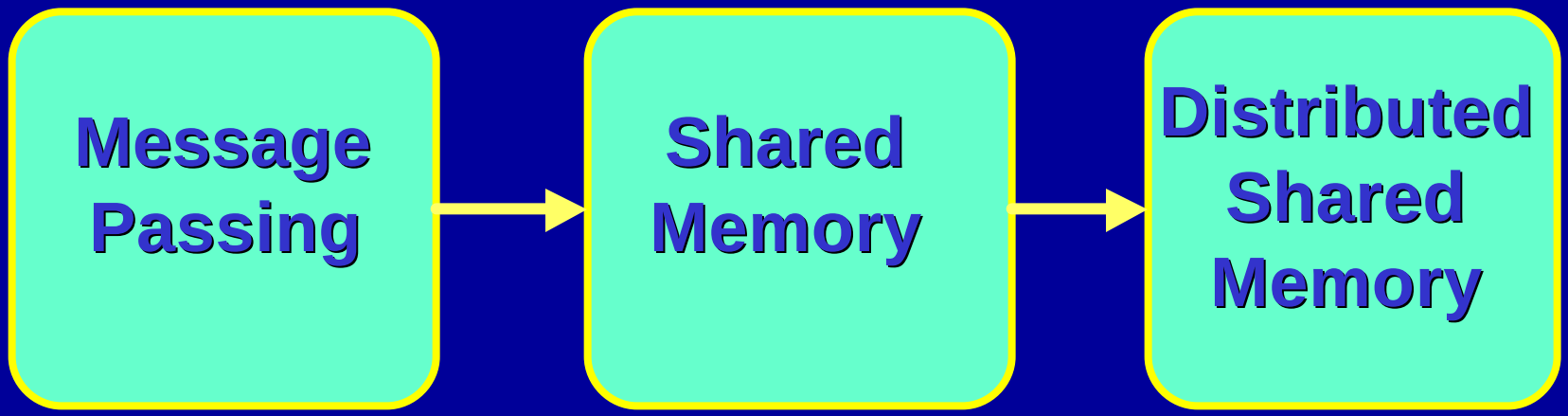
Numerical Methods

- Atmosphere- spherical harmonics, FFT,FD, Lagrangian, semi-implicit
- Ocean-FD, solution of Laplacian equation, semi-implicit
- Sea Ice-FD

Sequential Execution of PCM



Moving from Message Paradigm to Distributed Shared Memory Paradigm

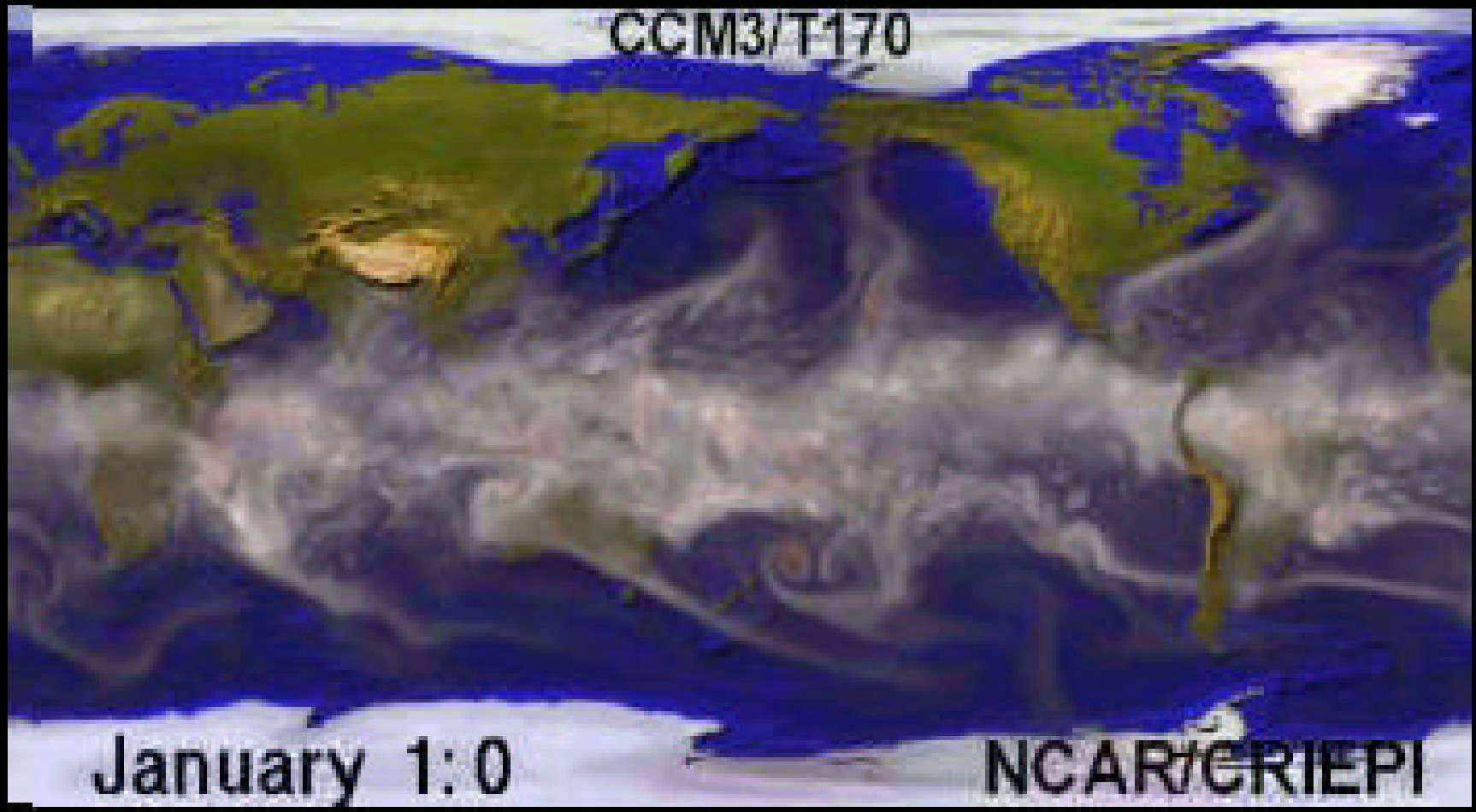


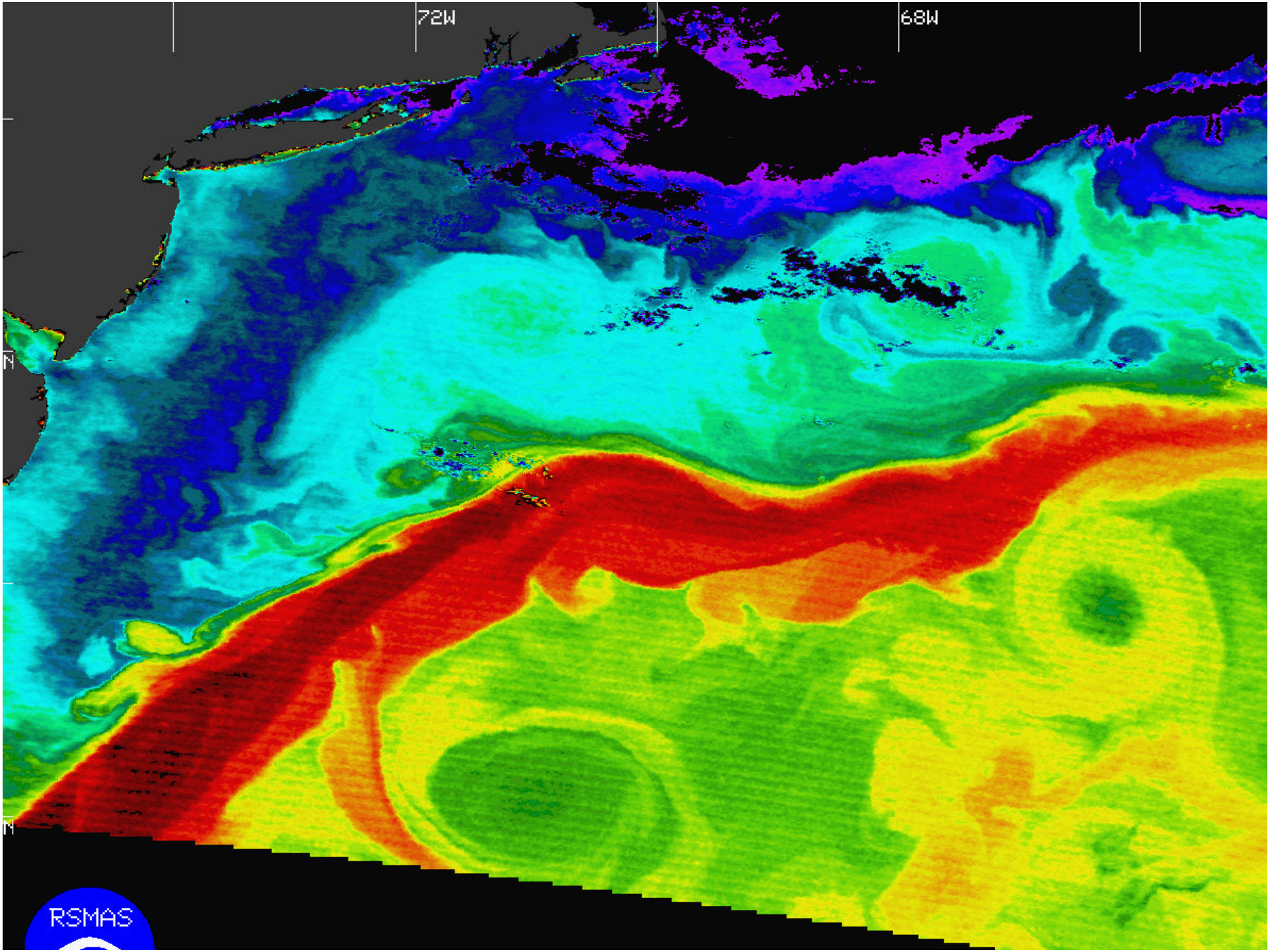
MPI Communication between PEs

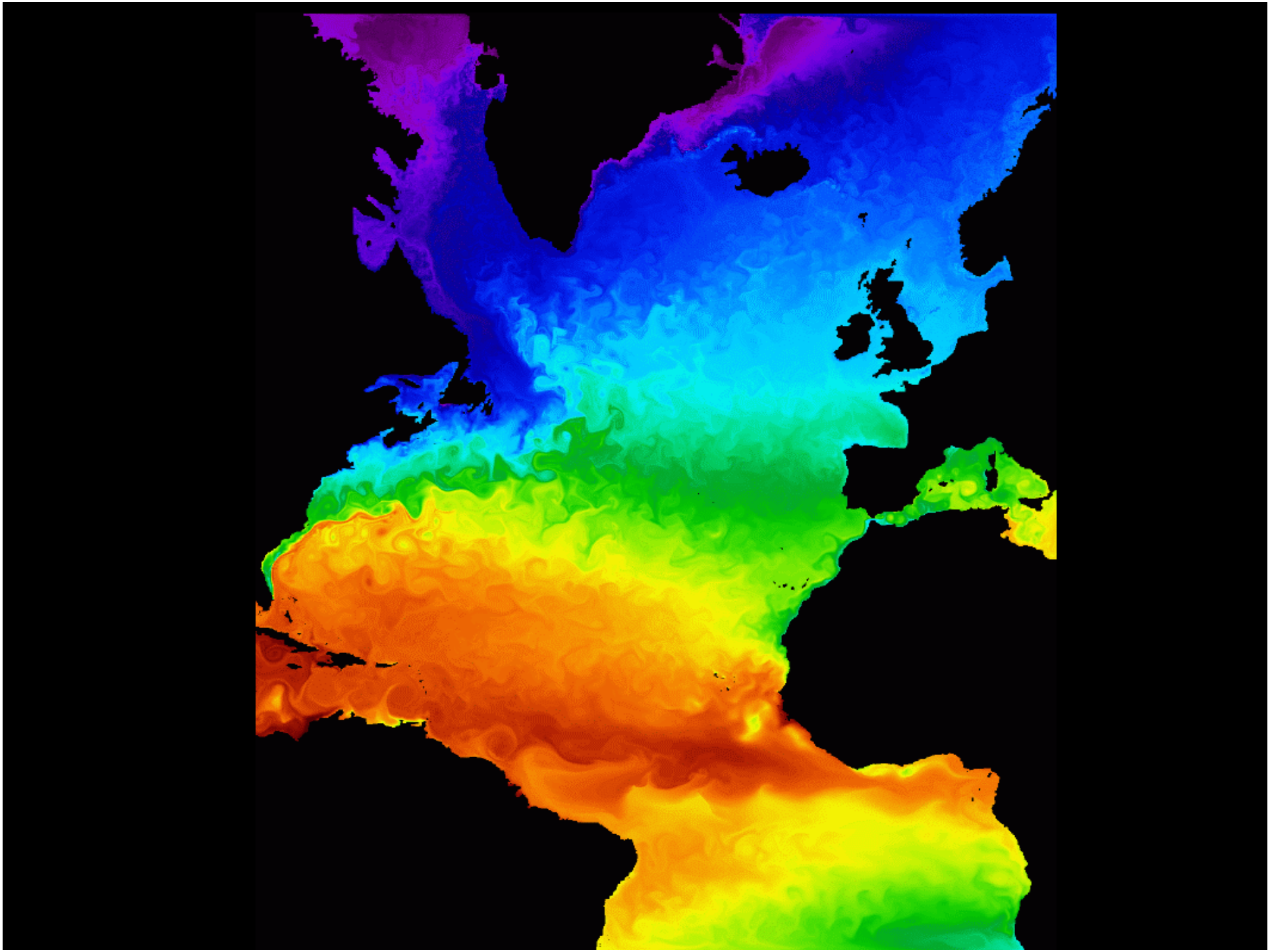
Open MP directives within node

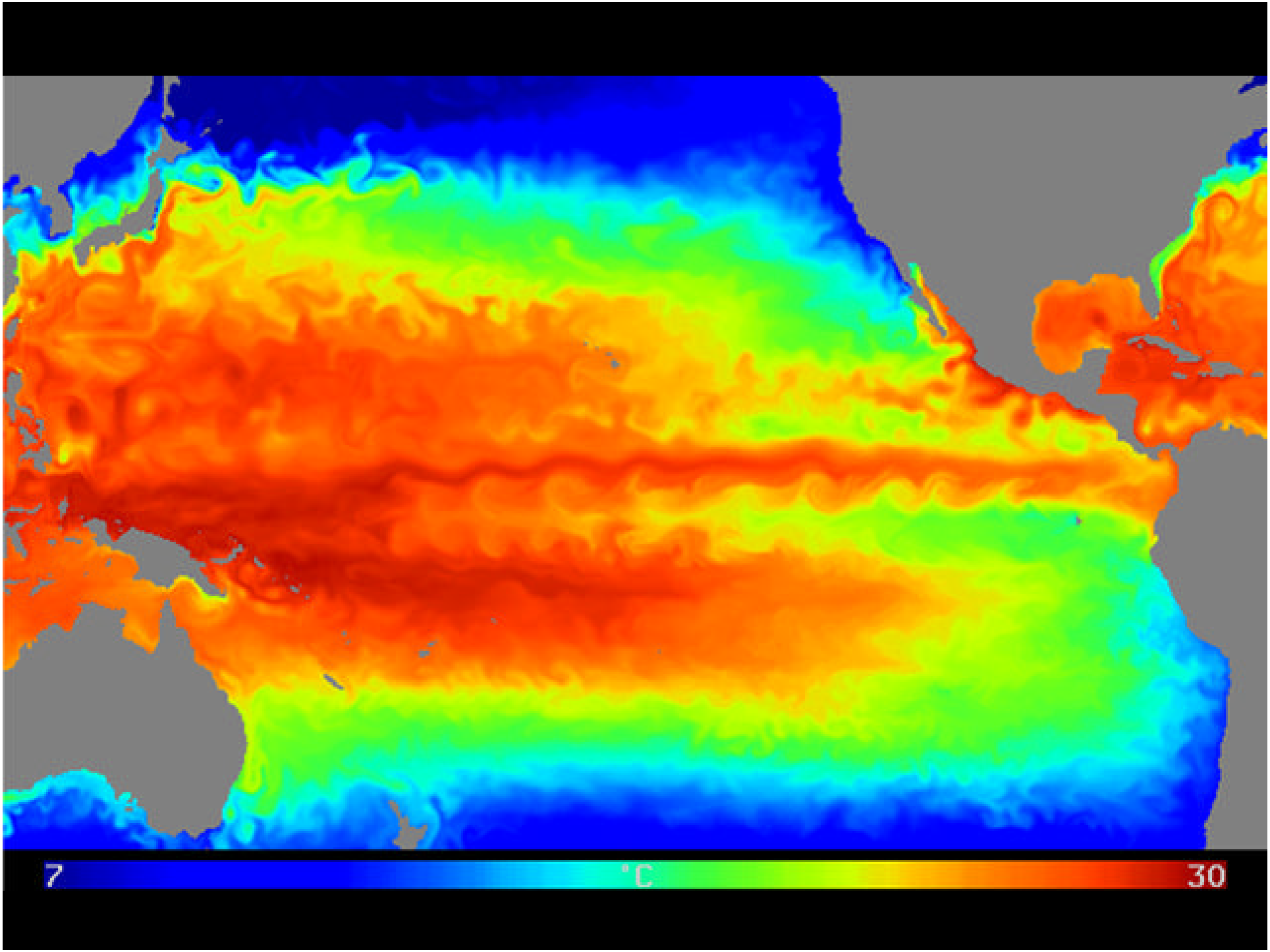
Open MP directives within node and message passing between nodes

Global Atmosphere

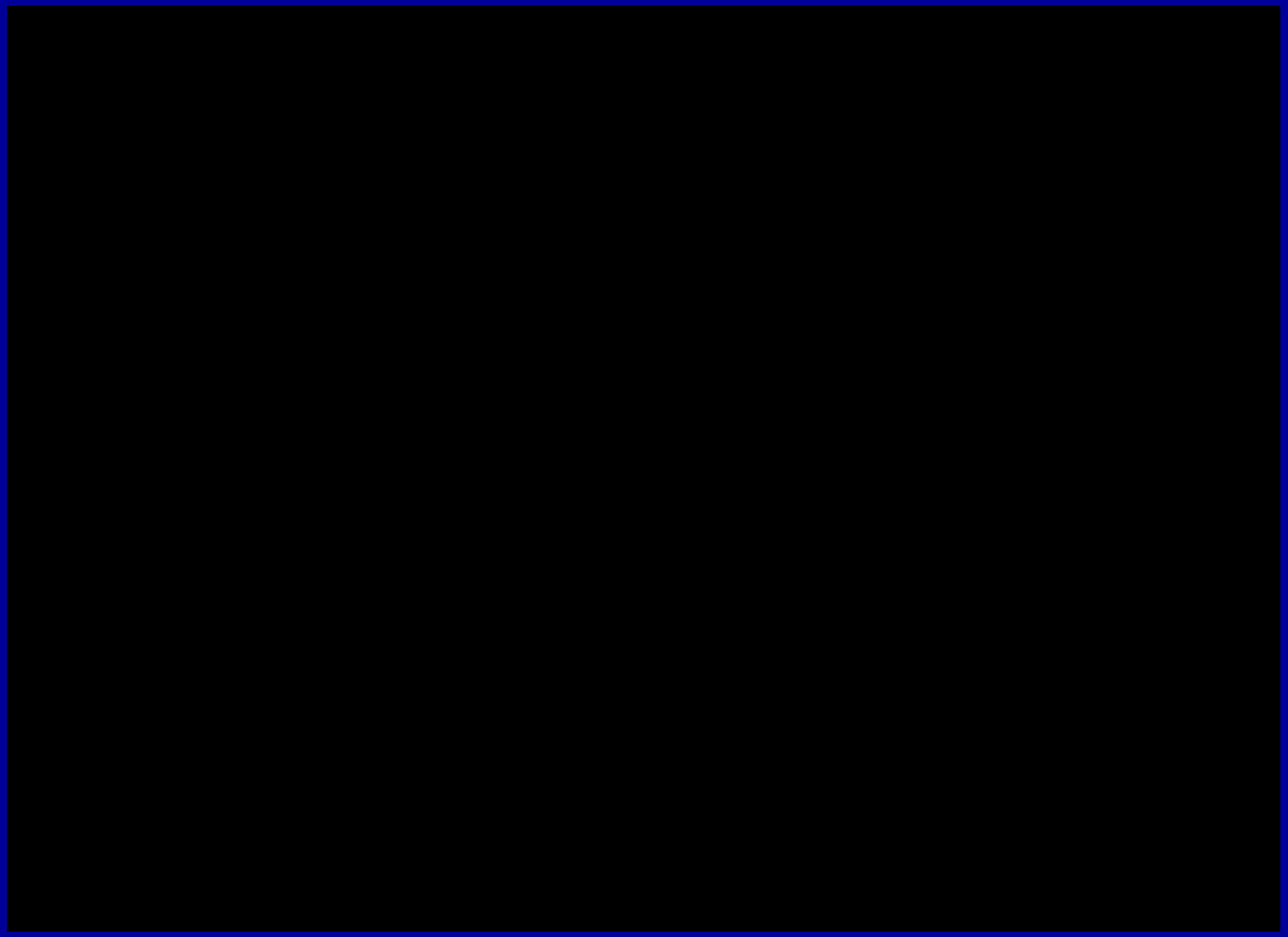



72W
68W
N
N
RSMAS

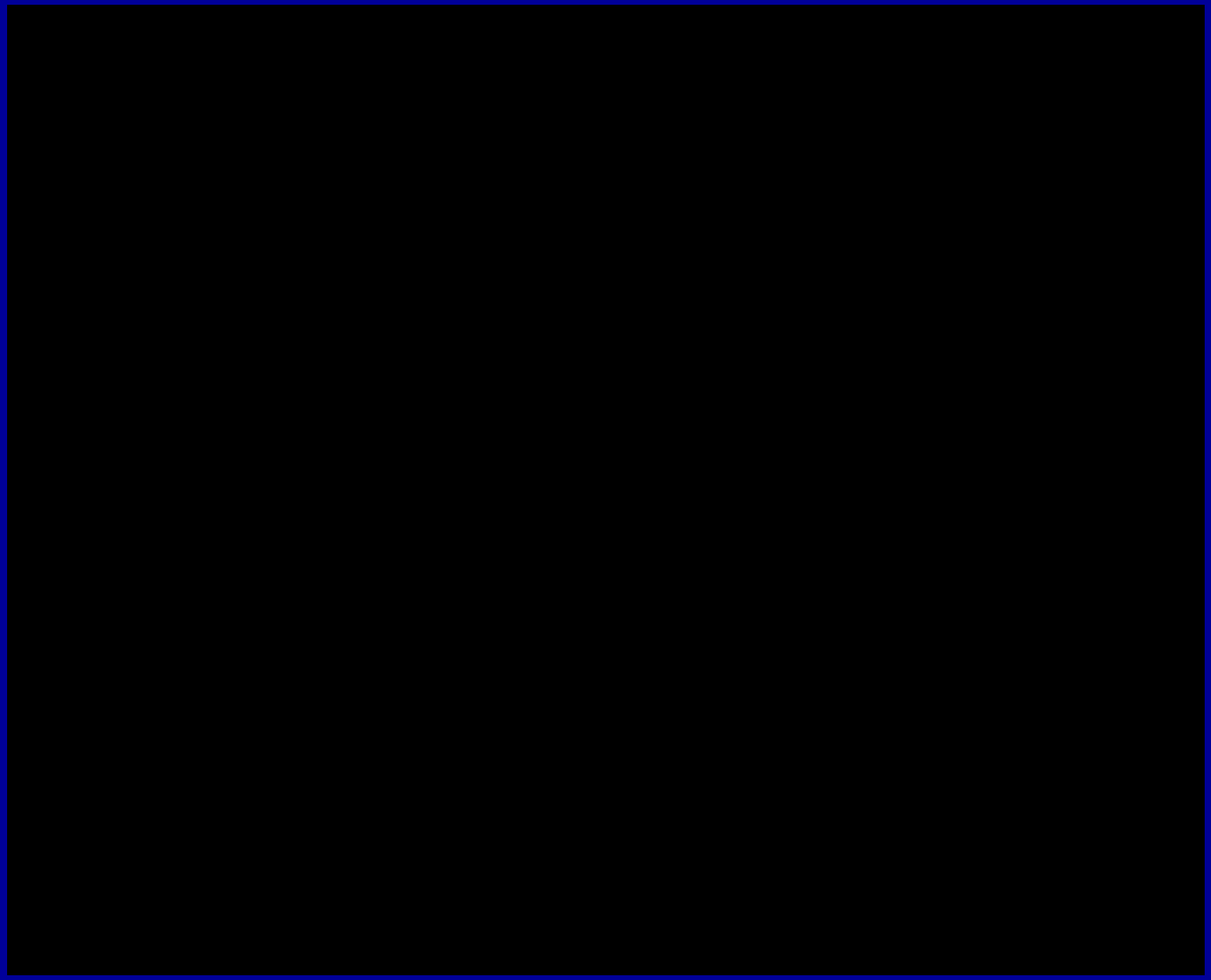



7
°C
30

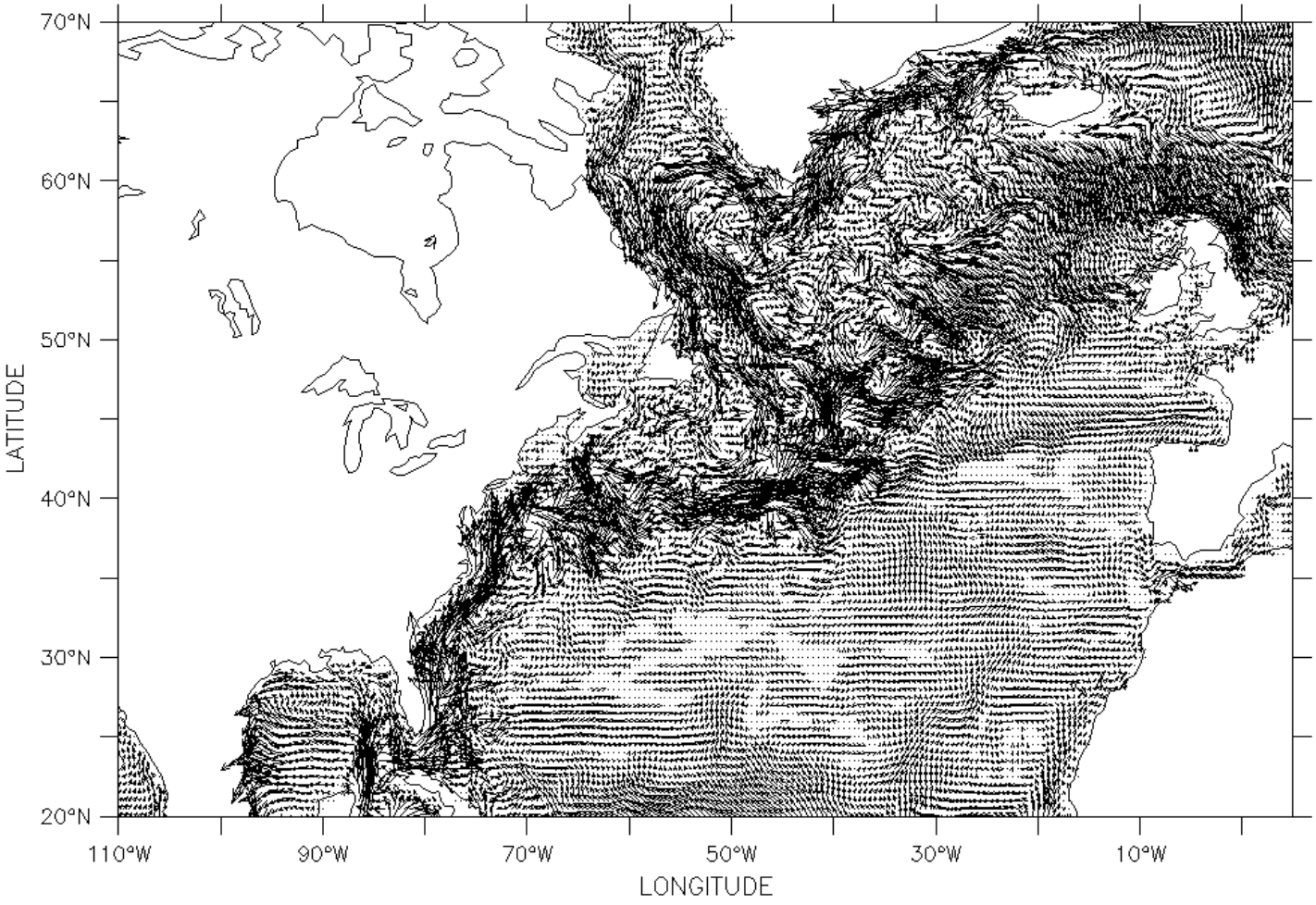
Global Ocean



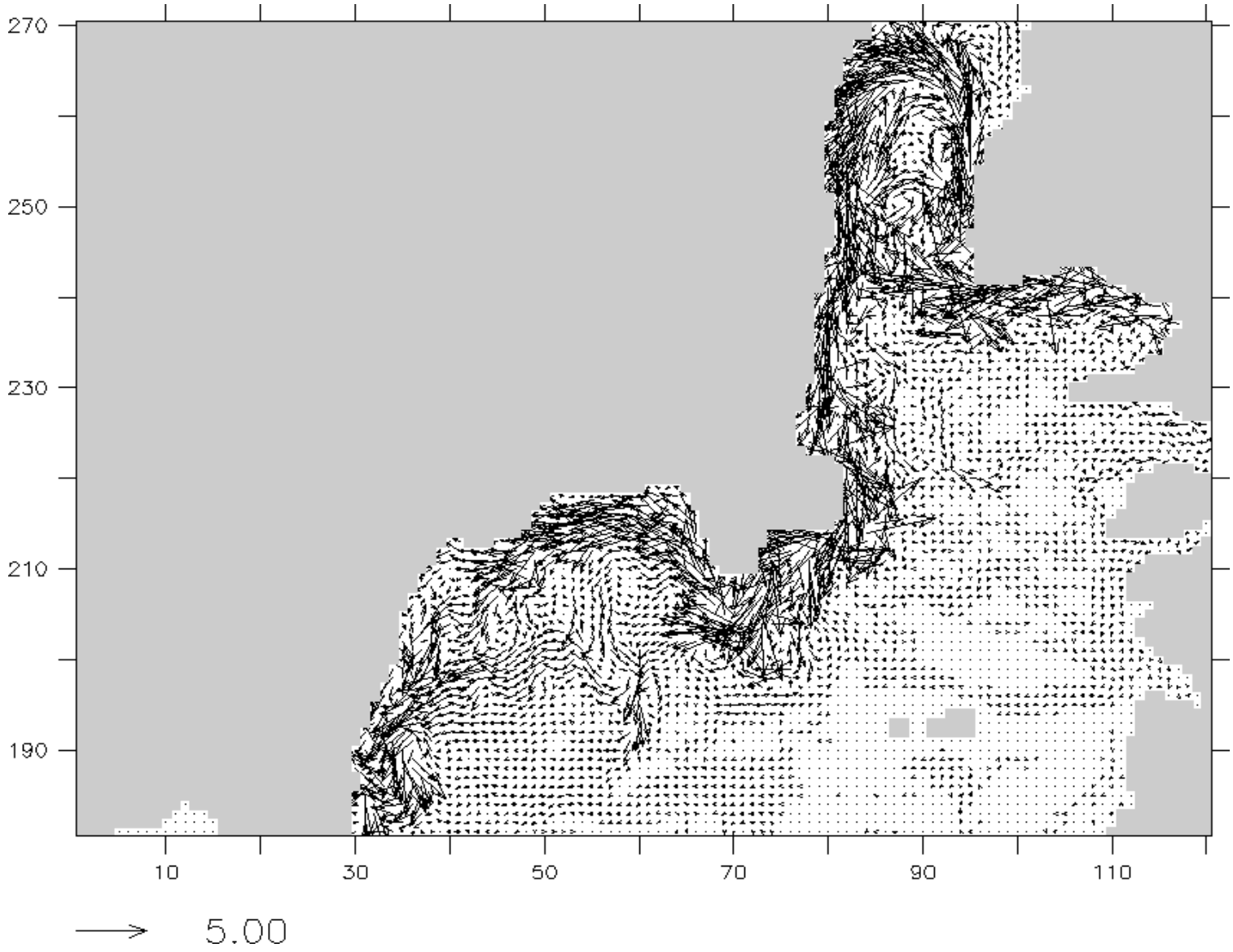
Sea Ice

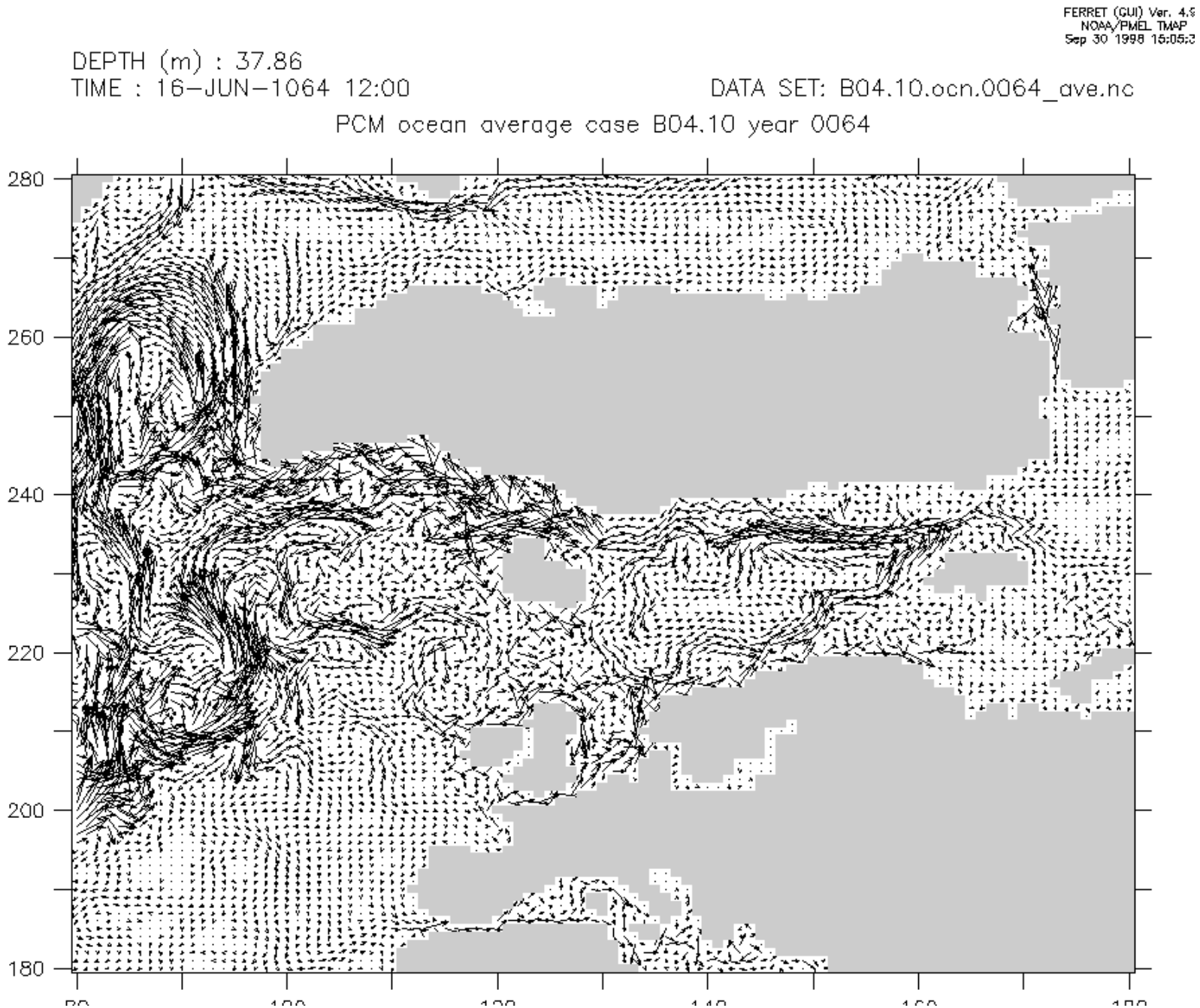


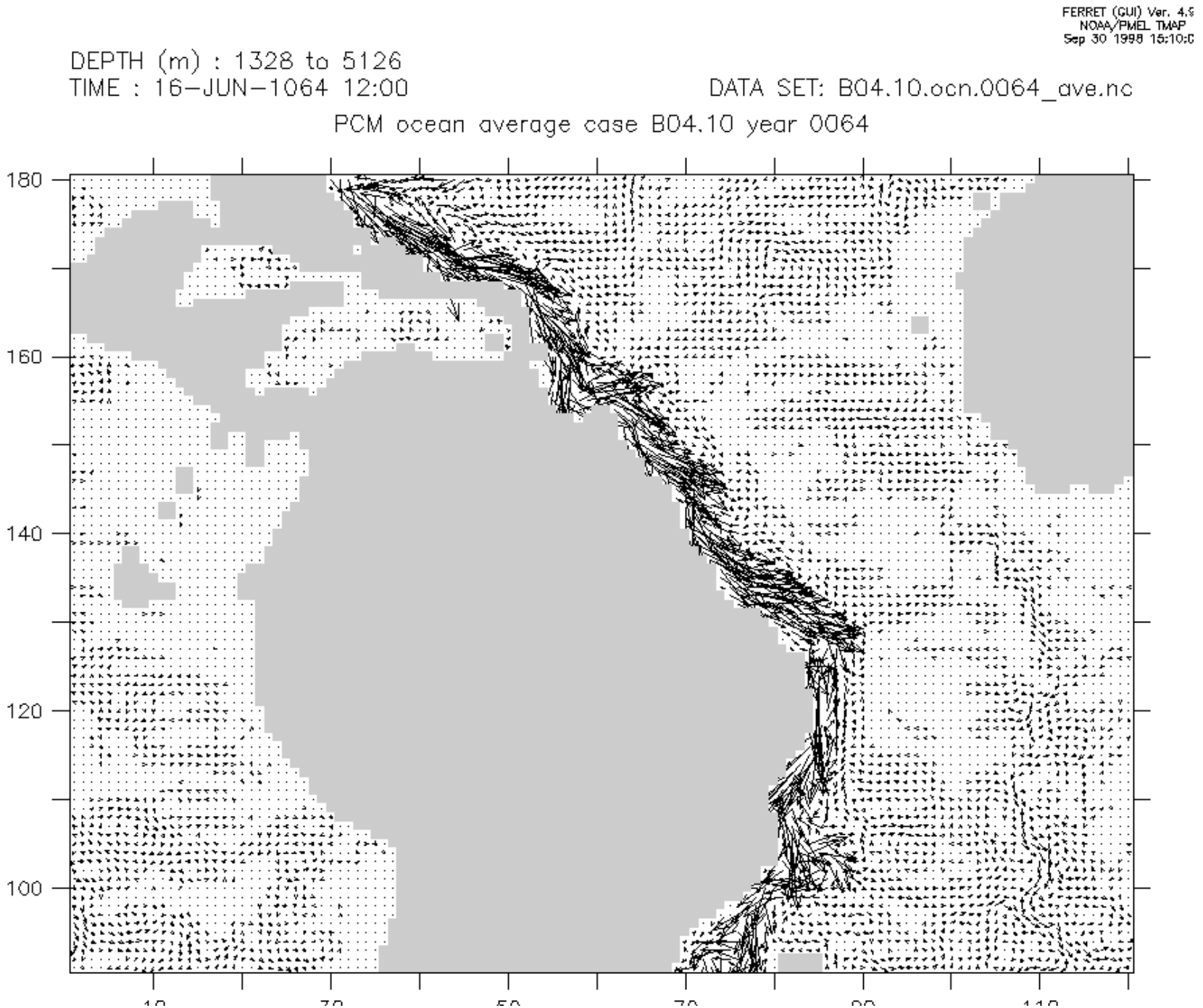
Ocean Surface Currents



Deep/Abyssal Northwest Atlantic




FERRET (GUI) Ver. 4.8
NOAA/PMEL TMAP
Sep 30 1998 15:05:3
DEPTH (m) : 37.86
TIME : 16-JUN-1064 12:00
DATA SET: B04.10.ocn.0064_ave.nc
PCM ocean average case B04.10 year 0064
280
260
240
220
200
180

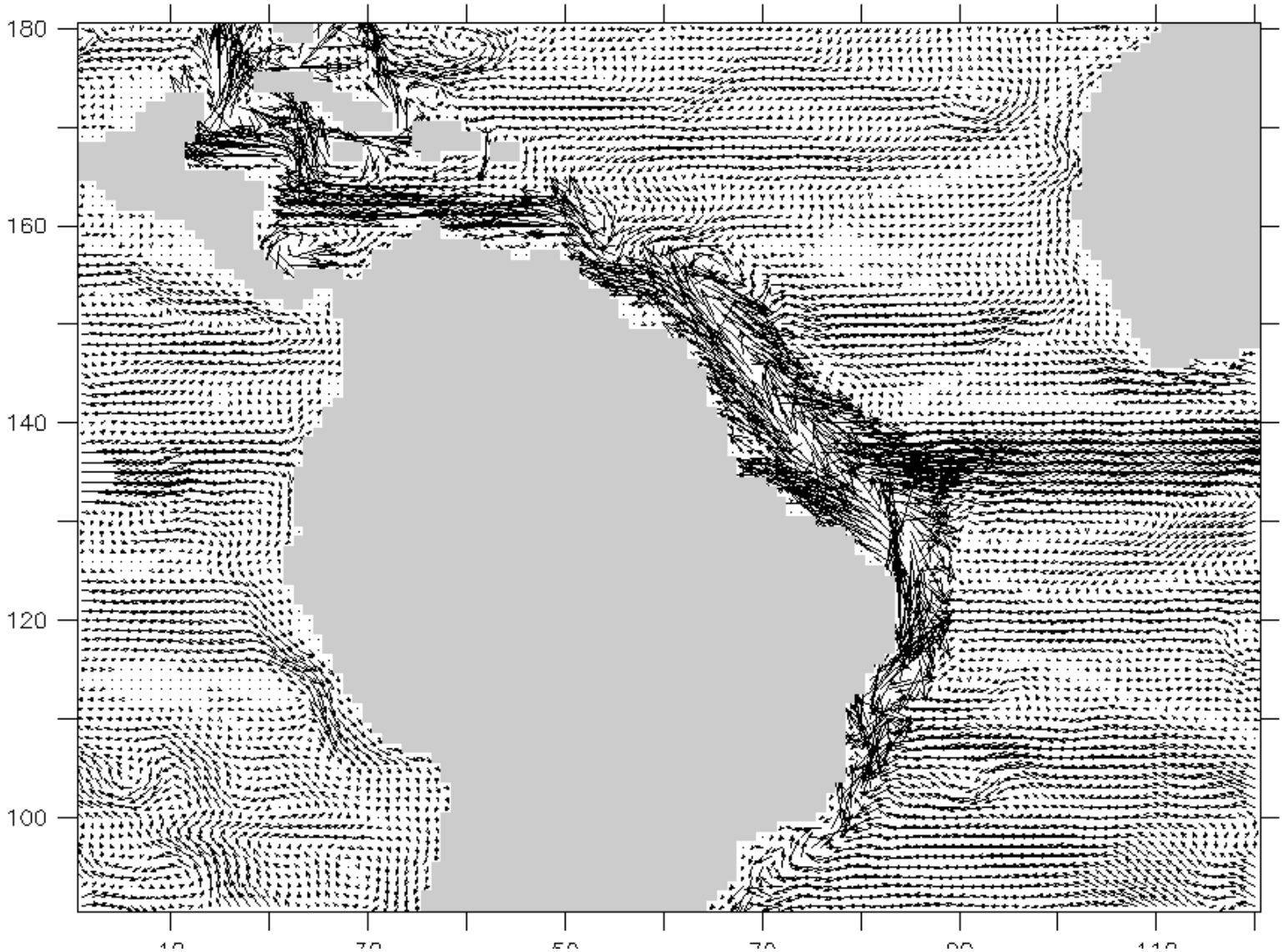

FERRET (GUI) Ver. 4.8
NOAA/PMEL TMAP
Sep 30 1998 15:10:0
DEPTH (m) : 1328 to 5126
TIME : 16-JUN-1064 12:00
DATA SET: B04.10.ocn.0064_ave.nc
PCM ocean average case B04.10 year 0064
180
160
140
120
100

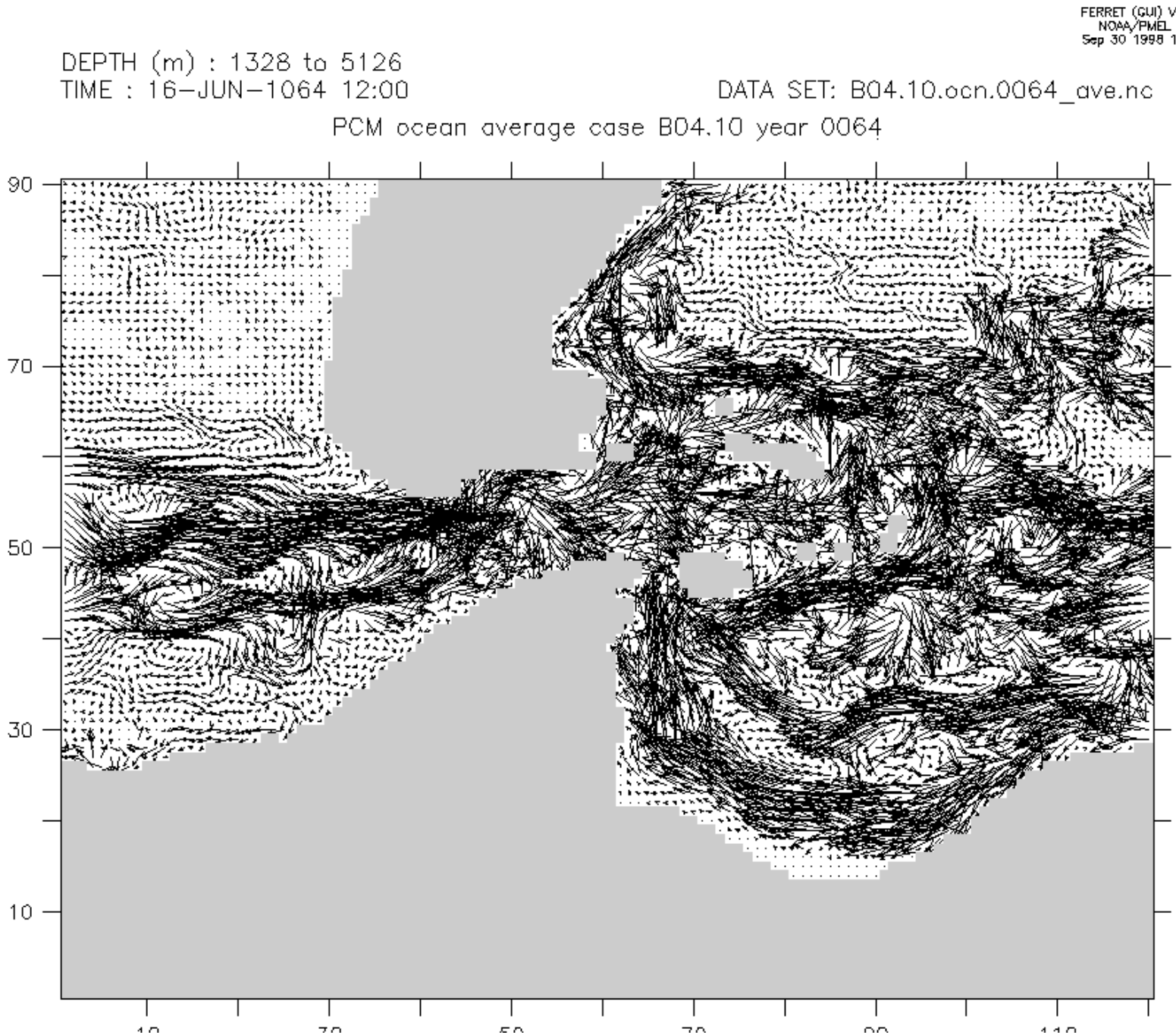
FERRET (GUI) Ver. 4.9
NOAA/PMEL TMAP
Sep 30 1998 15:19:1

DEPTH (m) : 25.21 to 311.5
TIME : 16-JUN-1064 12:00

DATA SET: B04.10.ocn.0064_ave.nc

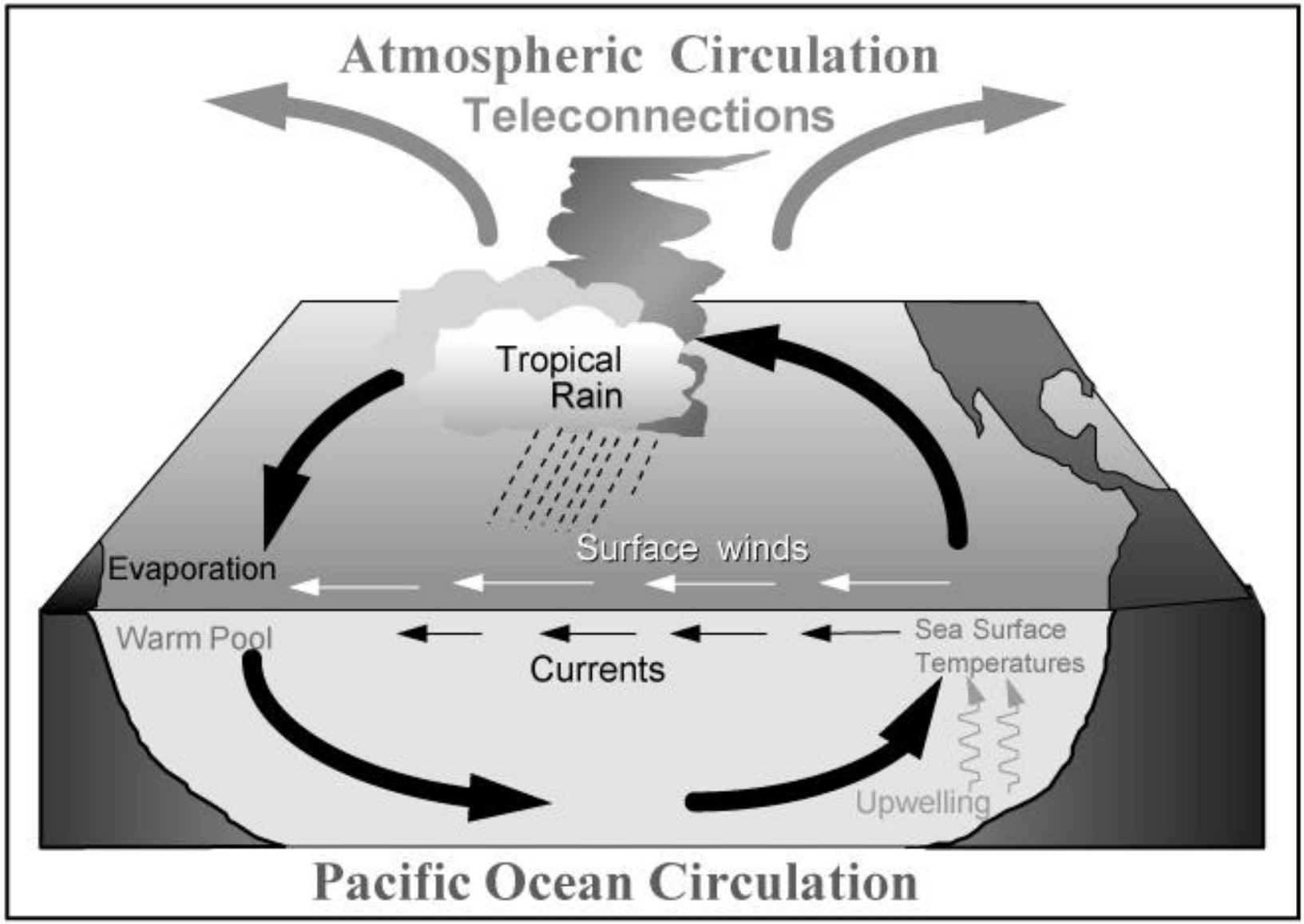
PCM ocean average case B04.10 year 0064




FERRET (GUI) Ver. 4.8
NOAA/PMEL TMAP
Sep 30 1998 15:08:5
DEPTH (m) : 1328 to 5126
TIME : 16-JUN-1064 12:00
DATA SET: B04.10.ocn.0064_ave.nc
PCM ocean average case B04.10 year 0064
90
70
50
30
10

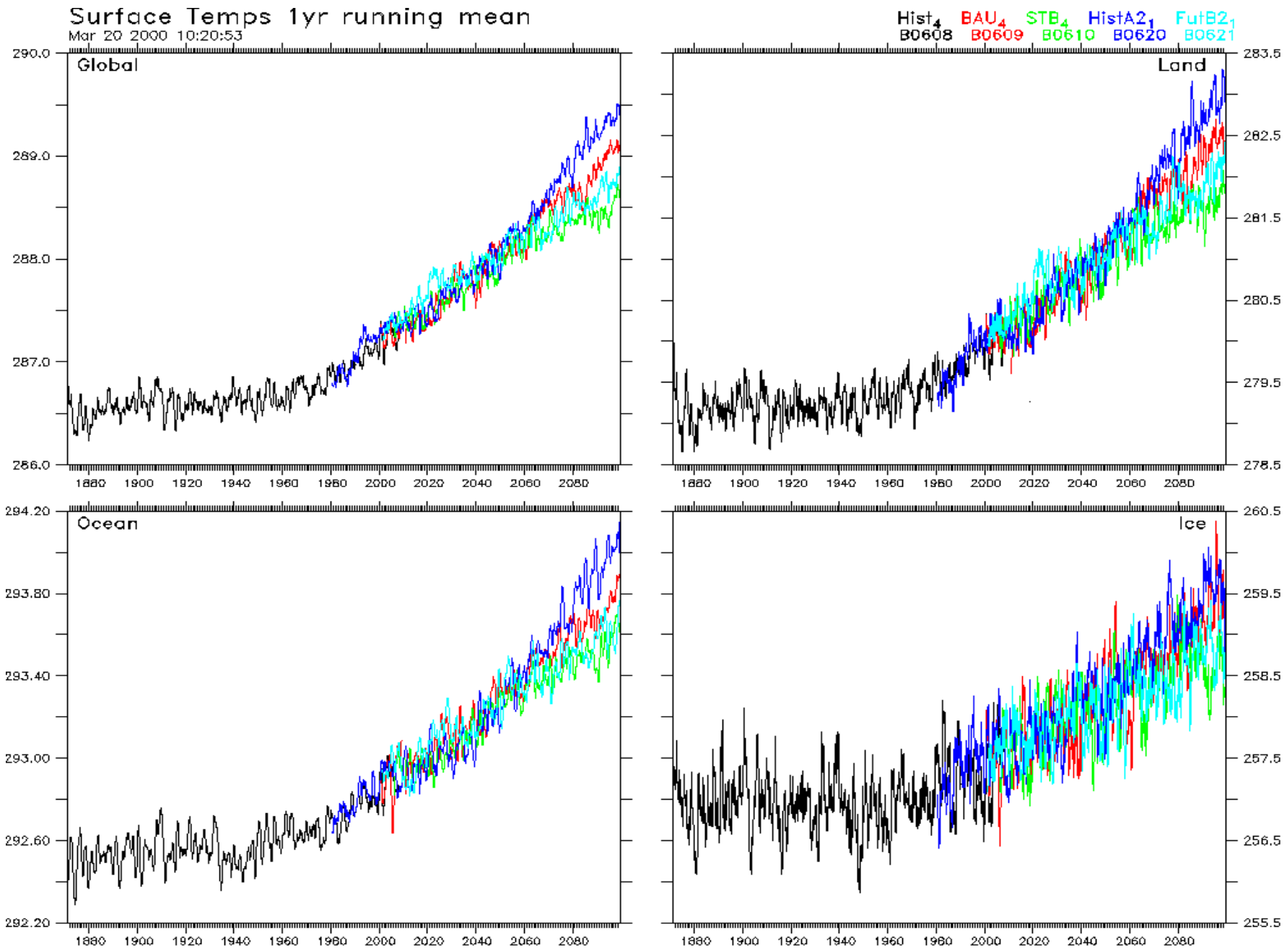
Regional Climate Aspects

- ENSO
- Arctic Oscillation
- North Atlantic Oscillation
- Antarctic Circumpolar Wave


Atmospheric Circulation
Teleconnections
Tropical
Rain
Surface winds
Evaporation
Warm Pool
Currents
Sea Surface
Temperatures
Upwelling
Pacific Ocean Circulation

Examples of Climate Change Experiments

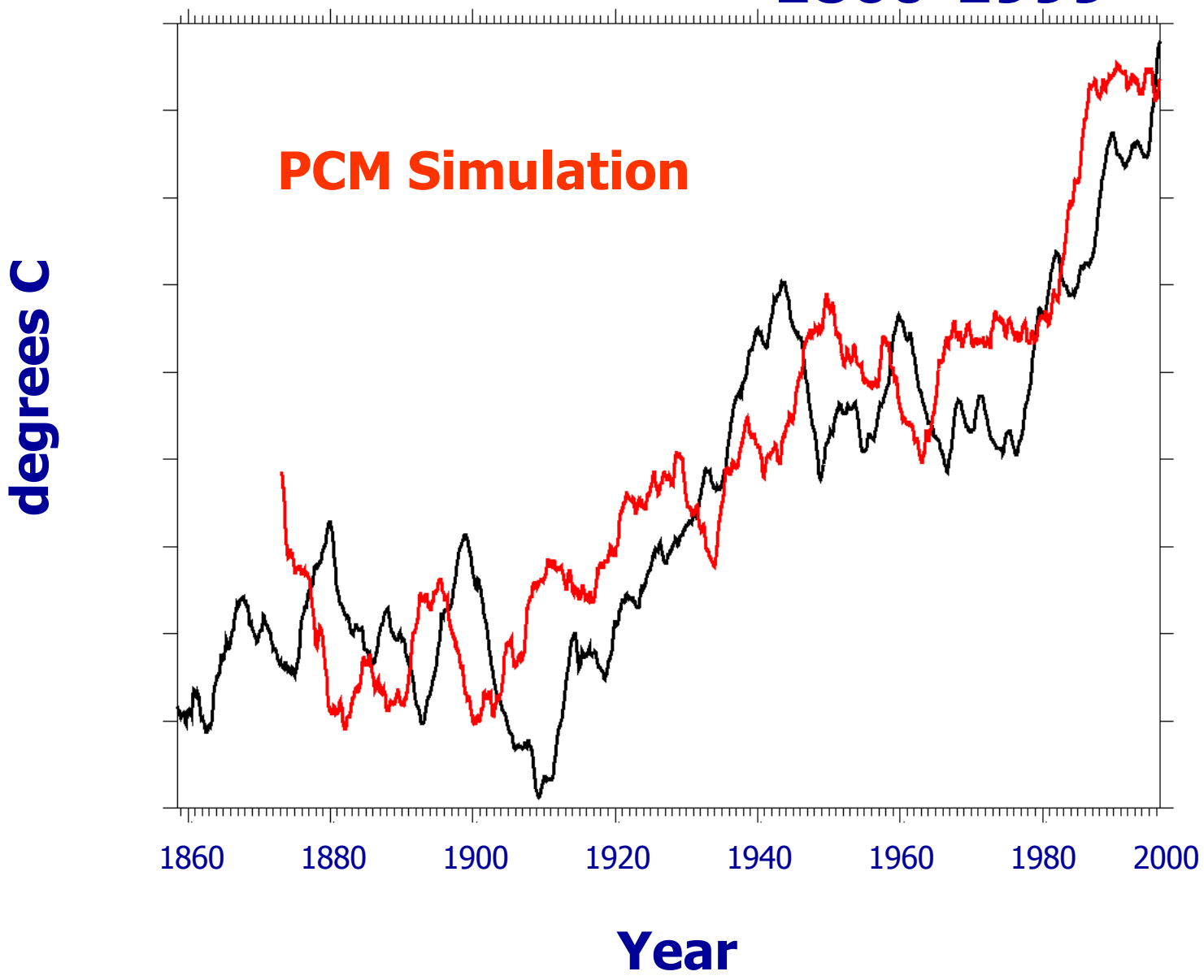
- Greenhouse gases
- Sulfate aerosols (direct and indirect)
- Stratospheric ozone
- Biomass burning
- Historical simulations
- Various energy/emissions use strategies

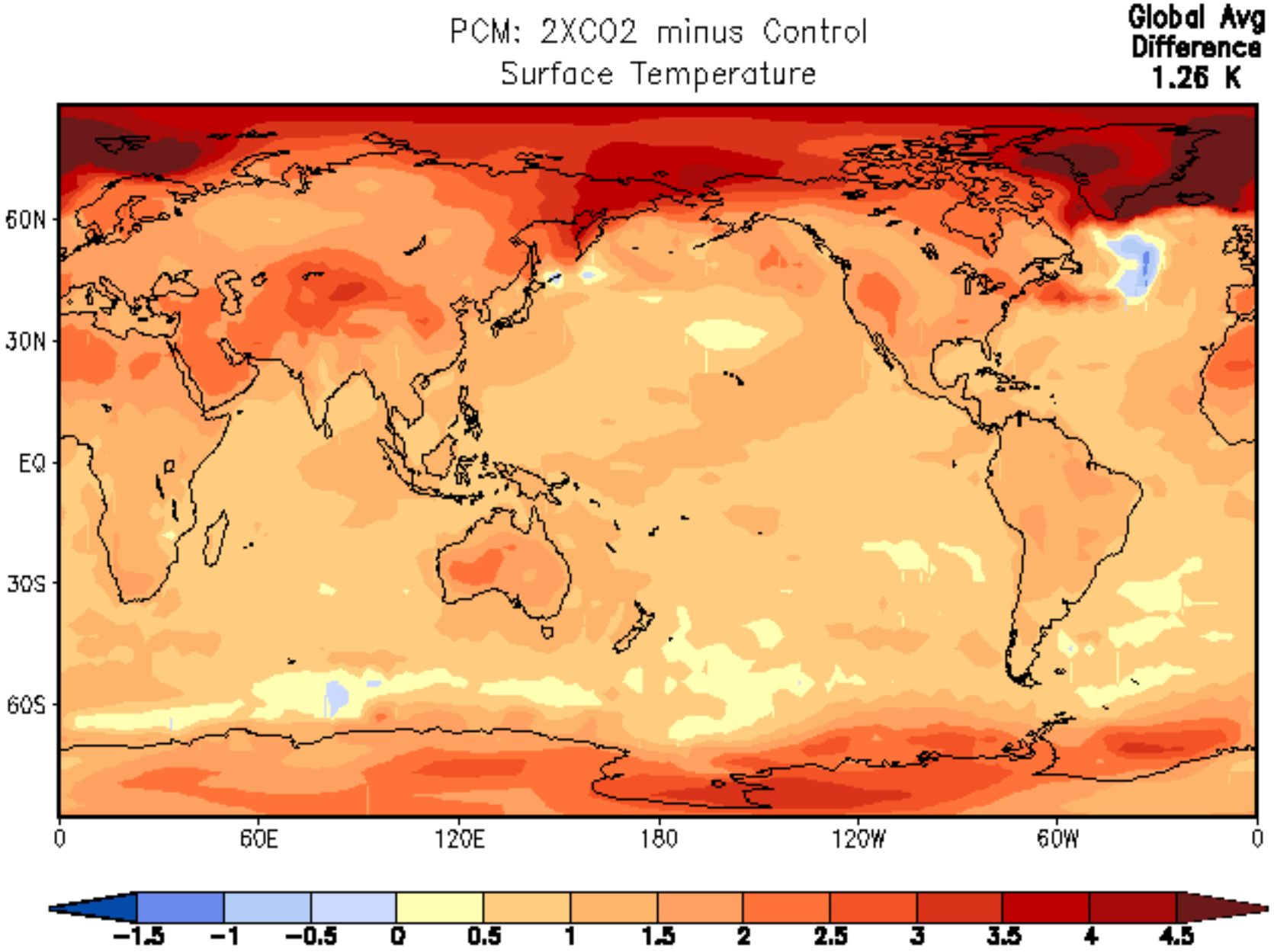

Surface Temps 1yr running mean
Mar 20 2000 10:20:53
Hist4 B0608
BAU4 B0609
STB4 B0610
HistA2 1 B0620
FutB2 1 B0621
Global
Land
Ocean
Ice
290.0
289.0
288.0
287.0
286.0
283.5
282.5
281.5
280.5
279.5
278.5
294.20
293.80
293.40
293.00
292.60
292.20
260.5
259.5
258.5
257.5
256.5
255.5
1880 1900 1920 1940 1960 1980 2000 2020 2040 2060 2080

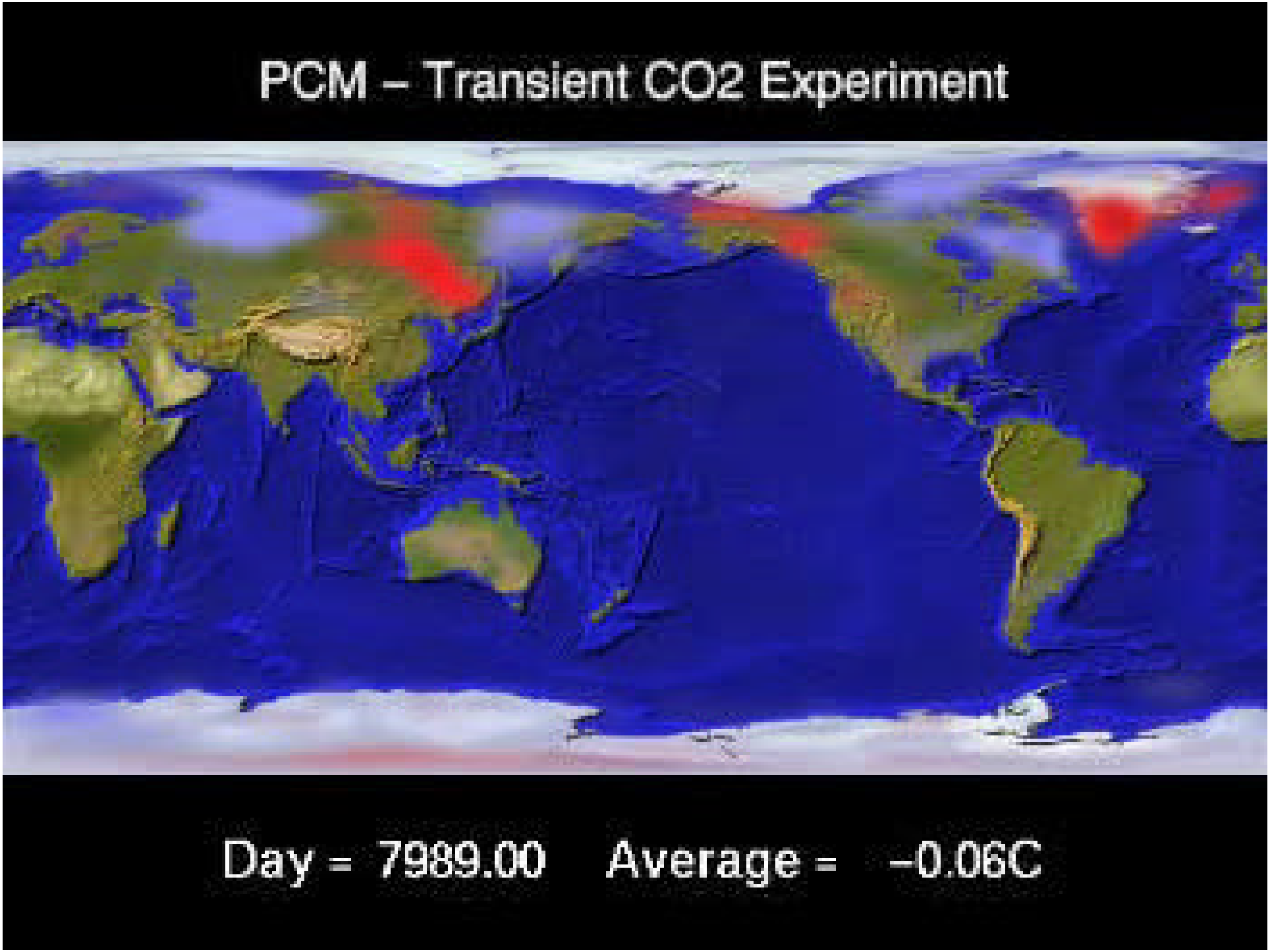
Solar Variability Simulations

- In addition to Greenhouse gases and sulfate aerosol effects
- One of the ensemble shows a global surface temperature change similar to the observed record

Global Surface Temperature Anomaly 1860-1999

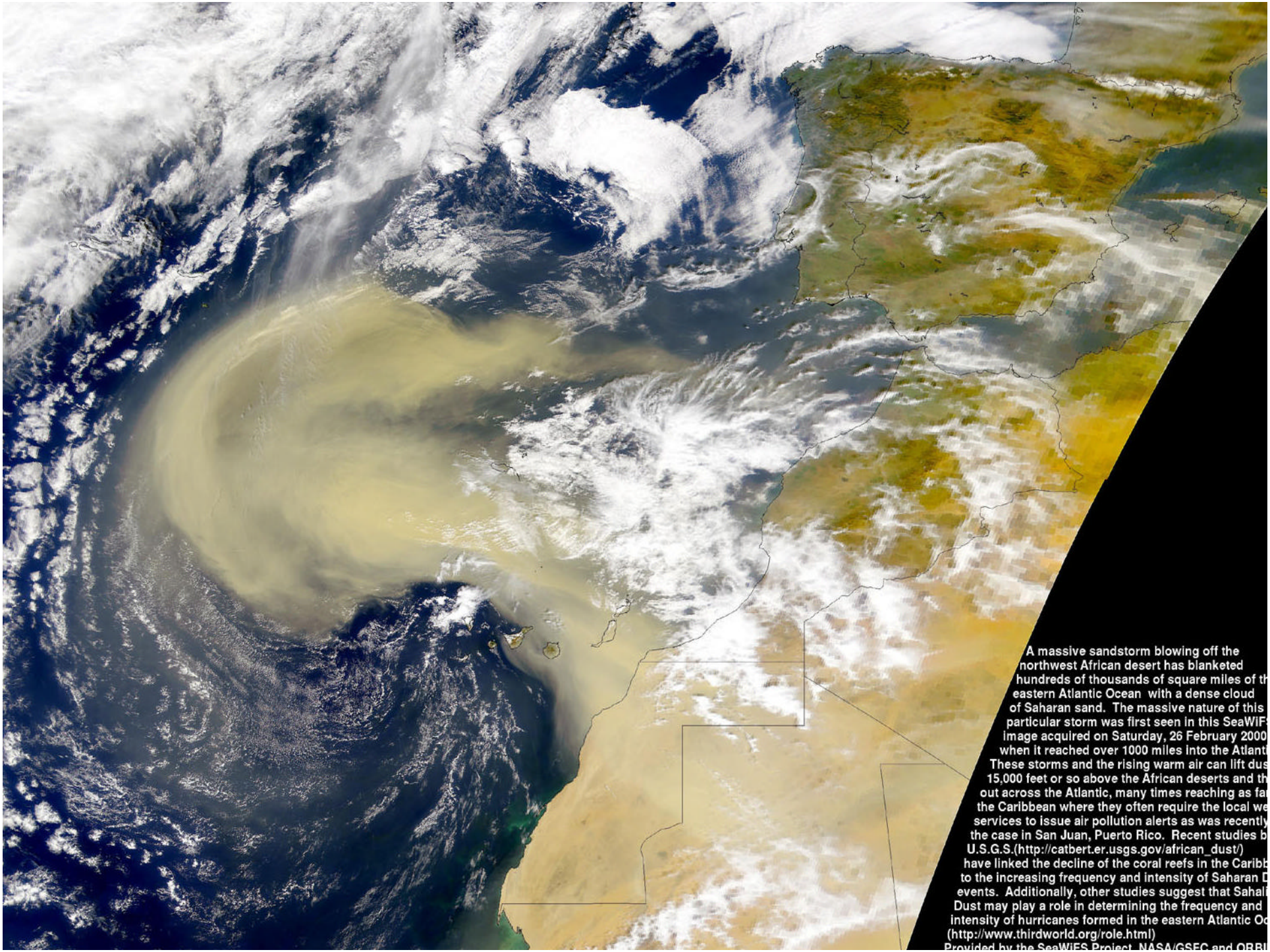


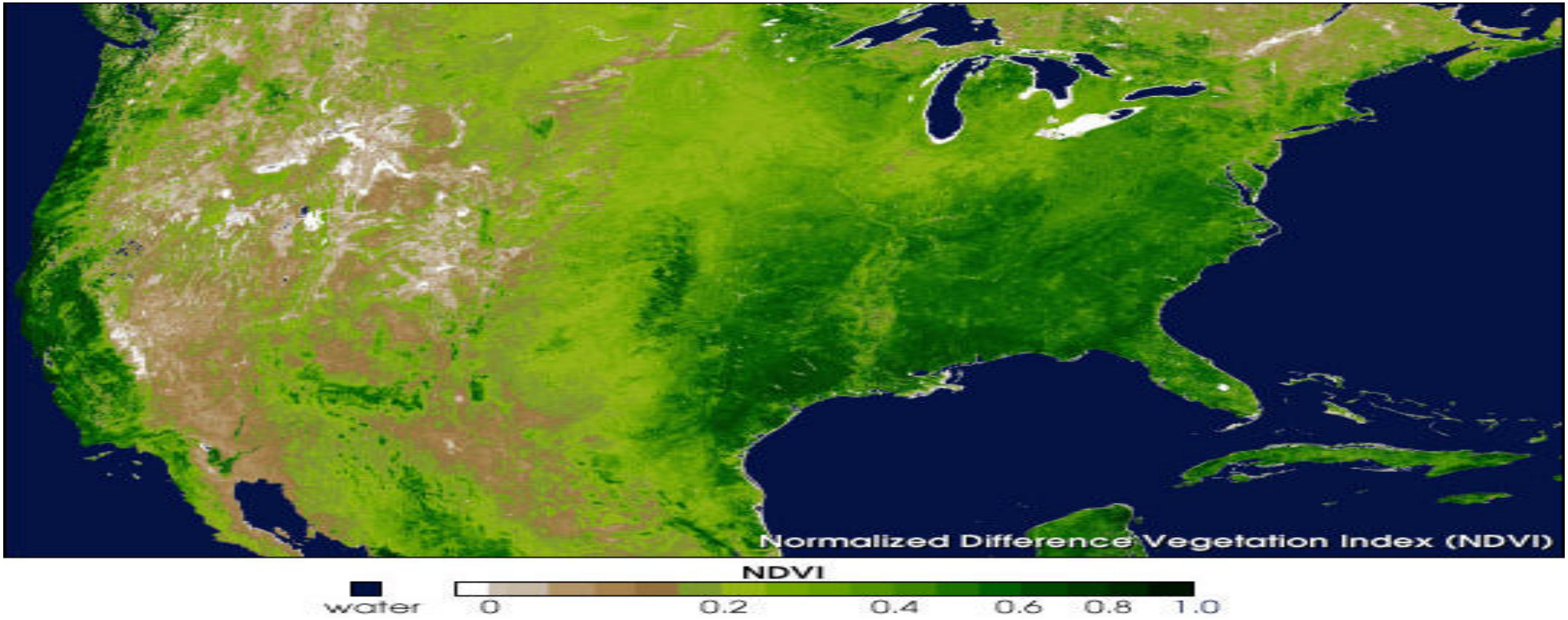

PCM: 2XCO2 minus Control
Surface Temperature
Global Avg
Difference
1.26 K
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
−1.5
−1
−0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

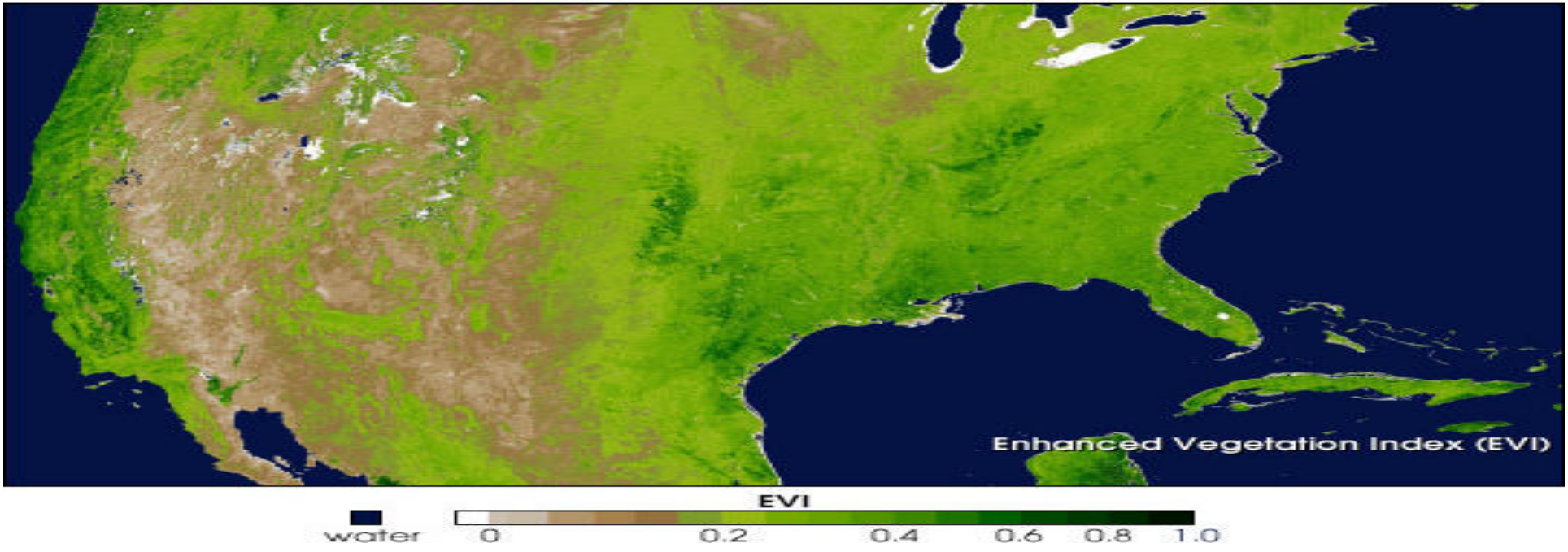

PCM – Transient CO2 Experiment
Day = 7989.00 Average = −0.06C

Present and Future Emphasis for Climate Modeling

- More detailed interactions of atmosphere, land/vegetation/river runoff, ocean and sea ice
- Use of large parallel clustered computer systems
- Paradigm -- distant collaborations

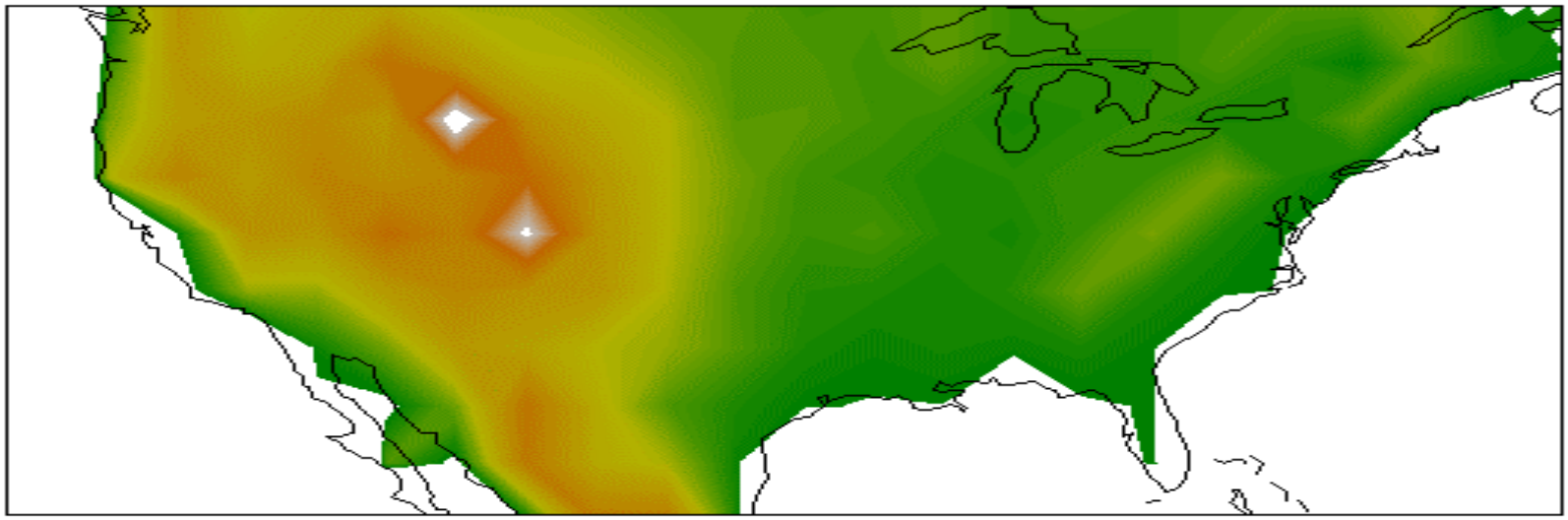

A massive sandstorm blowing off the
northwest African desert has blanketed
hundreds of thousands of square miles of th
eastern Atlantic Ocean with a dense cloud
of Saharan sand. The massive nature of this
particular storm was first seen in this SeaWiF
image acquired on Saturday, 26 February 2000
when it reached over 1000 miles into the Atlanti
These storms and the rising warm air can lift dus
15,000 feet or so above the African deserts and th
out across the Atlantic, many times reaching as fa
the Caribbean where they often require the local we
services to issue air pollution alerts as was recently
the case in San Juan, Puerto Rico. Recent studies b
U.S.G.S.(http://catbert.er.usgs.gov/african_dust/)
have linked the decline of the coral reefs in the Caribb
to the increasing frequency and intensity of Saharan D
events. Additionally, other studies suggest that Sahali
Dust may play a role in determining the frequency and
intensity of hurricanes formed in the eastern Atlantic Oc
(http://www.thirdworld.org/role.html)
Provided by the SeaWiFS Project, NASA/GSFC and ORBI


Normalized Difference Vegetation Index (NDVI)
NDVI
water
0
0.2
0.4
0.6
0.8
1.0

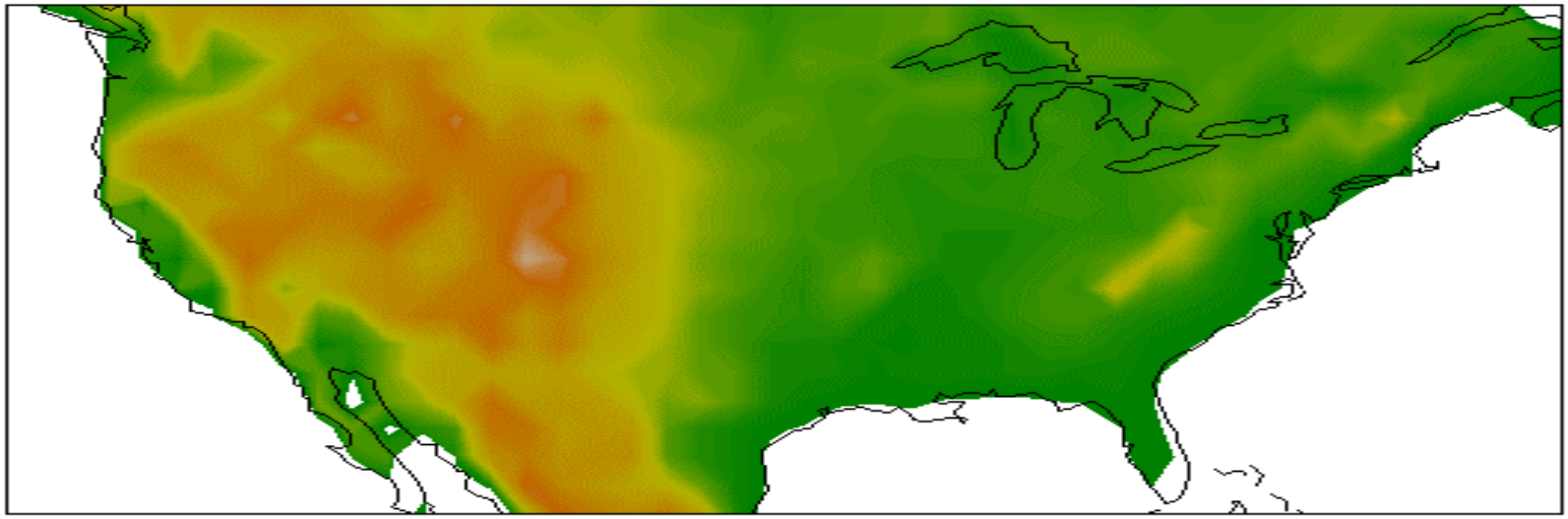

Enhanced Vegetation Index (EVI)
EVI
water
0
0.2
0.4
0.6
0.8
1.0

Model topography

T42 resolution



T85 resolution



Parallel Computers

PCM 1.1

2/3º POP

27 km sea ice

T42 CCM3.2

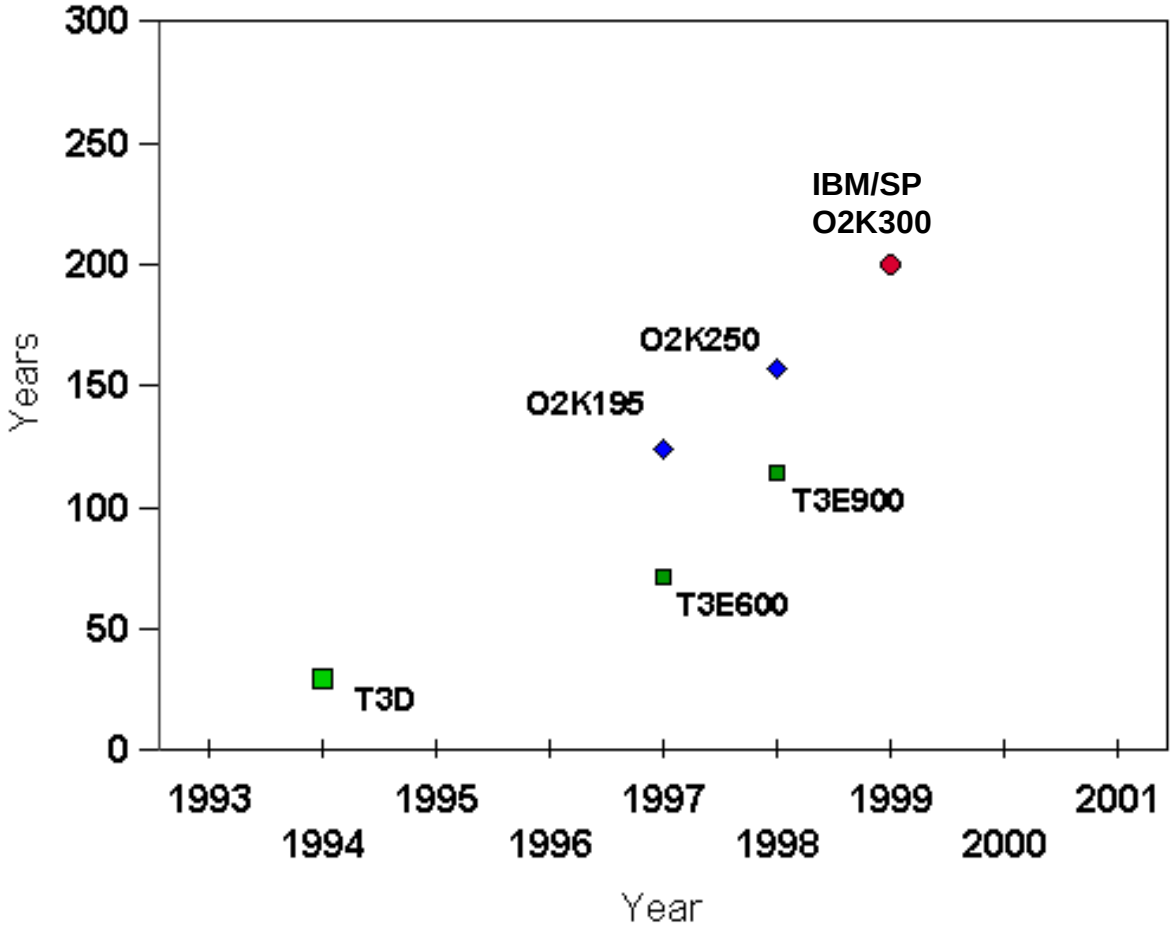
PCM 1.1 has been run on the following distributed and shared memory systems:

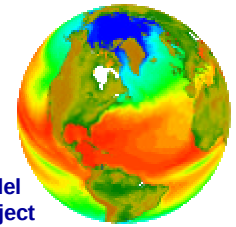
- CRAY T3E900
- SGI Origin 2000/128
- HP SPP2000
- IBM SP2
- Sun Starfire
- DEC/Compaq Alpha Cluster
- Linux Cluster

Parallel Climate Model

Simulated Years per Wallclock Month

64pes





DOE/UCAR Parallel
Climate Model Project

Need Help from Applied Mathematics Community

- Remapping
- Laplacian solver on cluster computer systems
- Global sums, fast FFTs
- Re-coding for distributed cluster computers system
- Better use of caches
- Improved numerical methods for atmosphere, ocean, sea ice, and hydrological system

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

Animation Credits

- The atmospheric animation was from the Community Climate Model at T170 resolution. This model was developed by the NCAR Climate Modeling Section. The graphics were prepared by Don Middleton of NCAR.
- The ocean animation makes use of the LANL POP model and was prepared by the scientists at the Naval Postgraduate School (NPS)
- The sea animation uses the Zhang model of the NPS.

The End

More information can be found at
http://www.cgd.ucar.edu/ccr/pcm/