Global Climate Modeling and Numerical Biogeochemistry Science in a Tera-scale Computational Environment

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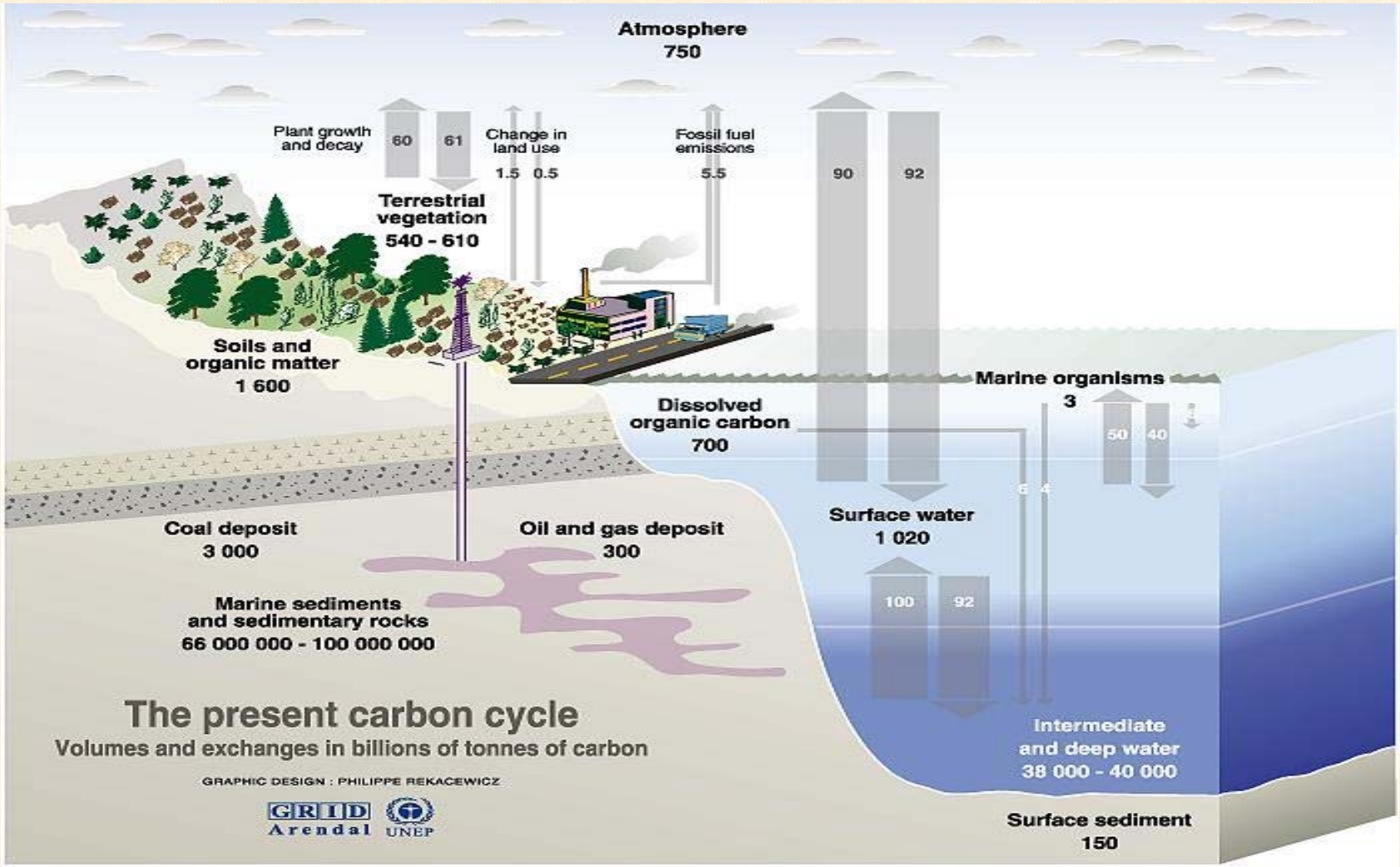
Outline

- Global Earth System Modeling
- Fully Coupled Model (CCSM2)
- Case Study #1: Geophysical Statistics and Ecosystem Niche Evolution (1870-2100)
- Case Study #2: Global Iron Simulation and Ocean Biologic Response
- Overview of Climate and Carbon Research (CCR)

Earth System Model



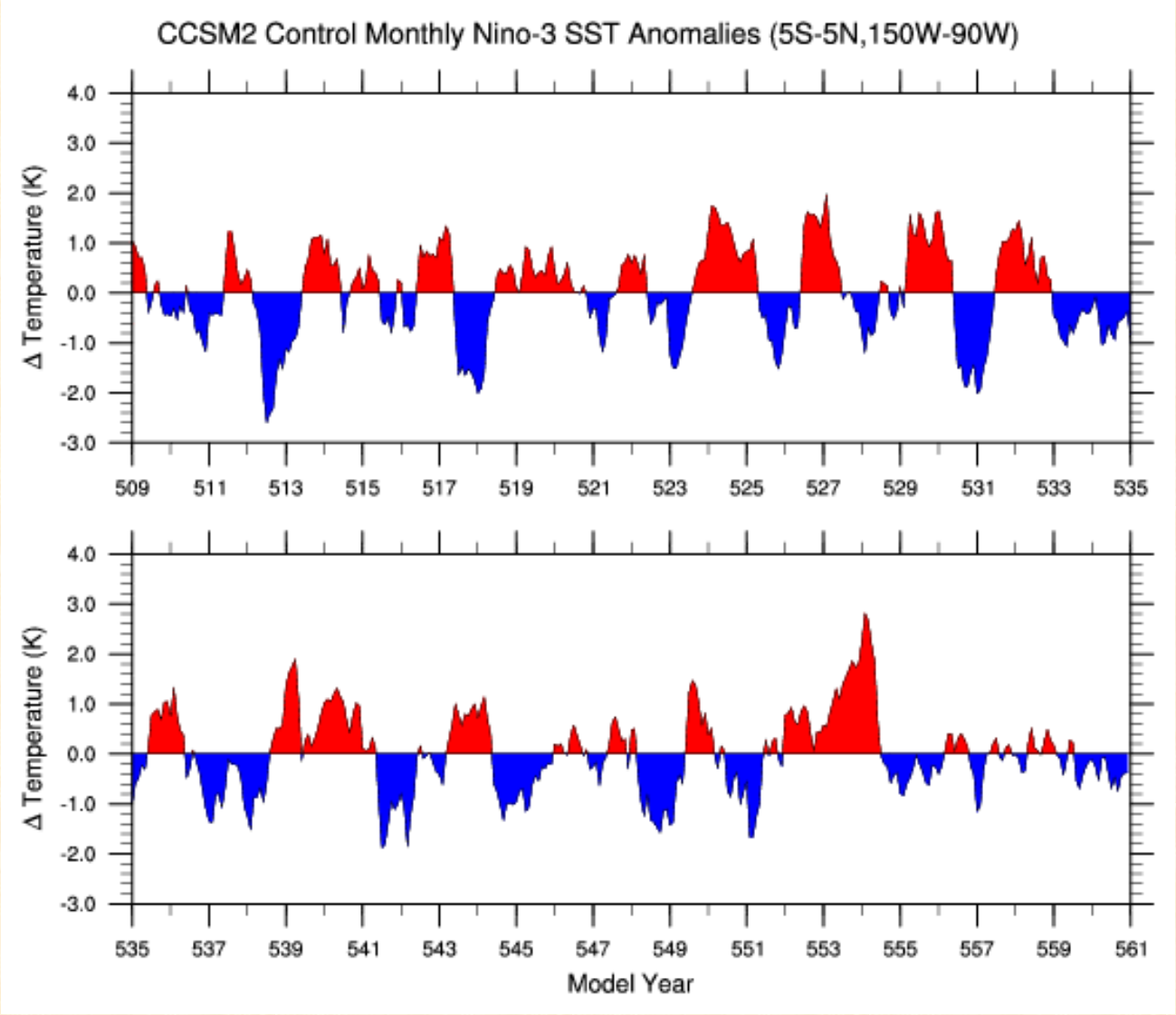
Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

CCSM2 Description

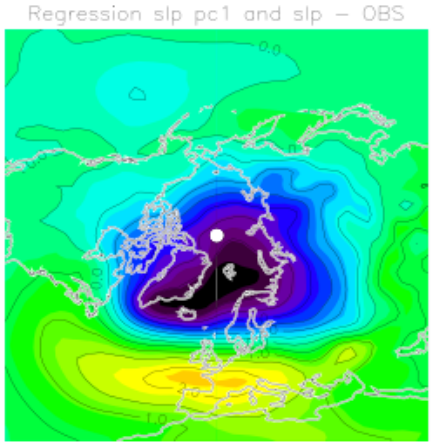
- CAM2:
  - Improved Longwave Radiation & Clouds
  - Prognostic Cloud Water Formulation
  - Changes to Convective Precipitation
  - Increased Vertical Resolution
- CCSM Ocean Model
  - POP1.4 (with displaced NP into Greenland)
  - Anisotropic horizontal viscosity formulation
  - Increased Horizontal Resolution
  - Revised formulation of G-M Eddy scheme

CCSM2 Description

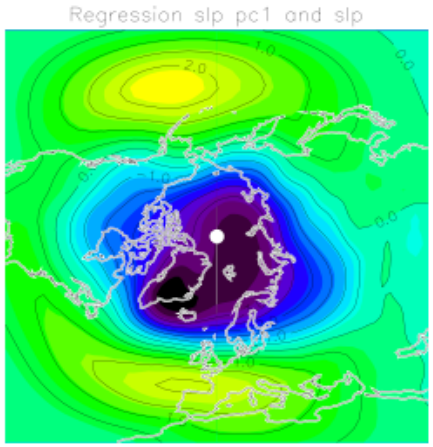
- CSIM
  - New Elastic-Viscous-Plastic(EVP) ice rheology
  - New Thermodynamic model, including multi-category ice thickness scheme
- CLM
  - New biogeophysics formulation
  - Multilayer soil water and T(z) formulation
  - Multilayer snow model with compaction
  - River runoff scheme


CCSM2 Control Monthly Nino-3 SST Anomalies (5S-5N,150W-90W)
Δ Temperature (K)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
509
511
513
515
517
519
521
523
525
527
529
531
533
535
535
537
539
541
543
545
547
549
551
553
555
557
559
561
Model Year

NAO SLP Pattern

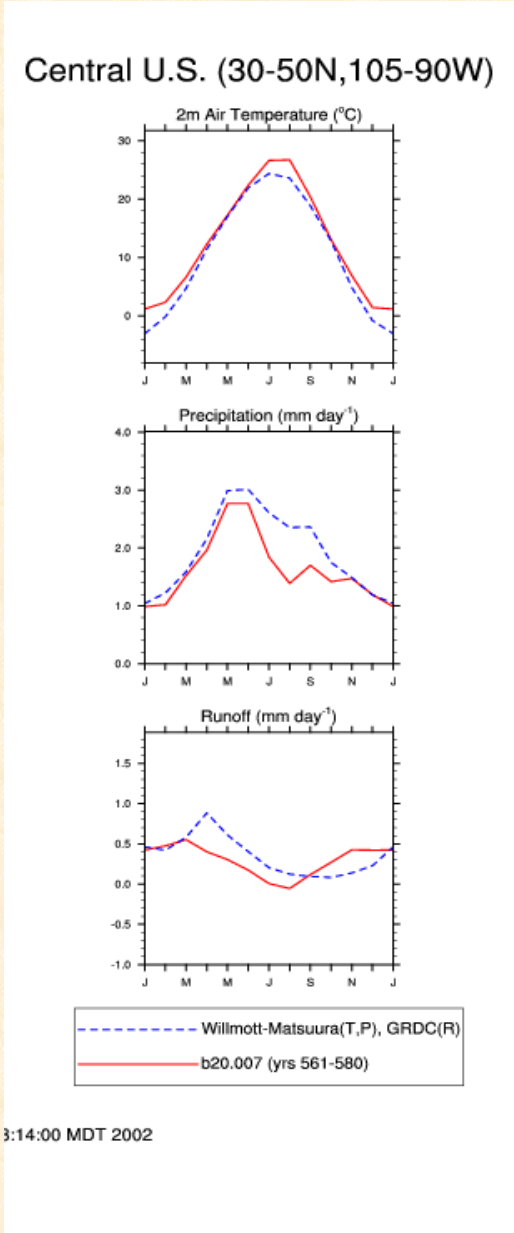


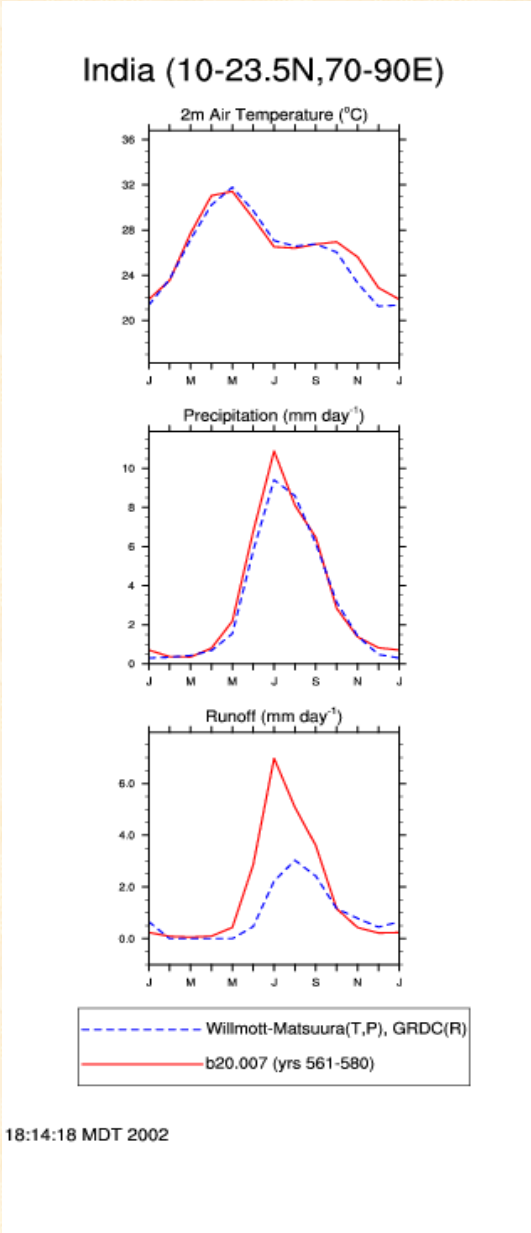
From 50 Years of NCEP Reanalysis



From 300 Years of CCSM2 Control Simulation

Based on Nov-April seasonal average Sea Level Pressure

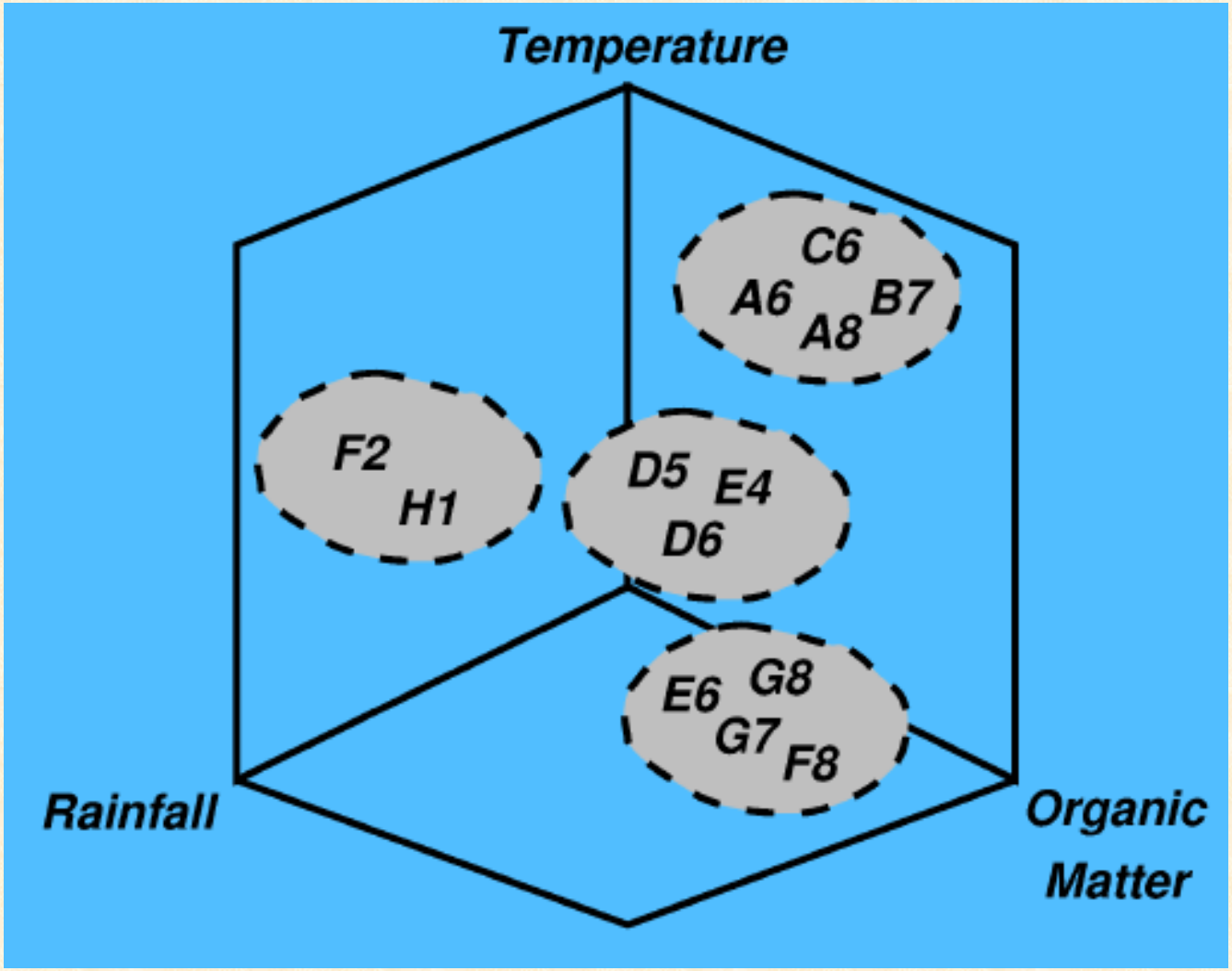

Central U.S. (30-50N,105-90W)
2m Air Temperature (°C)
Precipitation (mm day⁻¹)
Runoff (mm day⁻¹)
J M M J S N J
Willmott-Matsuura(T,P), GRDC(R)
b20.007 (yrs 561-580)
:14:00 MDT 2002


India (10-23.5N,70-90E)
2m Air Temperature (°C)
Precipitation (mm day⁻¹)
Runoff (mm day⁻¹)
J M M J S N J
Willmott-Matsuura(T,P), GRDC(R)
b20.007 (yrs 561-580)
18:14:18 MDT 2002

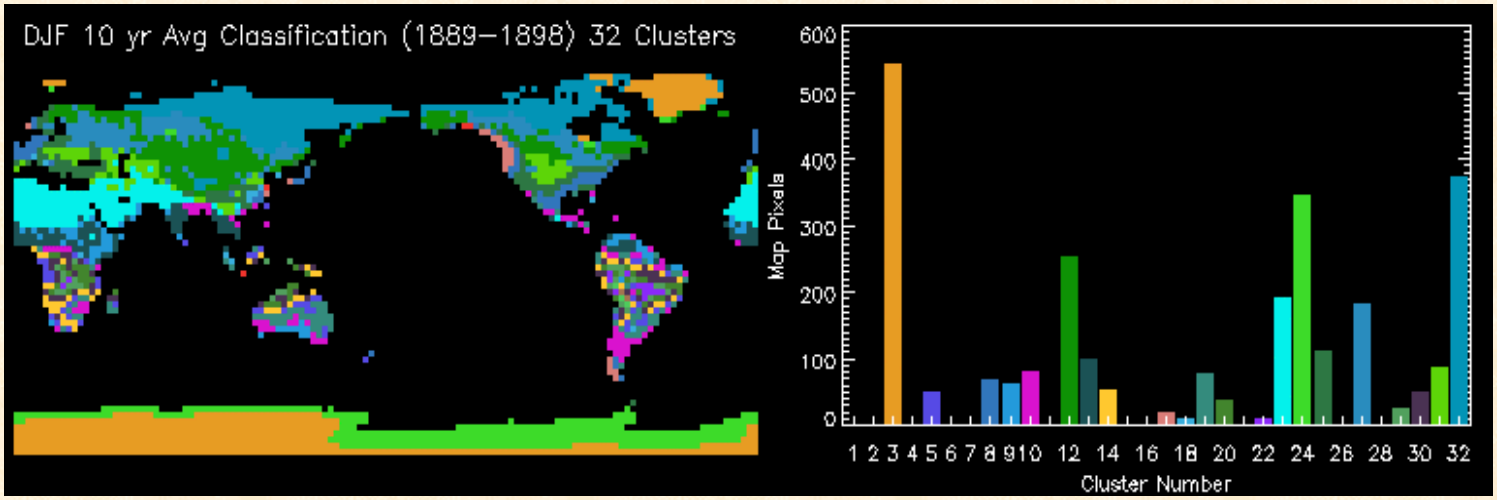
Case Study #1

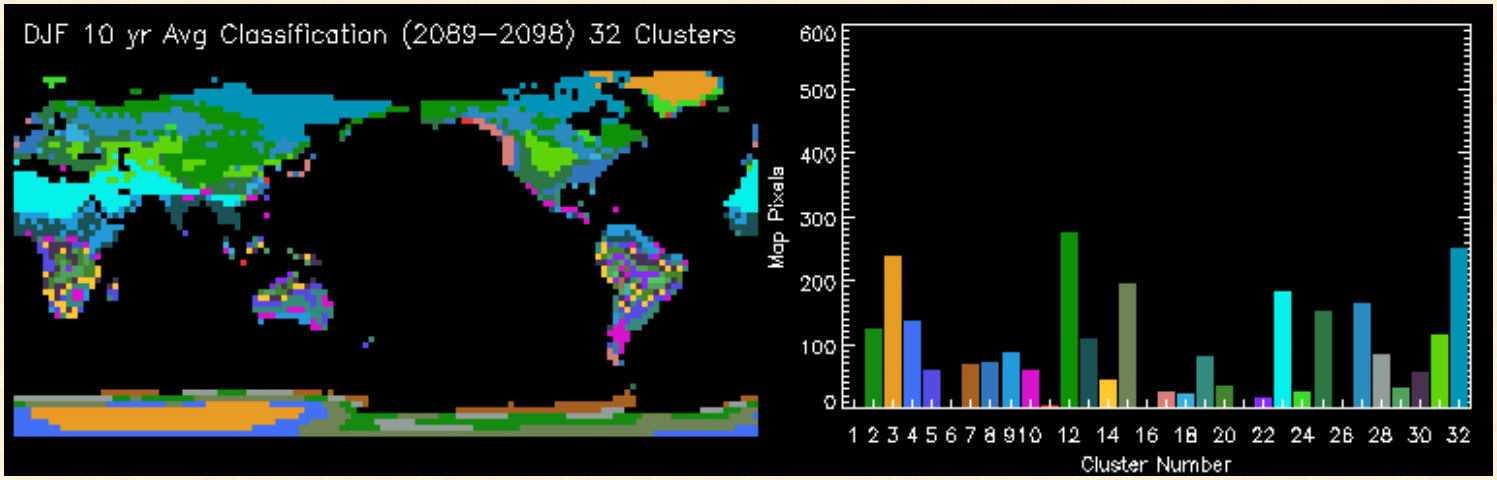
Ecosystem Niche Evolution Computed from A Fully Coupled Climate Model (PCM) for the time period 1870-2100

Ecosystem Niche Clustering

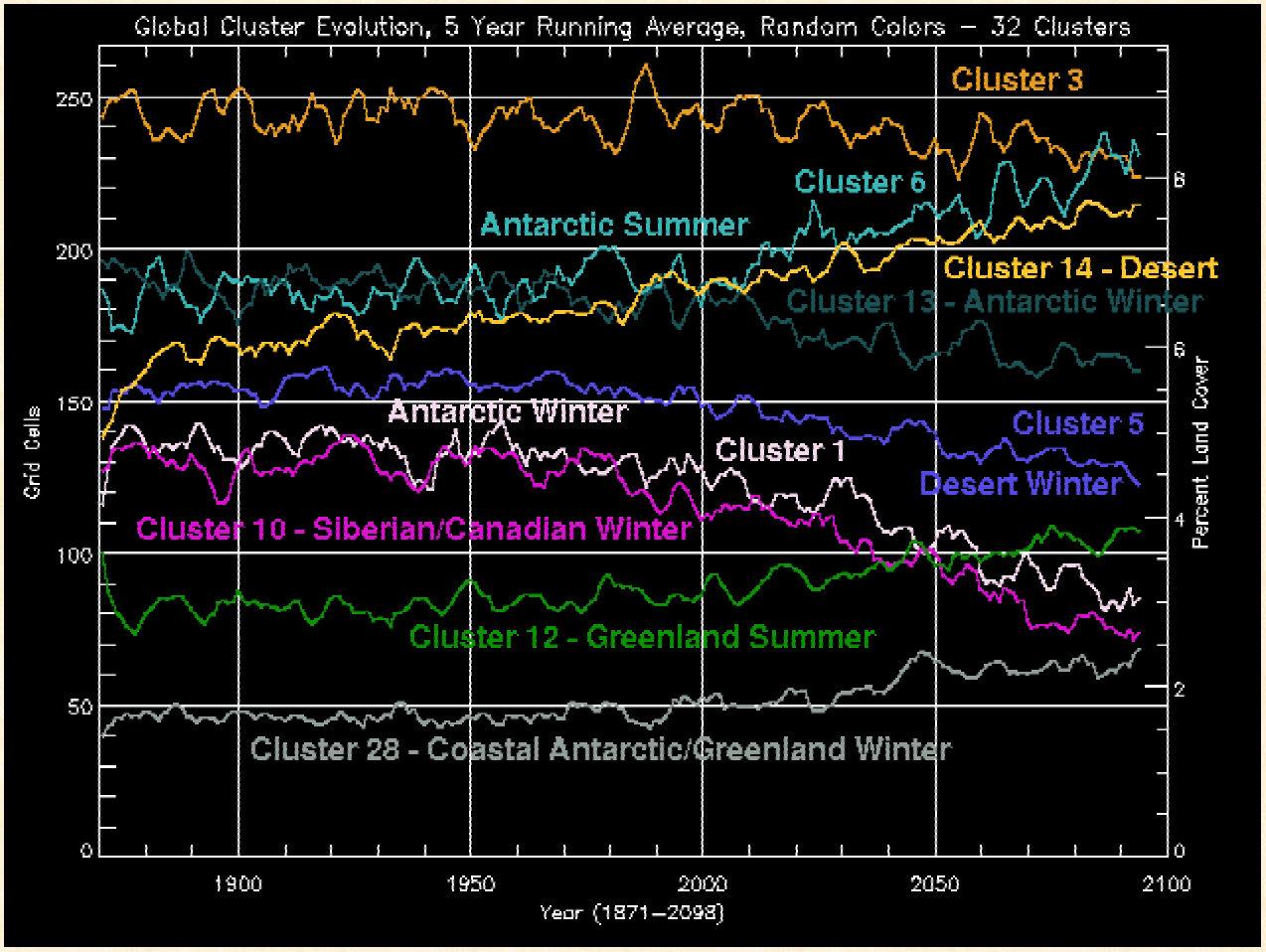


Cluster Distribution Changes (1870-2100)





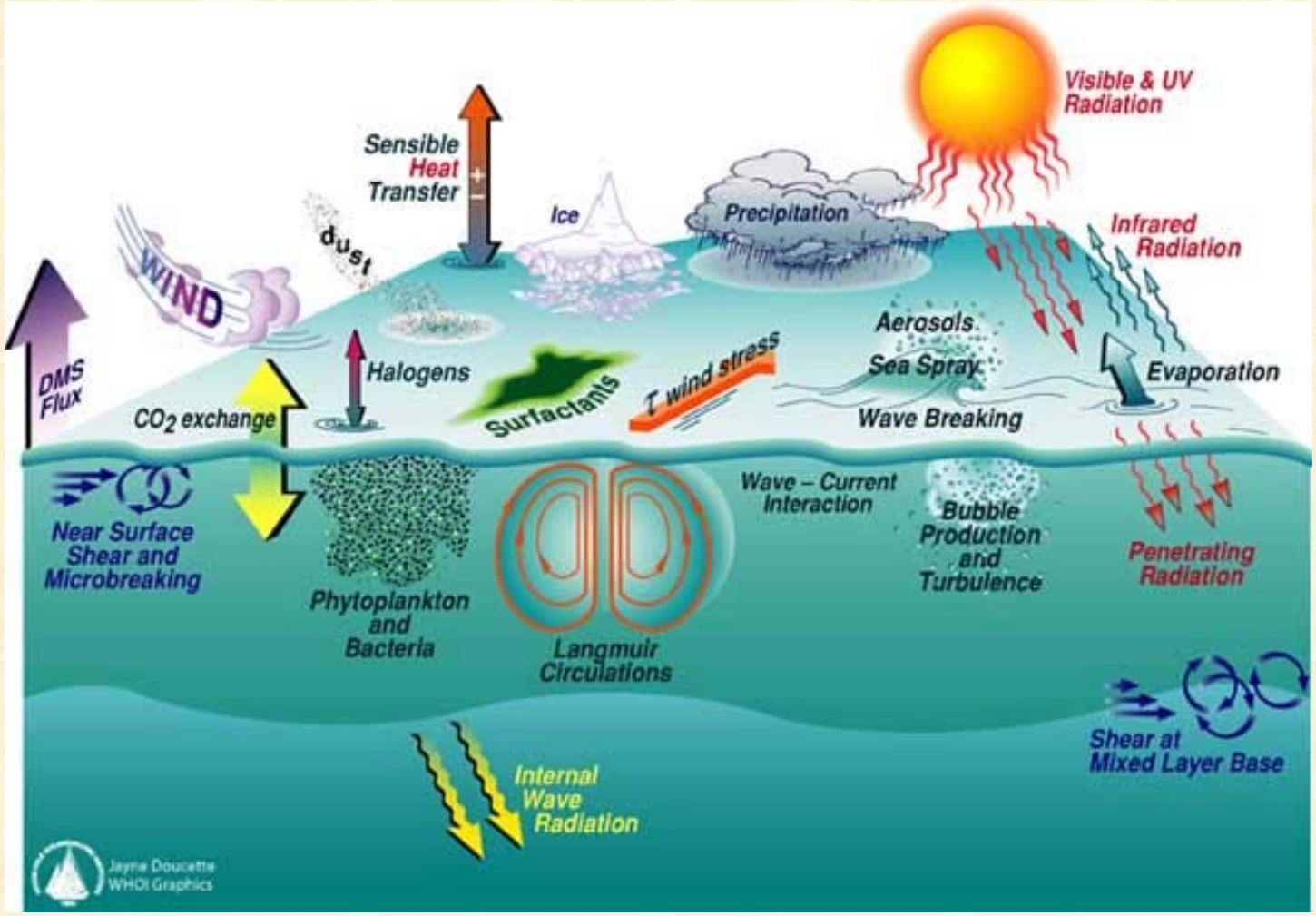
Time Trend of Cluster Changes (1870-2100)

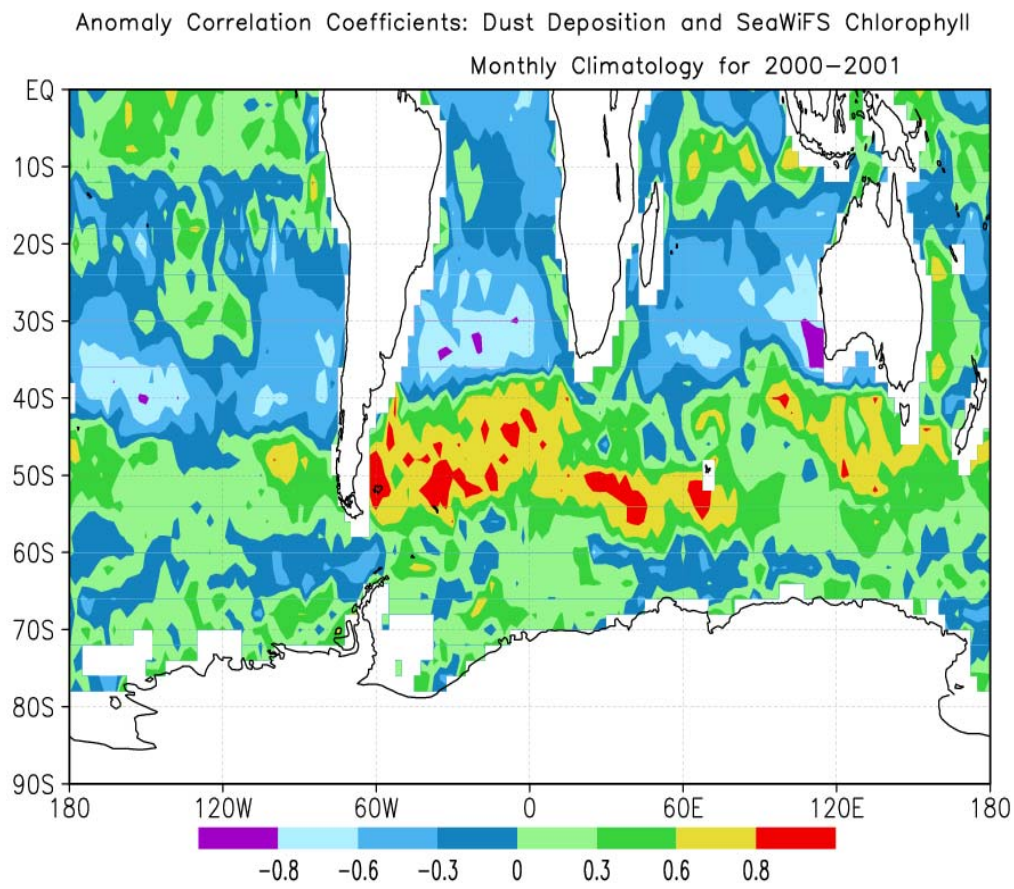


Case Study #2: Coupling Climate Models with NASA Satellite Data

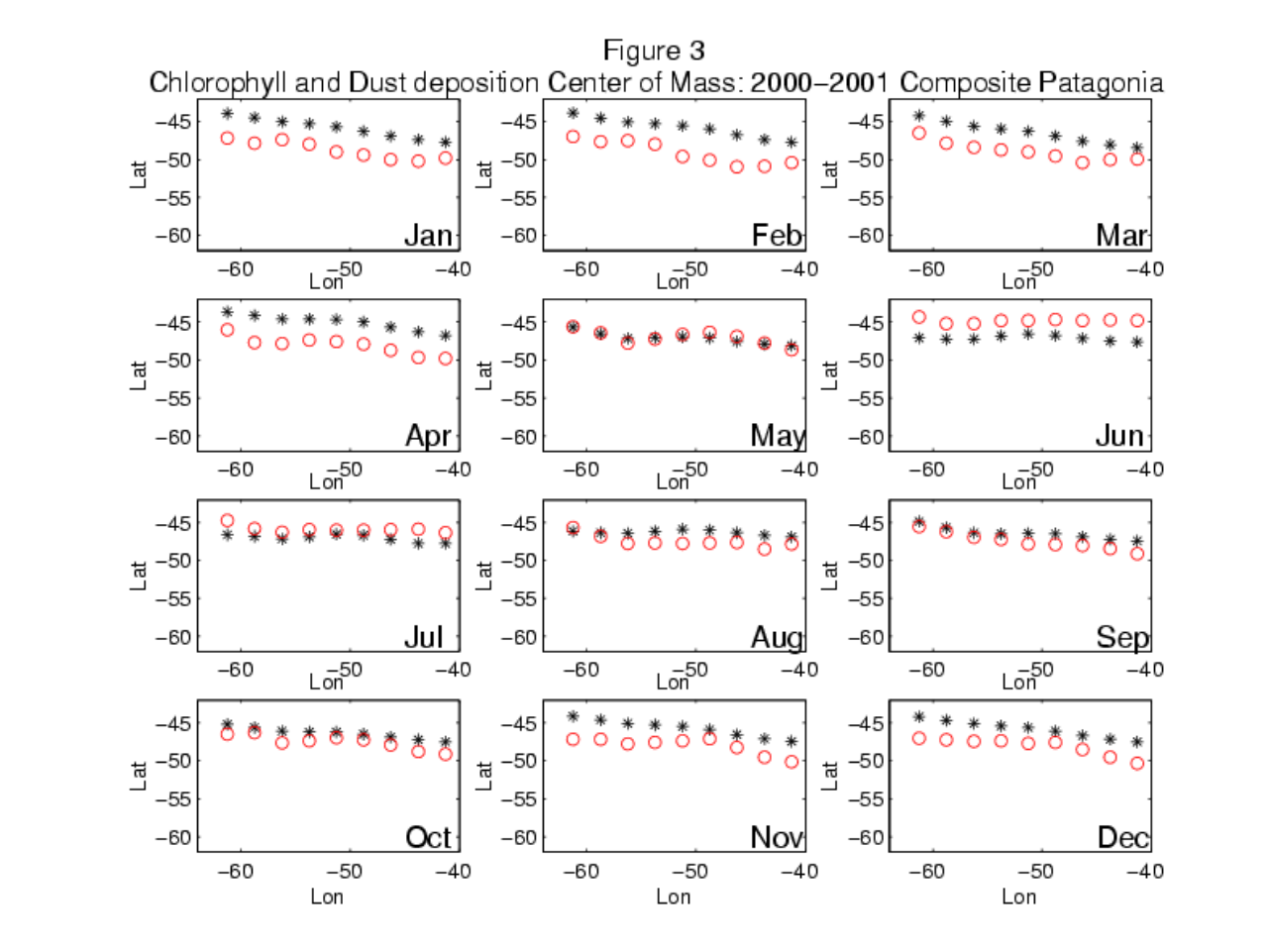
- Global Atmospheric Dust Simulation Based on NASA DAS (Ginoux et al., 2001)
- Coupled for statistical analysis with SeaWifs ocean color

Surface Ocean Lower Atmosphere Study (SOLAS)

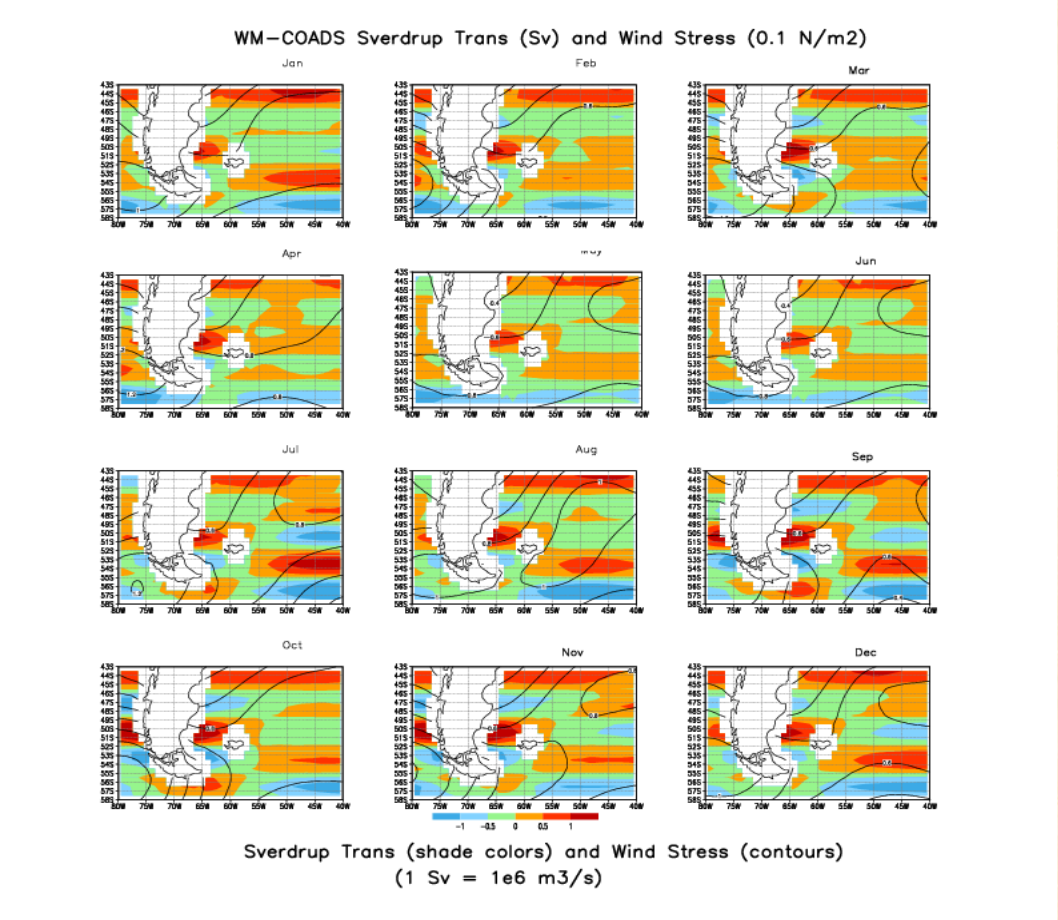



Anomaly Correlation Coefficients: Dust Deposition and SeaWiFS Chlorophyll
Monthly Climatology for 2000–2001
EQ
10S
20S
30S
40S
50S
60S
70S
80S
90S
180
120W
60W
0
60E
120E
180
−0.8
−0.6
−0.3
0
0.3
0.6
0.8

Centroid of Fe Flux and Ocean Color (o=ocean color x=Fe Flux)

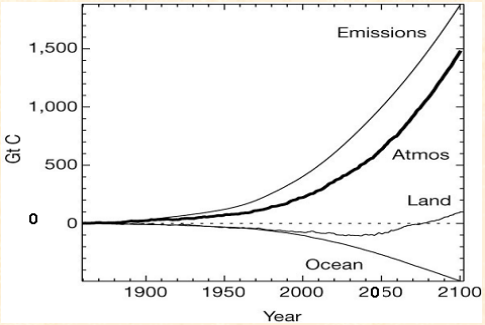


Sverdrup Transport (red=Northward)

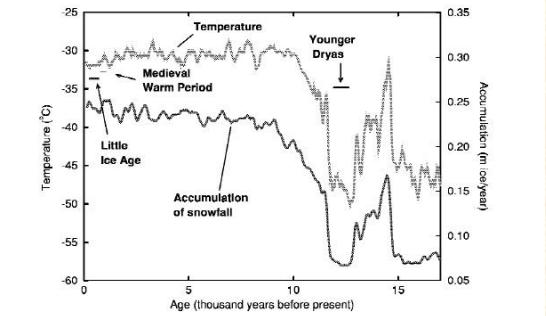


Three Focused Basic Science Research Tasks

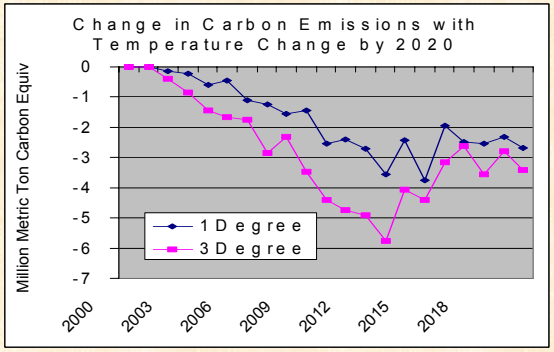
- **Carbon cycle feedbacks**
  - a) temperature acclimation
  - b) diffuse radiation



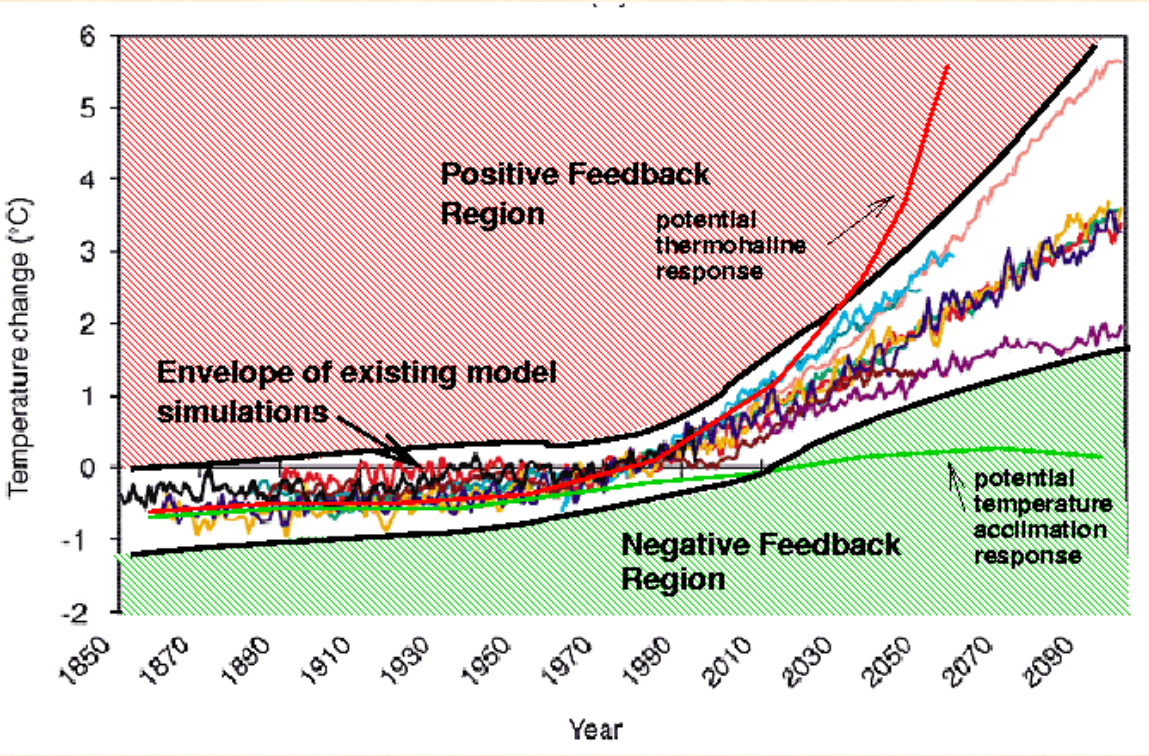
- **Water cycle feedbacks**
  - a) ocean circulation
  - b) soil moisture



- **Energy/economics feedbacks**
  - a) heating/cooling day change
  - b) technology adaptation

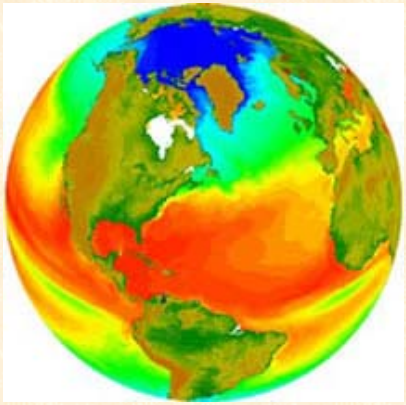


Climate Feedbacks May Result in 'Outside the Envelope' Results



Computed global mean temperature for the time period 1850 – 2100

Path for Input of New Climate Feedback Theory



Climate Feedback Theory

↓

Theory (Method Development)

↓

Algorithm Development

↓

Preliminary Design Phase

↓

Prototyping (Implementation)

↓

Detailed Design Phase

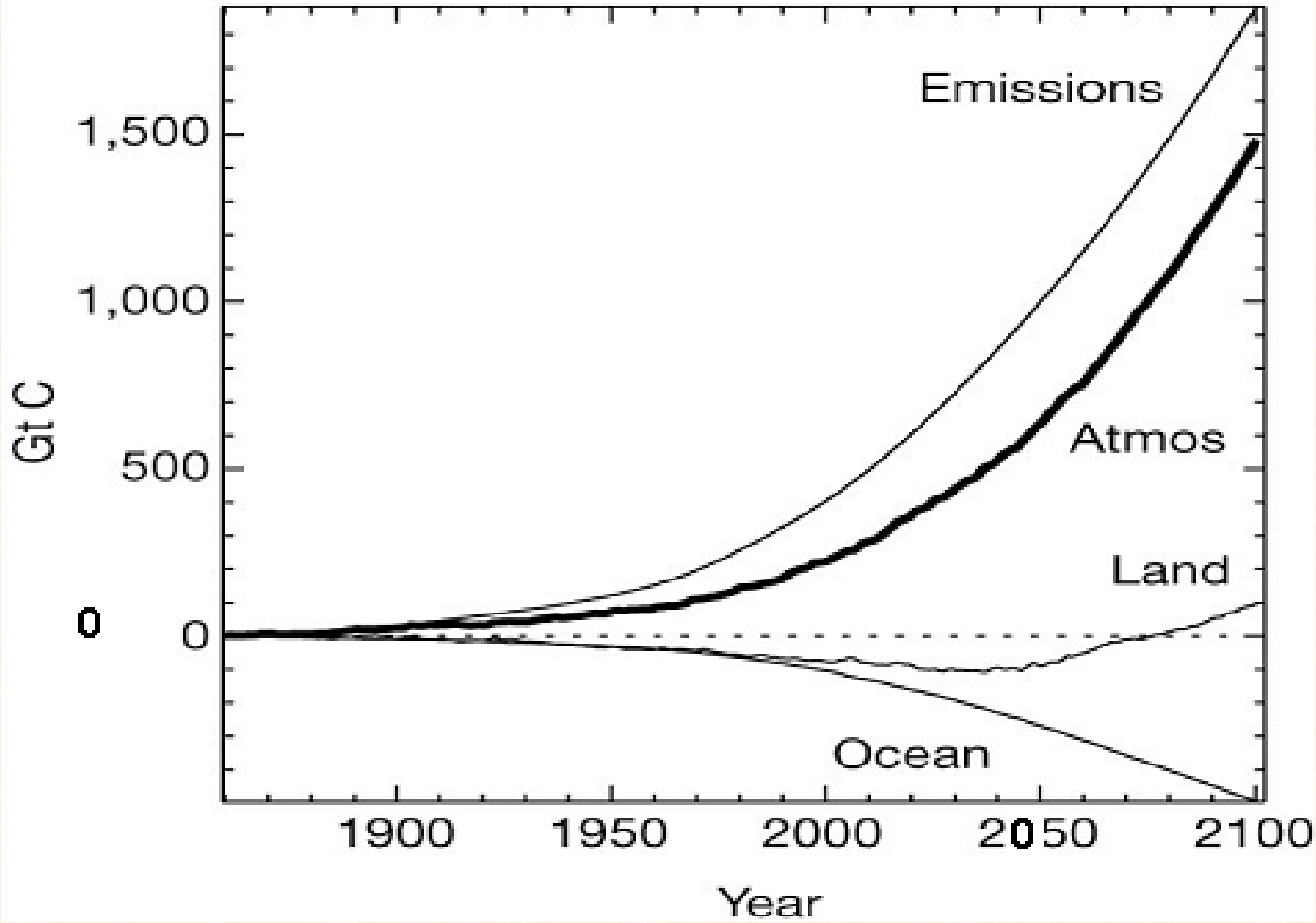
↓

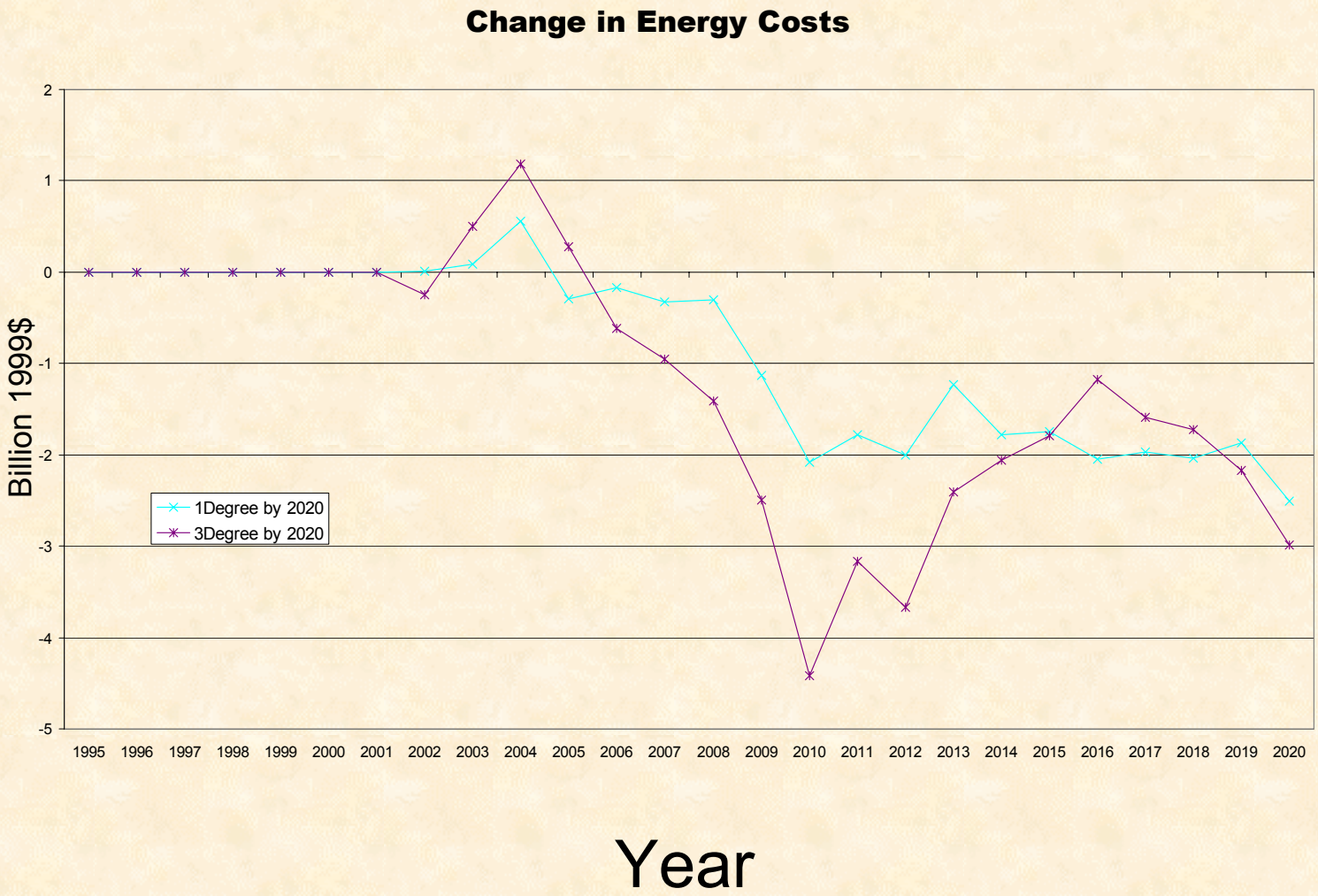
Implementation Phase

↓

New Climate Model Simulations

Cox et al., Nature




Change in Energy Costs
Billion 1999$
2
1
0
-1
-2
-3
-4
-5
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
1Degree by 2020
3Degree by 2020
Year

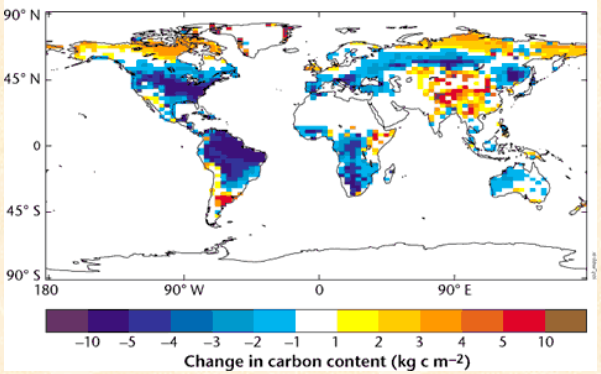
SciDAC Enabling Technologies

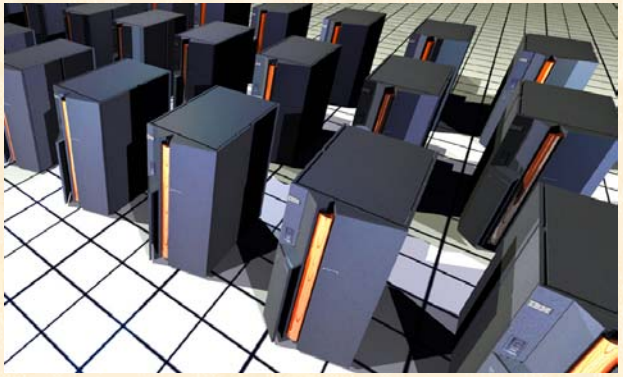
Leveraged ORNL expertise in enabling technologies to create the infrastructure for the Climate and Carbon Research (CCR) science research focus

- **Model coupling framework**
  - CCSM2 National coupled climate model
  - NASA ESMF - allow parallel models to plug together
- **Collaborative technologies**
  - Earth System Grid
  - Provides transparent access to analysis capabilities for researchers throughout the country
- **Integrated Software Infrastructure Centers**
  - Algorithms, solvers, applied mathematics

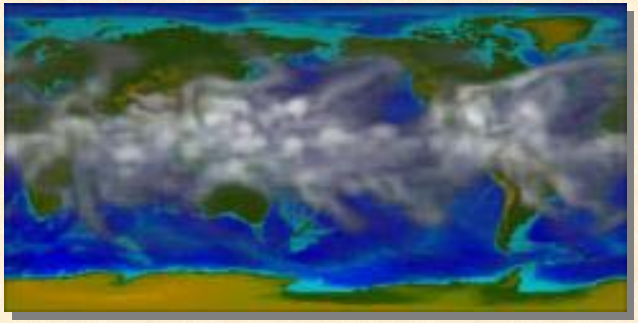
Why DOE and ORNL?

- DOE mission is to predict climate on decadal to century time scales
- Global carbon cycle prediction is an imperative for DOE
- Significant resources allocated to the hardware side of computational sciences by MICS
- The CCR has been created to build a national climate and carbon science base to policy and technology decision support



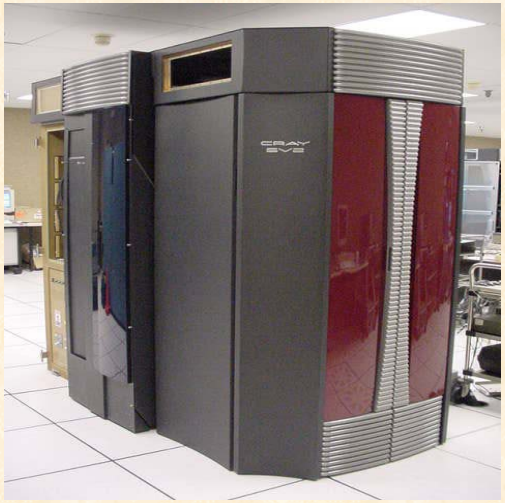


Why Now?



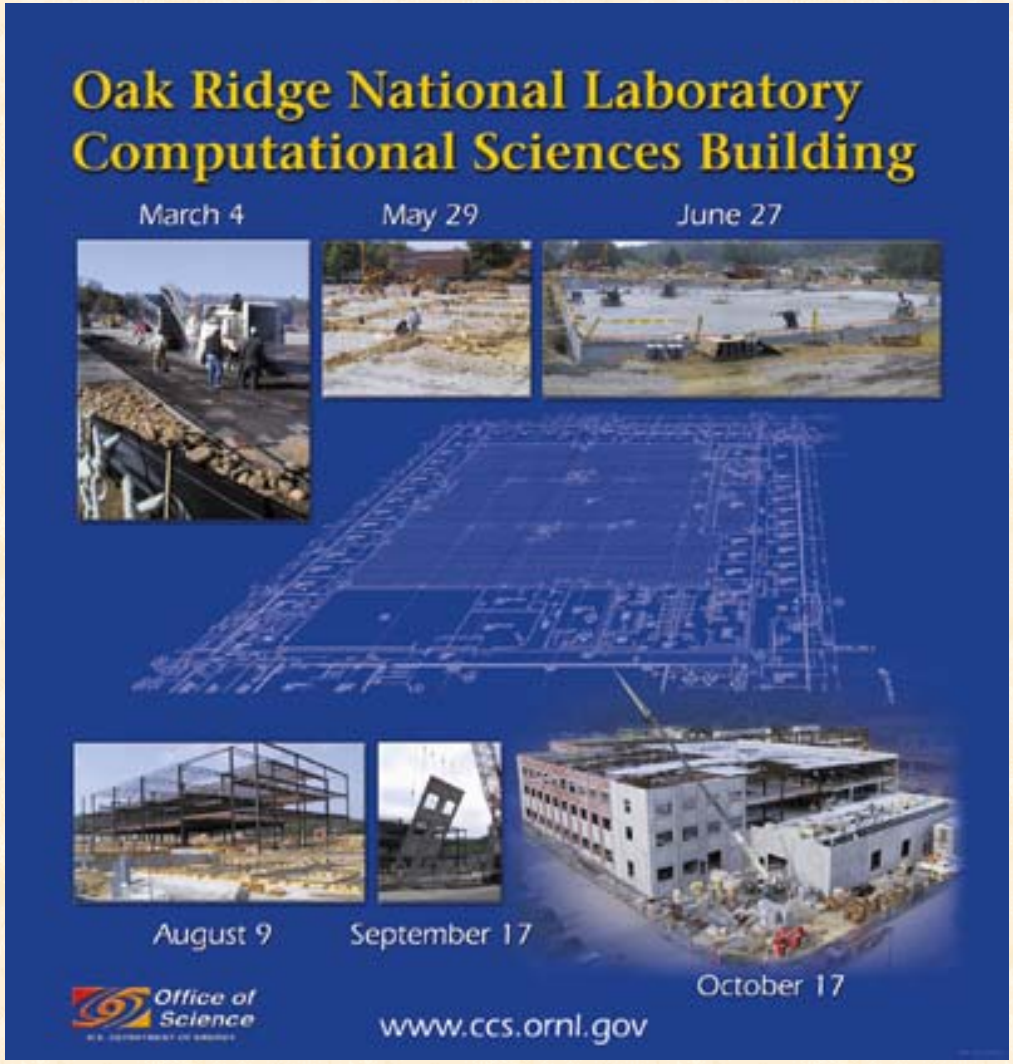
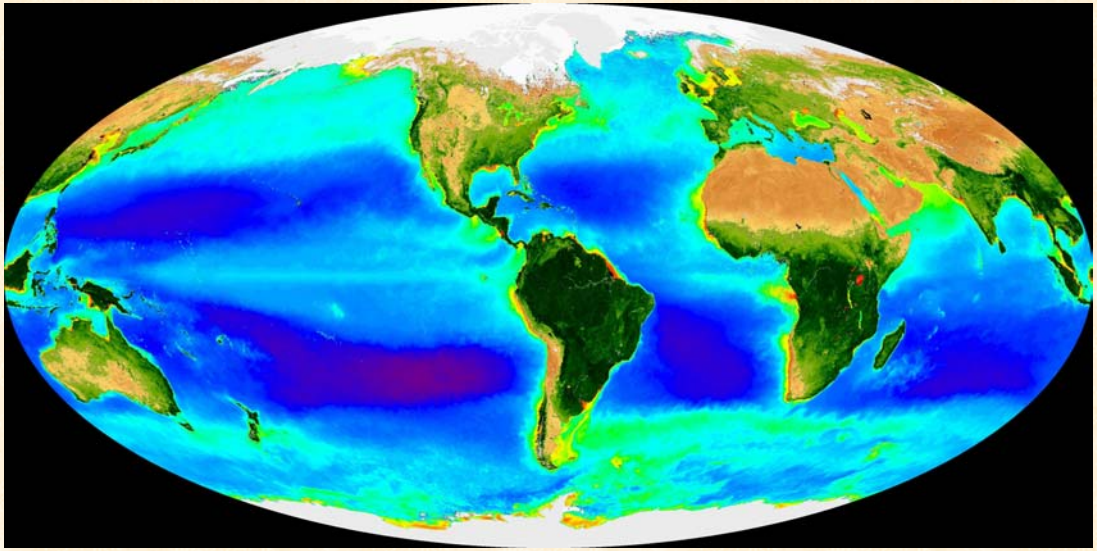
- The science of climate, carbon, water and energy prediction is new
- Accelerated Climate Prediction Initiative/SCIDAC provide enabling technologies
- Japanese Earth simulator response: Computer platforms ~$500M
- Collaborators are LBL, PNNL, ANL, LANL, LLNL, core universities, NASA, NCAR and other national laboratories

SciDAC
Scientific Discovery through Advanced Computing
DOE Office of Science ASCR BER BES FE HENP MICS



Downstream opportunities

- Demonstrate scientific value of US response to Japanese Earth Simulator at ORNL ($500M)
- Climate Change Research Initiative
- Technology adaptation (NCCTI)
- JICS/Core university climate science adds to ORNL expertise
- 2005 National Assessment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