SciDAC
Scientific Discovery through Advanced Computing

Office of Science
U.S. DEPARTMENT OF ENERGY

COLLABORATIVE DESIGN AND DEVELOPMENT OF THE COMMUNITY CLIMATE SYSTEM MODEL FOR TERASCALE COMPUTING (CDDCCSMTC)

Hereinafter referred to as the CCSM Consortium

Bob Malone, Phil Jones (LANL)

John Drake (ORNL)

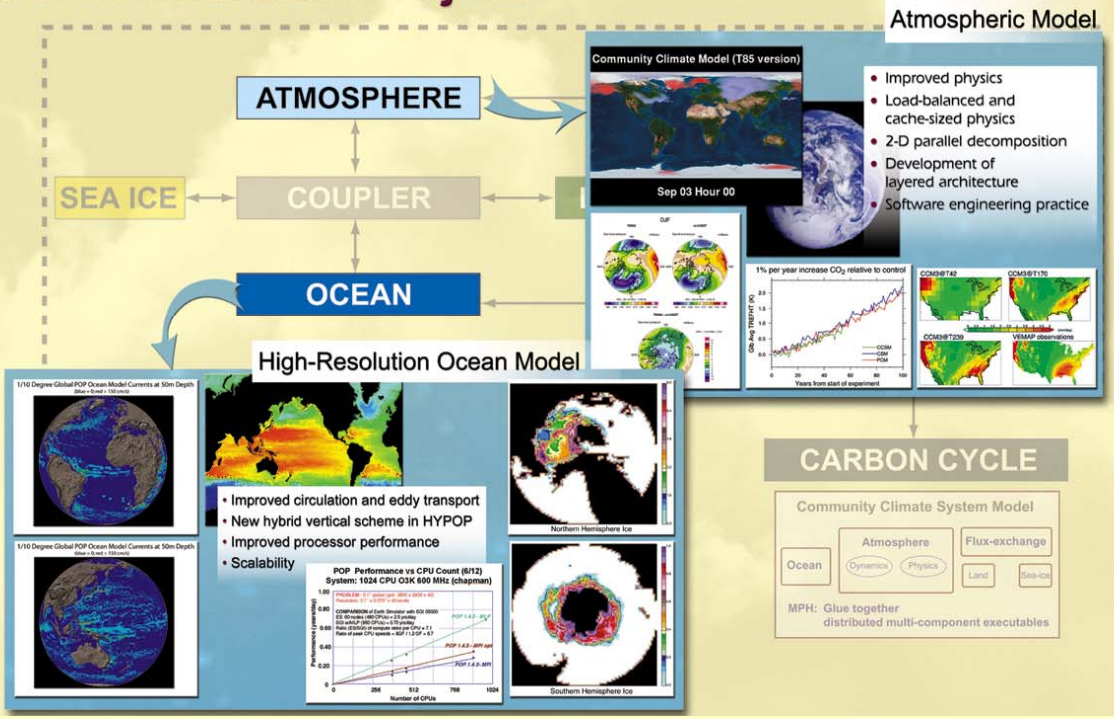
On behalf of all the consorts

Community Climate System Model Consortium Project

Building a fully coupled, global climate model that provides state-of-the-art computer simulations of theEarth's past, present, and future cimate states

	PNNL	Pacific Northwest
L	ANL	Los Alamos
NCA	R	National Center of Atmospheric Research
	ANL	Argonne
	LLNL	Lawrence Livermore
ORN	L	Oak Ridge
DO	E	Department of Energy
	LBNL	Lawrence Berkeley

DOE, NSF, and NASA working together to build the Community Climate System Model



The SciDAC CCSM Consortium consists of **PI:** R. Malone[4], J. Drake[5] , **Site-Contacts:** C. Ding[2], S. Ghan[6], D. Rotman[3], J. Taylor[1], J. Kiehl[7], W. Washington[7], S.-J. Lin[8], **Co-Is:** J. Baumgardner[4], T. Bettge[7], L. Buja[7], S. Chu[4], T. Craig[7], P. Duffy[3], J. Dukowicz[4], S. Elliot[4], D. Erickson[5], M. Ham[5], Y. He[2], F. Hoffman[5], E. Hunke[4], R. Jacob[1], P. Jones[4], J. Larson[1], J. Lamarque[7], W. Lipscomb[4], M. Maltrud[4], D. McKenna[7], A. Mirin[3], W. Putman[8], W. Sawyer[8], J. Schramm[7], T. Shippert[6], R. Smith[4], P. Worley[5], W. Yang[2]

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Science Goals

- Assessment and prediction
  - IPCC, national assessments
  - Energy policy implications
- Regional climate prediction
  - High resolution, downscaling, water
- Atmospheric chemistry/ocean biogeochemistry
  - Carbon cycle
  - Aerosols

Project Goals

- Software
  - Performance portability
  - Software engineering (repositories, standardized testing – No Code Left Behind initiative)
- Model Development
  - Better algorithms
  - New physical processes (esp. chemistry, biogeochemistry)

Coupler Architecture

New Issues:

- **Single executable**
- **Naming conflicts, eg. POP_initial**
- **Chemical fluxes**
- **Vectorization: performance, performance, performance**
- **Single run - ensemble simulation**

Version 1.0 Released November 2002

- **MPH3 (Multi-Processor Handshaking)**
- **Model Coupling Toolkit (MCT)**
- **CPL6 -- Implemented, Tested, Deployed (Old news…)**
- **ESMF/CCA Demos**

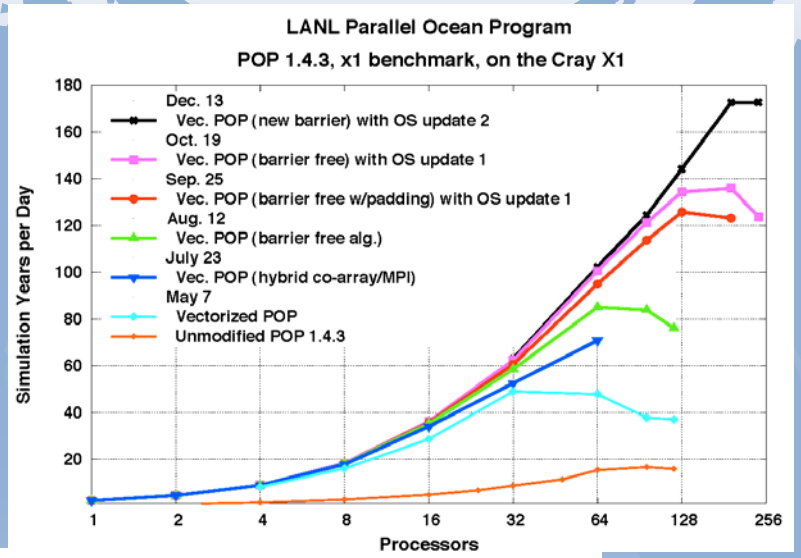
DOE(and NSF) SciDAC Efforts on Porting CCSM to the CRAY X1

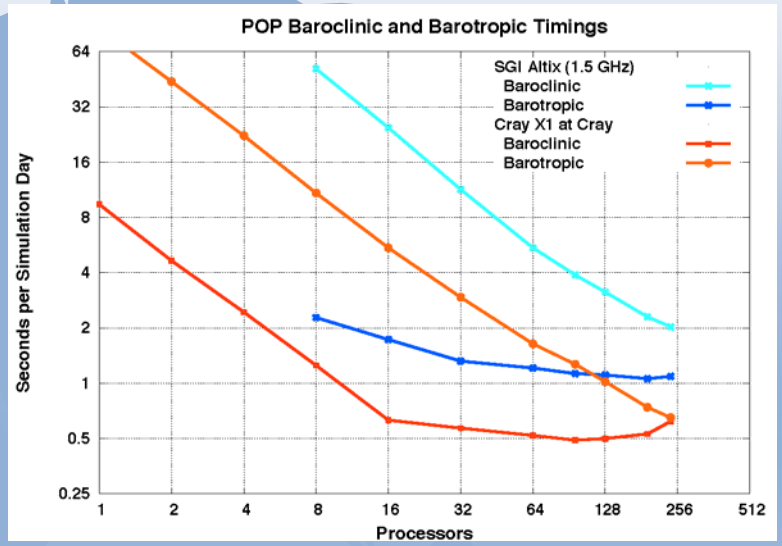
- **Organizational workshop ORNL/LANL/CRAY held Nov2002**
- **Follow on workshops Feb2003 in Boulder, June2003 in Breckenridge, …, May2004 Boulder**
- **Represented: NCAR, NASA-GSFC, ORNL, LANL, LBNL, Cray, NEC, Fujitsu, CRIEPI**
- **Goals**
  - Implement vector version of CCSM3
  - Achieve production readiness for impact on IPCC simulations.
  - Coordinate vectorization efforts
- **Cray partnership team: Ilene Carpenter, John Levesque, Matt Cordery**
- **ORNL team: Pat Worley, Forrest Hoffman, Trey White, John Drake**
- **LANL team: Phil Jones, Phil Lipscomb**
- **NCAR team: Tony Craig, Brian Eaton, Tom Henderson, Mariana Vertenstein**
- **NEC team: Yoshikatsu Yoshida, Dave Parks, John Snyder**
- **CCSM3 release June 2004 with MPP/vector and cache support**

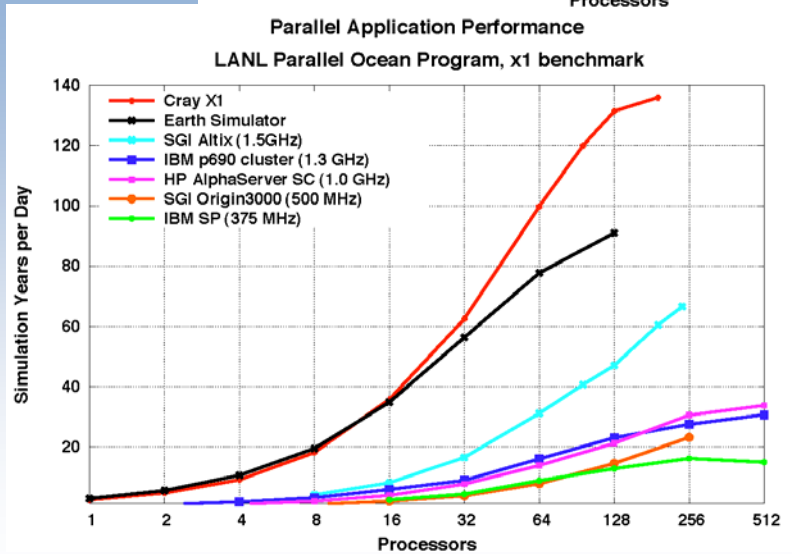
Performance Portability

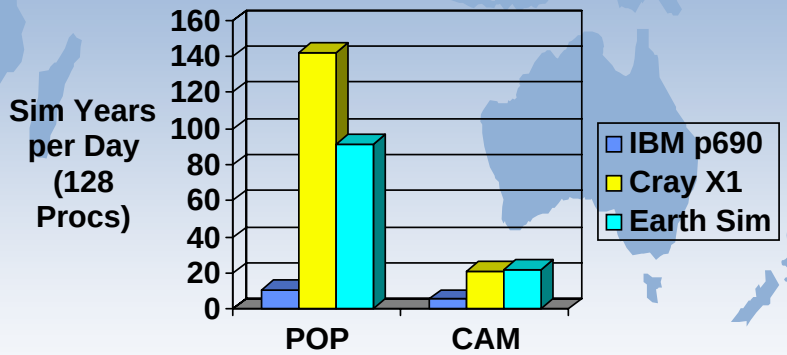
- Vectorization
  - POP, CICE easy (forefront of retro fashion), POP2
  - CLM rewritten
  - CAM required some effort
- Blocked/chunked decomposition
  - Sized for vector/cache
  - Load balanced distribution of blocks/chunks
  - Land elimination in POP2
  - Hybrid MPI/OpenMP
- Performance modeling w/ SciDAC PERC project

Performance

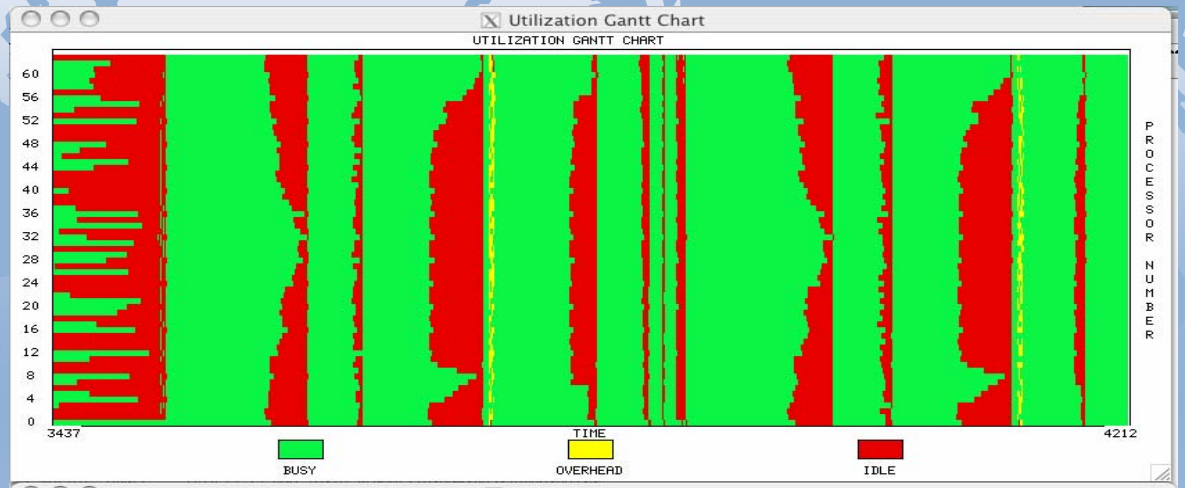


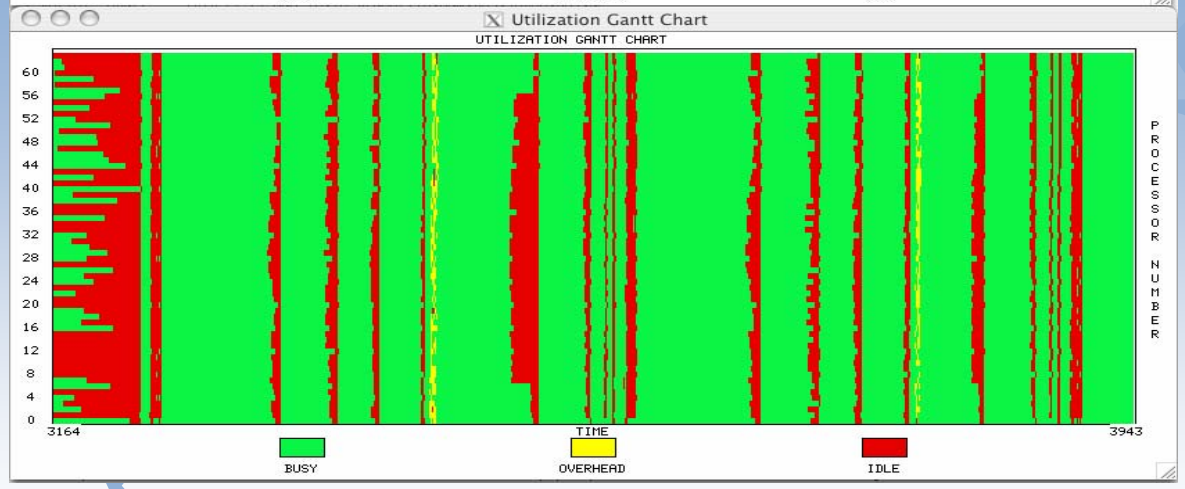






CAM Load Balance Results





Lin-Rood Optimization
A. Mirin

- Objectives
  1. MPI performance of the 1-D (latitudinal) decomposition,
  2. MPI performance of the multi-2D decomposition methodology, and
  3. OpenMP performance.
- Results

Atmospheric Model Summary

- CAM porting, optimization, and performance evaluation work on the
  - Cray X1, SGI Altix
  - IBM p690 cluster (Colony and Federation)
  - NEC SX (wotking with Eaton, Parks and Snyder)

- Development activities
  - vectorization (Cray and NEC) and merge with development branch
  - special load balancing algorithms targeting SMP clusters
  - "optimal" static load balancing
  - collective communication options for spectral dycores
  - runtime tuning options for communications in physics and spectral dycores (SWAP library).
  - aggregating collective communication calls in the physics.
  - evaluating library FFT calls for use in CAM (not important currently)

- FV Core on IBM NHII in lat-vert decomposition
- DAO's mod_comm replacing PILGRIM
- Modcom unification steps
- Blocked dynamics interface in EUL and SLD

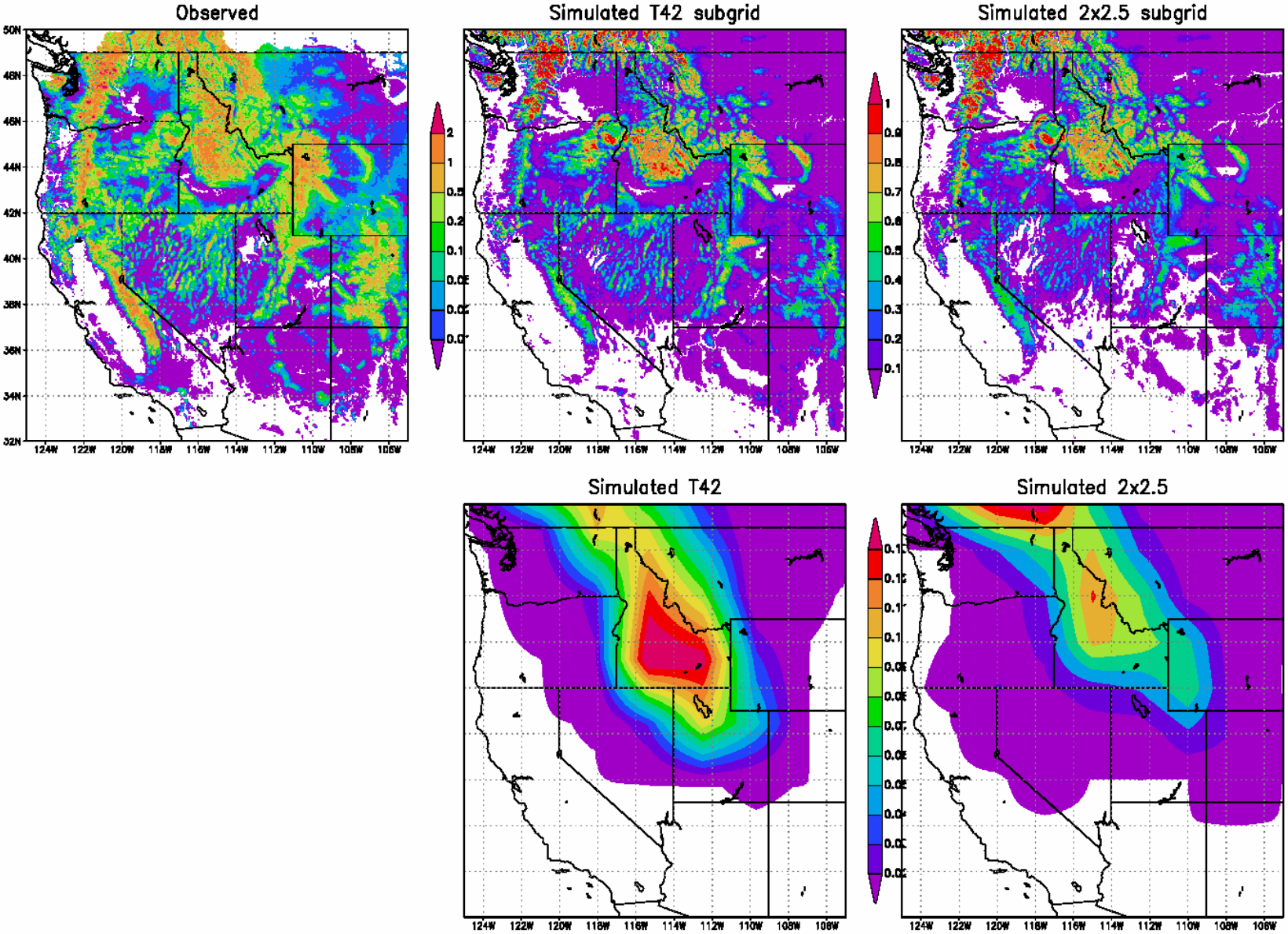
Community Atmospheric Model Plans (May04)

- Continue Optimizations for IPCC
  - Vector version for Cray X1 and NEC SX7 (June 2004)
  - IBM p690 improvements
- Increased resolution for spectral cores
  - SLT 2-D decompositions October 2004
  - SLD reduced grid Dec 2004
  - SLD lagrangian vertical coordinate June 2005
  - SLD new advection (incremental remapping?) October 2005
- Toward a chemical atmosphere model
  - Increased resolution (B ->D) for Lin-Rood Oct 2004
  - WACCM configurations, chemistry, vectorization Oct 2004
  - Advection optimization Dec 2004
- IPCC Simulations with subgrid orography Jan 2005
- T170 Eulerian and FV (D-grid) downscaling of selected IPCC runs
- Implications of SP-CAM
- Revision of software design and the Unified Model
  - Block/ESMF dycores Dec 2004
  - Utility layer standardization March 2005

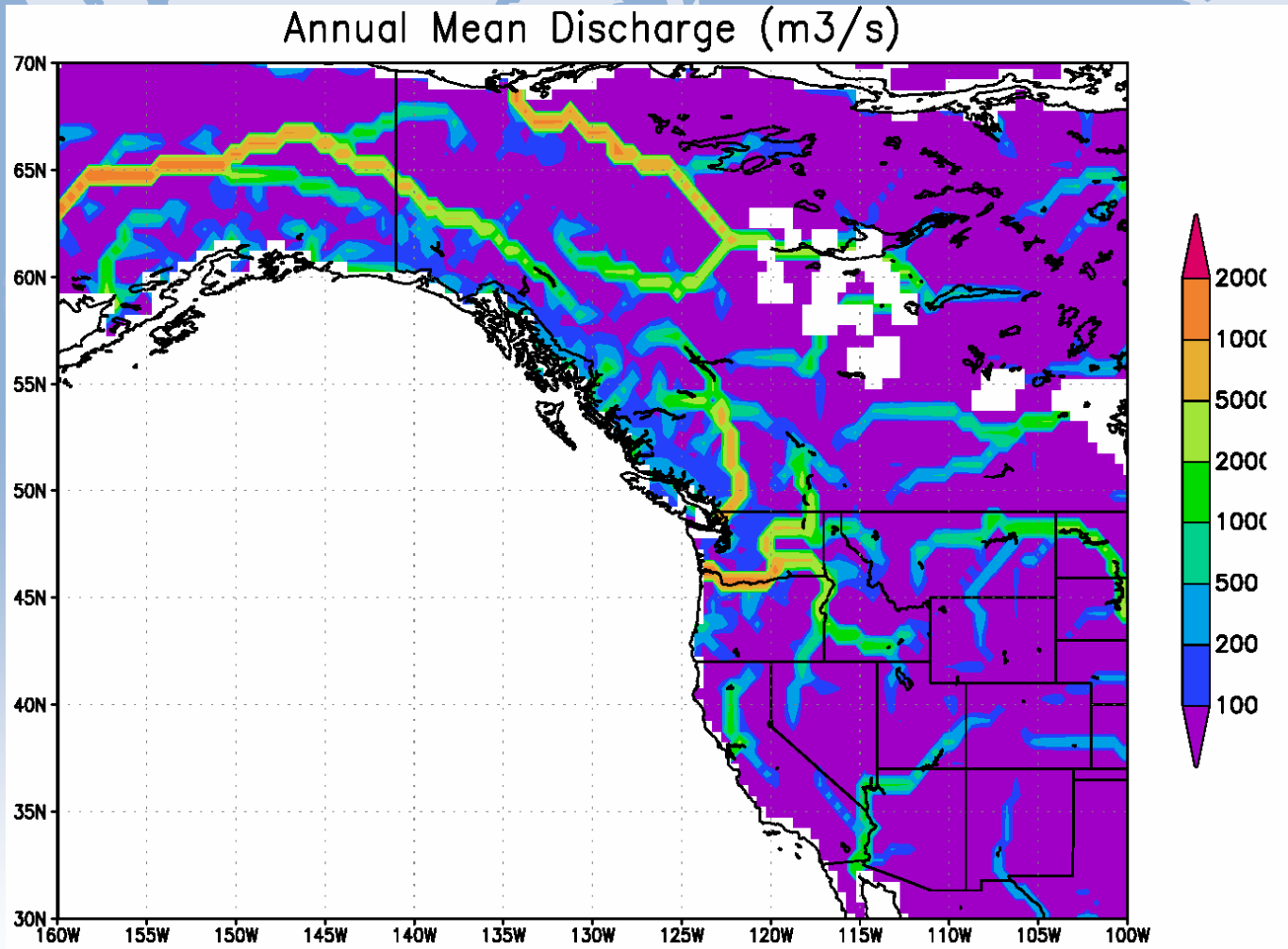
- Single executable CCSM (with NCAR people) Completion date: October 2004.
A prototype codes has been done and
sent to NCAR.

- Integrating parallel netCDF into Ziolib Complete: Nov 2004.
- Incorporating ZioLib into CAM: Completion date: December 2004.

March Snow Water Equivalent (m)



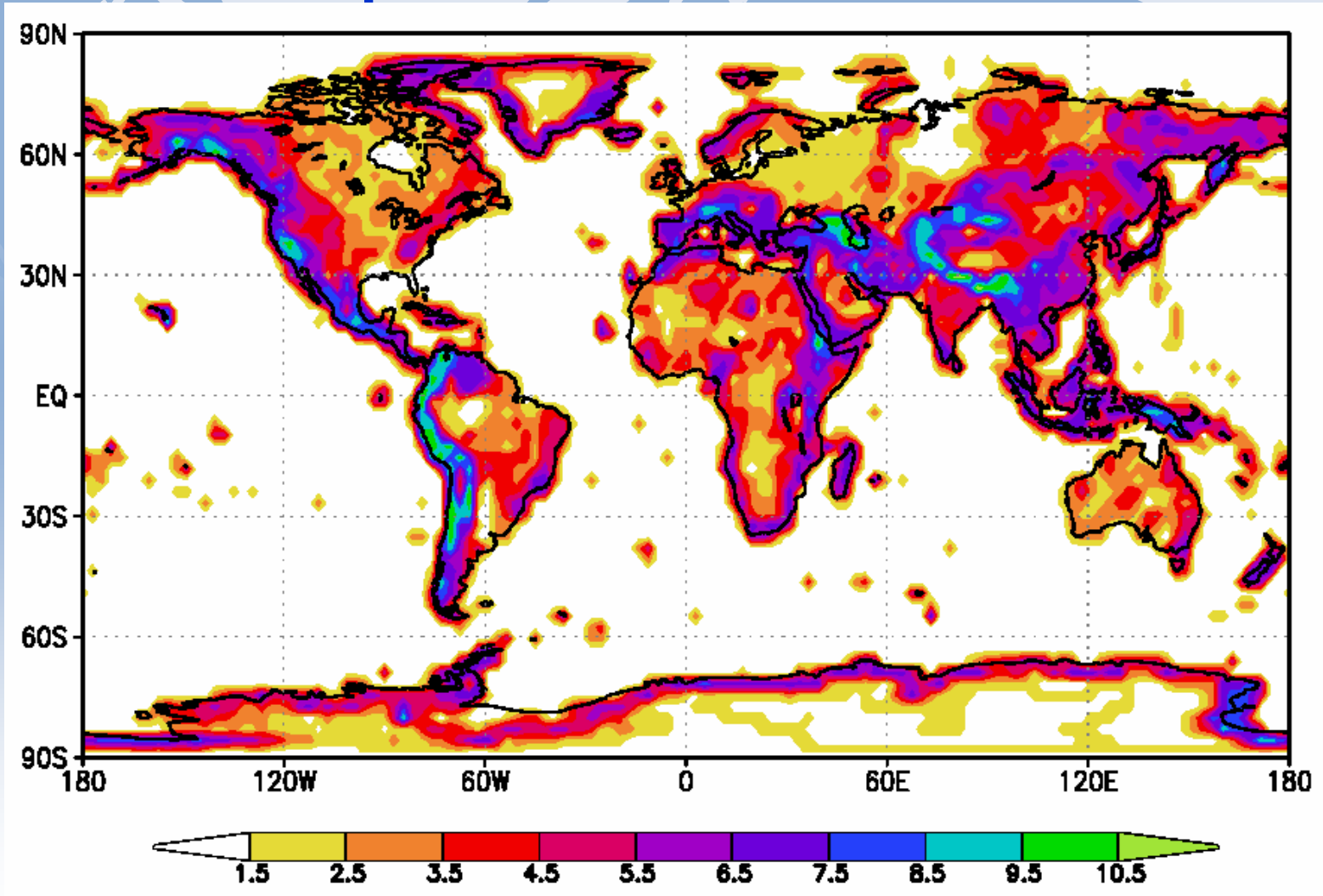
River Discharge



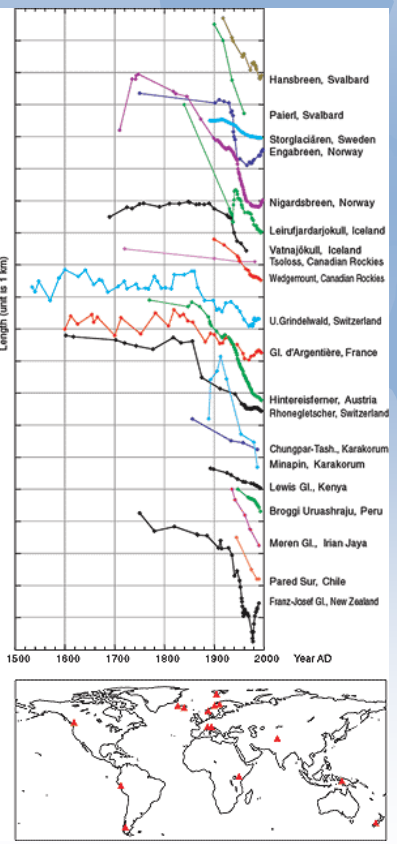
Code Changes

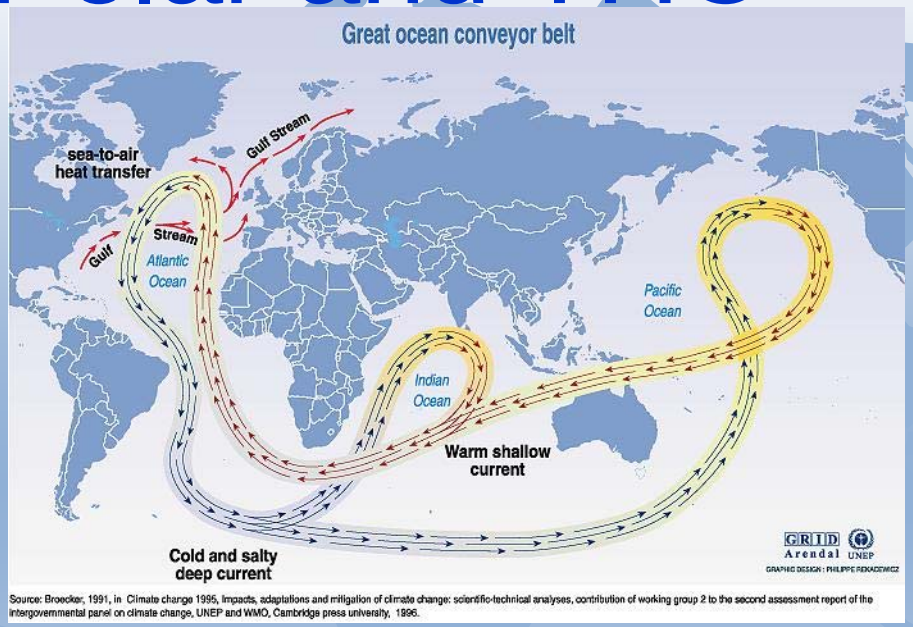
- Unlike any other parameterization
  - All column physics applied to each elevation class
- Mostly manifest at higher levels
  - phys_grid
    - phys_grid_init
    - create_chunks
    - scatter_field_to_chunk
    - gather_chunk_to_field
  - phys_types
  - dp_coupling
  - history

Computational Burden

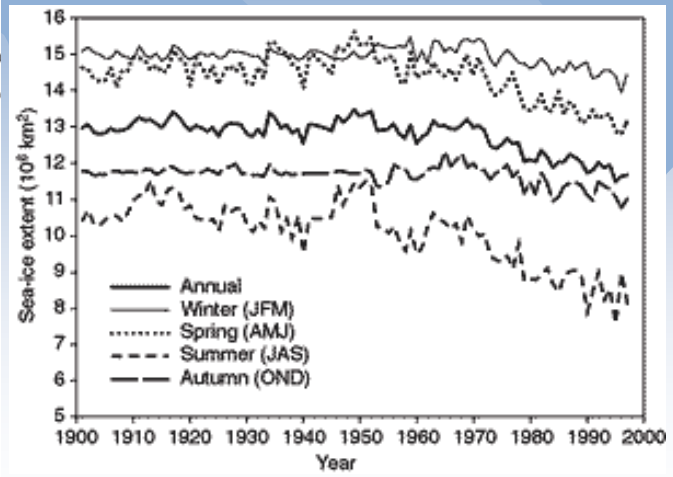


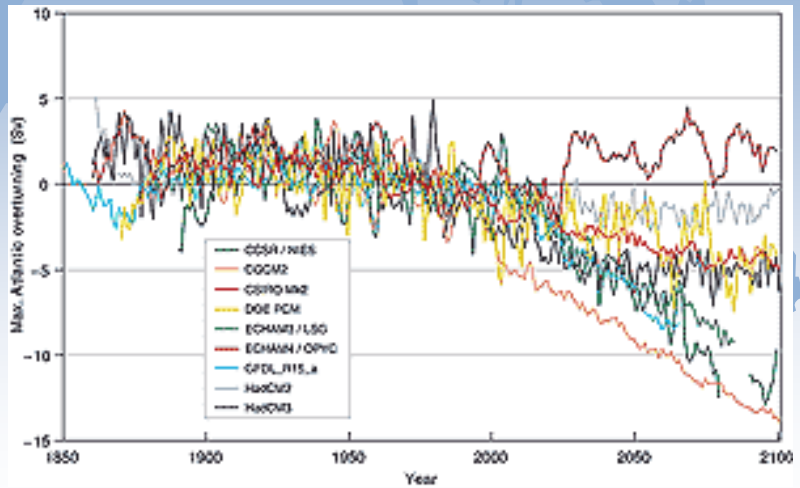
Polar and THC





Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

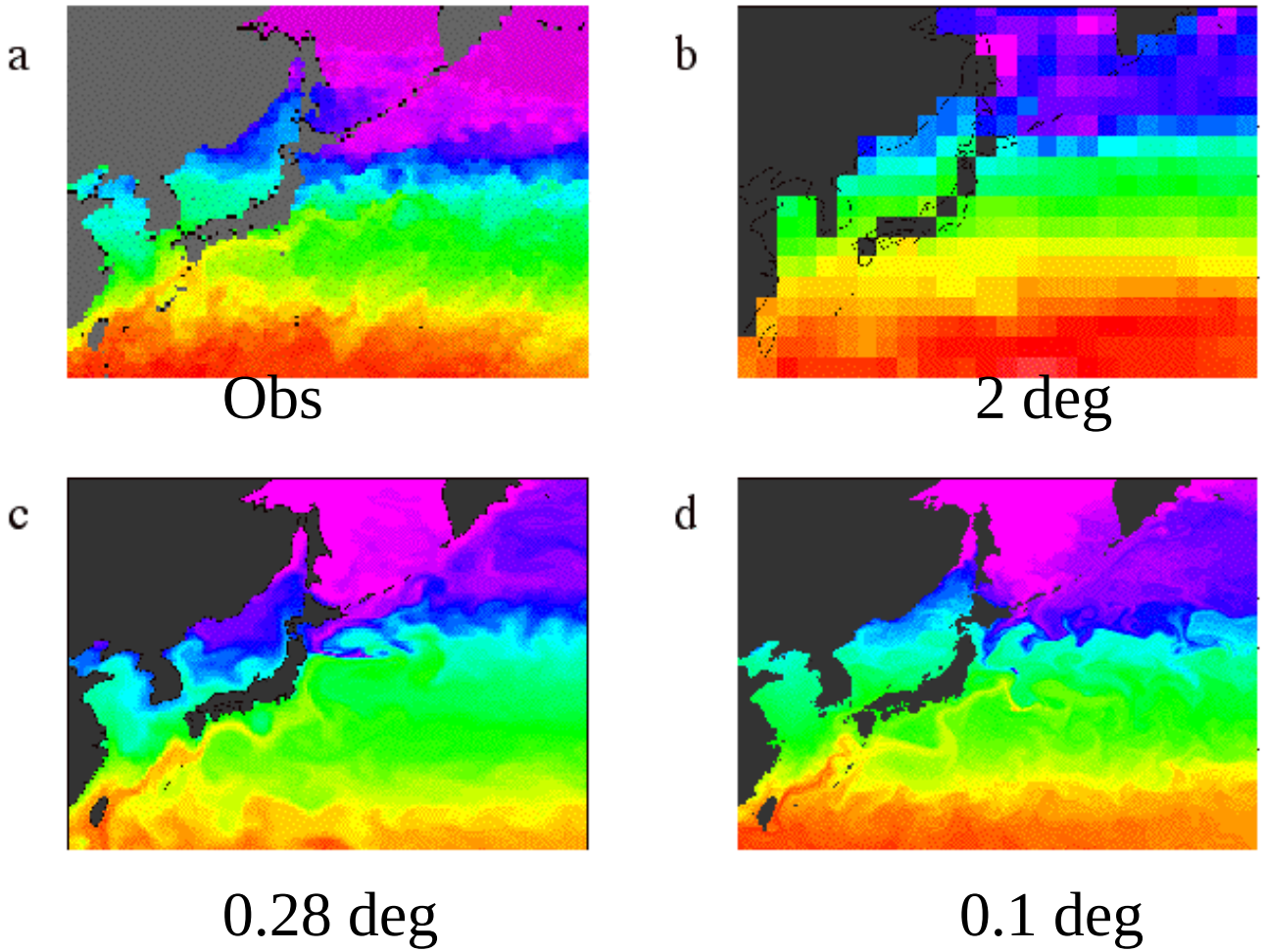




HYPOP

- Arbitrary Lagrangian-Eulerian vertical coordinate
  - Keep Lagrangian in deep ocean
  - Remap to z-coordinate in mixed layer
  - CSU SciDAC
- New time stepping/mode splitting
- Progress
  - Model currently working in z-coord mode
  - Examining vertical grid generators
  - Testing

Eddy-Resolving Ocean

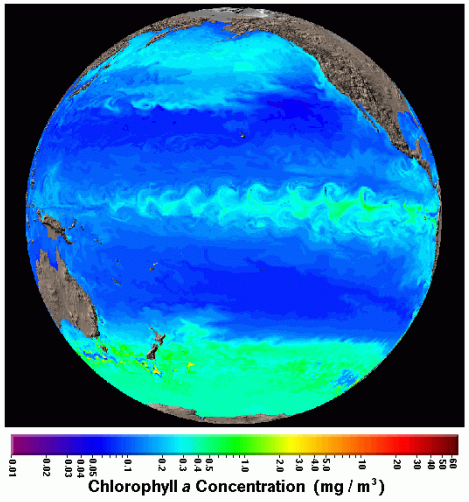


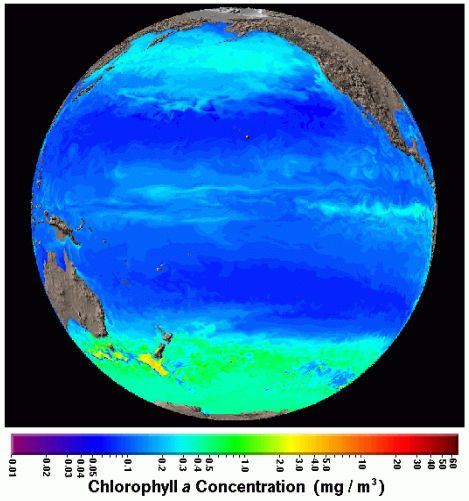
Ocean Biogeochemistry

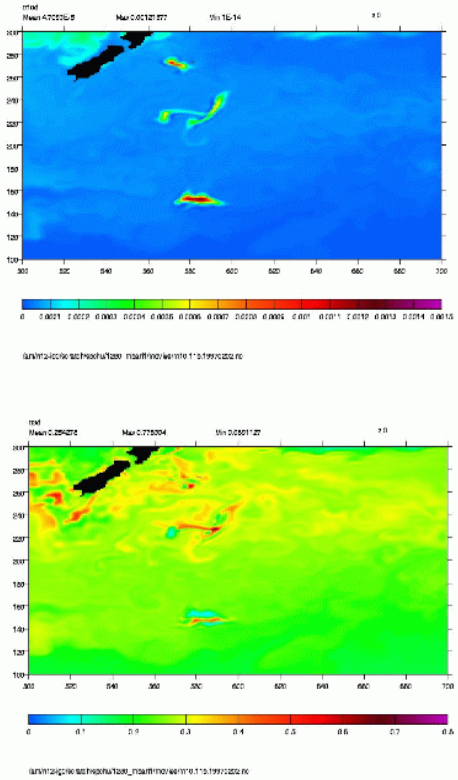
- LANL Ecosystem Model
  - nutrients (nitrate, ammonium, iron, silicate)
  - phytoplankton (small, diatom, coccolithophores)
  - zooplankton
  - bacteria, dissolved organic material, detritus
  - dissolved inorganic carbon (DIC), alkalinity
  - trace gases (dimethyl sulfide, carbonyl sulfide, methyl halides and nonmethane hydrocarbons)
  - elemental cyclings (C,N,Fe,Si,S)

Ocean Biogeochemistry

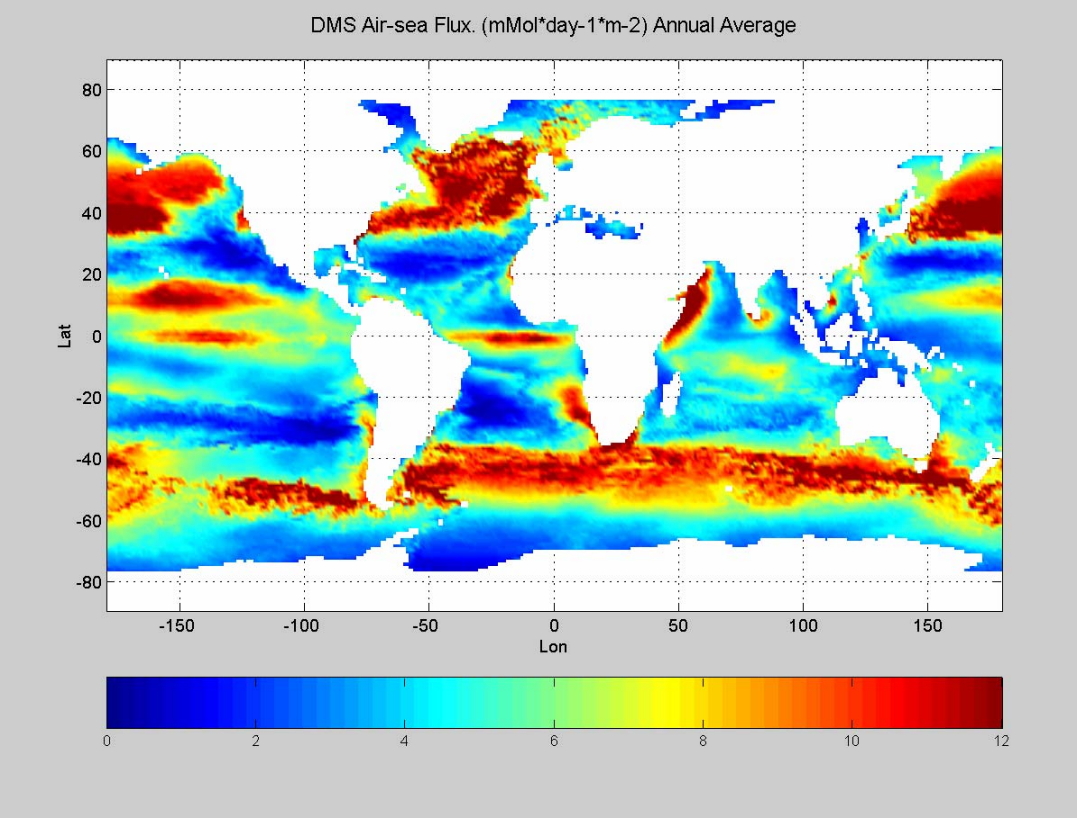
- **Iron Enrichment in the Parallel Ocean Program**
- **Surface chlorophyll distributions in POP for 1996 La Niña and 1997 El Niño**







Global DMS Flux from the Ocean using POP



The global flux of DMS from the ocean to the atmosphere is shown as an annual mean. The globally integrated flux of DMS from the ocean to the atmosphere is 23.8 Tg S yr-1

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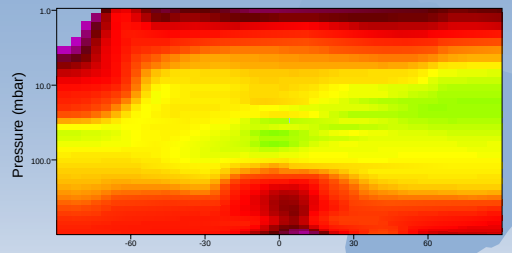
Atmospheric Chemistry

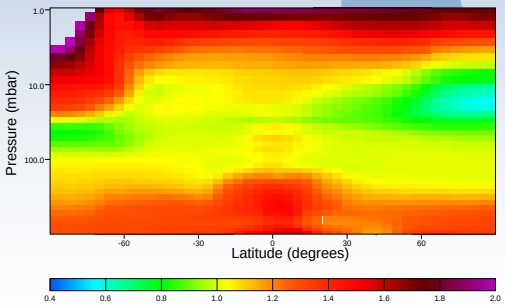
- **Gas-phase chemistry with emissions, deposition, transport and photo-chemical reactions for 89 species.**
- **Experiments performed with 4x5 degree Fvcore – ozone concentration at 800hPa for selected stations (ppmv)**
- **Mechanism development with IMPACT**
  - **A) Small mechanism (TS4), using the ozone field it generates for photolysis rates.**
  - **B) Small mechanism (TS4), using an ozone climatology for photolysis rates.**
  - **C) Full mechanism (TS2), using the ozone field it generates for photolysis rates.**

A)

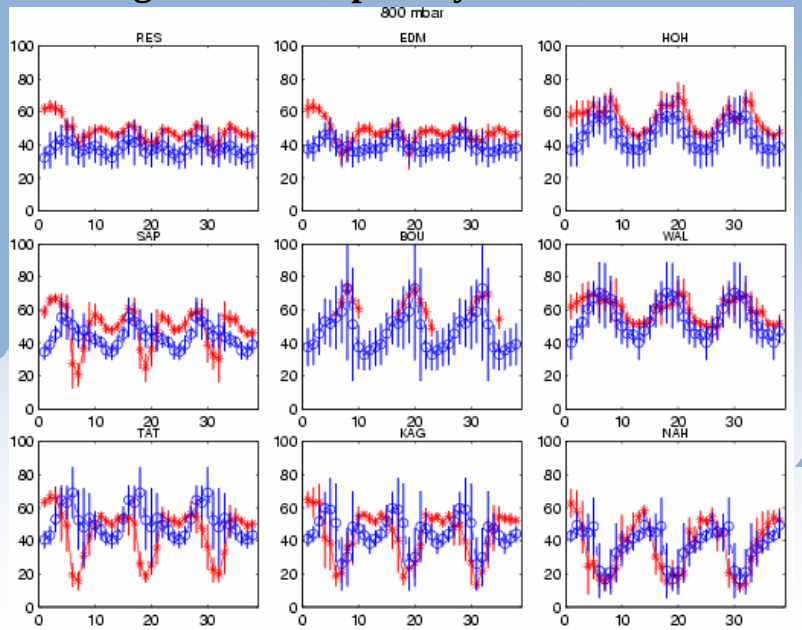


Zonal mean Ozone, Ratio A/C

B)

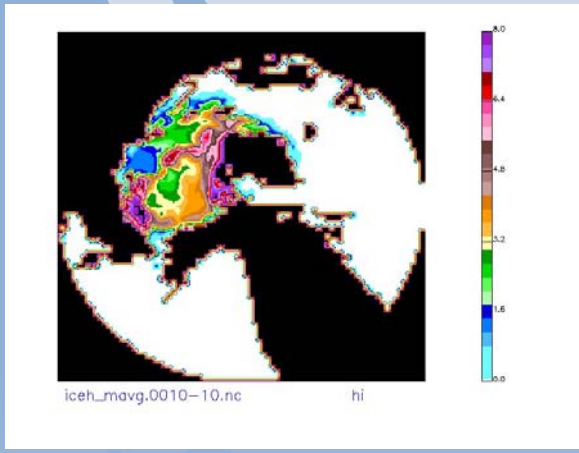


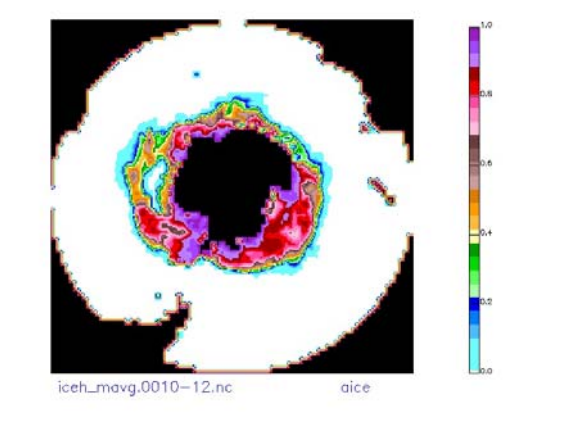
Zonal mean Ozone, Ratio B/C



CICE

- **Incremental Remapping for Sea Ice and Ocean Transport**
  - Incremental remapping scheme that proved to be three times faster than MPDATA, total model speedup of about 30% --added to CCSM/CSIM
  - CICE3.0 restructered for vector Community Sea Ice Model
- **Sensitivity analysis and parameter tuning test of the CICE code**
  - Automatic Differentiation (AD)-generated derivative code

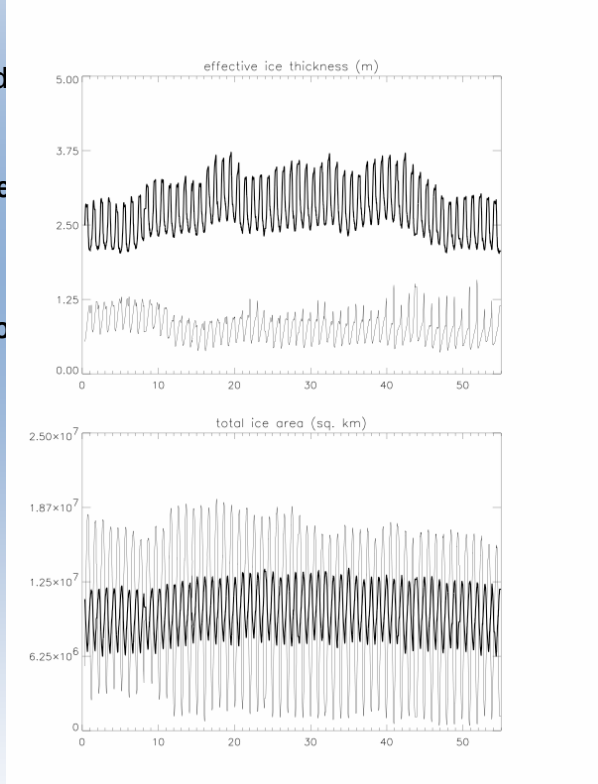


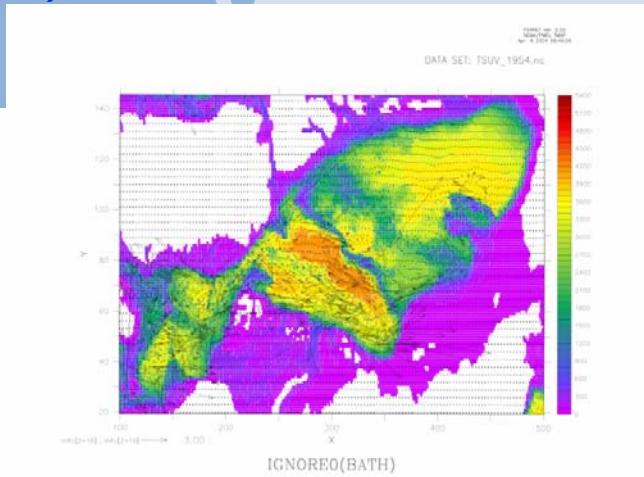


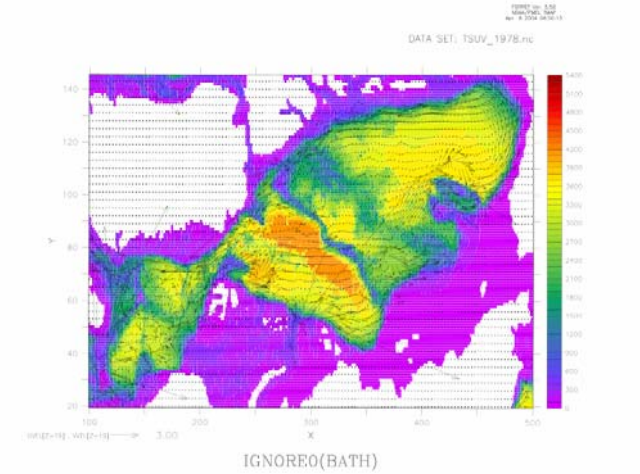
AOMIP on the Cray X1

study by Elizabth Hunke (LANL)

- **Arctic Ocean Model Intercomparison Project (AOMIP) run has finished 1948-2002.**
- **It's global, 0.4 deg, coupled POP2.0 and CICE3.1_beta.**
- **phoenix: produces 14.4 model hours pe processor- wallclock hour. (Currently running with 60 processors)**
- **cheetah: 8.4 model hours per processo wallclock hour.**

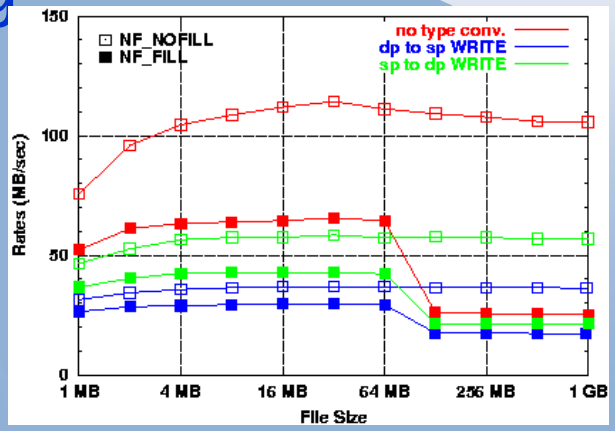


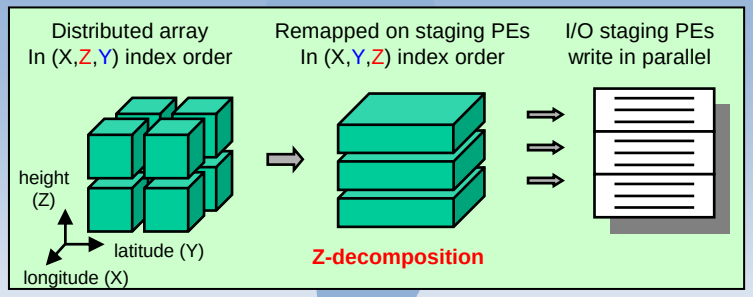


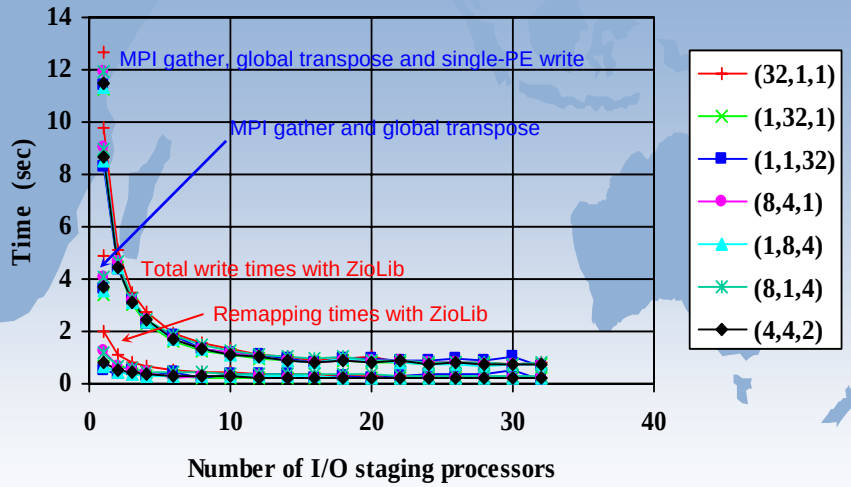


Parallel I/O
C. Ding

- Supporting multiple precision output
- ZioLib and parallel NetCDF development

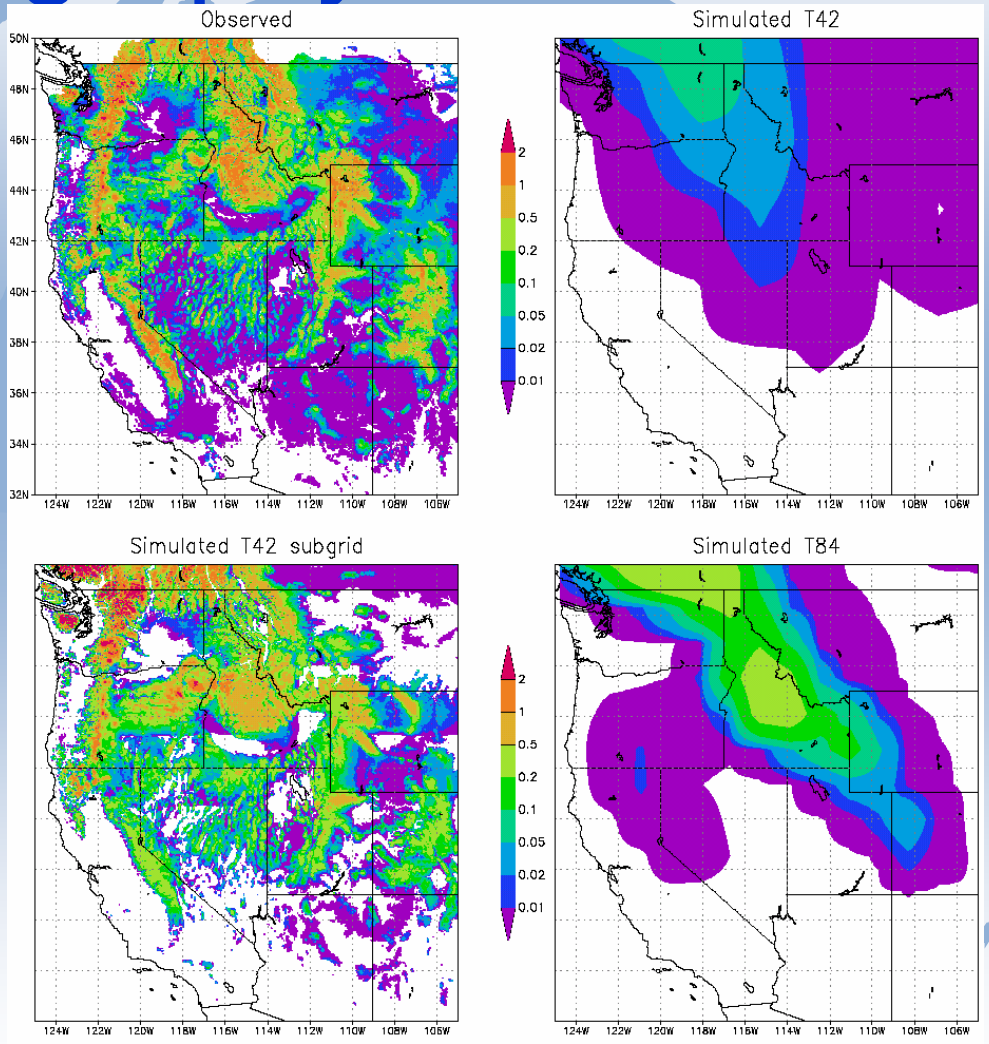






Subgrid Orography Scheme

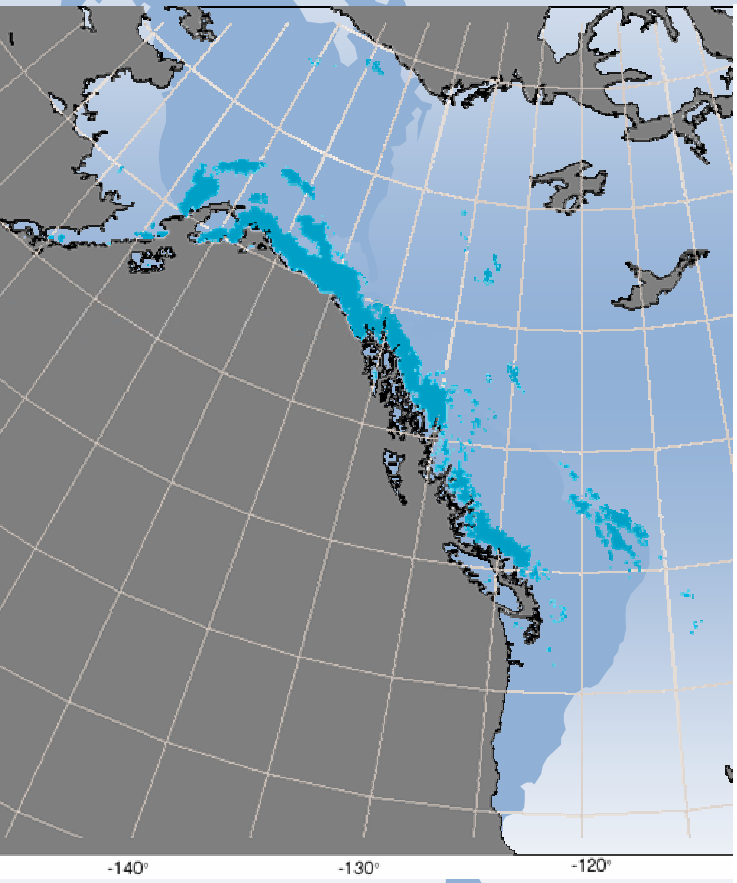
- **Reproduces orographic signature without increasing dynamic resolution**
- **Realisitic precipitation, snowcover, runoff**
- **Month of March simulated with CCSM**

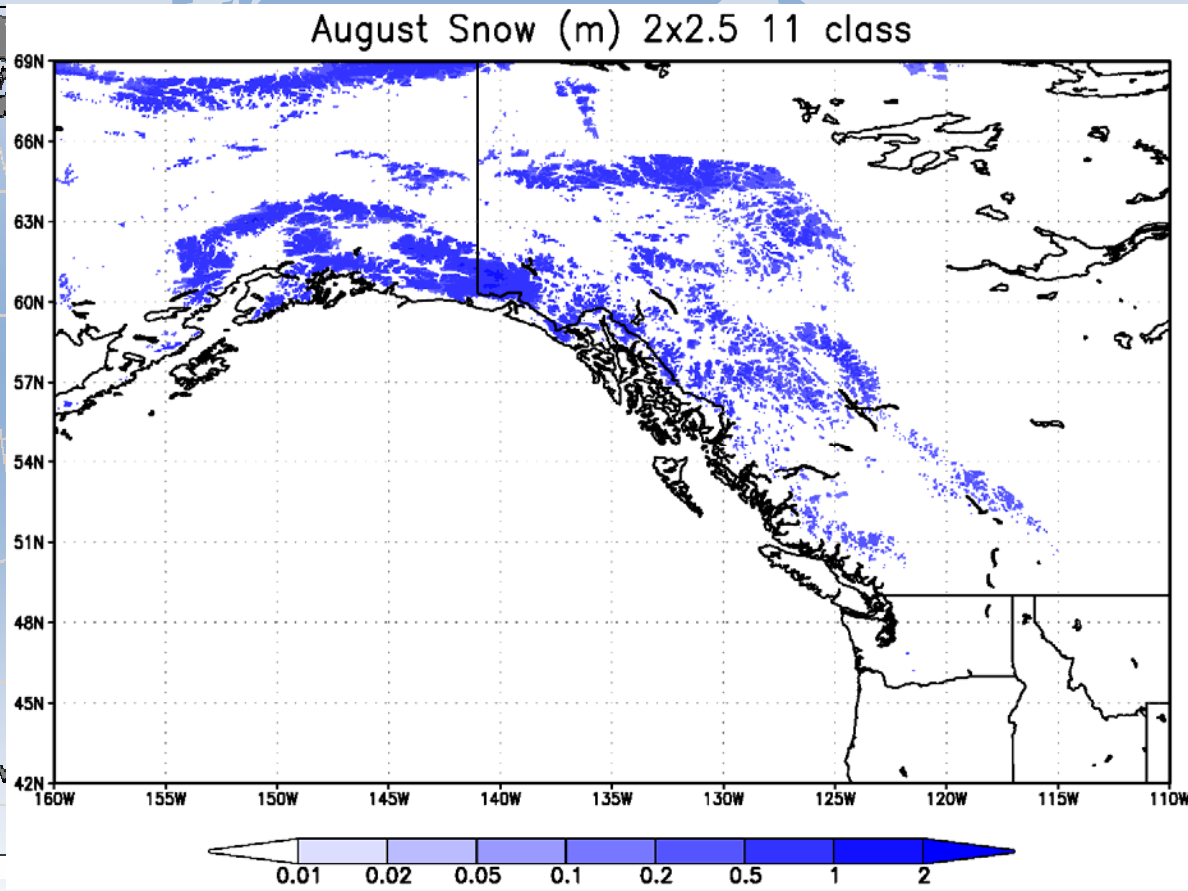


Progress

- Scheme applied to CAM and CLM
  - Euler dycore
  - Finite-volume dycore (1-D and 2-D domain decomposition)
- Developmental branch updated to cam2_0_2_dev55 (IPCC physics)
- Bit-for-bit agreement between SP, SMP, SPMD
- Restarts bit-for-bit agreement
- Bit-for-bit agreement with dev trunk if subgrid scheme turned off
- Energy conservation demonstrated
- Load balancing within nodes for both dycores
- Load balancing between nodes for both dycores (FV 1-D only)
- Runoff distributed according to elevation of river transport model surface elevation
- Simulations at T42 and 2x2.5º resolution

North America Glaciers





Greater Emphasis on Snowpack

- 70% of runoff in Western US is from snowmelt.
- Mountain snowpack is heavily relied on as a natural water reservoir.
- Simulations of greenhouse warming by regional climate models suggest a 50% reduction in mountain snowpack in the Cascades and Sierras during this century.
- A similar sensitivity can be expected in any region marginally cold enough for significant snow accumulation.
- Greenland icepack is expected to melt, but how soon?
- The subgrid orography scheme can be used in CCSM to explore these issues for the whole Earth.

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