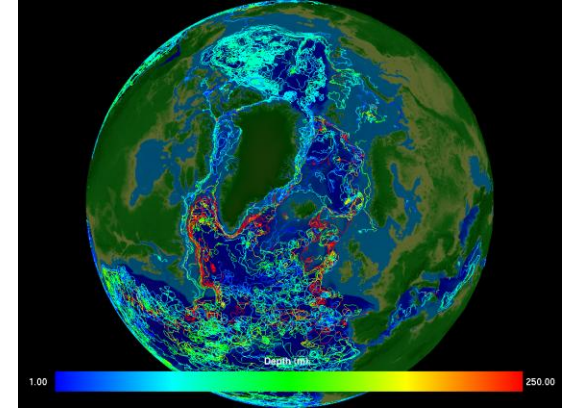




Ultra-High-Resolution Coupled Climate Simulations:



A LLNL Grand Challenge Computational Project

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And numerous collaborators

Multi-investigator, Multi-institutional

- **Co- Investigators**

- Detelina Ivanova, James Boyle, Steve Klein, Bor Chan, Lawrence Livermore National Laboratory
- Mariana Vertenstein, John Dennis, Frank Bryan, Nancy Norton, Tony Craig National Center for Atmospheric Research
- Mathew Maltrud, Elizabeth Hunke, Phil Jones, Los Alamos National Laboratory
- Pat Worley Oak Ridge National Laboratory
- Rob Jacob Argonne National Laboratory

- **Collaborators**

- Warren Washington, Peter Gent, Phil Rasch, National Center for Atmospheric Research
- Ricky Rood, University of Michigan
- John Drake, Oak Ridge National Laboratory
- Bruce Cornuelle, Sarah Gille, Teresa Chereskin, Scripps Institution of Oceanography

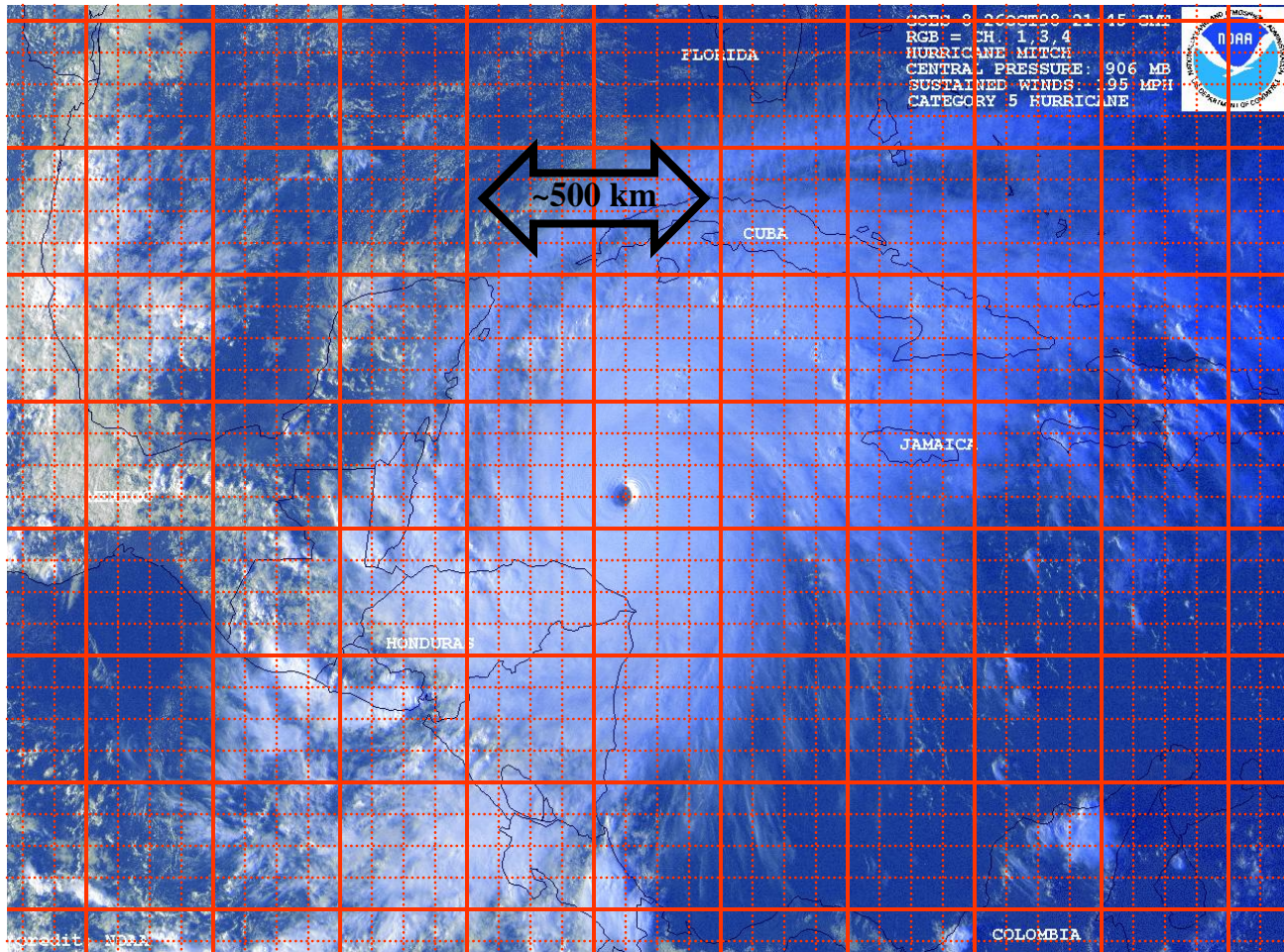
Computing Needs Relative to IPCC Version

- Throughput required ~5 years/day for ensemble simulation (century/month)
- Long integration times/ensembles required for climate
 - non-deterministic problem with large natural variability
 - long equilibrium time scales for coupled systems
- Quality of solutions are resolution and physics limited
 - balance horizontal and vertical resolution, and physics complexity

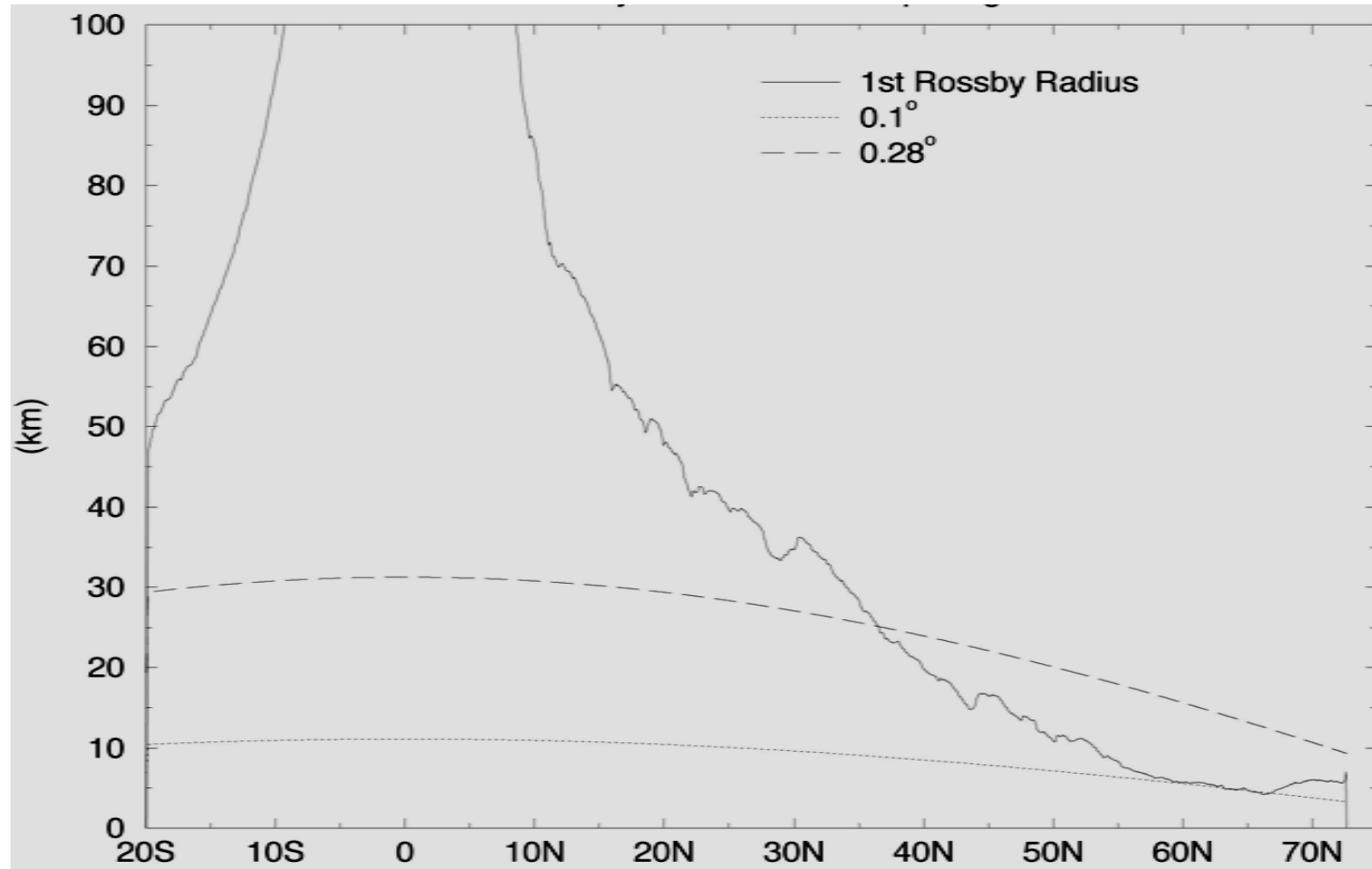
<i>Issue</i>	<i>Motivation</i>	<i>Compute Factor</i>
Spatial resolution	Provide regional details	10^3 - 10^5
Model completeness	Add “new” science	10^2
New parameterizations	Upgrade to “better” science	10^2
Run length	Long-term implications	10^2
Ensembles, scenarios	Range of model variability	10
Total Compute Factor		10^{10} - 10^{12}

~2°(2000) vs ~0.5°(2007)

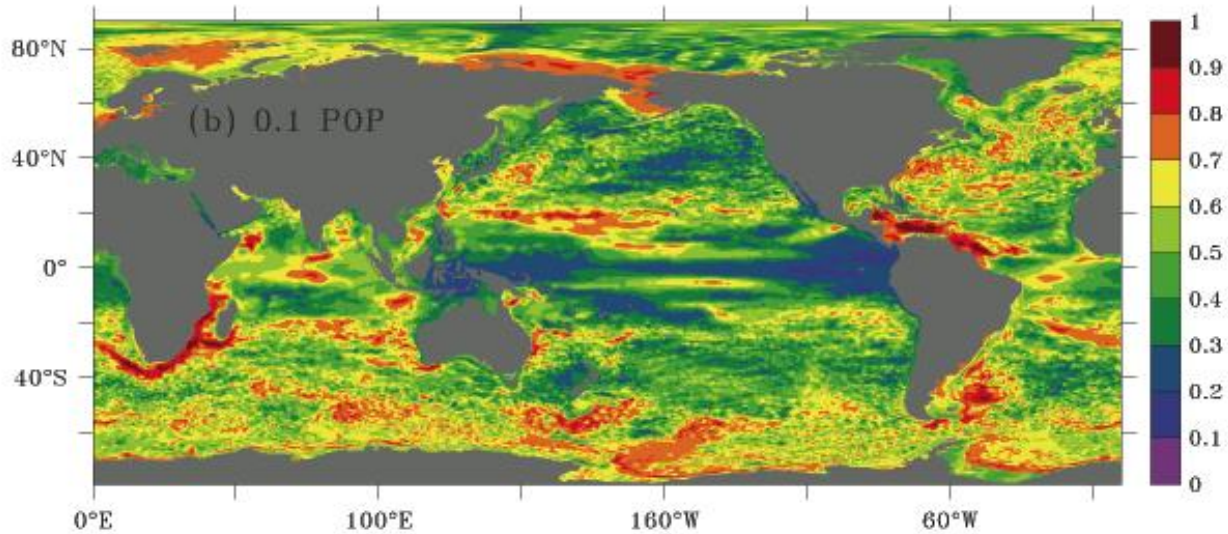
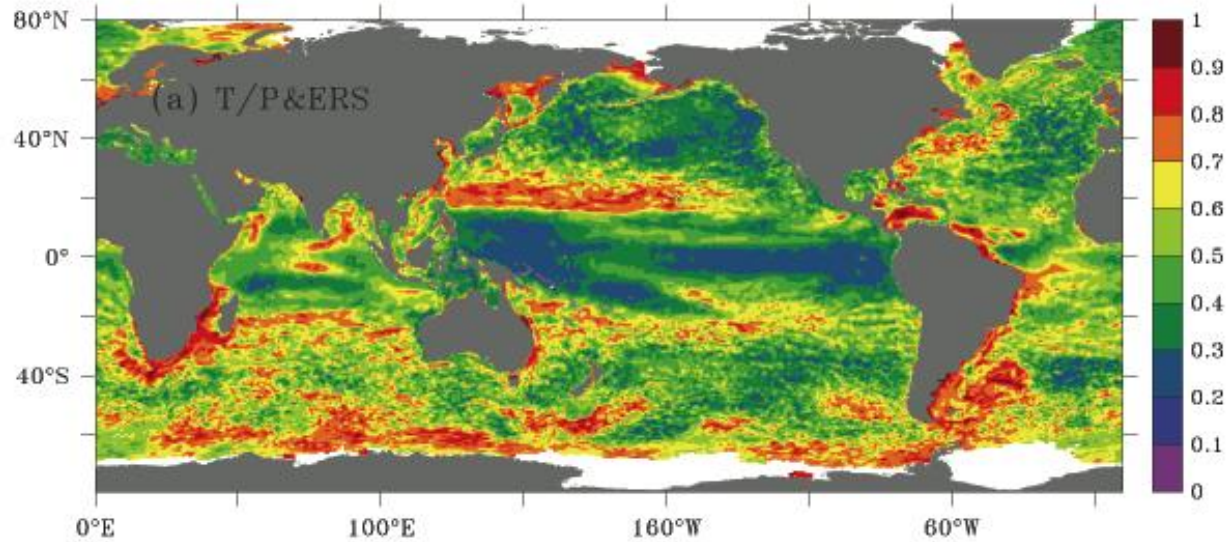
Better Simulation of Tropical Cyclone Impacts on Climate



First Baroclinic Rossby Radius versus Grid Spacing in 0.1° and 0.28° Parallel Ocean Program (POP) Simulations



The fraction of mesoscale variability relative to the total amount is fairly well simulated (McClean et al., 2006)



Mesoscale:Total RMS SSHA Ratio

Original Plan

- Start with CCSM3 Finite Volume version used for LLNL 1 deg lat/lon atmosphere coupled to 1 degree ocean/ice
- Confirm correct solutions on Atlas port
- Systematically increase resolution on components
 - 0.1 degree POP/CICE forced by climatology produced from atmospheric observations
 - 0.5 and 0.25 degree CAM coupled to 1.0 degree POP from prior GC
- Anticipated potential problems
 - Parameterization adjustments
 - Machine scaling
 - New system behavior
 - I/O

Revisions

- Switch to new coupling strategy (June)
 - CCSM3 coupler was designed primarily for IBM SP systems in 2002-03
 - CCSM4 coupler nearly complete - suited for XT3/4 and Blue Gene class machines
 - Software engineering improvements for scalability
 - Major model improvements not compatible with old code, especially ocean
- Switch to Tripole POP/CICE grid (September)
- Use improved atmospheric forcing for POP/CICE (December)

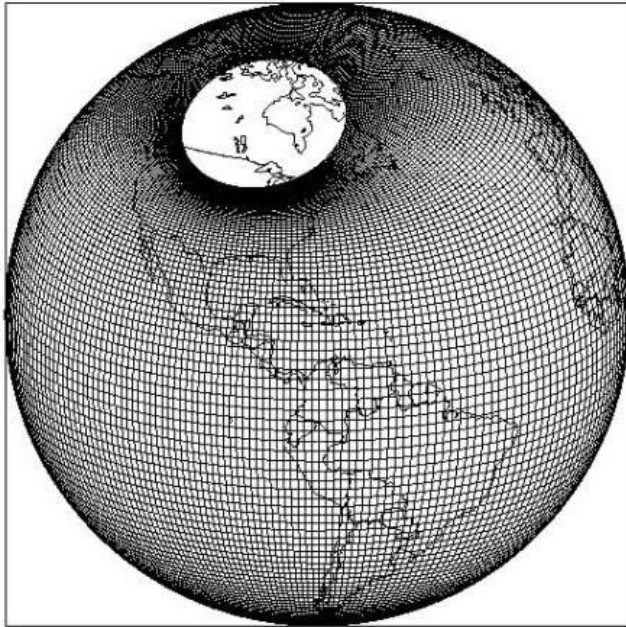
CCSM4 Component Codes Ported to Atlas

- **CAM 3.5:** passes port validation (perturbation growth) test
- **Coupled POP2/CICE**
 - needed to convert mpi send to synchronized send to avoid memory overflow when performing gathers
 - code successfully runs with 0.1° tripole and dipole grids
 - performance tests have been carried out for various block sizes and processor counts
- **CCSM4 beta configuration run for 23 simulated days**

High-Resolution Atmospheric Capability

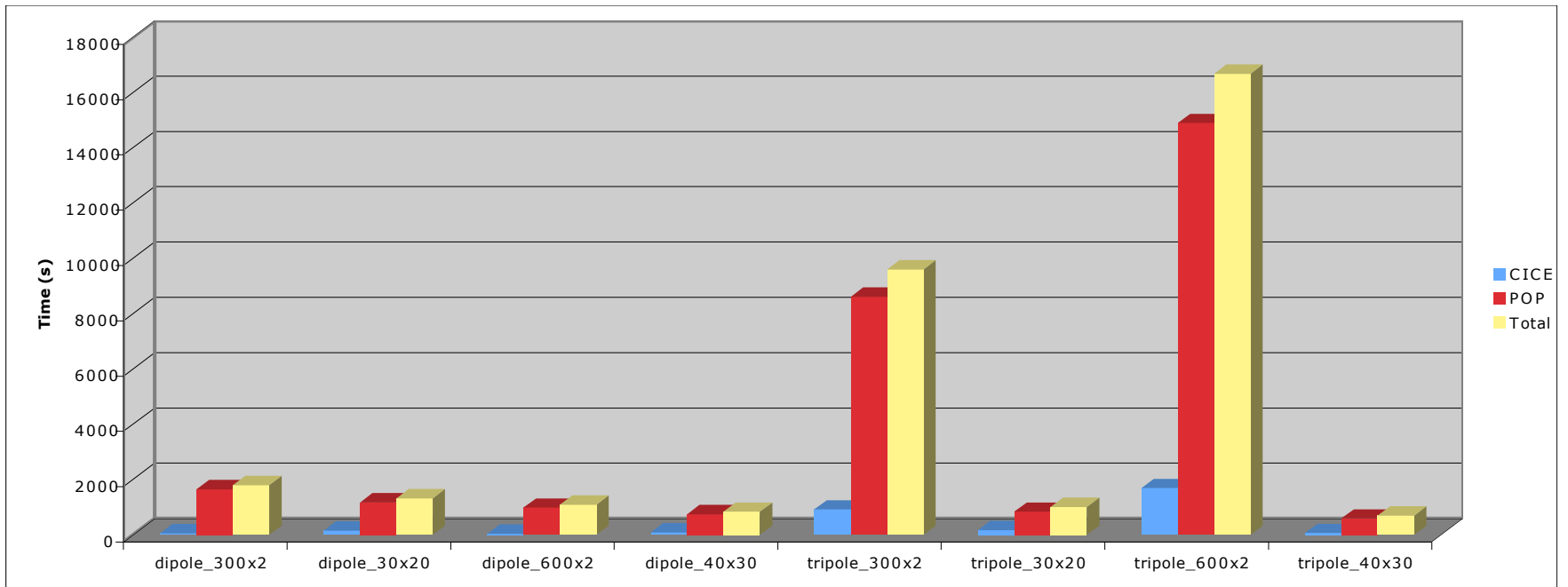
- CAM 3.5 uses the finite-volume dynamical core at all relevant atmospheric resolutions
 - 1° (0.9×1.25)
 - 0.5° (0.47×0.63)
 - 0.25° (0.23×0.31)
- With FV-dycore, as resolution increases, unrealistic “boreal winter polar night jet” increases in magnitude to the point where it affects the allowable dynamics time step. Problem addressed through various filtering procedures
- At 0.5° resolution CAM remains stable when coupling at radiation frequency (hourly)
- At 0.25° resolution, radiation frequency and coupling interval must be limited to 30 minutes to maintain stability

Model Performance Tests: Dipole versus Tripole Grids



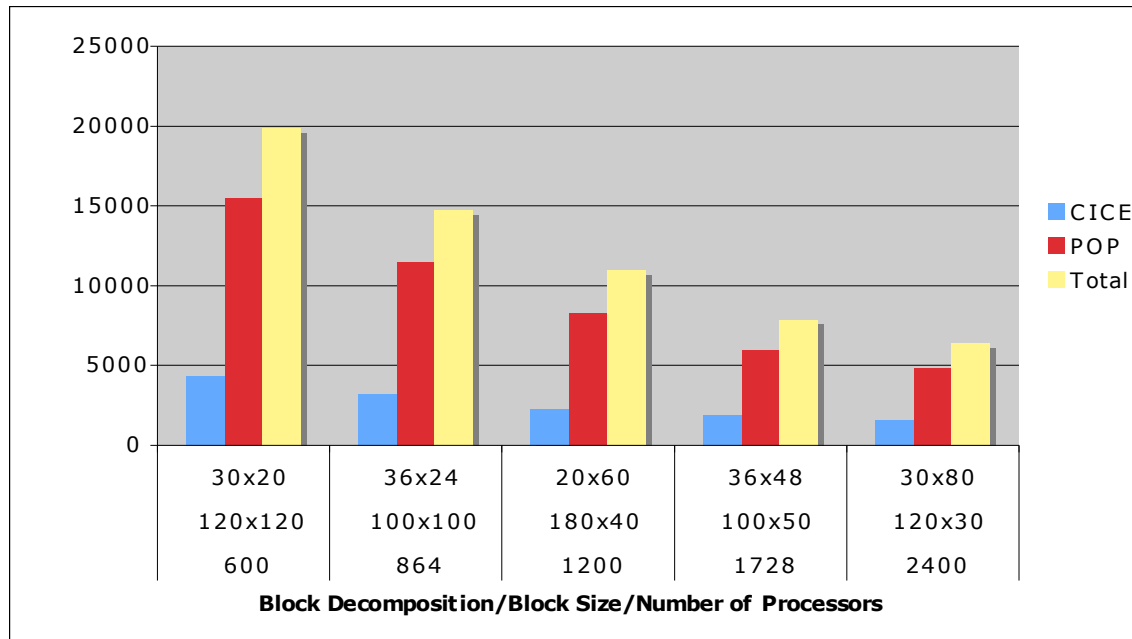
Timings from the Dipole Grid - Tripole Comparisons

1 day test runs without I/O with different block decomposition



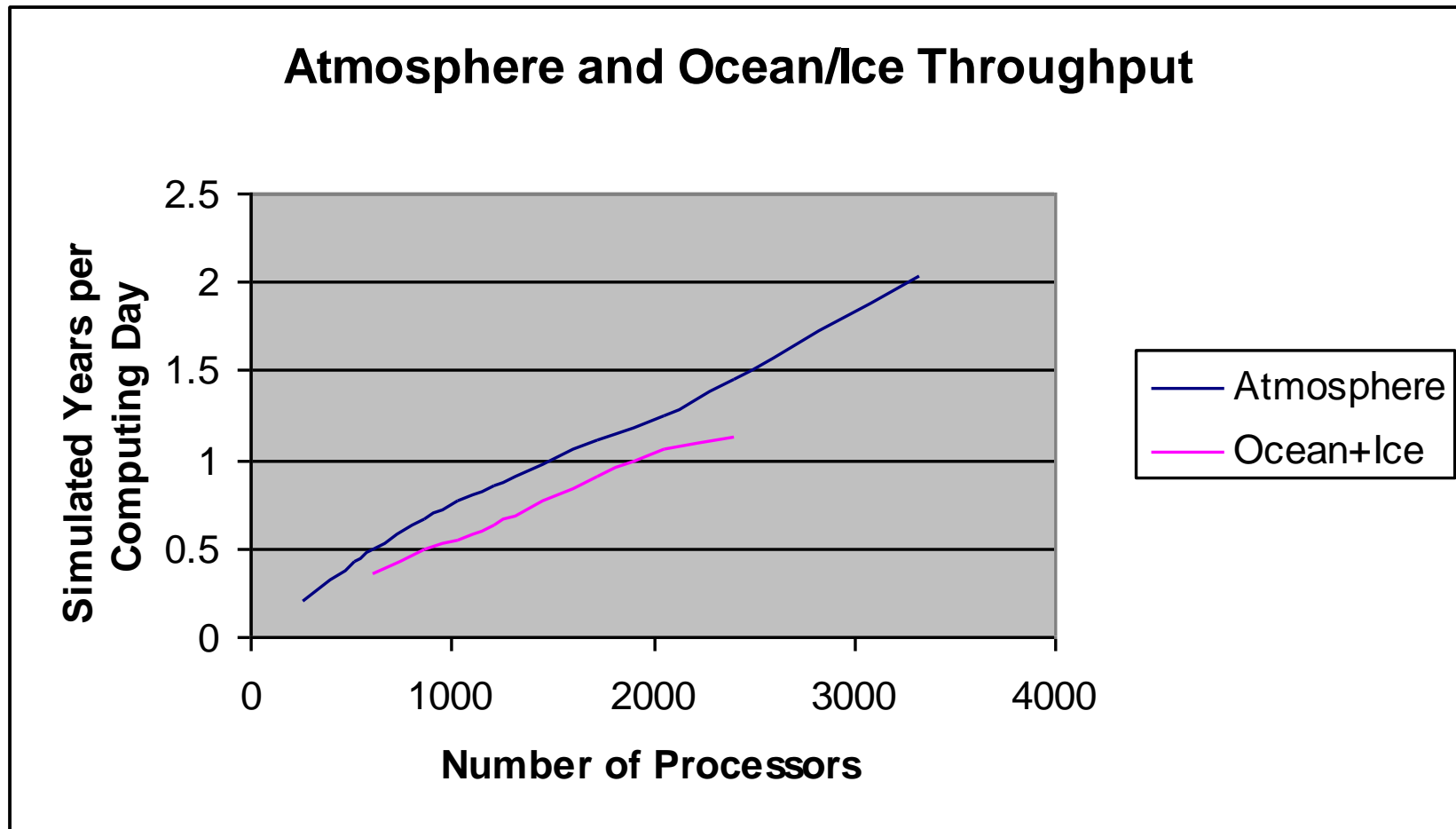
Timer	dipole_300x2	dipole_30x20	dipole_600x2	dipole_40x30	tripole_300x2	tripole_30x20	tripole_600x2	tripole_40x30
CICE	64.28	153.52	41.52	93.16	920.67	172.2	1693.15	67.42
POP	1654.75	1173.35	987.12	744.64	8615.54	837.12	14897.66	591.85
Total	1804.04	1327.58	1098.13	838.82	9593.88	1009.99	16682.67	700.04

Timings and Scaling Tests: Global 0.1° Coupled POP-CICE



# processors	Block Size	Block Decomp	CICE	POP	Total
600	120x120	30x20	4329.94	15493.65	19855.59
864	100x100	36x24	3217.93	11473.28	14715.08
1200	180x40	20x60	2236.25	8253.23	10953.86
1728	100x50	36x48	1875.54	5980.24	7861.54
2400	120x30	30x80	1548.07	4835.18	6387.5

Scaling and Throughput



0.1°, 40-level Global Coupled Ocean/Ice

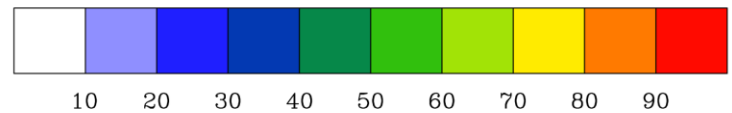
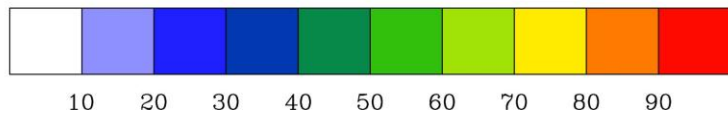
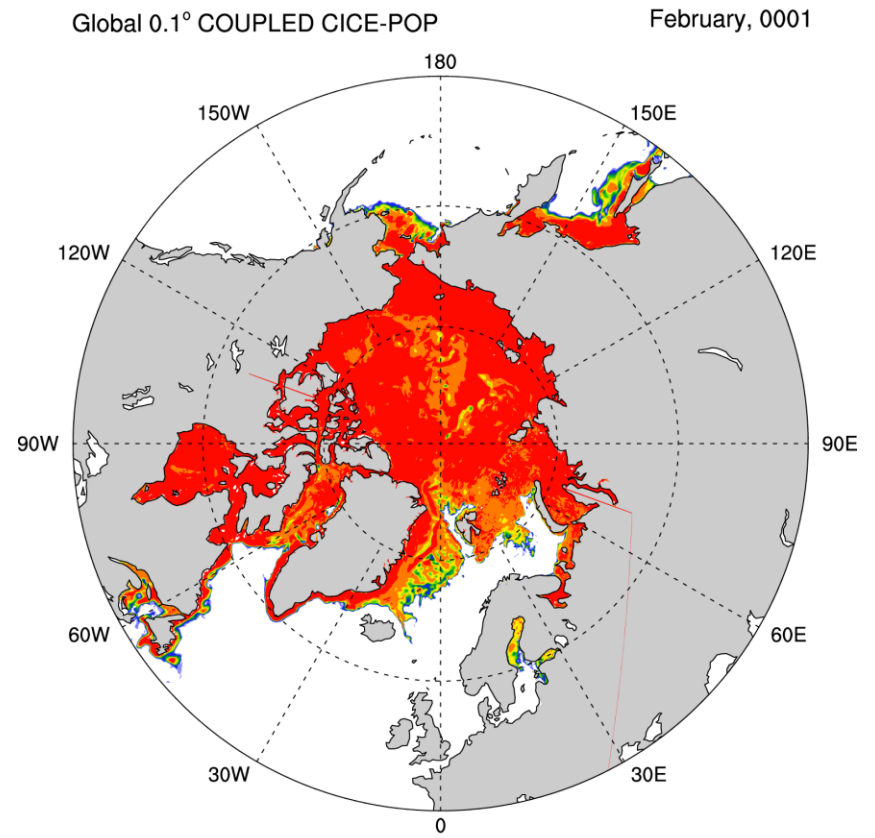
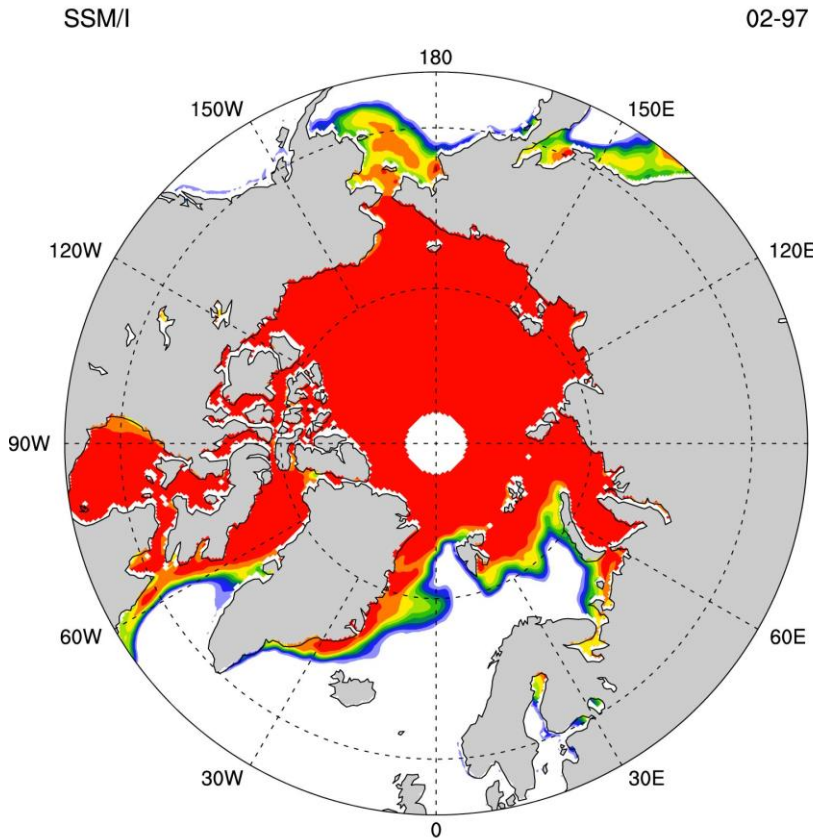
- LANL POP2.0 and CICE4.0
- Completed 2-y global 0.1° coupled POP-CICE simulation on dipole grid (Hudson Bay) forced with corrected NCEP/NCAR reanalysis daily fluxes for 1995-1996.
- Topography: Sandwell and Smith (71S-67N), IBCAO (66N-90N), & BEDMAP (66S-79S). Partial bottom cells.
- Initial ocean state: 15-y spun-up state from stand-alone tripole 0.1°POP
- Completed 2-y global 0.1° coupled POP-CICE on the tripole grid (poles in Alaska and Siberia) with partial bottom cells forced by a daily climatology (1979-2003) of corrected NCEP/NCAR reanalysis atmospheric fluxes.

Tripole Coupled POP-CICE Simulation

Comparison of simulated Arctic Ice Concentration with SSM/I observations

Ice Concentration (%)

Arctic Monthly Ice Concentration (%)



GLOBAL 0.1DEG POP-CICE SIMULATION

Part of the UHRCCS project is to perform global 0.1 deg coupled ocean-sea ice (POP-CICE) model simulation forced with atmospheric reanalysis product.

Set UP

- *Model Version:* LANL POP2.0 (Revision 89) and CICE4.0 (Revision 129)
- *Grid:* Tripole type (2 North Poles located on land in Siberia and Alaska) 3600x2400x42
- *Topography:* Partial Bottom Cell Topography
- *Forcing:* 10year Spin-up with daily Normal Year CORE Climatology including daily fields of long-wave and short-wave radiation, surface wind, air temperature and humidity and monthly precipitation. Next 50 year real time daily forcing.
- *Initialization:* Ice cover initialization is latitude and sst dependent with ice extent limits 70N and 60S and nonlinear ice thickness distribution, POP is initialized with 15 year restart file from the LANL Tripole POP stand alone run

Set Up (continued)

- *Coupling*: CICE-POP exchange fluxes every 3 hours instead of previously used in such coupled model simulation daily exchange. This will minimize the effect of aliasing of inertial oscillations.
- *Restoring*: To limit the sea surface salinity drift commonly observed in a standalone ocean simulations a SSS restoring is applied with relaxation time scale of 6 months. To exclude the under ice ocean areas where the restoring is not desired an ice mask (defined by the ice edge at each ice model time step) is used to delineate under ice regions from the open ocean.

Testing

- Completed 2-y global 0.1° coupled POP-CICE simulation on dipole grid (Hudson Bay) forced with corrected NCEP/NCAR reanalysis daily fluxes for 1995-1996.
- Completed 2-y global 0.1° coupled POP-CICE on the tripole grid with partial bottom cells forced by a daily climatology (1979-2003) of corrected NCEP/NCAR reanalysis atmospheric fluxes.
- Currently, testing global 0.1 coupled POP-CICE on tripole grid with partial bottom cells forced by daily climatology of Normal Year CORE atmospheric fluxes.

Progress since 12/2007

- Developed new forcing routines to accommodate Common Ocean-ice Reference Experiments (CORE) Data set.

The switch from NCEP/NCAR to CORE forcing product have been done to assure the science quality of the POP-CICE simulation.

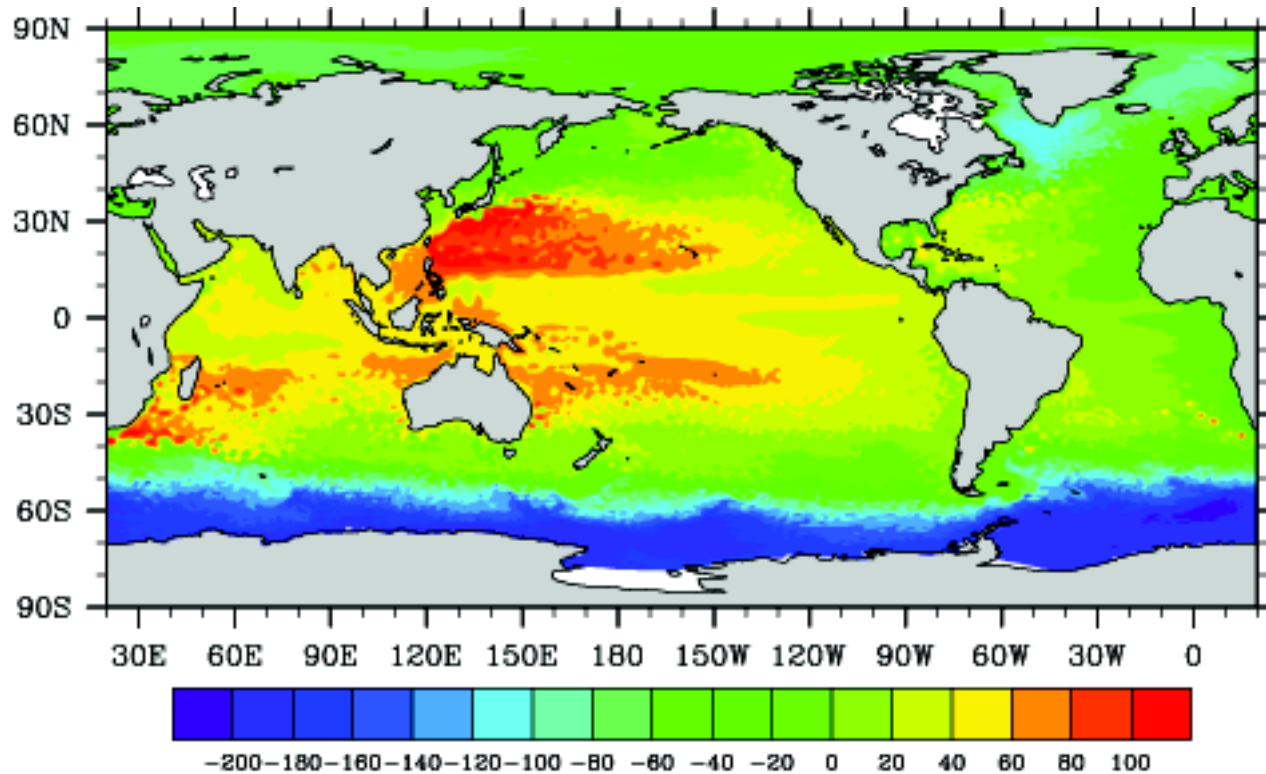
- Upgrading to the latest model versions of LANL POP and CICE including the new infrastructure

: Creating locally at LLNL POP-CICE version by- checking out the latest model versions (POP V89, CICE V.129) from the LANL repositories on Atlas, coupling via E. Hunke's driver routines and implementing D. Ivanova's CORE forcing routines.

The new infrastructure is expected to improve the model performance on a tripole domain.

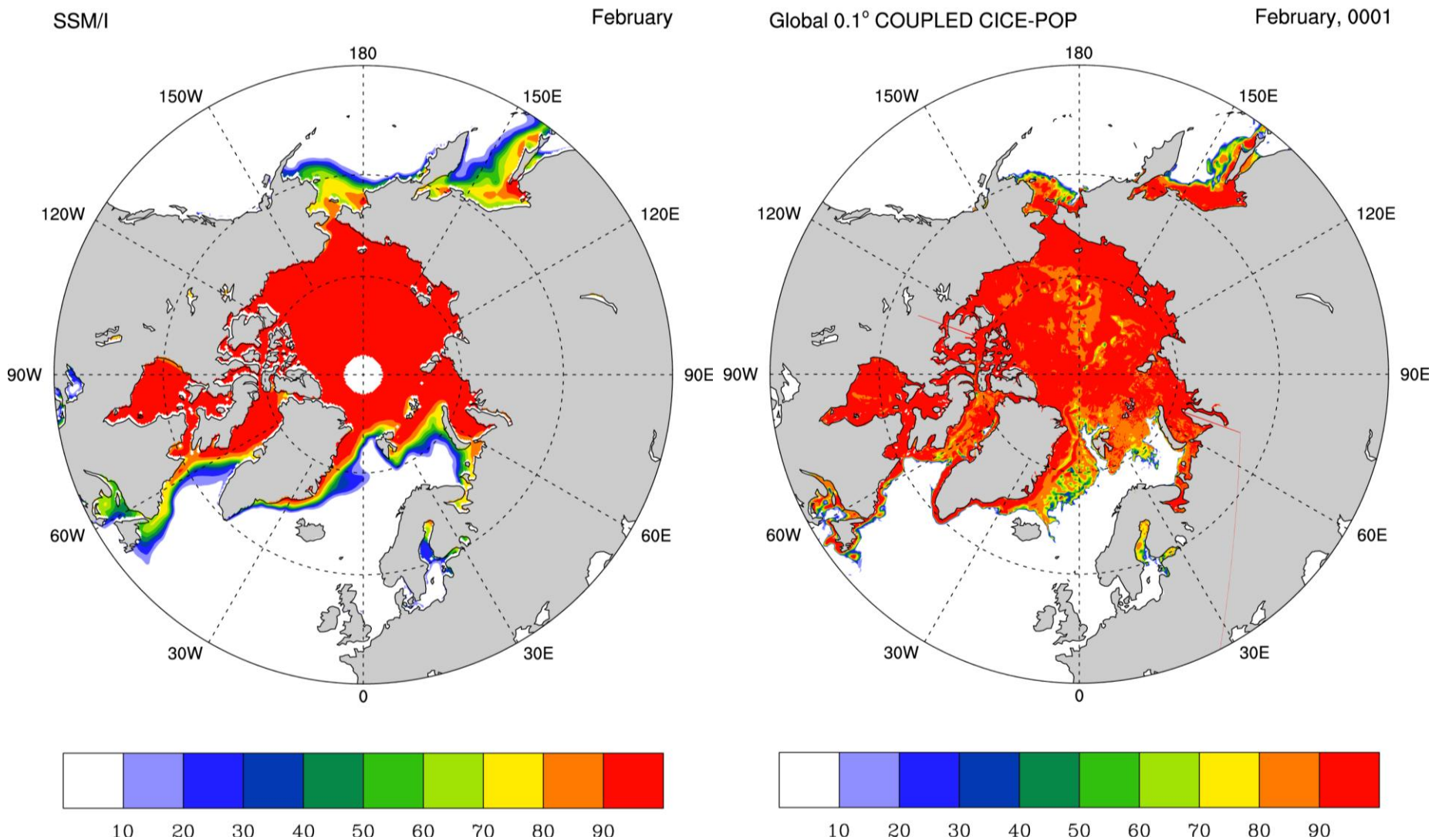
Preliminary results from the 2-year Dipole Coupled POP-CICE NCEP/NCAR forced run

Global Sea Surface Height (cm) from 12/0001



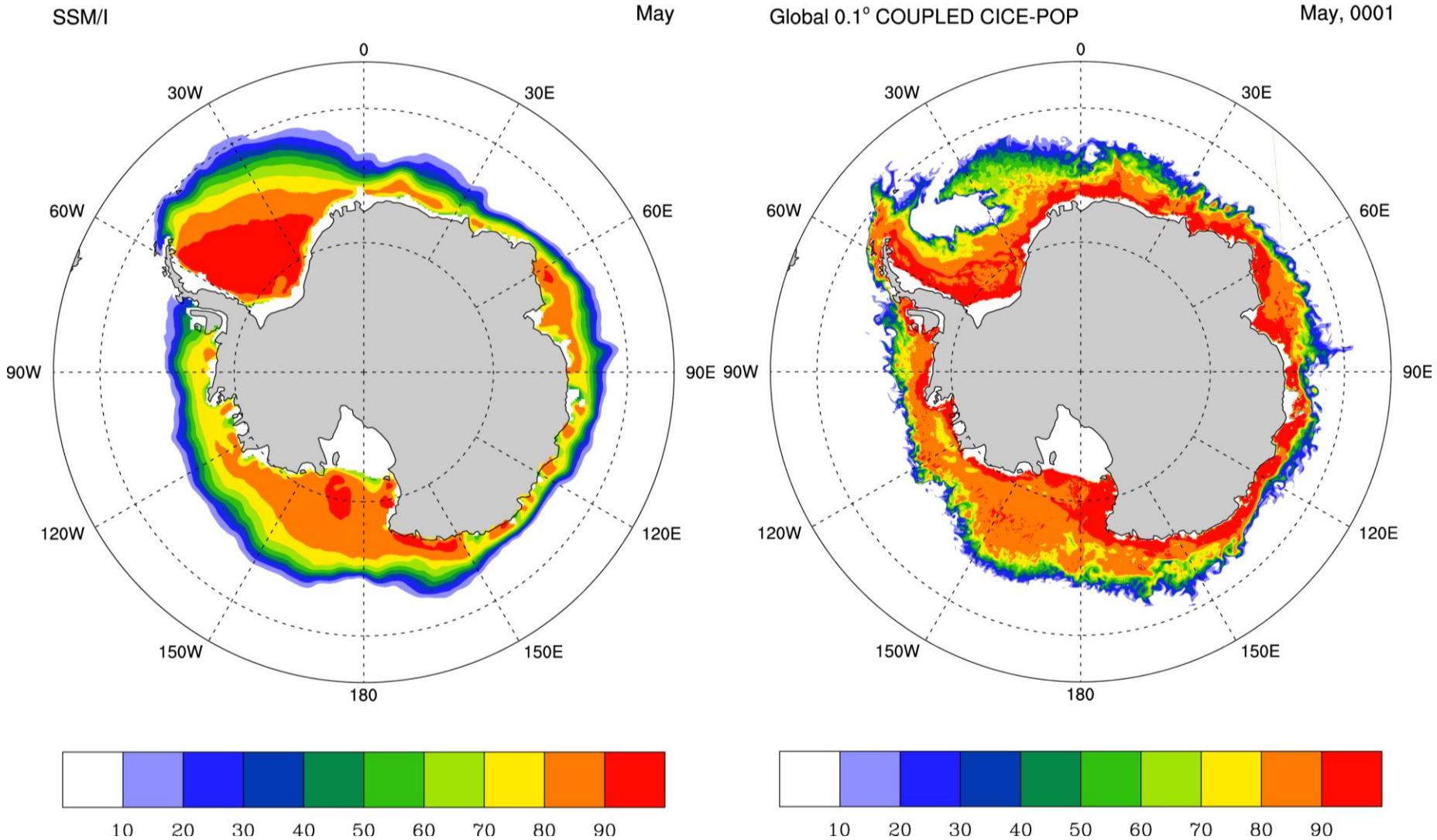
Preliminary results from the 2-year Tripole Coupled POP-CICE NCEP/NCAR forced run

Arctic Ice Concentration (%). Mean February climatology from SSM/I observations (left)
and mean monthly field 02/0001y from the model (right)



Preliminary results from the 2-year Tripole Coupled POP-CICE NCEP/NCAR forced run

Antarctic Ice Concentration (%). Mean May climatology from SSM/I observations (left)
and mean monthly field 05/0001y from the model (right)



Future Plans

- 0.1° Tripole Standalone Ocean/Ice
 - 50-y POP/CICE simulation forced with NCEP/NCAR corrected reanalysis fluxes for 1948-2004, initialized from 10-yr daily climatological simulation.
 - 50-y POP/CICE simulation forced with climatological NCEP/NCAR forcing to assess model drift.
 - Investigate variability over this period and compare with available observations (LLNL, post-doc D. Ivanova)
- 50 year fully coupled CCSM simulation and comparison with present day observed climate