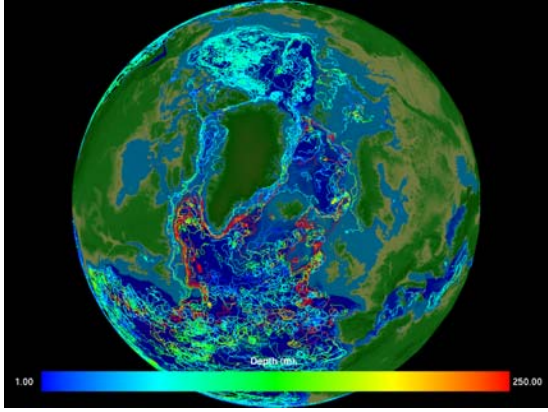
Ultra-High-Resolution Coupled Climate Simulations:



A LLNL Grand Challenge Computational Project

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And numerous collaborators

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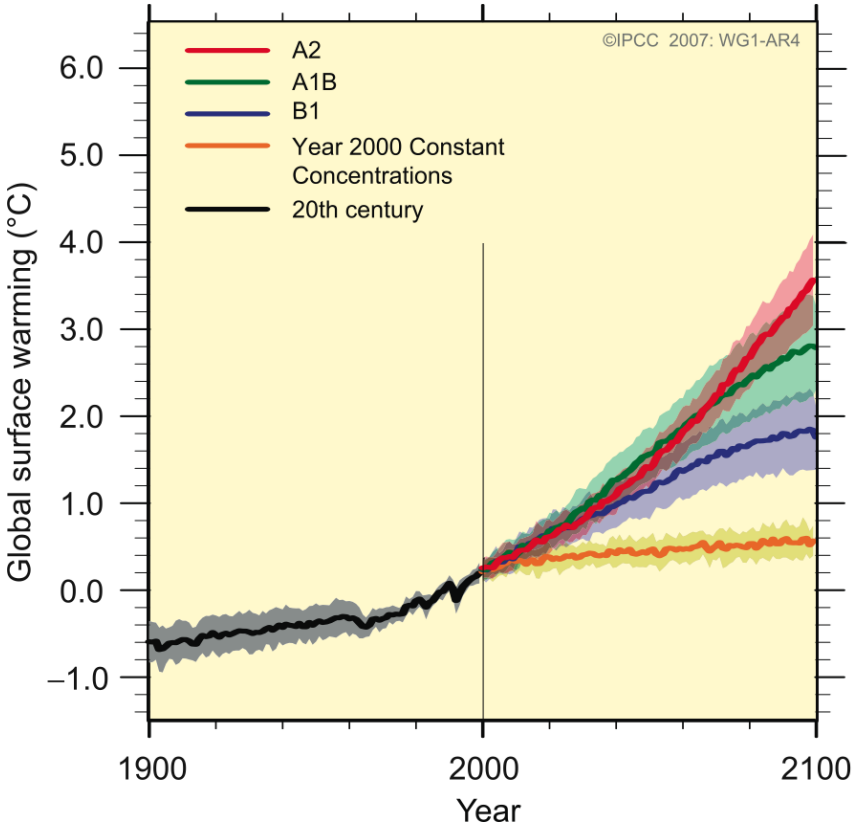
Climate Model Applications

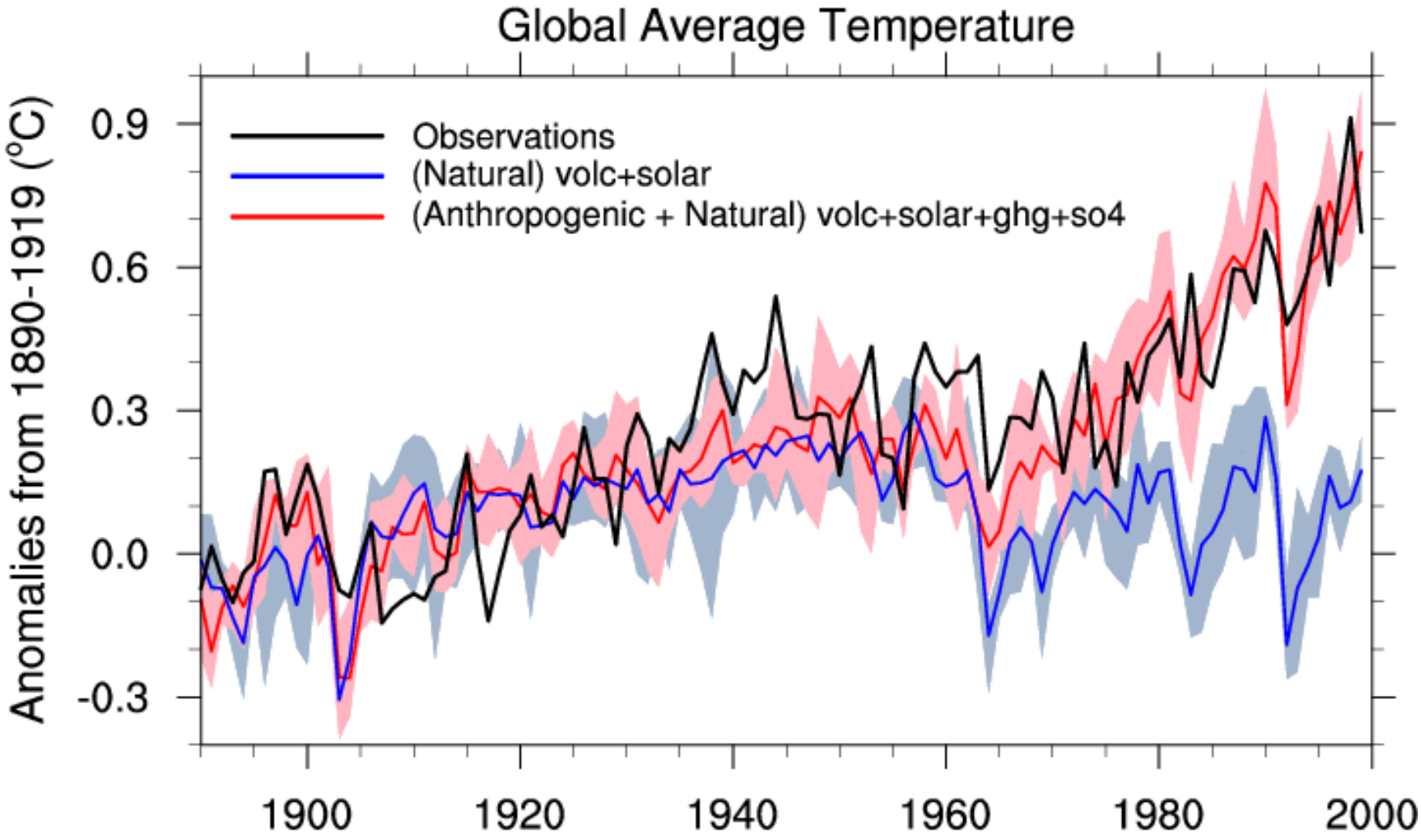
- 1990-1992: Bounding Global Climate Change--***Required a few, coarse resolution equilibrium model runs.***
- 1993-1998: Estimating Future Climate Change--***Required a few (~10), medium resolution time-dependent runs.***
- 1999-2005: Predicting the Effects of Greenhouse Gas Scenarios ***Requires many (~1000) high resolution, time-dependent runs.***
- 2006-2015: Aspen Global Change Institute Report
  - Predicting the consequences of energy scenarios ***Requires many (~1000s) Earth system model, time dependent runs***
  - Predicting the climate of the next several decades: ***Requires multiple ensembles (10*100) very high resolution, time dependent climate model runs***

The Climate Change Prediction Problem

- Global warming to date is .5 – 1.0 K in a global mean temperature of 287 K
- For the next 30 years, looking for effects of 1-5 w/m**2 forcing out of 235 w/m**2 average
- Required to get local to global scales correct simultaneously
- Weakly-forced, highly nonlinear, multi-scale system



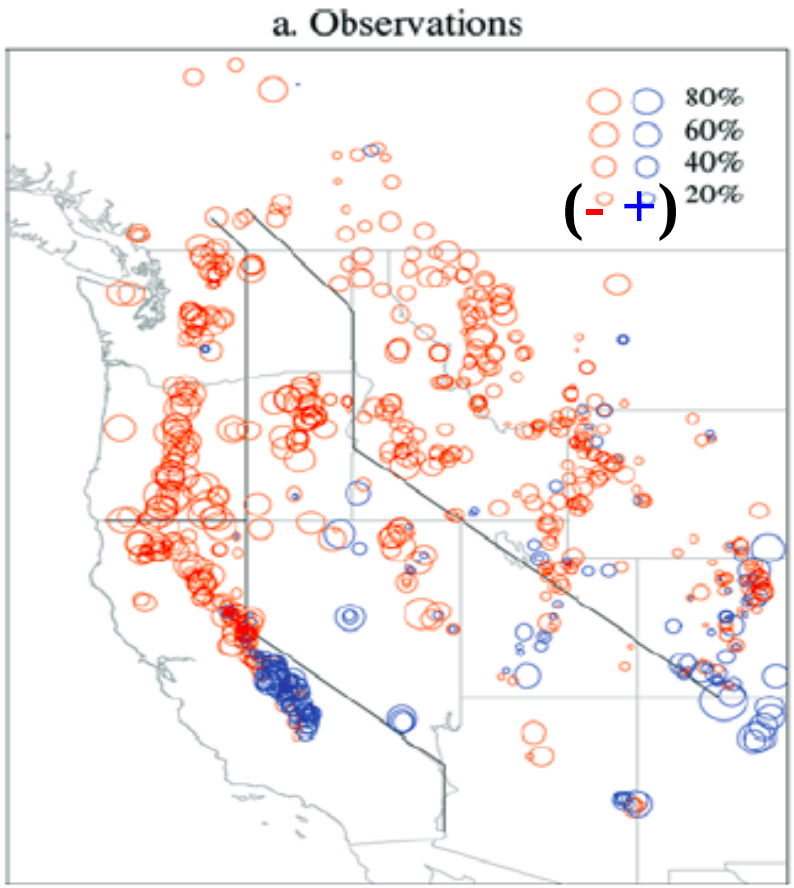
We can confidently predict global average temperature changes, …



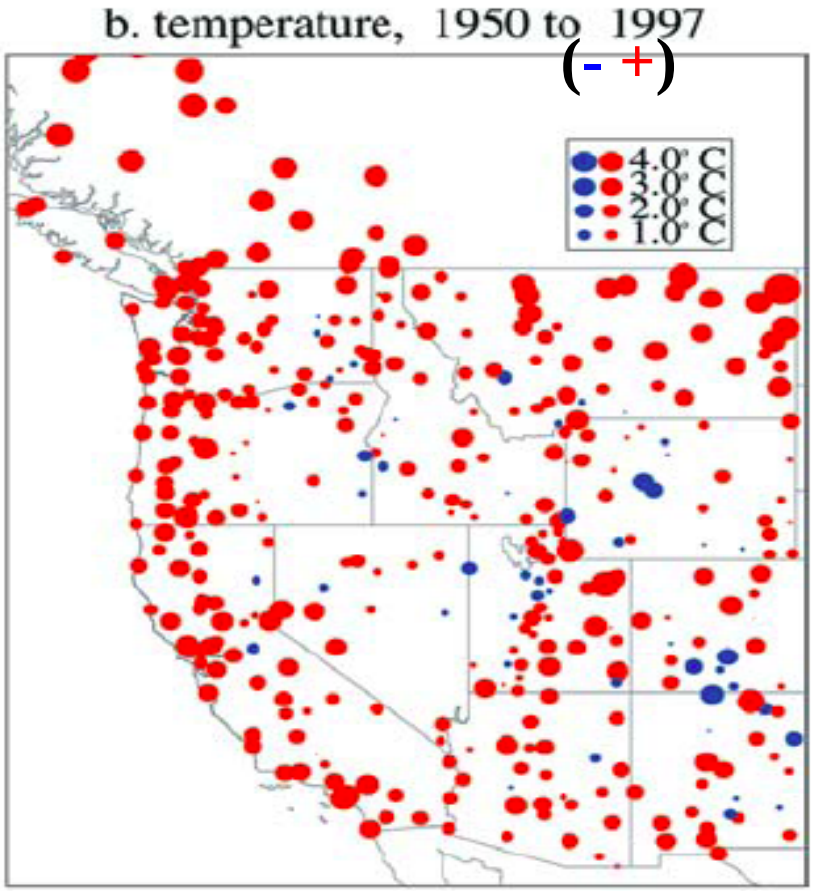
…but, can we predict this?

Observed Change 1950-1997

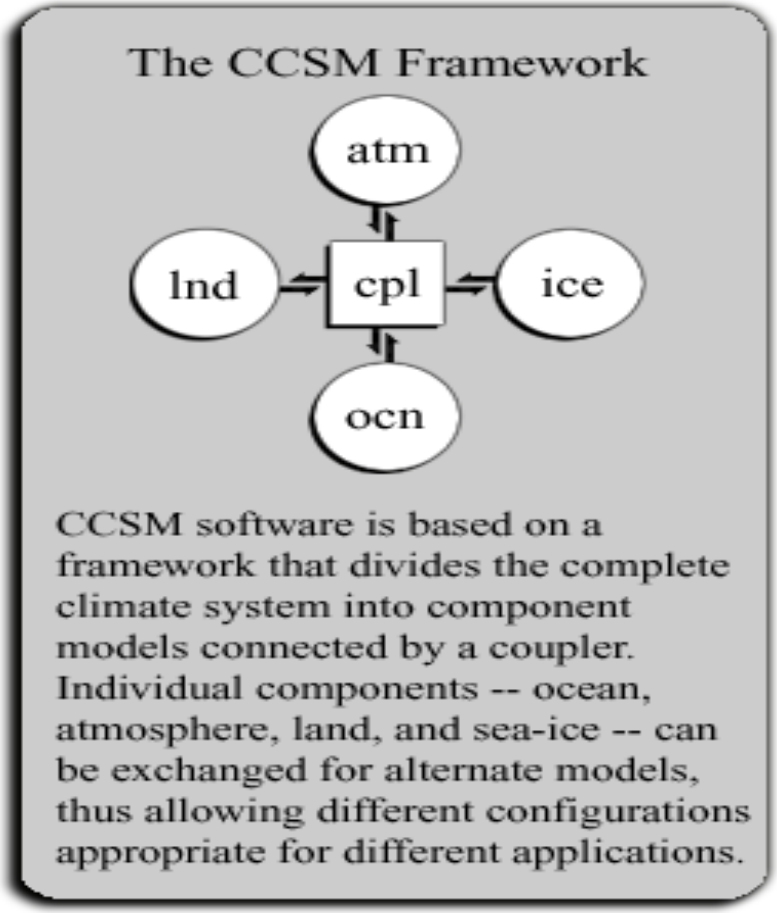
Snowpack



Temperature



Community Climate System Model



- Community Atmosphere Model (CAM)
- Community Land Model (CLM)
- LANL Parallel Ocean Program (POP)
- LANL CICE sea ice model
- Coupler based on ANL Model Coupling Toolkit (MCT)

Computing Needs Relative to IPCC Version

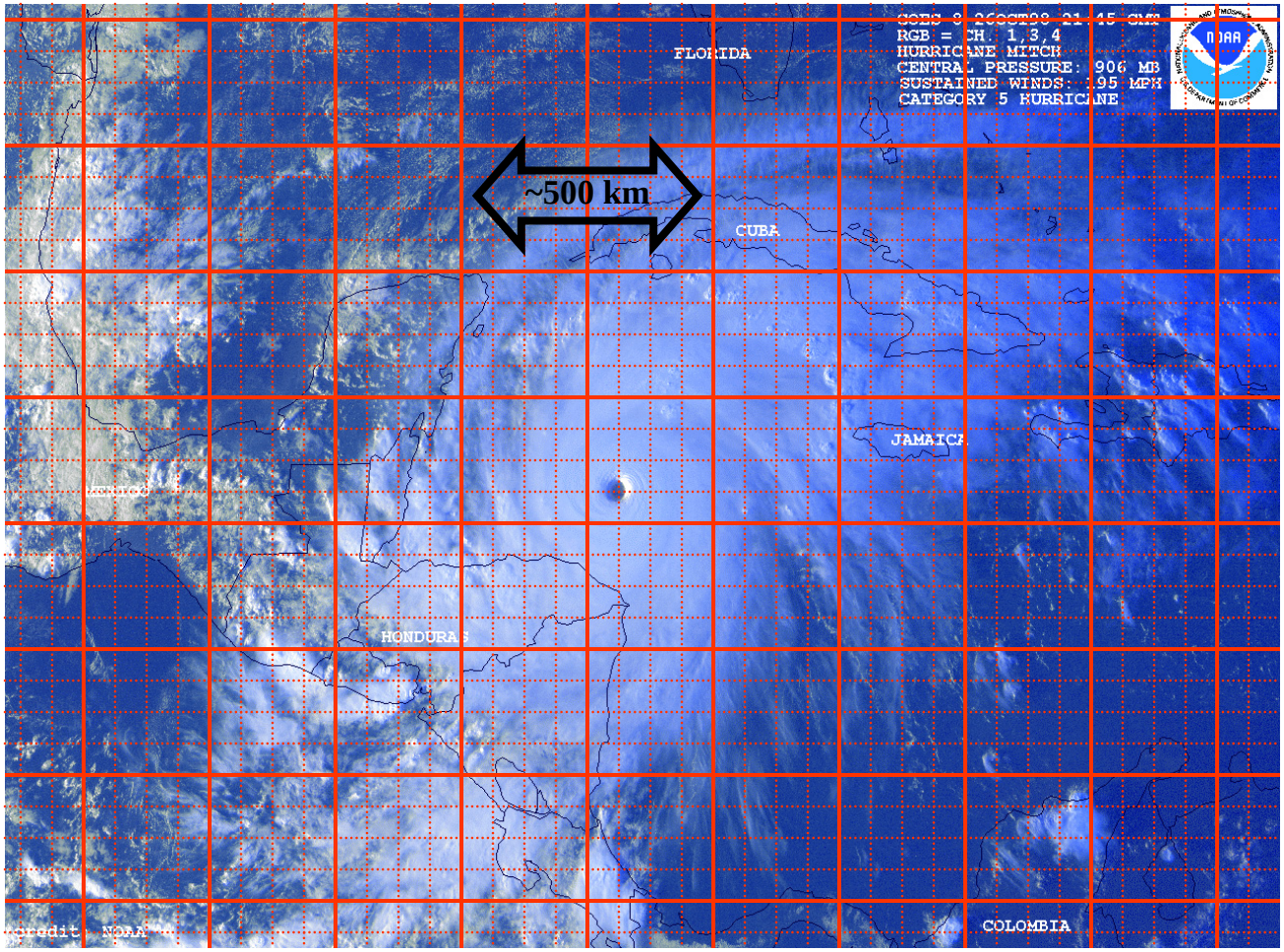
- Throughput required ~5 years/day for ensemble simulation (century/month)
- Long integration times/ensembles required for climate
  - non-deterministic problem with large natural variability
  - long equilibrium time scales for coupled systems
- Quality of solutions are resolution and physics limited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

Issue	*Motivation*	*Compute Factor*
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}

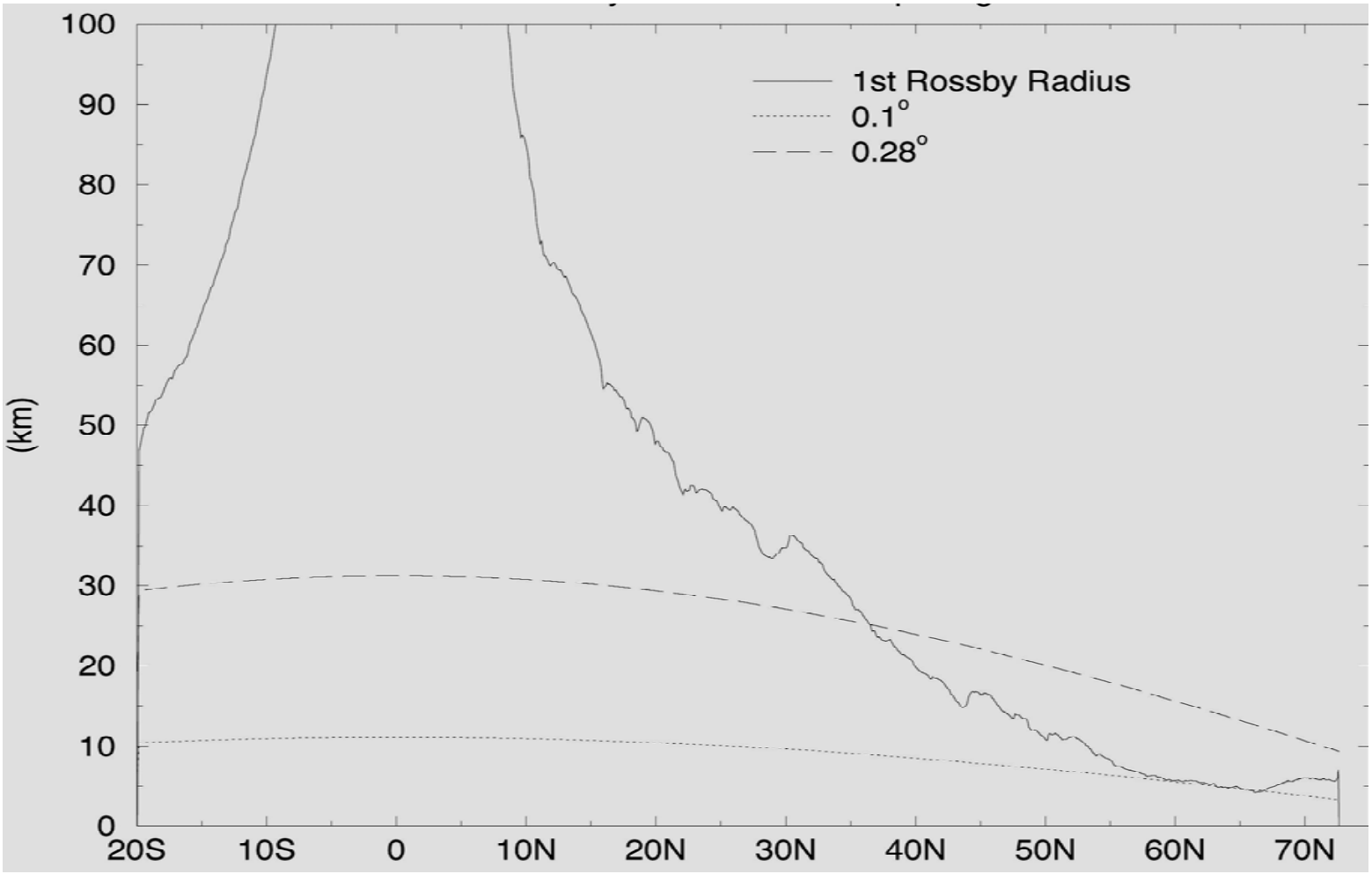
Ref: ***A SCIENCE-BASED CASE FOR LARGE-SCALE SIMULATION Volume 2 (2004)***

~*2°* (2000) *vs ~0.5°* (2007)

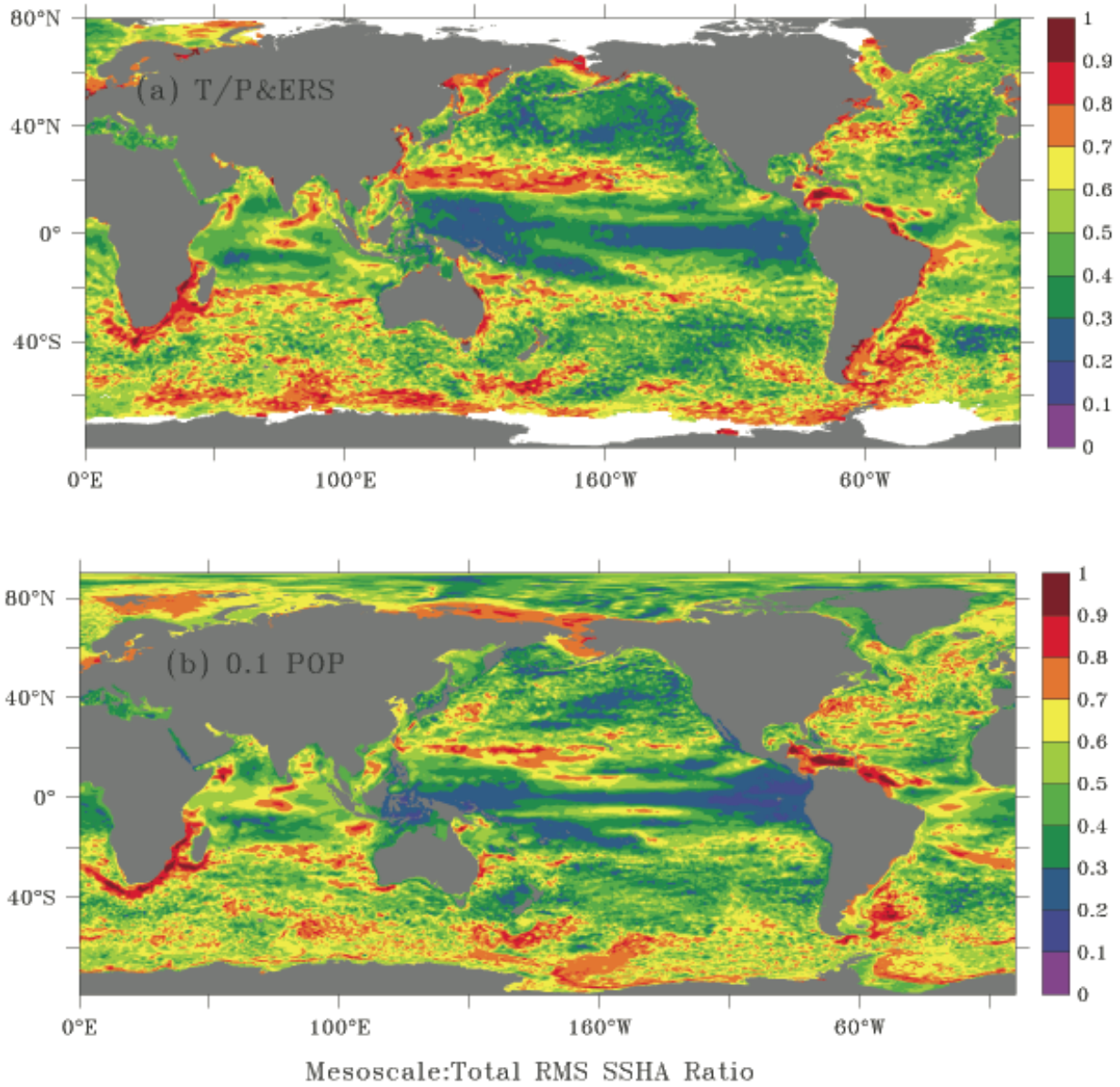
Better Simulation of Tropical Cyclone Impacts on Climate



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)



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

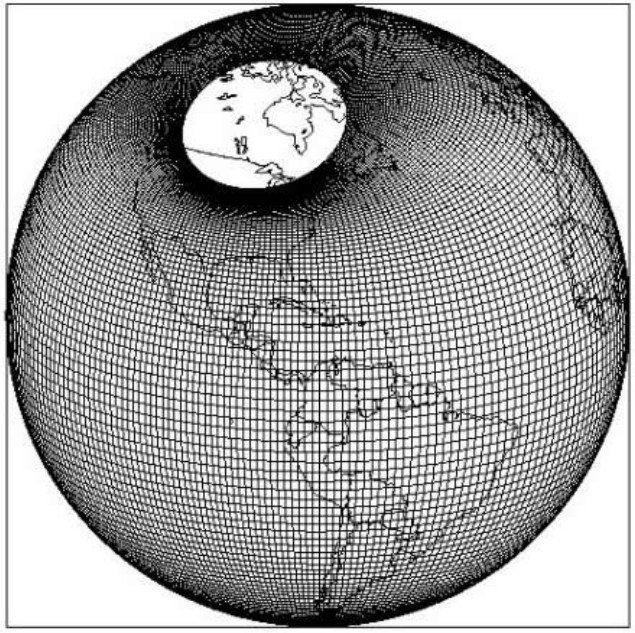
- **CAM 3.5:** passes port validation (perturbation growth) test

- **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

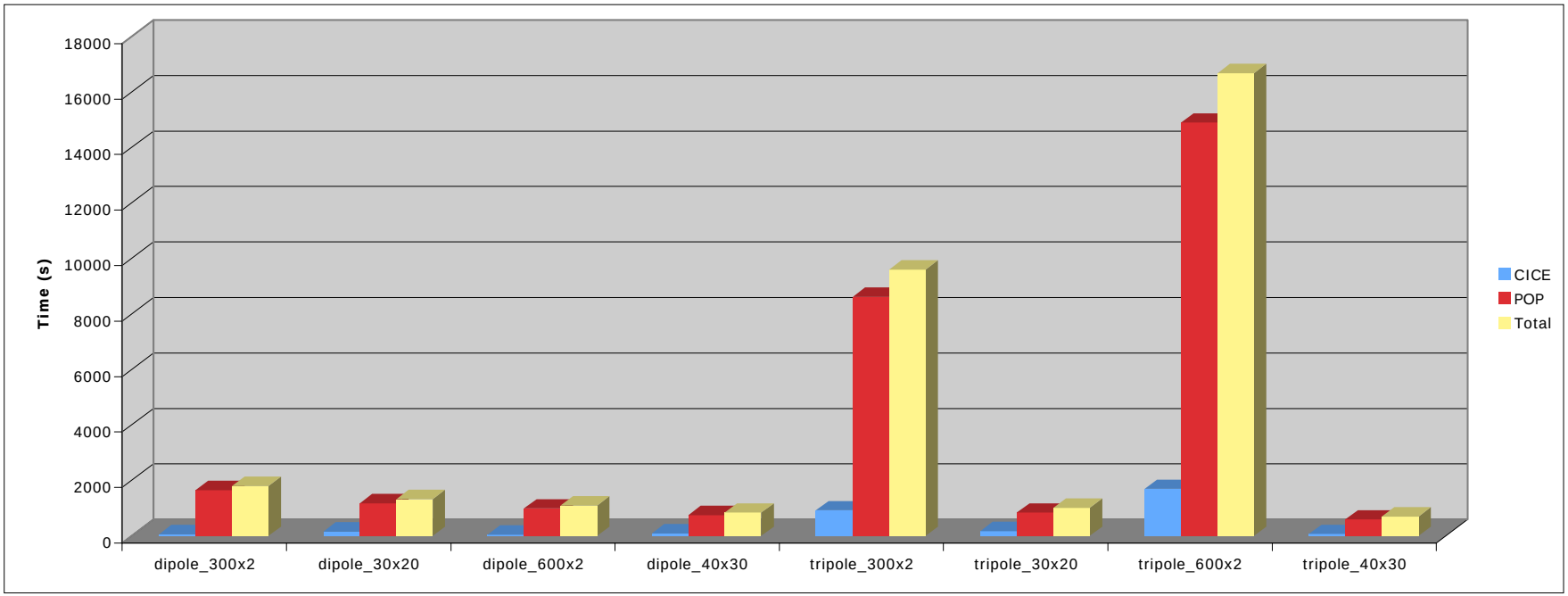
- CAM 3.5 uses the finite-volume dynamical core at all relevant atmospheric resolutions
  - 1° (*0.9x1.25*)
  - 0.5° (*0.47x0.63*)
  - 0.25° (*0.23x0.31*)
- With FV-dycore, as resolution increases, unrealistic “boreal winter polar night jet” increases in magnitude to the point where it affects the allowable 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



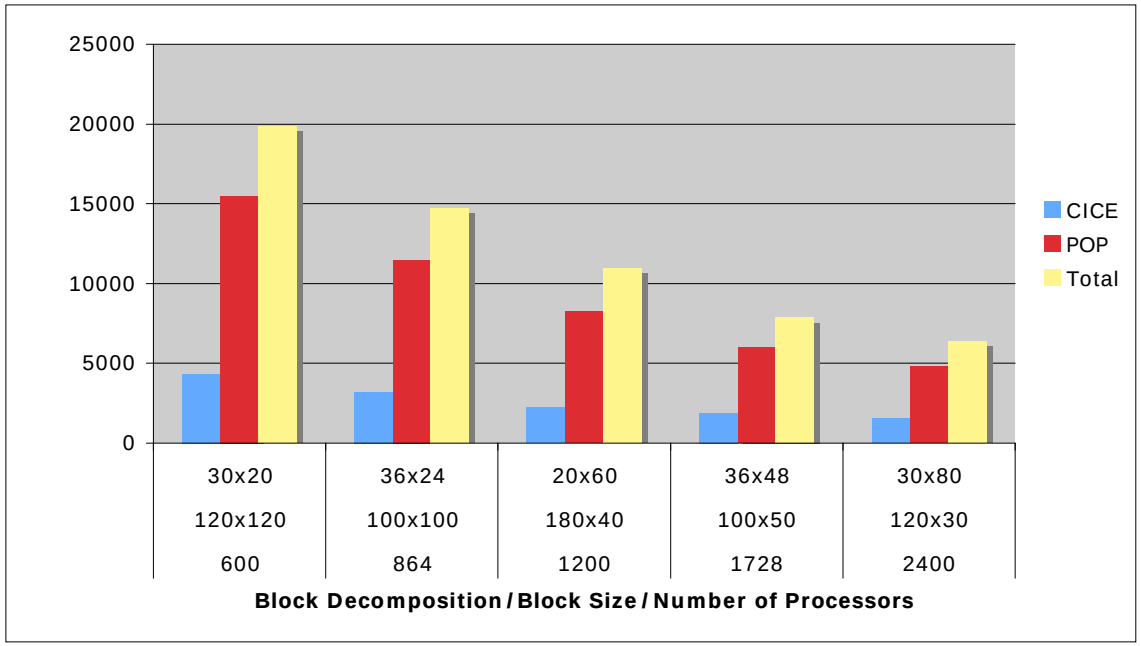
Timings from the Dipole Grid - Tripole Comparisons

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



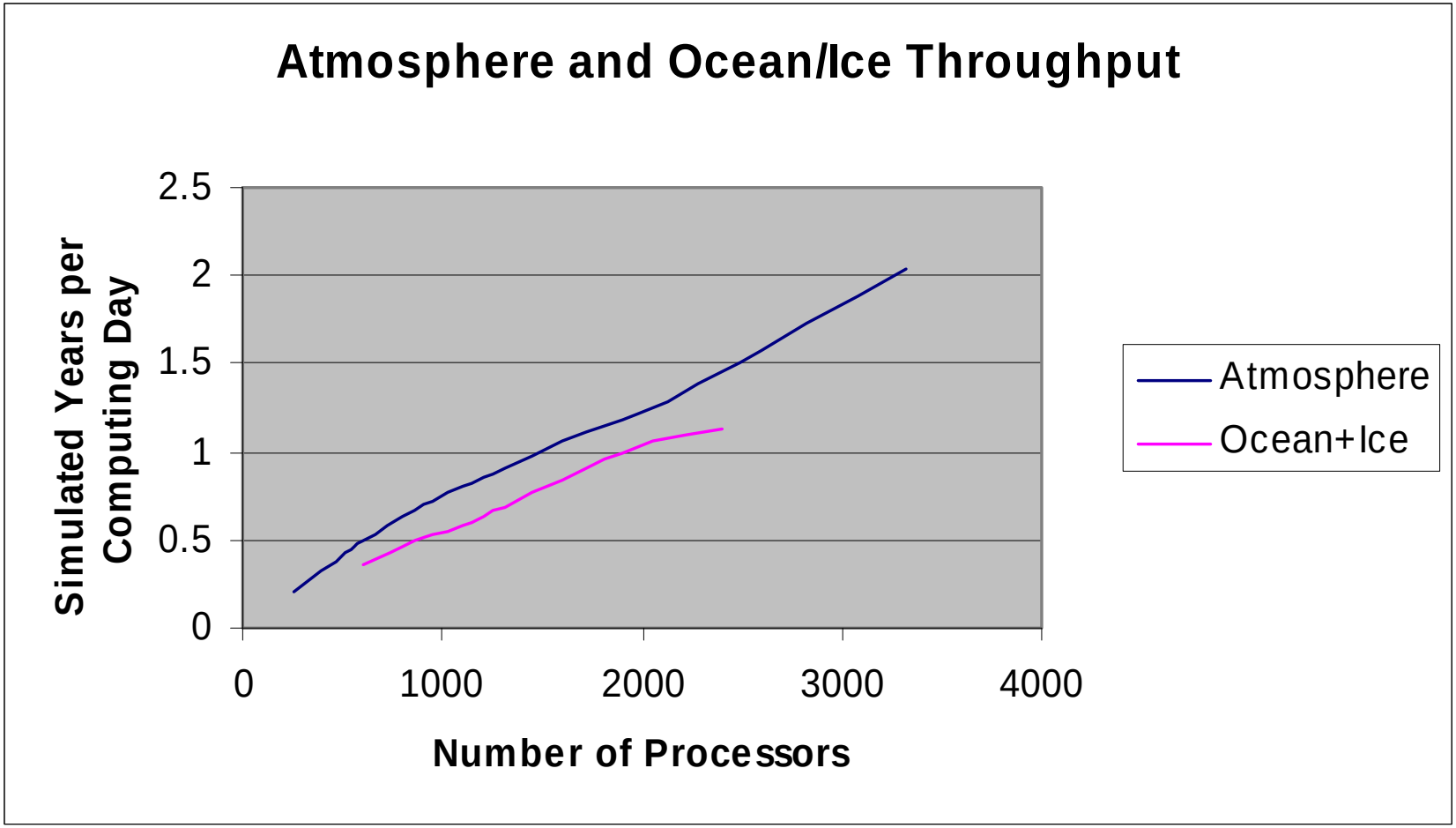
Timer	dipole_300x2	dipole_30x20	dipole_600x2	dipole_40x30	tripole_300x2	tripole_30x20	tripole_600x2	tripole_40x30
CICE	64.28	153.52	41.52	93.16	920.67	172.2	1693.15	67.42
POP	1654.75	1173.35	987.12	744.64	8615.54	837.12	14897.66	591.85
Total	1804.04	1327.58	1098.13	838.82	9593.88	1009.99	16682.67	700.04

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



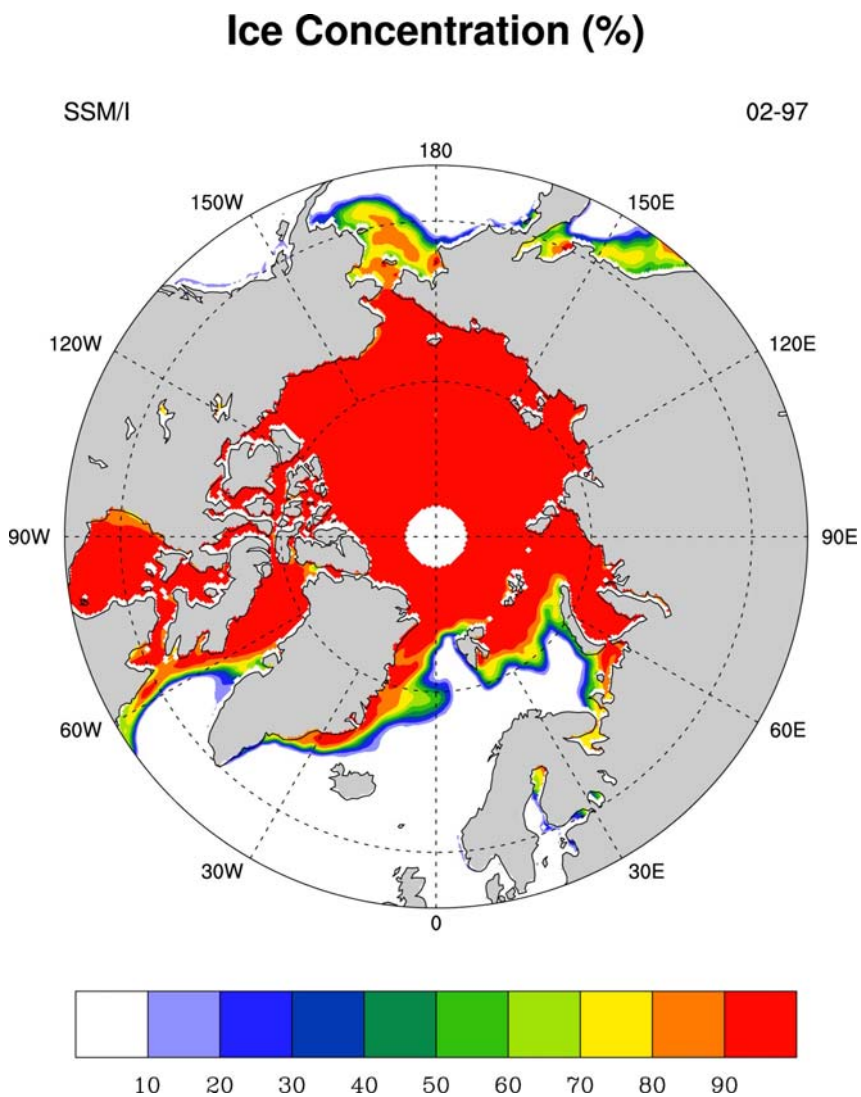
Current Speed from 0.1 POP

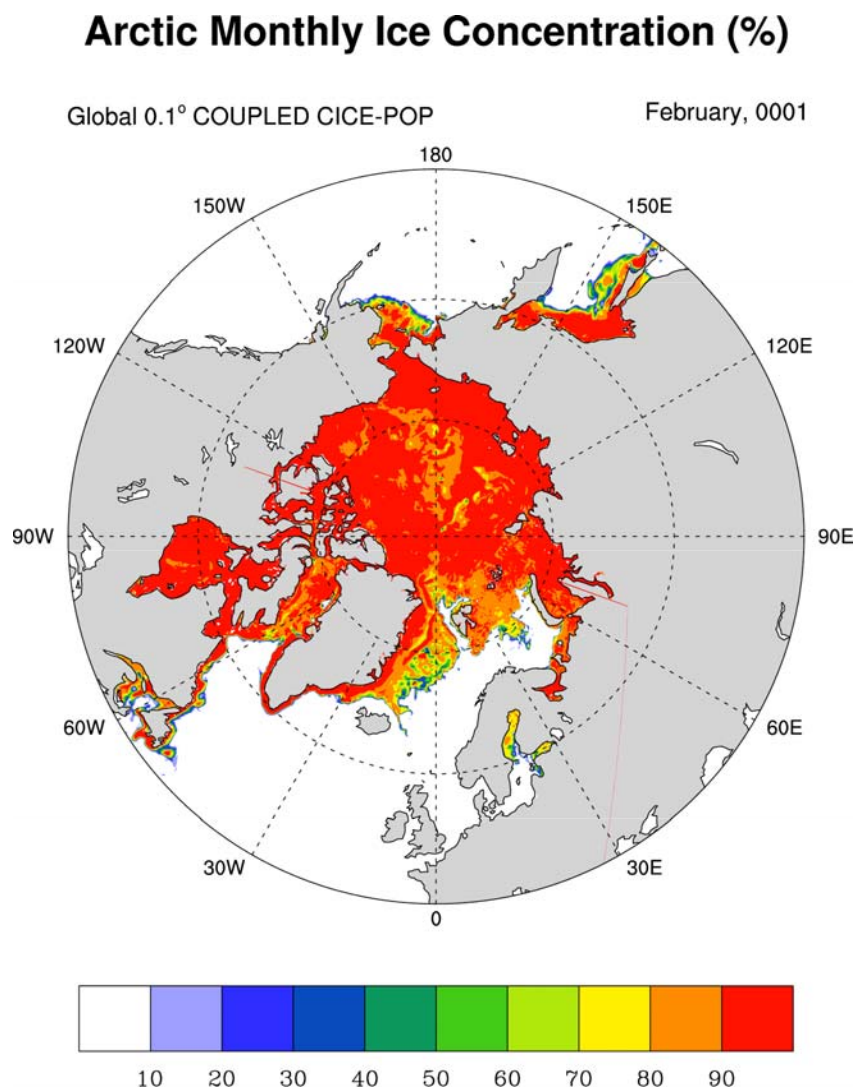
0.1°, 40-level Global Coupled Ocean/Ice

- 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





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