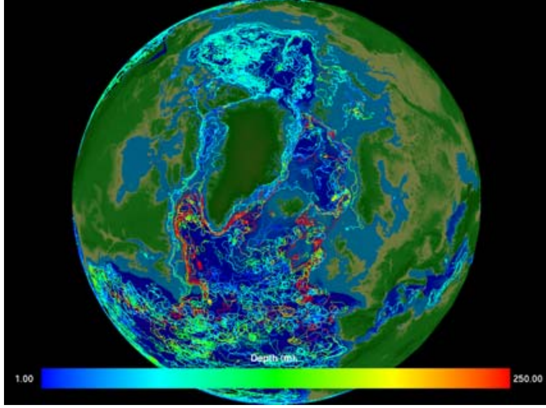
Ultra-High-Resolution Coupled Climate Simulations:



A LLNL Grand Challenge Computational Project

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CCSM OMWG Meeting, Boulder, Colorado
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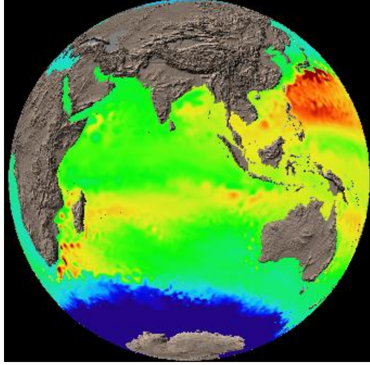
Project Goals



- **Overall Goal**: Carry out a multi-decadal simulation on the LLNL Atlas machine whereby 0.25° atmosphere/land is coupled to 0.1° tripole ocean/ice.

- **Intermediate Milestones**:
  - port individual components and coupled code to Atlas
  - develop capability to run CAM at 0.25°
  - develop capability to run POP2/CICE at 0.1°on tripole grid
  - extend CCSM to desired resolution (*0.23x0.31_tx0.1v2* grid)

Atlas is LLNL's newest and most powerful institutional computing resource

- Consists of 1152 nodes, each with eight 2.4-GHz Opteron CPUs
- Theoretical system peak performance = 44.2 Tflop/s
- Contains 16 GB memory per node
- Uses Infiniband switch and *mvapich*
- Supports Intel, Portland and Pathscale compilers
- Uses Lustre file system
  - scheduled January 2008 upgrade should improve parallel I/O performance substantially

Codes Ported to Atlas

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

- **CCSM 3.5 (*ccsm3_5_beta* series)**
  - only porting issue involved recoding of system call
  - Atlas configuration files are now maintained in NCAR archive
  - code has been tested at 1° ATM with 1°OCN (*0.9x1.25_gx1v5* grid)
- **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

Global 0.1° Coupled POP-CICE

- LANL POP (V2.0) and CICE (V3.4?)

- Completed 2-year global 0.1° coupled POP-CICE simulation with dipole grid (Hudson Bay) configuration, uses NCEP/NCAR reanalysis daily forcing for 1995-1996.

- *Now underway*: 10-year spin-up of the global 0.1° coupled POP-CICE configured on the tripole grid with partial bottom cells,forcing consists of daily climatology (1979-2003) of NCEP/NCAR reanalysis atmospheric fields (prepared by Y. Kim, SIO).

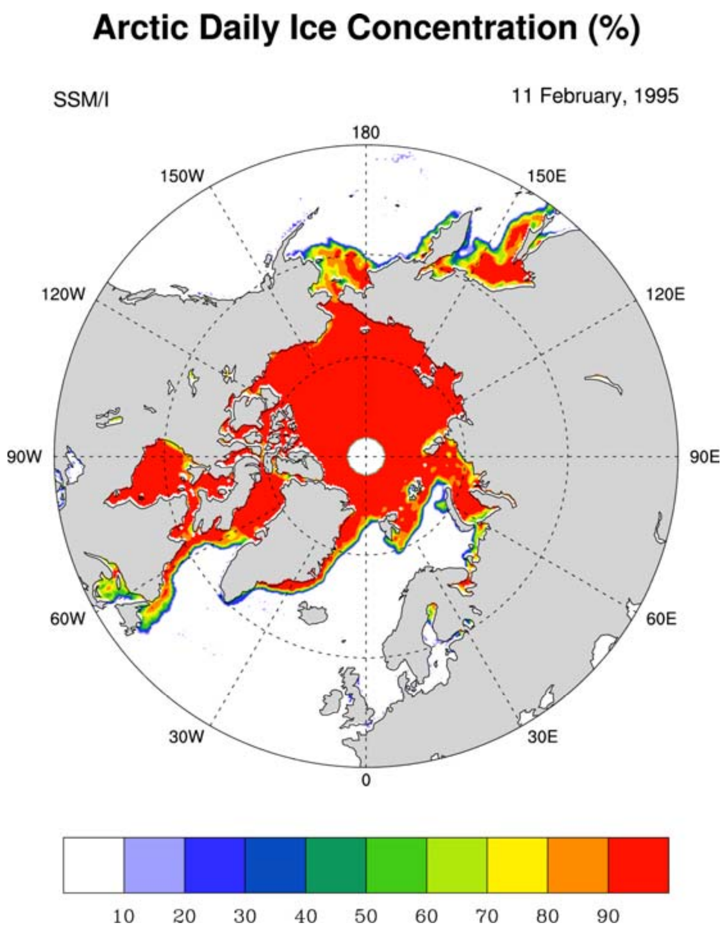
- Ocean initial condition: 15-year global stand-alone POP

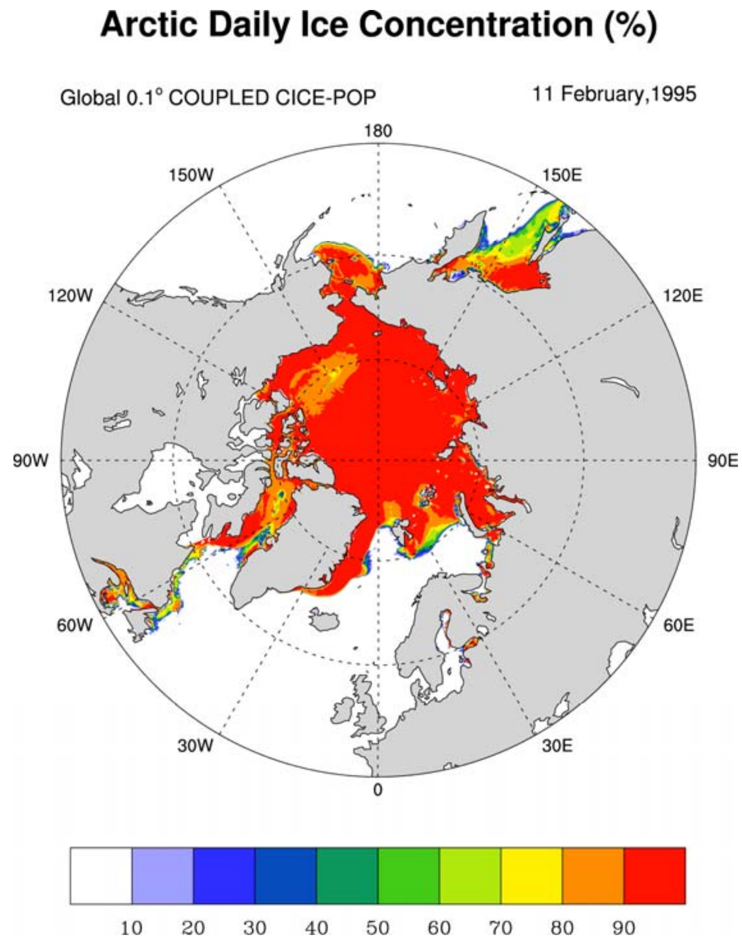
- Ice mask (defined by ice edge at each ice model time step) is used to delineate under ice regions from the open ocean where SSS restoring (relaxation time scale is 6 mo) is implemented to limit drift.

- 3-hourly coupling:mitigation of aliasing of inertial oscillations

Preliminary results from the 2-year Dipole Coupled POP-CICE run

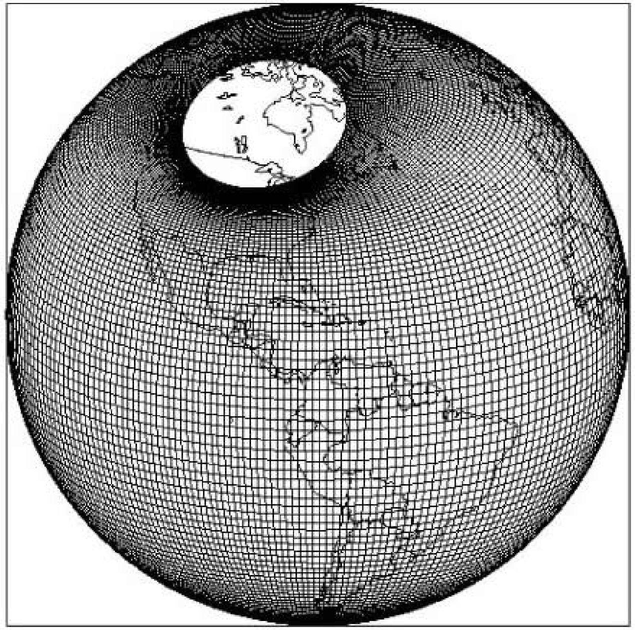
Comparison of simulated Arctic Ice Concentration with SSM/I observations





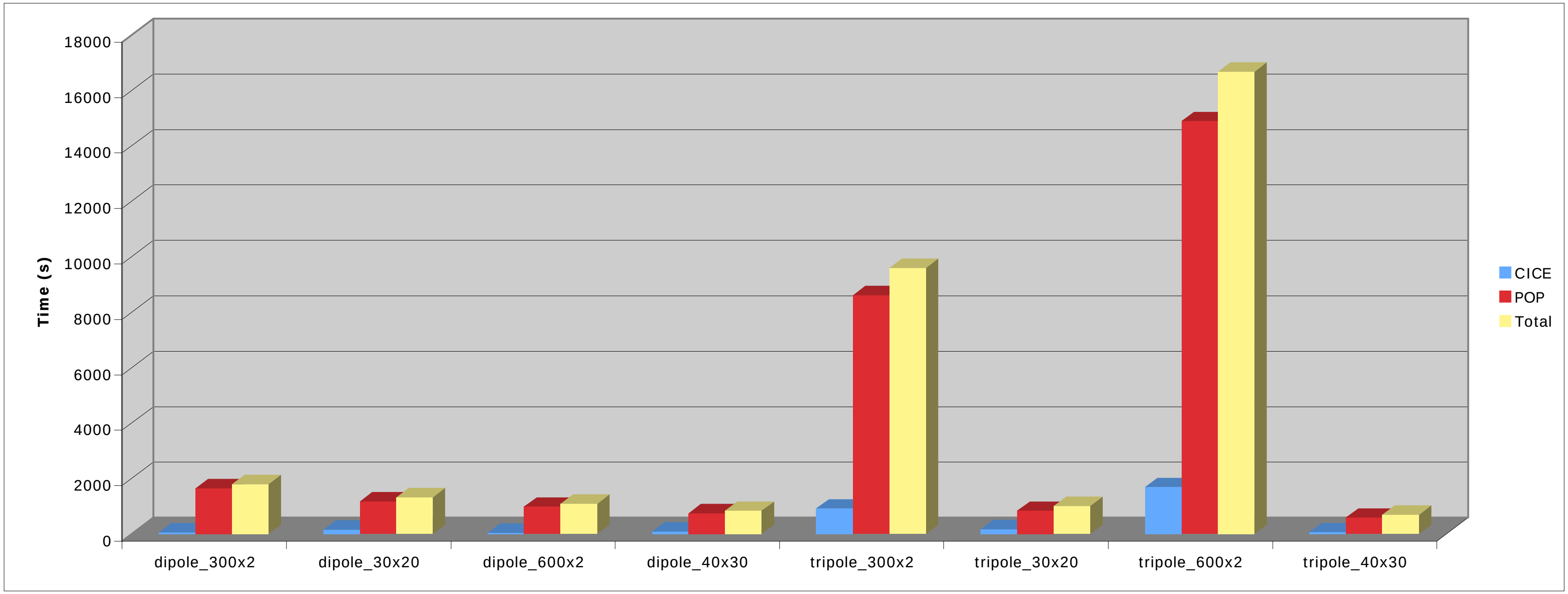
Testing Model Performance: Dipole versus Tripole Grids

Model setup	**Dipole**	**Tripole**
Topography	pbc	pbc
Forcing	daily climatology	daily climatology
	3yrs mean 1996-1998	25yrs mean 1979-2004
Initialization	1year restart	15years restart
	LLNL dipole POP run	LANL tripole POP run
	stand-alone	stand-alone



Timings from the Dipole - Tripole comparison cases

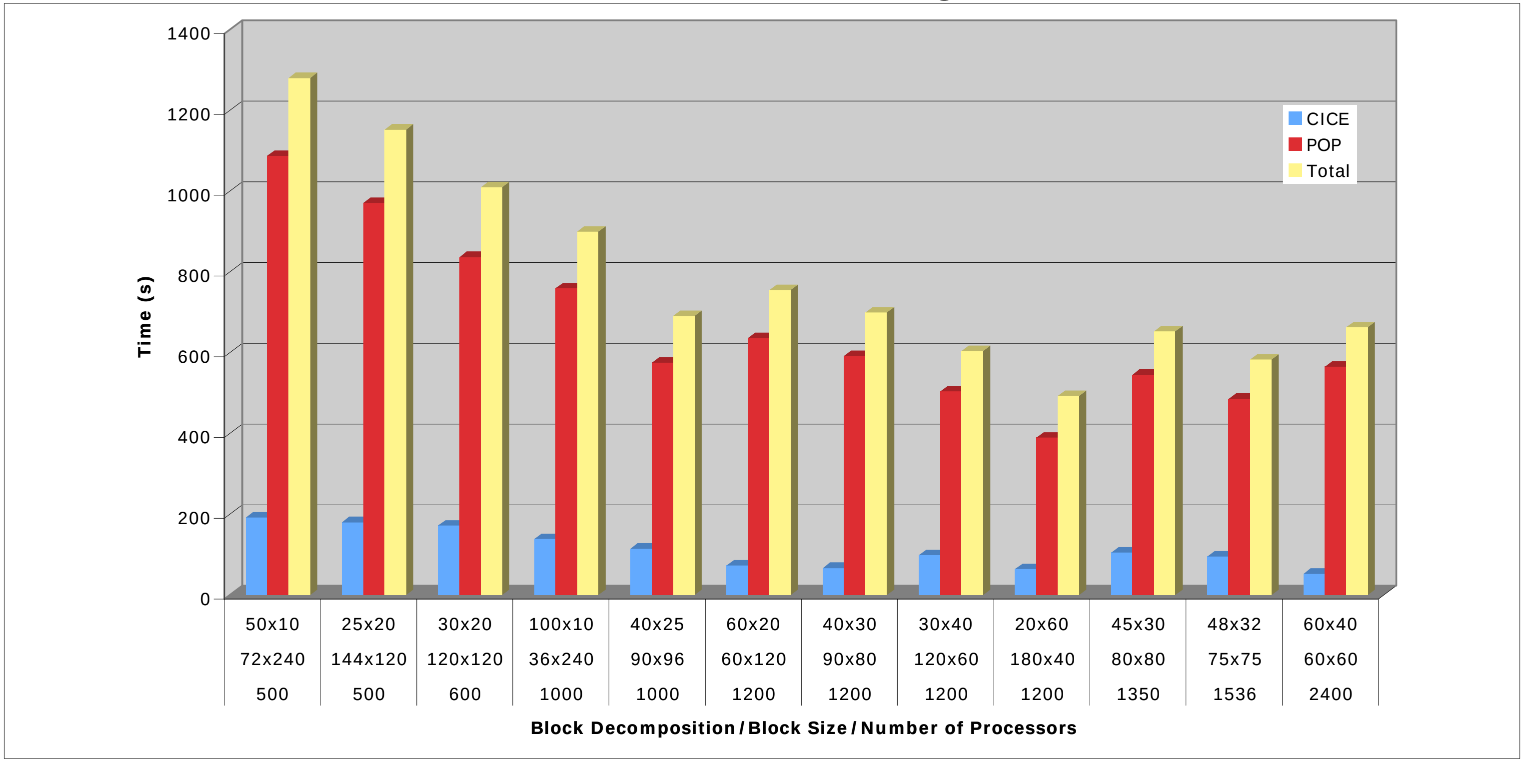
1 day test runs without I/O with different block decomposition



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

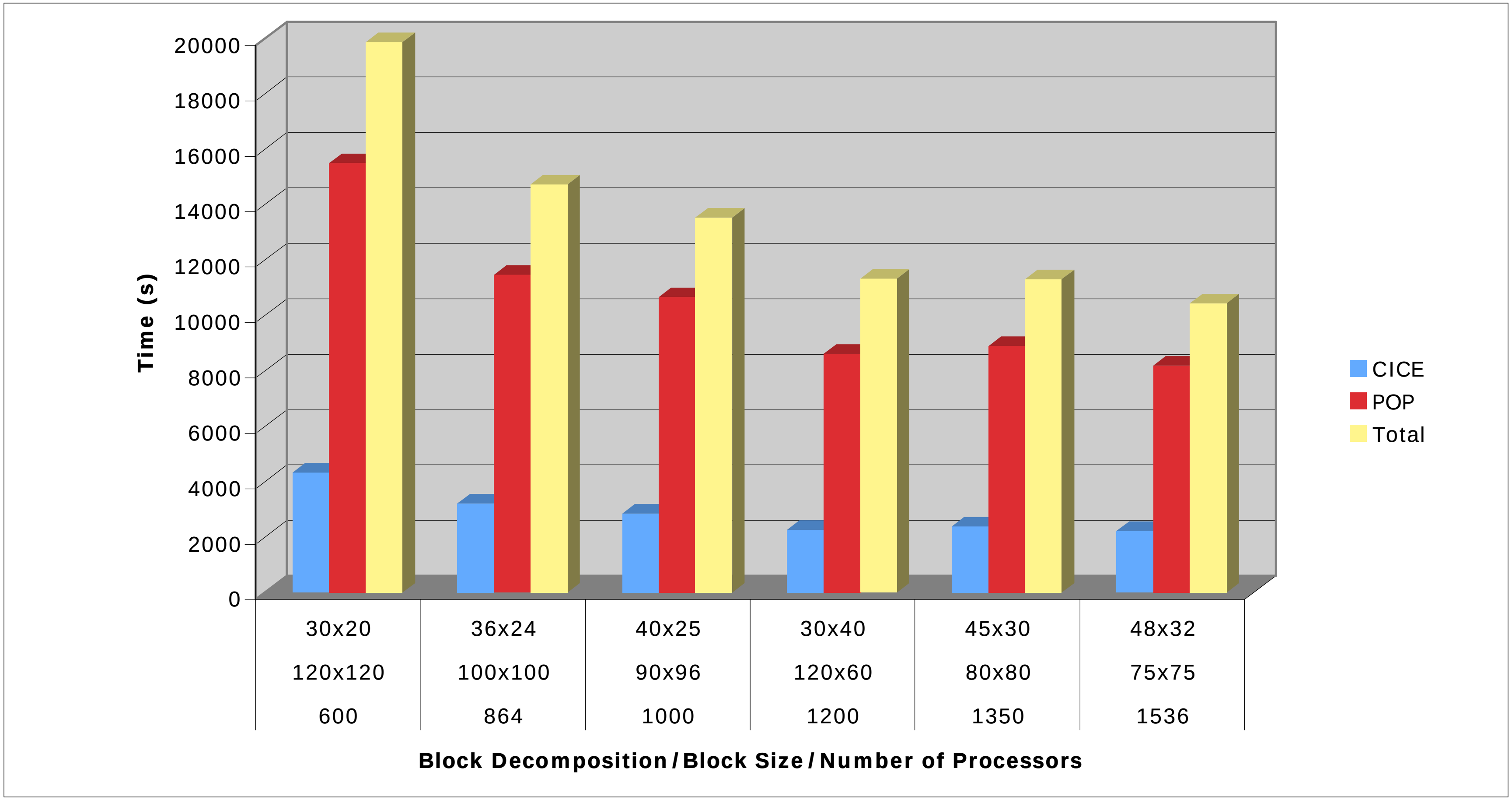
2) Tripole scaling tests without I/O: 1 day.

In red are the best timings



# processors	Block Size	Block Decomp	CICE	POP	Total
500	72x240	50x10	191.92	1087.73	1280.37
500	144x120	25x20	180.59	971.29	1152.66
600	120x120	30x20	172.2	837.12	1009.99
1000	36x240	100x10	139.12	759.63	899.58
1000	90x96	40x25	115.05	575.25	690.89
1200	60x120	60x20	73.34	636.35	755.79
1200	90x80	40x30	67.42	591.85	700.04
1200	120x60	30x40	99.22	504.25	604.11
1200	180x40	20x60	64.64	389.97	493.15
1350	80x80	45x30	105.83	546.02	653.28
1536	75x75	48x32	95.92	486.06	583.72
2400	60x60	60x40	52.95	565.32	663.12

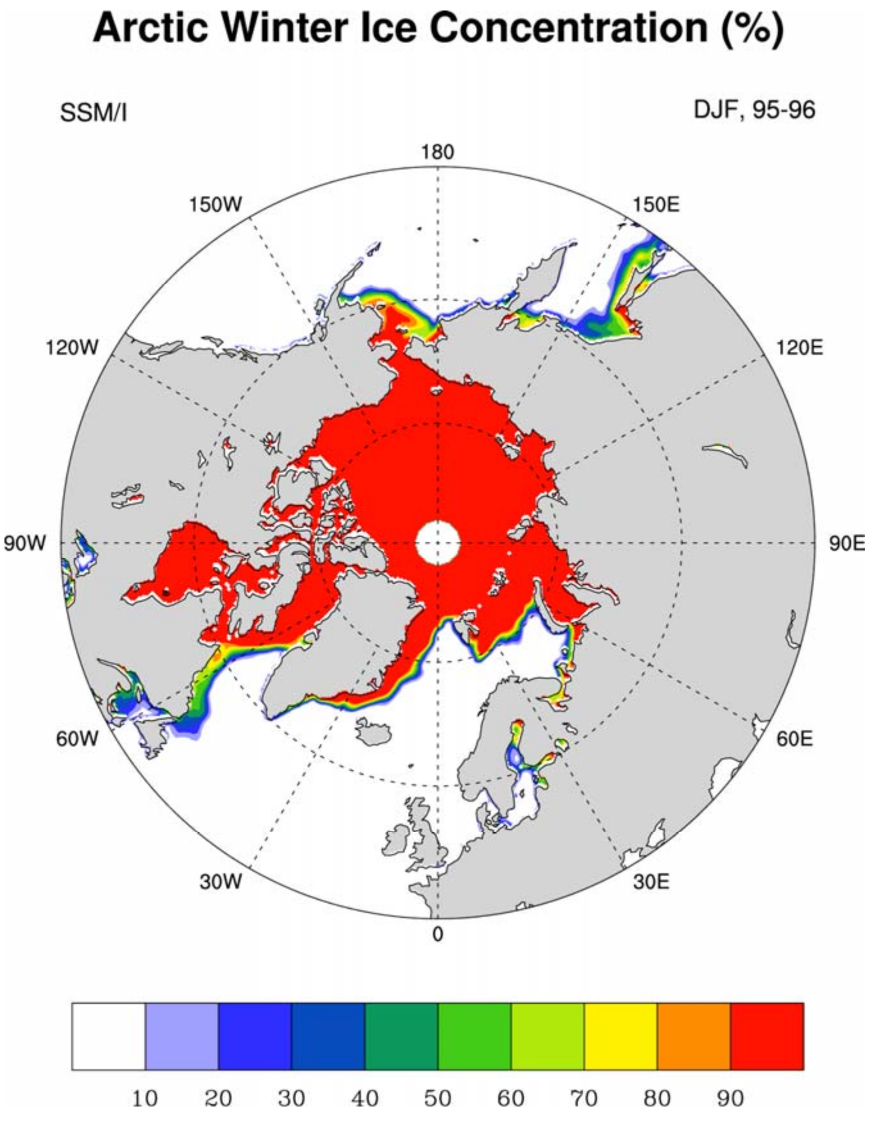
3) Tripole scaling tests with I/O: 1month, monthly output

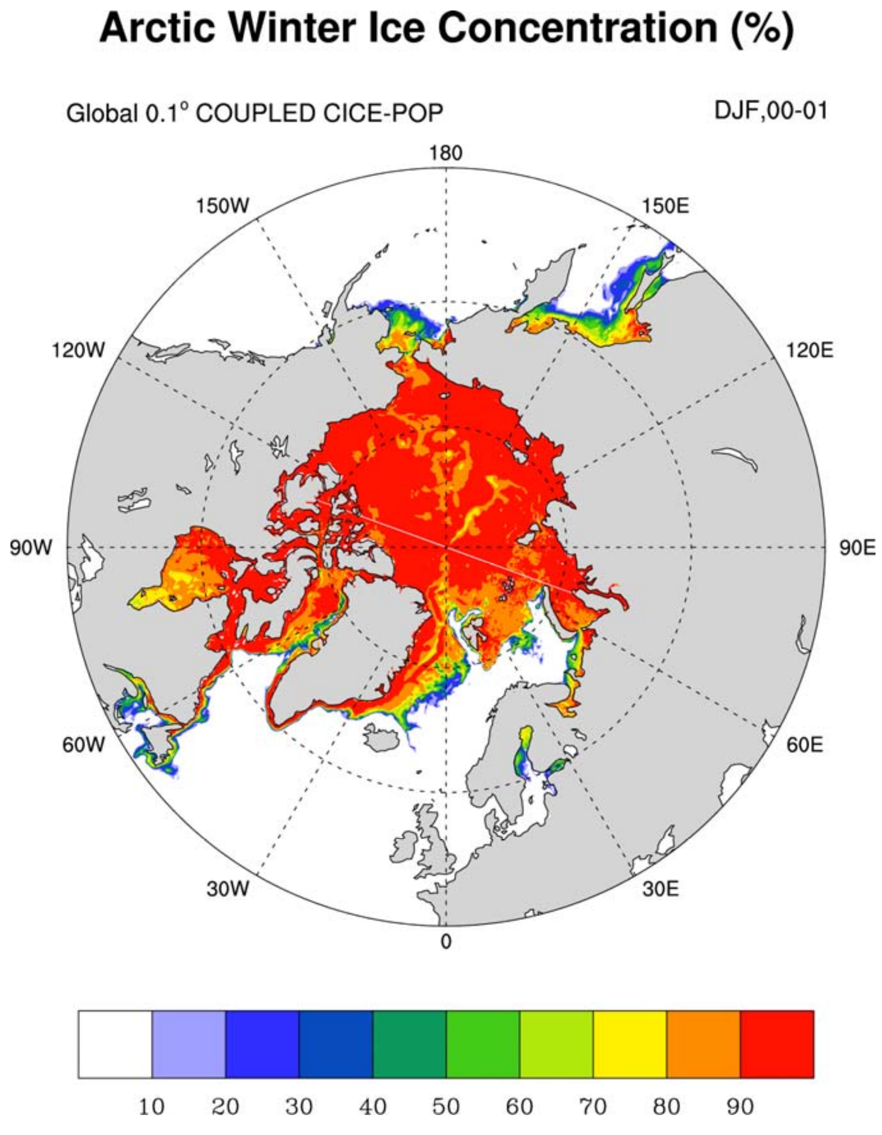


# processors	Block Size	Block Decomp	CICE	POP	Total
600	120x120	30x20	4329.94	15493.65	19855.59
864	100x100	36x24	3217.93	11473.28	14715.08
1000	90x96	40x25	2849.42	10658.03	13533.3
1200	120x60	30x40	2260.56	8611.11	11327.12
1350	80x80	45x30	2375.54	8903.5	11301.21
1536	75x75	48x32	2230.97	8190.75	10442.99

Tripole Coupled POP-CICE Simulation

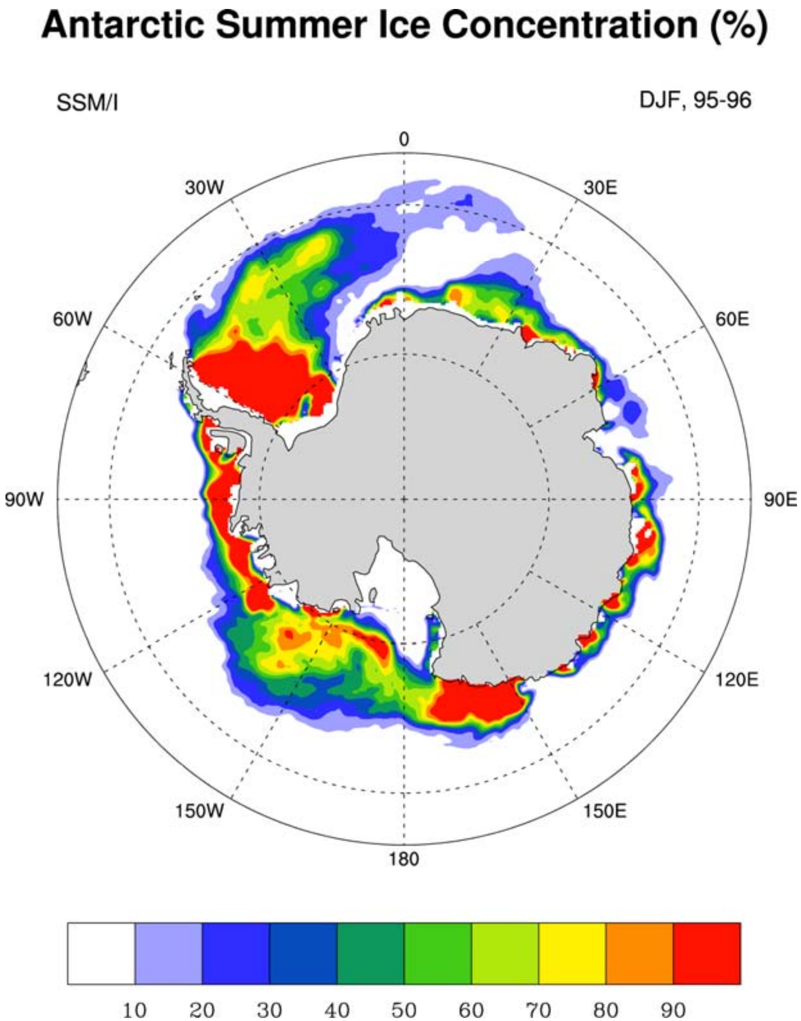
Comparison of simulated Arctic Ice Concentration with SSM/I observations

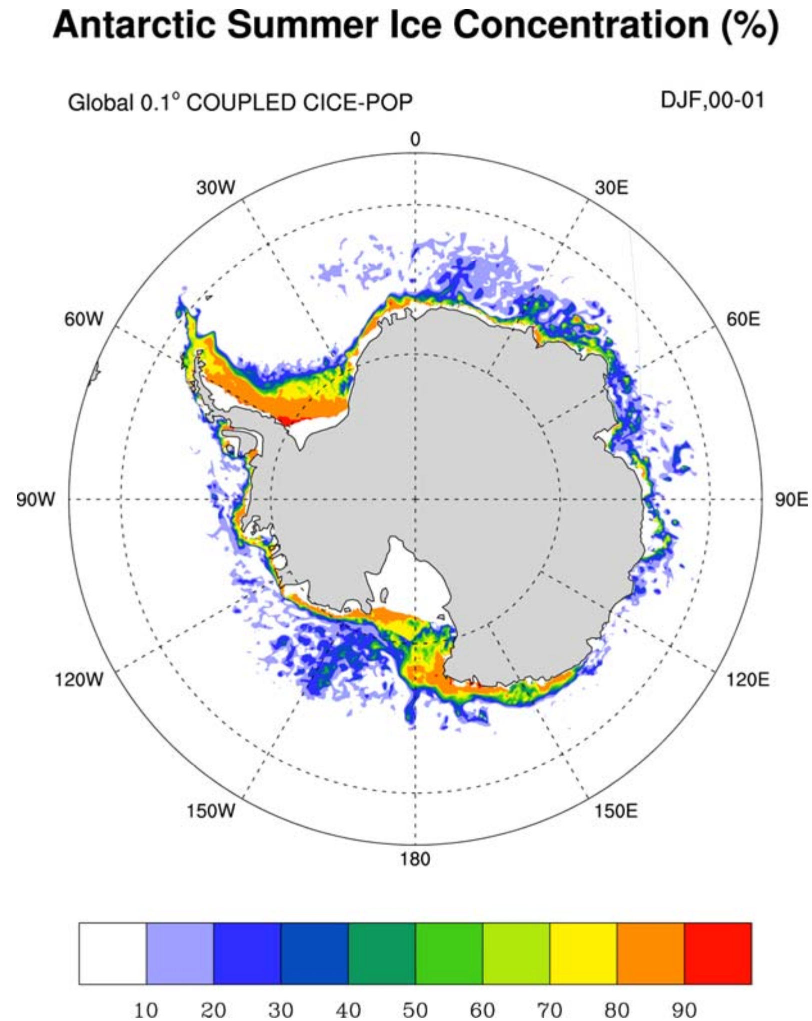




Tripole Coupled POP-CICE Simulation

Comparison of simulated Antarctic Ice Concentration with SSM/I observations





Future Plans: 0.1° Tripole Ocean/Ice

- 50-y POP/CICE simulation forced with NCEP/NCAR 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 and change over this period and compare with observations.
- Southern Ocean residual circulation (Cerovecki, SIO)
- Effect of eddies on intermediate water formation- Walin analysis (Cerovecki, SIO)
- Role of eddies in polynya formation (Ivanova, LLNL)

High-Resolution Atmospheric Capability (Mirin, LLNL)

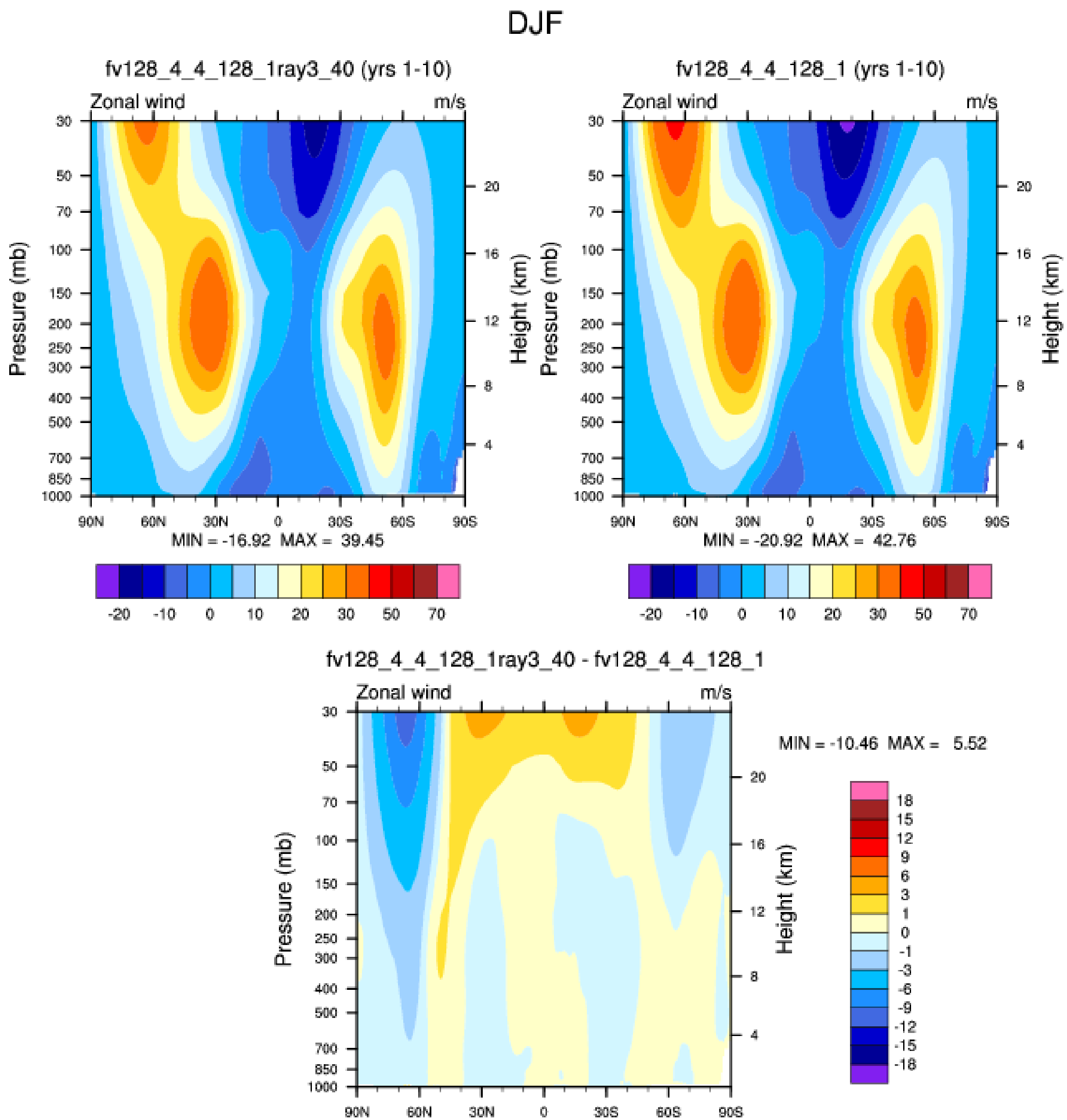
- CAM 3.5 (tag *cam3_5_23*) has using finite-volume dynamical core (FV-dycore) at all relevant atmospheric resolutions
  - 1° (*0.9x1.25*)
  - 0.5° (*0.47x0.63*)
  - 0.25° (*0.23x0.31*)

High-resolution atmospheric capability

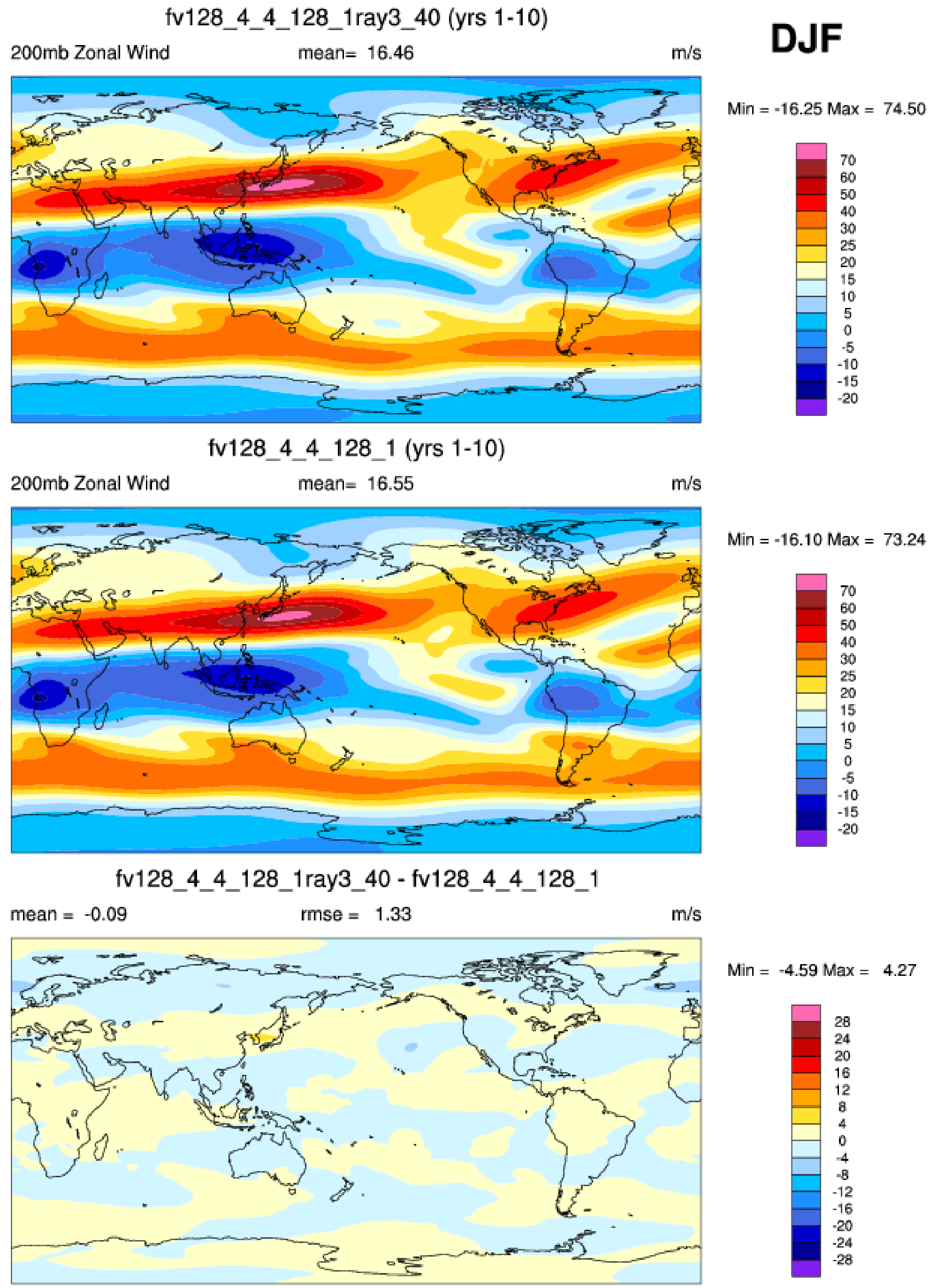
- With FV-dycore, as resolution increases, polar jet increases in magnitude (perhaps due to breakdown in gravity wave drag parameterization) to the point where it affects the allowable dynamics time step.

  – polar jet is remedied through addition of Rayleigh friction (centered at model top) or filtering of intermediate velocity field (*Putman* filtering)
  – 10-year validation tests of these terms at 0.5° show that their inclusion does not adversely affect the solution
  – Tests of these terms at 0.25° show that they enable the code to maintain stability at reasonable time step

Global Zonal Averaged wind



200 mb Zonal Wind



High-Resolution Atmospheric Capability

- 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

Coupler mapping files

- Coupler mapping files connect (1) the atmosphere and ocean grids, and (2) the river runoff grid to the ocean grid
- Atmospheric grids of relevance are *0.9x1.25*, *0.47x0.63* and *0.23x0.31*; ocean grids of relevance are *gx1v5* and *tx0.1v2*
- Coupler mapping files have been created using Scrip for tensor product of above ATM grids with above OCN grids, except for *0.23x0.31_gx1v5* (Scrip produces negative weights at a few locations in the Arctic)
- We have *not succeeded* in creating a runoff mapping file connecting the 0.5-deg river runoff grid to the *tx0.1v2* ocean grid (Scrip code hangs)

CCSM with Dead Components

- CCSM can be run with *dead* components to evaluate memory and communication patterns of coupled system
- As a test, CCSM was run on Atlas with dead components at *0.9x1.25_gx1v5* resolution
- *0.23x0.31_tx0.1v2* resolution with dead components has met with partial success
  - code temporarily modified to address absence of runoff mapping file
  - initial case executes successfully
  - restart case encounters memory error
    - data read in from restart file must be scattered in smaller chunks
    - solution to this problem is in process

Future plans – CCSM with dead components

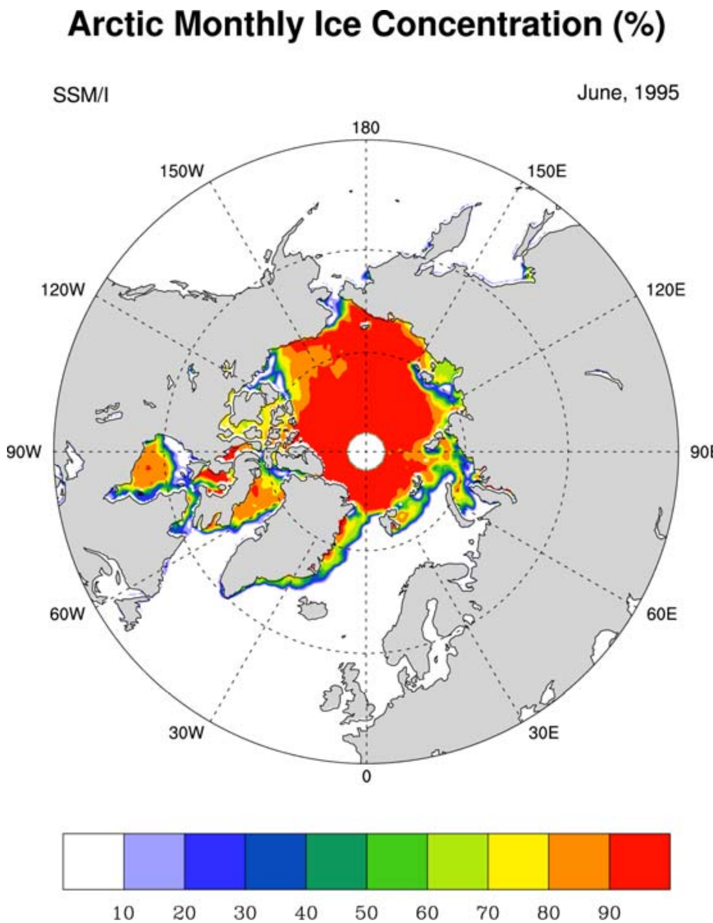
- Assure that code is able to restart successfully
- Ascertain minimum number of processors for each component so that code fits into memory
- No show-stopper is anticipated
  - individual components already run at hi-res

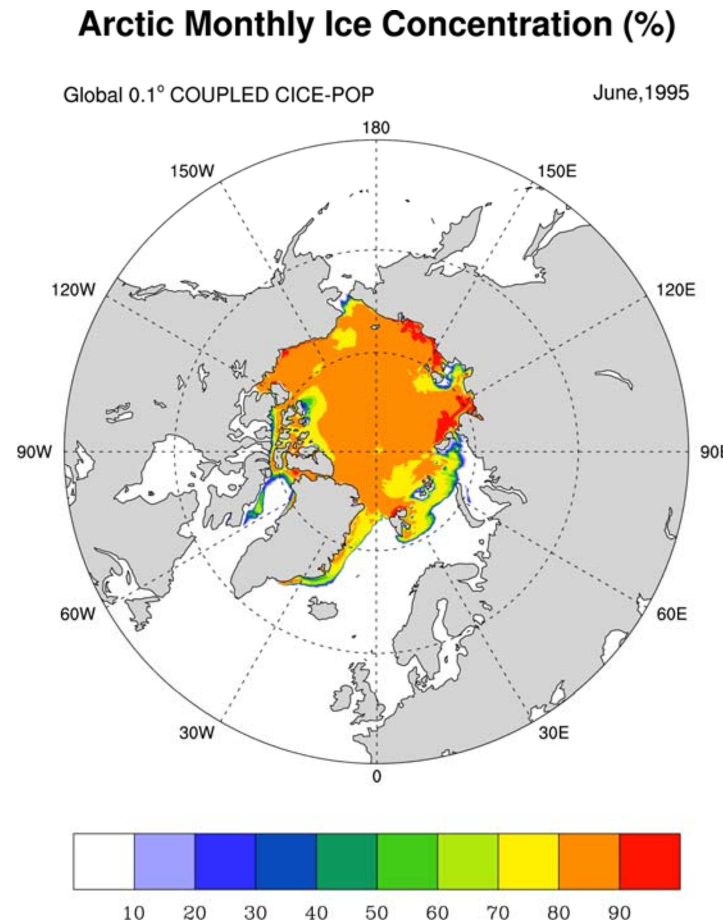
Future plans - high-resolution atmosphere

- Initially test hi-res ATM using 1-deg ocean
- Run CCSM at *0.47x0.63_gx1v5* on Atlas;
  - aim for 30-min physics time step and 1-hr coupling time
  - no show-stopper is anticipated
- Run CCSM at *0.23x0.31_gx1v5* on Atlas
  - this is contingent on being able to construct coupler mapping file
  - aim for 15-min physics time step and 30-min coupling time
  - CCSM has never been run at such a high atmospheric resolution

Future Plans – CCSM with 0.1° Tripole Ocean/Ice

- To run CCSM with *tx0.1v2* ocean grid
  - LANL POP2/CICE must be incorporated into CCSM
  - if runoff effects are to be included, need to create runoff mapping file
- Initially run with data atmosphere model
- Run with progressively finer ATM grids, beginning with 1°, then 0.5°, and finally 0.25°
  - test coupled mode as economically as possible
- Carry out multi-decadal calculation at 0.25-deg ATM coupled to 0.1° tripole OCN


Arctic Monthly Ice Concentration (%)
SSM/I
June, 1995
180
150W
150E
120W
120E
90W
90E
60W
60E
30W
30E
0
10
20
30
40
50
60
70
80
90


Arctic Monthly Ice Concentration (%)
Global 0.1° COUPLED CICE-POP
June,1995
180
150W
150E
120W
120E
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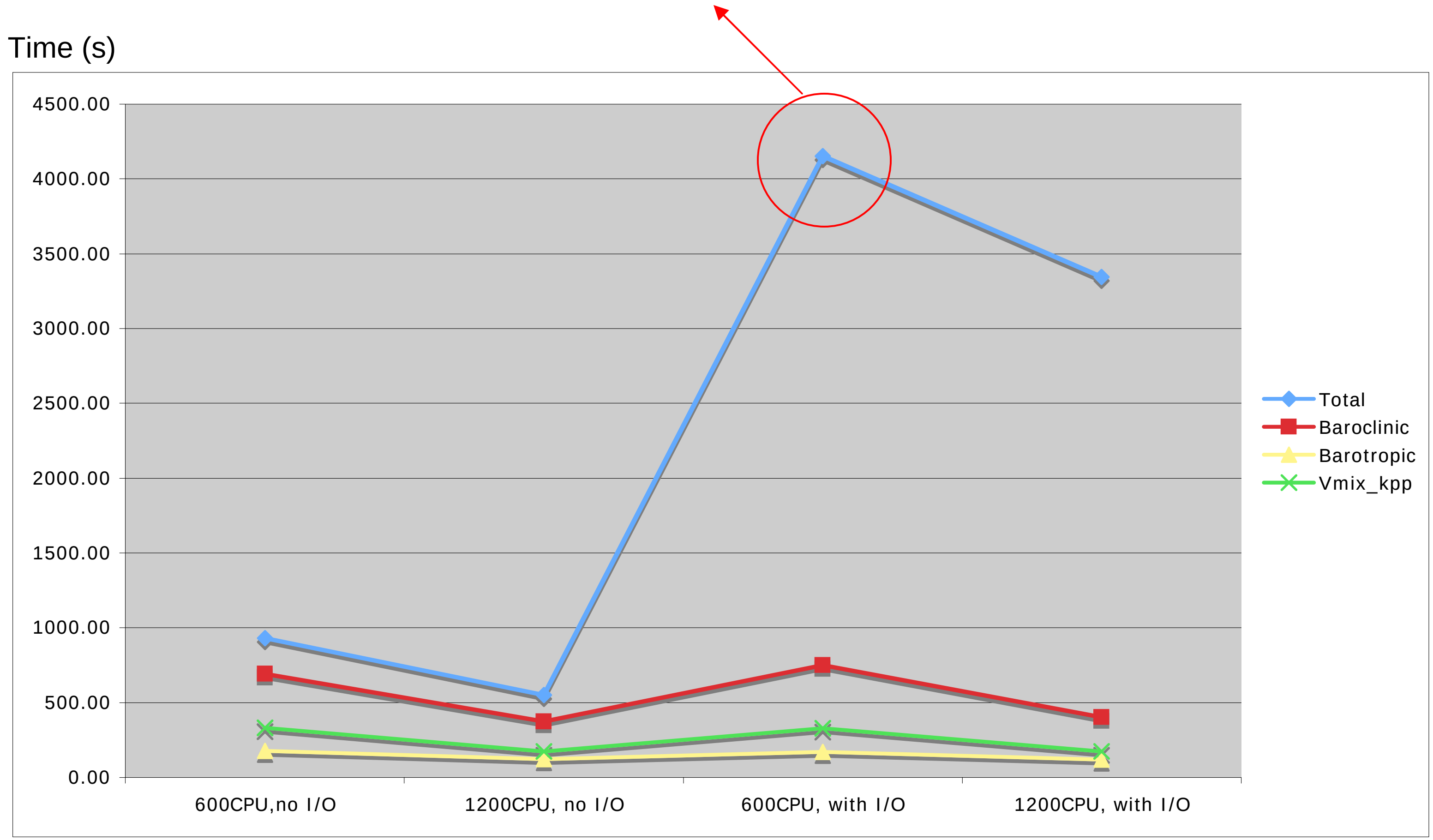
Global POP 0.1° PBC Timings and Scalability Tests on Atlas

Serial I/O takes 3x longer than the non I/O computation - need Parallel I/O!



4) Accuracy of the Solution

Variable	Average Difference	STD
Mean T	2.73203E-08	6.52467E-08
Mean S	6.91145E-09	1.41117E-08
Mean KE	-6.27896E-05	0.000293442
Mean SL	-5.62228E-08	2.51531E-07