CICE Performance In CESM

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CESM SEWG Meeting

Motivation

- CICE performance is typically on the critical path with respect to overall CESM performance and in some cases is playing an important role in limiting CESM throughput
- With the current decompositions, CICE runs effectively on only limited pe counts

Goals

- Understand better where time is spent in CICE
- Understand better how CICE cost varies as we change the decomposition or increase the number of processes
- Explore alternative decompositions depending on the outcome of the above assessments
- Look for some low hanging fruit wrt code optimization
- Reduce the cost of CICE in CESM and provide more opportunities to run on a wider range of processes

Results:

Net CICE performance improvement on hopper

- Using updated decompositions and masked halos seems to
  - improve performance by > 20% for most cases
  - allow us to run on relatively arbitrary processor counts

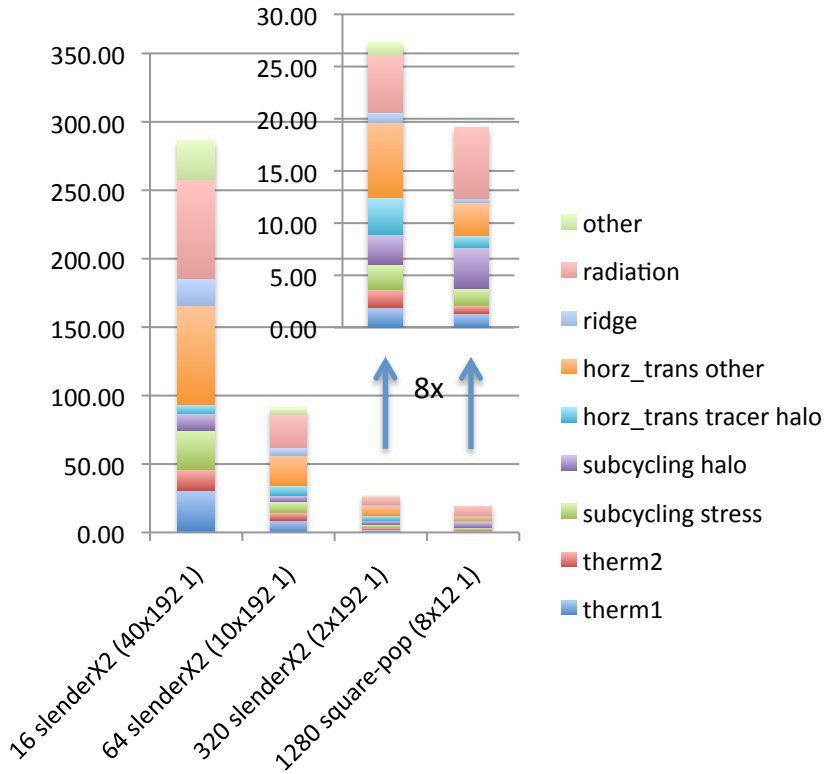
at gx1v6 (time to run 20 days)
16 pes, 272s --> 212s (22%)
64 pes, 91s --> 69s (24%)
320 pes, 27s --> 21s (22%)
1280 pes, 19s --> 10s (43%)

at tx0.1v2 (time to run 10 days)
1200 pes, 582s --> 361s (38%)
4800 pes, 148s --> 112s (24%)
18000 pes, 68s --> 68s (0%)

CICE Performance in CESM1.1

- Computation
  - Physics – computations only where there is sea ice (therm1, therm2)
  - Radiation – new dEdd implementation is expensive. computations only where there is sea ice and the sun is up.
  - EVP subcycling – stress/stepu, cycled about 100 times per cice timestep
  - Horizontal Transport
- Communication (halo updates)
  - EVP subcycling, cycled about 100 times per cice timestep
  - Horizontal Transport (tracer updates)
  - bound_state (therm2, etc)

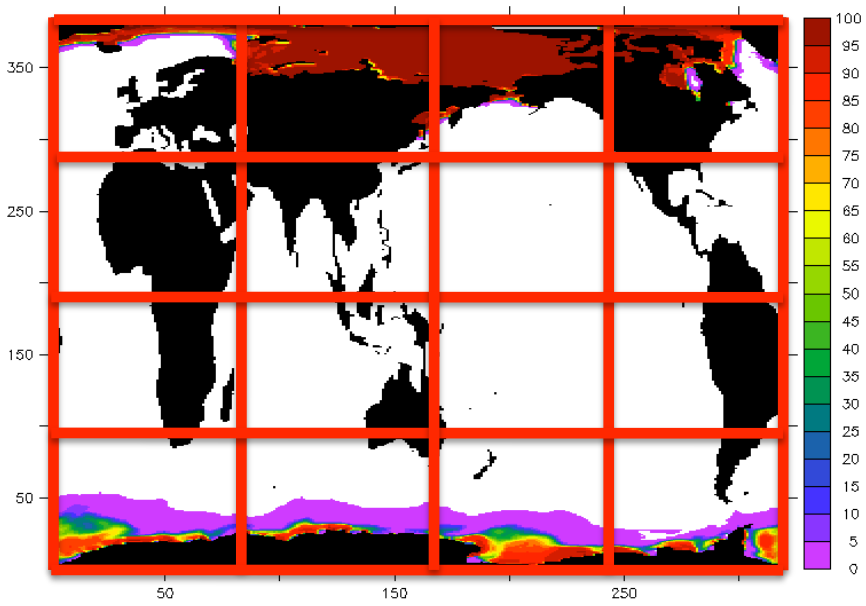
CICE, gx1v6, 16, 64, 320, 1280 pes, NERSC hopper
20 day runs, time in seconds



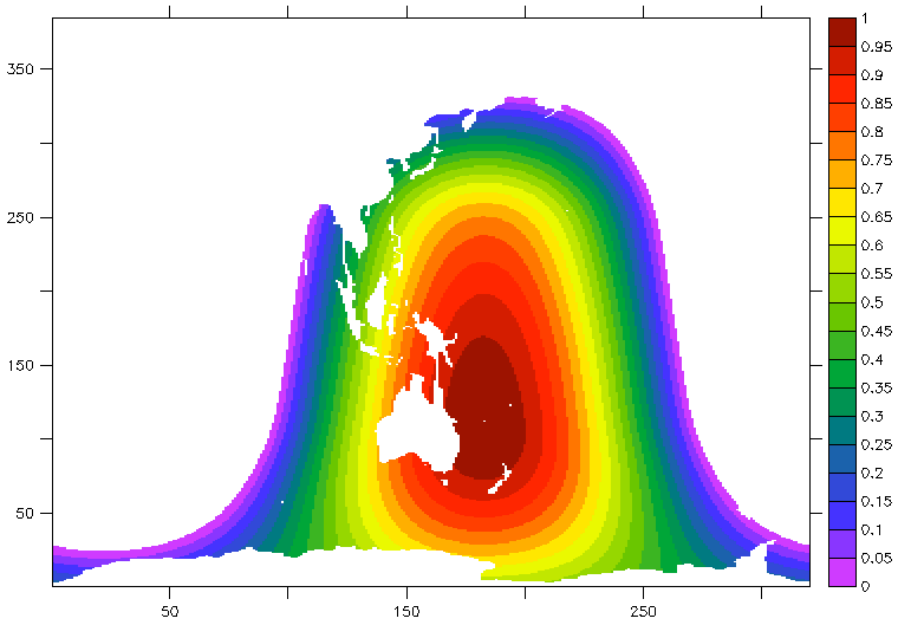
**Performance is ultimately limited by slowest processor*

Performance of CICE

- Computational performance driven by load imbalance to zeroth order, dominant term at low process counts and important at high process counts
  - CICE computations generally done only where there is sea ice
  - Large areas of the CICE grid never have any sea ice
  - The radiation computation done where there is sea ice and the sun is up
  - CICE varies seasonally and sun angle varies on diurnal cycle and seasonal timescales
- Communication is nearest neighbor halo update, it is a critical term at high process counts
  - Want to minimize number of messages and size of messages and maximize relative nearness of neighbors in communication network



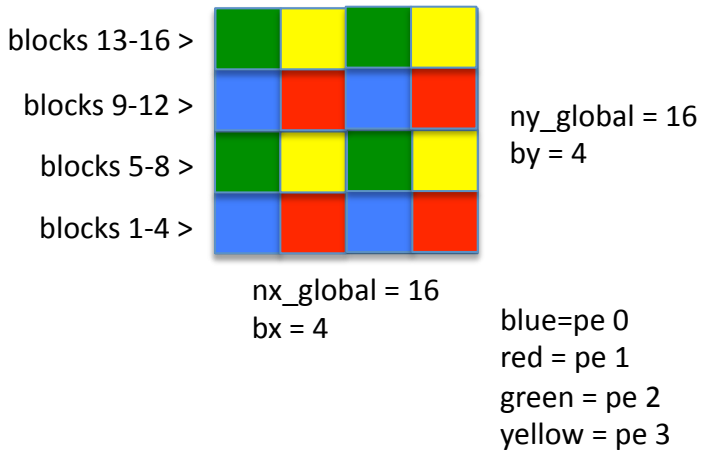
Mask and sample Jan 1 sea ice coverage



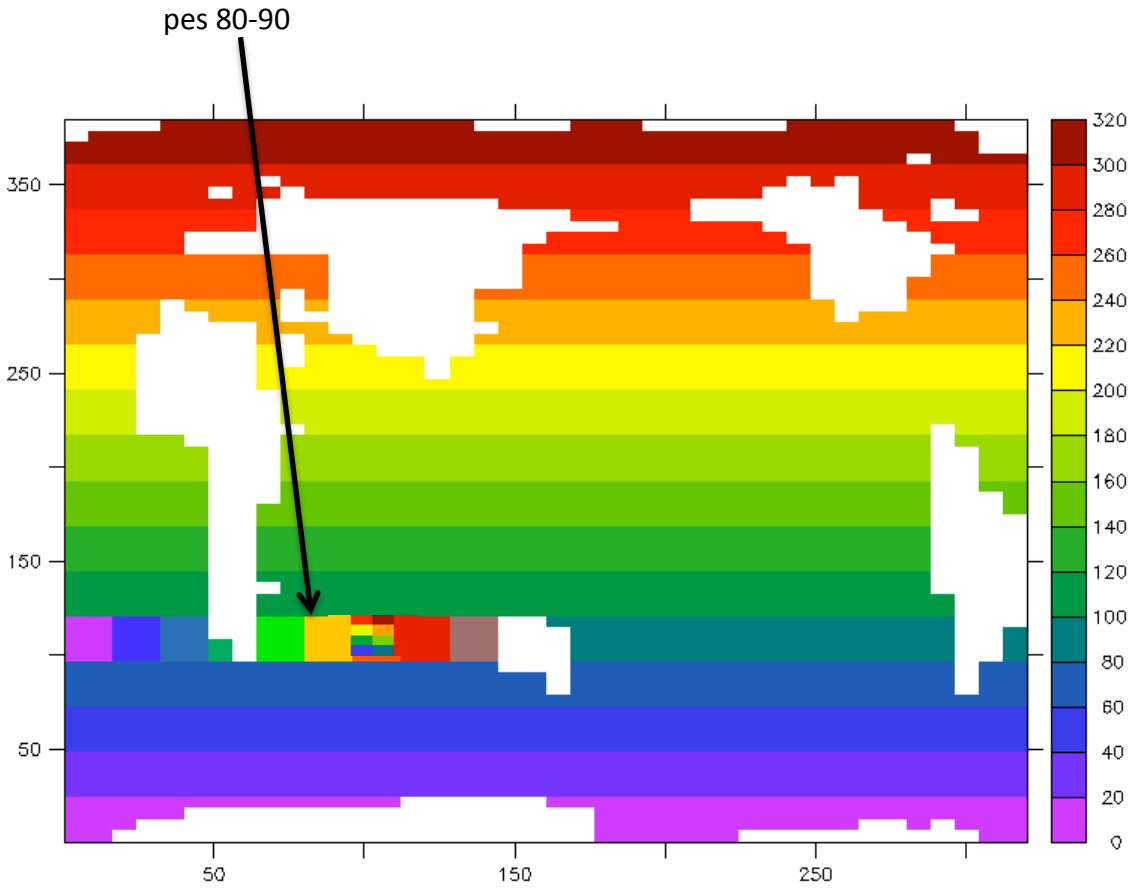
Solar Angle on Jan 1 at 0Z

Decomposition is a Critical Performance Tuning Knob

- CICE decomposes the horizontal grid across processes (tasks and/or threads)
- For a given global grid size, “nx” by “ny”
- Define a blocksize, “bx” x “by”
- Label the blocks
- Distribute blocks to processes using some decomposition strategy
  1. Cartesian Square-POP
  2. Cartesian SlenderX1
  3. Cartesian SlenderX2
  4. Spacecurve (Dennis)
  5. Roundrobin (New-ish)
  6. Blkrobin (New)
  7. Blkcart (New)



1. cartesian square-pop



block allocation to processors

Blocks aligned into contiguous “squares”

blocksize = 8 x 6, 8 blocks per processor

Good

- size of halo (low aspect ratio)
- number of neighbors (8)

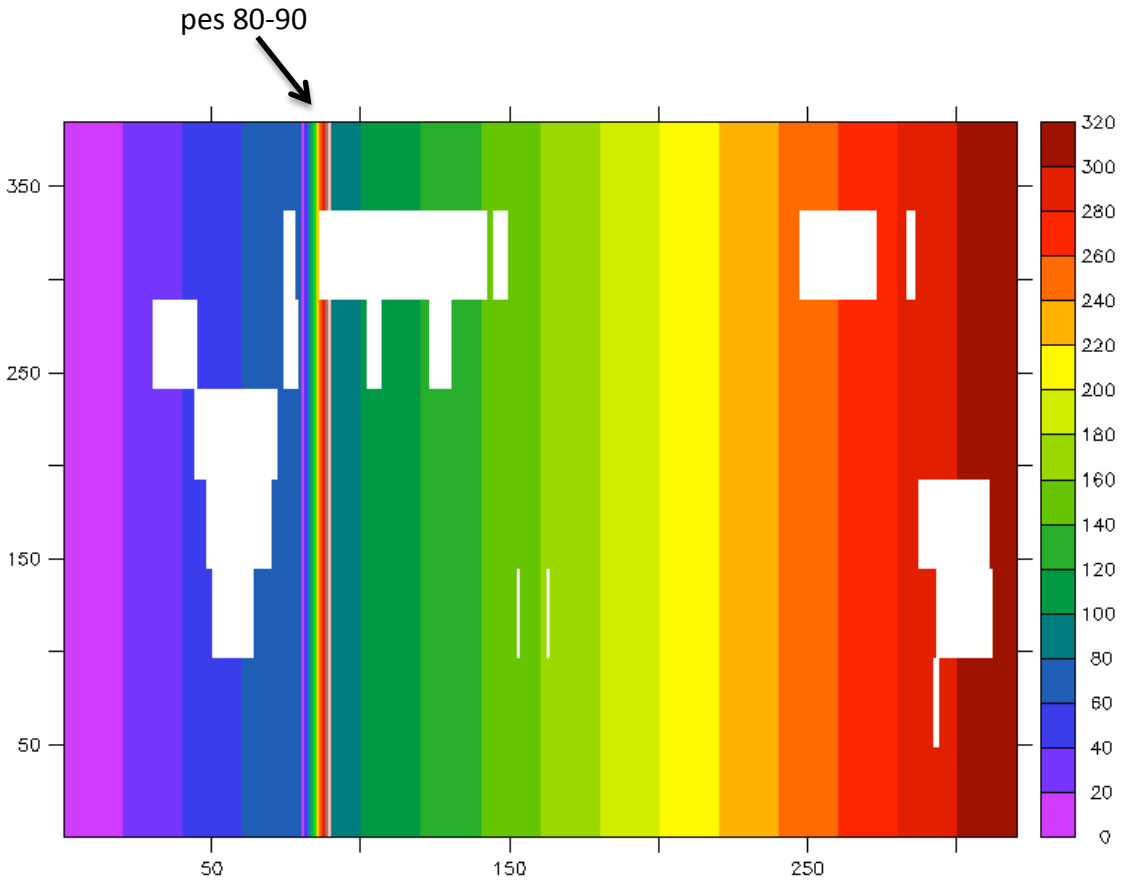
OK

- limited pe counts

Poor

- cice load balance (N/S and radiation)
- land block elimination

2. cartesian slenderX1



block allocation to processors

Blocks aligned “vertically”, span entire J index space

blocksize = 1 x 48, 8 blocks/processor

Good

- cice load balance (N/S and radiation)
- number of neighbors (2)

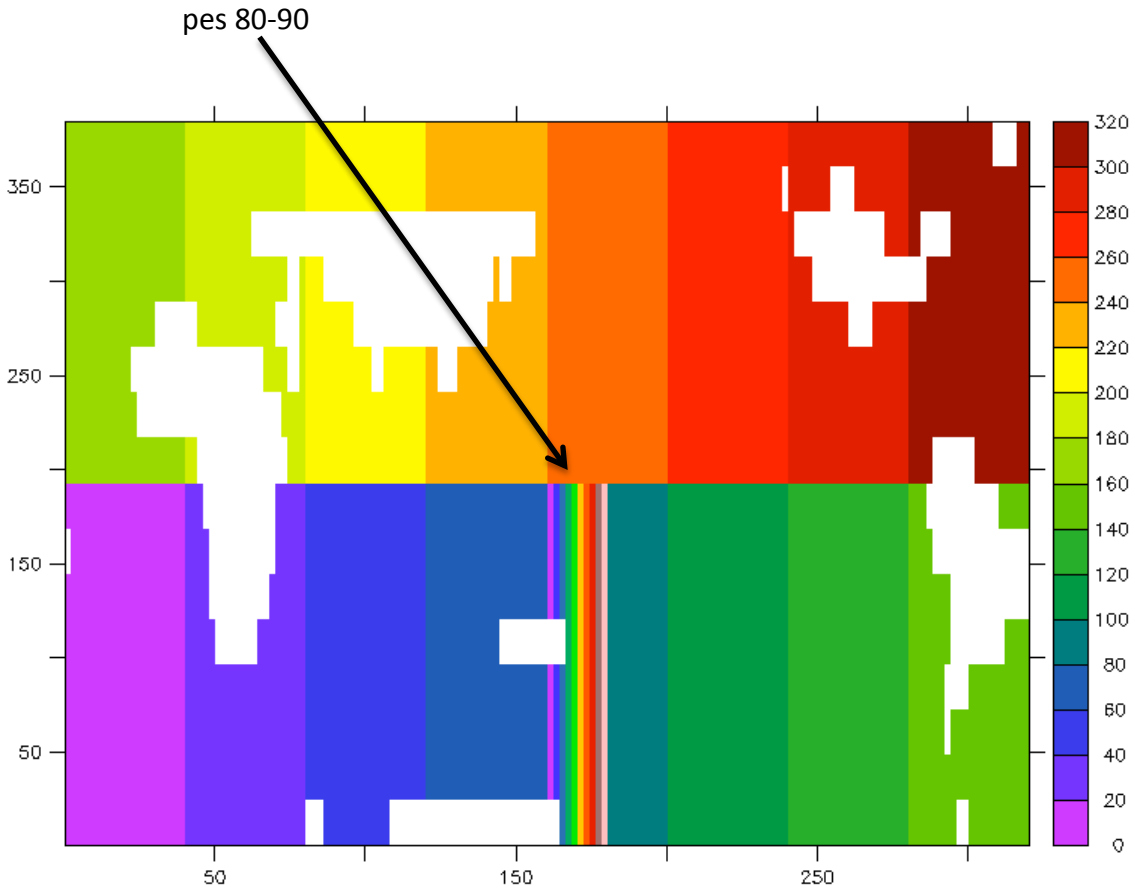
OK

- size of halo (high aspect ratio)

Poor

- limited pe counts (320, 160, 80, 64, etc)
- land block elimination

3. cartesian slenderX2



block allocation to processors

Blocks aligned “vertically”, span half J index space

blocksize = 2 x 24, 8 blocks per processor

Good

- cice load balance (N/S)
- number of neighbors (5)

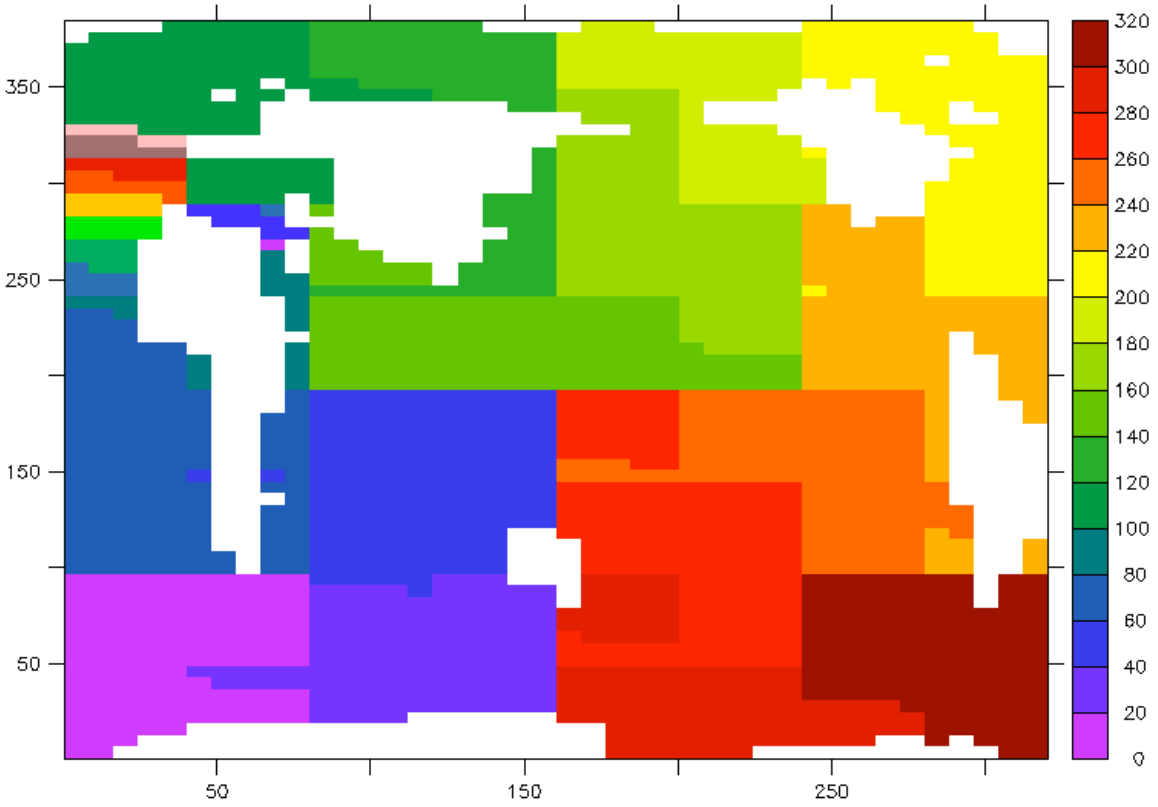
OK

- cice load balance (radiation)
- size of halo (high aspect ratio)

Poor

- limited pe counts (640, 320, 160, 80, 64, etc)
- land block elimination

4. spacecurve*



block allocation to processors

Blocks allocated linearly along spacecurve after land block elimination

blocksize = 8 x 6, 8 blocks/processor

Good

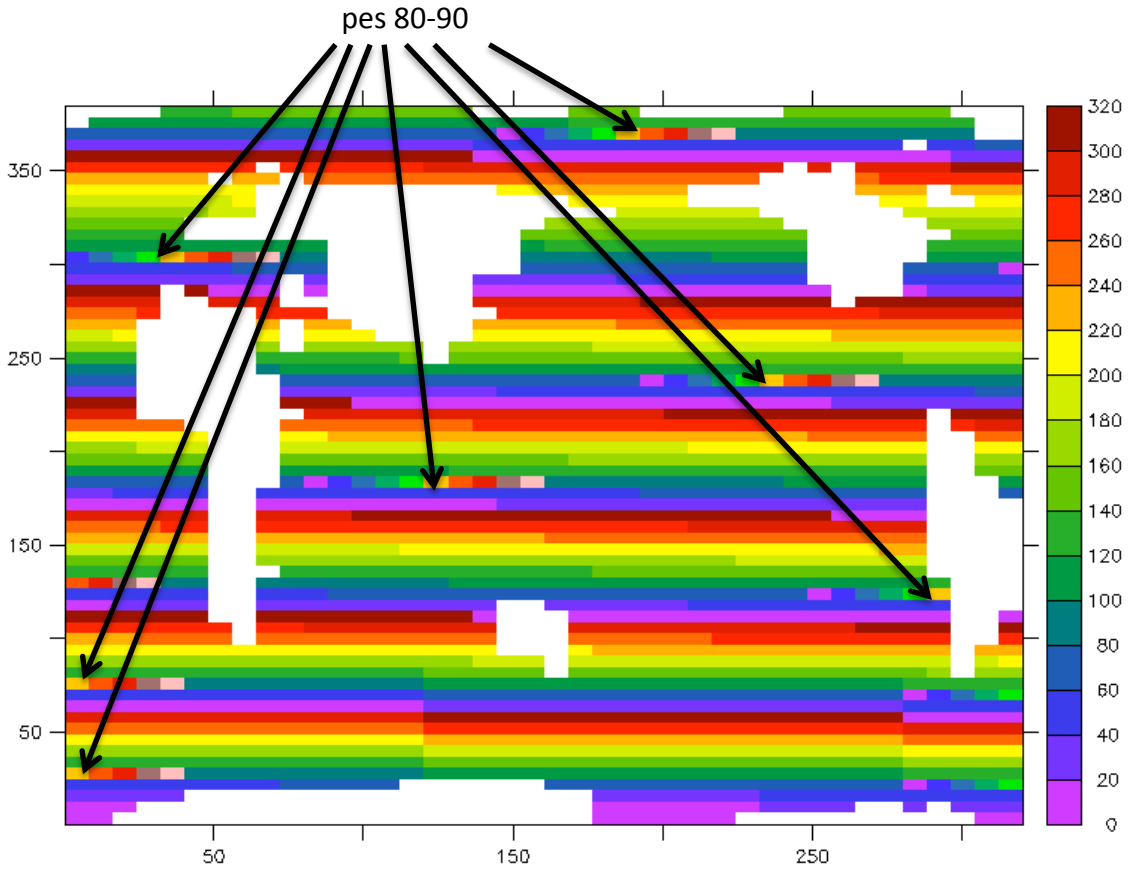
- size of halo
- number of neighbors (~8)
- flexible pe counts
- land block elimination

Poor

- cice load balance (N/S and radiation)

*credit to John Dennis

5. roundrobin



block allocation to processors

Blocks allocated round robin (left to right) after land block elimination

blocksize = 8 x 6, 8 blocks/processor

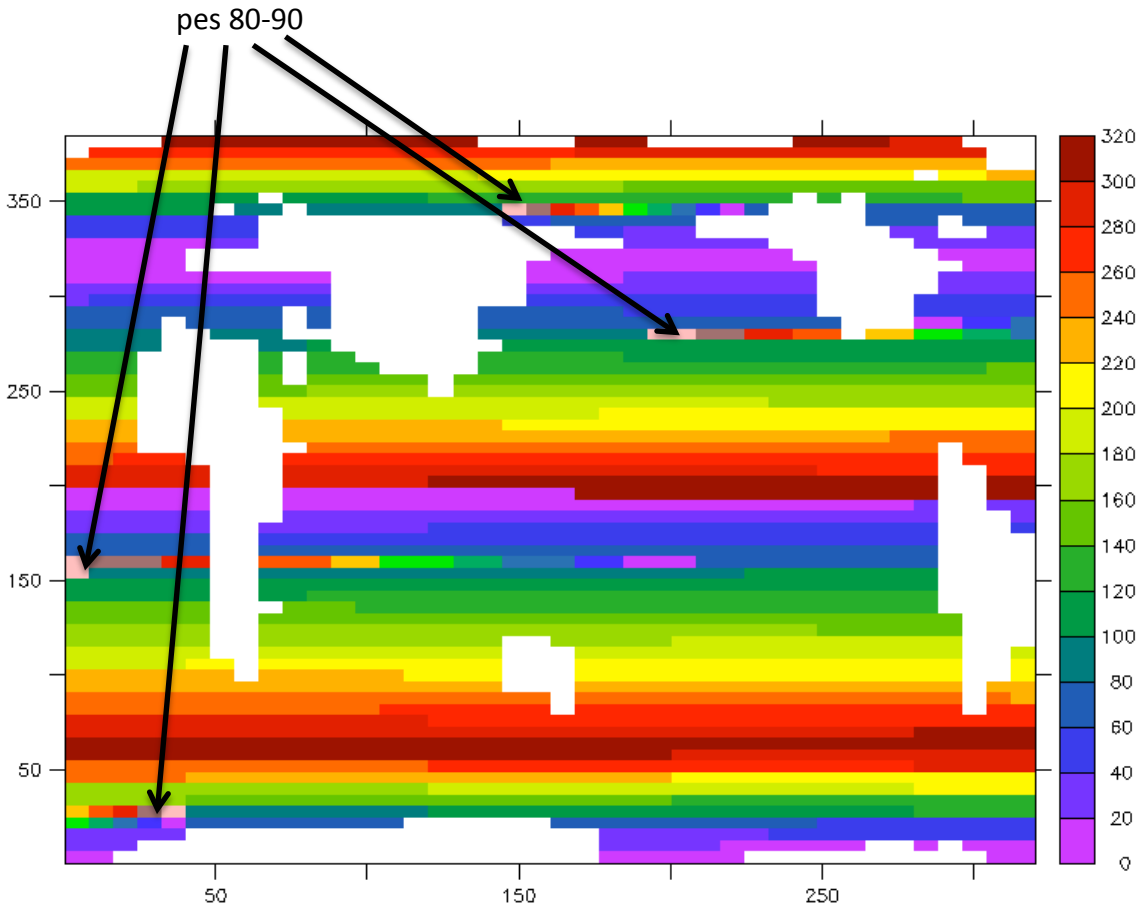
Good

- cice load balance (N/S and radiation)
- arbitrary pe counts
- land block elimination

Poor

- size of halo (local blocks not contiguous)
- number of neighbors (2+6*number of blocks/processor)

6. blkrobin



block allocation to processors

Blocks allocated round robin "grouped" (back and forth) after land block elimination

blocksize = 8 x 6, 8 blocks/processor

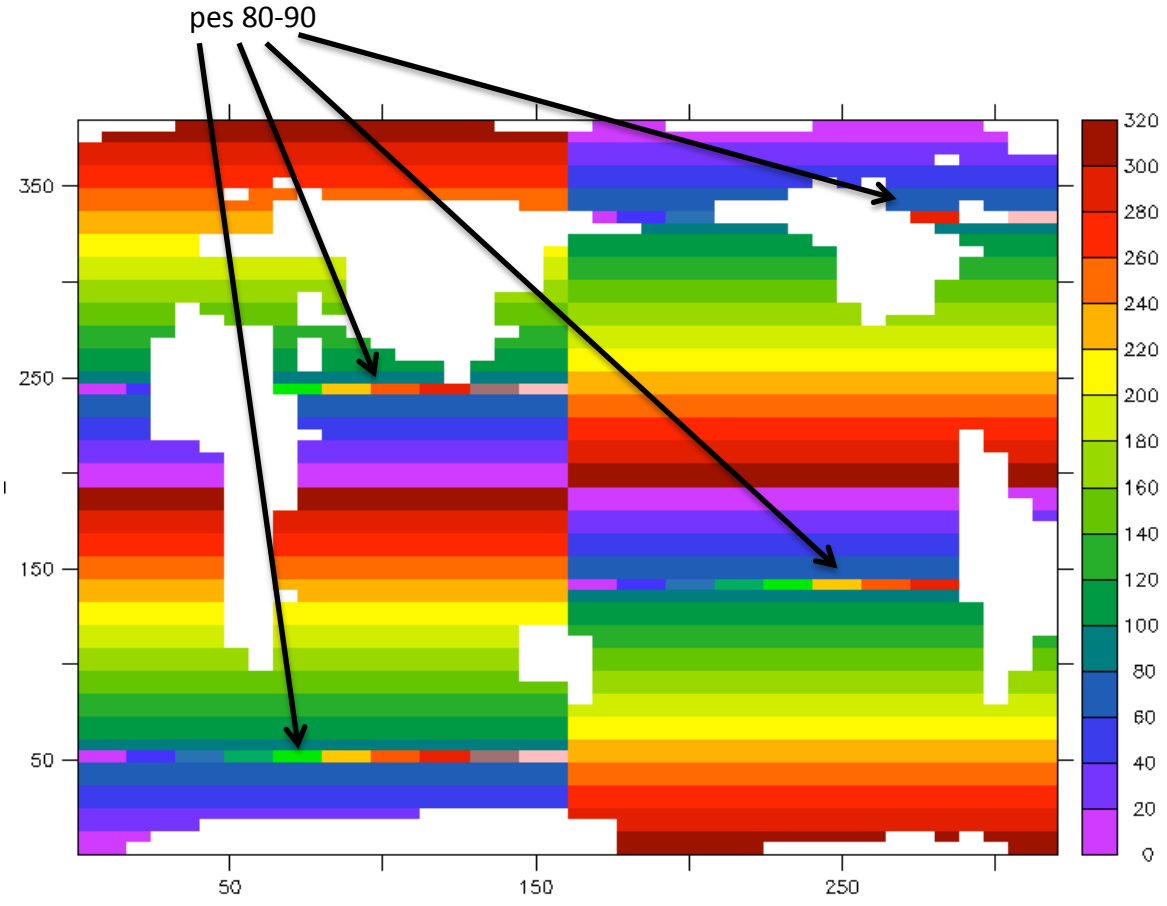
Good

- cice load balance (N/S and radiation)
- arbitrary pe counts
- land block elimination

OK

- size of halo (local blocks partly contiguous)
- number of neighbors (26)

7. blkcart



block allocation to processors

Blocks allocated into quadrants preserving neighbors.

blocksize = 8 x 6, 8 blocks/processor

Good

- cice load balance (N/S and radiation)
- number of neighbors (8)

OK

- size of halo (local blocks partly contiguous)
- somewhat flexible pe counts (multiples of 4 blocks per processor)

Poor

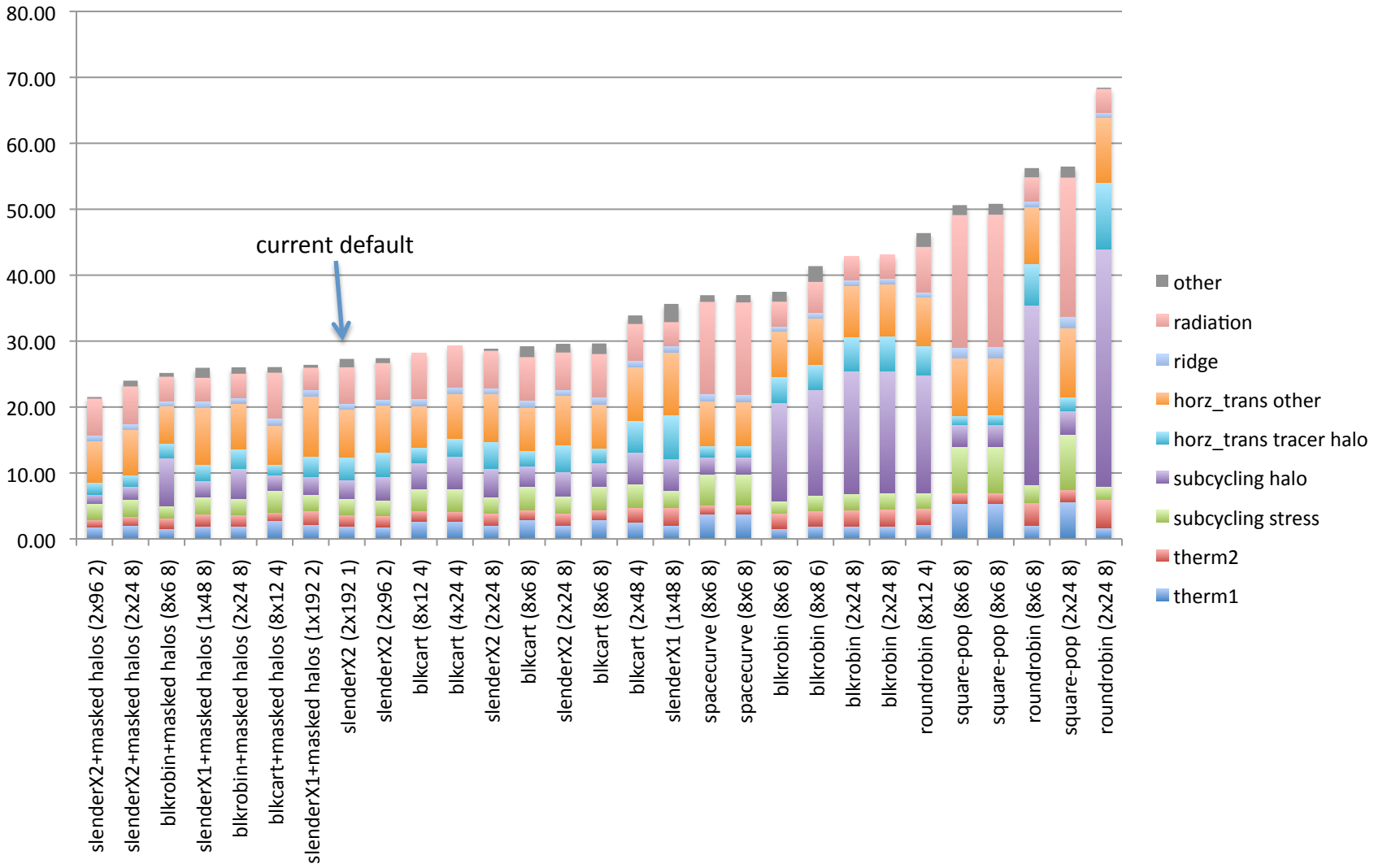
- land block elimination

Grading CICE Decompositions

decomposition	cice load balance north/south	cice load balance radiation	number of neighbors	amount of data to communicate	land block elimination in decomp	flexibility wrt pe counts
1. cartesian square-pop	F	F	B	A	F	C
2. cartesian slenderX1	A	B	A	C	F	F
3. cartesian slenderX2	B	C	B	B	F	F
4. spacecurve	D	D	B	B	A	A
5. roundrobin	A	A	D	D	A	A
6. blkrobin	B	A	C	C	A	A
7. blkcart	B	A	B	C	F	C

CICE Timing Testing

for gx1v6, 320 pes, hopper
(time for 20 days)



CICE Code Changes

- New Decompositions
- Masked Halos
  - Most of the data “haloed” in CICE is unnecessary
  - Can update the halo data structure on the fly quickly to remove both messages and gridcells that don’t need to be communicated
  - There may be some overhead in setting up the masked halo
  - Set via namelist, default is “on”
- Overlapping Work and Communication
  - Attempted in subcycling with limited success
  - Works well if communication and work are about the same
  - Load imbalance across processes impacts effectiveness
  - Has some overhead
  - Set via namelist, default is “off”

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16 pes, 272s -> 212s (roundrobin+masked halos, 20x48, 8)
64 pes, 91s -> 69s (blkrobin+masked halos, 10x24, 8)
320 pes, 27s -> 21s (slenderX2+masked halos, 2x96, 2)
1280 pes, 19s -> 10s (spacecurve+masked halos, 8x6, 2)

at tx0.1v2 (time to run 10 days)

1200 pes, 582s -> 361s (blkrobin+masked halos, 40x30, 6)
4800 pes, 148s -> 112s (blkrobin+masked halos, 15x15, 8)
18000 pes, 68s -> 68s (spacecurve, 6x6, 14)

Status

- bit-for-bit validation continues (displaced pole/tripole, threading, decomps, masked halos, various hardware)
- Running performance tests on other platforms
- Updating automatic cice decomp generation tool to provide “reasonable” default decomps for all resolutions and pe counts
- Improved weighting for spacecurve decomp being explored (John Dennis)
- Hope to have an updated CICE version in CESM1.1 in July
- High resolution exploration on Yellowstone high priority

Conclusions

- Using updated decomps and masked halos seems to
  - improve performance by > 20% for most cases
  - allow us to run on relatively arbitrary processor counts
- Now have a better sense of how the CICE performance varies with resolution and decomposition – how do we share this information with the community?
- Determining the optimal block size, decomposition, and thread count for a given resolution, target processor count, and hardware still requires testing
- Still want to understand performance better at highest resolution and highest processor counts
- Future Work ?
  - "CICE performance simulator"
  - Other decomposition strategies
  - Allow distinct dynamics and physics decompositions (like CAM)
  - Persistent Communication (Monika Lücke, GRS)
  - More detailed algorithm profiling to identify poorly performing kernels