Improvements in CAM Throughput at Scale

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Context of this research

- Polar singularity limits ability to effectively domain-decompose in longitude
- Long-term solution is to use more favorable grid
  - cubed sphere (finite-volume, spectral element)
- In near term (including IPCC AR5), we need to live with the longitude-latitude grid
- Approach: add parallelism and address scaling bottlenecks

CAM Throughput has Improved

We have more than doubled the performance of the Community Atmosphere Model on the Cray XT4/5 and are seeing similar improvements on the IBM BG/P. This has come about through a combination of adding additional parallelism, enabling different sections of CAM to execute at their own process count, implementing improved communication protocols particularly relevant at scale, and removing other scalability bottlenecks.

*Throughput improvement is problem-dependent.
* Work carried out over past 2.5 years under SciDAC-2.

Improvements reported at AMWG 2008

- We added additional parallelism and enabled different sections of code to execute at their own process count
  - —allow one vertical level per subdomain
  - —assign more (computational) processes to physics than dynamics
  - —advect multiple tracers concurrently
  - —larger longitude-latitude than latitude-vertical decomposition
  - —overlap of main dynamics and tracer advection subcycles

Resulting scalability bottlenecks

- Communication inefficiencies due to large number of messages
- Less ability to hide communication latency
- Inefficiencies computing global sums
- Input/output inefficiencies
- Memory overflows (in particular associated with communication)

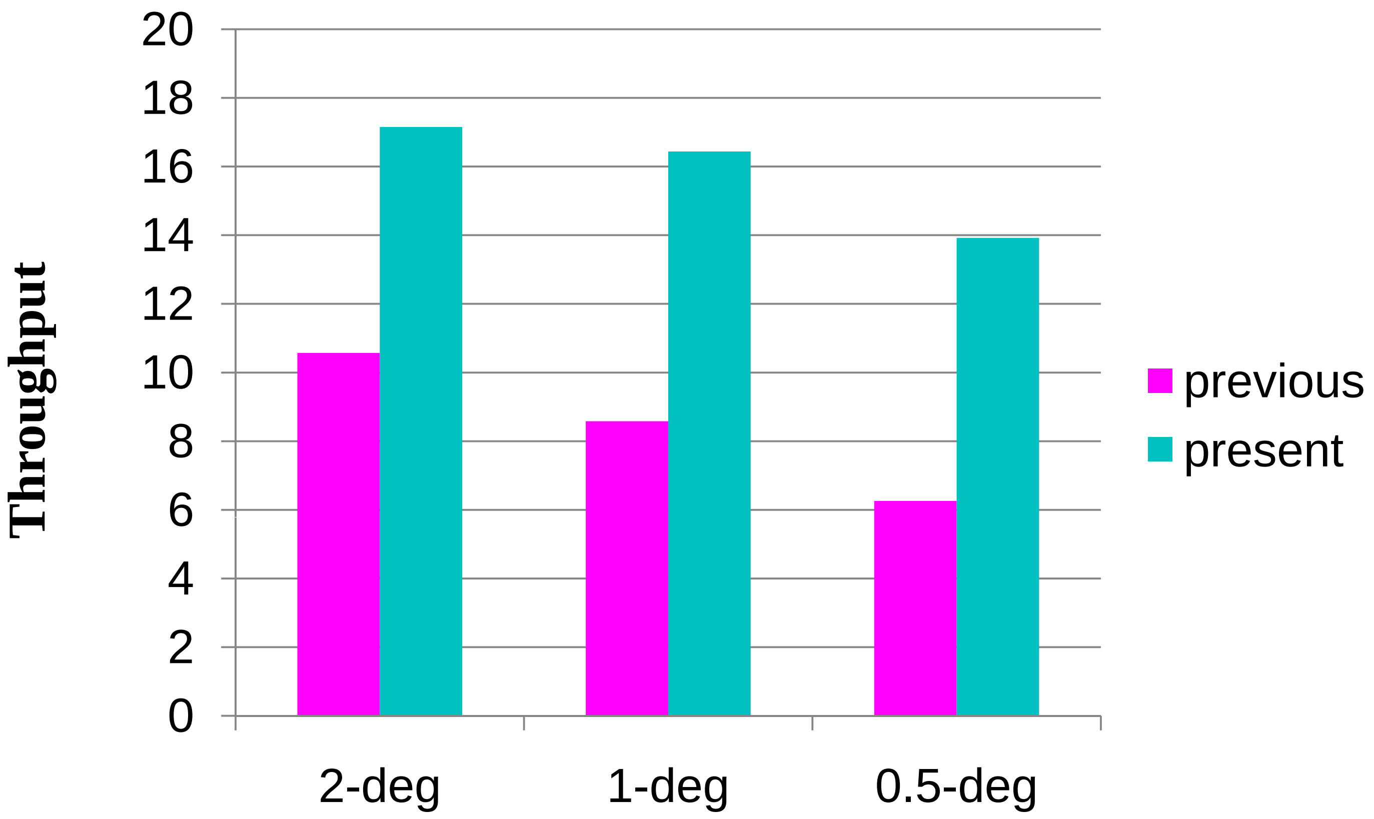
We have removed communication bottlenecks at scale

- Improvements to FV dynamics transposes (*mod_comm*)
  - all-to-all option
  - hypercube-based (*swap*) ordering of communications
  - ability to transpose 2 variables simultaneously
  - ability to transpose arbitrary number of tracers concurrently
  - handshaking (wait to issue send until matching receive is issued)
  - throttling (limit number of outstanding requests)
  - blocking vs. non-blocking send
- Improvements go hand-in-hand with those in dynamics-physics transposes and spectral dycore communications
- Apply flow control (handshaking, throttling) to global gathers
- Different code sections can use different options

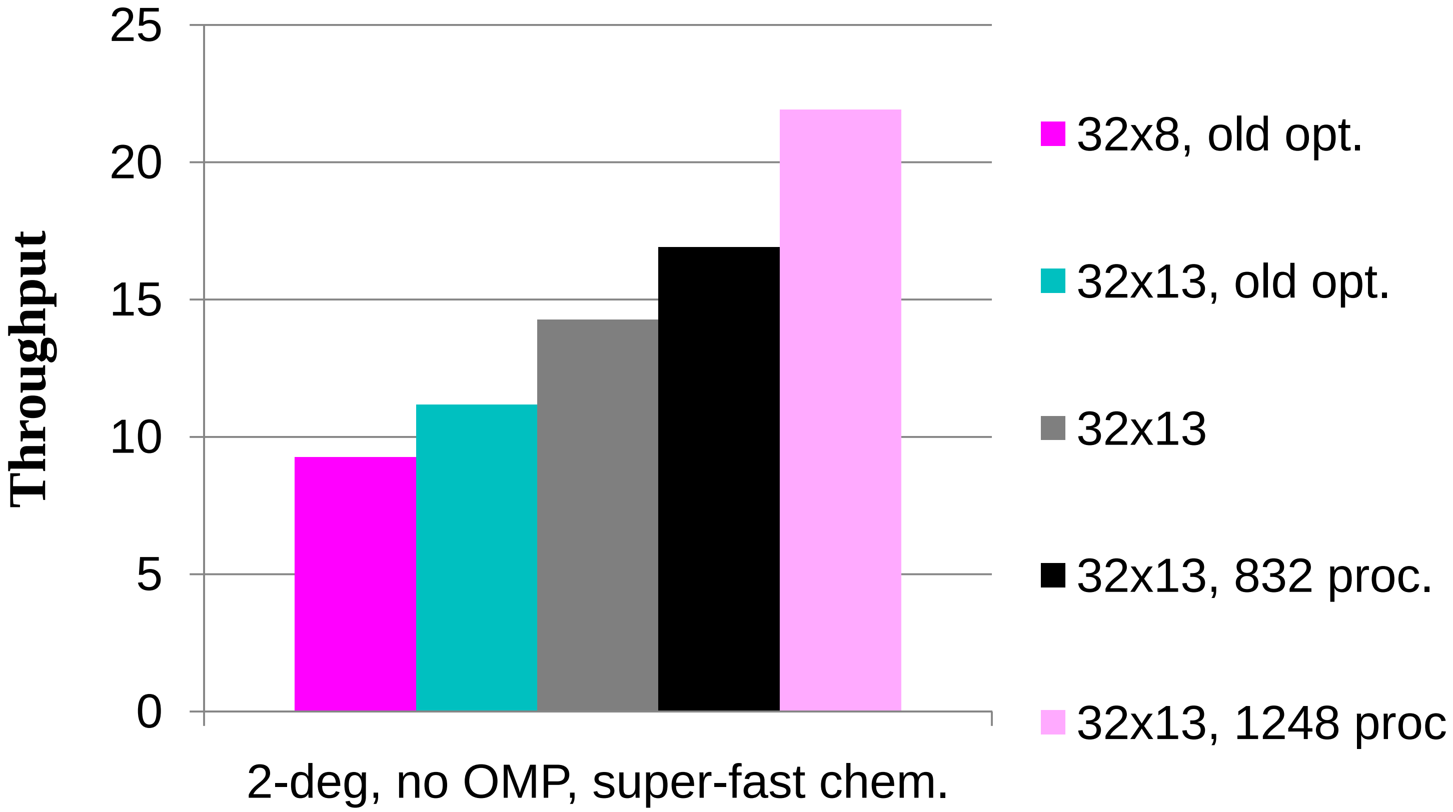
We have removed other scaling bottlenecks

- Fast reproducible distributed sum algorithm (replaces one-process-computes algorithm)
  - —used in physics and dynamics
- Non-transpose-based geopotential algorithm that eliminates real*16
- (Parallel I/O is being addressed as a wider collaboration.)

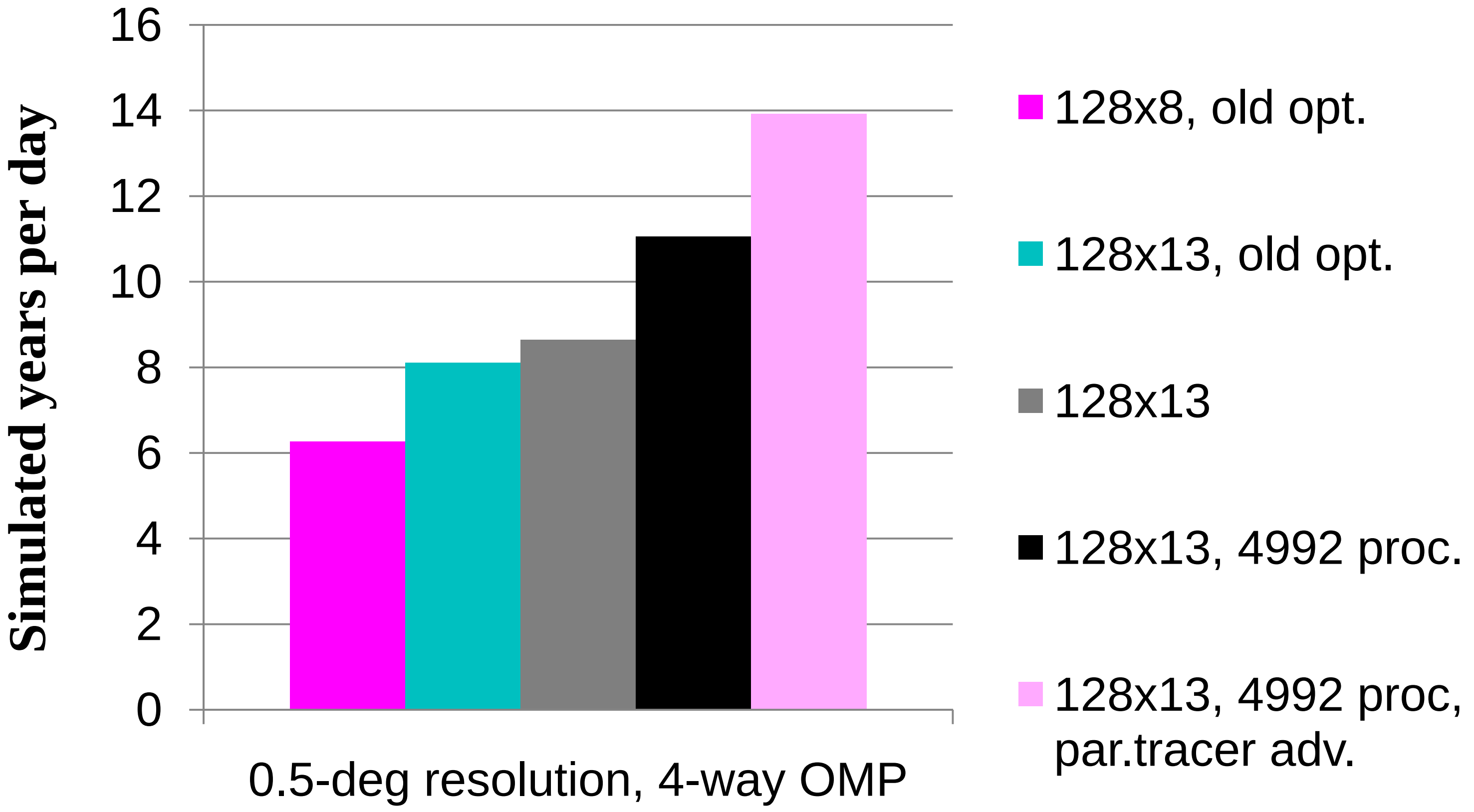
CAM with 4-way OpenMP on Cray XT4



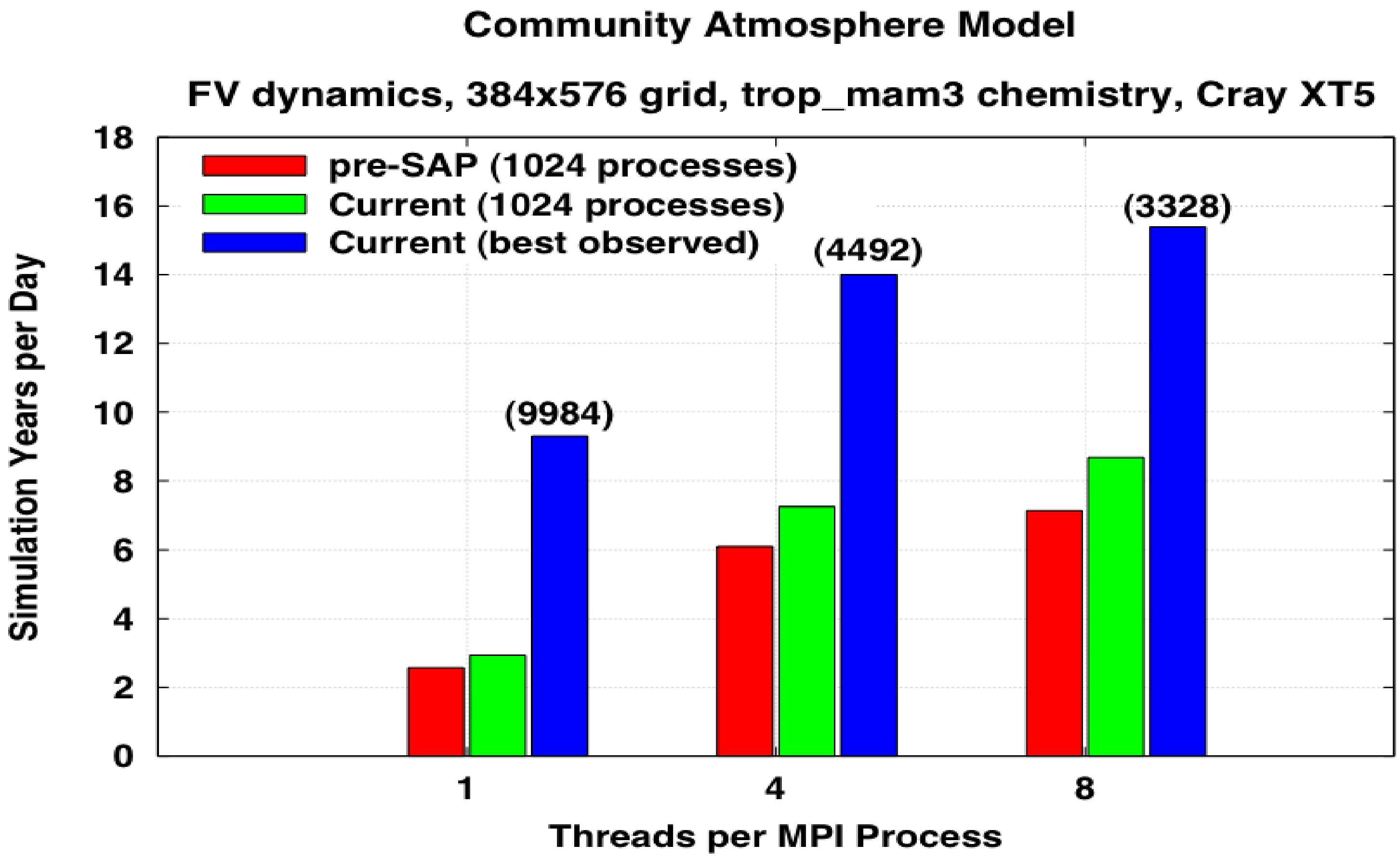
Breakdown of performance improvement



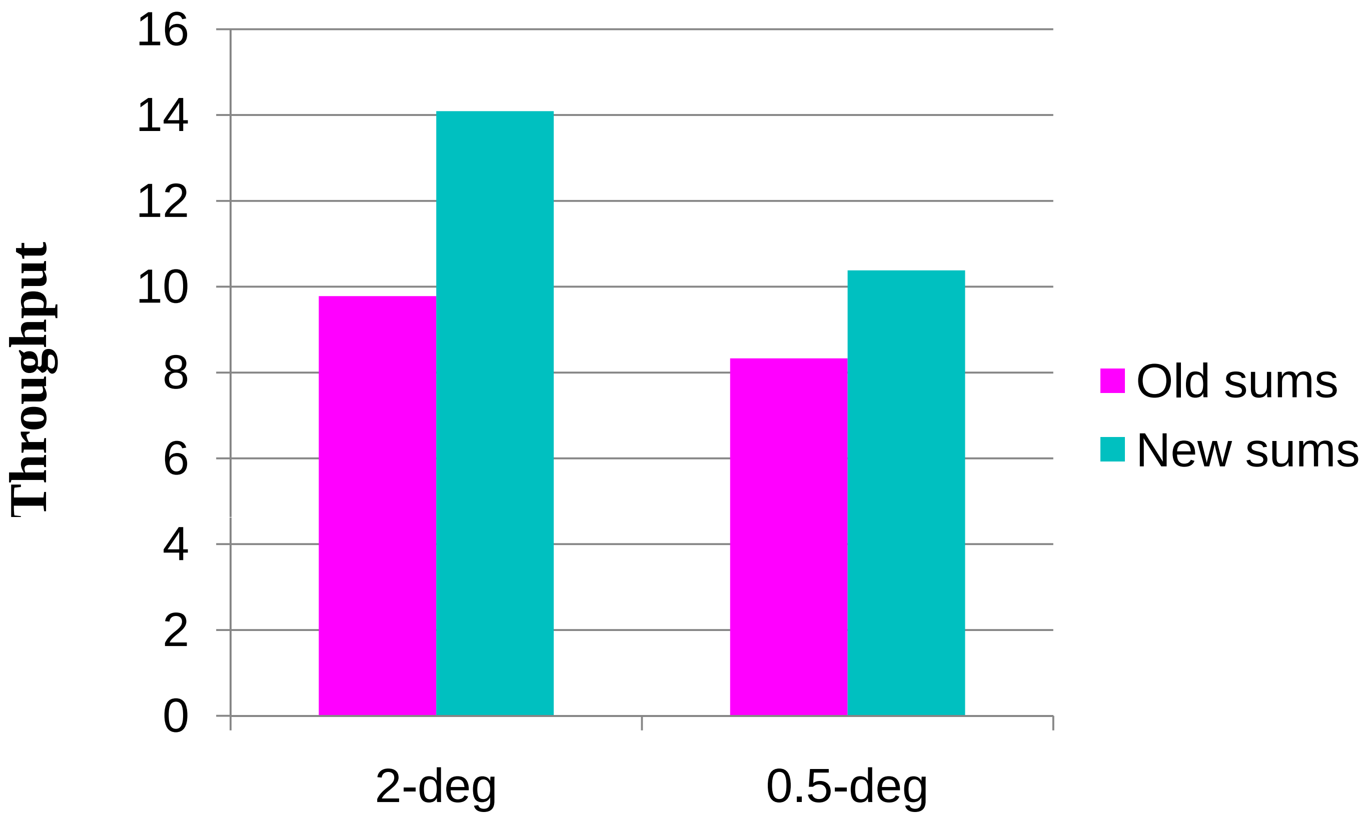
Breakdown of performance improvement



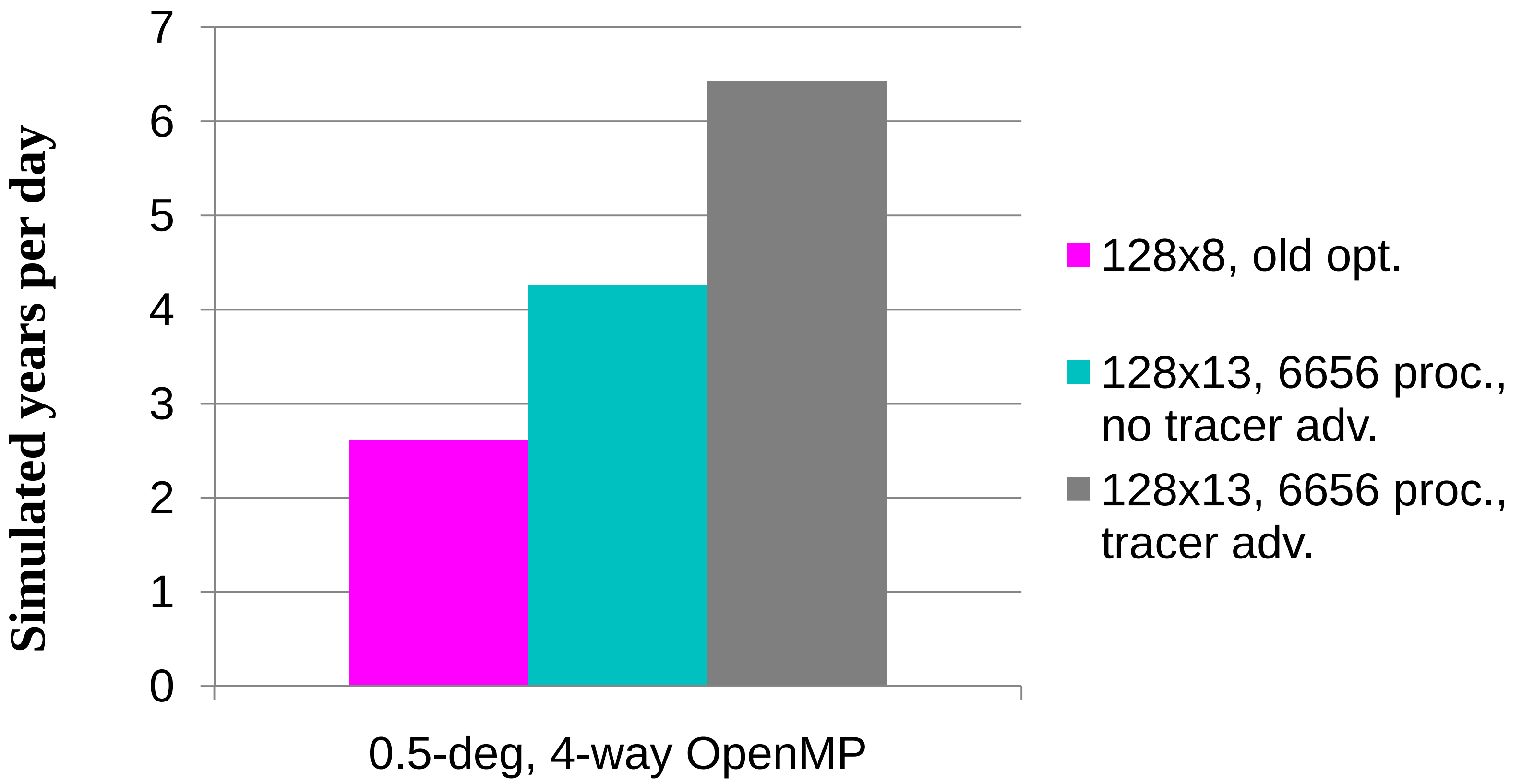
Improved throughput on Cray XT5 (vs OpenMP)



Fast reproducible distributed sums



Performance improvement with trop_mozart chemistry



Upcoming tasks in support of AR5

- Implement and evaluate additional OpenMP in FV dycore
  - presently limited to number of levels per subdomain
- Establish default optimization settings as function of
  - problem type
  - resolution
  - architecture
- Run benchmark tests to understand costs of different physics and chemistry options
- Determine optimal processor configurations considering
  - available machine cycles
  - maximum time to solution
- Benchmark, evaluate and optimize CCSM4 release on AR5 target architectures

Other plans

- Characterize, optimize and evaluate performance at greater scale as CCSM evolves toward earth system model and targets emerging petascale systems
- Extend atmospheric model scalability improvements to other components
- Exploit vectorization (e.g., Opteron SSE and BG/P double hummer)
- Improve memory usage throughout model
- Continue support for and evaluation/optimization of dycores on cubed sphere grid
  - HOMME spectral element dycore
  - Finite-volume dycore

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Example communications bottleneck

- FV 1-deg grid: transpose from 39x64 longitude-latitude decomposition to 64x13 latitude-vertical decomposition
  - — one-third of target tasks show order-of-magnitude larger compute time
  - — those particular tasks post receive requests to (primary) source tasks that themselves are posting receive requests
  - — the primary source tasks are themselves receiving send requests from their own (secondary) source tasks (particularly ones that are not target tasks)
  - — the resulting contention causes the delay
  - — solution is *handshaking*: delay send requests from secondary source tasks until primary source tasks are ready
  - — equal size decompositions are less likely to cause a problem since the secondary source send requests come naturally later in real time