Lawrence Livermore National Laboratory

Performance Improvement of the Community Atmosphere Model with Spectral Element Dynamical Core through Hybrid Parallelism

September 2011

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This work performed under the auspices of the U.S. Department of Energy by
Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

LLNL-PRES-499276

Support provided by SciDAC

Work performed under auspices of

Performance Engineering of the Community Climate System Model

a SciDAC Science Application Partnership aligned with

A Scalable and Extensible Earth System Model for Climate Change Science

CAM-SE is slated to be the dynamical core of choice in the upcoming CAM5.2 release.

- **The Community Atmosphere Model (CAM) supports several dynamical cores**
  - **the Spectral Element (SE) dynamical core, based on HOMME, is the latest**
- **We address performance improvement of CAM-SE through hybrid (MPI+OpenMP) parallelism**
- **Using latest OpenMP implementation, we observe a *doubling of throughput* on the ALCF Intrepid BG/P compared to what was previously attainable.**

CAM-SE has several forms of parallelism

- **Distributed memory (MPI) across spectral elements**

- **Shared memory (two OpenMP implementations)**
  - **original implementation across elements**
  - **recent implementation within element**
  - **both implementations are active but cannot be used together pending support for nested OpenMP constructs**

OpenMP across elements was revived under this effort

- **Originally implemented by others but not maintained**
- **Each time step consists of parallel region wrt elements**
- **Certain operations must be limited to a single thread**
  - **MPI communication**
  - **time step advance**
- **Certain operations must be delineated by shared memory barriers**
  - **those involving shared variables**
  - **CAM reproducible distributed sum**

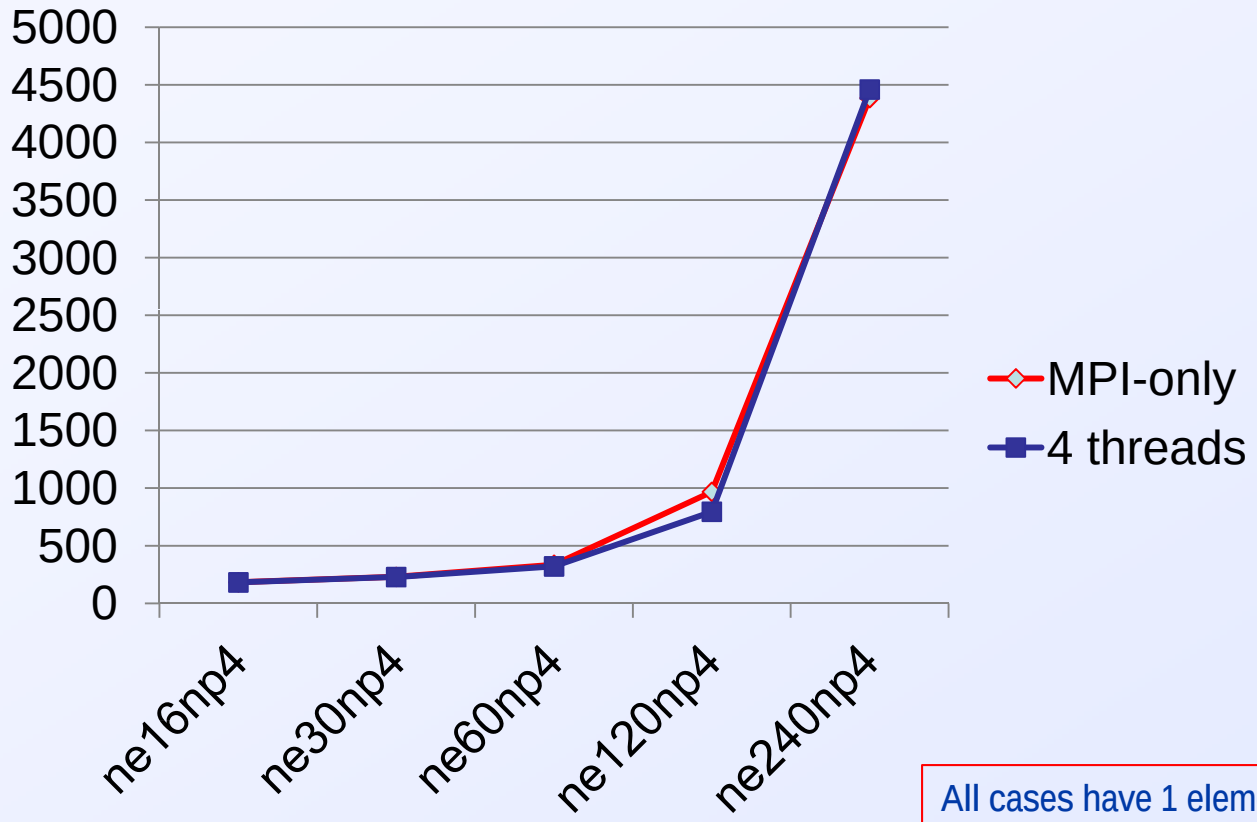
Original OpenMP competes with MPI for parallelism

- **Competition is because both are across elements**
- **At given cpu count, MPI with OpenMP benefits from fewer tasks, hence less likely to encounter bottlenecks with collective operations**
- **However, MPI with OpenMP might have more memory contention**

At scale, performance is generally superior or comparable with OpenMP

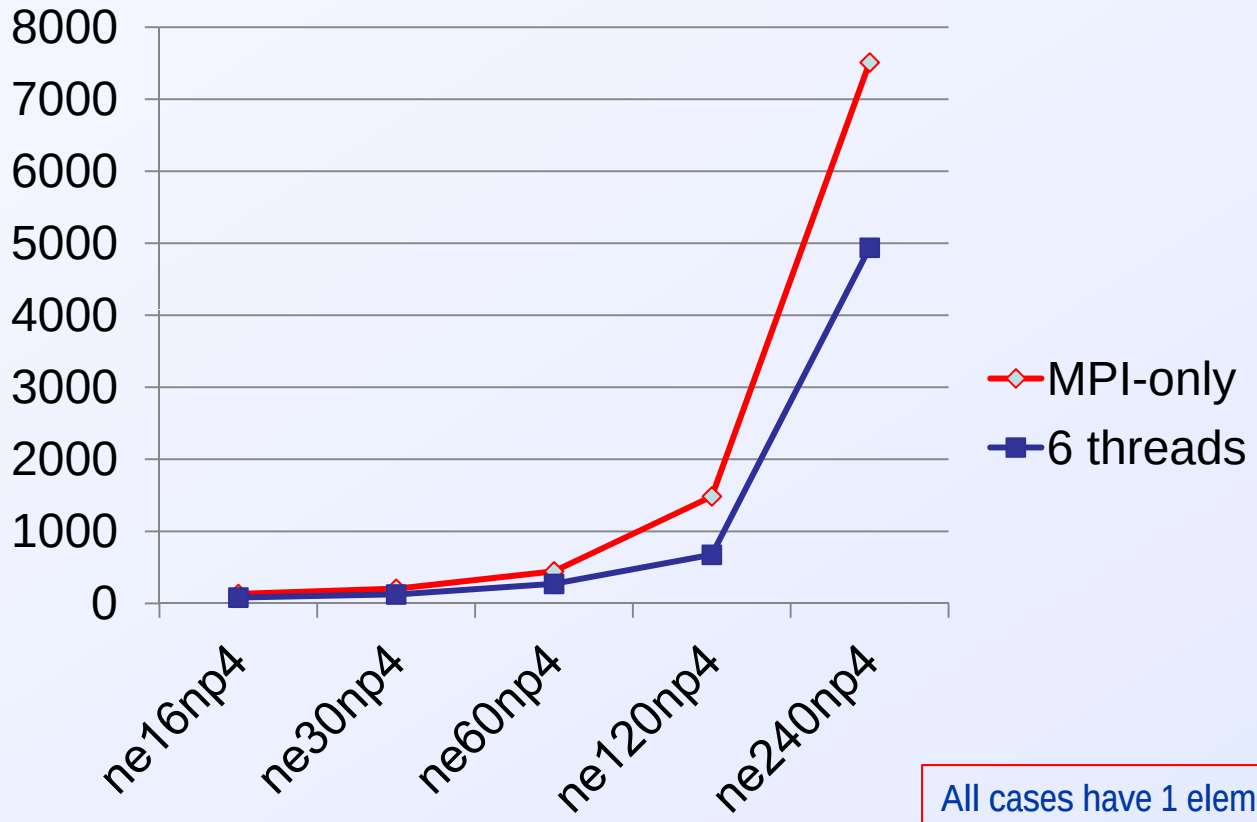
- **We compare CAM-SE (cam4_9_11) performance with and without OpenMP at fixed cpu count**
  - **on 5 grids ranging from 2-deg to 0.125-deg**
  - **on IBM BG/P (Intrepid) and Cray XT5 (Jaguarpf)**
  - **at large process count (often 1 element per thread)**
- **Cases are generally run for a month**
- **Energy fixer is active**

Intrepid execution time (seconds)



All cases have 1 element per thread, except for 0.125-deg, which has 4 elements per thread

Jaguar execution time (seconds)



All cases have 1 element per thread, except for 0.125-deg, which has 4 elements per thread

More instanciations needed due to performance variability

Global summation is jaguar hot spot

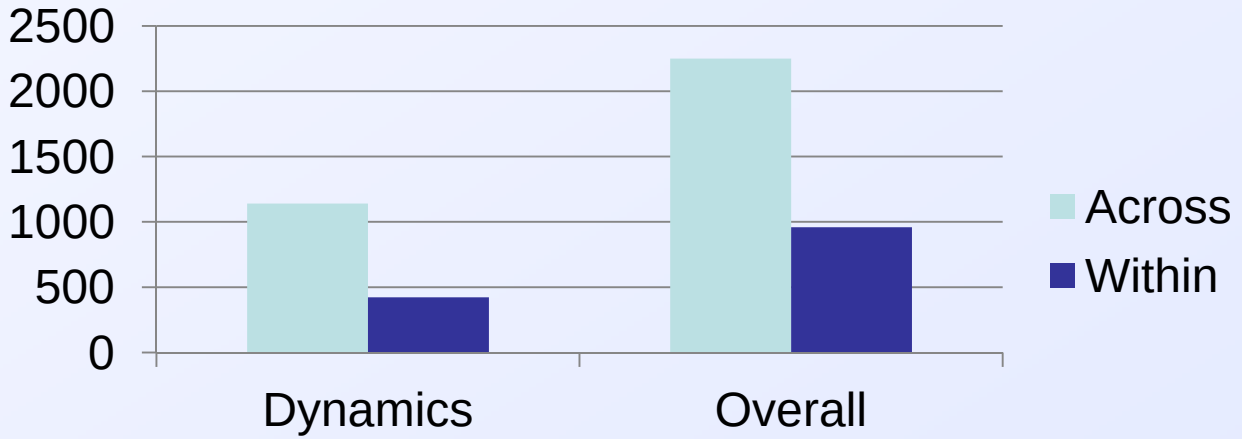
- **At scale with MPI-only, over 50% of execution time is spent in global sum**
- **The vast majority of this time is spent in the energy fixer**
- **Good news – recent improvements to formulation obviate need for energy fixer**

We have implemented OpenMP within an element

- **Adds additional parallelism to that with MPI**
- **Cannot coexist with OpenMP across elements**
  - **precompile directives separate both OpenMP implementations**
- **Parallel loops within subroutines (sometimes encompassing calls to other subroutines)**
- **Loops are with respect to vertical level, tracer index or horizontal index**
  - **not as efficient as OpenMP across elements,**
  - **however, this OpenMP implementation adds parallelism**

Maximum throughput more than doubles with trop_mozart

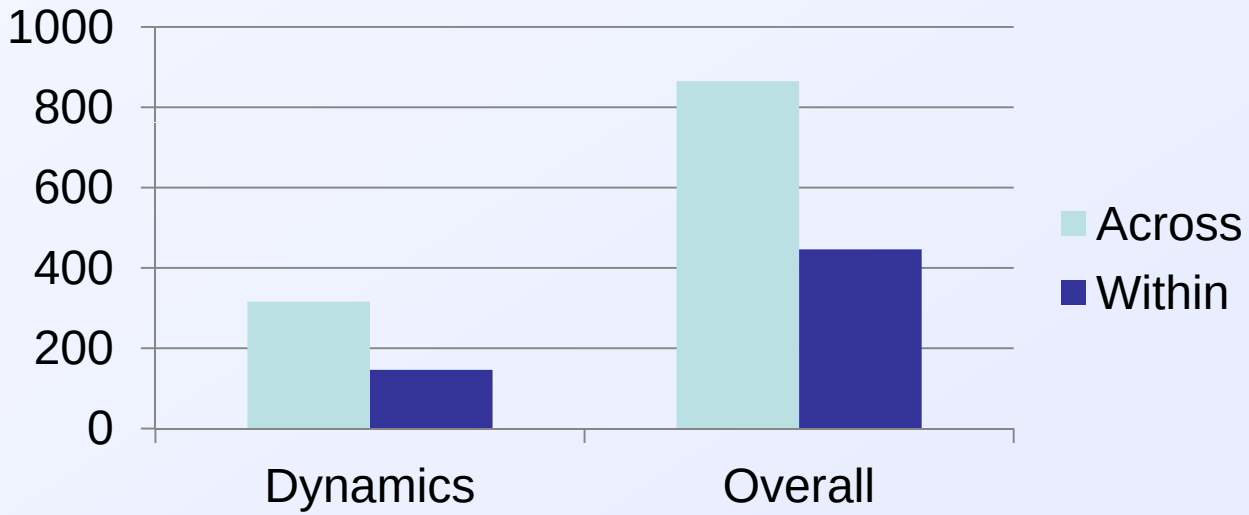
- **Consider ne30np4 with cam5_1_02 on Intrepid**
  - **OpenMP across elements uses maximum allowable thread count of one thread per element, whereas OpenMP within element enables additional threads**
  - **we measure time spent in dynamics and overall time**



- **For (4-way) OpenMP within element, code executes 2.35 times faster; dynamics throughput is 2.7 times faster.**

Maximum throughput approximately doubles with trop_mam3

- **Consider ne30np4 on Intrepid (cases run multiple times for one simulated month)**



- **For (4-way) OpenMP within element, code executes 1.94 times faster; dynamics throughput is 2.16 times faster.**

Miscellaneous issues

- **Tremendous variability of timings on jaguar and sierra (Intel Westmere, infiniband, LLNL)**
  - **most likely due to network contention and routing**
  - **variability is greatest at scale**
  - **difficult to compare algorithms**
- **Intrepid chosen as primary platform for this study because of more consistent timings**
  - **maximum partition is 32768 nodes**
  - **cannot test at scale finer than ne60np4 (which requires 21600 nodes)**

Related improvements and future directions

- **We have enabled physics to execute with more MPI tasks than dynamics (relevant for comprehensive physics and chemistry)**
- **We are addressing concurrent advection of tracers**
  - **particularly relevant for comprehensive chemistry/aerosols**
  - **additional MPI tasks also to be used for physics/chemistry**
- **Future plans include level-dependent timestep for tracer advection**
- ***Support for future architectures should include both swim lanes***
  - ***single source with directives and code restructuring***

Summary

- **We have resurrected original OpenMP implementation (across elements) in CAM-SE (Homme) and implemented an alternative formulation (within element) whose parallelism extends that of MPI**
- **OpenMP within element enables use of more threads (and cores)**
- **On Intrepid BG/P with trop_mozart chemistry, maximum attainable throughput improves 2.35-fold**
- **With trop_mam3 chemistry, improvement is 1.94-fold**