Reduced precision microphysics parameterizations in CAM

John Dennis, Dan Milroy, Andrew Gettelman

CISL Computational & Information Systems Laboratory

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

Do all calculations in CAM/CESM need to be performed in double precision?

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

History/Motivation

- Historically:
  - Climate models: double-precision
    - Small per MPI rank problem size means less cache pressure
    - 4-byte calculations cost same as 8-byte
    - Needed for conservation
    - Simpler
  - Weather models: single -precision
    - Large per MPI rank problem size means significant cache pressure → advantage to reducing size of variables
- Now:
  - Vector instruction sets means that single-precision rate is potentially 2x that of double-precision

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Computational & Information Systems Laboratory

CISL

What are the implications of the use of single precision in CAM/CESM?

NCAR

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

Potential implications of single precision

- Is correctness maintained?
- Does it reduce code execution time?
- Does it negatively impact maintainability?

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Approach

- Previous results:
  - WACCM implicit solver [kernel] → 1.97x speedup
  - Solver was trivial to vectorize
  - Virtually no ‘if’ tests in computational kernel
- Want something more challenging!
  - Morrison Gettelman Microphysics version 2
  - Relatively expensive: ~5% of total CAM cost
  - Complex code with lots of ‘if’ tests
  - Extensive experience optimizing code base
  - Willing collaborator (KEY)

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Optimization approach: vectorize everything

```
real, intent(in)  :: t   ! Temperature in Kelvin
real, intent(out) :: es  ! SVP in Pa

 ! uncertain below -70 C
 es = 10.**(-7.90298*(tboil/t-1.)+ &
     5.02808*log10(tboil/t)- &
     1.3816e-7*(10.**(11.344*(1.-t/tboil))-1.)+ &
     8.1328e-3*(10.**(-3.49149*(tboil/t-1.))-1.)+ &
     log10(1013.246))*100.
```

1 single-precision result
1 double-precision result

```
integer, intent(in) :: vlen
real, intent(in)  :: t(vlen)   ! Temperature in Kelvin
real, intent(out) :: es(vlen)  ! SVP in Pa
integer :: i
 ! uncertain below -70 C
 do i=1,vlen
     es(i) = 10.**(-7.90298*(tboil/t(i)-1.)+ &
        5.02808*log10(tboil/t(i))- &
        1.3816e-7*(10.**(11.344*(1.-t(i)/tboil))-1.)+ &
        8.1328e-3*(10.**(-3.49149*(tboil/t(i)-1.))-1.)+ &
         log10(1013.246))*100.
 enddo
```

8 single-precision results
4 double-precision results

Vectorization is necessary!

Computational & Information Systems Laboratory
CISL
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Is correctness maintained?

- Did not pass CESM verification test
  - The changes are statistically distinguishable from natural variability
- Does appear to pass initial evaluation by Andrew.

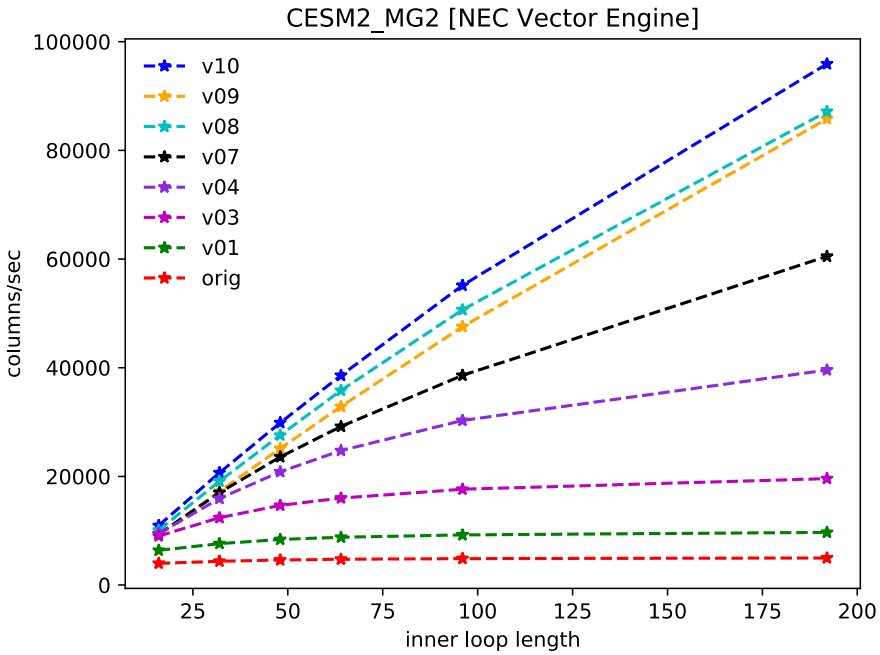
CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Does it reduce execution time?

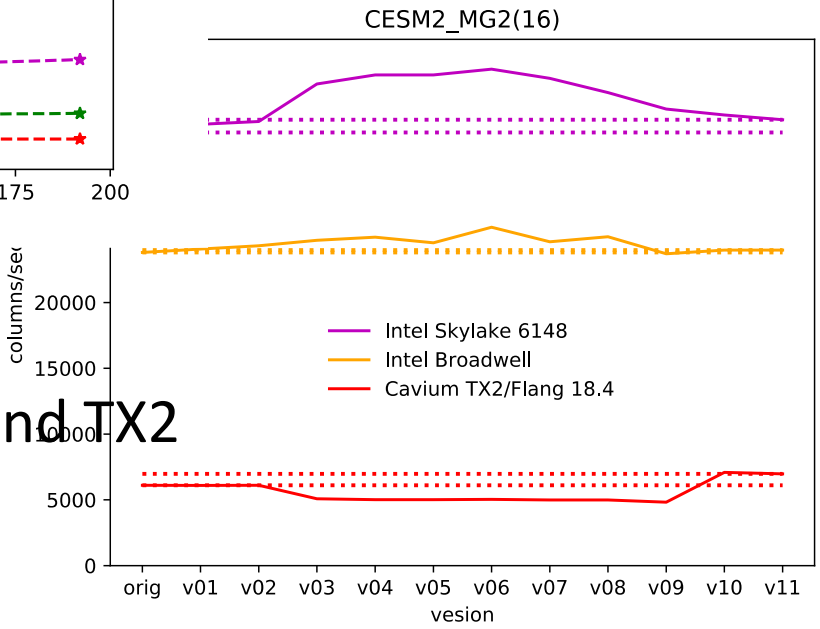
- MG2 calculation only
  - Cheyenne
    - Kernel: R4 → 1.35x speedup versus R8
    - In CAM: R4 → 1.22x speedup versus R8
- Current R8→R4 speedup is equivalent of Broadwell to Skylake speedup.
- Variation across different MPI ranks:
  - 2x speedup on a few execution paths
  - Additional execution paths could be optimized?
- Overall impact on CAM: ~ 0.5%
  - Very large overhead in actually calling MG2 from CAM
  - Other parameterizations in CAM are significantly more expensive (CLUBB)

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Extreme vectorization of the CESM2_MG2 kernel



~20x speedup on NEC VE



Performance neutral for Xeon and TX2

Computational & Information Systems Laboratory

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

Does it negatively reduce maintainability?

- Single point to switch from 8-byte to 4-byte calculations ☺
- Multiple entry points into modified code
  - Certain MG2 utility routines are called outside main subroutine
  - Saturation vapor pressure calculations called from multiple locations in CAM
  - Need to include both 4-byte, 8-byte, vector and scalar versions of numerous subroutines ☹
- Constants: Maintain separate 8-byte and 4-byte versions or type conversion of 8-byte constant?

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Recommendation for new parameterizations

- Simplified support for reduced precision will be in next version of CESM
- Develop new parameterization that can be switch between single and double precision
  - Focus on 4-byte version
  - Scientific justification for 8-byte
- Think of calculation on groups of points not single model grid-point

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

Conclusions/Future work

- Use of single-precision does not break correctness
- Achieves speedup comparable to next generation of processor
- Does currently impact code maintainability due to the call structure of CAM
- Should future parameterizations be single-precision?

CISL Computational & Information Systems Laboratory
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
NSF

CISL Computational & Information Systems Laboratory

Questions?

dennis@ucar.edu

NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF