Experience with mixed-precision within physics parameterizations

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History/Motivation

- Historically:
  - Climate models: 64-bit floating-point
    - On Cray vector systems -> single precision is 64-bit floating-point
    - Small per MPI rank problem size means less cache pressure
    - 4-byte calculations cost same as 8-bytes
    - Needed for conservation
    - Simpler
  - Weather models: 32-bit floating-point
    - Large per MPI rank problem size
    - Lower precision floating reduces cache pressure
- Now:
  - Vector instruction sets means that 32-bit floating-point is potentially 2x that of 64-bit floating-point

Impact of 32-bit floating-point

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

Approach

- Previous results (WACCM implicit solver)
  - Thrashes L2 cache
  - Code is highly vectorize
  - Virtually no ‘if’ tests in computational kernel
  - 1.97x speedup
- 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)

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
```

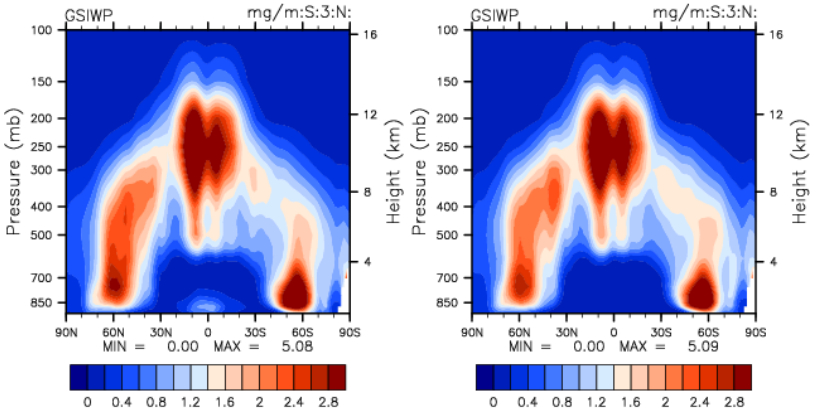
8 single-precision results
4 double-precision results

Is correctness maintained?

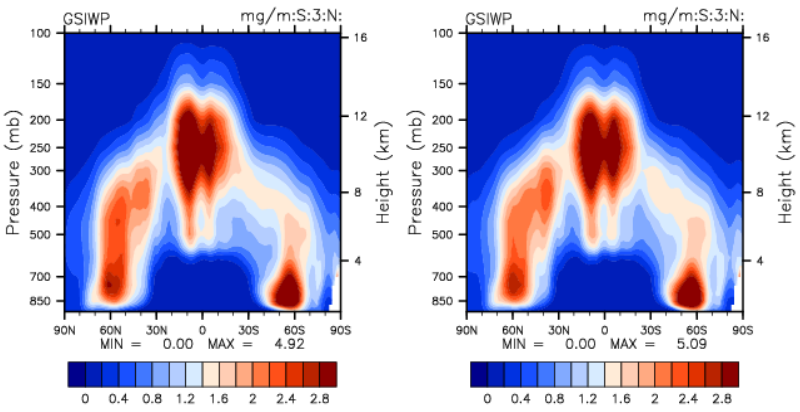
- Did not pass CESM verification test
  - The changes are statistically distinguishable from natural variability
- Systematic differences are apparent in climatological averages (AMWG diagnostic package)
- Look at three different configurations of CAM
  - MG2-CAM-default:
    [64-bit everywhere]
  - MG2-CAM-mixed:
    [32-bit in MG2]
  - MG2-GammaWV-SP:
    [32-bit gamma functions in saturation vapor pressure calculations]

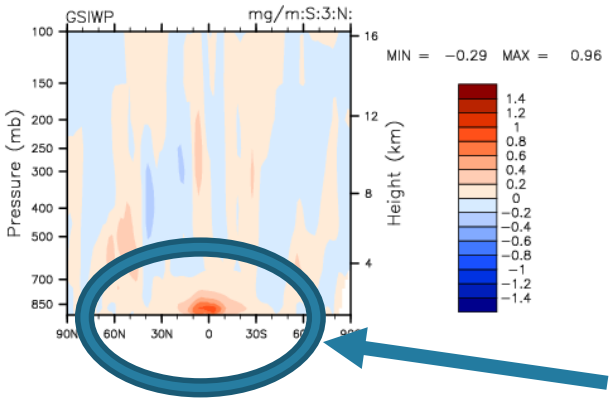
Global annual mean for SIWC (snow plus ice water content)

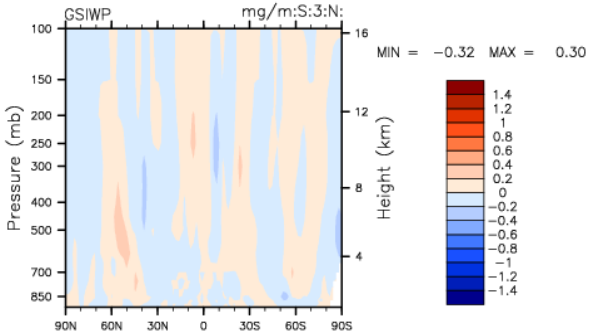
MG2-CAM-mixed



MG-gamaWV-SP







Systematic bias at equator

D. Milroy, A. Baker, J. Dennis, A. Gettelman, D. Hammerling, “Investigating the Impact of Mixed Precision on Correctness for a Large Climate Code”, Correctness 2019 workshop to appear

Impact of 32-bit floating-point

- Is correctness maintained?

  Not really
- Does it reduce code execution time?

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
  - Could 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)

Potential implications of 32-bit floating-point

- Is correctness maintained?

  Not really
- Does it reduce code execution time?

  Somewhat
- Does it negatively impact maintainability?

Negatively impact 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 vector and scalar versions of numerous subroutines ☹
  - 4-byte and 8-byte versions generated by templating capability with CAM
- Constants: Maintain separate 8-byte and 4-byte versions or type conversion of 8-byte constant?

Potential implications of 32-byte floating-point

- Is correctness maintained?

  Not really
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  Somewhat
- Does it negatively impact maintainability?

  Yes

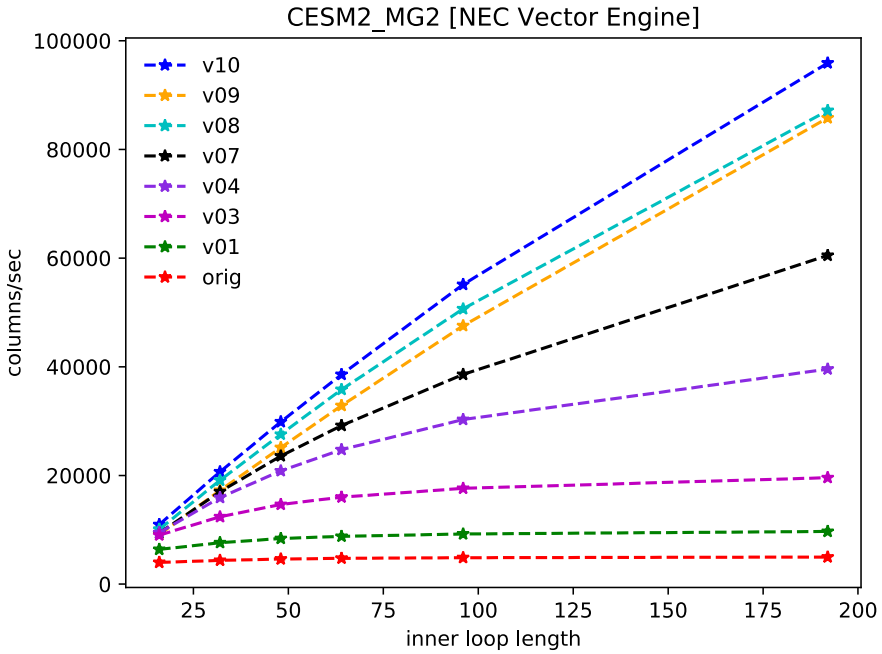
Some reflections

- Parameterization tuned using 8-byte floating-point
  - Can correctness issues in 4-byte version be eliminated by tuning?
- Simplified support for reduced precision will likely 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

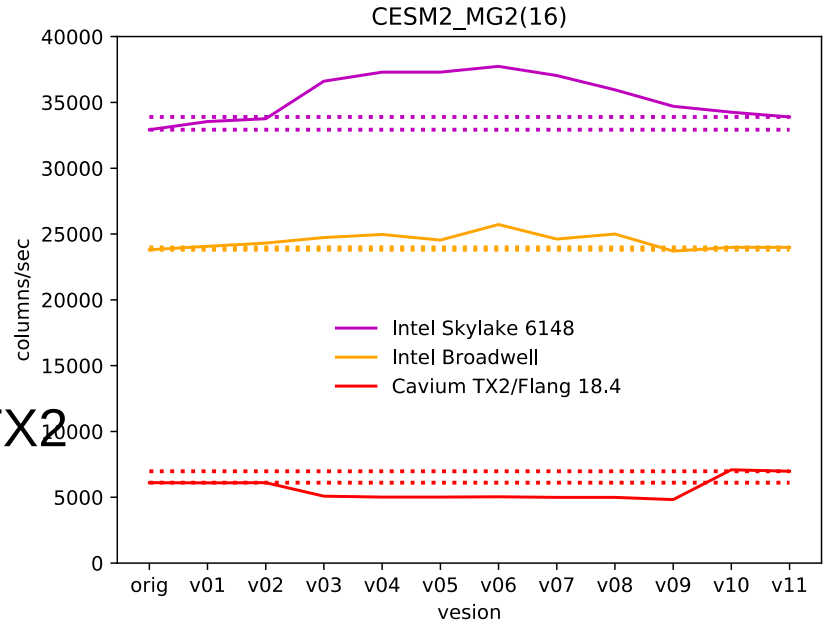
Conclusions/Future work

- Achieves speedup comparable to next generation of processor
- Use of 32-bit floating-point currently breaks correctness
- Does currently impact code maintainability due to call structure in CAM
- Should future parameterizations be 32-bit floating-point?

Extreme vectorization of the CESM2_MG2 kernel



~20x speedup on NEC VE



Performance neutral for Xeon and TX2