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AMWG Mtg
2/10/14

Using Macro+Microphysics as a Testbed for Improved Time-Integration Methods *(A Sociological Experiment)*

Is Better Physics Timestepping Needed?

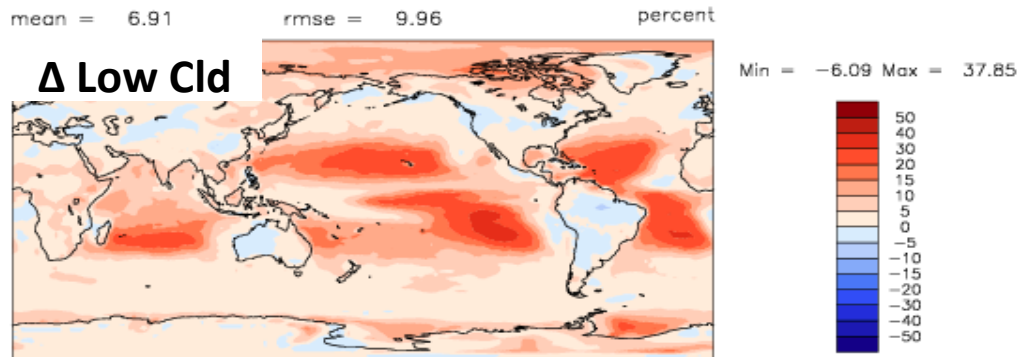


Fig 1: Change in low cloud fraction due to changing the physics parameterization Δt from 30 min to 7.5 min. Based on 5 yr 2° atmosphere-only simulations with Y2K SST

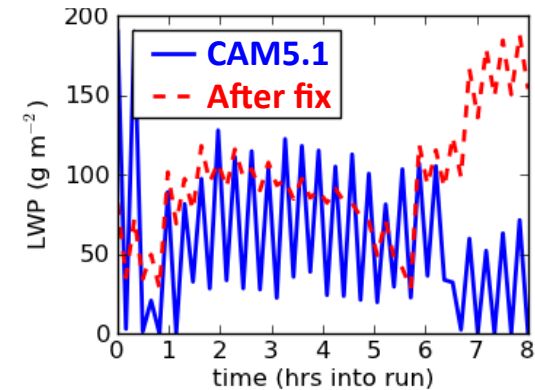


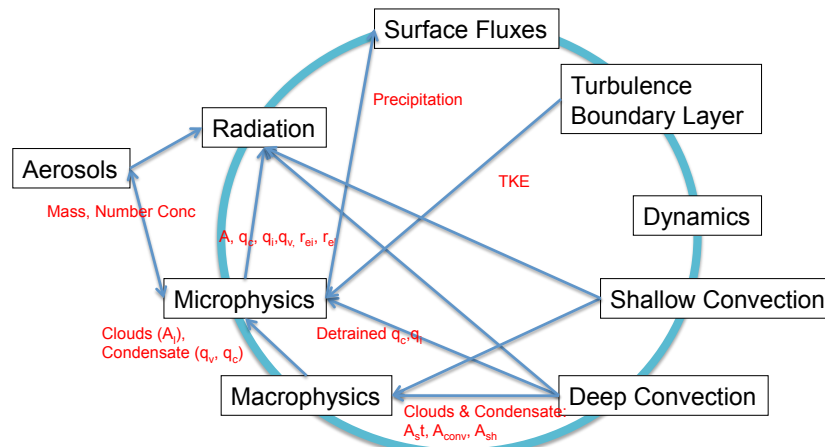
Fig 2: Liquid water path before & after microphysics from a single-column MPACE-B run.

Yes! CAM5 is very sensitive to Δt (Fig. 1) and pathological coupling issues exist (Fig. 2)

But CAM isn't Easy to Work With

CAM5 Physical Processes

from Physics Lecture 1 in 2010 CESM Tutorial (by A. Gettelman)



- CAM is complex
- Processes interact (often implicitly through pointers)

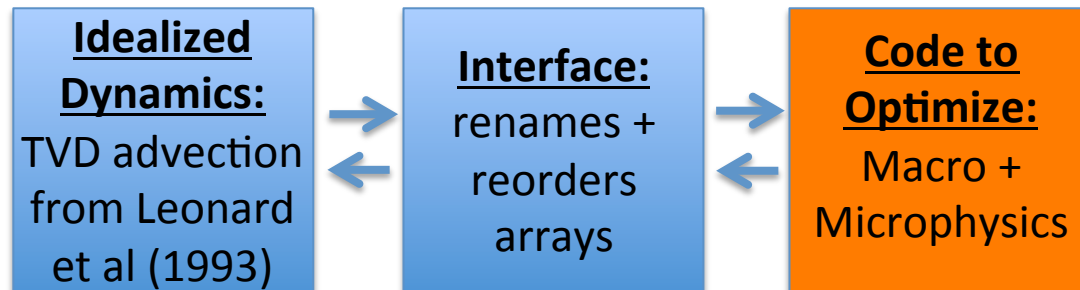
Is a *Chunk* of CAM Accessible for Mathematicians?

Yes:

- *Recent macro+micro development removes dependencies & makes code readable by non-experts*
- *A community effort provides means to run these codes in isolation*

Kinematic Driver (KiD) Framework

- Designed for idealized microphysics intercomparisons (Shipway + Hill '12)
- It provides driving conditions for the macro+micro code we want to test



MG2 Microphysics

- Microphysics is actually a collection of sub-processes
- Sean Santos' efforts with MG2 make it really easy to understand/tinker with
- Andrew and Hugh have already ported MG2 to KiD

PDF Macrophysics:

- Macro = sub-grid cloud fraction + liquid condensate mass calculations
- Using my parameterization for simplicity: if supersaturated mass is s , then

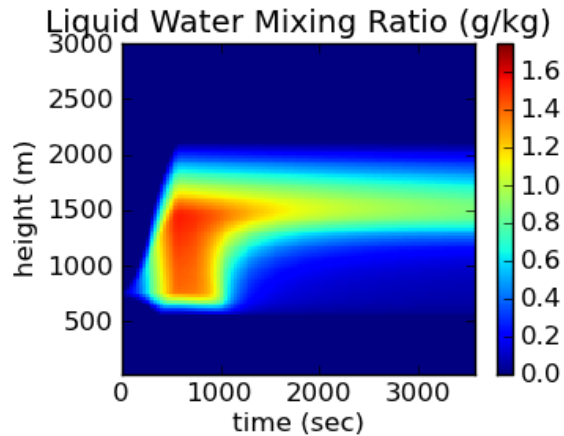
Macro is NOT implemented in KiD yet

$$\text{Cloud Fraction} = \int_0^{\infty} PDF(s) ds$$

$$\text{Cloud Mass} = \int_0^{\infty} s \cdot PDF(s) ds$$

Test Cases

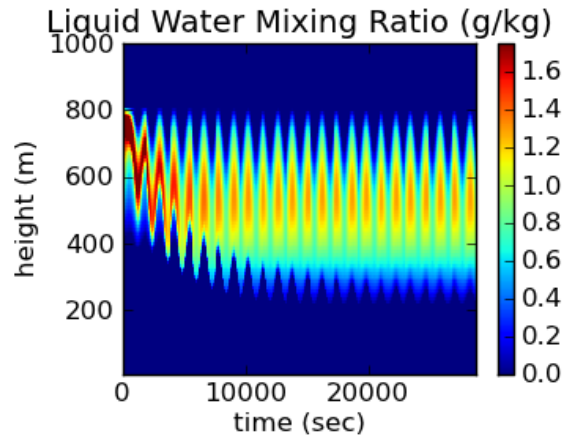
'warm1': steady updraft



Mimics an updraft which is:

- uniform in height
- increases in magnitude to 600s, then disappears
- $\theta \approx 300$ K in lower atmos (so warm procs only)

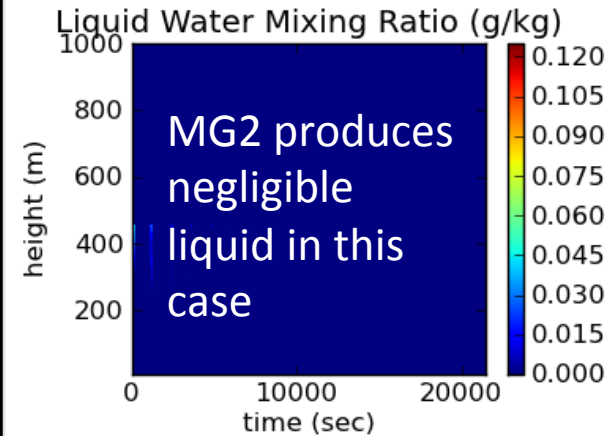
'warm7': Subtrop Sc



Mimics subtropical stratocumulus:

- w is height-dependent and varies sinusoidally in time
- Moisture is continually added to maintain cloud
- $\theta = 288$ K in BL (so warm procs only)

'mixed1': mixed-phase Sc



Mimics mixed-phase Sc:

- w varies sinusoidally in time and $|w|$ increases with height
- Moisture is continually added to maintain cloud
- $\theta = 257$ K in BL (so mixed-phase)

there are other cases we could use – these just caught my fancy

Not Just Doable, But Useful!

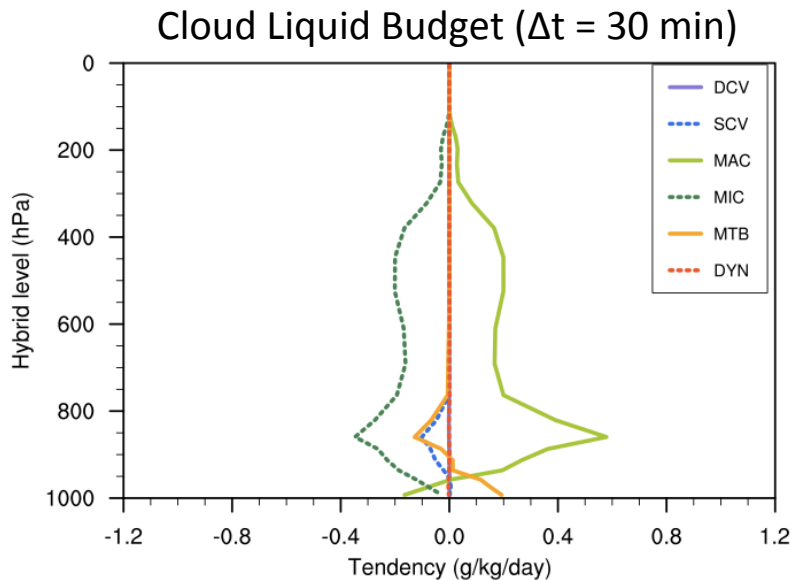


Fig: Global-ave q_c budget from 1 month 2° CAM5 run. Courtesy Hui Wan

- *Macro/micro balance dominates the q_c budget at default Δt*

- *Δt sensitivity is largely explained by reducing mac+mic time step*
 - *but mac+mic is not the whole story*

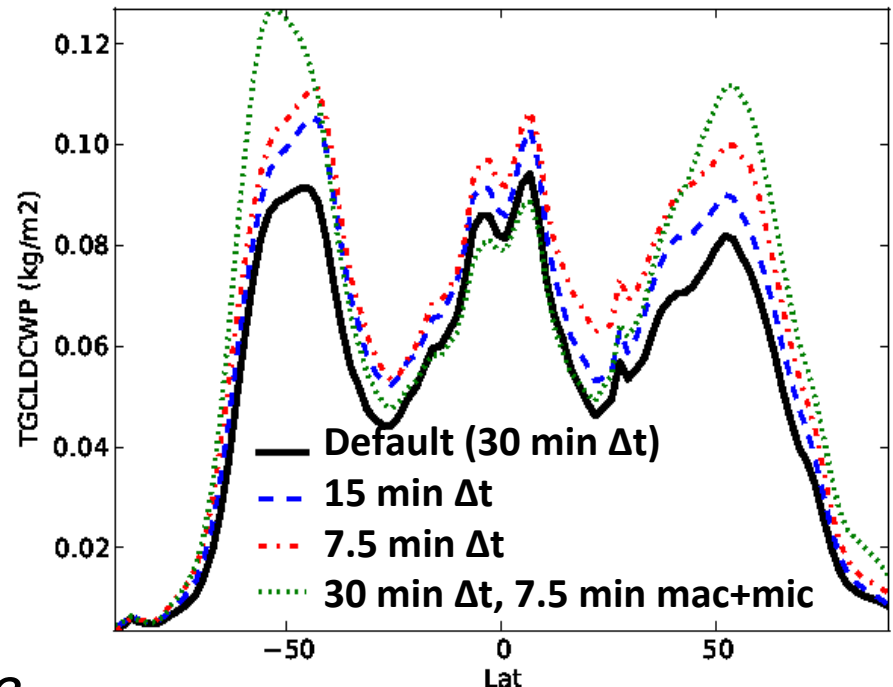


Fig: Zonal-ave LWP from last 4 yrs of 5 yr CAM5 runs employing various time steps

Targets for Improvement

1. “Conservation Checks”:
Condensate often goes negative...
and treatment of this case is crude

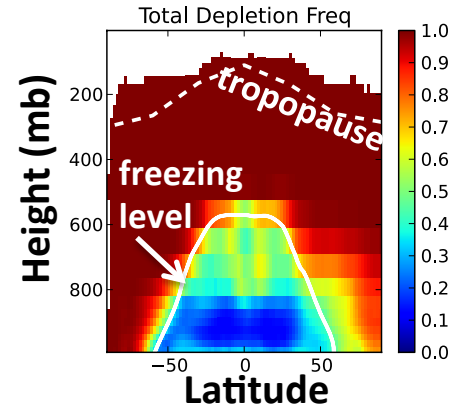


Fig: Frequency of micro completely removing cloud liquid

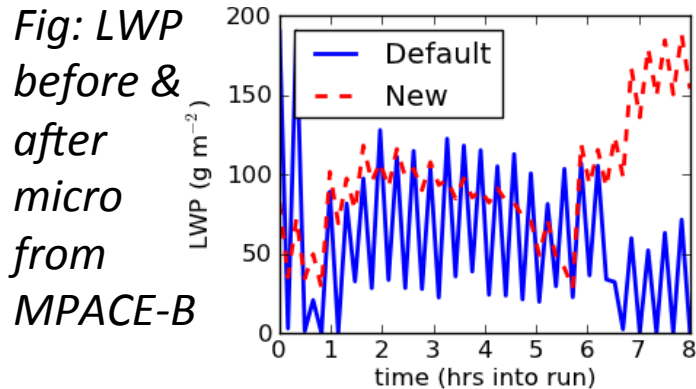


Fig: LWP before & after micro from MPACE-B

2. Multi-scale interactions between sub-processes are missing (macro, micro, ice nucleation, precip, etc)

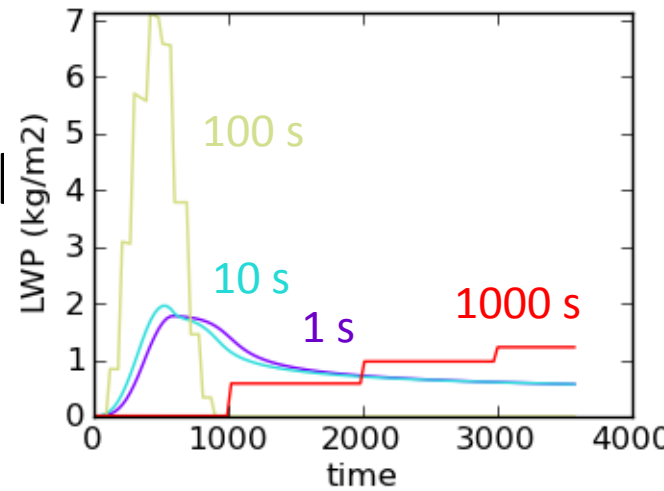


Fig: LWP from 'warm1' as micro Δt changes (subcycling dynam to use 1s Δt).

3. Numerical convergence is still an issue. Improved computational efficiency is needed

So – Want to Collaborate?

- My goal: make CAM parameterizations accessible to math folks and see what happens
 - Carol Woodward's FastMath team is signed on so *something* will happen
 - I will be working on these issues as well
 - I would love to get other people involved...



Fig: Example of the prize you could win for coming up with the best time-stepping implementation

Thanks!



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How Important is Macro+Micro?

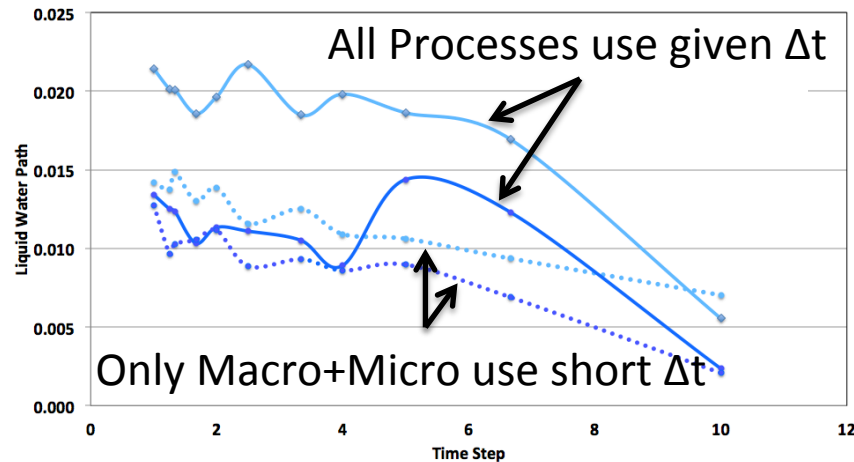


Fig: Time-average LWP as a function of macro+micro Δt when all processes use that timestep (solid) and when macro+micro are substepped and all other processes use the default (20 min) Δt . Colors represent different ensemble members. From MPACE-A single-column runs.

- Macro+Micro are a major but not the sole source of Δt sensitivity in MPACE-A runs

MG2 Flowchart

dynamics,
convection,
etc

Remove
supersaturation

melt qs/homog
frz qr again

Update state

*MG2 is mostly parallel
split but sedimentation
is sequential split*

Get final fallspds
substep for CFL
stability:
compute mass flux
convergence
use to update
state

Modify rates
to prevent
negative
condensate

Update state

Compute Tendencies for:

drop activ
qi nucleat
melt qs/homog frz qr
autoconv qc
autoconv qi
get init fallspeeds
immers frz
contact frz
qs aggreg
accret qc→qs
secondary qi prod
accret qr→qs
hetero qr frz
accret qc→qr
qr self-collect
accret qi→qs
evap/sublim qr/qi
berg qs
qi depos/sublim

Target for Improvement: Δt Convergence

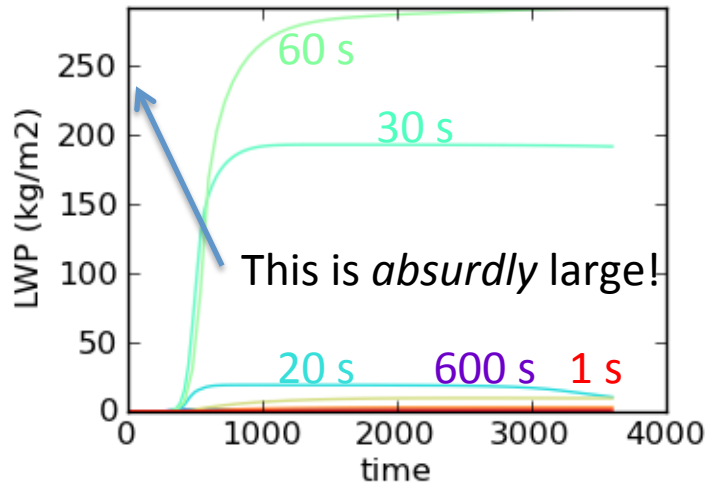


Fig: LWP from 'warm1' as Δt for **both** micro and dynamics is changed.

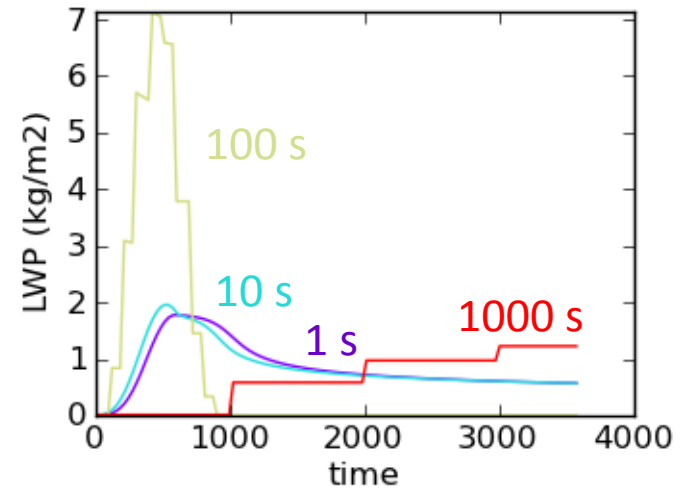


Fig: LWP from 'warm1' as micro Δt changes (subcycling dynamics to use 1 s Δt).

- Using full-model Δt anywhere near that used by CAM doesn't work because the dynamics CFL is quickly surpassed
- Calling micro less frequently suggests a 10 s timestep is needed for convergence (CAM uses a 15 min micro Δt)

Subcycling Dynamics

Subcycled dynamics in prev slide had micro tend = 0 for all steps when micro wasn't called. What if micro tend was instead trickled in over all dynamics substeps?

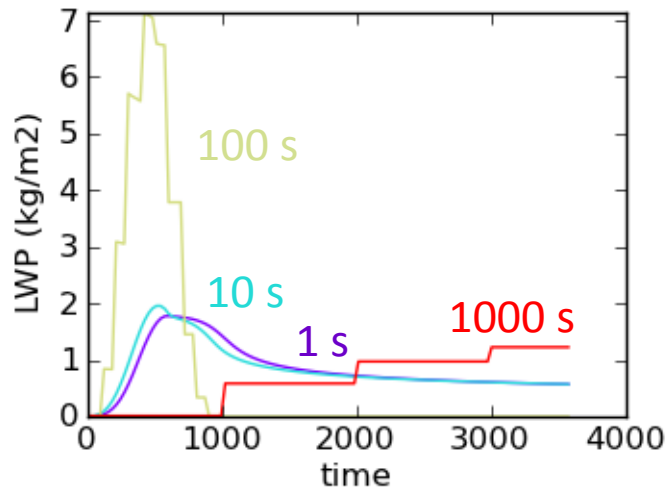


Fig: micro tend applied only when micro called

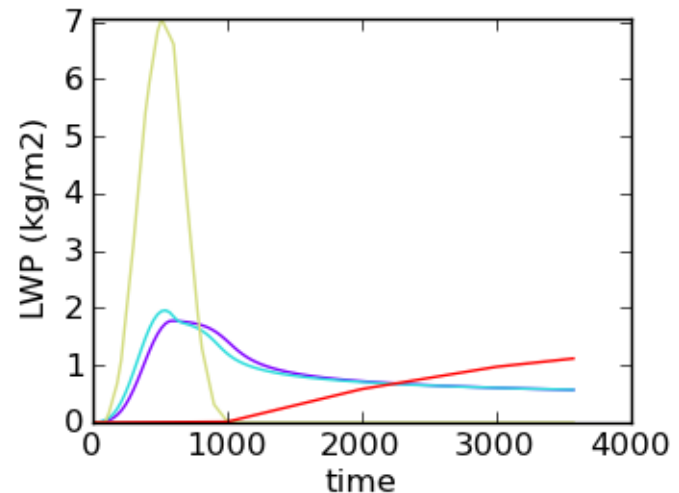


Fig: Micro tend applied every dynamics substep