Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Cloud Water Budget in CAM5 and Sensitivity to Model Numerics

Hui Wan[1], Phil Rasch[1], Kai Zhang[1], Minghuai Wang[1], and Peter Caldwell[2]

[1] Pacific Northwest National Laboratory
[2] Lawrence Livermore National Laboratory

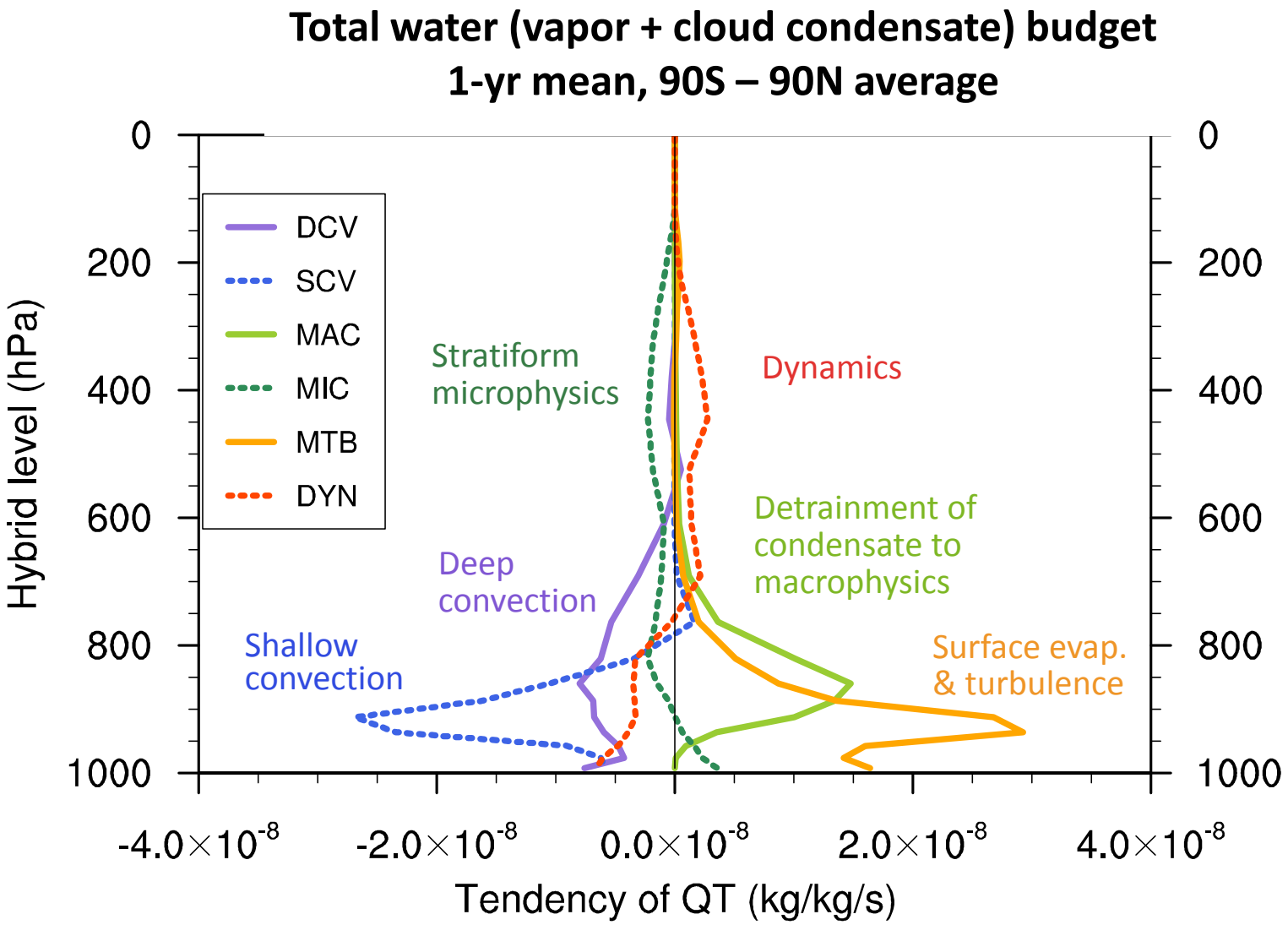
Motivation

- Strongly compensating processes (push-pull problems) are common in GCMs (e.g., Beljaars et al., 1999, 2004, ECMWF)
- Crude numerics can lead to significant systematic error at climate scale
- Purpose of our cloud water budget analysis
  - Identify strongly compensating processes
  - Search for numerical artifacts
  - Develop methods to reduce numerical errors

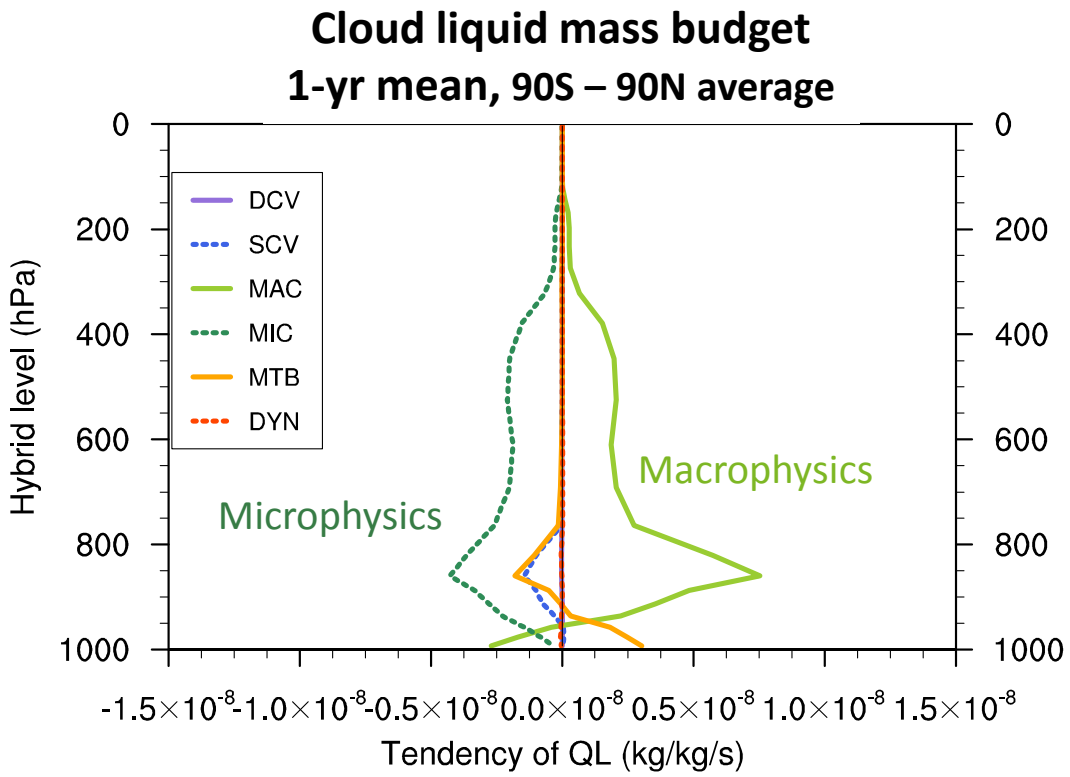
What We Analyze

- CAM5.1.31 (from Peter). Droplet activation fix switched on.
- Water species
  - Water vapor
  - Cloud condensate (liquid/ice, mass/number)
- Balance between different tendencies terms
  - At the *TPHYSBC/AC* level (major parameterizations)
  - Inside the stratiform cloud microphysics (microphysical process rates)
- "Raw" budget (according to the terminology of Larson, 2006 JGR)
  - Simply track the tendency from each parameterization
  - Needs some interpretation to link to physics
  - Is the budget the model numerics operates on
  - Also reveals conceptual artifacts in the model (e.g., Bergeron)

An Overview


Total water (vapor + cloud condensate) budget
1-yr mean, 90S – 90N average
Hybrid level (hPa)
0
200
400
600
800
1000
DCV
SCV
MAC
MIC
MTB
DYN
Stratiform microphysics
Dynamics
Detrainment of condensate to macrophysics
Deep convection
Shallow convection
Surface evap. & turbulence
-4.0×10-8
-2.0×10-8
0.0×10-8
2.0×10-8
4.0×10-8
Tendency of QT (kg/kg/s)

An Example of the Push-Pull Problem



Why are we paying attention to this?

- Macrophysics acts to restore equilibrium, but
- Microphysics is formulated as a time evolution problem ➔ Sensitive to
  - form of the differential equation
  - initial condition

Lessons Learned from a Toy Problem

- H_2SO_4 gas equation in the aerosol-climate model ECHAM-HAM

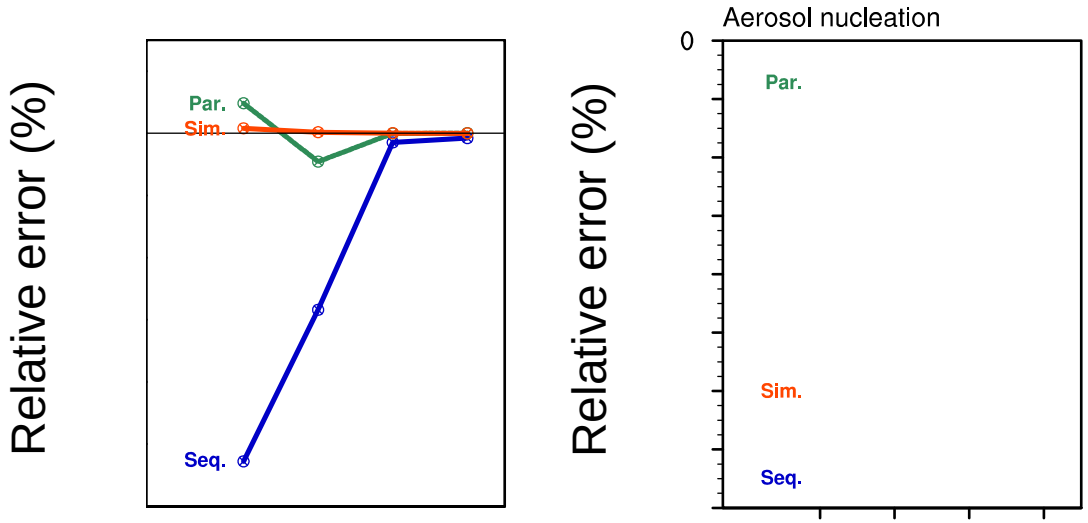
$$\frac{dS}{dt} = \boldsymbol{P} - \boldsymbol{C \cdot S} - \boldsymbol{N(S)}$$

$\boldsymbol{P}$	$\boldsymbol{C \cdot S}$	$\boldsymbol{N(S)}$
Transport and chemical production	Condensation on pre-existing aerosol particles	Aerosol nucleation

Strongly compensating

The Toy Problem

Test of numerical convergence



- Both sequential and parallel splitting can cause large errors when used with long time step
- Accurate results can be obtained efficiently by solving sources and sinks simultaneously

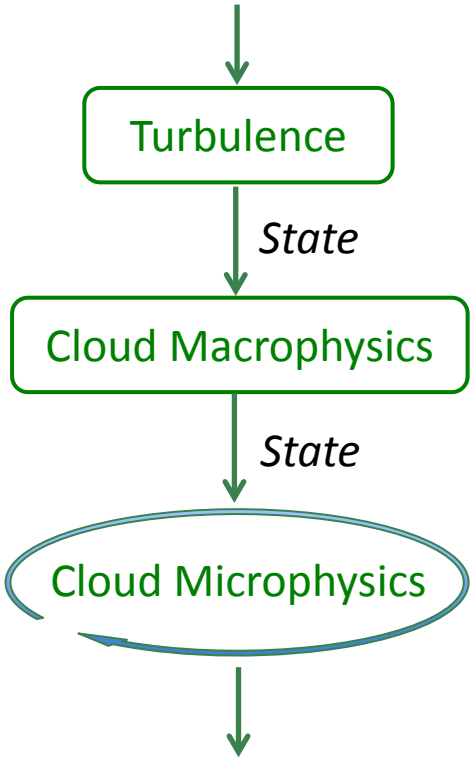
(Wan, Rasch et al., 2013 GMDD)

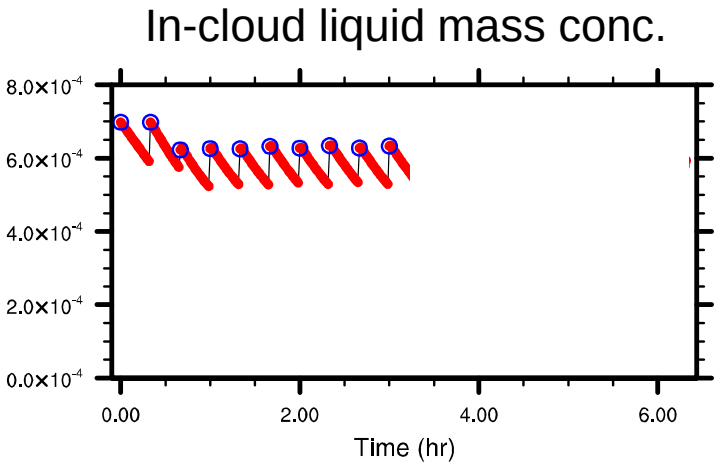
Back to Clouds in CAM5

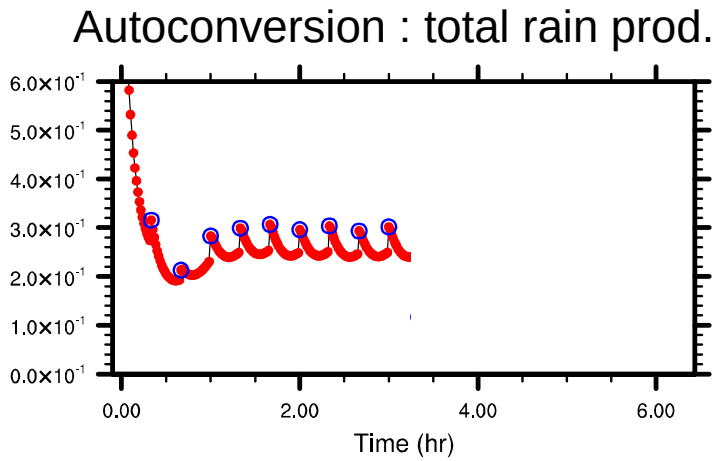
- The Morrison-Gettelman microphysics is evolving towards a prognostic precipitation scheme
- Possibly use sub-stepping to address the CFL and accuracy issues associated with the rain/snow fall speed
- How does the cloud microphysics behave under the current sequential splitting framework?
  - SCAM simulations of the DYCOMS RF2 case (drizzling stratocumulus)

Sequential Splitting + Sub-stepping

- Model time step = 20 min (blue circles)
- Microphysics time step = 1 min (red dots)

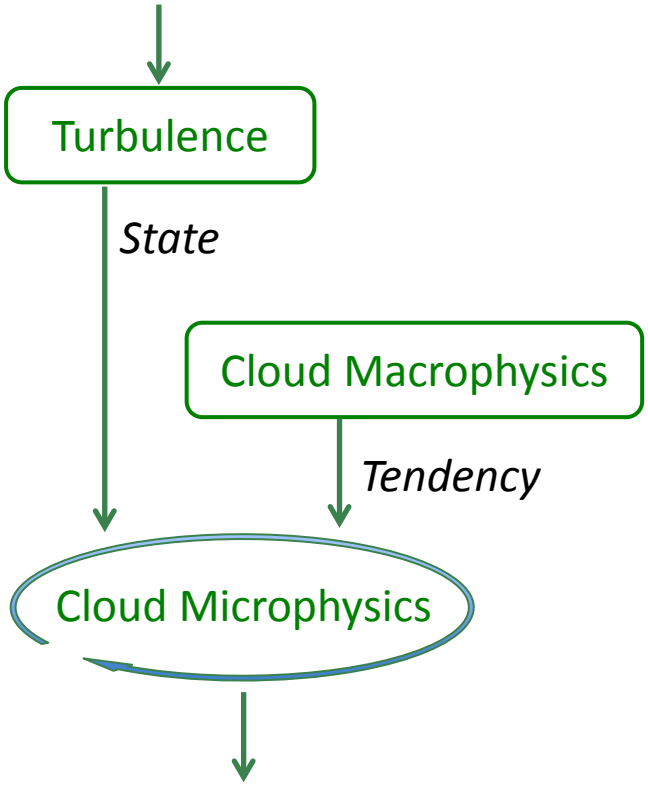


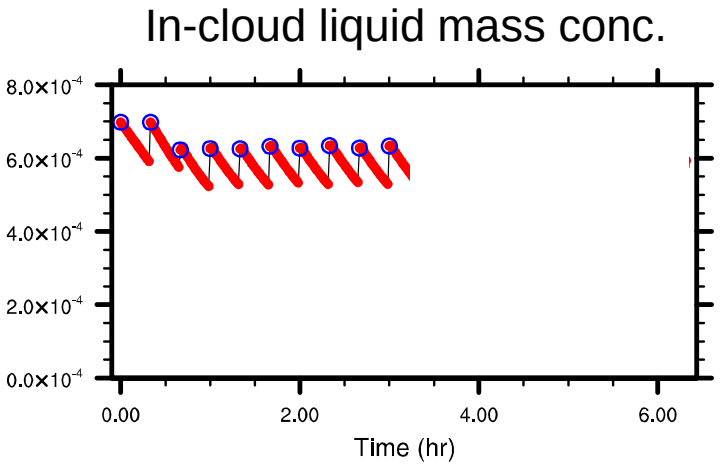


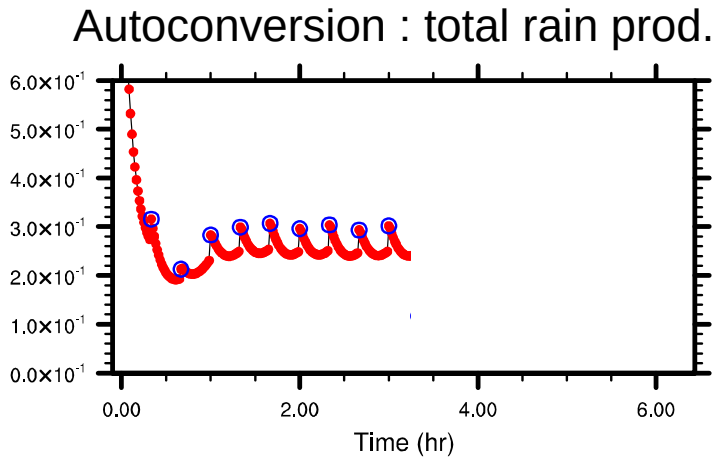


Macro-Micro Coupling

- Model time step = 20 min (blue circles)
- Microphysics time step = 1 min (red dots)







Why Even Stronger Oscillations?

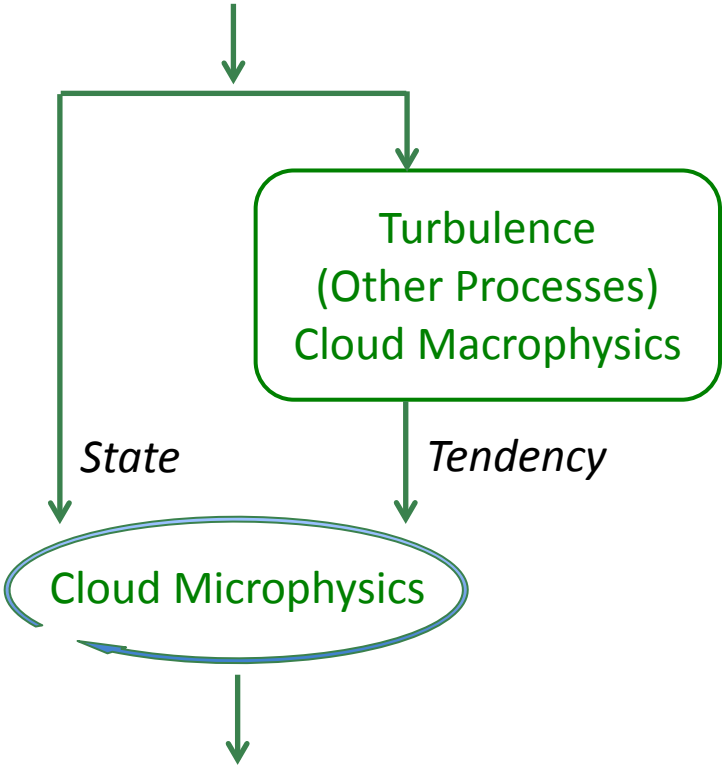
Note turbulence (vertical diffusion) and shallow convection in the low-latitudes

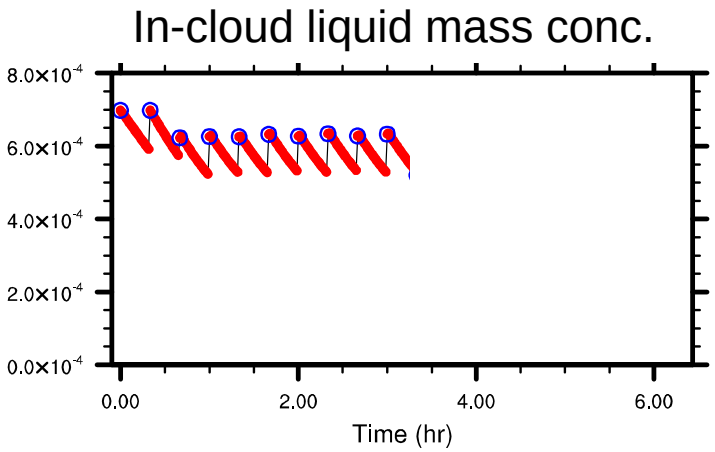
Cloud liquid mass budget
1-yr mean,40S – 30N average

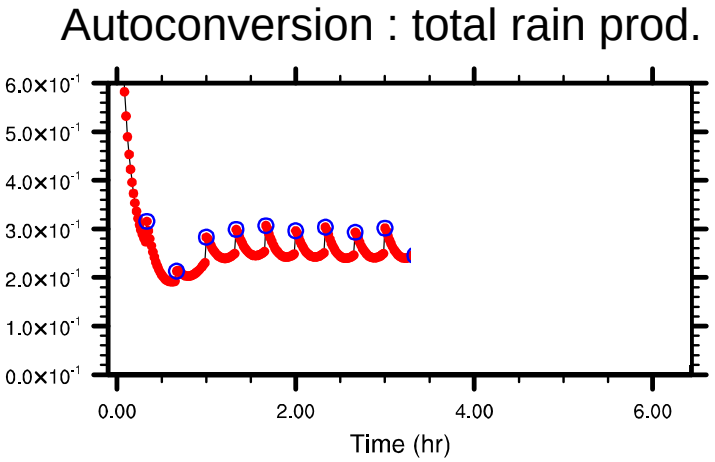
- There are more than 2 processes pushing and pulling!

Combine Sources and Sinks

- Model time step = 20 min (blue circles)
- Microphysics time step = 1 min (red dots)







Some Other Push-Pull Problems in CAM5

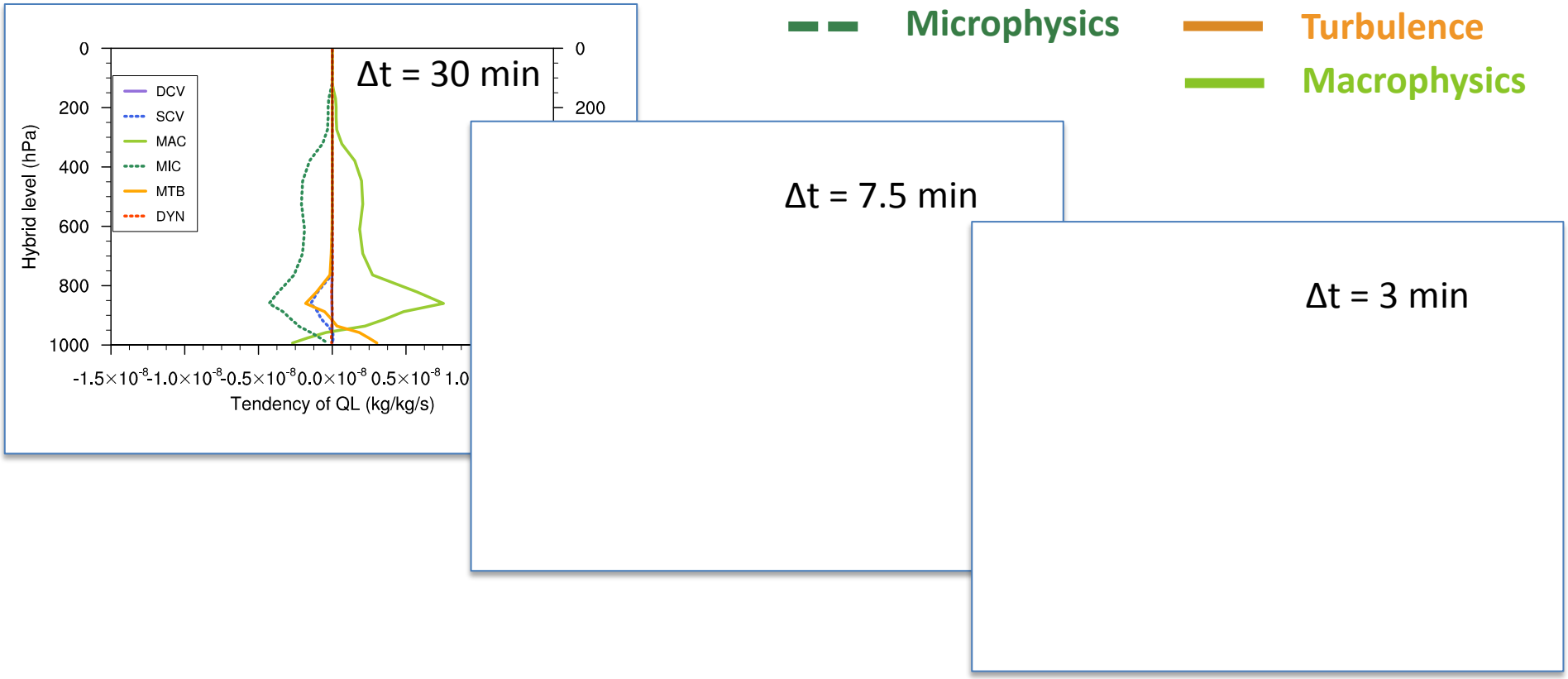
- Cloud droplet number:
  activation vs. evaporation (macrop) + microphysics
- Ice crystal mass:
  vapor deposition + Bergeron vs. autoconversion to snow
- Ice crystal number:
  convective detrainment + in-situ nucleation vs. ice sublimation

- Model intercomparison with PNNL-MMF and ECHAM-HAM is planned

Another Concern Regarding the Cloud Budget

Cloud liquid mass budget, 90S – 90N average

Microphysics Turbulence Macrophysics



- As Δt is further decreased (down to 1 min), the mean state seems to converge, but many tendency terms become even stronger
- Are we approaching a benchmark solution or not?
- We are looking into the cause and impact of this sensitivity

Summary

- Cloud water budget analysis reveals strong sources and sinks in CAM5
- Toy problem and SCAM simulations give warning of numerical artifacts, and provide hints to possible solutions
- Balance between processes shows strong sensitivity to model time step. Cause and impact are under investigation.

Acknowledgements

- *PNNL Linus Pauling Postdoc Fellowship and LDRD program*
- *DOE Climate Modeling Program – Aerosol, Clouds, and Precipitation Science Focus Area*
- *DOE SciDAC project on Multiscale Methods for Accurate, Efficient, and Scale-Aware Models of the Earth System*