Cloud Water Budget in CAM5 and Sensitivity to Model Numerics

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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

- Shallow convection
- Deep convection
- Stratiform microphysics
- Detrainment of condensate to macrophysics
- Surface evap. & turbulence
- Dynamics

Hybrid level (hPa)

Tendency of QT (kg/kg/s)
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$_2$SO$_4$ gas equation in the aerosol-climate model ECHAM-HAM**

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

- Transport and chemical production
- Condensation on pre-existing aerosol particles
- Aerosol nucleation

Strongly compensating
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)
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)

Turbulence → State → Cloud Macrophysics → State → Cloud Microphysics

In-cloud liquid mass conc.

Autoconversion : total rain prod.
Macro-Micro Coupling

- Model time step = 20 min \(\text{blue circles}\)
- Microphysics time step = 1 min \(\text{red dots}\)

Turbulence → State → Cloud Macrophysics

Cloud Macrophysics → Tendency → Cloud Microphysics

In-cloud liquid mass conc.

Autoconversion : total rain prod.
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)

In-cloud liquid mass conc.

Autoconversion : total rain prod.
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

- As $\Delta t$ 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.

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