Bringing climate physics (better radiation) to cloud models and the MMF

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Radiation is a weak link in the MMF and in SAM

SAM's current radiation package (optics + solver) comes from CAM 3. It's no longer state-of-the-art, especially for absorption by gases, and NCAR is replacing it with RRTMG

Even the old radiation package us expensive, and we take shortcuts: radiation is computed every *N* times compared to other processes

I implemented RRTMG (the next-generation scheme for CAM) in SAM

Oops - it's about six times slower. That won't work

About this time Bjorn called me with the same problem in LES simulations of stratocumulus using a different (and very streamlined) code

Broadband spectral integration is the issue

Radiative transfer is fundamentally non-linear, and properties vary with wavelength

RRTMG uses a *k*-distribution

$$F(i,j,t) = \sum_{b}^{B} w_b \sum_{g}^{G(b)} w_g F_{b,g}(i,j,t)$$

Effects of clouds, etc.

Effects of gases

Flux per *g*-point

In RRTMG, *B* and *G* are both about 16 - flux estimates take 240 calculations

Can we possibly afford realistic radiation?

Reducing the frequency of radiation calculations is a bad idea for practical and conceptual reasons

Accuracy in radiation don't degrade gracefully in number of bands/*g*-points

We had an insight that amounts to computational judo

What if...

Doing the entire calculation every *N* time steps costs the same as doing 1/*N* calculations every time step.

We took this idea to the extreme

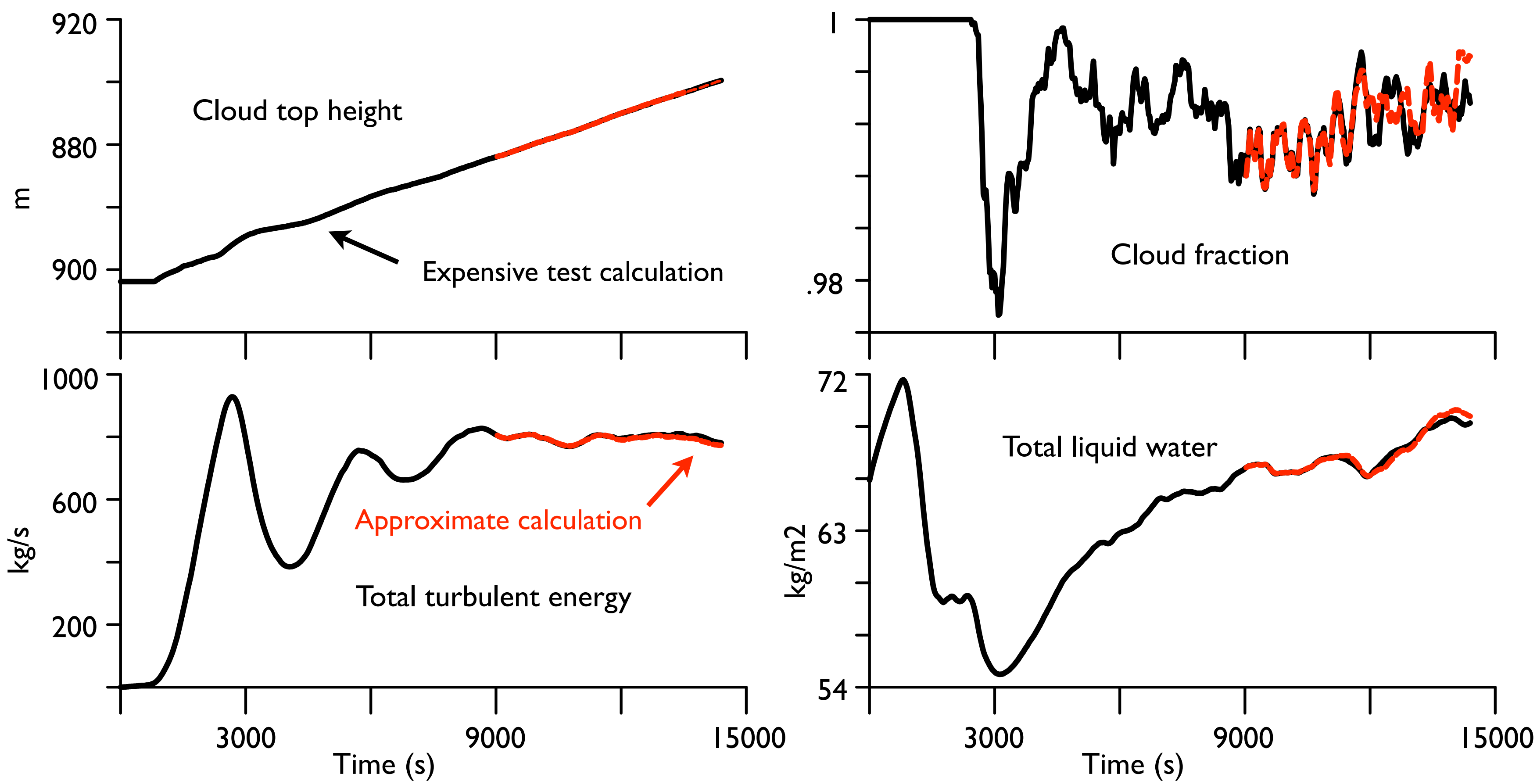
$$F(i,j,t) = \sum_{b}^{B} w_b \sum_{g}^{G(b)} w_g F_{b,g}(i,j,t)$$

becomes

$$F(i,j,t) \approx w_{b'} F_{b',g'}(i,j,t)$$

where *b'*, g' pair is chosen randomly at each grid point and done every time step

We built this. It works like a champ.



How this works

This trick spreads out the correct calculation in time and space

The sampling introduces lots of noise but *no systematic errors* - so the circulation isn't changed
("Heating rate errors are orthogonal to the flow.")

Formally, this is a Monte Carlo sample of the calculation we'd like to do but can't afford, so...

"Monte Carlo spectral integration"

Why does it work?

Uncorrelated noise can't excite organized motions (c.f. Shutts stochastic parameterizations)

We did a scaling analysis for well-mixed stratocumulus comparing
  the energy excited by noise at a given time & space scale
with
  the energy expected from organized flow
to demonstrate this

The idea should work just as well for cloud resolving models (SAM, VVM)

What’s next?

We now have a way to make state-of-the-art radiative transfer calculations in cloud-scale models

We needed this for the MMF but it’s very good for cloud models in general

We also have a theoretical framework to assess other approximations (especially 3D vs 1D radiative transfer)

We’re moving the idea into the MMF in stages (implementation in RRTMG, tests with stand-alone SAM, then testing the full MMF)