Adapting LES radiation to models at large scales

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Why we started sampling radiation in time

Because the usual compromise

Compute radiative heating rates every N time steps, apply these uniformly in time

leads to the usual disadvantages

Heating rate errors are correlated with the flow (largest where things are changing quickest)

No theoretical basis: no guidelines for choosing N, and no way of knowing when this choice is affecting the solution

Computational efficiency is unknowable

Our solution for cloud-scale models

Monte Carlo Spectral Integration (Pincus and Stevens 2008)
approximates $G \sim 100$ calculations every N time steps

$$F(x, y, z, t) = \sum_g^G w_g F_g(x, y, z, t)$$

with $G' \sim 1$ calculations every time step

$$F(x, y, z, t) \approx \frac{G}{G'} \sum_g^{G'} w_g F_g(x, y, z, t)$$
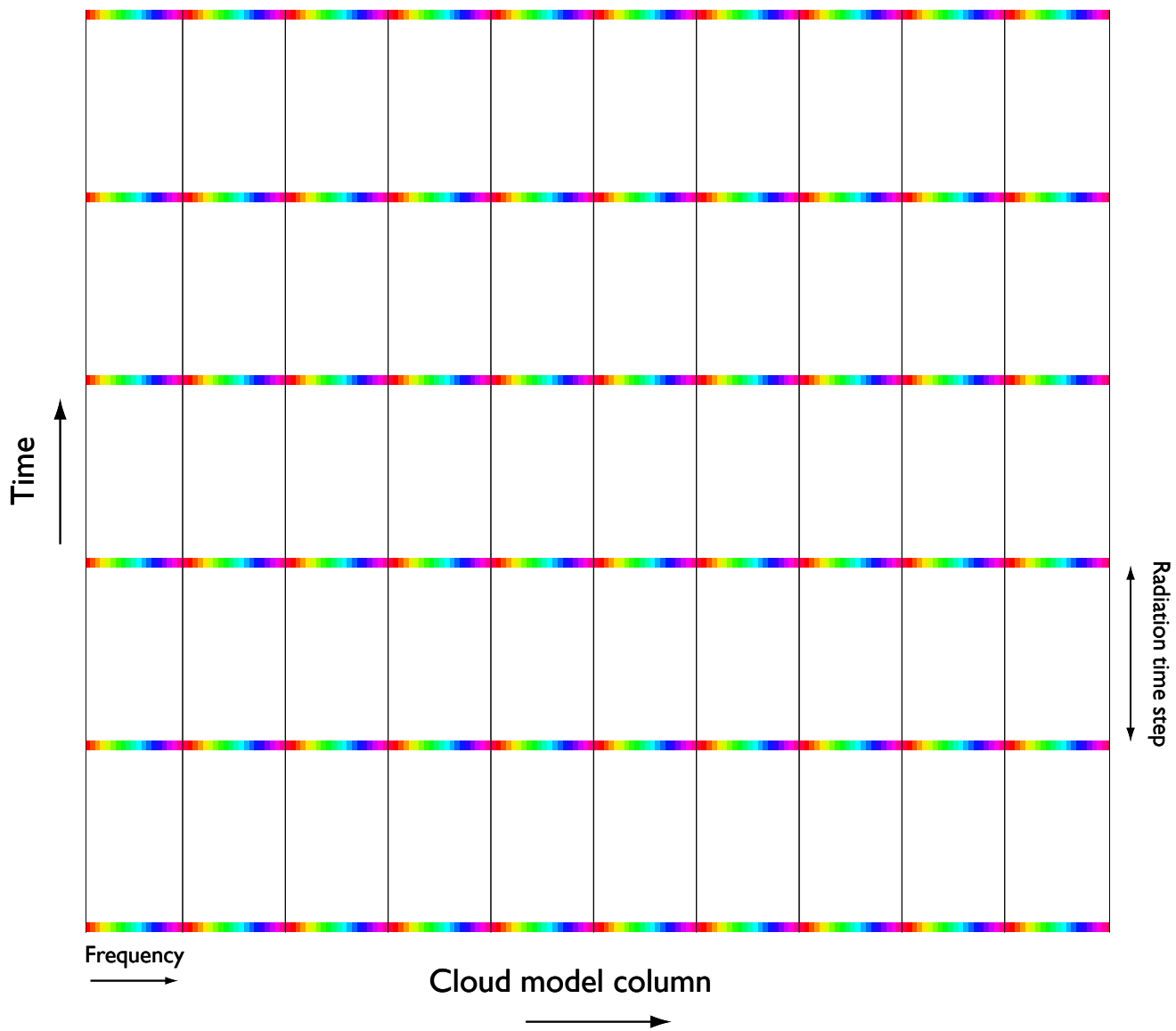
$$G' << G$$

to the infrared and beyond

visible

ultraviolet

Frequency

Time

Radiation time step

Frequency

Cloud model column

We are exploring variants of McSI in global models

McSI samples temporal variability, distributes computation cost more uniformly over time

McSI is orthogonal to methods for sampling cloud variability (Monte Carlo Independent Column Approximation; McICA)

Our implementation: ECHAM6 coupled to

    RRTMG k-distribution for gas optics

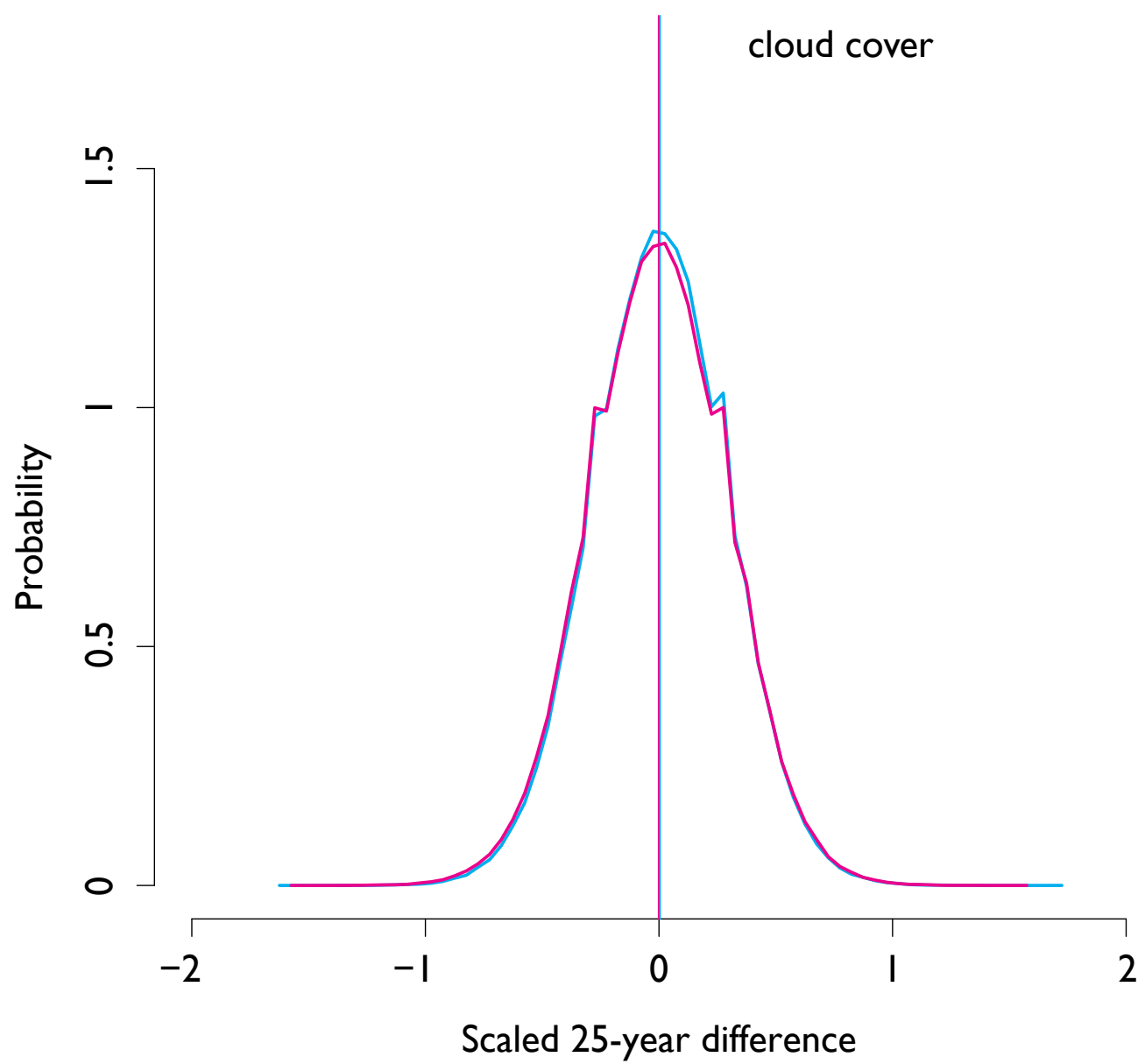   Home-grown aerosol, cloud optics

    Default RRTMG treatment of max-ran overlap

Example: AMIP runs

    T31L19, 40 minute time step, T63L31, 12 minute time step

    Reference runs call radiation every time step

    Compare radiation every two hours, roughly equivalent MCSI

cloud cover

Why can random sampling noise introduce biases?

MCSI works in large-eddy simulation because the scaling of approximation errors is opposed to the scaling of the energy in the flow:
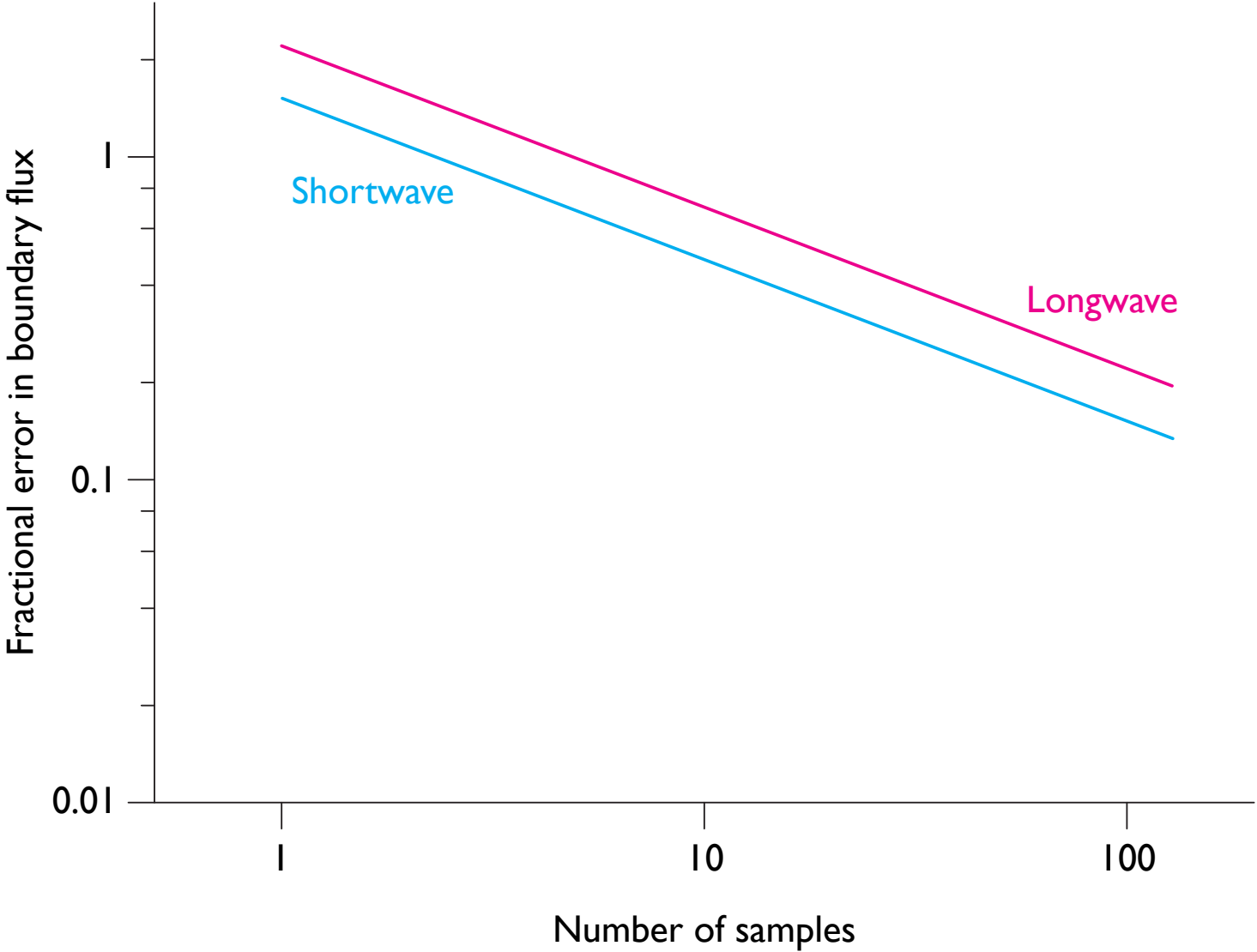
$$\frac{e'_l}{\overline{e}_l} \propto \left(\frac{\sigma_B}{\overline{B}_l}\right)^{2/3} \frac{\delta x}{l} \left(\frac{l}{h}\right)^{1/9}$$

Interactive surface temperature changes this scaling

perturbations are diffused only in time, not in space

there are potentially more non-linearities in global models

Moving McSI from idealized large-eddy simulations to global models

　　works in a general way

but is harder than it seems

　　Perturbations aren't mixed efficiently at the surface; parameterizations can be more non-linear

Smarter sampling can reduce large perturbations and make the method tractable