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

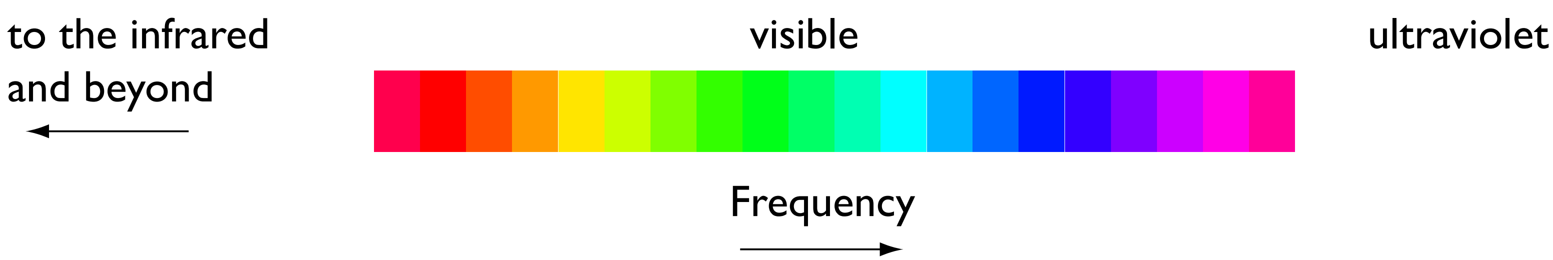
Monte Carlo Spectral Integration (Pincus and Stevens 2008) approximates *G* ~ 100 calculations every *N* time steps

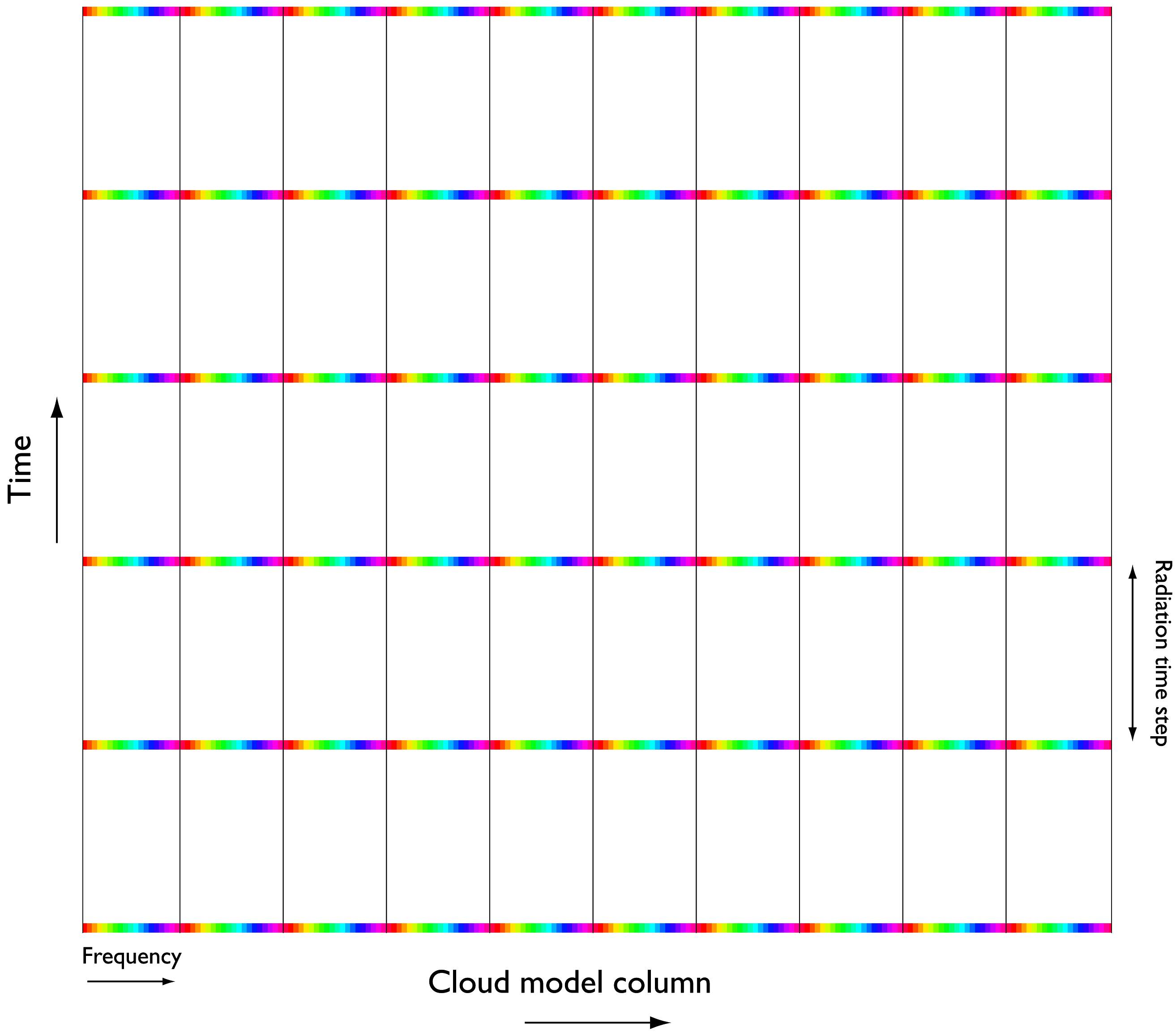
$$F(x,y,z,t) = \sum_{g}^{G} w_g F_g(x,y,z,t)$$

with G' ~ 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

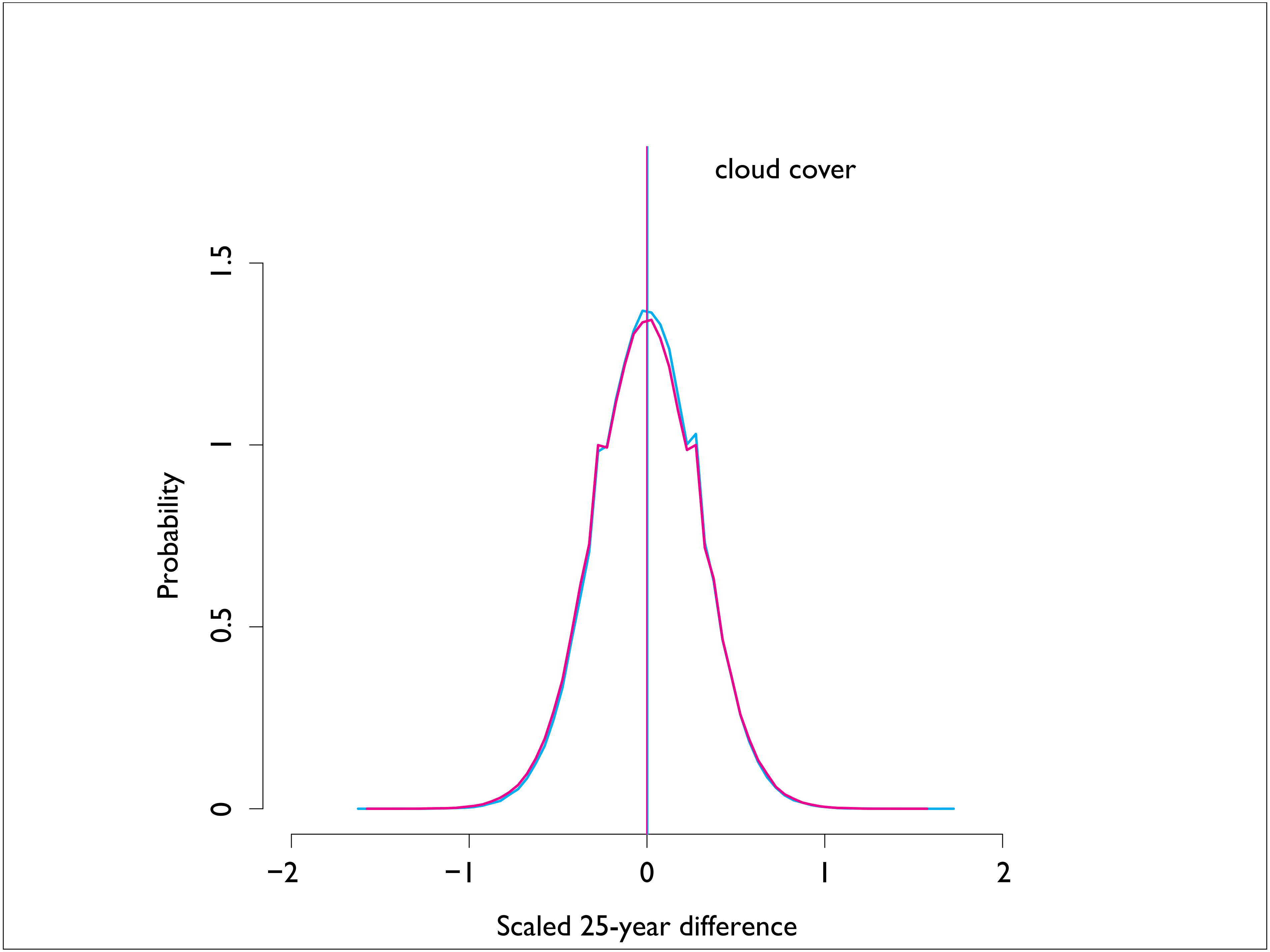
- McSI samples temporal variability, distributes computation cost more uniformly over time
- McSI is orthogonal to methods for sampling cloud variability (Monte Carlo Independent Column Approximation; McICA)

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
Probability
0
0.5
1
1.5
−2
−1
0
1
2
Scaled 25-year difference

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:

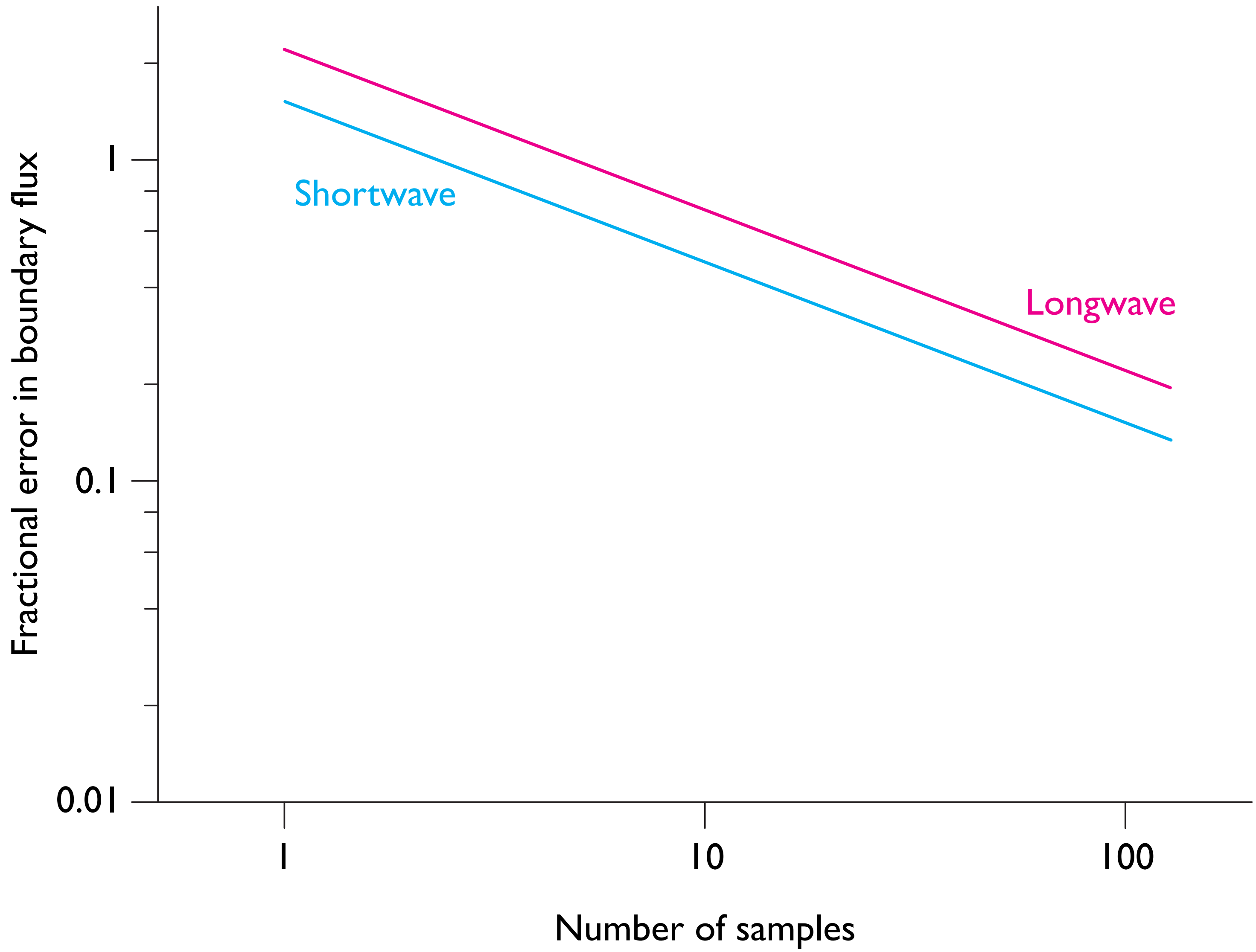
$$\frac{e_l'}{\overline{e}_l} \propto \left(\frac{\sigma_B}{\overline{\overline{B}_l}}\right)^{2/3} \frac{\delta x}{l} \left(\frac{l}{h}\right)^{1/9}$$

Interactive surface temperature changes this scaling

perturbations are diffused only in time, not in space

there are potentially more non-linearities in global models

Smarter sampling in spectral space



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