Paths to accuracy for radiation for global models

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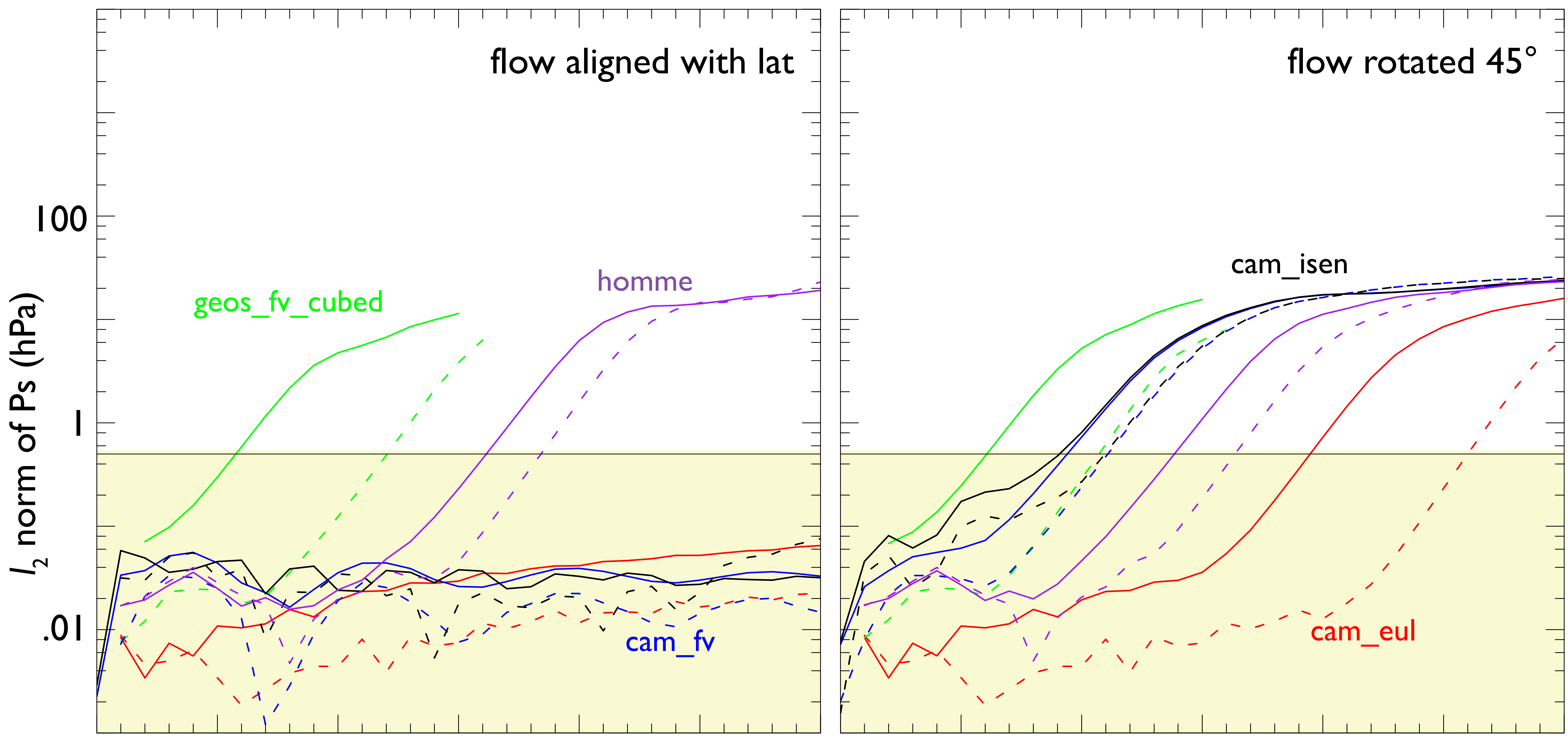
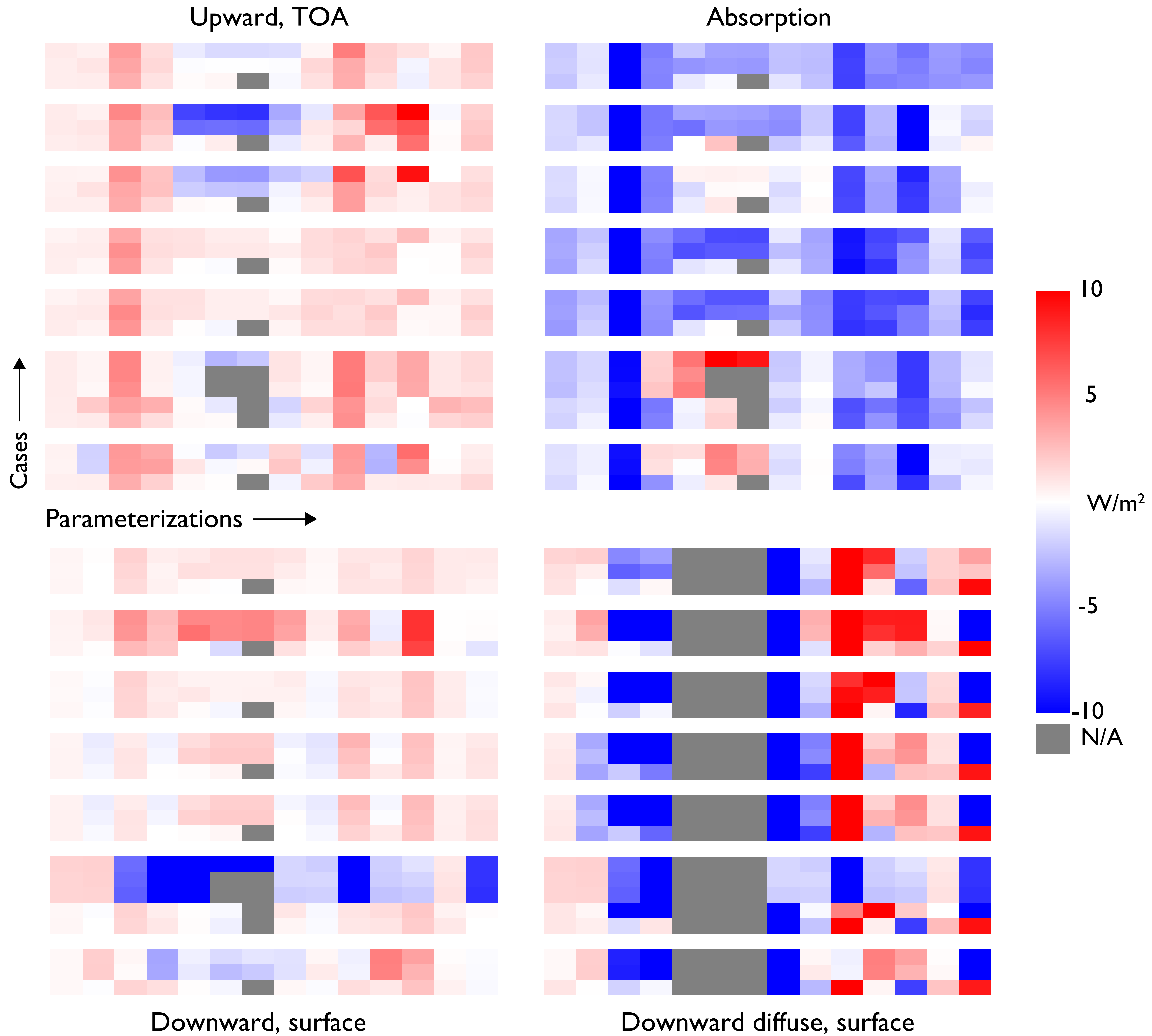


Lauritzen et al., 2010, doi:10.3894/JAMES.2010.2.15


Upward, TOA
Absorption
Downward, surface
Downward diffuse, surface
Cases
Parameterizations
10
5
W/m²
-5
-10
N/A

NOTES AND CORRESPONDENCE

On the Effects of the Temporal and Spatial Sampling of Radiation Fields on the ECMWF Forecasts and Analyses

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8 February 1999 and 7 June 1999

ABSTRACT

The author's explore the implications of the temporal and spatial sampling of the radiation fields and tendencies upon the fields produced by the ECMWF system in operational-type forecasts, four-month seasonal integrations, and analyses. The model is shown to be much more sensitive to economies in the temporal than in the spatial description of the cloud–radiation interactions.

In 10-day forecasts, the anomaly correlation of geopotential shows little sensitivity to a more complete representation of the cloud–radiation interactions, but temperature errors display a stronger dependence on the temporal representation. The difference increases with height, particularly in the tropical areas where interactions among convection, clouds, and radiation dominate. In pointwise comparisons over five days, the approximate temporal representation introduces only small differences in total cloudiness, surface temperature, surface radiation, and precipitation.

In four-month seasonal simulations, the small errors seen in 10-day forecasts build up and a better temporal resolution of the radiation produces a colder stratosphere through cloud–radiation–convection interactions. The spatial sampling in the radiation computations appears beneficial to the operational model, inasmuch as, close to the surface, it smooths an otherwise wavy radiative forcing linked to the spectral representation of the surface pressure.

The impact of the temporal/spatial sampling in the radiation calculations is usually much weaker in the analyses when and where observational data are available, but can be felt if the density of observations becomes smaller. On the contrary, the effect of the temporal/spatial interpolation is important on the sensitivity parameters derived from perpetual July simulations with perturbed SSTs.

Radiation accuracy isn't cheap, so we compromise:

"radiation time steps" >> "physics time steps"

"radiation grid" >> "physics grid"

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We ~~assume~~ hope this works under all circumstances

Awkward convergence (see also: resolution dependence)

Optimality is impossible

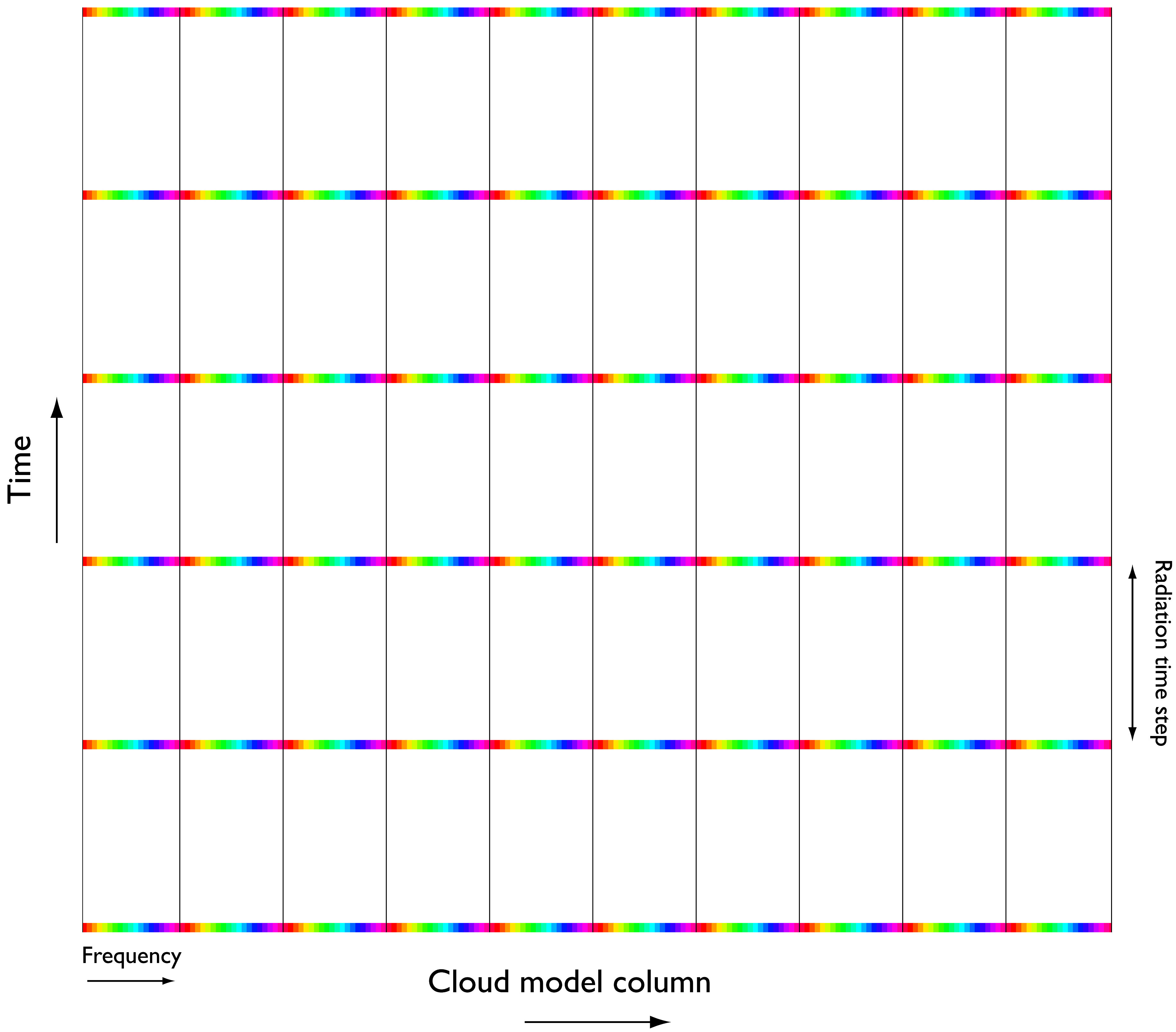
An alternative for high-resolution models

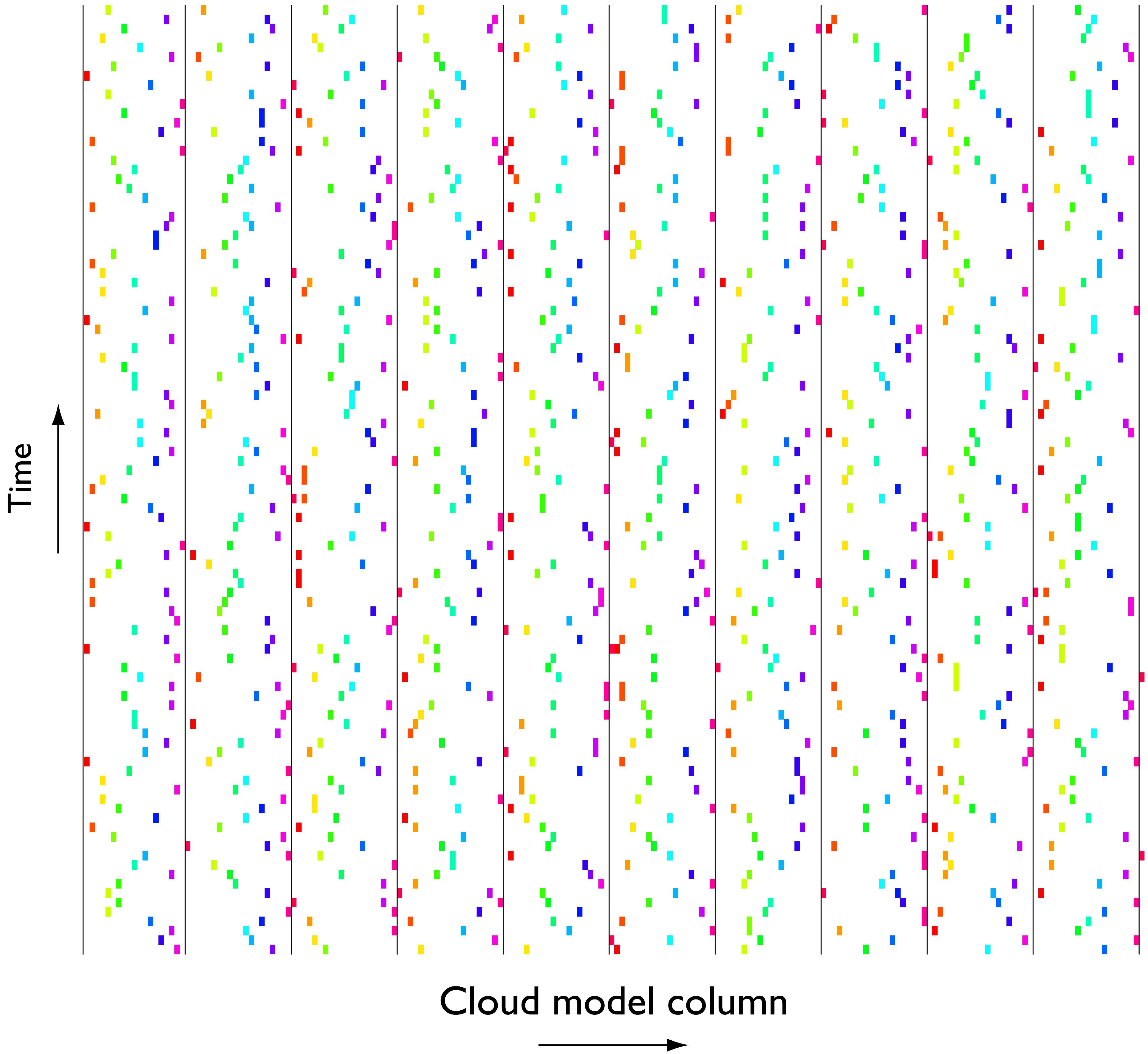
Heating rates imply broadband radiation: weighted sums of *O*(100)

Decreasing the resolution for radiation is to make
spectrally dense calculations sparsely in time and/or space

For large-eddy simulations these densities can be swapped

Monte Carlo Spectral Integration (Pincus and Stevens, 2009):
choose a single spectral interval randomly in space and time
scale to broadband calculation
repeat


Time
Radiation time step
Frequency
Cloud model column


Time
Cloud model column

A solution for high-resolution models

Heating rates imply broadband radiation: weighted sums of *O*(100)

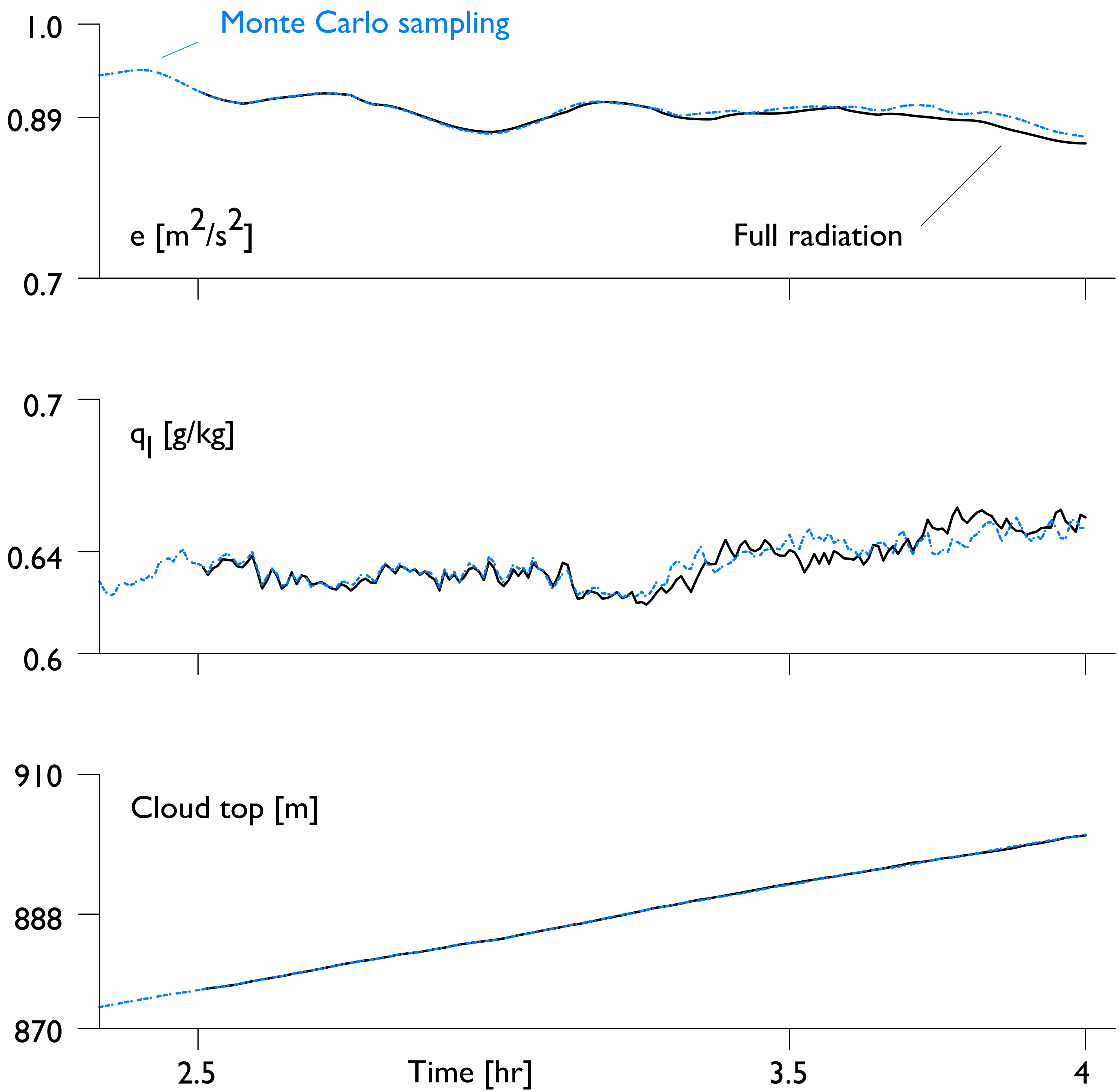
Decreasing the resolution for radiation is to make spectrally dense calculations sparsely in time and/or space

For large-eddy simulations these densities can be swapped

> Monte Carlo Spectral Integration (Pincus and Stevens, 2009): choose a single spectral interval randomly in space and time
> scale these to broadband calculation
> repeat

This has nice numerical properties (random error, convergence)

It works well*


Monte Carlo sampling
1.0
0.89
0.7
e [m²/s²]
Full radiation
0.7
0.64
0.6
q_l [g/kg]
910
888
870
Cloud top [m]
2.5
Time [hr]
3.5
4

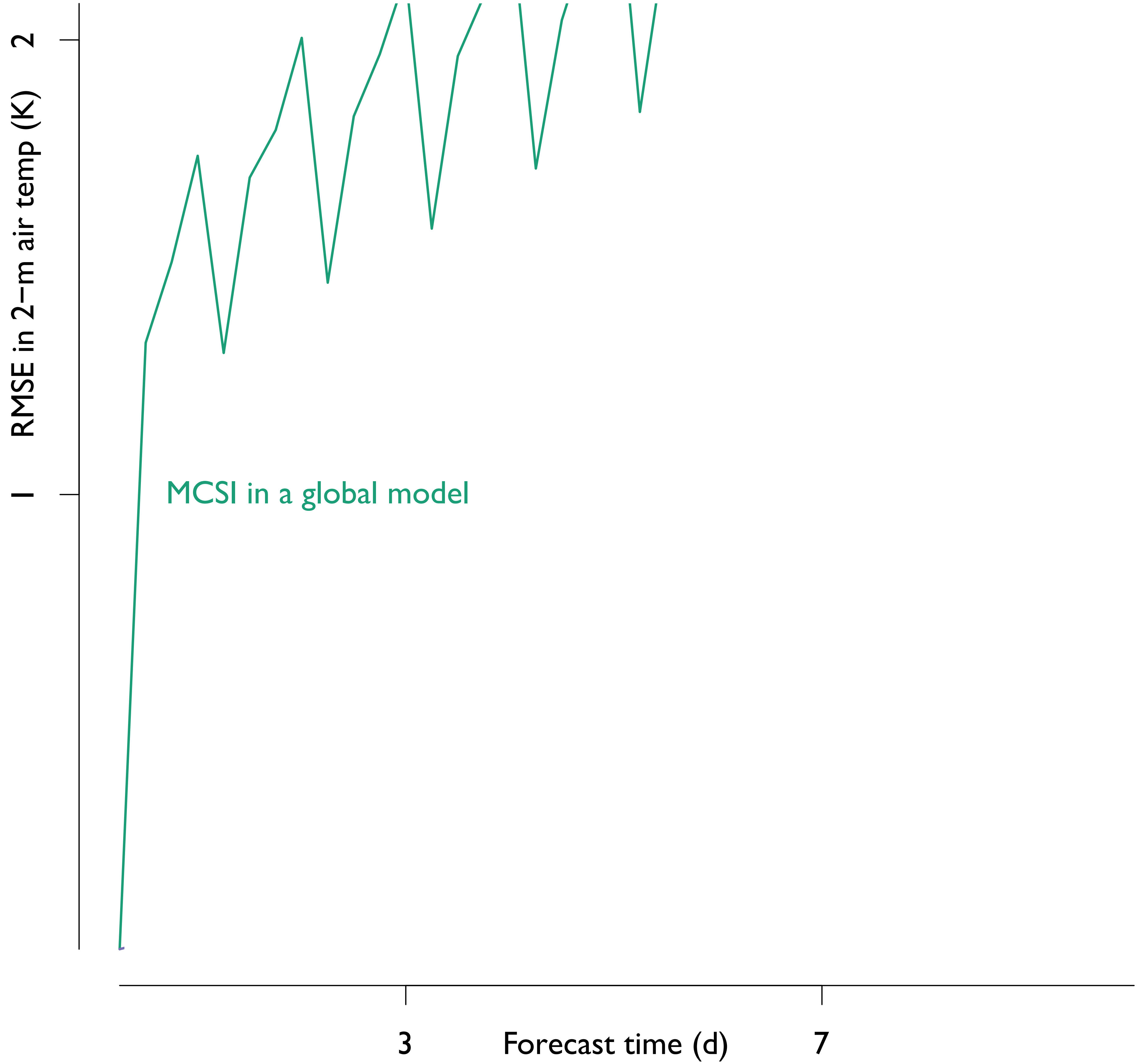
Assessing radiative approximations using ECHAM6

Radiation is PSrad, a drop-in replacement for RRTMG

Resolution is T63L47 with 7.5 minute time step

30 day forecasts with 29 member ensemble starting
1 Apr {1976-2004}

Comparison is with "reference forecast"
(radiation called every time step)



RMSE in 2−m air temp (K)
2
1
MCSI in a global model
3
Forecast time (d)
7

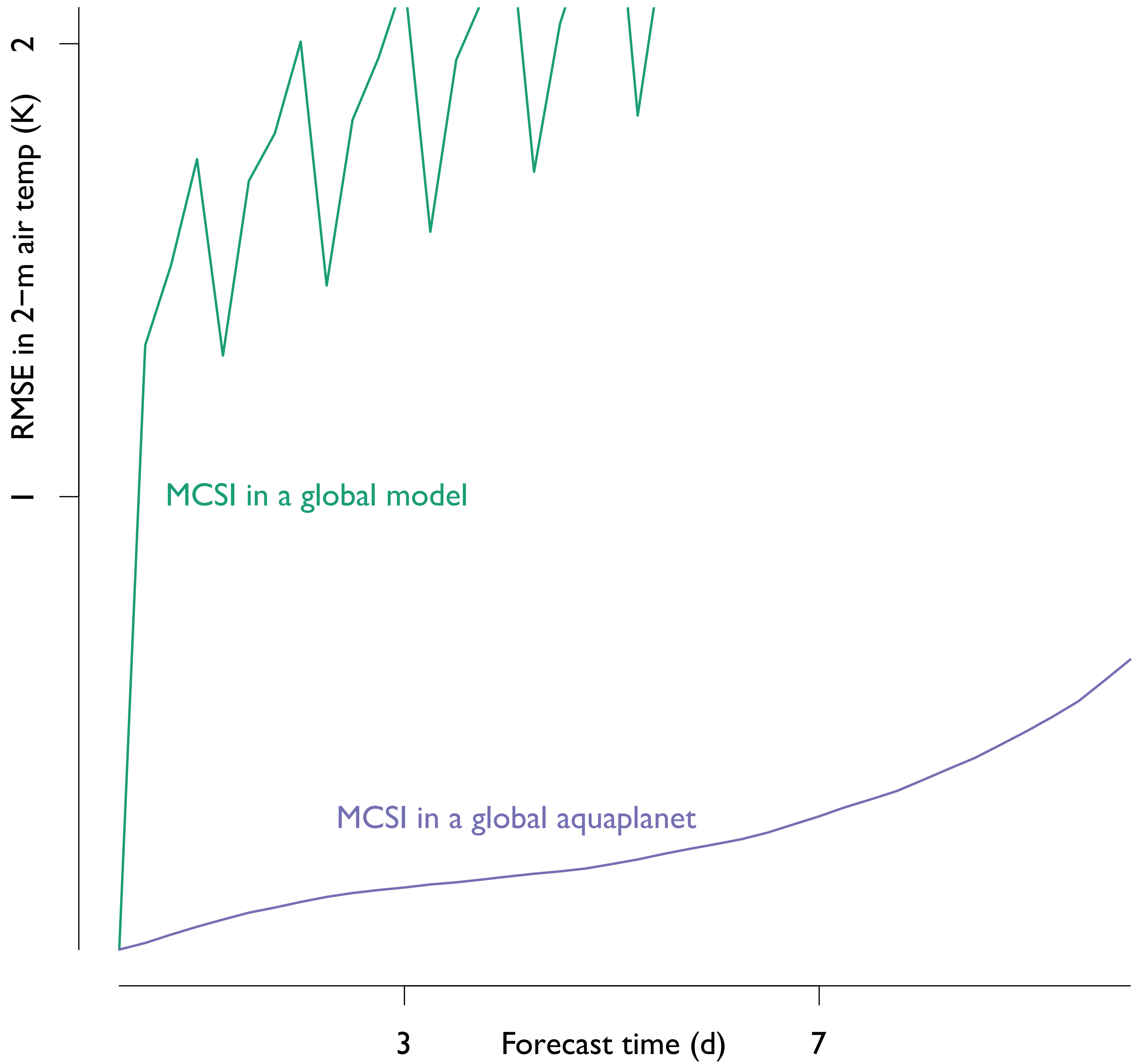
MCSI works in LES because the scaling of approximation errors is opposed to the scaling of the energy in the flow:

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

Interactive surfaces change this scaling

perturbations are diffused only in time, not in space

More non-linear parameterizations may magnify perturbations



RMSE in 2−m air temp (K)
2
1
MCSI in a global model
MCSI in a global aquaplanet
3
Forecast time (d)
7

Spectral sampling: the US middle-school football model

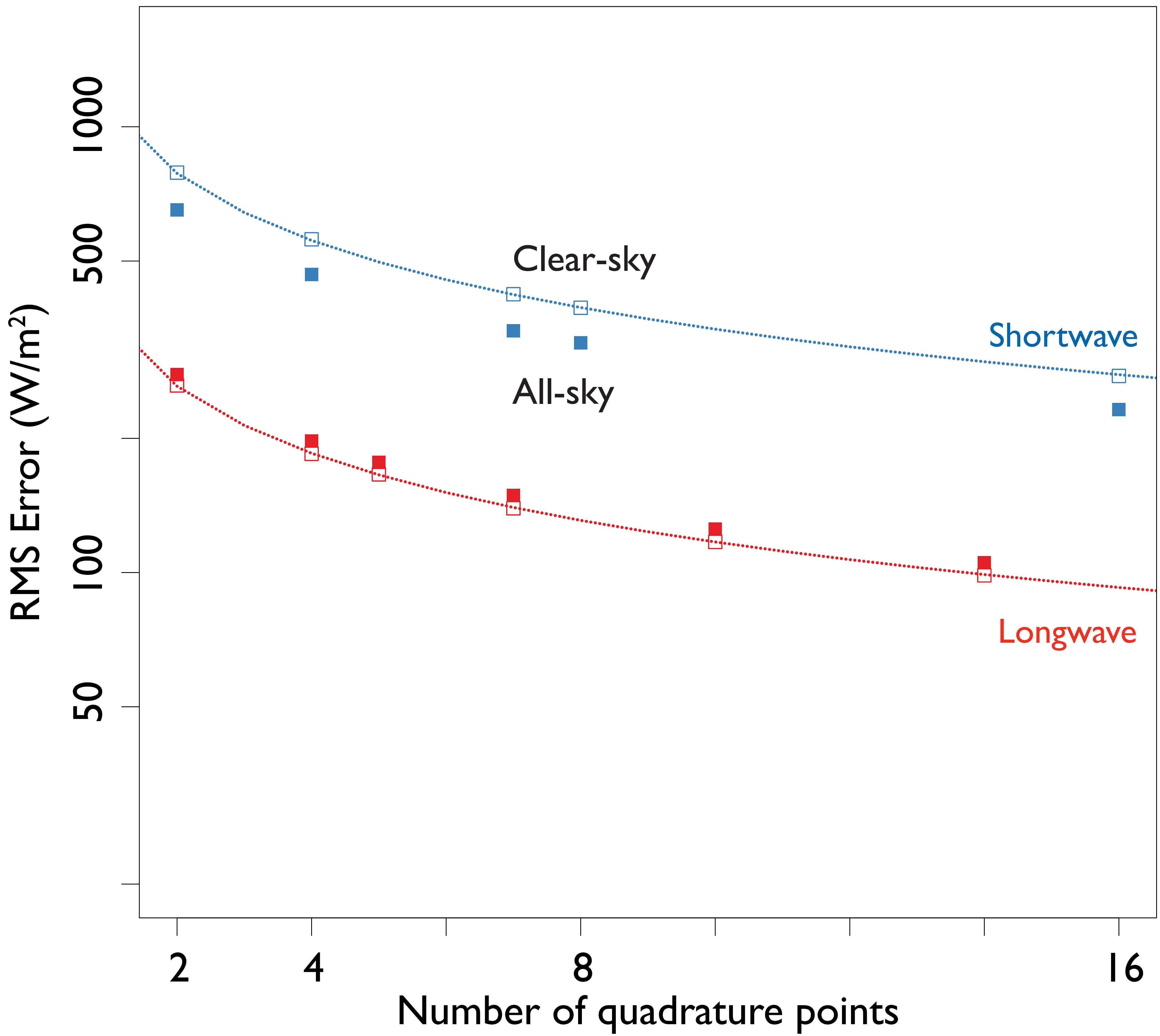
We seek to bound errors in surface fluxes

Increasing the number of Monte Carlo samples is slow $(1/\sqrt{n})$

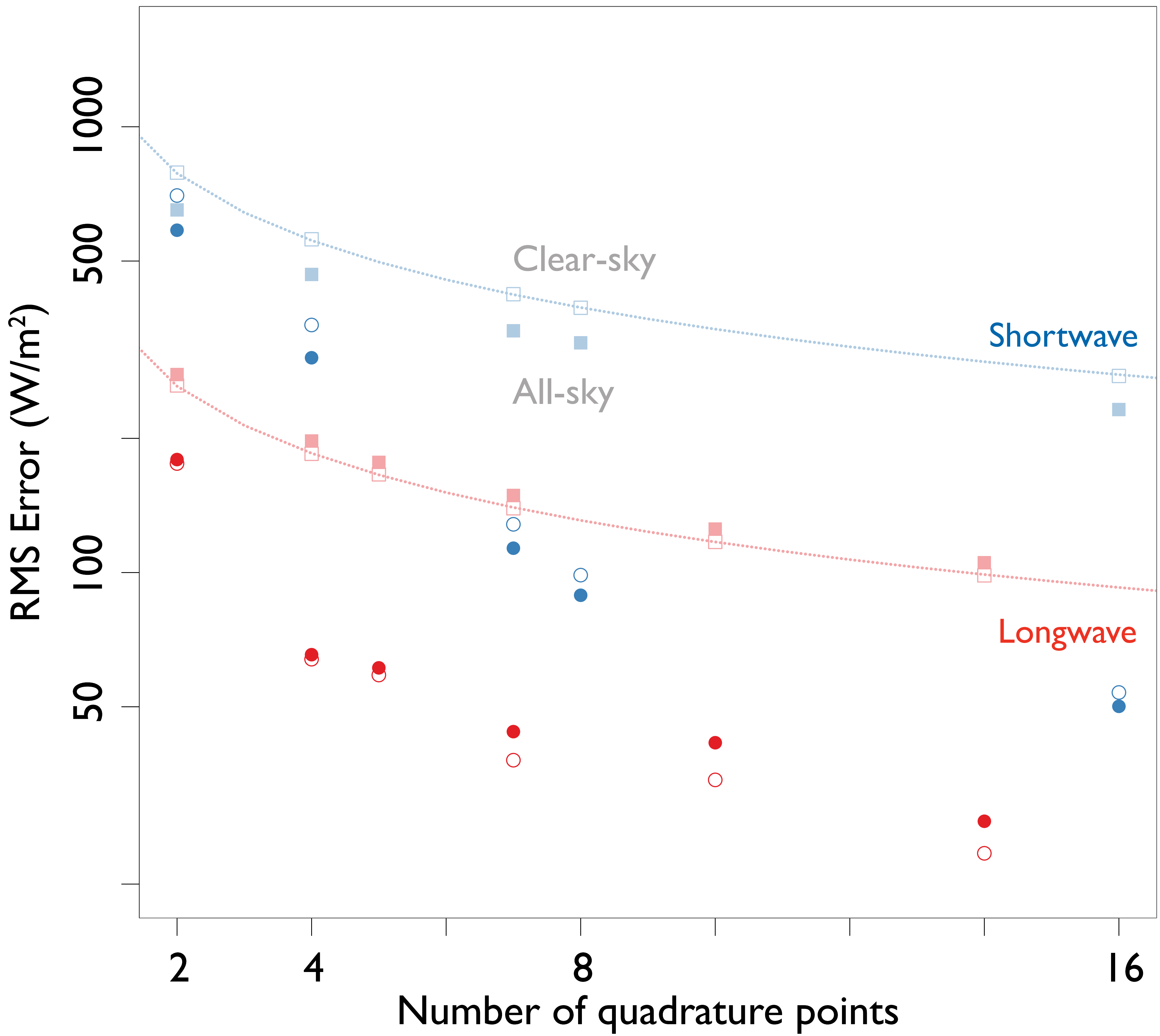
We create a *league* of *g*-point *teams*

- all teams are the same size
- all *g*-points are on used exactly once
- teams are chosen to minimize errors

Leagues are optimized offline using clear-sky fluxes



RMS Error (W/m²)
1000
500
100
50
Clear-sky
All-sky
Shortwave
Longwave
2
4
8
16
Number of quadrature points


RMS Error (W/m²)
1000
500
100
50
Clear-sky
All-sky
Shortwave
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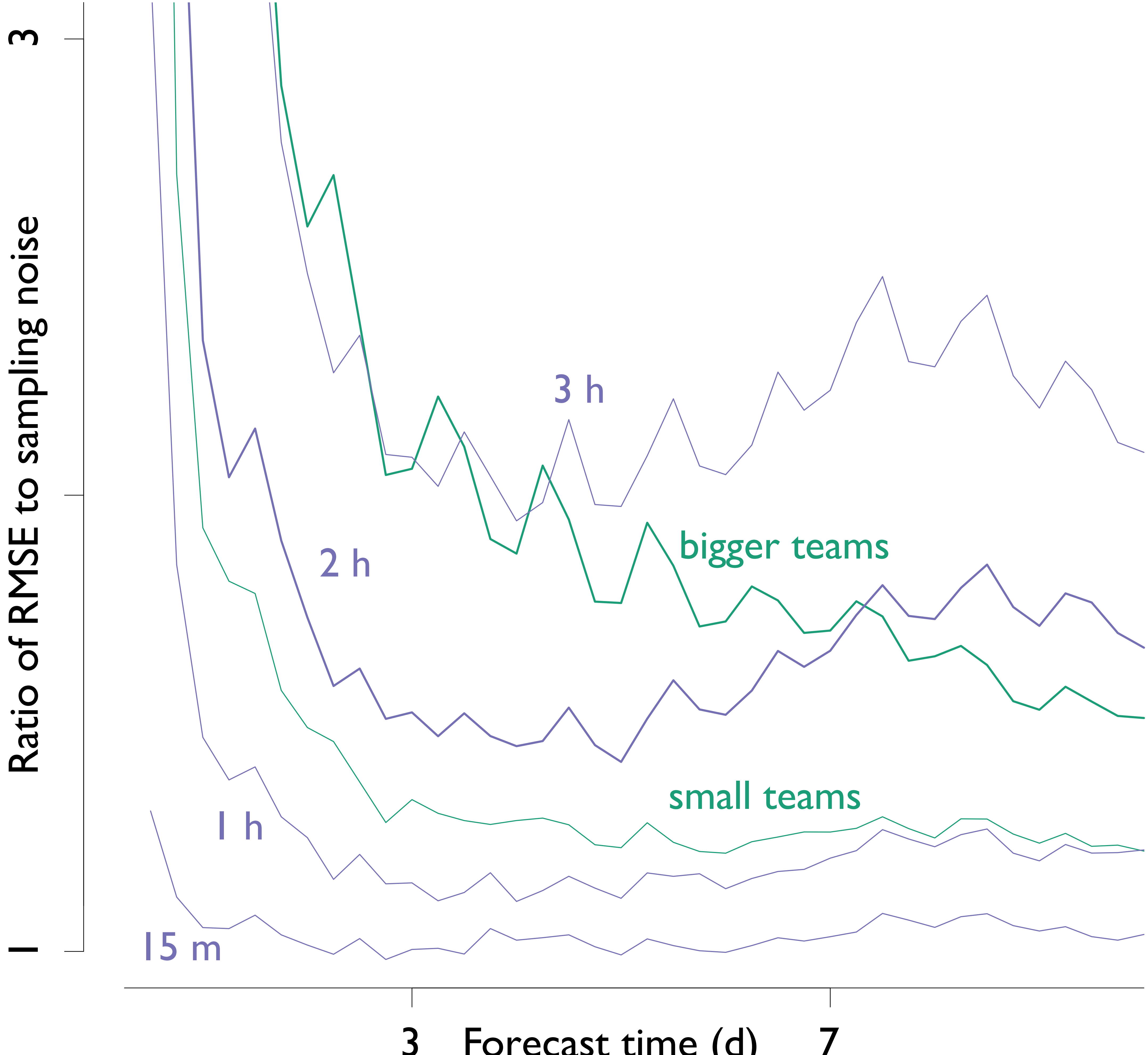
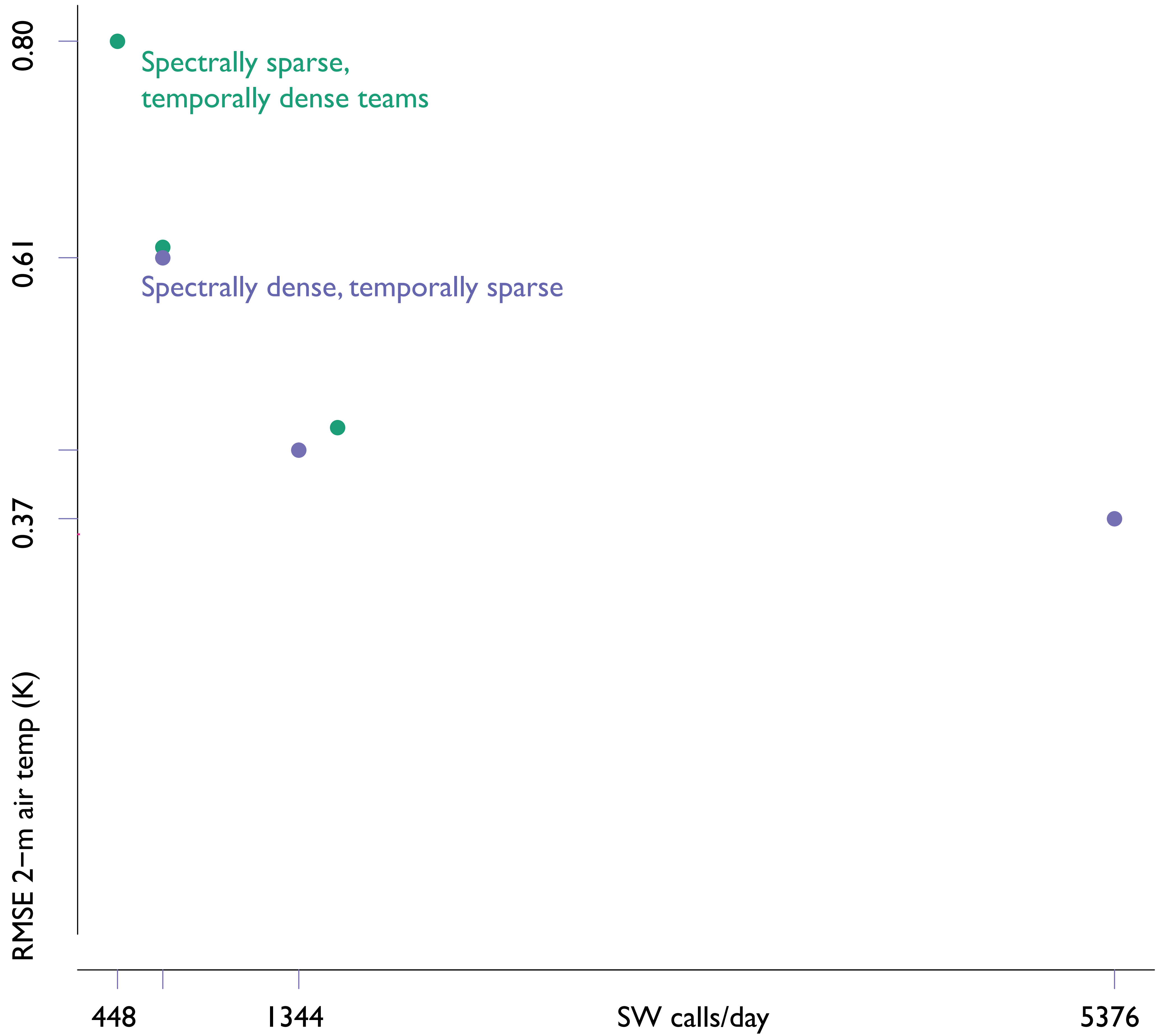
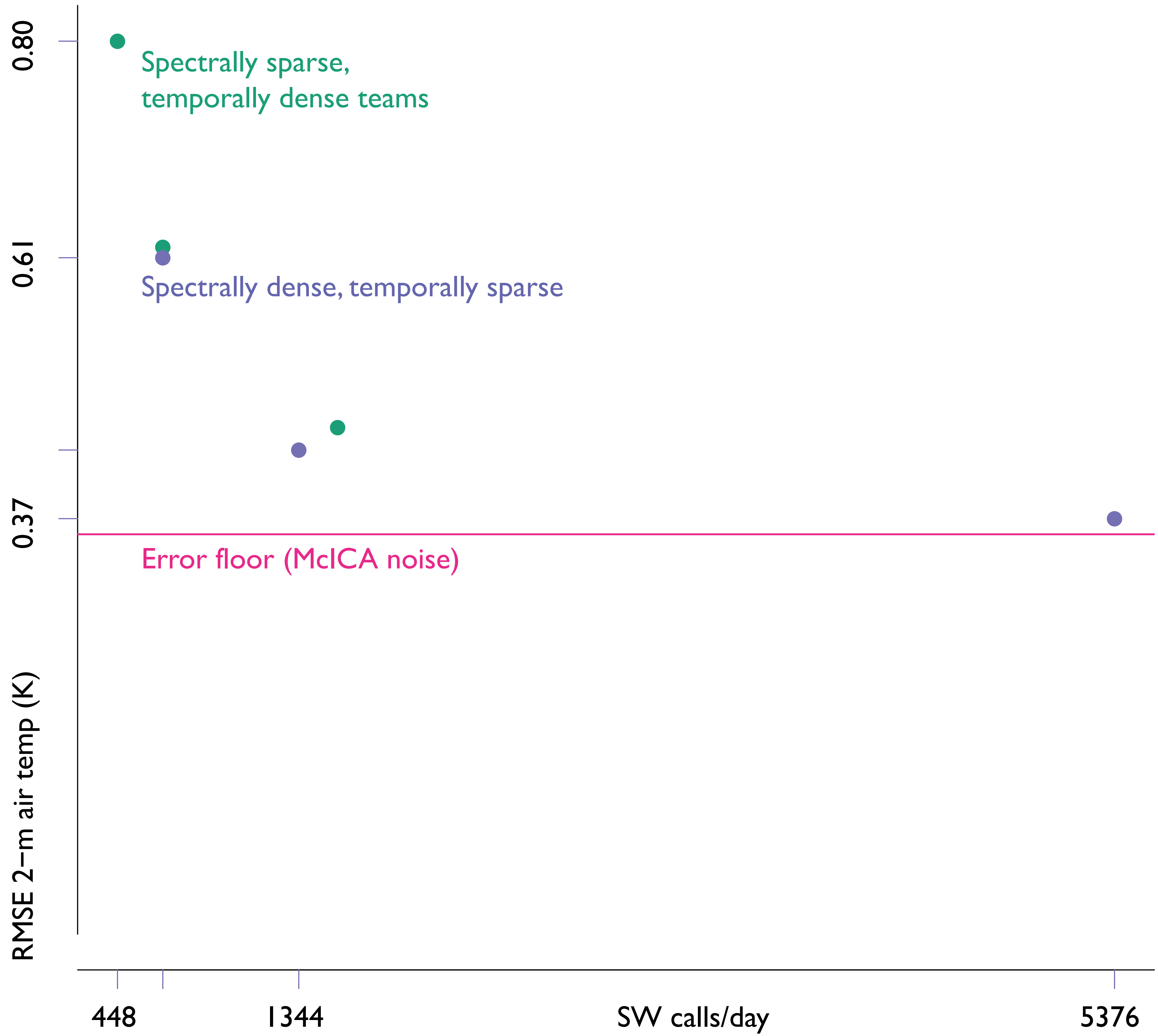
16
Number of quadrature points



3
1
Ratio of RMSE to sampling noise
3 h
2 h
1 h
15 m
bigger teams
small teams
3
Forecast time (d)
7



0.80
0.61
0.37
RMSE 2−m air temp (K)
Spectrally sparse,
temporally dense teams
Spectrally dense, temporally sparse
448
1344
SW calls/day
5376



Spectrally sparse,
temporally dense teams
Spectrally dense, temporally sparse
Error floor (McICA noise)
0.80
0.61
0.37
RMSE 2−m air temp (K)
448
1344
SW calls/day
5376

Practical details and conceptual considerations

We re-implemented RRTMG to permit flexible spectral sampling (and we are happy to share)

Sampling cloud states (McICA) is orthogonal to spectral sampling

Errors in perfect-model forecasts are comparable to reducing resolution

But there's conceptual appeal (and maybe practical benefit) in

- consistency/convergence, and so scale independence
- simplicity