Evaluating alternative strategies for coupling radiation to global models in weather and climate applications

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Practical considerations

Radiation parameterizations are accurate but expensive

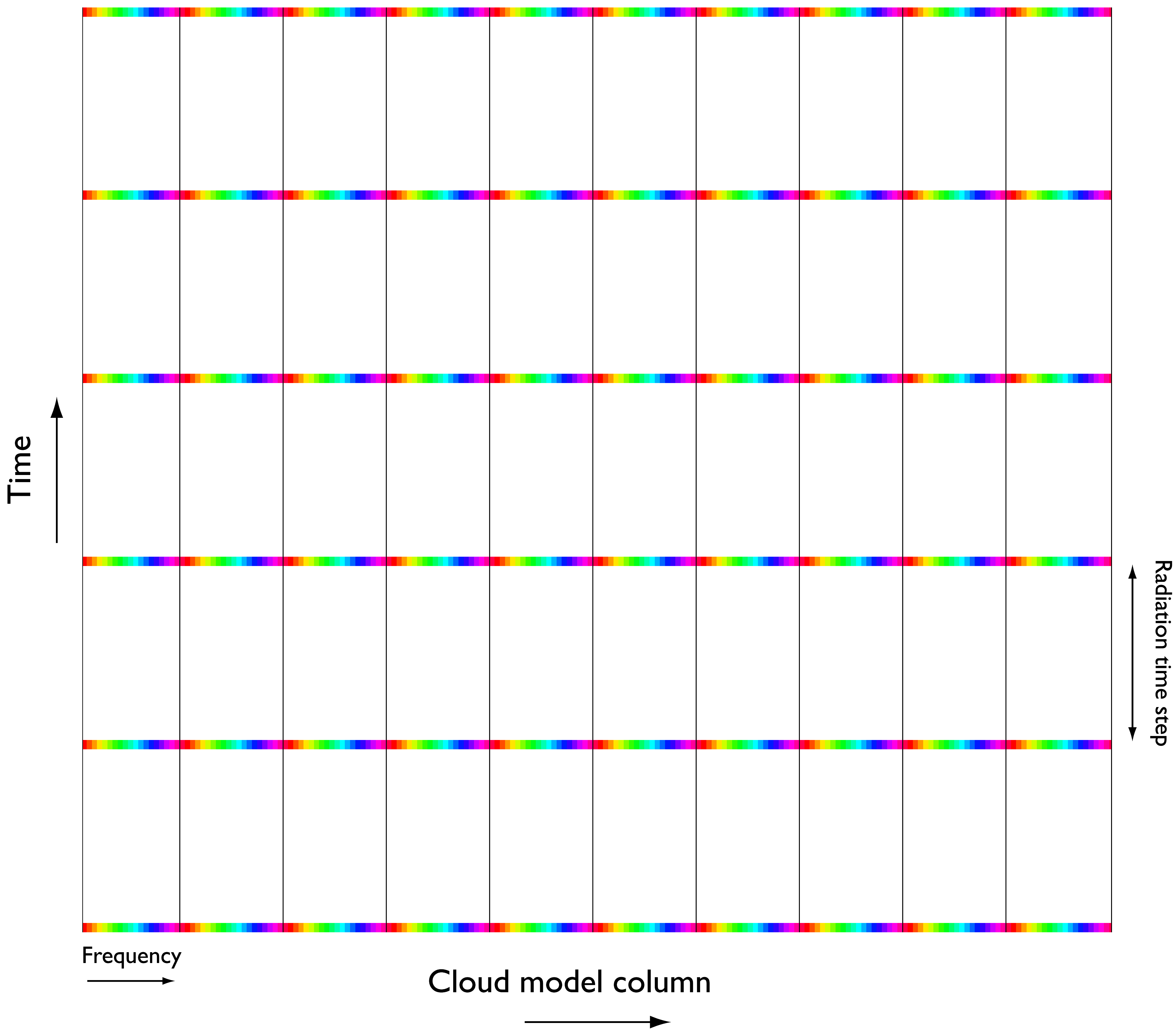
We have been exploring alternatives to the approximation

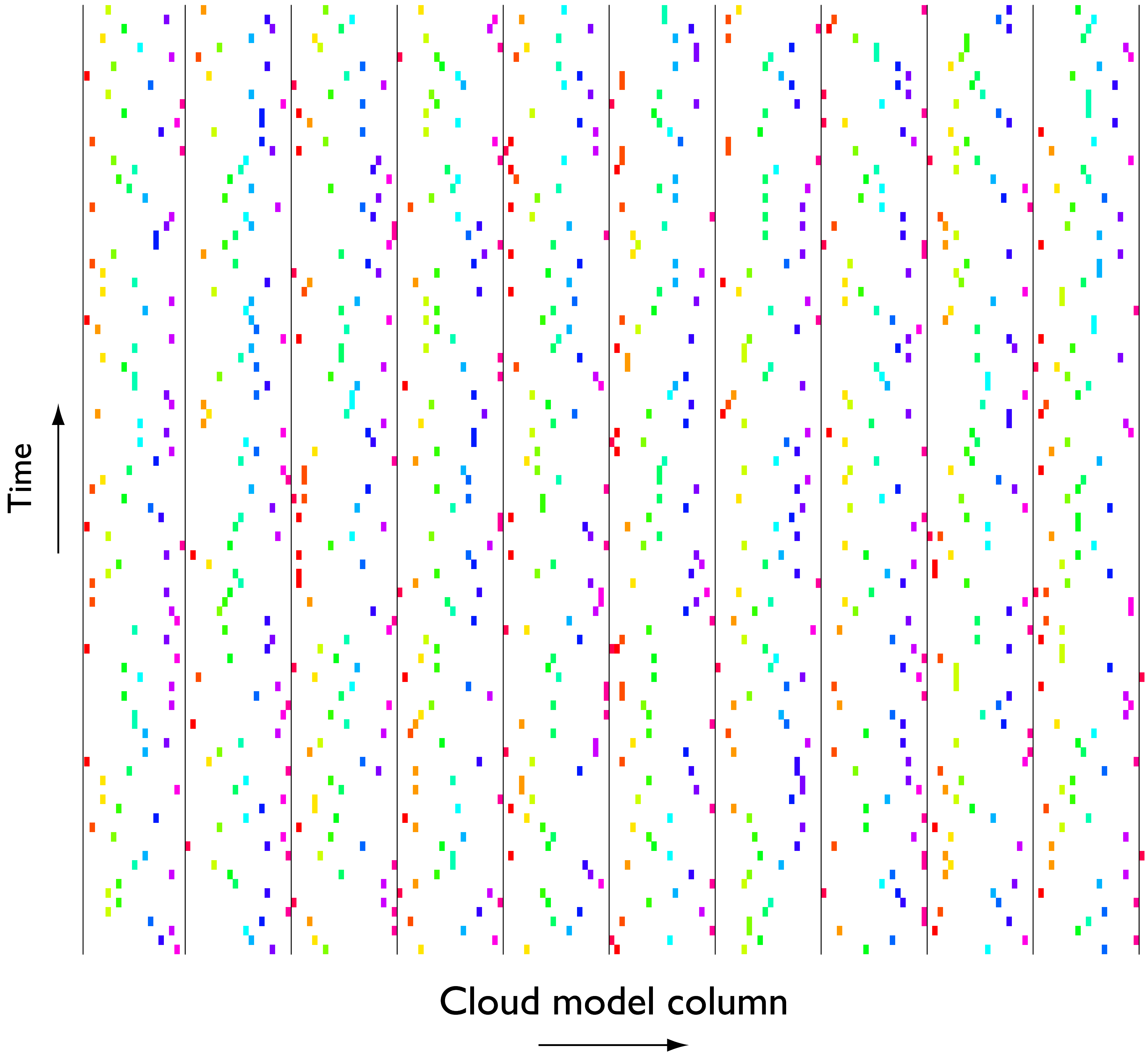
$$F(x, y, z, t) \approx c(x, y, t) \sum_{g}^{G} w_g F_g(x, y, z, t_{\mathrm{rad}}(t) \mid t_{\mathrm{rad}}(t) - t \leq \Delta t_{\mathrm{rad}})$$

focussing on spectrally-sparse, temporally-dense approximations

$$F(x, y, z, t) \approx \frac{G}{G'} \sum_{g(i \in [1..G])}^{G'} w_g F_g(s'; x, y, z, t)$$

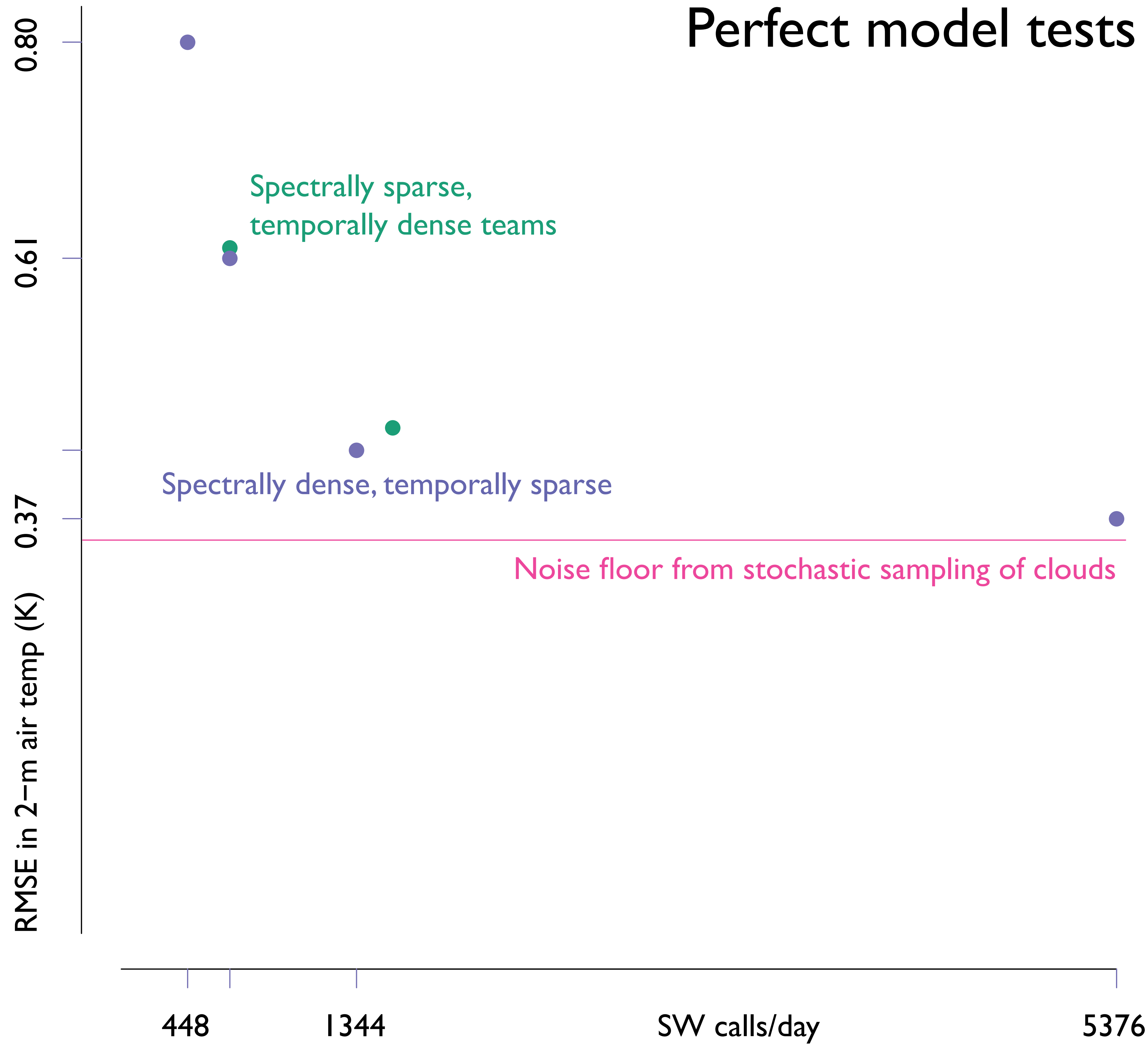
where subsets of spectral quadrate points are chosen to minimize error in surface fluxes


Time
Radiation time step
Frequency
Cloud model column



Time
Cloud model column

Perfect model tests



Pincus and Stevens, 2013, doi:10.1002/jame.20027

Radiation error in imperfect models

Utility of new approximations could come from

reduced errors and/or

reduced computational cost

We suspect that the error introduced by radiation/model coupling approximations is small relative to other sources

Experiments with ECMWF deterministic IFS

Spectral resolution T1279, 10 minute time step

Radiation computed at T511, 1 hour time step

Radiation scheme is PSrad, a vectorized reimplementation of existing scheme (RRTMG) that allows for spectral sampling

Short forecasts for two four month seasons (summer, winter)

Evaluation of 2 m air temperature against European station observations

Focus on times with greater errors (winter night, summer day)

Can forecasts be improved by changing radiation coupling?

I'll show

broadband radiation every time step (~6x)

broadband radiation every column (~6.2x)

30 spectral samples every time step, grid point (~4.5x)

15 spectral samples every time step, grid point (~2.3x)

30 spectral samples every 3rd step, grid point (~1.5x)

15 spectral samples every 3rd step, grid point (~0.75x)

11 spectral samples every step, grid point (~1.6x)

One piece of dirty laundry…

Computation times shown are theoretical

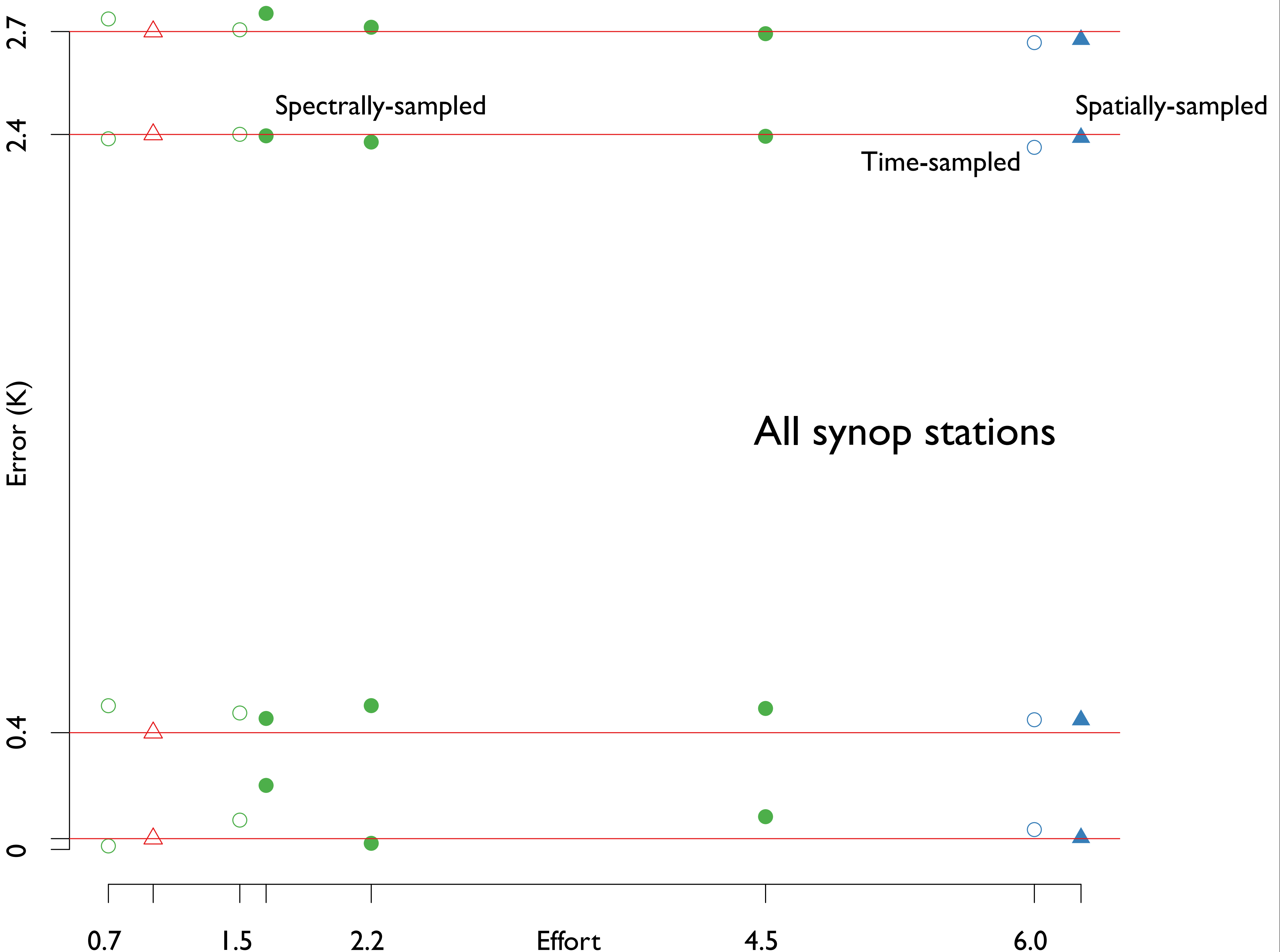
In practice, AER's implementation of gas optics is extremely inefficient when different columns use different spectral points

- Broadband integration with PSrad is ~2x slower than RRTMG

Calls to radiation incur overhead (units conversion, etc.)

- More frequent calls are also expensive

Making this idea practical will require substantial recoding


Spectrally-sampled
Spatially-sampled
Time-sampled
All synop stations
Error (K)
2.7
2.4
0.4
0
0.7
1.5
2.2
Effort
4.5
6.0

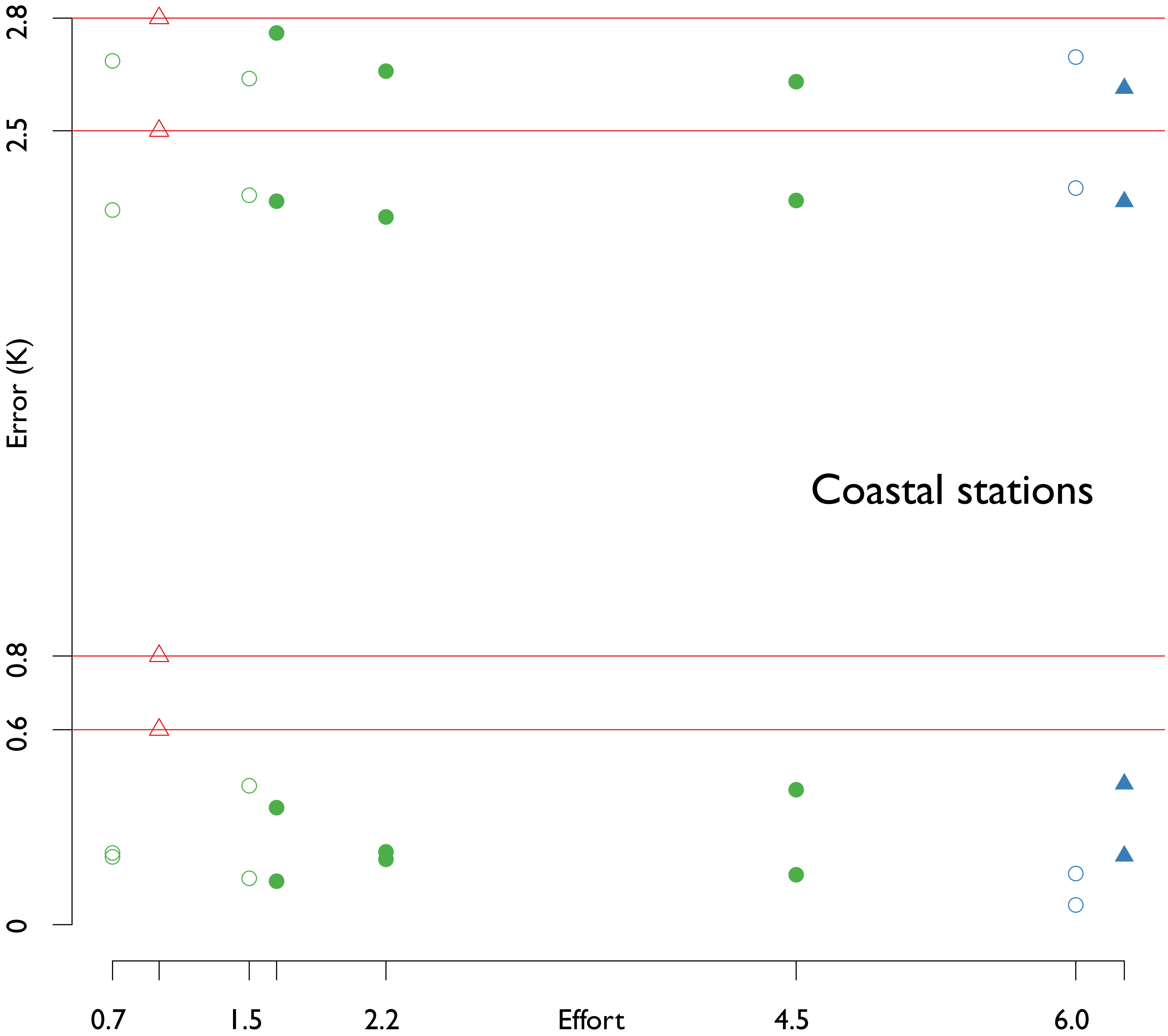
Searching for a signal

Radiation affects 2 m air temperature through skin temperature

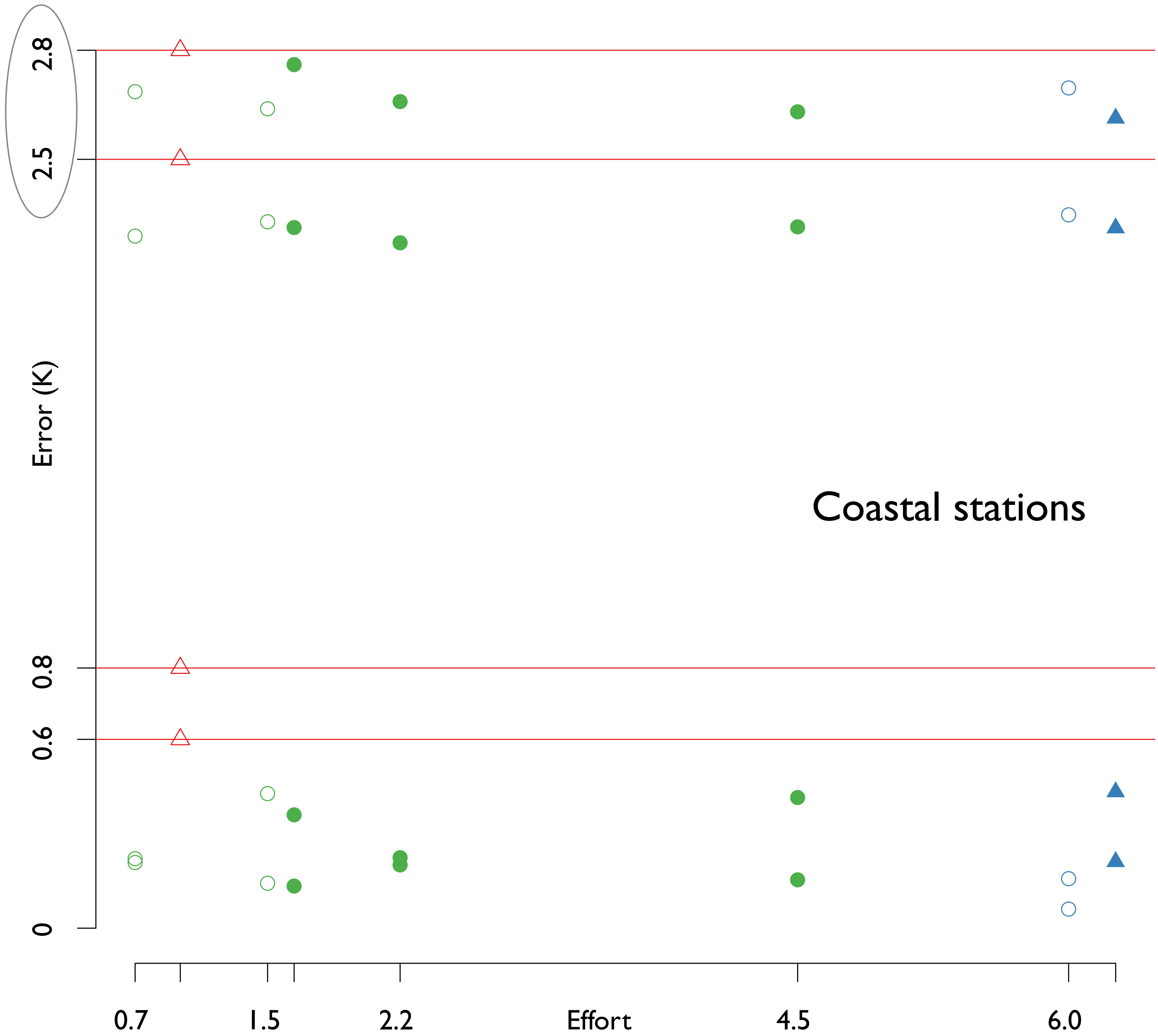
itself a function of heat capacity, emissivity, and hence

land-sea mask

We identify the subset of ~75 synop stations in which interpolation to the radiation grid changes the land-sea mask



Coastal stations
Error (K)
Effort
2.8
2.5
0.8
0.6
0
0.7
1.5
2.2
4.5
6.0



2.8
2.5
Error (K)
0.8
0.6
0
Coastal stations
0.7
1.5
2.2
Effort
4.5
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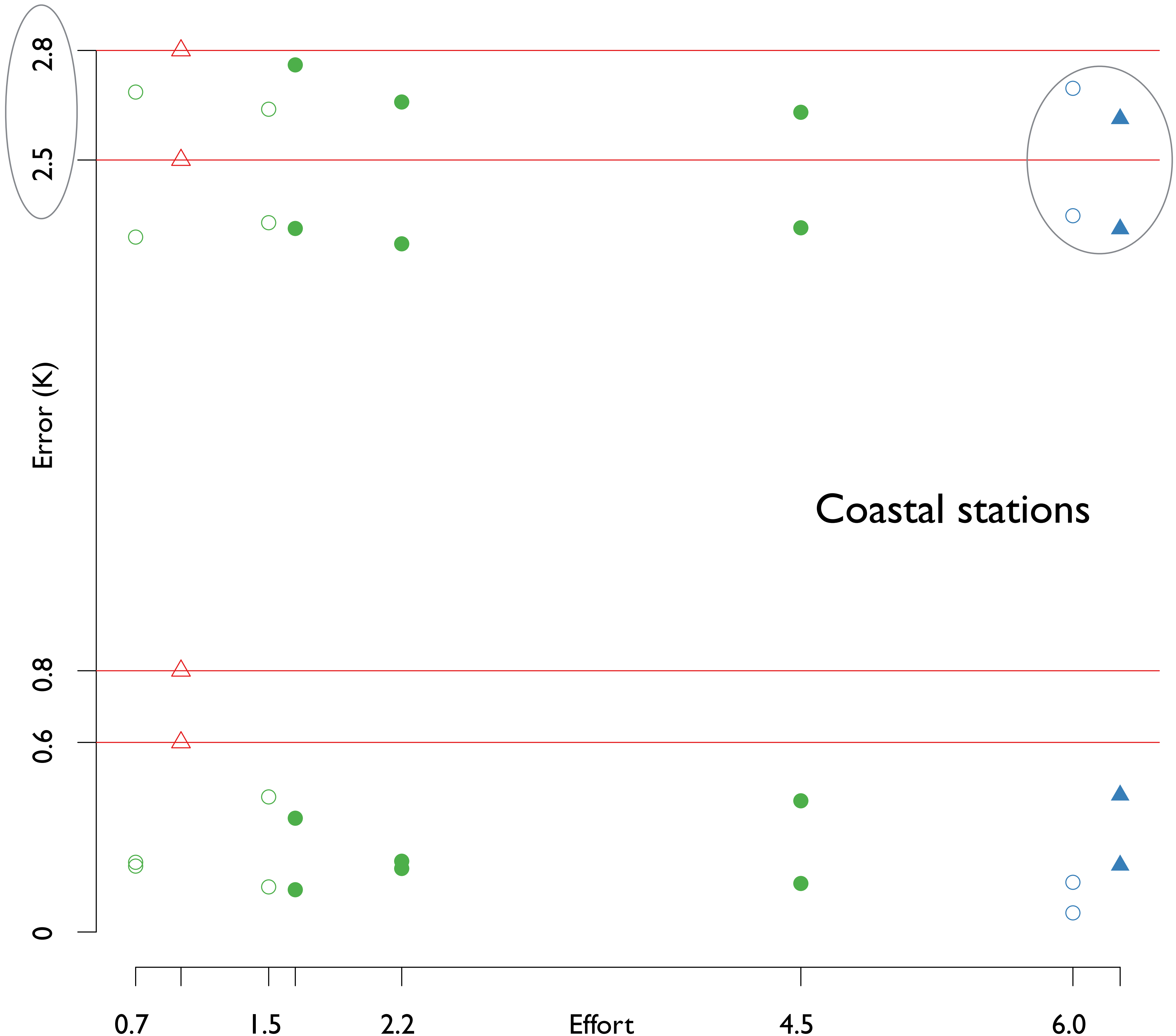

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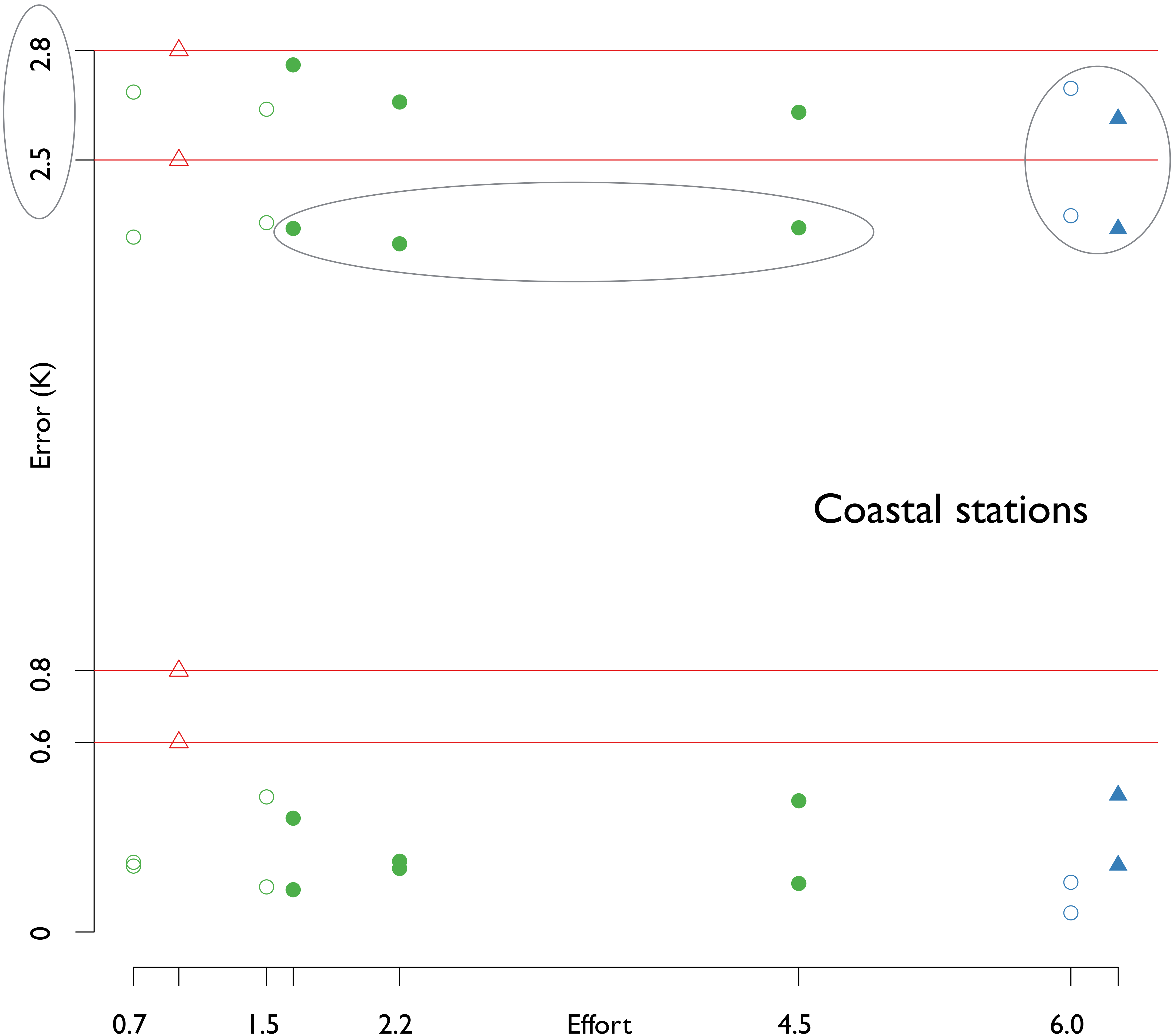

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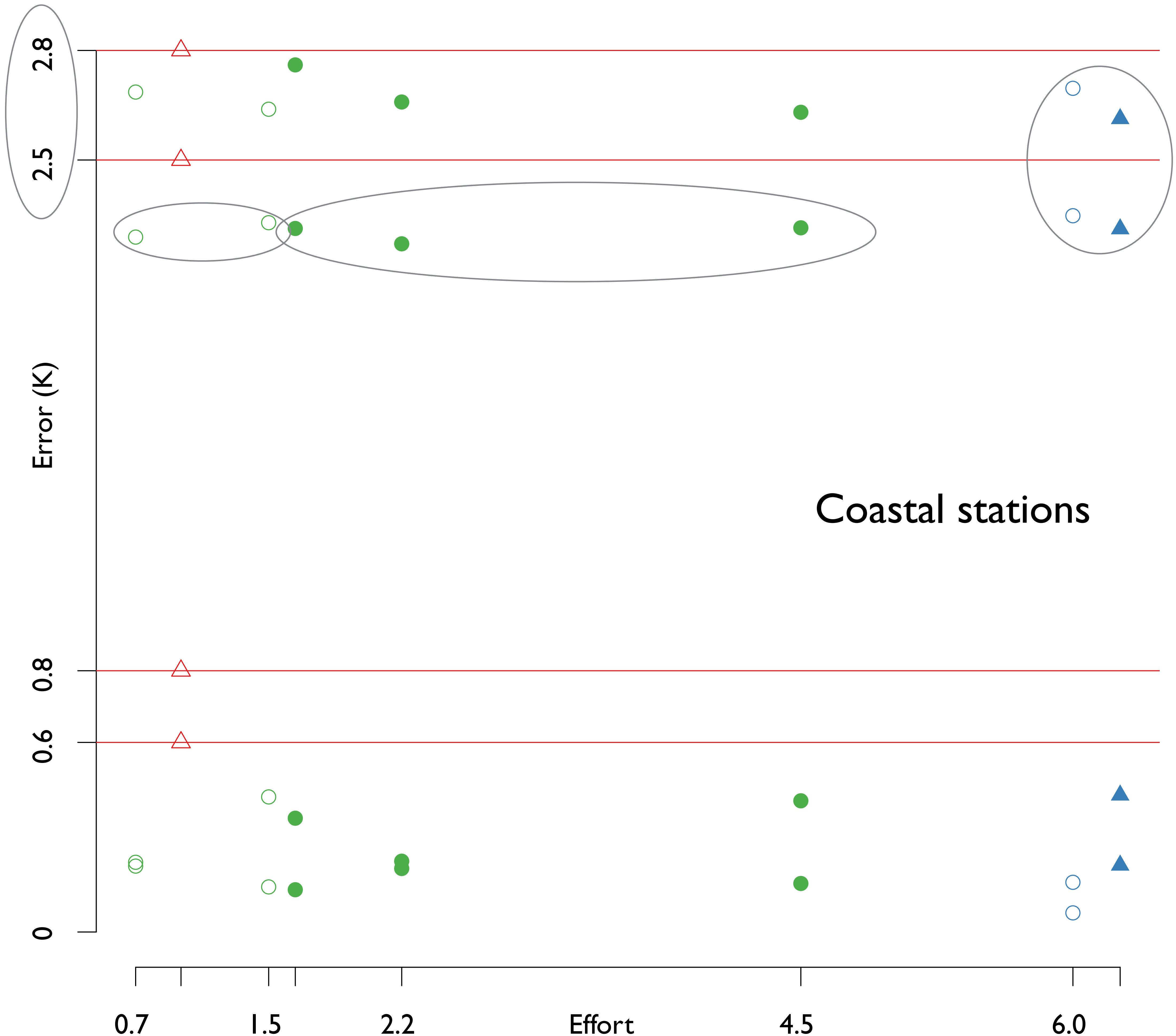
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4.5
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Initial assessment for numerical weather prediction

Improving radiation/physics coupling doesn't make short-term forecasts appreciably better…

…because radiation (including sparse-in-time approximation) isn't a leading source of error most of the time

Spectral sampling may achieve much of the (limited) benefit of more frequent or more spatially-dense radiation calculations

Limited temporal sampling does not degrade spectrally-sampled calculations

Please take both conclusions with a big grain of salt

Sensitivity in ECHAM 6.2 (a cautionary tale)

ECHAM 6.2 replaced RRTMG with PSrad but is used to make broadband calculations every 2 hours (vs 10 min physics step)

The other change addressed an inconsistency in the cloud scheme

- Many more low clouds appeared, especially in the Tropics

Increased cloud feedbacks contributed to large reductions in total feedback (from -1.65 to -0.85 $W\text{-}m^{-2}/K$)

Reference runs reproduce this feedback

Spectrally-sampled runs (11 samples) do not

- feedback increases to -1.10 $W\text{-}m^{-2}/K$ due to clouds

This sensitivity is undesirable

The utility of spectral sampling in global models

Temporally-dense, spatially-sparse coupling of radiation is more complicated in global models than in LES

- For the moment results are situation dependent

Book-keeping may be the strongest motivation

Implementation needs refinement

- Watch the skies for RRTMGP