Reimagining Radiation in Earth System Models

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Radiation in models of the earth system

Radiation is the fuel for the atmospheric heat engine

The radiation problem is extremely well-understood at a fundamental level.
Radiation for ESMs is convergent, making a series of well-defined approximations to a benchmark approach

Machine learning might increase computational speed; this would be analogous to using statistical fits for advection.

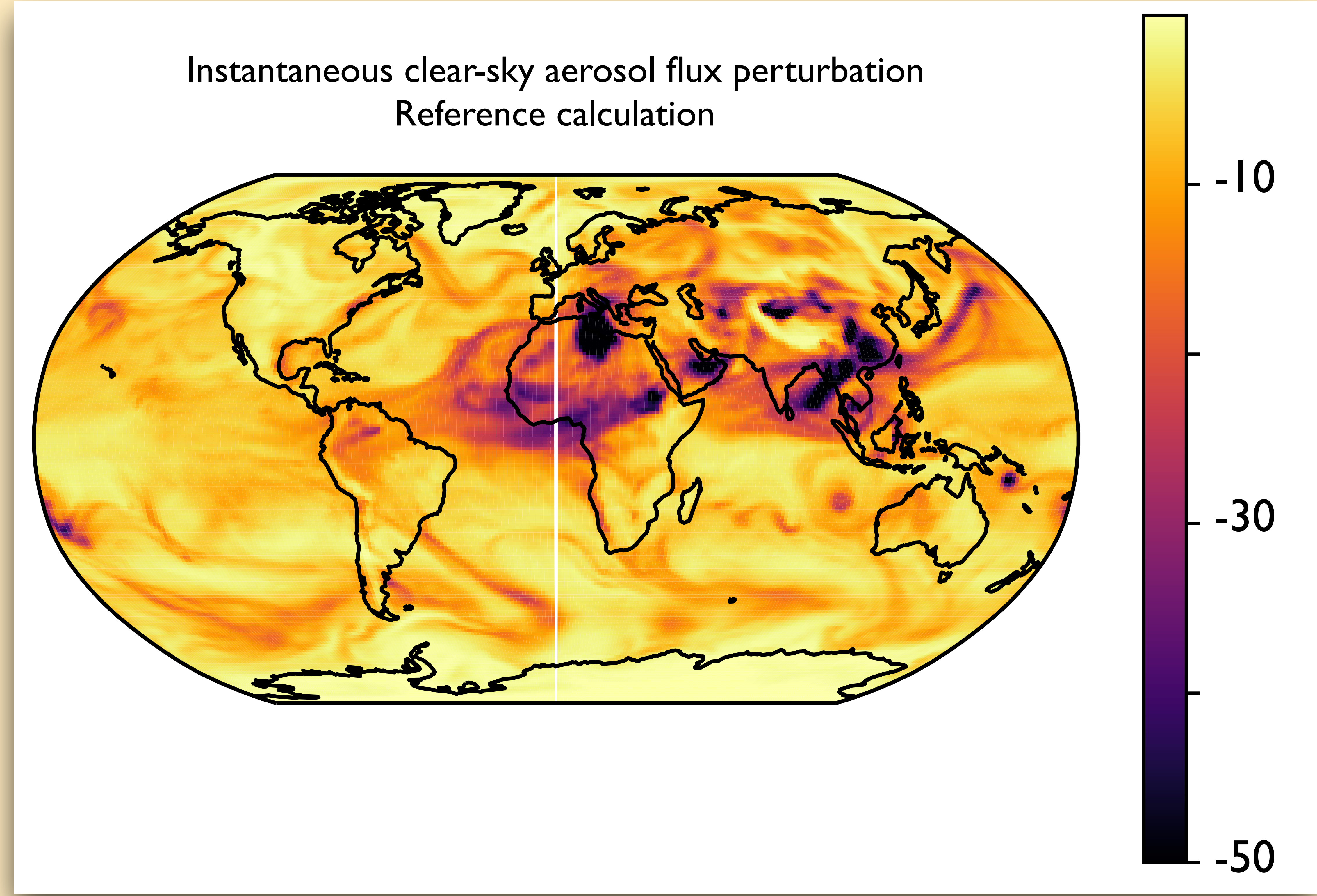
Radiation in any domain (atmosphere, ocean, land surface) requires its own coupling: between the physical state of the earth system and its optical description

Errors in radiative fluxes arise from some combination of

- errors in state
- incorrect coupling of physical and radiative states
- approximation errors

No bonus points for guess which one dominates

Approximation error is well-characterized…



Freidenreich, Jones, Paynter: RFMIP Aerosol IRF

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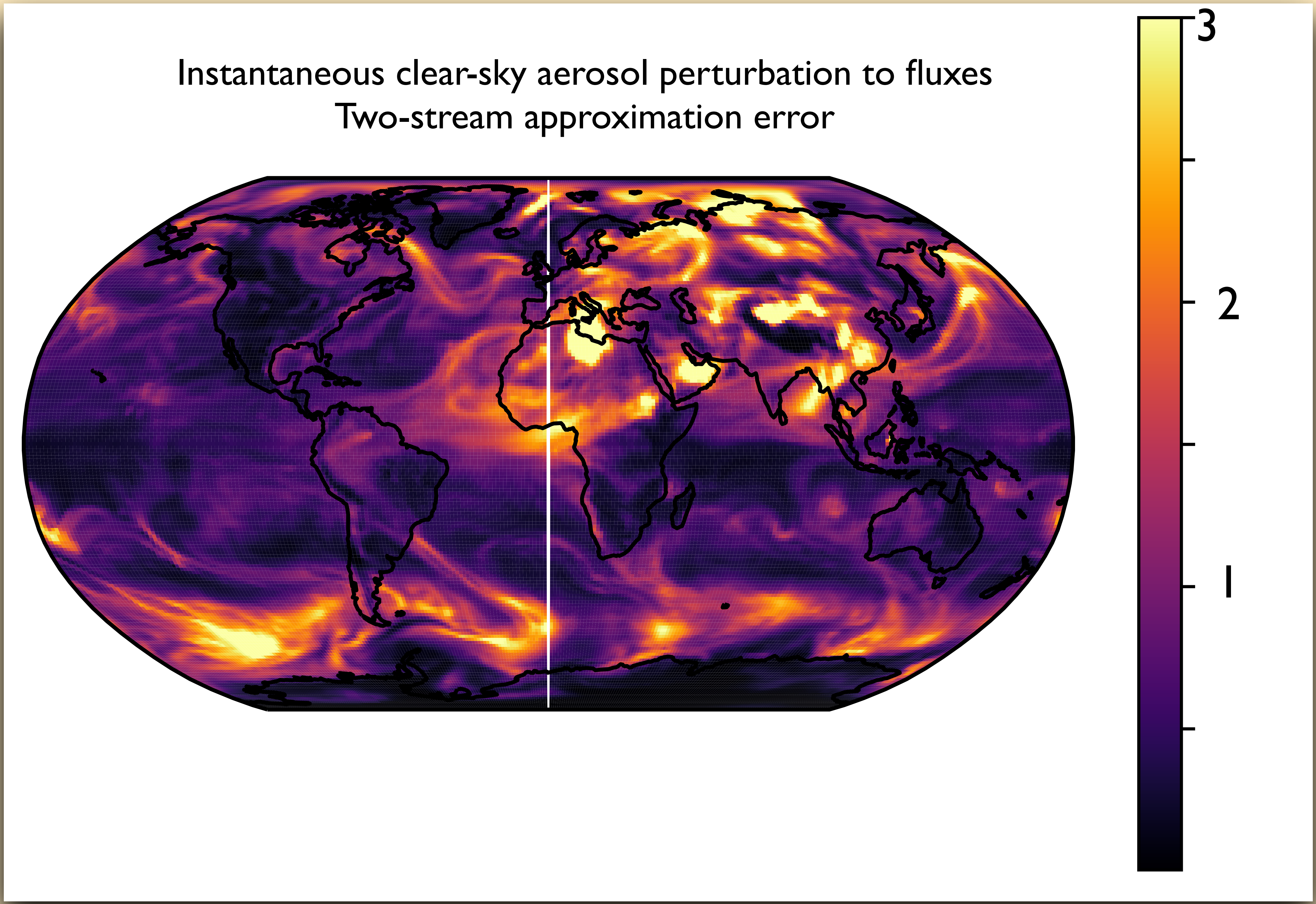

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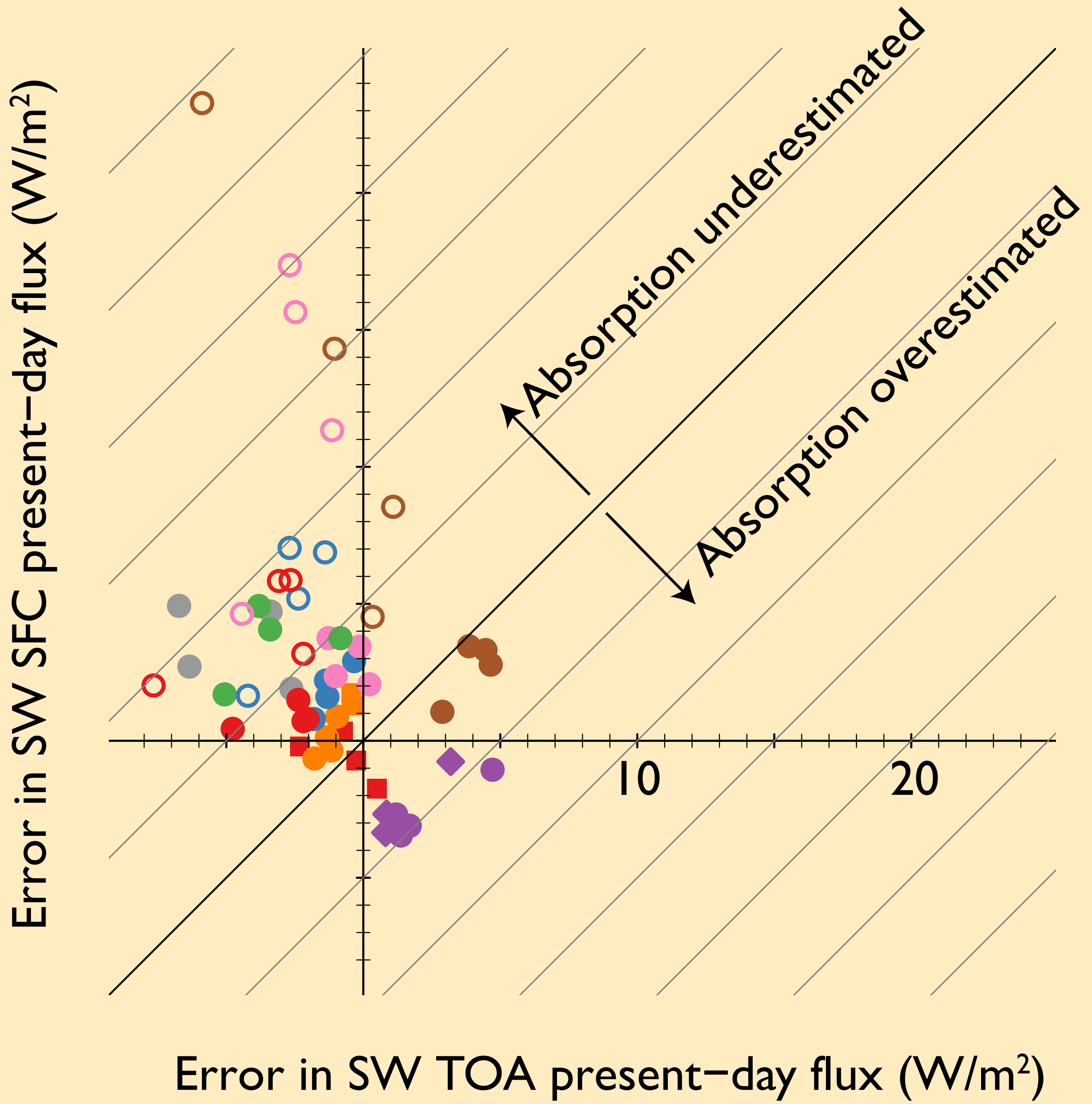
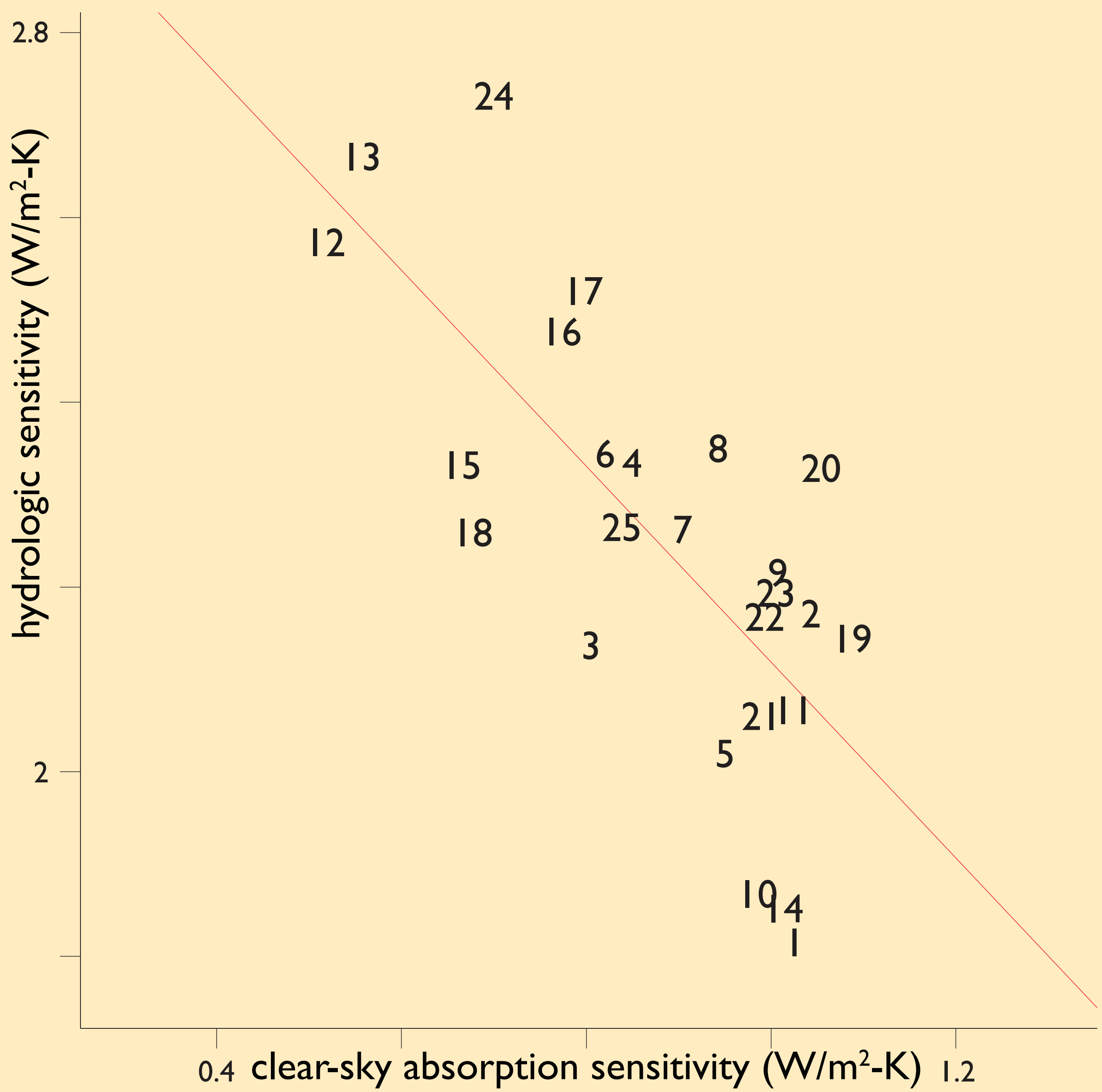
… but new information can be hard to incorporate





Pincus et al. 2015:10.1002/2015GL064291

after DeAngelis et al.:10.1038/nature15770

The future is unknowable

"How would one design an earth system model if one had complete freedom?"

…given that it's nearly impossible to know what people will want, or how code will be most efficiently written on novel computing architectures…

I've just been through this exercise in developing a new radiation code:
RTE+RRTMGP, the successor to RRTMG.

We built a radiation toolbox serving a range of needs

on-line use in an ESM etc.
off-line use for interpreting ESMs e.g. making radiative kernels
exploring ideas

We are trying to balance accuracy, efficiency, and flexibility

Designing a radiation library

Strict separation of concerns: gas optics, condensate optics, transport, reduction

RRTMGP provide gas optics, RTE transport and basic reduction

Data and code are disjoint. Data can be targeted to applications

Multiple columns: exposes more parallelism, matches problem size to architecture

Small (~120 lines), high-efficiency kernels with language-interoperable interfaces: accessible, replaceable, traceable (because unit testing)

The underlying algorithms have been used in the community for 20+ years

Accommodating a multiplicity of needs

Users have more freedom/responsibility in coupling than usual: by requiring radiative inputs we require users to be explicit about microphysics, macrophysics, and overlap.

Kernels are bound together with classes (currently Fortran 2003). Classes

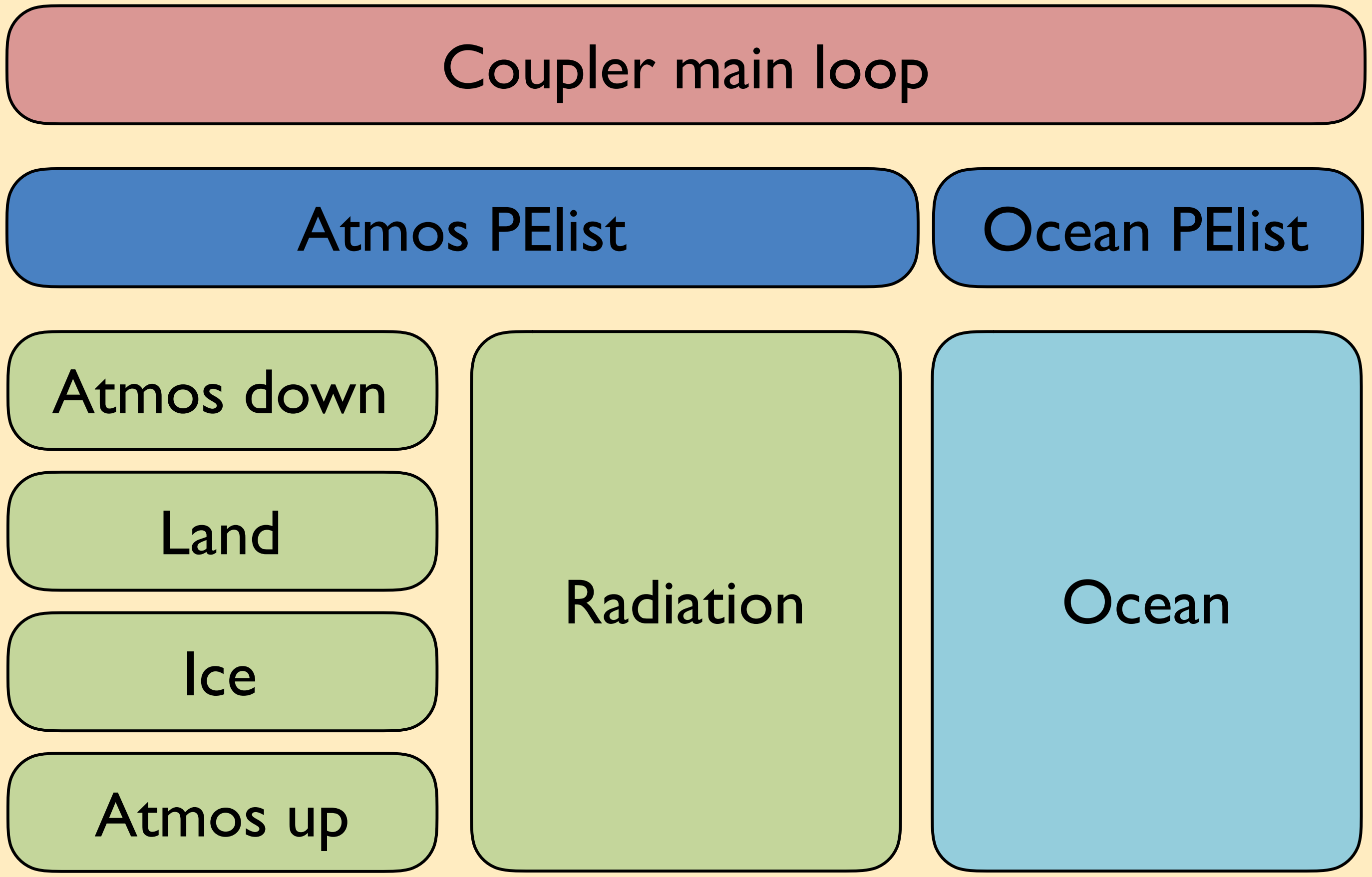
- bundle related data, code
- hide unimportant details
- provide facilities (e.g. adding clouds to clear-sky)
- increase efficiency by minimizing data transfer

We will see how much people hate the classes. They do provide a way to safely provide access to fine-grained calculations without moving lots of data around.

This reduces the urgency of the "trade-offs between modularity of ESM components and integration of components with each other"

Reimagining the coupling of radiation (i)

Radiation is a significant part of the computational budget of most earth system models. This has inspired some creative thinking.

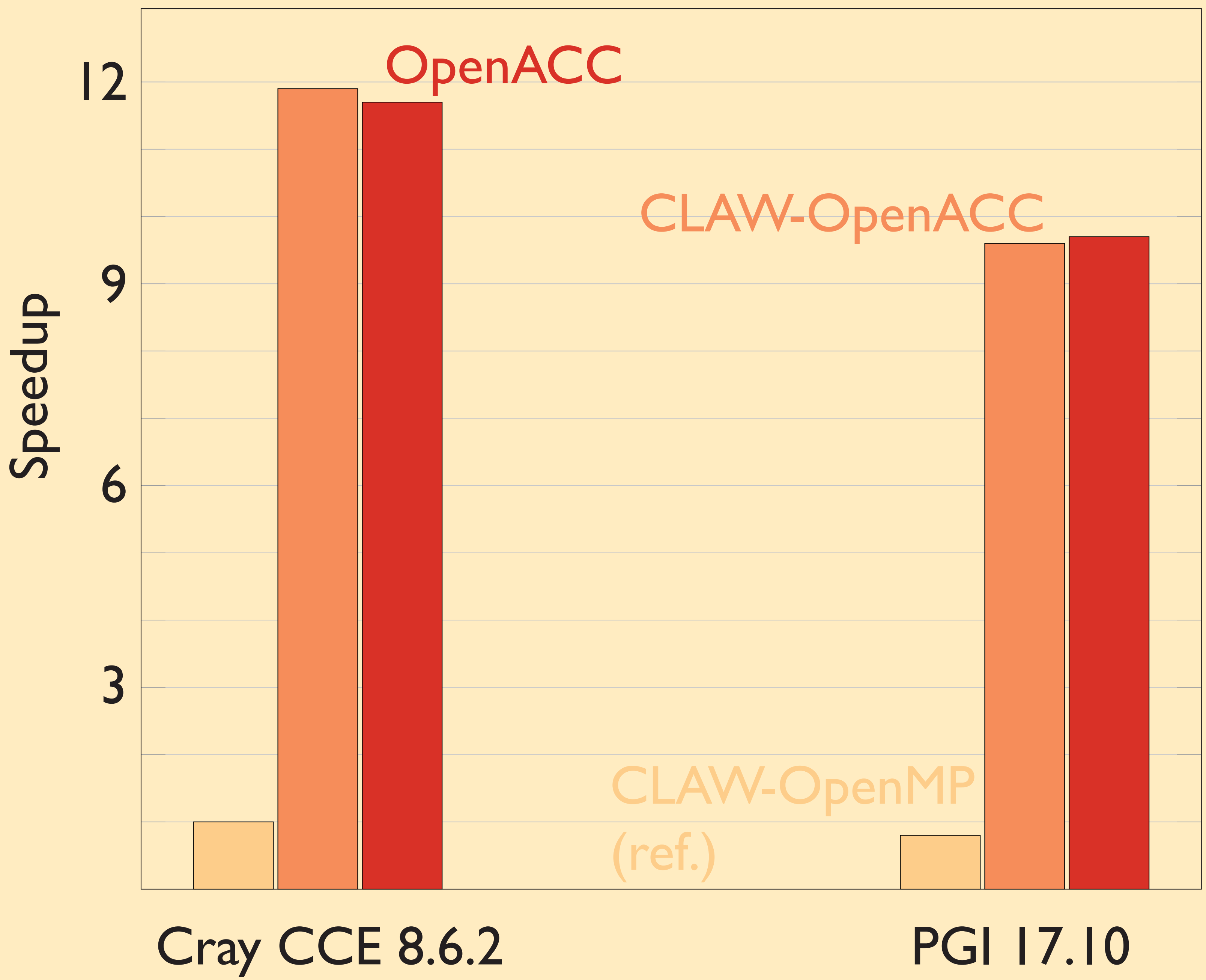


But as long we we're shipping the radiation problem off to its own computational domain…

after V. Balaji et al., 2016: 10.5194/gmd-9-3605-2016

Exploiting agility

Most radiative transfer calculations are atomic; the rest have a dependence only in one dimension. This makes them good candidates for new architectures.



Valentin Clément, ETH (PASC 18)

RTE focuses on the radiative transfer problem: inputs are described in purely optical terms.

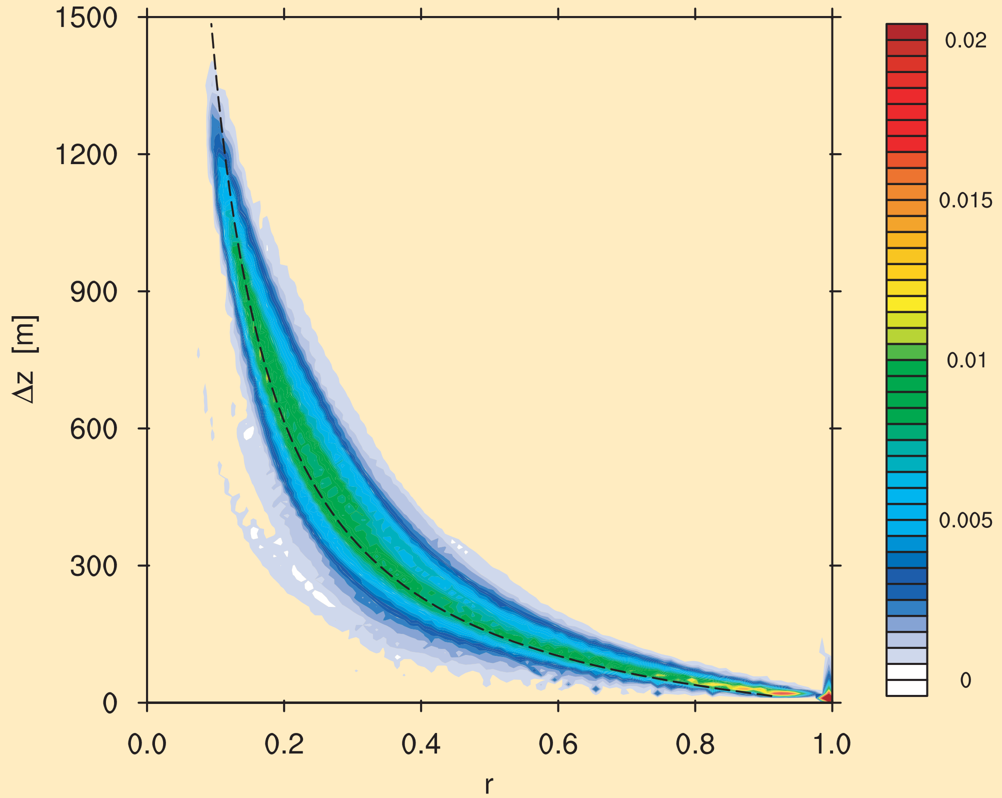
This punts a range of translation issues to users to address.

Example: "overlap" describing the vertical structure of clouds can significantly impact radiative fluxes, e.g

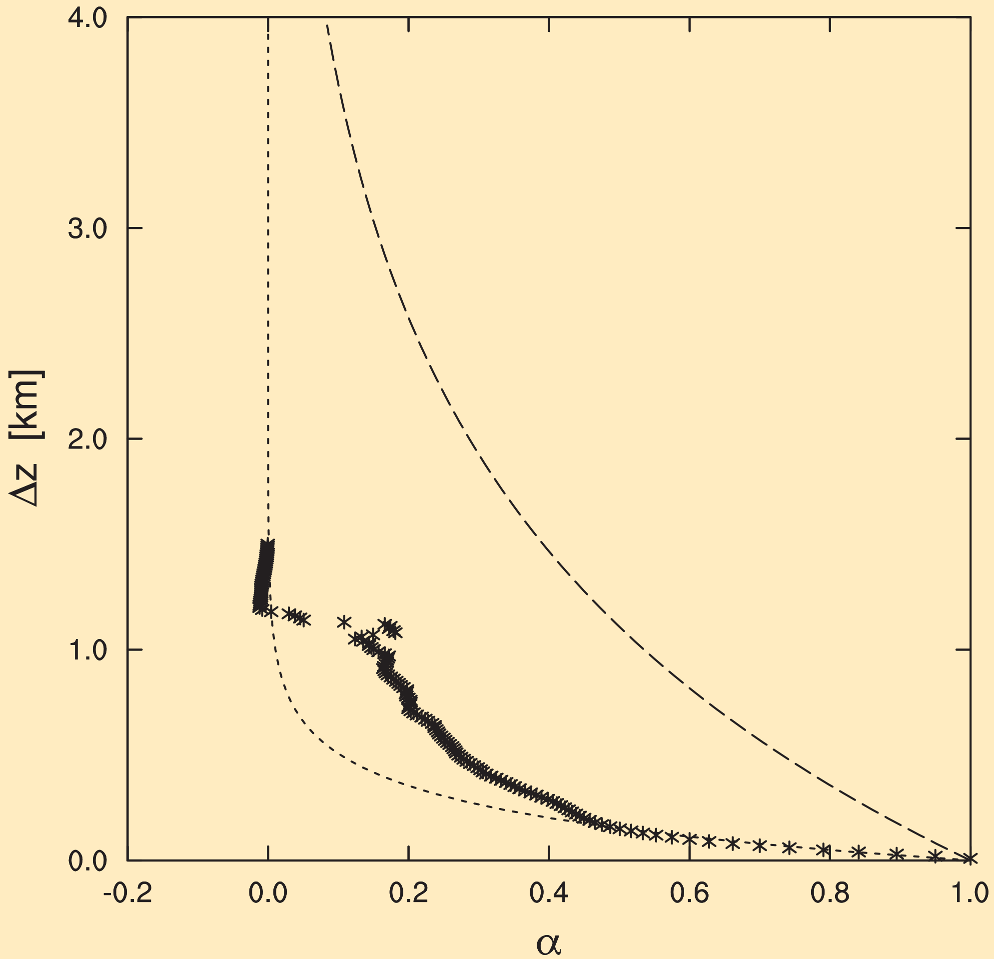
	1 km	2 km	max-ran	max
OLR	0.8	1.2	2.1	2.5
Reflected solar	-5.4	-7.4	-9.1	-11.9
Net radiation	4.6	6.2	7.0	9.4

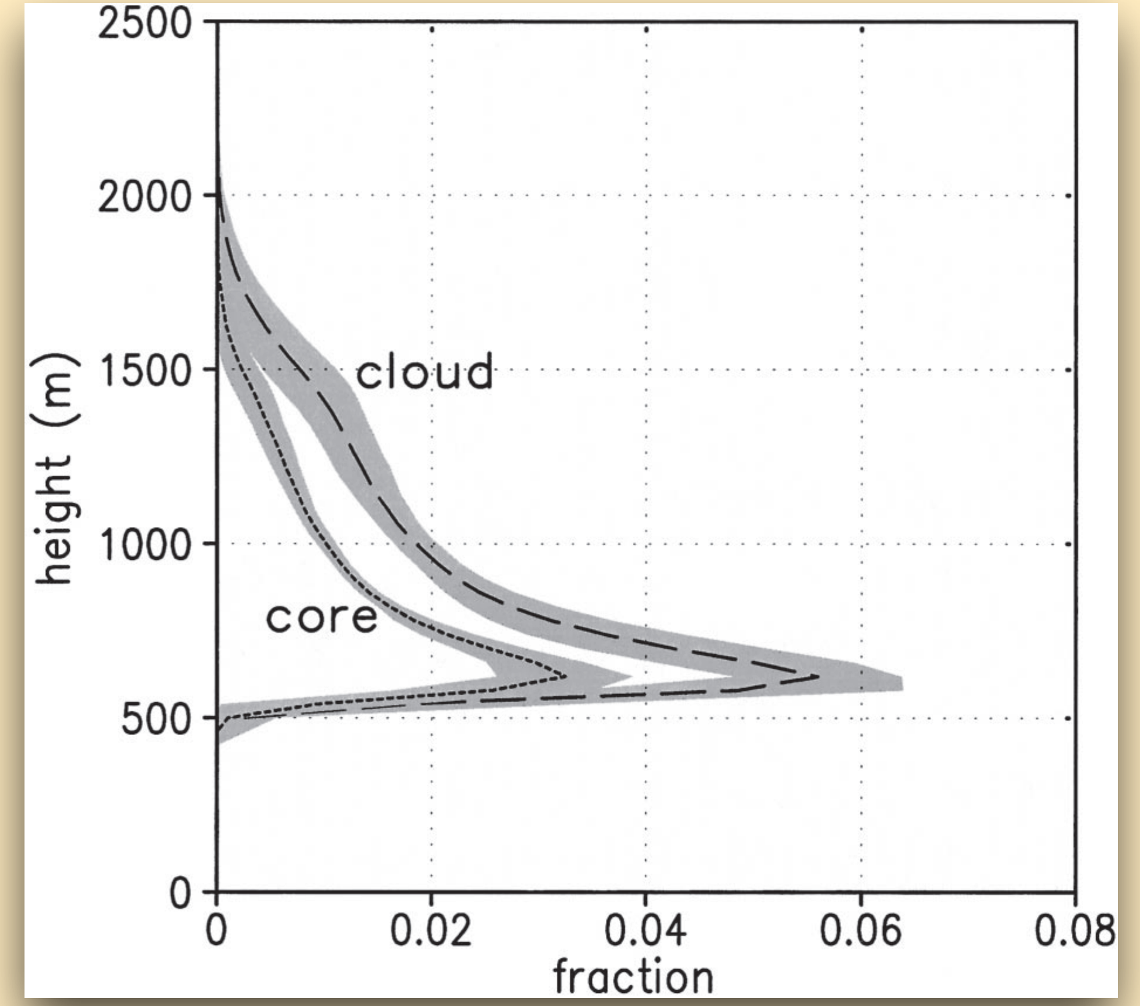
See also: subgrid inhomogeneity

Pincus et al. 2006: 10.1175/MWR3257.1



b)





Neggers et al. 2011: 10.1029/2011JD015650

Siebesma et al. 2003:
10.1175/1520-0469(2003)60<1201:ALESIS>2.0.CO;2

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The problem is not well-posed: this is uncertainty (or ambiguity)

Pincus et al. 2006: 10.1175/MWR3257.1

The future is high-resolution: clouds

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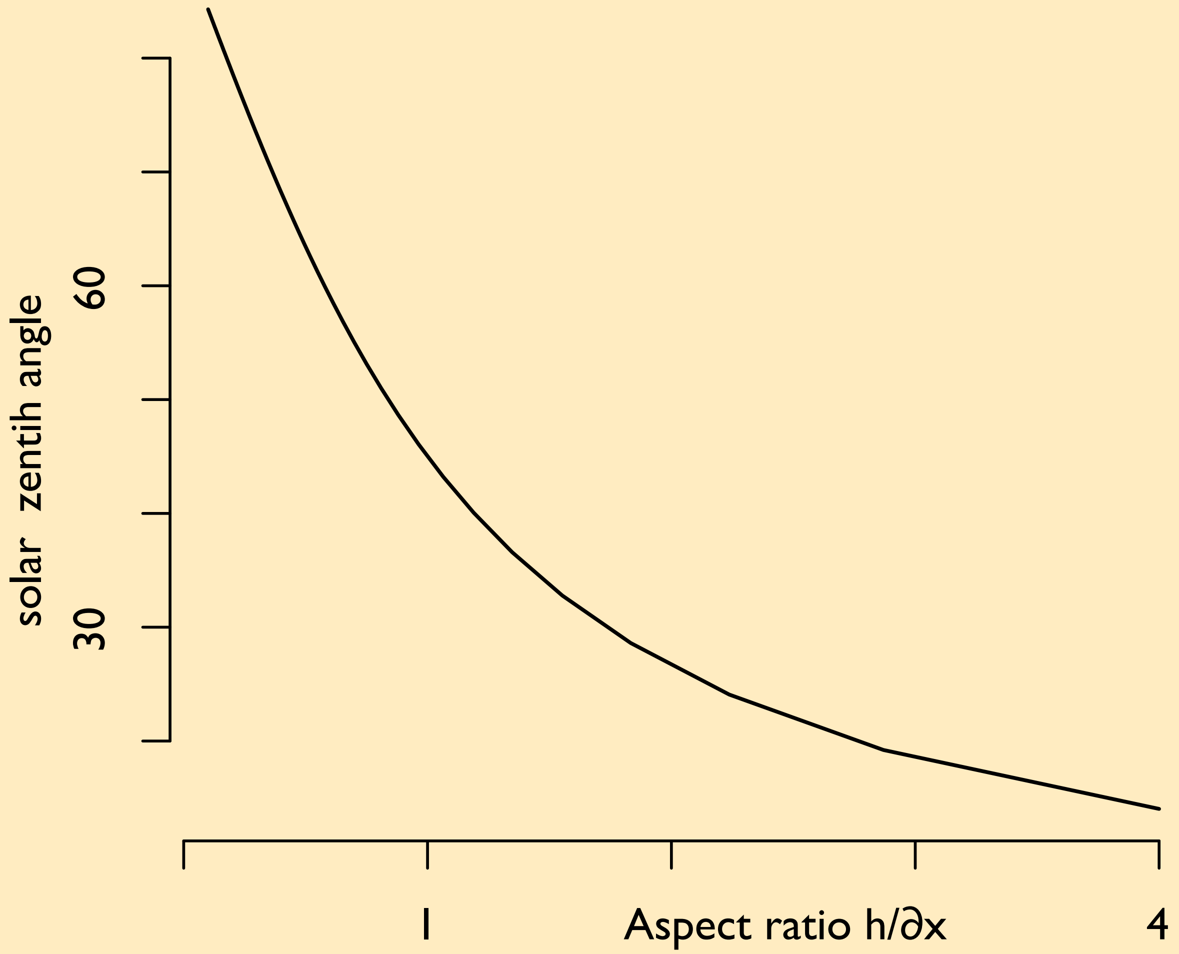
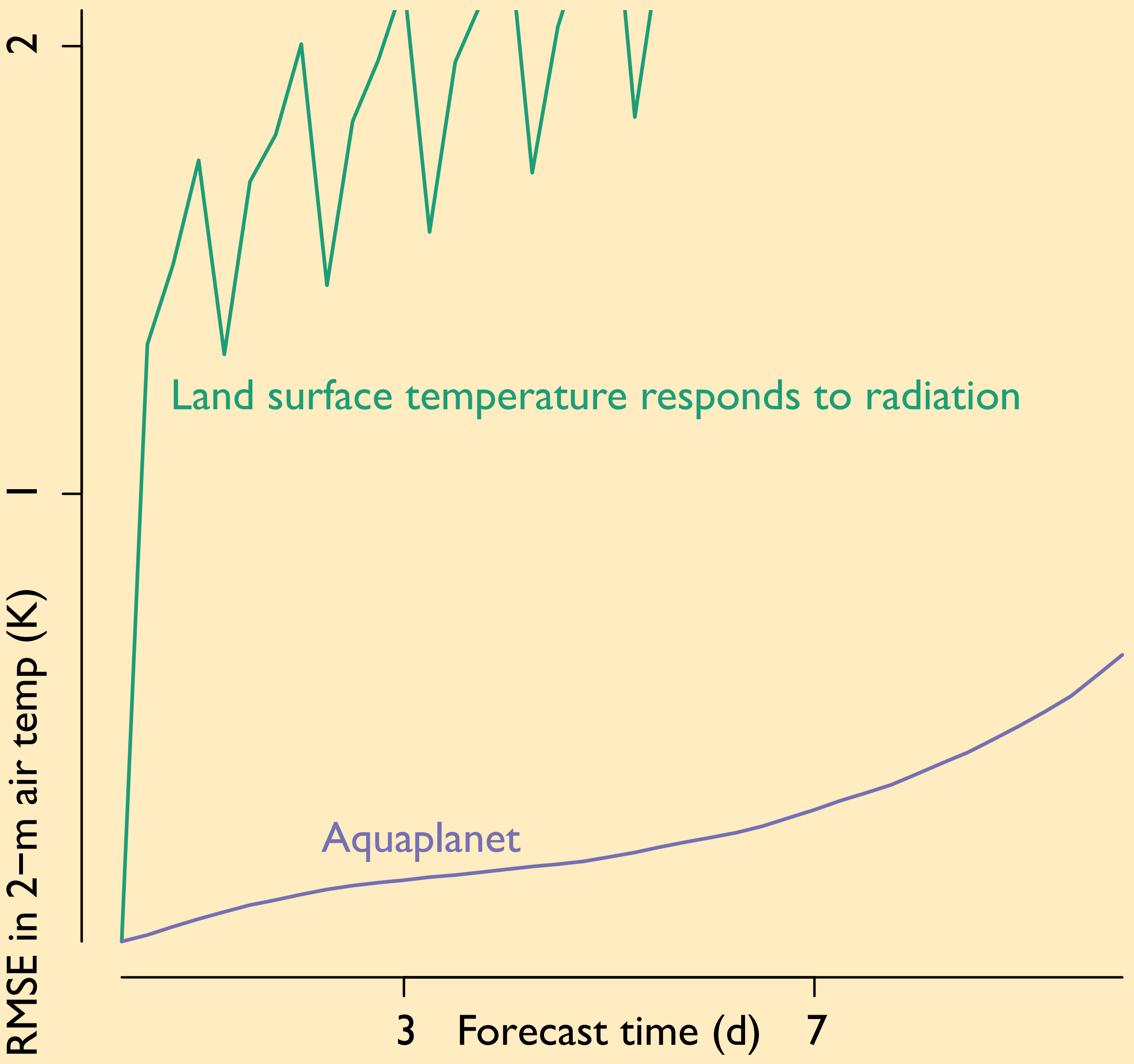
The largest impacts are on the direct solar beam. This can be treated simply but requires inter-column communication

It's most relevant over land surfaces





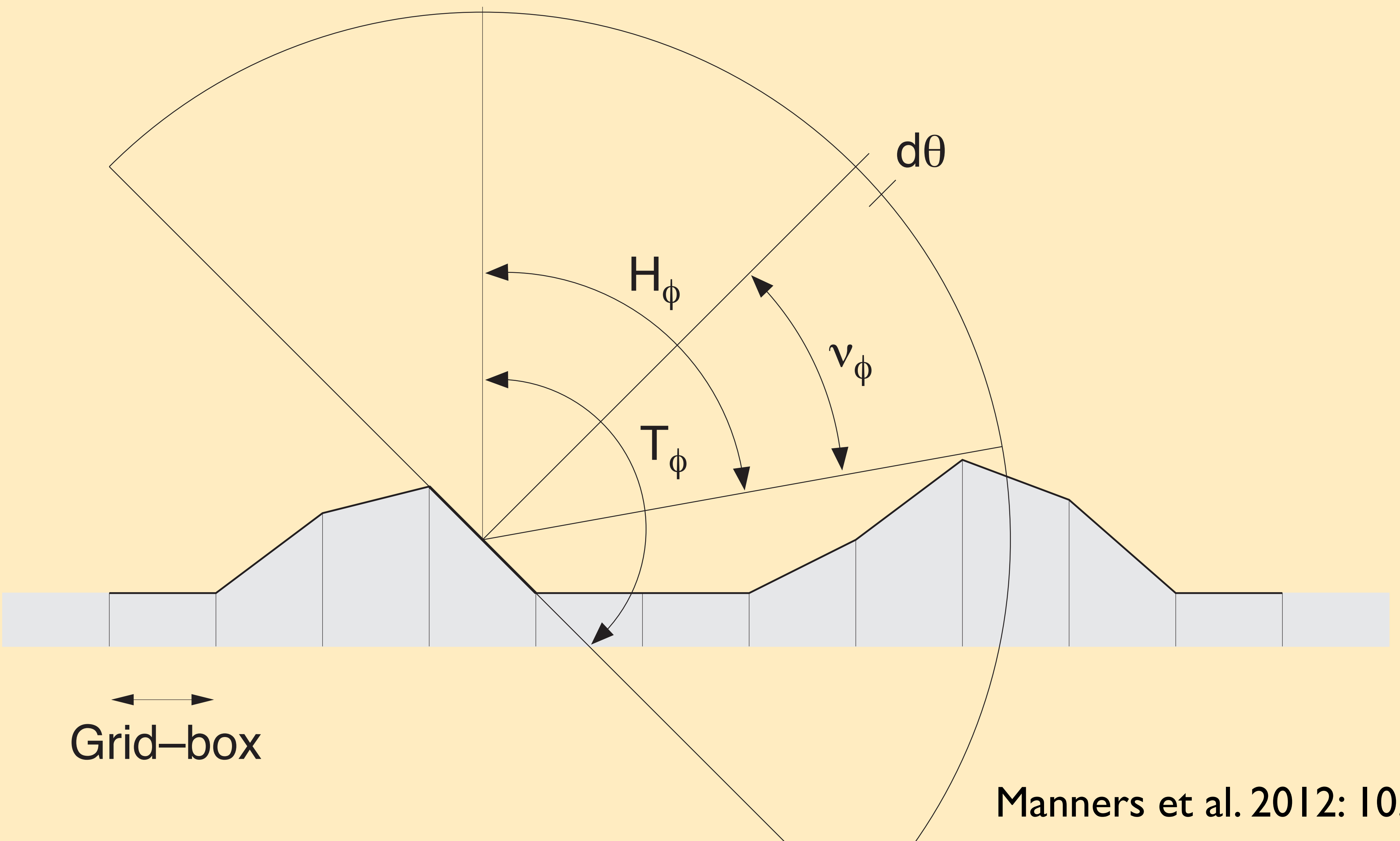
Pincus and Stevens 2013:10.1002/jame.20027

The future is high-resolution: terrain

… and speaking of rocks, topography impacts radiation by affecting

- how much of the sky can be seen
- the angle at which sunlight strikes the ground

These impacts are more important because they persist but are calculable offline

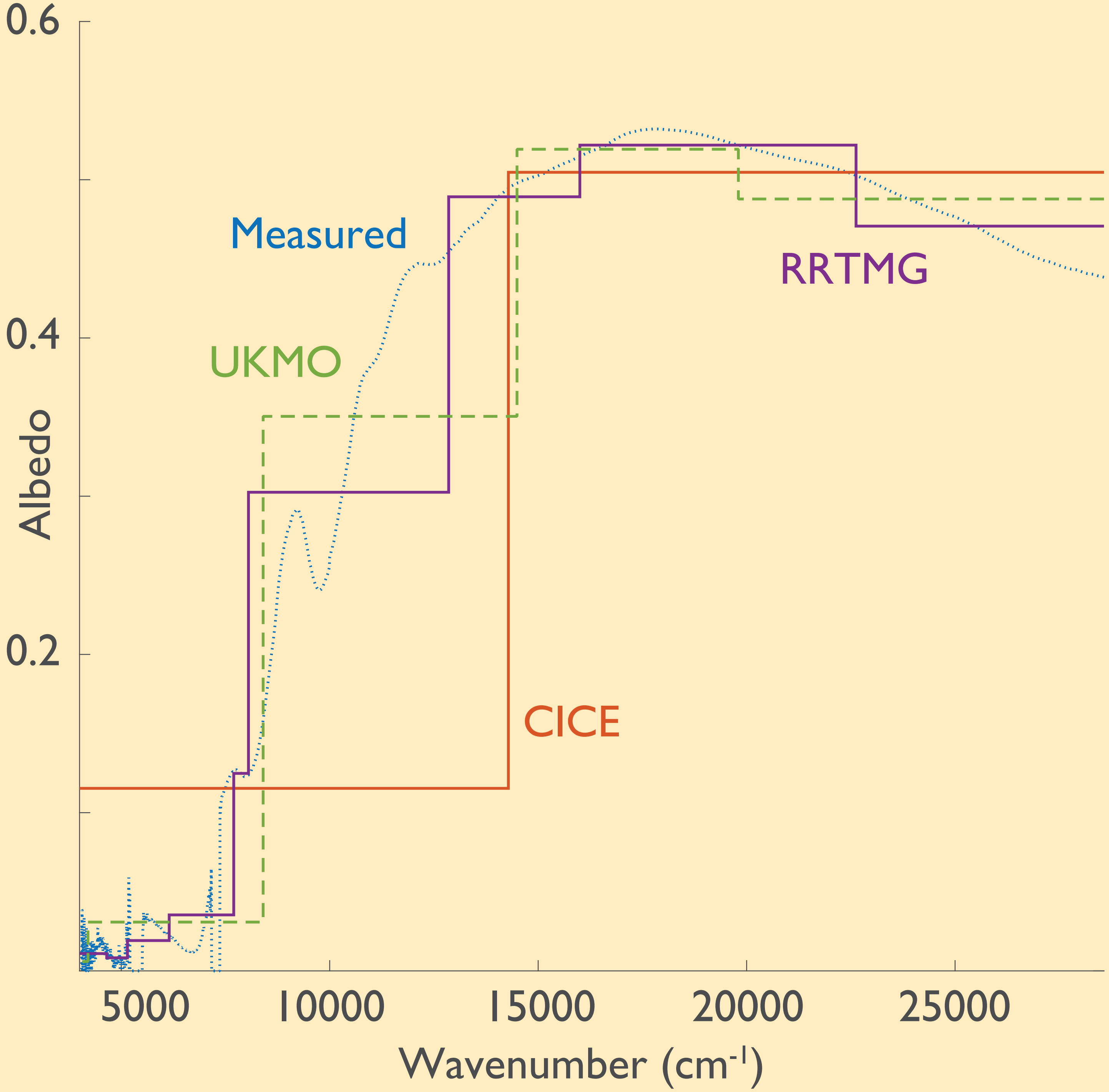


Manners et al. 2012: 10.1002/qj.956

The future is coupled modeling

Radiation is treated as part of each domain's submodel

communication through coupler encourages brevity
loss of spectral detail implicated in sea surface temperature biases

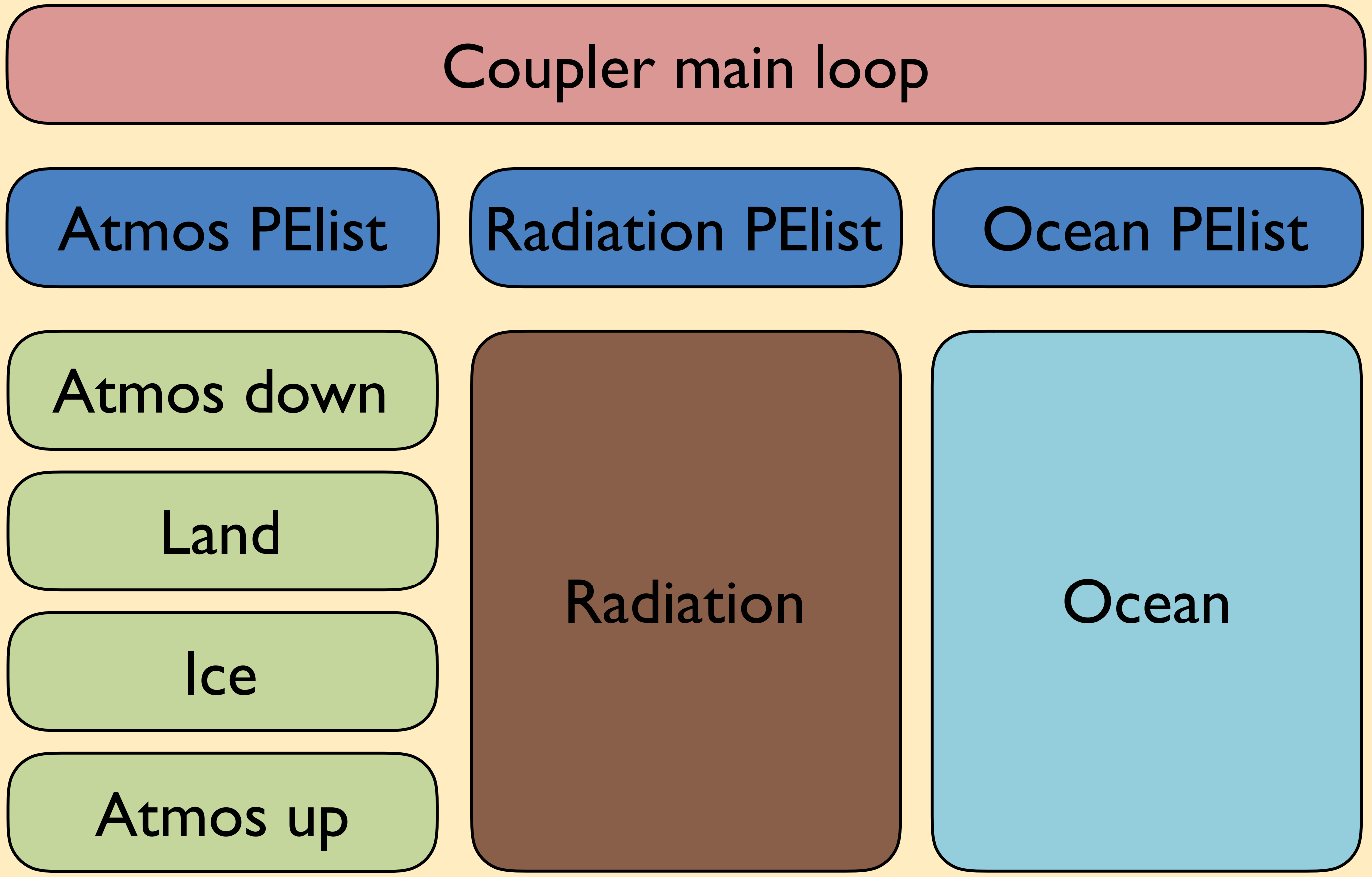


Andrew Roberts, NPS

Reimagining the coupling of radiation (ii)

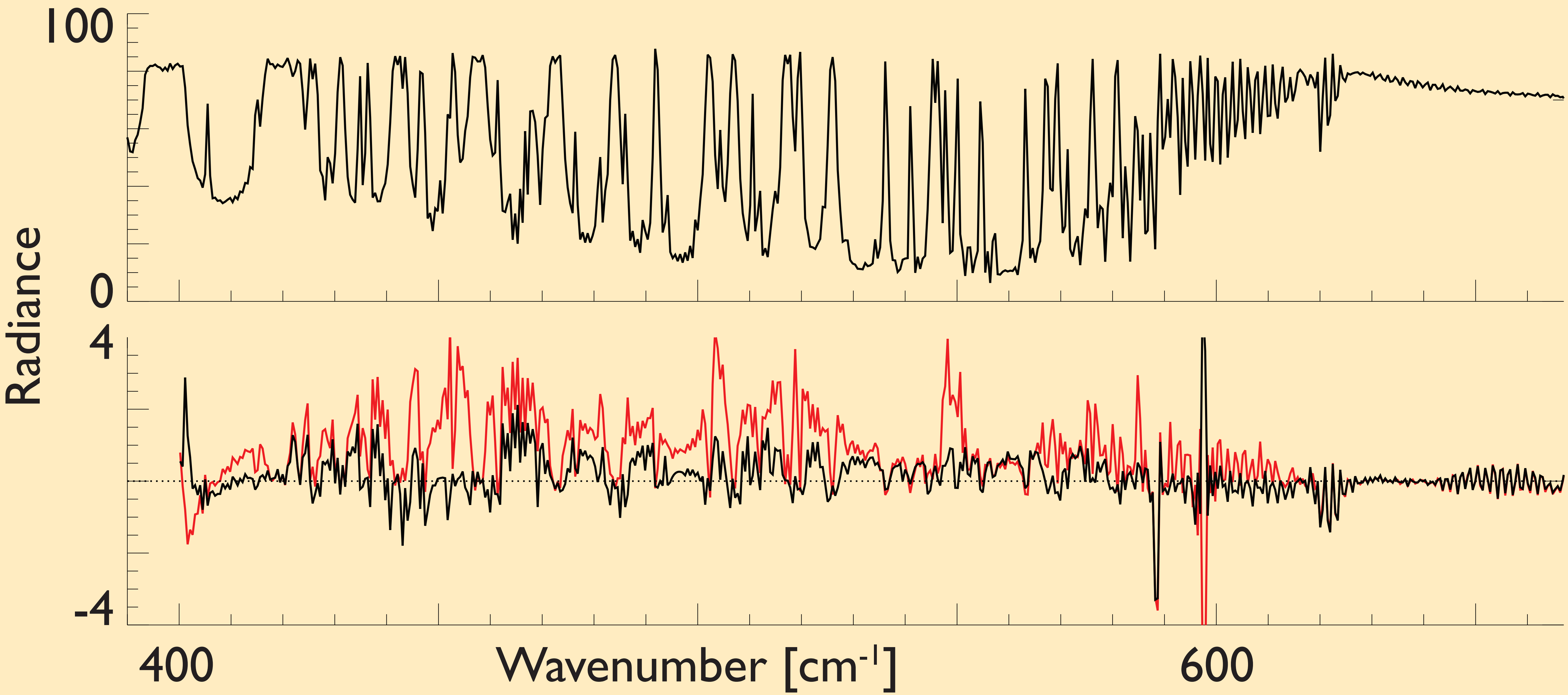
Why not consider radiation its own domain?

Communicate compact state information
expand to account for spectral detail
calculate, reduce, and communicate compact profiles



In a perfect world (i)

Basic spectroscopic research is the foundation of ESM modeling and assimilation of satellite radiances. In a perfect world this work would be better coordinated and have more consistent funding



after Delamere et al. 2010:10.1029/2009JD012968

In a perfect world (ii)

… we would exploit flexibility

The UKMO radiation model provides some support for user-defined *k*-distributions.

There is a community need for general tools that build gas optics parameterizations from line-by-line simulations with user control over

- the sets of atmospheric conditions being tuned for
- spectral partitioning
- cost functions
- …