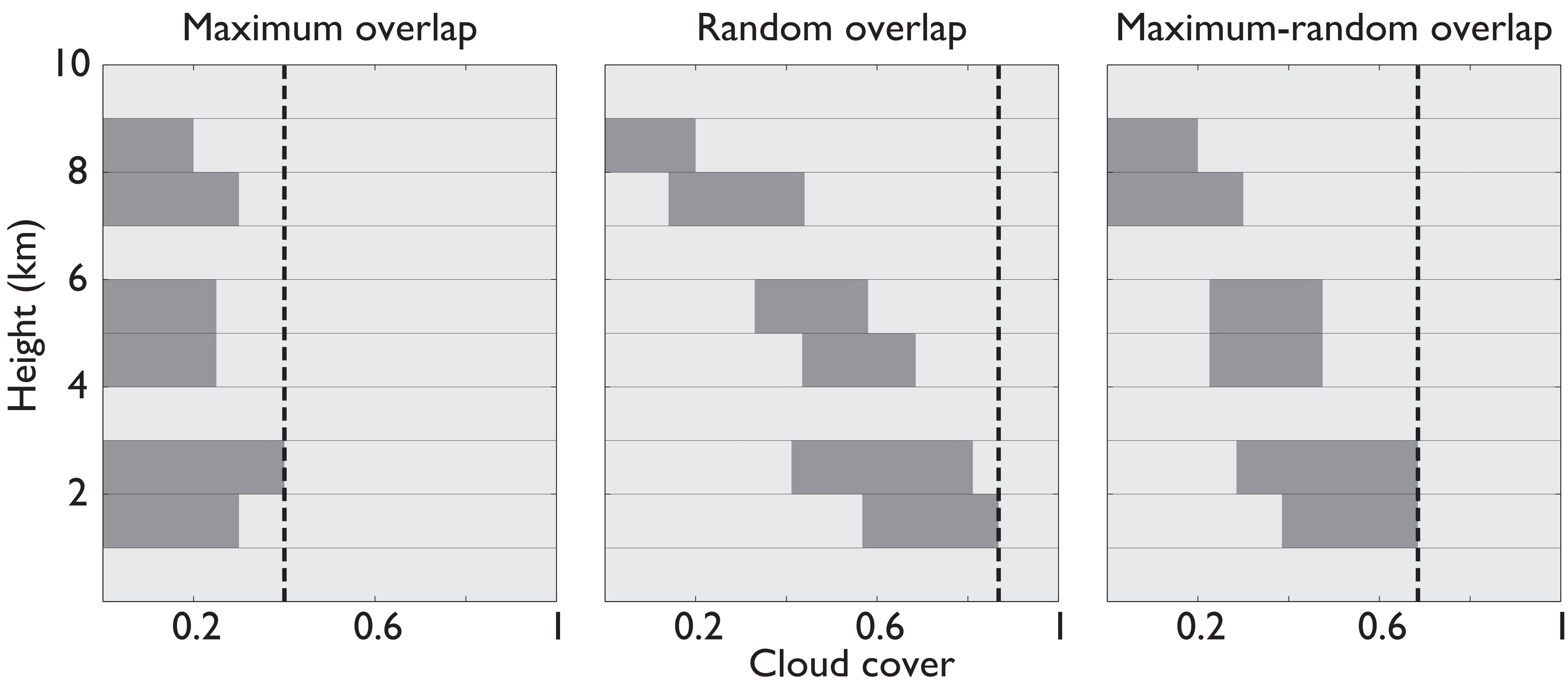
Clouds in global models are variable

There's explicit variability within grid columns:

Vertical structure ("overlap") + fractional cloudiness = internally variable columns

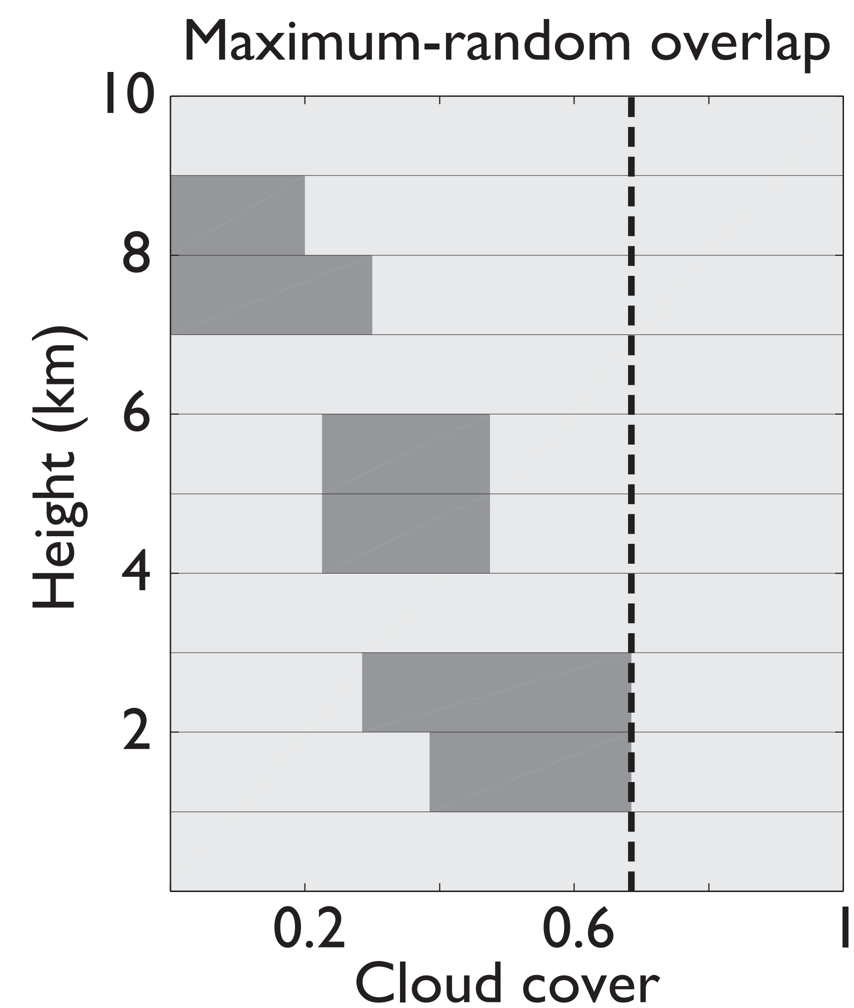
Let's take a look at how overlap gives rise to variability



After Hogan and Illingworth, 2000

The cloudiness in each layer is the same but they're arranged differently
Note that total cloud cover (dashed line) depends a lot on the overlap assumption (though this is sort of an extreme case)

Focus on max-random overlap - how many different arrangements are there?



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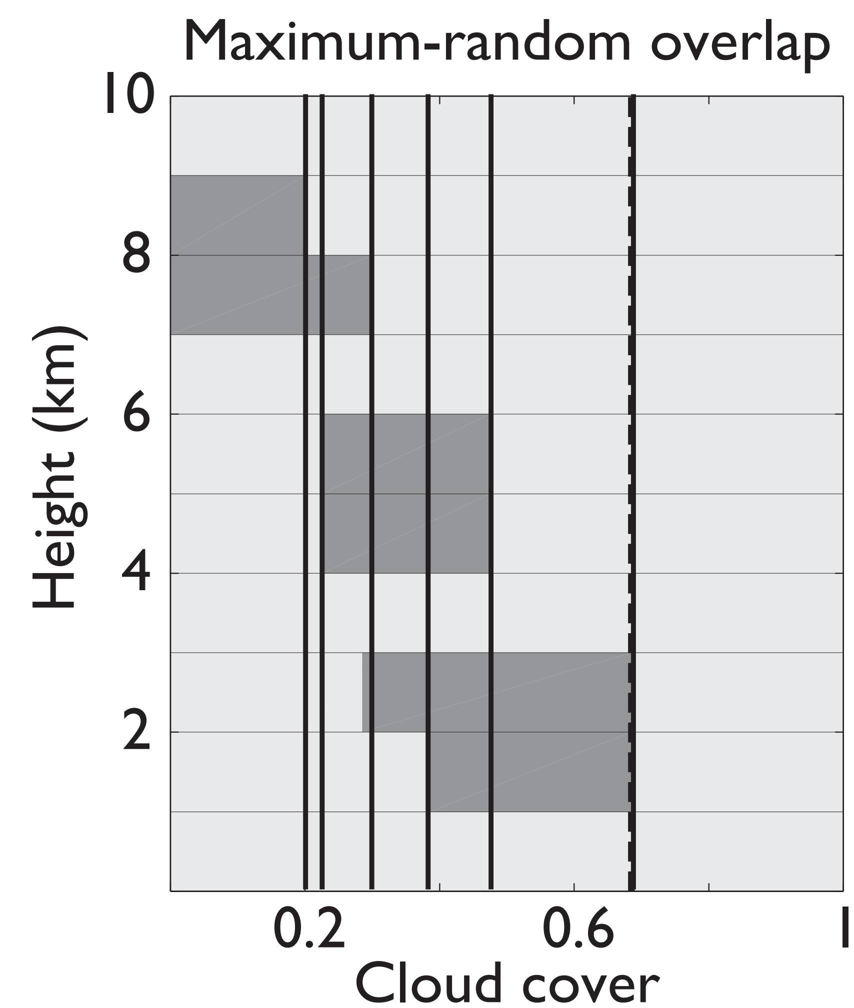
Six cloudy configurations



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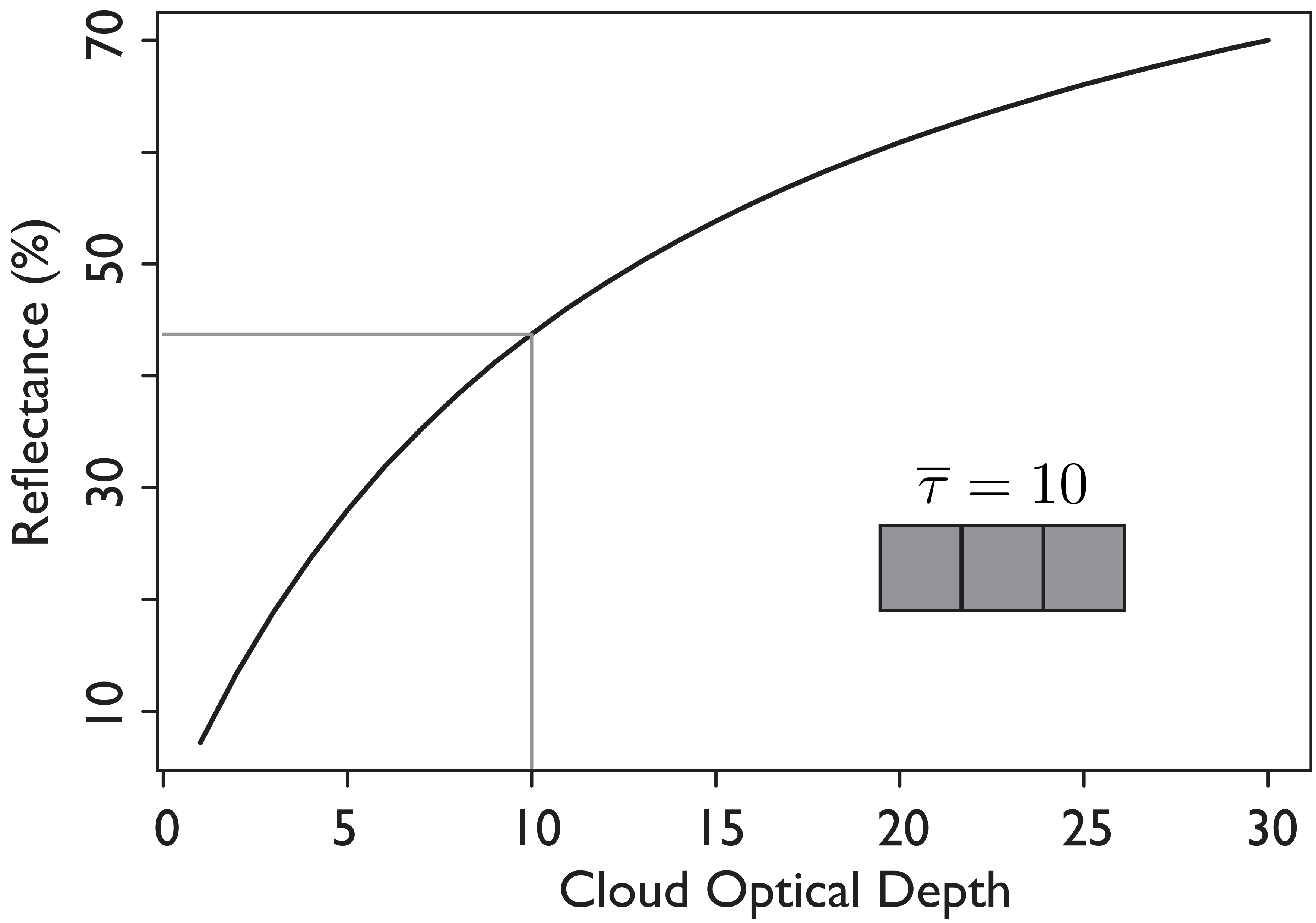
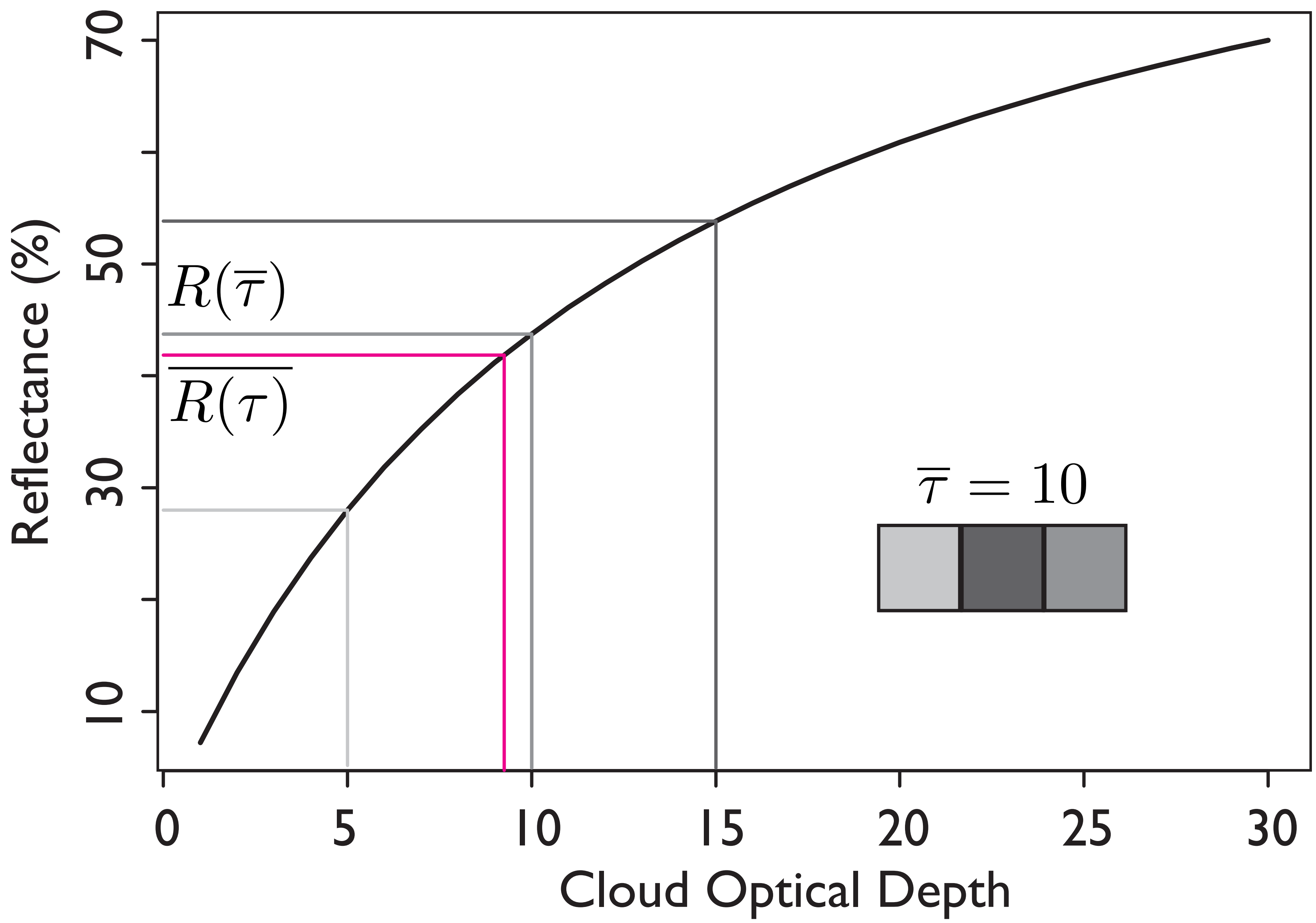


Reflectance (%)
10
30
50
70
0
5
10
15
20
25
30
Cloud Optical Depth
$\overline{\tau} = 10$



Reflectance (%)
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50
30
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$R(\overline{\tau})$
$\overline{R(\tau)}$
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5
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15
20
25
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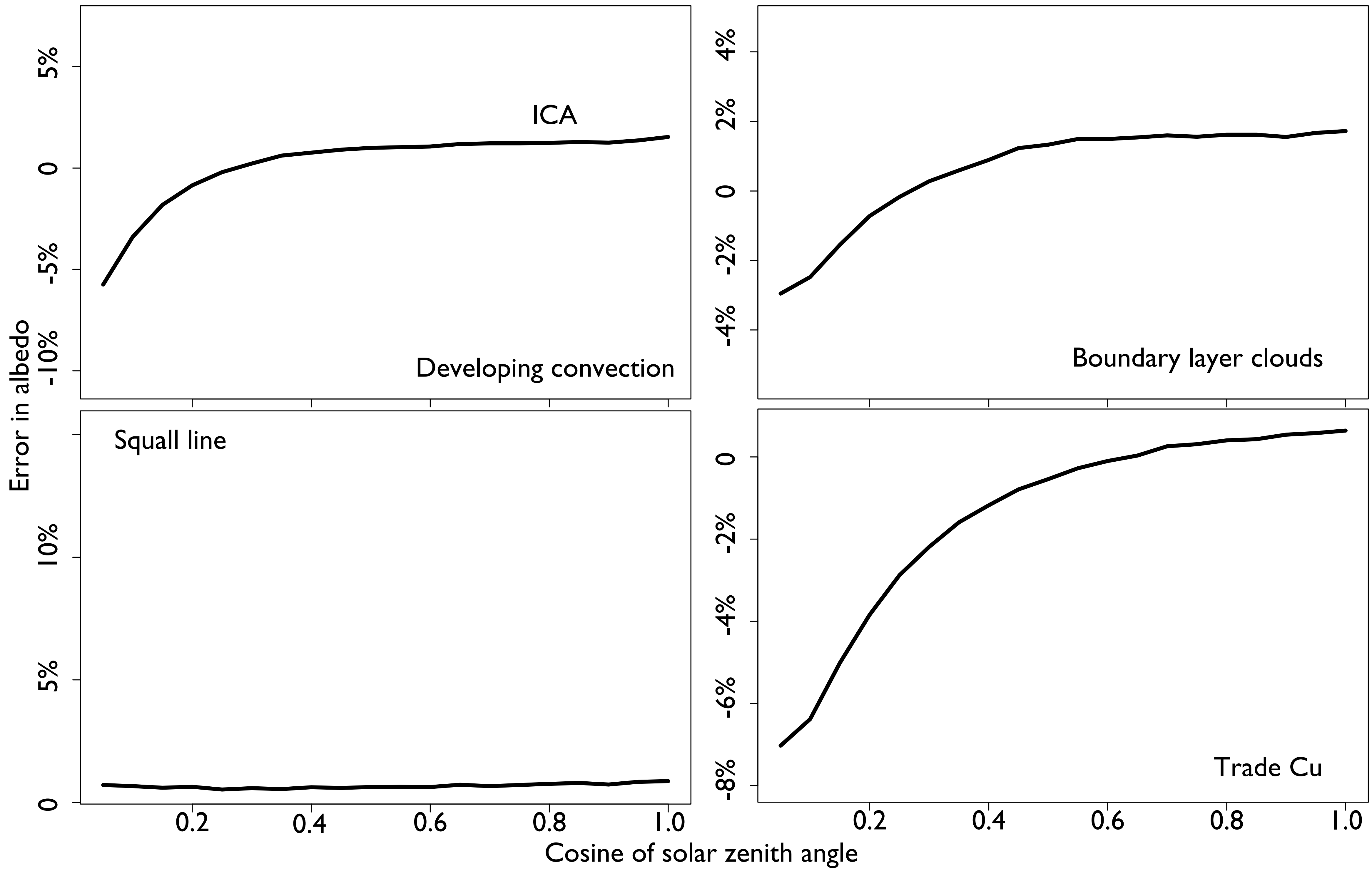
Cloud Optical Depth

Reflection from simulated cloud fields (Barker et al., 2003)



This calculation is most relevant for climate – surface vs TOA fluxes

The black lines shows the 3D minus 1D difference – it's small at most solar zenith angles

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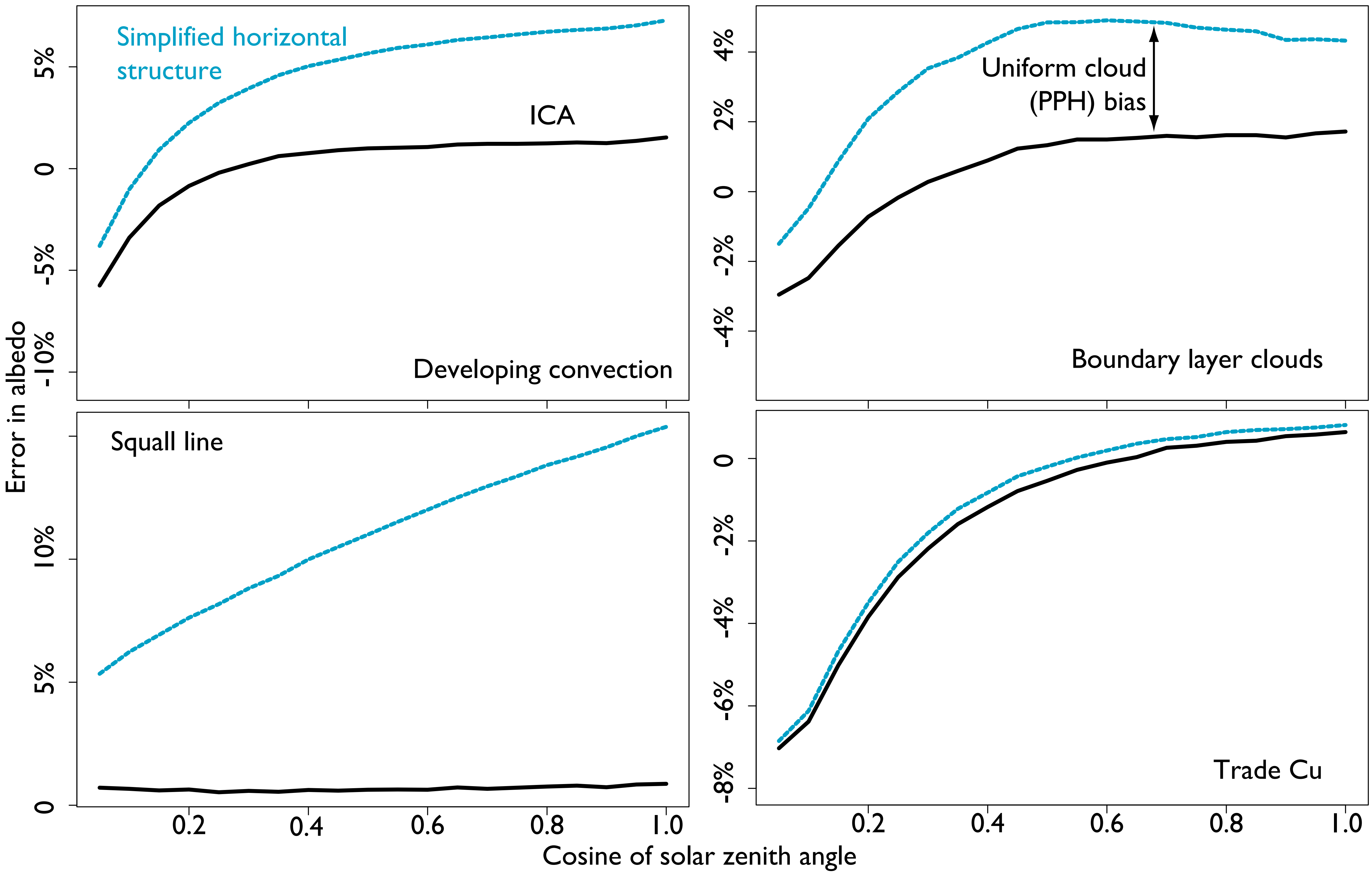

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Current ways of treating sub-grid variability in radiation

Vertical structure

Cloud variability is treated quasi-analytically within the radiation scheme

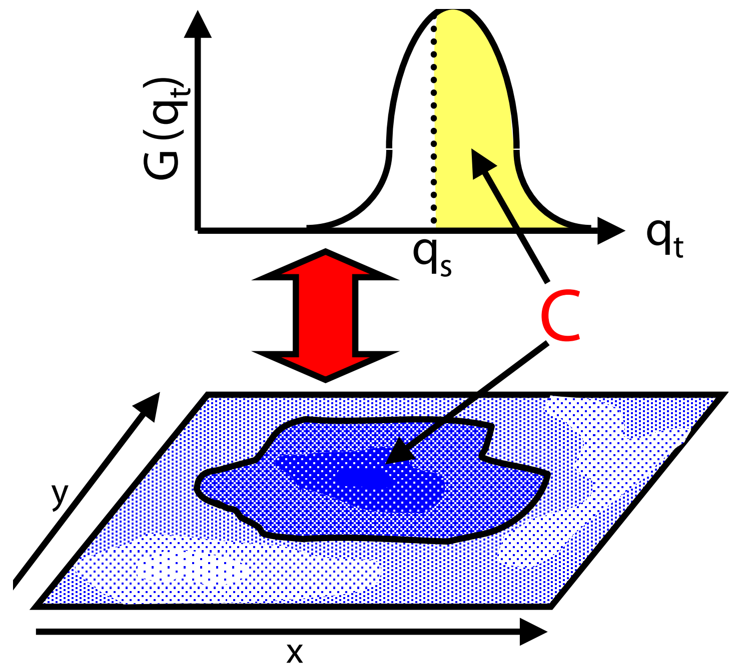
Horizontal variability

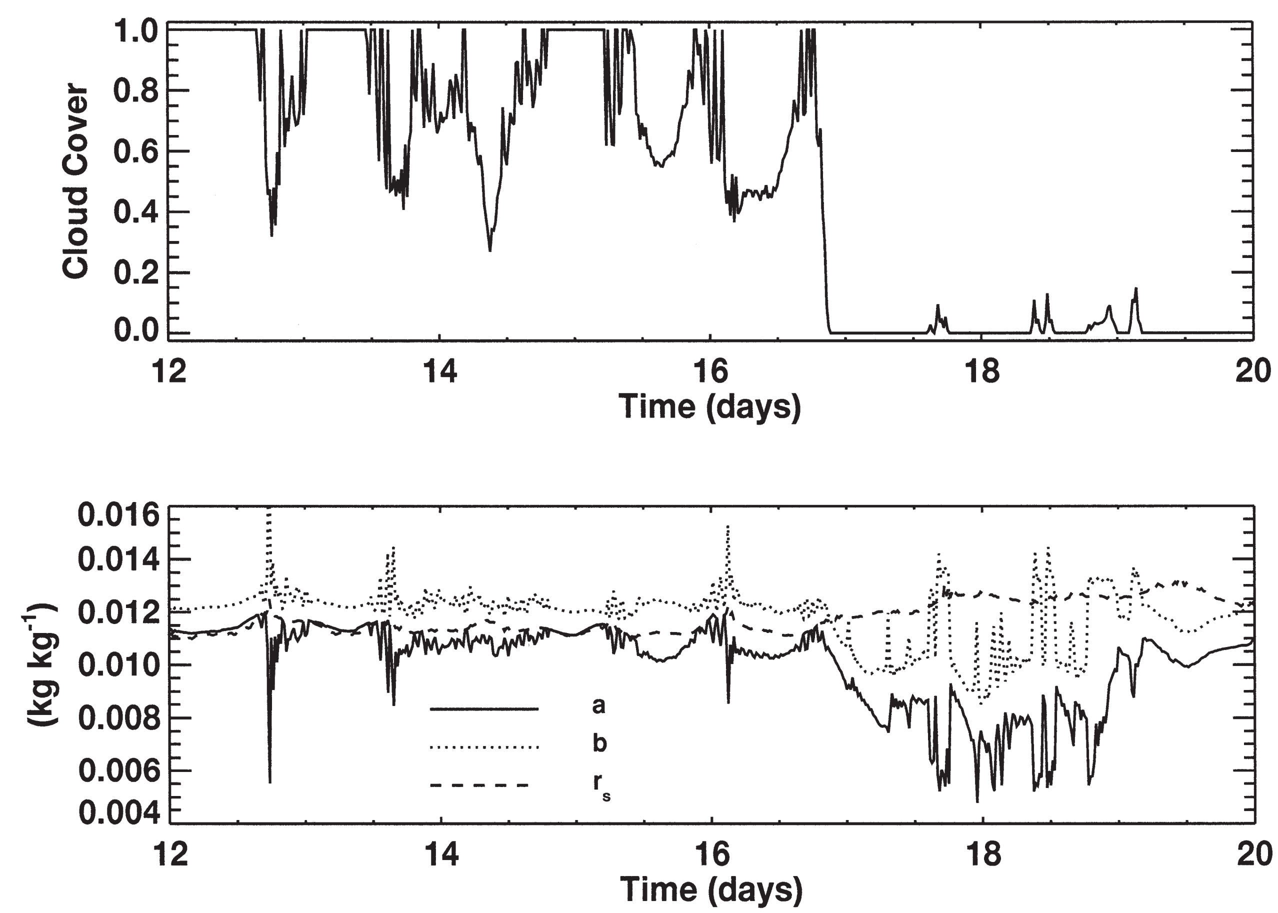
All* models "tune" cloud optical properties relative to the values implied by cloud water/ice contents

These are unsatisfactory solutions

The fundamental problem applies to other parameterizations, too

All the tunings can be explained by not knowing how to account for sub-grid-scale variability





Adrian Tompkins (2001, 2008)

Radiation in an assumed-PDF scheme

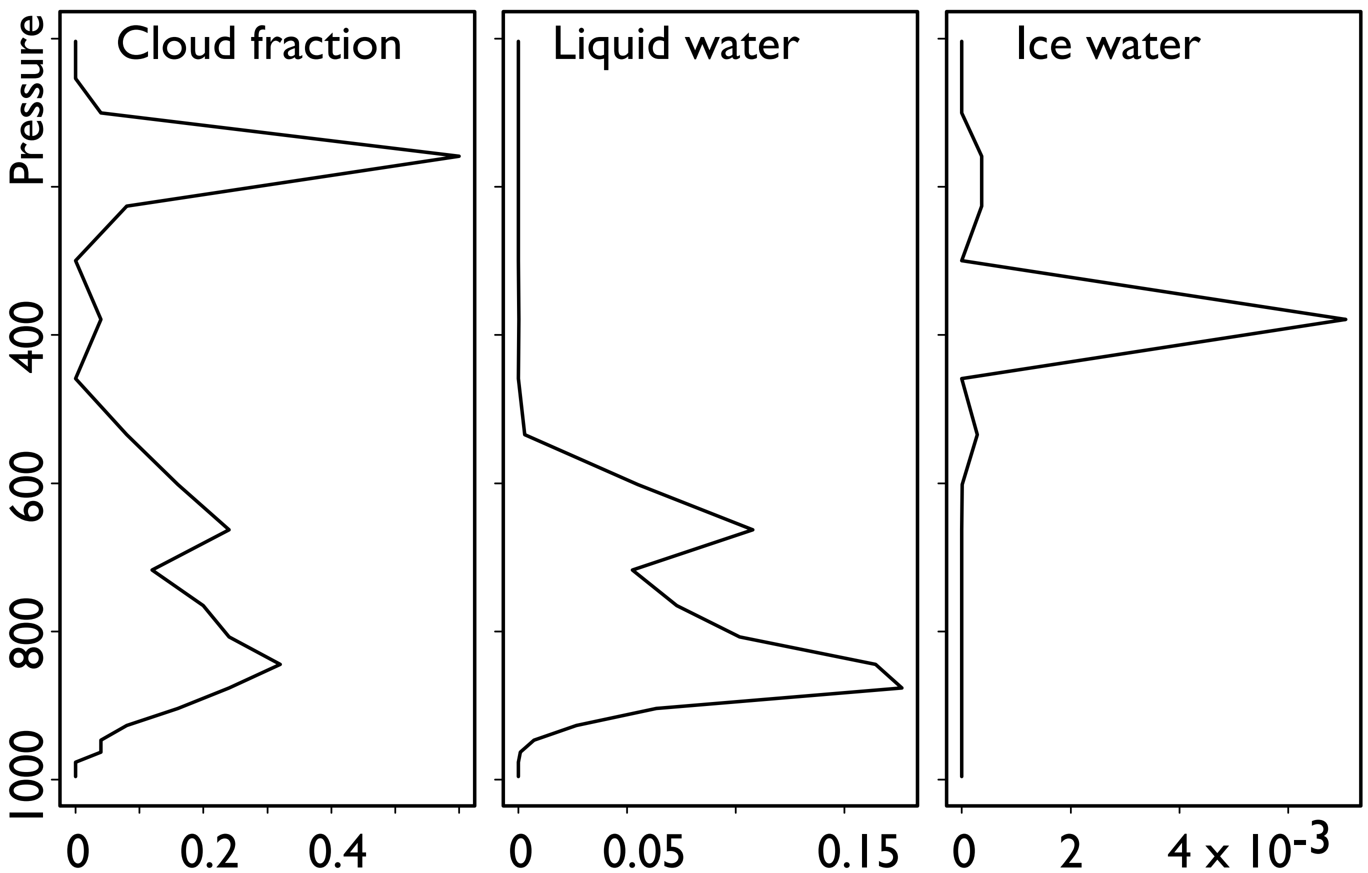
We were working on an assumed-PDF scheme for the GFDL climate model

To start we built a hybrid scheme: diagnostic PDF + new overlap

Radiation is non-local, so analytic integration doesn't work

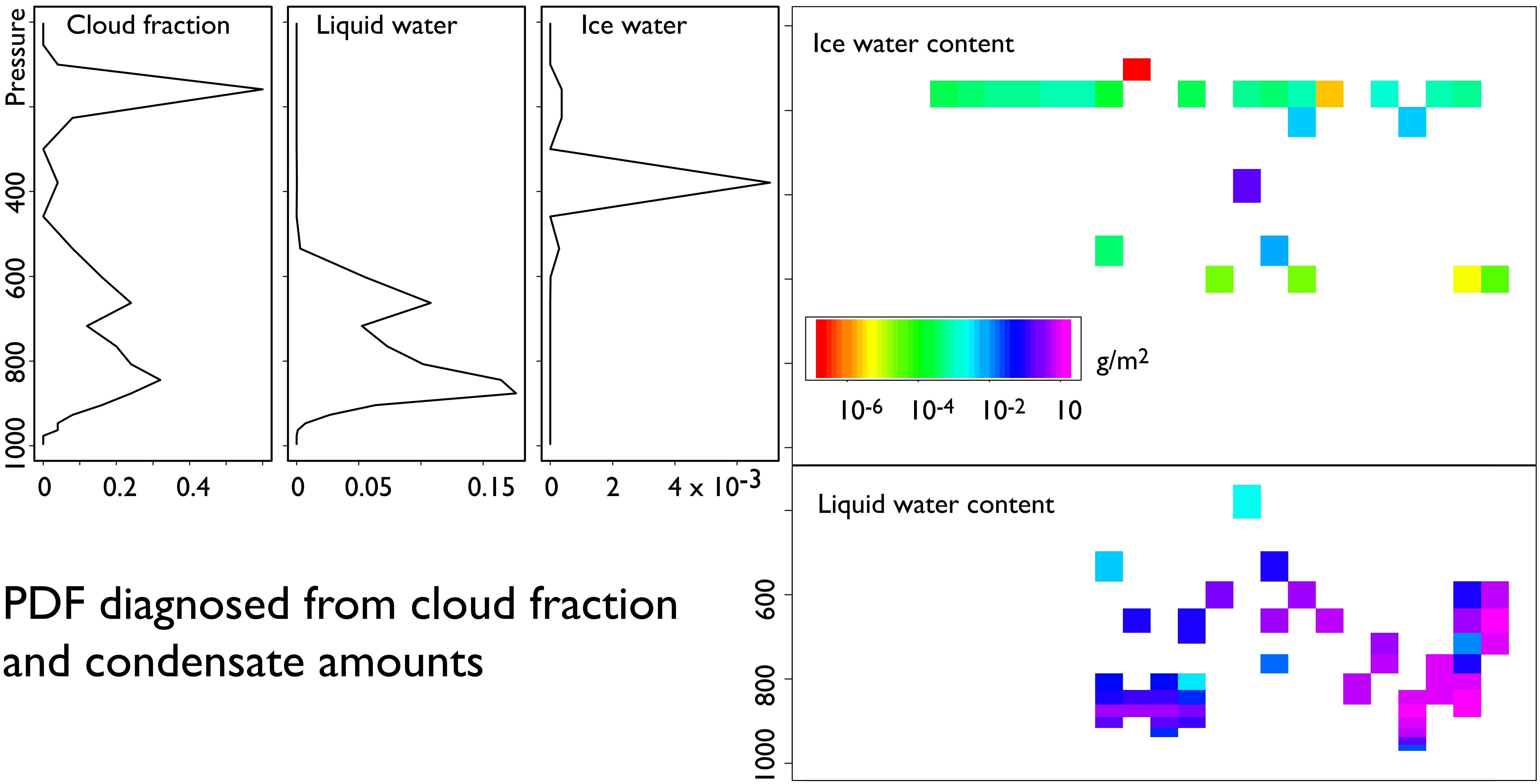
A PDF makes enumerating *all* configurations impractical (and the radiation cost is unbearable)

- But constructing samples is straightforward



Pincus et al., 2006

Here’s an example of how you’d do this in practice.



PDF diagnosed from cloud fraction and condensate amounts

Pincus et al., 2006

Here's an example of how you'd do this in practice.

Radiation for random samples

The ICA is a 2D integral over cloud state and spectral interval

$$\overline{F}(x,y,t) = \sum_{s}^{S} w_s \left(\sum_{b}^{B} w_b \sum_{g}^{G(b)} w_{g(b)} F_{s,b,g}(x,y,t) \right)$$

So how will you do the radiation? You could do the ICA, that would be very expensive – you'd need a lot of samples

There are various ways to refine this for higher accuracy but you get the point

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We approximate this integral with a Monte Carlo sample

$$\overline{F}(x,y,t) \approx \sum_{b}^{B} w_b \sum_{g}^{G(b)} w_{g(b)} F_{s',b,g}(x,y,t)$$

i.e. each g-point uses a different random sample from the PDF of possible states *within* each column

So how will you do the radiation? You could do the ICA, that would be very expensive – you'd need a lot of samples

There are various ways to refine this for higher accuracy but you get the point

It's an approximate answer to the correct problem

It's unbiased in the mean (over time and/or space)

It's flexible: any description of clouds and/or overlap works

Monte Carlo sampling noise is the main drawback

- The amount of noise depends on the cloud fields, and so on the global model being used
- Single-sample estimates from global models are O(10) W/m^2 in TOA fluxes
  (Heating rates are a few percent)

To be useful a global model would have to be able to absorb this much shaking at small scales

Can global models absorb that much noise?

Well, the first few models we worked with didn't fall over

The formal test - is an ensemble of models run using McICA statistically different from an ensemble of models run using the full ICA?

The plot shows the faction of the area in 15-member ensembles in which near-surface air temperature differs at the 95% level between McICA and control runs.

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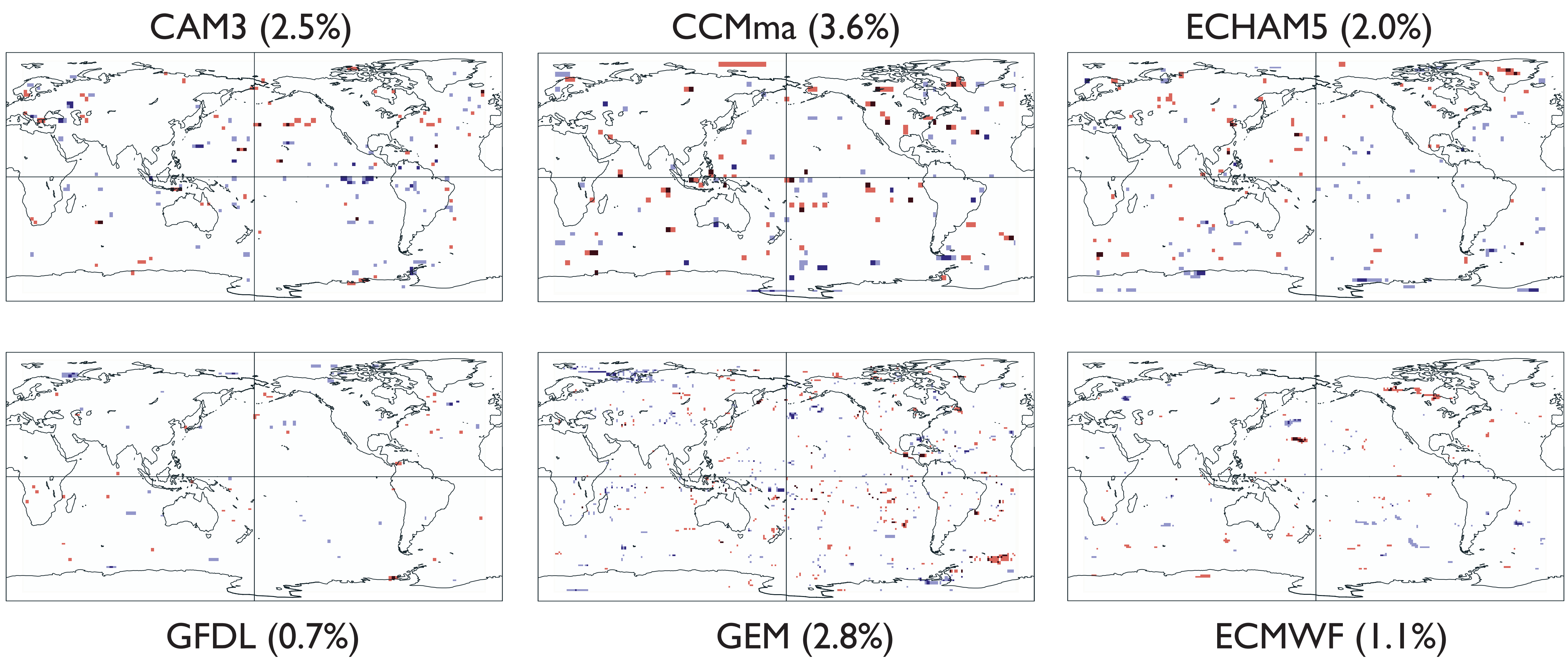

(Barker et al., 2008)

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Prospects (ii)

- McICA is a simple solution to a long-standing problem
  - The decoupling of cloud structure from radiation is particularly appealing to global modelers
  - In one model an explicit PDF obviated the need for tuning
- McICA has been adopted by weather forecasting (ECMWF) and climate modeling centers (GFDL, NCAR)
- Adoption was quick - partly because it's so easy to implement