How to prepare satellite-based cloud information for use by modelers

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How satellite observations of clouds are being used by (climate) models and how this might be made easier

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A plea

- Don't worry too much about "modelers"
- Over-emphasizing "evaluation of climate models"
  - diminishes the many utilities satellite observations have
  - diminishes what we learn by disagreeing

There are as many needs as users

Weather models require observations for

~~assimilation~~
verification

Climate models mostly use observations for verification

In both cases

observations may be required across timescales

models must "down-scale" to pixel scale, then aggregate up, implying utility for many approaches to aggregation

Let's begin with climate models…

the small-scale part, and show that both phenomena progressively dry the boundary layer as climate warms.

The small-scale component of mixing

Lower-tropospheric mixing parametrized within a GCM grid cell cannot be directly diagnosed from model output (although it contributes to the convective terms in the water vapour budget; see below). We assert, however, that an atmosphere's propensity to generate such mixing can be gauged by observing the thermal structure just above the boundary layer in ascending, raining regions. As discussed above, air there is either transported directly from the boundary layer with minimal precipitation via lower-tropospheric mixing, or indirectly by ascending in deeper, raining clouds and then descending. The air would arrive cool and humid in the former case, but warmer and drier in the latter case owing to the extra condensation, allowing us to evaluate which pathway dominates by observing mean-state air properties.

To do this we use an index *S*, proportional to the differences $\Delta T_{700-850}$ and $\Delta R_{700-850}$ of temperature and relative humidity between 700 hPa and 850 hPa (*S* taken as a linear combination; see Methods Summary) averaged within a broad ascending region which roughly coincides with the region of highest Indo-Pacific ocean temperatures (the Indo-Pacific Warm Pool; Fig. 1). Of the full set of 48 models used in this study, those with a less negative $\Delta T_{700-850}$ in this region consistently show a more negative $\Delta R_{700-850}$ there (Fig. 2a), and the variations in each quantity are quite large. We interpret this as strong evidence that both quantities are dominated by variations, evidently large, in the amount of lower-tropospheric mixing in the ascent region, with higher *S* indicating stronger mixing.

Small-scale lower-tropospheric mixing of moisture is part of the overall source of the water vapour that is associated with the parametrized convection, M_{small}. This quantity is available from nine of the models (see Methods Summary). It always exhibits strong drying

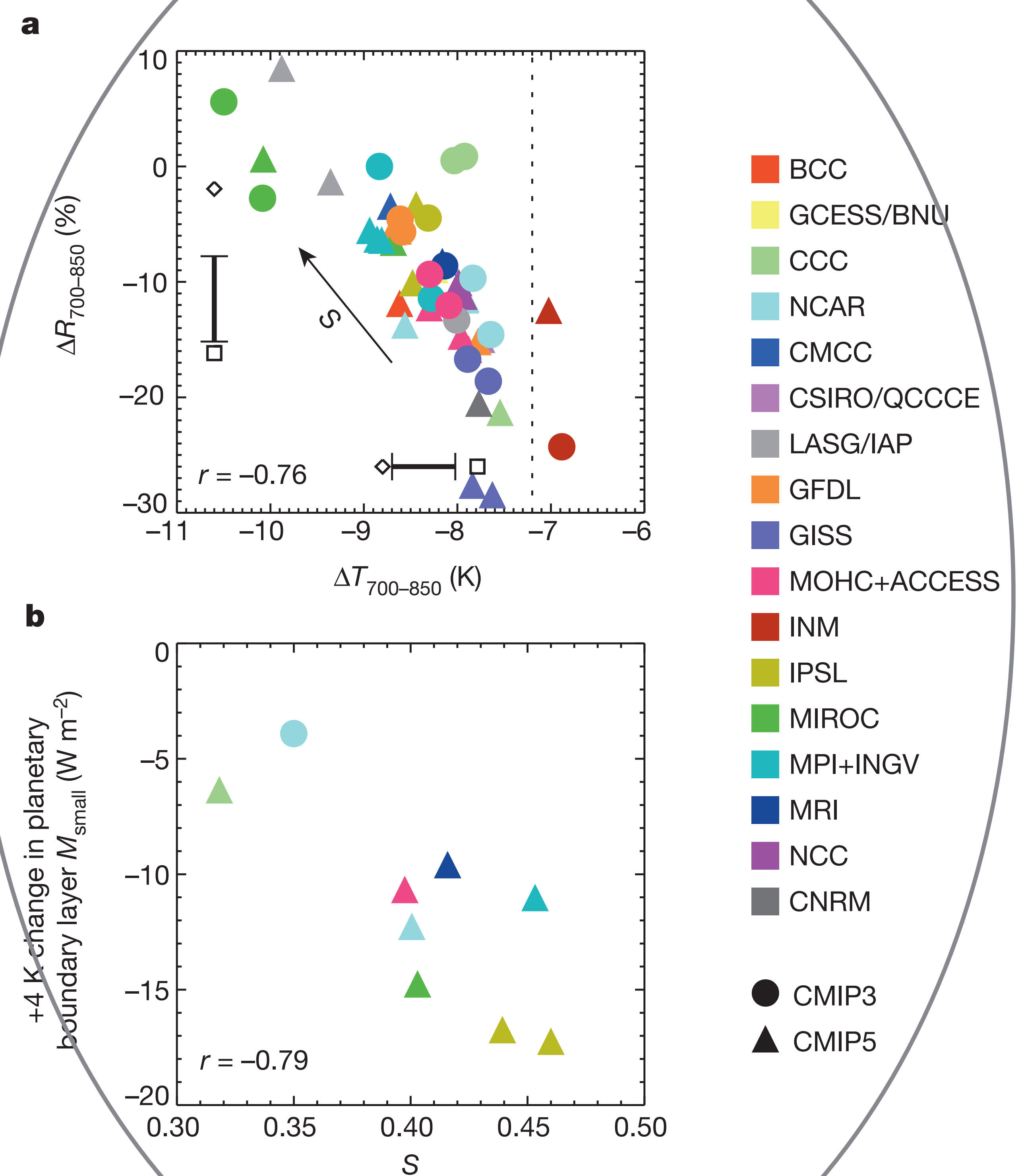

Figure 2 | Basis for the index *S* of small-scale lower-tropospheric mixing and its relationship to the warming response. **a**, $\Delta T_{700-850}$ versus $\Delta R_{700-850}$, each averaged over a tropical region of mean ascent (see Fig. 1), from all 48 coupled models. For reference, a saturated-adiabatic value of ΔT is shown by dotted line at −7.2 K, and a dry-adiabatic value (not shown) would be about −16 K. Error bars are 2σ ranges. **b**, Change in small-scale moisture source M_{small} below 850 hPa in the tropics upon +4 K ocean warming, versus *S*

a Low sensitivity

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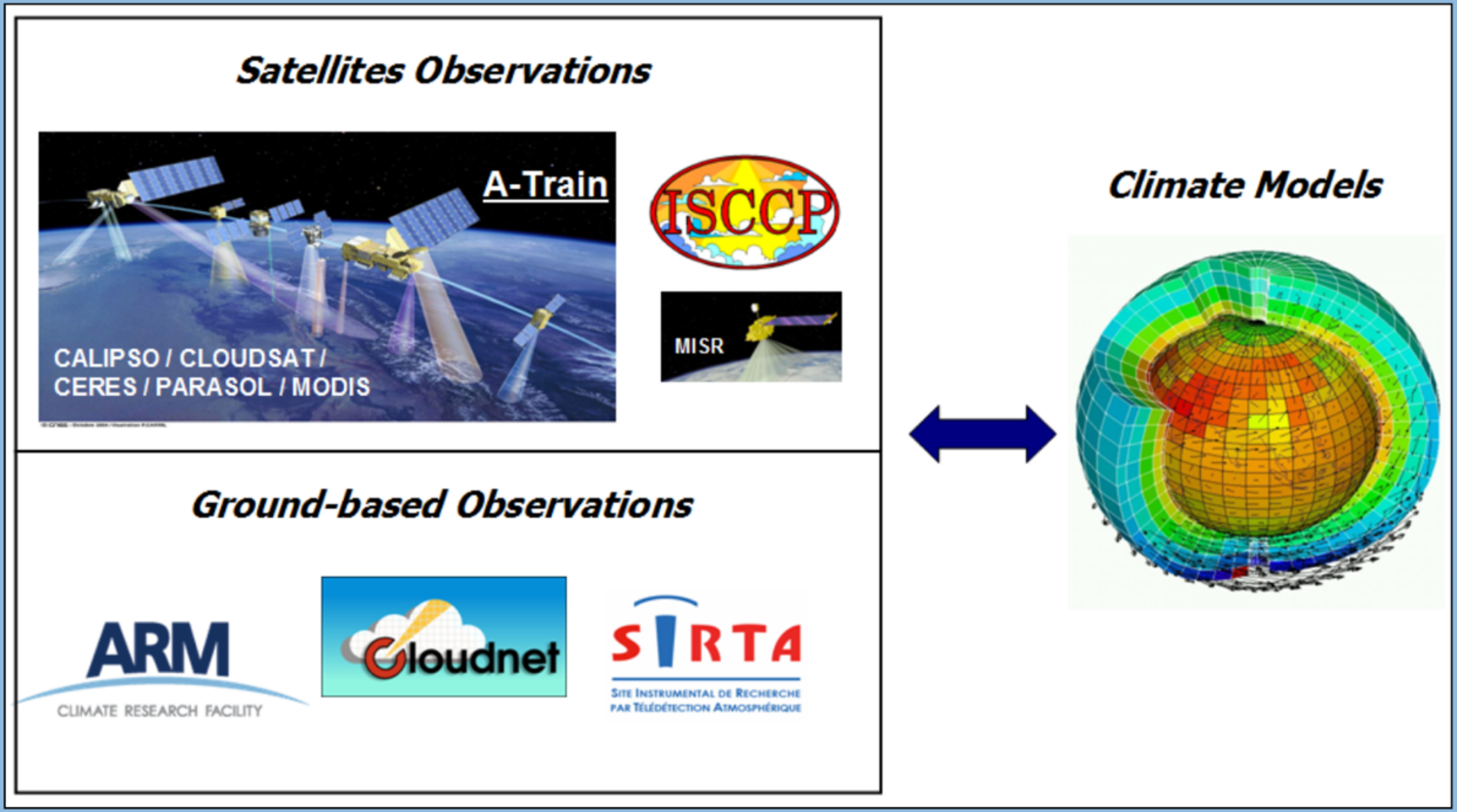
The ESG paradigm doesn't really fit CREW (among others)

- In ESG, each field has unique provenance and is distinct
- Details relevant to observations are difficult to express
  - e.g. calibration changes, commonality in sensors/algorithms, …
- ESG may become more observation-friendly over time

CFMIP-OBS: Cloud Observations for model evaluation

CFMIP Observations for Model evaluation

The Cloud Feedback Model Intercomparison Program has designed a protocol to evaluate clouds in climate and weather prediction models based on satellite observations (http://cfmip.metoffice.com/CFMIP2_experiments_March20th2009.pdf)



Why is it important to evaluate the cloudiness simulated by numerical models ?

The representation of clouds and cloud-related processes is critical for climate prediction over a wide range of space and time scales : for Numerical Weather Prediction (NWP), for climate prediction at seasonal to decadal timescales, and for the prediction of the long-term climate response to anthropogenic perturbations at the global and regional scales. This stems from the strong interaction of clouds with the global Earth's

On data formats and other boring details

Uniformity of expression

- paves the way towards wider use
- can obscure relevant distinctions
- requires investment, clear thinking and coordination

And anyway the main difficulty isn't how data is formatted

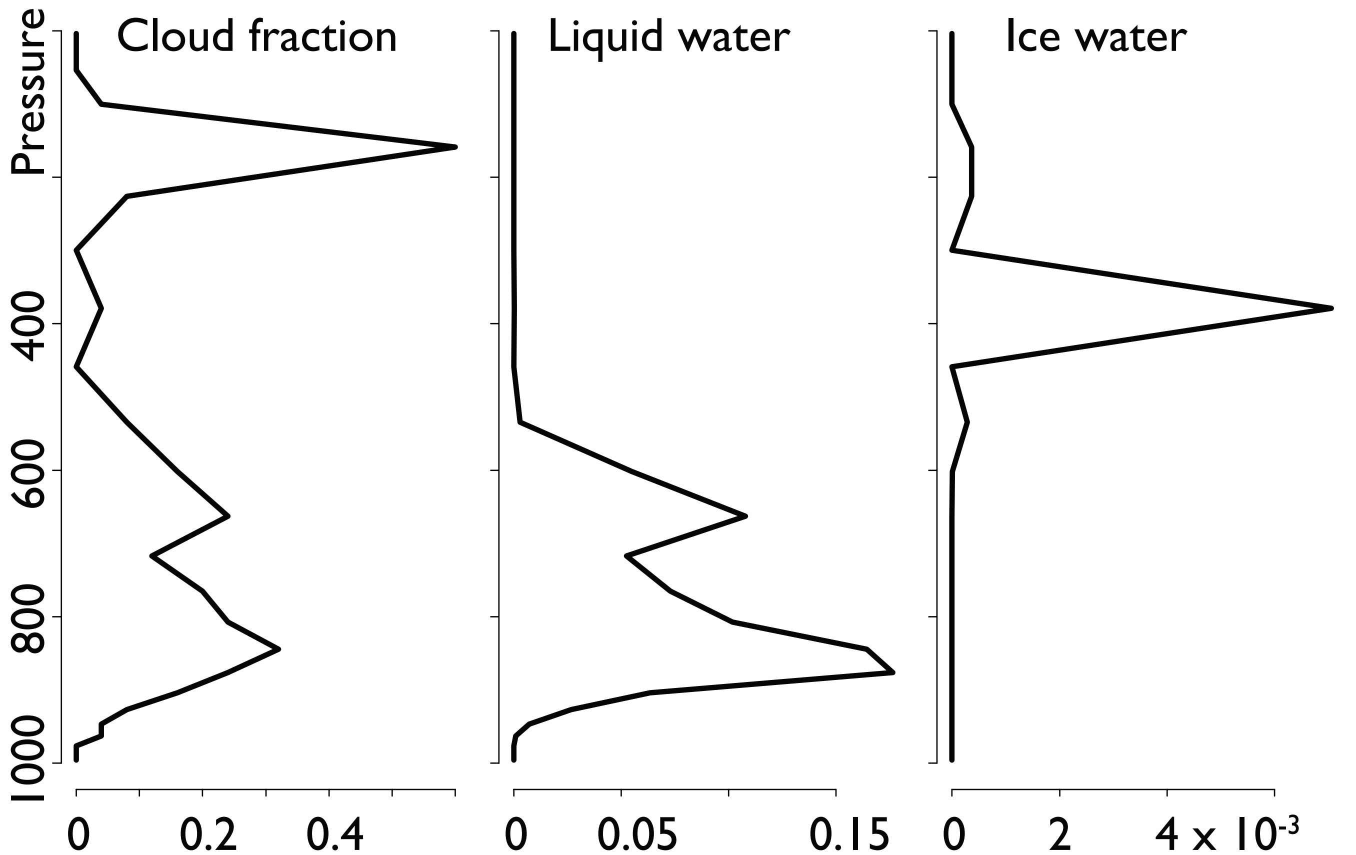
Towards a common language

"Direct comparisons" are uninformative

- Observations have their own personalities
- Model state is very far from observable

This has motivated the development of observation proxies ("satellite simulators")

Mapping model state to synthetic pixels



Pincus et. al (2006),10.1175/MWR3257.1

Simple observation proxies (“simulators”)

E.g. MODIS simulator uses sub-column inputs of $r_{e(l,i)}(z), \tau_{(l,i)}(z) \text{ or } q_{(l,i)}(z)$

Provides “pixel-level” estimates of

$$p_c = \int_{\mathrm{TOA}}^{\tau=1} p(z)\sigma_c(z)dz$$

(when > 700 mb, use ISCCP IR)

$$P = \int_{\mathrm{TOA}}^{\tau=1} P(z)\sigma_c(z)dz$$

(can be “undetermined”)

$$\tau = \int_{\mathrm{TOA}}^{\mathrm{sfc}} \sigma_c(z)dz$$

(no errors, as ISCCP simulator)

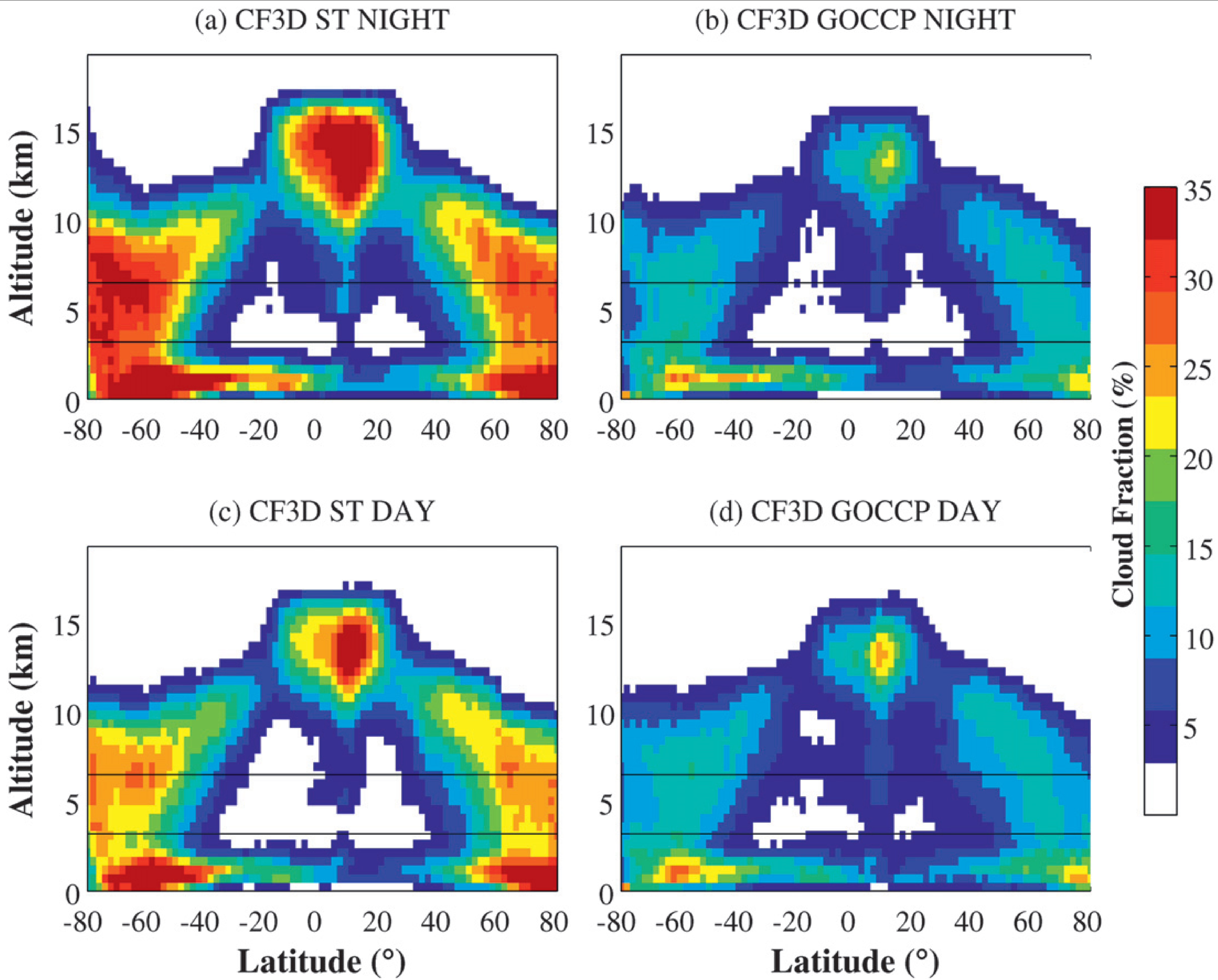
$$r_e = F^{-1}(F(r_e(z)))$$

(pseudo-retrieval based on near-IR fluxes)

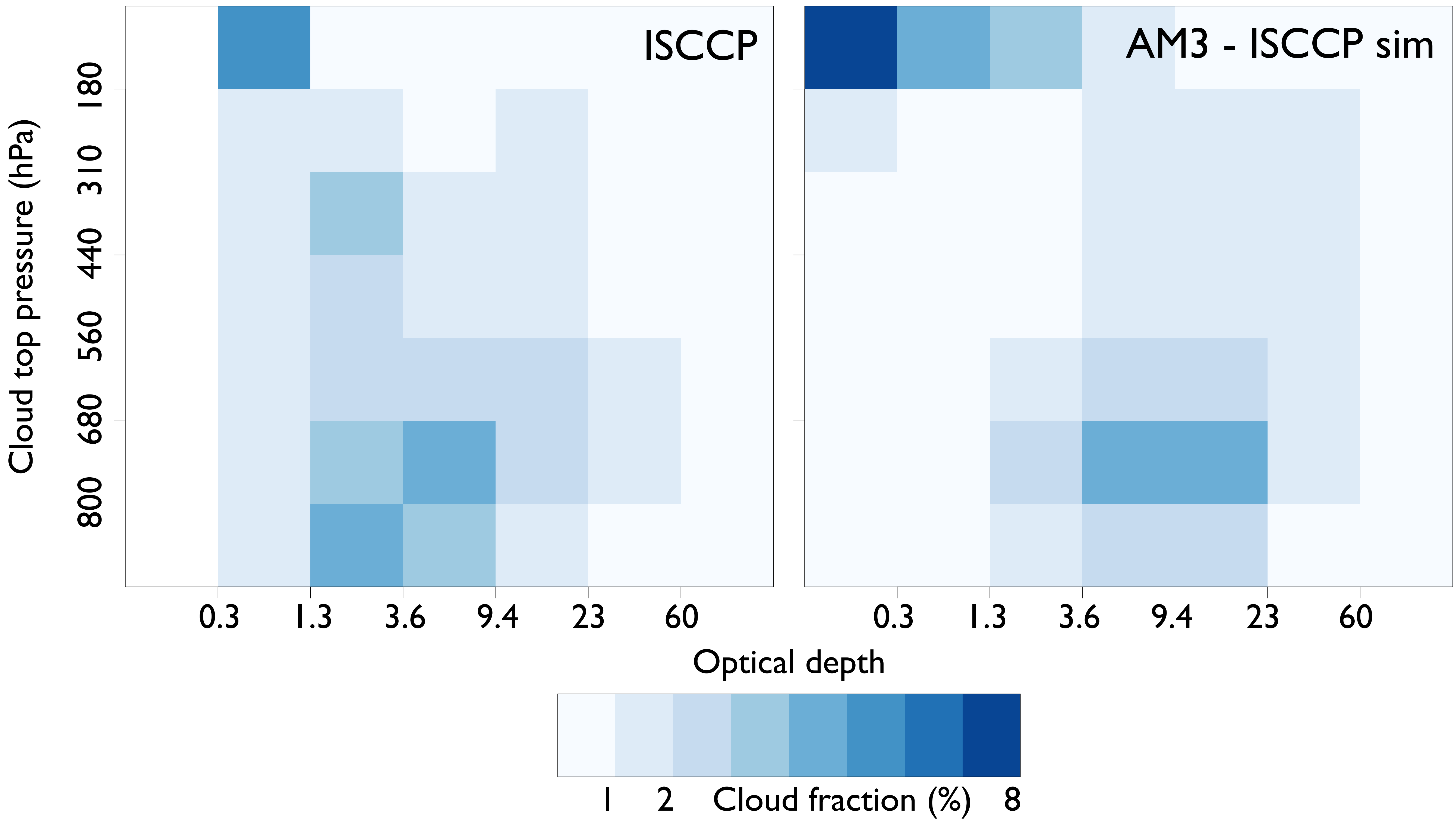
Aggregates in space and time as MODIS does

"… a data set (GOCCP), that diagnoses cloud properties from CALIPSO observations exactly in the same way as in the simulator (similar spatial resolution, same criteria used for cloud detection, same statistical cloud diagnostics). This ensures that discrepancies between model and observations reveal biases in the model's cloudiness rather than differences in the definition of clouds or of diagnostics."

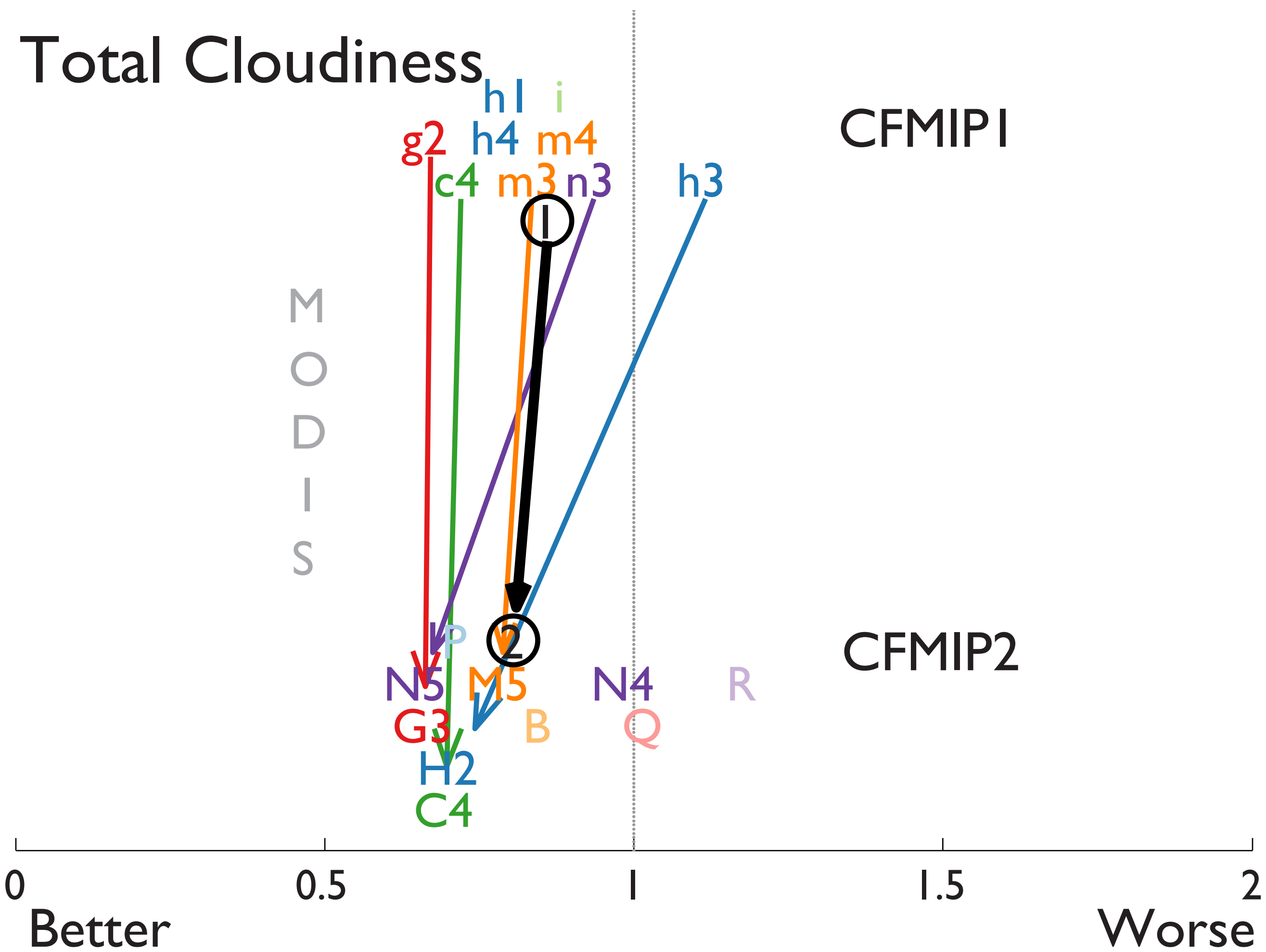
Chépfer et al., (2010), 10.1029/2009JD012251



Chépfer et. al (2013), 10.1175/JTECH-D-12-00057.1



Pincus et. al (2012), 10.1175/JCLI-D-11-00267.1

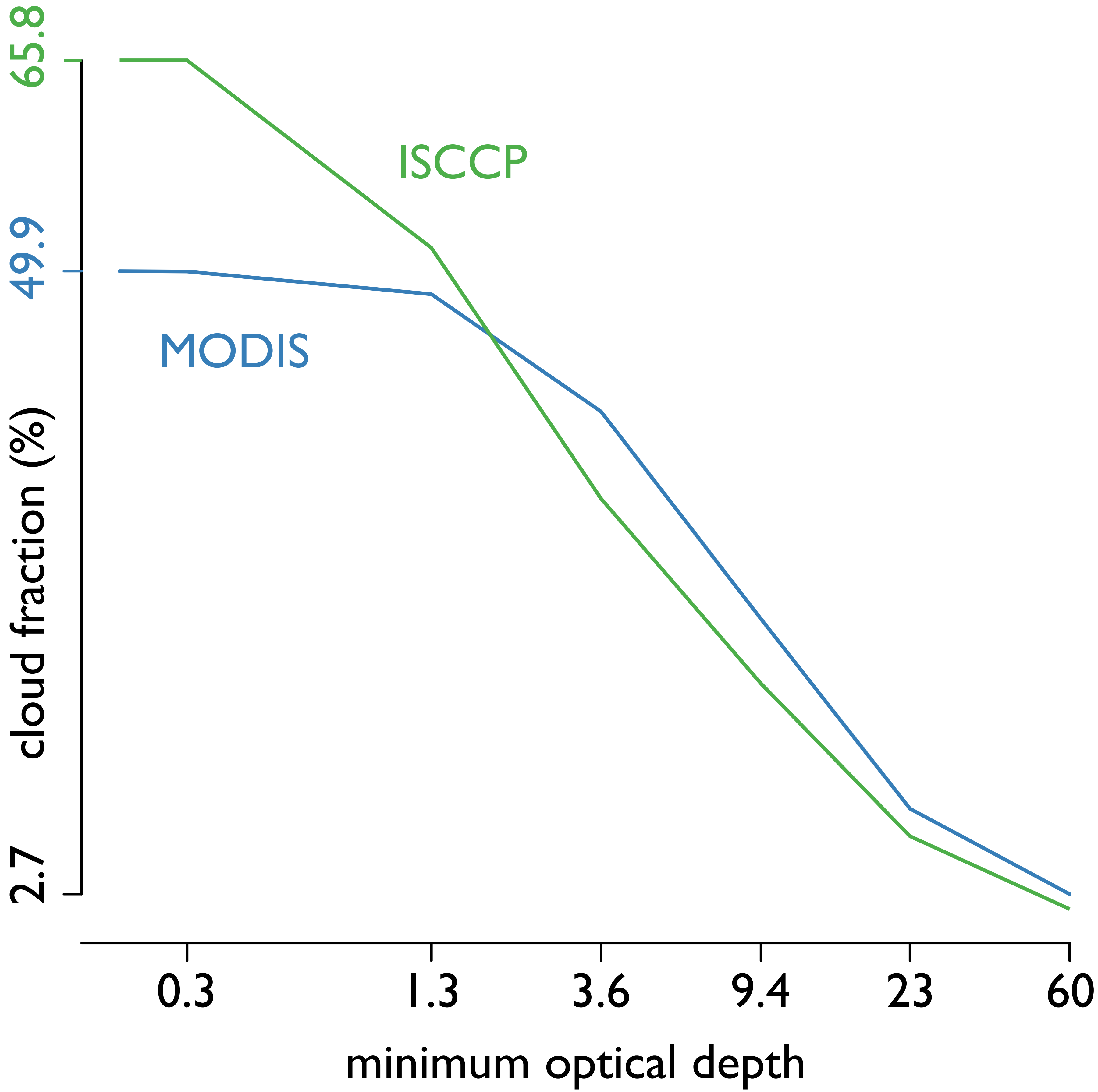


Klein et. al (2013), 10.1002/jgrd.50141

Simulators are meant to account for the personality of each observing system (detection thresholds, interpretations, etc.)

Some retrieval errors aren't expressed

- dependencies are neglected (e.g. geometric dependencies)
- ancillary information is perfect
- pixels are always fully cloudy



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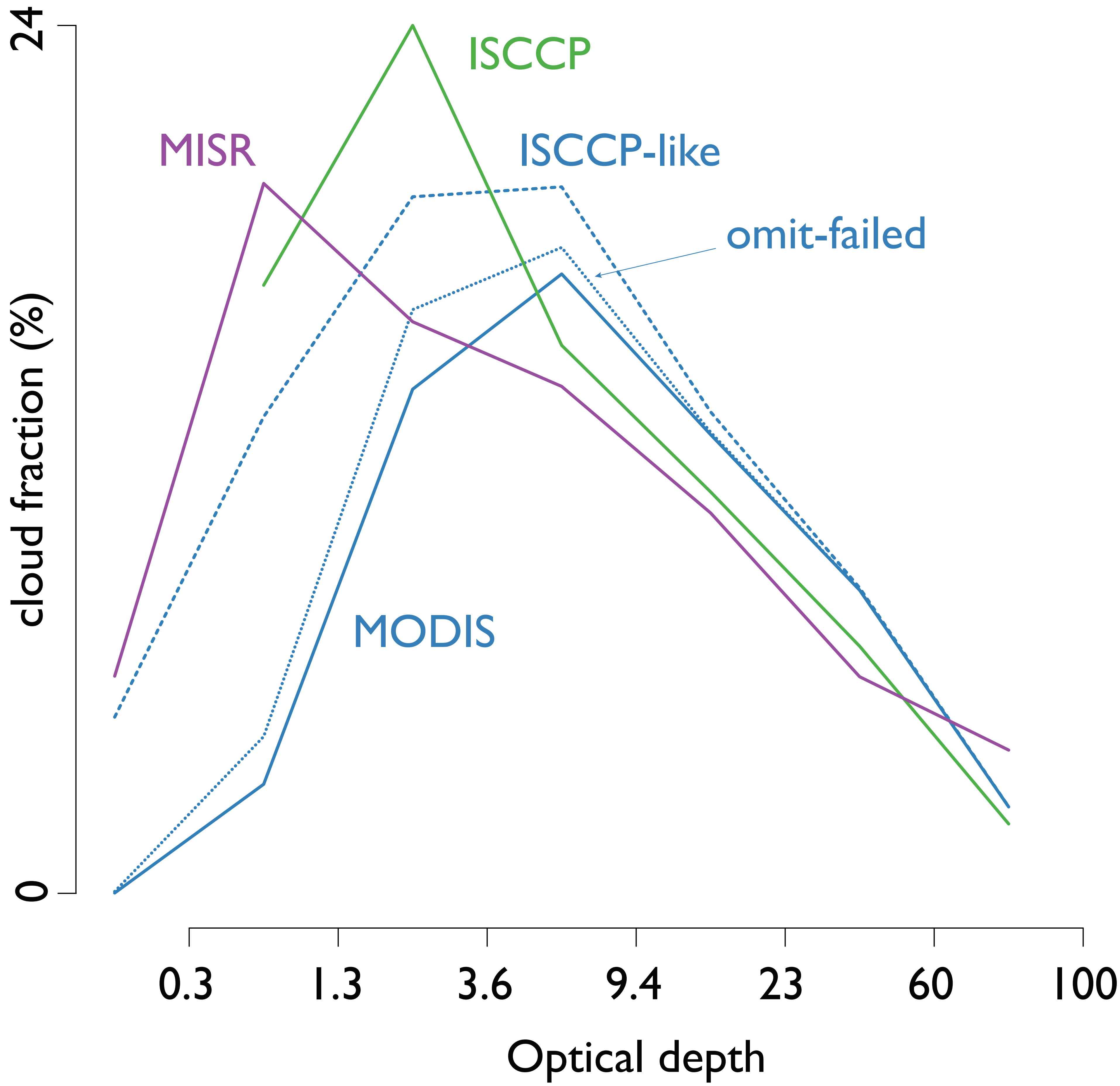
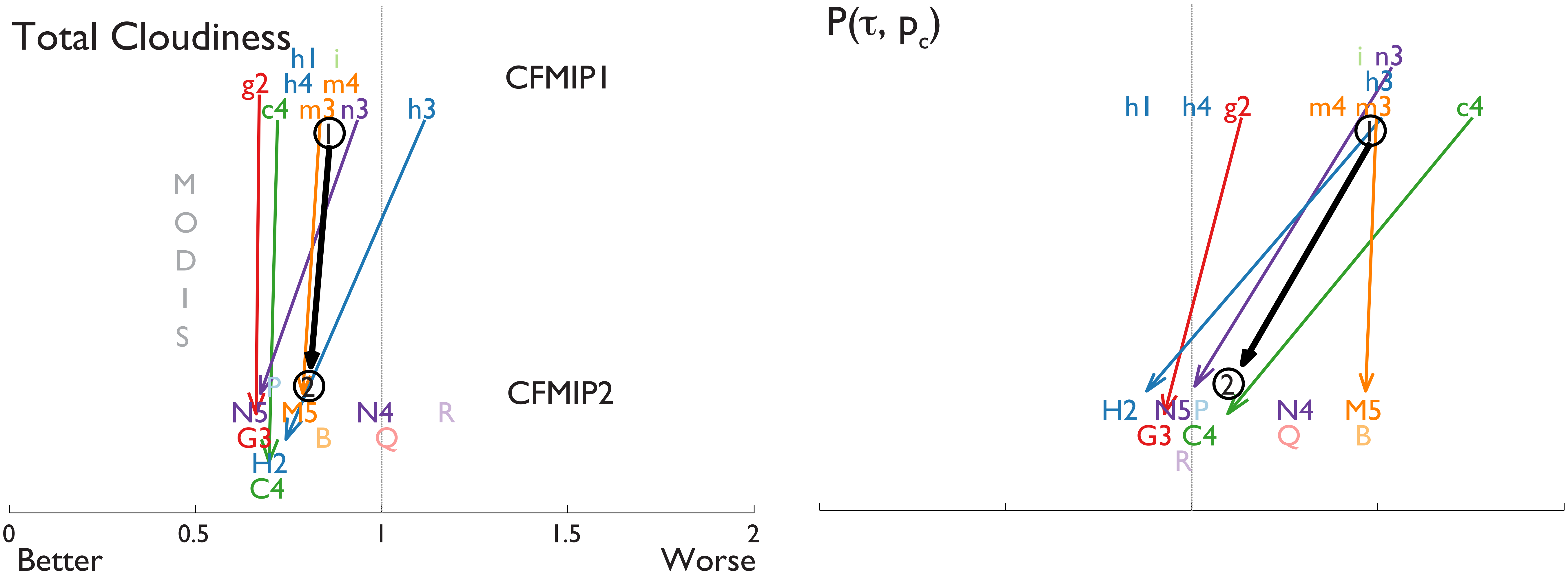


ISCCP
MISR
ISCCP-like
omit-failed
MODIS
24
0
cloud fraction (%)
0.3
1.3
3.6
9.4
23
60
100
Optical depth



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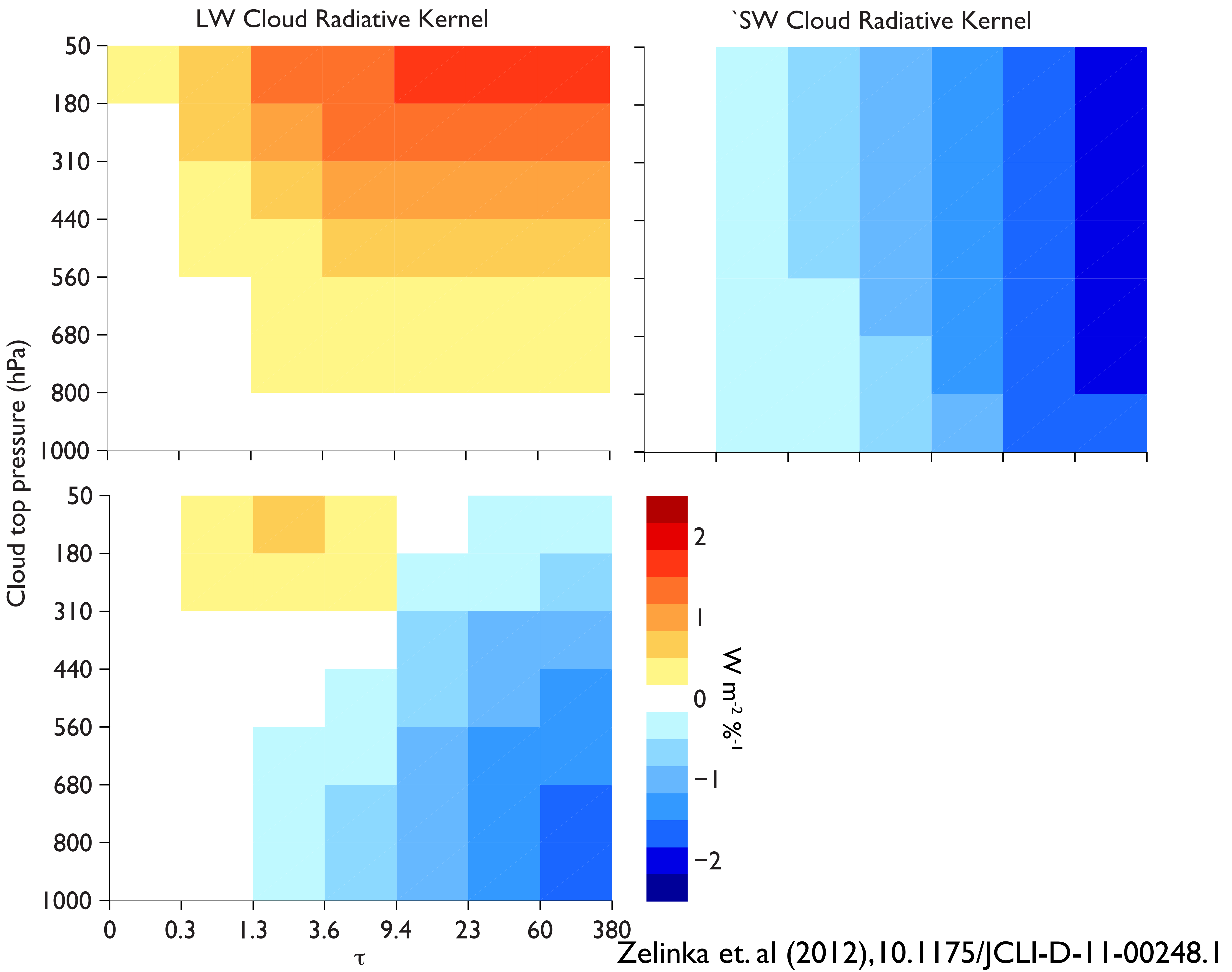
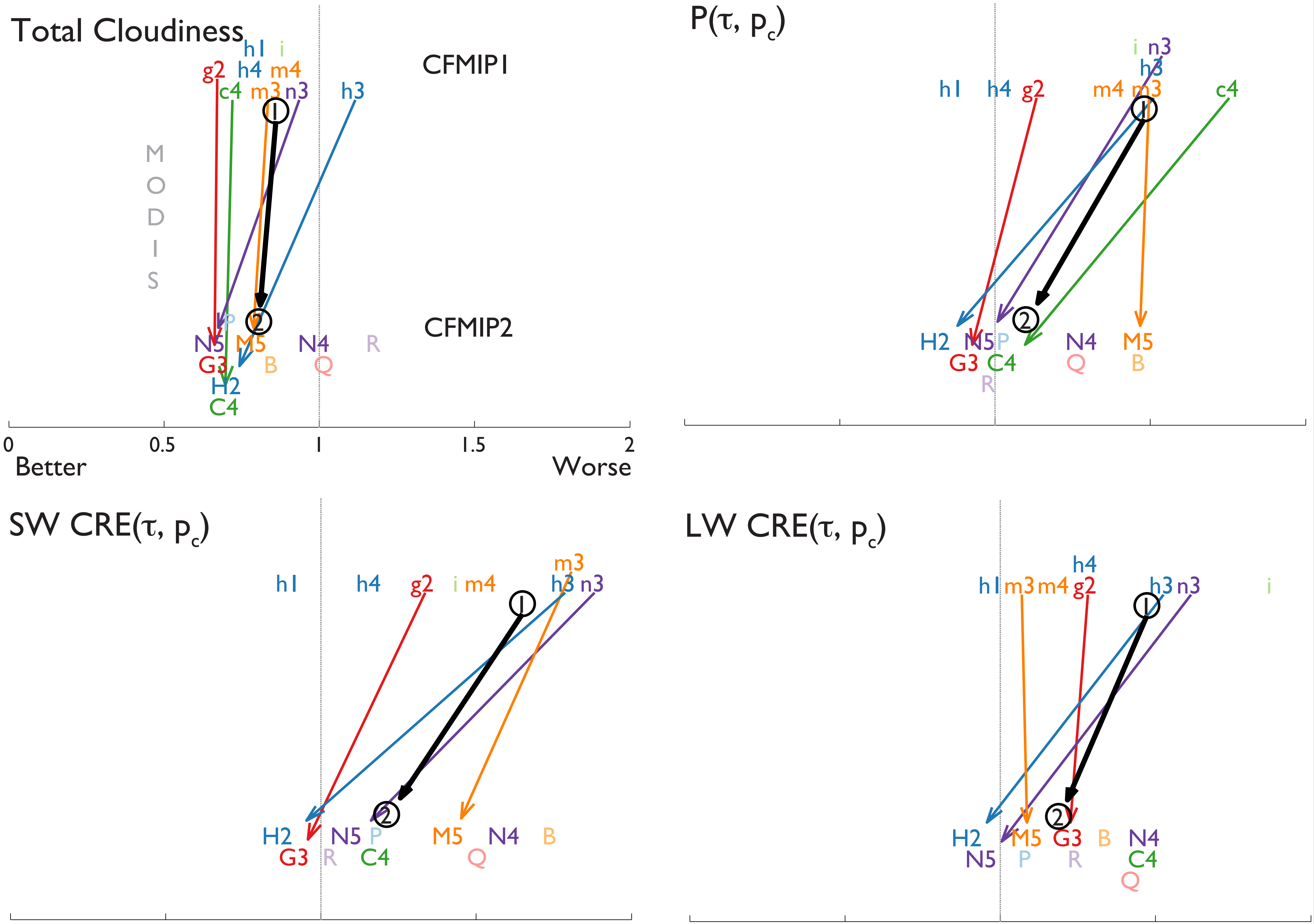


Zelinka et. al (2012), 10.1175/JCLI-D-11-00248.1



Total Cloudiness
CFMIP1
CFMIP2
MODIS
h1 i
g2 h4 m4
c4 m3 n3 h3
1
2
N5 M5 N4 R
G3 B Q
H2
C4
0
0.5
1
1.5
2
Better
Worse
P(τ, p_c)
i n3
h3
h1 h4 g2 m4 m3 c4
H2 N5 P N4 M5
G3 C4 Q B
R
SW CRE(τ, p_c)
m3
h1 h4 g2 i m4 h3 n3
H2 N5 P M5 N4 B
G3 R C4 Q
LW CRE(τ, p_c)
h4
h1 m3 m4 g2 h3 n3 i
H2 M5 G3 B N4
N5 P R C4
Q

Error/uncertainty estimation

It would be very useful in general to have error and/or uncertainty estimates for aggregated quantities

This is really hard

- for well-characterized uncertainties one still needs a statistical model for multi-pixel estimates

- much (most?) of the error and uncertainty in passive retrievals comes from (systematic, conditional) failures of conceptual models

Are there alternatives to aggregating single-pixel retrievals?

Boring technical details can have a big impact

- Some homogenization of formats, etc. would ease adoption
- "Some" could become "too much" pretty quickly

There's a large, thriving community of people using satellite observations to look at climate models

The errors in models are mostly more blunt than require e.g. four ways of estimating cloud-type height

New simulators will need to show significant diagnostic skill to be widely adopted

A plea

Don’t worry too much about “modelers”

Over-emphasizing “evaluation of climate models”

- diminishes the many utilities satellite observations have
- diminishes what we learn by disagreeing