What we mean by “cloud:” The perils of evaluating climate models with satellite observations

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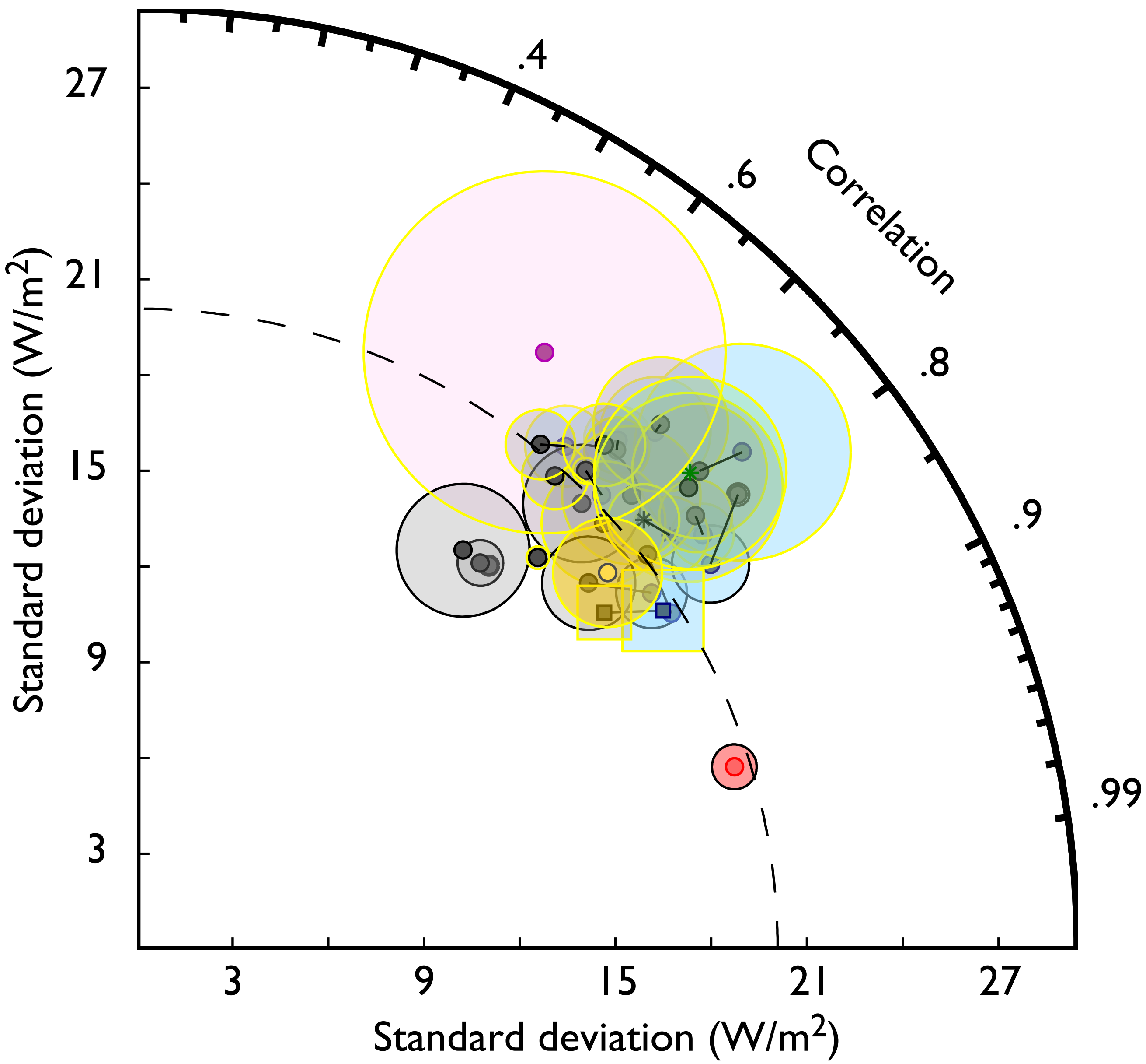
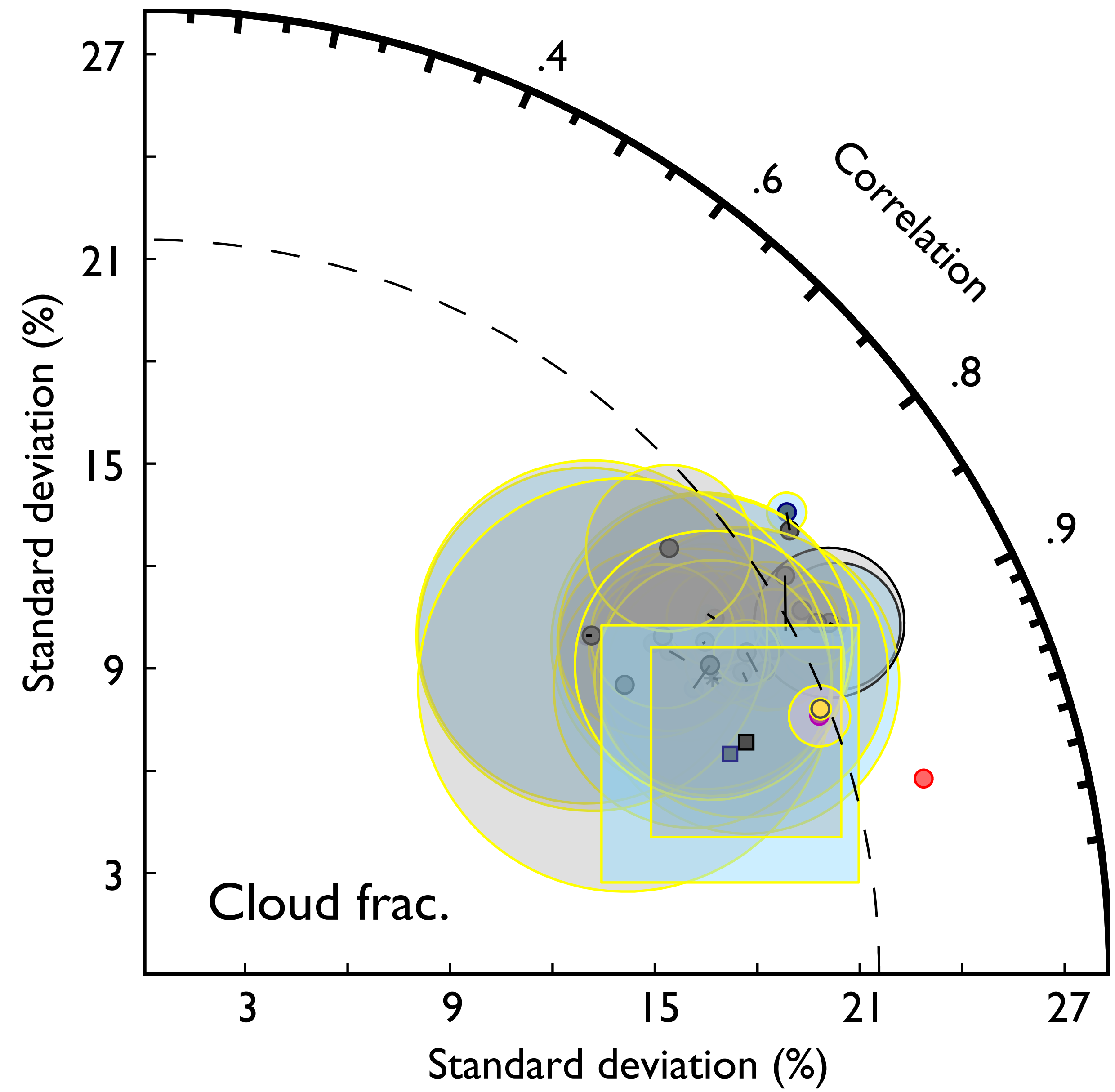
Based on Pincus et al, manuscript submitted to *J. Climate*





Pincus et al., 2008

Making fair comparisons

We want to be able to attribute *differences* between observations and models to *model errors*

Some comparisons (e.g. temperature) can be direct, but satellites don't observe model cloud states

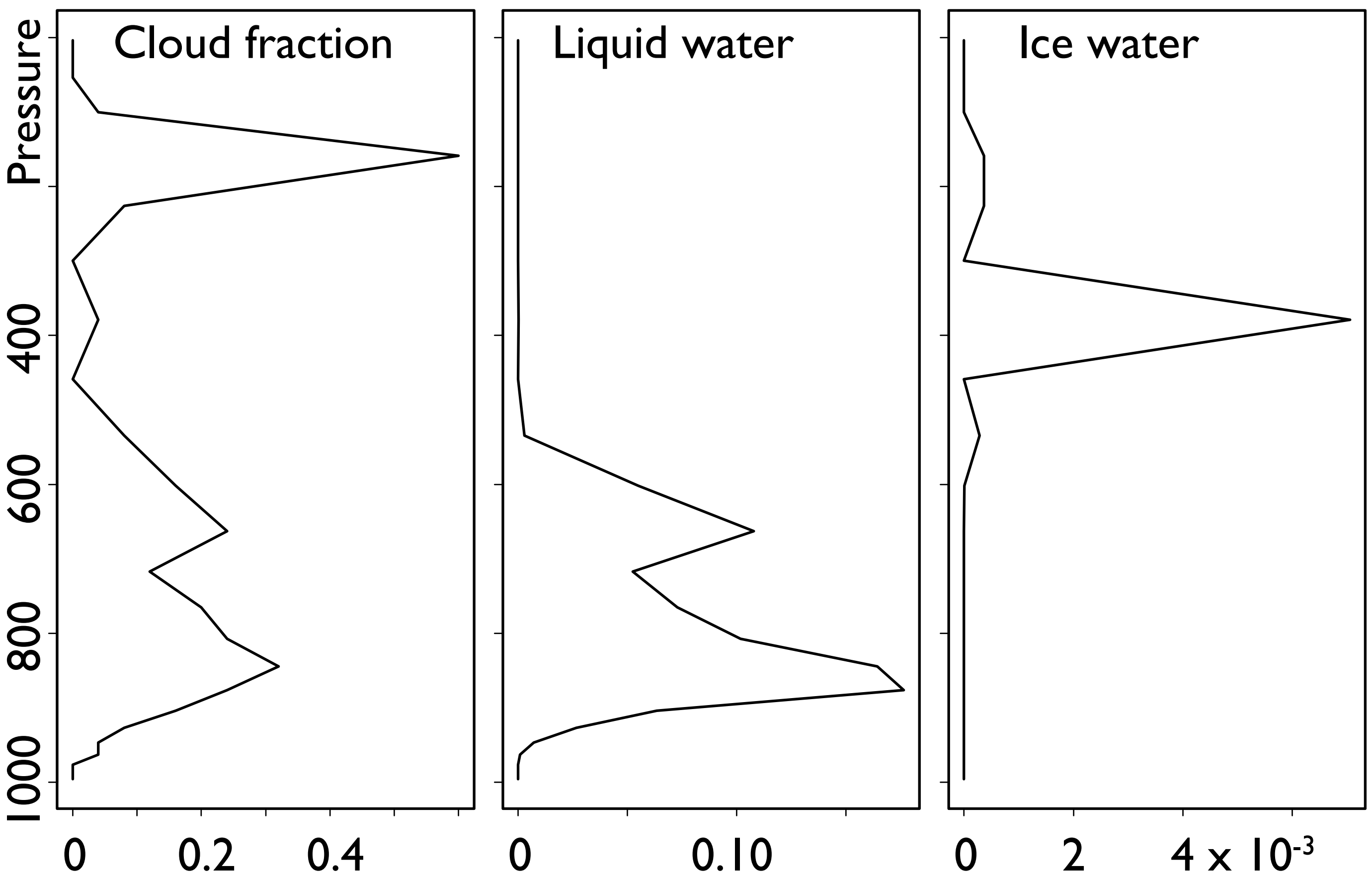
We require models of

sub-grid scale distribution of cloudiness

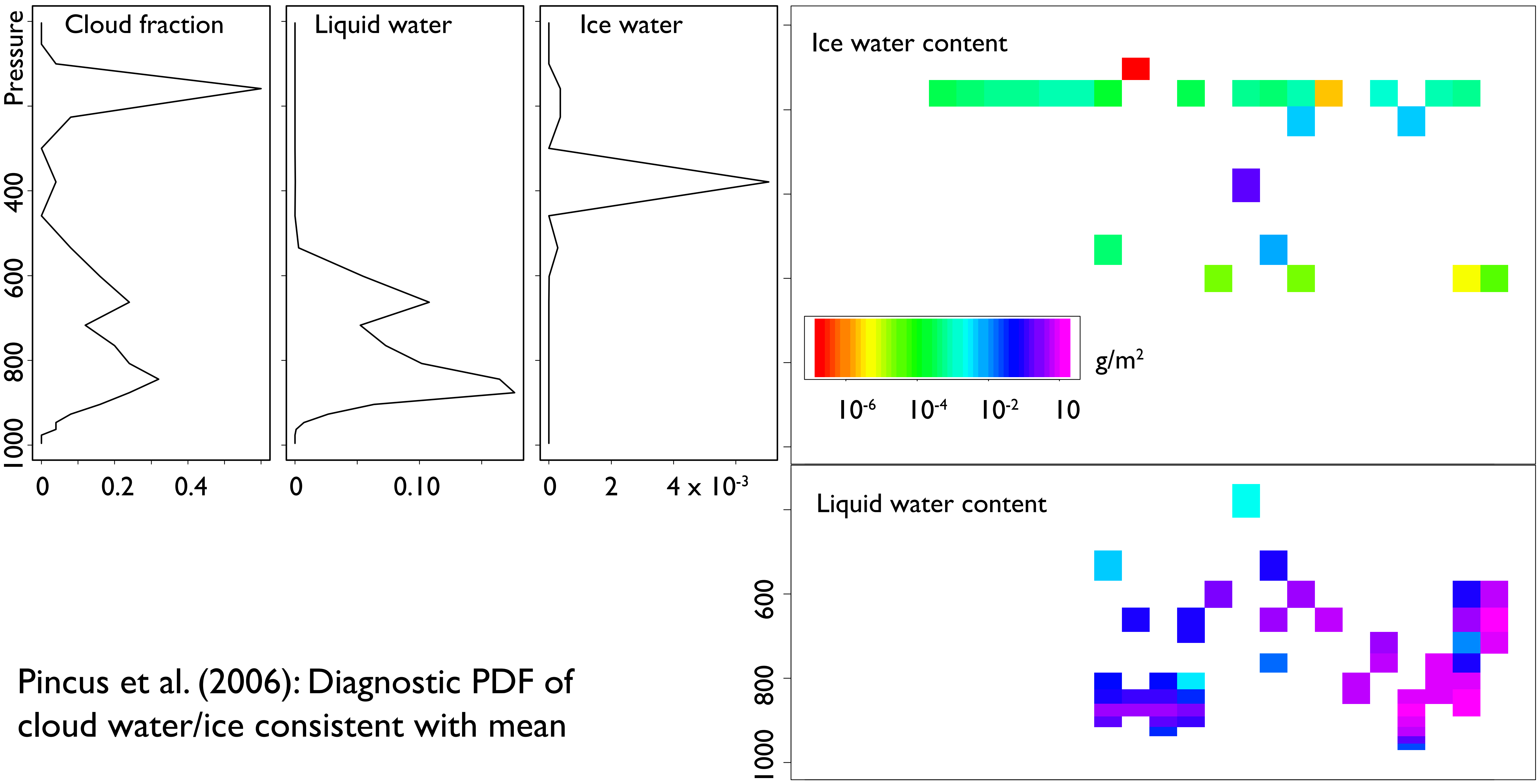
observational process

These are embodied in "instrument simulators" that operate on subcolumns

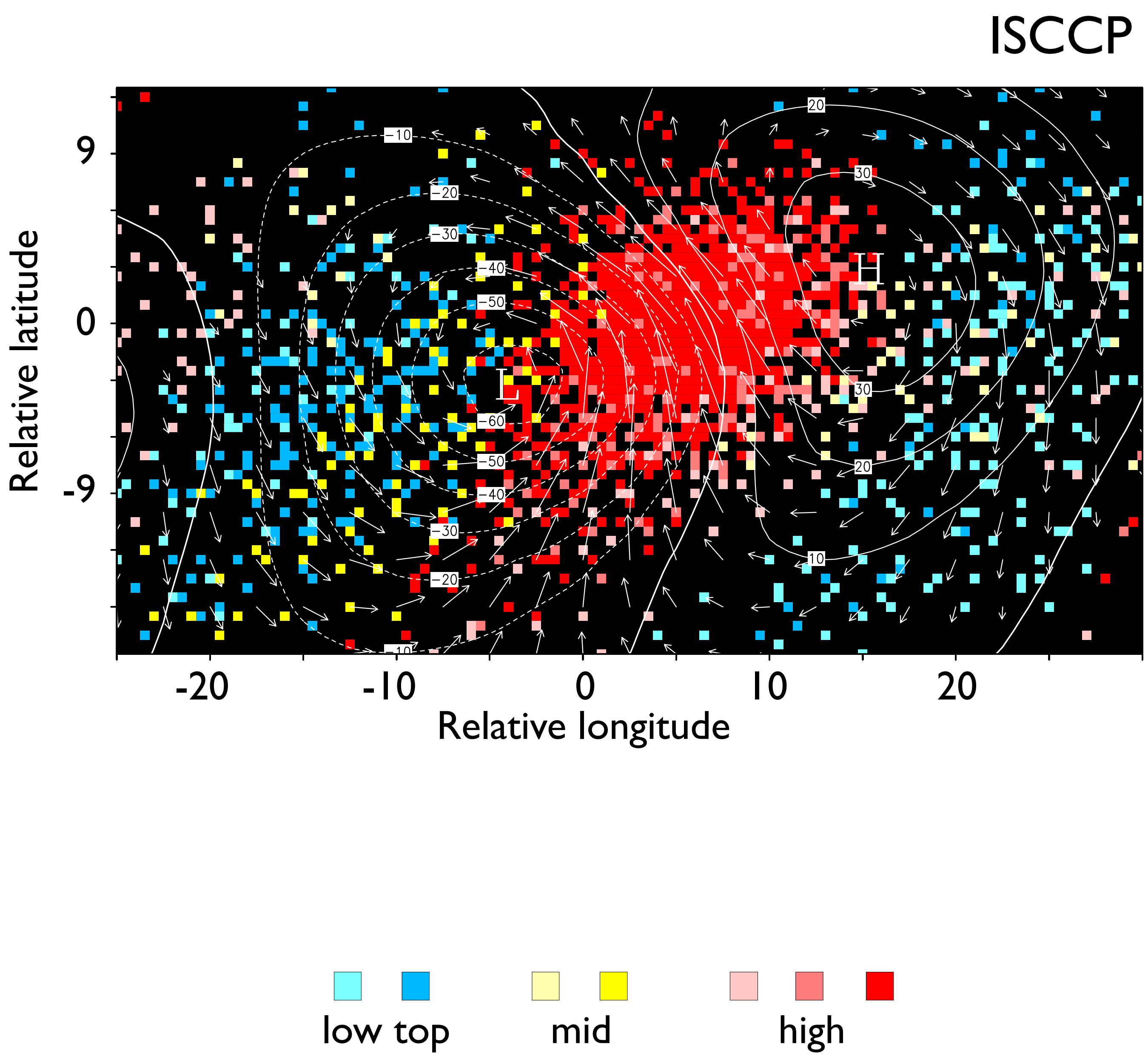
Sampling model state to treat fractional cloudiness/masking

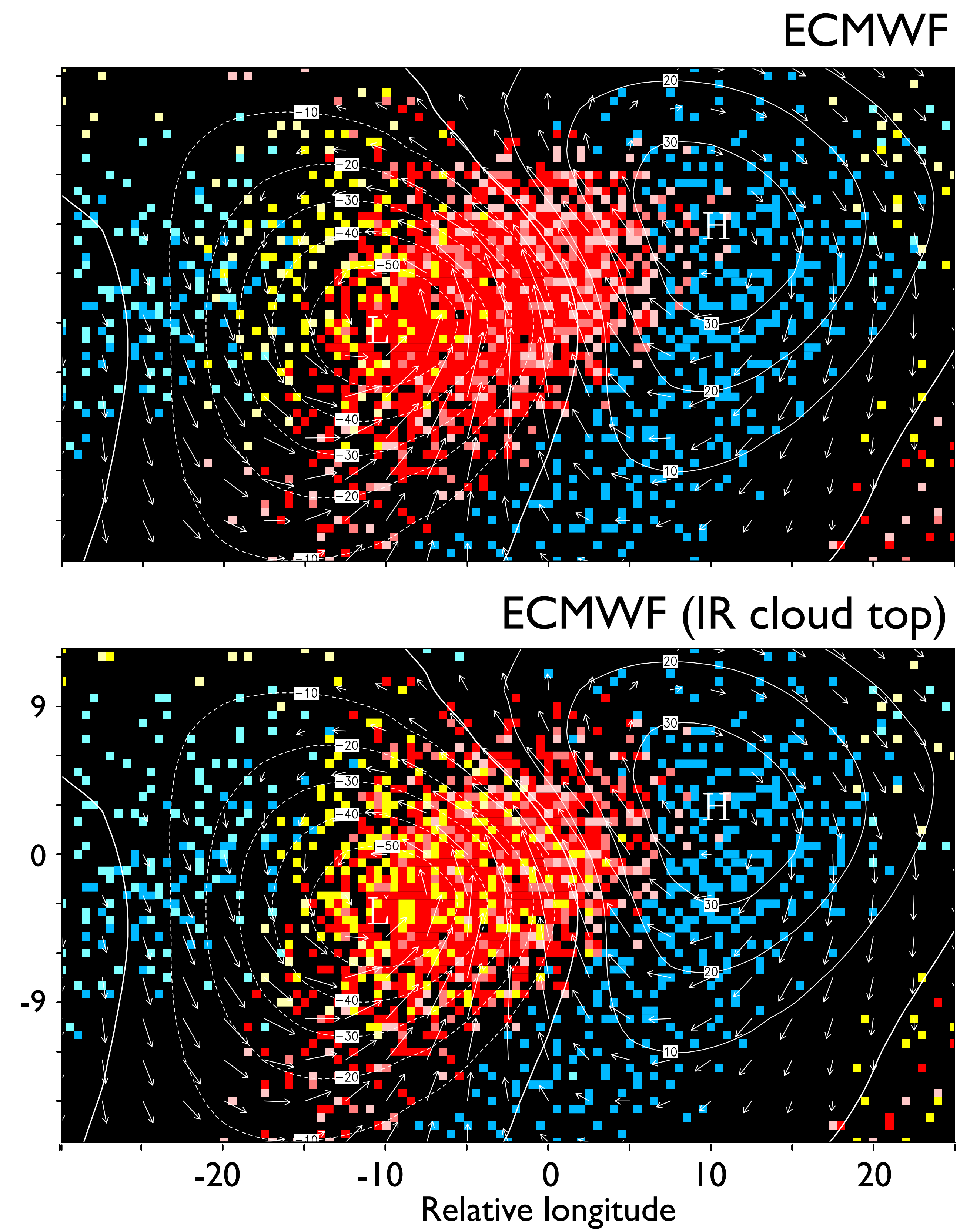


Sampling model state to treat fractional cloudiness/masking



Pincus et al. (2006): Diagnostic PDF of cloud water/ice consistent with mean





After Klein and Jakob, MWR, 1999

A MODIS simulator for climate models (i)

Accepts sub-column inputs of $r_{e(l,i)}(z), \tau_{(l,i)}(z) \text{ or } q_{(l,i)}(z)$

Provides subcolumn 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)

A MODIS simulator for climate models (ii)

Estimate liquid, ice water path from optical thickness, particle size

Aggregate sub-columns

cloud fractions (total, liquid, ice, high, middle, low)
in-cloud linear means of all quantities
in-cloud logarithmic mean for optical thickness
optical thickness/cloud top pressure joint histogram
(18 statistics total)

A MODIS simulator for climate models (iii)

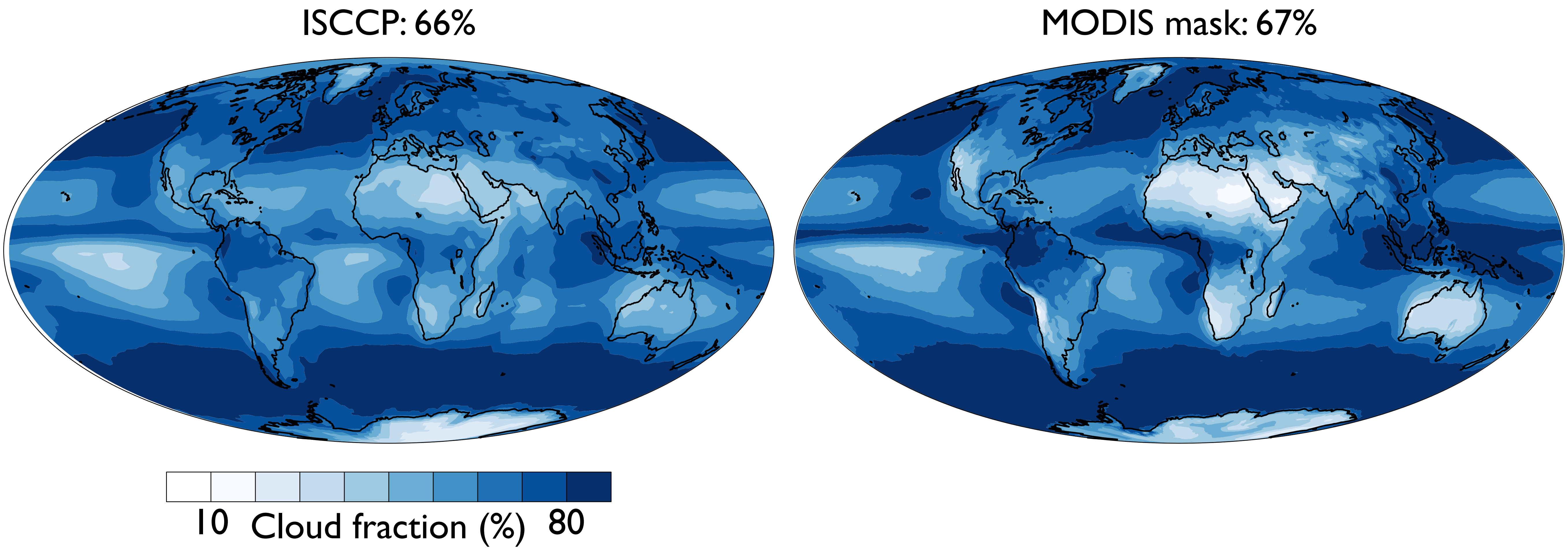
MODIS simulator distributed as part of the larger COSP package

Available in essentially every GCM,
though MODIS output is not required for CMIP5

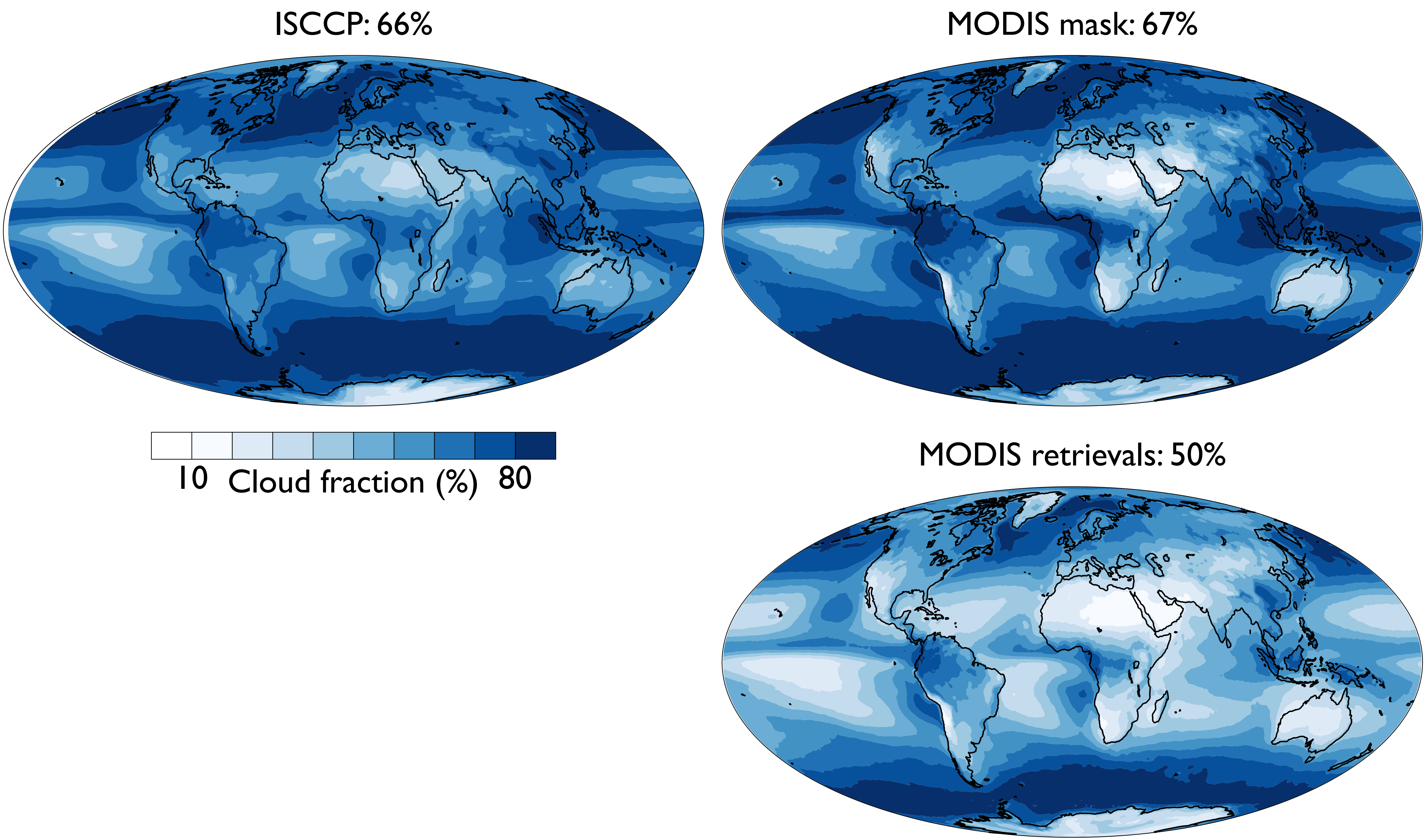
We provide a customized data set for comparisons

Included results from cloud mask and cloud retrievals -
and that’s where the fun begins

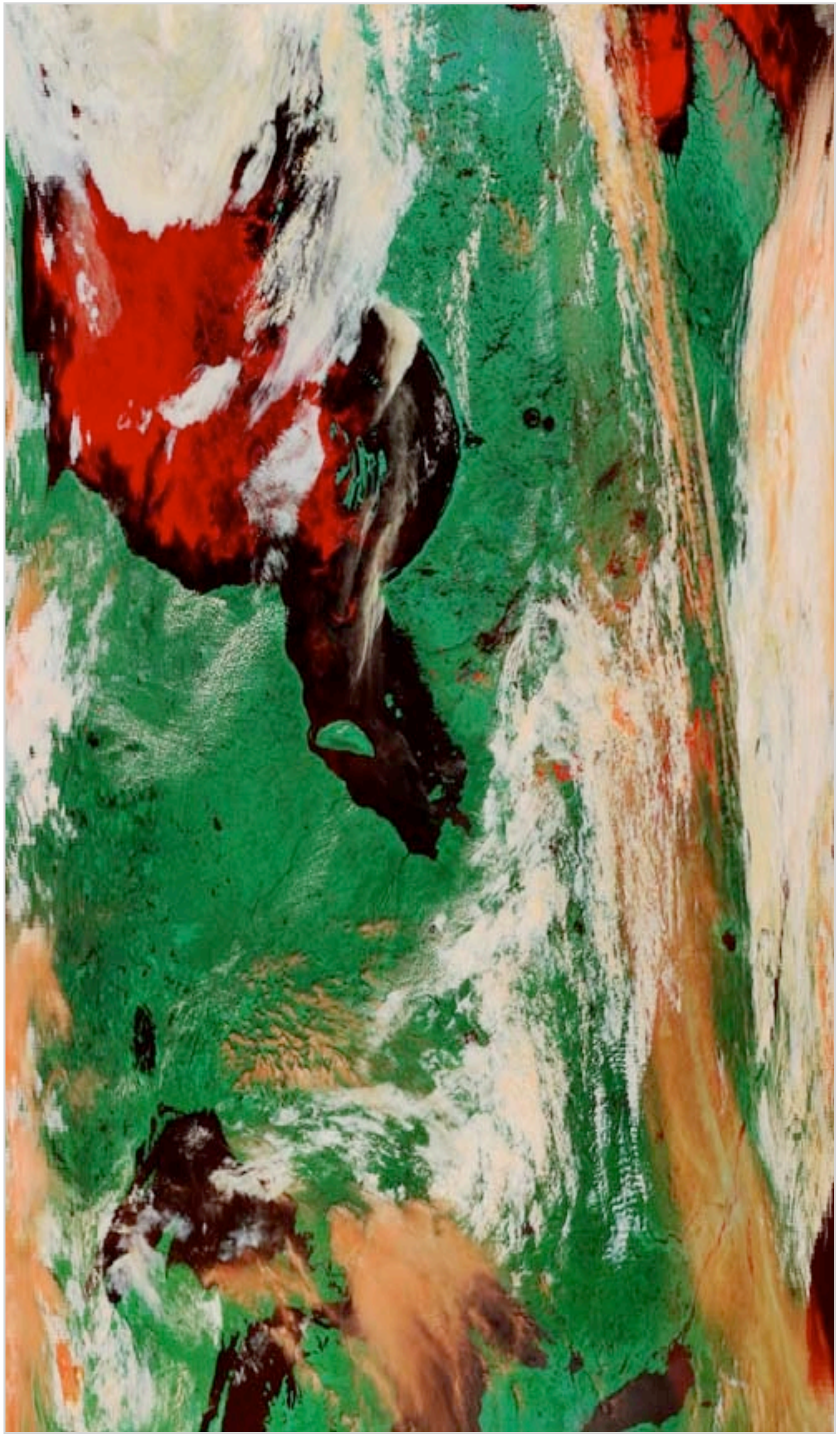
How much of the planet is cloudy?



How much of the planet is cloudy?



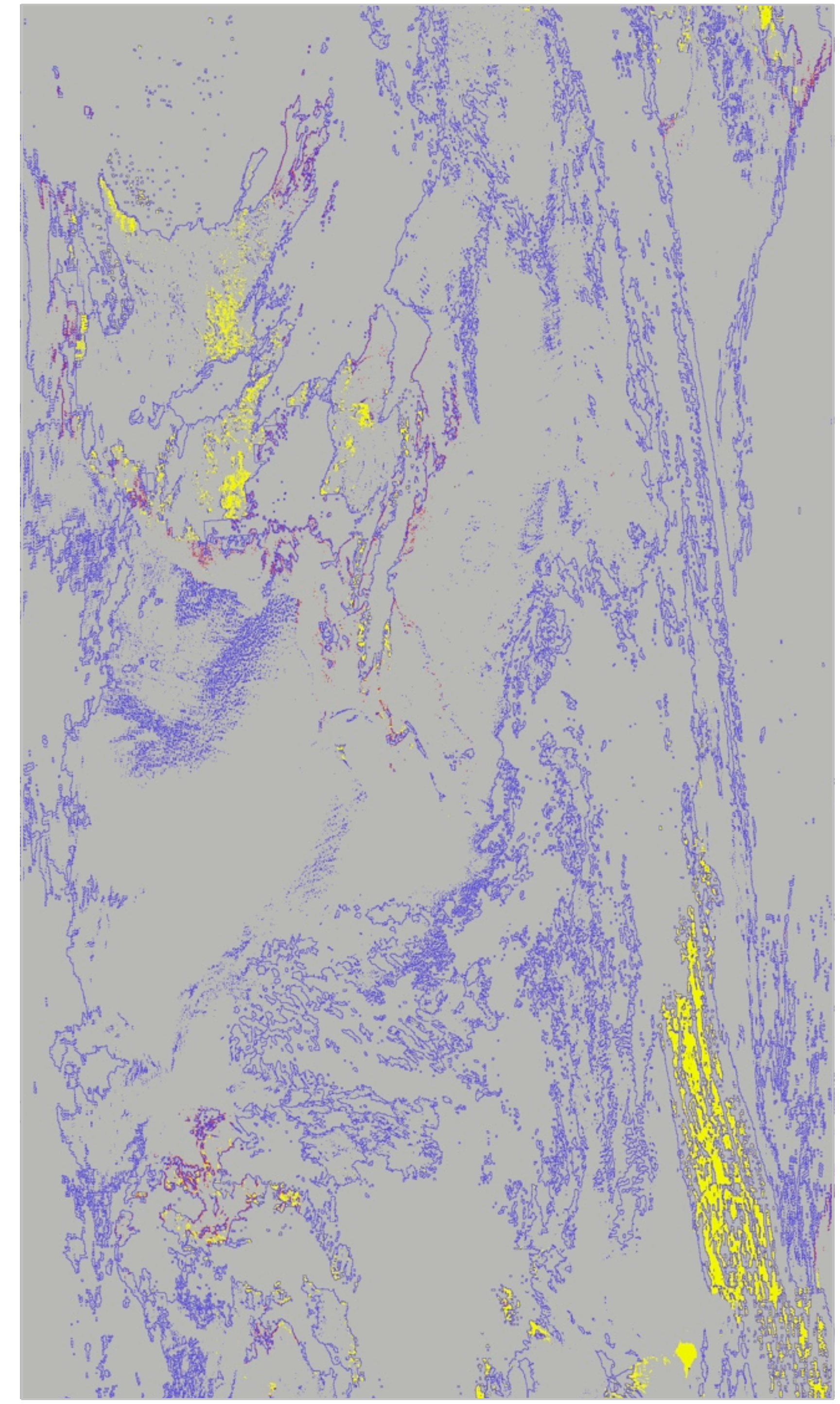
SWIR composite



Cloud Mask overall conf.

probably clear
clear
cloudy
probably cloudy

"Clear Sky Restoral"

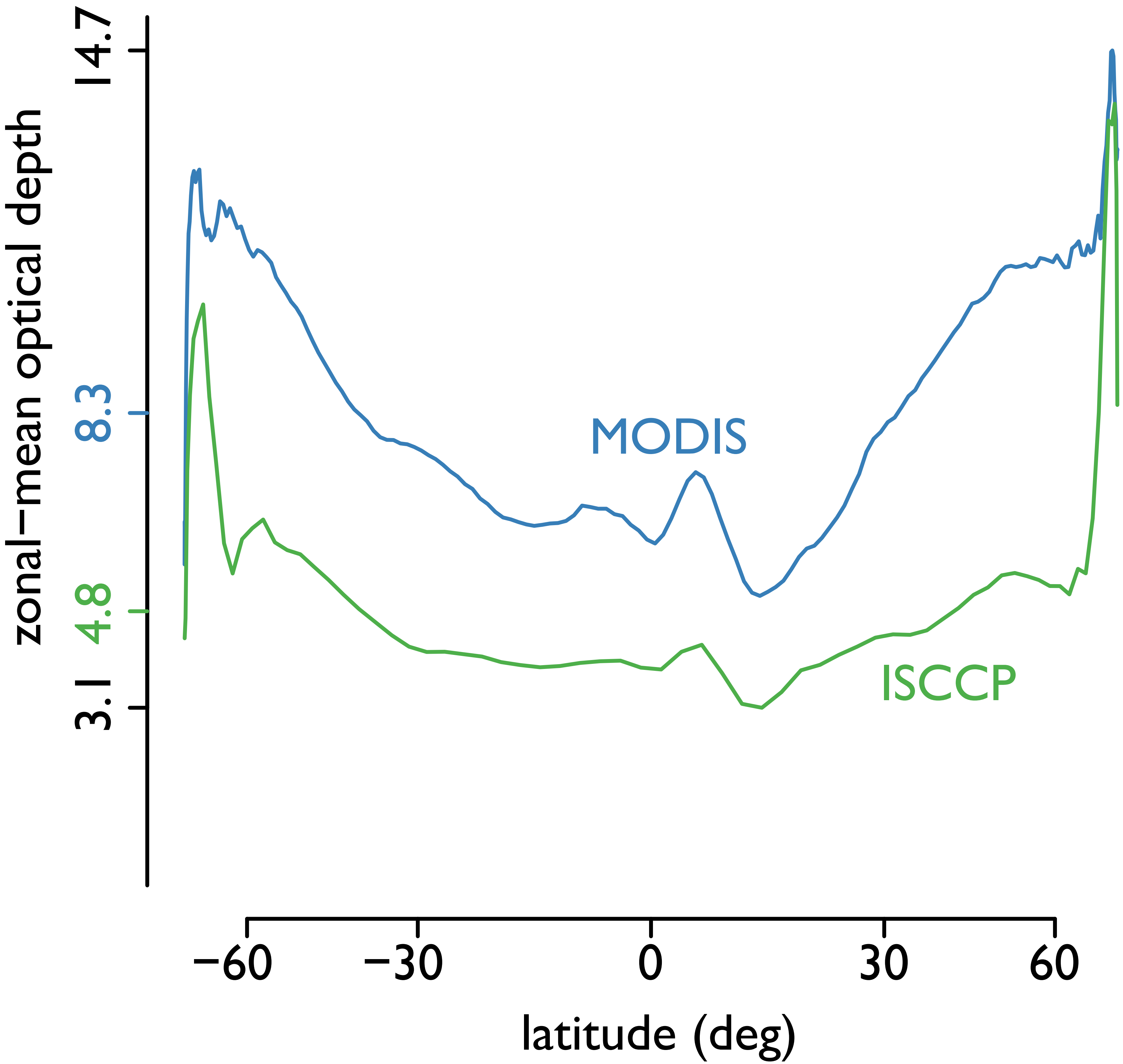


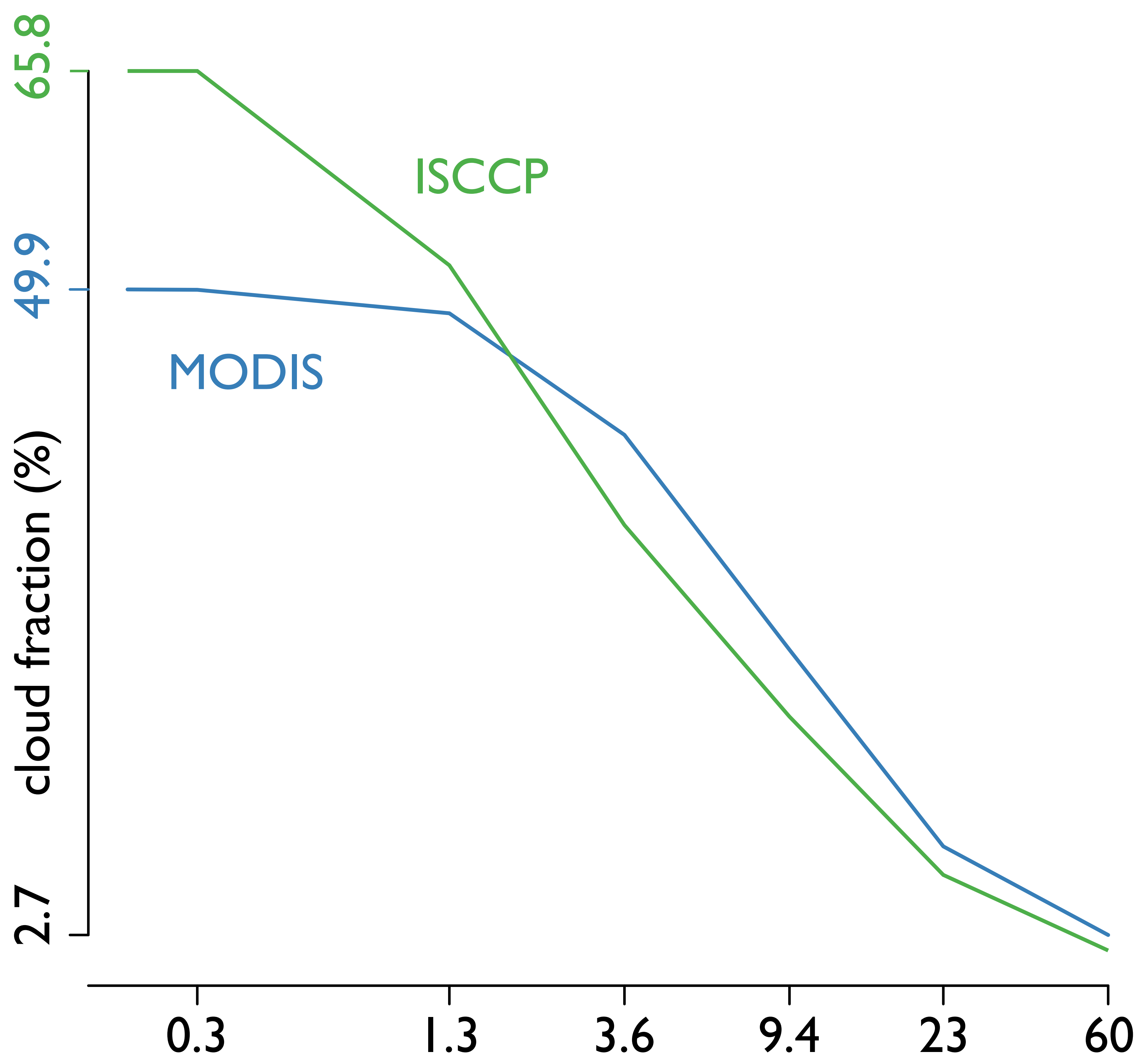
spatial/spectral tests
edge detection
250m cloud mask

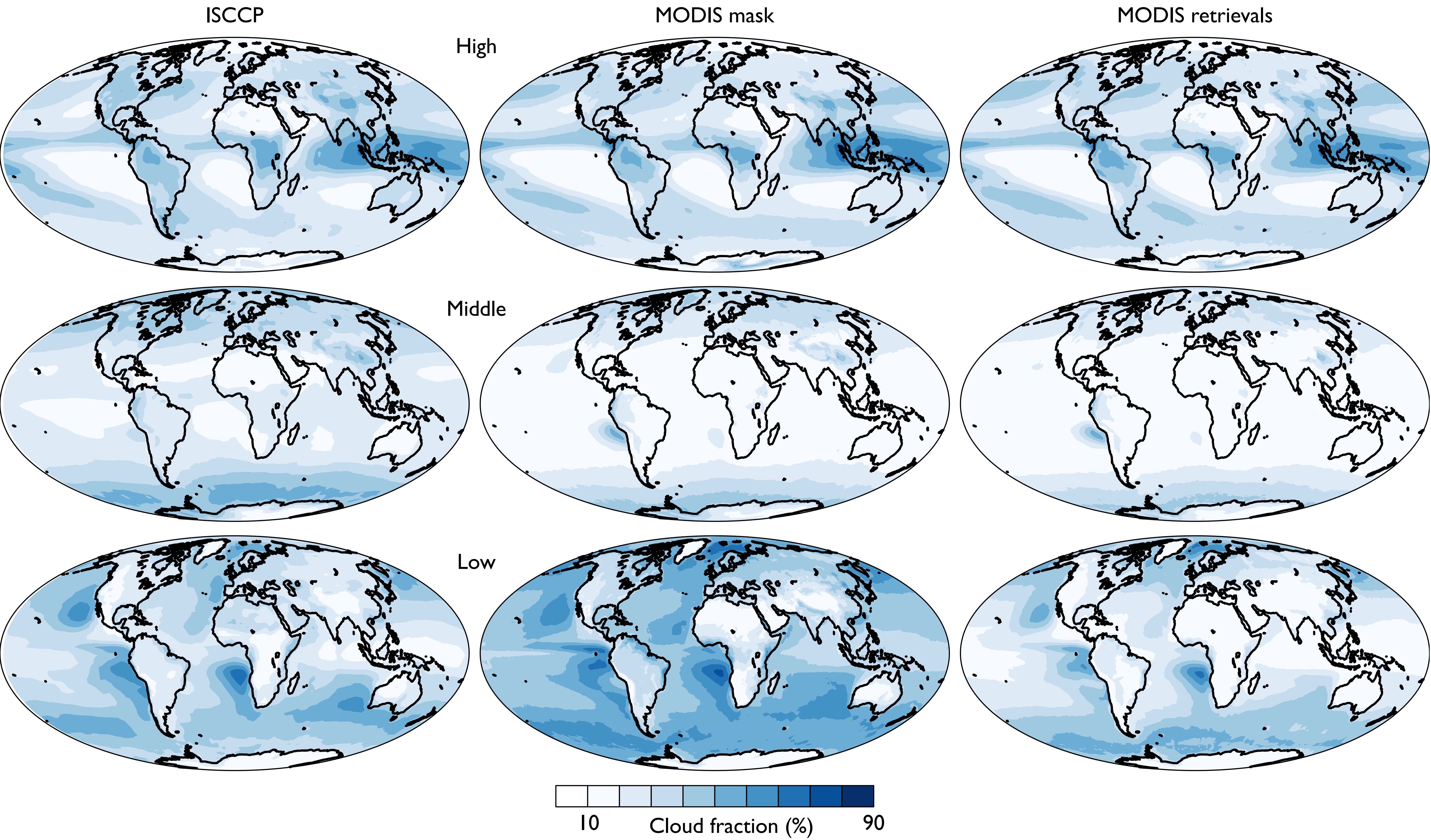
Clear-sky restoral was introduced in Collection 5

One practical goal was to reduce the very large particle sizes obtained from MODIS 2.1 μm observations, but...

Clear-sky restoral didn’t change average particle size values much because retrievals at cloud edges were failing


14.7
8.3
4.8
3.1
zonal−mean optical depth
MODIS
ISCCP
−60
−30
0
30
60
latitude (deg)


65.8
49.9
2.7
cloud fraction (%)
ISCCP
MODIS
0.3
1.3
3.6
9.4
23
60
minimum optical depth



ISCCP
MODIS mask
MODIS retrievals
High
Middle
Low
10
Cloud fraction (%)
90

Observation

Pixels are removed by clear-sky restoral mostly because they are near cloud edges or are inhomogeneous at 250 m scale

This population is

nearly all the clouds observed by ISCCP with $\tau < 1.3$

assigned high cloud top pressure by MODIS but distributed through the atmosphere by ISCCP (~1/3 are consistent with failed retrievals by ISCCP)

Interpretation

Roughly 15% of the planet is covered by clouds less than 1 km in size

- Omitting these pixels leads to truncation errors
- Literal interpretations of retrievals is inappropriate

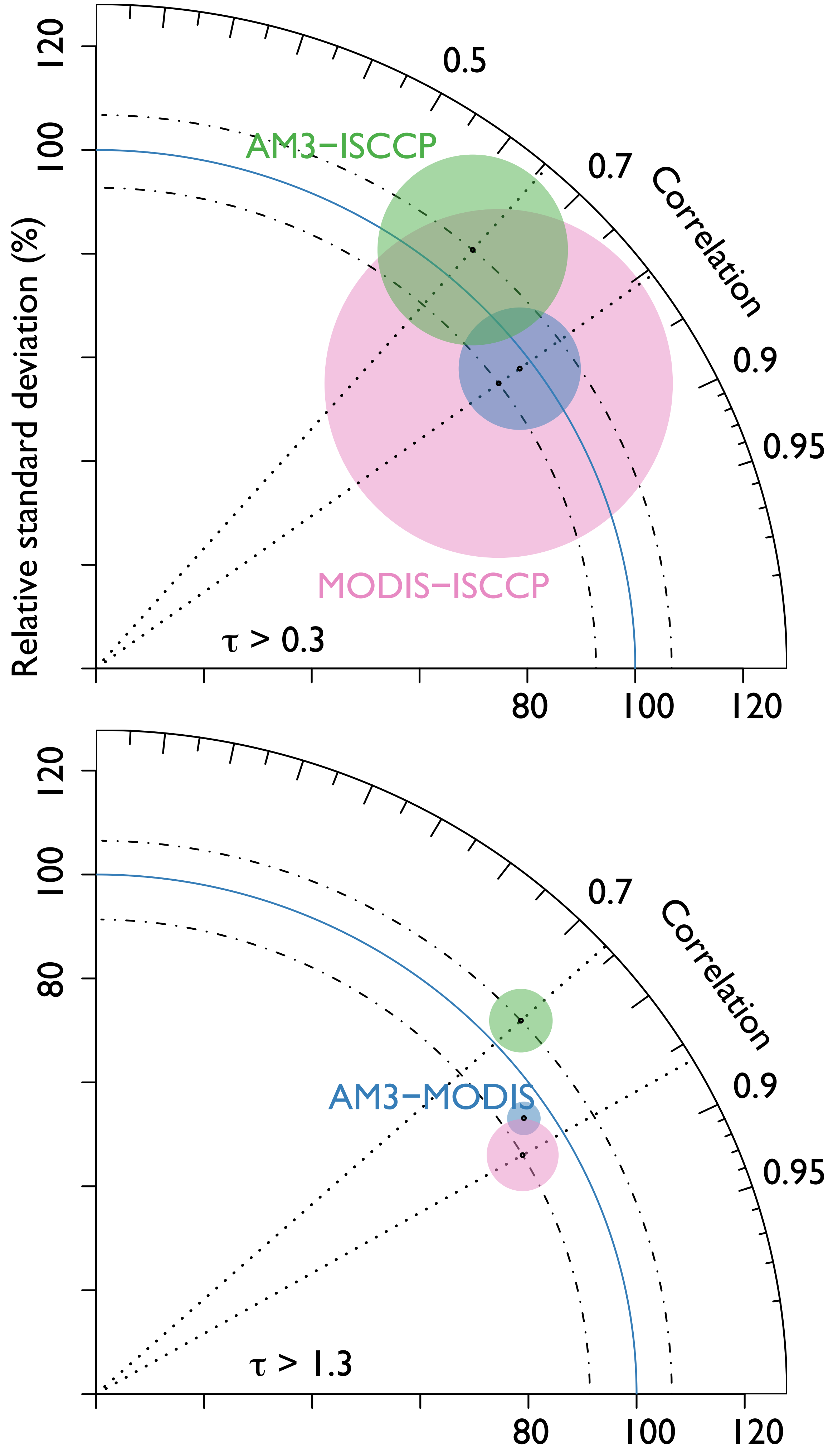
Implication

Cloud fraction estimates explicitly depend on detector resolution and sensitivity

Large-scale models have no concept of spatial scale below the grid size

Total cloudiness is a fragile basis for comparison

Comparisons among observations (and between models and observations) are fair only when the same population is included



Relative standard deviation (%)
120
100
0.5
0.7
0.9
0.95
Correlation
AM3−ISCCP
MODIS−ISCCP
τ > 0.3
80
100
120
120
100
80
0.7
0.9
0.95
Correlation
AM3−MODIS
τ > 1.3
80
100
120

Working with the climate modeling community means

- doing some translation
- understanding our observations more fully
- acknowledging when we simply can’t speak the same language