

Evaluating Clouds in CESM2 using satellite-based observations

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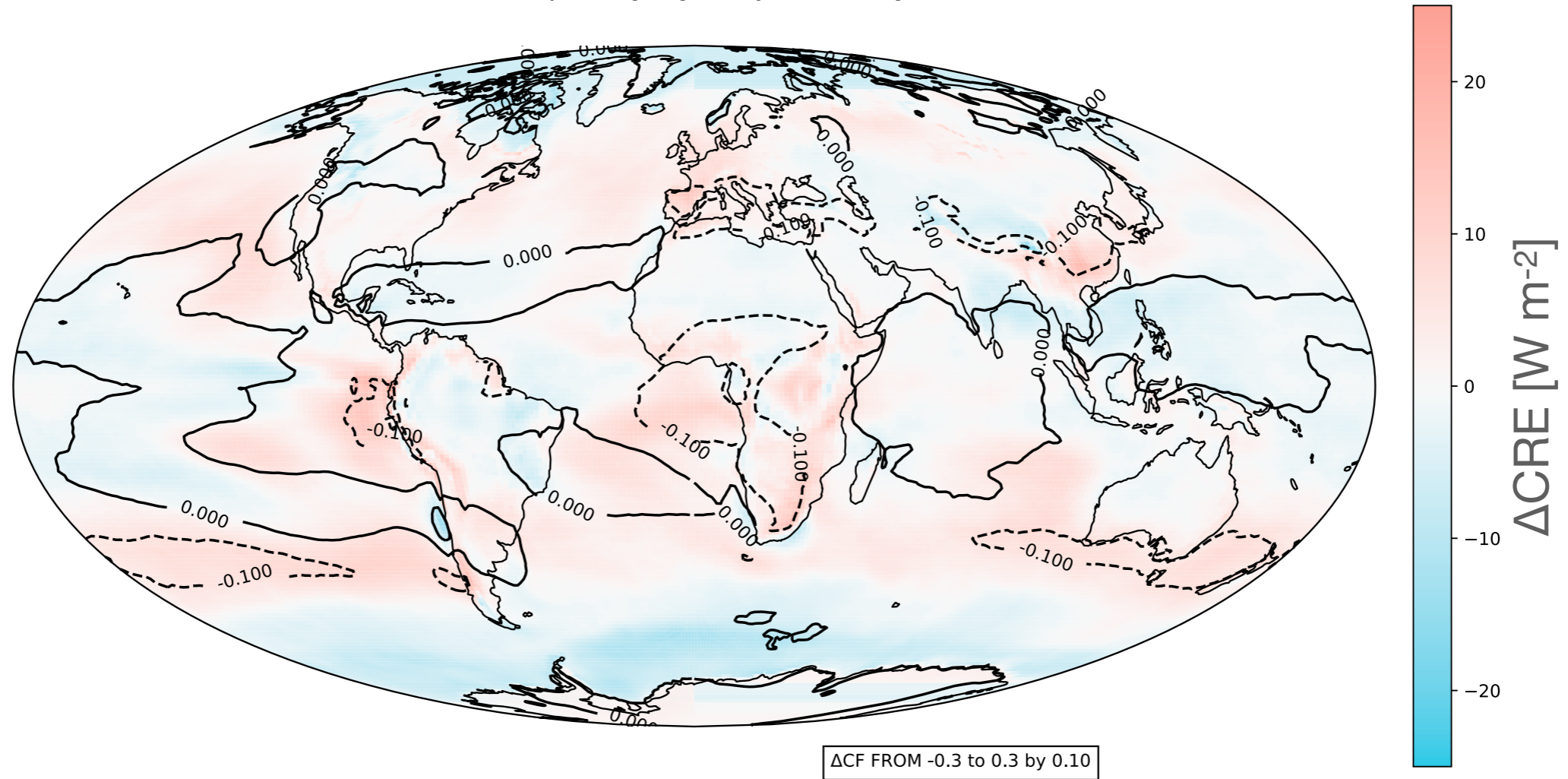
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- ❖ This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977
- ❖ *This work also supported by DOE through subcontract No. B631711 under Prime Contract No. DE-AC52-07NA27344*
- ❖ Portions of this study were supported by the Regional and Global Model Analysis (RGMA) component of the Earth and Environmental System Modeling Program of the U.S. Department of Energy's Office of Biological & Environmental Research (BER) via National Science Foundation IA 1844590.

Some motivation

Uniform Warming
(amip-p4k) - amip



Does CESM2 have any significant biases in cloud cover and/or cloud radiative effect?

How do such biases compare to other CMIP6 models?

simulated climate

“amip”

1950/1979 - 2014
Monthly observed SST/ice

“historical”

1850-2014
Realistic forcing

CMIP6

33-ish models; all ensemble members available @tod
12-ish with COSP output

observational basis

CERES EBAF Ed4.1

Monthly radiative fluxes.
Nominal 1° resolution.
2001-2018

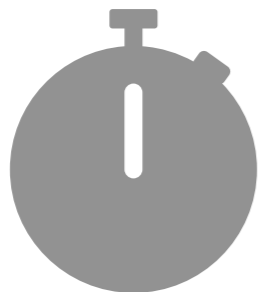
ISCCP H-series

Monthly cloud cover, binned by cloud-top pressure & cloud optical depth.
Nominal 1° resolution.
1984-2018*

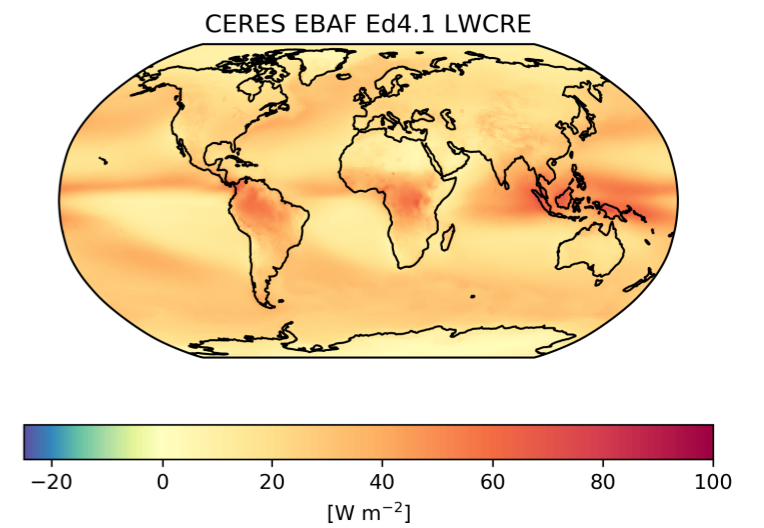
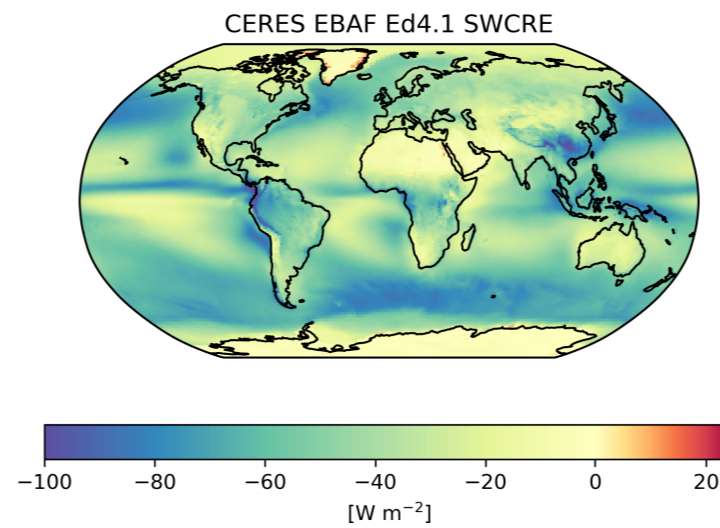
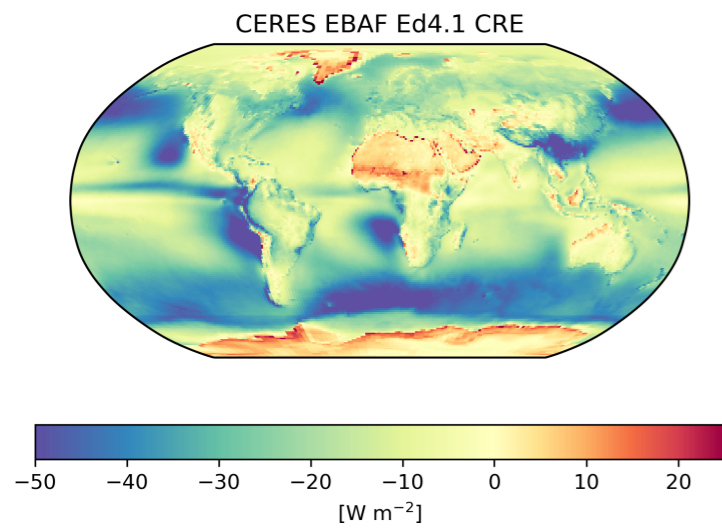
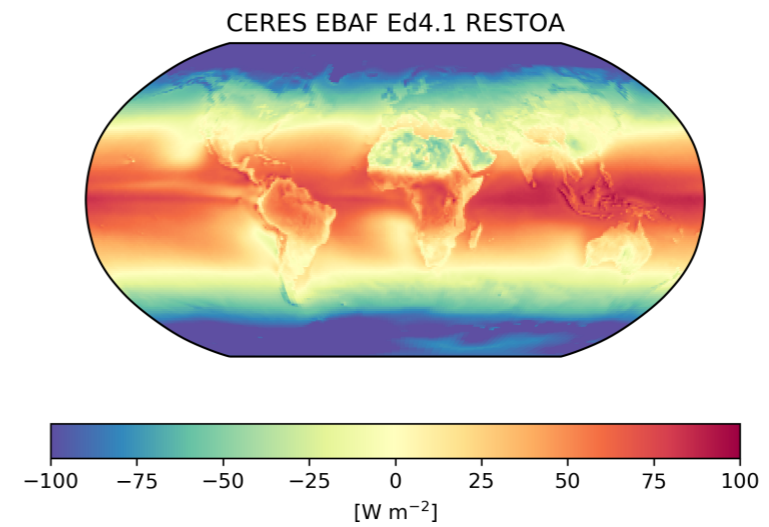
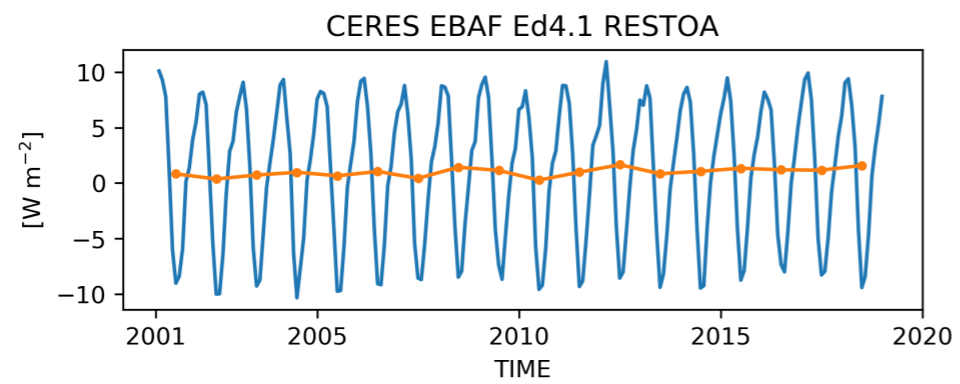
CALIPSO GOCCP v3.1.2

Monthly cloud cover binned by height.
Nominal 2° resolution.
2006-2019

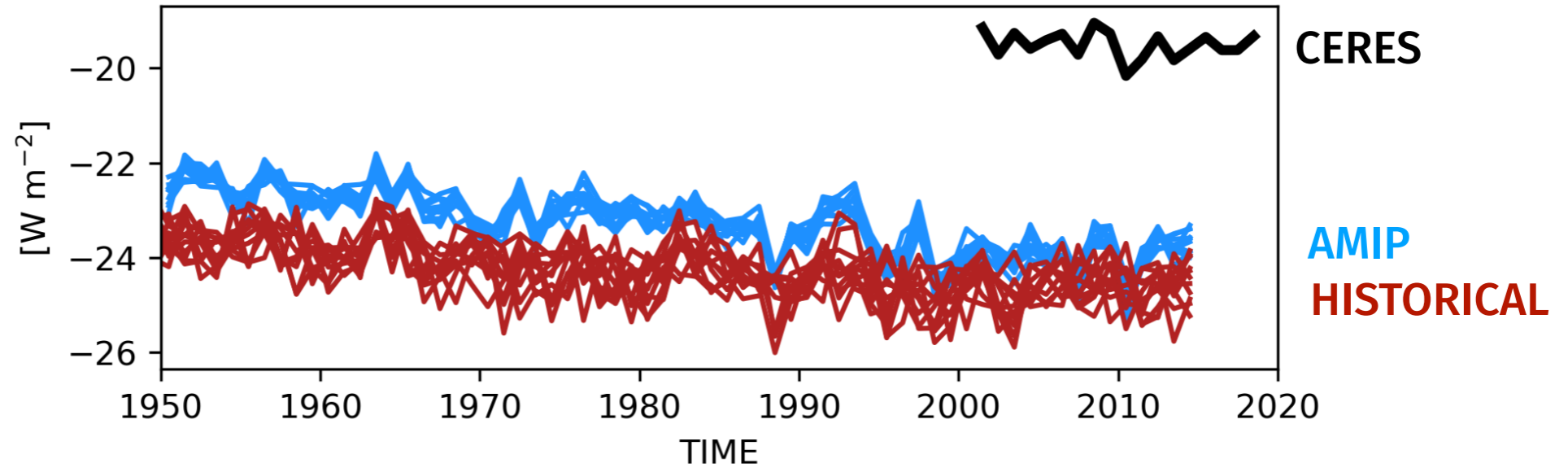
MODIS
MISR
CloudSat



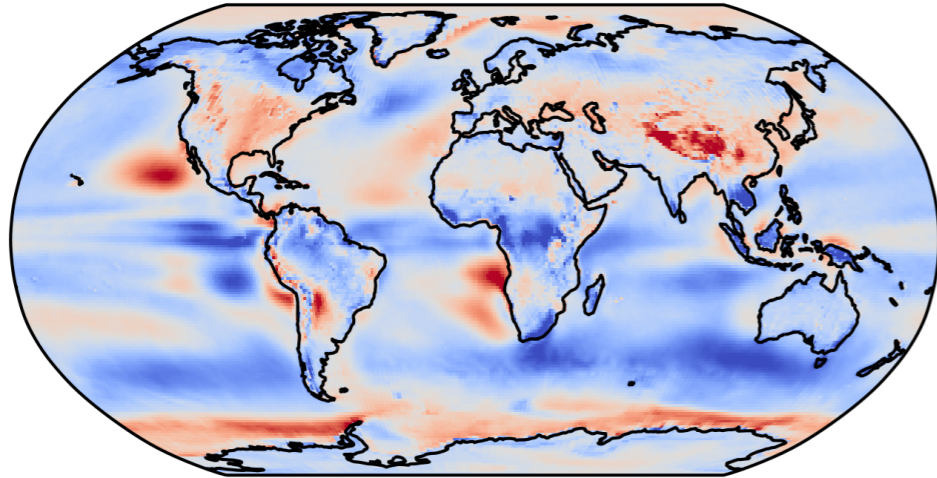
CERES EBAF Ed4.1



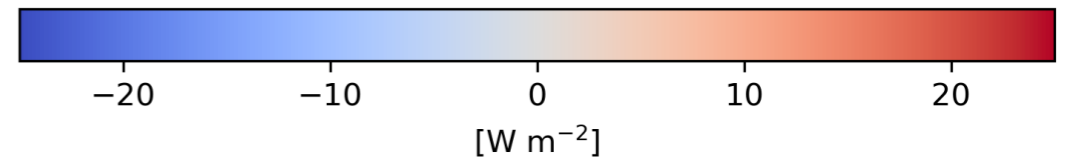
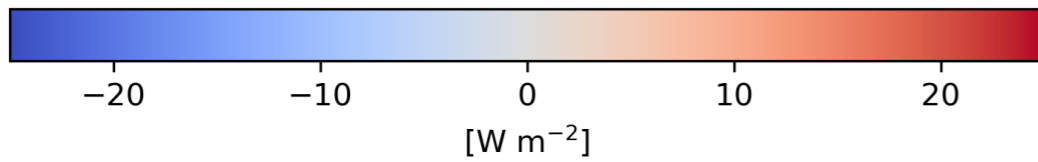
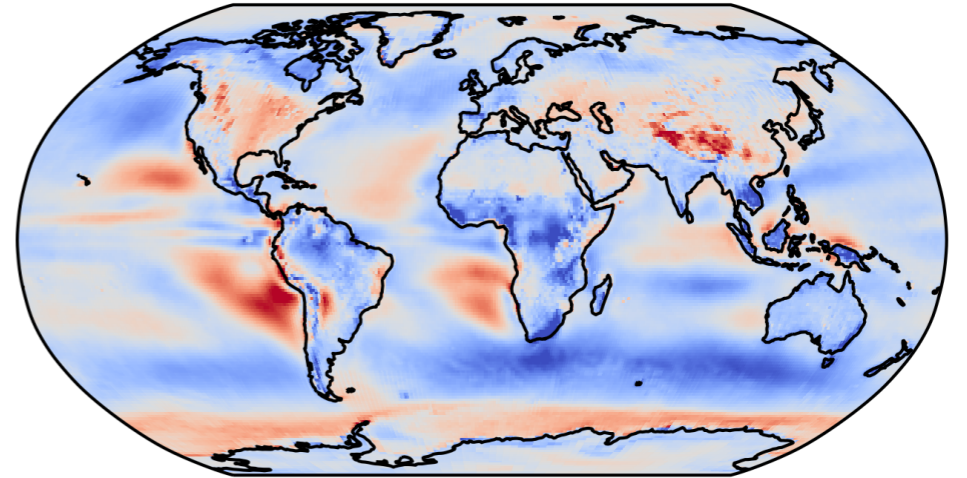
CESM2 CRE



CRE: CESM2 Historical (ens. mean) - CERES

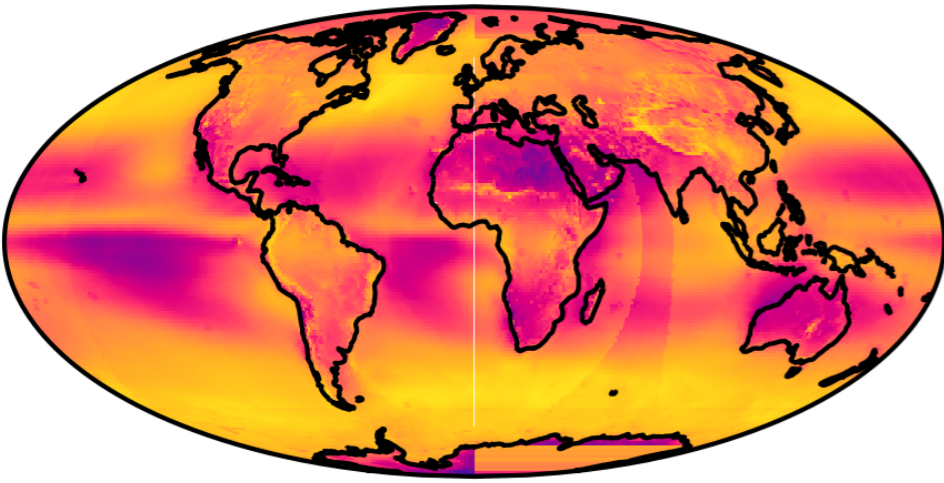


CRE: CESM2 AMIP (ens. mean) - CERES

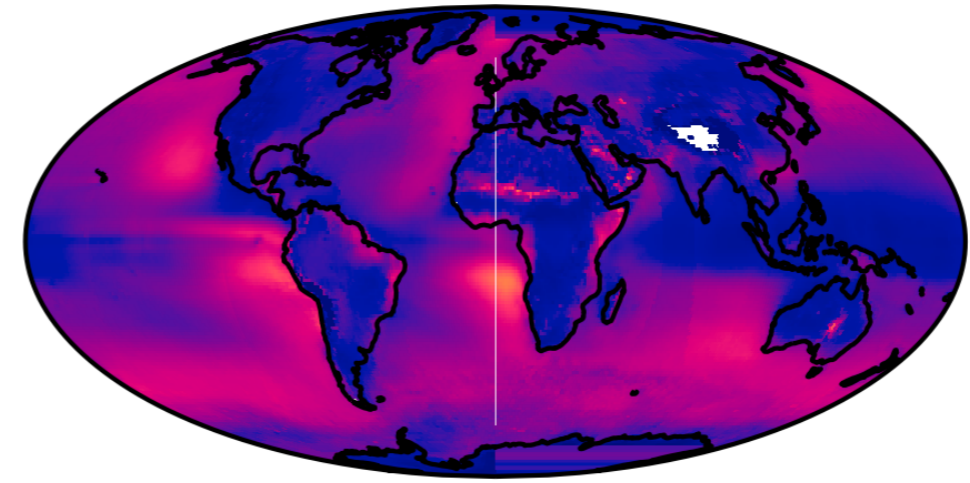


Blue
Model is reflecting too much shortwave

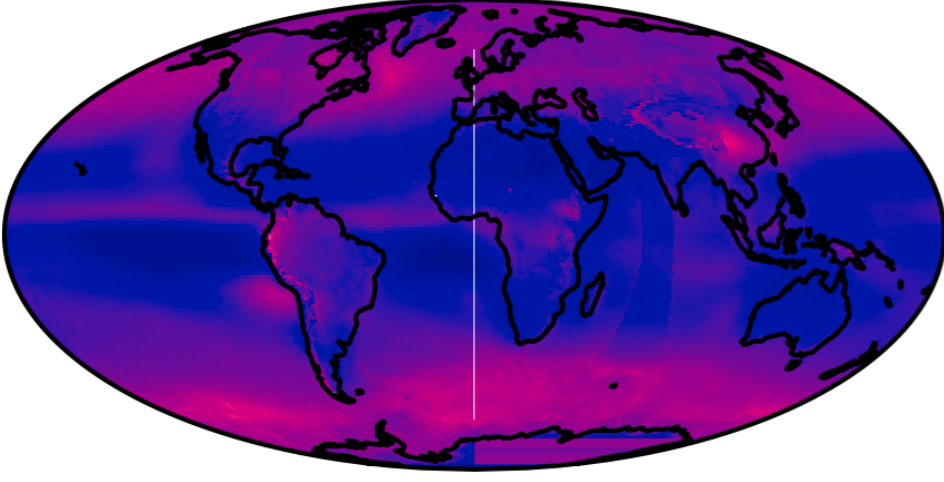
Total cloud fraction Avg: 67.5



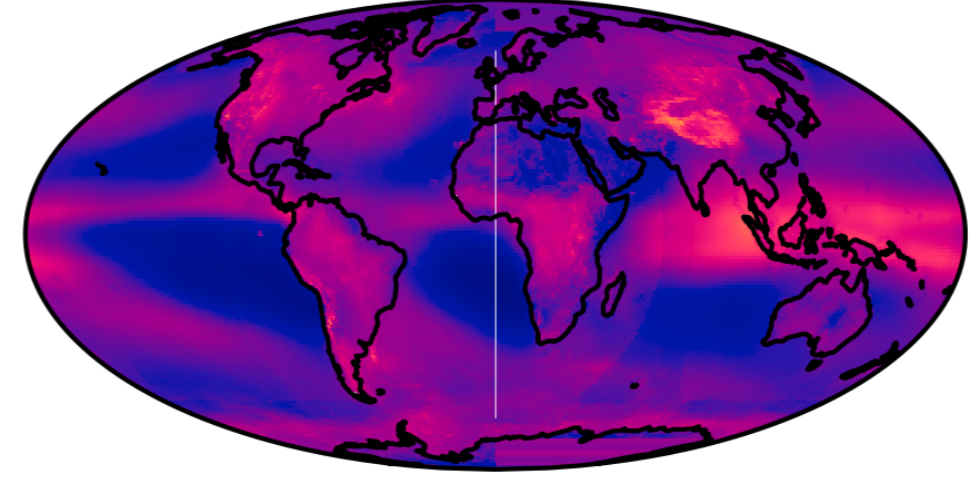
Low cloud fraction Avg: 23.6



Mid cloud fraction Avg: 19.3



High cloud fraction Avg: 24.7

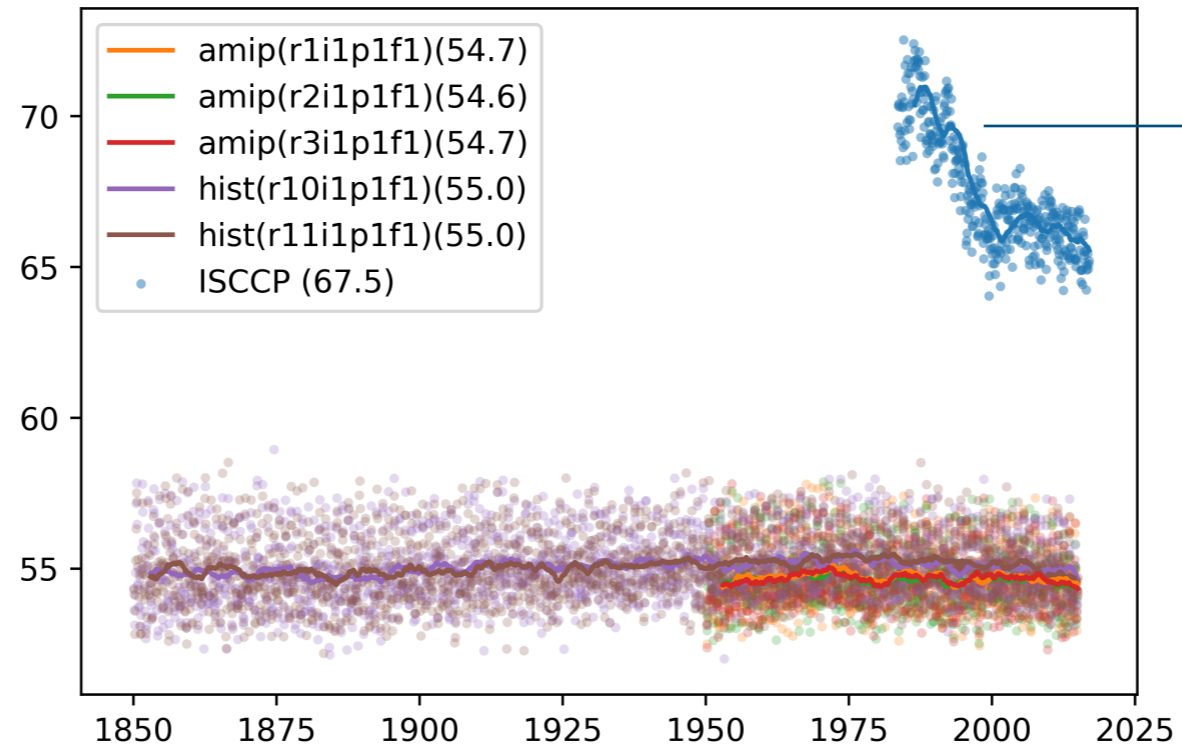


Note artifacts — especially in Indian Ocean. Persists 1984-1998.

CALIPSO climatology is qualitatively similar; without artifacts but with shorter record.

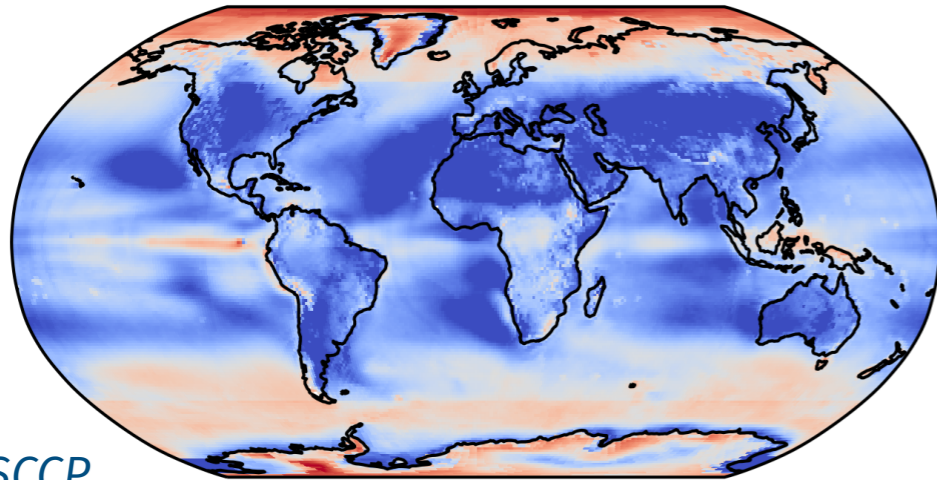


ISCCP (total), CESM2, amip + hist

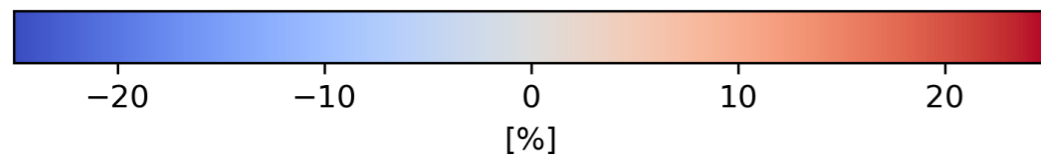


Spurious trend. 😞

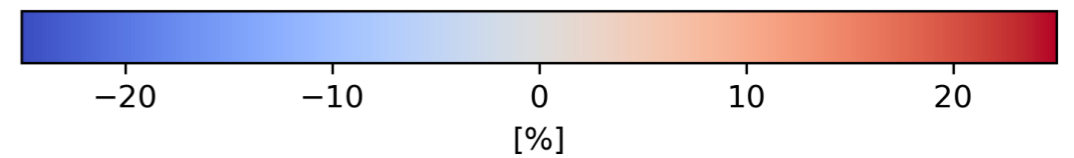
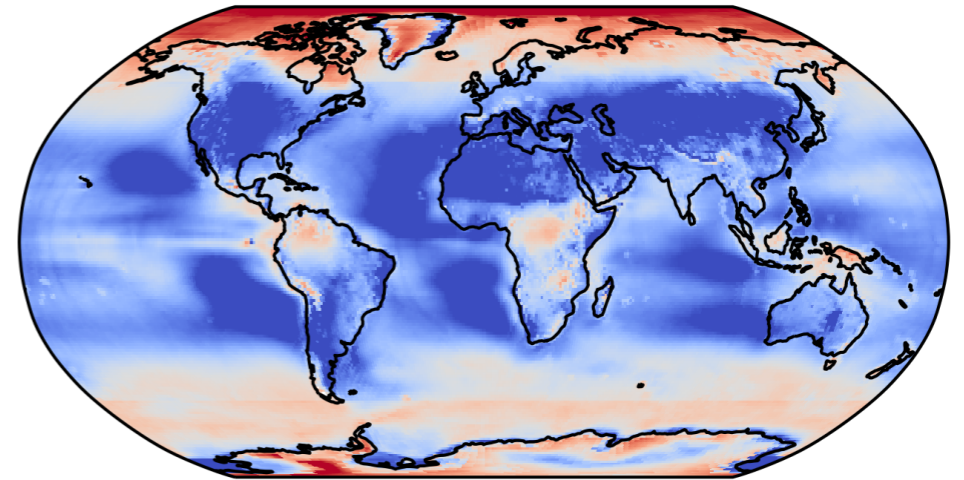
CF: CESM2 Historical (ens. mean) - ISCCP



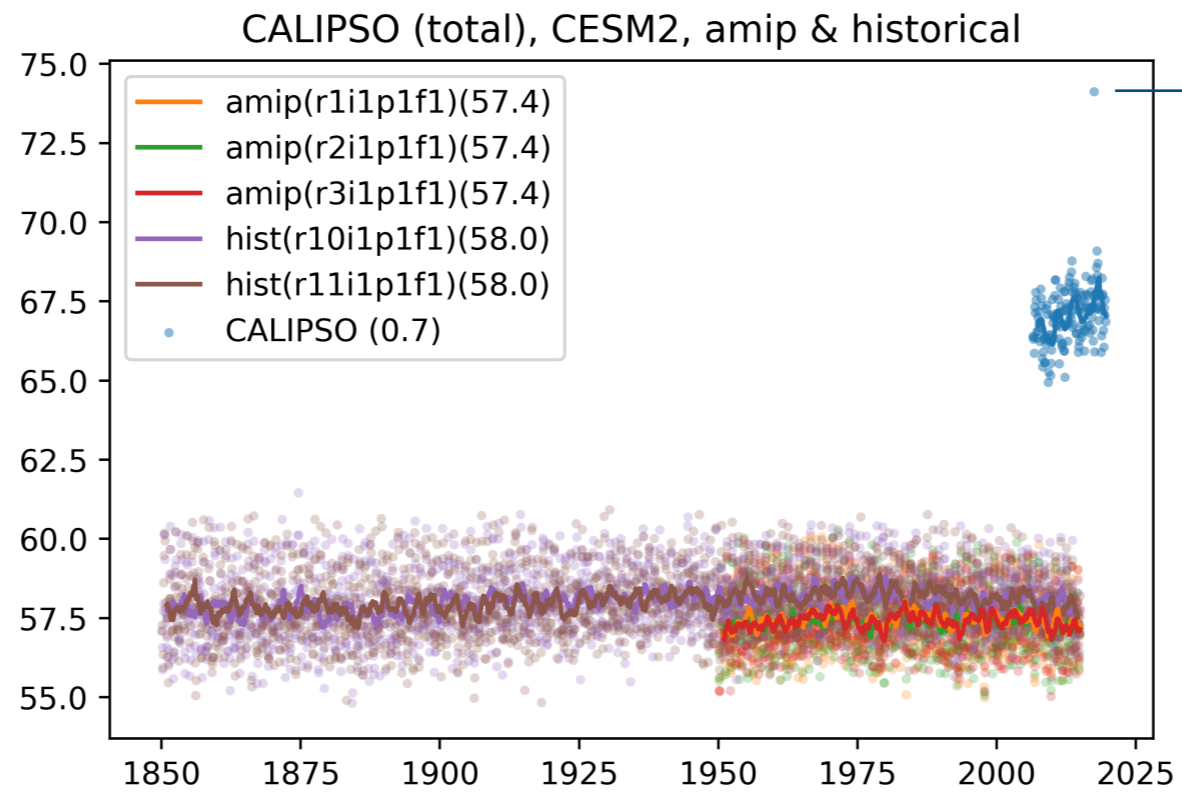
Use ISCCP
1999-2018.



CF: CESM2 AMIP (ens. mean) - ISCCP

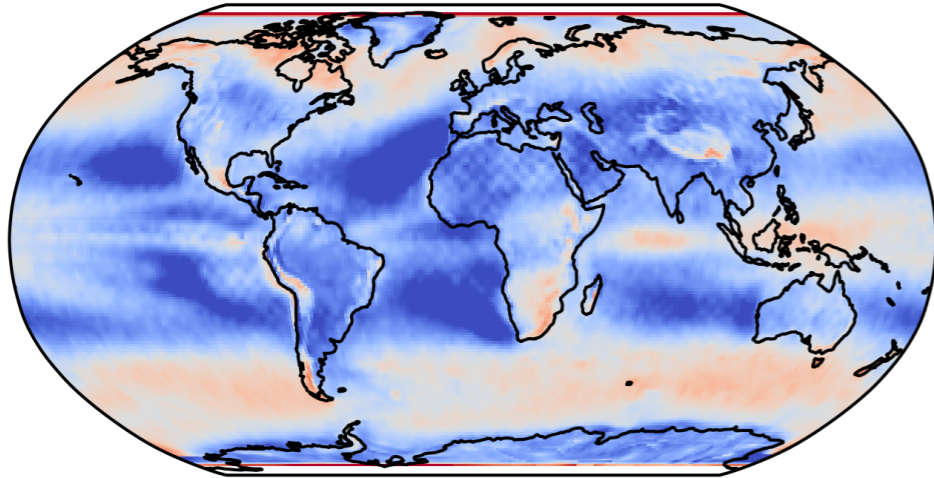


Blue
Model has too little
cloud cover

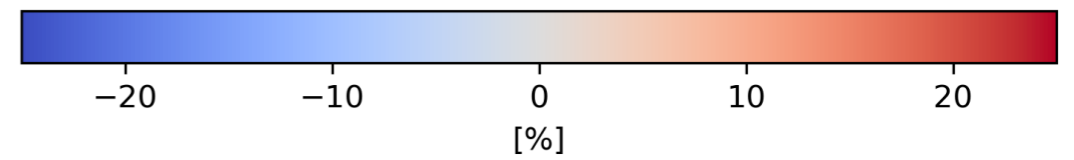
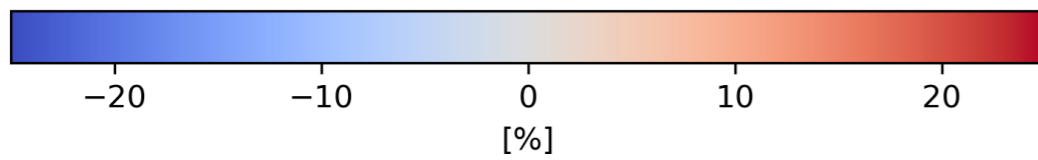
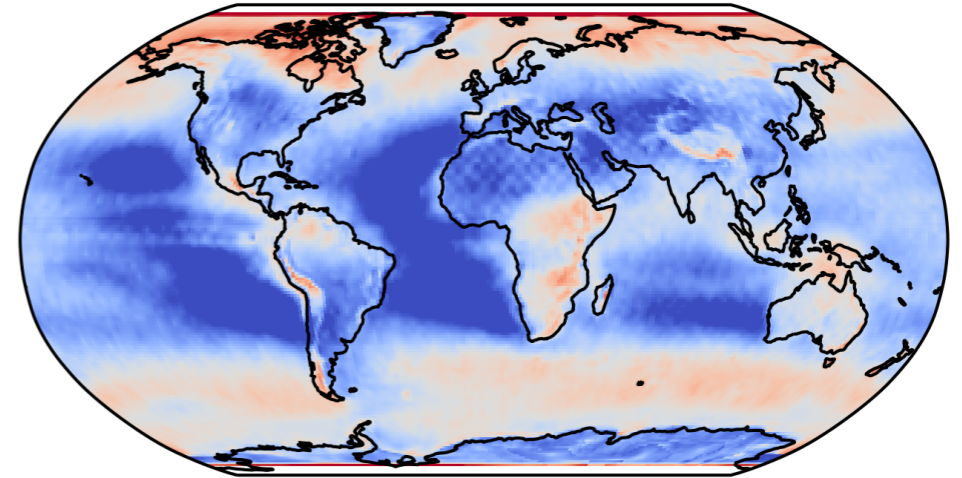


Spurious month? 🤔

CF: CESM2 Historical (ens. mean) - CALIPSO

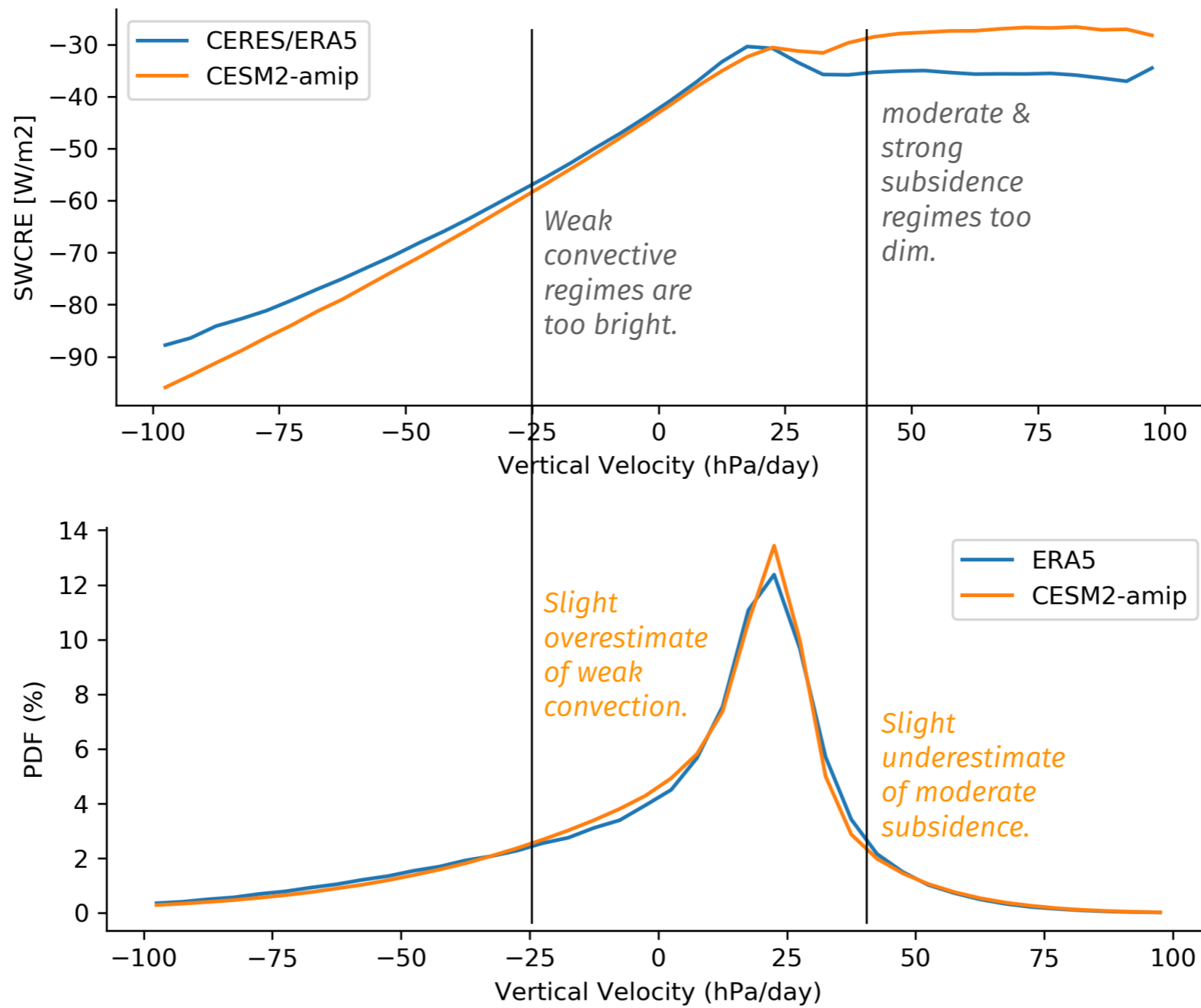


CF: CESM2 AMIP (ens. mean) - CALIPSO



Blue
Model has too little
cloud cover

Dynamical regimes (ω_{500})



Multi-model context

These large errors are cause for concern.

How do the CESM2 errors compare with other climate models.

For simple comparison, use normalized mean squared error (NMSE).

$$\text{NMSE} = \frac{[(\bar{X}_m - \bar{X}_o)^2]}{[\bar{X}_o']}$$

$$\text{NMSE}(X_m) = U + C + P$$

$$U = \left(\frac{[\bar{X}_m] - [\bar{X}_o]}{\sigma_o} \right)^2$$

$$C = \left(r - \frac{\sigma_m}{\sigma_o} \right)^2$$

$$P = (1 - r^2)$$

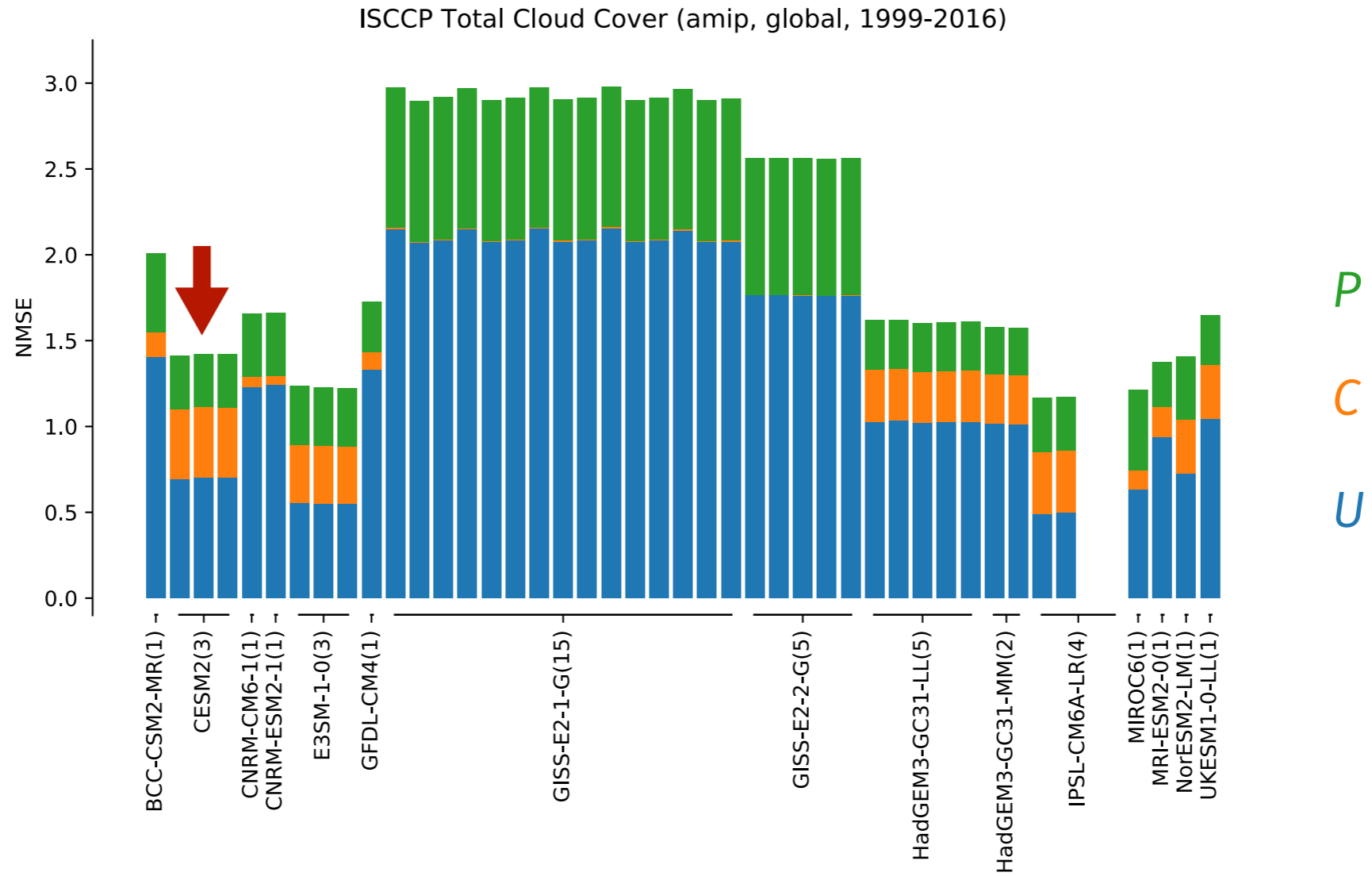
Temporal average

$$\bar{\chi} = \frac{1}{N_t} \sum_t \chi_t(\lambda, \phi)$$

Spatial average

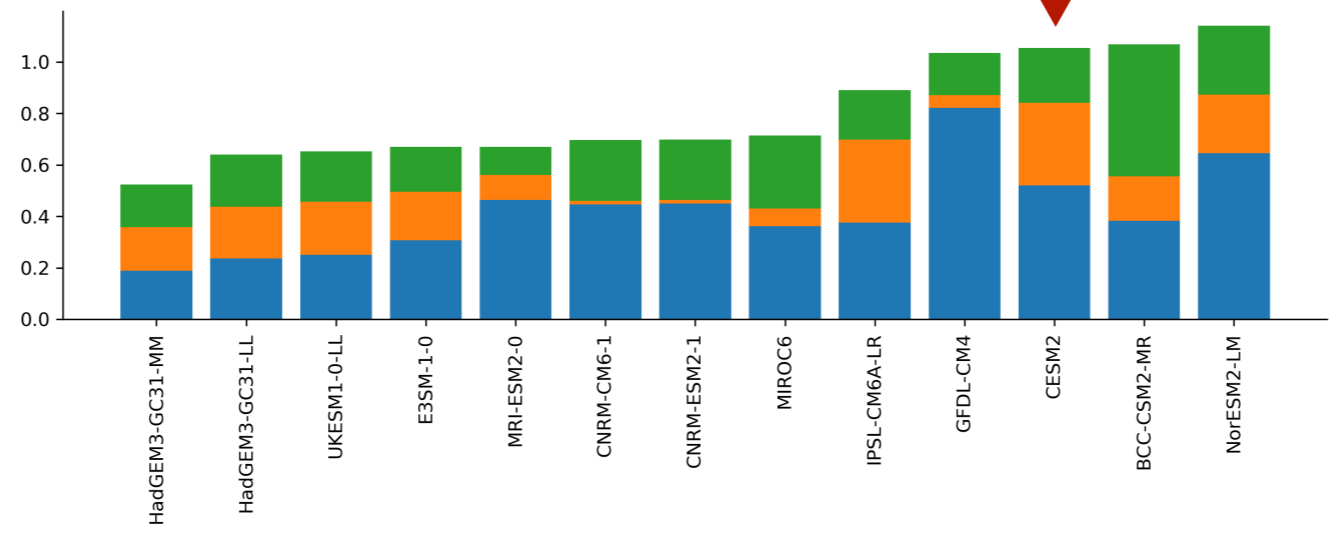
$$[\chi] = \frac{\sum_i \cos(\phi_i) \chi_i}{\sum_i \cos(\phi_i)}$$

Structural error variability is large.

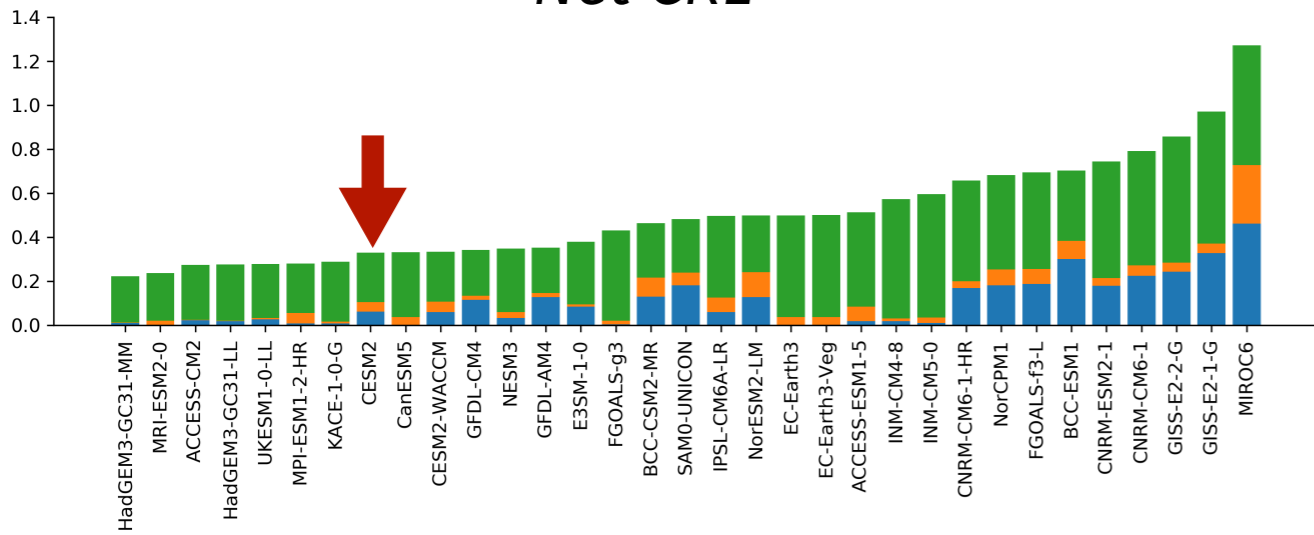


Internal variability appears negligible.

CALIPSO Total Cloud



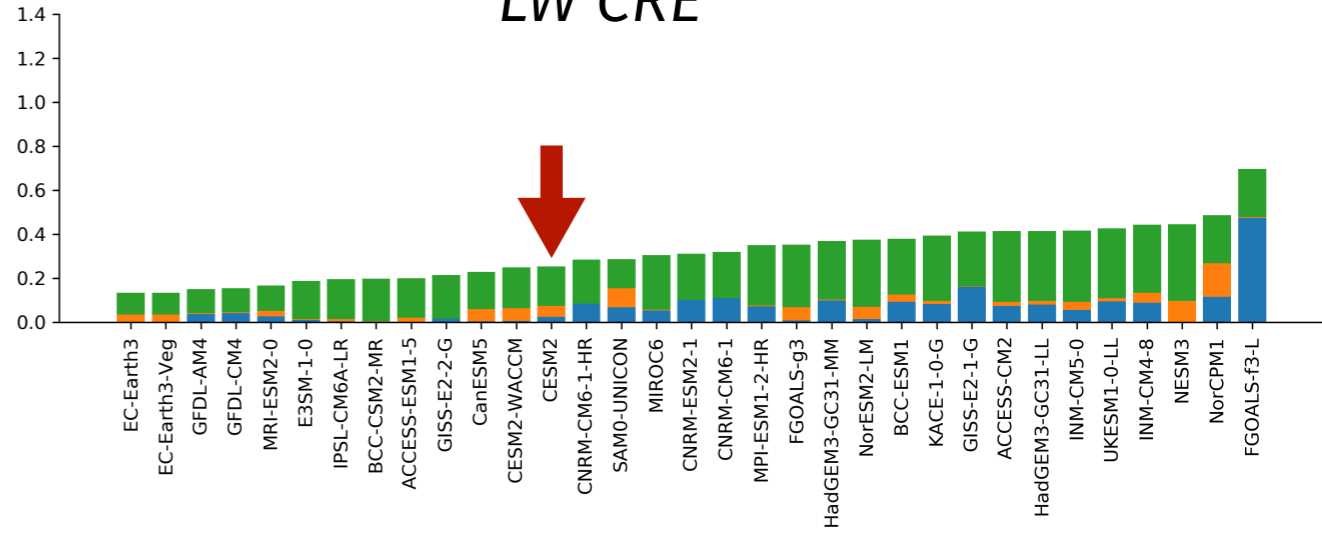
Net CRE



SW CRE

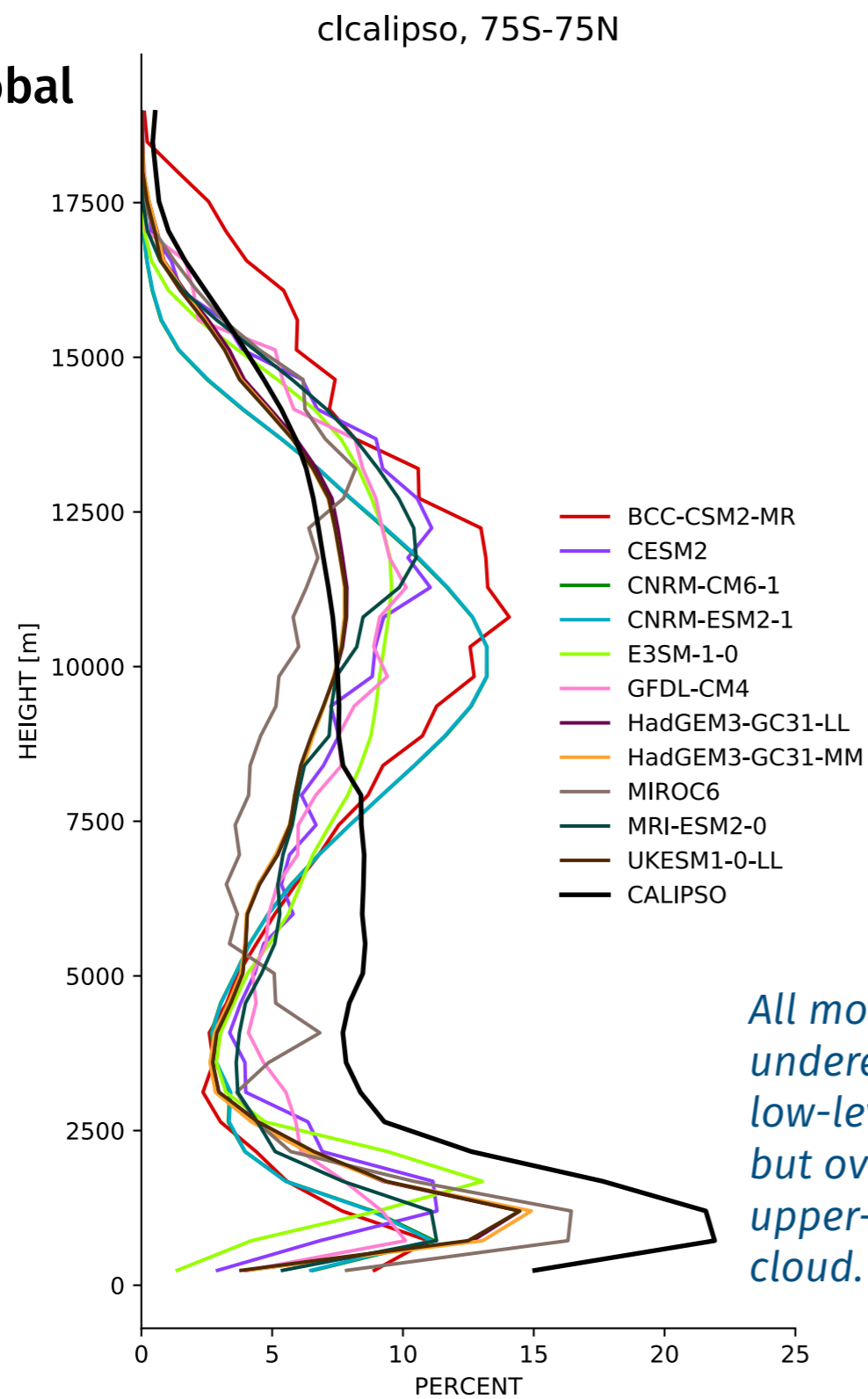


LW CRE



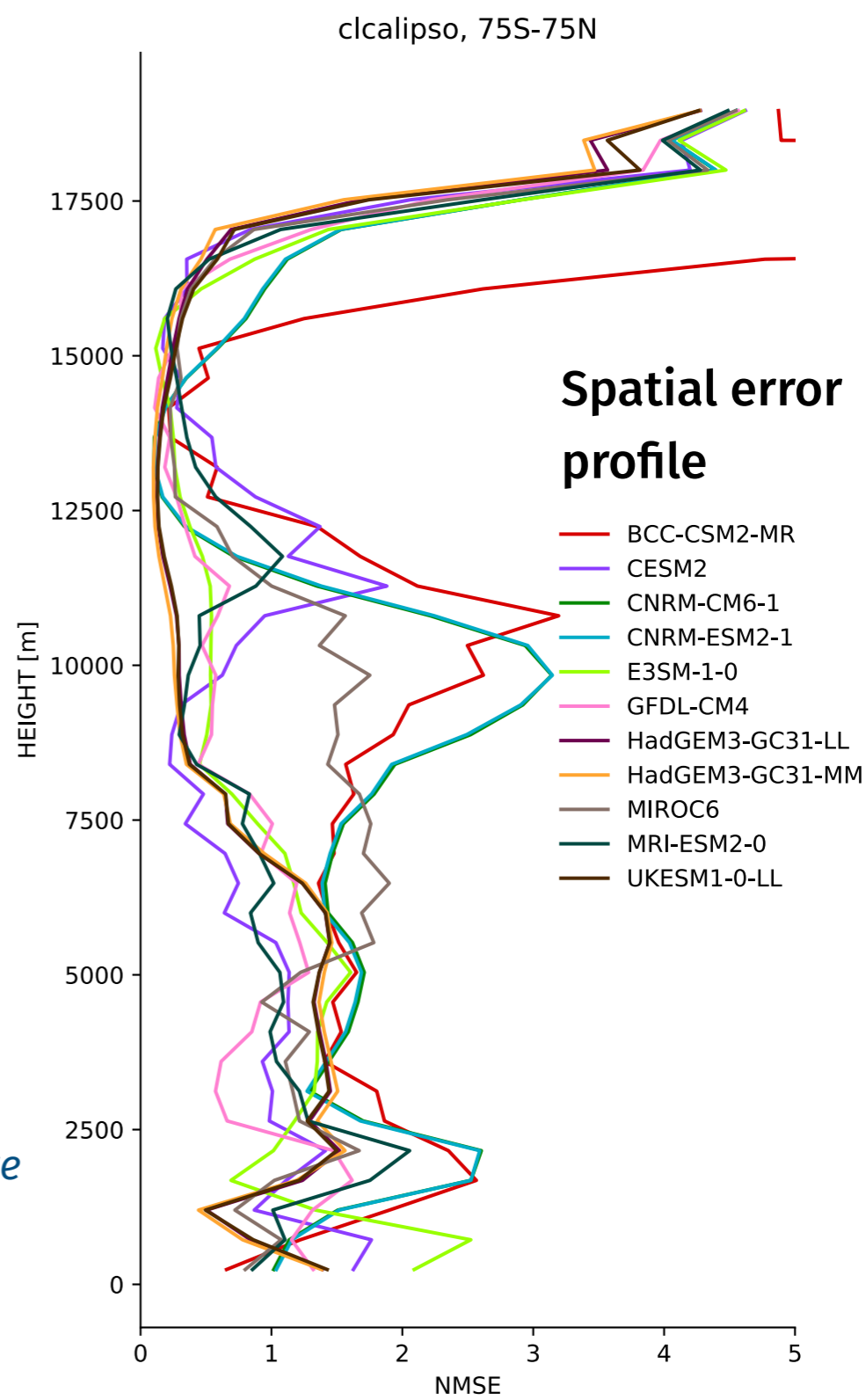
*More models
because CRE does
not rely on COSP.*

CALIPSO global mean cloud profile



All models underestimate low-level cloud, but overestimate upper-level cloud.

Spatial error profile



Preliminary findings

Identified large errors in cloud cover in CESM2

- ▶ CERES, ISCCP, CALIPSO (also MODIS & MISR, not shown)
- ▶ Spatially widespread; tropics have too little cloud cover but oceans reflect too much shortwave.
- ▶ Half of total cloud-cover error from “unconditional” bias; while most of low-cloud error & SWCRE error from “phase” error.
- ▶ Vertical structure shows strong bias that changes with height.

Similarly large errors found in other models

- ▶ ISCCP spatial errors are similar across most models
- ▶ CALIPSO spatial errors show CESM among the worse performers
- ▶ All models underestimate low-level clouds w.r.t. CALIPSO GOCCP

Cloud cover is observationally constrained, but many current climate model appear to be have unacceptably large errors.

