# Combining the MODIS COSP product with CERES gridded data to evaluate the radiation budget of the GEOS model

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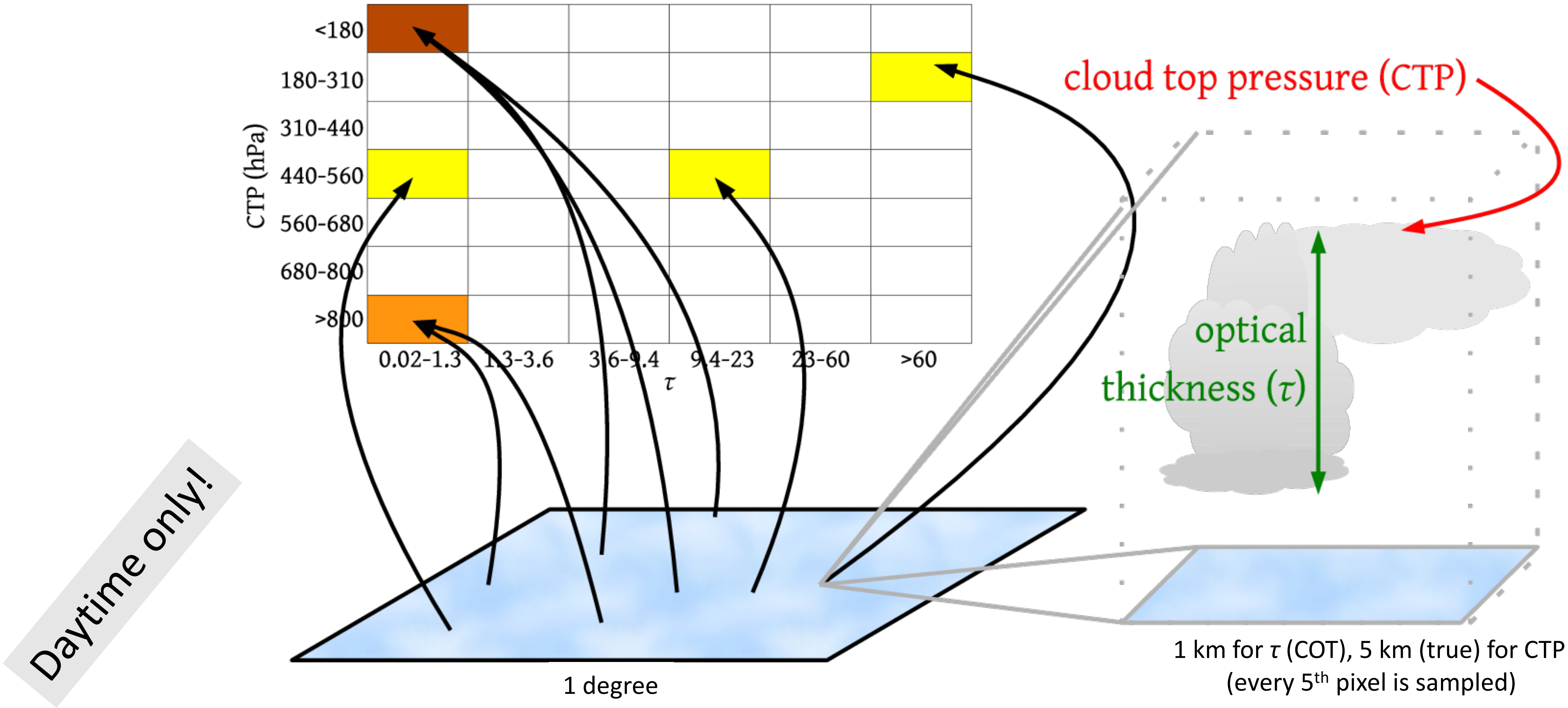
# Motivation and approach

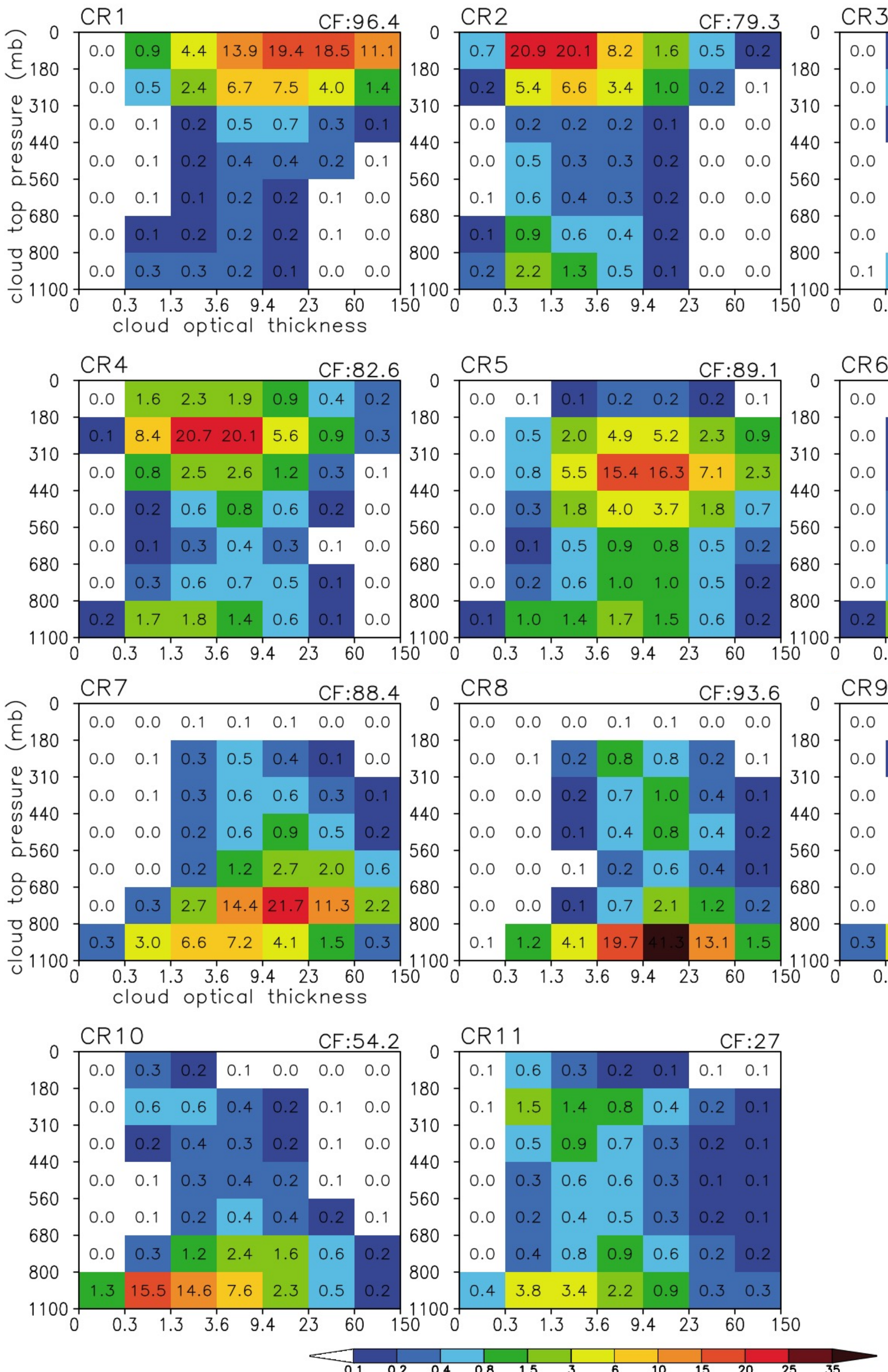
- Breakdown of cloud radiative effect (CRE) errors in GCMs by cloud class provides insight on model performance
  - Is there cancelation of errors among cloud classes?
- We use cloud regimes (CRs) as cloud classes
  - Defined as having similar CF histograms in CTP-COT space
  - MODIS ”COSP” product includes such CF histograms and provides observed CRs used as reference
  - The MODIS simulator (in COSP package) produces counterpart CF histograms in GCMs
- Ultimately we compare observed (CERES SYN1deg) and modeled CREs by CR

# MODIS Joint CTP-COT cloud fraction histograms




***MODIS cloud regimes are obtained by k-means clustering of such histograms***

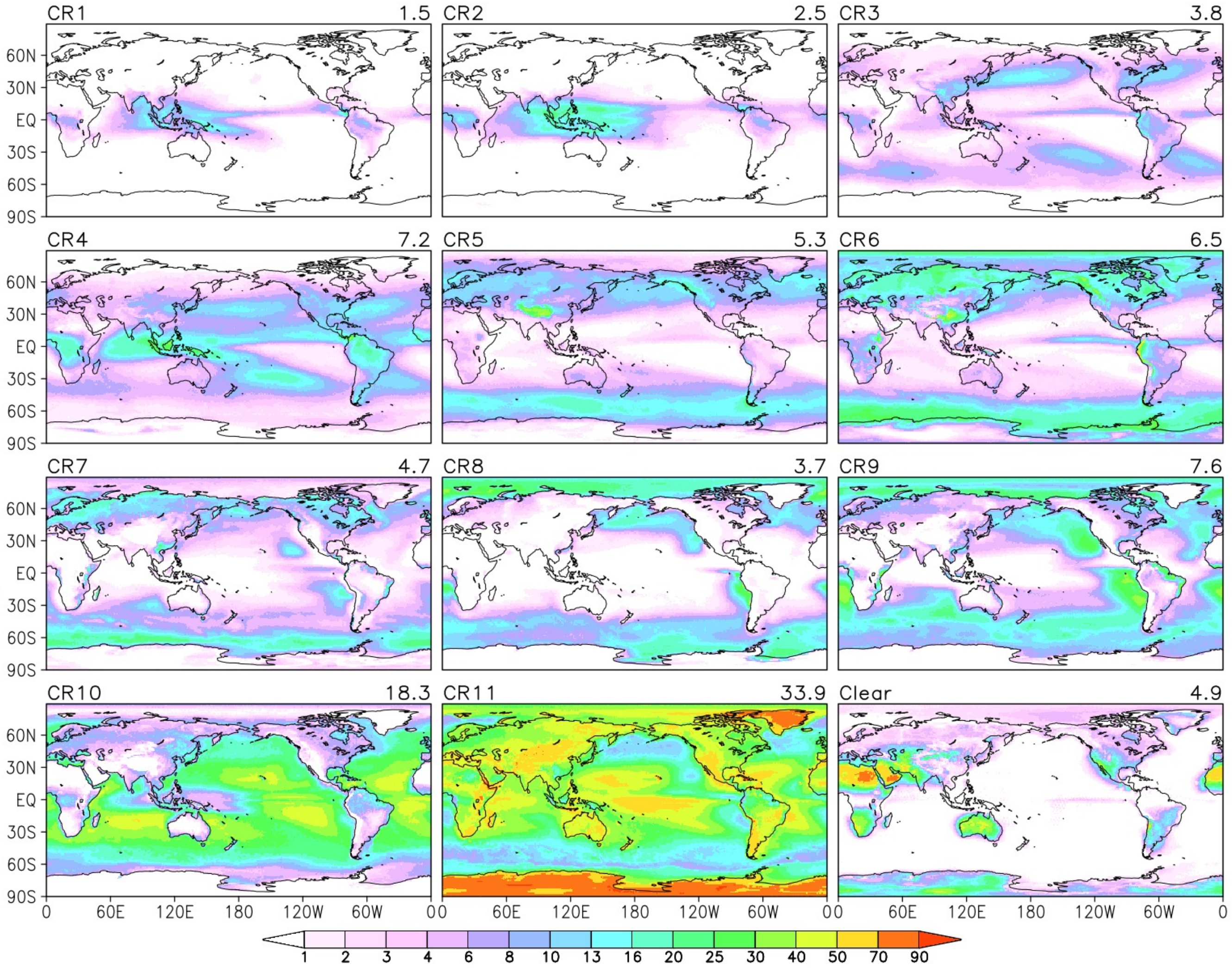
Courtesy of Jackson Tan




# MODIS COSP product and Cloud Regimes (CRs)

- Daily (daytime) CF histograms in CTP-COT space, merged Terra-Aqua
- Dec 2002 to Nov 2020
- Subject to k-means clustering, K=11
- Similar CRs as Cho et al. (2021)

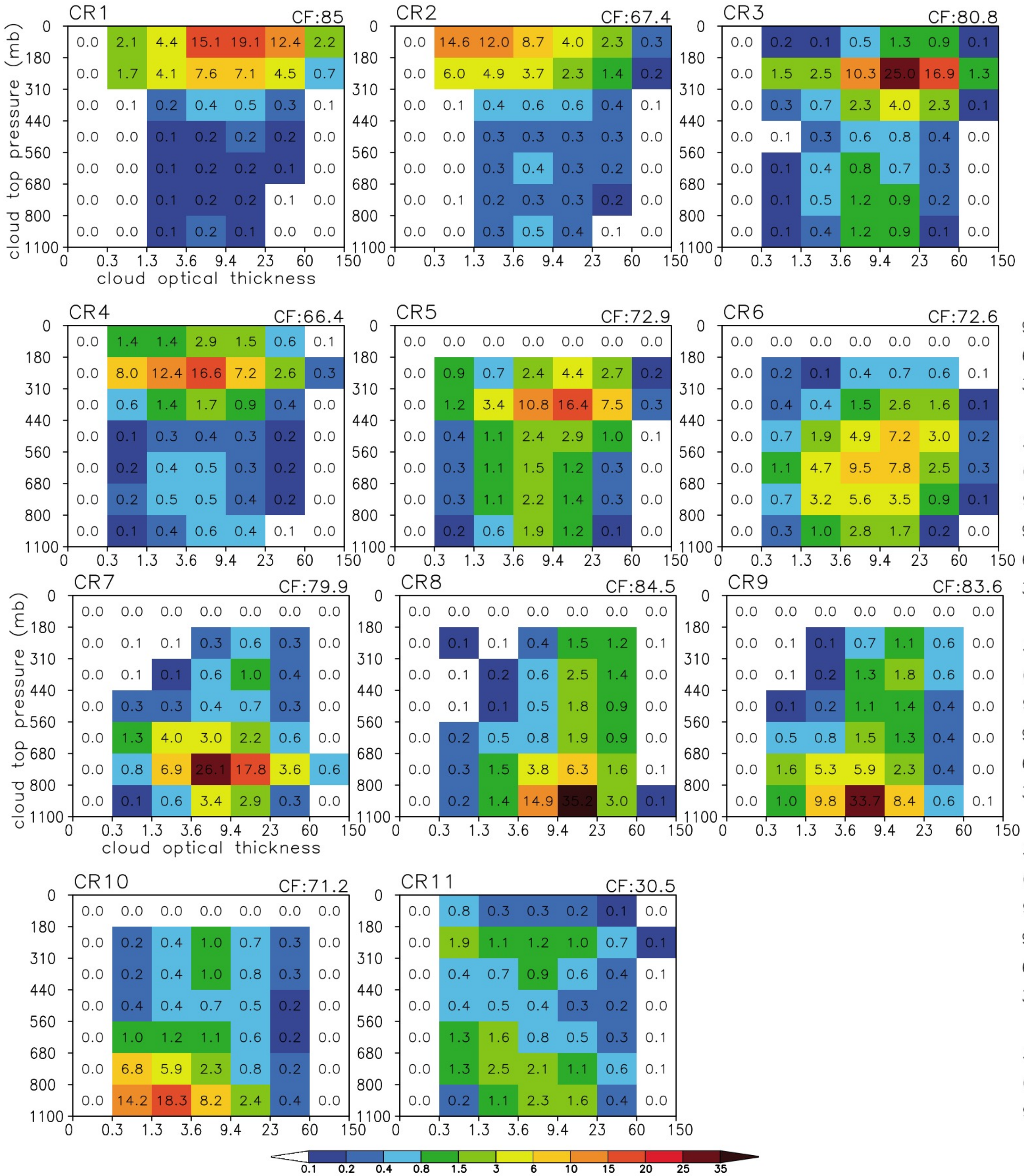
Global CF ≈ 56%

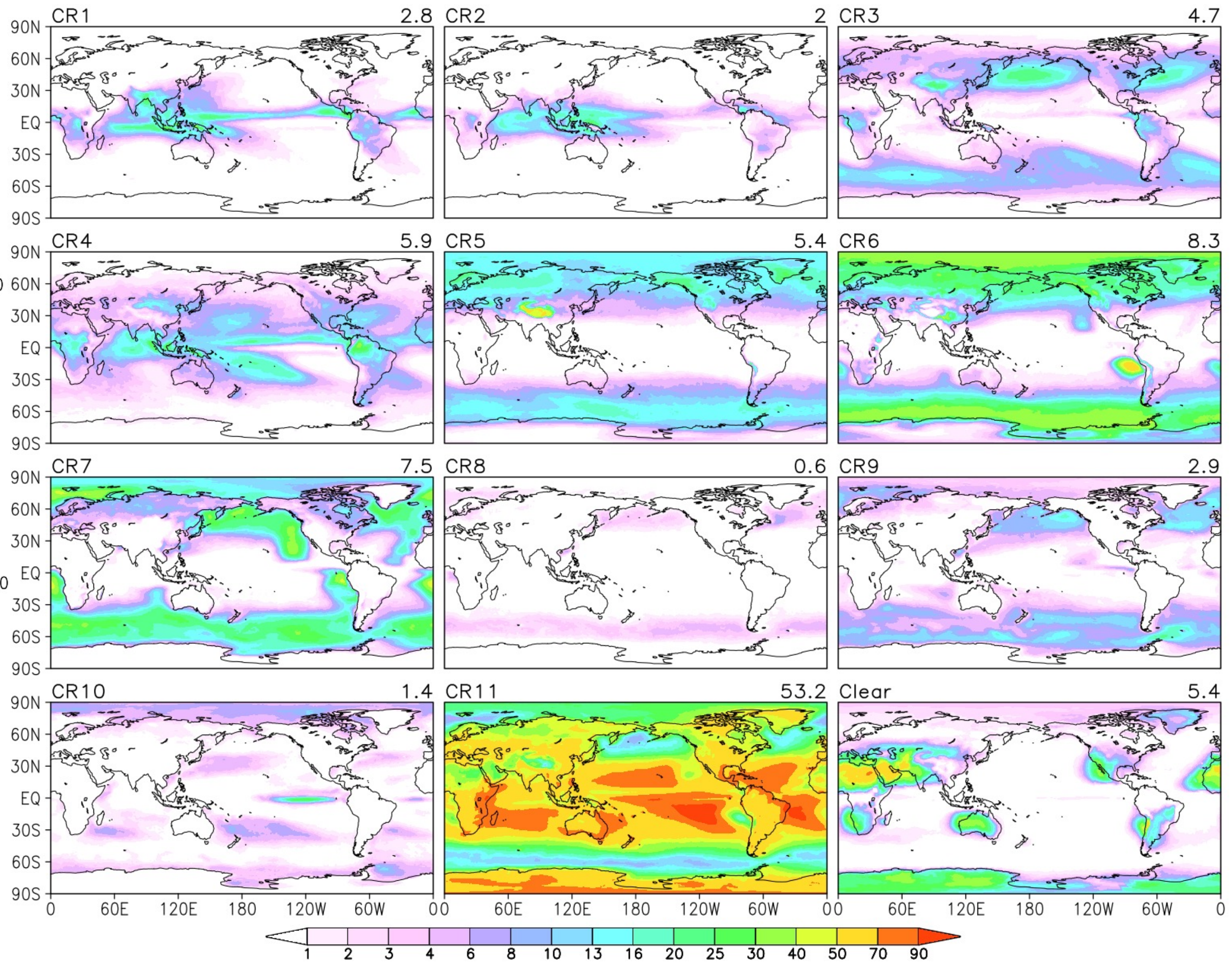


# GEOS Cloud Regimes

- Jason 2.0 tag, 2M μphysics, Dec 2002 to Nov 2016, prescribed SST
- Daily (daytime) CF histograms in CTP-COT space from MODIS simulator
- Assign to closest (by Euclidean distance) observed CR
- Centroids will look similar, but not their frequency of occurrence (RFO)

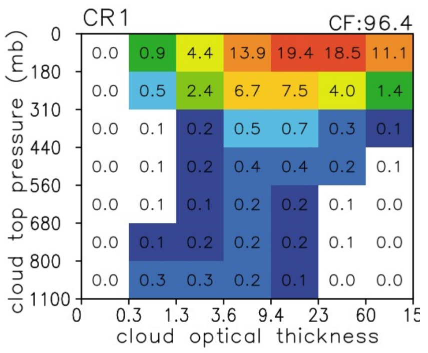
Global CF ≈ 50%

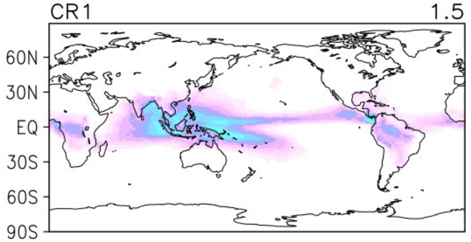


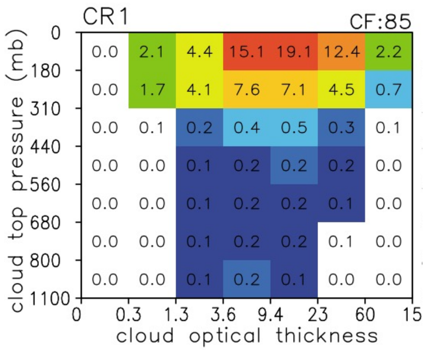
# A closer look

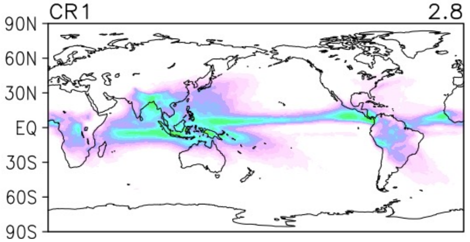
## Observations



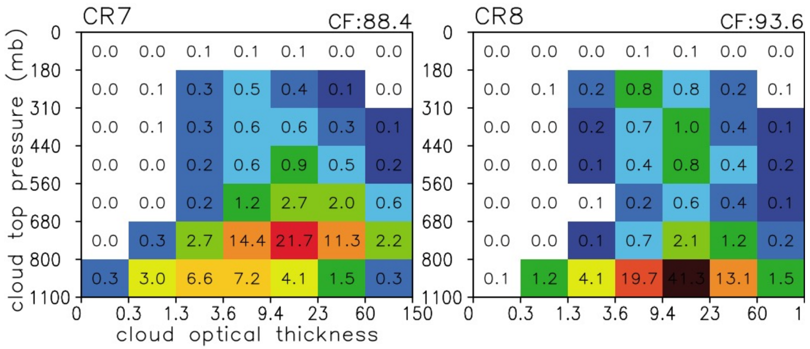



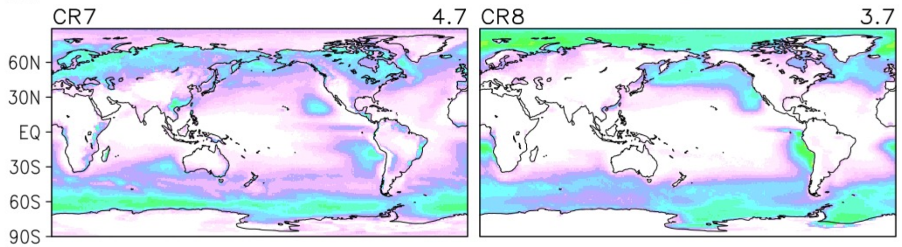

## Model

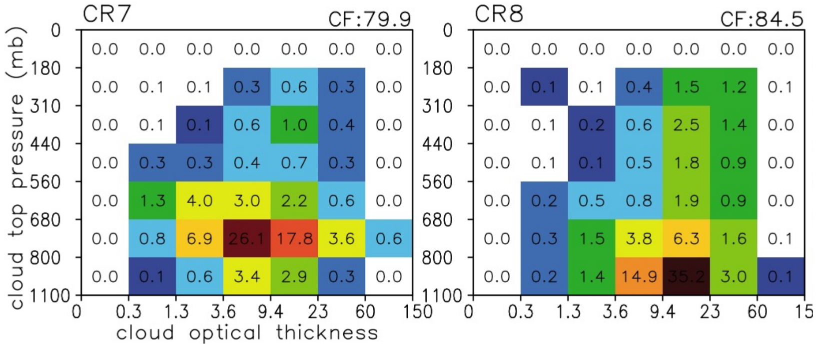


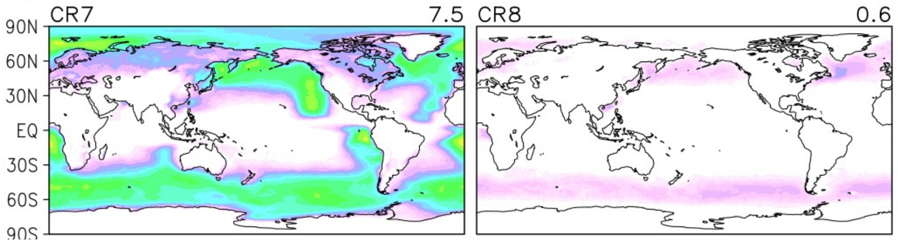




*More frequent in model, less cloudy*




*Model does not distinguish between CR7 and CR8*

# GEOS CRE error decomposition

$$\Delta CRE = \bar{f} \times \Delta r + \bar{r} \times \Delta f + \Delta r \times \Delta f$$

Error contribution due to erroneous regime radiative properties under correct (observed) mean RFO

Error contribution due to erroneous regime RFO under correct (observed) mean CRE

"Covariance error"; contribution due to combinations of erroneous regime RFO and CRE

$\Delta CRE$ = overall CRE error for CR examined

$\bar{f}$ = mean observed frequency (RFO)

$\bar{r}$ = mean observed CRE (*from CERES SYN1deg daily*)

Dec 2002 to Nov 2019

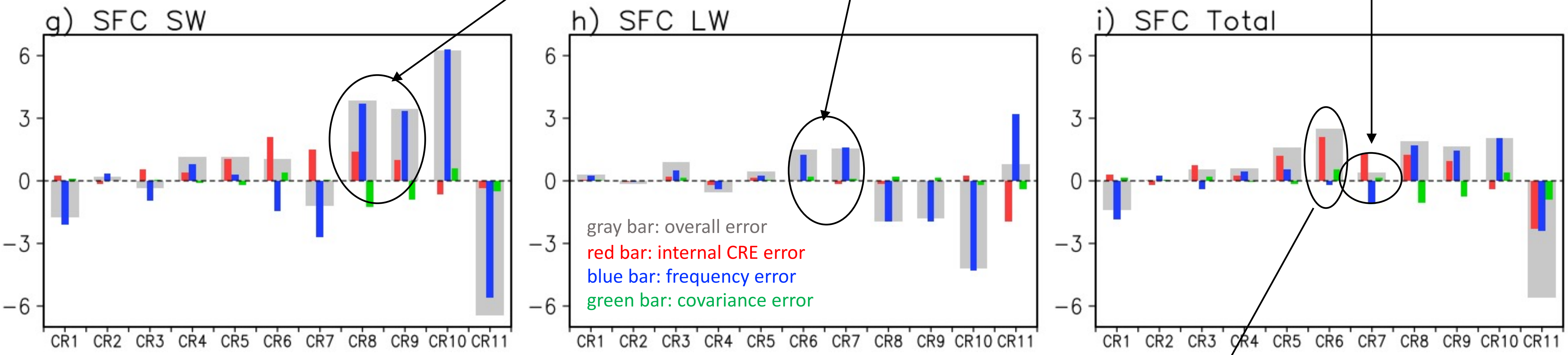
$\Delta f$ = RFO error

$\Delta r$ = CRE error when regime occurs

# CRE error bar graph: interpretation

*Most error comes from frequency biases $\bar{r}\times\Delta f$*
*(gray ≈ blue)*

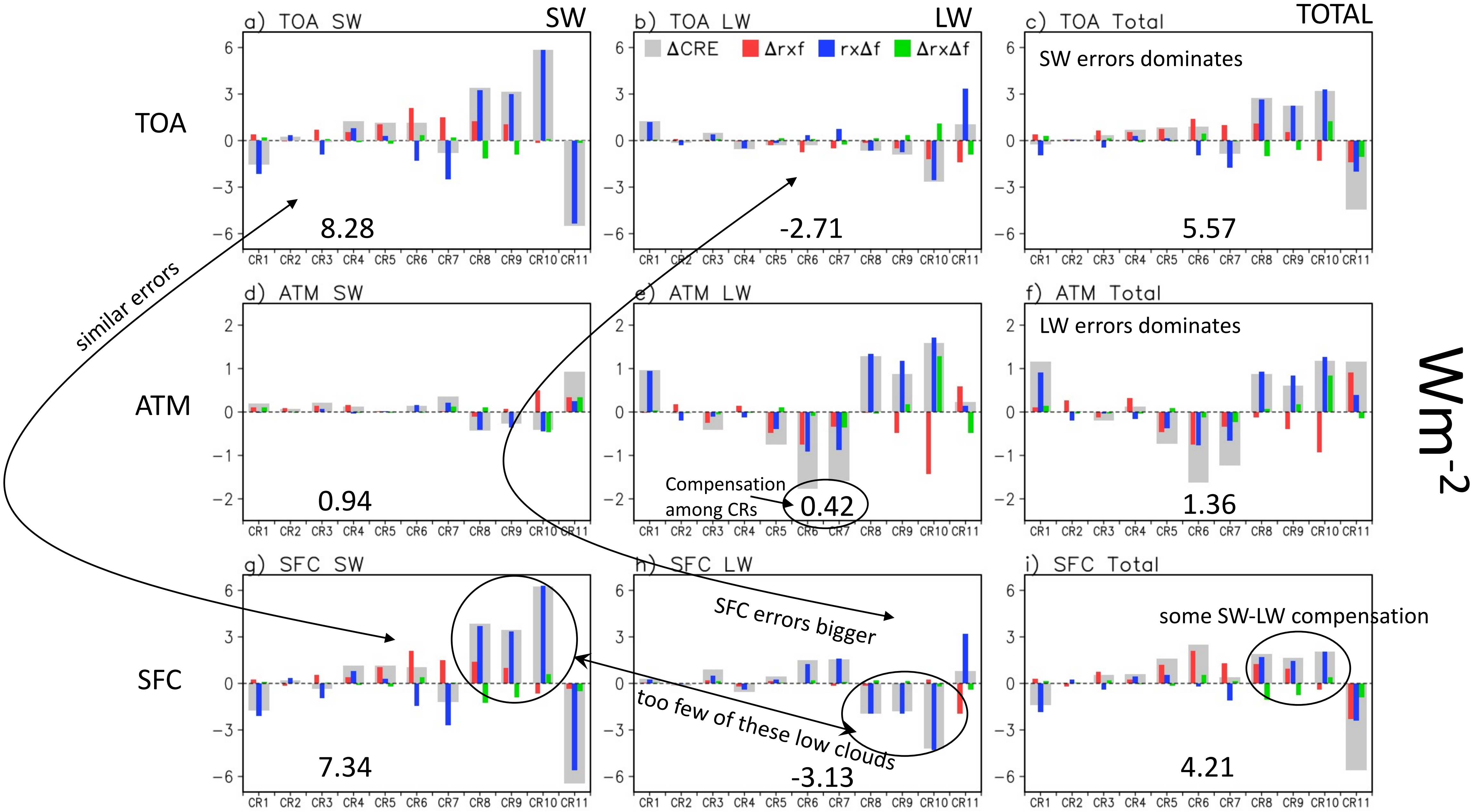
*Error cancellation*
*(gray ≈ 0, red ≈ – blue*
*also gray SW ≈ – gray LW)*




*Most error comes from CR radiative property biases $\bar{f}\times\Delta r$*
*(gray ≈ red)*

- All CREs are derived from (down – up) fluxes
- Positive values: Model underestimates

# Full CRE error decomposition



# Q: Why not use EBAF?

A: *Cloud Regimes are defined daily, need to pair them with daily fluxes*

# Q: Why not use (daily) FBCT*?

A: *To derive the cloud regimes or to also perform the full model validation?*

**Q: Why not for both?**

A: *I can indeed derive FBCT cloud regimes, but I cannot repeat the analysis I've shown*

**Q: Why not?**

A: *I don't have CRE for overcast grid cells (no clear-sky flux) and I don't have SFC fluxes*

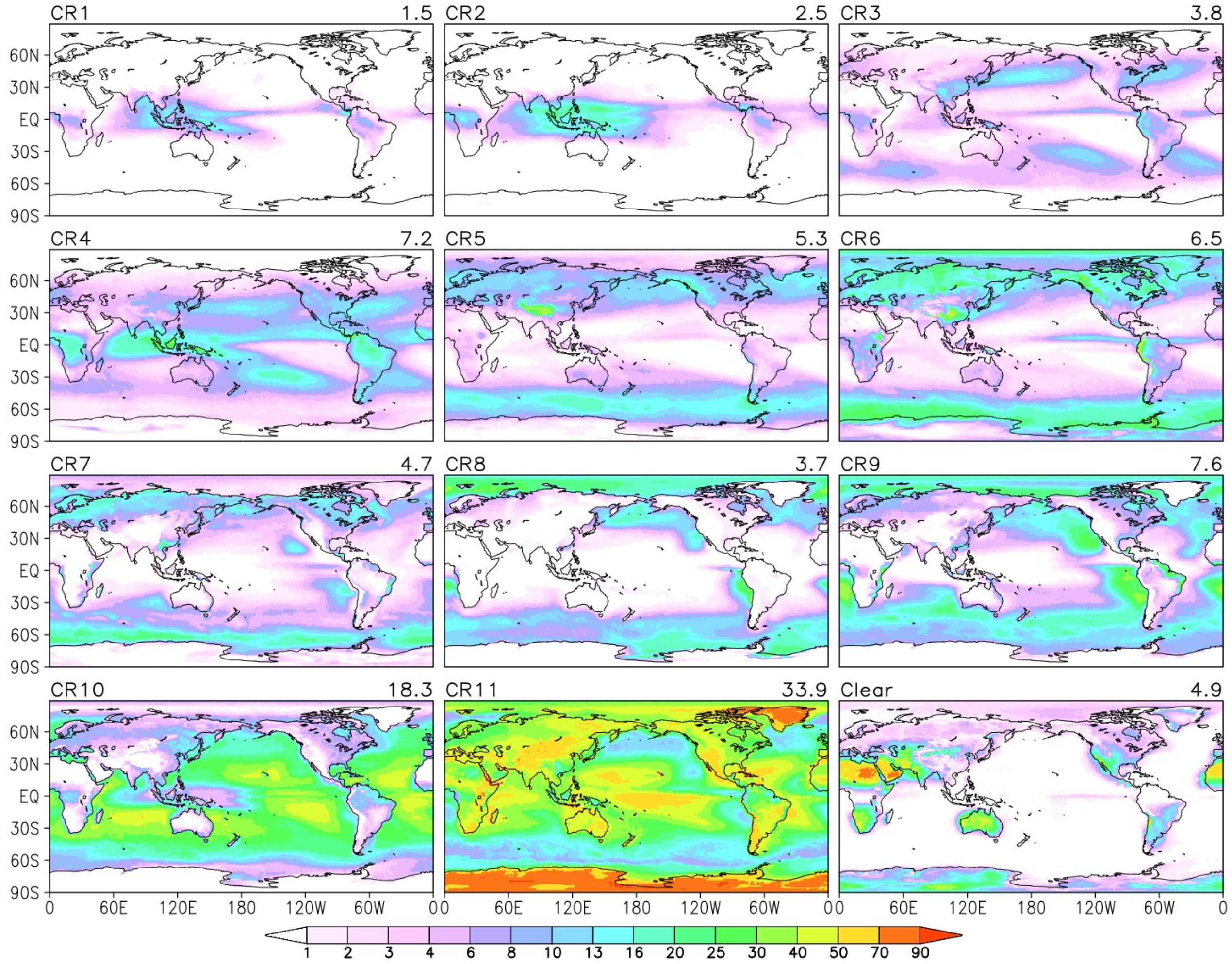
**Q: Is there anything you can do with FBCT then?**

A: *Well, I can combine FBCT Cloud Regimes with SYN1deg fluxes. But let me first compare COSP MODIS vs FBCT MODIS clouds*

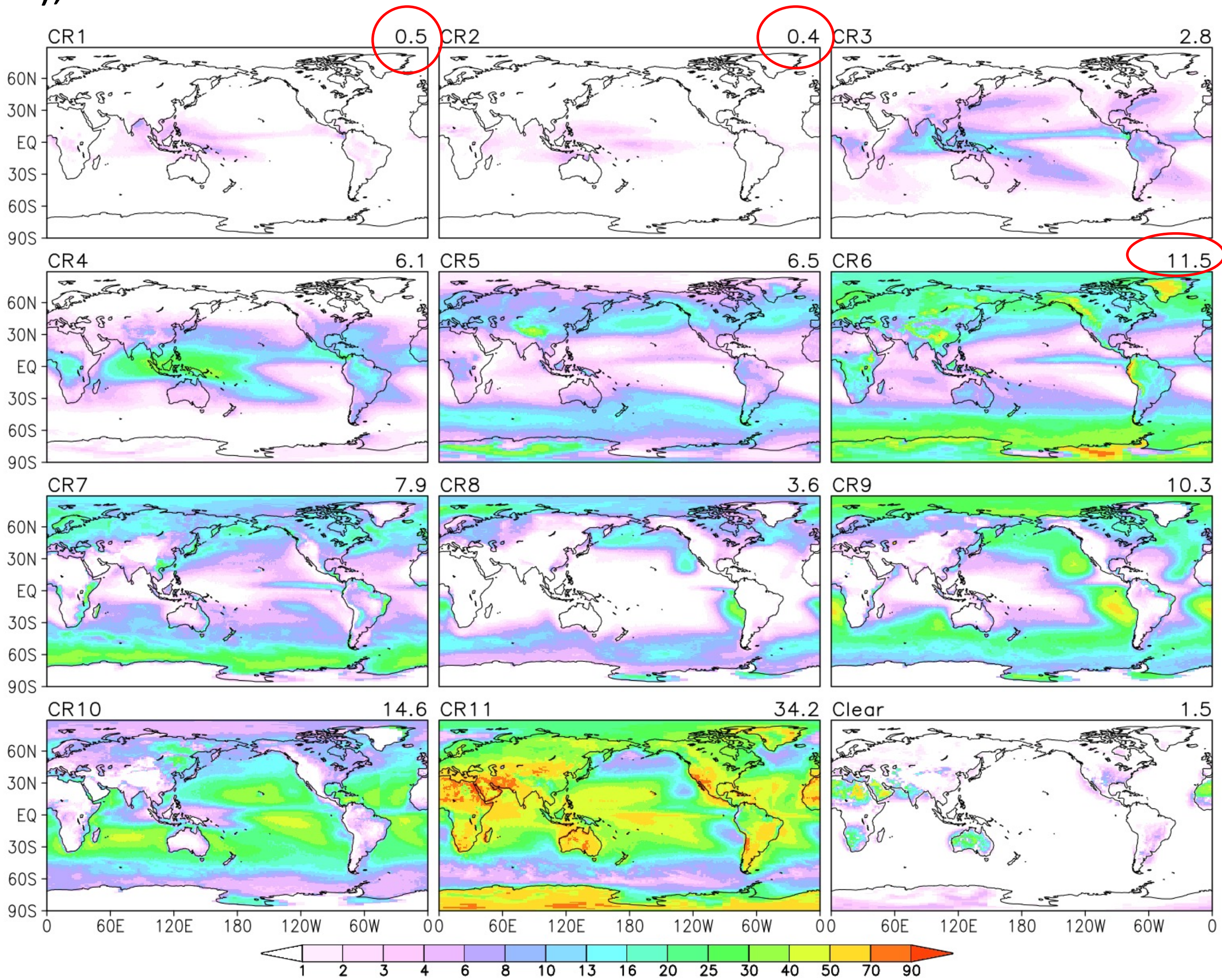
*CERES FluxByCldType product

# Compare MODIS COSP with MODIS FBCT (1)

- Assign (”force”) FBCT CF histograms to MODIS COSP centroids
  - Centroids will look (kinda) similar by design (backup slides), but RFOs will differ




MODIS COSP




MODIS FBCT

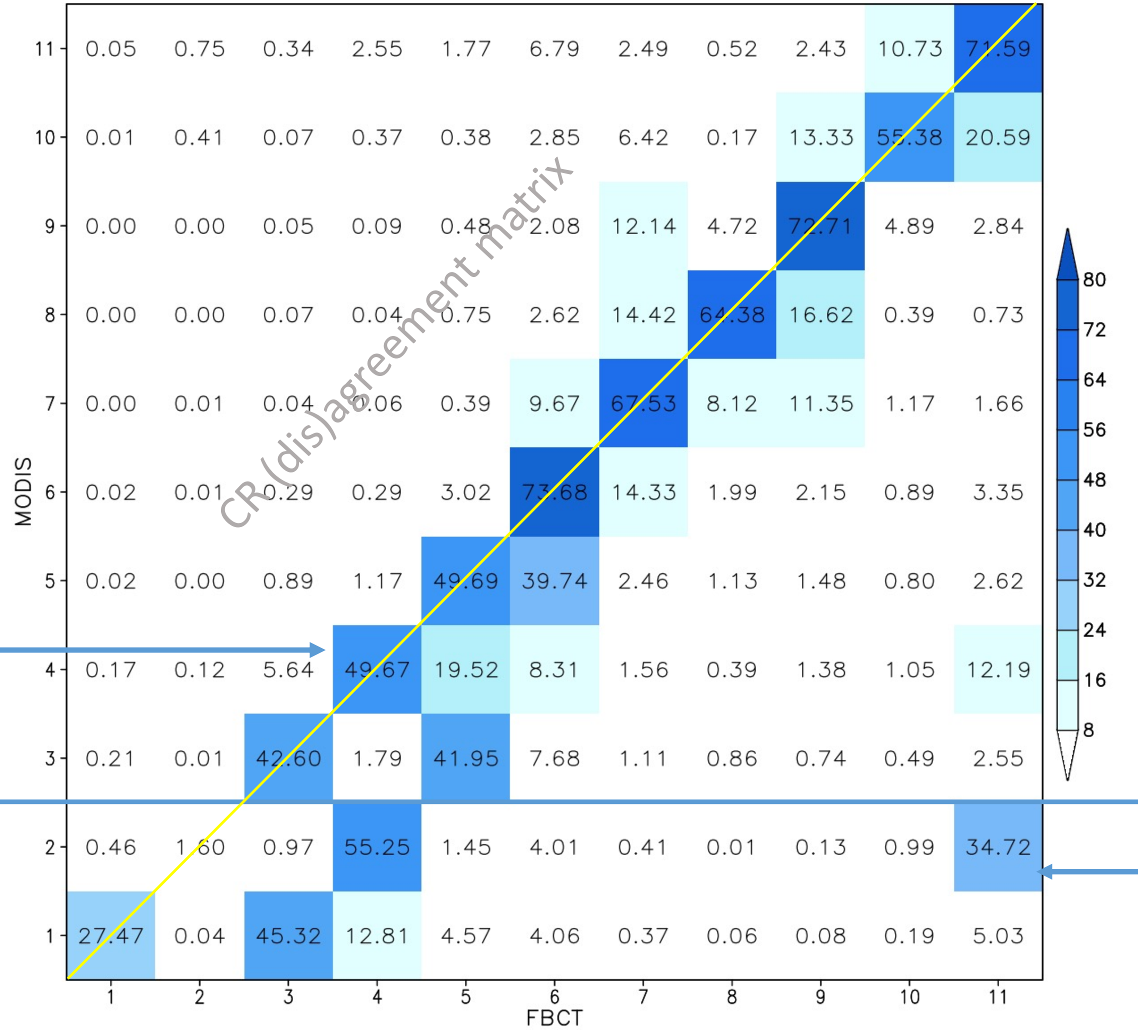
*Hard to find CR1 and CR2, too much CR6*

# Compare MODIS COSP with MODIS FBCT (2)

- Assign ("force") FBCT CF histograms to MODIS COSP centroids
  - Centroids will look similar by design, but RFOs will differ

% of time FBCT gives CR4
when MODIS COSP is CR4

Adds to 100%

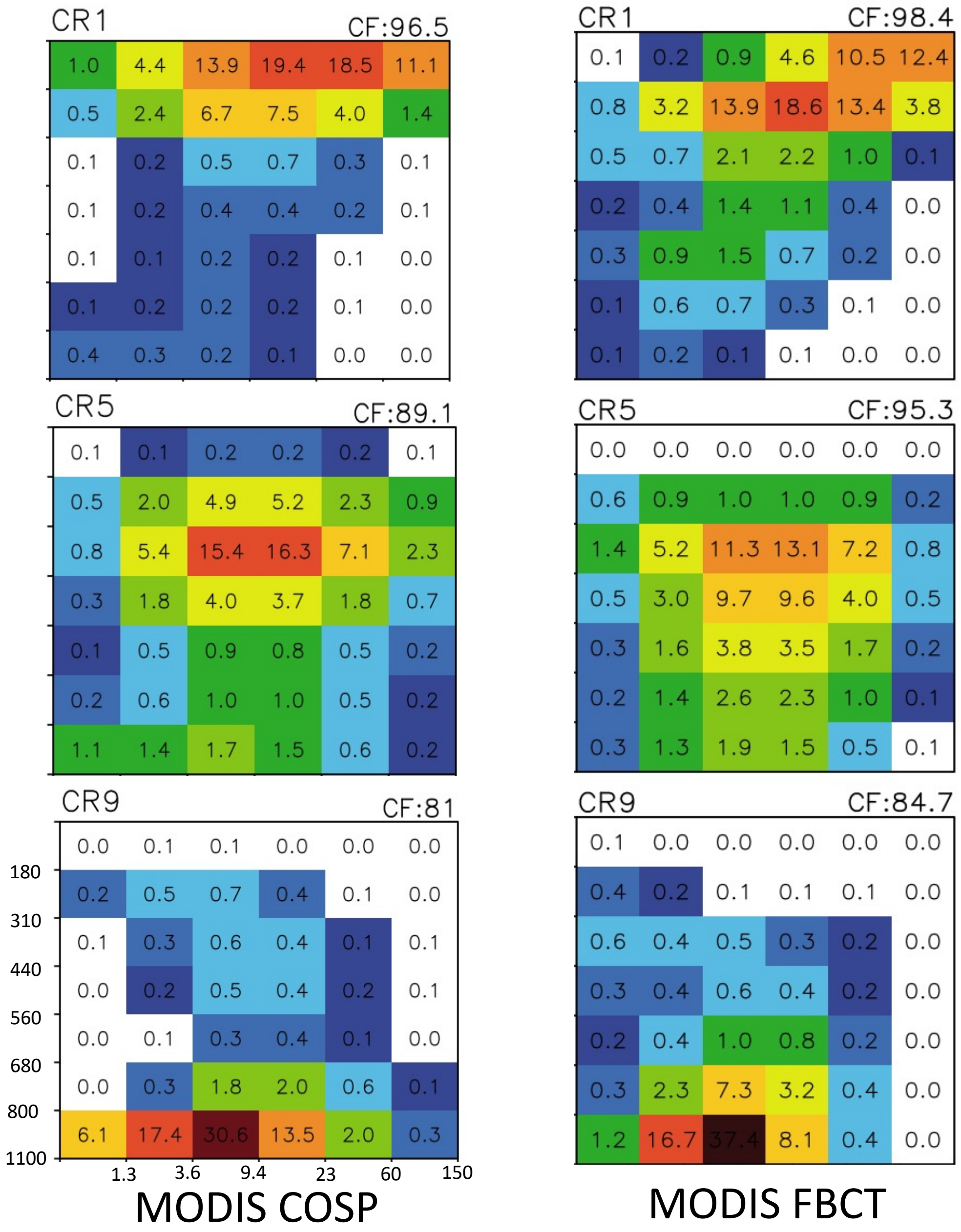



% of time FBCT gives CR11
when MODIS COSP is CR2

# Compare MODIS COSP with MODIS FBCT (3)

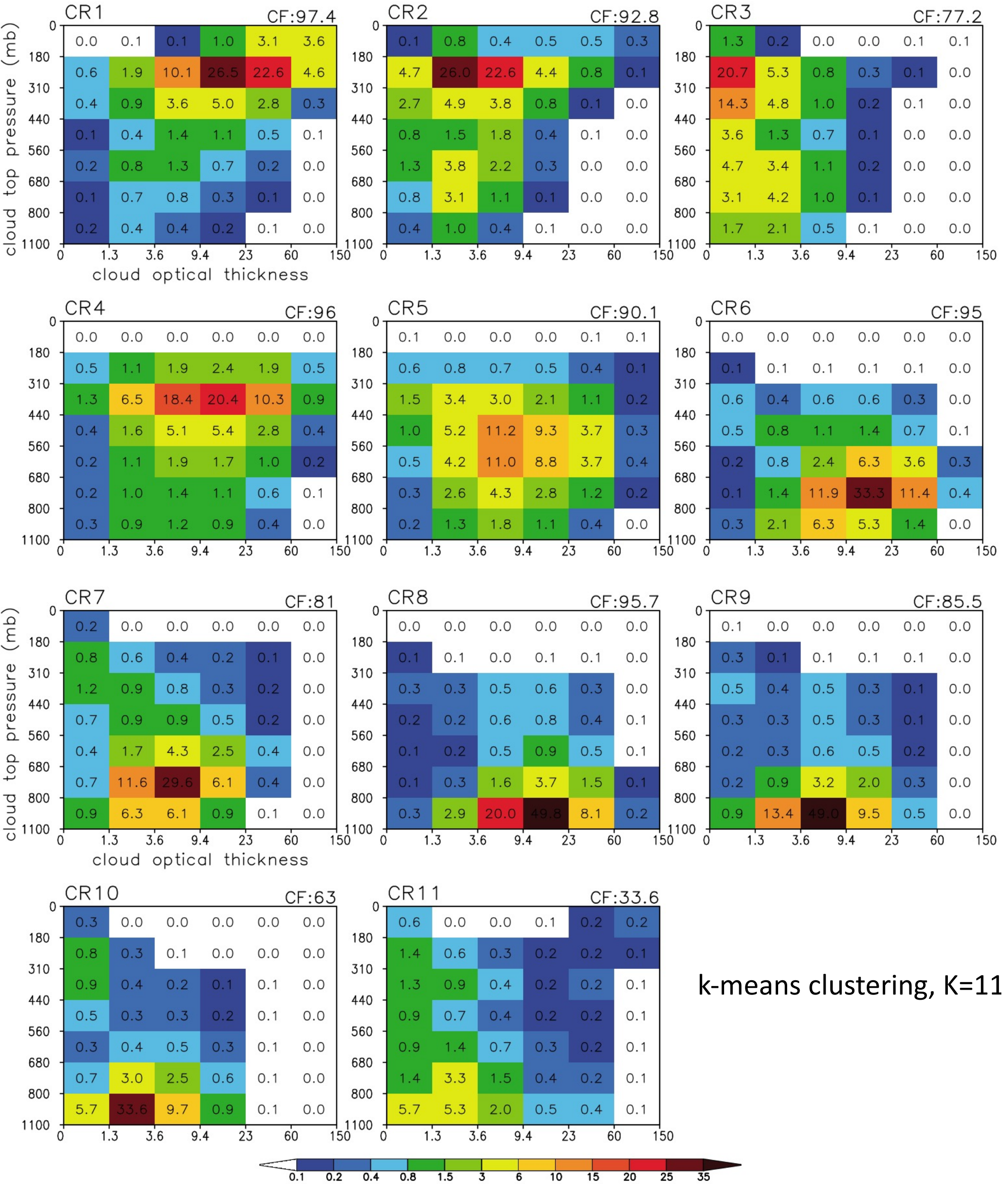
- Composite (average) CERES CF histograms for occurrences (location, time) of MODIS CRs
  - RFOs by definition will be the same, but mean histograms (centroids) will look different

*Full comparison in backup slides*

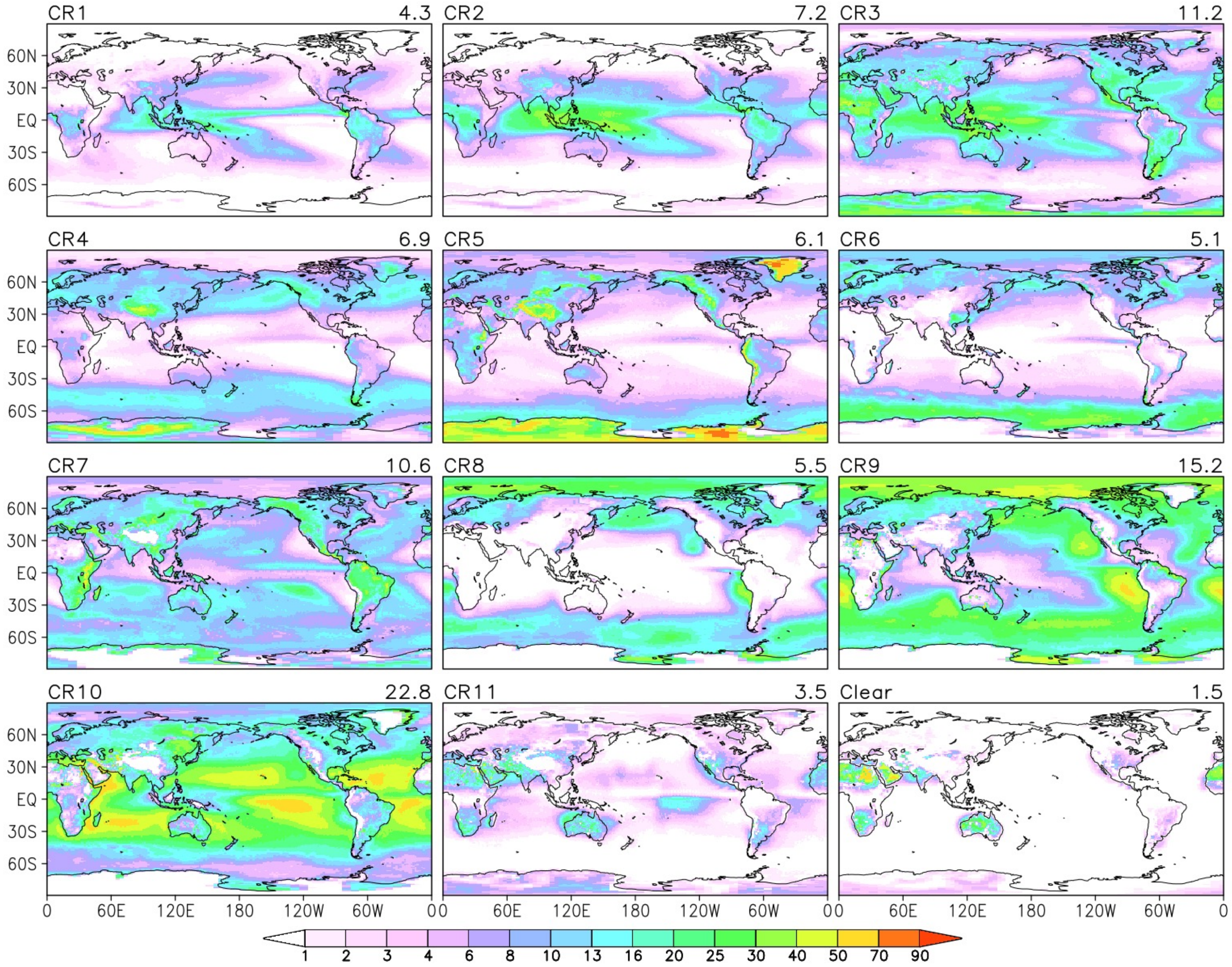



*FBCT CFs are larger! Globally, ~65% vs ~56%*

# FBCT MODIS Cloud Regimes




k-means clustering, K=11




*Can repeat evaluation of GEOS, but still with SYN1deg fluxes (backup slides).*

# Take-home messages

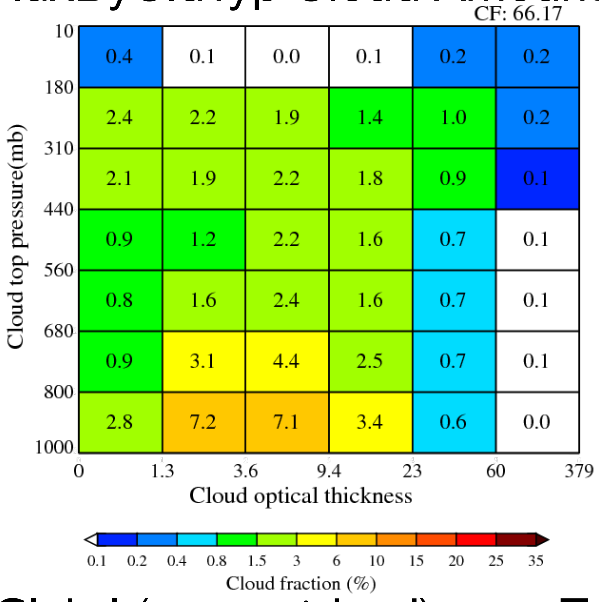
- A regime-based decomposition of GEOS CRE errors is more insightful
  - Can get CRE errors by cloud class
  - For full picture need *daily* CREs at both TOA and SFC
- MODIS FBCT clouds appear different from those in MODIS COSP
- Can derive FBCT Cloud Regimes
  - But cannot do (full) model evaluation using solely FBCT (CRE not always available, no SFC fluxes)

# Questions?

# Backup Slides

**CERES : 2002.7 – 2018.12 monthly data**

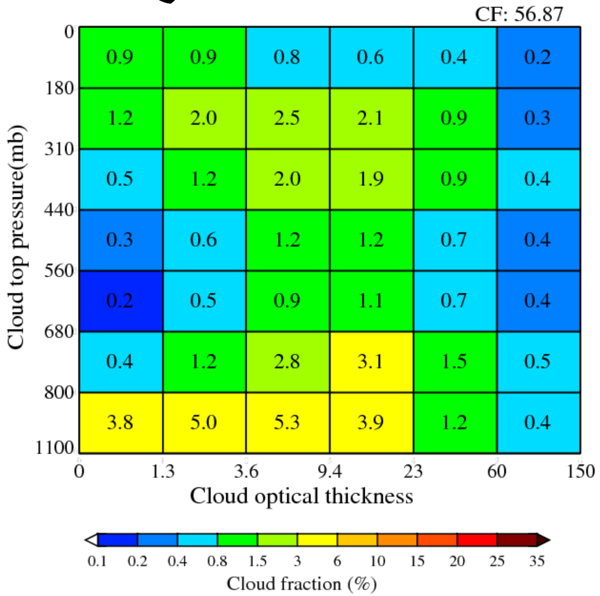
FluxByCldTyp Cloud Amount - Total




Nayeong's results using FBCT JH:
Those datasets are not very close.
Total CF 66.17 vs 56.87

Global (area weighted) mean Total CF

**MODIS AQUA and TERRA C6.1, Period : 2003.1.1 – 2018. 12 . 31 (16 years), Equal-angle L3 data (as is)**

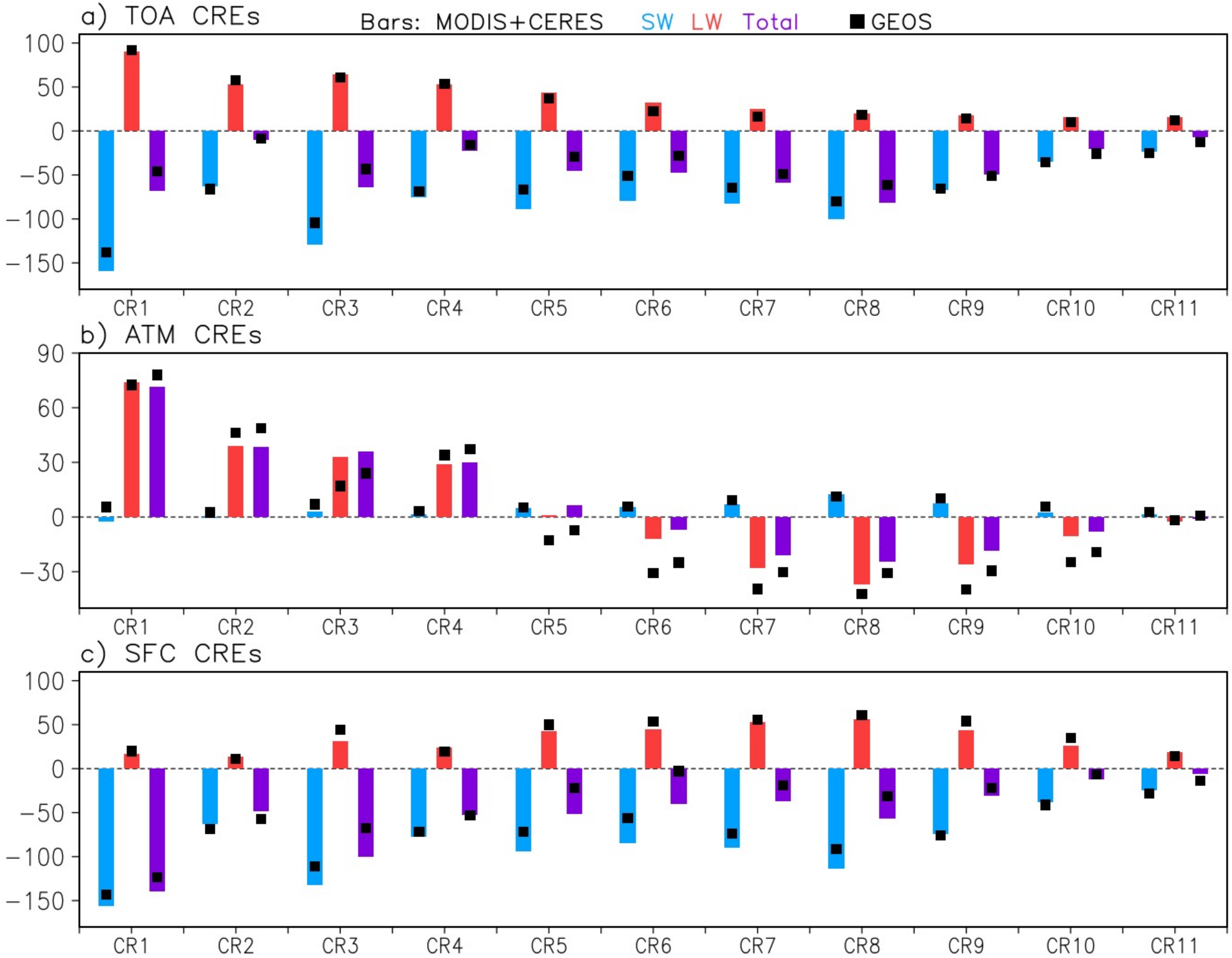



DAILY MODIS

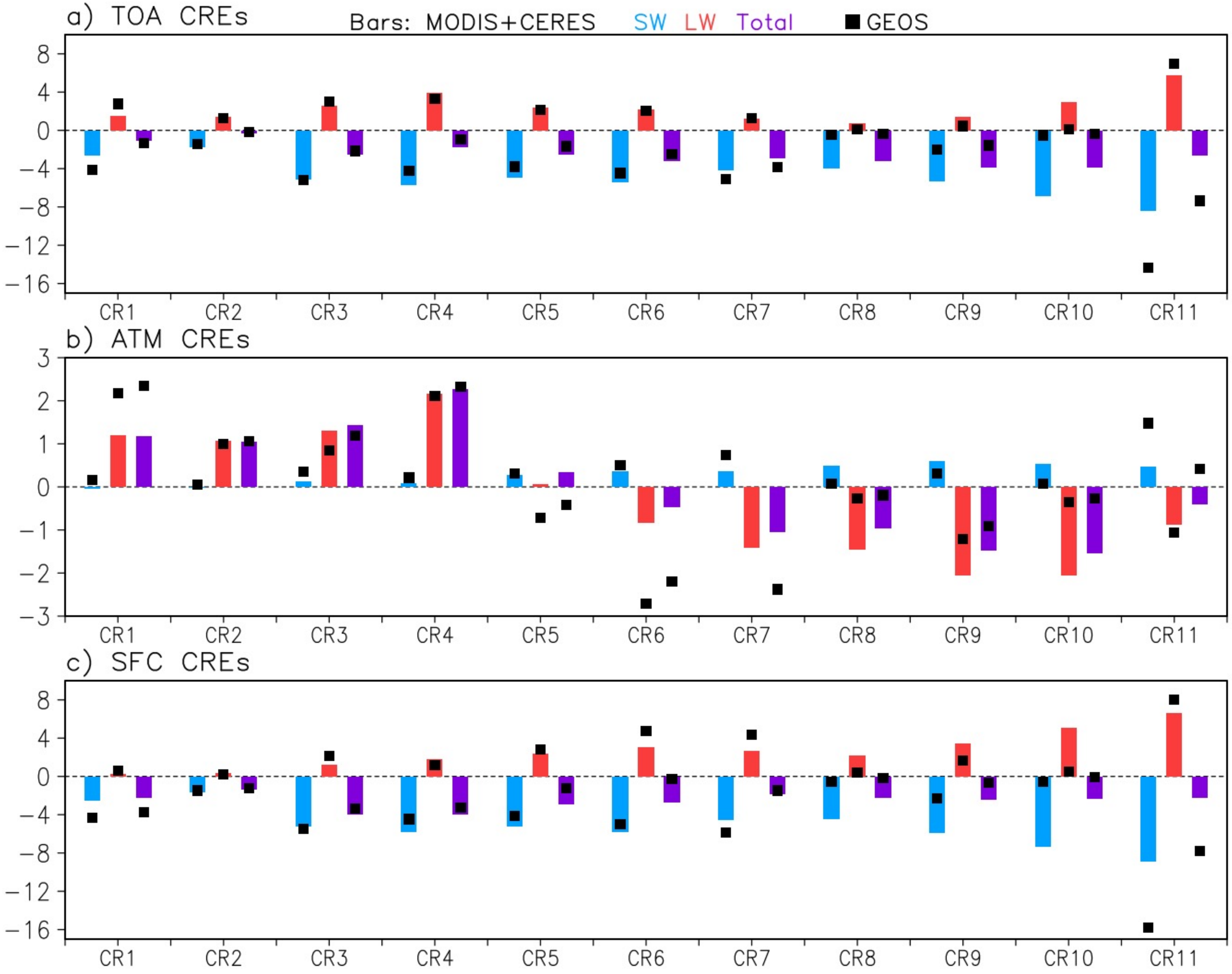
Daily MODIS definition = Average of Terra and Aqua centroids.

if (Aqua GE 0) and (Terra EQ 'Nan') = Aqua centroids
if (Aqua EQ 'Nan') and (Terra GE 0) = Terra centroids

# CR CREs


a) TOA CREs
Bars: MODIS+CERES SW LW Total
GEOS
100
50
0
−50
−100
−150
CR1 CR2 CR3 CR4 CR5 CR6 CR7 CR8 CR9 CR10 CR11
b) ATM CREs
90
60
30
0
−30
CR1 CR2 CR3 CR4 CR5 CR6 CR7 CR8 CR9 CR10 CR11
c) SFC CREs
100
50
0
−50
−100
−150
CR1 CR2 CR3 CR4 CR5 CR6 CR7 CR8 CR9 CR10 CR11

# CR CREs x RFOs



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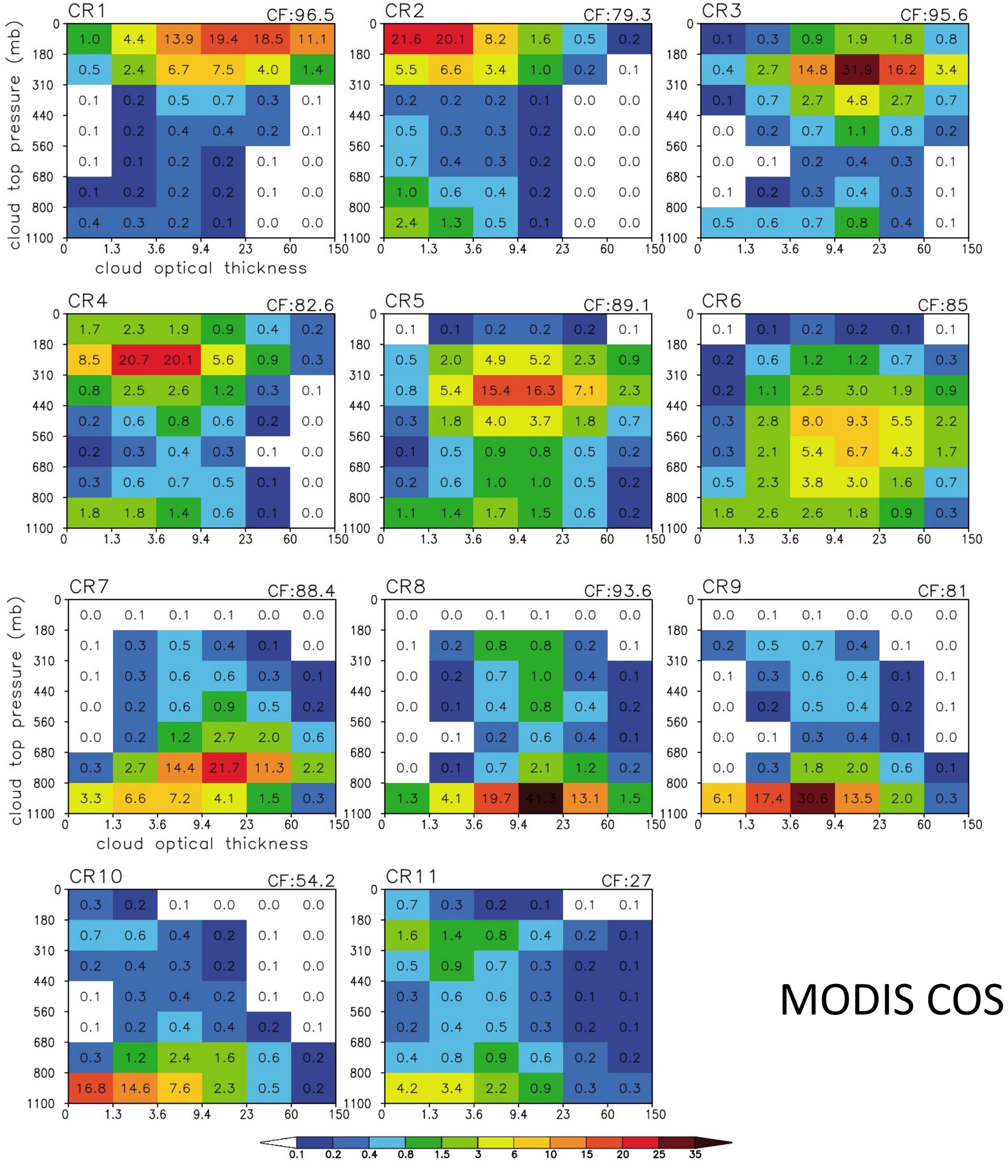
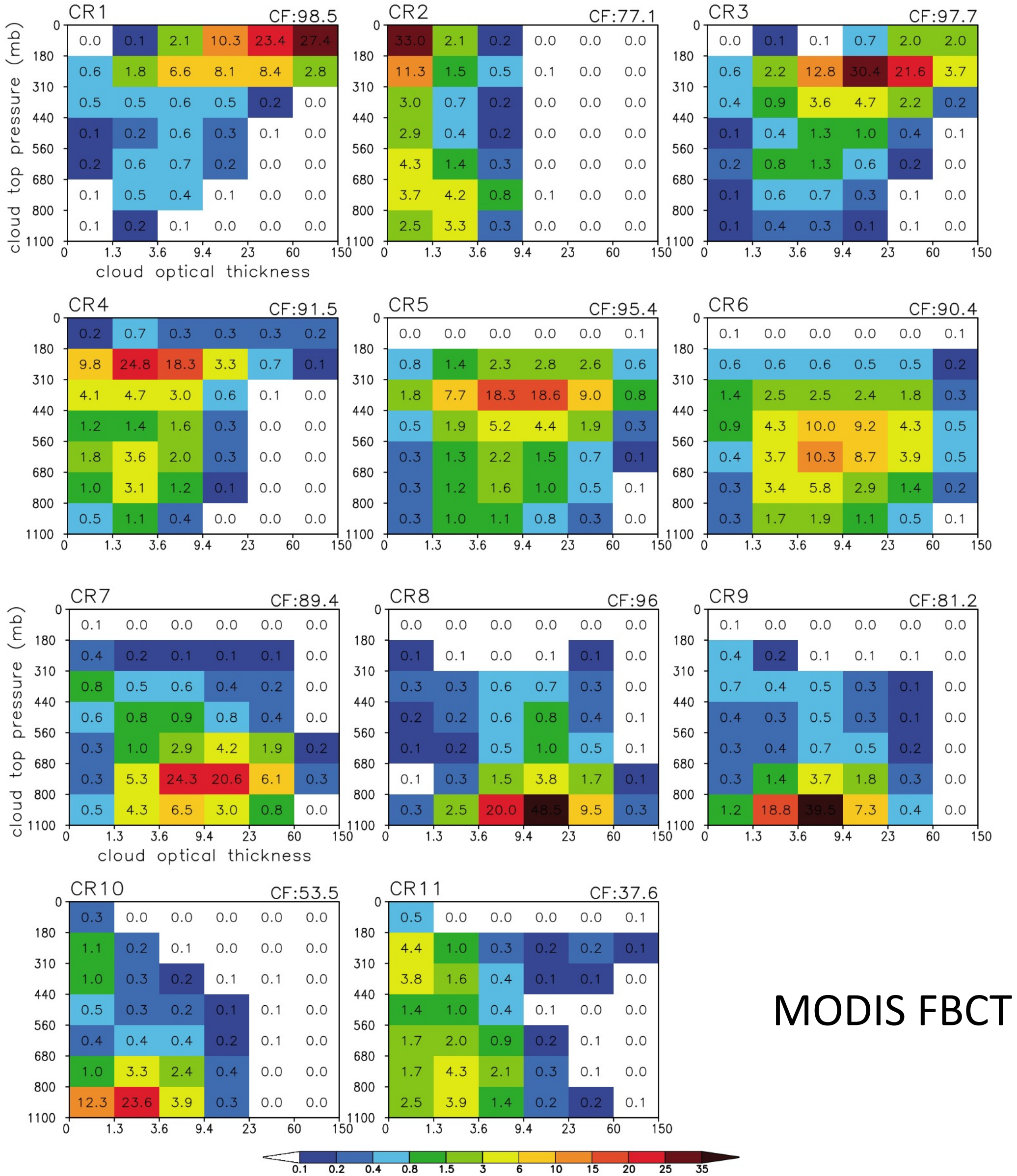


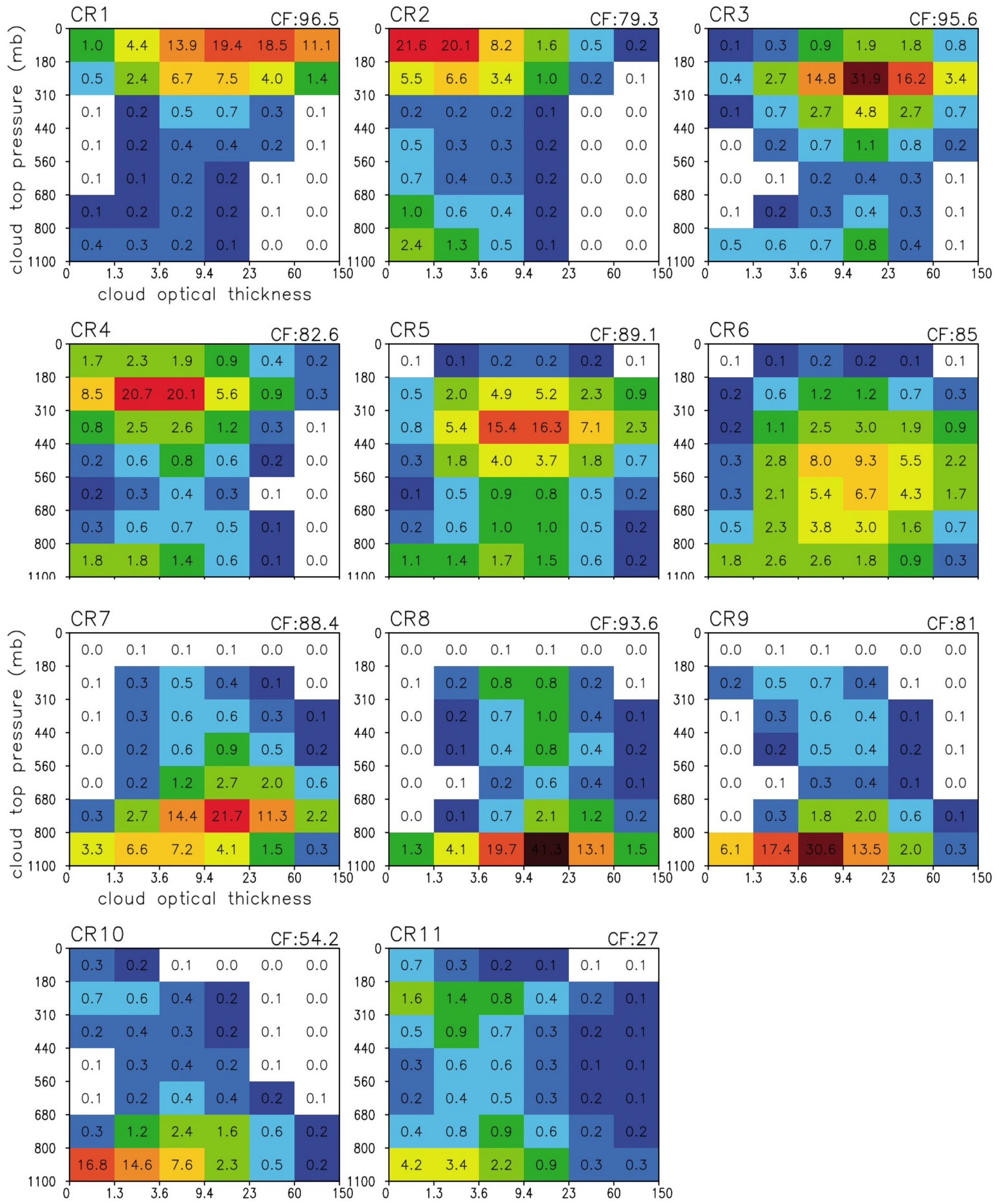

MODIS COSP

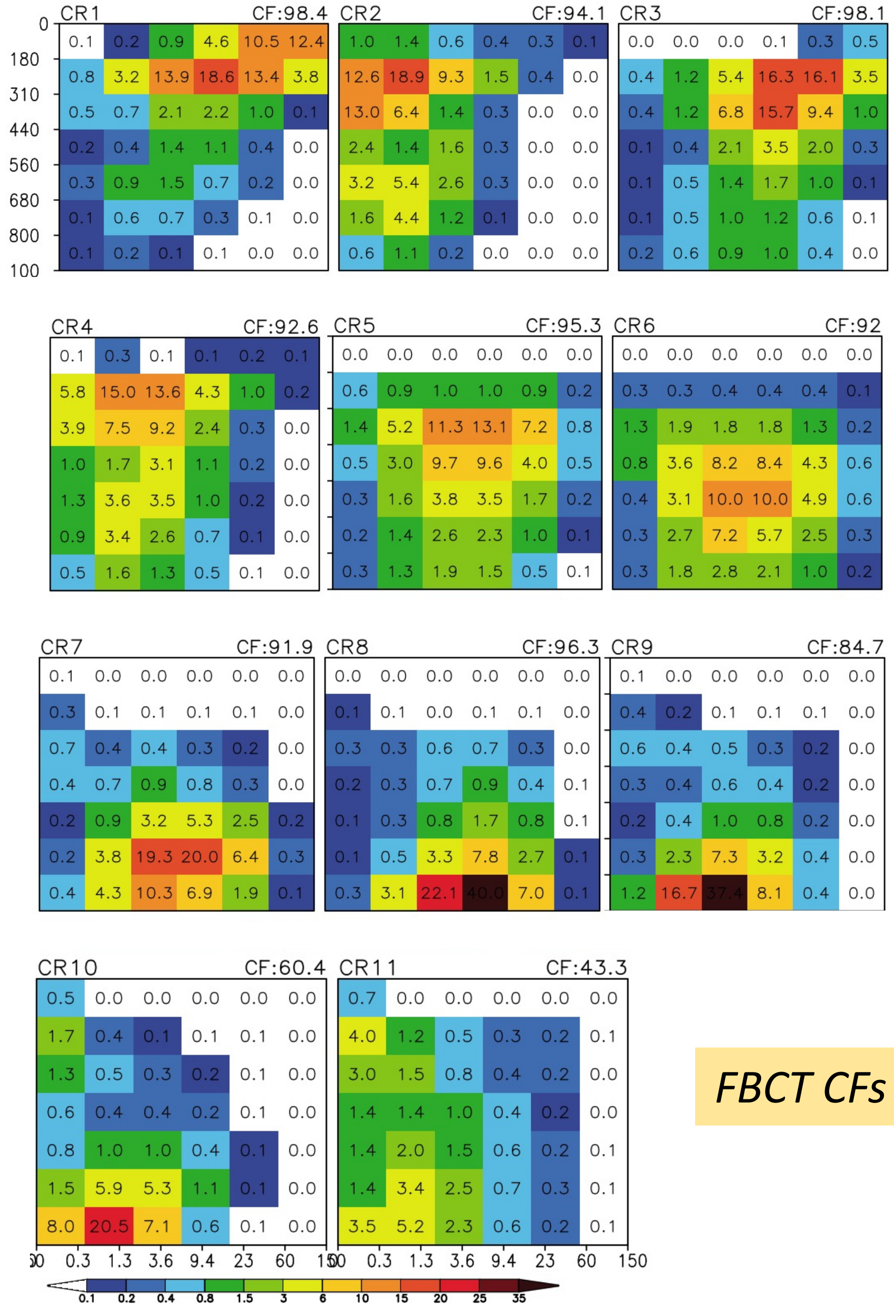



MODIS FBCT

- Composite (average) CERES CF JHs based on MODIS CR occurrences (location, time)
  - RFOs by definition will be the same, but mean histograms (centroids) will be different

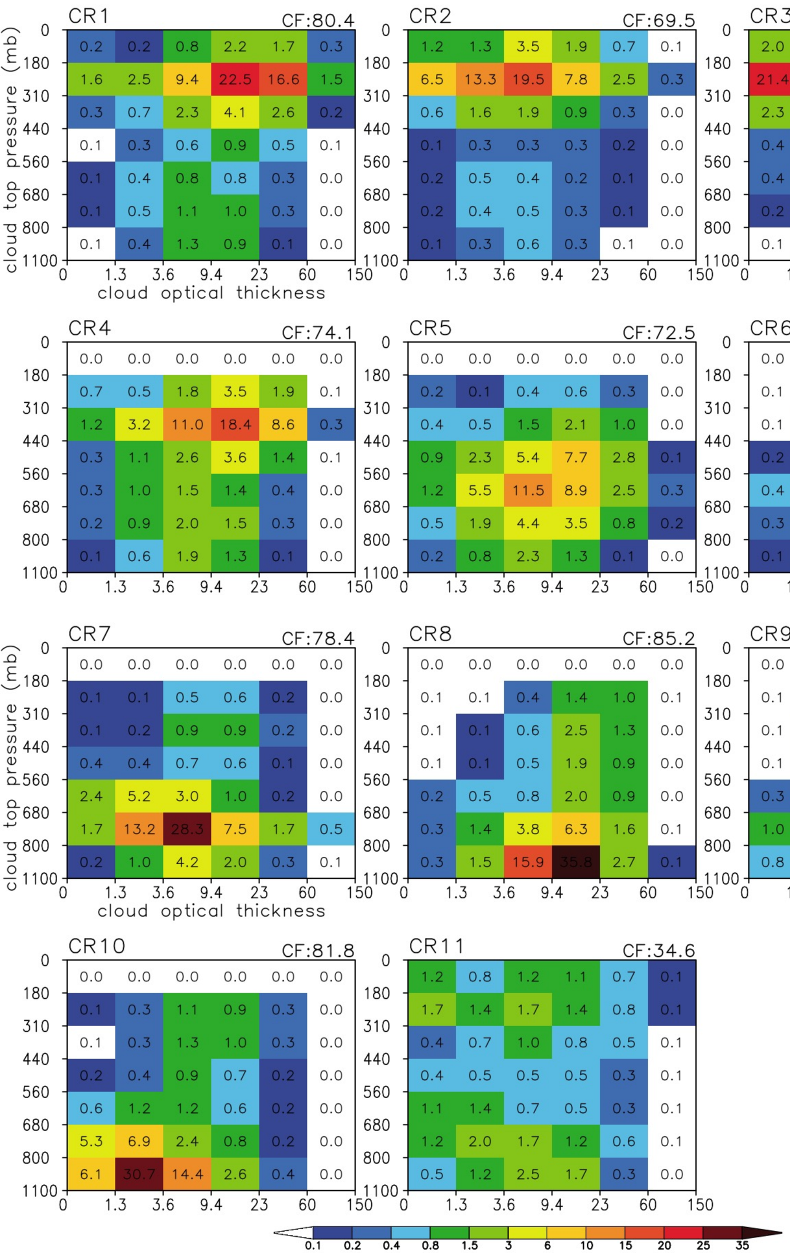
# Compare MODIS COSP with MODIS FBCT (2)

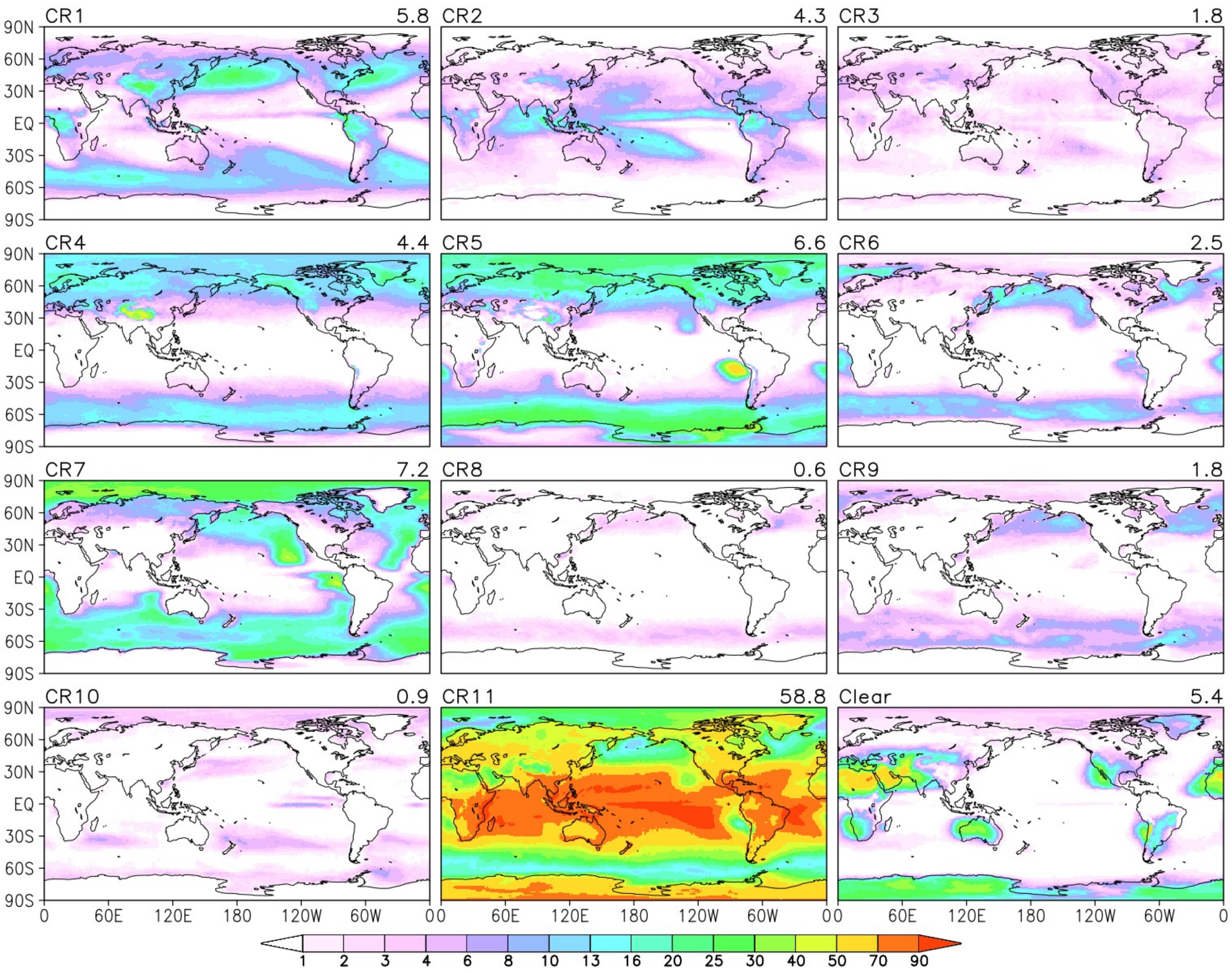


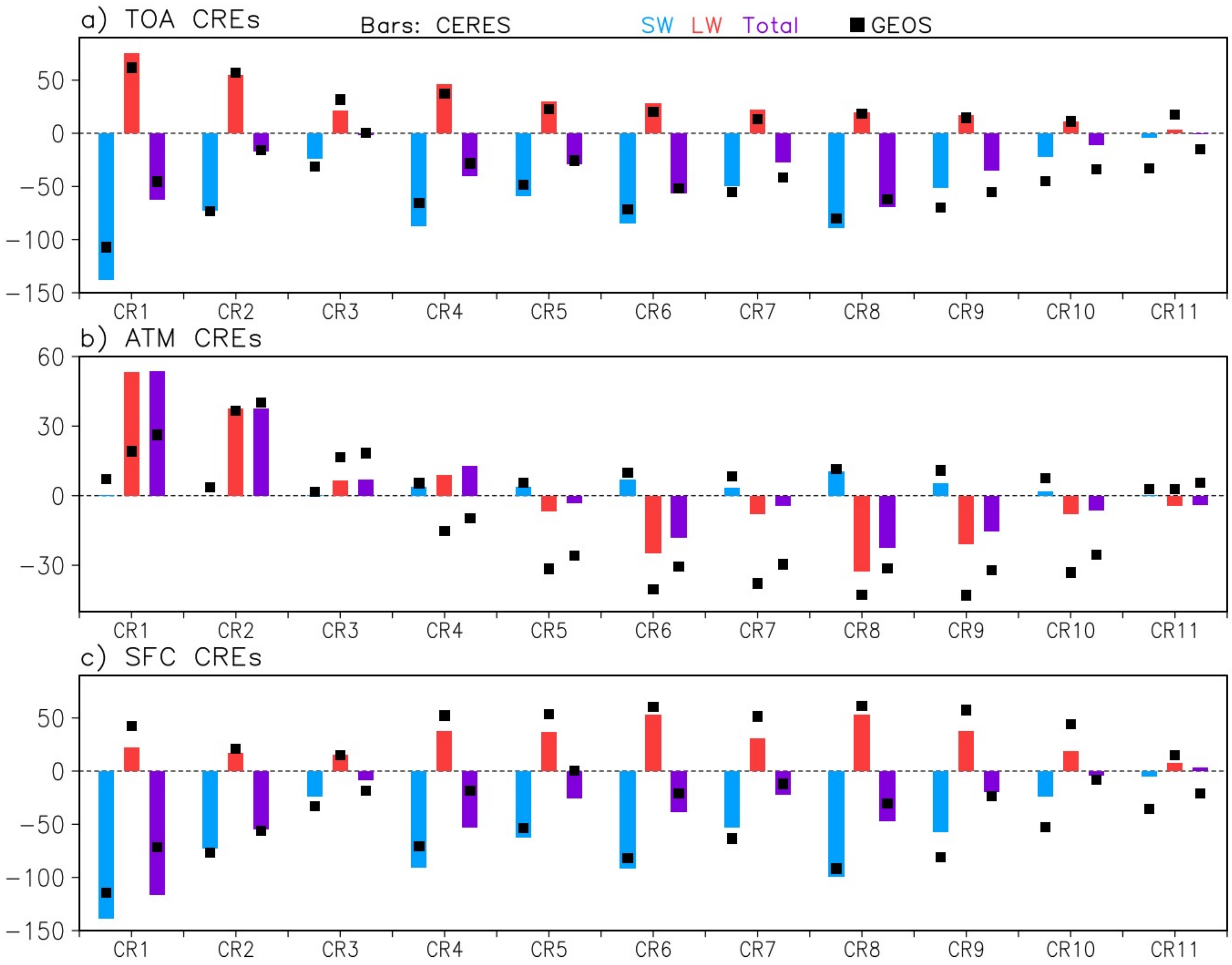

*FBCT CFs are larger!*

# GEOS forced (July 2002 ~ June 2016) to FBCT CRs

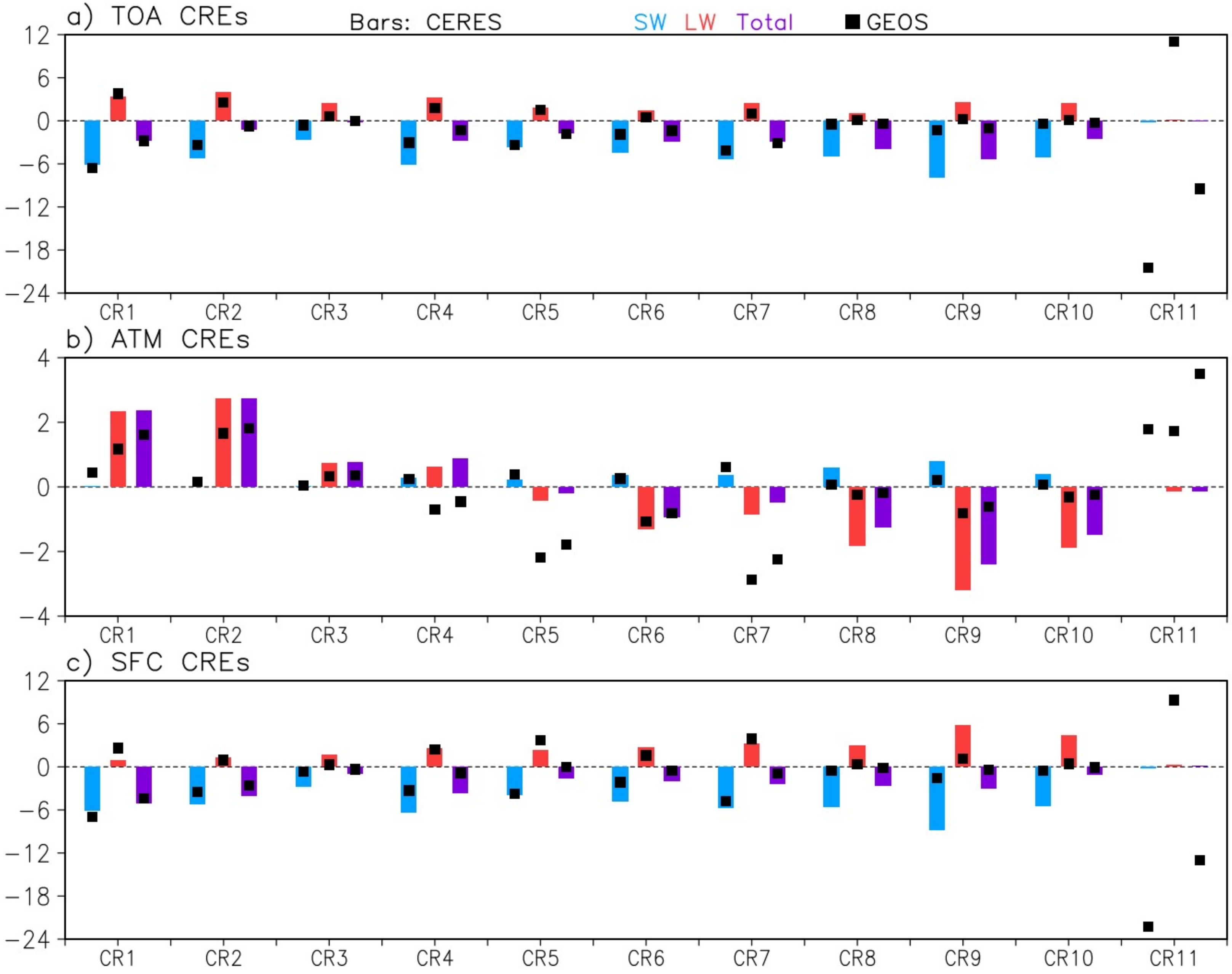


# CR CRE comparison between FBCT and GEOS



# CR CREs x RFOs comparison between FBCT and GEOS



CRE Error decomposition, GEOS with FBCT