

Evaluating Rainfall Errors in Global Climate Models through Cloud Regimes

Jackson Tan

NASA Postdoctoral Fellow

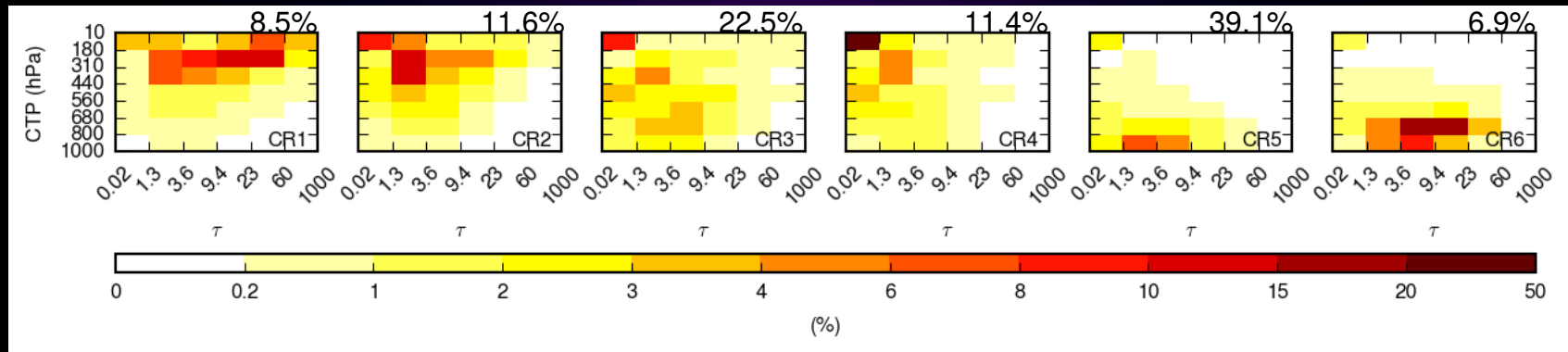
Goddard Space Flight Center / Universities Space Research Association

With contributions from: Lazaros Oreopoulos, Christian Jakob, Daeho Jin



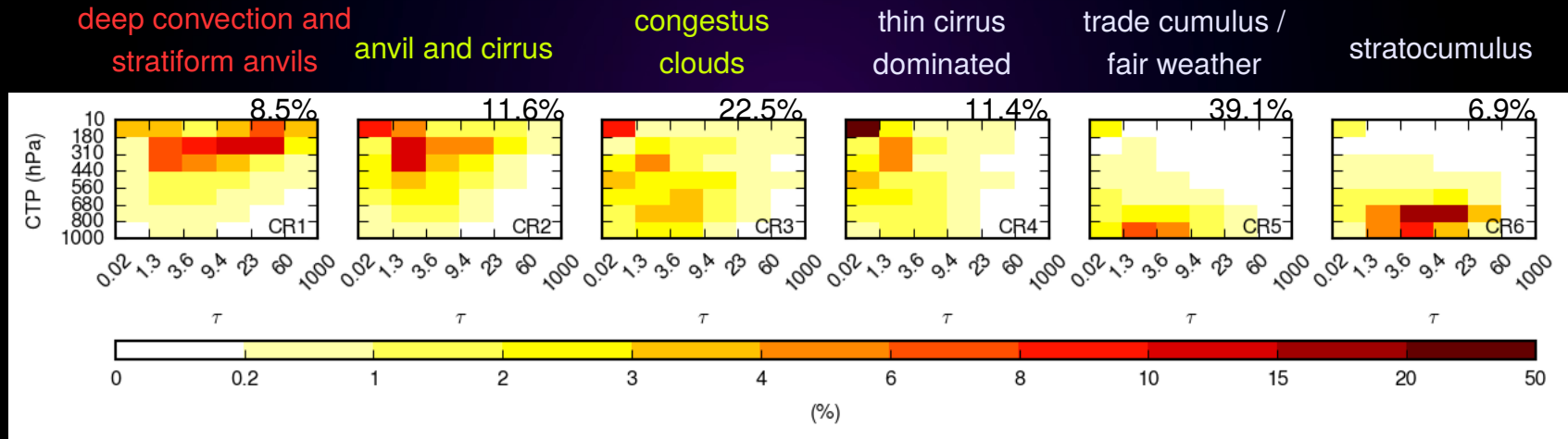
Using ISCCP CRs as Proxies for Conv. Env.

ISCCP D1 daytime-averaged joint-histograms + *k*-means cluster analysis in tropics ($\pm 15^\circ\text{N/S}$) \rightarrow 6 cloud regimes



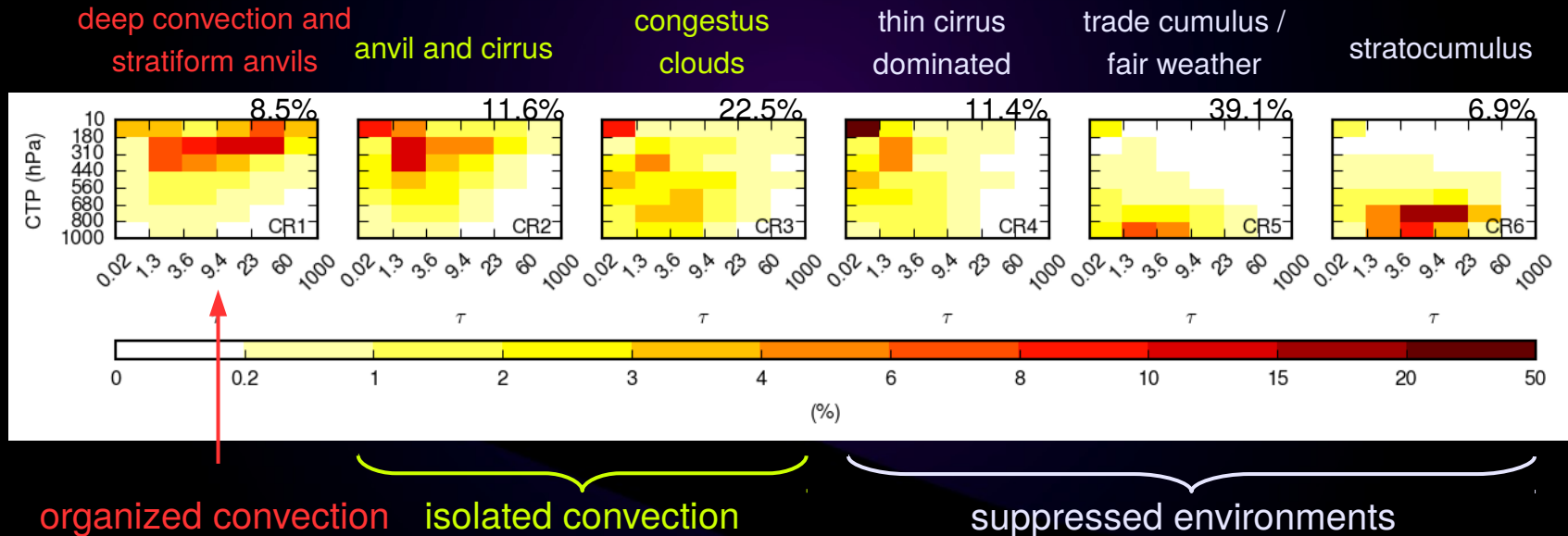
Using ISCCP CRs as Proxies for Conv. Env.

ISCCP D1 daytime-averaged joint-histograms + *k*-means cluster analysis in tropics ($\pm 15^\circ\text{N/S}$) \rightarrow 6 cloud regimes



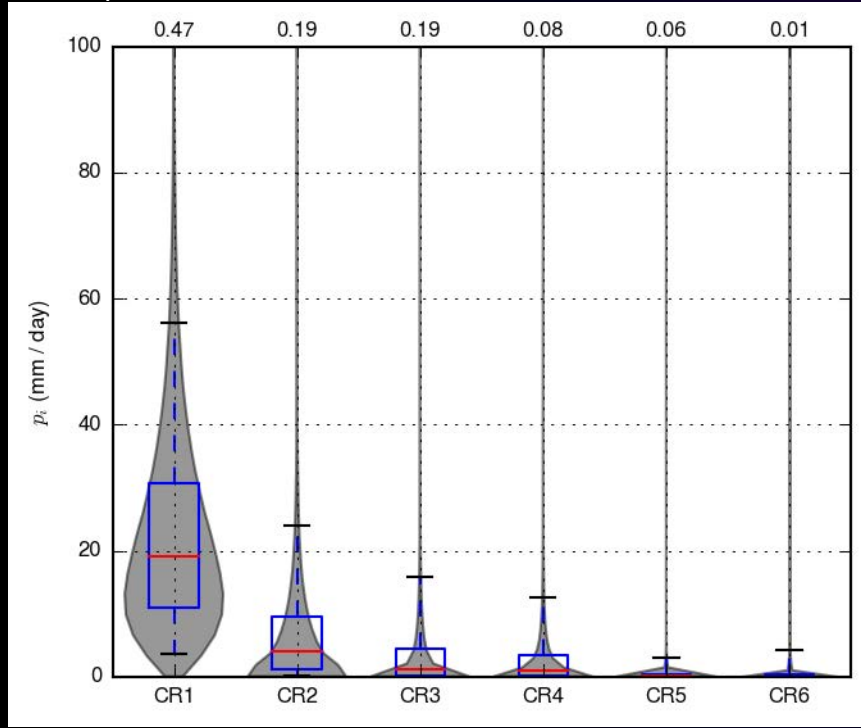
Using ISCCP CRs as Proxies for Conv. Env.

ISCCP D1 daytime-averaged joint-histograms + *k*-means cluster analysis in tropics ($\pm 15^\circ\text{N/S}$) \rightarrow 6 cloud regimes



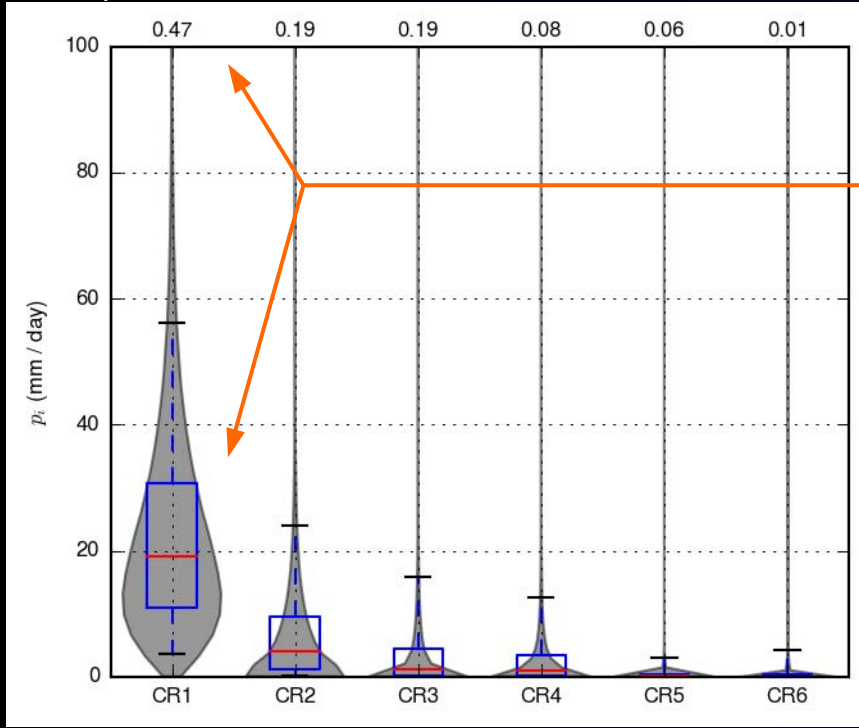
CRs Have Distinct Rain Rate Distribution

Composite with TRMM 3B42



CRs Have Distinct Rain Rate Distribution

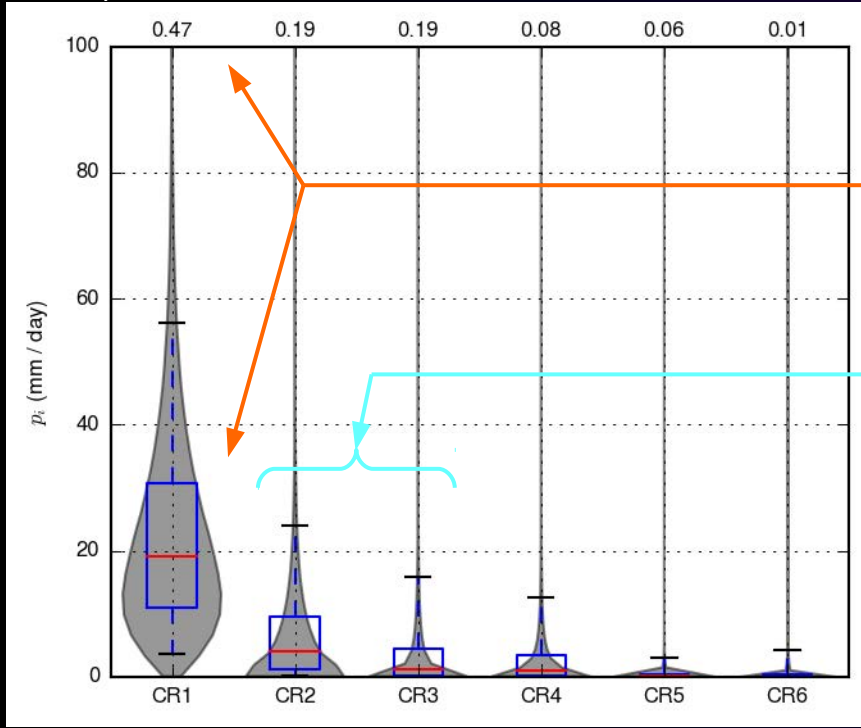
Composite with TRMM 3B42



CR1 is associated with high occurrence of rainfall and rain intensities and contributes to nearly half the total tropical rainfall

CRs Have Distinct Rain Rate Distribution

Composite with TRMM 3B42

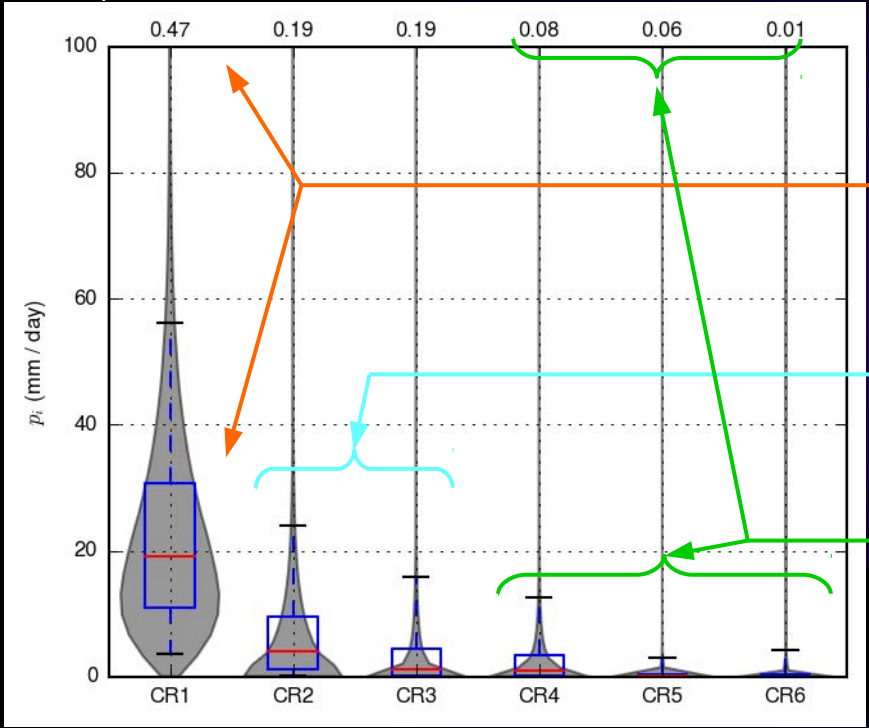


CR1 is associated with high occurrence of rainfall and rain intensities and contributes to nearly half the total tropical rainfall

CR2 and CR3 have lower rain rates than CR1 and higher incidences of dry days.

CRs Have Distinct Rain Rate Distribution

Composite with TRMM 3B42



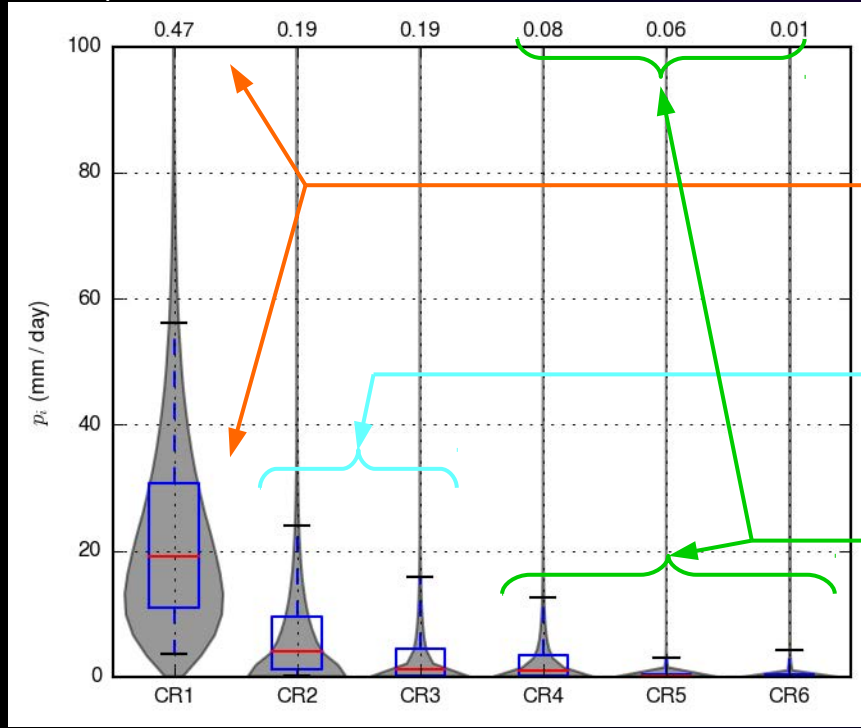
CR1 is associated with high occurrence of rainfall and rain intensities and contributes to nearly half the total tropical rainfall

CR2 and CR3 have lower rain rates than CR1 and higher incidences of dry days.

CR4, CR5 and CR6 have low rain rate distributions and low contributions to total rainfall

CRs Have Distinct Rain Rate Distribution

Composite with TRMM 3B42



CR1 is associated with high occurrence of rainfall and rain intensities and contributes to nearly half the total tropical rainfall

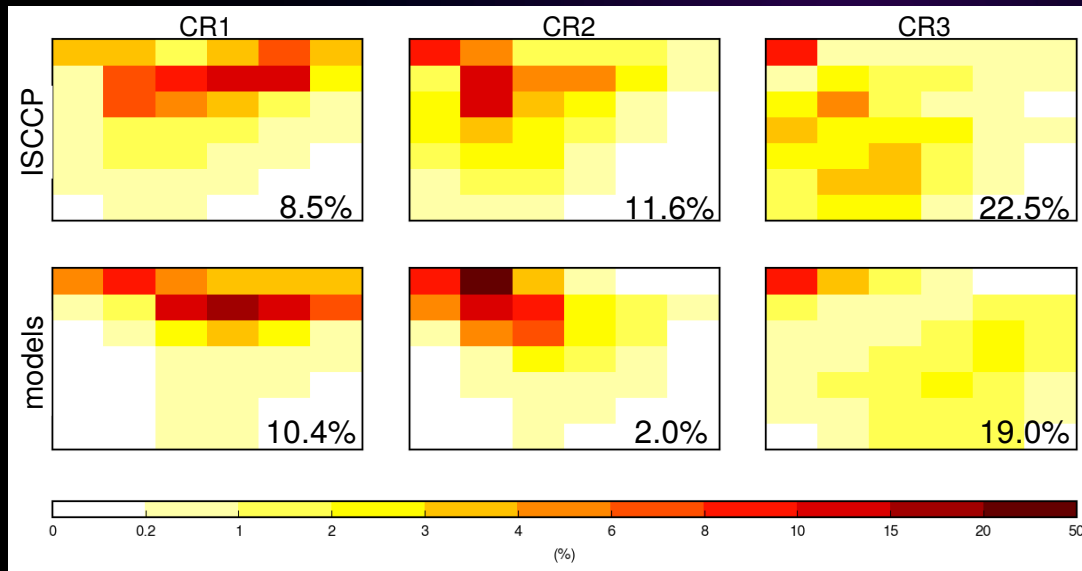
CR2 and CR3 have lower rain rates than CR1 and higher incidences of dry days.

CR4, CR5 and CR6 have low rain rate distributions and low contributions to total rainfall

Focus only on CR1 to CR3 due to their combined dominance in contribution to tropical rainfall (85% total)

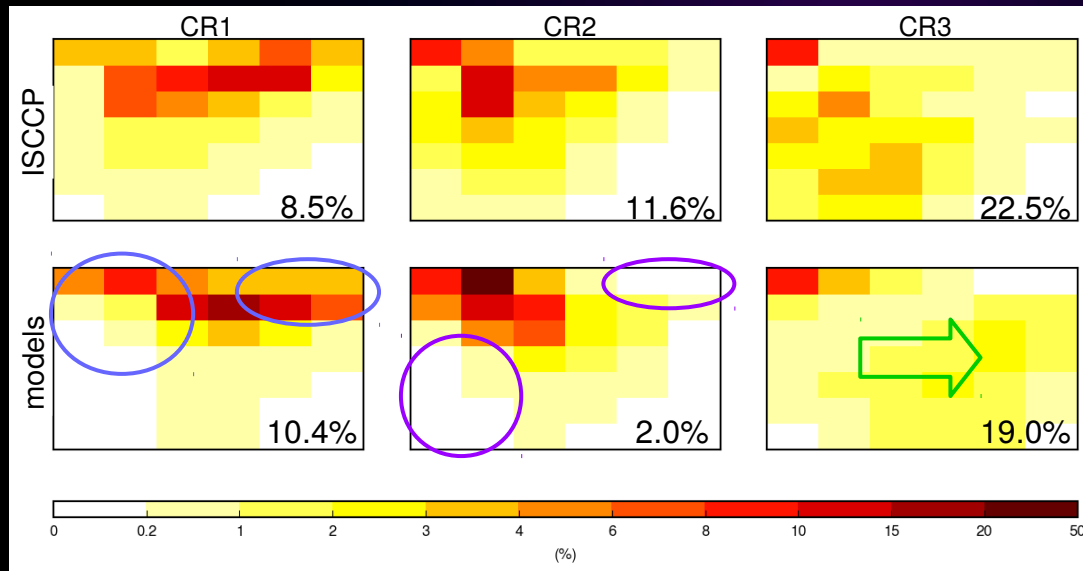
Defining Cloud Regimes in GCMs

- CMIP5/CFMIP2 GCMs produces ISCCP-like joint-histograms
- assign model joint-histograms (2001 to 2008) from AMIP experiment to the closest observed CR centroids based on Euclidean distance between the 42 bins



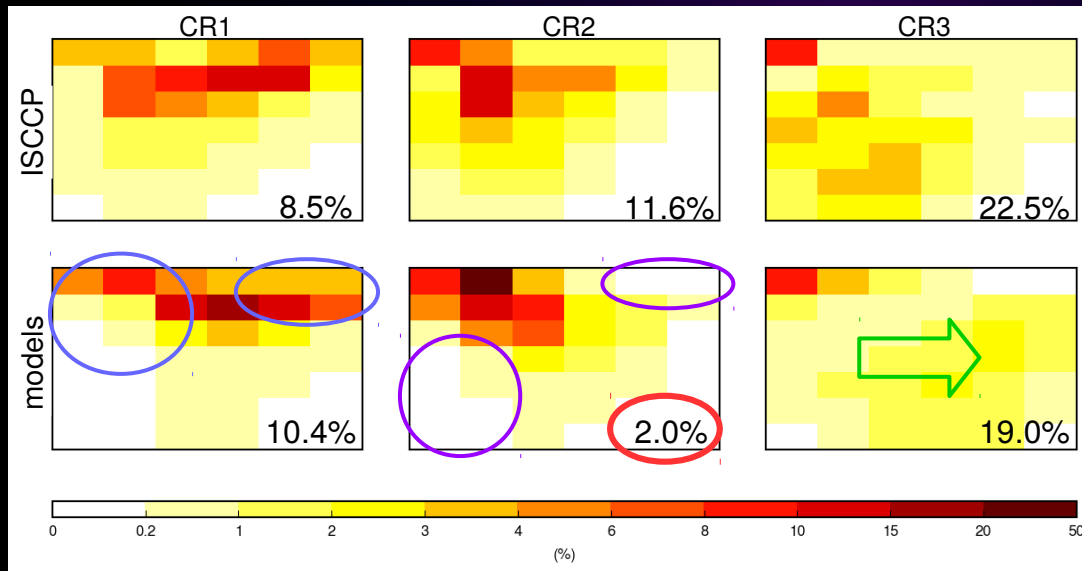
Defining Cloud Regimes in GCMs

- CMIP5/CFMIP2 GCMs produces ISCCP-like joint-histograms
- assign model joint-histograms (2001 to 2008) from AMIP experiment to the closest observed CR centroids based on Euclidean distance between the 42 bins



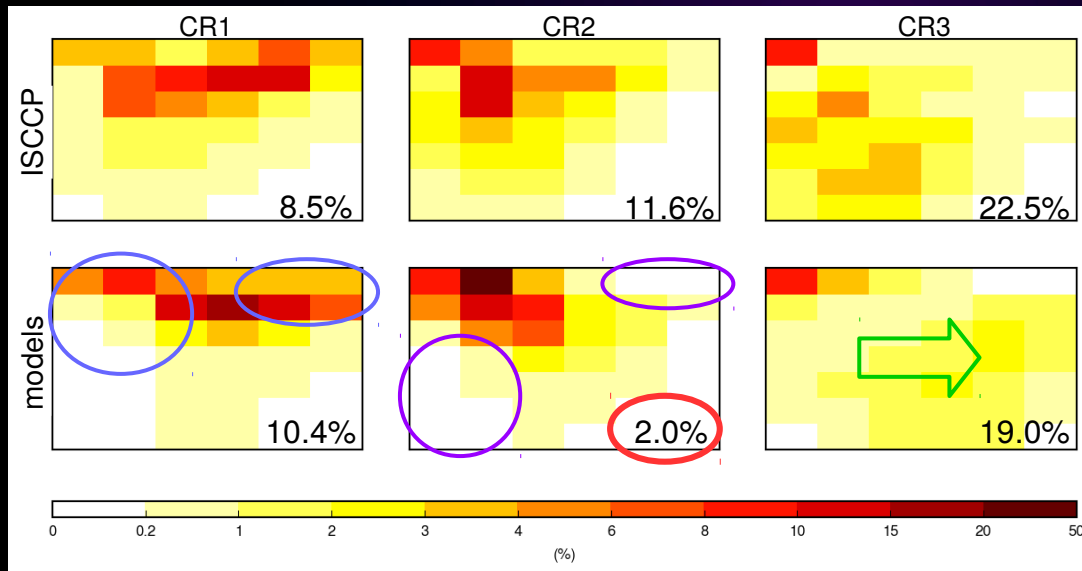
Defining Cloud Regimes in GCMs

- CMIP5/CFMIP2 GCMs produces ISCCP-like joint-histograms
- assign model joint-histograms (2001 to 2008) from AMIP experiment to the closest observed CR centroids based on Euclidean distance between the 42 bins



Defining Cloud Regimes in GCMs

- CMIP5/CFMIP2 GCMs produces ISCCP-like joint-histograms
- assign model joint-histograms (2001 to 2008) from AMIP experiment to the closest observed CR centroids based on Euclidean distance between the 42 bins

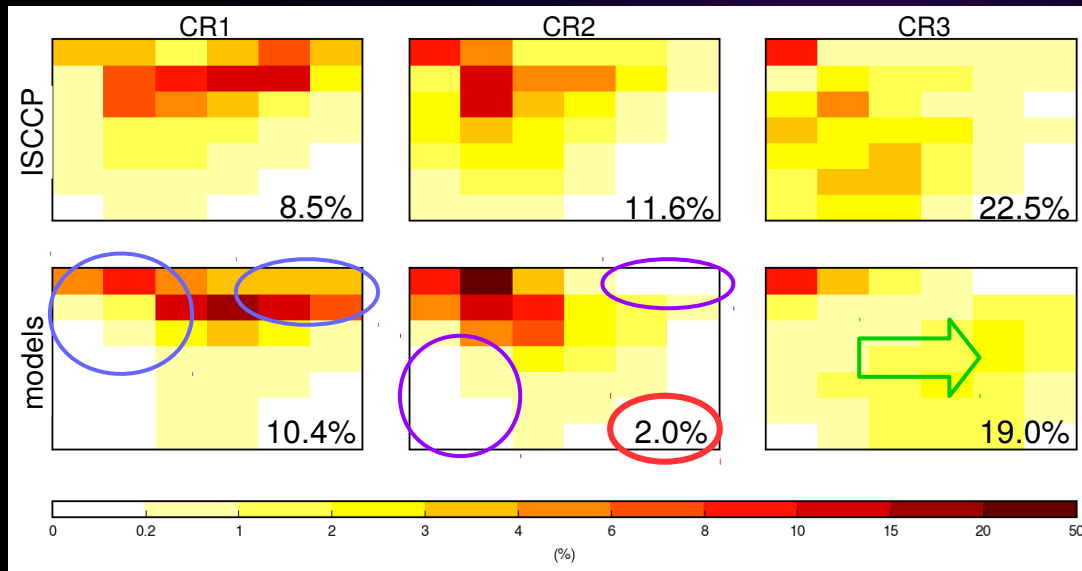


Use cloud regimes to dissect errors in model rainfall through simulated cloud properties.



Defining Cloud Regimes in GCMs

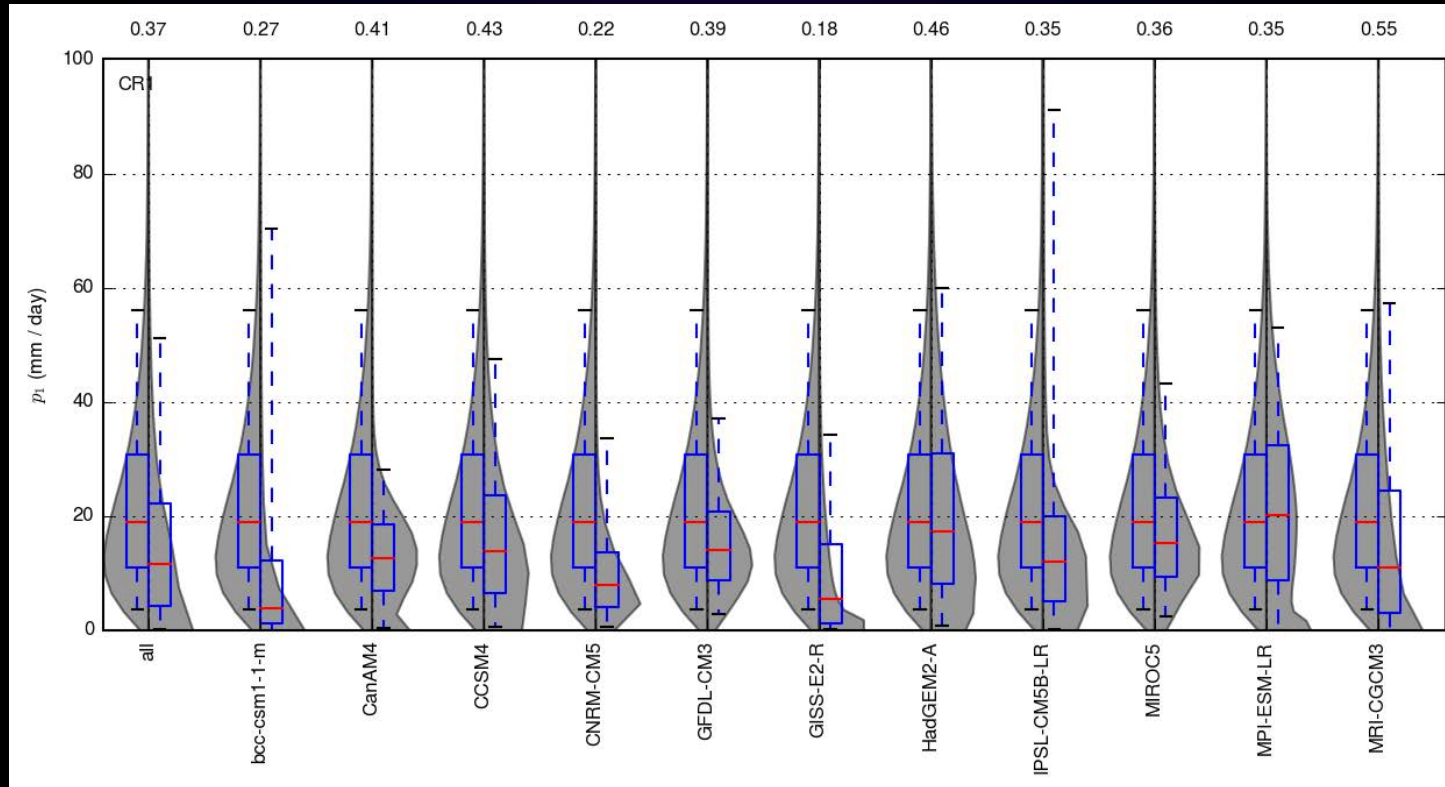
- CMIP5/CFMIP2 GCMs produces ISCCP-like joint-histograms
- assign model joint-histograms (2001 to 2008) from AMIP experiment to the closest observed CR centroids based on Euclidean distance between the 42 bins



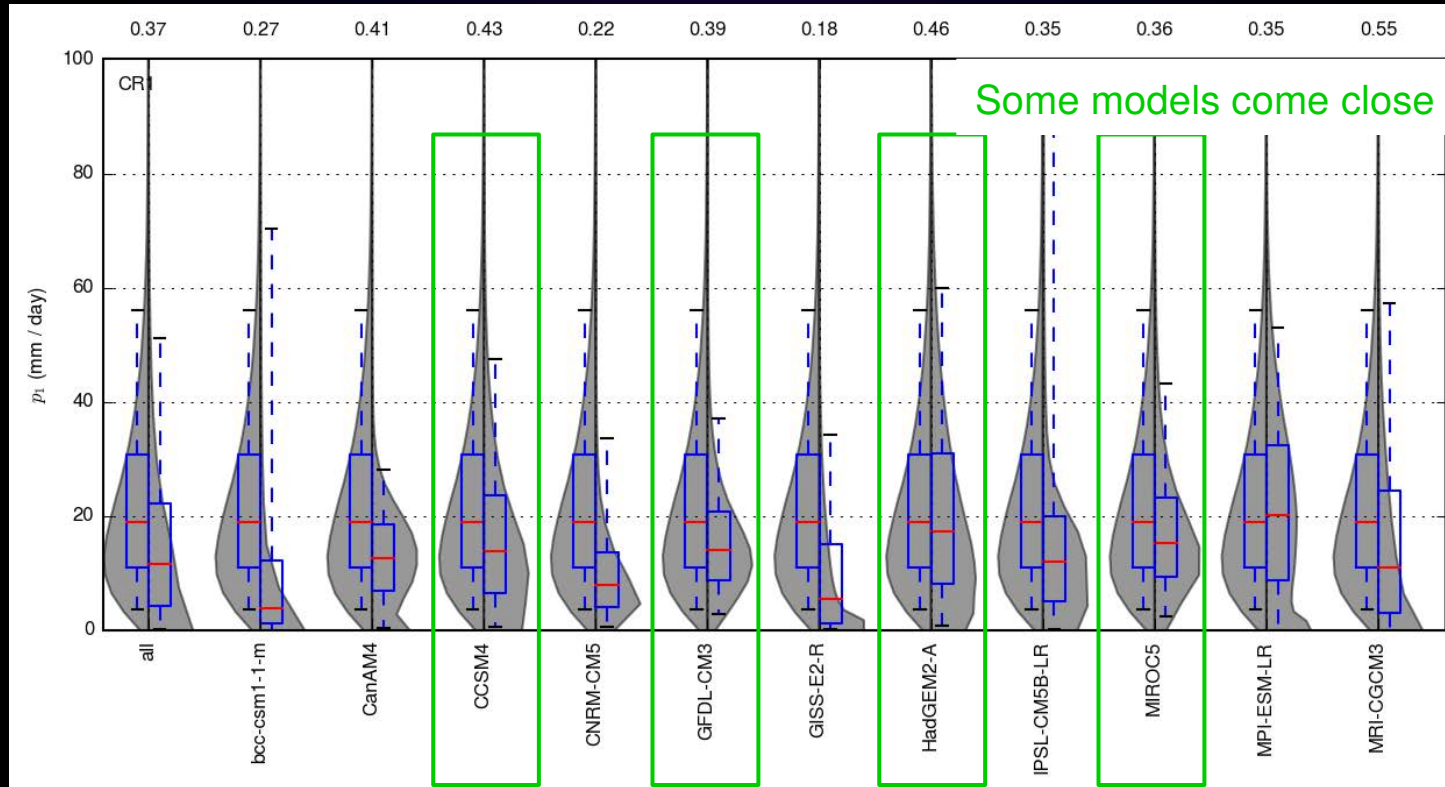
Use cloud regimes to dissect errors in model rainfall through simulated cloud properties.

submitted to Clim. Dyn., under review

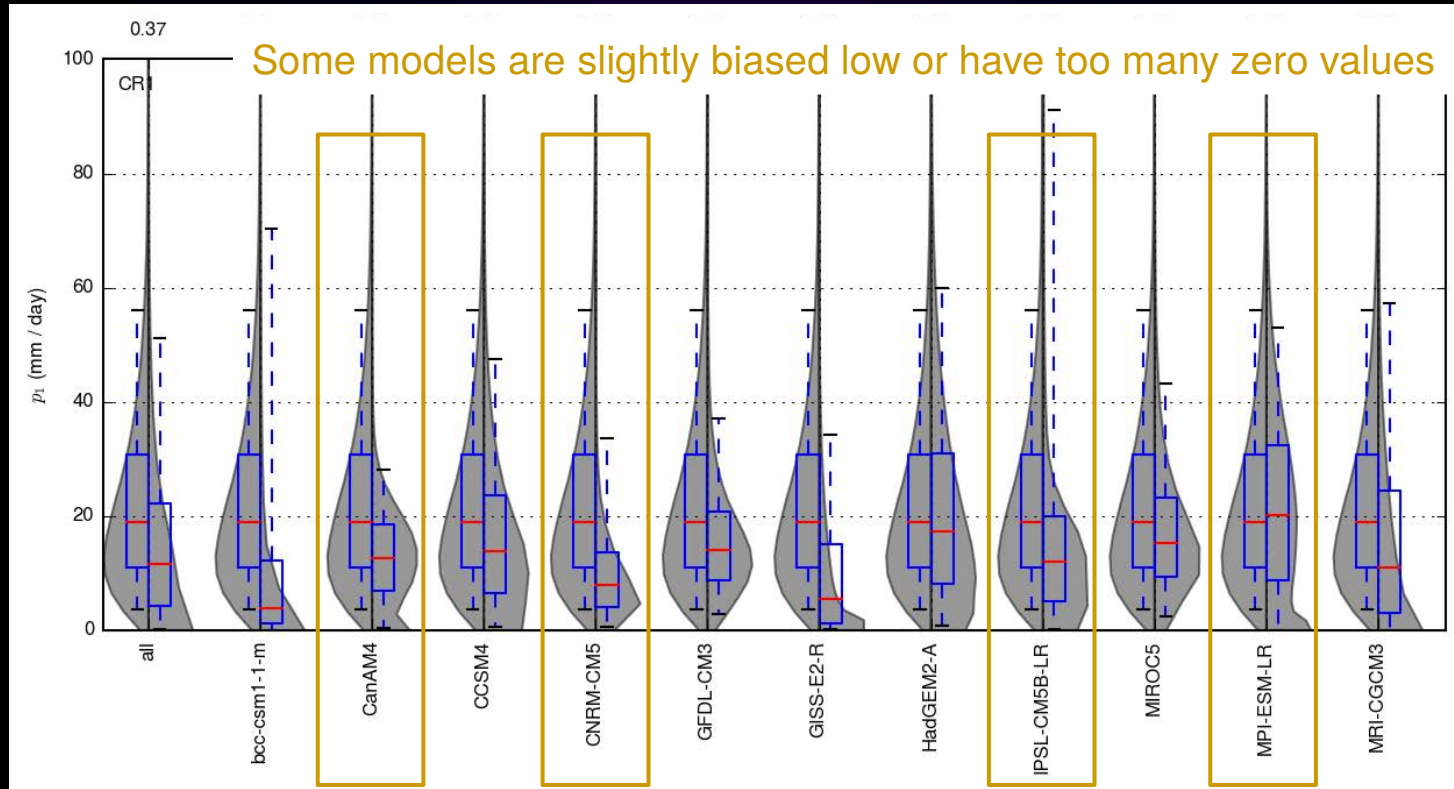
GCMs Generally Underest. CR1 Rainfall



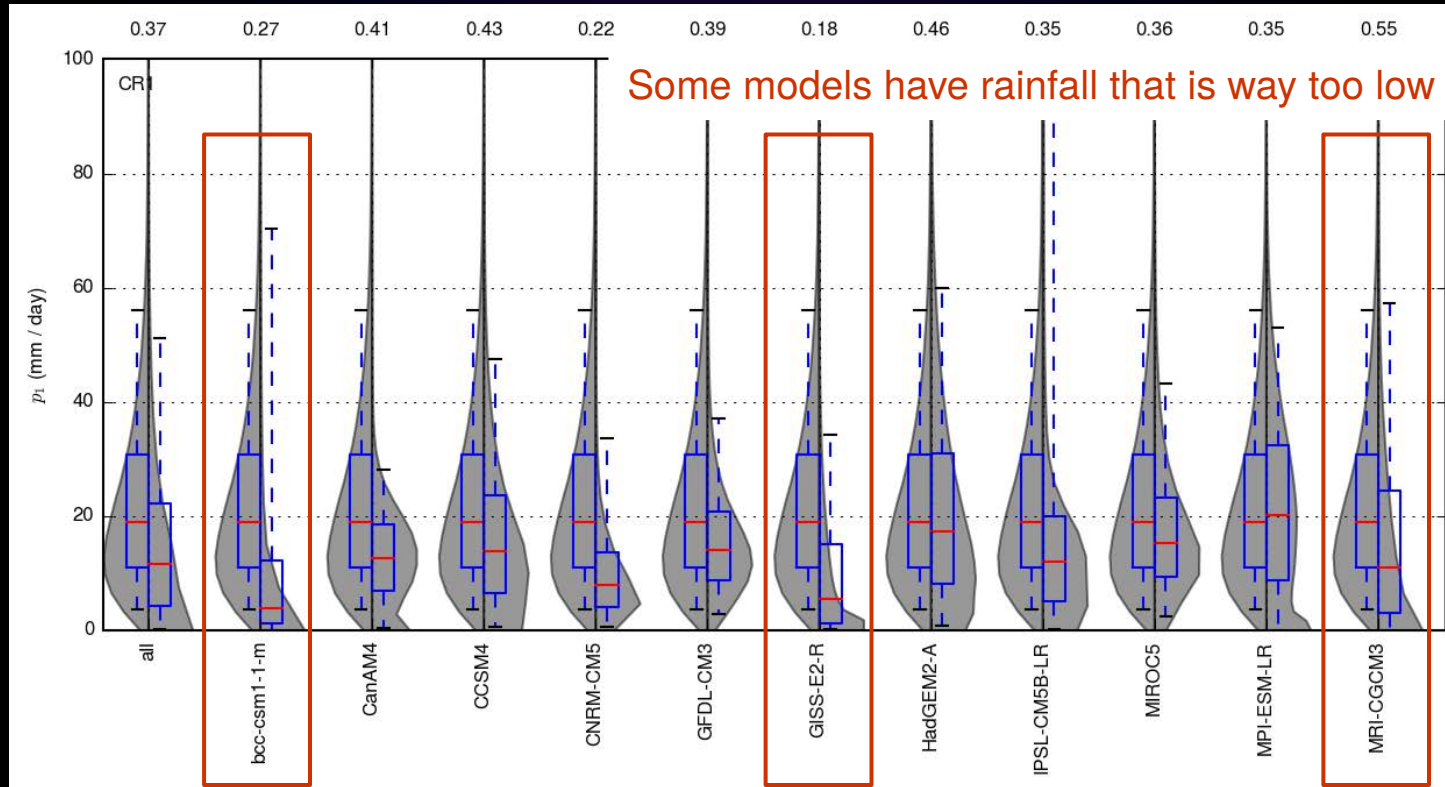
GCMs Generally Underest. CR1 Rainfall



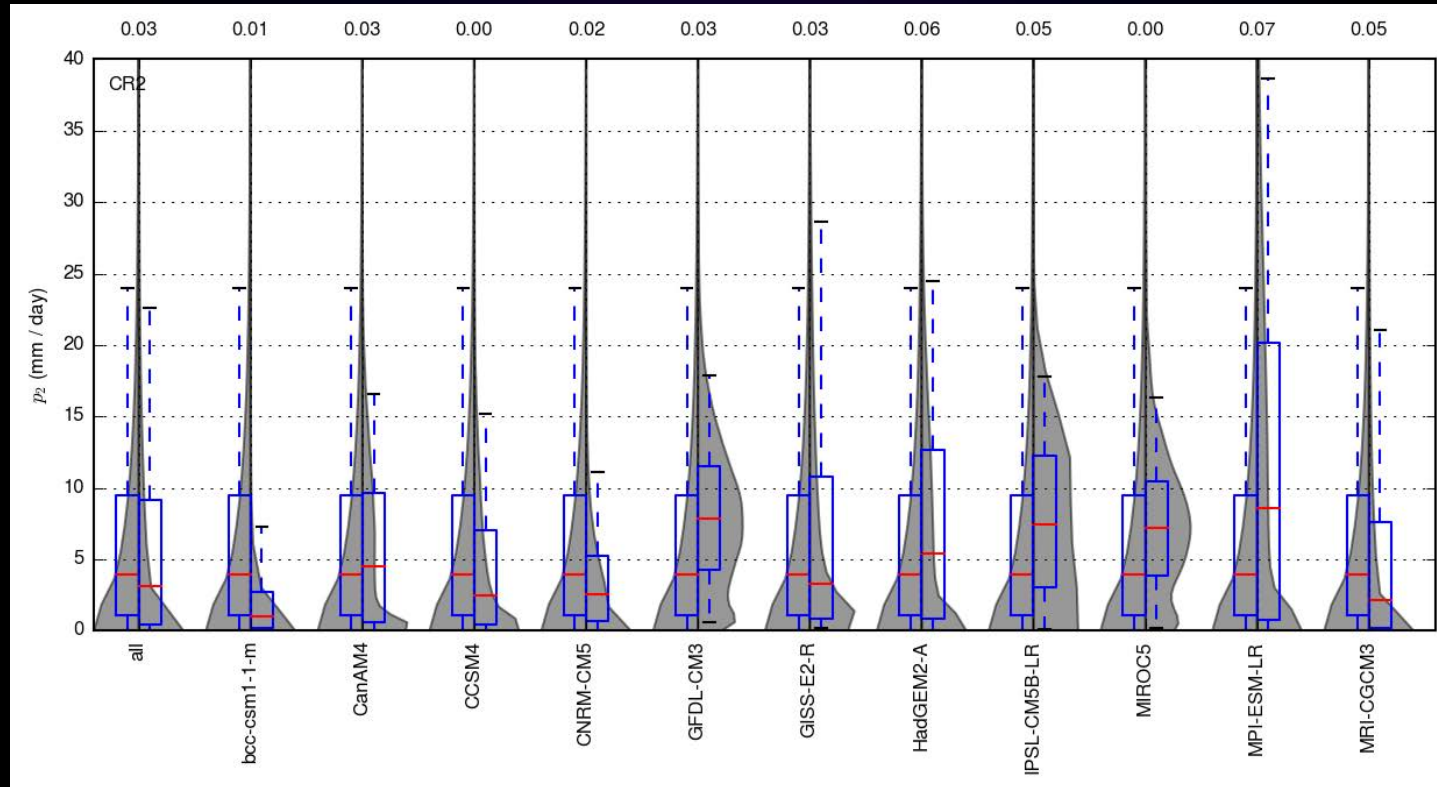
GCMs Generally Underest. CR1 Rainfall



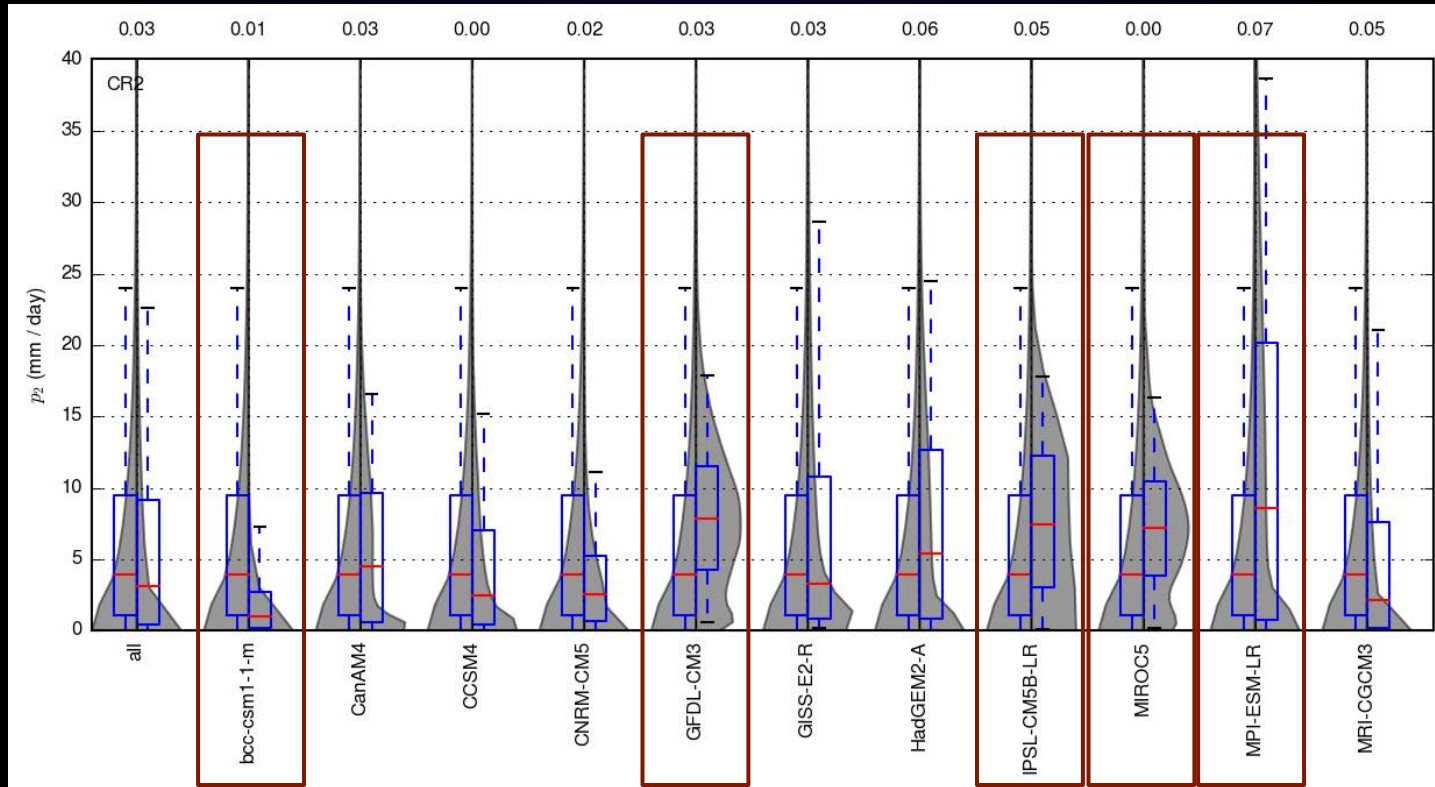
GCMs Generally Underest. CR1 Rainfall



GCMs Overest. and Underest. CR2 Rainfall

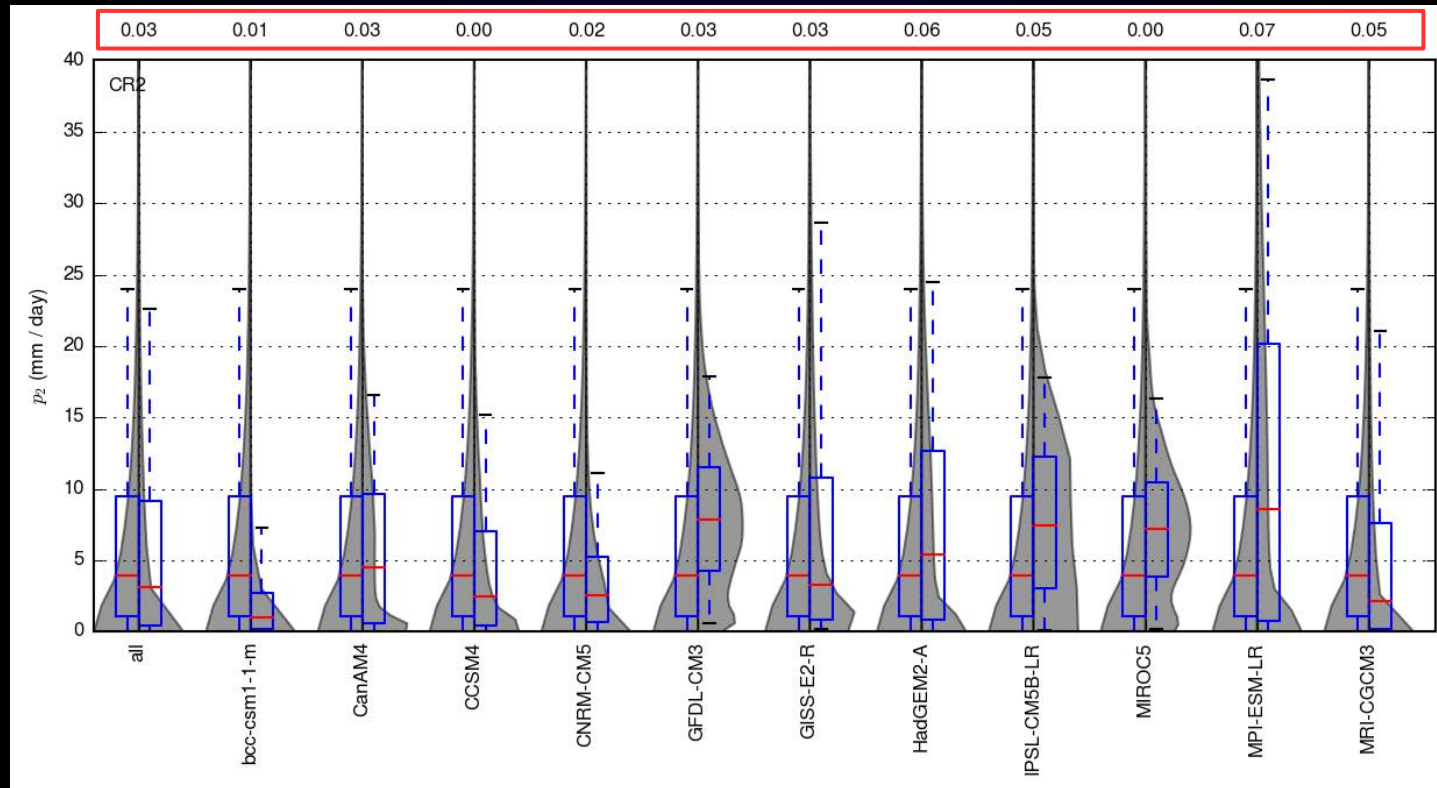


GCMs Overest. and Underest. CR2 Rainfall

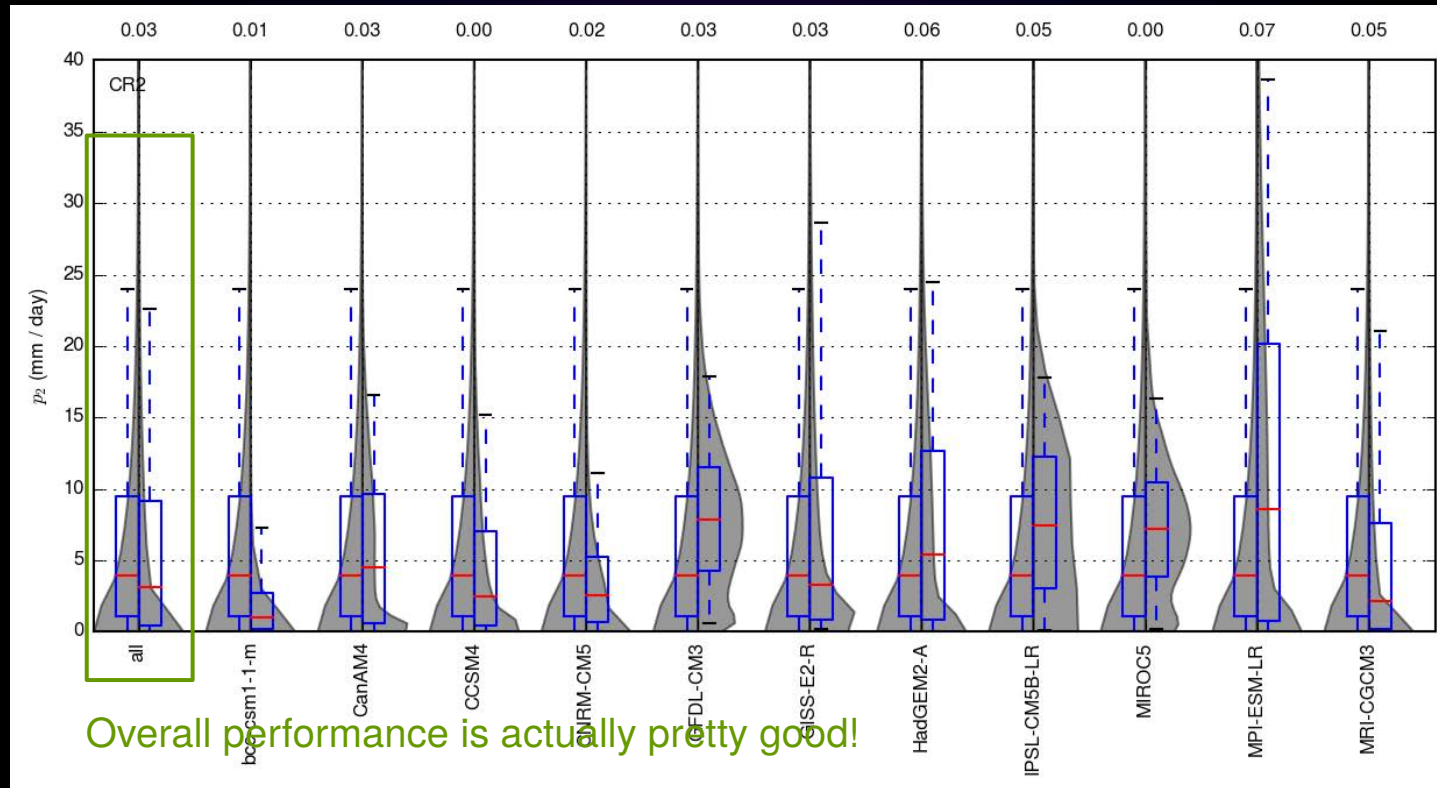


GCMs Overest. and Underest. CR2 Rainfall

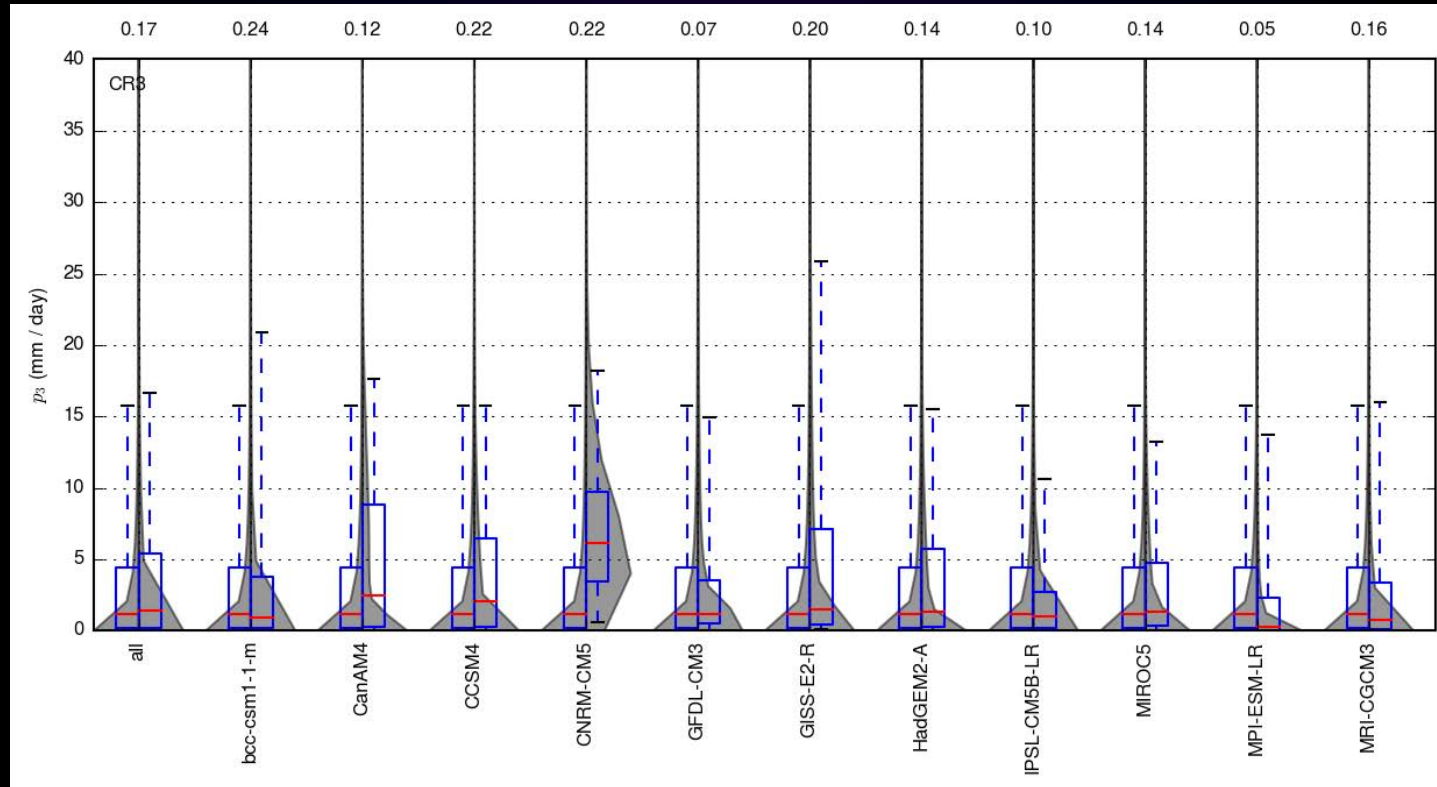
Contribution from CR2 is low (obs: 0.19)



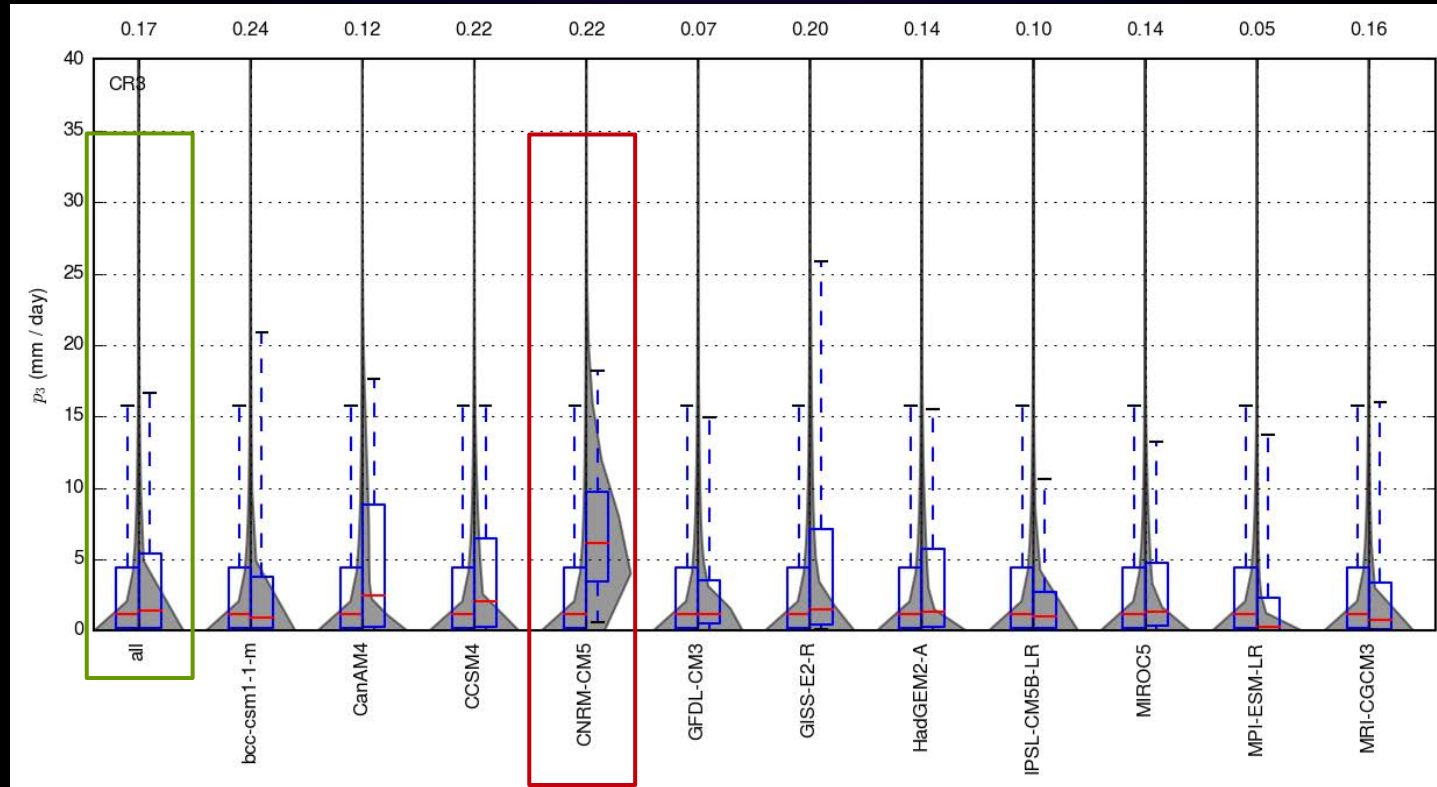
GCMs Overest. and Underest. CR2 Rainfall



GCMs Generally Capture CR3 Rainfall



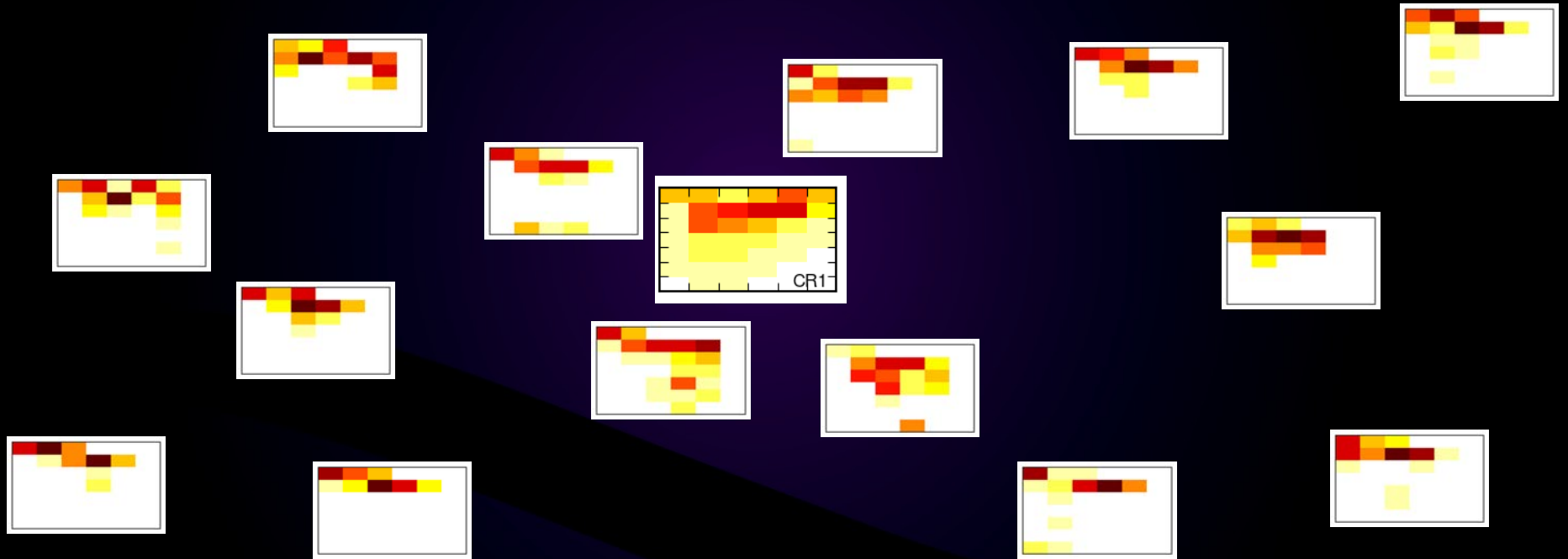
GCMs Generally Capture CR3 Rainfall



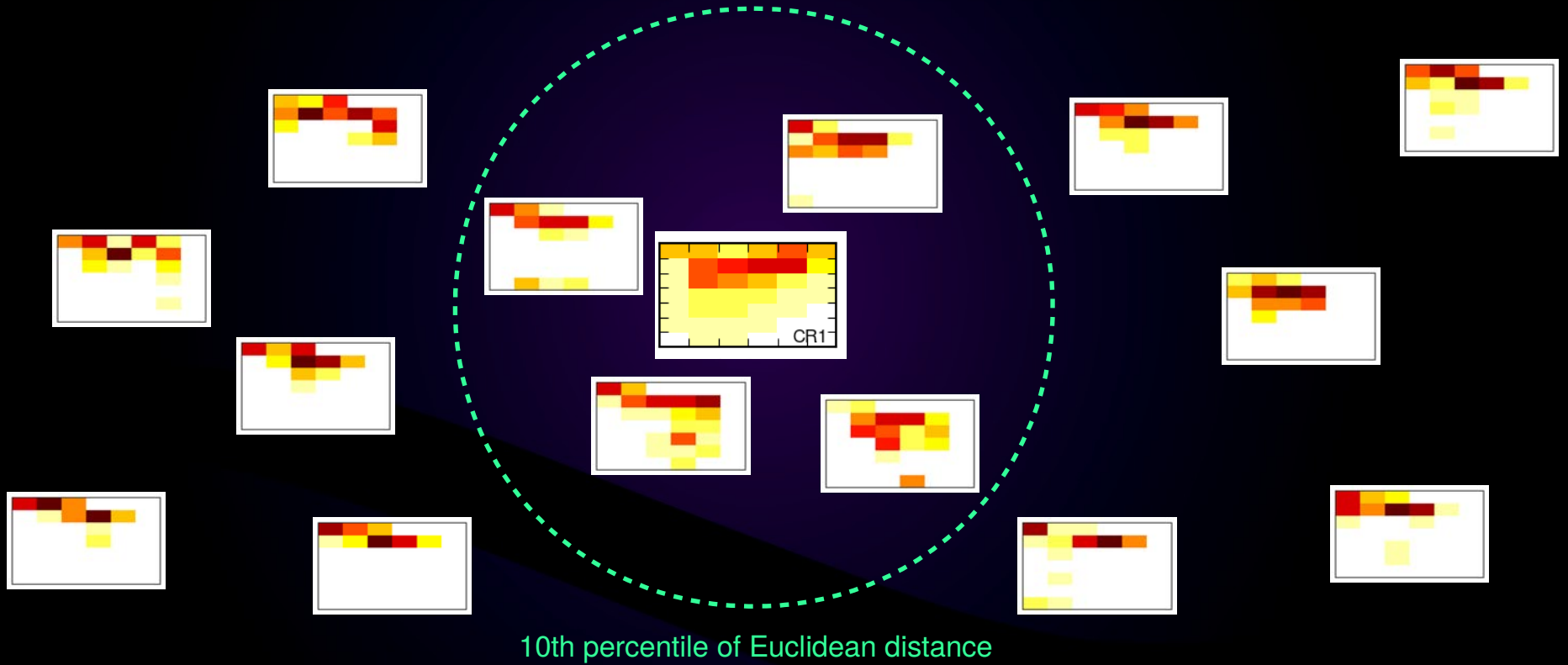
Selecting the Best Matching CRs

We are asking a lot out of the models! They must get the clouds right and the rainfall right. Could it be the clouds that is the issue?

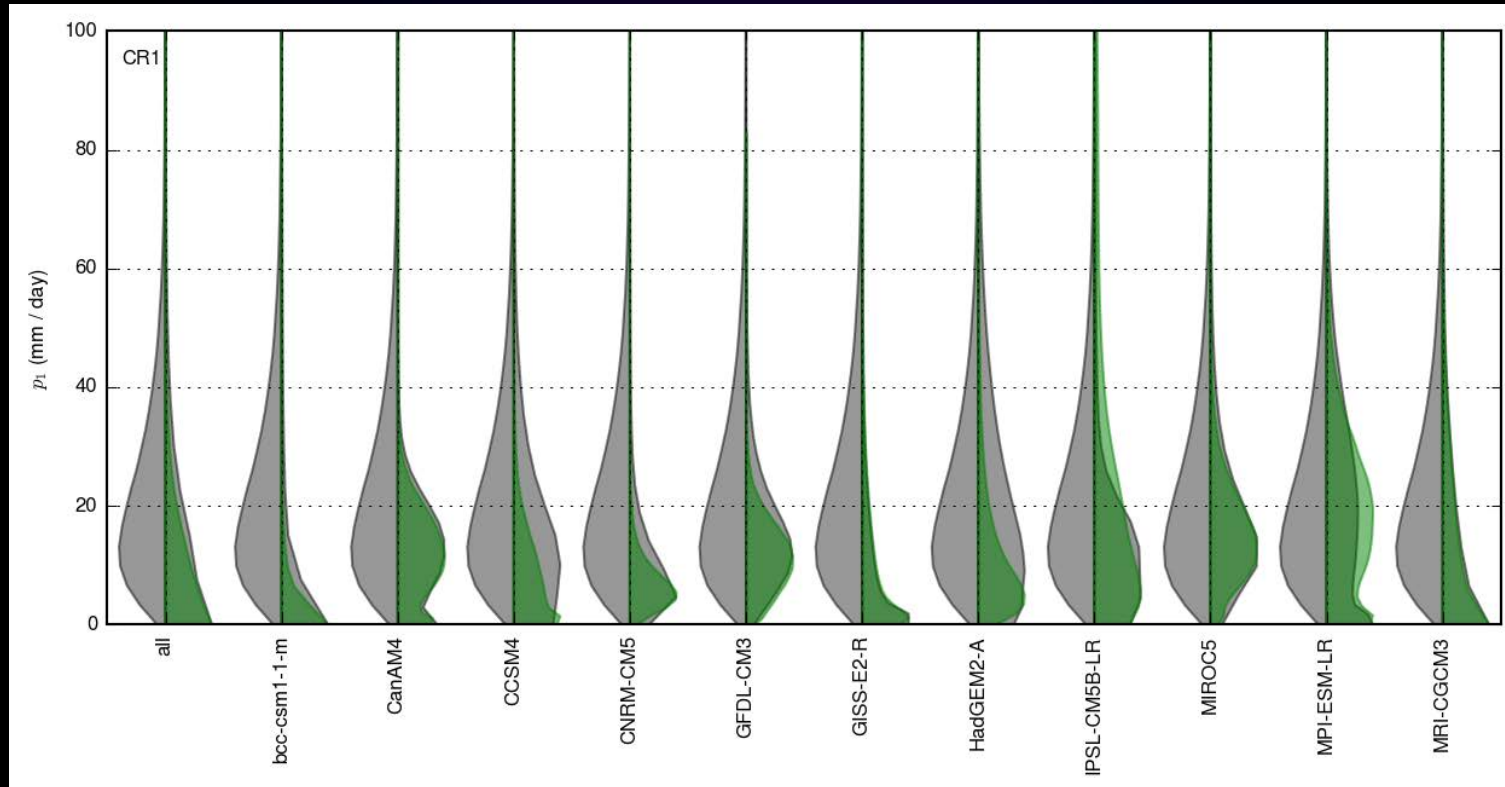
Selecting the Best Matching CRs



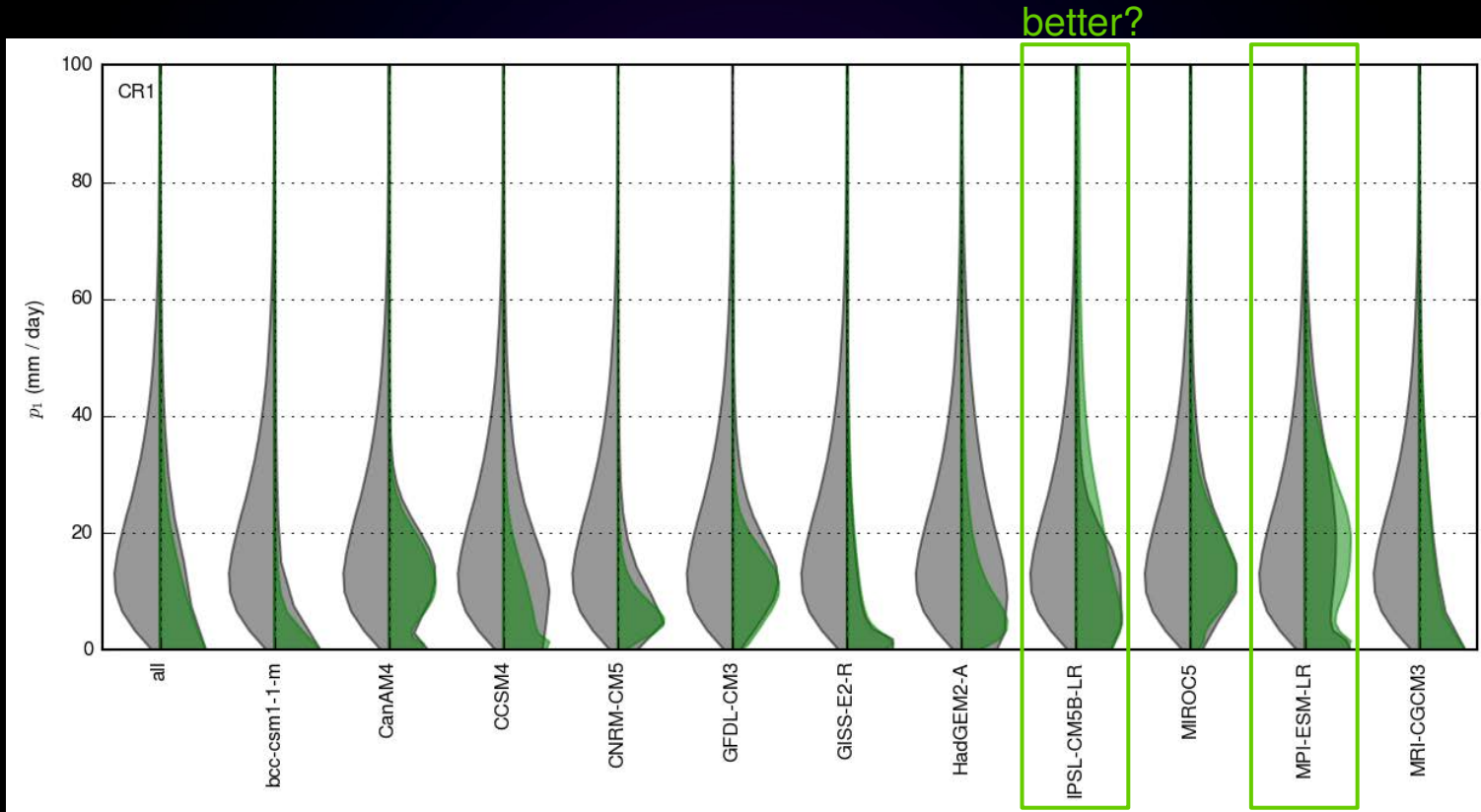
Selecting the Best Matching CRs



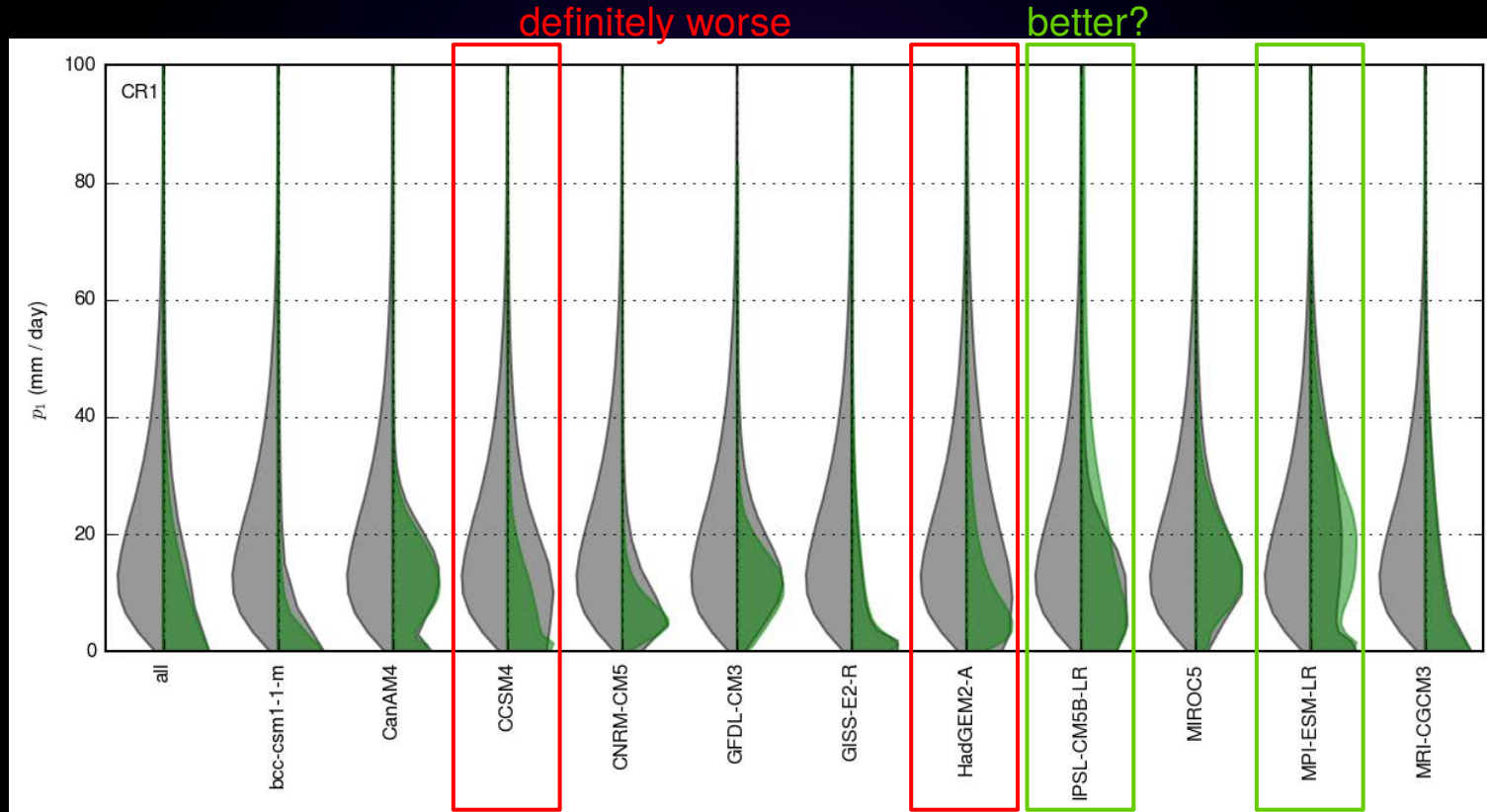
Best Matching CRs \neq Better Rainfall



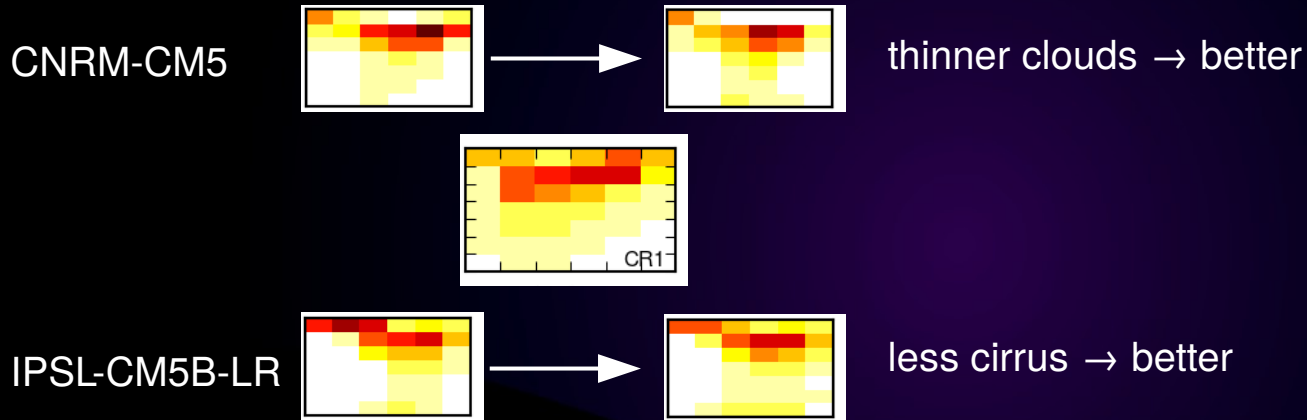
Best Matching CRs \neq Better Rainfall



Best Matching CRs \neq Better Rainfall



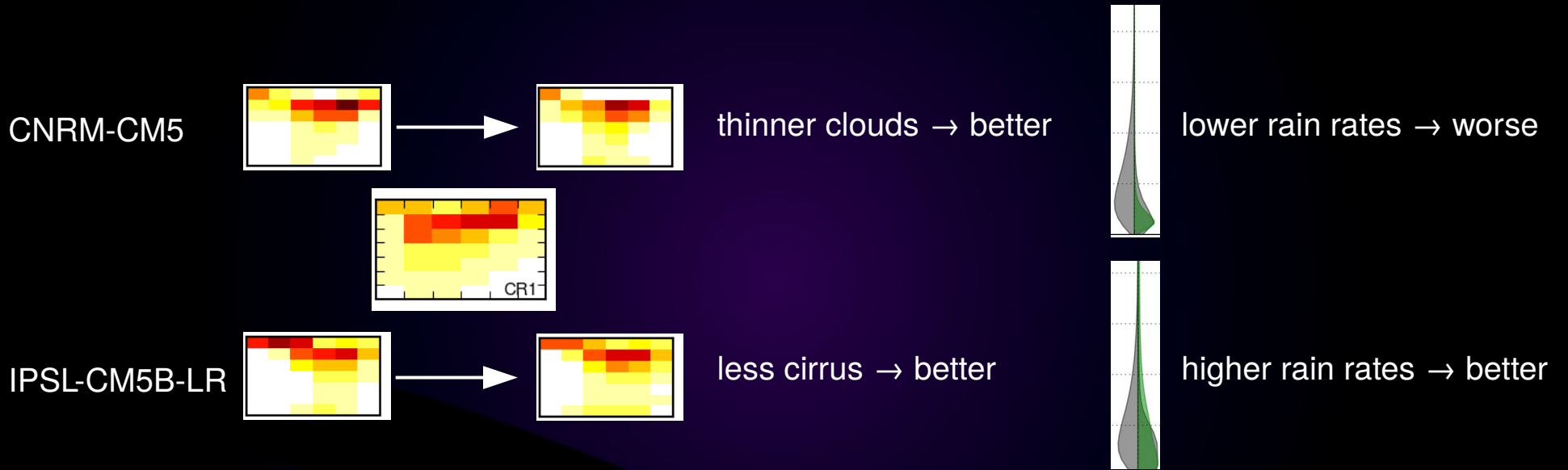
Why the Best CRs Do Not Improve Rainfall



Why the Best CRs Do Not Improve Rainfall



Why the Best CRs Do Not Improve Rainfall



The incorrect absolute rainfall associated with clouds of a particular height and thickness is responsible for the model's erroneous representation of rainfall.

Conclusions

- GCMs underestimate CR1 rainfall to varying degrees. GCMs variously overestimate and underestimate the rain rate distribution of CR2 and CR3, but they average out on aggregate.
- Restricting to CRs that best match the observed centroids do not necessary improve the rain rate distribution → absolute rain rates associated with each CTP- τ bin is incorrect.

Conclusions

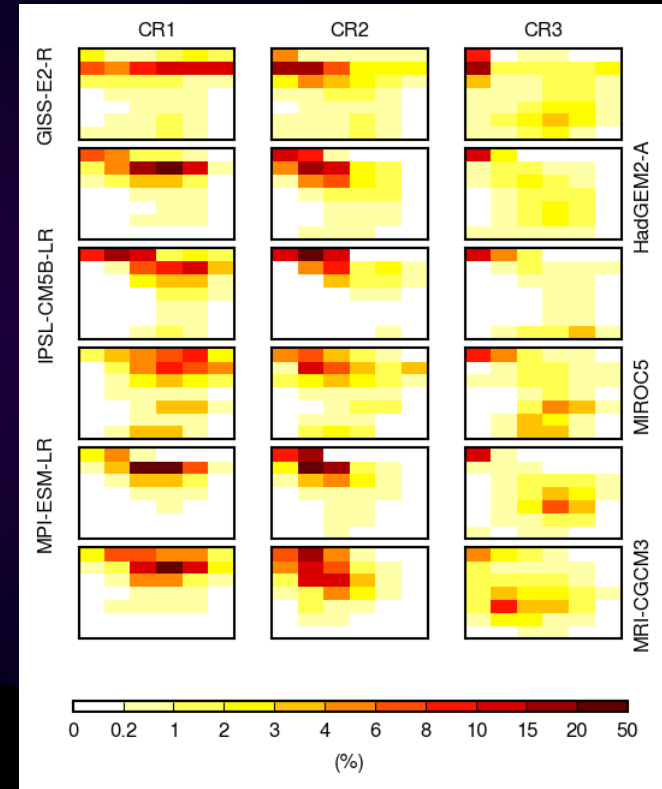
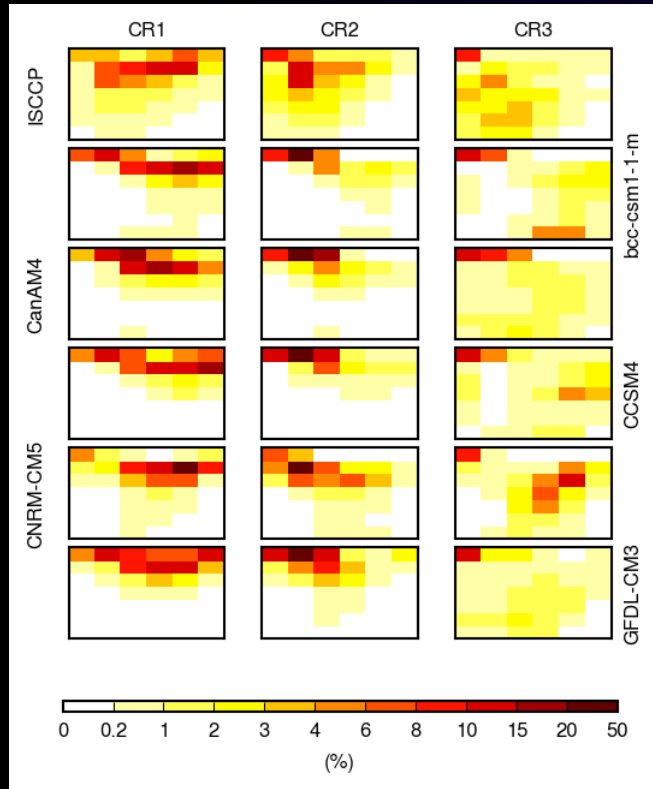
- GCMs underestimate CR1 rainfall to varying degrees. GCMs variously overestimate and underestimate the rain rate distribution of CR2 and CR3, but they average out on aggregate.
- Restricting to CRs that best match the observed centroids do not necessary improve the rain rate distribution → absolute rain rates associated with each CTP- τ bin is incorrect.

Cloud regimes are an informative way to evaluate how well GCMs represent the properties of different cloud systems.

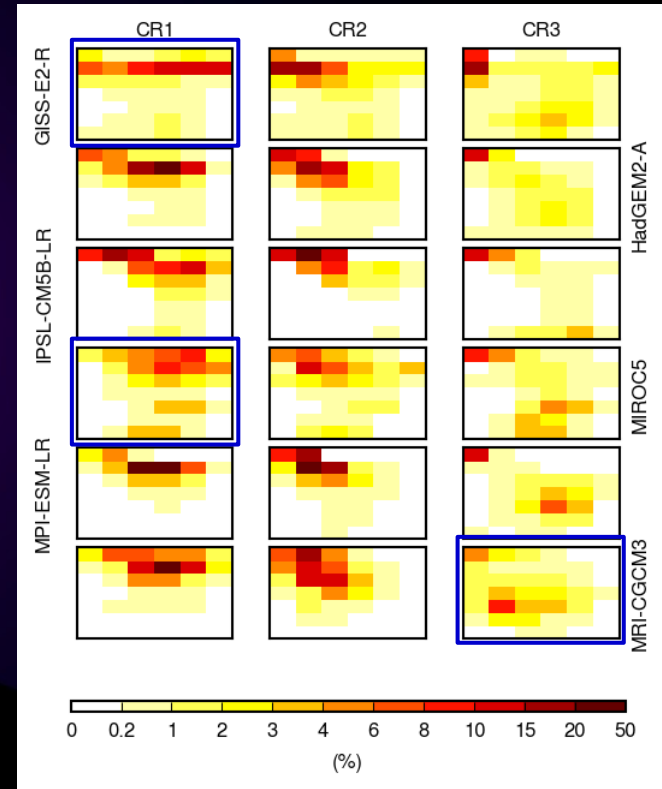
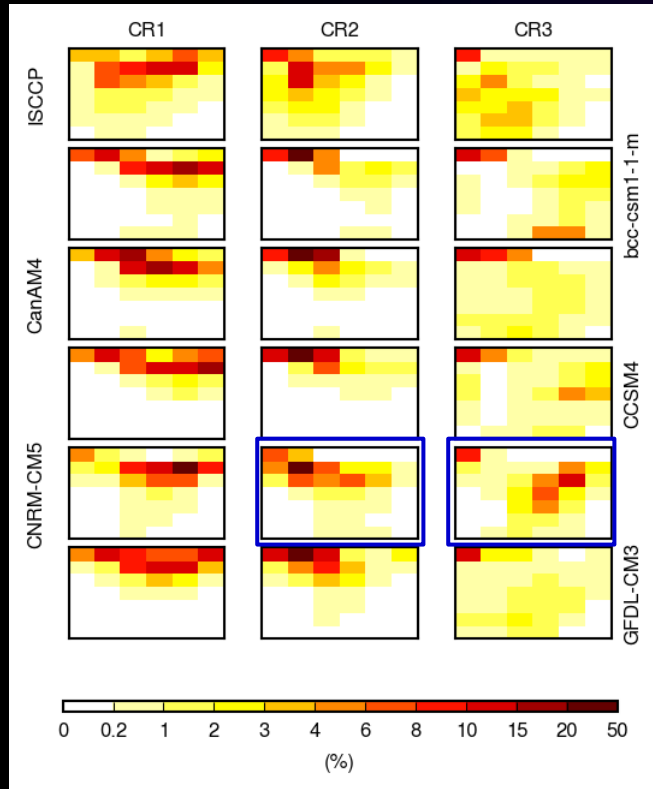
Additional Slides



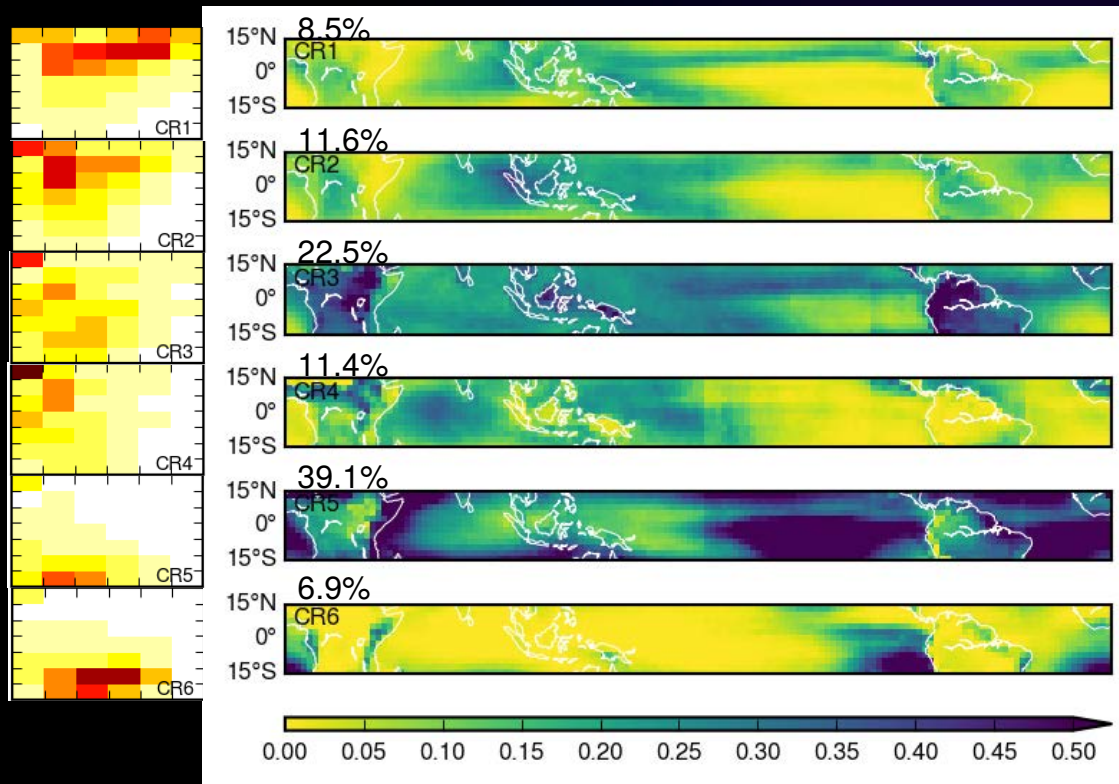
Considerable Variation between Models



Considerable Variation between Models



ISCCP CRs Identify Different Conv. Env.



CR1: regions of intense organized convection

CR2: regionally similar to CR1, slightly broader

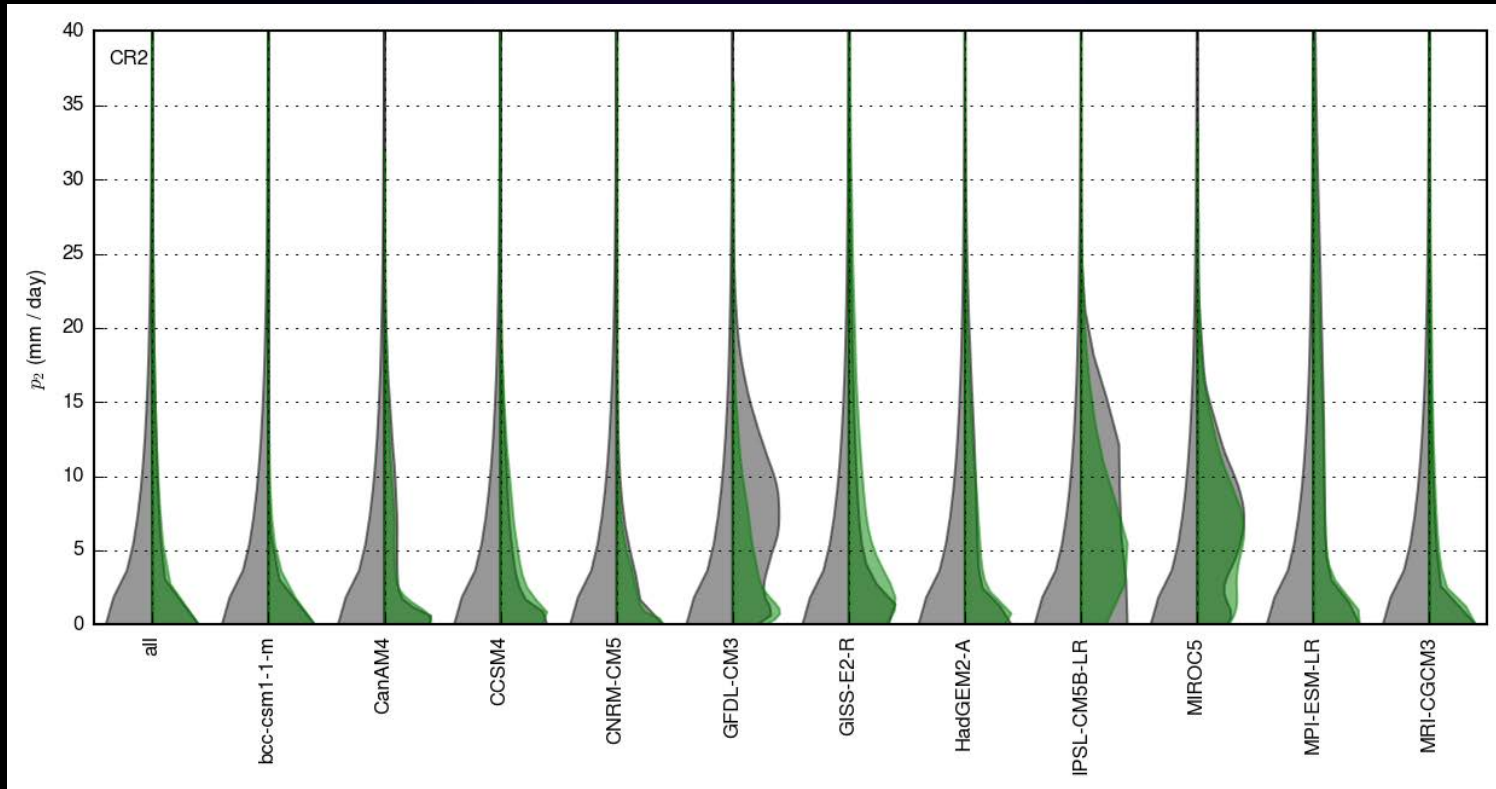
CR3: congestus clouds; more over land

CR4: thin cirrus; may be ISCCP artifact

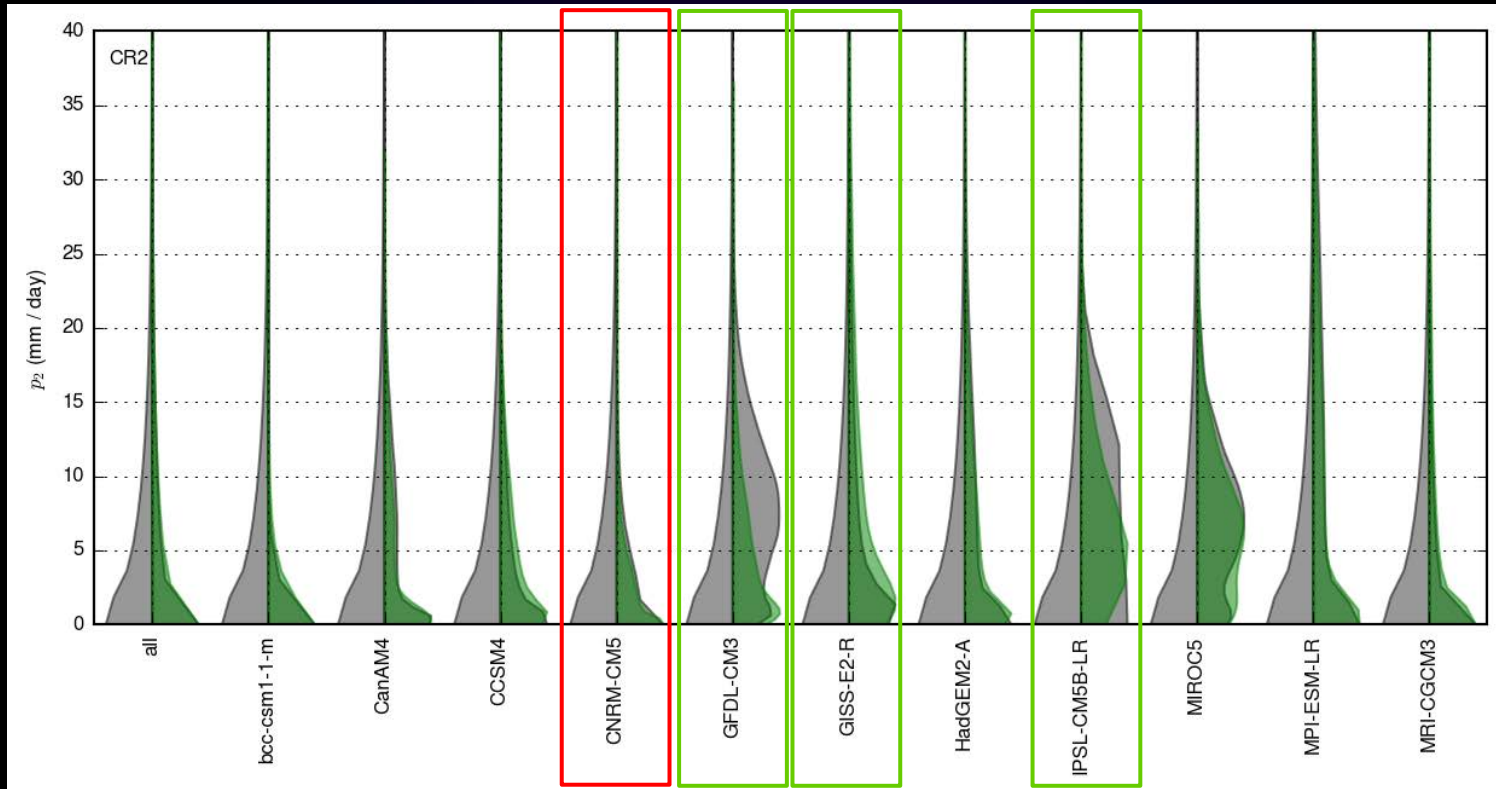
CR5: fair weather cumulus

CR6: stratocumulus

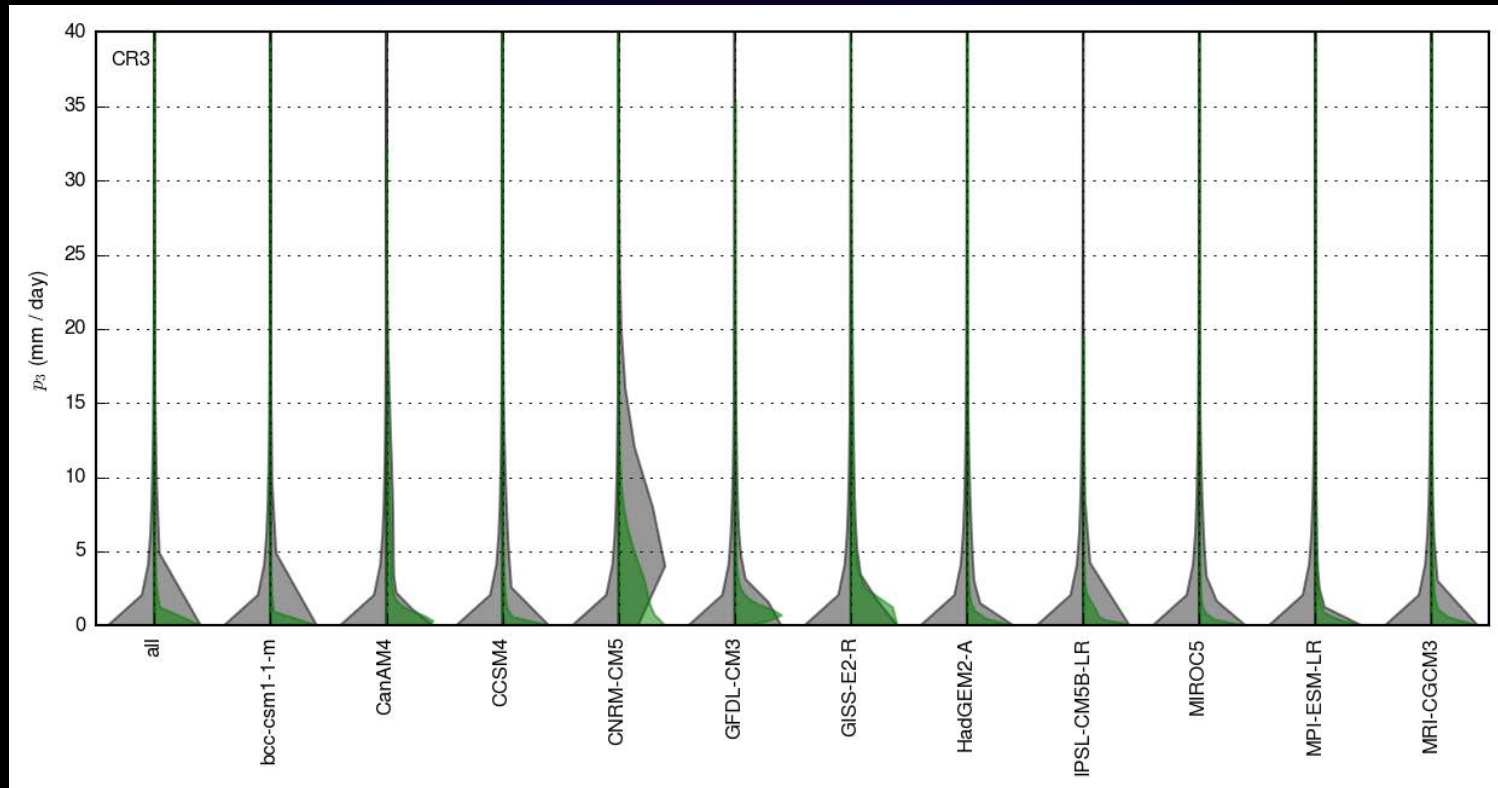
Best Matching CRs \neq Better Rainfall



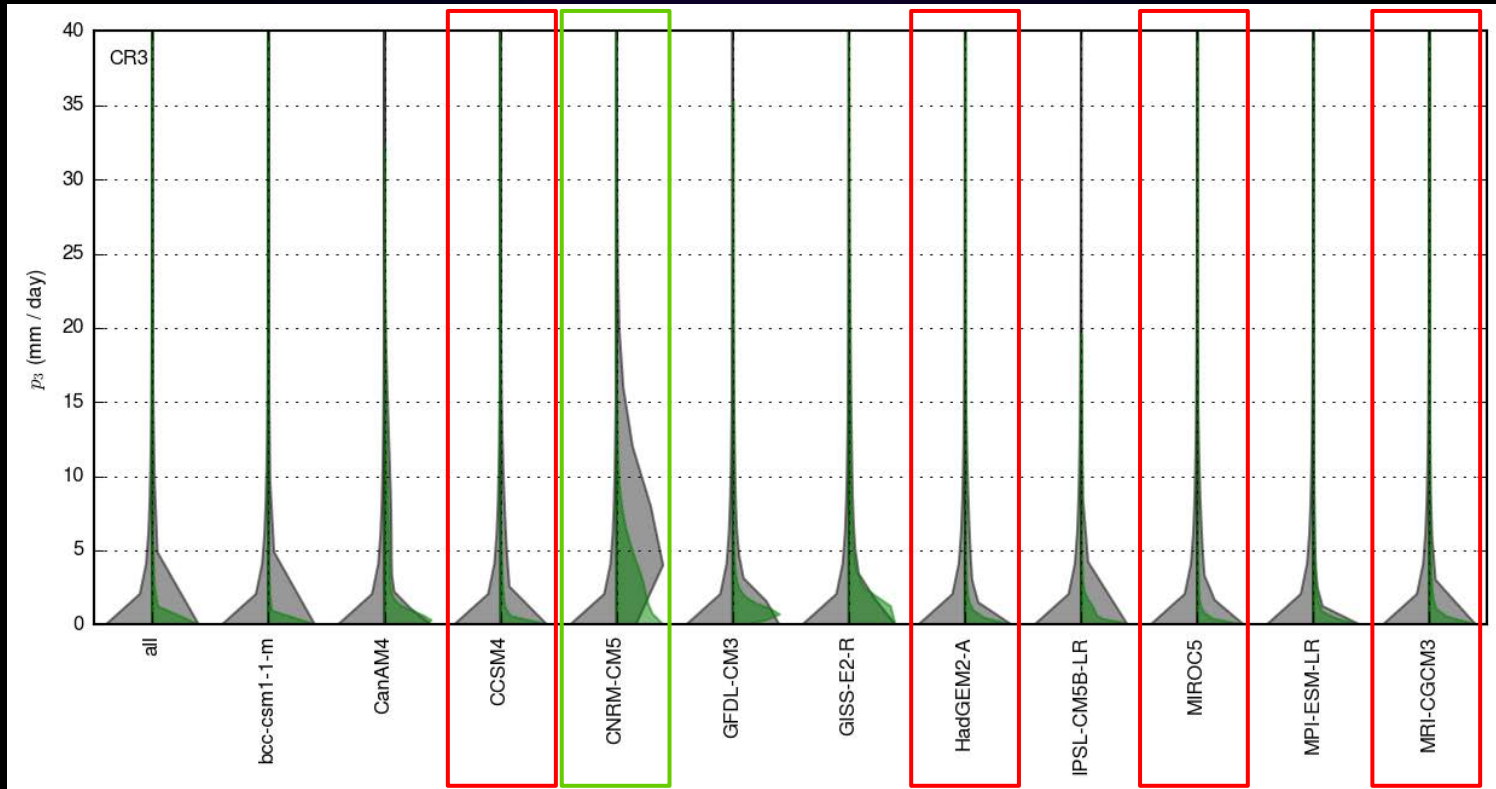
Best Matching CRs \neq Better Rainfall



Best Matching CRs \neq Better Rainfall



Best Matching CRs \neq Better Rainfall



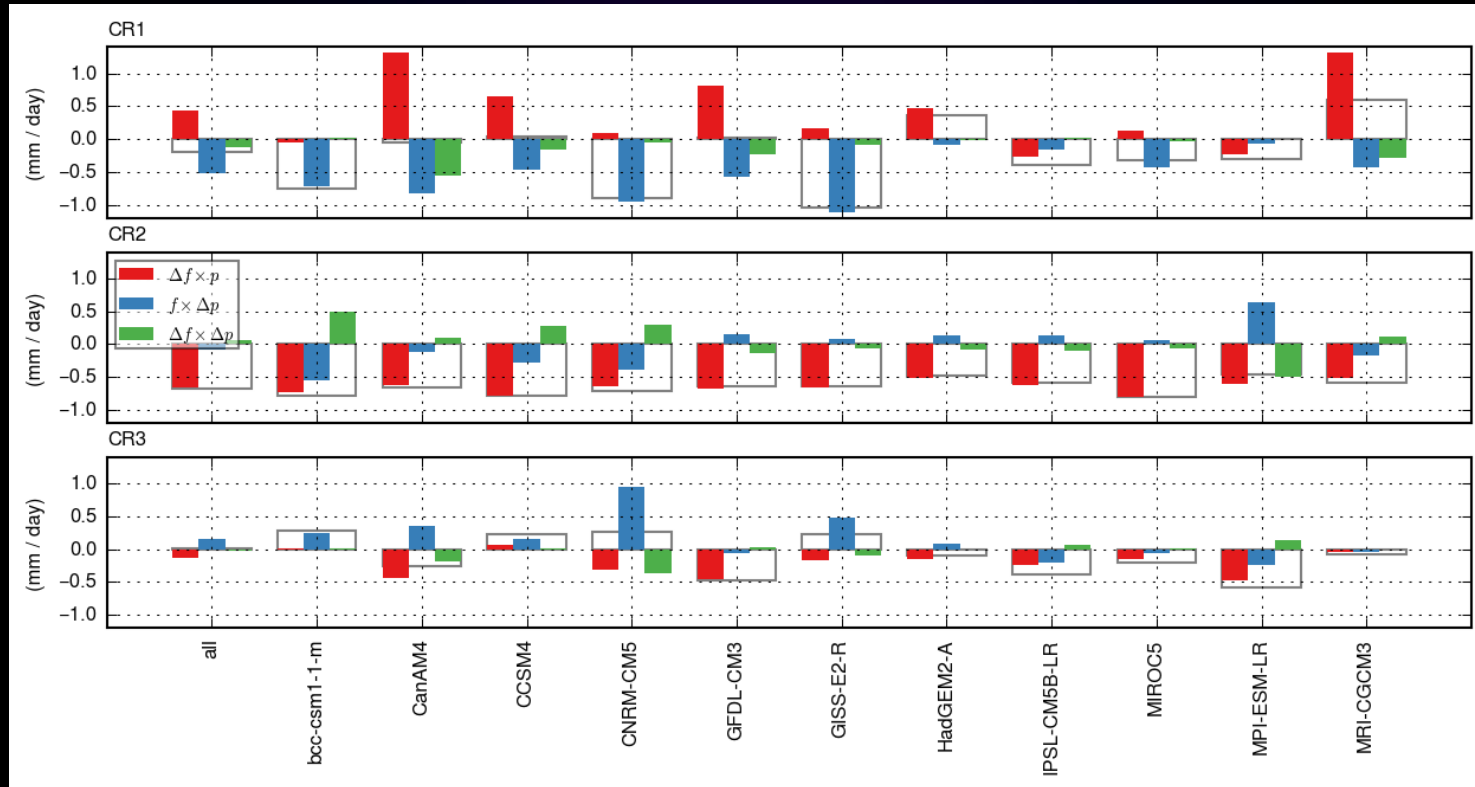
Decomposing the Rainfall Error by CRs

$$P = \sum_i (f_i \times p_i)$$

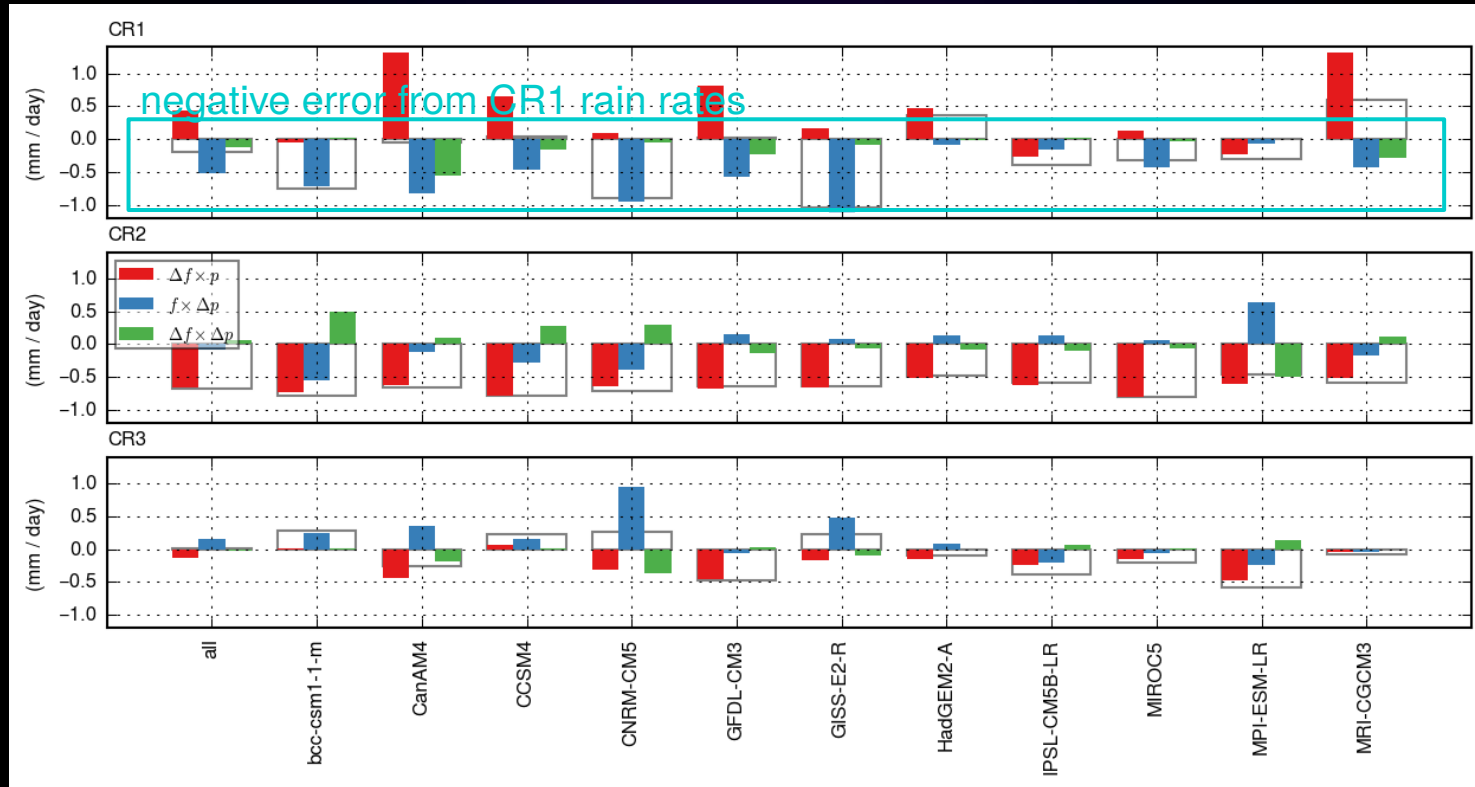
$$\Delta P = \sum_i (\Delta f_i \times p_i + f_i \times \Delta p_i + \Delta f_i \times \Delta p_i)$$

- If we express total rainfall as a linear combination of regime occurrence and rainfall, we can decompose the contributions to rainfall errors into three terms.
- Δ : model minus observations
- $\Delta f \times p$: contribution due to error in CR frequency of occurrence
- $f \times \Delta p$: contribution due to error in CR rainfall

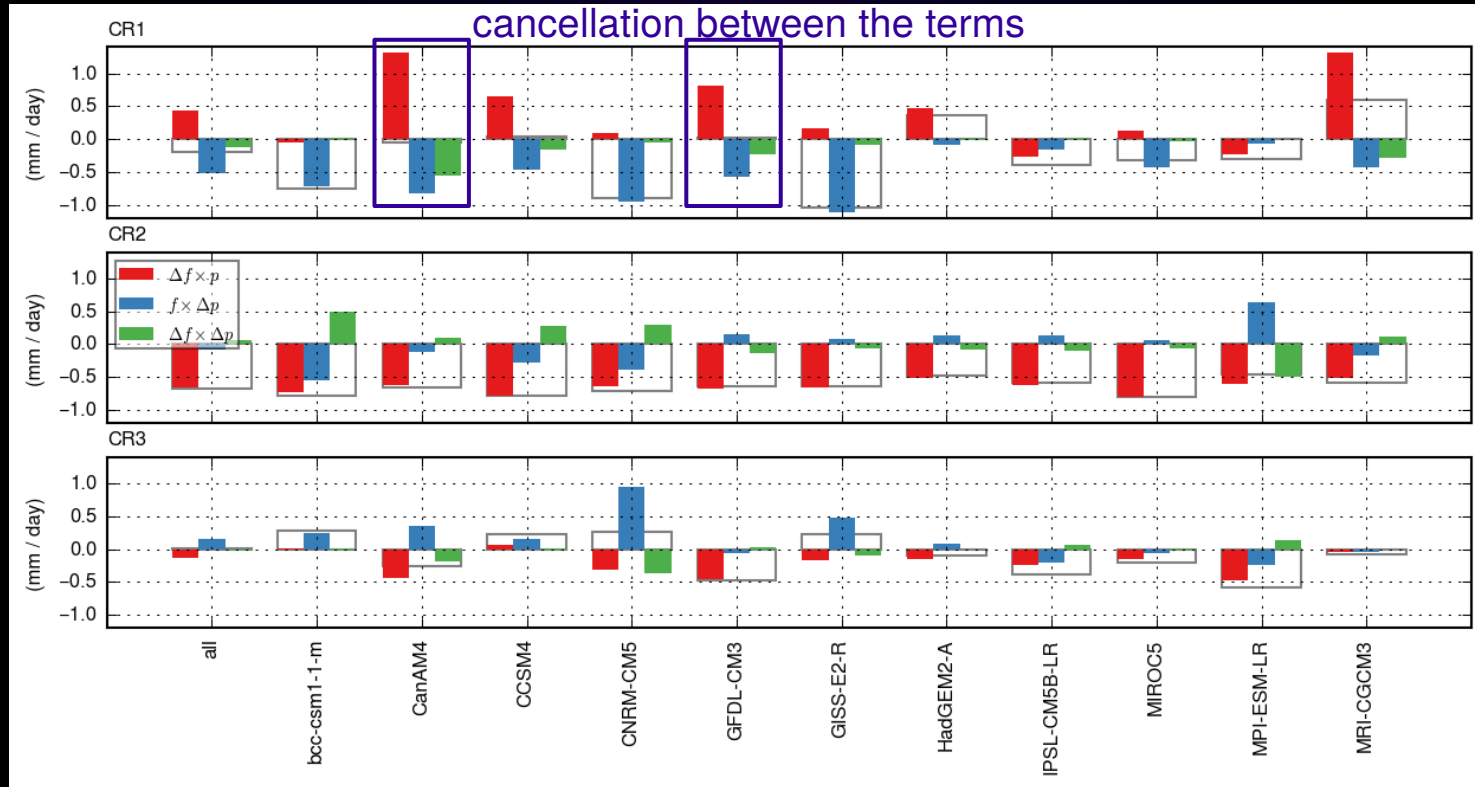
Decomp. Shows Cancellations within CRs



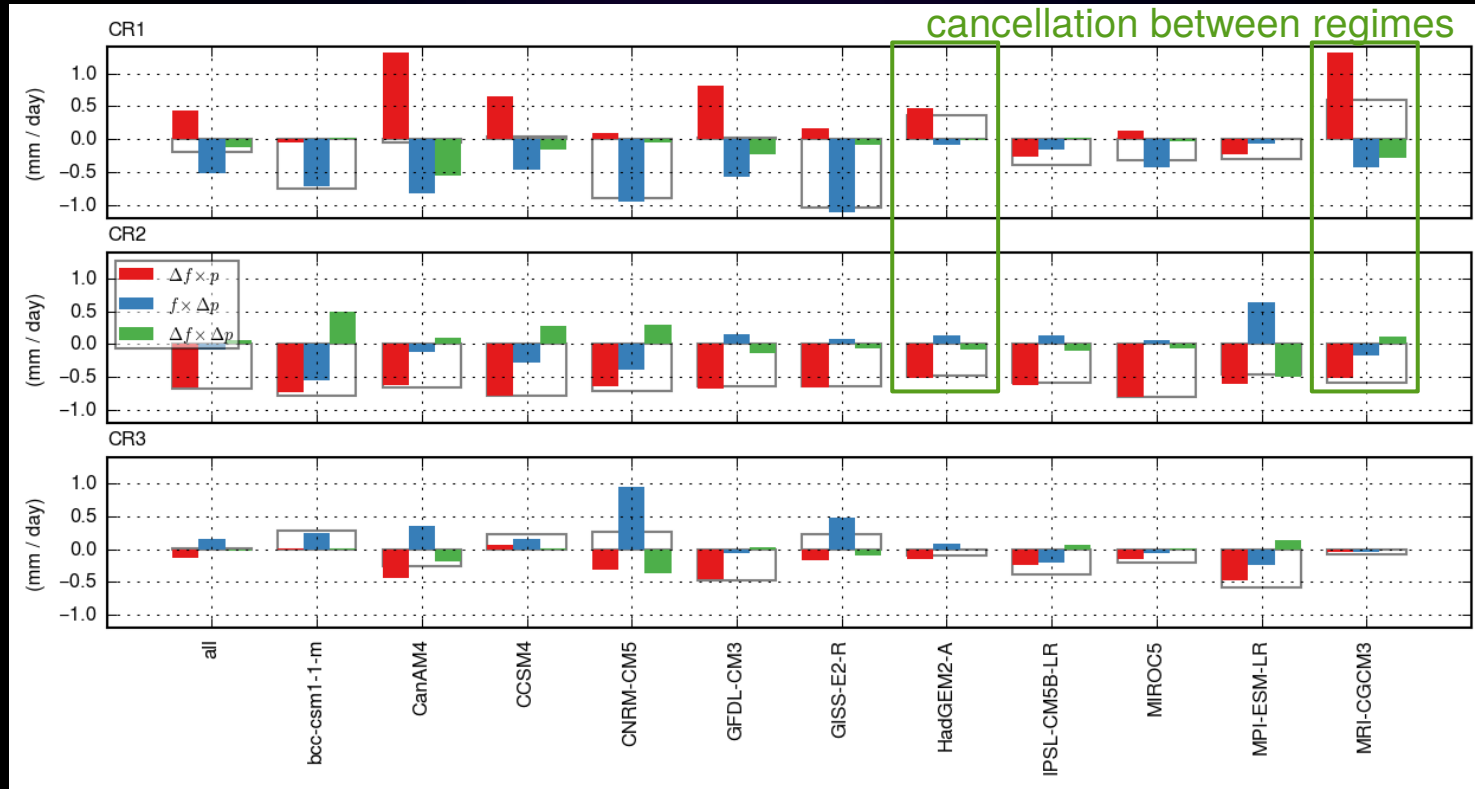
Decomp. Shows Cancellations within CRs



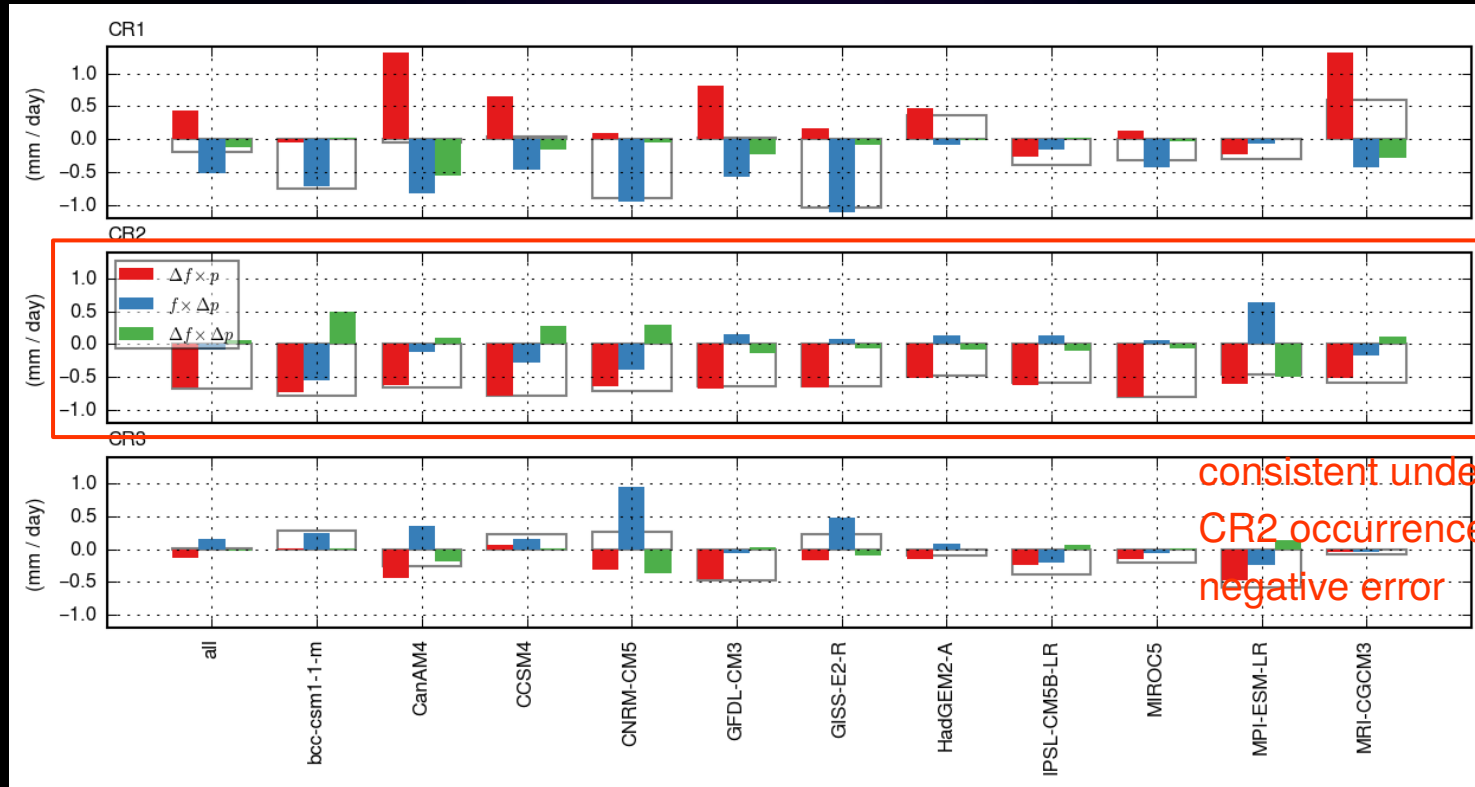
Decomp. Shows Cancellations within CRs



Decomp. Shows Cancellations within CRs

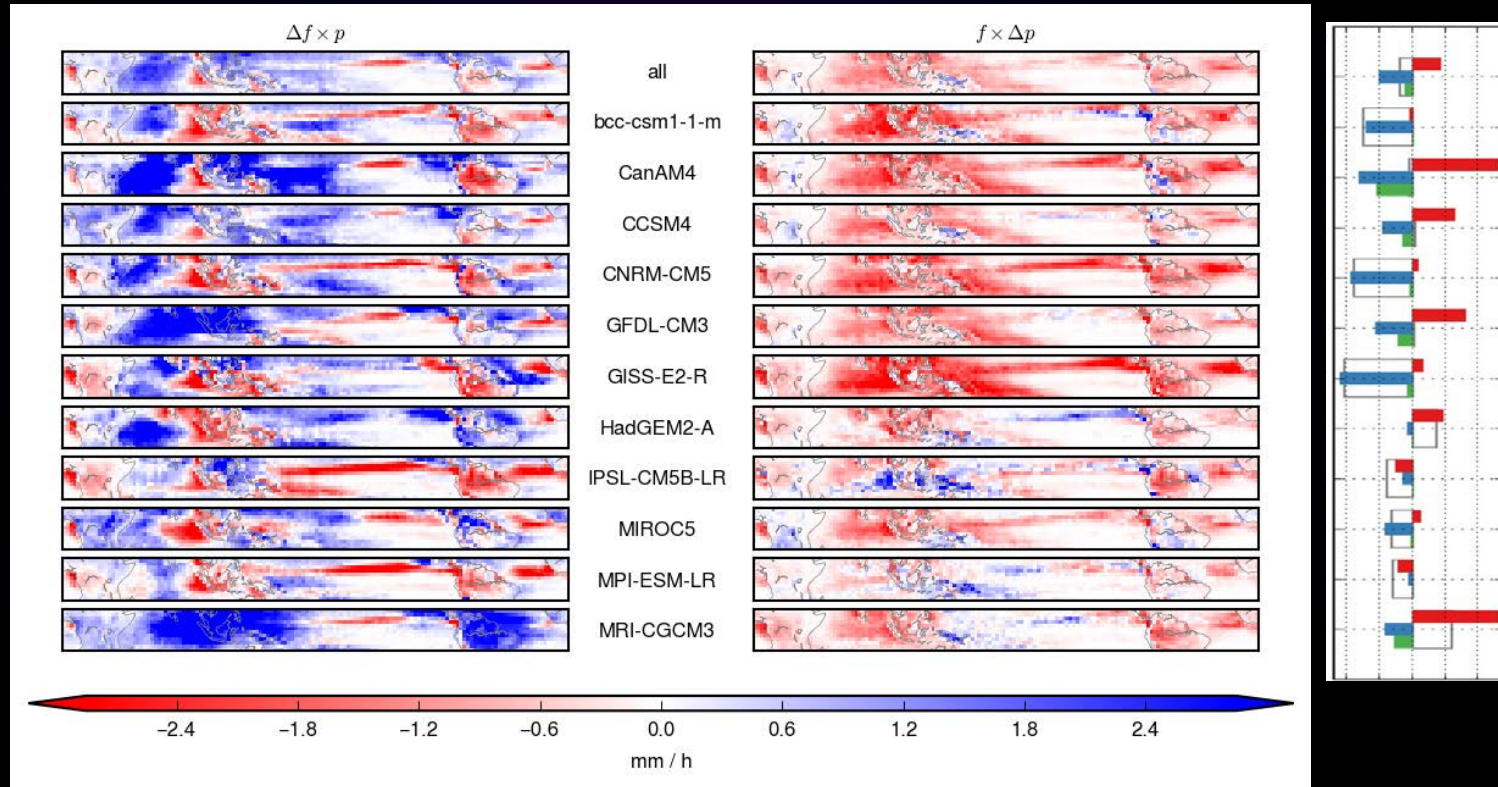


Decomp. Shows Cancellations within CRs

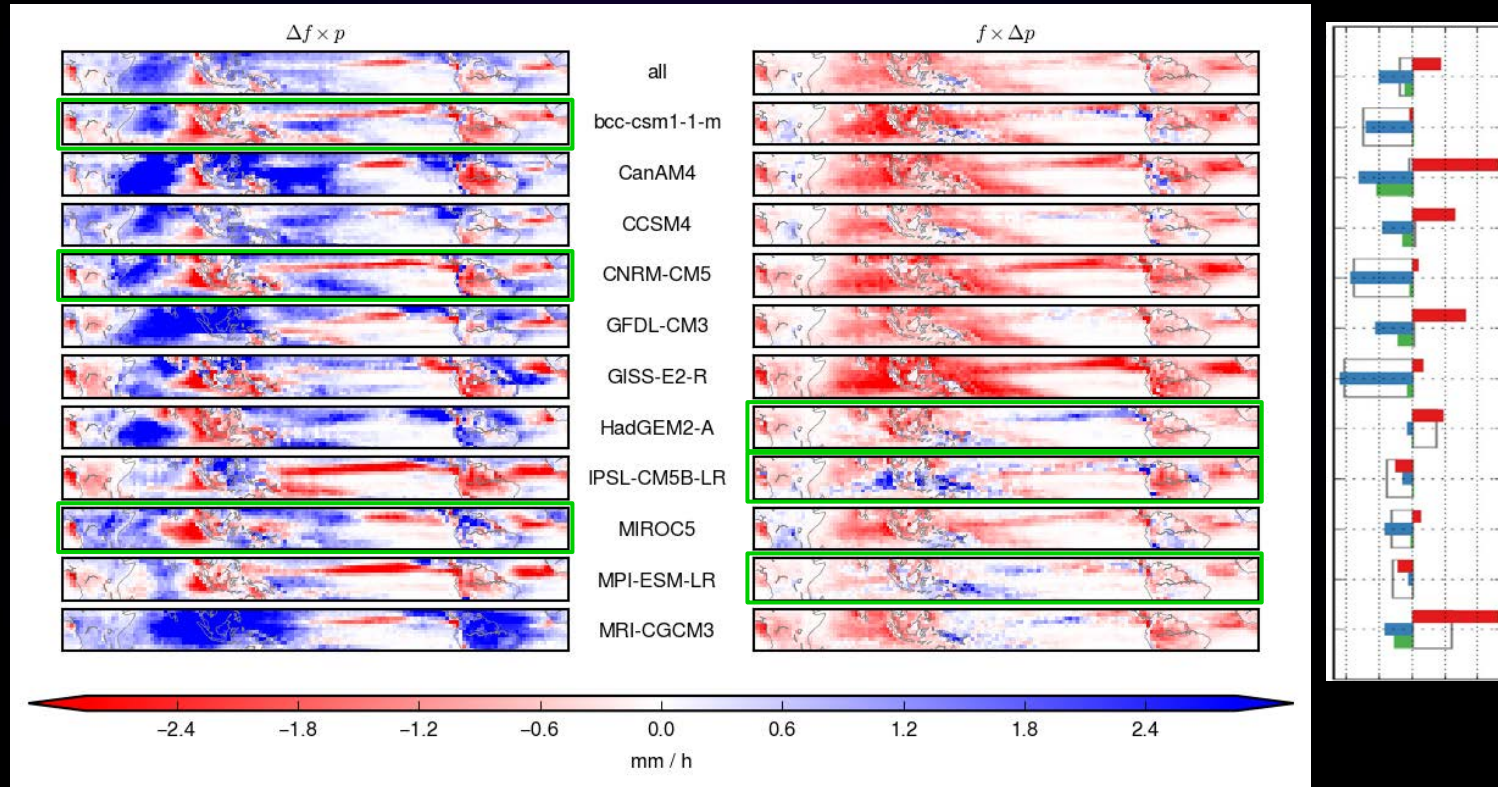


consistent underestimation of CR2 occurrence leads to negative error

Cancellations between Different Regions



Cancellations between Different Regions



Compensating Errors in Model Evaluation

- There are compensating errors between terms, between CRs and between regions.
- Cancellation between terms: long-term averages (e.g. monthly) may not reveal such errors.
- Cancellation between CRs: evaluations that do not categorize by system type (e.g. evaluating different rain rate bins) may not be able to distinguish the presence of such errors
- Cancellation between regions: global averages may not be able to identify such errors.