NCAR catalyst U.S. DEPARTMENT OF ENERGY Office of Science

Rainfall characteristics in CMIP models

Angeline Pendergrass

National Center for Atmospheric Research

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CGD Climate & Global Dynamics a laboratory of NCAR

Why improve precipitation in climate models?

- To accurately simulate atmospheric circulation and coupled climate system interactions affected by fluxes of water and energy, which affect the ocean, land surface, biosphere, and cryosphere
- Precipitation is a primary manifestation of climate influencing the natural and human-managed environment, and people, and so it should be a key variable in climate models
- Many impacts of climate change are driven by precipitation, and users are increasingly trying to extract information about future precipitation from climate model projections – often indirectly (via downscaling, bias correction, …)

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- Many impacts of climate change are driven by precipitation, and users are increasingly trying to extract information about future precipitation from climate model projections – often indirectly (via downscaling, bias correction, …)
- **Nonetheless, we often hear that precipitation isn't that good in climate models**

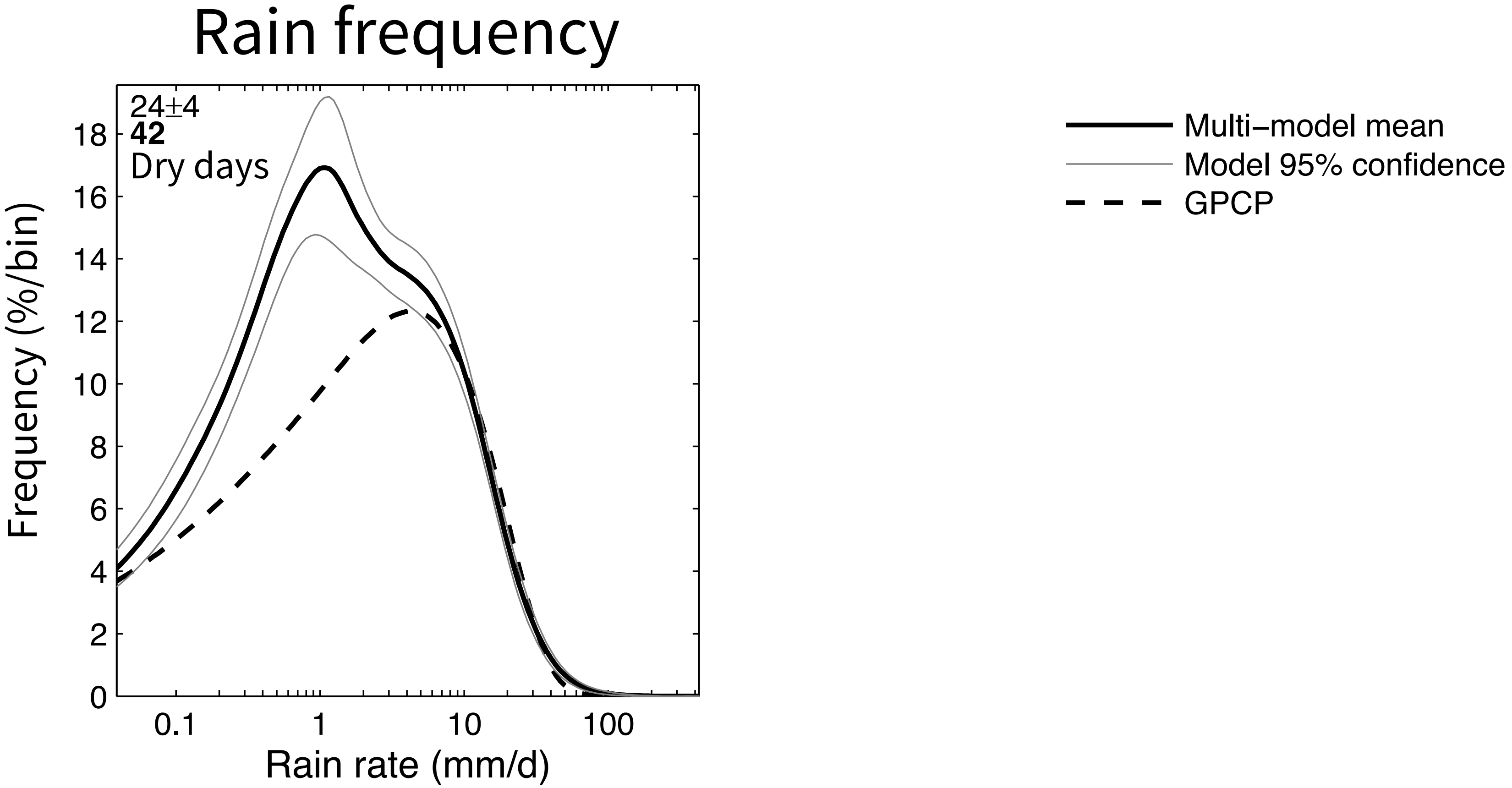
Outline

- Precipitation in CMIP5 models
  - The distribution of precipitation
  - Re-corfirming light rain bias
  - Unevenness of contributions from heavy precipitation

- Evaluating precipitation in CMIP models (ongoing work)

- Thoughts about future work and efforts

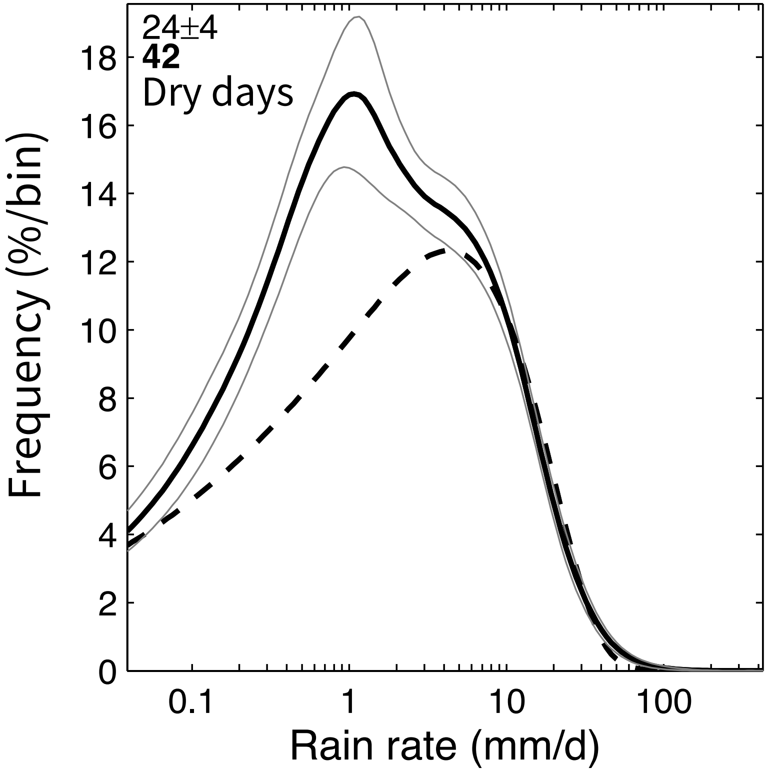
CMIP5 daily precipitation distribution



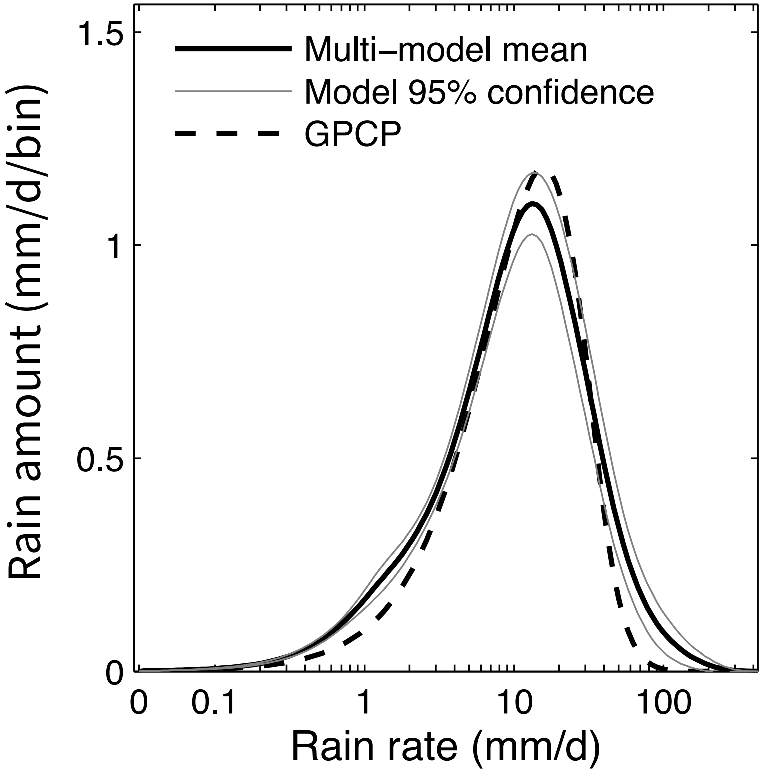
Pendergrass and Hartmann (2014) *J Clim*

CMIP5 daily precipitation distribution

Rain frequency



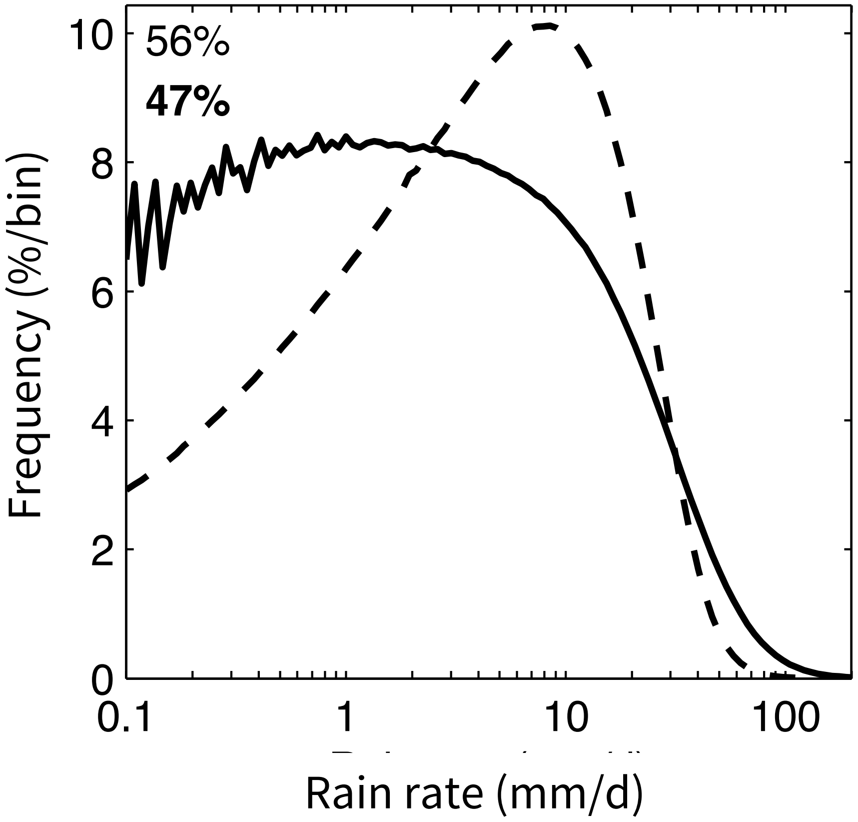
Rain amount



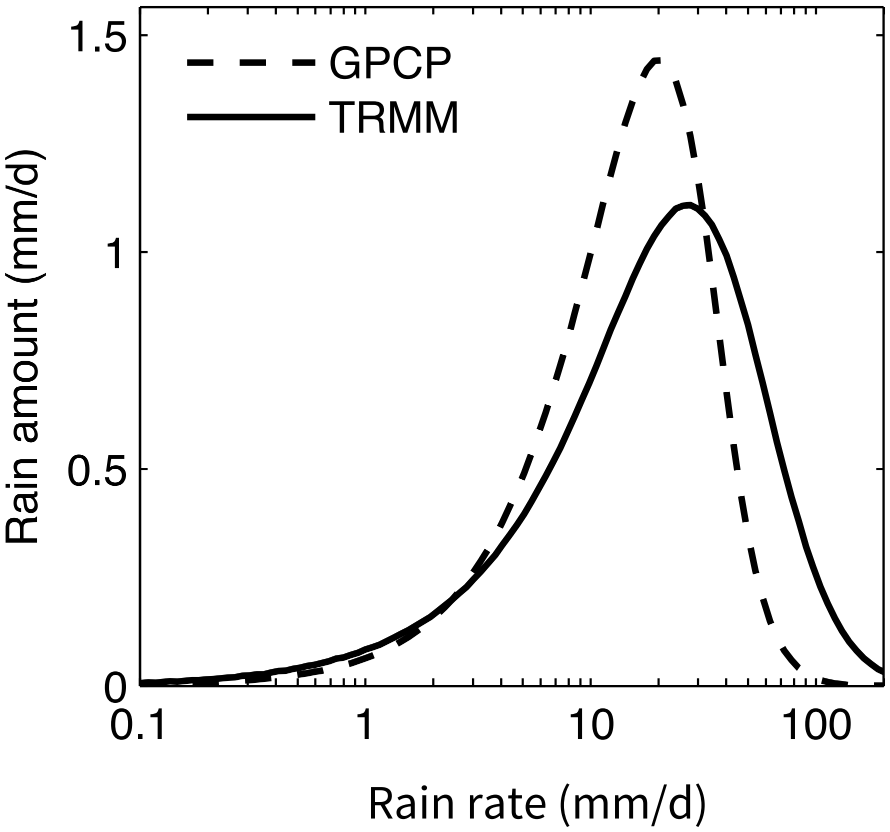
Pendergrass and Hartmann (2014) *J Clim*

Observed daily precipitation distribution

Rain frequency



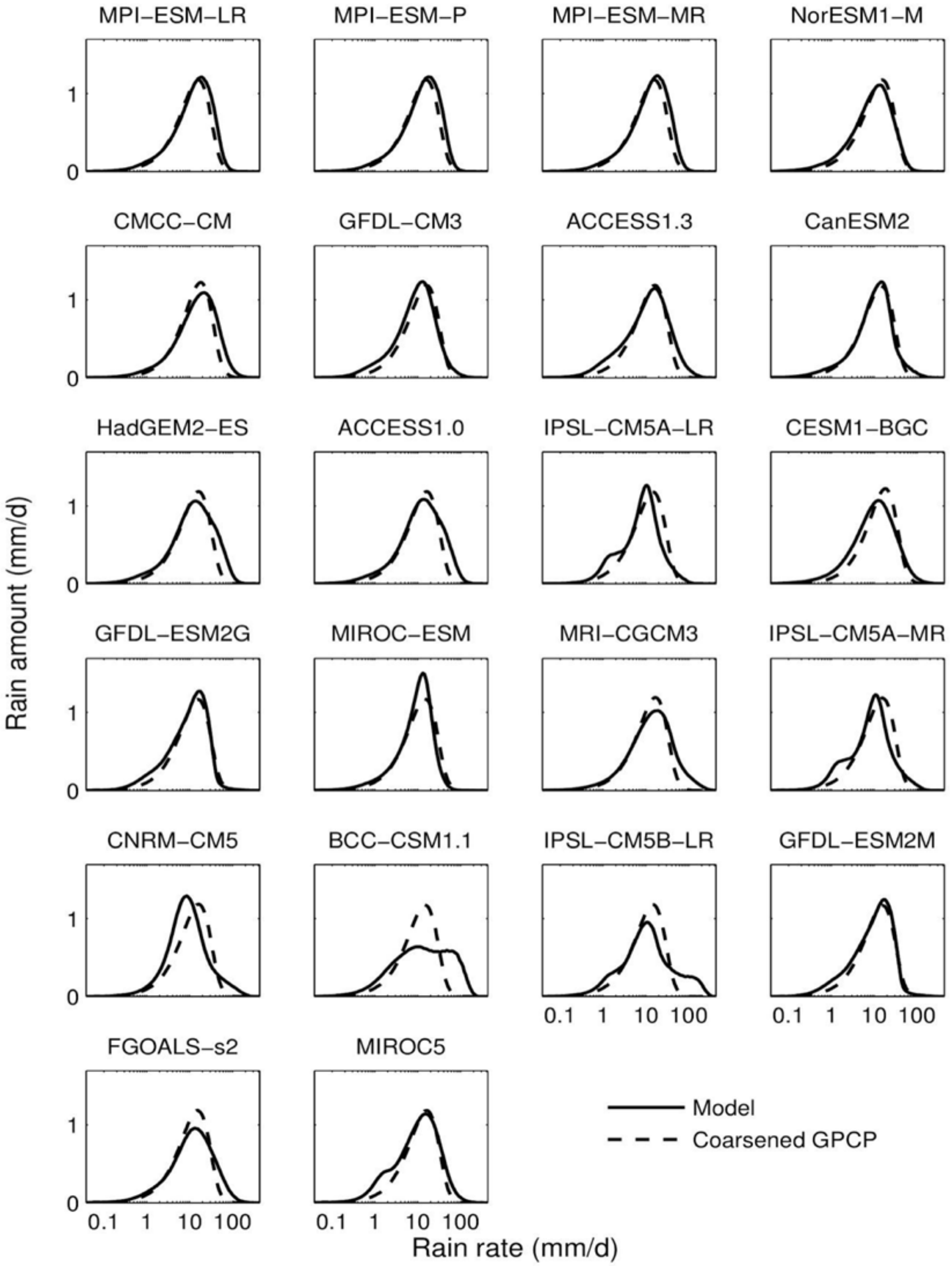
Rain amount



Pendergrass and Deser (2017) *J Clim*

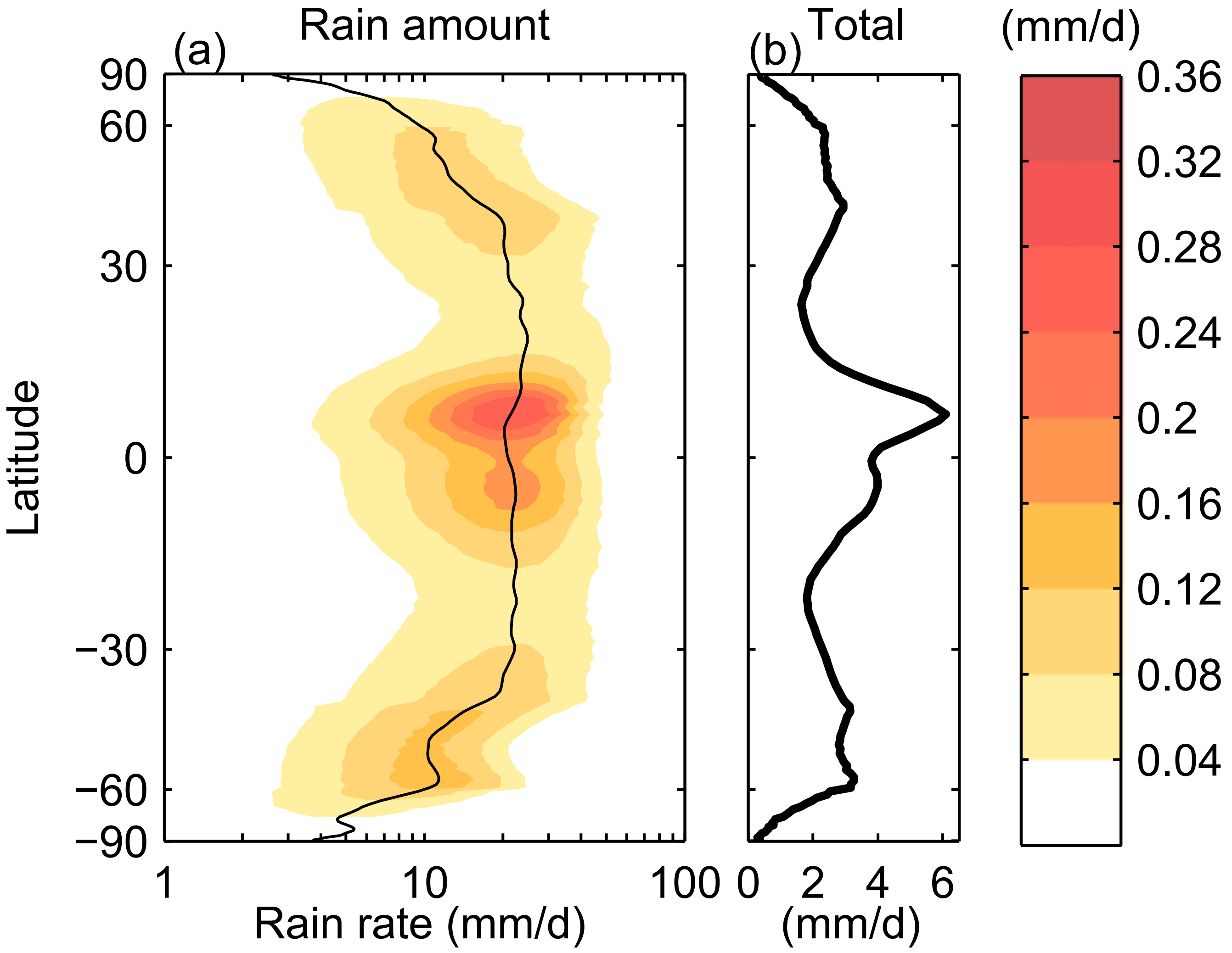
CMIP5 rain amount distributions: Global

- Distribution calculated at each grid point, then globally averaged
- Compared against GPCP 1dd coarsened to model grid



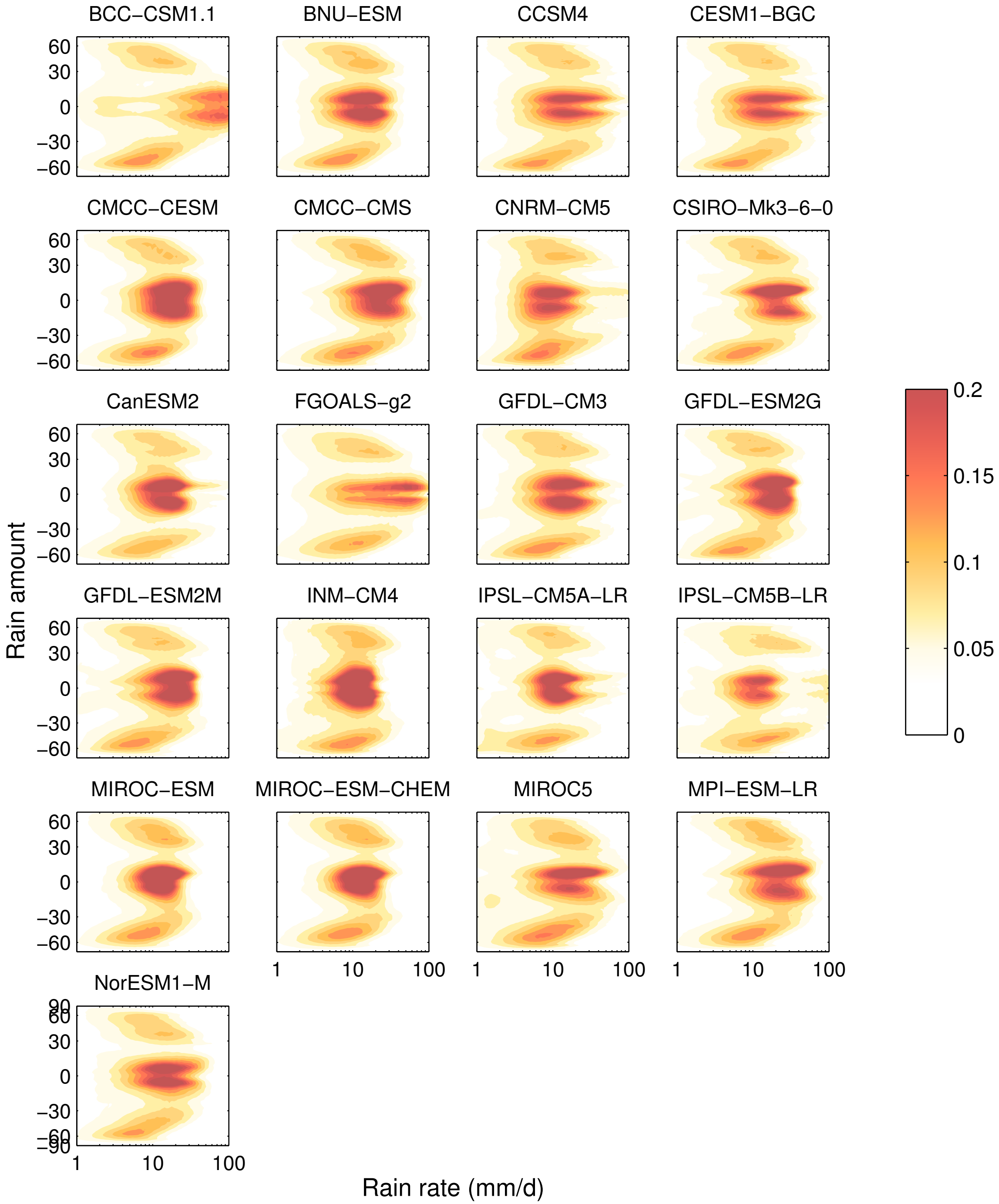
Pendergrass and Hartmann (2014) *J Clim*

Observed zonal mean rain amount distribution

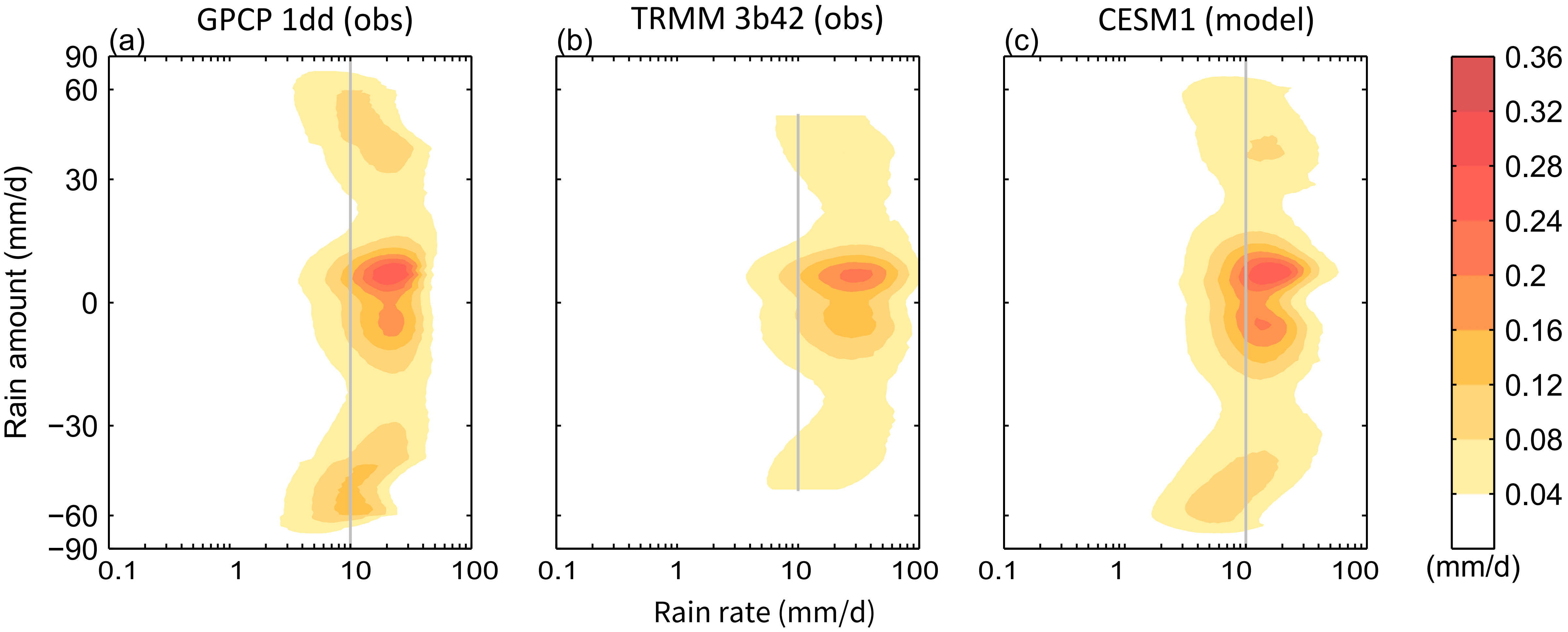


Pendergrass and Deser (2017) *J Clim*

CMIP5 rain amount distributions: Zonal mean

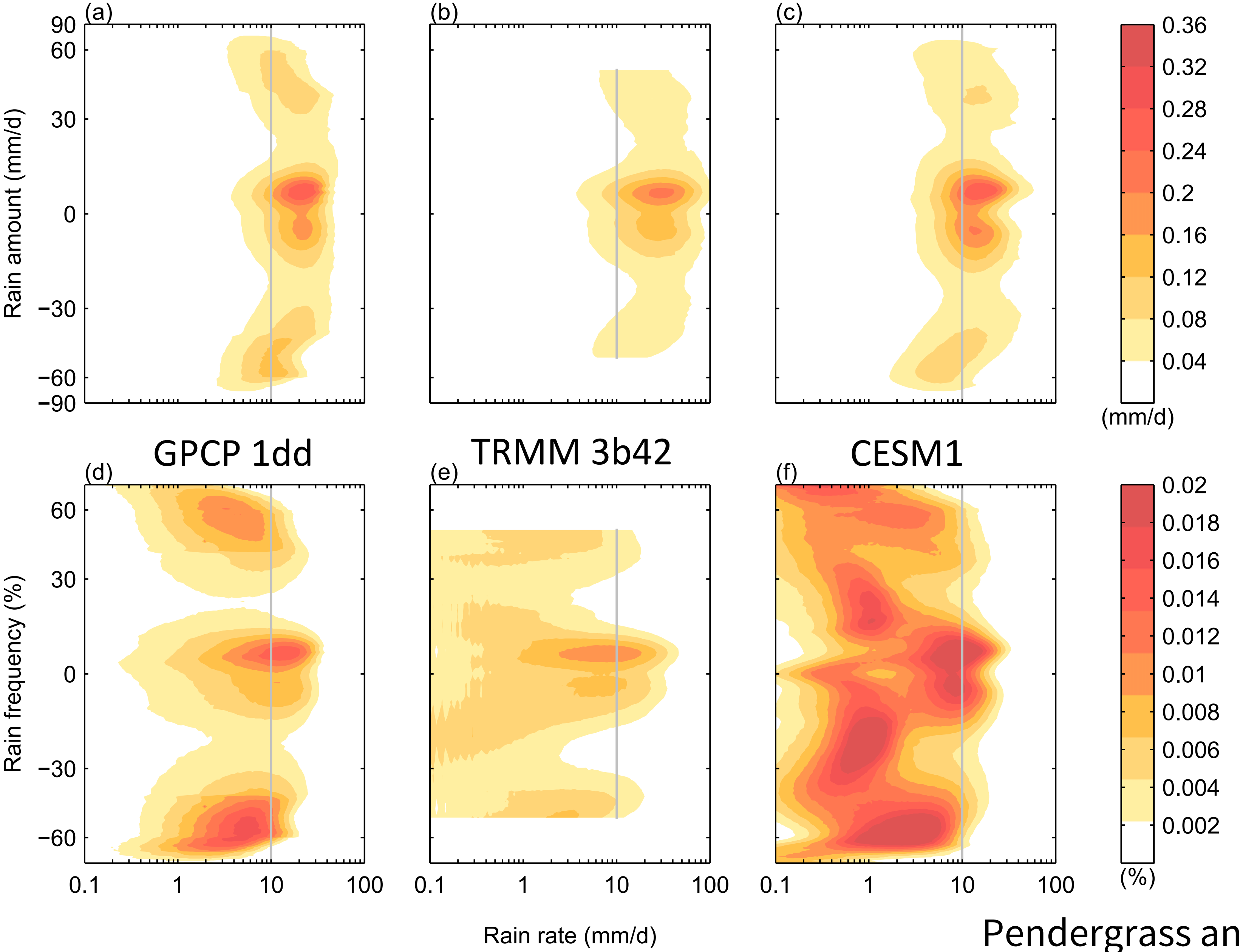


Zonal mean rain amount distributions



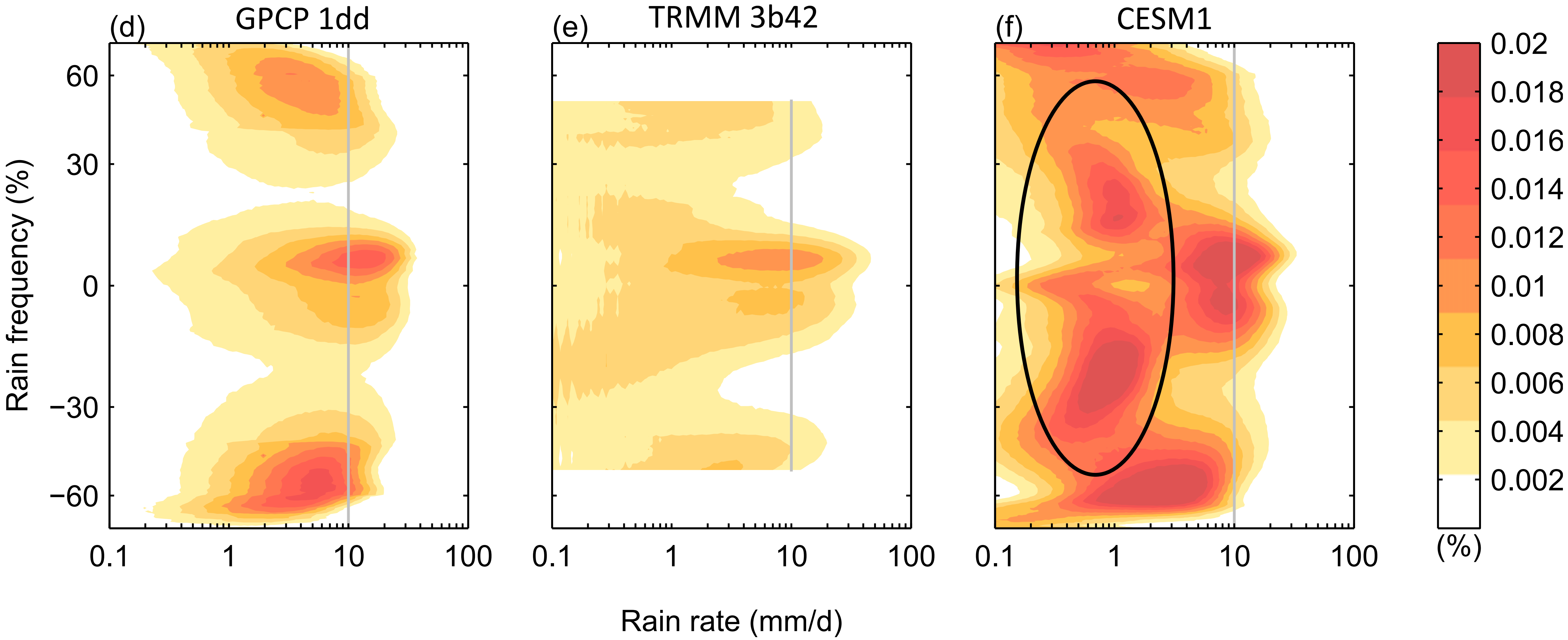
Pendergrass and Deser (2017) *J Clim*

Zonal mean distributions



Pendergrass and Deser (2017) *J Clim*

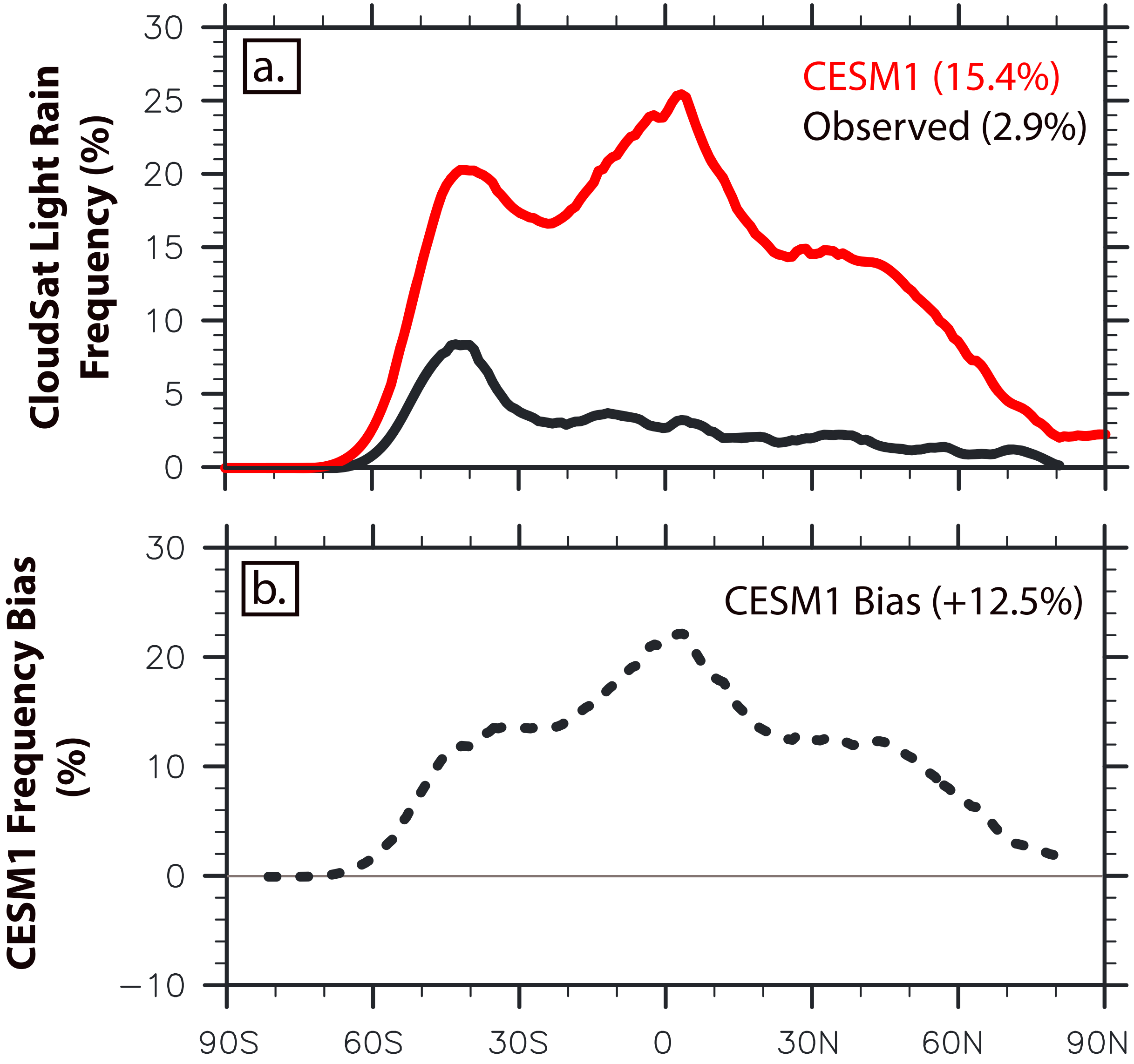
Zonal mean rain frequency distributions



Pendergrass and Deser (2017) *J Clim*

Light rain bias persists in CESM1 compared to CloudSat

- CloudSat captures light rain frequency more accurately than measurements going into GPCP, TRMM, and GPM
- Satellite simulators for precipitation enable apples-to-apples comparison
- Extends work on cloud satellite simulators – could be scaled across models, and to GPM



Kay et al (2018) *JGR*

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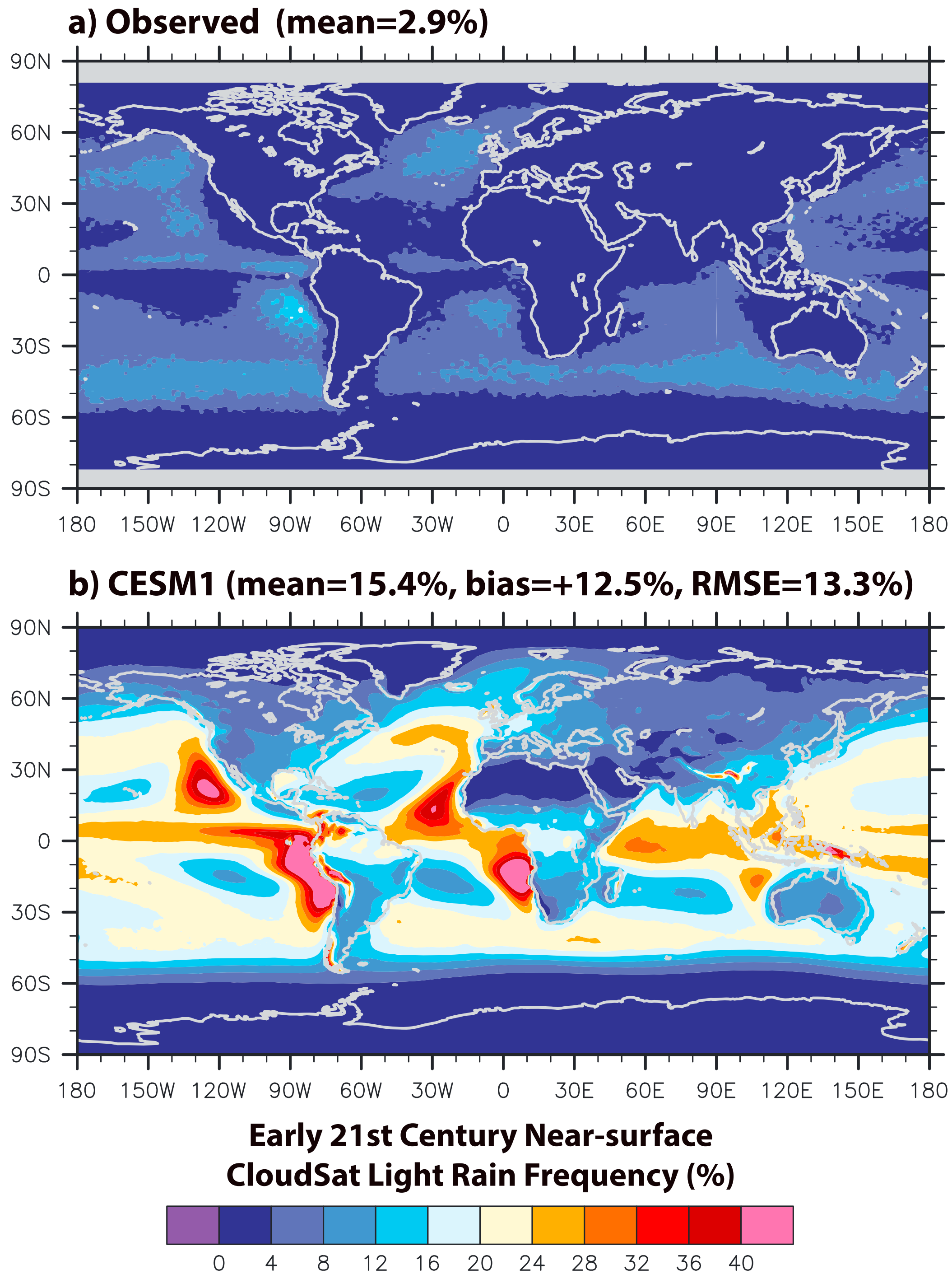


Kay et al (2018) *JGR*

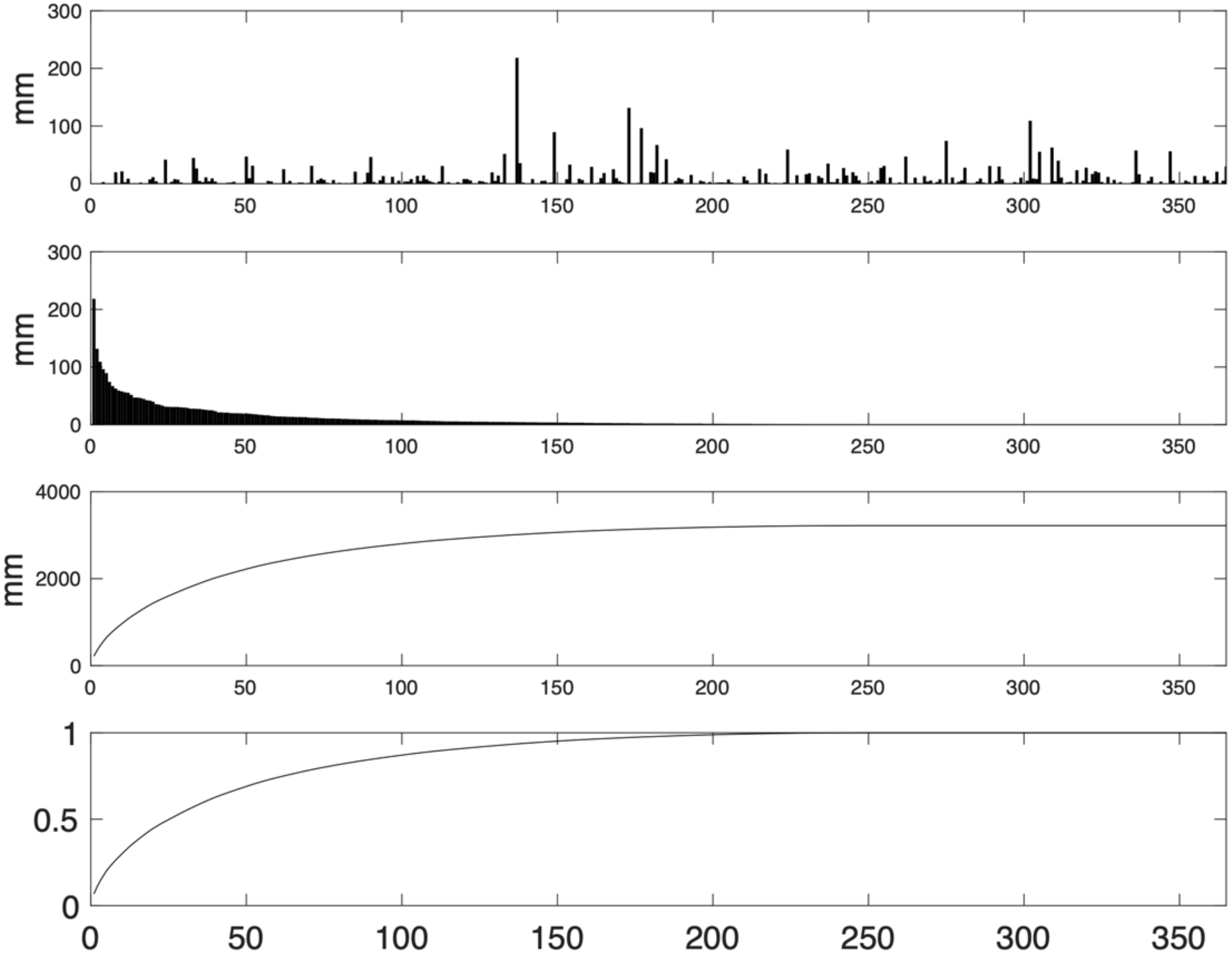
Unevenness of precipitation

One year of daily precip

Sort wettest to dryest

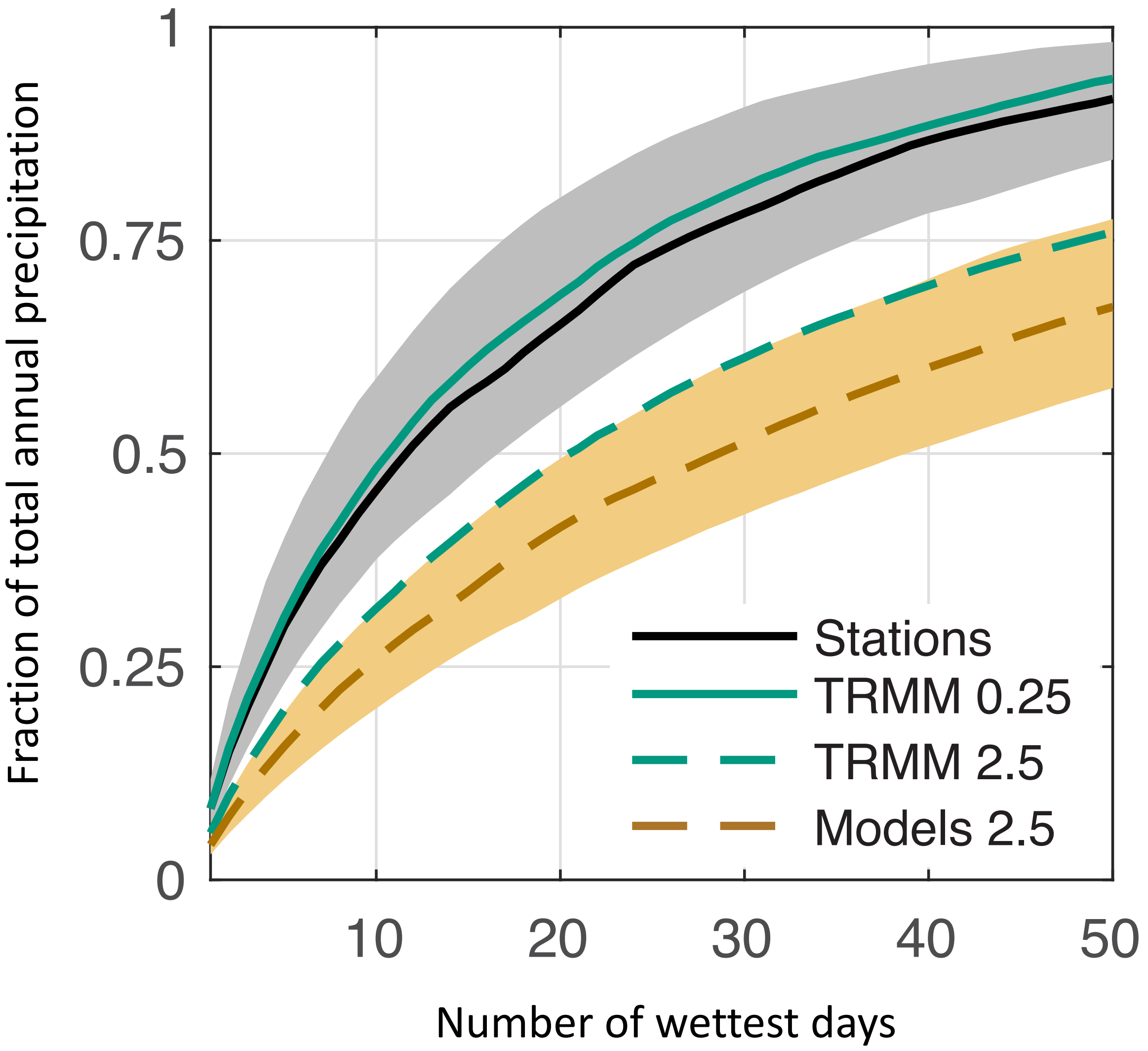
Cumulatively sum

Normalize by total precip



Pendergrass and Knutti (2018) *GRL*

Unevenness of precipitation in observations and CMIP5 models



Models underestimate unevenness,
even when resolution is accounted for

Pendergrass and Knutti (2018) *GRL*

Assessing simulation of precipitation in Earth System Models

Identify targets for improvement

Team of experts identifies useful measures for gauging how well models simulate precipitation

+

Develop capability to gauge model quality

Baseline metrics incorporated into a model evaluation capability and used to assess current models

→

Improve simulated Precipitation

Modelers provided with metrics capability to serve as a target for improving newer model versions

- Inspired by the lack of objective and systematic benchmarking of simulated precipitation
- Date/venue: July 1-2, 2019 in Rockville, MD

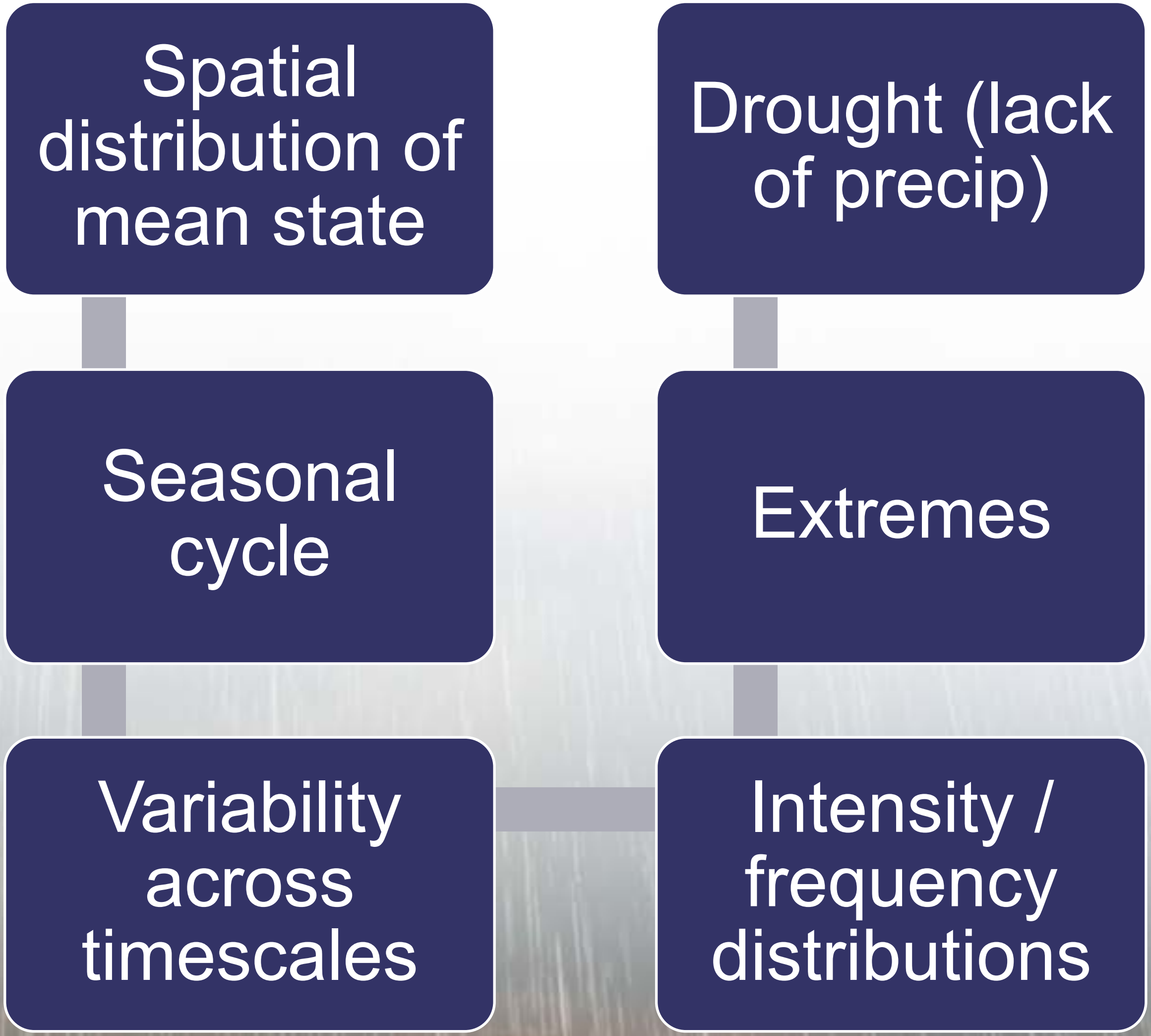
Renu Joseph (DOE), Angie Pendergrass (NCAR), Peter Gleckler (LLNL), Christian Jakob (Monash Uni), Ruby Leung (PNNL)

https://climatemodeling.science.energy.gov/news/doe-host-precipitation-metrics-workshop

Baseline metrics

Scope of phase 1: CMIP6 DECK + Historical simulations with standard output

- piControl
- AMIP
- 1pctCO2, abrupt4xCO2
- Historical
- Data: monthly, daily, and 3h mean precip, monthly prsn



Spatial distribution of mean state

Seasonal cycle

Variability across timescales

Drought (lack of precip)

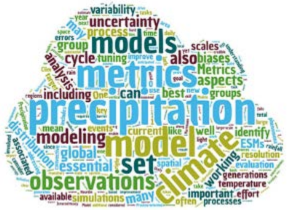
Extremes

Intensity / frequency distributions

Baseline metrics: Tiers

- Spatial distribution of mean state
  - RMS error / MAE of mean state
  - Pattern correlation
  - Monthly mean snow amount
- Seasonal cycle
  - Amplitude+phase of seasonal cycle (first two harmonics)
  - or: Monthly score (RMS error?) following iLAMB
- Variability across timescales
  - Standard deviation at different timescales
    - Daily, weekly / synoptic, intraseasonal, interannual, ENSO
    - Absolute and relative
    - Seasonal breakdown
  - Diurnal cycle – phase and amplitude
- Intensity / frequency distributions
  - Simple Daily Intensity Index (SDII)
  - Unevenness (number of days for half of annual precip)
  - Mean and variance of daily precip
    - Cutoff precip rate
    - Power law scale
  - Perkins score (goodness of fit) - various moments
  - Fraction of precipitating days
- Extremes
  - Rx1day
  - Rx5day
  - 20-y return values (from GEV)
  - Rx3h
  - Seasonal breakdown
- Drought (lack of precip)
  - Frequency of SPI spells below a threshold
  - Consecutive Dry Days

Baseline metrics: CMIP6 evaluation



- Baseline metrics will be incorporated into the PCMDI Metrics Package (PMP) and run on simulations in the CMIP archive, as well as a suite of observational datasets (likely FROGS, Roca et al., 2019)

- An initial study and report will use the baseline metrics to evaluate CMIP6 DECK and Historical simulations
  - And also compare them against previous generations (CMIP3 and 5) to evaluate change over time

- Simultaneously, an effort on Exploratory Metrics is including more process-oriented diagnostics

Future studies to address biases in CMIP models

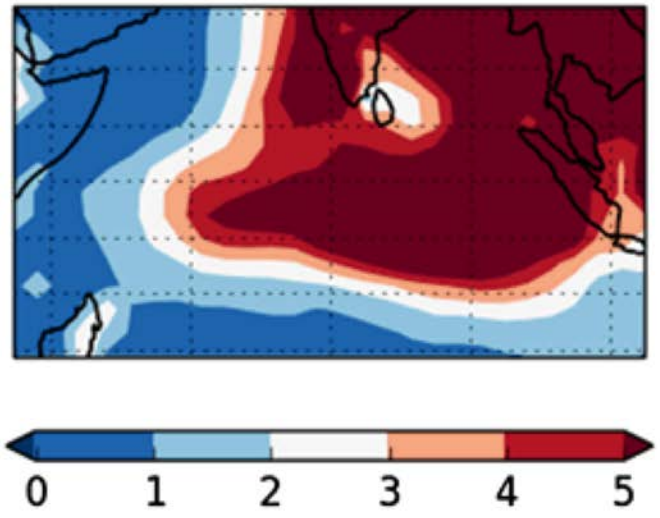
- Working with observations
  - Understanding differences among observational datasets for moments beyond mean precipitation – its intensity distribution, and variability across timescales
  - Developing a gridded observational dataset focused on the higher moments
  - Quantifying uncertainty

- Intriguing process-oriented model development approach: Stochastic parameterization

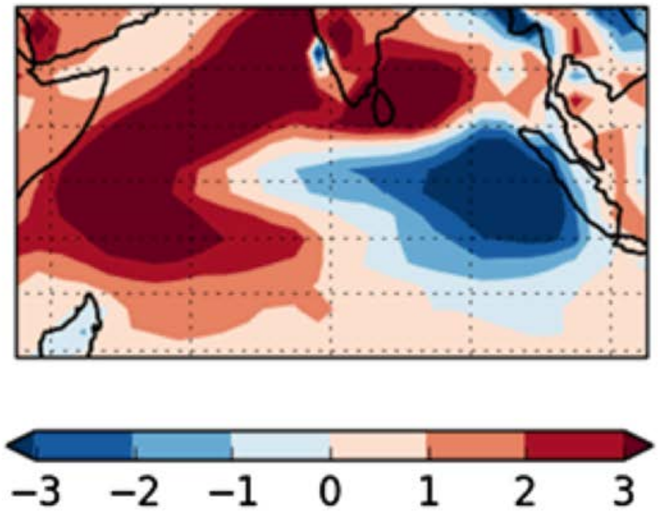
- Focused effort on improving precipitation for the next generation of climate models, using the precipitation benchmarking as a guide

Stochastic parameterizations can improve monsoon precip.

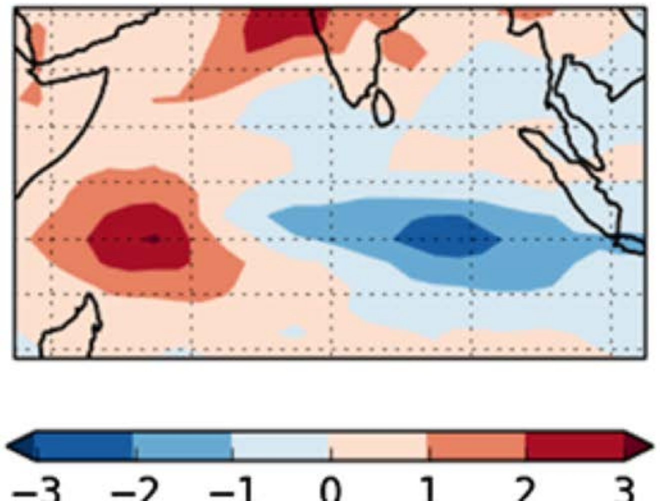
GPCP



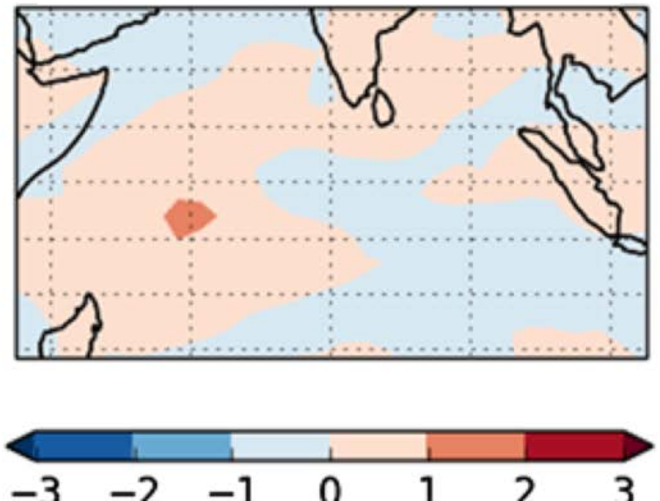
Control (deterministic) - GPCP

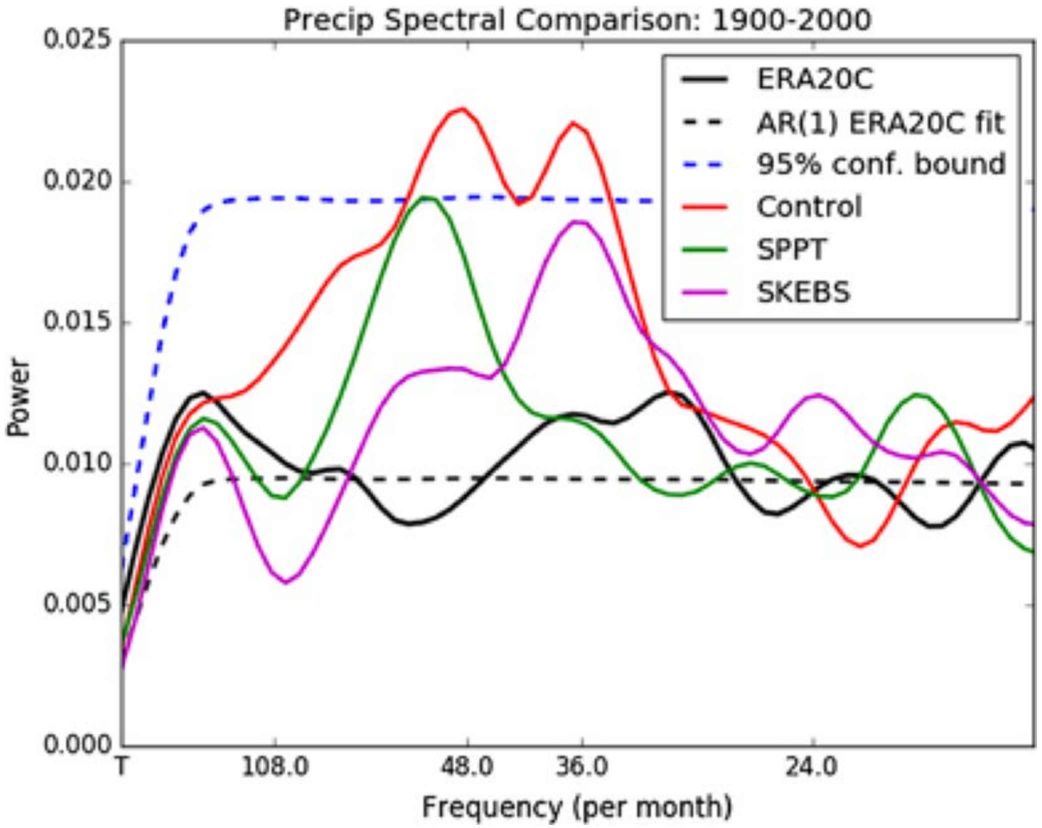


SKEBS (stochastic) - GPCP



SPPT (stochastic) - GPCP





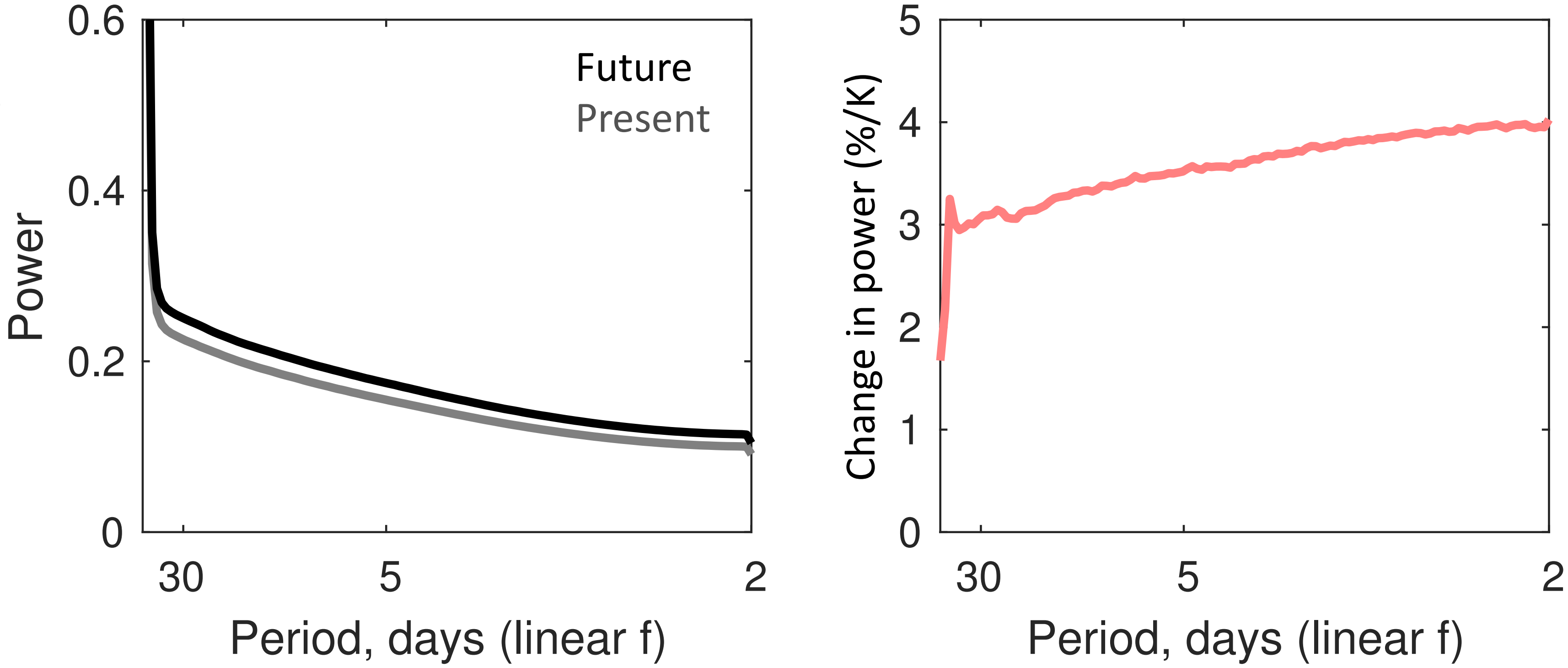
Strømmen et al., (2017) *Climate Dynamics*

Questions / Comments?

apgrass@ucar.edu

Precipitation variability: Power spectral density change from present to RCP8.5

CMIP5

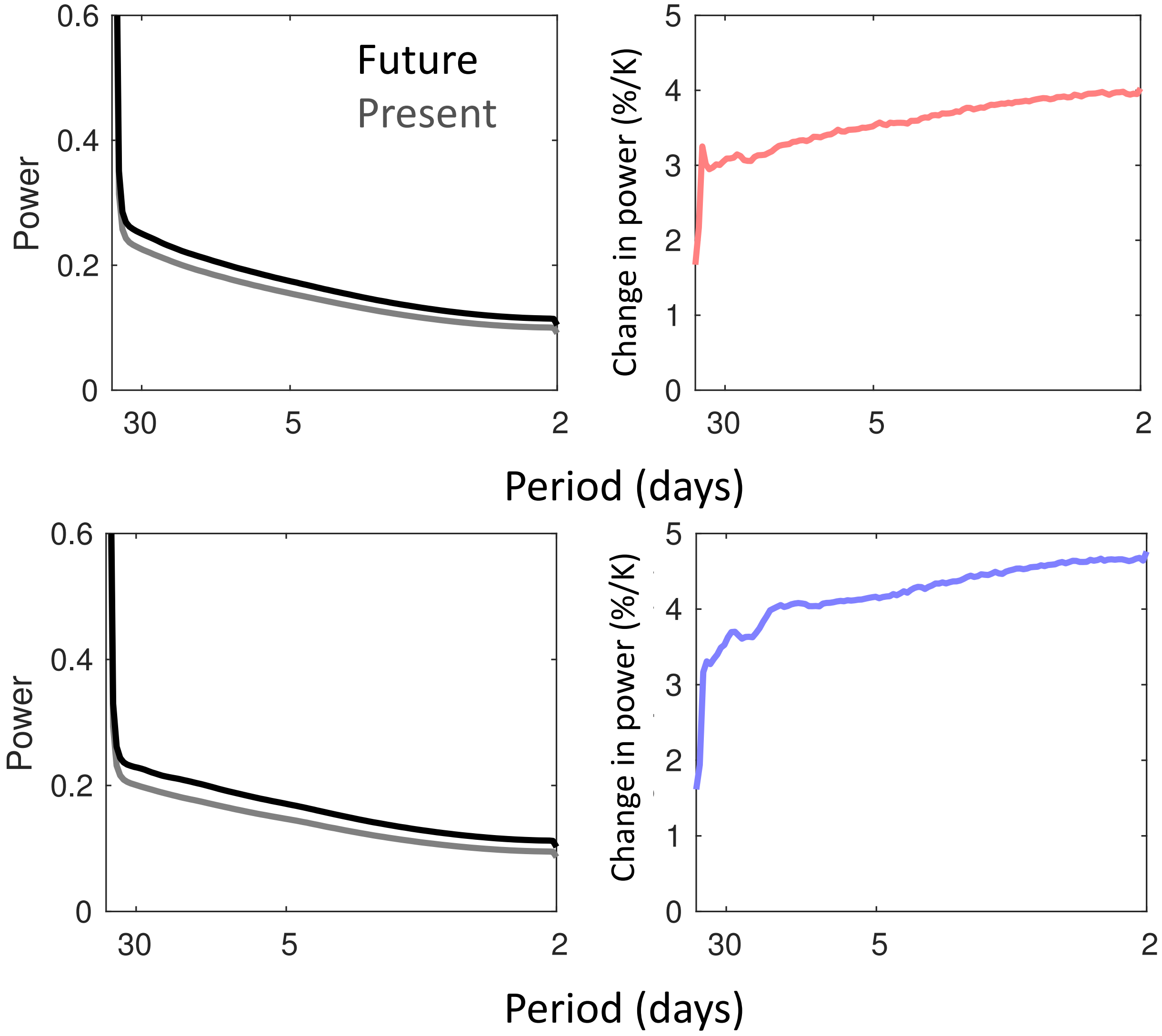


Period (days)

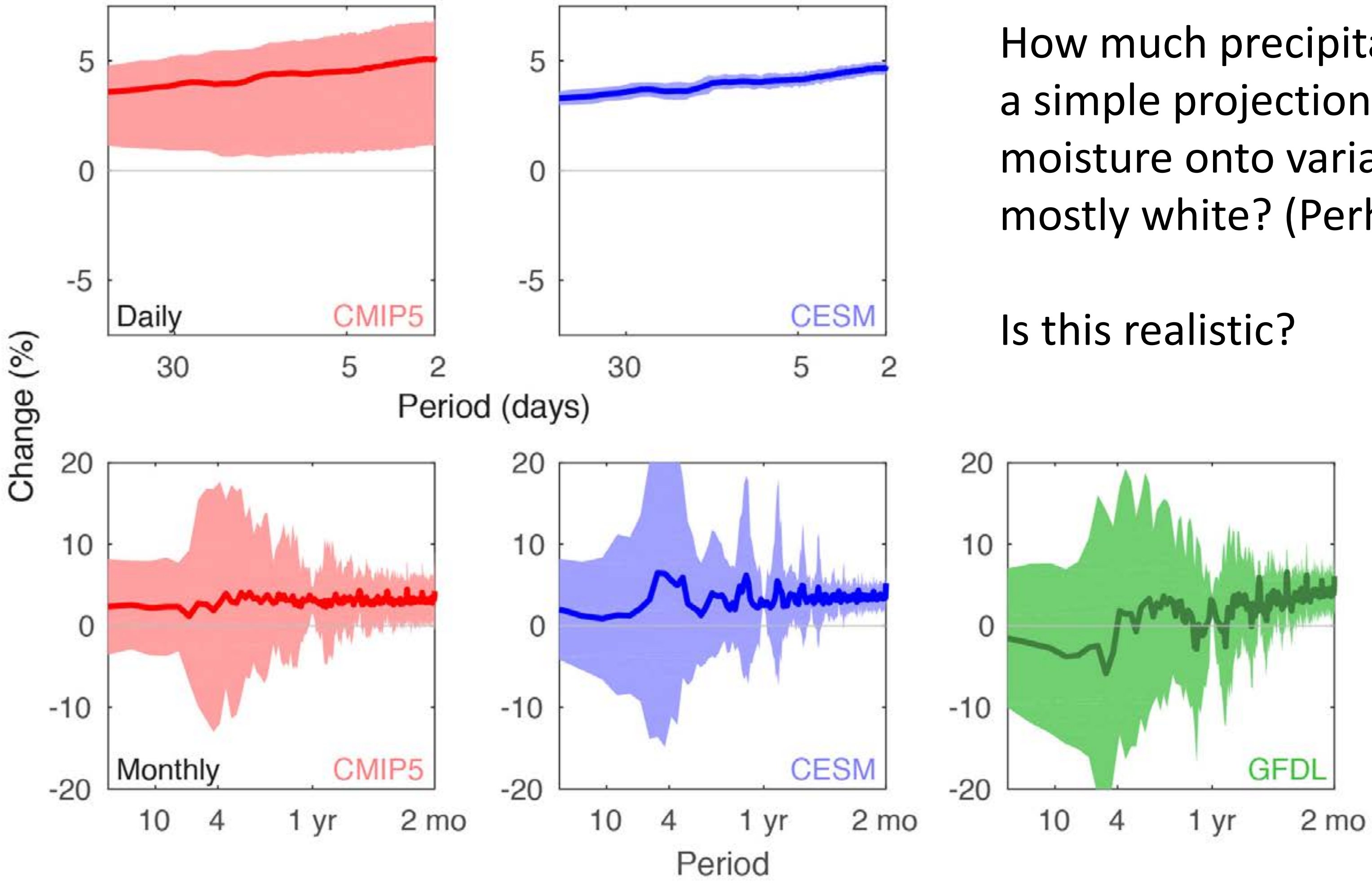
Precipitation variability: Power spectral density change from present to RCP8.5

CMIP5

CESM1



Precipitation variability: Power spectral density change from present to RCP8.5



How much precipitation change is a simple projection of increased moisture onto variability that is mostly white? (Perhaps a lot)

Is this realistic?

Pendergrass et al (2017) *Scientific Reports*

Beyond the baseline: Exploratory metrics

- Standard metrics decomposed into their components contributing to model biases
- Metrics relating model biases to processes or phenomena to inform model development
- Relationships that connect model biases to their regional-to-global implications
- Emergent relationships that connect model biases to model responses to perturbations
- Use-inspired metrics connected with impacts

Exploratory metrics: Hierarchy

Space and time scales	Phenomena and impacts	Relationships and processes
Mean state		Relationships between variables such as: - P-moisture - P-T - P-omega - P-MSE - P-entrainment/trigger
Seasonal cycle	Monsoon regional features (e.g., monsoon depression, Meiyu rainfall jump), precipitation in Mediterranean climate	
Synoptic	Frontal, extratropical cyclones, atmospheric rivers	
Sub-daily	Orographic precipitation, mesoscale convective systems	Teleconnection relationships such as: - Influence of ENSO-PNA on P - MJO-TC connection and impacts on P - MJO-AR connection and impacts on P
PDF	Intensity-duration-frequency curve	
Extremes	Tropical cyclones, severe convective storms, compound extremes, composites of top 10 events	Emergent relationships to constrain projected changes in P
Tropical variability		
Mid-to-high latitude variability		

CMIP5 rain frequency distributions: Zonal mean