Evaluating precipitation in climate models

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Weather forecast

Initial condition problem

Goal: improve for specific time over, e.g., climatology or persistence

Climate projection

Boundary value problem (for atmosphere)

Goal: accurately estimate distribution and/or its change as forcing (or parameters) changes

Weather forecast	Climate projection
Initial condition problem	Boundary value problem (for atmosphere)
Goal: improve for specific time over, e.g., climatology or persistence	Goal: accurately estimate distribution and/or its change as forcing (or parameters) changes
Many observed realizations to test on	Very few observed realizations

Motivation

- Precipitation in climate models is could be improved, e.g., persistent systematic biases

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- Precipitation in climate models is could be improved, e.g., persistent systematic biases

- Targeting key metrics for skill has helped weather forecasting improve dramatically

Z500 anomaly correlation, 12 month running mean

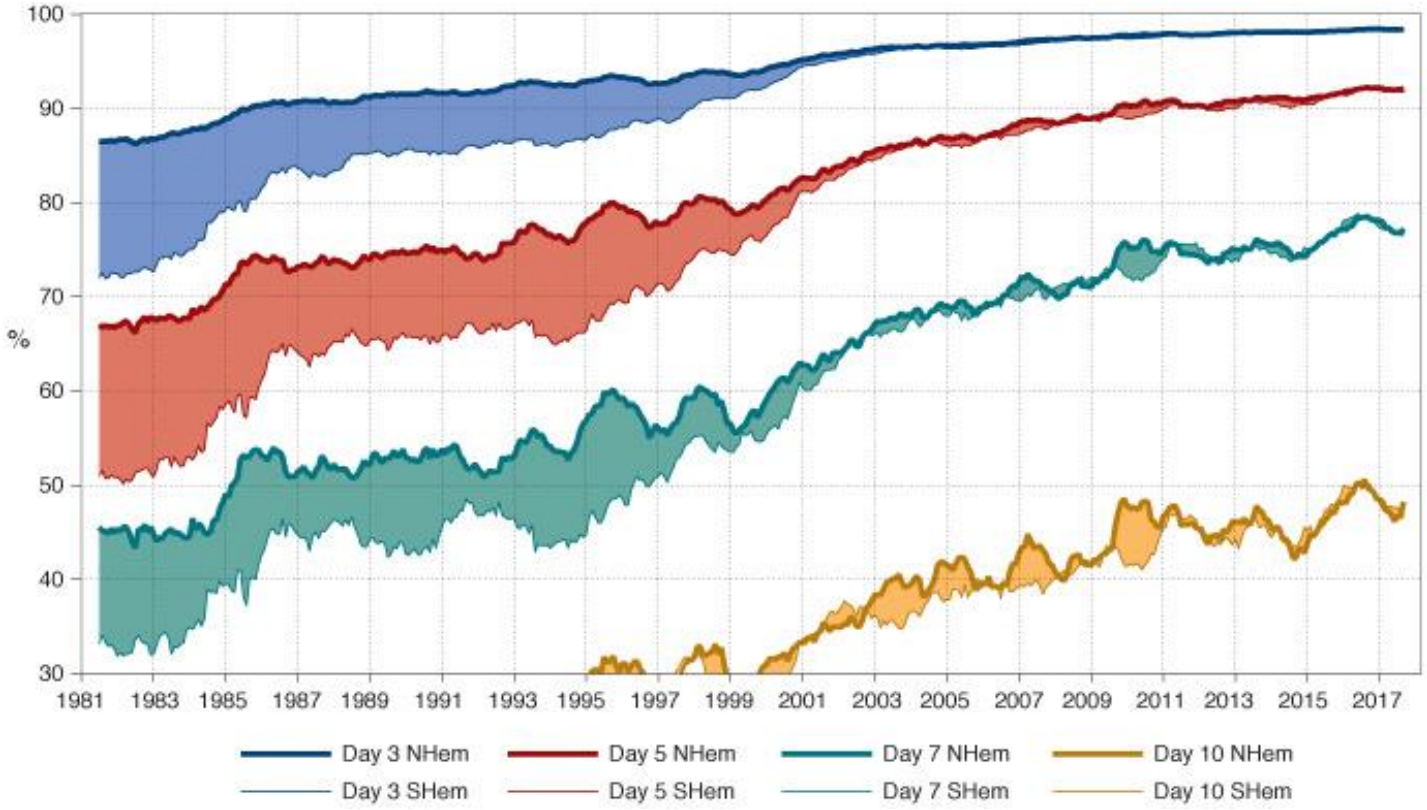


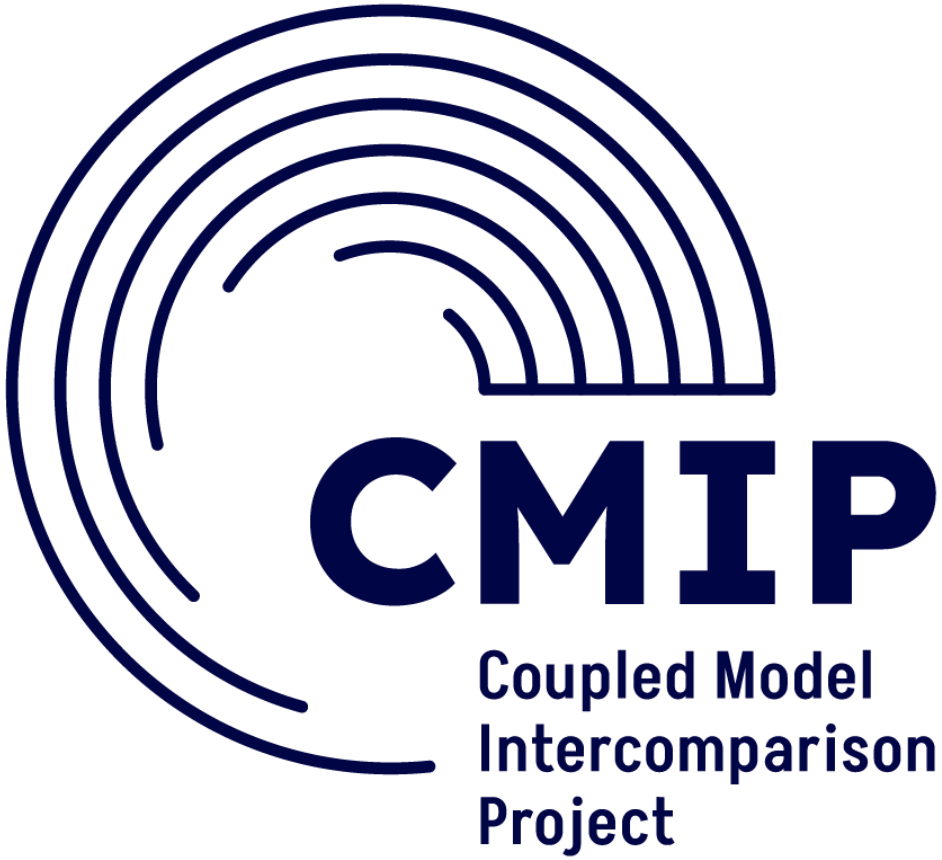
Figure: https://www.ecmwf.int/en/about/media-centre/news/2018/noaa-satellite-launch-20-years-ago-marked-start-new-era

Motivation

Our goal (inspired by the success in weather forecasting):

Facilitate improvement in precipitation in climate models by providing a benchmark for modeling groups

- A suite of metrics characterizing precipitation holistically
- Appropriate observational range for each metric to serve as a target



CMIP6

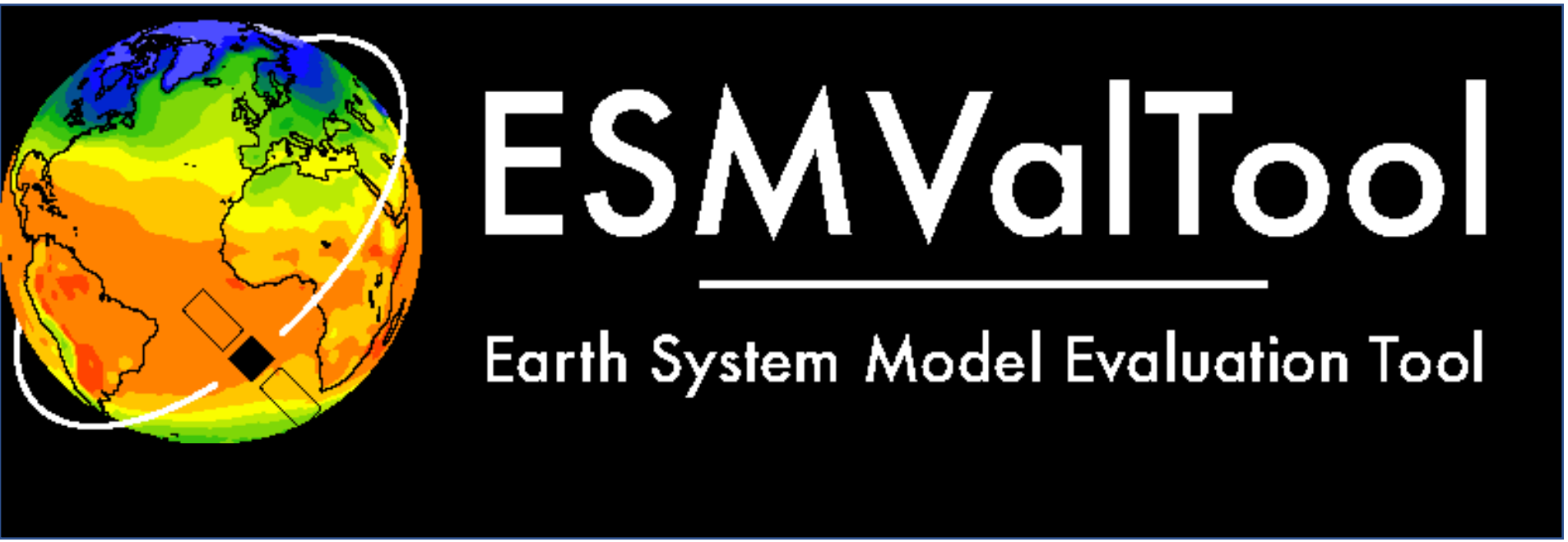
- Include
  - Global atmosphere
  - Land
  - Sea ice
  - Atmospheric chemistry
  - Ocean*
  - …

*some simulations have prescribed SST

- 100 climate models (49 groups)*
- Most have resolution ~100 km
  - “High resolution” subset 25-50 km
- All run for hundreds of years or more!
- CMIP6 completed ~2021
  - CMIP7 planning currently underway

*Numbers: Hausfather 2019 *Carbon Brief*

CMIP Model Benchmarking and Evaluation Tools
https://wcrp-cmip.org/tools/model-benchmarking-and-evaluation-tools/



PCMDI Metrics Package

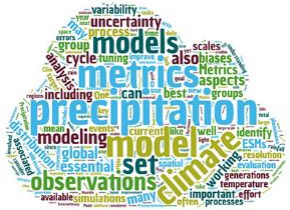
Quick look:

https://pcmdi.llnl.gov/metrics/

Includes all models that submit to CMIP

Lee, J., **Gleckler**, P. J., **Ahn**, M.-S., Ordonez, A., Ullrich, P. A., Sperber, K. R., Taylor, K. E., Planton, Y. Y., Guilyardi, E., Durack, P., Bonfils, C., Zelinka, M. D., Chao, L.-W., Dong, B., Doutriaux, C., Zhang, C., Vo, T., Boutte, J., Wehner, M. F., Pendergrass, A. G., Kim, D., Xue, Z., Wittenberg, A. T., and Krasting, J.: Systematic and objective evaluation of Earth system models: PCMDI Metrics Package (PMP) version 3, Geosci. Model Dev., 17, 3919–3948, https://doi.org/10.5194/gmd-17-3919-2024, 2024.

Benchmarking Precipitation in Climate Models

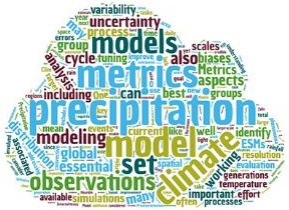


U.S. DOE, 2020: *Benchmarking Simulated Precipitation in Earth System Models Workshop Report*. U.S. Department of Energy Office of Science, Biological and Environmental Research (BER) Program, https://climatemodeling.science.energy.gov/sites/default/files/RGMA_Precip_Metrics_workshop_0.pdf.

Ahn, M.-S., Ullrich, P. A., Gleckler, P. J., Lee, J., Ordonez, A. C., and Pendergrass, A. G.: Evaluating precipitation distributions at regional scales: a benchmarking framework and application to CMIP5 and 6 models, Geosci. Model Dev., 16, 3927–3951, https://doi.org/10.5194/gmd-16-3927-2023, 2023.

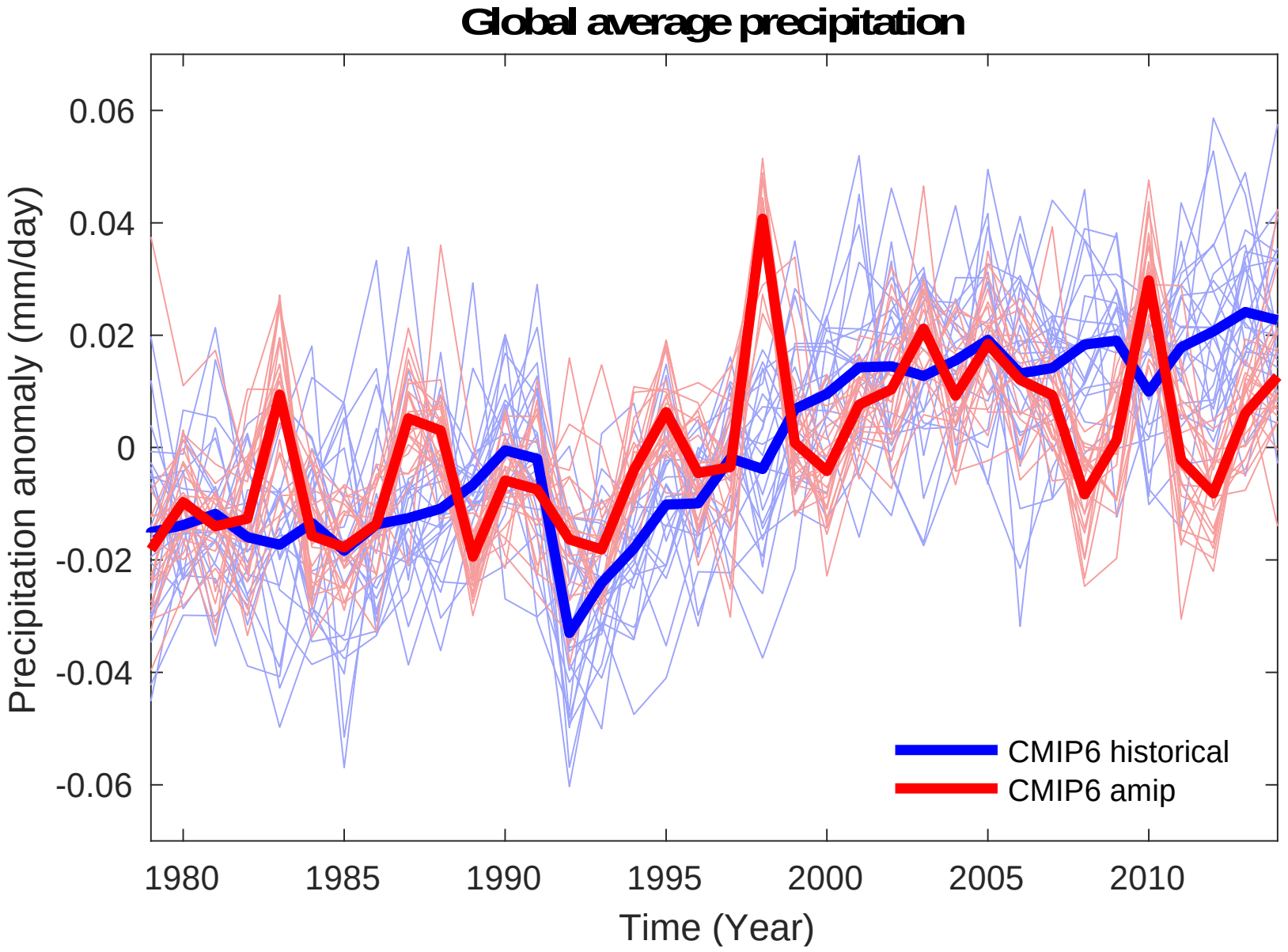
Benchmarking Precipitation in Climate Models: PMP

Tier 1 metrics



- Spatial distribution of mean state
- Seasonal cycle
- Variability across timescales
- Drought (lack of precip)
- Extremes
- Intensity / frequency distributions

Historical simulations *with prescribed SST*



All simulations:
historical forcings
- GHGs
- Aerosols
- Volcanos

Ocean: full

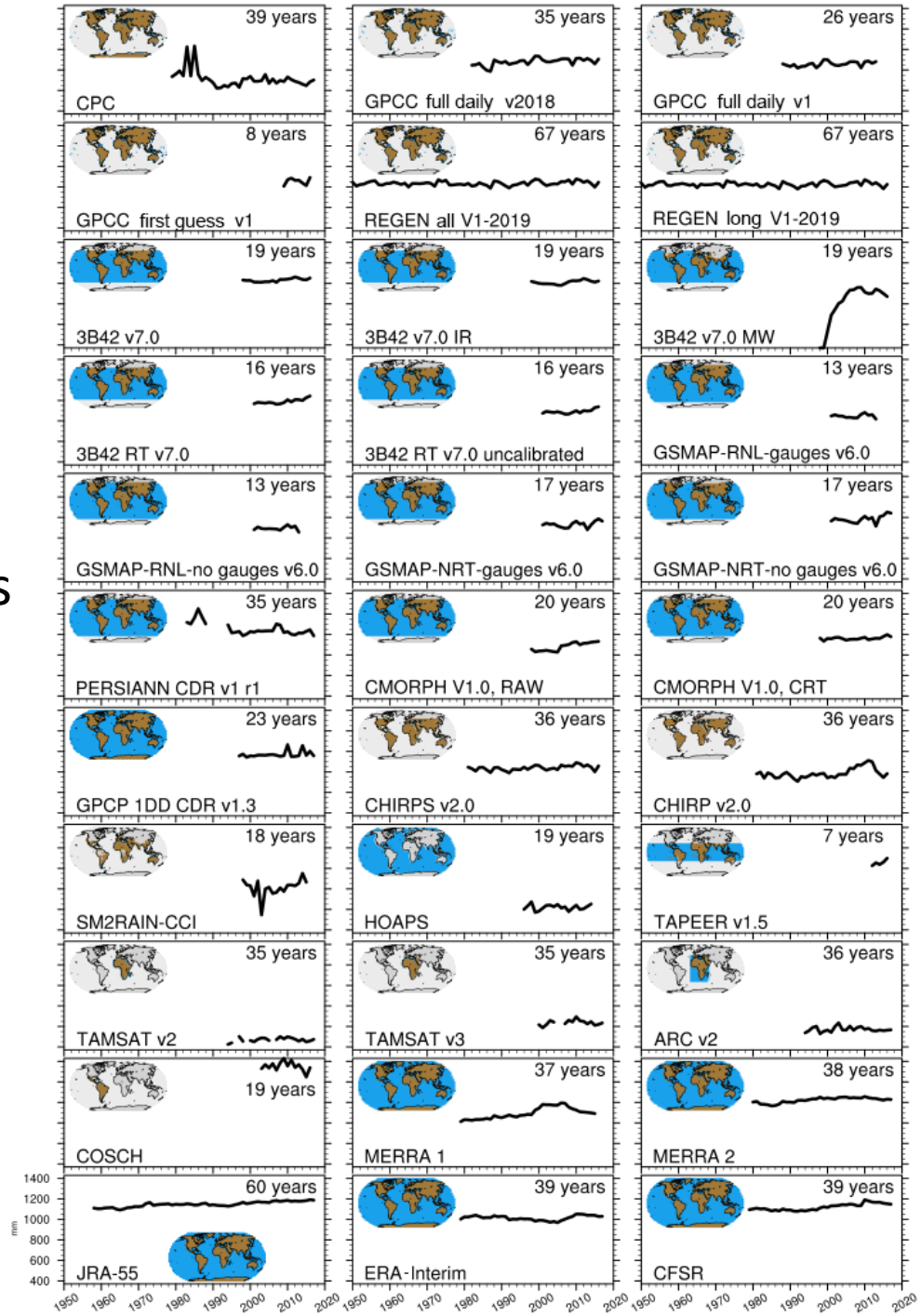
Prescribed, observed SST ("AMIP")

Figure: courtesy of Flavio Lehner

Ground-based datasets

Satellite-based datasets

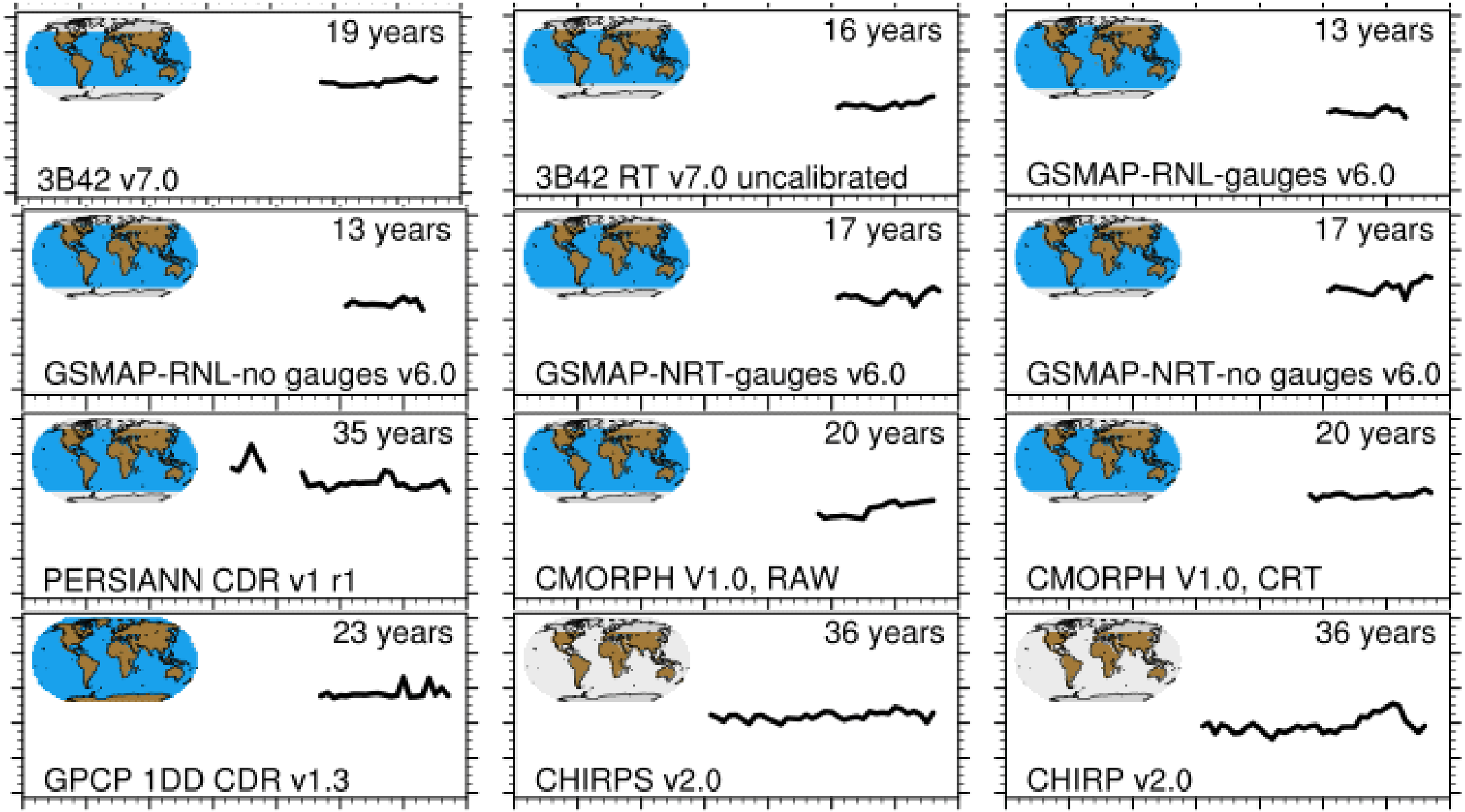
Reanalysis



Discrepancies exist among observational products for precipitation

Roca et al., (2019)

Satellite-based datasets



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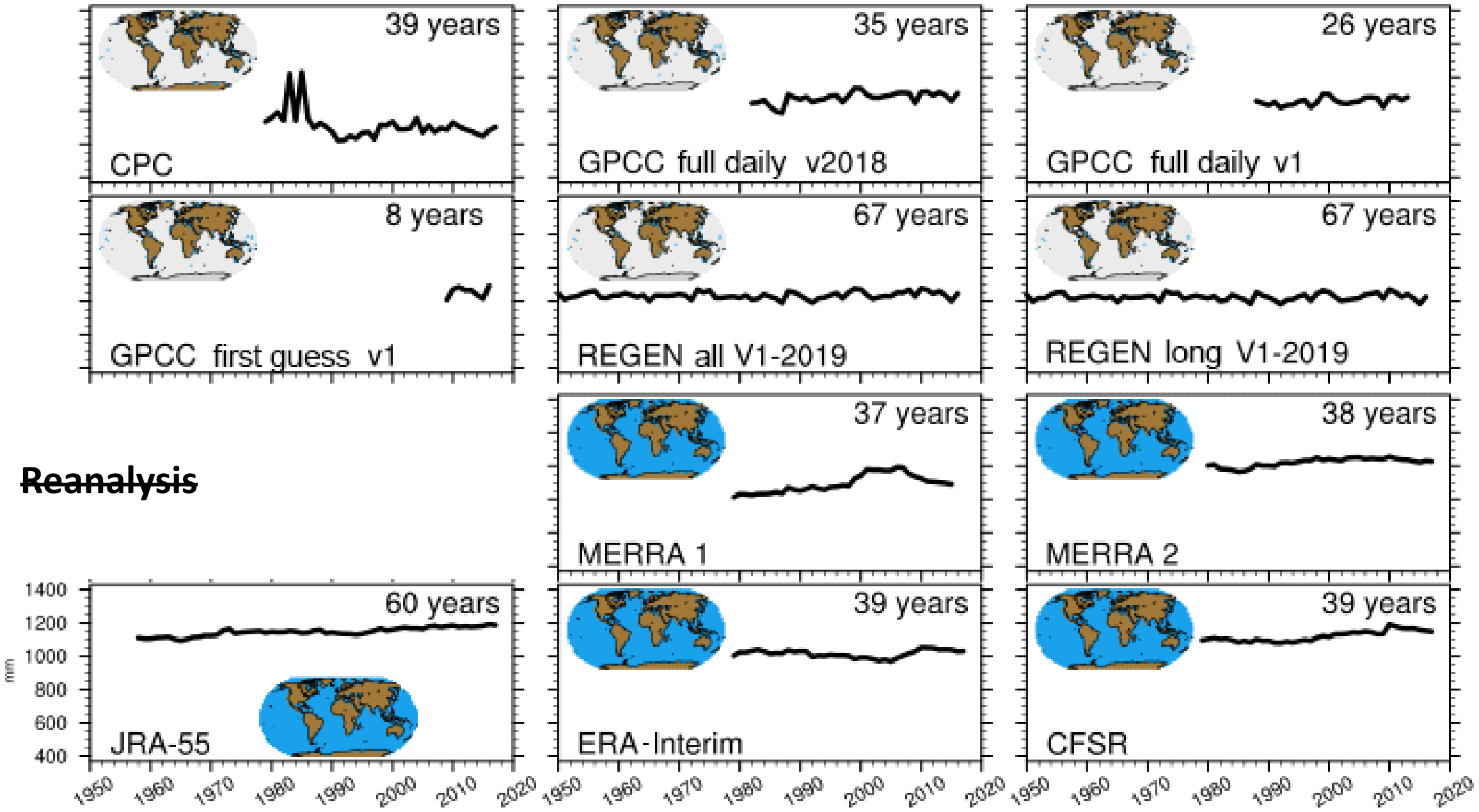

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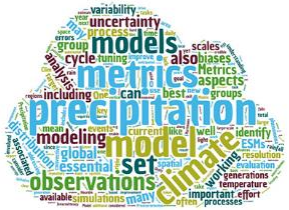

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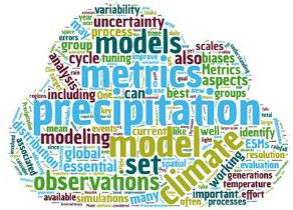
Benchmarking Precipitation in Climate Models: PMP

Tier 1 and 2 metrics



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

Lee et al, (2024) *GMD*

Benchmarking Precipitation in Climate Models: PMP

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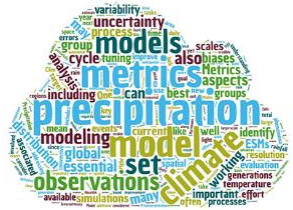

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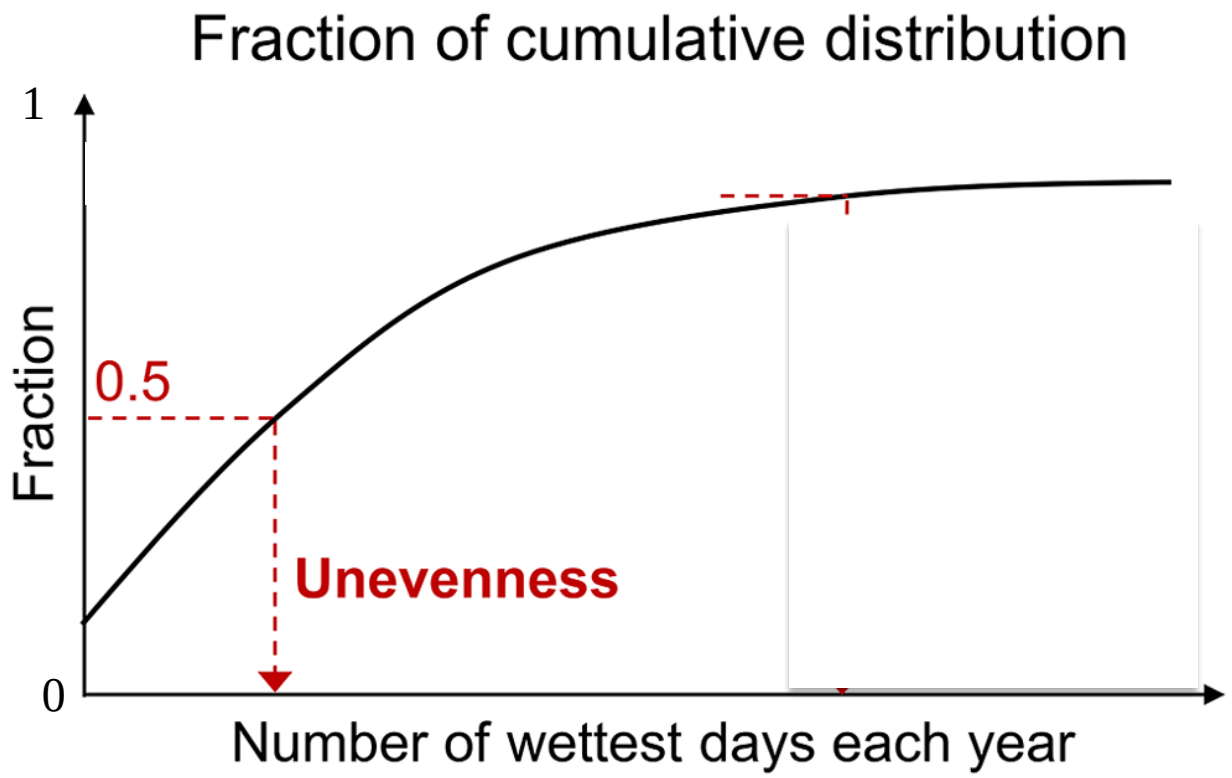
Lee et al, (2024) *GMD*

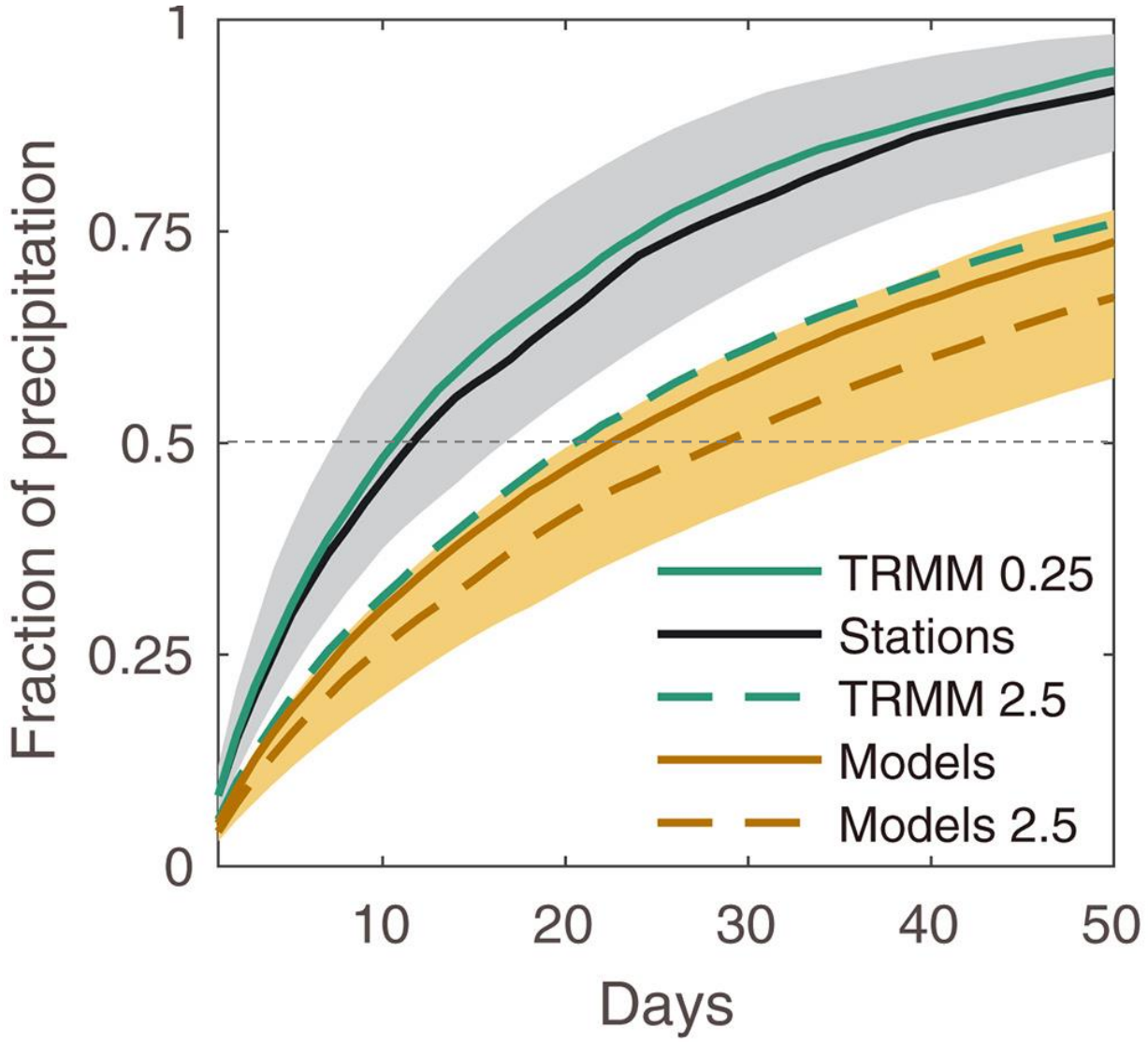
Unevenness: Number of days in which ½ of precipitation falls each year



Fraction of cumulative distribution as a function of the number of wettest days. Unevenness gauges the number of wettest days for half of the annual precipitation.

Ahn et al., (2023), *GMD*

Unevenness: Number of days in which ½ of precipitation falls each year



CMIP5 models had a bias overall on this measure

Bias appears much worse when resolution of models and observations is not accounted for

Pendergrass and Knutti (2018) *GRL*

PCMDI - Metrics

https://pcmdi.llnl.gov/metrics/

Program for Climate Model Diagnosis & Intercomparison

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Home | About | Research | CMIP6 | MIPs | Publications | Software | CMIP Data (ESGF Portal)

Research > Metrics

PCMDI Simulation Summaries: CMIP mean state and variability (v1.6.2)

The PCMDI Metrics Package (PMP) is a capability that is used to produce a diverse suite of "quick-look" objective summaries of Earth System Model (ESM) agreement with observations. The PMP is routinely applied to multiple generations of CMIP, including the most recent results from CMIP6 as they become available. These results are regularly updated as additional simulations become available, new analysis are included, and as presentation improvements and corrections are made.

- Mean Climate
- Benchmarking Simulated Precipitation
- El Niño–Southern Oscillation (ENSO)
- Extratropical Modes of Variability
- Madden-Julian Oscillation (MJO)
- Monsoon Characteristics (example)
- *Update history*

Results are also accessible from the Coordinated Model Evaluation Capabilities (CMEC) website.

Intensity/Frequency Distribution

The precipitation distribution metrics are applied to three tiers of domains below:
Domain 1 (D1): Large domain commonly used in the PMP (Tropics and Extratropics with separated land and ocean)
Domain 2 (D2): Large domain clustered by precipitation (Domain 1 with separated heavy, moderate, and light precipitation regions)
Domain 3 (D3): Modified IPCC AR6 regions (Global domain partitioned into 62 regions, Ahn et al. 2023a)
All plots below are **interactive portrait charts** for three tiers of domains unless otherwise stated.

Metric	CMIP6-amip	CMIP5-amip
Amount Peak	D1, D2, D3	D1, D2, D3
Amount P10	D1, D2, D3	D1, D2, D3
Amount P90	D1, D2, D3	D1, D2, D3
Frequency Peak	D1, D2, D3	D1, D2, D3
Frequency P10	D1, D2, D3	D1, D2, D3
Frequency P90	D1, D2, D3	D1, D2, D3
Unevenness	D1, D2, D3	D1, D2, D3
Fraction of Precipitating Days	D1, D2, D3	D1, D2, D3
Simple Daily Intensity Index (SDII)	D1, D2, D3	D1, D2, D3
Perkins Score	D1, D2, D3	D1, D2, D3
Bimodality	D1, D2, D3	D1, D2, D3

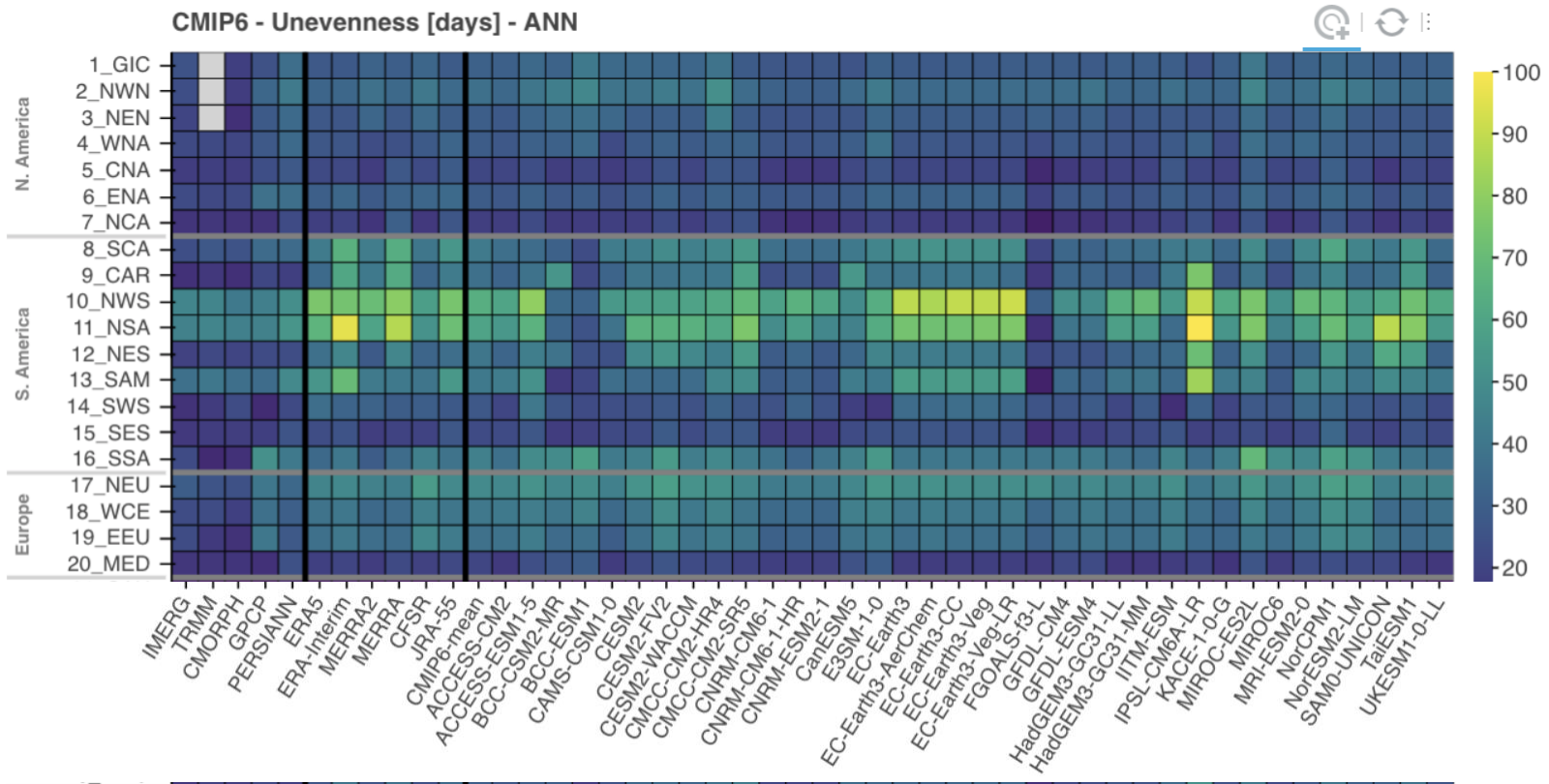
- **Bar chart of large domain averaged Unevenness** (CMIP6-histotical)

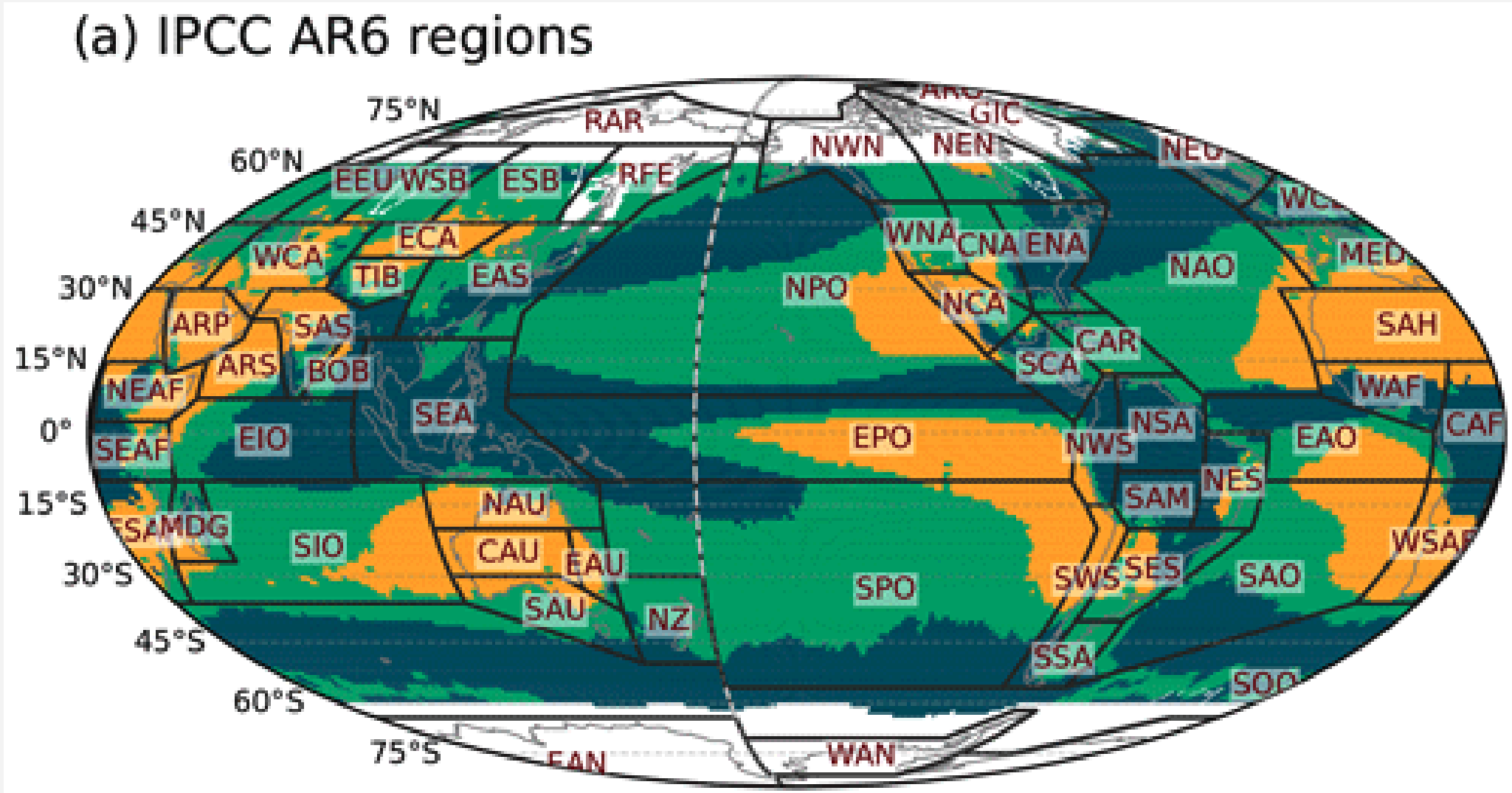
Precipitation Distribution Metrics

Dropdown menu selects MIP, METRIC, or SEASON
Tab selects a plot for Metric Value, Bias, or Bias with a monotone colormap
Bias is calculated based on the range of satellite-based observations (If MODEL is out of OBS range, *Bias = MODEL - nearest OBS*)

Select MIP | Select METRIC | Select SEASON *: current selection

Metric Value | Metric Bias | Metric Bias (monotone color)

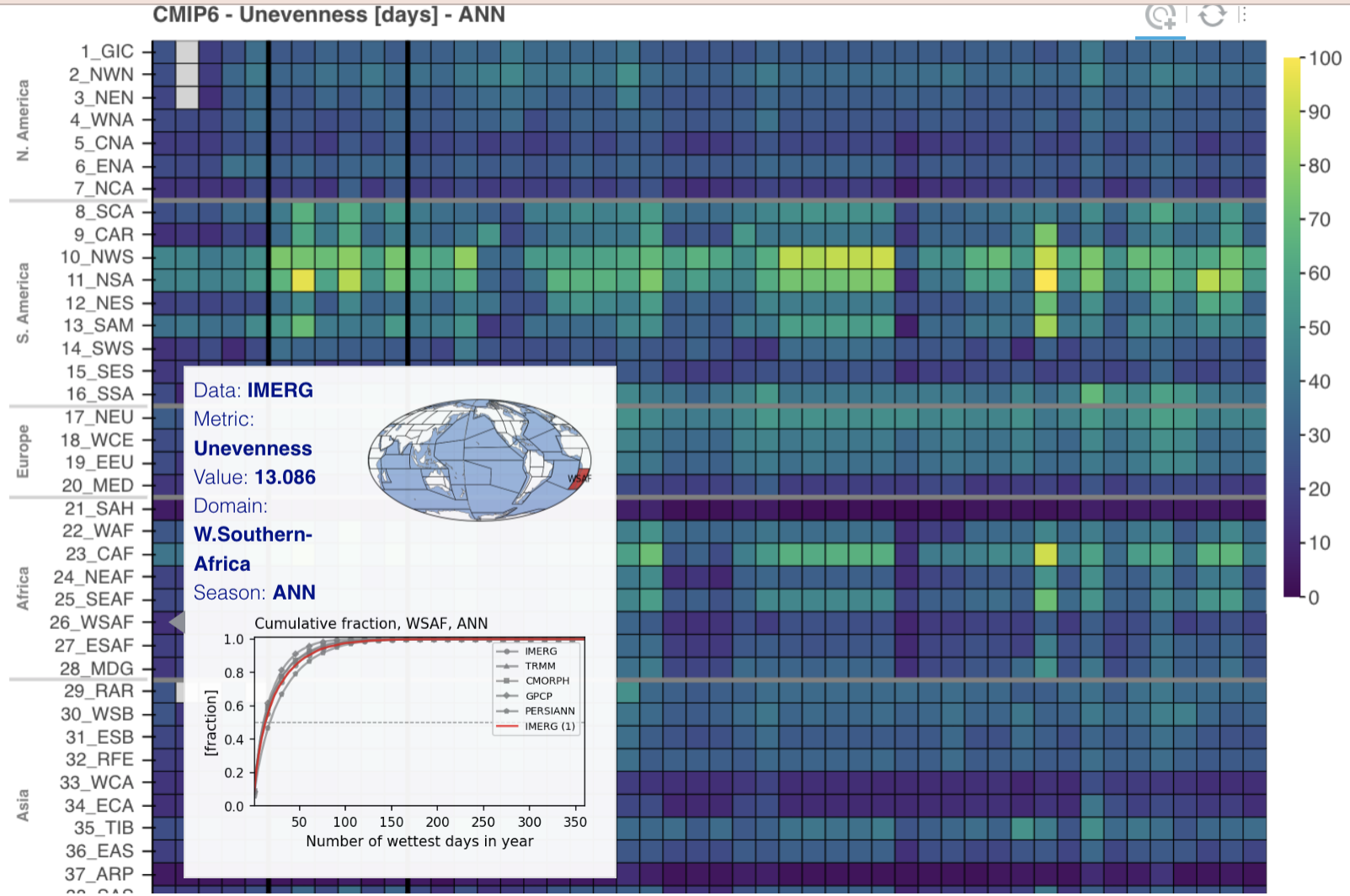




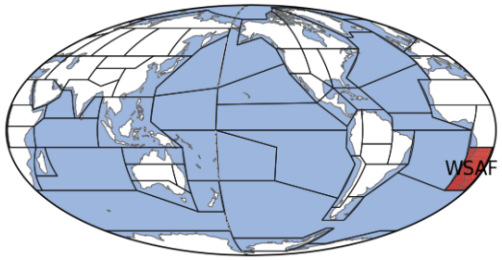
Ahn et al (2023)

Interactive plot

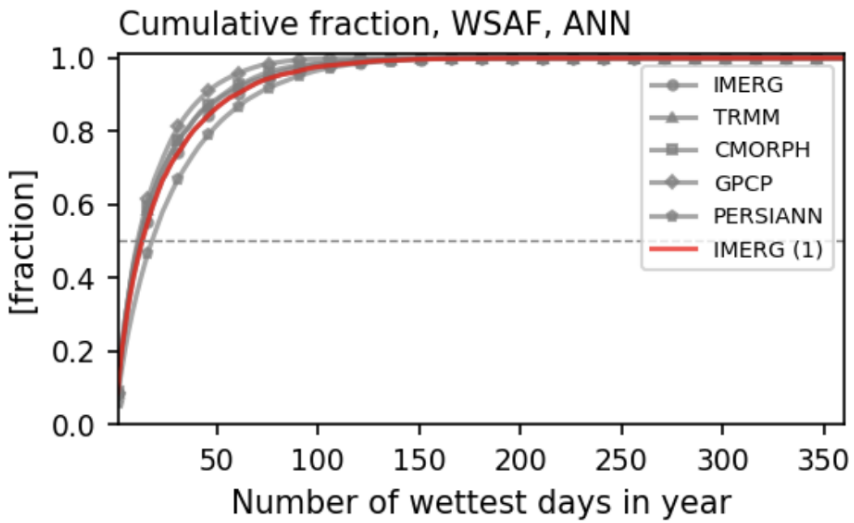
pcmdi.llnl.gov/pmp-preliminary-results/interactive_plot/precip/intensity.frequency_distribution/AR6.modified_domain/interactive_p...



Data: **IMERG**
Metric: **Unevenness**
Value: **13.086**
Season: **ANN**
Domain: **W.Southern-Africa**



Dive Down Diagnostics

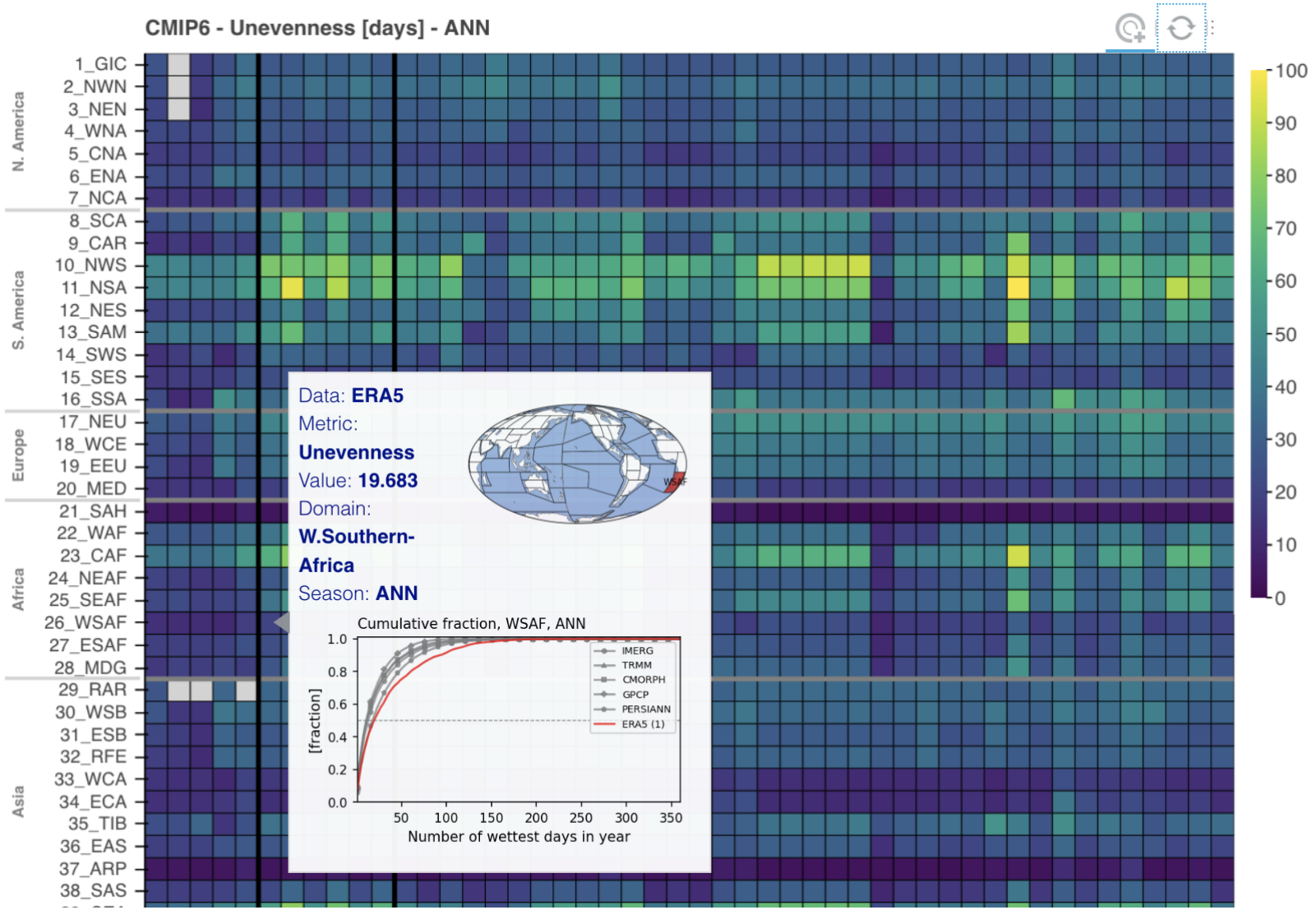


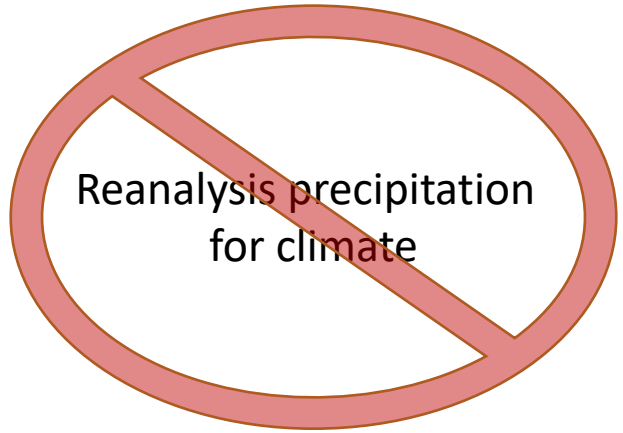
Thick and thin red lines respectively represent the realization mean and each realization.
The number in parentheses next to the model name is the number of realizations.

Interactive plot | Interactive plot: Dive Down

pcmdi.llnl.gov/pmp-preliminary-results/interactive_plot/precip/intensity.frequency_distribution/AR6.modified_domain/interactive_p...

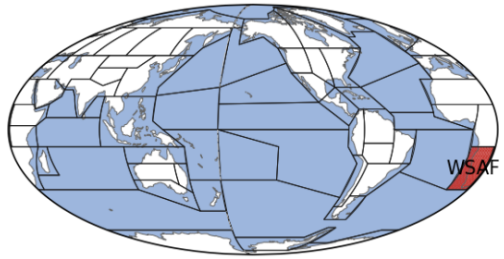
Metric Value | Metric Bias | Metric Bias (monotone color)





see Bador et al., (2020)

Data: **CMIP6-mean**
Metric: **Unevenness**
Value: **21.600**
Season: **ANN**
Domain: **W.Southern-Africa**



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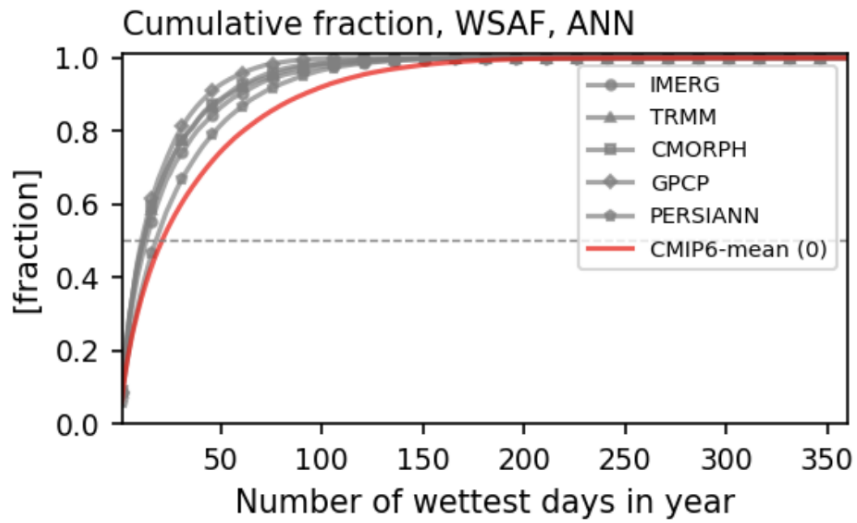

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Bias = model – nearest obs (satellite only)

A few steps from “portrait plot,”
Gleckler et al (2008)
Performance Metrics for Climate Models

Concluding remarks

- Precipitation Benchmarking suite evaluates historical precipitation against observations
  - Quick looks for all models with relevant simulations in CMIP5 and CMIP6
  - Code package available: https://github.com/PCMDI/pcmdi_metrics

Ongoing work

- Exploratory metrics for PMP precip benchmarking (Leung et. al., 2022)
- Evaluating improvement with resolution
- Confronting earth system model trends with observations

Confronting Earth System Model Trends with Observations

The Good, the Bad, and the Ugly | March 13–15, 2024 in Boulder, CO

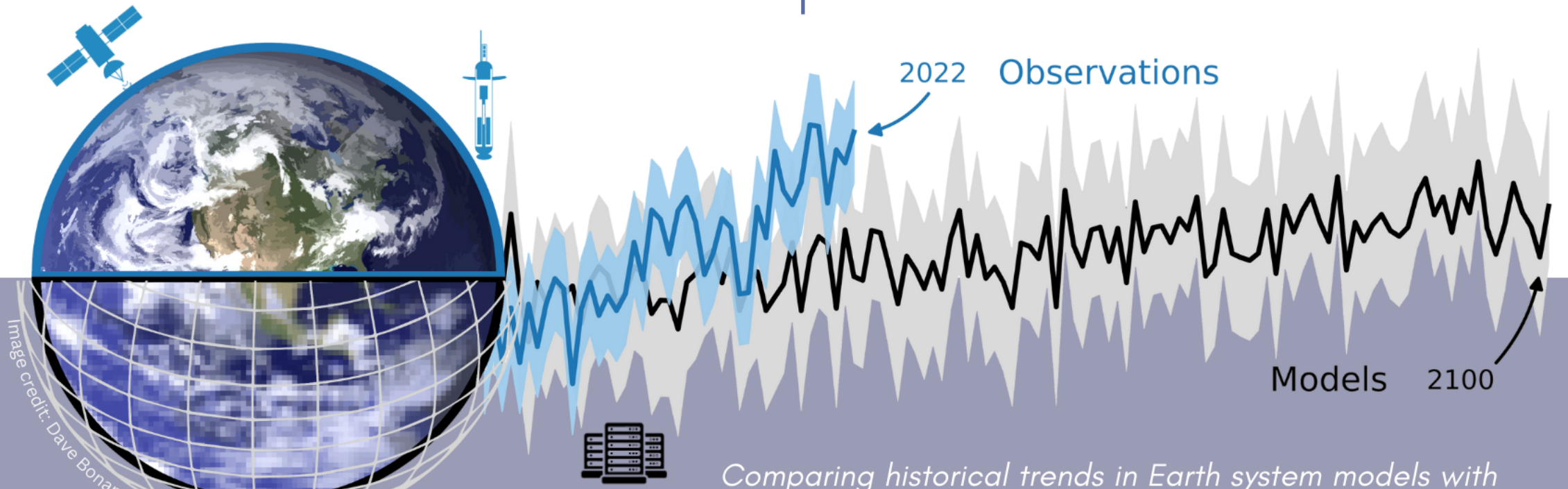

Image credit: Dave Bonan

Comparing historical trends in Earth system models with observations to identify and understand where models are performing well and poorly to focus the community on where more work is needed to ensure credible projections moving forward. Supported by:

Scientific Organizing Committee:
Tiffany Shaw, co-chair, The University of Chicago
Isla Simpson, co-chair, NCAR
Paulo Ceppi, Imperial College London
Amy Clement, University of Miami
Erich Fischer, ETH Zurich
Kevin Grise, University of Virginia
Angie Pendergrass, Cornell University
James Screen, University of Exeter
Tim Woollings, University of Oxford
Robb Jnglin Wills, ETH Zurich

Scan for website

References

Ahn, M.-S., P. A. Ullrich, P. J. Gleckler, J. Lee, A. C. Ordonez, and A. G. Pendergrass, 2023: Evaluating precipitation distributions at regional scales: a benchmarking framework and application to CMIP5 and 6 models. *Geoscientific Model Development*, **16**, 3927–3951, https://doi.org/10.5194/gmd-16-3927-2023.

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Leung, L. R., and Coauthors, 2022: Exploratory precipitation metrics: spatiotemporal characteristics, process-oriented, and phenomena-based. *Journal of Climate*, **1**, 1–55, https://doi.org/10.1175/JCLI-D-21-0590.1.

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Roca, R., L. V. Alexander, G. Potter, M. Bador, R. Jucá, S. Contractor, M. G. Bosilovich, and S. Cloché, 2019: FROGS: a daily 1° × 1° gridded precipitation database of rain gauge, satellite and reanalysis products. *Earth System Science Data*, **11**, 1017–1035, https://doi.org/10.5194/essd-11-1017-2019.

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PCMDI Metrics Package: https://pcmdi.llnl.gov/research/metrics/