Benchmarking Simulated Precipitation in Earth System Models: Workshop Report

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Workshop organizing committee:

Peter Gleckler (LLNL), Christian Jakob (U. Monash), Ruby Leung (PNNL), Angie Pendergrass (NCAR)

DOE sponsoring program-area:

Regional and Global Modeling and Analysis (Renu Joseph)

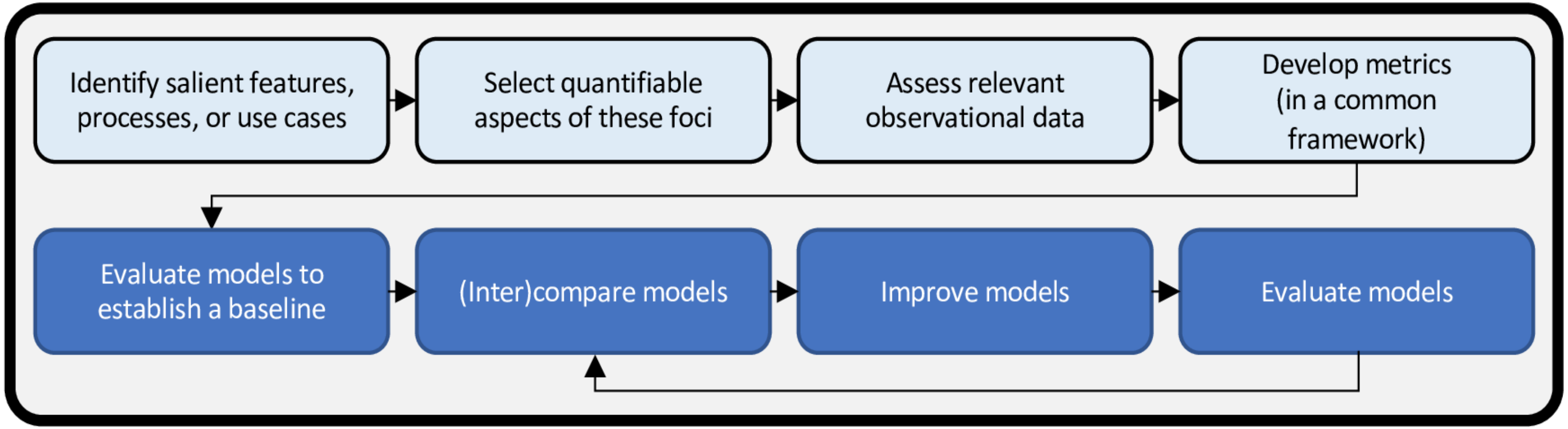
U.S. DEPARTMENT OF ENERGY

Office of Science

Office of Biological and Environmental Research

Why we need this workshop

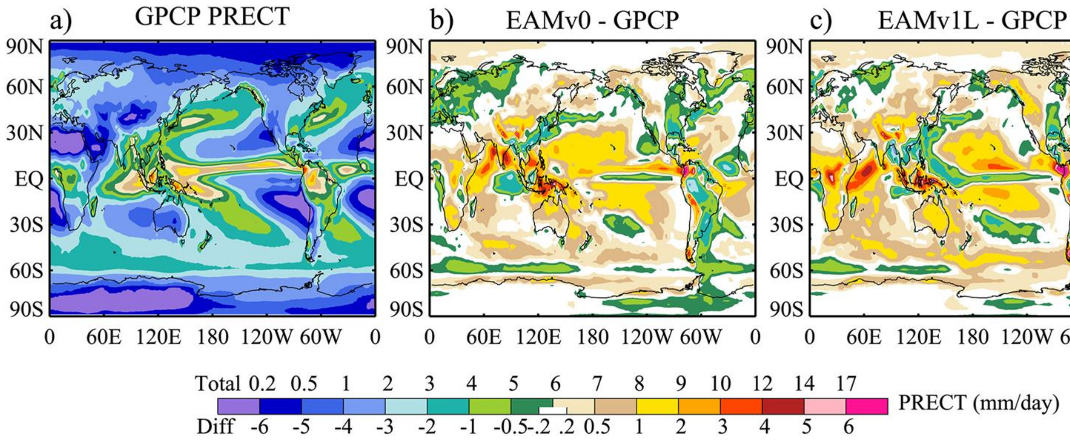
- Inspired by the lack of objective and systematic benchmarking of and the need to improve precipitation simulated by Earth System Models
- Community input via DOE 2018 AGU Town Hall and international modeling working groups
- Date/venue: July 1-2, 2019 in Rockville, MD



E3SM as an example

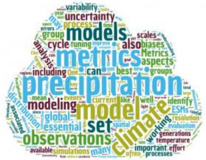
Variables used in UQ analysis and model tuning for E3SM:
(1) high-level cloud fraction (CLDHGH), (2) middle-level cloud fraction (CLDMED), (3) low-level cloud fraction (CLDLOW), (4) shortwave cloud forcing (SWCF), (5) longwave cloud forcing (LWCF), (6) net longwave flux at the model top (FLNT), (7) net radiation flux at the model top (RESTOM), (8) column-integrated total precipitable water (TMQ), and (9) **total precipitation (PRECT)**.

(Qian et al. 2018 JGR-Atmospheres)

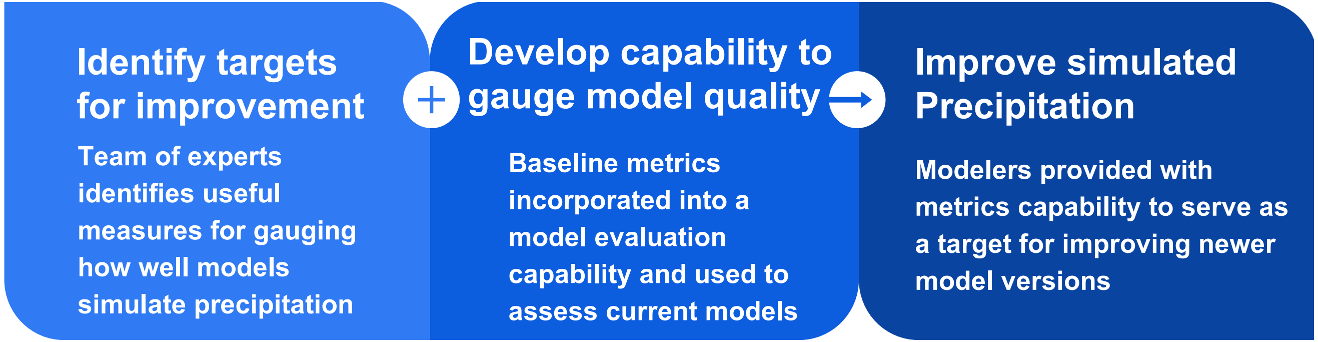


(Xie et al. 2018 JGR-Atmospheres)

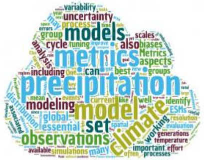
Workshop objectives



- To identify precipitation characteristics that will be used to establish a limited set of benchmarks for gauging the consistency between ESMs and observations → **baseline metrics**.
- To assess state-of-the-science methods used to evaluate simulated precipitation, and to identify areas of research where well-established metrics are needed but currently lacking → **exploratory metrics**.



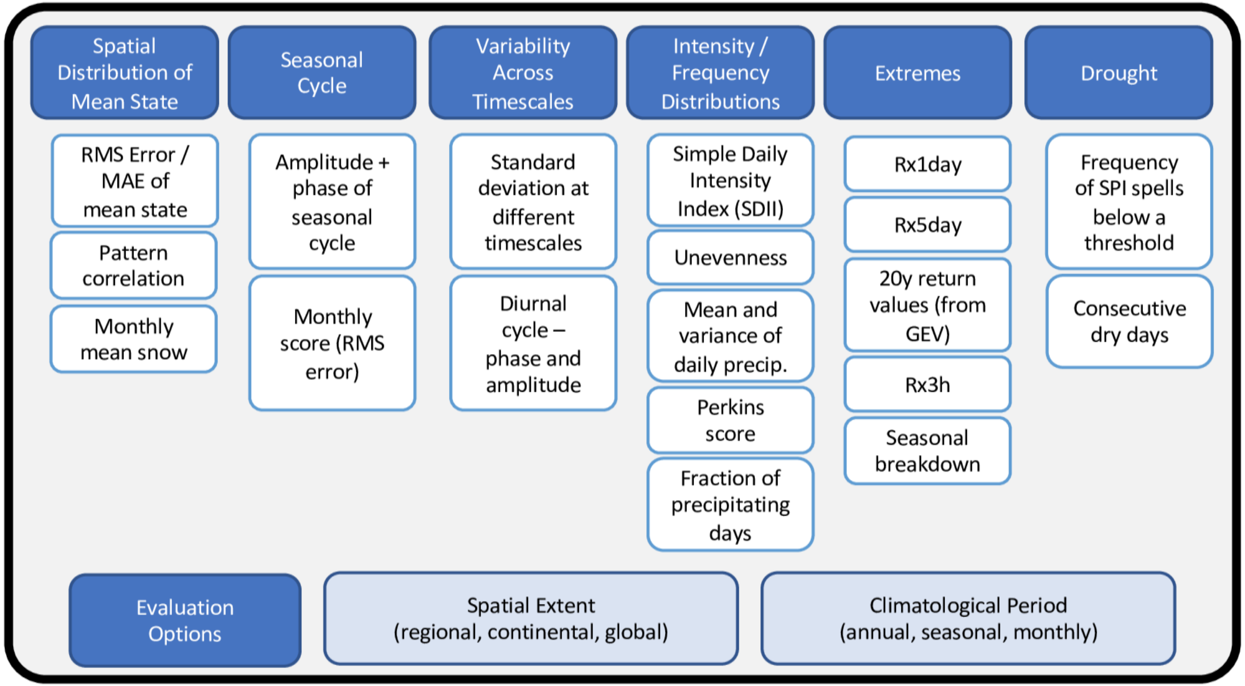
Workshop participants and structure



- ~ 40 workshop participants including:
  - Model developers interested in improving simulated precipitation
  - Observational experts liaising with international teams
  - Experts in model analysis of precipitation
  - Practitioners gauging model skill with performance metrics
  - Experts in impact-related and use-inspired metrics
  - Scientists involved in research topics where established metrics are lacking but desired (fronts, tropical cyclones, atmospheric rivers, etc.)
- Each workshop participant presented their views in plenary sessions
- Breakout groups met to discuss **baseline metrics**, **exploratory metrics**, and **next steps**

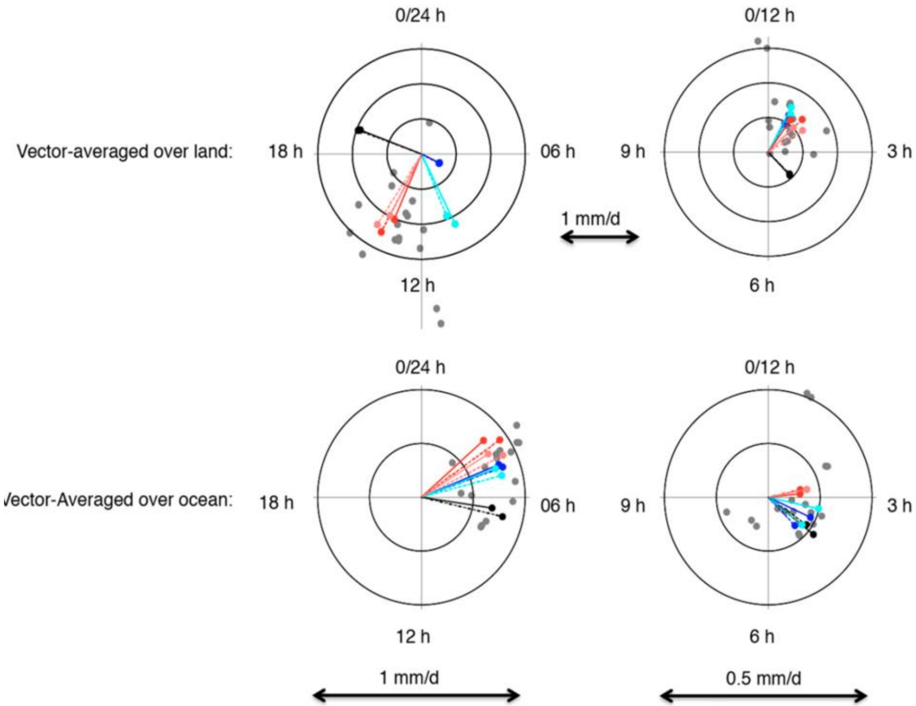
Baseline metrics: overview

- A limited set of observed characteristics to be used for model benchmarking
- Only require observed and simulated precipitation data
- Divided into tier 1 (e.g., global and annual mean) and tier 2 (e.g., regional and seasonal) and to be applied to a common set of simulations (e.g., CMIP6 DECK)



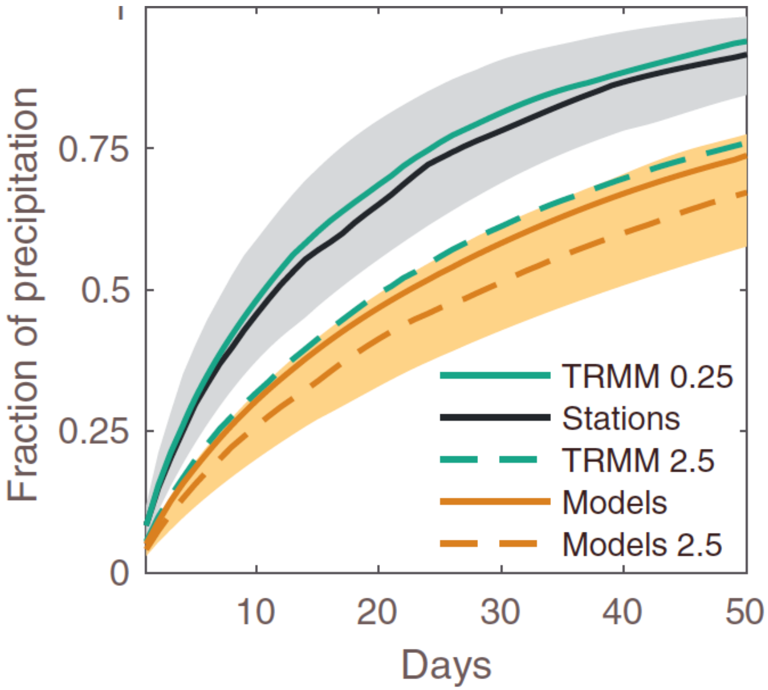
Baseline metrics: examples

Harmonic dial plots of the amplitude and phase of Fourier components



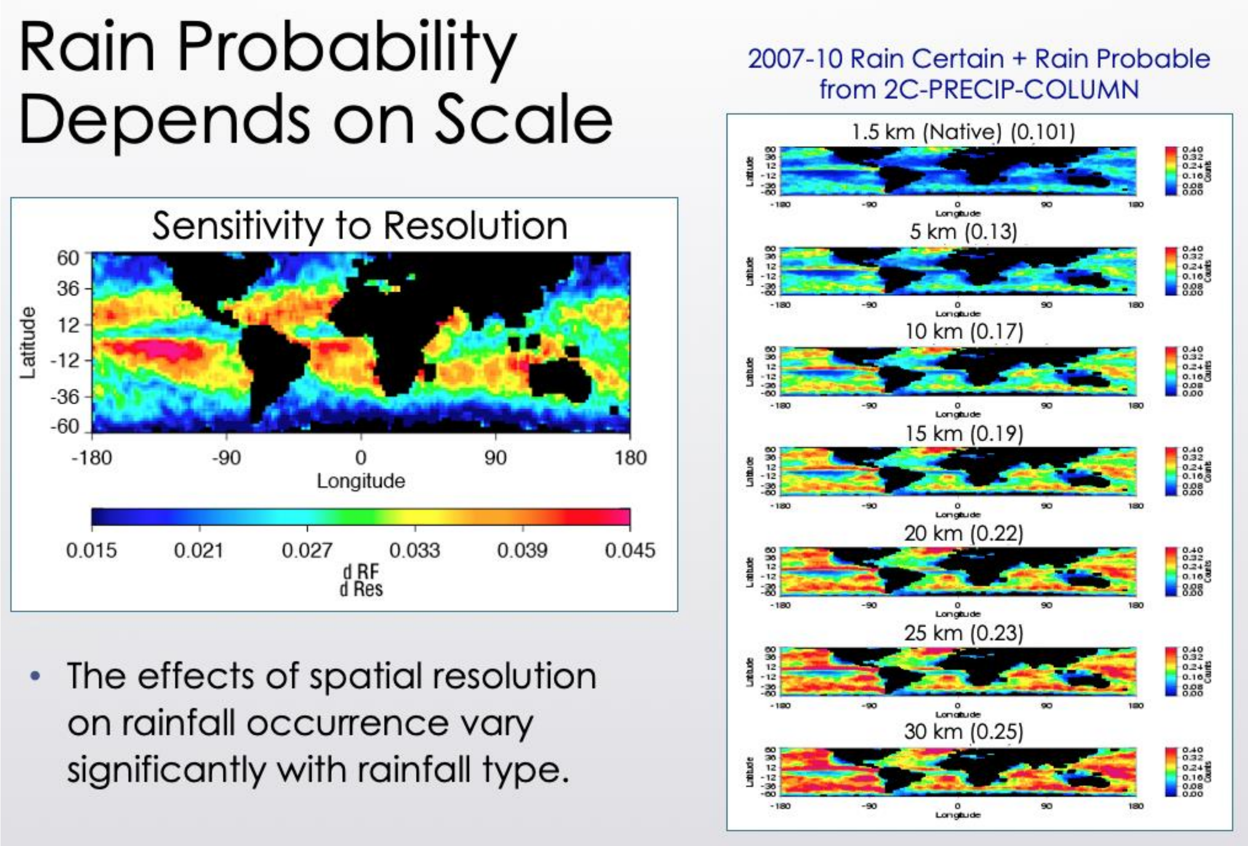
(Covey et al. 2016)

Unevenness of precipitation



(Pendergrass and Knutti 2018)

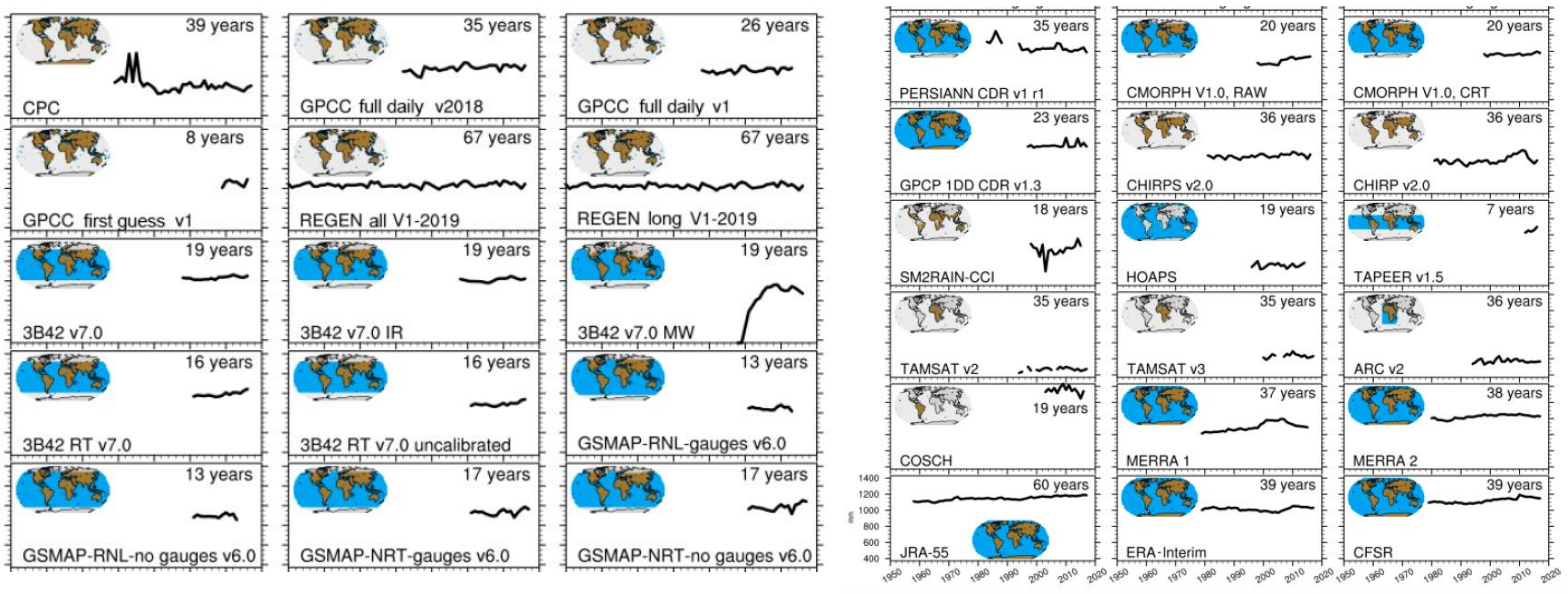
Baseline metrics: examples



(T. Lécuyer, University of Wisconsin-Madison)

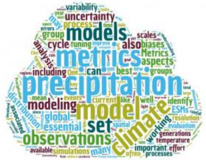
Baseline metrics: observational uncertainty

Time series of annual total daily precipitation in millimeters (mm)
averaged over each data set domain



(Roca et al. 2018)

Exploratory metrics: overview

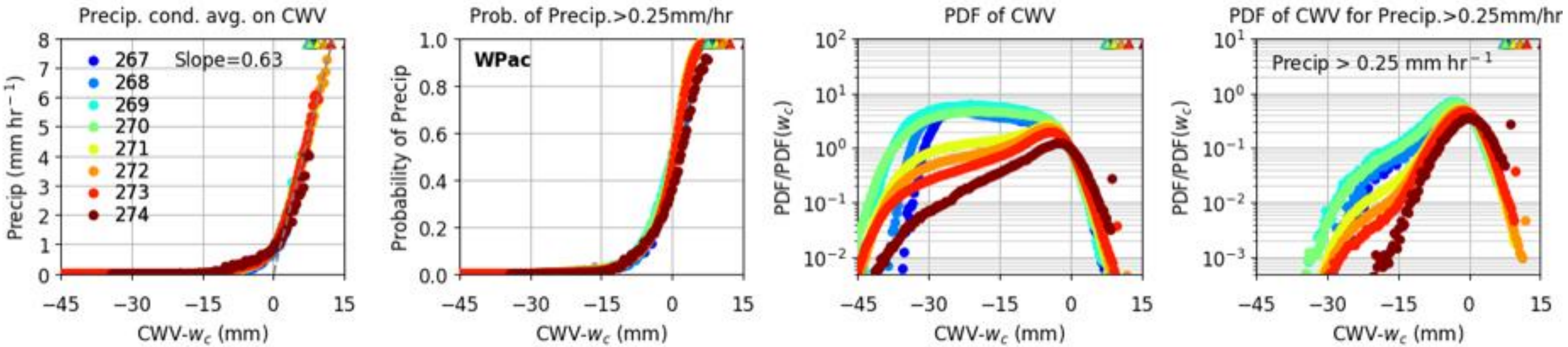


- Benchmark increasingly diverse aspects of precipitation to meet the needs of different user communities (model developers, earth system scientists, impact researchers and stakeholders)
- Often require more than just precipitation data

Exploratory Metrics		
Process-oriented Metrics	Regime-oriented Metrics	Use-inspired Metrics
Diurnal cycle of precipitation	Frontal precipitation	Fraction of wet days
Character of the distribution of precipitation rates	Extratropical + tropical cyclones	Average length of consecutive wet periods
Emergent constraints on precipitation	Mesoscale convective systems	Decorrelation time of precipitation
Orographic precipitation	Monsoonal precipitation	Intensity-duration-frequency curves
Teleconnections	Weather states	Correlated extremes

Exploratory metrics: examples

Process-oriented metrics:
Relationship between precipitation and moisture



(David Neelin, UCLA)

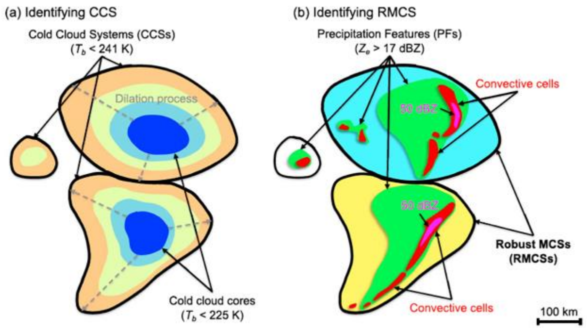
Exploratory metrics: examples

Regime-oriented metrics:
Precipitation generation mechanisms

Precipitation regimes:

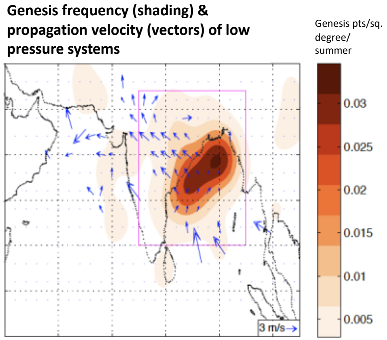
- Frontal systems
- Extratropical cyclones
- Atmospheric rivers
- Tropical cyclones
- Mesoscale convective systems
- Orographic systems

Tracking of mesoscale convective systems



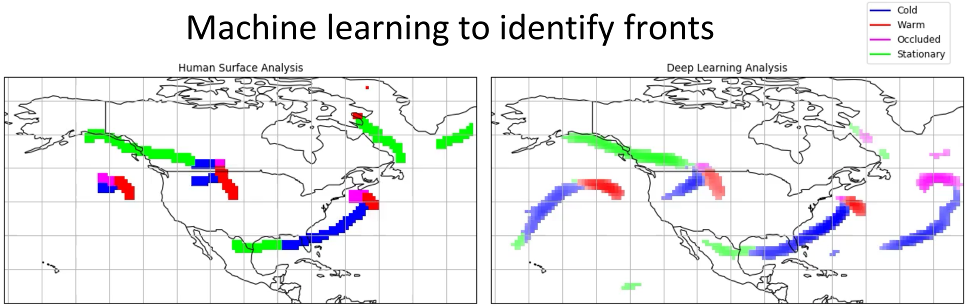
(Feng et al. 2018)

Tracking of monsoon depression



(Boos et al. 2015)

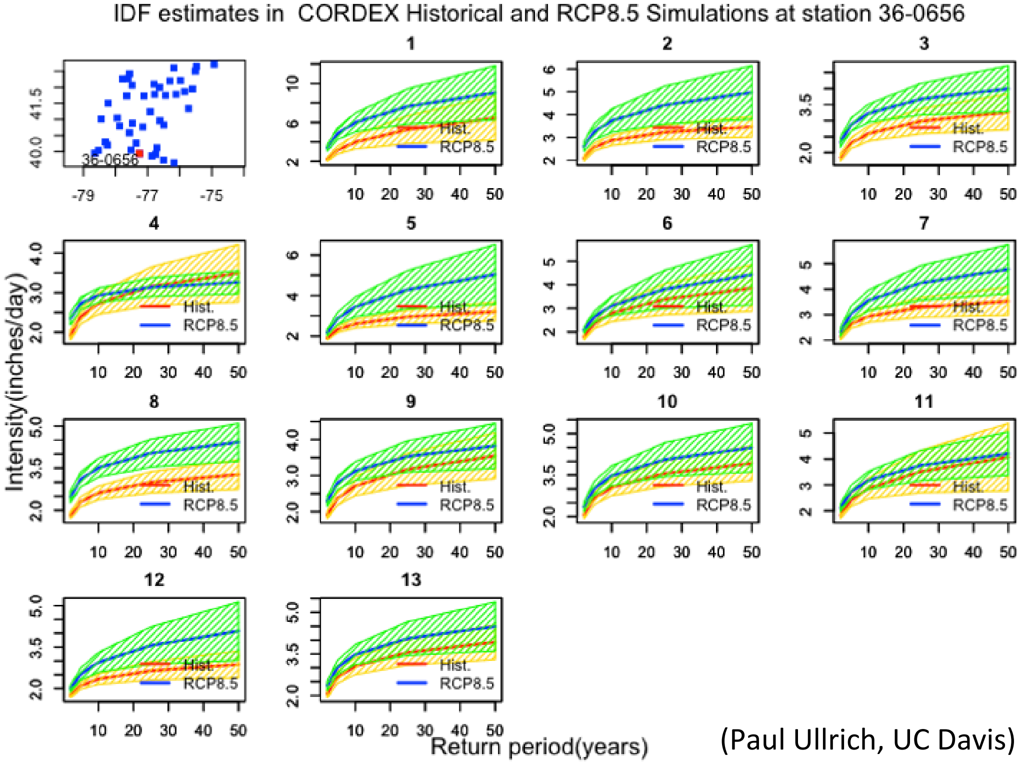
Machine learning to identify fronts



(Ken Kunkel, NCSU)

Exploratory metrics: examples

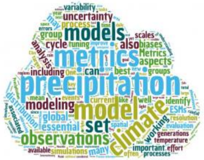
Use-inspired metrics:
Precipitation intensity-duration-frequency (IDF)



IDF used in hydrologic design

(Paul Ullrich, UC Davis)

Exploratory metrics: research needs

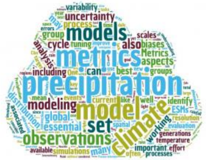


- Synthesizing analysis into succinct metrics.
- Relating precipitation characteristics with storm characteristics and large-scale environments.
- Improving physical interpretation of the metrics.
- Developing emergent constraints.
- Characterizing uncertainty of tracking methods for precipitation regimes.
- Characterizing uncertainty in observation data.

Next steps: Research community engagement

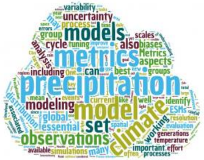
- National and international activities
  - Global Energy and Water Cycle Experiment (GEWEX) Data Assessment Panel, International Precipitation Working Group (IPWG)
  - Collaboration with World Climate Research Program (WCRP) – briefing for Working Group on Numerical Experimentation (WGNE) and GEWEX Global Atmosphere and System Studies (GASS)
  - Outreach at 2020 EGU meeting
  - DOE and NOAA follow-up workshop as part of US GEWEX (weather to multi-decadal timescales)
- ESM model evaluation capabilities
  - Implement baseline metrics in PCMDI Metrics Package (PMP)
  - Coordinate with other precipitation-related capabilities such as ARM Data-Oriented Metrics and Diagnostics Package; International Land Model Benchmarking (ILAMB); NOAA Model Diagnostic Task Force (MDTF); ASoP Package; Coordinated Model Evaluation Capabilities project (CMEC)

Next steps: Baseline metrics



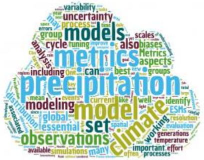
- Implement baseline metrics in a common analysis framework (PMP) and provide capability to modelers.
- Apply metrics to CMIP6 DECK and historical simulations and compare with previous generations (CMIP3 and CMIP5).
- Working with the WCRP to promote an initiative to stimulate the challenge and hopefully bring resources to modelers to address it.
- Revisit with next-generation models to see how well models have improved.

Next steps: Exploratory metrics



- A working group to collaborate on a manuscript: discuss the need for exploratory metrics, introduce an initial set of exploratory metrics, and apply them to CMIP6 model outputs to demonstrate their usefulness for different communities of users.
- Initial set of exploratory metrics:
  - Coherence in space and time
  - Frontal precipitation
  - Top 10 extreme events
  - Convection onset
  - Orographic enhancement
  - Monsoon
  - Mesoscale convective systems
  - Madden-Julian Oscillation

Summary of outcomes



Precipitation Workshop Activities

Needs and Gaps in Research Community

- Earth system models have struggled to simulate precipitation.
- In general, precipitation observations have large spread that varies temporally and spatially.
- Precipitation is highly relevant in light of climate impacts.
- Many precipitation metrics exist, but there is no prioritization or standardization.
- No standard package for applying these metrics to models in general.
- Metrics that facilitate understanding of precipitation processes, model biases, and their implications.

Identification/Categorization of Baseline and Exploratory Metrics

Baseline metrics:
- Spatial distribution of mean state
- Seasonal cycle
- Variability across timescales
- Intensity/frequency distributions
- Extremes
- Drought

Exploratory metrics:
- Process-oriented metrics
- Regime-oriented metrics
- Use-inspired metrics

Model Improvement and Process Understanding

- Evaluate models to establish a performance baseline.
- Models are intercompared to understand intermodal spread.
- Modeling groups identify errors or avenues for model improvement.
- Comparison of models against baseline allows groups to monitor progress.
- Explore metrics that facilitate process understanding, identify sources of model biases, and support stakeholder needs.
- Baseline metrics and intercomparison revisited periodically.

Addressing DOE BER Science Grand Challenges

1. Integrated Water Cycle: Precipitation metrics are essential for benchmarking model skill in representing the integrated water cycle and assessing credibility of model predictions of future changes.

2. Drivers and Responses in the Earth System: Precipitation connects all components of the coupled human-Earth system. Process- and regime-based precipitation metrics may be used to provide new insights connecting precipitation responses to the multiple drivers.

3. Data-Model Integration: A complete precipitation metrics framework allows for direct assessment of models against observation in light of uncertainty.