ETH zürich

Drought Persistence Error in Models and Observations

Heewon Moon, Lukas Gudmundsson, Sonia I. Seneviratne

GEWEX, 2018 May

Uncertainties in evaluating simulations of drought

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  - e.g. magnitude, severity, persistence
  - e.g. precipitation, soil moisture, runoff

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  - Internal (natural) climate variability

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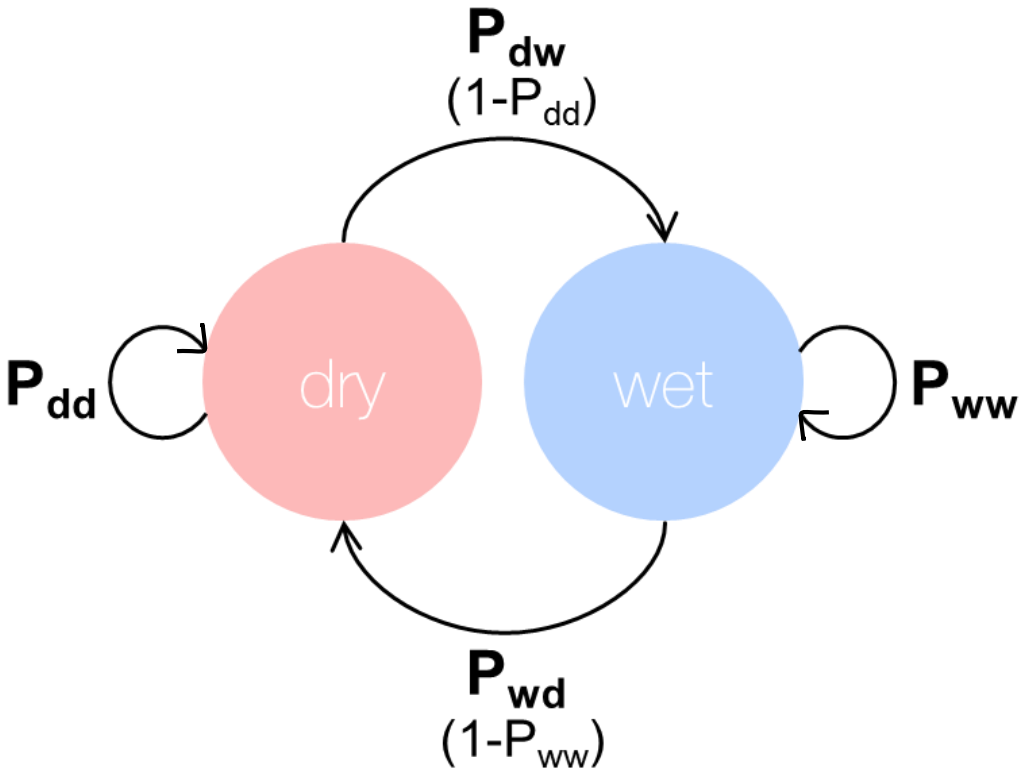
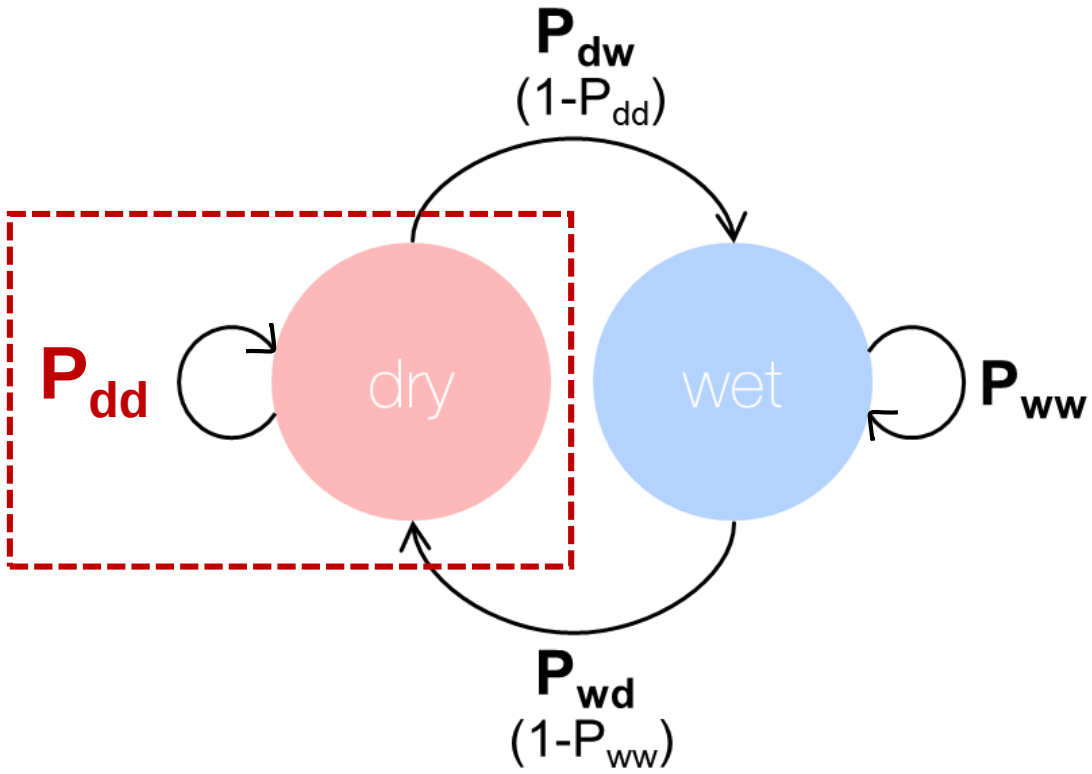
Dry-to-dry transition probability (P_{dd})

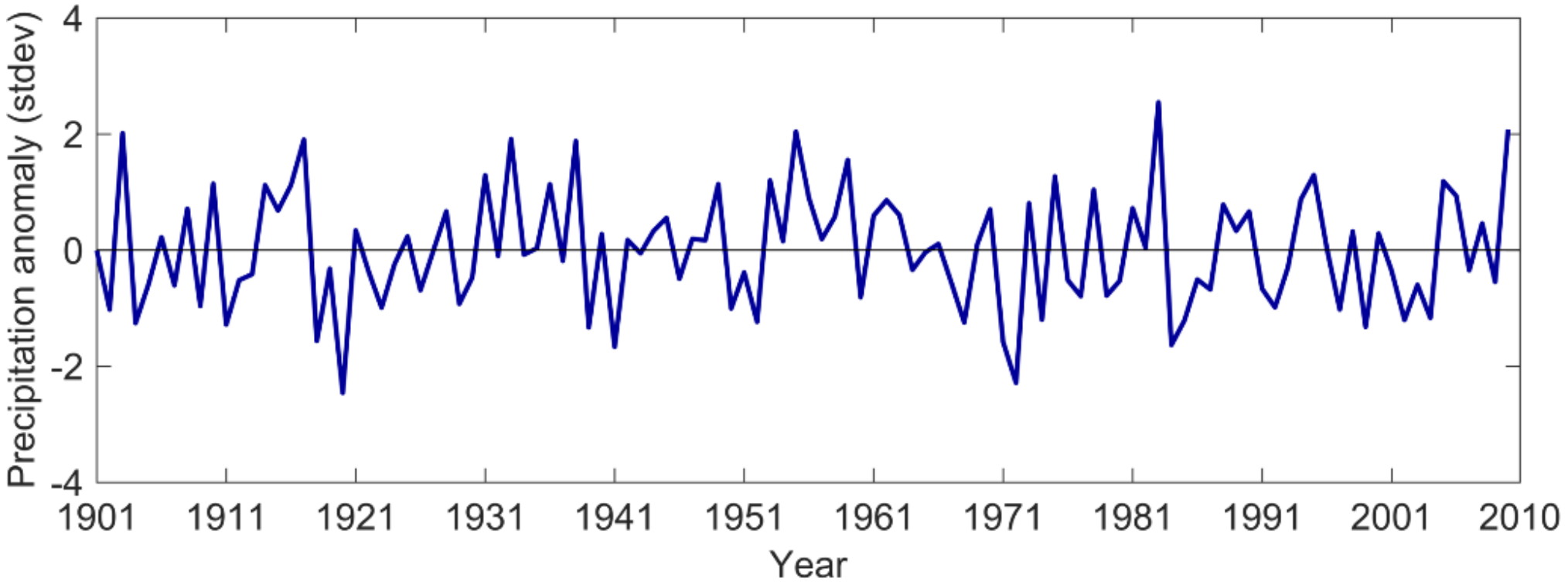


Dry-to-dry transition probability (P_{dd})

Drought persistence



Estimating P_{dd} from precipitation anomaly



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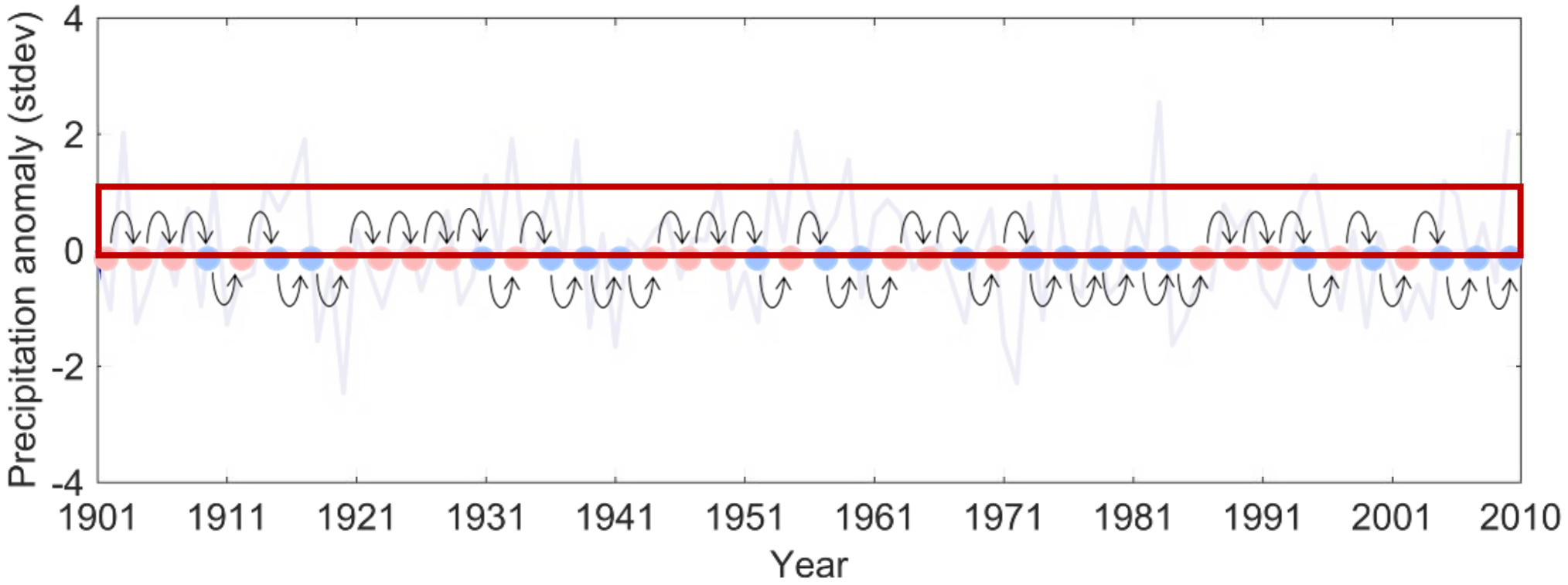
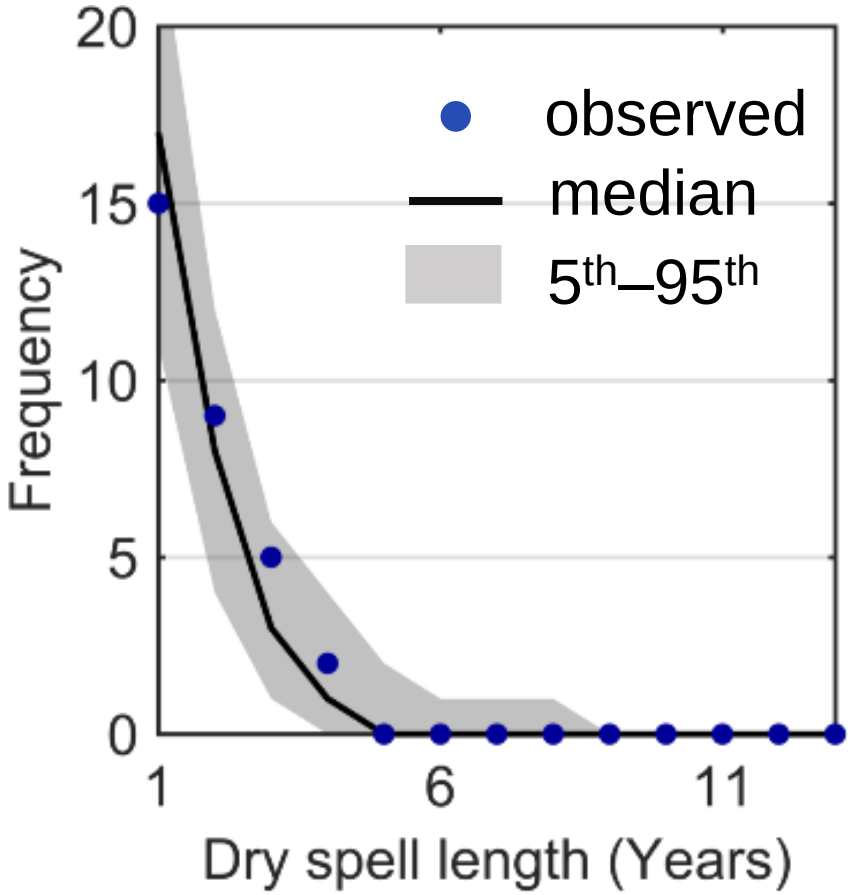
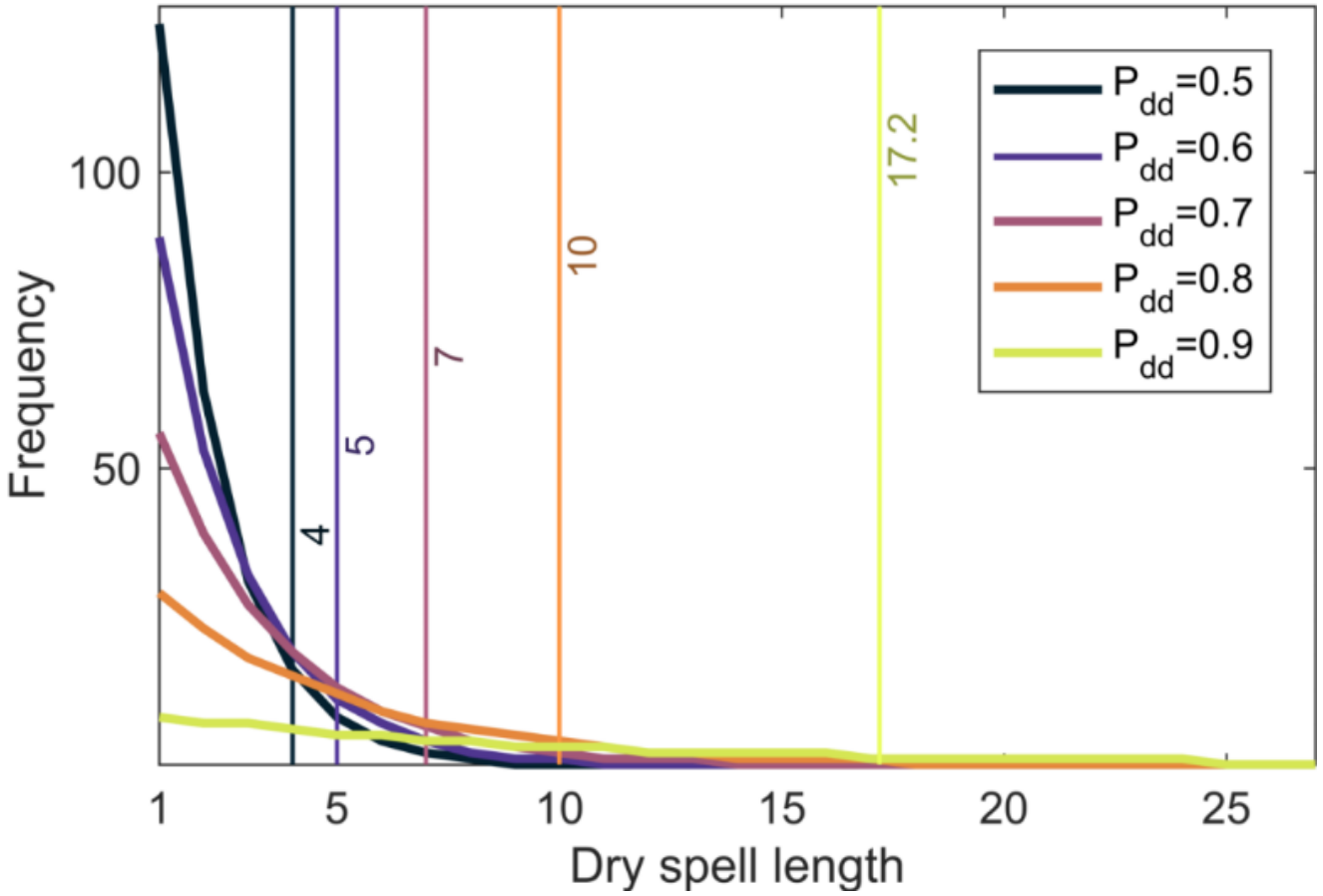


Transition probabilities for simulating dry spell length distribution



- Series of dry or wet status simulated using a set of transition probabilities
- Observed and simulated dry spell length distribution agrees well

90th percentile dry spell lengths with varying P_{dd}



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Datasets

Observation-based references

- GPCC, UDEL, CRU, 20cr, ERA-20c

Climate models

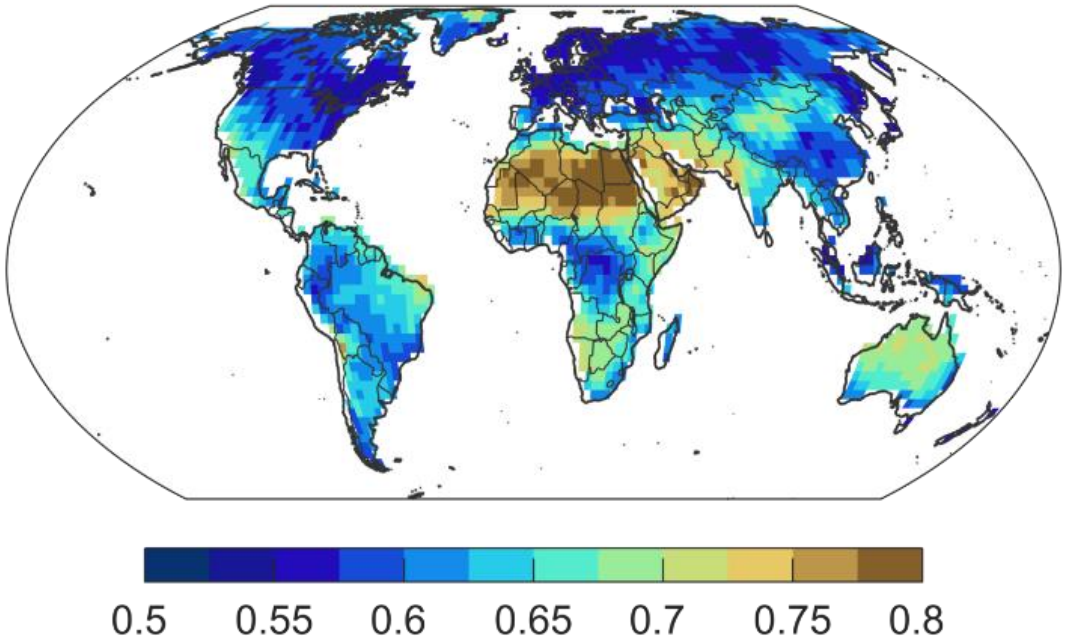
- **13 GCMs with 3-10 ensemble runs** in CMIP5 (**62** runs in total)

2.5˚ X 2.5˚ resolution

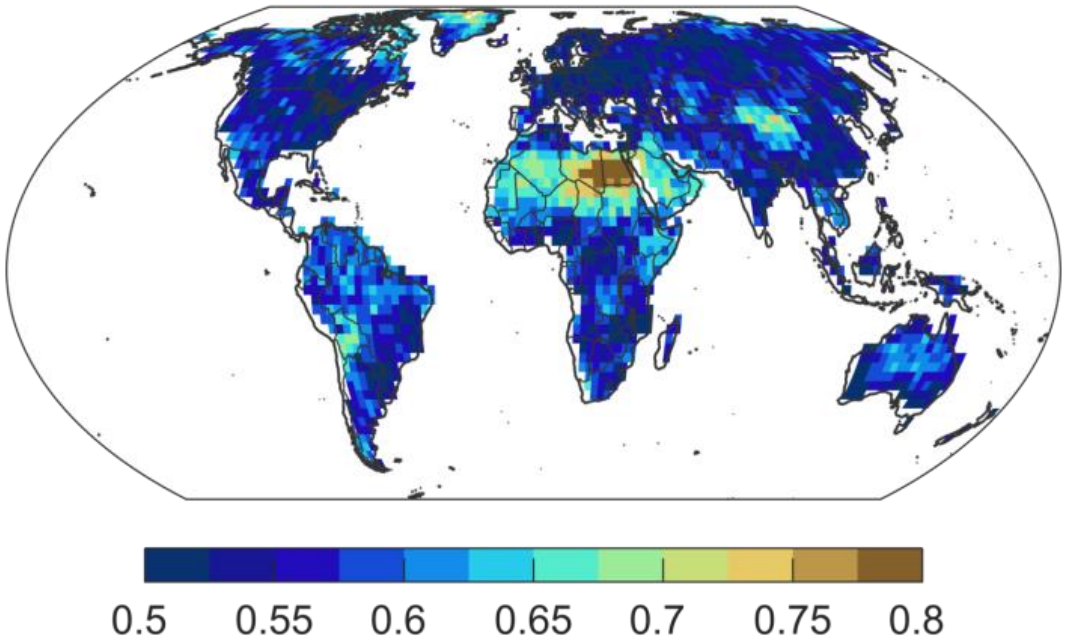
1901 - 2010

Observed mean drought persistence (P_{dd})

month-to-month

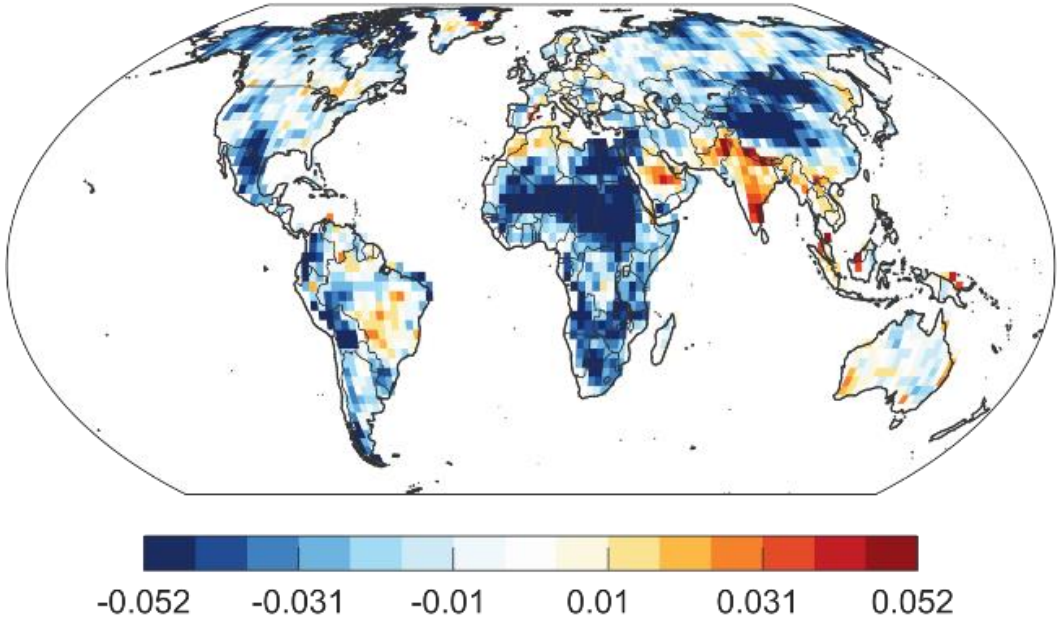


year-to-year



Multi-simulation mean drought persistence error

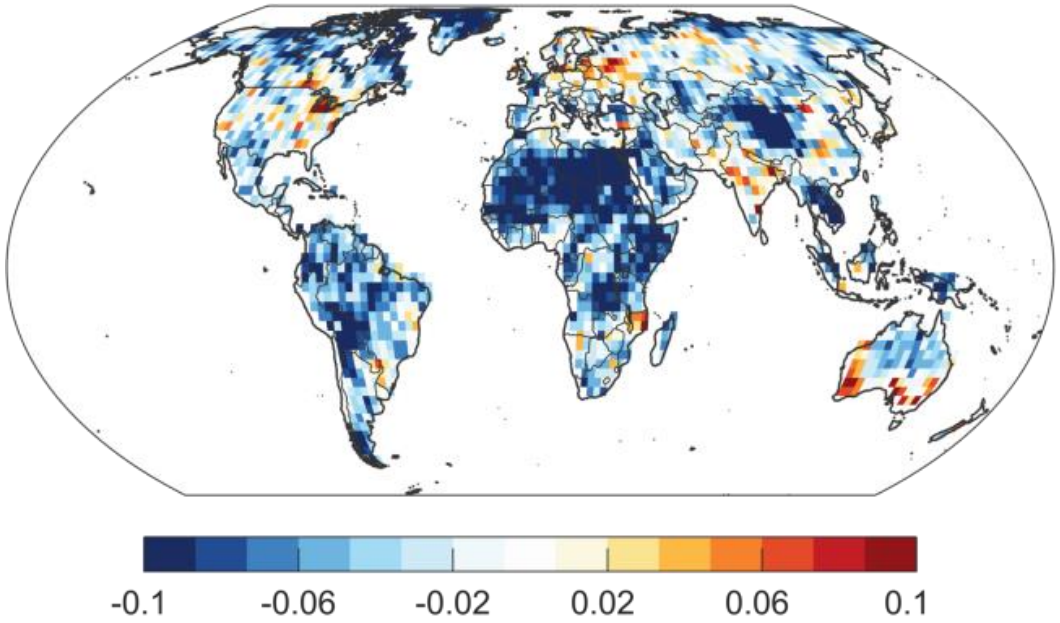
month-to-month



underestimation (shorter drought)

overestimation (longer droughts)

year-to-year

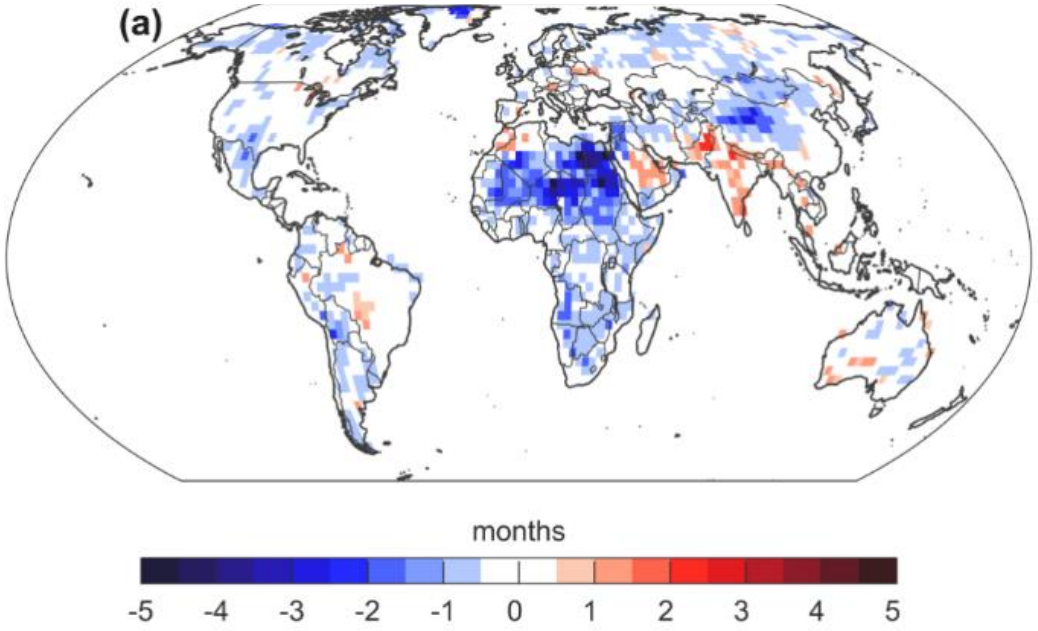


underestimation (shorter droughts)

overestimation (longer droughts)

Multi-simulation mean drought length error (converted from P_{dd})

monthly



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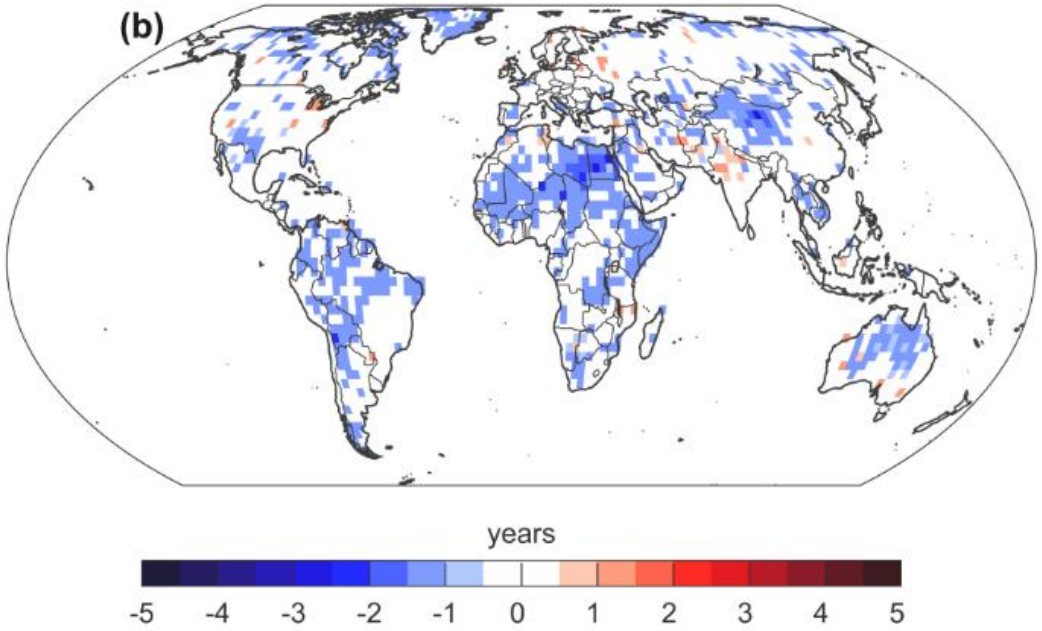
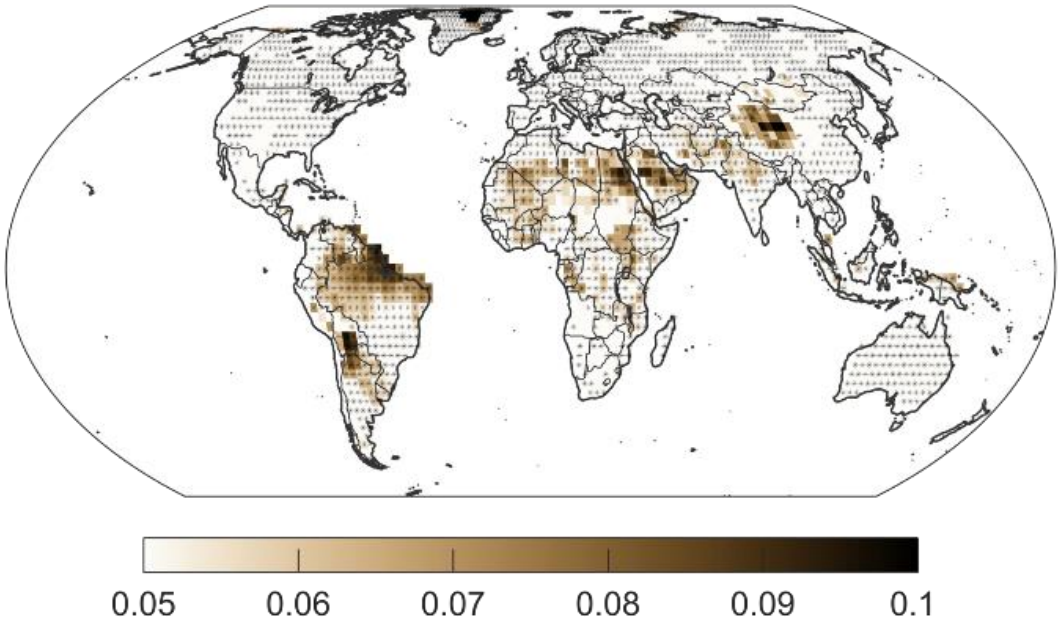


underestimation (shorter drought)

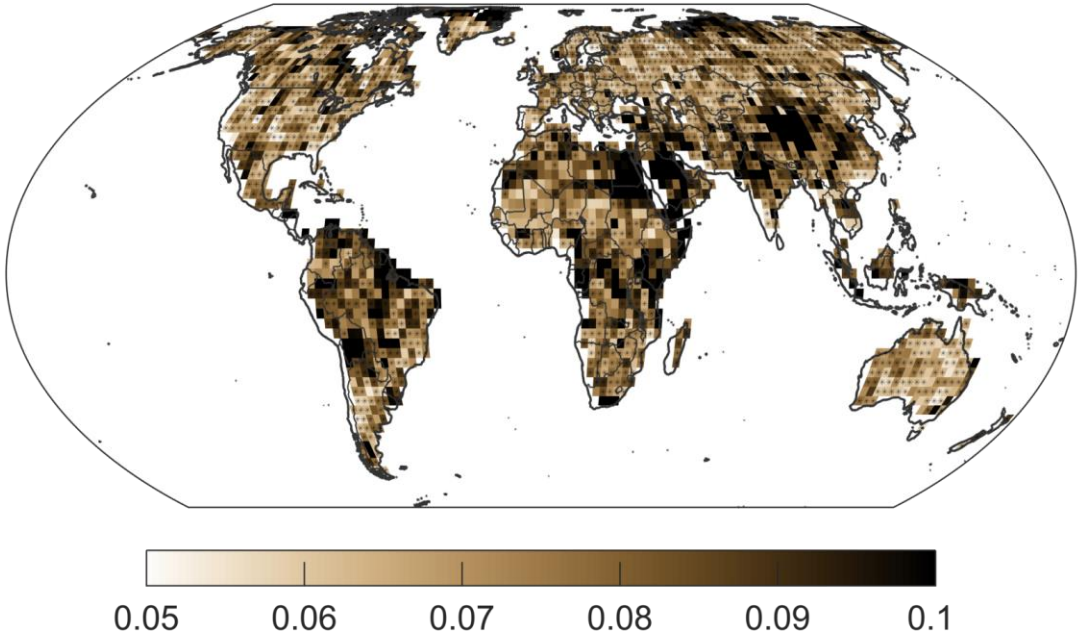
overestimation (longer droughts)

Standard deviation of drought persistence error

month-to-month

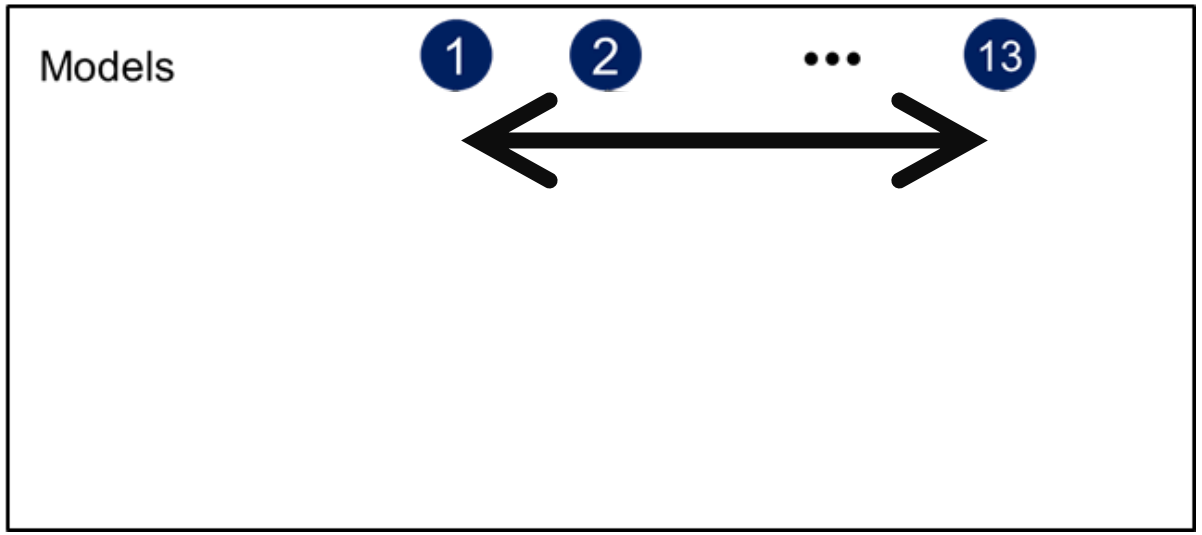


year-to-year



Structure of the uncertainty in model error

$$P_{dd}\ error = P_{dd\ model} - P_{dd\ observation}$$



model uncertainty

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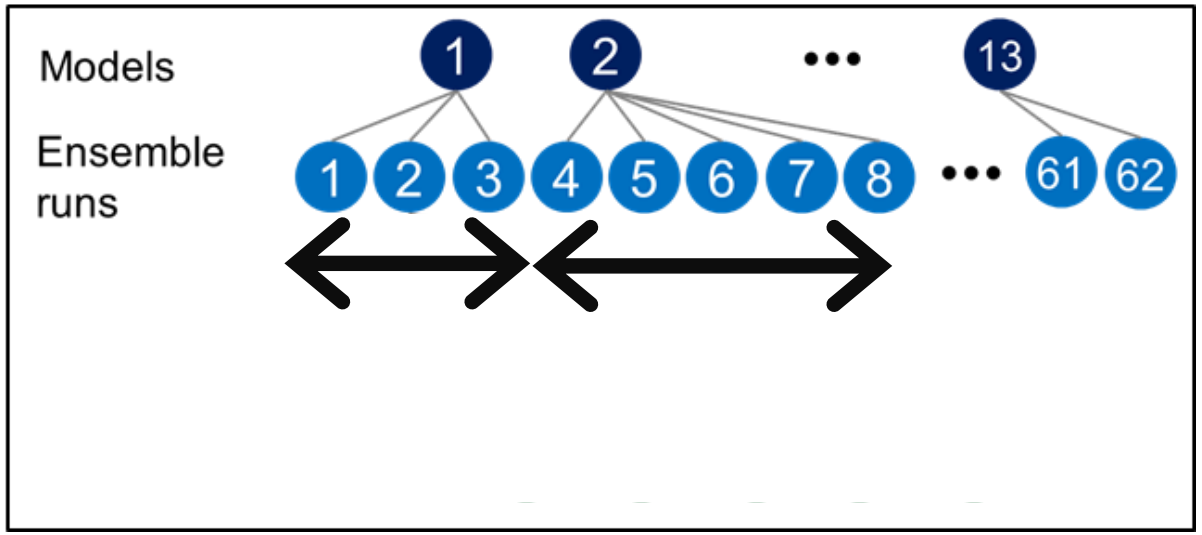

internal variability

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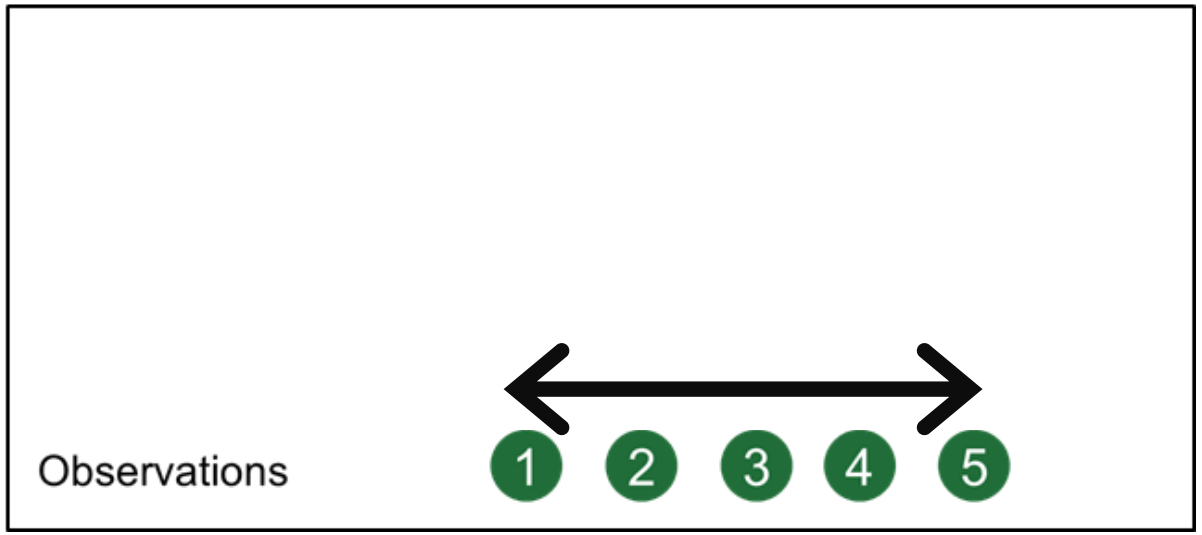

observation uncertainty

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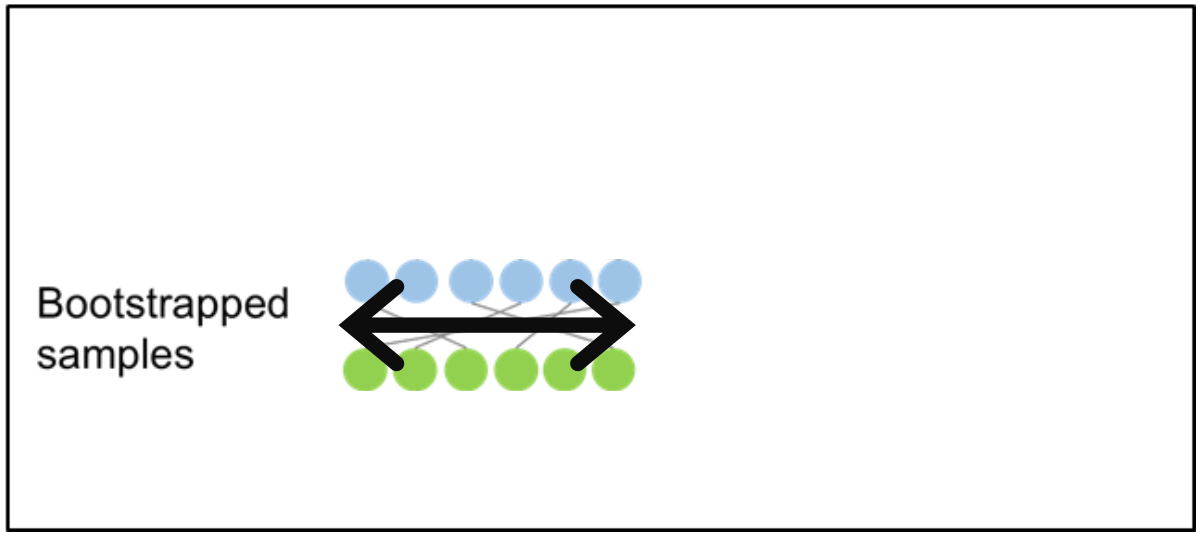

estimation error

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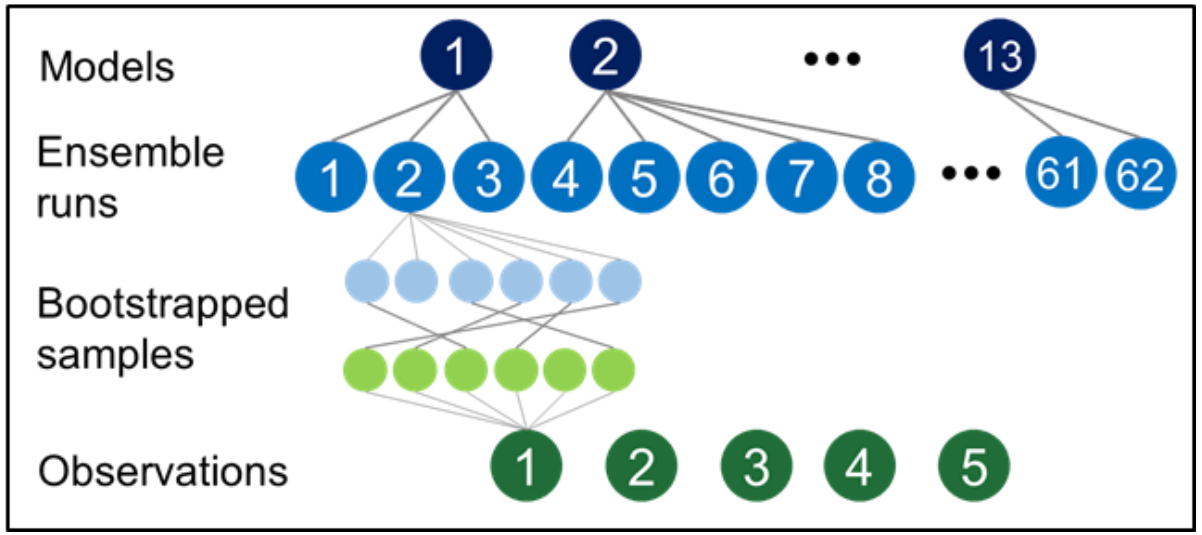


model uncertainty

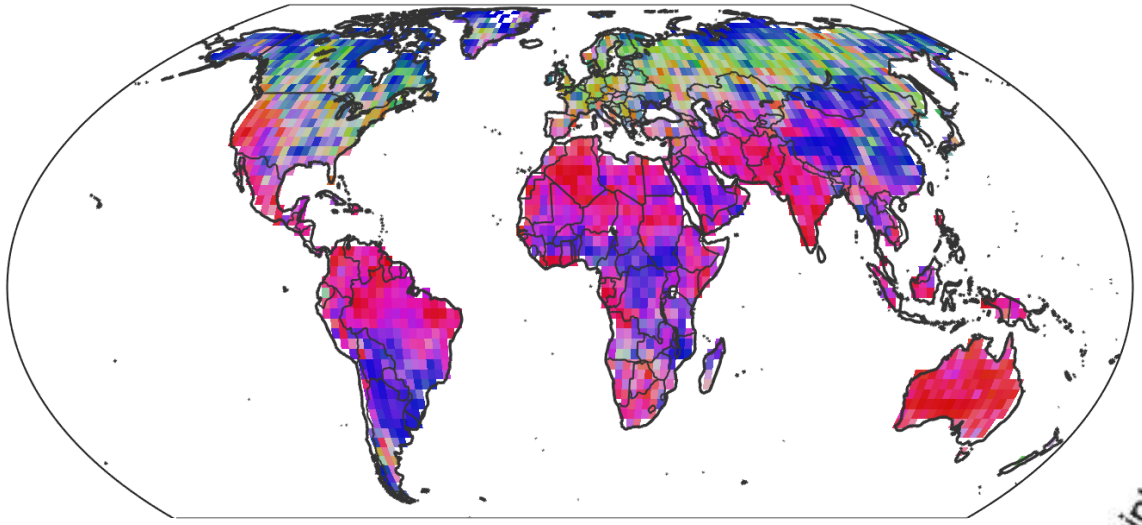
internal variability

estimation error

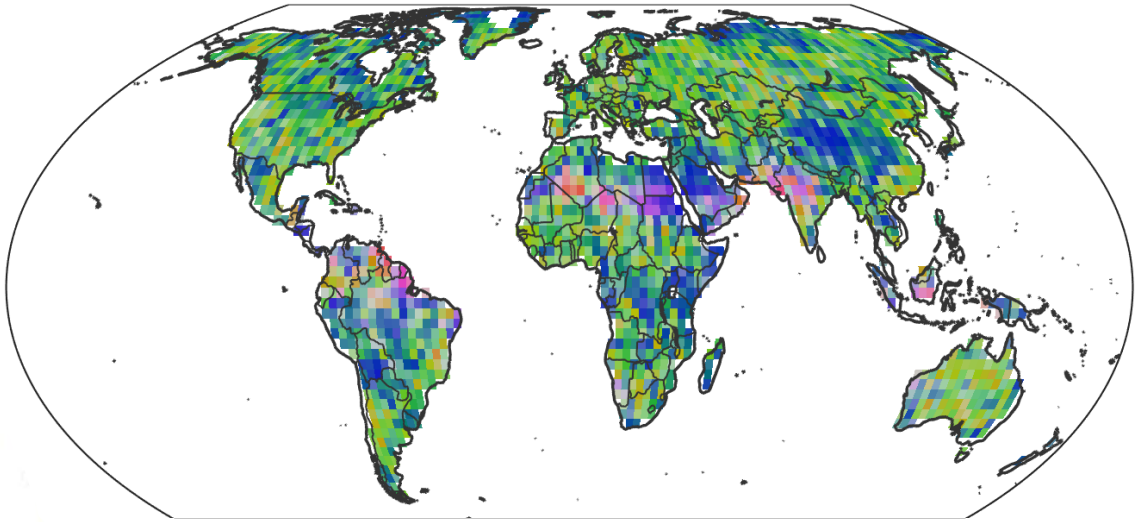
observation uncertainty

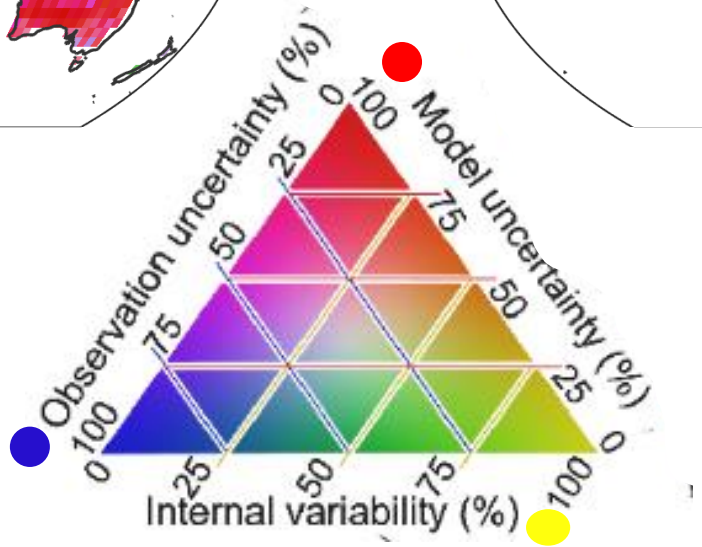
Partitioned uncertainty in drought persistence error

month-to-month



year-to-year





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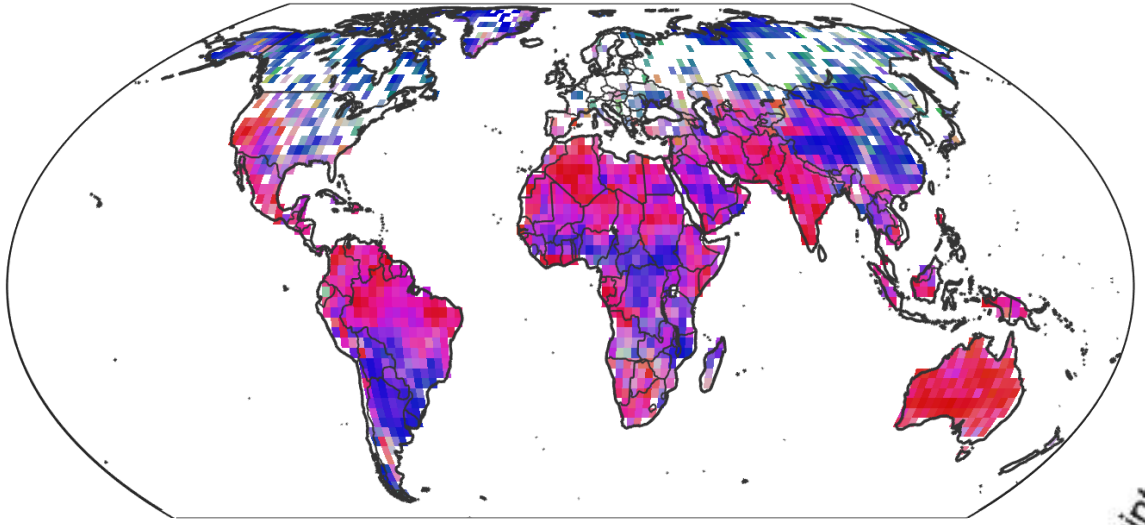

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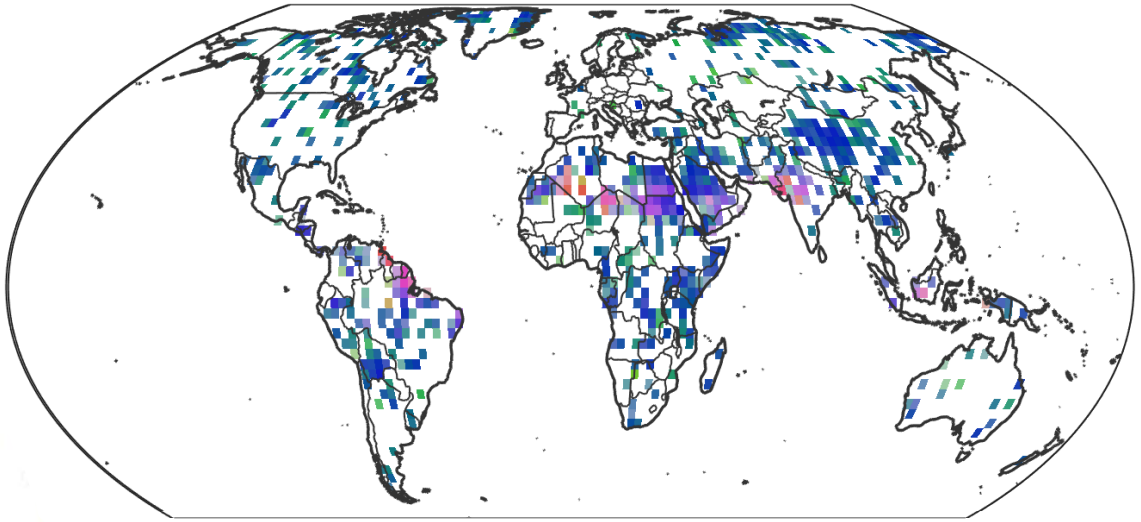
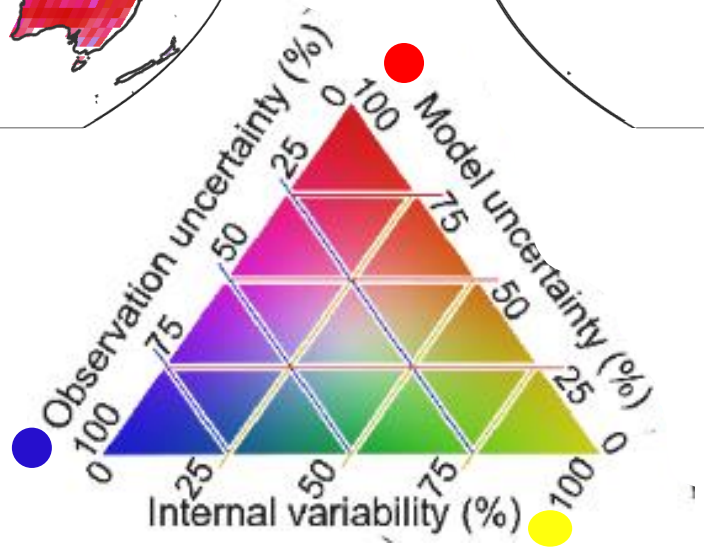
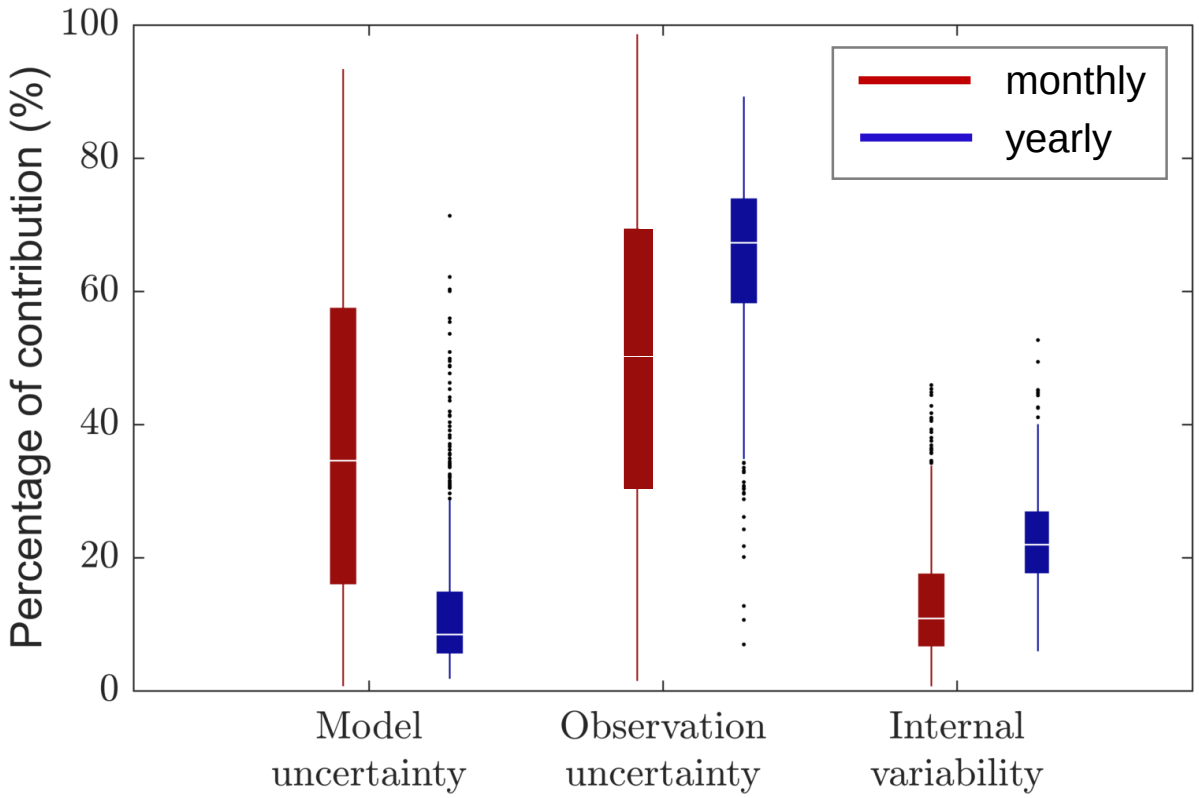




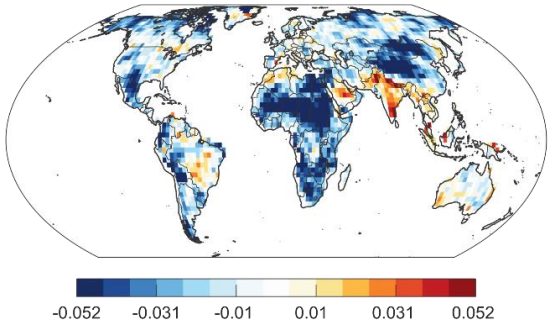
Global summary of contribution from each source

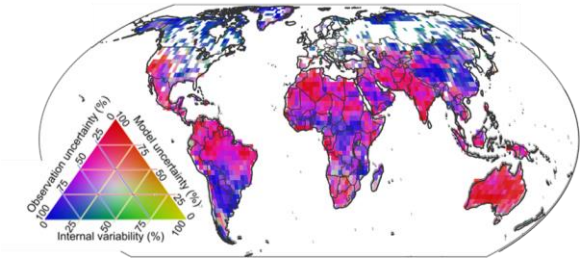


- Only the valid grid cells are considered
- In monthly scale, observation and model uncertainty range outside the internal variability
- In yearly scale, observation uncertainty is the single most substantial source

Key Results

- **Consistent underestimation** of drought persistence (P_{dd}) in current GCMs.
- **Observation and model uncertainty dominate** spread in monthly drought persistence error
- Statistical error prevents in-depth analysis on yearly drought persistence





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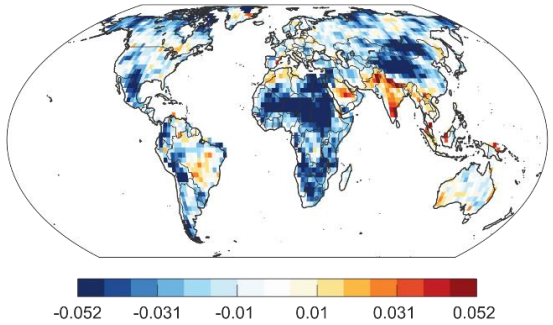

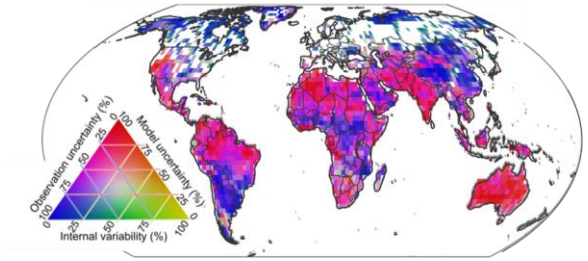

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- Uncertainty partitioning applicable to other validation measures

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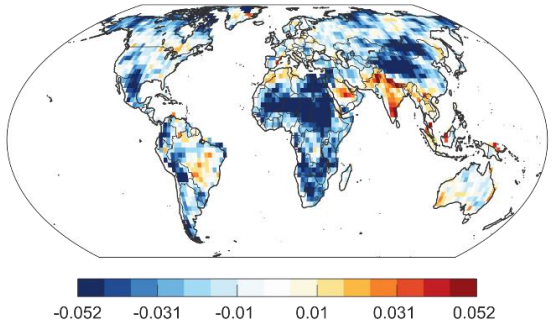

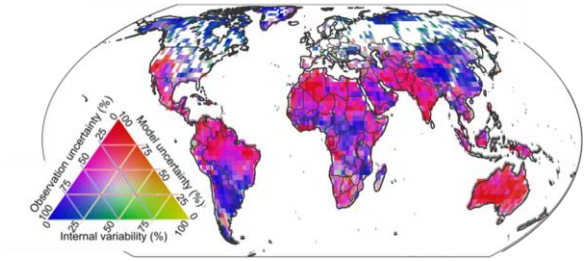

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Thank you!

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more details in **Moon et al., 2018, JGR-Atmospheres**

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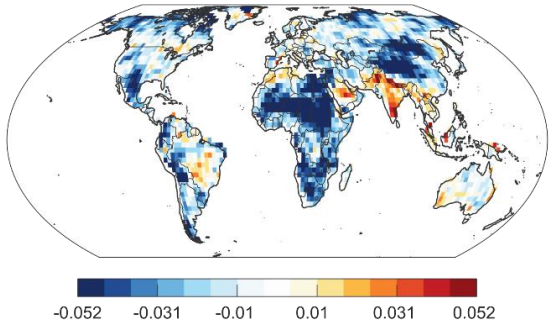

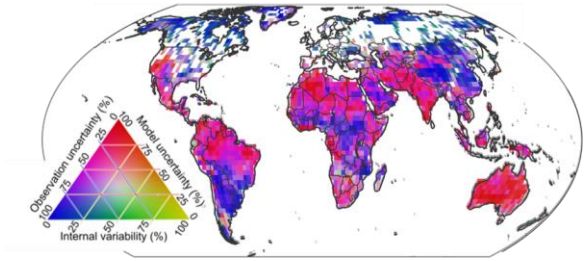

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Supplementary

ANOVA approach for partitioning variability of error, E_{or_mb}, *where, m = 1,…,number of models (M); o = 1,…, number of observations (O);* r_m *= 1,…,number of ensemble members in model m (*R_m*), b= 1,…,number of bootstrapped samples(B)*

$$\text{Total SS} = \sum\sum\sum\sum\left(E_{or_mb} - \bar{\bar{E}}\right)^2 = SS_{\,between\ models} + SS_{\,between\ observations} + SS_{\,between\ ensembles} + SS_{\,between\ bootstrapped\ samples}$$

$\bar{\bar{E}}$: $total\ mean\ of\ error$ $\overline{E_m}$: $mean\ error\ of\ model\ m$ $\overline{E_o}$: $mean\ error\ of\ observation\ o$

$\overline{E_{mo}}$: $mean\ error\ of\ model\ m\ and\ observation\ o$ $\overline{E_{r_m}}$: $mean\ error\ of\ ensemble\ rm$

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$$SS_{\,between\ models} = \sum_{m=1}^{M} BR_m O(\overline{E_m} - \bar{E})^2$$

$$SS_{\,between\ observations} = \sum_{o=1}^{O} (R_1 + \cdots + R_M) B(\overline{E_o} - \bar{E})^2$$

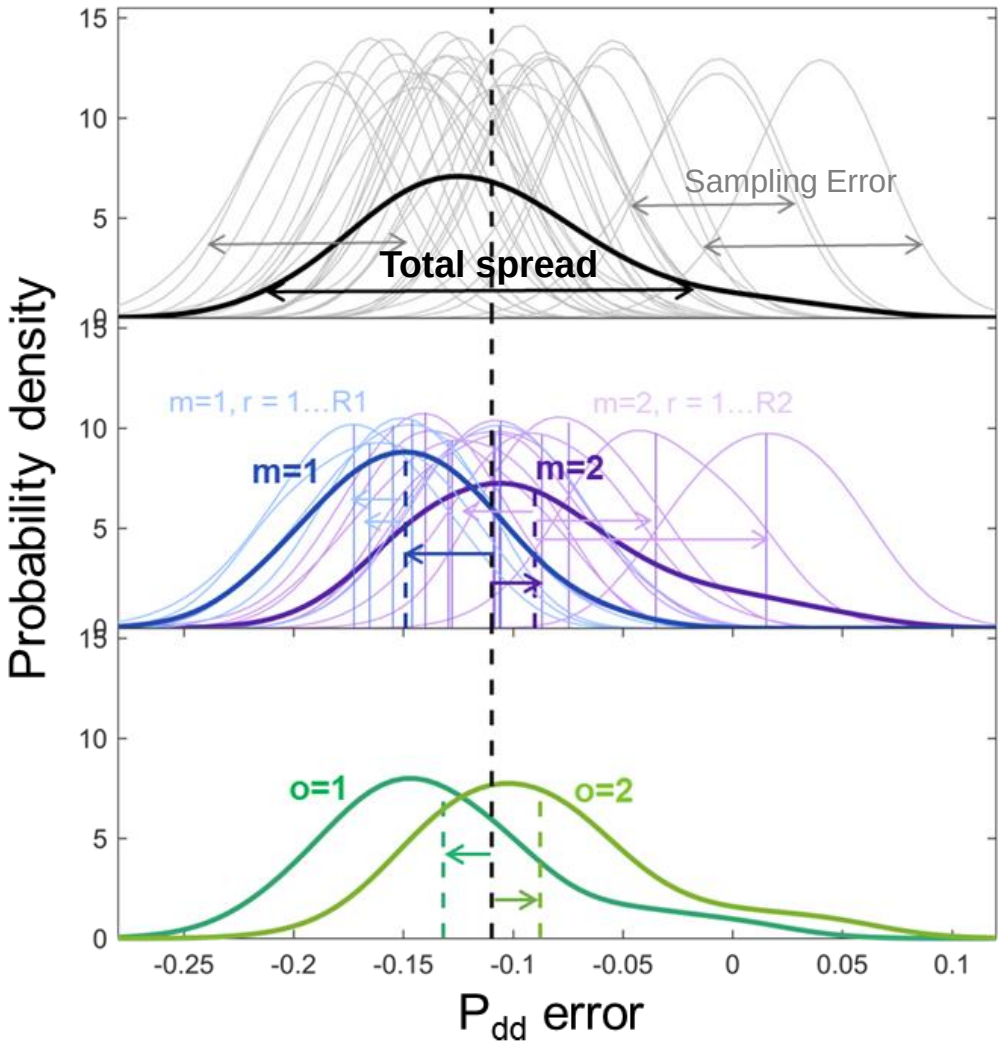
$$SS_{\,between\ ensembles} = \sum_{m=1}^{M}\sum_{r_m=1}^{R_m} BO\left(\overline{E_{r_m}} - \overline{E_m}\right)^2$$

$$SS_{\,between\ bootstrapped\ samples} = \sum_{m=1}^{M}\sum_{r_m=1}^{R_m}\sum_{b=1}^{B}\sum_{o=1}^{O}\left(E_{r_mbo} - \overline{E_{r_mo}}\right)^2$$

$\bar{E}$: *total mean of error* $\overline{E_m}$: *mean error of model m* $\overline{E_o}$: *mean error of observation o*

$\overline{E_{mo}}$: *mean error of model m and observation o* $\overline{E_{r_m}}$: *mean error of ensemble rm*

Example of partitioning with
2 models and 2 observations



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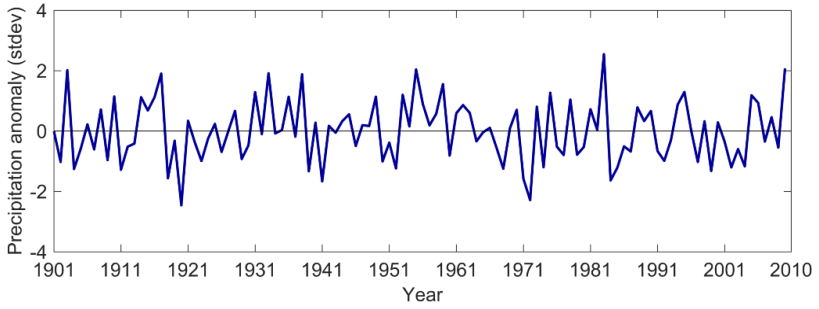
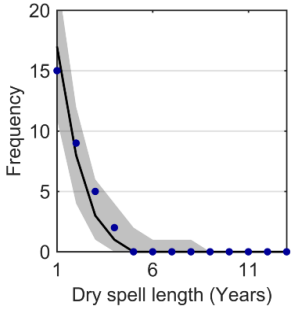
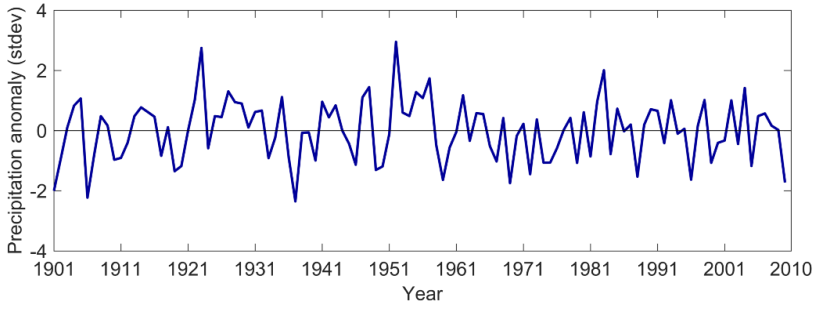
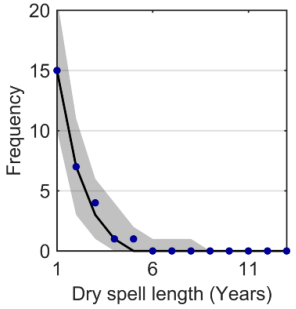
India



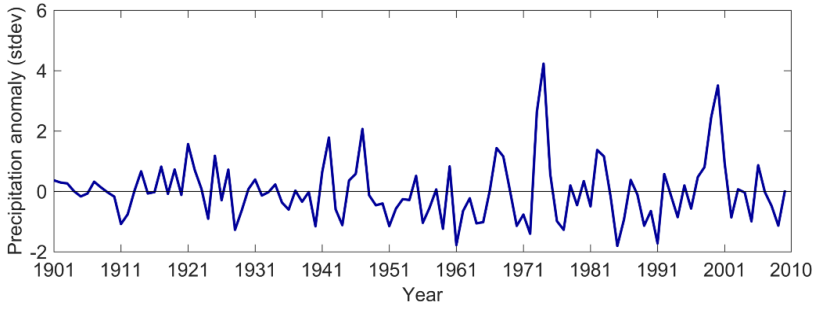


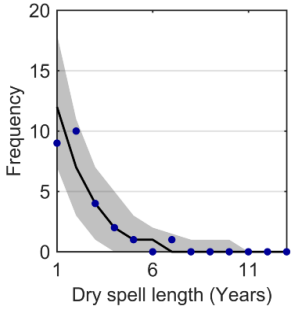
Northern Europe





Central North America





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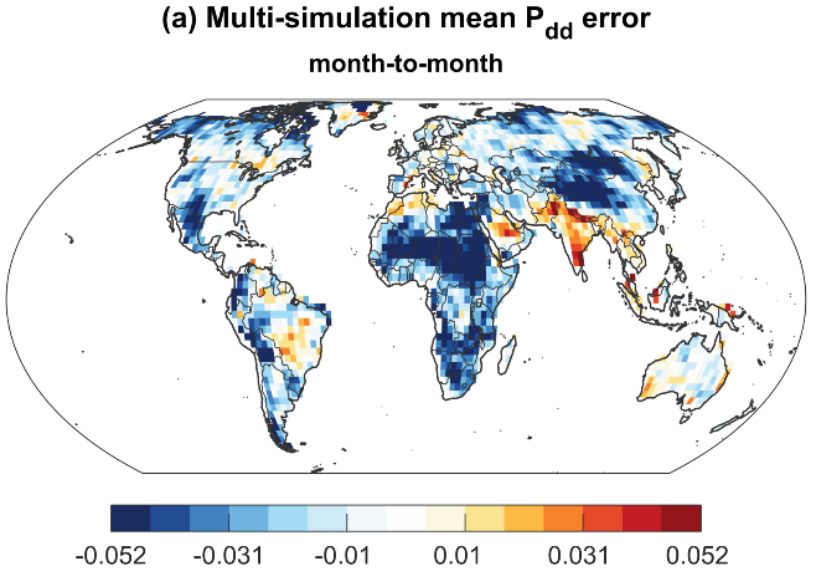
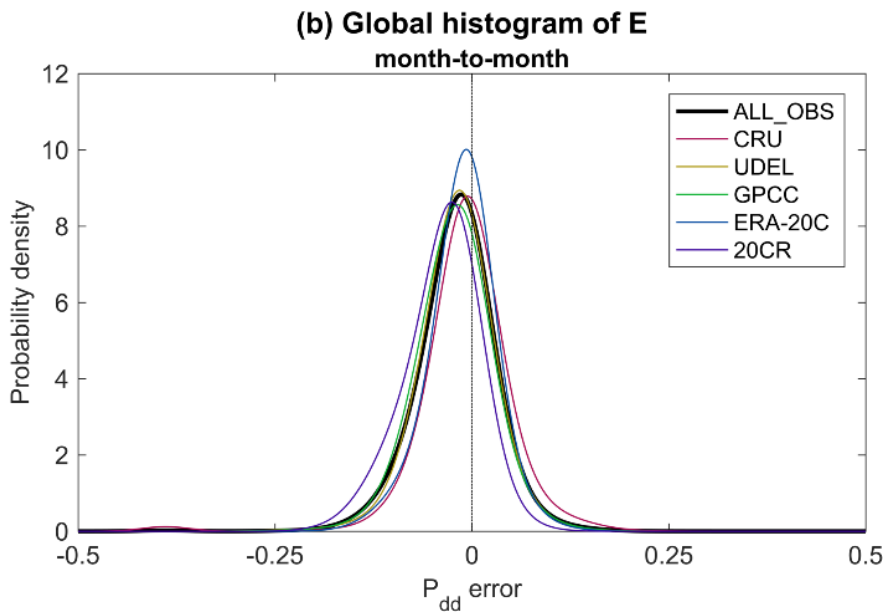
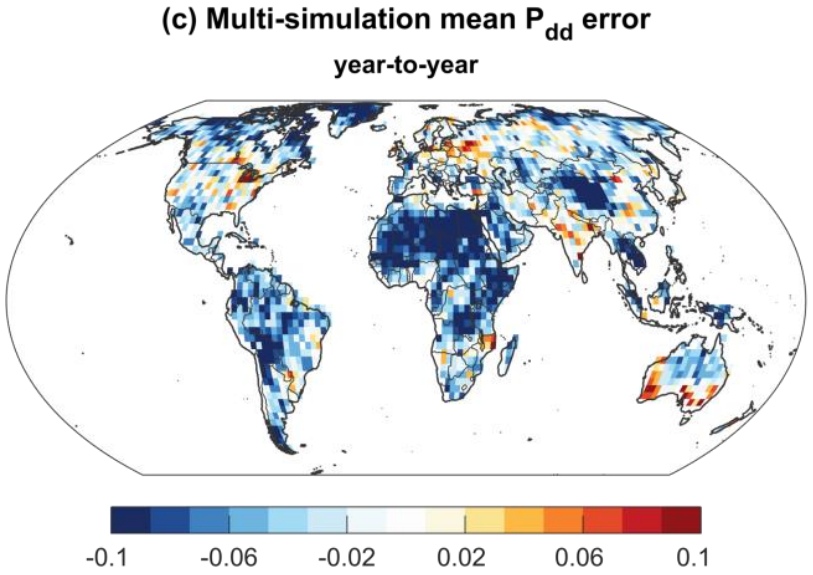
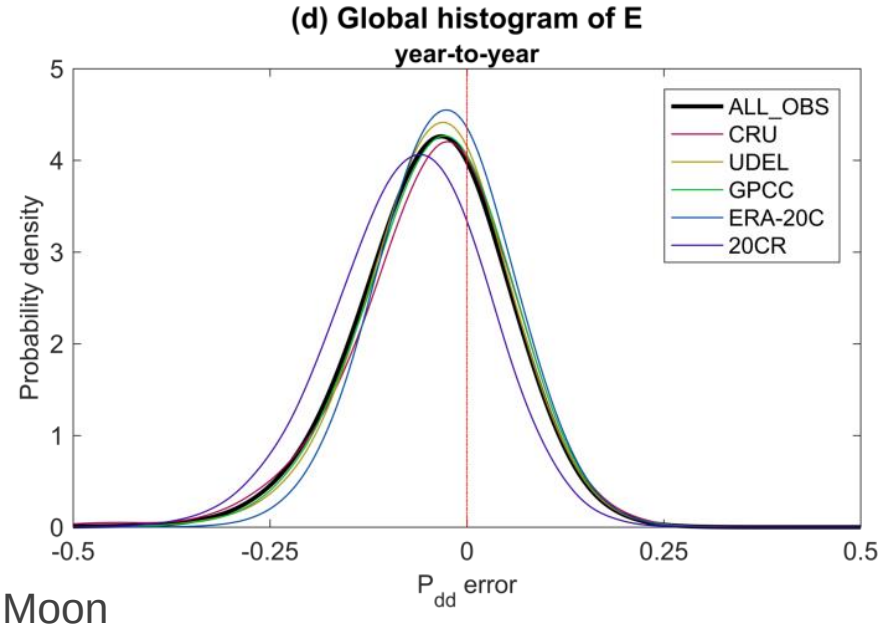

(a) Multi-simulation mean P_{dd} error
month-to-month
-0.052
-0.031
-0.01
0.01
0.031
0.052


(b) Global histogram of E
month-to-month
Probability density
P_{dd} error
ALL_OBS
CRU
UDEL
GPCC
ERA-20C
20CR


(c) Multi-simulation mean P_{dd} error
year-to-year
-0.1
-0.06
-0.02
0.02
0.06
0.1


(d) Global histogram of E
year-to-year
Probability density
P_{dd} error
ALL_OBS
CRU
UDEL
GPCC
ERA-20C
20CR

H.Moon

- ✓ Mechanisms lead to several years of persisted drought conditions are not well established
- ✓ Evidence of underestimating extremely prolonged droughts, in current climate models (Ault et al., 2014 ; Cook et al., 2010)
- ✓ Long term persistence of precipitation generally underestimated (Kumar et al., 2013)

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- ✓ Do climate models well simulate moderate drought persistence?
- ✓ How are the uncertainties in P_{dd} error quantified?

- ✓ What are the processes that lead drought persistence in different region?
  - How are they related to model error?

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- ✓ How is drought persistence related to persistence in other variables?

  e.g. with number of consecutive hot days or heatwave index

Global summary of contribution from each source