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Evaluation of multi-year droughts in global SMILEs

EGU25-17357

1 Introduction: Multi-year droughts (MYD)

In recent years, consecutive drought years have affected large areas of the world, such as Europe in 2018-2020 and Northern America in 2020-2023. Drought conditions pose considerable risk to agriculture, forestry, ecosystems or water and energy supply. Multi-year droughts bear the potential to aggravate such impacts due to water deficit build-up over a longer period without sufficient recovery during wet seasons. Adaptation strategies usually work for limited time and rely on recovery periods (e.g., regarding storage lakes). Multi-year droughts thus strongly challenge current drought preparedness and adaptation measures.

With changing climate, droughts are projected to increase worldwide in duration and frequency. Due to legacy effects of depleted soils and self-intensification processes, the risk for full years of water deficits rises further. For well-informed adjustment of adaptation to multi-year droughts, a comprehensive assessment of their risks under current and future climate conditions is required. Therefore, it is crucial to assess the skill of climate models in simulating multi-year droughts globally. This contribution presents preliminary results regarding the representation of multi-year droughts in 3 SMILEs compared with ERA5Land reanalysis during the period 1991-2020.

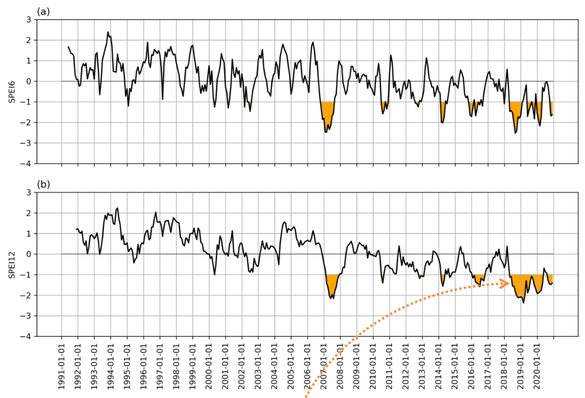


Fig. 1 | SPEI6 and SPEI12 in Western-Central Europe (WCE) during 1991-2020. Orange shading indicates periods with SPEI < -1 (drought). Data set: ERA5Land (Muñoz Sabater 2019).

Multi-year drought
- Drought indicator below threshold *t* during period *p* (cf. Van der Wiel et al. 2023)
- Accounting for temperature *and* precipitation trends: standardized evapotranspiration index (SPEI) which is based on the climatological water balance (PET – PR, Vicente Serrano et al. 2009)
- Accounting for long-term accumulation of water deficits vs. seasonality: SPEI12 vs. SPEI6

2 Data & Methodology

Data
- ERA5Land reanalysis (Muñoz Sabater 2019)
- 3 CMIP6 single-model initial-condition large ensembles (SMILEs) to account for internal climate variability and to increase the sample size (⇨ rare events)
- forcing: historical + SSP2-4.5
- period: 1991-2020

Model	Members	Reference
MIROC6	50	Shiogama et al. 2023
CanESM5	50	Swart et al. 2019
ACCESS-ESM1.5	30 (of 40)	Ziehn et al. 2020

Drought indicator
- SPEI6, 12 (log-logistic distribution, MLE) computed per region
- Thornthwaite approach for PET
- Calibration per member and model

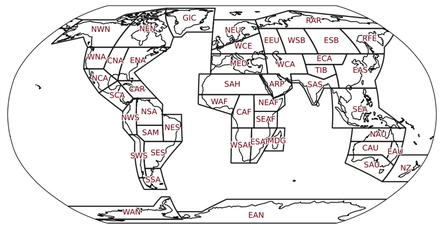


Fig. 2 | Overview of considered regions, following Iturbide et al. 2020.

3 Representation of drought frequency in global SMILEs

drought, if SPEI < -1

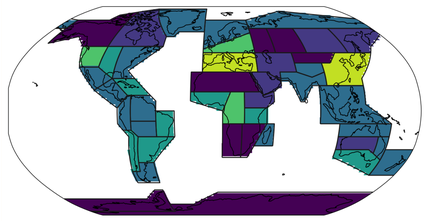


Fig. 3 | Droughts per year in ERA5Land during 1991-2020, based on SPEI6.

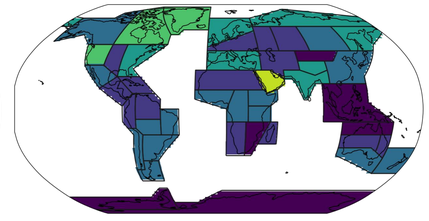


Fig. 5 | Same as Fig. 3, but for SPEI12.

SPEI6

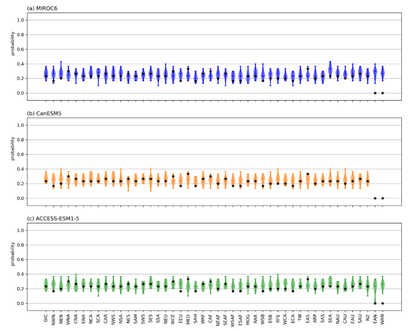


Fig. 4 | Droughts per year in 3 SMILEs during 1991-2020, based on SPEI6. Black stars represent the ERA5Land value per region. Violinplots represent member spreads.

SPEI12

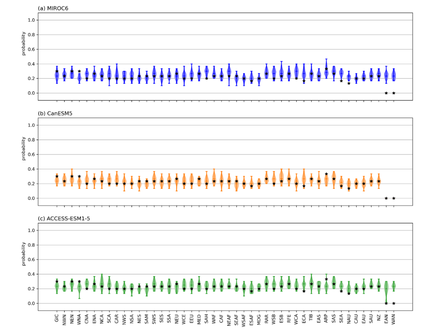


Fig. 6 | Same as Fig. 4, but for SPEI12.

4 How often are drought years followed by another drought year?

Conditional probability of having a drought, given the previous year already experienced drought conditions
- Drought occurrence of one year: min. 4 months with SPEI6 or SPEI12 < -1

⇨Indication of temporal drought clustering

SPEI6

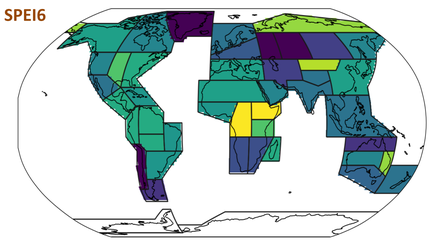


Fig. 7 | Conditional probability in ERA5Land during 1991-2020, based on SPEI6.

SPEI12

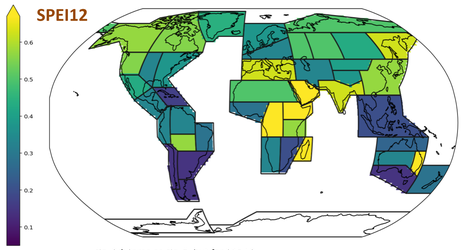


Fig. 9 | Same as Fig. 7, but for SPEI12.

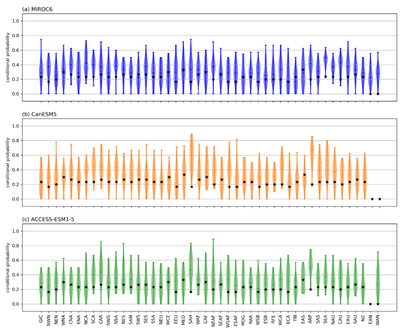


Fig. 8 | Conditional probability in 3 SMILEs during 1991-2020, based on SPEI6. Black stars represent the ERA5Land value per region. Violinplots represent member spreads.

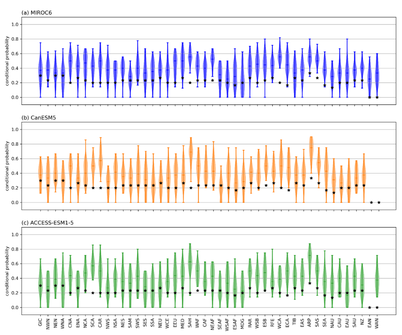
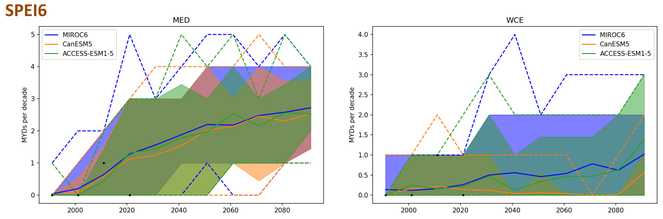


Fig. 10 | Same as Fig. 8, but for SPEI12.

5 Preliminary findings & Outlook

Findings
- Observed drought frequency in reference period very similar across regions and comparable between SMILEs and ERA5Land (⇨ definition criteria per member)
- MYD: rare in observations (≤ 1/decade), more prevalent in SMILEs
- SMILEs vs. ERA5Land:
  - Good representation of drought frequency and temporal drought clustering for SPEI6 in SMILEs
  - Good representation of drought frequency, but overestimation of temporal clustering for SPEI12 in SMILEs
- SPEI6 vs. SPEI12: MYD in SPEI6 with 'interruptions' due to seasonality, as opposed to SPEI12 which detects continuous, long-term water deficits
- Regions:
  - Dry regions with particularly strong (overestimation of) temporal drought clustering in SMILEs (e.g., SCA, SAH, WAF, ARP, ESB)
  - Higher temporal clustering for SPEI12 than for SPEI6 in ERA5Land
  - Larger variance of temporal drought clustering for SPEI12 than for SPEI6 between regions

SPEI6



SPEI12

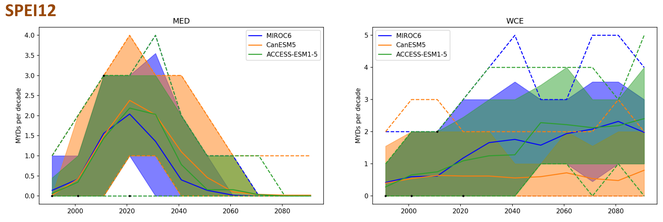


Fig. 11 | MYD frequency per decade for 3 SMILEs and ERA5Land (black dots). Thick lines: ensemble mean frequency per SMILE; shading: 5th-95th percentile per SMILE; dashed lines: min-max range per SMILE. For region abbreviations refer to Fig. 2.

Outlook
- **Region check**: Which regions are well (or poorly) represented?
- **Model check**: Which SMILEs perform well or poorly in the regions?
- **Indicator check**: Which components of the water balance drive the performance? (PR, PET/ T)
- **Trends**: How often do MYD occur under different global warming levels and how do models differ? *Hypothesis, based on Fig. 11*: trends of SPEI resulting in more consecutive years below thresholds
  ⇨ higher temporal clustering
  ⇨ less, but longer MYD

6 Open question

Trends in SPEI due to global warming
- Water balance becomes more often negative, outside values during calibration period
- SPEI values unrealistically low/no data ⇨ affecting drought frequency & duration
- But: calibration during full period ⇨ no droughts under current conditions

Any ideas?

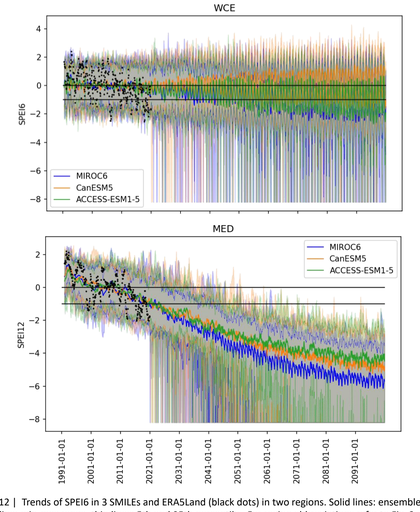


Fig. 12 | Trends of SPEI6 in 3 SMILEs and ERA5Land (black dots) in two regions. Solid lines: ensemble mean, shading: min-max range, thin lines: 5th and 95th percentile. For region abbreviations refer to Fig. 2. Horizontal lines indicate 0 (separating wet and dry conditions) and -1 (drought condition).

Co-funded by the European Union

References: Iturbide et al. (2020): An update of IPCC climate reference regions for subcontinental analysis of climate model data: definition and aggregated datasets. https://doi.org/10.5194/essd-12-2959-2020 | Muñoz Sabater, J. (2019). Era5-land hourly data from 1950 to present [Dataset]. Copernicus Climate Change Service (C3S) https://doi.org/10.24381/cds.e2161bac | Shiogama et al. (2023): MIROC6 Large Ensemble (MIROC6-LE): experimental design and initial analyses. https://doi.org/10.5194/esd-14-1107-2023 | Swart et al. (2019):The Canadian Earth System Model version 5 (CanESM5.0.3). https://gmd.copernicus.org/articles/12/4823/2019/ | Thornthwaite, C. W., (1948): An approach toward a rational classification of climate | Van der Wiel et al. (2023): Large increases of multi-year droughts in north-western Europe in a warmer climate. https://doi.org/10.1007/s00382-022-06373-3 | Vicente-Serrano et al. (2009): A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index, 10.1175/2009JCLI2909.1. | Ziehn et al.(2020): The Australian Earth System Model: ACCESS-ESM1.5. https://doi.org/10.1071/ES19035 |
Acknowledgements: We thank Urs Beyerle for providing access to the CMIP6-NG data at the server of ETH Zurich. Computations for the analyses were made on the LRZ's SuperMUC of BAdW and funded via GCS by BMBF and StMWFK.