Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure
and Water Management*

KARIN VAN DER WIEL, THOMAS BATELAAN, NIKO WANDERS

LARGE INCREASES OF MULTI-YEAR DROUGHTS IN NORTH-WESTERN EUROPEAN IN A WARMER CLIMATE

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AIM STUDY

- Three dry years in a row: 2018, 2019, 2020
- National water authority, water boards, ministry, etc
  - *"Is this due to climate change?!?!"*
  - *"What about multi-year vs single-year events?"*

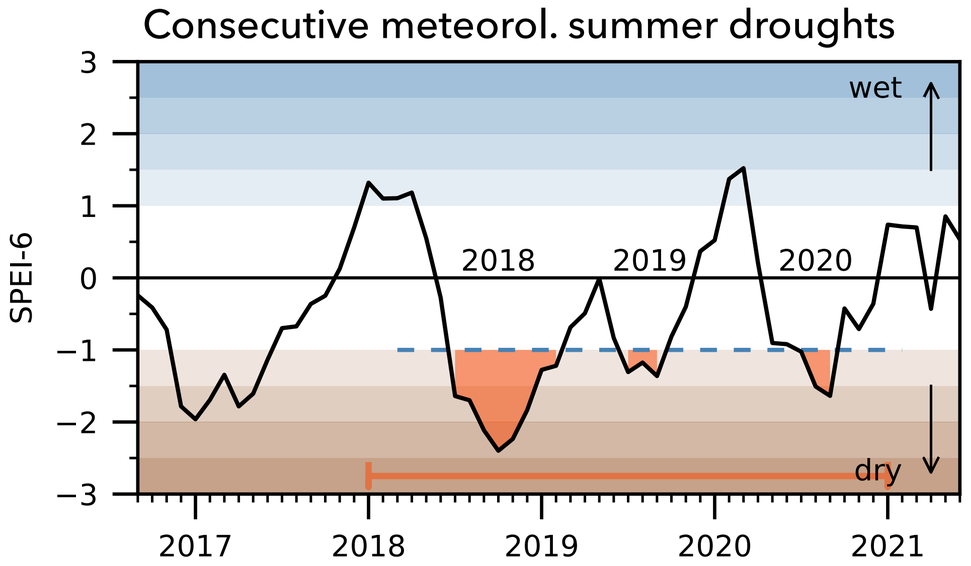
Exploratory analysis of MYD occurrence in the Rhine basin using large ensemble climate model simulations

- Focus on likelihood in present and warmer climate(s)
- & temporally compounding processes in a 'typical' MYD event

Photo: DVHN

DATA

- Gridded observations, reanalysis
- Multi-model Large Ensemble Archive
  - 7 coupled models; 16-100 ens. member; RCP8.5
  - All data regridded to 2° x 2°; box around the Rhine basin



MYD EVENT DEFINITION

- Consecutive meteorological summer drought
  - Min. 2 summers (Jun-Nov) with SPEI-6 < 1
- Long-duration hydrological droughts
  - Min. 12 consecutive months with SPEI-12 < 1

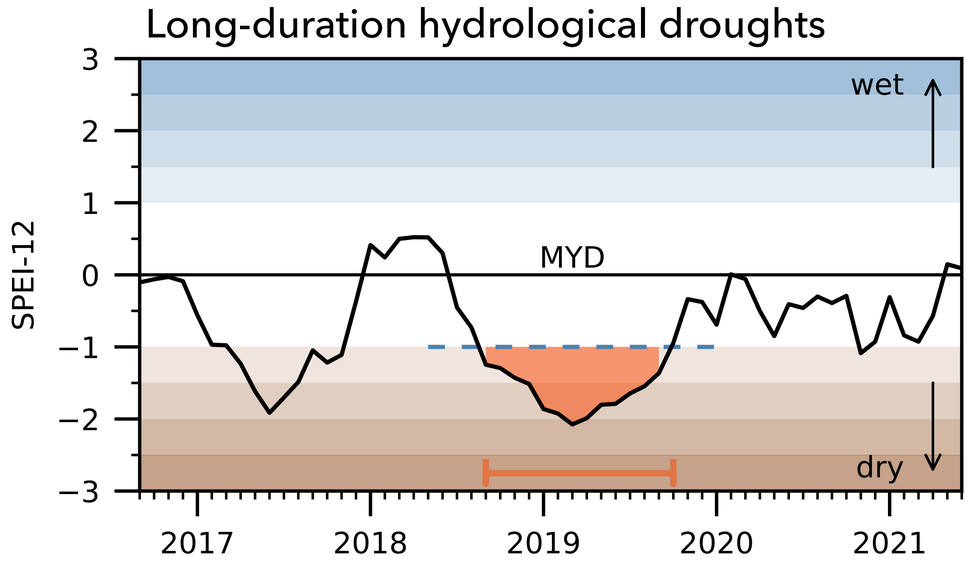
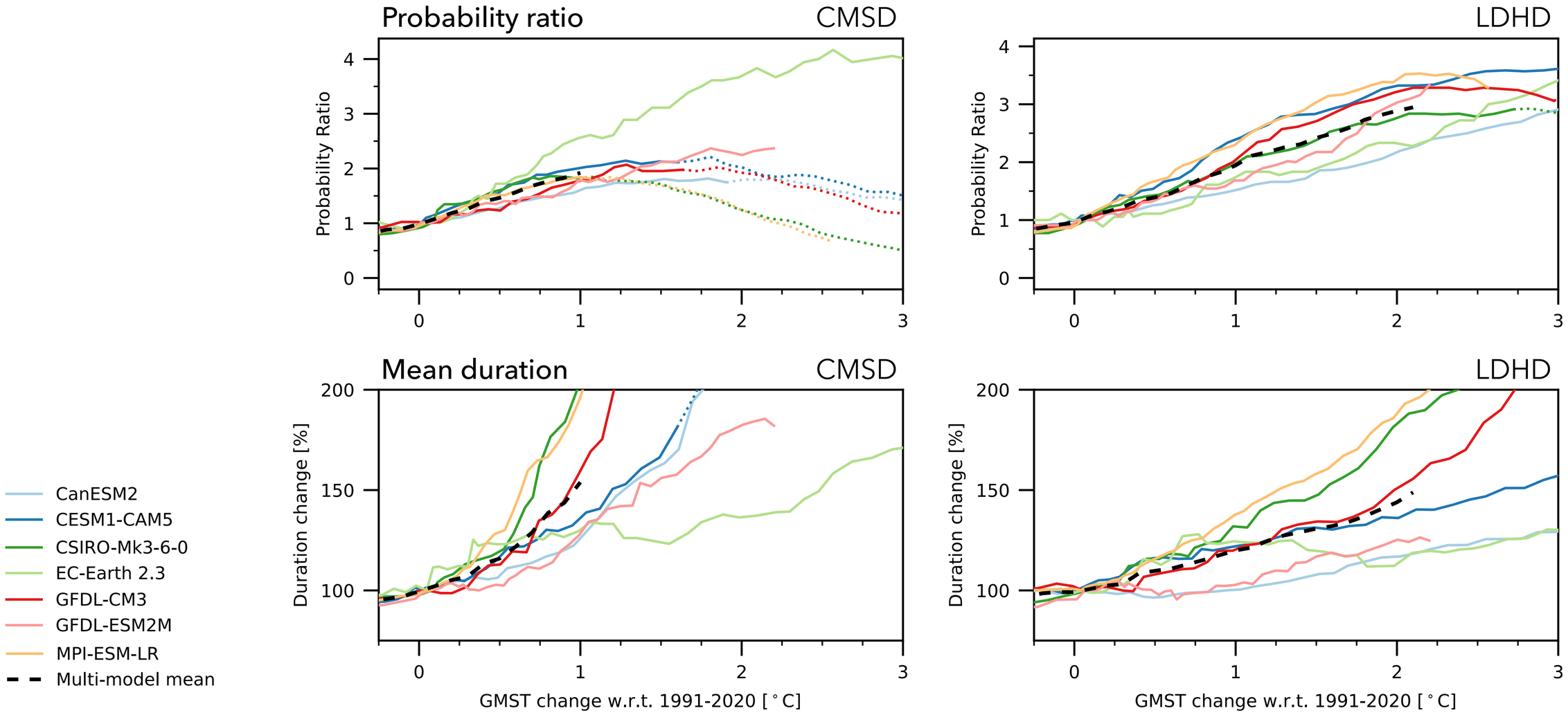


Figure based on ERA5 data; SPEI time series calibrated for 1961-2020

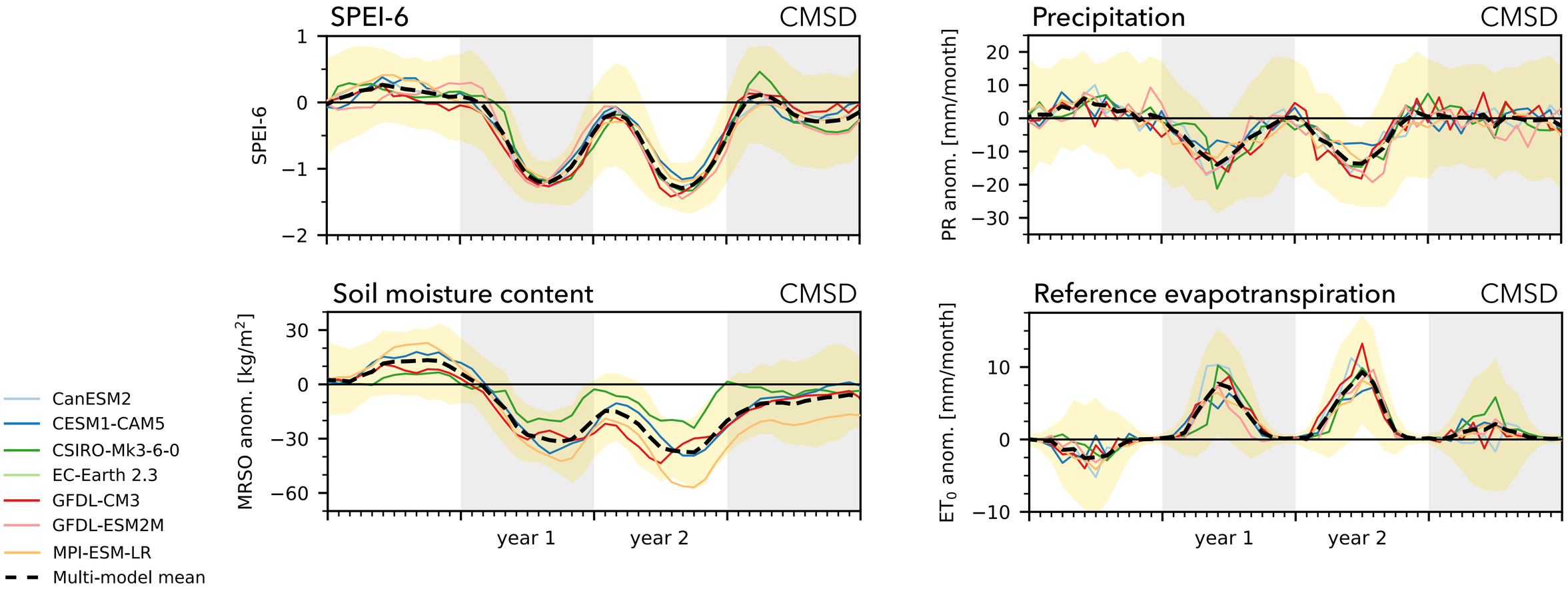
MYD LIKELIHOOD IN WARMER CLIMATES

- Doubling of events with 1 °C extra warming; increased event duration



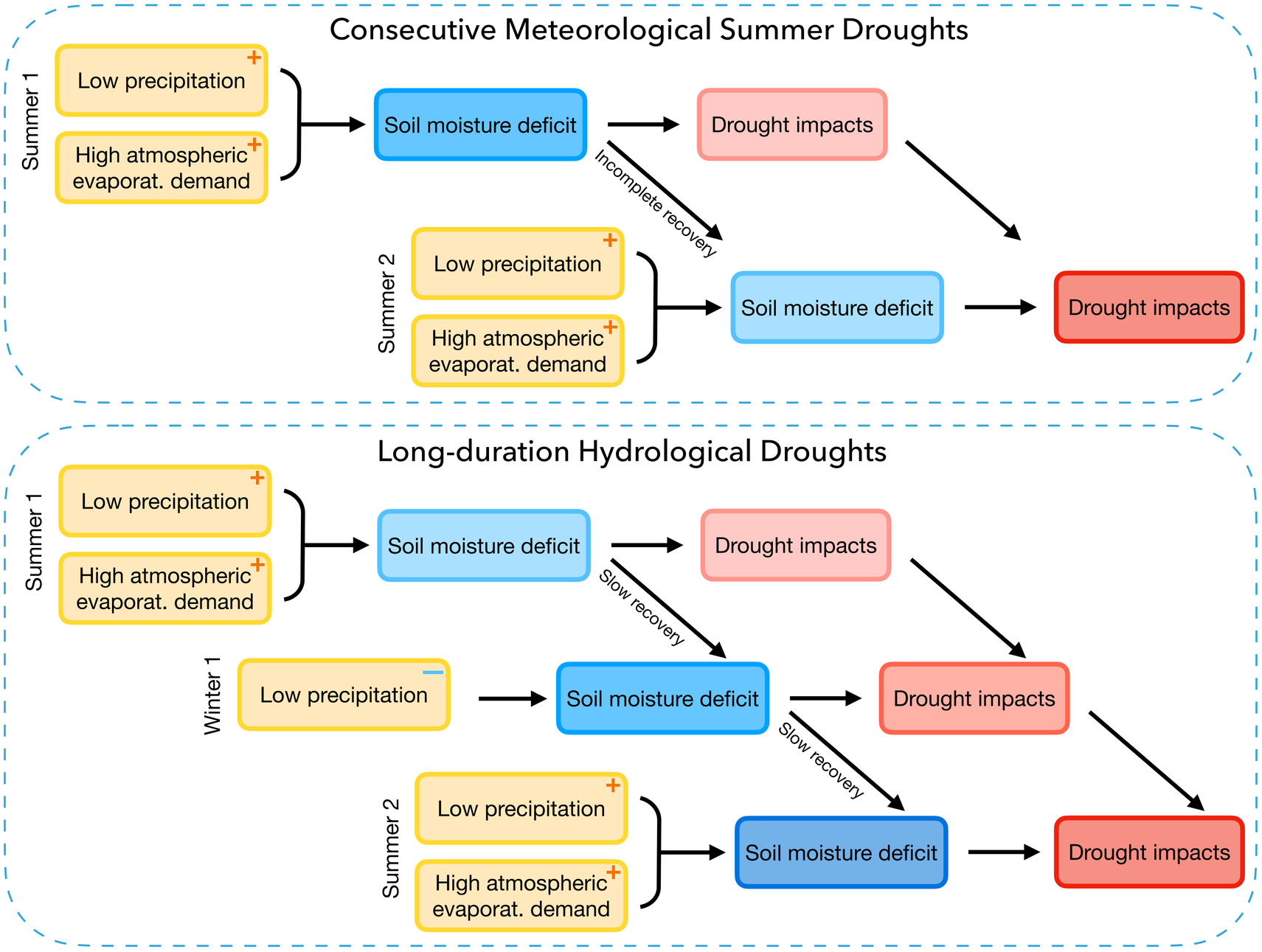
MYD PHYSICAL PROCESSES

- Composite analysis on all MYD events in 1991-2020.
- Shown here for consecutive meteorological summer droughts



MYD PHYSICAL PROCESSES

- Low precipitation, high evapotranspiration
- Incomplete soil moisture recovery



Meteorological driver
Soil moisture response
Natural/societal impact
Causal link
\+ Higher risk due to climate change
− Lower risk due to climate change

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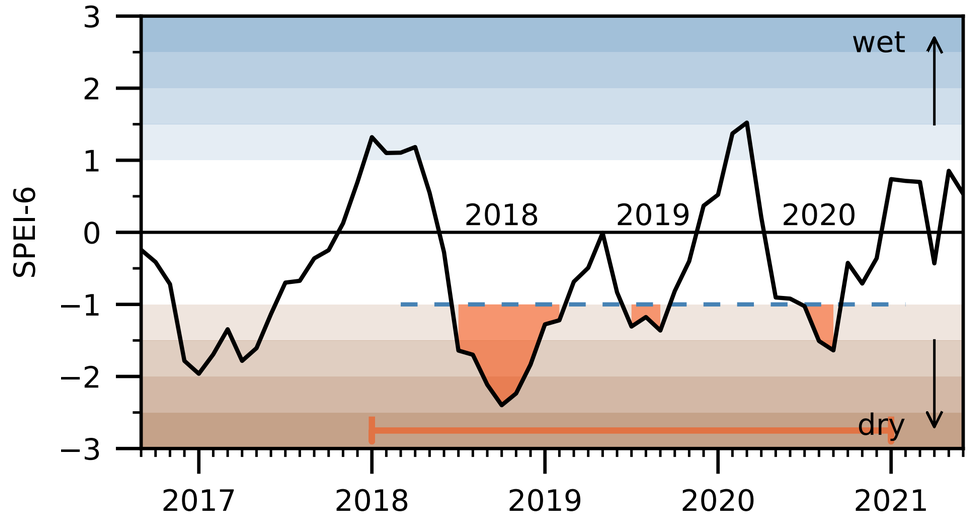

- Doubling of events with 1 °C additional warming; increased event duration
- Due to large trends in mean climate, plus bit extra due to trend in climate variability

Thank you!

Paper in review at Climate Dynamics

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EXTRA SLIDES

STRONG INCREASE OF PROBABILITY OF NORTHWESTERN EUROPEAN MULTI-YEAR DROUGHTS IN A WARMER CLIMATE

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Three consecutive dry summers in western Europe (2018-2019-2020) had widespread negative impacts on society and ecosystems, and started societal debate on (changing) drought vulnerability and needs to revise adaptation measures. To facilitate that discussion, we investigate multi-year droughts in the Rhine basin, with a focus on event probability in the present climate and in future warmer climates. Additionally, we studied the temporally compounding physical processes leading to multi-year drought events. A combination of multiple reanalysis datasets and multi-model large ensemble climate model simulations was used to robustly analyse the statistics and physical processes of these rare events. In these data, we identify two types of multi-year drought events (consecutive meteorological summer droughts and long-duration hydrological droughts), and show that these occur on average about twice in a 30 year period in the present climate, though natural variability is large (zero to five events in a single 30 year period). Projected decreases in summer precipitation and increases in atmospheric evaporative demand, lead to a doubling of event probability in a world 1 °C warmer than present and an increase in the average length of events. Consecutive meteorological summer droughts are forced by two, seemingly independent, summers of lower than normal precipitation and higher than normal evaporative demand. The soil moisture response to this temporally compound meteorological forcing has a clear multi-year imprint, resulting in a relatively larger reduction of soil moisture content in the second summer and potentially more severe drought impacts. Long-duration hydrological droughts start with a severe summer drought followed by lingering meteorologically dry conditions. This limits and slows down the recovery of soil moisture content to normal levels, leading to long-lasting drought conditions. This initial exploration provides avenues for further investigation of multi-year drought hazard and vulnerability in the region, which is advised given the projected trends and vulnerability of society and ecosystems.

DATA – MORE DETAILS

- Gridded observations, reanalysis
- Multi-model Large Ensemble Archive
  - Model resolutions 1° to 2.8°, regridded to 2° x 2°
- Monthly data
- Rhine-box, land points in 46-54°N, 2-12°E

Observations	Time period	# ens. members
E-OBS	1950-2020	1

Reanalyses		
ERA5	1950-2020	1
JRA-55	1958-2020	1
ERA-20C	1900-2010	1
20CRv3	1836-2015	1

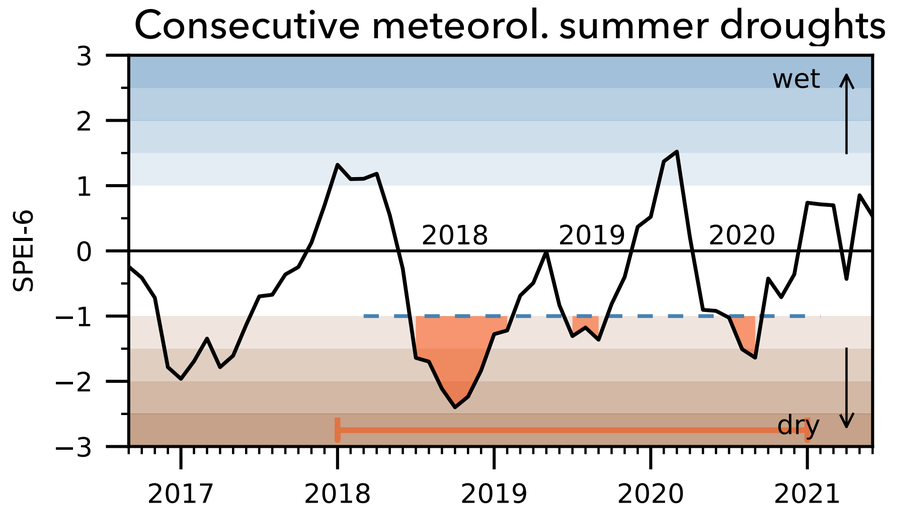
Climate models		
CanESM2	1950-2100	50
CESM1-CAM5	1920-2100	35
CSIRO-MK3.6	1850-2100	30
EC-Earth 2.3	1860-2100	16
GFDL-CM3	1920-2100	20
GFDL-ESM2M	1950-2100	30
MPI-ESM-LR	1850-2099	100

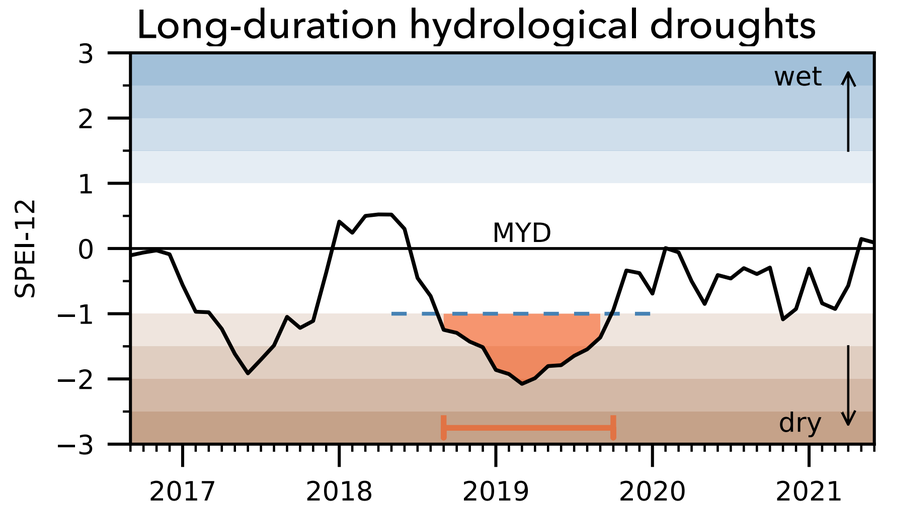
METHODS – MORE DETAILS

- SPEI, normalised monthly water balance between ET_0 and PR
  - Different accumulation periods:
    - SPEI-6 meteorological drought
    - SPEI-12 hydrological drought

MYD event definition

- Consecutive meteorological summer drought
  - Min. 2 summers (Jun-Nov) with SPEI-6 < 1
- Long-duration hydrological droughts
  - Min. 12 consecutive months with SPEI-12 < 1





SPEI = Standardised Precipitation Evapotranspiration Index
ET_0 = reference evapotranspiration (Makkink used here)

MYD RISK IN PRESENT-DAY CLIMATE

- Counted MYD events (per definition) that start in 1991-2020 in all time series
- On average 2 MYD per 30 years
  - Large model differences
  - Internal variability in a single 30-year record very large

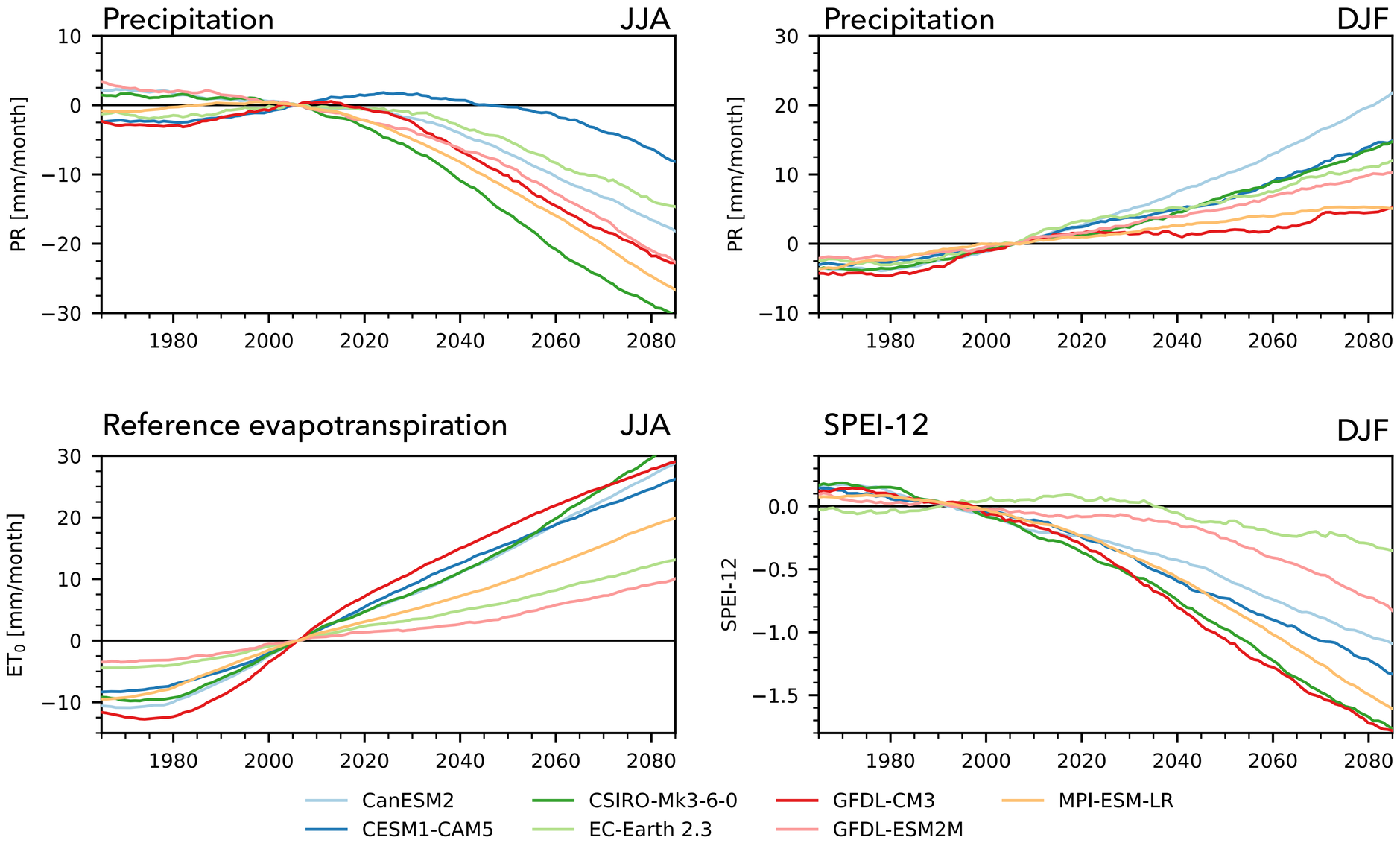
	Consecutive Meteorological Summer Droughts				Long-duration Hydrological Droughts			
Observations	**Frequency [#/30yrs]**		**Duration [years]**		**Frequency [#/30yrs]**		**Duration [months]**	
E-OBS	2		2		3		13.3	
Reanalyses								
ERA5	1		3		3		12.3	
JRA-55	1		3		3		15.7	
ERA-20C	0				1.5		16.0	
20CRv3	0				1.2		12.0	
Climate models								
CanESM2	2.28	(0 – 4)	2.5	(2.0 – 4.0)	2.02	(0 – 5)	16.5	(12.0 – 28.0)
CESM1-CAM5	2.00	(0 – 5)	2.7	(2.0 – 5.0)	1.89	(0 – 5)	15.3	(12.0 – 22.8)
CSIRO-Mk3-6-0	2.30	(1 – 5)	2.4	(2.0 – 3.6)	2.50	(0 – 5)	15.6	(12.0 – 25.3)
EC-Earth 2.3	1.06	(0 – 3)	2.4	(2.0 – 3.2)	1.12	(0 – 3)	14.1	(12.0 – 18.1)
GFDL-CM3	2.15	(0 5)	2.4	(2.0 3.9)	2.40	(1 4)	16.2	(12.0 26.6)
GFDL-ESM2M	1.87	(0 4)	2.5	(2.0 4.0)	1.87	(0 5)	16.2	(12.0 25.8)
MPI-ESM-LR	2.27	(0 – 5)	2.5	(2.0 – 4.0)	2.05	(0 – 5)	15.5	(12.0 – 25.6)
Multi-model mean	1.99		2.5		1.98		15.6	

MYD LIKELIHOOD IN WARMER CLIMATES – MORE DETAILS

- Doubling of events with 1 °C extra warming; increased event duration

	Consecutive Meteorological Summer Droughts				Long-duration Hydrological Droughts			
	Probability Ratio		Duration change [%]		Probability Ratio		Duration change [%]	
Model name	+1 °C	+2 °C	+1 °C	+2 °C	+1 °C	+2 °C	+1 °C	+2 °C
CanESM2	1.72	–	129	–	1.71	2.40	102	120
CESM1-CAM5	2.00	–	138	–	2.35	3.15	122	136
CSIRO-Mk3-6-0	2.08	–	190	–	2.22	3.16	130	183
EC-Earth 2.3	2.59	4.00	129	137	1.58	2.21	123	112
GFDL-CM3	1.74	–	152	–	2.18	3.48	117	145
GFDL-ESM2M	1.72	2.28	128	190	1.70	3.17	109	130
MPI-ESM-LR	1.95	–	194	–	2.60	3.80	136	183
Multi-model mean	1.97	–	151	–	2.05	3.05	120	138

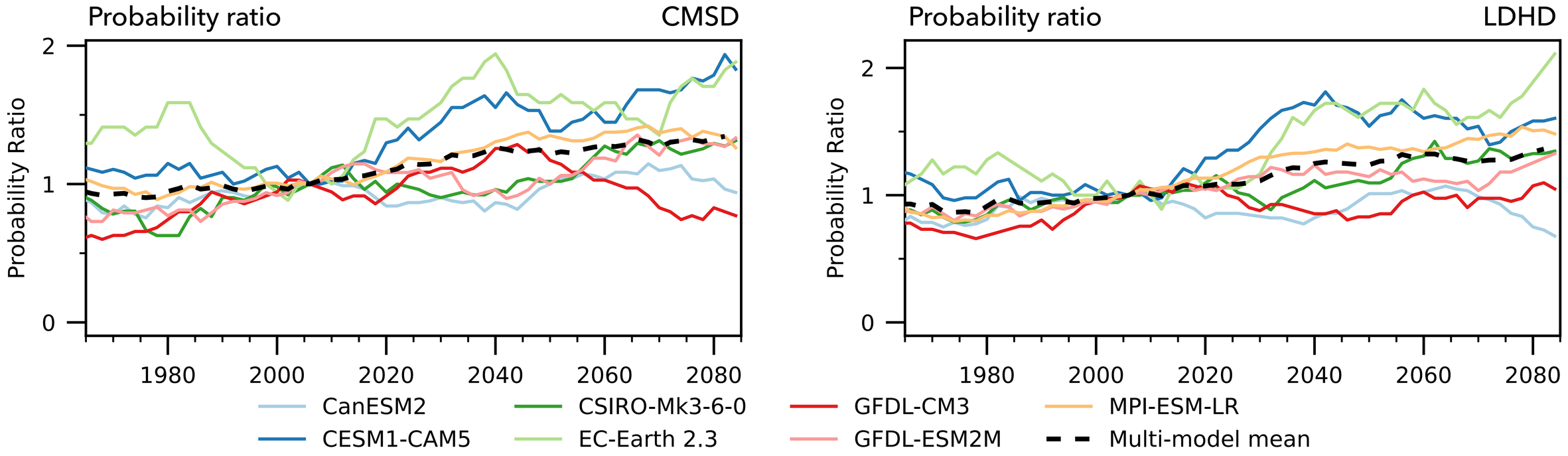
TRENDS IN RELATED CLIMATE VARIABLES



INFLUENCE OF TRENDS IN CLIMATE VARIABILITY

- MYD risk also increases if we remove mean climate change from all input variables
- Approximately 10 – 20% of the total change due to the trend in variability

(following *Van der Wiel & Bintanja, 2021*)



CONSECUTIVE METEOROLOGICAL SUMMER DROUGHTS – BAD LUCK OR . . . ?

- Break multi-year connections, shuffle years among ensemble members.
- Repeated 100 times
- No evidence for physical processes leading to consecutive years of meteorological drought.