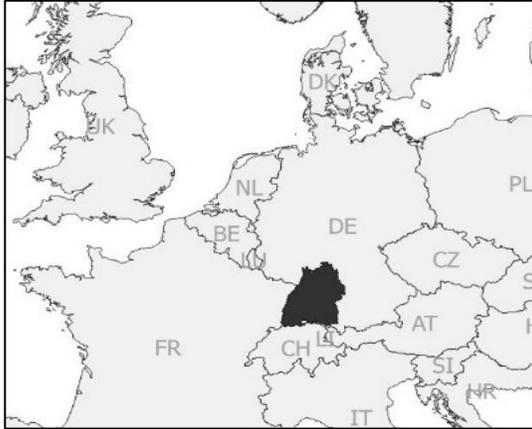
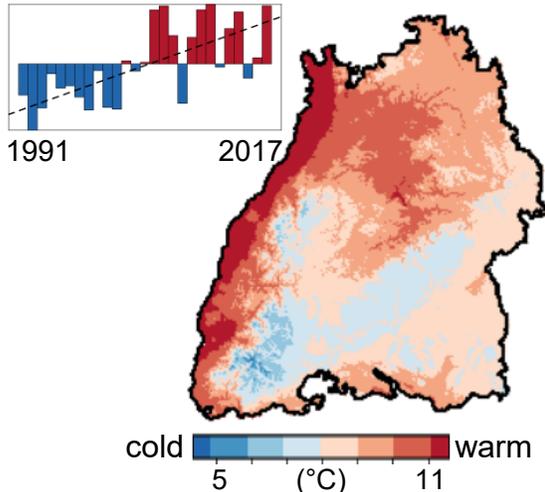


## (1) Study region and climate

Southwestern Germany

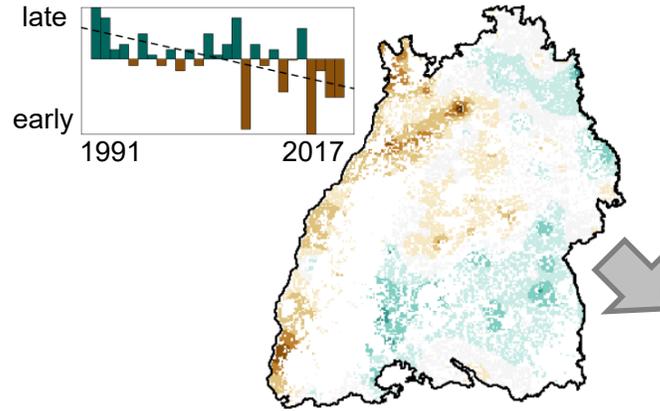


Annual average temperature

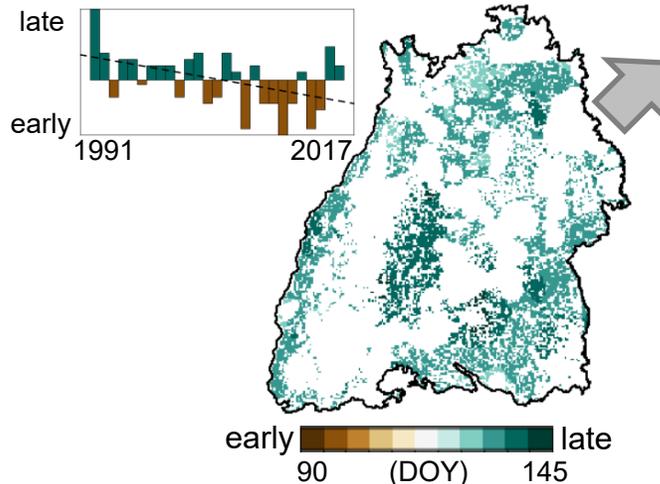


## (2) Variability in phenology

Shooting Winter Wheat (WW)



Emergence Maize

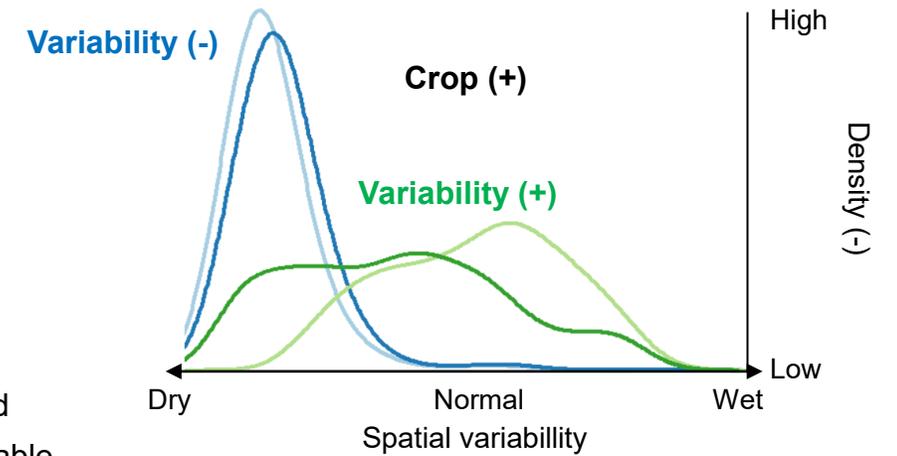


### Scenarios

- WW fixed
- WW variable
- Maize fixed
- Maize variable

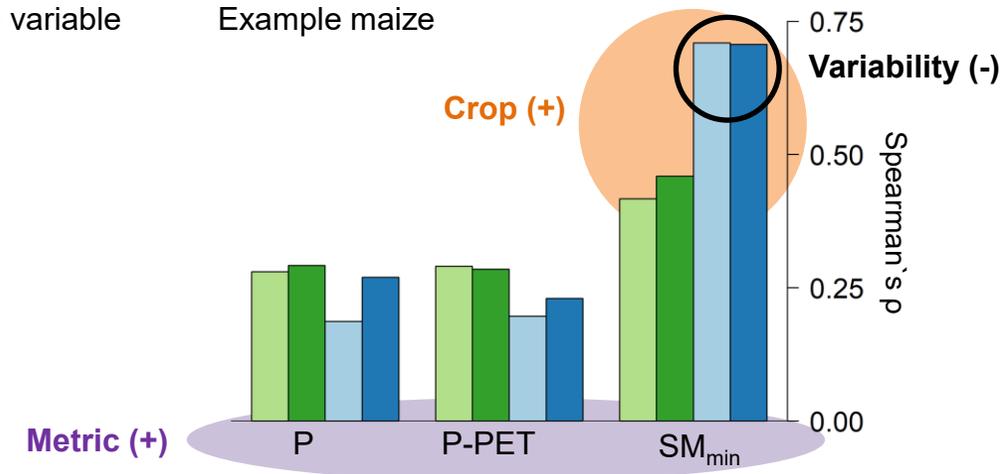
## (3) Variability in drought conditions

Example minimum SM 1991



## (4) Correlation with crop yield

Example maize



# Background information and outline

## Motivation and objectives

### Study region

#### Methods:

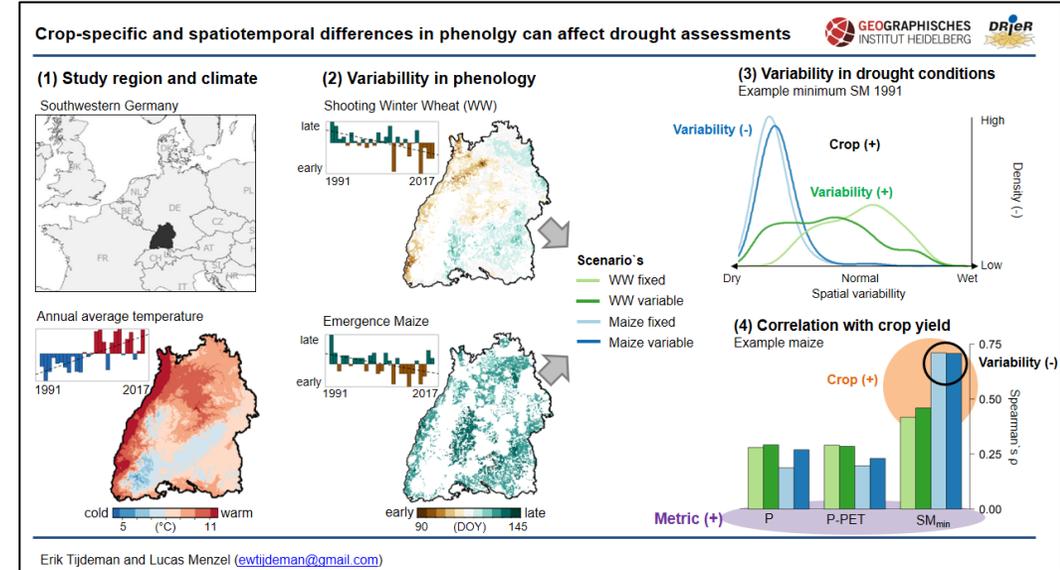
- (Potential) evapotranspiration modelling
- Interpolation of phenological data
- Growing season scenarios
- Growing season water balance terms
- Growing season drought metrics

#### Results:

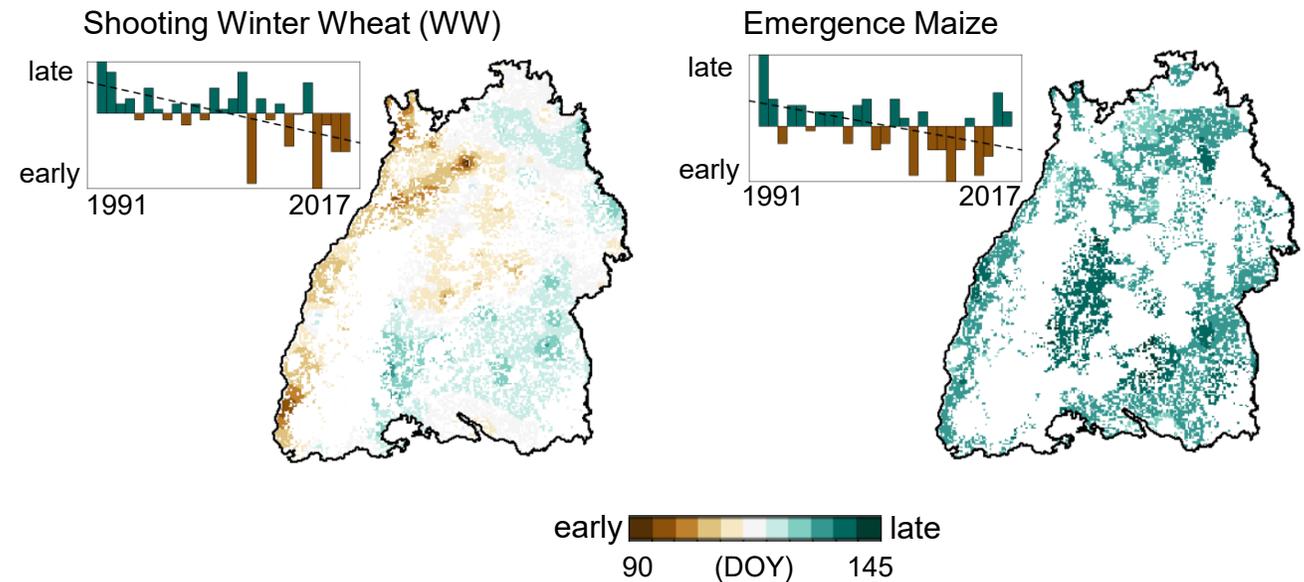
- Variability among drought metrics and scenarios
- Disagreement among drought metrics and scenarios
- Reasons for the disagreement
- Correlation with crop yield data

## Discussion and ongoing work

## Conclusion

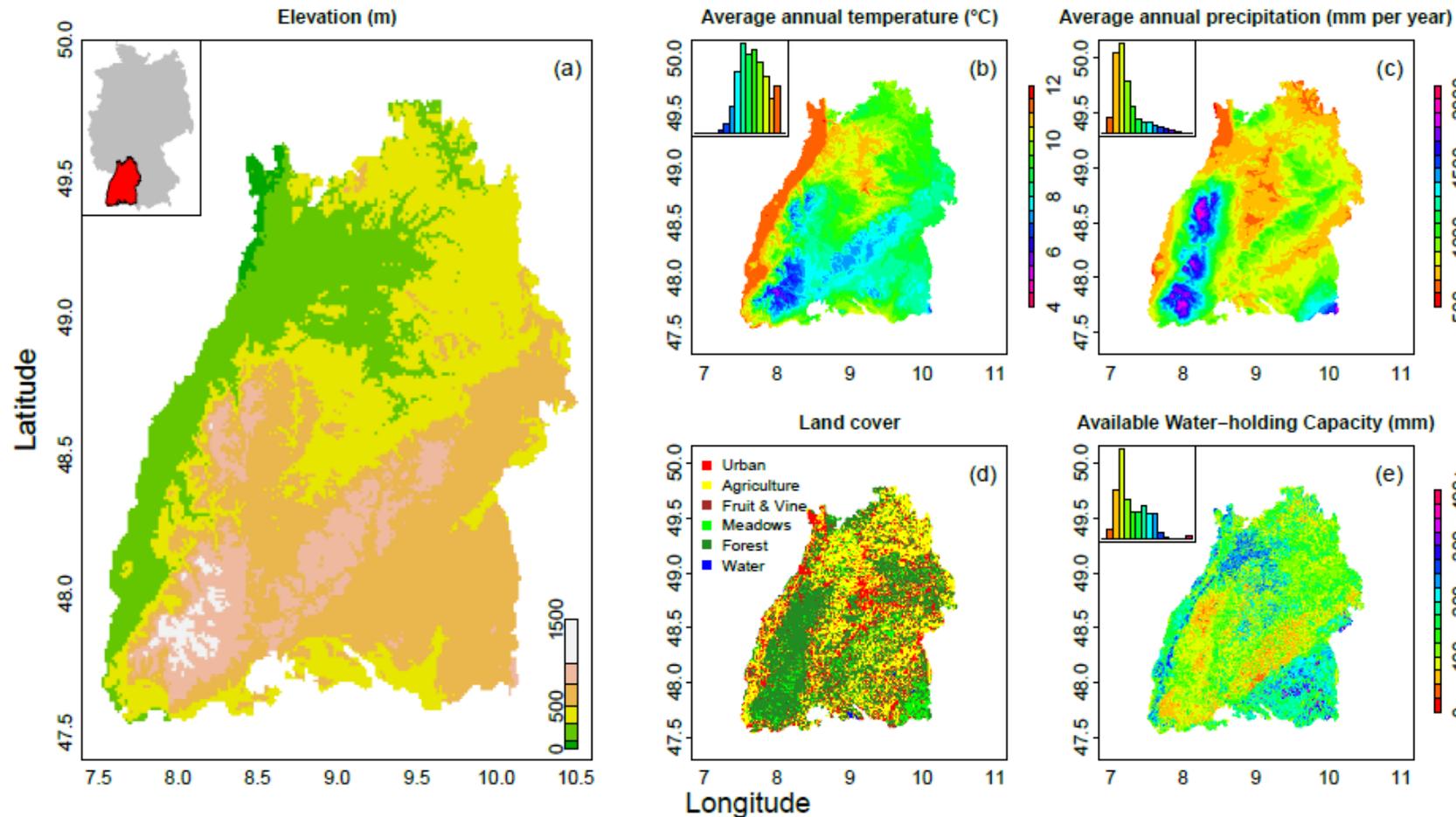


Drought metrics are often derived and compared for static time windows. However, phenological phases vary in space, time, and among crops (see examples on the right). In this contribution, we aim to:



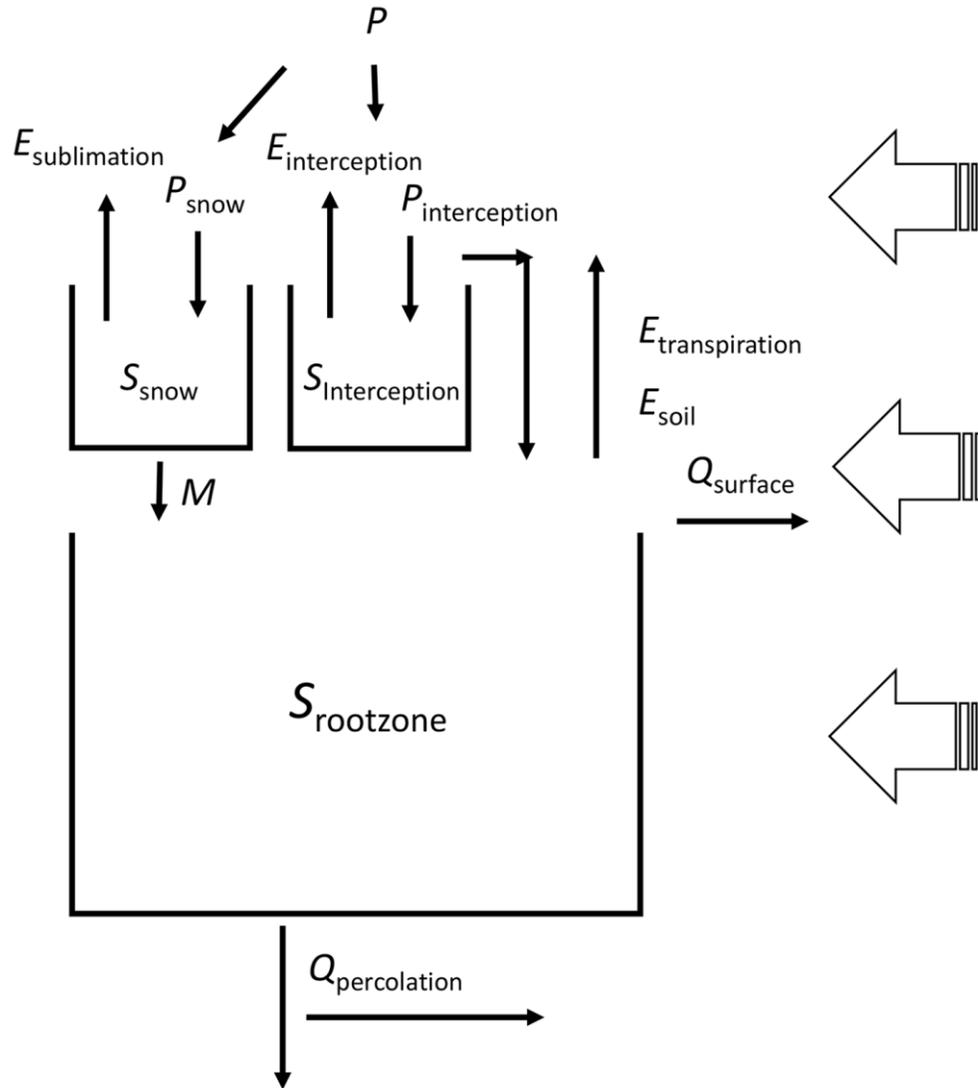
## Objectives:

1. derive different drought metrics over the growing season,
2. investigate how these drought metrics change when considering crop specific and spatiotemporal differences in growing season, and
3. assess which drought metrics and growing season configurations have the strongest correlation with crop yield anomalies.



- Baden-Württemberg is located in southwestern Germany (a).
- The region has a diverse climate, with dry and warm areas located in the lower elevated regions such as the Rhine valley (b-c).
- Equally variable are the region's land use and root zone soil storage characteristics (d-e).

# (Potential) evapotranspiration modeling for all agricultural grid cells



## Input

### (a) Meteorology

Precipitation  
Temperature  
Rel. Humidity  
Wind  
Global radiation

### (b) Land cover

LAI  
Vegetation height  
Emerging and Harvest date

### (c) Soil information

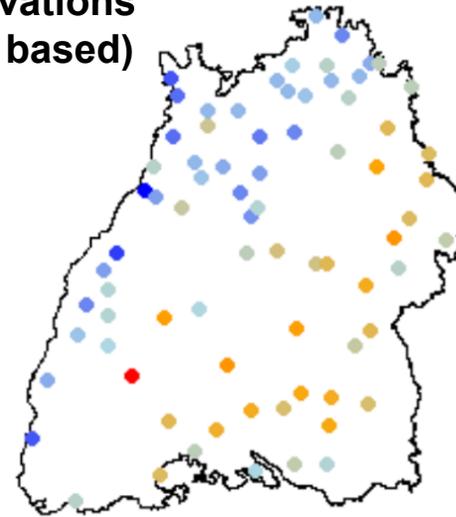
Depth  
Field capacity  
Wilting point  
Air capacity

- We used the TRAIN model to simulate (potential) evapotranspiration for the period 1991-2017 for all agricultural grid cells in the study region.
- The model set-up was similar to Tijdeman et al. (2021) but with the available water-holding capacity of the root zone set to a relatively high value (200 mm) to approach PET on most days.

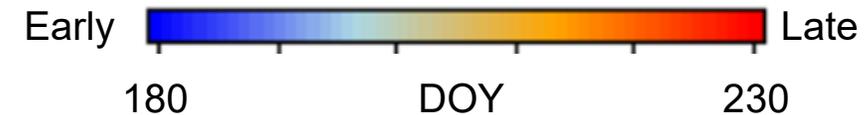
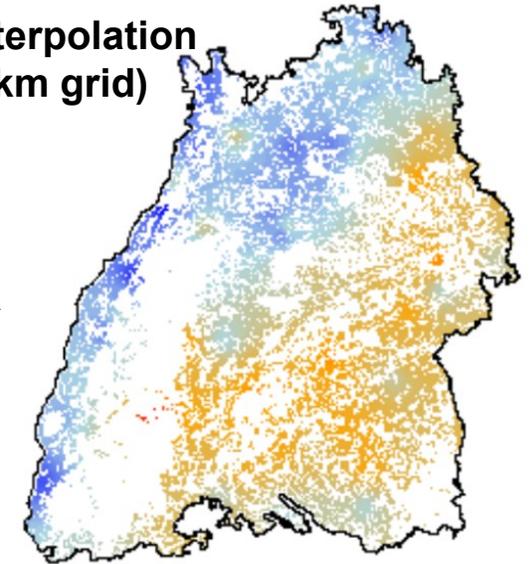
- Phenological observations associated with the start and end of the growing season (table below) stem from the German Weather Services (DWD)<sup>1</sup>
- Phenological observations were interpolated to all agricultural grid cells on a 1 km resolution grid using a k-nearest neighbor inverse distance weighting approach (k = 5; see example right).

## Harvest date Winter wheat 2018

Observations  
(point based)



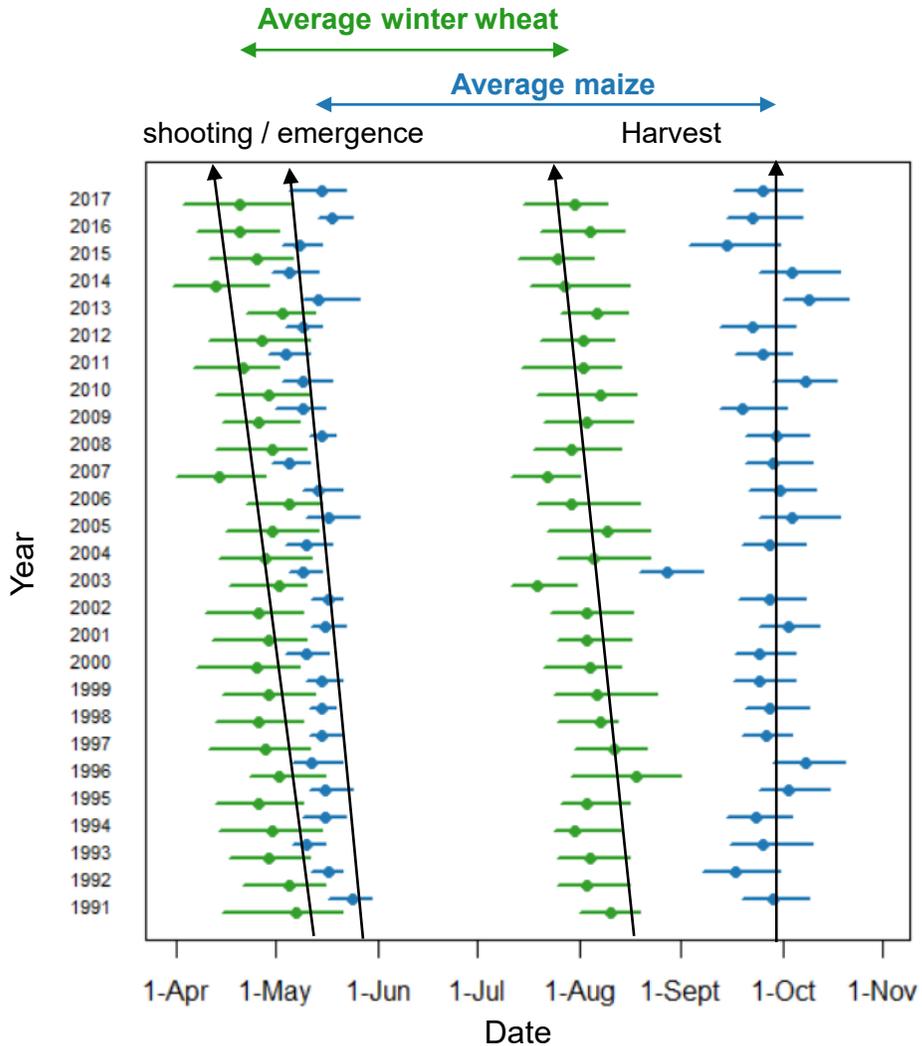
Interpolation  
(1km grid)



Winter Wheat		Maize	
Phenological phase ID	Description	Phenological phase ID	Description
15	Beginning of shooting	12	Beginning of emerge
24	Harvest	24	Harvest

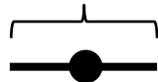
1) [https://opendata.dwd.de/climate\\_environment/CDC/observations\\_germany/phenology/](https://opendata.dwd.de/climate_environment/CDC/observations_germany/phenology/)

# Variability in phenological data & scenarios



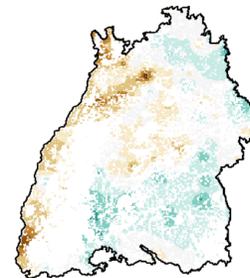
## Spatial variability

90% range



Average

E.g. shooting date WW



Temporal changes (trends)



- Phenological observations vary in space, time, and among crops (figure left).
- Based on these phenological observation, we derived four different growing season scenarios.
  - Two scenarios based on fixed growing season conditions
    - **Average winter wheat**
    - **Average maize**
  - Two scenarios based on spatially and temporally varying growing seasons.
    - **Variable winter wheat**
    - **Variable maize**

# Different water balance terms over the growing season

Different water balance terms (V) were derived for each growing season (year, scenario) and grid cell

Average precipitation: ( $\bar{P}$ )

$$\bar{P} = \frac{\sum_{j=1}^n P_j}{n}$$

Climatic Water Balance: ( $\bar{P} - \overline{PET}$ ), with:

$$\overline{PET} = \frac{\sum_{j=1}^n PET_j}{n}$$

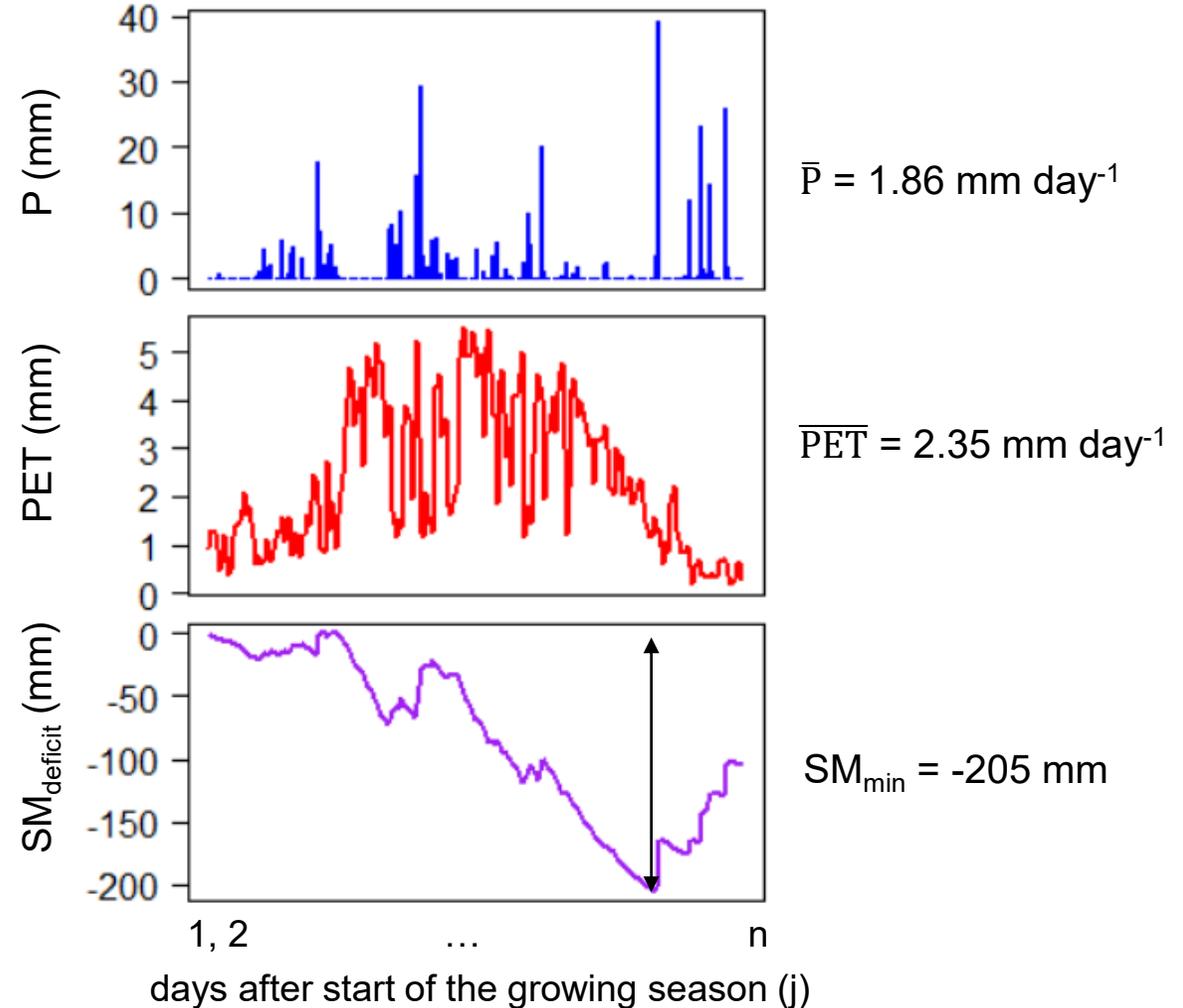
Minimum soil moisture reached: ( $SM_{min}$ )

$$SM_{deficit,j} = \min(SM_{deficit,j-1} + P_j - PET_j, 0)$$

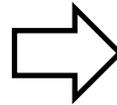
$$SM_{min} = \min(SM_{deficit})$$

for  $j = 1, 2 \dots n$  ← (end growing season)

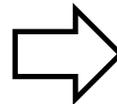
↙ (start growing season)



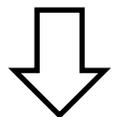
- All water balance terms ( $V$ ) of different grid cells and growing season scenarios were transferred to anomalies (percentiles,  $p$ ) using Weibull plotting positions.
- Regional average anomalies were derived by ranking regional average percentiles.
- The derived percentile time series were classified into different categories:



$$p_V = \frac{\text{Rank}(V)}{(n+1)}$$

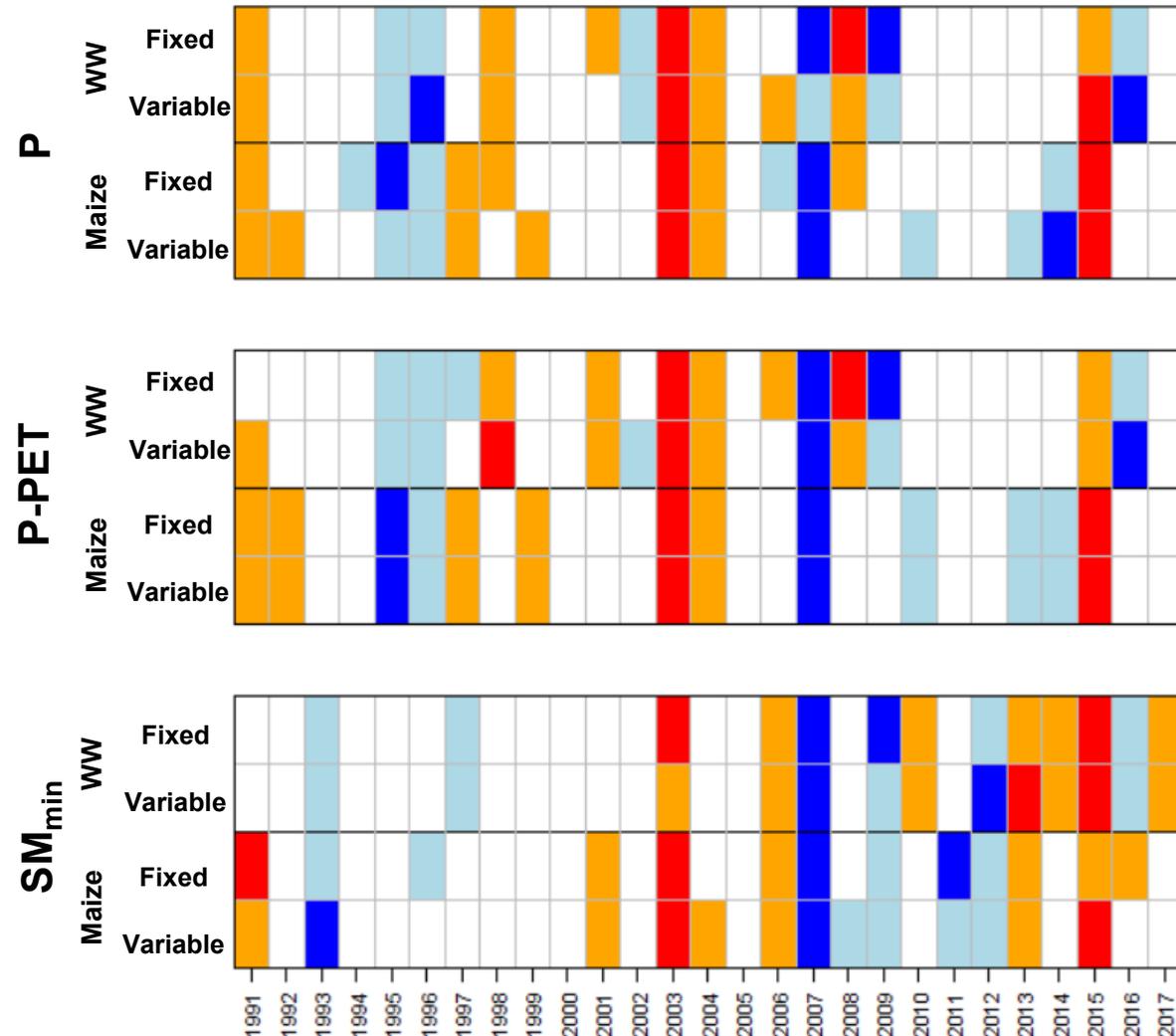


$$p_{V,avg} = \frac{\text{Rank}(\overline{p_V})}{(n+1)}$$



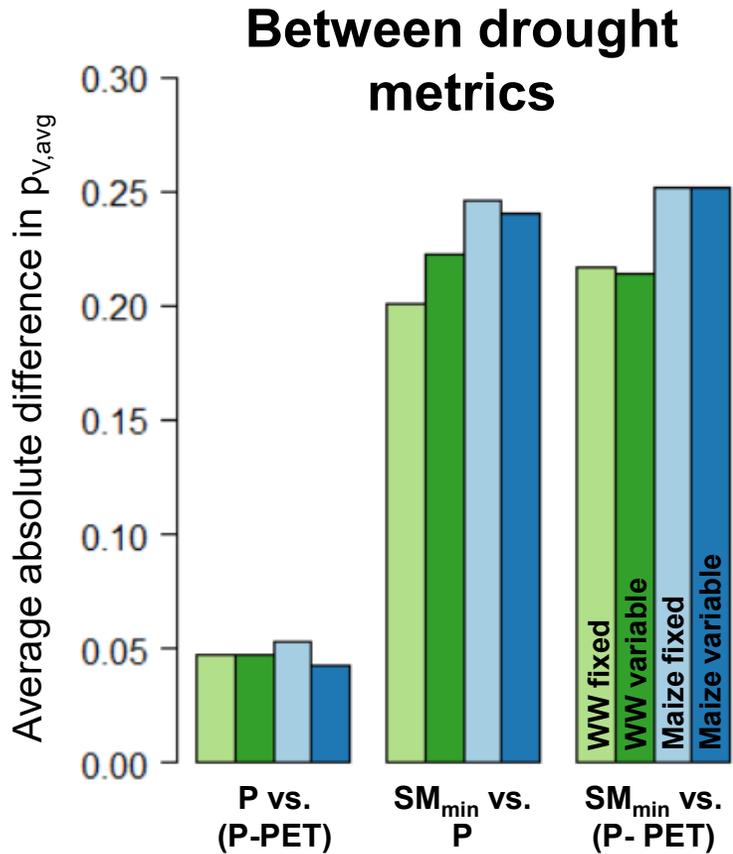
Very dry	Dry	Normal	Wet	Very wet
 $p \leq 0.1$	 $0.1 < p \leq 0.25$	 $0.25 < p < 0.75$	 $0.75 \leq p < 0.9$	 $p \geq 0.9$

# Variability in drought conditions

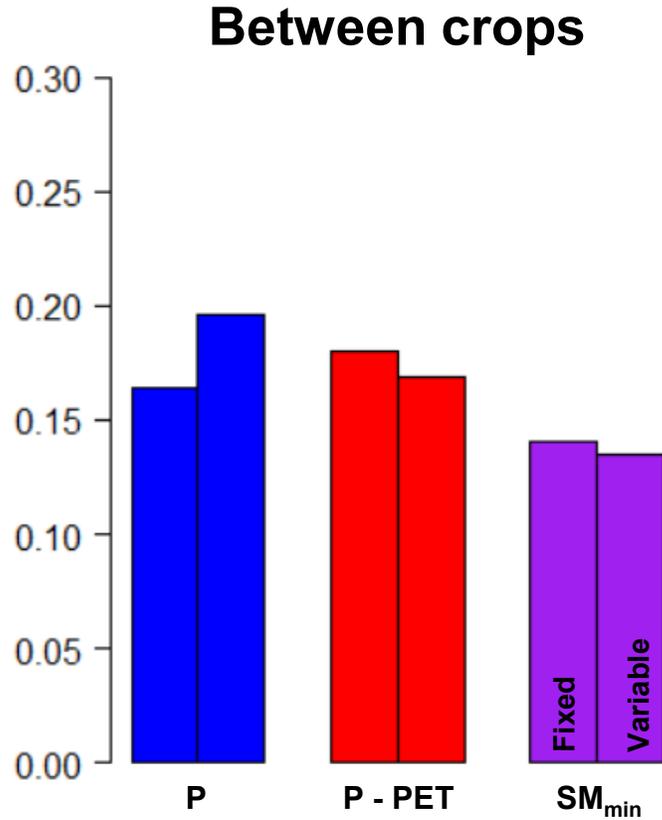


- Left figure reveals generally dry and growing seasons according to  $p_{V,avg}$  for different drought metrics and different growing season scenarios.
- $p_{V,avg}$  for prominent drought years (2003, 2015) often agrees on drought conditions.
- For other years, there can be quite a large variability in drought conditions depending on the considered variable, crop, or both.
- Drought conditions can further vary depending on whether a fixed or variable growing season was considered.

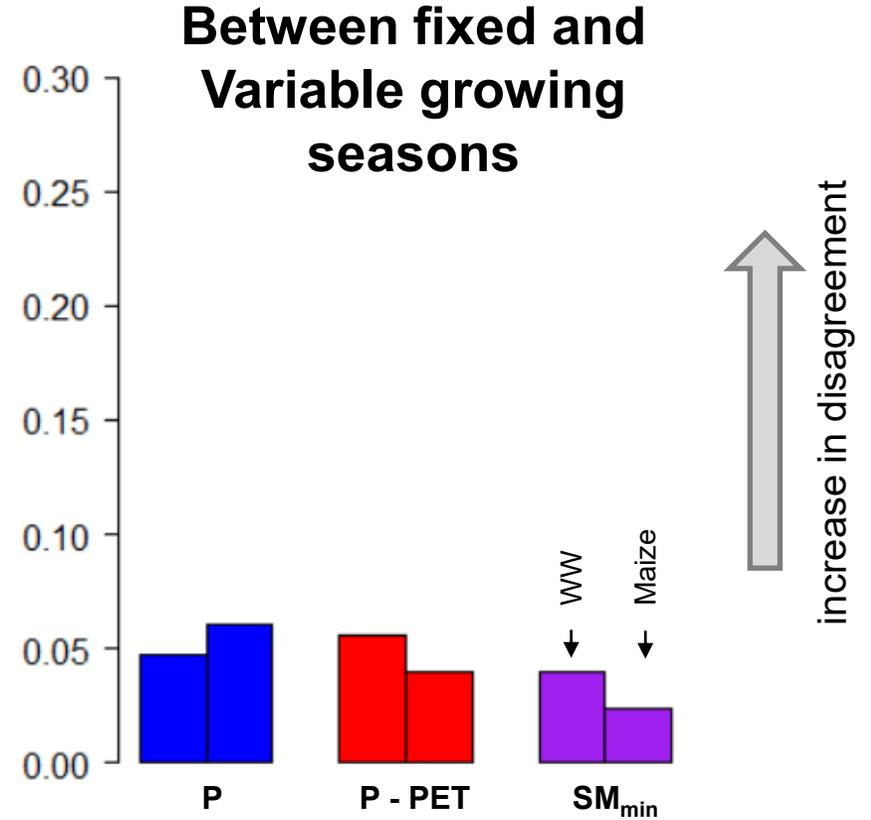
# Disagreement among drought metrics and scenarios



Strongest disagreement found between SM<sub>min</sub> and other meteorological drought metrics



Considering crop specific differences in growing season also causes distinct differences

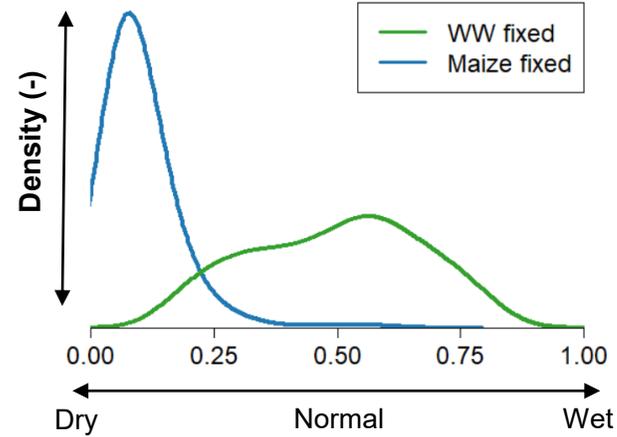


Differences between fixed and variable growing seasons of the same crop are relatively small

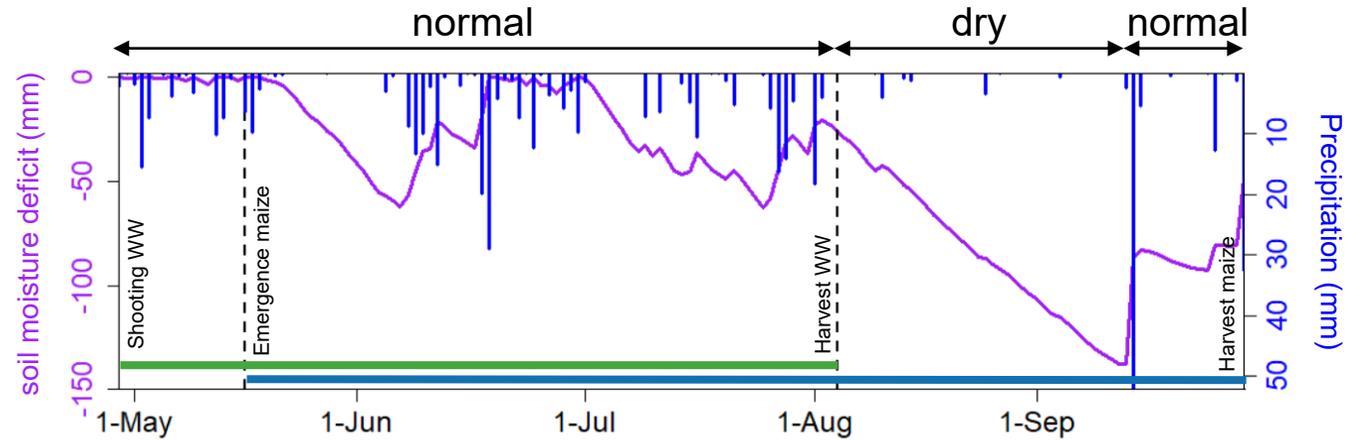
# Reasons for the disagreement

Disagreement between crops

**Minimum SM in 1991**

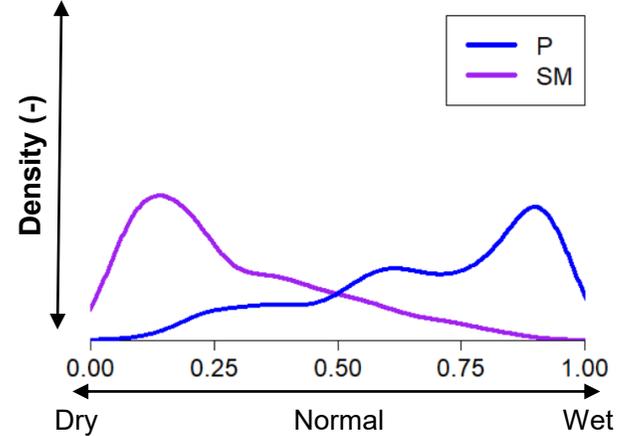


→ timing of growing season and meteorological dry spells

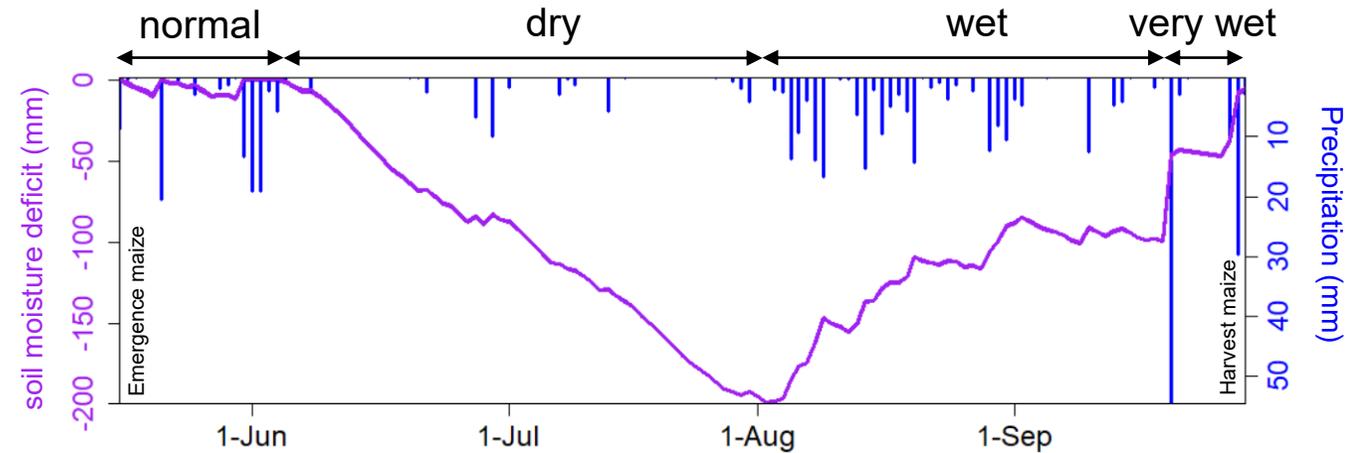


Disagreement between drought metrics

**Maize fixed in 2006**

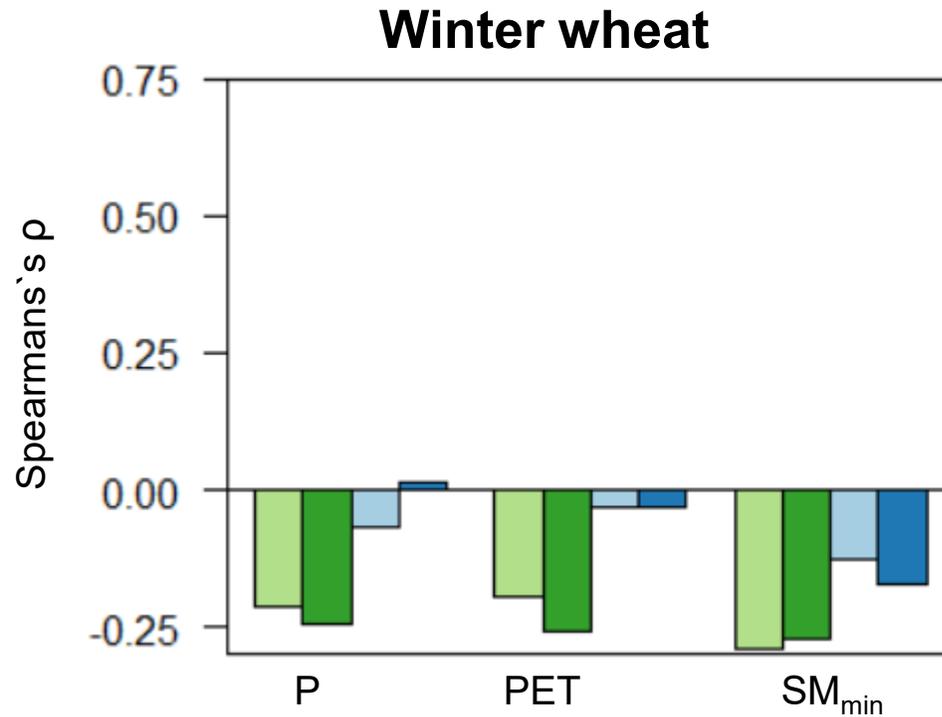


→ uneven distribution of precipitation over the growing season

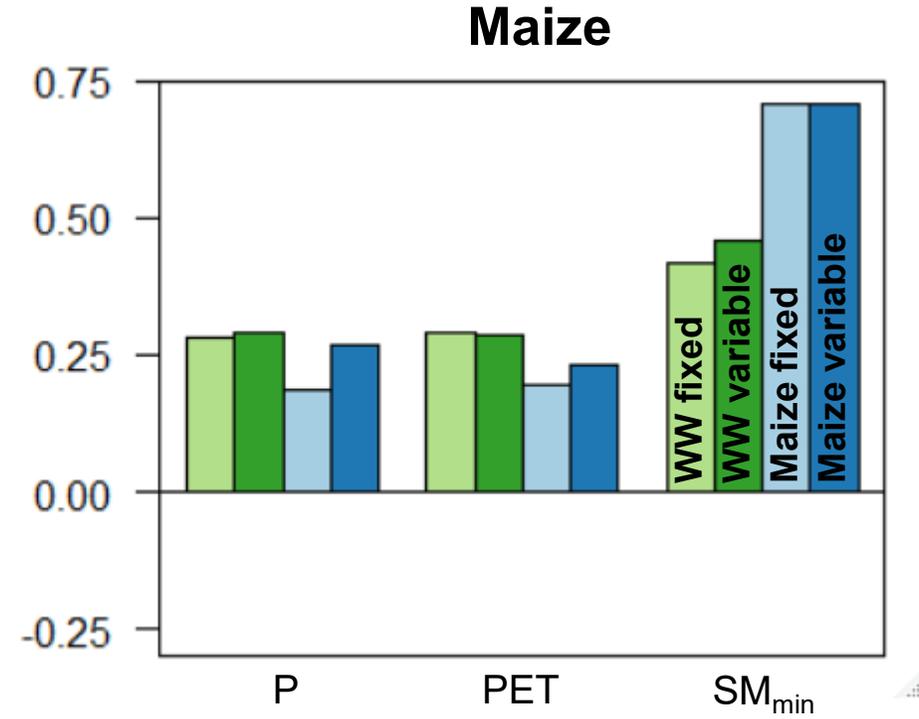


Spatial variability ( $p_v$ )

# Correlation between $p_{V,avg}$ and detrended yield anomalies



Weaker and negative correlations for winter wheat yield anomalies



Stronger correlations for maize yield anomalies, especially for minimum soil moisture derived for a maize specific growing season

- Interpolation now based on k-nearest neighbor inverse distance weighing approach. Other interpolation approaches might be more suitable.
- Minimum soil moisture now based on the largest cumulative deficit that could develop during the growing season. We are currently developing different LAI and vegetation height scenarios to simulate actual SM (e.g. table right).
- Lack of correlation for winter wheat does not imply insensitivity to drought. There might be non-linear relationships as well as other more suitable (non)drought metrics.

Winter Wheat			Maize		
Phenological phase ID	Description	LAI / Height	Phenological phase ID	Description	LAI / Height
-	Pre-development	LAI / height set to 0.01	-	Pre-development	LAI / height set to 0.01
15	Beginning of shooting	Start to increase to 5 / 0.8	12	Beginning of emerge	Start to increase to 5.5 / 0.8
18	beginning of heading	Stay at 5 / 0.8	5	Beginning of flowering	Stay at 5.5 / 0.8
21	Beginning of Yellow ripeness	LAI starts to decrease to 3.5	21	Beginning of Yellow ripeness	LAI starts to decrease to 4
24	Harvest	LAI / height back to 0.01	24	Harvest	LAI / height back to 0.01

- Growing season drought conditions vary depending on the used drought metric and growing season scenario.
- Strongest was the disagreement between drought metrics e.g. the climatic water balance (P-PET) and minimum soil moisture.
- Drought metrics could further disagree depending on the considered growing season scenario.
  - Crop specific differences in growing season matter most.
  - Spatiotemporal differences in growing season matter less.
- Maize yield anomalies correlate well with minimum soil moisture and lesser with precipitation and the climatic water balance over the growing season.
  - Not only amount but also timing of precipitation matters.
- Considering crop specific differences in growing season further improved the correlation with maize yield whereas considering spatiotemporal differences had no effect.

## updates / contact?



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