Index-based framework for assessing climate change impact on cereals in Poland

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Objective

To analyse the effects of projected climate change on two agriculture-related topics: changes in crop phenology and changes in soil water content (agricultural drought).

Framework

Integration of plant growth and hydrological processes in one model as water stress is one of principal yield-limiting factors.

Basis for this study

Both deficit and excess of soil moisture can negatively affect crop growth:

<u>Limited soil moisture</u>: decreased plant water uptake and plant tissue dehydration reducing shoot and root growth, as well as membrane integrity (Wang *et al*., 2016).

<u>Over-supply of soil water</u>: reduction of oxygen transport rates in the soil, with adverse consequences to root metabolism and delaying root development (Wang *et al*., 2016, Raes *et al*., 2006).

Methods

SPRING BARLEY:

Changes in planting and harvest dates

Changes in soil water content conditions

Hydrological projections:

SWAT
Soil & Water Assessment Tool

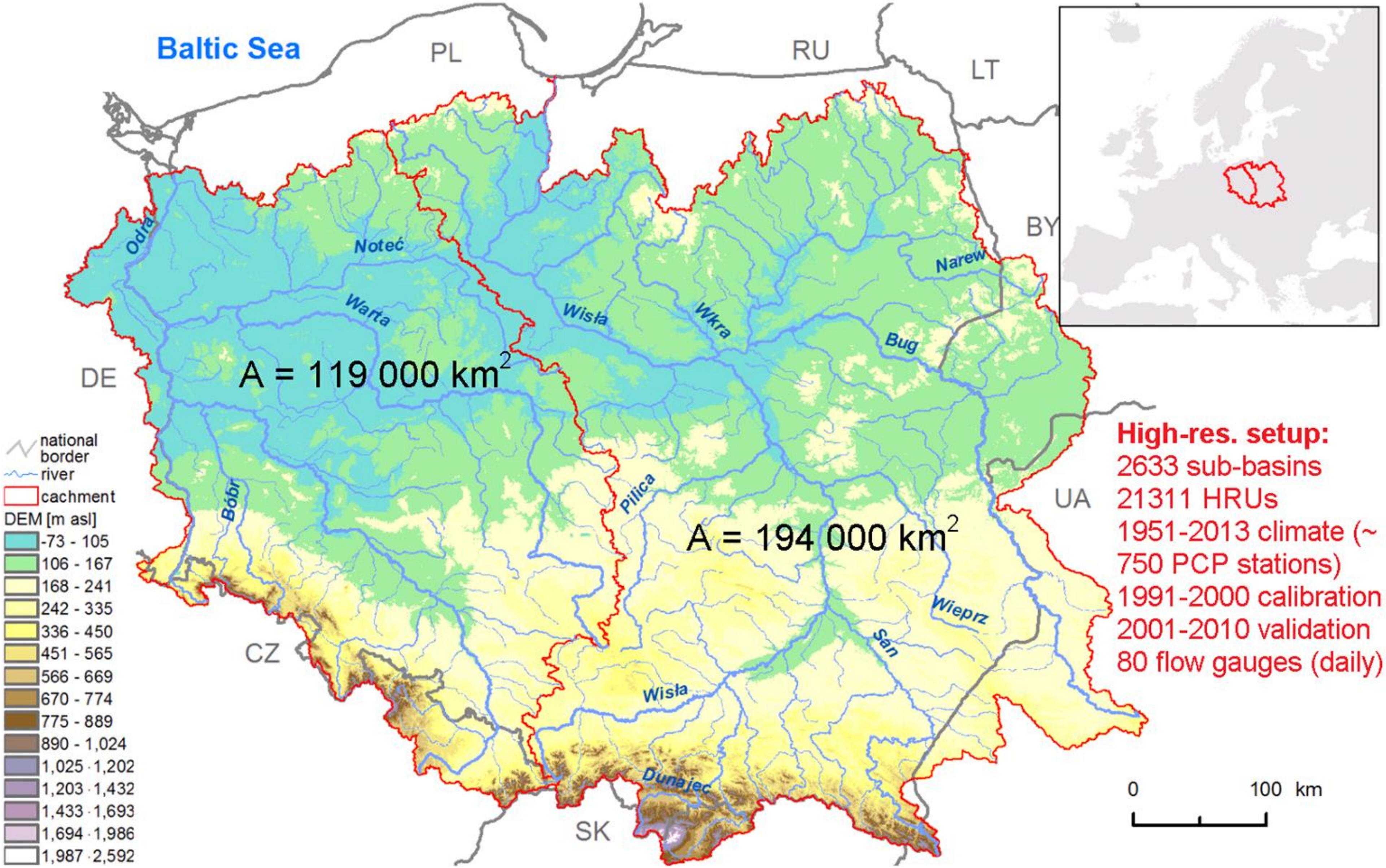
Climate projections:
9 bias corrected EURO CORDEX GCM-RCM

Greenhouse gas concentration:
RCP's:
4.5 (intermediate)
8.5 (high)

Time frame:

- Historical Period (1974-2000)
- Future (2024-2050)

Study area: a high-resolution SWAT model setup



High-res. setup:
- 2633 sub-basins
- 21311 HRUs
- 1951-2013 climate (~ 750 PCP stations)
- 1991-2000 calibration
- 2001-2010 validation
- 80 flow gauges (daily)

Piniewski *et al.*, HSJ, submitted

Modelling with SWAT

SWAT (Soil & Water Assessment Tool) model (Arnold et al., 1998) was **calibrated and validated** for the Vistula and Odra basins (Piniewski et al. HSJ, submitted).

SWAT (Arnold et al., 1998) takes into account:

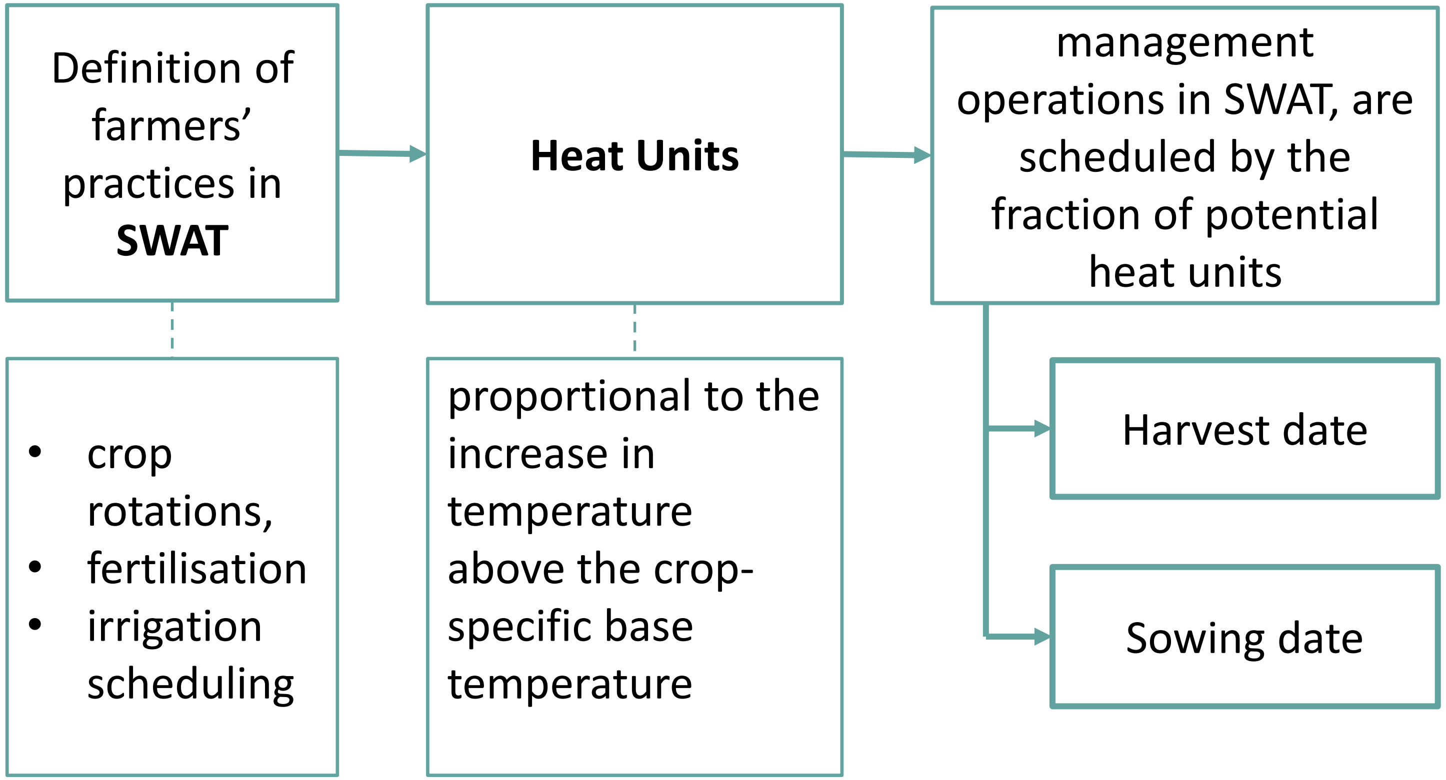
- water,
- temperature,
- nitrogen and phosphorus stresses as plant growth constraints.

Although SWAT simulates crop yield, these results are not presented due to the lack of accurate, observed yield data for model calibration and validation. Hence, a **proxy** of occurrence of crop losses is used instead: **soil water content** simulations from SWAT.

SWAT
Soil & Water
Assessment Tool

Methodology

Projections of changes in planting and harvest dates.



- Mimicing the spatial and multi-annual variability of the timing of operations, related to plant phenological phases.
- This assessment is based solely on temperature changes, whereas in practice, for example, wet soils during spring may delay sowing, particularly for heavy soils (Olesen *et al*., 2012).

Results

Projections of changes in planting and harvest dates.

- Climate warming is likely to trigger an advancement of both sowing and harvest (similar magnitude).
- Sowing and harvest dates are expected to advance by 6-13 days for the future horizon.

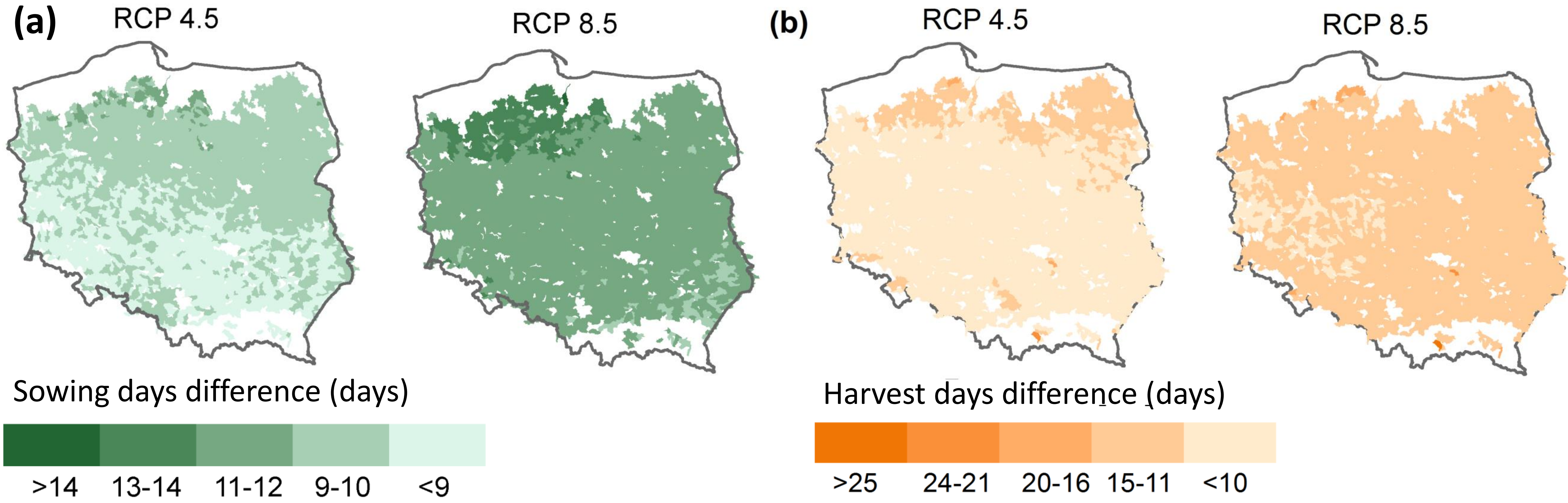


Figure 1 Ensemble mean changes of (a) sowing and (b) harvest dates of spring cereals between the near future horizon 2024-2050 and the reference period 1974-2000. White spaces are related to low fractions of a given crop in particular areas.

Methodology
Modelling of historical agricultural droughts
Identifing agricultural droughts with Weather Indices.

Weather indices (Institute of Soil Science and Plant Cultivation)

→ Spring cereals (mean index for spring barley and oats)

→ Identified years with the lowest values of WIs associated with droughts using available literature (Górski et al., 2008)

Quantification of the effects of meteorological conditions on crop growth in a given location.

Data from 34 climate stations of IMGW.

- WI above 100% refers to conditions above the average (i.e. leading to potentially **higher yields**)
- WI below 100% refer to conditions below the average (thus leading to weather-related **crop losses**). **Extremely low values of WI** can be proxies for extremely low crop yields

Methodology

Modelling of historical agricultural droughts

Identifing agricultural droughts with soil water content (SWAT).

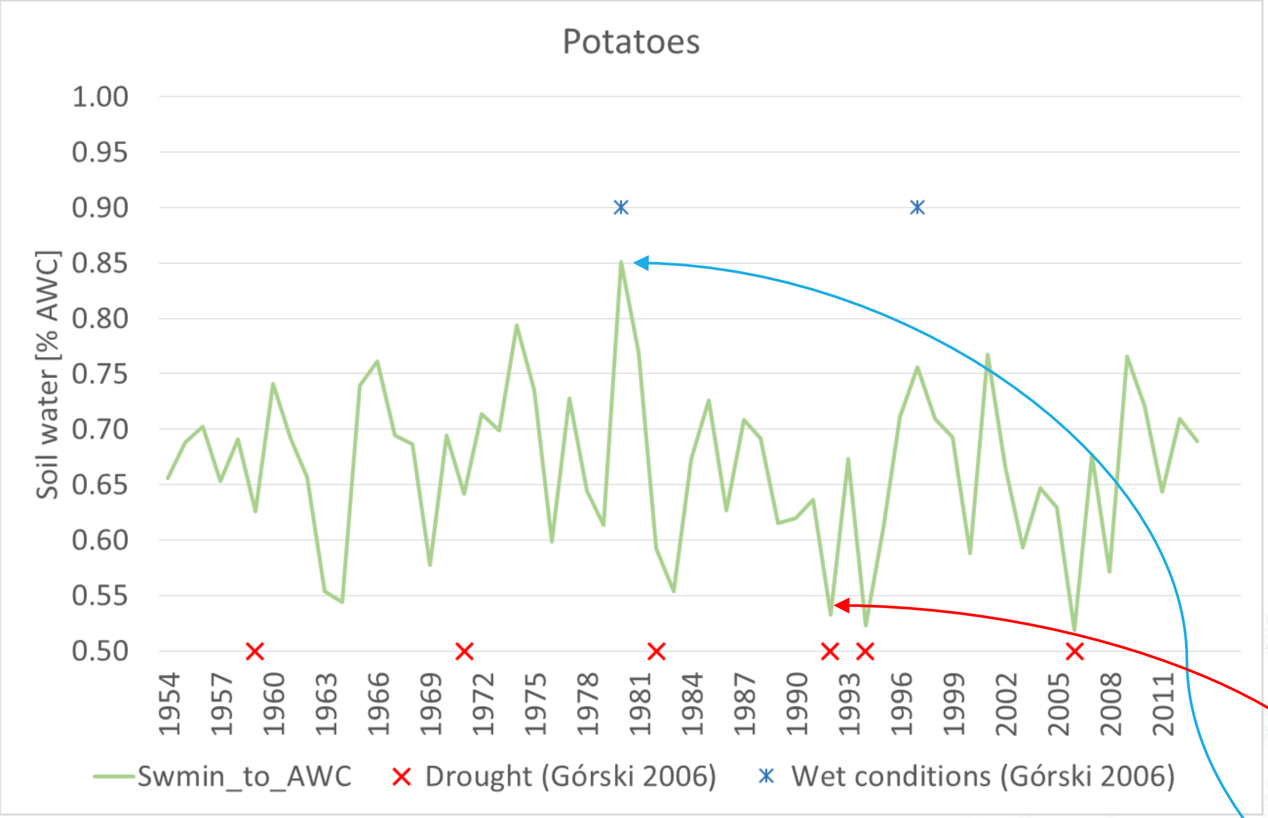
Soil water content (SWC) simulations from SWAT → Data was standardized with respect to the available water capacity (AWC) (%) → Temporal comparison of SWC simulations with crop-specific WIs

monthly outputs

According to soil type

For each year we calculated the **annual minima of SWC in the critical growth periods (denoted as *SW_{crit}*): May-June for spring cereals.**
(highest crop- and soil-specific thresholds of climatic water balance defined in the Decree of the Minister of Agriculture and Rural Development)

Simulated soil water content vs. water-related crop losses



1992 – largest historical drought-related loss

1980 – largest historical excessive water-related loss

Górski, 2006

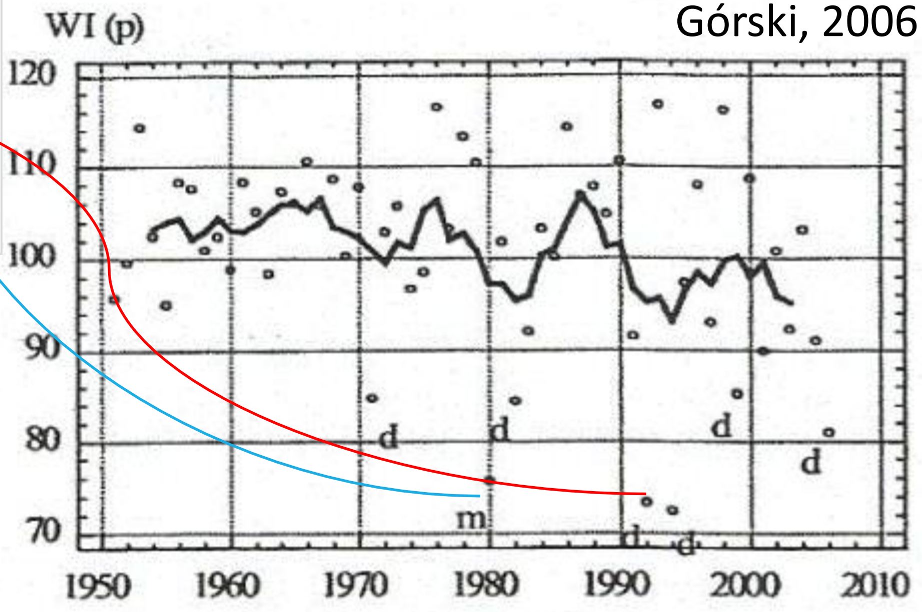


Figure 10. Potato weather index WI (p) in Poland (mean value for 20 localities)

Comparison of the simulated soil water index SW_{crit} from SWAT with the weather index for spring cereals.

- For spring cereals, six years wit droughts were identified: 1979, **1992**, 1994, **2000**, 2006 and **2008**.

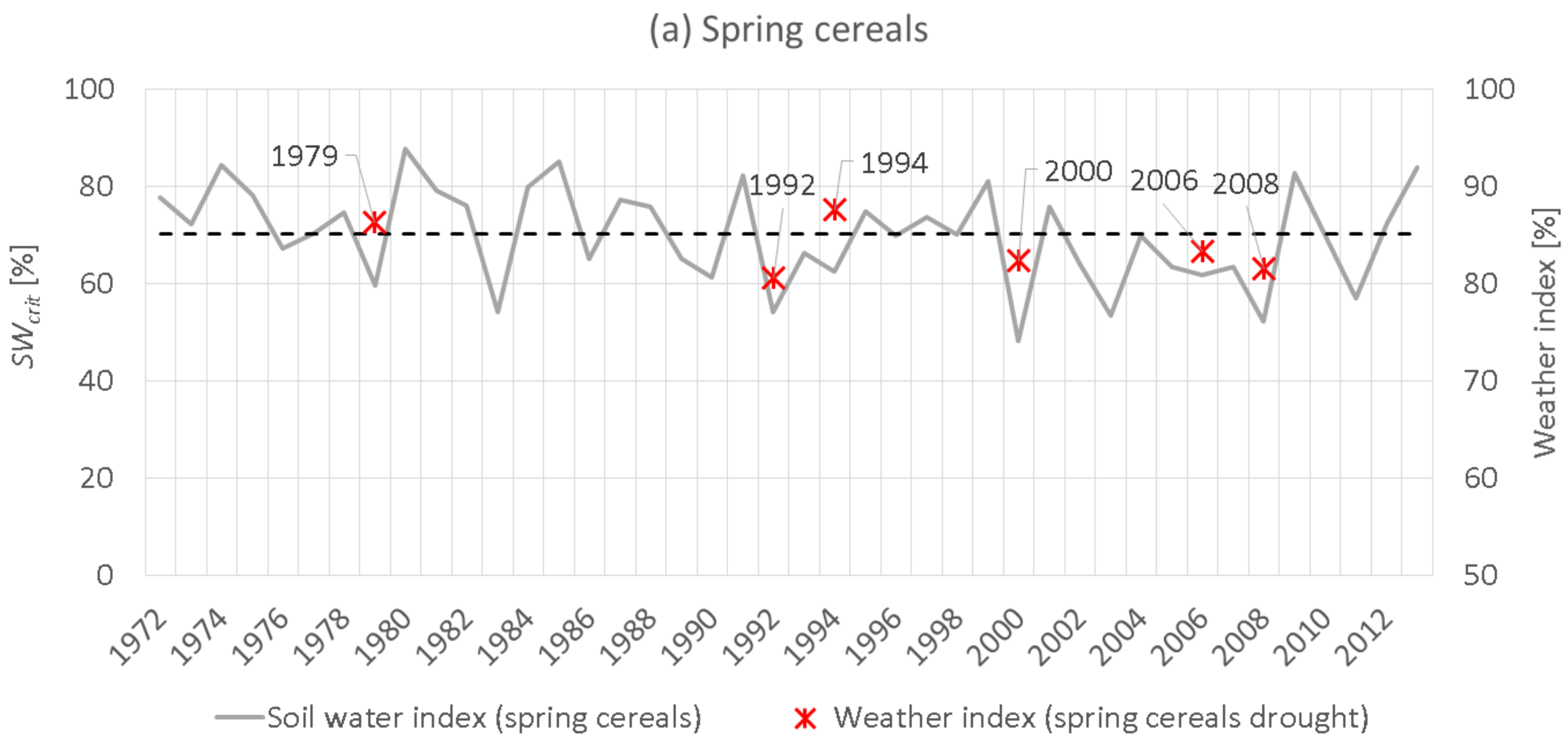
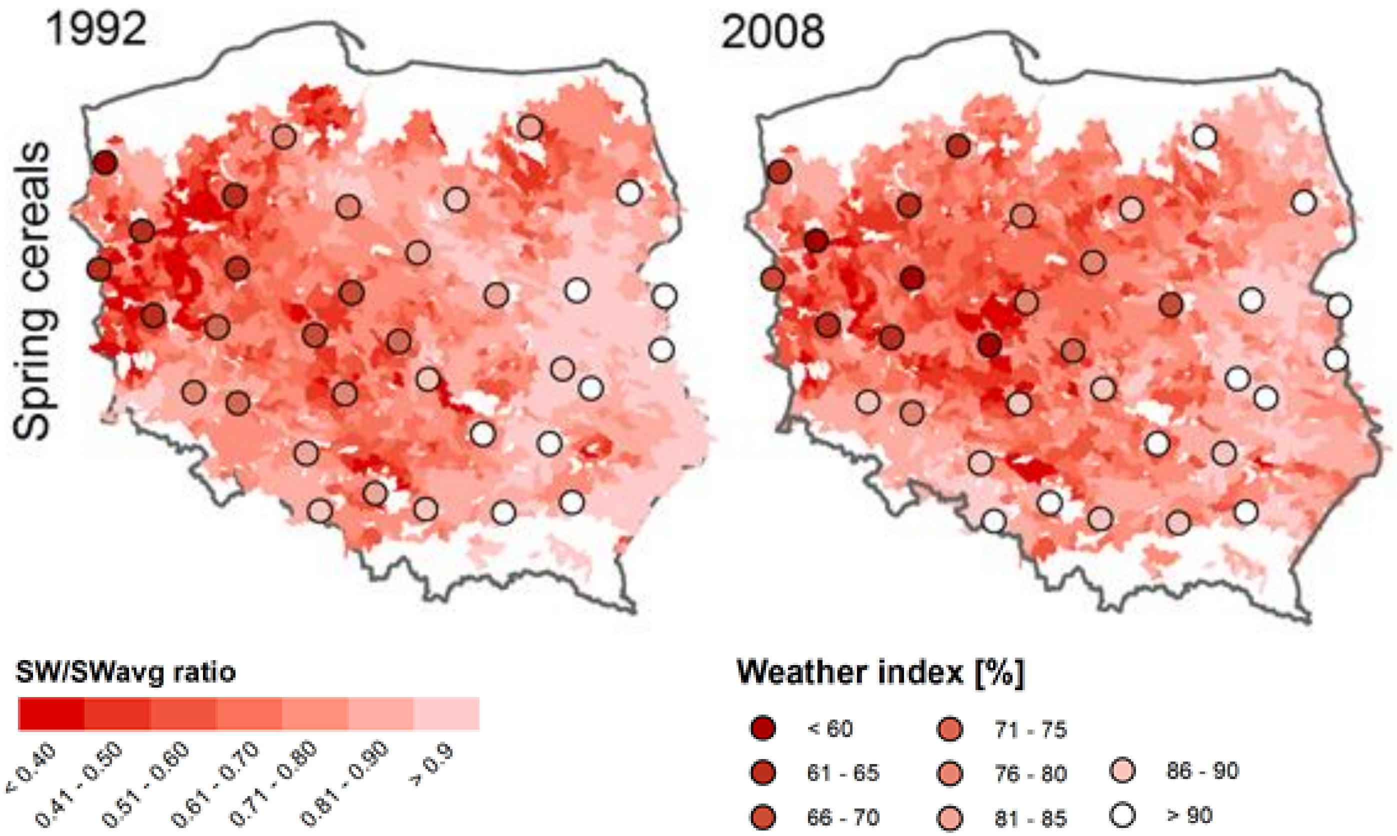


Figure 2 Comparison of the simulated soil water index SW_{crit} from SWAT with the weather index for (a) spring cereals. Only WIs for drought years are shown. Dashed lines refer to the multi-annual mean values of soil water indices.

Results

Comparison of the simulated soil water index SW_{crit} from SWAT with the weather index for spring cereals (spatial analysis).



- Values of SWC crit that were lower than 1 correspond to conditions below the average.
- A visible **spatial correlation** between the simulated soil water indices and the station-based weather indices.

Figure 3 Maps of SWAT-based estimates of soil water content in drought years (as of 30 June for spring cereals) as fraction of multi-annual mean soil water content versus maps of station-based weather indices (points) for spring cereals in selected drought years. White spaces are related to low fractions of a given crop in particular areas.

Methodology

Projections of changes in soil drought conditions affecting crops

Soil Water Content in critical growth periods $\boldsymbol{SW_{crit}}$

Calculated for each hydrological response unit (HRU)

5th percentile denoted as **deficit soil water index** $\boldsymbol{DSWI_5}$

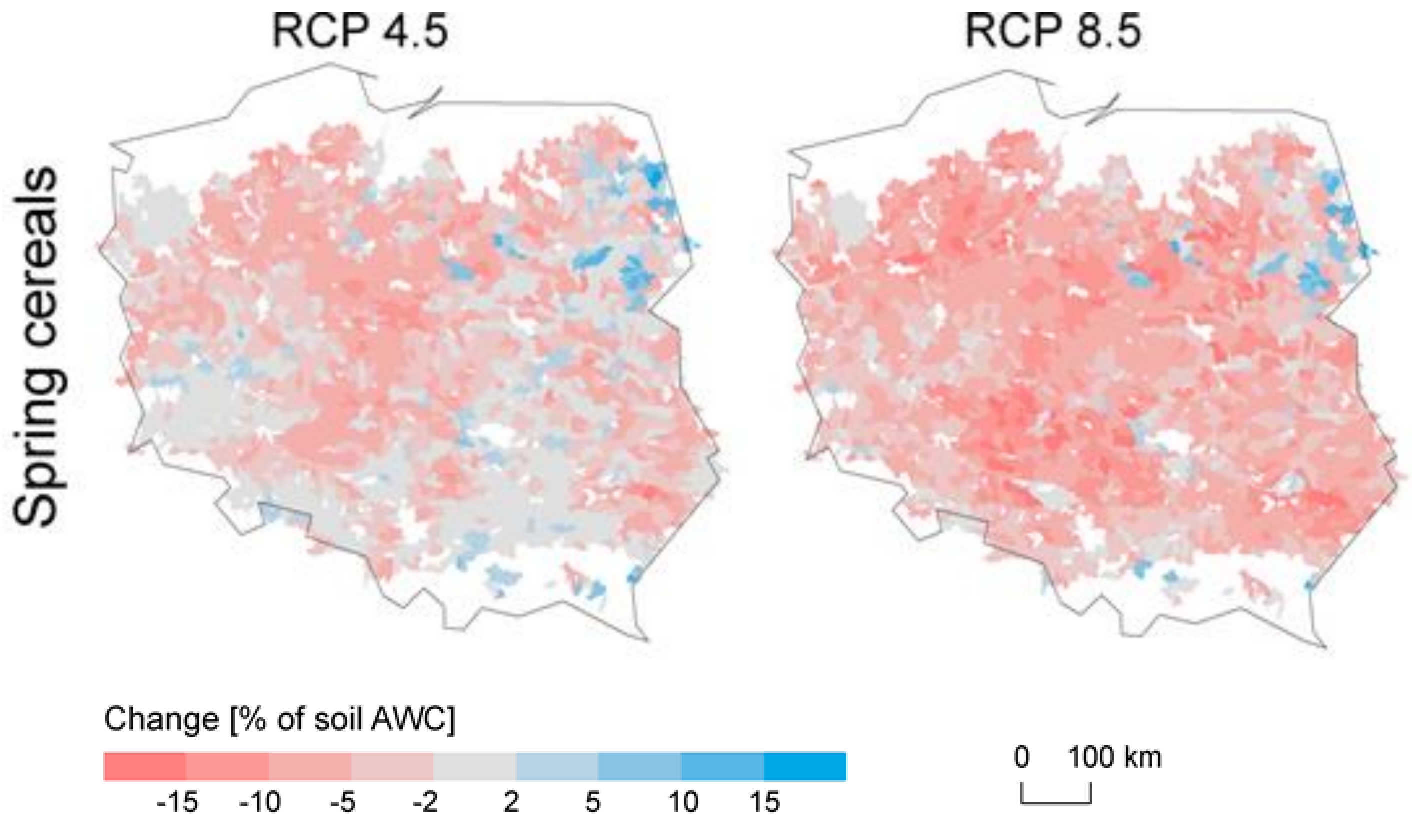
Based on 27 annual values representing the simulation period

The effect of climate change

- The difference between the future horizon and the reference period, for each climate model.
- multi-model ensemble median

Results

Projections of changes in soil drought conditions affecting crops



- The magnitude does not usually exceed 5% and rarely exceeds 10% (understood as the soil water content relative to the plant's available water capacity).

Figure 4 Ensemble median of projected changes in soil water deficit indicator (*DSWI*$_5$) for spring cereals, potato and maize. Changes are expressed as differences between the near future period 2024-2050 and the reference period 1974-2000. White spaces are related to low fractions of a given crop in particular areas.

Conclusions

- There is a multitude of **other factors** (e.g. CO_2 fertilisation effect, technological development) affecting future crop yields that were not analysed here.
- Projections are associated with a robust signal of mean annual **temperature increase** (ranging between 0.7 and 1.8 ^{o}C) and a moderate signal of annual **precipitation increase** (3.5-11%), producing an increase in mean annual runoff by 5-38%.
- Since the climate warming leads to **increased evapotranspiration**, whereas **increased precipitation leads to increased infiltration**, the combination of both may result in **highly uncertain changes in soil water conditions**. We focus our attention on indicators representing **extremes** rather than average conditions.
- SWAT model developed for the VOB is capable of **capturing spatio-temporal soil drought conditions** (leading to crop losses).
- Prevailing **decreases in deficit soil water index** $DSWI_5$ for spring barley can be interpreted as the climate change-driven **increase in soil drought** conditions in the critical growth period of spring cereals.

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Projected changes in hydroclimatic variables

The multi-model ensemble (MME) median change in mean annual:

Temperature

RCP 4.5 RCP 8.5

NF (2024 – 2050)

FF (2074 – 2100)

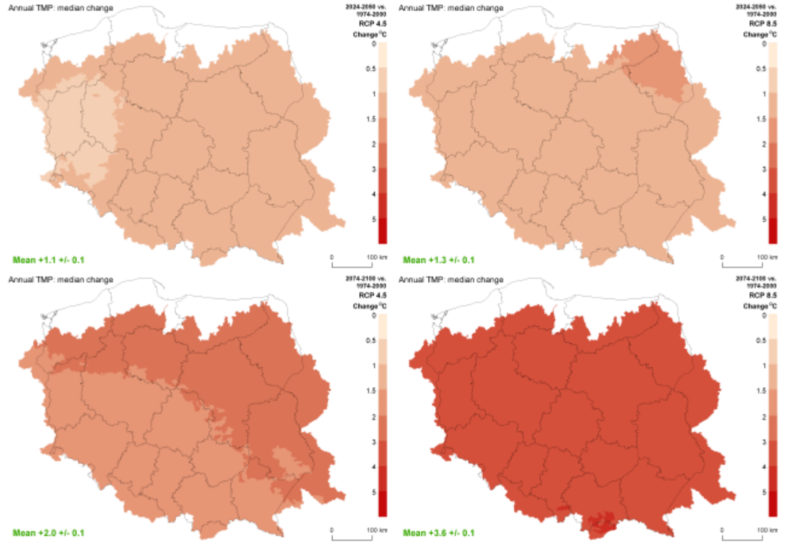

Figure 2: The MME median change in mean temperature for the near and far future under RCPs 4.5 and 8.5.

Precipitation

RCP 4.5 RCP 8.5

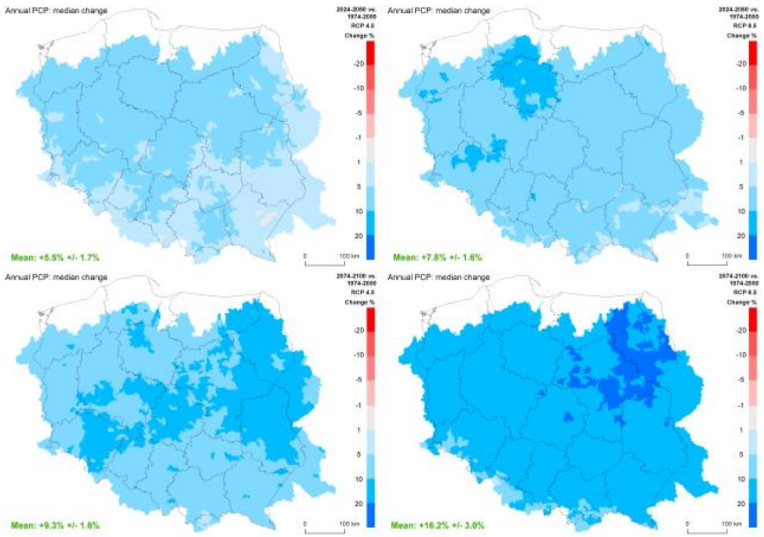

Figure 5: The MME median change in mean annual precipitation for the near and far future under RCPs 4.5 and 8.5.

Runoff (SWAT)

RCP 4.5 RCP 8.5

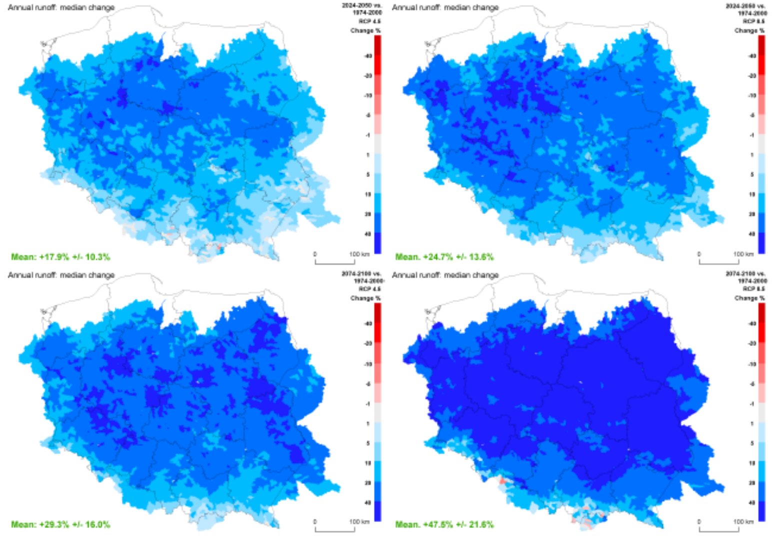

Figure 11: The MME median change in mean annual runoff for the near and far future under RCPs 4.5 and 8.5.

Piniewski et al., Met Zeit, submitted