IUGG BERLIN 2023

THE 28TH GENERAL ASSEMBLY

Ongoing changes in soil moisture conditions in the Vistula catchment

Emilia Karamuz, Tesfaye Belay Senbeta, Ewa Bogdanowicz,

Jarosław Napiórkowski, Monika Kalinowska

Humdrought Project - Sheng project financed by Polish National Science Centre (contract 2018/30/Q/ST10/00654)

Institute of Geophysics
Polish Academy of Sciences

NATIONAL SCIENCE CENTRE
POLAND

Ongoing changes in soil moisture conditions in the Vistula catchment

<u>Outline:</u>

- Introduction
- Motivation, aim of the study
- Materials and methods
- Results
- Conclusions

Introduction

- In the last two decades, a significant deterioration of soil moisture conditions has been observed in Poland.
- Ongoing climatic changes result in shifts in the beginning and duration of thermal seasons as well as periods of occurrence and accumulation of snow cover.
- The aggregate adverse effects of these alternations are putting intense pressure on the natural environment.
- Soil moisture shortages in the first phases of the growing season are particularly severe.
- They limit the possibilities of carrying out agro-technical work and maintenance treatments such as fertilising or spraying, contributing to significant losses in agricultural cultivation.

Motivation and aim of the study

- A more detailed analysis of this phenomenon is needed, mainly looking at the long-term trends of soil moisture conditions on a seasonal basis, which remain unclear, especially for the early spring period.

- **This study examines changes in soil moisture and evaporative stress conditions for the period 1980-2020.**

The key scientific questions:

- Is a drying trend observed in the Vistula catchment?
- Which parts of the Vistula catchment are most significantly affected by the drying trend?
- How are changes in soil moisture manifested in a seasonal perspective?

Vistula River near Warsaw on April 23, 2020.
The state of the hydrological drought in April this year was the worst in the history of measurements

- Soil moisture is a significant factor in the functioning of the ecosystems
- Moisture in the soil control productivity, providing water for plant growth and transpiration.
- Recent, more frequent events with a deficit of soil water have severe ecological, economic, and social impacts

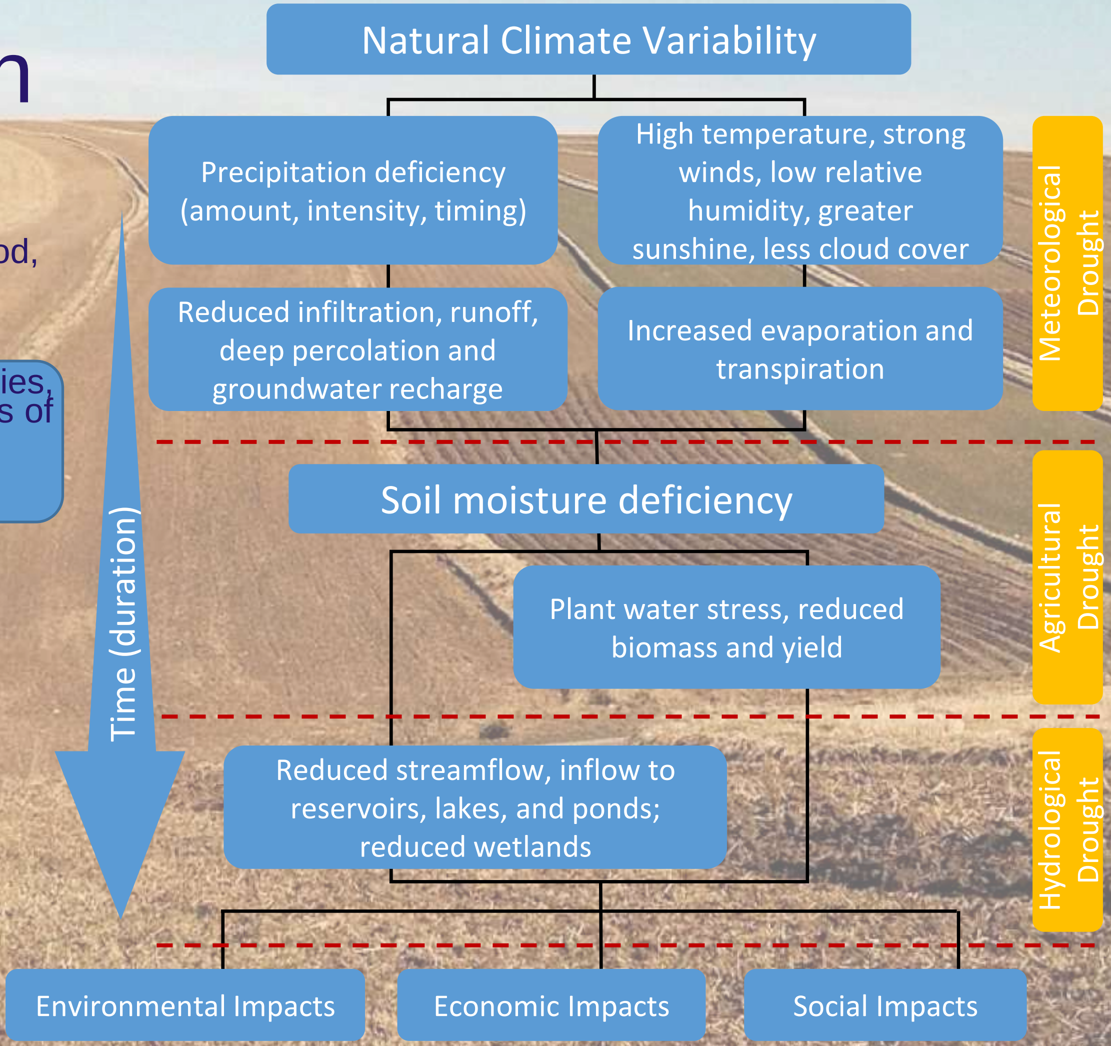
Drought formation

Drought starts from a deficiency of precipitation (enhanced by heat waves) over an extended period, resulting in a water shortage.

Complex interplay between precipitation deficiencies, or excessive evapotranspiration, and the demands of human and environmental water use that may be exacerbated by inefficiencies in water distribution, planning, and management

Drought classification:

- meteorological,
- agricultural,
- hydrological, and
- socioeconomic.



Soil moisture data

- In-situ measurements are extremely scarce
- Satellite-based RS data help to overcome the observational gap
- Land Surface Models (driven by RS data) provide long-term estimates of land surface conditions, including Soil Moisture
- GLEAM – Global Land Evaporation Amsterdam Model,
  - version 3.5a;
  - simulations available for 1980-2020

GLEAM
Global Land Evaporation Amsterdam Model

- It estimates the different components of terrestrial evaporation.
- Intermediate outputs of the model include:

root-zone soil moisture (SMroot), $[m^3/m^3]$

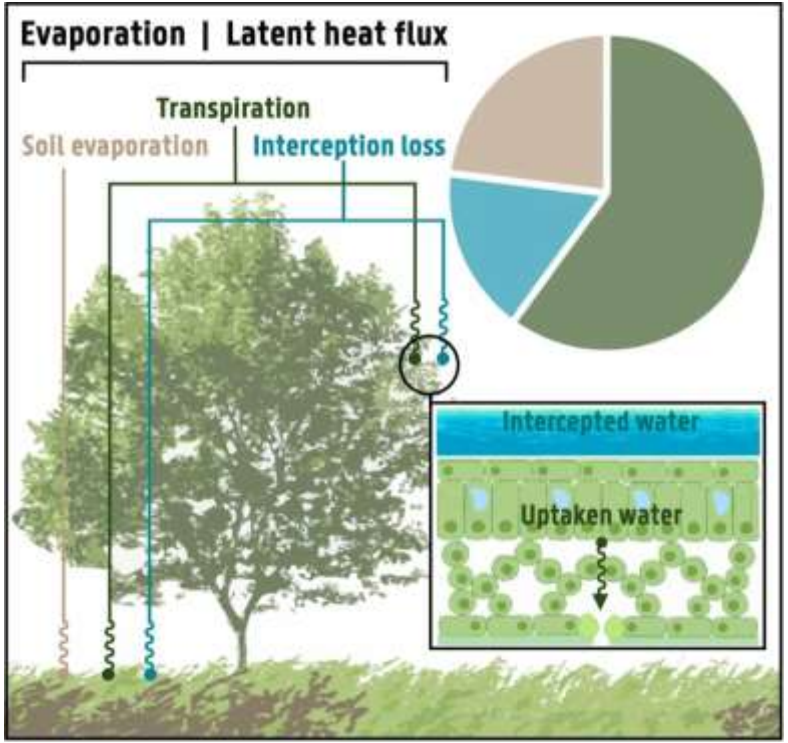
surface soil moisture (SMsurf); 0-10 cm $[m^3/m^3]$

evaporative stress (S); S = (E – Ei)/Ep [–]

- **E** - Actual evaporation [mm/day]
- **Ep** - Potential evaporation [mm/day]
- **SMroot** - Root-zone soil moisture $[m^3/m^3]$
- **SMsurf** - Surface soil moisture; 0-10 $[m^3/m^3]$

Datasets are organised in netcdf files.

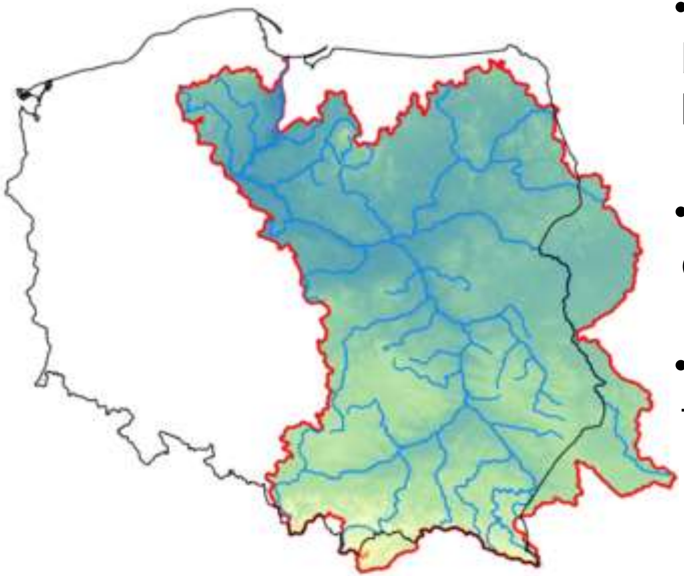
There is one netcdf file per variable and per year, and they are stored as a 3D array with dimensions 720 x 1440 x ndays



Martens et al. (2017, GMD).

Study area

VISTULA River catchment:
Area: 193,960 km^2
River lenght: 901 km



- 87% of drainage basin area lies within Poland.
- The Polish part of the Vistula basin covers 54% of the total land area in Poland.
- It has important social and economic significance.
- The basin is inhabited by more than half of Poland’s population.

<u>Land use structure:</u>

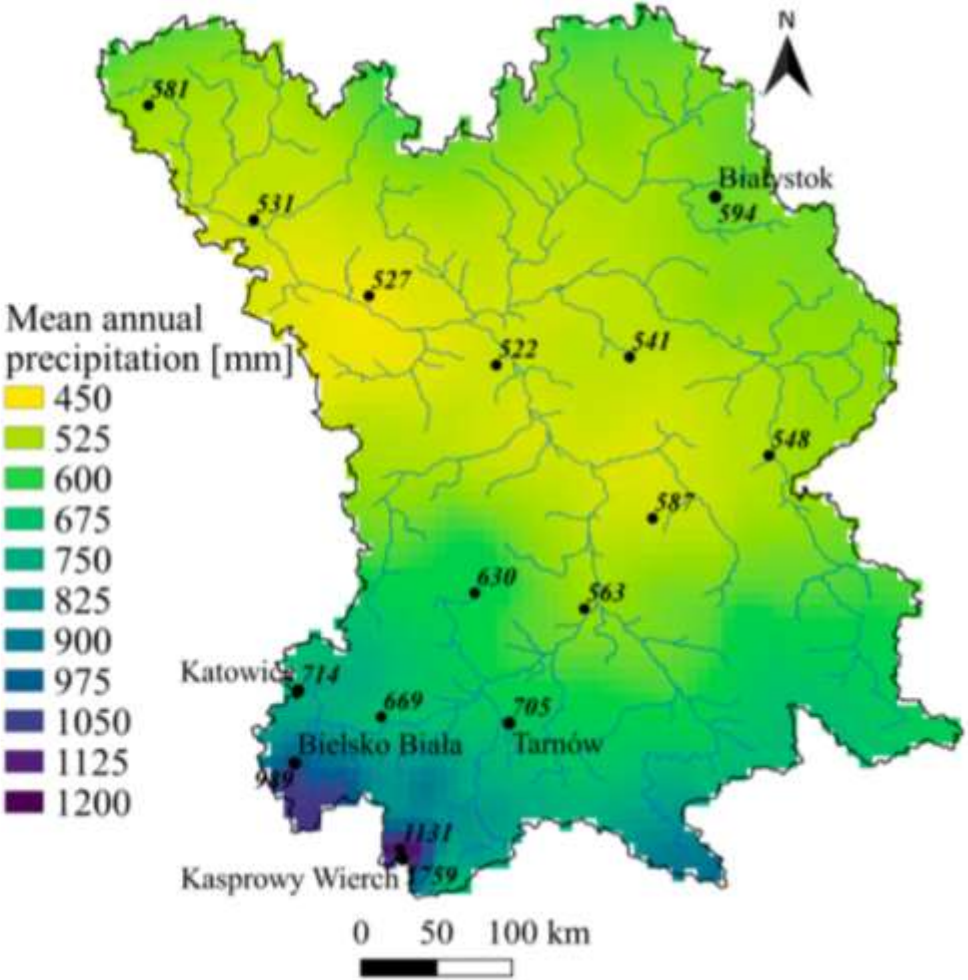
- 66% arable land,
- 29% forests and semi-natural ecosystems,
- 3% urbanized areas ,
- 1,5 % water bodies.

CLIMATE

The climate of the Vistula River basin is mainly continental, with variations between the mountainous southern part of the Upper Vistula and a wet, temperate climate at its lower northern part.

Precipitation patterns

- Average annual rainfall varies between 500–700 mm
  - with extreme annual precipitation at mountain stations
- Precipitation below 500 mm occurs only over a relatively small area of the river basin
  - central area of the western part of the basin (green-yellow area)
- Increased sums in the range of 600–700 mm and more are noted in the uplands (green area in the southern part of the catchment area)
- Generally, average rainfall totals decrease from southwest to northwest.



Spatial distribution of mean annual precipitation in the Vistula catchment based on E-OBS 20.0e data 1951-2019.

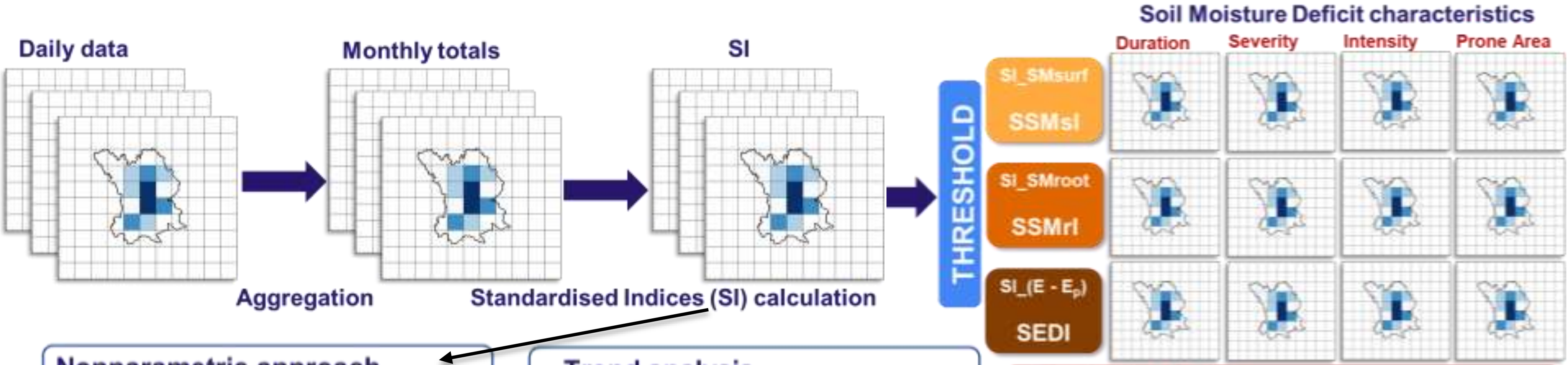
Materials and methods

Duration – period from the onset time to end time of a drought event

Severity – sum of SI values during a drought event

Intensity – ratio of severity to duration

Prone Area – area under drought



Nonparametric approach
- Empirical probability
  - Gringorten ploting position method

Trend analysis
- Modified Mann Kendall test

Standardised Indices:
SSMsl – *Standardized Soil Moisture Surface Index*
SSMrl – *Standardized Soil Moisture Root-zone Index*
SEDI – *Standardized Evapotranspiration Deficit Index*

Soil Moisture Data

Global Land Evaporation Amsterdam Model
- gridded dataset from satellite observation – v3.5a version

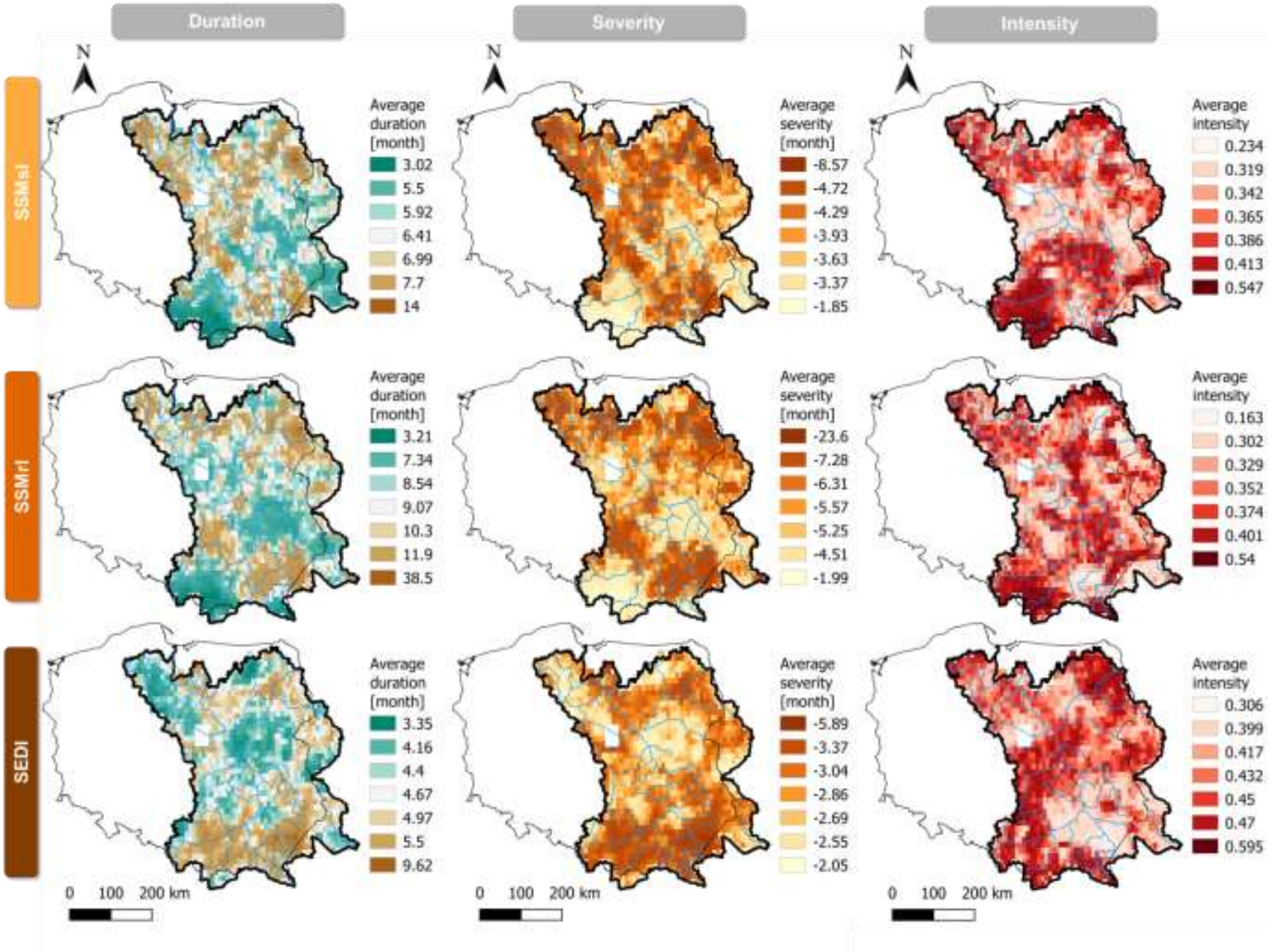
- **E** - Actual evaporation [mm/day]
- **Ep** - Potential evaporation [mm/day]
- **SMroot** - Root-zone soil moisture [m^3/m^3]
- **SMsurf** - Surface soil moisture; 0-10 [m^3/m^3]

Spatial pattern of Soil Moisture deficit in the Vistula catchment – average characteristics for 1980-2020

SSMsI *Standardized Soil Moisture Surface Index*

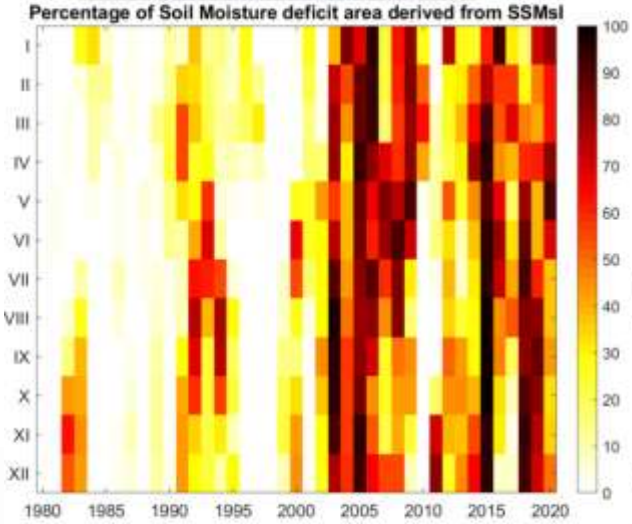
SSMrI *Standardized Soil Moisture Root-zone Index*

SEDI *Standardized Evapotranspiration Deficit Index*

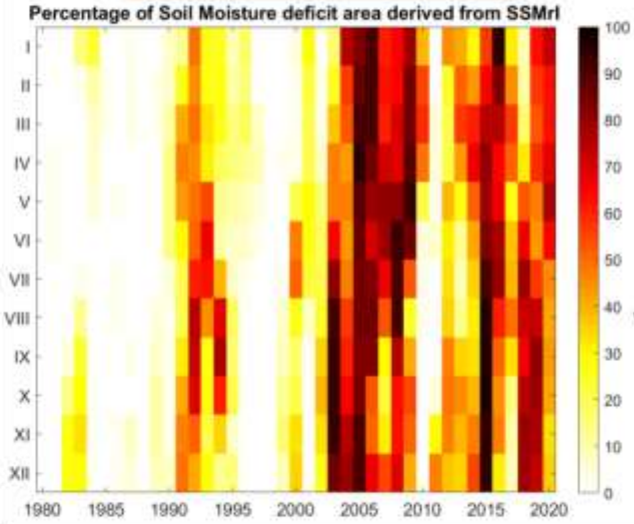


Area under Soil Moisture and Evapotranspiration deficit

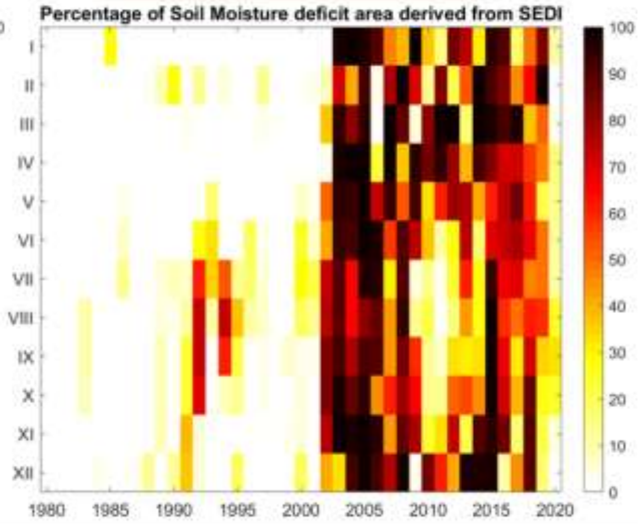
SSMsI



SSMrI



SEDI



SSMsI *Standardized Soil Moisture Surface Index*

SSMrI *Standardized Soil Moisture Root-zone Index*

SEDI *Standardized Evapotranspiration Deficit Index*

Changes (per decade) in Soil Moisture and Evapotranspiration deficit

Season		SSMsI	SSMrI	SEDI
Spring	PA	5.2	3.9	2.7
	AI	0.09	0.05	0.1
	AS	120	81	63
Summer	PA	2.5	4.3	1.8
	AI	0.06	0.07	0.1
	AS	52	93	37
Autumn	PA	2.3	3	1.4
	AI	0.07	0.08	0.07
	AS	47	77	47
Winter	PA	5.1	5	0.06
	AI	0.05	0.06	0.05
	AS	121	108	1.2

PA - PERCENTAGE AREA AI - AREA INTENSITY AS - AREA SEVERITY

statistically significant

statistically insignificant

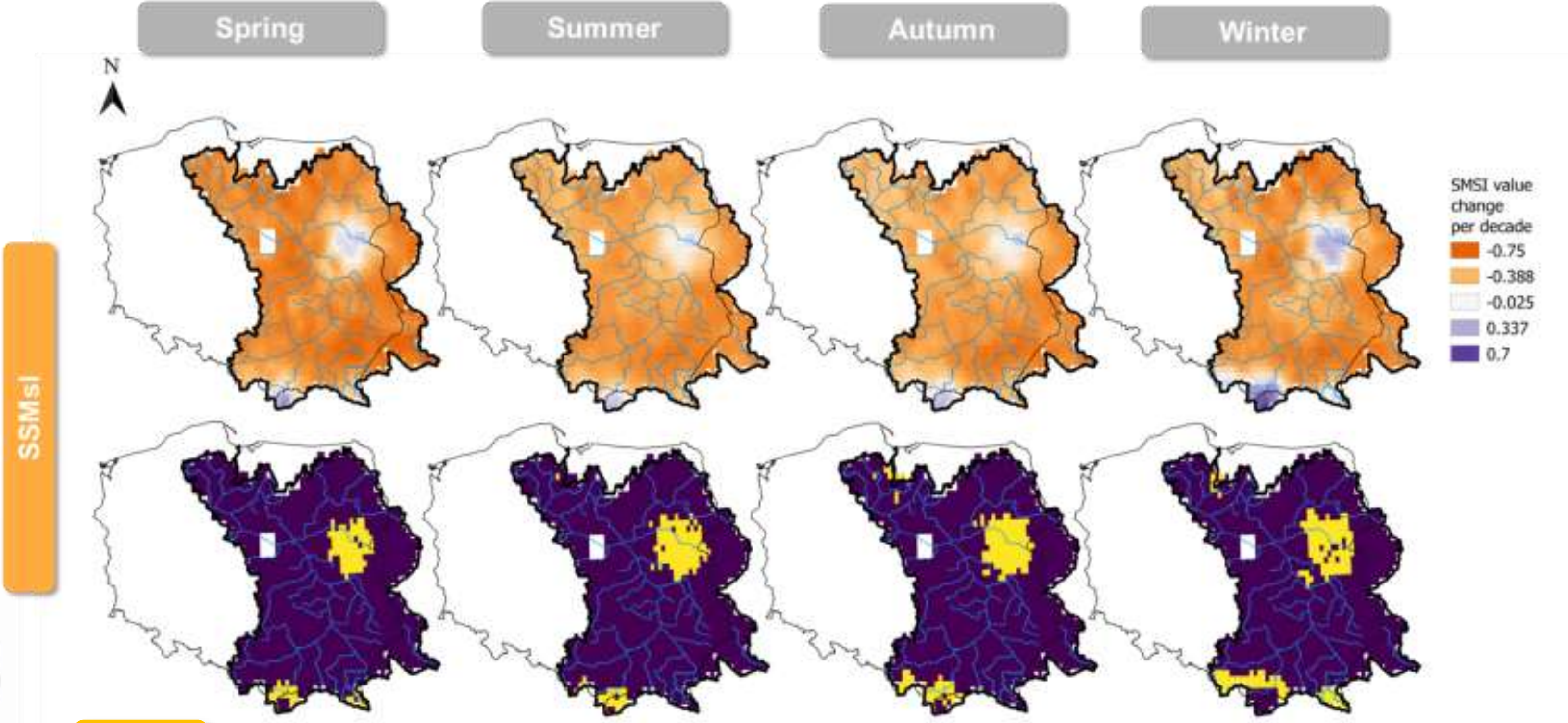
In spring and winter we see the greatest positive changes in the percentage of area under drought (area under drought pressure increases)
The same pattern is observed for drought area severity, especially for *SSMsI and SEDI.*

SSMsI *Standardized Soil Moisture Surface Index*

SSMrI *Standardized Soil Moisture Root-zone Index*

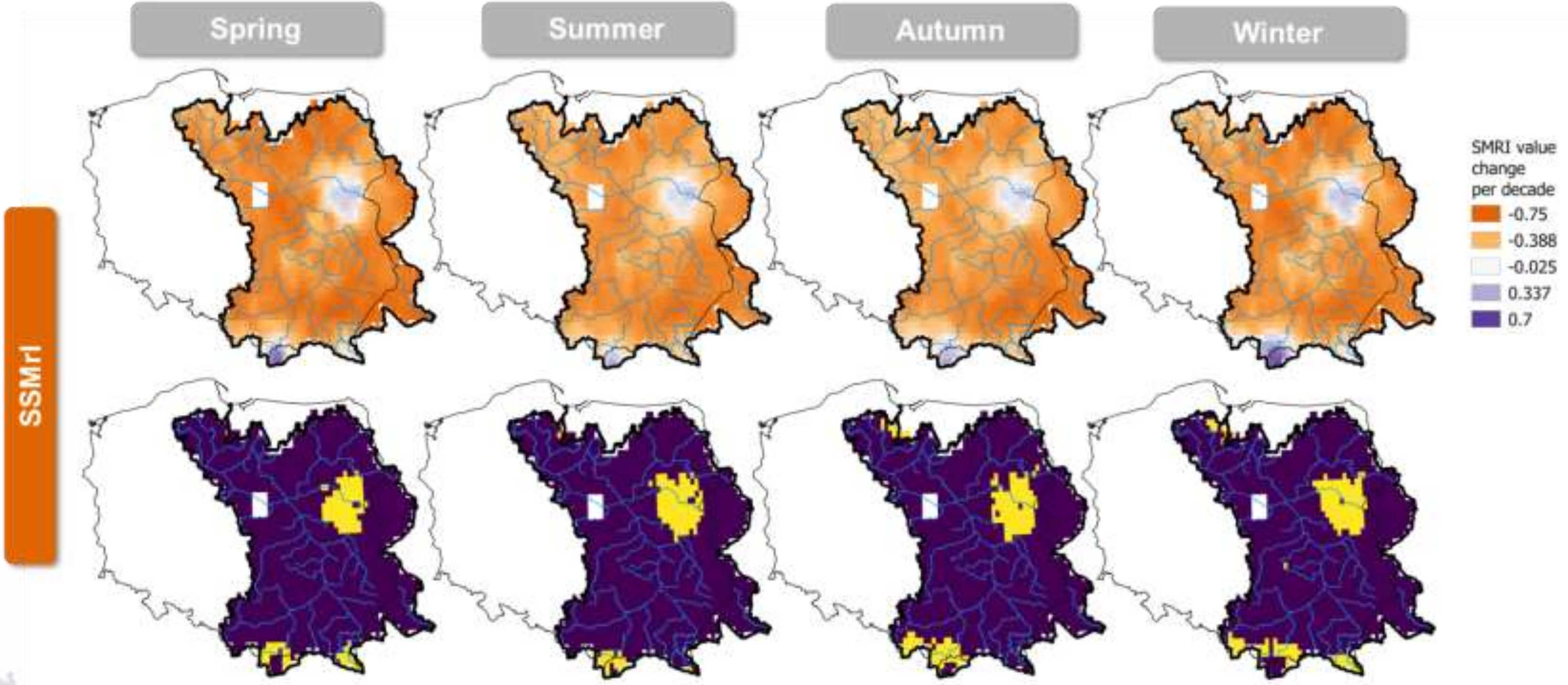
SEDI *Standardized Evapotranspiration Deficit Index*

Seasonal changes in the direction of Soil moisture and Evapotranspiration deficit.



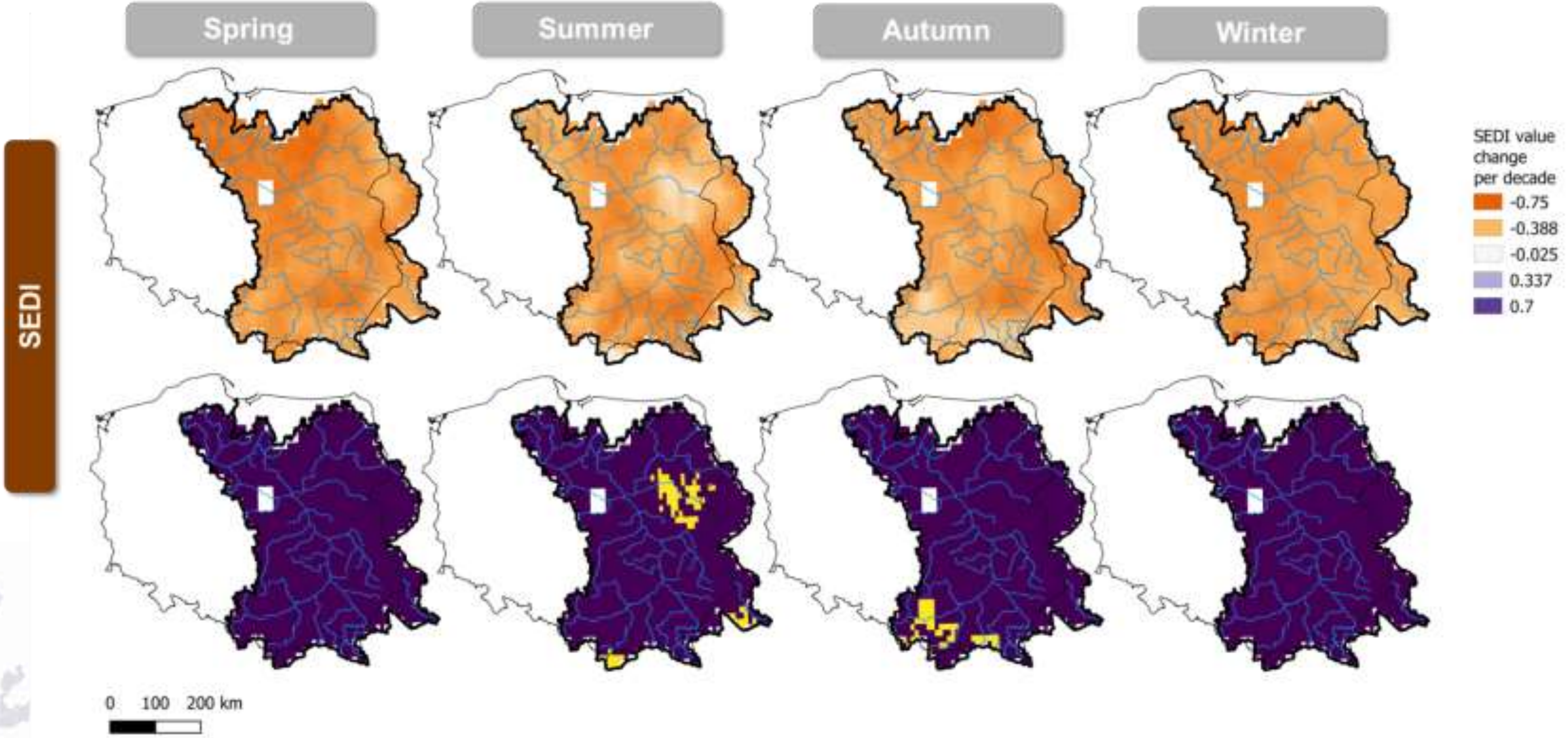
SSMsI *Standardized Soil Moisture Surface Index*

Seasonal changes in the direction of Soil moisture and Evapotranspiration deficit.



SSMrI *Standardized Soil Moisture Root-zone Index*

Seasonal changes in the direction of Soil moisture and Evapotranspiration deficit.



SEDI *Standardized Evapotranspiration Deficit Index*

Conlusions

- GLEAM provides access to soil moisture data on a global scale, offering a valuable alternative to sparse in-situ measurements.
- Soil moisture varies at interannual and seasonal scales, reflecting an impact of variable precipitation recharge and heat waves.
- Signals of extreme soil drought occur across the whole catchment.
- In the last two decades (starting from 2003), a strong signal of the Vistula catchment drying has been observed (clearly reflected in the PA under drought)
- The dynamics of the changes taking place in the Vistula Catchment are strongest during the spring and winter seasons.
- The Vistula catchment exhibits a drying trend for the entire area. Statistically significant for almost the whole basin, for all considered indexes.


Thank You for your attention !