Analysis of groundwater resources in Poland based on in-situ and satellite data

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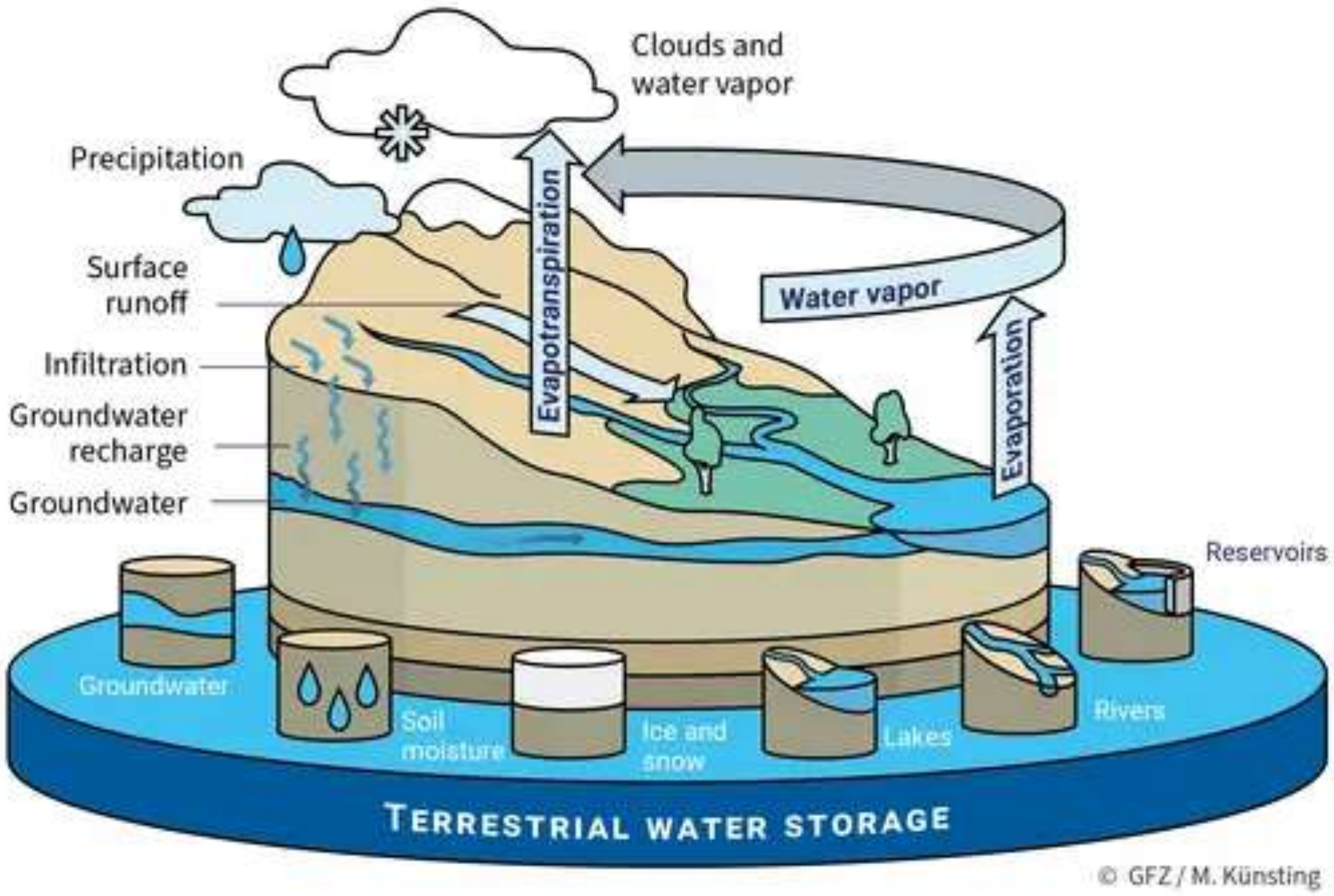
Terrestrial water storage

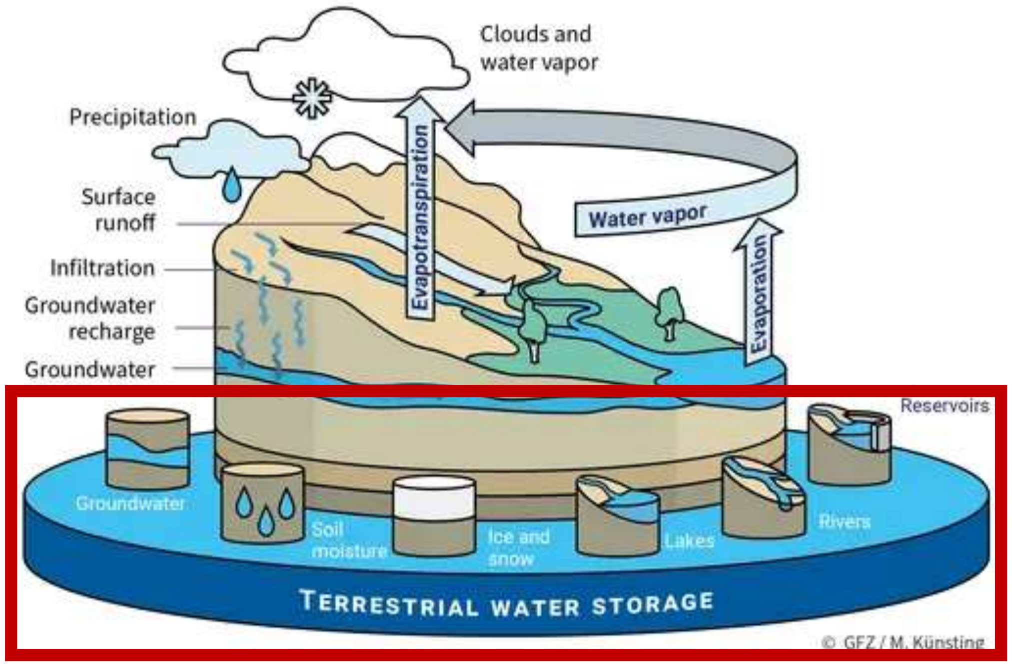
Terrestrial water storage (TWS) – total amount of water stored on and beneath the Earth's surface. It encompasses all forms of water in the terrestrial hydrological cycle, including:

- **Groundwater** (water stored in aquifers beneath the surface)
- **Soil moisture** (water held in the unsaturated soil layer above the water table)
- **Snow and ice** (seasonal snow cover and glaciers.
- **Surface water** (rivers, lakes, reservoirs, wetlands)
- Water in **biomass**



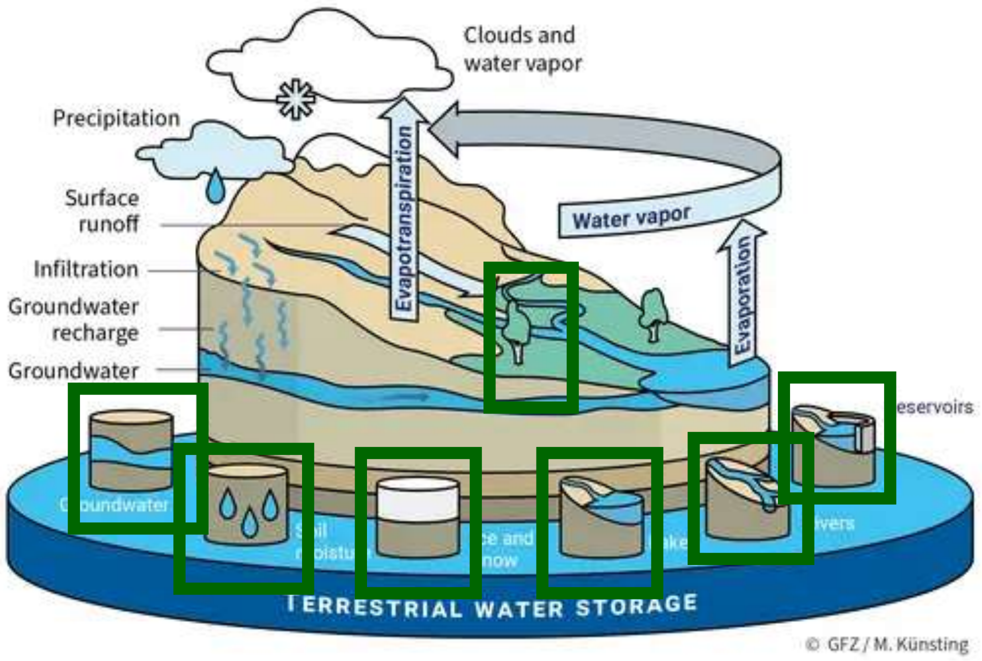
Measuring TWS

Satellite gravimetry (GRACE/GRACE-FO)



total water storage changes from observations of variations in Earth's gravity field

Hydrological models



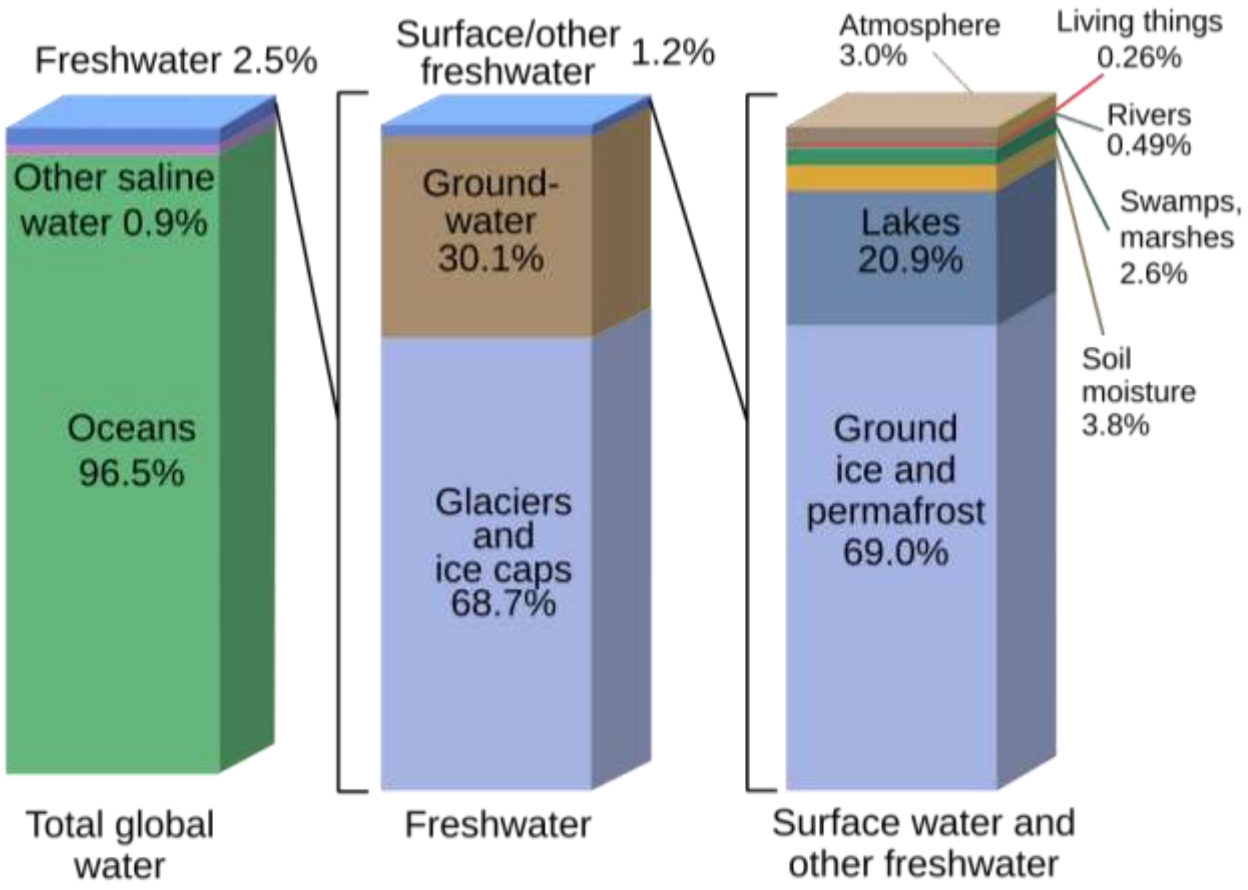
water storage changes based on meteorological measurements, satellite data and models of precipitation, temperature, evapotranspiration, etc.

Groundwater

- Largest freshwater reservoir in the hydrological system
- Primary source of fresh water for domestic, agricultural, and industrial purposes
- Accounts for **approximately 70% of drinking water resources used in Poland** (according to the information from hydrogeological survey)

Main challenges:

1. Climate change and associated extreme weather phenomena
2. Excessive exploitation
3. Groundwater is susceptible to long-term chemical and microbiological contamination that is difficult to remove



Source: https://water.usgs.gov/edu/gallery/watercyclekids/earth-water-distribution.html

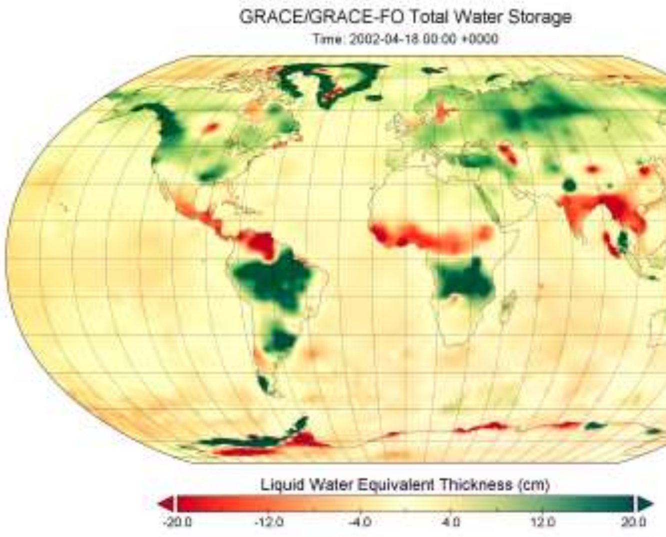
Measuring groundwater resources

In-situ groundwater measurements

Over 1400 measuring points from the national monitoring network

- Point measurements of groundwater level (not groundwater content)
- Data with uneven distribution, measurement frequency, and time series length
- To obtain groundwater storage (GWS) from water level, we need information on **specific yield**

Satellite gravimetry (GRACE/GRACE-FO missions)



Source: https://www2.csr.utexas.edu/grace/RL06_mascons.html

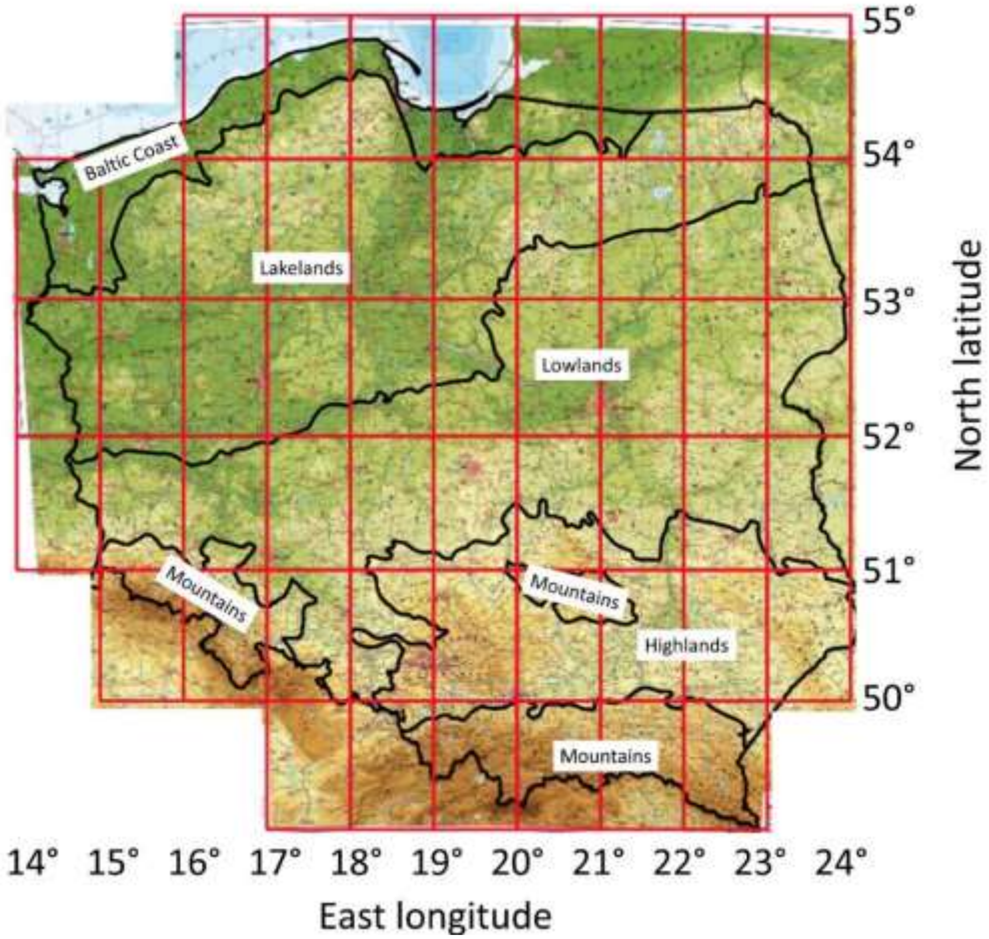
- Global gridded data for TWS
- Same spatial resolution for the entire globe, monthly data available from 2002 to present
- To obtain GWS, we need to remove other water storage components (soil moisture, water in snow and biomass) usually using hydrological models

GWS from GRACE/GRACE-FO (satellite-based GWS)

$$TWS = GWS + SWS + SnWS + CWS$$

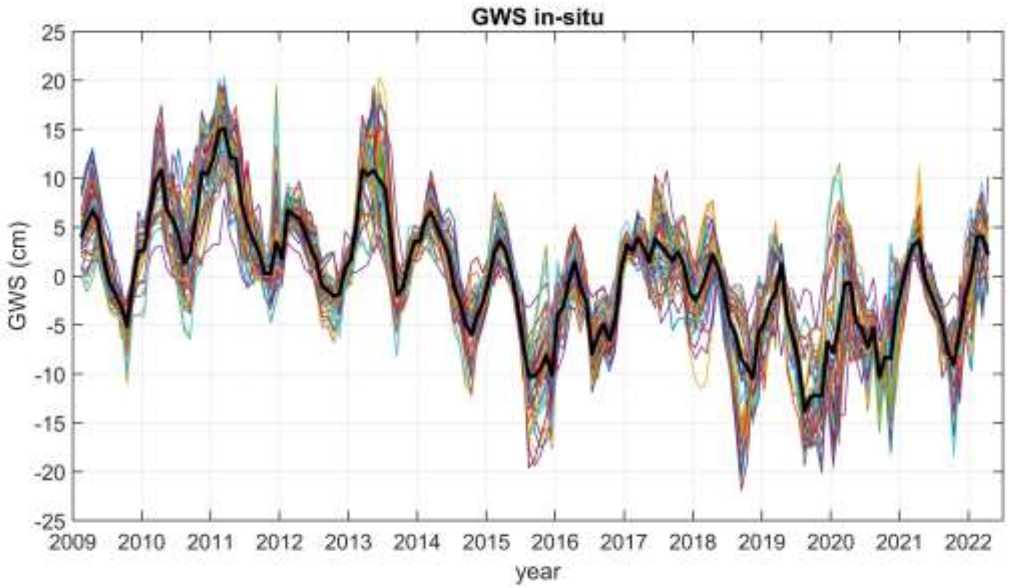
terrestrial water storage	groundwater storage	soil water storage	snow water storage	canopy water storage
TWS from GRACE/ GRACE-FO	unknown	TWS from hydrological models		

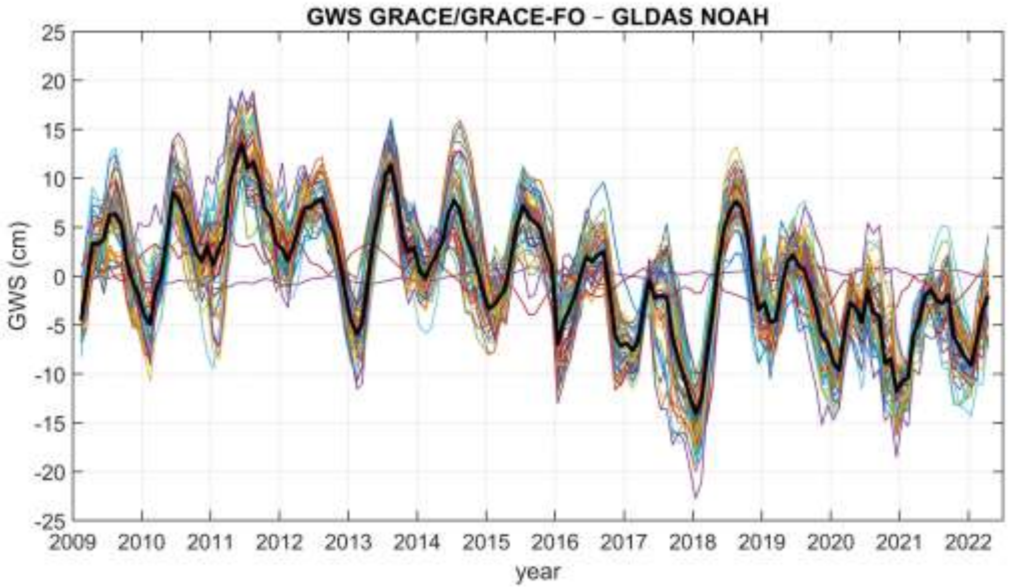
GWS in Poland



- Analyses in 1-degree grids
- **Satellite-based GWS**: SWS, SnWS, CWS taken from GLDAS model were removed from GRACE/GRACE-FO-based TWS in each grid
- **In-situ GWS:** measurements from wells located within one grid were averaged
- Analyses performed for:
  - different physiographic zones (Baltic coast, lakelands, lowlands, highlands, mountains),
  - different hydrodynamic zones (recharge, discharge, transit),
  - different aquifer types (porous, porous-fractured, fractured/karstic)

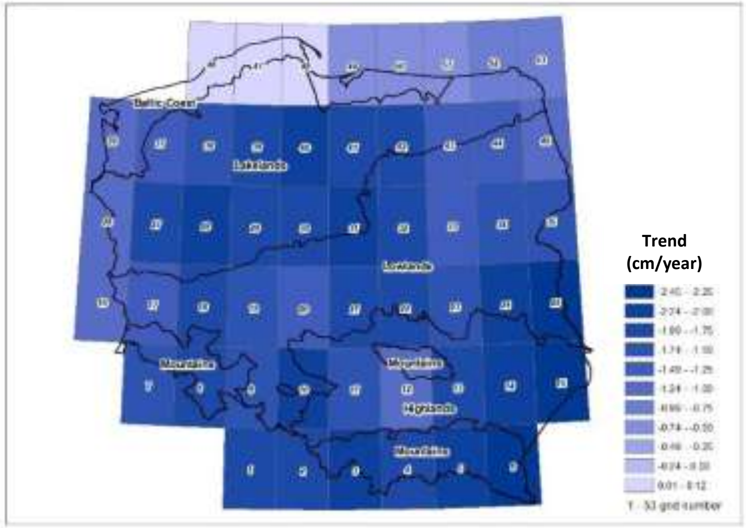
GWS in Poland – in-situ vs satellite-based





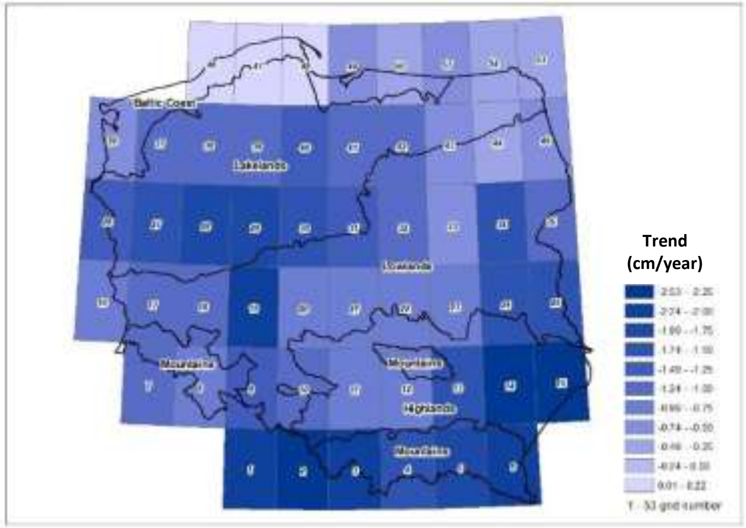
Trends in GWS (between 2009-2022)

satellite-based GWS



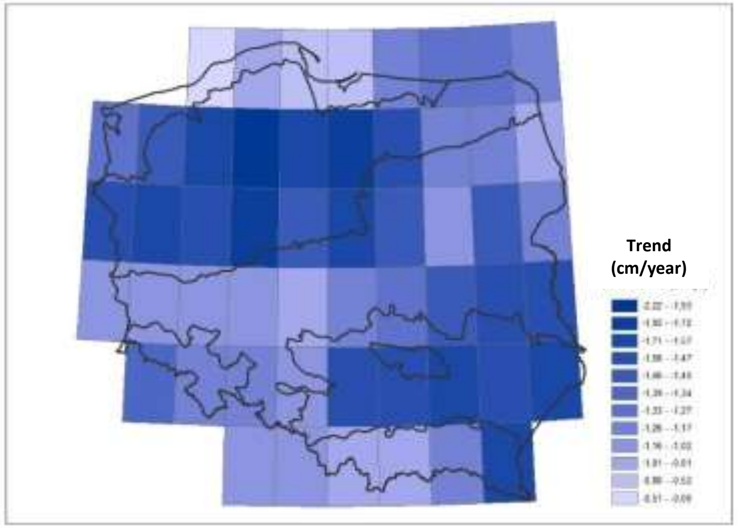
−2.45 to +0.12 cm/year
mean −1.56 cm/year

in-situ GWS



−2.53 to +0.22 cm/year
mean −1.16 cm/year

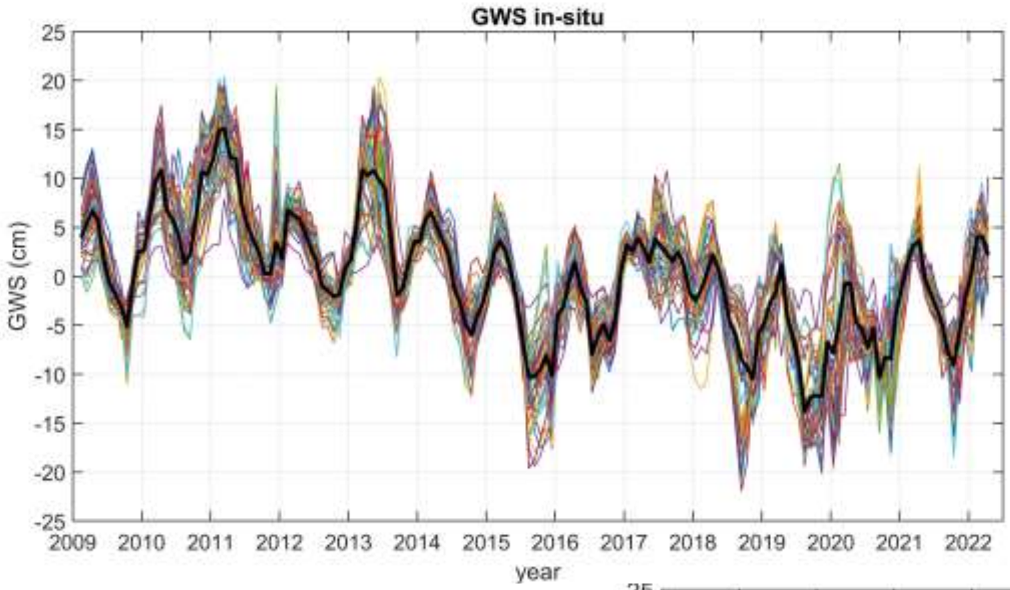
GRACE/GRACE-FO-based TWS

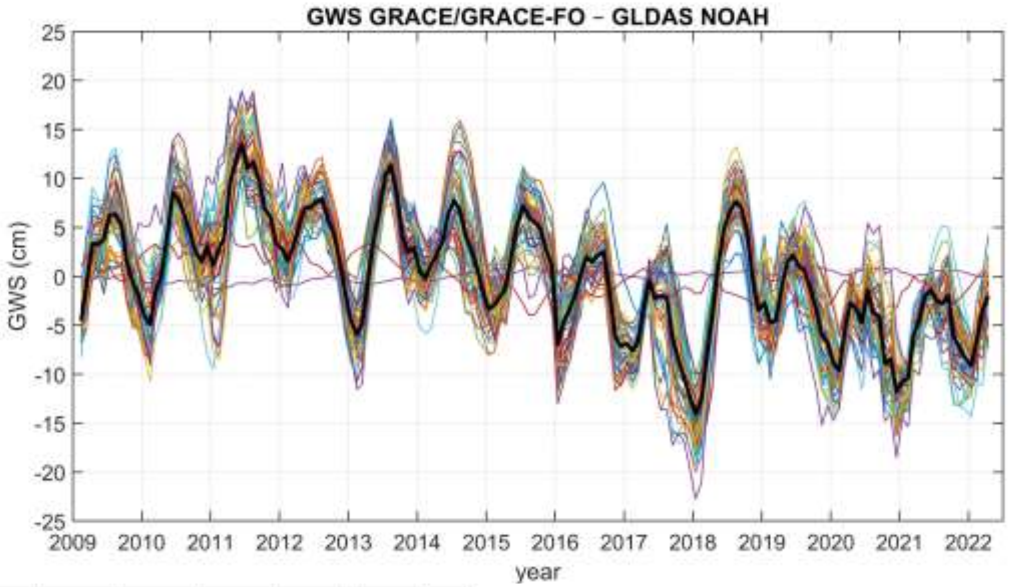


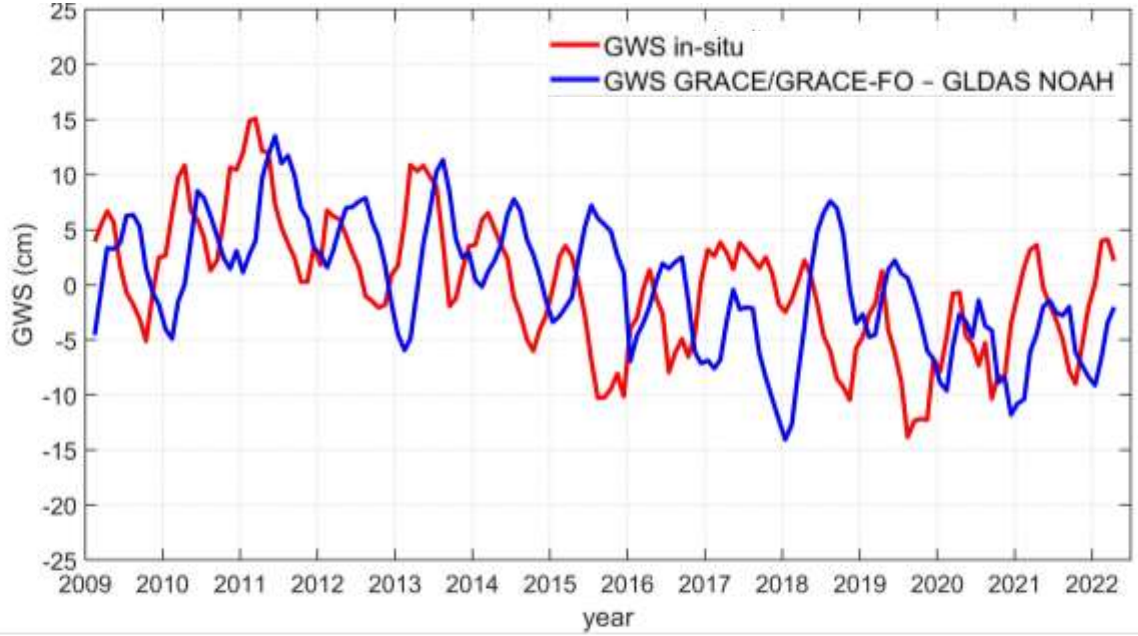
−2.22 to −0.06 cm/year
mean −1.23 cm/year

- The highest decline values were noted in south-eastern Poland and Greater Poland Lakeland, while the minimum decrease was observed in the north
- Negative trends in GWS are correlated with an observed negative trends in GRACE/GRACE-FO-based TWS

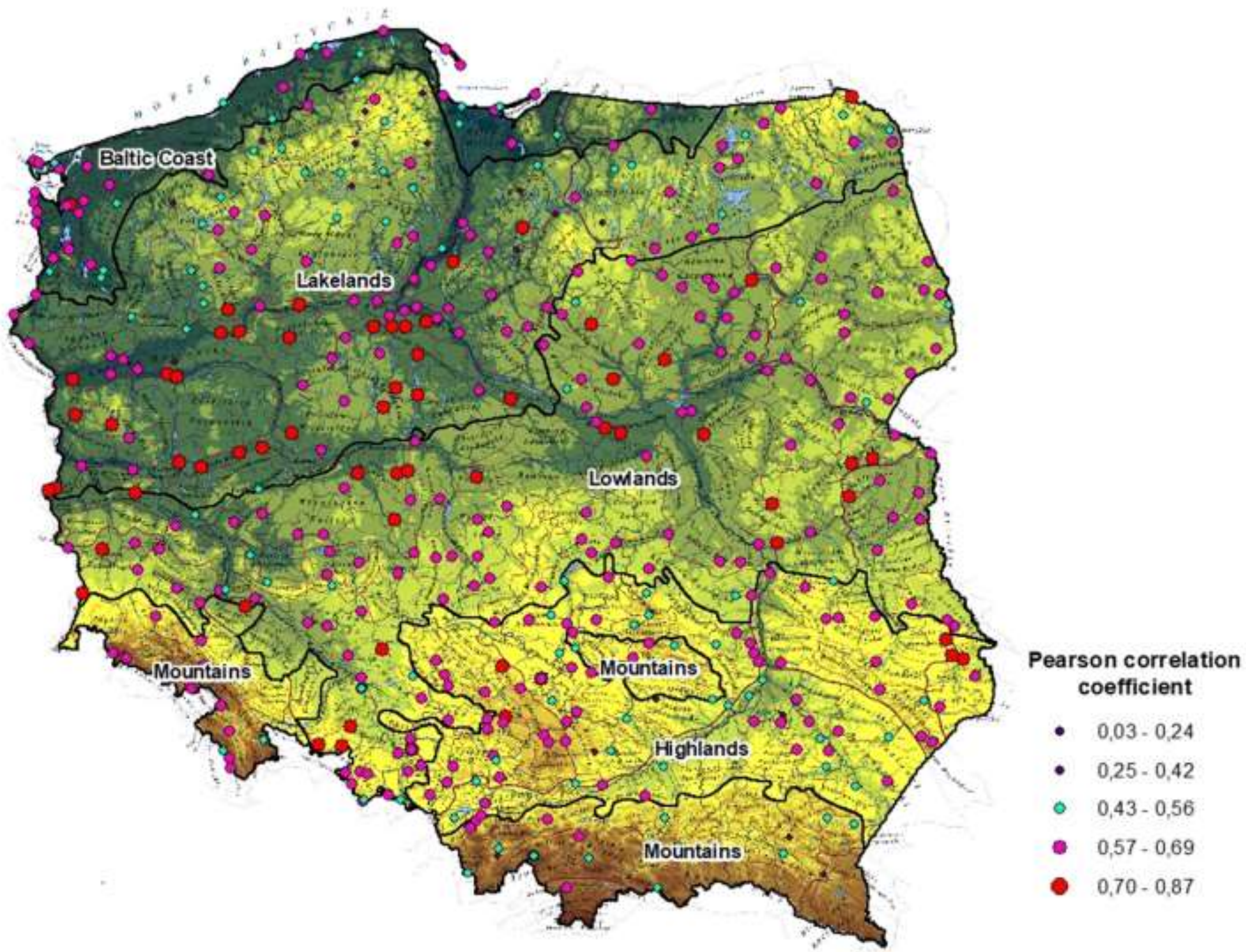
GWS in Poland – in-situ vs satellite-based







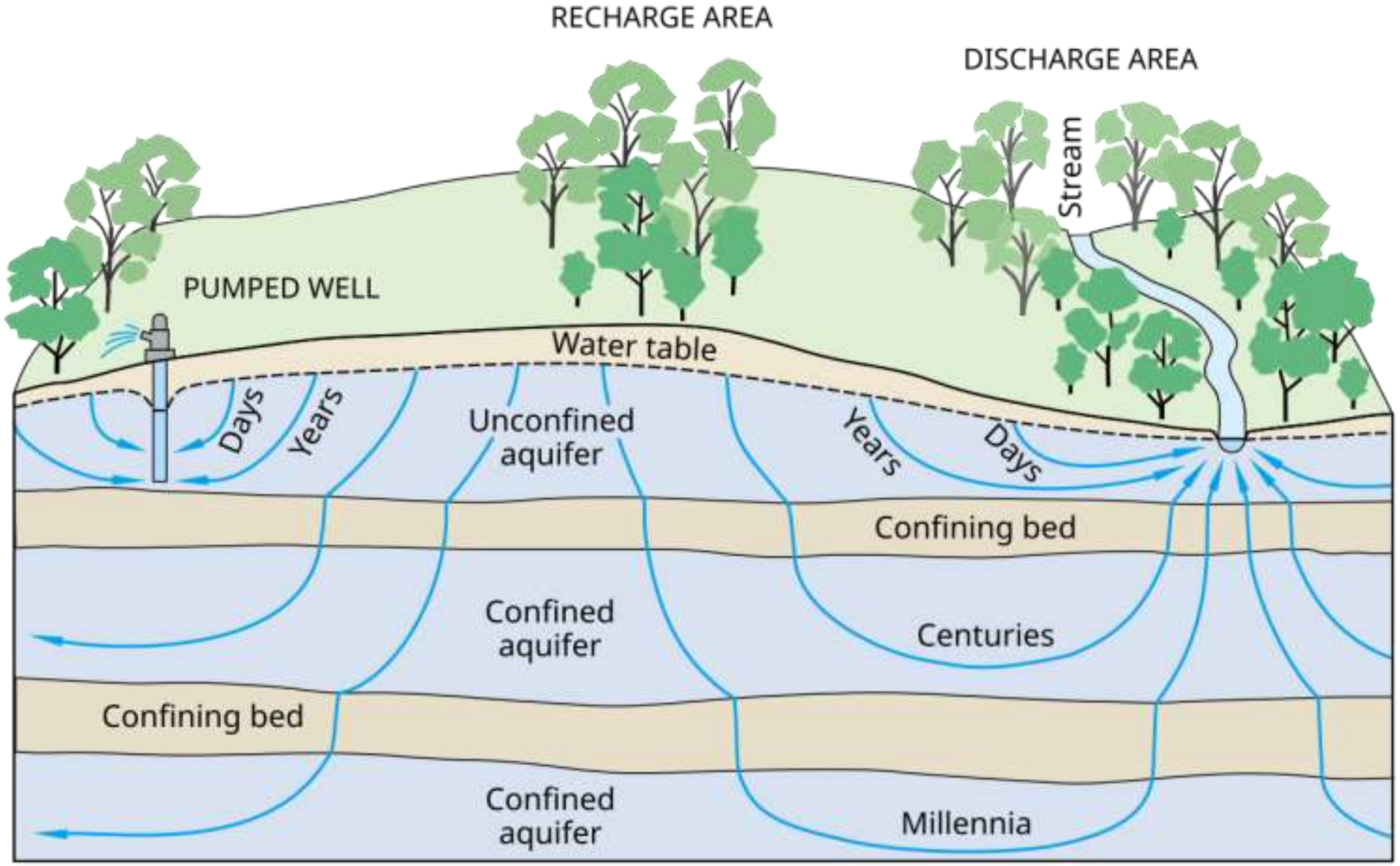
In-situ vs satellite-based GWS



- Correlations above 0.70 are commonly found throughout the area of Lowlands.
- The agreement between satellite-based and in-situ GWS decreases in the northern and southern parts of the country.
- However, this is not caused by the worse performance of GRACE in these areas, but primarily due to the dominance of monitoring points that represent the local groundwater circulation systems and points lacking clear seasonal cycles in groundwater level fluctuations.

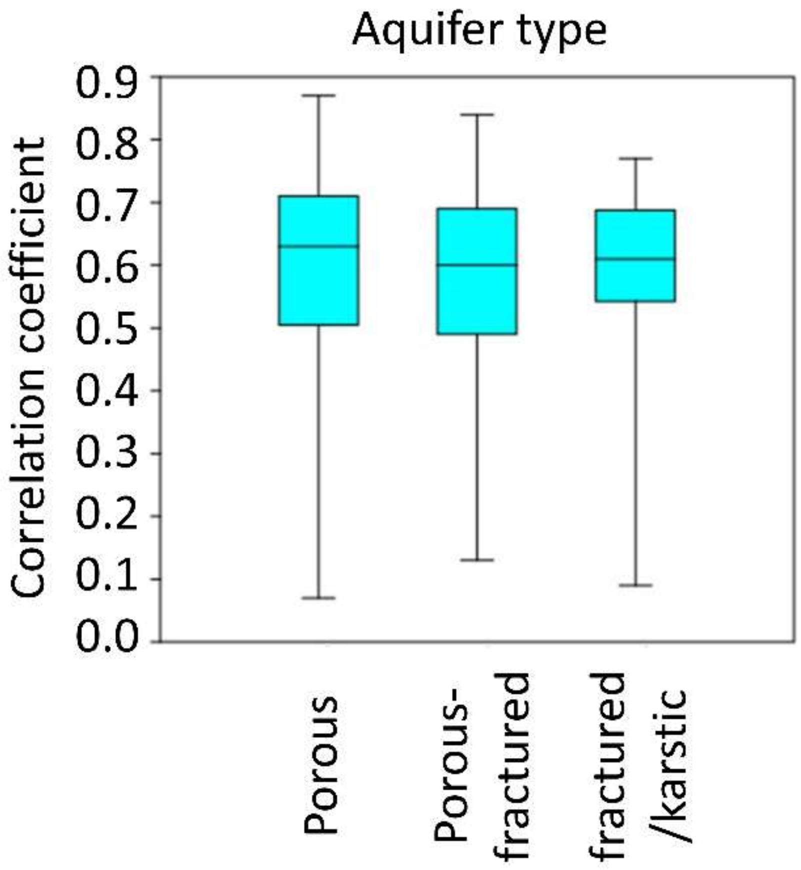
Well location is crucial

- type of water table (unconfined vs confined)
- aquifer type (porous, porous-fractured, fractured/karstic)
- hydrodynamic zone (recharge vs discharge vs transit)
- depth of water table
- physiographic zones (coast, lakelands, lowlands, highlands, mountains)



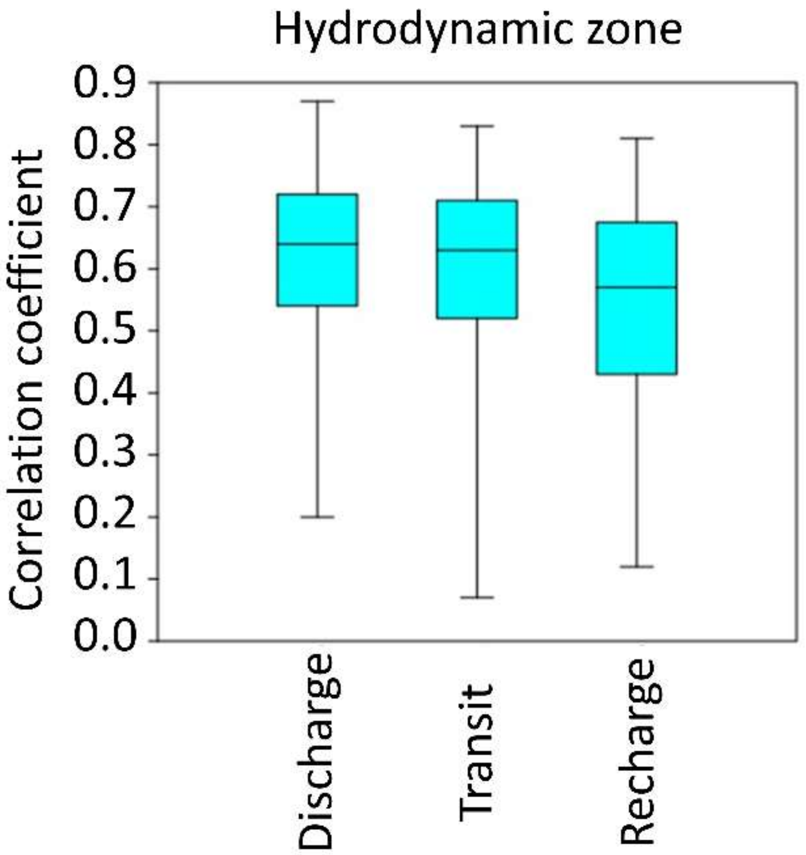
Source: T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley - Ground Water And Surface Water A Single Resource. U.S. Geological Survey Circular 1139

Different aquifer types



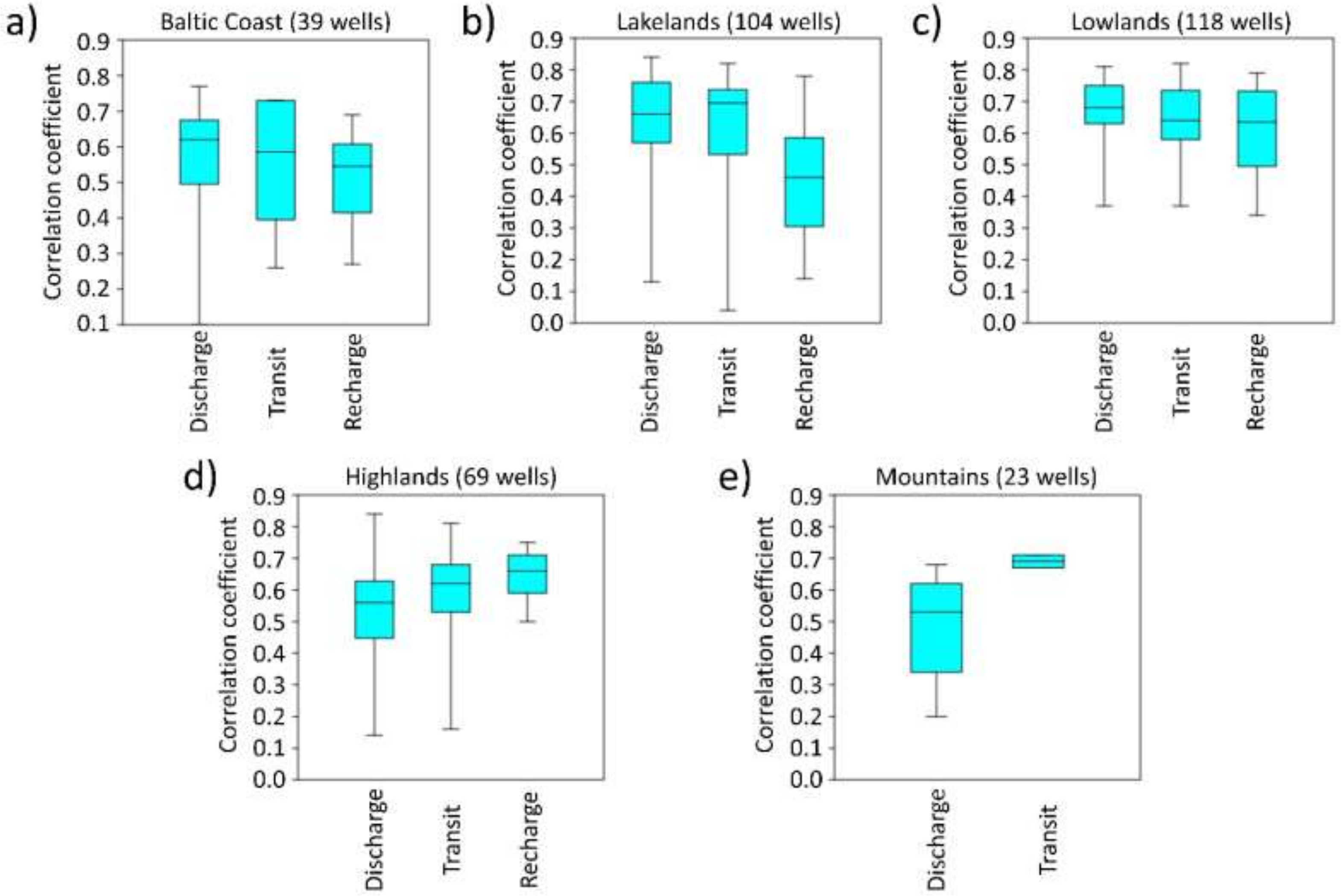
- Points located in the fractured/karstic aquifer exhibit only slightly higher but more uniform level of agreement between satellite-based GWS and in-situ GWS than points located in other aquifers.
- This is related to faster water exchange in these areas.

Different hydrodynamic zones



- The correlation in the discharge and transit zones is higher (0.65) and has a less dispersed distribution than in the recharge zone (0.59).
- This indicates that satellite-based GWS best reflects the changes in dynamic groundwater resources, which exhibit a strong seasonal cycle.

Different physiographic zones



- In the Highlands and Mountains areas, there is a reversed correlation tendency compared to Lowlands: points in the discharge zone show lower correlation with satellite-based GWS than points located in the transit zone.
- The reason are disturbances caused by the mountainous river regime.
- The results for the Baltic Coast are not representative due to increased GRACE/GRACE-FO errors in coastal areas (problem of separating signals from land and sea).

Conclusions

- We observe negative trends in GWS changes across the entire area of Poland for both in-situ and satellite measurements (on average over 1 cm/year).
- In the lowland region of central Poland and parts of the southeast, the most intense decreases in GWS were observed. Conversely, minimal decreases in GWS were observed in the region of Baltic Coast and parts of north-eastern Poland.
- Satellite-based GWS changes match in-situ GWS data best in discharge and transit zones. In these zones we observed strong seasonal signals because of rapid water exchange.
- Better agreement between satellite-based and in-situ GWS was found in fractured and karst bedrock due to rapid water exchange.
- In the valley systems in-situ GWS tends to agree better with satellite-based TWS than with satellite-based GWS, because the groundwater table is located close to the surface (no unsaturated zone associated with soil water storage).
- In the comparison of in-situ and satellite-based GWS, the proper selection of monitoring wells as well as understanding hydrodynamic conditions are crucial.

Thank you