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Use of Copernicus data for developing a geoportal to support agricultural management monitoring in Poland

Abstract. This article focuses on mapping agricultural productivity, which can be assessed using vegetation and environmental satellite indices (e.g., NDVI, NDWI). It highlights the main agricultural risks in Poland, namely spring frosts and agricultural droughts. The significance of employing remote sensing indicators to create maps supporting agricultural management at national and voivodeship levels is emphasised. The article demonstrates how such maps can be developed using selected satellite-derived indices for agricultural monitoring across different administrative levels. Furthermore, it discusses access to satellite data from the European Copernicus Programme, including land cover, vegetation condition, and weather data (e.g., ERA5). The paper presents the results of a project undertaken by the Institute of Geodesy and Cartography in Poland (IGiK), which developed a geoportal designed for institutions involved in supporting agricultural development in Poland – KOWR (National Support Centre for Agriculture; in Polish: Krajowy Ośrodek Wsparcia Rolnictwa) and ARMA (Agency for Restructuring and Modernisation of Agriculture; in Polish: Agencja Restrukturyzacji i Modernizacji Rolnictwa).

Keywords: geoportal, agricultural maps, agriculture in Poland, Copernicus Programme, remote sensing data

1. Introduction

Satellite data plays a crucial role in environmental remote sensing, enabling precise monitoring and analysis of changes on the Earth's surface. There is an increasing amount of research on the impact of vegetation and environmental satellite indicators in policy and governance contexts (De Sherbinin et al., 2013), with evidence suggesting that in selected contexts, indicators can significantly influence issue framing and bring about changes in policy and management practices (Morse, 2011). Copernicus is the earth observation component of the European Union's Space programme, designed to observe our planet and its environment for the benefit of all European citizens. At its core, it provides information services based on satellite earth observation data and in situ (non-space) sources. Copernicus is implemented through a series of dedicated satellites (the Sentinel family) and supporting missions (including existing commercial and public satellites).

A map can be conceptualized as a spatial model representing the Earth's surface or specific geospatial phenomena through symbolized and abstracted forms derived from satellite remote sensing data. As noted by Campbell and Wynne (2011), such maps function as both visual and analytical instruments, supporting the interpretation, classification, and communication of geospatial information captured by remote sensing sensors. By transforming raw satellite imagery into thematic or topographic representations, maps facilitate spatial analysis and inform decision-making processes. Within this framework, maps are not merely static visualizations but are used as conceptual and representational models that generalize and structure continuous remote sensing data into discrete, interpretable spatial patterns (MacEachren, 1995; Longley et al., 2015). Consequently, maps play a vital role in bridging the gap between complex satellite data and human spatial perception.

The use of Copernicus data in agricultural mapping can help address a wide range of thematic issues. According to Żyszkowska et al. (2012), agricultural maps may encompass the following categories:

− agricultural land: including land use, agricultural land cover, and grassland distribution;

− agricultural production: such as crop production, sowing volumes, harvests, yields, yield forecasting, and animal populations;

− general agricultural maps: covering agricultural commodities, production trends, commodity structure, agricultural productivity, and indicators of local economic development;

− agricultural landscape: including land use, soil types, and agricultural complexes;

− natural conditions for agricultural development: such as land use and land cover maps, agrometeorological conditions, and agricultural land classification;

− hunting: including the delineation of hunting district ranges;

− socio-economic factors influencing agricultural development: such as farm structure, agricultural intensity, and levels of agricultural development.

This article focuses on presenting information about field freezing within a geoportal designed for employees of Polish agencies that support agricultural development. Frost heave is a direct consequence of frost affecting plants that are not covered by snow-ice crystals disrupt plant tissues, causing irreversible damage to the protoplasm. Frost damage is the most common during snowless winters but may also occur in early spring or autumn. Plant roots are particularly vulnerable to frost.

In addition, the article addresses agricultural drought. The National Drought Mitigation Centre (n.d.) defines agricultural drought as a combination of meteorological (or hydrological) drought characteristics and their impacts on agriculture. Drought detection and monitoring focus on precipitation deficits, differences between actual and potential evapotranspiration, soil moisture deficits, or reduced water availability.

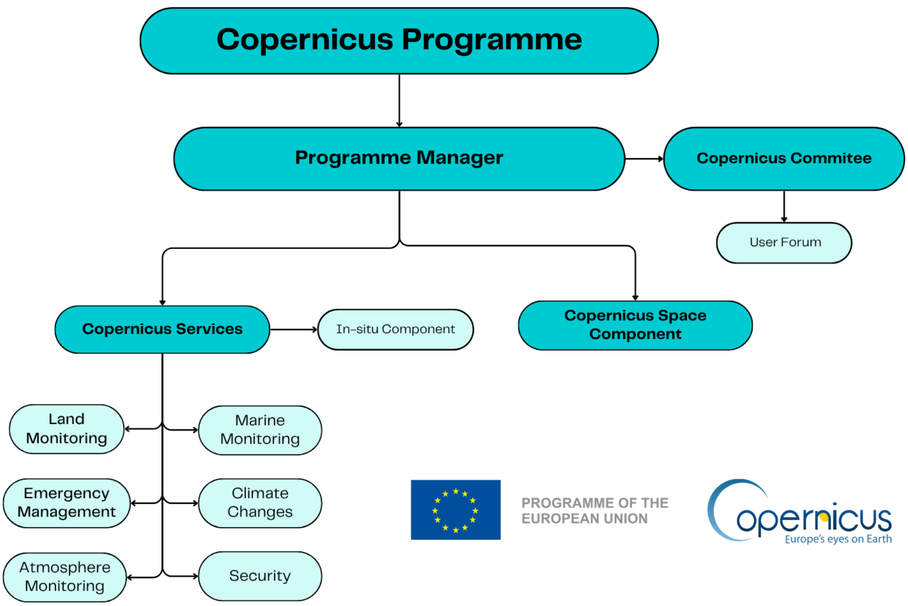

Figure 1. An overview of the governance structure of the Copernicus Programme. Source: own elaboration based on Copernicus documentation

2. Copernicus Programme

The Copernicus Programme is operated by the European Commission (Figure 1; Copernicus, n.d.). It is conducted in cooperation with the Member States, the European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), EU Agencies and Mercator Océan, the European Environment Agency (EEA), and the Joint Research Centre (JRC). Since the launch of the Sentinel-1A satellite in 2014, the European Union initiated a process to deploy a constellation of nearly 20 additional satellites by 2030, with the Sentinel-1C radar satellite being the most recently launched (on December 5, 2024).

The European Space Agency is responsible for developing the space segment of the Copernicus programme, including Sentinel-1, Sentinel-2, and Sentinel-5P satellites as well as the land component of the Sentinel-3 mission. EUMETSAT is responsible for the operation of the Sentinel-3 satellites and implementing the maritime mission. It is also tasked with managing and delivering products from the Sentinel-4 and Sentinel-5 instruments, as well as the Sentinel-6 satellites. The earth observation missions that supply data to Copernicus services are divided into two groups:

− sentinels − satellites developed for the specific needs of the Copernicus programme. Sentinel-1, -2, -3 and -6 are dedicated satellites, while Sentinel-4 and -5 are instruments on board EUMETSAT weather satellites;

− support missions that are operated by national, European or international organisations.

2.1. Copernicus services

The Copernicus service offering is based on the processing of environmental data collected from earth observation satellites and in situ sensors. These services transform satellite and in situ data into value-added information through processing and analysis, including the generation of maps from satellite imagery. The services provided by the Copernicus Programme are categorised by thematic area into the following domains:

− Atmosphere (Copernicus Atmosphere Monitoring Service – CAMS, n.d.): air quality and atmospheric composition, ozone layer and ultraviolet radiation, emissions and surface fluxes, solar radiation, climate forcing;

− Marine (Copernicus Marine Service or Copernicus Marine Environment Monitoring Service, n.d.): information on the state of the Blue (physical), White (sea ice), and Green (biogeochemical) ocean, on a global and regional scale;

− Land (Copernicus Land Monitoring Service – CLMS, n.d.): systematic monitoring of biophysical parameters, land cover and land use mapping, thematic hot-spot mapping, imagery and reference data, ground motion;

− Climate Changes (Copernicus Climate Change Service – C3S, n.d.);

− Security (Copernicus Service on Support to EU External and Security Actions, n.d.): border surveillance, maritime surveillance, support to EU External and Security Actions, R&D for EO Security;

− Emergency (Copernicus Emergency Management Service – Copernicus EMS, n.d.): mapping and early warning component.

2.2. Access to Copernicus data

The purpose of the Copernicus Programme is to provide free and open access to data from the Sentinel missions. Most of the data is openly available and free of charge. In addition to Sentinel data, the Copernicus Programme provides information from a global network of other satellites (Copernicus Contributing Missions) as well as from land, air, and sea sensors.

Access to Copernicus data is crucial for various types of users, including earth observation (EO) institutions. According to a survey (Figure 2) conducted by the European Association of Remote Sensing Companies (EARSC), the main sources of data are the newly developed Copernicus Data Space Ecosystem (23%) and the long-established Sentinel Hub platform (also 23%). Other important platforms providing access to Copernicus Programme data include the DIAS platforms, Amazon Web Services, and Google Earth Engine (EARSC, 2024).

Copernicus Space Data Ecosystem (CDSE) Portal

The Copernicus Space Data Ecosystem (CDSE) portal currently provides access to

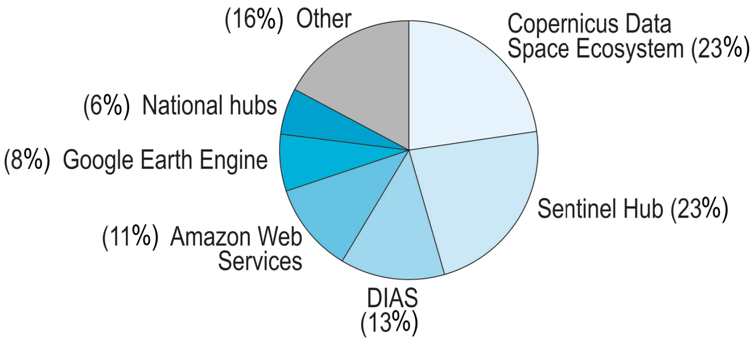

Figure 2. The results of the 9th EARSC (2024) survey on the European Earth Observation (EO)

reference products from Sentinel-1, -2, -3, and -5P satellites, as well as the Copernicus Contributing Missions (n.d.). It is presently the primary method supported by the European Commission for accessing Copernicus data. CDSE offers visualisation tools to facilitate data search and exploration, alongside a range of data processing capabilities. Additionally, it provides on-demand processing and access to a cloud computing environment.

Sentinel Hub

Sentinel Hub is an engine for processing petabytes of satellite data from Sentinel or Landsat imagery (SentinelHub, n.d.). Through it, earth observation data are readily available for viewing, visualisation, and analysis. Data collected here is available via an API, but can also be downloaded, for example, as .shp files or WMS/WMTS addresses.

Data and Information Access Services (DIAS)

To simplify and standardise access to satellite data, the European Commission has funded the implementation of five cloud-based platforms. These platforms are collectively known as Data and Information Access Services (DIAS; n.d.). The five DIAS online platforms allow users to discover, manipulate, process and retrieve Copernicus programme data and information: CREODIAS, WEkEO, Mundi, Onda, Sobloo. Each DIAS platform provides access to Copernicus Sentinel data as well as information products from the six Copernicus operational services (CAMS, CMS, CLMS, C3S, Copernicus EMS, security services), along with cloud-based tools (open source and/or on a pay-per-use basis).

Amazon Web Services

Amazon Web Services (AWS; n.d.) is the most comprehensive and pervasive global cloud, offering more than 200 full-featured services from data centres around the world. Earth observation (EO) data hosted on AWS can be used in a start-up, enterprise or research institution.

Google Earth Engine

Google Earth Engine (GEE; n.d.) is a computing platform that enables users to perform geospatial analyses using Google's infrastructure. Analyses conducted within GEE can be shared with users through the Apps module, which generates applications with unique web addresses. This module also facilitates the creation of intuitive user interfaces featuring buttons, sliders, and list selectors.

3. Vegetation and environmental satellite indicators

Satellite indicators measure environmental conditions (e.g., vegetation health, drought, frost, or flood risks) continuously across time and space. Currently, available free-of-charge satellite data allows measurements with a resolution of up to 10 m (e.g., Sentinel-2 data). Timescale availability is also important – from one day (e.g. Sentinel-3, 100 m resolution), to several (e.g. Sentinel-1, and 2). The following vegetation and environmental satellite indicators are important from the perspective of managing agricultural production (Table 1):

Table 1. Vegetation and environmental satellite indicators, depending on the type of satellite in the Sentinel family

Sentinel	Indicators
Sentinel 2	NDVI, NDWI, LAI, NDII, NDMI, PPI
Sentinel 3	GDD, TCI

− Normalized Difference Vegetation Index (**NDVI**) – an index that determines the condition of vegetation (Chen et al., 2021). It is computed based on spectrometric data in two specific bands: red and near-infrared, possible to calculate using, for example, data from Sentinel-2;

− Normalized Difference Water Index (**NDWI**) – index established to monitor changes in water content of leaves, using near-infrared (NIR) and short-wave infrared (SWIR) wavelengths (Gao, 1996) or changes related to water content in water bodies, using green and NIR wavelengths (McFeeters, 1996), possible to calculate using, for example, data from Sentinel-2;

− Leaf Area Index (**LAI**) – this index is a dimensionless index measuring the one-sided green leaf area over a unit of land [m^2/m^2] (Yan et al., 2019), possible to calculate using, for example, data from Sentinel-2;

− Normalised Difference Infrared Index (**NDII**) – this index detects the water content of the tree canopy (Hardisky et al., 1983) and has been studied for monitoring drought conditions (Móricz et al., 2018), possible to calculate using, for example, data from Sentinel-2;

− Normalized Difference Moisture Index (**NDMI**) – a standardised indicator that uses infrared data to display moisture conditions (Ochtyra et al., 2020), possible to calculate using, for example, data from Sentinel-2;

− Plant Phenology Index (**PPI**) – a vegetation index that is optimised towards effective monitoring of vegetation phenology. It is derived from a radiative transfer solution using reflectance in visible-red (RED) and near-infrared (NIR) spectral domains (Jin & Eklundh, 2014); possible to calculate using, for example, data from Sentinel-2;

− Growing Degree Day (**GDD**) – used to estimate the growth and progress of several crops and pests during the growing season (McMaster & Wilhelm, 1997), possible to calculate using, for example, data from Sentinel-3;

− Temperature Condition Index (**TCI**) – determines stress on vegetation due to temperatures and excessive wetness. Conditions are estimated in terms of maximum and minimum temperatures and modified to reflect the different responses of vegetation to temperature (Kogan, 1995), possible to calculate using, for example, data from Sentinel-3.

The use of meteorological reanalyses developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) is also crucial in environmental analyses. One of the most widely used datasets is ERA5-Land, a global meteorological dataset regarded as one of the most advanced tools for analysing meteorological conditions worldwide. ERA5-Land represents an upgrade over its predecessors, incorporating state-of-the-art technology and improved algorithms (Muñoz-Sabater et al., 2021). The data are available at a spatial resolution of 0.1 degrees (approximately 9 km), providing detailed information on meteorological conditions across various regions of the Earth from 1950 to the present, thus enabling the analysis of climate trends over several decades. ERA5-Land covers a wide range of meteorological parameters, including air temperature, humidity, wind speed, atmospheric pressure, precipitation, and others. These parameters are available at different atmospheric levels.

The agriculturally important parameters that are included in the ERA-5 Land dataset:

− Soil temperature level 1 (K) – temperature of the soil in layer 1 (0–7 cm), ECMWF Integrated Forecasting System.

− 2 m temperature (K) – temperature of air at 2 m above the surface of land, sea or inland waters. The temperature at 2 m height is calculated by interpolating between the lowest level of the model and the Earth's surface, taking into account atmospheric conditions.

− Snow cover (%) – information about the coverage of the ERA-5 grid by snow.

− Total precipitation (m) – the accumulation of liquid and frozen water, including rain and snow, that falls on the Earth's surface. The sum of large-scale precipitation and convective precipitation.

− Snowfall (m of water equivalent) – accumulated total snow that has fallen to the Earth's surface.

− Evaporation from vegetation transpiration (m of water equivalent) – the amount of evaporation from vegetation transpiration.

4. FPCUP Agriculture Project

4.1. Project aims and objectives

The Europe-wide Framework Partnership Agreement on Copernicus User Uptake (FPCUP; n.d.) exemplifies the successful application of Copernicus data across various fields. Under this agreement, institutions from multiple EU countries are developing systems and portals to promote the use of Copernicus data among European citizens. Several projects within this Partnership, including Common System and Platform Based on Copernicus Data and Services for Agricultural Agencies in Poland – FPCUP Agriculture (n.d.) and Open Data Framework for the Baltic Sea Drainage Basin – FPCUP Baltic (n.d.), have been implemented at the Institute of Geodesy and Cartography (IGiK) in Poland.

The primary outcome of the FPCUP Agriculture initiative is a system and web service integrating products and analyses based on the Copernicus Programme, developed by IGiK to address the needs and requirements of identified users in Poland's agricultural sector. This initiative is expected not only to improve the usability of Copernicus data by agricultural agencies – and through them, by regional and local authorities as well as individual farmers (a goal strongly advocated by the European Commission) – but also to enhance cooperation between agencies such as ARMA (Agency for Restructuring and Modernisation of Agriculture; in Polish: Agencja Restrukturyzacji i Modernizacji Rolnictwa) and KOWR (National Support Centre for Agriculture; in Polish: Krajowy Ośrodek Wsparcia Rolnictwa), whose collaboration to date has been limited. Strengthening this cooperation is anticipated to improve overall performance and cost efficiency.

4.2. System prototype and user needs analysis

As part of the project, two services were developed with maps of the risk of freezing in Poland. The pilot service was designed in the Google Earth Engine environment, while the final service (System) was prepared using one of the DIAS – CREODIAS CloudFerro.

The decision to build the prototype application in the Google Earth Engine environment (Figure 3) was made after analysing available market solutions (such as CloudFerro cloud services and commercial website development). Factors such as cost, ease of implementation, and flexibility in collecting user feedback and making adjustments and improvements to the

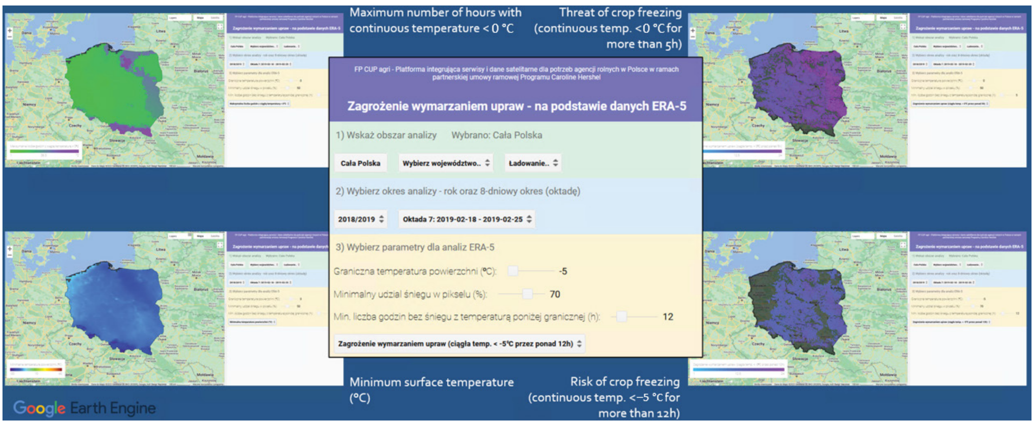

Figure 3. The prototype version of the system includes a range of available products and options. Frost risk calculated based on ERA5 reanalysis data

final version of the service were considered. The final service was later built on one of the DIAS platforms.

The final System and service architecture was developed based on experiences gained from the prototype version of the System and consultations with end-users. Feedback from users was collected during the initial consultation phase, survey, and training.

The survey was conducted between 4 and 18 March 2022 and was completed by 70 employees of agencies supporting the development of agriculture in Poland (ARMA and KOWR). As part of the survey, participants were asked six questions − five related to the proposed service and one concerning the participant's organization.

At the beginning of the survey, the main assumptions of the project were presented, and the topic of access to Copernicus products was explained.

In the first question, respondents were asked to indicate which satellite data/products from a given selection they considered useful in their work. Based on the responses, it can be observed that for the survey participants, the most useful product was the mask for agricultural areas, followed by the product with identifying crop areas prone to frost danger (Figure 4).

In the second question, respondents indicated that all functionalities proposed for implementation in the service are important from their point of view, particularly the ability to analyze data by administrative units (Figure 5).

The third question was open-ended, and respondents were asked to suggest additional functionalities of the service that, in their opinion, would be useful for supporting agricultural analysis. Most participants indicated the need for products identifying flooded areas (floods) and areas affected by agricultural drought. In the question concerning the nature of the training sessions/workshops/seminars to be organized in later stages of the project, respondents noted that the most useful elements would be use cases from both Poland and the world, as well as a presentation of the service developed within the project.

Based on a survey and meetings with agency representatives, the main issues (product availability and service functionality) to be addressed by the agencies were identified (Table 2). It was assumed that the System would be presented to the staff of Polish institutions, therefore, the study was conducted exclusively in the Polish language version.

4.3. Final version of the System

The System (FPCUP Agriculture, n.d.) runs on Ubuntu, installed in a CloudFerro DIAS cloud environment (Figure 6). All services are running in containers using Docker Compose. These services are as follows:

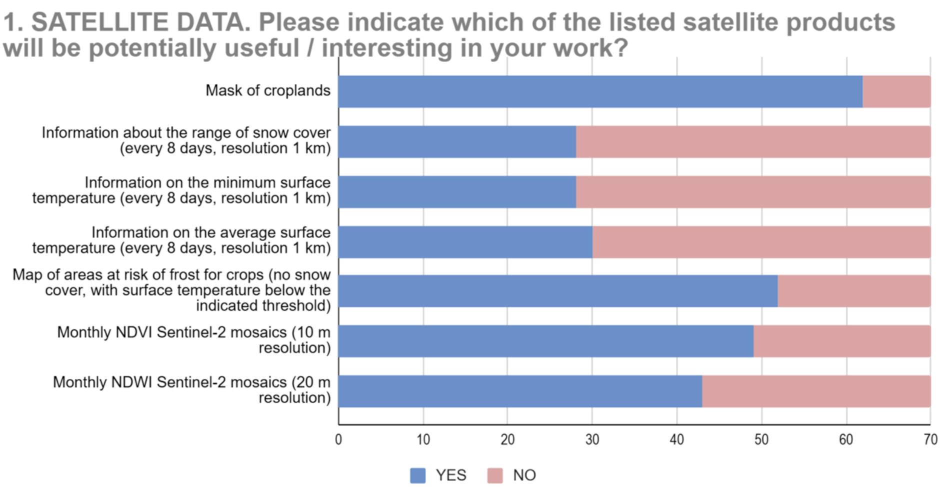

Figure 4. Respondents' opinions on the proposed satellite data placed on the system

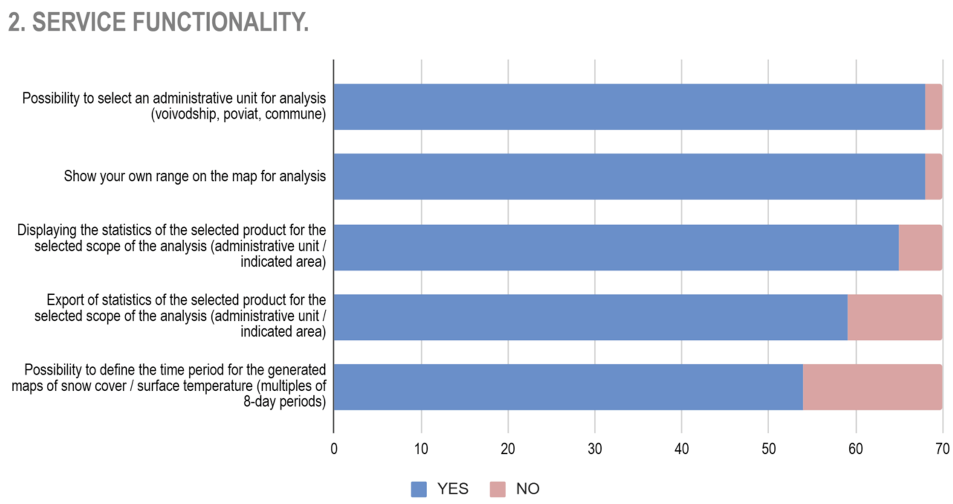

Figure 5. Respondents' opinions on the proposed system's functionalities

Table 2. Product availability and service functionality in the System

Number	Description	Status in System
1. Product availability		
1.1	Mask of croplands	Available/fulfilled
1.2	Information about the range of snow cover	Available/fulfilled
1.3	Information on the minimum surface temperature	Available/fulfilled
1.4	Information on the average surface temperature	Available/fulfilled
1.5	Map of areas at risk of frost for crops (no snow cover, with surface temperature below the indicated threshold)	Available/fulfilled
1.6	Temporal NDVI Sentinel-2 mosaics	Available/fulfilled
1.7	Temporal NDWI Sentinel-2 mosaics	Available/fulfilled
2. Service functionality		
2.1	Possibility to select an administrative unit for analysis (voivodeship, district, commune)	Available/fulfilled
2.2	Show your range on the map for analysis	Available/fulfilled
2.3	Displaying the statistics of the selected product for the selected scope of the analysis (administrative unit / indicated area)	Available/fulfilled
2.4	Export of statistics of the selected product for the selected scope of the analysis (administrative unit / indicated area)	Not available/not fulfilled
2.5	Possibility to define the period for the generated maps of snow cover/surface temperature (multiples of 8-day periods)	Available/fulfilled

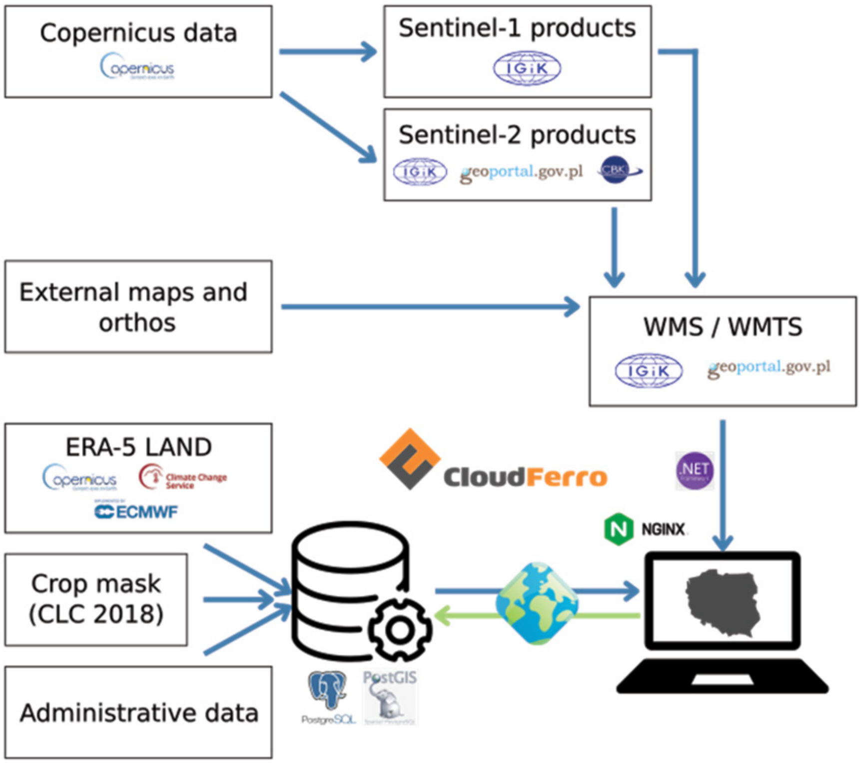

Figure 6. The diagram of the final system and service architecture

− PostgreSQL with PostGIS – Stores and serves administrative subdivision and frost data (administratice data, crop mask, Era5-Land data);

− GeoServer – Serves administrative subdivision and frost data in a format suitable for display in the application. May eventually serve as a server for other data;

− Proxy Service – A .Net application that enables CORS security to be bypassed for external WMS and WMTS services and serves season and period data to the application by retrieving it from the database (Sentinel-1 and Sentinel-2 products and mosaics; external data – ortophotomaps, maps and topographic geodatabase);

− Nginx HTTP Server – Hosts the frontend application and distributes traffic to the other services accordingly.

The system consists of several sections:

− Search panel – allows searching for any administrative unit in Poland (voivodeship/district/municipality) by selecting it from hierarchical lists of all administrative units or by typing in at least three letters of a desired unit's name;

− Frost risk section – section with crop frost risk products based on ERA-5 Land data;

− Copernicus Sentinel-1 section – this section consists of three temporal mosaics developed by IGiK, highlighting land cover/land use changes by using each RGB layer as a carrier of information from a specific period. Each layer is a median composite of all available Sentinel-1 scenes (ascending orbits) over some time specific to each product;

− Copernicus Sentinel-2 section – one can browse through the list of products based on Sentinel-2 imagery;

− Drought Information Satellite System (DISS) 2024 – information on drought in 2024, prepared based on a model developed at IGiK;

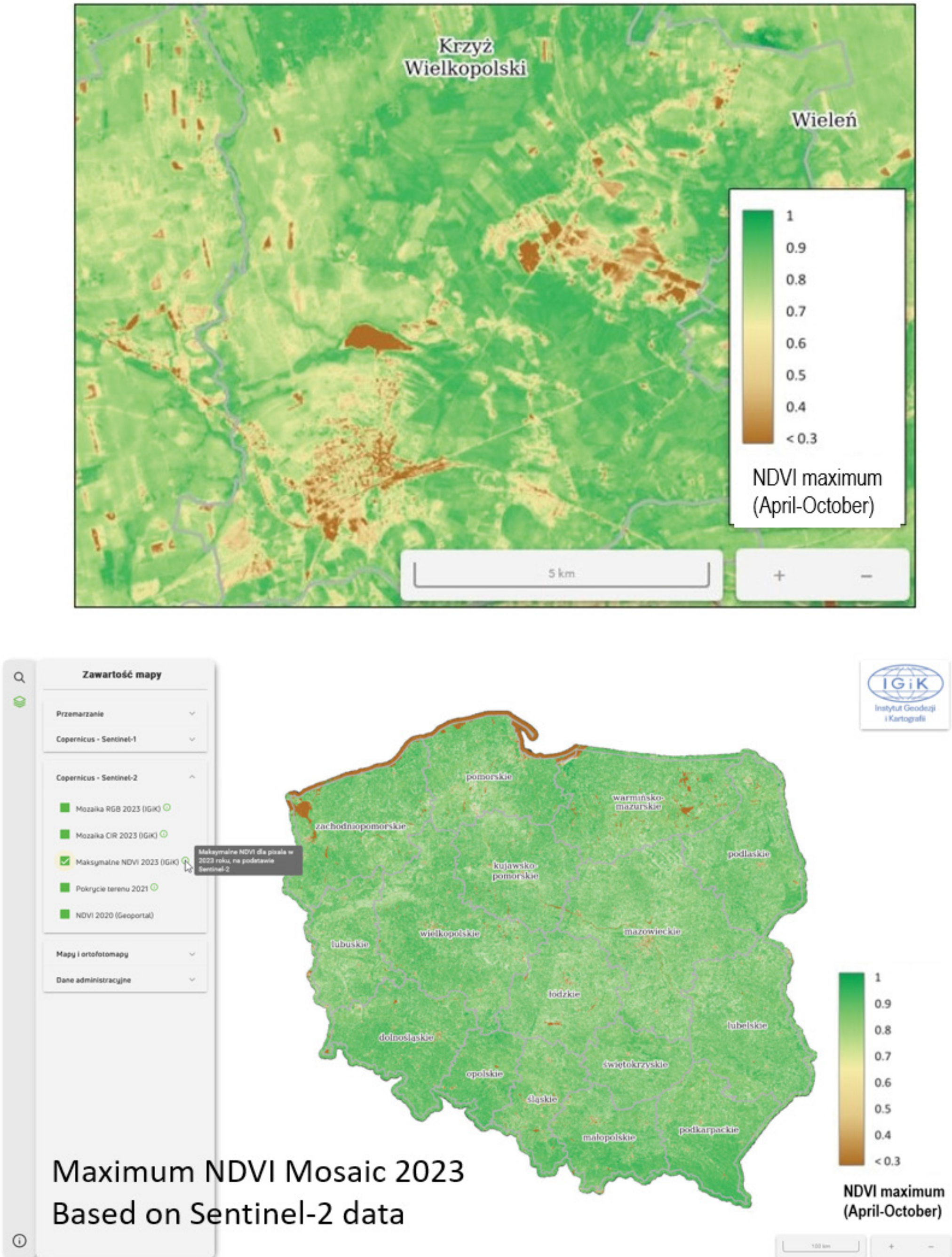

Figure 7. Maximum NDVI mosaics of Poland (2023). Top – detailed view; Bottom – general overview

− Thermal Condition Index (TCI) 2024 – information on moisture conditions prepared from Sentinel-3 satellite data released by CAMS;

− Other maps and orthophotomaps section – this section contains auxiliary layers from various external sources, which are not based on Copernicus data but can provide users with additional information about their area of interest;

− Administrative data section – layers of administrative (voivodeship/district/municipality) and cadastral parcels boundaries. Although this section is located at the bottom of the menu, its layers are always displayed on top of other selected products.

4.4. Plant's health maps (NDVI, Sentinel-2)

The Normalized Difference Vegetation Index (NDVI), derived from Sentinel-2 data, is widely used to assess plant health. It is a simple yet effective index for monitoring vegetation and detecting changes in vegetation patterns and biodiversity. NDVI values typically range from –1 to 1, with higher values indicating healthier and denser vegetation cover. NDVI can be calculated using data from various satellite platforms. However, its accuracy can be influenced by atmospheric conditions, soil background, and canopy structure (Figure 7).

4.5. Water content of leaves maps (NDWI, Sentinel-2)

The Normalized Difference Water Index (NDWI) is particularly suitable for mapping water bodies. Water bodies are characterised by strong absorption and low reflectance in the visible to near-infrared (NIR) wavelength range. NDWI utilises the green and NIR bands of remote sensing imagery to exploit this spectral behaviour. In most cases, NDWI effectively enhances water-related information, facilitating

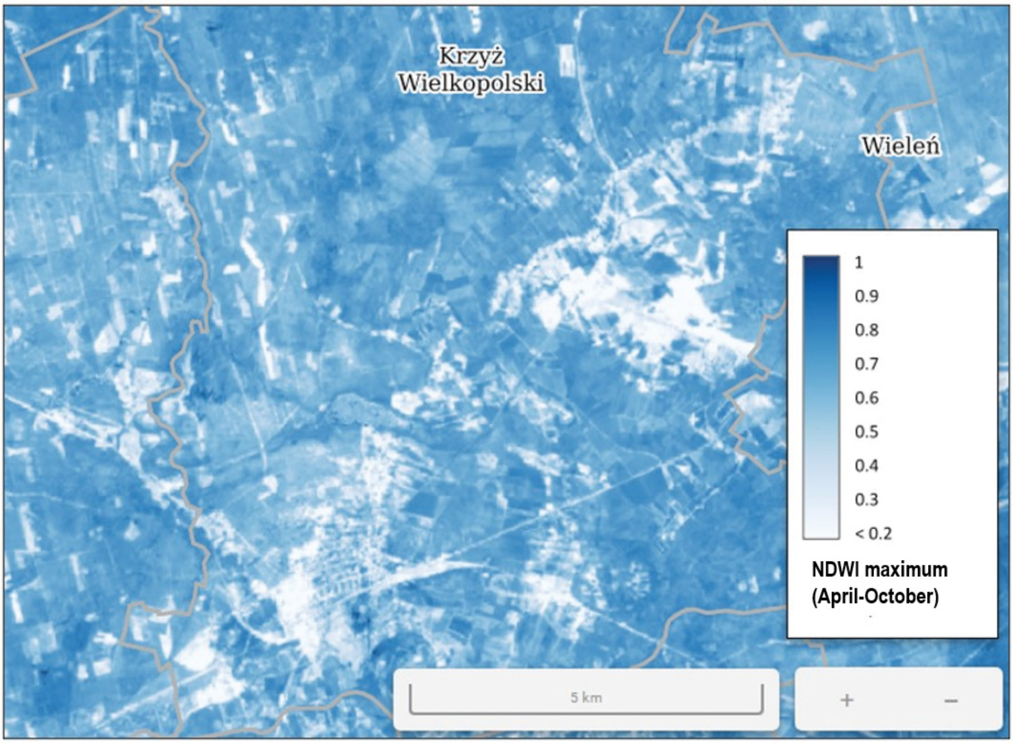

Figure 8. NDWI mosaics of Poland (2023) – detailed view. NDWI effectively enhances water detection in most cases

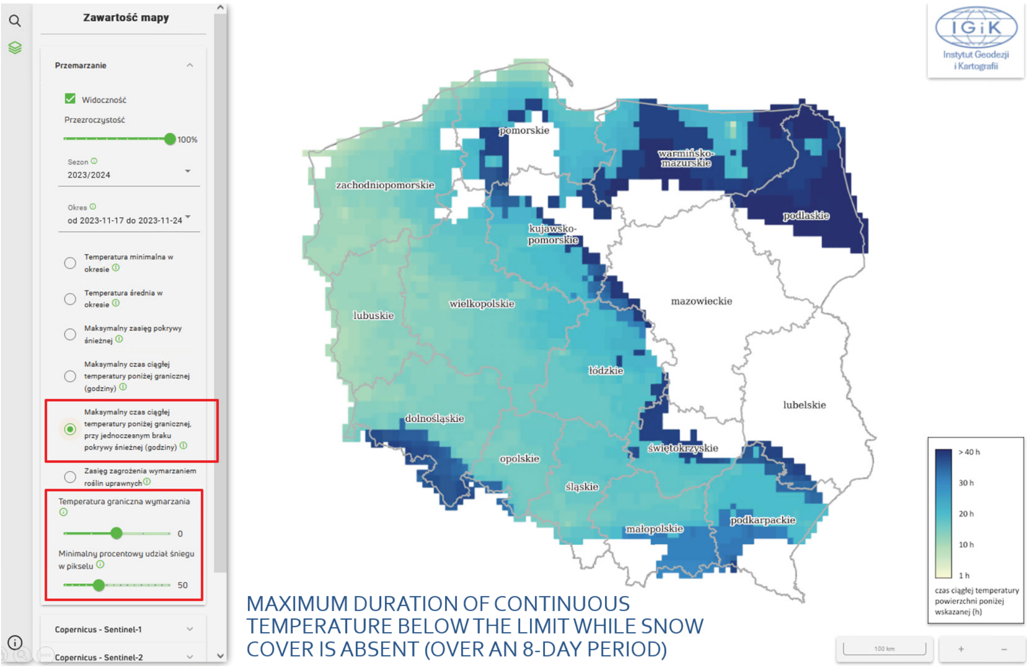

Figure 9. Maximum duration of continuous sub-threshold temperature periods in the absence of snow cover

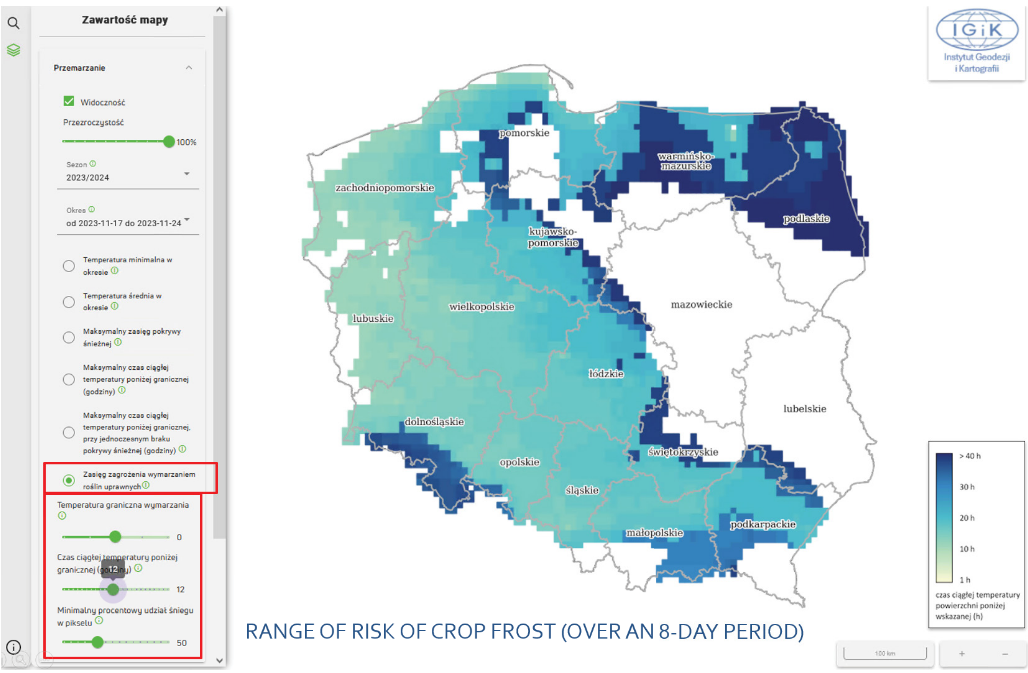

Figure 10. Spatial extent of crop frost risk

improved water body detection. Values for water bodies typically exceed 0.5, while vegetation exhibits considerably lower values, allowing for clear differentiation between vegetation and water. Built-up areas usually show positive values ranging from zero to 0.2 (Figure 8).

4.6. Frosk risk maps (ERA-5 Land)

The Frost Risk section utilises ERA5-Land data. Users can select the season and the eight-day analysis period from drop-down menus, choose one of the available products, and adjust its settings where applicable. Additionally, there is a toggle to either disable the visibility of all products in this section or to set their transparency to a specified value within a range of 0 to 100.

The list of available products contains:

− minimum surface temperature over 8 days;

− mean surface temperature over 8 days;

− maximum extent of snow cover over 8 days with the selection of a minimal percent of snow in a pixel;

− maximum duration (in hours) of continuous temperature below the limit (over 8 days) with the selection of a threshold temperature in a range from –2 to 2 °C;

− maximum duration (in hours) of continuous temperature below the limit while snow cover is absent (over 8 days) with the selection of a threshold temperature in a range from –2 to 2 °C and a minimal percent of snow in a pixel (Figure 9);

− risk of crop frost area with the selection of a threshold temperature range from –2 to 2 °C, a minimal percent of snow in a pixel, and a minimal time (in hours) of continuous temperature below the given threshold (Figure 10).

4.7. Seasonal crops changes maps (Sentinel-1)

In the RGB compositions maps (Figure 11), each of the three image layers corresponds to two months of the growing season, resulting

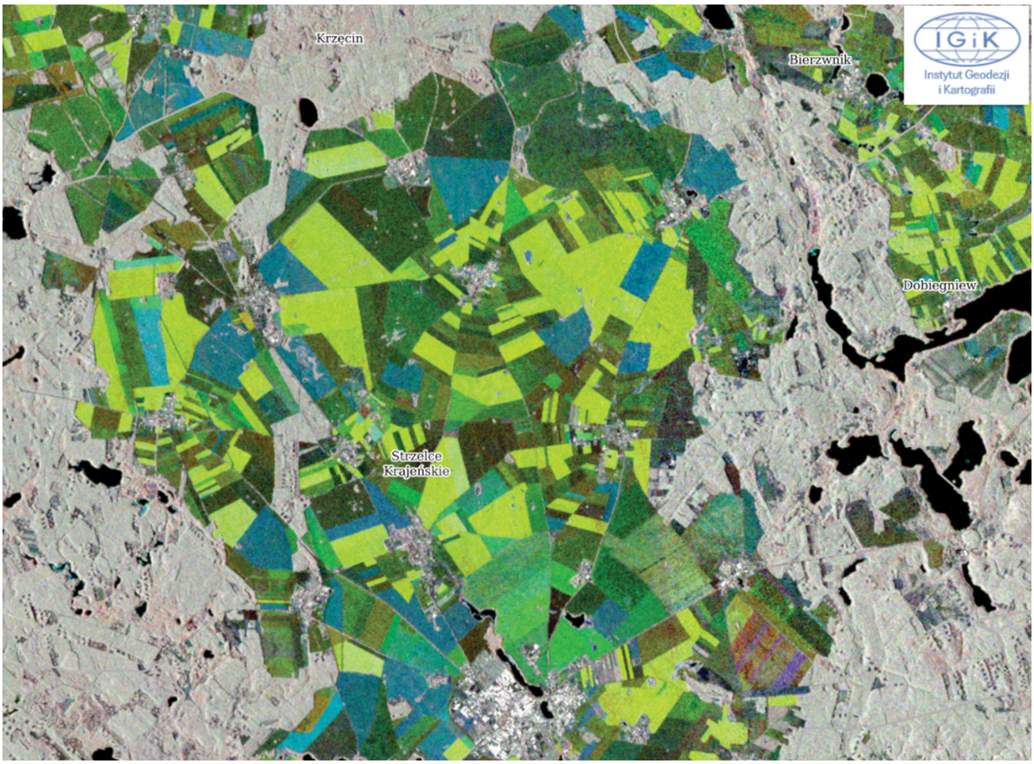

Figure 11. Seasonal Sentinel-1 RGB mosaic (2022): Red – April/May, Green – June/July, Blue – August/September

in individual colours highlighting seasonal changes in the analysed surface state (roughness and moisture). For example, yellow colours in arable fields indicate the presence of winter crops (low roughness and no vegetation after the August–September harvest period), while blue tones indicate spring crops, with bare soil or sparse vegetation at the beginning of the season (April–May).

4.8. Agriculture drought maps (TCI and DISS, Sentinel-3)

The **Thermal Condition Index (TCI)** is a numerical representation of the thermal state within a given area. Understanding TCI values provides valuable insights into the thermal dynamics of a region, aiding in various applications such as environmental monitoring, agricultural planning, and climate research.

The Land Surface Temperature (Synthesis and Thermal Condition Index) dataset from Sentinel-3 (from 2017 to the present) is a comprehensive global resource that offers insights into the Earth's thermal conditions with a 5-kilometre spatial resolution. Updated every 10 days, this dataset amalgamates surface temperature data from various sources, including satellite observations and ground measurements, to present an integrated view of the planet's thermal dynamics. The inclusion of the Thermal Condition Index enables a more nuanced analysis by categorising regions based on their thermal profiles. It can help identify areas under thermal stress or regions experiencing cooler-than-average temperatures. This high-resolution, regularly updated dataset is crucial for many applications, such as climate studies, agricultural forecasting, environmental surveillance, and managing the effects of natural disasters. By balancing comprehensive spatial coverage with frequent temporal updates, it serves as a vital tool for monitoring and responding to both global and local shifts in climate patterns, including the detection and assessment of agricultural drought.

The TCI ranges from 0 to 100 or from 0 to 1. Interpretation of TCI values reveals distinct thermal conditions: lower values, falling between 0 and 20, signify cooler temperatures, often associated with colder seasons or regions with minimal thermal activity. Moderate values, spanning from 20 to 60, indicate relatively normal thermal conditions, reflecting typical seasonal variations where temperatures neither lean towards extremes of cold nor heat. On the other hand, higher values, ranging from 60 to 100, suggest warmer temperatures, potentially indicating elevated thermal activity or the presence of hotspots within the area of interest (Figure 12).

The **Drought Information Satellite System** (DISS; n.d.) index is presented, based on the synergistic use of meteorological data and information derived from satellite images (Dabrowska-Zielinska et al., 2020, Figure 13). The DISS is calculated for agricultural land, as determined based on Corine Land Cover 2018 (Classes 211, 242; Kosztra et al., 2017). The DISS index allows us to monitor drought phenomena in various climatic and environmental conditions. The approach utilizes two indices for constructing a drought index: (1) the hydrothermal coefficient (HTC), which characterizes meteorological conditions across the study area over a long-term period; and (2) the temperature condition index (TCI) derived from Sentinel-3 LST product (5 km resolution). The DISS values are divided into five classes, corresponding to the drought-moisture degree of the agricultural land: high moisture, good moisture, average moisture, drying, and drought (Figure 13). The DISS drought index can be applied to generate drought maps for particular ten-day periods of the growing seasons (from April to the end of September).

For more comfortable viewing of the agricultural drought data (DISS, TCI), a second service was developed, displaying statistics for the administrative units of Poland. The architecture of this second system is similar to that described in section 3.3 of the article. Two language versions were developed for the second service. For each date selected in the calendar, a drought map is displayed. Clicking on a selected administrative unit provides information on agricultural drought classes (Figure 14).

Further work envisages the development of a service for monitoring soil moisture in agricultural areas in Poland. Integration of data from two platforms (Drought Information Satellite System, n.d.; FPCUP Agriculture, n.d.) will also be performed to produce comparative statistics on drought and frost risk for selected administrative units in Poland.

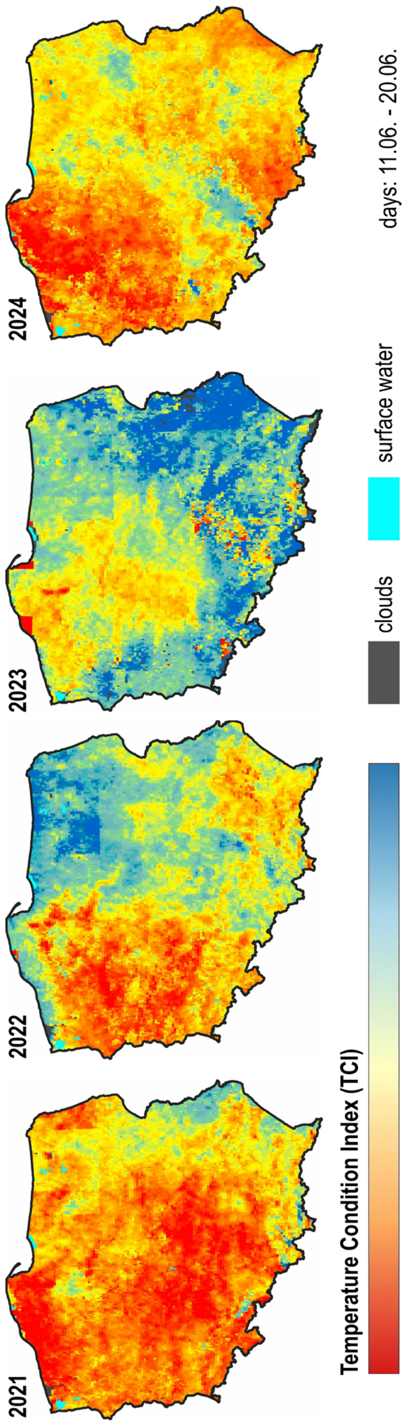

Figure 12. Thermal Condition Index (TCI)

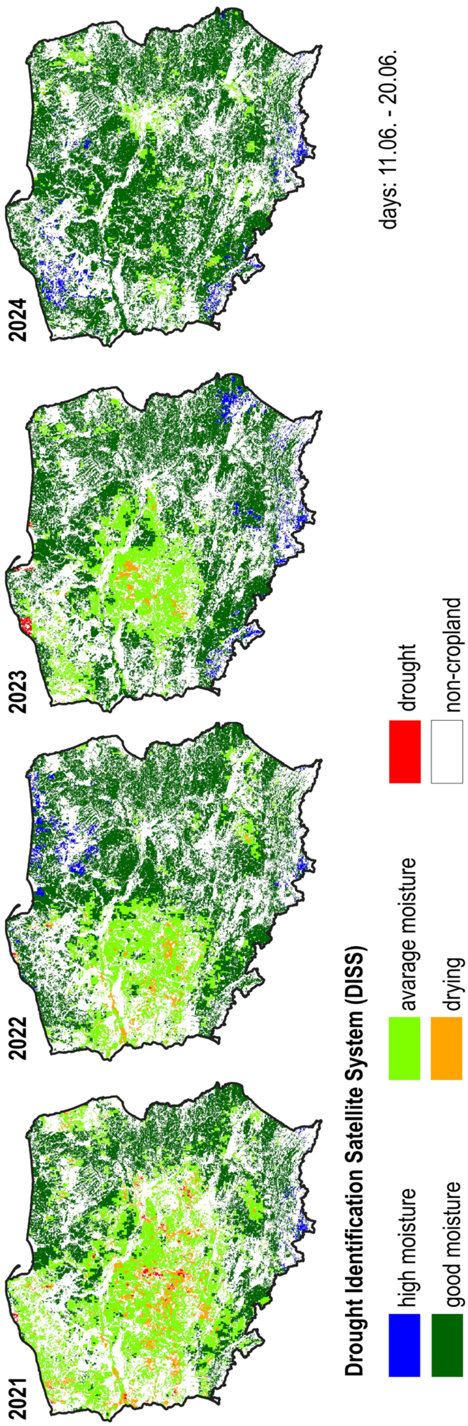

Figure 13. Drought Information Satellite System (DISS)

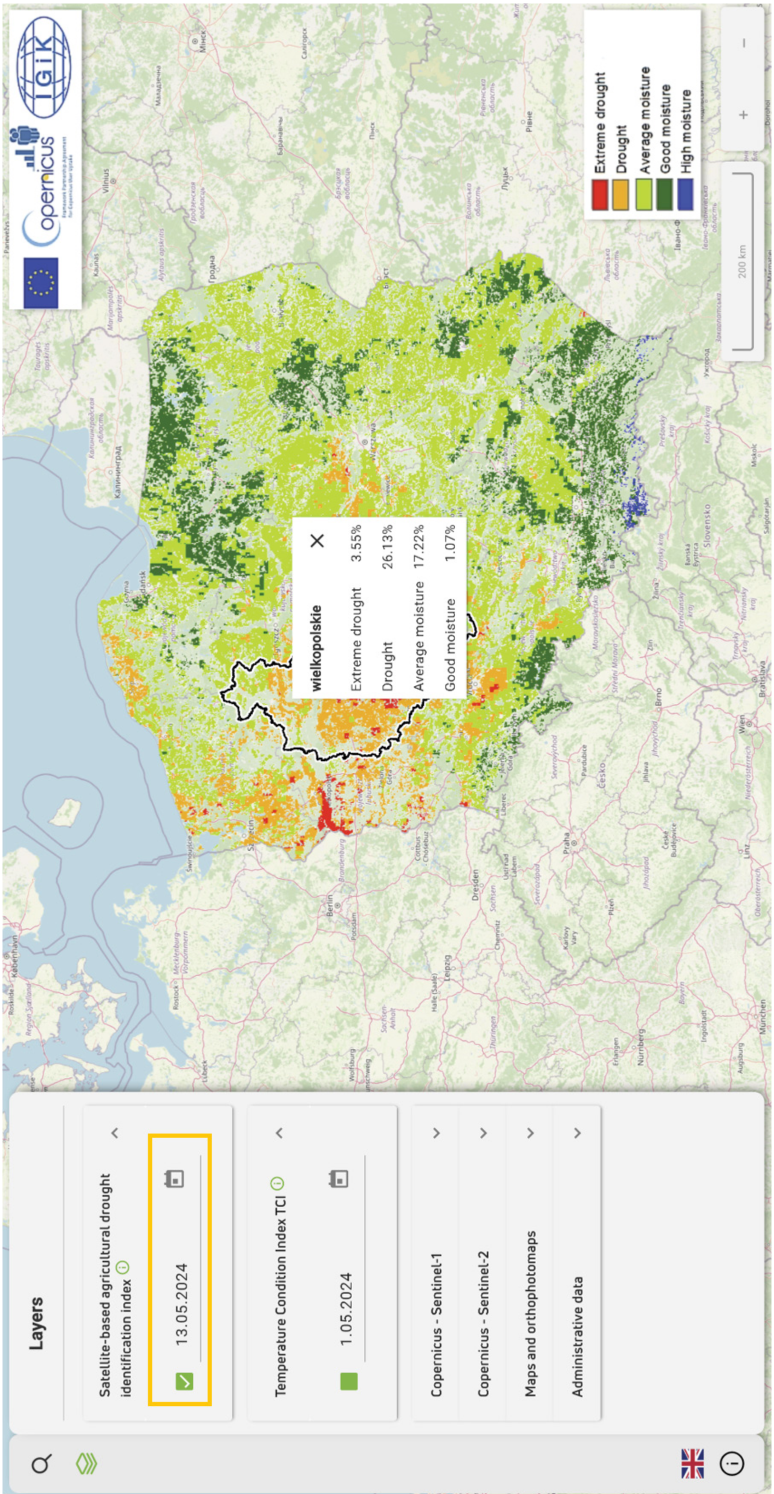

Figure 14. Agricultural drought monitoring service for Poland based on Sentinel satellite data

5. Conclusions

The developed System (serwisagri.fpcup.pl) is planned to be continuously updated – crop frost risk data for May 2024 and subsequent data for 2025 will be included, as meteorological data indicate the possibility of frost risk conditions (database update). There are also plans to add other layers to the service based on Sentinel-1 and Sentinel-2 products, e.g., High Resolution Layers (2018), WorldCover 2020/2021 (adding WMS/WMTS layers). Additional user feedback collected in the coming months may also influence the decision to introduce new functionalities or data sets into the service.

Frost hazard is particularly significant for fruit trees and winter cereals. The administration and management of areas affected by frost are especially important for institutions such as the ARMA, which prepares financial aid for agricultural producers in response to crop damage. An example of such damage is the dieback of fruiting trees, berry bushes, or strawberries due to the spring frost in 2023 (ARMA, 2023). For institutions like ARMA, it is crucial to quickly verify whether and where damage has occurred. The system developed by IGiK can support this type of work.

The data generated by the system can also serve as baseline information for the Local Data Bank (in Polish: Bank Danych Lokalnych; n.d.), managed by Statistics Poland. This database collects data at the level of administrative units. For certain agricultural topics (e.g., identification of planted areas for selected crops or land use classification), the discussed Copernicus products may be utilised. Moreover, the data may be used as input for the Geostatistics Portal (n.d.), also maintained by Statistics Poland.

Concluding on topics related to the implementation of satellite data (products or indicators) in the preparation of maps and statistical data to support the management of agriculture in Poland, it should be mentioned that this subject overlaps with the statements of the common agricultural policy in Poland 20 years of membership of the EU and the challenges for the coming years. This is particularly relevant to sections 5 and 12 (after Drygas et al., 2024, p. 11, 13):

"Point 5: The revision of the Common Agricultural Policy's instruments has to increase the use of income stabilisation tools to compensate for losses due to various types of unforeseen events, such as deep price fluctuations on global agricultural markets, increasingly frequent extreme weather events in recent years (droughts, floods, freezing during the growing season, lack of snow cover for winter crops, tornadoes) (...)."

"Point 12: Establishing a wider use of modern technologies in agriculture is one of the conditions for ensuring the competitiveness of Polish agriculture, apart from further professionalisation of farms. This includes both precision agriculture (Agriculture 3.0) and the technology of Agriculture 4.0. (...) New technologies make it possible to apply practices, the operation of which requires competence and preparation at a different level than before. The use of artificial intelligence, automation, robotisation and digitalisation allows better handling of production, environmental or market risks that cannot be controlled by the farmer."

Consequently, modern agricultural tools – including maps, applications, and geoportals – should rely on data and products derived from the most up-to-date sources. Satellite data, particularly provided by the Copernicus Programme, appears to be a valuable source for preparing agricultural maps at national, regional, and local (communal) levels. However, appropriate data processing and the adaptation of map products to meet the needs of end users must always be taken into account.

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References

Amazon Web Services. (n.d.). https://aws.amazon.com/earth/

ARMA, Agencja Restrukturyzacji i Modernizacji Rolnictwa. (2023). *Pomoc finansowa dla producenta rolnego w związku ze szkodami w uprawach owocujących drzew owocowych, owocujących krzewów owocowych lub truskawek, spowodowanymi wystąpieniem w 2023 r. przymrozków wiosennych, gradu lub huraganu, które objęły co najmniej 30% i mniej niż 70% danej uprawy.* https://www.gov.pl/web/arimr/pomoc-finansowa-dla-producenta-rolnego-w-zwiazku-ze-szkodami-w-uprawach-owocujacych-drzew-owocowych-owocujacych-krzewow-owocowych-lub-truskawek-spowodowanymi-wystapieniem-w-2023-r-przymrozkow-wiosennych-gradu-lub-huraganu-ktore-objely-co-najmniej-30-i-mniej-niz-70-danej-uprawy

Campbell, J. B., & Wynne, R. H. (2011). *Introduction to remote sensing* (5th ed.). Guilford Press.

Chen, P., Liu, H., Wang, Z., Mao, D., Liang, C., Wen, L., Li, Z., Zhang, J., Liu, D., Zhuo, Y., & Wang, L. (2021). Vegetation dynamic assessment by NDVI and field observations for sustainability of China's Wulagai River Basin. *International Journal of Environmental Research and Public Health, 18*(5), 2528. https://doi.org/10.3390/ijerph18052528

Climate Changes. (n.d.). https://climate.copernicus.eu/

Common System and Platform, Based on Copernicus Data and Services, for Agricultural Agencies in Poland. (n.d.). https://fpcup.pl/agri/

Copernicus Atmosphere Monitoring Service. (n.d.). https://atmosphere.copernicus.eu/

Copernicus Contributing Missions. (n.d.). https://dataspace.copernicus.eu/

Copernicus Emergency Management Service. (n.d.). https://emergency.copernicus.eu/

Copernicus Land Monitoring Service. (n.d.). https://land.copernicus.eu/en

Copernicus Marine Service. (n.d.). https://marine.copernicus.eu/

Copernicus Service on Support to EU External and Security Actions. (n.d.). https://sesa.security.copernicus.eu/

Copernicus. (n.d.). https://www.copernicus.eu/en

Dabrowska-Zielinska, K., Malinska, A., Bochenek, Z., Bartold, M., Gurdak, R., Paradowski, K., & Lagiewska, M. (2020). Drought model DISS based on the fusion of satellite and meteorological data under variable climatic conditions. *Remote Sensing, 12*(18), 2944. https://doi.org/10.3390/rs12182944

Data and Information Access Services. (n.d.). https://www.copernicus.eu/en/access-data/dias)

De Sherbinin, A., Reuben, A., Levy, M. A., & Johnson, L. (2013). *Indicators in practice: How environmental indicators are being used in policy and management contexts*. Center for International Earth Science Information Network; Yale Centre for Environmental Law & Policy.

Drought Information Satellite System. (n.d.). https://copernicusdroughtservice.fpcup.pl/

Drygas, M., Nurzyńska, I., Dudek, M., & Wieliczko, B. (2024). *Wspólna polityka rolna w Polsce – bilans 20-lecia członkostwa w UE i wyzwania na kolejne lata. Podsumowanie*. EFRWP, IRWiR PAN. https://doi.org/10.53098/978-83-967511-4-0

European Association of Remote Sensing Companies. (2024). *European Earth Observation Industry Survey*. https://earsc.org/2024/11/18/earsc-industry-survey-2024/

Framework Partnership Agreement on Copernicus User Uptake. (n.d.). https://www.copernicus-user-uptake.eu/

Gao, B.-C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment, 58*(3), 257–266. https://doi.org/10.1016/S0034-4257(96)00067-3

Geostatistics Portal. (n.d.). https://portal.geo.stat.gov.pl/en/home/

Google Earth Engine. (n.d.). https://earthengine.google.com/

Hardisky, M. A., Klemas, V., & Smart, R. M. (1983). The influence of soil salinity, growth form, and leaf moisture on the spectral radiance of Spartina alterniflora canopies. *Photogrammetric Engineering and Remote Sensing, 48*(1), 77–84.

Jin, H., & Eklundh, L. (2014). A physically based vegetation index for improved monitoring of plant phenology. *Remote Sensing of Environment, 152*, 512–525. https://doi.org/10.1016/j.rse.2014.07.010

Kogan, F. N. (1995). Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research, 15*(11), 91–100. https://doi.org/10.1016/0273-1177(95)00079-T

Kosztra, B., Büttner, G., Hazeu, G., & Arnold, S. (2017). *Updated CLC illustrated nomenclature guidelines*. European Environment Agency.

Local Data Bank. (n.d.). (https://bdl.stat.gov.pl),

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). *Geographic information science and systems* (4th ed.). Wiley.

MacEachren, A. M. (1995). *How maps work: Representation, visualization, and design*. Guilford Press.

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing, 17*(7), 1425–1432. https://doi.org/10.1080/01431169608948714

McMaster, G. S., & Wilhelm, W. W. (1997). Growing degree-days: One equation, two interpretations. *Agricultural and Forest Meteorology, 87*(4), 291–300. https://doi.org/10.1016/S0168-1923(97)00027-0

Móricz, Á. M., Szeremeta, D., Knaś, M., Długosz, E., Ott, P. G., Kowalska, T., & Sajewicz, M. (2018). Antibacterial potential of the *Cistus incanus* L. phenolics as studied with use of thin-layer chromatography combined with direct bioautography and in situ hydrolysis. *Journal of Chromatography A, 1534*, 170–178. https://doi.org/10.1016/j.chroma.2017.12.056

Morse, S. (2011). Harnessing the power of the press with three indices of sustainable development. Ecological *Indicators, 11* (6), 1681–1688. https://doi.org/10.1016/j.ecolind.2011.04.016

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Souhail Boussetta, Choulga, M., Harrigan, S., Hersbach, H., Martens, B., Miralles, D. G., Piles, M., Rodríguez-Fernández, J. N., Zsoter, E., Buontempo, C., & Thépaut, J.-N. (2021). ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. *Earth System Science Data, 13*(9), 4349–4383. https://doi.org/10.5194/essd-13-4349-2021

National Drought Mitigation Centre. (n.d). https://www.drought.gov/topics/agriculture

Ochtyra, A., Marcinkowska-Ochtyra, A., & Raczko, E. (2020). Threshold- and trend-based vegetation change monitoring algorithm based on the inter-annual multi-temporal normalized difference moisture index series: A case study of the Tatra Mountains. *Remote Sensing of Environment, 249*, Article 112026. https://doi.org/10.1016/j.rse.2020.112026

Open Data Framework for the Baltic Sea Drainage Basin. (n.d.). https://fpcup.pl/fpcup-baltyk/

SentinelHub. (n.d.). https://www.sentinel-hub.com/

Yan, G., Hu, R., Luo, J., Weiss, M., Jiang, H., Mu, X., Xie, D., & Zhang, W. (2019). Review of indirect optical measurements of leaf area index: *Recent advances, challenges, and perspectives. Agricultural and Forest Meteorology, 265*, 390–411. https://doi.org/10.1016/j.agrformet.2018.11.033

Żyszkowska, W., Spallek, W., & Borowicz, D. (2012). *Kartografia tematyczna*. PWN.