Available Agrometeorological Data Sources in Croatia

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Precision agriculture (PA) is a data-driven approach to farming that uses a range of ICT solutions—remote sensing, Internet of Things (IoT), artificial intelligence (AI)—to improve and increase crop yields and the profitability of agricultural production, while reducing the amount of resources needed for food production, such as the amount of water, fertilizers, herbicides, and insecticides. Croatia consists of three main geographical regions: the Pannonian and para-Pannonian plains in the north and north-east, the central mountain belt in the west and south, and the Croatian coastal area. The Pannonian plains are the most fertile agricultural regions in Croatia, enriched by alluvial deposits from the Sava and Drava rivers. The central mountain belt offers some arable, meadow, and pasture land, while the coastal region is mostly barren and mountainous with little agricultural land.

Keywords: remote sensing ; ground-based sensing ; ERA5-Land ; Agri4Cast ; precision agriculture

1. Copernicus Climate Data Store and ERA5-Land Dataset

The Copernicus services mainly rely on data from the Sentinel satellites, which are owned by the European Union and used primarily for Earth observation. The first satellite was launched in 2014. Additionally, some of the data are obtained from ground-based meteorological stations, ocean buoys, and air quality sensors [1]. These in situ measured data are used to calibrate and verify the satellite data and to provide reliable and consistent information.

The Copernicus climate data archive includes the ERA5 dataset, a fifth-generation global atmospheric reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF). Covering the period from January 1950 to the present, ERA5 serves as a comprehensive resource of Earth observation. The dataset utilizes a more advanced version of the ECMWF Integrated Forecast System model, offering increased temporal output and higher horizontal and vertical resolutions [2].

The data used in the study are from the ERA5-Land dataset. Compared to ERA5 and the old ERA-Interim, the main advantage of ERA5-Land is the improved horizontal resolution, which is 9 km compared to 31 km (ERA5) or 80 km (ERA-Interim), while the temporal resolution is hourly, as in ERA5. ERA5-Land provides higher resolution data based on an additional examination of the land component of the ECMWF ERA5 climate reanalysis [3][4]. This reanalysis method seamlessly integrates observations and models to fill data gaps, contributing valuable insights about global weather and climate patterns.

The ERA5-Land dataset relies on atmospheric forcing derived from ERA5 near-surface meteorology state and flux fields [3]. Parameters such as air temperature, specific humidity, wind speed, surface pressure, and surface fluxes, including radiation and precipitation, are crucial parameters of the ERA5-Land dataset. A careful interpolation process is applied to transform these parameters from the ERA5 resolution to the ERA5-Land resolution, with precision improved by a linear interpolation method based on a triangular mesh. The hourly atmospheric forcing for ERA5-Land is maintained consistently over its entire production period. This is achieved by assimilating conventional meteorological and satellite observations using a four-dimensional variational assimilation system (4D-Var) and simplified extended Kalman filter (SEKF) systems. The ECMWF land surface model, specifically, the Carbon Hydrology-Tiled ECMWF Scheme for Surface Exchanges over Land (CHTESSEL) forms the core of the ERA5-Land model. Further details about the model can be explored in the Integrated Forecasting System (IFS) documentation [5].

The Climate Data Store (CDS) is the core of the Copernicus Climate Change Service, also known as C3S [6]. The CDS provides free access to information about past, present, and future climate observations, and serves as a one-stop site for users to explore climate data. It provides a variety of quality-controlled climate data that are made available to users in a consistent and dependable manner. The Copernicus site [7] emphasizes that the environmental data processed by Copernicus services are derived from Earth observation satellites and ’in situ’ sensors. These sensors, whether ground-based, in the ocean, or in the air, offer precise measurements at specific sites. Notably, for CDS, satellite observations are

integrated into the calculations, enhancing both the accuracy and spatial resolution of the model for ERA5-Land parameters explored by this study. CDS API is a service that provides programmatic access to CDS data in Python (using the CDS API client).

Table 1 lists the selected parameters from the ERA5-Land dataset. The dataset also contains other data types that were not explored in this study (For a more extensive list of comparable parameters from the three data sources, please refer to [8]); however, those mentioned were selected since they are informative for PA and were adequate for the subsequent statistical analysis. The data are retrieved through the CDS API, which is accessed via a Python script. To properly download the data, users must first register and then generate a *.cdsapirc* file.

Table 1. ERA5-Land parameters selected for the statistical analysis.

Name	Unit	Description
2 m temperature	**K**	**air temperature at 2 m above the surface of land, sea, or inland waters**
soil temperature level 1	**K**	**temperature of the soil in layer 1 (0–7 cm) of the ECMWF Integrated Forecasting System**
total precipitation	**m**	**accumulated liquid and frozen water, including rain and snow**

2. Agri4Cast Portal

The Agri4Cast data collection, developed by the Joint Research Centre (JRC) and its Monitoring Agricultural ResourceS (MARS) unit, has been an important resource of agrometeorological information to EU member states since 1975. This comprehensive dataset contains daily weather data from a network of at least 4200 weather stations, characterised by an irregular distribution and density. In addition, the dataset contains data from six weather forecast products, five of which come from ECMWF and one from the Copernicus programme. These forecast products exhibit variations in forecast depth and have a different number of possible realisations, referred to as “members”. The ECMWF weather products, including the ERA model, contribute valuable forecast data to the Agri4Cast collection. Given the non-uniform distribution of weather stations and the varying distances between them, both the observed weather data and the forecast products are then interpolated onto a fixed 25 × 25 km grid that matches the grid used by ERA and E-OBS [9]. The grid-based data acquisition assumes homogeneity within the 25 × 25 km grid cells. To achieve this, two different interpolation methods are used. Precipitation is interpolated using regression kriging, while the Crop Growth Monitoring System (CGMS) is used for the interpolation of all other meteorological elements [10].

In contrast to ERA5-Land, this dataset in not based on satellite observations, but rather on the following two components:

- daily weather information from a large synoptic weather station network, and
- six different weather forecast products, which provide a comprehensive and versatile resource for agrometeorological analyses.

Through the Agri4Cast portal, users can submit requests and download agrometeorological data for Europe. The desired data are filtered by country and then by region within each country before downloading. For the Republic of Croatia, data are provided for the continental and Adriatic regions, as well as for each county within these regions. When submitting a request, a user can specify one or more datasets to download and the desired time period. The data are available from 1 January 1979. The portal is updated once a year, and the previous year’s data are usually made available in January. The Agri4Cast data are usually available 15 min after selecting the appropriate parameters and submitting the request, after which the user is notified via an e-mail address used during registration on the site. The generated data are provided as a CSV file.

The parameters from the Agri4Cast dataset used in the analysis are listed in **Table 2**.

Table 2. Agri4Cast parameters selected for the statistical analysis.

Description	Unit
average daily temperature	**°C**
sum of precipitation per day	**mm**

3. PinovaMeteo

PinovaMeteo is an in situ agrometeorological station developed by the company Pinova from Čakovec, Croatia. It is used in orchards, vineyards, vegetable gardens, plant nurseries and farms, and allows users to check current and historical measurements via mobile and web applications. The PinovaMeteo station is fully automated and connected to the Internet, so users do not need to visit it to collect data. The station is powered by a solar panel during the day and operates at night with a battery that is charged during the day. The PinovaMeteo station continuously collects data every 10 min and submits data to a backend server every half an hour or hour (more or less frequently depending on the user's needs and battery state).

The parameters measured by the PinovaMeteo agrometeorological stations are listed in **Table 3**.

Table 3. PinovaMeteo parameters used in the statistical analysis.

Description	Unit
air temperature	**°C**
soil temperature	**°C**
rainfall	**mm**

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