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Report on Earth Observation Data Characteristics, Suitability, and Accuracy

Spatially Explicit Digital Twin of the Greek Agro-Hydro-System

DT-Agro

ID 14815

1. Introduction

This report is part of the DT-Agro project, which involves creating a spatially explicit Digital Twin of the Greek Agro-Hydro-system. A Digital Twin is a virtual model of real-world systems that uses real-time data inputs which can predict system responses under different conditions using real-time data inputs. Across several scales, from farm-parcel to regional and national, DT-Agro aims to integrate real-time data, simulations, and decision-making tools. The model focuses on the relationships between water, soil, food, the environment, and energy, giving vital insights for sustainable agriculture and resource management.

This research focuses primarily on the identification, evaluation, and simplification of Earth Observation (EO) data sources and methods for initializing, evaluating, and adapting DT-Agro. The Agro-Hydro-System, which DT-Agro will simulate, includes all hydrological processes influenced by agricultural activities such as irrigation, nutrient cycling, and land use changes. Accurate and timely EO data is essential for modeling these processes, making it possible to optimize agricultural practices and manage water resources efficiently. One significant advantage of having geographically detailed and near real-time data is that it allows for the evaluation of agro-hydrological models in data-scarce locations. DT-Agro will use EO tools in a novel way to provide real-time and spatially explicit data for evaluating and improving the spatial representation of states and fluxes, and ultimately to constantly update models' state variables to represent actual conditions, increasing their operational predictive potential.

The primary goals of this research are to identify and evaluate EO data sources and procedures that will be used as input data for DT-Agro. The suitability of these data sources for initializing, validating, and ongoing updates to Digital Twin will also be assessed. To guarantee that DT-Agro can accurately and instantly replicate real-world agricultural and hydrological circumstances, it is imperative to optimize the collection and handling of this data.

2. DT-Agro and the Agro-Hydro-System

DT-Agro will model the Agro-Hydro-System, which refers to the hydrological processes within a catchment, influenced by agricultural activities. These include changes to spatial structures, input fluxes (water, nutrients, carbon), and climate factors. The system is modeled at multiple scales, considering interactions between soil, water, vegetation, and atmospheric processes.

To achieve this, DT-Agro relies heavily on EO data that provides continuous, spatially explicit, and near real-time information. This data will facilitate simulations that predict system responses to varying environmental and management conditions, providing insights into irrigation requirements, crop stress, soil moisture, and groundwater storage. These insights will inform better decision-making processes, improving resource use efficiency and sustainability in agriculture.

3. Description of Work

The work outlined in this report focuses on identifying EO data sources and techniques relevant to the scope of DT-Agro, evaluating their characteristics and suitability, and streamlining their acquisition and processing for real-time use. Special emphasis is placed on high temporal and spatial resolution datasets that monitor potential and actual evapotranspiration (ETa), soil moisture, crop stress, vegetation development, and other related parameters. This includes datasets that monitor key agro-hydrological variables such as crop coefficients (K_c), soil erosion, soil degradation, and terrestrial water storage changes.

This work is separated into three main tasks. **Task T3.1** will identify and evaluate existing and emerging EO data sources (M1–6). This includes evaluating EO datasets that accurately represent soil moisture, vegetation health (using NDVI for K_c), real evapotranspiration, precipitation, land surface temperature, vegetation types, vegetation cover fraction (f cover), and groundwater storage (using GRACE data). These datasets will be assessed based on their geographical and temporal resolutions, correctness, and usefulness for modeling processes at both the local and regional levels.

Task T3.2 will conduct a complete review of the accuracy of the received EO data (M1-12). This entails evaluating several data sources and validating them against ground truth measures. The accuracy of EO datasets will be assessed using key metrics such as Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). This validation ensures that the data used in DT-Agro reflects actual agricultural and hydrological conditions, thereby improving the system's predictive potential.

Task T3.3 will focus on speeding the collecting, processing, and transformation of data from the specified EO data sources to ensure it is ready for incorporation into spatial databases and effective use by DT-Agro. This assignment includes automating data pipelines, preparing the data to remove errors, and ensuring that the data format is consistent with the DT-Agro modeling framework. The goal is to ensure that the real-time EO data is smoothly and efficiently integrated into the system, allowing for continuous simulation updates. Task T3.3 is anticipated to be finished in M18, marking the end of DT-Agro's data collection, processing, and integration operations.

4. Identification and Evaluation of EO Data Sources (T3.1)

As part of Task T3.1, various EO datasets were identified and evaluated for their relevance to DT-Agro's agro-hydrological modeling. High temporal and geographic resolution datasets that monitor soil moisture, crop stress, vegetation growth, potential and actual evapotranspiration (ETa), and other relevant factors are given special attention. This covers soil erosion, soil degradation, crop coefficient (K_c), and changes in terrestrial water storage, among other important agro-hydrological variables.

Soil Moisture

Soil Moisture is an important hydrologic condition variable for several Earth and environmental science applications, affecting both the global environment and human culture. Potential applications include weather forecasting, drought monitoring, water resource management, agricultural plant production, natural disaster prevention (e.g., wildfires, and floods), and monitoring ecosystem response to climate change (Babaeian et al., 2019). Monitoring soil moisture levels on a large scale is crucial for managing agricultural water resources. It improves plant water availability, efficiency, and productivity, while also reducing the risk of negative environmental impacts. Soil moisture is an effective indicator of drought conditions and flood risks, and hence plays a unique role in their forecast. Saturated soil is unable to absorb extra water, resulting in increased surface runoff and subsequent flooding. This parameter is a critical factor for understanding water availability for crops, and datasets from satellite platforms provide essential soil moisture data. These datasets are valuable for modeling the water cycle within the Agro-Hydro-System and for optimizing irrigation management by continuously monitoring water availability in soils.

Many sources provide timely, high-resolution soil moisture data that is appropriate for regional study. For example, NASA's SMAP (Soil Moisture Active Passive) mission delivers 36-kilometer-resolution radiometer-based soil moisture estimates with updates every two to three days. SMAP data is accessible via NASA's Earthdata portal and is especially trustworthy for tracking more general environmental and hydrological trends. This mission uses a combination of an active radar and a passive radiometer to provide global measurements of surface soil moisture (Brown et al., 2013). Another useful tool is the Copernicus Global Land Service, which provides daily soil moisture data with a resolution of one kilometer. This near-real-time dataset, which spans Europe, is ideal for monitoring changes in Greece's agricultural zones and water resource management.

The ESA Climate Change Initiative (CCI) Soil Moisture dataset is particularly helpful because it offers a long-term, standardized dataset that incorporates data from several satellite sources. This Programme started in 2010 and produces an updated soil moisture product annually. This data, which is available every day and has a resolution of 0.25° (~28 km), is perfect for analyzing the effects of climate change in Greece and researching past soil moisture trends. It makes analysis easier for Greek regions and is accessible via Google Earth Engine or the ESA CCI Open Data Portal.

By combining EO and in-situ data at a resolution of roughly 31 km, ECMWF's ERA5 Reanalysis provides a useful dataset for high-frequency soil moisture data. ERA5, which is accessible through the Copernicus Climate Data Store, offers hourly and monthly options and is helpful for in-depth analyses of soil moisture variability unique to the Greek climate and seasonal conditions.

The MERRA-2 dataset (Modern-Era Retrospective Analysis for Research and Applications, Version 2), created by NASA's Global Modeling and Assimilation Office (GMAO), is a large global reanalysis dataset that includes useful soil moisture data for locations throughout the world, including Greece. MERRA-2 provides hourly temporal resolution and geographical resolution of approximately 0.5° x 0.625° (about 50 km at the equator), with data from 1980 to the present (Gelaro et al., 2017). Soil moisture data is available at different depth levels making it useful for a variety of applications that require both surface and root-zone moisture data.

The collection combines satellite observations and model simulations to generate consistent land surface and atmospheric characteristics for climate studies and modeling. MERRA-2's temporal coverage makes it ideal for tracking long-term soil moisture patterns, which are crucial in agricultural impact studies. This high-resolution temporal data is also appropriate for short-term drought monitoring and forecasting, providing insights into moisture dynamics across several soil layers that are critical for crop production and agricultural sustainability assessments. MERRA-2 soil moisture data, which is available through NASA's GES DISC and Earthdata portals (Gelaro et al., 2017), is widely used in hydrological and environmental research, aiding projects that require reliable, long-term climate records.

A number of these datasets, such as SMAP and CCI soil moisture, are combined into a single, easily accessible platform by Google Earth Engine (GEE). In Greece, GEE facilitates scripting, data extraction, and visualization for specialized soil moisture research. Together, these resources provide a flexible toolkit for soil moisture analysis throughout Greece, encompassing a range of temporal depths and resolutions appropriate for several uses, from regional farming to more extensive environmental monitoring.

Vegetation Indices

Vegetation indices (VIs) are mathematical combinations of primarily red, green, and infrared spectral bands. They aim to identify functional correlations between crop characteristics and remote sensing measurements (Chlingaryan et al., 2018). Vegetation indices use spectral interactions to generate values that can be examined to provide information about the state and behavior of vegetation across landscapes. They are important tools that assess vegetation cover, health, and dynamics by utilizing the spectral properties of vegetation detected by satellite sensors.

- **The Normalized Difference Vegetation Index (NDVI)**

In the DT-Agro project, the primary index used is the Normalized Difference Vegetation Index (NDVI). It offers vital information about the density and health of vegetation and is derived from satellite-based Earth observation data. The NDVI estimates the difference between red light, which vegetation absorbs, and near-infrared light, which vegetation strongly reflects; to determine how green or vigorous the plant life is in each location. Therefore, a number between -1 and 1 is produced, with higher values (usually between 0.2 and 0.8) denoting healthy, dense vegetation and lower values denoting stressed or sparse vegetation, barren ground, or water.

Because this index helps to track crop health, vegetation development, and land cover in almost real-time—all critical for precisely modeling the Agro-Hydro-System—NDVI is particularly significant in the context of DT-Agro. DT-Agro can assess how crops respond to various climatic and environmental situations, such as droughts, heavy rainfall, and temperature fluctuations, by analyzing NDVI data on a regular basis. This is especially important in areas where agriculture is strongly dependent on precision water management and irrigation procedures.

One of the most important applications of NDVI in DT-Agro is determining crop coefficient (K_c), which is used to calculate the crop's water requirements via evapotranspiration. The NDVI-to-K_c connection enables a spatially detailed tracking of crop water usage, which is a critical aspect in irrigation scheduling. Satellite-derived NDVI, notably from platforms such as Sentinel-2 and Landsat, has excellent geographic resolution and frequent revisits, making it suited for farm- and regional-scale monitoring.

NDVI-based crop coefficient (K_c) data can be obtained from a variety of satellite sources, each with a different geographical and temporal resolution appropriate for agricultural monitoring. Satellites such as Sentinel-2 are often utilized for NDVI-to-K_c data. Sentinel-2, part of the European Space Agency's Copernicus program, collects high-resolution NDVI data at 10-meter resolution and has a 5-day revisit duration. Its spatial and temporal precision make it perfect for determining precise K_c values at parcel level.
The Landsat satellites, particularly Landsat 8 and Landsat 9, also give NDVI data at a 30-meter resolution over a 16-day period. While they have lesser geographical and temporal resolutions than Sentinel-2, they are useful for long-term monitoring and historical study of crop coefficients. Landsat's record also supports historical K_c trend research.
Lastly, the MODIS sensors on the Terra and Aqua satellites provide lower-resolution (250-500 meter) NDVI data with daily and 8-day composites. Though not appropriate for small parcel analysis, MODIS is useful for regional-scale K_c assessments and tracking crop water use patterns over larger agricultural areas.

Land Surface Temperature (LST)

Land Surface Temperature (LST) is essential for evaluating the heat stress that crops might experience, which directly affects evapotranspiration rates. Several reliable sources provide LST data suitable for agricultural and hydrological applications, offering insights that support sustainable water and land management. One of the most widely used sources of LST data is the Moderate Resolution Imaging Spectroradiometer (MODIS), operated by NASA. Mounted on the Terra and Aqua satellites, MODIS provides LST data at a 1 km spatial resolution with high temporal frequency, capturing measurements every 1-2 days. Terra captures daytime LST readings, while Aqua provides nighttime readings, which helps distinguish between diurnal temperature variations. The MODIS archive extends back to 2000, providing a rich historical dataset for long-term trend analysis, which is particularly useful for understanding seasonal shifts and temperature anomalies that can affect crop productivity. Freely accessible via

NASA's Earthdata portal, MODIS data is ideal for large-scale, consistent LST monitoring across Greece.

The European Space Agency's Sentinel-3 satellites also provide LST data through the Sea and Land Surface Temperature Radiometer (SLSTR). Sentinel-3 offers a 1 km spatial resolution and a revisit time of 1-2 days, delivering accurate LST readings over land. The availability of Sentinel-3 data via the Copernicus Browser ensures free and open access to European data, ideal for localized applications within Greece. Sentinel-3's measurements are particularly relevant for DT-Agro, as they provide complementary data to MODIS, enabling cross-validation and refining of LST measurements for increased accuracy.

LST data from satellites such as MODIS and Landsat are used to track surface temperature variations, making it possible to identify heat-related stress and adapt irrigation practices accordingly.

Vegetation types

Vegetation types and the percentage of soil covered by vegetation (fcover) are crucial for understanding land use and its effects on soil erosion and water retention. Vegetation cover fraction (fcover), also known as fractional vegetation cover (FVC) or percentage vegetation cover, is a metric used to quantify the proportion of ground surface covered by vegetation. In DT-Agro, fcover provides valuable information on the stages of crop development, soil conservation potential, and overall ecosystem health. This allows DT-Agro to make informed, timely decisions regarding irrigation needs, erosion prevention, and sustainable land management, particularly in diverse and sensitive agricultural regions such as those in Greece. EO datasets from the Copernicus Global Land Service and MODIS provide comprehensive vegetation classification and soil cover data, which help in modeling the impact of agricultural practices on soil health and erosion.

Digital Elevation Models (DEMs)

Digital Elevation Models are essential for hydrological modeling providing information about the topography of an area for hydrological modeling, soil erosion evaluation, and watershed management. There are numerous DEM sources for Greece that offer a range of access options to meet the specific requirements of different applications.
The Copernicus DEM, created by the European Space Agency (ESA) as part of the Copernicus program, is one major source. The Copernicus DEM provides high-resolution elevation data at 30- and 90-meter resolutions across Europe, including Greece. In agricultural planning and management, terrain-influenced elements like soil erosion and water flow are critical, and this data is particularly useful for modeling them. The Copernicus Open Access Hub provides users with access to the Copernicus DEM.

NASA's Shuttle Radar Topography Mission (SRTM) also produces DEM data, which is frequently used in hydrological and environmental research. The SRTM DEM provides global coverage, including Greece, at a spatial resolution of 30 meters (Farr & Kobrick, 2000). SRTM data can be freely available on platforms such as NASA's Earthdata Search and the USGS Earth Explorer, and it is ideal for large-scale applications requiring consistent elevation data across several regions.

The ASTER Global Digital Elevation Model (GDEM), developed by NASA and Japan's METI, is another useful DEM resource. The ASTER GDEM offers elevation data at 30-meter resolution and global coverage (Abrams et al., 2020), including Greece. This dataset is useful for thorough terrain study and has been widely adopted in environmental and agricultural research. ASTER GDEM is available through NASA Earthdata and the USGS Earth Explorer.

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The ALOS World 3D (AW3D30) dataset is a source of high-resolution Digital Elevation Model (DEM) data, particularly helpful for agricultural, hydrological, and environmental management applications, making it an ideal candidate for integration with DT-Agro. AW3D30, developed by the Japan Aerospace Exploration Agency (JAXA) utilizing data from the Advanced Land Observing Satellite (ALOS), offers global coverage at a 30-meter spatial resolution, including Greece. This dataset provides more recent and thorough topographic information than many other DEMs, making it excellent for accurate terrain study and modeling.

Groundwater storage changes

Groundwater storage changes are monitored through the GRACE (Gravity Recovery and Climate Experiment) mission, which provides satellite-based data on large-scale variations in groundwater. The GRACE mission, launched in March 2002 by NASA and German Aerospace Center and ended in October 2017. GRACE data are often aggregated or spatially averaged within study regions and offer essential information on long-term trends in groundwater storage variations (Gerdener et al., 2022), which is a critical factor for irrigation planning and long-term agricultural sustainability in Greece.

Actual evapotranspiration (ET_a)

Actual evapotranspiration (ET_a), a vital metric in water balance and crop stress assessments, is derived using EO data such as land surface temperature (LST) and vegetation indices using models that approximate the water flux between soil, vegetation, and the atmosphere. In the context of DT-Agro, it provides insights into real-time water consumption and availability, helping in efficient irrigation management and water resource planning. LST is important for calculating evapotranspiration because it reflects the thermal characteristics of the land surface, which change depending on soil moisture, vegetation cover, and meteorological conditions. When LST is high and soil moisture or NDVI is low, it can suggest water stress.

Crop and soil moisture levels are assessed using vegetation indices, which represent vegetation health, density, and cover. For ET_a estimates, NDVI is used as a proxy for canopy cover and photosynthetic activity, which influences transpiration rates. MODIS and Sentinel-2 datasets provide accurate estimates of ETa, which help assess water requirements and crop water use.

Meteorological Data

Meteorological data, especially precipitation, is another important dataset for DT-Agro. To produce quantitative estimates of precipitation, satellite-based remote sensing techniques have been developed. Satellite-based precipitation products offer global coverage and near-real-time availability, making them suitable for use in areas with limited gauges (Li et al., 2022). Precipitation data obtained from satellite-based sources, such as the Global Precipitation Measurement (GPM) mission, plays a crucial role in estimating water inputs into the system and predicting potential crop stress caused by drought or excessive rainfall.

One of the most extensive ways to gather precipitation data from Earth observation sources is through the Global Precipitation Measurement (GPM) Mission. NASA and the Japan Aerospace Exploration Agency (JAXA) jointly operate GPM, which provides high-resolution, near-real-time worldwide precipitation data. GPM uses its dual-frequency radar and microwave imager to provide data on rain rates, snowfall, and precipitation intensity across a variety of climate zones. This data is accessible through platforms like NASA's Earthdata and GES DISC (Goddard Earth Sciences Data and Information Services Center), where users can tailor their data downloads by choosing spatial and temporal parameters. Because of its great spatial resolution and frequent updates, GPM data is particularly useful for agricultural and hydrologic applications.

The Climate Prediction Center's (CPC) Unified Gauge-Based Analysis of Global Daily Precipitation is another reliable source of precipitation data. This dataset uses satellite and ground-based gauge data to generate daily global precipitation estimates. The National Oceanic and Atmospheric Administration (NOAA) manages it, and it covers multiple places with historical records dating back to the 1970s, making it useful for long-term climate and trend analysis. CPC precipitation data is available on NOAA's websites and Earthdata, allowing users to monitor daily, monthly, and seasonal averages to aid in area water resource planning and crop management.

For high spatial resolution, the Tropical Rainfall Measuring Mission (TRMM) dataset, which preceded GPM, provides historical precipitation data. While TRMM data is no longer operational, it is still useful for analyzing long-term rainfall patterns and variability, particularly in tropical and subtropical locations. TRMM data is available through NASA's Earthdata Search portal, and it serves as a fundamental dataset for a variety of agricultural and hydrological research projects around the world.

Furthermore, the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 Reanalysis dataset contains precipitation predictions that combine satellite and observational data using complex modeling approaches. ERA5, available through the Copernicus Climate Data Store, provides hourly data with high spatial resolution, making it useful for investigating both short-term weather occurrences and long-term climate implications.

5. Evaluation of EO Data Accuracy (T3.2)

In Task T3.2, the accuracy of the identified EO datasets is evaluated to ensure their reliability and suitability for use in DT-Agro. This task focuses on validating satellite-based measurements against ground-truth data, where available, and performing accuracy assessments using standard metrics such as RMSE and MAE.

For soil moisture, data from SMAP satellite mission is validated against field-based soil moisture sensors. These comparisons ensure that the satellite data accurately reflect real-time conditions in the soil, making them reliable for managing irrigation and tracking water availability.

NDVI-derived crop coefficient (K_c) are compared with ground-based measurements of crop water usage. This ensures that the K_c values generated from NDVI data provide accurate estimates of crop evapotranspiration and water needs, which is essential for efficient irrigation management.

Evapotranspiration (ET_a) estimates derived from LST and NDVI data are validated using field-based measurements of water balance. This step is critical for ensuring that EO-based ET_a values accurately represent actual crop water use, which influences water resource management and planning.

Precipitation data obtained from satellites are compared to local meteorological station data to verify their accuracy in estimating rainfall. Accurate precipitation data is vital for estimating water inputs into the Agro-Hydro-System and predicting crop water requirements.

LST data from MODIS and Landsat satellites is validated by comparing satellite-derived temperature estimates with ground-based measurements. Accurate temperature data is important for assessing crop stress caused by heat, enabling proactive irrigation management to mitigate heat stress.

For vegetation types and soil cover (f cover), EO datasets are compared with field observations to ensure accuracy in classifying vegetation types and estimating the extent of soil cover by crops. Accurate vegetation classification is necessary for understanding land use and the impacts of agricultural practices on water and soil health.

Digital Elevation Models (DEMs) are compared with high-resolution topographic maps to validate their accuracy in representing landforms and slopes, which are essential for simulating water flow and erosion patterns.

Groundwater storage data from mission GRACE (Gravity Recovery and Climate Experiment) are compared with local groundwater observations to evaluate its effectiveness in capturing trends in groundwater availability. Accurate groundwater data is essential for understanding long-term water resource sustainability in Greece.

7. Conclusion

The integration of Earth Observation (EO) data into agro-hydrological models and more specifically into DT-Agro represents a significant advancement in agricultural and water resource management. By leveraging the continuous improvements in EO technology and the vast amounts of spatially explicit data available, DT-Agro is poised to become a powerful tool for understanding and managing the complexities of the water-soil-food-environment-energy nexus. The development of DT-Agro relies on high-resolution EO datasets, which are soil moisture, NDVI-derived crop coefficients, actual evapotranspiration, meteorological data, land surface temperature, vegetation types, and groundwater storage. These datasets provide real-time insights into the behavior of the Agro-Hydro-System. They allow for a two-way flow of information between the real-world system and the digital twin, enabling continuous updates and better decision-making.

The three primary tasks-identifying and evaluating EO data sources, assessing data accuracy, and streamlining data processing-are essential to the success of DT-Agro. The evaluation of existing and emerging EO data ensures that the selected datasets are both relevant and accurate, while the streamlining of data processing ensures that these datasets are readily usable for DT-Agro’s spatial databases and models. Together, these efforts ensure that DT-Agro remains a robust and adaptable tool capable of reflecting real-time agricultural and hydrological conditions in Greece, while offering predictive capabilities that can inform strategic decisions at multiple scales, from farm-parcel to regional and national levels.

The ability to utilize near real-time EO data, including those related to crop stress, evapotranspiration, and soil moisture, provides a distinct advantage in data-scarce regions, allowing for continuous monitoring and adjustments in agricultural practices. This integration of real-time data will not only improve the accuracy of the digital twin's simulations but also offer a dynamic and interactive approach to model management that can lead to more sustainable and efficient water use in agriculture. Furthermore, the system's predictive potential can aid in mitigating risks related to climate variability, such as droughts, by enabling timely interventions.

In summary, DT-Agro represents a significant leap forward in the use of EO data for agro-hydrological modeling, creating a digital twin that reflects real-world conditions and improves our capacity for sustainable resource management. By enhancing the accuracy of hydrological and crop models and providing an efficient means for continuous data assimilation, DT-Agro will help drive innovation in agriculture and water resource management, supporting both local farmers and national policymakers in achieving better environmental and economic outcomes.

References

Abrams, M., Crippen, R., & Fujisada, H. (2020). ASTER Global Digital Elevation Model (GDEM) and ASTER Global Water Body Dataset (ASTWBD). *Remote Sensing*, *12*(7), 1156. https://doi.org/10.3390/rs12071156

Babaeian, E., Sadeghi, M., Jones, S. B., Montzka, C., Vereecken, H., & Tuller, M. (2019). Ground, Proximal, and Satellite Remote Sensing of Soil Moisture. *Reviews of Geophysics*, *57*(2), 530–616. https://doi.org/10.1029/2018RG000618

Brown, M. E., Escobar, V., Moran, S., Entekhabi, D., O'Neill, P. E., Njoku, E. G., Doorn, B., & Entin, J. K. (2013). NASA's Soil Moisture Active Passive (SMAP) Mission and Opportunities for Applications Users. *Bulletin of the American Meteorological Society*, *94*(8), 1125–1128. https://doi.org/10.1175/BAMS-D-11-00049.1

Chlingaryan, A., Sukkarieh, S., & Whelan, B. (2018). Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: A review. *Computers and Electronics in Agriculture*, *151*, 61–69. https://doi.org/10.1016/j.compag.2018.05.012

European Commission Directorate-General Joint Research Centre. *Surface Soil Moisture 2014-present (raster 1 km), Europe, daily - version 1*. Retrieved from Copernicus Land Monitoring Service. Additional details available at https://land.copernicus.eu/en/products/soil-moisture

Farr, T. G., & Kobrick, M. (2000). Shuttle radar topography mission produces a wealth of data. *Eos, Transactions American Geophysical Union*, *81*(48), 583–585. https://doi.org/10.1029/EO081i048p00583

Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., Randles, C. A., Darmenov, A., Bosilovich, M. G., Reichle, R., Wargan, K., Coy, L., Cullather, R., Draper, C., Akella, S., Buchard, V., Conaty, A., da Silva, A. M., Gu, W., … Zhao, B. (2017). The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). *Journal of Climate*, *30*(14), 5419–5454. https://doi.org/10.1175/JCLI-D-16-0758.1

Gerdener, H., Kusche, J., Schulze, K., Ghazaryan, G., & Dubovyk, O. (2022). Revising precipitation – water storages – vegetation signatures with GRACE-based data assimilation. *Journal of Hydrology*, *612*, 128096. https://doi.org/10.1016/j.jhydrol.2022.128096

Li, W., Jiang, Q., He, X., Sun, H., Sun, W., Scaioni, M., Chen, S., Li, X., Gao, J., & Hong, Y. (2022). Effective multi-satellite precipitation fusion procedure conditioned by gauge background fields over the Chinese mainland. *Journal of Hydrology*, *610*, 127783. https://doi.org/10.1016/j.jhydrol.2022.127783

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