MAGDA

INNOVATIVE SENSING FOR FARMING

METEOROLOGICAL ASSIMILATION FROM GALILEO AND DRONES FOR AGRICULTURE

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D6.1 Water Balance Simulations

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0.3	29.10.2023	FW	contributions to the document
0.4	30.10.2023	GRED	Final contributions to the document
1.0	31.10.2023	European Union Agency for the Space Programme	Version 1.0 finalized and submitted for revision
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Executive Summary

The agricultural sector accounts for a substantial portion of global water usage, making efficient water management critical, especially with the growing demands of an expanding population and the challenges posed by climate change. In this context, the Horizon Europe MAGDA Project is centred on improving the release of extreme weather events forecasts and irrigation advisory tailored to farmers' needs for three pilot demonstrator regions. MAGDA utilises multi-scale systems that integrate cutting –edge technologies such as GNSS (Galileo), weather drones, and Copernicus EO derived datasets, facilitating data collection at various levels and thereby improving weather forecasting and irrigation advisories. This initiative leverages the high-resolution Weather Forecast- and SPHY hydrological models to create a powerful tool for water resource management and farm decision support, utilizing a rich array of static and dynamic inputs.

In Deliverable 6.1, a preliminary water balance simulation has been established to form the foundation for an Irrigation Advisory Service. Water balance simulations have been conducted for three pilot areas in France, Italy, and Romania utilizing the SPHY simulation model. The primary objective of this deliverable is to demonstrate the accurate prediction of grid cell water balances, which is crucial for calculating daily irrigation requirements.

To demonstrate this, the initial step involves setting up the model and then calibrating its parameters using remote sensing data through a sensitivity analysis. A parameter set is chosen through the sensitivity analysis and with this set a further calibration with remote sensing data is done. Finally, the accuracy of the model is further validated using in situ data on root zone soil moisture specifically collected in Romania in 2018.

The spatial results indicate a generally high correlation between the SPHY model's evapotranspiration output and remote sensing data for the pilot areas in France and Italy, although adjustments to certain input parameters are needed for better performance. The Romanian sites show less correlation. For the root zone soil moisture, the correlation is less high than the evapotranspiration and the results emphasize the importance of in situ validation for model calibration. Based on these assessments and performance evaluations, the report identifies two blueprint designs for the operational irrigation service, focusing on flexibility, scalability, computational challenges, and user familiarity.

The conclusion underscores the selection of blueprint 2 for the operational irrigation advisory service due to its scalability and potential for widespread application, in contrast to blueprint 1, which faces challenges in scaling due to soil moisture heterogeneity.

The way forward involves enhancing the SPHY model's historical analysis, refining parameters, and integrating more robust in situ data. The next steps include developing algorithms for irrigation, NDVI, and precipitation to establish the operational irrigation advisory service.

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Acronyms & Abbreviations

Term	Description
API	Application Programming Interface
CGLS	Copernicus Global Land Service
DEM	Digital Elevation Model
EO	Earth Observation
FAO	Food and Agricultural Organization
FMS	Farm Management System
GNSS	Global Navigation Satellite System
IAS	Irrigation Advisory Services
LAI	Leaf Area Index
MAD	Management Allowable Depletion
NDVI	Normalized Difference Vegetation Index
PCR	PCRaster
SSM	Surface Soil Moisture
SPHY	Spatial Processes in Hydrology
SWI	Soil Water Index
WRF	Weather Research and Forecasting
RMSE	Root Mean Square Error
DOY	Day Of Year

1 Introduction

1.1 Project background

1.1.1 MAGDA concept

The agricultural sector is the largest human-induced water user in most countries. According to the Food and Agricultural Organization (FAO), approximately 70% of the world's water supply is extracted and used for agricultural purposes. As the global population continues to expand, the demand for water for the cultivation of food is rapidly increasing. Additionally, in many areas, climate change is expected to lead to a higher frequency and magnitude of extreme events such as droughts and floods. The agricultural sector, in this context, has the potential to assume a key role in water conservation efforts by striving for a more efficient water use by achieving "more crop per drop", through innovative irrigation practices.

Against this background, Irrigation Advisory Services (IAS) are agricultural extension services and powerful management instruments to achieve the best efficiency in irrigation water use. These systems are often conceptually oriented to simulate or predict crop water demand, providing a set of options. The introduction of IAS could advance irrigation practices and water efficiency in the near future, while providing an economic advantage for farmers: the adoption of new irrigation management systems can both increase farmers' income and reduce energy costs.

The MAGDA project aims at providing an integrated – but modular – system to provide both severe weather forecasts and irrigation advisories enhanced by means of various satellite-borne, drone-borne and ground-based weather-observing technologies. The weather forecasts will be produced by weather models ingesting a wide array of atmospheric observations and will be used as an input for the irrigation advisory, next to being used for generating warnings for extreme weather events. The warnings and irrigation advisories will ultimately be channelled through a Farm Management System to ensure the capability to effectively reach farmers and agricultural operators.

Figure 1. MAGDA concept visualization

1.1.2 MAGDA targets

The target of the MAGDA project is to build a system based on hardware, software and data sources components to monitor and process environmental quantities, to deliver to farmers information and suggestion to improve the management of their farms.

In order to monitor the progress of system implementation, a set of key performance indicators will be defined according to the specific of each target. The main targets are:

- Successful deployment of hardware systems (EGNSS receivers, meteodrones and in-situ sensors).
- Successful setting of pre-processing tools (GNSS data, in-situ data and Copernicus data).
- Successful setting and implementation of the weather and hydrological models.

1.1.3 MAGDA tools structure

MAGDA system will be based on a suite of tools for pre-processing GNSS data, in-situ data and Copernicus data, for weather and hydrological modelling as well as tools for farm management (Table 1). A detailed description of MAGDA tools is provided in D3.1, section 4.1.9.

Table 1. MAGDA tools description

Developer	Tools	Description
GRED	Atmospheric water vapor / soil moisture monitoring service	low-cost GNSS stations and BREVA cloud-based GNSS processing software
MM	Drone observation service	perform atmospheric measurements along the vertical direction
CAP2020	In-situ sensors	perform ground-bases observation of key meteorological variables
CIMA	WRF	provide weather forecast for early warning of extreme events
FW	SPHY-Irrigation	provide irrigation advisory based on a hydrological water balance model
CAP2020	FMS	provide an operational tool (adaptive dashboard and APIs) for farm management system

In the framework of MAGDA project all these tools will be integrated into a system (Figure 2) in order to provide operationally improved weather forecasts by assimilating the new spatial technologies and irrigation advisory direct to farmers and agriculture operators.

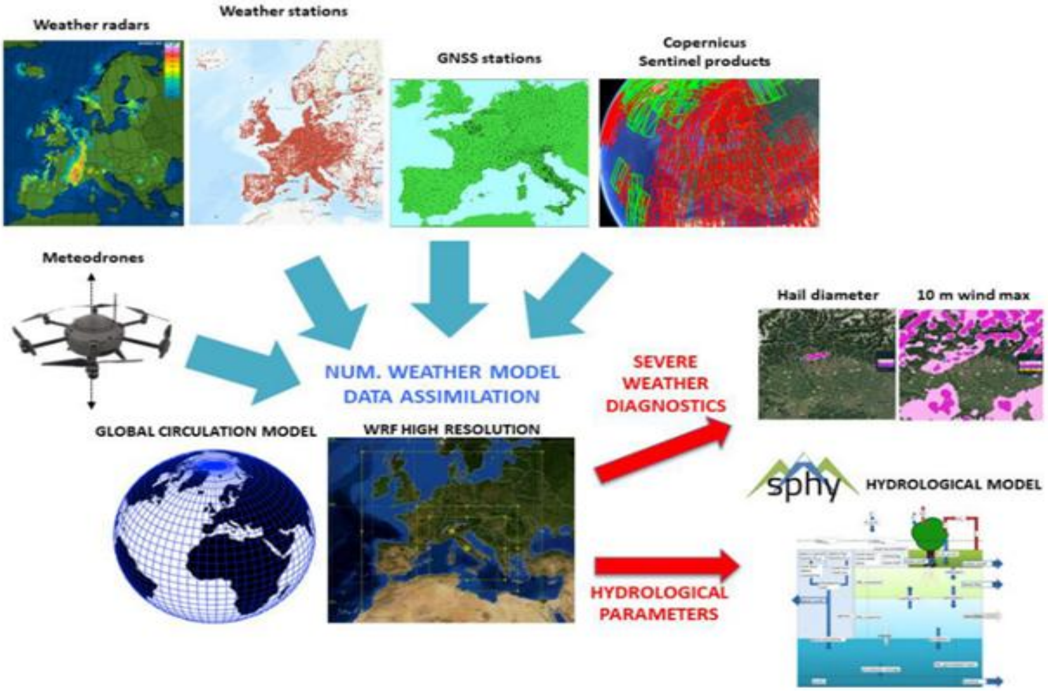

Figure 2. MAGDA forecast concept

1.2 Pilot areas and demo sites

The pilot areas for the MAGDA project are multiple farms located in multiple countries. The pilot areas are situated in Beaune (FR), Piedmont (IT), Braila (RO). The SPHY Model will be run for all three pilot areas. Furthermore, every pilot area has multiple demo sites. These demo sites mostly consist of farms, which will be monitored for the eventual irrigation advisory service. Most demo sites have GNSS and/or a weather station installed on the premises of the farm.

Figure 3. Locations of the three pilot areas across Europe.

1.2.1 Burgundy, France

The pilot area in Burgundy (France) covers Beaune, a well-known vineyard area. Sensors will be deployed on vineyard fields owned by la Maison Louis Jadot.

The possible interest in the outcome of the project for Maison Jadot include:

- better anticipation of extreme events such as frost & hail impact.
- more usable decision-making data. They rely on an existing Farm Management System, but the data is not very usable, and neither very reliable.
- Even if they cannot irrigate, they are very interested in knowing better the water status of the vineyard. There are some levers to activate, especially soil management.
- Better understanding of their (micro) climate and its evolution due to climate change.

Figure 4 shows the pilot area in Beaune, France, including the five MAGDA demo sites.

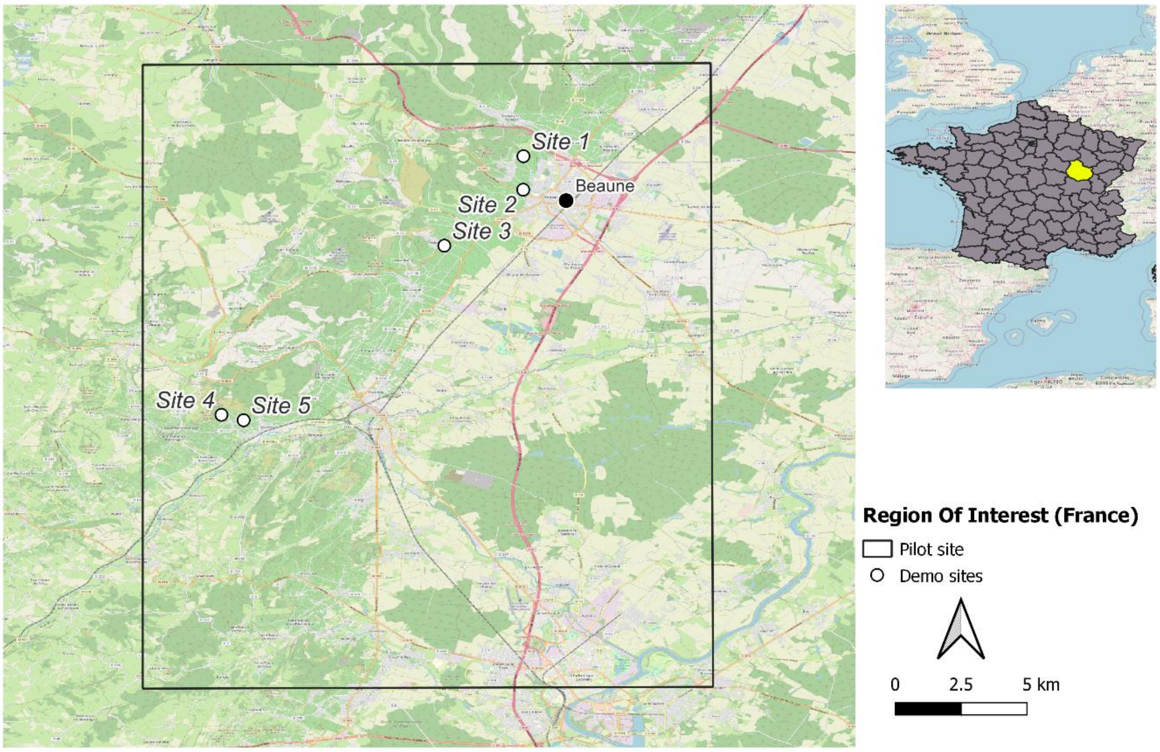

Figure 4. Pilot area in Beaune, France, including the five MAGDA demo sites.

1.2.2 Piedmont, Italy

The Italian case studies will focus on the site proposed by the Italian Confederation of Farmers – Cuneo section (ICF-C). Situated in Piedmont region (north-west Italy), the area between Cuneo and Saluzzo is recognized as a major hub for fruit production in both Italy and Europe. The bigger plantations have a greater inclination towards experimenting cutting-edge technologies, and they have already formed a partnership with the CIA to pursue this goal. Their attention is currently centred on anticipating late frost, heatwaves, and rainfall events. Since weather forecasts already provide accurate predictions of frost and heatwaves, the focus in the MAGDA project will be on the rainfall events forecast improvement, not only the most intense one (i.e., causing floods), but also on normal rainfall days. In fact, rainfall can have a significant impact on fruit crops and their susceptibility to pests and diseases

(Yadav et al., 2023). Providing more accurate rainfall forecast can help in developing effective management strategies and ensuring the health and productivity of fruit orchards.

- Site 1 grows apples and peaches. Irrigation is localized, with soil moisture sensors (tensiometers) already in place to define when and where to irrigate. Soil moisture sensors are already in place (tensiometers).
- Site 2 grows apples, cherries, almonds, hazelnuts. No localized irrigation at the time of the site inspection. No sensors already in place.
- Site 3 grows apples, peaches, plums. Irrigation is localized, regulated by soil moisture sensors. "Watermark" soil moisture sensors are already in place.

Figure 5 shows the pilot area in Piedmont, Italy, including the three MAGDA demo sites.

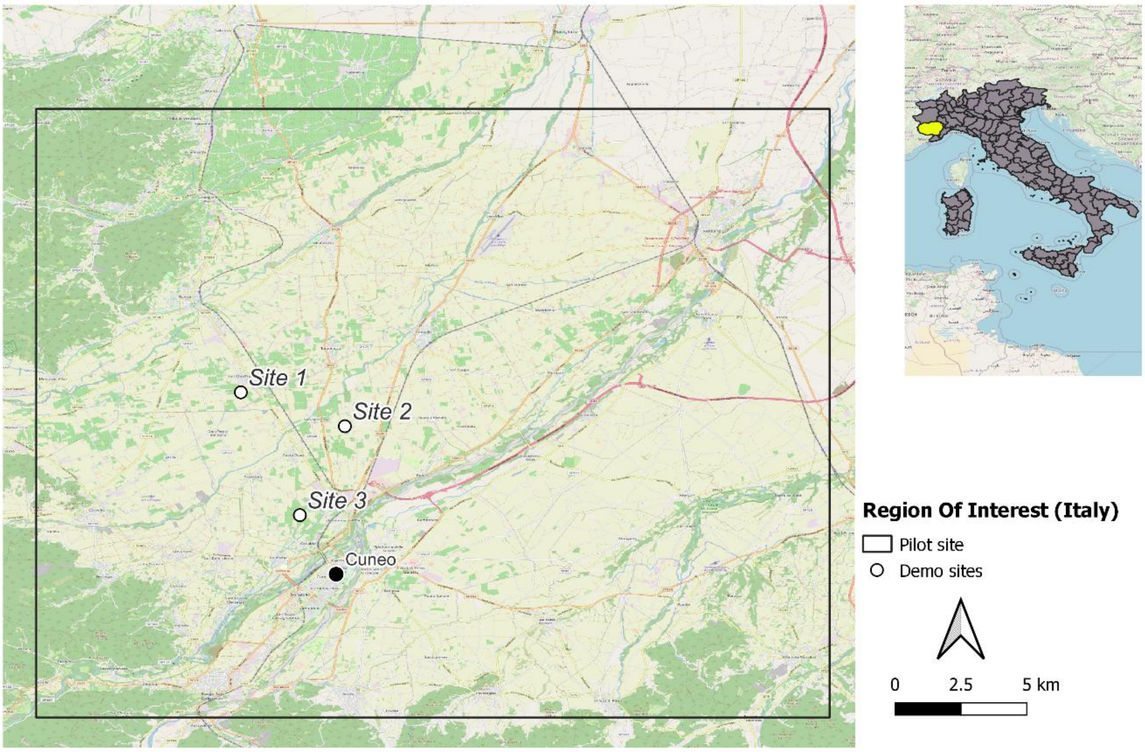

Figure 5. Pilot area in Piedmont, Italy, including the three MAGDA demo sites.

1.2.3 Braila, Romania

In Romania, the demonstration sites are in the South-East of the country, in the Brăila County that includes fields owned by Agriculture Research and Development Station Brăila, with long expertise in irrigation and drainage activities. These fields are in the Brăila Plain and in the Danube River Floodplain (Embanked Great Island of Danube River, Brăila).

The capillary rise induced by water table variation is an important water input for crop water needs between April and June when the Danube water levels record high values. For the rest of the crop season, the irrigation is required in order to avoid crop losses and to ensure high crop productivity. Brăila county is the most important agriculture area in Romania due to the high fertility of the soils and to the presence of the Danube lower sector that ensures water resources for irrigation. The demonstrator in Romania will be focused on the summer crops (April-September) such as corn, sunflower and soybean.

There are no sensors in place and the irrigation system consists of a channel network for water conveyance, electric pumping stations stations, and a network of buried pipes of various orders for water distribution. Irrigation water is delivered at specific outlets where farmers connect their overhead distribution equipment for applying sprinkler irrigation (centre pivots, front advanced lateral irrigation systems, travellers, etc.) in the field.

Figure 6 shows the pilot area in Braila, Romania, including the two MAGDA demo sites.

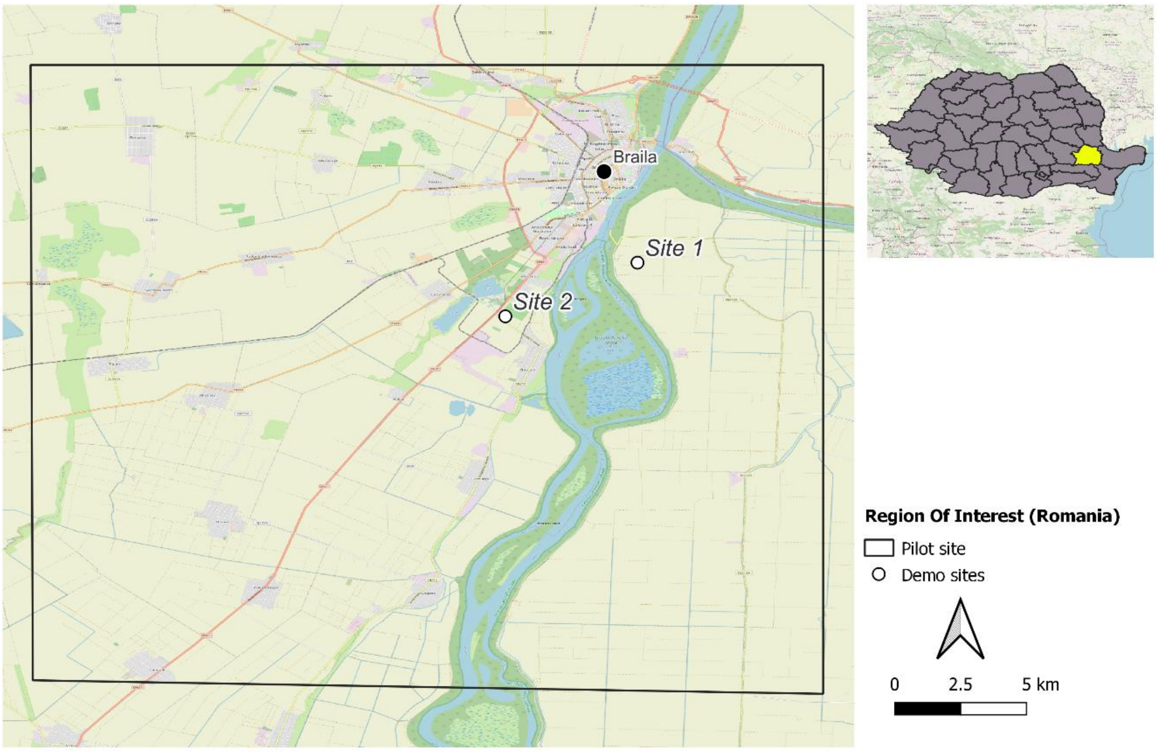

Figure 6. Pilot area in Braila, Romania, including the two MAGDA demo sites.

1.3 Report objectives

Within the MAGDA project, FutureWater is leading WP6 on Hydrological modelling and Irrigation Advisory. The objective of work package 6 is to demonstrate the possibility of an operational irrigation advisory service, that gives daily advice on irrigation water requirements of a field, based on the hydrological model SPHY (Spatial Processes in Hydrology).

Work package 6 exists of three subtasks:

- 6.1: Simulating the water balance in SPHY, using remote sensing and in-situ data.
- 6.2: Implementation of operational irrigation advisory service.
- 6.3: Irrigation advisory results validation.

In this report, focus is on deliverable 6.1: “Water Balance Simulations”. The purpose of deliverable 6.1 is to simulate the water balance for all three sites, assuming, amongst others, soil properties, planting dates and irrigation practices. Furthermore, this deliverable will also show a preliminary blueprint of deliverable 6.2, the operational irrigation advisory service. With the simulation of the water balance through SPHY, the model can be calibrated and validated. With the results of the calibration, a choice will be made about the final blueprint for deliverable 6.2. This report has three specific objectives:

1. Model the water balance for all demo sites.
2. Assess model performance for both seasonality and accuracy.
3. Select blueprint for irrigation advisory service based on model performance.

1.4 Relation to other tasks and deliverables

The MAGDA project consists of multiple work packages, which all work towards the ability to provide valuable information about severe weather and irrigation operations directly to farmers and agricultural operators through a farm management system, whilst using several observation services to improve the weather forecasts and irrigation advisory service.

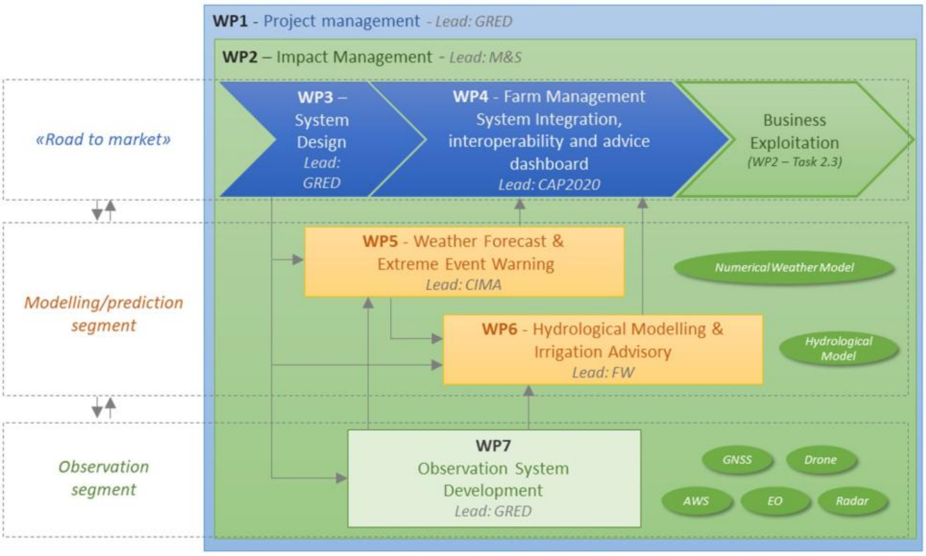

Figure 7. Overview of main activities within MAGDA

As can be seen from Figure 7, Work package 6 links directly to all the work packages, as it is one of the end-user-oriented services. Deliverable 6.1 aims at modelling the water balance for the demo sites, therefore it is related to the following other MAGDA tasks and deliverables:

Receives inputs from:

Table 2. Input from other tasks and deliverables

Deliverable	Due Date	Input for D6.1
D3.1	30.04.2023	User requirements analysis (the farm location and farm characteristics)
D7.1	28.02.2023	Data retrieval systems

Provides outputs to:

Table 3. Output for other tasks and deliverables

Deliverable	Due Date	Output from D6.1
D6.2	30.04.2023	Implementation of operational Irrigation Advisory Service
D4.1	31.10.2023	Report on MAGDA Environment

1.5 Reading guide

First, chapter 2 gives a brief overview of the SPHY model and the methodology we will uptake for this exercise. Chapter 2 will also elaborate on the input data that was used for the SPHY model, the remote sensing data that was used to calibrate and the in-situ data used for validation. Chapter 2 ends with a brief overview of the possible blueprints for the irrigation advisory. In chapter 3 the results of the water balance modelling exercise are presented and in chapter 4, these results are discussed. Finally, in chapter 5, the conclusion of the deliverable is presented, alongside the choice for which blueprint will be used for the irrigation advisory service of deliverable 6.2.

2 Methodology

The goal of this exercise is to model the water balance for all demo sites in SPHY. In doing so, a baseline for modelling irrigation water requirements for farmers is established. This chapter will first elaborate on the SPHY model and why it was used for the MAGDA project. Furthermore, it is shown how the water balance in SPHY is set up and the input variables for the model are described. The chapter will finalize with an overview of two blueprints for the Irrigation Advisory Service.

The flowchart provides an overview of the different steps that were taken during this project. The following sub-sections will be dedicated to explaining each step.

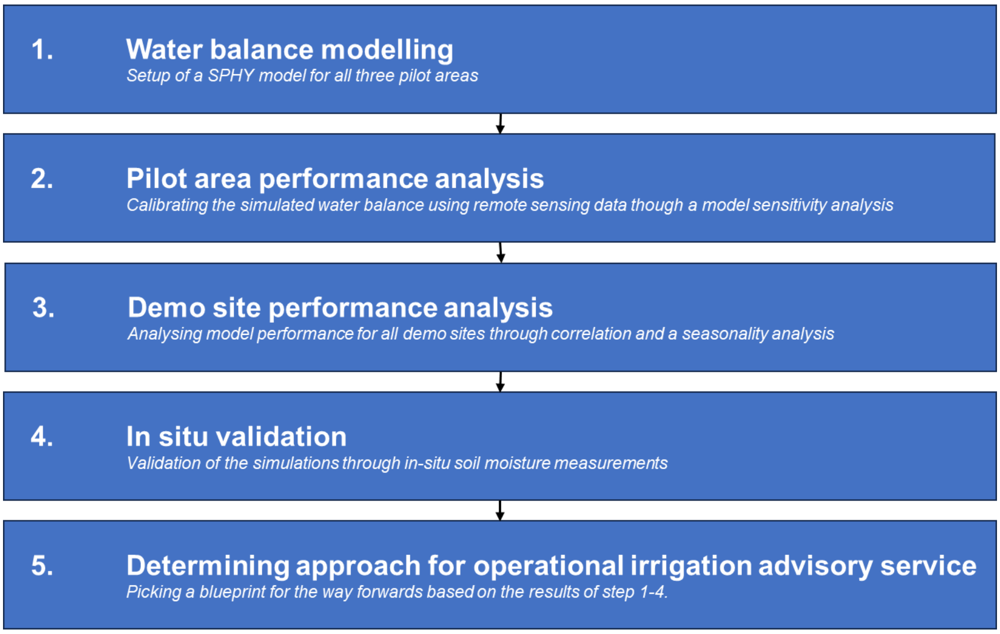

Figure 8. Flowchart representing the project methodology.

2.1 Step 1: Water balance modelling

2.1.1 SPHY model concept

The Spatial Processes in Hydrology (SPHY)[1] model is an open-source, spatially distributed, bucket-type model in which the main terrestrial hydrological processes are conceptually quantified by simulating the changes in water storages and fluxes over time and space (Terink et al., 2015). SPHY was developed with the explicit aim to simulate terrestrial hydrology at flexible scales, under various land use and climate conditions.

SPHY is written in the Python programming language using the PCRaster dynamic modelling framework (Karssenberg, 2002; Karssenberg et al., 2010). In order to minimize the number of input parameters,

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[1] SPHY is an open-source model and can therefore be freely downloaded from www.sphymodel.com, along with supporting documentation. A full description of the model principles and some applications can be found there as well. The current version of SPHY is also available in GitHub is v3.0 (https://github.com/FutureWater/SPHY)

and avoid complexity and long model run-times, SPHY does not include energy balance calculations, and is therefore a water balance based model. The main terrestrial hydrological processes are described in a physically consistent way so that changes in storages and fluxes can be assessed adequately over time and space.

SPHY integrates the same modelling framework of most of the key components existing in other well-tested models as SWAT (Gassman et al., 2007), PCR-GLOBWB (Van Beek et al., 2011), SWAP (Dam et al., 1997) and HimSim (Immerzeel et al., 2012). But, compared to other hydrological models that typically focus on the simulation of streamflow only, the SPHY model has several advantages:

1. It integrates most relevant hydrological processes.
2. It is setup in a modular way.
3. High flexibility and wide range of applicability.
4. Able to ingest remote sensing data and variables (e.g., NDVI).
5. Can be applied for operational and strategic decision support.
6. Open source and software code in public domain (GitHub).

Figure 9 is a schematization of all hydrological processes that can be included in SPHY, depending on local conditions. The basic concept consists of a two-layer coupled ‘leaky bucket’ model, below a vegetation layer. Incoming fluxes are rainfall and upward seepage. Outgoing fluxes include evapotranspiration, interception, surface runoff, downward seepage and lateral drainage from the root zone or subsoil. Interaction between the root zone and subsoil can take place through capillary rise or percolation. Soil physical properties are important input to the model as they strongly influence these fluxes.

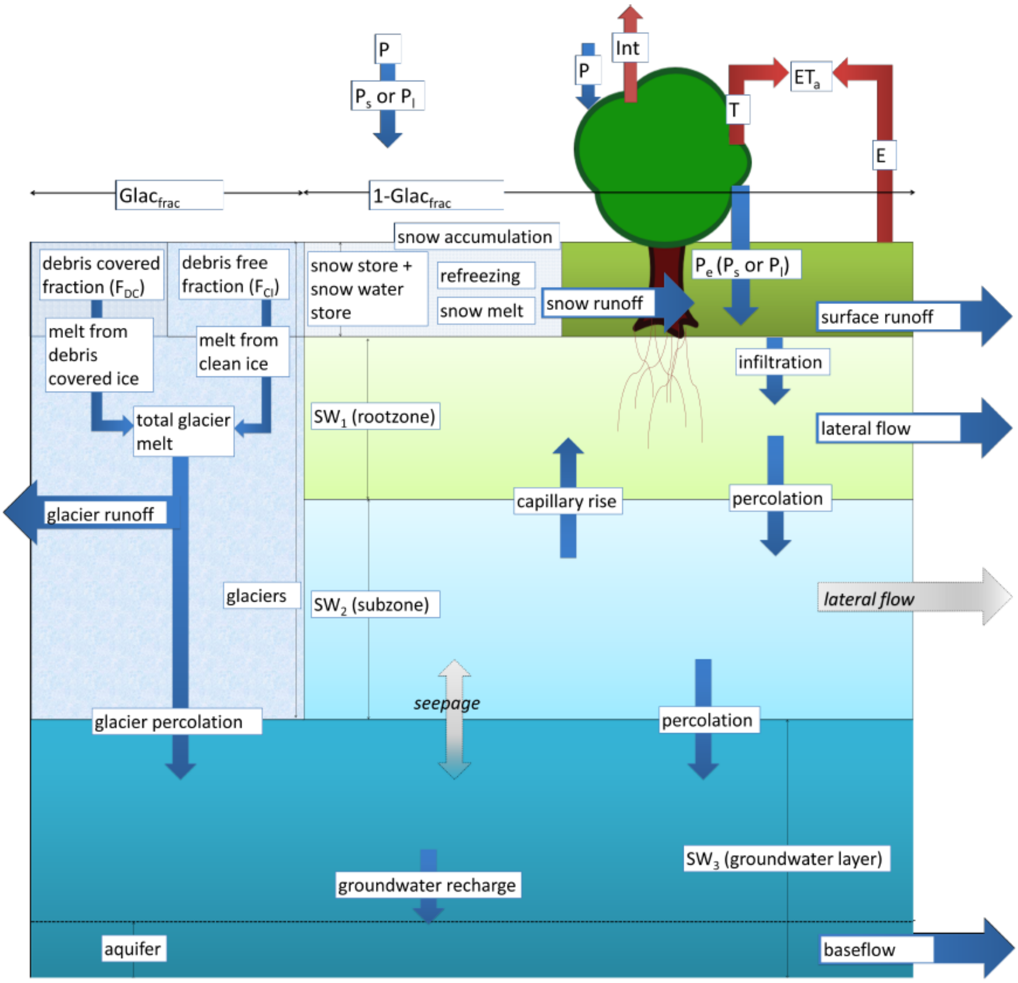

Figure 9. SPHY modelling concepts. The fluxes in grey are only incorporated when the groundwater module is not used. Abbreviations are explained in the text.

2.1.2 Applications

The SPHY model has been applied and tested in various studies ranging from real-time soil moisture predictions in flat lands, to operational reservoir inflow forecasting applications in mountainous catchments, irrigation scenarios in the Nile Basin, and detailed climate change impact studies in the snow- and glacier-melt dominated Himalayan region. SPHY has been used successfully for multiple ends, both for analysis and training purposes, in the subsections below specific examples are listed.

Climate Change Impact and Adaptation

SPHY is used in impact studies to quantify the impact of future climate change on water resources and to assess the effects of climate change adaptation measures. SPHY allows detailed quantification of the effects of climate change for water resources on different spatial and temporal scales, and for particular sectors of interest. Subsequently, the effects of different climate change adaptation measures can be assessed in high detail.

Water and Energy

SPHY has demonstrated its usefulness for energy-related water management issues. SPHY is used to assess long-term projections of water availability for hydropower, assessments of local and regional hydropower potential, as well as in operational reservoir inflow forecasting services.

SPHY was successfully used in a Water and Energy assessment in the project "Hydrological Assessment for Hydropower in the Lukhra River". This hydrological assessment delivered river flow estimates for an intake location of a potential hydropower plant in the Lukhra river, Georgia. The daily flow calculations for the site can be used in the hydropower calculations, and to assess the overall profitability of the planned investment, considering energy prices, demand, etc.

Capacity Building

It is becoming increasingly important to collect more (scientific) knowledge about the sustainable use of our natural resources and to share this knowledge as much as possible with as many people and organizations as possible. It is therefore important that sharing knowledge leads to the training of people who can further develop and disseminate this knowledge. Therefore, FutureWater also participated in Capacity Building activities regarding SPHY. Here SPHY has been used successfully in India for the Swiss Agency for Development and Cooperation (SDC) for a training in Integrated Water Resources Modelling under a Changing Climate in the Indian Himalayas. Participants for the training were drawn from various state government departments and educational institutions in Uttarakhand.

2.1.3 Modules

SPHY enables the user to turn on/off modules (processes) that are relevant/irrelevant for the area of interest. This concept is very useful if the user is studying hydrological processes in regions where not all hydrological processes are relevant. A user may for example be interested in studying irrigation water requirements in central Africa. For this region, glacier and snow melting processes are irrelevant, and can thus be switched off. The advantages of turning off irrelevant modules are two-fold: (i) decrease model run time, and (ii) decrease the number of required model input data. It should be noted, however, that the hydrologic model structure should be specific to the catchment's characteristics (Pomeroy et al. 2007; Clark et al. 2008; Niu et al. 2011; Essery et al. 2013; Clark et al., 2015a, 2015b). It is therefore essential that the user knows which catchment characteristics and processes should be included in their modelling framework.

Within SPHY different modules are available, that can be turned off. Figure 10 represents an overview of the six modules available: glaciers, snow, groundwater, dynamic vegetation, simple routing, lake/reservoir routing, soil erosion and sediment transport. All modules can run independently of each other, except for the glacier module. If glaciers are present, then snow processes are relevant as well (Verbunt et al. 2003; Singh and Kumar 1997). Since melting glacier water percolates to the groundwater layer, the glacier module cannot run with the groundwater module turned off. Two modules are available for runoff routing: (i) a simple flow accumulation routing scheme, and (ii) a fractional flow accumulation routing scheme used when lakes/reservoirs are present. The user has the option to turn off routing, or to choose between one of these two routing modules.

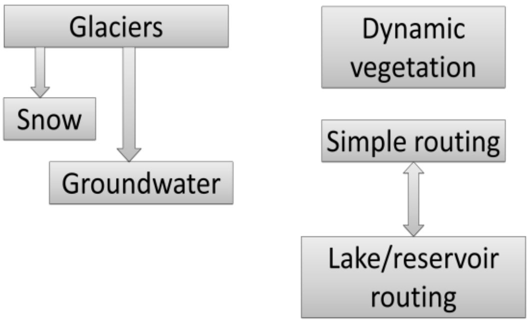

Figure 10. Modules of the SPHY model that can be switched on/off.

SPHY is an open source hydrological model package, and therefore in constant development. Multiple irrigation modules were created for different ends, but they were all not published within the SPHY model package. For example, in 2016 a version of the irrigation module was created for a project, but was not perceived mature enough to include in a new version release. Therefore, a state-of-the-artirrigation module was still missing in SPHY, and it was developed and added to the SPHY model as part of the MAGDA project. This time the irrigation module was tested extensively and perceived ready for publication. The next step is adding the irrigation module to the SPHY model code (and the gitbook) with the release of SPHY4.0, expected later this year.

2.1.4 SPHY for MAGDA - Irrigation module development

In the SPHY model that was set-up for MAGDA, the focus is mainly on root zone processes (soil moisture content, evapotranspiration) and the groundwater module is thus switched off. The relevant hydrological processes that are integrated in the SPHY model for MAGDA are rainfall runoff processes, evapotranspiration processes, the simulation of dynamic vegetation cover, and the simulation of root zone soil moisture contents. SPHY allows the user to use a dynamic vegetation module based on remote sensing in order to incorporate changing vegetation cover and corresponding rainfall interception and transpiration. The use of remotely sensed NDVI for determining the crop factor Kc for evapotranspiration calculations is a proved methodology. Furthermore, as this project aims to calculate irrigation water requirement, an irrigation module was integrated in the latest version of SPHY.

This irrigation module able to simulate the irrigation water applied (*Irr*) in an irrigated pixel. *Irr* values are computed based on the assumption that irrigation inputs are applied to meet the adjusted water requirements of a crop at a particular timestep. Irrigation requirements depend on soil moisture status, the irrigation strategy adopted by farmers, and the irrigation efficiency of the crop system. Irrigation efficiency factor accounts the distribution and application losses of a system.

Irrigation is computed as:

$$Irr = \frac{\mathrm{RAW} * \left(1 - MAD_f\right)}{Irr_{eff}} * Mask\_cro$$

Equation 1

$$IrrL = Irr * \left(1 - Irr_{eff}\right)$$

Equation 2

Here Irr is calculated as the irrigation water applied in mm/day and is dependent on RAW, MAD_f, Irr_{eff} and Mask_crop. RAW is the Readily Available Water Content, which is calculated through the following formula:

$$RAW = TAW * d$$

Here, TAW is Total Available Water Content and is defined by the following formula:

$$TAW = RootField - RootDry$$

Following, RootField is the field capacity and RootDry the wilting point of a certain pixel and d is the depletion factor. The depletion factor is defined by the following formula:

$$d = \max(min(Pmap + 0.04 * (5 - ETpot), 0.8), 0.1)$$

MAD_f *is* a scalar which accounts the management strategy or the crop's tolerance to stress conditions. The $RAW*(1-MAD_f)$ product in Equation 1 defines the MAD (Management Allowed Depletion) term introduced by Allen et al. (Allen et al., 1998). MAD_f values <1 is adopted when a certain tolerance to stress is allowed (e.g. crops which allow deficit irrigation), while values >1 are adopted when extra irrigation is required to avoid severe impacts due to water or salt stress conditions.

Furthermore, Irr_{eff} is the irrigation efficiency of a certain farmer, set for a certain pixel. This depends on the irrigation system. For example, drip irrigation is more efficient than flood irrigation.

Finally, Mask_crop is a binary parameter that accounts for the duration of the growing season. The parameter is set up at each simulation timestep and it adopts values of 0 (no-irrigation) or 1 (irrigation). The duration of the growing season is set up by the user according to the crop typology and the crop intensification and irrigation scheduling. The irrigation period for perennial crops/tree cover most of the year, while in row crops the length of this period relies on the cropping system (shorter in single-cropping systems than in multiple-cropping ones).

2.1.5 Model input data

SPHY requires static data as well as dynamic data. For the static data, the most relevant are digital elevation model (DEM), slope map, land use type and soil characteristics. The main dynamic data consists of NDVI and climate data, such as precipitation and temperature. Since SPHY is grid based, optimal use of remote sensing data and global data sources can be made. For example, the Normalized Difference Vegetation Index (NDVI) can be used to determine the leaf-area index (LAI) in order to estimate the growth stage of land cover.

In Table 4, all input parameters (dynamic and static) needed for the SPHY model are summarized. In the subparagraphs that follow, each input parameter is explained, and the data used for it as well. All maps are created using QGIS and PCRaster (PCR).

Table 4. Overview of all input data required for SPHY.

Input maps / tables	Name in SPHY model	Description of parameter	Unit
Basins	Basins.map	Map with subbasins. Because the study area is not a natural catchment, but farm fields, it is assumed that the whole area is one basin.	[-]
Calibration points	calibration_points.map	Time series of the model output will be created at these locations. The calibration points have the same location as the sensors by CAP2020, so that output from the model can be easily compared to measured data.	[-]
Clone	Clone.map	Boundary map for resampling and clipping all input maps.	[-]
DEM	Dem.map	Height grid of the study area.	MASL
Land use	Landuse.map	Map with different land use classes (irrigated, agriculture, non-irrigated agriculture, urban, bare soil, nature and water)	[-]
Latitude	Latitude.map	Map with latitudes, based on the location of the study are	WGS84 degrees
Slope	Slope.map	Map with the slope of the study area based on the DEM	m/m
Soil map	Soil.map	Map with the different soil types, based on the soil types, maps for each soil parameters are created.	[-]
	Root_dry.map	Permanent wilting point root zone	Mm/mm
	Root_field.map	Field capacity root zone	Mm/mm
	Root_ksat.map	Saturated hydraulic conductivity root zone	Mm/mm
	Root_sat.map	Saturated water content root zone	Mm/mm
	Root_wilt.map	Wilting point root zone	Mm/mm
	deep_field.map	Field capacity subsoil	Mm/mm
	deep_ksat.map	Saturated hydraulic conductivity subsoil	Mm/mm
	deep_sat.map	Saturated water content subsoil	Mm/mm
Climate forcing data	NDVI, Precipitation, Tmax, Tmin, Tavg	.map timeseries of climate data, used to force the data	
Tables	Paved.tbl, root_depth.tbl, laimax.tbl, depletion.tbl, irrigation.tbl, Kc.tbl	These tables correspond with land use and can be used to calibrate the model.	

Furthermore, the first map that created is the clone map. With the clone map, all input maps are clipped and resampled, so every map for a specific demo site has the same projection, extension, and cell size. Each demo site has another projection, as the results need to be in meters and the demo sites are too far away from each other to be in the same projection (Table 5).

Table 5. Cell size and projection for each demo site

Location	Projection	Cell size
France, Burgundy	WGS 84 – UTM Zone 31 N	100 x 100 m
Italy, Piedmont	WGS 84 – UTM Zone 32 N	100 x 100 m
Romania, Braila	WGS 84 – UTM Zone 35 N	100 x 100 m

Digital Elevation Model

The Digital Elevation Model (DEM) was obtained from the Shuttle Radar Topography Mission (SRTM). The STRM, launched in 2000, is an international project spearheaded by the U.S. national Geospatial-Intelligence Agency (NGA) and the U.S. National Aeronautics and Space Administration (NASA). This mission provides data globally available at 30-meter resolution.

Figure 11 shows the DEM data obtained for one of the pilot areas (Piedmont, IT).

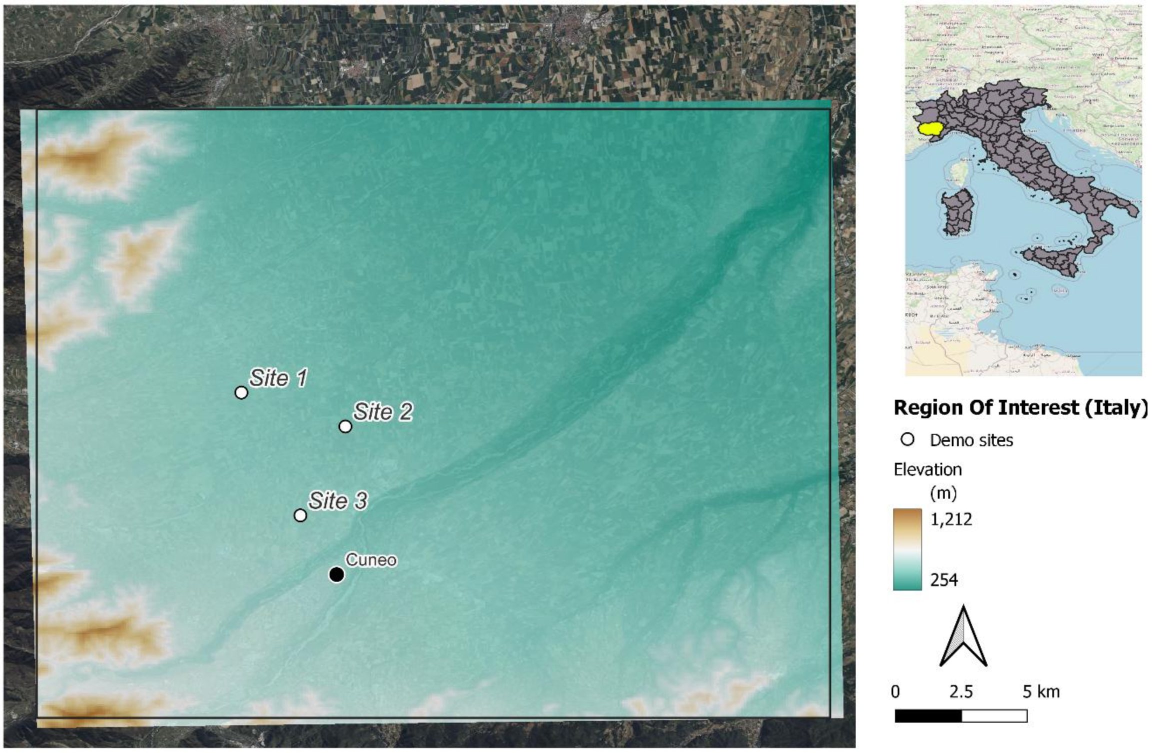

Figure 11. DEM of the pilot area in Piedmont, Italy, one of the three areas within the MAGDA project.

Slope

Directly from the DEM map, a slope map is derived using the slope algorithm of PCRaster. Here for each cell, the algorithm calculates the slope on basis of the elevation DEM of its eight nearest neighbours in the 3x3 cell window. The third-order finite difference method is used. The slope on the result is given in dZ/dX, which is the increase in height (vertical direction dZ) per distance in horizontal direction (dX), yielding a value between 0 and 1. This result value is often referred to as a percentage. Thus, if slope returns a value of 0.12, one says a slope value of 12 %.

Land use data

To create a lookup table for the rootzone depth and ingest it into the model as land use input parameter, a dataset with multiple agricultural distinctions is needed. Therefore, the CORINE Land

Cover (CLC) product was used, which offers a 100 meters resolution pan-European land cover and land use inventory with 44 thematic classes, ranging from broad forested areas to individual vineyards. The product is updated with new status and changes in layers every six years – with the most recent update made in 2018. Within the area of interest, 21 of the 44 classes in the CLC land use set were available. These 21 land use classes were brought back to 9 land use classes: Rainfed agriculture, vineyards, fruit trees and berry crops, pastures, agromixed (irrigated), forest, shrubland and water. In Romania the land use classes differed from the Italian and French land use classes. In Romania, no vineyards were identified in the pilot area and an additional class inland marches was identified.

Figure 12 shows land use data obtained for one of the pilot areas (Piedmont, IT).

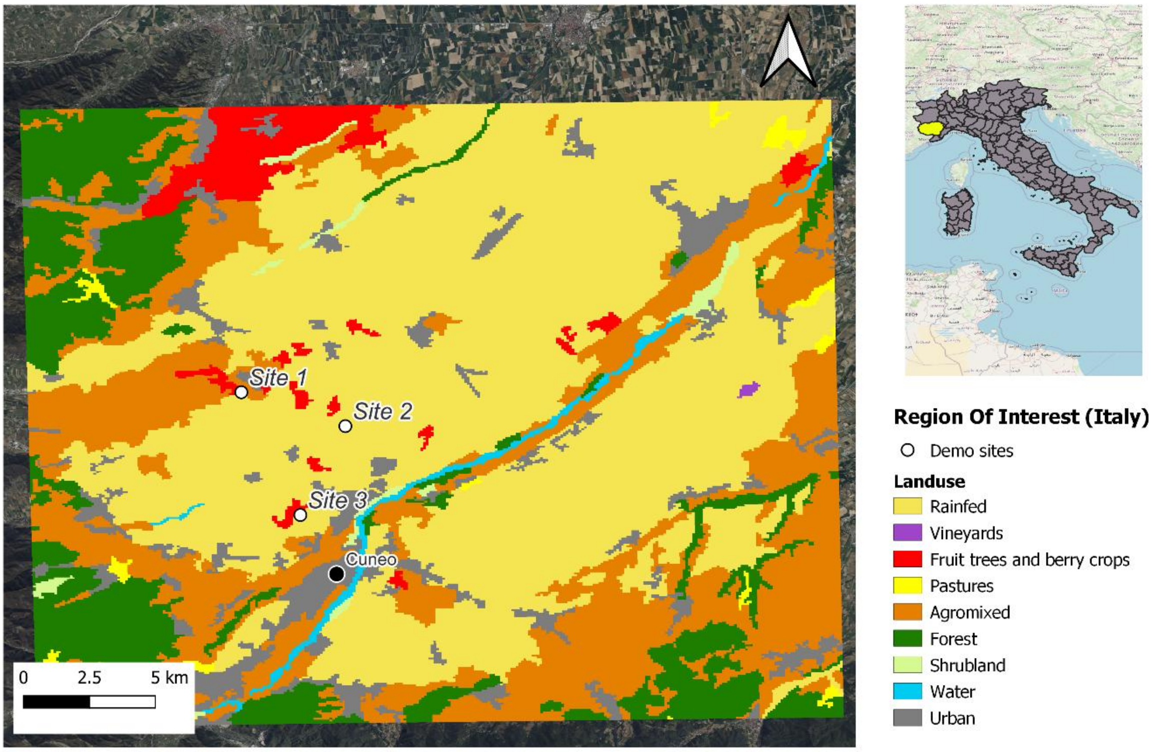

Figure 12. Land use map for Piedmont, Italy, one of the three pilot areas in the MAGDA project.

Soil maps

Hydraulic soil properties in this study were derived from HiHydroSoil. Since 2011, more soil data has become available and calculation algorithms have been improved, which made it possible to create the global-scale gridded soil dataset SoilGrids 1km with a higher resolution and improved accuracy (Hengl et al., 2014). As SoilGrids1km does not include soil hydraulic properties typically needed for hydrological modelling, FutureWater released a global dataset of soil hydraulic properties based on the application of pedotransfer functions: HiHydroSoil (de Boer, 2016). This dataset is available in the public domain and has been used by the research, NGO, and consultancy communities worldwide to improve their access to data on soil hydraulics. The release of SoilGrids250m in 2017 and the continuous development of computation and storage capacities, has prompted FutureWater to develop HiHydroSoil v2.0. This database contains a comprehensive inventory of soil hydraulic variables in gridded format. It is available at the global level, with a spatial resolution of 250 meters.

The soil hydraulic properties contained by the HiHydroSoil v2.0 dataset that are used in the MAGDA project are summarized in Table 6. The datasets are available at different depths: 0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100 cm, 100-200cm. The first five layers are averaged and used for the root zone; the sixth layer (100-200 cm) is used for the deep zone.

Table 6. Soil hydraulic properties contained by the HiHydroSoil v2.0 dataset

Name	Variable	Unit	Used for SPHY maps
WCsat	Saturated Water Content	m^3/m^3	Root_sat.map, deep_sat.map
Ksat	Saturated Hydraulic Conductivity	cm/d	Root_ksat.map, deep_ksat.map
WCpF2	Water content at pF2 (field capacity)	m^3/m^3	Root_field.map, deep_field.map
WCpF3	Water content at pF3 (critical point)	m^3/m^3	Root_wilt.map
WCpF4.2	Water content at pF4.2 (permanent wilting point)	m^3/m^3	Root_dry.map

Precipitation

Precipitation is a climate forcing for the SPHY model. For this historical analysis, data was retrieved from CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data). CHIRPS is a rainfall dataset that combines rainfall estimates from both rain gauge and satellite observations, and it is created and maintained by the Climate Hazards Group (CHG) at the University of California, Santa Barbara (UCSB). It provides global coverage and data is available on a daily timescale at approximately 5 kilometres resolution.

Figure 13 presents the interannual monthly mean precipitation for one of the pilot areas (Piedmont, IT).

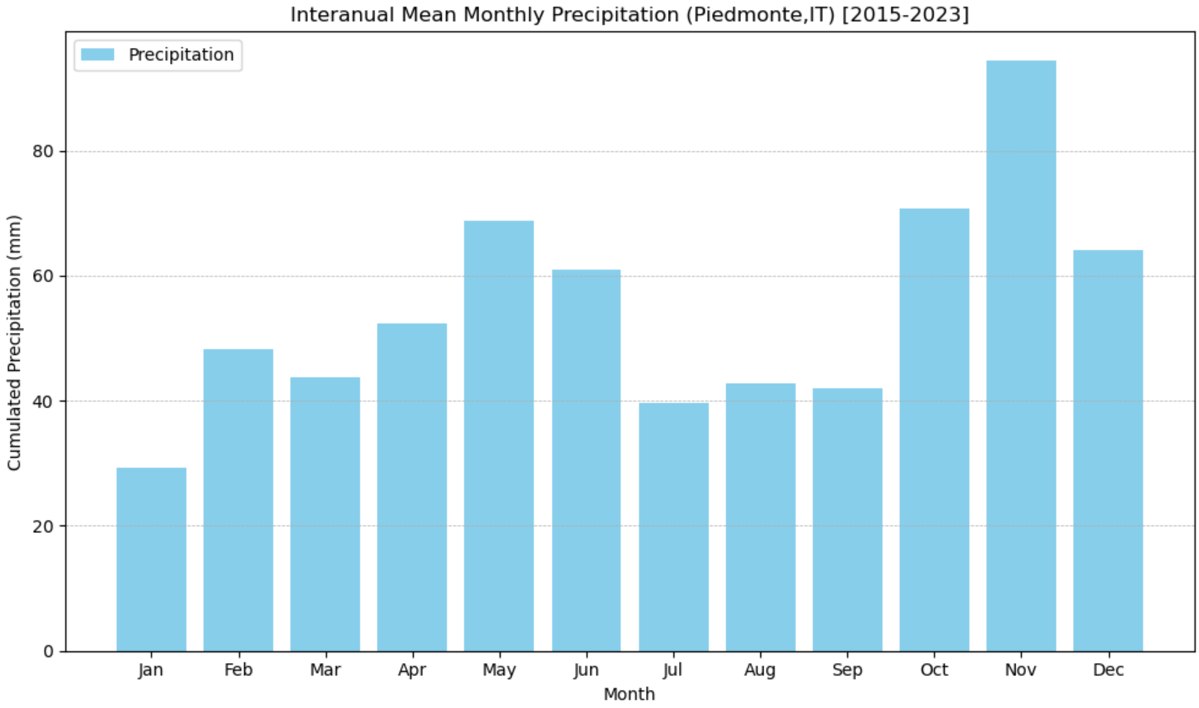

Figure 13. Mean Monthly Precipitation in Piedmont, Italy, one of the three pilot areas in the MAGDA project.

Temperature

Besides precipitation, the SPHY model makes us of temperature (maximum, average and minimum) maps as climate forcings. These maps were retrieved from the ERA5-Land reanalysis dataset, produced by ECMWF (European Centre for Medium-Range Weather Forecasts). ERA-5 Land offers global hourly data at 11 kilometres resolution.

Figure 14 shows the interannual monthly mean temperature for one of the pilot areas (Piedmont, IT).

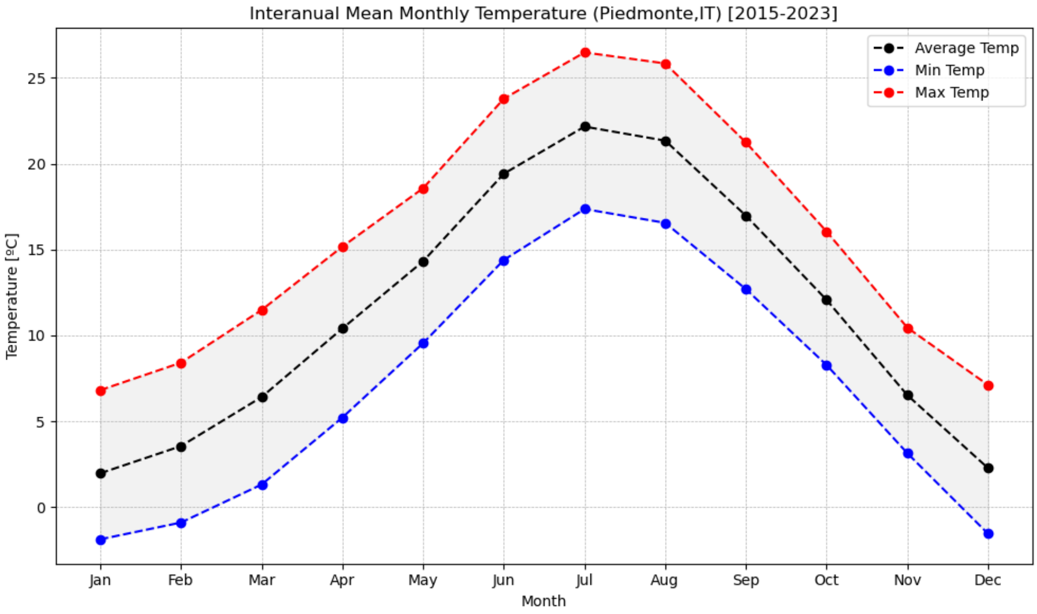

Figure 14. Mean Monthly Temperature in Piedmont, Italy, one of the pilot areas in the MAGDA project.

NDVI

The Normalized Difference Vegetation Index (NDVI) is a key input to the SPHY model. These maps were obtained from two sources: PROBA-V (from January 2015 - December 2020) and Sentinel-3 OLCI (July 2020 onwards). Both missions were developed by the European Space Agency (ESA) and provide global coverage at 300 meters resolution. Within MAGDA, the 10-day composites are processed to be ingested into the SPHY model.

Figure 15 shows the monthly mean NDVI for one of the demo sites in Piedmont, Italy.

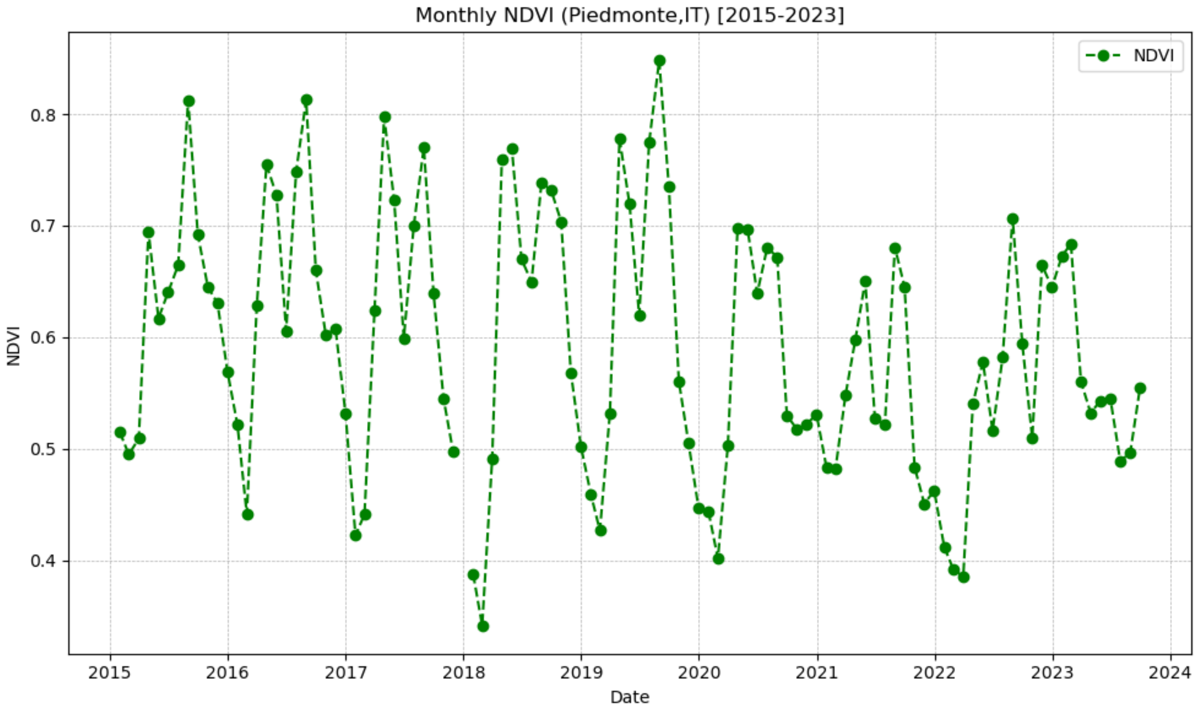

Figure 15. Monthly Mean NDVI in one of the demo sites in Piedmont, Italy.

Input tables

Next to the static and dynamic maps, the SPHY model makes use of several input tables. These tables define several parameters based on land use classes. The parameters that are defined through a table are depletion fraction, irrigation parameters, Crop coefficient (Kc), LAImax, percentage of paved area and root depth. To pick the values, literature was consulted. Some values could also be introduced as constant values, when modelling heterogeneous areas it is recommended to provide the model with spatial maps of these constants varied by land use/land cover class. For example, $\mathrm{LAI}_{\mathrm{max}}$ typically depends on vegetation type and should be listed in a lookup table, the values chosen for the simulations come from Sellers et al., 1996.

Values for the land use-specific tabular value of the depletion fraction can be obtained from Allen et al., 1998. But also the root depth, management allowable depletion, start of season and end of season are derived from Allen et al., 1998. Furthermore it was assumed that only urban land use has a fraction of paved areas.

Table 7. Parameter values used by the Italian model per land use class.

	Depletion	Irrigation - Start of season	Irrigation - End of season	Irrigation – MAD	K_c	LAI_{max}	Paved	Root depth
1 Rainfed Agriculture	0.4	0	0	0	1	8.0	0	300
2 Vineyards	0.45	94	285	1.179	0.7	6.0	0	1000
3 Fruit trees	0.5	60	273	1.395	0.95	6.0	0	1000
4 Pastures	0.6	0	0	0	1	8.0	0	500
5 Agromixed	0.4	128	296	0.963	0.8	7.0	0	500
6 Forest	0.7	0	0	0	1	8.0	0	1500
7 Shrubland	0.6	0	0	0	0.75	5.0	0	500
8 Water	0.6	0	0	0	1.05	5.0	0	0
9 Urban	0.6	0	0	0	0.75	5.0	0.25	100

2.2 Step 2: Pilot area performance analysis

This paragraph explains the methodology for the calibration of the water balance simulation using remote sensing data in chronological order. The goal of this deliverable is to prove that the water balance of a grid cell can be predicted accurately, for calculating daily irrigation requirements. To probe this, the first step is to calibrate the model's parameters with remote sensing data through a sensitivity analysis.

2.2.1 Model sensitivity analysis

After creating the input maps and tables, all modules of SPHY that are not required for the current study are turned off in the model configuration file. After adapting the configuration file, the first model run is executed by running the sphy.py script. The new SPHY version, developed for MAGDA, has the great advantage of being able to run multiple scenario's at once. Within the model, the following (extreme) parameters were amended to evaluate its sensitivity to each of these parameters.

Table 8 gives an overview of the different parameters that were used to generate 10 scenarios, which were run for all three pilot areas. The first column shows if the irrigation module is turned on (=1) or off (=0) for a particular simulation. With this parameter we want to confirm that modelling soil moisture and evapotranspiration is improved compared to the model setup without the irrigation module, especially in land use classes with irrigation. Furthermore, the management allowable depletion (MAD) is linked to the irrigation module and shows the pattern in which irrigation is applied. MAD accounts for the management strategy or the crop's tolerance to stress conditions. Values <1 are adopted when a certain tolerance to stress is allowed (e.g. crops which allow deficit irrigation), while values >1 are adopted when extra irrigation is required to avoid severe impacts due to water or salt stress conditions. It is interesting to see if we could see such irrigation patterns in the historical analysis.

Finally, the root depth scalar is a parameter that adjusts the root depth for all land use classes. Because root zone soil moisture is a very important parameter for this exercise, it is interesting to see the influence of the root depth on the results. In this case we applied a root depth scalar, which means that we multiply the original values from the root depth table with this scalar. The range was chosen from very small (0.1) to double the amount of root zone (2).

Table 8. Adjustable Parameters in SPHY

Parameter Scenario	Irrigation module turned on? (1=yes, 0=no)	Management Allowable Depletion (MAD)	Root depth scalar[2]
1. v101	1	1	1
2. v102	1	1	0.5
3. v103	1	1	0.1
4. v104	1	1.5	1
5. v105	1	1.5	0.5
6. v106	1	1.5	0.1
7. v107	1	0.5	1
8. v108	1	0.5	0.5
9. v109	1	0.5	0.1
10. v110	1	1	2
11. v111	0	N.A.	1

2.2.2 Remote sensing calibration

The model outputs consist of maps of daily evapotranspiration and soil moisture for each pilot area. The best scenario among the sensitivity analysis, which is the most correlated scenario with actual evapotranspiration from remote sensing data for the demo sites, will be used in the next step to assess the performance of the model at the demo sites (point level).

Actual evapotranspiration was chosen as the variable to calibrate on, as this variable is the most reliable and is spatially more uniform as opposed to soil moisture which has great spatial variability.

2.2.3 Remote sensing data

In this paragraph the remote sensing datasets used for comparison with the model outputs are described.

Table 9 provides an overview of the Copernicus datasets that were processed by MeteoRomania and delivered for comparison purposes.

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[2] Initial root depth values were chosen based on FAO56

Table 9. Overview of Remote Sensing Data Sources from Copernicus

Product	Availability	Platform/Sensor	Coverage	S_{RES}	T_{RES}
Soil Water Index - SWI (CGLS)	2015-01 / 2022-12	Sentinel-1 C-SAR & Metop ASCAT	Europe	1km	Daily
Actual Evapotranspiration	2016-05/2022-12	Sentinel-2 + Sentinel-3 + ERA5	Global	20m	10 days

Actual Evapotranspiration

Actual Evapotranspiration was computed using Copernicus optical data sources (Sentinel-2 MSI Level 2), thermal data from Sentinel-3 SLSTR (Sentinel-3 LST) and the ERA-5 reanalysis meteorological dataset. Combining these datasets, the evaporation calculation employed the algorithm developed by Guzinski et al. in 2020 for the SNAP Toolbox. Temporal resolution is 10 days, and spatial resolution is 20 meters, providing high quality data to be compared with SPHY outputs in the next step.

Figure 16 shows a snapshot of daily evapotranspiration for Piedmont, Italy.

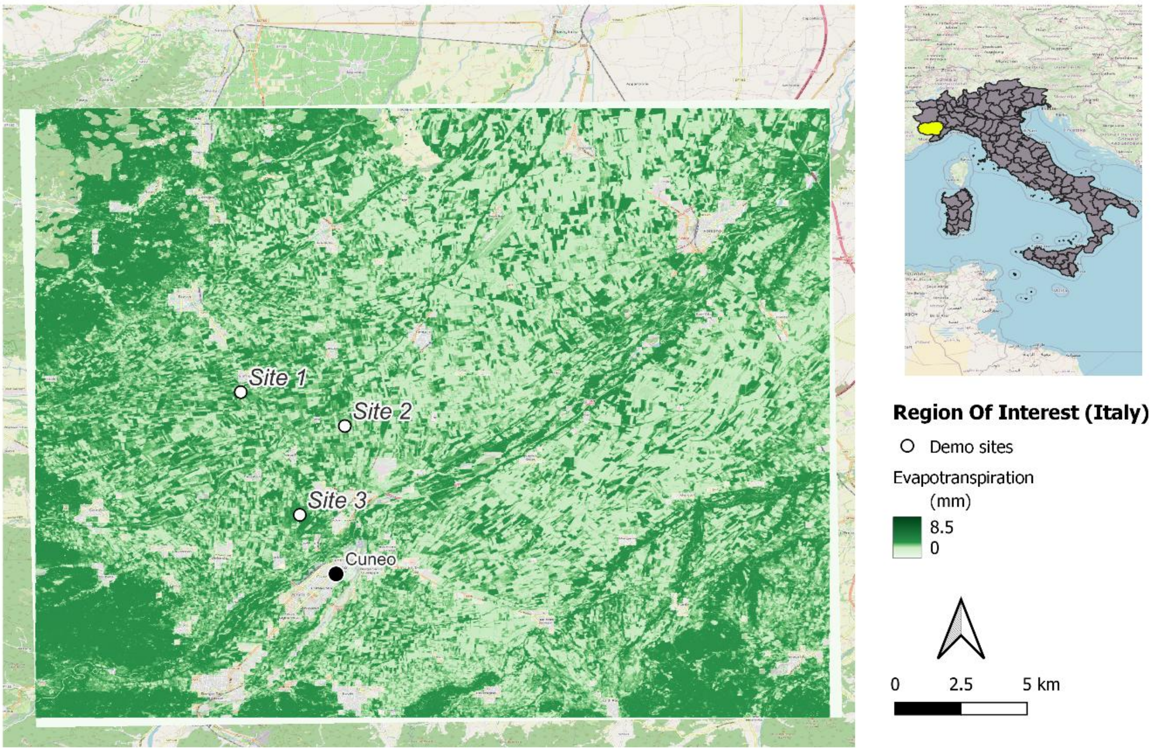

Figure 16. Snapshot of daily evapotranspiration data in Piedmont, Italy, one of the pilot areas in the MAGDA project.

Figure 17 shows the interannual monthly evapotranspiration for Piedmont, Italy, one of the pilot areas in the MAGDA project.

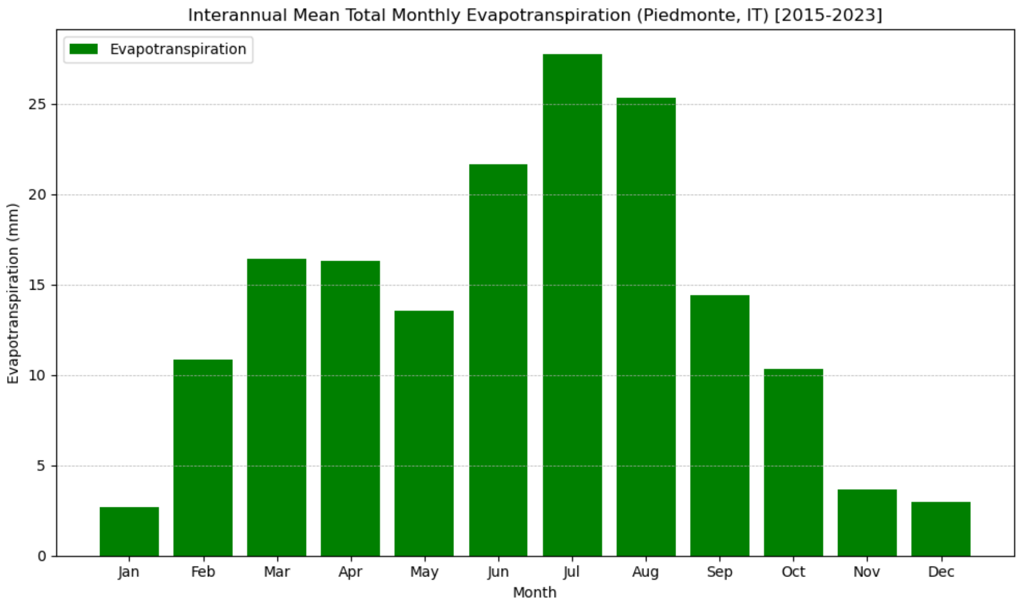

Figure 17. Interannual mean total monthly evapotranspiration in Piedmont, Italy, one of the demo sites in the MAGDA project

Soil water index (SWI) - CGLS

The SWI product describes soil water content on a 1-kilometre spatial sampling. It is derived using a data fusion approach from microwave radar data observed by the Metop-A/B/C ASCAT and the Sentinel-1A/B CSAR satellite sensors. The major advantage of the Soil Moisture Index is that it offers information on soil moisture at different levels, making it useful for various types of studies.

For this exercise, SWI060 was chosen in order to be compared with SPHY soil moisture outputs. Figure 18 represents SWI060 versus SSM in Piedmont, Italy.

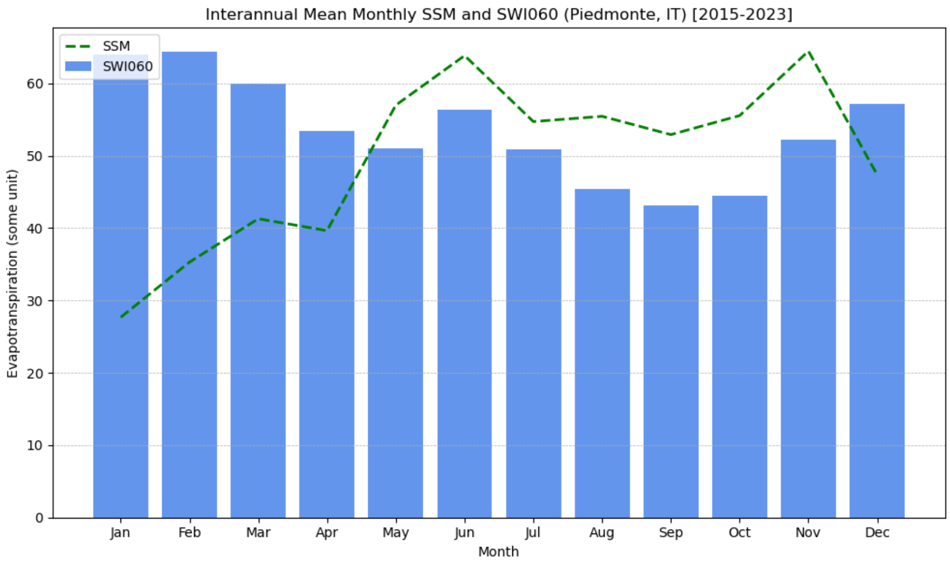

Figure 18. SSM and SWI interannual mean in Piedmont, Italy, one of the pilot areas in the MAGDA project.

2.3 Step 3: Demo site model performance analysis

Step 3 of our analysis comprises of the model performance analysis of the demo sites. In step 2, the best parameter set is chosen from the sensitivity analysis, based on the spatial correlation with evapotranspiration and root zone soil moisture. With the best spatial correlations in mind, we proceed to the calibration of the demo sites.

The SPHY model output at the demo sites is compared to the Soil water index, and actual evapotranspiration data of Copernicus. Here the Soil Water Index is compared to the soil moisture output of the model. Soil Water Index was chosen as the remote sensing dataset to compare with, because SSM CGLS soil moisture content data only shows the top layer of the soil, which is more likely to demonstrate irrigation patterns than actual soil moisture content.

For both evapotranspiration and soil water index scatterplots are generated, comparing the remote sensing data to the SPHY output. These graphs will show if further adjustments to the input data of SPHY are needed. Finally, graphs are made to show the model output and remote sensing data as a daily and monthly average from 2015-2023. With these daily and monthly average graphs we can check how well the seasonality of the parameters is modelled. For all parameters the R^2 and RMSE are calculated.

The seasonality plots to compare the soil moisture content output of SPHY with the Soil Water Index from remote sensing data were normalized to better compare the results, as soil water index and soil moisture content are not the exact same value like actual evapotranspiration from remote sensing and SPHY are. Normalized, the root zone soil moisture output from SPHY can be compared better to the soil water index.

2.4 Step 4: In situ validation

Using in-situ data is a better option than remote sensing when you want to calibrate your model. The MAGDA project therefore has included in situ sensors at most of the demo sites. In June 2023, the sensors were installed. The sensors were provided by Cap2020 and roughly 2.5 month of available data is now available to analyse to make a preliminary validation on the in situ data. The soil moisture measurements are taken in the field at a depth of 30 cm. Furthermore, the data is collected every 5 minutes and aggregated to a daily scale. Unfortunately the measurements had some problems in the beginning. This means some of the data is missing and not the entire 2.5 months can be analysed.

Next to the data of Cap2020, MeteoRomania provided soil moisture measurement at demo site 2 in Romania from the 1st of April till the 1st of September 2018. Here, the volumetric water content [mm/mm] is measured at 20, 40, 60 and 100 cm. Therefore, this analysis provides only show a preliminary validation of the model output with the in-situ data from Romania (2018). For the purposes of the validation, only the soil moisture is taken into account. In this validation, the root zone soil moisture output of the SPHY model in compared to the in situ measurements.

2.5 Step 5: Determining approach for operational irrigation advisory service.

After the present exercise, an operational irrigation advisory service will be demonstrated within the MAGDA project that runs on a continuous basis, forced by the weather forecasts of the Weather Research and Forecasting (WRF) model by CIMA. This model will provide 5 days of forecasting data, which will eventually be shown in a demonstrator in this project. Next to a demonstrator, an operational system will be made, using only two-day lead time forecasts in Italy, providing irrigation advisory on a daily basis. The end goal of the irrigation advisory service is for farmers in the region to be able to access an application where they can find irrigation application advice. Therefore, an important factor in choosing the blueprint for the irrigation model is scalability.

As soil moisture content is a challenging parameter to simulate and there are multiple ways to calculate irrigation water requirements, various blueprints for the irrigation advisory service were made. The plans are described in this chapter, both scalable and needing in-situ sensor data. In the conclusion chapter, the best option for the operational irrigation advisory service will be selected, depending on the obtained results of the water balance modelling exercise.

As stated earlier, the introduction of irrigation advisory services (IAS) for farmers are powerful management instruments to achieve the best efficiency in irrigation water use, by achieving “more crop per drop”. The introduction of IAS could advance irrigation practices and water efficiency in the near future, while providing an economic advantage for farmers: the adoption of new irrigation management systems can both increase farmers’ income and reduce energy costs. There are multiple ways of going about modelling irrigation water requirement, which all have certain pros and cons. In the blueprints the different methods will be described, and a flowchart and a possible future layout for the farm management system are presented.

2.5.1 Blueprint option 1: Soil moisture content modelling with SPHY

For blueprint option 1, it is assumed the model can simulate the soil moisture content for the whole region of interest accurately. The soil moisture content will then be used to calculate irrigation requirements, by comparing it to on an irrigation threshold. This threshold is calculated in the irrigation module through field capacity, readily available water and the management allowable depletion and is a fixed value. A crop should be irrigated when the soil water content is less or equal to the irrigation threshold.

The MAD values chosen are based on values of FAO56 and will be incorporated based on land use in the irrigation module. The output of the irrigation module is then the irrigation quantity [mm] that is needed to adjust the soil water content value back to the level of the irrigation threshold.

In this option for the blueprint, SPHY will be run in an operational mode, ingesting data from the weather forecast model daily and generating the outputs directly in SPHY as well. The outputs will be presented in a table and spatial maps of soil water content are available as well. The irrigation schedule is based on the predicted rainfall and evapotranspiration values in the coming 48 hours.

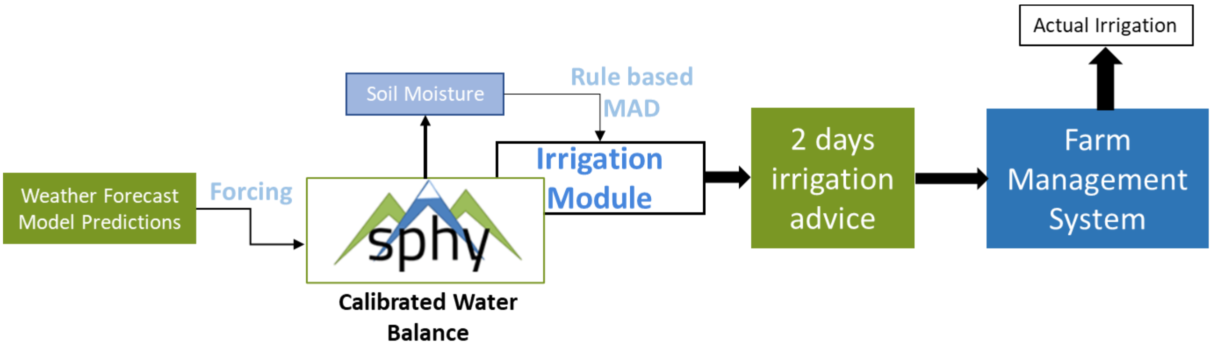

Figure 19. Flowchart of blueprint 1

Table 10 shows an example of how the irrigation advisory service could look like on the farm management system. For this particular site, the irrigation threshold is 0.25 m^3/m^3. On day 0 here the modelled soil water content is 0.29 m^3/m^3, which is not lower than 0.25 m^3/m^3, so no irrigation is advice. On day 1, which is tomorrow, the modelled soil water content is 0.24 m^3/m^3, which is below the threshold. Therefore irrigation advice is given. On day 0, the modelled soil water was replenished to the threshold level, so no irrigation advice is given.

Table 10. Example of Irrigation Advisory Service Blueprint 1

	DAY 0		DAY 1		DAY 2	
Site (Irr threshold = 0.25)	**Modelled Soil water content [m^3/m^3]**	**Irrigation advice [mm]**	**Modelled Soil water content [m^3/m^3]**	**Irrigation advice [mm]**	**Modelled Soil water content [m^3/m^3]**	**Irrigation advice [mm]**
Italy, Piedmont	0.29	0	0.24	10	0.25	0

The advantage of this method is that it is a very accurate way to model irrigation water requirements. A disadvantage of this method is that modelling soil moisture can be unreliable if not calibrated well enough, as soil moisture is a very heterogenous part of the water balance. Another disadvantage is that this model is hard to scale to larger areas, as it has to be calibrated again if new regions are added.

2.5.2 Blueprint option 2: Point based evapotranspiration modelling

For blueprint 2, it is assumed the SPHY soil moisture results are not accurate enough to ingest in an operational way. Therefore, this blueprint calculates irrigation water requirements based on daily crop evapotranspiration and effective precipitation through a point based method, using both SPHY effective precipitation data and the forcing data of the Weather Forecast model by CIMA.

The irrigation water needs of a certain crop can be calculated through the difference between the crop water need and that part of the rainfall which can be used by the crop (the effective rainfall). For all crops and the irrigation water need can therefore be calculated by subtracting the effective rainfall from the crop water need. SPHY is then run for all three sites, to simulate a spatial grid with information on how much rainfall is effectively infiltrating to the root zone and how much is stored in the canopy daily. With this information, daily effective precipitation can be predicted based on the weather forecast system and can be subtracted from the daily crop evapotranspiration. Furthermore, also the excess rainfall is taken into account. This way, the farmer does not irrigate if the plots received high amounts of rainfall the previous week.

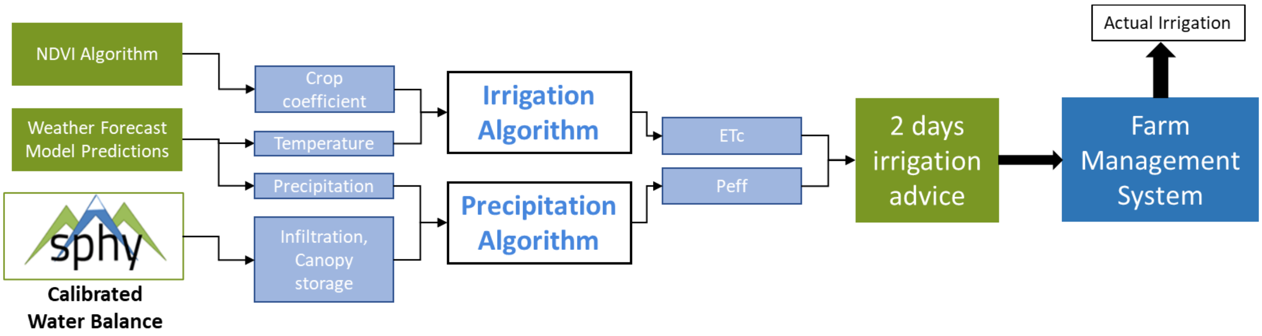

Figure 20. Flowchart of blueprint 2

Table 11 shows an example of how the irrigation advisory service could look like on the farm management system. In this case, every day the crop evapotranspiration is calculated through reference evapotranspiration through the Hargreaves formula and Kc, based on an NDVI algorithm that takes the growing crop into account.

On day 0 here the crop evapotranspiration is 3.5 mm and the effective rainfall is 5 mm. That means that on day 0, the root zone received 1.5 mm extra water. On day 1, the crop evapotranspiration is 4.5 mm and the effective rainfall is 1 mm. That means that the crop needs 3.5 mm extra water, but we still have 1.5 mm in the soil from the rainfall event of yesterday. That means that the irrigation advice will tell the farmer to irrigate 2 mm. The mm's can be converted to m3 or to minutes if field and irrigation system dimensions are known. Also for this blueprint, the advice is generated daily for day 0, day 1 and day 2.

Table 11. Example of Irrigation Advisory Blueprint 2

	DAY 0				DAY 1			
Site	**Crop Evapotrans-piration [mm]**	**Effective Rainfall [mm]**	**Excess Soil water [mm]**	**Irrigation Advice [mm]**	**Crop Evapotrans-piration [mm]**	**Effective Rainfall [mm]**	**Excess Soil water [mm]**	**Irrigation Advice [mm]**
Italy, Piedmont	3.5	5	0	0	4.5	1	1.5	2.0

The advantage of this method is that it relies on the most common FAO-based method to calculated irrigation water requirements, based on evapotranspiration and effective precipitation. Farmers have typically some knowledge on the underlying concepts. The innovative aspects of this blueprint, compared to the typical implementation of the FAO-based method is, that:

(1) current and local (NDVI-based) crop conditions are used, instead of tabulated crop coefficients that are not necessarily representative for current and local conditions,
(2) locally calibrated (SPHY-based) and thus more accurate estimates of effective precipitation are used, instead of tabulated values

Next to that, this method is very easily scalable to large extents, with no additional calibration needed.

3 Results

In this chapter the results of the water balance simulations are shown and they are compared to the remote sensing data, to see if we are able to accurately predict soil moisture content and evapotranspiration through the water balance simulations. Next to remote sensing, also a preliminary validation with in situ data was done.

3.1 Pilot area model performance analysis

The SPHY model was run from January 2015 till September 2023, with daily time steps. As explained in section 2.2, the SPHY model was run for 11 different scenarios for each of the three pilot areas.

The results of this analysis indicated the sensitivity of the model for each parameter. Based on an extensive comparison of SPHY's output data with remote sensing data on evapotranspiration and root zone soil moisture, Table 12 shows the best combination of parameters for each pilot area. This set of parameters was also used for the demo site model performance analysis in paragraph 3.2.

Table 12. Best model parameters for each pilot area

Pilot area	Parameter Scenario	Irrigation application	Management Allowable Depletion (MAD)	Root depth scalar[3]	Average Pearson correlation
Burgundy, France	**V101**	1	1	1	0.74
Piedmont, Italy	**v101**	1	1	1	0.72
Braila, Romania	**v101**	1	1	1	0.45

Running all the different scenarios in SPHY, it was found that using the irrigation module gave better results in terms of correlation with evapotranspiration than running the simulation without it.

Furthermore, root zone depth proved to be a very sensitive parameter. Setting the root depth scalar to a small value (scalar = 0.1) had the greatest impact on the results in terms of decrease in correlation. A slightly bigger (scalar = 2.0) did not have as much effect.

Management Allowable Depletion (MAD), being linked to the irrigation module, had less sensitivity regarding the results. Using 1 as the MAD number had the most correlation with the remote sensing data in every pilot area. The different irrigation strategies were thus not easily derived from the remote sensing data.

Using the best set of parameters described in section 3.1, Figure 21, Figure 22 and Figure 23 show a spatial map of correlation. This shows the correlation per pixel between the output of the SPHY model compared to remote sensing data. All pixels that have a lower correlation than 0.3 are not shown in the figures. The figures below show a high dependency with land use, which makes sense, as a lot of input tables are linked to land use. It also shows that although the sensitivity analysis gave

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[3] values based on FAO56

high correlation in general for France and Italy, some of the parameters for specific land use types in the input data might need some adjustments.

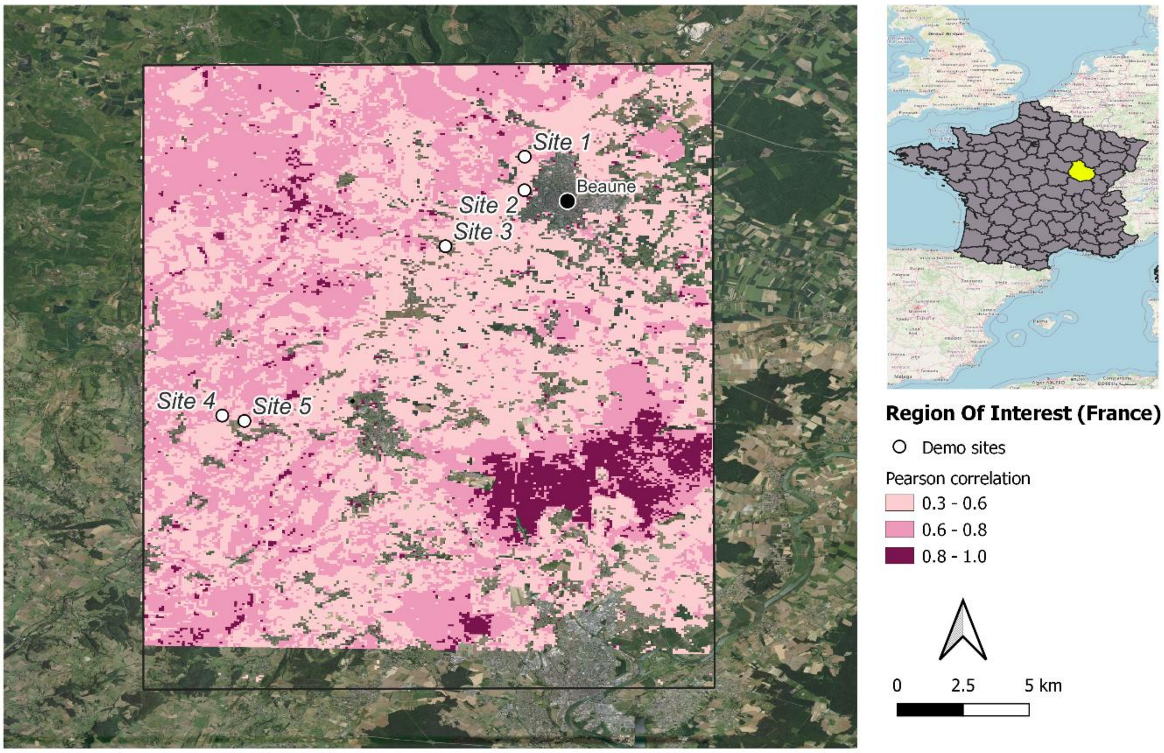

Figure 21. Spatial Pearson Correlation for Burgundy, France

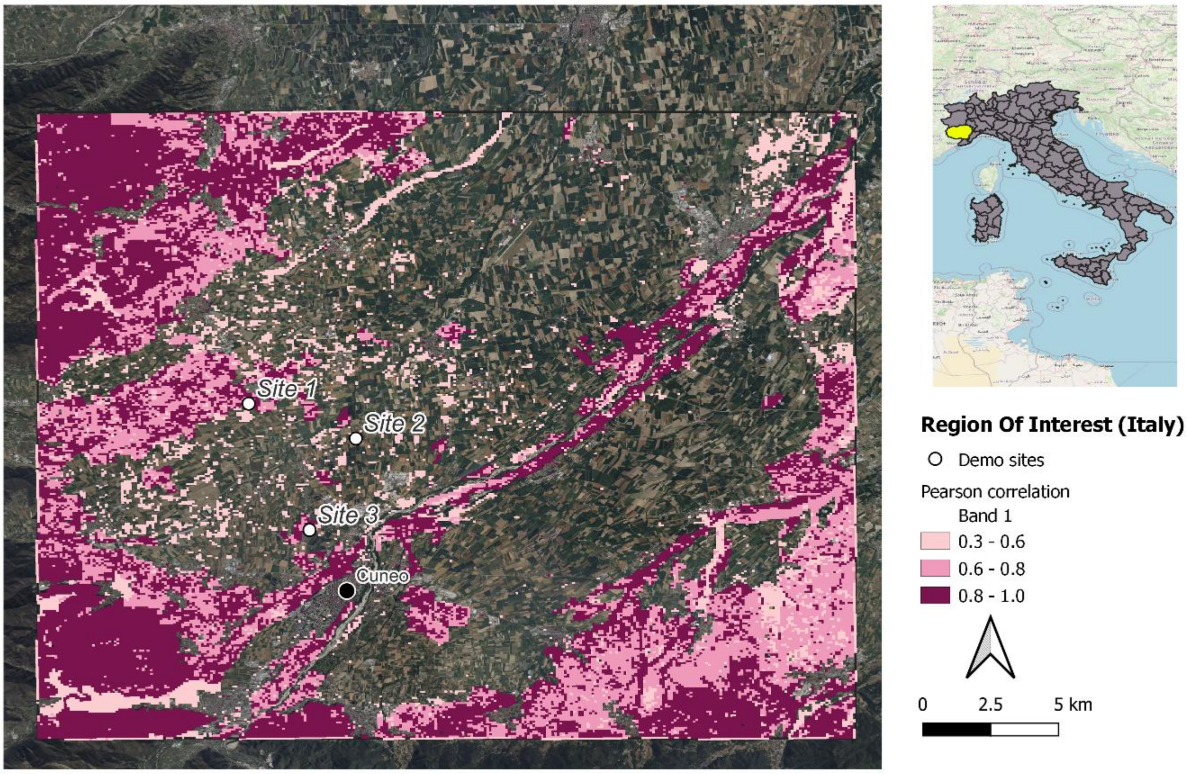

Figure 22. Spatial Pearson Correlation for Piedmont, Italy

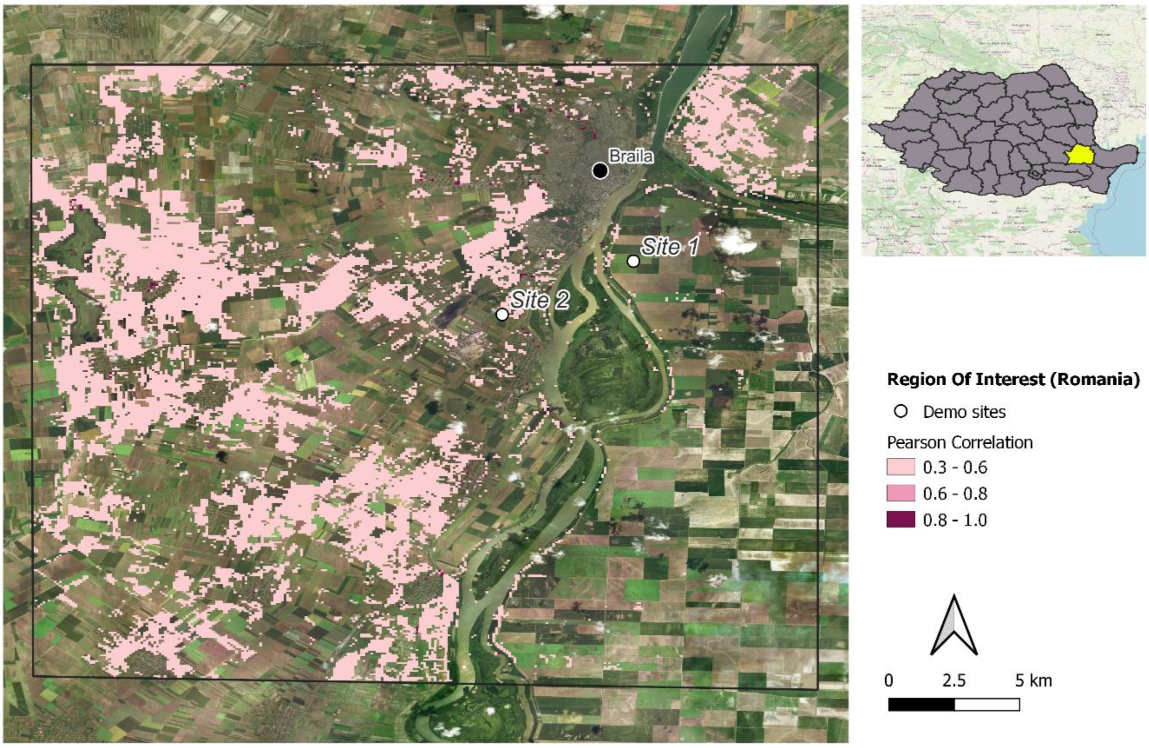

Figure 23. Spatial Pearson Correlation for Braila, Romania

3.2 Demo site model performance analysis

With the best parameter set known from the sensitivity analysis from the pilot area model performance sensitivity analysis, the next step is to analyse the demo sites in greater detail. In the demo site model performance analysis we will focus on both actual evapotranspiration and soil moisture content output of SPHY and compare it with the remote sensing data. Next to that, we will also look at the ability of the SPHY model to capture seasonality, which means how well the model can capture the changes (in seasons) over time.

For both the scatterplots and the seasonality analysis, only the days of year (DOY) that were specified as the growing season for the specific pilot areas were taken into account.

3.2.1 Actual evapotranspiration

Correlation analysis

Figure 24 shows the correlation between the actual evapotranspiration calculated from SPHY and actual evapotranspiration from remote sensing for every demo site. The scatterplots show that SPHY in the current setup, underestimates the actual evapotranspiration for most demo sites. As could be seen from the spatial correlation for the pilot areas as well, the SPHY output for the demo sites in France and Italy have a higher correlation with the remote sensing data than the pilot area in Romania.

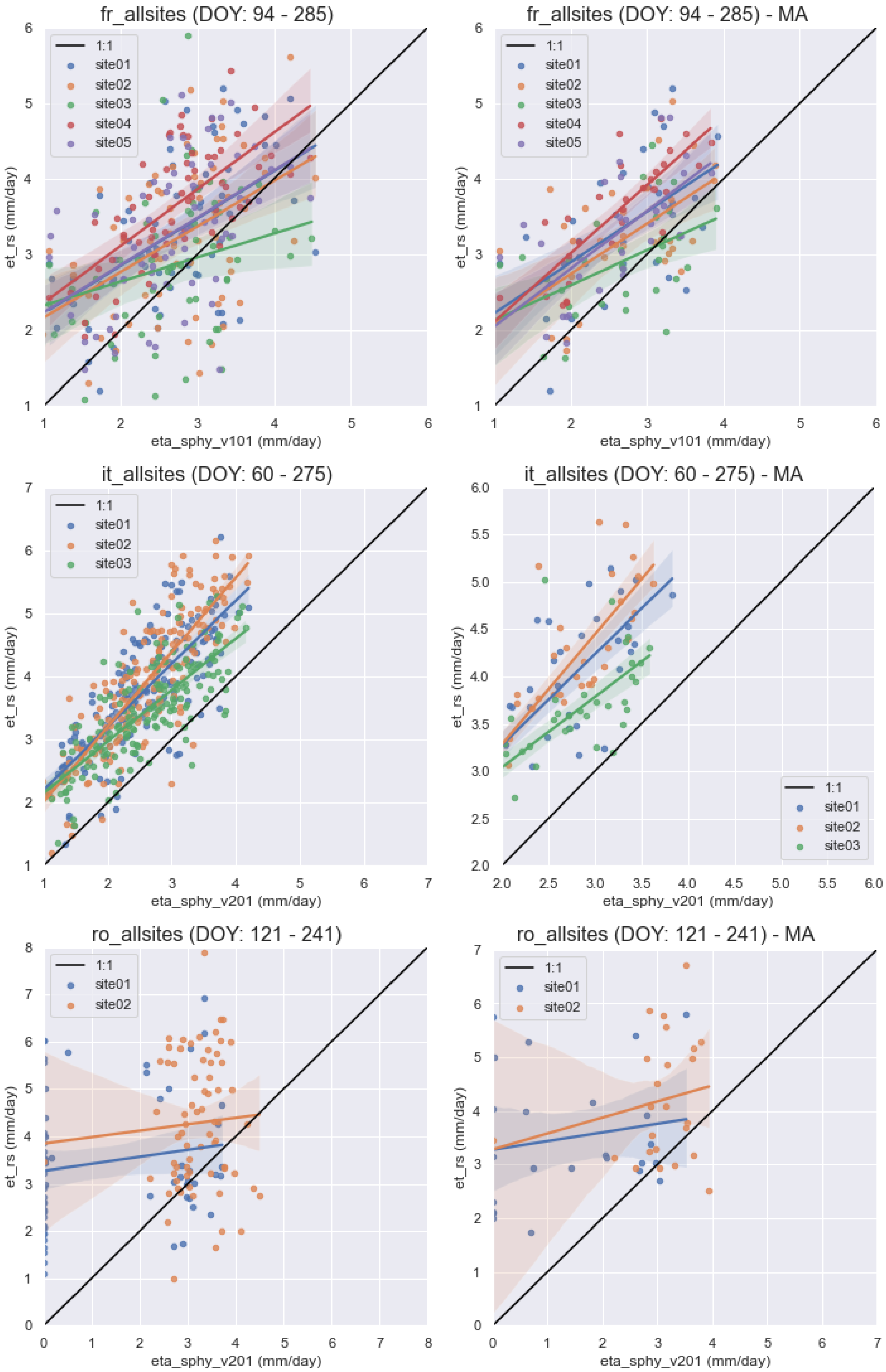

Figure 24. Scatterplots showing evapotranspiration from SPHY vs. Remote Sensing data for all pilot areas. Left: daily values; Right: Monthly average values.

Seasonal trend analysis

Next to calculating the correlation between the Actual evaporation from SPHY and Remote Sensing, the seasonality was also calculated. This was done to see if the SPHY output follows the same pattern as the remote sensing data. Looking at the monthly evapotranspiration for the French demo sites, the beginning of the planting season is modelled more accurately than the end of the season.

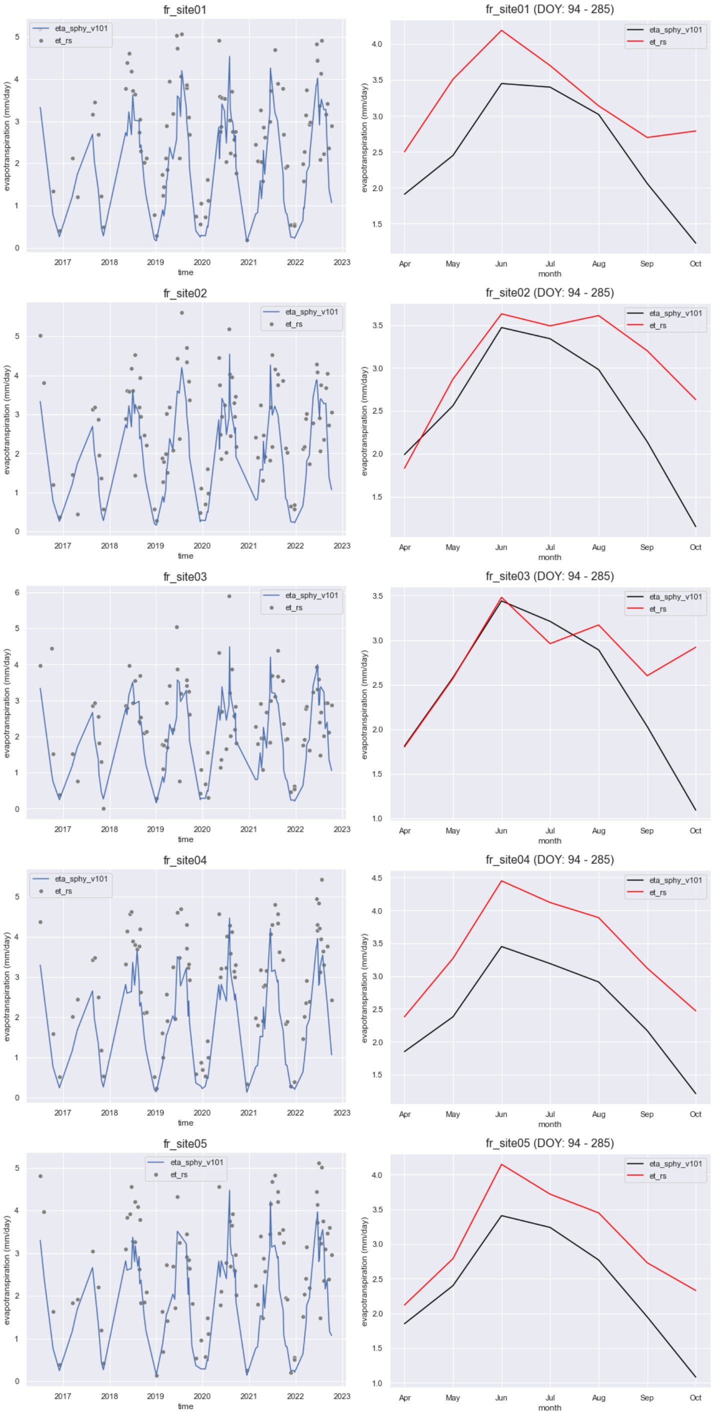

Figure 25. Seasonality plots showing actual evapotranspiration from SPHY vs. Remote Sensing data for France. Left: daily values; Right: Monthly average values.

The daily evapotranspiration plots show that SPHY does model the seasonality of the evapotranspiration well. For the French demo sites, SPHY underestimates the evapotranspiration.

In Figure 26 the seasonality for the Italian demo sites are modelled. The evapotranspiration from SPHY and Remote sensing follow the same pattern, for both the monthly and daily values. Again, the SPHY output values are underestimated.

Figure 27 shows the Romanian seasonality graphs. The values of the Romanian sites show that the model for Romania needs some adjustments, as the correlation is low and the seasonality is not modelled well, especially if you look at the monthly values.

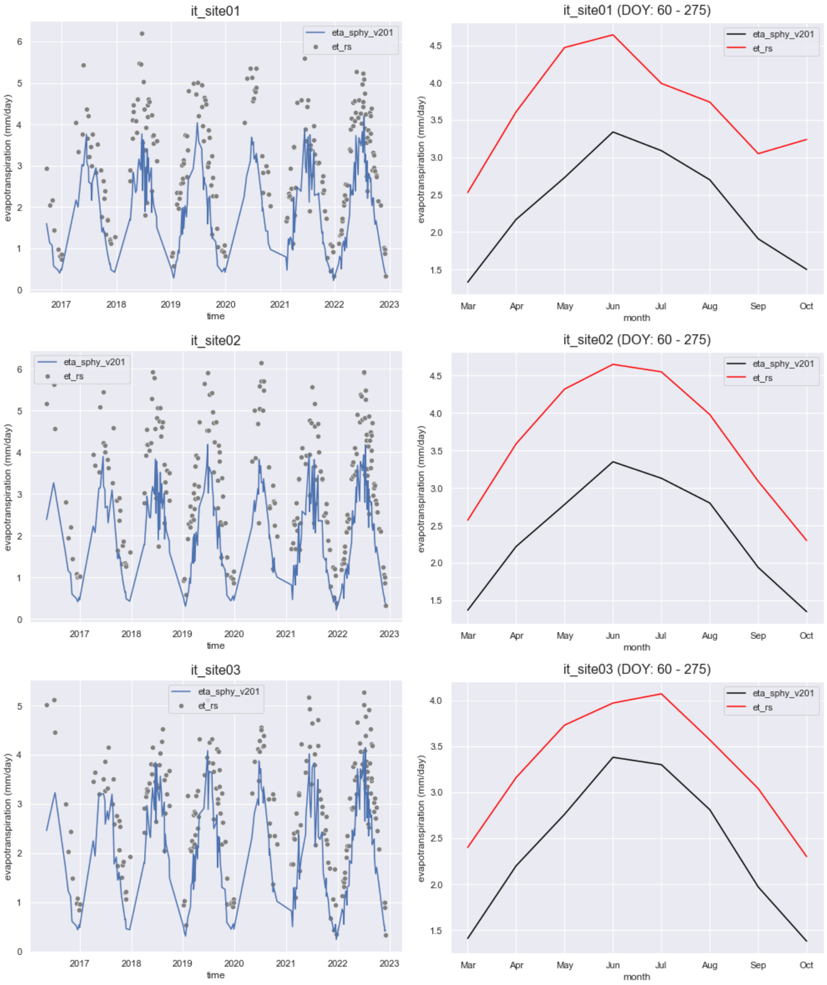

Figure 26. Seasonality plots showing actual evapotranspiration from SPHY vs. Remote Sensing data for Italy. Left: daily values; Right: Monthly average values.

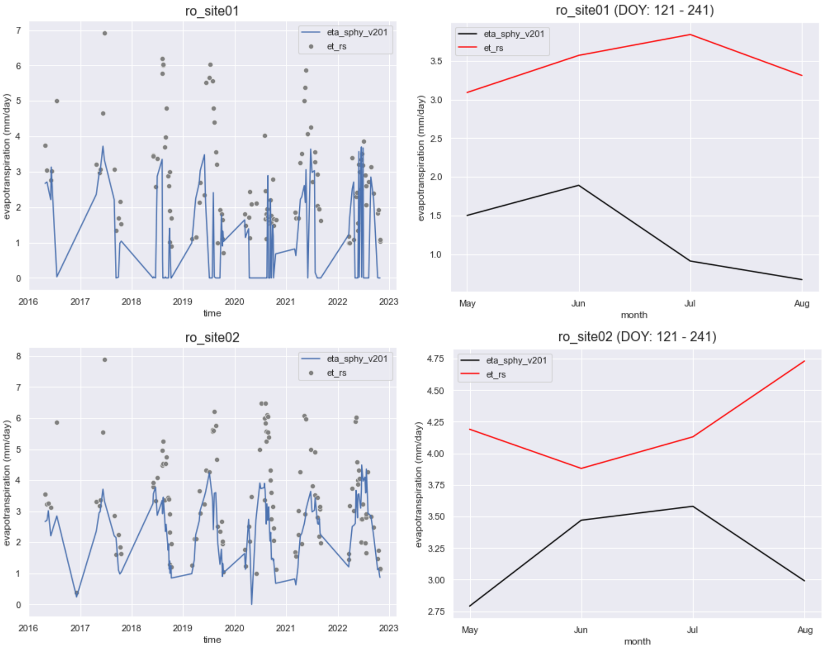

Figure 27. Seasonality plots showing actual evapotranspiration from SPHY vs. Remote Sensing data for Romania. Left: daily values; Right: Monthly average values.

3.2.2 Soil moisture

Correlation analysis

Next to evapotranspiration, which is a more reliable parameter to calibrate the model with, we also want to take a look at soil moisture. Soil moisture is a very important output parameter of the SPHY model, as it needs to be modelled accurately to take it into account in the operational irrigation advisory service. The scatterplots for the demo sites of France, Italy and Romania (Figure 28) show that the SPHY output is also underestimated in terms of soil moisture when it is compared to the remote sensing data.

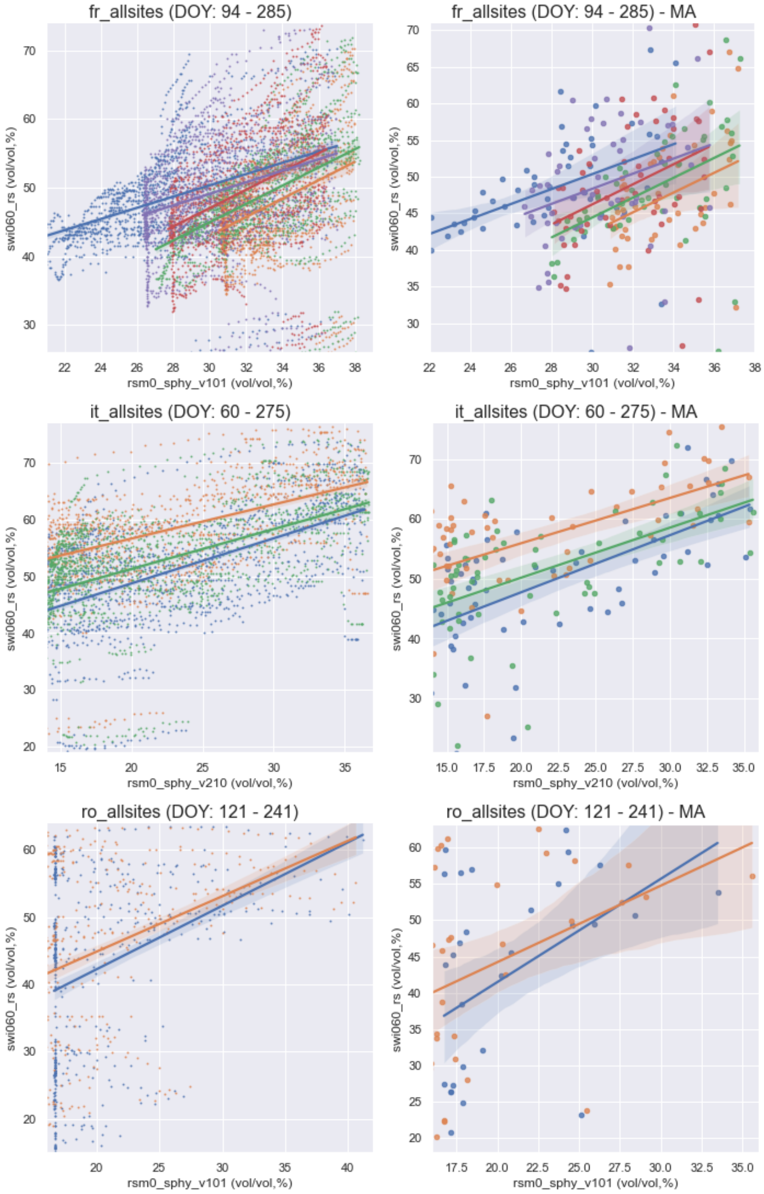

Figure 28. Scatterplots showing soil moisture from SPHY vs. Soil Water Index from Remote sensing for all pilot areas. Left: daily values; Right: Monthly average values.

Seasonal trend analysis

For France, the seasonality of the SPHY output and the Remote Sensing coincide quite a lot and the seasonality of root zone soil moisture is modelled quite well. The monthly seasonality analysis shows that for July and August, the values are overestimated a bit.

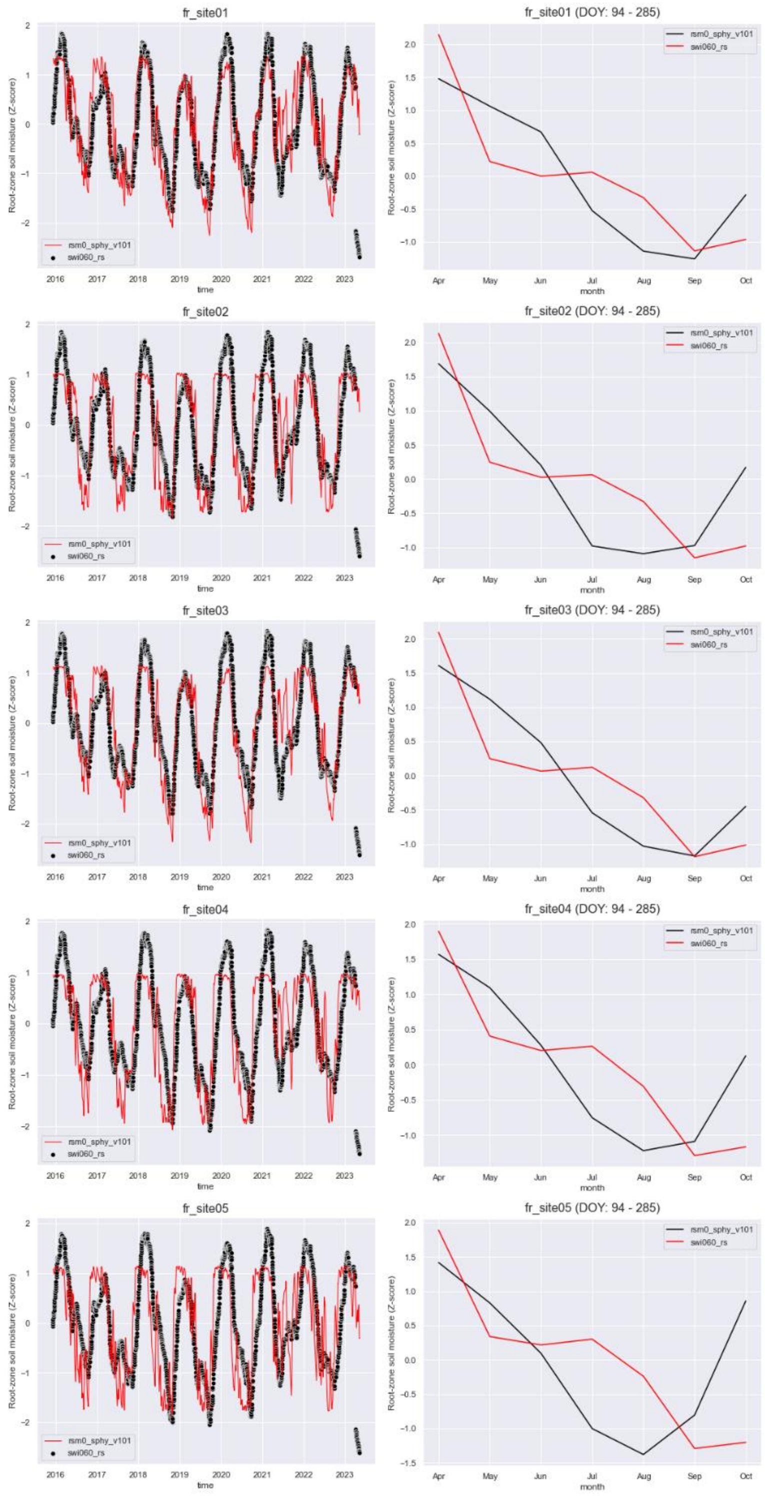

Figure 29. Left: Seasonality plots with daily normalized soil moisture values, Right: Seasonality plots with interannual monthly average soil moisture values for France

Figure 30 shows the seasonality plots for Italy, which show that some high values and low values from the remote sensing data do not coincide with the SPHY model output. The monthly soil moisture content plots coincide a little better, but there the values are also under- and overestimated.

Finally, Figure 31 shows the seasonality plot for the Romanian Demo sites. The Romania demo site SPHY model output captures the peak values of the remote sensing quite well, but a lot of low values are modelled that are not in the remote sensing data, or the data doesn't capture low values from the remote sensing data. The monthly soil moisture data does not coincide at all.

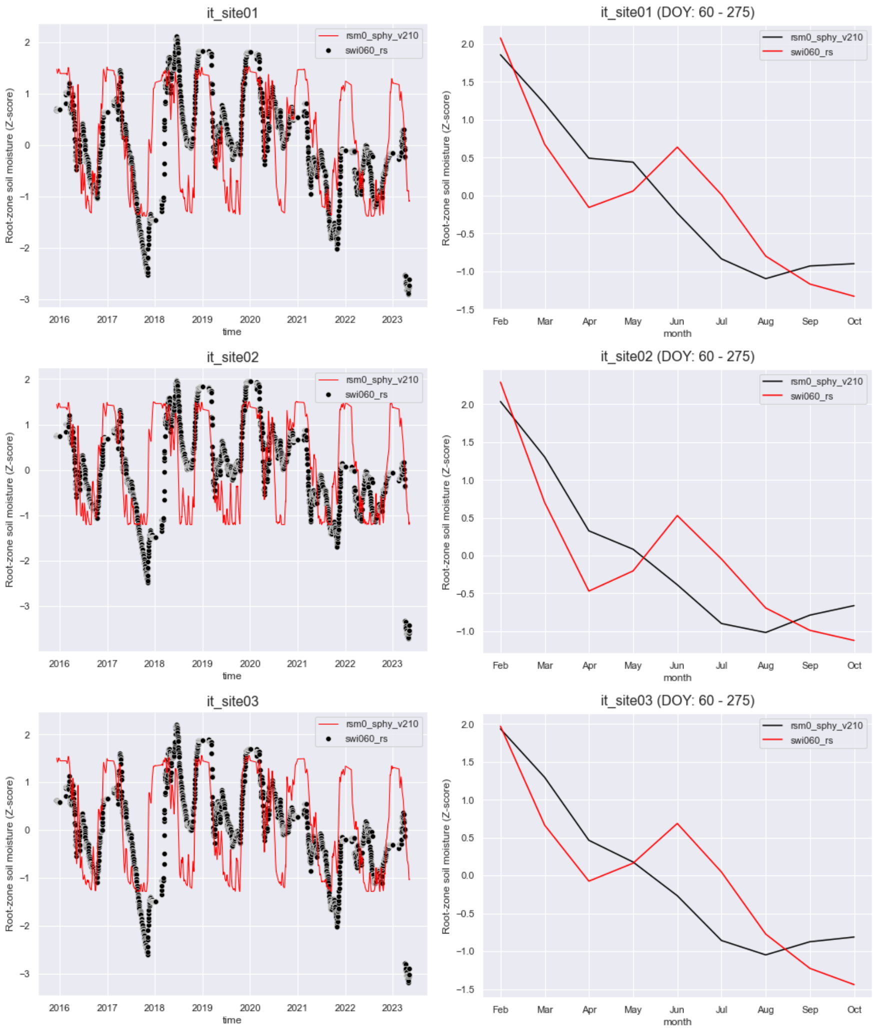

Figure 30. Left: Seasonality plots with daily evapotranspiration values, Right: Seasonality plots with interannual monthly average evapotranspiration values for Italy

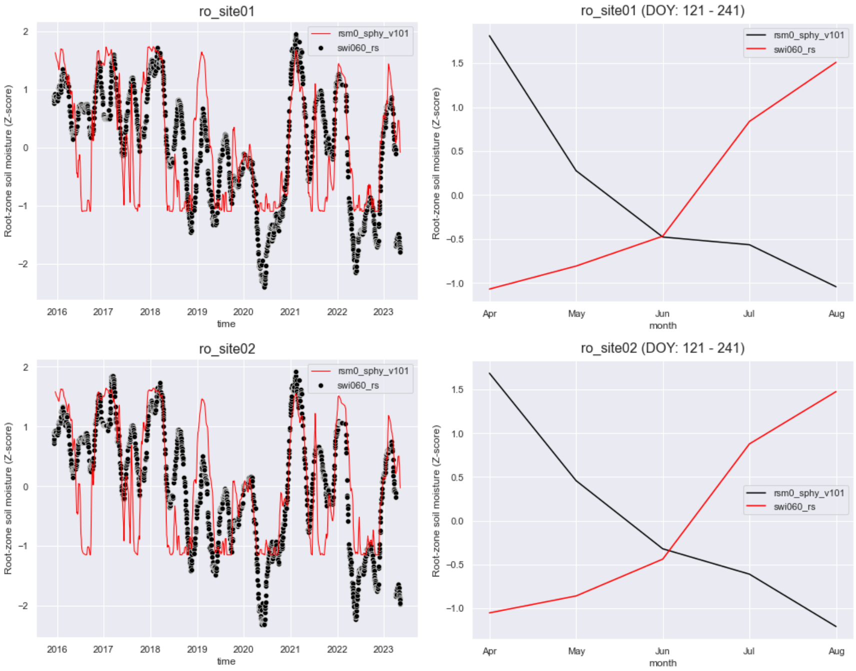

Figure 31. Left: Seasonality plots with daily evapotranspiration values, Right: Seasonality plots with interannual monthly average evapotranspiration values for Romania

3.3 In situ validation

Figure 32 shows the correlation between the in situ data of demo site 2 in Romania with the output for demo site 2 in SPHY. Although SPHY underestimates the root zone soil moisture when you compare it to the in situ measurements, higher output values of SPHY do correlate well with the in situ values.

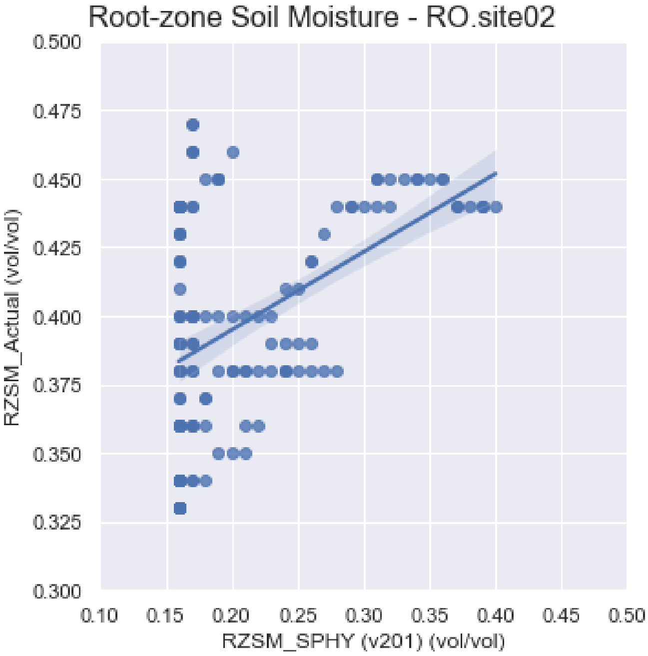

Figure 32. Comparison of root-zone soil moisture (RZSM) values from SPHY simulations and field measurements (40-cm depth average value). Period of analysis: From 01/04/2018 – 01/09/2018

4 Discussion

In this chapter the water simulations results are discussed, as well as the effect of this on the different blueprint options for the operational irrigation advisory service that were presented in section 2.5. Within this exercise a preliminary water balance simulation study was executed, to see if we could model soil moisture accurately on a large scale.

First of all, the calibration of root zone soil moisture was done with Soil Water Index (SWI). The soil water index was chosen as the product for the comparison, as the product has a fine scale (~1km) and it represents deeper soil layers (+-100cm), in contrast to other soil moisture remote sensing products, which only show the top layer (+- 5cm). But, the calibration of the root zone soil moisture with the Soil Water Index (SWI) product also has downsides, as the Soil water index does not represent volumetric water content in m^3/m^3 like root zone soil moisture modelled by SPHY does. Therefore it is very logical correlations with SWI are not very high. Nevertheless, it is interesting to see if the model captures the seasonality, and to an extent the model output is capturing this seasonality.

Furthermore, the results show that in general high correlations have been found for the SPHY evapotranspiration output for the demo sites with the actual evapotranspiration remote sensing data. Next to that, the seasonality, especially that of France, is captured well. On the other hand, the values from the SPHY output are a bit low compared to the remote sensing data. Although the scenario analyses has tested the sensitivity for different parameters, the model will probably perform better when certain input parameters are adjusted.

As could be seen in Paragraph 3.1, the spatial correlation maps of ETa from SPHY with Remote Sensing show a dependency with land use. This makes sense, as a lot of the input tables rely on land use as well. Therefore, based on the land use types with weaker correlations, adjustments willbe made to several input parameters as part of the activities to create an operational irrigation advisory service.

For the final step in the modelling exercises, an in situ validation of the model was execute for Demo site 2 in Romania. The SPHY output for Romania had the lowest correlation from all three sites when compared to remote sensing and this was also visible when comparing the model output to measured in situ root zone soil moisture data. That is why, in next steps it is important to calibrate the model with more in situ data, which luckily becomes more and better available during this project.

Based on the water balance assessments and site-specific performance evaluations, the next step is to make a decision on the design (blueprint) of the operational irrigation service. Key decision criterea are:

a. Flexibility to adjust the tool to local conditions.
b. Potential to upscale the approach to other sites.
c. Computational challenges related to resolution and data workflow.
d. Familiarity of the concepts with the users (farmers, extension services, etc).

5 Conclusion

The spatial results indicate a generally high correlation between the SPHY model's evapotranspiration output and remote sensing data for the pilot areas in France and Italy, although adjustments to certain input parameters are needed for better performance. The Romanian sites show less correlation. For the root zone soil moisture, the correlation is less high than for the evapotranspiration and the results emphasize the importance of in situ validation for model calibration. Nevertheless, for both evapotranspiration and root zone soil moisture, the seasonality is captured by the SPHY model output, especially in France.

Based on the criteria in chapter 4 and the performance of the model, the presented blueprint option 2 appears to be more favourable. This draft solution design (blueprint) combines the most commonly used FAO-based method for irrigation water requirement calculations with operational remote sensing (NDVI), weather forecasts, and locally representative values from SPHY. In the next phase the two blueprint options will be further discussed with the MAGDA partners and a final decision is made on the design components the operational irrigation module.

Furthermore, in both blueprints a historical SPHY analysis is needed to generate an accurate water balance model. Therefore, the next step in this project is to improve the historical analysis in SPHY for all demo sites through adjusting parameters in the model. Next to that, we will have more robust in situ data, which we can also calibrate the model with. Finally, we will also start writing the irrigation, NDVI and precipitation algorithms for the setup of the operational irrigation advisory service.

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