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Final project Report

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Publishable Summary

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Executive summary

The ERMES project aimed at developing methods and tools to create and disseminate added-value information for the rice farming sector, by integrating optical and satellite remote sensing data from several sources, crop models and in-situ data collected by end-users. In particular, in the European context, ERMES aimed at developing:

- **customised regional-scale monitoring services**, useful for public authorities and/or private actors interested in small-scale monitoring, not actually covered by existing systems (e.g. AGRI4CAST JRC MARS), of the on-going growing season, and
- **customised local-scale monitoring services**, able to provide added-value information useful for farmers as support for implementing more rational, economically and environmentally friendly management practices.

In the context of emerging countries, ERMES aimed also at demonstrating the usefulness of some of the developed regional-scale services for filling the gap of information on agricultural systems.

To this aim, a **complex rice monitoring system** was developed, exploiting Remote Sensing (RS), and crop modelling techniques, and advanced ICT solution to provide actable information for agricultural management at either regional or local scale. The system includes two main downstream services line, developed in the COPERNICUS framework. The **Regional Rice Service** focuses on creating and disseminating Near Real Time (NRT), spatialized information at regional scale concerning, for example, surface of rice cultivated areas, status of the rice season, forecasted biotic risks and Yield forecasts at rice district level. The **Local Rice Service** focuses instead on integrating high-resolution RS imagery (mainly commercial), local weather and field data, and modelling solutions to provide information supporting implementation of more sustainable (economically and environmentally) agropractices.

The system was operationally tested during 2015 and 2016, demonstrating **its robustness and flexibility** in coping with unforeseen situations thanks to the redundant and complementary nature of its data sources and products. This high level of operationality constitutes a significant demonstration of the quality of the job conducted by the ERMES consortium. It also allowed constantly and effectively demonstrating and disseminating ERMES results towards end users and stakeholders, including public authorities, insurance/reinsurance companies, single farmers or consortia and agro-consulting providers. The very positive feedback gathered from these different target groups suggests that the market is starting to be mature for the development of services for the agriculture sector supported by high-level scientific evidence, if data processing is customised to respond to end users' needs, support for its use is provided, and information conveyed to interested stakeholders in a timely and user-friendly way. This document provides a brief non-technical synthesis of activities conducted within the project in its three years lifespan. It highlights its main scientific and technical achievements, and provides insights about potential future exploitation of the developed services.

1 Summary of project context and objectives

The agricultural sector is currently facing several important challenges due to factors such as increasing worldwide food demand, increasing price competition due to effects of market globalization and food price volatility, and the needs for more environmentally and economically sustainable farming systems in developed countries.

In this context, availability of high-quality information concerning the spatial and temporal variability of distribution and status of crops is of paramount importance to perform regional/continental scale monitoring and support innovative solutions at local/farm scale, focused on improving productivity and reducing costs whilst minimizing environmental impacts. This kind of information can nowadays be derived from the **integration of high-quality geo-spatial data** (e.g., remotely sensed images, meteorological data) - fundamental to monitor both the main seasonal drivers of crop growth and the overall crop status -, **detailed, in-situ user-collected data**, and **crop modelling solutions** able to simulate and forecast the effects of environmental conditions on crop development and final yield.

Integrated **agro-monitoring systems** based on these three components are a key asset for monitoring and improving agricultural practices, thereby addressing the UN international millennium goal to reduce global poverty and climate change and the European Common Agricultural Policy striving for a more economically and ecologically sustainable agriculture.

The fundamental components of integrated agro-monitoring systems, at either regional or farm scale, are:

1. reliable, operational and affordable **sources of geo-spatial** data (e.g., Remote Sensing data, weather data);
2. customized algorithm and solutions to generate value-added information from those data;
3. ad-hoc Information Communication Technology (ICT) systems devoted to **in-situ data collection, data handling and dissemination of information** to stakeholders.

Several examples of crop monitoring systems based on the aforementioned components were developed in the past years by researchers, institutional bodies (mainly for crop monitoring at national/continental scale) or the private sector (mainly for precision agriculture applications). These systems can be divided in two main categories, addressing the needs of different stakeholders: ***i)*** **large-area agro-monitoring, early warning and yield forecasting systems**, and ***ii)*** **farm-scale systems for crop management support**.

The former category is intended to provide decision makers information on potential crop production shortages, useful to coordinate relief initiatives (e.g., WFP - FSMS *https://www.wfp.org/food-security/assessments/food-security-monitoring-system*), control food prices' volatility (e.g., FAO – AMIS *http://www.amis-outlook.org/*) and provide information needed to implement micro-insurance programs (e.g., Public-private partnership RIICE project, *http://www.riice.org/*). These kind of monitoring systems are traditionally more focused on developing countries, where even basic information about cropping systems is often lacking. Farm-scale monitoring systems are instead more diffused in first-world countries, where they are used to support the improvement of agricultural practices, aiming at increasing production, reducing costs and allowing a more rational and environmentally friendly use of fertilizers and agro-chemicals.

Implementing more flexible and integrated monitoring systems, capable of addressing the needs of both local and regional stakeholders, could therefore create useful synergies, and allow a better overall analysis of problems of the agricultural systems (which may range from highly-localized to continental). Furthermore, such systems could benefit from more efficient and effective hardware/software solutions based on modularity and re-use of approaches and assets.

1.1 The ERMES project

Within the aforementioned framework, the **ERMES project** (An Earth obseRvation Model based RicE information Service) aimed at developing methods and tools to create and disseminate added-value information for the rice farming sector, based on the integration of optical and satellite remote sensing data from several sources, crop models and in-situ data collected by end-users. ERMES wanted also to explore the possibilities offered by the European COPERNICUS programme (*www.copernicus.eu*) for development of operational services based on free-of-charge Earth Observation (EO) data (e.g., Proba-V, Sentinel-1/2A). Additionally, ERMES aimed at tightly integrating its crop modelling solutions within a structured data flow.

In particular, **in the European context** (where agriculture is well developed and technologically advanced), ERMES aimed at developing:

i) **customised regional-scale monitoring systems** – not actually covered by existing systems (e.g. AGRI4CAST JRC MARS) - useful for public authorities and/or private actors interested in small-scale monitoring (e.g., Insurance companies, millers and traders) of the on-going growing season;

ii) **customised local-scale monitoring systems** able to provide added-value information useful for farmers/cooperatives to support implementation of more rational, economically and environmentally friendly management practices.

In the context of **emerging countries**, ERMES aimed instead at demonstrating the usefulness of some of the developed regional-scale services for filling the gap of information on agricultural systems (**where**, **when** and **how much** is produced), and at supporting the creation of regional/national scale monitoring systems for food security/climate change adaptation purposes.

Due to the different needs of interested stakeholders, which ranged from public authorities to single farmers, these objectives translated in the development of two separate but interconnected services: the first focused on regional monitoring of crop conditions and yield forecasting, while the second on spatial variability analysis and crop modelling at farm-scale. Both services exploit satellite EO data (at different spatial and temporal resolutions), meteorological data and forecasts, and advanced modelling solutions to provide a variety of information useful for crop monitoring and management purposes. Information generated within the two services is then disseminated to stakeholders using state-of-the-art and user-friendly web platforms, and through a dedicated mail alerting system ().

The services have been developed, tested and validated in Europe within study areas in **Italy**, **Spain** and **Greece**, countries that account for around 80% of total rice production in the EU. Additionally, part of the ERMES regional services were also tested and demonstrated in the **Senegal River Valley** and in the **Gambia**, thanks to collaboration with international organizations involved in rice monitoring in West Africa (AfricaRice of CGIAR - Consultative Group for International Agricultural Research - and IFAD – The International Fund for Agricultural Development).

This document provides an overview of the main characteristic of the products and ICT tools developed within the project (*§2.1 - 2.4*), and highlights how the ERMES system was exploited during 2015 and 2016 to demonstrate the usefulness of innovative agro-monitoring systems (*§ 2.5*), and promote their adoption with either regional or local potential users and stakeholders, both in Europe and in emerging countries (§ *3.1*, *3.2*). Some considerations concerning the successfulness of the project and the possibilities for further exploitation of its results are also summarized in § *3.3*.

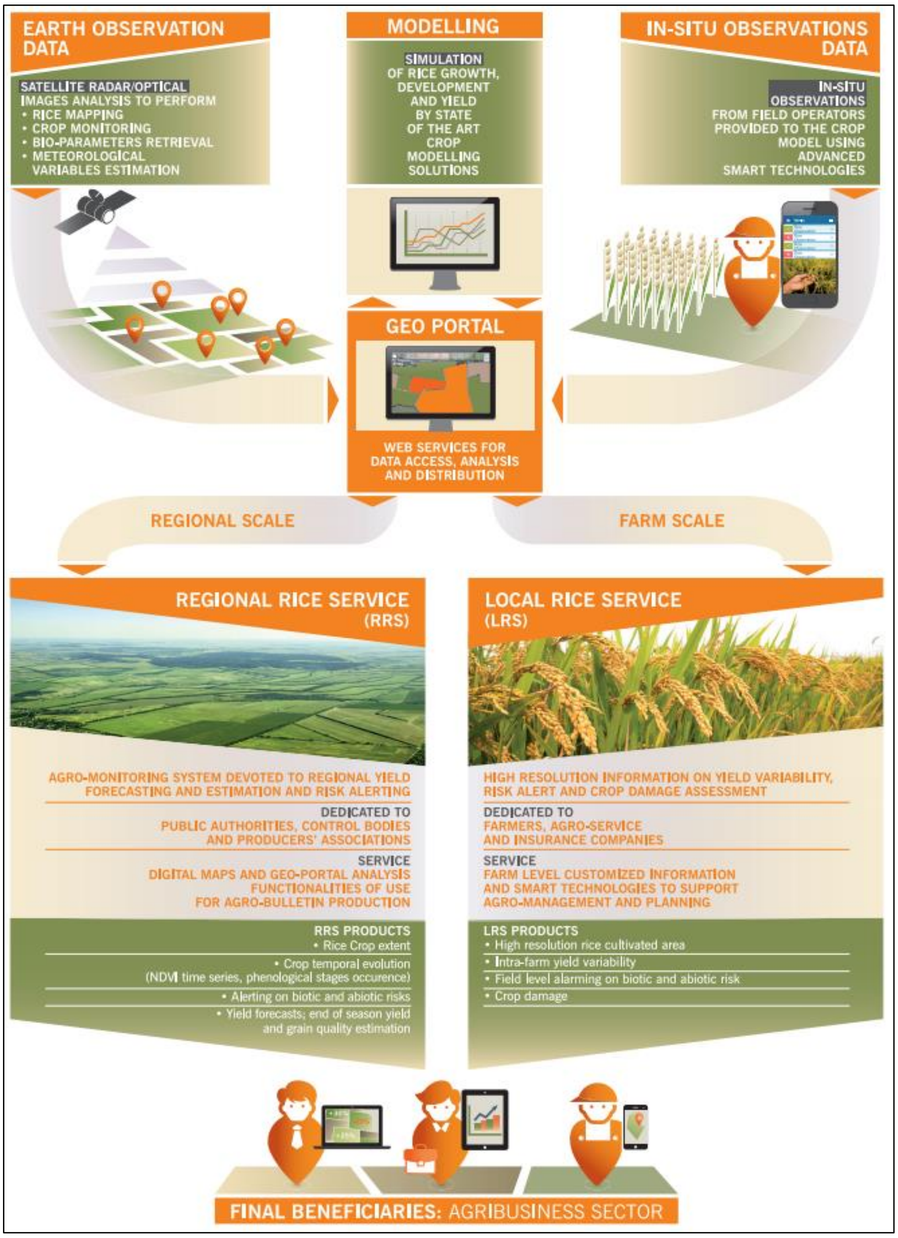


Figure 1.1: From data to information: a schematic overview of the ERMES services (Extracted from the ERMES official brochure)

2 Description of main S & T results/foregrounds

Within the ERMES project, several data products providing useful information for rice crop monitoring and management were developed, integrated and disseminated using dedicated software tools as two prototype of downstream services devoted to regional- and local-scale applications.

The main results and foreground of the project consist therefore in:

1. The **processing chains** developed for the generation of the different products;
2. The **ICT services and tools** developed for information collection and dissemination;
3. The **overall ERMES system**, integrating all products and services within a common architecture able to deal with the complex data flow required for the functioning of the system and the Near Real Time (NRT) provision of data and information to end-users.

In this section, we provide a brief overview of the main characteristics of the ERMES products developed for the two services (*§ 2.1 - 2.2*) and of the ICT tools implemented for their dissemination *(§ 2.3*), as well as of the overall architecture of the ERMES agro-monitoring system (*§ 2.4*). We then provide real-world examples of how the system was implemented in 2015 and 2016 in Europe and West-Africa as a tool for supporting rice monitoring and management at various scales (*§ 2.5*).

2.1 The ERMES Regional Rice Service main products

The ERMES Regional Rice Service (RRS) has the main objective of providing an innovative agro-monitoring system to stakeholders interested in information about the on-going rice season over large areas (i.e., regional/district scale). Its target audience includes therefore **public authorities** (e.g., regions, provinces, municipalities, environmental protection agencies, etc.) with the mandate of *i)* providing official cultivated surface and yield statistics; *ii)* monitoring the agricultural system; *iii)* developing, supporting and implementing agro-policies, and *iv)* providing information to farmers concerning potential risks of biotic/a-biotic injuries or best-practices for cultivation. Other interested entities include private subjects such as **insurances/reinsurances** companies working in the agricultural sector, **traders/millers** or **large cooperatives of farmers**, who could benefit from accurate information about the on-going season to define suitable market strategies. The ERMES RRS focuses therefore on creating and disseminating Near Real Time (NRT) spatialized information derived from the integration of RS images, weather data and crop modelling. To achieve this objective, dedicated processing chains were developed by different ERMES partners in order to generate information concerning the following topics of interest for regional stakeholders:

1. Surface of rice cultivated areas for the on-going season (early and end of season release) and dynamics of flooded areas (ERMES products EP_R1 and EP_R7);
2. Status of the rice season compared to average conditions (spatial and temporal anomalies), in terms of meteorological conditions and crop status (as derived from satellite NDVI/LAI maps) (ERMES products EP_R2, EP_R3, EP_R4) ;
3. Current and forecasted biotic risks for rice cultivations, based on crop modelling solutions (ERMES Product EI_R3);

4. Yield forecasts at regional/rice district level, based on crop modelling solutions (ERMES Products EI_R2, EI_R4).

The main ERMES products developed within the project for these purposes and included in the RRS are summarized in Table I, along with their data sources, main characteristics and usefulness for stakeholders and relevant scientific publications by ERMES partners. Accuracy of the different products was assessed exploiting the ad-hoc validation schemes reported in Table I, and was found to be satisfactory. All RRS products are based on the use of free of charge satellite and meteorological data, thus allowing the development of a cost-effective NRT solution for rice (or - more in general – agricultural) monitoring over large areas.

2.2 The ERMES Local Rice Service (LRS) main products

The ERMES Local Rice Service (LRS) was developed with the main objective of providing the private sector (farmers or agro-services such as agro-consultants, operators/producer of variable rate technologies machineries or insurance companies) with information at field/farm scale. Such information targets **optimization of the cropping** system (i.e., yield increase), reduction of costs (monetary and environmental), and **supporting monitoring/damage quantification activities**. In particular, the analysis of users' requirements highlighted that one of the main topics of interest for rice farmers is the **optimization of nitrogen fertilization**, achievable in case information about phenological stage (When), nutritional status (How much) and field variability of crop status (Where) is available. Insurance companies were also found to be particularly interested in high-resolution information about within-field crop variability, which can aid their activities in damage assessment related to farmers' insurance claims. ERMES LRS focuses therefore on integrating high spatial resolution RS data, local weather data, dedicated modelling solutions and field information **provided by farmers** to create added-value information concerning:

1. **Constant** (i.e., persisting for several years) **and seasonal** (i.e., observed in the on-going season) **intra-field variability** in rice crop status and development;
2. Current and forecasted **potential risk for rice blast infection** at field scale;
3. **Crop development stage** and its relationships with the most suitable periods for fertilization.

The main ERMES products developed for these aims and included in the LRS are summarized in Table II, along with their data sources, main characteristics, usefulness for stakeholders and relevant scientific publications by ERMES partners. Differently to the RRS, due to their focus on providing information at rice parcel level, LRS products exploit also Very High Resolution (VHR) satellite data (e.g., RapidEye, WorldView)[1]. Additionally, the LRS benefits from the use of a dedicated local modelling solution based on the use of customized parameterization, high-quality information concerning agricultural practices provided by users, retrieval of biophysical parameters at field scale and local meteorological data retrieved from weather stations. This permits an accurate simulation of rice development, thus allowing to provide actable information concerning, for example, the more suited periods for Nitrogen fertilization (§ 2.5.2).

[1] VHR data were acquired from commercial retailers, or provided to ERMES free of charge in the framework of the ESA-DWH initiative.

Table I: Characteristics of the main products of the ERMES Regional Rice Service

PRODUCT (PRODUCT CODE)	PARTNER RESPONSIBLE FOR PRODUCTION	INPUT DATA	DESCRIPTION (SPATIAL/TEMPORAL RESOLUTIONS)	USEFULNESS FOR STAKEHOLDERS	METHODOLOGY	VALIDATION SCHEME
Rice crop maps (EP_R1) **Rice flooding maps (EI_R7)**	SARMAP	Time series of SAR/Optical decametric images from: Sentinel-1/2A; Landsat 8 - OLI	Regional maps of rice crop extent[1]; Multitemporal maps of flooding in paddy rice fields[2] *(30 m spatial resolution; [1]Once/twice per year [2]Decadal - NRT)*	Provide in season estimates of rice cultivated areas and allow monitoring interannual variations in rice extent Monitoring irrigation practices	Multi-temporal Sigma nought rule based Rice Detection - MSRD (MAPscape-RICE) [2, 3, 4]	Against field observation two rice seasons (2014 , 2015)
Phenological maps (EP_R2)	CNR-IREA	Time series of MODIS 250m EVI images (MOD13Q1)	Maps of dates of occurrence of sowing and flowering for rice *(2x2 km grids; Computed once per year about 3 weeks after sowing and after flowering)*	Highlighting anomalous conditions on rice development; Input for crop model simulations	PhenoRice algorithm [5,6]	Against aggregated field observations of sowing dates two rice seasons (2015, 2016)
Leaf Area Index maps (EP_R3)	UVEG	Time series of Proba-V / MODIS 1Km LAI products (GEOV2; MOD15A2)	LAI maps derived from existing coarse resolution products *(2x2 km grids; Decadal – Near Real Time)*	Highlighting anomalous conditions on rice development; Input for crop model simulations	Reprocessing of Copernicus and MODIS products	Inter-comparison with LAI ERMES local products for two rice seasons (2015, 2016)

[2] Holecz et al. (2015) On the use of temporal-spectral descriptors for crop mapping, monitoring and crop practices characterization, in IGARSS. IEEE, 2015, pp. 161–164.

[3] Fontanelli et al. (2015) Rice monitoring using SAR and optical data in northern Italy in IGARSS. IEEE, 2015, pp. 1527 –1530.

[4] Stroppiana et al. (2017). In season monitoring of rice area and flooding dynamics from satellite data. *In writing*

[5] Busetto, L., Ranghetti, L. (2016) MODISTSP: an R package for automatic preprocessing of MODIS Land Products time series. Computers & Geosciences, Volume 97, December 2016, Pages 40–48

[6] Boschetti et al., (2017) PhenoRice: a method for automatic extraction of spatio-temporal information on rice crops using satellite data time series. Remote Sensing of Environment – Remote Sensing of Environment, Volume 194, 1 June 2017, Pages 347–365

Table II: Characteristics of the main products of the ERMES Regional Rice Service (continued)

PRODUCT (PRODUCT CODE)	PARTNER RESPONSIBLE FOR PRODUCTION	INPUT DATA	DESCRIPTION (*SPATIAL/TEMPORAL RESOLUTIONS*)	USEFULNESS FOR STAKEHOLDERS	METHODOLOGY	VALIDATION SCHEME
Meteorological maps ***(T, P, RH, ws, Rad)*** **(EP_R4)**	CNR-IMAA	TIGGE time series at 0.25° resolution	Maps of the main meteorological drivers for rice development for current day and 6-days forecasts *(2x2 km grids; Daily - NRT)*	Highlighting anomalous conditions on rice development; Input for Model	Interpolation of ECMWF-TIGGE data (Swibank et al., 2016) and calibration with the MARS data	Against Ground Meteorological Stations (GMSs) close to rice fields
Potential risk for Rice Blast ***(Pyricularia Oryza)*** **infection (EI_R2)**	UMIL	ERMES RRS Products *(Phenology and Meteo)*	Maps of current and forecasted potential risk for rice blast infection *(2x2 km grids; Daily - NRT)*	Highlighting periods of high risk for rice Blast infection due to unfavourable climate conditions	WARM regional crop modelling solution [7,8,9]	Compared to information retrieved in grey literature or supplied by local institutions and farmers
Rice yield forecast (EI_R3-4)	UMIL	ERMES RRS Products *(Phenology and Meteo)*	Forecasted rice yield *(Province - Rice District level; Estimated twice a year at flowering and end of season)*	Providing early estimates of rice yield for the on-going/recently finished rice season	Post processing of WARM regional crop modelling solution and historical official yields [6,9]	Cross-validation against 2000-2013 official yield statistics for 13 seasons

[7] Pagani et al. (2017) A high resolution, integrated system for rice yield forecast at district level (submitted for publication to "Agricultural Systems").

[8] Busetto et al. (2017) Downstream services for rice crop monitoring in europe: from regional to local scale. IEEE Journal on Selected Topics in Applied Remote Sensing , Volume: PP, Issue: 99.

[9] Boschetti at al. (2015) Assimilating seasonality information derived from satellite data time series in crop modelling for rice yield estimation, Remote Sensing of Environment, Volume 194, 1 June 2017, Pages 347–365.

Table II: Characteristics of the main products of the ERMES Local Rice Service

PRODUCT (PRODUCT CODE)	PARTNER RESPONSIBLE FOR PRODUCTION	INPUT DATA	DESCRIPTION (*SPATIAL/TEMPORAL RESOLUTIONS*)	USEFULNESS FOR STAKEHOLDERS	METHODOLOGY	VALIDATION
Constant pattern maps (EP_L2)	CNR-IMAA	VHR/HR archive multitemporal images	Maps of rice parcels zones with constant behaviour over several years *(2 – 30 m, Produced only once (static layer)*	Identify areas of low growth due to soil inhomogeneity, useful to support variable-rate basal fertilization and seeding density	Hierarchical clustering based on Expectation Maximization [10]	Clustering validity indexes; ANOVA analysis for vegetation vigour
Seasonal pattern maps (EP_L3)	AUTH	VHR RS data (Rapideye; Worldview; COSMO-Skymed)	Maps of within-field spatial variability expressed as: 1) comparison to field average conditions, and 2) 3-classes clustering *(2-5 m, Produced in key moment of the crop cycle (e.g. emergence, tillering, panicle initiation))*	Detect crop status anomalies to support planning of variable rate nitrogen fertilization; Detect crop damage/weeds infestations	Fuzzy clustering of normalized intra-field anomalies on Vegetation Index / Backscatter maps[11]	Comparison with field LAI measurements and destructive biomass sampling
LAI HR Maps (EP_L4)	UVEG	Sentinel-2A and Landsat-OLI multitemporal images	LAI maps *(30 m; Decadal)*	Highlight anomalous areas within rice fields; Provide recalibration information for crop modelling solutions	Inversion of PROSAIL RTM calibrated for rice crops by machine learning techniques [12, 13, 14]	Comparison with field LAI measurements with different instruments and with PocketLAI smartApp

[10] Casa et al. (2017) Early stage variable rate nitrogen fertilization of silage maize driven by multi-temporal clustering of archive satellite data (2017) Advances in Animal Biosciences: Precision Agriculture (ECPA) 2017, (2017), 8:2, pp 288–292

[11] Stavrakoudis et al (2017) Supporting Variable Rate Fertilization in Rice Using VHR Satellite Imagery. (In writing – to be submitted to “Remote Sensing”)

[12] Campos-Taberner et al. (2016) Multitemporal and multiresolution leaf area index retrieval for operational local rice crop monitoring. Remote Sensing of Environment, 187, 102-118

[13] Campos-Taberner et al. (2017) Exploitation of SAR and Optical Sentinel Data to Detect Rice Crop and Estimate Seasonal Dynamics of Leaf Area Index. Remote Sensing 9 (3), 248

[14] Campos-Taberner et al. (2015) Mapping leaf area index with a smartphone and Gaussian processes. IEEE Geoscience and Remote Sensing Letters 12 (12), 2501-2505

Table II: Characteristics of the main products of the ERMES Local Rice Service (continued)

PRODUCT (PRODUCT CODE)	PARTNER RESPONSIBLE FOR PRODUCTION	INPUT DATA	DESCRIPTION (SPATIAL/TEMPORAL RESOLUTIONS)	USEFULNESS FOR STAKEHOLDERS	METHODOLOGY	VALIDATION
Development Stage simulation (EI_L1)	UMIL	Information provided by farmers Local weather data and forecasts; ERMES LAI maps	Simulations of development stage; (Field scale; Daily)	Provide forecasts about crop phenological stage useful for planning top dressing fertilizations	WARM model local customized solution [15]	Comparison with field LAI and biomass measurement and phenological observations.
Potential risk for Rice Blast infection *Magnaporthe oryzae B. Couch* (EI_L3)	UMIL	Information provided by farmers; Local weather data and forecasts; ERMES LAI maps	Simulations of potential risk for rice blast infection (Field scale; Daily)	Provide forecasts about potential biotic risks useful for planning agro-chemicals treatments	WARM model local customized solution [15]	Compared to information supplied by local institutions and farmers for 1 season; Grey-literature analysis

[15] Bregaglio et al. (2016) Coupling a generic disease model to the WARM rice simulator to assess leaf and panicle blast impacts in a temperate climate, European Journal of Agronomy, 76, 107–117

2.3 Information dissemination and collection: ERMES geoportals, mail alerts and AgriNotebook

Although high-quality products tailored to the needs of end are of utmost importance in the context of an agro-monitoring system, their timely and user-friendly dissemination to stakeholders is also paramount to obtain truly effective downstream services.

Recognizing this need, two geo-portals for dissemination of products and information were specifically developed by ERMES partner UJI to allow efficient access to the rice-monitoring information produced for regional and local services (*ermes.dlsi.uji.es*).The two geoportals allow retrieving, visualizing, comparing, interpreting and interacting with the various ERMES data products using a minimal, user-centered and user-friendly interface which ensures that all stakeholders (even those not familiar with traditional GIS-based interfaces) have access to easily understandable and useful information. In essence, the local and regional geoportals are map-based Web applications, offering the following shared functionalities:

- **Authentication:** allows registration and authentication of registered users, allowing them access to data products regarding their region (Spain, Italy, and Greece) and scale (local or regional);
- **Visualization:** allows visualizing data products in the form of raster maps, based on a thematic and temporal selection (e.g. NDVI, January 7; Seasonal Pattern map – field variability, June 26, etc.).
- **Data charting:** allows visualizing graphs showing time series of a selected parameter (e.g., NDVI, LAI, air temperature), for a selected point. Long-term averages of the same parameter derived from historical data are also shown, allowing easy detection of anomalies. For the case of meteo data products, one-week forecasted data are also shown and highlighted;
- **Exporting and downloading:** information visualized in the geoportal, from maps to temporal charts, can be exported as pdf files, images or CSV format (for charts). Furthermore, data products are linked to the GET-IT catalogue, through which they are available for full metadata browsing and download.

More specifically, the regional geoportal (Figure 2.3) provides a **Near Real Time overview of the current growing season conditions** over large areas, allowing its users to detect anomalies in rice development. Additionally, it provides access to daily estimates and forecasts of the risk of blast infection, one of the more dangerous and impacting pathogens affecting rice cultivations [16].

The local geoportal provides instead very specific **information for rice fields belonging to the authenticated users**. For each of their fields, farmers are able to visualize the detailed maps concerning constant and seasonal patterns (Figure 2.9a, c), which provide useful information for performing precision agriculture activities such as Variable Rate fertilization (Figure 2.9b, d). Additionally, the local geoportal provides access to user-collected in-situ data, alerts and parcel-level yield forecasts generated by the ERMES local crop modelling solution (e.g., blast infection risk, crop development stage, biomass plant growth). To be accurate, this type of highly personalized service requires however very detailed information about cultivation practices on a per-field level. To obtain such fine-grained, field-level

[16] Granell et al., (2017) A Conceptual Architecture and Service-oriented Implementation of a Regional Geoportal for Rice Monitoring. (*In writing*) To be submitted to the Special Issue "Recent Advances in GIS and Remote Sensing for Sustainable Agriculture" of *ISPRS International Journal of Geo-Information*.

information, which is only available to the farmers themselves, a dedicated **web-based and mobile application** (*AgriNotebook*) was developed within ERMES. *AgriNotebook* allows to document in detail their agricultural practices and to store in-situ information, thus allowing farmers or field operators recording geo-tagged information about cultivation practices (e.g., sowing date, variety, fertilization and pest-control treatments) and occurrence of particular problems (e.g., weeds infestations, pest attacks) (Figure 2.1). Additionally, farmers can share their observations through a mail alerting system, thus providing real-time notification of risk factors to their peers. As such, it is extremely valuable for covering all aspects and stages of the rice crop season, and its generality makes it applicable to other crop types as well. Thanks to *AgriNotebook*, farmers have therefore the possibility to overview and visualize all relevant information regarding their cultivation workflow (i.e. replacing the traditional "field notebook"), to export recorded data (e.g., for legally mandatory reporting practices), and to obtain more accurate, added-value information for decision support through the local geoportal.

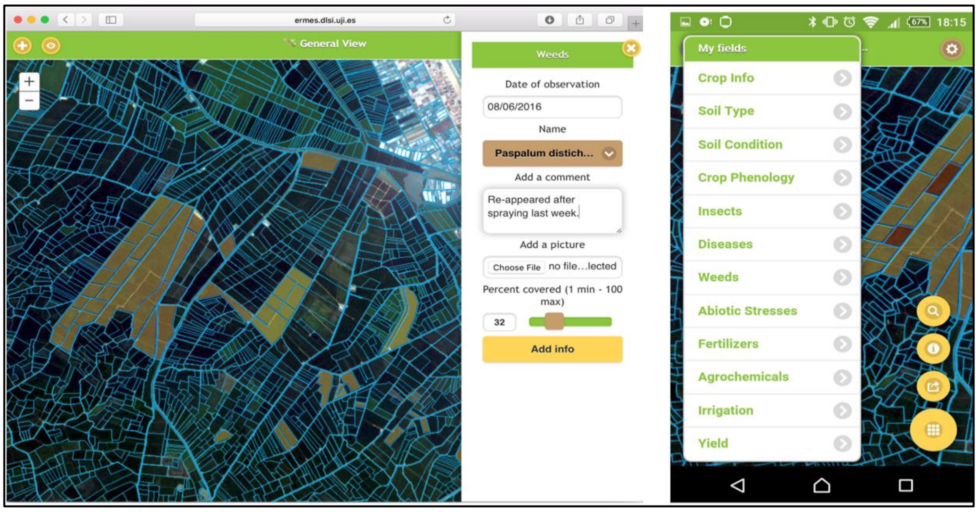


Figure 2.1: Web-based desktop (left) and native mobile app (right) versions of AgriNotebook.

2.4 Overall architecture of the ERMES agro-monitoring system: bridging the gap from data to information

From the above, it is clear that to work operationally, the ERMES system **required a robust yet flexible underlying (software and hardware) architecture** allowing to *i)* retrieve, transform and process a variety of heterogeneous data sources (e.g., RS data, weather data, user-provided data), *ii)* run crop-modelling simulations, *iii)* manage, store and serve the resulting data and data products, *iv)* disseminate timely and crop-relevant information through pull-based visualization (geoportals) and push-based notification (e-mail alerts). Due to the volume of data involved, and the computational cost of (some of the) transformation and processing at hand, the architecture had to be highly scalable and distributable. Finally, due to the time-sensitivity of (some) data products, a high degree of automation of the workflow from raw data to information dissemination was fundamental.

The system developed with this aim within the project (Figure 2.2) can be conceptually subdivided into four heavily interconnected sub-systems. Those systems communicate through a collection of Application Programming Interfaces (APIs) and services and ad-hoc scripting, allowing automating the I/O flows leading to data/information deployment, hereby reducing human intervention to a minimum. These characteristics are of fundamental importance in the framework of downstream services dedicated to the agriculture sector, for which **fast information deployment during the growing season is of utmost importance**. The four sub-systems of the ERMES architecture and their connections are briefly described hereafter.

2.4.1 Data gathering and products' generation

This sub-system is a collection of individual components each of which gathers the necessary input data and generates one of the ERMES products described in Table I and II. Each component was independently developed and maintained by one of the ERMES partners, using their own hardware/software architecture and proprietary algorithms. The resulting data products are successively deployed to the Data Management and/or Crop Modelling sub-systems. This distributed approach was **preferred over a centralized system** for generation of products for various reasons, among which *i)* the heterogeneity of ERMES data sources and output products (e.g., spatial and temporal granularity), *ii)* the different characteristics and requirements of the algorithms used to produce them (e.g., programming languages and degree of automation/required human intervention), and *iii)* the computational complexity and resource requirements of some of those algorithms. This approach also allowed ERMES partners to more easily intervene on their processing chains (e.g., for testing and problem-solving purposes), thus allowing greater and easier control on generation and validation of products.

The data gathering and generation sub-system includes also the *AgriNotebook* application (§ 2.3). The detailed parcel-level information collected by users through it is stored in the agro-practices database for further integration with the ERMES–WARM database (§ 2.4.3), providing valuable information to increase the accuracy of the modelling system for simulations at local scale, and allowing visualization and overviewing of agricultural practices in the local geoportal.

2.4.2 Data Management

Most ERMES data products are deployed to a dedicated FTP file repository, which also stores ancillary datasets such as administrative units or field boundaries vector files. The file repository acts as an interface to a GeoDatabase optimized to generate the necessary geospatial services for data access, retrieval and visualization. This GeoDatabase combines an ESRI File Geodatabase and mosaics data models to provide a convenient schema for handling time-series of raster images, which is a common pattern among ERMES data products. Once mosaics are in place, counterpart geospatial services are set up to deploy the corresponding data products on the Web as queryiable service endpoints. A series of scripts were developed to automate the data flow from the FTP file repository to mosaics datasets, and subsequently to generate the corresponding geospatial services. These scripts run periodically (nightly) and are synchronized with data product uploads, as to ensure timely delivery of new products to stakeholders. The FTP file repository is also interfaced with a dedicated on-line catalog (*get-it.ermes-fp7space.eu/*) based on GET-IT (Geoinformation Enabling ToolkIT starterkit®), which allows discovering and accessing available ERMES products using standard OGC requests (CSW, WMS, WCS, WFS) as implemented in common GIS software.

Finally, ERMES user-collected data about agro-practices and other information of interest provided by users through *AgriNotebook* is stored in a dedicated database, which is exposed through a Restful service-based API for data access and retrieval.

2.4.3 Crop Modelling

The modelling solutions communicate with other ERMES sub-systems through the **ERMES-WARM DB**, a dedicated postGIS data base storing all inputs required to run the model (as derived from other ERMES products or provided by ERMES users through *AgriNotebook*), and all of its outputs.

The DB interfaces with the FTP file repository through dedicated “R” scripts tasked to *i)* retrieve raster maps containing data to be used as inputs for the model (e.g., weather data, LAI time series) and store their information in fast-access tables, and *ii)* convert some specific model outputs (e.g., blast infection risk estimate for the RRS) to raster maps, and *iii)* transfer them to the file repository for deployment.

Execution of these scripts is triggered whenever a new dataset is discovered within the repository, or at the end of a model run, thus ensuring synchronization of inputs and outputs. The core of the Crop Modelling sub-system are the ERMES-WARM regional and local rice solutions for rice modelling, which are alternative customizations of the rice-specific Water Accounting Rice Model (WARM)[17]. Minimum input requirements for both solutions are constituted by *i)* **daily weather data** (temperature, precipitations, air humidity, wind speed and radiation), *ii)* **information on grown variety** (or variety group), and *iii)* base **agricultural practices** (sowing date; irrigation). This information allows the model to simulate a variety of information (e.g., development stage, biomass in the different plant organs, risk for blast infection and its impact on yield, cold-induced spikelet sterility, etc.). Simulations are run daily, exploiting both past and forecasted weather data (up to 6 days), with the elementary simulation unit corresponding to the cells of a 2 km × 2 km regular grid for the RRS, and to single rice field for the LRS.

In the RRS, different ERMES EO products are used as additional spatially distributed inputs to reduce the uncertainty in model results (Table I). In particular, phenological maps derived from MODIS are used to initialize the sowing dates, and simulations are conducted for the most common variety groups grown in the areas. Multitemporal coarse-resolution LAI maps from tillering to flowering are assimilated in the modelling solution (through forcing and/or recalibration schemes), allowing to better simulate seasonal crop dynamics for each simulation unit. In the LRS, both sowing dates and variety are instead initialized using information provided by farmers or ERMES personnel using *AgriNotebook*, allowing a very accurate simulation of rice crop development for each field triggered whenever a new dataset is discovered within the repository, or at the end of a model run, thus ensuring synchronization of inputs and outputs.

[17] R. Confalonieri, A. S. Rosenmund, and B. Baruth, (2009). An improved model to simulate rice yield”. Agronomy for Sustainable Development, vol. 29 (3), 463–474, doi: 10.1051/agro/2009005

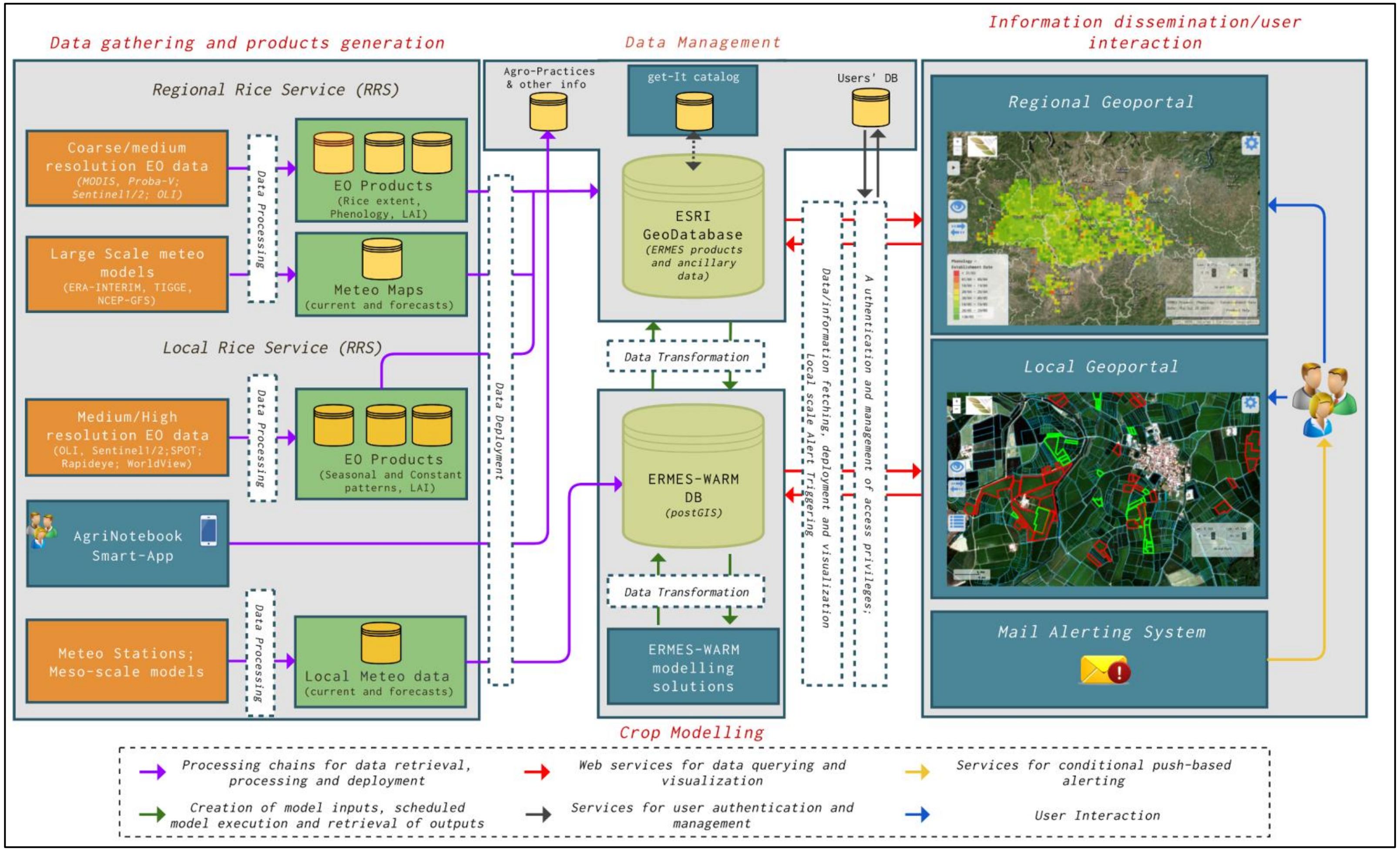


Figure 2.2: Overall architecture of the ERMES system (from Busetto et al., 2017). The ERMES system can be subdivided into four sub-systems: i) "Data gathering and products generation", ii) "Data Management", iii) "Crop Modelling" and iv) "Information dissemination and user interaction". These sub-systems are heavily interconnected, and communication between them occurs through a collection of specifically developed Application Programming Interfaces (APIs) and services. This allows components within each sub-system to be technology- and implementation-independent, and supports various end-user applications to be built on top of them

2.4.4 Information dissemination to end users

The last component of the system is dedicated to disseminating of the generated products and information towards end users. These include ERMES satellite-derived data products stored in the GeoDatabase, in-situ collected user-generated data stored in the Agro-Practices database and crop modeling results stored in the ERMES-WARM database. The main dissemination tools used to this aim are the **ERMES regional and local geoportals** (§ 2.3), which interface with the other components of the system to guarantee an automatic deployment of information as soon as it is generated (i.e., new products are automatically exposed to users as soon as they are uploaded to the system). The front end of both geoportals was implemented with the ArcGIS API for JavaScript, which is an optimized Software Development Kit (SDK) for accessing and interacting with server-side ArcGIS services. Data products were conveniently exposed as an array of geospatial web services, following standards-based Restful ArcGIS/OGC interfaces. Since most data are of raster type, they were handled as tiled images for visualization. To manage and access ERMES-WARM and AgriNotebook data, custom, dedicated Restful Web services were developed using Node.JS, to ease data query and data modification operations. These services are heavily used by both geoportals to govern data retrieval, and accessed by the Mail Alerting System. This is implemented as a series of Python scripts, which exploit crop modeling results to send the alerts to local stakeholders.

Besides the geoportals, which require an "active" intervention (i.e., pull-based) and which use may still be challenging for technologically illiterate actors, information derived from selected ERMES local data products is also **directly pushed to users using an automatized and personalized mail alert system**. This is the case of local data products related to blast risk and crop development stage monitoring at field scale, which are used to trigger alert mails under specific conditions (i.e., in the case of occurrence of forecasted high blast risk periods, or when the best periods for nitrogen fertilization periods are being reached). This "push-based" communication allows for a more direct and faster interaction with farmers, and is particularly important when information is useful only for a narrow span of time, as it is the case of data aimed to support specific agro-practices.

2.5 The ERMES system at work: highlights of selected results

After the design phase, the different functionalities of the ERMES system were progressively implemented to run pre-operationally during the 2015 rice growing season. This allowed presenting the ERMES products and services to end-users, in order to receive feedback for refining and tuning preliminary products, data flows and dissemination schemes. The whole system was further operationalized and tested during the 2016 European rice growing season exploiting the full suite of ERMES products and services.

The next sub-sections highlight some significant products and results obtained and disseminated in the three European ERMES study areas in 2015 and 2016, focusing on real-world exploitation of the provided information by ERMES end-users. Exportability of some sub-systems modules and products line was also demonstrated in West Africa, for which some results are also shown. More than an analysis of products quality (which is the subject of dedicated publications), this is intended to provide an overview of the different kinds of information that the ERMES system is able to provide, and their usefulness in satisfying the needs of different stakeholders.

2.5.1 Regional Rice Service: Monitoring the rice season at regional scale

As described in Section 2.1, ERMES RRS is focused on providing information useful to monitor the development of the rice season in NRT on a regional/district scale. This can be achieved by interacting with the regional geoportal. Examples of maps and charts that can be visualized in the regional geoportal are shown in Figure 2.3, for the Greek study area, highlighting the amount and diversity of information that can be retrieved and analysed.

Rice crop maps (Figure 2.3 a – *EP_R1*) allow understanding the spatial distribution of rice cultivations and their interannual variations. Since those maps are generated during the rice season, they allow obtaining estimates of the total area invested at rice before official statistics compiled from farmers' declarations for the CAP subsidies are available. ERMES users such as Ente Nazionale Risi in Italy were interested in assessing the contribution that this geospatial product could have in providing yearly statistics of cultivated areas to the Ministry of Agriculture and Eurostat. Potential applications of the product for CAP control is also under investigation, in particular in collaboration with the OPEKEPE Greek authority (www.opekepe.gr/english/).

Multitemporal flooding maps derived as a side product by the rice crop mapping processing (*EI_R7*) chain are also important to agro-monitoring authorities to understand and monitor irrigation practices. This is particularly relevant in Italy, where more and more farmers are switching from broadcast seeding in water, to row seeding on dry soils both to reduce costs related to irrigation, and to simplify farming activities adopting the same sowing machineries used for winter wheat or corn. This change is developing so quickly that in some areas of Lombardy it was estimated that dry seeding increased from 30% up to 80% of the total rice cultivated area in the last 10 years. These changes can lead to both positive (e.g., reduction of water needs, methane CH4 greenhouse gasses emission, etc.) and negative (e.g., reduction of wet areas favorable for some animal species, water table level or increase of nitrous oxide (N2O) emission, etc.) effects on the environment. For example, the Regional Plant health service of Lombardy Region was particularly interested on these data and analysis, due to the potential environmental issues related to the different phytosanitary treatments permitted on dry and flooded rice fields.

Estimates of sowing dates (Figure 2.3 b - *EP_R2*) is also a fundamental information to infer cultivated variety (long or short cycle) and potential problems in the current season (e.g., delays in sowing due to adverse meteorological conditions). Charts of time series of **weather parameters** (air temperature, radiation, relative humidity and rainfall) and **Leaf Area Index** (Figure 2.3c, d, e, f, g - *EP_R3*, *EP_R4*) allow analysts to monitor rice growth on the different areas. In particular, comparison with long-term averages allows easily highlighting anomalies in climatic conditions and/or crop status. Finally, daily simulations of potential **risk of rice blast infection** (Figure 2.3h - *EI_R2*) allow identifying high-risk periods in the areas of interest.

When analysed on longer periods, daily blast risk estimations provide insights on potential production losses in a given year. For example, counting the number of days identified as being at "high risk" in the last 14 years (Figure 2.4), highlights how the ERMES modelling solutions identified meteorological conditions in the 2015 growing season as particularly likely to facilitate the spreading of the disease. This was verified by the Valencian Farmers Association (AVA-Asaja), which estimated a 15% decrease in rice yield and losses of around 5.6 million C compared to previous years (https://goo.gl/W1o4q8).

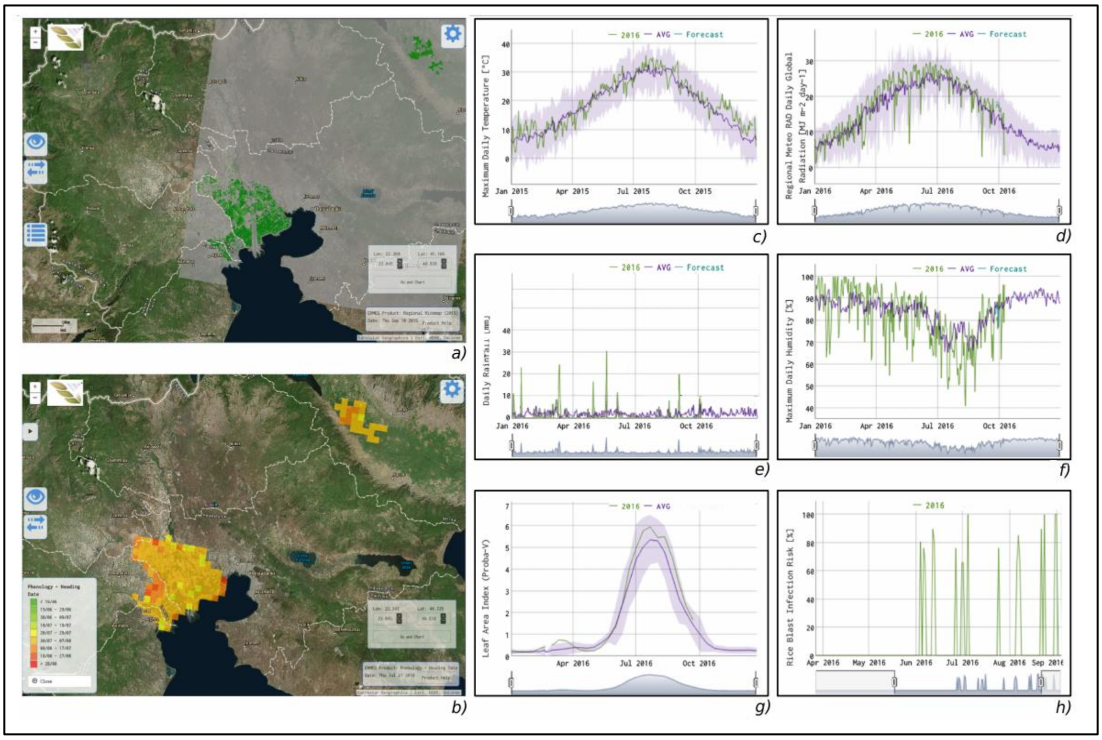


Figure 2.3: Example of products derived from ERMES RRS in 2016. a) Rice crop maps, phenological maps and multitemporal info about weather conditions and rice blast risk, as visualized in the ERMES regional geoportal; b) Example of blast risk alert bulletins produced for ERMES Italian regional end user "ERSAF"; c) Map of Sowing Dates anomalies with respect to the short term average aggregated at municipality level for the Italian regional study area, used in the JRC-MARS July 2016 bulletin; d) 2016 rice forecasting bulletin for the Italian districts released at maturity stage for end user ENR.

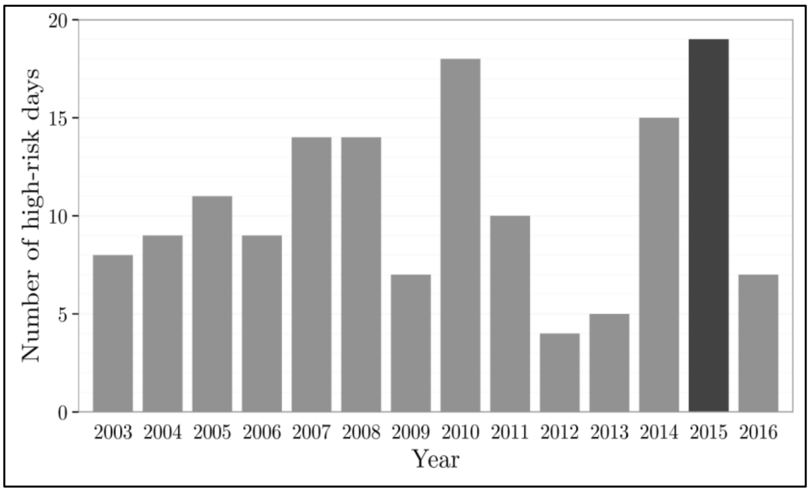


Figure 2.4: Total number of days simulated as "high risk" in the June-August period in the Valencia area, for the 2003-2016 period

Finally, RRS products are the fundamental input for the **ERMES yield forecasting system**, which is used to estimate rice yield on administrative units both within and immediately after the end of the cultivation season (*EI_R3-4*). Figure 2.5 shows results obtained for three regional study areas in Greece, Spain and Italy, by comparing forecasted yields with official statistics referred to the last 12 years. The regional modelling solution was able to explain about 70% of inter-annual variability of official yields, with Mean Absolute Error in cross-validation of 0.12 (Italy), 0.20 (Spain) and 0.30 (Greece) ton ha-1. The slightly worse results obtained in Greece are explained on the one hand by the higher interannual variability observed in the area, and on the other hand by the lower representativeness of the parametrization used for the Greek simulations with respect to the rice varieties grown in the area (also due to the recent increase in cultivation of high-yield varieties such as Ronaldo). These preliminary results are very encouraging in view of the development of a regional yield forecasting system.

These examples of high-level exploitation demonstrate the usefulness of the information provided and the degree of operativity of the downstream services, which were able to produce information of interest in NRT and without significant interruptions.

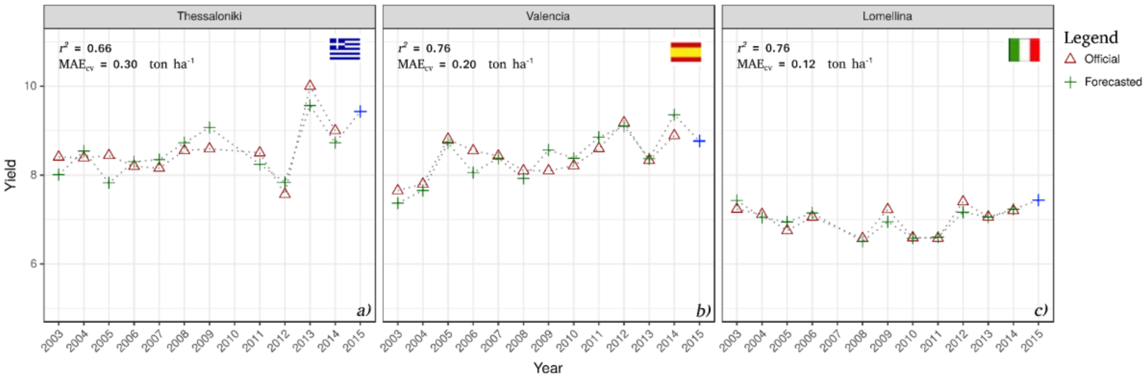


Figure 2.5: ERMES-WARM yields forecasts (+) compared to official statistics (Δ) referred to the last 12 years

Part of the ERMES regional products were also generated, tested and demonstrated in West Africa in the Senegal River Valley and in The Gambia, thanks to collaboration with international organizations involved in rice monitoring in West Africa (AfricaRice of CGIAR - Consultative Group for International Agricultural Research - and IFAD – The International Fund for Agricultural Development). For example, rice/land cover maps were produced for the Gambia and Senegal River Valley and were considered very useful by Users, due to the lack of official and coherent high-resolution information at national scale on crops' distribution. Information provided by Phenological maps (Figure 2.5)[18], produced by both MODIS and Sentinel-1 data, were also appreciated by AfricaRice. These products can in fact improve knowledge about the spatial and temporal variability of rice cropping practices, which is a key information for better assessing the potential impacts of unfavorable weather conditions on rice yield. This is a very important issue, in particular if climate change issues are taken into account, and AfricaRice is currently actively working in this field of analysis due to its importance for food security issues and to support appropriate planning.

18 Busetto et al. (2016). Variations in rice cultivation practices in the senegal river valley between 2003 and 2014: an analysis based on MODIS time series. ESA Living Planet Symposium 2016, Prague, Czech Republic

2.5.2 Local Rice Service: high-level spatial information as a support for agro-practices

The ERMES LRS service provides tools and information of immediate use to farmers for improving their cultivation practices, with the objective of maximizing cash inflow and minimizing environmental impact through optimization of fertilization practices and phytosanitary treatments. This information is disseminated through the local ERMES geoportal, which allows visualizing ERMES high-resolution raster maps related to intra-field crop growth anomalies (either constant or specific to the growing season) and field-scale information about crop development stage and rice blast risk derived from the ERMES local modelling solution.

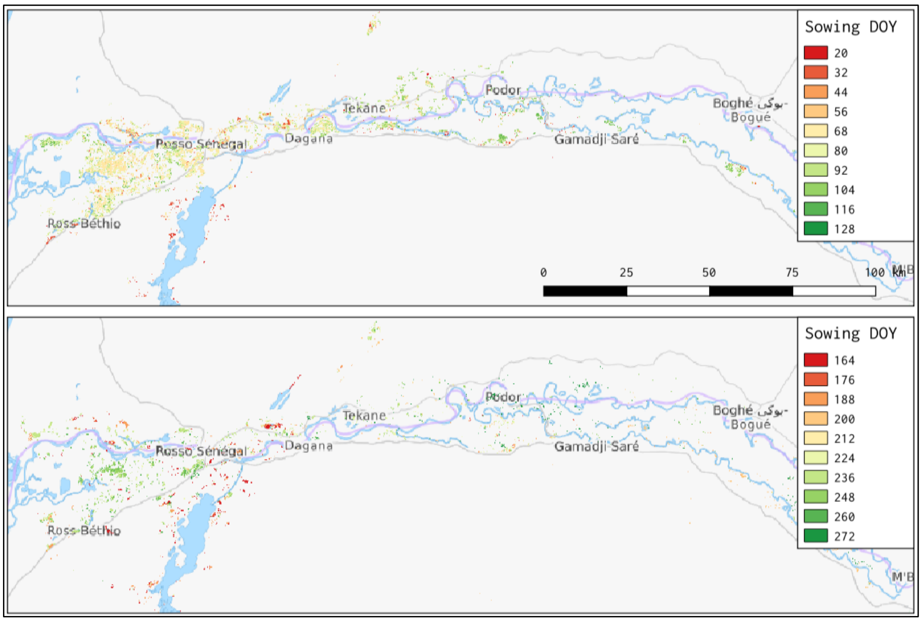


Figure 2.6: Rice Start sowing dates maps for 2016 derived from Sentinel-1/OLI for the dry (top) and wet (bottom) rice seasons for the Senegal River Valley.

Examples of maps and charts that can be visualized in the local geoportal are shown in Figure 2.7. Once logged-in in the Local Geoportal, farmers can see their fields highlighted (Figure 2.7a), and easily visualize ERMES products specific to those fields, as well as the information they provided through AgriNotebook.

Constant and Seasonal pattern maps allow analysing the spatial variability of crop growth within a specific rice field. In particular, **Constant Pattern maps**, derived from analysing archives of decametric/sub-decametric of satellite images (Figure 2.7b - EP_L2) aim at identifying problems in the field related to inhomogeneity of soils characteristics. This information is needed to support farm planning (e.g., choice of crop/varieties, crop rotation and soil movement) and to perform precision farming agro-practices such as variable-rate pre-sowing basal fertilization and sowing density.

Conversely, **Seasonal Pattern maps** (EP_L3) highlight the intra-field spatial variability at different time points of the on-going growing season. Optical and/or Synthetic Aperture Radar (SAR) high-resolution satellite images are used to divide each field in different clusters, as a function of the relative difference between the satellite signal (e.g., Vegetation Indexes, backscatter) in the different pixels and its average value over the whole parcel. In particular, COSMO-SkyMed X-band data at 3 m resolution acquired every 8 days at the beginning of the season allowed to highlight patterns in crop emergence and tillering development. These anomaly maps - produced on a regular basis thanks to the all-weather SAR acquisitions - provide the farmers information on crop failure at the first stages of the growth cycle that can be recovered by specific intervention (Figure 2.7c). CSK data is instead less useful to highlight crop status spatial variability in later periods of the rice cycle, when closing-up of the canopy makes radar backscatter rather homogeneous. To perform crop status assessment in those later stages, RapidEye (5 m spatial resolution) or Worldview (2 m) optical imagery were acquired in the most important periods for rice's top-dressing fertilization (tillering – around mid-June - and panicle initiation – around mid-July - stages). Both RapidEye and Worldview imagery provided valuable information in this context, allowing end-users to identify areas in need of higher/lower nitrogen inputs (Figure 2.7d) based on analysis of Vegetation Indexes' spatial variability. Besides their lower spatial resolution, RapidEye imagery proved in particular to be a very useful data source, since it allows coverage of reasonably large areas with sufficient resolution for precision agriculture applications, and with a quite favorable price per hectare as compared to WorldView.

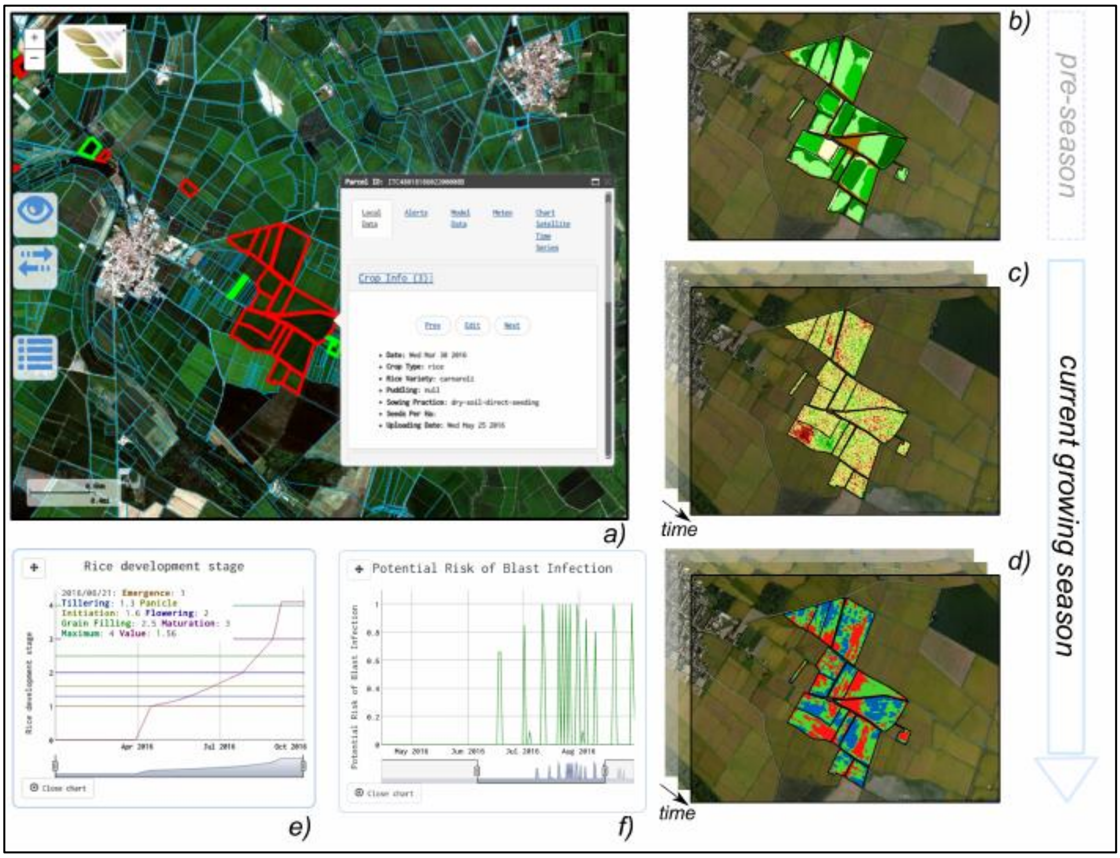


Figure 2.7: Examples of 2016 ERMES local products, as retrievable from ERMES local geoportal. a) Interface of the local geoportal, with rice fields belonging to the user highlighted (red ones correspond to fields with active alerts), and interface for visualization of information supplemented via AgriNotebook shown. b) Constant Pattern map for a farm in the Italian local study area (in the map, different colors correspond to different clusters identified in each field as a function of soil and biomass persistent patterns). Seasonal pattern maps from c) Cosmo-SkyMed (CSK) at 3 m resolution for 03/04/2016 (different colors are linked to anomalies in backscatter signal with respect to the field average), and d) RapidEye for 14/06/2016 (red, green and blue colors correspond respectively to below-average, average and above-average status). For each of its fields, the user can also visualize time series of simulated Crop Development Stage (e), and rice blast infection risk (f) (From Busetto et al., 2017).

Near real time **high resolution LAI maps** (*EP_L4*) were produced using state-of-the-art machine learning algorithms trained on radiative transfer modelling data specifically generated to characterize rice features. In particular, availability of both LANDSAT OLI/ETM+ (Operational Land Imager/Enhanced Thematic Mapper) and Sentinel 2-A imagery in 2016 allowed reconstructing a very dense temporal data set of HR LAI maps, useful to monitor crop development at field level. Anomalous drops in LAI time series can help identifying problems/damages at field level due to the effects of plant diseases or other factors (Figure 2.8). Sentinel/OLI data are instead less useful for precision agriculture applications due to the typically small size of paddy rice fields, which makes the statistical analysis of intra-parcel spatial variability difficult in many cases.

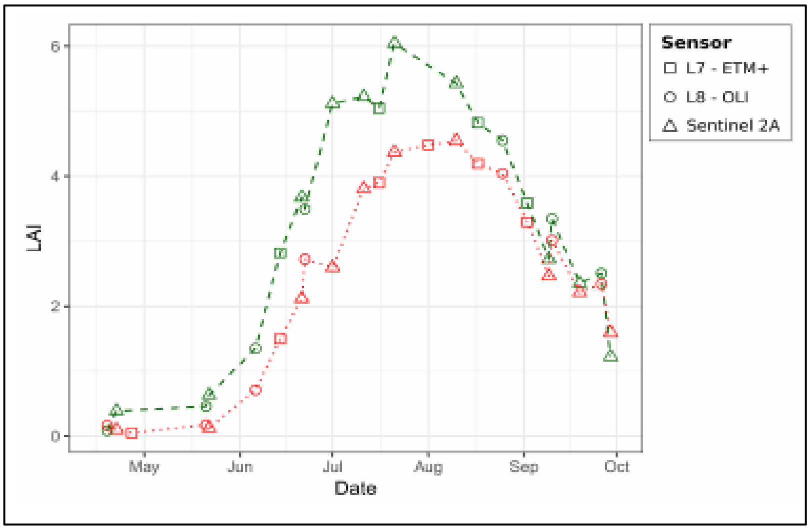


Figure 2.8: Average LAI time series derived from Sentinel-2A and Landsat 7/8 data for two fields of the Italian local study area with the same sowing date and rice variety. The red line corresponds to a field damaged by an incorrect herbicide treatment.

Finally, in addition to EO data, local crop modelling results provide real time and forecasted information on **rice development stage** for each field (Figure 2.7e - *EI_L1*), allowing farmers to properly plan fertilization/phytosanitary treatments as a function of simulated impending phenological stage. The same information can be used for triggering mail alerts when development stage approached 1.3 (tillering) and 1.6 (panicle initiation), which correspond to the **best periods for top-dressing nitrogen fertilization**. In addition, information on risk for rice blast infection Figure 2.7f - *EI_L3*) based on local weather data (and therefore more accurate than their “regional” counterpart) may provide support for rational application of pesticides.

Since agro-chemicals treatments are currently usually scheduled on fixed calendar dates, a more ecologically (and economically) sustainable farm management can be reached exploiting this information. This is particularly true if taking into account climate-change issues, which are often out-pacing the use of agro-practices based on tradition or business-as-usual scenarios. It is for example worth mentioning that, in the three years of the ERMES project, Europe faced anomalous and extreme condition in terms of temperature, rainfall and humidity, the most evident of which was the temperature anomaly recorded in July 2015 that was the hottest period since meteorological measurements.

As in the case of the regional service, ERMES local products were also used as the building blocks for more advanced analyses and applications. A typical example is the use of the constant/seasonal pattern maps as a support for VRT treatments. Starting from intra-field variability maps, farmers in the Italian and Greek study areas, with the assistance of companies selling machinery and of ERMES personnel acting as “agro-consultant”, were able to derive accurate prescription maps for nitrogen fertilization, as shown in Figure 2.9 (a, b) (pre-sowing conditions) and (c, d) (cover fertilization).

Full-field experiments conducted in 2014, 2015 and 2016 demonstrated that such prescription maps allowed a better management of field variability, leading to higher yield homogeneity and lower fertilization costs as compared to a standard fertilization scheme. For example, Figure 2.9 highlights the effects of adopting VRT fertilization techniques, comparing the intra-field yield variability observed in 2014 (No VRT, Figure 2.9 e), 2015 (first year of VRT adoption, Figure 2.9 f) and 2016 (second year of VRT adoption, Figure 2.9 g). Although the difference in maximum yield was also due to more favorable weather conditions, the 2015 and 2016 maps are clearly more homogeneous and a strong increase in minimum yield can be observed. Finally, field variability maps were also used by Cattolica Assicurazioni consultants to support activities related to the assessment of crop damage (e.g., hail damage).

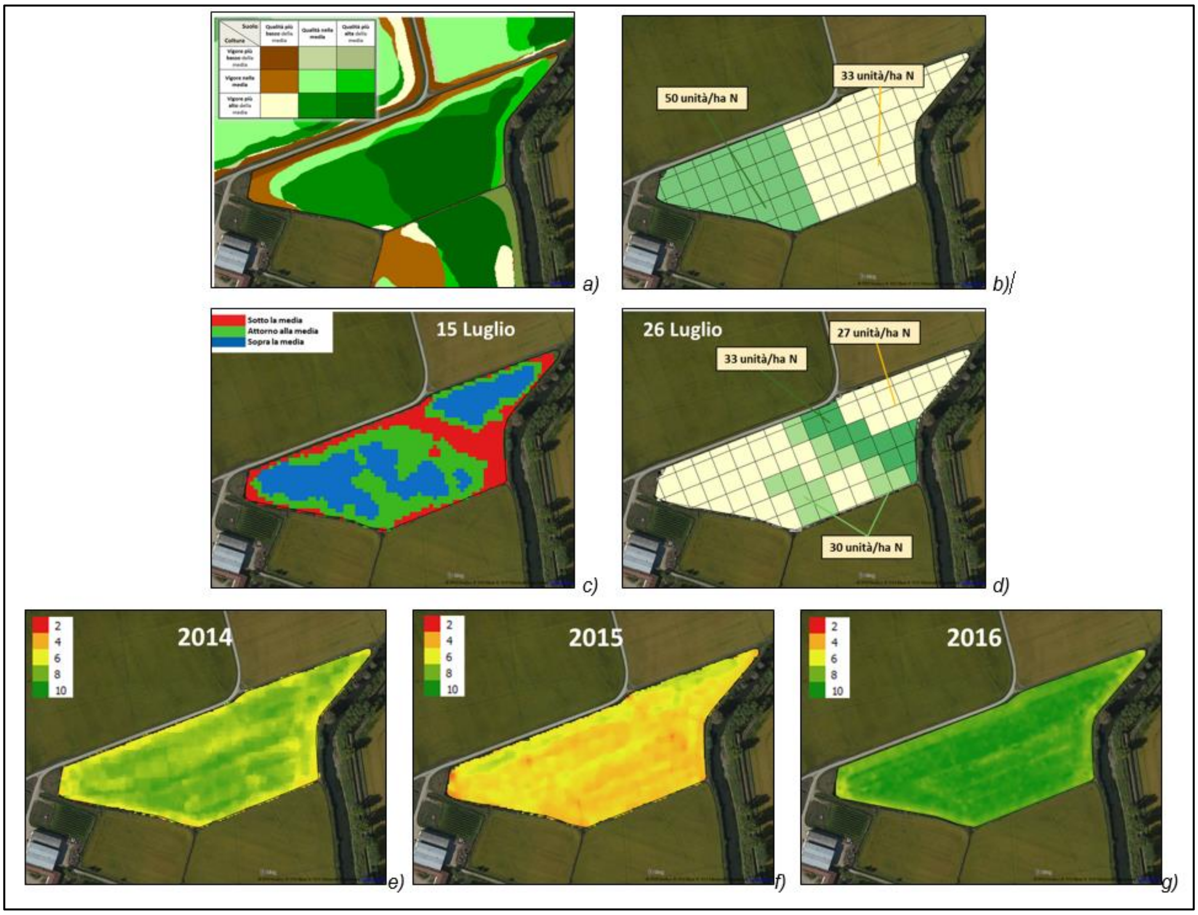


Figure 2.9: Examples of a) ERMES constant pattern map, b) pre-sowing prescription maps to compensate overall soil differences, c) seasonal patterns (red colors correspond to lower crop vigour), d) full cover fertilization prescription map. Yield maps from harvester for: e) 2014 (no VRT), f) 2015 (first year) and 2016 (second year) experimentation.

3 Project impact, dissemination activities and perspectives for future exploitation

The objective of the ERMES project was to create an integrated system allowing to **exploit information from different sources and different levels** of spatial and temporal granularity (Earth Observation data, crop modelling, user-collected data), to p**rovide information useful for various crop monitoring/management applications**. This required tackling several problems, connected mostly to *i)* the development of algorithms able to derive useful information from the available data sources in a fast, automated and reliable way, and *ii)* the creation of suitable tools for disseminating that information to different stakeholders in an easy-to understand format and exploiting user-friendly web interfaces. The ERMES agro-monitoring system, thanks to its modularity, allows coping well with all these issues, providing a huge amount of data products and NRT information concerning rice cultivations unprecedented within a single, unified platform. The system was operationally tested during 2015 and 2016, demonstrating its robustness and flexibility in coping with unforeseen situations thanks to the redundant and complementary nature of its data sources and products.

During its lifespan, the ERMES project demonstrated the **maturity of EO, crop modelling and ITC solutions** in providing cost-effective solutions for developing innovative monitoring systems for the rice (and more in general, agricultural) sector. Starting from scratch (though exploiting previous experience of partners), the ERMES consortium was able to develop, a **complex, operational and deeply integrated rice monitoring system**. This allowed generating NRT information from regional to local scale **considered very useful by many different actors and end users** involved in ERMES activities in various capacities.

At the end of the project, the following key considerations can be drawn on ERMES achievements and impact:

1. The usefulness of ERMES services was demonstrated by the **strong involvement of different ERMES end-users and stakeholders**, including public authorities, insurance/reinsurance companies, and single farmers or consortia. ERMES services were used both as a platform to perform expert-based crop monitoring, and as the basis for producing customized added-value information, such as biotic risk and yield forecast bulletins, NRT flood maps, or within filed variability maps fundamental to create prescription maps for VRT Nitrogen fertilization. This kind of **high-level exploitation** revealed the maturity of integrated EO and crop-modelling systems, strengthened by in-situ user-collected data, as a support for agro-monitoring at different scales.
2. Several stakeholders manifested **interest in providing funding** to maintain some of the regional service functionalities, in particular for what concerns biotic risk simulation and alerting. On the local side, strong interest and positive feedback was obtained concerning the ERMES products related to **NRT mapping of intra-field variability and phenological stage estimation**. These products could be (and were already) used for improving management practices (e.g., Nitrogen fertilization), allowing reducing costs (amount of agrochemical adopted), improving yield (field homogenisation) and lowering the environmental impact of cultivations.
3. The aforementioned considerations suggest that **the market is starting to be mature** for the development of services for the agriculture sector supported by underpinning science, if information

is conveyed to interested stakeholders in a timely and user-friendly way. On the local side, the adoption of monitoring systems similar to ERMES could also be facilitated by the reform of the EU Common Agricultural Policy, which re-routes a significant portion of EU subsidies for agriculture towards sustaining innovative and more environmentally sustainable agricultural practices. These changes are targeting to lead the European agricultural sector towards production of high quality and environmentally friendly goods, and will undoubtedly aid the adoption of innovative crop management systems.

4. Finally, although ERMES was mainly focused on European agriculture (and specifically on rice), its methods and technologies can be also exploited for other crops and in other areas of the world. In particular, activities conducted in the West Africa study areas demonstrated that the ERMES regional services could be proposed as a **country-level monitoring system in developing countries**, where accurate information on crop status and dynamics are even more needed due to food-security issues.

The remainder of this section provides further insights on the aforementioned key points, by *i)* summarizing the activities conducted to demonstrate ERMES potential impact (products and tools) towards involved end-users (§ *3.1*), *ii)* describing the dissemination activities conducted to present the project and promote its results towards the scientific community, stakeholders and future end-users (§ *3.2*), and *iii)* providing insights concerning the potential future exploitation of ERMES services (§ *3.3*).

3.1 ERMES impact: achievements and end-users feedback

The ERMES project was planned and executed to allow demonstrating and testing the developed services and tools during two complete rice seasons (2015-2016) by actively working with end users.

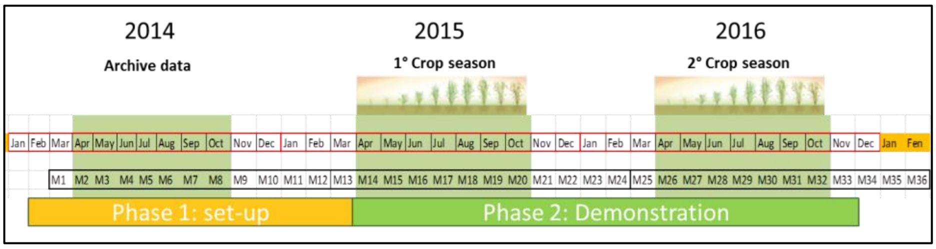


Figure 3.1: Overview of the ERMES implementation phases: Service set-up and Service Demonstration

The first year of demonstration activities (2015 rice season) allowed testing the processing chains and tools developed in the "set-up" phase to generate the main operative ERMES products and disseminate them to the public. During autumn 2015 and spring 2016, the complete portfolio of ERMES regional and local products was promoted and showcased to active potentially new end users, in an effort to better explain generated information usefulness and expand the user base for the 2016 demonstration season. To this aim, ERMES products were disseminated using the ERMES geoportals, and directly presented to users and stakeholders during specific meetings and public events. These dissemination events showed a generally positive appreciation of the proposed products and services, provided useful feedback for their improvement and allowed in some cases to involve new users in the project.

Activities of the **second year of ERMES demonstration** (rice season 2016) strongly benefited from 2015 experience, and were very satisfactory. In particular, improved automation of processing chains for products generation, their transformation into inputs useful for the WARM model and model running allowed to produce in Near Real Time all the foreseen Remote Sensing based products, and to perform semi-automatically daily runs of the WARM model. Problems observed during the first year of demonstration were solved during the months preceding the beginning of the 2016 rice season, resulting in more reliable results. The products and services supplied to ERMES users in the second year were therefore characterized by greater accuracy, as demonstrated by validation results, and by a really good timeliness. Moreover, 2016 demonstration activities were **extended also to the two ERMES extra-European study areas**, namely the Senegal River Valley and The Gambia, for which some of the ERMES products related to the RRS were generated and delivered to the identified end users (Ministry of Agriculture of Gambia; AfricaRice, IFAD). Although further interaction with West African public institutions would be required to guarantee the uptake of the proposed technological solutions, ERMES demonstration activities were received very positively, and allowed to raise interest on the potentiality offered by EO based solution for crop identification and monitoring.

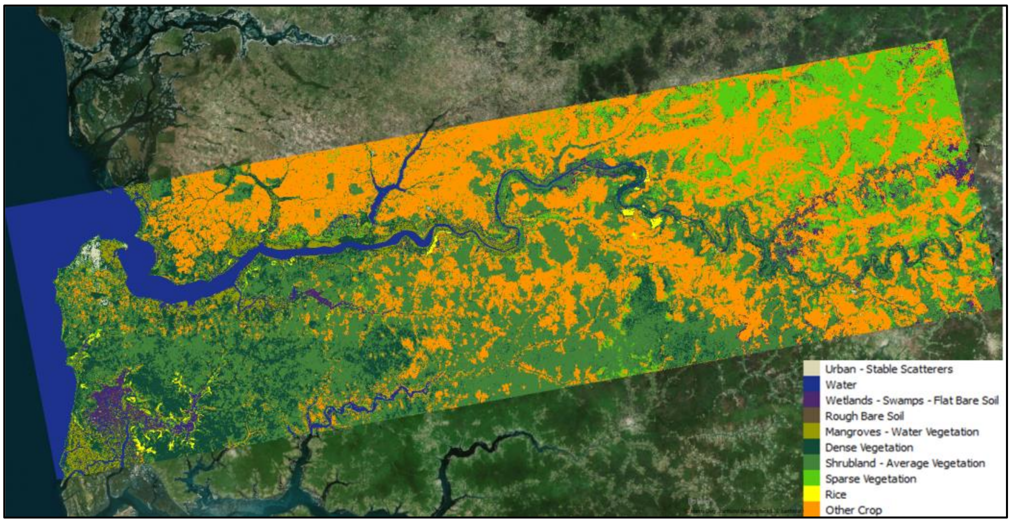


Figure 3.2: Land Cover Map obtained for the Gambia study area

A very important demonstration of the high potential of ERMES services for real-world exploitation is given by the fact that the full operational level achieved allowed both regional and local end users to directly use some of the ERMES products as supplementary information sources for their activities. At regional level, dedicated customizations of ERMES modelling outputs were provided to the plant-health service of the Lombardy Region, allowing them to produce daily bulletins of current and forecasted rice blast infection risk, aggregated at municipality scale.

Those bulletins were automatically sent to technicians of the organization, and deployed on a dedicated section of its website (*goo.gl/IszwQ4*, Figure 3.3b). The same information was considered useful for the private sector. Società Cattolica Assicurazioni, one of the main Italian insurances company, provided its clients with risk information derived from RRS by SMS messages, as a support for rational use of agrochemicals and reduction of the risk of yield losses. Summarized spatial datasets derived from standard ERMES products were also used by the MARS service of the European Commission as support information for the production of their 2016 crop monitoring bulletins (*goo.gl/j9MvYx*, Figure 3.3a). Finally, prototypes of a rice yield forecast bulletin that exploit modelling output was realized for the three countries and disseminated in late July and early September (goo.gl/fRZ3ci, Figure 3.3c).

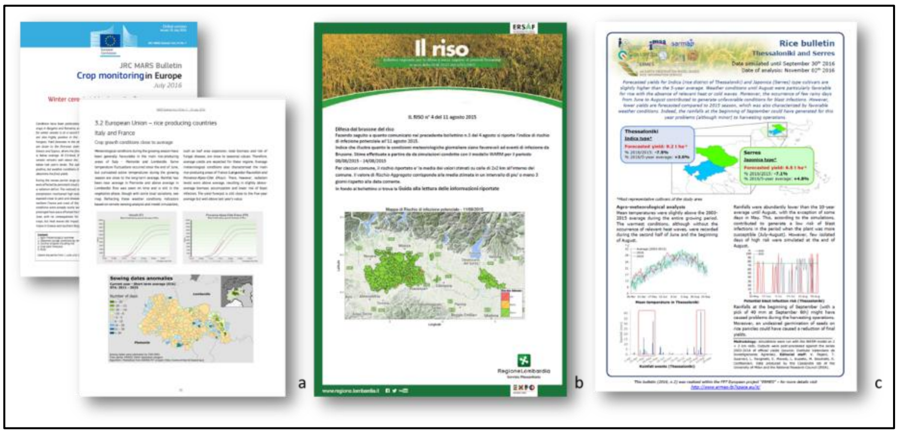


Figure 3.3: Example of ERMES information exploited in agro-monitoring bulletin in 2016: at European level JRC MARS bulletin (a), at regional level in Italy by ERSAF (b) and for Greece (c).

For what concerns LRS products, these were operationally generated and provided to interested farmers. As in the case of the regional service, those products were also used as the building blocks for more advanced analyses and applications. For example, two Italian farmers exploited the Constant and Seasonal pattern products in their operational workflows as geo-spatial information to be used as inputs for the implementation of "precision farming" agro-practices, allowing a more rational and sustainable management of fertilizers. A similar exploitation schema was also followed in Greece, thanks to the effort of ERMES partner DEMETER (acting as "super user") and end user Christos Plastiras (Farmer and service provider). In this case, a preliminary cost benefit analysis allowed also quantifying in the potential reduction of costs for Nitrogen fertilization achievable by adopting ERMES-like services (see § 3.3.3.2 for details).

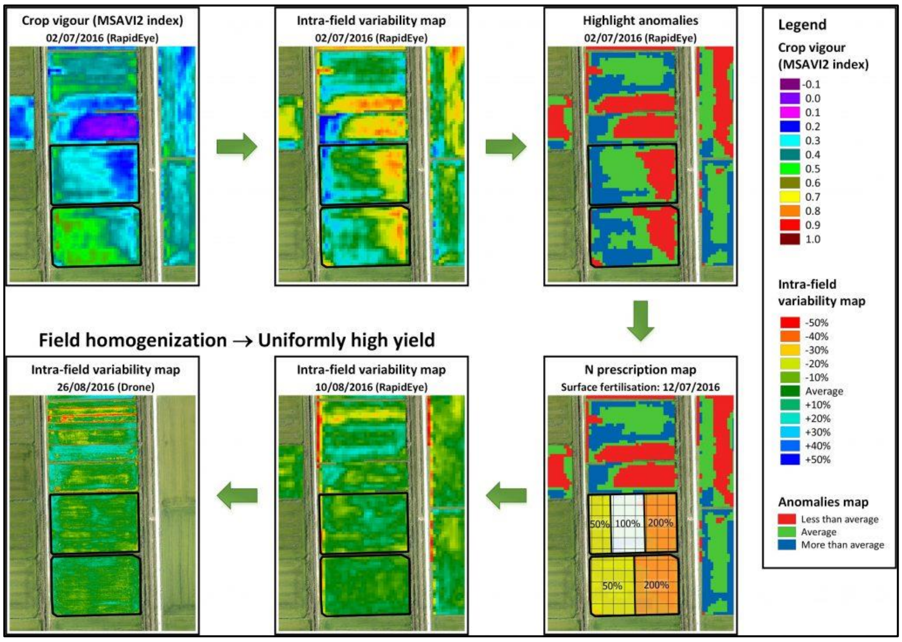


Figure 3.4: Application of variable rate fertilization in two rice paddies within the Greek experimentation station.

The aforementioned **examples of high-level exploitation** demonstrate the usefulness of the information provided and the degree of operativity of the developed services - which were able to produce information of interest in NRT and without significant interruptions -, and allowed to assess the possible benefit and potential market interest of the proposed solutions.

3.2 Dissemination of ERMES results

Dissemination activities were devoted to present ERMES concepts and results towards *i)* potential end users and stakeholders, *ii)* the scientific community and *iii)* the "broader" agricultural sector and the general public.

- Dissemination and promotion of ERMES achievements **towards end-users and stakeholders** was performed during several meetings, often organized by ERMES partners, taking also advantage of the functionalities of the ERMES regional geoportal to demonstrate the main products. In particular, results were illustrated during **ERMES open days** conducted in the three ERMES European countries in 2015 and 2016. The showcased products were generally positively appreciated, and interest in their future use was reported by several end users. This was made possible by the **strong integration level and operationality** reached by the ERMES services, thanks to the effort dedicated by partners in developing NRT processing chains and user-friendly dissemination tools. Dissemination and **networking activities with extra-European stakeholders and end users** were also conducted, mainly in the context of interactions with ERMES extra-European end users (AfricaRice and the International Fund for Agricultural Development - IFAD), international meetings attended by sarmap personnel, and international conferences and workshops.
- **ERMES scientific achievements** were presented in *scientific publications* in journals and as presentations or posters for scientific conferences. At the end of the project lifetime, ERMES-related scientific activities resulted in **18 papers** already published or approved for publication on **peer-reviewed journals**, **14 Proceedings** and **10 Abstracts** of scientific conferences. One additional paper is currently under submission as invited paper for a special issue on crop modelling for the "Agricultural Systems" journal, while five are in various stages of writing. In particular, a manuscript co-authored by all partners of the Consortium and describing the ERMES crop monitoring system as a whole was recently accepted for publication on the Special Issue on Precision Agriculture of the IEEE *Journal on Specific Topics in Applied Remote Sensing* (JSTARS)[19].
- **"Broader" dissemination towards the agricultural sector and the general public** was achieved exploiting the ERMES website (*www.ermes-fp7space.eu*), which was continuously updated in its contents, and by issuing specific newsletters to highlight the main achievements of the project. Several *brochures, leaflets and dissemination materials* were produced to facilitate dissemination of the main results and achievements, and used during meetings to facilitate interaction. ERMES activities were also presented to new audiences during events dedicated to the agro-sector, and through *press articles* published on important magazines focused on agriculture and rice. **Several initiatives of scientific divulgation** were also performed during the project lifetime. In particular, it is important to mention the ones connected with the EXPO "Feeding the Planet Energy for Life" event held in Milan in 2015.

[19] Busetto et al. (2017) Downstream services for rice crop monitoring in europe: from regional to local scale. Accepted for publication on IEEE JSTARS.

3.2.1 Interaction with end users: collection of feedback on services usefulness

A fundamental objective of ERMES dissemination activities was the evaluation of users' satisfaction and the collection of their feedback. A *core group of regional and local end-users* was therefore identified already at the proposal stage, and progressively expanded during the project lifespan.

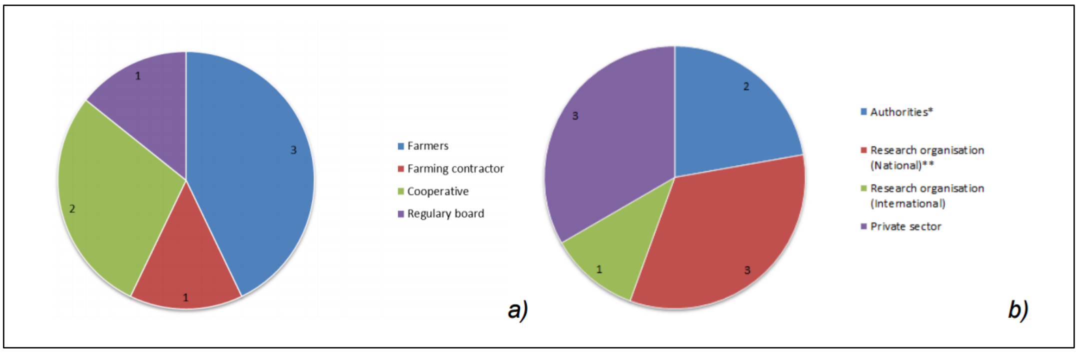


Figure 3.5: Categorization of users involved in the project for the local (a) and regional (b) ERMES Rice Service.

The assessment of users' satisfaction was conducted in two rounds, after the conclusion of the 2015 and 2016 rice growing seasons, and in particular during the ERMES final Open Days (For further info, see: *Spain*; *Greece*, *Italy*). The main findings of these user evaluation activities can be briefly summarized as follows.

1. Evaluation and satisfaction level about ERMES services **varied among users and countries**, due to **different needs** (e.g. monitor rice blast on large areas, apply fertilizers or herbicide at the right phenological phase, looking for damaged rice), **usual workflows** (familiarity with spatial information or not) and **spending capacity** (e.g. willingness to invest in new technology, especially for the farmers). Nonetheless, the obtained feedback about the demonstrated services and products was very positive at both local (farmers, agriculture cooperatives) and regional (trade companies, insurances, public authorities) level in all the three countries.
2. Interaction with users **revealed the need for further customization of the developed services and products, as well as of consultancy-like activities and expert analysis of the provided information data to achieve a good level of user engagement**. The consortium faced therefore extra-work in providing customized solutions (e.g. to CRDO, IPLA, JRC) or products (e.g., to IPLA, PHS) and analyses (e.g., to farmers to allow them to perform VRT precision farming experiments). This has to be kept in mind in the sake of future exploitation of ERMES services.
3. Focusing on the different target groups of ERMES services, the following considerations emerged:

- **Farmers** demonstrated a very strong interest for the ERMES Seasonal Pattern maps related to within field variability of plant status provided during the cropping season. Besides the maps provided by ERMES Consortium, this kind of service is not currently operationally available in any of the three European study areas, although some farmers are seemingly ready to use this type of information to aid the use of VRT techniques or, at least, to monitor their fields. Farmers highlighted however the need for specialists able to provide *i)* assistance in handling of spatial data and *ii)* technical support for proper exploitation of the services (e.g., to translate variability maps in fertilization prescription maps). Farmers from all areas reported to be willing to pay for the services, and underlined that the service costs should be shared by a large group of farmers to make it cost-effective. These findings are very important in the framework of future exploitation of local scale ERMES-like services (See also § 3.3).

- **Private companies** (insurance sector and providers of agro-consulting services) working with farmers reported that ERMES services could allow them to introduce supplementary service lines (e.g., provision of monitoring bulletins and added-value agro-consulting information to farmers); this aspect was considered of extreme importance to emerge on the market as a "more innovative" (i.e. trustable) company, thus providing them a competitive advantage.
- **Public authorities** needs and interest depends on their scale of work (e.g., regional/district level in Italy, closer to field level in Spain and Greece) and specific topic of interest (water management at broad scale is important only for Italian authorities, pest occurrence at field level and crop damages mainly for Spain and Greece ones). Only the rice blast risk assessment was of interest for authorities in all three countries – in relation also to foreseen EU directives devoted to reduce the use of pesticides. In Spain and Greece, regional authorities that work in close contact with local users showed also great interest for maps related to plant dynamics/anomalies as a tool to detect damages. Conversely to what emerged from interaction with farmers, it was harder to delineate the inclination of public authorities in investing in ERMES product and services unless within the framework of specific public budget for contract research. This is mainly due to the fact that *i)* their spending capacity depends on policies and institutional mandates subject to unforeseeable changes, *ii)* decision making is often subject to bureaucratic constraints. **A very positive feedback was obtained also form the JRC MARS unit,** who expressed their willingness to include some of the regional ERMES services to the already existing JRC monitoring programs (if they would be customized to their specific needs and procedures and extended to all European rice producing countries)

4. WEB 2.0 tools are considered fundamental to easily access geo-information generated in NRT. An **assessment of the Usability of ERMES tools**, as performed during the open days exploiting specific questionnaires, provided positive feedbacks in all the three countries.
5. Outcomes of Extra-European demonstration and satisfaction assessment in West Africa showed that there is an open market for applying mapping/monitoring services based on Sentinel imagery in developing countries, where even very basic information concerning characteristics of cropping systems is often lacking.

User satisfaction assessment activities were very useful for understanding which products are considered of value and could be promoted for ERMES services beyond the project lifespan (§ 3.3).

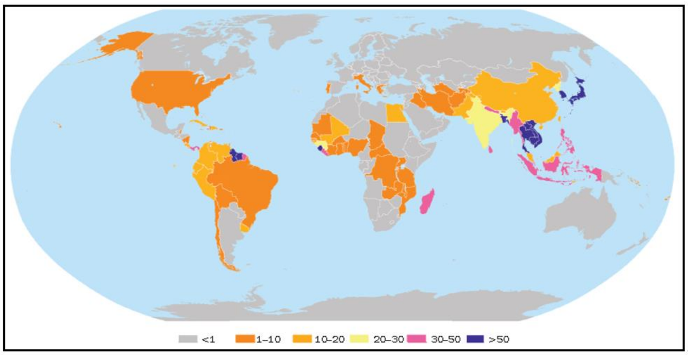
3.3 Perspectives for future exploitation

This section provides some insights on the foreseen possibilities for future exploitation and commercialization of ERMES products and services[20]. A global picture on global rice cultivation and its main challenges is first given (§ 3.3.1), followed by a brief analysis of the main actors and stakeholders involved under different roles in the rice market in Europe (§ 3.3.2), and by a description of three services lines based on ERMES considered promising for further exploitation and commercialization (§3.3.3).

[20] For a much more exhaustive picture dissertation on this, see ERMES Deliverable 3.10

3.3.1 Rice cultivation: a global picture

Rice is one of the most important crops in the world, in terms of cultivated area, total production, and importance as a staple food (in particular in low- and lower-middle-income countries). Globally, rice cultivations cover more than **160 M ha**, with a total production estimated in 2016 estimated at about 750 M ton y^{-1}, resulting in about **494 M ton** of milled rice (AMIS 2016 – Figure 1). Rice is by far the most important crop in Asia, where it often covers more than 30% of total cultivated area. Rice is however very important also in other parts of the world. In Africa, for example, rice is the main traditional staple food in part of western Africa (Guinea, Guinea-Bissau, Liberia, Sierra Leone), where many countries are however not self-sufficient in satisfying their internal demand and the recent increase in production is still lower than the corresponding increase in **domestic consumption** (Africa Rice Center, 2007). Rice is also the most important source of calories in many Latin American countries, although it is less dominant than in Asia because of the importance of wheat and maize in regional diets. Finally, within Europe, despite total production being marginal with respect to the global one (EU-28 ~ 1% world production), rice agriculture has a long historical tradition and economic importance in Mediterranean countries. The leading European producers are Italy (50%), Spain (28%), and Greece (9%) (EU RICE ECONOMIC FACT SHEET 2015). European production is however able to satisfy only about two thirds of the internal demand leading to an annual import of about 1 million tons of milled rice.



a)

	2014	2015	2016 F	2016/2015 Change
	million tonnes, milled eq.			%
World	**494.4**	**490.1**	**494.4**	**0.9**
China (Mainland)	141.5	142.7	143.4	0.5
India	105.5	103.4	105.6	2.2
Indonesia	44.4	45.8	45.1	-1.5
Bangladesh	34.5	35.0	34.8	-0.4
Viet Nam	29.2	29.4	28.9	-1.6
Thailand	22.0	19.0	20.1	5.6
Myanmar	16.9	16.5	16.8	1.9
Philippines	12.4	11.7	12.2	4.4
Brazil	8.2	8.5	7.5	-11.6
Japan	7.8	7.6	7.7	1.2
United States	7.1	6.1	7.3	20.1
Pakistan	7.0	6.6	6.6	0.0

Countries ranked according to their position in 2014-2016 average production.
F=forecast

b)

Figure 3-6: a) Percentage of total crop area cultivated with rice (IRRI, 2010) and b) production of milled rice in 2014-2016 (AMIS 2016).

Global rice production more than tripled between 1961 and 2008, with a compound growth rate of 2.49% per year, due to both to increasing cultivated area and average rice yield. In particular, the trend in average yield has been positive in all parts of the world although the rates of growth varied by region.

Focusing on Europe, the annual EU rice production over the last years has been of about **1.8 million tons** (milled basis) over an area of approximately **450,000 ha** (about two-thirds of *Japonica* (~ 6.3 ton ha^{-1} y^{-1}) and one-third of *Indica* rice (~ 7.5 ton ha^{-1} y^{-1}). In the period 2010-2015, average European rice yield was quite stable, but cultivated area decreased of about 6% for Japonica and 28% for Indica rice (EU, 2015). This different trend testifies a clear trend of changing from Indica to Japonica rice production to face extra-European competition. Rice prices on the EU market are higher than on the world market, reaching approximately 550 € per ton of milled rice (as compared to about 325 € per ton for Asian rice). This condition, mostly related to higher production costs, limits the competitiveness of European rice producers in the global market.

Within the aforementioned context, the main global challenges for rice production are currently:

1. **Climate change** – Globally, rice is one of the crops more sensitive to climate change, mainly because of its concentration in tropical and flood-prone areas. Higher temperatures and droughts could reduce global rice yields by 12-14% by 2050. This doesn't account other effects, such as increasing yield instability, farmers being forced out of rice due to water shortages, and loss of prime rice land due to frequent flooding (IRRI, 2010);
2. **Trade restrictions** – Partly because of high trade restrictions, only 7% of global rice production is traded. This together with erratic government interventions makes rice prices relatively unstable;
3. **Production losses due to pests** – Combination of surveys, experimental, and modelling approaches have shown that 120 to 200 M ton of grain yield are lost yearly to pests in Asia (Savary et al., 2012);
4. **Fertilization** – The need for nitrogen fertilization is a major cost in rice production, typically accounting for 15% to 30% of total production costs depending upon government subsidies and labour costs.

In the European context, the following more specific challenges play an important role:

1. **Duty trade of rice**: Around 300 000 tons (30% of total EU rice imports) come as duty-free imports from countries benefiting from the EBA[21] agreement. This is driving down EU rice prices making farming activity at risk.
2. **Unbalance of rice production**: due to the fact that the rice imported is of Indica type at low cost in recent years, EU rice market switched towards more EU production of japonica rice (short/medium grain). This generates an unbalanced market situation with risks of price reduction for both rice categories.
3. **Transparency and traceability**: The new trend of importing milled-rice ready to be sold to final consumers is making the traceability of rice more complicated. For this reason, European rice producers are making pressure on the Commission for a labelling system able to certify the provenience of European rice.
4. **Rice Blast control**: Rice Blast (*Pyricularia Oryza*) is a fungus which constitutes the major constraints in rice production. The most efficient and popular chemical product for its control is the active substance tricyclazole, which was withdrawn by the European Commission in 2010 (EFSA, 2013[22]). It remained in the market with short derogation licenses of 120 days until 2016, whereas it has been banned since 2017. Although alternative products for blast control exist (e.g., Amistar), their lower effectiveness makes farmers expecting yield losses in the coming years.
5. **Nitrogen fertilization**: Especially during the vegetative phase, rice requires quite consistent inputs for mineral N, normally provided as urea. However, the peculiar irrigation techniques contribute to the low nitrogen use efficiency of rice paddies, since part of the element is lost because of denitrification and leaching, with the latter directly involved with groundwater pollution. In this context, the European Nitrates Directive (1991) is encouraging a more strict application of nitrogen. This, besides guaranteeing a better protection of the environment, could lead to rice yield reduction.

[21] *Everything but Arms* (EBA) is an initiative of the European Union under which all imports to the EU from the Least Developed Countries are duty-free and quota-free, with the exception of armaments.

[22] EFSA (2013). Reasoned opinion on the modification of the existing MRL for tricyclazole in rice European Food Safety Authority. EFSA Journal, 11(4):3198

6. **Heavy metals in grains**: Another aspect that will affect the rice market in the coming years is related with heavy metals. Indeed, European regulations are expected to further lower the admissible thresholds for heavy metals in the grain (both rough and milled).
7. **Water management**: In Italy, the new trends in water management in rice field, that is switching from traditional continuous flooding to either dry sowing and delayed flooding or – to a lesser extent – aerobic management of the rice field (e.g. periodic surface irrigation), opens up new scenarios potentially critical for the environment (Romani, 2008). In particular, four main impacts are expected in relation to this water management changes: *i)* Decline of "artificial wetlands" that host the majority of water birds in Mediterranean areas (Fasola and Ruiz, 1996), *ii)* reduction of ground water table recharge, resulting in higher irrigation requirements for other crops (Cesari de Maria et al. 2016), *iii)* Increase in nitrogen leaching in groundwater (Confalonieri et al . 2006), and *iv)* Increase in weeds competitiveness, in turn generating a higher requirements of chemicals control.

3.3.2 Rice stakeholders and value chains in Europe

3.3.2.1 Public authorities and institutions

At global / transnational level, rice prices are influenced by international fluctuations because the international trade volume is very low (< 8%), although in Europe it accounts for about 30% of the market. Moreover, rice availability is strongly related to food security issues and any unexpected shocks to demand or supply (e.g. adverse weather conditions, natural disasters, and political decisions) in one of the major exporting countries can significantly affect international prices[23]. To manage this situation international initiatives have been promoted in order to provide information to reduce price volatility (e.g., *GEOGLAM*, *AMIS*). Focusing on Europe, *the MARS Unit* of the EC Joint Research Centre, is working since the 90s on large-area agricultural monitoring activities, providing timely forecasts, early assessments, and the scientific expertise for efficient monitoring and control of agricultural production in the EU. In 2005, the MARS monitoring and forecasting system was extended to rice, with dedicated approaches, given the peculiarities of this crop.

At the EU level, rice production is controlled and supported by EU policies adopted by national governments and implemented by local authorities (e.g. Regions). The EU provides also subsidies to rice production that encourages also adoption of environmental sustainable practices, which are currently fundamental to prevent the collapse of the rice production system under the international competition.

At national/regional level, since rice production in Europe is localised in districts with specific characteristics deriving from natural wetlands/coastal areas, and has historical, cultural and economic importance, dedicated national/regional authorities for rice crop monitoring are present in some of the main European rice-producing countries. For example, considering the ERMES-involved countries, in Italy the *Ente Nazionale Risi* (ENR) is a public institution active since 1931, working on data collection, statistical analysis, market monitoring, technical support to farmers and the Agriculture Ministry, and research and experimentation. In Greece, an important role is played by the *Cereal Institute of the Hellenic Agricultural Organization* (DEMETER), the main Greek foundation specialized on cereal research. In Spain, no "centralized" institutions are present, regional authorities such as the *Instituto*

[23] This is for example what world the faced in 2008, when rumours on possible production shortages strongly inflated rice price, that passed from less than 400$/ha to more than 800 $/ha in just a few months.

Valenciano de Investigaciones Agrarias (IVIA) in Valencia and the *Institut de Recerca i Tecnologia Agroalimentaries* (IRTA), in the Ebro region are actively involved in both monitoring and research activities related to rice cultivations (Ballesteros R 1997).

3.3.2.2 Farmers and the private sector

The number of rice farms in Europe diminished dramatically in the last 25 years in all European countries. For instance, the total number of farms decreased to one-half in Italy and to one-fifth in Valencia, Spain (*http://ricepedia.org/rice-around-the-world/europe*). In the same period, the mean surface area per farm increased in rough proportion to the reduction in the number of farms (from 20 to 47 ha in Italy and from 1.9 to 4.7 in the Valencia area). The trend in the increase in average farm dimensions was accompanied by high mechanization. Despite the increase in working capacity, in relation also to predisposition to adopt innovation in mechanization, production costs are higher than in most Asian countries and in the U.S., due mostly to the high costs of inputs: water, fertilizers, agrochemicals, seeds, machinery, fuel, and labour.

The structure of the rice production chain, hence the actors in rice farming, can be depicted by analysing the main factor costs and main revenue streams related to rice farming activities[24].

For what concerns costs, Table 3-1 reports results of financial analyses conducted by the chamber of commerce of Vercelli (Camera di Commercio di Vercelli., 2013, 2017), considering four farm typologies: 1) small farms (~ 50 ha) directly managed by the owner, 2) small farms managed by external contractors, 3) medium farms (150 ha) and 4) large farms (300 ha). It highlights that the average cost per hectare is about 3 K€ and that big farms are more efficient relative to small farms. The average costs reported are also in line with other European countries as confirmed by information provided by Greek ERMES partner DEMETER (see D10.3 for details). Excluding land rental, production factors and labour impact for about 40% on rice production costs. Machinery costs impact for about 15%, with the notable exception of small farms using external contractors, for which machinery costs rise to levels as high as 30%. Table 3-1 also allows identifying the main categories of private companies acting, in different capacities, in the European rice market. Those include machinery manufacturers and resellers, seed companies, fertilizers and agro-chemicals producers, crop insurers and commodity traders. While for seeds the supply chain involves small companies, the other categories are usually dominated by international players, in particular for what concerns machinery and agro-chemicals. Some of the most important actors for the different categories are linked-to in Table 3-3.

For what concerns income, the two main revenue streams for rice farmers are rice selling to millers or wholesale dealers, and subsidies from the Common Agricultural Policy (CAP) of the EU. Concerning the former, “high value” rice varieties (e.g. carnaroli for “risotto”) can be sold for up to 490 €/ha while common rice is bought at about 265 €. On average in Europe paddy rice is paid about 300 €/ha. These prices are however subject to somehow high volatility due to several factors (See Section 1). Concerning subsidies, Table 3-2 provides a scenario of the average subsides for rice farming for the 2015-2018

[24] The Italian rice sector, being the more developed in Europe and involving more than 4000 farms, is used here as an example to analyze the characteristics of European rice farming systems and the relations with suppliers of goods and services. The cost reported are in line with other European countries as confirmed by information provided by ERMES partner DEMETER.

period. In 2015, subsidies amounted to around 880 €/ha, but were already reduced to 780 €/ha in 2017 and are expected to fall down to about 688 €/ha in 2019. Additionally, since the CAP reform of 2013, subsidies are also increasingly geared towards supporting adoption greening practices. That means that financial incentives for production are also linked to requirements in terms of environment-friendly agricultural practices: for example, with regard to water management and use of agrochemicals.

Table 3-1: Aggregated farming costs for four typologies of farms (derived from Camera di Commercio di Vercelli, 2013):

		Small (50ha)	Small* (50ha)	Medium (150ha)	Large (300 ha)
LAND	Rent	€ 32,500.00	€ 32,500.00	€ 97,500.00	€ 195,000.00
PRODUCTION FACTOR	Irrigation	€ 10,850.00	€ 10,850.00	€ 32,550.00	€ 65,100.00
	Seeds	€ 8,085.00	€ 8,085.00	€ 23,100.00	€ 45,738.00
	Fertilizer	€ 19,240.00	€ 19,240.00	€ 55,500.00	€ 109,890.00
	Crop protection	€ 13,520.00	€ 13,520.00	€ 39,000.00	€ 77,220.00
MACHINERY	Machinery rent	€ 2,055.00	€ 44,205.00	-	-
	Machinery maintenance	€ 10,300.00	€ 500.00	€ 30,200.00	€ 47,980.00
	Machinery depreciation	€ 16,793.00	€ 1,392.00	€ 49,020.00	€ 77,115.00
ENERGY	Fuels	€ 10,000.00	€ 5,000.00	€ 30,000.00	€ 60,000.00
	Electricity	€ 1,750.00	€ 1,750.00	€ 5,250.00	€ 10,500.00
INSURANCE	Insurance -	€ 1,500.00	€ 1,500.00	€ 4,500.00	€ 9,000.00
	Insurance crop	€ 4,500.00	€ 4,500.00	€ 13,500.00	€ 27,000.00
SALARIES	personnel	€ 17,400.00	€ 1,830.00	€ 36,000.00	€ 59,760.00
OTHER	Other maintenance	€ 1,250.00	€ 1,250.00	€ 3,750.00	€ 7,500.00
	Other cost	€ 17,680.00	€ 11,731.00	€ 47,225.00	€ 92,476.00
	TOTAL COST	**€ 167,423.00**	**€ 157,853.00**	**€ 467,095.00**	**€ 884,279.00**
	Total Cost per hectare	**€ 3,348.46**	**€ 3,157.06**	**€ 3,113.97**	**€ 2,947.60**
*** managed by external contractor**					

Table 3-2: scenario of CAP payment for the rice sector (derived from Camera di Commercio Vercelli, 2016)

Subsidy ca	2015	2016	2017	2018	2019
Decoupled direct aids [€/ha]	520	486	454	422	392
Greening aids[€/ha]	260	243	227	211	196
Coupled payments for rice [€/ha]	100	100	100	100	100
Total[€/ha]	**880**	**827**	**781**	**733**	**688**

Considering these two sources of income, rice farmers can therefore earn about 2800 € ha (average production of 6.5 t/ha x 300 €/ha + 880 €/ha subsidies).

Table 3-3: Examples of major private actors involved in the rice (agriculture) value chain in Europe

Category	Main players (Examples)
Seed companies	**Sapise (**http://www.sapise.it**)** **MELZI d'ERIL (**www.melzideril.it**)** **Tecnoseed (**http://www.tecnoseed.com**)** **Almosementi (**www.almosementi.eu**)** **SIS - Società Italiana Sementi (**http://www.sisonweb.com**)** **Hellenic Agriculture Organization – DEMETER (**www.elgo.gr**)**
Suppliers of pesticides	**Dow Agrosciences (**www.dowagro.com**)** **BASF (**www.basf.com**)** **BAYER (**www.bayer.com**)** **Syngenta (**www.syngenta.com**)** **DU PONT DE NEMOURS FRANCE S.A.S. (**http://www.dupontdenemours.fr**)** **NISSAN CHEMICAL INDUSTRIES LTD (**http://www.nissanchem.co.jp/eng/products/agro/index.html**)** **MITSUI CHEMICALS INC (**http://eu.mitsuichem.com/index.htm**)**
Suppliers of fertilizers	**EuroChem (**www.eurochemgroup.com**)** **Agrium (**www.Agrium.com**)** **Yara (**www.yara.com**)** **Asociación Nacional de Fabricantes de Fertilizantes (**www.anffe.com**)** **Hellagrolip SA (**www.hellagrolip.com**)**
Suppliers of precision farming machinery	**John Deer – Monosem European market leader in precision planters (**http://www.monosem.com/**,)** **Case New Holland (**https://www.caseih.com/**)** **Gruppo Maschio Gaspardo** http://www.maschio.com/ **CLAAS (**http://www.claas.cz/cl-pw-en/products/easy/precision-farming**)** **Amazone (VRT fertilization speaders) (**http://www.amazone.net/6.asp**)** **Kubota Tractor Corporation (**http://www.kubota.com)
Agricunsultancy and precision farming solutions	**SPREKTRA AGRI** http://www.spektra-agri.it/index.html **Vantage Italia - partner trimble -** http://www.vantage-italia.com/ **AGRICULTURAL SUPPORT** http://www.agriculturalsupport.it/ **Micasense Atlas (**https://www.micasense.com/atlas/**)**
Crop insurers	**Gruppo Cattolica Assicurazioni (**www.cattolica.it **)** **Assicurazioni Generali (**www.generali.it **)** **Axa (**www.axa.it **)**
Re-Insurance companies	SCOR - https://www.scor.com/
Milling industry and agro-business	**Mundi riso (**http://www.mundiriso.it/) **Unilever (**https://www.unilever.it/) **Ebro Foods (**http://www.ebrofoods.es/) **CÀMARA ARROSSERA DEL MONTSIÀ (**http://www.lacamara.es **)** **Kellogg's**

Based on the aforementioned analysis, the study of Camera di Commercio Vercelli (2013, 2016) concluded that, the current income vs. cost budget for European rice farms is generally negative (with the only exceptions of large farms), and that most farms are surviving thanks to the accumulated resources in the good years and trying to keep the expenses and salaries at a minimum. To overcome this problem, farms are therefore in the need of increasing their profits. This can be accomplished in three ways: *i)* increasing rice production, *ii)* reducing production costs and *iii)* increasing selling price. With reference to points *i)* and *ii),* the 2016 update of Vercelli Chamber of Commerce study highlights three main possible ways by which this could be accomplished for the Italian rice farming sector:

- The introduction of hybrid high-yield rice varieties;
- A more targeted use of human and financial resources;
- The introduction of new agro-techniques (e.g., similar to 'Rice-Check[25]).
- The introduction of precision farming techniques, particularly targeted to optimizing fertilization.

In this context of low margins in particular for small farms (<50 ha the majority of Italian farms), the proposed solution of adopting innovative precision farming schemes seems particularly promising because it allows both reducing production costs and reducing environmental impact, hence potentially allowing farmers to benefit from additional greening subsidies from the CAP. Precision farming is also pushed from the EU with specific founding schemes framed in the Rural Development Program (Precision agriculture and the future of farming in Europe, 2016).

With reference to point *iii)*, the only way for European farmers to increase the selling price of their product would be to compete in product quality and safety. In this framework, they could leverage the opportunity that prime-world consumers are willing to pay more for environmentally friendly products. Also in this context, introducing precision agriculture practices could therefore represent a key asset for rice farmers, since it could allow a better and more environmentally friendly management of rice fields together with the possibility to record agro-practices and hence certify the product quality.

These developments are sustained by different initiatives of the agro-industry to support/force farmers to produce in a safe and sustainable way in order to respond to consumers' requests. The SAI (Sustainable Agriculture Initiative) Platform is the more advanced example in this context. SAI is a global initiative born in 2002 for supporting the development of sustainable agriculture worldwide, which involves all food chain stakeholders (from food companies to farmers). SAI **represents the biggest global food industry initiative for sustainable agriculture**: at present, it includes around 90 members including Nestlè, Danone, Unilever, Ebro, Tesco, Coca-Cola and many others. The platform started with voluntary memberships by farmers and companies but numerous initiatives at national level are emerging thanks to it. For example, the SAIRISI (https://goo.gl/zw4Dg0) initiative, specific for the rice sector, started in Italy in February 2016. It involves actors such as Unilever, Migros, Ebro Foods (Mundi Riso), and Kellogg's in partnership with Ente Nazionale Risi (national rice research centre), with the objective of promoting sustainable rice cultivation.

3.3.3 ERMES value proposition

Although most ERMES products and tools were positively appreciated by involved end-users (*§ 3.2.1*), outcomes of dissemination and user evaluation activities and a critical analysis of the current structure of the production chain of rice activities *(§ 3.3.2*) led to the identification of two main services lines showing the highest potential for further exploitation and commercialization. These services lines are detailed in the next sections.

[25] Ricecheck is an extension program developed in the 1980s by the New South Wales Department of Primary Industries (NSW DPI) to improve productivity through improved crop management in the rice industry (Singh et al. 2005)

3.3.3.1 RRS - Historical extent-yield service at regional level

- ***OVERALL DESCRIPTION***

This service provides estimates of historical rice crop extent and yield at regional level based on advanced monitoring, mapping and modelling algorithms (PhenoRice – MAPscape-Rice – LAI inferred from operational EO product - WARM or ORYZA modelling solutions) using data provided from former and new coarse/medium resolution satellite sensors which allows reconstructing the historical time-series and secures continuity for monitoring of the on-going season.

The service exploits products from EO data processing and modelling solutions developed within the ERMES RRS. In particular, historical rice extent/phenology information derived from archive MODIS data (ERMES product EP_R2), and present/future information (at higher spatial resolution) from Sentinel-1/2 data (ERMES Product EP_R1), coupled with regional rice yield modelling solutions (ERMES Product EI_R3-4), are the key components of the system[26].

The service has the unique ability to provide standardized, reliable historical and current yield estimates at district level and/or on regular grid of about two sqkm resolution in a more accurate way than what is currently available, which is based on country level statistics or very localized and discontinuous sampling points. It also has the capability to detect actual seasonality and crop intensity (number of crop seasons per year), exploiting current season operational LAI time series (e.g. Copernicus Proba-V or MODIS) and integrate them as inputs to advanced modelling solutions able to take into account meteorological influence and abiotic and biotic risks on crop growth. This allows near real time crop monitoring, which is a topic of strong interest for food security analyses.

- ***MAIN MARKET SEGMENTS***

The aforementioned characteristics make the service of interest for two main market segments:

1. Insurance/micro-insurance sector

Insurance and reinsurance firms would clearly benefit from availability of medium resolution past and up-to-date information concerning yield and yield variability, fundamental to define payouts in the framework of the implementation of index-based insurance schemes. Nowadays, the insurance sector conducts estimations based on official records that may be appropriate at a national and, partially, at province level, but are insufficient at finer administrative levels (i.e. district and village level). Insurance companies are however strongly interested in knowing the seasonal yield potentials at sub-district level in order to better define payouts.

In this framework, at present the most promising market is in **emerging countries** (https://ccafs.cgiar.org/themes/index-based-insurance), where index-based micro-insurance schemes are considered a potentially strong market. Swiss Re (2010) estimated a potential of US$ 33 billion in premiums from a robust worldwide micro-insurance industry marketed to low-income but not destitute individuals, only a small fraction of which has been tapped by now. Agricultural micro-insurance benefits from this general development and tremendous potential exists not only for insurer revenues but also for improving the lives of many. Nevertheless, as remarked by Biener et al. (2014), to make this a reality, a

[26] See ERMES deliverables D5.6, 9.7 and 9.8 for further details on the products and their usefulness

number of additional problems in the micro-insurance market must be solved, such as financial literacy, trust in governments and outside organizations, administrative costs of product sale and delivery, and the basic availability of underlying services.

In the European context, this service is instead of lesser interest, since in many countries hail insurance is nearly the only existing type of crop insurance (JRC, 2009). As pointed out by Bielza Diaz-Caneja et al. (2008), implementation of index-based, broad-cover insurance schemes in the EU is slowed down by the fact that index-based products are better suited in homogeneous areas, where all farms have correlated yields. The heterogeneity of cultivated areas typical of many European countries may therefore strongly reduce the efficiency of index-based insurances. Additionally, practical difficulties arise from the requirement of a formal recognition by the Governmental authorities of natural disasters in the different countries, as it would have to be linked to a certain threshold for the indexes used. Finally, the need for compliance with European and international regulations could delay the development of this kind of insurance schemes[27].

2. Extra European authorities (Governments and NGOs)

Up-to-date information concerning past and current characteristics of cropping systems, as well as near real time data, allowing to identify anomalies in crop growth in the on-going season, are of strong interest for public authorities and NGOs **involved in agro-monitoring activities.** This information is particularly beneficial in emerging countries, where even basic data concerning the agricultural systems is often missing, since it could help to define mitigation strategies for food security issues also in relation to climate change scenarios.

These considerations are substantiated by the positive evaluation of end users concerning the tests carried out in Gambia and the Senegal River Valley. Further work is however required to promote adoption of these services. It is in fact worth mentioning that, generally, governmental authorities have well-established procedures and are keen to operate autonomously. This means that, although governmental authorities are open to options helping them in improving their services in cost effective ways, new external services require time to be adopted and trusted, also due to the need for technological and knowledge-transfer activities.

- ***FORESEEN SCHEME FOR FUTURE EXPLOITATION AND COMMERCIALIZATION***

The exploitation of the historical extent-yield service line is foreseen as direct service provision or as licensing of the software solution. Direct service provision is primarily meant to the **(re-)insurance sector**, where the interest is exclusively related to the information provided; licensing of the software – including know-how transfer – is primarily intended to **national authorities**, who are keen to have in-house solutions and knowledge, due in particular to the sensitive nature of the information.

[27] "*insurances have to comply with European and international regulations. If insurance was to be considered within the CAP framework, the subsidies should comply with WTO green box criteria. Subsidies to index insurance could be considered as payments (made either directly or by way of government financial participation in crop insurance schemes) for relief from natural disasters (Paragraph 8 of Annex 2 of WTO Agreement on Agriculture), because indexes are intended to reproduce yield or production risks. However, it is not clear whether an index insurance by its nature can be considered under the Green Box, given that its nature is not to compensate the actual loss of an individual, but the loss indicated by a parameter (a farmer that did not suffer from a loss could potentially benefit from compensations)* - Bielza Diaz-Caneja et al., (2008), Agricultural Insurance Schemes Executive Summary – page. 3

In South-East Asia, in the framework of the Remote sensing based Information and Insurance for Crops in emerging Economies (RIICE) initiative, International re-insurers and National primary insurers have developed a rice micro-insurance scheme. Within this scheme, a key parameter is to set the payout, which typically is derived from the analysis of historical yield data. In this context, the historical extent-yield product developed in ERMES has been already proposed by sarmap to the re-insurance companies (SwissRE, RIICE partner). A first pilot test is currently on-going in the Red River Delta region (Vietnam) for the two crops season of 2016, where Sentinel-1 based yield estimates (validated with an accuracy of 93%) and official statistics at district level are available as reference.

Conversely, West Africa is currently an open and almost untapped market for remote sensing based solutions aimed at crop/environmental monitoring activities, and the current lack of up-to-date and high quality spatial information on the characteristics of rice (and other crops systems) facilitates the interest by involved organizations. In this context, the service line could be marketed either through direct service provision, or in a licensing framework (for which an extensive work of technological transfer has to be foreseen). Thanks to relationships built during the lifespan of the ERMES project, the early adopters of this service would include the main West African rice-producing countries (e.g., Senegal, Gambia, and Mauritania). In particular, networking activities conducted between sarmap and the International Fund for Agricultural Development (IFAD) allowed posing the basis for the future establishment of an official collaboration with this international organization. In the framework of this potential future collaboration, ERMES services and products concerning regional monitoring of rice fit in particular in two already active programmes: the *Adaptation for Smallholder Agriculture Programme* (ASAP), and the *Platform for Agricultural Risk Management* (PARM) initiative.

Concerning Europe, notwithstanding the higher uncertainties for uptake, during the ERMES project Italian insurer Società Cattolica Assicurazioni demonstrated a great interest in regional based services, particularly for what concerns estimation of potential yield at sub-district level and identification of the yield gap components (information derived exclusively from modelling solutions), since yields can be reduced either by not insured factors or by insured factors (leading to compensation). Contacts are currently ongoing between UMIL, CNR-IREA and Società Cattolica Assicurazioni to further test and develop dedicated services in the next years.

Despite the recognized positive results and evaluations, (particularly from the Plant Health Service of Regione Lombardia and JRC MARS), provision of the regional service to European public authorities (e.g., governments, regional monitoring authorities, etc.), from a commercial perspective, has more uncertainty due to, on one hand, the limited dimension of the rice extent and, on the other hand authority's difficulties in economically sustain new service lines, even if they provide low cost solutions if compared to the existing work flows based on field surveys. A key finding was that the adoption of new solutions could occur only when there is a clear mandate for which the regional agency is in charge, since technicians and operators are usually not willing to substitute their on-going workflow, if not supported by political decisions. Although this barrier may hinder the commercialization of a regional rice monitoring service in the European Context, there is however still room to continue its development within research contracts[28] or projects[29] involving them. In conclusion, although there is no maturity for a short-term

[28] New contracts signed by the research group with external clients (e.g. Agency or authorities).

[29] Application to public funded research programmes potentially under the Copernicus framework and/or specific regional funds such as the ones related to agro-monitoring and environmental activities.

business exploitation in Europe in the public sector, the Services could be still kept active through dedicated public funding. This opportunity is currently being pursued by ERMES partners CNR-IREA and UMIL, in particular through contact with Italian authorities and the MARS unit of the Joint Research Centre.

Independently from the area, it is important to underline that, while the services could be initially focused on rice producing countries, their extension to other crop types (e.g., corn, wheat) is considered of paramount importance to guarantee the economical sustainability of the service line in the medium/long term.

3.3.3.2 LRS - Seasonal patterns-yield variability service at farm level – European/prime world Context

- ***OVERALL DESCRIPTION***

This service provides geo-spatial information on seasonal and multiannual within-field crop status variability at farm level to farmers/farmers' cooperatives/agro-consulting companies, in the European/first world context. Provided information is aimed at **supporting full exploitation of variable rate technologies (VRT) in farming activities to optimize agro practices**, thus allowing reducing both management costs and the environmental footprint.

More specifically, provision of the required added value information is based on the use of products derived from EO data processing chains and modelling solutions developed within the ERMES Local Rice Service. Constant Pattern maps derived from archived satellite data (ERMES Product EP_L2) and Seasonal Pattern maps derived from commercial and free of charge imagery (ERMES Product EP_L3) during the on-going season are used to identify management units for the application of Precision Agriculture practices based on the use of VRT machinery (e.g. for nitrogen fertilization). Information about phenological development stages (ERMES Product EI_L1), and possibly information on biotic risks (ERMES Product EI_L2) derived by crop modelling, are used as support information to identify the optimal period for agro practices[30]. Moreover, the efficient and user-friendly ICT tools developed during the project (AgriNotebook and Geoportal), are used to disseminate the resulting information to users, and collect from them the data required for running the modelling solutions.

The service is characterized by the following unique selling points:

- Use of specific and unique algorithms tailored to rice monitoring (applications exist for cash crop such as vineyard - http://www.terrasystem.it/en/vitimap.htm - and orchard, and wheat - *https://www.farmstar-conseil.fr/* - but not for rice);
- Use of automatized solutions integrating and processing information coming from users (smart app, local sensors), meteo station and geo-spatial data (satellite/aerial/drone);
- Use of advanced techniques for identification and delineation of areas of the field with different characteristics (i.e., soil patterns, crop status) to define GIS ready products characterizing different management zones within the field, ready to be used in VRT machinery;

[30] See ERMES deliverables D5.6 , 9.7 and 9.8 for further details on the products and their usefulness

- Expertise gained during the 3 years of the project in translating geo-spatial data into actable information/advice for farmers and/or data directly usable by VRT machinery.

Thanks to this, the service would allow its customers to make full use of advanced machinery for VRT fertilization, thus guaranteeing a higher return of the investment. In case of licensing to agri-consulting companies or machinery manufacturers (see below), the service would provide them a competitive advantage by introducing the use of earth observation technologies in the rice sector.

The service has a potential market, first of all, in rice producing countries of Europe and the first-world, where precision farming is becoming a more and more appealing practice to reduce management costs and environmental impacts, also thanks to the increasing alphabetization of farmers concerning geo-spatial data, and high-profile technological solutions for farming, and to the support by public financial framework (PAC and Rural Development Program, *https://ec.europa.eu/agriculture/rural-development-2014-2020_en*). Extension in other areas of the world could be considered after the service is well-established, based on future expansion of the precision agriculture sector.

As in the case of the regional service, it is also important to highlight that the service, currently tailored on rice, should be in the future extended to other crop types (cereals, meadows, etc.) to allow for both a larger user-base and a lower cost per hectare, since a single image could be used to provide information for different crops and for more than one potential customer.

- ***MAIN MARKET SEGMENTS***

The aforementioned characteristics make the service of great interest for three main potential market segments:

1. Big farms and farmers cooperatives

The final beneficiaries of the exploitation of this service are farmers interested in investing in innovation of agro practices (also exploiting the opportunities of new regulations for CAP subsidies) allowing them to increase competitiveness on the market by: *i)* reducing production costs, *ii)* improving product quality and traceability, and *iii)* reducing environmental impacts.

Experiments conducted during the ERMES project demonstrated in fact the usefulness of ERMES solutions for reducing production costs through a more economical use of fertilizers, and improving yield through the better management of intra-field variability. For example, in Greece, a potential reduction in production costs of about 65 €/ha (~ 83€/ha are expected when full VRT technology is adopted) through optimization of nitrogen fertilization was demonstrated. Besides, Italian demonstration proved that when VRT technologies are adopted an increase in production of about 3%, corresponding to an average increase in income of around 72 €/ha (not considering potential further reductions costs) is possible. These estimates are confirmed by other experiences of Precision Farming in rice: according to Chio (2016 - https://goo.gl/3VmYkm), a total benefit of about 170 €/ha can be achieved when a full adoption of precision farming solutions are adopted.

Since the purchase of the high-resolution Remote Sensing imagery, needed to provide the service, is usually subject to a “minimum covered area” constraint, results of ERMES cost-analysis showed that the service would not however be economically sustainable for small/medium farm owners. For example, for a medium-sized farm of 100ha, the cost of imagery alone would result in an expense of 70-150 €/ha, depending on data spatial resolution and type (satellite or drone). Potential customers of the service are therefore either large farms (e.g., about 200 - 300 hectares), or groups/cooperatives of farmers willing to share the costs of the service to make it more beneficial.

2. Agro-consultancy companies

Interaction with farmers highlighted the need for technical support for a proper exploitation of the information contained in ERMES field variability maps (Constant and Seasonal patterns). Stand-alone provision of the service without a complementing agro-consultancy activity could therefore result in a low customer satisfaction. This agro-consultancy activity could be provided either as a component of the service itself ("Internalization"), which would require integrating the Consortium team with additional competences in agronomy and agri-consulting, or by an external company.

This opens up opportunities for two scenarios of collaboration between ERMES consortium and agro consultants for commercialization of the service:

- development of partnerships between the ERMES consortium and agro-consultancy firms;
- "licensing" of the service to agro-consultancy firms. This would be achieved by selling the ERMES field variability maps and modelling results data to the aforementioned companies, on a per-year and per-hectare basis.

3. VRT machinery manufacturers and service contractors

The full exploitation of advanced agricultural machinery is often hampered by the lack of properly analyzed and high-quality geo-spatial information required to "guide" the application of practices based on VRT management. VRT machinery manufacturers are therefore interested in added-value spatial information allowing to improve the usefulness and ease of use of their products, thus allowing them to: i) increase the market penetration of their products, and ii) define new service lines based on VRT, also including agro-consulting. For example, Trimble acquired Agri-Trend - http://www.agritrend.com/ - in 2015 to provide turnkey solutions for rational (economical) farm management. It is important also to mention that not all farms are equipped with VRT machineries, and that, quite often the small ones (30-50 ha) are directly managed by service contractors. This agro-business category can be therefore interested in the acquisition of EO-based geo-spatial information to provide requested VRT advance service to the farm.

As in the case of agri-consultancy, this opens up opportunities for commercialization of the Seasonal patterns-yield variability service through the licensing of ERMES field variability maps and modelling results data to the aforementioned companies, on a per-year and per-hectare basis.

- ***FORESEEN SCHEME FOR FUTURE EXPLOITATION AND COMMERCIALIZATION***

The exploitation of the Seasonal patterns-yield variability service line is foreseen as direct service provision of added value geo-products or as licensing of the software solution, depending on the market segment[31].

[31] Concerning the former, the Cassandra Lab of the University of Milan – agronomists and modelling experts in the ERMES consortium – are for example exploring the possibility of creating a University Spin-off for the provision of innovative tools for agriculture (e.g., smart apps, modelling solution services).

At present, it is however not easy to define the potential market of ERMES services for rice sector in Europe, also due to uncertainty related to international price pressure, and low margin for farming activities (see §2). Italy and Greece are the more promising initial market areas for the ERMES-LRS service, as also highlighted from the positive interest of the users during the project and open days. In particular, in Italy more than 100 rice farms exist, with a cultivated area greater than 200 ha (Camera di Commercio di Vercelli 2013), while in Greece contractors manage large number of smaller farms covering up to 700 ha (ERMES end user in Thessaloniki area). In terms of potential market in Italy the target rice extent that could be covered by the service is about 90,000 ha while DEMETER estimated that in Greece (Thessaloniki district) about 6,000 ha could be served.

Although a better definition of the business plan for service delivery, including a more exhaustive analysis of services offered by potential competitors is felt to be required to foster future exploitation of LRS, ERMES partners are already exploring several possibilities for the future uptake of the LRS service. In Italy, identified potential early adopters include entrepreneurs from the Italian group of farmers "Distretto terre della Lomellina", the largest Italian farm “Azienda Agricola Bonifiche Ferraresi S.p.A:” (*http://bonificheferraresi.it/it/home*), the “Spektra-agri s.r.l.” (software/Precision Farming solution provider associated with Trimble) and AGRICULTURAL SUPPORT (http://www.agriculturalsupport.it/),

For what concerns Greece, the Plastiras group, working in the rice sector both as direct farmer and as service contractor for other owners, thanks to the positive ERMES demonstration results has already invested in new VRT machineries (fertilization spreader of 2.5 ton capacity along with the proper tractor computer to operate the fertilization) and is proposing a multi-year collaboration with DEMETER/AUTH to further test and finalize ERMES service.

Concerning the VRT machinery manufacturers market segment, prototype products similar in concept to the ERMES “Constant/Seasonal Pattern” ones for various winter and summer crop types are being provided for evaluation purposes to an important VRT machinery manufacturer[32] whose key interest is in monitoring the on-going crop evolution in key regions in Europe (in primis East Europe) and North America.

[32] Non disclosure agreements are in effect between sarmap and the aforementioned company

References

Africa Rice Center, Overview of recent developments in the sub-Saharan African rice sector, 2017.

Ballesteros R. Rice production and research in Spain. In : Chataigner J. (ed.). Activités de recherche sur le rizen climat méditerranéen . Montpellier : CIHEAM, Cahiers Options Méditerranéennes; n. 24(2), p. 161-164, 1997.

Biener C., Eling M., Schmit J.T., Regulation in Micro-insurance Markets: Principles, Practice, and Directions for Future Development, World Development, 58, 1: 21–40, 2014.

Camera di Commercio Vercelli, Il bilancio economico dell'azienda agricola, I Quaderni No 8, 2013 - http://images.vc.camcom.it/f/studiestatistica/46/4698_CCIAAVC_1022014.pdf.

Camera di Commercio Vercelli, Il bilancio economico dell'azienda agricola, 2016 - http://images.vc.camcom.it/f/Varie/74/7446_CCIAAVC_2722017.pdf.

Cesari Sandra de Maria, Rienzner Michele, Facchi Arianna, Chiaradia Enrico Antonio, Romani Marco, Gandolfi Claudio (2016) Water balance implications of switching from continuoussubmergence to flush irrigation ina rice-growing district. Agricultural Water Management 17, 1108–119,

Chio, Agricoltura di precision; reddito a portata di mano, 39° Fiera in Campo, Vercelli, 2016 - http://www.risoitaliano.eu/customcontents/CHIO.pdf.

Confalonieri Roberto, Gusberti Davide, Bocchi Stefano, Acutis Marco (2006) The CropSyst model to simulate the N balance of rice for alternative management. Agronomy for Sustainable Development, Springer Verlag/EDP Sciences/INRA, 2006, 26 (4), pp.241-249.

EU, Rice Economic Fact Sheet, DG-AGRI, 2015.

Fasola, M., Ruiz, X.,The value of rice fields as substitutes for natural wetlands for waterbirds in the mediterranean region. Waterbirds 19, 122–128. doi:10.2307/1521955, 1996.

IRRI, Rice in the Global Economy, Strategic Research and Policy Issues for Food Security, 2010.

JRC, Risk Management and Agricultural Insurance Schemes in Europe, EUR 23943, 2009.

Precision agriculture and the future of farming in Europe, Scientific Foresight Study, 2016 - http://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf

Romani, M., Tecnica colturale. Bayer CropScience, Milano, 2008 - URL: http://www.colturaecultura.it/content/tecnicacolturale-3.

Savary Serge, Ficke Andrea, Aubertot Jean-Noël and Hollier Clayton (2012) Crop losses due to diseases and their implications for global food production losses and foodsecurity, Food Security, 2012.

Swiss Re, Micro-insurance – Risk protection for 4 billion people, Sigma No 6/2010, Zurich, 2010.