Agris on-line Papers in Economics and Informatics

Volume VI Number 4, 2014

Supporting a Regional Agricultural Sector with Geo & Mainstream ICT – the Case Study of Space4Agri Project

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Abstract

Agriculture is a global issue nowadays. At the European level, it is a sector, in which we are investing many resources. In particular, the Agri-Food sector plays a central role in the policies of the European Commission and the Horizon 2020 research and innovation program, as well as being the main theme of Expo 2015 that will be held in Milan, Lombardy. In the Lombardy region, the farmers represent 2% of the entire population, cultivating about 80% of the agricultural land. Increasing needs to develop a common body of knowledge shared at the regional and national level so as to make it possible to effectively monitor cropping systems, water stress and impacts of climate changes affecting more frequently the territory, are becoming more and more urgent. In this context, the project Space4Agri (S4A) intends to support the regional and local needs in terms of management of the agriculture sector, by designing and developing an information and knowledge based platform for managing geospatial and mainstream information by making it accessible over the Internet by standard communication technologies (Geo&Mainstream ICT). This platform has been designed to allow data workflows integrating i) spatial data and observations, ii) non-spatial information available from existing agronomic databases, iii) data collected in the field by farmers, agronomists and volunteers using mobile applications, iv) data collected by unmanned aerial sensors, and/or data produced by researchers as a result of applying scientific analysis on high quality remote sensing data. Foreseen results of the Space4Agri project and from other similar ongoing research activities may significantly spur the socio-economic development of Europe and create new growth opportunities for companies, public administrations, students and citizens.

Key words

Agriculture, Geo & Mainstream ICT, Space4Agri, Lombardy.

Introduction

Agriculture is a global issue nowadays. Two principal factors are influencing the agricultural sector; one is an economist's view that agriculture is a key pro-poor strategy for economic growth (Batchelor et al., 2014, Charvat et al., 2014a). The second is a concern for food security, based on the recognition that natural resources are limited, farm sizes are getting smaller, populations are increasing, and that climate change and water scarcity threaten the security of basic food production (Batchelor et al., 2014). There is broad agreement that agricultural productivity needs to improve. The introduction of modern technologies to improve crop yield, provide information to enable better in-field management decisions, reduce chemical and fertilizer costs through more efficient application, permit more accurate farm records, increase profit margin and reduce pollution. In other words, farm with precision to optimize inputs and outputs. Even though technology has the potential to help alleviate the problem facing future generations, an integrated approach is needed to promote its use among farmers (Seelan et al., 2003). The ways in which agriculture should be developed remain hotly debated (Batchelor et al., 2014). At the European level, it is a sector, in which we are investing many resources. In particular, the Agri-Food sector plays a central role in the policies of the European Commission and the Horizon 2020 research and innovation program, as well as being the main theme of Expo 2015 - Feeding the planet energy for life, which will be held in Milan, Lombardy. The Lombardy region is Italy's leading agricultural

area; the farmers represent 2% of the entire population, cultivating about 80% of the agricultural land (Acutis et al., 2014). Modern agriculture has a major impact on the environment (Charvat et al., 2014a). Farms and pastures can cause erosions, desertification, chemical pollution and water shortages, these risks need to be monitored and managed in an effective and efficient way (Lackóová et al., 2013). One way for an improved sustainable agriculture is the application of geoinformatics. Agro-geoinformatics, a branch of geoinformatics, is critical for agricultural sustainability, food security, environmental research, bioenergy, natural resource conservation, land use management, carbon accounting, global climate change, health research, agricultural industry, commodity trading, economy research, education, agricultural decision-making and policy formulation. Agro-geoinformatics, is the science and technology about handling digital agro-geoinformation, such as collecting, processing, storing, archiving, preservation, retrieving, exploring, transmitting, accessing, visualizing, analysing, synthesizing, presenting, and disseminating agro-geoinformation (Han et al., 2012). Agro-geoinformation, can play a key role in the agricultural decision-making and policy formulation process. Recent advances in geoinformatics have created new opportunities to apply agro-geoinformation for agricultural management, monitoring, and planning (Kaivosoja et al., 2014). Geospatial irrigation data that is detailed, comprehensive, consistent, and timely is needed to support studies tying agricultural land use change to aquifer water use and other factors (Brown et al., 2014).

Within this frame, the Space4Agri (S4A) project aims at developing innovative methodologies for the integration of earth observations into monitoring activities of the agricultural sector in Lombardy (http://space4agri.irea.cnr.it/it). The objective of S4A is to answer the needs from a regional and national level for the agro-food sector to support in an efficient and effective way the planning and management of cropping systems, providing information on water stress and impacts of changing climate affecting more frequently the territory. In this context, the project intends to design and develop an information knowledge platform for managing geospatial and mainstream information based on standard communication technologies (Geo & Mainstream ICT). The S4A project consists of seven work packages (WP): WP1, examining the state of art of the user and system needs. WP2, WP3, and WP4 are the core of the project covering the three main technological and scientific areas SPACE, AERO and IN-SITU, respectively. The first focuses on the data analysis performed on remote sensing, (extraction of crop information data acquired by Earth Observation systems). The second aims at designing and developing software interface for flying planning and control of Unmanned Aerial Vehicles (UAV or drones), and finally the third develops a system for both acquisition of in-situ data and sharing and dissemination of all the data created relevant for the project. The interaction of these three WPs will allow integration of:

- Satellite data for monitoring of the environment and the territory (SPACE).
- Aeronautical technologies, such as a UAVs or drones, which will be more precise in monitoring and promoting the understanding of the agro dynamics at the local scale (AERO).
- Smart technologies and methodologies to capture, collect and exchange information via sensors or through reports from operators in the agricultural sector (IN-SITU).

WP 5 will test the methodologies developed within WP2, 3, and 4. WP 6 will evaluate the economic impact of these developed technologies on the Lombardy region and finally, WP7 is in charge of project's dissemination and divulgation activities.

Very few public bodies, in Italy, maintain an active SDI with a portal to make in situ data available routinely; among them meteorological data are the most common type of data published by, for example, Emilia Romagna (ARPA_EMR), Lombardy (SIAR_L, and ARPA_L), Tuscany (ARPA_T), Puglia (SIAR_P), Veneto (ARPA_V) and the Ministry of Agriculture (Ministero delle Politiche Agricole Alimentari e Forestali).

Within the S4A project, WP4 has the objective of developing smart technologies to validate and calibrate products derived from satellite data or acquisitions by drones and or to support the collection of in-situ observations regarding crop status and development as well as alert situations in Lombardy. This information is useful in the ordinary management of agriculture, and in case of alert resulting from stress conditions or diseases of crops. The data will come

from in-situ sensors (such as infrastructure of agro-meteorological stations), or will be collected through special applications (App), the so-called „human sensors“, i.e. operators in the field. Among these operators, in addition to farmers, volunteer users may also be involved, as individual citizens or students cooperating in the project. According to the latest experiences of citizen science, nowadays spread globally, many volunteers actively contribute to scientific research. Furthermore, data collection by citizens was reported with a higher frequency comparing to data collected by public bodies (Charvat et al., 2014b).

The present article will describe the results achieved so far in building the S4A information and knowledge platform supporting the following objectives of IN-SITU (WP4):

1. To design and implement a Spatial Data Infrastructure (SDI) for the management and sharing of images and products obtained from the processing of remotely sensed data. Additionally, measurements from the sensors, data from existing databases, and agronomic data from in-situ observations acquired by the actors of the agricultural world using smart technologies developed within the project itself.
2. To provide information specific to the user profile (public, administration) and location (farmer) on regional level based on analysis performed on data collected and managed by S4A SDI.

Materials and methods

General Uses Cases of the Space4Agri information and knowledge platform

This section gives an overview of the three use cases based on experts' knowledge of the domain that have been a foundation for the design and implementation of the S4A information and knowledge platform. The use cases represent the roles of users and the flow of data starting from acquisition by meteorological stations, sensors on satellites or drones, and experts in the field, to further processing to yield new valuable information, and dissemination by communication channels to targeted stakeholders. The three proposed use cases have been modelled and are described in the following text.

Use case 1. Distribution of authoritative agro meteo information to target users

Figure 1 schematically represents the workflow of how data from heterogeneous sources are collected, processed, and transformed for allowing the regional operator and the decision maker, to efficiently visualize and analyze them in order to provide end users (the public and farmers), with synthetic relevant information on ongoing agro-meteo and crop conditions in the form of bulletins. The dissemination channel must select and send the personalized information using the most suitable means (emails, web portal, and/or sms) that is relevant to each target user. The workflow is assembled by a starting phase of data collection by different sources as meteorological stations, satellites, and in-situ by experts and farmers through smart applications installed on their mobile devices. This information is integrated into SDI and processed by experienced researchers/analysts. The outputs of the analysis is turned into knowledge by experts and provided to the decision makers who may exploit it for taking decisions on the policies for the agro sector, and may identify and communicate personalized relevant information to the stakeholders, the public and farmers.

The use case fosters the application of Smart technologies for both collecting in-situ observations (qualitative and quantitative) performed by experienced operators using mobile devices and publishing them in real time on the Internet; it also considers disseminating personalized information to stakeholders based on their interests, type of crops they cultivate, and context, region where their estate is located and current season. Remote observations can be used for the identification of anomalies of crop conditions due, for example, to abiotic and biotic factors (Hatfield, Pinter, 1993; Qin, Zhang, 2005; Bhattacharya, Chattopadhyay, 2013). Satellite data can be analysed in conjunction with field observations and data acquired by meteorological station networks to produce additional spatially distributed information on crop development (crop phenology), crop status and, with the support of crop growth models, yield forecast (Nouvellon et al., 2001; Doraiswamy et al., 2004). The final goal of this use case is the provision of the relevant personalized information that is currently under-utilized or not publicly available to farmers and the public through newsletters, bulletins or other means of communication and practices.

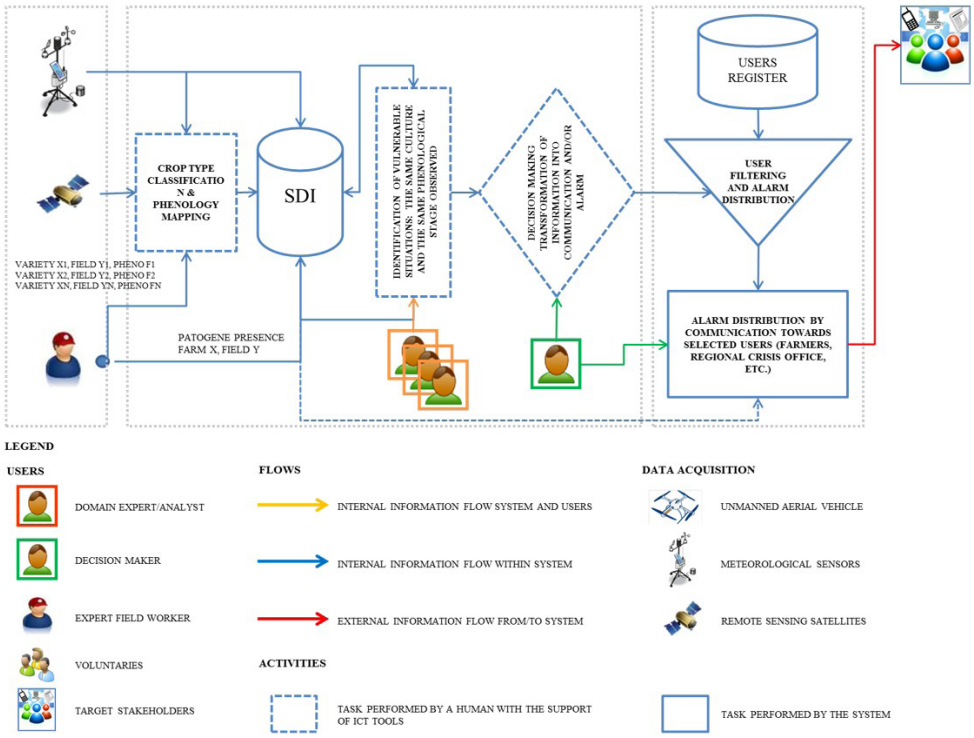

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Figure 1: Schematic representation of the workflow representing the use case 1 (the legend applies all use case diagrams).

Use case 2. Generation of information on anomalous states of the crop

Figure 2 represents the workflow of how the data are collected, processed, analysed and transformed for the dissemination of information on anomalous states of the crops. As described in the use case 1 the workflow is assembled by a starting phase of data collection. The crop typology (Fontanelli et al., 2014) and stages are detected by remote observations through the computation of indicators and/or in-situ observations collected by volunteers (Voluntary contribution by students, citizens). The observations of critical conditions (stress/late season crop) in agricultural areas of the Lombardy region trigger an alert map that is published in S4A SDI thus highlighting that something anomalous might be ongoing. The regions affected by the anomaly shown on the alert map are more closely analysed by experienced researchers/ analysts. The output of the analysis can provide either knowledge on the actual ongoing situation or uncertainties that may require further in-situ investigations at a local scale in specific regions, possibly by planning flights of UAVs or field surveys, in order to verify if something anomalous is actually occurring. Both knowledge and advices to perform further investigations are delivered via communication channels to the decision makers so that they may take decisions in the early warning phases and send alerts to the stakeholders on the current critical situation or guide operators in the field to check the status of the crops.

Use case 3. Knowledge based forecast of potential critical situations

The workflow schematically represented in figure 3 shows how data are collected, processed, analysed and transformed for communication of knowledge-based forecast of potential future critical situations. As described in the previous use cases the workflow is assembled by a starting phase of data collection by Meteorological station, satellites, and by experts. Additionally observations from drones can be included if available. These observations of a critical condition (stress/late season crop) are cross analysed by the expert with respect to the specific season drivers (meteorological and agro-practises) to foresee the possible evolution of a critical situation. The output of the analysis is converted into maps on a possible evolution of the critical situation of the crops in specific areas, and is distributed via communication channels, to the decision makers. The final stage is a filtering and dissemination

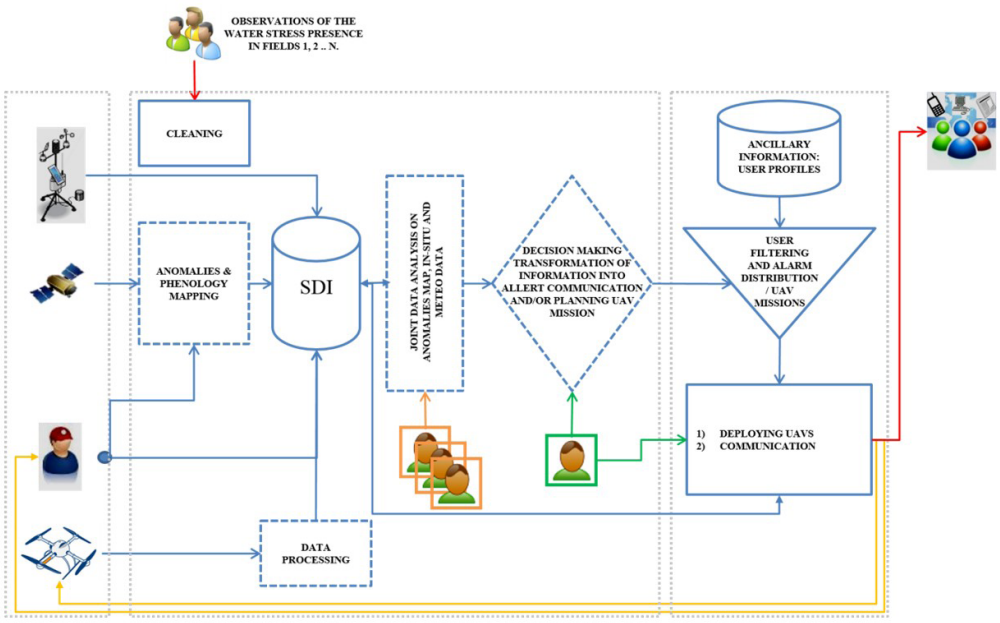

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Figure 2: Schematic representation of the workflow representing the use case 2.

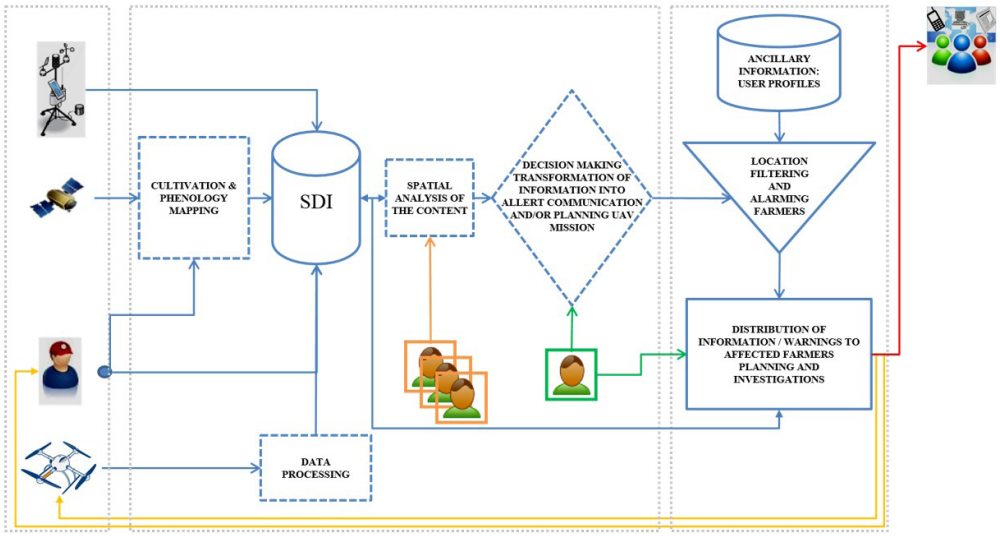

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Figure 3: Schematic representation of the workflow representing the use case 3

of the forecasts and distribution of possible advices on how to prevent the crisis to target stakeholders.

Architecture of the S4A information and knowledge based platform

The overall architecture of the S4A platform is depicted in figure 4, encompassing also representations of applications developed or deployed and configured to the project needs.

S4A Core Methods component

The core of the platform consists of three basic layers defined in the computer software developments. **Application layer** is an abstraction layer reserved for communications protocols and methods designed for process-to-process communications in the Internet model. **Domain layer** is the part of the program that encodes

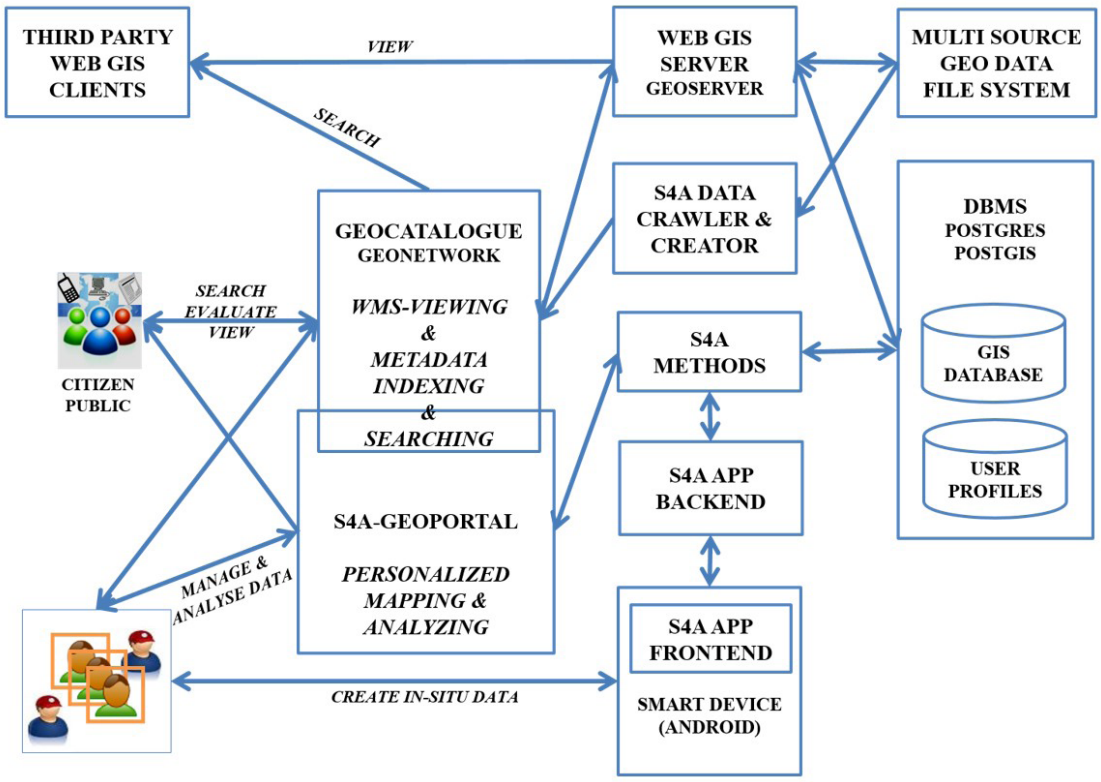

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Figure 4: Main components of S4A information and knowledge based platform.

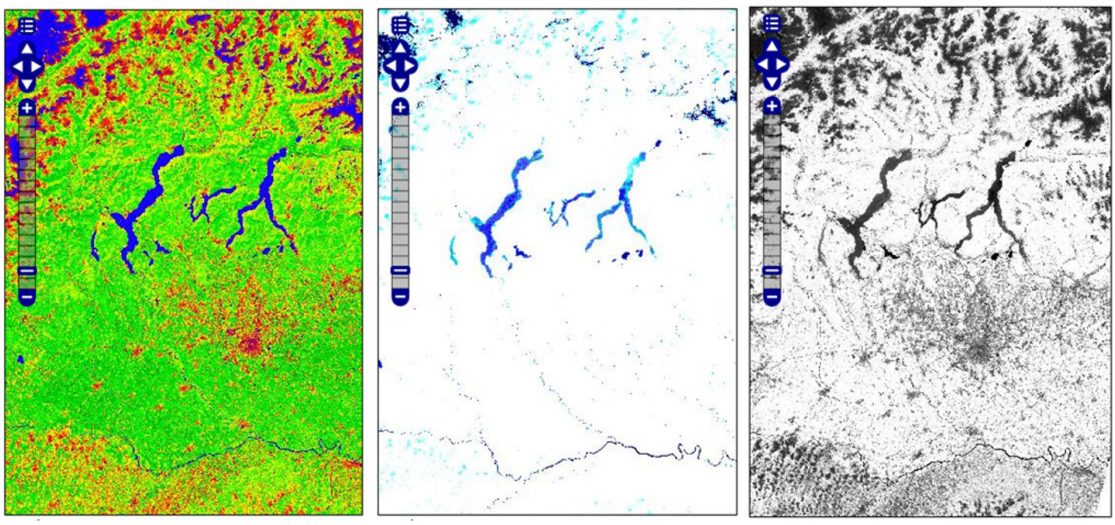
the real-world business rules that determine how the data can be created, displayed, stored, and changed. **Data access layer** is a layer of a computer program which provides simplified access to data stored in persistent storage of some kind, such as an entity-relational database. Web service component allows users applications (e.g. S4A mobile application) interacting with the core layers in a standardised REST (Representational state transfer) manner. REST has become a popular method for publishing **Web services** as a Web-friendly alternative to SOAP, which is primarily focused on defining and addressing web resources (like documents and images) and for managing their representations (Riva, Laitkorpi, 2009). **Web layer** encompasses end-user applications allowing human interactions with the platform through the World Wide Web system with a web browser. The core components of the platform are being implemented with Java programming language.

Web GIS server component

In order to provide a straightforward and standardized way of handling different sources of the geospatial data, a Web GIS server application has been incorporated into the platform architecture. Common set of functionalities for a Web GIS server can be dissemination of maps, query, search, feature editing, transformation, advanced geoprocessing, delivery of Web Services (OGC, REST), in a customizable and scalable way and with acceptable performance measures (Fu, Sun, 2010). Requirements originating from the use cases include management and publication time series of geospatial raster (Remote Sensing images, or outputs from data analysis) and vector (agriculture, meteo data) datasets. Additionally various spatial analysis are requested as well as statistical representations of time-series raster data of vegetation, meteo and other indexes (NDVI, EVI, NDFI). An important component of the S4A platform is a database management system (DBMS). Since the most data relevant for the project are georeferenced, a GIS database has been defined as a system component. GIS database allows handling and integrity of spatial data with consistent DBMS through spatial data formats and functions definitions and all this in high performance with high data

volumes (Fu and Sun, 2010). In order to accomplish the requirements on S4A Web GIS server component, we have used GeoServer opensource software, which is designed to ensure interoperability by publishing data from any major spatial data source using open standards (Giannecchini, Aime, 2013). Relevant geospatial data are being published on S4A GeoServer instance from the data server devoted to remote sensing experts from the institutes involved in the project. Currently products of remote sensing data as phenology classification maps of vegetation indexes are made available as raster data layers for viewing (WMS – Web Map Service) and downloading (WCS – Web Coverage Service) (Fig. 5).

Vector data of agricultural parcels and observations collected by the smart mobile application are stored in the a GIS database described in the next section and exposed via GIS server in the web, this available for viewing (WMS) and downloading (WFS – Web Feature Service) from within any OGC compliant GIS clients (Fig. 6).



EVI map **NDFI map** **NDVI map**

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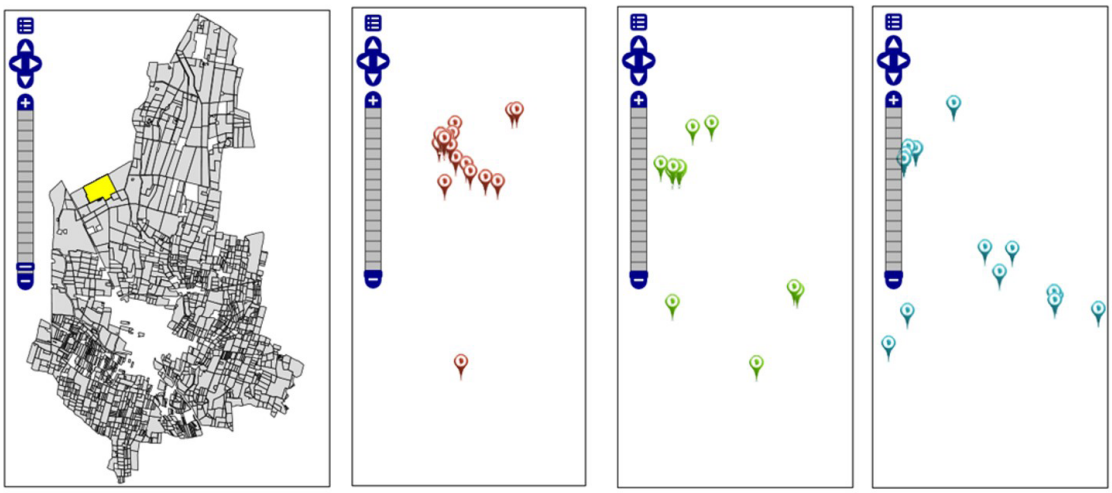
Figure 5: Raster data published on the web as vegetation and meteo indexes maps via OGC WMS.



Agricultural fields **Observations – general** **Observations - tillage** **Observations - phenology**

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Figure 6: Vector data published on the web as map features via OGC WMS.

DBMS and S4A database model

The underneath GIS database has been implemented using PostgreSQL, which is an opensource object-relational database management system (ORDBMS) with an emphasis on extensibility and standards-compliance. Additionally, it allows to manage geographic objects through its extension – PostGIS, which is opensource and freely available to download and install. PostGIS adds extra data types (geometry, geography and others) to the PostgreSQL database. It also adds functions, operators, and index enhancements that apply to these spatial data types. These additional functions, operators, index bindings and types augment the power of the core PostgreSQL DBMS, making it a fast, feature-plenty, and robust GIS database management system (Obe, 2011).

The database model is built on six basic concepts and relationships among them (Fig. 7) modelled as follows: an agricultural field (S4A_FIELD_FEATURETYPE), which represents a piece of territory delimitated by boundaries with information about a tillage status on it (S4A_FIELD_TILLAGE) with an aggregation of information about a culture type cultivated (S4A_FIELD_CULTURE), phenological stage of the respective culture (S4A_CULTURE_PHENOLOGY) and geospatial reference of geometry based on existing data about agricultural parcels provided by SIAR Lombardy (SIARL_AGRI_PARCELS). S4A_CULTURE_PHENOLOGY package is defined as a list of culture types with crop stages, each one with its own timestamp. It can have a geospatial reference of a point type or be associated to a field.

In-situ observations modelled for mobile application can be of three types: (1) General observation of any kind of information related to the project context or beyond; (2) Observation of a phenological status of a particular crop and (3) observation of tillage on a particular field. General observation is modelled by the feature type S4A_OBSERVATION shown in figure 8. Observations collected by expert users are assigned to a field based on coordinates and spatial relation to the fields' boundaries. On the other hand the observations collected by volunteers are represented as points features acquired in the field.

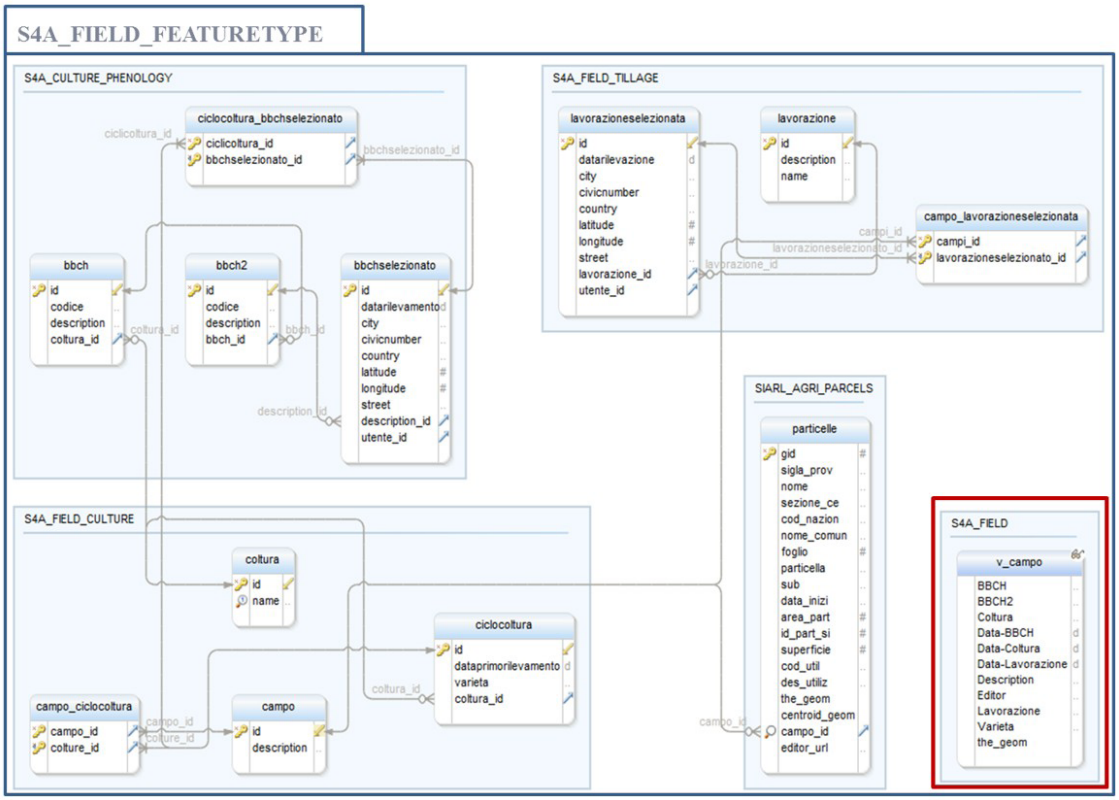

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Figure 7: Model of the S4A_FIELD_FEATURETYPE aggregating information about culture, phenology, and tillage .

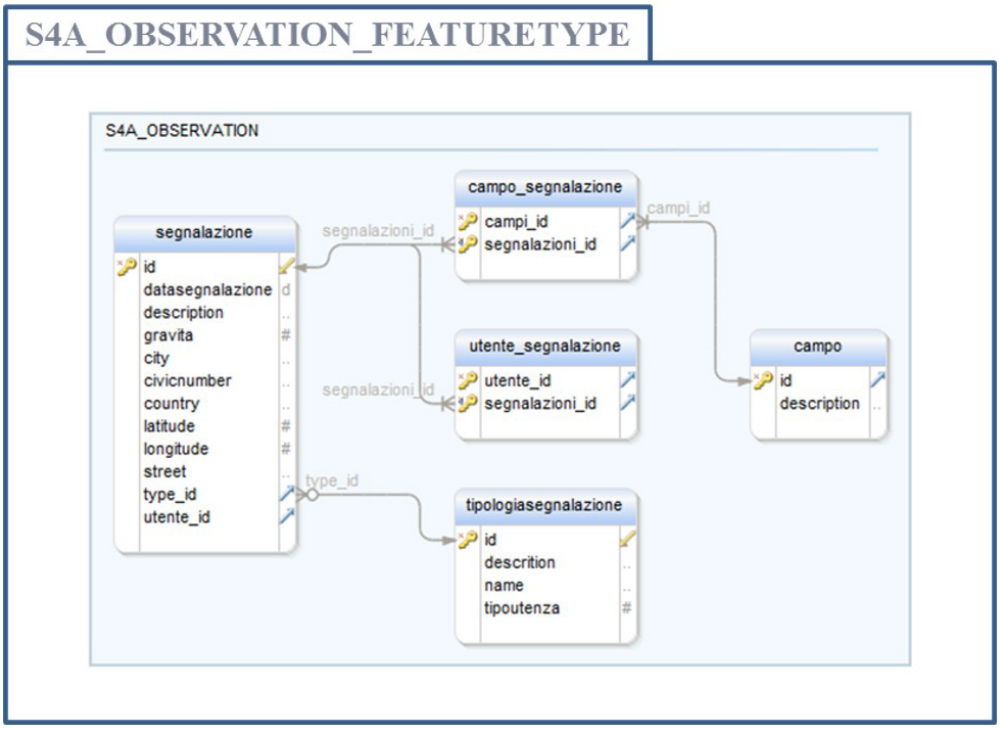

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Figure 8: Model of the S4A_OBSERVATION_FEATURETYPE covering both expert and volunteer users.

Space4Agri mobile app

Another component integrated into the S4A platform architecture is a mobile application, which provides an interface for users collecting in-site data. A mobile app is a computer program designed to run on smartphones, tablet computers and other mobile devices. The one implemented in S4A has been developed for Android platform. It allows registered users to create information in the form of a free text description, and/or photograph of the land. Additionally, categorized information to specify the crop type, phenological status and field tillage can be collected. The crop status has been implemented on a base of an agronomic ontology - BBCH (Dal Monte et al, 2010).

Geocatalogue

The geocatalogue indexes and maintains metadata records of S4A spatial data and thus allows searching for desired information sources about a specific semantics the user is interested in. This facility is offered to ease the selection based on a data fitness of use, obviously when the volume will be huge. GeoNetwork opensource software has been used to implement the described functionality. The metadata is created for each dataset published as a WMS layer with Web GIS server described above, extended by theme specific information and made available via publicly available web portal. Geocatalogue application embeds also a geospatial data viewing functionality, which is provided to the user. In this manner, the data can be searched, elaborated and used.

S4A Geoportal

An important component from the user perspective, which is currently in the development phase, is a personalized geoportal application. The geoportal will in addition of advanced functionalities as e.g. time-series data elaboration, data downloader tool, provide a personalized way to access the relevant data based on information stored in user profiles database. Authorised users will be able to visualize the content (e.g. agricultural parcels, or field observations, thematically related datasets) linked to their account at the initial login into the geoportal. Geoportal is being developed within the same framework as the core S4A methods components in order to ensure efficiency in communication to the core methods. Naturally, methods and functionalities available from the currently existing open source solutions (e.g. GeoNetwork and GeoServer) will be incorporated into new developments.

Results and discussion

S4A platform is the result of innovative combination of three components of the technical-scientific domain: Technologies Aerospace, Earth Observations and Geo & Mainstream ICT.

The first three main ICT results achieved in the projects at the current state are the following:

1. An Integrated data platform for publishing and serving S4A geospatial data products: this is implemented through the Geoserver toolkit and actually manages a) vector layers of the cadastral parcels of the estates of the farmers involved in the project located in 14 distinct municipalities; b) raster images of indicators which are resulting from remote sensing data analysis, such as NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index), Chlorophyll concentration, NDFI (Normalized Difference Fraction Index); c) geotagged free text reports, possibly associated with a photograph, d) geotagged phenological categorizations of the crops' stages based on BBCH taxonomy; and e) geotagged categorizations of tillage observed in fields, generated through the Smart APP by Volunteers and Farmers. This platform is compliant with OGC web services (WMS, WFS, WCS and CSW) and thus all layers listed above can be discovered and served to any OGC compliant application with use of CSW, WMS, WFS and WCS interfaces. The main originality of the S4A lies in the integration of authoritative information (e.g. SIARL data), research information (CNR/IREA remote sensing products) and volunteers' information (collected by S4A app) in an integrated data platform.
2. A catalogue service to search for specific thematic layers served by the S4A platform with embedded geospatial data viewer to display results of search in an overlay mode in order to facilitate correlations analyses between indicator maps and in-situ field observations, textual reports and fields' practices.
3. A final important result of the project is the smart app currently available for mobile devices powered by Android, which allows the collection of in-situ observations related to i) field condition and management (tillage dates and agronomic practices), ii) crops (type, varieties and phenological stage in BBCH scale) and iii) conditions indicating the presence of the parasite. The application, currently in the prototype beta version, will be made available to the operators of a public administration, farmers, researchers, students and the public who want to be involved in the project activities.

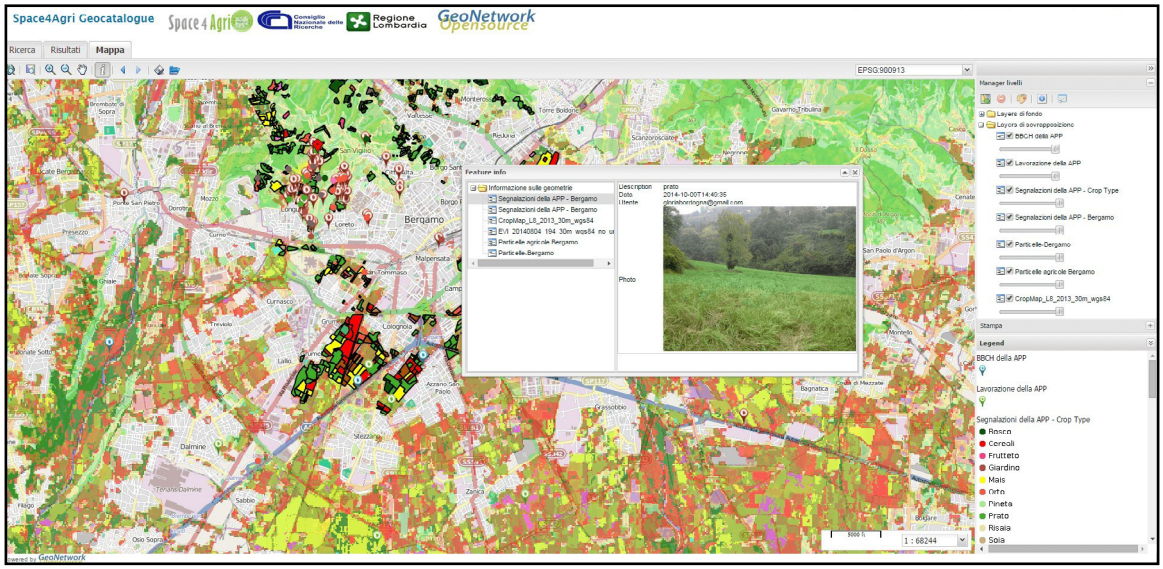

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Figure 9: S4A integrated data platform presentation layer for data discovery and use deployed on GeoNetwork opensource and connected with GeoServer via OGC interfaces.

Conclusion

The S4A project is in its halftime, thus the results represent the prototype solution, which can be used for the technology transfer in the real implementation in the regional or national agricultural sector. Nevertheless, beta version of the S4A platform components is running and currently in the testing phase. One of the following steps in this respect will be to introduce the S4A platform and particularly the S4A APP to voluntary farmers and students of agricultural high schools in the region as potential representatives of volunteers in order to provide a test-bed of the S4A products as well as support educational process.

Additionally, the remote sensing experts discovered advantages of having their data published through an SDI, thus they tend to provide more data for publishing almost on a daily basis. As an example, instead of searching for data in the file system of the data server (e.g. IREA data server has capacity 100TB and more than 90% is used), they may use an SDI catalogue to search and OGC services to use the data directly in their tools (e.g. GIS clients as QGIS) that the use on a daily base.

The S4A project has shown already quite high potential of integrating the geo and mainstream ICT into a common platform, while developing a complex information system for a specific domain, e.g. agricultural sector.

The data available through the S4A platform may significantly support regional administration, which is distributing funds among farmers, in the verification process. Farmers' declaration versus analysed status resulting from a combination of heterogeneous data sources as remote sensing products, in-situ observations collected by mobile devices and monitoring data acquired from UAV missions. The final score may bring significant savings of public sector expenses as well as join forces together in order to enhance the current situation in agricultural sector, and not only there.

Acknowledgements

„This work has been conducted in the frame of Progetto Space4Agri supported by AQ-Regione Lombardia-CNR, Convenzione Operativa n. 18091/RCC, 05/08/2013)“

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