UNIVERSITY OF LJUBLJANA
FACULTY OF ECONOMICS

MASTER’S THESIS

KEY OPPORTUNITIES AND BARRIERS OF EARTH OBSERVATION DATA USE IN THE AGRICULTURAL SECTOR

Ljubljana, May 2018

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AUTHORSHIP STATEMENT

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LIST OF ABBREVIATIONS

BUFR - Binary Universal Form for the Representation of meteorological data

EO – Earth Observation

EUMETSAT – The European Organisation for the Exploitation of Meteorological Satellites

GPS – Global Positioning System

GRAS - Global Navigation Satellite System Receiver for Atmospheric Sounding

MSI – Multi Spectral Instrument of Sentinel 2 mission

NDVI – Normalized Difference Vegetation Index

NIR – Near Infrared

RGB – Red Green Blue

ROI – Region of Interest

SAR – Synthetic Aperture Radar

SNAP – Sentinel Application Platform

VAS – Value-added services

INTRODUCTION

Remote Sensing is the science of collecting data of an object from a distance. This technique allows monitoring or measuring various phenomena found on Earth using remote sensors usually positioned on planes, satellites or drones (Pidwirny, 2006). Remote sensing techniques are widely applied in various industries, such as agriculture and agronomy, forestry, weather and biodiversity (Remote Sensing Major Applications Area, 2016). With respect to agriculture and agronomy, these techniques are highly relevant for the specific problems of monitoring agricultural activities. The continuous growth of the world population - up to nine-billion as predicted - also drives the need to increase the agriculture produce. Yet, this production improvement should be aligned with the minimization of the environmental impact of agriculture (i.e. the effect that different farming practices have on the ecosystems around them). It represents a challenge as, on one hand, agriculture is greatly influenced by the current climate changes, and, on the other hand, competes with non-food production areas such as urban expansion and biofuel production. This tradeoff urges the need to improve the mechanisms of monitoring these changes and transitions, especially in the decision making of policies and investments (Atzberger, 2013, p. 950). Enhancing the opportunities for better monitoring and forecasting crop yields remains a challenge to be addressed.

Over the last decade, there was a significant interest and progress shown in practical applications of Earth Observation data (hereinafter: EO data). These advances addressed the availability of remote sensing data, as well as their spectral and spatial resolution. Furthermore, the technological progress related to geographic information systems (hereinafter: GIS) and the Global Positioning System (hereinafter: GPS) increases opportunities for using the remote sensing data. Generally, these advancements resulted in market changes, as private companies are continuously playing an important role by either providing satellite remote sensing data or acting as value-adding firms that work with end-users. In other words, nowadays, the idea is to keep expanding the commercialization and appliance of EO data in various sectors (National Research Council, 2001). Worth mentioning are also the benefits that European Union's Earth Observation Programme brings, by allowing free access to satellite data. This programme, known as Copernicus, allows service providers to develop ever-more reliable and qualitative applications for their needs (European Commission, 2016).

Taking into consideration the literature review, it is evident that alongside with the high interest regarding Earth Observation appliance for the mentioned industries, there is a constant need to perform further development within this domain.

Hence, a major driver underlying this research is to better understand Earth Observation through the analysis of its environment, various opportunities, and obstacles that it poses to agriculture in general.

The main purpose of the thesis is to define, analyze, and shed some light on the existing obstacles and opportunities in using EO data, specifically in agriculture. It aims thus to identify the activities, processes, and challenges of the chain along EO data and decision makers. My master thesis research goals include: elaborating the benefits of remote sensing in agriculture, defining the current obstacles of remote sensing in agriculture, examining cases, solutions, approaches of EO data applicability, understanding better the EO data opportunities and obstacles through interviews with experts and identifying valued features and difficulties (if any) through data maneuvering by using Sentinel Application Platform (hereinafter: SNAP), Copernicus public data and Quantum Geographic Information Software (hereinafter: QGIS). The research questions that will be examined are: what is the role of remote sensing in agriculture? How does the interpretation of satellite images work? What kind of opportunities and obstacles are encountered on EO data appliance?

The research design is of exploratory nature, aiming to provide insight and understanding about the role of Earth Observation in agriculture monitoring. Data collection is unstructured, and the data analysis is non-statistical. The research is a combination of the theoretical and empirical part. The former consists of Earth Observation background information acquirement. It is a summary of reliable, accurate, and up-to-date materials including several research papers, scholarly papers, and cases, as well as online courses related to remote sensing provided by GIS and Earth Observation University. All this information will serve as a very good start to understand better Earth Observation, its relevant terminology, and the processes. Furthermore, this theoretical research is highly useful for moving on with the empirical part of the thesis.

The empirical part covers interviews with experts and data maneuvering. The first interviewee will be with the Chief Executive Officer of Vision Space Technologies GmbH. His background knowledge from business and aerospace perspective will be helpful in clarifying the market needs and trends, as well as identifying the possibilities for a specific solution that can contribute in this field. The second interview will be conducted with a Meteorological Product Software Engineer at the European Organization for the Exploitation of Meteorological Satellites (hereinafter: EUMETSAT). His expertise will help in having a broader perspective about satellite data and processes related to them. The third interview with the software developer will be very useful for discussing the software related problems for the recommended service. In general, in-depth interviews and open-ended questions will enable to receive qualitative information by allowing experts to demonstrate their knowledge and perspectives about EO data. In regards to data maneuvering, I will show examples using SNAP, QGIS, and Copernicus public data. As an approach, it will allow to practically see the steps of working with the data and to find out the possibilities and difficulties (if any). This software usage part is valuable to analyze the user perspective. Finally, followed by the idea of providing a recommendation, the last part of the thesis focuses on rice crop. Consequently, the architecture of the following service will be discussed: A near real-time service via web that provides information about the development and status of rice, as one of the main five worldwide crops. This service could be used by different stock market shareholders (analysts, buyers, sellers, brokers, etc.) for forecasting crops and predicting the price.

The thesis is organized in the following way: it begins with a brief introduction of remote sensing science. Then, the general advantages and limitations that remote sensing implies in agriculture based on cases are given. The next chapter, *Earth Observation Industry analysis* gives an overview of the market change, trends, and the currently available solutions provided. The content follows by the chapter *Understanding satellite imagery*, that, as the name implies, explains vegetation spectral signature and image interpretation. The perspective of advantages and disadvantages of remote sensing is complemented by the interviews with experts and software usage. Based on the results, the thesis is finalized with the discussion about the recommended service.

1 REMOTE SENSING SCIENCE

1.1 Introduction to Remote Sensing

Capturing pictures from the sky is not news anymore. In fact, the photographic images of Earth were recorded since 19th century, while the information from remote sensing has been used for economic reasons since 1930s. In the last decade, due to significant advancement in Computer Science, geography and remote sensing, economists have great opportunities to use the remotely sensed data/information (Donaldson & Storeygard, 2016). By definition, *remote sensing* means: "obtaining data about objects through the instrument that does not have a direct contact with the object". The platforms located "at a distance" can be satellites, aircrafts, drones etc., which carry sensors to observe the earth's surface (What is Remote Sensing, n.d.). As according to (Basso, Cammarano, & Carfagna, n.d., pp. 1-10), remote sensing is one of the many techniques used for crop growth/quantity forecasting. These other techniques are:

1) the traditional method (i.e. measuring the crop status by experts);

2) crop simulation models (statistical, process based models).

It is known that 75% of Earth's surface is water, while the rest is vegetation. Some shades of this vegetation, recognizable with the green color, can be depicted by the naked eye, but nowadays thanks to many instruments and satellites, this vegetation can be analyzed way more better (National Oceanic and Atmospheric Administration, 2013). The data collected by orbiting machines offer greater spatial, temporal, and spectral resolution. Along with that, the algorithms and processing power used to interpret this data are becoming more and more sophisticated (Donaldson & Storeygard, 2016). The typical characteristics of satellite remote sensing systems are: spatial, temporal, and spectral resolutions. Below is a brief explanation for each of them:

- Spatial resolution defines the pixel size of satellite images covering the earth surface;
- Temporal resolution defines the revisiting frequency of a satellite sensor for a specific location;
- Spectral resolution defines the number of spectral bands in which the sensor can collect reflected radiance. Noteworthy, except the number, the position of bands in the electromagnetic spectrum is also important.

Unfortunately, there is always a tradeoff between these resolutions, i.e. an image with high spatial resolution has a low spectral resolution and vice versa (Characterization of Satellite Remote Sensing Systems, n.d.).

1.2 General advances and opportunities

The advances that remote sensing brought are numerous. Some advancements are listed below:

There is a high availability of satellite data that are capable of discriminating crop yields on individual fields (Lobell, 2013).

Remote sensing/electromagnetic imaging has the ability to exceed the capabilities of the human vision. Electromagnetic imaging from satellites, in fact, reveals much more information about what's actually happening in the leaves of plants and even inside the canopy (Guan et al., 2017). Remote sensing provides data from the near-infrared region of the spectrum. This data in combination with information from the visible spectrum, where chlorophyll absorbs energy at specific wavelengths, enables to receive information that helps to identify stressed plants before the symptoms become visible. Farmers certainly benefit from the early warning as they are able to respond quickly and reduce the damage caused to the plants and poor yield (Monitoring crop status, n.d.).

Vegetation cover of each crop changes at different rates. Data from different dates (multi-date) from one growing period is what makes it possible to identify the different crop types. In addition, the planting and harvesting dates are also different. The combination of this data with remote sensing data enables the discrimination between different crops as well as their identification. When a crop is under stress, it is reflected differently under spectrum, which leads to a wrong crop identification. In order to avoid such a case, usually remote sensing data collection data from more than two dates in one growing season is applied.

Remote sensing technology benefits include: a) spatial coverage over a large geographic area; b) availability during all seasons; c) efficient analysis; d) information in a timely manner (Mosleh, Quazi, & Chowdhury, 2015, p. 771).

Remote sensing is an excellent alternative of the traditional methods (e.g. field surveys, literature reviews, map interpretation, collateral and ancillary data analysis) by eliminating the time consuming problem, the expensive nature and also the date lagges. Additionally, it offers practical and economical means to study vegetation cover changes, especially over large areas (Xie, Sha, & Ma, 2008). Remote sensing, in a nutshell defines the "what is happening right now" in a study area by providing images in a fast and cost-efficient manner.

One of the most important advantages of remote sensing information is that it decreases the need for labor and material intensive methods by providing a quantification of the actual state of crop for large area. Compared to crop models which provide a continuous estimate of growth over time, remote sensing has the benefit of providing a multispectral assessment of instantaneous crop condition within a given area (Dadhwal, n.d.).

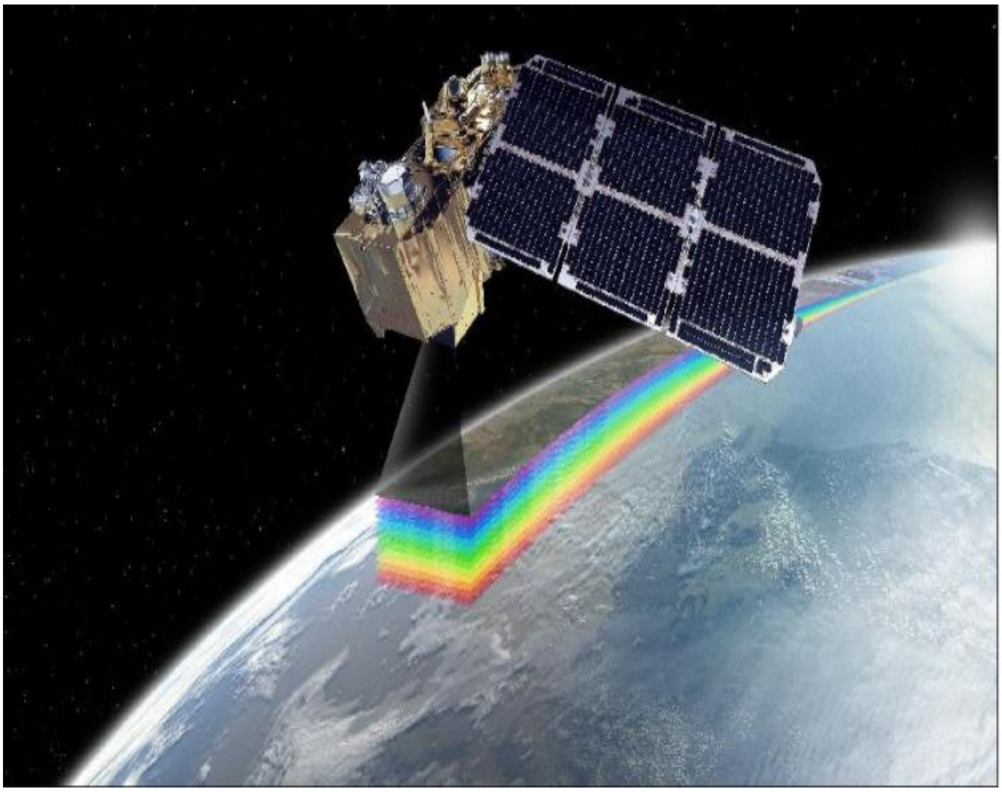
1.3 European Space Agency & Copernicus programme

Taking care of planet Earth and life supported by it, is one of the core mission of European Space Agency. Satellites are continuously collecting information about land, ocean, ice and the atmosphere, inspired by the strong desire of understanding how earth works and how it changes. European Space Agency mission is working specifically with this aim: providing answers about Earth, be it related to gravity, moisture, soil or salinity of oceans. The satellites operating under the Copernicus programme are called Sentinels. Near real-time crop growth monitoring and yield forecasting information for the European Union and its neighbourhood, are provided by the Joint Resource Center. This center is also working on extending monitoring and forecasting activities worldwide (Crop yield forecasting, n.d.).

The European Union's Earth Observation Programme information services based on satellite Earth Observation and in situ (non-space) data, allows service providers to develop ever-more reliable and qualitative applications that are *user-friendly***.** The Copernicus programme works on increasing the awareness among agricultural end-users for the potential use of EO data and the new opportunities for service providers. Finally, the big advantage is that, these products developed based on Copernicus data, are very functional and can be easily adapted to different scales and user needs. For instance, one of Copernicus projects (Sentinel-2) generates four added value products: *images without clouds* produced on a monthly basis, *crop masks* which indicate the location of cultivated fields, crop types which automatically identify the dominant cultures in an area, and the Leaf Area Index which is a realtime indicator of the level of vegetation (European Commission, 2016). Furthermore, Copernicus is known for the following specifics:

- Sentinel-2 (i.e. one of the satellites operating under Copernicus programme) carries the Multispectral Instrument (hereinfter: MSI). MSI is characterized with 12 spectral bands, 290 km swath width and high revisit frequency and is able thus to support a wide range of land studies and programmes. Along with this, it reduces the time required to build an European cloud-free image archive. Also, data for land cover/change classification, atmospheric correction and cloud/snow separation are provided by the spectral bands of Sentinel-2. MSI provides measurements with the following resolutions: spatial, temporal and radiometric (ESA, 2015). Figure 1 illustrates the Sentinel 2 Spacecraft in orbit. The colors represent the spectrum.

Figure 1: Illustration of the Sentinel – 2B spacecraft in orbit



Source: Copernicus: Sentinel-2 (n.d.).

- Copernicus programme sentinel Quadratic has already operational satellites Sentinel 1, 2 and 3 satellites. This means that, now, it is possible to observe every point in the European continent, with a resolution of 10 m, in the visible band, with a revisit time of 5 days at the Equator (3 days at central europe latitudes). Data are freely available and a tremendous amount of information can be harvested out of every single pixel (Primavera, 2016).

- Agriculture and precision farming are the most promising market in terms of the impact of Copernicus while exploring Earth Observation. Users, or more specifically the intermediate users, have various profiles: startups, Small Medium Enterprises, large companies and purely scientific players. Additionally, this market brings up to 13% of Copernicus revenues. All in all, Copernicus encourages better informed decision making, long term planning and better deployment solutions (European Commission, 2016).

1.4 General limitations

After the analysis of advancements, this section remarks some recognized limitations that remote sensing encounters.

Results of vegetation mapping are problematic in terms of three key points: a) the accuracy of the chosen classification system about the actual vegetation community composition; b) the effectiveness of real distinction of features within the mapping unit and c) the correct interpretation of mappings from the side of photo interpreters. Additionally, the same vegetation type on ground may have different spectral features in remote sensed images. Obtaining accurate classification results becomes hard also in the case when different vegetation types may possess similar spectra. Currently, no method (traditional unsupervised classification or the supervised classification), can give 100% accuracy. In fact, searching for improved classification methods is always a hot research topic. Hence, applying effective classifiers or developing new powerful classifiers suitable for specific applications remains a challenge (Xie, Sha, & Ma, 2008).

In general, there is a lack of awareness about Copernicus programme and remote sensing applications among entrepreneurs and users. Three other typical barriers are the constant needs for:

- Intelligent software - Earth Observation images need to be used by non-experts of remote sensing, Earth Observation imagery should be easily accessible and understood by them.
- Business model - geo-information and EO data related services, in principle shall exceed the commercialization objective, and contribute to the social purposes as well. But, in reality, this is not the case. Majority of the customers of EO data/information complain for the high prices, which shows that there is a need for a better business model that ideally would not be only revenue based.
- Free data availability does not fully solve the problem. Especially in developing countries, where although free, this data would require at least a computer with good storage capacity and that is not affordable most of the time (Lemmens, 2008).

Remote sensing data fusion is one of the techniques that aims to integrate the information acquired with different spatial and spectral resolutions from sensors mounted on satellites, aircraft and ground platforms to produce fused data that contains more detailed information than each of the sources. But, despite the general development in fusion techniques, it remains problematic to have the multi-source data fusion within varying spatial and temporal resolutions (Zhang, 2010). One of the main difficulties remains the consolidation of data that comes from various sources, like ground data and satellites. It becomes even harder when this data has to be collected in real-time.

There is a high necessity to ensure and improve the link to decision makers, as there is a big gap between the (end-)users and Earth Observation specialists. In the majority of cases, remote sensed data alone is not very valuable. Other data combined with information coming from various data sources (e.g. in situ) or sensors remains very important. Moreover, the different uses of satellite data in agricultural applications means that there are different requirements in terms of measured parameters, spatial, temporal and spectral resolution, accuracy, availability, timeliness etc**.**

The level of technology and the data products/services should be aligned. However, this differs from country to country (Agriculture and Earth Observation, 2017, pp. 1-3).

Earth Observation industry needs to develop a cost-effective, robust, scalable way to deliver value-added solutions to government and commercial customers (State of the Industry, 2013).

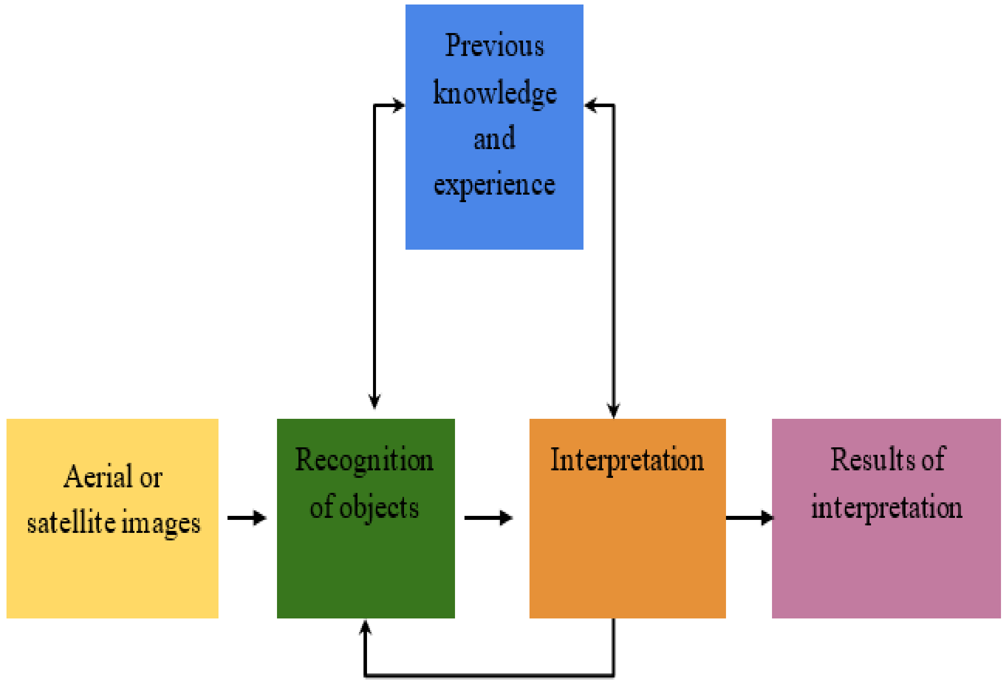
Remote sensing image interpretation remains also a problem. More specifically, the problems of multilevel analysis, analysis methods, multitemporal analysis, high-frequency of observation, background knowledge, lack of expertise, scale up and data quality (Gançarski, 2014). Image interpretation is problematic because of unfamiliarity with scale and resolutions, lack of understanding of remote sensing physics and lack of understanding proper spectral character of each object (Sivakumar, 2010). The figure below illustrates briefly the process of image interpretation. The general visual interpretation of satellite images is very complex. But, as seen in Figure 2, two important steps are: the recognition of objects (streets, fields, rivers) and the true interpretation. The first one means recognizing at an image what one already knows based on the previous knowledge and experience. The interpretation is like a conclusion that is highly influenced from both the previous knowledge and the recognition of objects.

Accessing accuracy of an image is very important but having a single, all-purpose measure to do it is impossible. Each measure has its own benefits and limitations (Xie, Sha, & Ma, 2008).

Jungle of data categories, national practices, tools, and formats represents another obstacle. First, the word "jungle" in terms of data categories means that there is a broad spectrum from weather to food prices and from food production statistics to satellite indices. This means that tools should be designed to bring all the data to a common measure in the final stage of analysis. Second, national practices jungle is a consequence of the fact that all national meteorological and agro meteorological were developed individually, and even on the opposite directions. Third, tools, and formats problem is linked with the data processing and the need to standardize those (Gommes, n.d.).

Some other worth mentioning barriers of remote sensing are: the inability of many sensors to obtain cloud free images (exception are the microwave sensors) and the relatively low spatial resolution achievable with many satellite-borne Earth remote sensing instruments.

Figure 2: Image interpretation process



Source: Adapted from Visual Image Interpretation (n.d.).

Additionally, remote sensing large quantities of data require lots of processing, as well as storage and analysis. Another issue is that data can be very costly when purchased from private vendors/value-adding resellers - something that together with intellectual property restrictions can limit the dissemination of products from such sources (National Research Council, 2001). According to (State of the Industry, 2013), some relevant issues include:

The need to demystify geospatial data and clearly articulate the value, benefits and the cost-effective approach required deriving information. It takes weeks or even months to receive the data from the sensor to the desktop for processing. As a result, the data becomes less important if not able to be used in the decision making.

Missions that are 100% government operated and controlled run the risk of losing political support and, as a result, funding for next-generation missions.

High costs are a restraint for Earth Observation market growth. Commercial imagery providers must get development, build and launch costs down and reduce imagery prices to be attractive to the general public and achieve economies of scale, spurring thus the growth of value-added service providers as well.

The global investment community still doesn't understand the Earth Observation industry from a manufacturing perspective, as well as government's influence about it. This lack of investment could hold back the development of new sensors, and ways in which to provide near real-time and on-demand products.

There is an inability to diversify beyond the defense and national mapping sector. For a long time, the focus was on defense and intelligence solutions, and the industry hasn't been proactive in identifying equally valued opportunities in adjacent and vertical markets (State of the Industry, 2013).

Other challenges mentioned by startups that are already providing solutions related to EO data, include the following:

- Satellites offer Big Data but little control - despite the huge amount of data provided by satellites, this data is still in low resolution and this makes it difficult to analyze at the plant level. The lack of daily revisit especially for some plants brings its own limitation.
- Multiple data sources mean more data, but their integration remains a problem. Artificial Intelligence and machine learning are used, but still not enough to completely solve the problem. In other words, data is very irregular, fragmented, and noisy due to effects.
- There is a lack of data standardization in the agriculture industry. This forces companies to use combination of technologies for the collection. The connection with internal physiological and biological properties of crops on a plant level is an additional barrier as its empirical evidence from the ground and agronomic modeling is required (Ivanov, 2017).

2 EARTH OBSERVATION INDUSTRY ANALYSIS

2.1 Value-Added Services market growth

The industry of Earth Observation is expected to enter a transition phase of oversupplying imagery and lower data prices where, as a result, hundreds of satellites are planned to be launched in the near future. This will decrease the demand of value-added services, i.e. services/applications that transform raw data into information. Certainly, the value-added services (hereinafter: VAS) market will not disappear. Instead, it is expected that data providers/operators will move down the Earth Observation industry value chain towards the end user, by providing more value addition/processing to the raw data. For instance, an added value can be to decrease time taken between image acquisition and delivery to the customer or to the providers of information products. On the other hand, the decrease in demand of VAS would cause changes in the highly fragmented information product market. This market would need to take their business in the opposite direction, by moving up in the value-chain and incorporating VAS within their final products and services. In summary, it is expected that government will continue to have a need for VAS. But, VAS as a segment is expected to converge as a necessity to be delivered within the information product and as part of data sales respectively, since the barriers to enter the information product market will decrease (Rousseau, 2015).

2.2 Market solutions

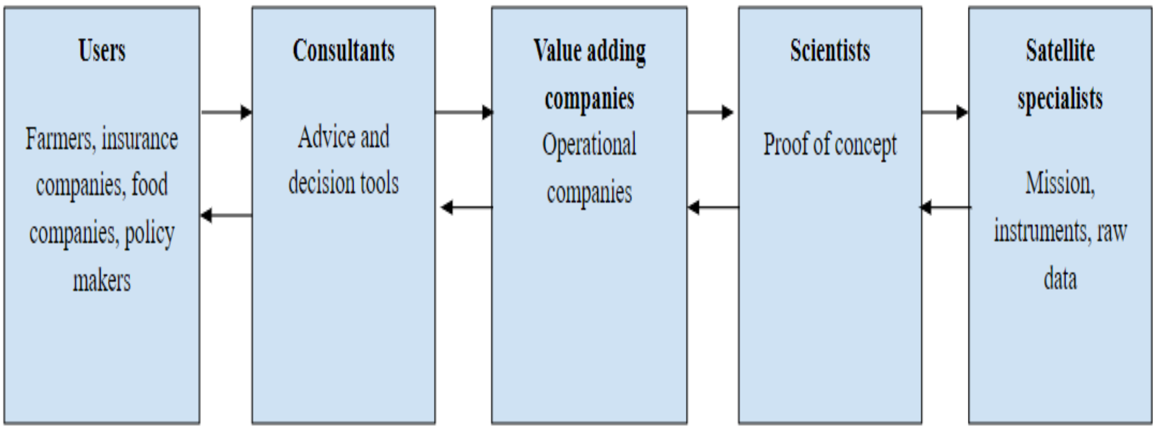
This section illustrates the information chain between Earth Observation and final users (decision makers) and it gives an overview of several solutions of applied remote sensing in crop forecasting. Starting with the former, the information chain looks as follow (see Figure 3). Satellite specialists provide the raw and mission data. Value adding companies have a key role in the chain to operate with these data, in order to make it valuable in terms of decision making. Their role is to especially make it as more user friendly as it possible, so that their customers can really benefit from it. The end-users can be farmers, food companies, or policy makers.

Despite of the existence of some use cases to close the gaps between this chain, there are still links that are not closed fully or do not operate optimally (Agriculture and Earth Observation, 2017, pp. 1-3).

Farmer and agribusinesses benefit constantly from the available resources and use of big data as the enabler to get maximum yields. Companies working on this are many, like The Climate Corporation, aWhere, FarmLogs, OnFarm, FarmersEdge, Agribotix, AgDNA, Conservis (Manning, 2015). In addition, Table 1 lists some of the major players in the geospatial services.

In addition to web services and platforms, there are plenty of apps available in the market that aim to simplify the daily operations for farmers. Similarly, these applications are a result of the continuous need for more precision farming and successfully field-level analysis (Ivanov, 2017). Considering the advantage of precision farming and the tremendous changes that it brings in terms of cost reduction and improvements of accuracy production, the number of applications is various and huge.

Figure 3: Earth Observation data chain



Source: Adapted from Agriculture and Earth Observation (2017) p. 2.

Table 1: List of market agricultural solutions

Country	Company name	Domain
New Mexico	Descartes Lab	Descartes Lab is a game changer in crop prediction. In a nutshell, the company thanks to its techniques based in machine learning, gets information about which crop is growing by analyzing tons of pixels from satellites, eliminating so the need to talk to tons of farmers to get that information. (Brokaw, 2016)
USA	Planet Labs	Planet Labs uses Business Intelligence and small satellites to provide the imagery data to agriculture businesses. It sent 71 provide near-constant, high-resolution pictures of what's happening on Earth. (Quan, 2014)
USA, Boston	Ecometrica	Geospatial intelligence and mapping applications. More on www.ecometrica.com
Germany	Geo cledian	Startup providing geospatial services. More information can be found on www.geocledian.com

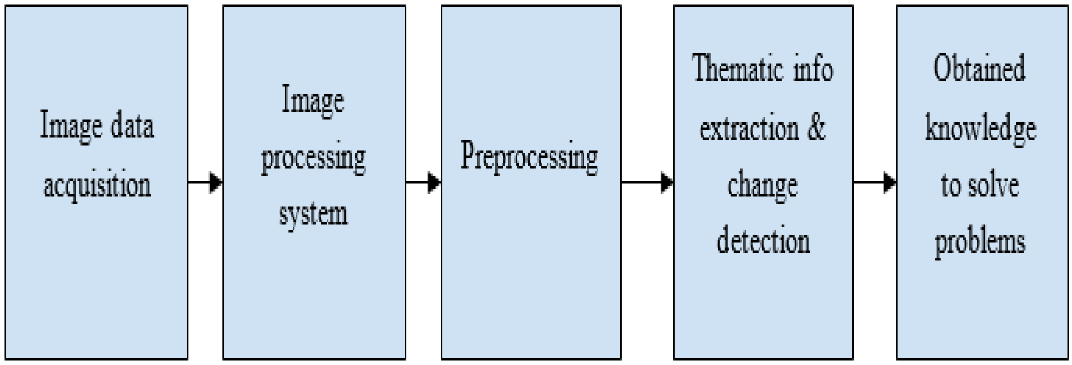
Source: own work.

3 UNDERSTANDING SATELLITE IMAGERY

3.1 Earth Observation process chains

Satellites provide raw data, that later need to be processed into useful information. This process is very complex, but it can be said that, in principle, it includes five steps (see Figure 4).

Figure 4: Processing chain of raw data to information



Source: Data application of the month (n.d.).

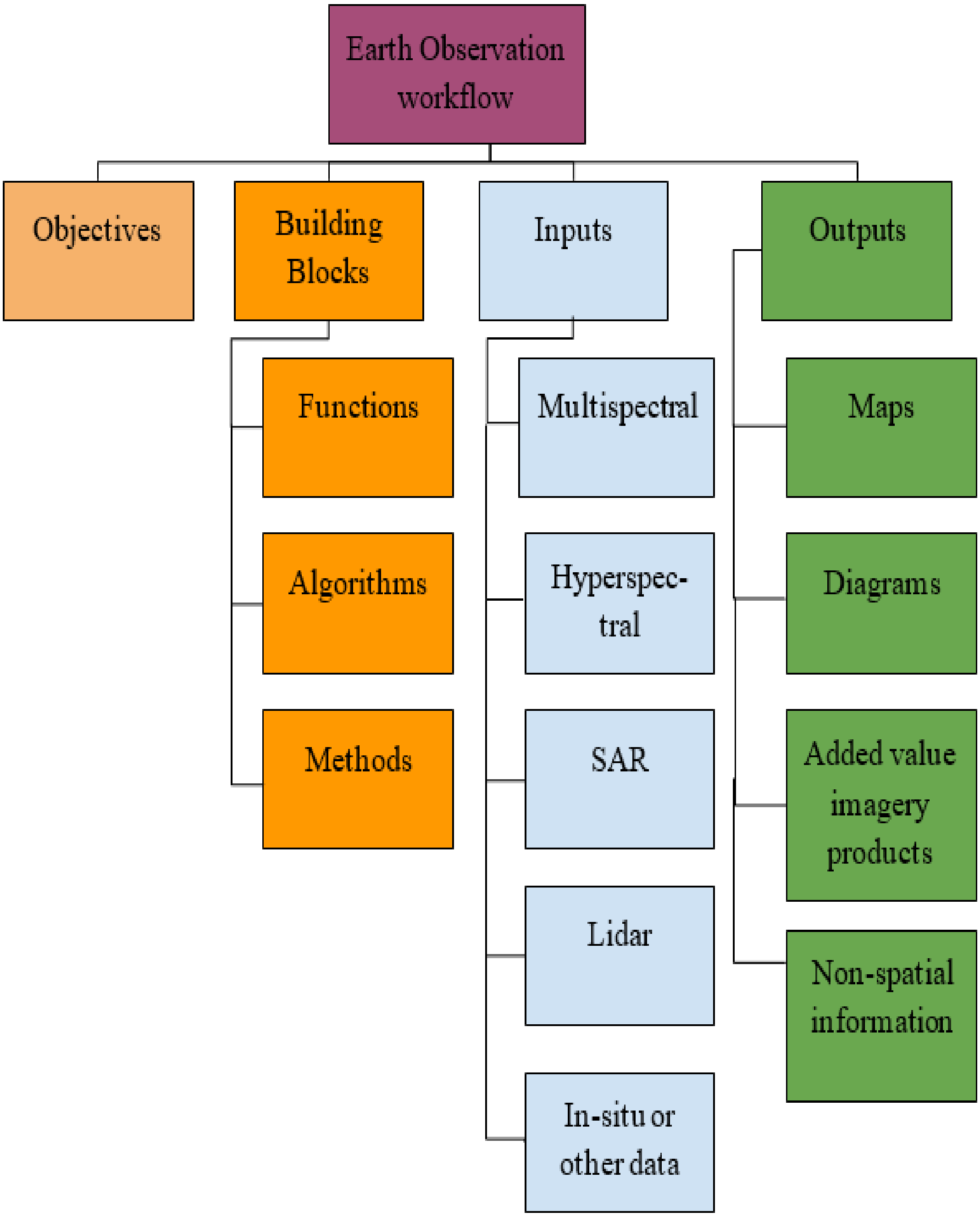
Satellite imagery is available for free and the image archives are continuously growing. Free satellite data can be obtained in two different ways: optical (passive) way and active/ Synthetic Aperture Radar (hereinafter: SAR) way. The difference between both is mainly the type of sensors. Among the optical (passive) images, there are SPOT imagery (with very high resolution), the ASTER data archive, Earth Observation-1 Sensor Web (with high resolution), Landsat and Moderate Resolution Imaging Spectroradiometer Level 1 (with medium resolution). SAR (active) images with high resolution are SENTINEL 1 imagery (Data application of the month, n.d.).

Figure 5 presents the Earth Observation workflow. It is the chain of processes that is composed of the building methods (functions, algorithms, methods). Earth Observation images or remote sensing images are the minimum requirement as an input. In some cases, in-situ or other measurements might be needed. Depending on the objective of the work-flow, the output (data/information) can be maps, diagrams or enhanced imagery products.

The functions, algorithms, and methods represent the core of the Earth Observation work-flow. Functions are usually data independent, i.e. more simple in usage and can be re-used for various data and applications. Methods are more complex processes and therefore cannot be re-used for various data and applications. Algorithms are data dependent and aim to perform more complex and specific tasks.

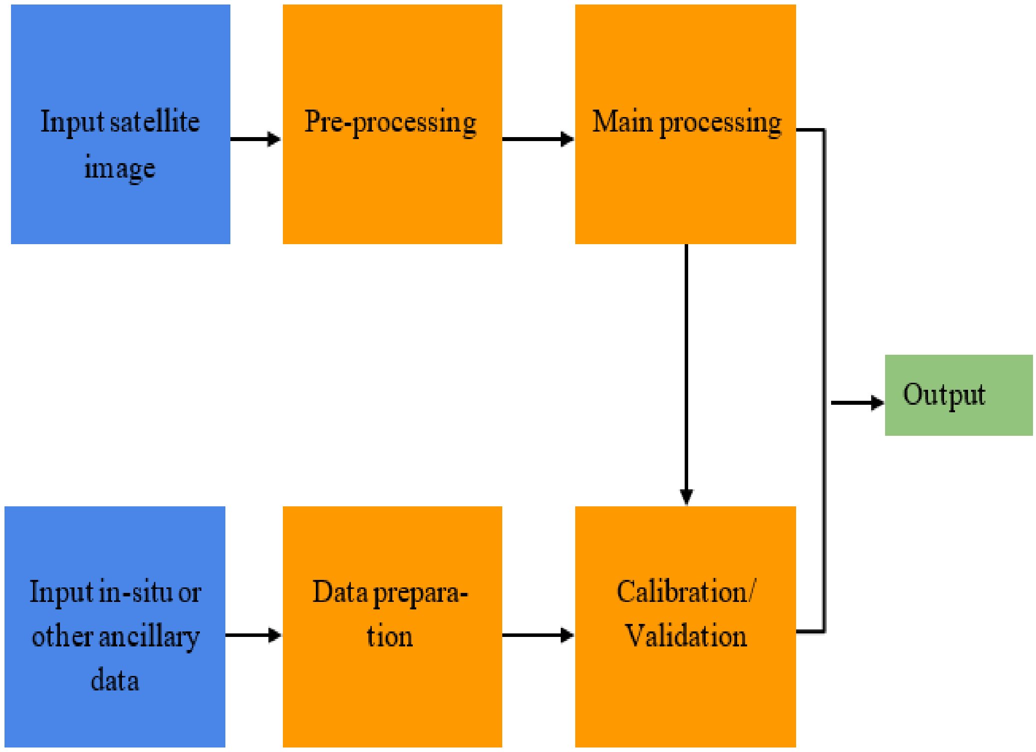
An illustration of workflow would look like in Figure 6. As previously stated, the satellite image is given as the input. If the in-situ data is necessary, then it is processed in parallel. Both of them (in-situ data and the satellite image) feed the calibration, and as a result the output is obtained (GEO University, n.d.).

Figure 5: Workflow of Earth Observation



Source: GEO University (n.d.).

Figure 6: A typical workflow for Earth Observation

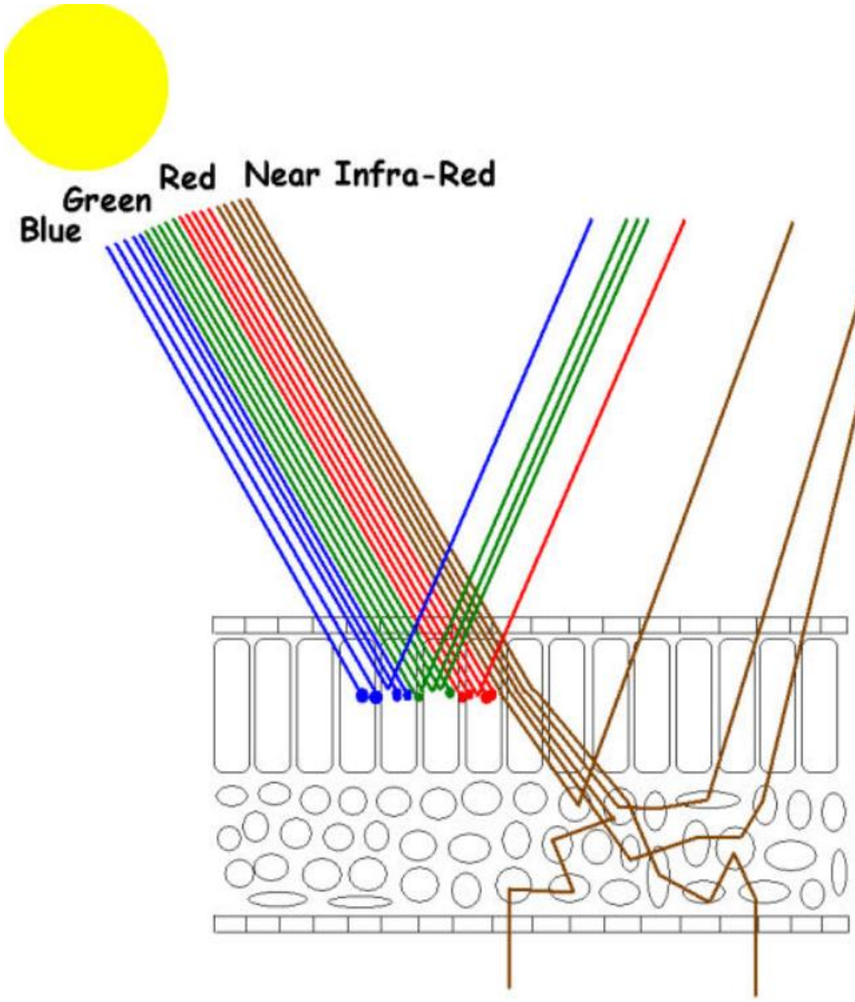


Source: GEO University (n.d.).

3.2 Vegetation Spectral Signature

In order to understand satellite images, it is important to have a brief explanation of vegetation spectral signature first. Starting with Figure 7, that demonstrates the interaction of leaf structure with the electromagnetic energy, it can be seen that four colors are present: blue, green, red, and the near infrared (hereinafter: NIR). The leaf has two layers of cells. One is the *palisade parenchyma*, where most of chlorophyll resides (chlorophyll is the protein that captures the solar energy and is the key protein in the process of photosynthesis). Other pigments residing in this level are also very important for the absorption of light (especially in the blue and red part). In this case, it is noteworthy that out of all colors, NIR is not affected by those pigments, which means that, it can penetrate almost completely in the palisade parenchyma. Then, it reaches the other level of the leaf (spongy parenchyma) where a lot of irregular cells reside, which enables the circulation of gases. These air spaces cause refraction of the NIR energy in various directions. Half of the energy reflected comes from the lower epidermis, and the other half comes from the upper epidermis. Remote sensing thus, will record a very low signal at the blue and red regions. The green region would be a bit stronger, while the NIR would be the region reflecting the strongest signal. Figure 8 illustrates these variations of reflectance, where it can be seen that, vegetation has low reflectance in the visible region and high reflectance in the NIR.

Figure 7: Cellular leaf structure and its interaction with electromagnetic energy

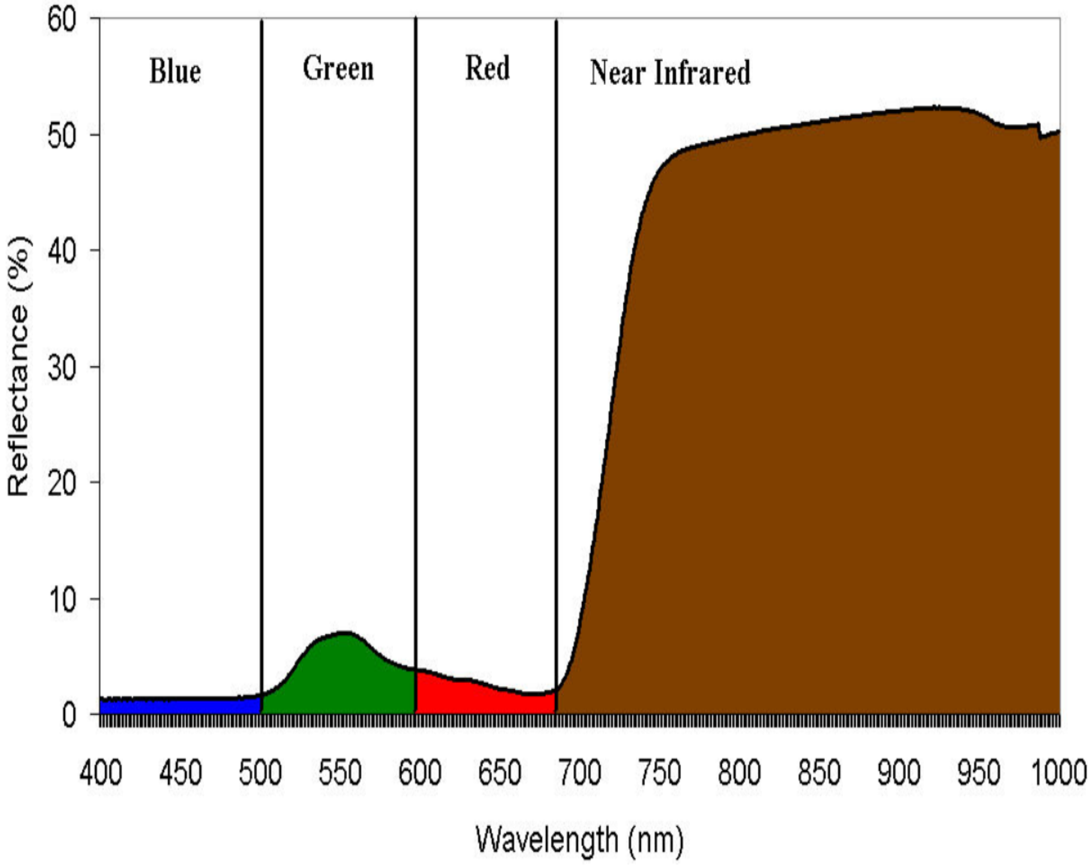


Source: Supplement - Vegetation Spectral Signature (n.d.).

Given the brief explanation of vegetation spectral signature, it is now easier to move on the satellite image interpretation. Satellite images are indeed full of information. Using satellite images one can detect how well crops are growing, or other information such as the place where a fire/storm is burning. In order to fully understand this information, usual steps to be taken into account are:

- looking for a scale - before interpreting an image, the scale should be known, i.e. the level of detail that the image represents;
- looking for patterns, shapes and textures - identifying features such as bodies of water (rivers, lakes, oceans);
- defining colors and shadows - in true color images, colors are associated with what a person sees in reality, i.e. blue - water areas, shades of green - plants, grey - building areas;
- Interpreting based on the a priori knowledge - local knowledge for specific areas is always very helpful to more accurate interpretation (Riebeek, 2013).

Figure 8: Vegetation spectral signature



Source: Supplement - Vegetation Spectral Signature (n.d.).

Image interpretation can be visual, digital, or a combination of both. The advantages of visual interpretation are: the simplicity of the method, low cost equipment, the subjectivity and quality, and the concreteness. The digital image processing, on the other hand, has the benefit of being cost-effective for large geographic areas and repetitive interpretations. It also brings consistent results, is compatible with other digital data and it enables simultaneous interpretations of several channels (Sivakumar, 2010).

Satellite imagery can be in different colors. Some are in true colors - similar as one would distinguish at the real scene directly. But, quite often, satellite images are in false-color. This means that they incorporate the detection of features hard to be found in the true - color images. In images like these, ocean might appear red, for instance. Hence, it becomes mandatory to know in advance the properties of rainbow for that specific image (Andy, 2014). According to the study (Svatanova, 2016), true and false color images bring the same results when it comes to object identification. But, as expected, false color images are better to analyze details such as water bodies and watercourses. Another interesting result is also the speed of interpretation. Experts (policemen, fireworks) show better results in identifying a fire threatening compared to random people. In summary, the results of this study show that false color images are easier to interpret by non-experts. Additionally, the object identification on satellite data accuracy of the reality is not as important as the contrasts of color to the surrounding of the identified object (Svatanova, 2016).

As stated in (How satellite technology is predicting crop yields, 2016), satellite images besides the historic information, can still be used as part of a forward-looking forecast. The capability to directly monitor crops continuously and on large scales (state and countries sizes), makes satellites into the best tools for detecting new or unusual changes in crops.

3.3 Vegetation extraction from remote sensing imagery

Extracting vegetation information from imagery is the part of image interpretation that is mostly relevant for agriculture. Image classification means extracting the distinct classes (e.g. vegetation species, land use categories) from raw remotely satellite data. There are two types of techniques to extract vegetation from preprocessed images: the traditional and the improved classifiers.

The traditional method can be unsupervised or supervised classification. Unsupervised classification methods (usually K-mean and ISODATA clustering algorithms) are characterized by relying on spectrally pixel-based statistics, with no prior knowledge of the characteristics of the themes being studied (Xie, Sha, & Ma, 2008). The benefit of these methods is the ability to have automatic conversion of raw data into useful information as higher classification accuracy is achieved. In contrast to this, supervised classification (characterized mostly with Maximum Likelihood classification) is known for using learning and established classification from a training dataset.

Besides the traditional classifiers, the other methods, *improved methods*, work on expanding the specific techniques or spectral features in order to achieve better classification results. In principle, these improved methods can be applied for some specific problems, and as such, they should be used cautiously. In other words, these algorithms will be still demanded as long as there are no super classification methods that can be applied universally (Xie, Sha, & Ma, 2008).

3.4 Crop forecasting

This section describes briefly the crop forecasting background and methodology. Crop forecasting usually shall take place months before the harvest. There are various techniques to actually forecast crops. It is important to mention that crop forecasting relies on models. Models are simply computer programs that explain the plant - environment interactions in quantitative terms. They would need information (*model inputs*), such as factors that affect crop yields which after going through model, result in *outputs* - maps of crop conditions and yields. Typical examples of inputs are: weather data, crop calendar (crop stages), crop reports, satellites (variables such as Normalized Difference Vegetation index (hereinafter: NDVI)), farm inputs and other similar factors. In addition, reference data are also used as input data. Reference data represent the good knowledge of actual farming practices in the areas being covered, like for instance which crops are grown, and where, and how. It also covers, particularly for agro meteorological crop forecasting, climate and soil information. Outputs can be crop yield maps, crop condition maps or other indicators (Gommes, Bernardi, & Petrassi, n.d.).

3.4.1 Crop yielding models

By definition, a model aims to simulate the way in which a crop responds to its environment. Models are usually calibrated, which means that outputs are empirically related to crop yield through standard regression techniques. Yield function is the result. It is used to calculate yield estimates based on model outputs. Models can be categorized as follows:

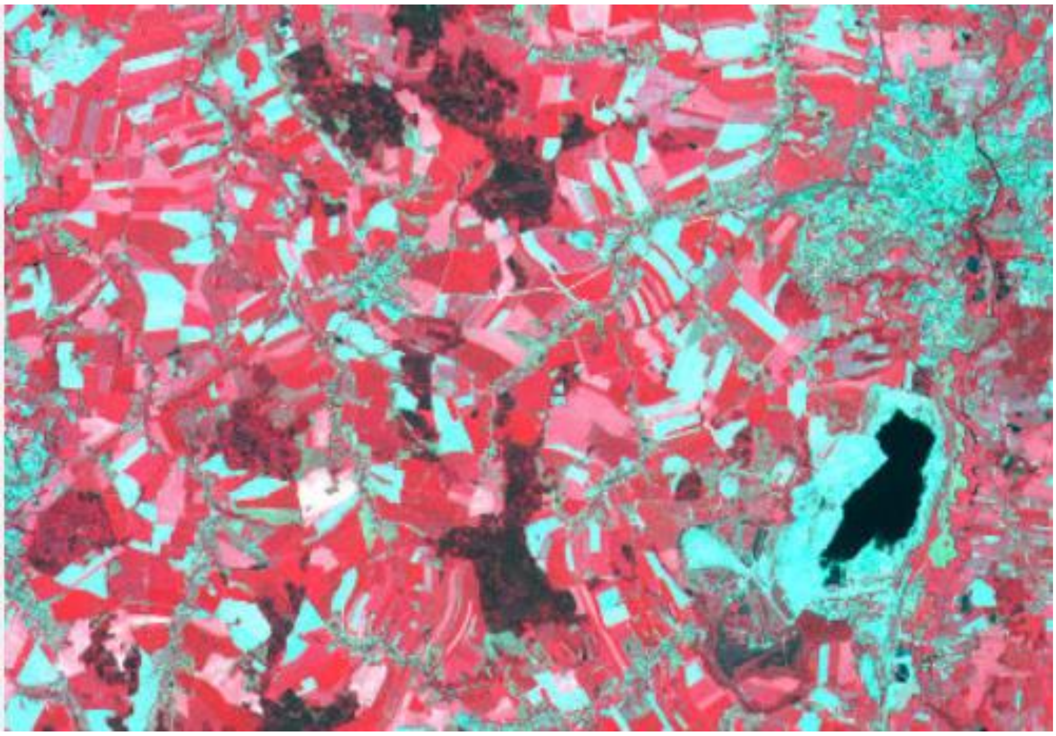
- Mechanistic models - they use mechanisms of plant and soil processes to simulate the growth of specific crops. They incorporate fairly detailed and computation-intensive simulations.
- Functional models - simplified simulation of complex processes.
- Statistical models - based on yield information for large areas, they combine a secular trend and variations due to weather conditions (Gommes, Bernardi, & Petrassi, n.d.).

3.4.2 Crop yield estimation

Crop estimation can be done using remote sense data only, or by also utilizing other forms of data used in models for simulation. If the first method is used, historical data is very important. Namely, a relationship between the vegetation indices at a particular growth stage of the crop and the final crop yield must exist. The higher the amount of historical data, the more accurate results are (Crop Yield Estimation: Crop Yield Forecasting, n.d.). Figure 9 is a simple example that shows how this works. The images (false color in this case) were taken by SPOT 2 and SPOT 5 satellites, near Berzorf Lake, Germany.

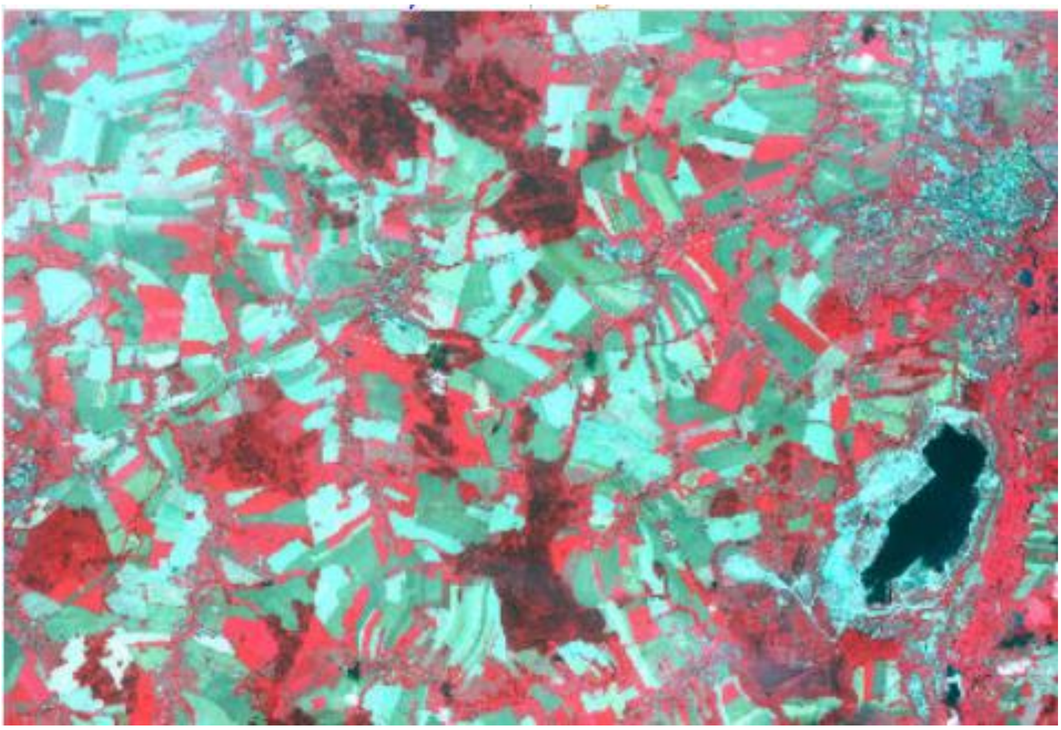
As it can be noticed, during May, the picture looks more "red" which means that a lot of vegetation is present, hence high NIR reflectance. Crops in May are in their growth peak. In August, in contrast, as shown in Figure 10, less "red" shows that the plant is actually focusing on producing the crop and not the green biomass. Finally, the "cyan" color is a result of the combination of blue and green. This means that empty fields have similar green and red reflectance and what is seen is the bare soil. Similarly, various other satellite images can be analyzed and information can be obtained by defining and understanding the meaning of the colors.

Figure 9: Crop in May 2005



Source: Crop Yield Estimation:
Estimating crop yield using only remote sensing data (1/2) (n.d.).

Figure 10: Crop in August 2005



Source: Crop Yield Estimation:
Estimating crop yield using only remote sensing data (1/2) (n.d.).

4 METHODOLOGY

4.1 Research questions

The research design is of exploratory nature, aiming to provide insight and understanding about the role of Earth Observation in agriculture monitoring. Data collection is unstructured and the data analysis is non-statistical. The research is a combination of the theoretical and empirical part. The former consists of Earth Observation background information acquirement, while the latter covers interviews with experts and the software usage. Additionally, the web service recommendation is discussed. The idea about this service is a result of the previous research conclusions, which show up the need to better decision making and a lack of the service of this kind.

Led by the major driver of this research, which is to better understand Earth Observation through the analysis of its environment, various opportunities and obstacles that it poses to agriculture in general, this section describes the methodology used in order to answer the defined research questions: What is the role of remote sensing in agriculture? How does the interpretation of satellite images work? What kind of opportunities and obstacles are encountered on EO data appliance? These research questions serve as guiding points for discussion with interviewees.

4.2 Interviews with experts

The topic of this research was chosen in consultation with Mr. Carvalho. He is the Chief Executive Officer of Vision Space Technologies GmbH. The topic choice was based on a concrete business idea that this company wants to implement. Vision Space Technologies operates in the aerospace and security sectors. Hence, Earth Observation appliance in FinTech industry is an interesting area to invest in. I was given the chance to have continuous interviews with Mr. Carvalho. His background knowledge from business and aerospace perspective, were very helpful in clarifying constantly the market needs and trends, as well as identifying the possibilities for a specific solution that can contribute in this field. The interviews were conducted time after time, depending on the research progress, during four months.

The flow of the interviews went as follows: First, I had to do a research about Earth Observation and remote sensing science, and see how this technique is used in agriculture. The first interview included questions regarding space and satellite terminology. All in all, it was an introduction about satellites' functionality and their capabilities. After the additional summary given by Mr. Carvalho, I was guided to focus the further research on European Space Agency Programme. Thus, the next part of the research was to find out more about the services provided by this programme, in particular. I was given an overall idea on what is provided in the market. Along with that, an important part was to understand the *know-*

how of these services. The second interview was based on several discussions about a list of services already found (provided also at the appendix of the thesis) and further clarifications on the functionality of these services. The experience of Mr. Carvalho was extremely helpful in this part, as he could easily understand the concepts, especially when sometimes they were not fully explained by the companies' websites. After going through the opportunities, the next part was to understand the barriers. The information about challenges would be useful to come up with an idea that can improve the existing barriers. Considering the above, the questions about the third interview were conducted as a result of the research results.

During the research, more specifically after the third interview with Mr. Carvalho, it became necessary to have a more detailed and a broader perspective about satellite data and processes related to them. That's why, talking to an expert who is working in this field, was the approach that would specifically help. Taking the advantage of the partnership that Vision Space Technologies has with European Space Agency, I could contact an employee of EUMETSAT regarding this information. The interviewee is Mr. Leonid Butenko. He is currently working as Meteorological Product Software Engineer at EUMETSAT. The interview was face-to-face and did not follow a strict structure but, rather, its flow was based on finding common points between his expertise and the needs of the research. It lasted for an hour and included five open ended questions. The open questions allowed to receive large amount of content, by allowing Mr. Butenko demonstrate his knowledge.

After the interview with Mr. Butenko, I was consulting Mr. Teixeira, the software developer at Vision Space Technologies. His experience in software development was especially important while discussing the proposal about the web service. Similarly as with Mr. Carvalho, the interviews were in line with the progress of the thesis during four months.

4.3 Software

Softwares represent a very important part in dealing with EO data. The empirical section covers the part of data maneuvering using SNAP, QGIS, and Copernicus public data. This approach allows practically seeing the steps of working with data and finding out the possibilities and difficulties (if any).

Data was based on Copernicus Programme -Copernicus Open Access Hub. The online courses provided by (GEO University, n.d.) and online tutorials like (Mallon Technology Ltd, 2016), (Indra Labs, 2016), (EO Open Science, 2017), helped to understand how to approach the data and how to work with the examples that can be found at the results section. Examples include the downloading process of products/images, and some steps that can applied to these images after they are downloaded. For instance: chlorophyll mapping, pins placing for better classification or calculation of NDVI.

5 RESULTS

5.1 Interview findings

The interview with Mr. Carvalho helped me understand the broad picture about EO data and the business potential behind it. He explained how EO data is increasingly being used by several industry sectors. The general aim is to cut costs, increase productivity, and/or generate business lines addressing new market demands. Nonetheless, the applicability of EO data to some of the trendy sectors is not fully unveiled. Fintech/InsurTech, an industry that Vision Space Technologies wants to be involved in, represents a huge potential, as according to his knowledge, there are already applications supporting this sector. Certainly, many paradigms could be explored. The goal of the business idea is to explore different paradigms of EO data applications that could revolutionize the industry. These could be, for instance, solutions that allow cost reduction to take action based on near-real time analysis. Mr. Carvalho, stressed one of the biggest challenges - the gaps in the chain of EO data. In between these processes, he mentioned, there is a chance to come up with solutions for consumers. It is for sure, that the available solutions work with this approach in mind. One big advantage is that, thanks to Copernicus programme, the barrier for accessing data is removed. But, the process of transforming this data into information is complex. Exploring the current market solutions would help to understand the *know-how* and serve as a guidance to come up with similar or even better solutions that can be supported by the company. One important aspect to keep in mind is the sensitivity of remote sensing regarding the crop type. For crops like coffee, sugarcane, it is way more complicated to monitor the growth cycles. Hence, the possible solution shall focus on commodities, like rice or grain. Stakeholders are in a constant need for more information that helps their decision making. Hereby, it is important to mention that Business Intelligence is also quite helpful, as it can comprise strategies and technologies to do the data analysis of the EO products and provide the end users (stakeholders) with the information they need.

The key points provided from the software development perspective, discussed with Mr. Teixeira, are as follows: First, one should analyze the system structure. In this case, the system architecture needs to consider the huge amount of data that it needs to handle, in order to make the predictions for a large number of areas around the world. System scalability shall be examined while designing this web service. This is particularly important, as the objective is to gather a vast number of users around the world. The public interface, i.e. methods that will be available for the web service users, needs to be also very well thought. Developers of third party apps should find it simple to use. Simplicity would allow them to take full advantage of the system for providing added value for their users. As for the infrastructure, and taking into account the scalability needed for a project like this, potential solutions include cloud computing options like Amazon Web Services or Google App engine.

I had the chance to talk to Mr. Butenko, who is currently working as Meteorological Product Software Engineer at EUMETSAT. He shared a bit from his daily work. Following are some of the main points he went through during the interview.

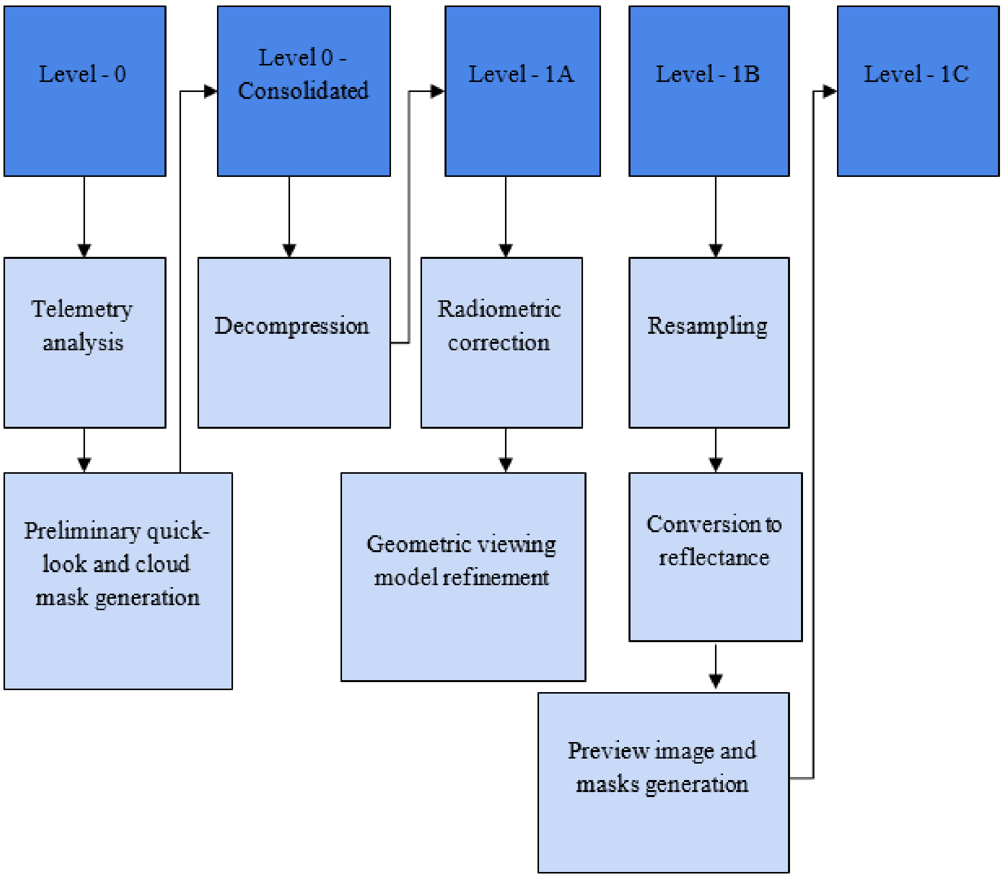
The core activity of EUMETSAT is to supply weather and climate-related satellite data, images and products – 24 hours a day, 365 days a year. The main customers of EUMETSAT are the National Meteorological Services of Member and Cooperating States in Europe, and other users worldwide. In order to provide this data, there are many instruments that software engineers work with. Mr. Butenko, works with Global Navigation Satellite System Receiver for Atmospheric Sounding (hereinafter: GRAS) instrument. This instrument provides stratospheric and tropospheric temperature and humidity profiles that can be assimilated into Numerical Weather Prediction models. GRAS needs a full system to provide products. Daily, it supports a minimum of 500 atmospheric profiles. On the question of giving a brief explanation about the process of obtaining data, he stated that GPS satellites rise or set on Earth's limbs. This process is known as occultation. GRAS tracks the phase of GPS signals at Metop satellite over an occultation interval. Due to Earth's atmosphere, there is a phase delay caused each time the GPS signal traverses the Earth's atmospheric limb. Bending angles are derived through comparing this measured phase with the expected phase if the atmospheric problem would not exist. In general, eight satellites for navigation purposes can be tracked with GRAS. Additionally, this instrument can track two satellites for rise and two for set occultation measurements (What is GRAS, n.d.). In regards of the type of data they provide, Mr. Butenko said that they do provide data in Level O and Level 1. In a nutshell, they provide this data to clients who later use them in their models. Figure 11 (Processing Levels, n.d.), shows the different levels that the image goes through before it is provided to the user. There are practically five levels, i.e. Level-0, Level-0 Consolidated, Level-1A, Level-1B, and Level-1C. Level-0 and Level-1A products are Payload Data Ground Segment internal products not made available to users.

When asked about the biggest obstacles while working with raw data, according to him, one of the biggest limitations is actually reading/decoding the data. It certainly depends on the data, but generally speaking, it requires a lot of tools to transform them in a readable form. Furthermore, some other issues in this aspect are:

- The lack of possibility to visualize the data. Not all data can be visualized. In fact, some data can be used in the models of clients, but still are not able to be visualized.
- There is also a high need for data standardization. Generally speaking, the most used data format is still Binary Universal Form for the Representation of meteorological data (hereinafter: BUFR). This brings its disadvantages since BUFR format is perceived as complex. It cannot be integrated into Web Services, is not suitable for external public data exchange, and is World Meteorological Organization community specific. BUFR is usually the most required format. There are however, clients that want this data in a more readable format, such as in File Transfer Protocol (Satellite Data Formats and Standards, n.d.).

– The existence of different formats results automatically in a need of addressing different limitations.

Figure 11: Processing levels from Level 0 to Level -1C



Source: Adapted from Processing Levels (n.d.).

Another barrier, according to Mr. Butenko, is also the lack of clarification about users' needs. "They know what kind of data we provide," - he says - "but don't know how to practically make use of it. And this is an answer, we cannot provide." Applying the data remains always a challenge. However, there are also cases when users know exactly their needs and they even suggest additional requirements that can help them predict better. For instance, the main clients, weather forecast companies, come up with these suggestions that would help their data accuracy.

An additional issue is the lack of agreement between institutions, as well as the lack of communication between countries and global navigation satellite systems. Most of these systems refuse to cooperate. They even change protocols without informing in advance. All in all, there is a competition nature in between, and this limits to bring out the best results for using EO data. Besides, there are innovation problems. Most satellites were developed

30 years ago, which means that they do not fit with current electronics and modern technology. Finally, another problem is that processing time is not the same for all data. Some of them require lots of processing, while others less. If the latter case, then data can be sent to clients immediately after it is captured. Time accuracy is very important. Near-real time service means that the difference between the measured and actual data delivery is only two hours. If it requires more time, then the data is already considered old.

5.2 Copernicus data

As mentioned in the first part of the thesis, Copernicus represents one of the most sophisticated and ambitious earth observation programme to date. It is the programme headed by European Commission in partnership with European Space Agency. Sentinel satellites are the devices used for Earth Observation. So far, there are three types of Sentinels: Sentinel 1 (responsible to emergency response), Sentinel 2 (responsible for land monitoring), Sentinel 3 and Sentinel 6 (responsible for ocean and water monitoring) and Sentinel 4 and Sentinel 5 (responsible for atmosphere monitoring). For each Sentinel mission, there is another division of satellites into A and B (European Space Agency, 2017). An interesting fact to mention is that, data provided from these satellites is sometimes just a number, or a few numbers. But, that number is usually enough in understanding better the changes of our planet (European Space Agency, 2016).

5.2.1 Accessing and downloading data from Copernicus

This section describes the step by step procedure for accessing and downloading data from Copernicus.

1. Accessing the website https://scihub.copernicus.eu/ and choosing Open *Hub*.

2. Sentinel map shows up as in Figure 12.

3. After creating an account, the platform shows the tools that can be used: navigation map tool, pan activation, and polygon. Region of Interest (hereinafter: ROI) means drawing a box around the area that the user is interested to focus on (see Figure 13).

4. The search criteria option in left upper corner allows choosing and filtering based on various criteria such as mission, date, product type and so on. Figure 14 illustrates these options. In this case, Sentinel 2 mission is chosen (as this satellite is responsible for land covering) and the range of dates: 29.08.2017-30.08.2017 (the dates are chosen randomly).

5. After clicking the search button, the results as in Figure 15 are shown. Herein, it is worth to mention that due to large amount of data, data loading might take some time. Green highlighted rectangles correspond to the results in the left.

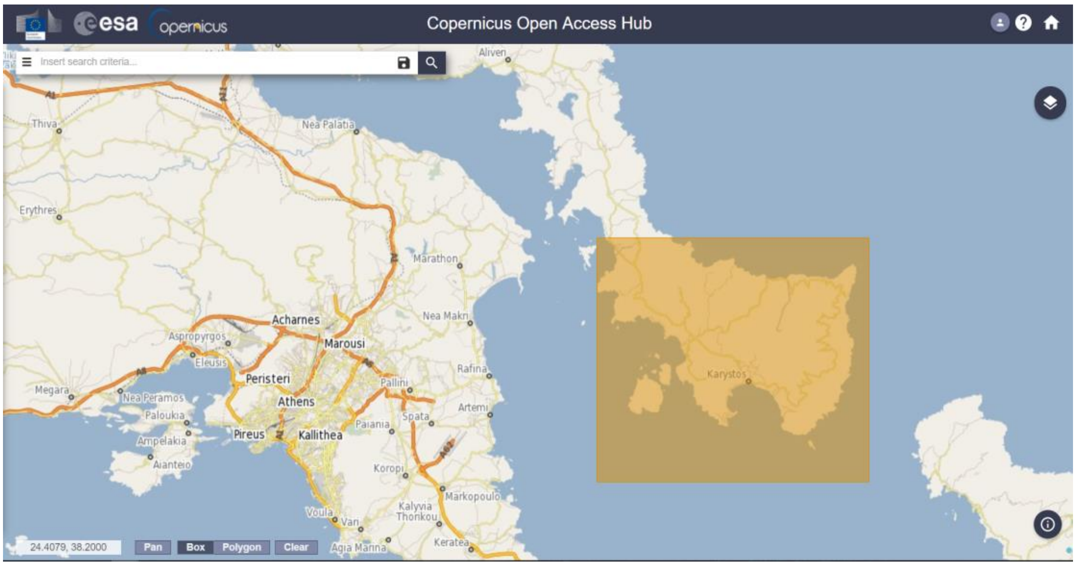
6. The view (“eye”) option gives more information about the product/platform/instrument. In this section, data can be downloaded (see Figure 16).

7. After downloading it, data needs to be opened, in this case, with SNAP. The Red Green Blue (hereinafter: RGB) window can be shown by clicking: Window - Open RGB (see Figure 17 and Figure 18).

Figure 12: European Space Agency Platform mapping

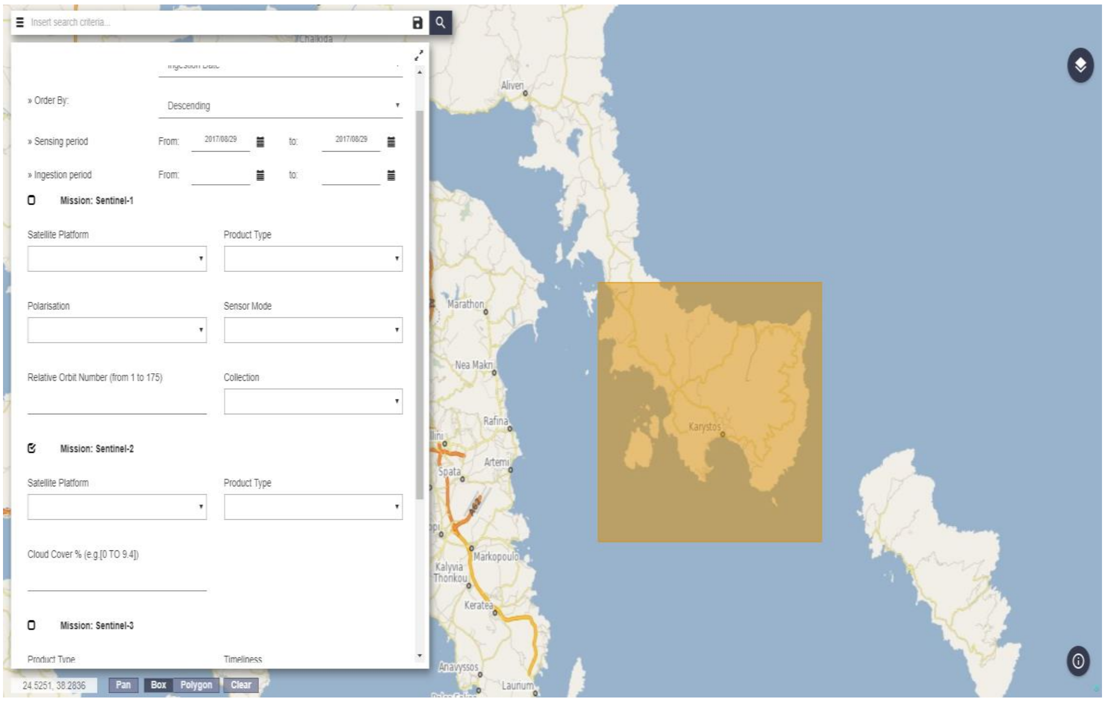
Source: own work.

Figure 13: Drawing ROI



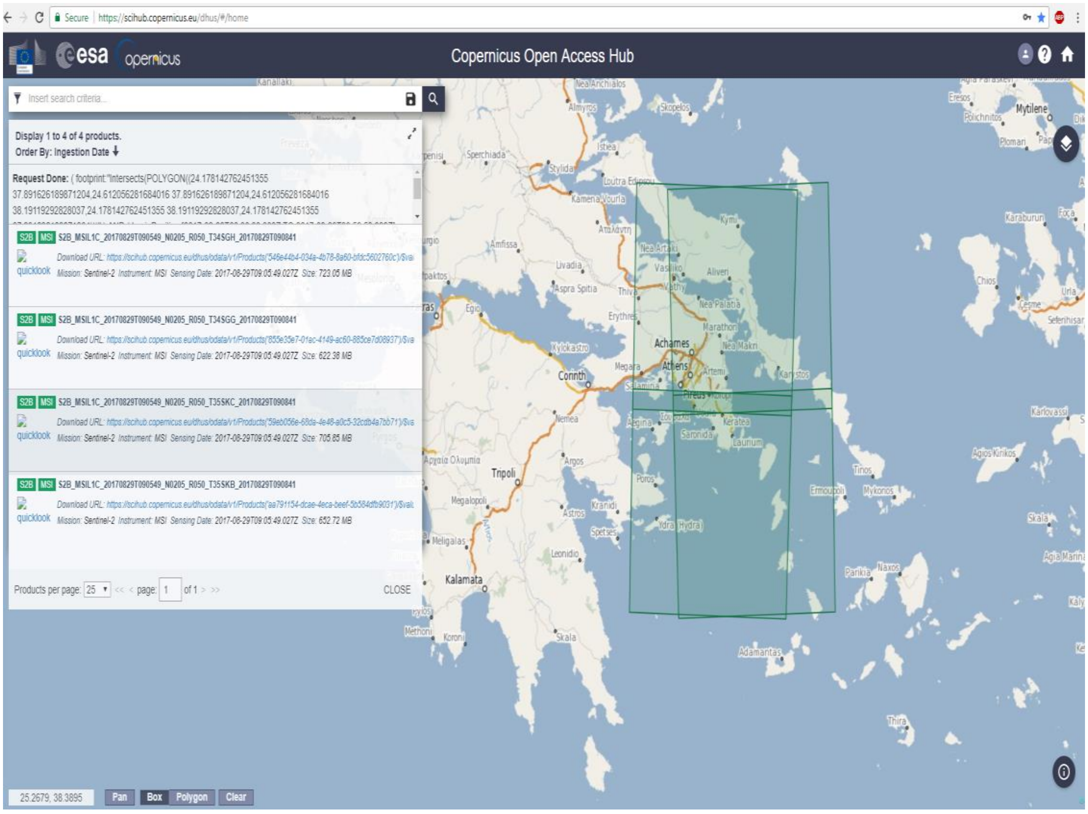
Source: own work.

Figure 14: Search criteria options



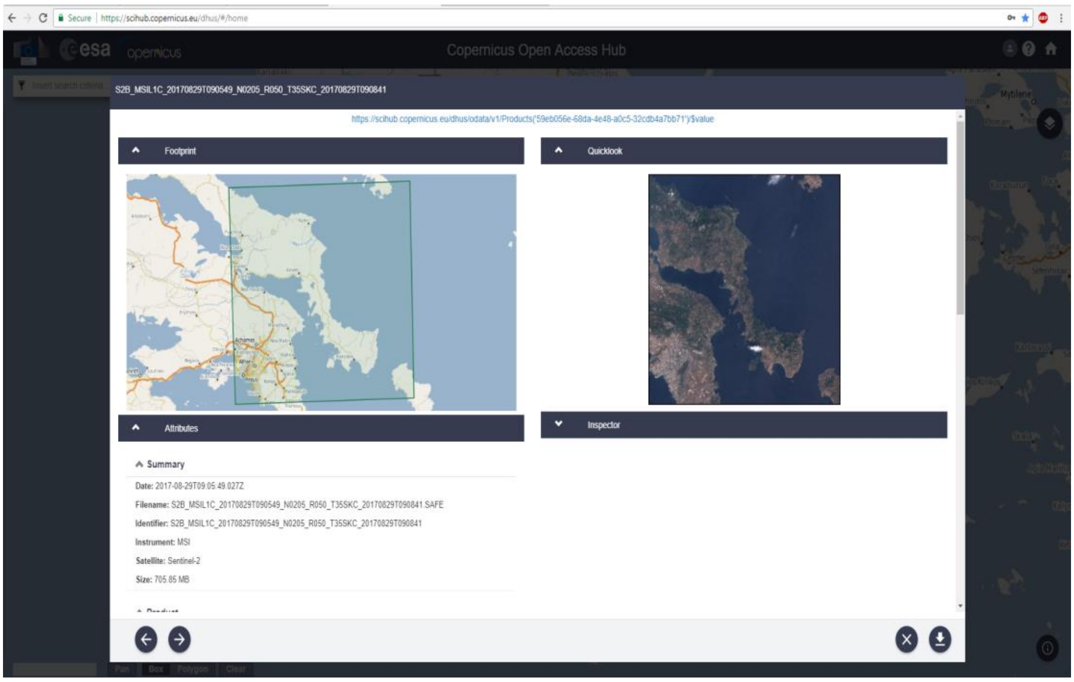
Source: own work.

Figure 15: The results shown after the search criteria



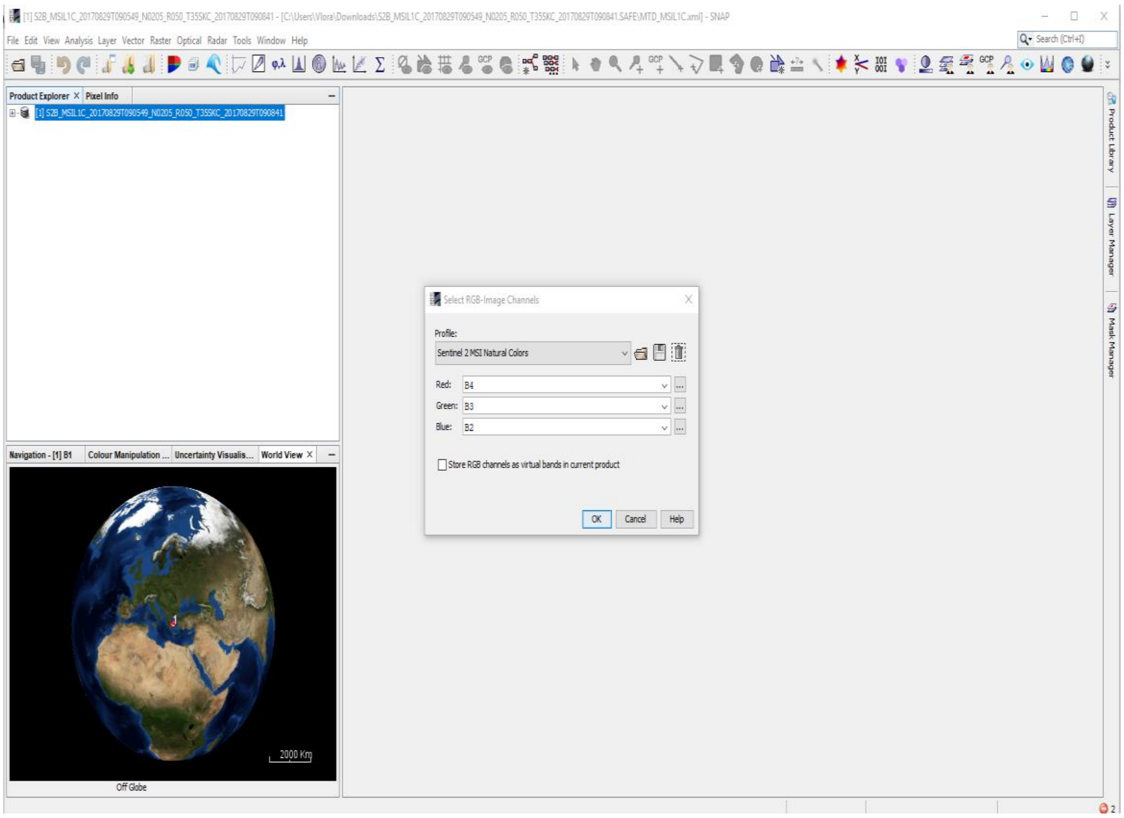
Source: own work.

Figure 16: Summary of data



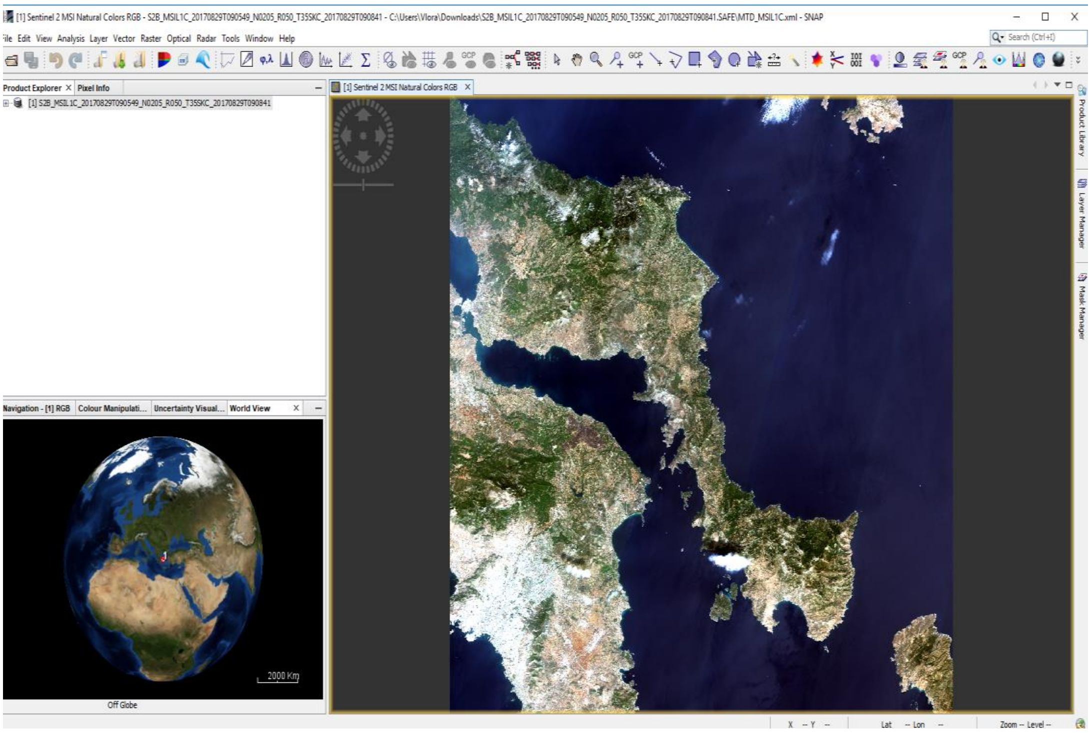
Source: own work.

Figure 17: Opening the RGB



Source: own work.

Figure 18: The RGB of the chosen ROI



Source: own work.

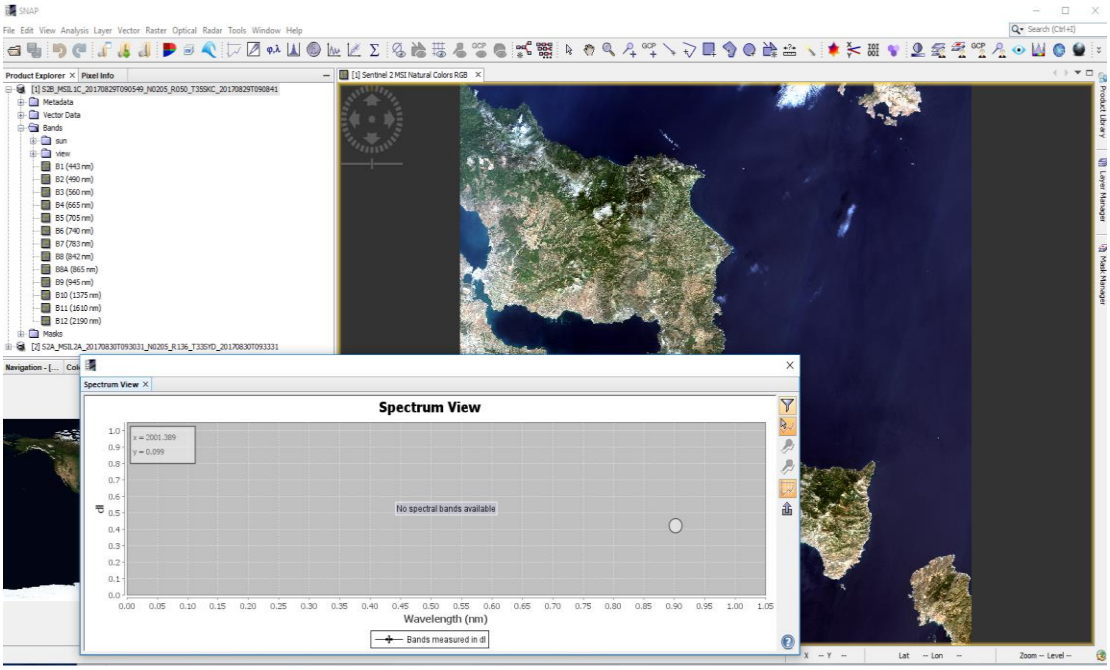
Based on the previous steps, it can be seen that downloading data from Copernicus is very straightforward and fast. By just some some clicks, satellite images can be downloaded in one’s device. The user interface is simple to navigate with and satellite images from all over world can be obtained. One of the disadvantages, in this part, is the big size of images. This means that, in case of more images, a lot of space is needed. In addition, good internet connection is also very important. Another alternative to download the images (shown in the previous steps), is having them in jp2 format. This can be done by accessing http://sentinel-pds.s3-website.eu-central-1.amazonaws.com/. This alternative allows the user to be more selective in data. In this case, one can eliminate the problem of big data sizes, as only some bands can be selected, and not necessarily the 13 bands (Mallon Technology Ltd, 2016).

5.2.2 SNAP

SNAP is a common architecture for all Sentinel toolboxes. Fast image display and navigation, advanced layer management that allows manipulation of new overlays, rich ROI definition for statistics and various plots, easy bitmask definition and overlay are some of the great features provided by SNAP (SNAP, n.d.). Through the following examples, I’ll try to demonstrate the ease and features of using data with SNAP. These are the steps that describe how to show the spectral plot control.

1. The image is opened in RGB. In the toolbar menu, the *Spectrum View* is selected, something that shows the window as in Figure 19.

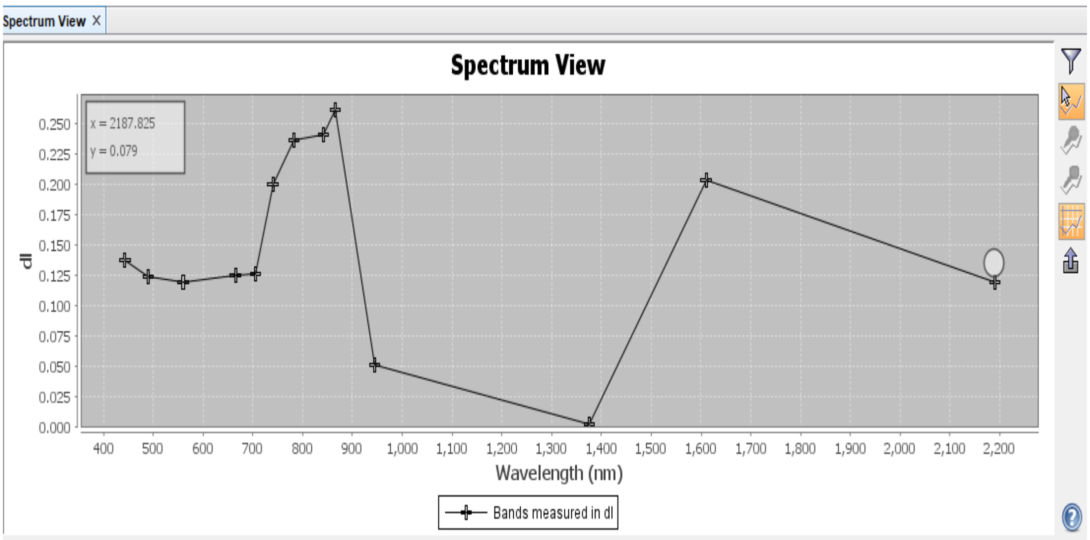
Figure 19: Spectrum View



Source: own work.

2. The filtering option allows choosing the desired symbol. After applying, by placing the cursor in different places of image, different spectrum views are shown. One example is shown in Figure 20.

Figure 20: Spectrum View of a specific point

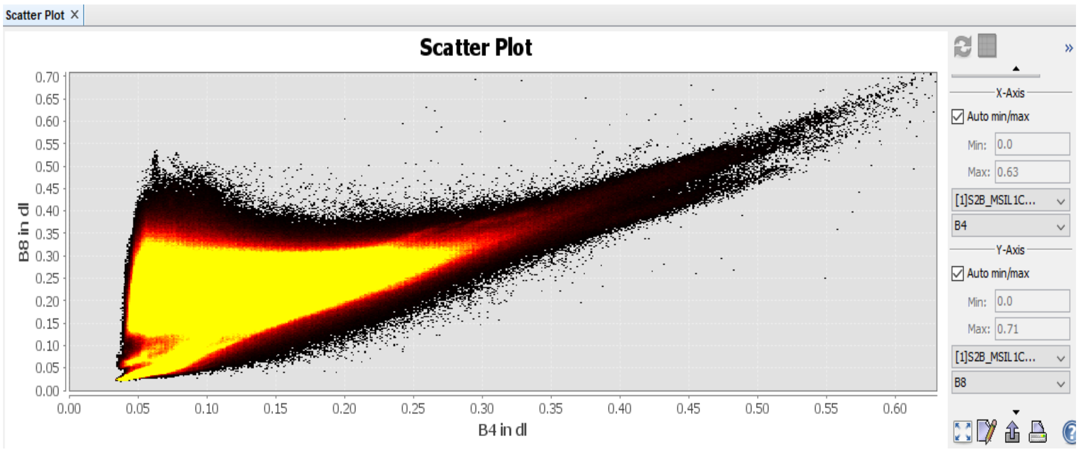


Source: own work.

5.2.2.1 Scatter Plot

Scatter plot is another feature to be used. In the same S2B image, after showing the RGB picture, in the menu bar the *scatter plot* is selected. In the left part, at the X and Y axes the bands are selected. In this example, B4 and B8 are chosen. This scatterplot shows the relationship between both bands, as well as the spectrum distribution for the chosen product (the result is shown in Figure 21):

Figure 21: Scatter Plot

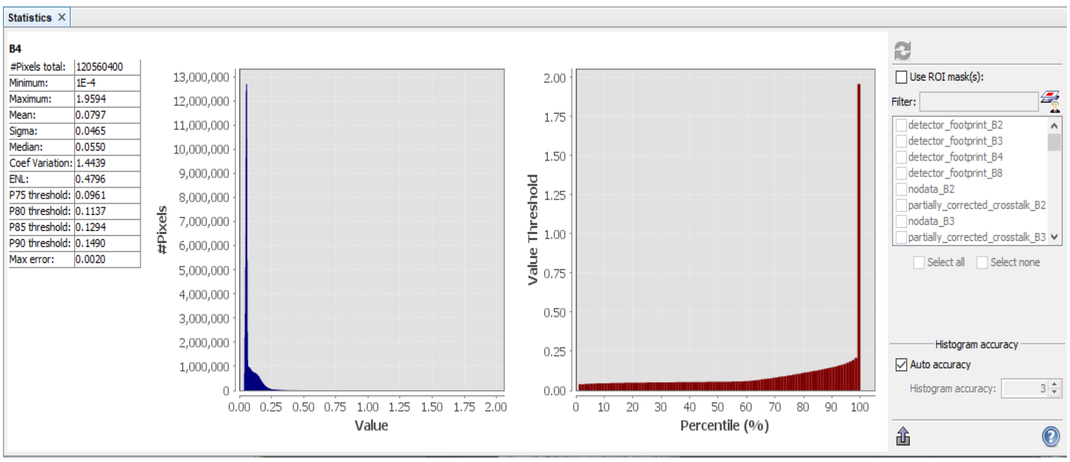


Source: own work.

5.2.2.2 Computing Statistics of data

SNAP gives also the option to compute various data statistics. After choosing a specific band (in this case B4), in the menu bar, *statistics* is chosen. The result is as follows, where Pixels details, the threshold values are shown (see Figure 22).

Figure 22: Statistic analysis of data

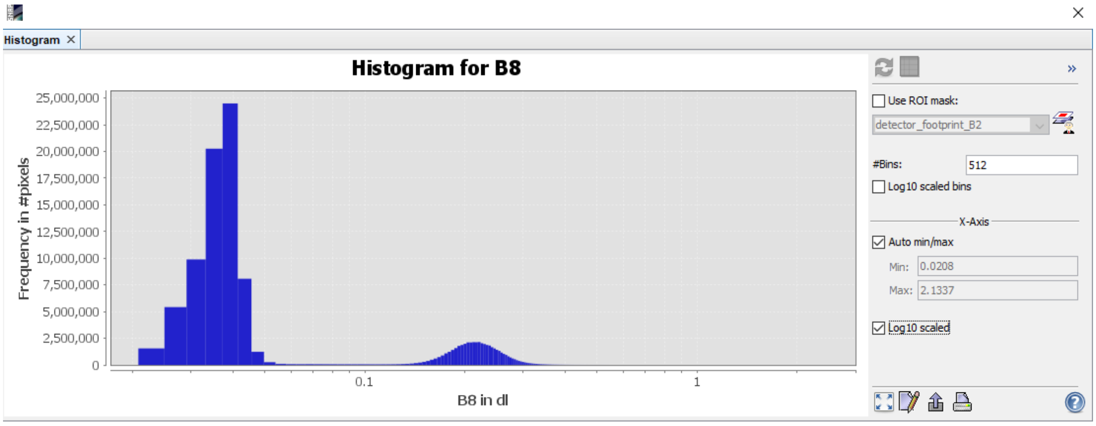


Source: own work.

5.2.2.3 *Histograms*

Creating histograms is an easy task to do in SNAP. By just choosing the band (in this case band 8), and the histogram option in the menu, this result is shown (see Figure 23).

Figure 23: Histogram for Band 8

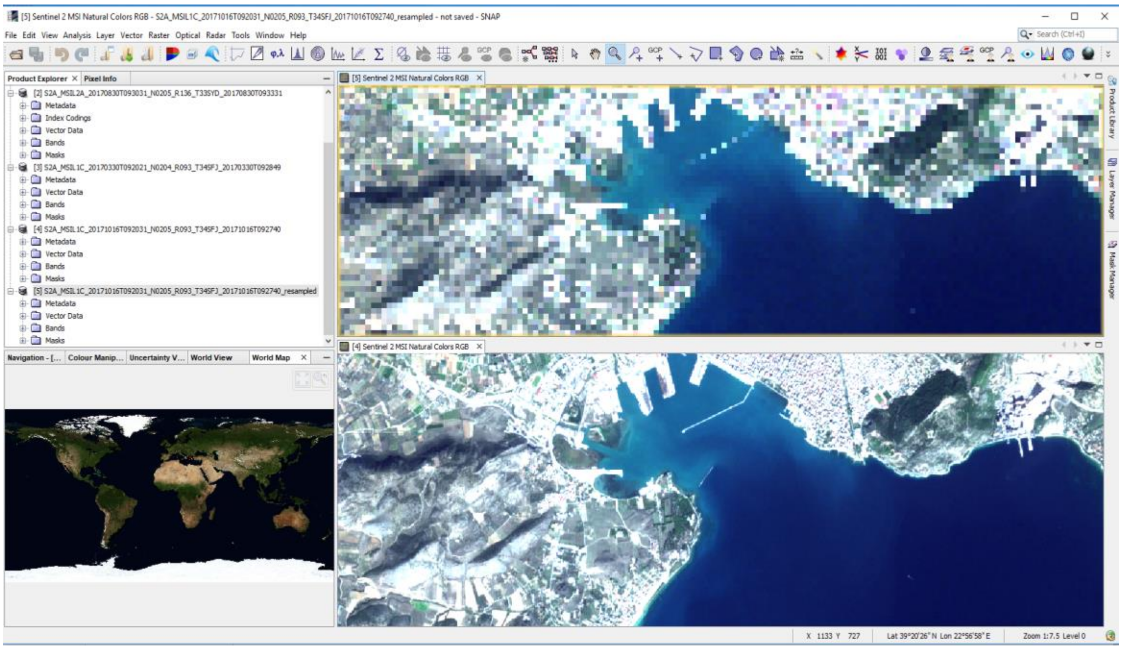


Source: own work.

5.2.2.4 *Resampling image*

Figure 24 shows the feature of resampling an image and the difference in their spatial resolution when zoomed in.

Figure 24: Resampling image



Source: own work.

5.2.2.5 *Chlorophyll Mapping*

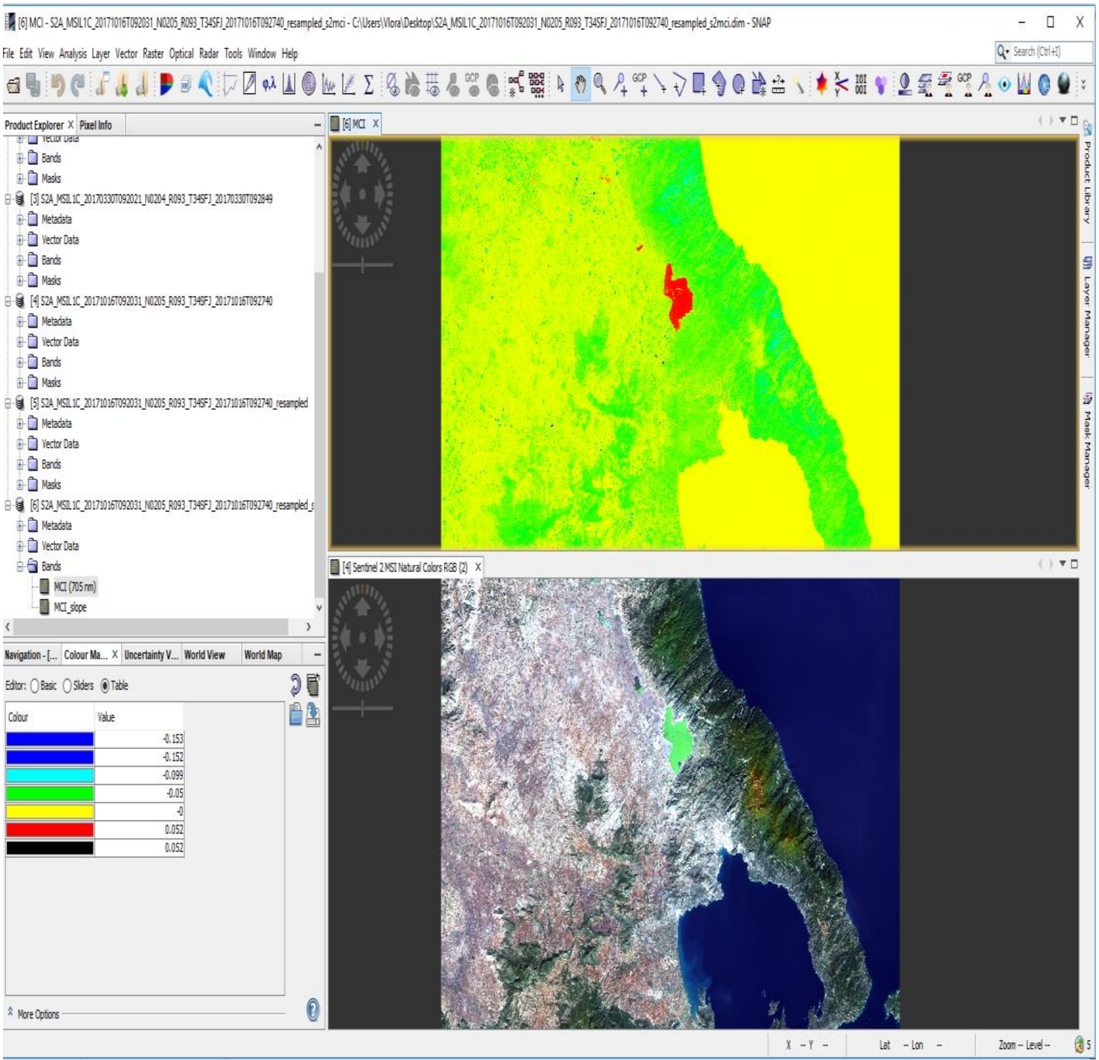
In the same resampled image, the chlorophyll mapping can be done as follows:

1. By choosing the steps: Optical - Thematic Water Processing - S2 and MCI Processor. After running it, new products are created (note under bands, *MCI* is created) and the resulted picture is shown as in Figure 25. The chlorophyll is notes in the red color.

2. The colors were changed from gray scale to the current ones (see Figure 26), to visualize the results better. This was done by importing the color palette and choosing view*_water_ch.cpd.*

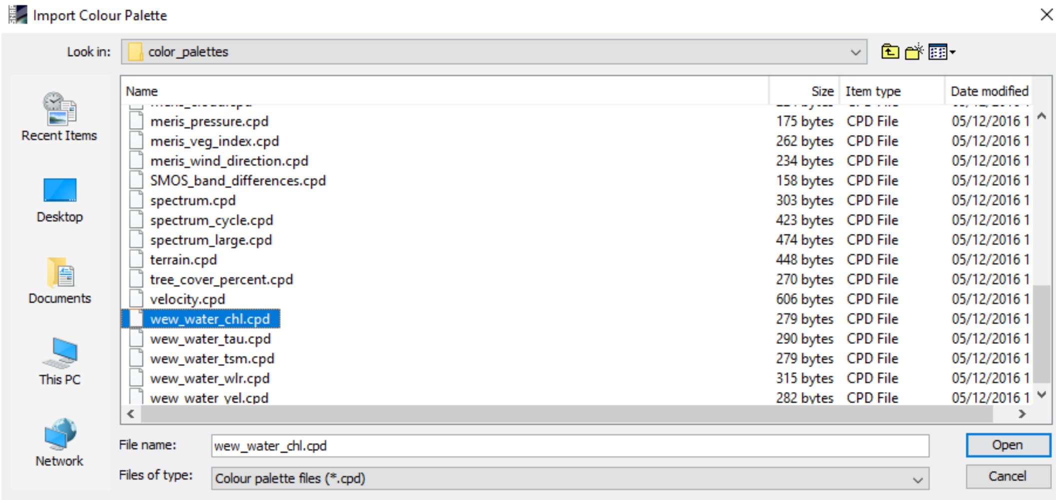
3. Finally, it is important to note that the values shown are relative chlorophyll values, as the original ones need to also consider the *in* situ data.

Figure 25: Chlorophyll Mapping



Source: own work.

Figure 26: Changing the result colors



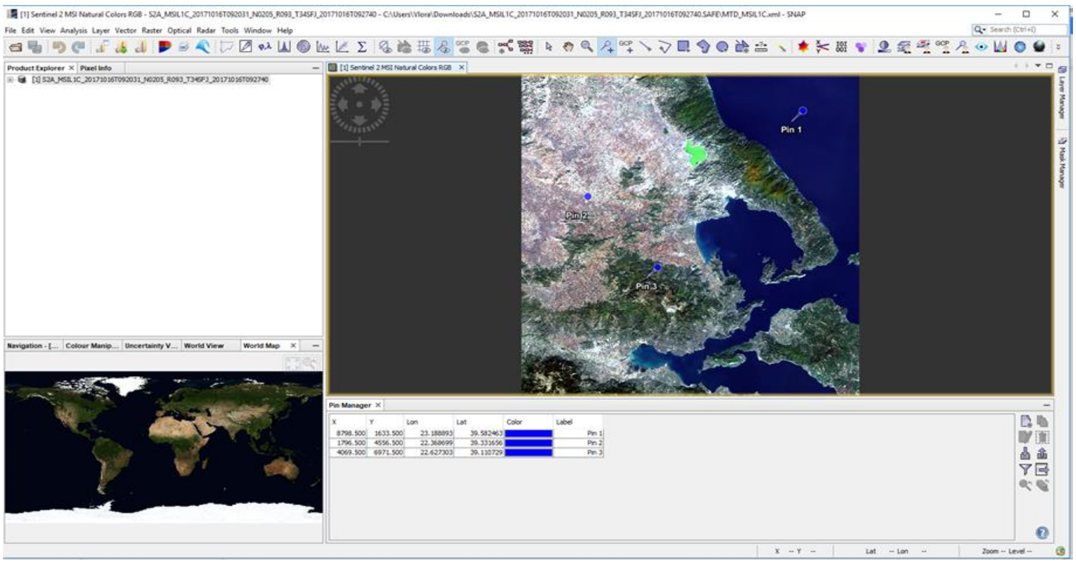
Source: own work.

5.2.2.6 *Pins and their management*

Pins are an awesome tool to showcase the different types of classification of the image. If for instance, the user would like to showcase the land, water, and forest of the image, they can be added by just few steps.

1. After opening the product, the *pin placing tool* is located at the menu bar. Pins can be placed in different places, such as in water, land, and forest. An example is shown in Figure 27.

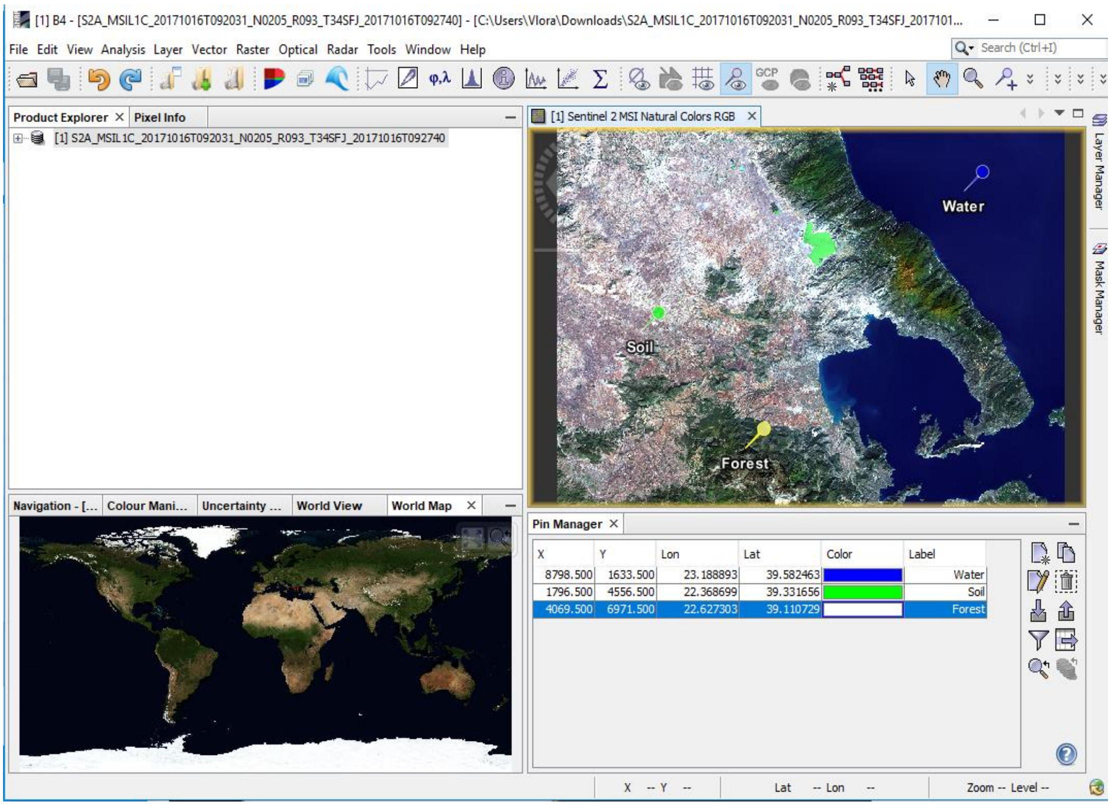
Figure 27: Placement of pins



Source: own work.

2. *Pin Manager* button enables other properties like: change of pins names and colors respectively, pixel coordinates/position. Figure 28 shows some changed properties.

Figure 28: Pin Manager properties



Source: own work.

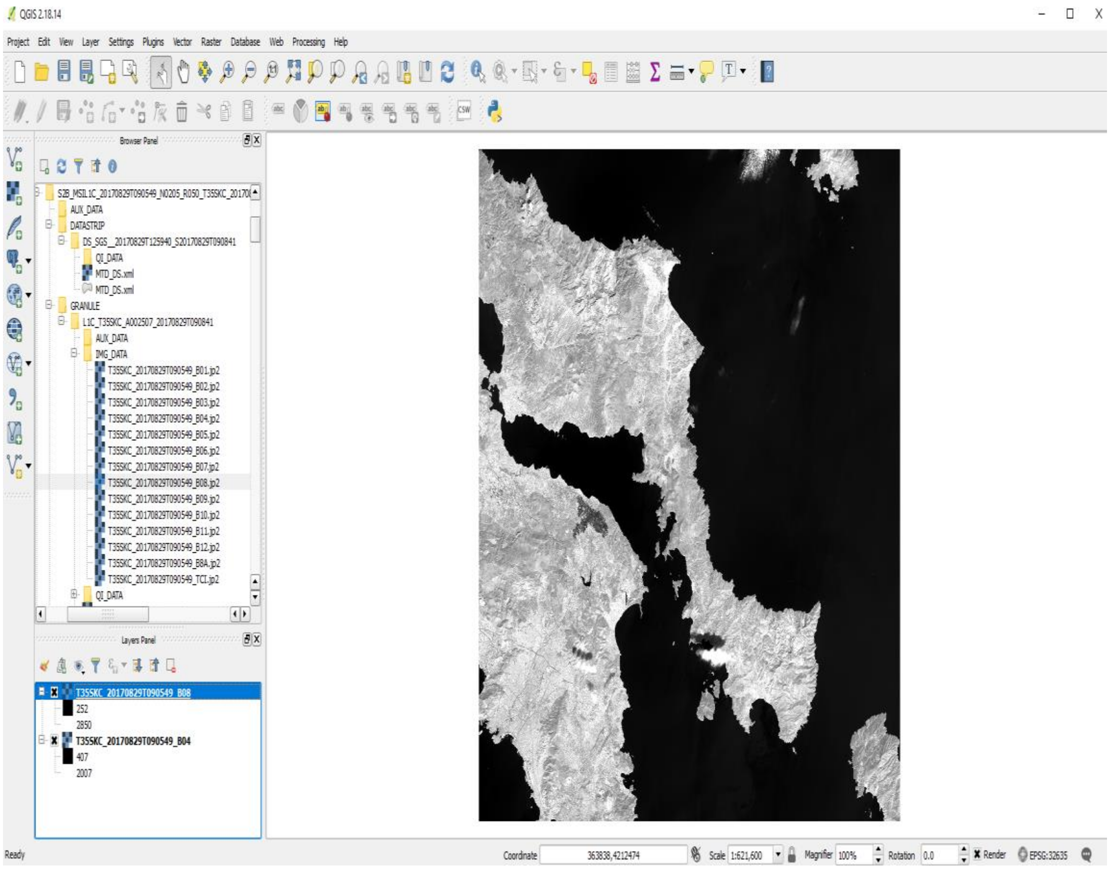
The previous examples show some of the many features that can be applied to an image with SNAP. By using this powerful Earth Observation application, various useful changes can be applied at the satellite image. Mostly, they help in the readability, like for instance the usage of pins. As seen, by placing the pins, it becomes easier for the user to define the classification of the image. Similarly, the chlorophyll mapping is another example that can be easily applied and is highly helpful for defining the interesting area for the user. But, it was hard for instance, to really make use of statistics without further information. The information about bands of the image is not clearly defined, as depending on the software, they may differently represent the red or green bands.

5.2.3 QGIS example - calculating NDVI

QGIS is a free and Open Source GIS. It allows users to create, edit, visualize, analyze, and publish geospatial information on various operating systems (QGIS, n.d.). The following example shows how to calculate the NDVI using QGIS. The necessary bands are NIR and Red (B8 and B4 respectively).

1. NIR and Red bands loaded (as shown in Figure 29).

Figure 29: NIR and Red band loaded



Source: own work.

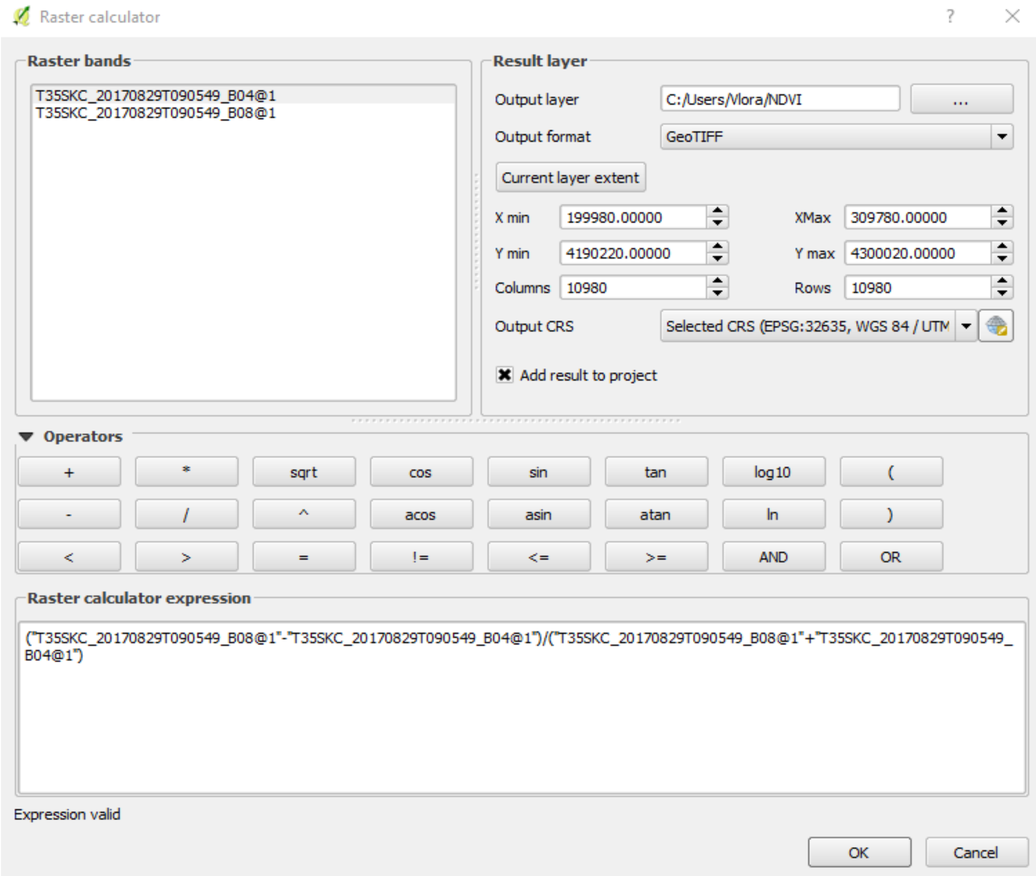
2. By using the Raster Calculator (Raster - Raster calculator), the actual NDVI formula can be added: NDVI = (NIR-Red)/(NIR+Red). In this example, B8 and B4. At the *output layer*, the location and name (NDVI, in this case) of the geotiff are specified (see Figure 30).

3. After applying it, it takes a while until this result (see Figure 31). The bands should be unselected, and on the left side, the values -0.238261 (black color) and 0.57111 (white color), show up. The picture is still not so user friendly and some further operations can be done to make the changes more visible.

4. By following the sequence: properties - single band pseudo color – PRGn, minus values correspond to purple, while highest numbers to the positive values (as shown in Figure 32). The higher the value, the higher the vegetation and vice versa.

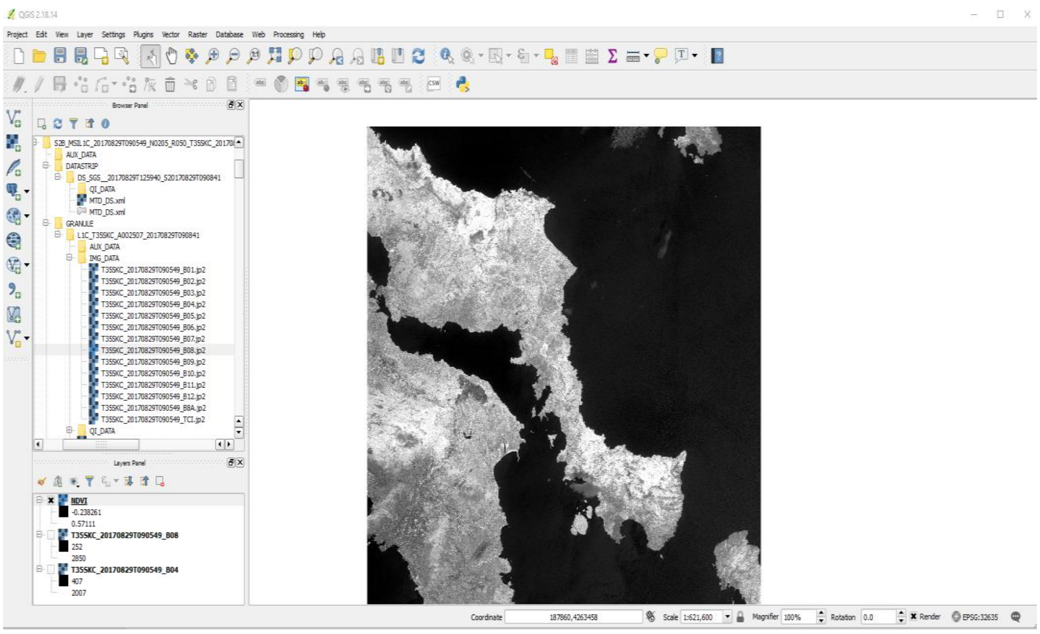
5. The final result looks like in Figure 33.

Figure 30: Raster calculator



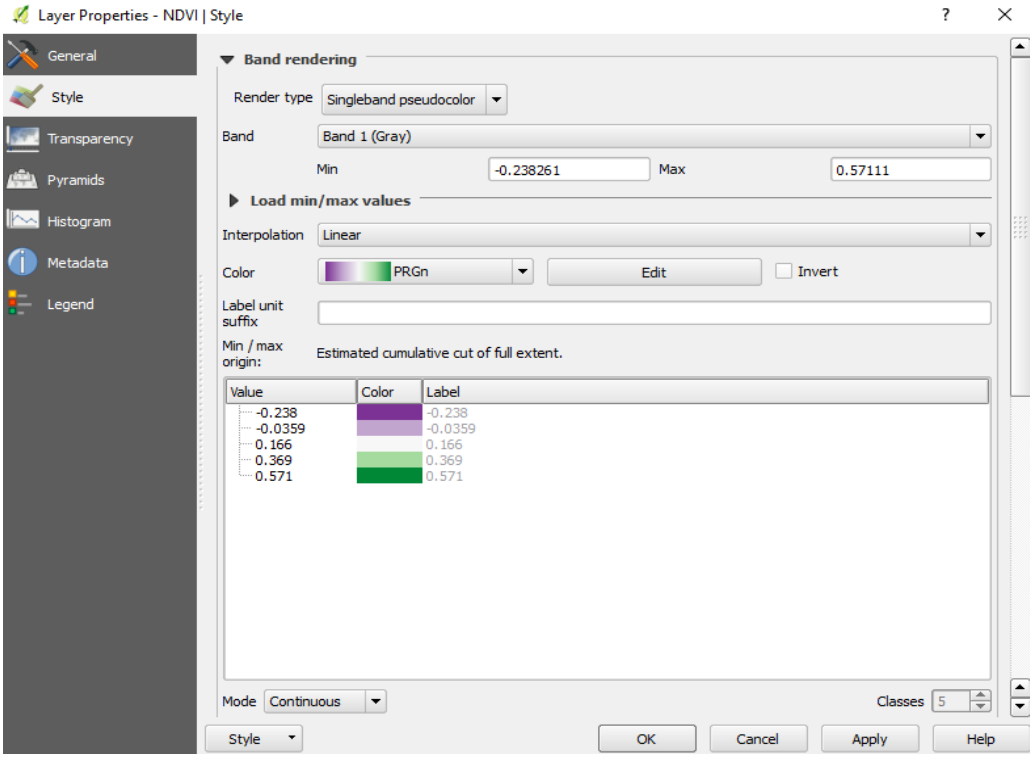
Source: own work.

Figure 31: NDVI values



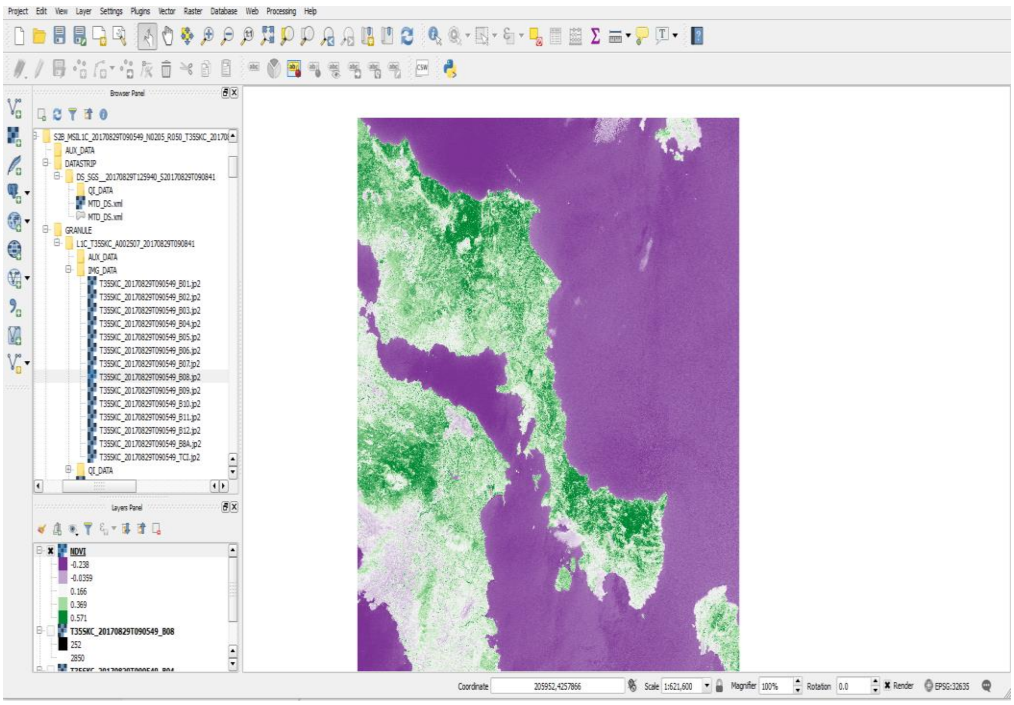
Source: own work.

Figure 32: Changing NDVI style



Source: own work.

Figure 33: Vegetation shown in other Purple, red and green.



Source: own work.

The shades of green clarify the vegetation better. The minus values of NDVI are actually glaciers and lakes, the white color represent mostly the bare soil, while the green are the valleys and the irrigated areas.

This example shows how to come up with more informational images, by just some steps. NDVI, as noted, is one of the most common measures in agriculture. Thus, the opportunity to see some basic information that farmers are mostly interested in, can be easily solved in QGIS. One of the biggest advantages worth to mention, is that since QGIS is an open source GIS software, it is valuable for all parties with no funding’s possibilities, like researchers, commercial companies, and so on. The open source brings also the advantage of having free access to original codes for any software modifications. But, QGIS becomes hard to be used, in case of both: no previous GIS knowledge and lack of knowledge for data processing. Furthermore, it has a very technical documentation which makes it less user friendly for non-experts. From this perspective, one is limited in terms of using all the features of the software.

6 DISCUSSION

6.1 Main findings

The results showed that, there is indeed a lot of potential and interest for investment in the agriculture monitoring. Thus, products based on Earth Observation are many. Mr. Carvalho stated many times that indeed, businesses are willing to invest in space related services. In his words, this is a very hot topic. EO data is provided for free with the main aim of serving society. The availability of data is a huge advantage as it allows contributing from various perspectives. The free access though, is not news. What has changed is the development of more efficient storage and processing capacity. Making sense of data remains complex, as it is hard to come up with quantitative terms and answer the typical questions from the farmer perspective, like: what is the amount of yield production increase/decrease in the following years? This is a question that requires previous experience, especially in data interpretation. Based on the research and cases, this process for providing the right information to stakeholders is very complex. It requires knowledge from data science, geography, and business approaches. Vision Space Technologies GmbH, due to lack of experts from each field, finds it more convenient to come up with a middleman kind of solution. Furthermore, another differentiation that could be offered is targeting a specific market. The section of Recommendations will explain the details about this.

Regarding the software usage, a remarkable finding is that the downloading process and accessing the data is a relatively simple process. Yet, when it comes to further processing using SNAP or the QGIS software, it becomes complex for non-experts users in GIS or image processing.

6.2 Implications and Recommendations

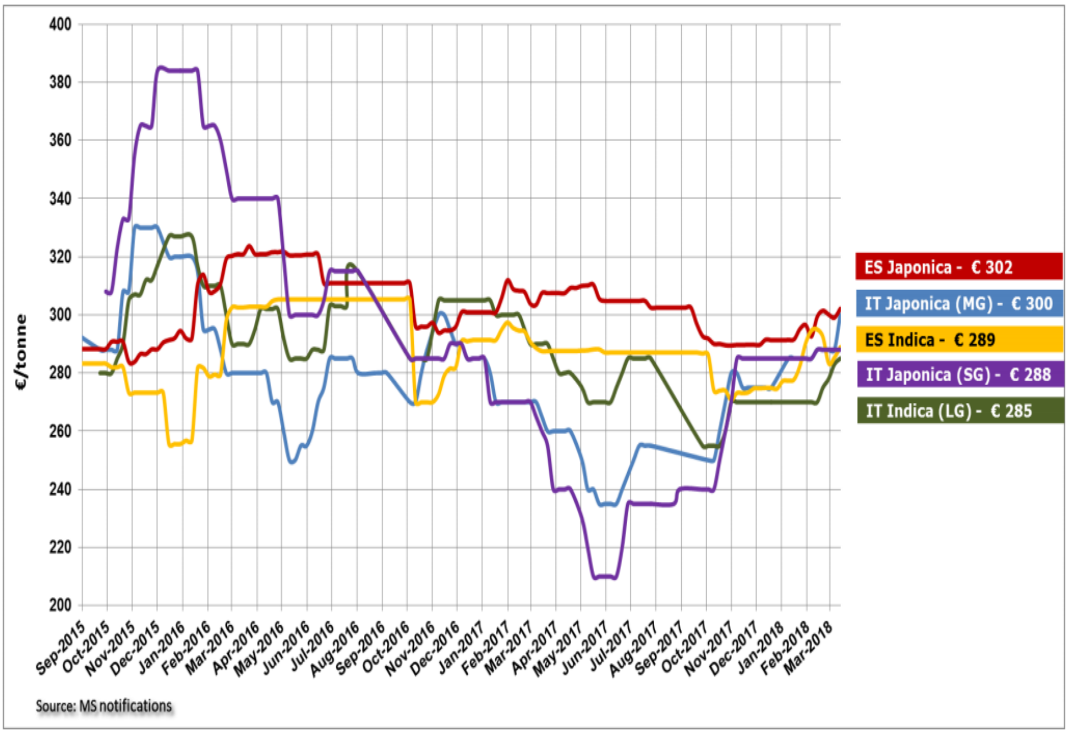
Based on the results and the overview of the situation, this part focuses on rice crop: a) it firstly includes the rice market overview and b) a proposal that could later be converted into a real service for this specific crop.

6.2.1 Rice market overview

The international trade of rice market is still thin. It is characterized by government intervention that is strong (namely: state trading and self-sufficiency agendas), large informational flows, high level of segmentation and high concentration in exports (Agricultural Market Information System, 2016).

The current European Union market prices expressed in tons according to (European Commission, 2018) vary as shown in Figure 34.

Figure 34: World Rice Market



Source: European Commission (2018).

The European Union imports yearly circa 1.2 million tons of milled rice. The European Union rice, in fact, does not represent a significant role at global level - it is less than 1% (European Commission, n.d.).

Rice is one of the most important cereal grains, consumed in different parts of world. It is the third highest produced agricultural commodity worldwide. The exporting countries (ordered by those that export the most) are: India, Thailand, Vietnam, Pakistan, United States, Burma, Cambodia, Uruguay, Brazil, and Argentina. Importing countries, on the other hand, are China, Nigeria, the European Union, Saudi Arabia, Philippines, Cote d'Ivoire, Iran, Indonesia, and Iraq (Nag, 2017).

But, how is the price of rice set worldwide? Since the concentration of rice is focused in only some countries, this means that even a small change in supply, demand, or policy would lead to tremendous changes in rice prices. This already happened during the price crisis in 2007-2008. Although rice is typically consumed where it is produced, the international rice market has shown a tremendous increase - translated in numbers from 7.5 million tons annually in the 1960s to an average of 28.5 million tons during 2000 to 2009. This information and figures illustrate that the rice market is very interesting and opens up different opportunities to analyze (Rice prices and market, n.d.). Considering also the analysis of current services provided, it is obvious that the role of remote sensing in this chain is very important.

6.2.2 Web service proposal

The idea is to provide a near real-time service via web, which provides information about the development and status of rice, as one of the main five worldwide crops. Given the research results, currently, the available solutions offer images as products that can be further processed. That said, what users usually get is not a final product, but a semi-final image that still needs to be processed. Another observed feature of these services offered from companies like Planet Lab and others listed at Table 1 is that they usually focus on some specific countries. The idea is to provide a similar solution, but with the feature of functioning with worldwide data, since Copernicus programme already covers worldwide areas.

Why is this information important? Rice production can be adjusted not only by market demand but also by offer (current status of worldwide crops). By shortening or extending the supplement accordingly to both ends (demand/supply), farmers can produce more accurately, i.e. avoiding the situations of consumer surplus or shortage. Governments would be also provided with more information - something that would improve their decision making and allow for better land management for producing the different types of agricultural commodities. Furthermore, as according to (Reyes, 2015), there are many factors that contribute in the uncertainty of rice crops. These factors include: climate change, the booming population, rising urbanization, the fact that rice represents a political commodity, government policies, and last but not least, the lack of price transparency. The latter is especially a relevant factor where the proposed web service could serve as a solution to help improve it.

The target customers of the proposed web service are people involved in stock market, importers, and exporters of rice (as the parties interested the most for the price), people in the value chain of rice stocks and governments. Governments could be particularly interested in this service especially for the crops from which the country depends mostly on. The target customers are *not* end users/random buyers of rice as they would not be able to decide on the price anyways.

The web service and the information it will provide would lead to interesting further analysis on how things can change later in the market. Basically, what could be the implications in the competition? One possible scenario is that the reaction would be similar as in changes for other commodities. Thus, if a party/country knows better the information for the price and crops, then the decision for importing needs to be very well thought. The same would apply to those countries who export. All in all, more information would certainly cause an increase of price transparency.

The presence of the mentioned projects indicates that the opportunity has been noticed by companies already. Hence, investing into these kinds of services is a way to go. The advantage of the proposed solution is that along with the data, it will be able to provide also the price forecast. The idea is to make the correlation of price and proper resolution of worldwide crops. How would this forecast be possible? It will be based on historical data for rice first, and then be correlated with geospatial data. The historical information can be obtained from sources like: Markets Insider (http://markets.businessinsider.com/commodities/rice-price) or Index Mundi (https://www.indexmundi.com/).

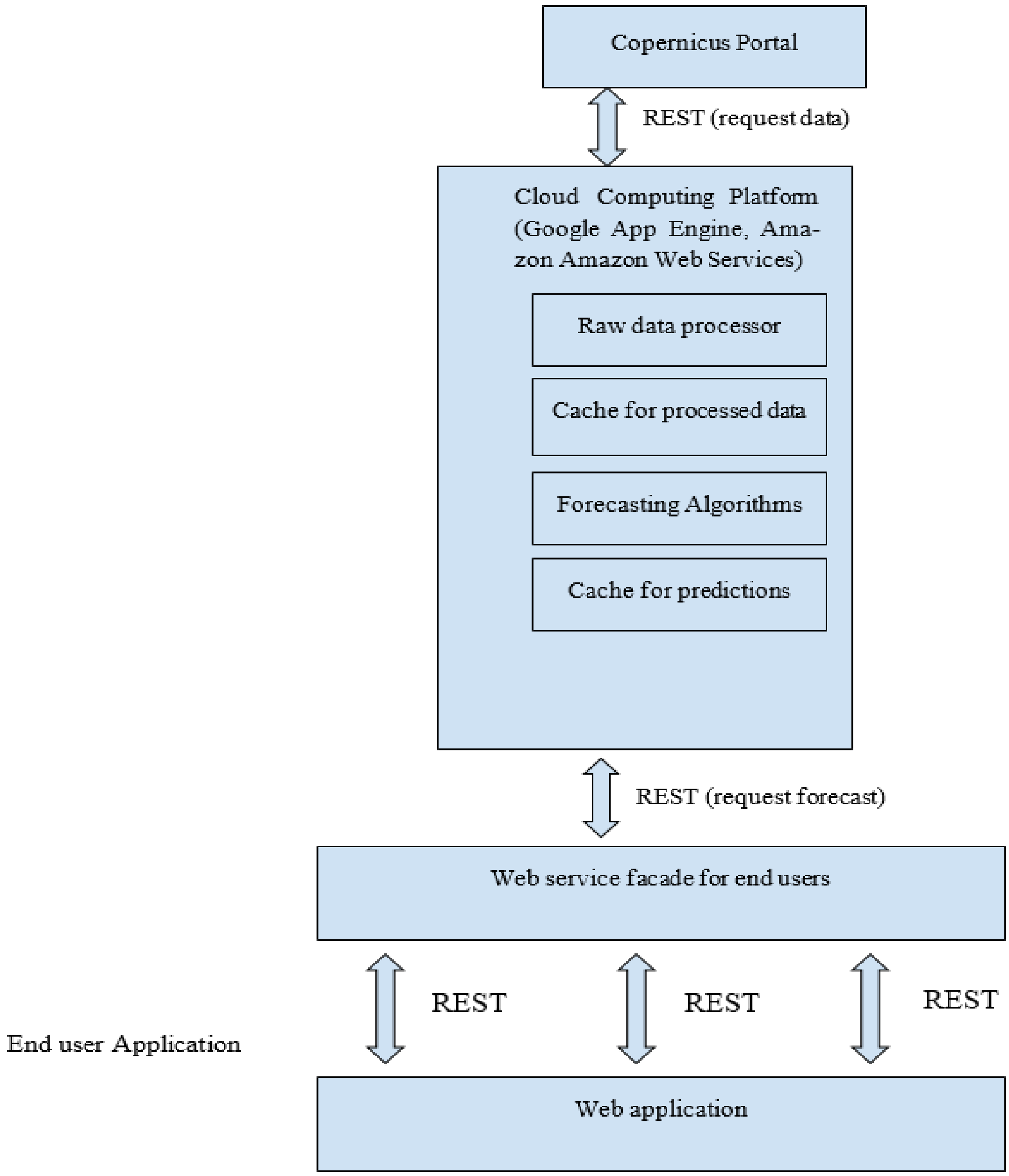
The web service will basically provide firsthand information for the stock exchange players that make the decision about the rice price. Figure 35 illustrates the proposed solution. As it can be noticed, the solution is comprised of two main parts:

a) An application responsible for forecasting the rice growth using the data provided by the Copernicus program and
b) A web service that allows end user applications to access these forecasts in an easy manner.

The forecast application will take advantage of the Representational State transfer (hereinafter: REST), Application Programme Interface provided by the Copernicus portal (https://spacedata.copernicus.eu) in order to access the raw data needed for the predictions. The application will also implement the caching mechanisms. These mechanisms will allow reducing the number of requests made to the Copernicus Application Programming Interface which as a result, will minimize the data processing needed for converting the raw data into valid inputs for the forecasting algorithms. The application is about to run on a cloud computing provider (Google App Engine, Amazon Web Services, etc.) - a choice that enables easy scalability and cost minimizations. A RESTful Application Programming Interface will be also provided by the application, something that will enable other applications to have an easy access to this forecasting information.

The second part of the proposed solution is a web service that will be responsible to relate the communication with the forecast application. This is especially important to developers, as the parties interested in creating end user applications by having access to the forecasting data.

Figure 35: Web service architecture



Source: own work.

The web service facade targets those users interested in developing end user applications. The Web app targets customers who simply want access to the web app providing the forecasting. Some potential barriers and key points worth to be mentioned are the following:

- Limitations regarding the access of the data (limit of requests/periodicity of the data)
- Definition of interfaces that are generic enough to accommodate the needs of different clients
- Developing a scalable application in order to cope with the varying amount of requests and that keeps under control the operational costs as well as the performance.

6.3 Limitations

Some limitations worth to be mentioned are listed below:

- Difficulties to understand the competitive advantages of the available geospatial services. Usually, there is a lack of transparency provided by companies about the real added value of their service.
- During the research and interviews, one of the major difficulties was to explain the problems in layman's terms.
- Softwares although claimed to be very user friendly, still require background knowledge in geography related science and GIS.
- For simplicity reasons, whilst using the software, there were only two - three images used. In real cases, especially for forecasting reasons, multiple images would be needed.
- The thesis covers web service architecture only, but not the prototype/implementation due to both: time and complexity constraints.
- The proposed web service focuses in one crop only (rice). This is because each crop has its own specifics and requirements. For simplicity reasons, focusing in one crop only would be a good start to extend further in other crops.
- Methods limitations: the unstructured interviews allowed indeed for more flexibility and possibility for further clarifications. But, in the same time, they were not enough to clarify all the problems that the appliance of Earth Observation encounters in agriculture.
- Remotely sensed imagery is just a small part of the process that aims turning remote sense data into useful information and reliable forecast. Other information, like climate and fieldwork would be necessary to complete the whole picture.

6.4 Avenues for further research

In terms of further research, some directions that could be approached are:

- Future research should refer to the adjustments of the web service for other crops;
- Inclusion of other softwares or programmes in terms of processing data could be possible;
- Additional experts and EO data users can be included. This would broaden the perspectives of advantages and limitations encountered in this field.

CONCLUSION

This thesis addresses the various opportunities and barriers of EO data used in the agriculture sector, where remote sensing is considered as one of the most advanced techniques applied. By examining the various solutions in the market, it can be concluded that indeed, the number of businesses and companies that are eager to work on this chain, is high. As according to the literature review and the interviews with experts, Earth Observation is a very promising discipline. The contribution of this thesis was to clarify some of these opportunities, and based on them, analyze the barriers and the potential area to improve upon.

Enablers such as free availability of satellite data, the technological advancements related to GIS, storage processing, and cloud computing technology, remain the most significant opportunities of Earth Observation data appliance. Software related opportunities show that satellite data accessing and downloading process is easy and simple to follow. Yet, turning the remote sensing data into useful and reliable forecasts requires the experience of analysts for better imagery interpretation. This becomes especially clear, after using SNAP and QGIS software where background knowledge, either in GIS or image processing, is highly useful. That's one of the most obvious barriers, as there is a lack of usability for all level of users and one is limited to using all the features of the available software. Additionally, the user should always consider the different parameters like the variety of crops, crops specifics and weather conditions. In this regard, the research goal of including all obstacles and opportunities might not be fully complete, as these parameters were excluded.

The expertise of the interviewees was essential in defining and understanding better both the barriers and the opportunities. Among others, the insights gained by these interviews are: the need to close the gaps between the chain in EO data and decision makers, i.e. the necessity to simplify, and make the whole process more efficient, the problems of data readability, data visualization, data integration, and its transformation into information, as well as the jungle of data categories, national practices, tools, and practices.

The results of the research lead to a recommendation for a web service that aims to provide information about the development and status of rice. Stakeholders are in a constant need for more information based on which they can improve their decision making about the agriculture produce. This kind of web service would be very relevant in helping the forecast of rice development, and as a result, its price too. The target market for this service includes stock market importers and exporters, people in the value chain of rice stocks, governments. Further development regarding the web service is its testing and implementation. Its expansion for other crops remains a further interesting opportunity.

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APPENDIXES

APPENDIX 1: Glossary of Terminology

Table 1: Glossary of Terminology

Term	Definition
Temporal resolution	The amount of time needed to revisit and acquire data for the exact same location. When applied to remote sensing, this amount of time depends on the orbital characteristics of the sensor platform and sensor characteristics. The temporal resolution is high, when the revisiting delay is low and vice-versa. Temporal resolution is usually expressed in days. (Khorram, Koch, Van der Wiele, & Stacy, 2012, pp. 17-22)
GIS	GIS is a computer system capable of for capturing, storing, checking, and displaying data related to positions on Earth's surface. (GIS, n.d.)
Stocks	Global inventories, which are calculated based on the level of ending stocks at the close of national crop seasons of the individual countries. (Stocks and utilization, n.d.)
The stock-to-use ratio	The sum of ending stocks of all countries divided by their total utilization. (Stocks and utilization, n.d.)

Source: own work.

APPENDIX 2: List of market agricultural solutions

Table 2: Additional examples of market agricultural solution

Country	Company name	Domain
Germany	Green Spatial Intelligence (Greenspin) Startup	Providing up-to-date growth and harvest forecasts. They aim to complement the current services that provide satellite alone with additional information such as interpretation and recommendation for action. More on www.greenspin.de
France	Institute France	In space is an association created to help bridge the gap between companies. Developing applications related to EO data and their potential customers. (Probst et al., 2016)
Norway	Globesar	Globesar AS turns abstract satellite measurements into valuable and useful geospatial information. (Probst et al., 2016)
Brazil	Gamaya	Gamaya focuses in forecasting yield of sugarcane in Brazil. More on www.gamaya.com

Source: own work.

Table 2: Additional examples of market agricultural solutions (cont.)

Romania	Terrasigna	Terrasigna aims to move users closer to the data and tools by creating various ecosystems and interconnected platforms. Hence, it addresses the technical challenges related to the huge amounts of EO data. More on www.terrasigna.com
Germany	Mundialis	Evaluating RS and the processing of geodata, based on the powerful computing centers. To be more specific, data from the European Copernicus is used. These kinds of data are evaluated automatically where as a result standardized web services are offered. More on www.mundialis.de
England	Catapult	Simplifying access to EO data and by providing data processing and IS which enable development of various applications. More on www.catapult.org.uk

Source: own work.

APPENDIX 3: Interview scenario

The interviews are necessary in exploring and answering better the research question of the thesis. The following questions were addressed to Mr. Carvalho, the Chief Executive Officer of Vision Space Technologies GmbH.

1. What are the various satellite systems?
2. In a nutshell, how do satellites monitor the agriculture?
3. What happens with the data that satellites capture?
4. What are the trends of space industry?
5. How can small and medium enterprises contribute in space industry?
6. What are the typical products/services provided by companies?
7. Is Vision Space Technologies also interested to jump in FinTech industry?
8. What are the aims of European Space Agency in regards of satellite data?
9. How is in fact decision making improved once this data is obtained?
10. According to you, what is the biggest challenge that Earth Observation appliance encounters?
11. What are some examples of services that Vision Space Technologies GmbH would be capable of providing?
12. What are some limitations that should be considered for the potential service?
13. What are some opportunities that would support the creation of a service?

Below are the questions addressed to the software developer, Mr. Teixeira.

1. What is the first key point that should be taken into consideration while thinking for a web service?
2. What are the opportunities that a web service of this kind can provide?
3. What are the challenges that should be considered for a typical web service?
4. How about the infrastructure? What options could support the tasks of the service?

The following questions were addressed to Mr. Butenko, the Meteorological Product Software Engineer at EUMETSAT.

1. Dear Mr. Butenko, could you please briefly describe your daily job?
2. How does the process of obtaining data work?
3. Can you tell more about the type of data that EUMETSAT provides?
4. What are some limitations you encounter while working with (raw) data?
5. According to you, are there any other obstacles that influence the overall process of data providing/processing?