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Regione Puglia

WP3

Deliverable 3.2.2

**Provision of 2x2-6x6km
(depending on the area)
microclimatic level remote
sensing indices to forecast
water stress for the Region
of Epirus**

**Irrigation indices from
Remote Sensing data**

Programme
2014 2020

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IR2MA

**Large Scale Irrigation
Management Tools for
Sustainable Water
Management in Rural
Areas and Protection
of Receiving Aquatic
Ecosystems**

Subsidy Contract No: I1/2.3/27

Project co-funded by
European Union, European
Regional Development Funds
(E.R.D.F.) and by National Funds
of Greece and Italy

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D3.2.2 DSS adaption and extension / Provision of 2x2-6x6km (depending on the area) microclimatic level remote sensing indices to forecast water stress for the Region of Epirus

Involved partners:

PB2 Region of Epirus

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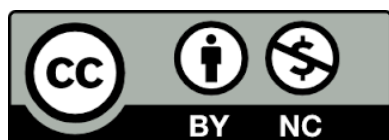
Christos Iosifidis, MSc

Place and time: Athens, June 2021

IR2MA

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1. Introduction

The goal of the project is the implementation of services for irrigation indicators at the microclimate level based on remote sensing data within the project "*IR2MA - Large Scale Irrigation Management Tools for Sustainable Water Management in Rural Areas and the Protection of Aquatic Recipient Ecosystems*", which has been included in the European Territorial Cooperation Operational Program "*Interreg Greece - Italy 2014-2020*" accession decision A / A 898 with no. patent 81391 of 26/07/2018 (ΑΔΑ: ΨΦΣΠ465ΧΙ8-ΙΘΥ) and has received MIS code: 5003280.

This report is the deliverable of the implementation of the WP3 work package "*D3.2.2 DSS adaptation and extension / Provision of 2x2-6x6km (depending on the area) microclimatic level remote sensing indices to forecast water stress for the Region of Epirus*".

Remote sensing is the science of obtaining qualitative and measuring information of a phenomenon or an object from a distance, i.e. without physical contact with the phenomenon or object under study. In practice, remote sensing uses sensors of various technologies through which information is collected and then analyzed regarding objects or areas. Based on the above, remote sensing can be considered to cover a huge range of applications, both in geosciences where the term is more widely known and in other sciences (astrophysics, astronomy, medicine, biology, physics, etc.). From aerial photography, espionage and commercial satellites, to telescopes, radar, sonar, MRI and X-rays, the methods used make up the science of remote sensing.

Especially in geosciences, the term is more common and remote sensing applications have a wider scope than any other scientific discipline. Remote sensing studies in a unique way the natural phenomena of the earth such as weather, atmosphere, oceans, vegetation, soil geology, urban environment, agriculture, natural disasters (fires, floods, earthquakes, landslides, droughts, storms, tornadoes, glaciers, etc.), anthropogenic interventions in the environment, urban pollution and many other phenomena of the natural earth surface. The unique feature of remote sensing, to provide information without the need for an on-site visit of the scientist without the intervention in the study area and at a very low cost, is one of the main advantages over other methods of information collection.

In addition to the remote sensing methods of our ancestors (for observing nature from high ground to observing the stars), remote sensing began around 1850, with the first photographs from a balloon and then the evolution is historically tied with the evolution of flying machines (balloons, airplanes and then artificial satellites). Nowadays, special emphasis has been given to the observation of the earth's surface by satellite platforms (satellite receivers) and by airborne receivers, digital or analog. In particular, with the advent of the digital age and the simultaneous development of computer science, computer vision and artificial intelligence, remote sensing has entered a purely digital age and has become one of the best fields of application of the above most theoretical sciences.

In terms of remote sensing sensors technology and characteristics, they are divided into active and passive depending on whether they record a natural radiation (such as the reflected part of solar radiation from a material) or whether they scan their target with artificial radiation with intended to measure return radiation (eg Radar, Lidar, Sonar). In addition, sensors are divided according to their resolution, which can be of four types:

1. Geometric resolution (or spatial resolution) determines the minimum surface area to be observed. In digital imaging, this is defined as the size of the pixel on the ground, usually in meters.
2. Spectral resolution refers to the ability of the receiver to perceive information at different wavelengths of electromagnetic radiation. The intervals of the EM spectrum that the receiver can take individual measurements are called the remote sensing imaging channels or bands. There is data with three channels that produce color images (in the range of red, green and blue spectrum) while there is data that can have information in infrared, ultraviolet, even X-rays. In addition there are receivers with a large number of channels that cover almost the entire EM spectrum and are called hyperspectral receivers.
3. Radiometric resolution refers to the ability of a receiver to record a large number of discrete EM intensity values and is measured in bits for digital displays. For example, an 8-bit image may include in one of its channels 256 brightness levels that when rendered on a screen can be rendered in 256 different shades of gray or discrete palette colors.
4. Finally, temporal resolution refers to the ability of the sensor to repeat its measurement over the same study area. E.g. The Sevis sensor takes a picture every 15 minutes over the same area while the Thematic Mapper receiver takes a picture every 13 days.

Remote sensing is an invaluable tool for monitoring, recording, and protecting the natural environment with applications in many categories of natural disasters and phenomena (e.g. landslides, floods, droughts, earthquakes, fires, water pollution, tsunamis, etc.). In Greece, too, the contribution of remote sensing is considered very important in recent years with the often catastrophic phenomena of fires and therefore is an integral part in terms of crisis management and decision making.

During the implementation of the project, the appropriate infrastructure was developed for the long-term monitoring of the Region of Epirus through the downloading, processing, storage, and analysis of remote sensing data. The data are organized in an appropriate spatial database infrastructure for their systematic analysis.

2. Remotely sensed geospatial data

The term geospatial data describes the information that identifies the geographical location as well as the features of natural or man-made objects, as well as various imaginary boundaries on earth.

From the definition of geospatial data, we understand that they have two components:

- One component is the so-called spatial component which describes the location, shape, orientation, and size of an object in two-dimensional or three-dimensional space.
- The second component describes an object through non-spatial features which are also referred to as thematic or descriptive features.

Images from maps and satellites as well as the topology of a road network are typical examples of geospatial data. Maps can provide not only location information (spatial component) for borders, rivers, and roads but also more detailed information (descriptive features) related to sites such as altitude, soil type, land use, and annual rainfall.

Geospatial data is typically represented in modern computer systems in two main ways. They are represented as either vector data or raster data. Below we describe in detail these two ways of representation, presenting the advantages and disadvantages of each.

The vast majority of geospatial data sets tend to exhibit specific properties and are therefore categorized in the most important, interesting, and scientifically challenging category of data sets, that is, in the "*Big Data*".

2.1. Big geospatial remotely sensed data

"*Big Data*" is characterized by what is often referred to in the literature as a multi-V model. In particular, and focusing on geospatial data, this model encapsulates five key properties of "*Large Geospatial Data*" (Laney 2001):

- Volume: The "large" data sets are those that are very large in terms of required storage space.
- Velocity: This property refers to how fast new data arrives in the system for import and pre-processing but also how fast a big data processing system has the ability to execute processing queries on data submitted by multiple users.
- Variety: The term diversity refers to different types of data, non-aligned data structures as well as inconsistent semantics.
- Veracity: Validity refers to how much trust can be given to the content of the data given the reliability of their sources (Zhou et al 2013).
- Value: This property corresponds to the monetary value that a company can derive through the use of Big Data computing technologies.

Although the choice of properties (Vs) used to explain the term Big Data is often arbitrary and varies with the content of technical reports and articles found on the internet - for example, Viability now tends to become a new property - Volume, speed and diversity (Russom 2011), (Zikopoulos et al 2012) are the objects of interest to the scientific community and are more common. The aim of this project is the collection, processing, storage of remote sensing data, which meet all the above

conditions. The design of the spatial database of the present project aims at the use of both forms of geospatial data, ie, the pictorial (raster) and the vector (vector) data models.

The raster geospatial data sets (Baumann, Nativi 2012) demonstrate all the properties of the multi-V model that characterizes Big Data. More specifically, raster data are large volumes of data. There are plenty of examples from various fields that confirm this feature. In social networking there are cases of datasets whose size reaches $10^8 \times 10^8$. In the field of earth sciences, ESA 1 plans to store 10^{12} images, each of which ranges from 500MB to 2GB or more. In addition, the speed of raster data receiving and storing is frightening. NASA's MODIS (Moderate Resolution Imaging Spectroradiometer) instrument, located on the Terra 2 and Aqua 3 satellites, records and sends about 1TB of raster data daily. The distributed sensors used in radio for astronomy (LOFAR: distributed sensor array farms for radio astronomy) collect 2 to 3 PB of data per year. In addition, the variety of raster data is huge as we can have data from sensors, images, statistics and various models. The areas of activity that produce and need raster data are many and heterogeneous such as health sciences, geosciences, engineering and multimedia applications. Finally, the validity of raster data plays a very important role in their use, and the measured and calculated data resulting from these sets of high volume, speed and variety must contain quality information to accompany them. Predefined procedures are often used to calculate errors in this data, but many times this does not happen, so there is a big question about how to avoid the spread of errors.

Vector geospatial datasets also play an important role in a wide range of applications which demonstrate these properties of the multi-V model. In addition to simple geospatial applications that include vector data management and processing, the most demanding application that includes vector data is motion data management and exploration. Traffic data (Pelekis et al 2014) are now ubiquitous mainly due to the automated collection of time-stamped location information from GPS-equipped devices. From the common smartphones we all have now, to software and hardware specifically designed to monitor traffic on land (e.g. cars), at sea (e.g. merchant ships) and in the air (e.g. commercial airplanes). Such a wealth of data, which demonstrates spatial and temporal reporting, can give impetus to innovative categories of applications and services of high social and economic impact, if it is possible to extract commercial and comprehensive knowledge from these raw data collections. Tracking 933 merchant ships operating in the Aegean Sea over a period of 3 days has led to the creation of a data set of 3 million GPS recordings for analysis. All these valuable data sets need innovative solutions so that they can be analyzed efficiently. Real-time analysis of large geospatial data to provide alerts and alternatives in the event of an emergency is critical.

From the above analysis it becomes clear that geospatial data constitute "large" data sets and also identify the various challenges that need to be overcome so that geospatial data can be used effectively and we can create innovative, sustainable and useful geospatial services and applications. data.

2.2. Vector data

Vector data is made up of simple geometric objects, which are based on mathematical expressions and consist of one or more interconnected nodes, to represent images in computer graphics (PC). A

node describes a position in space using two or even three axes. In the context of geospatial data, a location in space is usually represented by latitude, longitude and altitude. Such geometric objects are a point, a straight line, a polyline, a triangle and other polygons in two dimensions and a cylinder, a sphere, a cube and other polygons in three dimensions.

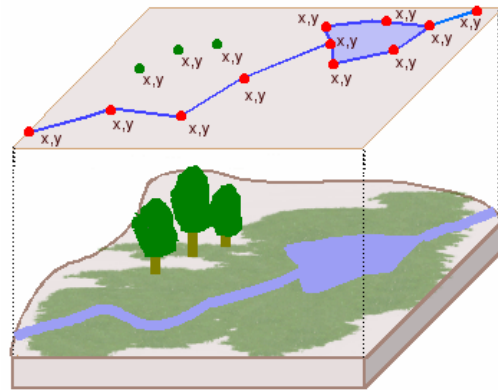


Figure 2.1: Vector Data in relation to the real world. (Source: www.geography.hunter.cuny.edu)

Vector data provides a way of representing real-world entities. An entity is anything that can exist in a place. Trees, houses, roads, rivers are all entities. Each such entity, in addition to the position, has additional information-characteristics, either in text form or in numerical form that describes it.

Map data is usually represented in vector format. Roads are usually represented as a polyline. Various geographical entities, such as large lakes, or even administrative entities, such as prefectures and countries, are represented by complex polygons. Some entities such as rivers can be represented either as complex curves or as complex polygons depending on whether their width matters.

Representing geospatial data in vector format has several advantages. The main ones are the following:

- Vector data has low storage requirements as the size of their representation on disk does not depend on the dimensions of the object they represent.
- The zoom in on a vector data representation can be made as large as possible without altering the visual effect of the representation.

2.3 Raster data

Raster data consists of pixels / pixels in a tile, in two or more dimensions. Each tile (Zeiler 1999) covers an area of constant size and contains a value that comes from a sensor and describes the conditions for the area it covers. A typical example of a two-dimensional raster image is a satellite remote sensing representation of an area.

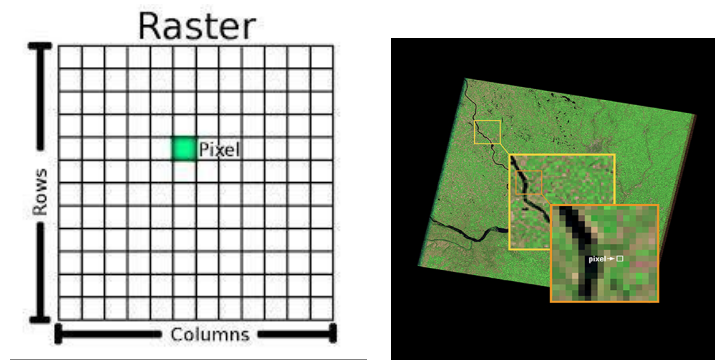


Figure 2.2: Digital image and pixels (left), satellite image and individual pixels (right).

The data also includes the spatial information, ie the position of the image, which is determined for example by the latitude and longitude of its angles, the spatial resolution of the image, which is determined by the total number of pixels that make up an image or more often in geospatial data from the area covered by each pixel and the spectral resolution of the image determined by the number of bands of the image for which it has information.

For a raster image, the higher the spatial resolution of the image, the more detail it has, but the cost of storage is proportional. That is, unlike vector data, here, more resolution requires more disk space. Also another disadvantage in relation to the vector data is that for a large focus (zoom in) the visual effect is not desirable as the tiles that make up the image become visible resulting in the loss of the sense of continuity and the various objects that are depicted are not easily discernible.

Raster data on the other hand is extremely useful when we want to present information that is continuous in an area and cannot be easily separated into entities speaking in terms of vector data. For example, a plain that usually has a wide variety of colors and vegetation density is very difficult to represent using vector data. Either we would have to use some very simple representation but thus lose valuable information or we would have to use some very complex representation by digitizing even the smallest detail, a task that would require a lot of time and effort.

Raster data is therefore the required representation when we have homogeneous features as the human eye is very capable of interpreting images and distinguishing small details that would be difficult to sufficiently digitize due to their quantity.

Raster data is not only capable of depicting real-world surfaces but can also depict more abstract concepts. For example, they can show rainfall trends for an area or illustrate the risk of fire in a place. In such applications each pixel in the raster image represents a different value. In the example (Figure 2.3) with the risk of fire, each pixel can contain a value on a scale from 1 to 10 for the risk in that area.

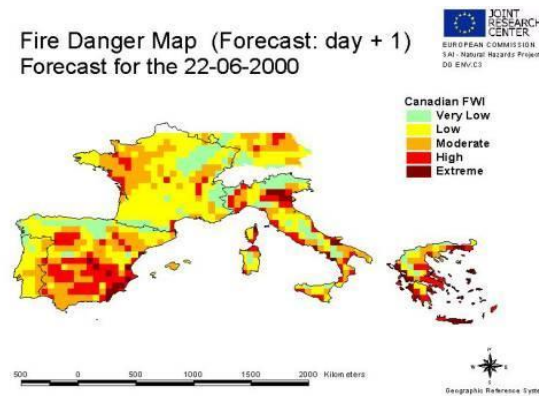


Figure 2.3. Fire risk forecast across Europe for 22-6-2000 in raster format. (Source: ec.europa.eu/echo/files)

It is common in applications and especially in the presentation of geospatial data to use joint vector and raster data as they complement each other in terms of their advantages. So raster images are usually used as base layers and overlapped with information from vector layers. For example, for the representation of a plain, a remote sensing representation of the plain can be used as a basic thematic level which is supposed to overlap with various vector thematic levels, for example a thematic level with the roads that cross it as well as a thematic level with the rivers that flow through it.

The following are categories of remote sensing data that will be required during the implementation of the project as well as their technical characteristics.

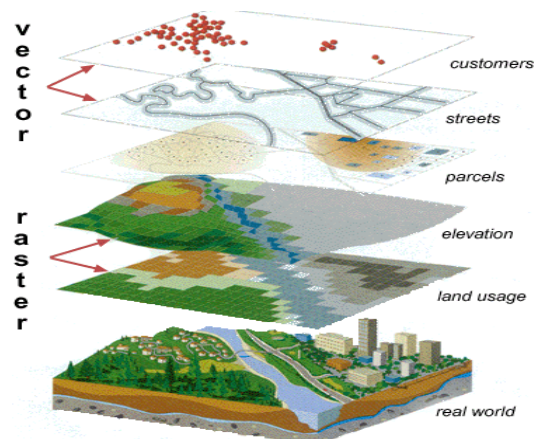


Figure 2.4: Overlap of information from pictorial and vector thematic levels. (Source: maprabu.blogspot.gr)

2.3.1. Optical satellite data of average spatial resolution

Since 1999, USGS, NASA, NOAA have been mapping optical satellite data of medium spatial resolution with MODIS satellite systems with a maximum spatial resolution of 250 meters.

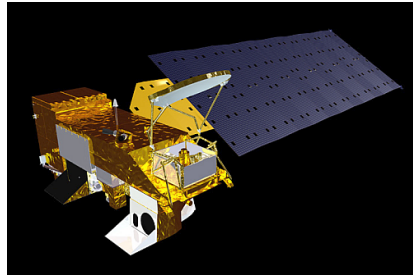


Figure 2.5: The MODIS satellite mapped in Greece since 1999

Recently, the European Space Agency ESA launched the Sentinel-3 satellite on 16/2/2016 which provides data with a maximum spatial resolution of 300 meters.

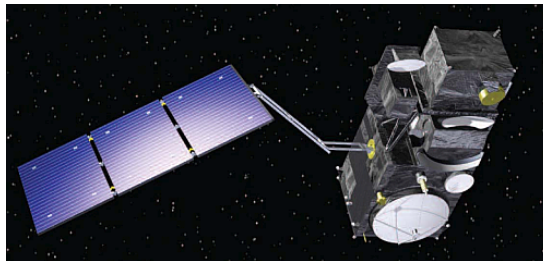


Figure 2.6: The Sentinel-3A satellite mapped in Greece since 16/2/2016

The table 2.1 presents the basic spectral characteristics of medium remote sensing satellite remote sensing data which are available free of charge from USGS and ESA.

Satellite system	Characteristics		
	Spectral and spatial resolution	Time resolution	Cost
MODIS	2 spectral bands @ 250m	≈ 1 day	free
	5 spectral bands @ 500m		
	28 spectral bands @ 1000m		
SENTINEL-3	21 spectral bands @ 300m	≈ 4 day	free

Table 2.1. The basic spectral characteristics of medium remote sensing satellite remote sensing data which are available free of charge

2.3.2. High resolution spatial optical satellite data

The next category of satellite data concerns data with spatial resolution from 10m to 60m. The following table summarizes the key spectral characteristics of high spatial resolution satellite data that are available free of charge from USGS and ESA satellite programs.

Since 1984, the USS USS, NASA, NOAA have been mapping optical satellite data of medium spatial resolution with the Landsat 5 TM satellite system with a maximum spatial resolution of 30 meters.



Figure 2.7: The Landsat 5 satellite mapped in Greece since 1984

Specifically above Central Greece and Epirus for example there is an image with a date of shooting from 28/09/1984.

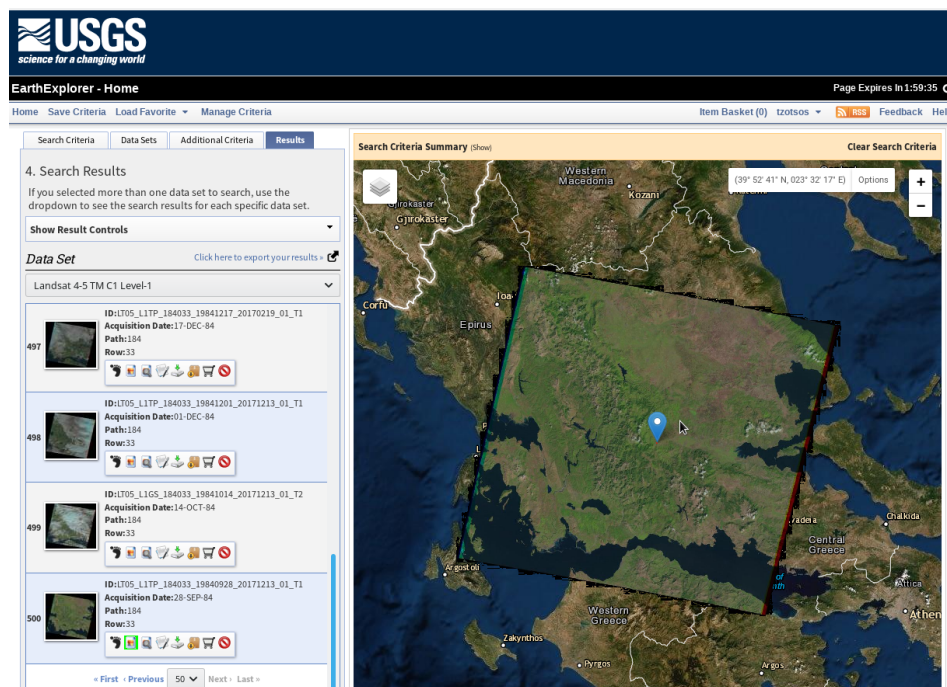


Figure 2.8: Excerpt from the USGS geospatial base with a Landsat 5 TM image in 1984.

Following the failure of the Landsat 6 launch in 1999, USGS, NASA, and NOAA mapped high-resolution optical satellite data with the Landsat 7TM satellite system.

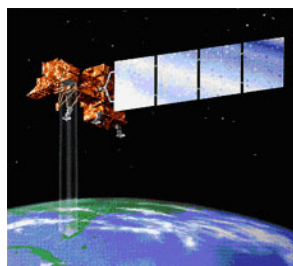


Figure 2.9: The Landsat 7 satellite mapped in Greece since 1999

However, after 31/5/2003 the sensor scanner presented a significant problem (in the “*scan line corrector*”) in the recording with the result that the whole series of pixels are not recorded.

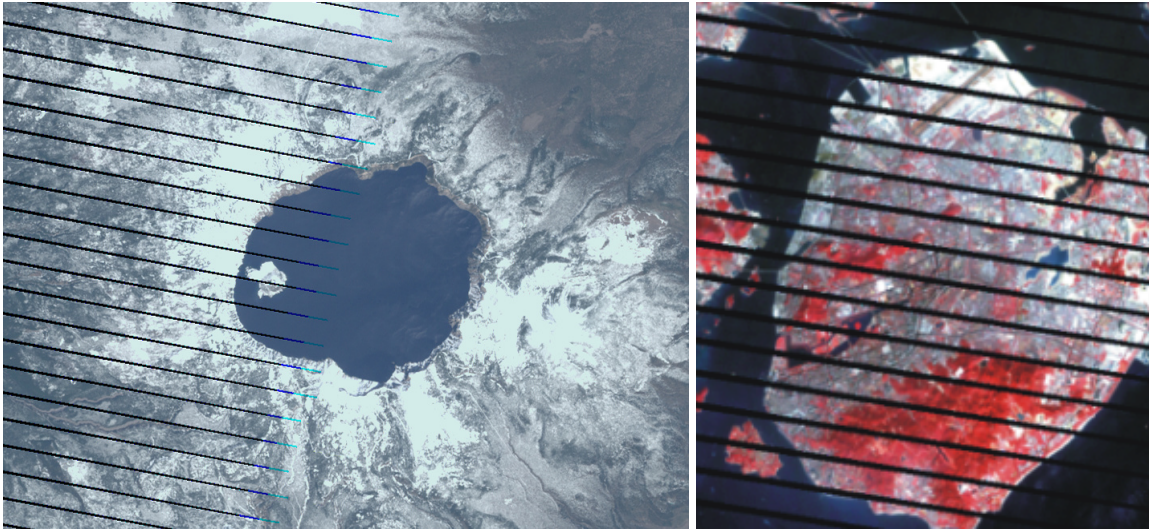


Figure 2.10: The Landsat 7 satellite that has been mapping Greece since 1999

Unfortunately this problem in Landsat 7 was and is permanent so we have new absolutely clear images worldwide from April 2003 onwards with Landsat 8 satellite with high spatial optical satellite data at 30 meters.



Figure 2.11: The Landsat 8 satellite mapped in Greece from 2013 onwards

Since the end of June 2015, the European Space Agency (ESA) has launched the Sentinel-2A satellite, which provides data with a maximum spatial resolution of 10 meters. Then, from March 2017, the Sentinel-2B was put into orbit, thus doubling the temporal resolution of the Sentinel 2 system.



Figure 2.12: The Sentinel-2 satellite mapped in Greece from the end of 2015 onwards

The table 2 presents the basic spectral characteristics of high spatial resolution satellite remote sensing data which are available free of charge from USGS and ESA.

Satellite system	Characteristics		
	Spectral and spatial resolution	Time resolution	Cost
LANDSAT 5 TM	6 spectral bands @ 30m 1 thermal @120m	> 15 days	free
LANDSAT 7	1 PAN @15m	≈ 15 days	free
	6 spectral bands @30m		
	1 thermal @60m		
LANDSAT 8	1 PAN @15m	≈ 15 days	free
	6 spectral bands @30m		
	1 thermal @60m		
SENTINEL-2A & SENTINEL-2B	4 spectral bands @10m	≈ 10 days (A) ≈ 5 days (A+B)	free
	6 spectral bands @20m		
	3 spectral bands @60m		

Table 2.2. The basic spectral characteristics of high spatial satellite remote sensing data which are available free of charge

2.3.3. Optical satellite data of very high spatial resolution

In addition to the satellite data provided free of charge by US and EU national programs presented in the previous two tables and reaching a spatial resolution of 10 meters (e.g. Sentinel-2) there are now several private companies providing commercial satellite data of very high spatial resolution, and specifically from 30cm up to 5m. The following table 2.3 summarizes the key spectral characteristics of very high spatial resolution satellite data available from private companies.

Satellite system	Characteristics		
	Spectral and spatial resolution	Time resolution	Cost
PlanetLabs	3 spectral bands @5m	≈ 1 day	≈ 0.95€ / km ²
RAPIDEye	4 spectral bands @5m	≈ 1 day	≈ 0.95€ / km ²
KazEOSat-2	1 PAN @1m	≈ 1 day	≈ 5.9€ / km ²

	4 spectral bands @4m		
Deimos	1 PAN @1m 4 spectral bands @4m	≈ 1 day	≈ 6.0€ / km ²
Worldview-2	1 PAN @50cm 8 spectral bands @2.4m	≈ 1 day	≈ 22€ / km ²
Worldview-3	1 PAN @34cm 8 spectral bands @1.38m 8 SWIR bands @7.5m 12 CAVIS bands @30m	≈ 1 day	≈ 29€ / km ²

Table 2.3. The basic spectral characteristics of very high spatial satellite remote sensing data

2.3.4. Radar satellite data

Finally, free radar satellite data from the two satellites SENTINEL-1A and SENTINEL-1B are available from ESA. Their main features are presented in table 2.4.

Satellite system	Characteristics		
	Spectral and spatial resolution	Time resolution	Cost
SENTINEL-1A & SENTINEL-1B	Strip Map Mode @5mx5m Wide Swath Mode @5m x 20m Extra-wide Swath Mode @25m x 100m Wave Mode @5m x 20m	≈ 1 day	free

Table 2.4. The basic spectral characteristics of remotely sensed radar data

3. Remote sensing raster data

During the implementation phase of this work package, the goal was to investigate the freely available remote sensing data and to collect the historical data for the study area. The second goal was to automate the process of uploading remote sensing data and automate the processing of important indices for the IR2MA system. At the same time, a key step in any remote sensing research work is in addition to the collection and preprocessing of data, the step of photo-interpretation, the process of recognizing phenomena and objects in remote sensing representations through image observation and methodical pattern recognition and recording.

Within the framework of the project, a system is specified that automatically collects remote sensing data, processes them and enters them in the geospatial database. During the project, a fully automated system for uploading and processing remote sensing data was developed.

For the implementation of the satellite monitoring system of the IR2MA project, it was chosen to use free data of high resolution. The system automatically connects to the USGS and Copernicus databases and alternatively to the respective data warehouses on Amazon Cloud Infrastructure (AWS) where this data is hosted and monitors the availability of new satellite receivers on a daily basis. If there is new data, it is downloaded to the spatial database of the project and serves all other systems of the project with Landsat 8 and Sentinel 2 images with a spatial resolution of 10-30m. The selection of the above data was based on a) their free availability, b) the extensive available literature of Landsat data and c) the research interest in investigating the Sentinel 2 data for the monitoring of vegetation parameters.

3.1. Landsat 7-8 data downloading

Searching and downloading Landsat data has been open to the public for a number of years and is done through multiple USGS services. The most common service is the EarthExplorer service (Figure 3.1)

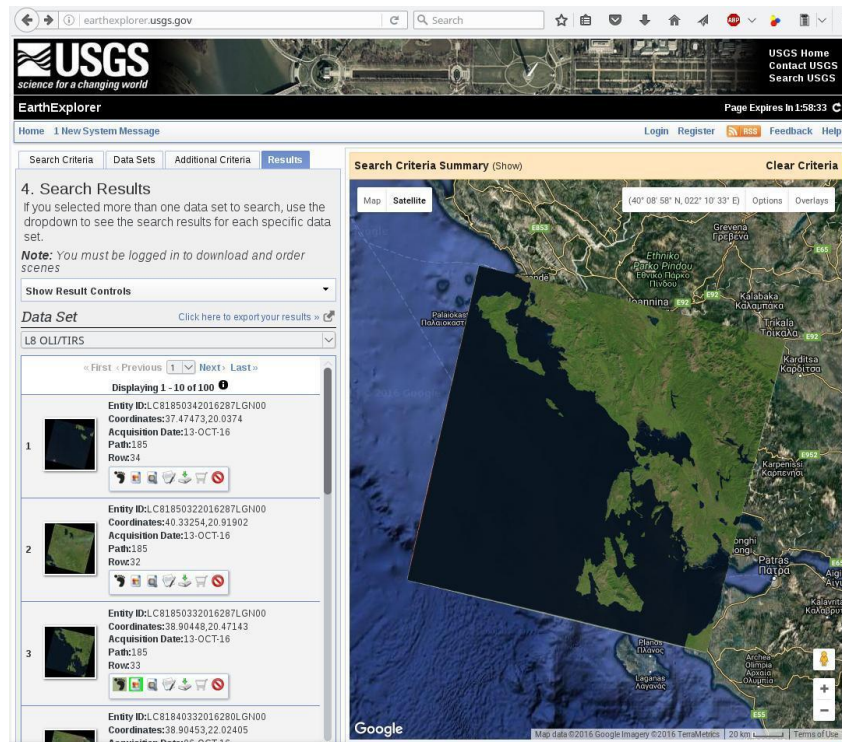


Figure 3.1: Search for Landsat remote sensing data

The service collected the Landsat image codes from 1974 until mid-2019. Then, via the available USGS BulkDownloadTool application, it was possible to download the satellite data (Figure 3.2).

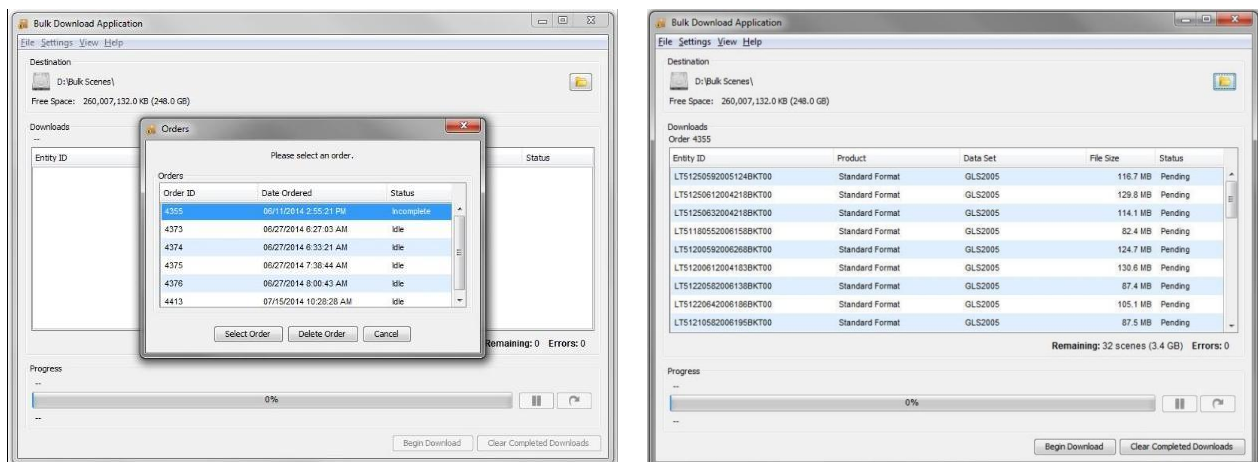


Figure 3.2: Bulk Landsat data upload

During this process, all the data that cover even partially the study area were downloaded. The images that cover the area are Flight Line Scenes 184, 183 and Series 033 and 034. All images available from EarthExplorer have been uploaded with the oldest being a 1974 Landsat 5 MSS image. much later with the first for the study area being 1984 (LT51850331984183XXX02) (Figure 3.3).

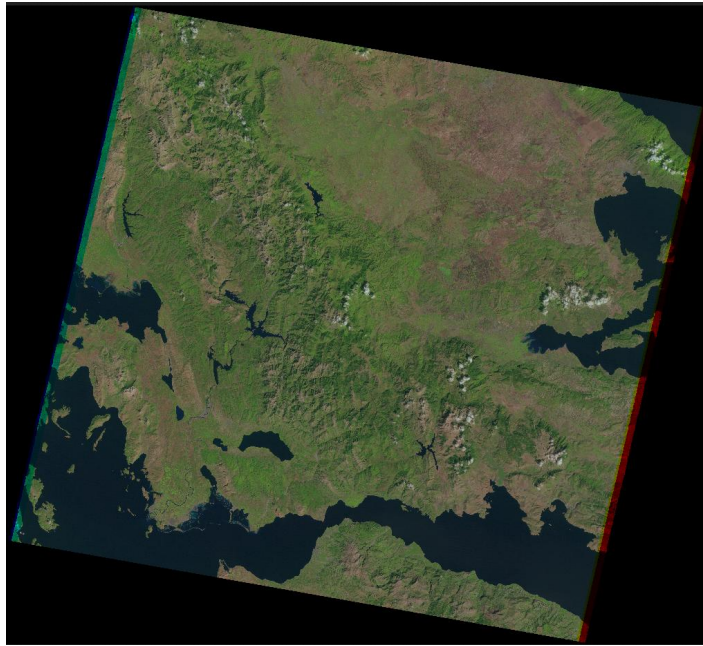
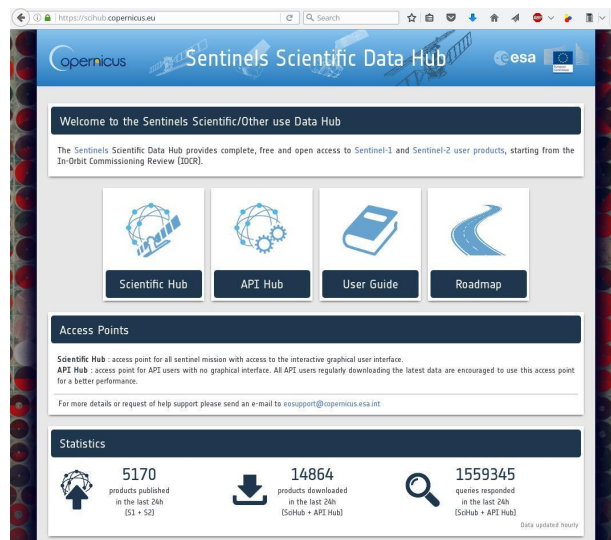


Figure 3.3: The oldest Landsat Thematic Mapper 5 image of the study area since 1984.

3.2. Sentinel 2A data downloading

Searching and uploading Sentinel 1 and 2 data is available to the general public through the European Union and ESA Copernicus SciHub service (<https://scihub.copernicus.eu/>). Figure 3.4 shows the Sentinel 2A and 2B multispectral data retrieval and upload process.



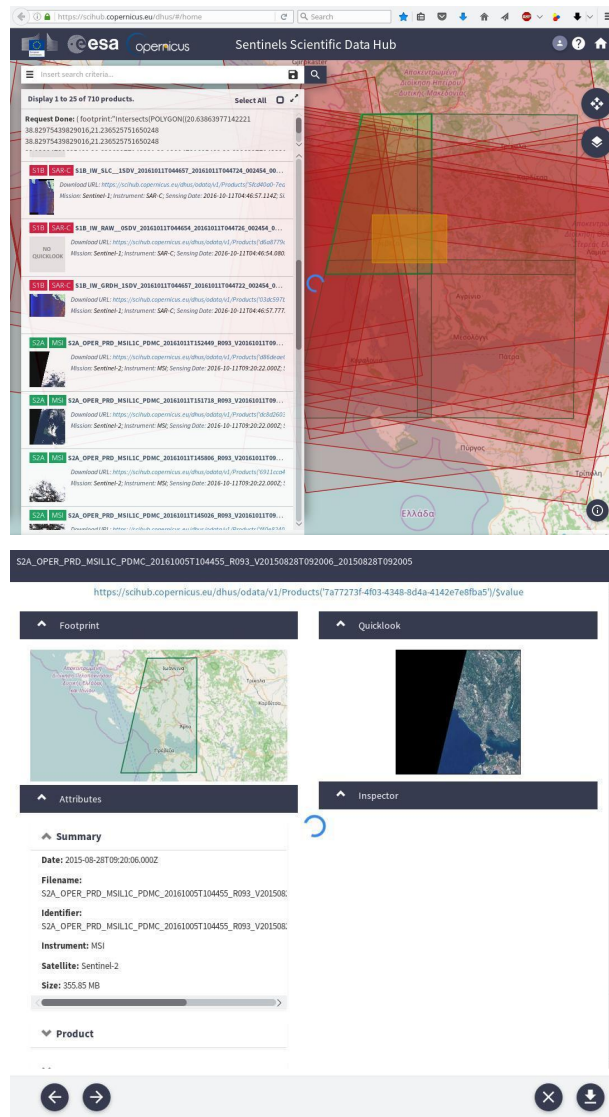


Figure 2.4-2.6: Access to Sentinel 1 and 2 data from the Copernicus SciHub service

As part of the project, all Sentinel 2A data from the beginning of 2018 that became available by mid-2021 was downloaded.

4. Processing Remote Sensing Data with FOSS

For the implementation of the Remote Sensing data processing workflows, the design of the project was to only use Free and Open Source Geospatial Software from the Open Source Geospatial Foundation (OSGeo) stack. OSGeo is a not-for-profit software foundation. OSGeo has US 501(c)(4) legal status as a not-for-profit organization. OSGeo's vision is to empower everyone with open source geospatial software.

This section provides details about the specific OSGeo and FOSS4G software that have been reused for the implementation of the IR2MA processing workflows.

4.1. GRASS GIS

The Geographic Resources Analysis Support System, commonly referred to as GRASS, is a Geographic Information System (GIS) providing powerful raster, vector, and geospatial processing engines in a single integrated software suite. GRASS GIS includes tools for spatial modeling, visualization of raster and vector data, management and analysis of geospatial data, and the processing of satellite and aerial imagery. It comes with a temporal framework for advanced time series processing and a Python API for rapid geospatial programming. GRASS GIS has been optimized for performance and large geospatial data analysis. It also can produce sophisticated presentation graphics and hardcopy maps. GRASS GIS has been translated into many languages and supports a huge array of data formats.

GRASS GIS is used around the world in academic and commercial settings as well as by many governmental agencies and environmental consulting companies. It runs on a variety of popular hardware platforms and is Free open-source software released under the terms of the GNU General Public License.

The GRASS GIS software includes more than 400 built-in analysis modules. Additionally, over 100 community supplied modules and toolboxes are available for free from the Add-on repository. After more than 30 years of continuous development GRASS GIS is both the longest maintained and largest Open Source GIS available. It is easily scriptable and versatile enough to be used both for batch data processing on massively-parallel supercomputers as well as a handy desktop GIS for handheld PDAs or netbooks.

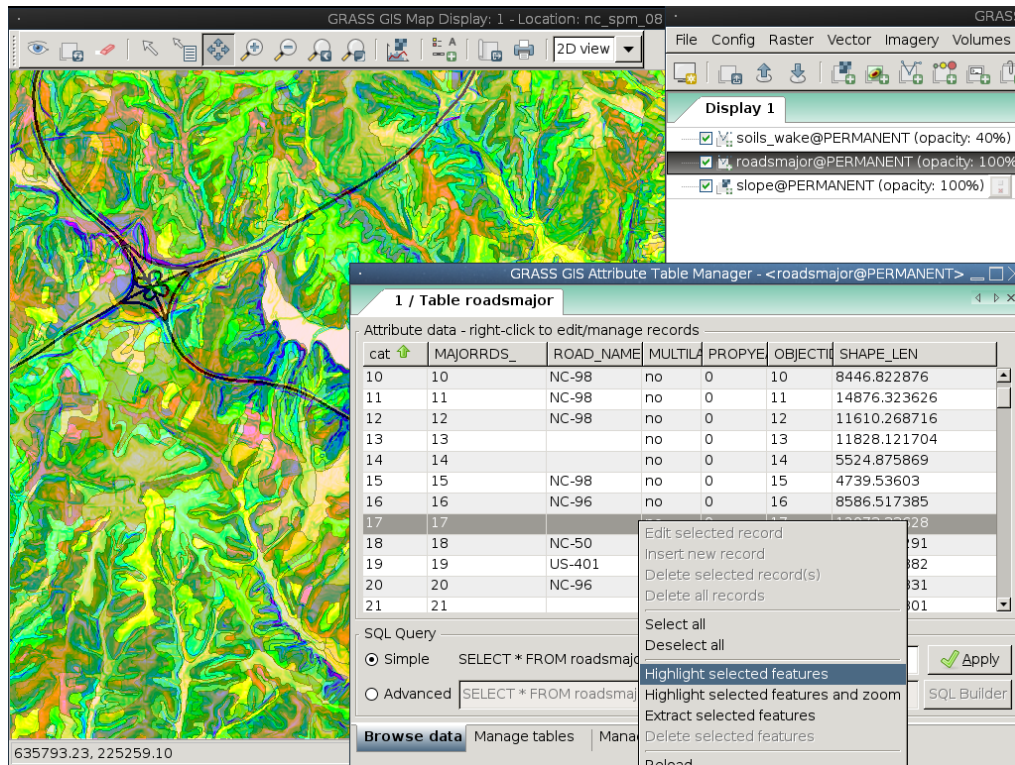


Figure 4.1. A GRASS GIS software example screenshot

Details

Website: <https://grass.osgeo.org/>

Licence: GNU General Public License (GPL) version 2+

Software Version: 7.8.5

Supported Platforms: GNU/Linux, Mac OSX, MS Windows

API Interfaces: C, Python, Bourne Shell

Support: <https://grass.osgeo.org/about/community/>

4.2. GDAL

Geospatial Data Abstraction Library (GDAL/OGR) provides command-line utilities to translate and process a wide range of raster and vector geospatial data formats. The utilities are based upon a cross platform, C++ library, accessible via numerous programming languages. As a library, it presents a single abstract data model to the calling application for all supported formats.

GDAL/OGR is the most widely used geospatial data access library. It provides the primary data access engine for many applications including MapServer, GRASS, QGIS, and OpenEV. It is also utilized by packages such as OSSIM, Cadcorp SIS, FME, Google Earth, VTP, Thuban, ILWIS, MapGuide and ArcGIS.

Core Features include:

- Command-line utilities for data translation, image warping, subsetting, and various other common tasks
- Highly efficient raster data access, taking advantage of tiling and overviews
- Support for large files - larger than 4GB
- Library access from Python, Java, C#, Ruby, VB6 and Perl
- Coordinate system engine built on PROJ.4 and OGC Well Known Text coordinate system descriptions
- Popular Supported Formats

GDAL supports over 140 raster formats, and OGR over 80 vector formats. These include:

- Raster: GeoTIFF, Erdas Imagine, SDTS, ESRI Grids, ECW, MrSID, JPEG2000, DTED, NITF, GeoPackage and more ...
- Vector: GeoPackage, ESRI Shapefile, GML, GeoJSON, AutoCAD DWG, MapInfo (tab and mid/mif), ESRI Coverages, ESRI Personal Geodatabase, DGN, PostGIS, Oracle Spatial, and more.
- Implemented Standards
- The OGR vector data model is compliant with the OGC Simple Features specification.

GDAL/OGR and PROJ.4

<http://www.gdal.org>

<http://proj.osgeo.org>



GDAL for Raster Data - The Geospatial Data Abstraction Library

Arc/Info ASCII Grid, **Arc/Info** Binary Grid (.adf), AIRSAR Polarimetric, Microsoft Windows Device Independent Bitmap (.bmp), BSB Nautical Chart Format (.kap), VTP Binary Terrain Format (.bt), CEOS (Spot for instance), First Generation USGS DOQ (.doq), DODS / OPeNDAP, New Labelled USGS DOQ (.doq), Military Elevation Data (.dt0, .dt1), **ERMapper** Compressed Wavelets (.ecw), **ESRI** .hdr Labelled, ENVI .hdr Labelled Raster, Envisat Image Product (.n1), EOSAT FAST Format, FITS (.fits), Graphics Interchange Format (.gif), GMT Compatible netCDF, **GRASS Rasters**, Golden Software ASCII Grid, Golden Software Binary Grid, Golden Software **Surfer** 7 Binary Grid, TIFF / **GeoTIFF** (.tif), GXF - Grid eXchange File, Hierarchical Data Format Release 4 (**HDF4**), Hierarchical Data Format Release 5 (HDF5), **Erdas Imagine** (.img), Vexcel MFF2, **Idrisi** Raster, Image Display and Analysis (WinDisp), ILWIS Raster Map (.mpr, .mpl), Japanese DEM (.mem), **JPEG** JFIF (.jpg), **JPEG2000** (JPEG2000, JP2KAK, JP2ECW, JP2MrSID), NOAA Polar Orbiter Level 1b Data Set (**AVHRR**), Erdas 7.x .LAN and .GIS, Daylon Leveller Heightfield, In Memory Raster, Vexcel MFF, Multi-resolution Seamless Image Database, Meteosat Second Generation, NDF, NITF, **NetCDF**, OGDII Bridge, PCI .aux Labelled, PCI Geomatics Database File, Portable Network Graphics (.png), PCRaster (.map), Netpbm (.ppm, .pgm), Swedish Grid RIK (.rik), RadarSat2 XML (product.xml), **ArcSDE** Raster, USGS SDTS DEM (*CATD.DDF), Raster Matrix Format (*.rsw, .mtw), SAR CEOS, **SGL** Image Format, USGS ASCII DEM (.dem), OGC Web Coverage Server, X11 Pixmap (.xpm)

OGR for Vector Data - Simple Feature Library

Arc/Info Binary Coverage, Comma Separated Value (.csv), DODS/OPeNDAP, DWG, **DXF**, ESRI Personal GeoDatabase, ESRI ArcSDE, **ESRI Shapefile**, FMEObjects Gateway, GML, **GMT Mapping**, **GRASS Vectors**, INTERLIS, **Google Earth KML**, Mapinfo File, Microstation DGN, Spatial **MySQL**, OGDII Vectors, ODBC generic database access layer, **Oracle** Spatial, PostgreSQL **PostGIS**, S-57 (ENC), SDTS, SQLite, UK .NTF, U.S. Census TIGER/Line, VRT - Virtual Datasource, Informix DataBlade

Figure 4.2. GDAL/OGR and PROJ.4 Raster and vector feature list

Details

Website: <https://gdal.org/>

Licence: X/MIT style Open Source license

Software Version: 3.2.1

Supported Platforms: Windows, Linux, Mac

API Interfaces: C, C++, Python, Java, C#, Ruby, VB6 and Perl

Support: <https://lists.osgeo.org/mailman/listinfo/gdal-dev>, <https://www.osgeo.org/service-providers/>

4.3. OrfeoToolbox

ORFEO Toolbox Library (OTB) is a high performance image processing library. It is primarily used for processing large remote sensing images such as those gathered by radars, satellites and aerial photography. OTB provides tools for optic and radar images (tridimensional aspects, segmentation, classification, changes detection, texture analysis, pattern matching, and optic/radar complementarities), many of which can be run on laptops with limited resources.

OTB is also shipped with a set of extensible ready-to-use tools for classical remote sensing tasks and a fully integrated application called Monteverdi, which is a fast viewer that allows users to visualize multiple layers, and call OTB processing tools from a menu entry.

OTB has been funded by the French Space Agency (CNES) in the frame of the Methodological Part of the ORFEO/Pleiades Accompaniment Program and has been actively developed since 2006. It is based on the ITK image processing library and is distributed as Free/Libre Open Source software (FLOSS).

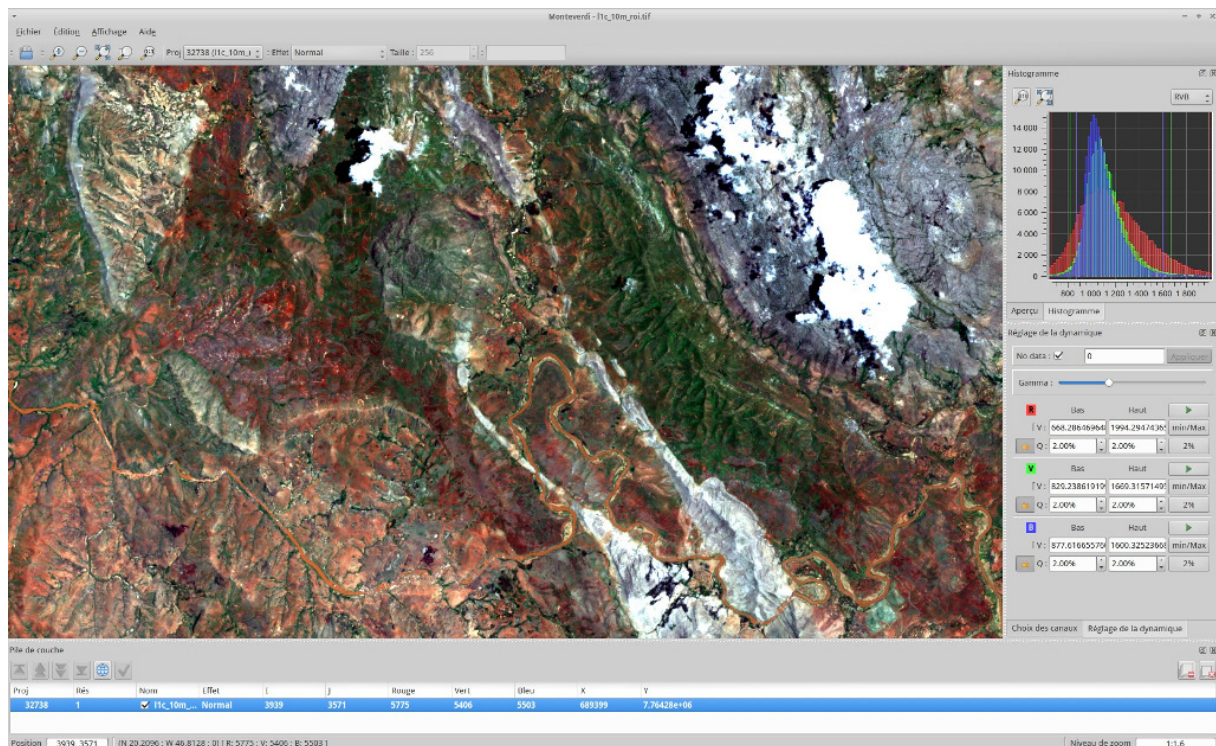


Figure 4.3. GDAL/OGR and PROJ.4 Raster and vector feature list

Core Features:

- image access: optimized read/write access for most remote sensing raster formats (also JPEG2000 formats), meta-data access and visualization;
- orthorectification using DEM, map reprojection and sensor model refinement
- optical and SAR calibration
- image fusion
- filtering: blurring, denoising, enhancement...
- feature extraction: interest points, alignments, lines...
- object detection
- large scale image segmentation: region growing, mean-shift, watershed, level sets...
- sample selection framework for training
- classification: both supervised and unsupervised algorithms coming from OpenCV , Shark, libSVM or custom implementations (K-means, Markov random fields, SVM, Random Forest, ...)
- regression using machine learning methods from OpenCV (SVM, Random Forest, ...)
- object-based image analysis
- geospatial analysis
- stereoscopic reconstruction from optical images
- SAR data analysis : calibration, polarimetry analysis
- change detection.

Details

Website: <https://www.orfeo-toolbox.org/>

Licence: Apache v2.0

Software Version: 6.6.1

Supported Platforms: Linux, Mac, Windows

API Interfaces: C++

Commercial Support: OSGeo service providers

4.4. QGIS

QGIS is a user-friendly, Open Source, GIS client where you can visualize, manage, edit, analyse data, and compose printable maps. It includes powerful analytical functionality through integration with GRASS, SAGA, Orfeo Toolbox, GDAL/OGR and many other algorithm providers. It runs on Linux, Unix, Mac OSX, and Windows and supports numerous vector, raster and database formats and functionality.

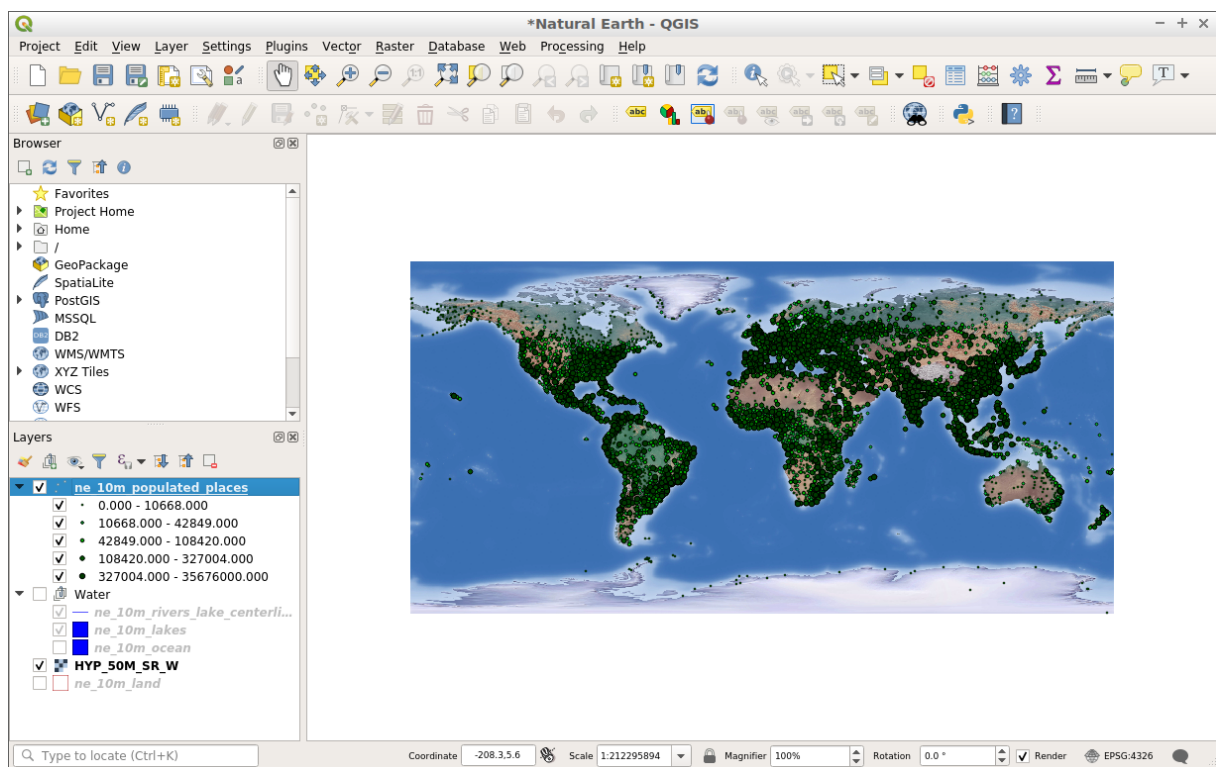


Figure 4.4. QGIS example screenshot

Core Features:

- Friendly graphical user interface:
 - identify/select features
 - edit/view/search attributes
 - on the fly projection
 - print composer
 - feature labeling

- change vector and raster symbology
 - add a graticule layer
 - and more ...
- Easy Viewing of many Vector and Raster Formats
 - database tables: PostgreSQL/PostGIS, Oracle Spatial, MS SQL Spatial, Spatialite
 - most vector formats: including ESRI shapefiles, MapInfo, SDTS and GML, OpenStreetMap vectors
 - raster formats such as digital elevation models, aerial photography or landsat imagery
- GRASS locations and mapsets
- Online spatial data served as OGC-compliant WMS, WMTS, WFS or WCS
- 2.5D rendering support
- Create, edit and export spatial data using:
 - digitizing tools for GRASS and shapefile formats
 - the georeferencer plugin
 - GPS tools to import and export GPX format, convert other GPS formats to GPX, or down/upload directly to a GPS unit
- Perform spatial analysis using integrated support for SAGA, OTB, MMGIS and GRASS including:
 - map algebra
 - terrain analysis
 - hydrologic modeling
 - network analysis
 - comprehensive searchable toolbox of functions
 - define and run reusable analysis routines by chaining functions using a graphical modelling tool
 - and many others
- Publish to the internet
- Extensible plugin architecture
- Implemented Standards:
 - OGC standards compliant (WMS, WFS, etc)

Details

Website: <https://www.qgis.org/en/site/>

Licence: GNU General Public License (GPL) version 2

Software Version: 3.16.4

Supported Platforms: Windows, Linux, Mac, Unix

Community Support: <https://qgis.org/en/site/forusers/support.html>

Commercial Support: https://qgis.org/en/site/forusers/commercial_support.html

4.5. PostgreSQL and PostGIS

PostgreSQL is a powerful, open source object-relational database system that uses and extends the SQL language combined with many features that safely store and scale the most complicated data workloads. The origins of PostgreSQL date back to 1986 as part of the POSTGRES project at the University of California at Berkeley and has more than 30 years of active development on the core platform.

PostgreSQL has earned a strong reputation for its proven architecture, reliability, data integrity, robust feature set, extensibility, and the dedication of the open source community behind the software to consistently deliver performant and innovative solutions. PostgreSQL runs on all major operating systems, has been ACID-compliant since 2001, and has powerful add-ons such as the popular PostGIS geospatial database extender. It is no surprise that PostgreSQL has become the open source relational database of choice for many people and organisations.

PostgreSQL comes with many features aimed to help developers build applications, administrators to protect data integrity and build fault-tolerant environments, and help you manage your data no matter how big or small the dataset. In addition to being free and open source, PostgreSQL is highly extensible. For example, you can define your own data types, build out custom functions, even write code from different programming languages without recompiling your database!

PostgreSQL tries to conform with the SQL standard where such conformance does not contradict traditional features or could lead to poor architectural decisions. Many of the features required by the SQL standard are supported, though sometimes with slightly differing syntax or function. Further moves towards conformance can be expected over time. As of the version 13 release in September 2020, PostgreSQL conforms to at least 170 of the 179 mandatory features for SQL:2016 Core conformance. As of this writing, no relational database meets full conformance with this standard.

PostGIS spatially enables the popular PostgreSQL object-relational database, allowing it to be used as a back-end database for geographic information systems (GIS) and web-mapping applications.

PostGIS is stable, fast, standards compliant, with hundreds of spatial functions and is currently the most widely used Open Source spatial database. PostGIS is used by diverse organisations from around the world, including risk-averse government agencies and organisations storing terabytes of data serving millions of web requests per day.

Database administration is available for desktop and the web via pgAdmin, phpPgAdmin, and others. Data import/export can be done by command line tools (shp2pgsql, pgsql2shp, ogr2ogr, dxf2postgis) or from desktop and web GIS clients. These clients can also map and manipulate PostGIS spatial data tables.

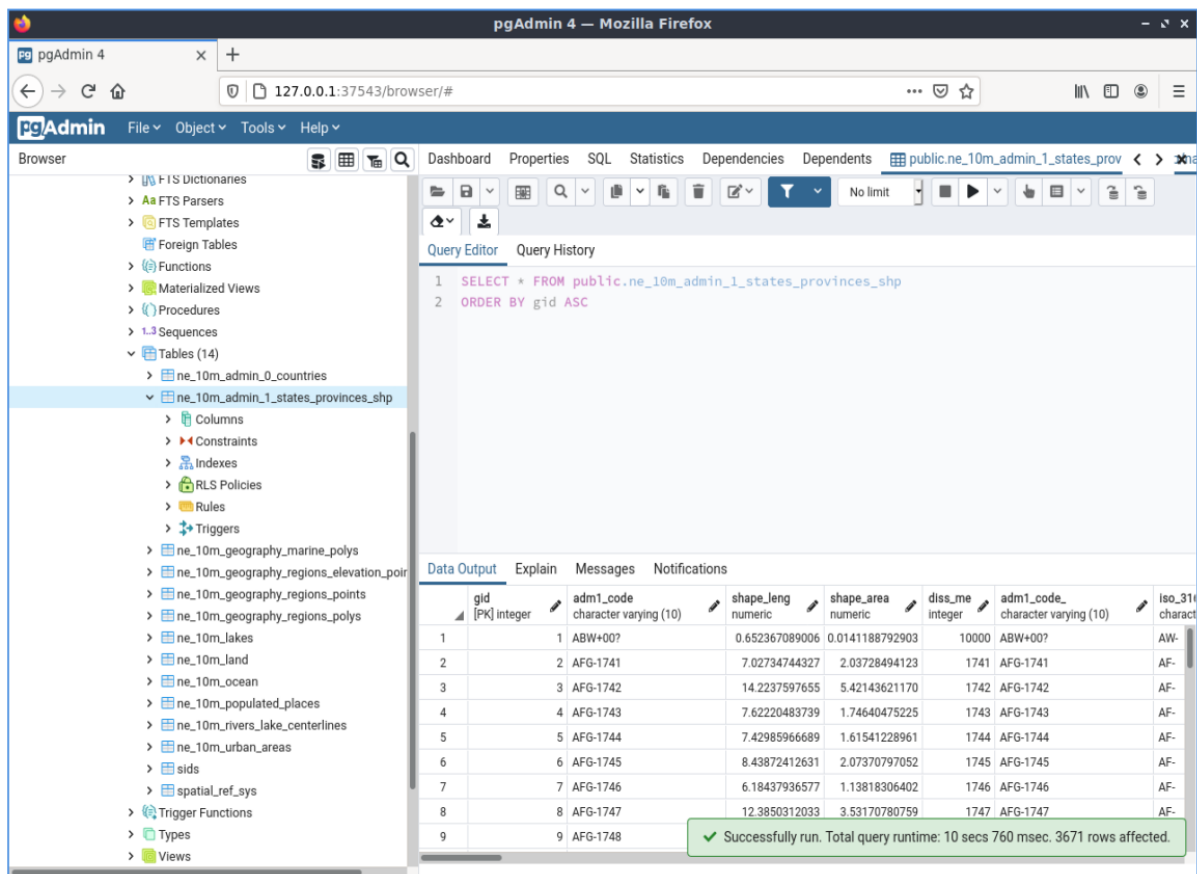


Figure 4.5. Management of PostGIS data from pgAdmin4

Core Features:

- Hundreds of spatial functions
 - Buffers, unions, overlays, distance and more
- ACID transactional integrity
- R-Tree spatial index
- Multi-user support
- Row-level locking
- Replication
- Partitioning
- Role-based security
- Table-spaces, schemas

Implemented Standards:

- OGC standards compliant (SFSQL)

Details

Website: <http://postgis.net>

Licence: GNU General Public License (GPL) version 2

Software Version: 3.1.1

Supported Platforms: Windows, Linux, Mac

API Interfaces: SQL

4.6. MapServer

MapServer is an Open Source geographic data rendering engine written in C. Beyond browsing GIS data, MapServer allows you create “*geographic image maps*”, that is, maps that can direct users to web content. For example, the Minnesota DNR Recreation Compass provides users with more than 10,000 web pages, reports and maps via a single application. The same application serves as a “map engine” for other portions of the site, providing spatial context where needed.

MapServer was originally developed by the University of Minnesota (UMN) ForNet project in cooperation with NASA, and the Minnesota Department of Natural Resources (MNDNR). Later it was hosted by the TerraSIP project, a NASA sponsored project between the UMN and a consortium of land management interests.

MapServer is now a project of OSGeo, and is maintained by a growing number of developers (nearing 20) from around the world. It is supported by a diverse group of organizations that fund enhancements and maintenance, and administered within OSGeo by the MapServer Project Steering Committee made up of developers and other contributors.

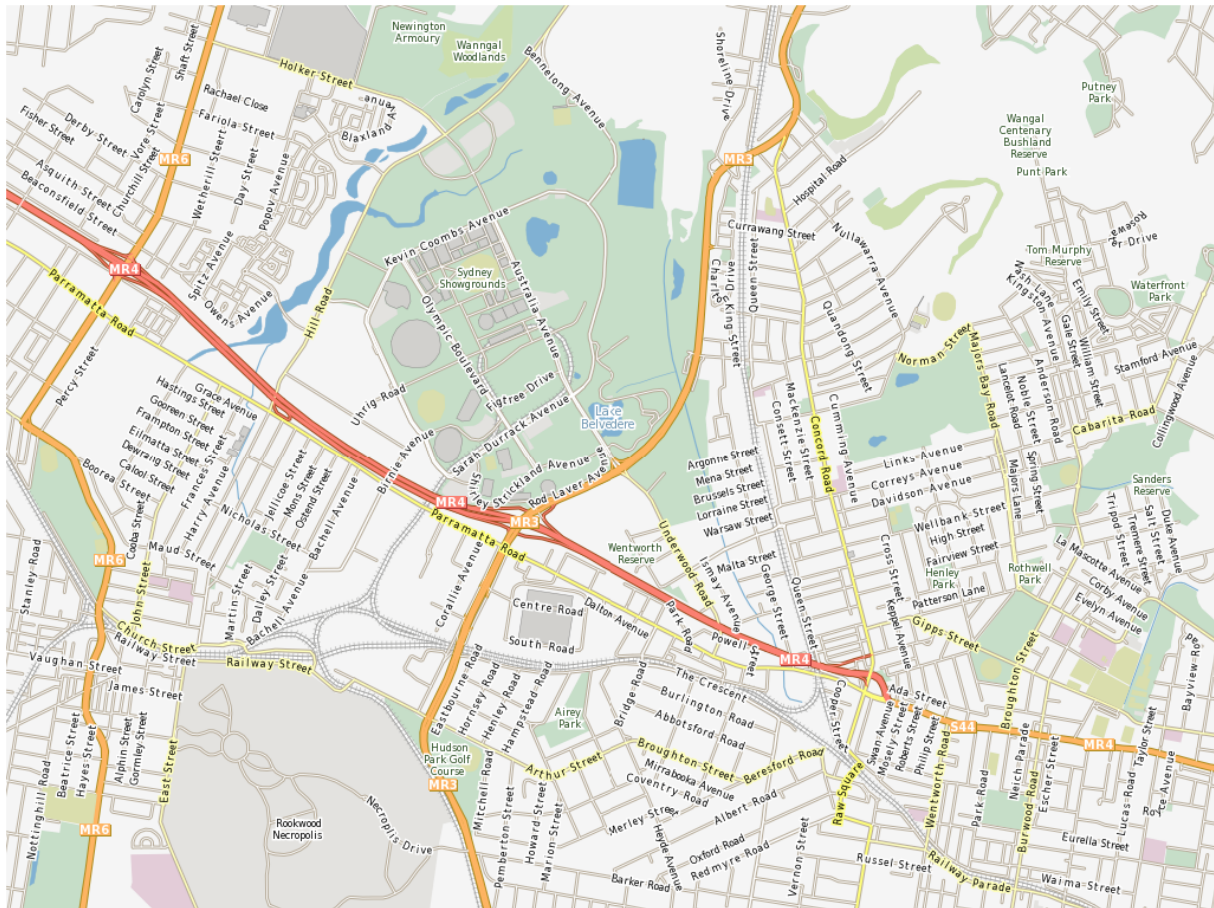


Figure 4.6. Mapserver in action

Core Features:

- Advanced cartographic output:
 - Scale dependent feature drawing and application execution
 - Feature labeling including label collision mediation
 - TrueType font support for labeling and symbolization
 - Map element automation (scalebar, reference map, and legend)
 - Thematic mapping using logical or regular expression-based classes
 - Pluggable renderer support with drivers for AGG, Cairo and others
 - Special provisioning for tiled output generation
 - Mask Layers
 - Precise Symbol Placement
 - Complex Multi Label/Symbol Symbology
 - Vector Fields
 - Label Leader Offsetting
 - SVG Symbology
 - Multiple Font Support
 - Dynamic Heatmaps
 - UTF Grid Support
 - Layer Compositing

- Sophisticated spatial query support:
 - Identify features by attributes, point, bounding box or geometry across one or more layers
 - Support for raster queries
 - Fully customizable, template driven output
 - OGR-based query output generation
- Support for popular scripting and development environments:
 - CGI/FastCGI
 - PHP, Python, Perl, Ruby, Java, and .NET
- Cross-platform support:
 - Linux, Windows, Mac OS X, Solaris, and more
- A multitude of raster and vector data formats
 - Native support for ESRI shapefiles, PostGIS and Oracle Spatial
 - Many other formats via GDAL and OGR
- Map projection support:
 - On-the-fly map projection with 1000s of projections through the Proj.4 library

Implemented Standards:

- Support of numerous Open Geospatial Consortium (OGC) standards
 - Web Map Service (WMS) (client/server)
 - Web Feature Service (WFS) (non-transactional, client/server)
 - Web Map Context (WMC)
 - Web Coverage Service (WCS)
 - Filter Encoding (FE)
 - Styled Layer Descriptor (SLD)
 - Geography Markup Language (GML)
 - Sensor Observation Service (SOS)
 - OM
- INSPIRE View Service compliant

Details

Website: <https://mapserver.org>

Licence: MIT-style license

Software Version: 7.6.2

Supported Platforms: Windows, Linux, Mac

API Interfaces: C, PHP, Python, Perl, Ruby, Java, and .NET

Support: <https://mapserver.org/community/>

4.7. Apache web server

The Apache HTTP Server Project is a collaborative software development effort aimed at creating a robust, commercial-grade, featureful, and freely-available source code implementation of an HTTP (Web) server. The project is jointly managed by a group of volunteers located around the world, using the Internet and the Web to communicate, plan, and develop the server and its related documentation. This project is part of the Apache Software Foundation. In addition, hundreds of users have contributed ideas, code, and documentation to the project. This file is intended to briefly describe the history of the Apache HTTP Server and recognize the many contributors.

Apache Software exists to provide robust and commercial-grade reference implementations of many types of software. It must remain a platform upon which individuals and institutions can build reliable systems, both for experimental purposes and for mission-critical purposes. We believe that the tools of online publishing should be in the hands of everyone, and that software companies should make their money by providing value-added services such as specialized modules and support, amongst other things. We realize that it is often seen as an economic advantage for one company to "own" a market - in the software industry, that means to tightly control a particular conduit such that all others must pay for its use. This is typically done by "*owning*" the protocols through which companies conduct business, at the expense of all those other companies. To the extent that the protocols of the World Wide Web remain "*unowned*" by a single company, the Web will remain a level playing field for companies large and small. Thus, "*ownership*" of the protocols must be prevented. To this end, the existence of robust reference implementations of various protocols and application programming interfaces, available free to all companies and individuals, is a tremendously good thing.

Furthermore, the Apache Software Foundation is an organic entity; those who benefit from this software by using it, often contribute back to it by providing feature enhancements, bug fixes, and support for others in public lists and newsgroups. The effort expended by any particular individual is usually fairly light, but the resulting product is made very strong. These kinds of communities can only happen with freely available software -- when someone has paid for software, they usually aren't willing to fix its bugs for free. One can argue, then, that Apache's strength comes from the fact that it's free, and if it were made "not free" it would suffer tremendously, even if that money were spent on a real development team.

The vast majority of Apache HTTP Server instances run on a Linux distribution, but current versions also run on Microsoft Windows, OpenVMS, and a wide variety of Unix-like systems. Past versions also ran on NetWare, OS/2 and other operating systems, including ports to mainframes.

Originally based on the NCSA HTTPd server, development of Apache began in early 1995 after work on the NCSA code stalled. Apache played a key role in the initial growth of the World Wide Web, quickly overtaking NCSA HTTPd as the dominant HTTP server. In 2009, it became the first web server software to serve more than 100 million websites. As of January 2021, Netcraft estimated that Apache served 24.63% of the million busiest websites, while Nginx served 23.21% and Microsoft is in third place at 6.85% (for some of Netcraft's other stats Nginx is ahead of Apache), while according to

W3Techs, Apache is ranked first at 35.0% and Nginx second at 33.0% and Cloudflare Server third at 17.3%.

5. OGC web services

The Open Geospatial Consortium (OGC) was founded in 1994 with the aim of making geographic information a key element of the global information infrastructure. OGC members - providers and users of technology - work together to develop open interface and coding standards, as well as best techniques, allowing developers to create information systems that can easily exchange spatial information and interact with other information systems. . Requirements range from complex programming and control of Earth tracking satellites, to displaying simple maps on the internet and encoding location information into a few bytes of information for composing messages and positioning geo-tagging. A quick look at the list of OGC working groups reveals the wide scope of OGC's current activity. (<http://www.opengeospatial.org/projects/groups/wg>)

Web Services Framework Of OGC Geoprocessing Standards

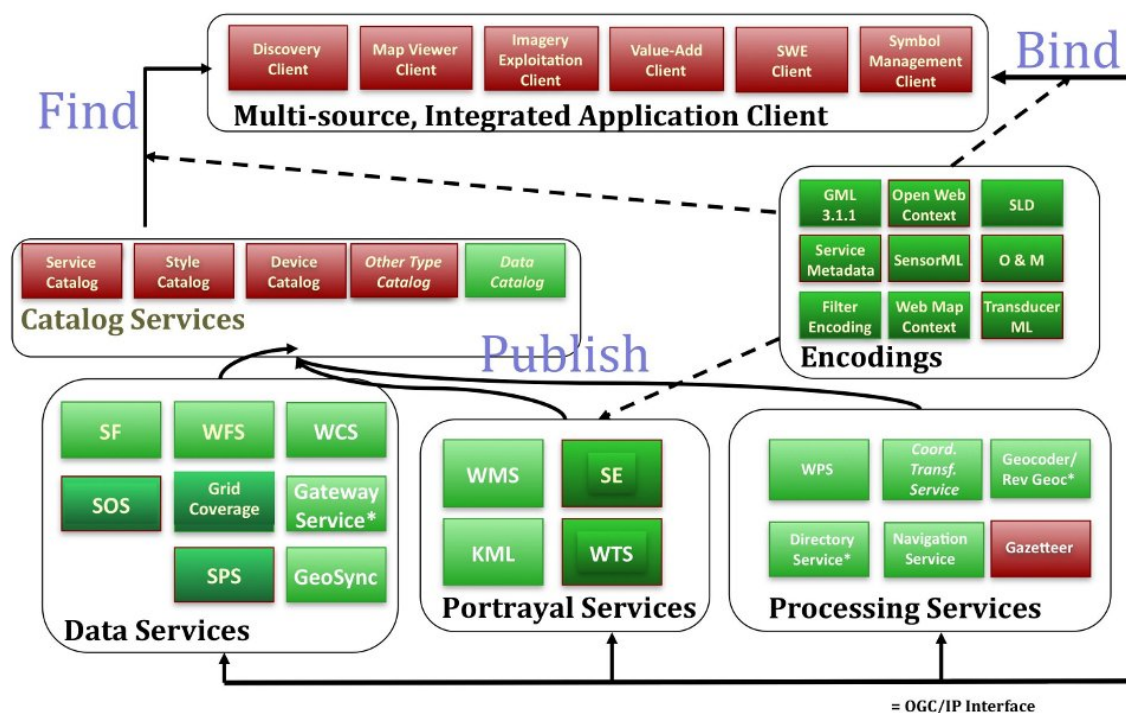


Figure 5.1: ORM reference model that provides a summary of OGC standards.

The OGC core template line includes OGC standards (<http://www.opengeospatial.org/standards>) for interfaces, coding, profiles, application schemes, and technical specification texts for work optimization. The OGC Reference Model (ORM) (<http://www.opengeospatial.org/standards/orm>) describes these standards and their relationship to the corresponding ISO standards. The ORM reference model provides a summary of OGC standards and is a valuable resource for defining specific application architectures.

When developing web application applications using OGC templates (and learning the relationships between templates) it helps to think of publishing, searching and linking as basic functions to be performed in an online services environment.

- Post: Resource providers advertise their resources.
- Search: End users and their applications can discover resources while running applications.
- Interface: End users and their applications can access and perform resource operations while running applications.

Most OGC standards have been developed in recent years within the online services environment, and these standards are collectively referred to as OGC Web Services (OWS). Figure 5.1 provides an overview of the architecture for OGC Internet Services. This schema identifies the general categories of services involved in various site processing and activities.

The acronyms in the figure 5.1 are defined below. Some of these OGC standards and more are published as "Consultation Texts", "Requirements" and "Reference Texts". (Note that some of these texts are candidate templates and are not yet available to everyone except OGC members.)

- Catalogue Service for the Web (CSW)
- Filter Encoding (FE)
- Geography Markup Language (GML)
- KML Encoding Standard (KML)
- Sensor Model Language (SensorML)
- Style Layer Descriptor (SLD)
- Sensor Observation Service (SOS)
- Web Coverage Service (WCS)
- Web Feature Service (WFS)
- Web Map Service (WMS)
- Web Processing Service (WPS)
- Sensor Planning Service (SPS)
- Web Terrain Service (WTS)
- Grid Coverage Service
- Coordinate Transformation Service
- Web Coverage Processing Service (WCPS)
- Web Map Tile Service (WMTS)
- Simple Features (SF)
- Sensor Web Enablement (SWE)
- XML for Image and Map Annotation (XIMA)
- CityGML
- GeosciML
- GML in JPEG 2000
- Observations and Measurements (O&M)
- Symbology Encoding

- Transducer Markup Language (TML)

5.1. OGC Web Map Service

OGC Web Map Service provides a simple HTTP protocol interface for requesting and retrieving georeferenced map images from one or more distributed spatial databases. The server's response to the request from each user is one or more images (in JPEG, PNG, etc.) that can be easily displayed in a browser and in local applications on the desktop. (<http://www.opengeospatial.org/standards/wms>)

The WMS standard defines three functions:

- GetCapabilities (required): Get metadata about the service, in computer-readable format (and from humans), description of WMS service information, and acceptable parameters when calling the service.
- GetMap (required): Get a map image whose spatial and geometric dimensions are fully defined.
- GetFeatureInfo (optional): Query to get information about a specific feature displayed on the map.

This template has been implemented in hundreds of software, many of which are listed at (<http://www.opengeospatial.org/resource/products/compliant>).

The OGC® Web Map Service Interface Standard provides a simple way to portray geographic data held in diverse data repositories.

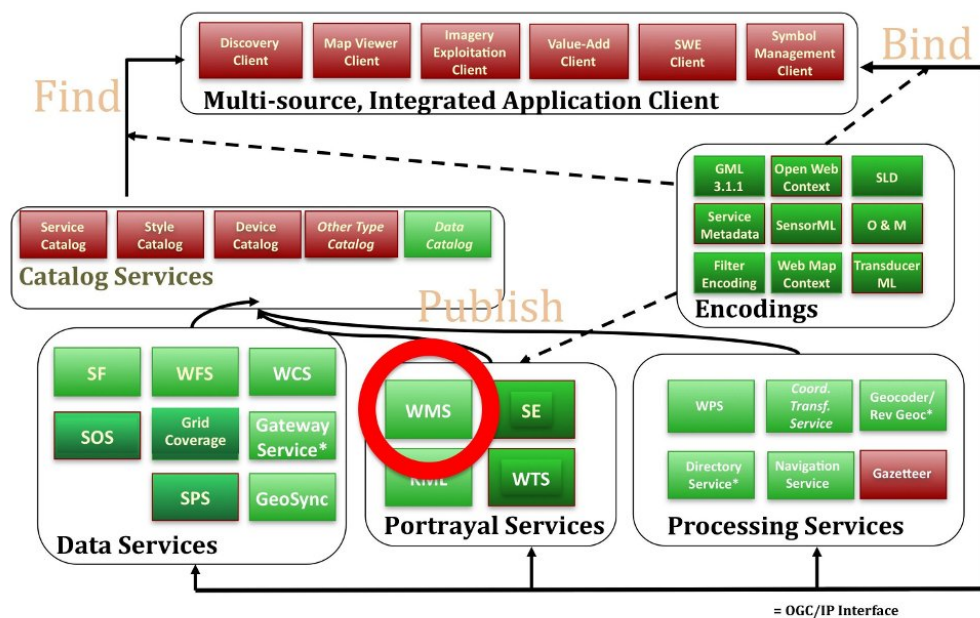


Figure 5.2: The WMS standard as a viewing service.

5.2. OGC Web Feature Service

The OGC® Web Feature Service template defines web features for retrieving and editing vector geographic features, such as roads or lake boundaries. (<http://www.opengeospatial.org/standards/wfs>)

The WFS standard defines procedures that allow its users to:

- Find out which feature sets are available (GetCapabilities)
- Describe the descriptive fields for the features (DescribeFeatureType)
- Retrieve a collection or piece of data through a filter (GetFeature)
- Add, correct or delete features (Transaction)

All WFS services support data entry and output using the Geography Markup Language (GML) standard. Some WFS services also support other encodings, such as GeoRSS or shapefiles.

Users typically interact with WFS services through browsers or GIS software, which allow them to access data levels from external sources over the Internet. A great example of using a WFS service to provide open and interoperable access to vast amounts of spatial information through a government website is the USGS WFS service provided as part of the development of the US National Spatial Data Infrastructure (NSDI) ([http:// frameworkwfs.usgs.gov/](http://frameworkwfs.usgs.gov/)). Selected spatial information levels are offered as WFS service information levels and through a browser interface provided by USGS.

The OGC® Web Feature Service Interface Standard provides access to feature data.

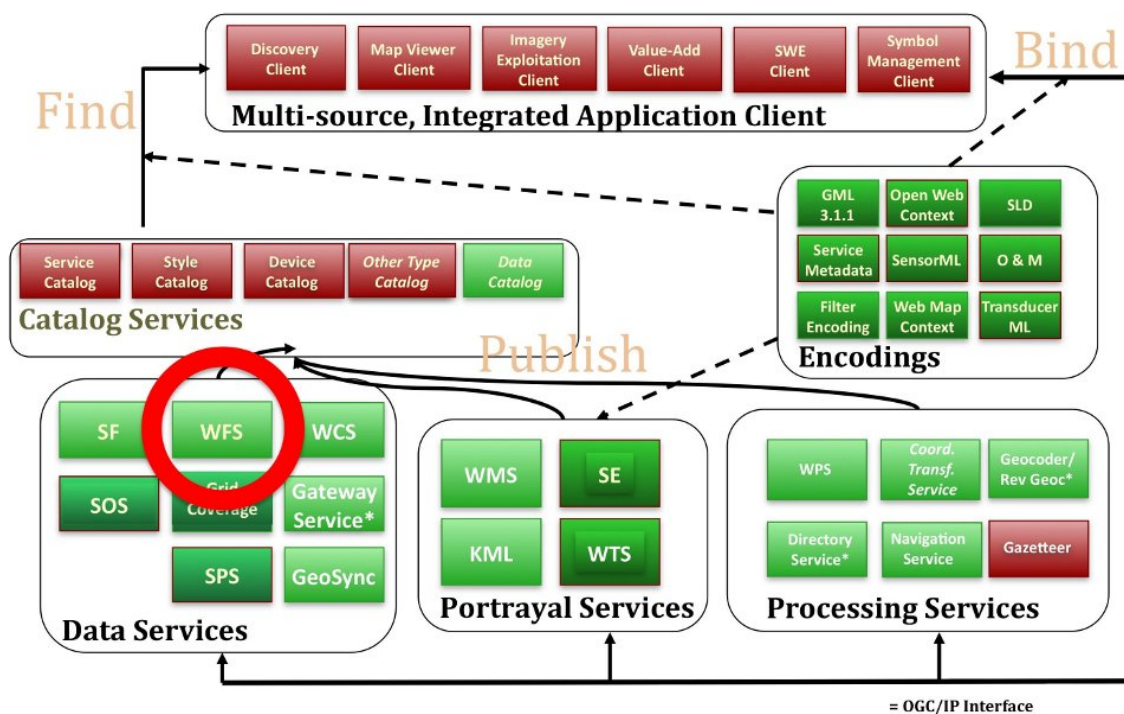


Figure 5.3: The WFS standard as a data transfer service.

5.3. OGC Web Coverage Service

The OGC® Web Coverage Service (WCS) standard defines a standard interface and functions that allow interoperable access to grid coverages. This term typically describes data such as remote sensing images, satellite imagery, digital aerial photographs, digital terrain models, and other phenomena that can be represented by values at each measurement point. (<http://www.opengeospatial.org/standards/wcs>)

The OGC WCS standard refers to an online data service. The WCS standard defines a data access service that allows grid data, such as digital terrestrial models, to be retrieved via HTTP. A server's response to a WCS request includes grid data metadata and output data whose pixels are encoded in a specific digital image standard such as GeoTIFF or NetCDF.

As with other OGC standards, there are many excellent examples of WCS services in use. One such example is the NDBC High Frequency (HF) Radar WCS service developed and published by the US NOAA Service (<http://hfradar.ndbc.noaa.gov/>). HF radar is used for remote sensing observation and measurement of ocean currents. Another example is NASA's WCS service for accessing AIRS (Atmospheric Infrared Sounder) system data:

```
http://idn.ceos.org/KeywordSearch/Metadata.do?Portal=webservices&KeywordPath=+Project%3A+Short_Name%3D%20EOS%20&EntryId =  
NASA_GES_DISC_AIRS_Atmosphere_Data_Web_Coverage_Service & MetadataView = Full &  
MetadataType = 1 & lbnode = mdlb1
```

This is a WCS service from the available Goddard Data and Information Center services that provide level 3 atmospheric data from NASA's Aqua satellite.

The OGC® Web Coverage Service Interface Standard enables access to coverages (satellite images, elevation data, etc.) held in diverse data repositories.

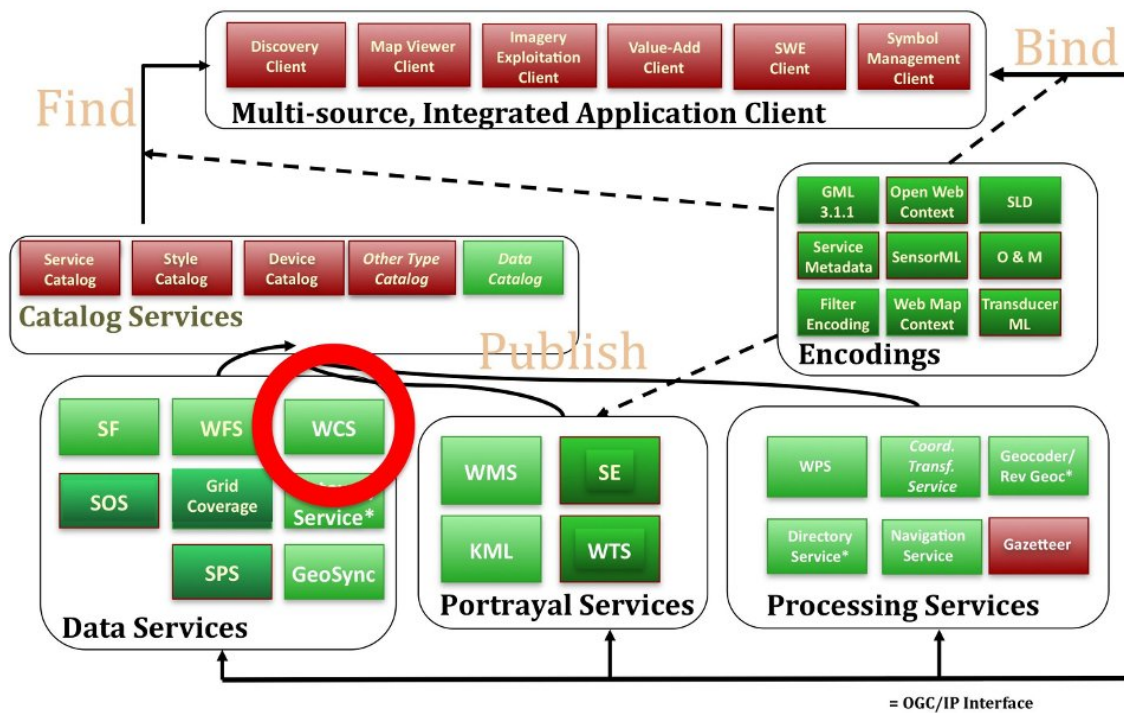


Figure 5.4: The WCS standard as a virtual data download service.

6. System architecture

The implementation of the project information system was carried out on private cloud infrastructure of EOfarm with the ability to store huge volumes of data and at the same time the availability of large volumes of system memory, as well as multiple computing cores to handle the processing of remote sensing data and other system calculations.

Due to the physical characteristics of the server, the implementation of the system was chosen following the good practice of implementing complex systems through containers technology and specifically in the Docker technology, applied on a GNU / Linux operating system. Based on this technology, the following services were defined for the project:

- Data Download Service
- Raster Storage Service
- Spatial Database Service
- Processing Service
- View and Download Web Services

Figure 6.1 presents in detail the graphical representation of the system architecture, as it was designed for the above hardware. The logic of the architecture was in the n-tier design, with the disconnection of the database from the web servers but also from the data storage unit for greater flexibility and future scalability. The following section describes the individual subsystems of the architecture.

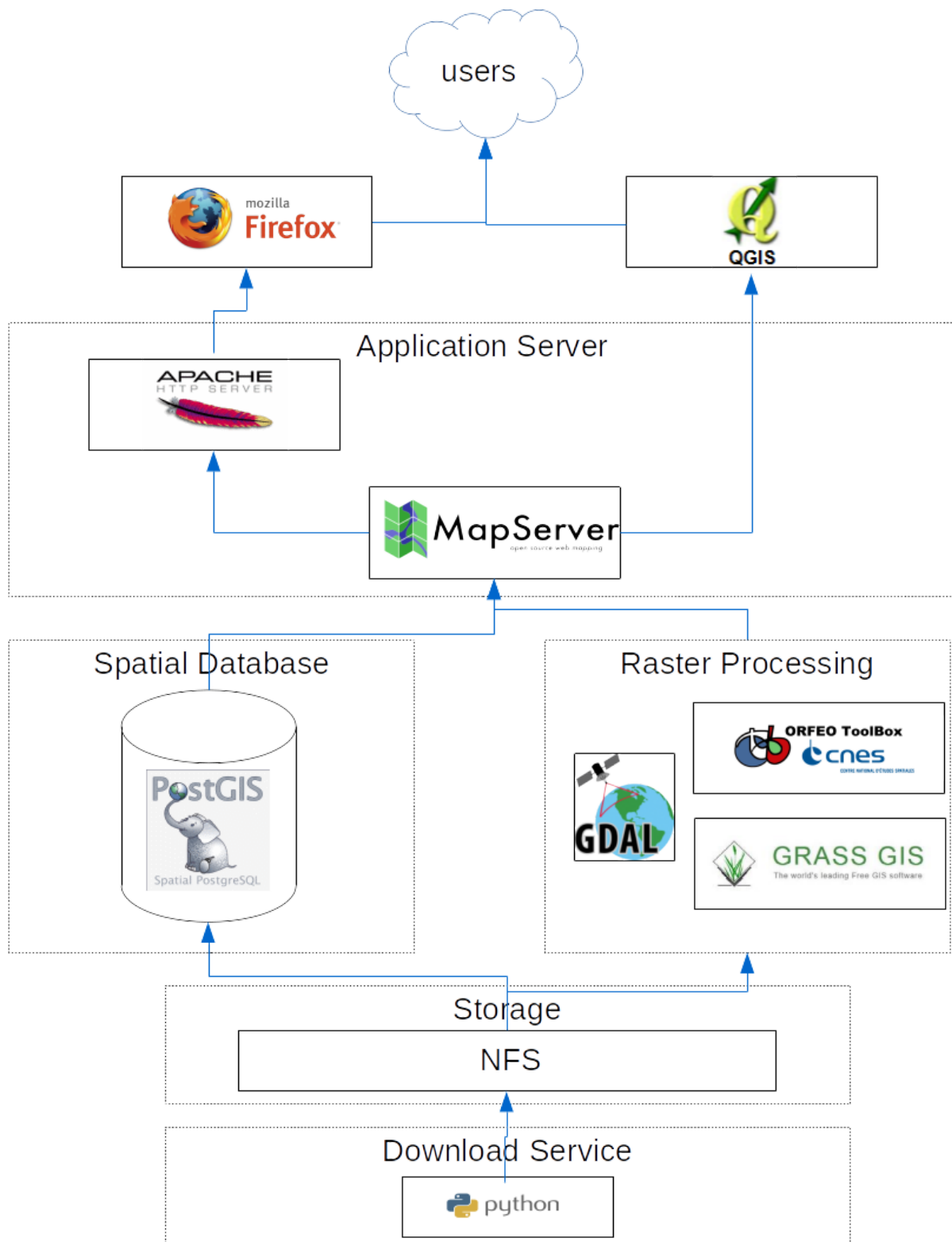


Figure 6.1 presents in detail the graphical representation of the system architecture

6.1. Data Download Service

This service consists of a container in which an appropriate code is implemented in Python programming language with the basic function of automatically uploading the remote sensing data Landsat and Sentinel from the international repositories to the project server. The service operates continuously and uploads new data within a few hours of its appearance in the USGS and ESA international repositories. The data is searched in the corresponding international spatial queries and uploaded to the NFS file system for distribution to other subsystems.

More specifically, the service is implemented by the appropriate Python scripts that are available as free software in the EOfarm GitHub repository (<https://github.com/EOFarm>). Uploading Landsat data required registration with the USGS EarthExplorer service so that data can then be downloaded using USGS Certified Data Access.

To download Landsat data 3 ways to use the code have been implemented:

(https://github.com/EOFarm/LANDSAT-Download/blob/master/download_landsat_scene.py)

- Repeat search with Landsat scene coordinates (eg 184,033) for MESSOLONGHI (parameter -s), start date (parameter -d), and end date (parameter -f). In case the expiration parameter does not exist, the current date is considered. Example usage: `download_landsat_scene.py -o scene -b LC8 -d 20190101 -s 184033 -u usgs.txt --output /mnt/data/LANDSAT8/N0/`
- Search a directory with Landsat scene coordinates (eg 184,033) for MESSOLONGHI (parameter -s), start date (parameter -d), and end date (parameter -f). In case the expiration parameter does not exist, the current date is considered. Example usage: `download_landsat_scene.py -o catalog -b LC8 -d 20190101 -s 184033 -u usgs.txt --output /mnt/data/LANDSAT8/N0/`
- Using image list, for example: `download_landsat_scene.py -o liste -l list_landsat8.txt -u usgs.txt --output /mnt/data/LANDSAT8/N0/`

For the download of Sentinel data an appropriate library has been implemented with the following parameters:

- Point or polygon coordinates
- Scene number
- Date

(https://github.com/EOFarm/Sentinel-download/blob/master/Sentinel_download.py)

The library was implemented based on the instructions of the well-documented ESA api: <https://scihub.copernicus.eu/userguide/5APIsAndBatchScripting>. To use the library, registration in the SciHub repository is required.

6.2 Raster Storage Service

This service consists of a container with a direct connection to the storage disks to which all the geospatial data are stored in a suitable structure in the file system. The service is implemented in the GNU/Linux operating system of the project server in an Internet NFS file system service, so that it can

share files access to other subsystems. The storage disks are implemented on a RAID 5 array and with simultaneous use of LVM technology for future capacity expansion.

This service stores both the raw data from the satellite imaging providers, as well as the intermediate results of the edits, as well as the system files of the database for protection from data loss from possible hardware failure.

6.3 Spatial Database Service

This service consists of a set of containers that implement the system database, where all the metadata of the raster data are stored and managed. This service is connected with the storage service to secure the content of the database. For the implementation of this service the PostgreSQL database was selected (more details in section 4.5) with the geospatial extension PostGIS.

More specifically for the IR2MA project an object-relational database schema was developed to store the metadata of the raster datasets that are ingested into the system. Such metadata include the spatial resolution, the dataset identifiers, keywords, bounding boxes, spatial reference systems, acquisition date and time etc. The schema of the spatial database is presented in Figure 6.2. In Figure 6.3 a spatial query to the spatial database is presented. The result set included all the available raster datasets of the IR2MA area of interest for the year 2020.

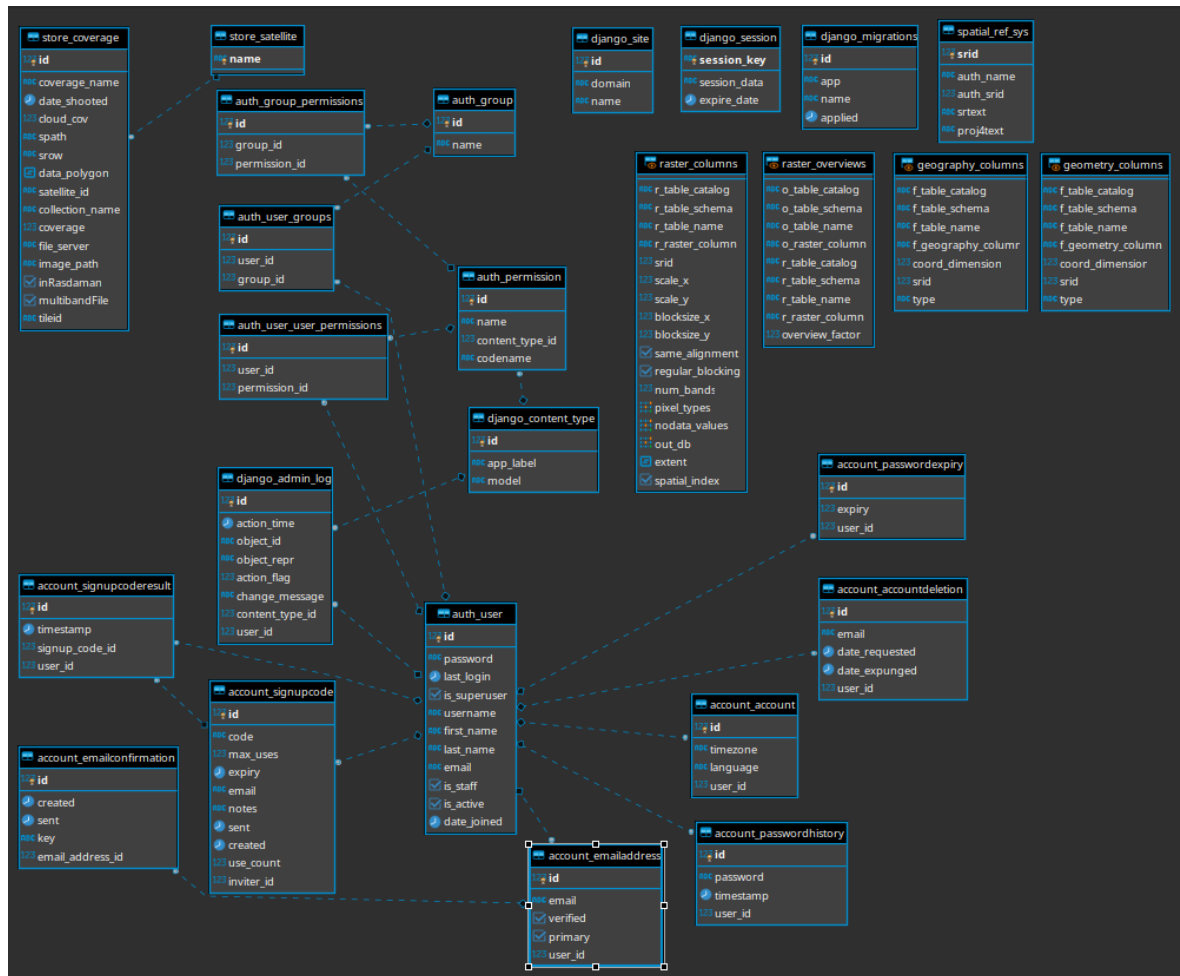


Figure 6.2: The ER diagram of the IR2MA spatial database

store coverage Enter a SQL expression to filter results (use Ctrl+Space)								
	id	coverage_name	date_shooted	cloud_cov	spath	srow	data_polygon	
11	18	LC81840332020083LGN00	2020-03-23	2	184	033	POLYGON ((21.00028	
12	19	LC81840342020083LGN00	2020-03-23	2	184	034	POLYGON ((21.00028	
13	20	LC81840332020099LGN00	2020-04-08	2	184	033	POLYGON ((21.00028	
14	21	LC81840342020099LGN00	2020-04-08	2	184	034	POLYGON ((21.00028	
15	22	LC81840332020115LGN00	2020-04-24	2	184	033	POLYGON ((21.00028	
16	23	LC81840342020115LGN00	2020-04-24	2	184	034	POLYGON ((21.00028	
17	24	LC81840332020131LGN00	2020-05-10	2	184	033	POLYGON ((21.00028	
18	25	LC81840332020147LGN00	2020-05-26	2	184	033	POLYGON ((21.00028	
19	26	LC81840342020147LGN00	2020-05-26	2	184	034	POLYGON ((21.00028	
20	27	LC81840332020163LGN00	2020-06-11	2	184	033	POLYGON ((21.00028	
21	28	LC81840342020163LGN00	2020-06-11	2	184	034	POLYGON ((21.00028	
22	29	LC81840332020179LGN00	2020-06-27	2	184	033	POLYGON ((21.00028	
23	30	LC81840342020179LGN00	2020-06-27	2	184	034	POLYGON ((21.00028	
24	31	LC81840332020195LGN00	2020-07-13	2	184	033	POLYGON ((21.00028	
25	32	LC81840342020195LGN00	2020-07-13	2	184	034	POLYGON ((21.00028	
26	33	LC81840332020211LGN00	2020-07-29	2	184	033	POLYGON ((21.00028	
27	34	LC81840342020211LGN00	2020-07-29	2	184	034	POLYGON ((21.00028	
28	35	LC81840332020227LGN00	2020-08-14	2	184	033	POLYGON ((21.00028	
29	36	LC81840342020227LGN00	2020-08-14	2	184	034	POLYGON ((21.00028	
30	37	LC81840332020243LGN00	2020-08-30	2	184	033	POLYGON ((21.00028	
31	38	LC81840342020243LGN00	2020-08-30	2	184	034	POLYGON ((21.00028	
32	39	LC81840332020259LGN00	2020-09-15	2	184	033	POLYGON ((21.00028	
33	40	LC81840342020259LGN00	2020-09-15	2	184	034	POLYGON ((21.00028	
34	41	LC81840332020275LGN00	2020-10-01	2	184	033	POLYGON ((21.00028	
35	42	LC81840342020275LGN00	2020-10-01	2	184	034	POLYGON ((21.00028	
36	43	S2B20200102T093309	2020-01-02	2			POLYGON ((21.00022	
37	44	S2A20200104T092401	2020-01-04	2			POLYGON ((21.00022	
38	45	S2A20200107T093351	2020-01-07	2			POLYGON ((21.00022	
39	46	S2B20200109T092249	2020-01-09	2			POLYGON ((21.00022	
40	47	S2B20200112T093249	2020-01-12	2			POLYGON ((21.00022	
41	48	S2A20200114T092331	2020-01-14	2			POLYGON ((21.00022	
42	49	S2A20200117T093321	2020-01-17	2			POLYGON ((21.00022	
43	50	S2B20200119T092219	2020-01-19	2			POLYGON ((21.00022	
44	51	S2B20200122T093209	2020-01-22	2			POLYGON ((21.00022	

Figure 6.3: The result of a spatial query

6.4 Raster Processing Service

This service consists of a set of containers in which the appropriate software is installed for the pre-processing and analysis of remote sensing data before being stored in the database management system.

The service is implemented by the free software of OSGeo:

- GDAL: The Geospatial Data Abstraction Library (GDAL / OGR) provides tools for converting and editing a wide variety of vector and raster formatting of geospatial data files. These tools are based on a portable (cross platform) C++ library accessible from almost all other programming languages. As a library it represents through an abstract model all the supported formulations. Today it is the most popular geospatial data management library. It works on the data access engine in many known software such as: MapServer, GRASS, QGIS, and

OpenEV. It is also supported by packages such as: OSSIM, Cadcorp SIS, FME, Google Earth, VTP, Thuban, ILWIS, MapGuide and ArcGIS.

- **GRASS GIS:** GRASS (Geographic Resources Analysis Support System) software is a Geographic Information System (GIS) that provides powerful geospatial processing mechanisms for vector data and visual data in a complete software suite. GRASS software includes tools for spatial modeling, visualization of pictorial and vector data, management and analysis of geospatial data, and processing of satellite images and aerial photographs. It also provides the ability to produce complex graphics for presentations and map printing. GRASS has been translated into 20 languages and supports a wide range of data standards. GRASS is used worldwide in academic and commercial applications as well as in many government agencies and environmental consulting firms. The software runs on many popular hardware platforms and is Free Software under the terms of the GNU General Public License. The GRASS program includes more than 400 units of analysis software. In addition, over 100 applications and toolbars are provided by the community at no cost to the community wiki. After 30 years of continuous development, GRASS software is at the same time the oldest and largest available Open Source Geographic Information System. It is easily scalable and flexible for use both in bulk editing processes and in a supercomputer environment as well as for use by a personal computer or handheld.
- **Orfeo Toolbox:** The Orfeo Toolbox (OTB) is a set of high performance image analysis software tools (library). Its main use is for the processing of remote sensing images such as those collected by radar, satellite remote sensing receivers and airborne receivers (aerial photographs). OTB provides tools for optical images and radar images (3D perspectives, image segmentation, sorting, change detection, texture analysis, pattern matching, optical data and radar imaging). OTB was established by the French Space Agency (CNES) under the Methodological Part of the ORFEO program. It has been under active development since 2006. OTB is based on the established ITK (v4) medical image analysis library and is free software.

The main function of the service is the implementation of pre-processing stages such as radiometric correction and geometric correction of data, immediately after retrieving data from data access sources and before storing in the geospatial database.

6.5 View and Download Web Services

This service consists of two sets of containers where the appropriate software is installed for the dissemination of remote sensing data to system users either via the Internet or through access from GIS software (e.g. QGIS) (Figure 6.1).

Viewing and downloading services are implemented by the free Apache Web Server software and the free MapServer software of OSGeo Organization. This software will aim to provide network access (internal or internet) to both local users and remote services (other project software subsystems). For

more details about MapServer please see section 4.6. MapServer containers have been deployed to the project cloud infrastructure, using the docker file presented in figure 6.2.

Through the deployment of MapServer, the end users of the system of the present project can access the data, either through web services (OGC WMS, WFS, WCS) or through direct connection of QGIS software to the service of viewing and downloading the remote sensing data.

The source code of the service is available on GitHub (<https://github.com/EOFarm/docker-mapserver>).

The View and Download web services were implemented for the entire set of remote sensing data (more details on Section 8)

```
FROM ubuntu:18.04
LABEL maintainer="info@eofarm.com"

# let's copy a few of the settings from /etc/init.d/apache2
ENV APACHE_CONFDIR=/etc/apache2 \
    APACHE_ENVVARS=/etc/apache2/envvars \
# and then a few more from $APACHE_CONFDIR/envvars itself
    APACHE_RUN_USER=www-data \
    APACHE_RUN_GROUP=www-data \
    APACHE_RUN_DIR=/var/run/apache2 \
    APACHE_PID_FILE=/var/run/apache2/apache2.pid \
    APACHE_LOCK_DIR=/var/lock/apache2 \
    APACHE_LOG_DIR=/var/log/apache2 \
    LANG=C \
    TERM=linux \
    MS_MAPFILE=/etc/mapserver/mapserver.map

RUN apt-get update && \
    apt-get install --assume-yes --no-install-recommends ca-certificates apache2
libapache2-mod-fcgid curl \
    libfribidi0 librsvg2-2 libpq5 libpng16-16 libjpeg8 libgif7 libgeos-c1v5
libfcgi0ldbl libgdal20 \
    libxslt1.1 libprotobuf-c1 libcap2-bin && \
    apt-get clean && \
    rm -rf /var/lib/apt/lists/* && \
    echo 'Allow apache2 to bind to port <1024 for any user' && \
    curl -L
https://github.com/kelseyhightower/confd/releases/download/v0.14.0/confd-0.14.0-linux-amd
64 > /bin/confd && \
    setcap cap_net_bind_service=+ep /usr/sbin/apache2 && \
    apt-get --purge autoremove -y curl libcap2-bin

RUN a2enmod fcgid headers status && \
    a2dismod -f auth_basic authn_file authn_core authz_user autoindex dir && \
    rm /etc/apache2/mods-enabled/alias.conf && \
    mkdir --parent ${APACHE_RUN_DIR} ${APACHE_LOCK_DIR} ${APACHE_LOG_DIR}
/etc/confd/templates/ /etc/mapserver /etc/confd/conf.d && \
    find "$APACHE_CONFDIR" -type f -exec sed -ri ' \
        s!^(\\s*CustomLog)\\s+\\S+!\\1 /proc/self/fd/1!g; \
        s!^(\\s*ErrorLog)\\s+\\S+!\\1 /proc/self/fd/2!g; \
        ' '{}' ';' && \
    sed -ri 's!LogFormat "(.*)" combined!LogFormat "%{us}T %{X-Request-Id}i \\1"
combined!g' /etc/apache2/apache2.conf && \
    echo 'ErrorLogFormat "%{X-Request-Id}i [%l] [pid %P] %M"' >>
/etc/apache2/apache2.conf && \
    chmod a+rx /bin/confd && \
    mkdir --parent /etc/confd/conf.d /etc/confd/templates /etc/mapserver
/docker-entrypoint.d

# Be able to install font as nonroot
RUN chmod u+s /usr/bin/fc-cache

EXPOSE 80

COPY runtime /
COPY target /usr/local/
```



```

ENV MS_DEBUGLEVEL=0 \
    MS_ERRORFILE=stderr \
    MAX_REQUESTS_PER_PROCESS=1000 \
    MIN_PROCESSES=1 \
    MAX_PROCESSES=5 \
    BUSY_TIMEOUT=300 \
    IDLE_TIMEOUT=300 \
    IO_TIMEOUT=40

RUN adduser www-data root && \
    chmod -R g+w ${APACHE_CONFDIR} ${APACHE_RUN_DIR} ${APACHE_LOCK_DIR} ${APACHE_LOG_DIR} \
    /etc/confd /etc/mapserver /var/lib/apache2/fcgid /var/log && \
    chgrp -R root ${APACHE_LOG_DIR} /var/lib/apache2/fcgid

ENTRYPOINT ["/docker-entrypoint"]

CMD ["/usr/local/bin/start-server"]

```

Figure 6.2: MapServer Dockerfile

For better management and scalability of services, one view and one download web service was implemented per product per year. Some examples of View Services (OGC WMS) are the following:

http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_SR_2020.map&service=WMS&request=GetCapabilities

http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_TIR_2020.map&service=WMS&request=GetCapabilities

http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_SR_2020.map&service=WMS&request=GetCapabilities

Accessing the service capabilities through a web browser is shown in Figure 6.3

Some examples of Download Services (OGC WCS) are the following:

http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_SR_2020.map&service=WCS&request=GetCapabilities

http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_TIR_2020.map&service=WCS&request=GetCapabilities

http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_SR_2020.map&service=WCS&request=GetCapabilities

Accessing the service capabilities through a web browser is shown in Figure 6.4

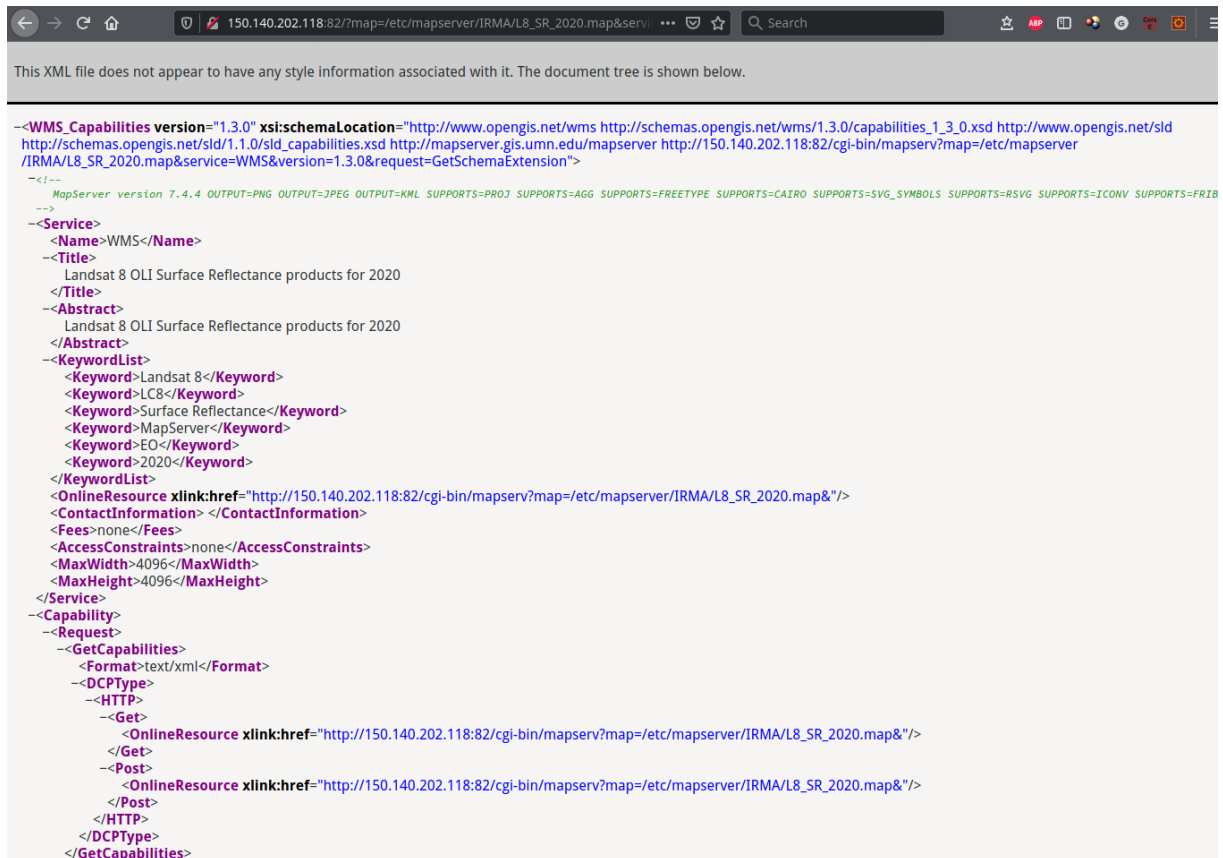


Figure 6.3: Accessing OGC WMS from the browser

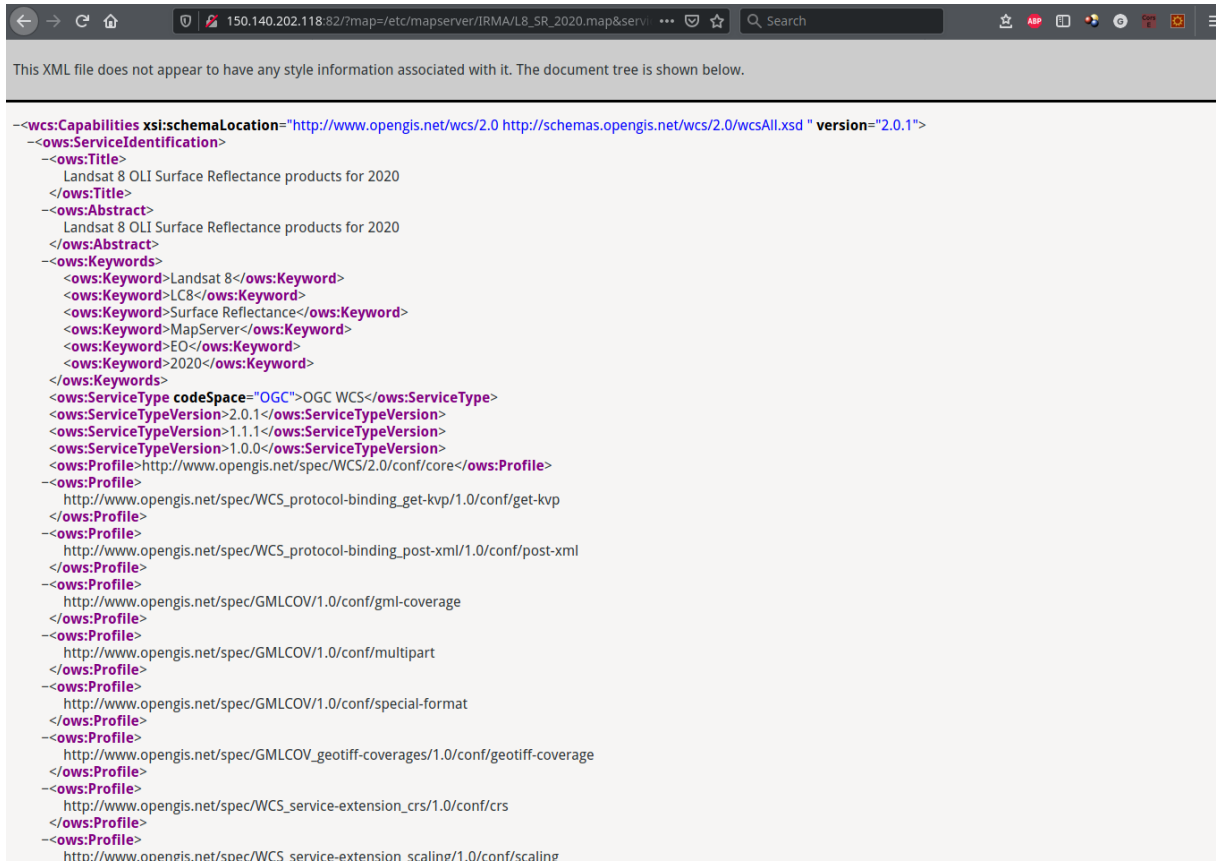


Figure 6.4: Accessing OGC WCS from the browser

7. Spectral indices

Spectral indices are combinations of spectral reflectance from two or more wavelengths that indicate the relative abundance of features of interest. Vegetation indices are the most popular type, but other indices are available for burned areas, man-made (built-up) features, water, and geologic features.

Vegetative Indices (VI) enable the acquisition of ecological information from satellite and drone data through the analysis of multi- or hyperspectral imagery bands. The reflectance of light changes with chlorophyll content, plant type, sugar content, water content within tissues and other factors. Due to this fact, the spectral reflectance responses captured by satellite imagery can reflect the interaction and coupling of carbon, nitrogen, and water cycles (Chang et al., 2016; Xue et al., 2017). A wide range of plant characteristics can be inferred through various indices. These indices are also used to improve the accuracy of classification algorithms. Indices enhance the spectral information and increase the separability of the classes of interest. All of these factors result in an increase in quality of the Land Use Land Cover (LULC) mapping produced (Ustuner et al., 2014). Indices have a dual function: providing information about plant growth and health as well as helping categorize different land classifications (mining, forest, bare soil, pasture, water surfaces, industrial etc.). The different combinations of vegetation indices also enhance spectral characteristics of some crops while suppressing others (Kuzucu et al., 2017).

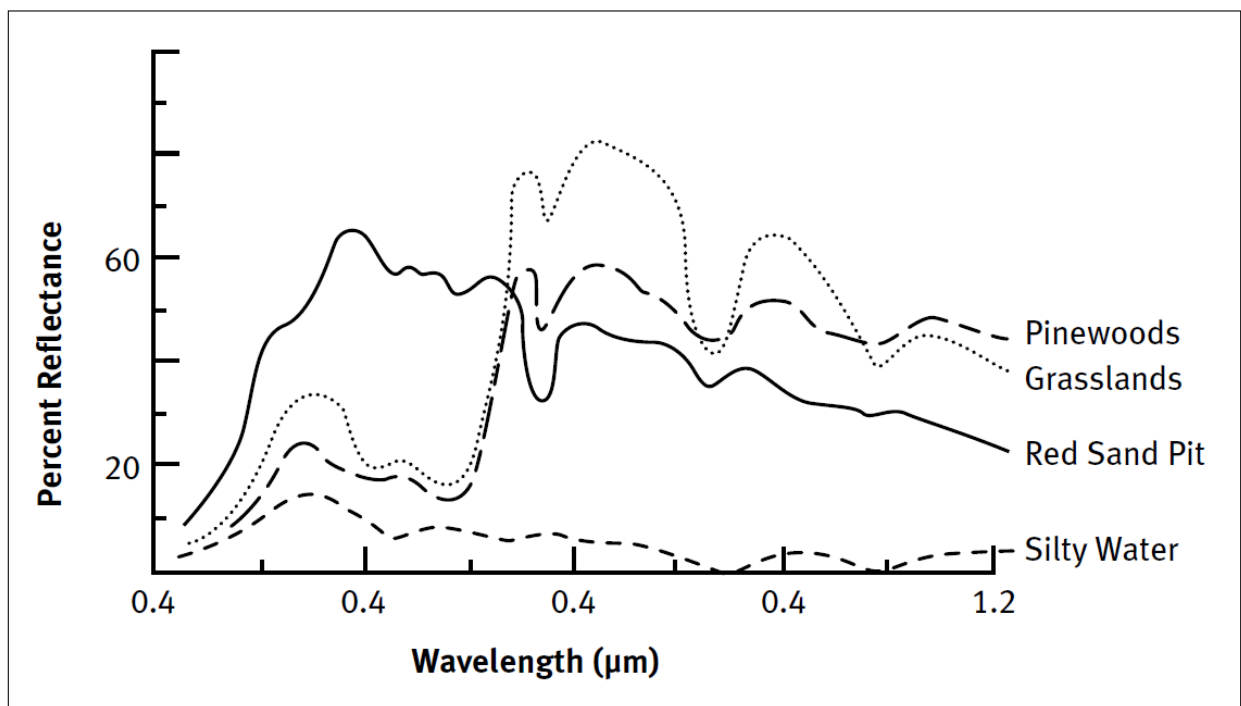


Figure 7.1. Spectral curves for various natural features (NASA, 2018)

7.1. Normalized Difference Vegetation Index (NDVI)

Though we often take the plants and trees around us for granted, almost every aspect of our lives depends upon them. They feed us, clothe us, absorb carbon dioxide, provide us with oxygen, and give us building materials and medications. When drastic changes occur to the vegetation around us, our health, economy, and environment are all affected. Twenty-five years ago, for instance, thousands of people starved when the vegetation in the Sahel region of Africa dried up during an extended drought. Over the past five decades deforestation in South America has left thousands of acres fallow and has destroyed many species including possible valuable medications.

In an effort to monitor major fluctuations in vegetation and understand how they affect the environment, 20 years ago Earth scientists began using satellite remote sensors to measure and map the density of green vegetation over the Earth. Using NOAA's Advanced Very High Resolution Radiometer (AVHRR), scientists have been collecting images of our planet's surface. By carefully measuring the wavelengths and intensity of visible and near-infrared light reflected by the land surface back up into space, scientists use an algorithm called a "Vegetation Index" to quantify the concentrations of green leaf vegetation around the globe. Then by combining the daily Vegetation Indices into 8-, 16-, or 30-day composites, scientists create detailed maps of the Earth's green vegetation density that identify where plants are thriving and where they are under stress (i.e., due to lack of water).

To determine the density of green on a patch of land, researchers must observe the distinct colors (wavelengths) of visible and near-infrared sunlight reflected by the plants. As can be seen through a prism, many different wavelengths make up the spectrum of sunlight. When sunlight strikes objects, certain wavelengths of this spectrum are absorbed and other wavelengths are reflected. The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 μm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 μm). The more leaves a plant has, the more these wavelengths of light are affected, respectively.

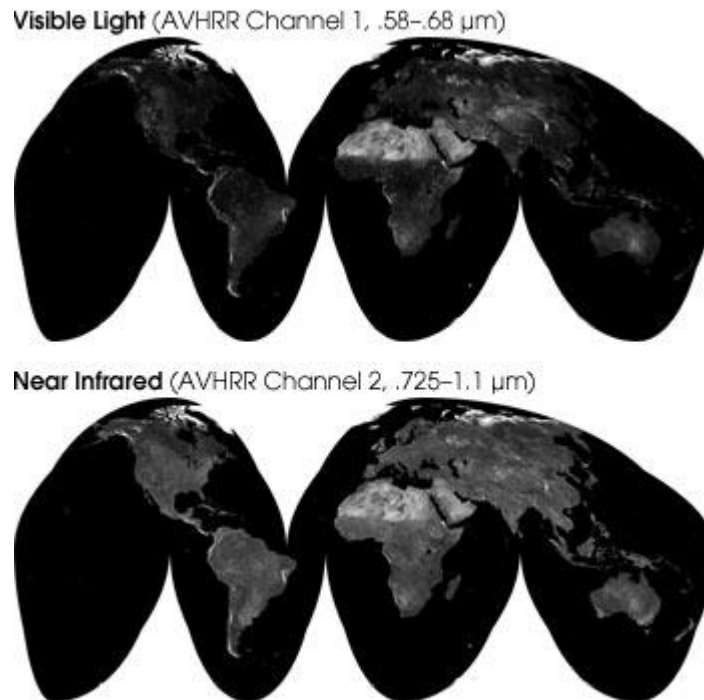


Figure 7.2. Visible and Near Infrared bands of AVHRR sensor (<https://earthobservatory.nasa.gov>, 2021)

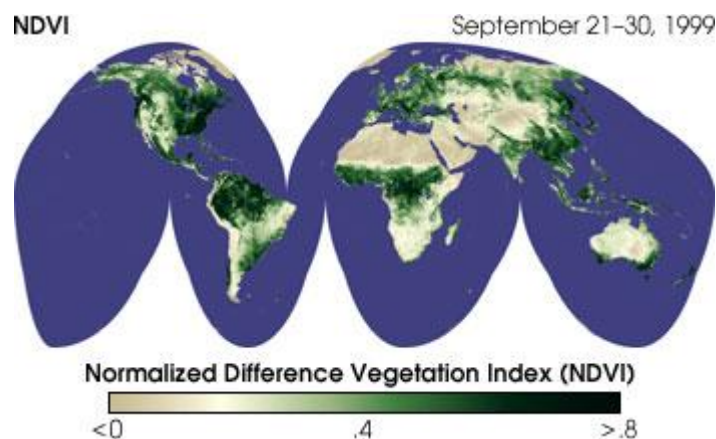


Figure 7.3. NDVI of AVHRR sensor (<https://earthobservatory.nasa.gov>, 2021)

Vegetation appears very different at visible and near-infrared wavelengths. In visible light (top), vegetated areas are very dark, almost black, while desert regions (like the Sahara) are light. At near-infrared wavelengths, the vegetation is brighter and deserts are about the same. By comparing visible and infrared light, scientists measure the relative amount of vegetation. (The variation in shade is more apparent in the detail of the U.S. West Coast).

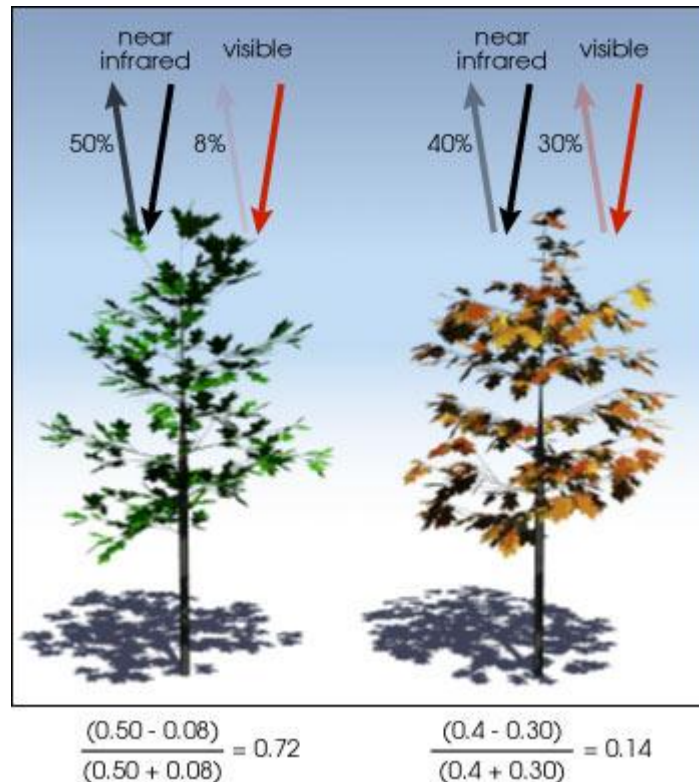


Figure 7.4. NDVI spectral response calculation examples (<https://earthobservatory.nasa.gov>, 2021)

NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation (left) absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation (right) reflects more visible light and less near-infrared light. The numbers on the figure 7.4 above are representative of actual values, but real vegetation is much more varied. (Illustration by Robert Simmon, Source: <https://earthobservatory.nasa.gov>, 2021).

Nearly all satellite Vegetation Indices employ this difference formula to quantify the density of plant growth on the Earth — near-infrared radiation minus visible radiation divided by near-infrared radiation plus visible radiation. The result of this formula is called the Normalized Difference Vegetation Index (NDVI). Written mathematically, the formula is (Eq. 7.1):

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

NIR – reflection in the near-infrared spectrum

RED – reflection in the red range of the spectrum

According to Eq. 7.1, the density of vegetation (NDVI) at a certain point of the image is equal to the difference in the intensities of reflected light in the red and infrared range divided by the sum of these intensities.

Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); however, no green leaves gives a value close to zero. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves.

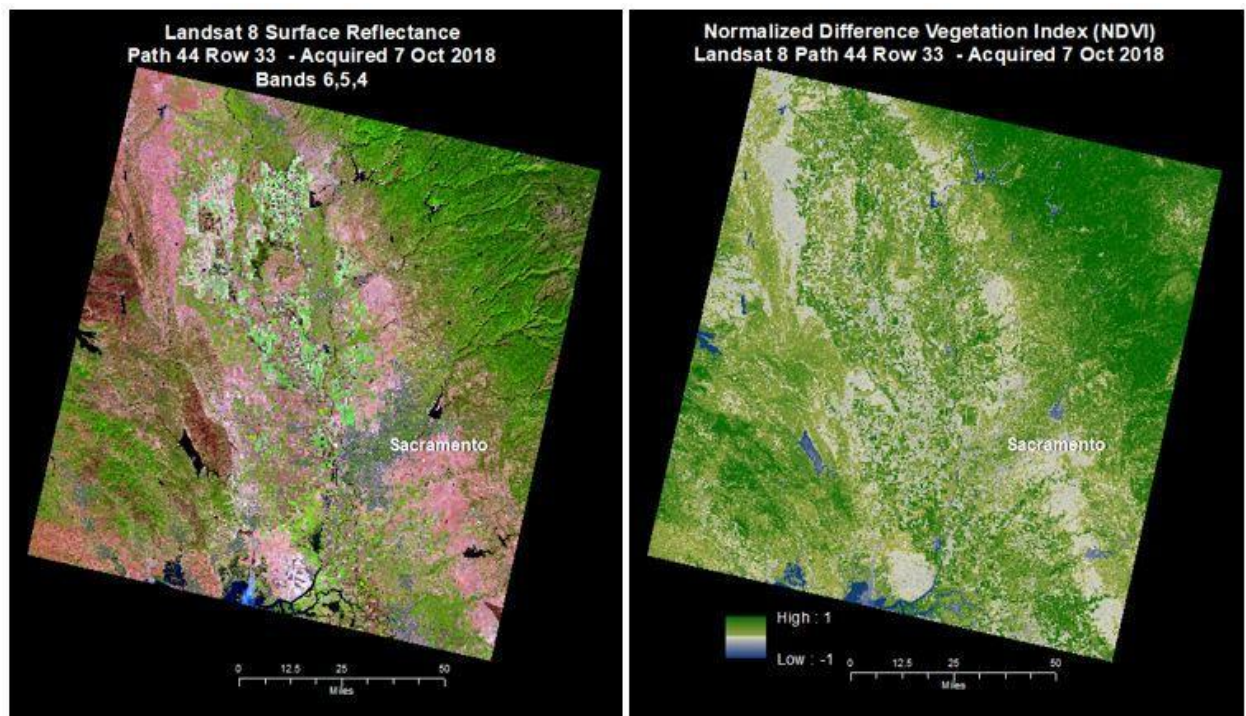


Figure 7.5. Landsat 8 Surface Reflectance (SR) and (right) the SR-derived Landsat Surface Reflectance Normalized Difference Vegetation Index (NDVI) (Source: <https://www.usgs.gov> 2021)

Landsat Surface Reflectance-derived Normalized Difference Vegetation Index (NDVI) are produced from Landsat 4–5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) scenes that can be successfully processed to Landsat Level-2 Surface Reflectance products.

NDVI is used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health. NDVI is calculated as a ratio between the red (R) and near infrared (NIR) values in traditional fashion:

- In Landsat 4-7, $NDVI = (Band\ 4 - Band\ 3) / (Band\ 4 + Band\ 3)$.
- In Landsat 8, $NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4)$.

Sentinel-2 Normalized Difference Vegetation Index (NDVI) included in the Radiometric Indices Processor of the ESA SNAP Toolbox. The NDVI product, exploits the strength and the vitality of the vegetation on the earth's surface, so much more active the chlorophyll of the plants, so much bigger is the boost of the

reflection level at the near infrared (0,78 – 1 μm). S2A data from 30 July 2016 acquired near Toulouse (Midi-Pyrenees, France) were downloaded from the Sentinel-2 Scientific Data Hub.

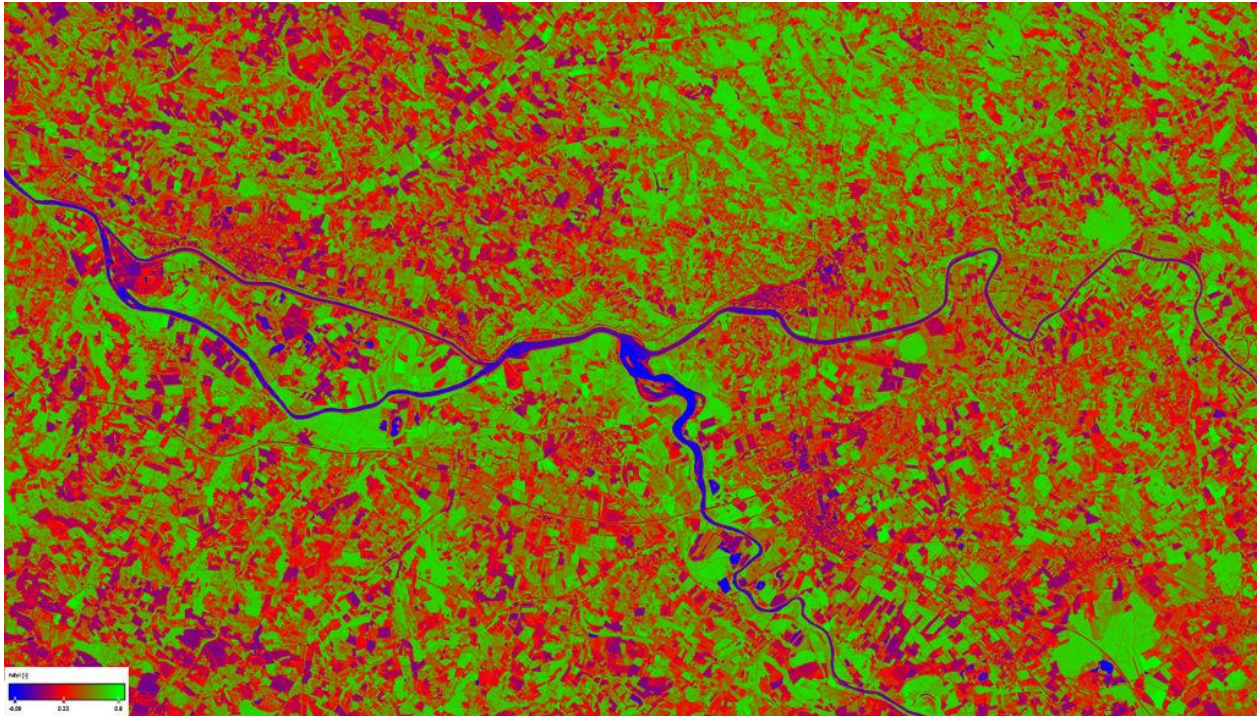


Figure 7.6. Sentinel-2 Normalized Difference Vegetation Index (NDVI) over Midi-Pyrenees - Copyright: Contains modified Copernicus data / ESA, 2016 (Source: <https://step.esa.int>)

7.2. Normalized Difference Water Index (NDWI)

Normalized Difference Water Index (NDWI) may refer to one of at least two remote sensing-derived indexes related to liquid water:

- One is used to monitor changes in water content of leaves, using near-infrared (NIR) and short-wave infrared (SWIR) wavelengths, proposed by Gao in 1996 (Eq. 7.2):

$$\text{NDWI} = \frac{(X_{nir} - X_{swir})}{(X_{nir} + X_{swir})}$$

- Another is used to monitor changes related to water content in water bodies, using green and NIR wavelengths, defined by McFeeters (1996) (Eq. 7.3):

$$\text{NDWI} = \frac{(X_{green} - X_{nir})}{(X_{green} + X_{nir})}$$

In remote sensing, ratio image or spectral rationing are enhancement techniques in which a raster pixel from one spectral band is divided by the corresponding value in another band. Both the indexes above

share this same functional form; the choice of bands used is what makes them appropriate for a specific purpose.

If looking to monitor vegetation in drought affected areas, then it is advisable to use the NDWI index proposed by Gao utilizing NIR and SWIR. The SWIR reflectance in this index reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies. The NIR reflectance is affected by leaf internal structure and leaf dry matter content, but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content.[Ceccato et al 2001 Remote Sensing of Environment 77 (2001) 22–33]

NDWI concept as formulated by Gao (Eq. 7.2) combining reflectance of NIR and SWIR is more common and has a wider range of application. It can be used for exploring water content at single leaf level as well as canopy/satellite level.

Different SWIR bands can be used to characterize the water absorption in the generalized form of NDWI as shown in eq. 1. Two major water absorption features in the SWIR spectral region are centered near 1450 nm and 1950 nm while two minor absorption features are centered near 970 and 1200 nm in a living vegetation spectrum. Sentinel-2 MSI has two spectral bands in the SWIR region: band 11 (central wavelength 1610 nm) and band 12 (central wavelength 2200 nm). Spectral band in NIR region with a similar 20 m ground resolution is band 8A (central wavelength 865 nm).

Sentinel-2 NDWI for agricultural monitoring of drought and irrigation management can be constructed using either combinations (Eq. 7.2):

- "NIR" band 8A (864nm) and band 11 (1610nm)
- "NIR" band 8A (864nm) and band 12 (2200nm)

Both formulations are suitable.

Sentinel-2 NDWI for waterbody detection can be constructed also by using (Eq. 7.3):

- "Green" Band 3 (559nm) and "NIR" Band 8A (864nm)



Figure 7.7. Sentinel-2 Normalized Difference Water Index (NDWI) from the following equation: $\text{Index} = (\text{NIR} - \text{MIR}) / (\text{NIR} + \text{MIR})$ using Sentinel-2 Band 8 (NIR) and Band 12 (MIR). This product is based on the open and free software suite Sentinel-2 Toolbox. Relevant citation: Gao, B.C., Remote Sensing of the Environment, p.257 (1996) (Source: <https://foodsecurity-tep.net>)

8. Using View and Download Services in QGIS

Using WMS and WCS in QGIS is the best way to view all data. The links for the WMS / WCS services are displayed in table 8.1.

	Landsat8	Sentinel2
Surface Reflectance	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_SR_2021.map&service=WMS&version=1.3.0&request=GetCapabilities	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_SR_2021.map&service=WMS&version=1.3.0&request=GetCapabilities
	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_SR_2021.map&service=WCS&version=1.0.0&request=GetCapabilities	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_SR_2021.map&service=WCS&version=1.0.0&request=GetCapabilities
Thermal Infrared	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_TIR_2021.map&service=WMS&version=1.3.0&request=GetCapabilities	
	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_TIR_2021.map&service=WCS&version=1.0.0&request=GetCapabilities	
NDVI	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_NDVI_2021.map&service=WMS&version=1.3.0&request=GetCapabilities	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_NDVI_2021.map&service=WMS&version=1.3.0&request=GetCapabilities
	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_NDVI_2021.map&service=WCS&version=1.0.0&request=GetCapabilities	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_NDVI_2021.map&service=WCS&version=1.0.0&request=GetCapabilities
NDWI	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_NDWI_2021.map&service=WMS&version=1.3.0&request=GetCapabilities	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_NDWI_2021.map&service=WMS&version=1.3.0&request=GetCapabilities
	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/L8_NDWI_2021.map&service=WCS&version=1.0.0&request=GetCapabilities	http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_NDWI_2021.map&service=WCS&version=1.0.0&request=GetCapabilities

Table 8.1. WMS / WCS OGC service links for the year 2021

The data is available (according to the project specifications) from viewing services (OGC WMS) but also from download services (OGC WCS) which have been properly implemented per product of the project and per year. In case we want to see the data of another year, we just change the year in the URL eg WMS of NDVI Sentinel2 for 2019:

http://150.140.202.118:82/?map=/etc/mapserver/IR2M/S2_NDVI_2019.map&service=WMS&version=1.3.0&request=GetCapabilities

All data for the years 2017-2021 can be found for browsing and/or local downloading at the following link: <http://150.140.202.118:81/IR2M/> with the username: irma and pass: 1rm@
Product preview is available as png files in <http://150.140.202.118:81/IR2M/PNG/>

The steps to use the above links in QGIS and view the images are the following:

1. Download QGIS from the link i case that is not already installed:
<https://qgis.org/en/site/forusers/download.html>
Use the LTR version as this is the most stable one.
2. Open QGIS.
3. From the '*Data source manager*' screen select the add WMS or add WCS icon (Figure 8.1)



Figure 8.1. OGC service icons

4. Select New in the '*Add Layer(s) from a Server*' dialogue box. In figures 8.2 and 8.3 new WMS and WCS connection dialogs are displayed.

Figure 8.2. OGC WMS service: Create a new connection

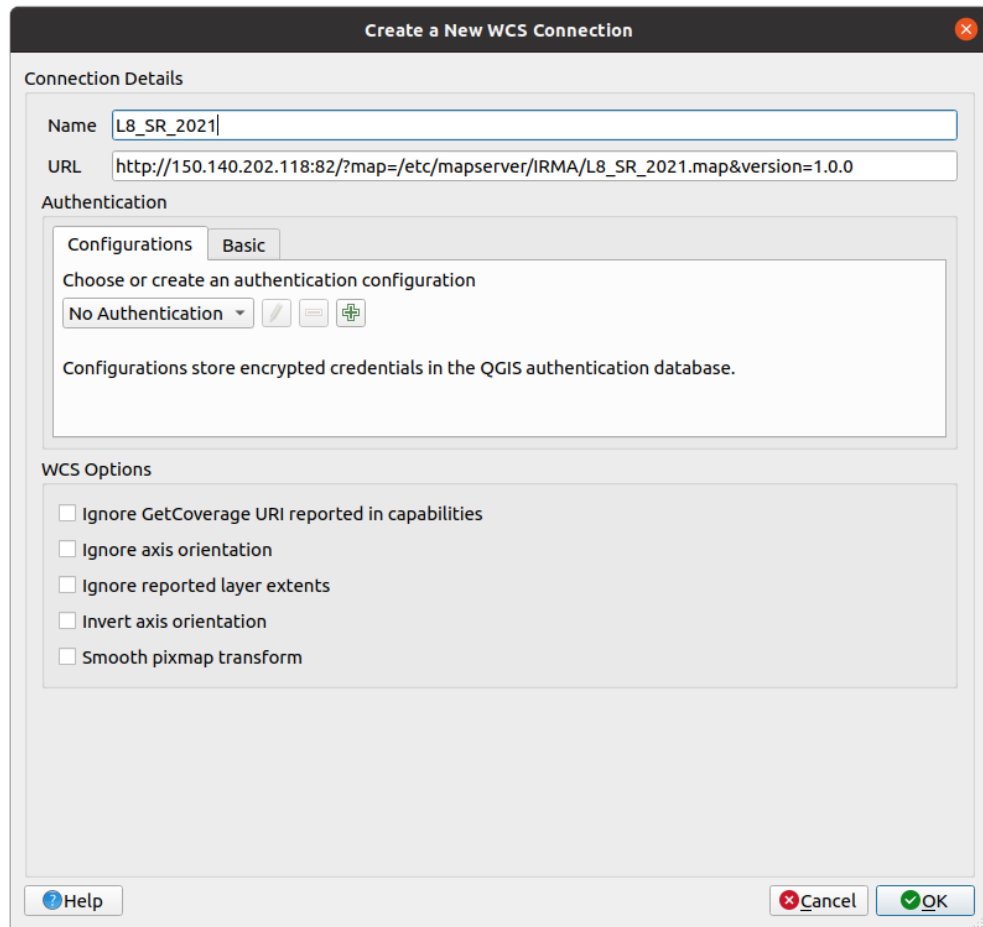


Figure 8.3. OGC WCS service: Create a new connection

5. In the '*Create a new WMS connection*' dialogue box, enter a name for the connection and the appropriate URL. Use the links from Table 8.1. for the corresponding services.
6. Select OK.
7. In the '*Add Layer(s) from a Server*' dialogue box, select Connect and then Add. The WMS or WCS should now be added. Alternatively layers can be added by the Browser tab. (Figure 8.4)

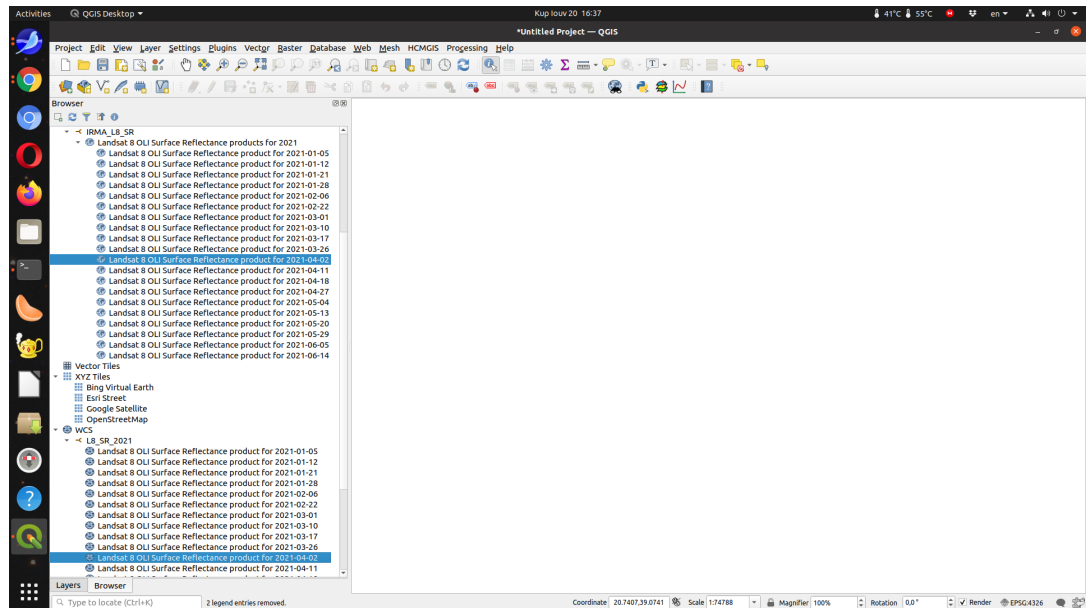


Figure 8.4. OGC WCS service links as displayed in Browser tab in QGIS

8. Select Close in 'Add Layer(s) from a Server' dialogue box.
9. The added images are displayed in the Layers tab (Figure 8.5)

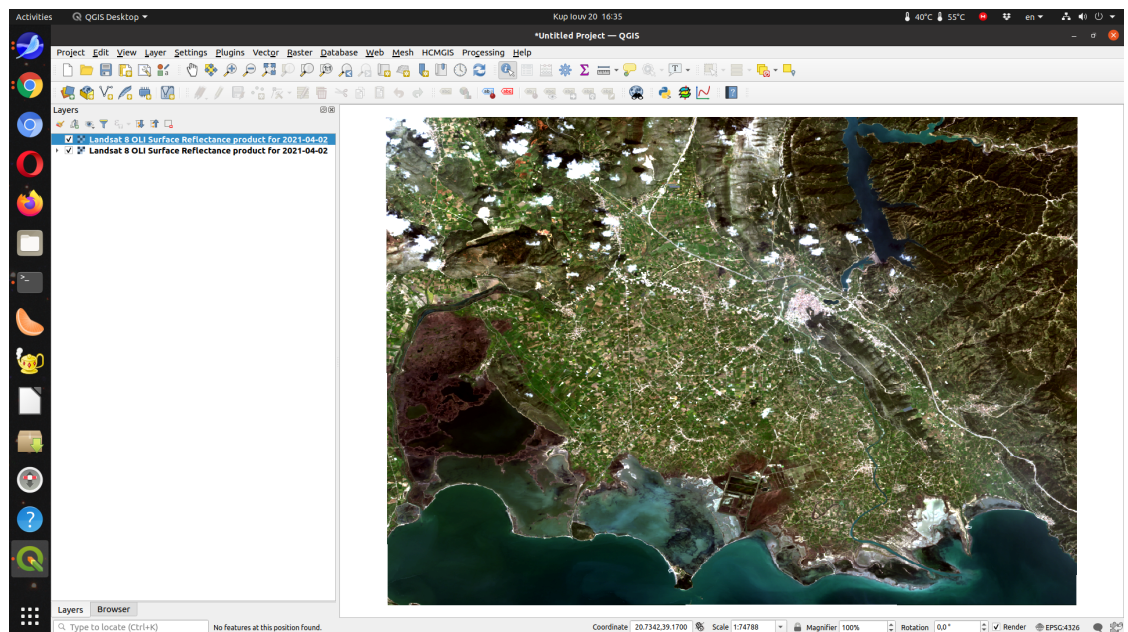


Figure 8.5. Images in QGIS Layers tab.

10. With right click open Layer properties and Symblology tab to switch to bands 432 RGB the Landsat8 OLI Natural Color Composite (Figure 8.6) or any other band combination.

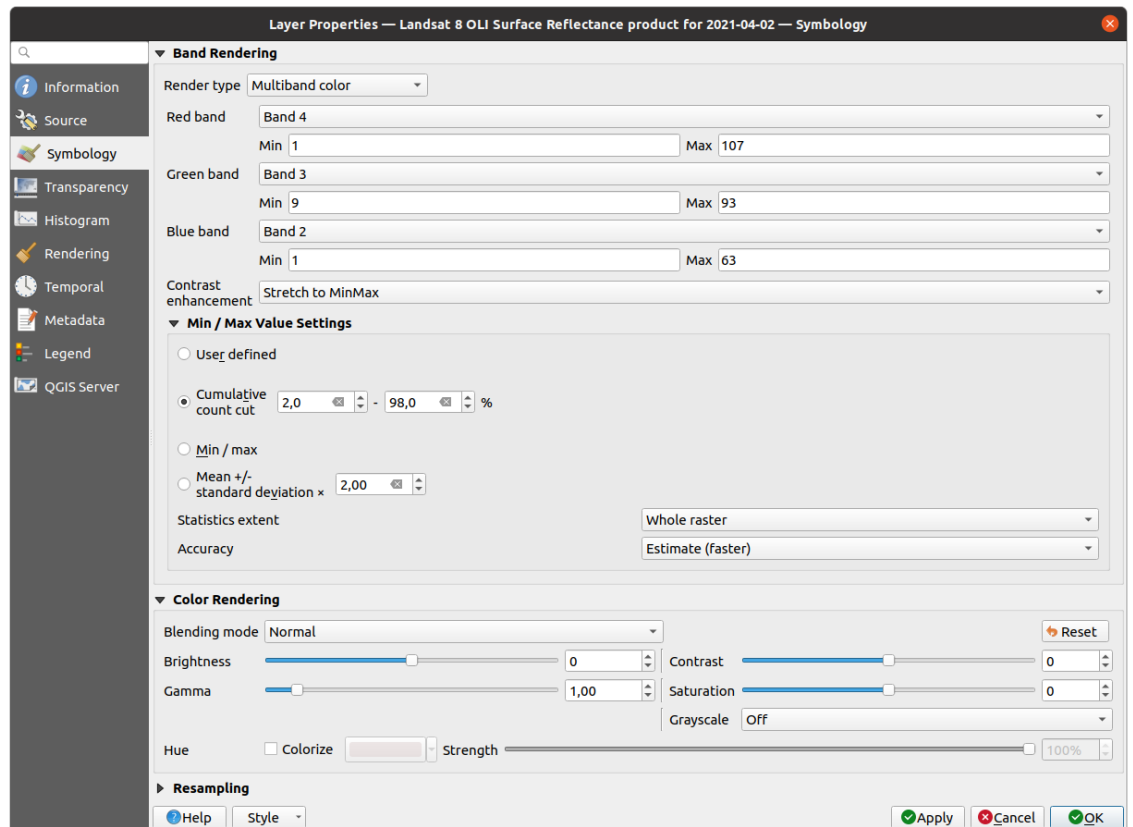


Figure 8.6. Color composite dialog in Layer Properties - Symbology tab.

11. In order to view discrete values at any pixel in the image we use the Identify Feature button (Ctrl+Shift+I) and the Results are displayed on the right (Figure 8.7). Use the left mouse click to select the layer (at Layers tab on the left) and expand the feature results tree (on the right).

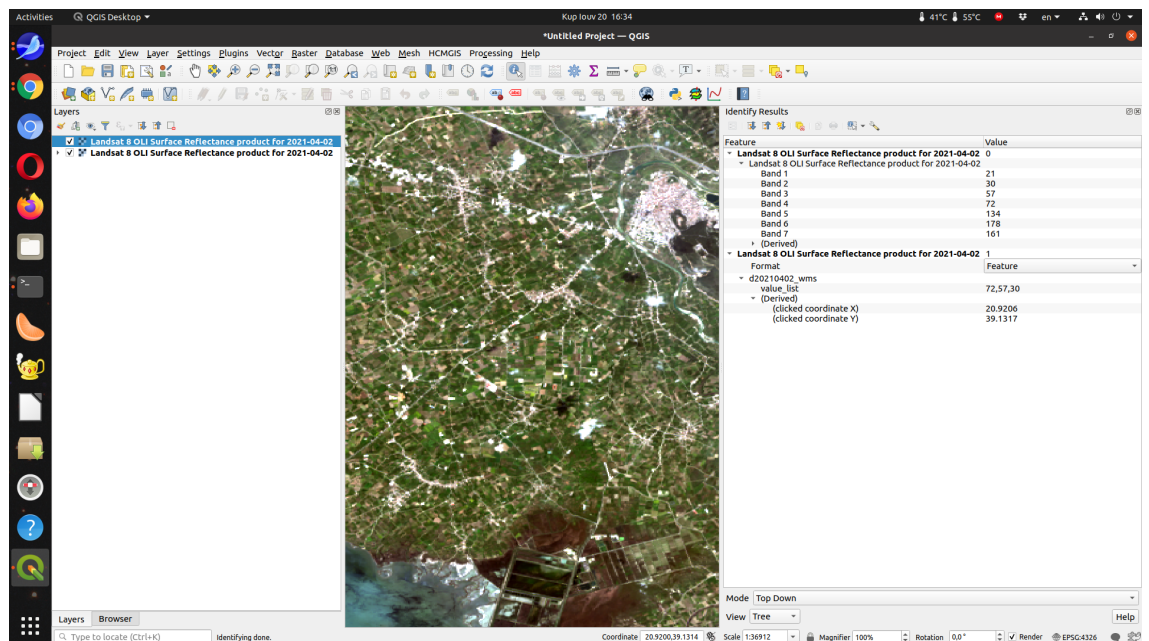


Figure 8.7. Feature identification and results.

12. Move the mouse in the image and keep a record of all points of interest by pressing the PrtScn button on the keyboard to get a few screenshots.

9. View Services in Jupyter Notebook

For the purpose of fast previewing the remote sensing data directly from the web, a simple web application was developed using the Jupyter Notebooks technology.

The Jupyter Notebook is a web application that allows you to create and share documents that contain live code, equations, visualizations and explanatory text.

It combines two components:

- A web application providing browser-based, interactive authoring of notebook documents.
- Notebook documents which store a representation of all content visible in the web application, including inputs and outputs of computations, explanatory text, mathematics, code, images, videos, graphs, maps, and other rich media representations of objects.

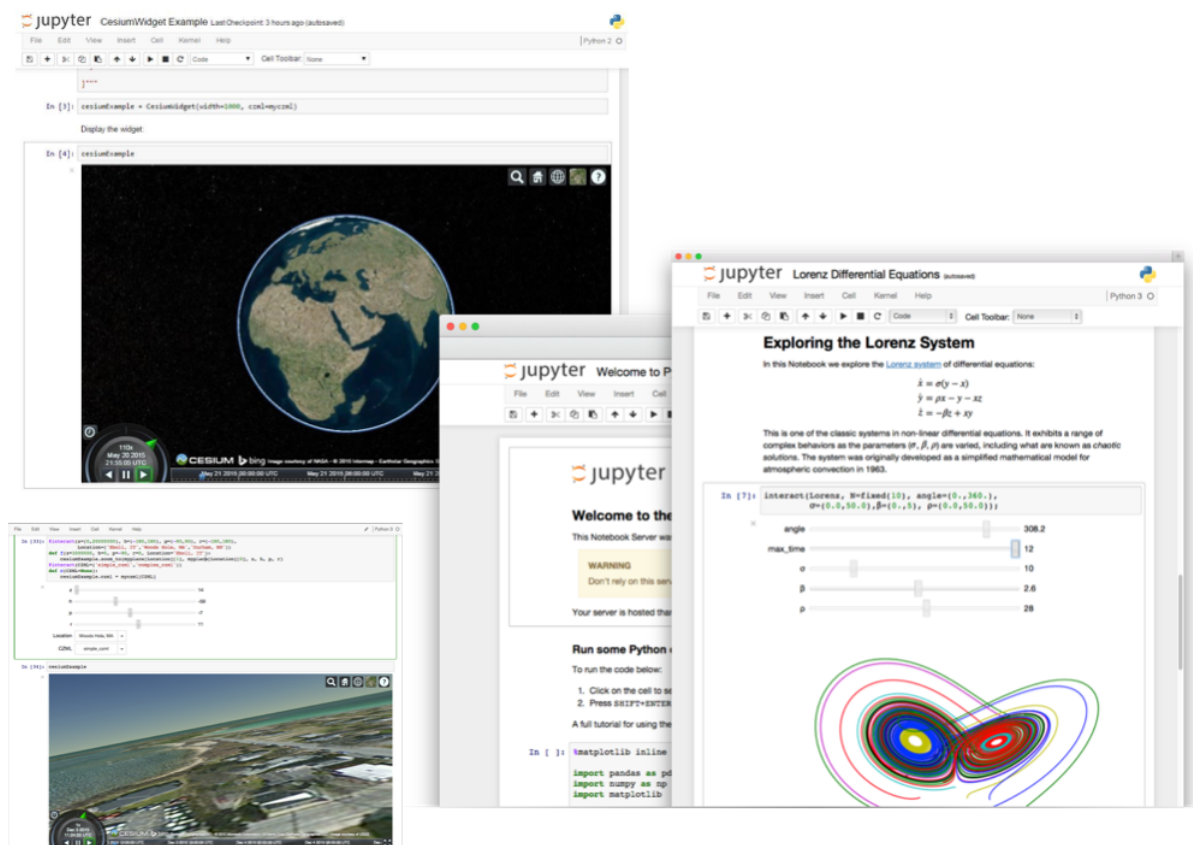


Figure 9.1. The Jupyter Notebook technology

Notebooks can be shared with others on GitHub, Dropbox, and the Jupyter Notebook Viewer. Uses include: data cleaning and transformation, numerical simulation, statistical modeling, machine learning and much more.

Core Features:

Create Jupyter Notebooks which can contain:

- Marked up text (with headings, styles, paragraphs, etc)
- Formulas, mathematics, plots, maps, ...
- Imported external libraries to add functionality
- Code from multiple programming languages, including Python, R, Julia, Bash and many more.

For the purposes of the project a Jupyter Notebook has been developed and is available on GitHub:

<https://github.com/EOFarm/IR2MA-demo>

The application needs docker and docker-compose to be installed on the host system.

Starting the application is as simple as running `./run.sh` in the terminal:

```
kalxas@kalxas-home:~/code/git/eofarm/ir2ma-demo> ./run.sh
WARNING: The Docker Engine you're using is running in swarm mode.

Compose does not use swarm mode to deploy services to multiple nodes in a swarm. All containers
will be scheduled on the current node.

To deploy your application across the swarm, use `docker stack deploy`.

Creating network "ir2ma-demo_default" with the default driver
Creating jupyterlab ... done

jupyterlab | [I 2021-06-25 14:25:41.558 LabApp] JupyterLab extension loaded from /opt/conda/
a/lib/python3.9/site-packages/jupyterlab
jupyterlab | [I 2021-06-25 14:25:41.558 LabApp] JupyterLab application directory is /opt/c
onda/share/jupyter/lab
jupyterlab | [I 2021-06-25 14:25:41.560 ServerApp] jupyterlab | extension was successfully
loaded.
jupyterlab | [I 2021-06-25 14:25:41.563 ServerApp] nbclassic | extension was successfully
loaded.
jupyterlab | [I 2021-06-25 14:25:41.564 ServerApp] Serving notebooks from local directory:
/home/jovyan/work
jupyterlab | [I 2021-06-25 14:25:41.564 ServerApp] Jupyter Server 1.6.2 is running at:
jupyterlab | [I 2021-06-25 14:25:41.564 ServerApp] http://jupyterlab:8888/lab
jupyterlab | [I 2021-06-25 14:25:41.564 ServerApp] http://127.0.0.1:8888/lab
jupyterlab | [I 2021-06-25 14:25:41.564 ServerApp] Use Control-C to stop this server and s
hut down all kernels (twice to skip confirmation).
```

Figure 9.2.Starting the IR2MA Jupyter Notebook

The web application is then available at <http://127.0.0.1:8888/lab>

For demonstration purposes the application is available at <http://147.102.109.27:8888> with “eofarm” as password. Navigate to <http://147.102.109.27:8888/lab/tree/notebooks/ir2ma.ipynb> and execute the notebook steps as in the following figures.

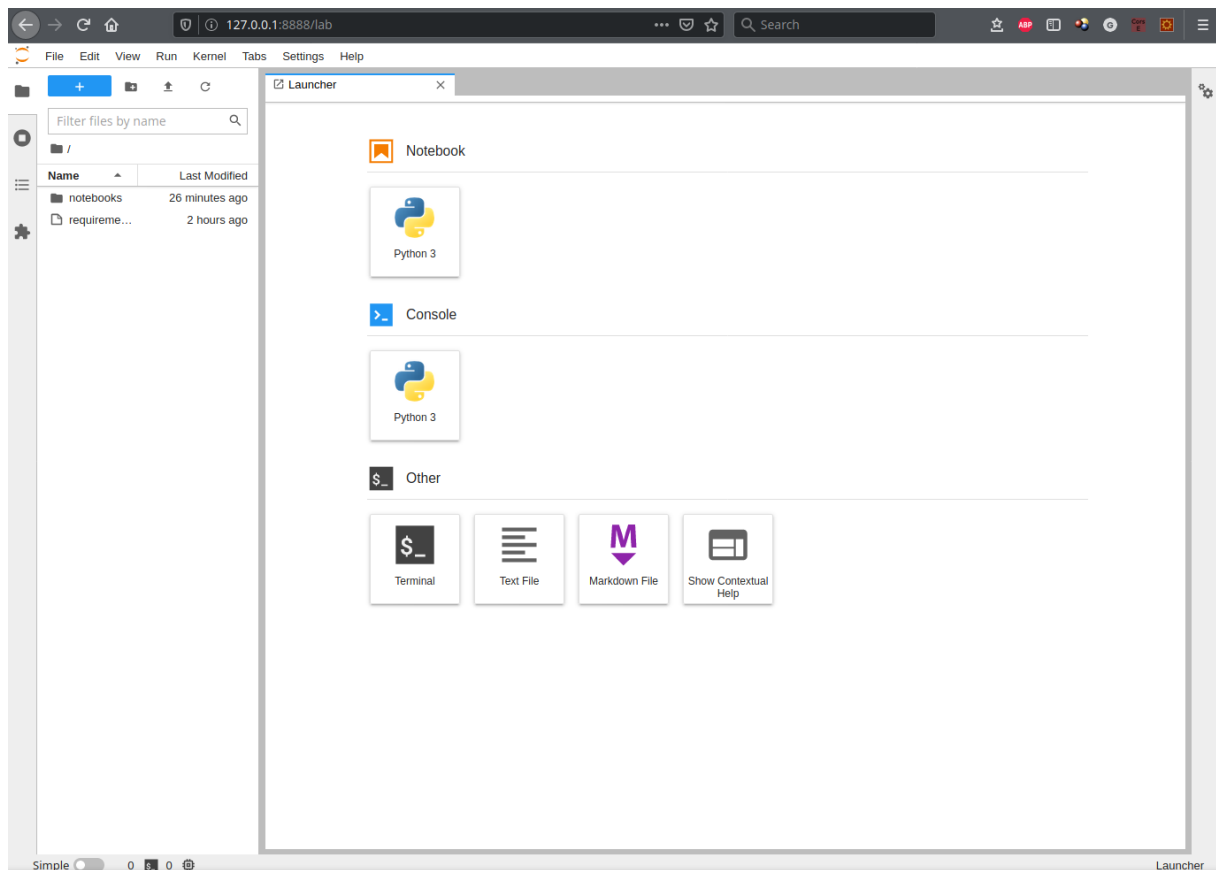


Figure 9.3. The IR2MA Jupyter Notebook landing page

From the left menu, the user can browse the available notebooks in a virtual folder. By double-clicking the `ir2ma.ipynb` file the notebook is ready to be executed.

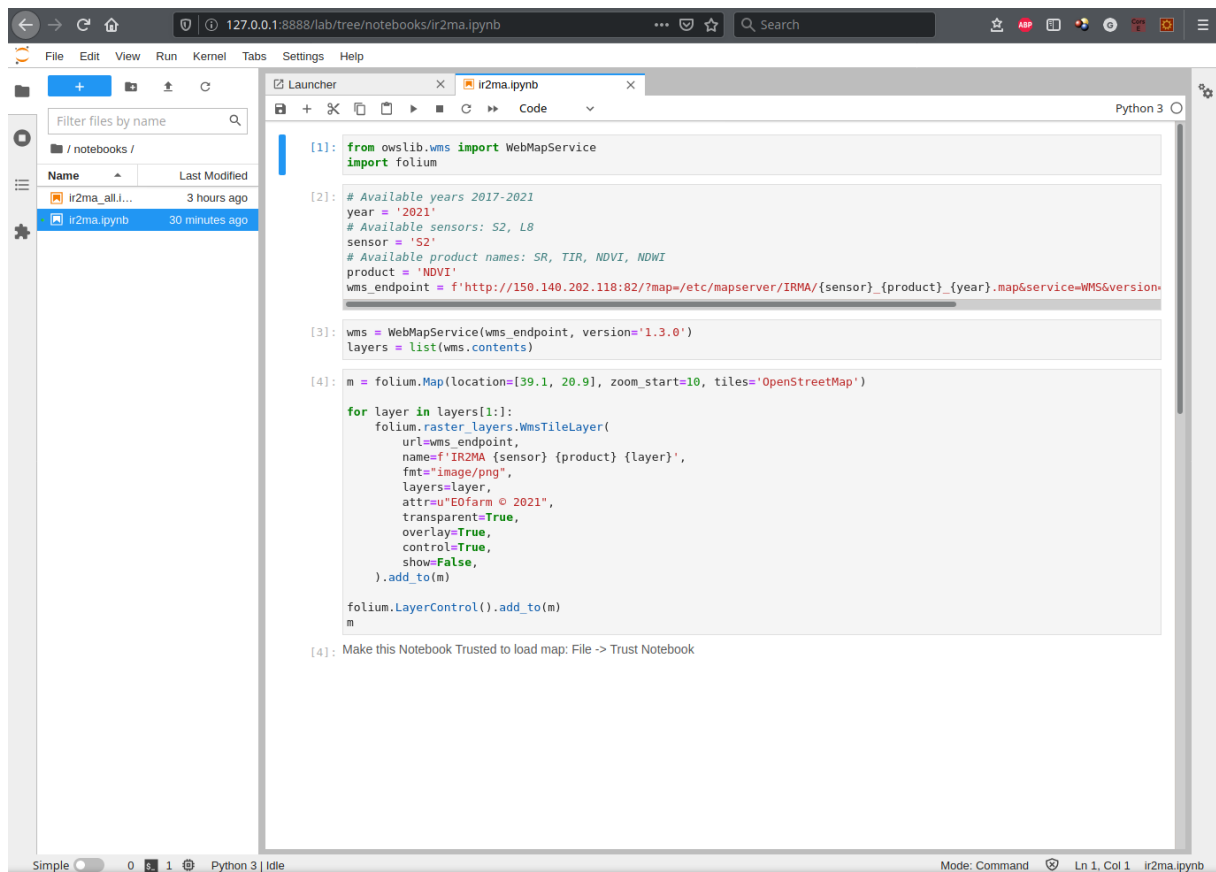


Figure 9.4. The ir2ma.ipynb notebook

The user just needs to set the python script parameters (year, sensor and product) and execute the notebook from the “*play*” button.

The result is presented in Figures 9.5 and 9.6

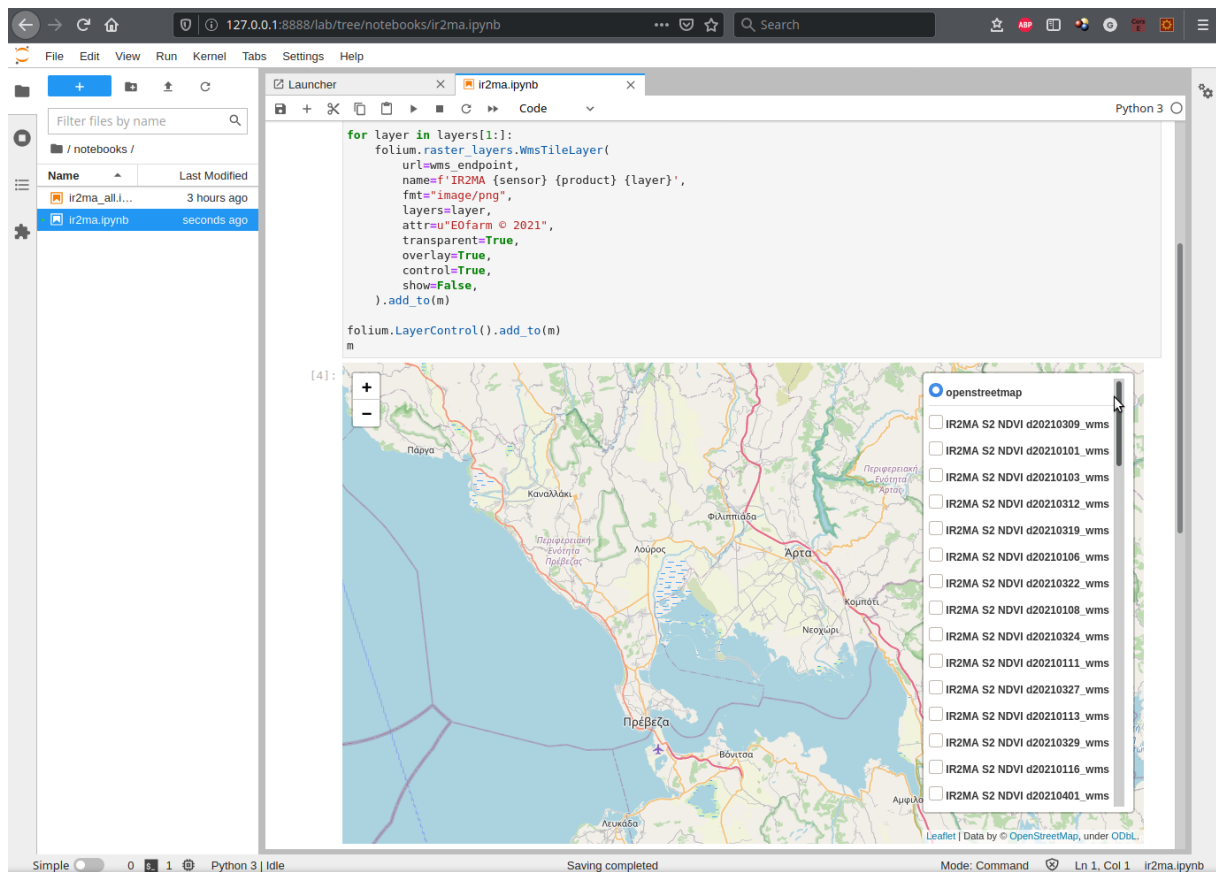


Figure 9.5.Loading the OGC WMS service on a notebook map. Layers are presented on the right

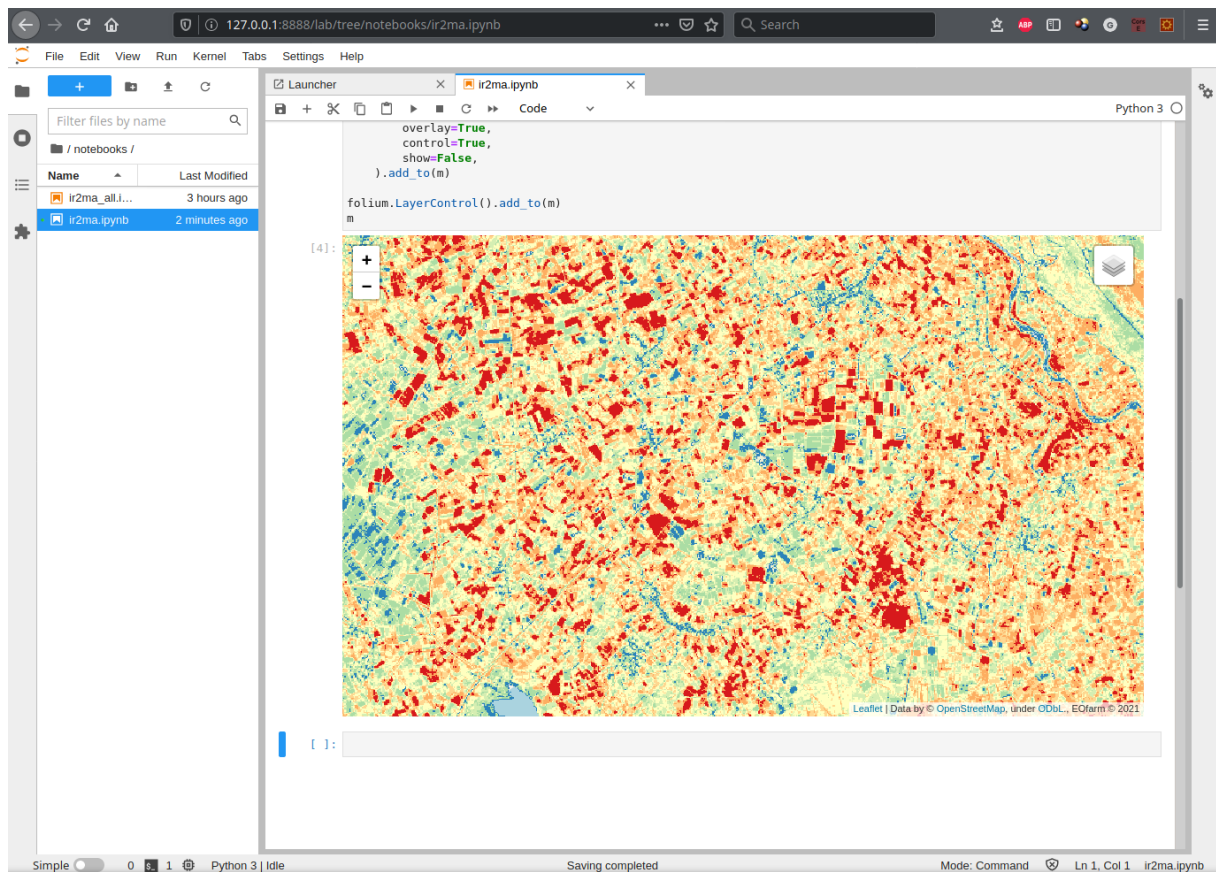


Figure 9.6.Loading an NDVI layer on a notebook map.

10. Conclusion

Within the framework of the work package of the project, the following deliverables were implemented:

1. Atmospherically corrected satellite data in the form of maps (surface reflectance raster maps)
Satellite remotely sensed data from the Landsat 8 OLI and TIRS and Sentinel 2A and 2B sensors were downloaded, stored in a file database and were processed into maps with geographical atmospherically corrected reflectance features for selected areas of the Epirus Region for a period of at least 4 (four) years. The geographical boundaries, the coverage area, concerns a continuously selected area within the Region of Epirus with a total area of approximately 450,000 acres and specifically of the GOEB Plain of Arta (TOEB of Arachthos Zone, TOEB Louros and TOEB Lamarinis) and of TOEB Grameritis as well as the Irrigation Network of the Municipality of Arta. The geographical boundaries of the areas were provided by the project partner IR2MA PB1 - University of Ioannina ELKE, in the form of a shapefile.

2. Selected spectral reflectance indices related to crop irrigation in the form of reflectance indices maps.

The maps from the 1st deliverable were processed due to special algorithms in order to calculate the NDVI and the NDWI. The processing of the remote sensing data and the computation of the indicators was done based on the current literature and is documented by recent international publications in internationally recognized scientific journals, books or related studies and / or in the proceedings of international prestigious conferences selected during the project. The implementation of the algorithms was performed with modern and open software development technologies.

3. Free online map view with filters in terms of data / indicators, time and space (OGC Web Map Service).

Remote sensing and indicator data maps are delivered in GeoTiff graphical files. Remote sensing data is freely available to anyone interested through an online viewing service (OGC WMS) with the ability to download selected maps through OGC WCS download service. The implementation of the algorithms was done with modern and open software development technologies. For the system architecture it has been taken into account that the system as a whole should be based on Free Software and Open Source Software (FOSS) which should be delivered within the project with an appropriate software license depending on the development technologies to be used.

4. Documentation report (current document) on the creation and display of maps and how they are interconnected with decision support systems based on the project standard.

Report is documented also with links to data and other useful sites in line and a reference section.

Synopsis in English language

The project concerns the documentation, production and display of maps of spectral indicators which are related to the irrigation of crops based on remote sensing data at microclimate level, for selected areas of the Epirus Region for a period of at least 4 (four) years. The monitoring led to the creation of a geospatial database which will be automatically updated with satellite images during and after the project and will be available directly to producers, planners and related public services. Requirement was this action to be based on open software FOSS, and to remote sensing data that are available for free beyond the end of the project.

The project is based on the scientific domain of Remote Sensing for the continuous monitoring of irrigation indicators at the microclimate level with satellite remote sensing imagery and the use of Geographic Information Systems, for the spatial analysis, representation and publication of results.

The primary remote sensing data is the free Landsat 8 and / or Sentinel 2 satellite data in the form of raster maps. Corrected remote sensing data was atmospherically corrected (surface reflectance) in the form of raster maps. Spectral indices that are related to crop irrigation in the form of raster maps and mean values were selected. The indicators were derived from a literature review and related to vegetation cover (NDVI) and soil moisture (NDWI). The resolution of the remote sensing data maps and indicators is at least 50x50m as defined by the project specifications. The geographical boundaries, the coverage area, describes a continuously selected area within the Region of Epirus with a total area of approximately 450,000 acres and specifically of the GOEB Plain of Arta (TOEB of Arachthos Zone, TOEB Louros and TOEB Lamaris) and of TOEB Grameritos as well as the Irrigation Network of the Municipality of Arta. The geographical boundaries of the areas were provided by the project partner IR2MA PB1 - University of Ioannina ELKE, in the form of a shapefile.

Remote sensing data and indicators cover a period of four (4) years (2018, 2019, 2020, 2021) with a maximum frequency of 7 days (provided they are available from ESA SciHub and USGS EarthExplorer or from the respective AWS repositories and whereas the data may be cloudy at this frequency).

Remote sensing and indicator data maps were delivered in GeoTiff graphical files. Remote sensing data is freely available to anyone interested through an online viewing service (OGC WMS) with the ability to download selected maps through OGC WCS download service. The implementation of the algorithms was performed with modern and open software development technologies. For the system architecture it has been taken into account that the system as a whole should be based on Free Software and Open Source Software (FOSS) which should be delivered within the project with an appropriate software license (compatible with Open Source Initiative - <https://opensource.org/licenses>) depending on the development technologies to be used.

The processing of the remote sensing data and the computation of the indicators was done based on the current literature and is documented by recent international publications in internationally recognized scientific journals, books or related studies and / or in the proceedings of international prestigious conferences selected during the project.

Within the framework of the work package of the project, the following deliverables were implemented:

1. Atmospherically corrected satellite data in the form of maps (surface reflectance raster maps)

2. Selected spectral reflectance indices related to crop irrigation in the form of reflectance indices maps.
3. Free online map view with filters in terms of data / indicators, time and space (OGC Web Map Service).
4. Documentation report (current document) on the creation and display of maps and how they are interconnected with decision support systems based on the project standard. Report is documented also with links to data and other useful sites in line and a reference section.

Σύνοψη στην ελληνική γλώσσα

Το έργο αφορά την τεκμηρίωση, την παραγωγή και την απεικόνιση χαρτών φασματικών δεικτών οι οποίοι σχετίζονται με την άρδευση καλλιεργειών με χρήση δεδομένων τηλεπισκόπησης, για επιλεγμένες περιοχές της Περιφέρειας Ηπείρου και για περίοδο τουλάχιστον 4 (τεσσάρων) ετών. Η παρατήρηση της περιοχής μέσω τηλεπισκόπησης οδήγησε στη δημιουργία μιας γεωχωρικής βάσης δεδομένων η οποία ενημερώνεται αυτόματα με δορυφορικές εικόνες κατά τη διάρκεια και μετά την ολοκλήρωση του έργου και είναι διαθέσιμη απευθείας σε παραγωγούς, σχεδιαστές και συναφείς δημόσιες υπηρεσίες. Απαιτήση ήταν, αυτή η μελέτη, να βασίζεται σε ανοιχτό λογισμικό ΕΛΛΑΚ και σε δεδομένα τηλεπισκόπησης τα οποία είναι διαθέσιμα δωρεάν και μετά το τέλος του έργου.

Το έργο βασίζεται στον επιστημονικό τομέα της Τηλεπισκόπησης για τη συνεχή παρακολούθηση των δεικτών άρδευσης σε επίπεδο μικροκλίματος με δορυφορικές εικόνες τηλεπισκόπησης και τη χρήση Συστημάτων Γεωγραφικών Πληροφοριακών (GIS) για τη χωρική ανάλυση, την αναπαράσταση και την δημοσίευση αποτελεσμάτων.

Τα κύρια δεδομένα παρατήρησης της γης είναι τα δωρεάν δορυφορικά δεδομένα Landsat 8 ή / και Sentinel 2 με τη μορφή εικόνων ράστερ. Τα δεδομένα αυτά διορθώθηκαν ατμοσφαιρικά και έτσι υπολογίστηκε η επιφανειακή ανακλώμενη ακτινοβολία με τη μορφή εικόνων / χαρτών ράστερ. Στην συνέχεια επιλέχθηκαν και υπολογίστηκαν φασματικοί δείκτες οι οποίοι σχετίζονται με την κάλυψη και την άρδευση των καλλιεργειών οι οποίοι επίσης διατίθενται με τη μορφή ράστερ εικόνων / χαρτών. Οι δείκτες προήλθαν από μια βιβλιογραφική ανασκόπηση και αφορούσαν την κάλυψη (NDVI) και την υγρασία (NDWI) του εδάφους. Η ανάλυση των χαρτών και των φασματικών δεικτών είναι τουλάχιστον 50x50m όπως ορίζεται από τις προδιαγραφές του έργου. Τα γεωγραφικά όρια για την περιοχή κάλυψης των δεδομένων αφορούν μια επιλεγμένη περιοχή εντός της Περιφέρειας Ηπείρου με συνολική έκταση περίπου 450.000 στρέμματα και συγκεκριμένα του ΓΟΕΒ Πεδιάδας Άρτας (ΤΟΕΒ Ζώνης Αράχθου, ΤΟΕΒ Λούρου και ΤΟΕΒ Λάμαρης) και των ΤΟΕΒ Γραμμενίτσας-Βλαχέρνας, Γλυκορίζου, Πέτα-Κομποτίου καθώς και του Αρδευτικού Δικτύου Δήμου Αρταίων. Τα γεωγραφικά όρια των περιοχών παρασχέθηκαν από τον εταίρο του έργου IR2MA PB1 - ΕΛΚΕ Πανεπιστημίου Ιωαννίνων, με τη μορφή shapefile.

Τα δεδομένα και οι δείκτες τηλεπισκόπησης καλύπτουν μια περίοδο τεσσάρων (4) ετών (2018, 2019, 2020, 2021) με μέγιστη συχνότητα 7 ημερών (υπό την προϋπόθεση ότι διατίθενται από το ESA SciHub και το USGS EarthExplorer ή από τα αντίστοιχα αποθετήρια AWS και ενδέχεται να υπάρχει σχετική νεφοκάλυψη).

Οι χάρτες δεδομένων τηλεπισκόπησης και δεικτών παραδόθηκαν σε αρχεία γραφικών τύπου GeoTiff. Τα δεδομένα τηλεπισκόπησης διατίθενται ελεύθερα σε όποιον ενδιαφέρεται μέσω μιας διαδικτυακής υπηρεσίας προβολής OGC WMS με δυνατότητα λήψης και τοπικής μεταφόρτωσης επιλεγμένων χαρτών μέσω της υπηρεσίας λήψης OGC WCS. Η εφαρμογή των αλγορίθμων πραγματοποιήθηκε με σύγχρονες και ανοιχτές τεχνολογίες ανάπτυξης λογισμικού. Για την αρχιτεκτονική του συστήματος έχει ληφθεί υπόψη ότι το σύστημα στο σύνολό του πρέπει να βασίζεται σε Ελεύθερο Λογισμικό και Λογισμικό Ανοιχτού Κώδικα (ΕΛΛΑΚ), το οποίο έχει παραδοθεί εντός του έργου με την κατάλληλη άδεια χρήσης λογισμικού (συμβατή με το Open Source Initiative - <https://opensource.org/licenses>) ανάλογα με τις τεχνολογίες ανάπτυξης οι οποίες χρησιμοποιήθηκαν.

Η επεξεργασία των δεδομένων τηλεπισκόπησης και ο υπολογισμός των δεικτών έγινε βάσει της τρέχουσας βιβλιογραφίας και τεκμηριώθηκε από πρόσφατες διεθνείς δημοσιεύσεις σε διεθνώς αναγνωρισμένα επιστημονικά περιοδικά, βιβλία ή συναφείς μελέτες καθώς και σε εργασίες διεθνών συνεδρίων τα οποία επιλέχθηκαν κατά τη διάρκεια της μελέτης.

Στο πλαίσιο αυτής της μελέτης ως πακέτου εργασίας του έργου, υλοποιήθηκαν τα ακόλουθα παραδοτέα:

1. Ατμοσφαιρικά διορθωμένα δορυφορικά δεδομένα με τη μορφή χαρτών (χάρτες raster με καταγραφή της ανακλαστικότητας από την επιφάνεια)
2. Επιλεγμένοι δείκτες φασματικής ανάκλασης οι οποίοι σχετίζονται με άρδευση καλλιεργειών με τη μορφή χαρτών δεικτών ανάκλασης όπως ο NDVI και ο NDWI.
3. Δωρεάν διαδικτυακή προβολή χαρτών με επιλογές: δεδομένων / δεικτών, χρόνου και χώρου (OGC Web Map Service).

Έκθεση τεκμηρίωσης (το τρέχον έγγραφο) σχετικά με τη δημιουργία και την απεικόνιση των χαρτών και τον τρόπο διασύνδεσής τους με συστήματα υποστήριξης αποφάσεων βάσει των προδιαγραφών του έργου. Η αναφορά τεκμηριώνεται επίσης με συνδέσμους προς δεδομένα και άλλους χρήσιμους ιστότοπους τόσο εντός του κειμένου όσο και σε μια ενότητα αναφορών.

Sinossi in lingua italiana

Il progetto riguarda la documentazione, produzione e visualizzazione di mappe di indicatori spettrali relativi all'irrigazione delle colture sulla base di dati di telerilevamento a livello di microclima, per aree selezionate della regione dell'Epiro per un periodo di almeno 4 (quattro) anni. Il monitoraggio ha portato alla creazione di un database geospaziale che sarà automaticamente aggiornato con immagini satellitari durante e dopo il progetto e sarà disponibile direttamente a produttori, pianificatori e relativi servizi pubblici. Il requisito era che questa azione fosse basata sul software aperto FOSS e sui dati di telerilevamento disponibili gratuitamente oltre la fine del progetto.

Il progetto si basa sul dominio scientifico del Telerilevamento per il monitoraggio continuo degli indicatori di irrigazione a livello di microclima con immagini di telerilevamento satellitare e l'uso di Sistemi Informativi Territoriali, per l'analisi spaziale, la rappresentazione e la pubblicazione dei risultati. I dati primari del telerilevamento sono i dati satellitari gratuiti Landsat 8 e/o Sentinel 2 sotto forma di mappe raster. I dati di telerilevamento corretti erano dati di telerilevamento corretti dal punto di vista atmosferico (riflettenza superficiale) sotto forma di mappe raster. Sono stati selezionati indici spettrali correlati all'irrigazione delle colture sotto forma di mappe raster e valori medi. Gli indicatori sono stati derivati da una revisione della letteratura e relativi alla copertura del suolo (NDVI) e all'umidità del suolo (NDWI). La risoluzione delle mappe e degli indicatori dei dati di telerilevamento è di almeno 50x50 m come definito dalle specifiche di progetto. I confini geografici, l'area di copertura, descrivono un'area continuamente selezionata all'interno della Regione dell'Epiro con una superficie totale di circa 450.000 acri e nello specifico della Piana GOEB di Arta (TOEB di Arachthos Zone, TOEB Louros e TOEB Lamarinis) e di TOEB Grameritos e la Rete di Irrigazione del Comune di Arta. I confini geografici delle aree sono stati forniti dal partner del progetto IR2MA PB1 - Università di Ioannina ELKE, sotto forma di uno shapefile.

I dati e gli indicatori del telerilevamento coprono un periodo di quattro (4) anni (2018, 2019, 2020, 2021) con una frequenza massima di 7 giorni (a condizione che siano disponibili da ESA SciHub e USGS EarthExplorer o dai rispettivi repository AWS e considerando che i dati potrebbero essere nuvolosi a questa frequenza).

Il telerilevamento e le mappe dei dati degli indicatori sono state fornite in file grafici GeoTiff. I dati del telerilevamento sono disponibili gratuitamente per chiunque sia interessato tramite un servizio di visualizzazione online (OGC WMS) con la possibilità di scaricare mappe selezionate tramite il servizio di download OGC WCS. L'implementazione degli algoritmi è stata eseguita con tecnologie di sviluppo software moderne e aperte. Per l'architettura del sistema si è tenuto conto che il sistema nel suo insieme dovrebbe essere basato su Software Libero e Software Open Source (FOSS) che dovrebbero essere consegnati all'interno del progetto con un'apposita licenza software (compatibile con Open Source Initiative - <https://opensource.org/licenses>) a seconda delle tecnologie di sviluppo da utilizzare.

L'elaborazione dei dati del telerilevamento e il calcolo degli indicatori è stato effettuato sulla base della letteratura corrente ed è documentato da recenti pubblicazioni internazionali su riviste scientifiche, libri o studi correlati riconosciuti a livello internazionale e/o negli atti di prestigiosi convegni internazionali selezionati durante il progetto.

Nell'ambito del pacchetto di lavoro del progetto, sono stati implementati i seguenti risultati finali:

1. Dati satellitari corretti dall'atmosfera sotto forma di mappe (mappe raster di riflettanza superficiale)
2. Indici di riflettanza spettrale selezionati relativi all'irrigazione delle colture sotto forma di mappe degli indici di riflettanza.
3. Visualizzazione gratuita della mappa online con filtri in termini di dati/indicatori, tempo e spazio (OGC Web Map Service).
4. Report di documentazione (documento corrente) sulla creazione e visualizzazione delle mappe e su come sono interconnesse con i sistemi di supporto alle decisioni basati sullo standard di progetto. Il report è documentato anche con link a dati e altri siti utili in linea e una sezione di riferimento.

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Also the following links retrieved June 2021:

- https://en.wikipedia.org/wiki/Normalized_difference_water_index
- https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_1.php
- <https://www.l3harrisgeospatial.com/docs/spectralindices.html>
- https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_2.php
- <https://medium.com/regen-network/remote-sensing-indices-389153e3d947>
- <https://www.usgs.gov/core-science-systems/nli/landsat/landsat-normalized-difference-vegetation-index>

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