REMOTE SENSING TUTORIAL

TELECAN

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canarias OBJETIVO de PROGRESO

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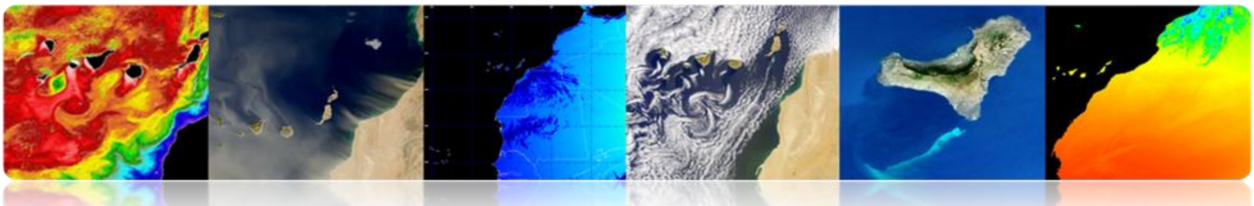
PROGRAMA MAC 2007 - 2013 Cooperación Transnacional

PREFACE

The project "Programme for the Development of Technological Networks and Application of Remote Sensing Data in West Africa" -with acronym TELECAN and code MAC/3/C181- was approved under the Second Call for Transnational Cooperation Programme Madeira-Azores-Canaries (MAC) 2007/2013, within Axis 3 - Cooperation with Third Countries and the Wider Neighborhood Joint. It has been promoted by the University of Las Palmas of Gran Canaria (ULPGC) and the Society of Economic Promotion of Gran Canaria (SPEGC), and 85% of its budget is co-financed by the European Regional Development Fund.

TELECAN is a three-year project led by the University of Las Palmas of Gran Canaria which aims at developing remote sensing products and services in strategic sectors in the region of the Canary Islands and West Africa through collaborative work between academic institutions in the Canary Islands, Morocco, Mauritania, Senegal and Cape Verde.

This **Tutorial for Education and Training** is one of the strategic lines of action that the project TELECAN wants to make available to all organizations, businesses or home users interested in remote sensing in order to encourage its use to improve the quality and competitiveness of products generated and to promote consolidation or creation of technology-based companies.



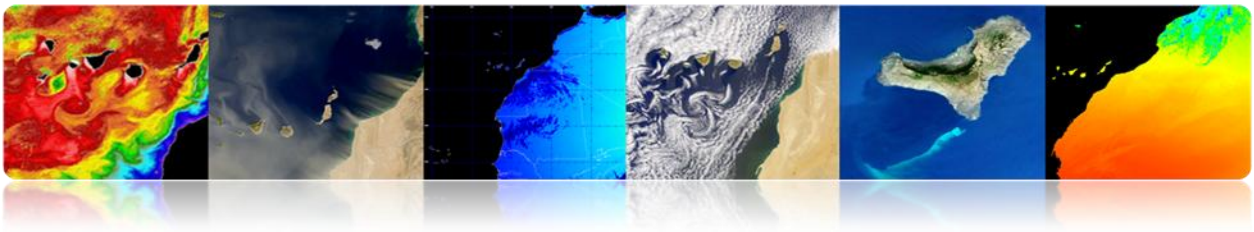
This **Remote Sensing Tutorial** has a technical and business orientation, with the overall objective of stimulating the use of remote sensing and creation of products and value added services. In addition, it aims at improving the training and skills of the project partners and Canary business & research in remote sensing. Further specific objectives are:

- Provide knowledge of space remote sensing, physical fundamentals, sensors and existing missions and land, atmospheric and marine products that could be obtained.
- Acquire knowledge on the techniques of digital image processing remote sensing aimed at improving and extracting relevant information for each application.
- Know the various data sources available for imaging.
- Know and properly handle the major existing software tools.
- Acquire the skills and abilities to generate remote sensing products and services and to extract as much information as possible from Earth observation satellite images.

Our needs may be grouped up focusing on training needs and breaking down the fundamental objective of this tutorial:

- ✓ Encourage the use of remote sensing.
- ✓ Facilitate the exchange of resources and knowledge of the subject.
- ✓ Meeting the training needs of users (continuos education).
- ✓ Extend the use to new users (companies and corporations).
- ✓ Establish common learning objectives.

Finally, note that the TELECAN TUTORIAL presented below contains the efforts and contributions of the universities of the Canary Islands, Morocco, Mauritania, Senegal and Cape Verde Islands achieved in different project meetings that have been held in Gran Canaria (2010), in Senegal (2011) and in Agadir (2012), as well as those of public institutions and companies related to the remote sensing of the Canary Islands.



STRUCTURE

This document entitled "REMOTE SENSING TUTORIAL TELECAN" prepared jointly by the chief scientists of the Telecan project (Francisco Eugenio / Javier Marcello, ULPGC and Ferran Marqués, UPC) by agreement of the Telecan Committee, is divided into two parts: Formation (theoretical) and Training (practical fundamentals).

FORMATION:

1. - Fundamentals of Remote Sensing

2. - Sensors and Remote Sensing Space Missions

3. - Remote Sensing Applications

4. - Radiometric, Atmospheric and Geometric Modeling

5. - Remote Sensing Images Processing

TRAINING:

1. - Collection and Analysis of Remote Sensing Images

2. - Tools Image Processing Software

3. - Modeling and Remote Sensing Image Processing

FORMATION PLAN

TELECAN

1. Remote Sensing Fundamentals

Introduction

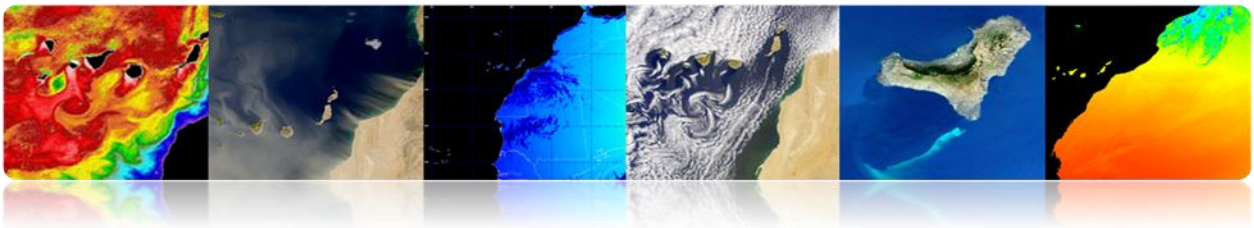
Remote sensing is a scientific discipline that integrates a broad set of knowledge and technologies used for observation, analysis and interpretation of terrestrial and atmospheric phenomena. Its main information sources are the measures and the images obtained with the help of aerial and space platforms.

As the name suggests, remote sensing implies a distance information acquisition without direct contact with the object being studied. As you are reading this text, you are performing yourself an act of remote perception: the light coming out a source is the physical entity, in this case it is the screen of your PC. This light travels through a certain distance until it is captured by a sensor, which are your eyes that send this light to a processor, your brain.

Information acquisition at distance implies the existence of a flow of information between the object being observed and the sensor. The bearer of this information is the electromagnetic radiation that may be emitted by the object or come from another body and could have been reflected by it. All bodies -planets, living beings, inanimate objects- emit electromagnetic radiation and the amount and type of radiation emitted depends largely on their temperature.

The current remote sensing systems, unlike the very first ones, have experienced a quick advance, especially in the last decade, with a technology essential in monitoring multiple processes that affect the Earth's surface and its surrounding atmosphere, large impact, especially, for our planet, such as climate change, deforestation, desertification, etc.

Thus, there are operational satellite systems that sample virtually every region of the electromagnetic spectrum, with spatial resolutions from 0.5 to 5,000 m. The great interest of the scientific community in spatio-temporal studies of global change, environmental monitoring and human impacts on it necessarily involves the use of remote sensing data.



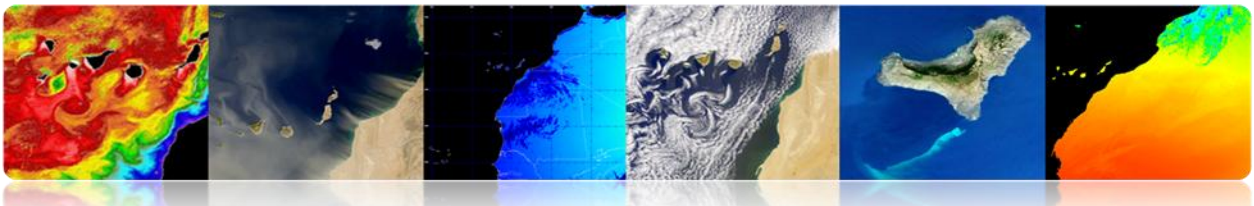
Remote sensing systems, particularly those located on satellites, provide a repetitive and synoptic vision of Earth which is of great interest in monitoring and analysing the effects of human activities on our planet such as the evaluation and monitoring of the environment -urban growth, hazardous waste-, detection and monitoring of global changes -atmospheric ozone depletion, deforestation, global warming-, exploration, both non-renewable resources -minerals, oil, natural gas- and renewable natural resources -oceans, forests, land-, meteorology -weather forecasting, atmospheric dynamic processes-, mapping -topography, land use, civil engineering, etc.

The objectives of this chapter are:

- Study of basic principles, advantages, limitations and elements of a spatial remote sensing system.
- Know the evolution of the Earth's space observation.
- Know and understand the remote sensing physical principles.
- Discriminate the spectral information from the different land cover.
- Study the orbits of the satellites and the physical laws that govern them.
- Observe and identify satellites visible from Earth.

CONTENTS

Remote Sensing Fundamentals

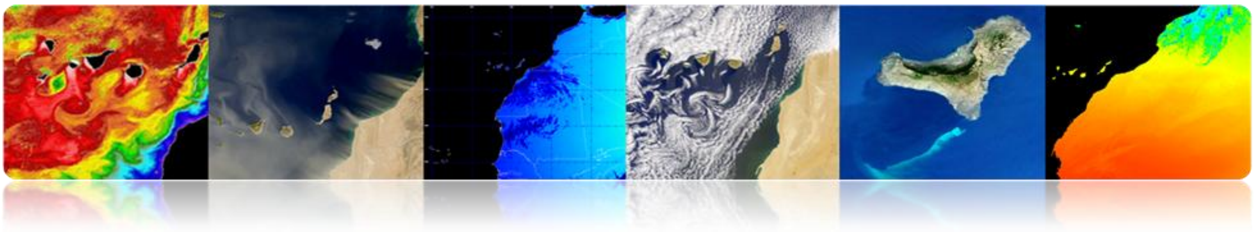


1.1. BASICS: DEFINITION AND OBJECTIVES

In a globalized world citizens are informed daily on the presence and effects of natural phenomena such as earthquakes, tsunamis, volcanic eruptions, forest fires, floods, etc.

In addition, humans have always had a special interest in contemplating nature and observe features of the territory.

Remote sensing is an essential tool to provide **Earth observation satellite images**, suitable for multiple desired applications.

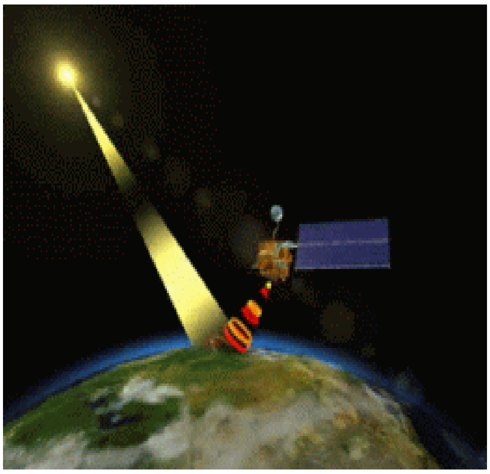


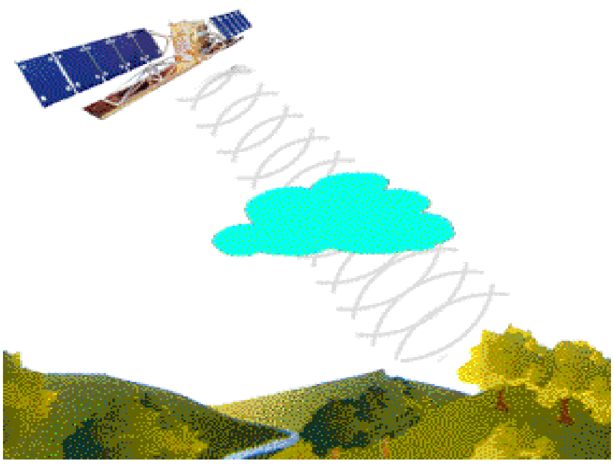
"REMOTE SENSING is an aerospace technology that uses electromagnetic energy to capture data from the Earth's surface and its surrounding atmosphere by remote sensing systems"

"ISPRS: measurement or acquisition of information from certain properties of an object or phenomenon, by a recording system that is not in physical contact with the object or phenomenon under study"

PASSIVE REMOTE SENSING

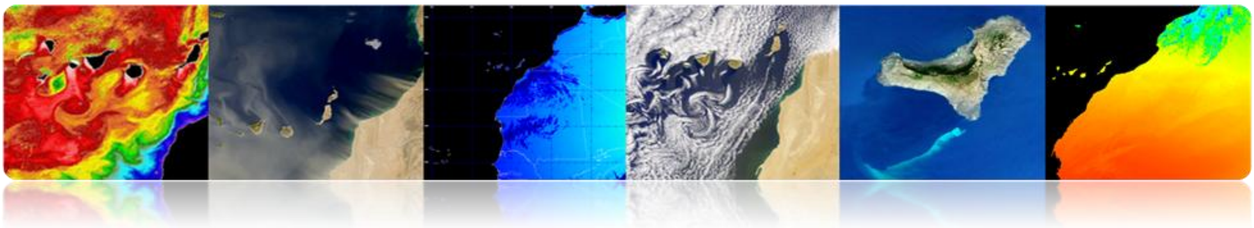
ACTIVE REMOTE SENSING





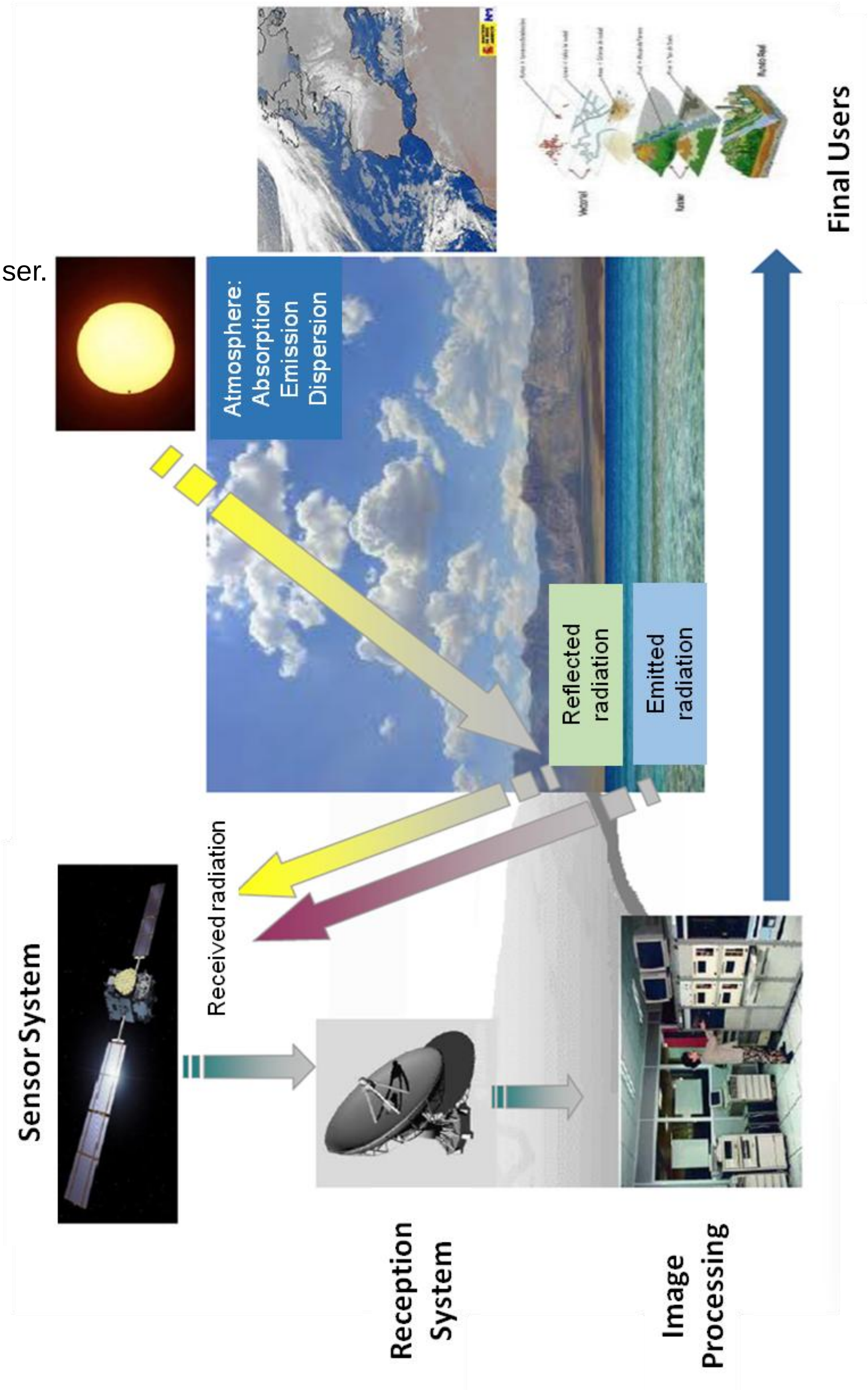
❑ REMOTE SENSING MAIN OBJECTIVE:

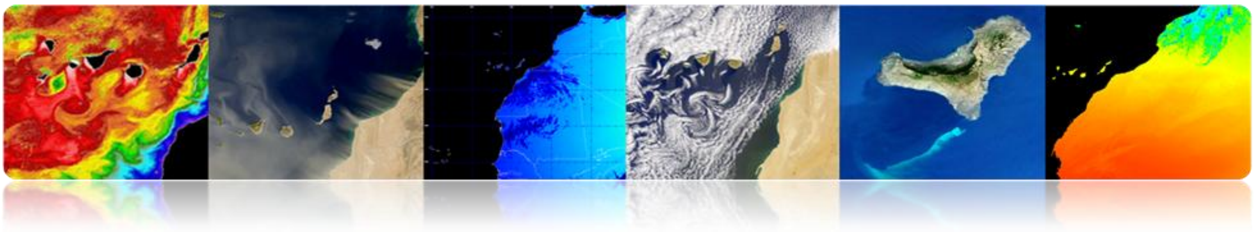
"Considerably improve our knowledge of our environment, facilitating the interpretation of the multiple processes affecting the planet"



❑ REMOTE SENSING: GENERAL SCHEME OPERATION

1. - Energy Source.
2. - Land cover.
3. - Atmosphere.
4. - Sensor system.
5. - Reception System.
6. – Images Processing.
7. - Interpreter and / or user.

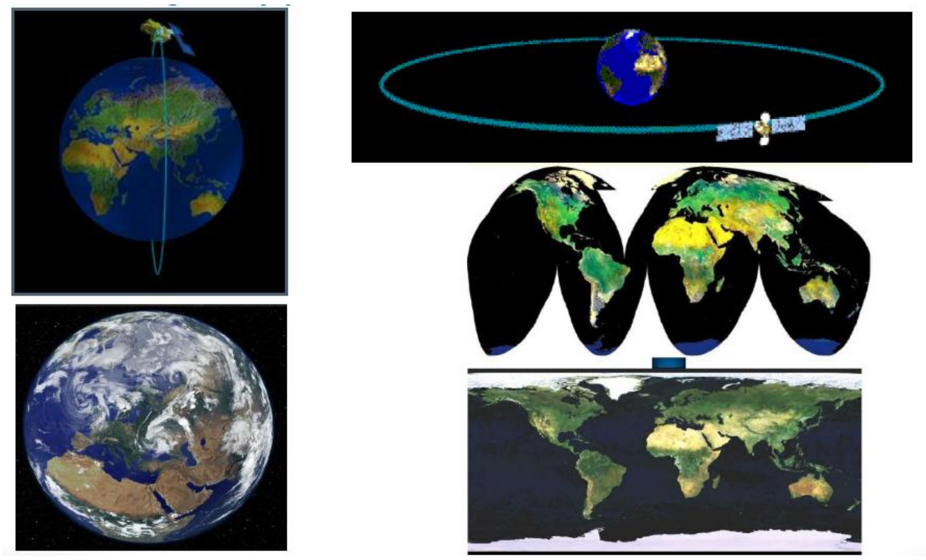




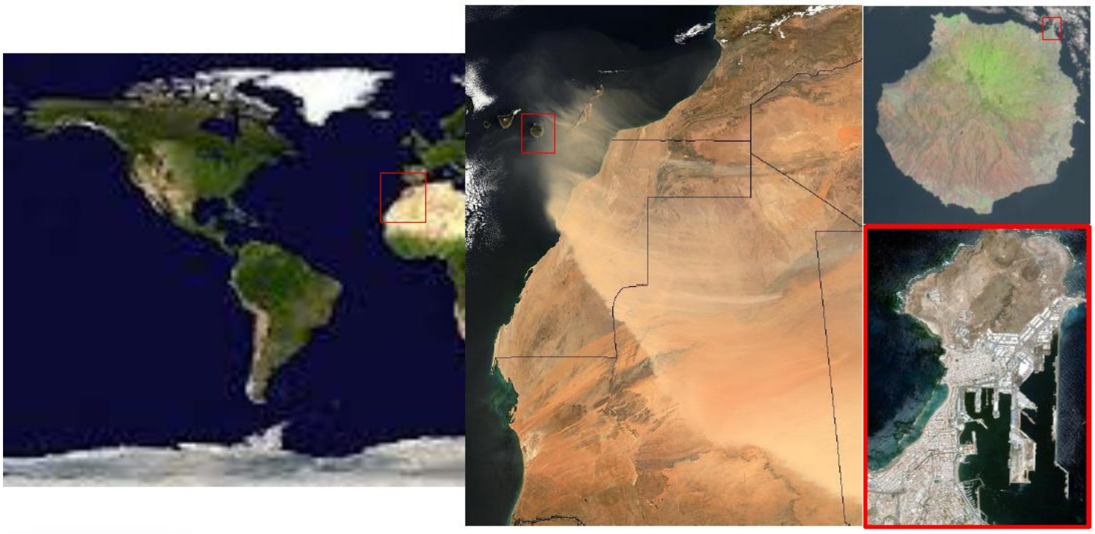
❑ REMOTE SENSING: SPATIAL INFORMATION TOOL

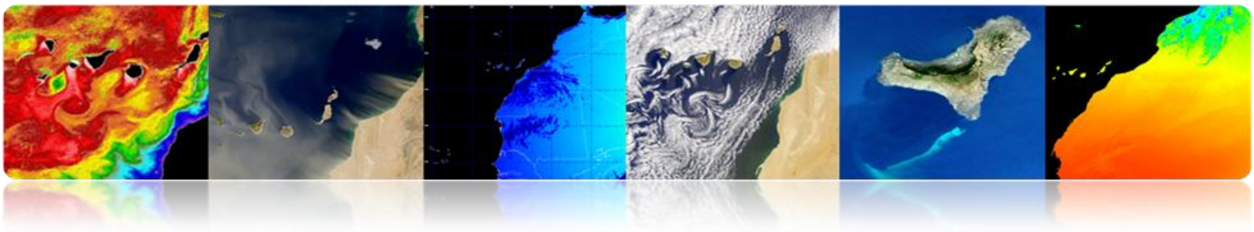
Advantage

- Global coverage and regular large areas of the Earth.

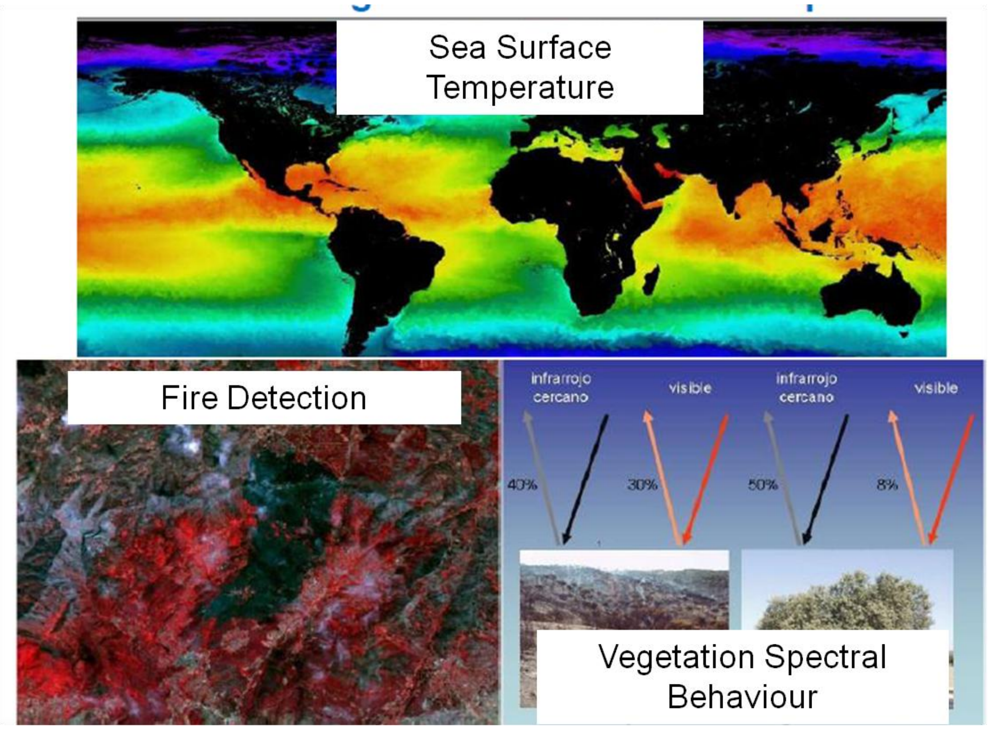


- Observation multiscale.

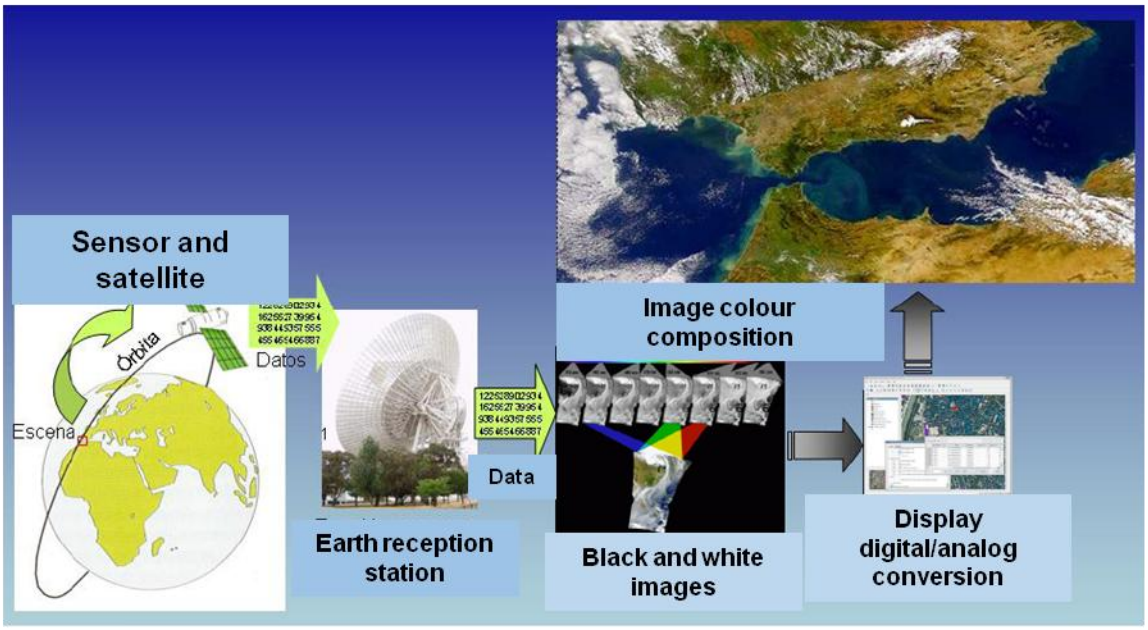


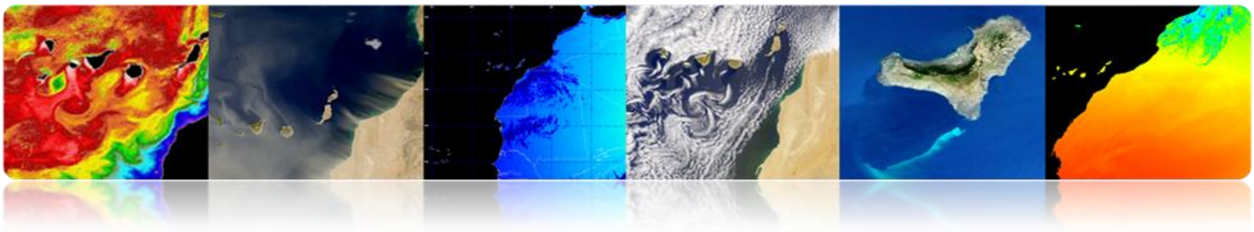


➢ Information on non-visible regions of the spectrum.



➢ Digital processing of the received images.



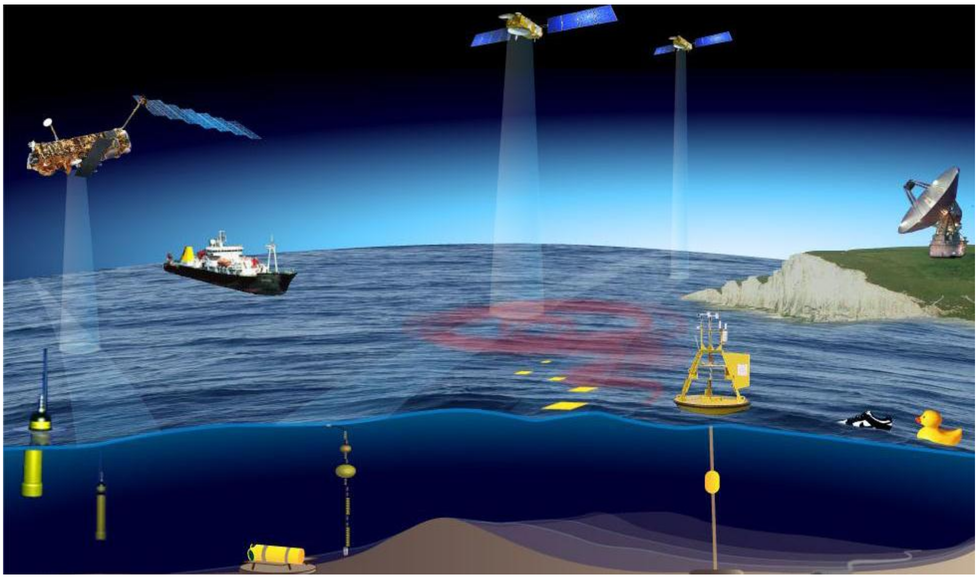


Limitations

- Models are NOT obtained with high accuracy in comparison with in-situ observations or aerial photography.

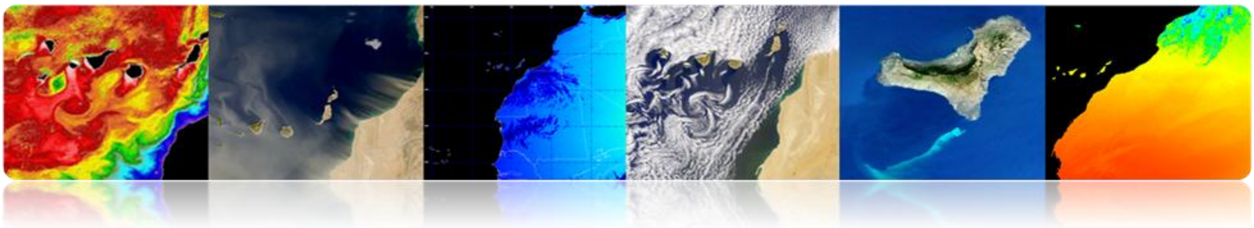
❑ REMOTE SENSING: COMPLEMENTARY TECHNOLOGIES

- In-situ observations



- Aerial photography

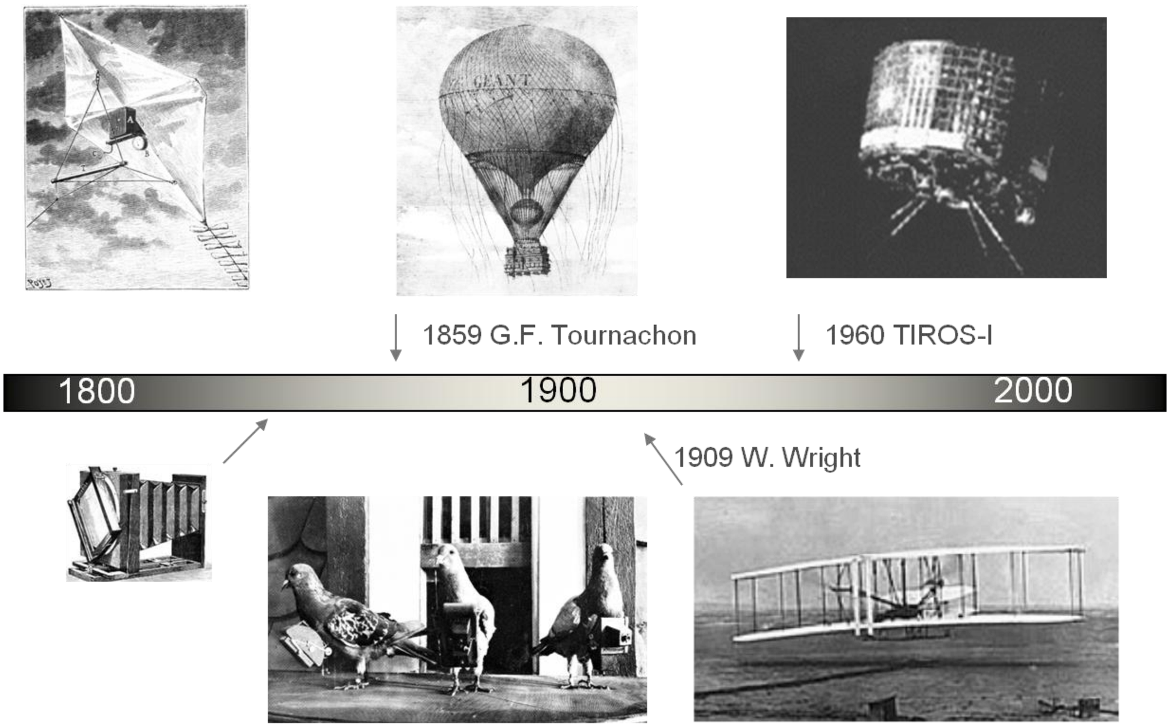
Daedalus 1268 (INTA)

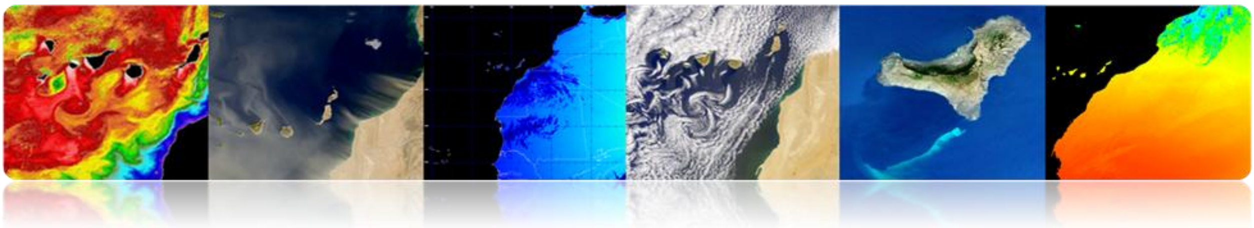


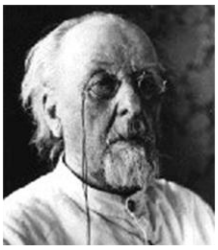
1.2. HISTORICAL EVOLUTION

❑ RELEVANT EVENTS

- The invention of photography made remote sensing possible.
- Remote sensing started in 1860 with a photograph of the Earth's surface, taken from a balloon by Tournachin.
- First Earth observation satellite in 1960 (TIROS-I).
- There are currently multiple public and private agencies and Research and Education Centers actively working in the field of remote sensing.



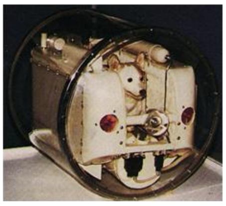


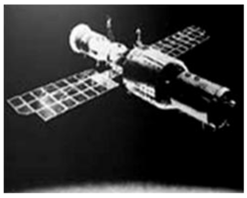


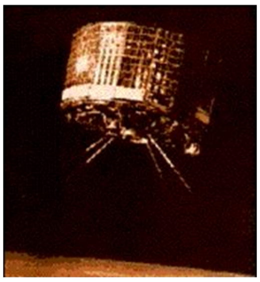
“The Earth is the cradle of humanity, but mankind will not continue forever in the cradle”

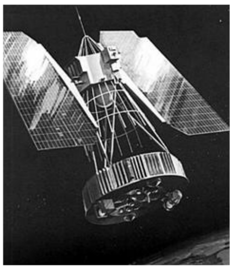
Konstantin Tsiolkovski, 1903

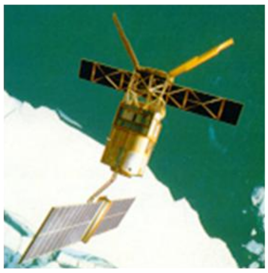
1957 1961 1969 1971



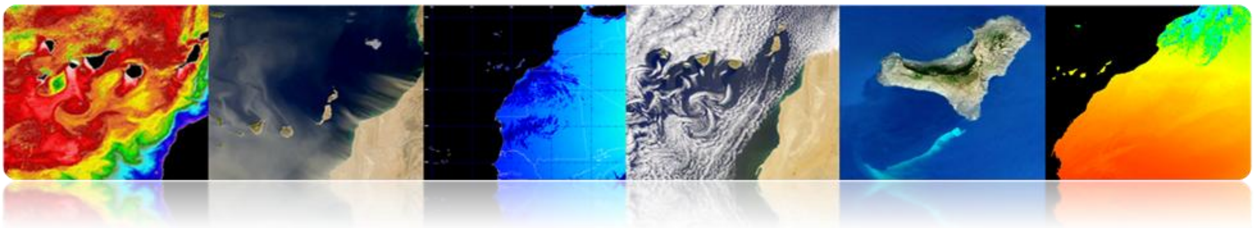






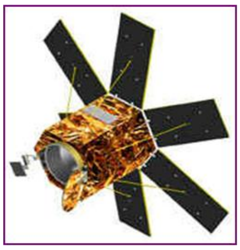


1960 1964 1972 1991



IKONOS | EROS | QUICK BIRD | ORBVIEW



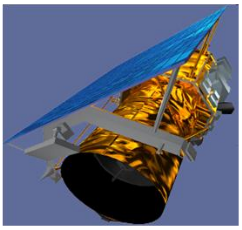
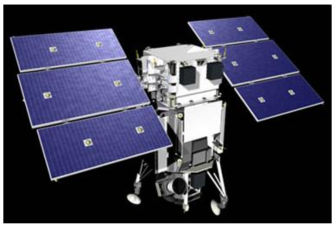
2000 2002 2004 2006


1m (Pan) 4m (Ms)


1.8 m (Pan)

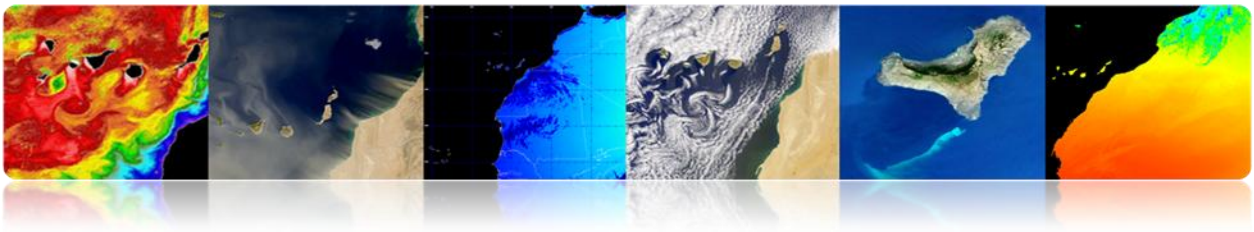

0.65 m (Pan) 2.4 (ms)

GEOEYE-1 | WORLDVIEW-1/2

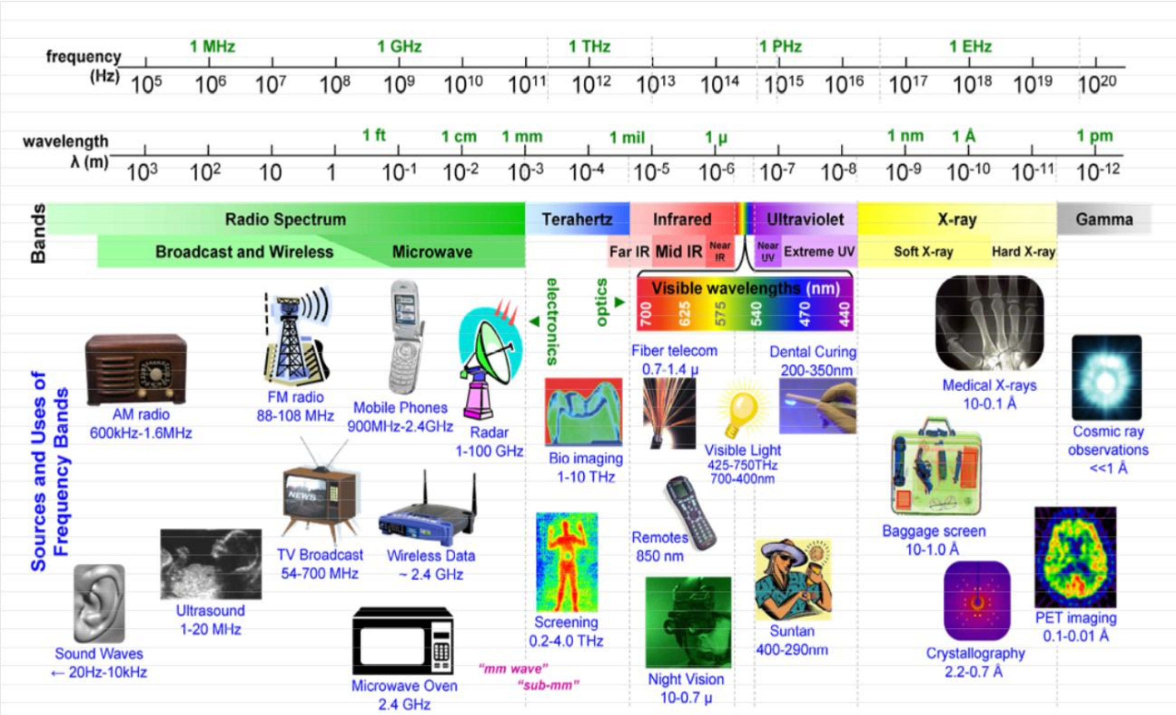
2008 2010 2012

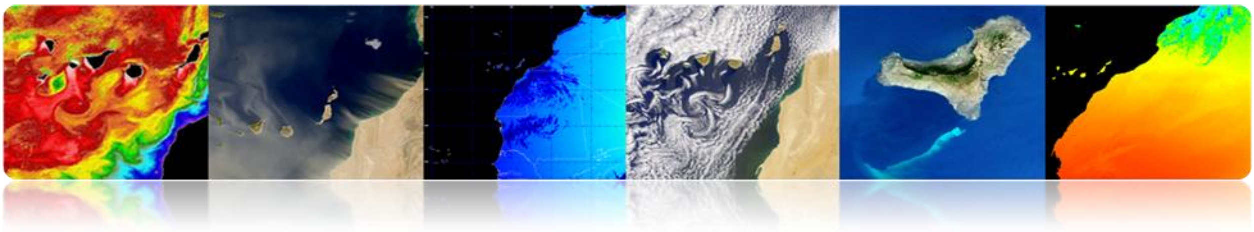




1.3. FUNDAMENTALS OF PHYSICS: GROUND COVERS SPECTRAL RESPONSE

❑ ELECTROMAGNETIC SPECTRUM: SOURCES AND USES OF THE FREQUENCY BANDS





❑ SPECTRAL REGIONS USED FOR REMOTE EARTH OBSERVATION

- Visible spectrum (0.4-0.7 μm): It is the frequency range of the human eye. Maximum solar radiation. Subdivided into three bands: R, G, B.

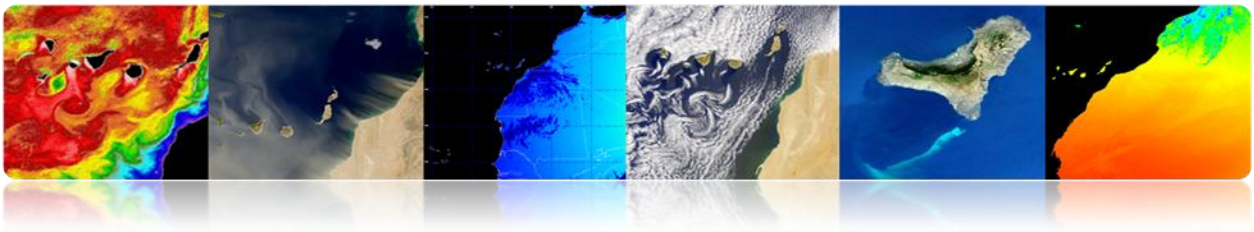
- Near-infrared (0.7-1.1 μm): Also called photographic reflected IR. It is the solar energy reflected by any body. Its behavior is similar to the visible spectrum.

- Middle infrared (1.1-8 μm): Solar radiation and emission mixing. The atmosphere is significantly affected. It is exploited to measure concentrations of water vapor, ozone, aerosols, etc.

- Thermal infrared (8-14 μm): Radiation emitted by the bodies themselves. Tp can be determined by a body (thermal IR). Images may be available at any time of the day.

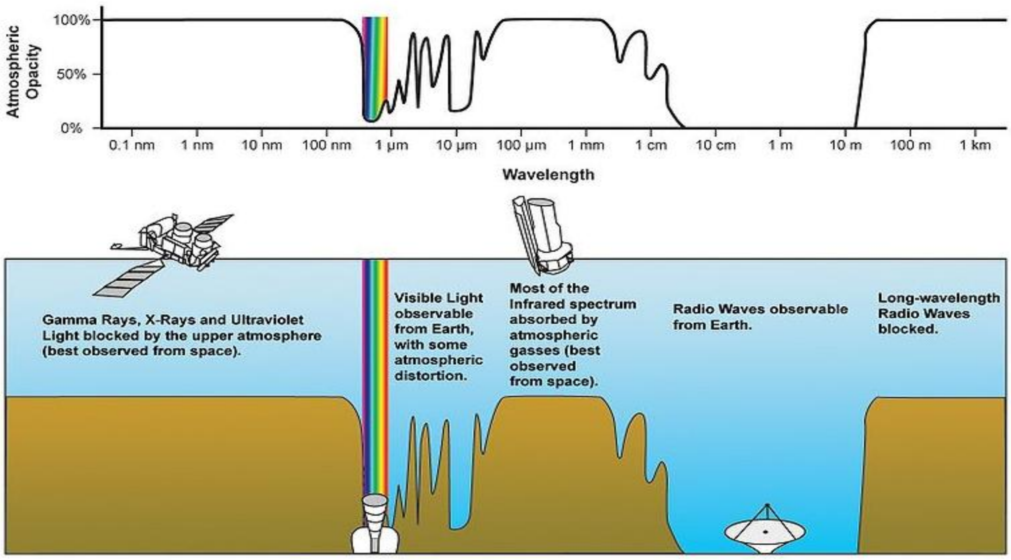
- Microwave (1mm-1m): There is a growing interest of Remote Sensing in this band. Atmospheric disturbances are minor and it is transparent to clouds. Active sensors are typically used.

Name	Wavelenght range	Radiation source	Surface property of interest
Visible (V)	0.4 – 0.7 μm	Solar	reflectance
Near InfraRed (NIR)	0.7 – 1.1 μm	Solar	reflectance
ShortWave InfraRed (SWIR)	1.1 - 3 μm	Solar	reflectance
MidWave InfraRed (MWIR)	3 – 5 μm	Solar, Thermal	Reflectance, temperature
Thermal InfraRed (TIR)	8 – 14 μm	Thermal	temperature
Microwave, radar	1 mm – 1 m	Passive: thermal Active: artificial	Temperature (P) Roughness (A)



❑ SPECTRAL REGIONS USED FOR REMOTE OBSERVATION OF EARTH:

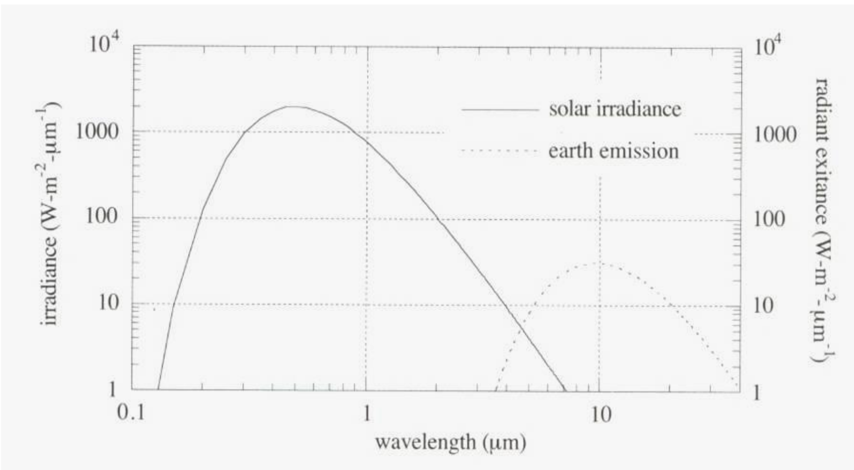
ATMOSPHERIC TRANSMISSIVITY

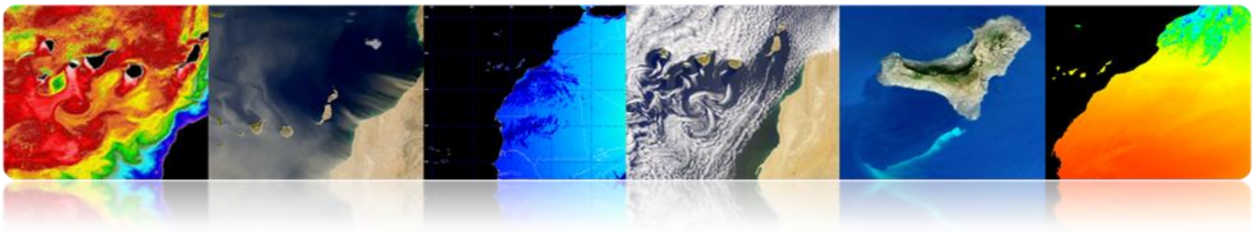


❑ EMISSION RATES USED BY REMOTE SENSING

1. Radiation reflected on Earth's surface emitted by the Sun. It depends on the characteristics of the surface or object (i.e., human vision and the environment).

2. Any body whose temperature is above absolute zero (0 K: -273 ° C) emits energy in the form of radiation (i.e., a camp fire emission).





❑ ELECTROMAGNETIC RADIATION LAWS

▪ Planck's Law

Provides the spectral radiance of a black body as a function of temperature.

Any object with T> 0K radiates energy.

T↑ ⇒ Energy ↑ (Radiation ↑ in ↓ λ)

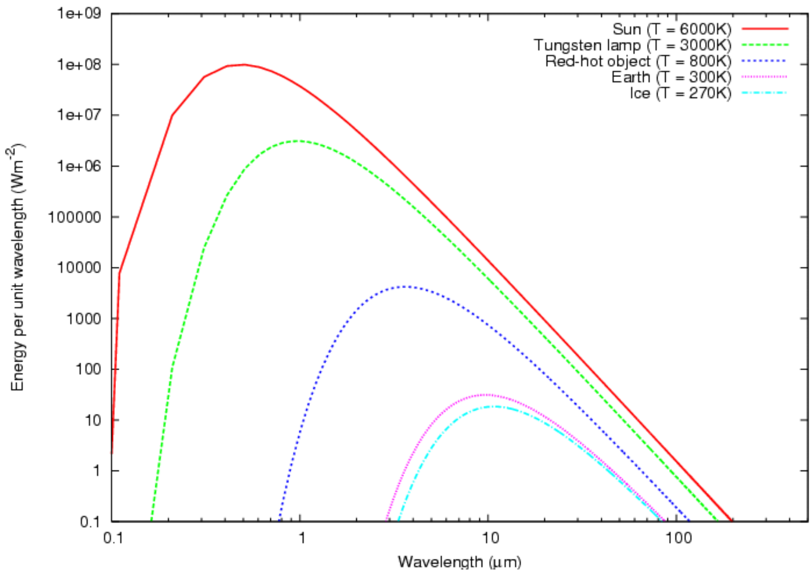
$$M_{\lambda,T} = \frac{C_1}{\lambda^5} \frac{1}{e^{C_2/(\lambda \cdot T)} - 1}$$

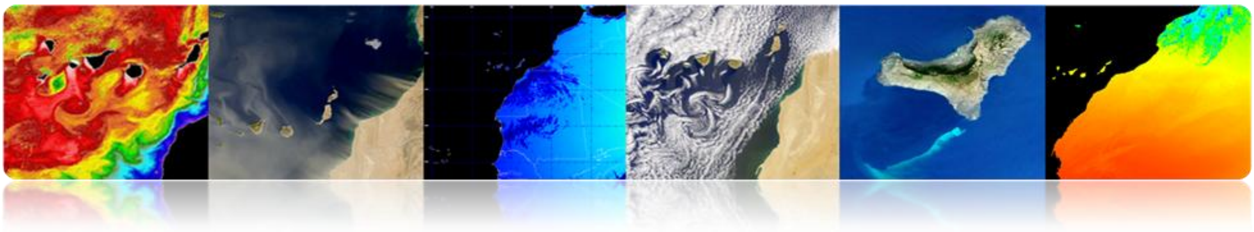
▪ Wien's Displacement Law

For a given temperature, there is a λ for which the electromagnetic energy is the peak.

$$\lambda_{\max} = \frac{2898(\mu m \cdot K)}{T(K)}$$

We can select the appropriate band for the detection of a phenomenon, if we know its temperature range.





▪ Stefan-Boltzmann Law

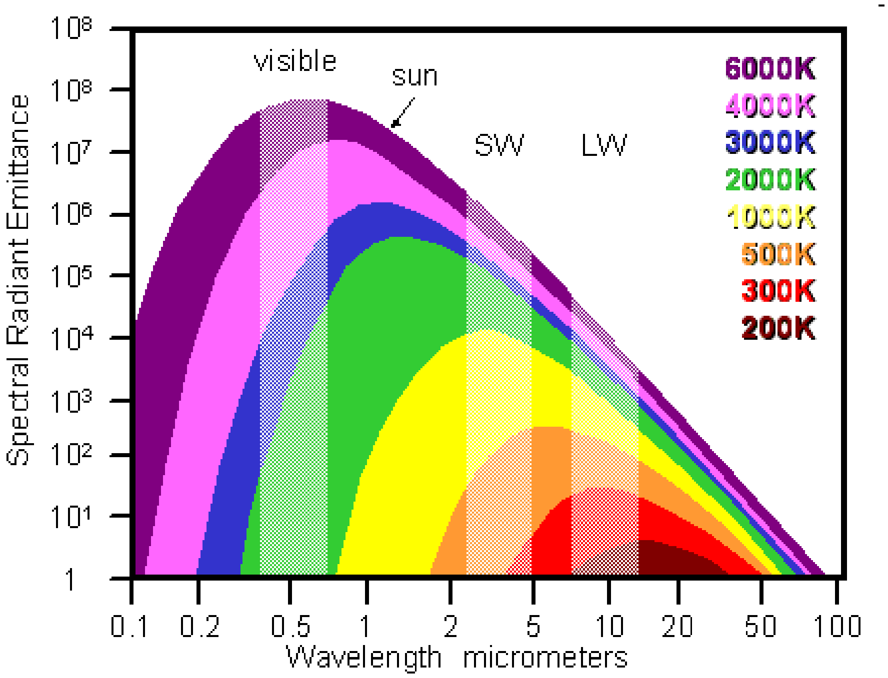
Provides the total energy emitted by a black body throughout the spectrum.

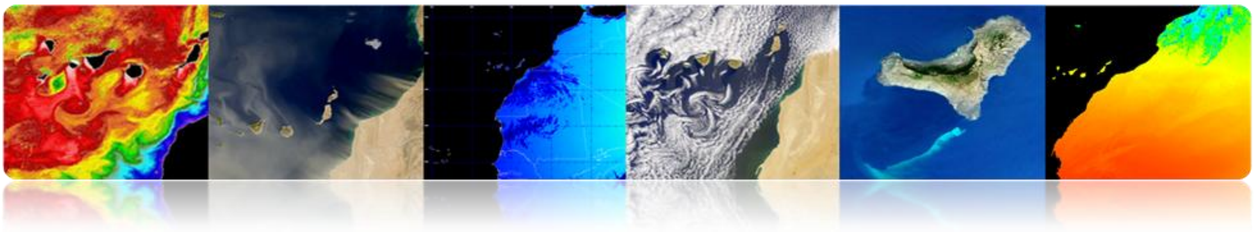
$$M = \sigma \cdot T^4$$

- Direct relationship between temperature and the amount of electromagnetic energy emitted.
- The hotter is the object, the more energy is generated.
- Small variations in temperature → Large variations in the energy emitted (T^4).
- Real bodies are not black bodies.

Emissivity

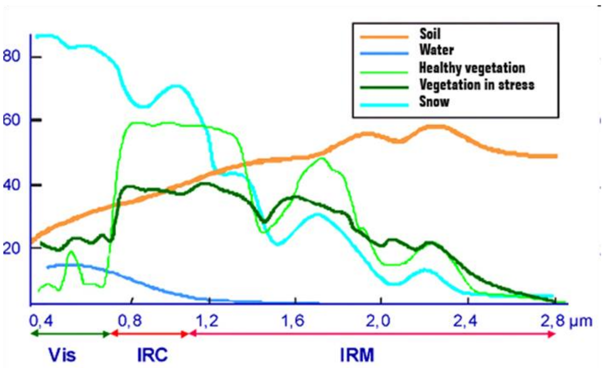
$$M_{real} = \varepsilon \, . \, M_{BB}$$

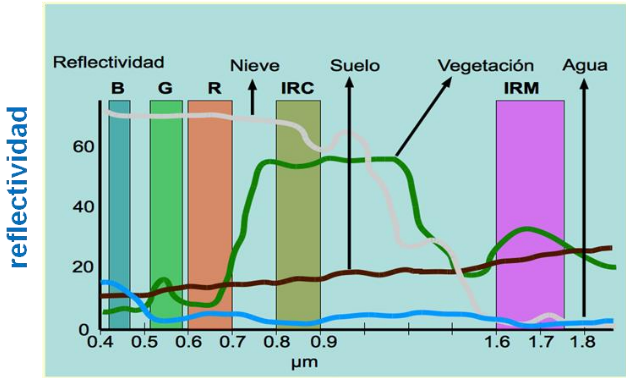




▪ Spectral Reflectivity

A real body has an emissivity and reflectivity that vary with wavelength → SPECTRAL SIGNATURE

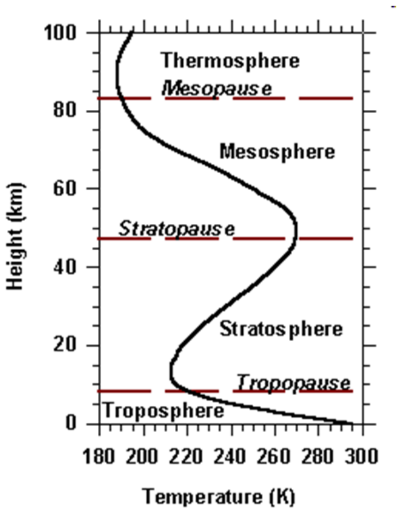


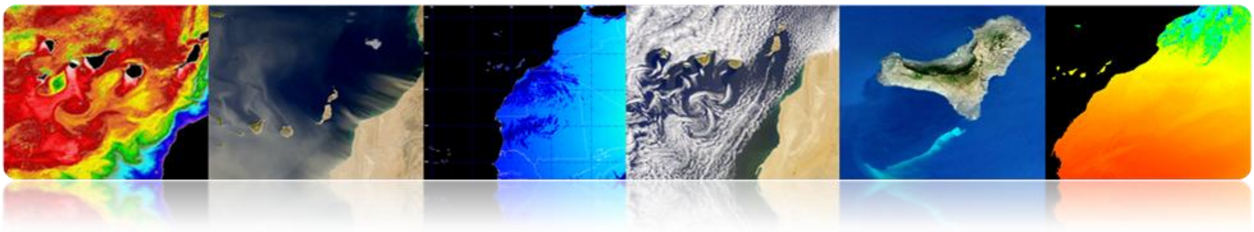


▪ Interactions of the Atmosphere

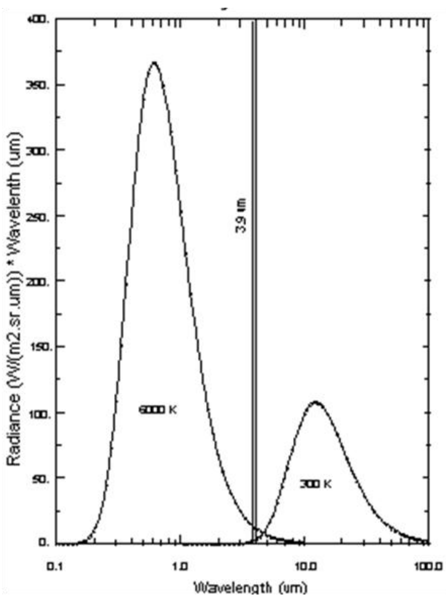
- The atmosphere is a mixture of gases at different layers.
- The first 80 kilometers contains more than 99% of the total mass of the Earth's atmosphere.

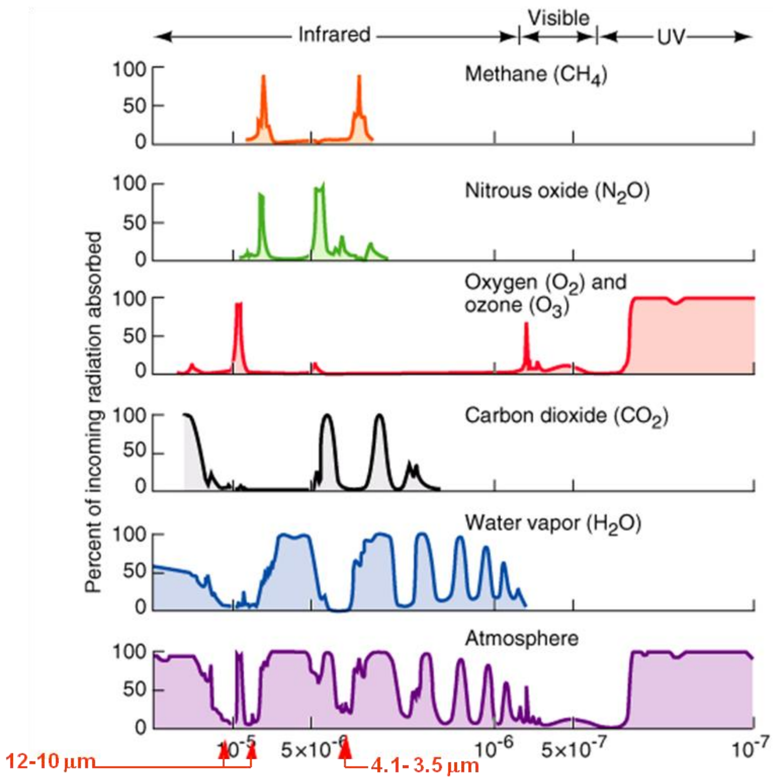
Gases Permanentes	Gases Concentración Variable
Nitrogen (N_2): 78% by volume	Water vapour (H_2O)
Oxygen (O_2): 20.95%	Ozone (O_3)
Argon (Ar): 0.93%	Sulphur dioxide (SO_2)
Carbon dioxide (CO_2): 0.033%	Nitrogen dioxide (NO_2)
Other noble gases (Ne, He, Kr, Xe)	Ammonia (NH_3)
Hydrogen (H_2)	Nitric oxide (NO)
Methane (CH_4)	Hydrogen sulphide (H_2S)
Nitrous oxide ($N2_O$)	Nitric acid vapour (HNO_3)
Carbon monoxide (CO)	

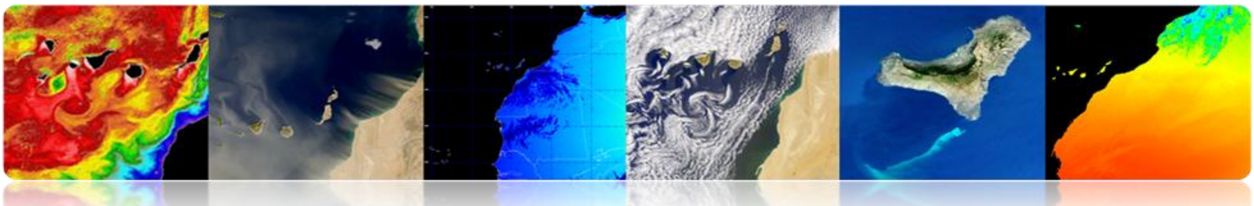




- When EM radiation travels through the atmosphere, it is absorbed or scattered by particles in the atmosphere.
- The atmosphere also emits→Thermal IR.







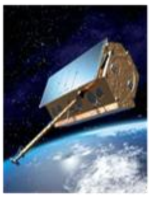
1.4. Remote Sensing Agencies and Public Organizations

❑ Main Agencies and Organizations

At regional (PET), national (PNOT-PNT), European (ESA) and global (NASA) level, the different space agencies continue to rely on remote sensing with new missions, allowing its application in many strategic sectors.

INTERNATIONAL

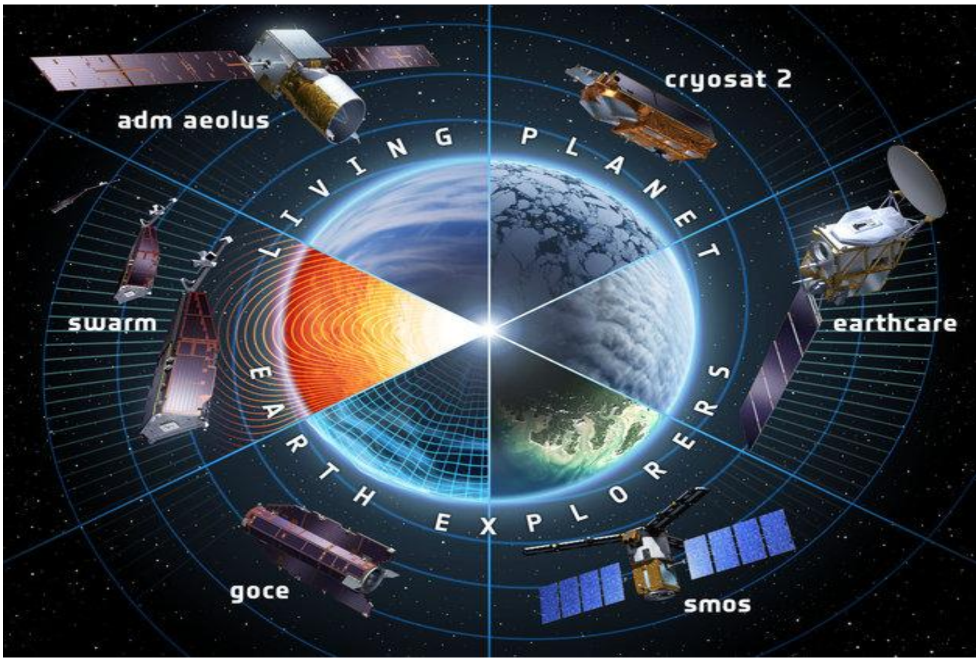
NATIONAL



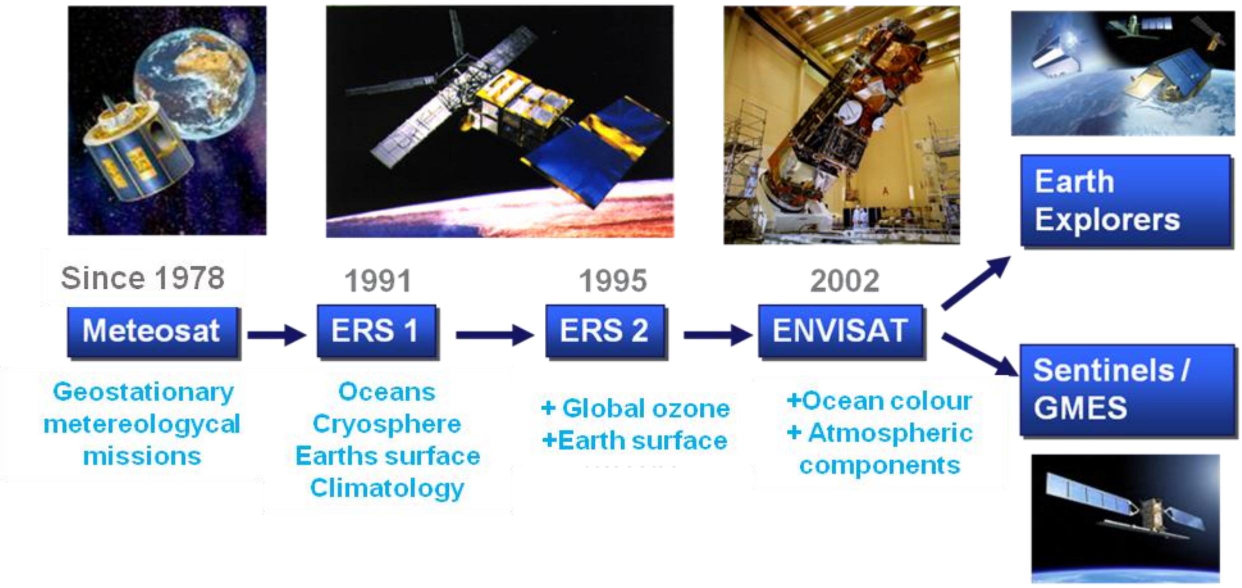
CANARY ISLANDS

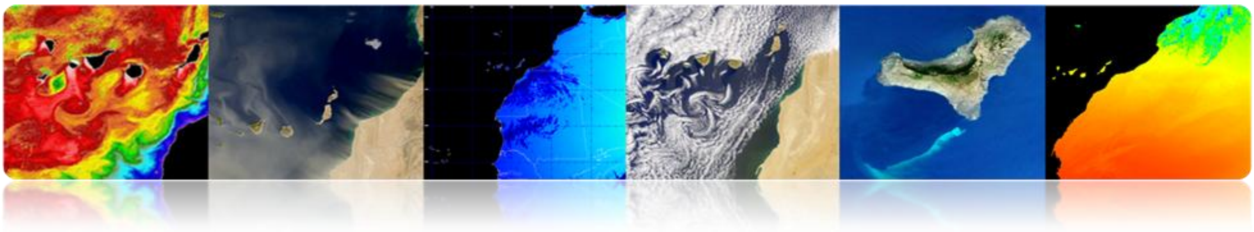
INTERNATIONAL

1. ESA: European Space Agency

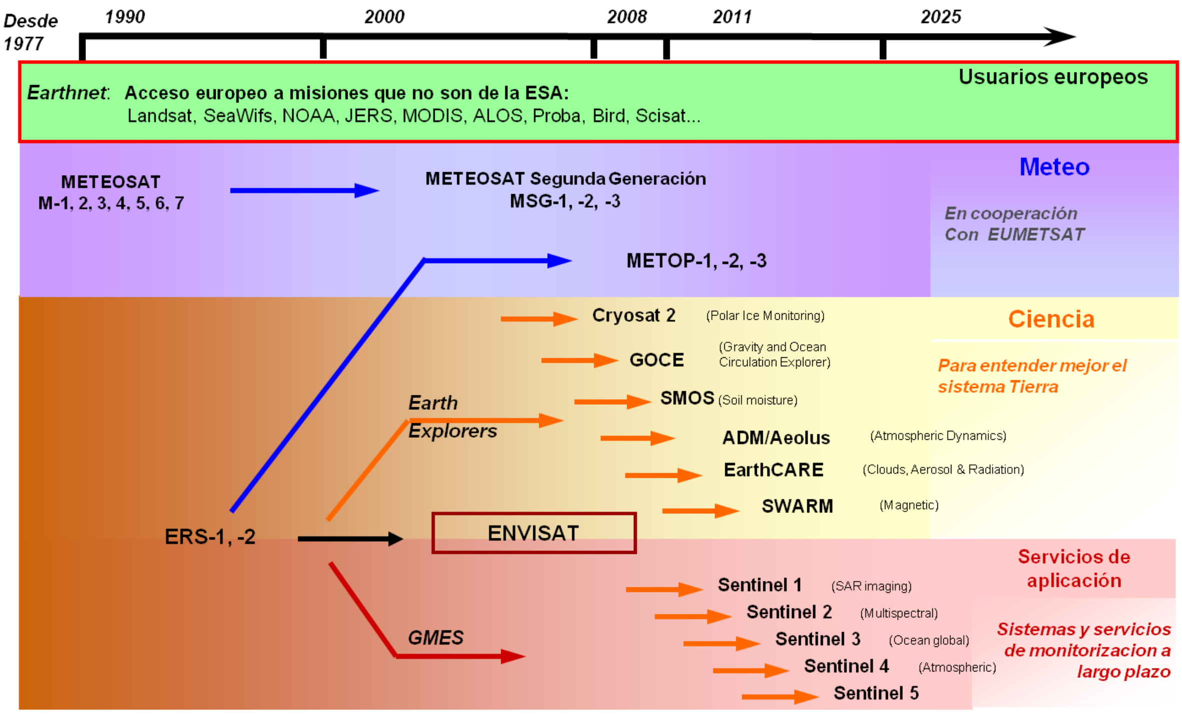


From past to present





Missions for Earth Observation controlled by ESA



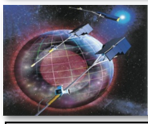
Scientific missions: "Earth Explorer"

GOCE – Misión gravitatoria
el gradiómetro más sensible, órbita extremadamente baja
Primer geoide completo publicado en Junio 2010
17 Marzo 2009

SMOS – Humedad del suelo y salinidad oceánica
ciclo del agua dulce, previsiones del tiempo,
clima y eventos extremos
2 Noviembre 2009

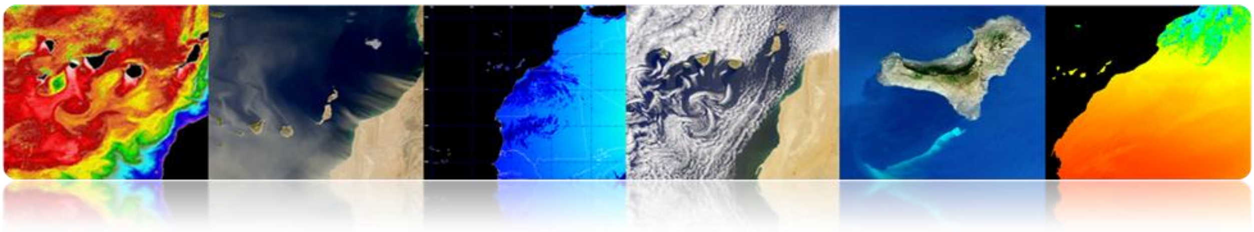
Cryosat-2 – Misión sobre el hielo
Espesor y fluctuaciones de las masas polares y del hielo marino y relación con las variaciones en el clima
8 Abril 2010

ADM/AEOLUS – Misión sobre el viento
perfiles de viento globales, predicciones del tiempo.
dinámica atmosférica y los procesos climáticos.
2012



SWARM – Misión magnética
campo geomagnético de la Tierra y sus variaciones temporales, el interior de la Tierra y su clima
2012

EarthCARE – Nubes y aerosoles (Europea – Japonesa)
interacciones nubes-aerosoles-radiación, predicción del clima y el tiempo
2013

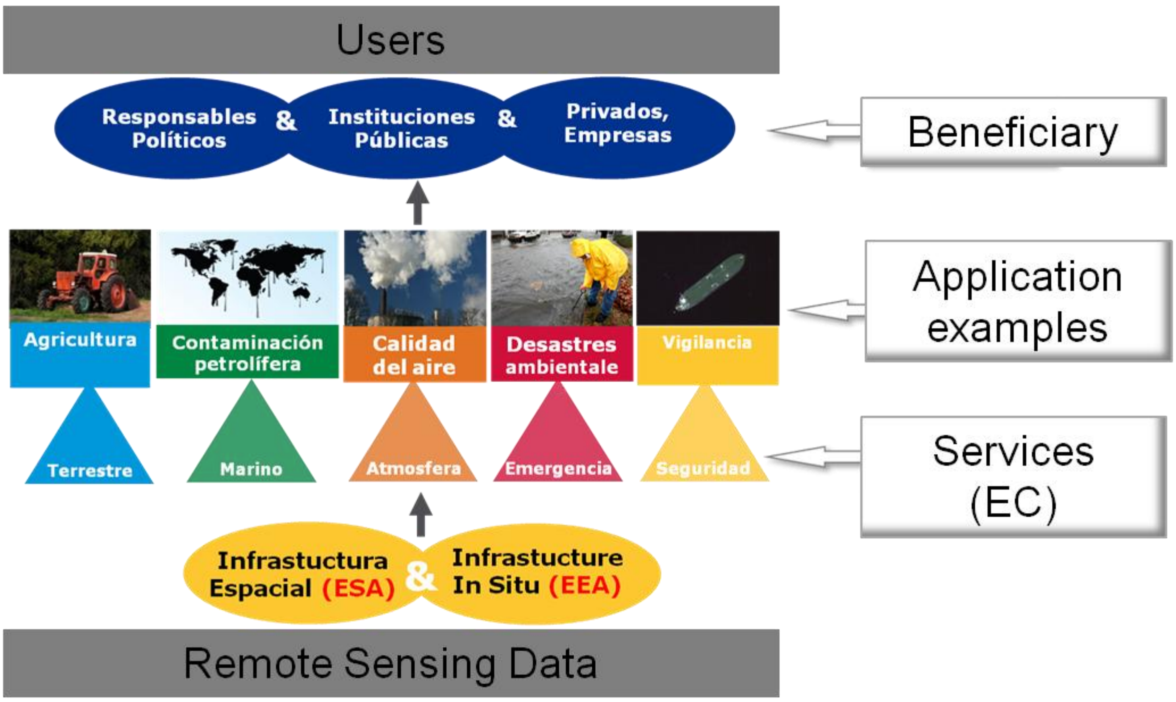


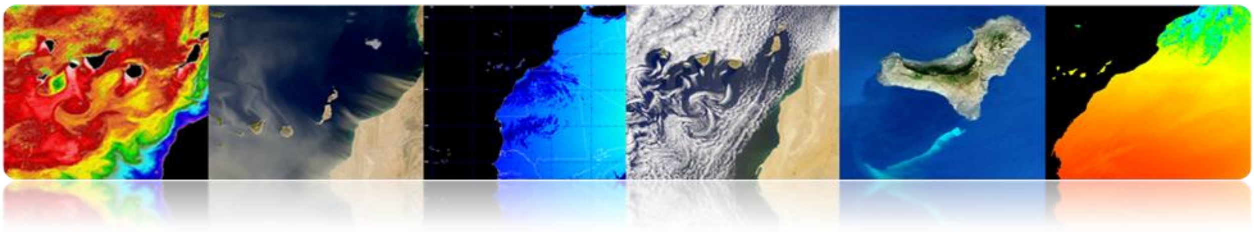
▪ GMES: The European Earth monitoring

- GMES, Global Monitoring for Environment and Security, is a joint initiative of the European Commission and the European Space Agency.
- GMES is a network for the collection and dissemination of data on the environment and security from space and in situ observations of the Earth.
- This system will support decision-making by public and private authorities in Europe and back up research.
- Following the example of meteorology, GMES develops operational services, but in other areas such as:

1. Emergency management.
2. Monitoring air quality.
3. Monitoring soil.
4. Monitoring the ocean, etc.

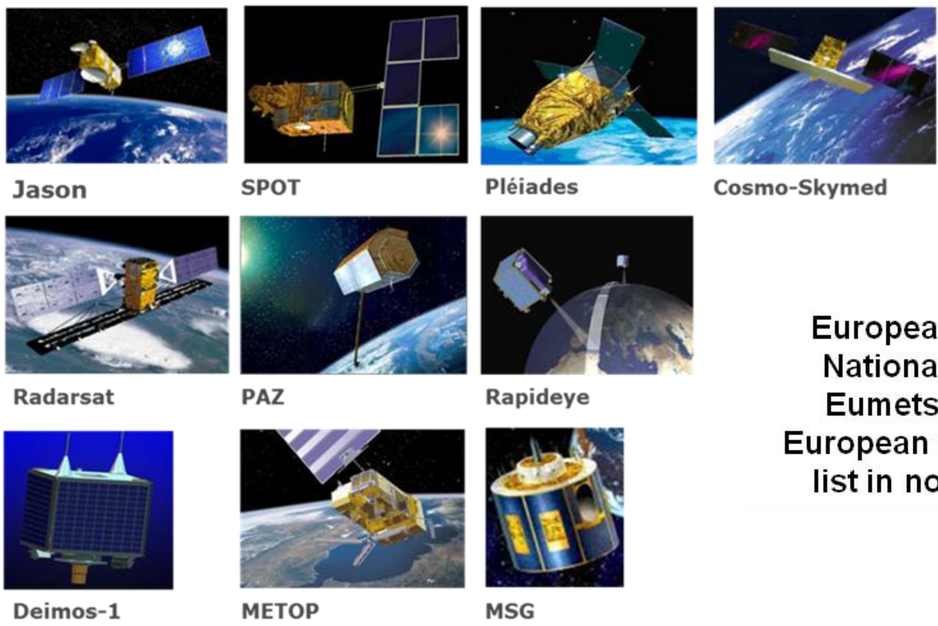
General Scheme





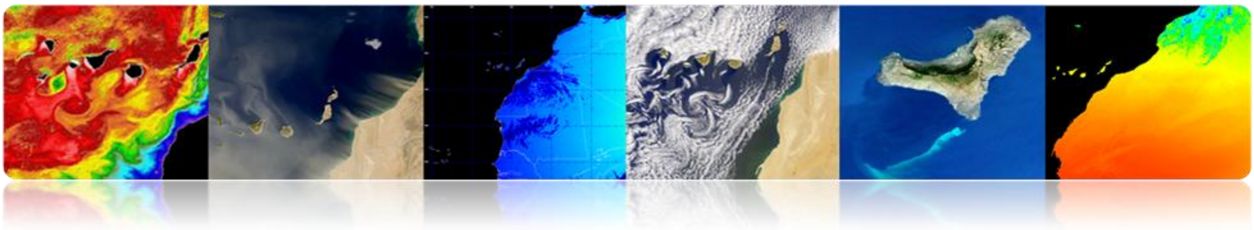
Space Segment

Missions that may contribute to GMES



European Members' National Missions, Eumetsat and non European missions (the list in not complete)

+ Ingenio, TerraSAR-X/Tandem-X, Enmap, Venμs, Altika, etc.



Missions dedicated to GMES

Sentinel-1: Mission SAR band C

- **Applications:**
  - Monitoring of sea ice and the Arctic environment.
  - Marine Surveillance.
  - Monitoring risks due to ground displacement.
  - Maps to organize humanitarian aid in crisis situations..

- **Four nominal operating modes:**
  - strip map (80 km swath, 5x5 m res.).
  - interferometric wide swath (250 km swath, 5x20mm.
  - extra wide swath (400 km swath, 20x40 m res).
  - wave (5X5 m res, images of 20x20 km).

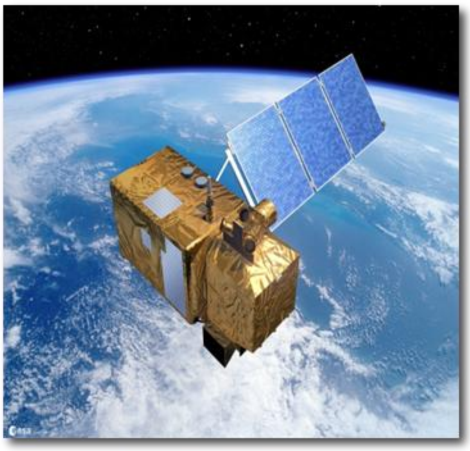
- **Helio-synchronous orbit at 693 km altitude**

- **Nominal 12-day revisit period**

- **Expected to last 7 years, having fuel for 12 years**

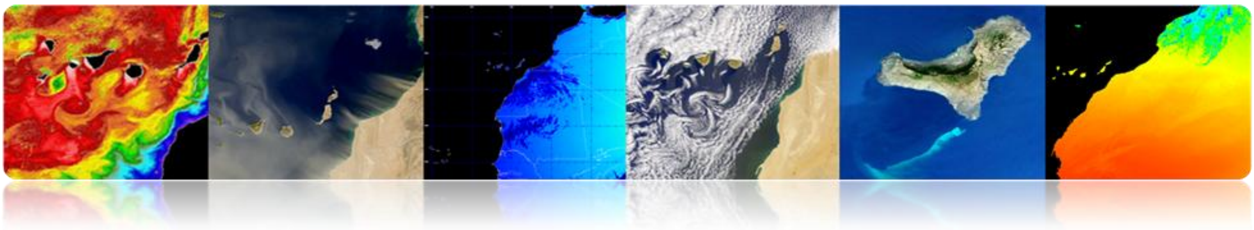
Sentinel-2: Mission super-spectral

- **Applications:**
  - Land cover maps.
  - Risk and fast hedge maps in case of emergencies.
  - Vegetation and chlorophyll maps.
- **Super-spectrometer with 13 bands (VNIR & SWIR)**
- **Spatial resolution: 10, 20 and 60 m**
- **Swath: 290 km**
- **Satellite mass: 1200 kg**
- **Revisit period: 5 days (without clouds) with 2 satellites**
- **helio-synchronous orbit at 786 km altitude**
- **Expected to last 7 years, having fuel for 12 years**



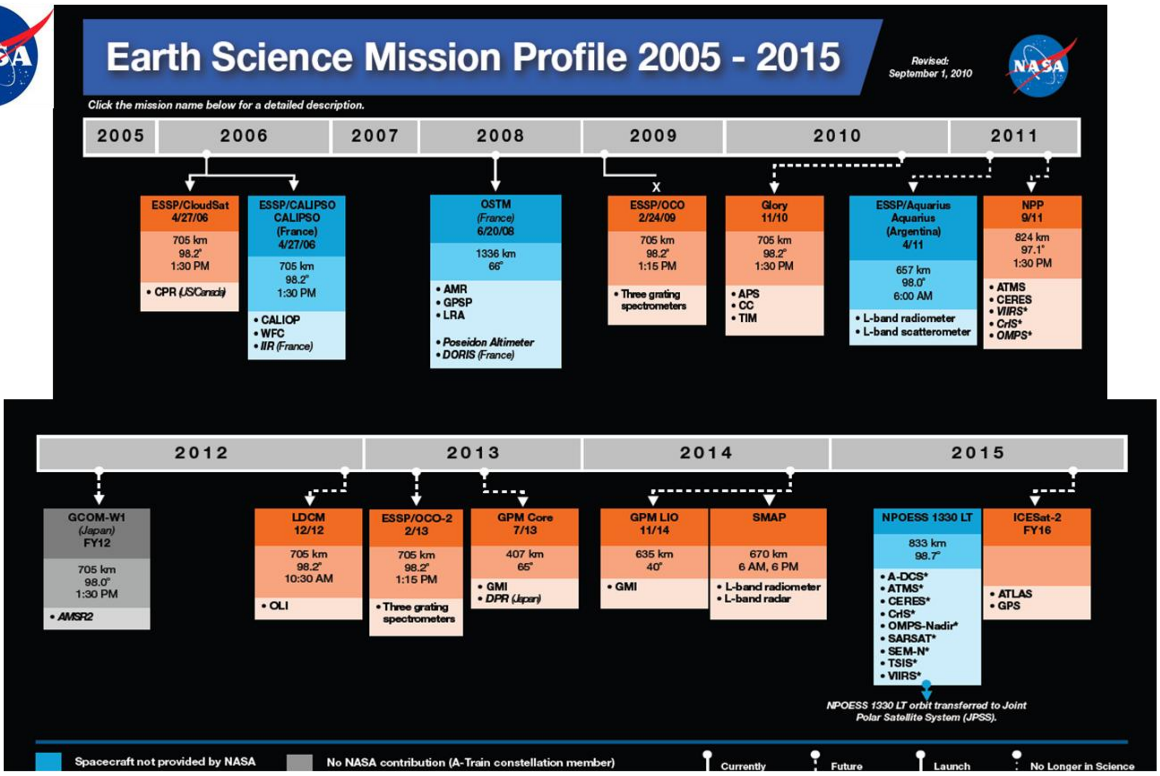
Sentinel-3 Mission: Global oceanic and terrestrial soil

- **Applications:**
  - Color and temperature of the sea surface and ground.
  - Topography of the sea surface and glaciers.
  - Topography of coastal areas, lakes and sea ice.
  - Vegetation maps.
- **Satellite mass: 1250 kg**
- **Helio-synchronous orbit at 814.5 km altitude**
- **Revisit period: 27 days**
- **Expected to last 7 years, having fuel for 12 years**



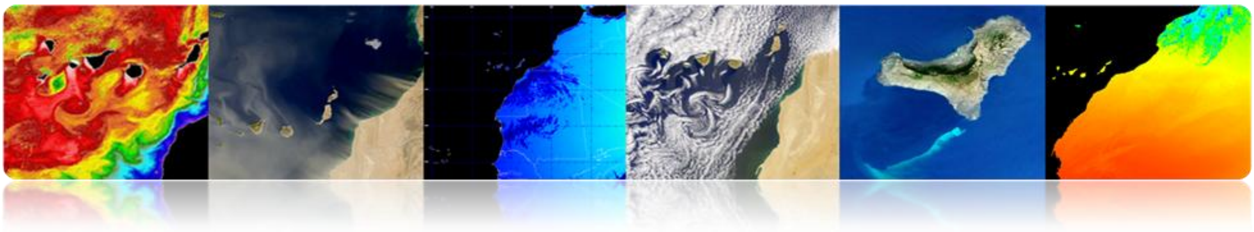
Spatial data access

2. NASA



Earth Science Mission Profile 2005 - 2015
Revised: September 1, 2010
Click the mission name below for a detailed description.
2005 2006 2007 2008 2009 2010 2011
ESSP/CloudSat 4/27/06 705 km 98.2° 1:30 PM
• CPR (US/Canada)
ESSP/CALIPSO CALIPSO (France) 4/27/06 705 km 98.2° 1:30 PM
• CALIOP • WFC • IIR (France)
OSTM (France) 6/20/08 1336 km 66°
• AMR • GPSP • LRA
• Poseidon Altimeter • DORIS (France)
ESSP/OCO 2/24/09 705 km 98.2° 1:15 PM
• Three grating spectrometers
Glory 11/10 705 km 98.2° 1:30 PM
• APS • CC • TIM
ESSP/Aquarius Aquarius (Argentina) 4/11 657 km 98.0° 6:00 AM
• L-band radiometer • L-band scatterometer
NPP 9/11 824 km 97.1° 1:30 PM
• ATMS • CERES • VIIRS* • CrIS* • OMPS*
2012 2013 2014 2015
GCOM-W1 (Japan) FY12 705 km 98.0° 1:30 PM
• AMSR2
LDCM 12/12 705 km 98.2° 10:30 AM
• OLI
ESSP/OCO-2 2/13 705 km 98.2° 1:15 PM
• Three grating spectrometers
GPM Core 7/13 407 km 65°
• GMI • DPR (Japan)
GPM LIO 11/14 635 km 40°
• GMI
SMAP 670 km 6 AM, 6 PM
• L-band radiometer • L-band radar
NPOESS 1330 LT 833 km 98.7°
• A-DCS* • ATMS* • CERES* • CrIS* • OMPS-Nadir* • SARSAT* • SEM-N* • TSIS* • VIIRS*
ICESat-2 FY16
• ATLAS • GPS
NPOESS 1330 LT orbit transferred to Joint Polar Satellite System (JPSS).
Spacecraft not provided by NASA
No NASA contribution (A-Train constellation member)
Currently
Future
Launch
No Longer in Science

NASA Earth Observatories
Jason-1
Landsat 7
QuikSCAT
ERBS
ACRIMSAT
Aqua
Terra
TOPEX/Poseidon
TRMM
SAGE III/METEOR-3M
UARS
SORCE
GRACE
SeaWiFS
EP-TOMS
NMP/EO-1
ICESat
Aura



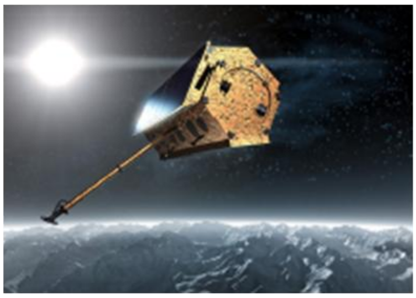
NATIONAL

- **PNOT: National Earth Observation Satellite**

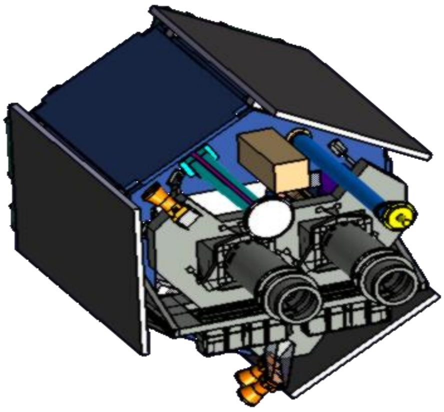
PNOT
Programa Nacional de Observación de la Tierra por satélite

← **Spanish Government**

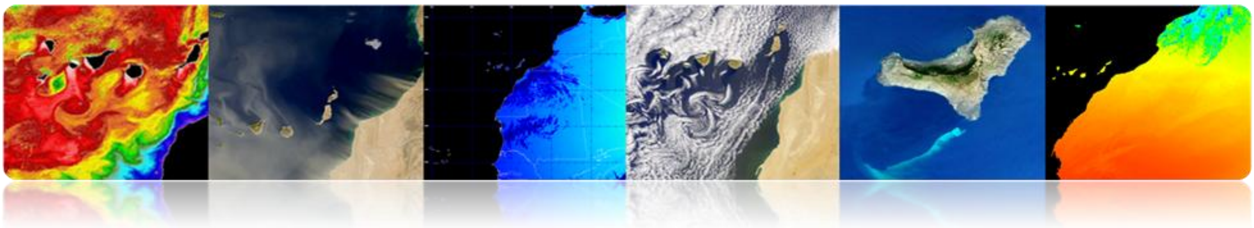
- Two satellites: INGENIO (radar) and PAZ (SAR)
- First Institutional OT Programme in Europe with both tecnologies: optique and radar
- Participation of Spain in international programmes (GMES,MUSIS)
- Double use (civil and militar)
- Autonomy and independence of Spain to obtain satellite data.
- Spanish government operator: INTA/HISDESAT



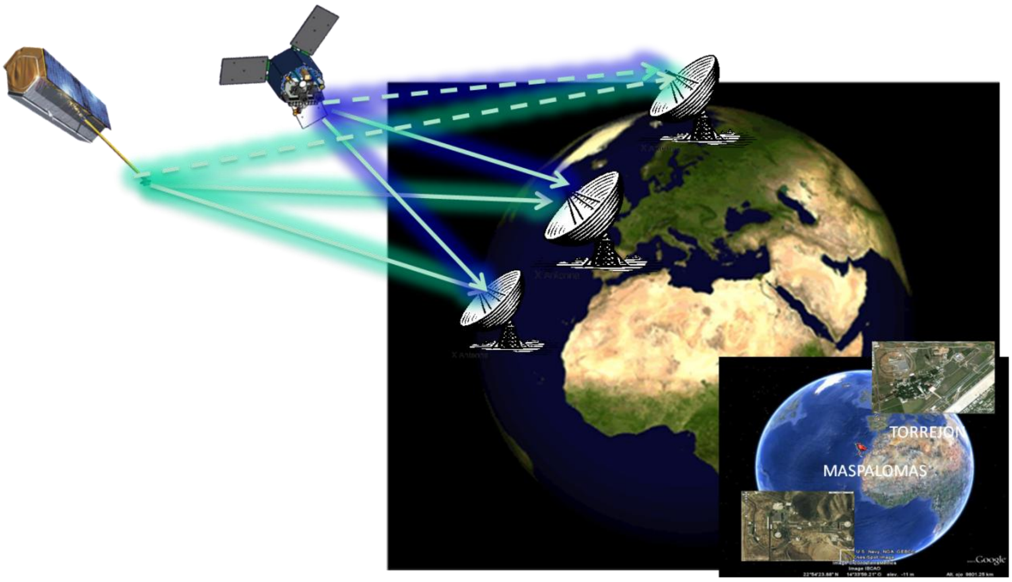
▪ INGENIO Satellite Services



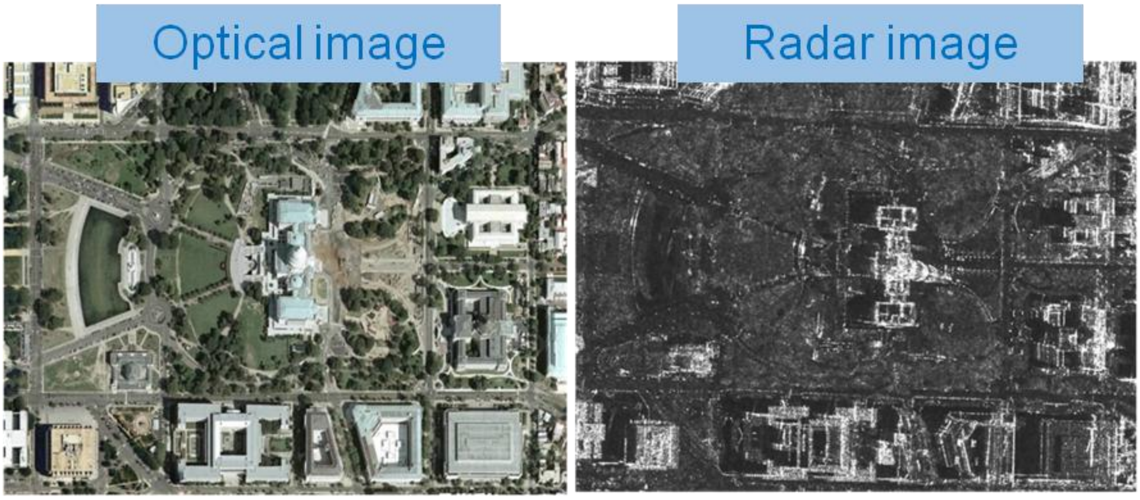
- Optical high resolution multispectral images.
- 1 panchromatic channel and 4 multispectral channels (R, G, B, NIR).
  - Sweeping width: 60 Km
  - PAN resolution: 2.5 m
  - MX resolution: 10m
- > 600 images / day (2.5 million km^2/día).
- Minimum 6 full annual coverage of the Spanish territory (max. 5º).
- Side entry: ± 40°.
- Min revisit time: 3 days (40° angle).
- Life cycle: 7 years.
- Mass: ± 750 Kg.
- Synchronous Helium Orbit. Height: ~ 670 km.
- LTDN ± 10:30 AM.

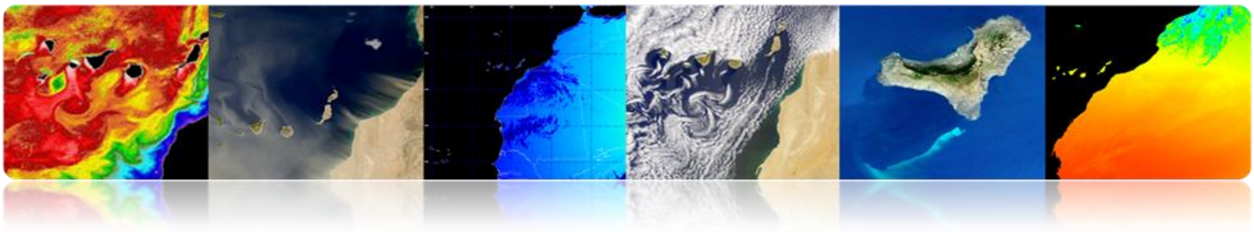


Ground Segment



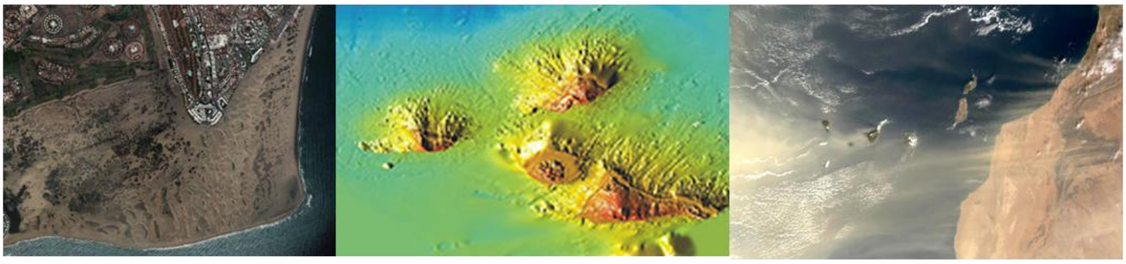
Difference between optical and radar images





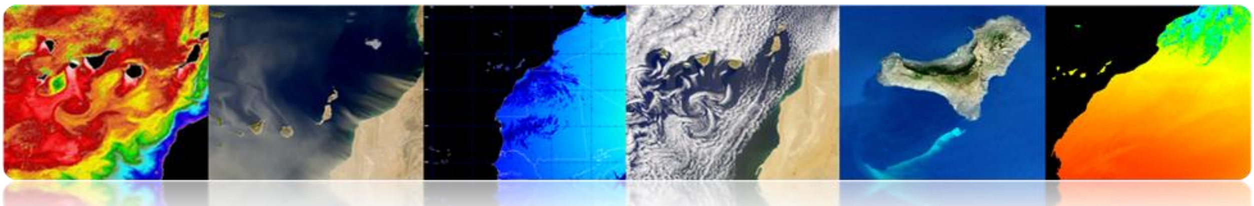
CANARY ISLANDS

PET's main objective in the Canary Islands is to stimulate development of services based on the use of remote sensing data and to promote operational applications and services integrating all existing capabilities.



- Integrate all Canary research groups, agencies and companies related to remote sensing.
- Encouraging the sharing and optimization of remote sensing resources available in the Canary Islands.
- Increase competitiveness and excellence of R & D related to remote sensing.
- Serve as a driving force for the development of new operational applications and services based on the use of remote sensing images.
- Promote the development and creation of technology-based companies.

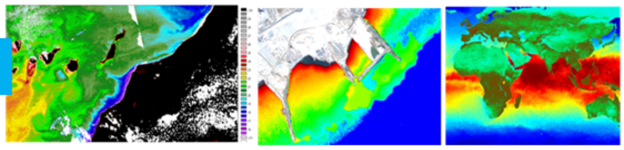
All these objectives aim at consolidating **scientific, technological and industrial** capacity in the field of **Remote Sensing in the Canary Islands**



- **Priority areas**

Field

MARINE



Priority fields

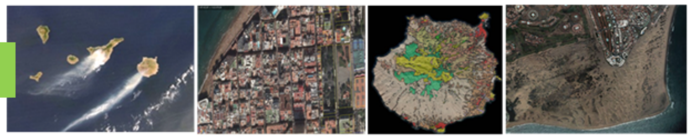
- Oceanography and Fisheries in the Canary Islands using data from remote sensing
- Sea Shore Management and Water Quality in the Canary Islands using data from remote sensing

Working fields

- Physic oceanography: currents, structures, temperature, salinity
- Biological oceanography: chlorophyll, productivity, upwellings
- Fisheries and aquaculture
- Meteorological effects involved: dust, winds
- Weather change, water quality, spilts

Fields

TERRESTRIAL

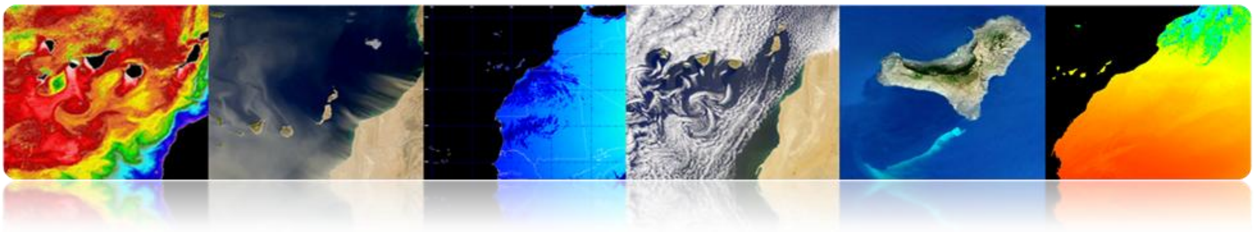


Priority fields

- Environment Protection in the Canary islands using remote sensing
- Prevention and Risk Management in the Canary Islands using remote sensing

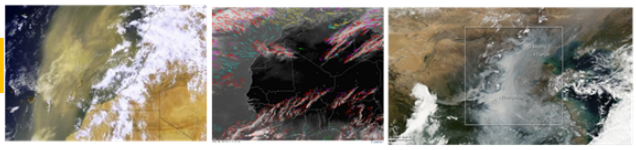
Working fields

- Environment: biosphere reserve, protected areas, dunes, etc.
- Inventory and vegetation and forest control
- Weather change: desertification, deforestation, erosion, etc.
- Vegetation and forest inventory
- Cartography of fuels
- Fires supervision
- Flooding, volcanic activity, etc.
- Maps of risk



Fields

ATMOSPHERIC

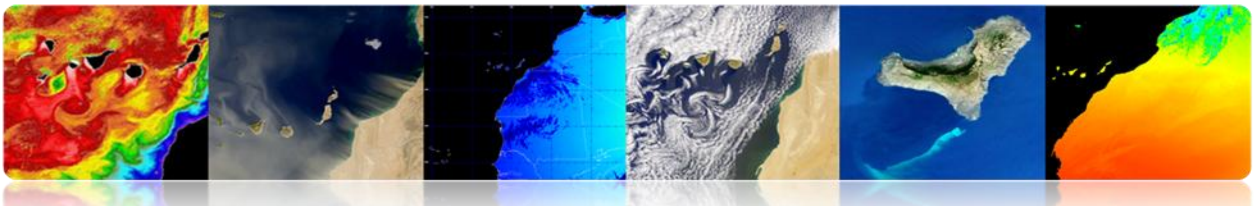


Priority fields

- Meteorology and Air Quality using using data from remote sensing
- Weather change in the Canary Islands using data from remote sensing

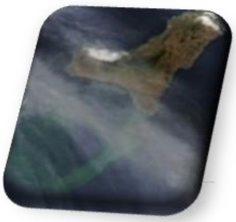
Working fields

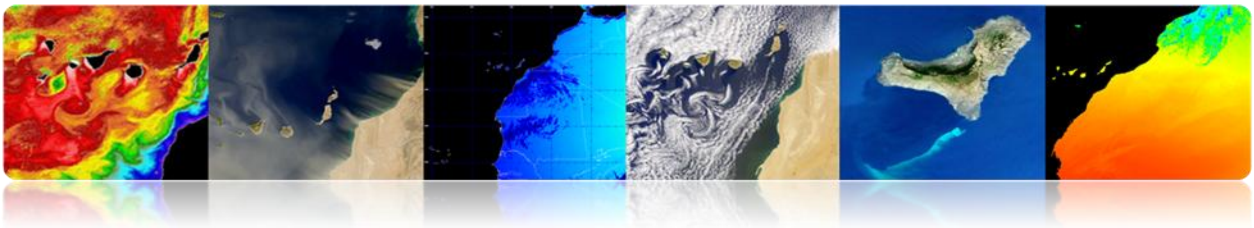
- Study of atmospheric gas.
- Weather forecast
- Prevention of catastrophes (storms, winds, etc)
- Renewable energies (wind, solar)
- Air quality: pollution, aerosols, dust, etc
- Weather change: global heating, rains, wind, aerosols, etc



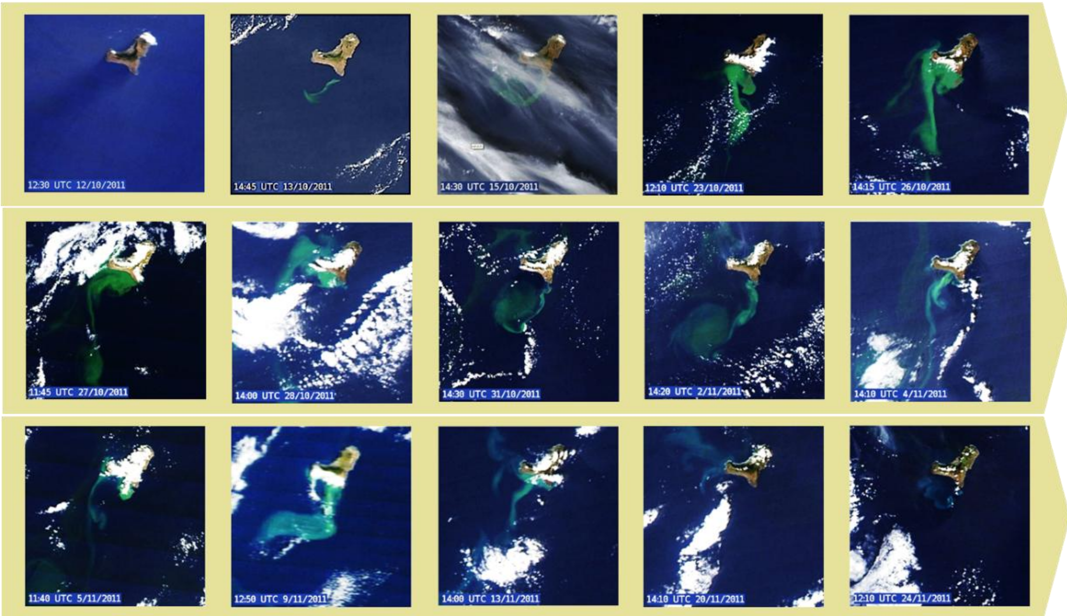
- **Difusion Activities**

El Hierro underwater volcano

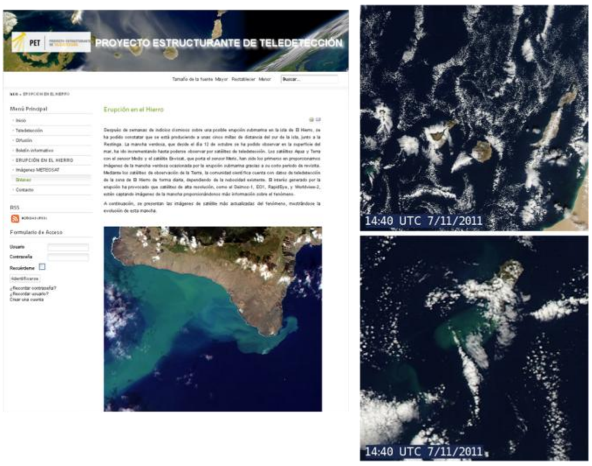


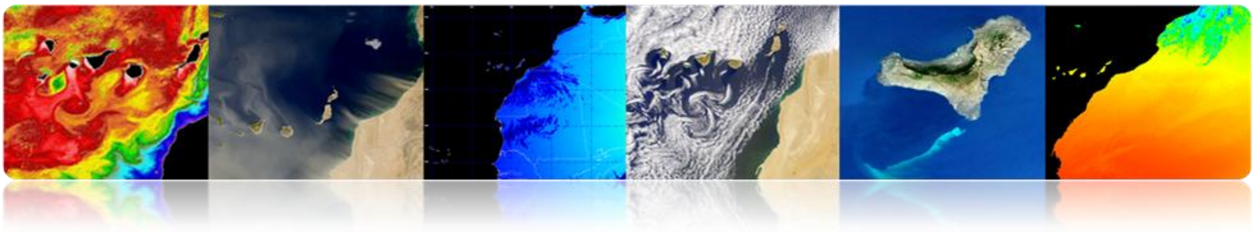


NASA MODIS RGB images multitemporal monitoring El Hierro submarine volcano (October, 2011)



Monitoring and diffusion of information via web submarine volcano: http://www.teledeteccioncanarias.es





Institutions:

- American Society of Photogrammetry and Remote Sensing.
- NASA Centers: Gooddard Space Flight Center, Ames Research Center, Jet Propulsion Laboratory (JPL).
- NOAA-National Oceanographic Administration Agency.
- Canadian Center for Remote Sensing.
- Remote Sensing Society: NRSC, UK.
- Centre National d'Estudes Spatiales CNES, France.
- Institute for Aerospace Survey and Earth Sciencies: ITC, Netherlands.
- Institute for Remote Sensing Applications, Ispra, EU.
- Spanish Association of Remote Sensing, …

University Departments:

- Environmental Research Institute of Michigan.
- Laboratory for applicatios of Remote Sensing, Purdue University, Indiana.
- Remote Sensing Unit, University of California, …

Specialized Magazines:

- IEEE Transactions on Geoscience and Remote Sensing.
- International Journal of Remote Sensing.
- Photogrammetric Engineering and Remote Sensing.
- Remote Sensing of Environment.
- Remote Sensing Reviews, …

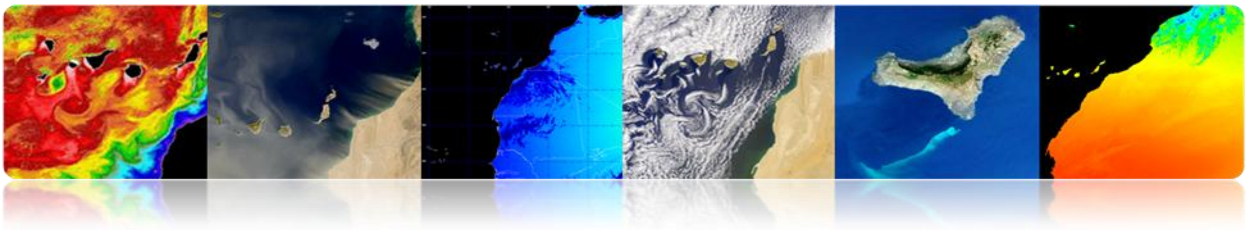
International Conferences:

- IGARSS.
- American Society of Photogrammetry and Remote Sensing.
- Remote Sensing Society.
- European Signal Processing.
- IASTED, …

Websites:

- http://www.itn.nl/ ~ bakker / noaa.html (NOAA).
- http://www.gsfc.nasa.gov/SEAWIFS.html (NASA-SEAWIFS).
- http://www.sat.dundee.ac.nk/ (Est. of Dundee, Scotland).
- http://www.eumetsat.de/eu/ (EUMETSAT).
- http:// www.eurimage.it/ (Eurimage), …

2. Sensors and Space Remote Sensing Missions



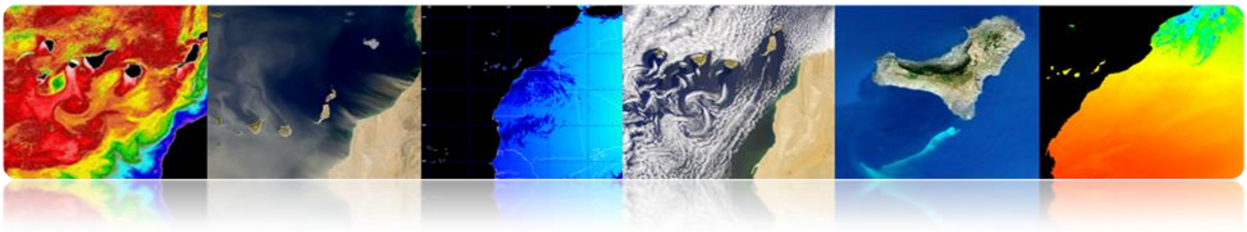
Introduction

In order to meet the needs of different data users, there are many remote sensing systems providing a wide range of spatial, spectral and temporal parameters. Some users may require frequent coverage with relatively low spatial resolutions (meteorology). Other users may want the highest possible spatial resolution with coverage repeated only infrequently (mapping), while some other users may need very high spatial resolution and frequent coverage in addition to a quick access to the images (military surveillance). Remote sensing data also can be used to initialize and validate large computational models, such as global climate models (GCMs), in order to simulate and predict changes in the Earth's environment. In this case, it may not be necessary to achieve a high spatial resolution due to computational requirements and it would be essential to accurately and consistently calibrate the sensor in space and time.

Wide range of spatial, spectral and temporal parameters

The unavoidable and unstoppable technological progress occurred over the last few years has led to the emergence and continuous improvement of on-board sensors on space platforms. Their spatial, spectral, radiometric and time resolutions have been improved resulting in a higher level of detail, accuracy and amount of information that enables the use of these images in new application areas.

Thus, each day the Earth is observed by a constellation of satellites. They are our eyes in space. These satellites are built and put into orbit by Space Agencies and International Organizations and they provide valuable information to help us to achieve a better understanding of our planet and to study the effects of human action on the environment. The conditions of life on Earth may be improved with these data.



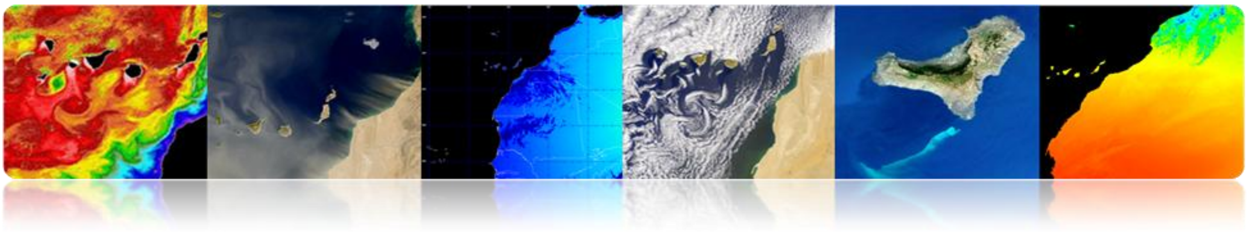
This chapter examines the operation of devices that capture remote sensing images and the platforms that support them. It pays special attention to the different types of remote sensing satellites. The last part of this chapter is dedicated to review the characteristics of remote sensing space missions more interesting at this point to the context of this project TELECAN. Spatial remote sensing missions are designed and put into orbit so quickly that this TUTORIAL TELECAN must necessarily be updated regularly, using the information available from different space agencies.

The objectives of this chapter are:

- Distinguish between sensors and space platforms;
- Know the main types of sensors used in remote sensing;
- Discriminate spatial, spectral, radiometric and temporal information from spatial-temporal characteristics of the sensors and space platforms;
- Understand the operation of satellites;
- Study the orbits of the satellites and the physical laws that govern them;
- Know the characteristics of the main space missions to observe the Earth.

CONTENTS

Sensors and Space Remote Sensing Missions



2.1. SENSORS AND PLATFORMS

❑ SENSORS

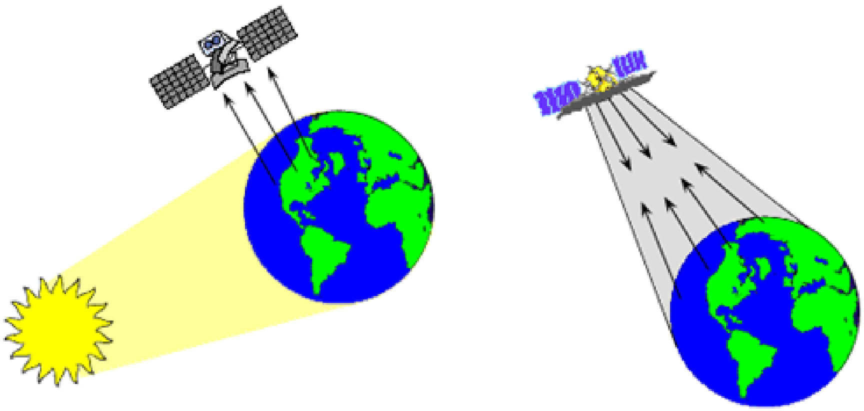
- **Systems used for the acquisition of the radiation emitted or reflected.**
  - Payload in space-based remote sensing systems.
  - Conversion of radiance in digital levels.

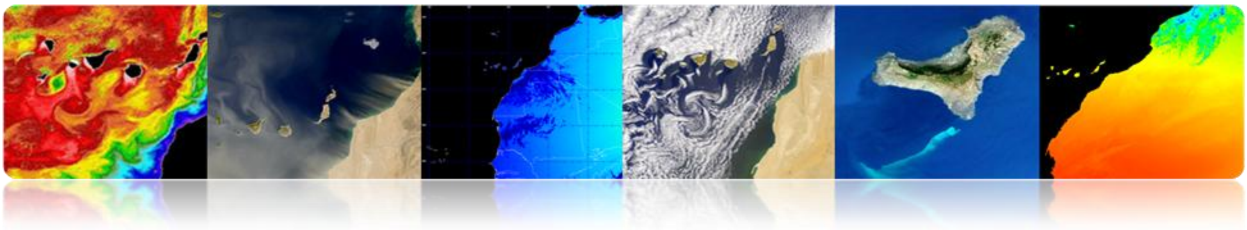
- **Classification**

1. **According to the radiation source:**

➢ **Passive sensors:** No light at the target, limited to receiving the energy emitted or scattered by the target.

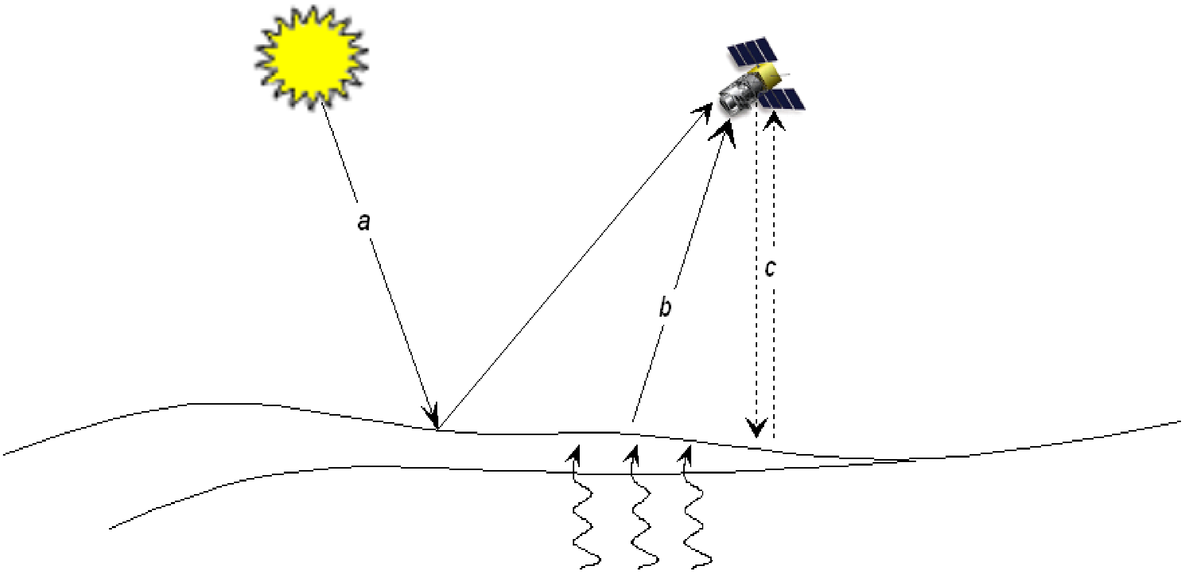
➢ **Active sensors:** Provide their own source of electromagnetic radiation.



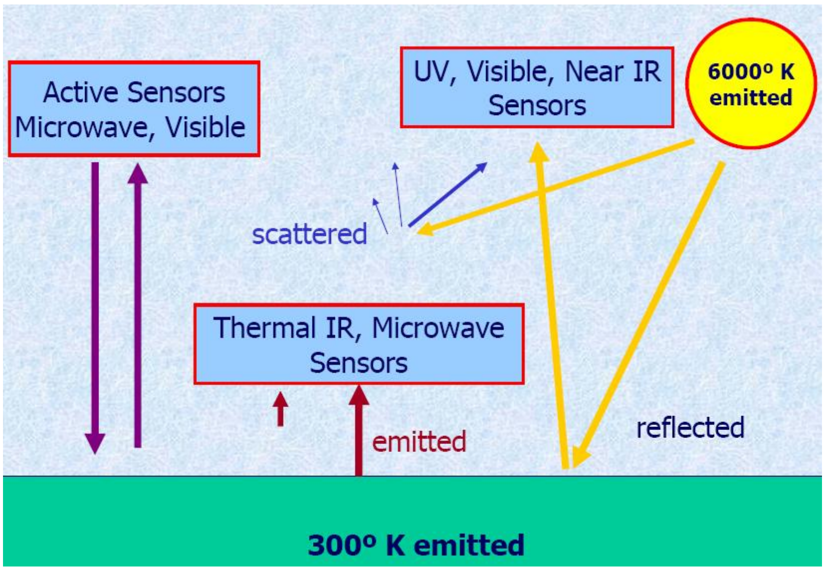


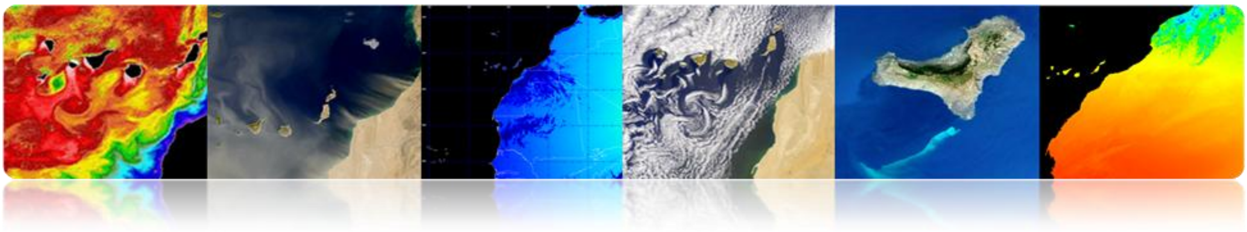
➢ **Remote Sensing forms**→ Methods of acquiring information by a remote sensor:

- Reflection (a).
- Emission (b).
- Emission-reflection (c).



2. Depending on the region of the spectrum used:

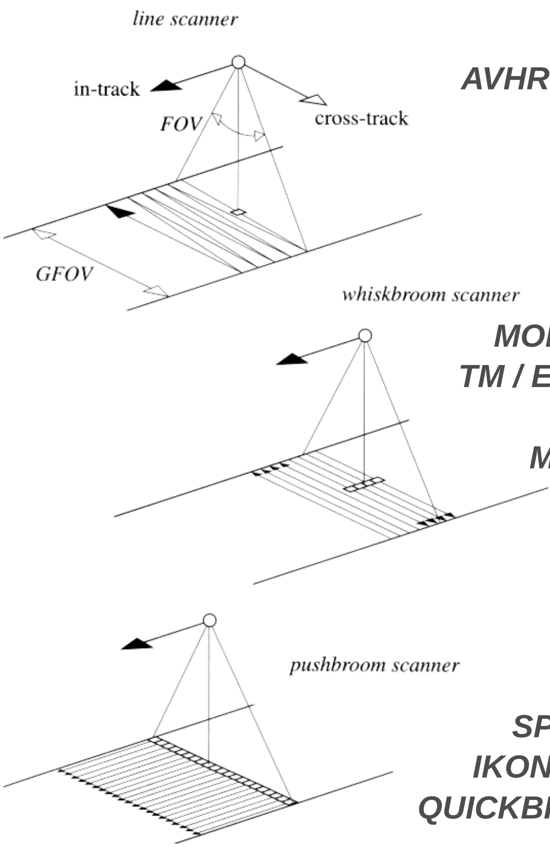




➢ Electro-optical sensors: Visible and IR

Scanning Technologies

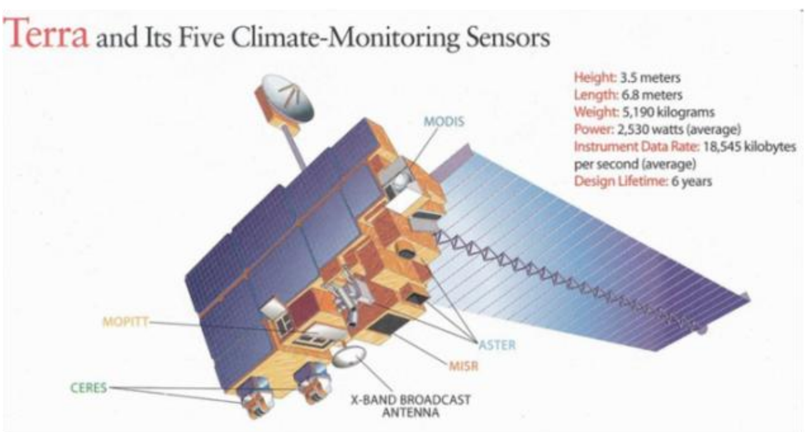
- Line scanner
- Wiskbroom scanner
- Pushbroom scanner

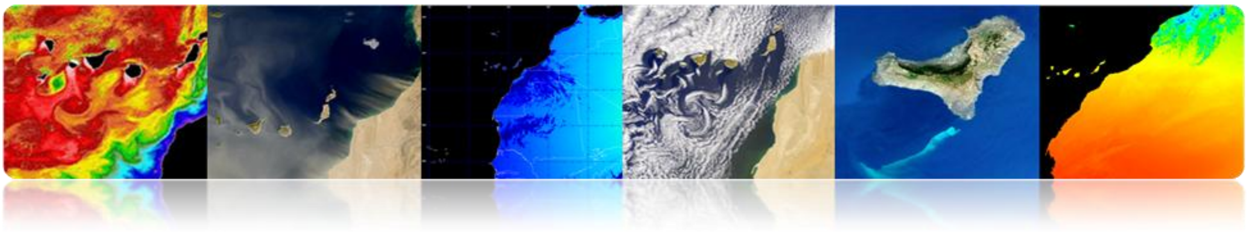


AVHRR

MODIS
TM / ETM
+
MSS

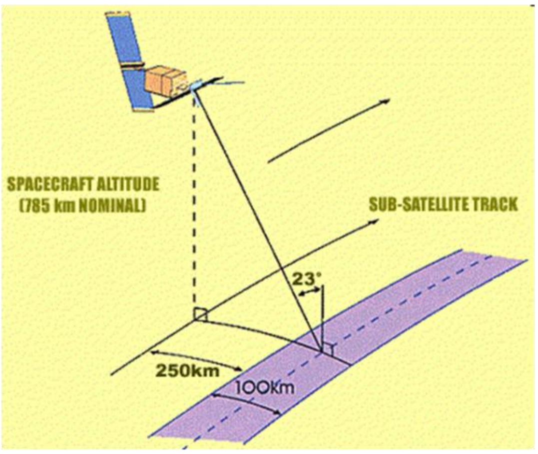
SPOT
IKONOS
QUICKBIRD

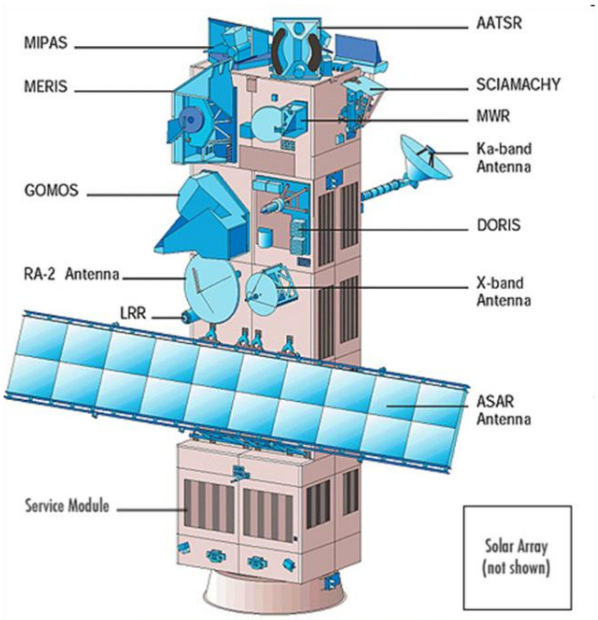




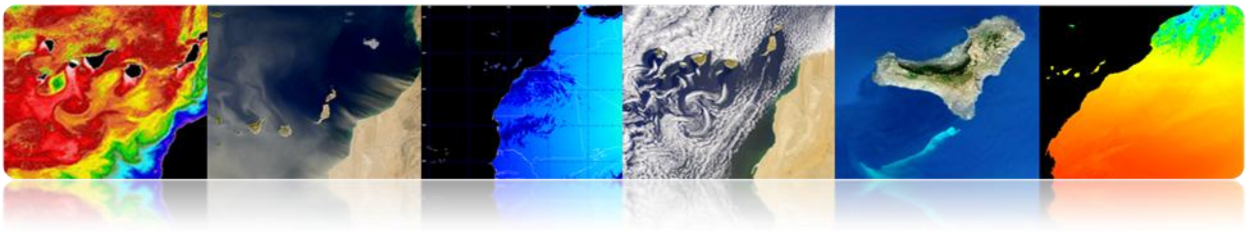
➢ Microwave sensors

- **Passive:** Microwave Radiometer
- **Active:**
  - SAR
  - Radar Altimeter
  - Wind scatterometer





http://envisat.esa.int/instruments/tour-index/



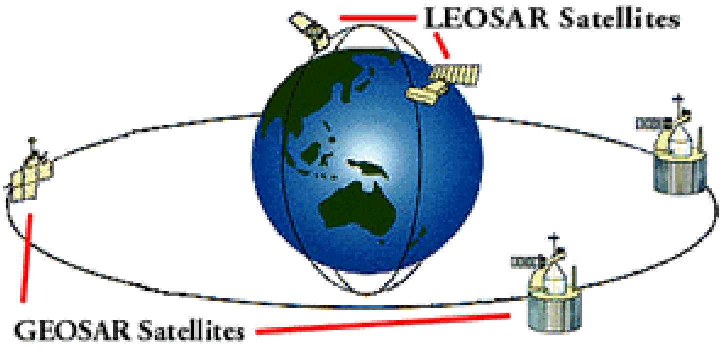
❑ PLATFORMS

- **Platforms at short distances**
  - **Instrumentation radars:** measure the reflectivity of objects and surfaces.
  - **Tomographic systems:** have biomedical and industrial applications.

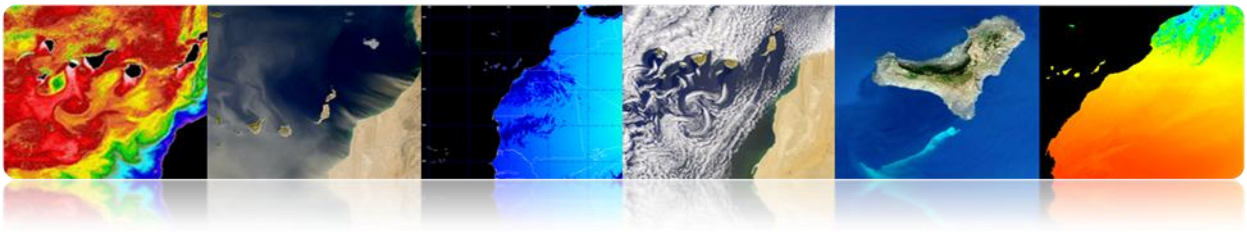
- **Platforms at large distances: satellites, planes / helicopters.**
  - **Considerations:**
    - ✓ Planes achieve a higher spatial resolution.
    - ✓ Satellites have a higher temporal resolution and coverage.
  - **Factors for the selection of a platform:**
    - ✓ The extension of the area to be covered.
    - ✓ The speed of development of the phenomena observed.
    - ✓ The functional characteristics of the instruments and sensors.
    - ✓ The availability and cost of data.

- **Parallelism**

Satellites describing a polar orbit (500-1000 km) or low altitude and geostationary satellites (36,000 km).



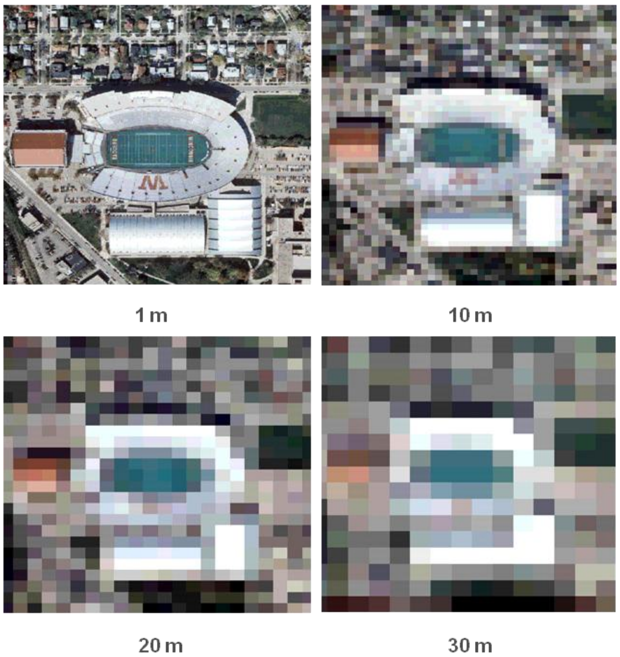
Images of different types of remote sensing platforms

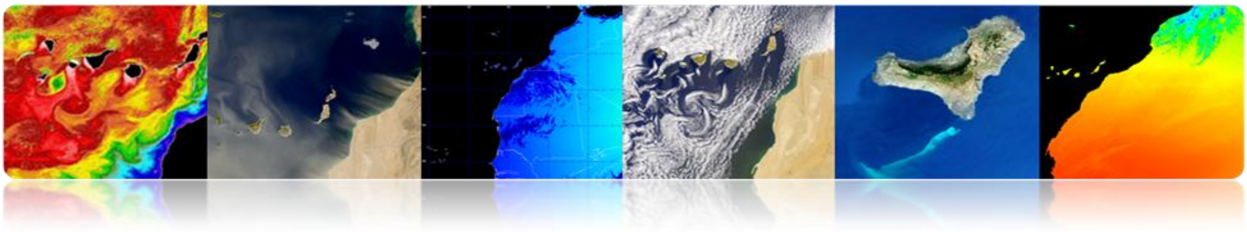


2.2. Resolution Sensors

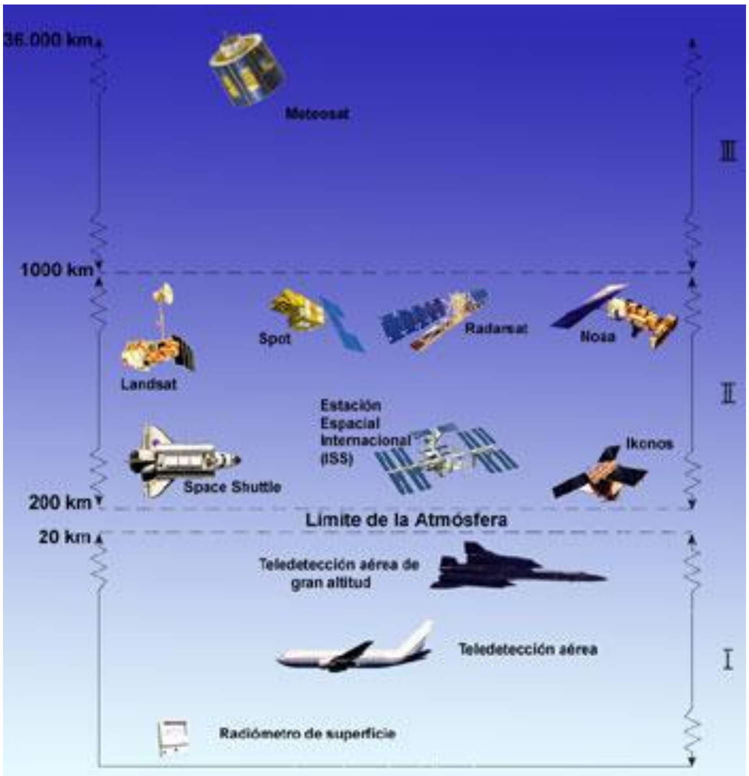
❑ Spatial Resolution

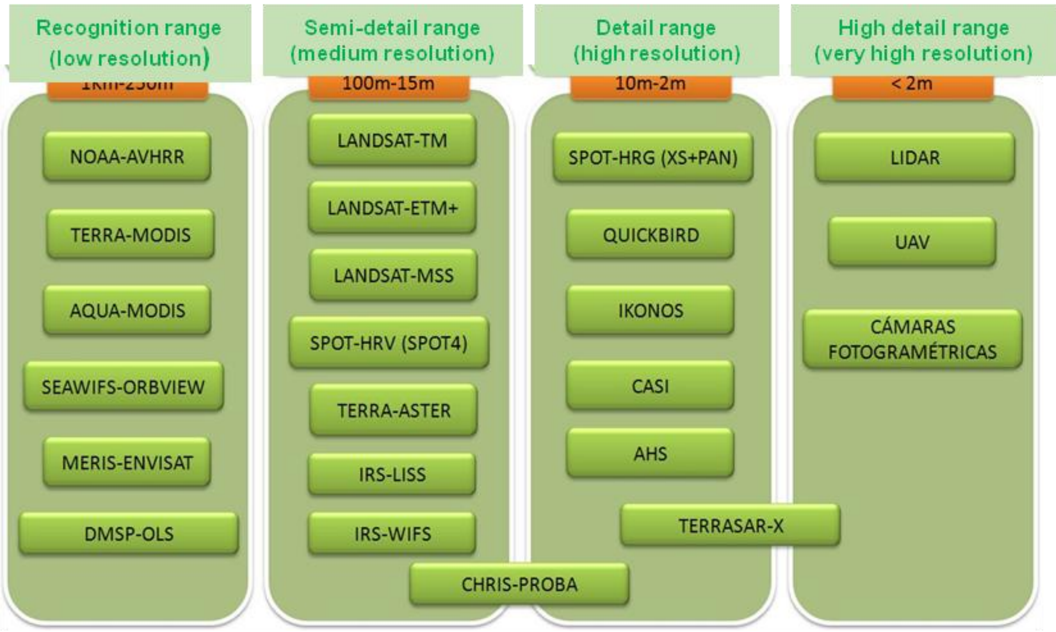
- It specifies the size of the pixel of the remote sensing image.
- Lowest distance between objects that can be solved by the sensor.
  - High spatial resolution: 0.5 - 4 m
  - Medium spatial resolution: 4-30 m
  - Low spatial resolution: 30-1000 m

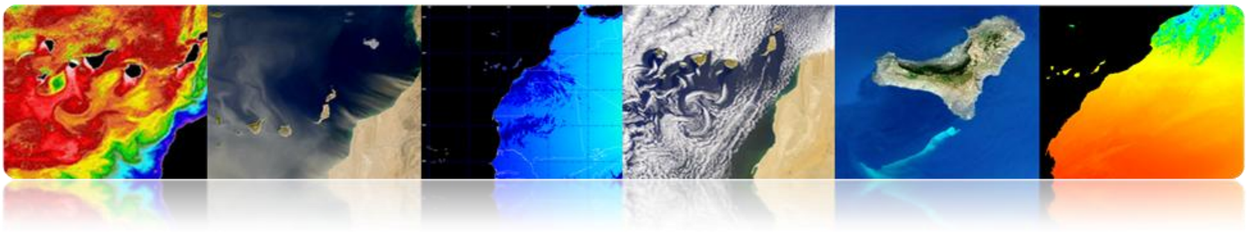




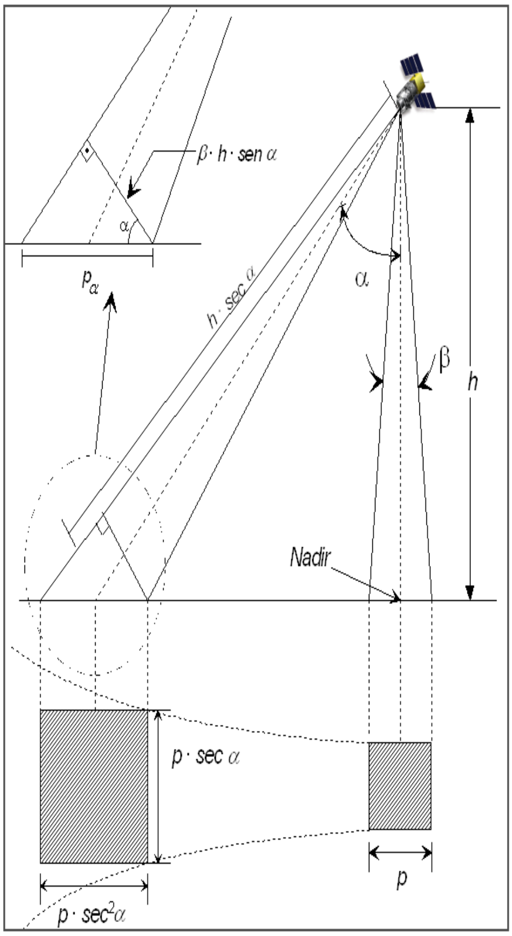
- **Spatial resolution scales:** Decreasing in resolution with the height of the scanning sensor.







- **Spatial resolution variation with the angle of observation of the sensor:** Effective size of the pixel on the Earth (GIFOV) is bigger at the extremities of the field of view than in the nadir.



AVHRR

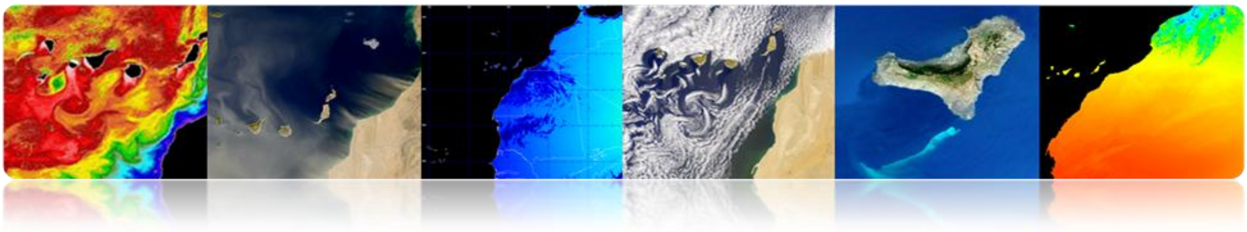
NADIR: 1.1 * 1.1 Km.

BORDE (55º): 6.5 * 2.4 Km.

QUICKBIRD

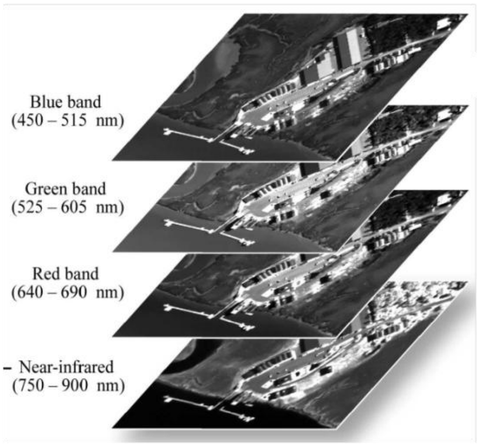
NADIR: 0.61 m (P), 2.44 m (M)

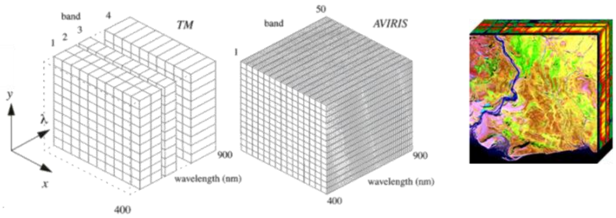
25º OFF-NADIR: 0.72 m (P), 2.88 m (M)

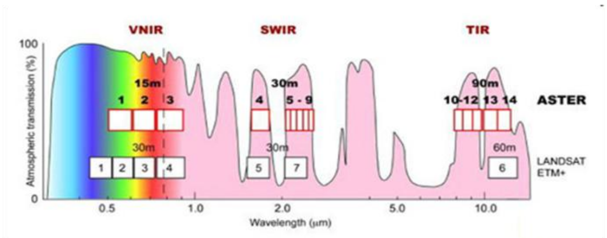


❑ SPECTRAL RESOLUTION

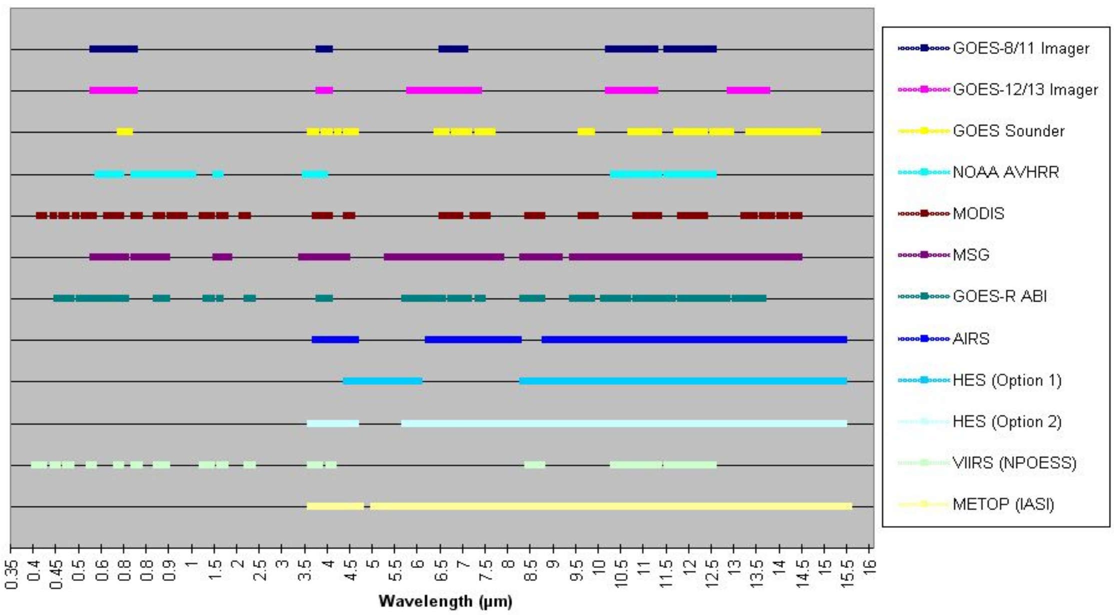
- Specifies the number of spectral bands in which the sensor can capture radiation.

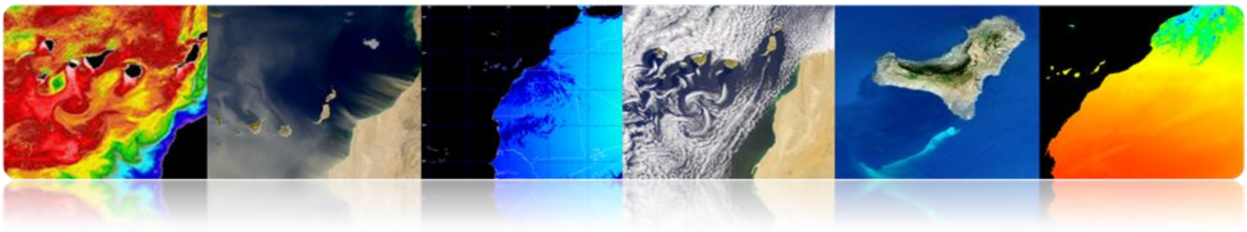






- The number of bands is not the only important aspect of spectral resolution: it is also essential the position of the bands in the electromagnetic spectrum.





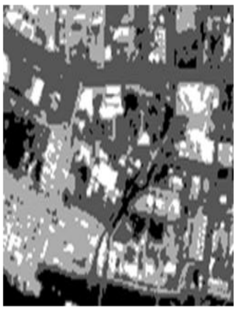
❑ Radiometric Resolution

- It is the sensitivity of a detector to variations in the intensity of the emitted, reflected or scattered electromagnetic energy that is being detected.

- Different levels of intensity that may be discriminated by the sensor within a band.

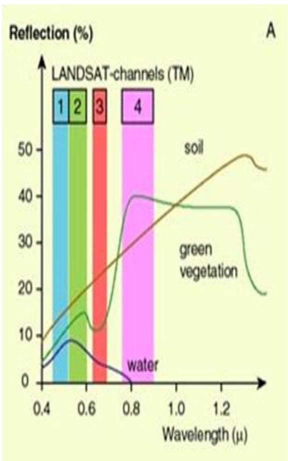
8 bits (256)

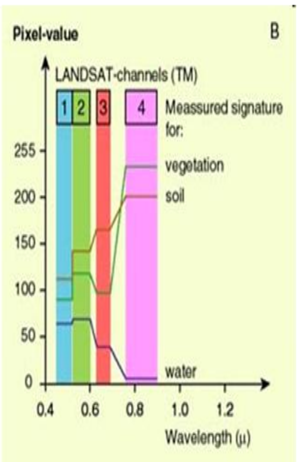
4 bits (16)

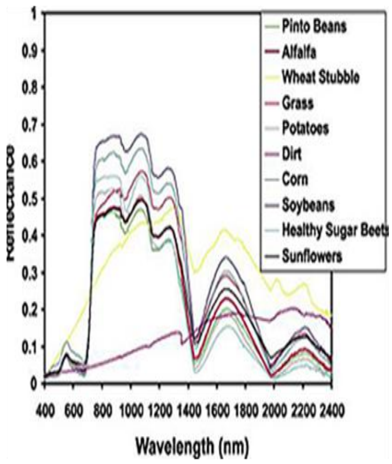


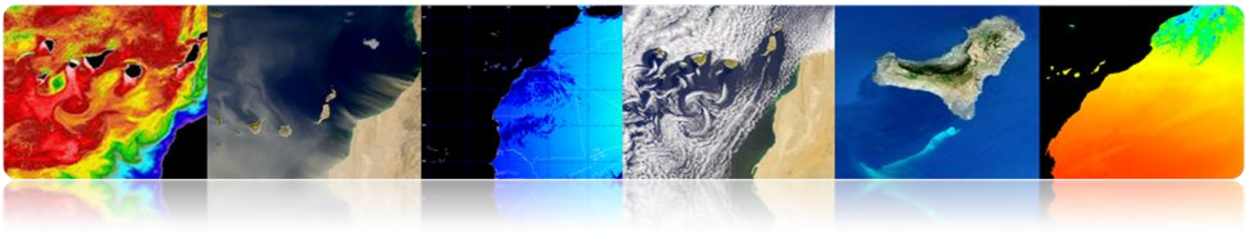
2 bits (4)

1 bit (2)









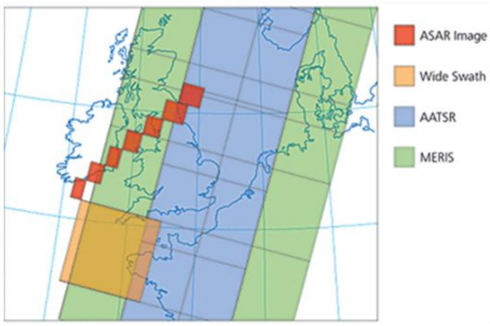
❑ TEMPORAL RESOLUTION

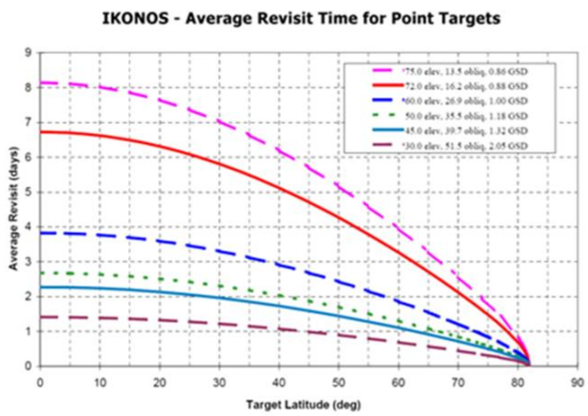
➢ It specifies satellite revisit frequency to a specific location (It depends on the latitude and the width of the swath).

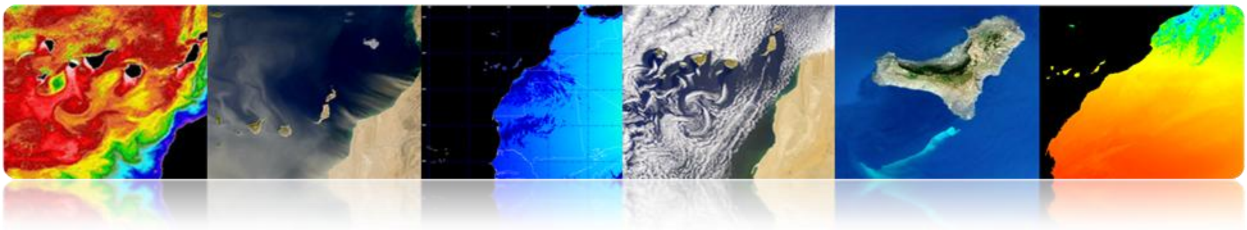
➢ Time is important when:

- ✓ Persistent clouds offer limited direct view of the surface of the Earth.
- ✓ Short-term phenomena (floods, oil spills, ...).
- ✓ Rapidly changing phenomena (atmospheric).

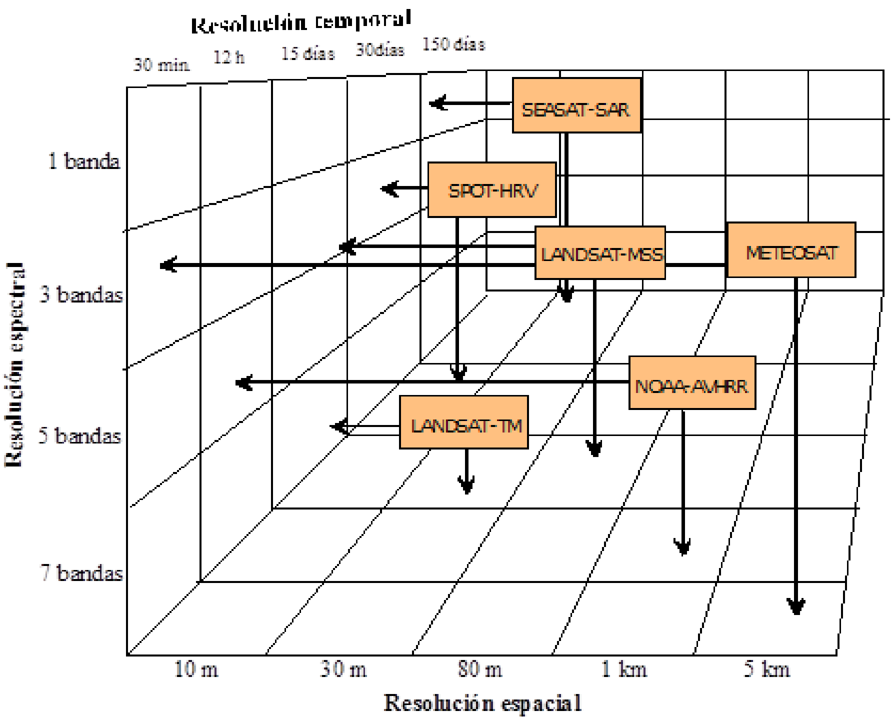
  - High temporal resolution: <1 day - 3 days
  - Medium temporal resolution: 4 - 16 days
  - Low temporal resolution:> 16 days

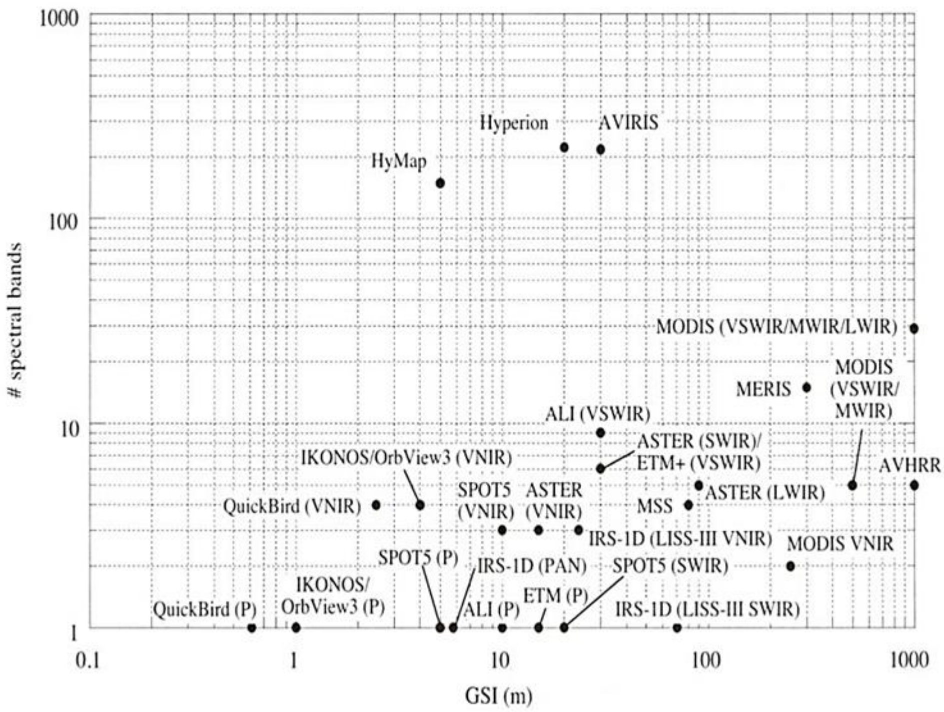






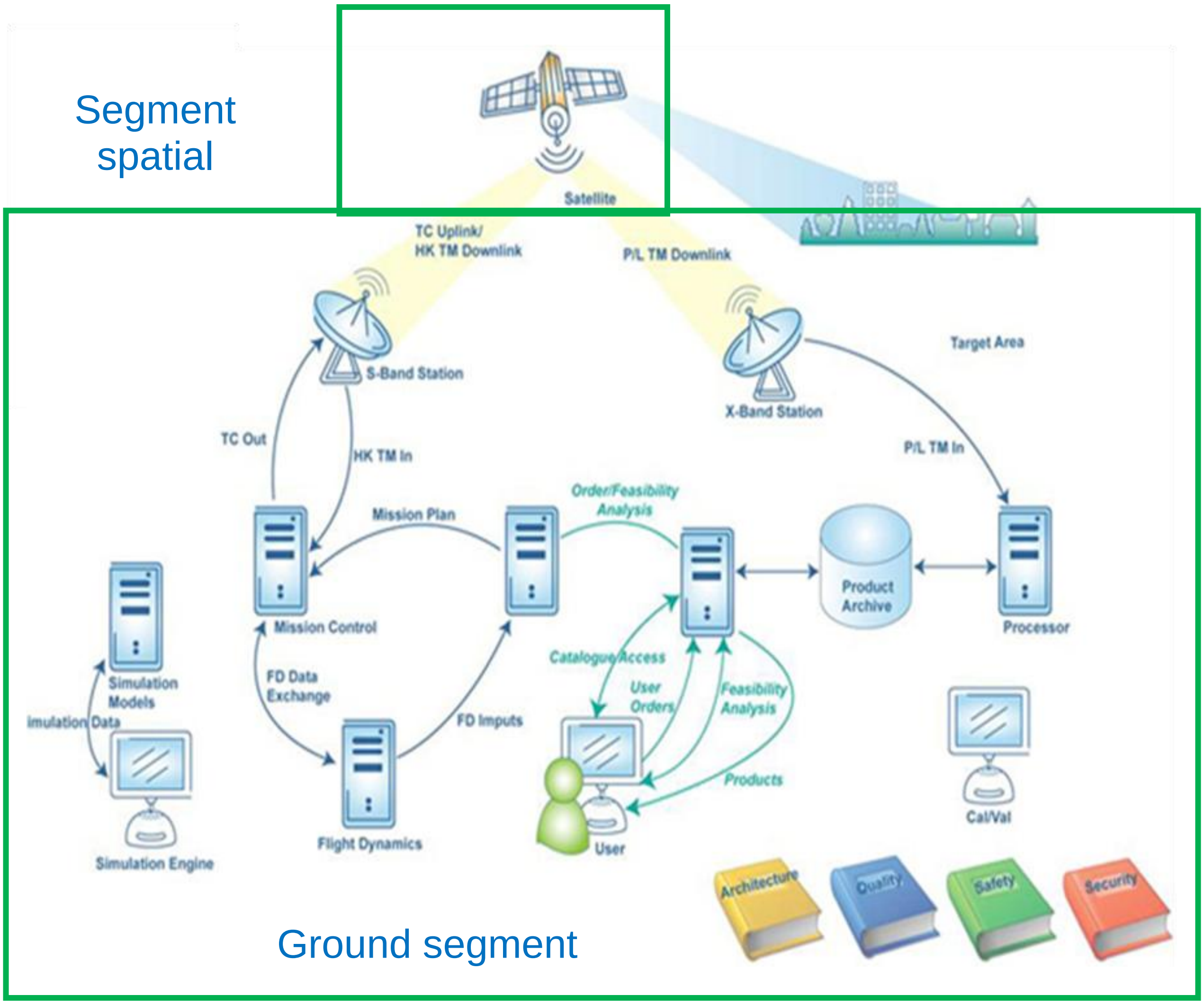
Relationship between all types of resolutions: Commitment

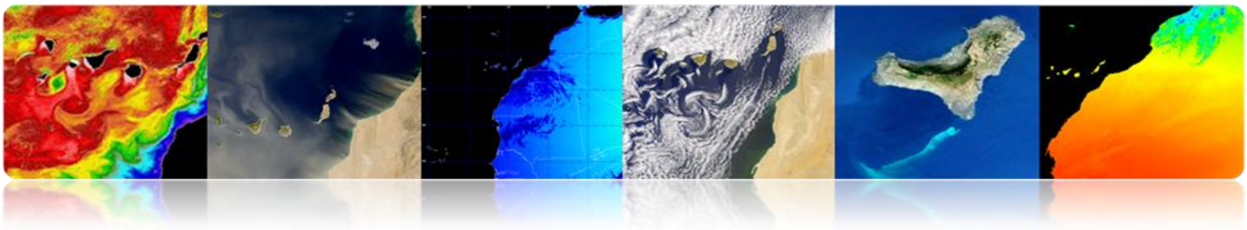




2.3. REMOTE SENSING SPACE SYSTEMS

Remote Sensing Space System Elements





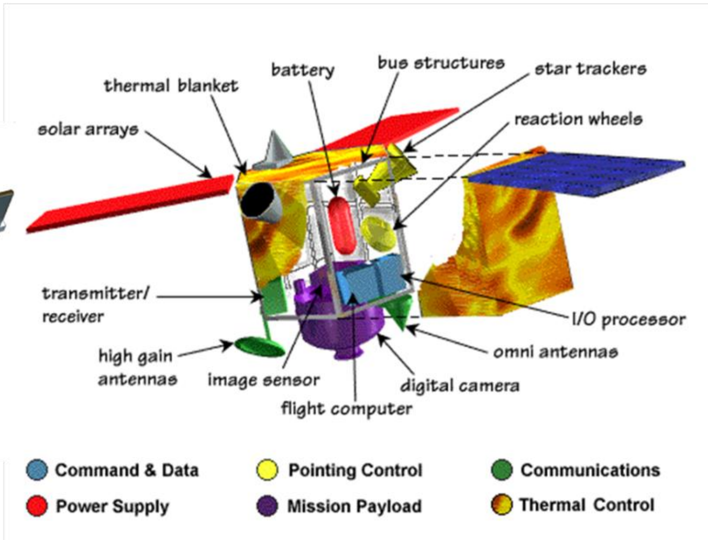
❑ SPACE SEGMENT

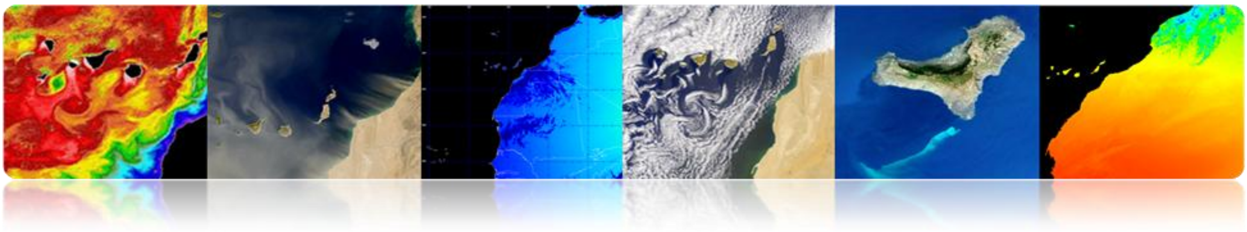
➢ **Satellite:** System placed in orbit for providing a particular application.

- **Space Platform:**
  - Attitude control.
  - Propulsion.
  - Electric Power.
  - TT & C (Tracking, Telemetry & Command).
  - Thermal Control.
  - Mechanical.

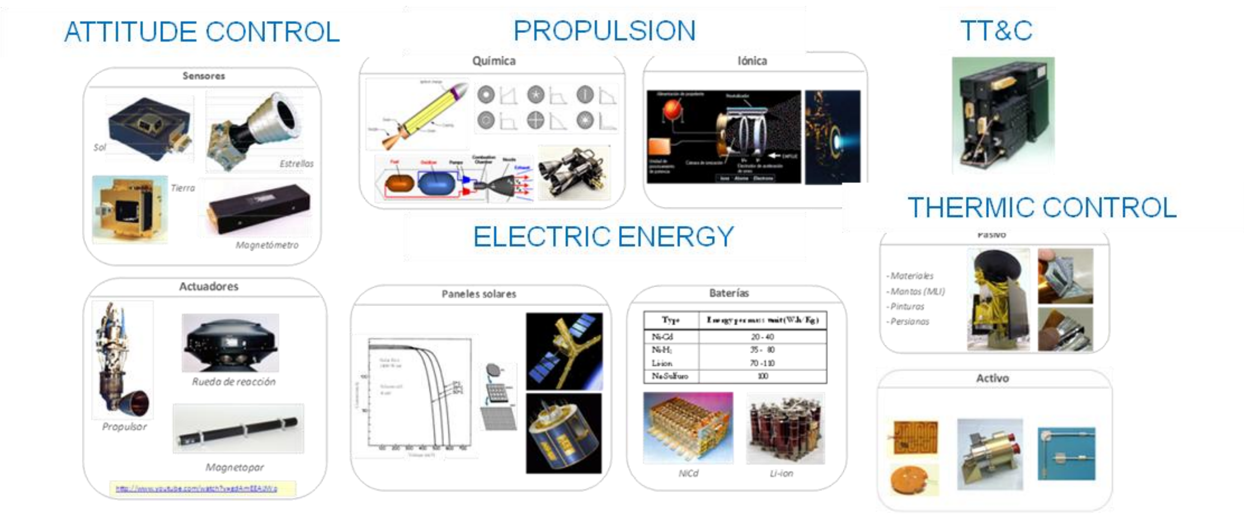
Remote Sensing Satellite Subsystems

Ikonos

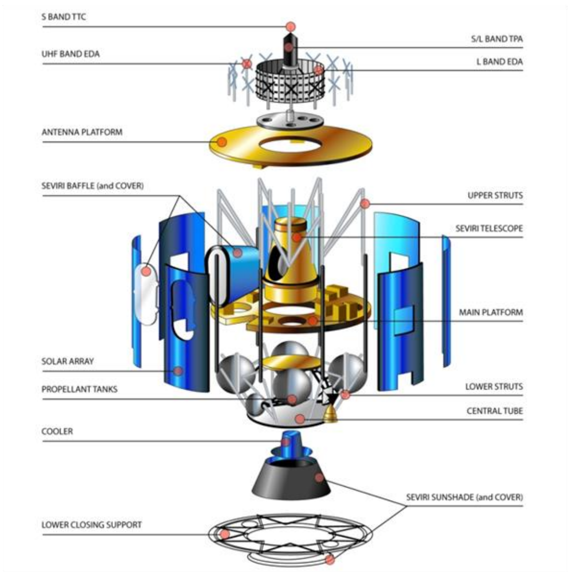


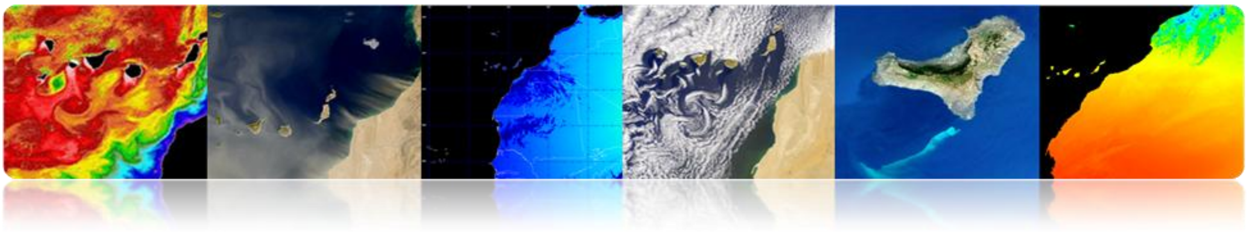


Different Space Platform Subsystems

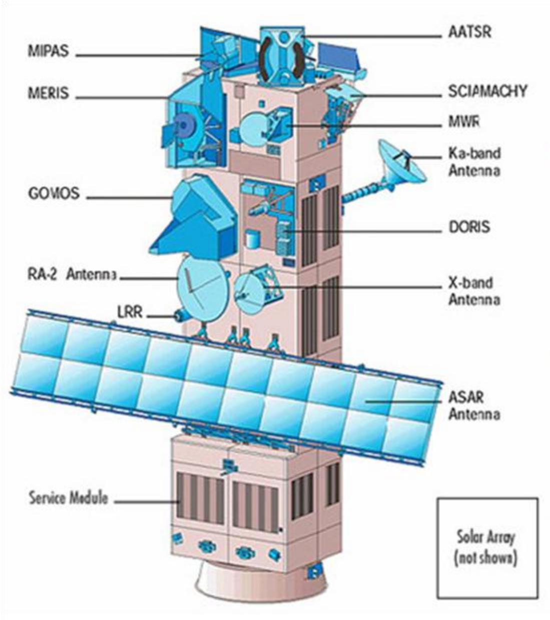


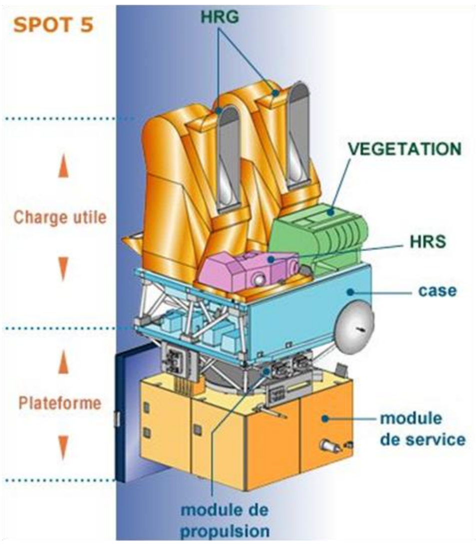
Structure

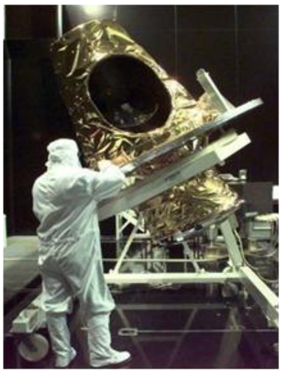




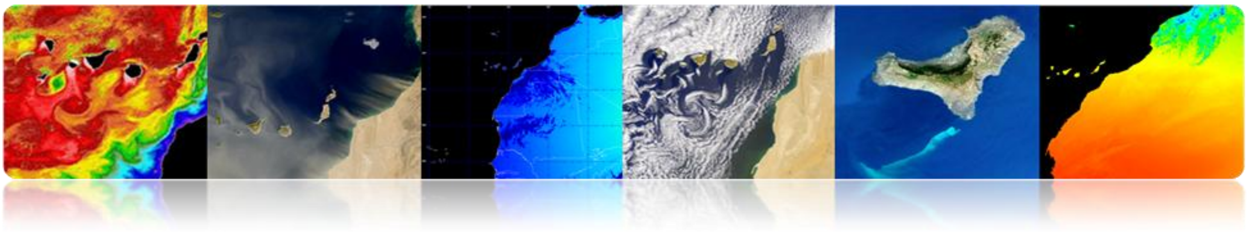
- **Payload:** Equipment designed to meet the specific application.







HRG TM SEVIRI

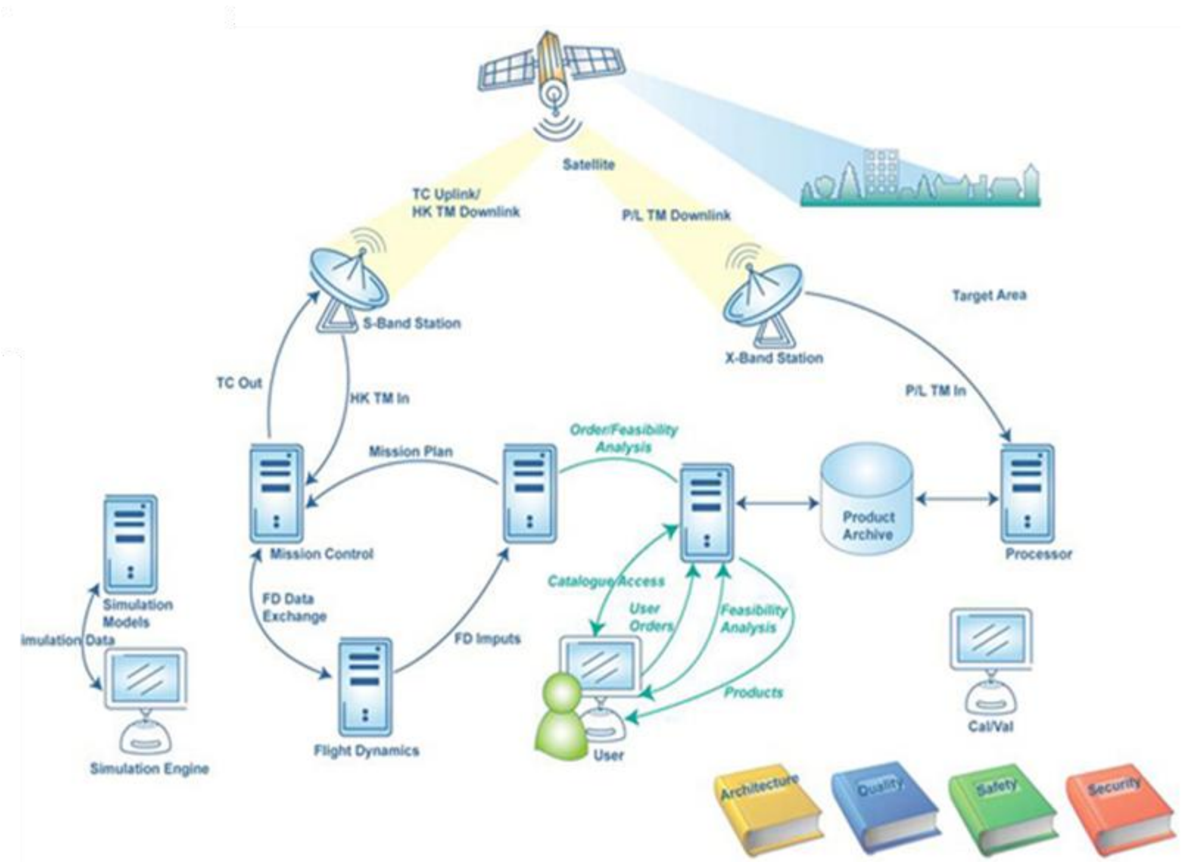


❑ GROUND SEGMENT

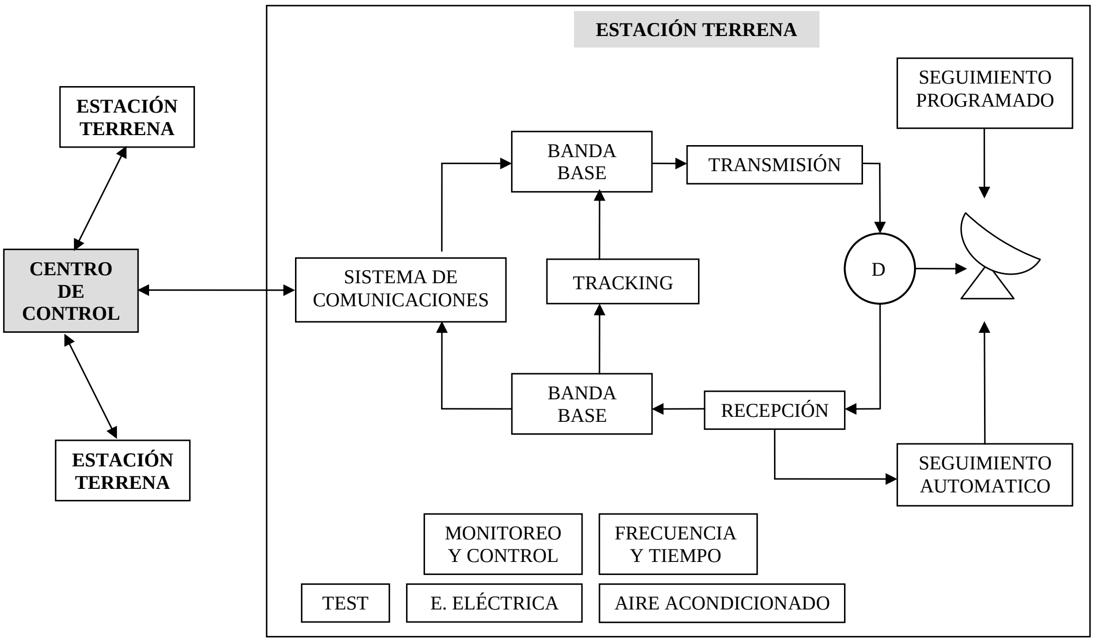
➢ **Architectures**

- **Flight Operation Segment → Satellite**
  - TT & C earth stations.
  - Control Centers.

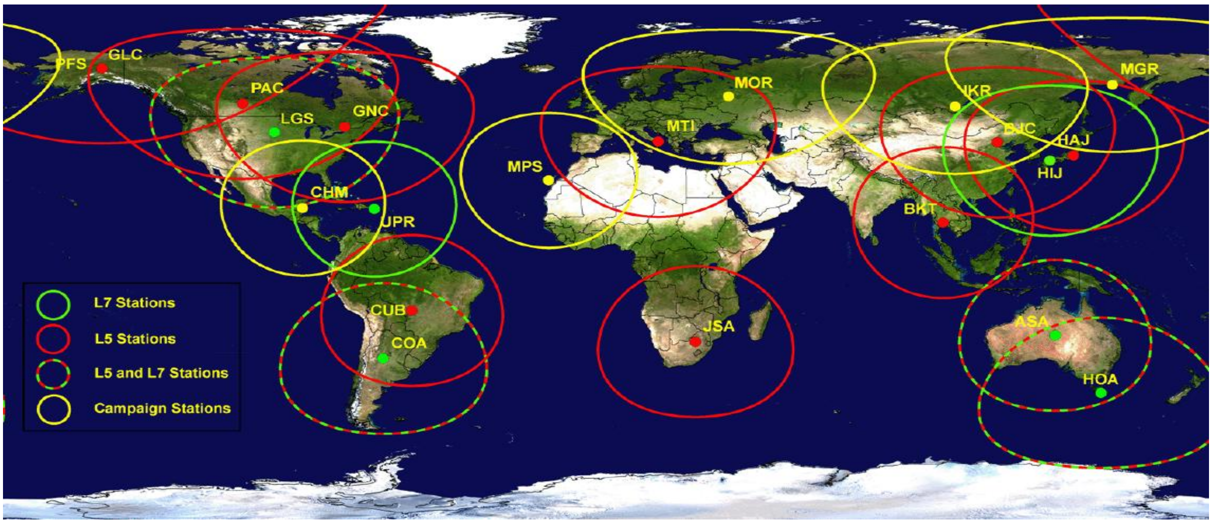
- **Payload Data Segment → Data**
  - Reception Stations.
  - Processing and Archive Centers.
  - Topic Centres.

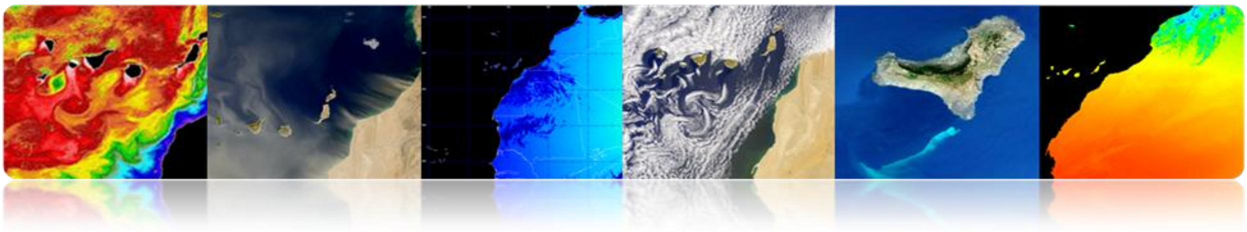


Block diagram of Earth station and TTC



Landsat 5 & 7 Space Program Stations





Examples of Earth Stations

2.4. ORBITAL PARAMETERS: TYPES OF ORBITS

❑ ORBITAL MECHANICS

- An orbit is the trajectory described by a spatial body around the Earth.

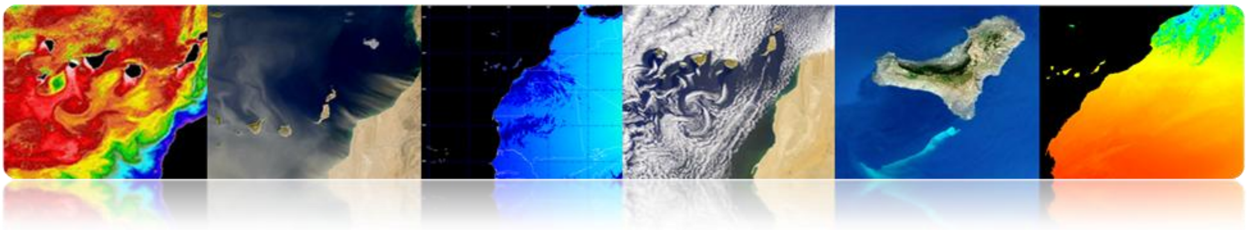
- The motion of the satellite around the Earth is mainly determined by the force of attraction between two bodies.

- Newton postulated that the attractive force was proportional to the masses and inversely proportional to the square of the distance between them.

$$F = GM\frac{m}{r^2}$$

where:

G = 6.672 10-11 $m^3Kg^{-1}s^{-2}$ (Universal Gravitational Constante).
M = 5.974 x 10^{24} kg (mass of the Earth).



➤ Cartesian Parameters

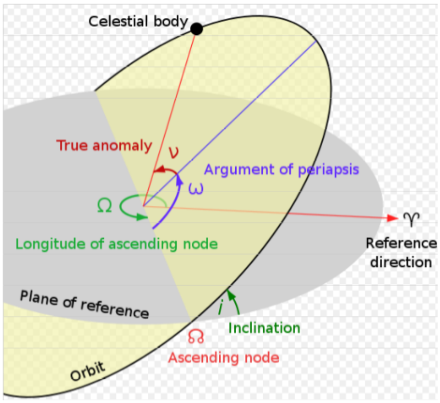
They describe the movement of the orbit using position and velocity vectors at a given time (epoch). It is fully defined with 6 parameters -3 position and 3 speed parameters.

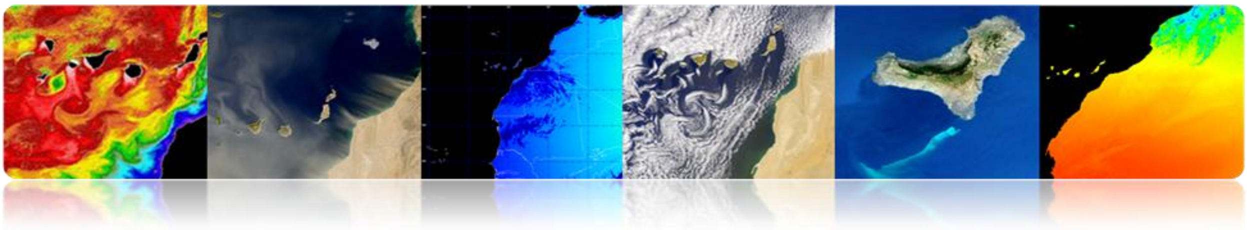
Space Shuttle STS66	
EPOCH 11/09/94 13:00:06.210 GMT	
X : -410.1438489632090 Km	Vx: -6.009935717301647 Km/s
Y : 333.6855095962104 Km	Vy: -1.961230487490145 Km/s
Z : -406.9395999999989 Km	Vz: 4.448585999999987 Km/s

➤ Keplerian parameters

Information on the size, shape and orientation of the orbit in a specified point in time.

Describe	Elemento	Símbolo
Tamaño de la órbita	Semi-eje mayor (Mean motion)	a
Forma de la órbita	Excentricidad	e
Orientación de la órbita	Inclinación	i
	Longitud del nodo ascendente	Ω
	Argumento del perigeo	ω
Posición del satélite	True anomaly (Mean anomaly)	ν

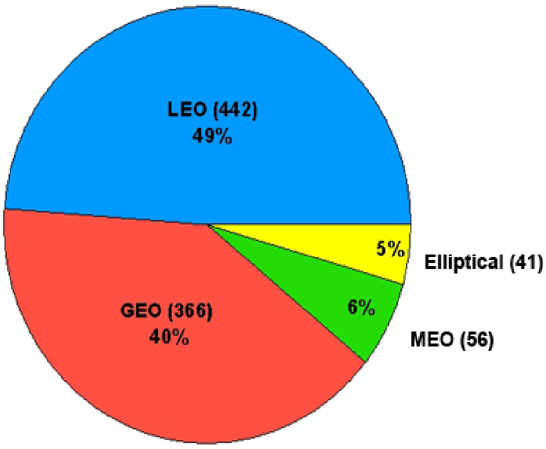




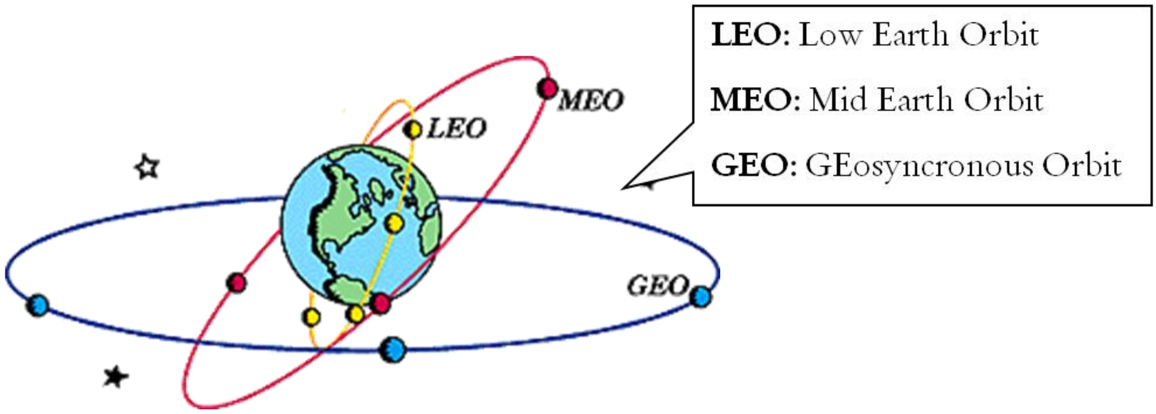
Types of Orbits

- Each space MISSION requires a specific orbit.

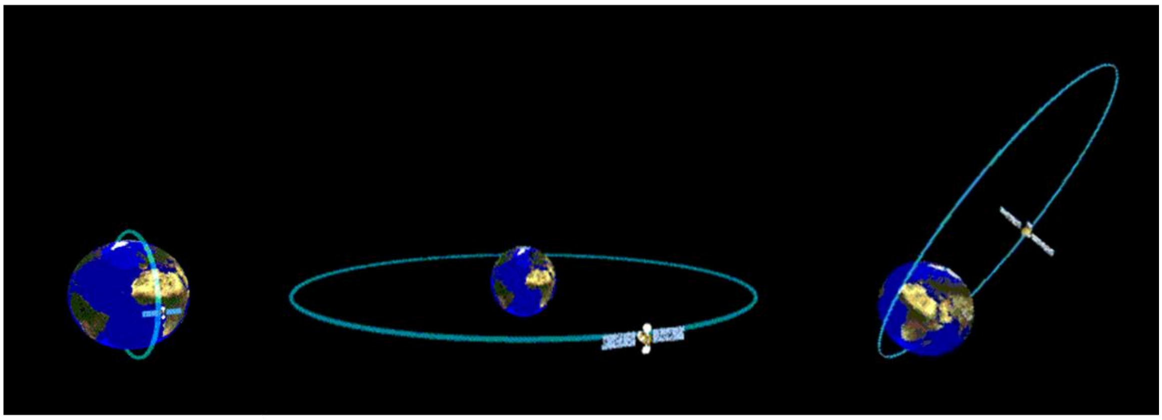
Mission	Type of orbit	Altitude	Period	Tilt
Communications Meteorological	Geostationary	35,786 Km (GEO)	24 hours	0 °
Earth Resources	Polar-synchronous	150-900 Km (LEO)	90 minutes	95 º
Navigation (GPS)	Semi-synchronous	20,230 Km (MEO)	12 hours	55 °
Space shuttle	Low orbit	300 Km	90 minutes	28.5 º or 57 º
Communication Intelligence	Molniya	Perigee: 7971 Km Apogee: 45,170 km	12 hours	63.4 º



➢ **Circular** LEO, MEO, GEO



➢ **Elliptical**

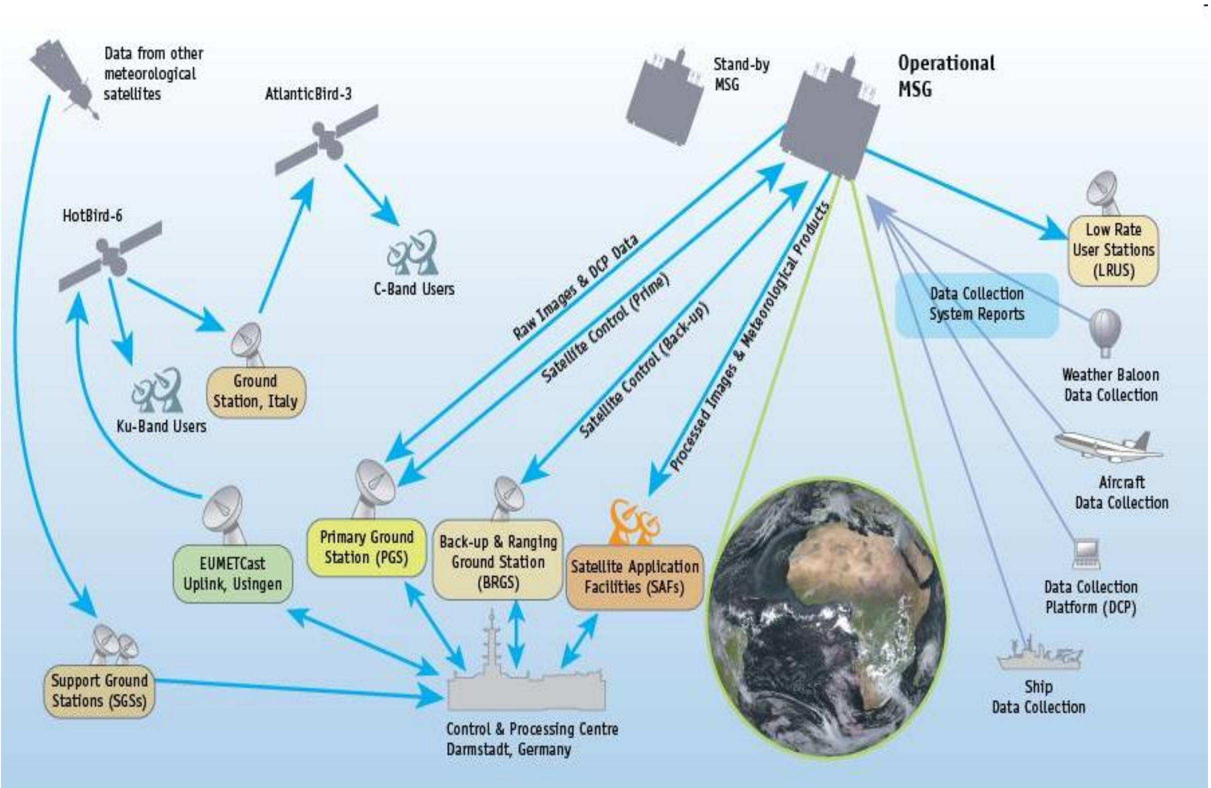


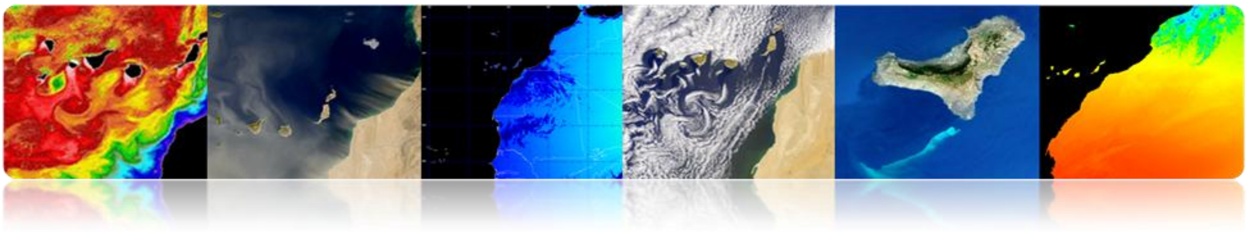
2.5. Space Missions

❑ Meteosat Second Generation

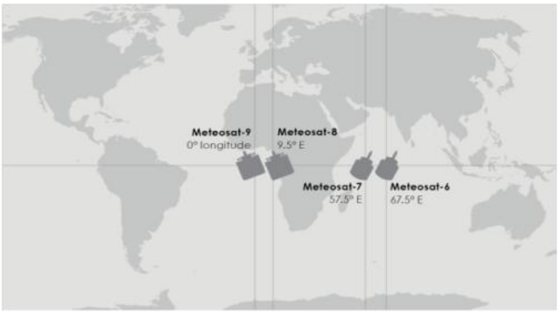
▪ MSG Program

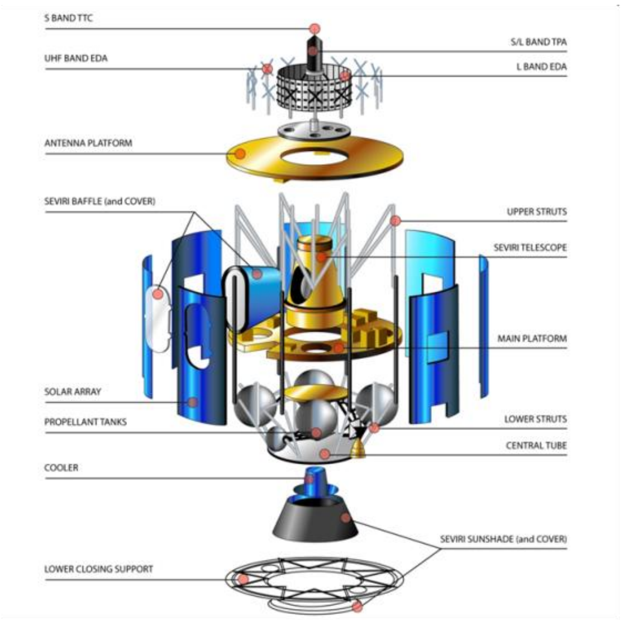
- The MSG program includes 4 satellites, ensuring services until 2018.
- MSG-1 (Meteosat-8) was launched in 2002 and MSG-2 (Meteosat-9) in 2005.
- MSG-3 was launched in July 2012.



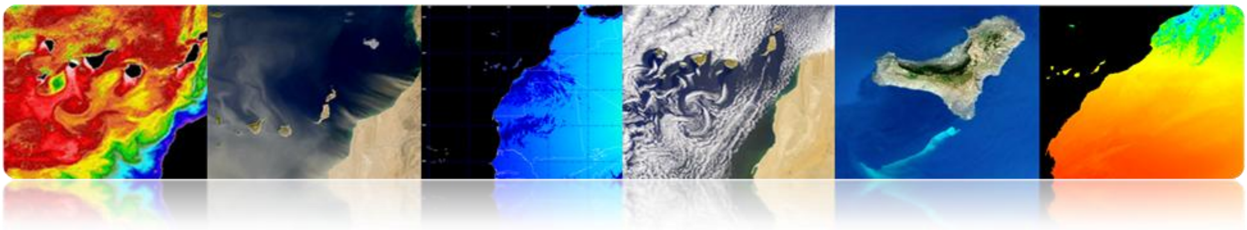


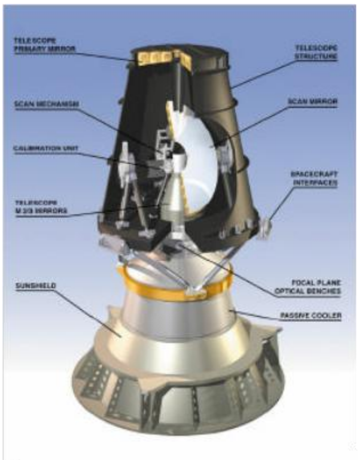
Space Segment

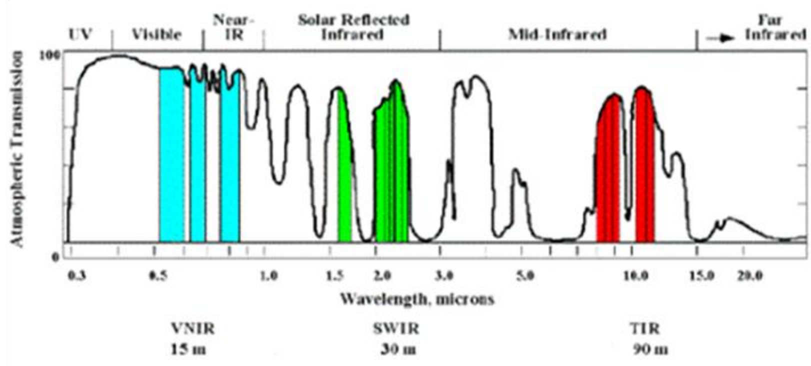




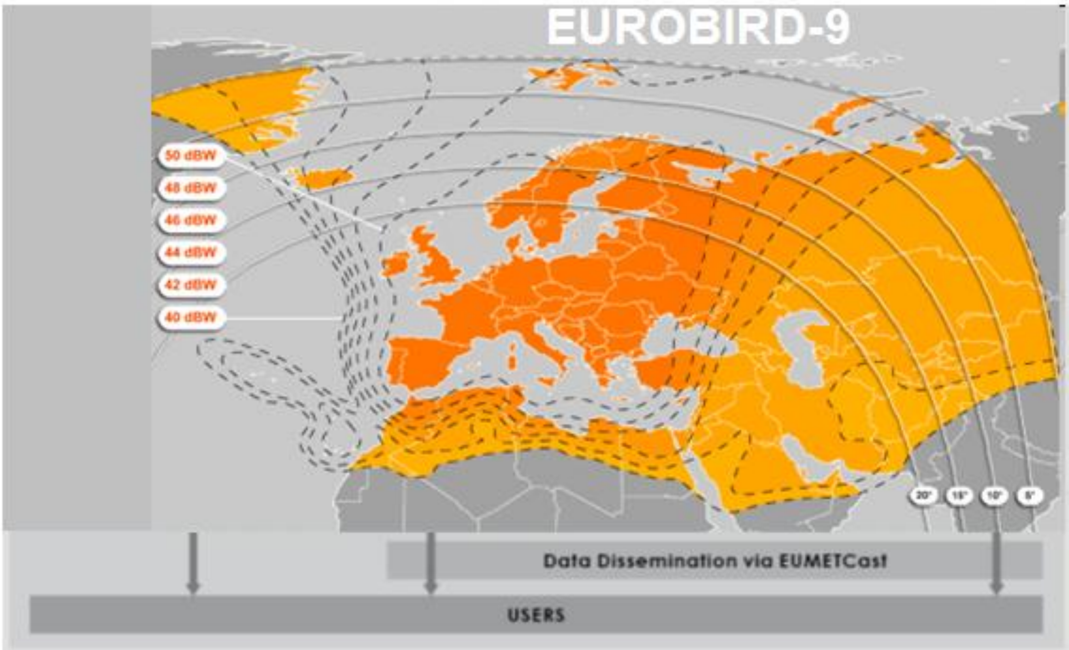
Channels	Central wavelength (um)	Spectral band (um)
VIS 0.6	0.635	0.56 to 0.71
VIS 0.8	0.81	0.74 to 0.88
IR 1.6	1.64	1.50 - 1.78
IR 3.9	3.92	3.48 - 4.36
IR 8.7	8.70	8.30 - 9.10
IR 10.8	10.8	9.80 - 11.80
IR 12.0	12.0	11.00 - 13.00
WV 6.2	6.25	5.35 - 7.15
WV 7.3	7.35	6.85 - 7.85
IR 9.7	9.66	9.38 - 9.94
IR 13.4	13.40	12.40 - 14.40
HRV		0.5 to 0.9

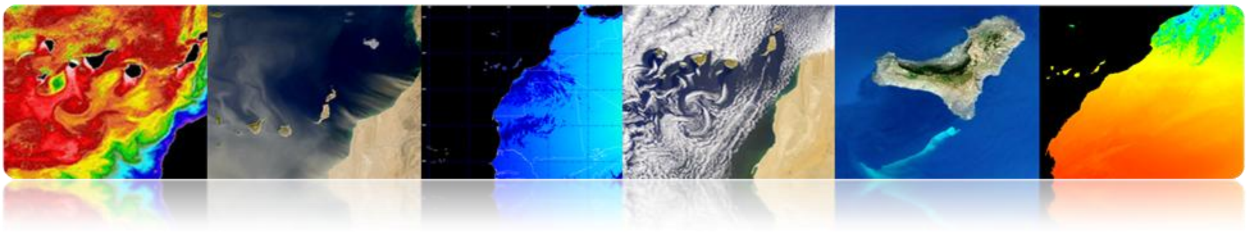


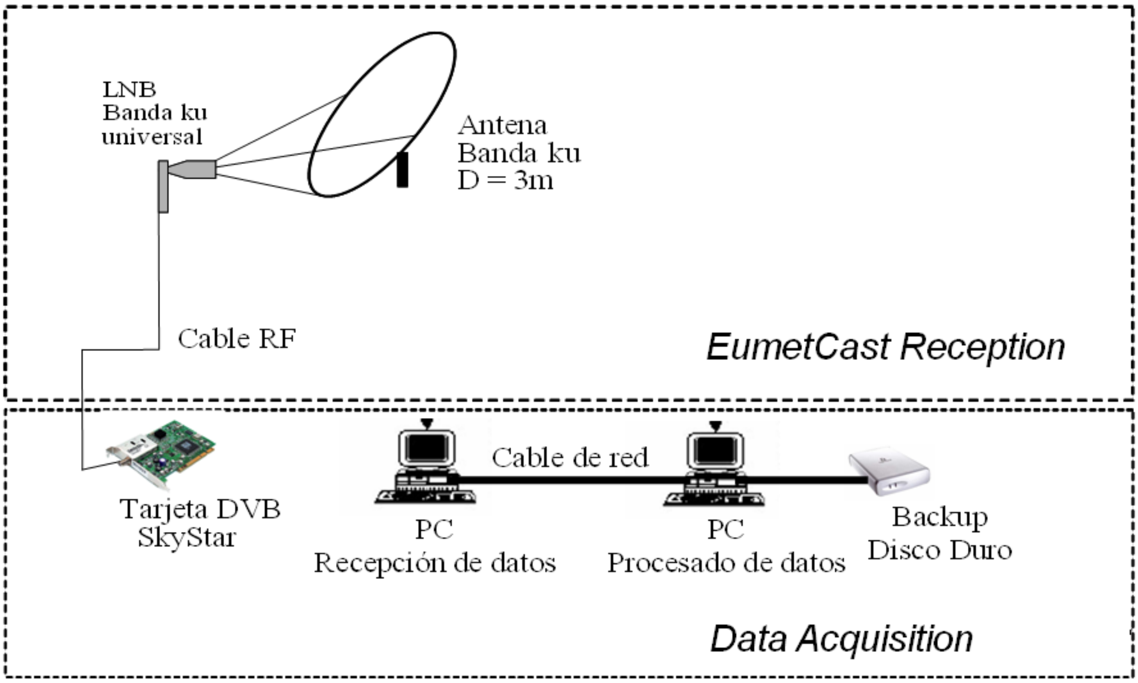




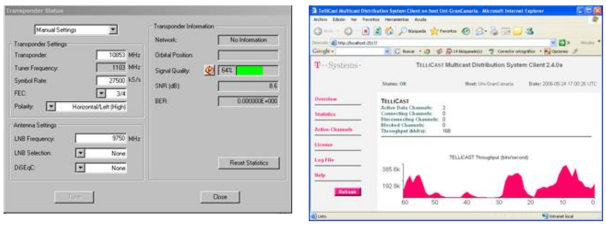
Ground Segment

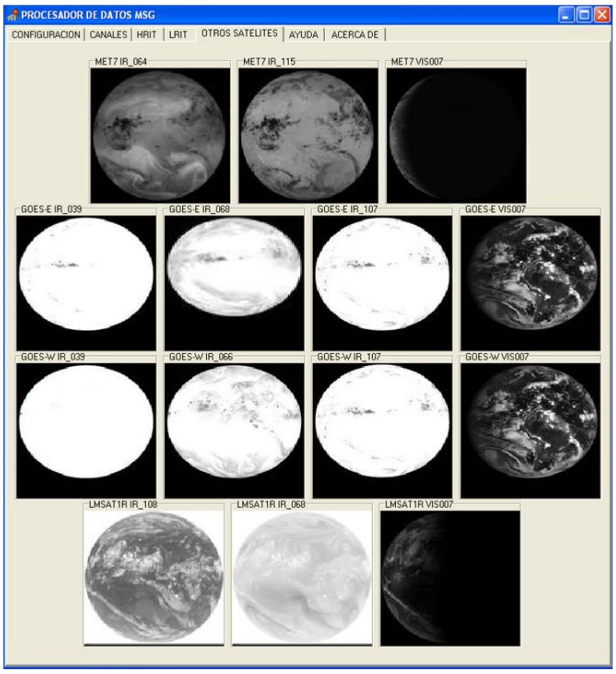




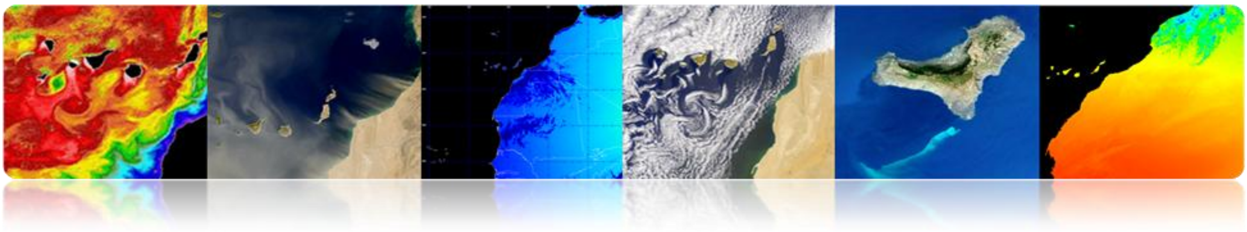


LNB
Banda ku
universal
Antena
Banda ku
D = 3m
Cable RF
EumetCast Reception
Tarjeta DVB
SkyStar
Cable de red
PC
Recepción de datos
PC
Procesado de datos
Backup
Disco Duro
Data Acquisition

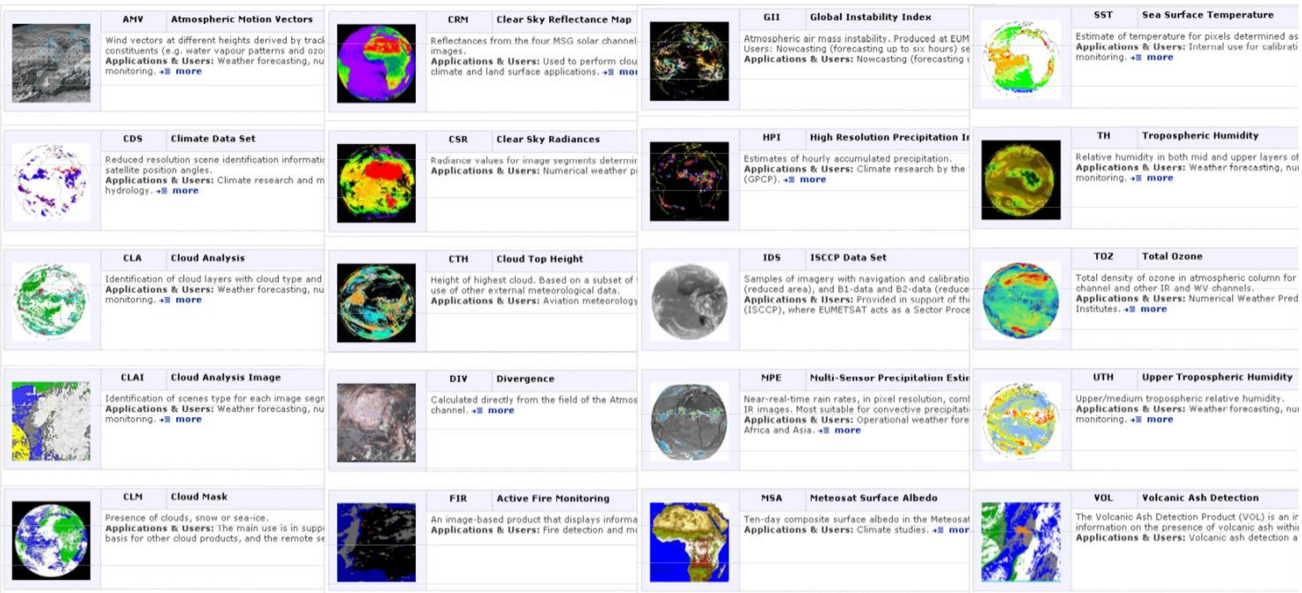




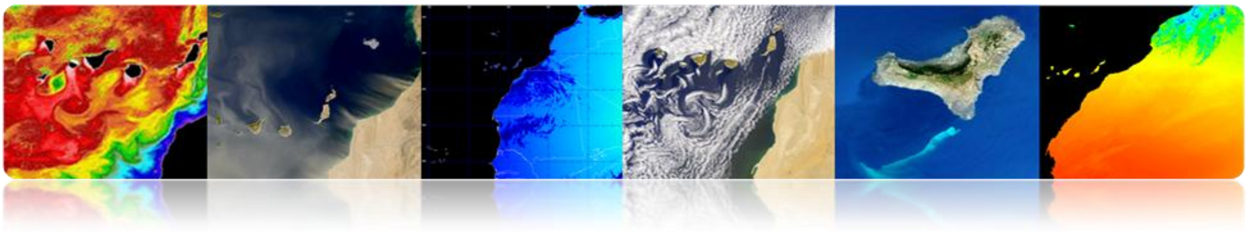
PROCESADOR DE DATOS MSG
CONFIGURACION
CANALES
HRIT
LRIT
OTROS SATELITES
AYUDA
ACERCA DE
MET7 IR_064
MET7 IR_115
MET7 VIS007
GOES-E IR_039
GOES-E IR_068
GOES-E IR_107
GOES-E VIS007
GOES-W IR_039
GOES-W IR_066
GOES-W IR_107
GOES-W VIS007
LMSAT1R IR_108
LMSAT1R IR_068
LMSAT1R VIS007



Products

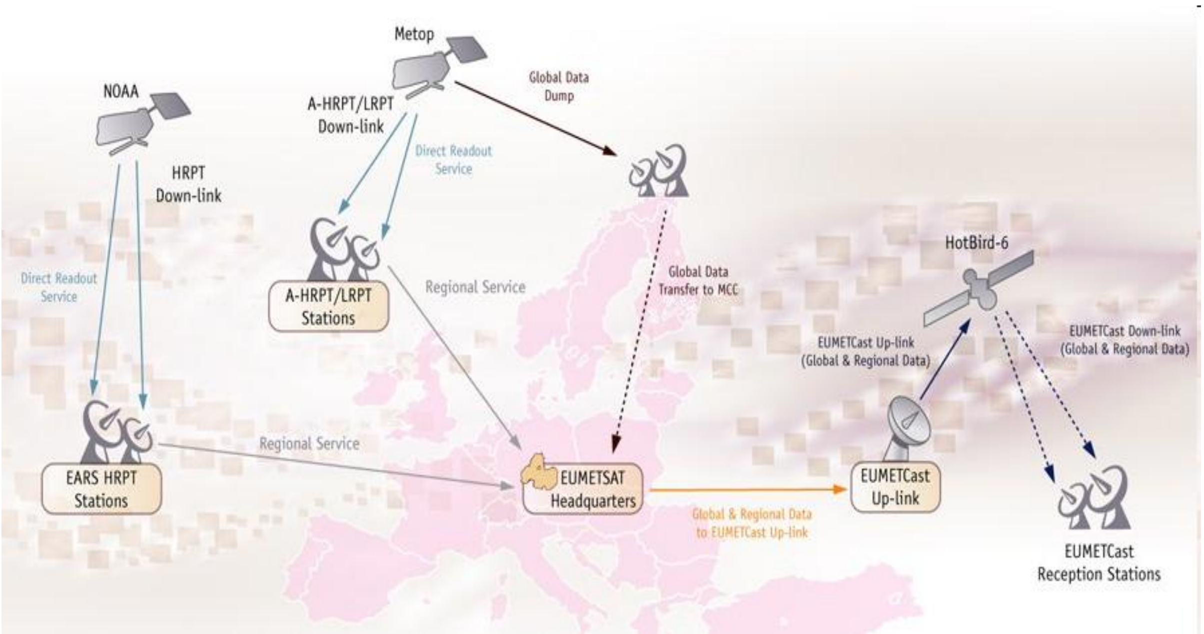


AMV	Atmospheric Motion Vectors	Wind vectors at different heights derived by track constituents (e.g. water vapour patterns and ozo **Applications & Users:** Weather forecasting, nu monitoring. more
CDS	Climate Data Set	Reduced resolution scene identification informatic satellite position angles. **Applications & Users:** Climate research and m hydrology. more
CLA	Cloud Analysis	Identification of cloud layers with cloud type and **Applications & Users:** Weather forecasting, nu monitoring. more
CLAI	Cloud Analysis Image	Identification of scenes type for each image segn **Applications & Users:** Weather forecasting, nu monitoring. more
CLM	Cloud Mask	Presence of clouds, snow or sea-ice. **Applications & Users:** The main use is in suppo basis for other cloud products, and the remote se
CRM	Clear Sky Reflectance Map	Reflectances from the four MSG solar channel images. **Applications & Users:** Used to perform clou climate and land surface applications. mor
CSR	Clear Sky Radiances	Radiance values for image segments determin **Applications & Users:** Numerical weather pr
CTH	Cloud Top Height	Height of highest cloud. Based on a subset of use of other external meteorological data. **Applications & Users:** Aviation meteorology
DIV	Divergence	Calculated directly from the field of the Atmos channel. more
FIR	Active Fire Monitoring	An image-based product that displays informa **Applications & Users:** Fire detection and mo
GII	Global Instability Index	Atmospheric air mass instability. Produced at EUM Users: Nowcasting (forecasting up to six hours) se **Applications & Users:** Nowcasting (forecasting u
HPI	High Resolution Precipitation Ir	Estimates of hourly accumulated precipitation. **Applications & Users:** Climate research by the (GPCP). more
IDS	ISCCP Data Set	Samples of imagery with navigation and calibratio (reduced area), and B1-data and B2-data (reduce **Applications & Users:** Provided in support of th (ISCCP), where EUMETSAT acts as a Sector Proce
MPE	Multi-Sensor Precipitation Estir	Near-real-time rain rates, in pixel resolution, coml IR images. Most suitable for convective precipitati **Applications & Users:** Operational weather fore Africa and Asia. more
MSA	Meteosat Surface Albedo	Ten-day composite surface albedo in the Meteosat **Applications & Users:** Climate studies. mor
SST	Sea Surface Temperature	Estimate of temperature for pixels determined as **Applications & Users:** Internal use for calibrati monitoring. more
TH	Tropospheric Humidity	Relative humidity in both mid and upper layers of **Applications & Users:** Weather forecasting, nu monitoring. more
TOZ	Total Ozone	Total density of ozone in atmospheric column for channel and other IR and WV channels. **Applications & Users:** Numerical Weather Pred Institutes. more
UTH	Upper Tropospheric Humidity	Upper/medium tropospheric relative humidity. **Applications & Users:** Weather forecasting, nu monitoring. more
VOL	Volcanic Ash Detection	The Volcanic Ash Detection Product (VOL) is an ir information on the presence of volcanic ash withi **Applications & Users:** Volcanic ash detection a



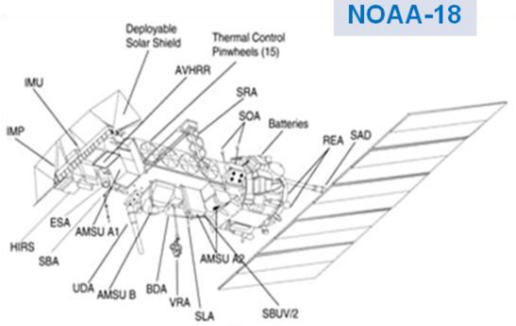
❑ NOAA-METOP

EUMETSAT Polar System (EPS) provides METOP and NOAA runs missions data



Space Segment

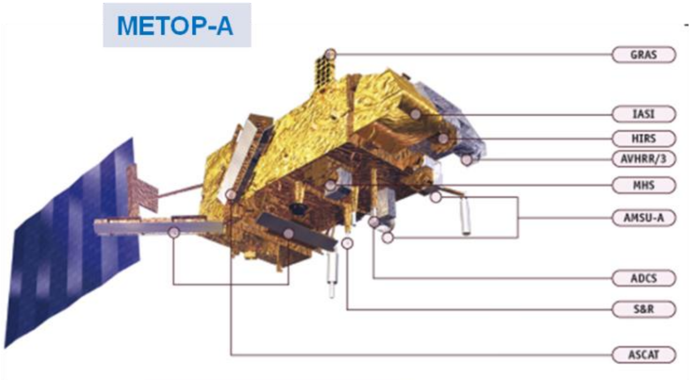
NOAA-18



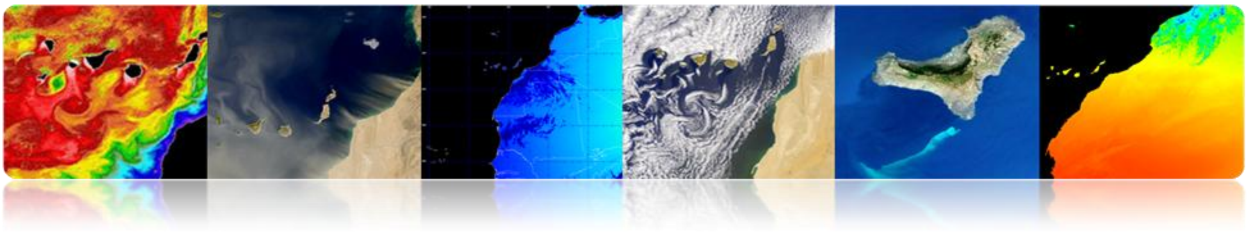
LEGEND

AMSU	Advanced Microwave Sounding Unit	SBUV/2	Solar Backscatter Ultraviolet Radiometer
AVHRR	Advanced Very High Resolution Radiometer	SEM	Space Environment Monitor
BDA	Beacon Transmitting Antenna	SLA	Search and Rescue Transmitting Antenna (L-Band)
*DCS	Data Collection System	SOA	S-Band Omni Antenna (2 of 6 shown)
ESA	Earth Sensor Assembly	SRA	Search-and-Rescue Receiving Antenna
HIRS	High Resolution Infrared Radiation Sounder	STX	S-Band Transmitting Antenna (1 of 4 shown)
IMP	Instrument Mounting Platform	*TED	Total Energy Detector
IMU	Inertial Measurement Unit	UDA	Ultra High Frequency Data Collection System Antenna
*MEPED	Medium Energy Proton/Electron Detector	VRA	Very High Frequency Real-time Antenna
REA	Reaction Engine Assembly		
SAD	Solar Array Drive		
*SAR	Search and Rescue		

METOP-A

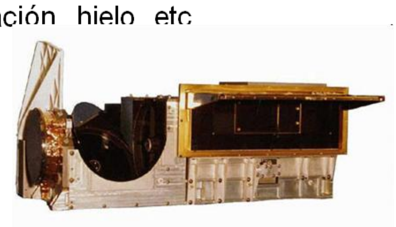


METOP-A	AM Primary
NOAA 11	Decomissioned 16 June 2004.
NOAA 12	Decommissions 10 Aug 2007
NOAA 14	Decommission on 23 May 07
NOAA 15	AM Secondary
NOAA 16	PM Secondary
NOAA 17	AM Backup
NOAA 18	PM Secondary
NOAA 19	PM Primary

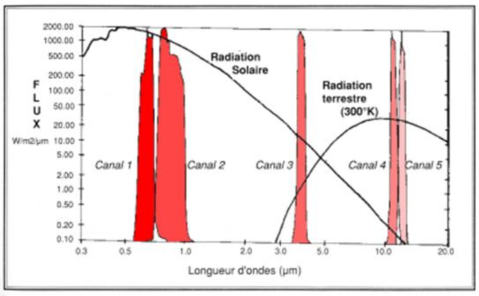


AVHRR

Radiómetro en el VIS/IR para medida global de cobertura de nubes, temperaturas del mar y tierra, vegetación, hielo, etc.



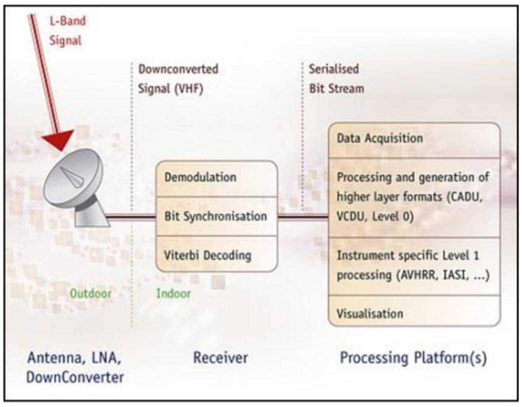
Scan Rate	6 Hz (0.1667 secs)
Scan Type	Continuous scan
Pixel IFOV (3dB beamwidth)	0.0745° (square)
IFOV size at Nadir	1.1 km
Sampling at Nadir	0.87 km
Earth View Pixels / Scan	2048
Swath	± 55.37°
Swath	± 1464 km
Spectral Range	0.6 to 12 μm
Lifetime	5 years (3 years design life)
Power	29 W
Size	300 mm x 360 mm x 800 mm
Mass	33 kg
Data rate	1.4 Mbps

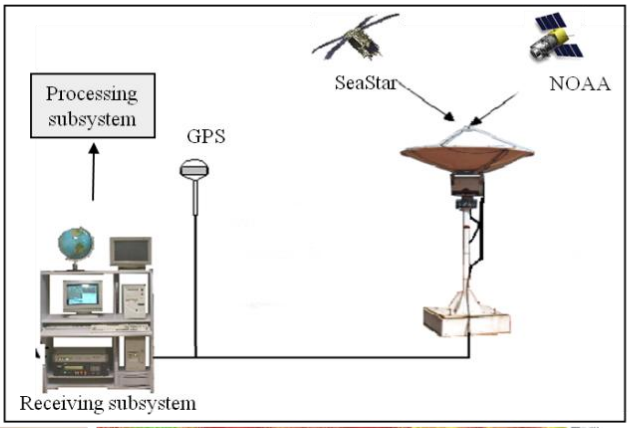


AVHRR/3 Channel Characteristics

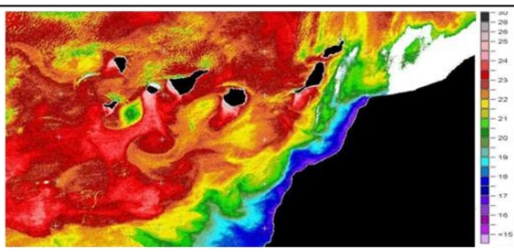
Band	Wavelength (μm)	Typical Use
1	0.58 - 0.68	Daytime cloud and surface mapping
2	0.725 - 1.00	Land-water boundaries
3A	1.58 - 1.64	Snow and ice detection
3B	3.55 - 3.93	Night cloud mapping, SST
4	10.30 - 11.30	Night cloud mapping, SST
5	11.50 - 12.50	Sea surface temperature

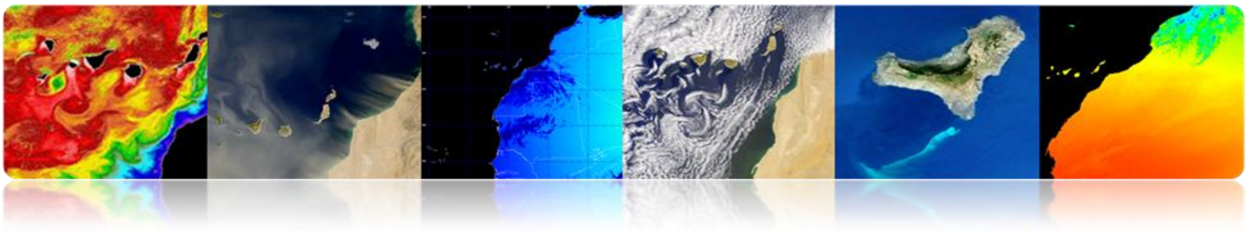
Ground Segment



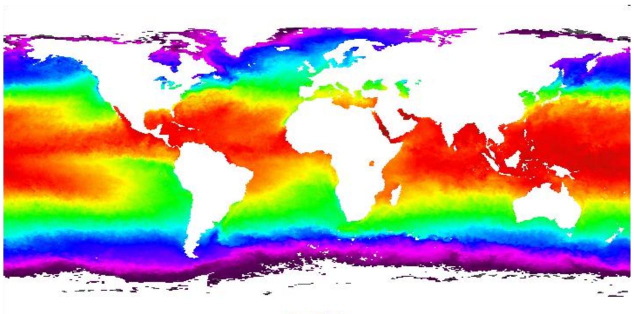




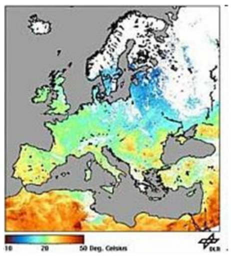





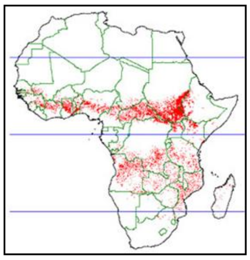
Products



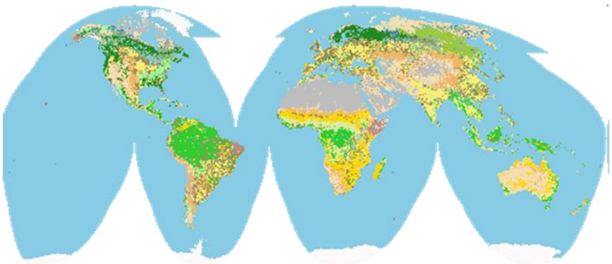
SST



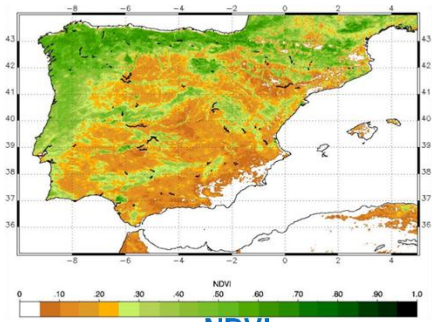
LST



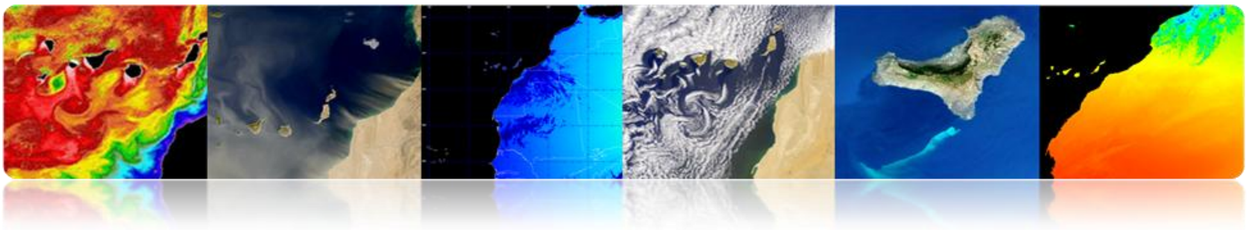
Fuegos



GLC



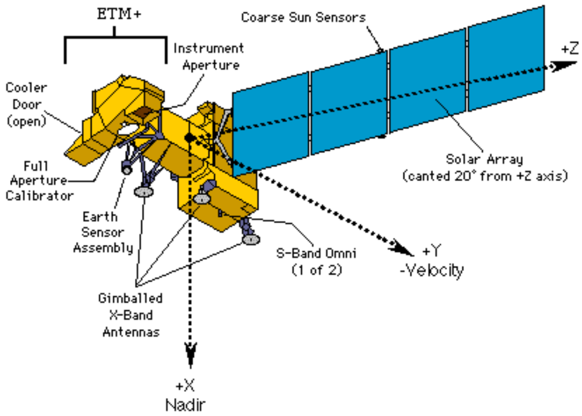
NDVI



❑ LANDSAT / SPOT

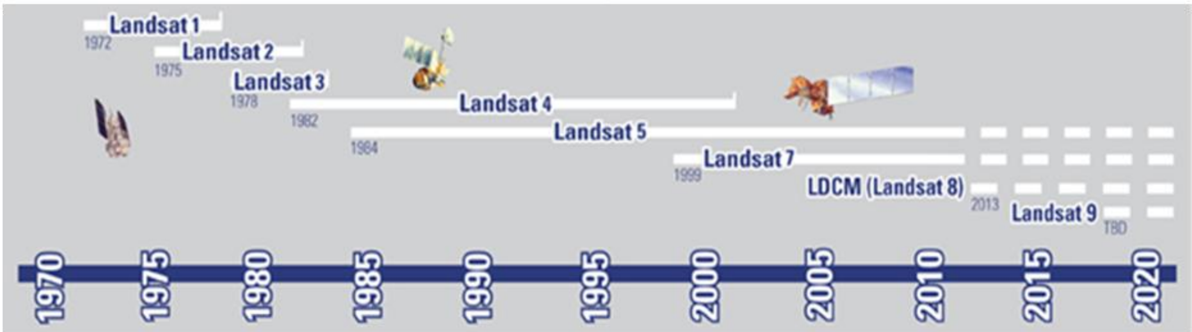
▪ NASA Satellites USGCS.

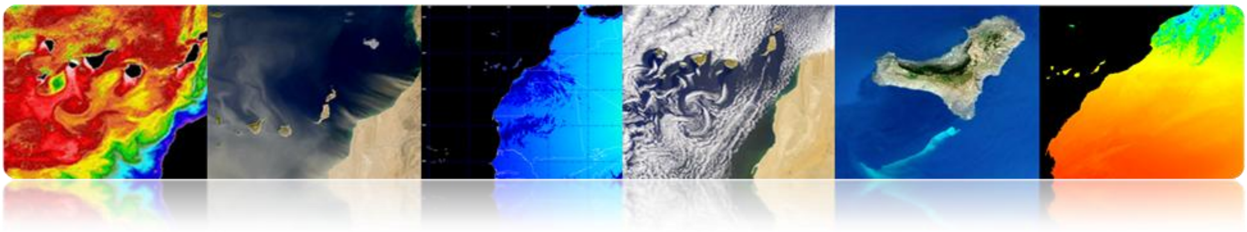
- LANDSAT 1 (1972)
- LANDSAT 2 (1975)
- LANDSAT 3 (1978)
- LANDSAT 4 (1982)
- LANDSAT 5 (1985)
- LANDSAT 6 (1993)
- LANDSAT 7 (1999)
- LDCM (Landsat 8) 2013



Satellite	Sensor	Bandwidths	Resolution
LANDSATs 1-2	RBV	(1) 0.48 to 0.57	80
		(2) 0.58 to 0.68	80
		(3) 0.70 to 0.83	80
	MSS	(4) 0.5 to 0.6	79
		(5) 0.6 to 0.7	79
		(6) 0.7 to 0.8	79
		(7) 0.8 to 1.1	79
LANDSAT 3	RBV	(1) 0.505 to 0.75	40
	MSS	(4) 0.5 to 0.6	79
		(5) 0.6 to 0.7	79
		(6) 0.7 to 0.8	79
		(7) 0.8 to 1.1	79
		(8) 10.4 to 12.6	240

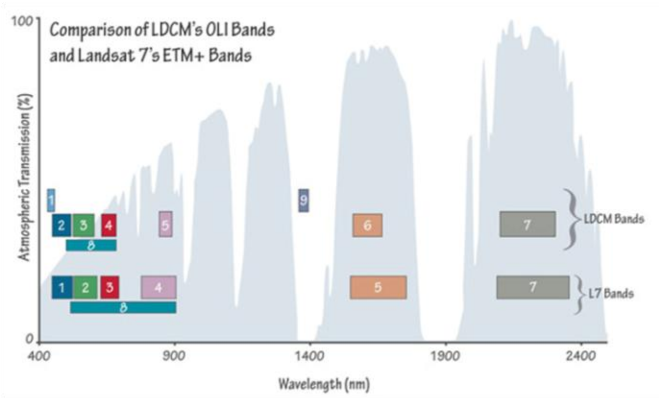
Satellite	Sensor	Bandwidths	Resolution
LANDSATs 4-5	MSS	(4) 0.5 to 0.6	82
		(5) 0.6 to 0.7	82
		(6) 0.7 to 0.8	82
		(7) 0.8 to 1.1	82
	TM	(1) 0.45 to 0.52	30
		(2) 0.52 to 0.60	30
		(3) 0.63 to 0.69	30
		(4) 0.76 to 0.90	30
		(5) 1.55 to 1.75	30
		(6) 10.4 to 12.5	120
		(7) 2.08 to 2.35	30
LANDSAT 7	ETM	(1) 0.45 to 0.52	30
		(2) 0.52 to 0.60	30
		(3) 0.63 to 0.69	30
		(4) 0.76 to 0.90	30
		(5) 1.55 to 1.75	30
		(6) 10.4 to 12.5	150
		(7) 2.08 to 2.35	30
		PAN 0.50 to 0.90	15

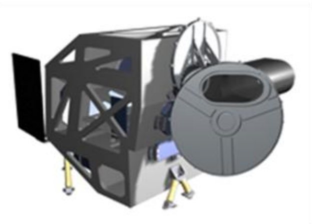


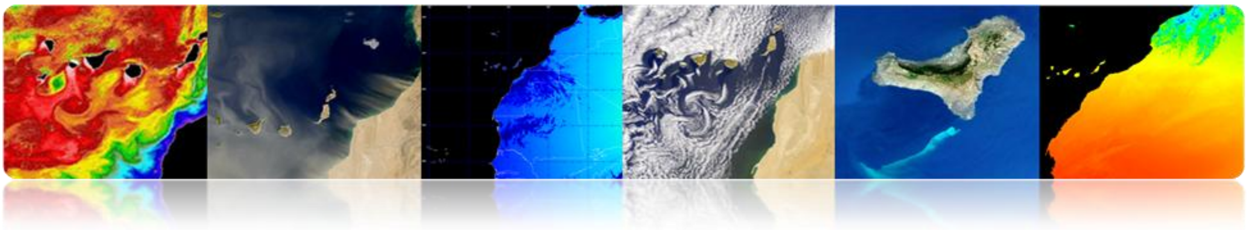


- **Landsat 8**

  - Spacecraft: Landsat Data Continuity Mission (LDCM).
  - Launch Vehicle: Atlas V-401
  - Launch Date: Feb. 11, 2013





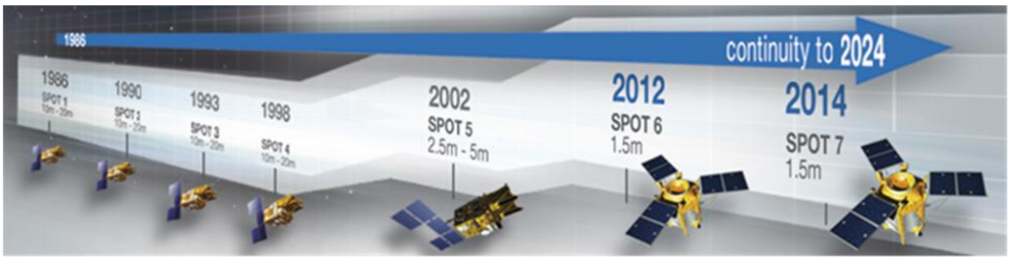


❑ SPOT

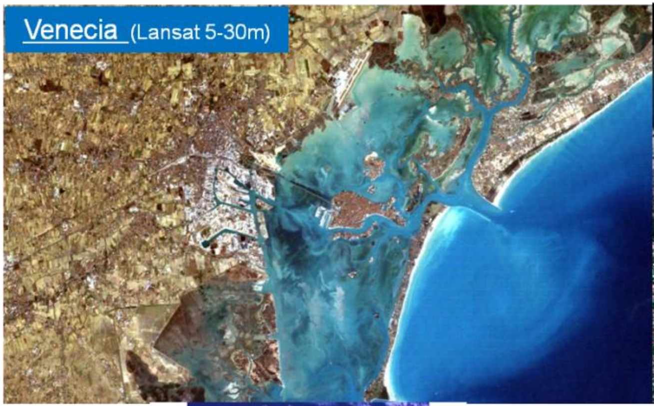
- **SPOT** (Satellite Pour l'Observation de la Terre). It is a medium / high resolution optical satellite.

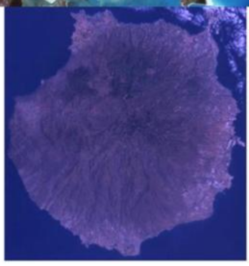
- Operated by Spot Image (Toulouse, France). Started by CNES (Centre National d'Etudes Satiales) in the 70s.

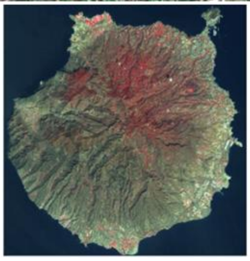
- Launched with Ariane 2, 3 and 4.
  - SPOT 1 (1986) with 10 m and 20 m MS PAN.
  - SPOT 2 (1990)
  - SPOT 3 (1993)
  - SPOT 4 (1998)
  - SPOT 5 (2002) with 2.5 m / 5 m and 10 m MS PAN.

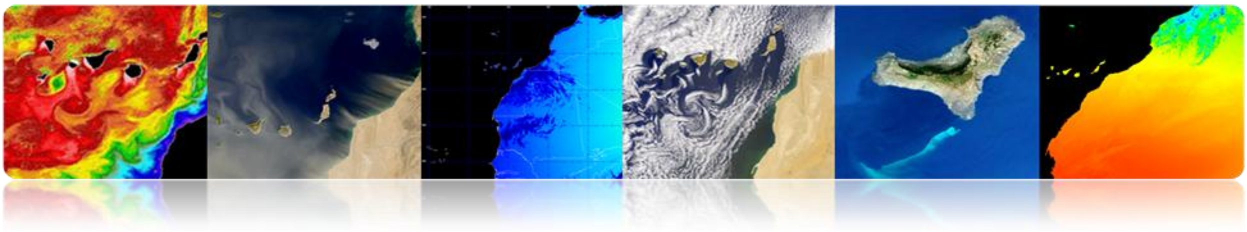


LANDSAT / SPOT Imagery







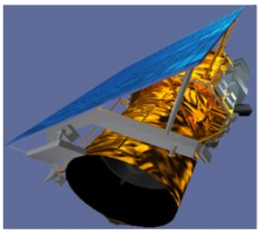
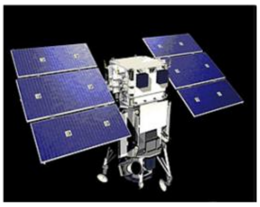


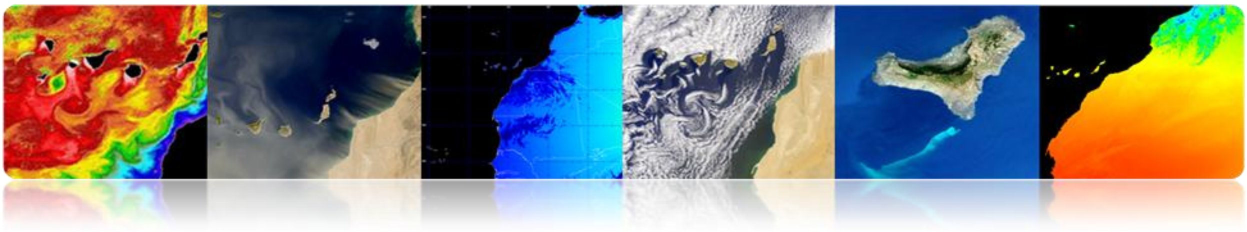
❑ GEOEYE / WORLDVIEW

High resolution missions: High resolution satellites are very complex instruments, with growing demand for its numerous applications in fields as diverse as mapping, natural resource identification, risk management and defense. The most important satellites are:

	QuickBird	IKONOS	GeoEye-1	WorldView-1
Resolution	0.6m	0.8m	0.5m	0.5m
Swath Width	16.5 km	11 km	15 km	15 km
Multi-Spectral	yes	yes	yes	no
DEM Accuracy	20 meter	20 meter	3 meter	3 meter
Average Revisit Time	3-4 days	2-3 days	2-3 days	3-4 days
Mapping Accuracy (w/out GCPs)	20-meter	10-meter	2-meter	3-meter
Agility	Limited Single Scan	Very/Stereo Multi-scan	Very/Stereo Multi-scan	Very/Stereo Multi-scan
Days to Collect 1° x 1°	25	8	5	8



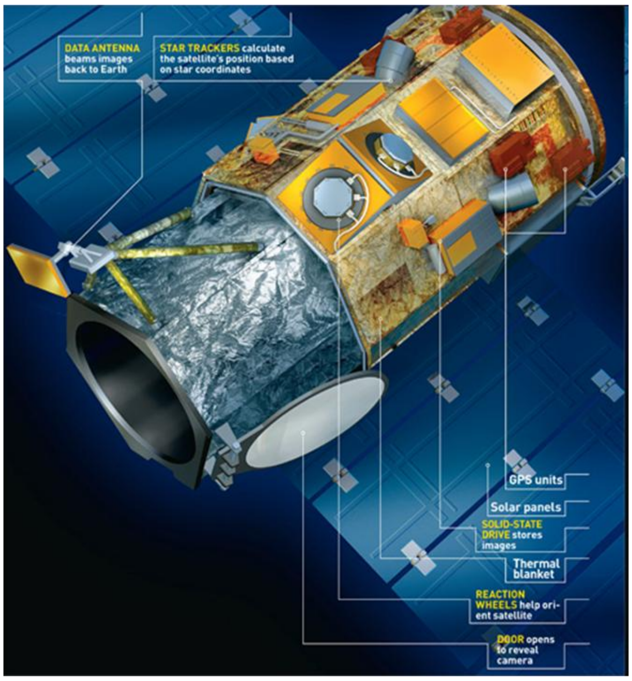



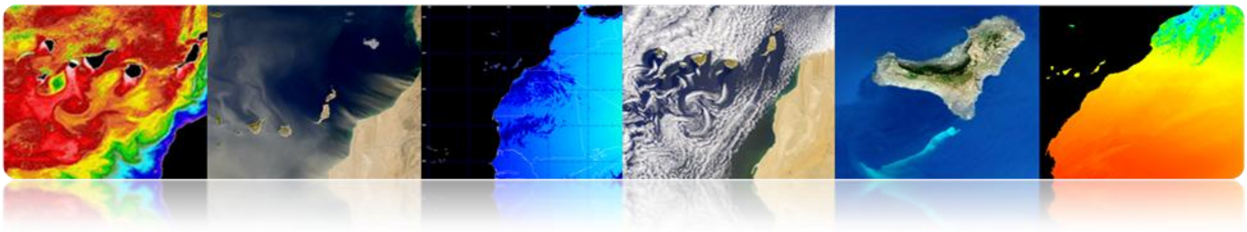


- ## GeoEye

Launch Vehicle	Delta II (launch date: September 6, 2008)
Launch Vehicle Manufacturer	Boeing Corporation
Launch Location	Vandenberg Air Force Base, California
Satellite Weight	1955 kg
Satellite Storage and Downlink	1 Terabit recorder; X-band downlink (at 740 mb/sec or 150 mb/sec)
Operational Life	Fully redundant 7+ year design life; fuel for 15 years
Satellite Modes of Operation	• Store and forward • Real-time image and downlink • Direct uplink with real-time downlink
Orbital Altitude	684 kilometers
Orbital Velocity	About 7.5 km/sec
Inclination/Equator Crossing Time	98 degrees / 10:30am
Orbit type/period	Sun-synchronous / 98 minutes

Space Segment





Sensor Exploration Features

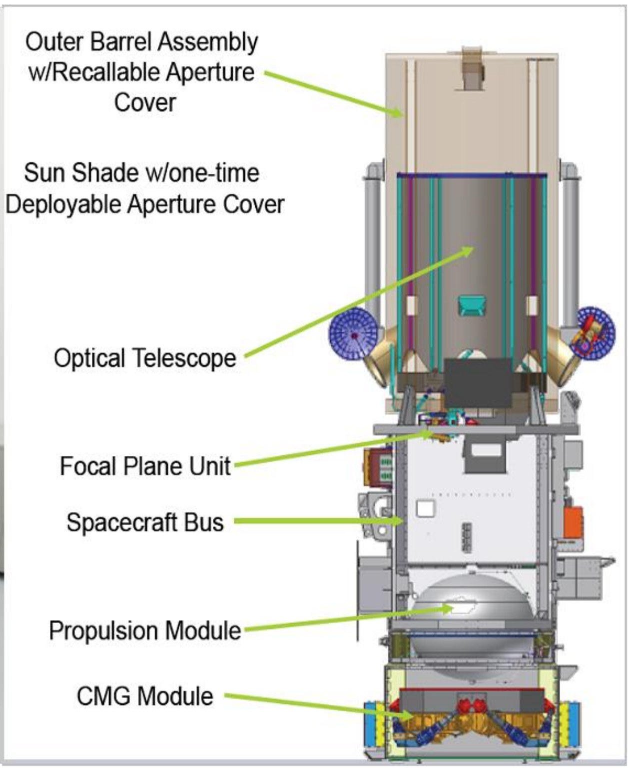
Camera Modes	• Simultaneous panchromatic and multispectral (pan-sharpened) • Panchromatic only • Multispectral only
Resolution	0.41 m panchromatic (nominal at Nadir) 1.65 m multispectral (nominal at Nadir)
Metric Accuracy/ Geolocation	CE stereo: 2 m LE stereo: 3 m CE mono: 2.5 m These are specified as 90% CE (circular error) for the horizontal and 90% LE (linear error) for the vertical with no ground control points (GCP's)
Swath Widths & Representative Area Sizes	• Nominal swath width - 15.2 km at Nadir • Single-point scene - 225 sq km (15x15 km) • Contiguous large area - 15,000 sq km (300x50 km) • Contiguous 1° cell size areas - 10,000 sq km (100x100 km) • Contiguous stereo area - 6,270 sq km (224x28 km) (Area assumes pan mode at highest line rate)
Imaging Angle	Capable of imaging in any direction
Revisit at 684 km Altitude (40° Latitude Target)	

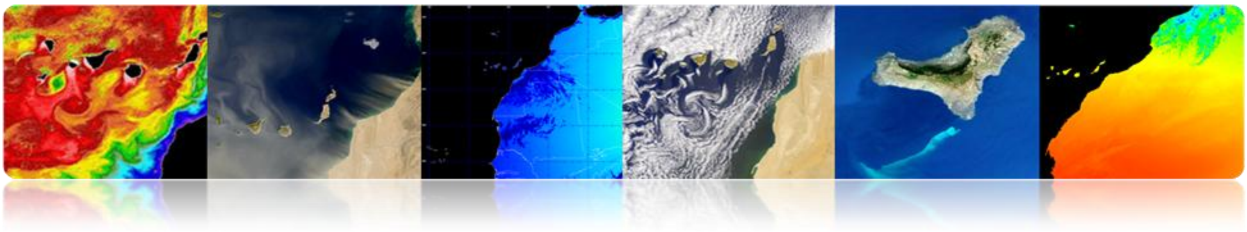
Imagery

- ## Worldview 2

	WorldView-2
Organization	DigitalGlobe
Mission Type	Earth observation
Contractor	Ball Aerospace & Technologies
Satellite of	Earth
Launch	October 8, 2009 on a Delta II
Launch site	Vandenberg Air Force Base
Mission duration	7.25 years
Mass	2,800 kg (6,200 lb)
Webpage	http://worldview2.digitalglobe.com/
	Orbital elements
Altitude	770 kilometers
Inclination	97.2 degrees
Orbital Period	100 minutes

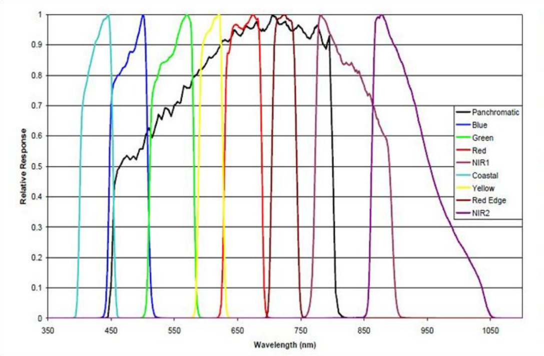
Space Segment





▪ Sensor Exploration Characteristics

- Helio synchronous orbit, 770 km altitude.
- 1 panchromatic channel (0.5 m), 8 multispectral channels (2m).
- Revisit period of 1.1 days (Max viewing angle 45°).
- Scene width 16.4 Km.



Bands	Center Wavelength	50% Band Pass	5% Band Pass
Panchromatic	0.632	0.464 – 0.801	0.447 – 0.808
Coastal	0.427	0.401 – 0.453	0.396 - 0.458
Blue	0.478	0.448 – 0.508	0.442 – 0.515
Green	0.546	0.511 – 0.581	0.506 – 0.586
Yellow	0.608	0.589 – 0.627	0.584 - 0.632
Red	0.659	0.629 – 0.689	0.624 – 0.694
Red Edge	0.724	0.704 – 0.744	0.699 - 0.749
NIR 1	0.831	0.772 – 0.890	0.765 – 0.901
NIR 2	0.908	0.862 – 0.954	0.856 - 1.043

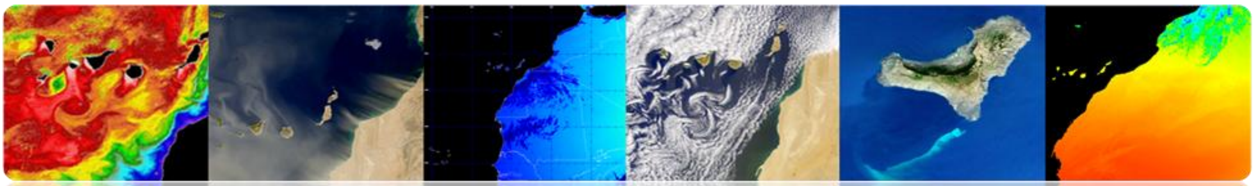
Imagery

Las Canteras – 2010

Maspalomas – 2009

4. Radiometric, Atmospheric and Geometric Modeling

3. Remote Sensing Applications



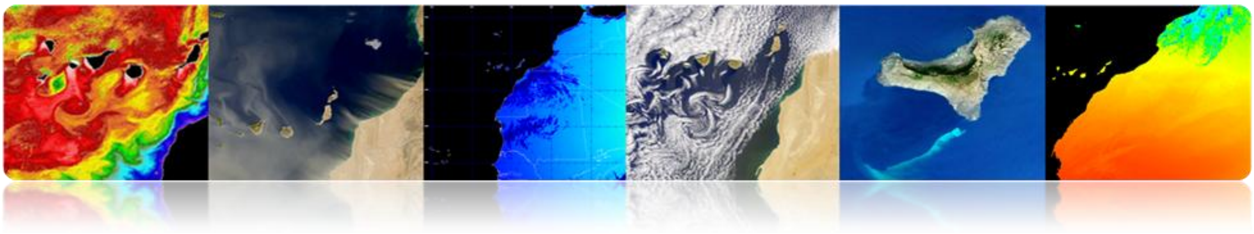
Introduction

Remote sensing techniques have changed dramatically since the beginning of this science. Its spectacular development since 1858 -when the French photographer Gaspard-Félix Tournachon raised his balloon over Paris to take the first aerial photography- has led to the modern sophistication of sensors on satellites around the Earth. These current sensors sample almost all possible regions of the electromagnetic spectrum, achieving spatial resolutions below one meter. Thus, spatial remote sensing currently allows the study of our planet by providing a synoptic and repetitive view that allows us to obtain data in a short period of time. In return, remote sensing images can only provide information about the most superficial layer.

In this context, remote sensing is applicable in the marine, terrestrial and atmospheric sector, allowing a systematic analysis of many geophysical parameters of great interest to researchers, businesses, governments and general public. The following chapter in this tutorial focuses on the description of the main applications of remote sensing grouped up into the three sectors mentioned above that are more interesting for the Canary Islands and Northwestern Africa.

Regarding marine applications, the ocean is the most influential element in controlling long-term stability of the Earth's climate. Not surprisingly it occupies 71% of the Earth area and it involves a complex web of relationships between physical, chemical, biological and geological processes. That is why its study should be approached from a multidisciplinary perspective. This tutorial will explore issues related to oceanography, coastal monitoring, marine productivity, water quality, etc. Specifically, parameters such as sea surface temperature, sea level, salinity, winds on the surface of the oceans, ocean currents, ocean color, water quality, bathymetry and coastal benthic classification will be described.

When referring to the land area we will focus on continental crust, which is formed by the continents and continental shelves. This crust has an average thickness of 35 km, although it is only possible to extract information from the upper layers by using remote sensing. With regard to the most important terrestrial applications analyzed by remote sensing, and included in this tutorial, management and monitoring of soil, plant and forest spaces, mapping, urban planning, agriculture, environment, prevention risk, as well as defense-related applications and security can be highlighted.



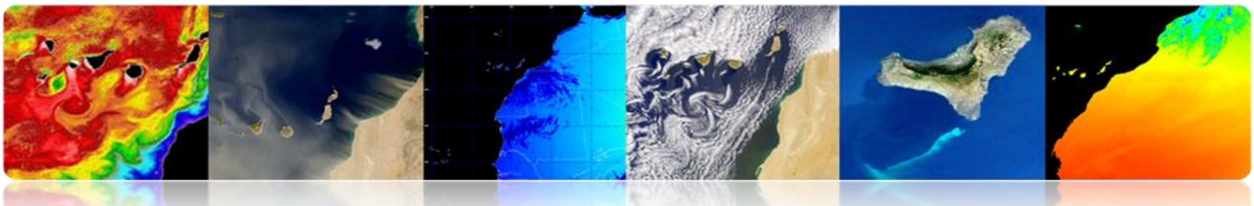
The Earth's atmosphere is the gaseous part of the Earth. It is the most external and less dense layer in the planet. It is comprised of one or more gases which vary in amount depending on pressure at different heights, being oxygen (21%) and nitrogen (78%) its main gases. Remote sensing has been a fundamental tool in the study and analysis of local and regional atmospheric conditions for many years. In this tutorial the main parameters associated with weather forecasting, study of gases in the atmosphere and, specially, greenhouse disaster prevention, renewable energy, air quality, aerosol concentration, etc. will be presented.

The objectives of this chapter are:

- Show marine applications of remote sensing space, identifying the most important physical, biological, chemical and geological parameters and analyze the main sensors and products available for them.
- Describe terrestrial applications of space remote sensing, identifying their main areas of application and describing the main available products and their key features.
- Study the atmospheric applications of remote sensing, and present operational products for weather forecasting as well as products related to scientific research of the atmosphere.

CONTENTS

Remote Sensing Applications



3.1. Marine Remote Sensing Applications

❑ Introduction

Main parameters to study with remote sensing:

Biological Oceanography

- Sea surface temperature (SST)
- Sea height (SSH)
- Salinity (SSS)
- Surface Winds
- Ocean Currents

Biological Oceanography

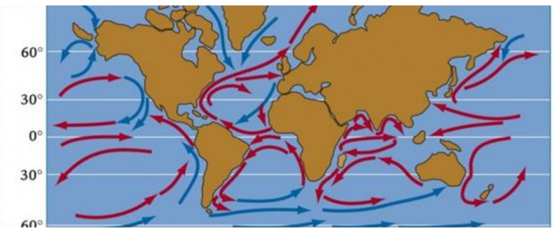
- Ocean color
- Water Quality
- Algae blooms
- Sea Grass

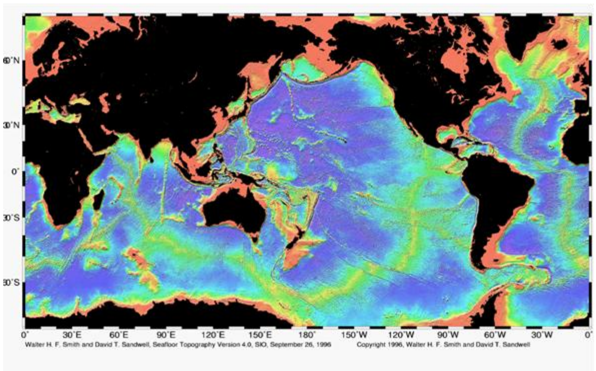
Chemical Oceanography

- Water quality
- Salinity (SSS)
- pH, calcite, etc.

Geological Oceanography

- Coastal management
- Bathymetry (erosion, sedimentation, etc.)



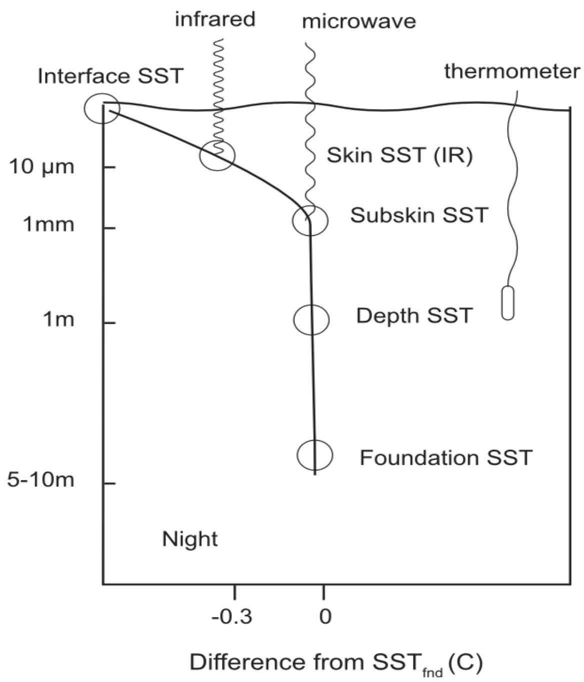


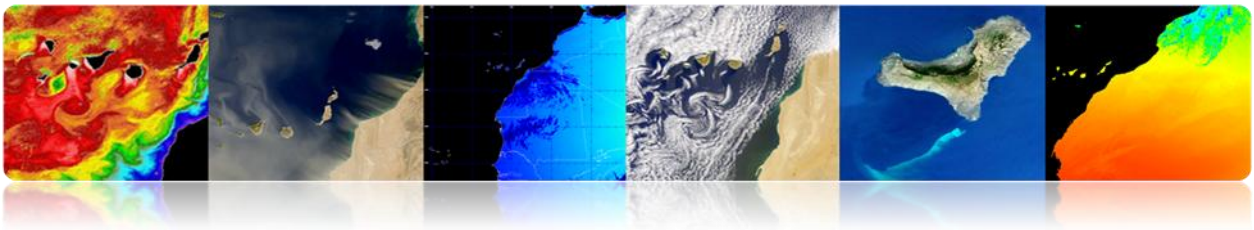
❑ SEA SURFACE TEMPERATURE (SST)

SST is the water temperature close to the ocean's surface.

Before 1980 measures were obtained from instruments installed on the coast, boats or buoys. From 1980 on, most global SST information comes from satellite estimates.

- The ocean emits radiation in the thermal IR and microwave band. The level received varies with sea temperature.
- There are radiometers working in these bands to measure the SST.
- Thermal IR radiation comes from the surface layer (first 10 microns). The microwave radiation comes from the first superficial millimeter (1 mm).
- IR sensors have a better resolution (1 km) than microwave sensors (25 km) but they are affected by clouds that absorb the radiation emitted.





▪ Radiometers in the thermal IR

▪ Methods for estimating SST multiband

The linear combination of radiances measured in two bands in the same atmospheric window provides a good estimate of the emitted radiation.

$$T_s = a_0 T_{11} + a_1 \cdot (T_{11} - T_{12}) + a_2$$

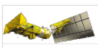
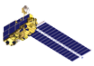
(Linear split-window equation)

Getting the coefficients (ai).

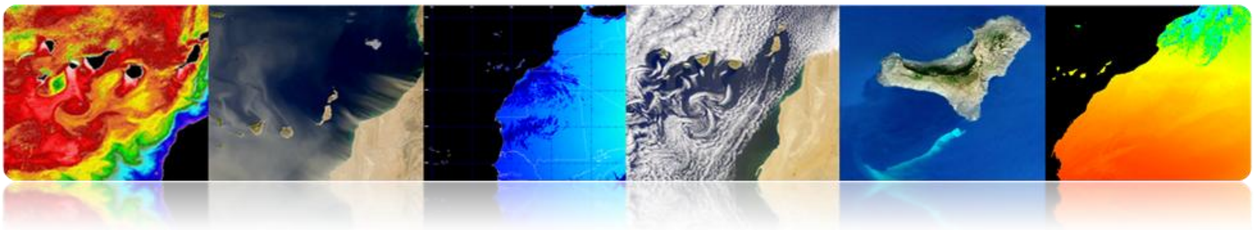
- Theory: radiative transfer model
- Regression: in-situ data and brightness temperatures

The great variability of the observation angle is an additional item due to difference in the optical path to cross through the atmosphere.

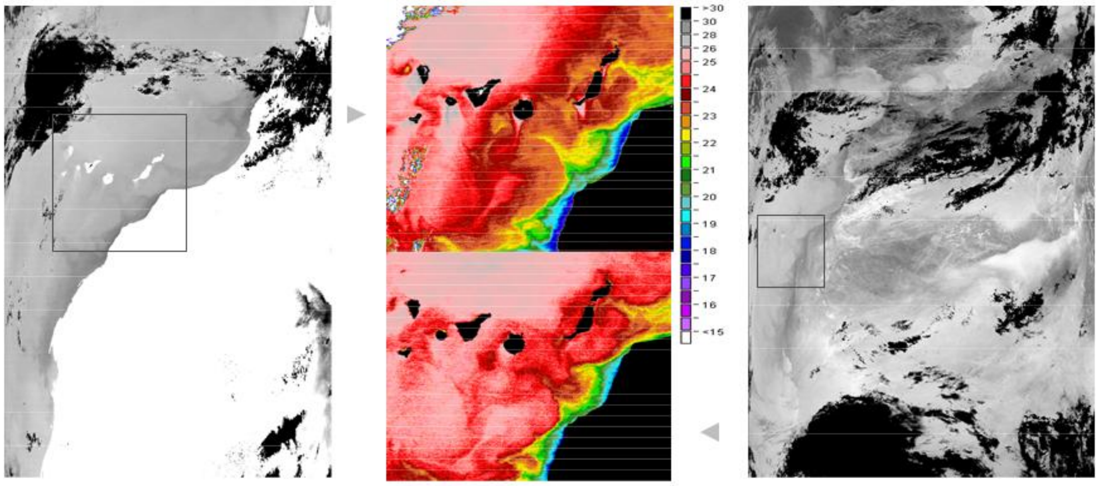
$$T_S = a_o \cdot T_{11} + a_1 \cdot (T_{11} - T_{12}) + a_2 \cdot (\sec\theta - 1) + a_3$$

- AVHRR  $SST = a_0 + a_1 \cdot T_{11} + \left[a_2 + a_3 \cdot (T_{11} - T_{12})\right](T_{11} - T_{12}) + \left[a_4 + a_5 \cdot (T_{11} - T_{12})\right](\sec\theta - 1)$
- MODIS  $SST = a_0 + a_1 \cdot T_{11} + a_2 \cdot (T_{11} - T_{12}) \cdot T_{est} + a_3 \cdot (T_{11} - T_{12})(\sec\theta - 1)$

  $SST4 = a_0 + a_1 \cdot T_{3.9} + a_2 \cdot (T_{3.9} - T_4) + a_3 \cdot (\sec\theta - 1)$



Sample images of sea surface temperature from thermal IR images



MODIS-AQUA
(28-August-04 14:05 hrs.)

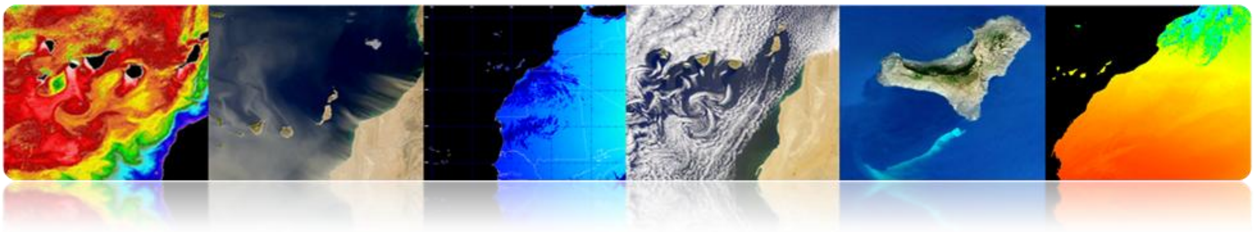
AVHRR-NOAA 16
(29-August-04 3:04 hrs.)

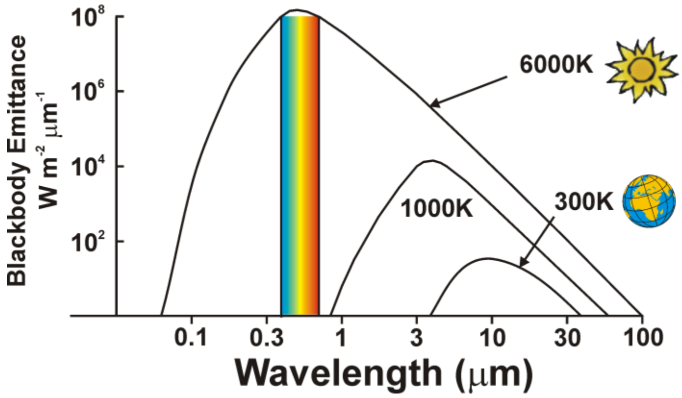
- **Microwave radiometers**

  - **Advantages:** The radiation is not affected by clouds and it is easier to correct atmospheric effects.

  - **Disadvantages:** Due to the lower signal intensity in the Planck radiation curve of the Earth in the microwave region, accuracy and resolution are poorer for the SST estimated in the passive microwave measurements compared to the SST obtained from measurements using the thermal infrared. The roughness of the sea surface generated by wind and precipitation also affect the microwave signal.

SST measurements are usually taken using the channel close to 7 GHz and a water vapor correction thanks to observations at 21 GHz. Other frequencies used for the correction of the roughness of the sea (including foam), precipitation and minimal effect provoked by clouds on microwave radiation are 11, 18, and 37 GHz.

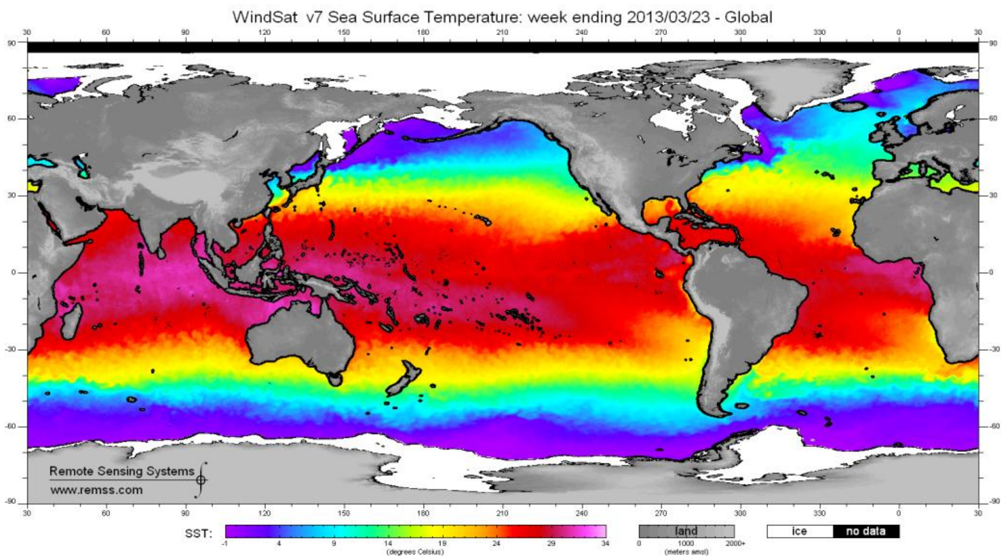


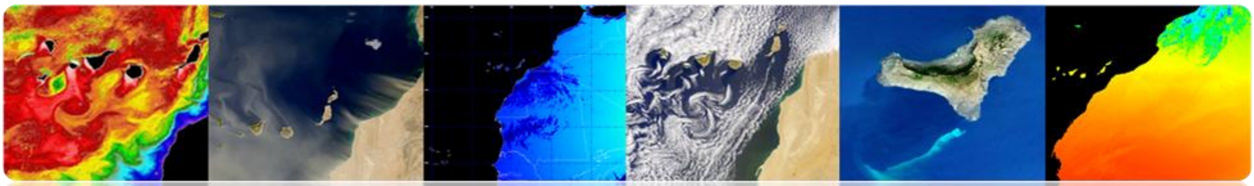


➢ **Passive microwave instruments used to obtain SST:**

- Scanning Multichannel Microwave Radiometer (SMMR on Nimbus-7 and Seasat)
- Tropical Microwave Imager (TMI on the Tropical Rainfall Measuring Mission)
- Advanced Microwave Scanning Radiometer (AMSR on Aqua and ADEOS II)
- WindSat in the Coriolis mission

Example image of sea surface temperature from microwave radiometers



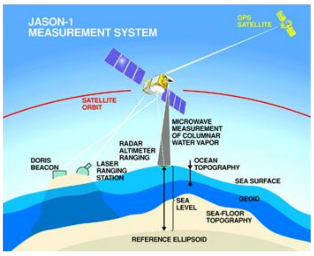


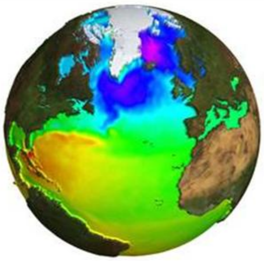
❑ SEA HEIGHT

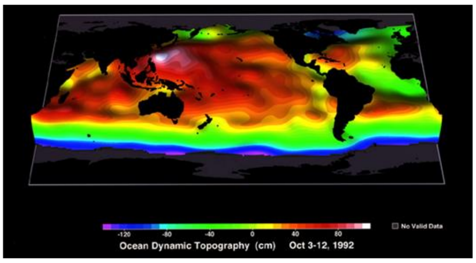
Sea surface topography is the height of the ocean surface relative to a level of no motion defined by the geoid which is the shape that the surface of the oceans would take under the influence of Earth's gravity and rotation alone, in the absence of other influences such as winds and tides. Variations in sea surface topography can be up to 2 meters and are caused by ocean circulation, temperature and salinity.

Topography provides information on tides, circulation and distribution of heat and mass in the Earth's global ocean.

Sea surface height (SSH) is measured using gauges or altimeters on board satellites. Altimetry combines the precise determination of the orbit with measuring the distance to the ocean surface by using microwave pulses. Reliable measurement is not an absolute parameter, but Sea Surface Height Anomaly (SSHA).





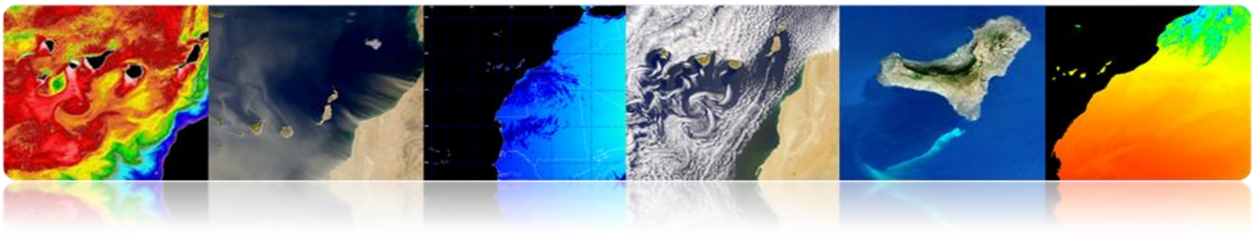


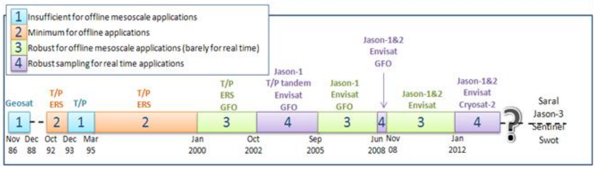
▪ Altimeters

Altimetry satellites basically determine the distance from the satellite to the target surface by measuring the round-trip time elapsed in a radar pulse delivered to the surface.

Radar altimeters permanently transmit signals to Earth, and receive the echo from the surface. The orbit of the satellites has to be known accurately (Doris system) and their position is determined in relation to an arbitrary reference surface, i.e. an ellipsoid.

Ku (13.6 GHz) is the frequency band used (Topex/Poseidon, Jason-1, Envisat, ERS, etc.).





Geos-3 and Seasat laid the foundation for a new generation of ocean satellites.

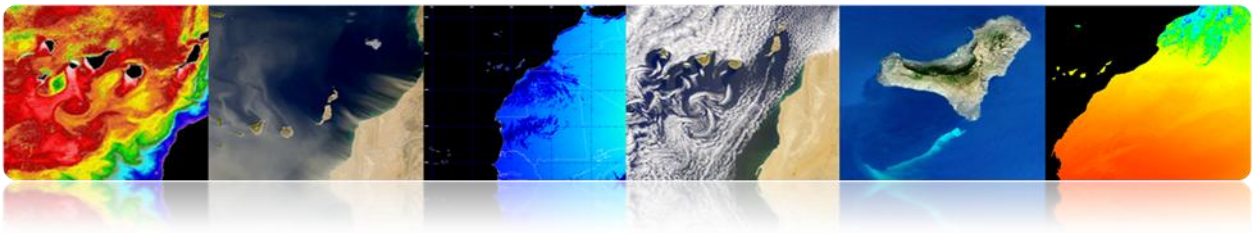
In the 1980s, only Geosat was launched into orbit, whose data were ranked at first.

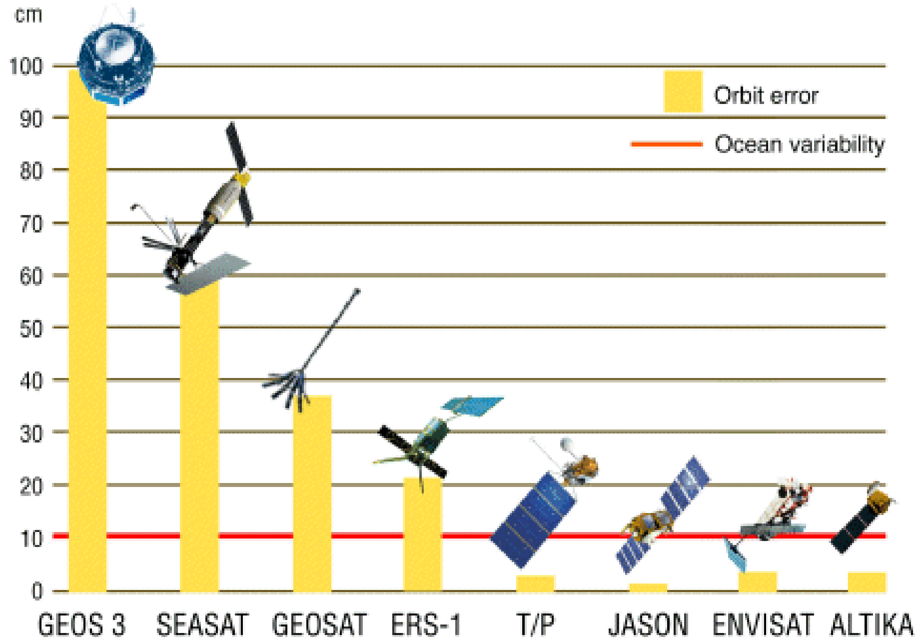
In the 1990s, Topex/Poseidon, with a precise orbit determination and location system as Doris allowed for better accuracy of satellite positioning and monitoring of height sea surface variations.

Altimetry began providing vital information for a larger user community with ERS-1 and later with ERS-2.

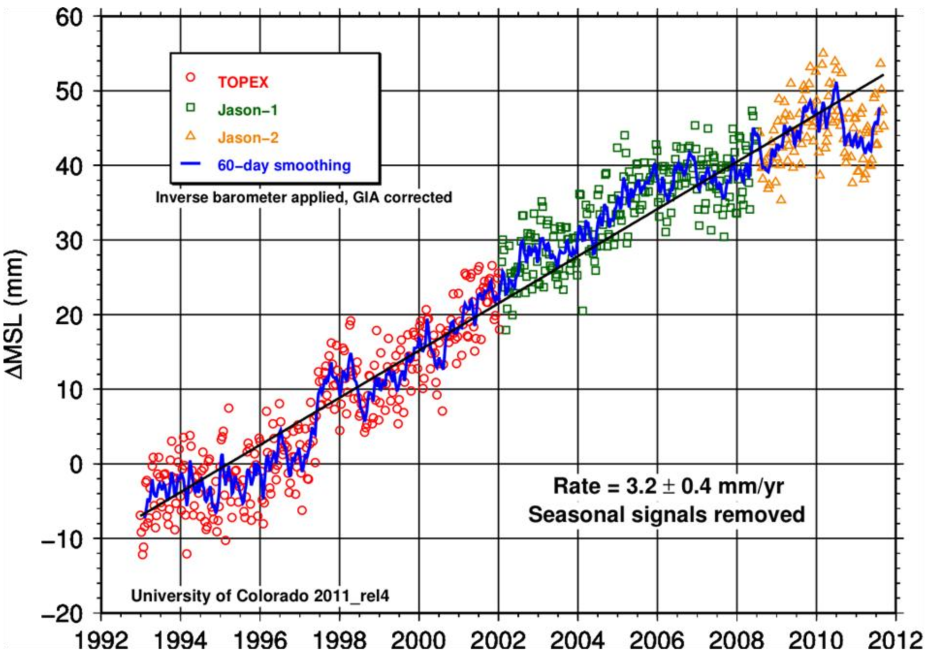
Jason-1 and Jason-2, with a relatively short repeat cycle (10 days), allowed to observe more often the same point in the ocean. Both satellites have a 5 day time span.

Envisat had a longer cycle (30 days from November 2010), but closer spacing between exploration bands (90 kilometers in the equator).

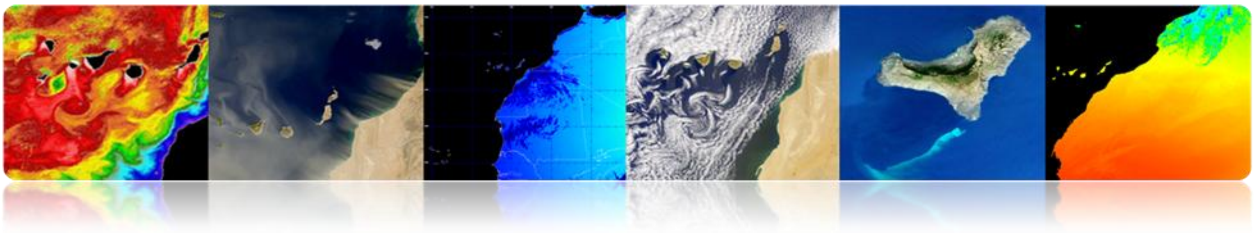




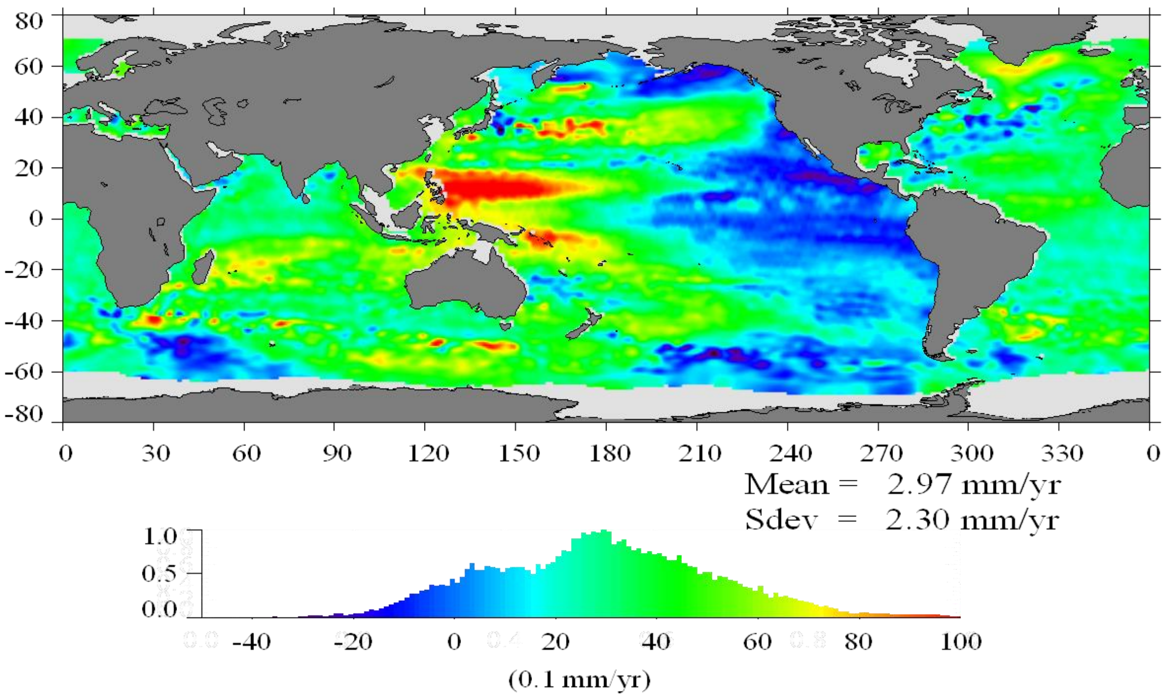
SSHA: Global mean sea level variations



http://podaac.jpl.nasa.gov/highlights/MEaSUREs_TPJAOSv1.0_SSH



SSHA: Regional mean sea level variations, interpolated onto a 1°x 1° grid 1993-2011

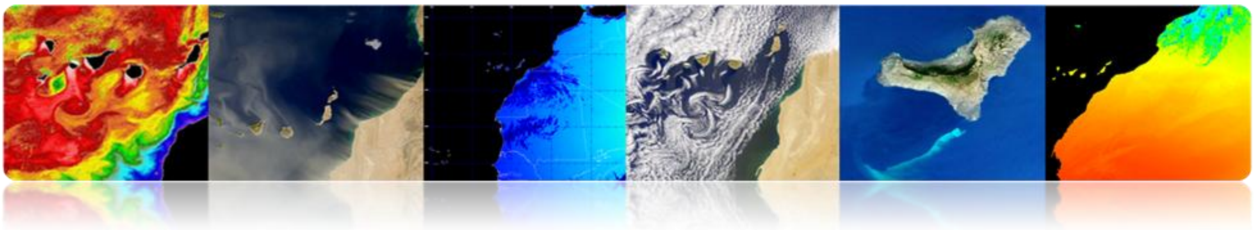


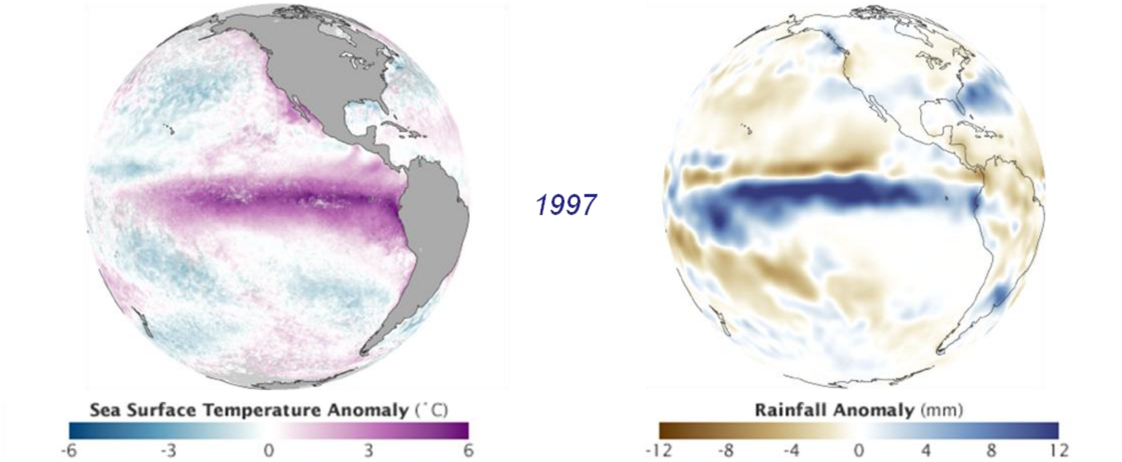
Temperature and height anomalies

Application combining data from temperature and sea level: El Niño

El Niño is caused by the occasional burst of warm surface waters in the Pacific close to Peru's and Ecuador's coast. El Niño brings severe weather patterns such as droughts, floods and cyclones.

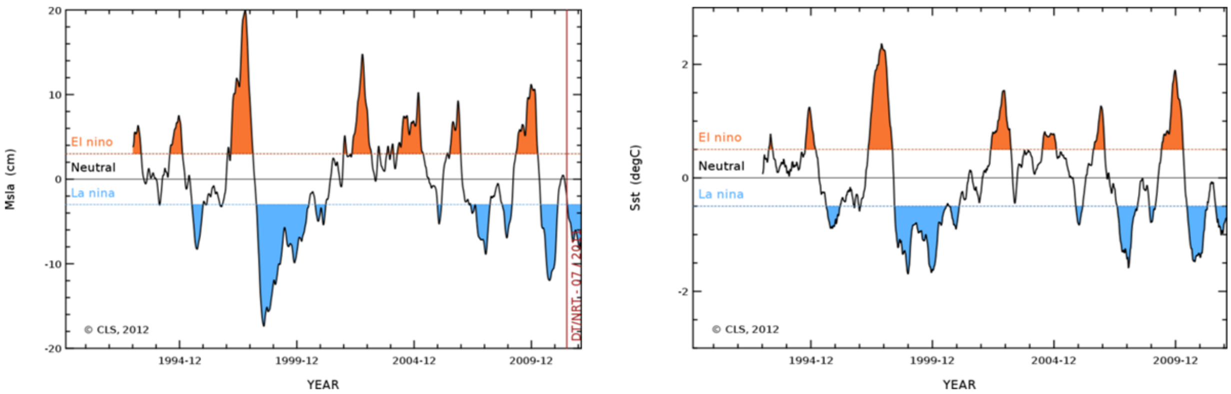
Nowadays, it is possible to predict El Niño from ocean data.



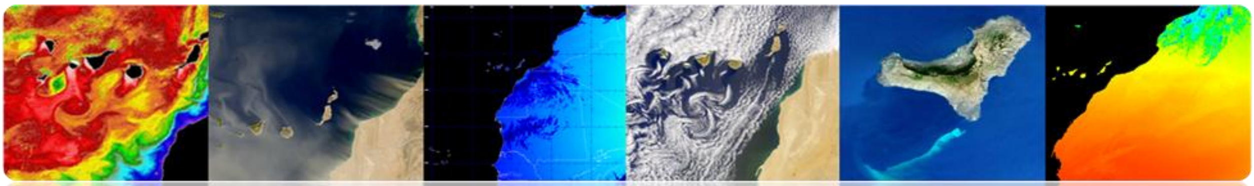


El Niño - La Niña

- El Niño / La Niña are quasi-periodic patterns that occur across the tropical Pacific Ocean roughly every five years.
- La Niña is an ocean-atmosphere phenomenon that is the counterpart of El Niño. During La Niña, the sea surface temperature in the equatorial area of the Eastern Central Pacific Ocean is lower than normal by 3-5° C.

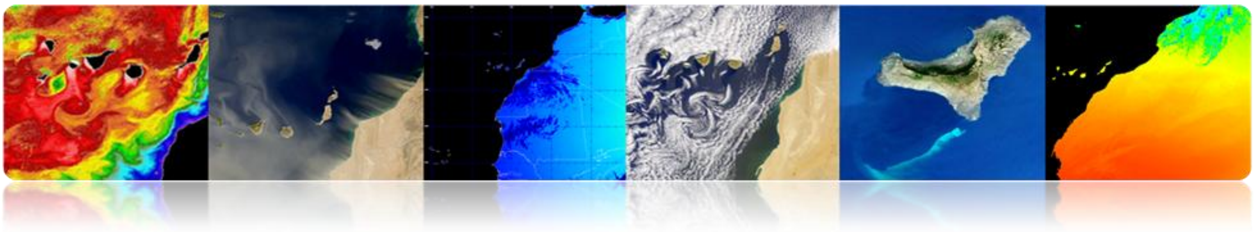


El Niño "the little boy" refers to the Christ child, because periodic is usually noticed around Christmas.



❑ SALINITY

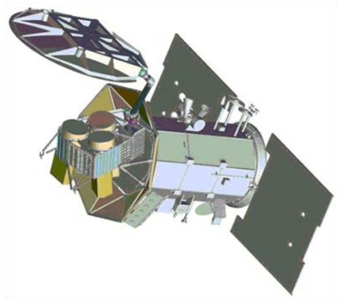
- It is defined in the ocean as the grams of salt per 1000 grams of water.
- One gram of salt per 1000 grams of water is defined as 1 psu (practical salinity unit). In the open sea the salinity range is usually 32-37 psu.
- Salinity varies due to evaporation and precipitation over the ocean, as well as river runoff and snow melting.
- Along with temperature, salinity is an important factor in contributing to the changes in the density of seawater and, therefore, in the circulation of the ocean.
- While sea surface temperature has been measured from space for more than three decades, the technology to measure sea surface salinity from space has only recently emerged. As oceans have 1,100 times the heat capacity of the atmosphere, ocean circulation becomes critical for the understanding of heat transfer through the Earth and therefore for the understanding of climate change.
- Sea Surface Salinity (SSS) can be measured by passive microwave radiometers working around 1.4 GHz.
- The power received by the radiometer is proportional to the microwave emissivity and the temperature of the ocean surface. Salt increases reflectivity and decreases emissivity of water. Thus, if the water temperature can be obtained by other means, the salinity may be deducted from the received radiation.
- Satellite remote sensing was not able to measure salinity up to the year 2009, when the platform SMOS (ESA) was launched. SMOS measures SSS by using 24 low noise radiometers in each arm. These arms are 4.5 m long and have an Y-shaped antenna. Its accuracy is 0.1-0.2 psu and its resolution is about 35 km.
- Aquarius (NASA) was launched in 2011 and includes a radiometer plus a scatterometer to measure salinity and to consider the effects of sea surface roughness in the signal reaching the radiometer.



Missions to measure salinity

SMOS (ESA)

Noviembre 2009



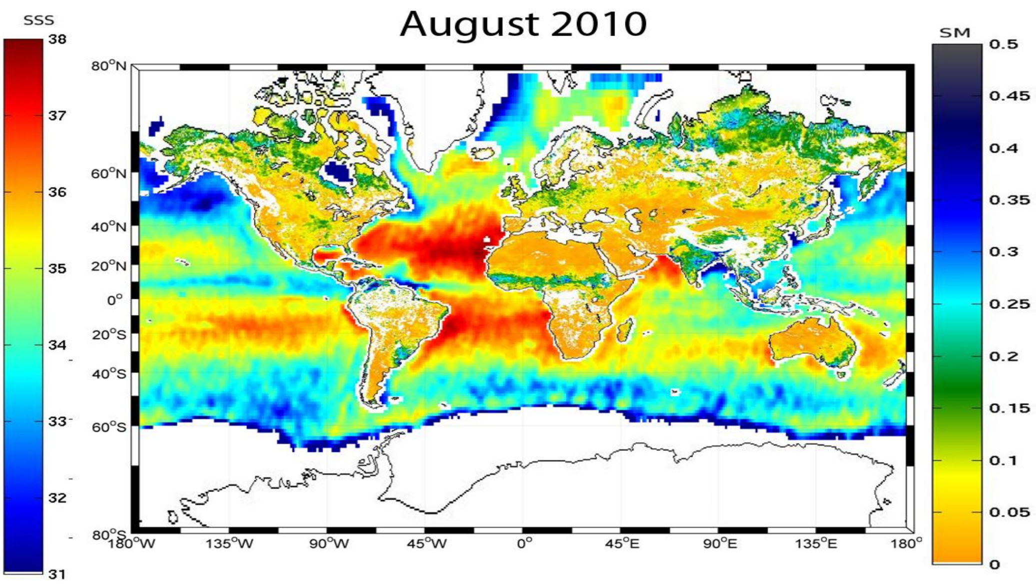
AQUARIUS (NASA)

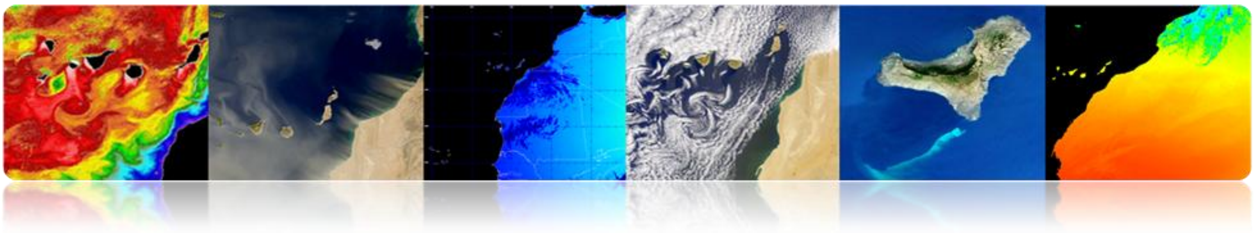
Junio 2011

http://www.cp34-smos.icm.csic.es/
http://www.esa.int/SPECIALS/smos/index.html
https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/smos

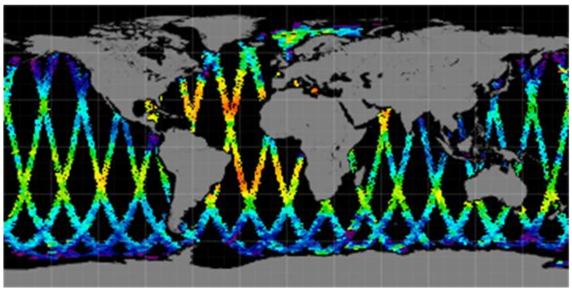
http://aquarius.nasa.gov/index.html

1st Global map salinity (SMOS)

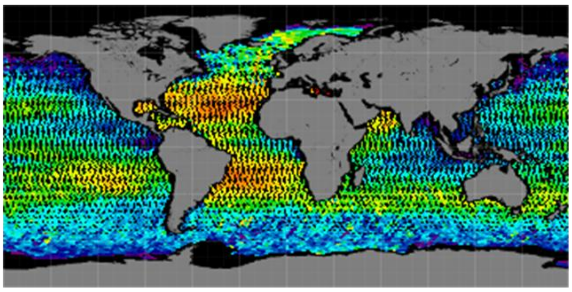




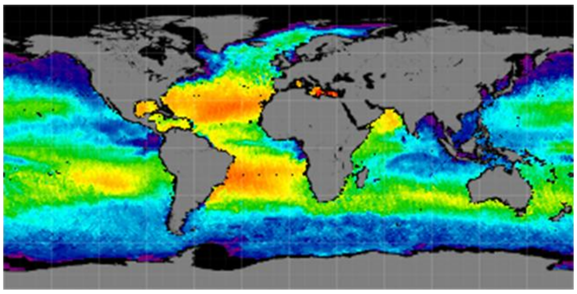
Salinity Maps (AQUARIUS)



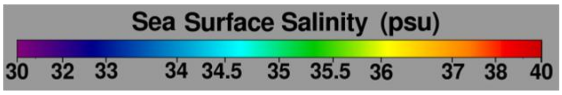
Mapa diario (1 Febrero 2013)



Mapa semanal (Febrero 2013)

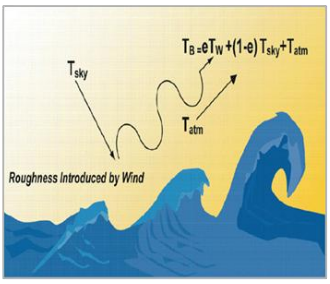


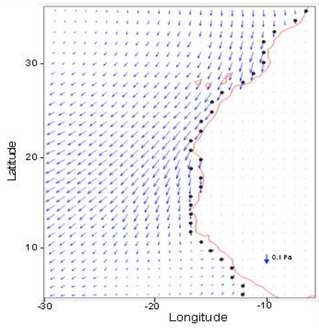
Mapa mensual
(Febrero 2013)



❑ SURFACE WINDS

- Ocean wind is the motion of the atmosphere relative to the surface of the ocean.
- Typically, winds over the ocean are measured with anemometers close to the surface and attached to buoys, platforms or ships. Winds can also be remotely measured by using Doppler radars that can capture the sea wind (the scope is usually limited to several hundred kilometers due to drop of the signal).
- More recently, advances in remote sensing satellites have allowed near surface wind measurements using passive and active instruments.



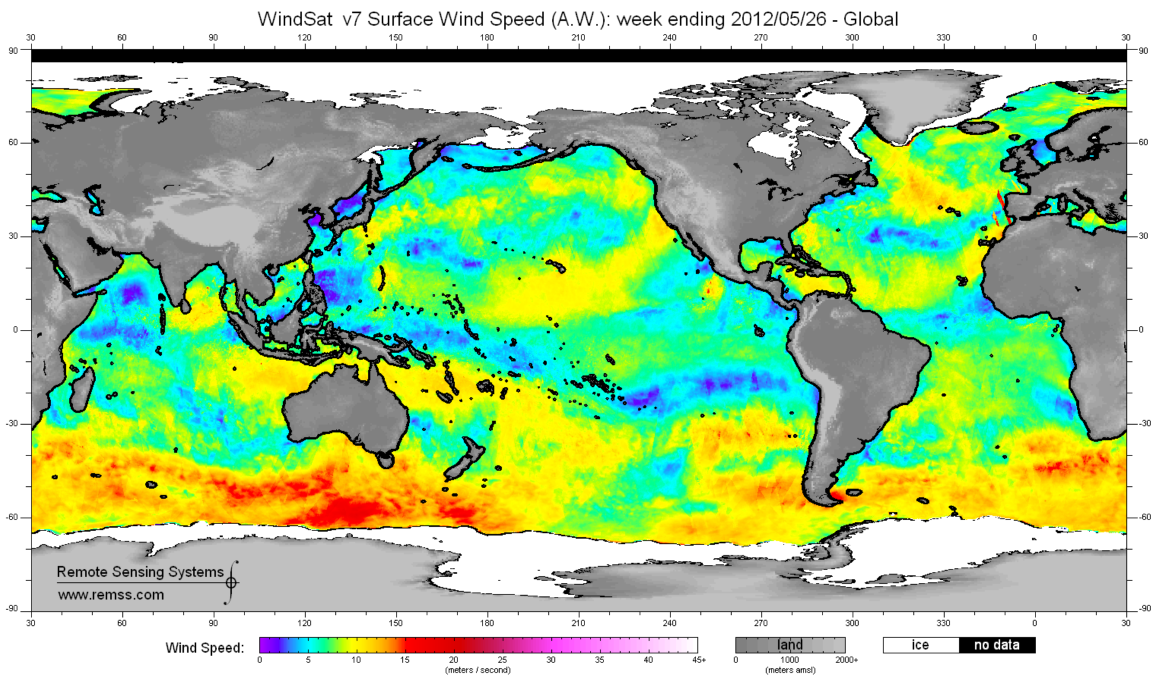


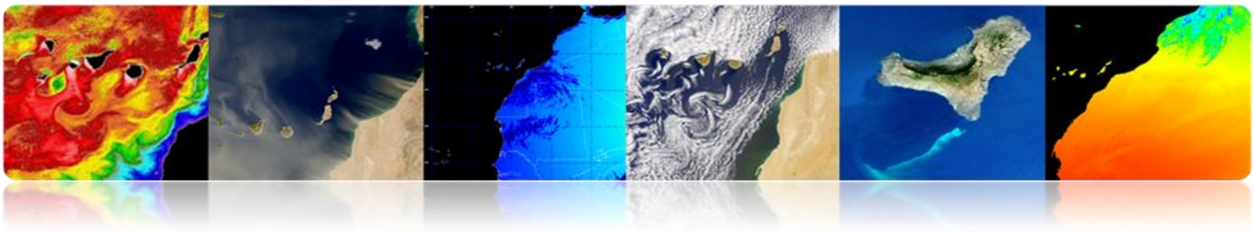
Remote Sensing Instruments

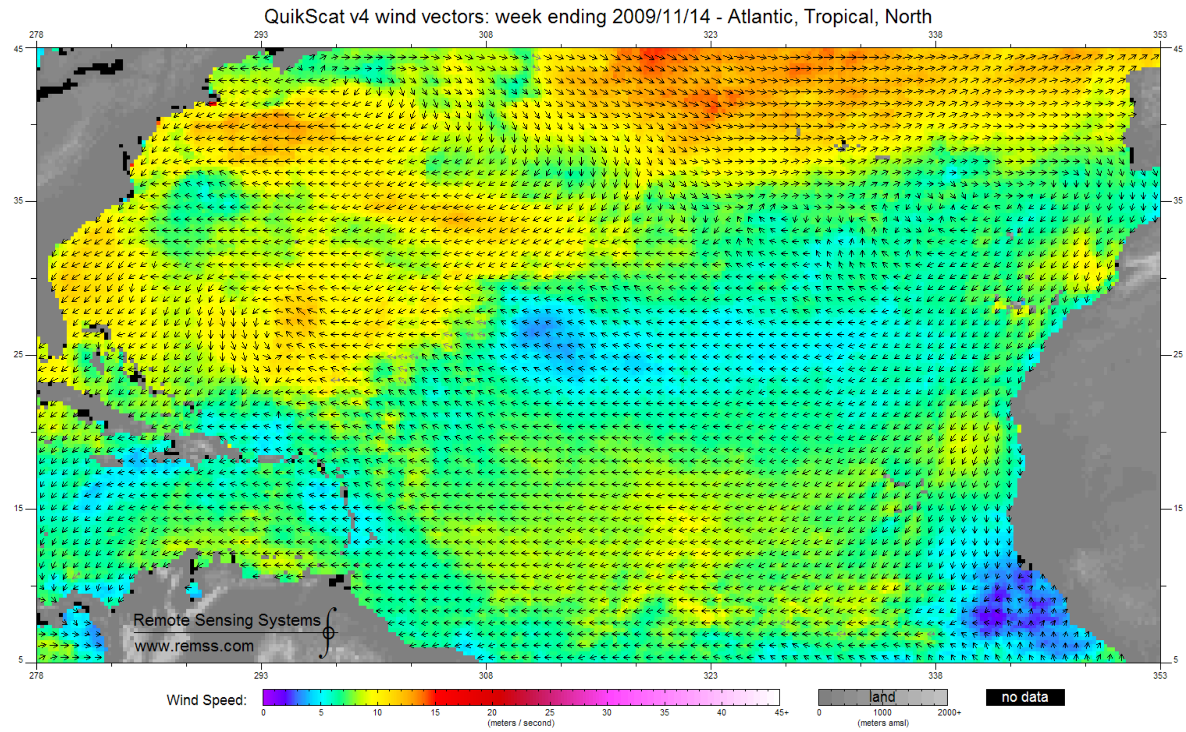
- **Passive Radiometer:** Ocean surface rapidly responds to the movement of air above it, which provides a different roughness pattern depending on the relative velocity and the wind direction in relation to the ocean surface. The roughness of the ocean surface provides a specific "brightness" that can be detected by using passive microwave radiometers and can be accurately translated to the wind velocity near the surface.

- **Active radars:** Specific microwave wavelengths are sensitive to Bragg scattering, which is a characteristic of centimeter-scale ocean surface waves, known as capillary waves. They are directly influenced by changes in the near-surface winds, which enable specialized radars, known as scatterometer, observe these changes. These radars transmit microwave pulses to the ocean surface, which immediately scatters a portion of the reflected energy back to the radar. Once the radar cross section is normalized, the near-surface wind speed can be calculated as a function of the backscattered energy. Unlike passive microwave radiometers, the active radar system can combine measurements from different azimuth angles to obtain the approximate direction of the wind.

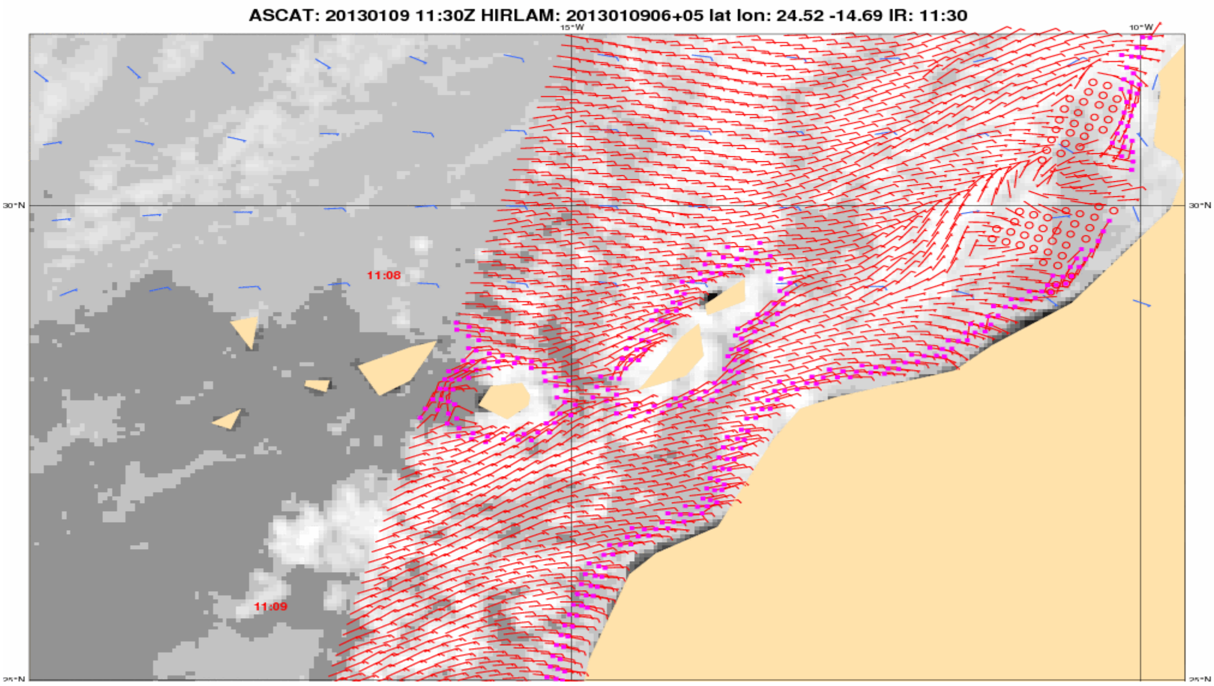
Example of surface winds



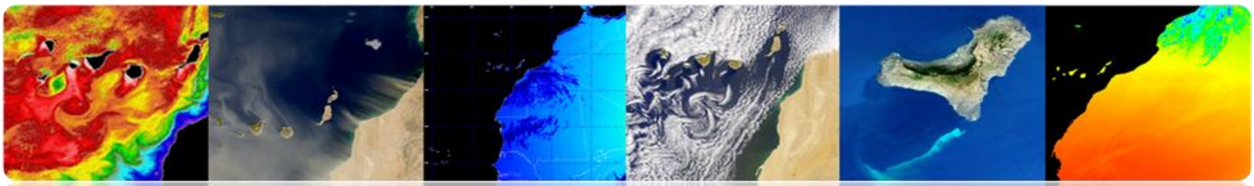




QuikScat v4 wind vectors: week ending 2009/11/14 - Atlantic, Tropical, North
Remote Sensing Systems
www.remss.com
Wind Speed:
(meters / second)
land
(meters amsl)
no data



ASCAT: 20130109 11:30Z HIRLAM: 2013010906+05 lat lon: 24.52 -14.69 IR: 11:30
11:08
11:09



❑ Marine Currents

Sea currents are continuous and direct movement of ocean waters, generated by forces acting on this medium. Ocean currents can flow great distances, and play a key role in determining the climate of many regions of the Earth.

Currents can be caused by wind pressure, thermohaline gradients or tidal force. These currents are also influenced by the Earth's rotation through the Coriolis deflection.

Ocean currents can be divided into surface streams (10%) and thermohaline currents (90%). Surface currents are primarily driven by the wind, while thermohaline circulation is due to variations in temperature and salinity (these streams are slow compared to the movement of surface).

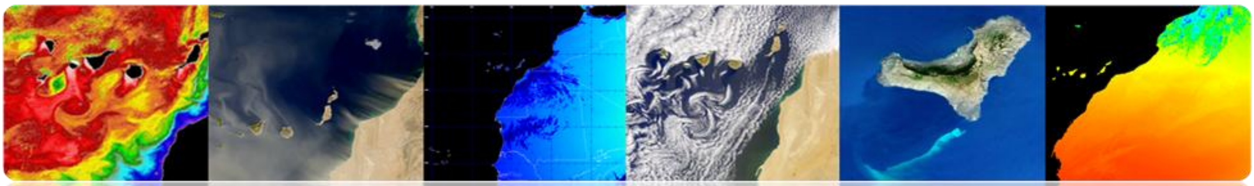
▪ Types of currents

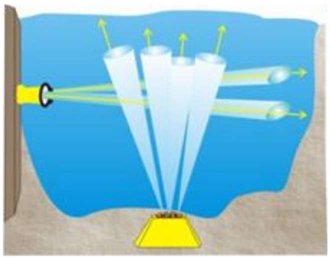
- **Large scale circulation**

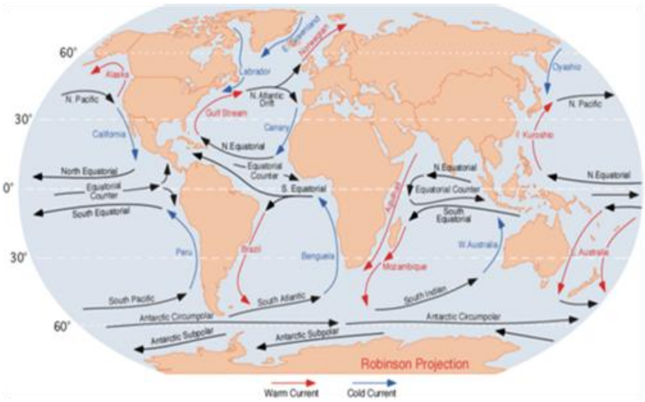
In the Northern hemisphere, currents flow around hills in clockwise direction and counterclockwise around valleys: The opposite phenomenon occurs in the Southern hemisphere. These currents form whirls around both sides of the equator. Another large scale circulatory phenomenon is planetary waves.

- **Mesoscale circulation**

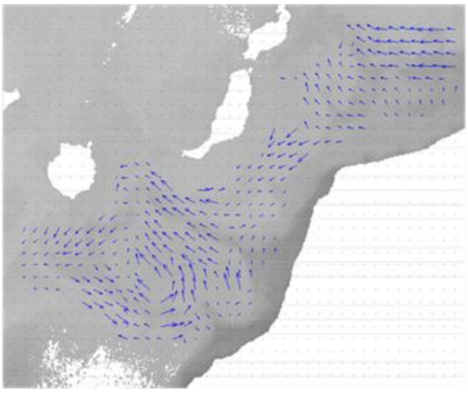
Mesoscale circulation is defined as an energetic phenomenon that at spatial scales ranges from ten to several hundred kilometers and at temporal scales ranges from a few days to several months. Mechanisms of genesis are mainly large scale circulation instabilities, interactions between currents and bathymetry, and pressure exerted by the wind.







Large-scale circulation

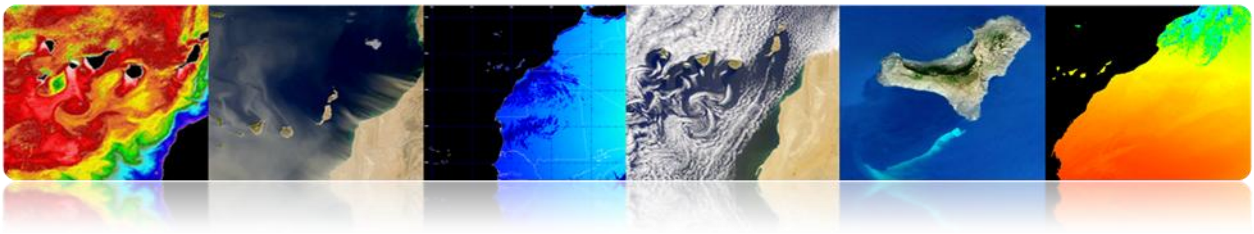


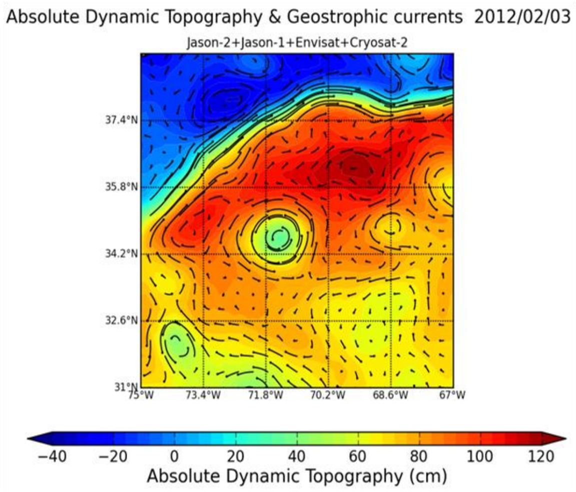
Medium-scale circulation

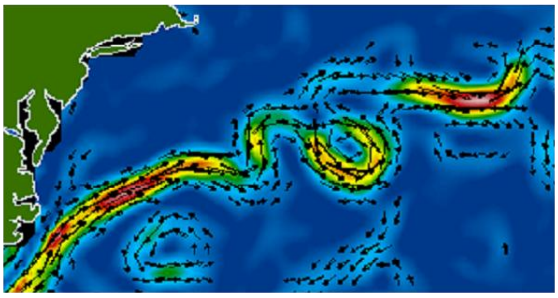
Currents can be estimated by using remote sensing altimeters (SSHA) or by calculating the optical flow in sequences of sea surface temperature or chlorophyll concentration images. However, in this case clouds could cause problems and the vector field can only be estimated in areas that are not completely uniform, i.e. mesoscalar structure areas.

- ## Altimeter

Ocean currents can raise the height of the sea surface up to one meter above the surrounding area. Therefore, currents can be calculated by measuring height variations with on-board satellite altimeters.



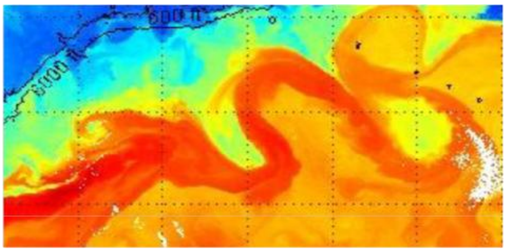




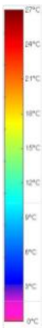
Altímetros (Envisat, Jason-1, Topex/Poseidon, and GFO)

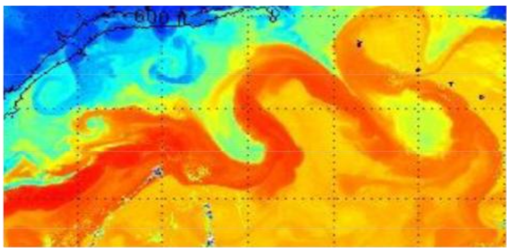
SST Sequences

It is the motion estimation in image sequences, typically using region matching techniques.

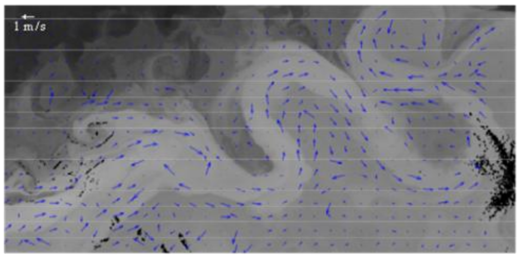


19 April 2005 18:37

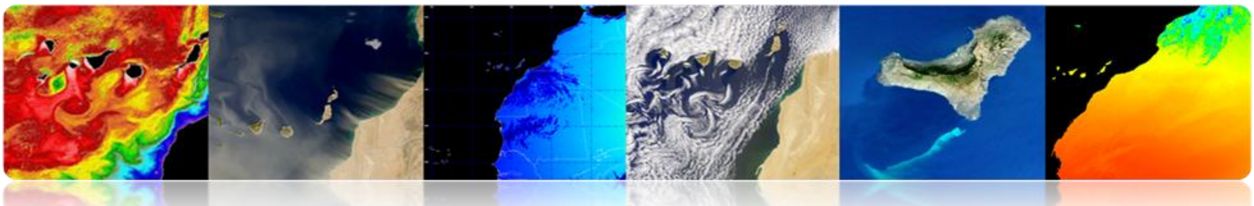




20 April 2005 2:29



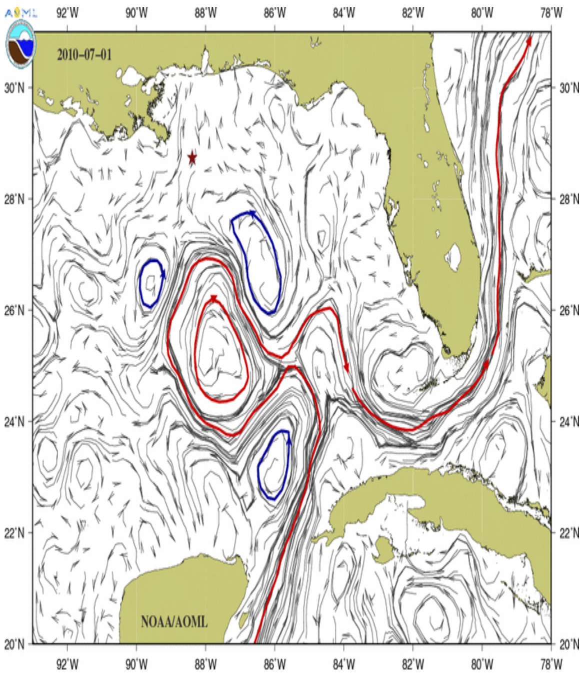
Estimación movimiento - MCC



▪ Eddies: ocean storms

These 50-300 km wide structures with a circular or elongated shape are similar to storms, but they occur in the ocean. They can be clearly seen in maps of sea surface anomaly from altimeters or in temperature images.

Eddies are important for ocean circulation and climate -for the transport of heat and movement-, and for marine biology and fisheries, as they cause the mixture of different types of ocean waters that influence conditions that allow the marine food chain to develop.



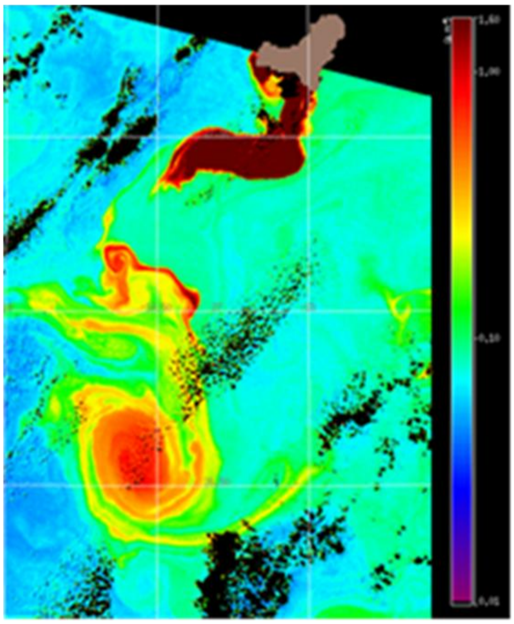
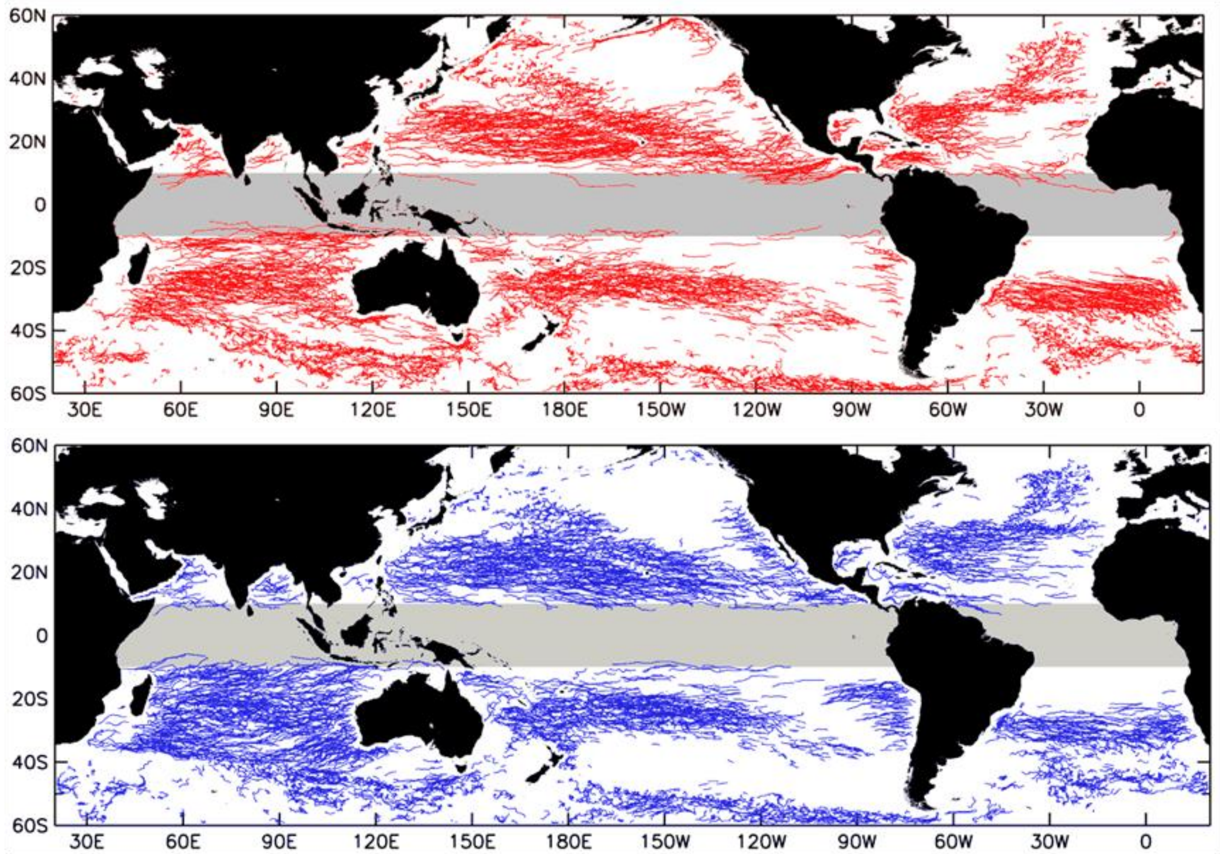


Imagen MERIS (ESA)

Over 10 years of satellite data, Analysis of Sea Level Anomalies, reveals the high activity areas twists or eddies during those years. Anticyclonic (see above) and cyclonic (see below) eddies are shown with lifetimes longer than 18 weeks. This information has been provided from altimetry data.

Both types of eddies move Westward, and with a slight tendency (less than 10°) to the equator or toward the poles, respectively.



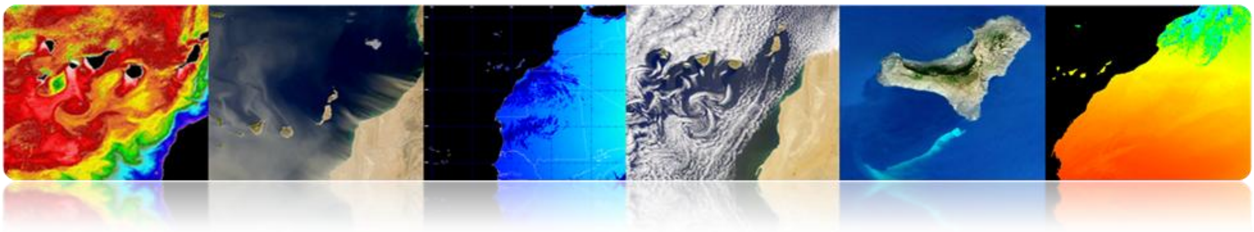
❑ OCEAN COLOR

It is the spectral radiation measurement obtained from the reflectance in the visible band.

Main objective: it is to extract concentrations of marine phytoplankton.

Phytoplankton is the set of aquatic autotrophic plankton, which has photosynthetic capacity and live dispersed in water. It is important to monitor phytoplankton because:

- It fixes carbon dioxide into organic matter.
- It plays a key role in the global carbon cycle and climate.
- It is responsible for about half of the Earth’s net primary production.
- It is the basics of the marine food chain.
- It affects several industries, mainly fishing.
- It helps to monitor coastal waters and their quality.



▪ Remote Sensing: Top Products

The main products obtained by satellite are:

- **Normalized water-leaving radiances (nLw)**

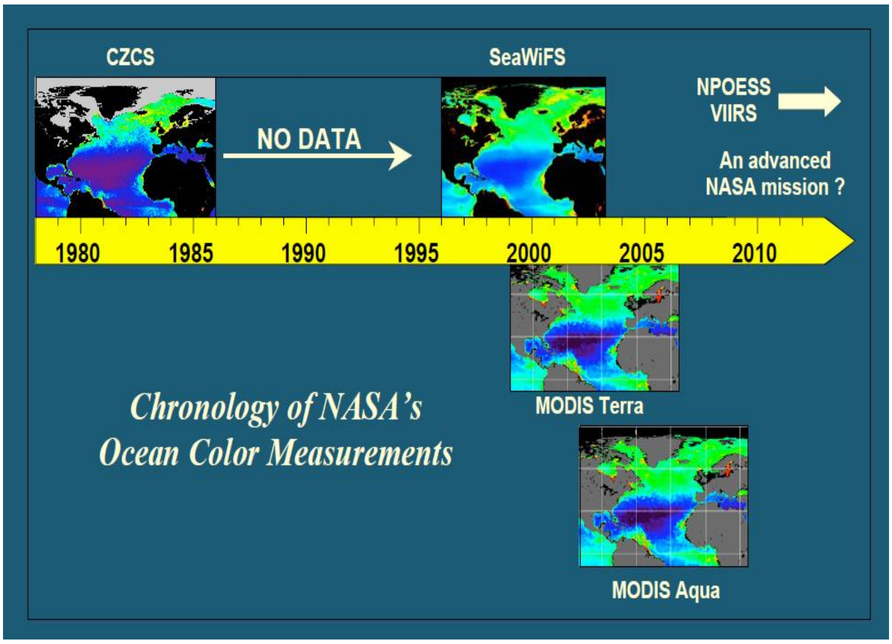
Radiance emerging from marine subsurface in each spectral band analyzed and spreads through interface sea-air.

Units:μW cm-2 sr-1 nm-1

- **Chlorophyll-a concentration (Chl)**

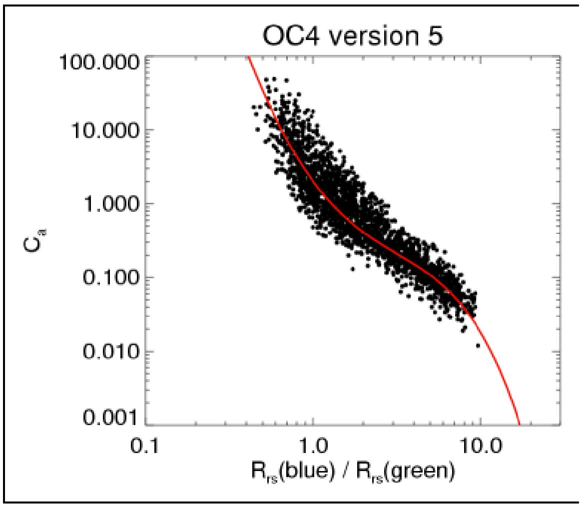
Phytoplankton primary photosynthetic pigment used as an index of phytoplankton biomass.

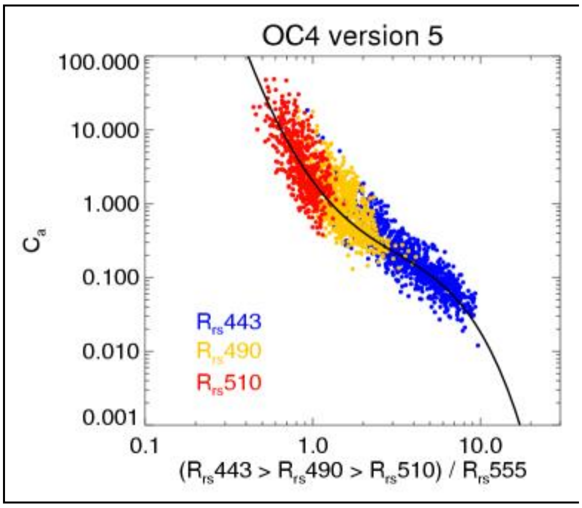
Units: mg m-3



❑ CHLOROPHYLL CONCENTRATION

- Open Oceans OC algorithms are the most widely used.
- There are variations depending on the number of bands in the range of green and blue.
- OC3 and OC4 algorithms are the most current and implemented for MODIS (NASA) and MERIS (ESA) sensors.





General expression of the algorithm

log10 (Ca) = (c0 R c1 + c2 + c3 + R2 R3 R4 + c4)

where R is log10 (max (Rrs 443, 489 Rrs, Rrs 510) / 555 Rrs)

Bands used

OC4 = 443> 490> 510/555

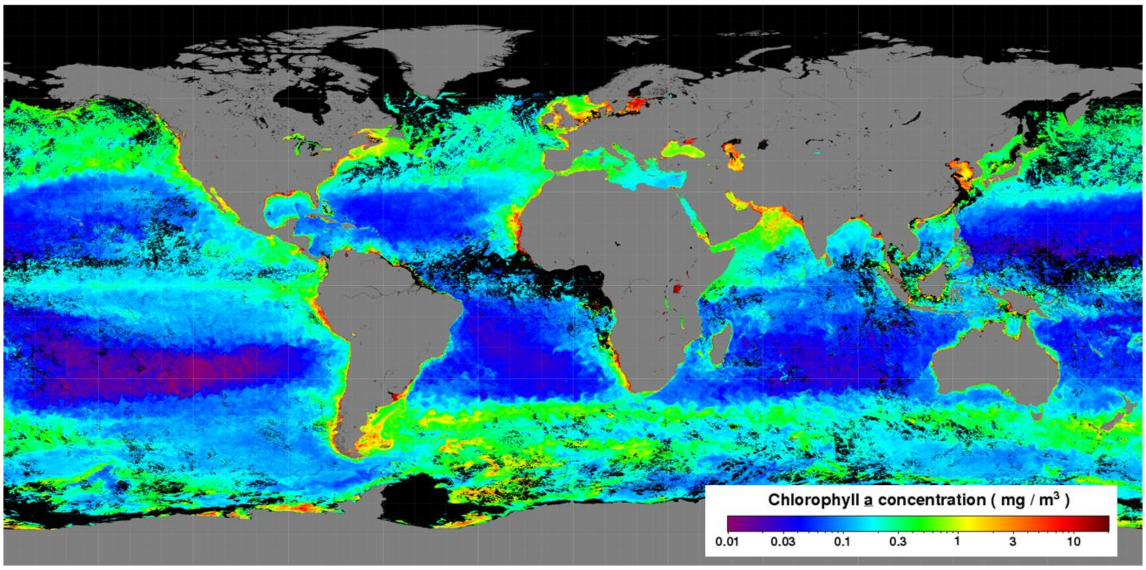
OC3 = 443> 490/555

OC2 = 490/555

Clark = 490/555

Carder = 490/555

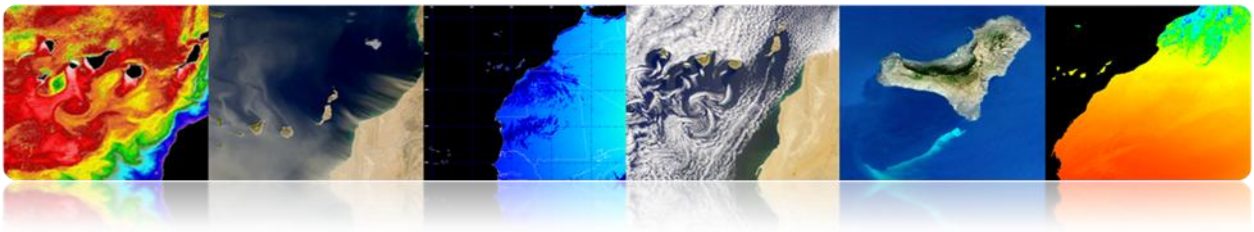
Monthly Map for February 2013 (MODIS-AQUA)

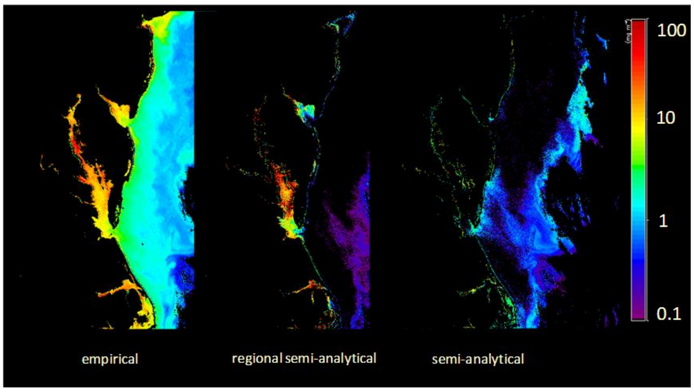


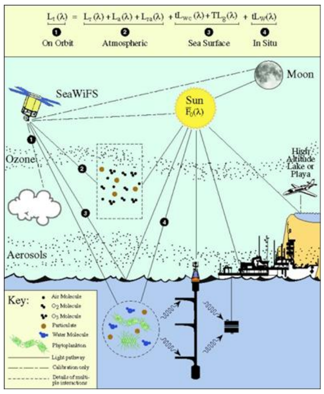
- ## Regional Scale (Case 2 waters)

The algorithms shown above cannot generally be used for coastal or inland waters, where the difficulty is greatly enhanced by:

- Temporal and spatial variability
- Pollution from land or seabed
- Aerosols (dust, pollution)
- Suspended sediments and CDOM
- Atmospheric effects and anthropogenic emissions

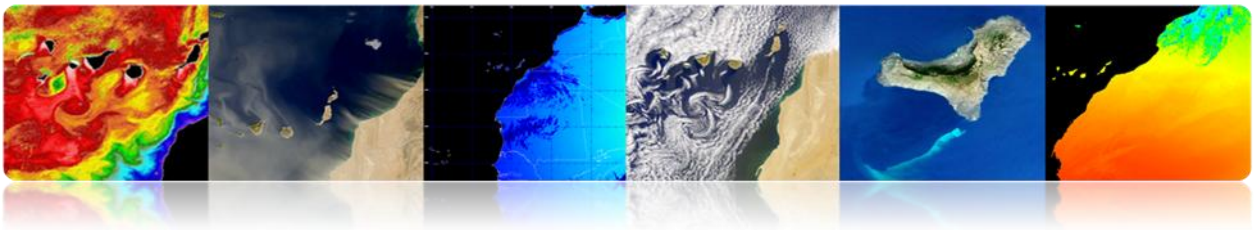




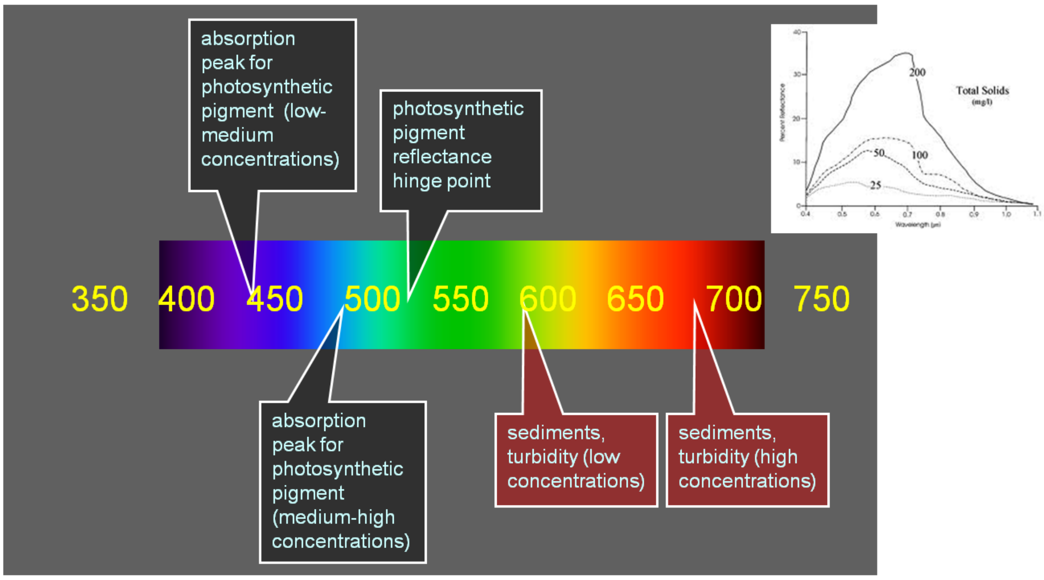


❑ WATER QUALITY

- Monitoring water quality by remote sensing is normally obtained by several key parameters: turbidity, temperature, chlorophyll, CDOM, etc.
- The direct relationship between the variation in the reflectivity of the channels and the variation of water quality parameters was studied by low and medium spatial resolution sensors (SeaWiFS, Modis MERIS, etc.) for open waters.
- Recently, the high-resolution WorldView2 satellite with 8 spectral bands has been launched and provides measurements of water quality in coastal or inland water with a resolution of 2 m.



Spectral characteristics



▪ Suspended Matter

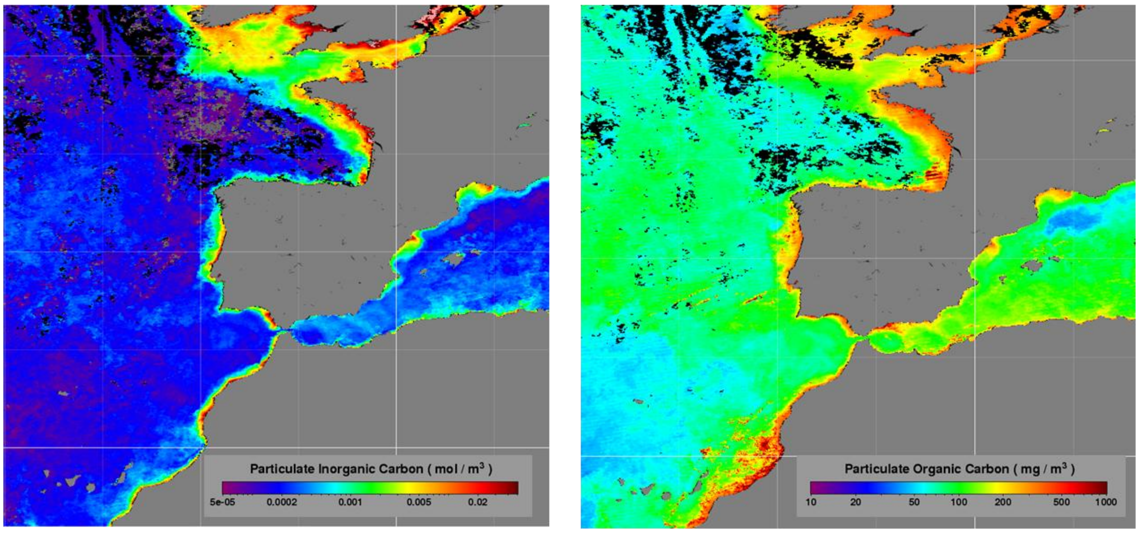
- **Turbidity** is defined as the lack of transparency of a liquid due to the presence of suspended particles. The more suspended solids are there in the water, the dirtier the water look and the higher its turbidity is. Turbidity is considered a good measure of water quality. The more turbid the water gets, the lower its quality is. Turbidity affects the degree to which light is scattered and absorbed by molecules and particles.

- **Shallow coastal waters** are often characterized by high turbidity caused by resuspension of bottom sediments or human-induced sediments (works, dredging, etc.).

- **Algorithms** that estimate **suspended matter** in the water (Total Suspended Mater - TSM) are based on the increased reflectivity of water in the red and green bands.

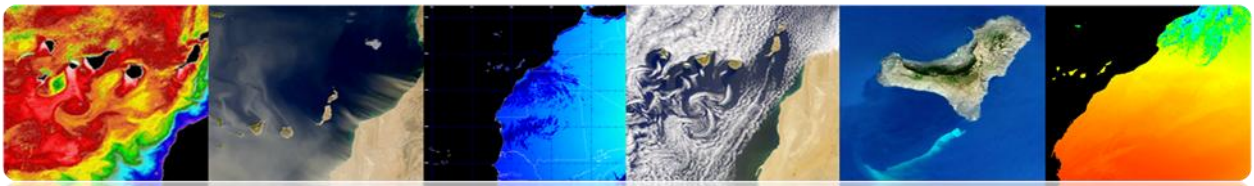
There is currently no accurate and reliable generic algorithm for quantification of TSM in coastal areas

- There are a variety of algorithms that calculate turbidity mainly using several bands near the red.
- Algorithms directly using a band reflectivity (i.e., polynomial) are more exposed to noise.
- MODIS provides 2 products of suspended particulate matter which are inorganic (PIC) and organic (POC) matter.



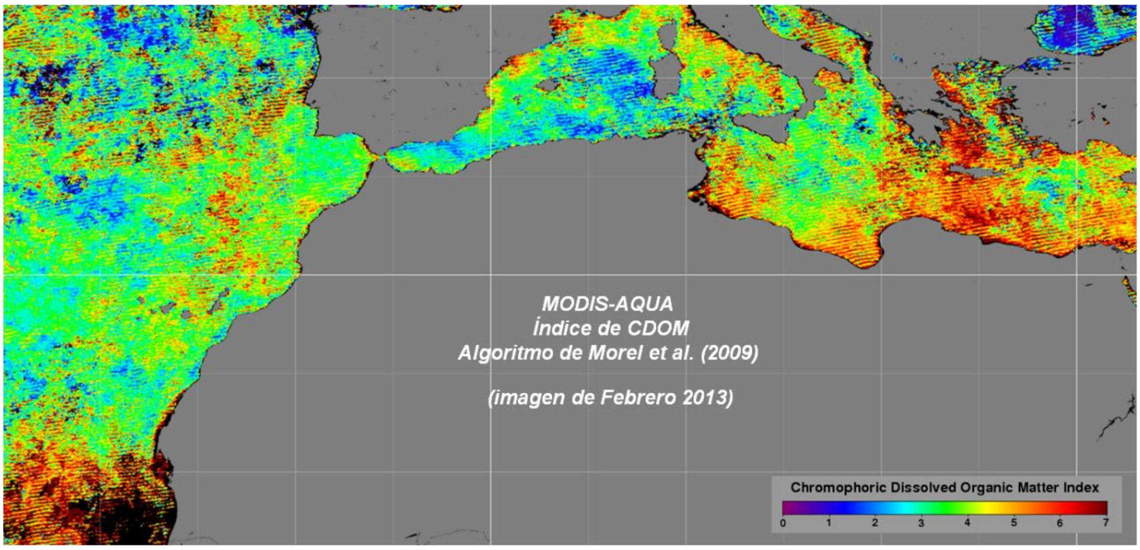
Dissolved Matter

- **Colored dissolved organic matter** (CDOM, yellow substance, gelbstoff) is the optically visible component of organic matter dissolved in the water. It has an important effect on the biological activity of aquatic ecosystems.
- CDOM absorbs short wavelengths (UV, blue), while clean water absorbs the higher wavelengths of the visible spectrum. That is why water turns into a greenish-yellow tone.



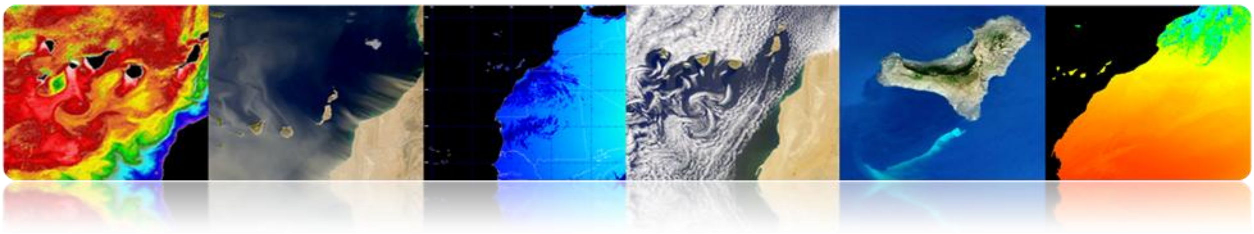
- Algorithms for estimating CDOM are normally based on the variation of the reflectivity of the yellow band. They are not robust or noisy.
- CDOM interferes with the remote detection of chlorophyll concentrations. Therefore, algorithms for the detection of CDOM are used for discriminating the matter against the photosynthetic pigments and inorganic suspended matter.
- Here we are an example of an algorithm for calculating CDOM:

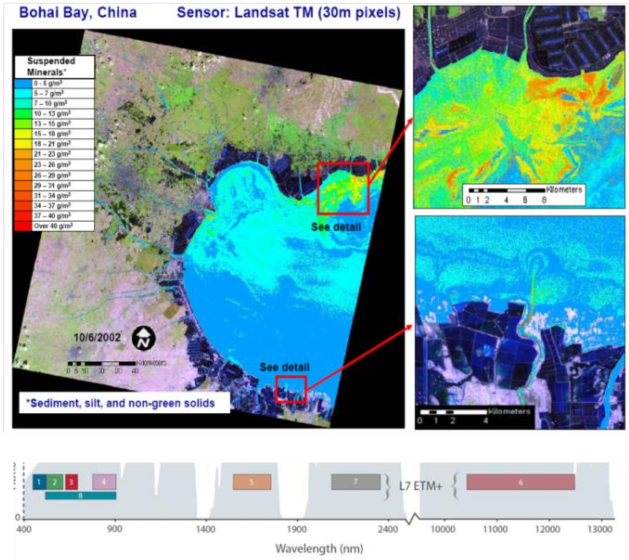
$$CDOM\ (mg/l) = 5456.63 * R\_605 + 298.45$$



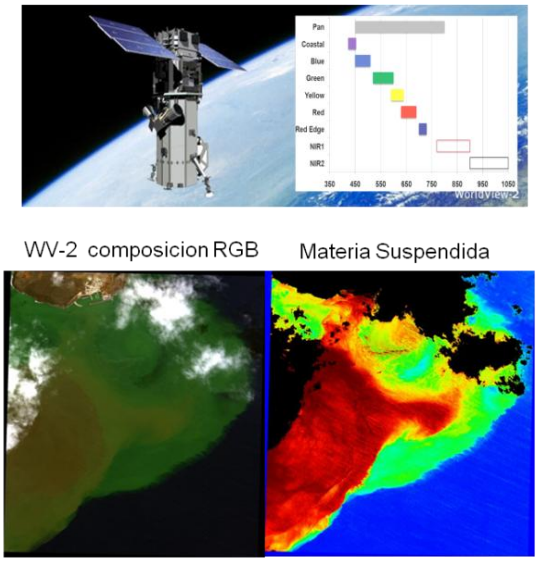
▪ Medium- High resolution

One of the main current challenges is to study water quality by using medium and high resolution satellite data.





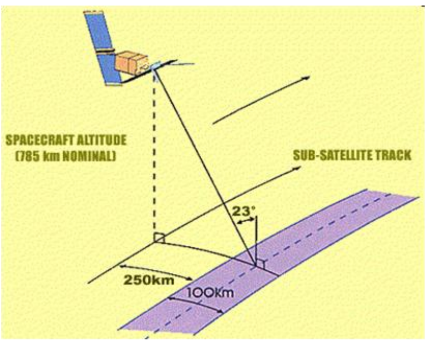
Landsat

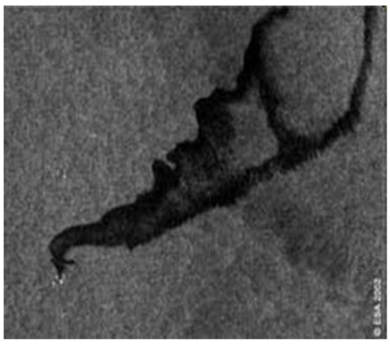


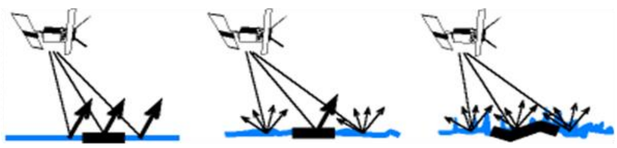
Worldview-2

▪ Oil spills

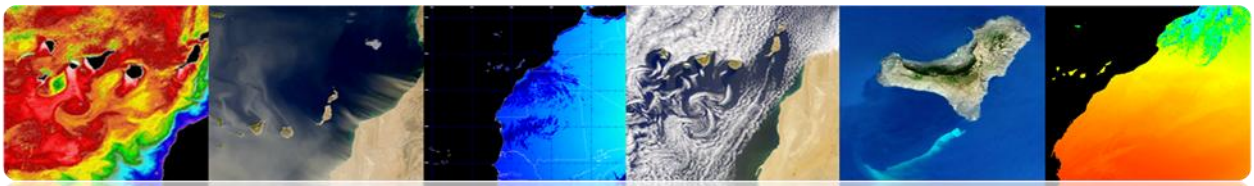
Another aspect of water quality is the detection of oil spills. This is possible using data from synthetic aperture radars (SAR) that detect the roughness of the sea. Oil spills are easily detectable under certain wind conditions, because the backscatter is much lower in areas contaminated by the spill.



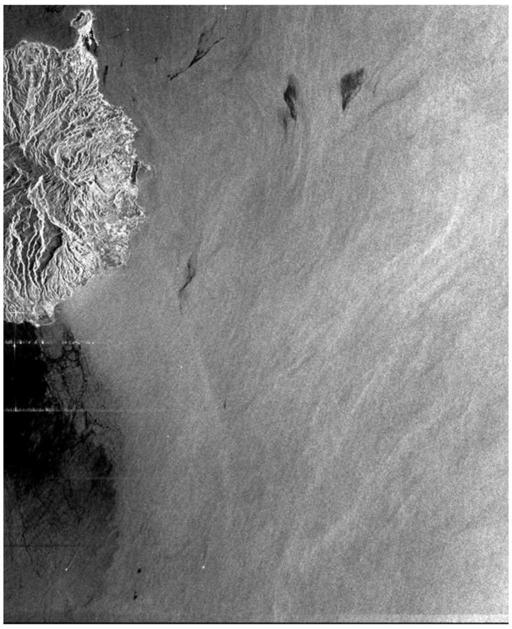




▪ Oil spills: a case study



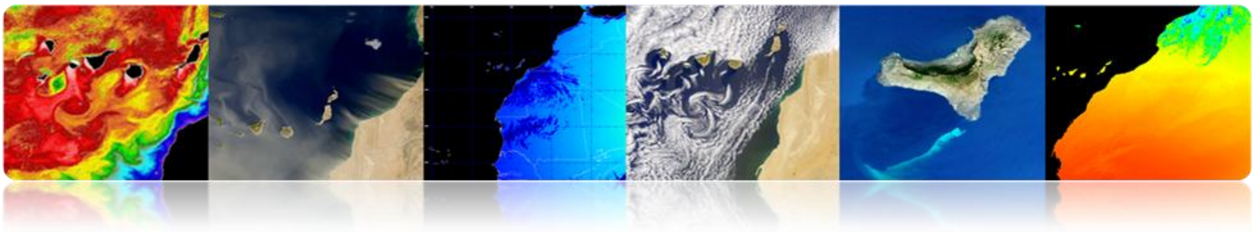
- ERGOS (Environmental Response Team for Black Tide)
- WWF/Adena, ESA, INTA, Directorate General of Coasts, Merchant Navy, SASEMAR and the Canary Islands' Government.
- Period: June 2000 - October 2002
- Area: Canary Islands (300, 000 km2)
- Detectability basically depends on wind speed (3-6 m / s), sea state and how old is the stain.

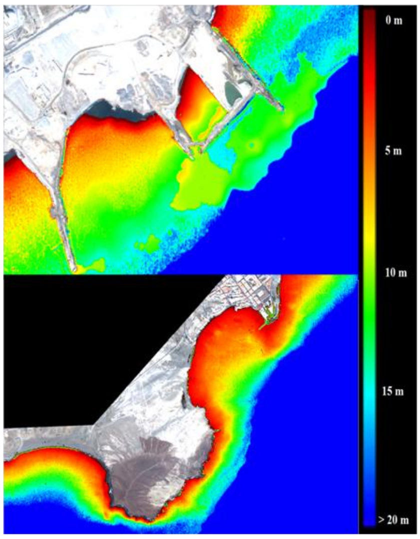


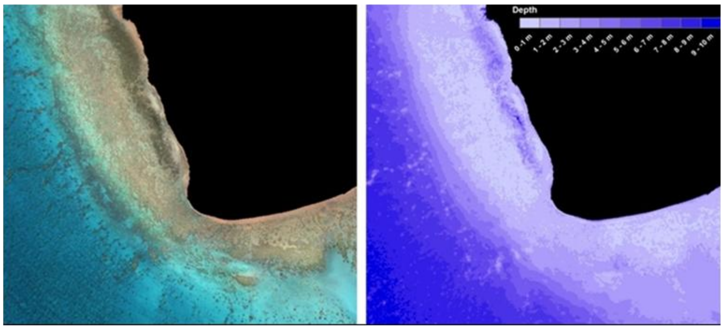
Year	Passes analyzed	Oil spills detected	Passes with spills
2001	84	58	69 %
2002	113	28	25 %
Total	197	86	44 %

❑ BATHYMETRY

A very recent application is to obtain the bathymetry of shallow coastal areas -up to 20 or 30 meters- from high resolution satellite data. It is a very complex issue, because only a few bands manage to penetrate far enough and the effects of seabed reflectivity have to be avoided.



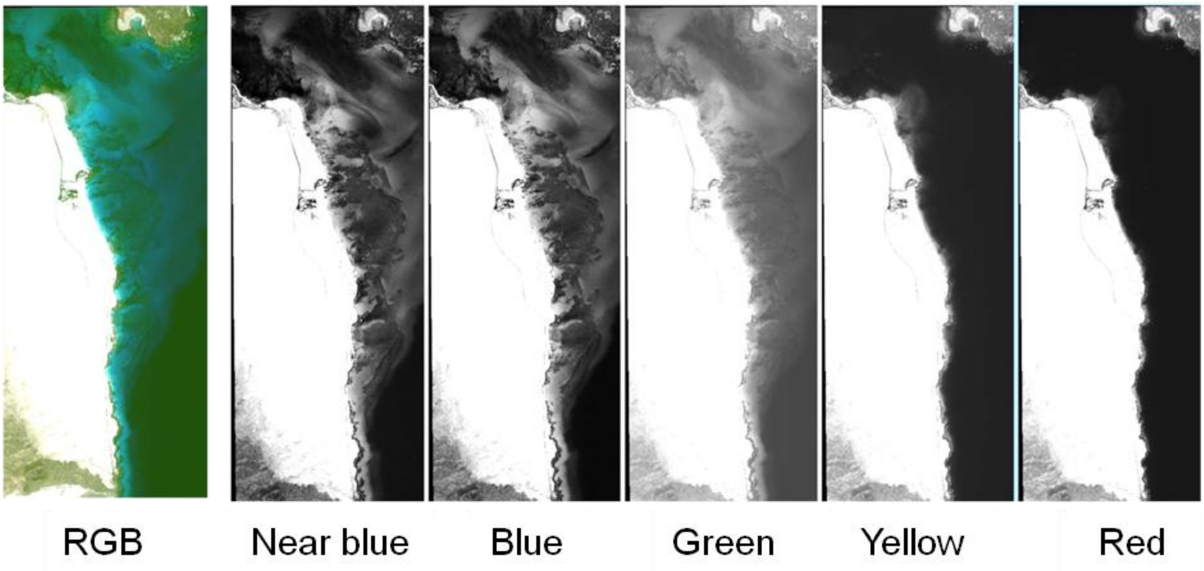


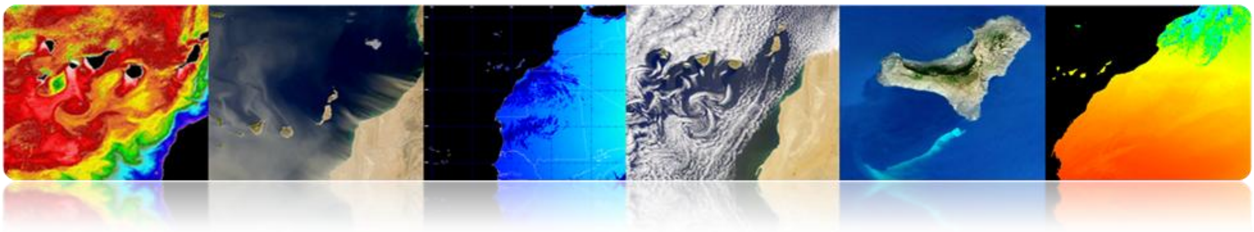


❑ BENTHIC CLASSIFICATION

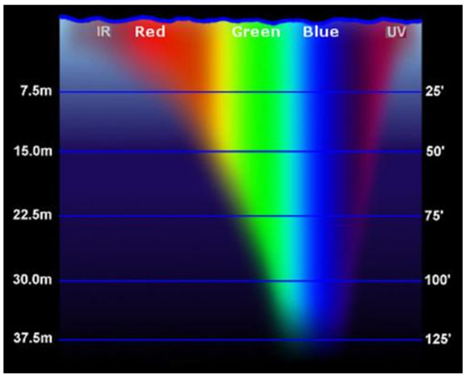
The classification of the seabed is a difficult issue to solve from remote sensing data. It is only possible a shallow depth classification, since light penetration in coastal waters is much lower than in the open sea and basically only just blue and green channels can penetrate.

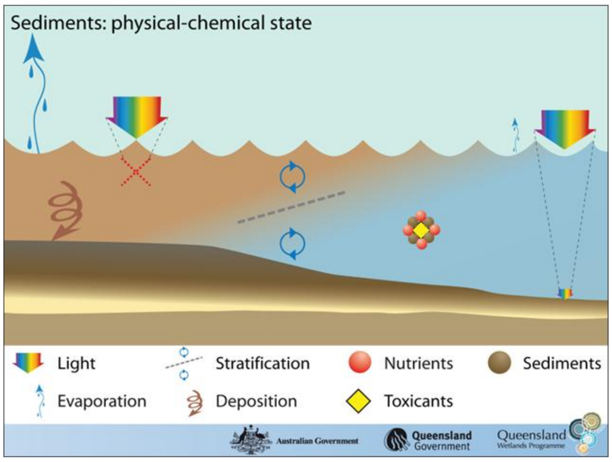
In this example image, worldview-2 shows that only the first 3 or 4 bands (up to yellow band) may be used.



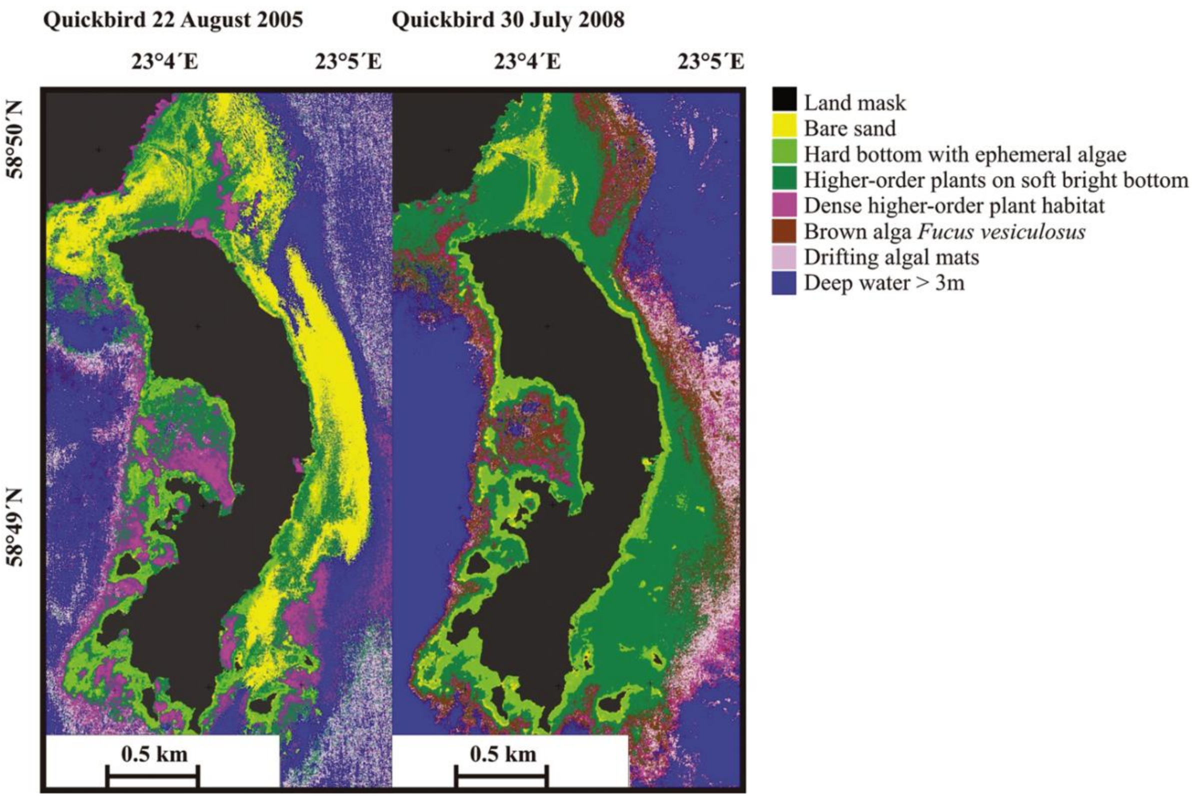


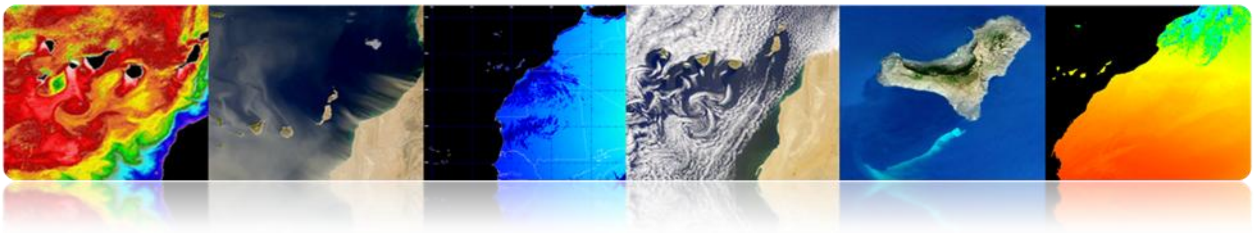
Furthermore, only homogenous classes that are separable at those wavelengths can be distinguished. Turbidity prevents seafloor classification.





Examples of Benthic Classification





3.2 TERRESTRIAL REMOTE SENSING APPLICATIONS.

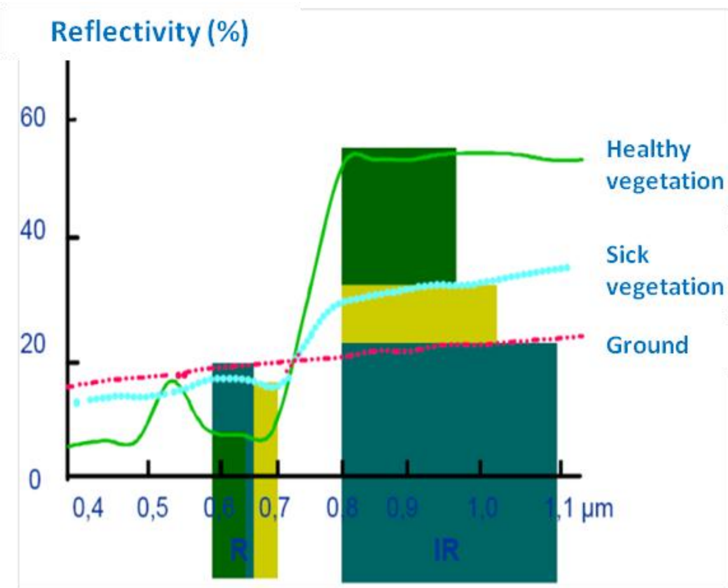
❑ VEGETATION AND FORESTS

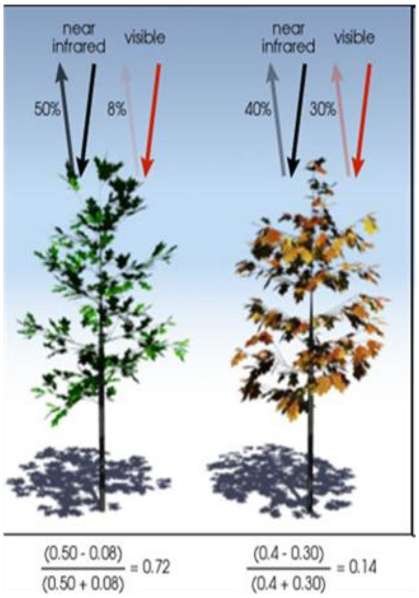
Terrestrial vegetation systems provide unique reflectance properties of the radiation received allowing characterization using remote sensing techniques.

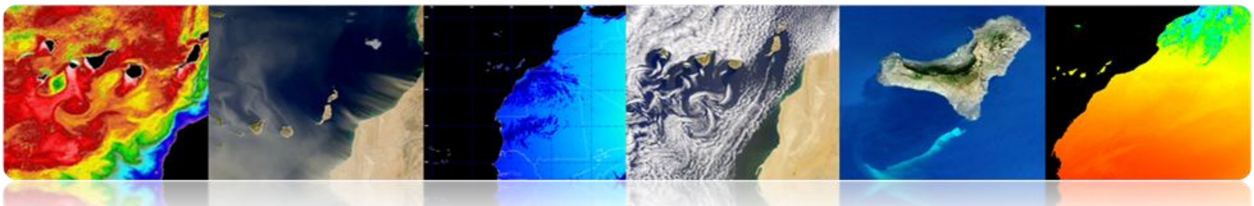
▪ Vegetation Indexes

Spectral indexes are combination of spectral bands to obtain the parameter of interest (vegetation, water, bare soil, etc.)

Vegetation **indexes** are calculated by combining reflectivity at different wavelengths to discriminate and extract vegetation information minimizing the influence of external factors such as soil, solar irradiance, illumination and observation geometry, etc.)







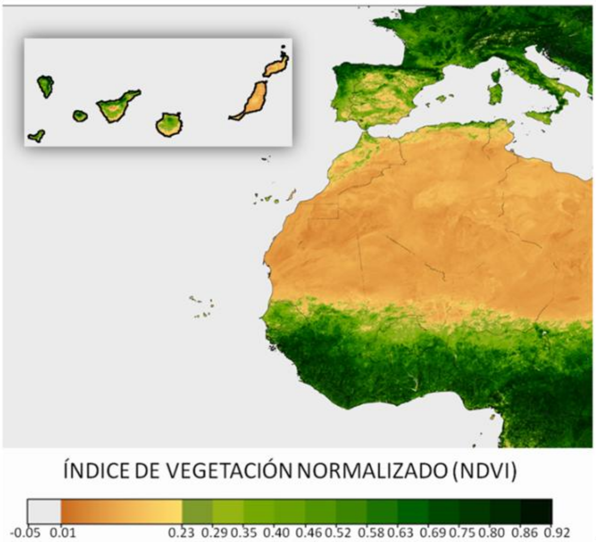
- There are many indexes for estimating vegetation:

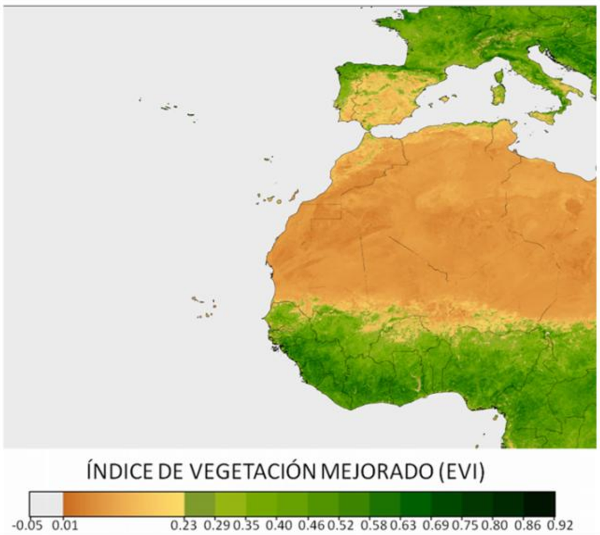
RVI	Ratio vegetation index	$RVI = \frac{R_{NIR}}{R_R}$
NDVI	Normalised difference vegetation index	$\boxed{NDVI = \frac{R_{NIR} - R_R}{R_{NIR} + R_R} = \frac{RVI - 1}{RVI + 1}}$
WDVI	Weighted difference vegetation index	$WDVI = R_{NIR} - aR_R$
SAVI	Soil-adjusted vegetation index	$SAVI = \frac{R_{NIR} - R_R}{R_{NIR} - R_R + L}(1 + L)$
SAVI2	Second Soil-adjusted vegetation index	$SAVI2 = \frac{R_{NIR}}{R_R + {}^{b}/_{a}}$

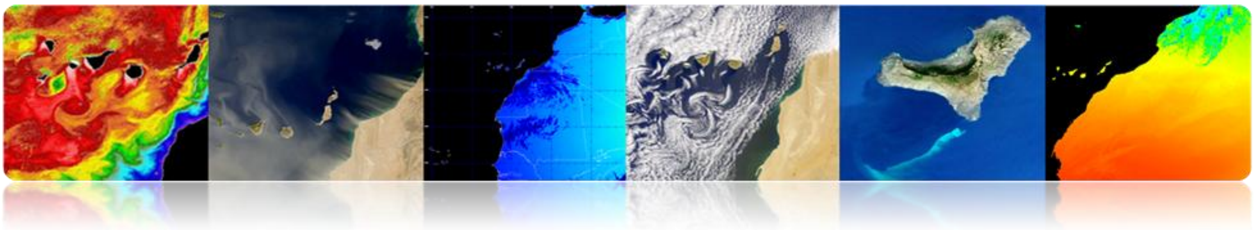
MSAVI2	Modified Second Soil-adjusted vegetation index	$MSAVI2 = \frac{1}{2}\left[2(R_{NIR} + 1) - \sqrt{2(R_{NIR} + 1)^2 - 8(R_{NIR} - R_R)}\right]$
ATSAVI[1]	Adjusted transformed soil-adjusted vegetation index	$ATSAVI = \frac{a(R_{NIR} - aR_R - b)}{aR_{NIR} + R_R - ab + X(1 + a_2)}$
EVI	Environmental vegetation index	$EVI = \frac{2.5(R_{NIR} - R_R)}{1 + R_{NIR} + 6R_R - 7.5R_B}$
NDVIverde	Green normalised difference vegetation index	$NDVI_{green} = \frac{R_{NIR} - R_{550}}{R_{NIR} + R_{550}}$
$\frac{R_{750}}{R_{550}}$	$\frac{R_{750}}{R_{550}}$	$\frac{R_{750}}{R_{550}}$
$\frac{R_{850}}{R_{550}}$	$\frac{R_{850}}{R_{550}}$	$\frac{R_{850}}{R_{550}}$

Examples of the most important indexes:

NDVI and EVI (MODIS / Aqua).



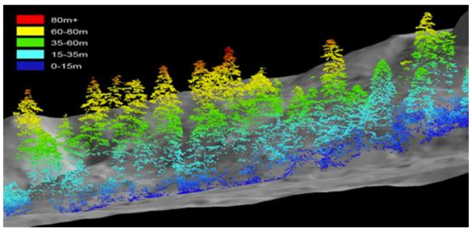


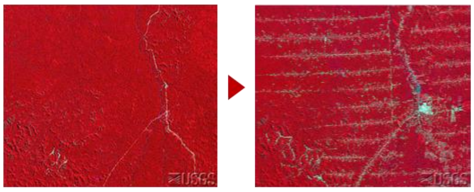


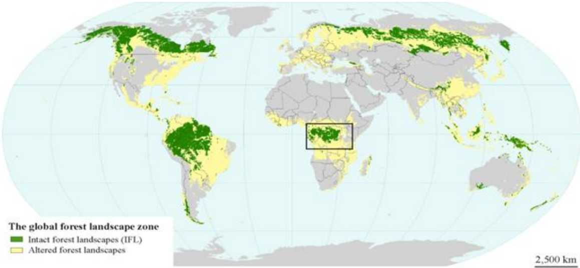
▪ Forests

Remote sensing is useful in forestry applications. Some important applications are the following:

- Forest cover
- Forest density (crown closure)
- Phenology (seasonality)
- Inventory of forest species
- Biomass estimate
- Deforestation
- Forest Protection
- Prevention, monitoring and evaluating fire



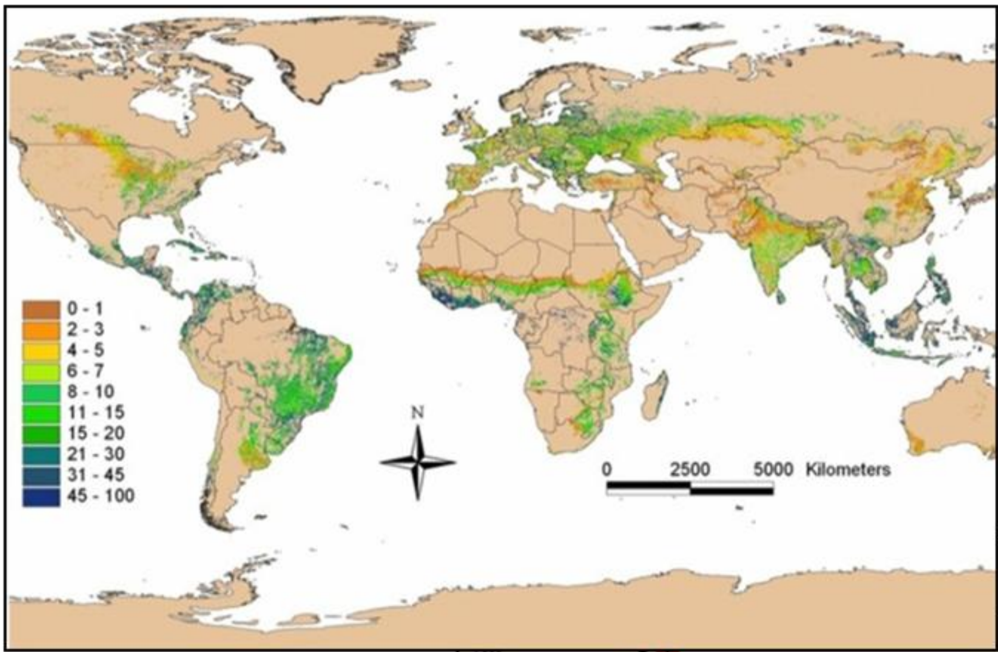




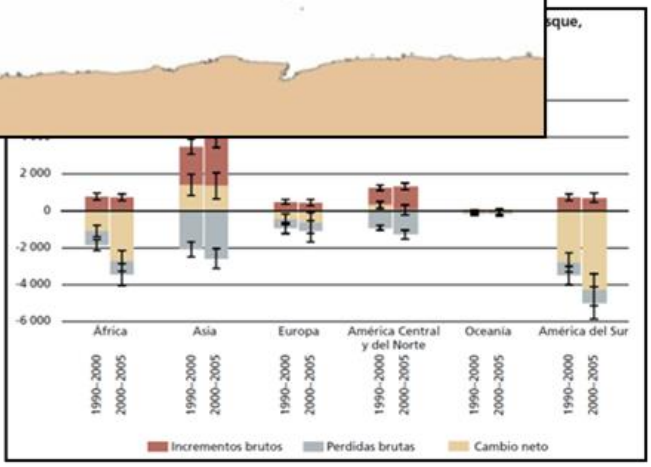
Global deforestation between 1990 and 2005 was annually 14.5 million hectares.

The results of the overall evaluation of forests by remote sensing show that in 2005 the world's forest cover was 3,690 million hectares, or 30% of the Earth's land area.

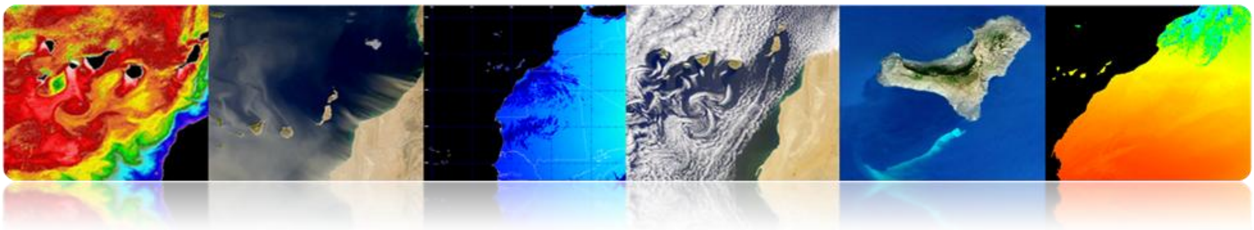
These new results indicate that the rate of deforestation in the world, mainly the conversion of tropical forests into agricultural land, was an average of 14.5 million hectares per year between 1990 and 2005. This finding is consistent with previous estimates.



Great losses in Africa and South America. Asian reforestation



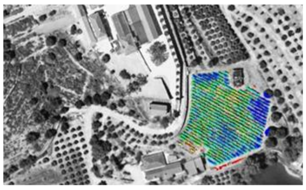
http://www.fao.org/forestry/fra/remotesensingsurvey/es/

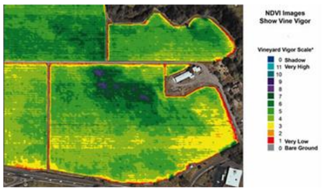


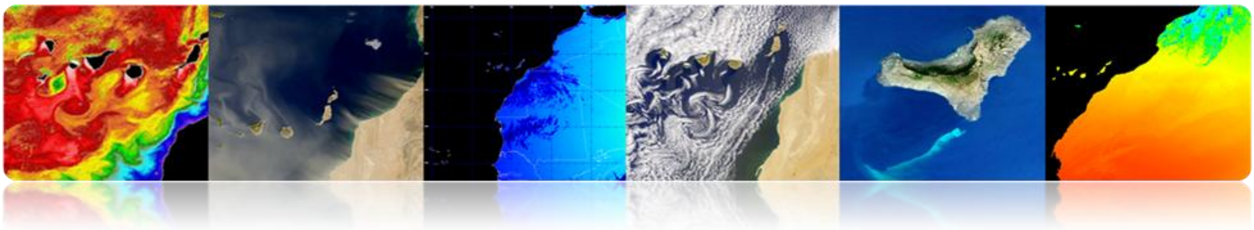
❑ AGRICULTURE

Agriculture is the economic mainstay of many countries. Remote sensing can provide large information:

- Crop extension
- Stock crops
- Agricultural production
- Forecast of harvests
- Selection and monitoring agricultural areas
- Evaluation of drought or flood damage
- Control of pests and crop diseases
- Detection of metabolic stress (water or nutrition)
- Precision agriculture







▪ Agricultural production

Example of applications:

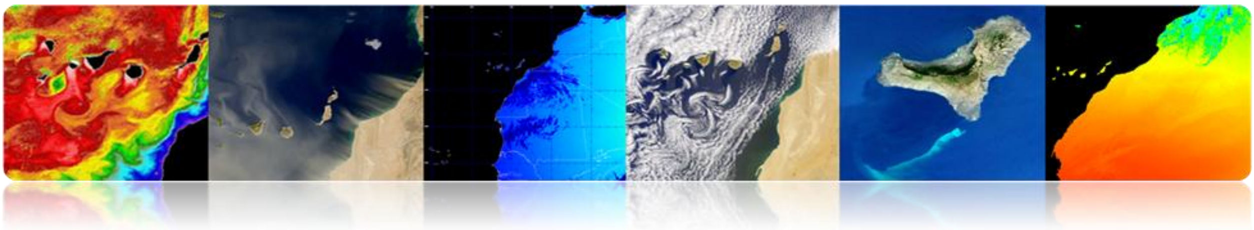
- Selection of suitable plots (better soil, moisture, etc.)
- Monitoring the evolution of crops (phenology, fertilization, etc.)
- Detection and damage assessment

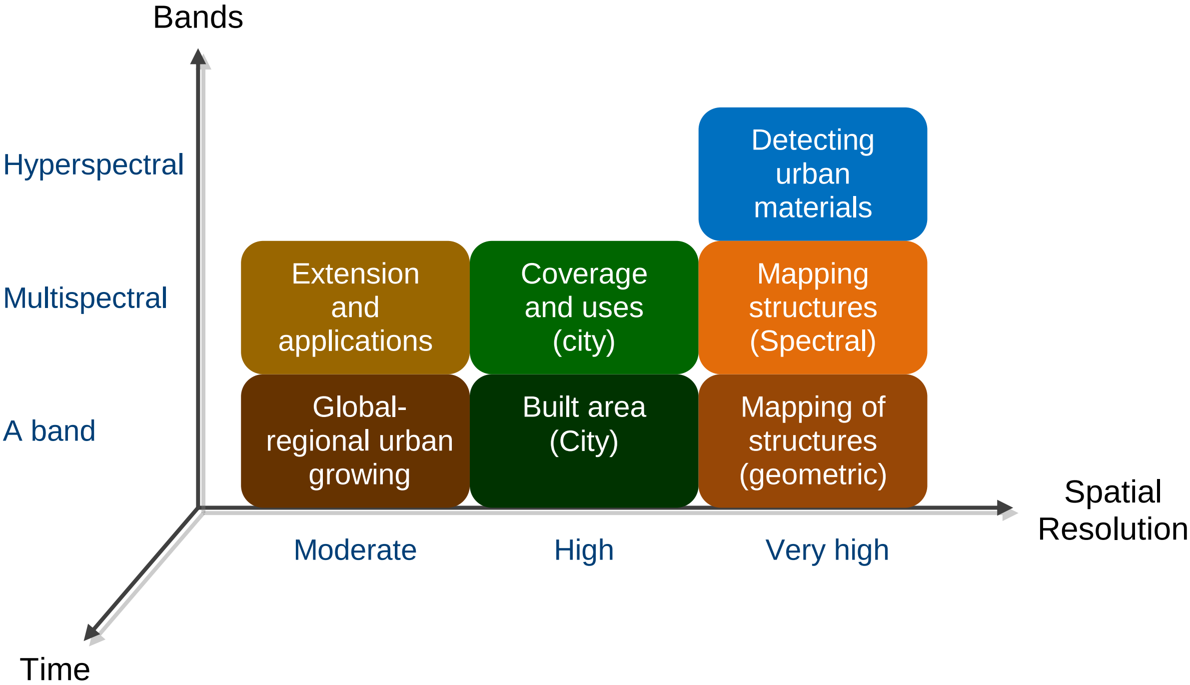
Example: progressive collection of wheat in June 2006

❑ URBAN MONITORING

▪ Urban applications of remote sensing

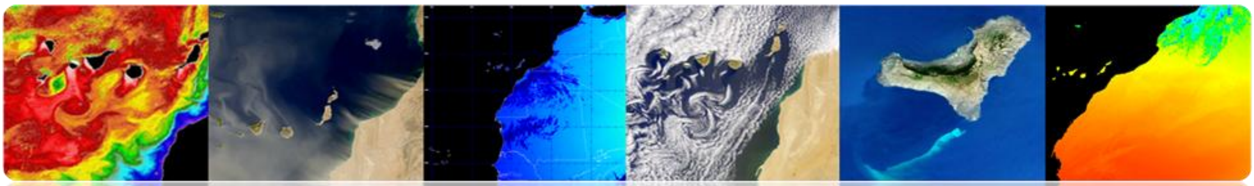
Remote sensing applications in urban areas depend mainly on the number of available bands and the spatial resolution of the sensor.

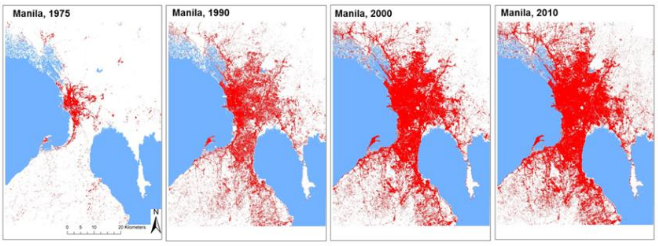




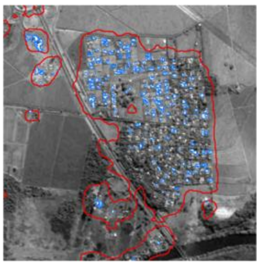
Different examples are presented below.

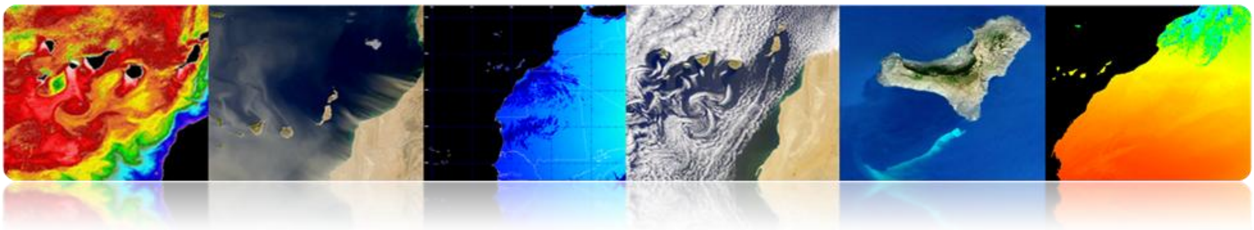
- **Extension and global/regional urban growth**
  - Mapping urban areas
  - Understanding urbanization
  - Analyzing and forecasting growth trends and land use change
  - Preventing environmental degradation and pollution
  - Global Economic Analysis (population, agricultural waste, industrial, commercial, etc.)





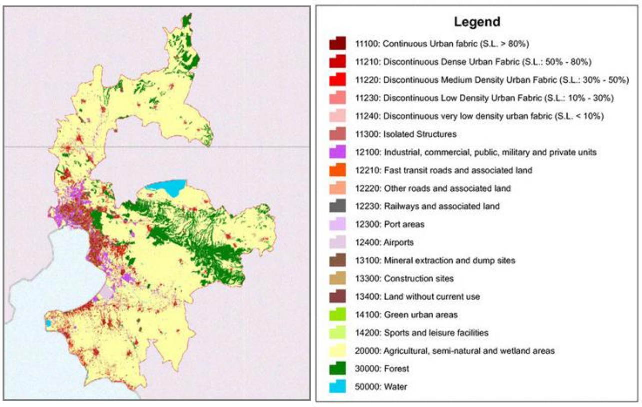
- **Extension and urban/rural growth**
    - Mapping urban city level
    - Estimating population
    - Understanding urbanization (city blocks, etc.)
    - Planning (ports, airports, roads, etc.)
    - Detecting clandestine constructions
    - Analyzing vulnerabilities and risks
    - Monitoring natural disasters
    - Analysing regional economics (population, decrease of agricultural activity, industrial and comercial activities, etc.)

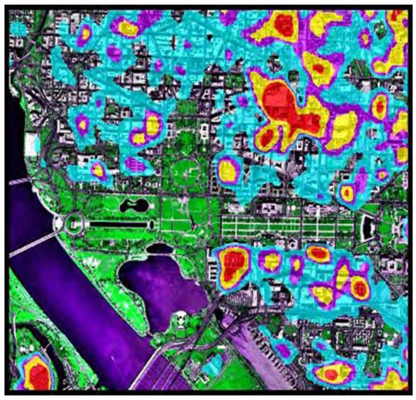


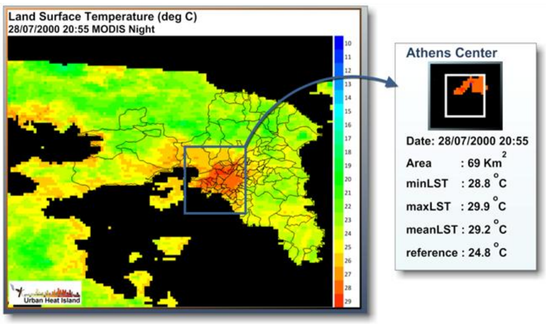


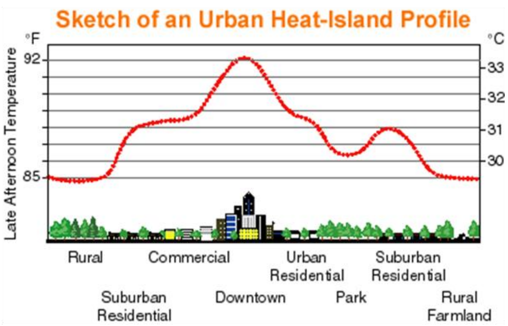
▪ Land use and environmental indicators

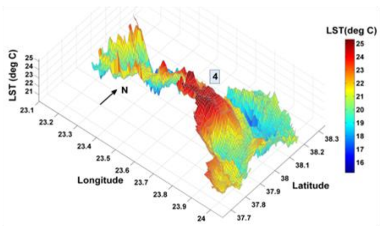
- Mapping land cover at regional, local or city level
- Mapping urban green areas (parks, forests, etc.)
- Characterizing and estimating drainage areas sealed (floods, etc.)
- Studying urban heat islands: the comfort of cities depends on the 3D structure of buildings, their geometry, building materials, landscaping, etc.

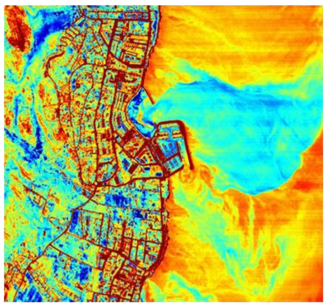


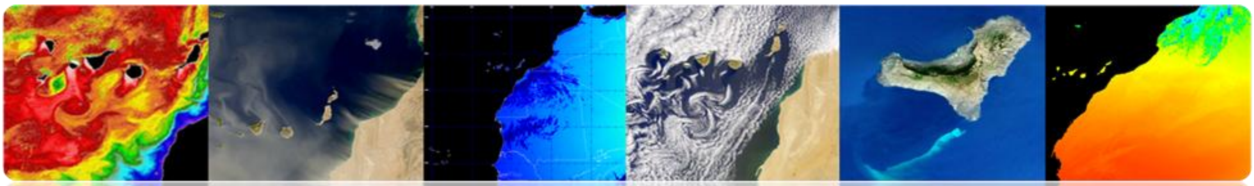












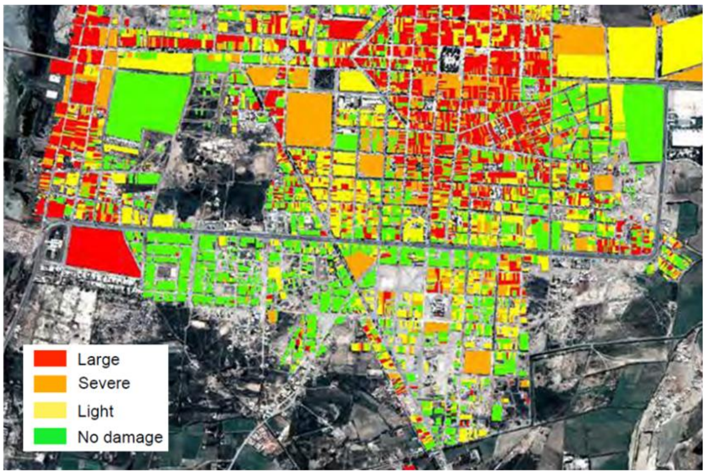
Vulnerability to disasters

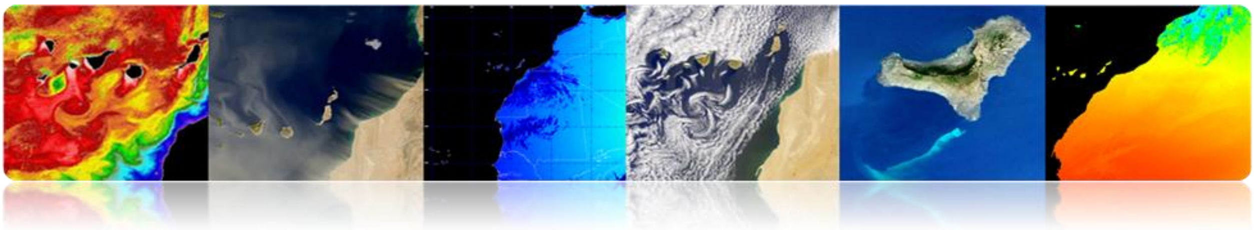
- Vulnerability maps at local level
- Hyperspectral optical sensors (can be combined with Lidar (height), SAR, etc.)

Damage assessment after disasters

Peru: Earthquake (7.9 degrees)

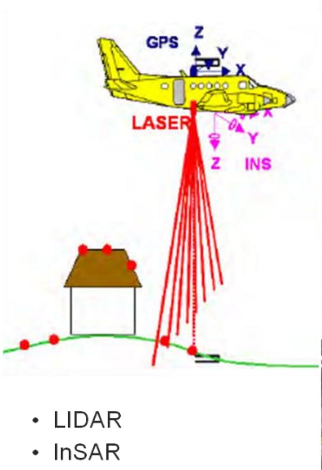
Study of change detection using SPOT-5





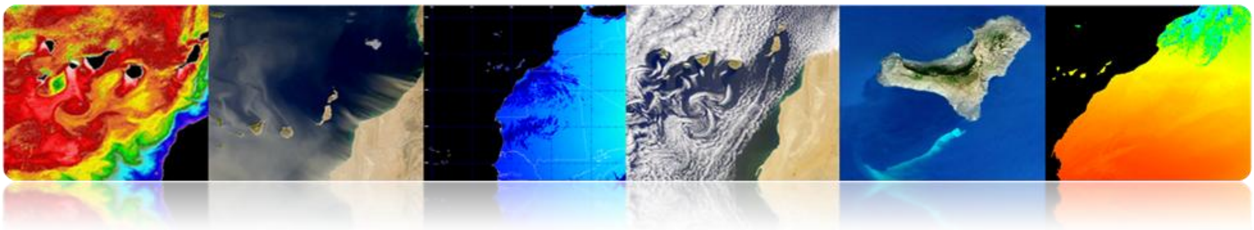
- ## Urban remote sensing at very high resolution

  - Level analysis at object level (building, road, bridge, etc.)
  - Detection and modeling of structures
  - 3D modeling of buildings.
  - Catastrophes, etc.



❑ LAND USE AND LAND COVER

- Economic development, population growth and climate variability have caused rapid changes in recent decades.
- Our life is linked to different land cover -water, forests, deserts, etc.- around us. When they change, our health, economy and environment may be affected.
- Remote sensing allows obtaining land use and land cover maps (LULC) that are becoming more and more reliable and are achieving a better spatial resolution.

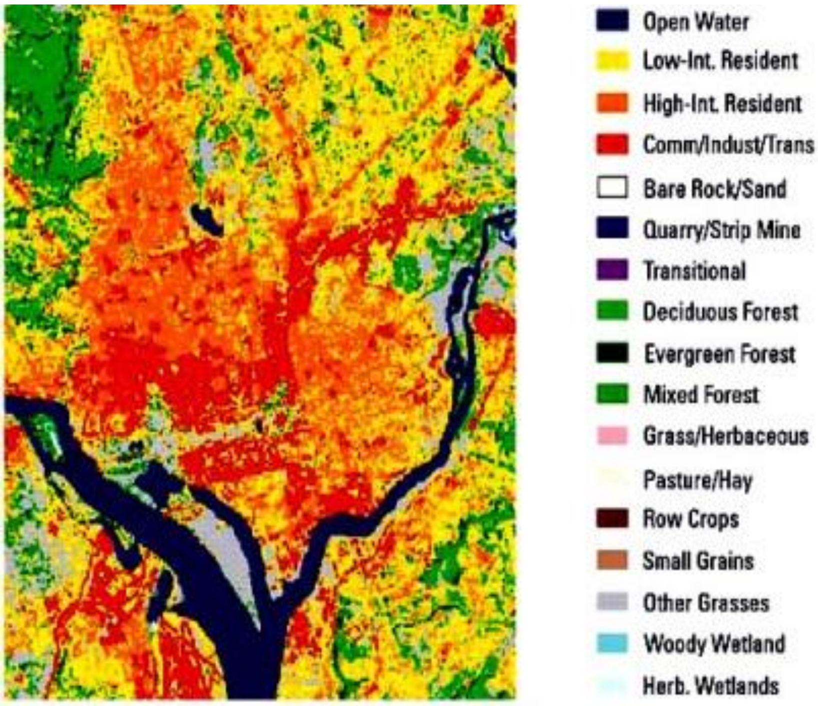


Class Selection

- There is no single standard for global LULC maps. The most commonly used are: Corine, LCCS (GlobCover, GLC2000), Anderson, IGBP, etc.

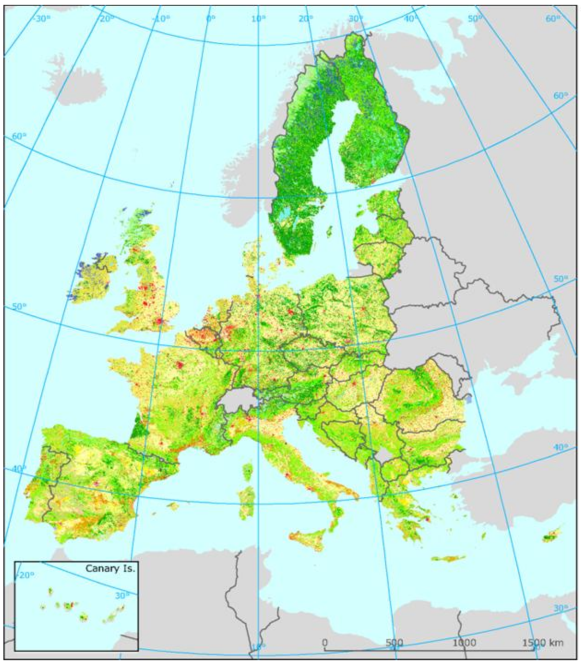
DATOS	*SENSOR*	*FECHA*	*RESOLUCION*	*TÉCNICA CLASIFICACIÓN*	**ESQUEMA DE CLASIFICACIÓN**
GLC2000	VEGETATION /SPOT4	Nov 1999 Dic 2000	1 km	Supervisada- No supervisada	LCCS (Nivel: regional y global)
CORINE	Landsat TM /SPOT	1999-2000	1:100.000 250 m	Fotointerpretación	Sistema jerárquico (44 clases)
GLOB-COVER	MERIS	Ene 2005 Jun 2006	300 m	Cluster no supervisado-Supervisada	LCCS (Nivel: regional y global)

- For regional analysis, it makes sense to choose the right classes for the study area.



- **CORINE LAND COVER**

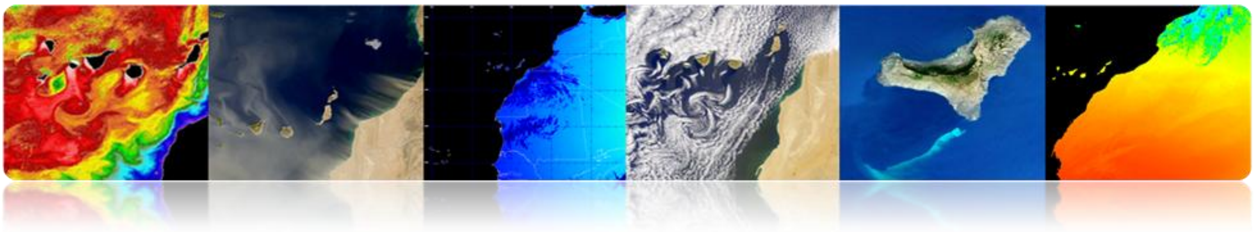
CORINE (Coordination of Information on the Environment) involved the creation of a database of land use in the European Union. It is run by the European Environment Agency.



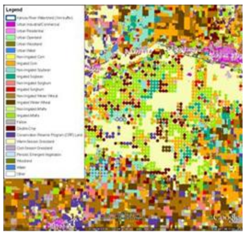
- **ANDERSON**

In 1972 Anderson developed a system of multilevel classes of land cover.

It is used primarily by the USGS using Landsat data.

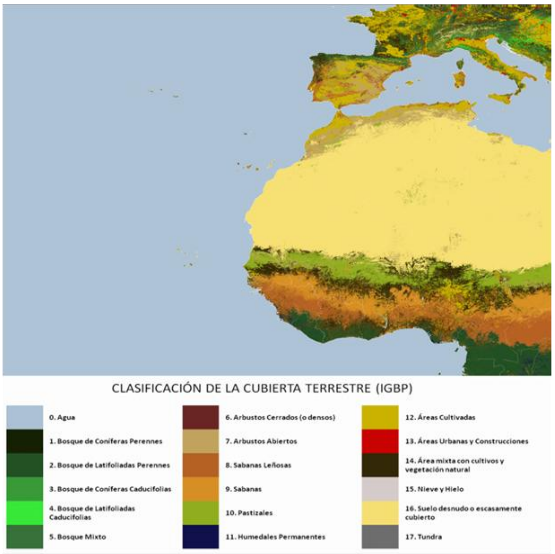


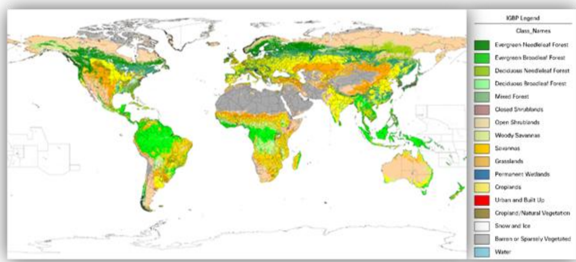
Level I	Level II
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications, and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	61 Forested Wetland
	62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats.
	72 Beaches
	73 Sandy Areas other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers



- **IGBP (International Geosphere-Biosphere Programme)**

International program for coordinating the interactions between biological, chemical and physical land processes and human systems at global and regional level (MODIS 500m).



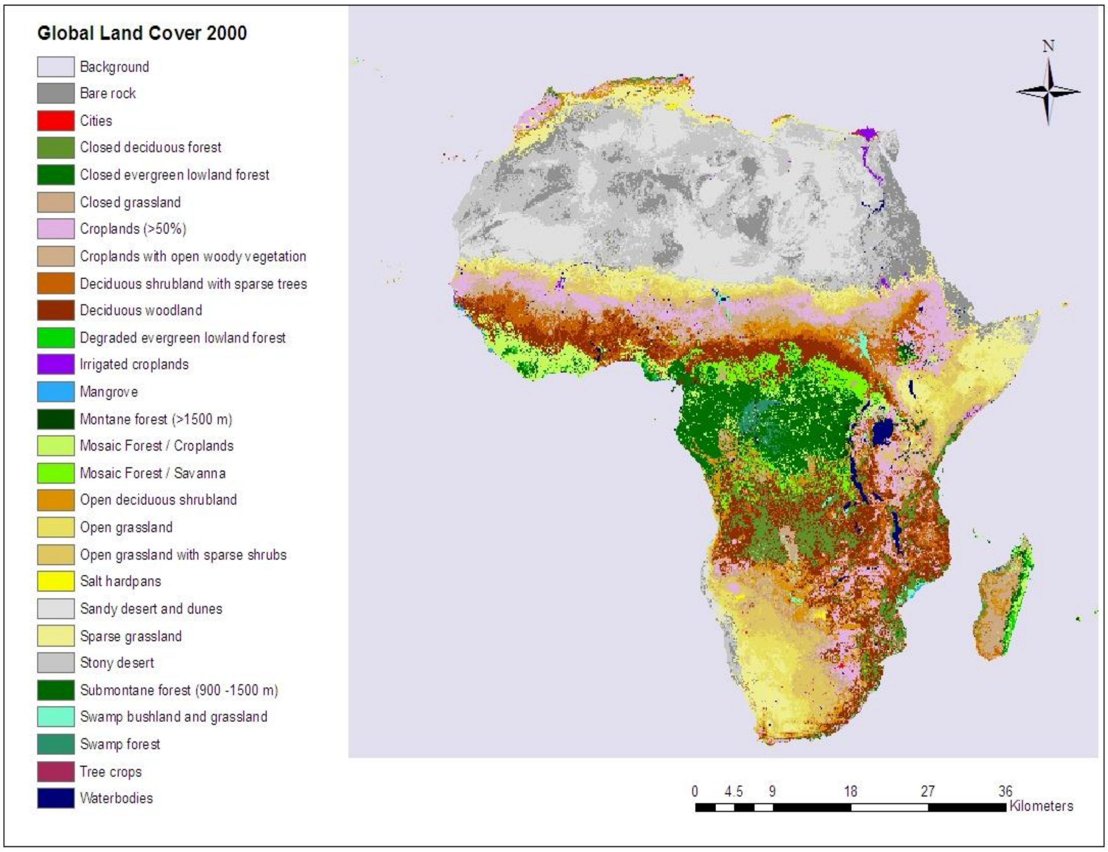


- **LCCS (Land Cover Classification System)**

Powered by FAO and UNEP (United Nations Environment Programme)

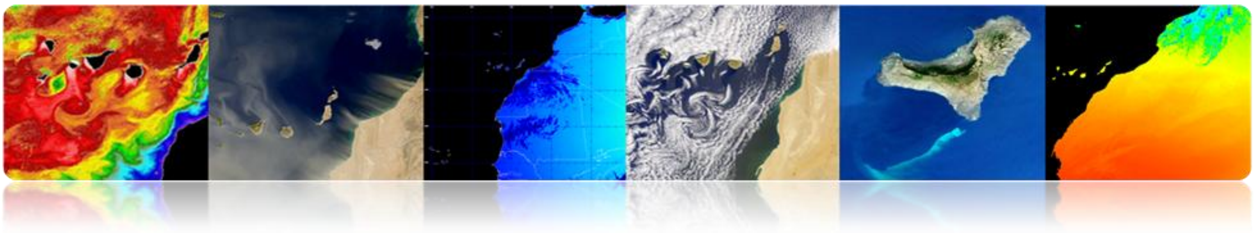
✓ GLC2000

Global land cover map for the year 2000 generated by more than 30 institutions using SPOT-Vegetation data (1 km)

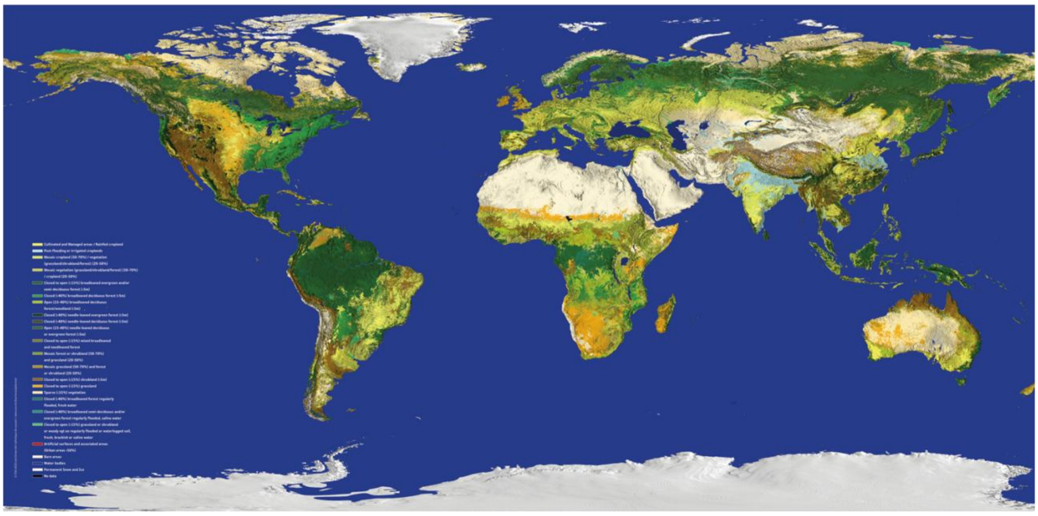


✓ GLOBCOVER

Global land cover map of the ESA made in collaboration with EEA, FAO, GOFC-GOLD, IGBP, JRC and UNEP using MERIS data (300 m)

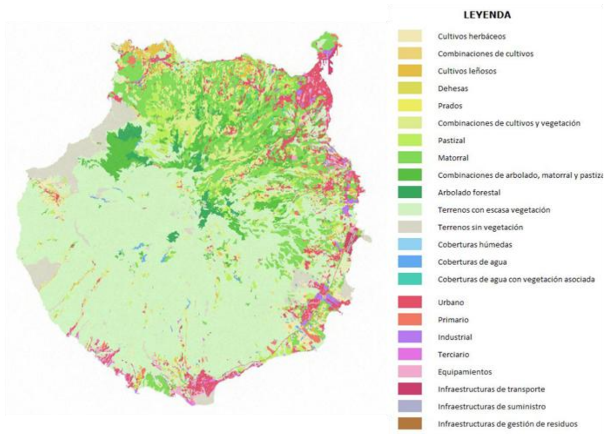


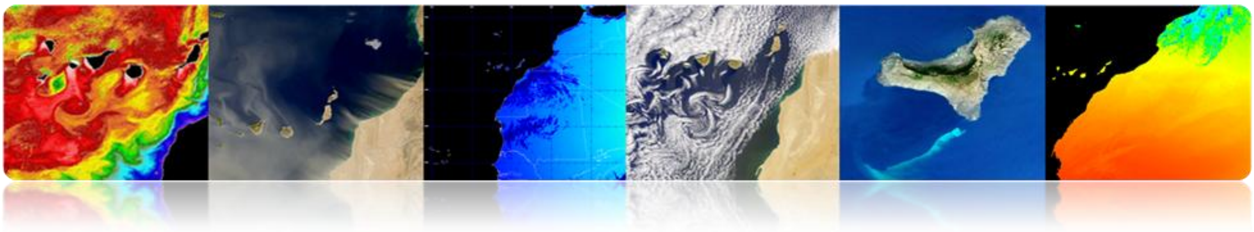
Globcover 2009 (ESA-Meris 300m)



- **SIOSE**

The Spain Information System on Soil Occupation aims at integrating information from databases and land cover of the Autonomous Communities and the Central Government. SIOSE uses multiple sources of information, including SPOT and Landsat data.

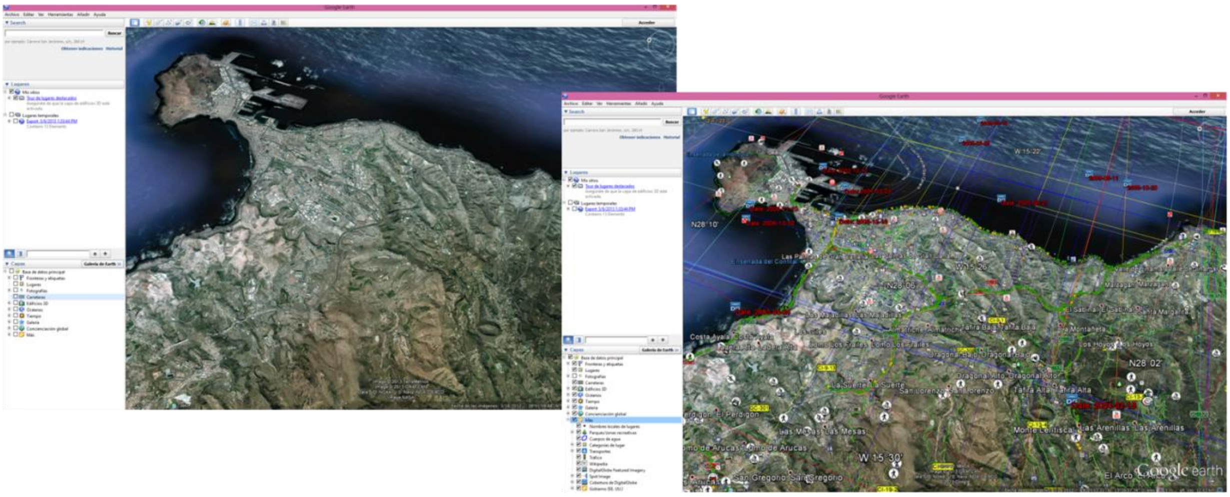




❑ Mapping and GIS

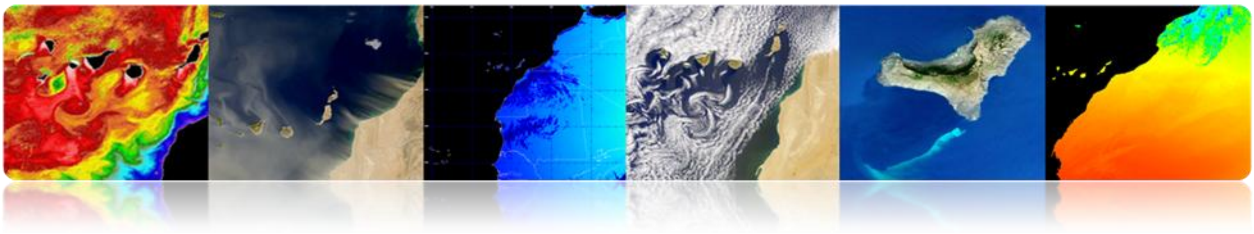
Remote sensing systems are very useful in mapping applications and geographic information systems thanks to the increasing in spatial resolution.

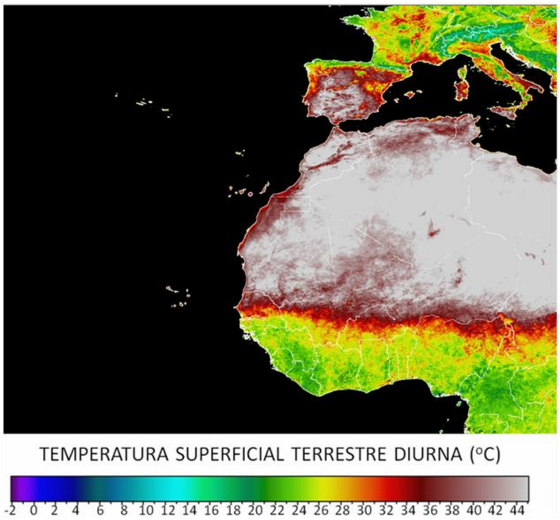
Example of Google Earth.

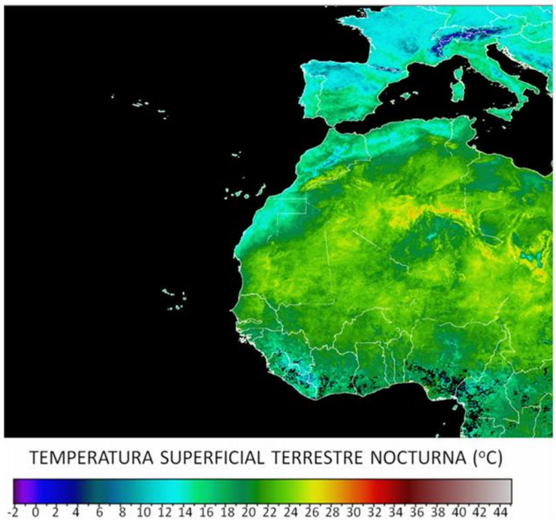


❑ Earth Surface Temperature

Land Surface Temperature (LST) is a parameter that serves as an indicator of energy balance and water on the Earth's surface for the detection of climate change. It is also useful to monitor the health of the vegetation or to analyze desertification processes or to be used as an input data model for weather prediction.







❑ NATURAL DISASTERS

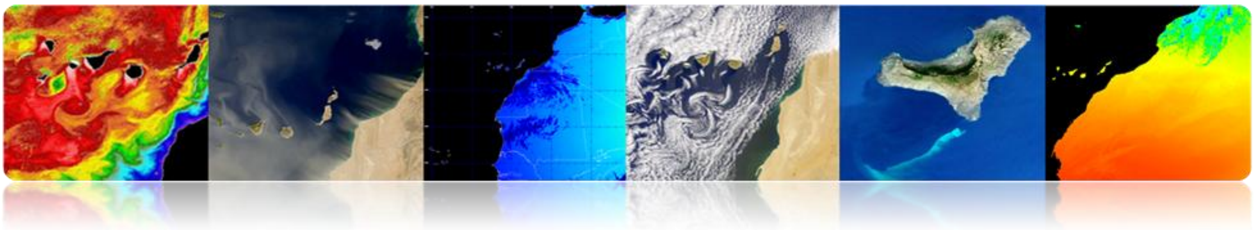
Remote sensing has enabled humanity to understand more clearly the dangers that threaten our planet.

It is essential for disaster management from the design of models of risk and vulnerability analysis, to early warning and damage assessment:

- Disaster prevention (lives, material and natural resources)
- Real-time tracking of a disaster
- Analysis of the effects after a natural disaster
- Tracking recovery activities

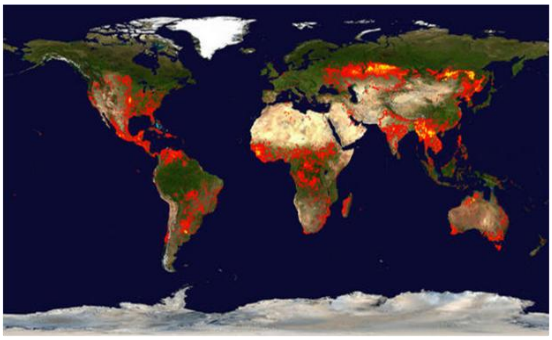
Types of Natural Disasters:

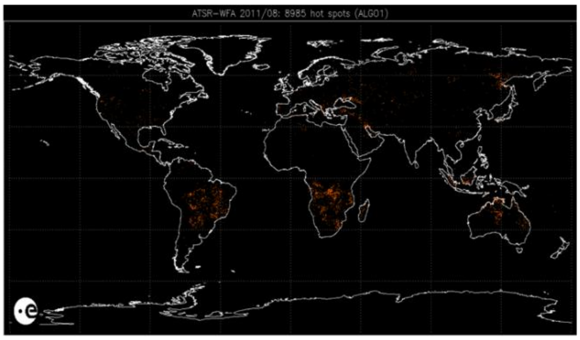
- Fire
- Floods
- Earthquakes, faults, etc.
- Eruptions
- Drought



▪ Fire

Global maps of fires from low resolution sensors in the thermal IR bands





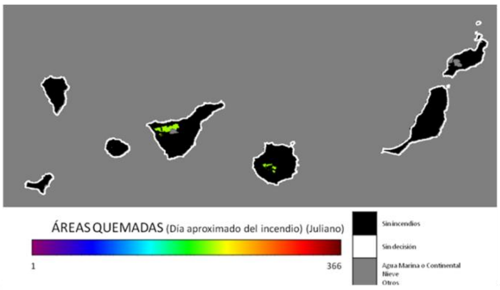
MODIS Rapid Response System Global Fire Maps
http://earthdata.nasa.gov/data/near-real-time-data/rapid-response

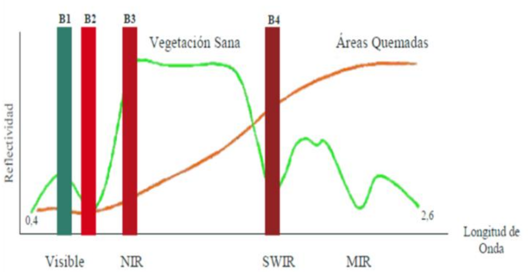
AATSR Global Fire Atlas
http://due.esrin.esa.int/wfa/

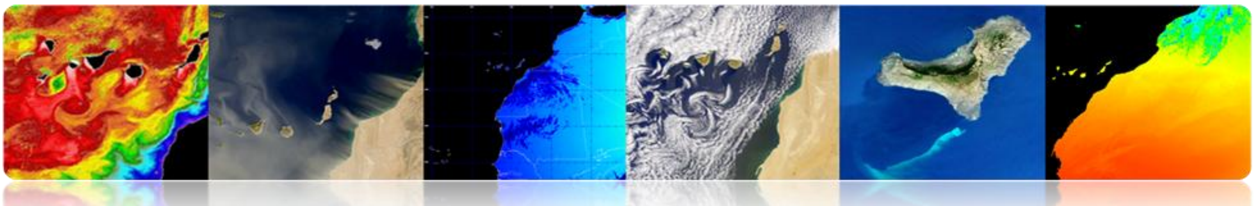
▪ Fire in the Canary Islands (summer 2007)

The main strategies for detecting the burned area are:

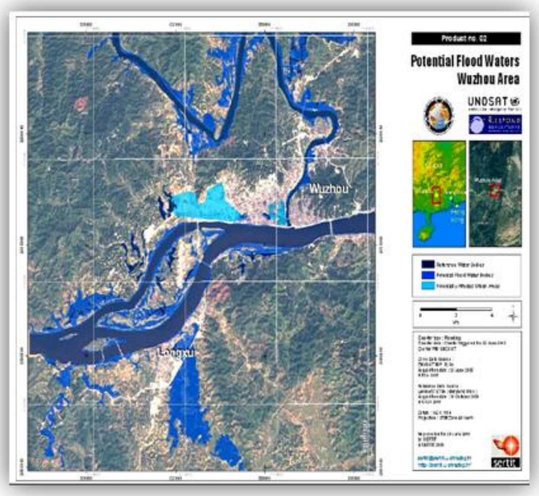
- A post-fire image: NBR index (Burnt Normalized Ratio) or Tasseled-Caps (Landsat)
- Images before and after the fire: change detection techniques (NDVI, NBR, PC, classification).

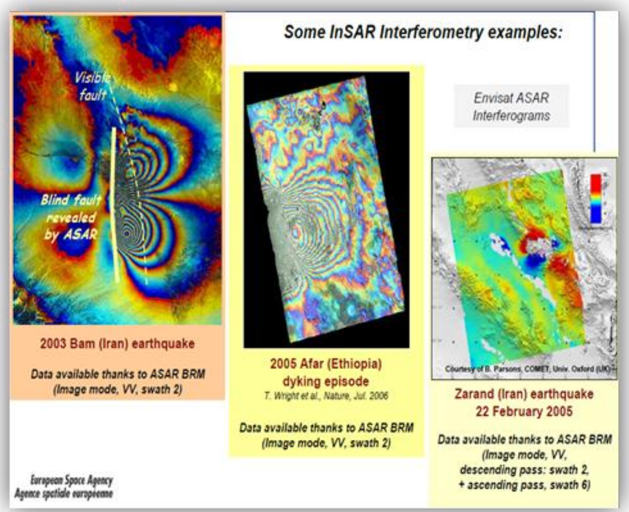






- **Floods and Earthquakes**

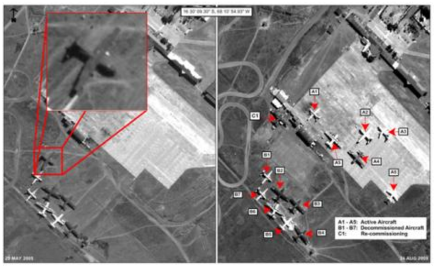


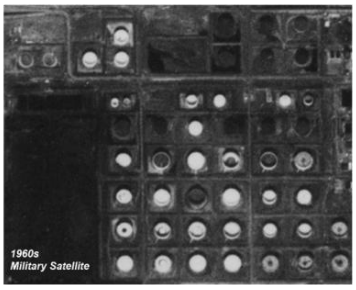


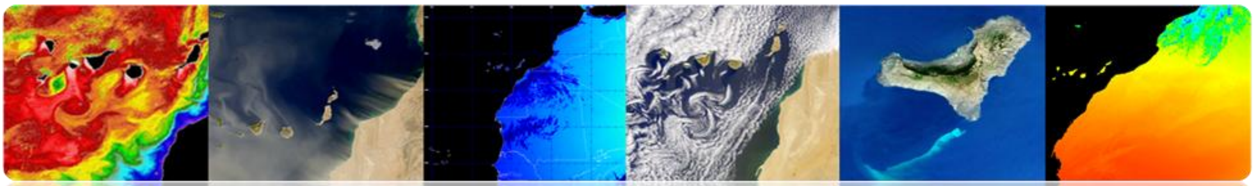
❑ DEFENSE

Remote sensing has been used for decades in areas such as:

- Security and Intelligence
- High-resolution mapping
- Verification of international treaties
- Border control
- Emergency Management
- Natural Disaster Monitoring

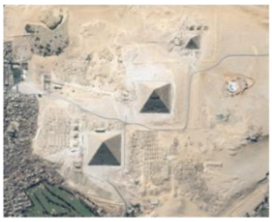


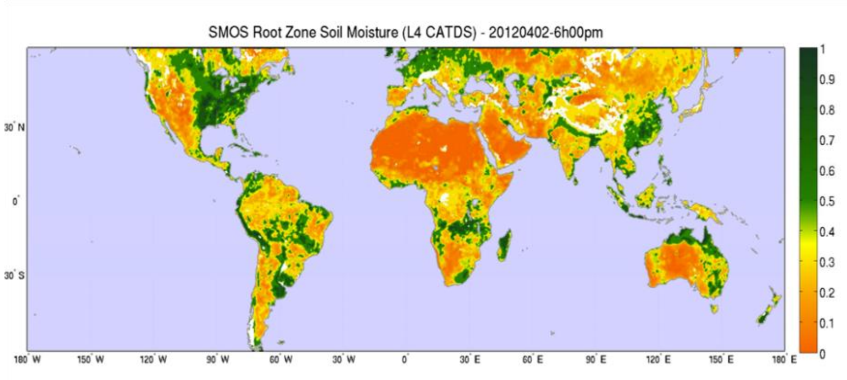


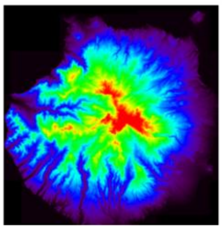


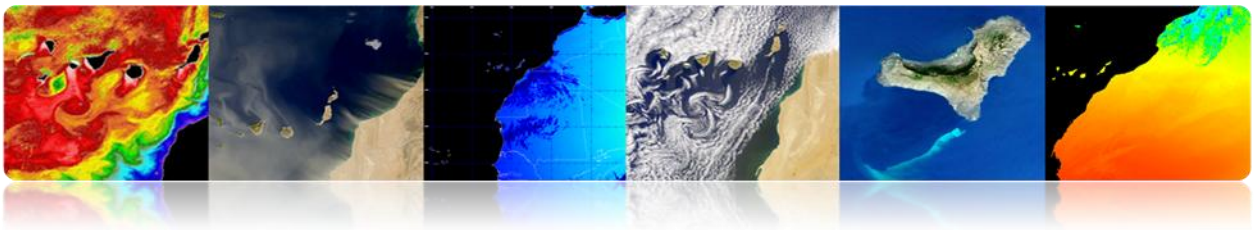
❑ OTHER APPLICATIONS

- Geology (minerals, sedimentation, erosion, etc.)
- Soil moisture
- Topography (digital elevation models of terrain)
- Archeology
- Geodesy





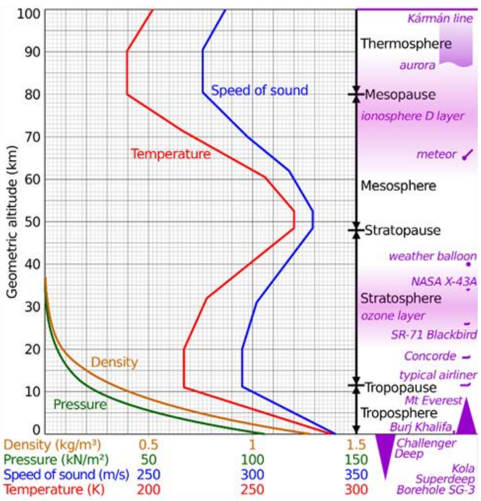


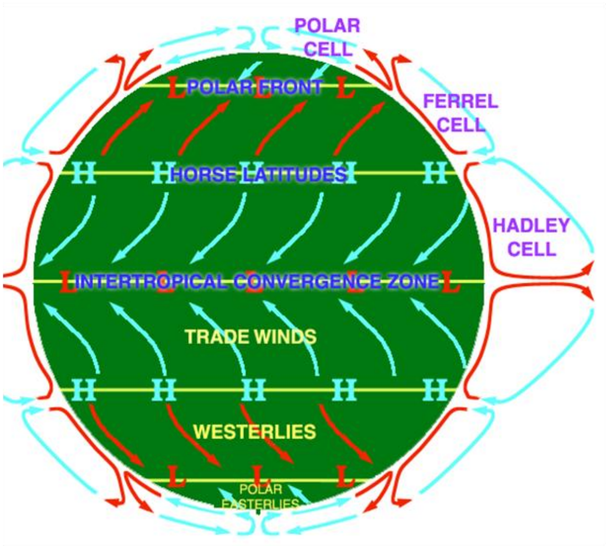


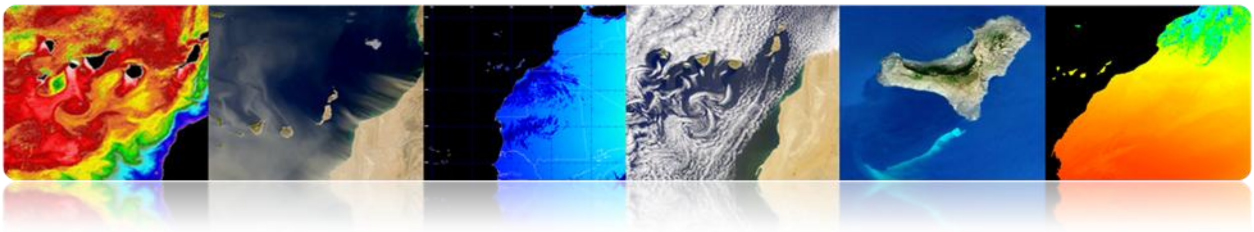
3.3 ATMOSPHERIC REMOTE SENSING APPLICATIONS

❑ INTRODUCTION

- The atmosphere is a mixture of gases.
- It has different layers.
- The first 80 kilometers contain more than 99% of the total mass of the Earth's atmosphere.
- Air circulation is a large-scale movement of air through the troposphere. It is the mechanism by which heat is distributed around the Earth.
- The large-scale structure of the atmospheric circulation varies from year to year, but the basic structure remains fairly constant as it is determined by the speed of the Earth’s rotation and the solar radiation difference between the equator and the poles.

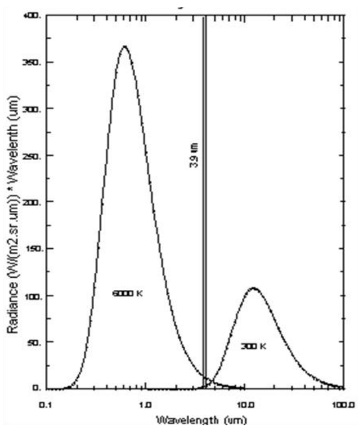


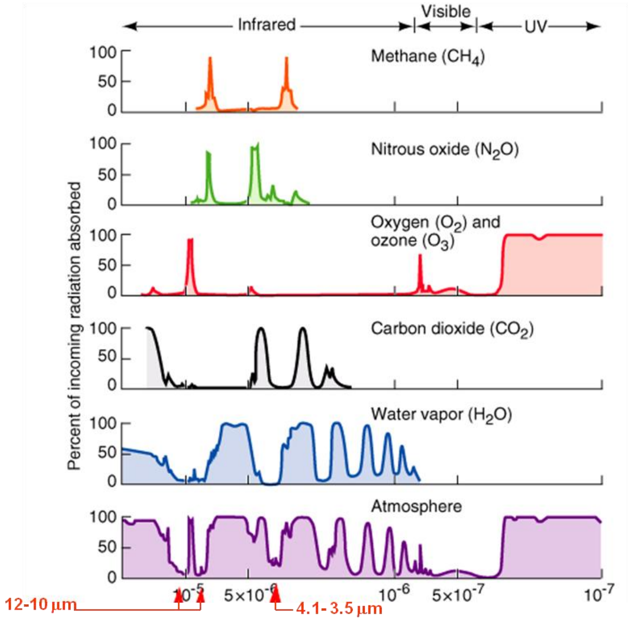




▪ Interactions of the atmosphere

- When EM radiation travels through the atmosphere absorbed or scattered by particles in the atmosphere.
- The atmosphere also emits→ Thermal IR





The main applications of remote sensing in the atmospheric field are:

- Weather forecast
- Study of atmospheric gases
- Prevention of disasters (storms, winds, etc.)
- Renewable energies (wind, solar)
- Air quality: pollution, aerosols, *calimas*, etc.
- Greenhouse gases
- Climate change

The main tasks of remote sensing in the atmospheric field are:

- Geostationary satellites (MSG): Predictions in real time (nowcasting)
- Polar satellites (ESA, NASA): Better spatial resolution

Atmospheric products generated by different agencies or remote sensing centers are presented below.

❑ EUMETSAT

EUMETSAT's main missions is currently Meteosat, a Second Generation Satellite, and, specifically, SEVIRI sensor, although data from other sensors in polar orbit are also used.

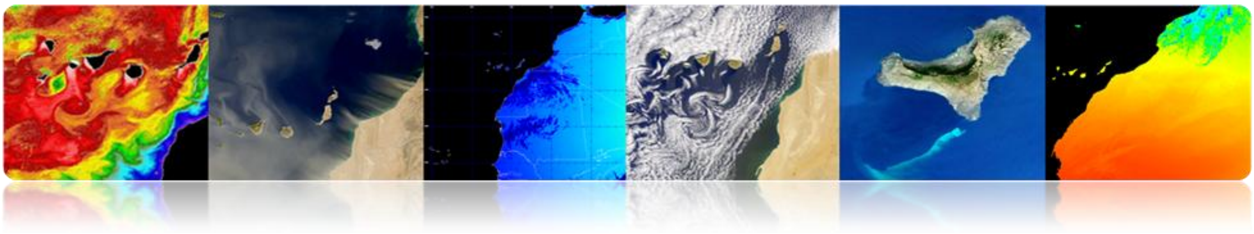
Some of the products supplied by EUMETSAT are presented and described below. They can be divided into:

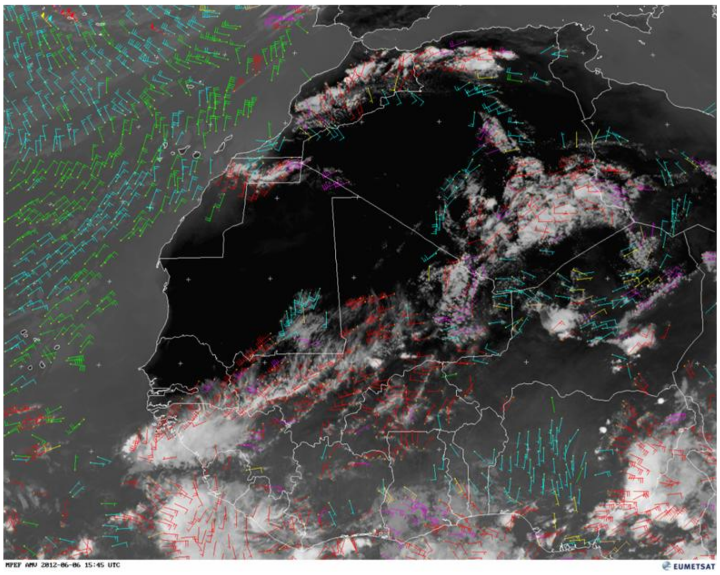
- Near real-time meteorological products
  http://oiswww.eumetsat.org/IPPS/html/MSG/PRODUCTS/
- Atmospheric products
  http://www.eumetsat.int/Home/Main/DataProducts/Atmosphere/index.htm?l=en

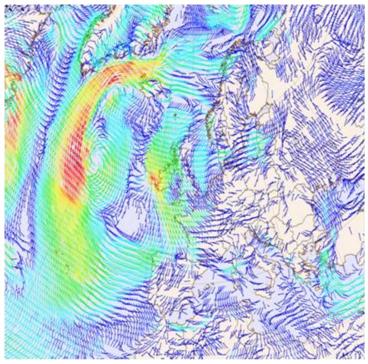
▪ Near real-time meteorological products

▪ Winds MSG (SEVIRI)

Atmospheric Motion Vectors (AMV) product consist of wind vectors estimated at different heights by tracking the movement of clouds and other atmospheric components (for example, patterns of water vapor and ozone).







- Winds are caused by changes in atmospheric pressure (air mass pushed downwards by gravity) leading to air movements.
- Pressure gradients propel winds with air that moves from higher pressure areas to lower pressure areas.
- Friction on the surface causes that very low altitude winds move more slowly and often in directions other than the high levels of the atmosphere.
- Air circulation is also affected by the heating of the sun.
- Techniques for remote sensing of winds are:

- **Winds of Clouds:** tracking clouds and water vapor in the VIS or IR bands (MSG).

- Tracking the movement of clouds in the geostationary satellite imagery is the oldest method to calculate wind vectors.

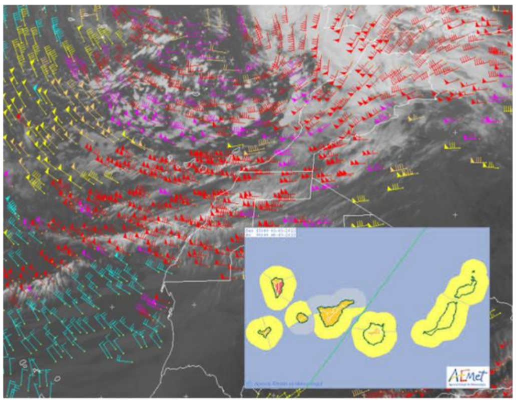
- The direction and speed is estimated by measuring the difference vector in the location of a particular cloud in two consecutive images, divided by the interval of time between two images (typically 15 or 30 min).
- Wind can be accurately estimated by using clouds that move passively with the winds: high-level cirrus and low level clouds -high cumulonimbus and orographic clouds are poor candidates.
- Problem: dependence on the presence of clouds in the picture (grid non-uniform).
- Solution:, images of water vapor (6.5 to 7.5 microns) allow to monitor the wind by the movement of water vapor in cloud-free areas.

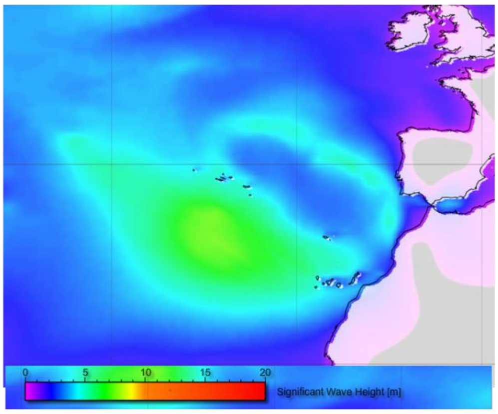
Procedure for obtaining vectors AMV

- Sea Surface Winds: analysis of the roughness of the surface of the oceans, with active or passive microwave sensors.

▪ Disaster Prevention: wind alert

AMV wind product correlated with the height of the waves on March 4, 2013.

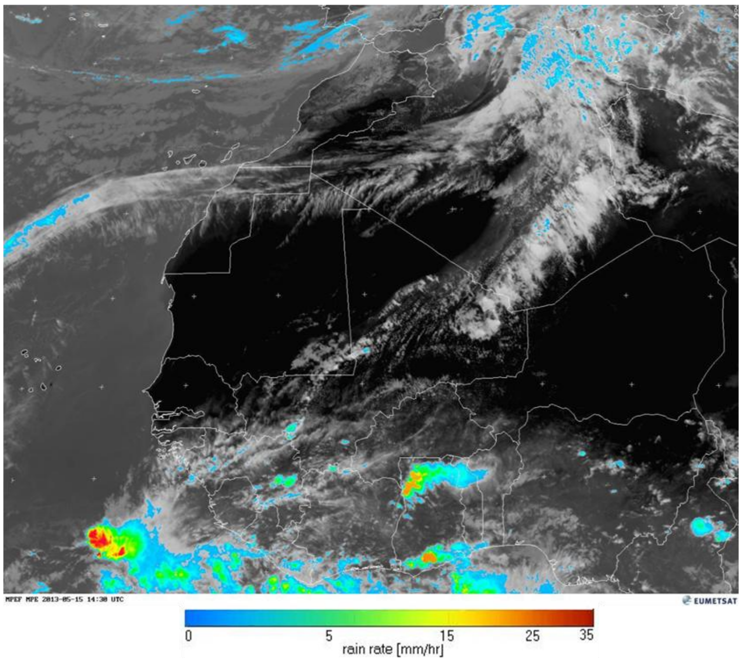


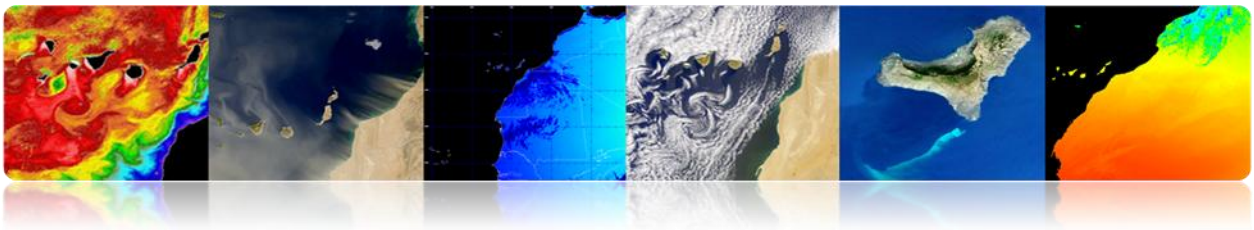


▪ Precipitation

Multi-sensor Precipitation Estimate (MPE) product consists of rain rates in real time in mm/hr for each Meteosat image in original pixel resolution. The algorithm is based on the combination of microwave measurements from polar satellites and images on Meteosat's IR channel.

Applications: operational weather forecasting in areas with little or no radar coverage, particularly in Africa and Asia.

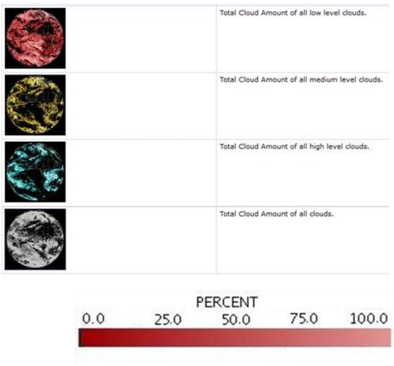


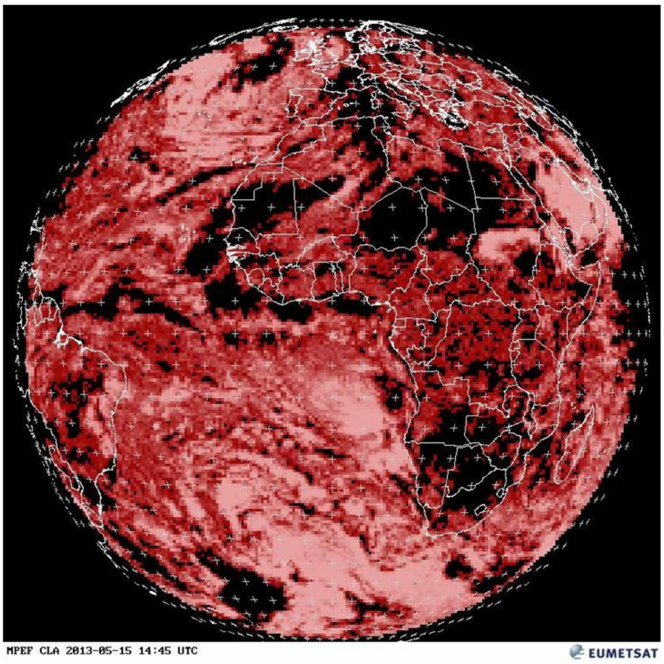


- **Clouds MSG (SEVIRI)**

Cloud Analysis (CLA) product provides an identification of cloud layers specifying the type of cloud coverage, height and temperature.

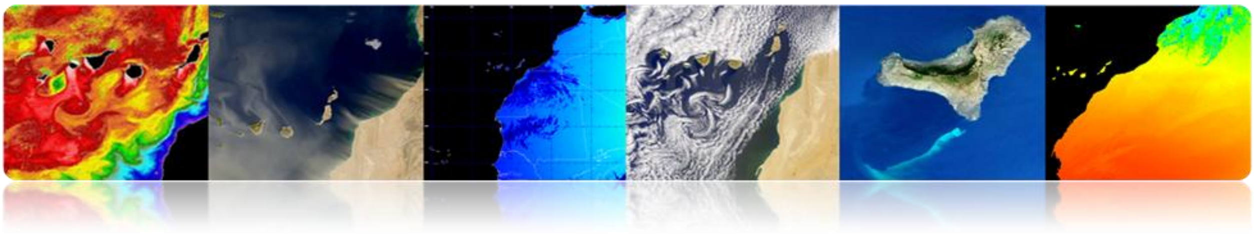
Applications: weather forecast, numerical weather prediction, climate research and monitoring.

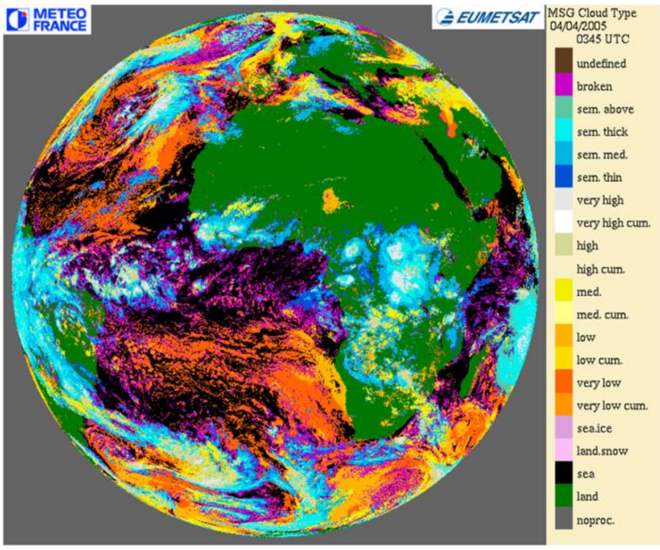


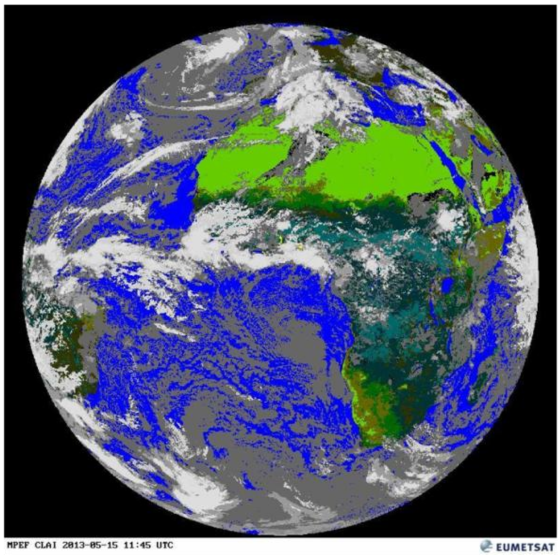


The Cloud Analysis Image (CLAI) product identifies types of clouds. This is a picture of the product obtained along with CLA.

Applications: Weather forecast, numerical prediction, climate research and monitoring.





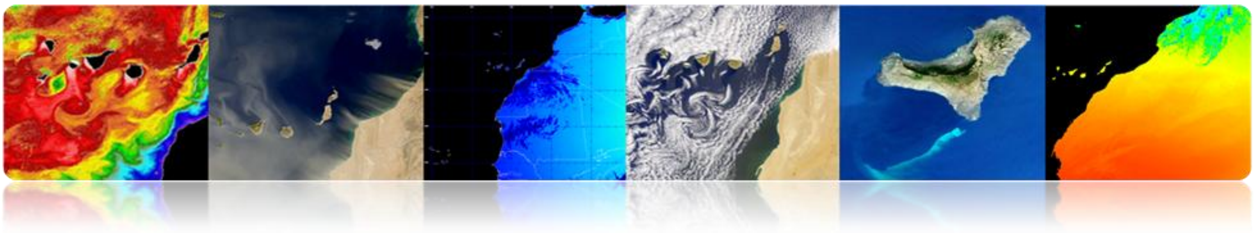


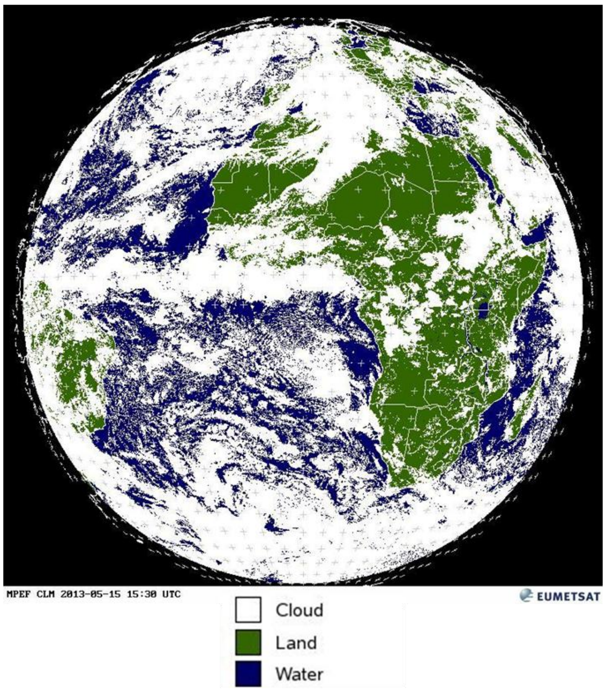
Cloud Mask (CLM) product is a mask that indicates the presence or absence of cloud in each pixel. Specifically, each pixel is classified as clear sky over the water, on land clear sky, cloud or not processed (outside the disk of the Earth).

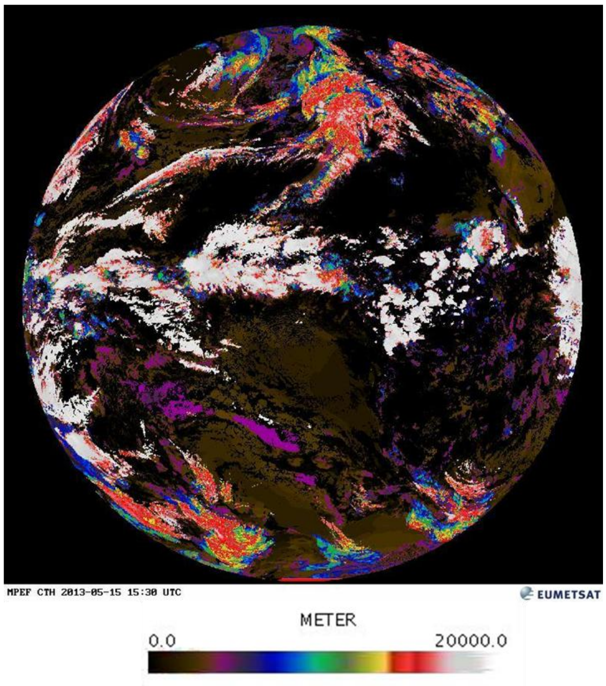
Applications: The main use is in support of the applications of short-term forecasting and for remote sensing of continental and oceanic surfaces.

The Cloud Top Height (CTH) product indicates the height of the highest clouds. It is obtained from the information extracted from the images and data of the cloud's analysis. It also makes use of other external weather data.

Applications: aeronautical meteorology.

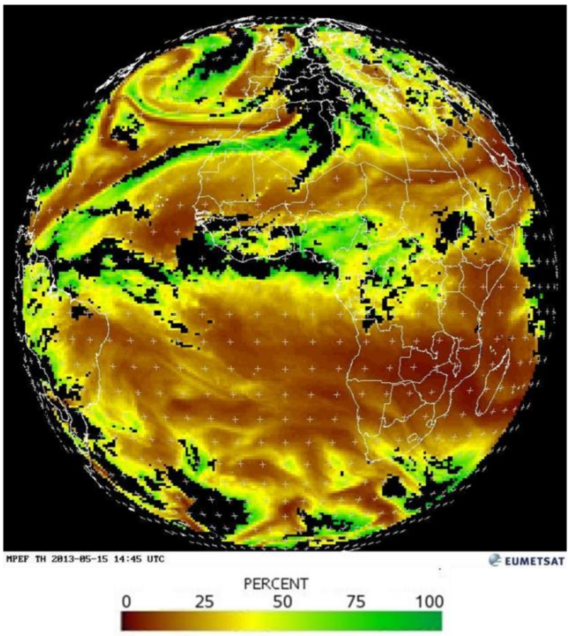




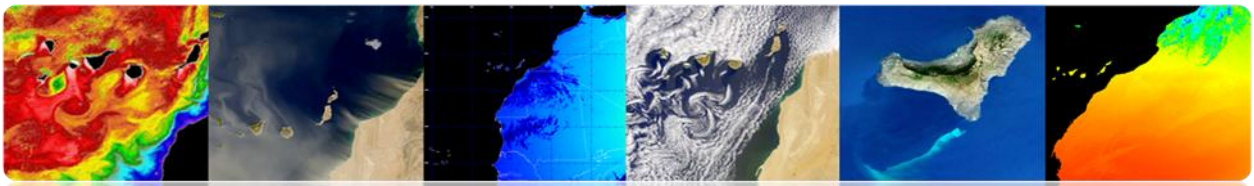


- **Moisture MSG (SEVIRI)**

The Tropospheric Humidity (TH) product provides the relative humidity in both the middle and the high troposphere.



The upper level is obtained from the middle layer relative humidity between approximately 600 hPa to 300 hPa using WV6.2 channel micrometers, while the average moisture in the troposphere represents the average value between 850 hPa and 600 hPa using WV7.3 channel microns.



▪ Atmospheric products

The available atmospheric data from satellites has benefits beyond its contribution to weather forecasting. The data accumulated in the EUMETSAT files help to detect and to understand the processes that affect climate change. Information on the composition of the atmosphere, obtained from satellite measurements, plays a vital role in the knowledge of the environment, and the environmental risk assessment, such as the destruction of the ozone layer in the stratosphere and the accumulation of pollutants in the atmosphere.

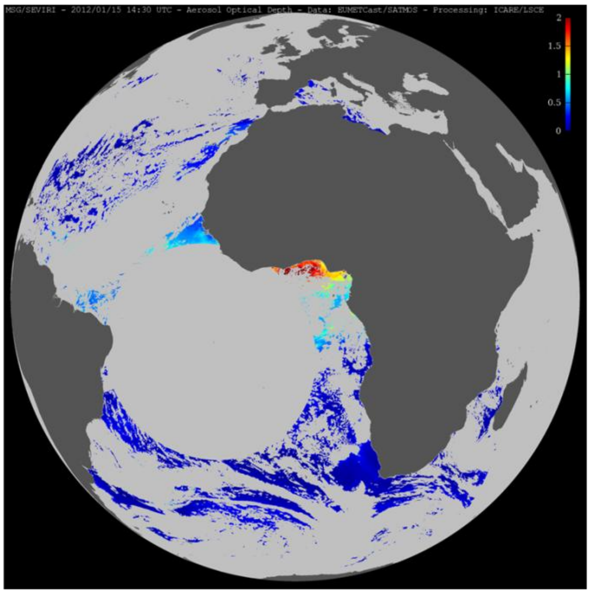
Some EUMETSAT meteorological products are:

- *Coastal Winds ASCAT at 12.5 km Swath Grid - Metop*
- *Aerosol Properties over Sea - MSG - 0 degree*
- *All Sky Radiances - MSG - 0 degree*
- *Atmospheric Motion Vectors - MSG - 0 degree*
- *Cloud Analysis - MSG - 0 degree*
- *Cloud Analysis Image - MSG - 0 degree*
- *Cloud Mask - MSG - 0 degree*
- *Cloud Top Height - MSG - 0 degree*
- *High Resolution Precipitation Index - MSG - 0 degree*
- *Total Ozone - MSG - 0 degree*
- *Tropospheric Humidity - MSG - 0 degree*
- *Volcanic Ash Detection (CAP) - MSG - 0 degree*

http://www.eumetsat.int/Home/Main/DataProducts/Atmosphere/index.htm?l=en

▪ Aerosols MSG (SEVIRI)

The product AES estimates the aerosols' optical thickness in pixels of clear sky over the sea in VIS0.6 channels, VIS0.8 and NIR1.6. Furthermore, it determines the coefficient of Angstrom. The product is a daily average. Applications include numerical weather prediction, research and climate monitoring.



- Aerosols are particles suspended in the atmosphere from natural and anthropogenic sources with sizes between 2 nm and 1 mm.
- Sources of aerosols: soil dust, sea salt, volcanic emissions, pollen, biomass burning or industrial combustion.
- Geographically one of the main sources that generate this atmospheric dust or haze is the Sahara desert and the Sahel region.
- Dust affects primarily climate -temperature and precipitation-, marine productivity, and health.
- Dust also affects directly and indirectly the Earth's radiation balance. On the one hand, it disperses outward incident solar radiation causing a cooling of the planet's surface, and on the other, it prevents that the radiation emitted by the Earth's surface escapes which causes warming.

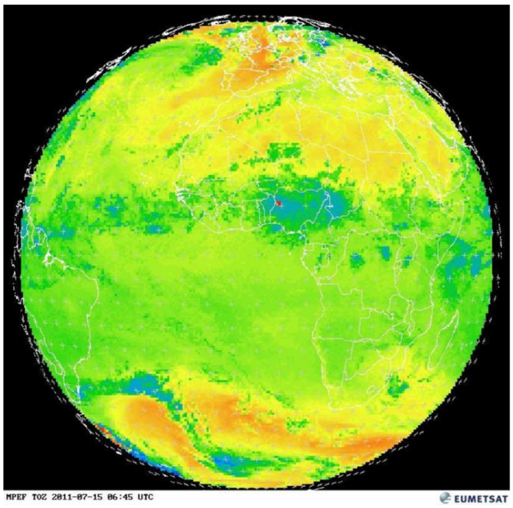
- It includes nutrients such as iron, phosphates or organic detritus, which have a positive effect on the ocean by fertilizing regions of low marine productivity.

- Furthermore, dust affects air quality and thus it has a detrimental effect on human health due to the transport of spores, fungi, bacteria or pesticides.

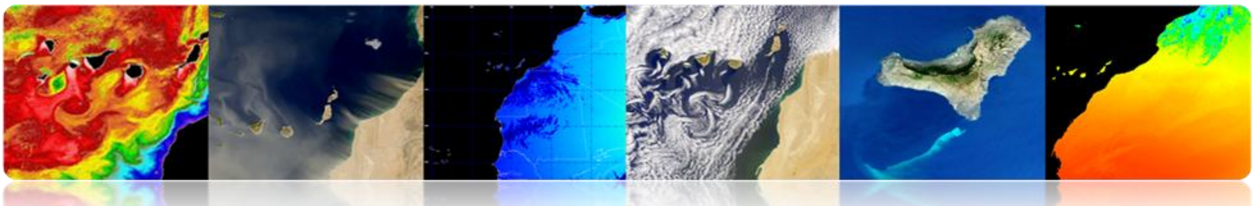
▪ Ozone MSG (SEVIRI)

The overall density of the ozone in the atmospheric column for each image segment is based on 9.7 micron channel (channel SEVIRI ozone) and other IR and WV channels.

This product is used by NWP centers, ozone monitoring services and research institutes.

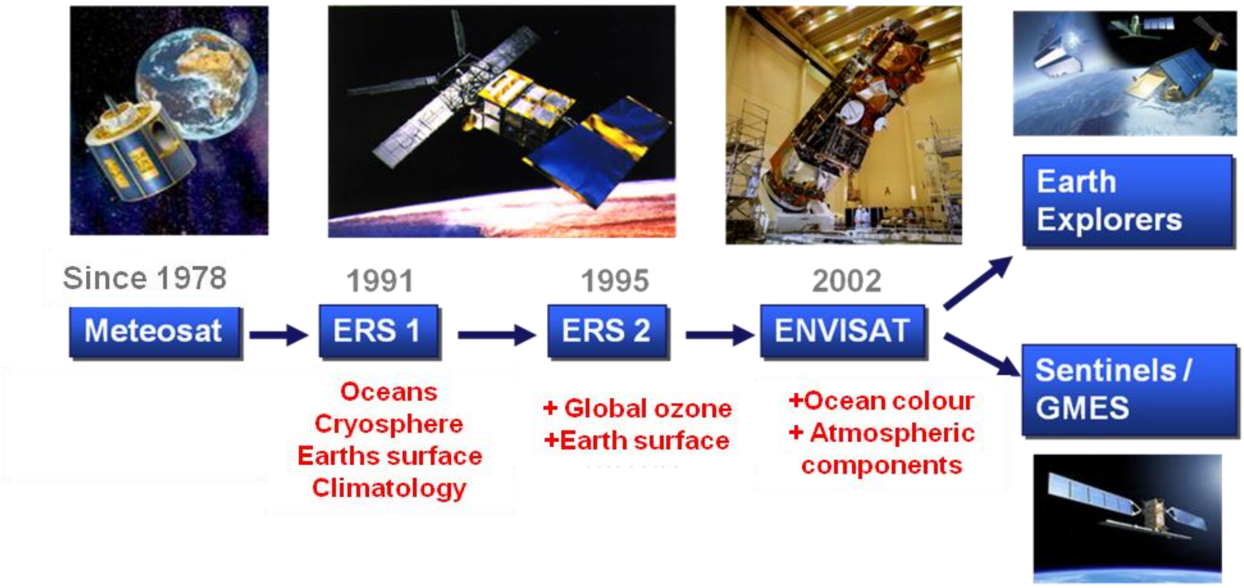


Other space agencies generate atmospheric remote sensing products.



❑ EUROPEAN SPACE AGENCY (ESA)

ESA has also launched several satellites to study the atmosphere, but since the creation of EUMETSAT, the objective is geared more to scientific studies than to operational services.

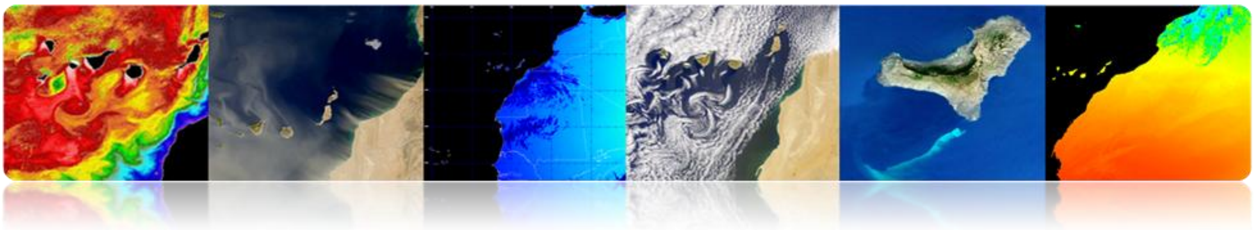


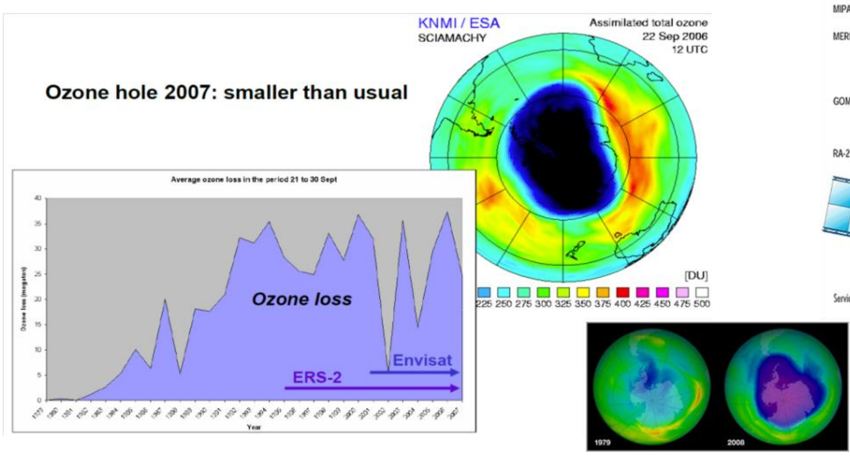
Some of the atmospheric parameters are described below.

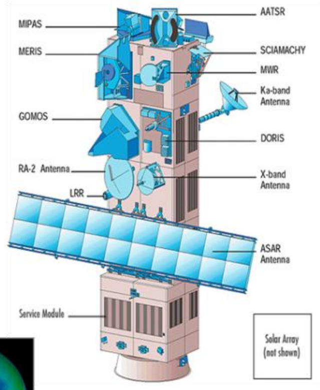
- **Ozone**

Hole in the ozone layer: area in the stratosphere where abnormal ozone reductions occur. It is an annual phenomenon observed during spring in the Polar Regions, followed by a recovery during the summer.

Lately, significant reductions have been found in this layer, especially in Antarctica. It seems to have been caused by a increasing in the concentration of chemicals, standing up chlorofluorocarbons (CFCs) used as refrigerants and aerosol propellants.



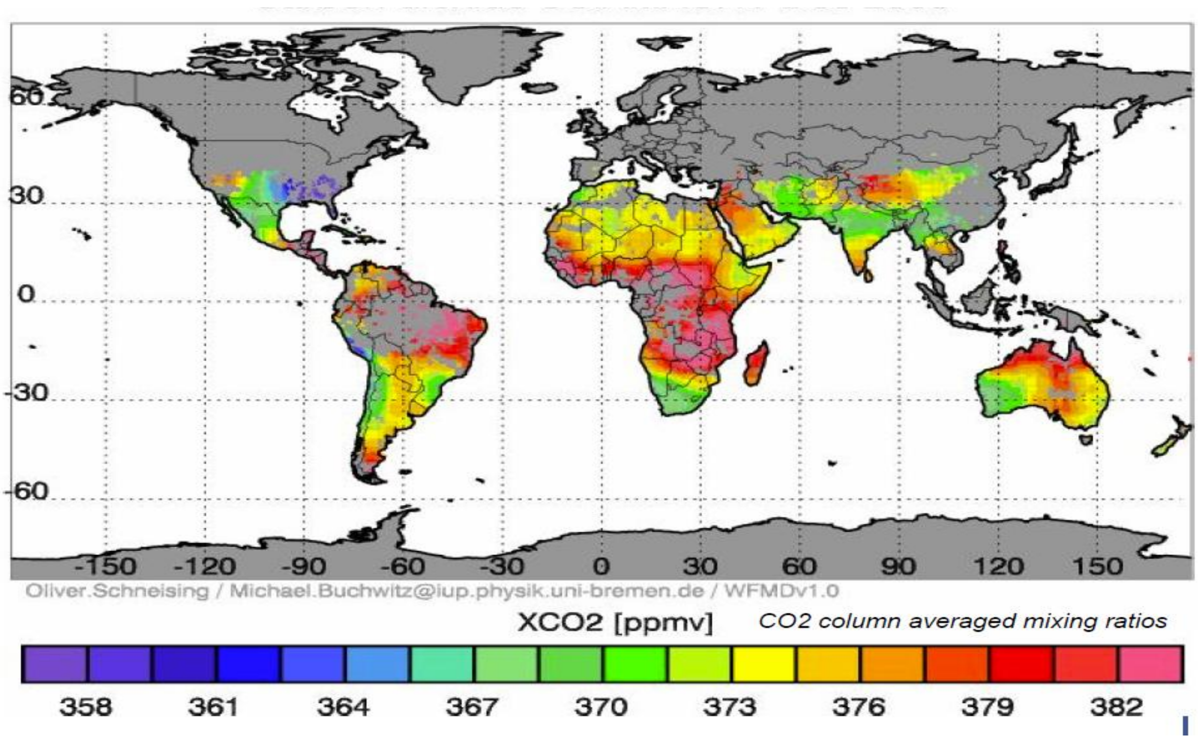


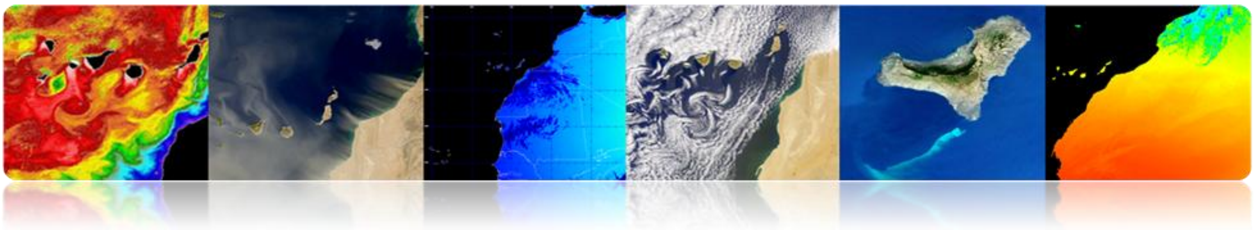


ENVISAT

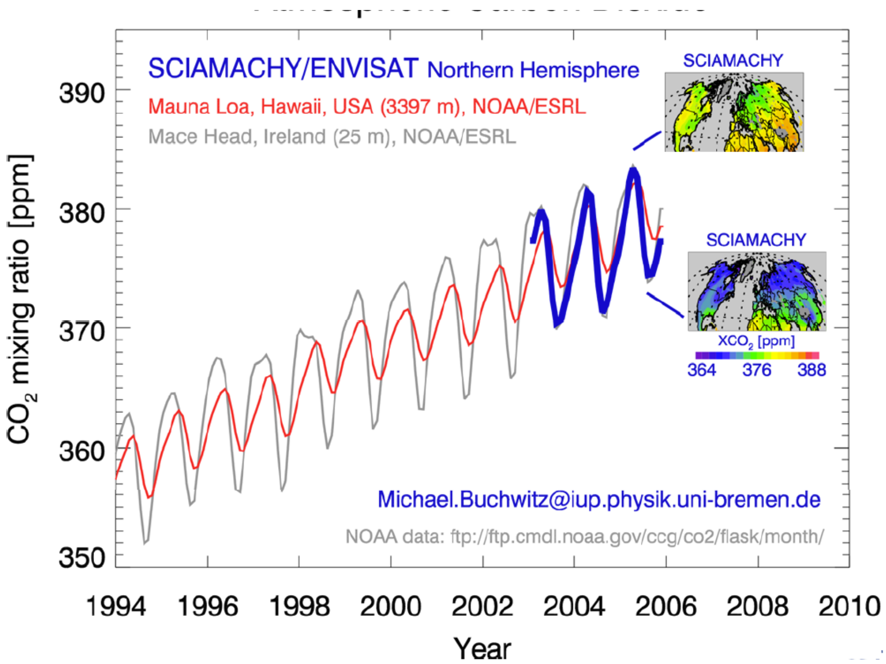
▪ Carbon Dioxide

It is the most important greenhouse gas that causes global warming. Despite the importance of CO_2, our current knowledge (mainly natural) of its sources and sinks is still insufficient.





SCIAMACHY ENVISAT satellite is the first instrument which can measure the global distribution of CO_2 with high sensitivity over land where the sources and sinks of CO_2 can be found. So far, it provides a global confirmation to based measures in some places.

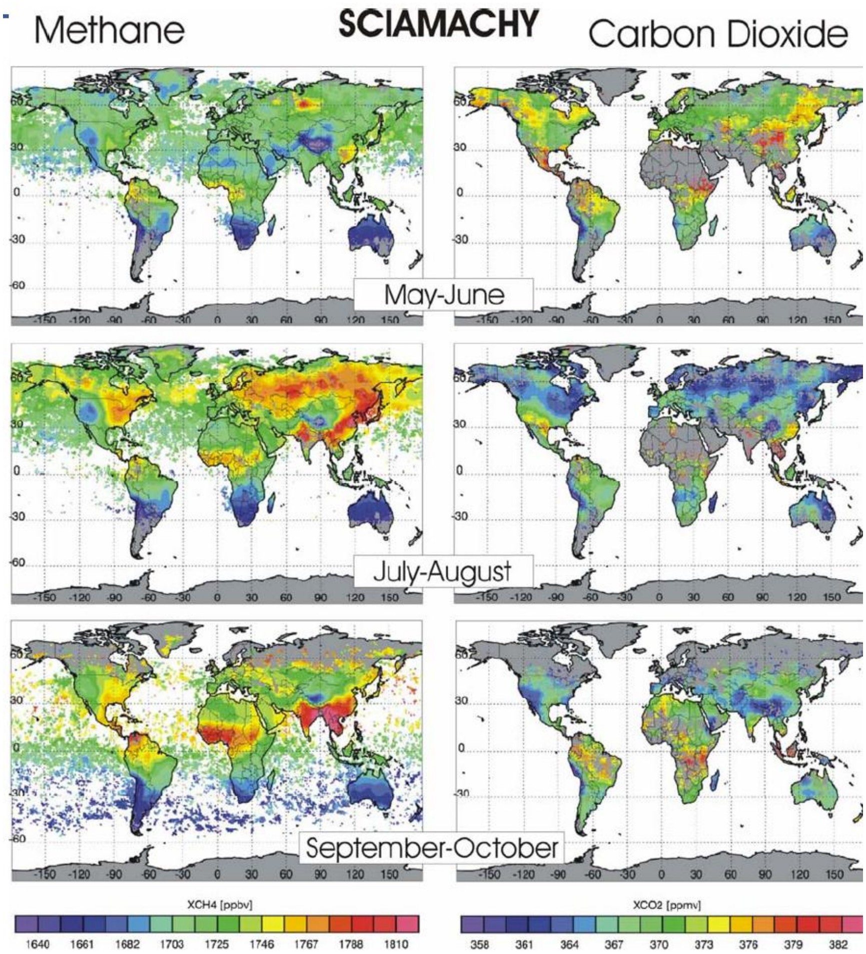


▪ Methane

It is the second most important greenhouse gas that affects global warming.

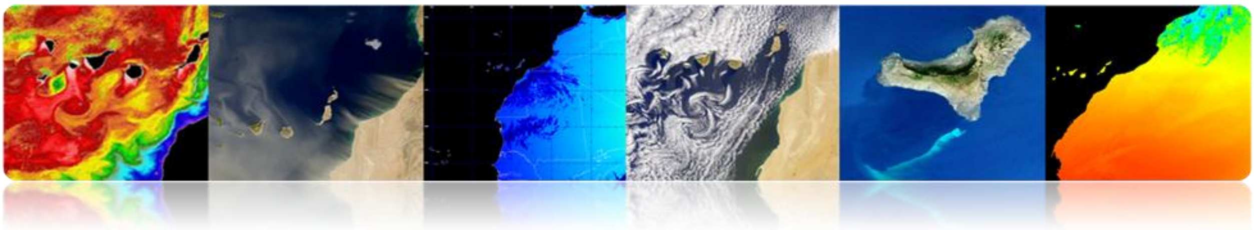
Despite the importance of this gas, our current knowledge of its sources is still unsatisfactory. Recently large quantities of methane in rainforests have been found thanks to SCIAMACHY. This founding points out to the possibility of the existence of methane sources not yet known or to a significant underestimation of the known sources.

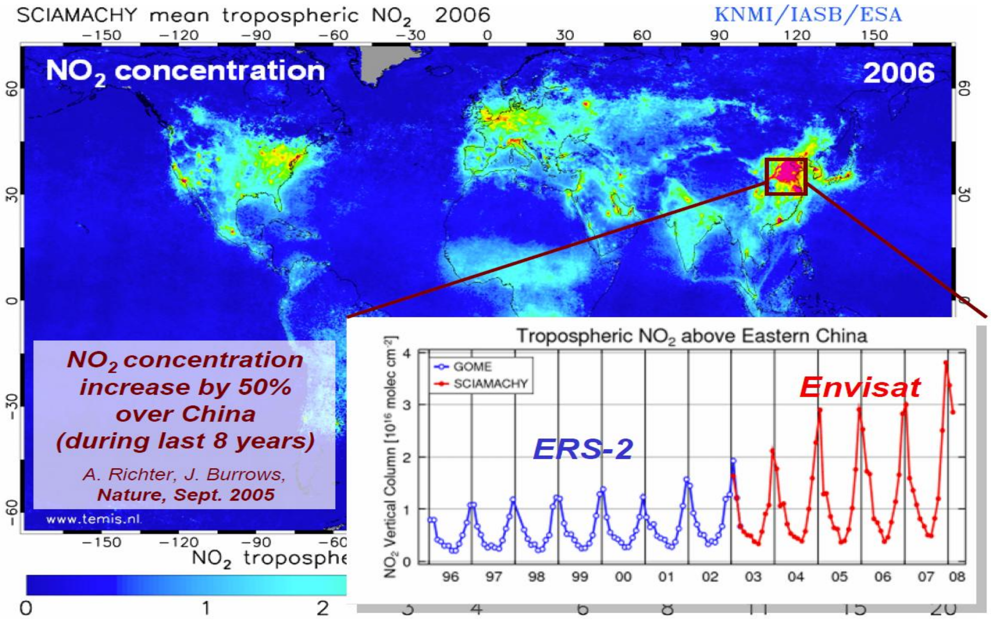
Important sources of methane are rice paddies, ruminants (cattle and sheep), wetlands and methane emissions from plants, which is possibly a major new source of methane discovered by SCIAMACHY that could explain the high level of methane



- ## Nitrogen dioxide

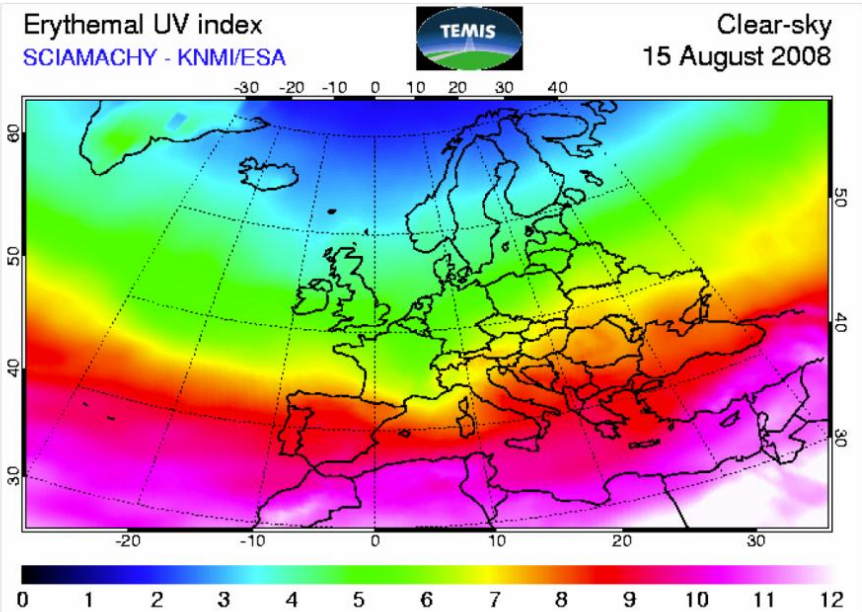
NO_2 is one of the main pollutants. It is brownish-yellow. It is formed in combustion processes at high temperature (motor vehicles, power plants), being a toxic and irritating gas prevalent in urban areas. It mainly affects the respiratory system.



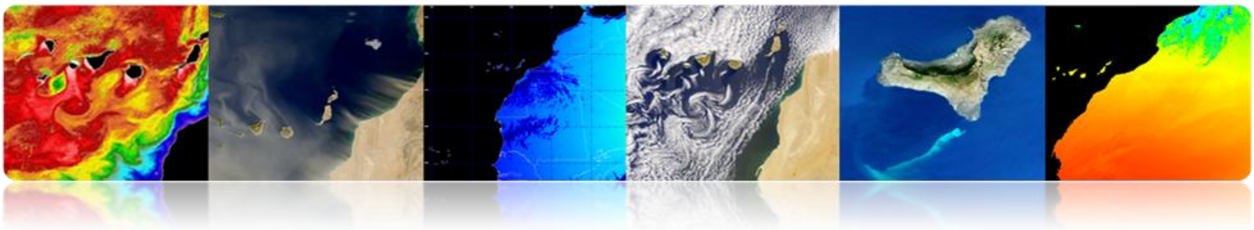


- ## Ultraviolet Index

The UV index is an indicator of the intensity of the Sun’s ultraviolet radiation on the Earth's surface. UV index also indicates the ability of the solar UV radiation to injure our skin.

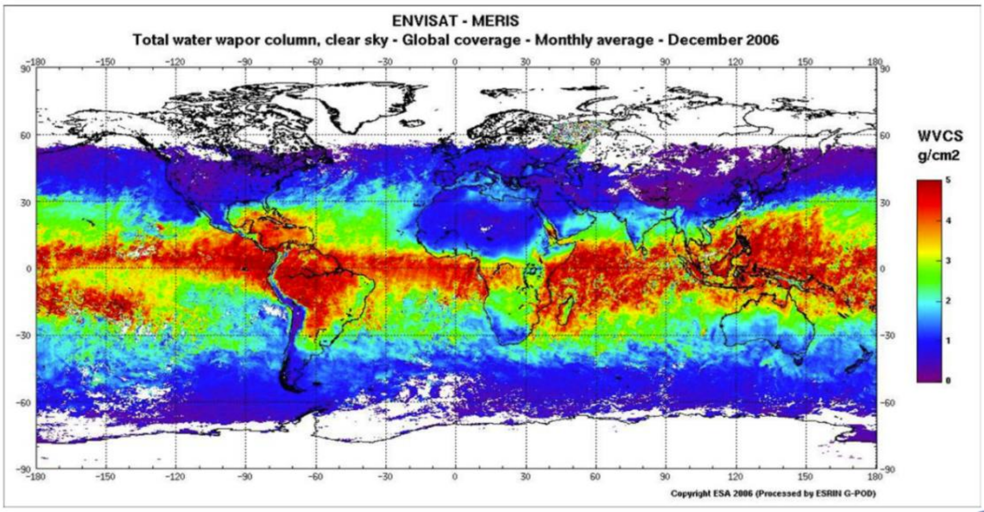


Riesgo	Índice UV
Bajo	<0-2
Moderado	3-5
Alto	6-7
Muy Alto	8-10
Extremadamente alto	> 11

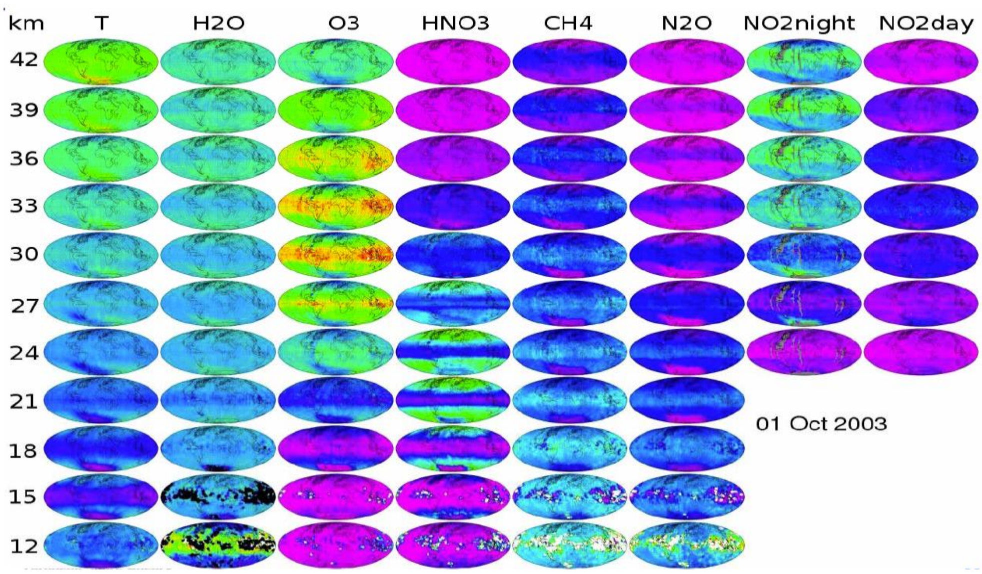


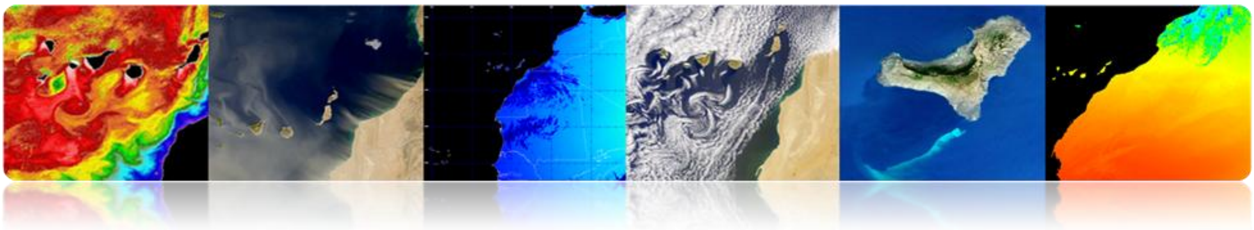
Water Vapor

Water vapor is a gas obtained by evaporation, boiling liquid water or ice sublimation. It is odorless and colorless. It is responsible for humidity and at high concentration it condenses and forms fog or, at higher concentrations, it produces clouds.



Sensor MIPAS (ENVISAT): allows 3D studies

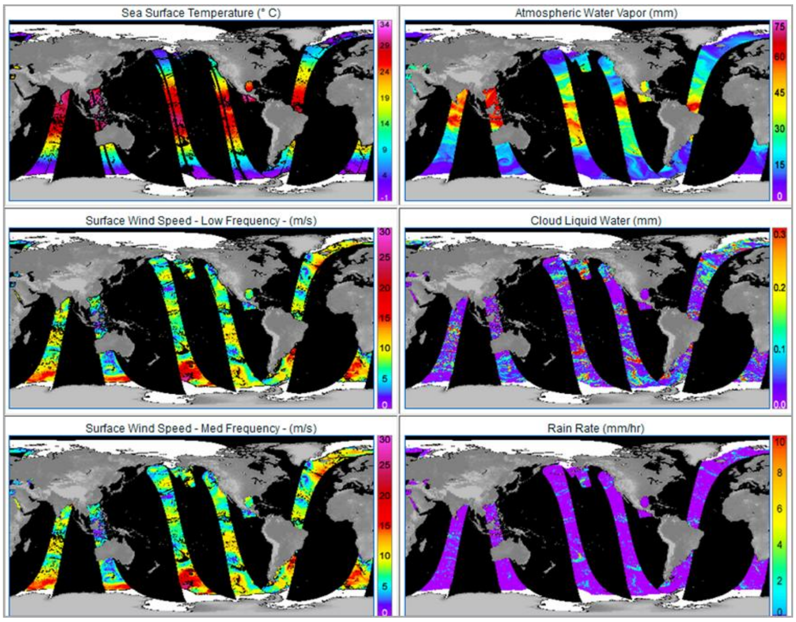




❑ Remote Sensing Systems (RSS - NASA)

Remote Sensing Systems is a research center supported primarily by NASA that focuses on the generation of products from microwave sensors.

http://www.ssmi.com/

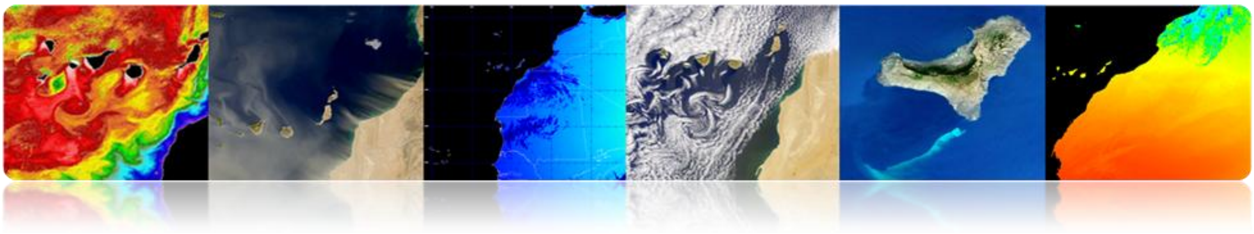


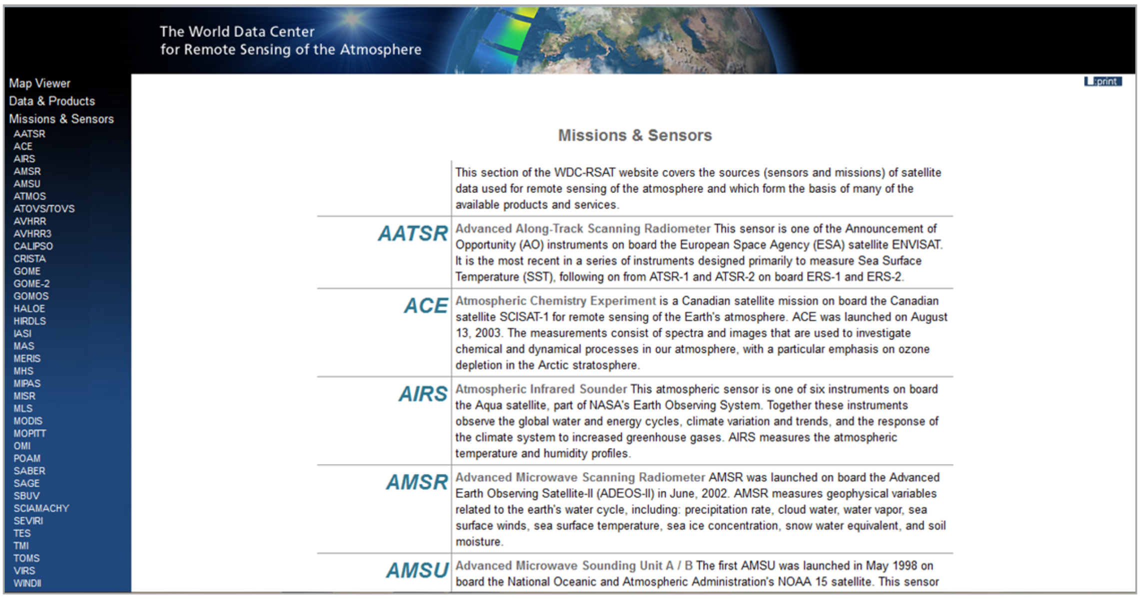
2013/05/16, UTC AM, WindSat

❑ German Aerospace Agency (DLR)

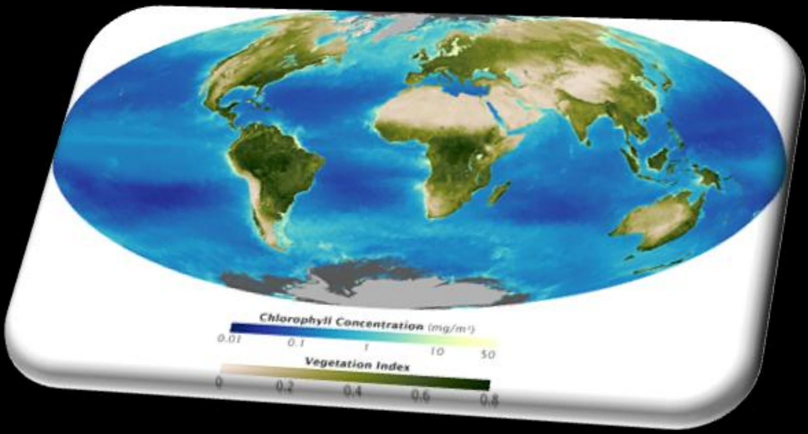
World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT)

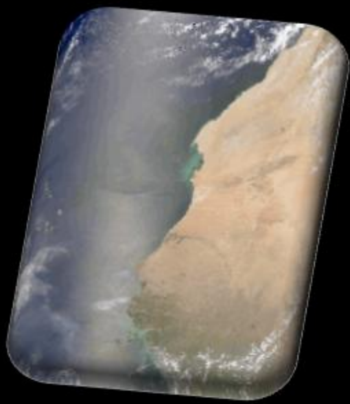
Since 2003 the German Remote Sensing Center DLR operates the WDC-RSAT. By using satellite data, this center offers scientists and the general public data free from many parameters and atmospheric missions.

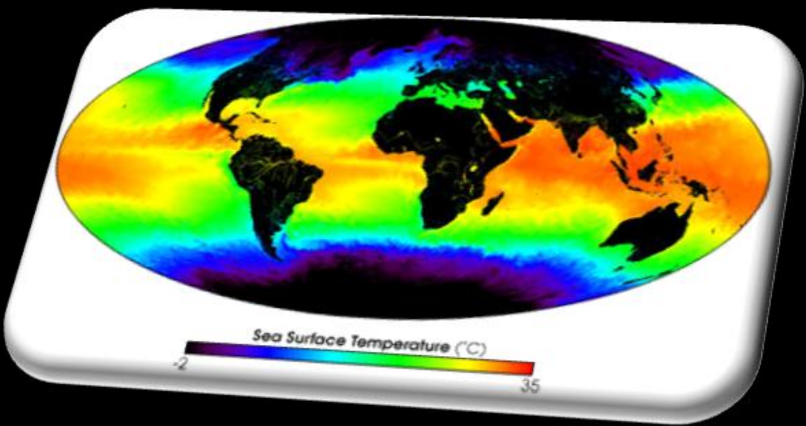


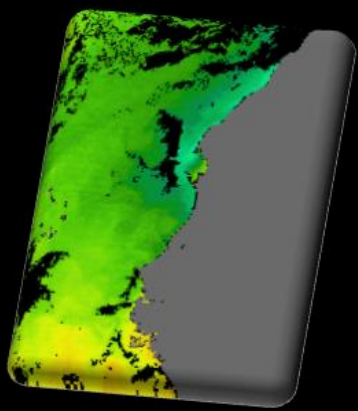


http://wdc.dlr.de/sensors/









4. Radiometric, Atmospheric and Geometric Modeling

Introduction

The technical complexity of the current remote sensing systems, the volume of the available data and the different levels of processing involved in obtaining geophysical parameters, require the establishment of a hierarchy of processes that allow to generate useful operational products (high level) for specific end users and for the scientific community. Typically, only a small ratio of the total available data is processed at the highest level (user level), which generally increases the cost of data at the processing level.

'Each processing level within the hierarchy requires more auxiliary data and it is more complex than the previous levels.'

The type and number of hierarchical processing levels obviously depends on the remote sensing system considered. A proper structuring of hierarchies in the main remote sensing systems (Landsat, SPOT, NOAA, NASA EOS, ERS-ESA) has enabled the creation of databases of consistent and reliable images.

The rapidly changing capabilities of computers and high speed computer networks, allow images to be acquired, processed at different levels and distributed to the scientific community in near real time, according to their requirements and operational applications.

As an example, in the next figure we show the flow chart of the hierarchical processing levels applied to NOAA-AVHRR/SeaStar-SeaWiFS data that are generally used in the main remote sensing systems.

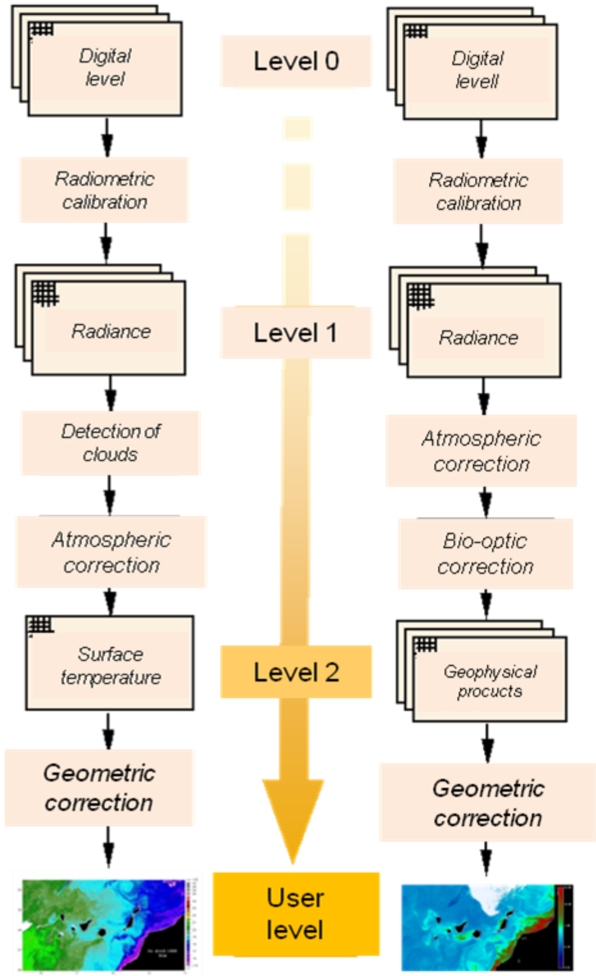
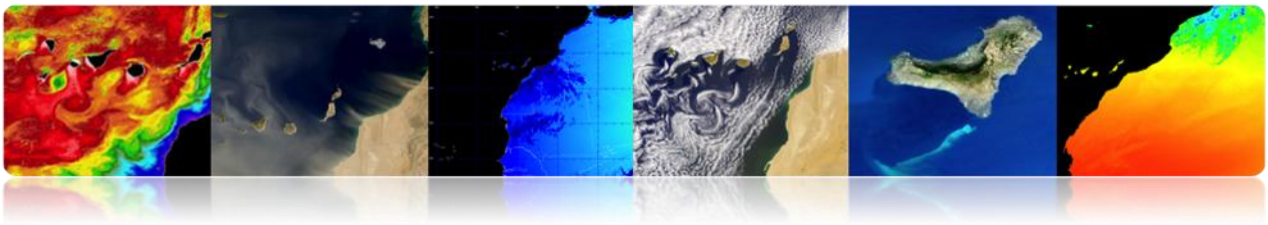


Fig.1. - Generic hierarchy of processing levels applied to NOAA-AVHRR data.

The first sections of this chapter analyze the sensor characteristics affecting the radiometric quality of the images and the atmospheric modeling applied to the data observed by the sensor. This is important to answer the question "What are we observing?" Another relevant question is "Where are we observing?" The answer to this question is determined by the images' geometric features.



The images taken by sensors located on-board of satellites contain geometric distortions, in addition to the radiometric errors related to the instrument characteristics and the presence of the atmosphere. Geometric distortions can be caused by many factors. The relative motion between the satellite, the exploration sensor and the Earth originate displacement errors of the pixels in the image obtained. The exploration features of the sensor, the Earth's curvature and variations, uncontrolled position and orientation of the geometric platform generate geometric errors with a different origin and complexity.

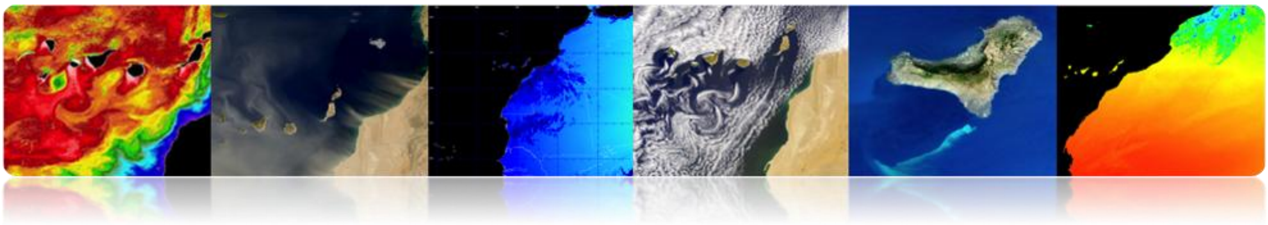
Next, the main sources of radiometric, atmospheric and geometric distortion and their effects on the image will be analyzed, as well as the basic techniques for cloud detection. Also the procedures used for their compensation will be reviewed and applied to the correction of images from different sensors.

The objectives of this chapter are:

- Distinguish among the main sources of error produced in Earth observation satellite images;
- Know the radiometric distortion factors caused by space platforms;
- Understand the atmospheric influence on the spectral radiance detected by the remote sensing sensor;
- Study the main sources of geometric distortion and the procedures for restoration of satellites images;
- Know cloud detection techniques.

CONTENTS

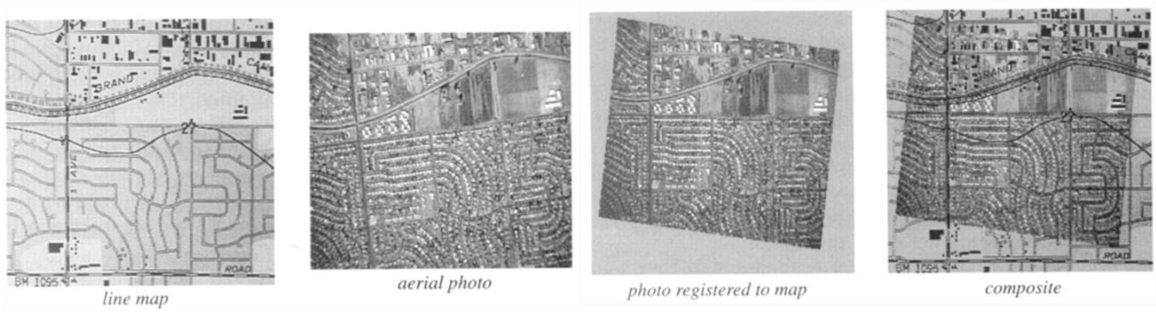
Radiometric, Atmospheric and Geometric Modeling



4.1 SOURCES OF ERRORS IN SPACE OBSERVATION

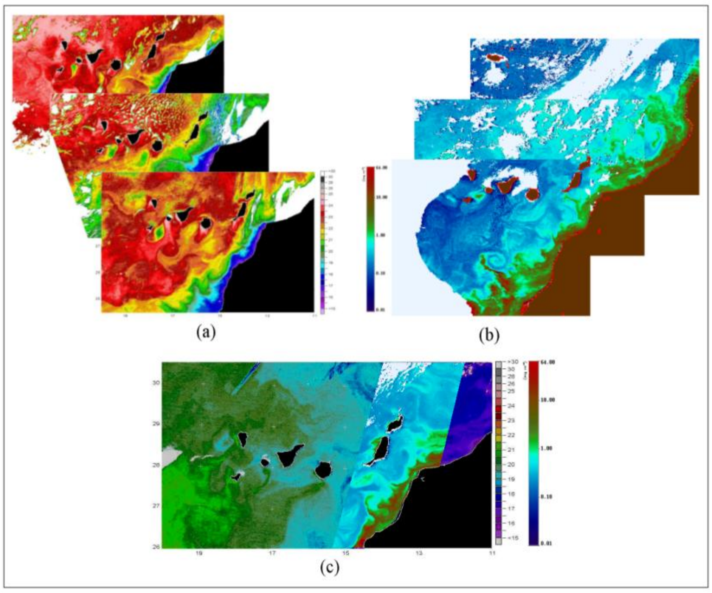
❑ APPROACHES TO THE USE OF REMOTE SENSING DATA

- **Centered Image:** Spatial relationship between different features on the Earth surface → Maps Creation: Photogrammetry



- **Centered Data:** High precision in the spectra-temporal calibrations.

Integration and comparison of multi-temporal and multi-sensor data



❑ SOURCES OF ERROR IN A SPATIAL IMAGE

What are we observing?

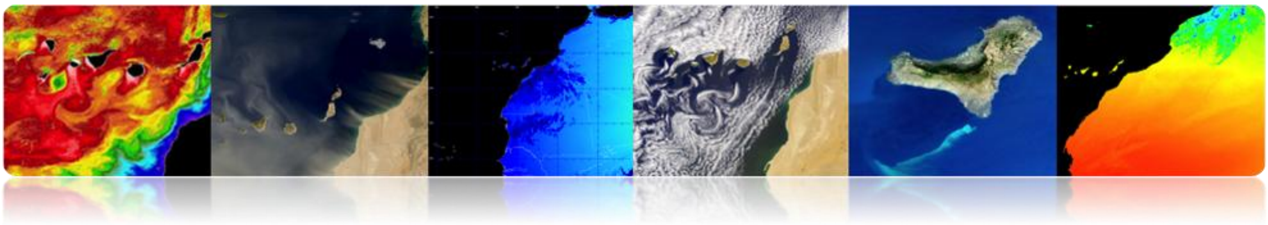
Radiometric and atmospheric properties.

Where are we observing?

Geometric characteristics of the images.

The images taken by sensors located on satellites contain:

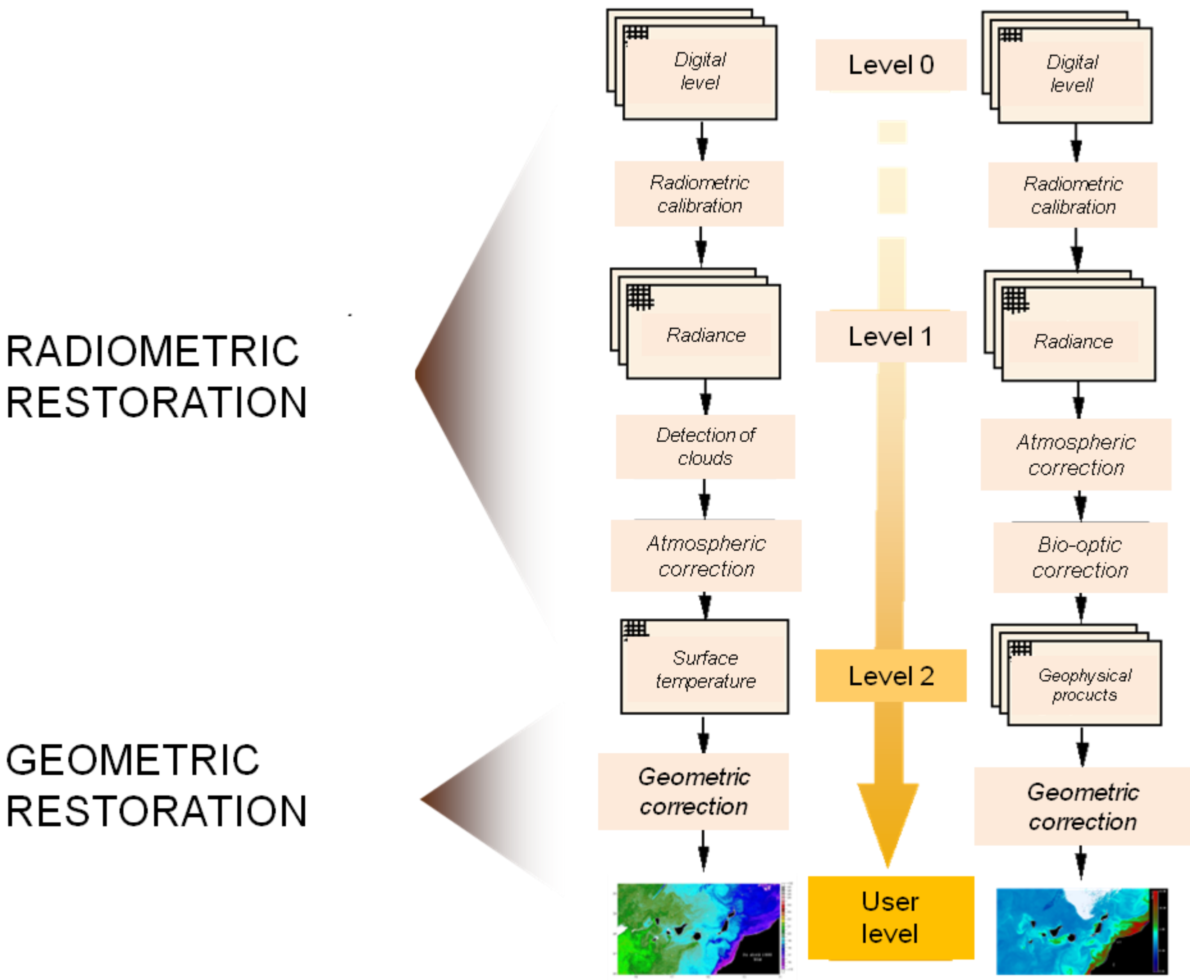
- **Radiometric errors:** instrument (sensor) and atmosphere presence.
- **Geometric errors:** Relative motion between the satellite, the exploration sensor and the Earth, exploration of the sensor, Earth curvature, platform variation.

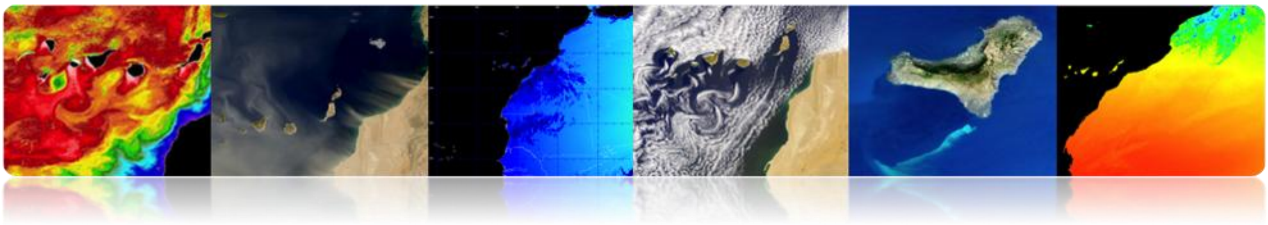


❑ SATELLITE IMAGE PROCESSING HIERARCHY

What are we observing?
Radiometric Modeling
Atmospheric Modeling

Where are we observing?
Geometric Modeling





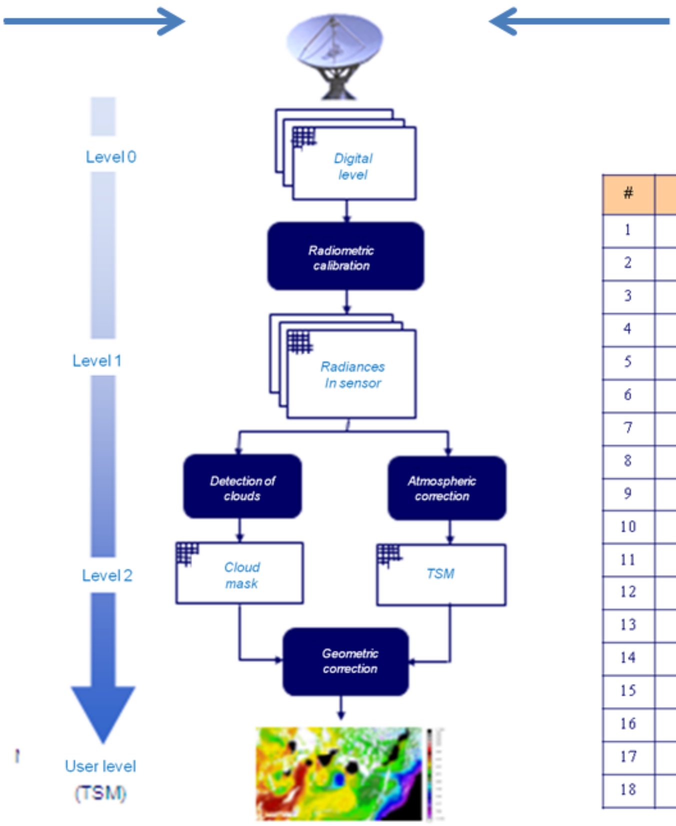
❑ SATELLITE IMAGE PROCESSING HIERARCHY: PREPROCESSED IMAGES TASKS.

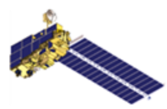
- **Radiometric Calibration:** Convert digital levels to radiance values or brightness temperature values.
- **Atmospheric correction:** Take into account the contribution of atmospheric radiation reaching the sensor (NDVI or SST recovery).
- **Geometric correction:** Correct distortions in the images received related to curvature and rotation of the Earth, sensor exploration and variations of the platform.
- **Detection of clouds:** Mask correctly cloudy pixels to ensure that the geophysical parameters obtained are representative of the Earth surface.

❑ SATELLITE IMAGE PROCESSING HIERARCHY: OBTAINING SST

AVHRR/3

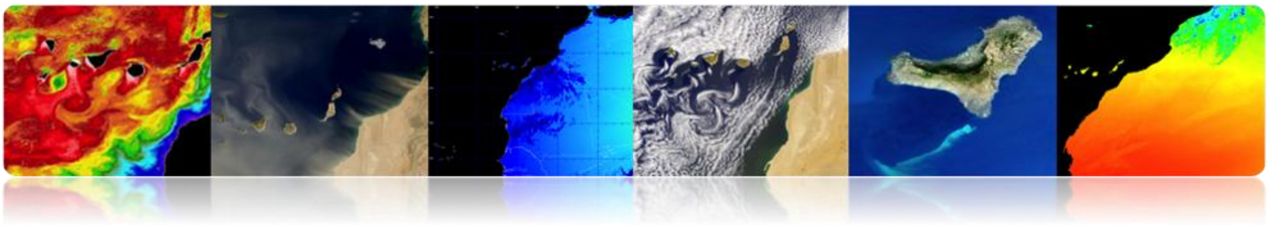
#	Band (μm)
1	0.58 – 0.68
2	0.725 – 1.0
3A	1.58 – 1.64
3B	3.55 – 3.93
4	10.3 – 11.3
5	11.5 – 12.5



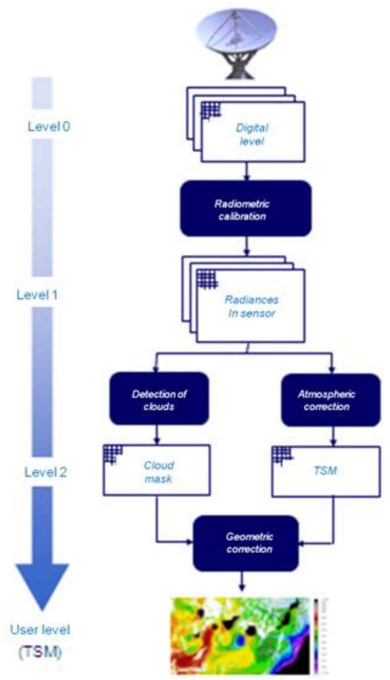


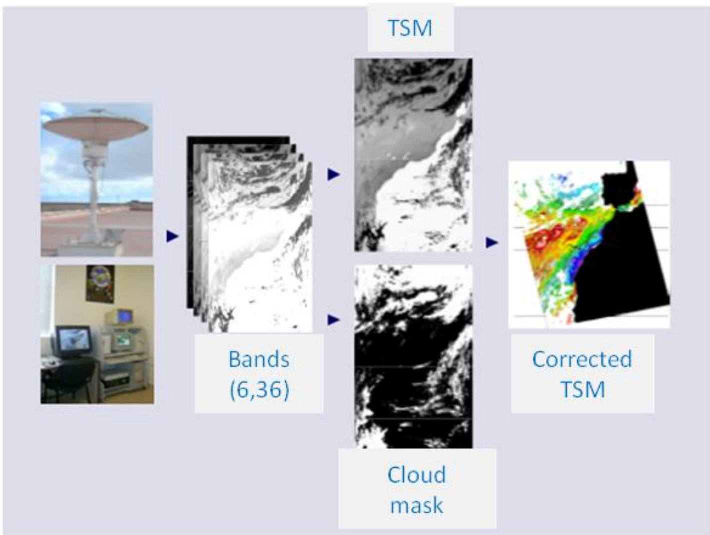
MODIS

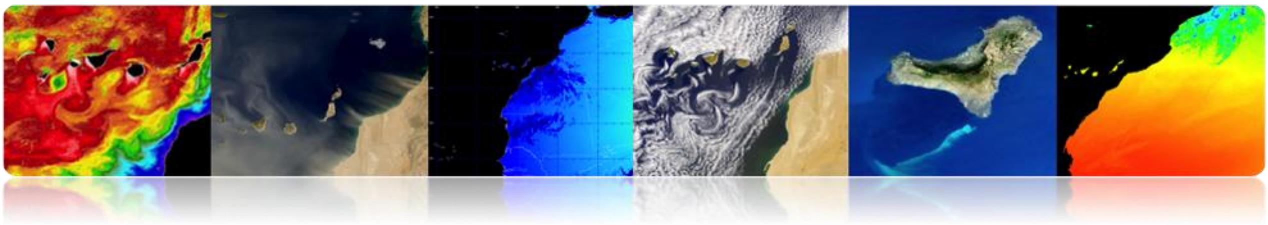
#	Band (nm)	#	Band (nm)
1	620-670	19	915 - 965
2	841-876	20	3.660 - 3.840
3	459-479	21	3.929 - 3.989
4	545-565	22	3.929 - 3.989
5	1230-1250	23	4.020 - 4.080
6	1628-1652	24	4.433 - 4.498
7	2105-2155	25	4.482 - 4.549
8	405-420	26	1360 - 1390
9	438-448	27	6.535 - 6.895
10	483-493	28	7.175 - 7.475
11	526-536	29	8.400 - 8.700
12	546-556	30	9.580 - 9.880
13	662-672	31	10.780 - 11.280
14	673-683	32	11.770 - 12.270
15	743-753	33	13.185 - 13.485
16	862-877	34	13.485 - 13.785
17	890-920	35	13.785 - 14.085
18	931-941	36	14.085 - 14.385



❑ SATELLITE IMAGE PROCESSING HIERARCHY: OBTAIN SST

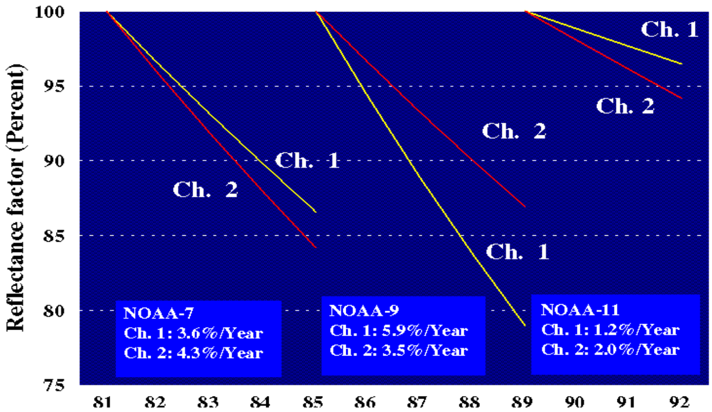






4.2 RADIOMETRIC MODELING

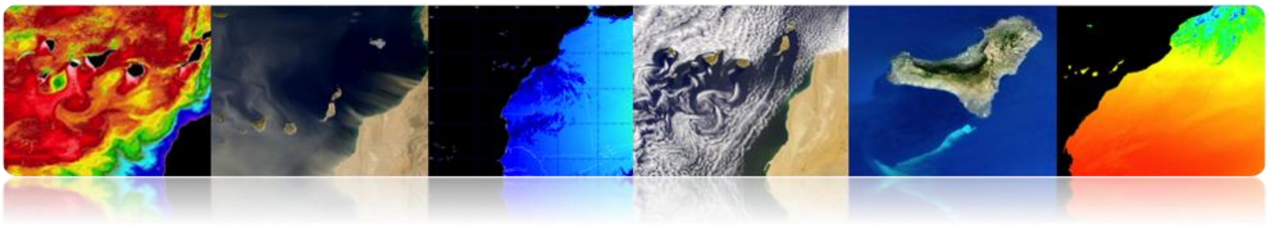
- Convert DN to radiance values: it is necessary to obtain geophysical parameters or to compare images from different sensors.
  - If the sensor were completely stable, pre-launch calibration would be enough.
  - Variations in thermal conditions and degradation of the instrument -response and sensitivity of detectors in the sensor over time- require incorporation of a dynamic calibration system in flight.



Example: WV2 Radiometric Modeling

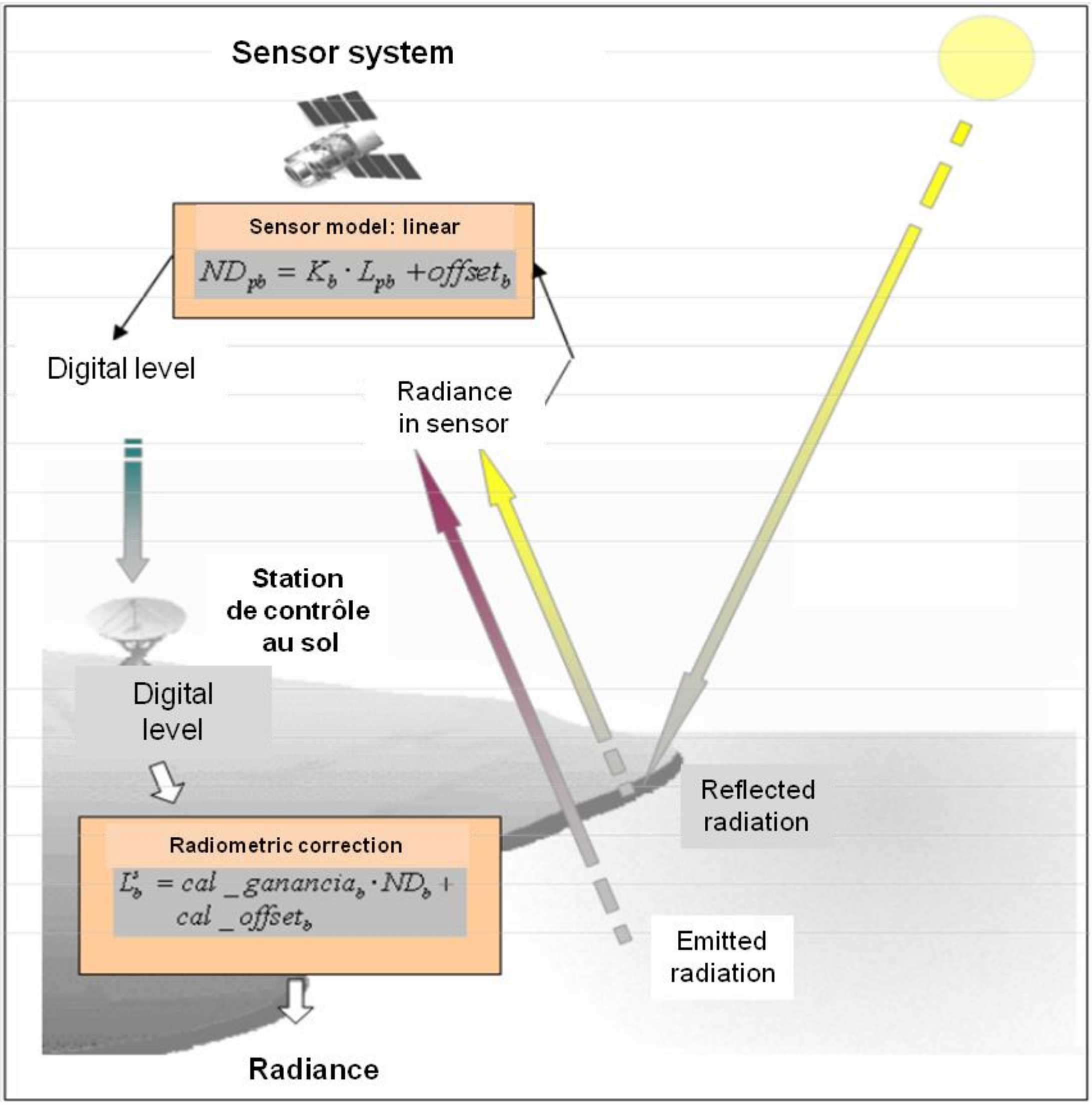
$$L_{\lambda\ Pixel,Banda} = \frac{K_{Banda} \cdot q_{Pixel,Banda}}{\Delta\lambda_{Banda}}$$

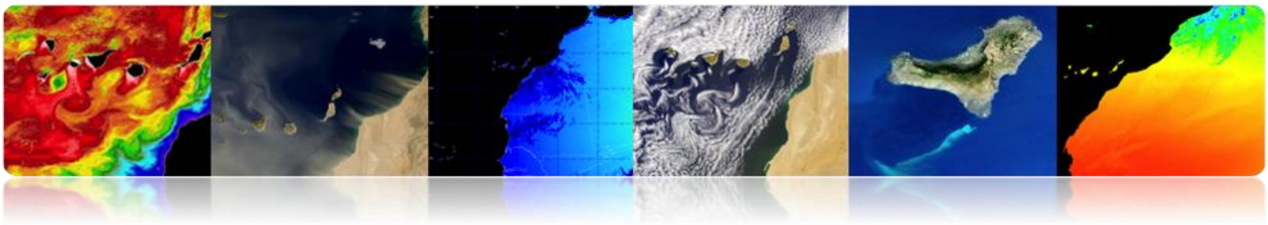
Banda espectral	$\Delta\lambda_{Banda}$ Ancho de banda efectivo [µm]	Factor de calibración
Pancromática	0.2846	3.788831e-02
Costera	0.0473	9.295654e-03
Azul	0.0543	1.260825e-02
Verde	0.0630	9.713071e-03
Amarillo	0.0374	5.101088e-03
Rojo	0.0574	1.103623e-02
Rojo extremo	0.0393	4.539619e-03
Infrarrojo cercano 1	0.0989	1.224380e-02
Infrarrojo cercano 2	0.0996	9.042234e-03



Example: AVHRR Radiometric Modeling: Linear Model

$$L = gain \cdot DN + offset$$

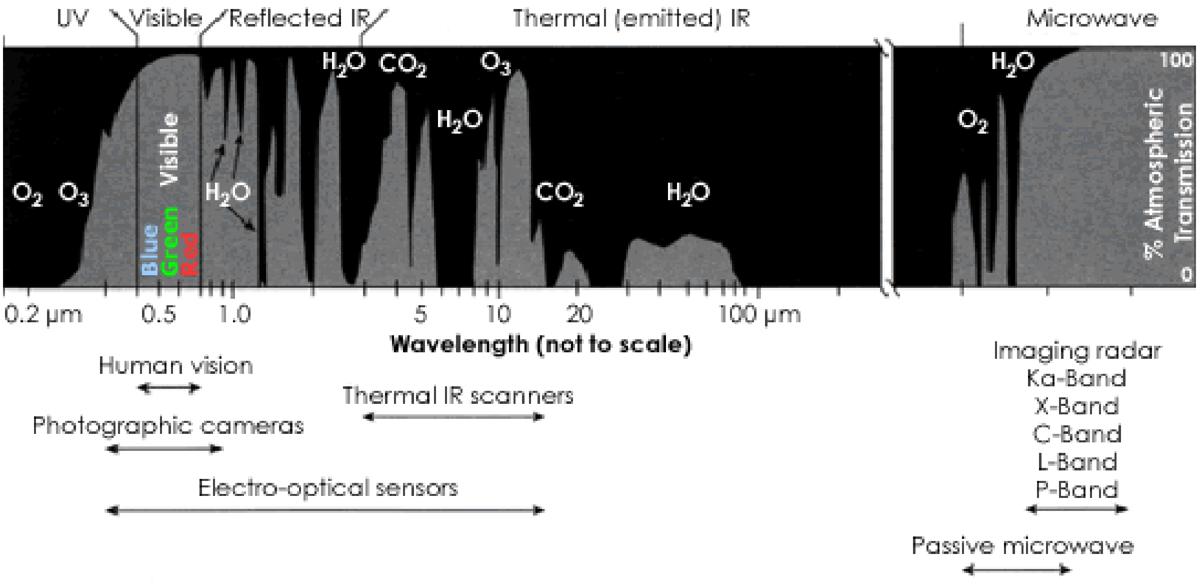




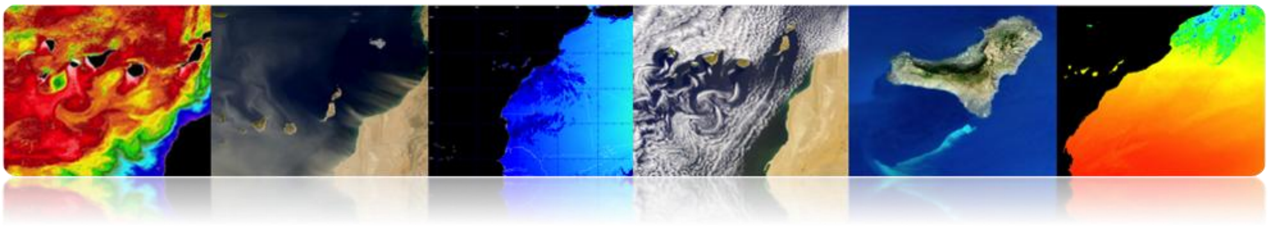
4.3 ATMOSPHERIC MODELING

- Disadvantage Remote Sensing: sensor receives data from the Earth's surface through the atmosphere.
- Absorption and scattering are atmospheric effects, but it is nearly transparent to electromagnetic radiation at many wavelengths.

Atmospheric windows



Atmospheric transmittance: Opacity of the Atmosphere



❑ ATMOSPHERIC CORRECTION: EFFECTS ON THE CALCULATION OF THE REFLECTIVITY

- Radiance received by the satellite :

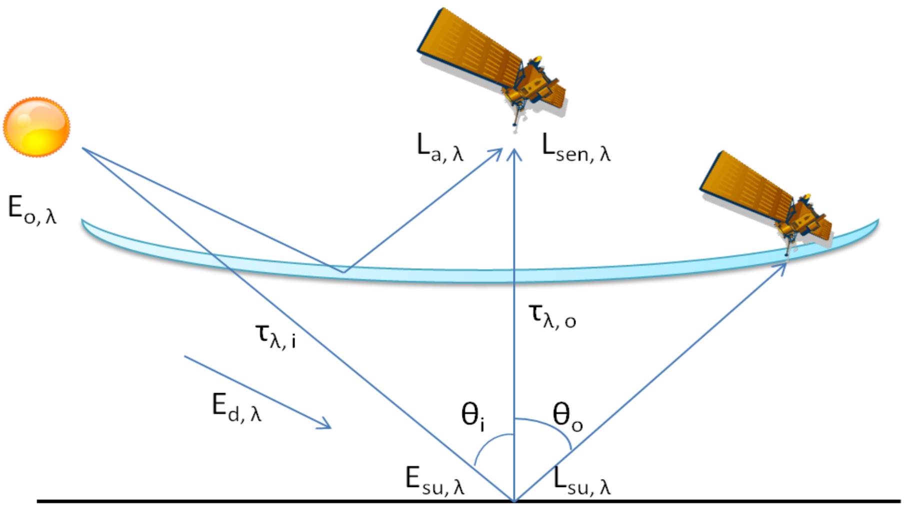
$$L_{sen,\lambda} = L_{su,\lambda} \cdot \tau_{\lambda,o} + L_{a,\lambda}$$

- Transmissivity in the upward direction

$$\tau_{\lambda,o} = exp\left(\frac{-\tau_{oz,\lambda} - \tau_{a,\lambda} - \tau_{r,\lambda}}{\cos\theta_o}\right)$$

- Actual reflectivity of land cover

$$\rho_\lambda = \frac{(L_{sen,\lambda} - L_{a,\lambda}) \cdot d_{ES}^2 \cdot \pi}{\tau_{\lambda,o}(E_{o,\lambda} \cdot \cos\theta_i \cdot \tau_{\lambda,i} + E_{d,\lambda})}$$



- In order to calculate the surface reflectivity (to estimate the atmosphere trasnmisivity, the diffuse irradiation and radiance due to atmospheric dispersion) → **ATMOSPHERIC CORRECTION**

❑ ATMOSPHERIC CORRECTION: METHODOLOGIES

- Laborious and complex procedures that require multiple inputs on the conditions of the atmosphere when the sensor capture the image.

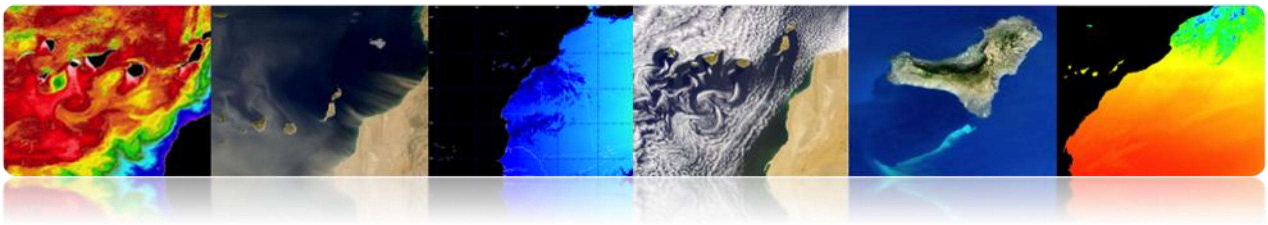
- Atmospheric model based **on in-situ** data and **data from other sensors** (multilook method).

- **Physical** model based on the **Radiative Transfer Equation**.

Usual: MODTRAN4, 6S, FLAASH (SW ENVI)
and ATCOR (SW ERDAS)

- Atmospheric model based on **data from the image itself**.

Usual: DOS and COST



❑ ATMOSPHERIC CORRECTION: MULTI-BAND METHOD TO RECOVER THE TSM.

- A simple linear combination of radiances at two wavelengths provides a good estimate of the radiation emitted by the surface.

$$T_s = a_0 T_{11} + a_1 \cdot (T_{11} - T_{12}) + a_2$$

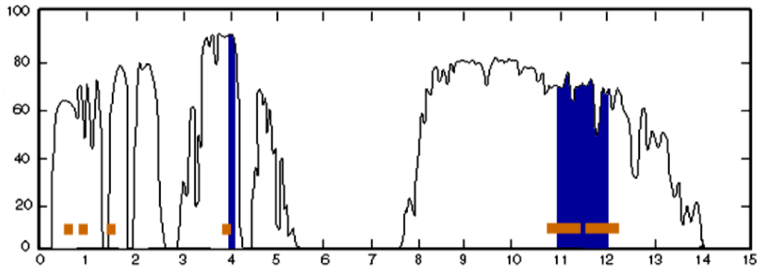
(Linear split-window equation)

T_S: Sea Surface Temperature

T_{11}: Brightness temperature channel 4

T_{12}: Brightness temperature channel 5

a_i: Coefficients

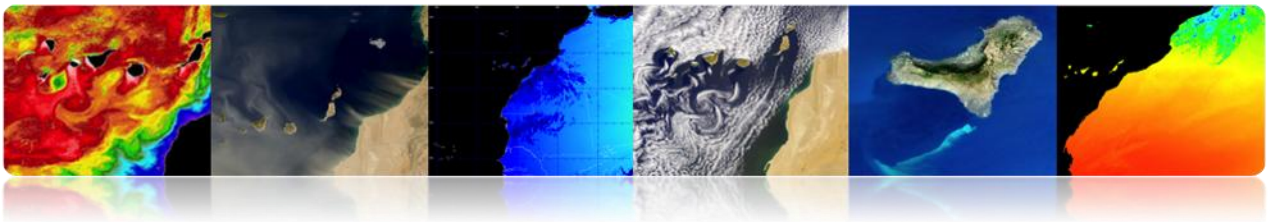


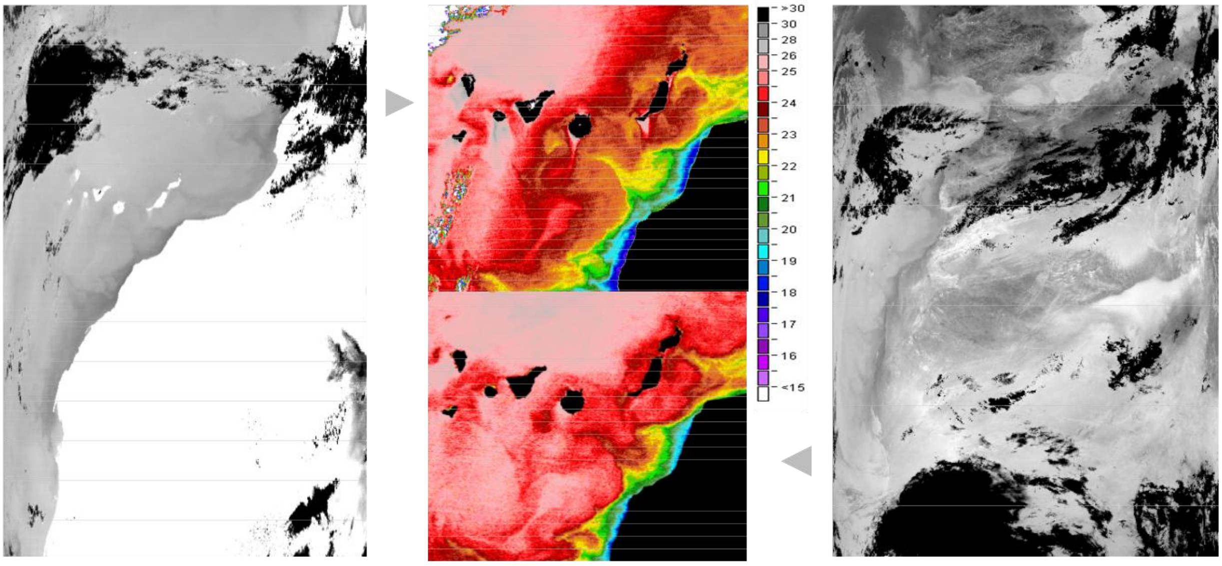
- **Coefficients:**

  - Theoretical, using a radiative transfer model.
  - Regression between in situ temperature data and brightness temperature.

  The great variability of the angle of observation -satellite zenith angle- causes a change in the optical path of the atmosphere:

$$T_S = a_o \cdot T_{11} + a_1 \cdot (T_{11} - T_{12}) + a_2 \cdot (\sec\theta - 1) + a_3$$



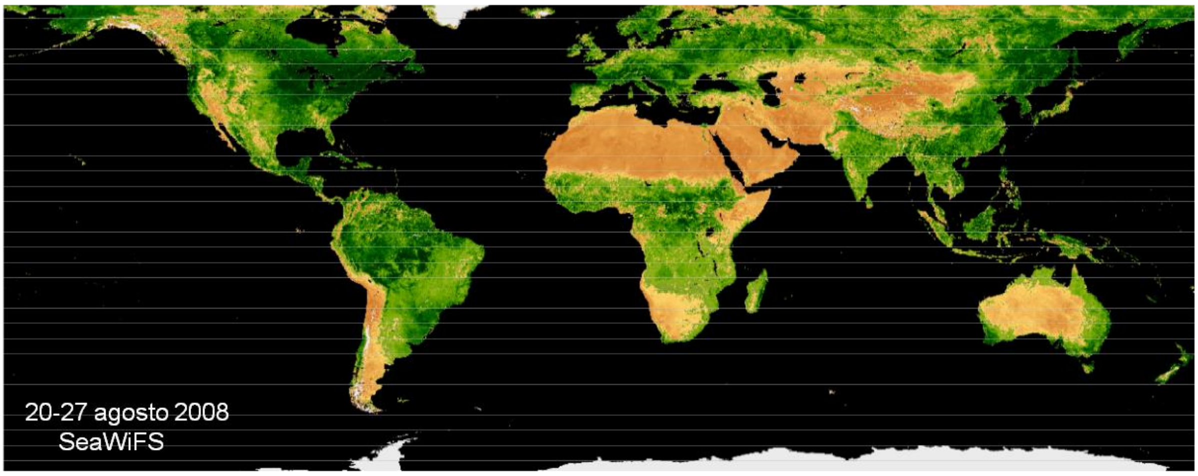


MODIS-AQUA *AVHRR-NOAA 16*

❑ ATMOSPHERIC CORRECTION: VEGETATION INDIXES

- Based on the relationship between NIR and R bands.
- Normalized Difference Vegetation Index (NDVI) is widely used. Its values run between -1 to 1.
- NDVI is a poor indicator of arid or semi-arid regions.

$$NDVI = \frac{\rho_{NIR} - \rho_{red}}{\rho_{NIR} + \rho_{red}}$$



❑ ATMOSPHERIC CORRECTION: SECOND SIMULATION OF A SATELLITE SIGNAL IN THE SOLAR SPECTRUM (6S) TO RECOVER REFLECTIVITY IN WORLDVIEW 2 (AND MODIS) IMAGES

The model is divided into five main parts:

- Geometric conditions.
- Atmospheric Modeling.
- Definition of the heights of the study area and satellite.
- Spectral conditions.
- Defining the type of soil.

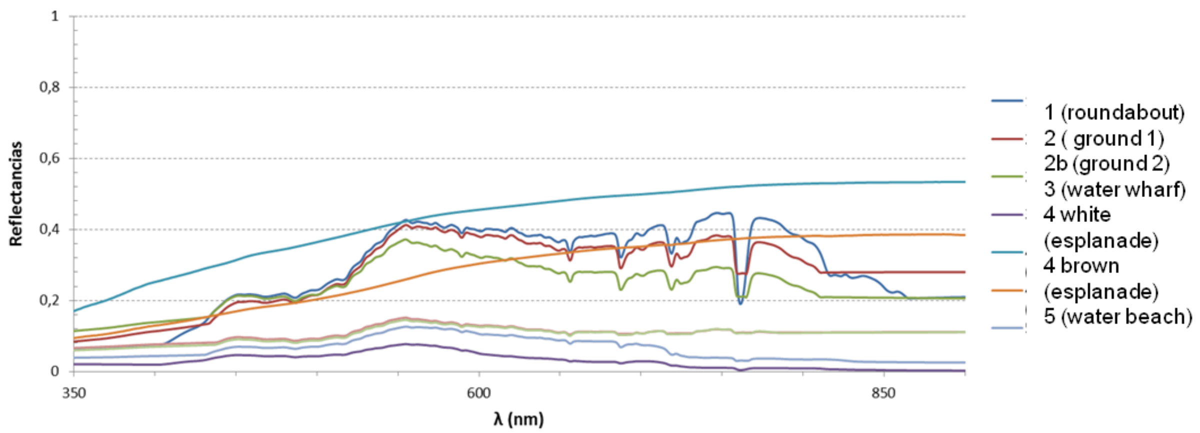
Fixed configuration:

- Atmospheric model.
- Heights of terrain and satellite. Satellite bands.
- Defining of the type of surface.

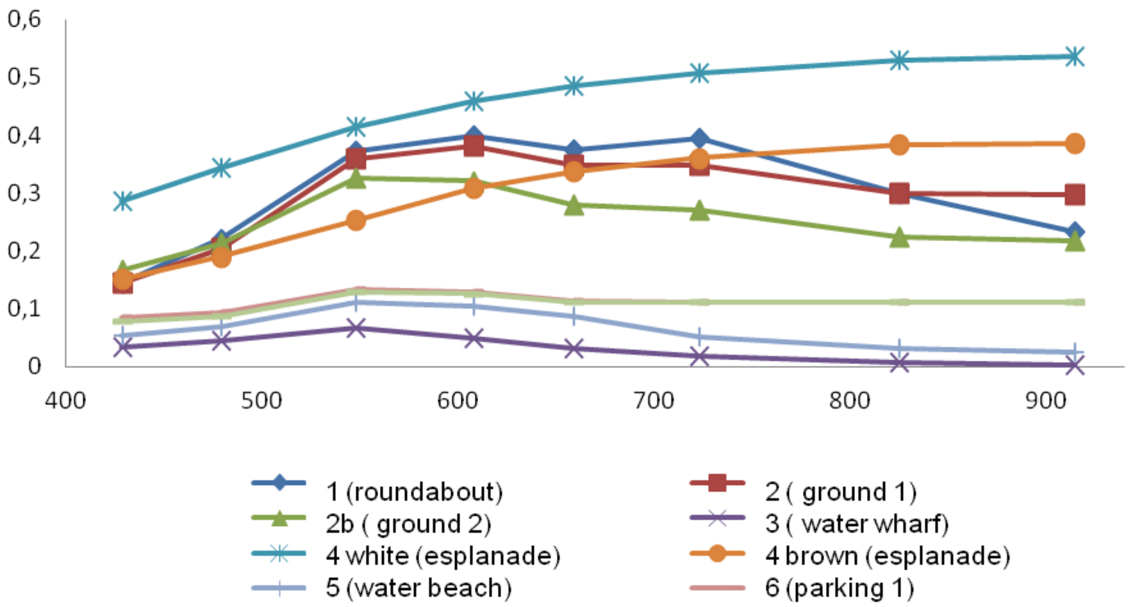
Settings for each image:

- Geometrical model -angles of the Sun and the satellite.
- Optical depth of the atmosphere -NASA database.

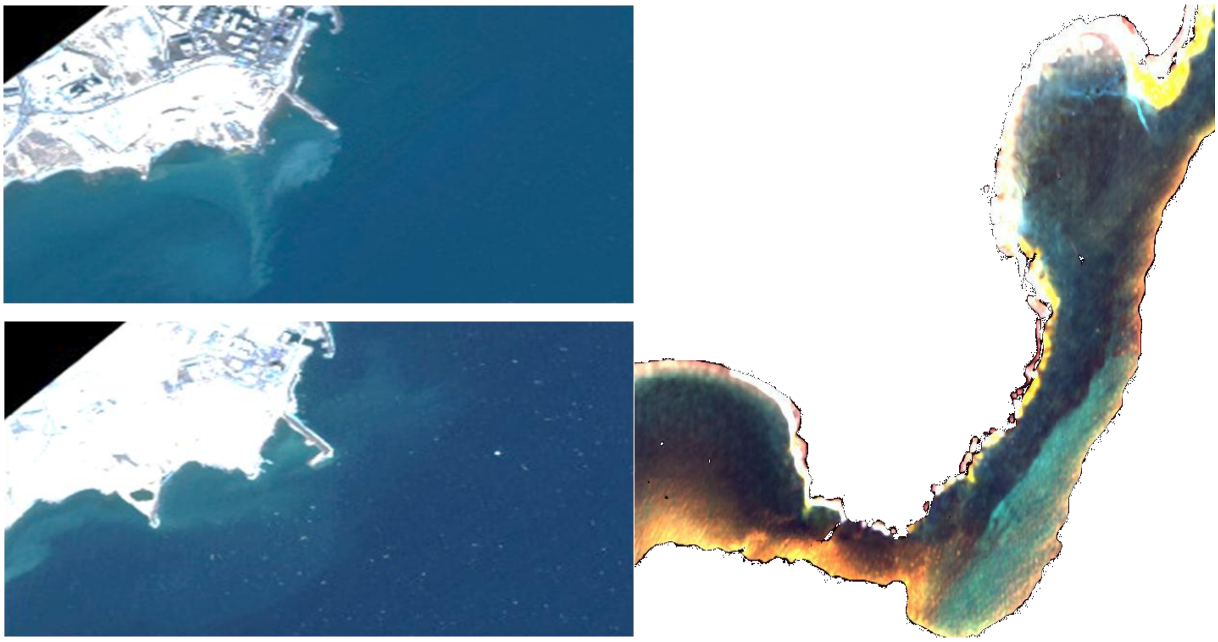
Radiometer Measurements



WorldView-2 Signatures



Atmospherically corrected WV2 Granadilla Imagery

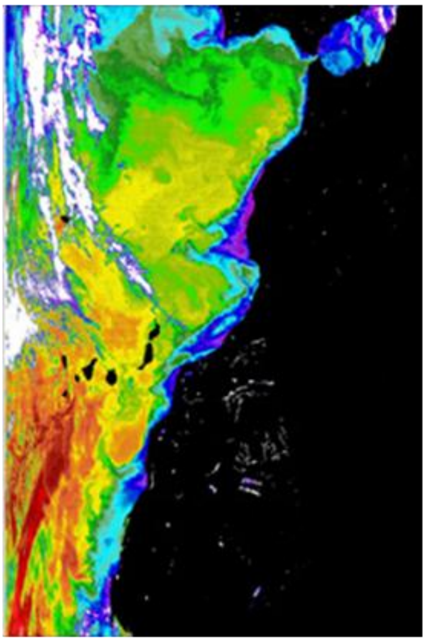


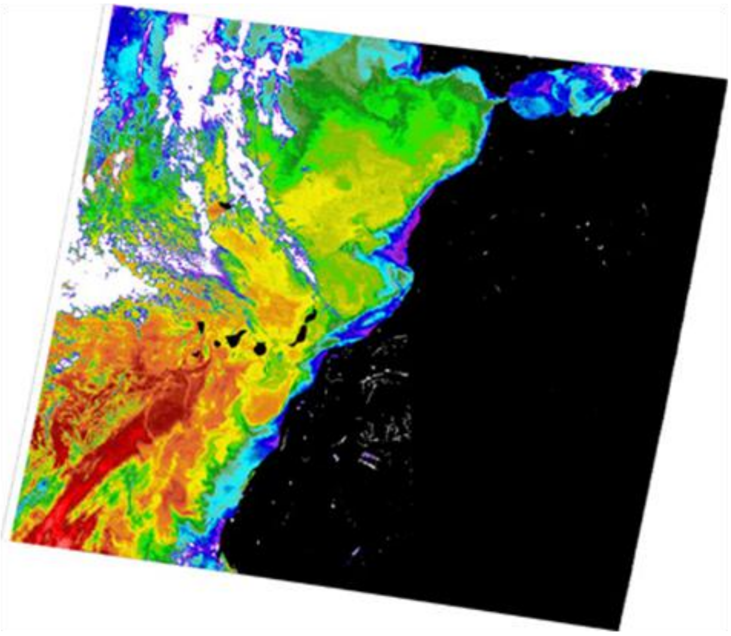
4.4 GEOMETRIC MODELING

- Digital images from space sensors contain geometric errors.

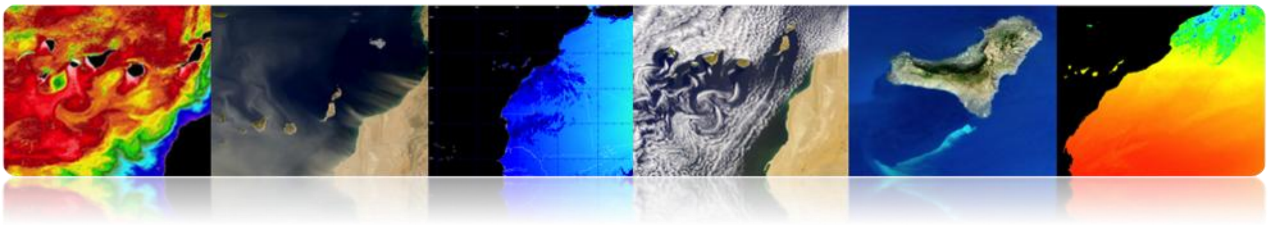
- Sources of geometric distortion:

  - Earth Rotation.
  - Panoramic distortion.
  - Curvature of exploration.
  - Earth curvature.
  - Platform variations.



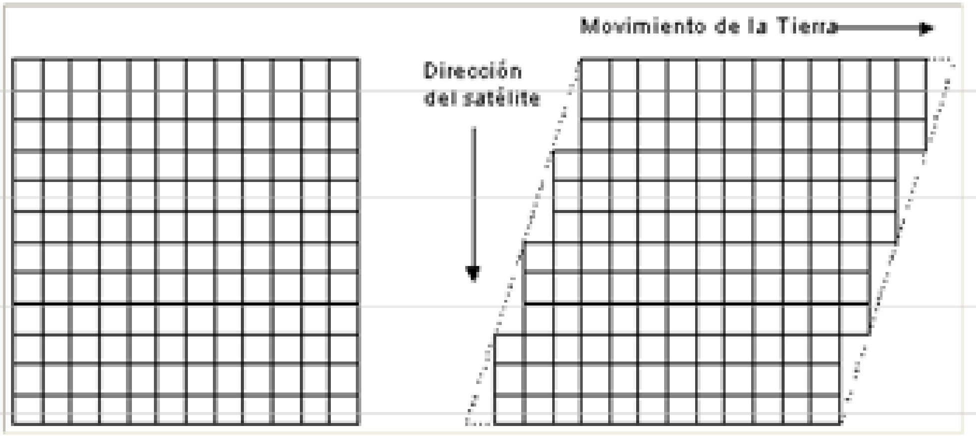


It is essential to have the exact location of any pixel, in order to compare images - multitemporal or multisensor analysis- or to validate satellite data with in-situ measurements→ **GEOMETRIC CORRECTION**



❑ GEOMETRIC CORRECTION: EARTH ROTATION.

Scanning sensors require a finite time to acquire a scene from the Earth surface: The last lines are erroneously displaced East in terms of what they represent on Earth -rotates from West to East.



❖ **Ejemplo:** *Imágenes procedentes de los satélites Landsat, tomadas en Sidney.*

* Velocidad angular del satélite es w_0=1.014 mrad/seg y la longitud de la imagen **L=185 Km.**,

El tiempo de exploración de los 185 Km es:

$$ts = L/(Re \cdot w_0) = 28.6\ seg \qquad (Re = 6378\ Km)$$

* Velocidad de la superficie de la tierra:

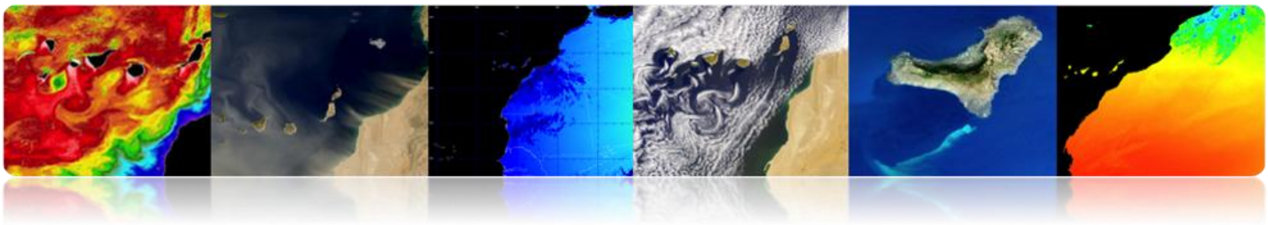
$$Ve = Re \cdot w_e \cdot \cos(lat) \qquad (w_e = 72.72\ \mu rad/seg)$$

En Sydney, lat=33.8°, tal que: Ve= 385.4 m/seg.

* Durante el tiempo de adquisición la tierra se mueve al E:

$$\boldsymbol{\Delta Xe = Ve \cdot ts = 11.02\ Km} \quad en\ 33.8^o\ de\ Latitud$$

(La imagen tendrá un **6% de distorsión** al E).



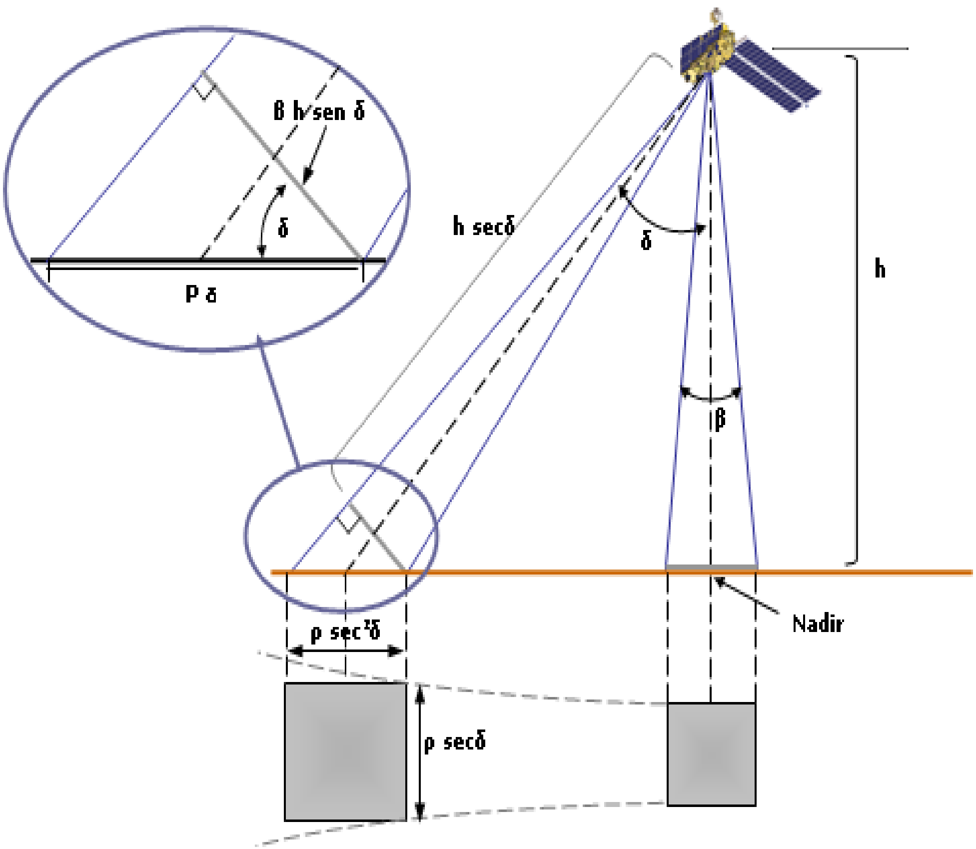
❑ GEOMETRIC CORRECTION: DISTORTION OVERVIEW.

It is constant as the instantaneous field of view (IFOV) from sensors on satellites: Effective size of the pixel on the Earth (GIFOV) is greater at the extremities of the field of view at nadir.

$$P_{\alpha} = \beta \cdot h \cdot \sec^2 \alpha = p \cdot \sec^2 \alpha$$

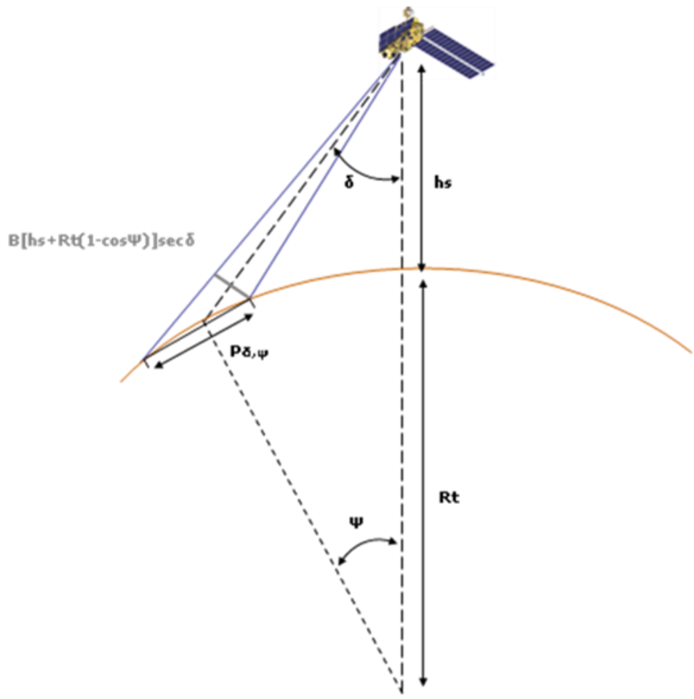
Consequences:

- Compression of the scene, which increases towards the edges of the scanned area.
- Effective spacing of the pixels on Earth increases with the exploration angle -error in the position of the pixels in the transverse direction.



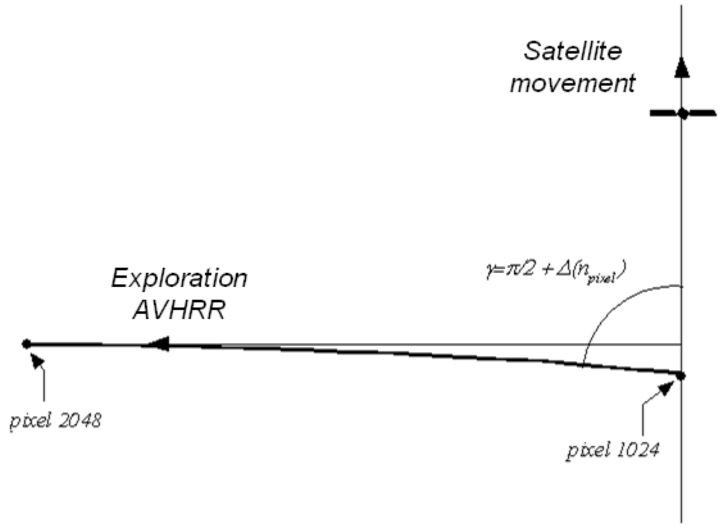
❑ GEOMETRIC CORRECTION: EARTH AND EXPLORATION CURVATURE.

i. **Satellites with high field of view (FOV):** the effect of the curvature of the Earth is important for high scan angles.



Earth curve

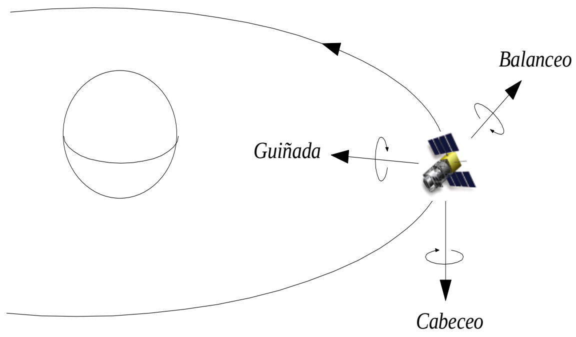
ii. **The sensor's rotating mirror requires a finite time to explore a full line:** During this time the satellite continues to move →Curvature of the scan line on Earth.

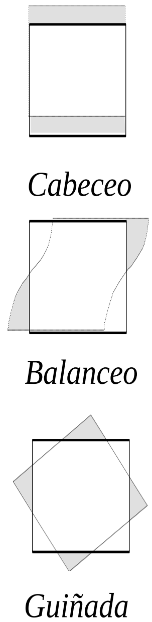


Exploration curve

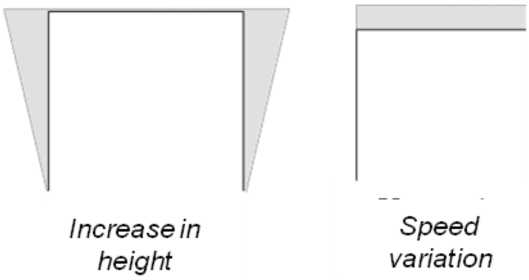
❑ GEOMETRIC CORRECTION: PLATFORM VARIATIONS.

An invariable orientation of the platform is essential in relation with the geometrical accuracy: A small change in the pointing angle causes a large variation in the points observed on Earth.

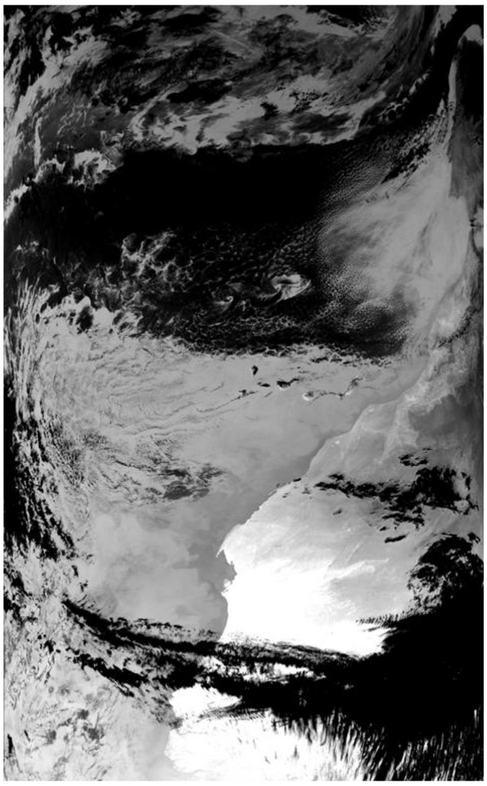


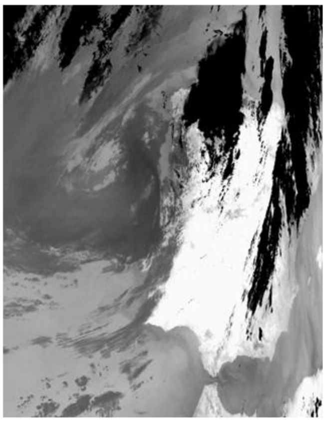


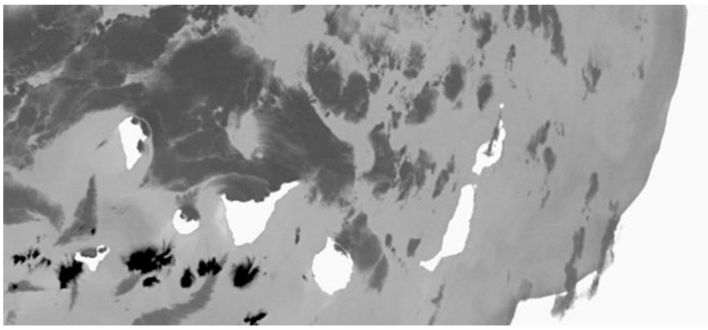
For a constant IFOV**, variations in the height and/or speed** of the platform results in scale changes in longitudinal and transverse directions to the sensor scanning.



❑ GEOMETRIC CORRECTION: EXAMPLE OF NOAA-AVHRR GEOMETRIC DISTORTIONS.







❑ GEOMETRIC CORRECTION: METHODOLOGIES

- **Orbital models: They are o**rbital parameters used to model the nature and extent of distortion sources on the basis of the geometry of the satellite orbit and the angle of view of the sensor.

- **Ground control points (GCP)** use mapping functions -general polynomial- obtained between GCP in both images.

  GCP *are locations on the Earth's surface that can be identified in the input image and whose position is known in the image or map (reference).*

- **Orbital Model + GCP** use a small number of control points to relocate the pixels that have been previously corrected by a geometric orbital model.

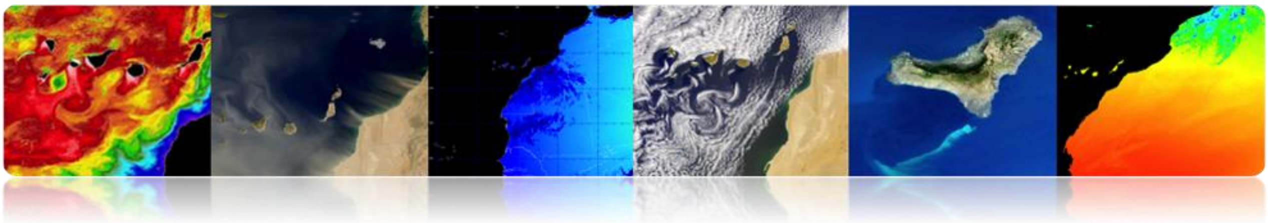
❑ GEOMETRIC CORRECTION: ORBITAL MODEL

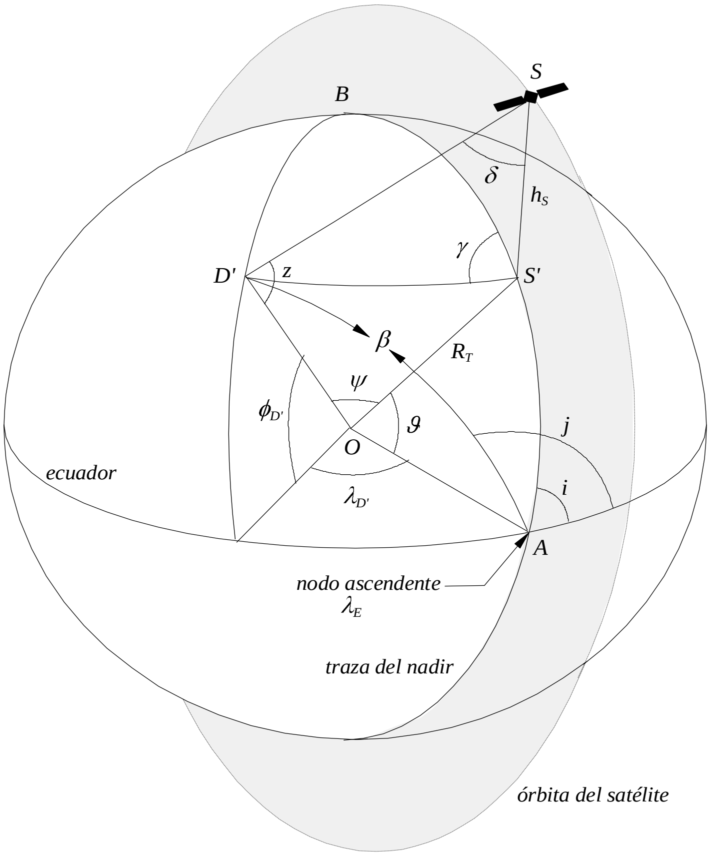
- **Modeling the nature and magnitude of systematic geometric distortions:**

  ✓ Geometry of the satellite orbit.
  ✓ Scanning geometry of the sensor.
  ✓ Geometry of the Earth.

- Good method for <u>low-resolution sensors</u> used in marine applications (hard to get GCP).

- Commonly used to correct systematic errors: Products that many users get from EOSAT, USGS or ESA.





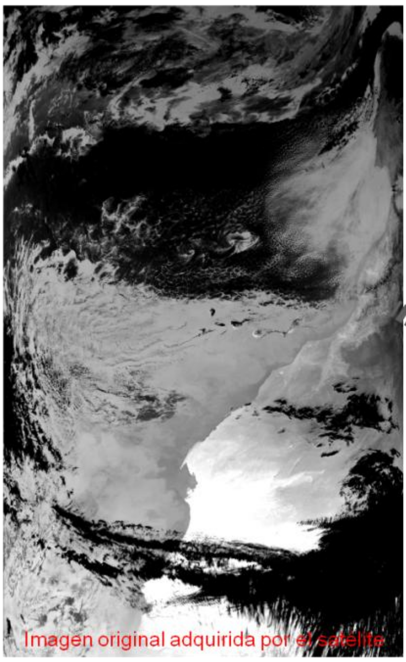
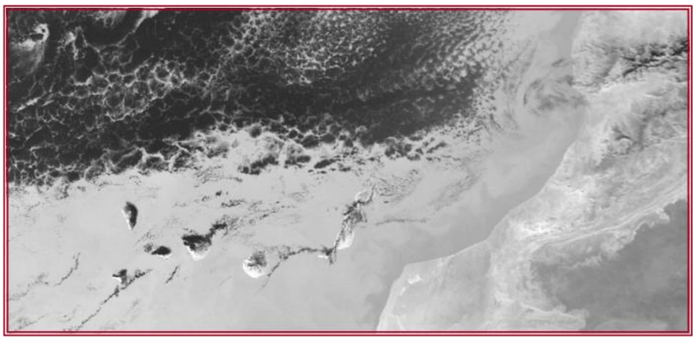


Imagen original adquirida por el satélite

Subescenas corregidas geométricamente



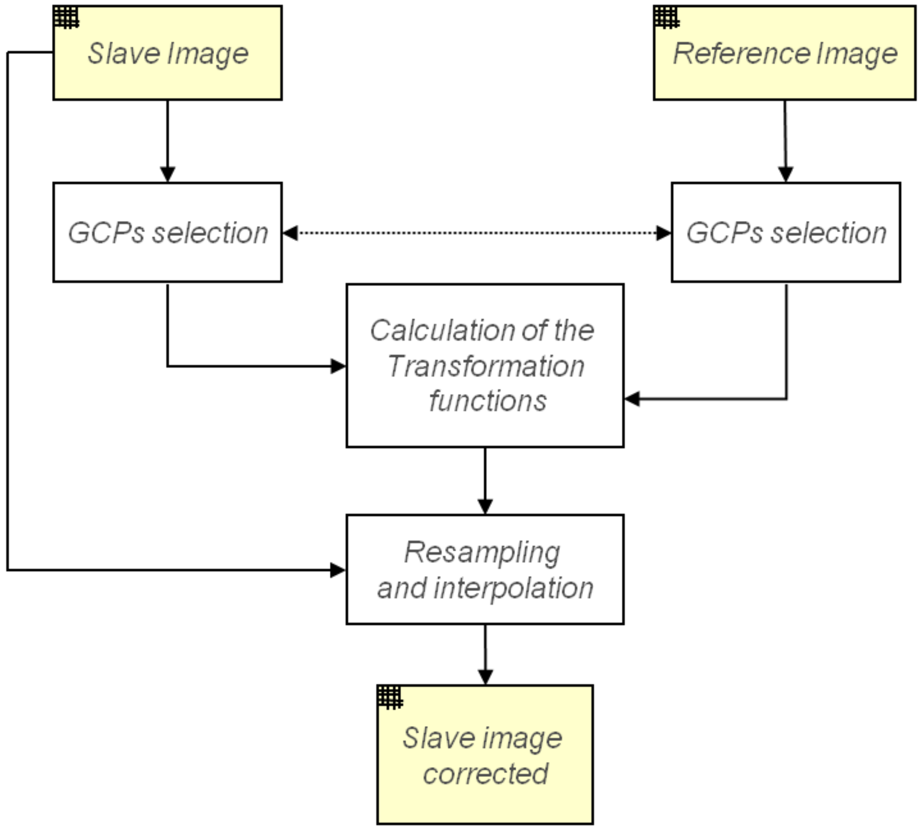
Problems

Lack of precision of the magnitudes involved in the satellite's position in space (accuracy of the orbital elements, altitude or orientation angles, displacements on the internal clock of the satellite).

Nº	Fuente de error	Dirección *X* = dir. de exploración *Y* = dir. de vuelo	Tipo / Origen	Comentario
1	Elementos orbitales	X,Y	BF / Orb	Parámetros nominales
2	Órbita circular y tierra esférica	X,Y	BF / Orb	Aproximación orbital
3	Errores de tiempo	Y	BF / H	Reloj del satélite y valor nominal de tiempo nodal
4	Parámetros de orientación - Balanceo - Cabeceo - Guiñada	 X Y X,Y	 AF / H AF / H AF / H	Desviación de los ángulos de orientación
5	Altura	X,Y	AF / Orb	Perturbaciones gravitatorias
6	Remuestreo	X,Y	BF / G	Redondeo (± 1/2 pixel de error)

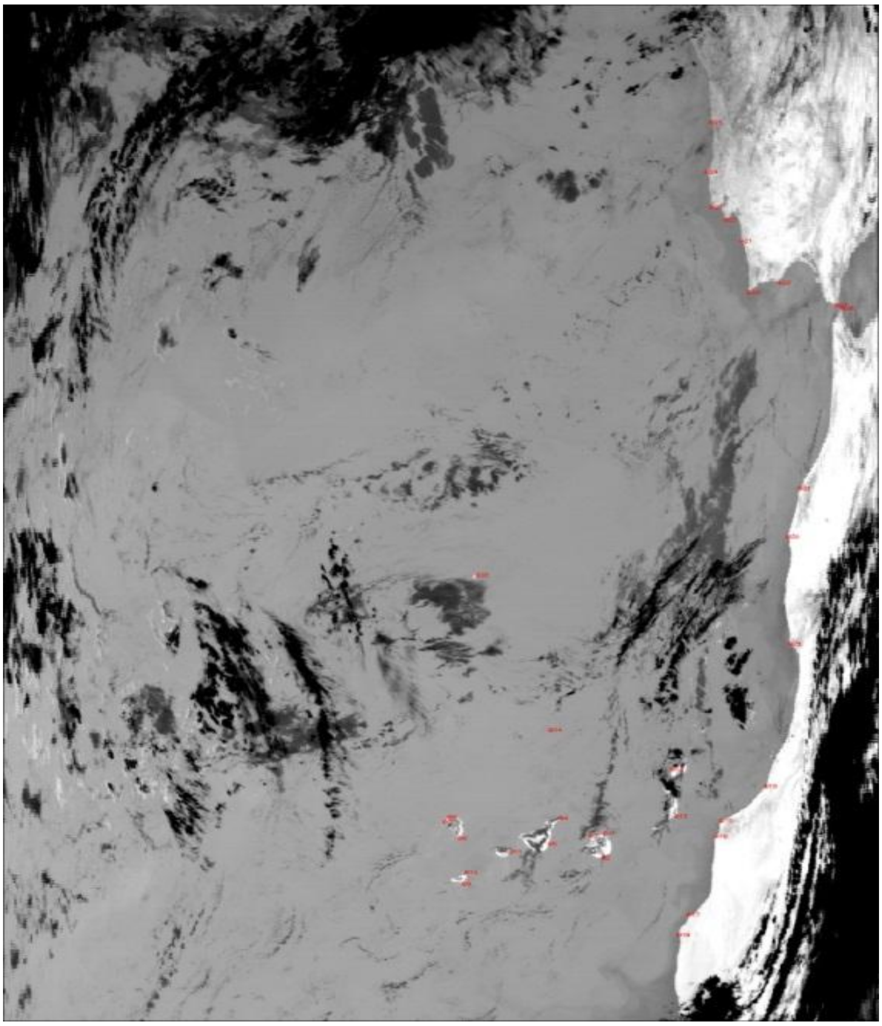
❑ GEOMETRIC CORRECTION: GROUND CONTROL POINTS (GCPS)

- It models directly corrections in the domain of the image, without explicit identification of the sources of distortion.
- Knowing the correspondence between a number of points (GCPs), the transformation function (typically related) to map the image 'slave' to the image or reference map (correspondence between the two images) can be determined.



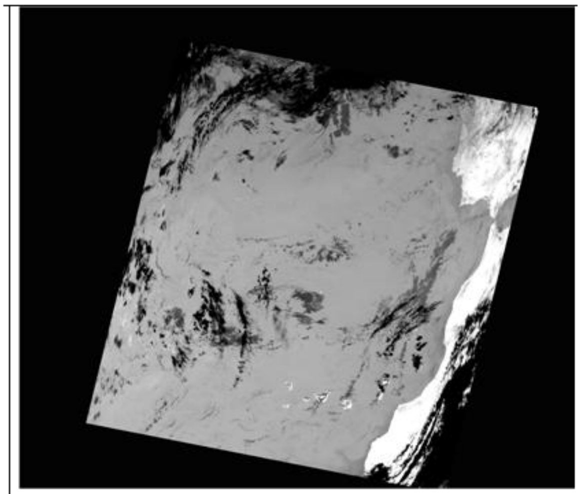
Problems

- Identify a high and spatially well distributed set of GCPs.
- Time consuming operator (area-based or feature-based methods).
- In many cases it is impossible due to occlusion by clouds.
- Uncertainty in the exact location of a region.

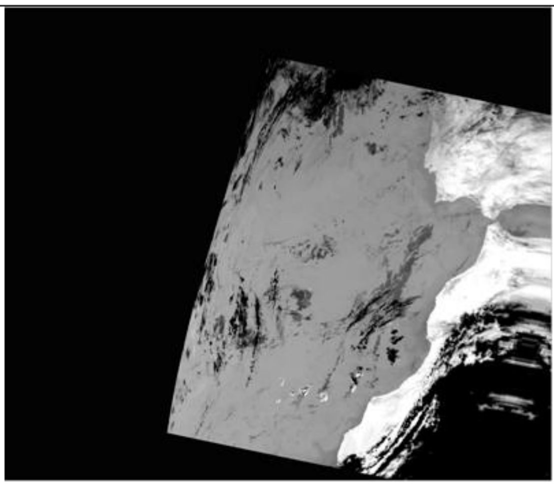


Example of geometric correction based on control points: Low resolution multisensorial images (MODIS sensor):

(a) Linear polynomial model.
(b) Quadratic polynomial model.

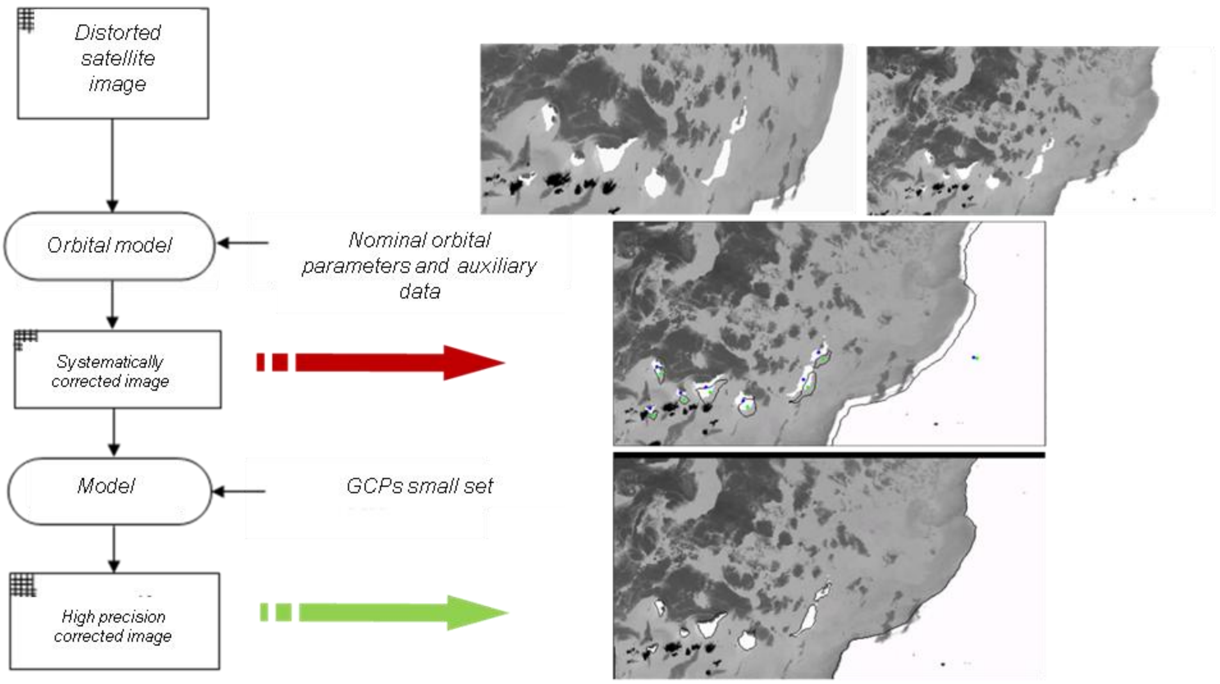


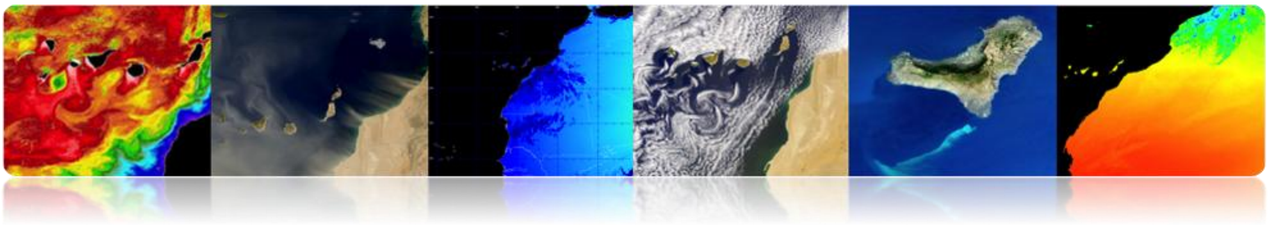
(a)



(b)

❑ Geometric correction: Orbital Model + Reduced Set (GCPs).



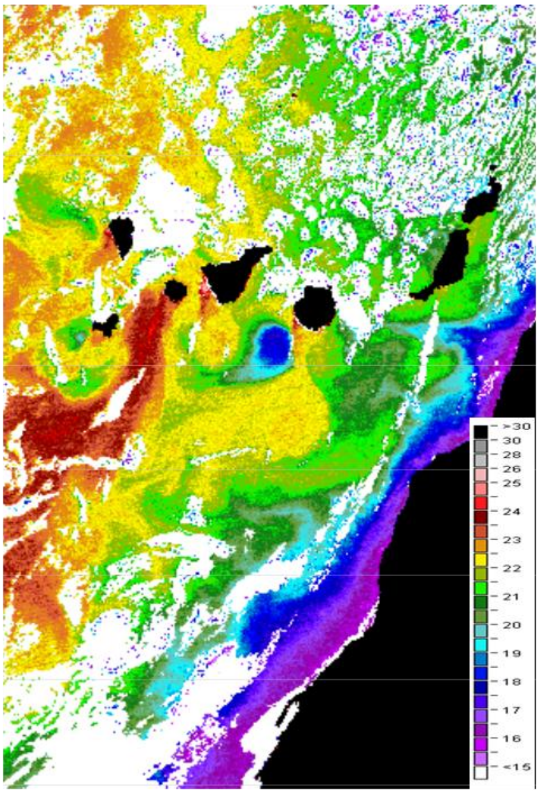


4.5 Cloud Detection

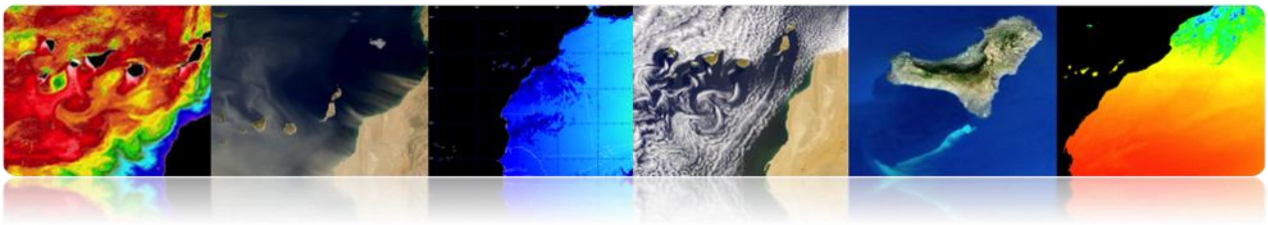
- **Objective:** Mask properly all the cloudy pixels.

- **Clouds are of interest for:**
  - Studies on climate.
  - Forecast.

- **Clouds are masking the signal of interest:**
  - Ocean color, SST, etc.
  - Properties of the Earth's surface, etc.



TSM MODIS-AQUA



❑ Cloud Detection: Algorithms

✓ **Multiband threshold methods**

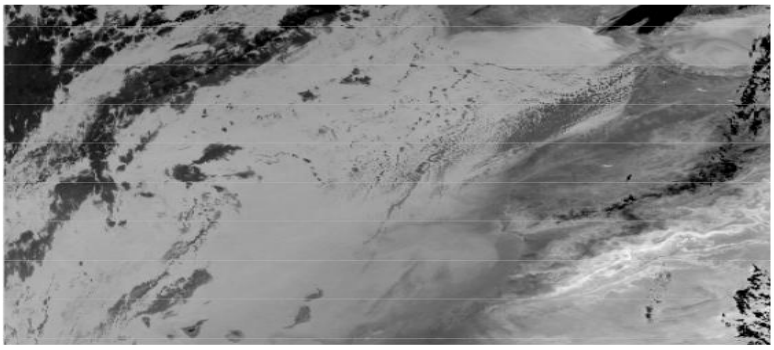
- Exploiting the spectral characteristics.
- Brightness, temperature.
- Problems: thresholds variables (area, day/night sensor bands, railway, etc.)

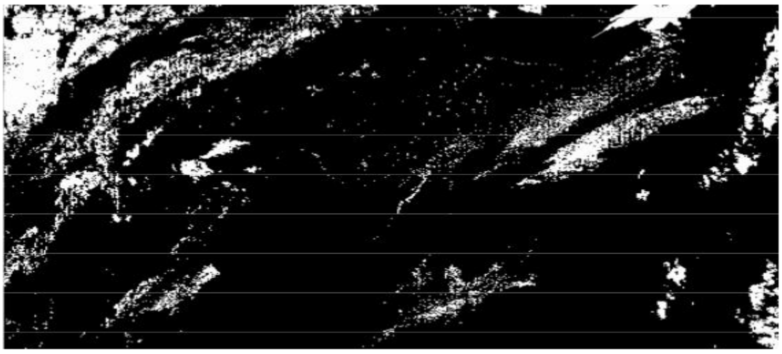
(Saunders and Kriebel 1988, CLAVR 1991)

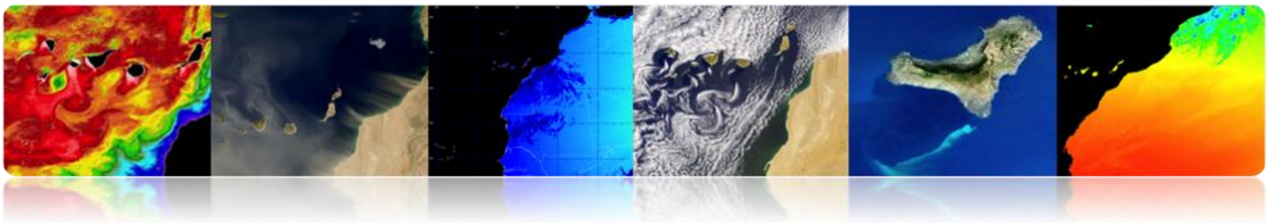
✓ **Extraction of features and classification**

- Spectral characteristics (clustering).
- Spatial characteristics (textures, DWT).
- Artificial neural networks.
- Problems: calculation times.

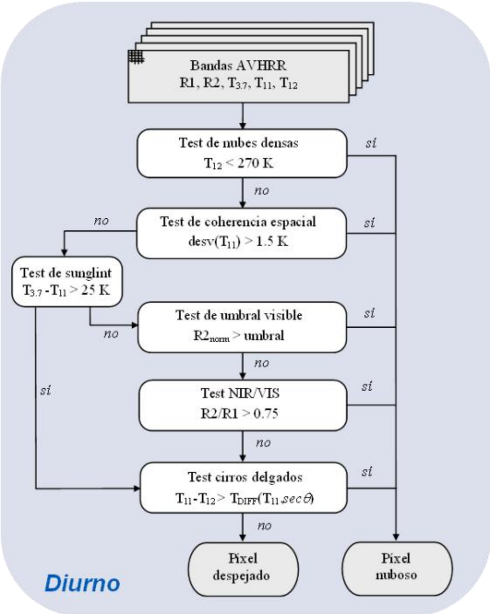
✓ **Multitemporal analysis**

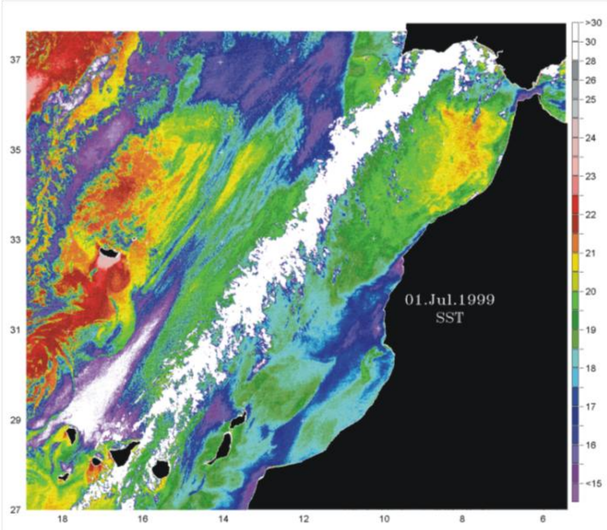




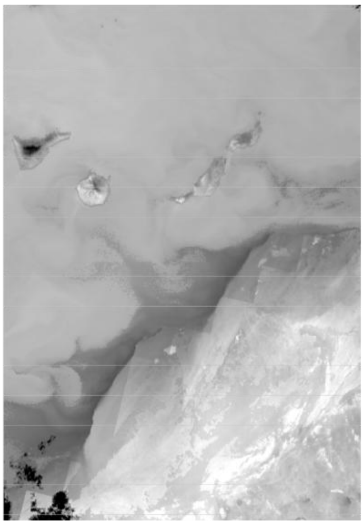


Saunders & Kriebel Multiumbral Algorithm



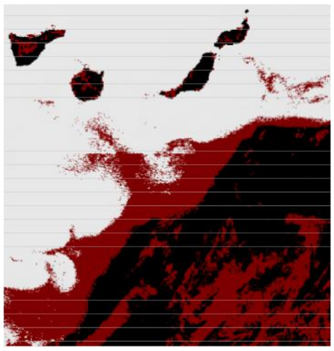


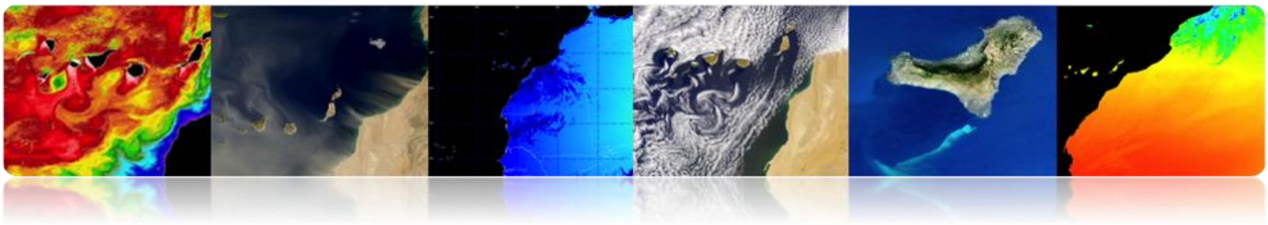
AATSR 'Cloud Screening' Algorithm



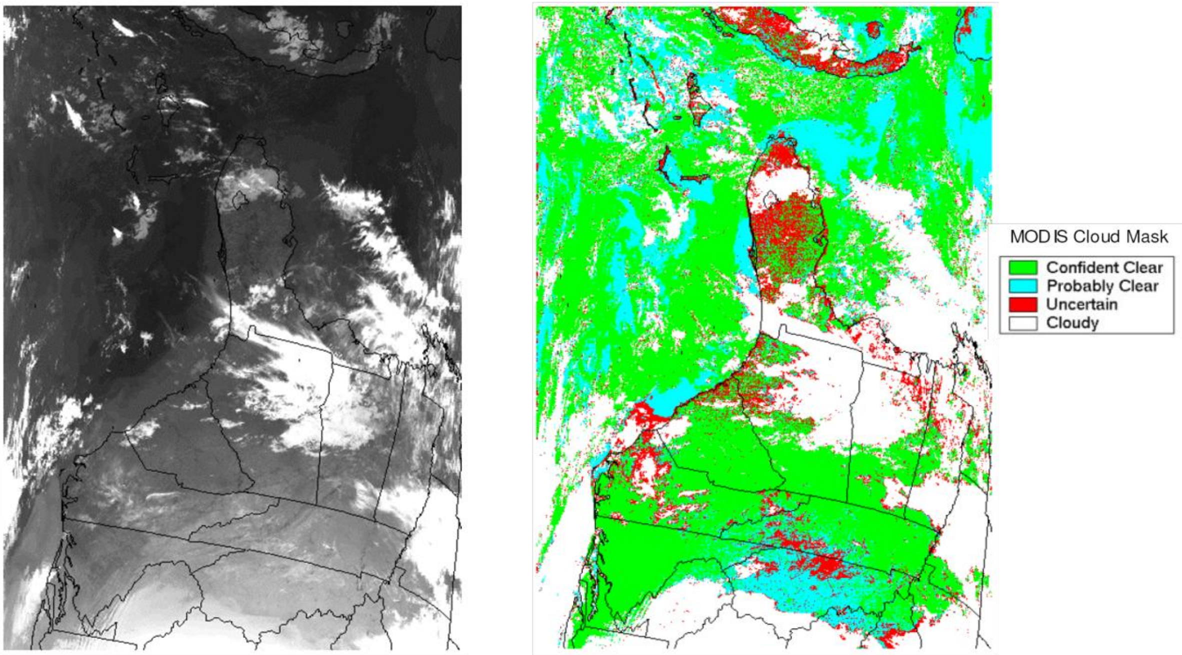
Test	Land/Sea	Day/Night
gross cloud test	Sea only	Day/Night
thin cirrus test	Land/Sea	Day/Night
medium/high level cloud test	Land/Sea	Night
fog/low stratus test	Land/Sea	Night
11 micron spatial coherence test	Land/Sea	Day/Night
1.6 micron histogram test	Sea only	Day
11/12 micron nadir/forward test	Sea only	Day/Night
11/3.7 micron nadir/forward test	Sea only	Night
infra-red histogram test	Sea only	Day/Night

•ENVISAT AATSR SST (August, 29th 2004 – 22:37 hr)





MODIS 'Cloud Masking' algorithm



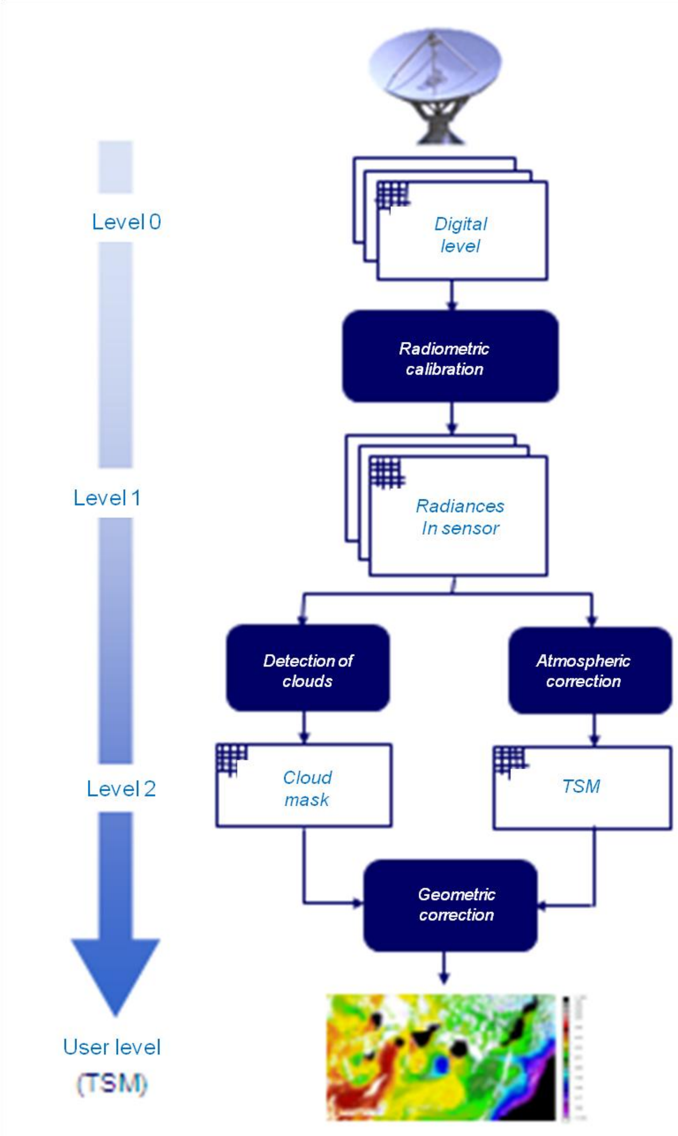
Terra MODIS data from April 6, 2003.

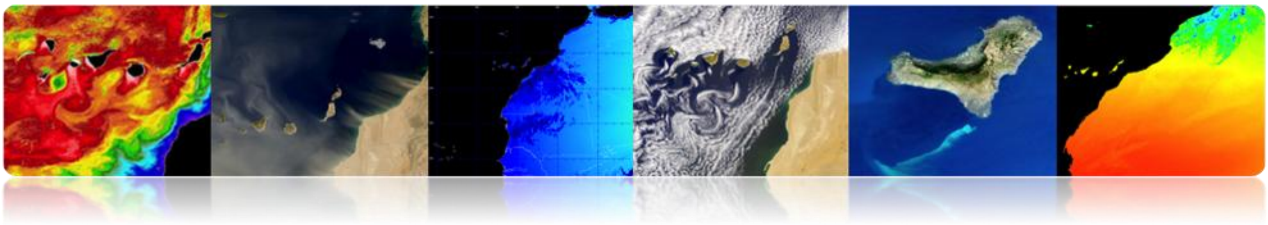
❑ SATELLITE IMAGE PROCESSING HIERARCHY

Example 1: AVHRR

Complete Procedure: Pre-processing of Earth Observation Satellite Images.

- Radiometric Calibration
- Atmospheric Correction
- Geometric Correction
- Cloud Detection

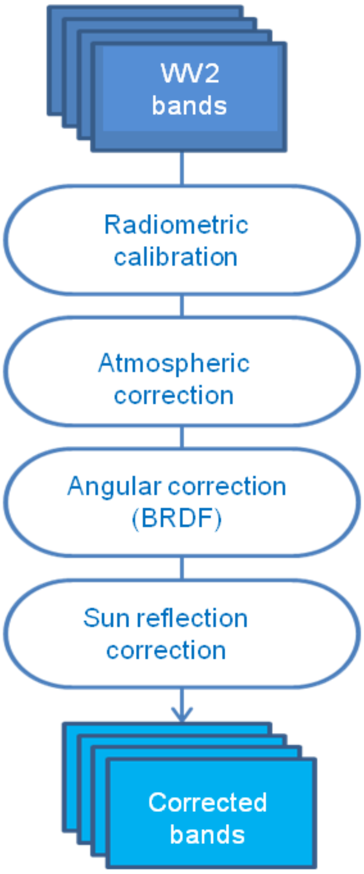


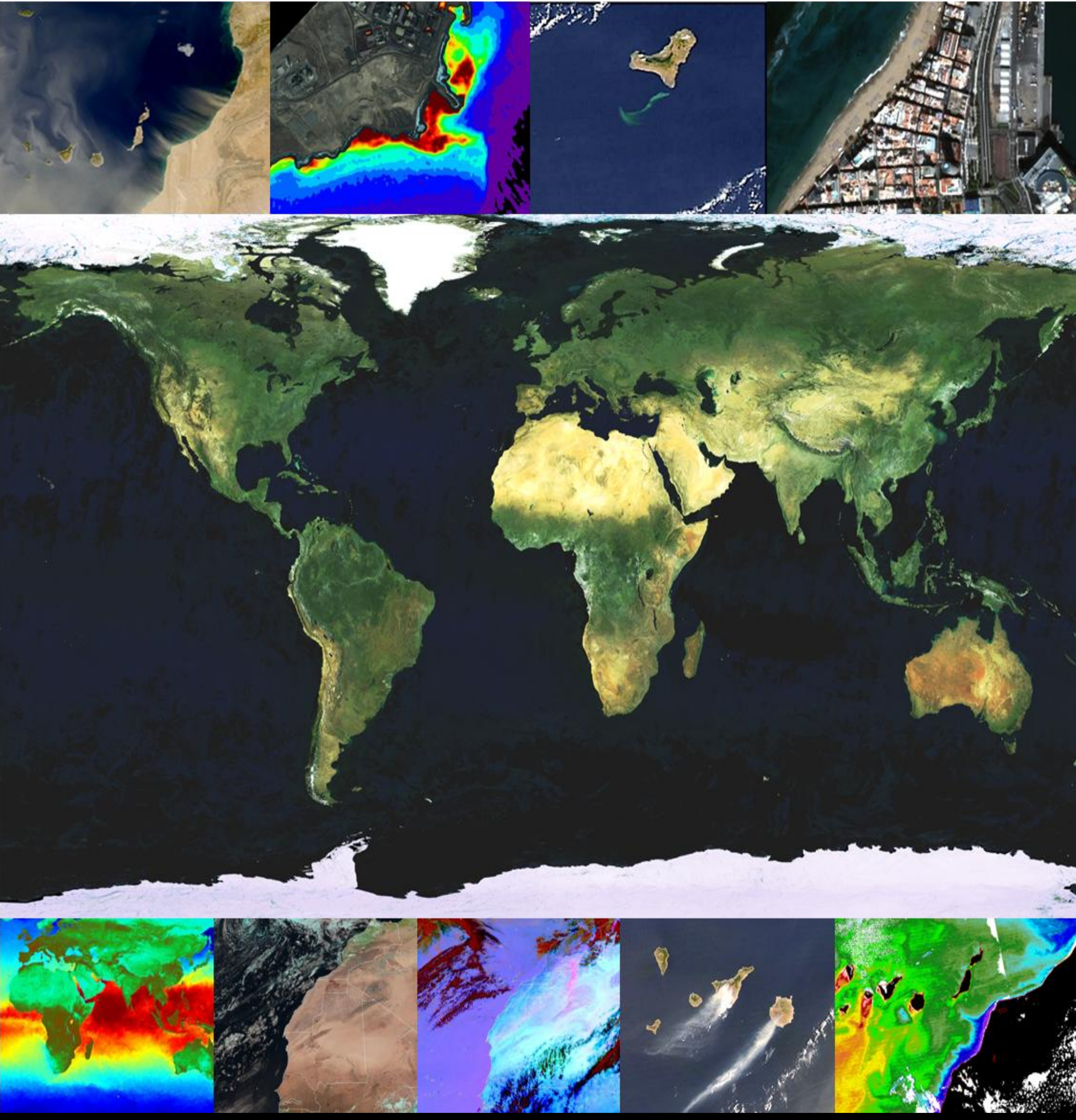


Example 2: WorldView 2

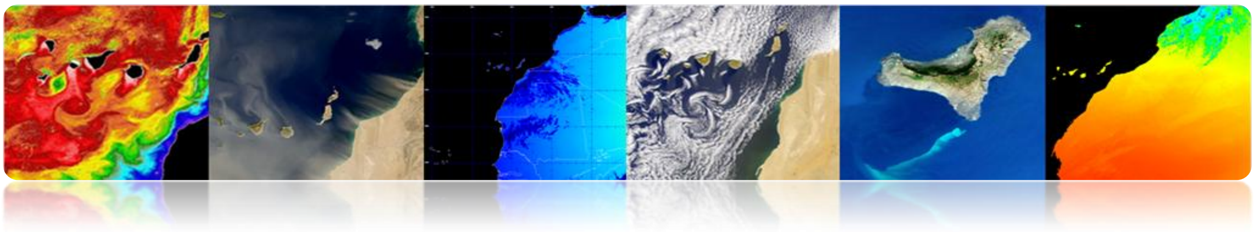
Complete Procedure: Pre-processing of Earth Observation Satellite Images.

- Radiometric Calibration
- Atmospheric Correction
- Solar Reflection Correction





5. Remote Sensing Image Processing



Introduction

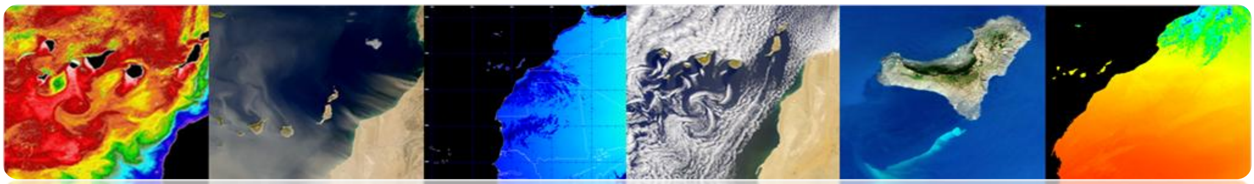
Digital image processing is the set of techniques applied to digital images in order to enhance visual quality or facilitate the search or extraction of information.

The interest of digital image processing methods lies in two main areas of application: i) the reconstruction or improvement of information that provides an image to be interpreted by a human being, and ii) information processing of a scene to allow automatic analysis by a machine.

These techniques have experienced a significant growth, being used currently, for a variety of problems in various fields such as medicine, geography, archeology, physics, astronomy, biology and, of course, remote sensing.

Throughout this chapter, most image processing techniques will be described. Thus, the contrast enhancement or color representation of the different spectral bands will be highlighted to facilitate visual interpretation. Other processing techniques described for image improvement are: generating spectral indexes applied mainly to the detection of vegetation, convolution filtering techniques, and techniques in the Fourier domain or fusion pixel level. These techniques are very useful to improve the spatial detail of multispectral high-resolution satellite images. Regarding the analysis of images, techniques oriented to automatic detection of structures in images will be described, as is the case of the Hough transform, mathematical morphology and other segmentation algorithms. Also the classification process to generate thematic maps will be discussed in detail and, finally, various techniques of motion estimation in image sequences will be presented.

In addition to the explanation of image processing techniques, representative examples are also included to assess the effects they produce in the image and thus facilitate the understanding and use of them.

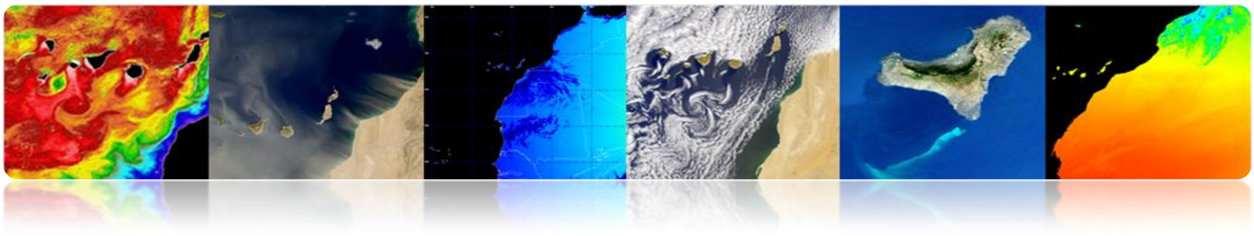


The objectives of this chapter are:

- Know the characteristics of a digital image and its main parameters.
- Describe various techniques for improving image quality for furthers analysis.
- Present the main techniques for image analysis, detailing the detection structures techniques, the thematic classification and the motion estimation.

CONTENTS

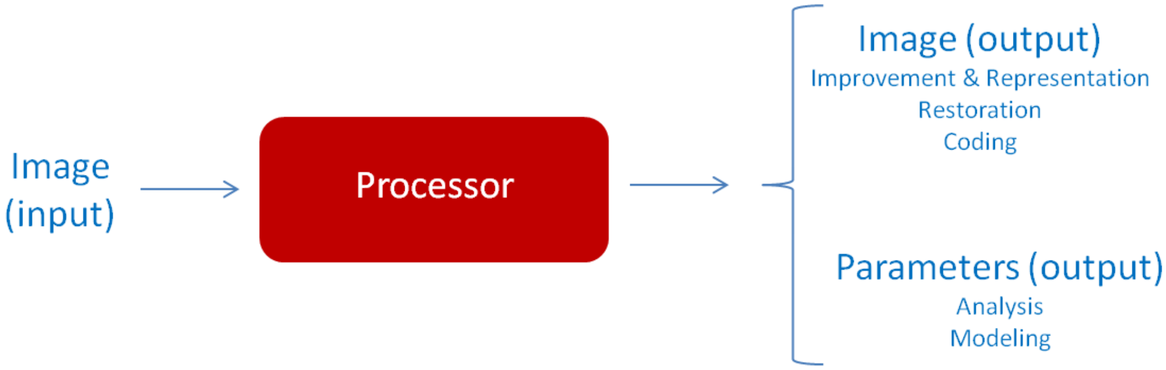
Remote Sensing Image Processing



5.1. Introduction to Image Processing

Digital image processing includes the set of techniques for processing and analysing images by using computers.

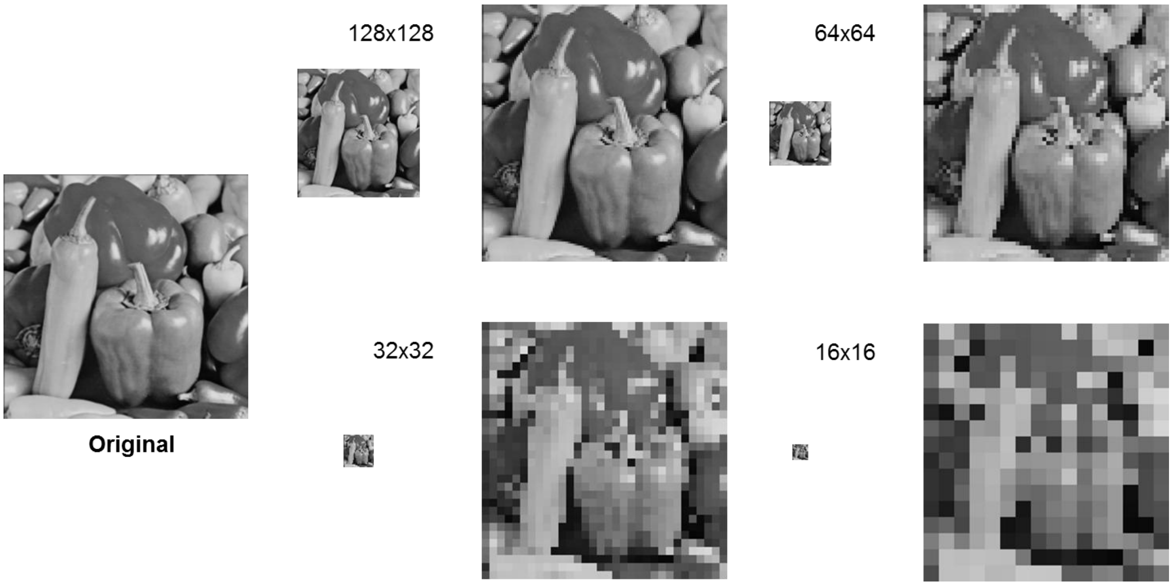
Image Processing System



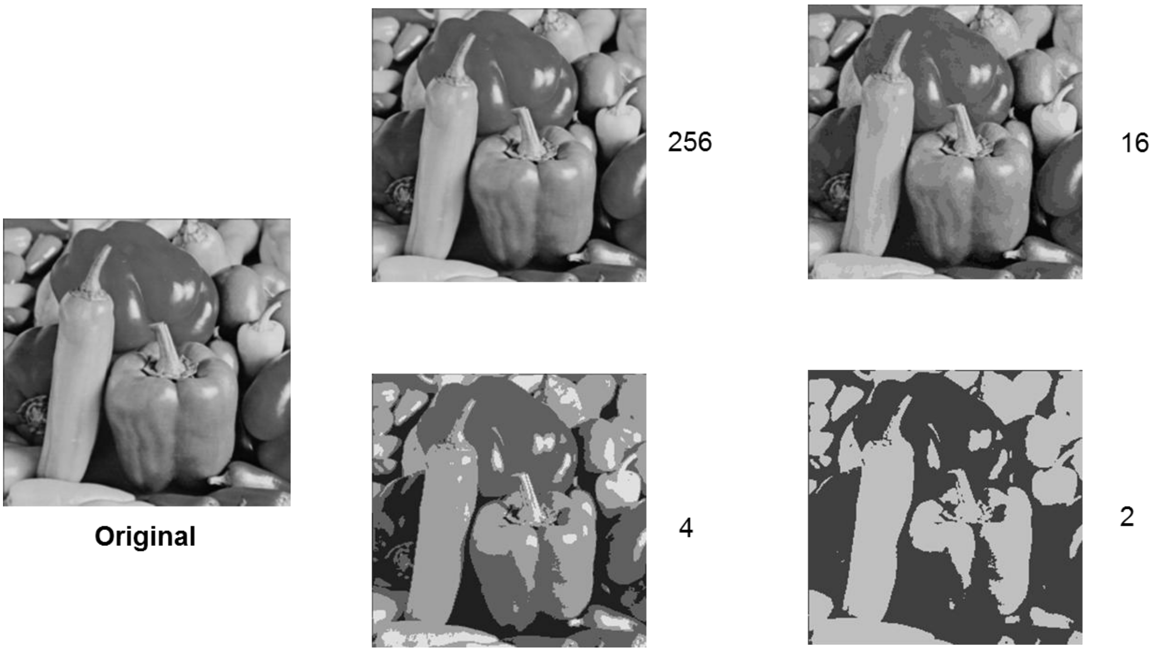
5.2. The Digital Image

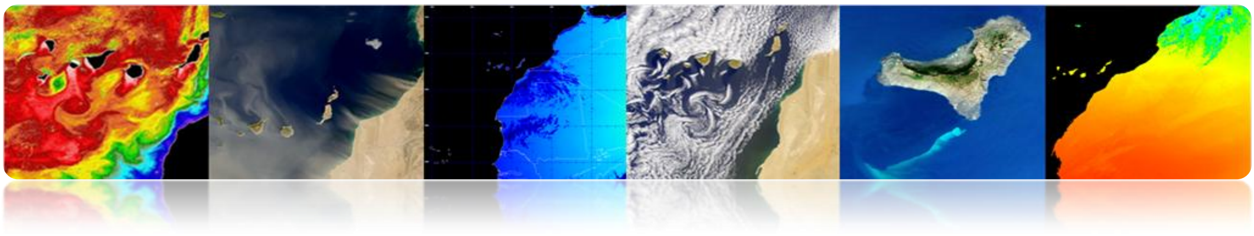
❑ A/D Conversion: Discrete Images

Sampling: Sampling is responsible for integrating in points the information which is in a given area. These points are the smallest elements that divide an image, called pixels.

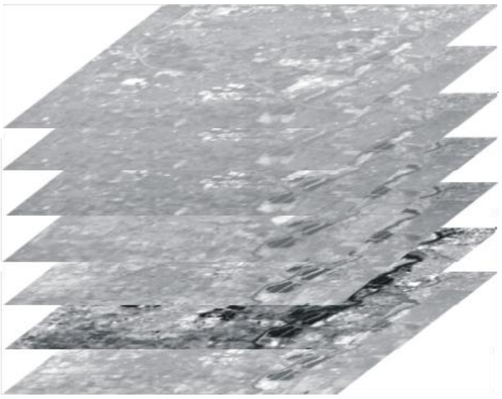


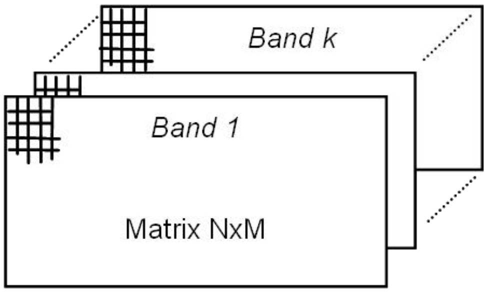
Quantification: Once sampled the image, the value of each pixel must be digitally encoded. This process of assigning a number of levels or bits to each pixel is called "quantization" of the image.





The digital image is formed by one or more matrices (e.g., sensor bands) of numbers (DN: digital levels). That is why they are generally multidimensional functions.

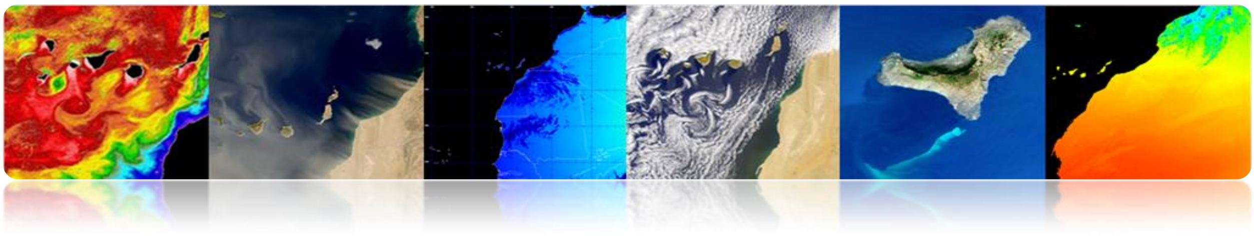


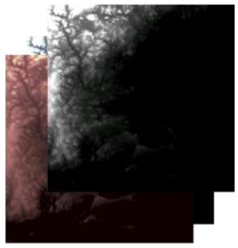


Types of digital images

Values represented by a digital image

- Intensity: scalar (one band)
- Color: vector R, G, B (3 bands)
- Material properties: (1 or more bands)
  - X-ray images: absorption
  - Ultrasound images: density
  - Infrared images: temperature
  - Remote sensing images: reflectivity



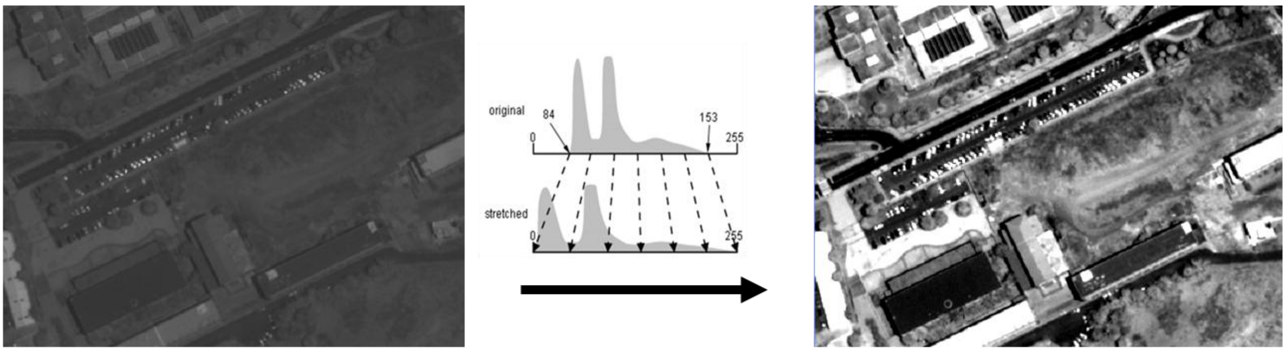


5.3. IMAGE ENHANCEMENTS

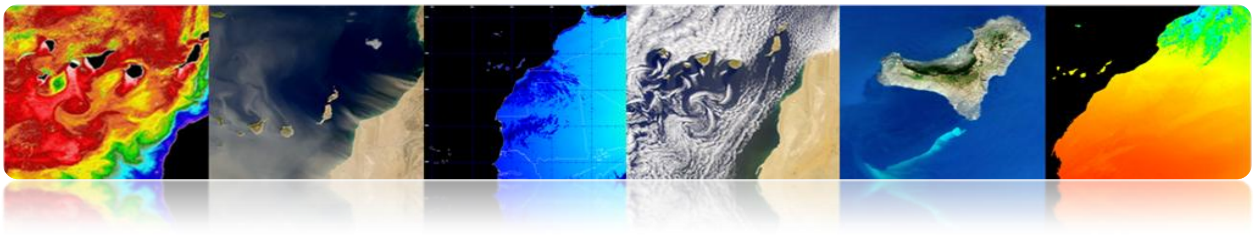
❑ CONTRAST ENHANCEMENT

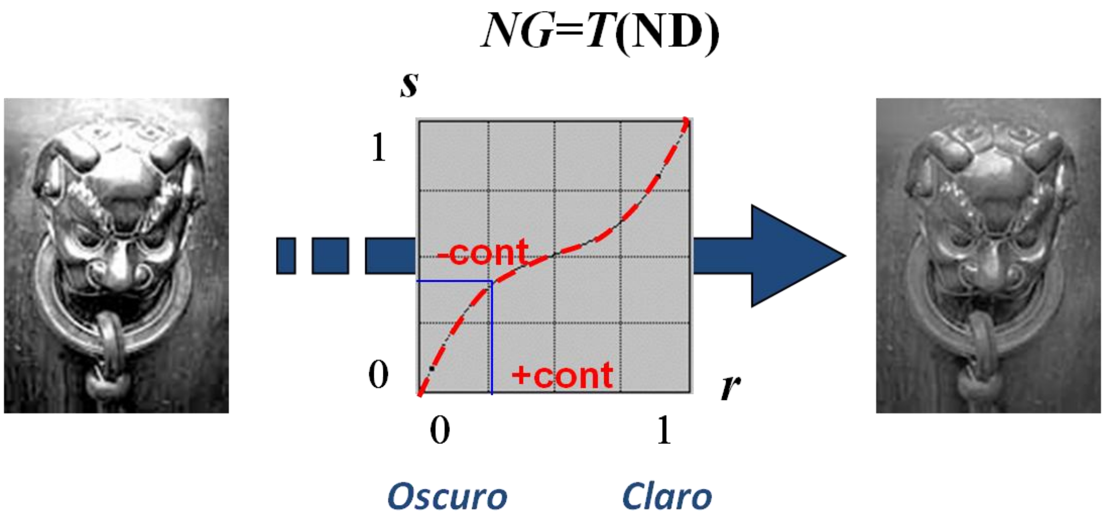
The sensor must be able to detect a high dynamic range of values, but one scene in particular has a very low contrast to encompass only limited radiance values.

The aim is to improve the visual quality of the image. This will make various transformations (min-max, saturation, equalization, etc.) to the image histogram.

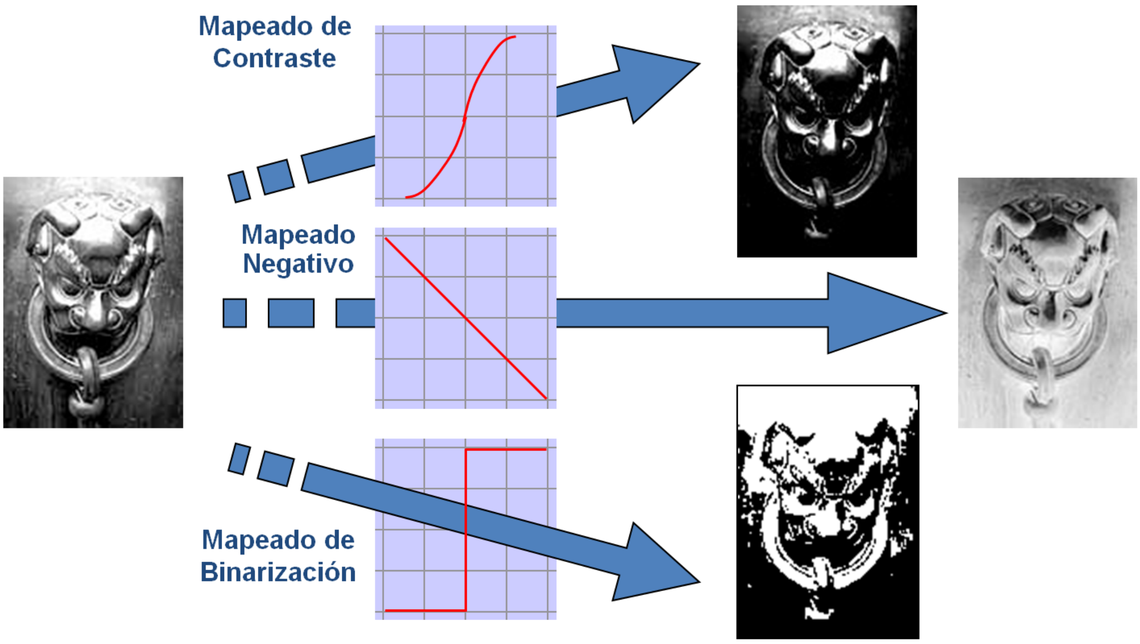


This involves applying a transformation that maps the original digital levels (ND) in gray levels (NG):

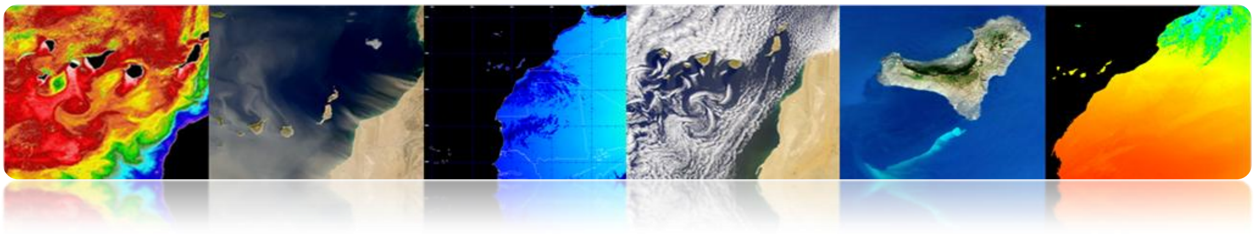




There are several possibilities of processing levels.

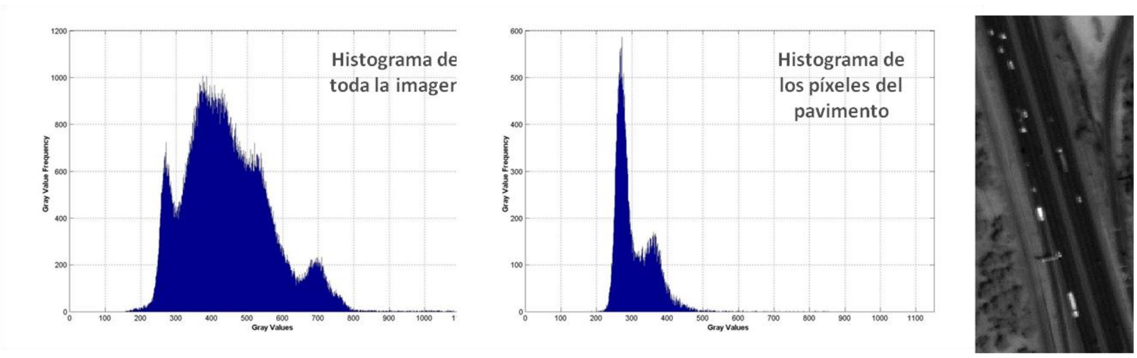


These changes are made for each pixel in the image as a separate element and independent of its position in the image using the histogram of the image.



- The histogram is the statistical distribution of the pixels of an image in terms of number of pixels for each (DN) possible value.
- It does not contain information on the spatial distribution of the pixels in the image.

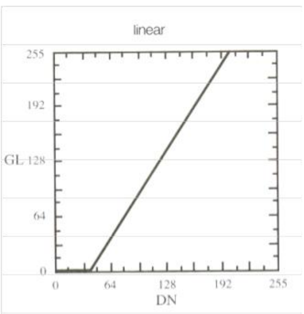
$$hist_{ND} = \frac{count(ND)}{NxM}$$

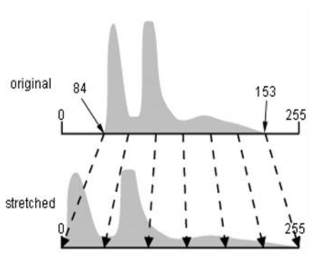


As an example, next we present some possible transformations.

- **Linear expansion**

Min-Max Stretch expands the dynamic range of the values to fill the full range of reproduction. GN: greyscale and DN: digital levels.





$$GL = \frac{255}{ND_{max} - ND_{min}}(ND - ND_{min})$$

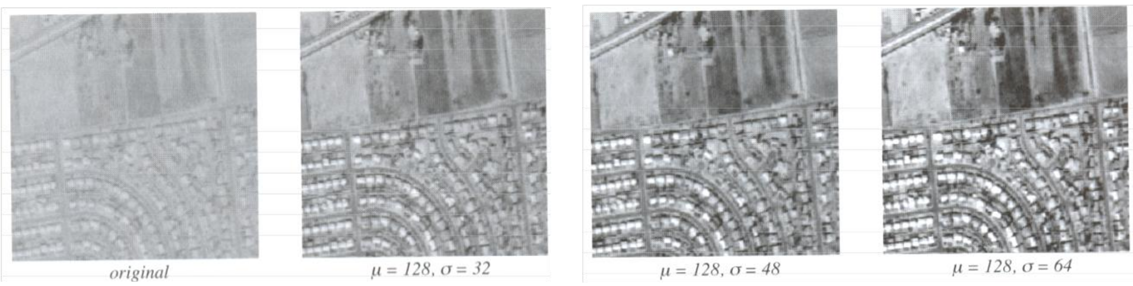
Use the minimum and maximum signal value → Sensitive to extreme values (outliers). Solution: Saturation stretch.

Same value for all the range → Sensitive to lower symmetric histograms. Solution: Non-linear stretch or histogram equalization.

- **Normalization expansion**
  - Robust algorithm (adapted from saturation stretch).
  - It is a linear expansion of a signal with a given mean and variance to cut the ends of the dynamic range.
  - It lets us to control the average value of the output image and to vary the contrast by adjusting the variance.

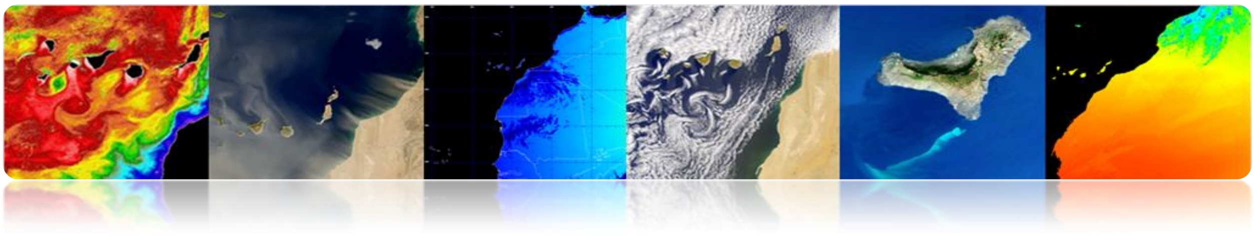
$$GL = \frac{\sigma_{ref}}{\sigma}(ND - \mu) + \mu_{ref}$$

$$GL = 255, \quad GL > 255$$
$$GL = 0, \quad GL < 0$$

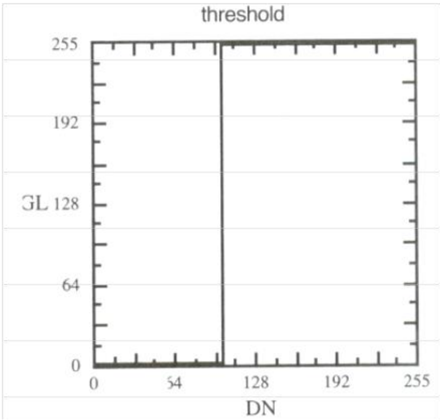


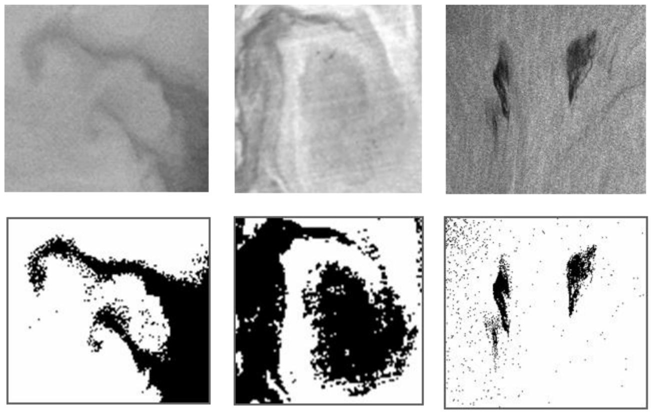
The mean is constant and the contrast varies by changing the variance.

- **Thresholding**
  - It is a transformation that classifies the image into two categories (binarized) based on a threshold on the original values of the image.
  - It requires a greater number of thresholds for a greater number of classes.



$$GL = 255, \quad ND \geq ND_T$$
$$GL = 0, \quad ND < ND_T$$





❑ COLOR REPRESENTATION

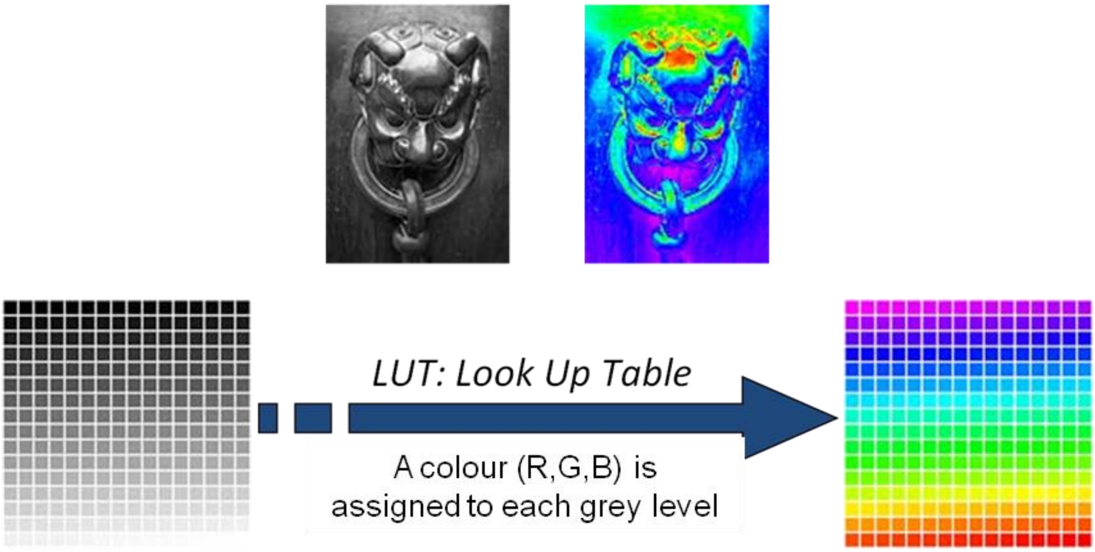
The human eye is more sensitive to colors than gray levels, so it is important the color representation of images for visual analysis.

This representation can be done in two ways:

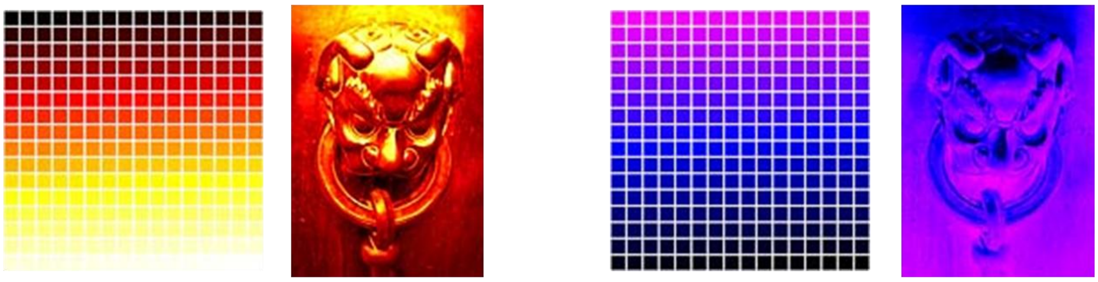
- <u>False color representation</u> (Pseudo): when a color table is applied to a grayscale band (LUT: Look-up table) or when red, green or blue colors are assigned to several bands that do not correspond to the true color.

- <u>True color representation</u>: when the image is taken by a sensor that captures these 3 bands of color: red, green and blue.

- **Pseudocolor one band**

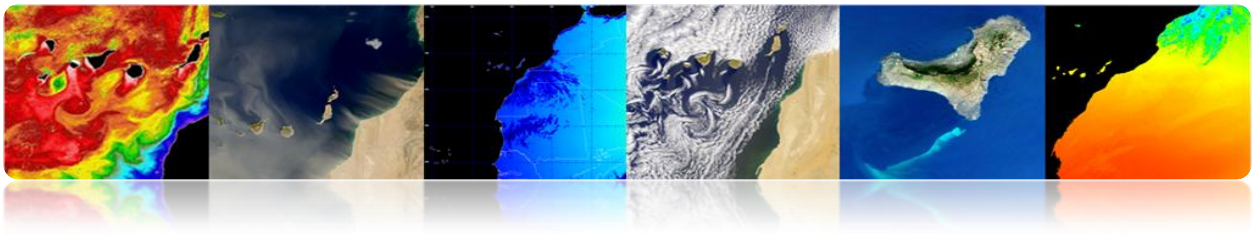


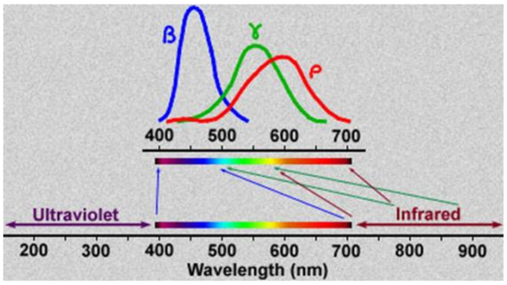
Other examples of LUT

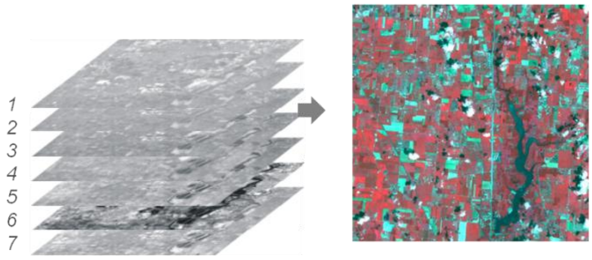


- **Pseudocolor multiband**

Channels with values in the non-visible spectrum are shifted to the visible spectrum.

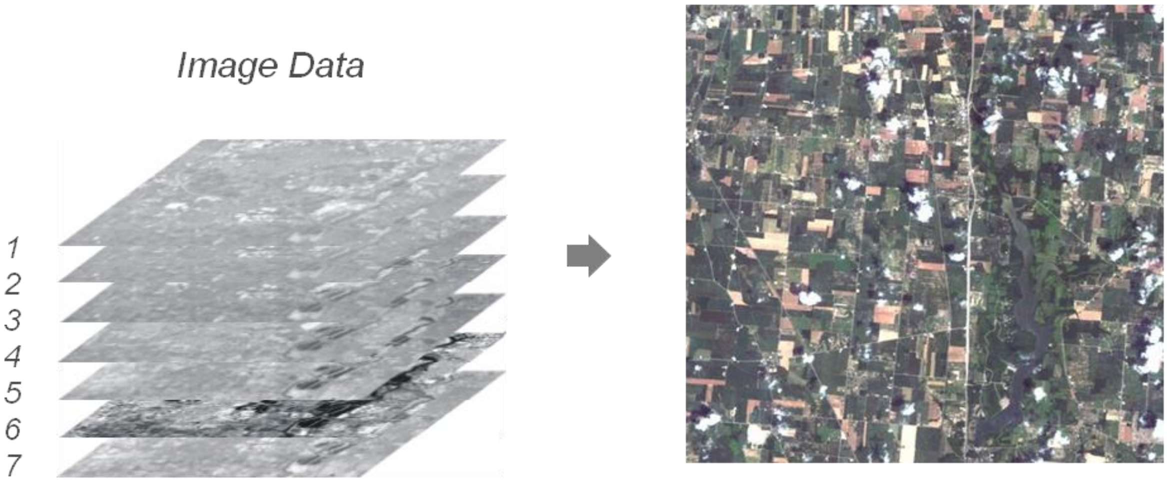






Composición:
Rojo: banda 4
Verde: banda 3
Azul: banda 1

- **True Color**

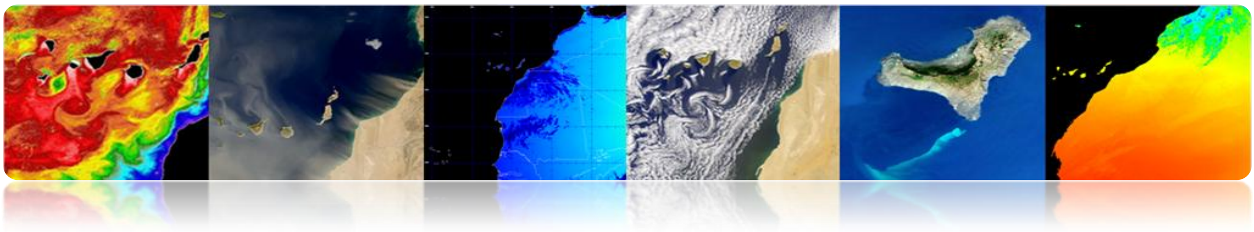


Composición:
Rojo: banda 3
Verde: banda 2
Azul: banda 1

❑ SPECTRAL INDEXES

They are combinations of bands for obtaining a parameter of interest for classification purposes (vegetation, water, minerals, etc.)

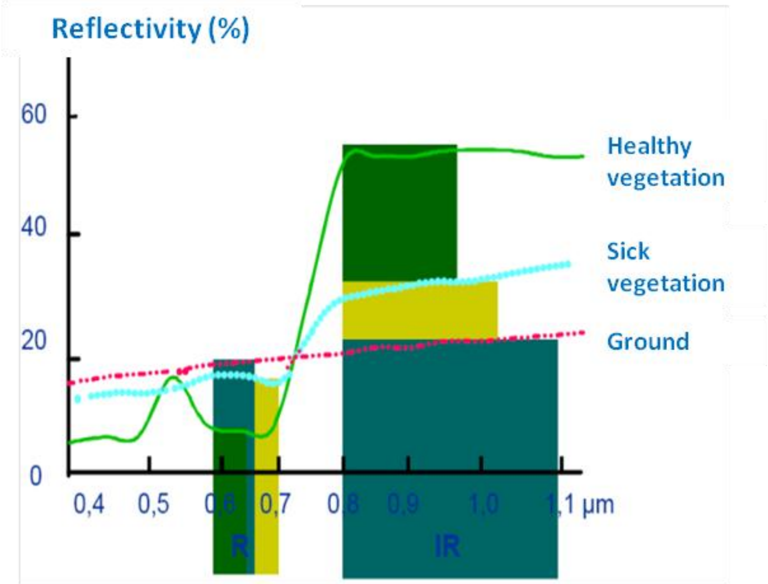
They are based on the behavior of the reflectivity parameter to maximize its discrimination.

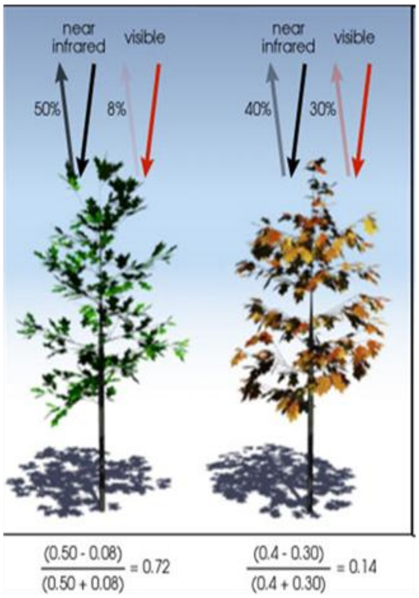


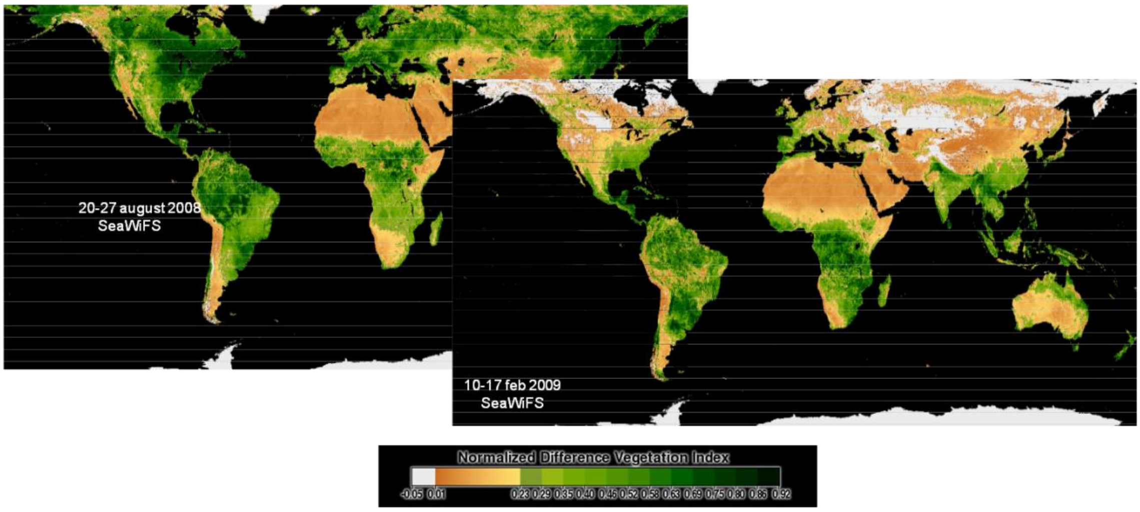
- **Vegetation indexes**

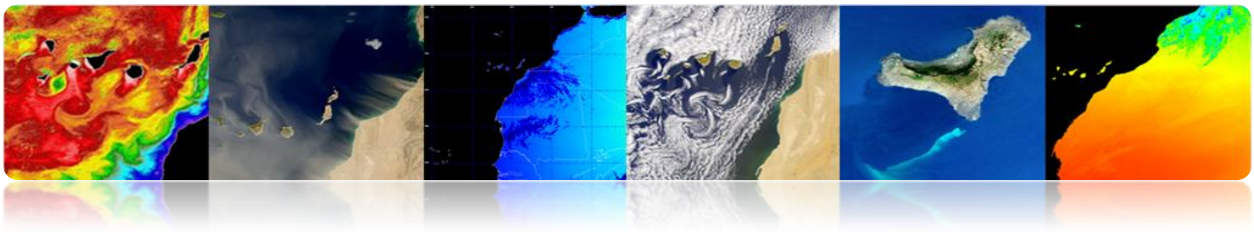
They are mainly based on relations between NIR and R bands.

Normalized Difference Vegetation Index (NDVI) is widely used. It generates values between -1 and +1. NDVI is an inaccurate indicator in arid regions.









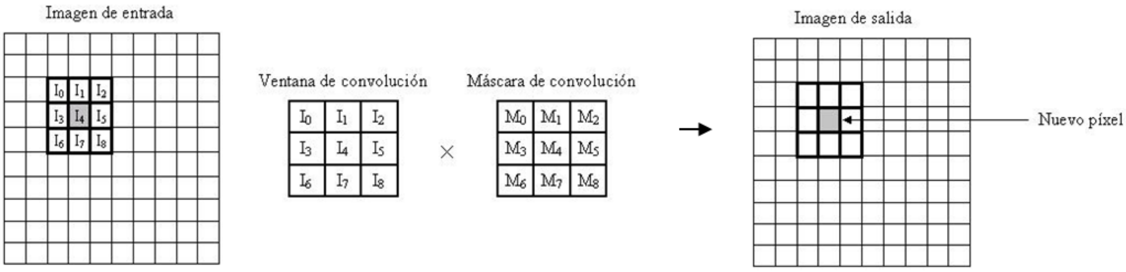
❑ CONVOLUTION FILTERING

Technique to modify the spatial information of the image using the digital values of the neighborhood (local filtering).

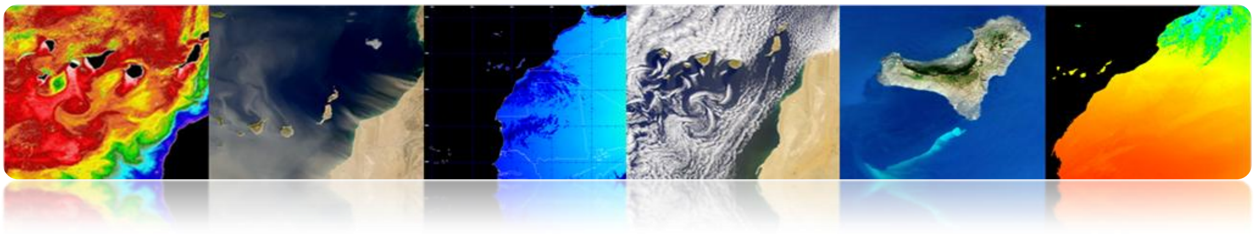
- A window that moves along rows and columns is used.

- An operation with the input image's pixels that fall within the window is carried out and the result is the new pixel of the image in the center position of the window.

type	output	examples	applications
linear	weighted sum	Low-Pass Filter (LPF) High-Pass Filter (HPF) High-Boost Filter (HBF) Band-Pass FIlter (BPF)	enhancement, sensor simulation, noise removal
statistical	given statistic	minimum, maximum median standard deviation mode	noise removal, feature extraction, *SNR* measurement
gradient	vector gradient	Sobel, Roberts	edge detection

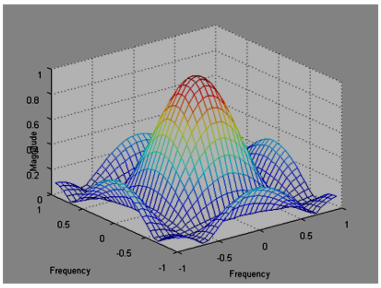


Example with original image and the lowpass and high pass filtered.



▪ Mask convolution (impulse response)

Averaging filters: reduce noise by means of spatial averaging

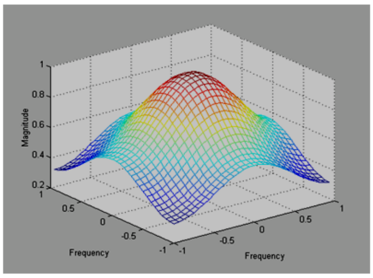


Averaging mask

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

Gaussian mask

.01	.08	.01
.08	.52	.08
.01	.08	.01

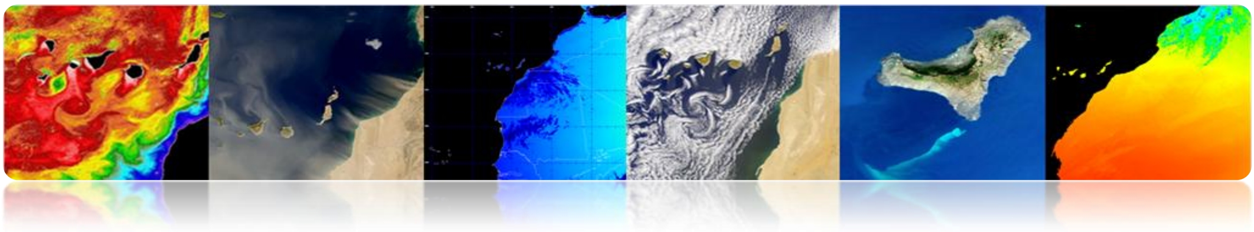


Original image

With noise (uniform)

Filter

Gaussian



Gradient filters: contour detector (approximation of the derivative)

$$f(x,y) \qquad\qquad f[m,n]$$

$$\nabla f = \begin{pmatrix} \partial f / \partial x \\ \partial f / \partial y \end{pmatrix} \qquad \nabla f \cong \begin{pmatrix} g_1[m,n] \\ g_2[m,n] \end{pmatrix} \ \text{directional detection}$$

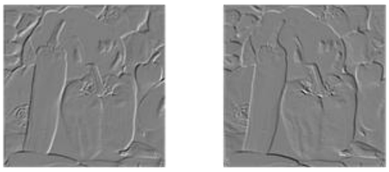
$$|\nabla f| = \sqrt{\left(\partial f / \partial x\right)^2 + \left(\partial f / \partial y\right)^2} \qquad |\nabla f| \cong \sqrt{g_1^{\,2}[m,n] + g_2^{\,2}[m,n]}$$

$$\text{direction of max change} \qquad \theta_{\nabla f} \cong \operatorname{arctg}\left(g_2[m,n] / g_1[m,n]\right)$$

- ## Edge Detector

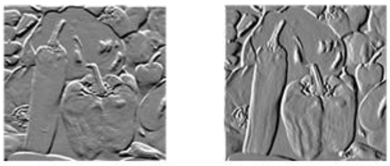
Roberts: Simple, asymmetric

$$\begin{array}{c|c} 1 & 0 \\ \hline 0 & -1 \end{array} \qquad \begin{array}{c|c} 0 & 1 \\ \hline -1 & 0 \end{array}$$



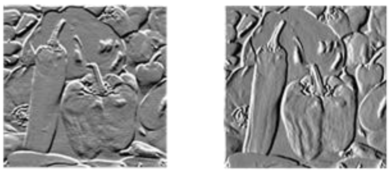
Prewitt: Higher gain, sensitive to noise

$$\begin{array}{c|c|c} -1 & -1 & -1 \\ \hline 0 & 0 & 0 \\ \hline 1 & 1 & 1 \end{array} \qquad \begin{array}{c|c|c} -1 & 0 & 1 \\ \hline -1 & 0 & 1 \\ \hline -1 & 0 & 1 \end{array}$$



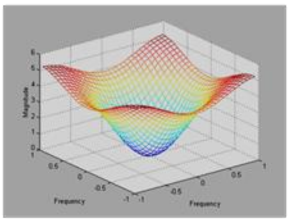
Sobel: Local soften

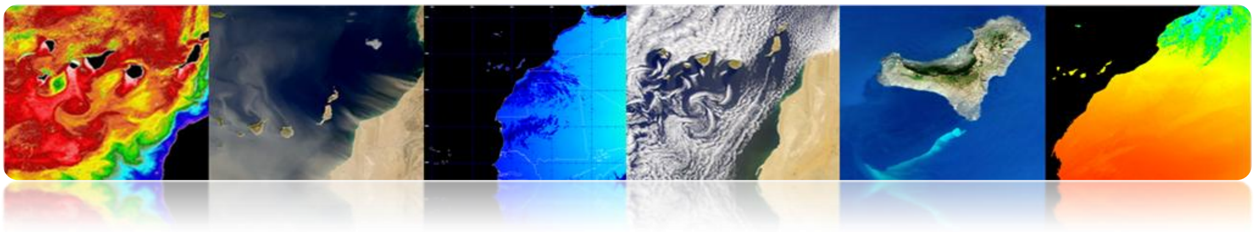
$$\begin{array}{c|c|c} -1 & -2 & -1 \\ \hline 0 & 0 & 0 \\ \hline 1 & 2 & 1 \end{array} \qquad \begin{array}{c|c|c} -1 & 0 & 1 \\ \hline -2 & 0 & 2 \\ \hline -1 & 0 & 1 \end{array}$$



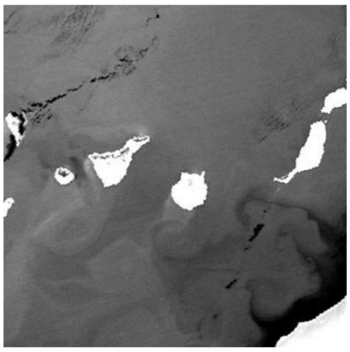
Laplacian: Second derivative aproximation

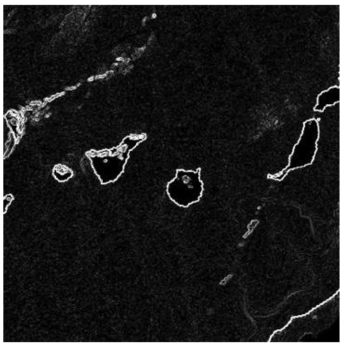
$$\begin{array}{c|c|c} 0 & -1 & 0 \\ \hline -1 & 4 & -1 \\ \hline 0 & -1 & 0 \end{array}$$





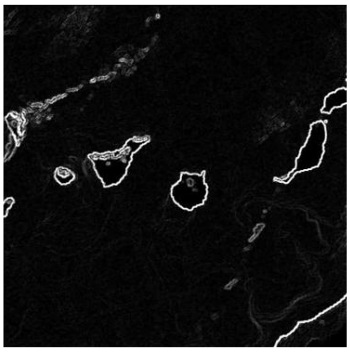
SST AVHRR

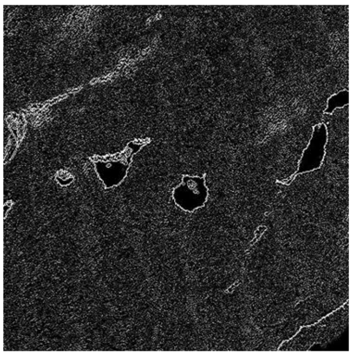




Roberts

Sobel



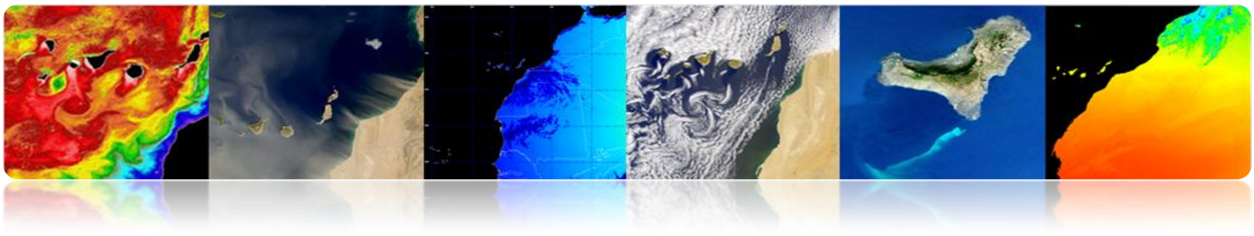


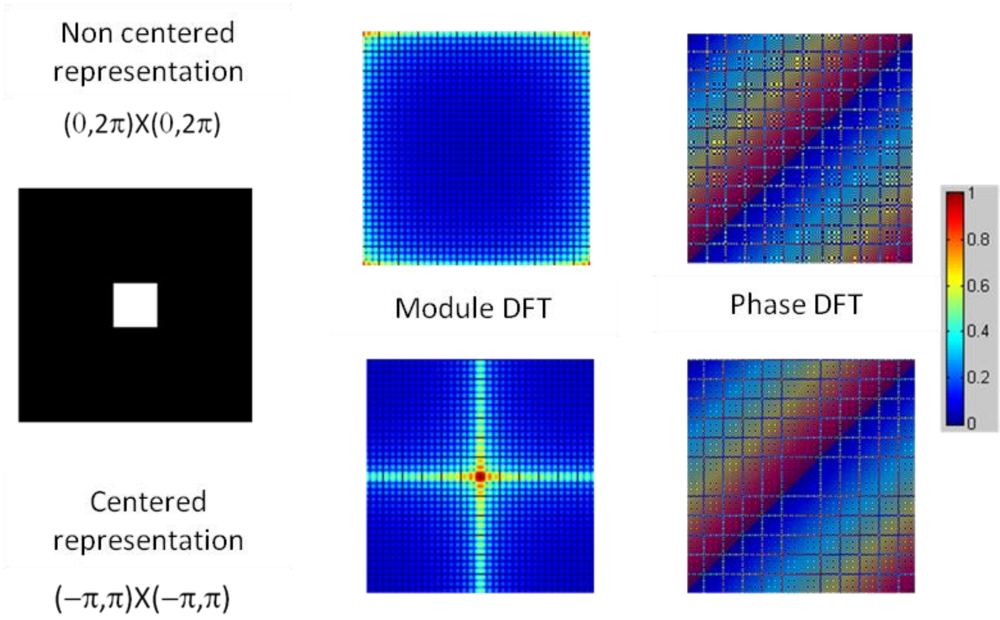
Laplacian

❑ FOURIER TRANSFORM

The Fourier transform applied on images provides information about the structures present in the image and can be used to filter out unwanted frequencies.

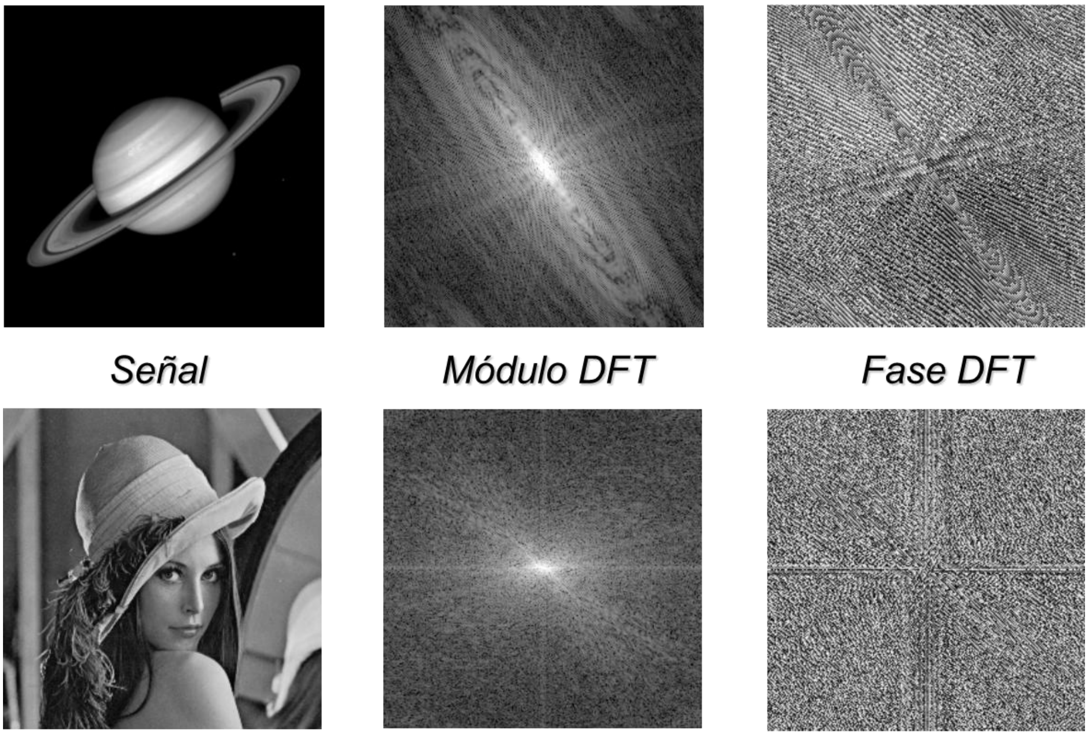
The Fourier transform of an image is composed of two types of information: the amplitude and the phase.



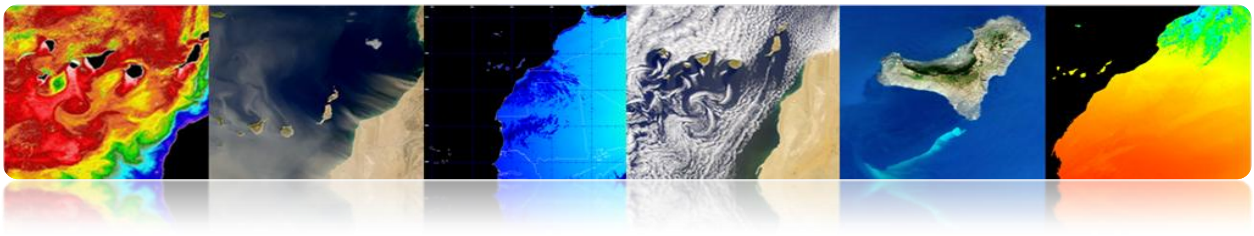


Non centered representation
(0,2π)X(0,2π)
Module DFT
Phase DFT
1
0.8
0.6
0.4
0.2
0
Centered representation
(−π,π)X(−π,π)

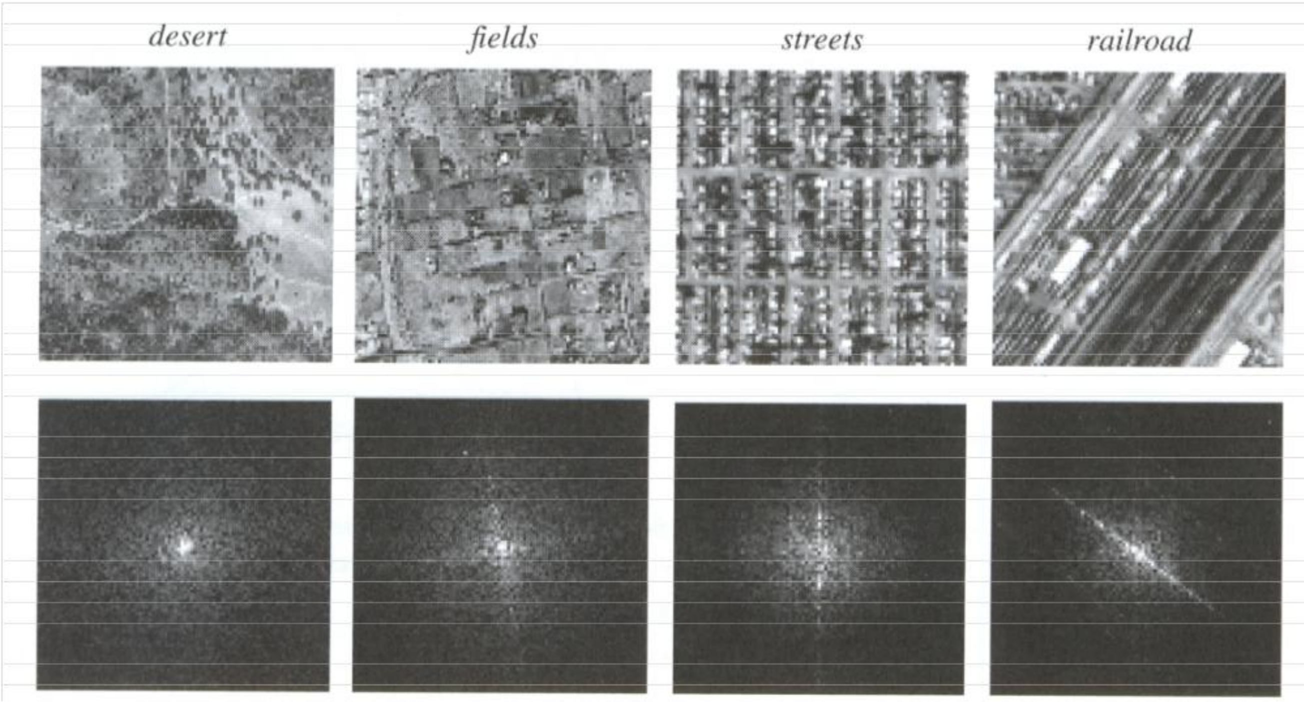
Examples



Señal
Módulo DFT
Fase DFT



The power spectrum (square of spectrum modulus) is used in the global spatial pattern recognition in the image.

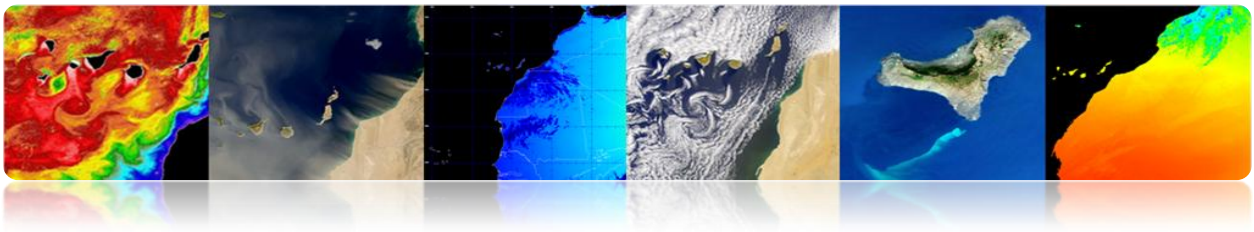


❑ IMAGE FUSION

It aims at improving the spatial quality of the multispectral image (MS) using the detail that provides the high-resolution panchromatic band (PAN), while preserving the spectral information.

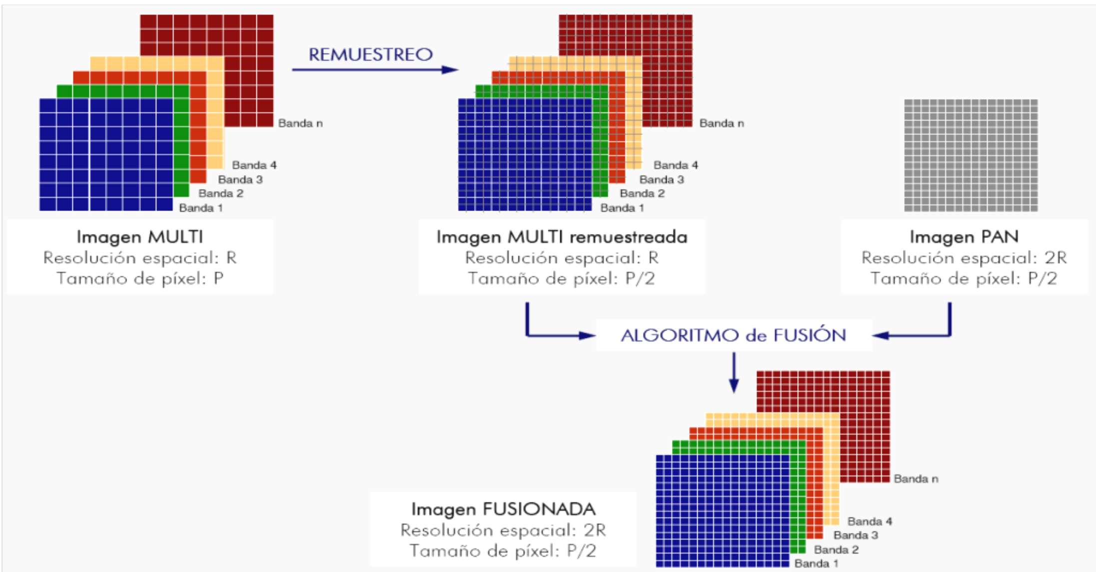
Objective:

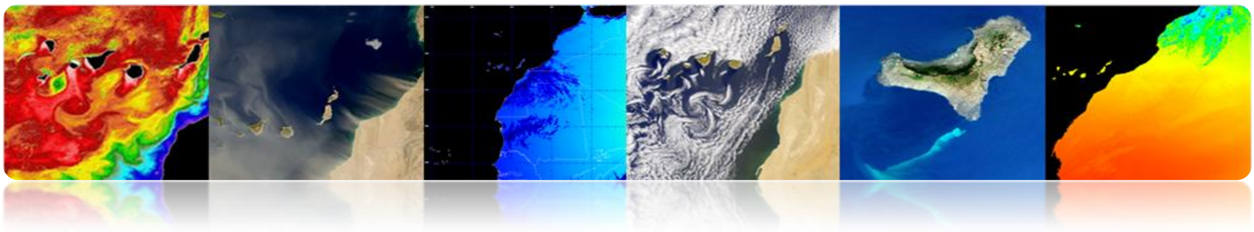
- Get images with high spatial and spectral resolution, from the PAN image (high spatial resolution, low spectral resolution) and multispectral bands (high spectral resolution, low spatial resolution).



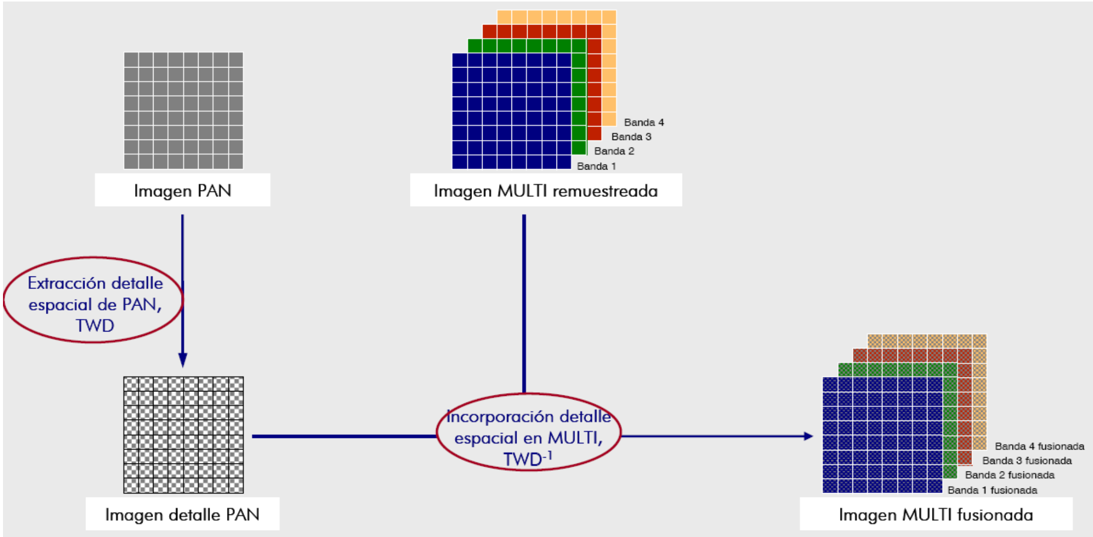
- Improve the visual quality to facilitate quality photo interpretation and GIS.
- Improve the detection and extraction of objects and features.
- Improve the thematic classification.
- Improve the detection of changes in the multi-temporal images.

General framework PAN-MS Fusion



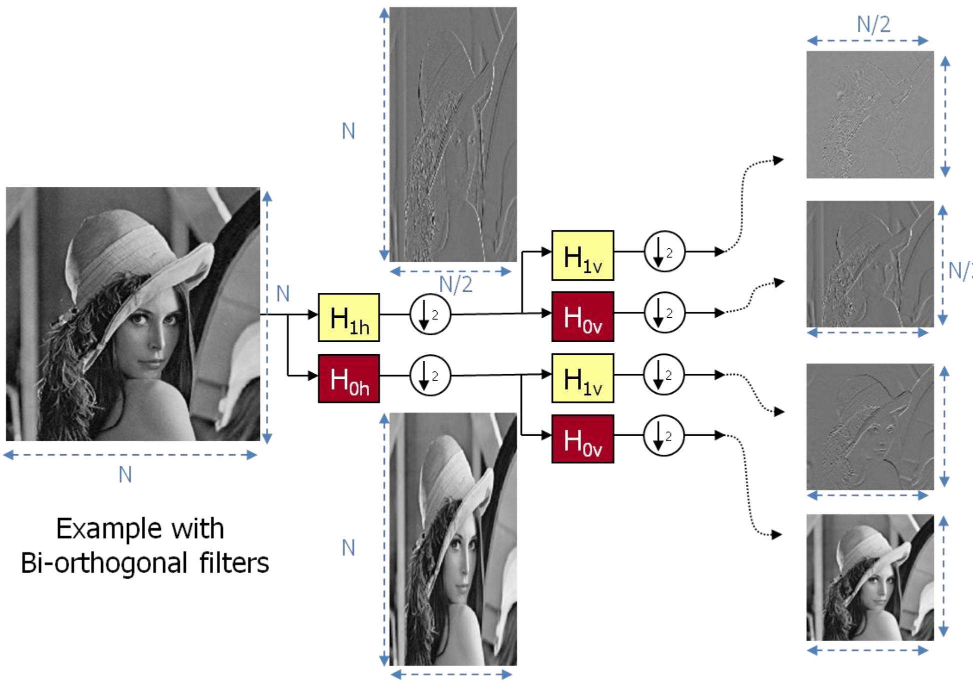


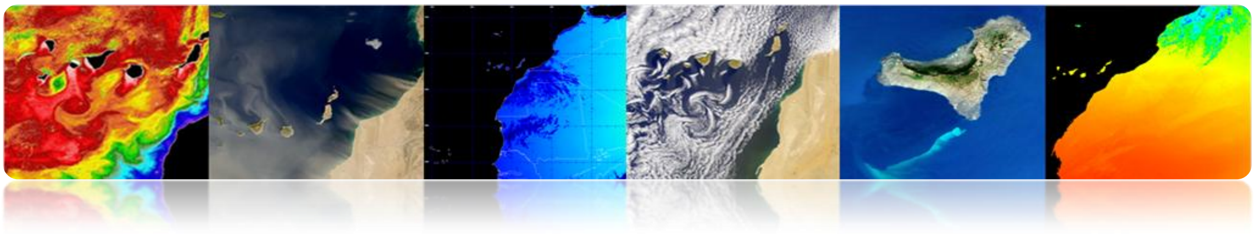
- ## Method based on Discrete Wavelet Transform:



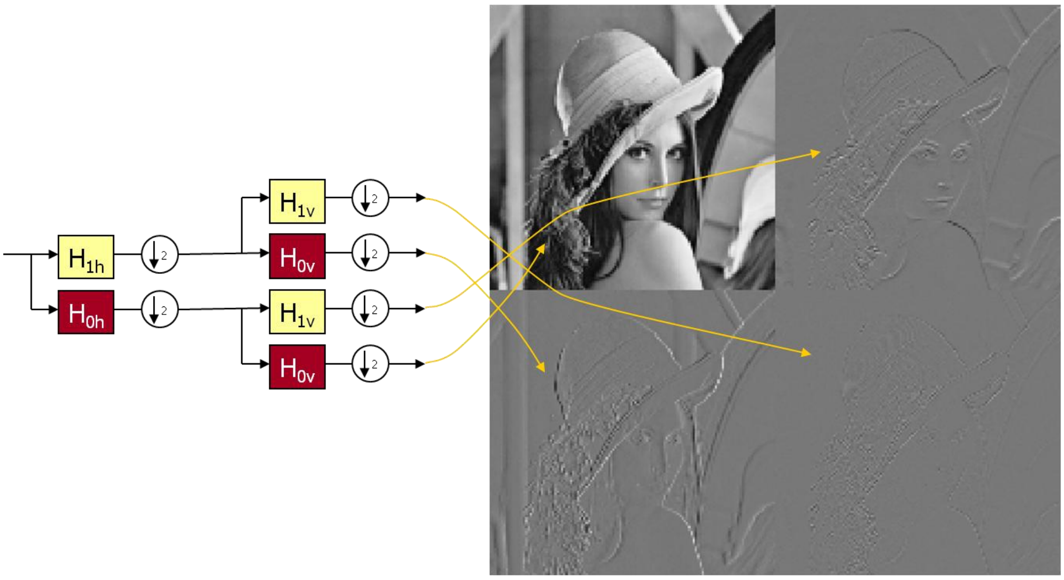
- ## Wavelet Transform

It provides a decomposition of the image into its components at different scales by using filters. In this way, each image is decomposed into its approximation and detail images.

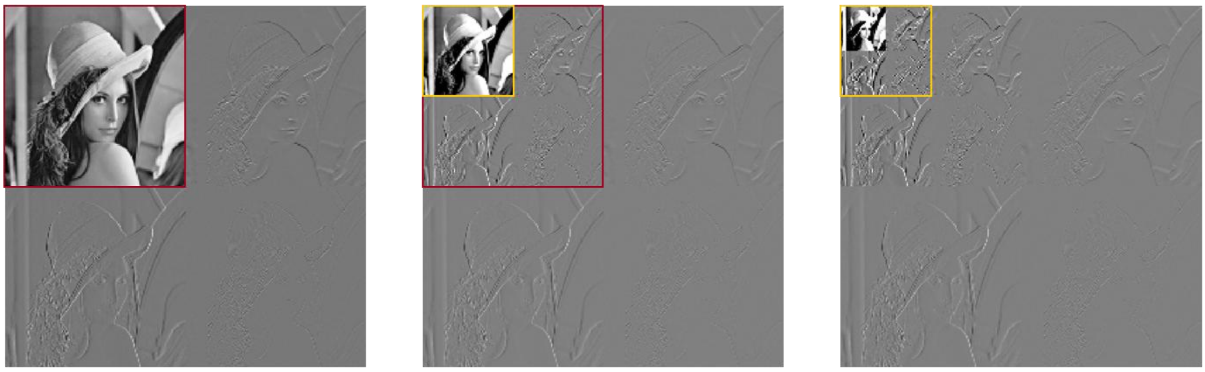




For its representation, the four outputs are joined into a single image.



It can be done at different levels returning to decompose the image approach



Example of a Quickbird image using the Mallat wavelet.

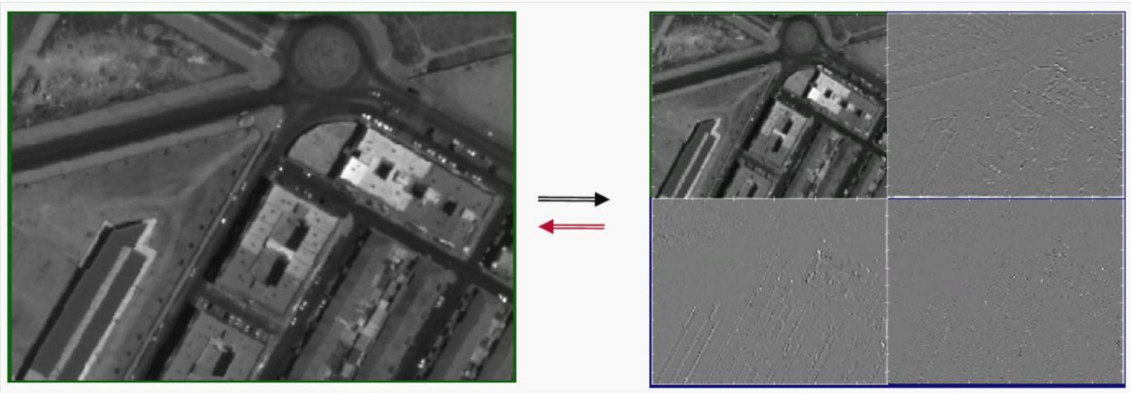
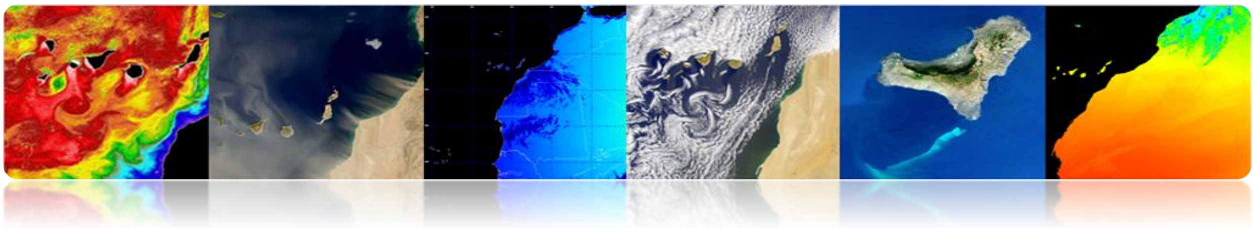


Imagen PAN *Primer Nivel*

Composición RGB de la multiespectral

Fusionada



5.4. IMAGE ANALYSIS

❑ FEATURE DETECTION

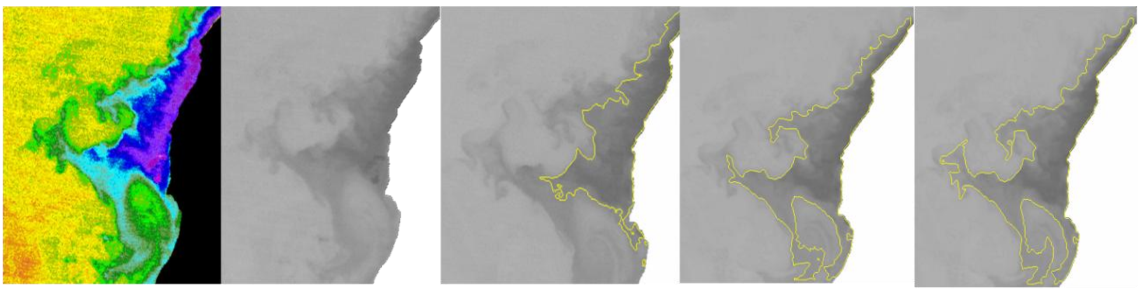
▪ Segmentation

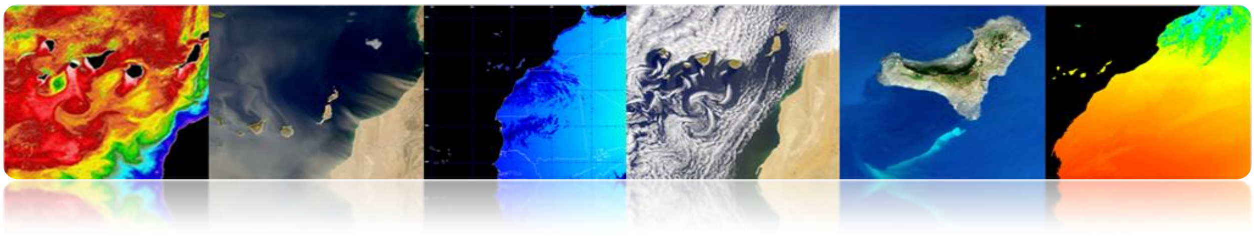
Segmentation is a first step in most image processing problems. It can be defined as finding a partition of the space (Image I) in n disjoint regions to get to satisfy a homogeneity criterion P (.):

$$\bigcup_{i=1}^{n} R_i = I \qquad \begin{array}{l} P(Ri) = True \\ P(Ri \cup Rj) = False \end{array}$$

The homogeneity criterion can be as simple (or complicated) as desired. Normally, criteria to approach to the semantics of the scene are defined.

This example of coastal upwelling shows the difficulty of segmentation, because objects have no sharp borders and each user may only be interested in a given area and, therefore, each segmentation would be different. As an example, some segmentations obtained by different algorithms are shown in the following image.





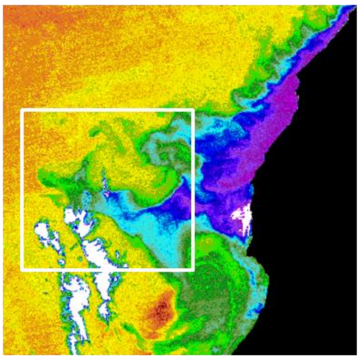
There are two basic segmentation algorithms families:

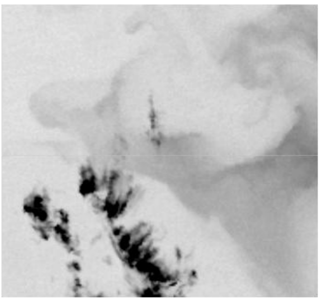
- Discontinuities detector→ Detect abrupt changes in the signal.
- Homogeneities Detectors → Detect areas with similar characteristics.

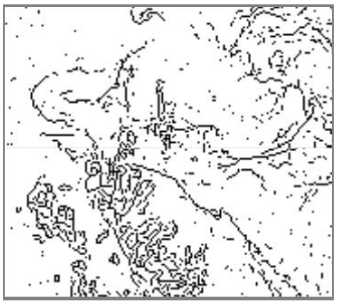
The use of additional information such as movement or depth improves the results.

• Discontinuities detectors

- Edge detectors filters are commonly used to detect discontinuities from gradient or Laplacian operators. Then edges are joint together to clearly delimit the objects.
- It is a complex and not always reliable process that may be affected by noise to a great extent.



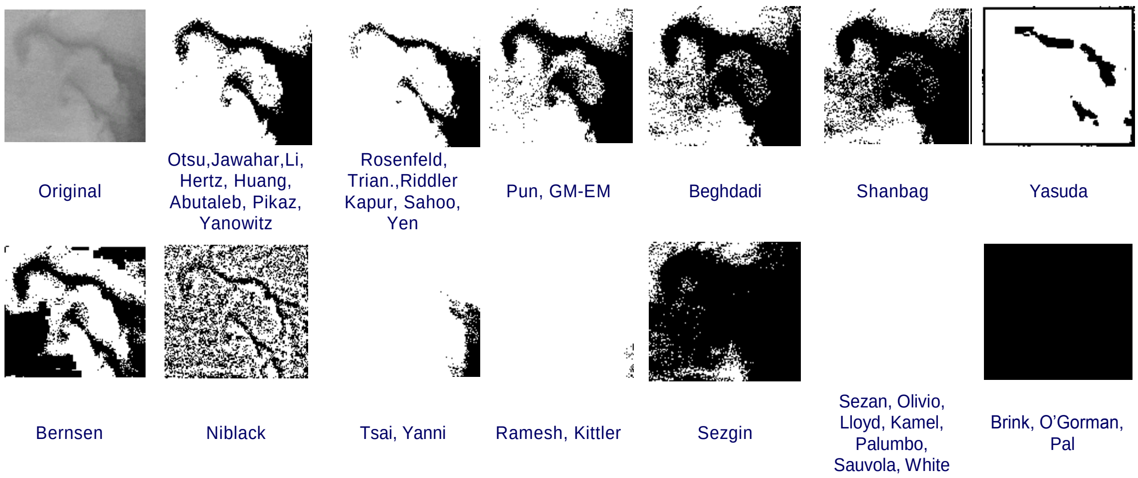




• Homogeneities detectors

Techniques based on the homogeneity of the pixels. The most common are:

- **Thresholding:** Detection using techniques based on manually or automatically thresholding. A global threshold for the image or local thresholds may be used.



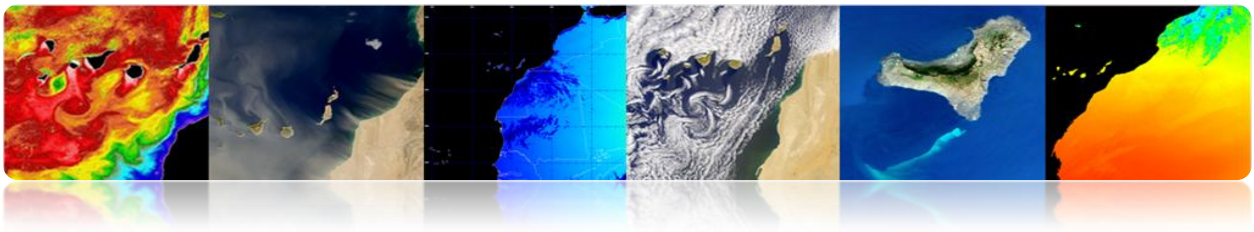
- **Region growing**

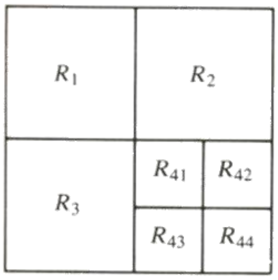
  It analyzes the Region Adjacency Graph (RAG). It merges similar regions and updates RAG with the new values. This process is iterated until a certain final criterion.

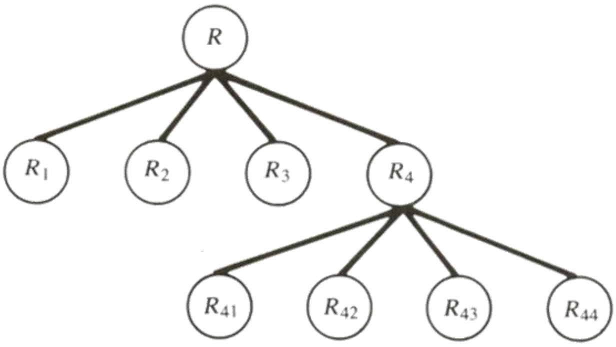
- **Split & merge**

  Split step: It divides the image into disjoint regions by analyzing the similarity criterion. This step is carried out by following a quadtree structure (QuadTree).

  Merge step: It merges tree leaves considering the similarity criterion. This step does not follow any predetermined structure.







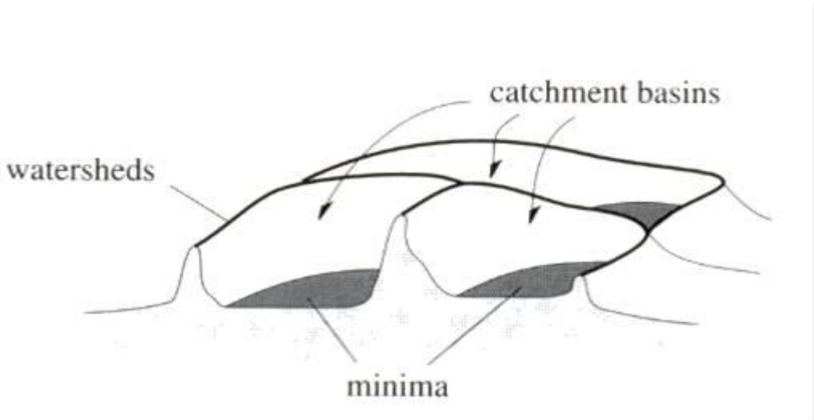
- ## Watershed

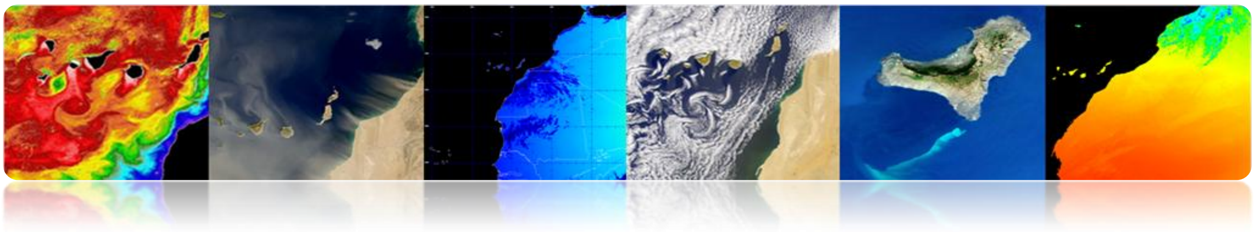
The watershed algorithm is a segmentation technique based on morphological tools that combines the concepts of region growing and edge detection:

- It groups up pixels around the minimum of the image.
- The boundaries of the regions are located at points (peaks) of maximum gradient of the image.

The process can be understood as the result of flooding a topographic relief:

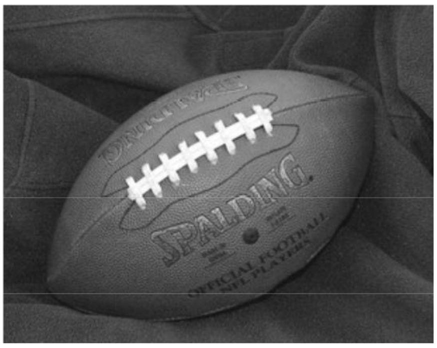
- It is interpreted as a relief image.
- The water is introduced by the minimum of the relief.
- When two are waterfronts meet together, a dam (contour) is built up.

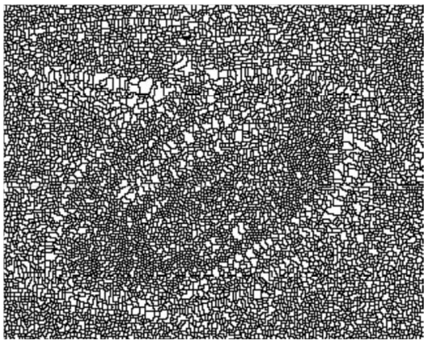




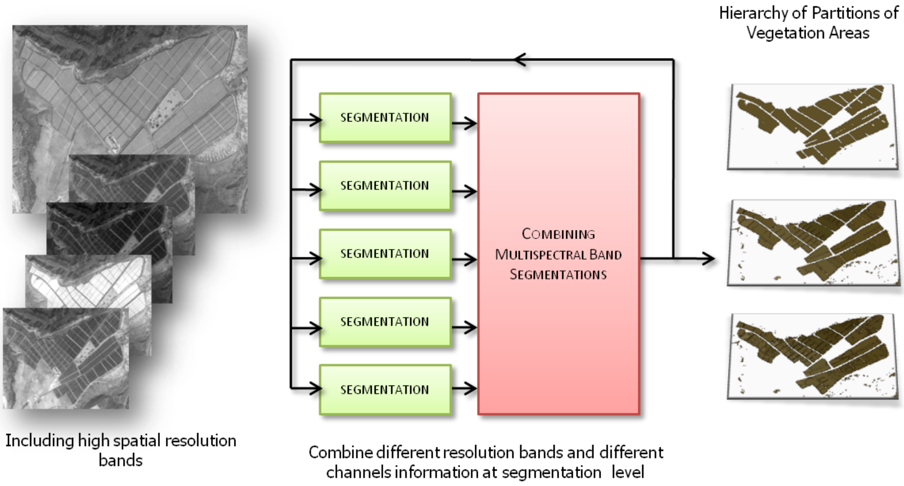
Advantage: The boundaries of the regions are correctly located.

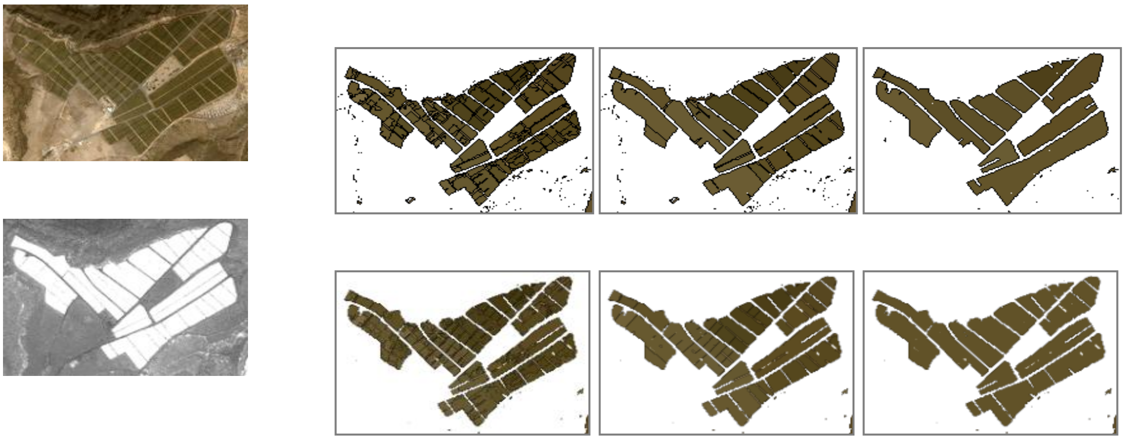
Disadvantage: It produces an over-segmentation of the image.





Example: segmentation of vegetation with various levels of detail

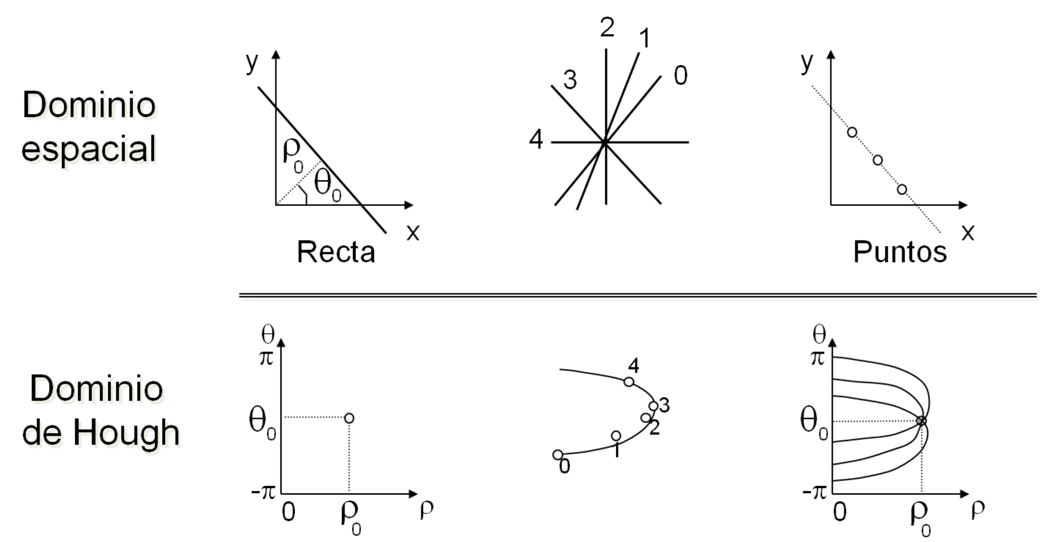


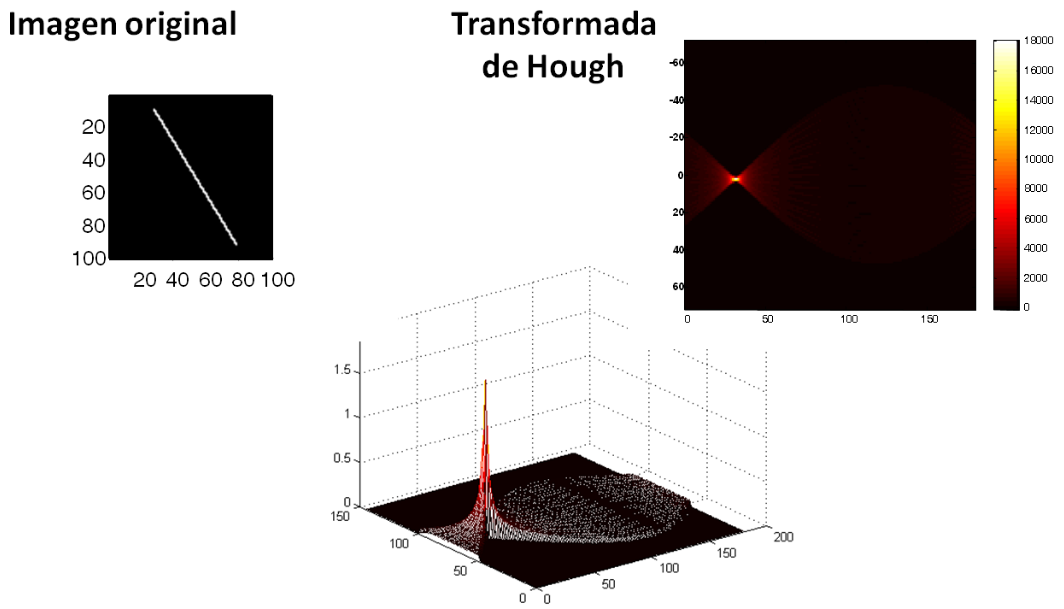


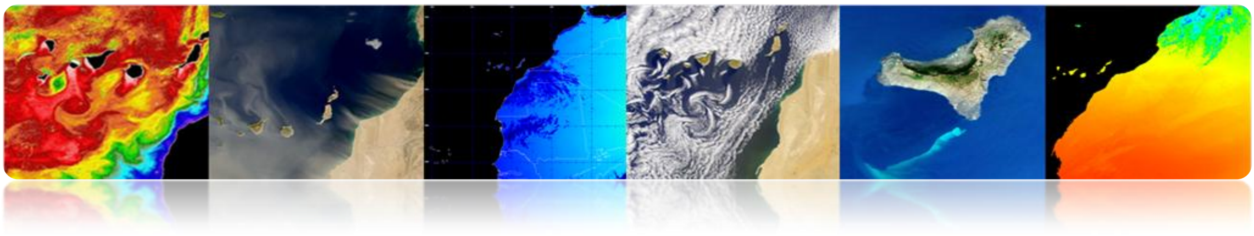
- ## Hough transform

This transform can be used to locate objects whose shape is known. The simplest example is the application of the Hough transform for locating lines or circular shaped figures.

Straight

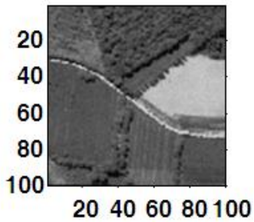




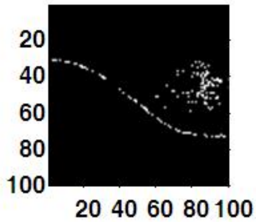


Examples

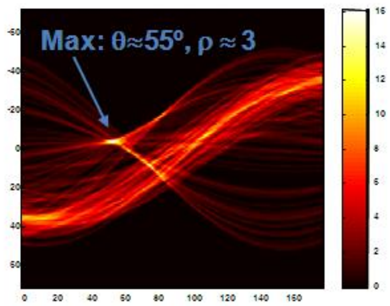
Original

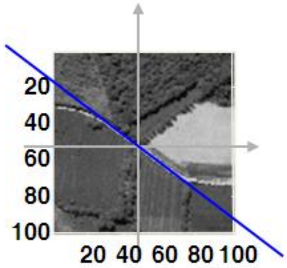


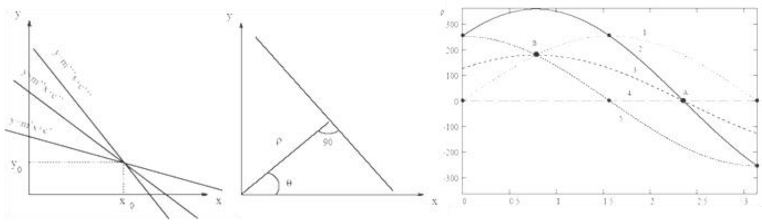
Binaria

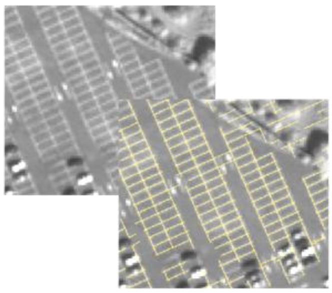


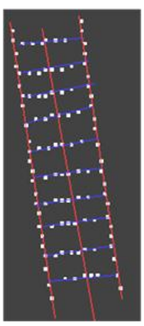
Hough

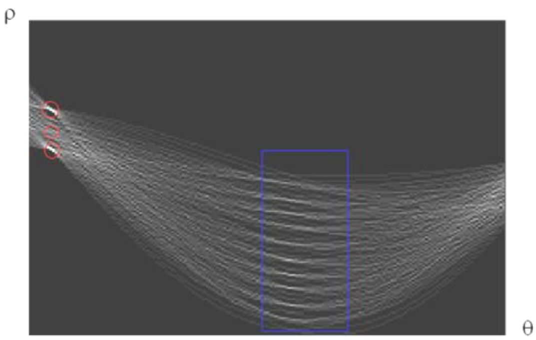


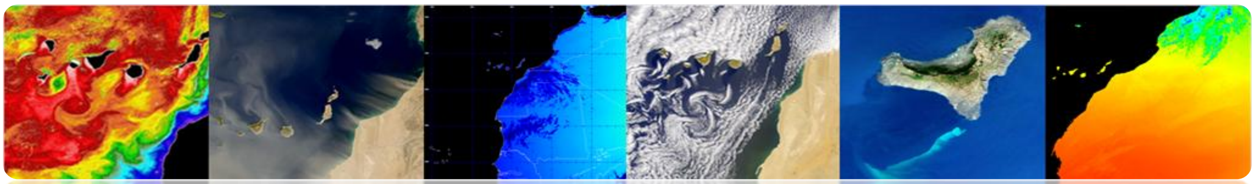




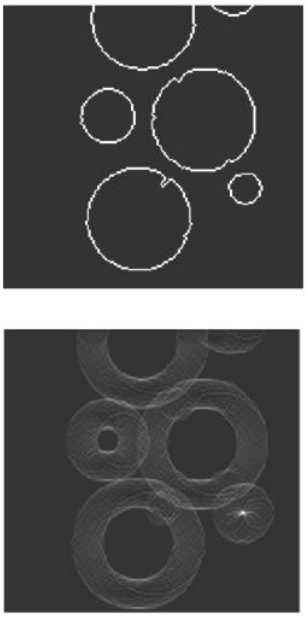


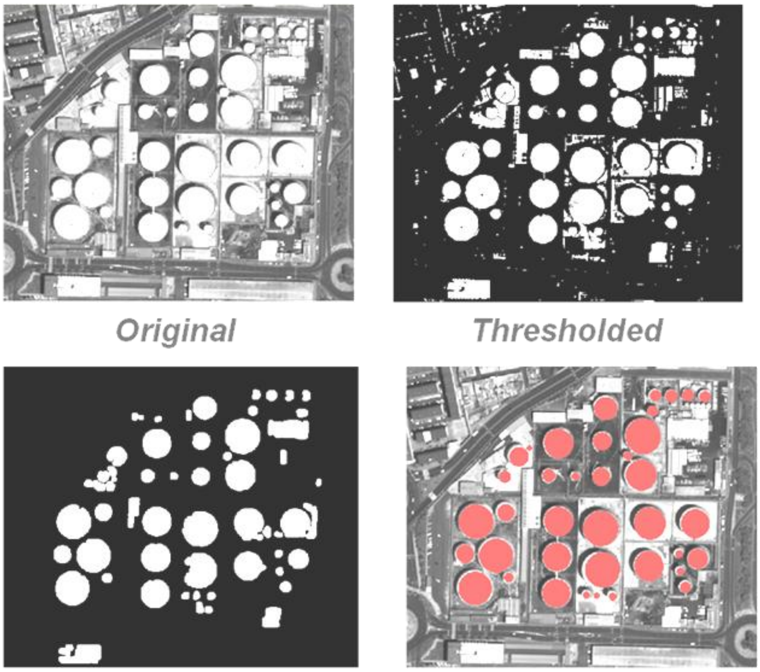






Circles





Original | Thresholded

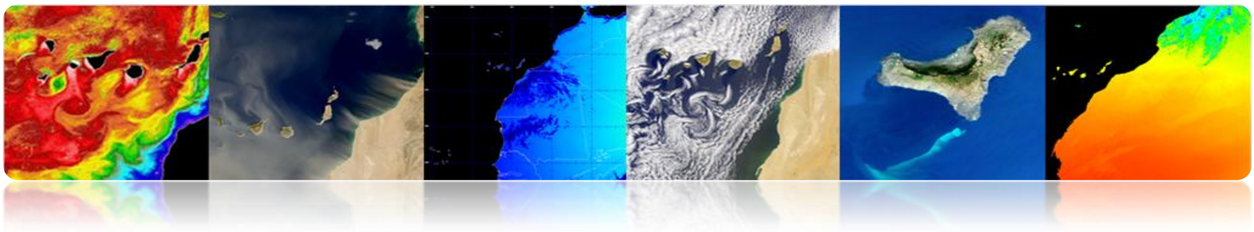
Morphologic op. | Segmented

- **Mathematical Morphology**

Powerful signal processing tools for filtering the scene specific elements preserving others.

Mathematical morphology was originally developed for binary images and further extended to functions and grayscale images. These nonlinear tools are based on management criteria and are not easily applicable to vector images.

- Example of morphological filters on binary images:
  - Erosion



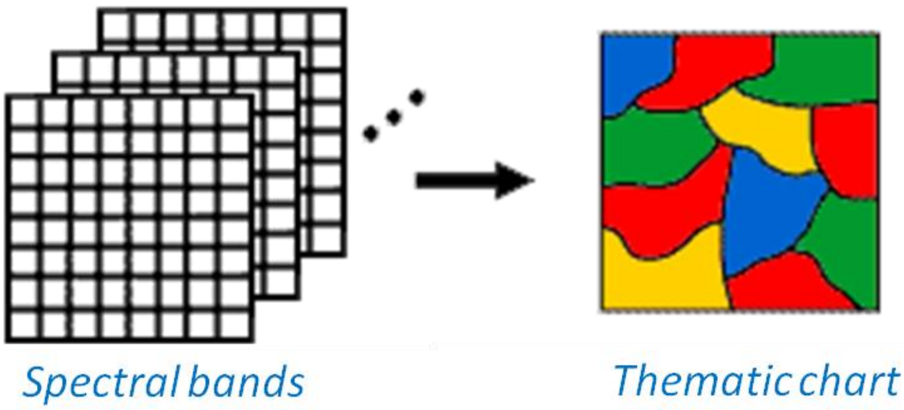
- Dilation
- Opening
- Closure

❑ THEMATIC CLASSIFICATION

It is the step for image analysis that aims at the generation of thematic maps from the input information for the end user.

In other words, it tries to transform numerical data into descriptive categories of images to identify the various elements of the image

The categories or classes selected for the thematic map should be able to be discriminated from the numerical data of the image.



There are various types of classifiers based on the information used:

- **Spectral classifier**

  It is based on the fact that the different classes of the image have different combinations of digital values in each band due to its reflectance or emittance.

- **Space classifier**

  It is based on analyzing the relationship between neighboring pixels, considering aspects such as texture, proximity, size, shape, repetition, etc.

- **Temporal classifier**

  It uses images on different dates to favor the classification process (e.g., crops or certain types of vegetation have different spectral properties depending on the season which facilitates identification).

- **Object-oriented classifier**

  It is a spatial and spectral hybrid classifier which typically includes pipeline stages prior to guide the classification so that each object is assigned entirely to a possible class.

Next, the spectral classifier and, more specifically, each typical classification step are described in greater detail.

Feature Extraction step (optional)

It is based on applying a spatial or spectral transformation to get the most interesting features for classification.

In this stage:

- The information of the image or original bands can be extracted.
- Unwanted variability in the spectral signatures (spectral indexes. Example: NDVI in the figure) can be deleted.

- Spectral separation of classes can be improved.
- The number of bands (Principal Component Analysis) can be reduced.


Training step

Select pixels representative of the desired classes to train the classifier. It can be done in a supervised or unsupervised way.

- **Separability**

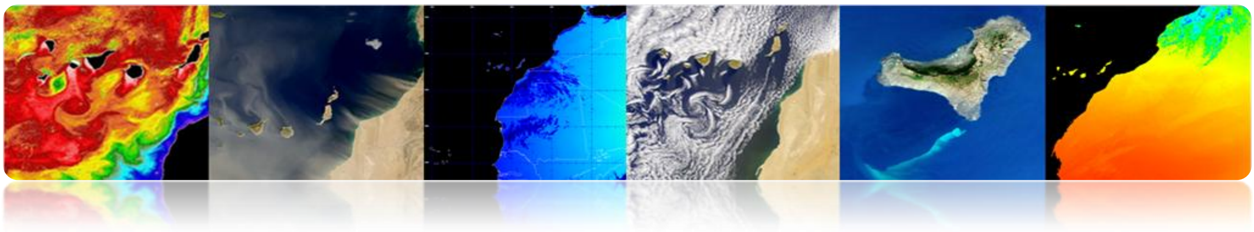
Before jumping to the training phase, it is recommended to analyze the separation of classes to assess a priori whether the classification is possible or if there will be some classes that will not be discriminated.

- It is insufficient to only use the distance between the means. It also requires the standard deviation or variance.
- Separability measures between classes:

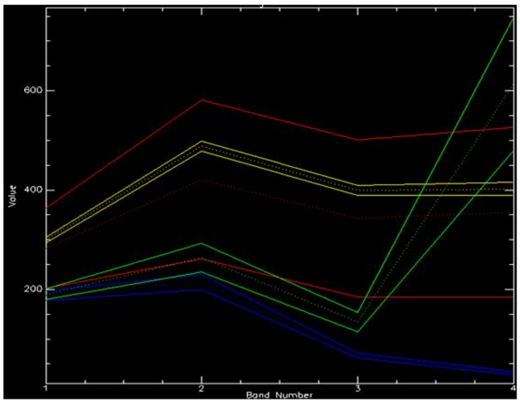
There are several measures of separability from Euclidean and angular distances. Some do not take into account the variance, that is to say, the spectral overlap between the classes, and they become less reliable (in the table there are examples of metric separability).

city block	$L_1 = \lvert \boldsymbol{\mu}_a - \boldsymbol{\mu}_b \rvert = \sum_{k=1}^{K} \lvert m_{ak} - m_{bk} \rvert$
Euclidean	$L_2 = \lVert \boldsymbol{\mu}_a - \boldsymbol{\mu}_b \rVert = [(\boldsymbol{\mu}_a - \boldsymbol{\mu}_b)^T(\boldsymbol{\mu}_a - \boldsymbol{\mu}_b)]^{1/2} = \left[\sum_{k=1}^{K} (m_{ak} - m_{bk})^2\right]^{1/2}$
angular	$ANG = \operatorname{acos}\left(\frac{\boldsymbol{\mu}_a^T \boldsymbol{\mu}_b}{\lVert \boldsymbol{\mu}_a \rVert \lVert \boldsymbol{\mu}_b \rVert}\right)$
normalized city block	$NL_1 = \sum_{k=1}^{K} \frac{\lvert m_{ak} - m_{bk} \rvert}{(\sqrt{c_{ak}} + \sqrt{c_{bk}})/2}$
Mahalanobis	$MH = \left[(\boldsymbol{\mu}_a - \boldsymbol{\mu}_b)^T \left(\frac{\mathbf{C}_a + \mathbf{C}_b}{2}\right)^{-1} (\boldsymbol{\mu}_a - \boldsymbol{\mu}_b)\right]^{1/2}$
divergence	$D = \frac{1}{2}tr\left[(\mathbf{C}_a - \mathbf{C}_b)(\mathbf{C}_b^{-1} - \mathbf{C}_a^{-1})\right] + \frac{1}{2}tr\left[(\mathbf{C}_a^{-1} + \mathbf{C}_b^{-1})(\boldsymbol{\mu}_a - \boldsymbol{\mu}_b)(\boldsymbol{\mu}_a - \boldsymbol{\mu}_b)^T\right]$
transformed divergence	$D^t = 2[1 - e^{-D/8}]$
Bhattacharyya	$B = \frac{1}{8}MH + \frac{1}{2}\ln\left[\frac{\lvert \mathbf{C}_a + \mathbf{C}_b \rvert}{2\lvert \mathbf{C}_a \rvert^{1/2} \lvert \mathbf{C}_b \rvert^{1/2}}\right]$
Jeffries-Matusita	$JM = \left[2(1 - e^{-B})\right]^{1/2}$

The Jeffries-Matusita distance is widely used. It is bounded to 2 for large class separations.

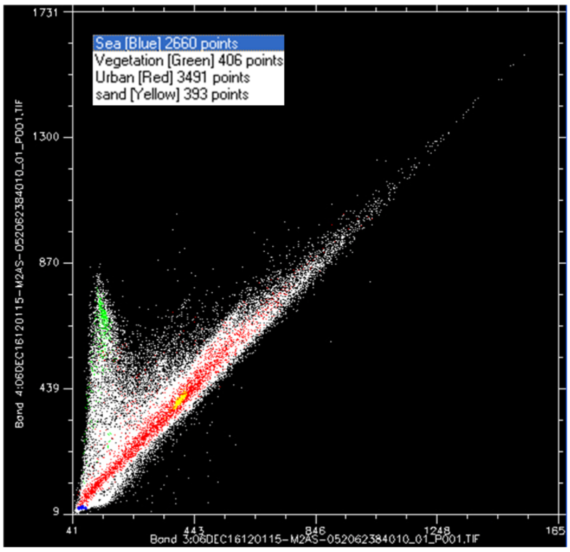


Example of Separability



Sea [Blue] 2660 points
Vegetation [Green] 406 points
Urban [Red] 3491 points
sand [Yellow] 393 points

Sea: 15,321.600 Meters²
Vegetation: 2,338.560 Meters²
Urban: 20,108.160 Meters²
sand: 2,263.680 Meters²




```
Input File: 06DEC16120115-M2AS-052062384010_01_P001.TIF
    ROI Name: (Jeffries-Matusita, Transformed Divergence)

Sea:
    Vegetation: (1.99998464 2.00000000)
    Urban: (1.98092992 2.00000000)
    sand: (2.00000000 2.00000000)

Vegetation:
    Sea: (1.99998464 2.00000000)
    Urban: (1.99533321 2.00000000)
    sand: (2.00000000 2.00000000)

Urban:
    Sea: (1.98092992 2.00000000)
    Vegetation: (1.99533321 2.00000000)
    sand: (1.94454226 2.00000000)

sand:
    Sea: (2.00000000 2.00000000)
    Vegetation: (2.00000000 2.00000000)
    Urban: (1.94454226 2.00000000)

Pair Separation (least to most):

Urban and sand - 1.94454226
Sea and Urban - 1.98092992
Vegetation and Urban - 1.99533321
Sea and Vegetation - 1.99998464
Sea and sand - 2.00000000
Vegetation and sand - 2.00000000
```

4 bandas

The classification algorithm must be trained. There are several possibilities:

Supervised Training

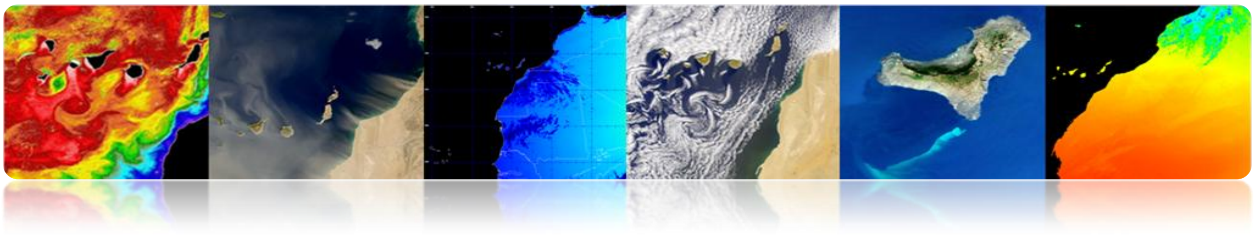
Training samples are labeled by the user (e.g., figure above). It involves prior knowledge of the terrain (in-situ data, maps, photo interpretation).

- All classes in the image must be taken into account to avoid errors (Solution: apply thresholds in the allocation phase).
- The analyst must select representative areas for each class to get the digital level range for each category.
- Training areas can be established through field visits, maps, photo interpretation, etc.
- Each training area (ROI) must include the range of variability of the class (Using more than one training area for each class).
- Number of pixels in training> 10*N (N: number of bands used). It is recommended 100 * N.
- There is no guarantee that classes will be distinguishable (one thematic ↔ 1 spectral)

Unsupervised Training

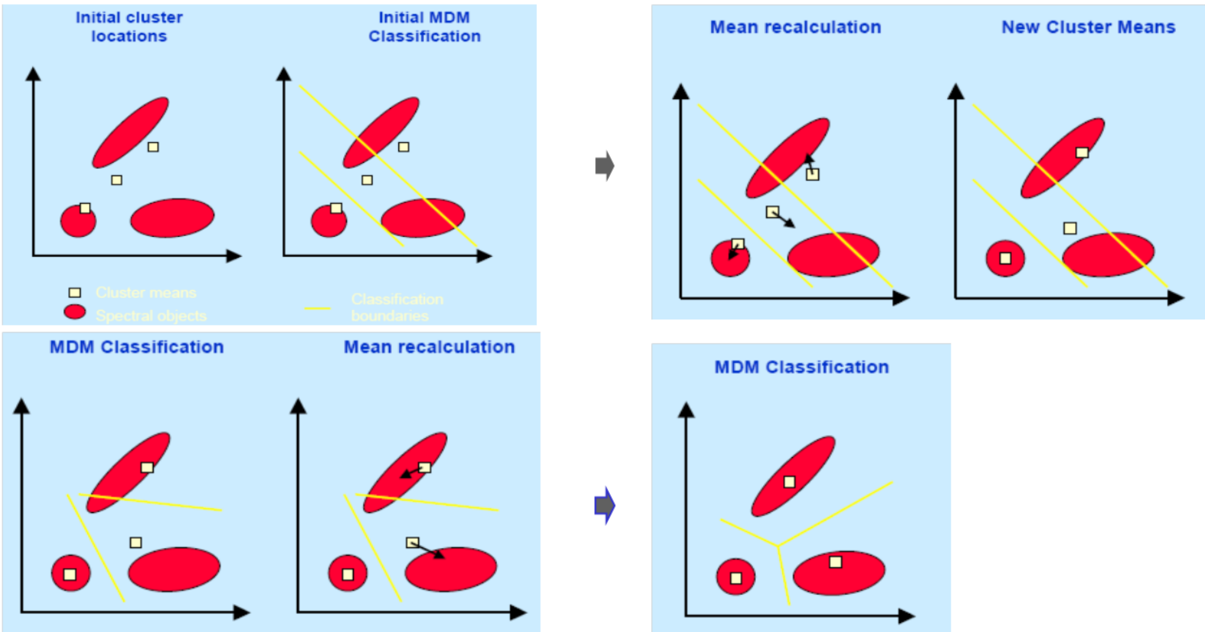
Training samples are not labeled. Classes are automatically determined.

- It does not require prior knowledge of the area.
- The algorithm locates concentrations or groups (clusters) of pixels with similar characteristics (assuming that classes have similar spectral values).

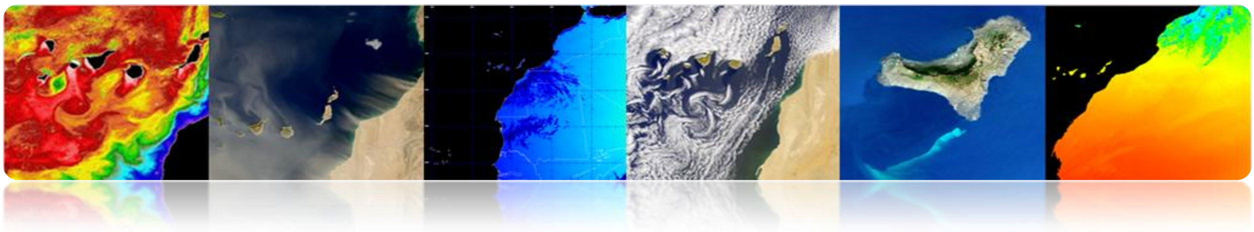


- The groups represent classes in the image, but then they have to be labeled according to our classes of interest.
- There is no guarantee that the obtained spectral classes correspond to classes of interest.
- The number of groups in the image is not known → use more than classes of interest.
- Generally the full image is classified (+ training assignment), instead of using the image areas for unsupervised training.
- Classical algorithms: K-means and Isodata.

Graphic illustration of operation of K-means algorithm on 2 bands



The iterative process is repeated until the change in the average values reaches a threshold.



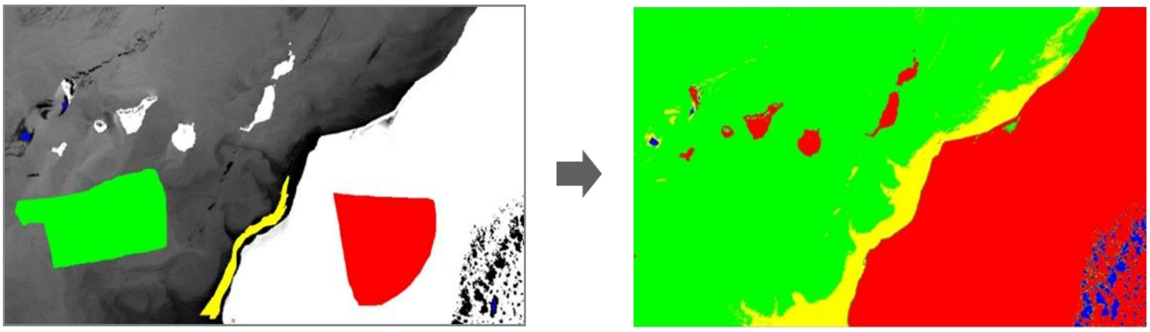
- **Mixer training**

It is performed combining both training types. There are several possibilities:

- First, unsupervised training (find representing spectral classes in sub-images) to guide the supervised training to select the separable thematic classes.
- First, supervised training for labeling the known classes, to guide unsupervised initialization of clusters.
- Applying the two methods separately and combine the results.

Assignment or Labelling step

This stage is to assign each pixel in the image to one of the existing classes. A thematic image is obtained.



Problem: Establish statistical limits for each class.

Techniques:

- Nonparametric:
  - Parallelepiped classifier
  - Minimum distance

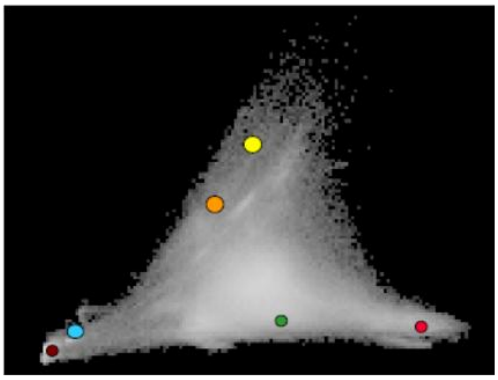
- Parametric
  - Maximum Likelihood Classifier

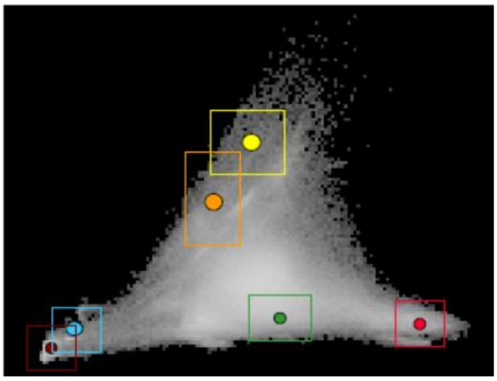
• Parallelepiped classifier

All image pixels with values within the centered parallelepiped mean value of a training class are assigned to that spectral class. It is the fastest of all.

There are different methods for determining the boundaries of parallelepipeds.

Problem: Overlapping limits and not all pixels are classified





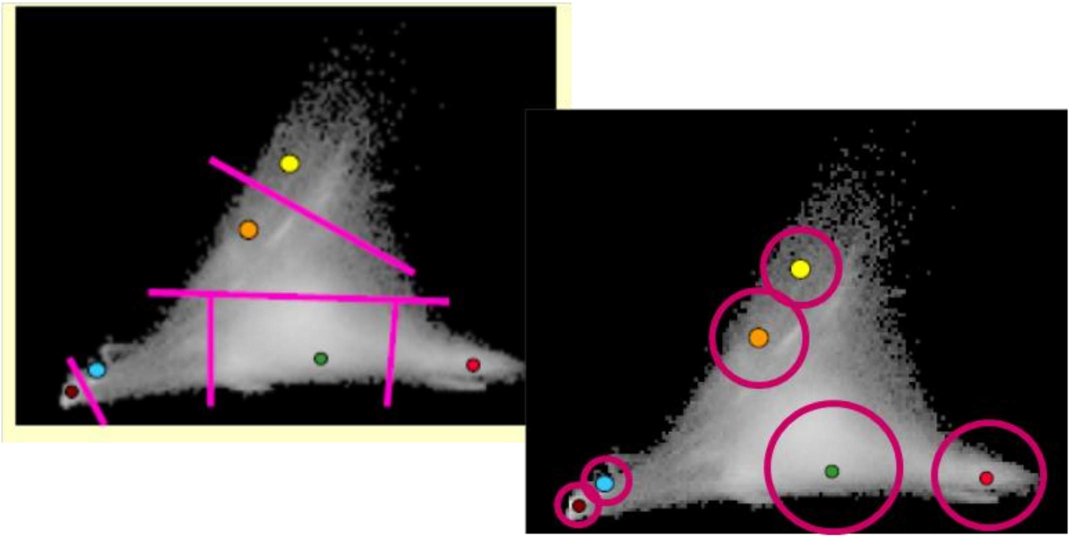
• Minimum distance classifier

The pixels of the scene are classified using the average distances to the training data. A pixel is assigned to the nearest class.

Decision surfaces are linear and they are determined from the average values (no variances) of the training data (modeling classes symmetrical like in the spectral domain → It is sometimes a problem!)

It is slower than the parallelepiped classifier.

There is an error when a class has not been considered ⇨All pixels are classified, even if the spectral value is far from the average. Solution: use a threshold so that the decision surfaces are circles centered in each middle class.



- **Maximum Likelihood Classifier**

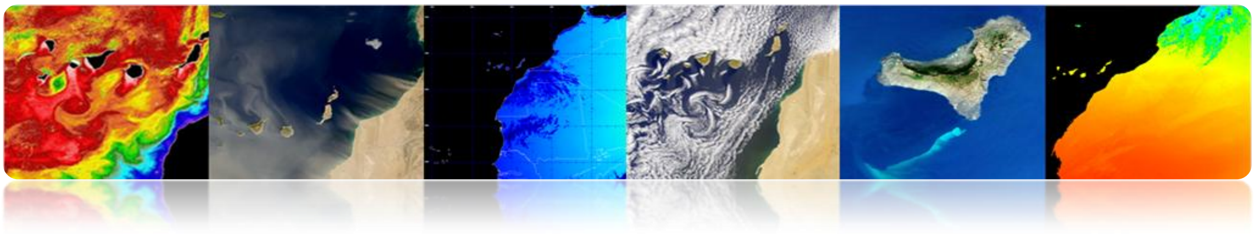
It uses the statistics of the training sets (mean and covariance) and the pixels are assigned to the class with the highest probability.

Each class is considered to have a normal distribution.

As the minimum distance classifier, all pixels of the scene are mapped to any of the classes (except thresholds are applied as shown in the figure).

It is slower than the previous classifiers.

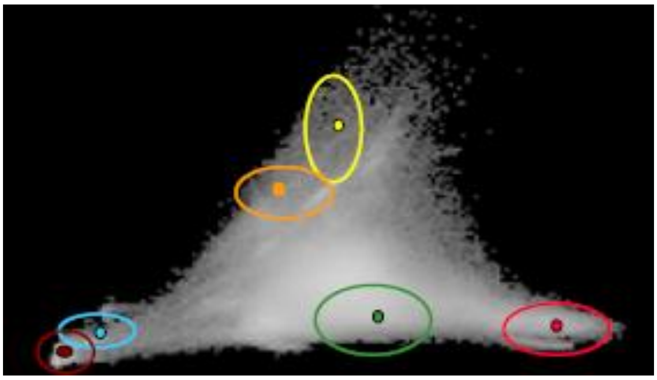
Theoretically offers the best classification.



- **Procedure**

  - The probability of a pixel is calculated for each class.

  - The pixel is assigned to the class with the highest probability.

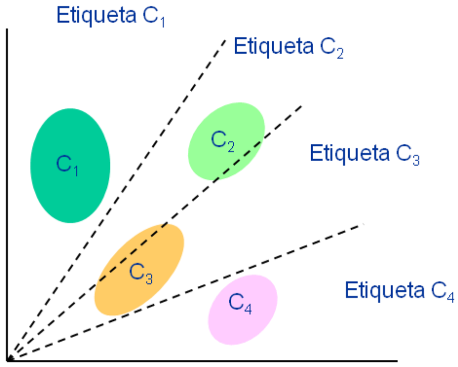


- **Spectral angular distance classifier**

It uses the spectral angle between classes to assign the pixels.

It is independent of the magnitude of the spectral vectors. It is therefore more robust to be insensitive to variations in topography, lighting, etc.

A maximum threshold allowed angle can be specified and pixels at greater angle are not rated.



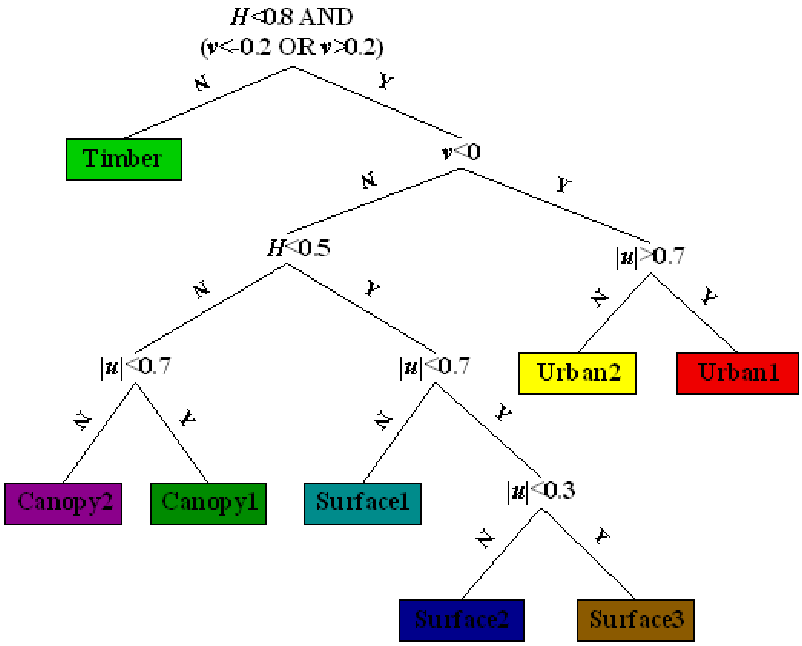
- **Decision tree**

It is one of the simplest but also more efficient methods.

Setting thresholds is quite laborious.

It consists on discriminating sequentially each category based on the spectral values, or the texture or the auxiliary information.

Rules are established for each class. These rules allow to discriminate each class from the variables or bands that best discriminate this class from the rest.

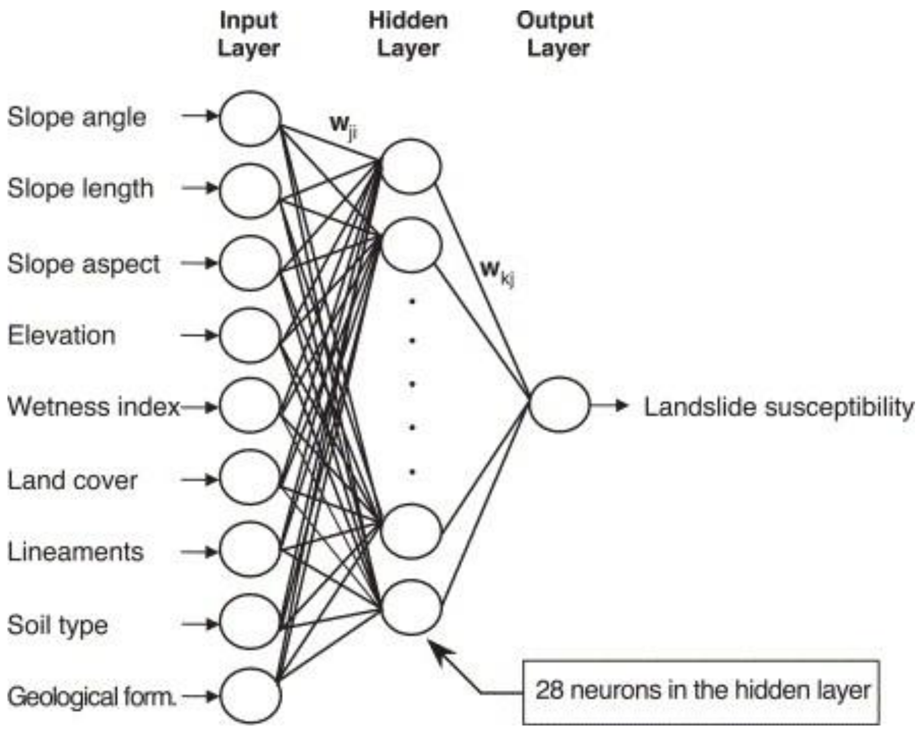


- **Neural Network**

Neural networks can predict from a sample of observed inputs and outputs. The learning objective is to estimate from known results about input data (training sample), to calculate later results from the remaining unknown input data.

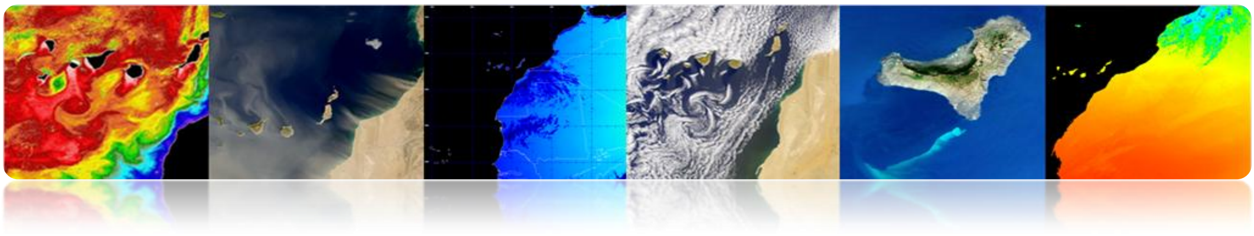
It consists of a set of simple elements (neurons) arranged in layers. The units in each layer are connected to the next layer through activing functions (weights are calculated iteratively during training).

Remote sensing is often used in back-propagation networks consisting of three layers (input, hidden and output).

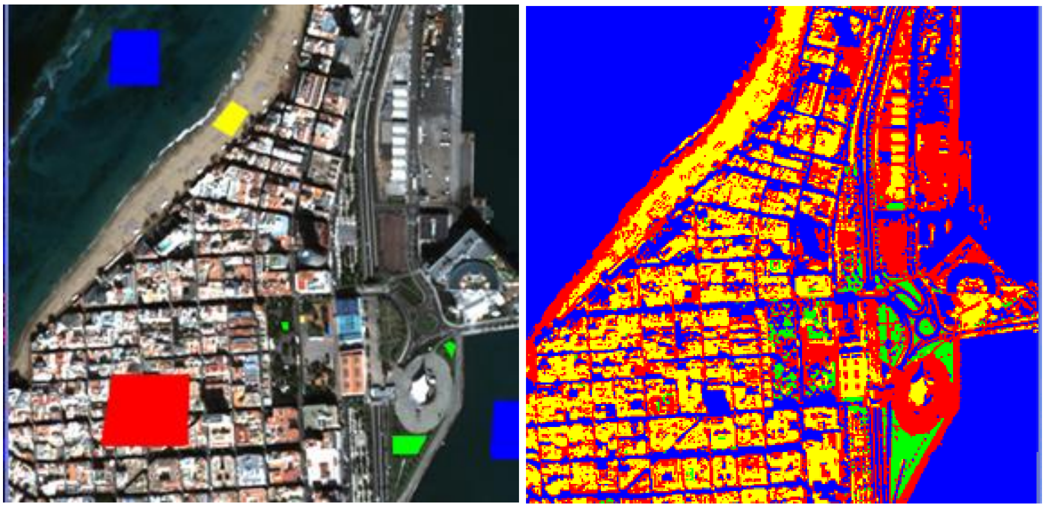


Advantages: it can include bands or auxiliary data of all types to improve the robustness and accuracy.

Problems: lack of general criteria for designing the structure of the network. The tedious training and the classification depends largely on the amount and quality of the training results. For this reason, SVM (Support Vector Machines) are more commonly used.

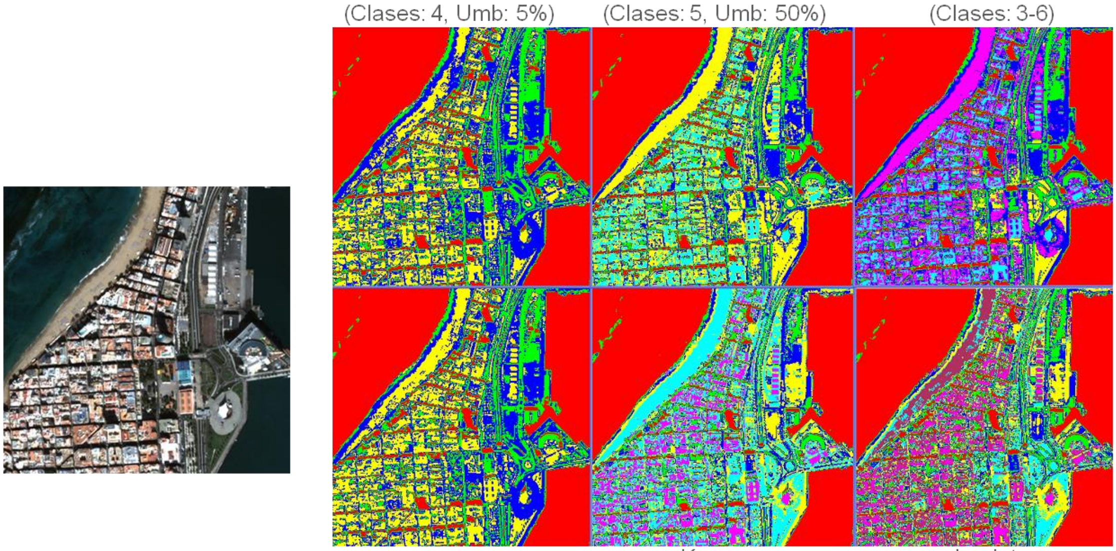


Example of results for a supervised classifier



Minimum distance classifier

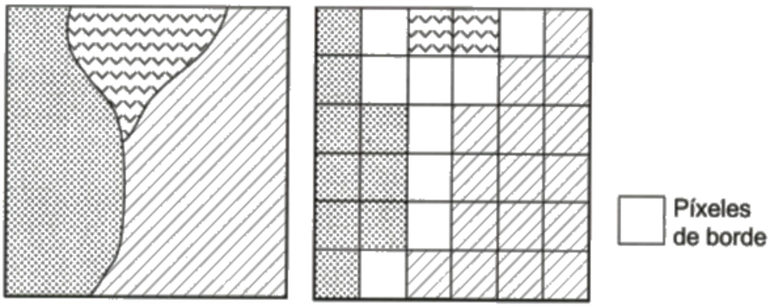
Example of results for an unsupervised classifier



- ## Classification accuracy

The accuracy of the classification must be verified. The main sources are:

- Soil structure (shape, direction and size of objects, spatial distribution of classes, degree of mixing, sloping terrain, etc.)
- Use of images with inadequate spatial or spectral resolution.
- Atmospheric influences
- Unsuitable acquisition dates



Common methods are:

- Visual
- Confusion / fail matrix
  - In-situ data -two independent sets, one for the training phase and others for evaluation- are commonly used.
  - Check the percentage of pixels of each image class classified correctly and incorrectly.
- Kappa Coefficient

- **Confusion Matrix**

  - Method to quantify the accuracy of a classification.
  - Square matrix (rows: actual classes, columns: classification classes)
  - Diagonal indicates the number of pixels classified correctly.
  - The off-diagonal values correspond to misclassifications.
    - Overall accuracy: correct/total pixels
    - Error of omission (Pixels of a class that is not detected as such): residue in rows.
    - Error of commission (Pixels incorrectly classified): residue in columns.
  - It allows to know the main conflicts between classes → redefine classes

- **Kappa Coefficient**

  - It measures the correspondence between the classified image and the reality, and the correspondence that would be obtained by simply making a random classification.
  - It seeks to measure the degree of adjustment due to classification accuracy by eliminating random factors.

    0: agreement due to coincidence

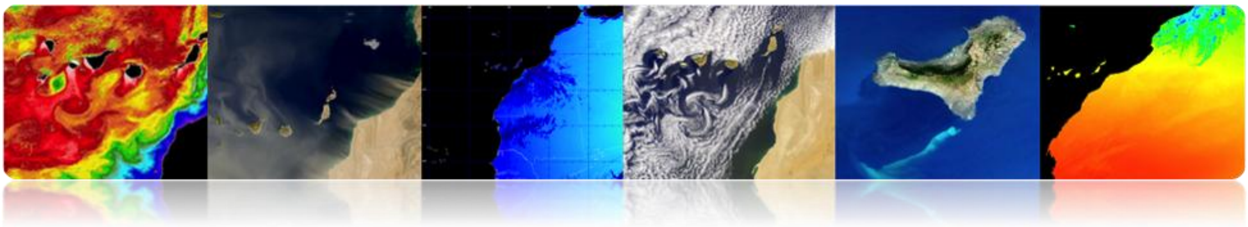
    1: total agreement image and reality

    Negative: misclassification

    - It allows comparing different methods (different confusion matrices).

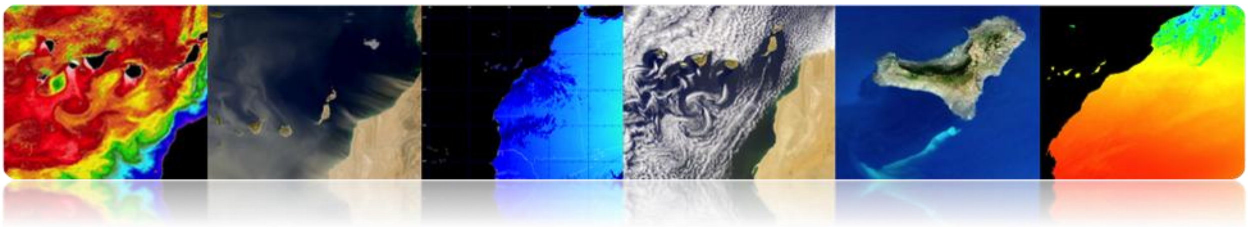
TRAINING PLAN

TELECAN



CONTENTS

ACQUISITION AND ANALYSIS OF REMOTE SENSING IMAGES



1.1. INTRODUCTION

The objective of this practice is to provide the necessary information for obtaining spatial remote sensing images, for high resolution and low resolution sensors.

We present here the main interfaces to access and download data from different sensors on board of satellites. There are a variety of image servers but we have focused on what we consider most significant for the type of data they provide or for having a more intuitive handling. Most servers present an interface from a web browser, but they also often offer the possibility of ftp access for downloading data. In some cases, they allow a direct download, and in others you have to make a request and wait for it to be processed.

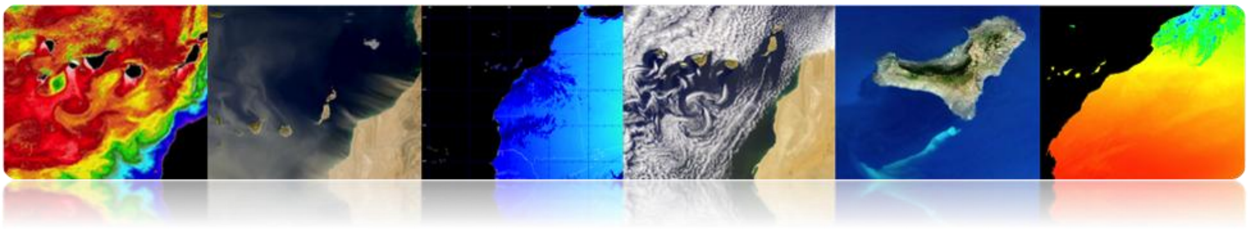
Furthermore, there are other applications which, apart from allowing to download the data, they provide utilities to perform different types of analyzes.

1.2. MEDIUM AND HIGH RESOLUTION IMAGES

Normally, you have to pay for medium and high spatial resolution images and they are usually quite expensive (increasing in price with the resolution of the sensor). Below there is a list with the access to the most used image catalogs and their prices.

❑ IMAGE CATALOG

The catalogs to access the remote sensing images of the major medium and high resolution satellites are:



Landsat

http://glovis.usgs.gov/

http://earthexplorer.usgs.gov/

Deimos

http://www.deimos-imaging.com/extcat/

SPOT

http://catalog.spotimage.com/PageSearch.aspx

Worldview, Quickbird

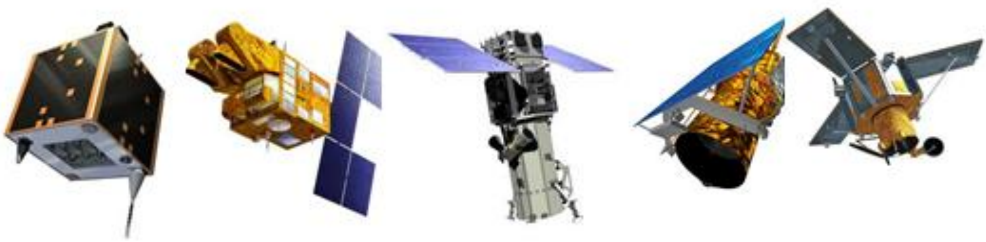
https://browse.digitalglobe.com/imagefinder/

Geoeye, Ikonos

http://geofuse.geoeye.com/maps/Map.aspx#

Rapideye

http://eyefind.rapideye.de/ [3]



These catalogs allow you to select a geographic area and view images in the file.

❑ COST OF THE IMAGES

In general, the cost of high resolution images is high, and it depends on the selected processing level. Here you are some links to satellite imagery providers where you can get prices for most high resolution satellites.

Astrium (Spotimage)

http://www.astrium-geo.com/en/122-price-lists

E-GEOS (Eurimage, Telespazio)

http://www.e-geos.it/products/prices_terms.html/

European Space Imaging

http://www.euspaceimaging.com/ordering/

DigitalGlobe + Geoeye

http://www.digitalglobe.com/purchase

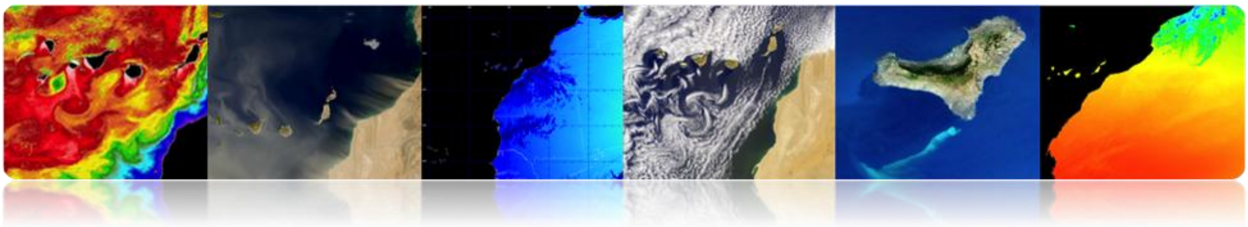
NPOC-INTA

http://www.crepad.rcanaria.es/es/npoc/distribucion.html

Aurensis - Telespazio

http://www.aurensis.com/page.php?id=349&lang=ESP

Note that the products of the Landsat satellite series are offered free of charge for non-commercial applications.



1.3. LOW RESOLUTION IMAGES

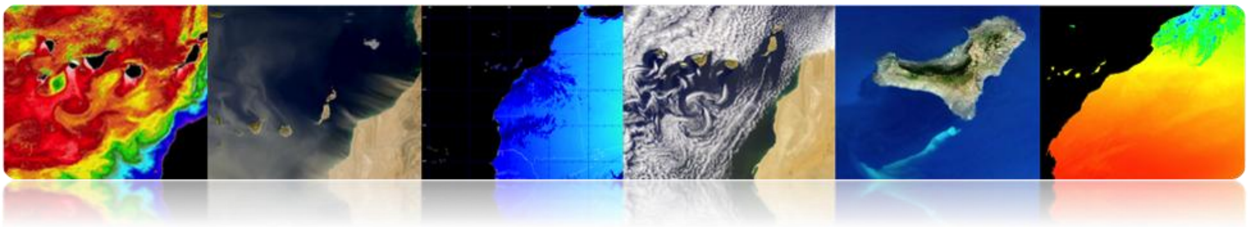
Low spatial resolution products are generally free of charge. There are many servers that allow their access and to download data. Among the most important servers, the following can be found:

Giovanni (http://disc.sci.gsfc.nasa.gov/giovanni)
OceanColor (http://oceancolor.gsfc.nasa.gov/)
LPDAAC (https://lpdaac.usgs.gov/)
PODAAC (http://podaac.jpl.nasa.gov/)
Laads (http://ladsweb.nascom.nasa.gov)
USGS (http://earthexplorer.usgs.gov/)
USGS (http://glovis.usgs.gov/)
ESA (http://earth.esa.int/EOLi/EOLi.html)
GMES (http://gmesdata.esa.int/web/gsc/home)
EUMETSAT (http://www.eumetsat.int/home/main/dataaccess/index.htm)

In Spain at national or regional level the most outstanding servers are:

INTA-NPOC (http://www.crepad.rcanaria.es/es/npoc/distribucion.html)
INTA-CREPAD (http://www.crepad.rcanaria.es/es/index.html)
PNT (http://www.ign.es/PNT/)
ACIISI-PET (Http://www.teledeteccioncanarias.es)

Some of the image servers shown above also allow certain analyzes in a way that, by selecting a specific area and a range of years, different mean maps, anomalies or graphical representations of data sets can be obtained.



Some of the previous access server products are described below. We specifically analyze:

- Access and download of marine, atmospheric or terrestrial data generated from space sensor:

  OceanColor (http://oceancolor.gsfc.nasa.gov/)

  LPDAAC (https://lpdaac.usgs.gov/)

  PODAAC (http://podaac.jpl.nasa.gov/)

  Laads (http://ladsweb.nascom.nasa.gov)

  Furthermore, most of these data can be accessed centrally making a request with the following application:

  Reverberation (http://reverb.echo.nasa.gov/reverb/)

- Access to satellite images, orthophotos and LIDAR:

  USGS (http://earthexplorer.usgs.gov/)

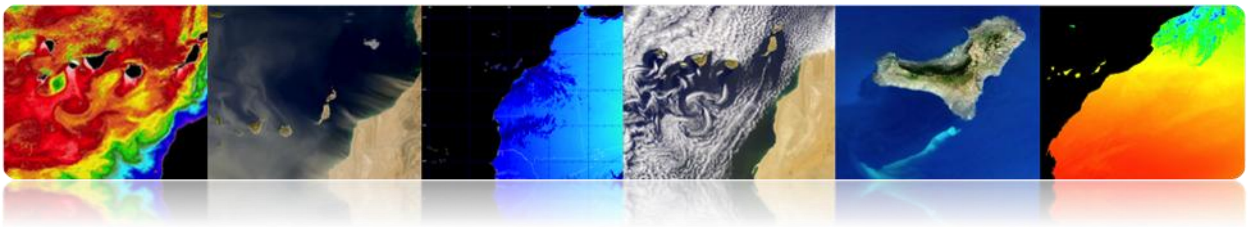
Most servers presented here belong to NASA. That is why they are the most accessible and documented. They also feature a variety of products that meet the expectations required.

Also, we will show the desktop application for accessing and downloading data stored and processed by the European Space Agency (ESA).

EOLISA (http://earth.esa.int/EOLi/EOLi.html)

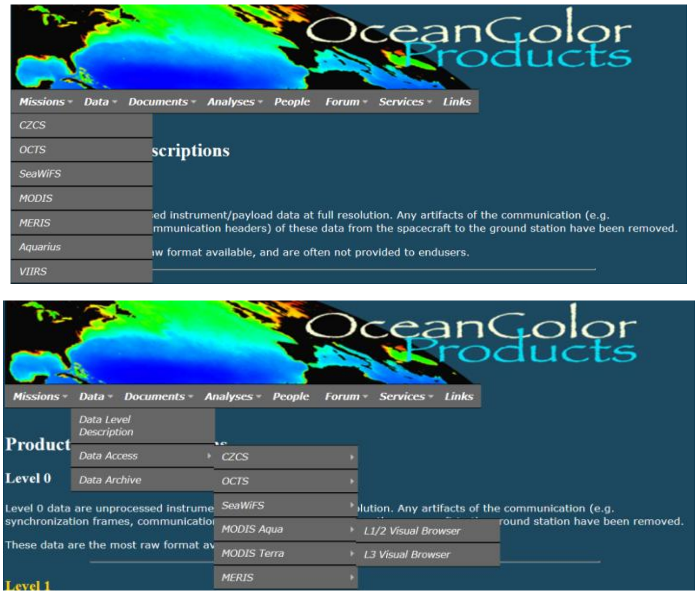
Finally, Giovanni a NASA's tool for making various types of analysis will be explained.

Giovanni (http://disc.sci.gsfc.nasa.gov/giovanni)



❑ OCEANCOLOR

In this web you can view, download and access information on oceanographic parameter products derived from different sensors' data. Here we are some screen shots of this web:



As we can see in the drop down menu, as it is shown in the figure on the right, data from CZCS sensors, OCTZ, SeaWiFS, MODIS, MERIS, Aquarius and VIIRS are processed and L1/L2 and L3 level products are generated. Geophysical parameters that can be downloaded are:

Remote Sensing Reflectance (Rrs)

Chlorophyll Concentration (chlor_a)

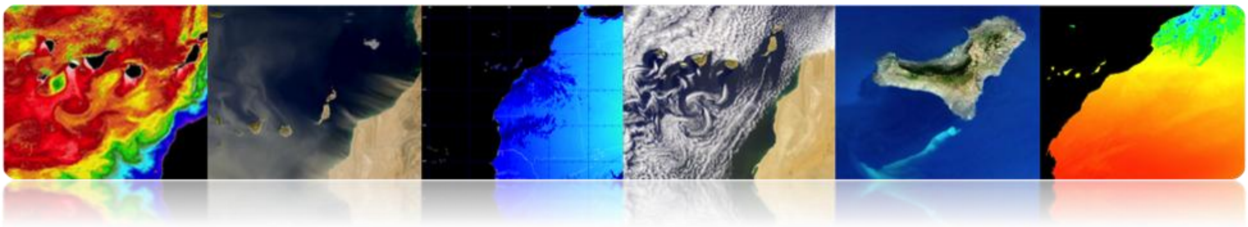
Diffuse Attenuation Coefficient at 490nm (Kd_490)

Particulate Organic Carbon Concentration (poc)

Particulate Inorganic Carbon Concentration (pic)

Colored Dissolved Organic Matter Index (cdom_index)

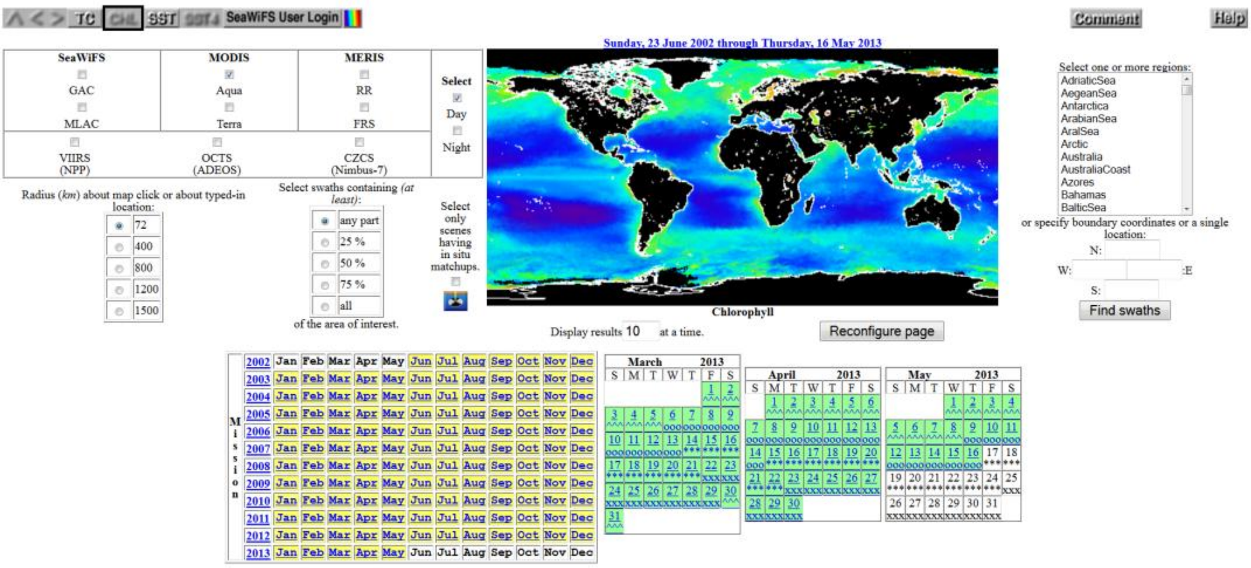
Daily Mean Photosynthetically Available Radiation (pair)



Instantaneous Photosynthetically Available Radiation (ipar)

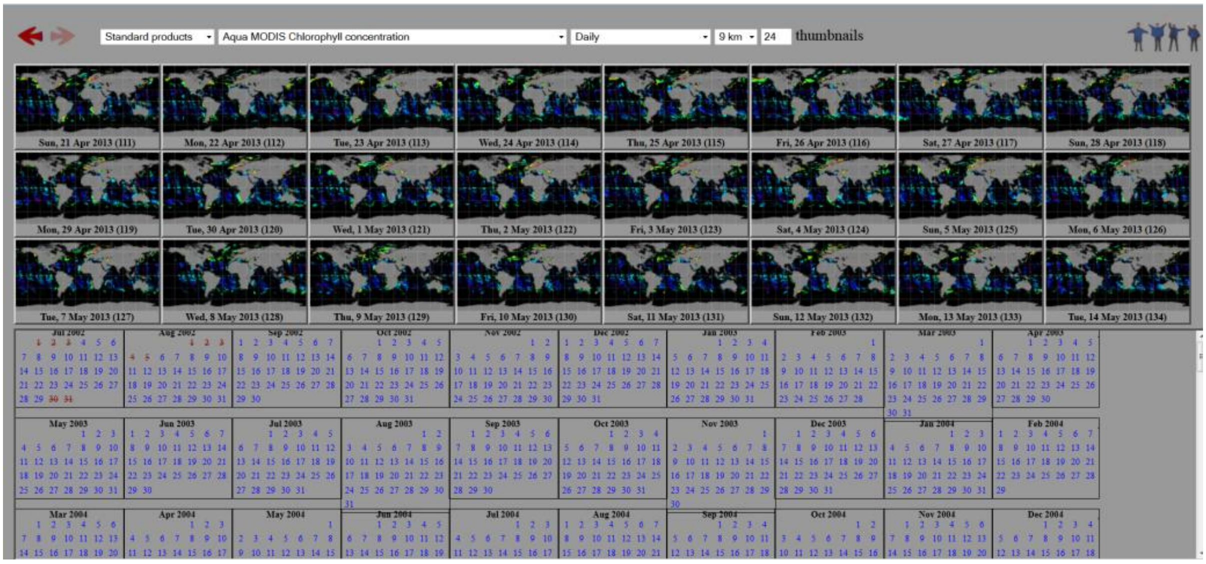
Normalized Fluorescence Line Height (nflh)

The interface to access to level 1 and level 2 is shown in the following figure:

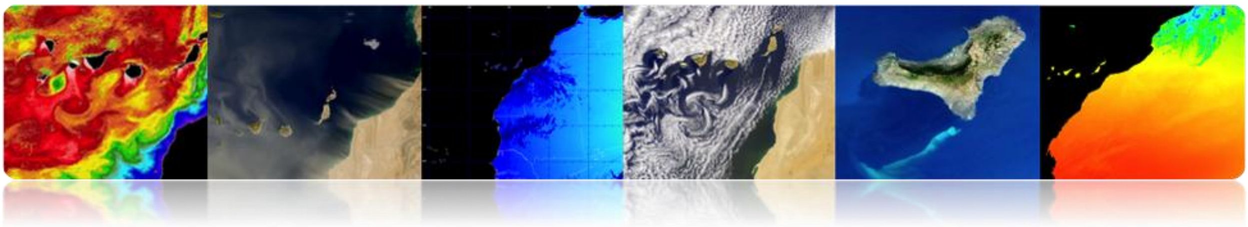


The access link is: http://oceancolor.gsfc.nasa.gov/cgi/browse.pl?sen=am

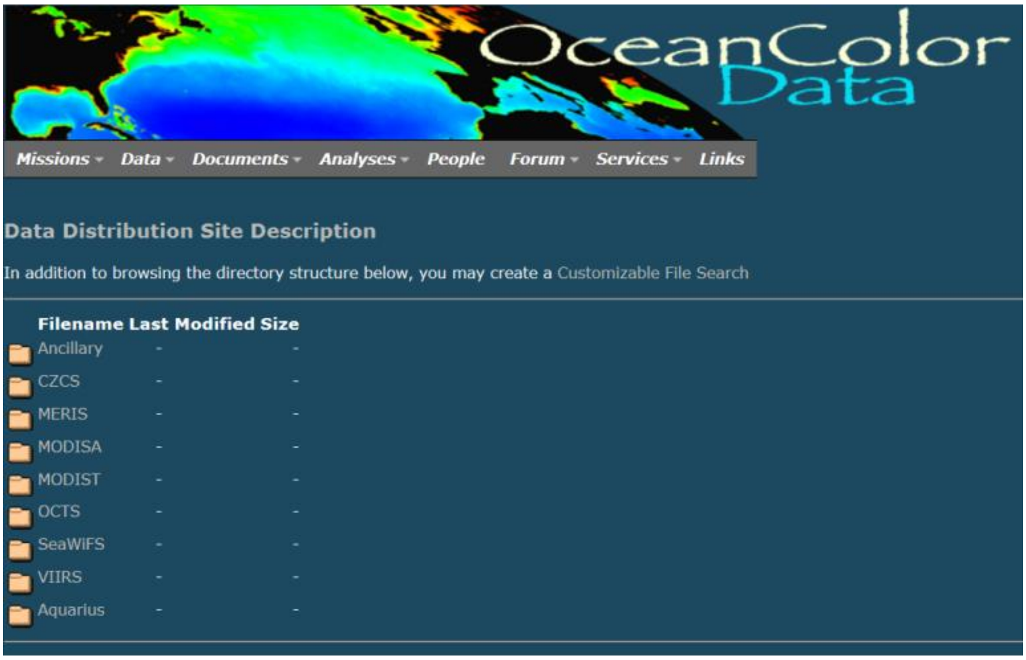
Here you are the Interface to L3 data:



The access link is: http://oceancolor.gsfc.nasa.gov/cgi/l3?per=DAY

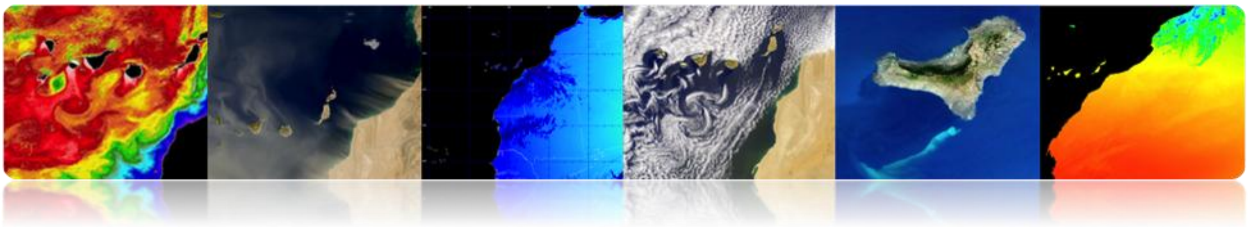


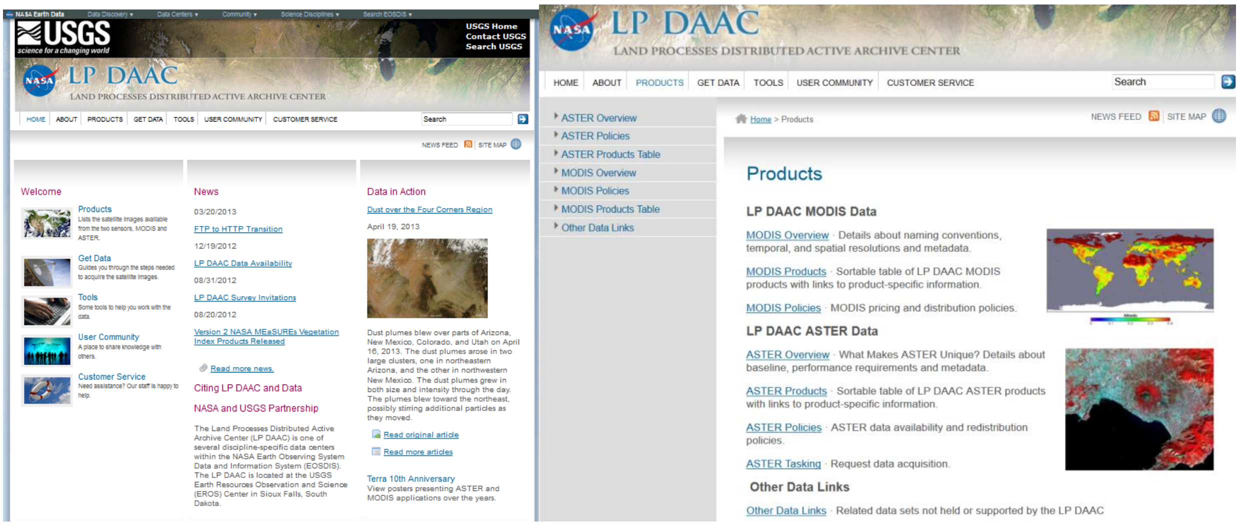
It also allows downloading data via http (http://oceandata.sci.gsfc.nasa.gov/)



❑ LPDAAC (Land Processes Distributed Active Archive Center)

LPDAAC belongs to the Data Information System (EOSDIS) from NASA's Earth Observing System (EOS). It is responsible for processing, storing and distributing data and land information products from ASTER and MODIS sensors onboard the Terra satellite, and MODIS onboard Aqua satellite. The following figure shows the web and, on the right side, the products available.





The most characteristic land parameters that can be downloaded from the web are:

Vegetation Indixes

Thermal Anomalies & Fire

Surface Reflectance Bands

Land Surface Temperature

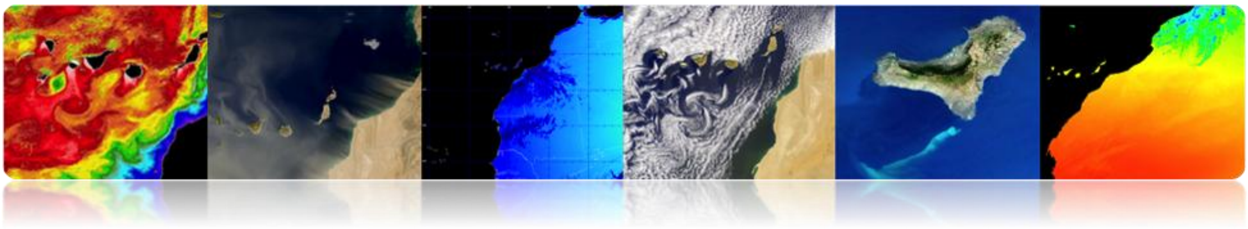
Land Cover Type

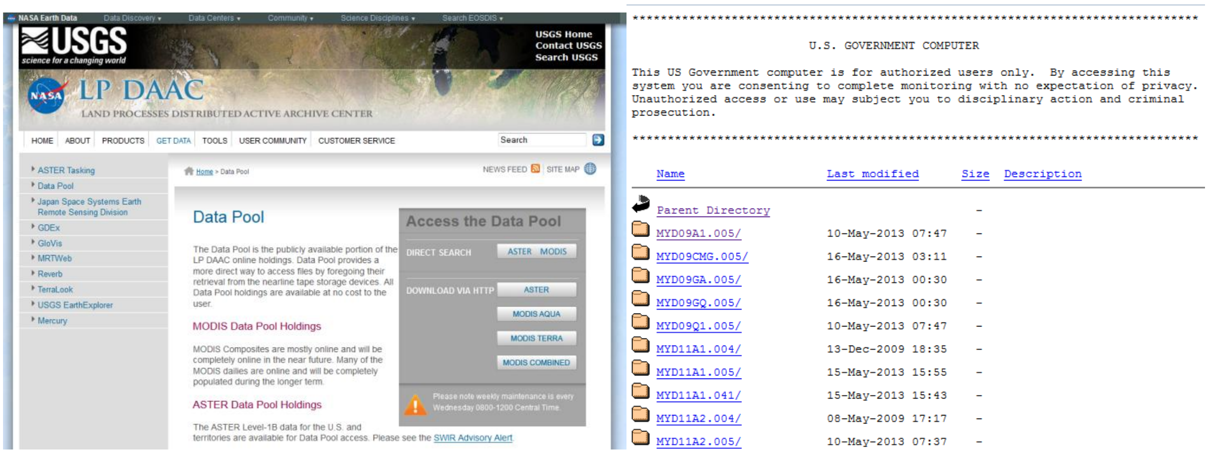
In the following link, you can obtain further details of these products.

https://lpdaac.usgs.gov/products/modis_products_table

Data can be downloaded for free from various media:

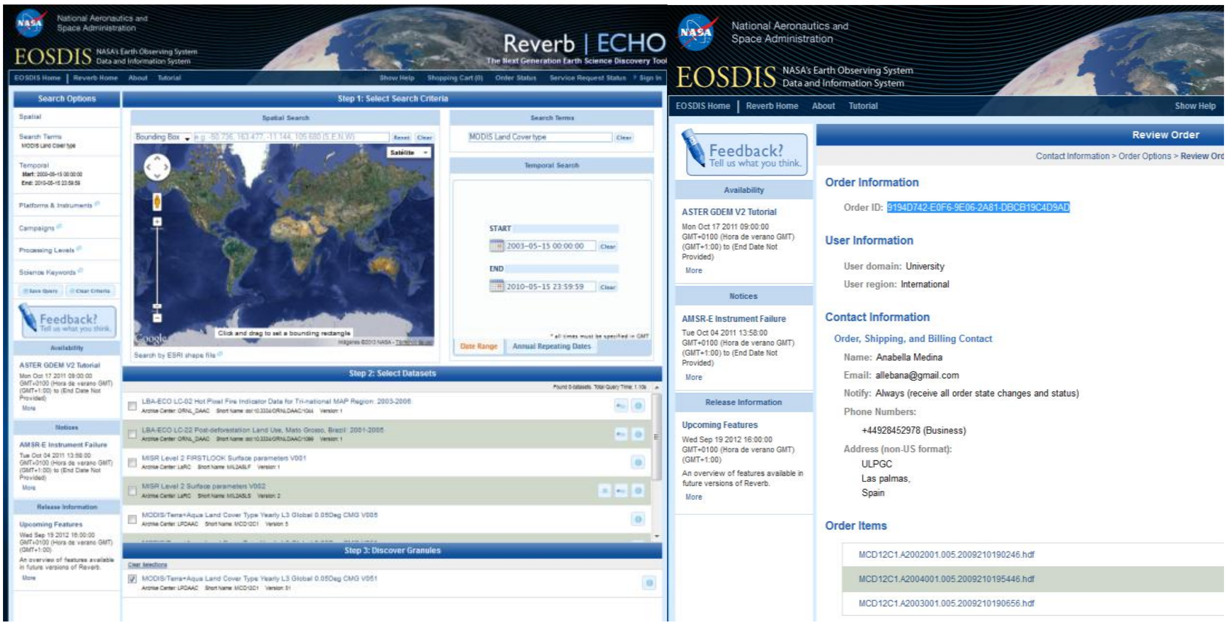
Data Pool is a data file that provides direct access to the products via ftp. The next figure shows two screen shots.

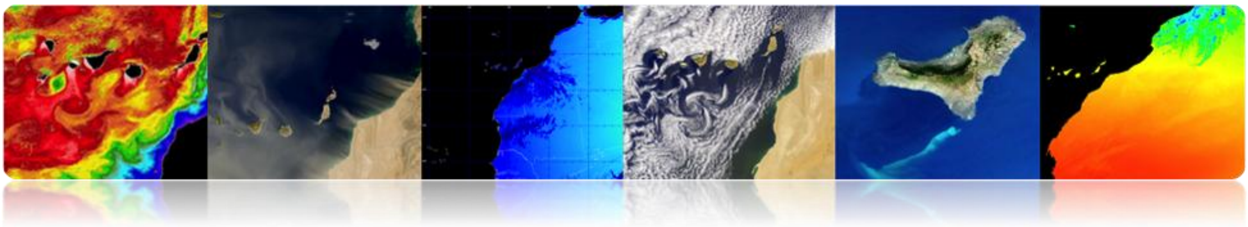




And the access link is: https://lpdaac.usgs.gov/get_data/data_pool

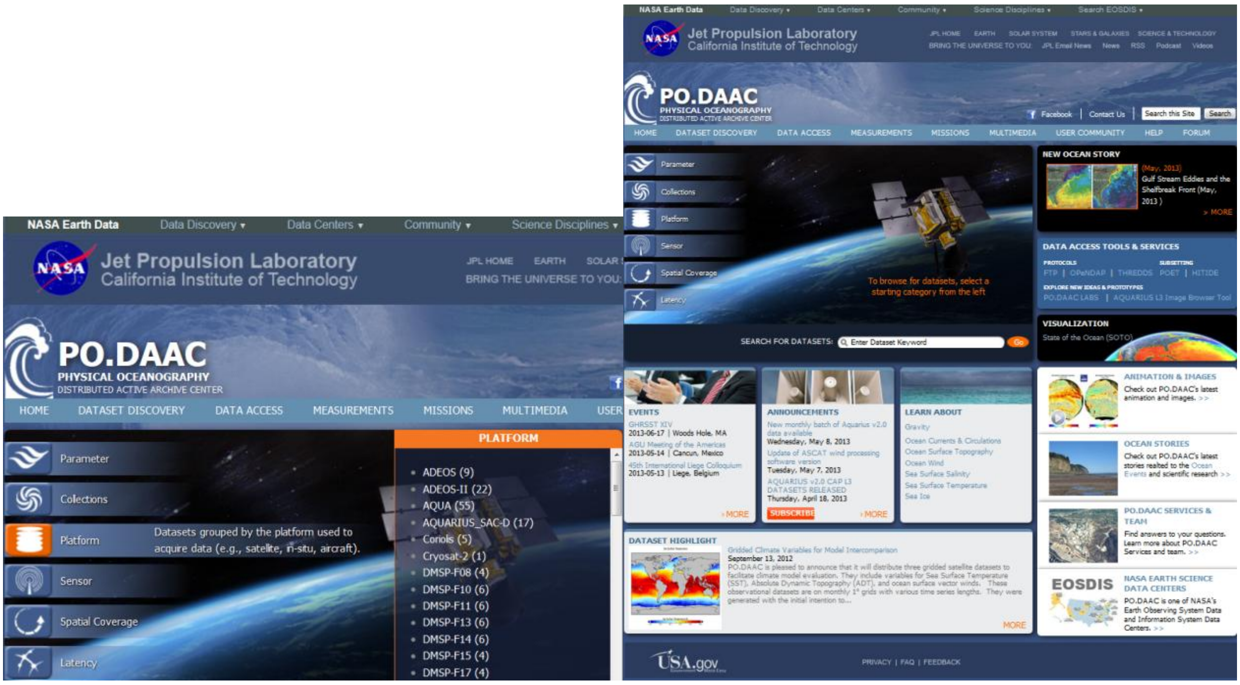
Reverberation is a tool that provides a web interface to centrally access to a complete Earth observation product database. It presents an attractive interface which, once completed the search criteria, a product is requested, which once processed can access, previous an email notice, to an ftp server for downloading it. The figure below shows how it looks. Furthermore, on the right image you can see information about the order placed.





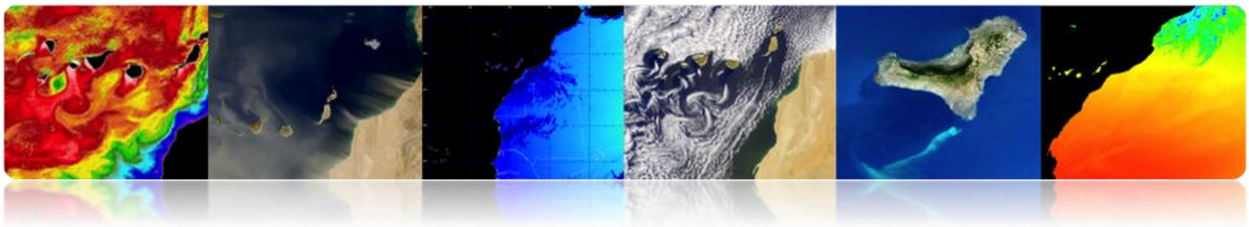
❑ PO.DAAC *(Physical Oceanography Distributed Active Archive Center)*

It belongs to the Data and Information System, EOSDIS Observing System from NASA's Earth Observing System (EOS). It is responsible for processing, storing and distributing ocean and climatic data from many satellites such as ADEOS, Aqua, AQUARIUS, Coriolis, Cryosat-2, DMSP, ENVISAT, ERS-1, GEOS-3, GFO, GOES, GRACE, GTS, ICOADS, JASON, METOP, MSG, MTSAT1R, NIMBUS, NOAA, Oceansat-2, QUIKSCAT, Terra, Topex / Poseidon and TRMM. Here we are an example of this web.

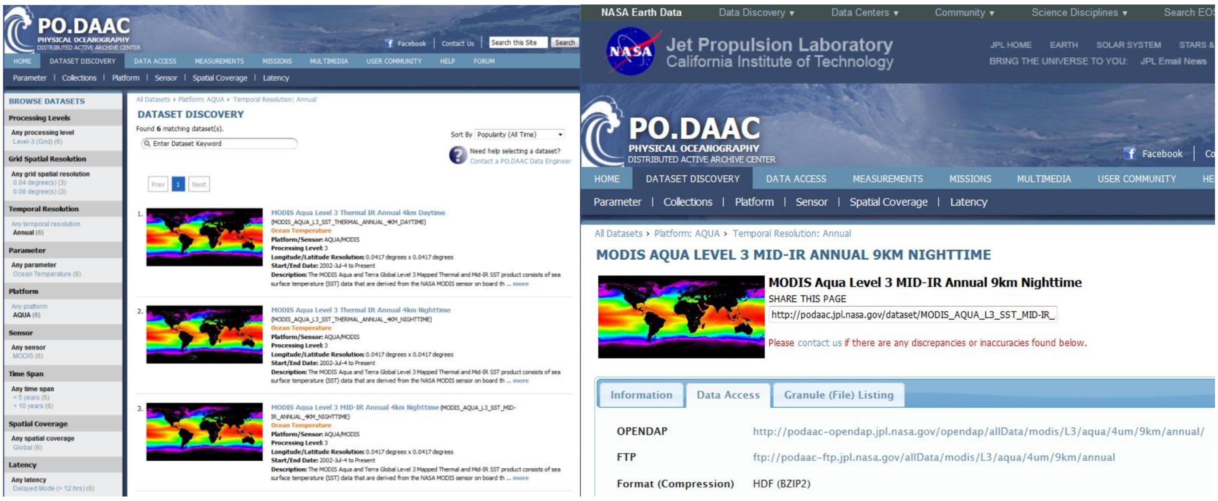


The main parameters that are responsible for processing in this center are:

- *Ocean Surface Topography (OST)*
- *Sea Surface Temperature (SST)*
- *Ocean Winds*
- *Sea Surface Salinity (SSS)*
- *Gravity*
- *Ocean Circulation*
- *Sea ice*



In this case, the data can also be downloaded from different media. The options are set once the parameter of interest is chosen:

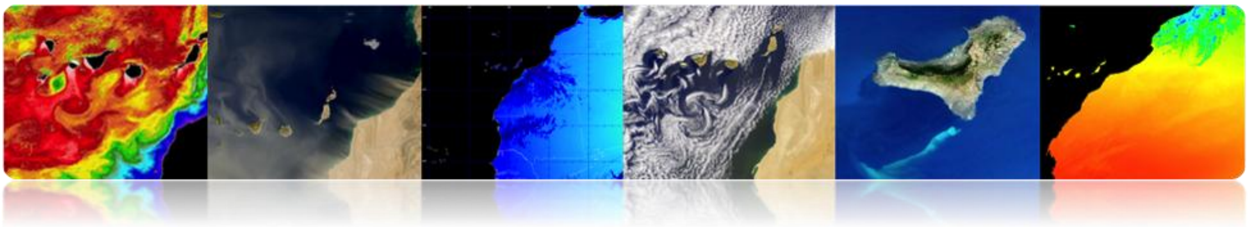


It also allows downloading data via direct access to ftp, as shown in the following figure.

Índice de ftp://podaac-ftp.jpl.nasa.gov/

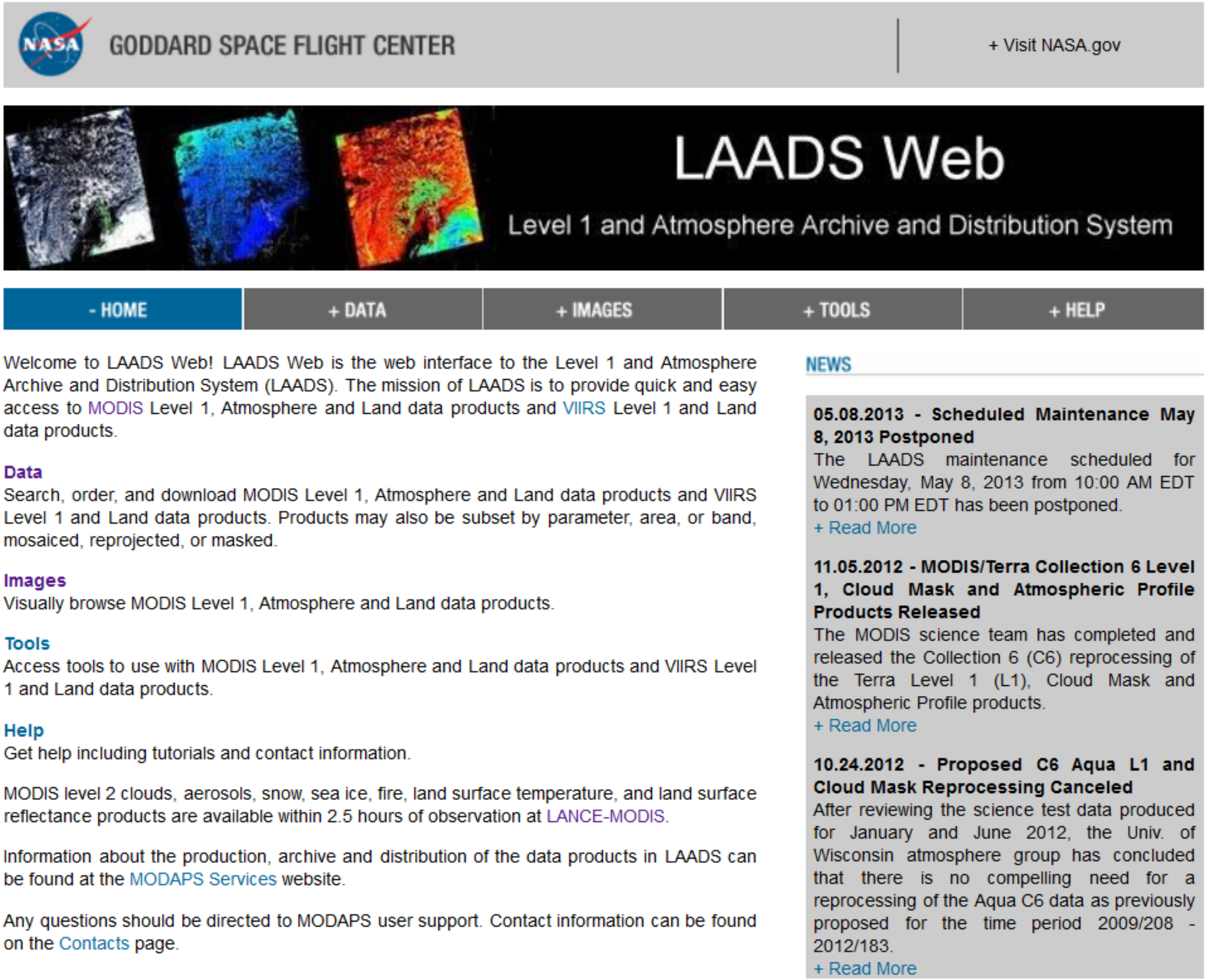
Subir al directorio superior.

Nombre	Tamaño	Última modificación	
GeodeticsGravity		28/07/2011	0:00:00
OceanCirculation		28/07/2011	0:00:00
OceanTemperature		06/09/2012	0:00:00
OceanWinds		17/02/2013	9:08:00
README	2 KB	25/10/2011	0:00:00
README.txt	1 KB	25/10/2011	0:00:00
SalinityDensity		28/07/2011	0:00:00
SeaIce		30/11/2012	11:06:00
SeaSurfaceTopography		07/05/2013	13:50:00
allData		15/03/2013	9:55:00
misc		19/10/2012	0:00:00

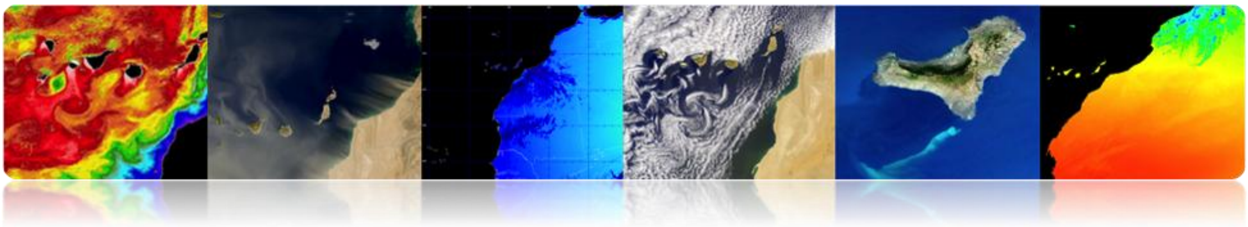


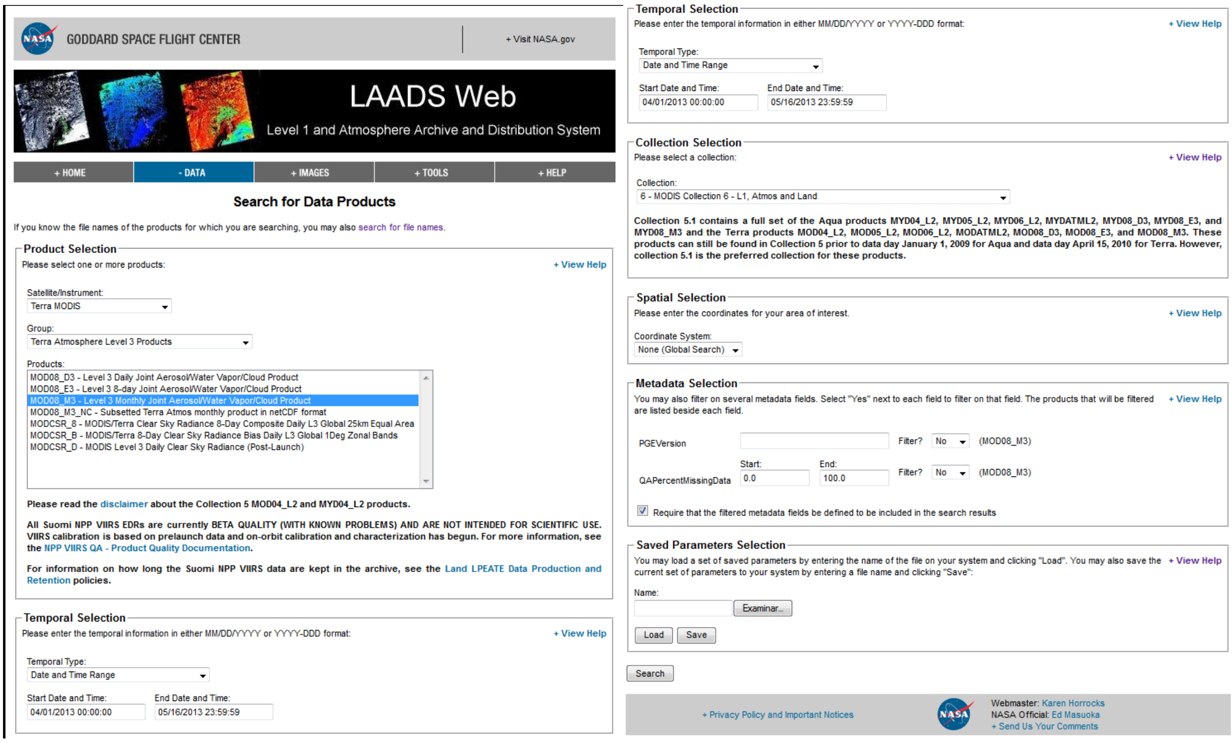
❑ LAADS (Level1 and Atmosphere Archive and Distribution System)

It belongs to the Data and Information System, EOSDIS from NASA's Earth Observing System (EOS). It is responsible for processing, storing and distributing atmospheric and terrestrial products from MODIS and VIIRS sensor.

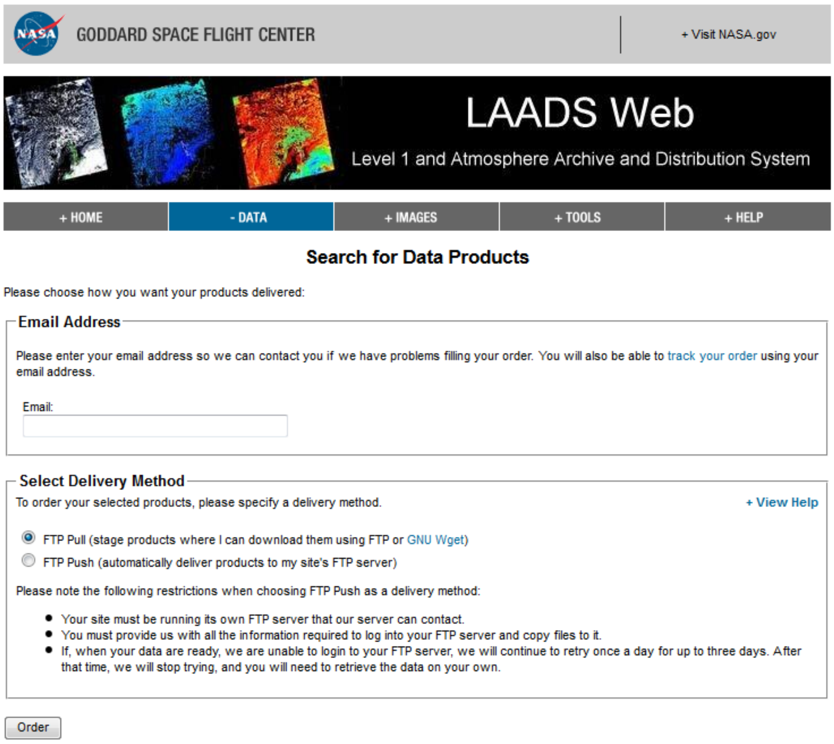


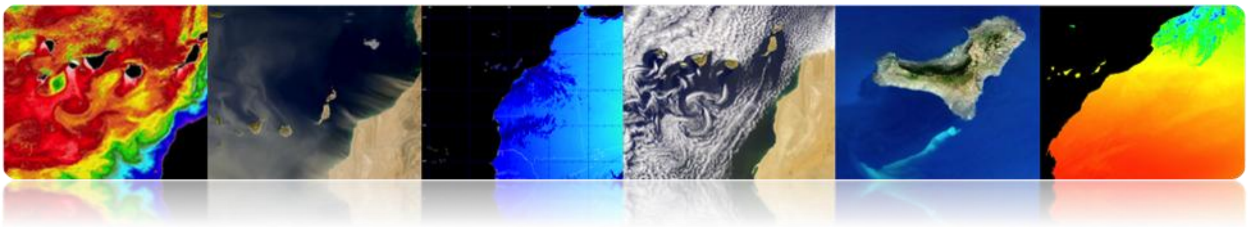
A form indicating the searching criteria has to be filled out previously to download the data.

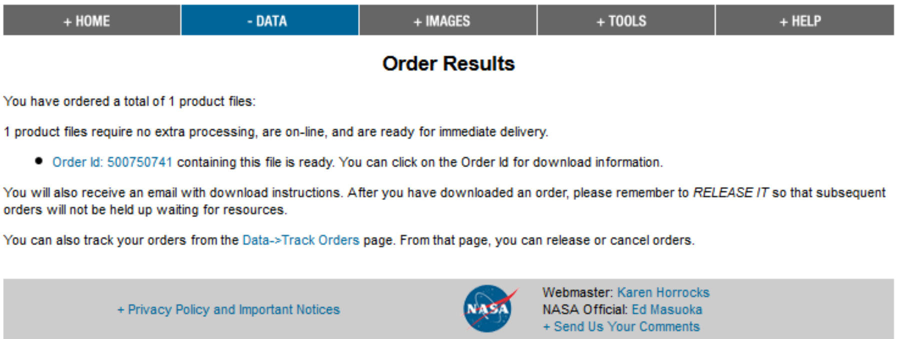




Then the order is placed and the product ordered, as it is shown in the following figure.







+ HOME | - DATA | + IMAGES | + TOOLS | + HELP

Order Results

You have ordered a total of 1 product files:

1 product files require no extra processing, are on-line, and are ready for immediate delivery.

- Order Id: 500750741 containing this file is ready. You can click on the Order Id for download information.

You will also receive an email with download instructions. After you have downloaded an order, please remember to *RELEASE IT* so that subsequent orders will not be held up waiting for resources.

You can also track your orders from the Data->Track Orders page. From that page, you can release or cancel orders.

+ Privacy Policy and Important Notices

Webmaster: Karen Horrocks
NASA Official: Ed Masuoka
+ Send Us Your Comments

Finally, in order to download the product, we access with the order identification number, once they have sent it to us via e-mail confirming that is processed.

In any case, we can avoid all the previous process by accessing directly via ftp as it is shown in the next figure.

Índice de ftp://ladsweb.nascom.nasa.gov/

Subir al directorio superior.

Nombre	Tamaño	Última modificación	
LandSeaMask_DEM		31/12/1969	0:00:00
MAIAC		31/12/1969	0:00:00
MAS		31/12/1969	0:00:00
NetCDF		31/12/1969	0:00:00
README	32 KB	18/04/2013	14:33:00
allData		31/12/1969	0:00:00
datapool		31/12/1969	0:00:00
geoMeta		31/12/1969	0:00:00
orders		31/12/1969	0:00:00
subsets		31/12/1969	0:00:00

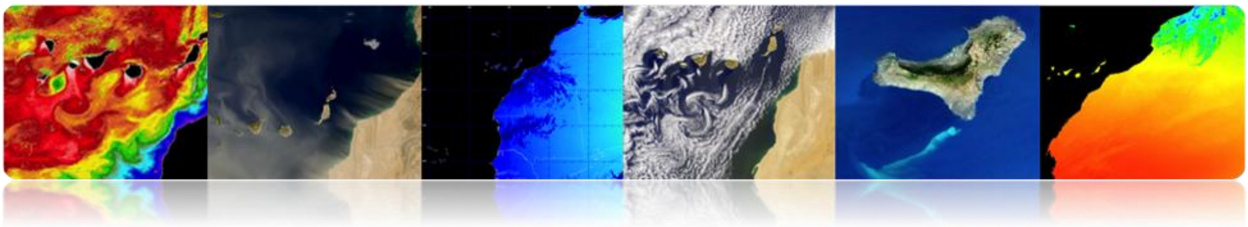
❑ EARTHEXPLORER

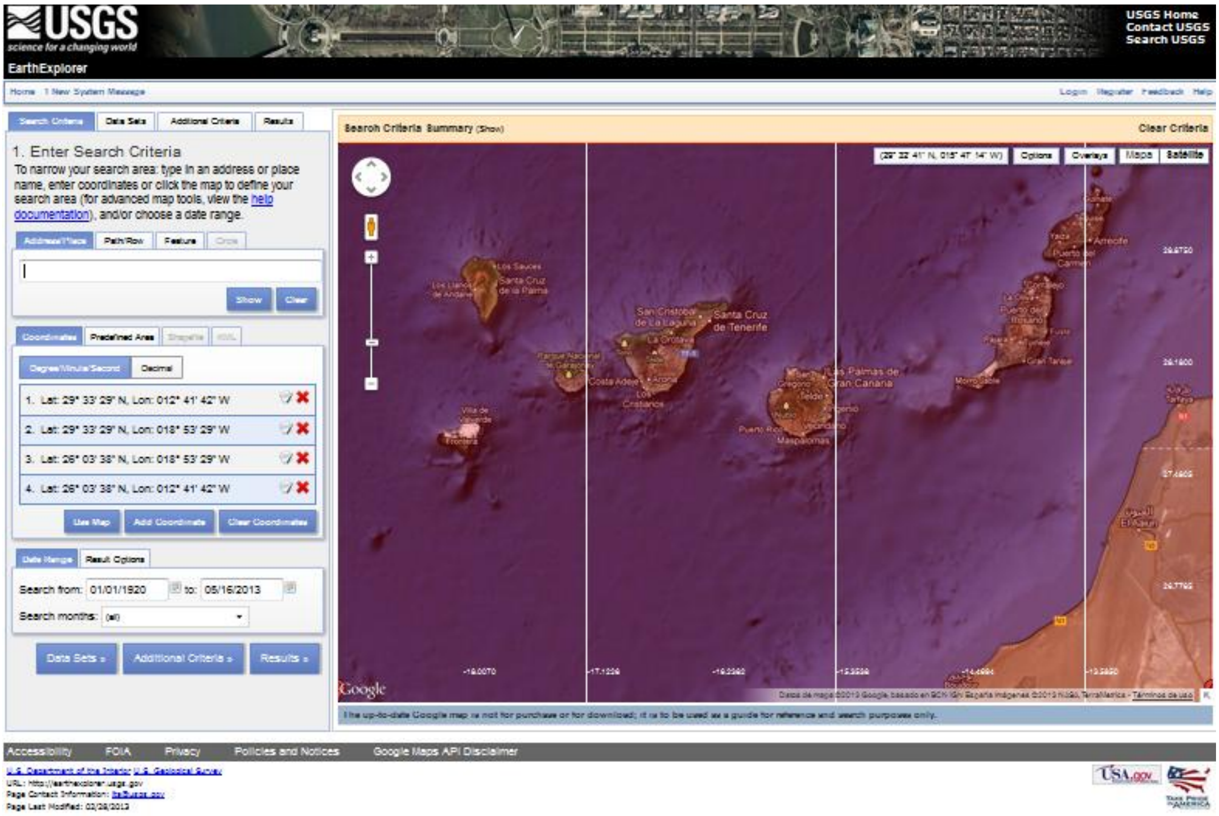
This tool provides an online search of different Earth observational data and to download data from U.S. Geological Survey (USGS). Most of them are free products, although sometimes you have to pay, if the product requires a priority processing. A dollar symbol ($) identifies these products. After selecting the area (used area), select Use Data Set Prefilter. The data that can be found are:

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)
AVHRR (Advanced Very High Resolution Radiometer)
Calibration / Validation Test Sites
Commercial Data Purchases (CDP) Imagery
Declassified Satellite Imagery - January
Global Land Survey (GLS)
Heat Capacity Mapping Mission (HCMM) Digital Source
EO-1 Advanced Land Imager (ALI) and Hyperion
Landsat 8 OLI (Operational Land Imager) and TIRs (Thermal Infrared Sensor) (will start publishing in May)
Landsat ETM + (Enhanced Thematic Mapper Plus)
Landsat MSS (Multispectral Scanner)
Landsat TM (Thematic Mapper)
Landsat TM (Thematic Mapper) Film Only
MODIS (Moderate Resolution Imaging Spectroradiometer) MRLC2001 (Multi-Resolution Land Characteristics 2001)
NLDC (NASA Landsat Data Collection)
OrbView-3

It can be accessed through the following link: USGS, http://earthexplorer.usgs.gov/

The interface features are shown in the following figure:

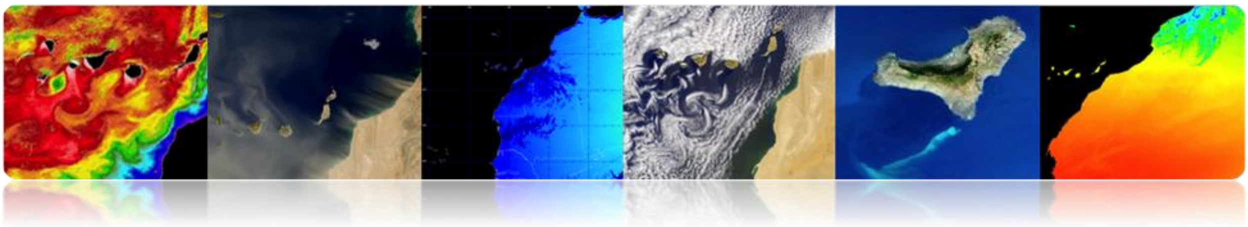


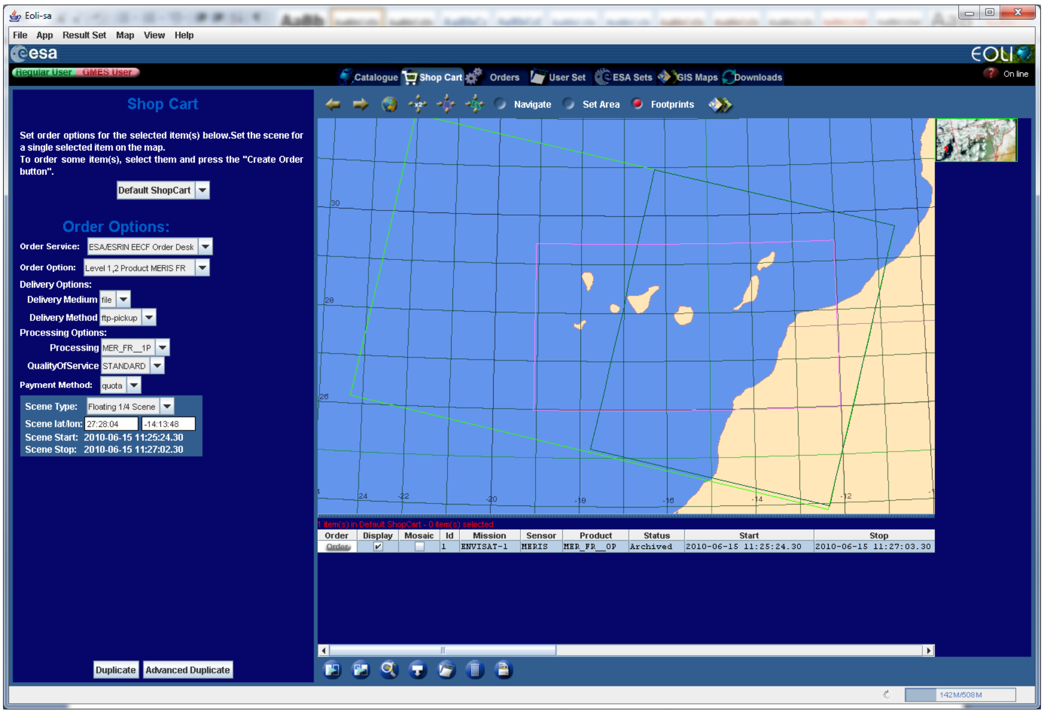


Finally, only registered users can download data. In the following link you can find a tutorial on using the interface:*http://earthexplorer.usgs.gov/documents/helptutorial.pdf*

❑ EOLI-SA

EOLI-SA (Earth Observation Link) is a desktop tool developed by the European Space Agency to access Earth Observation data catalog and to make the request for an order. Let us see this tool in the next figure:





The data accessible via EOLI-SA are:

ENVISAT (ASAR, MERIS, AATSR, MIPAS, SCIAMACHY, Radar Altimeter / MicroWave Radiometer)

ERS (Scenes SAR, SAR Wave Mode: FDC, Wind Scatterometer: FDC, Microwave Sounder, Altimeter,

Gome, Orbit Data)

PROBA (PROBA Chris)

LANDSAT (TM: RAW, SCAS; MSS: RAW, SCAS; RBV)

Terra / Aqua (L1B)

ESRB (SAR: PR1, GEC; VNIR: Level1, 2)

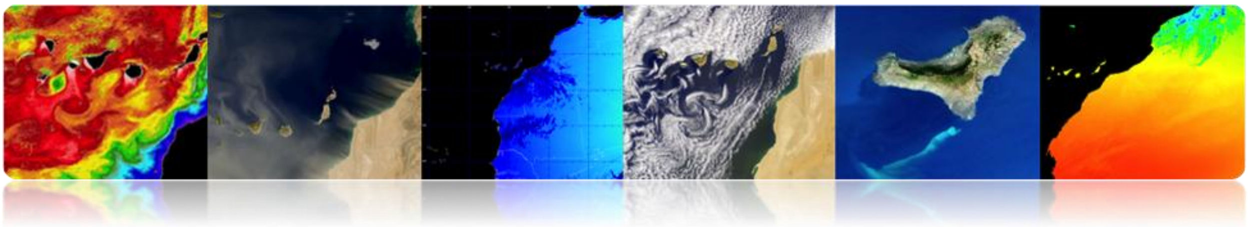
NOAA (AVHRR: SHARP 1B, 2A, 2B)

IRS (MOS: L1B)

SeaStar(SEAWIFS: L1A, L1B, L2A, L2B, L2C)

Nimbus(CZCS: L1, L2)

This tool can be downloaded at: http://earth.esa.int/EOLi/EOLi.html.



You can find more detailed information at:

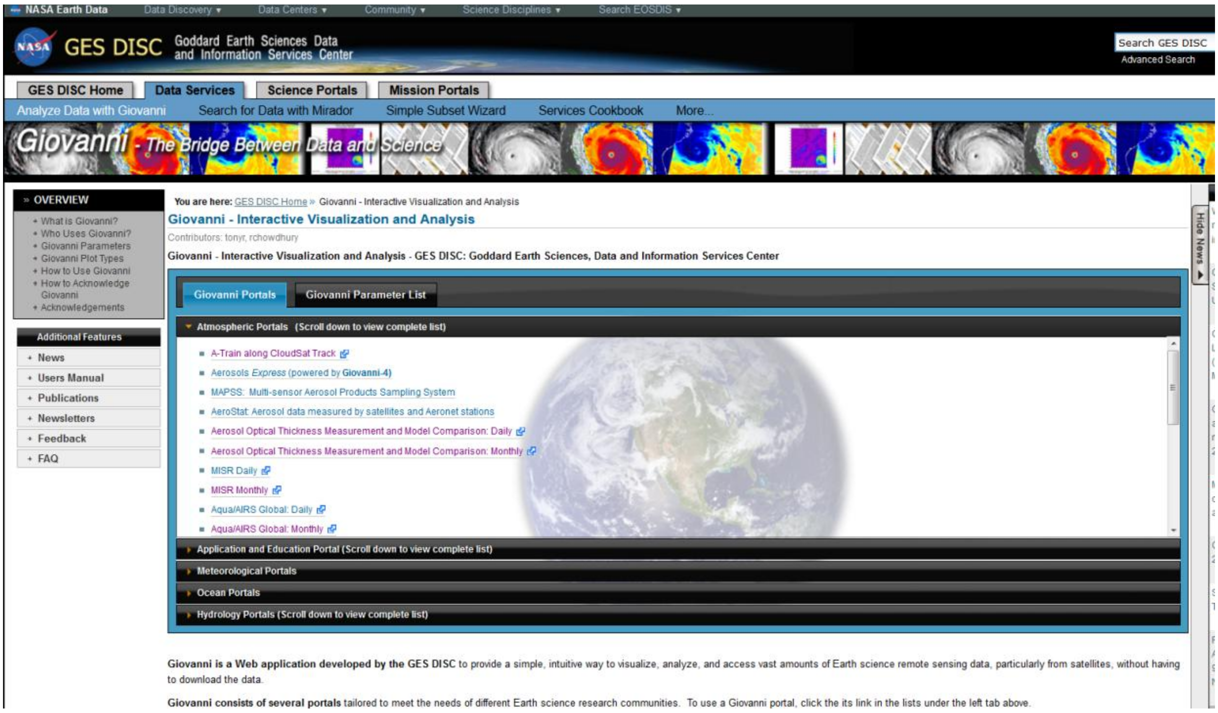
http://earth.esa.int/EOLIResources/Manual/html/ChapCatalogueWorkSpace.html

The following link shows the free data offered:

https://earth.esa.int/pi/esa?type=file&table=aotarget&cmd=image&id=520

❑ GIOVANNI

It is a web application developed by NASA to visualize, analyze and access remote sensing data from different databases. Giovanni is an acronym for GES-DISC (Goddard Earth Sciences Data and Information Services Center Interactive Online Visualization and Analysis Infrastructure). In the center of the main screen, data are classified by web sites. Each of these web pages has a variety of parameters from different sensors.



There are many web sites within each of the following categories:

- *Atmospheric Web sites*
- *Applications and Education Web site*
- *Meteorological Web site*
- *Ocean Web sites*
- *Hydrology Web sites*

In the following link, you can see a complete list of available geophysical parameters:

http://disc.sci.gsfc.nasa.gov/giovanni/additional/users-manual/G3_manual_Chapter_2_parameters.shtml

On the other hand, Giovanni has different types of representations:

Animation

Anomaly

Plot Area Lat-Lon, Time-averaged

Lat-Lon Plot, Difference Map

Latitude-Time Hovmøller Plot

Longitude-Time Hovmøller Plot

Correlation Plot

Comparison Plot

Plot Cross-Map (Latitude-Pressure)

Cross-Map Plot (Longitude-Pressure)

Cross-Map Plot (Time-Pressure)

Scatter Plot

Scatter Plot, Time-averaged

Curtain Plot

Time Series, Area-averaged

Time Series Difference

Time Series, Area Statistics

Vertical Profile

Zonal Mean

Histogram

Histogram, Area-Averaged

Histogram, Time-Averaged

The most common representations are:

Anomaly: it is calculated for a selected time period. It can be represented as a map of latitude/longitude or as a time series. It measures the difference of each value from the mean value in normal conditions.

Lat-Lon Area Plot Time-averaged: It obtains the mean value for each cell that belongs to the area selected by the user and it is represented in a 2D color map.

Lat-Lon Plot Difference Map: It performs a representation of the difference of two parameters or two different databases in a parameter. It is represented as a time series, where an axis shows the value in the other geophysical time.

Latitude-Time Hovmøller Plot and Longitude-Time Hovmøller Plot: Hovmøller maps -latitude versus longitude or longitude versus time- represent a longitudinal variation of a parameter versus time or a latitudinal variation versus time. They allow 2D representations of the changes occurred in one particular region during a given interval of time.

Scatter Plot or Scatter Plot Time-averaged: It is an XY representation of two different parameters. Temporal range is selected, and for each cell a mean value of X and Y are represented.

Time Series Area-averaged: It is a unique representation of the mean values of a parameter in a total area defined along a period of time.

Difference Time-Series: It similar to the previous one, but it represents the difference value between two parameters.

Once the web site is selected, the general procedure to follow to obtain the representation of a chosen parameter is:

1. Select the area of interest, indicating the latitude and longitude or select it graphically.
2. Start date/end date of the period under study.
3. Choose the parameter of interest.
4. Set the representation preferences.
5. Select the analysis you want to perform.
6. Download the data in the desired format.

- ## Practical examples

Example 1. Representation of a Chlorophyll Concentration map

Ocean web sites -> Water Quality Monthly Data

Example 2. Representation of a time series of chlorophyll concentration between 2001 and 2010

Ocean web sites -> Water Quality Monthly Data

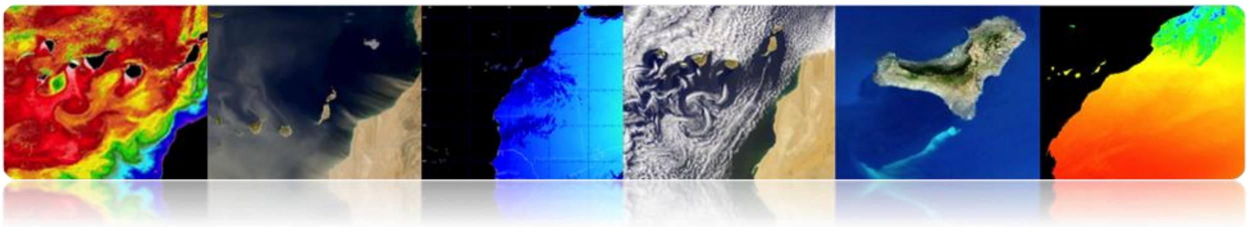
Example 3. Representation of a SST day and night difference map for February 2001-February 2010

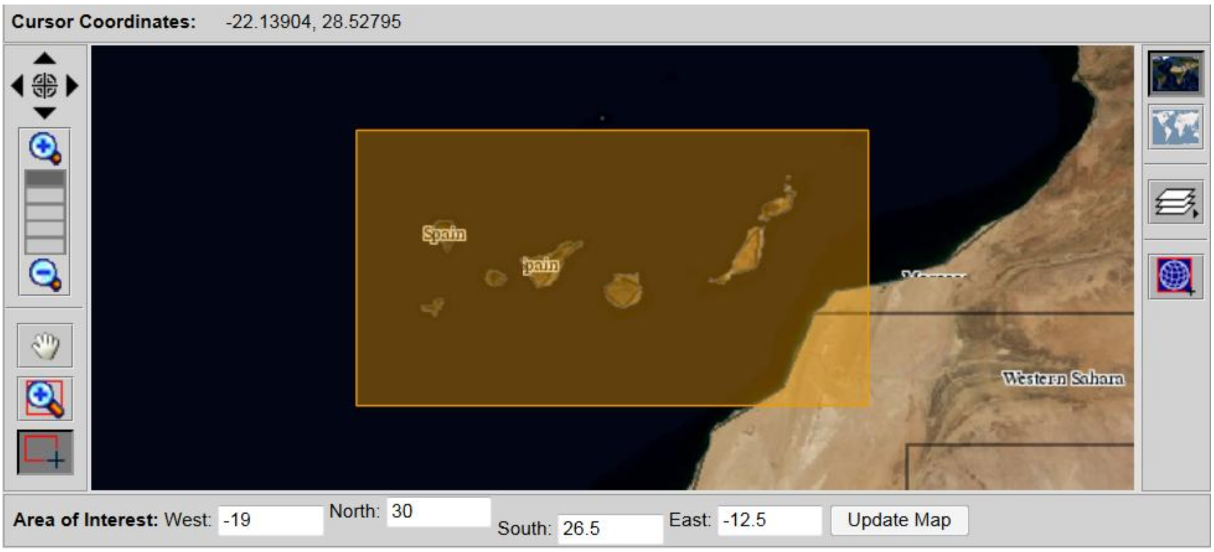
Ocean web sites -> Ocean color radiometry Online Visualization and Analysis

Example 4. Hovmøller night SST4 latitude and longitude graphic for 2001-February 2012

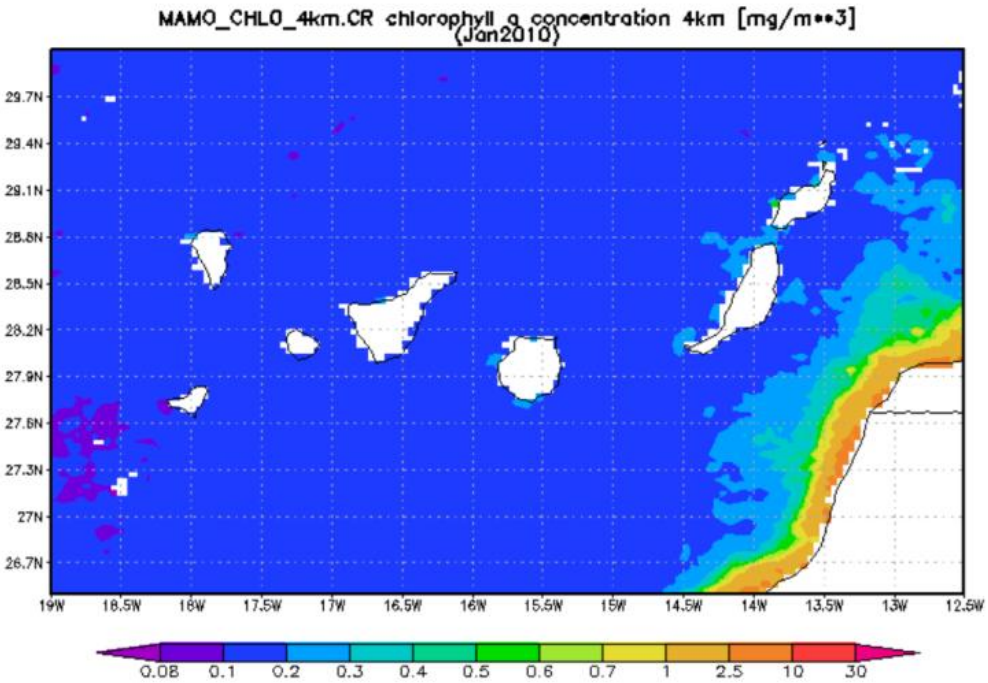
Ocean web sites -> Ocean color radiometry Online Visualization and Analysis

For different cases you can select the next area of study:

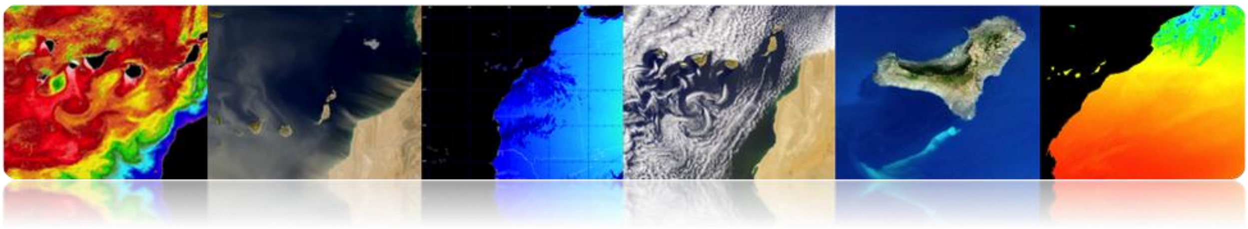




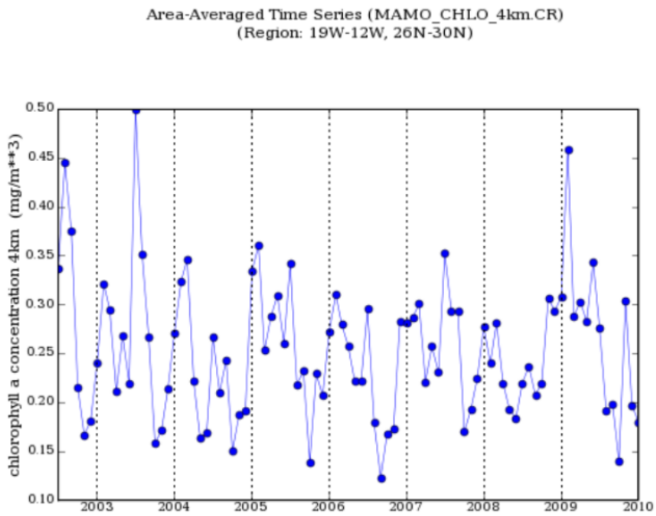
Practical Example 1



Chlorophyll concentration map, Lat-Lon map, Time-averaged.

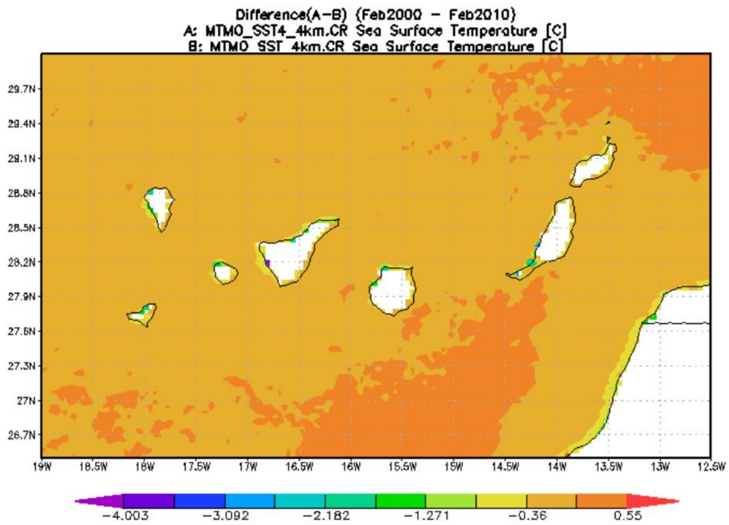


Practical Example 2

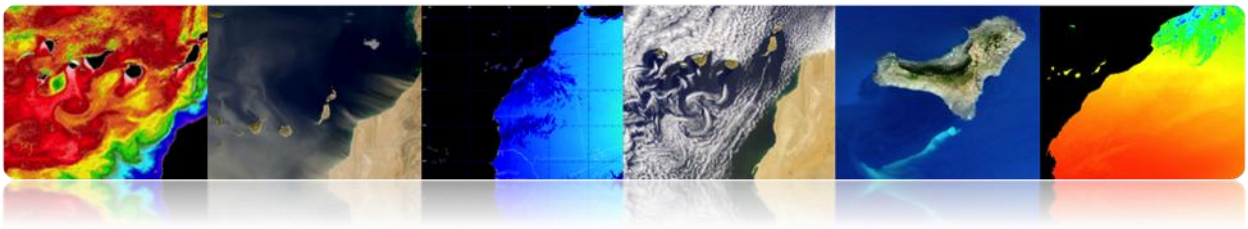


Average value of chlorophyll concentration time series (2001-2010)

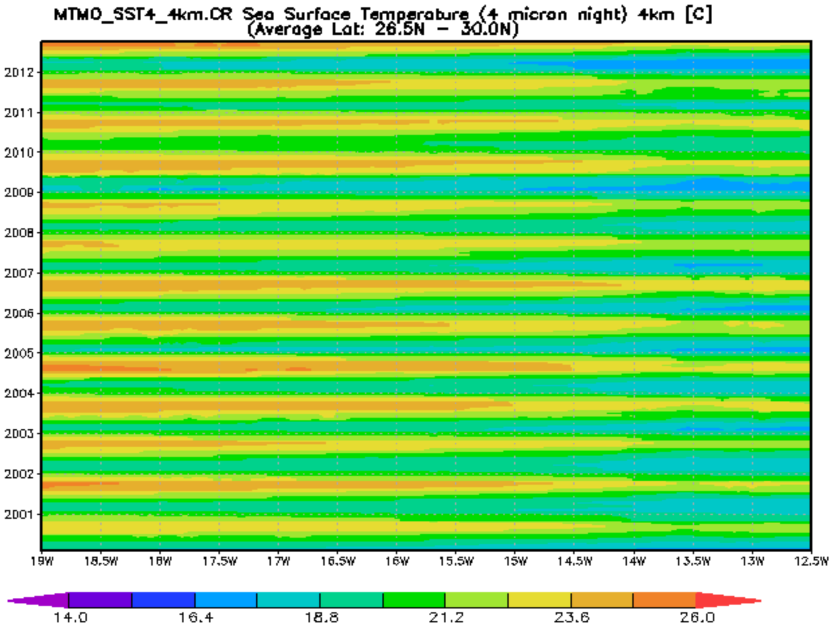
Practical Example 3

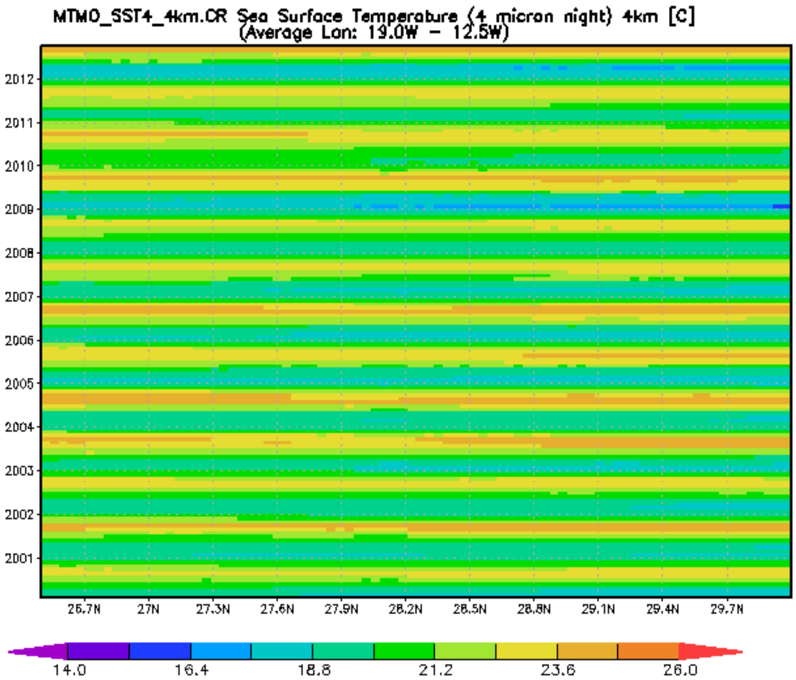


Lat-lon map of time-averaged diferencias

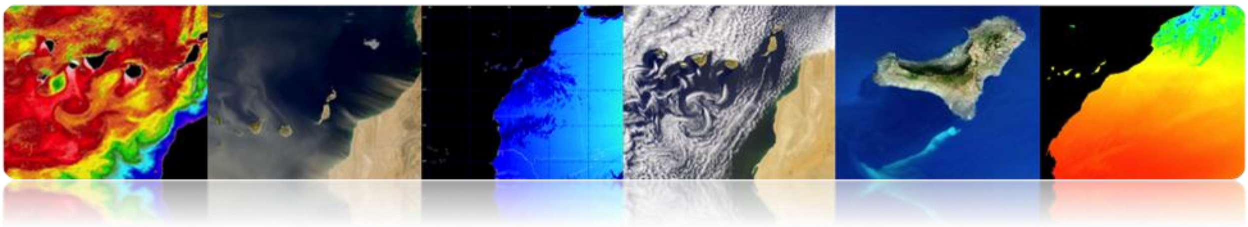


Practical Example 4



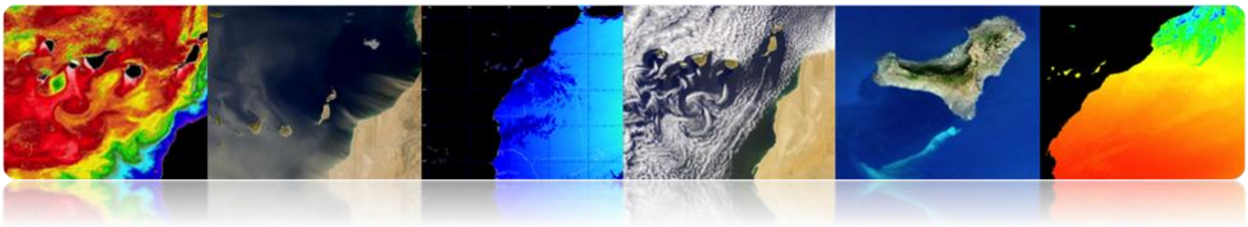


Hovmøller Graphics latitude and longitude



CONTENTS

REMOTE SENSING IMAGE PROCESSING TOOLS.



2.1. Introduction

The information collected by remote sensing sensors is processed and analyzed using software programs known as remote sensing processing tools.

There are a number of open source programs and many other payment programs to process this kind of information. Next, we present the most widely used tools for remote sensing image processing. In addition, an information summary of every tool’s main features is included.

❑ Commercial tools

ENVI: Program focused on the processing and analysis of images of all kinds. It is quite flexible reading formats and is very friendly for users. Made with IDL language, allows incorporating additional modules.

ERDAS: It is probably the largest commercial deployment program, being a standard for interchange formats, especially with GIS. It is available for a wide variety of platforms. It can be programmed using the Model Maker.

ESRI: ArcGIS is a suite of GIS products. It is grouped up into several applications for capturing, editing, analysis, processing, designing, printing and publishing geographic information. ArcGIS Desktop family of desktop GIS applications is one of the most widely used, including ArcReader, ArcMap, ArcCatalog, ArcToolbox, ArcScene and ArcGlobe, and various extensions.

Idrisi: It is a tool that incorporates many digital image analysis utilities. Due to its low price, it has been used extensively in remote sensing teaching. It has been developed by Clark University (USA).

E-Cognition: Program that incorporates multiple aspects of context analysis and mathematical morphology. It is ideal for spatial pattern recognition.

ER-Mapper: Australian program that collects most of the common features in remote sensing, being quite efficient in managing bulky images by incorporating innovative systems and virtual algorithms compression.

PCI-Geomatica: New version of the popular PCI Canadian program, in a scheme that incorporates more packages integrating its digital image analysis, orthorectification, map production and GIS. It provides quite powerful analysis tools, thanks to its close connection to the Remote Sensing Canadian Center. You can use a limited demo version, called Freeview.

DRAGON: Low Cost Program in Windows environment for digital image analysis. It is very appropriate for an educational setting.

Miramon: GIS and remote sensing program developed by the CREF of Barcelona University. It is a low cost program with wide functionalities.

❑ FREE TOOLS

Grass: Program focused on GIS and image processing. It has been developed by UNIX, on different platforms, but recently Linux and Windows (WinGRASS) versions have been created. It was initially developed as a military tool for the U.S. Army. NASA, NOAA, USGS, etc. are the organizations that use it among others.

Orfeo, Monteverdi: OrfeoToolbox (OTB) is a library of remote sensing image processing developed by CNES in 2006 with the aim of facilitating the use of images from different sensors. In particular, Orpheus constellation (Pleiades and Cosmo-SkyMed). Monteverdi is the most robust and operational version.

SeaDAS: NASA software tool for visualization, processing and analysis of images of ocean color sensors. It supports the main missions of NASA and, recently, ESA missions.

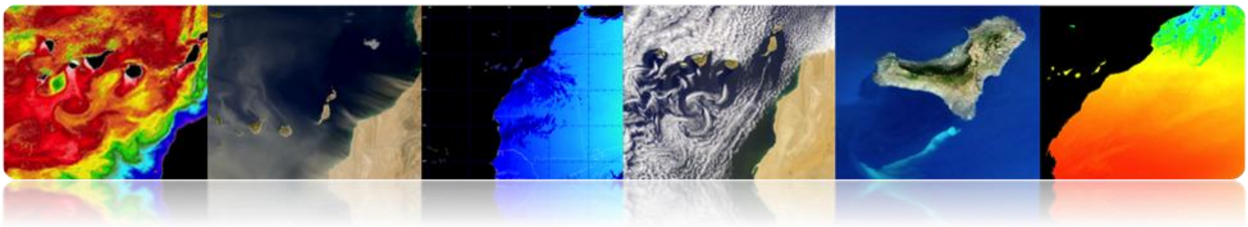
Multispec: Program developed by the University of Purdue, a pioneer in the 70s. It is very appropriate for the learning environment, since it only has a few hardware requirements. There is also a new version for 32-bit (32-bit version).

SPRING: Program developed by INPE (Brazil National Institute for Space Research). It has an extensive list of features, but it is primarily oriented towards the GIS environment. There are versions in Portuguese, English and Spanish.

Next, an introduction to various remote sensing image processing tools is presented. As free software applications, Monteverdi [*http://www.orfeo-toolbox.org/otb/monteverdi.html*] and SeaDAS [*http://seadas.gsfc.nasa.gov/*] have been selected. We also describe one of the most common commercial software in the field of remote sensing, ENVI [*http://www.exelisvis.com/ProductsServices/ENVI/ENVI.aspx*]. We will start by describing the main features of Monteverdi, a non-experts' software, to finish with the advanced users' ENVI application. We will also include SeaDAS, software historically linked to the processing of oceanographic images from NASA, and in its new version 7 it provides a lot of utilities in a new and intuitive graphical interface available for Windows.

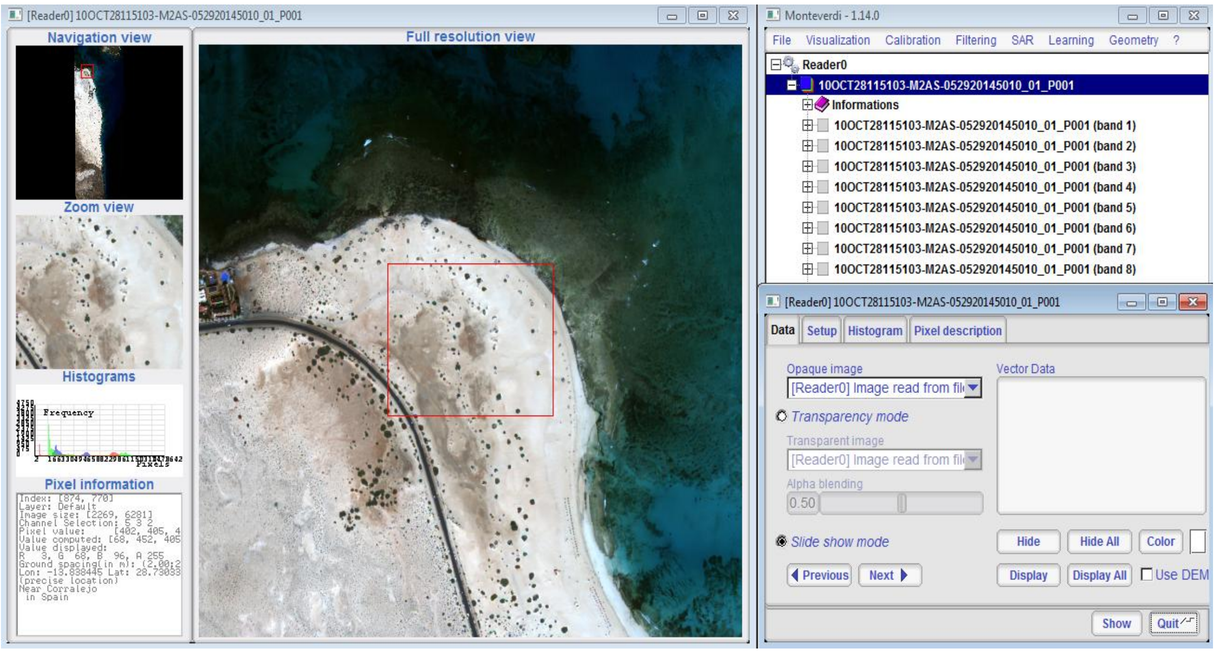
2.2. MONTEVERDI

Monteverdi is a computer application sponsored among others by the French Space Agency (CNES). It is a graphical program based on ITK and OTB libraries (Orfeo Toolbox) that provides tools for remote sensing image processing. OTB is distributed as an open source allowing full access to the algorithms used in the library. In addition to basic utilities, it allows the processing of high-resolution images such as SPOT, Quikbird, WorldView, Landsat, Ikonos, etc., and hyperspectral and radar images. This



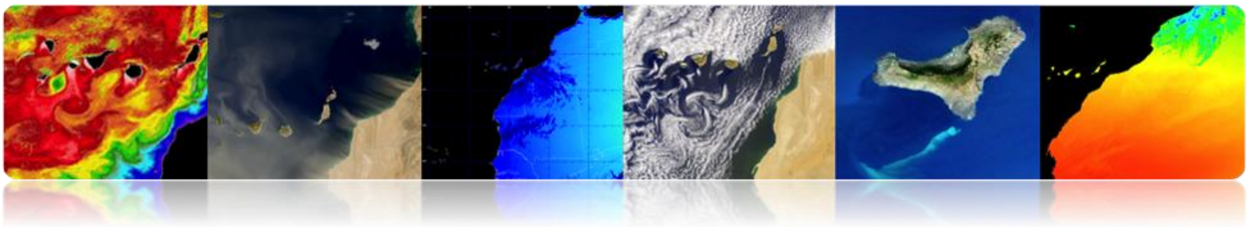
software is available for free for Linux, Unix and Windows. The latest stable version is 1.14, available for downloading at the following link:

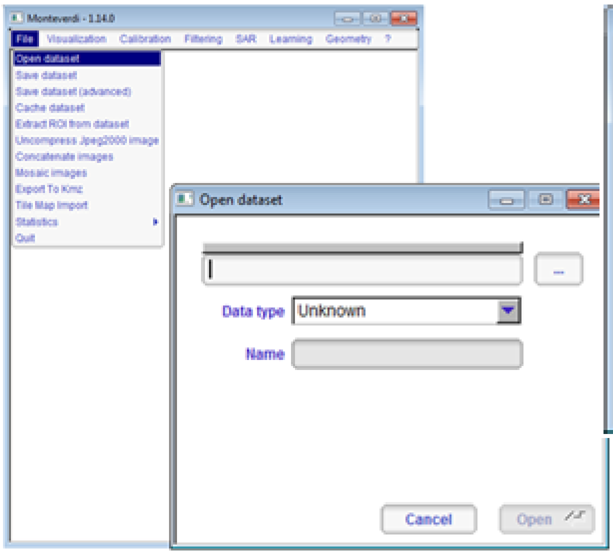
http://sourceforge.net/projects/orfeo-toolbox/files/Monteverdi/Monteverdi-1.14/Monteverdi-1.14.0-win32.exe/download

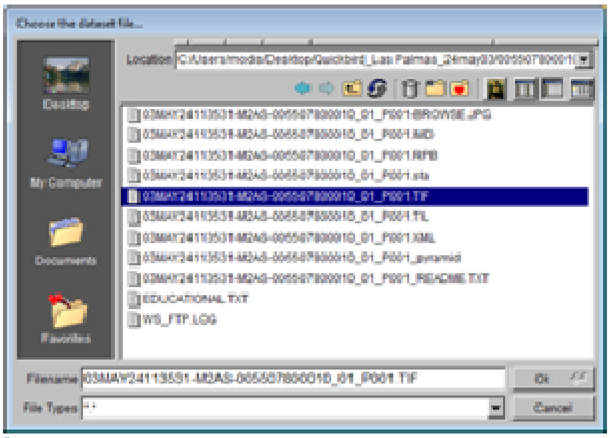


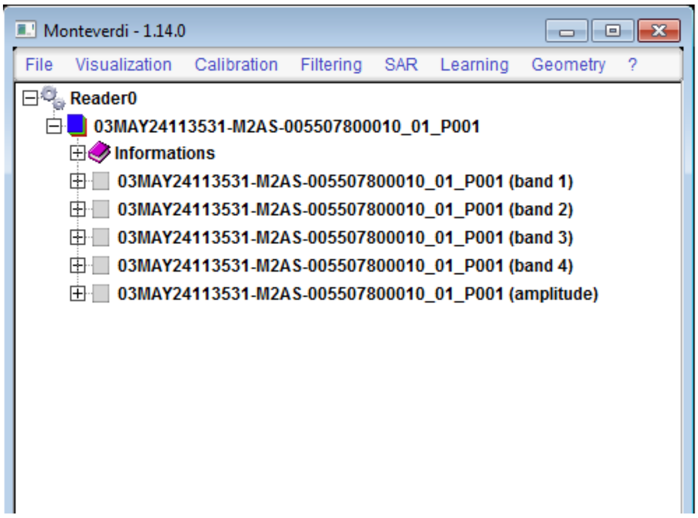
❑ MONTEVERDI BASICS

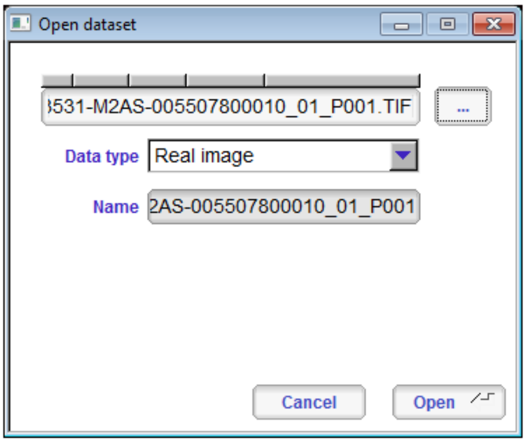
Monteverdi is a user-friendly graphical program for users with little knowledge in remote sensing. It allows using the principal image formats, as well as the use of some kinds of vector data. The figure shows an image loaded in the program. At the top of the interface menu under "File"→ "Open Dataset" menu, you can access a selection of image/vector to be loaded. After selecting the data, Monteverdi recognizes its type, and by pressing "open", the data is available in the main program interface.



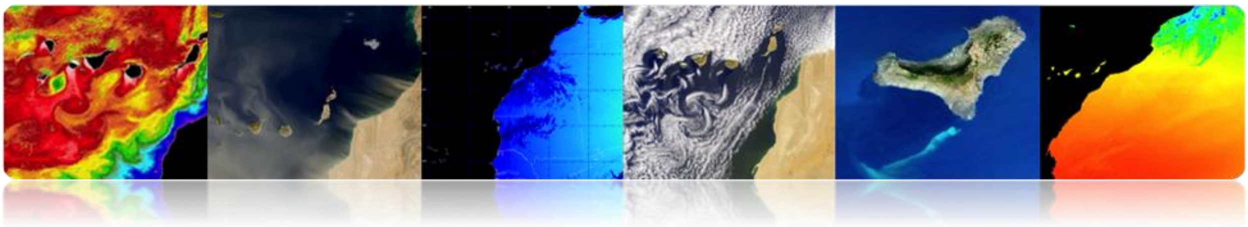


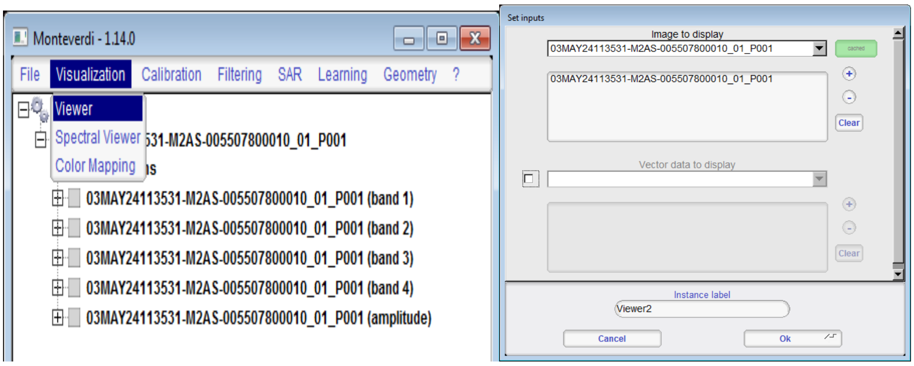


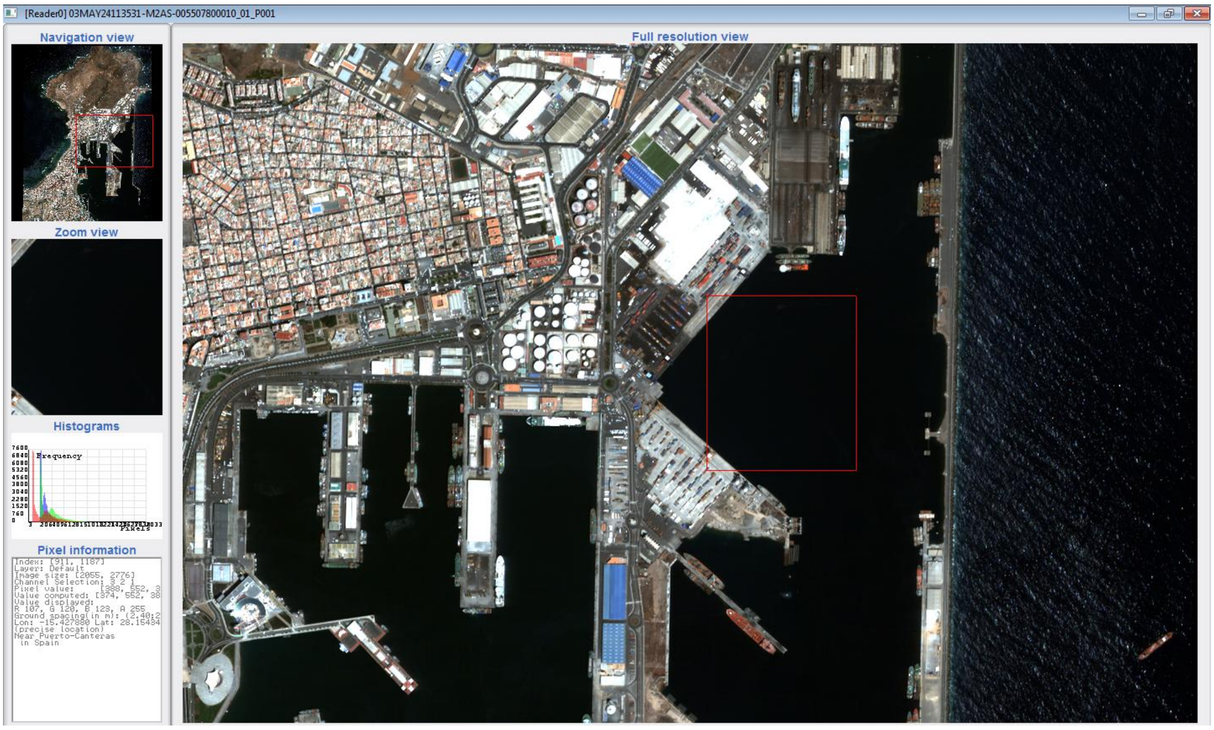




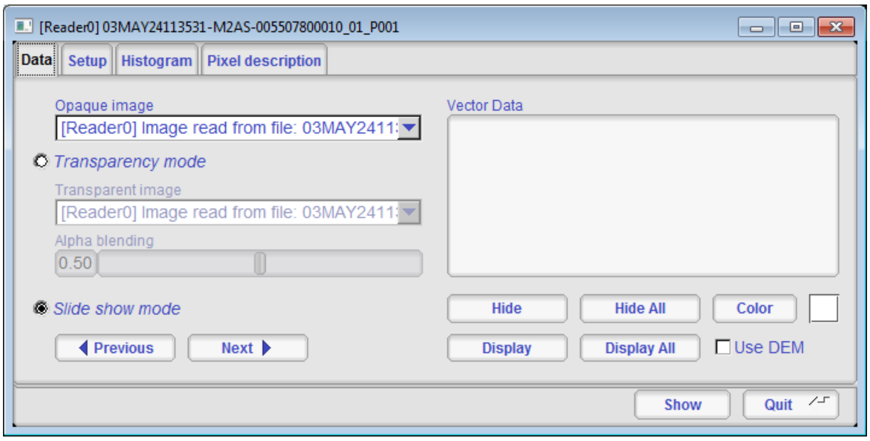
You can see the image by clicking "Visualization"→ "Viewer" in the top menu. Then a "Set inputs" window pops up. There you have to select the image or image channel to be displayed by pressing (+), adding it as "Input". After selecting the image -in our example a.tif image-, you press the Ok button. At that point you will see a display composed of navigation, zoom and high resolution. Also on the bottom left, a window with the histogram of the channels represented and the pixel information will appear.

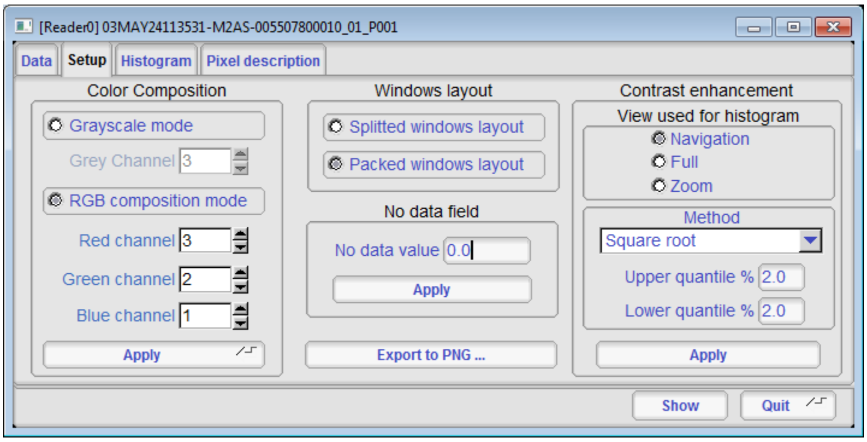


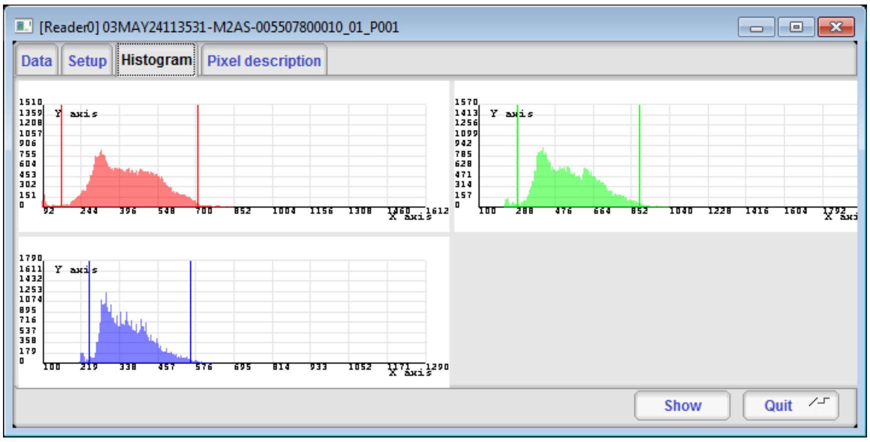


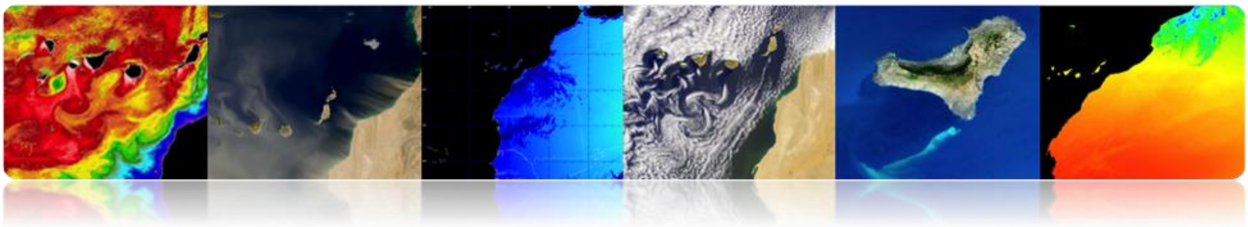


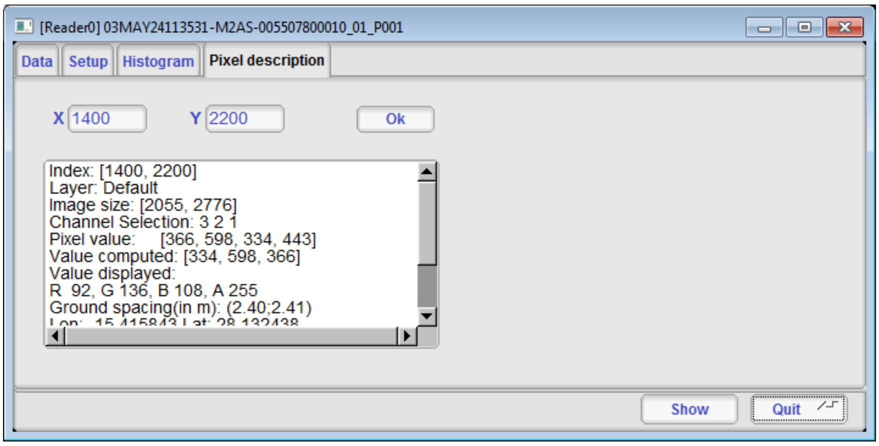
Next to display, there is another window with a menu that allows the management of data. Under "data" you can select the different data entered on the "set input", and the way they are represented (slides). "Setup" shows the configuration of the data in RGB color images or grayscale. It also allows you to configure the display in compact format or in separate windows, and to set the display method -linear, Gaussian, Square root. In "Histogram" you can see the histogram of the bands represented in the display. In the case of the straight-line method, the minimum and maximum parameters in the same histogram can be changed by shifting the vertical bars. Finally, "Pixel description" lets you access information according to a pixel position. These options are shown in the following figures.



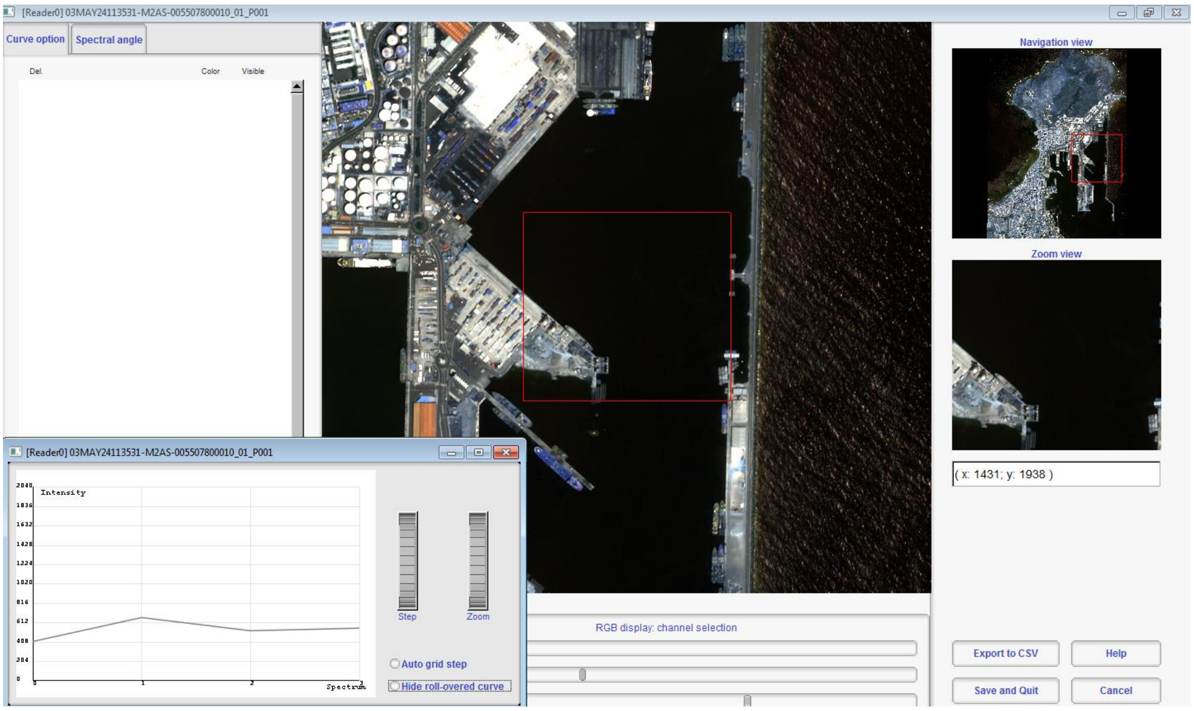


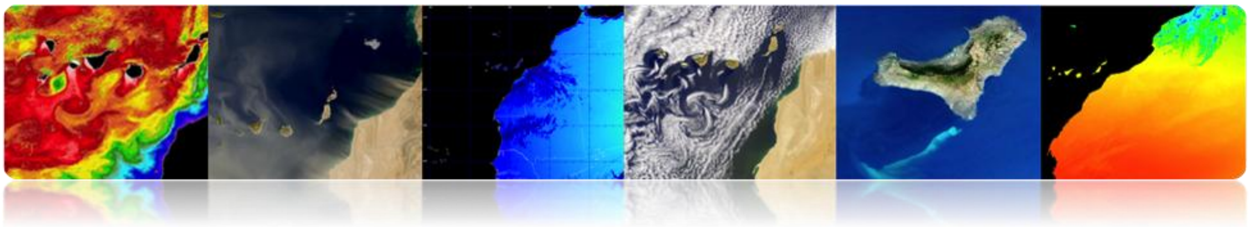




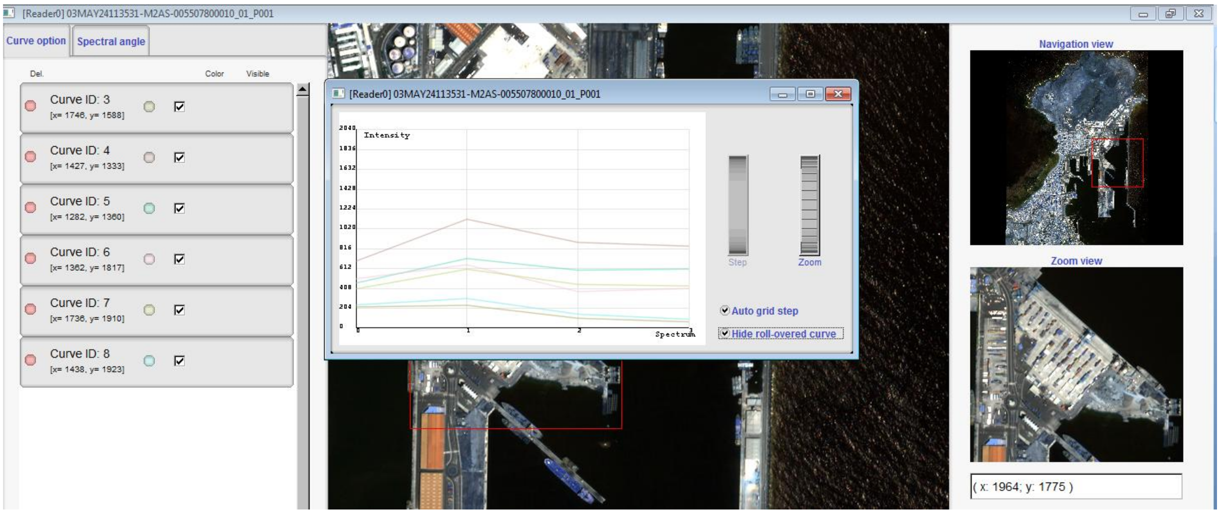


Continuing with the menu "Visualization", access to the "Spectral Viewer" where the "Set inputs" window will appear again and select the image previously uploaded in the program. Once the image is loaded, a viewer with navigation windows turns up and also bars to select the display channels, and, on the left, a list that allows to enter selected points with the values of the channels and the spectral angle. Besides, we can see another screen that represents a graph of the channel values of the selected pixel with the cursor next to the values of the stored points.

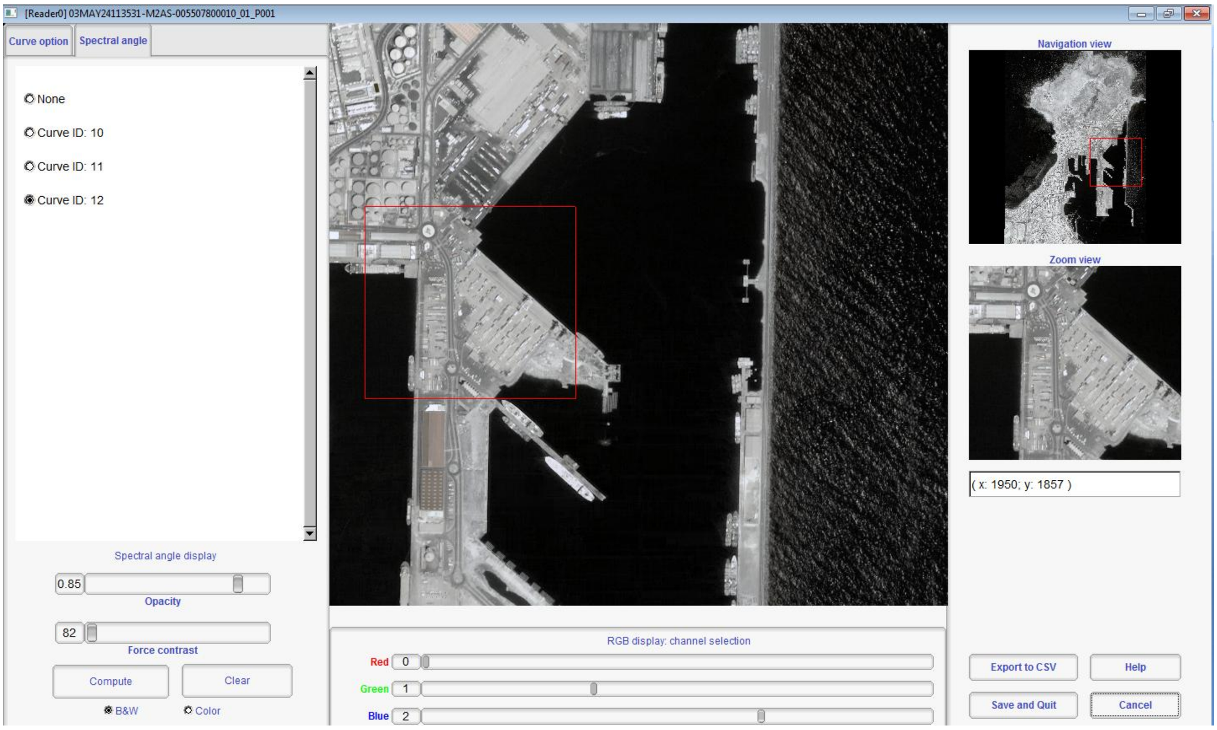




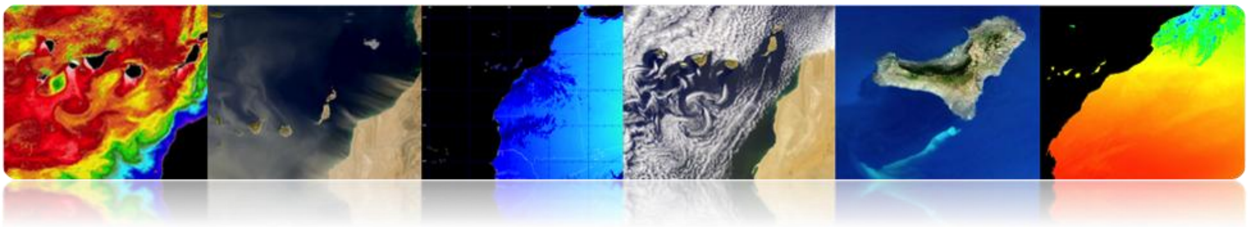
Right click to place items on the list. The figure shows the graphs window spectral channels of different selected points in the viewfinder.

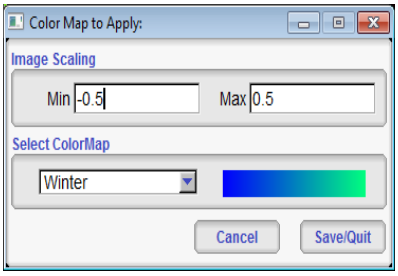


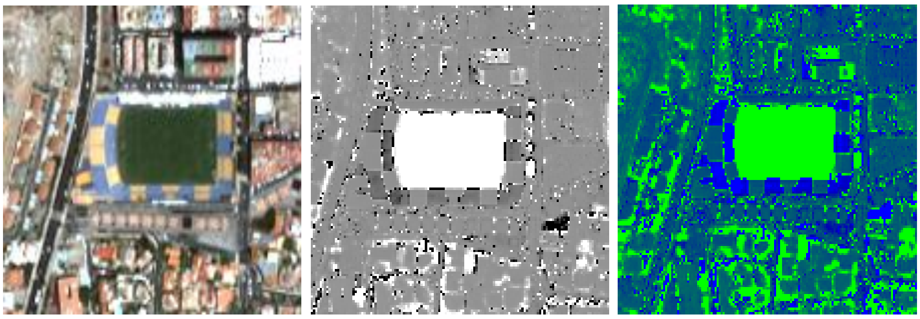
The following figure shows the spectral angle option which calculates the angle between the bands of one of the bands selected and the rest of the image. This provides an information relationship between the point and the image. In this example as we have selected the point of seawater into the port and there are no waves, the representation of this area is almost black, as it represents an angle close to zero, which indicates its relationship to that point.



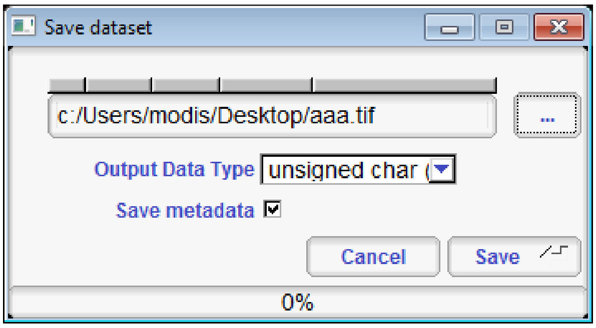
To finish with the "Visualization" menu, we access the "color mapping" option where the "Set inputs" window will appear again. The utility has as complete coloring using grayscale palette images, so that only one channel is selected. A typical example is to color a vegetation index such as NDVI. This index can be generated by a menu option "Filtering"→ "Feature extraction" → "Radiometric Indices extraction". Once the channel is loaded with the index, a "Color Map to Apply window" will appear. There you may select the desired palette and the minimum and maximum values to be represented. The figure shows the configuration of the palette Winter [-0.5 0.5], RGB image processed to obtain the NDVI, NDVI grayscale, and the result of the colored image.



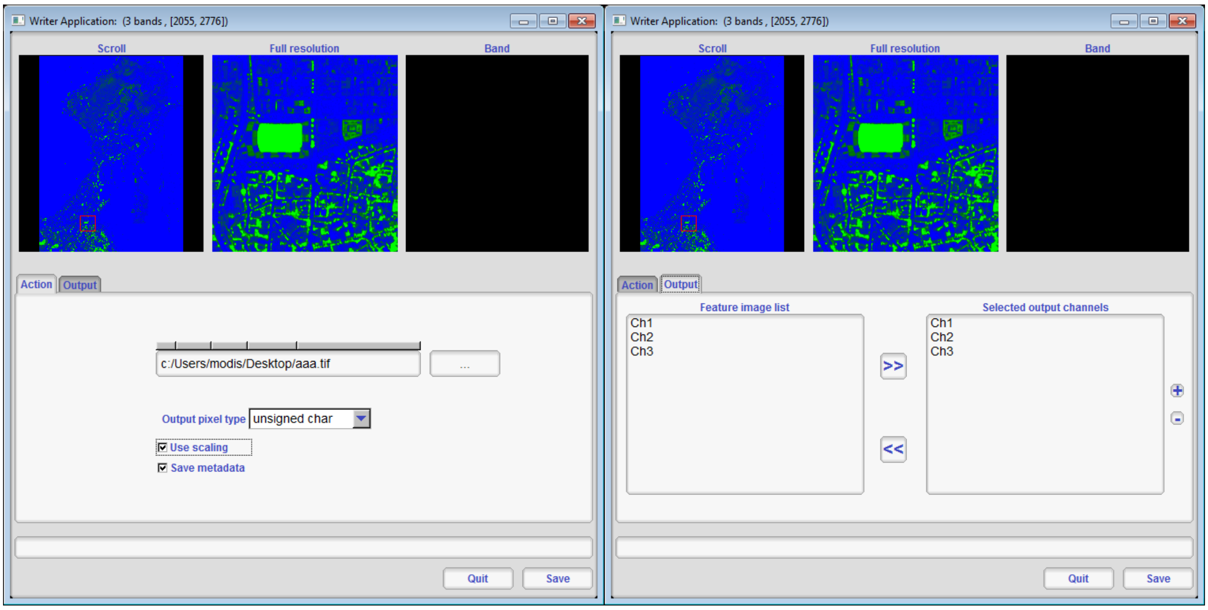




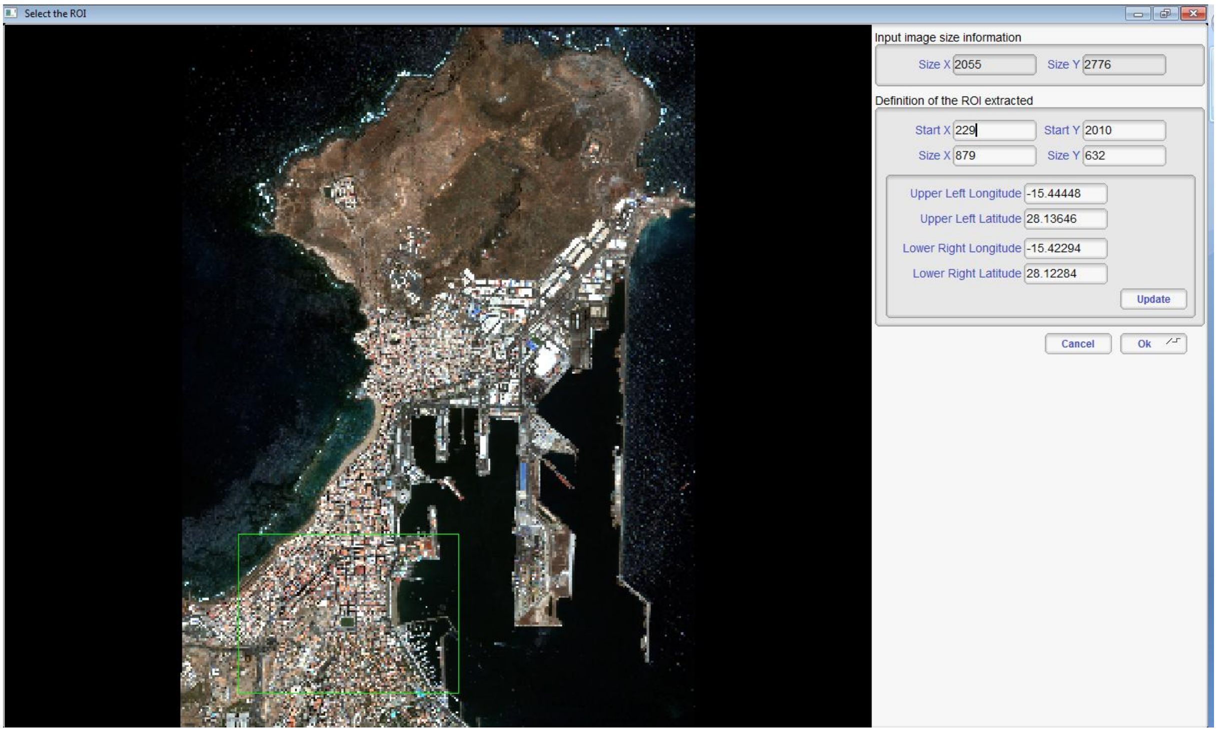
Another basic utility is to save the images to a disk. For example, we have created a colored image of NDVI that is stored in memory and we want to save it. To do this, go to "File" menu→ "Save dataset", and the window "Set inputs" will appear. There you select the image you want to save (Winter Color Map image). After pressing OK, a "Save dataset" window will appear where you will enter the route and type of image. We also introduce the data type that stores each pixel. In our case is an 8-bit RGB image that can be viewed by any viewer. Next, select the type "unsigned char", keep the "save metadata" and save it as tif image to store geographic information. The following figure shows the configuration of the window "save dataset".



If we need more configuration options when saving an image in a disk, the "save dataset (advanced)" option can be used. In this option, you may configure, among other features, the channels that you want to save and the ones that you do not want to store. The figure shows the "Writer Application" interface, which performs the advanced store of data.



To finish with the basic options of this tool, we will use the menu option "File"→ "Extract ROI from dataset". This option is very useful, if you want to cut a region of interest of an image. Let us get a square area of the image either in pixel positions or by using longitudes and latitudes. Next figure shows the "Select the ROI" interface that pops up after selecting the image to be trimmed.

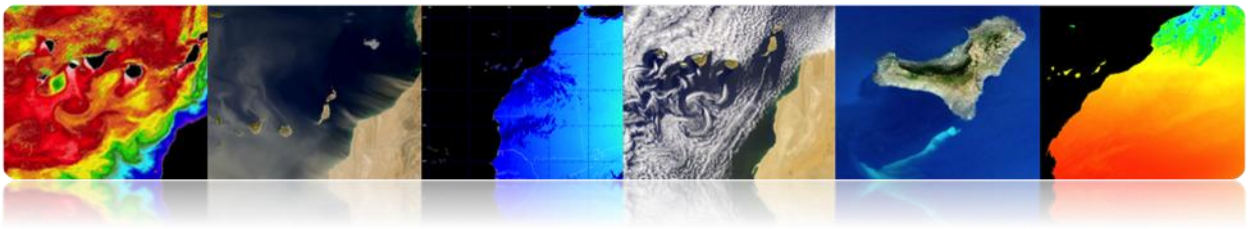


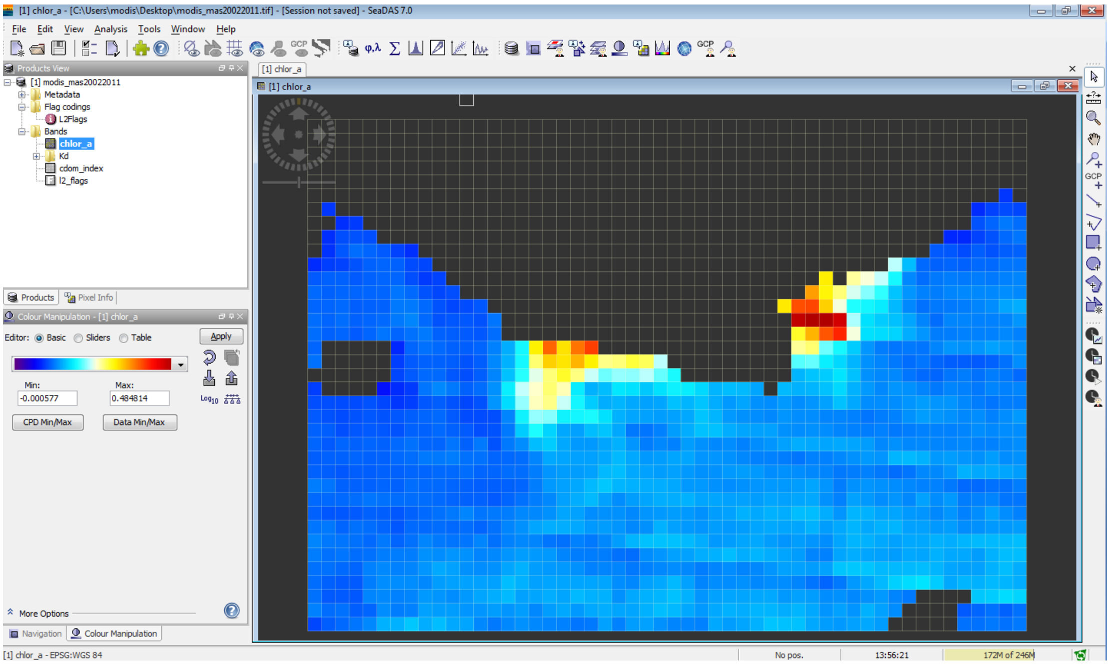
2.3. SEADAS

The SeaWiFS Data Analysis System, SeaDAS is an intuitive tool for oceanographic image processing and data based on "Ocean Color". The latest version 7 is the result of collaboration with the developers of the ESA and its package BEAM. Thanks to this collaboration the display is based entirely on BEAM framework which has introduced many more features compared to the latest version. Furthermore, this new version is available not only for Linux / Unix systems, but also available for the Windows platform. In contrast, BEAM integration has caused that the existing IDL module in previous versions is not yet available.

The software is available for downloading at the following at:

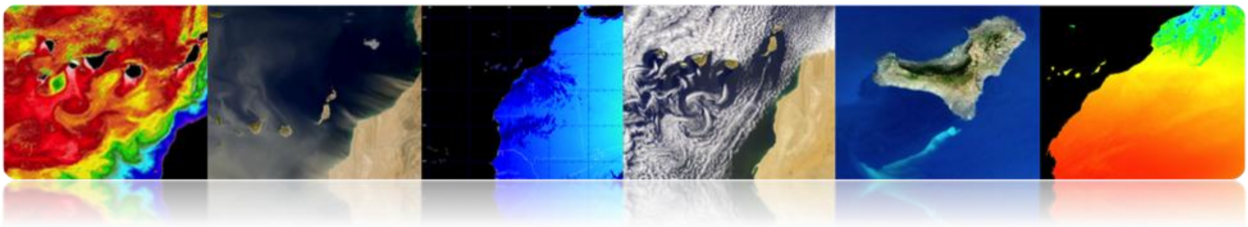
http://seadas.gsfc.nasa.gov/installers/

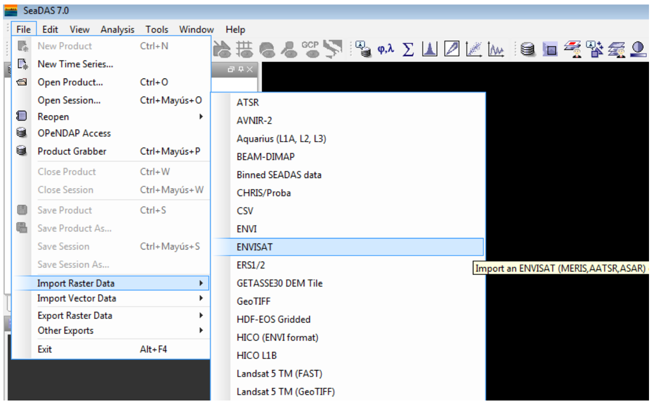


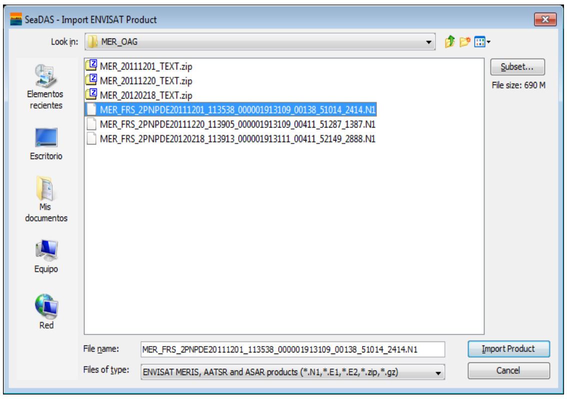


❑ SeaDAS Fundamentals

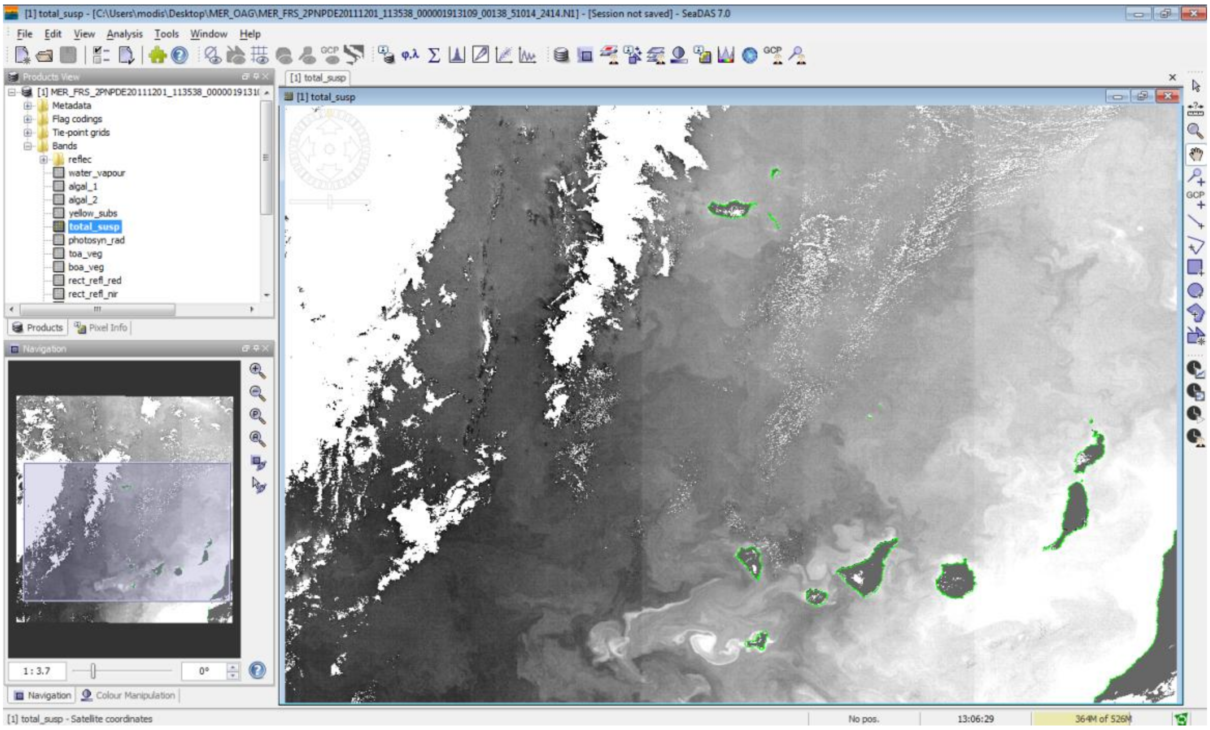
SeaDAS is a graphical program with a friendly user interface specialized in the processing of oceanographic data. It allows the use of most remote sensing data and vector data. The figure shows the load of an image in the program. At the top menu, under "File"→ "Import Raster Data", we can see a multitude of choices of sensors and image formats. After selecting the type of image to be imported, a selection window pops up where you enter the file path.

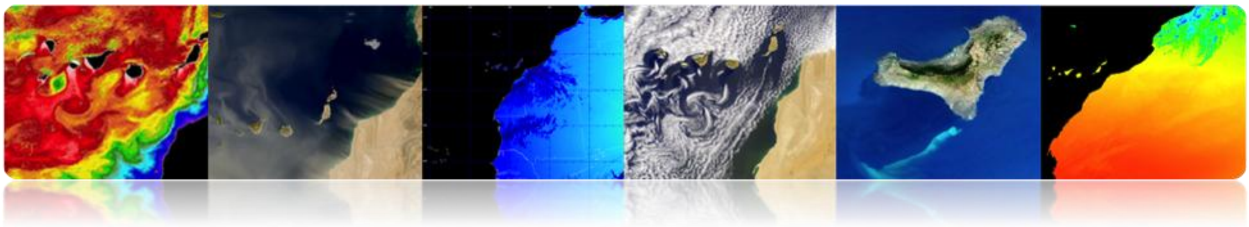




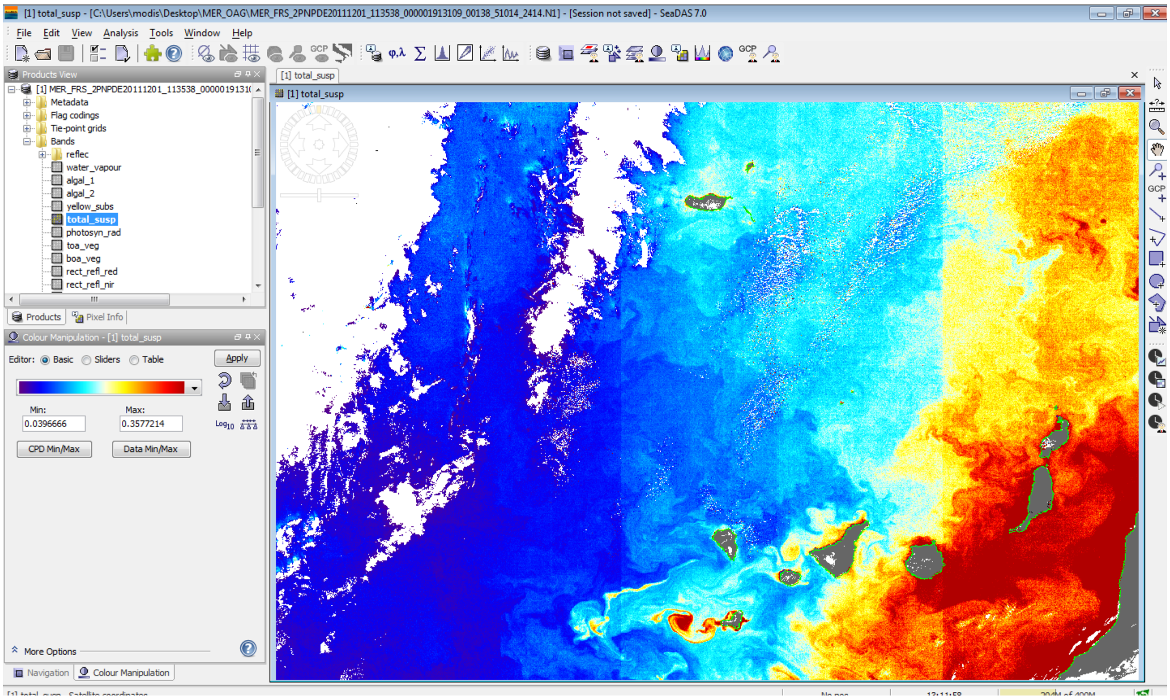


After loading the image, it will appear in the main interface in "Products View" the window. The figure shows the structure data of the image -format (HDF)- which includes metadata information, the flags, the grid information and physical information bands of L2 MERIS sensor's marine products. By double clicking on one of the bands or products -in this example it is the suspended matter in the water "total_susp"- a viewer is opened with the selected data.

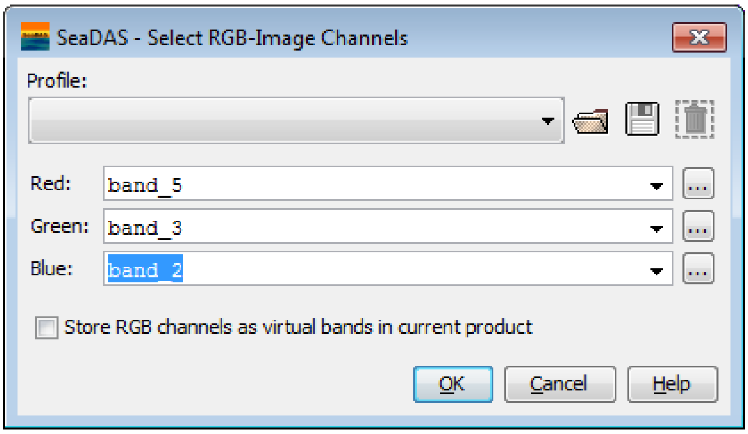


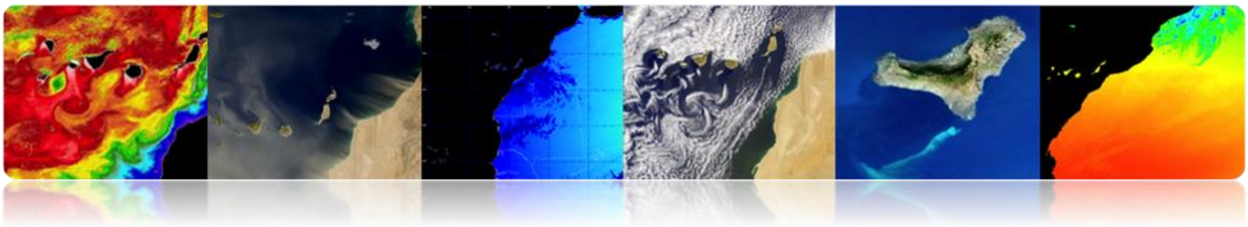


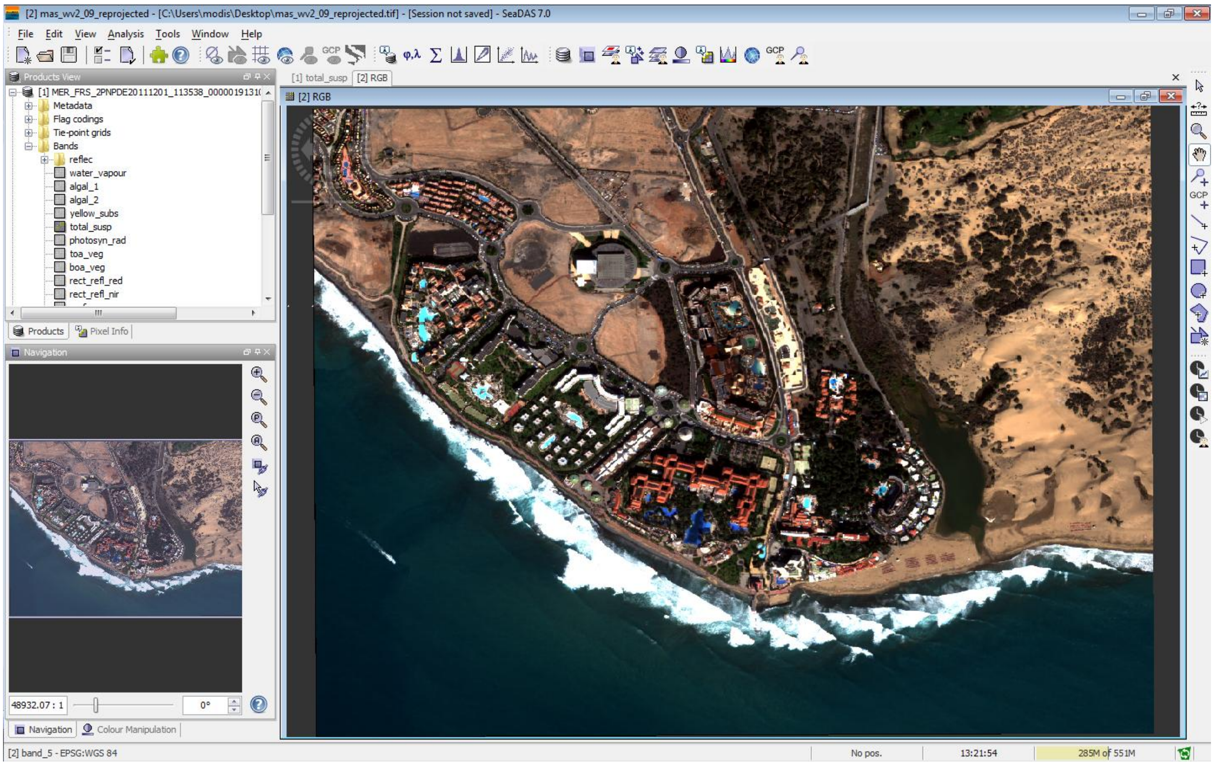
At the bottom left, we see two tabs, the navigation tab and another one called "Color Manipulation" which allows coloring the images in an easy way.



Another simple way to load images in SeaDAS is by dragging an image to "Products View". In our example, we may drag the Maspalomas WV" image reprojected. To view it in RGB, right click and we will see the "Open RGB image View", where a window for selecting the RGB bands turns up. After selecting the channel and press OK, a new viewer with the RGB image pops up.



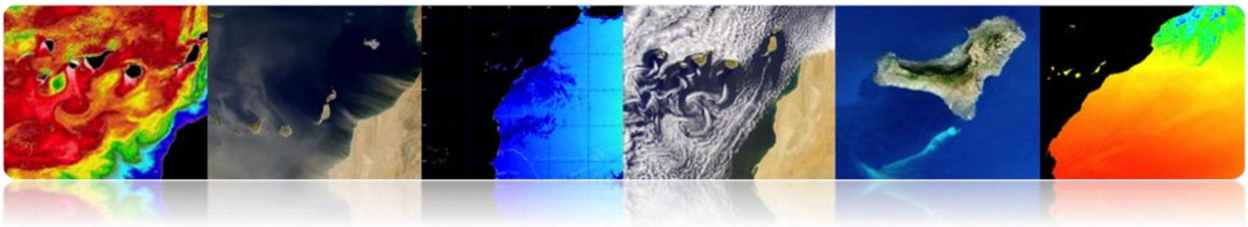


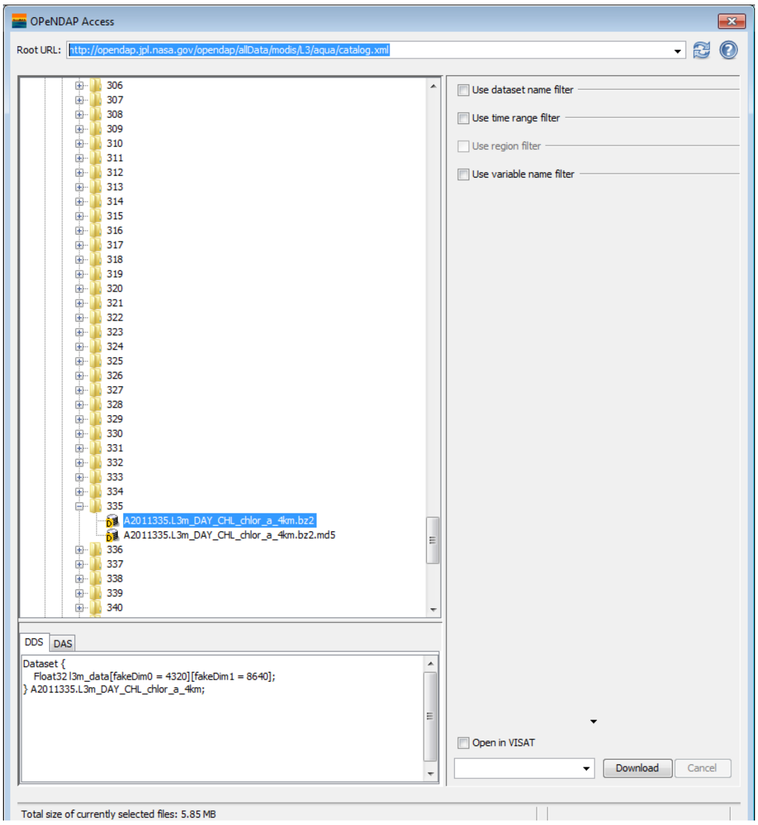


A very useful option to access NASA oceanographic data is to access via OPeNDAP. This allows you to download products directly from the database. Here you are a link to a database of NASA's Modis L3.

http://opendap.jpl.nasa.gov/opendap/allData/modis/L3/aqua/catalog.xml

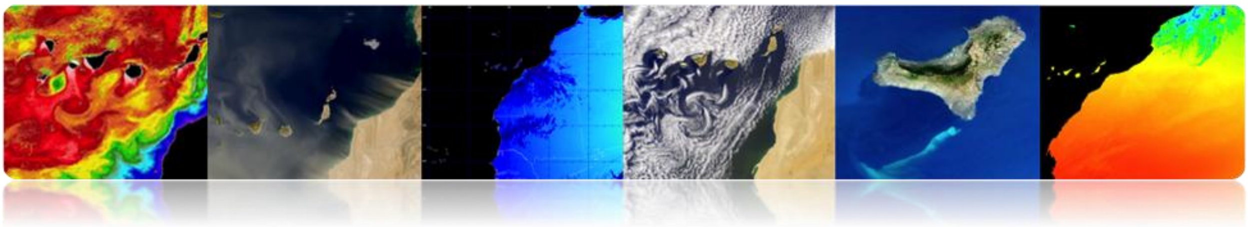
By selecting the "File" menu → "OPeNDAP Access", we see the following interface. For downloading meteorological products, select the file and click download.

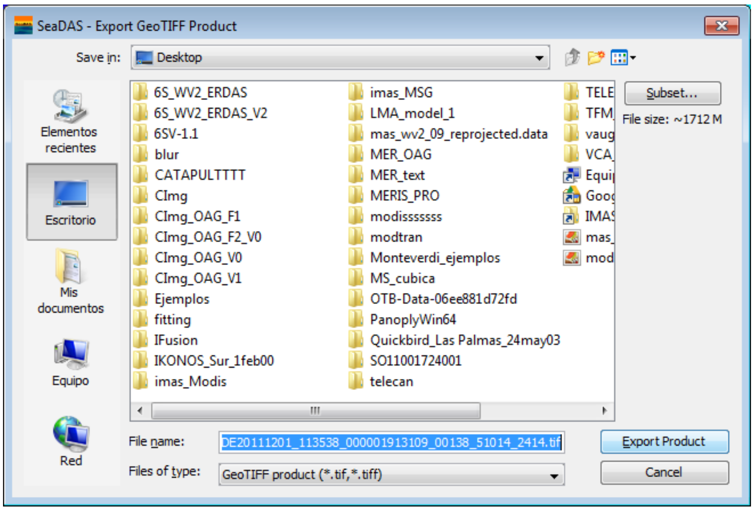




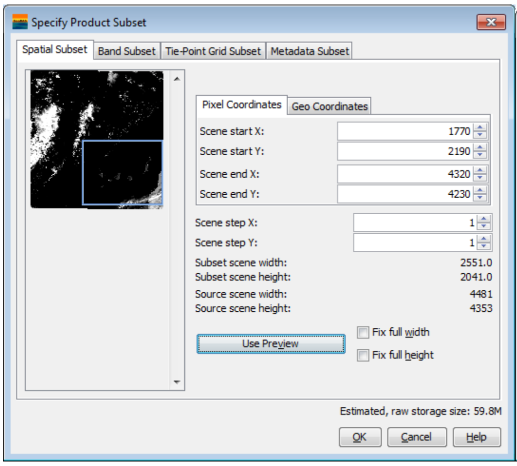
Another interesting use of this tool is to export an image or oceanographic product in a standard format, such as geotif. To perform this task, select the "File" menu → "Export Raster Data" → "GeoTiff", which brings up a window where you must enter the path of the file to be generated. However, you should previously press "Subset..." which will bring up another window configuration. In "Spatial Subset", select the area you want to save. In "Band Subset", select bands or products -in this example total_susp. In "Tie-Point Grid Subset", additional product information may be selected. Finally in the "Metadata Subset", the Metadata to be stored in the geotiff can be selected.

Once everything is configured, press the OK button, and the image with the areas and the selected products are generated.

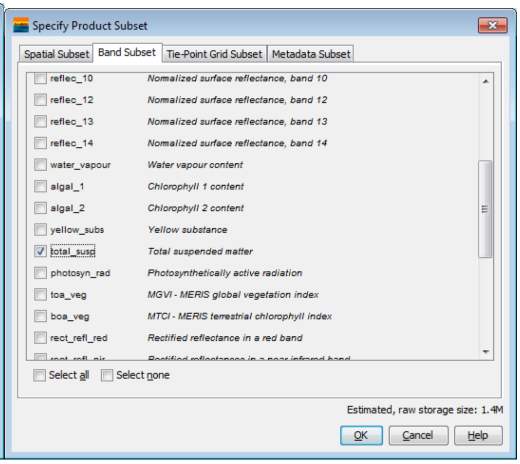




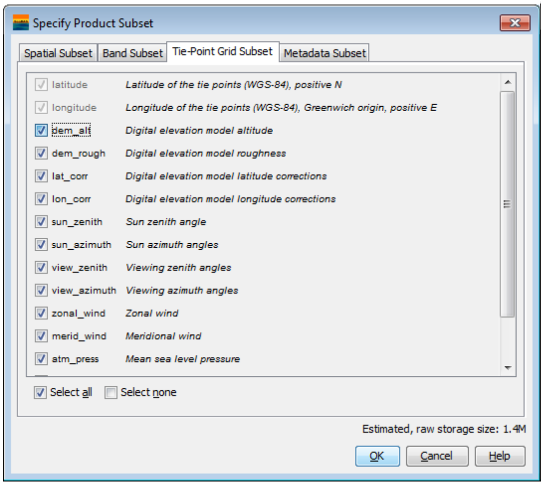
SeaDAS - Export GeoTIFF Product
Save in: Desktop
Elementos recientes
Escritorio
Mis documentos
Equipo
Red
6S_WV2_ERDAS
6S_WV2_ERDAS_V2
6SV-1.1
blur
CATAPULTTTTT
CImg
CImg_OAG_F1
CImg_OAG_F2_V0
CImg_OAG_V0
CImg_OAG_V1
Ejemplos
fitting
IFusion
IKONOS_Sur_1feb00
imas_Modis
imas_MSG
LMA_model_1
mas_wv2_09_reprojected.data
MER_OAG
MER_text
MERIS_PRO
modisssssss
modtran
Monteverdi_ejemplos
MS_cubica
OTB-Data-06ee881d72fd
PanoplyWin64
Quickbird_Las Palmas_24may03
SO11001724001
telecan
Subset...
File size: ~1712 M
File name: DE20111201_113538_000001913109_00138_51014_2414.tif
Files of type: GeoTIFF product (*.tif,*.tiff)
Export Product
Cancel



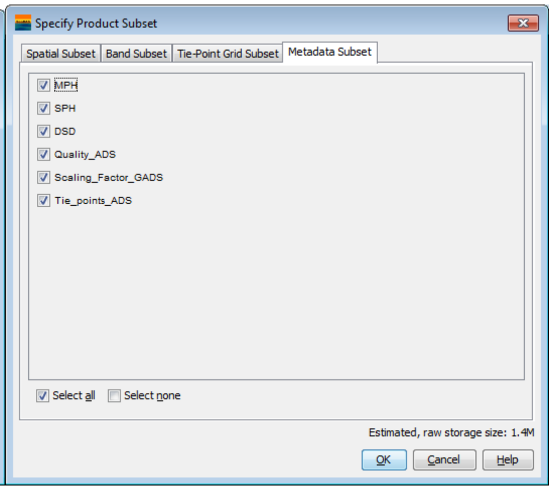
Specify Product Subset
Spatial Subset
Band Subset
Tie-Point Grid Subset
Metadata Subset
Pixel Coordinates
Geo Coordinates
Scene start X: 1770
Scene start Y: 2190
Scene end X: 4320
Scene end Y: 4230
Scene step X: 1
Scene step Y: 1
Subset scene width: 2551.0
Subset scene height: 2041.0
Source scene width: 4481
Source scene height: 4353
Fix full width
Fix full height
Use Preview
Estimated, raw storage size: 59.8M
OK
Cancel
Help



Specify Product Subset
Spatial Subset
Band Subset
Tie-Point Grid Subset
Metadata Subset
reflec_10 Normalized surface reflectance, band 10
reflec_12 Normalized surface reflectance, band 12
reflec_13 Normalized surface reflectance, band 13
reflec_14 Normalized surface reflectance, band 14
water_vapour Water vapour content
algal_1 Chlorophyll 1 content
algal_2 Chlorophyll 2 content
yellow_subs Yellow substance
total_susp Total suspended matter
photosyn_rad Photosynthetically active radiation
toa_veg MGVI - MERIS global vegetation index
boa_veg MTCI - MERIS terrestrial chlorophyll index
rect_refl_red Rectified reflectance in a red band
Select all
Select none
Estimated, raw storage size: 1.4M
OK
Cancel
Help



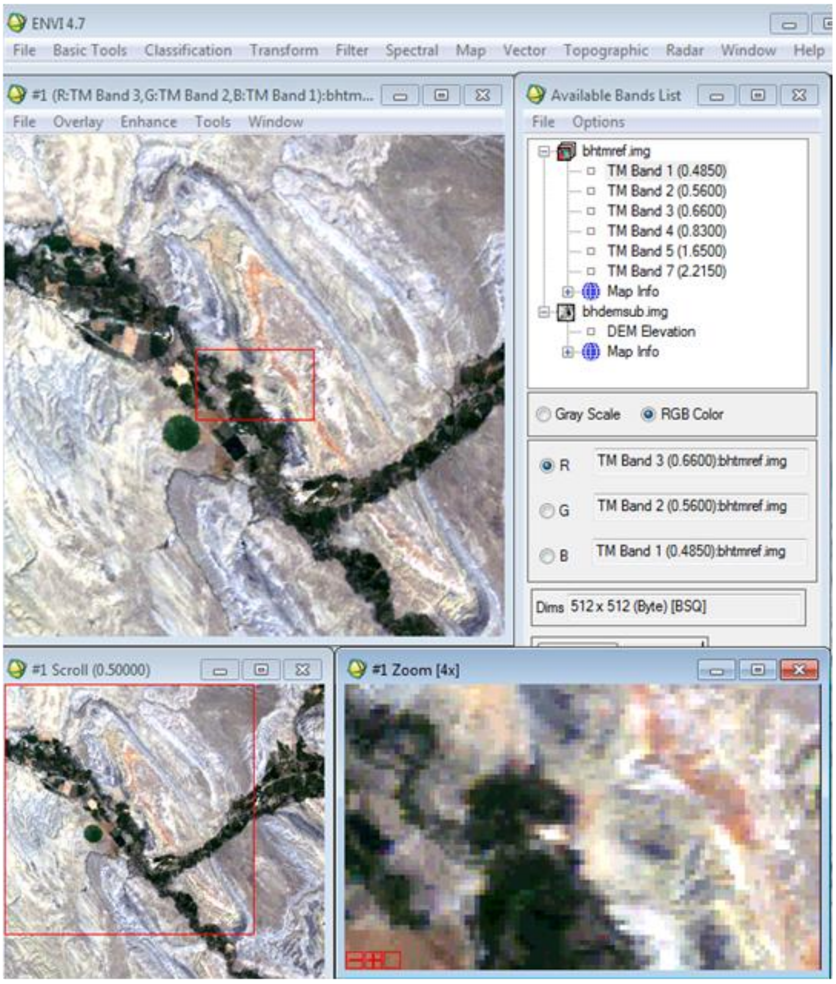
Specify Product Subset
Spatial Subset
Band Subset
Tie-Point Grid Subset
Metadata Subset
latitude Latitude of the tie points (WGS-84), positive N
longitude Longitude of the tie points (WGS-84), Greenwich origin, positive E
dem_alt Digital elevation model altitude
dem_rough Digital elevation model roughness
lat_corr Digital elevation model latitude corrections
lon_corr Digital elevation model longitude corrections
sun_zenith Sun zenith angle
sun_azimuth Sun azimuth angles
view_zenith Viewing zenith angles
view_azimuth Viewing azimuth angles
zonal_wind Zonal wind
merid_wind Meridional wind
atm_press Mean sea level pressure
Select all
Select none
Estimated, raw storage size: 1.4M
OK
Cancel
Help

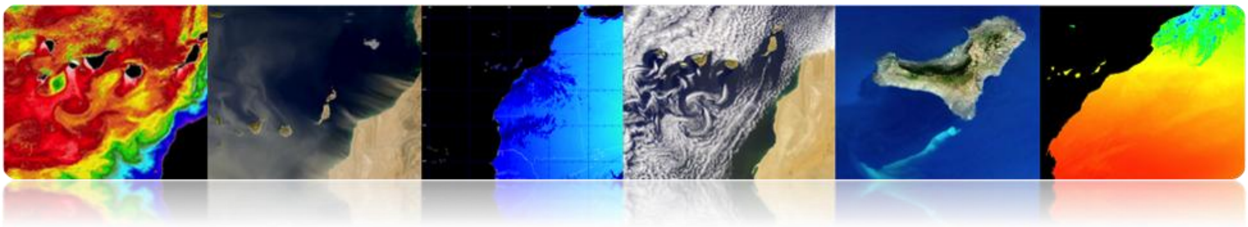


Specify Product Subset
Spatial Subset
Band Subset
Tie-Point Grid Subset
Metadata Subset
MPH
SPH
DSD
Quality_ADS
Scaling_Factor_GADS
Tie_points_ADS
Select all
Select none
Estimated, raw storage size: 1.4M
OK
Cancel
Help

2.4. ENVI

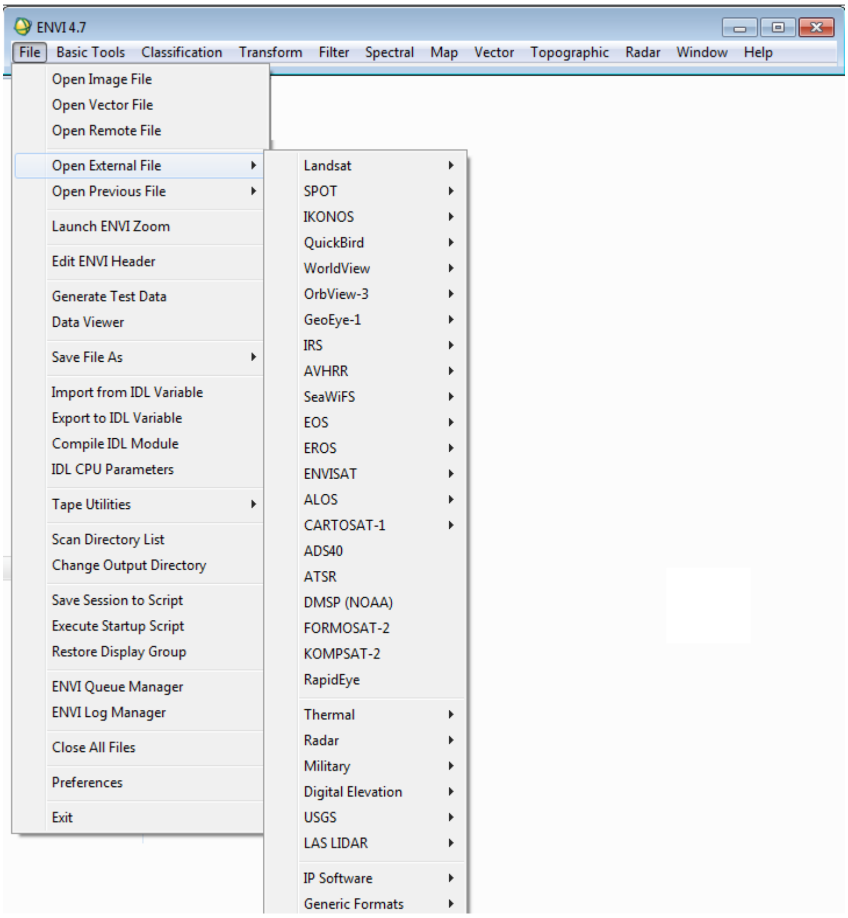
The "ENvironment for Visualizing Images" (ENVI) is an advance software for processing and analyzing space remote sensing images. It is one of the most widely used in the professional world for remote sensing image processing. It allows processing multiple types of satellite images and data, performing atmospheric corrections, image fusion, transformations, filters, geometric processing, classification, etc. The latest version of the program is 5, which improves its graphical interface, being more friendly than the previous versions. However, in the next practical examples, we will show version 4, which although it has a less intuitive interface, it retains the full potential of the tool.



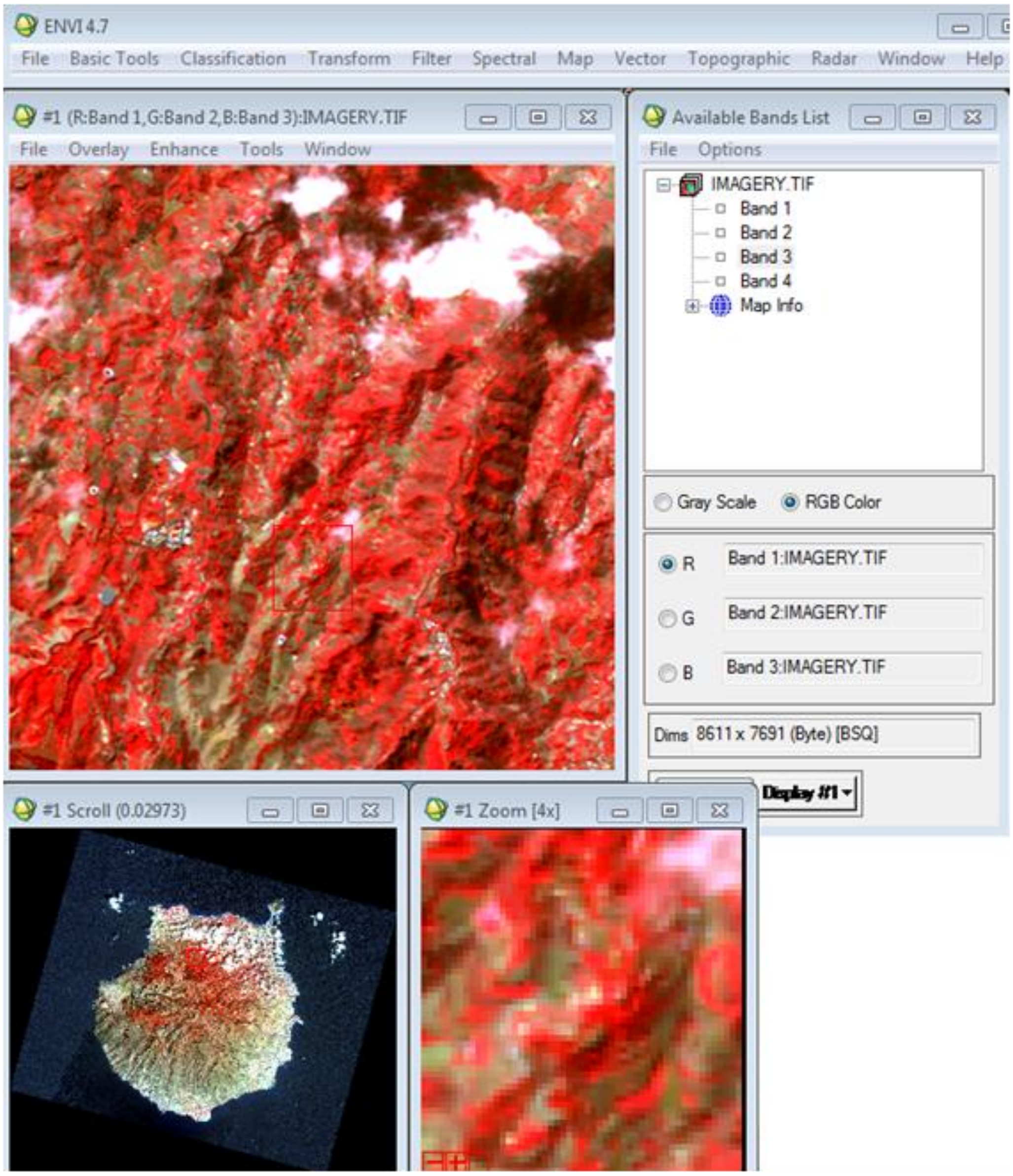


❑ ENVI FUNDAMENTALS

The basic use of ENVI program does not differ much from the previous program. The first menu option "File" provides all kinds of tools to open, save, and export images. Although you can use the generic option screen opening "Open Image File", it is better to use the "Open External File" because it has pre-configured the options and formats from a multitude of satellites and sensors. The figure shows the dropdown "Open Image File" menu to open an image.



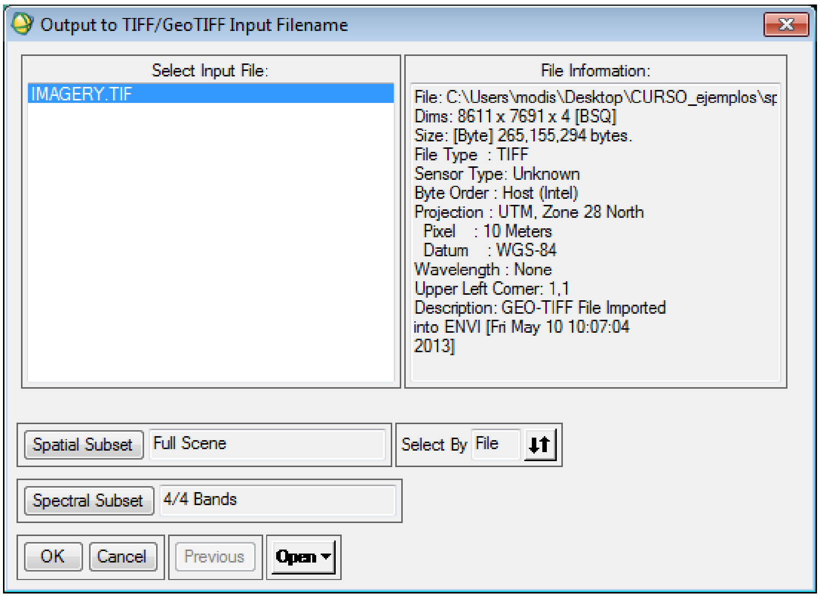
In this example we will open a SPOT image, in this case go to option and select SPOT "GeoSPOT", since it is stored in a geotiff image. At that moment, a window for selecting the file path turns up. Once it is selected, another window with the available bands will appear. Since it is a multispectral image, we will set the RGB image display. In order to do this, click on "RGB Color" and on the bands that we want to select as a red, green and blue (1, 2, 3) Channel. Finally, click the "Load RGB" button. As a result, the ENVI display will appear. We can observe a strange color setting, where the vegetation zone has a reddish color. This is because the sensor does not have the Blue channel -green, red, near infrared and mid-infrared-, so you are representing GR-NIR.

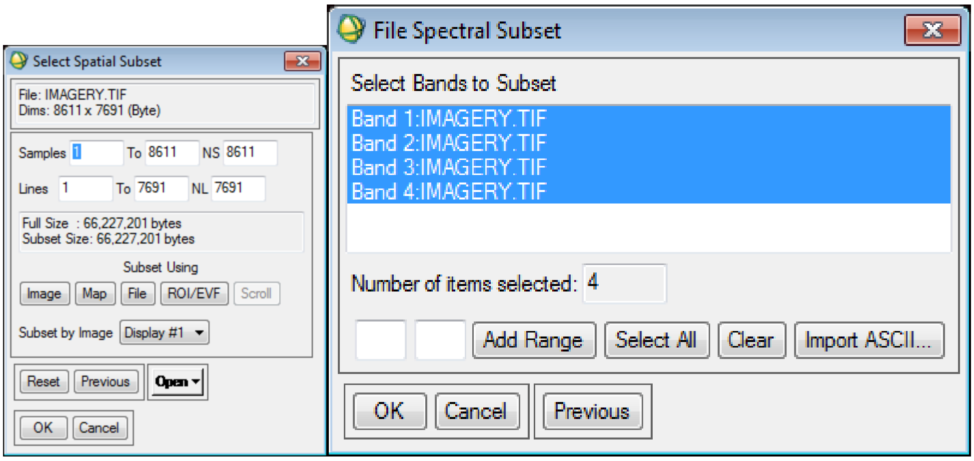


We can observe the presence of 3 viewers, the main one, a navigation viewer that displays the entire image, and a zoom [x4] viewer. Furthermore, we observe that once the image is loaded, the list of images' menu is linked to the viewers by the bottom button "Display # 1", which corresponds to the numbering of the Viewer windows. If you want to load a new image, you need to create a new display in the "Available Bands List".

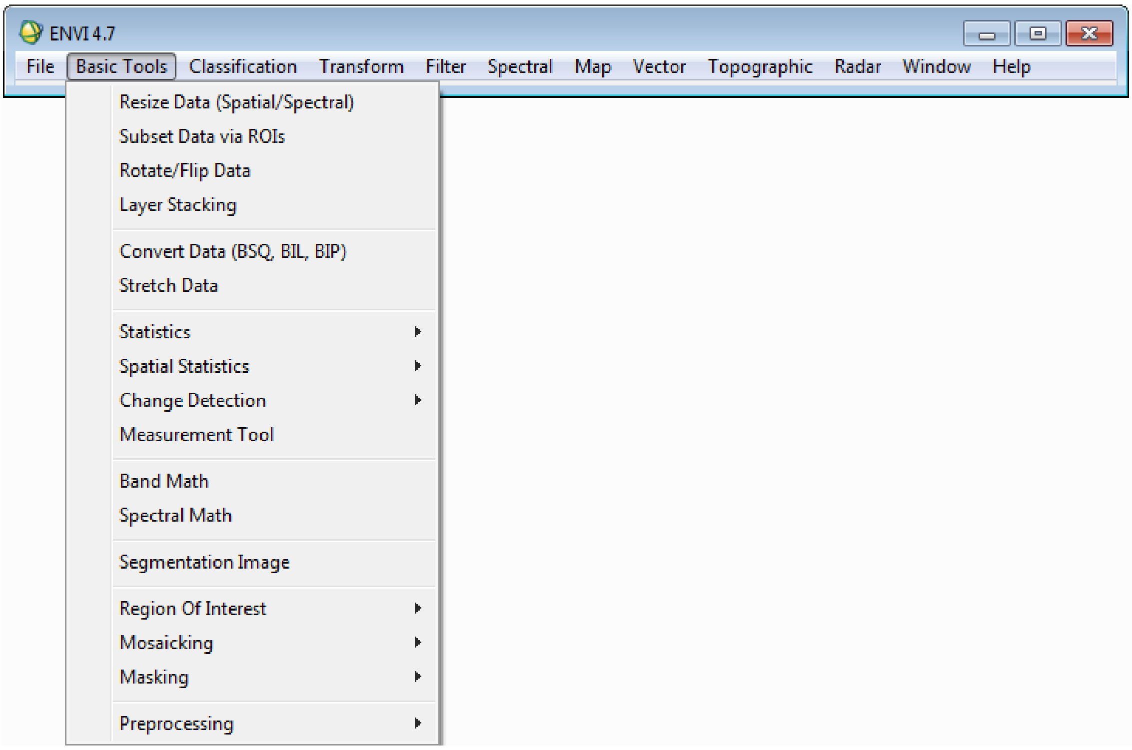
In the main viewer, there is also a top menu with multiple options. Under "File" you may modify display preferences. You may save in the disk or print what is displayed in the viewfinder. In "Overlay", among other options, you may enter grid lines, areas of interest and vector data. The menu "Enhance" provides options such as "stretching", "Histogram Matching" and filtering. "Tools" provides multiple options, such as how to link viewers to visualize the same areas. You may also create regions of interest ROI or color grayscale images, window location and value of the pixels, etc. The "Window" menu manage viewers and perform actions such as creating a new viewer and locking it, presenting information in the image, etc.

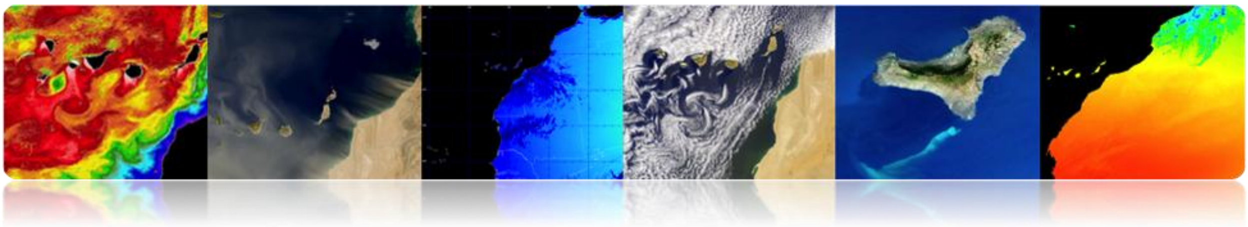
Another ENVI's basic utility is the "Save file as" (see figure) that allows to save to disk or open images processed by this program. In this menu we can choose a variety of image formats such as ENVI, ArcGIS, ERDAS, JPEG2000, GeoTIFF, etc. Once the format is selected -e.g. geotiff format- a selection window will appear allowing you to choose the data open in the program. In this interface, you may select the subset of the image space using "Spatial Subset", where you may select a specific area of the image. by introducing x-y points or by ROI. By clicking on "Spectral Subset", a window pops up where you can select the bands that you want to keep.





The "Basic Tools" menu contains a variety of useful functions for image manipulation, being the most outstanding the options for resizing images, cropping areas, changing the resolution of the pixels, image rotation, changing the storage format of the information -Interleave: BSQ, BIL, BIP. It also has statistics and measurement tools, image segmentation tools, mosaics, masks, etc. It allows to perform mathematical operations between bands. At the end of the list you find the option "Preprocessing", where there are tools for image calibration -obtaining radiance and reflectivity-, atmospheric correction, and other types of corrections.


ENVI 4.7
File
Basic Tools
Classification
Transform
Filter
Spectral
Map
Vector
Topographic
Radar
Window
Help
Resize Data (Spatial/Spectral)
Subset Data via ROIs
Rotate/Flip Data
Layer Stacking
Convert Data (BSQ, BIL, BIP)
Stretch Data
Statistics
Spatial Statistics
Change Detection
Measurement Tool
Band Math
Spectral Math
Segmentation Image
Region Of Interest
Mosaicking
Masking
Preprocessing



CONTENTS

IMAGE PROCESSING: CORRECTIONS AND THEMATIC CLASSIFICATION

3.1. INTRODUCTION

This practice is an introduction to the most common treatments performed with space remote sensing images. We will use Monteverdi, ENVI and SeaDAS. In the first part of this practice, we will see the different utilities that allow the realization of radiometric, atmospheric and geometric corrections, while in the second part, we will carry out processed oriented to the classification of different covers on an high resolution satellite image.

3.2. REMOTE SENSING IMAGES CORRECTIONS

Radiometric, atmospheric and geometric correction are the most important preprocessed remote sensing, designed to get the correct values of the energy reflected or emitted on any point of the Earth's surface.

Radiometric and atmospheric corrections -also called calibrated images- are a critical step in the processing of remote sensing images in the optical domain. The calibration allows obtaining a physical parameter independent of lighting conditions and even atmospheric conditions, allowing for example to work with images taken in different dates to detect changes.

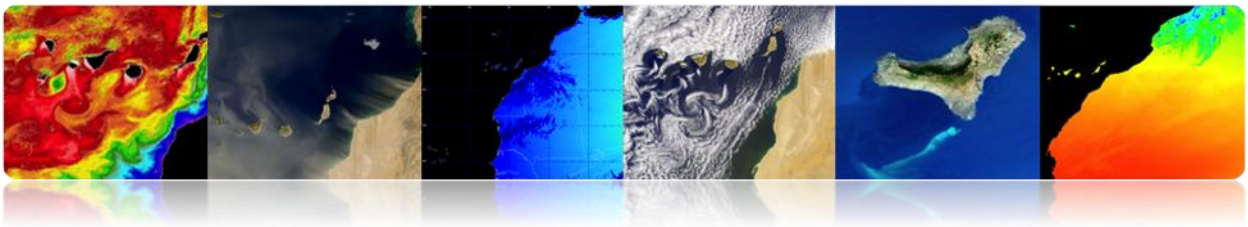
The geographic information management of remote sensing data is another point of great importance. Thanks to the geographical information contained in remote sensing data, images may be superimposed and their values may be compared. This requires using the same images projection models. Images must be registered to each other, which allows the images points to match properly.

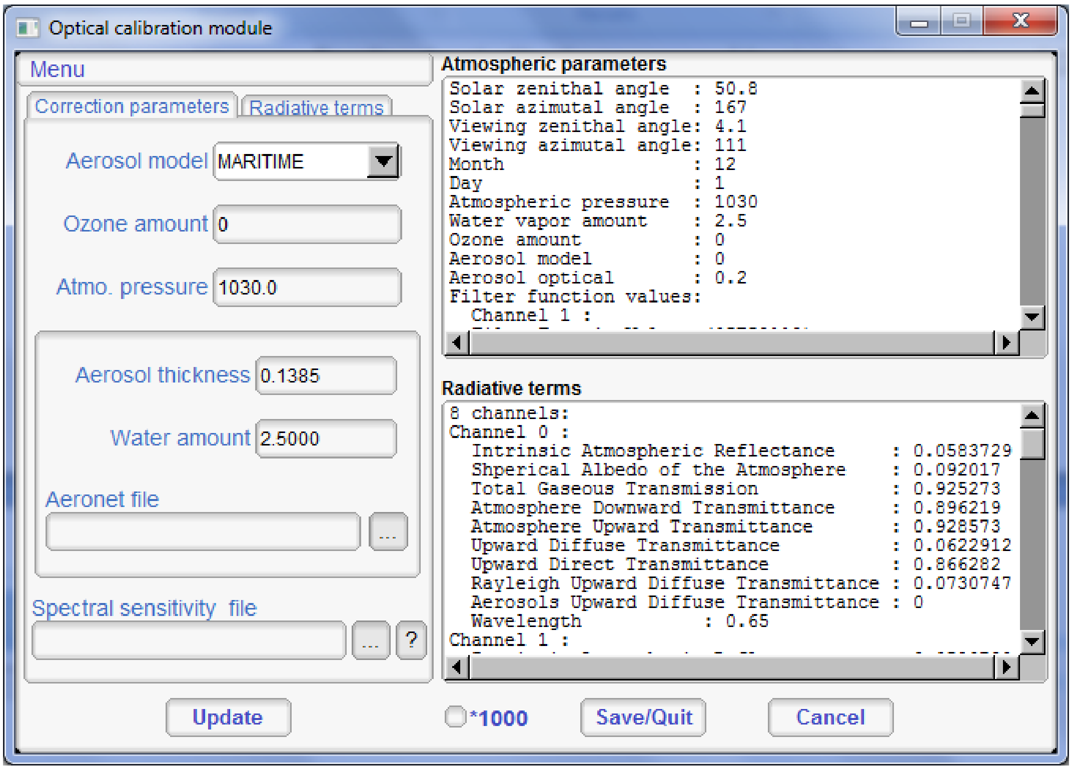
In the next sections, we present practical cases of these corrections for each one of the software tools described above (Monterverdi, ENVI and SeaDAS).

❑ MONTEVERDI

"Calibration"→ "Optical calibration" is Monteverdi's main menu. It allows the calibration of high and very high resolution images (IKONOS-2, SPOT4-5, QuickBird, WorldView2 and Formosat2). The calibration results in a luminance or radiance image, another high reflectivity of the atmosphere TOA image, another surface reflectivity TOC image, and a difference TOA-TOC image.

After selecting the option "Optical calibration" a "Set input" window pops up where you have to select the image you want to edit (e.g. WorldView-2 satellite). It is very important to check that this image is together with the metadata file that contains the necessary information to make corrections. For this reason, you have to make sure that the file name has not been modified from the original data and no metadata has been removed. Once OK is pressed, the calculation of the atmospheric correction using the 6S atmospheric model will be performed (Second Simulation of a Satellite Signal in the Solar Spectrum), which may last a few seconds. Once the calculation is complete, the following "Optical calibration module" window will pop up.





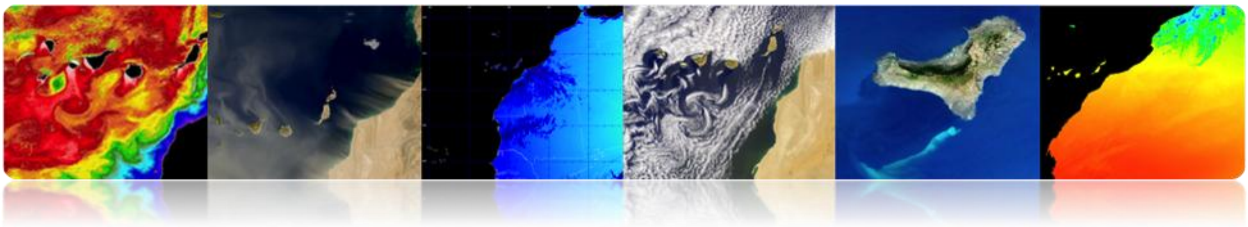
The type of aerosol that exists in this area (coastal, continental, desert, etc.) is configured in this module, and it is very important to introduce the optical thickness (Aerosol thickness) of the atmosphere. This data is available at:

http://disc.sci.gsfc.nasa.gov/giovanni/overview/index.html #

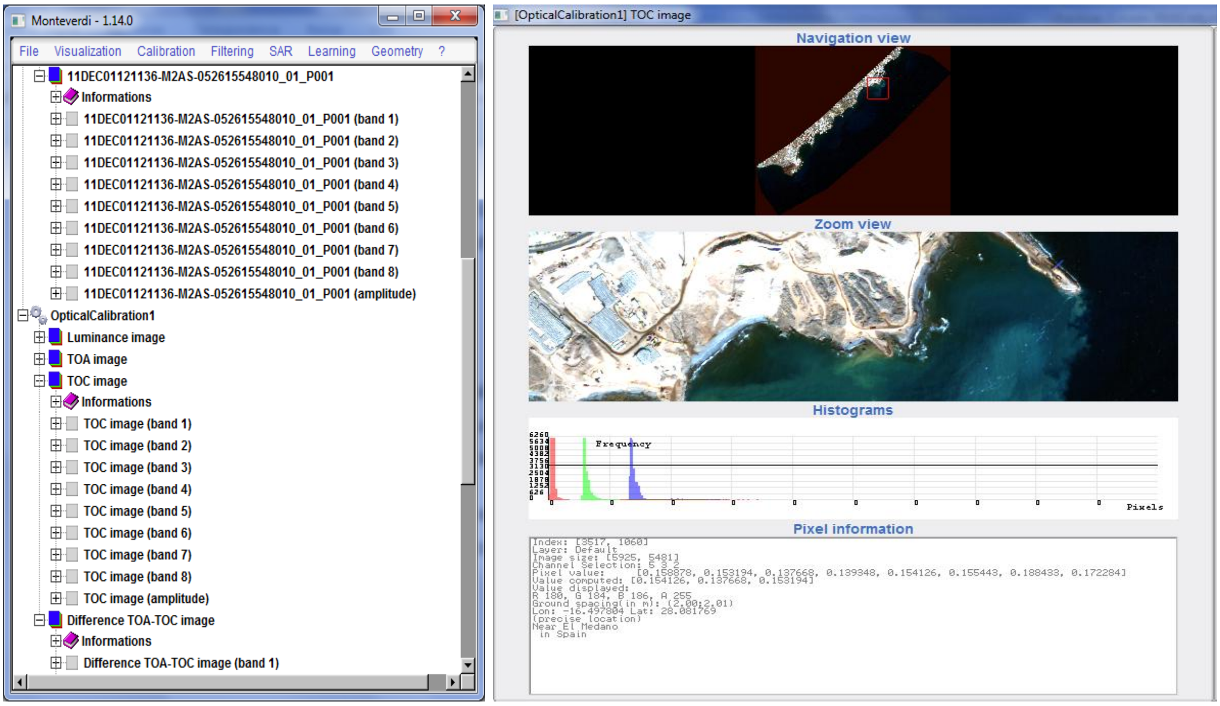
The result of the correction value can be improved by entering the ozone value and the atmospheric profile obtained by Aeronet system weather balloons. This data can be found at:

http://www.weather.uwyo.edu/upperair/sounding.html, ftp://ftpdatos.aemet.es/ozono/

It is advisable to provide the module with spectral sensitivity data of the satellite bands to complete the configuration. These spectral sensitivity data are provided by the companies managing the satellites. Once all this is configured, click "Save / Quit" to generate luminance calibrated images, TOA reflectivity and TOC.

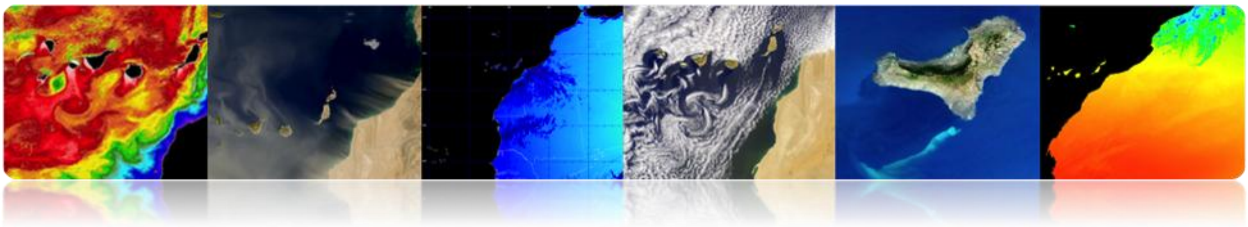


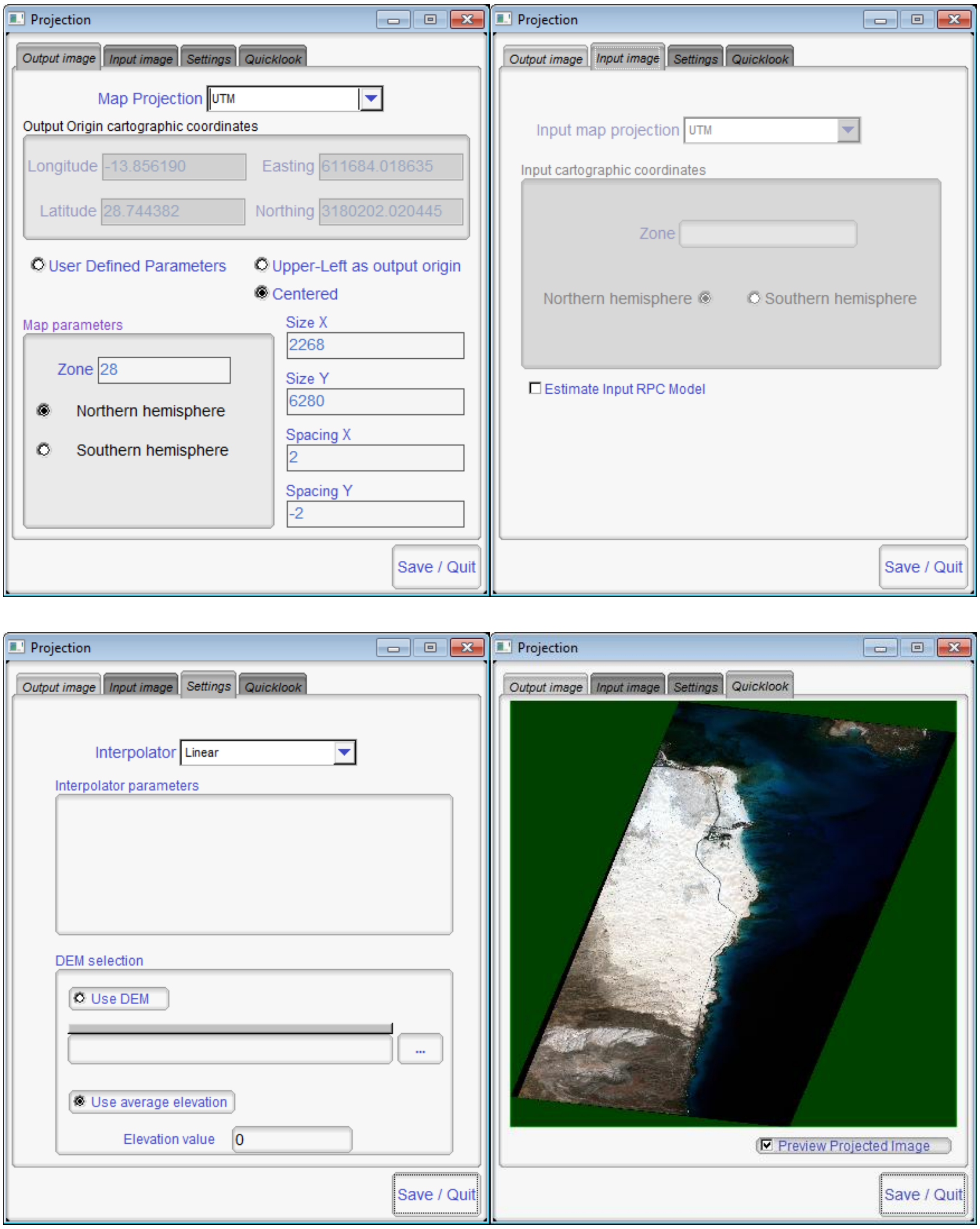
The following figure shows the main interface with the optical calibration results (luminance, TOA, TOC and TOA-TOC), and the TOC surface reflectivity image atmospherically corrected with data values between 0 and 1.



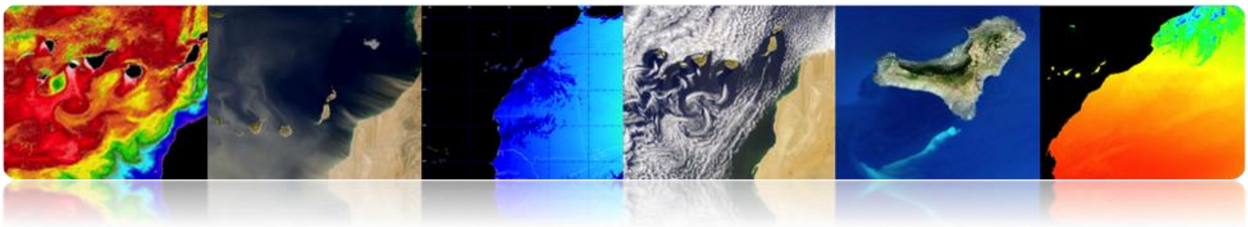
Monteverdi contains a few geometric correction utilities available in the main menu "Geometry", among which "Reproyect image", "Superimpose two images" and "Homologous points extraction" are the most outstanding.

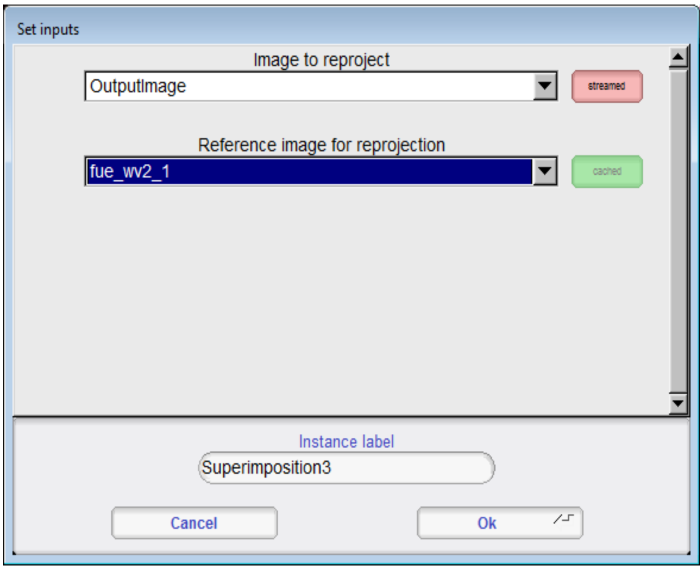
"Reproyect image" allows to modify the type of image projection. Once this option is selected, a "set input" window will pop up and there the image to be reprojected can be selected. Then the image is selected and the module "Projection" (see figure) pops up where you set the options of the new projection. In "Output image" you may configure the type of projection (UTM, LAMBERT2, WGS84, and EPSG). In "Input image" you can see the georeferencing format of the input image. In "Settings", you may configure the interpolation method used (linear, Nearest, BCO). Finally in "Quicklook", you can see a preview of the reprojection. After pressing the button "Save / Quit", the reprojected image is generated in the main interface.

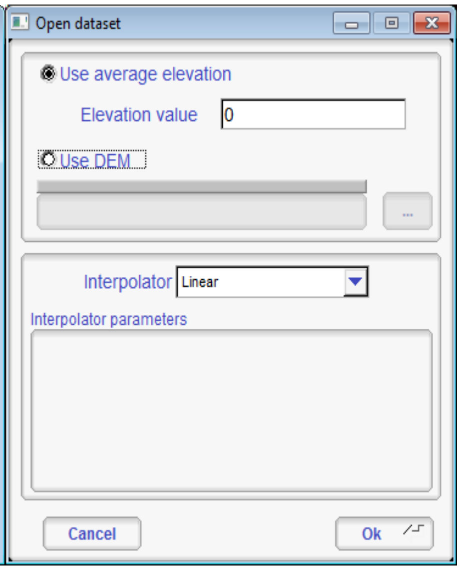




Selecting "Superimpose two images" opens a "Set inputs" window (see figure) where you have to select the image to be reprojected and the reference image. Pressing the OK button, makes the "Open dataset" window pop up, where you set interpolation and select the DEM elevation model, if available. Pressing the OK button generates the reprojected image in the main interface.

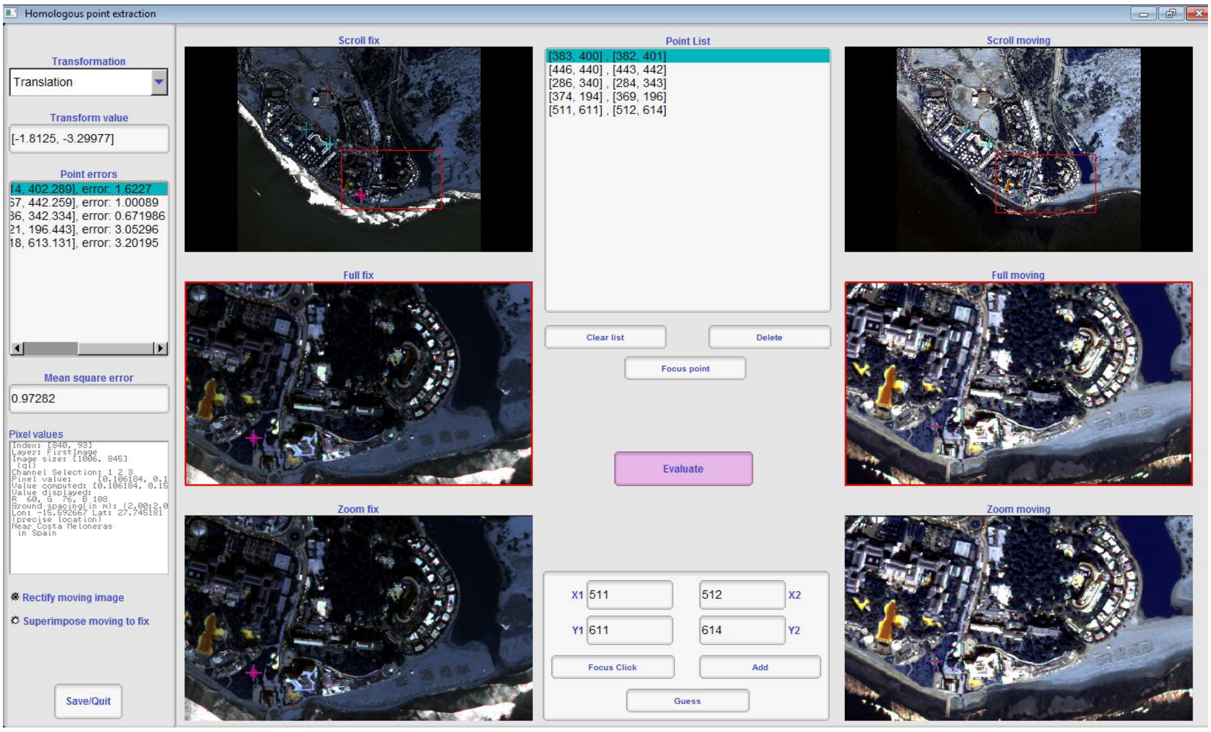






The result of this simple operation is a reprojected image based on the projection of the reference image.

Finally, selecting "Homologous points extraction" opens a "Set inputs" window where you have to select the reference image (Fix) and moving image (Moving). Pressing the OK button makes the "Homologous point extraction" module window pop up (see figure) where there will see two groups of viewers with fixed and moving images. In Viewers "Zoom", control points that are present in both images may be selected. They will be added to the list of "Point List" by clicking on "Add". Once you have selected the control points, select the processing method that allows calculating the displacement of the moving image with respect to the fixed one (Translation, Affine and 2D similarity). We also have to select the method of grinding the image (Rectify moving image, Superimpose moving to fix). With the parameters set, press the "Evaluate" button to obtain the displacement of the moving image with respect to the fixed. Moreover, we get the error produced between the different control points to perform the transformation. To finish, just press "Save / Quit" to save the result in the main interface.

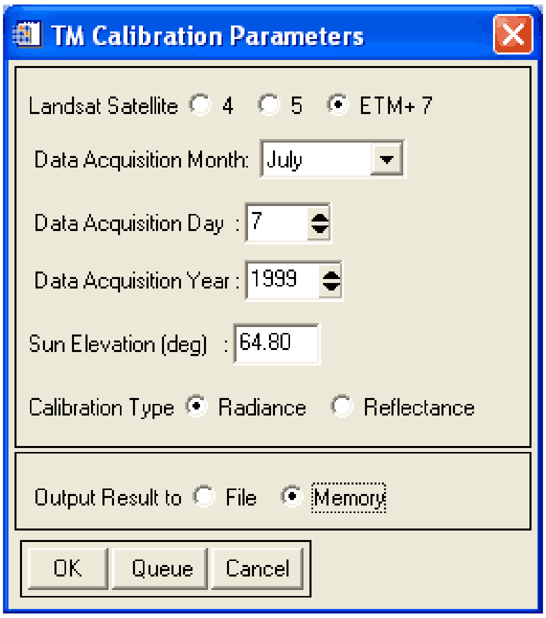


❑ ENVI

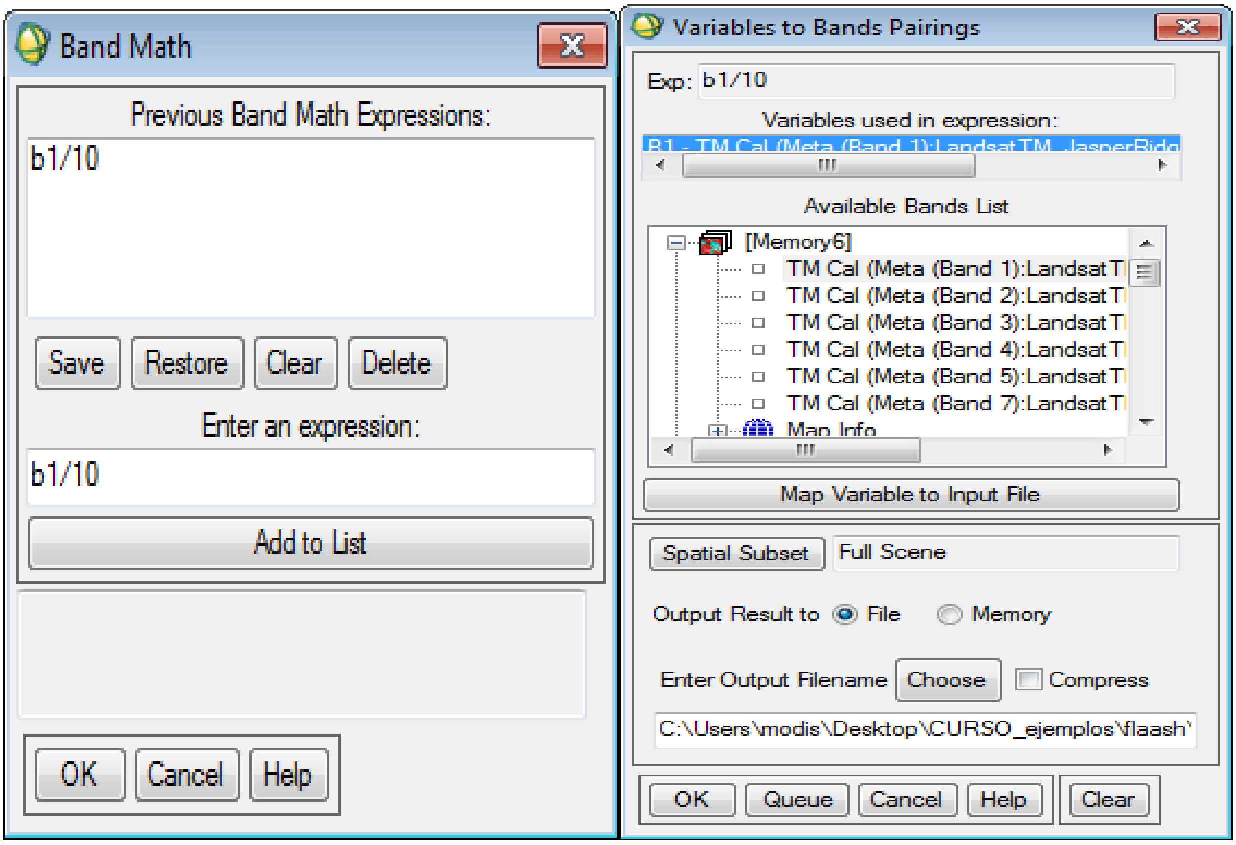
ENVI provides calibration utilities for many optical sensors of remote sensing satellites. Besides allowing to obtain the radiance or reflectivity TOA of the images, ENVI provides atmospheric correction modules and allows simple correction using methods based on extraction of dark pixels. In any case, FLAASH it the most widely used module to perform atmospheric correction. It is based on the atmospheric model MODTRAN (MODerate Resolution atmospheric TRANsmission).

To perform the calibration and atmospheric correction, we can use a LADSAT 7 image called LandsatTM_JasperRidge_HRF.FST.

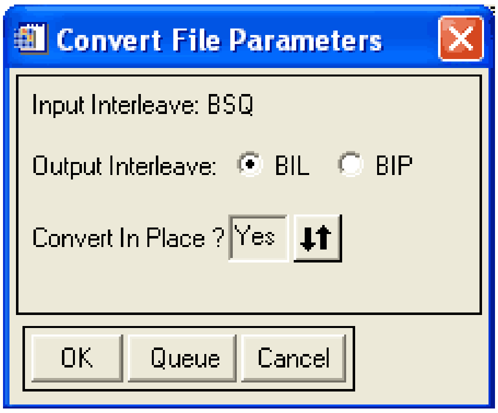
Then go to "Basic Tools"→ "Preprocessing"→ "Utilities Calibration"→ "Landsat TM", which displays a selection window of the image. Once we select the Landsat image, a calibration window pops up (see figure), where you set the satellite type, time of image acquisition, and solar elevation angle. This data is entered automatically by the program, since it get them from Metadata. If they were not available, we would have to provide them. Finally, we select the radiance or TOA reflectivity calculation and the output of the processed data. Select radiance, since it is the FLAASH algorithm's input data, and store the result in memory.



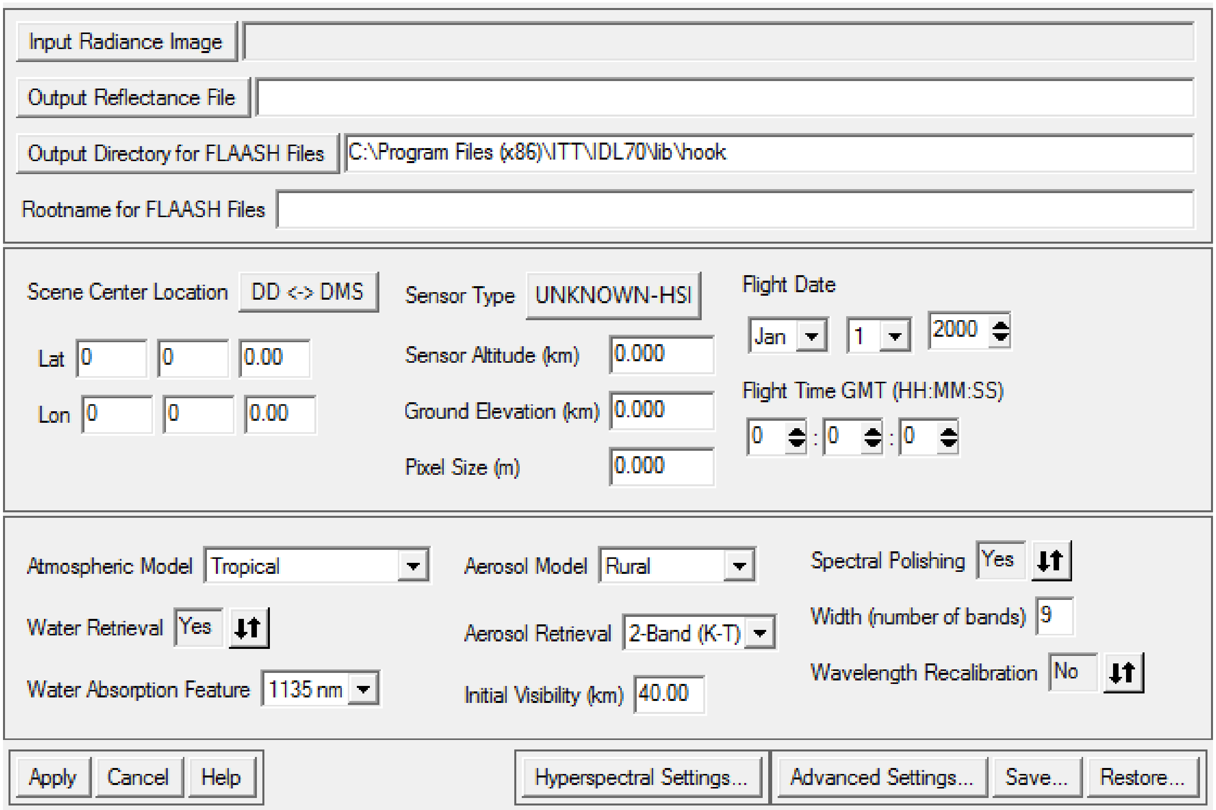
Next you need to make an adjustment of the physical units of the bands, since the radiance obtained is in [W / (m ^ 2 * sr * nm)], while FLAASH requires data in [μW / (cm ^ 2 * sr * nm)]. Thus we have to apply the bands a correction factor of 10. To do this, go to "Basic Tools"→ "Band Math" and a window pops up where you introduce the expression b1 / 10.0. Press OK and the "Variables to Bands Pairings" window pops up. Then select the band you want to divide by 10, e.g. band 1. Finally we set the path of the output image JasperRidgeTM_radiance.img and click OK.



Next we prepare the image for atmospheric correction. To do this we must change the *interleave*, since for spectral processing it is better to use BIP or BIL formats instead of BSQ, which is usually the default format used in the images. If you go to "Basic Tools"→ "Convert Data (BSQ, BIL, BIP)", a window pops up and allows you to select the image you want to process. Once it is selected, the following window pops up, where you select the interleave type you wish to select. Select YES in the "Convert In Place" option to modify it in the same image.

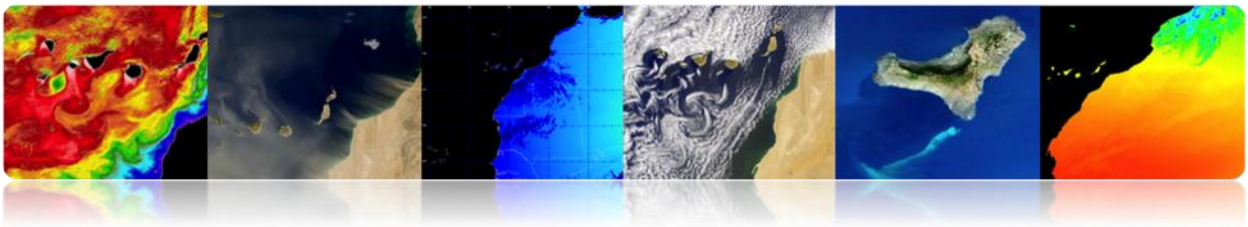


In this way we have created an image of radiance (band 1) configured correctly for the input format FLAASH. Then proceed to run the "Basic Tools"→ "Preprocessing" → "Utilities Calibration" → "FLAASH" module, where the following window pops up.

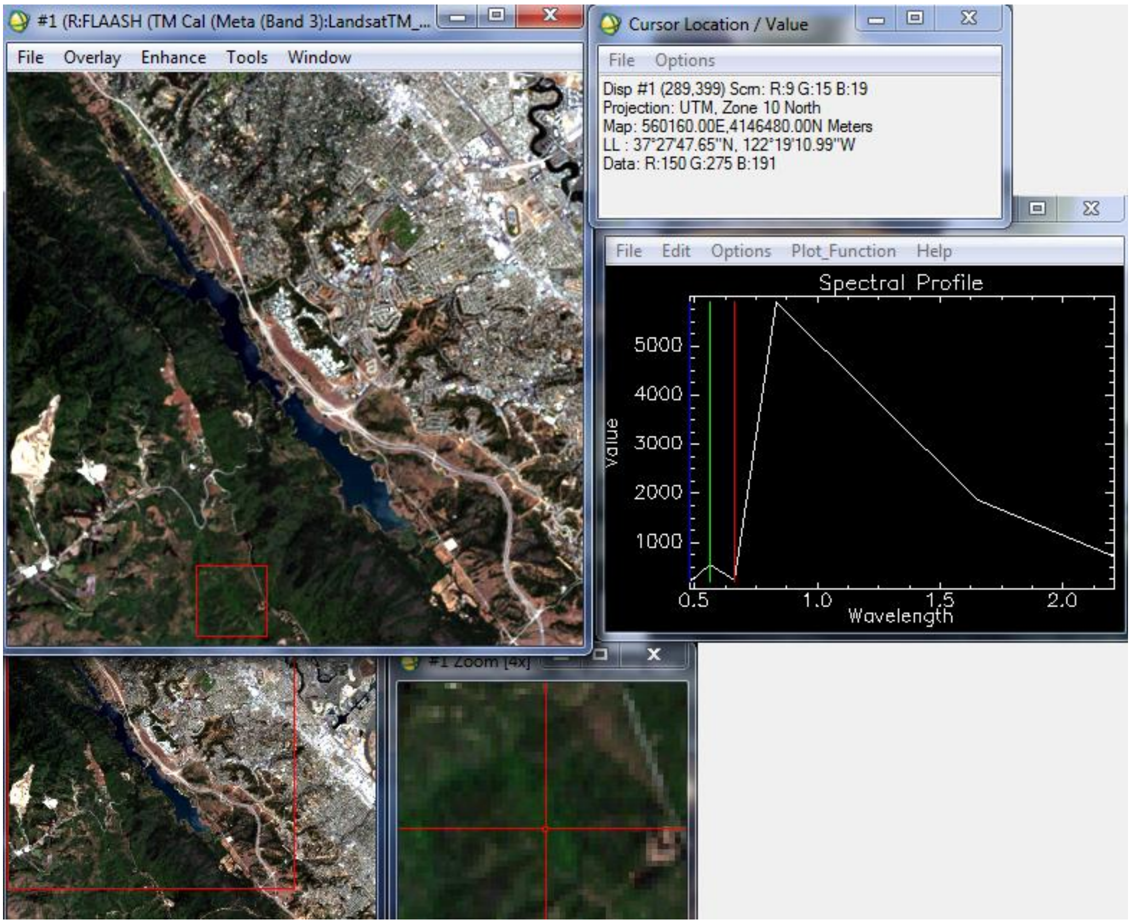


For configurating it:

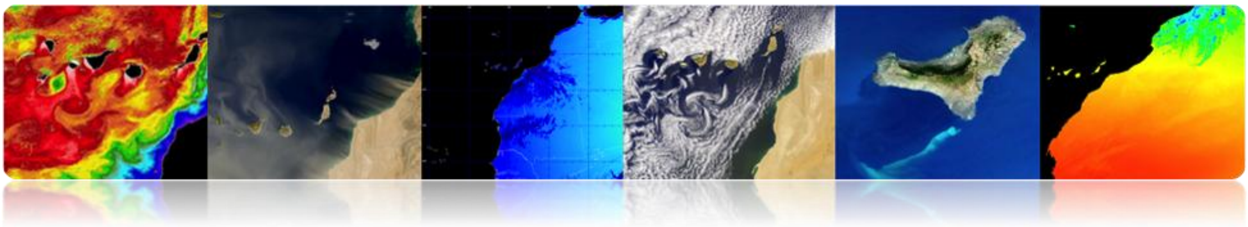
1. Press the "Input Radiance Image" button and select the image radiance. When the "Radiance Scale Factors" image dialog pops up, choose "Use Single scale factor for all bands". Since the units are correctly formatted, enter the value 1. If you had not done previously, you would have to enter a factor of 10.
2. Press the button "Output Reflectance File" and enter the path of the corrected image.
3. Press the button "Output Directory for FLAASH Files" to save the files needed to make the correction.
4. Introduce the root to the generated files in "RootName for FLAASH File".
5. Press the button "Restore..." where you can select the file with the configuration data required for the atmospheric correction of the image (JasperRidgeTM_template.txt). This will fill the geometric parameters of the satellite angle and sun, as well as the atmospheric settings and aerosols.
6. Press "Multispectral Settings" to see the functions of the filters of the bands. The bands used to calculate water vapor are not set because the satellite does not have bands that can be used for this purpose. For this reason, the "Water Retrieval" interface option indicates "No". In the same way, "Kaufman-Tanre Aerosol Retrieval" can be useful to see which bands have been used.
7. Finally, press "Apply" for atmospheric correction. The process may take a few seconds as you have to run the MODTRAN atmospheric model. Once the implementation finishes, the TOC surface reflectivity image in integer format (0-10000) is generated.



The following figure shows the corrected image JasperRidgeTM with surface reflectivity values between (0-10000). See the spectral profile that represents the value of the pixel channels selected by the cursor.

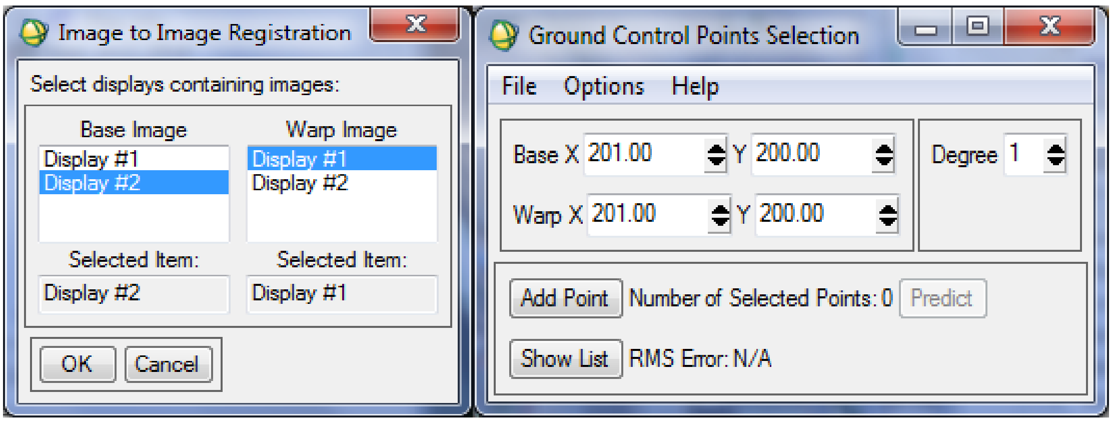


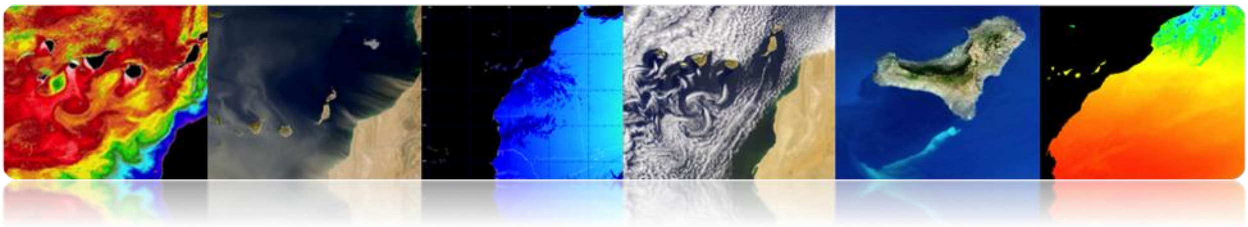
ENVI provides geometric correction utilities in the "Map" menu. In this menu, you can find modules for georeferencing multiple remote sensing satellite sensors. You can also find orthorectification modules, mosaic and registered. While georeferencing and orthorectification modules are used in the lowest levels of image processing, the registrant is a useful function when you want to compare images of the same geographical area.

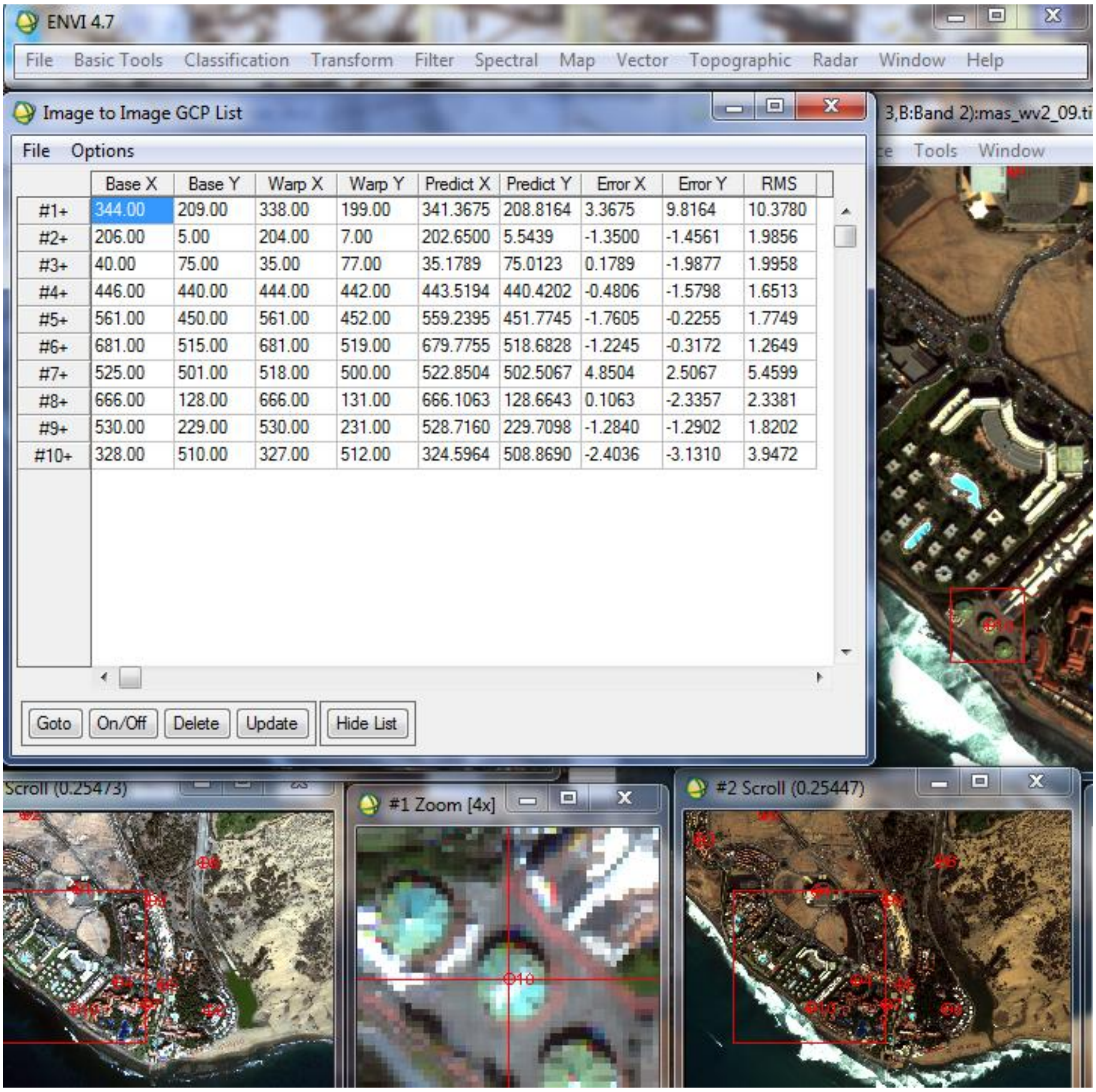


To use the registered module of ENVI, first you have to open in the viewers the two images that you will use for registration -in our example Maspalomas WV2 images. Then go to "Map"→ "Registration" → "Select GCPs: Image to Image". A display base dialog selection (in the example, we selected the image of 2009) pops up and also the Display to modify the image ("Warp") (image of the year 2013).

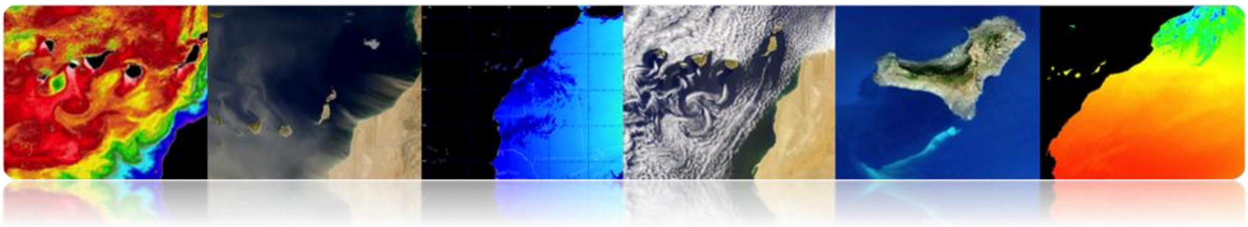
Press OK to display the manager to select the ground control points GCPs. Mark the control points in both viewers with a double click. In the "Options" menu, you can find the option "Automatically Generate Tie Points..." where the module selects control points automatically. This system cannot usually provide optimum results. For this reason, many times, you will have to it manually. Select each control point in both displays and then press "Add Point" to add the item to the list. After selecting enough points to make the registered list, select "Save GCPs to ASCII..." to save in the disk the list of points. The figure shows the viewers with the selection and the list of points that must be stored on disk.

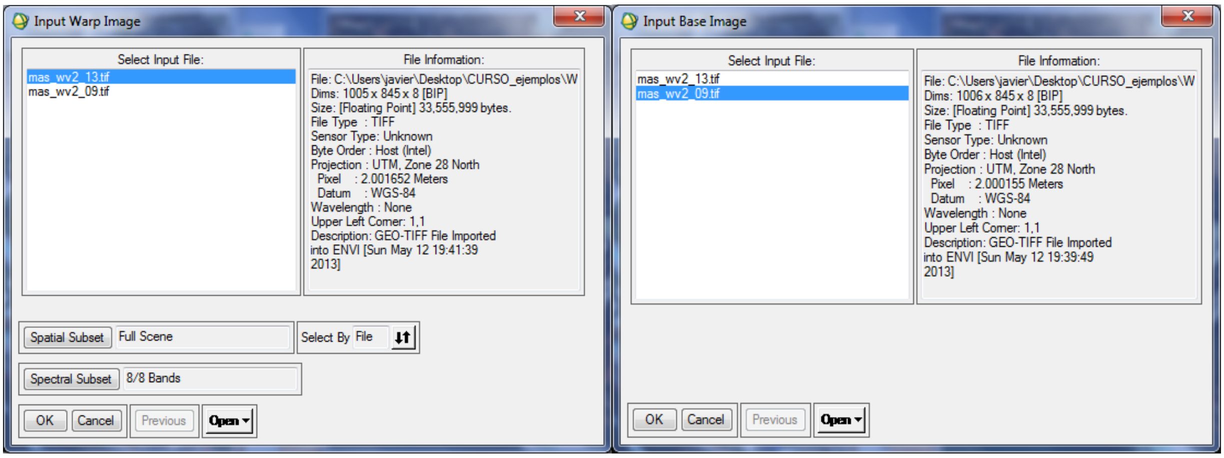




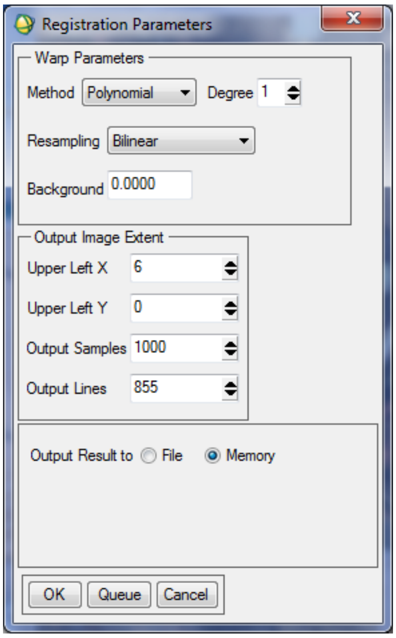


Once you have the control points for registration, perform the operation using the menu "Map"→ "Registration" → "Warp from GCPs: Image to Image". After selecting the menu option, a file selection dialog GCPs points pops up. There select the image to be modified, and then the reference image.

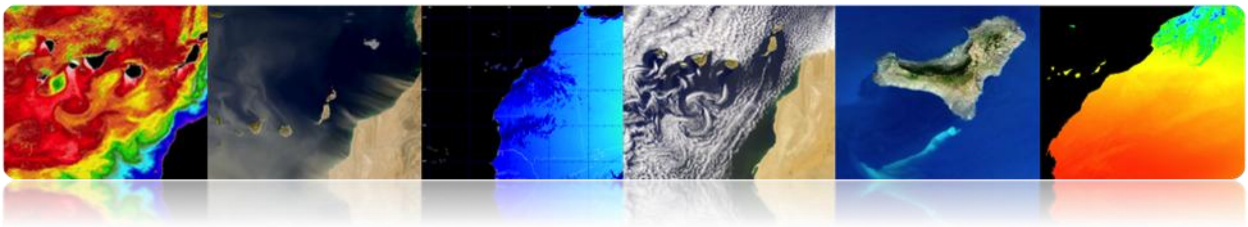


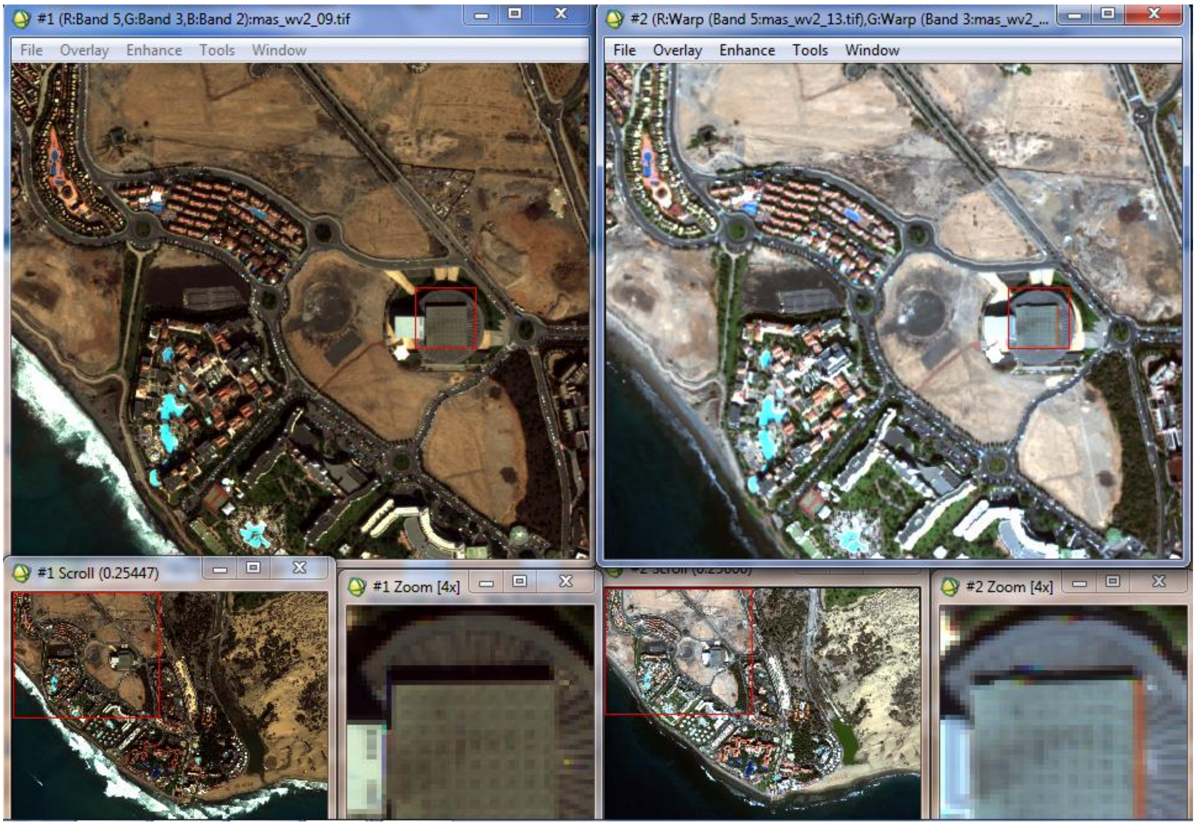


Once the selection of images is finished, a configuration window for the registered parameters pops up. You can select the method to deform the image to adjust it to the control points, such as the "Polynomial". You can also select the interpolation method, for example, "Bilinear". Once it is configured, press the Ok button to generate the registered image.

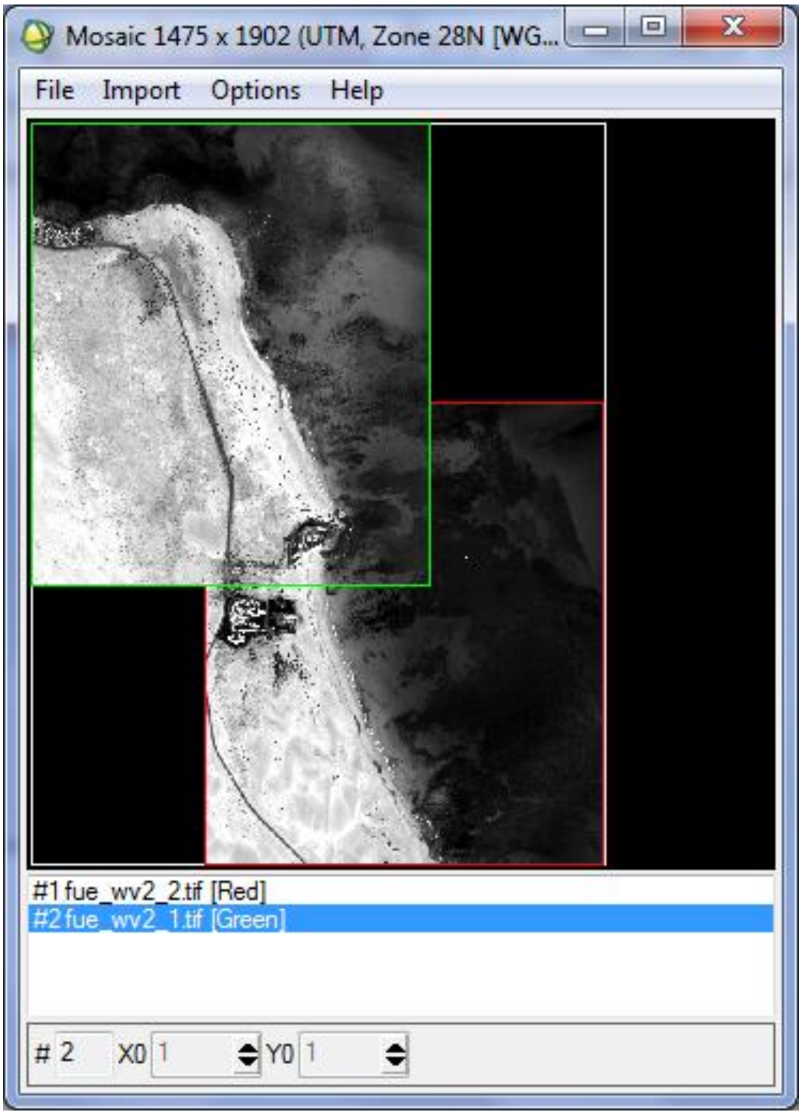


Finally we can compare the result by linking together the reference and the registered image.



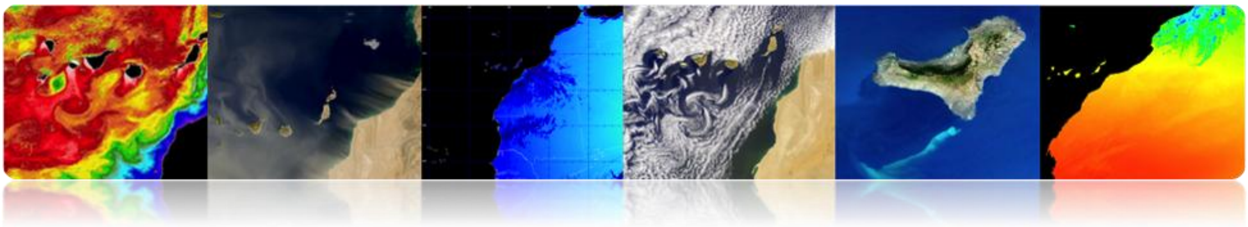


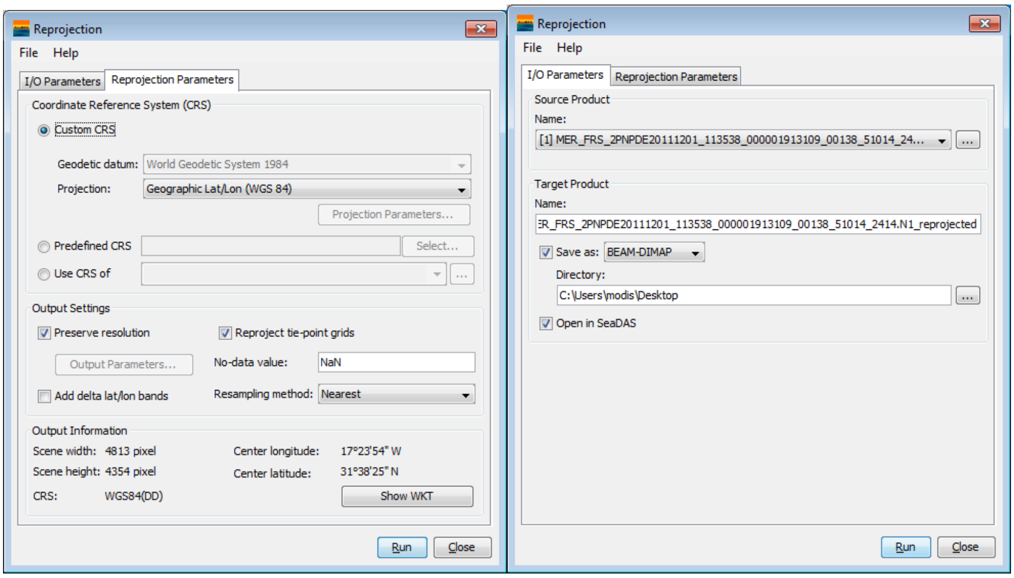
The mosaic module "Map" → "Mosaicking" → "Georeferenced" provides the utility to generate mosaics using georeferenced images. We are going to use the images WV2 to show it. Once the module is selected, a window "Map Based Mosaic" pops up. In this window, the mosaic is generated. Go to "Import" and select the 2009 and 2013 images. After a few seconds, a mosaic with the two images will be generated. The two regions are displayed separately by green and red edges. The two images overlap in the center prevailing the green edge image. Once the mosaic is generated, it can be saved to the disk.

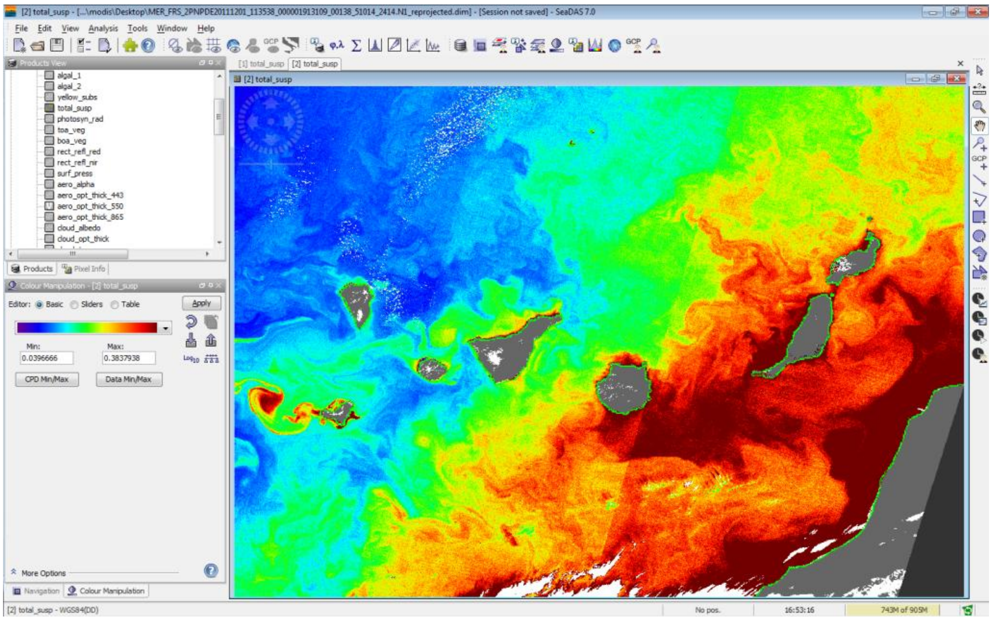


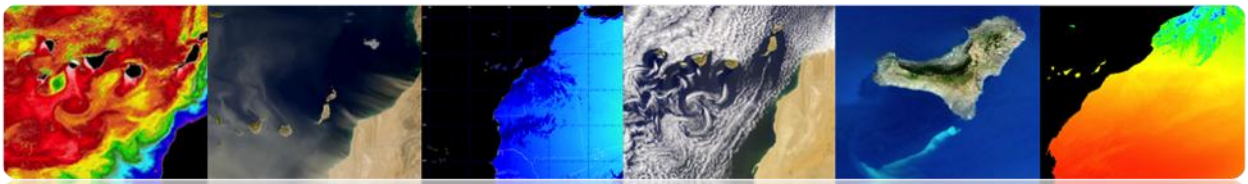
❑ SEADAS

SeaDAS allows reprojection of images accessing the menu "Tools"→ "Reprojection...". After the selection, a configuration window pops up to configure the parameters of the reprojection. In "Projection Parameters" the projection type may be set -geographic WGS84 by default- and it allows setting the interpolation method. The output data type and path is set in "I / O Parameter. Once the image is reprojected, which can take several minutes, the new image is stored on disk and accessible for viewing.




Reprojection
File Help
I/O Parameters
Reprojection Parameters
Coordinate Reference System (CRS)
Custom CRS
Geodetic datum: World Geodetic System 1984
Projection: Geographic Lat/Lon (WGS 84)
Projection Parameters...
Predefined CRS
Select...
Use CRS of
Output Settings
Preserve resolution
Reproject tie-point grids
Output Parameters...
No-data value: NaN
Add delta lat/lon bands
Resampling method: Nearest
Output Information
Scene width: 4813 pixel
Scene height: 4354 pixel
CRS: WGS84(DD)
Center longitude: 17°23'54" W
Center latitude: 31°38'25" N
Show WKT
Run
Close
Reprojection
File Help
I/O Parameters
Reprojection Parameters
Source Product
Name:
[1] MER_FRS_2PNPDE20111201_113538_000001913109_00138_51014_24...
Target Product
Name:
ER_FRS_2PNPDE20111201_113538_000001913109_00138_51014_2414.N1_reprojected
Save as: BEAM-DIMAP
Directory:
C:\Users\modis\Desktop
Open in SeaDAS
Run
Close





3.3. REMOTE SENSING IMAGES THEMATIC CLASSIFICATION

Classification is an important step, since it allows to generate a thematic map with the classes of interest from the numerical data of the spectral bands.

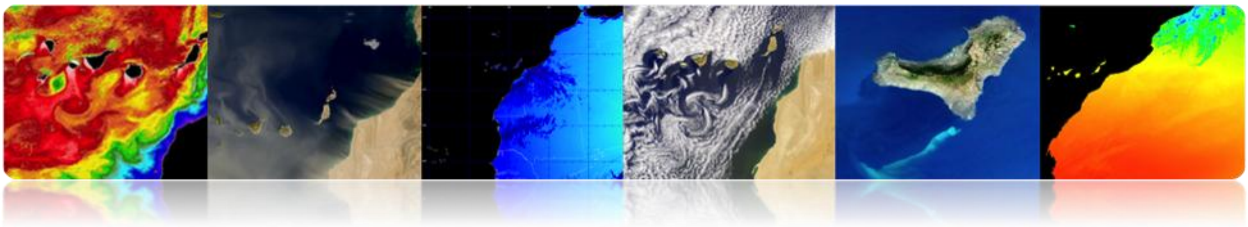
Next, we use ENVI and Monteverdi softwares to generate a classified image with a supervised and an unsupervised method. SEADAS does not allow making classifications.

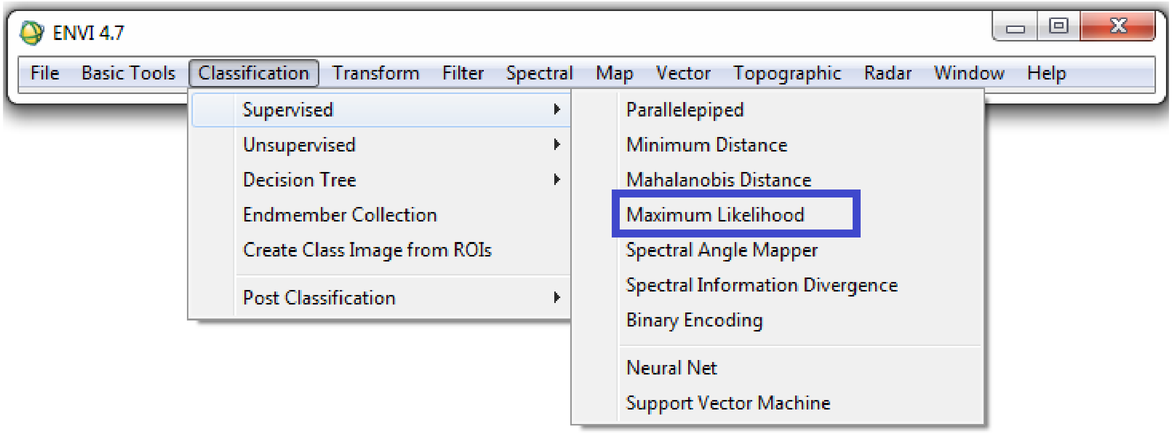
❑ ENVI

• Supervised Classification Process

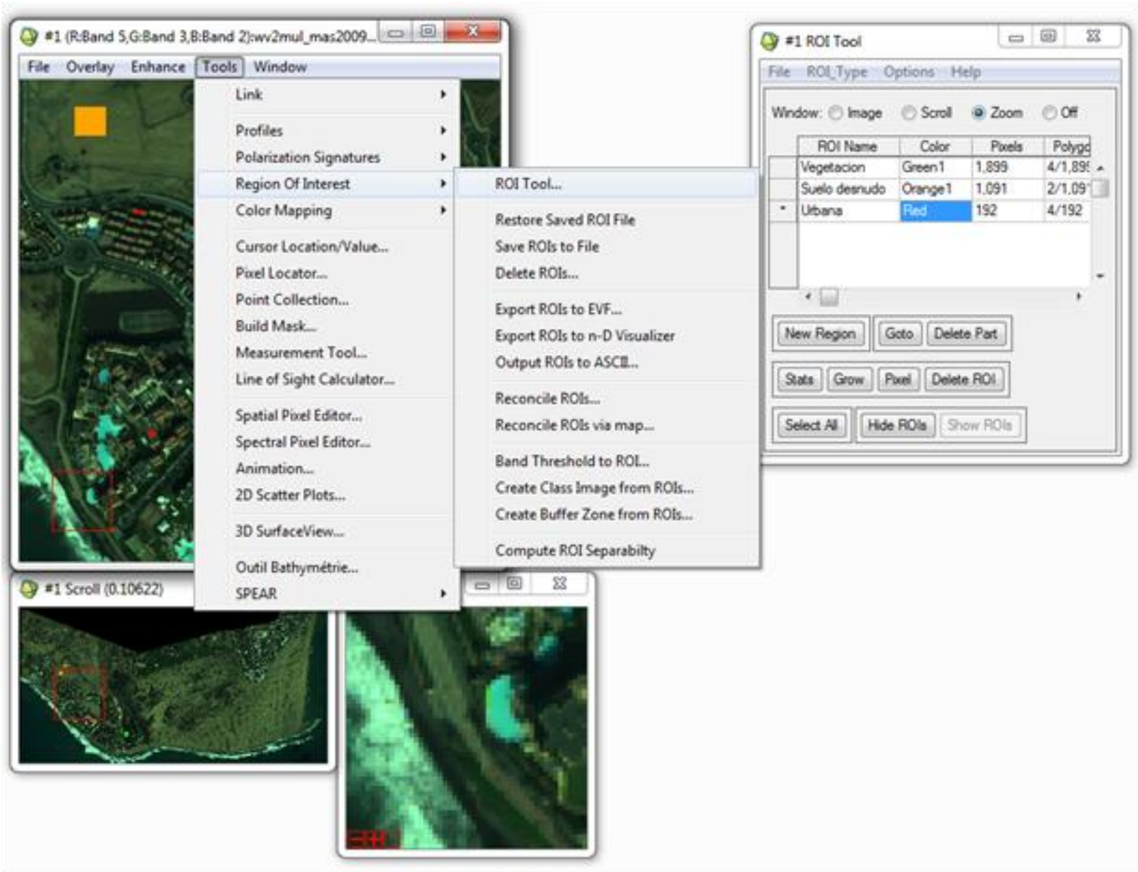
In the supervised classification, the user selects training areas. These training areas are defined as groups of pixels that represent a homogeneous area or material that will be associated with a class. Regions of interest (ROIs) are used in ENVI to create the training areas. Also, you can ensure separation of classes to avoid overlap between them by representing them on a n-dimensional (nD Visualizer) map.

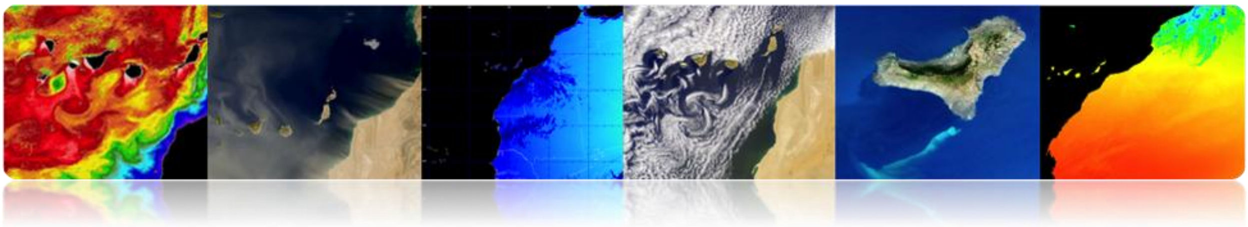
ENVI has implemented a variety of classification algorithms, as we can see in the following figure. In this practice we will focus on the Maximum Likelihood algorithm, because it provides one of the best results. Maximum Likelihood classifier assumes that the statistics for each class in each band are normally distributed and calculates the probability that a pixel belongs to a specific class. Unless you select a threshold, all pixels are classified. Each pixel is assigned to the class with the highest probability. If Maximum Likelihood is less than the specified threshold, the pixel is not classified.



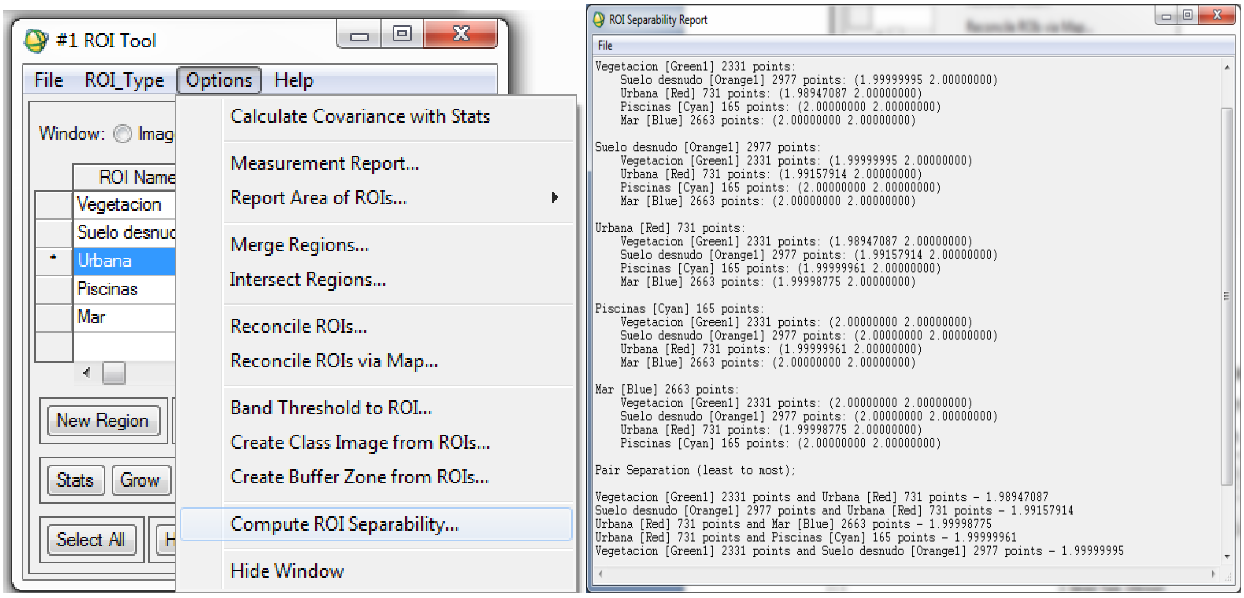


Before applying the classifier, it is necessary to create the regions of interest that we are going to associate to the classes that we want to get to the output of the classifier. Select Tool -> Region of interest -> ROI Tool.. and add the different classes, assigning a name and color, to be easy to identify them in the classified image.



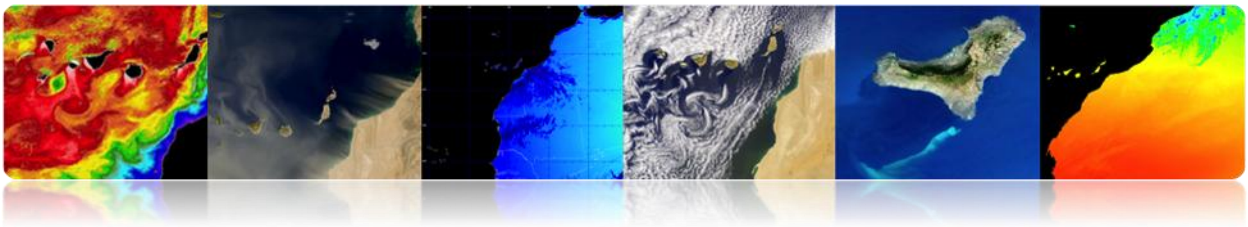


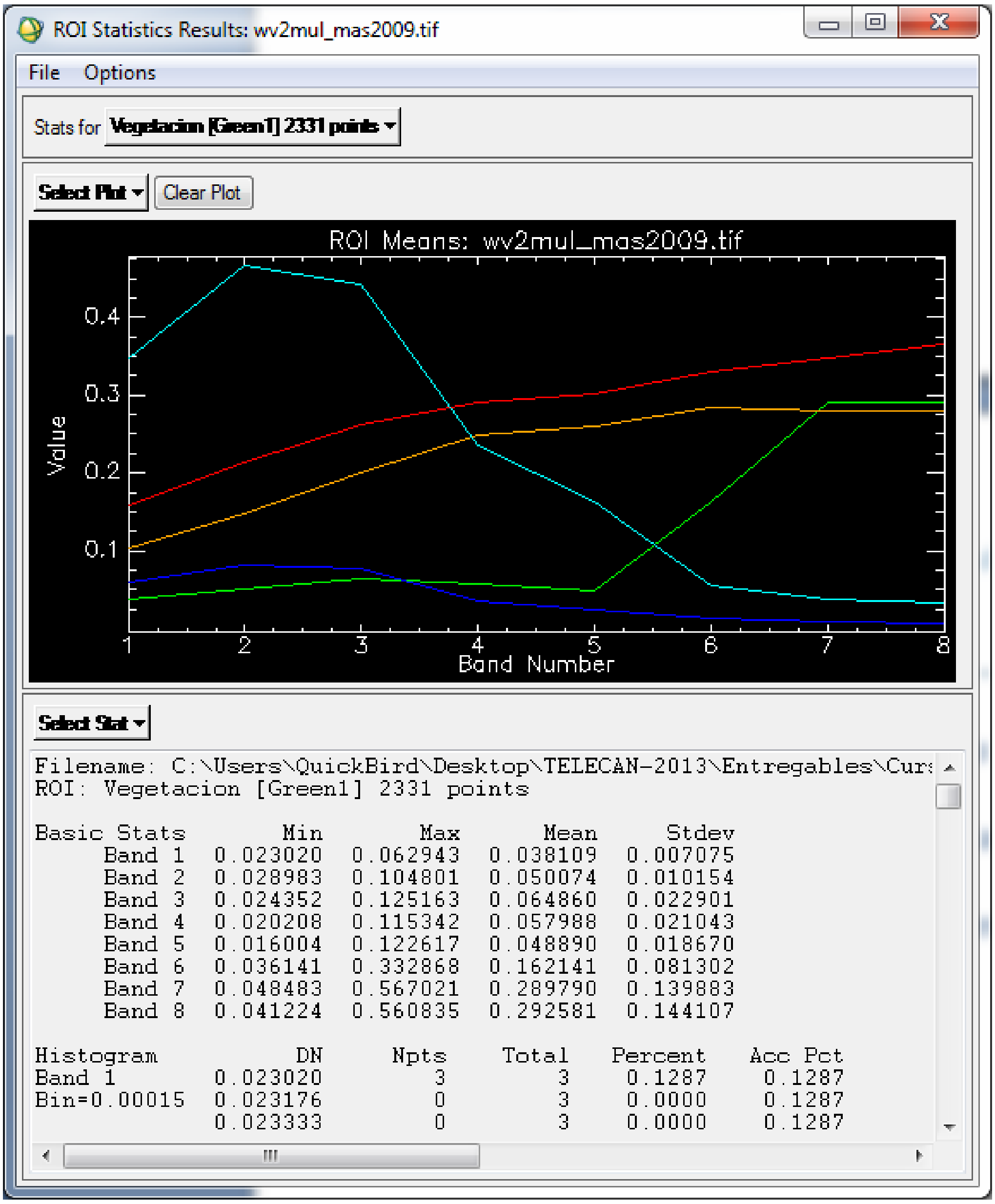
Once we have chosen several regions of interest for each class, we can make a separability analysis, as shown in the following figure. It returns the Jeffries-Matusita indexes and Transformed Divergence that measure the statistical independence of the pairs of ROIs. They have a range that goes from [0 2]. Values greater than 1.9 indicate good separability. For values less than 1,it is recommended to combine both classes.



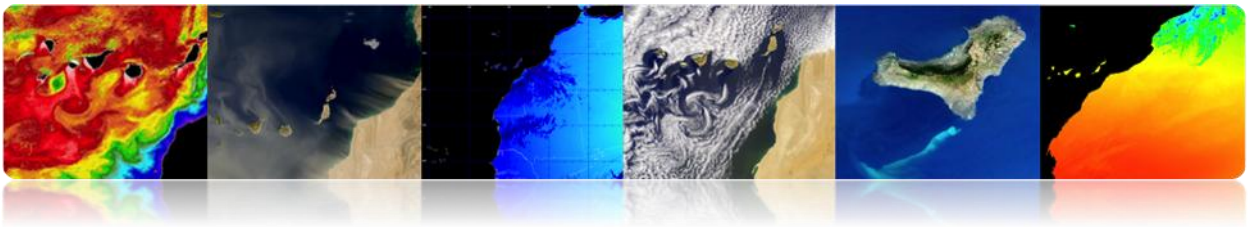
In the case shown above all classes have a good separability.

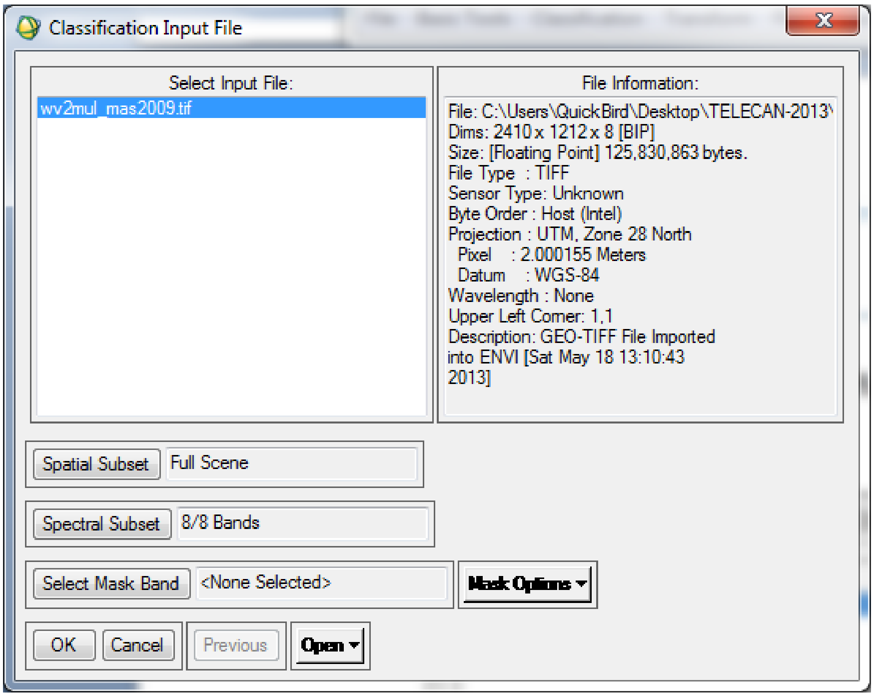
In addition, we also have the option of performing a statistical analysis of the classes. The information of ENVI is shown in the figure. We can obtain the spectral response of each of the classes created.



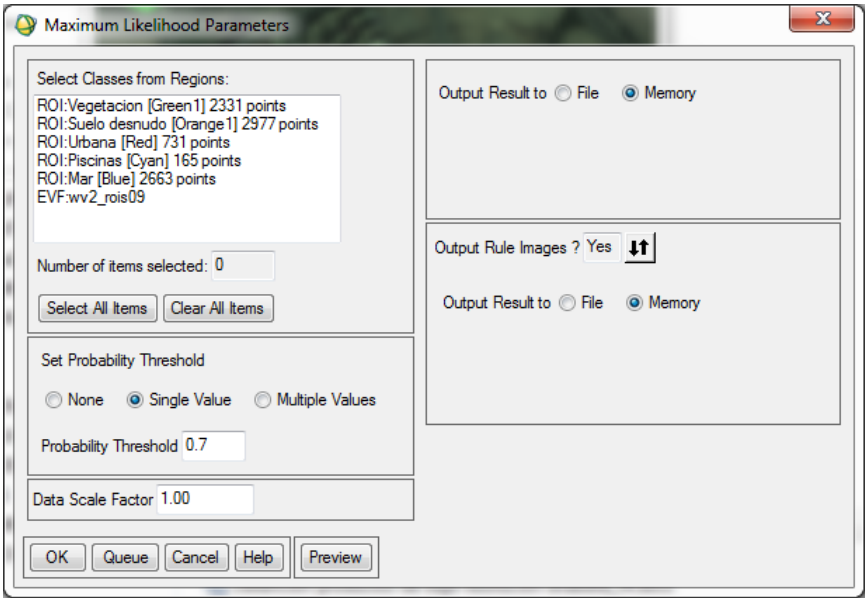


The next step is to save the ROIs to proceed to use them in the classifier. Close the window and select ROIs Tool on the Overlay-> Classification main menu. The following window pops up. As we can see, it allows limiting the classification to an area or specific bands. You can also add a mask to indicate pixels that are not used by the classifier.

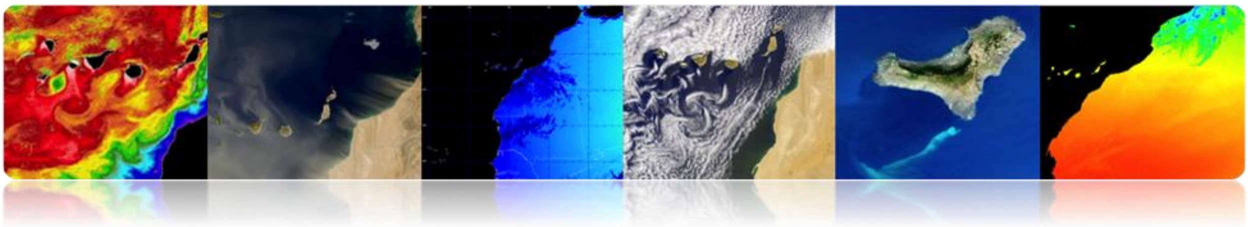




Select the configuration parameters of the classifier:

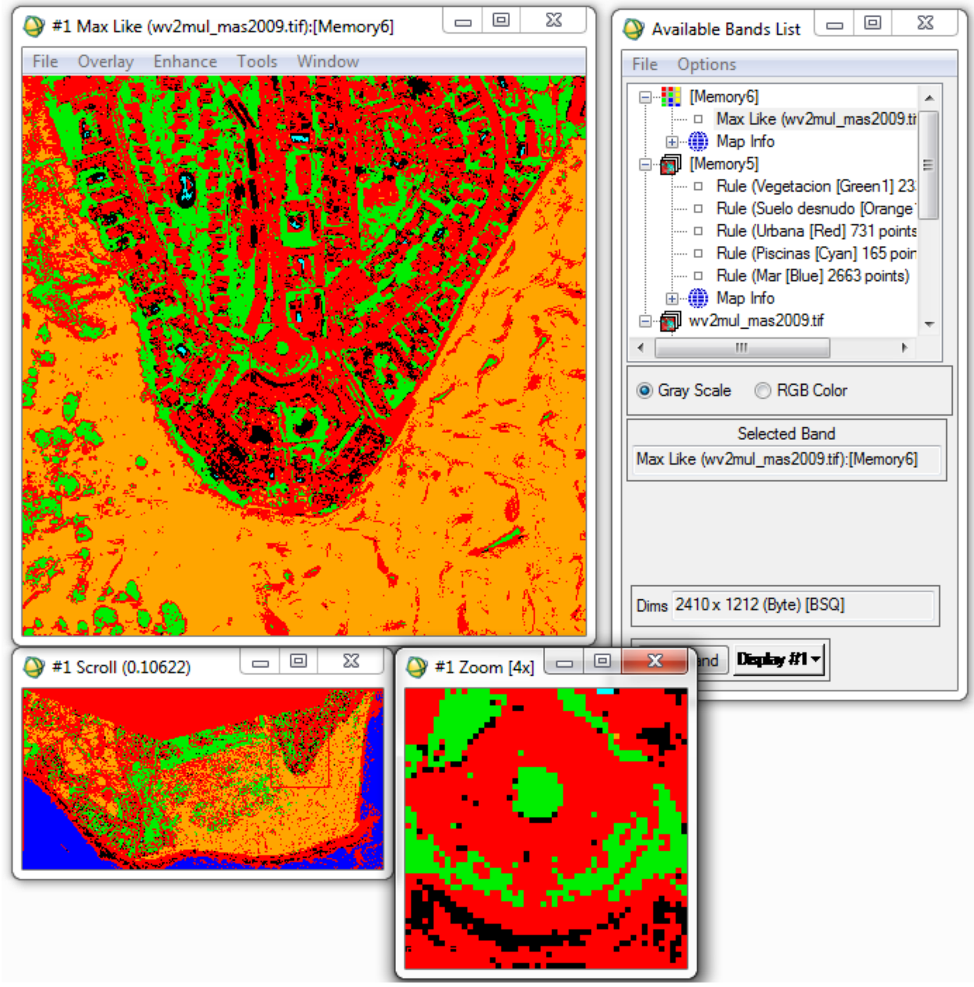


Single Value: Use a single threshold for all classes. Enter a value between 0 and 1 in the *Probability Threshold* field. ENVI does not classify the pixels with values below this value.

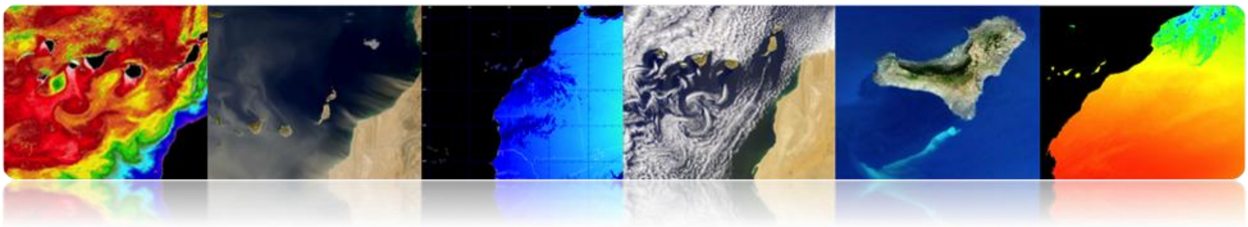


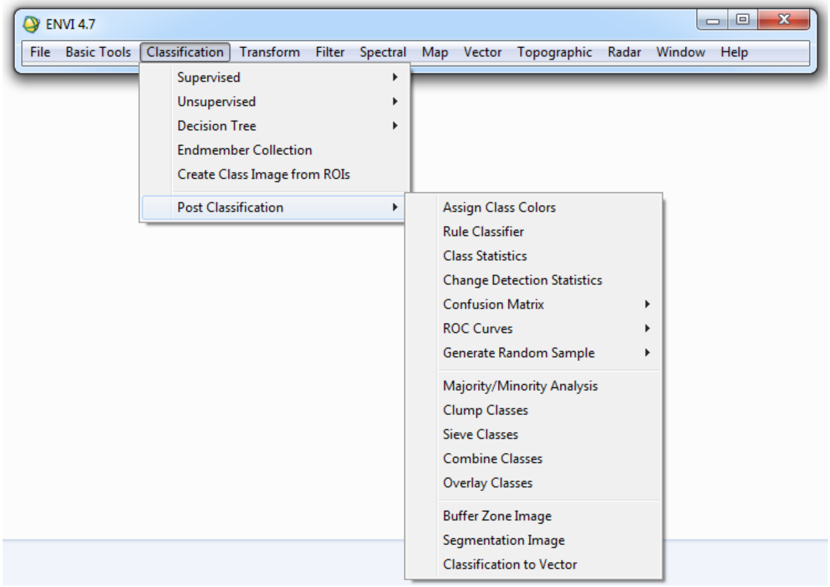
Data Scale Factor: A division factor used to convert scaled radiance or reflectance values to integers float values.

Rule Output Images: The rule images are created as an intermediate form before creating the image with the final allocation of classes. Then you can use the *Rule Classifier* to create likelihood images of each class. The white areas represent those belonging to that class. Also, we can preview before generating the final version.



The next method for improving the classification results is to perform a post-classification process, where we can apply filters (option *Majority / Minority Analysis*).





In that *Post Classification* menu, there is also the option to evaluate the accuracy of the classified image by calculating the confusion matrix and kappa coefficient.

Confusion Matrix: {M6} (640x400x1)

Overall Accuracy = (131003/256000) 51.1730%

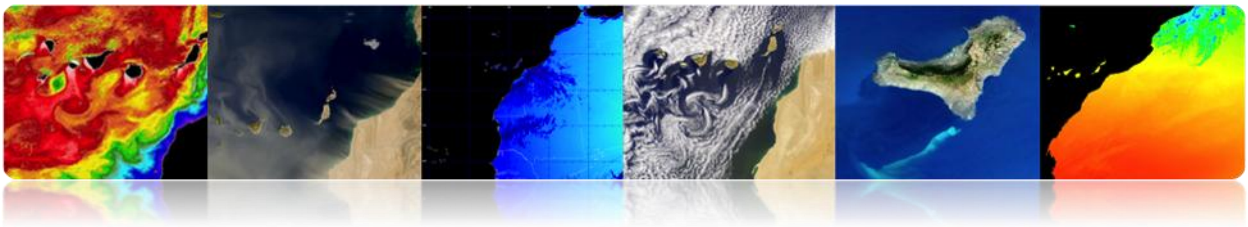
Kappa Coefficient = 0.2648

Ground Truth (Pixels)

Class	Unclassified	Grass	Forest	Swamp	Total
Unclassified	43689	26949	40	18001	88679
Grass	32835	64516	1741	3329	102421
Forest	8202	7277	4096	654	20229
Swamp	15227	10742	0	18702	44671
Total	99953	109484	5877	40686	256000

Ground Truth (Percent)

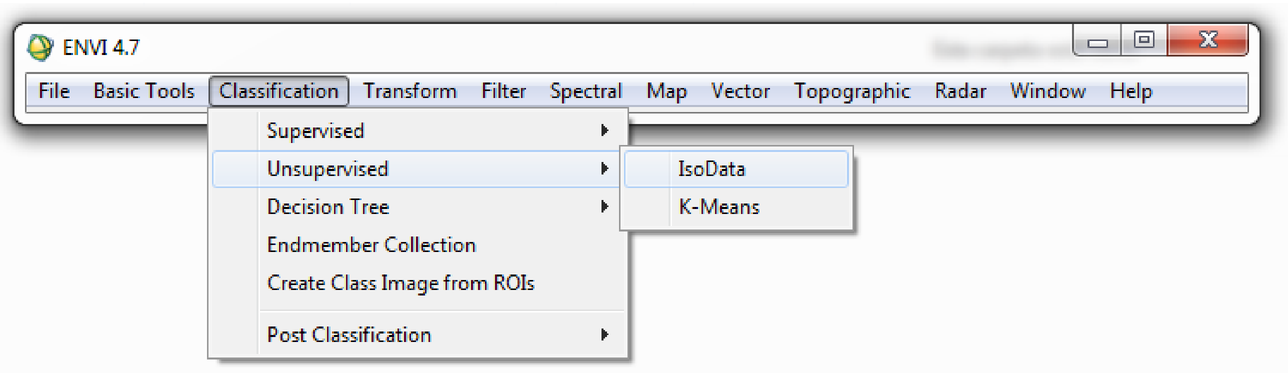
Class	Unclassified	Grass	Forest	Swamp	Total
Unclassified	43.71	24.61	0.68	44.24	34.64
Grass	32.85	58.93	29.62	8.18	40.01
Forest	8.21	6.65	69.70	1.61	7.90
Swamp	15.23	9.81	0.00	45.97	17.45
Total	100.00	100.00	100.00	100.00	100.00



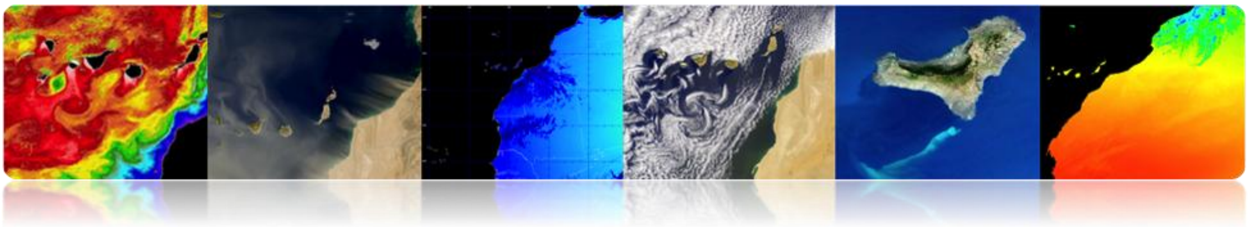
The confusion matrix evaluates the conflicts that occur between classes. To get it, a list of test points whose actual coverage is known is compared to a list of points deduced by the classifier. In a confusion matrix, rows correspond to the reference classes and columns correspond to the classification derived classes. The diagonal represents the points at which there has been agreement between the actual and derived classes. This matrix is very useful to measure the accuracy and reliability of the classifier. The example shows that for the *Class Grass,* 64516 pixels have been correctly classified. However 26949 pixels have been *Unclassified* (not classified), 7277 have been classified as *Forest* and 10742 as *Swamp*.

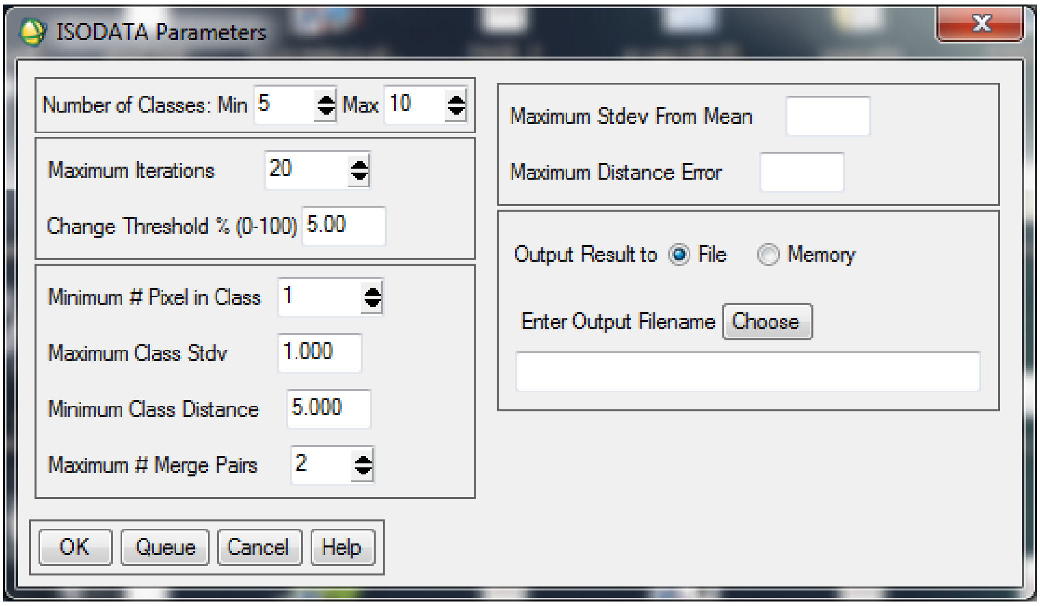
• Unsupervised Classification Process (ISODATA)

Within the unsupervised classification algorithms the most widespread is called ISODATA.



Here you are the configuration window ISODATA classifier.





Select the number of classes to be defined. This range is required for the algorithm groups and it divides the pixels based on thresholds.

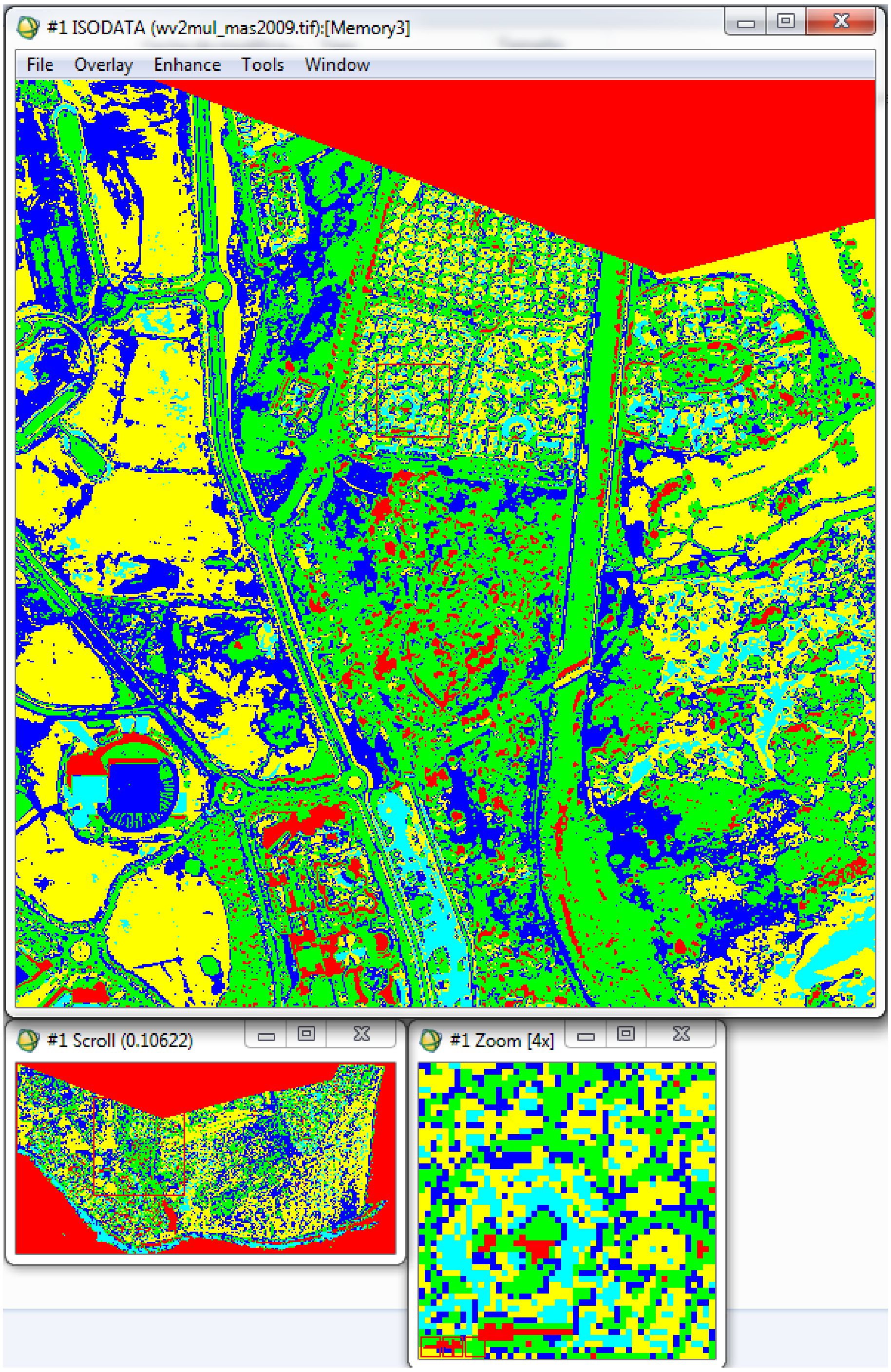
Introduce the maximum number of iterations and the threshold of change. The last one is used to terminate the iterative process, when the number of pixels in each class changes by less than the threshold.

Introduce the minimum number of pixels required to form a class.

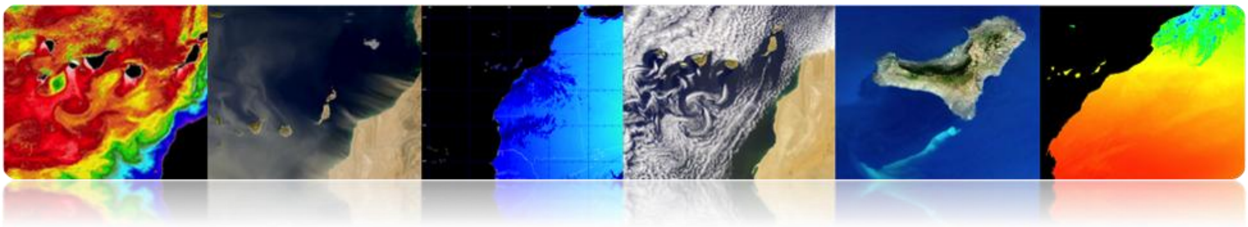
The next parameter defines the maximum standard deviation between classes (*Maximum Class stdv*) in digital levels (DN).

Finally, introduce the minimum distance between the means of each class -also in DN- and the maximum combined couples.

In principle, the unsupervised analysis becomes an iterative process where the user sets arbitrary values that are modified according to the results.



Filtering may applied to improve the classifier quality, merge classes, change colors, etc.



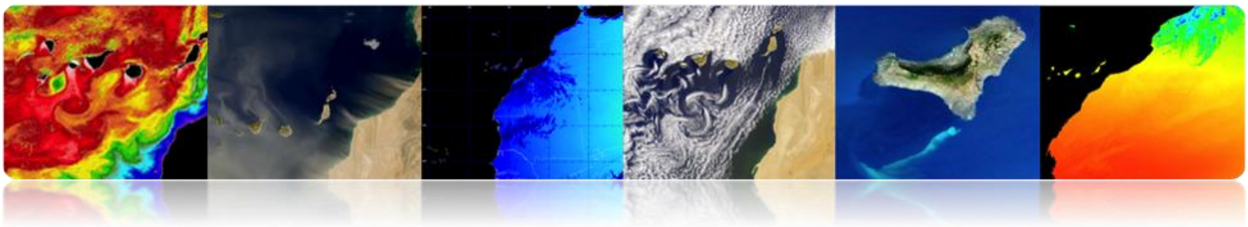
❑ MONTEVERDI

• Supervised Classification Process

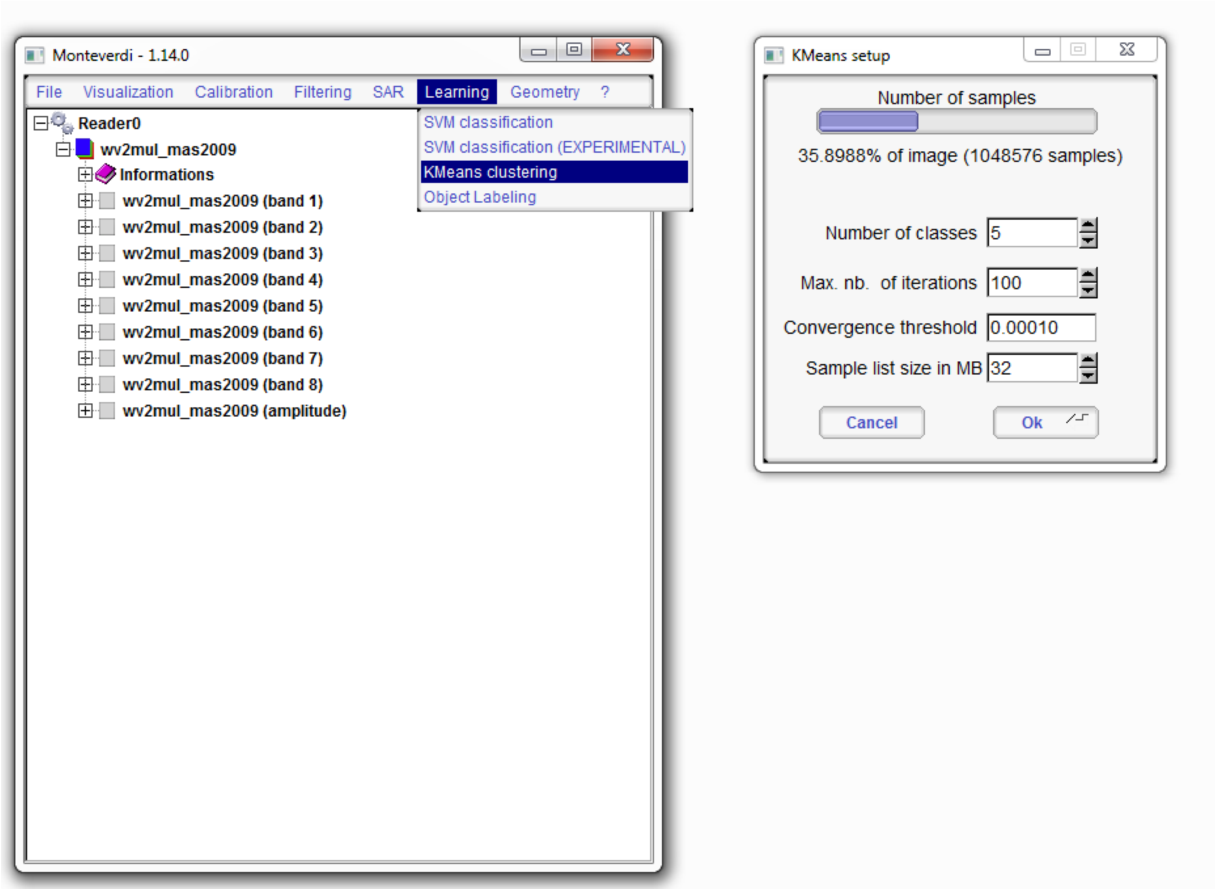
Next, we will make a practical procedure to define the different classes over the image, generating different regions of interest. Then we will run the classification algorithm to see the results we have got on the classification process. The process is quite similar following the options that appear on the screen.

• Unsupervised Classification Process

Next, we proceed to run an unsupervised algorithm. Specifically Monteverdi has implemented *KMeans* algorithm. Thus, we can compare the results obtained in both classifications.



The requested values will be completed by the tool. Then press OK.



Jefe de fila

Socios

Colaboran