STEREO II

Belgian Earth observation research programme

belspo

Twice in my life I've had the extraordinary privilege to view the Earth from the International Space Station ISS. Our planet is beautiful to behold but at the same time small and fragile in the immeasurable space that surrounds it. Unfortunately only a few people and scientists get the chance to observe the Earth directly from space. Luckily they can call on nearly two hundred Earth observation satellites that orbit the Earth and, day after day, gather a wealth of information.

Seen from space, Belgium is tiny, but when it comes to Earth observation research we can measure ourselves without hesitation with the larger countries. The Belgian long-term strategy has helped make this possible. The STEREO II Programme closes off a 30-year series of Belgian Earth observation programmes. It's clear that Earth observation research in Belgium has reached maturity. Its Earth observation community is extraordinarily dynamic. No less than a hundred research groups and 300 scientists were active within the Programme.

The knowledge they gathered thanks to the Programme resulted in more than 380 scientific articles. What pleases me particularly is the fact that established scientists are not the only ones that got a place within the Programme; young beginning scientists get plenty of opportunities as well.

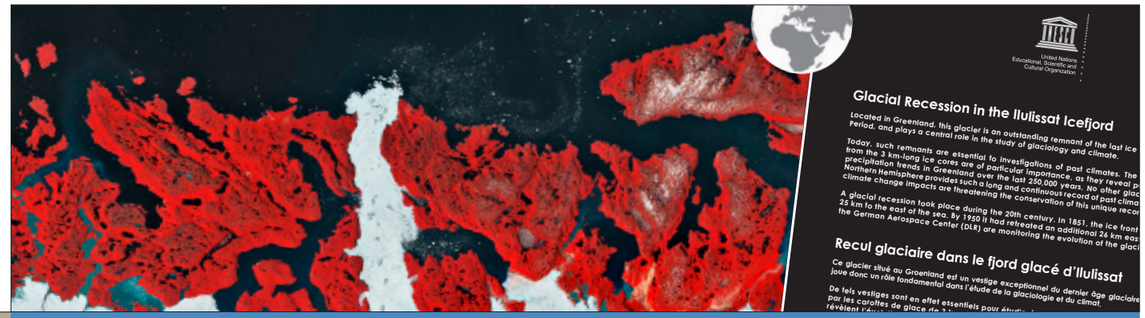
Earth observation has become an essential tool in a very diverse range of study areas, from archaeology in the Nile Valley to zooplankton studies in the river Scheldt and numerous other disciplines and study areas in between. Time and time again Earth observation helps us to better understand what happens on land and at sea, and what the effects are of climate change. This publication tries to summarise the rich variety of Earth observation research in the STEREO II Programme and offers an attractive sample of the most important research results. I invite you to discover along with me how Belgian scientists examine the Earth in all its facets, and hope you enjoy the read.

Frank De Winne
Head of the European Astronaut Centre
ESA Astronaut

EARTH OBSERVATION, WITHIN EVERYONE'S REACH

Since the launch of the first Earth observation satellite 40 years ago, remote sensing has gradually become an irreplaceable source of information on our planet, its continents, its oceans and its atmosphere. Satellite imagery provides information for scientific research as well as technological and industrial development. It is a fundamental assessment and warning tool, for instance, regarding the vulnerability of certain ecosystems and imbalances, many of which are linked to climate change (ocean degradation, desertification, deforestation, melting ice, etc.). It is also at the basis of the development of countless applications in increasingly common contexts, like Google Earth, which has now become part of our everyday lives.

The images delivered by civilian satellites have reached an unprecedented precision thanks to a resolution below 50 centimetres, providing a greater level of detail. Temporal coverage is also progressing: increasingly frequent acquisitions allow the near continuous monitoring of terrestrial ecosystems and resources on a local, regional and global level. There is now a considerable amount of archived data allowing us to better understand past evolutions and fine-tune models to predict future evolutions. The variety of observation platforms (from satellites to drones) and onboard instruments (optical imaging systems, radar, LiDAR, hyperspectral, etc.) has increased the types of parameters recorded and provides a range of information that can be combined to meet a vast number of problems. Finally, thanks to a broader offer, the cost of the images is becoming more democratic. In addition, following a trend to make Earth observation accessible to as many people as possible (scientists, political decision-makers, companies, citizens, etc.), more and more images are available for free.



Small country, big ambitions

On the international scene, Belgium is positioned as a knowledge centre in Earth observation. The Federal Science Policy (Belspo) in Belgium does indeed support a chain of excellence, from a high level of fundamental research and advanced engineering in image processing and interpretation, to the development of operational applications for an ever-increasing number of end-users. Here are a few important landmarks:

- In 1984, Belgium set up its own national Earth observation research programme. Thanks to continuity between the programme's different phases (Telsat, followed by STEREO I, II and III), the country has created a unique network of competences in the field over the past 30 years.

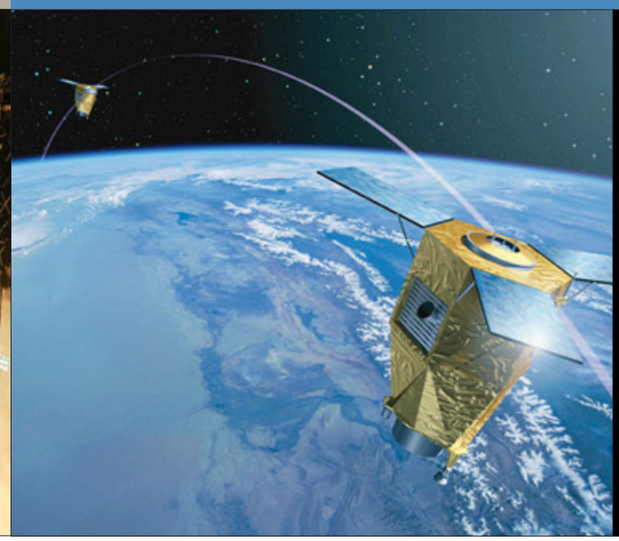
- Our country is an eminent contributing member – ranked 5th – of ESA (European Space Agency). It supports the activities of the intergovernmental organisations ECMWF (European Centre for Medium-Range Weather Forecasts) and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) in terms of weather and climate forecasting and environmental monitoring. We also actively participate in the EARSeL (European Association of Remote Sensing Laboratories) scientific network.

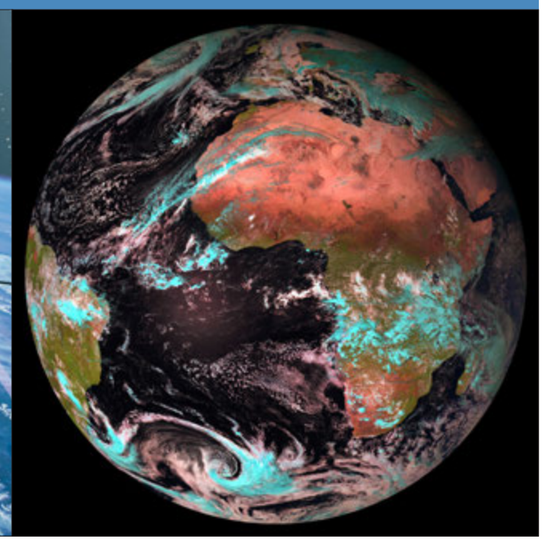
- We are behind several significant projects conducted by ESA, such as the design of flexible and innovative satellites in the PROBA family. The most recent one, PROBA-V, launched in 2013, is designed to monitor vegetation on a global level.

- The Federal Science Policy is also cooperating with UNESCO through projects that use satellite imagery to improve the monitoring and management of sites on the World Heritage list.

- Belgium also maintains bilateral collaborations, in particular with France, and participates in the Pléiades programme, a next-generation constellation that provides very high resolution data (see page 33).

All these initiatives are part of the priorities that fall under Copernicus, the European Earth Observation Programme for environment and security.





New trends in Earth observation

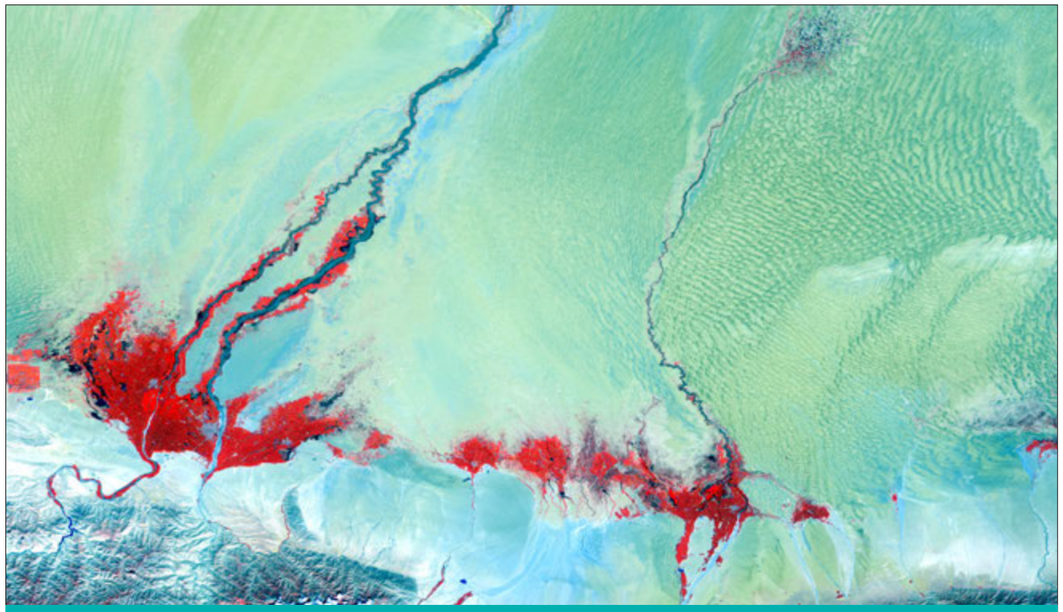
- Benefiting from developments in miniaturisation, satellites have continued to grow lighter and smaller. Easier to mass-produce and cheaper to send into orbit, microsatellites (between 10 and 500 kg), nanosatellites (between 1 and 10 kg) and even picosatellites (less than 1 kg) have become common.

- Observations from airplanes or remotely controlled drones are increasing and allow greater flexibility in terms of onboard sensors and the programming of acquisitions.

- More and more 'small' countries are acquiring their own observation satellite(s), targeting their areas and parameters of interest.

- Initiatives facilitating systematic access to local and global satellite data are increasing, both on the national and the international level. Hence, the Copernicus programme led by the European Commission offers free access to data from Sentinel satellites, the first of which was launched by ESA in 2014. This policy aims to stimulate the use of satellite data thus leading to as wide a range of operational applications as possible.

The next phase of the STEREO III programme (2014-2021) falls under the scope of these new trends. Besides support for advanced scientific research, STEREO III will place even greater emphasis on research results, in particular to allow the greatest number of people to benefit from them (public services, private sector, academic world, etc.).



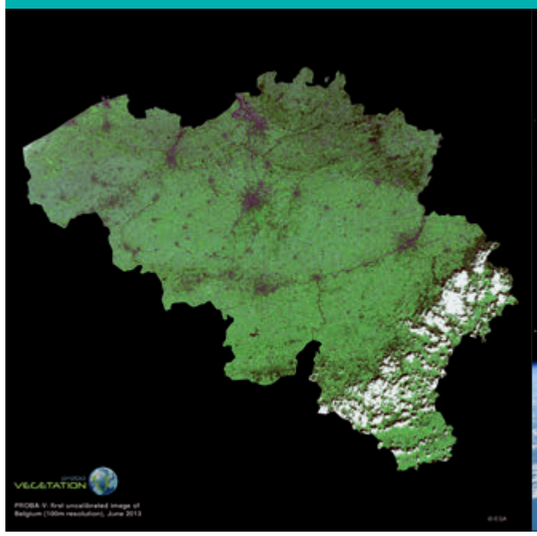
PROBA-V, for the global monitoring of vegetation

Launched by ESA in 2013, the PROBA-V satellite is the result of 100% Belgian impetus and development. The main task of this small craft (140 kg for less than 1 m³) is the continuous observation of the state of vegetation on a global scale. On board is an improved version of the VEGETATION sensor, which was already present on the SPOT-4 and SPOT-5 satellites. This new sensor delivers images daily at a resolution of 1 kilometre, in continuity with the old data, but also more precise images at a resolution of 300 metres. Since March 2015, PROBA-V even distributes complete coverage of the Earth every five days at a resolution of 100 metres. It operates within the ideal spectral bands to distinguish the types of vegetation cover, the different varieties, the growth levels of the plants cultivated and their state of health.

Available since 1998, VEGETATION images cover the Earth's entire surface every day. They have proved their usefulness in many applications and operational services, such as the monitoring of agricultural production, the forecasting of food crises, the monitoring of desertification and water resources, the detection of forest fires, etc.

The satellite was designed and developed thanks to Belgian expertise in the field of small flexible satellites. Belgian teams also look after the processing, production, distribution and archiving of its data. Belgium is now positioned as a decisive player in the production and distribution of global data to meet the specific needs of thousands of users worldwide.

More info at **proba-v.vgt.vito.be**



STEREO II REINFORCES BELGIAN EXPERTISE IN EARTH OBSERVATION

The large-scale research programme, STEREO II (2006-2014) consolidates the aptitudes Belgium has acquired over the past 30 years in the field of Earth observation, while expanding its international aspect.

The programme mainly finances two major types of projects: fundamental and thematic scientific research, and research aimed at the adaptation and transfer of scientific results to pre-operational applications by scientific teams for public services, private companies or NGOs (UNESCO,WWF, FAO, etc.).

By encouraging multidisciplinarity and synergies with research centres from all areas, the programme particularly allows researchers to participate in initiatives elaborated on a bilateral, European and global level. As a matter of fact, this international foothold is defined in the programme's protocol and is included in every stage of the monitoring of this research.

RIGOROUS PROJECT SELECTION

Six project calls were launched during the programme. After an initial test to see which projects met the criteria defined in the call, every proposal was systematically assessed in two phases (one written and one oral) by foreign experts specialising in the field of study. Once selected, every project was supervised annually by a steering committee composed of international experts who assessed the work already carried out and issued recommendations for the project's continuation. In total, more than 60 projects were conducted within the framework of STEREO II.

OBJECTIVES REACHED

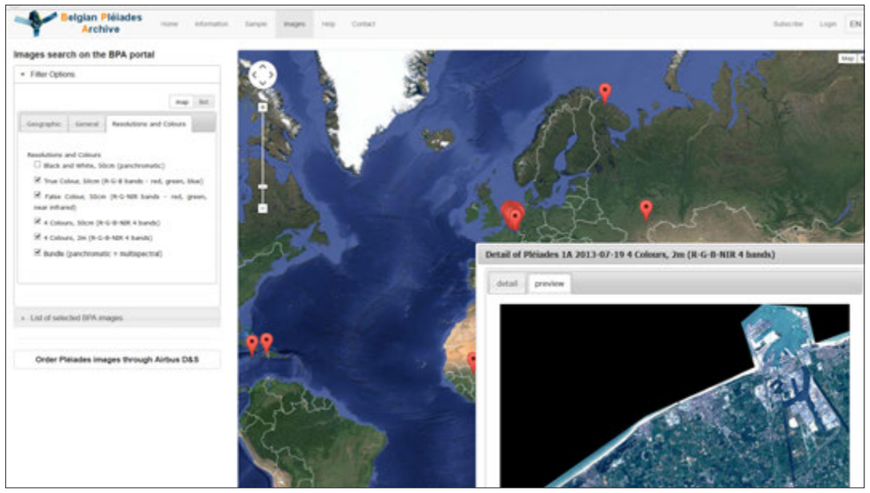
The projects were led by approximately 300 researchers spread between 87 teams, 36 of which were foreign. The programme's main objectives were achieved:

- several Belgian teams have become stakeholders in huge international programmes;
- by encouraging research theses and newly created laboratories, STEREO II has opened the way for many young scientists;
- the use of Earth observation data was integrated into different disciplines (biology, hydrology, epidemiology, oceanography, etc.), opening the door to a great variety of applications.

In view of the achieved results and a very positive external assessment of STEREO II, the programme has entered a new phase (STEREO III 2014-2020).

HIGHLY VISIBLE RESULTS

The visibility of the results of the financed projects is another major component of the STEREO II programme. The research stakes are relayed to the general public through the Earth Observation Helpdesk (EODesk). The latter also plays the role of interface between the data distributors and Belgian users, by helping these users to acquire the images. The EODesk also buys images necessary for all projects financed by



FOUR KEY PRIORITY AREAS OF RESEARCH

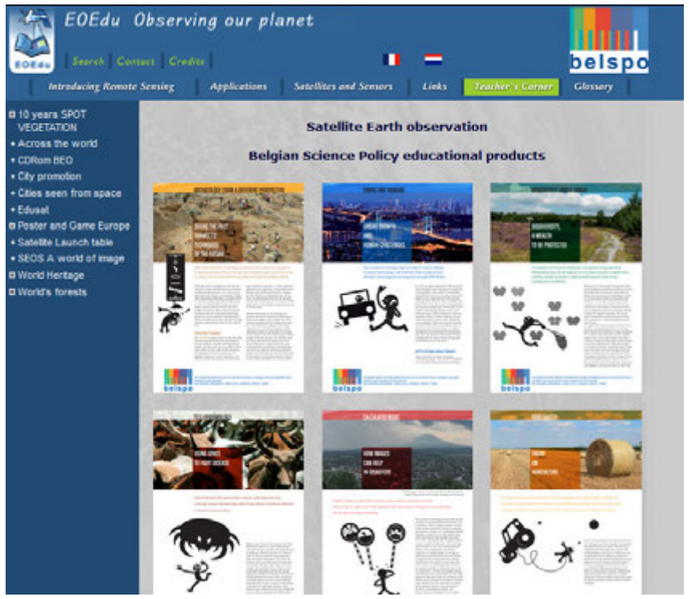
The STEREO II programme focuses on four major themes:

- Global monitoring of vegetation and the evolution of the earth's ecosystems;
- Local and regional environmental management (water, soil, forests and biodiversity, agriculture, coastal areas, urban and peri-urban areas, mapping);
- Health and humanitarian aid;
- Security and risk management.

Belspo. In particular, the ***Belgian Pléiades Archive*** (**pleiades.belspo.be**) gives Belgian institutional users access to very high resolution Pléiades images, among which a complete coverage of Belgium. These images can be used within the framework of their public service missions, and can be acquired for free or at preferential rates.

The **eo.belspo.be** website, also called the ***Belgian Earth Observation Platform***, is a targeted Earth observation information exchange platform for the Belgian and international scientific community. The ***EOEdu*** website (**eoedu.belspo.be**) on the other hand offers the general public access to more didactic information on remote sensing. It is also a window for the projects conducted within the framework of the programme, as well as the educational initiatives that have been developed (commented images, e-learning, themed posters, exhibitions, etc.).

Every year, a big Belgian Earth Observation Day is organised within the programme's framework. It allows STEREO teams to present their progress and is an excellent opportunity for the various space stakeholders to meet up.



Belgian Earth Observation Platform

STEREO II explores a very wide range of terrestrial and marine applications. Although multidisciplinary, the projects in this brochure have been grouped into a dozen or so themes to facilitate reading. You will find the project index on page 90, along with the list of coordinators and promoters.

VALORISATION OF THE PROJECTS AND PROMOTION OF REMOTE SENSING

CLIMATE CHANGE, WORLD HERITAGE AND SATELLITES

The exhibition illustrates how Earth observation can help to assess the effects of global warming on remarkable sites protected by UNESCO.
eoedu.belspo.be/unesco

IMAGING THE WORLD'S FORESTS

This travelling exhibition demonstrates the use of satellite imagery to protect the world's forests by highlighting the most striking evolutions: de- and reforestation, forest and grassland fires, threatened mangroves, etc.
eoedu.belspo.be/forests

CALAKMUL

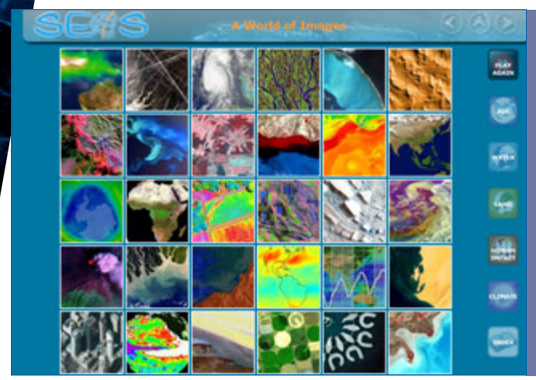
Tropical rainforests surrounding the immense Mayan site at Calakmul (Mexico) have been recognised as natural heritage, thus bestowing on Calakmul the rare title of "mixed cultural and natural world heritage". This recognition was obtained thanks to the use of a sophisticated Geographical Information System specifically dedicated to world heritage and developed by a Belgian consortium led by GIM, a company based in Leuven.

SIDSAT

The SIDSAT project draws attention to small island developing states which are often at the forefront of upheavals due to climate change. Multitemporal satellite images, accessible online, highlight the degradation of their environment.
sidsat.ugent.be

10 YEARS OF IMAGING THE EARTH

A series of seven posters show the whole Earth and its continents thanks to a mosaic of 10 years of daily images taken by the VEGETATION instrument. A dedicated website also features five major themes for each continent.
eoedu.belspo.be/vgt10



SEOS

SEOS (Science Education through Earth Observation for High Schools) is a European project aimed at integrating remote sensing into the science curricula in the last degree of high school. 15 eLearning tutorials have been developed and are available in a number of languages on the project's website. The module entitled 'A World of Images', developed by the EODesk, is a visual invitation to discover the entire project.
seos-project.eu/modules

HOW IMAGES CAN HELP IN DISASTERS

This article is based on the research projects:

GORISK
Vi-X
HYDRASENS
FLOODMOIST
RIMS
SPRINT

Satellite images are useful before, during and after a natural or anthropic accident: they can help to create a risk model, rapidly provide information to manage the crisis and assess the damage, and support rebuilding.

The increase in the frequency and, above all, the incidence of natural disasters has become a major problem. There is indeed a distinct increase in the number of disasters linked to meteorological (storms, cyclones, etc.), hydrological (floods, landslides, avalanches, etc.) and climatic (heat waves and extreme cold, drought, forest fires, etc.) events. Compared with roughly a hundred events recorded in 1980, there were more than twice as many in 2013. If we add geophysical events, such as earthquakes and volcanic eruptions, 210 million people on average are affected by natural disasters every year. Thanks to improved alert systems and more efficient mobilisation, these disasters cause fewer and fewer deaths, even if the population density is increasing, especially in vulnerable areas, such as coastal zones. In these increasingly built-up and inhabited areas, the disasters not only strike people but also their means of subsistence, their infrastructures and their environment. Indeed, a major increase has been observed in economic losses linked to natural or human disasters (oil slicks, technological accidents, etc.).
In 2013, they were estimated at no less than USD 130 billion.

The Nyiragongo volcano is a permanent threat to the city of Goma barely 15 km away. The 2002 eruption destroyed 10 % of the city.

Satellite images are irreplaceable when it comes to monitoring these disasters. Their precision, recurrence and the extent of the areas covered make them decisive tools in helping to manage crises. Sometimes, they are the only sources of information available in the devastated areas.
It were these unquestionable advantages that in fact led to the creation of the International Charter on Space and Major Disasters. Agencies and space organisations worldwide have signed the Charter. They promise to provide the necessary information as a matter of urgency to the authorities in charge of managing a disaster (see box on page 18).

While satellite resources are essential for emergency situations, they are also highly valuable before and after crises. Different research projects have studied how to improve each of the disaster management stages thanks to remote sensing:
- reducing the risk by identifying vulnerable points;
- creating a more accurate forecast by fine-tuning the forecasting models and the alert processes;
- organising aid and more efficient rebuilding systems that rely on precise and immediate information.

GPS station in the village of Kibumba, with left the Nyiragongo (stratovolcano) and right in the background the Nyamulagira (shield volcano).

TWO VOLCANOES UNDER CLOSE WATCH

In the east of the Democratic Republic of Congo, Goma, the capital of North Kivu, is situated at an altitude of 1,500 metres, between the north bank of Lake Kivu and the volcano Mount Nyiragongo. The population of this town on the Rwandan border has doubled in less than five years and now has almost one million inhabitants, many of whom are confined to refugee camps. The menacing Mount Nyiragongo and its permanent lava lake dominate the town. The volcano has been highly and continuously active since the last eruption on 17 January 2002. At the time, lava covered a tenth of the town in the space of just a few hours. Known as the biggest producer of sulphur dioxide in the world, its continuous gas plume escaping from the main crater releases up to 50,000 tons of SO_2 a day, causing pollution and major health problems in the region. Situated 15 kilometres north-east of Nyiragongo, Nyamulagira erupts every two to four years. Every time this happens, its lava flow sweeps through the Virunga National Park that extends below. It devastates hundreds of hectares of forest, crops, and sometimes whole villages. This threat adds to the high level of political instability and the many humanitarian crises the region has suffered for decades.

The multidisciplinary **GORISK** project, initiated by the Royal Museum of Central Africa and the Natural History Museum of Luxembourg, aims to develop new tools and specific services for the study and surveillance of these two volcanoes. The research should allow three local users (the Goma Volcanological Observatory, the United Nations Operations Agency – UNOPS – and CEMUBAC, a Belgian NGO specialising in healthcare in the Democratic Republic of Congo) to improve the surveillance of Nyiragongo and Nyamulagira, to manage the risks more effectively in the region of Goma, and to assess the impact of volcanic activity on the health of the population. In order to complete the existing surveillance systems, the project has focused on the contribution of ground-based and space technologies to detect ground deformations, the study of volcanic degassing and the production of useful maps to manage the risks.

GROUND STATIONS AND RADAR INTERFEROMETRY

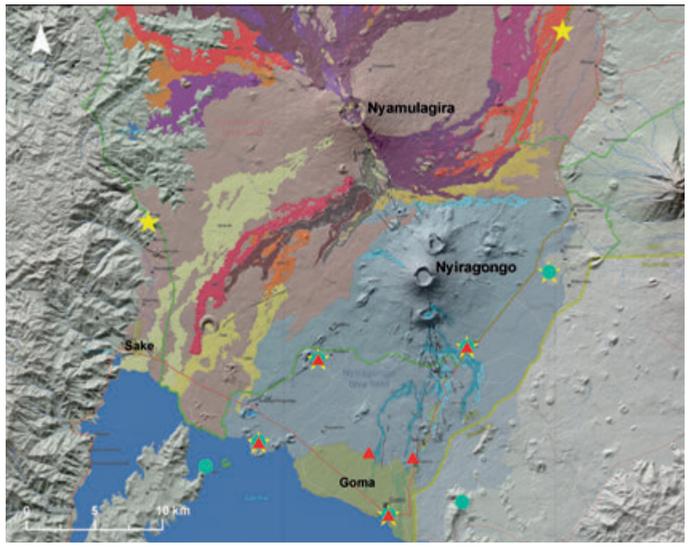
The project's cornerstone is interferometric synthetic aperture radar (or InSAR). Thanks to this recent remote sensing technique, it is possible to observe ground deformations linked to volcanic activity, for instance, based on series of 100 km x 100 km images with a subcentimetric resolution. Coupled with a permanent local network of GPS stations and inclinometers, InSAR opens the way for the study of the geodynamic processes that govern eruptive mechanisms. A better understanding of volcanic activity means an improvement in the assessment and management of the associated risks. Thanks to the project and support from the European Space Agency, the systematic acquisition of six new Envisat-ASAR images was programmed every month above Virunga between 2005 and 2012. This data harvest allowed researchers to produce more than 3,000 separate interferograms, i.e. graphic representations of variations in height, and study ground deformations associated with volcanic activity.

DANGER: GAS EMISSIONS

The passive degassing of the two volcanoes has also been examined. A gas measurement station was installed in Goma to monitor the flow of carbon dioxide and radon, and to establish a parallel with the volcanic activity.

The teams focused on mazuku, the depressions in which carbon dioxide of magmatic origin accumulates and reaches concentrations that are fatal for humans and animals. As for radon, it is produced relatively close to the surface and is conveyed by the CO_2 to the surface through fractures. These geochemical analyses provide a better understanding of the activity of the two volcanoes. The analysis of the gas flows and the possible link between their variations and volcanic activity aims to develop alert systems. In collaboration with the VISOR partner project (United States), the satellite surveillance of the sulphur dioxide plume is also being used to assess the impact of this gas on public health and on the pollution of surface water.

The project has also led to the production of a new volcanic map of the region and an updated map of the town of Goma, both very useful to establish contingency and evacuation plans for crisis events. The end of the project was marked by the eruption of Nyamulagira in January 2010. Luckily, this eruption didn't threaten the population of Goma but it nevertheless allowed the usefulness of the various tools developed to be tested and validated.



Map showing the location of monitoring instruments for the Nyiragongo and Nyamulagira volcanoes, including the GPS stations and inclinometers of the GORISK project. The lava flows of past eruptions are shown in different colors.

LAVA IN ALL ITS STATES

The project resulted in the creation of the Gorisk Scientific Network, which supports the services developed and actively continues to study and monitor volcanic activity in the Kivu basin. As part of the Stereo II programme, the **Vi-X** project more closely examines the geodynamic processes at work in Virunga, in order to improve the assessment of the volcanic risks. One of its objectives is to use the latest generation high-

Night view of the Nyiaragongo lava lake, the largest in the world (about 200 meters in diameter). Through regular overflows, it contributes to the gradual rise of the lower platform of the crater (a hundred meters per year).

resolution radar images, from the constellation of TerraSAR-X and TanDEM-X satellites. The initial results are promising: on the basis of TanDEM-X time series images, the researchers produced digital surface models (DMS) before and after the last eruption of Nyamulagira, which provided them, for the first time, with an accurate estimate of the volume of lava emitted.

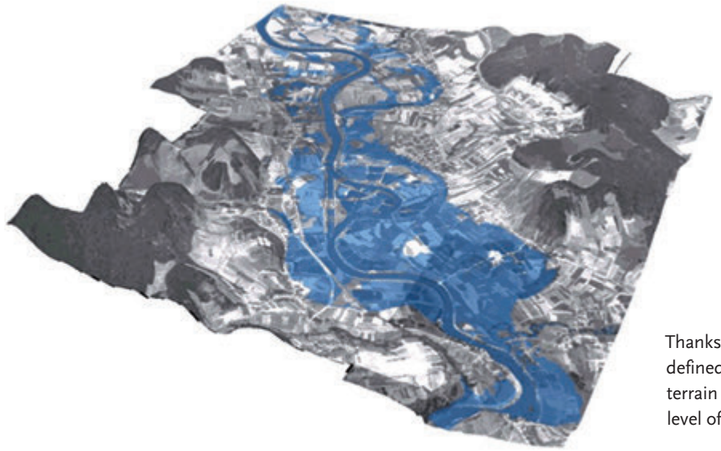
The DMS also revealed details of the landscape that weren't detectable on the basis of the previously available data. Their importance becomes clear in the knowledge that the highly fluid lava from Nyiragongo follows trajectories that can be deviated by very insignificant topographical elements. This more accurate DMS thus gives rise to more reliable simulations of flows and, therefore, a better estimate of the probability of invasion by lava. A technique allowing variations in the height of the lava lake to be monitored also seems promising and would provide a significant new forecasting tool. Indeed, observations of the lava lake reveal that as it continues to overflow onto the platforms in the crater, it is gradually rising, increasing the risk of the edifice cracking and the lava pouring out.

FLOOD ALERT

While the number of geophysical disasters (volcanic eruptions, earthquakes, etc.) remains relatively stable, this is not the case for extreme hydrometeorological events. Today, they are responsible for approximately two thirds of the damage caused by natural disasters. In 2013 alone, approximately 100 catastrophic floods were recorded worldwide, causing more than 8,000 deaths. According to the last assessment report issued by the Intergovernmental Panel on Climate Change (IPCC), the rise in these phenomena is a reflection of global warming. But the damage caused and the economic cost of flooding are also linked to other parameters: for instance, demographic evolution and life choices, which involve a growing number of people living in areas subject to flooding, but also the types of farming practices that determine the way in which the soil and elements of the landscape intervene in regulating water.

In Europe, floods are the most frequent disasters. In 2013, they affected approximately a million and a half people. Therefore, the European authorities recommend a set of measures to assess and manage the risk of flooding, in order to limit the consequences as much as possible.

How can we prevent flooding using satellite images? The large-scale **HYDRASENS** project brought together five research teams from Belgium and Luxembourg with the aim of better understanding the different processes that influence floods in catchment basins, and attempting to develop more reliable operational tools, such as flood forecasting models. The protection of inhabitants is indeed directly linked to the reliability of these models. The Belgian civil agencies traditionally work with flood forecasting models that are mainly based on the level of rivers, however, they don't take into account the ground's saturation level, i.e. its ability to absorb water. To integrate this major parameter, the researchers optimised a model combining hydrology and hydraulics, based on radar data. The tests were carried out on the basins of the Dyle in Belgium and the Alzette in Luxembourg, whose waters often rise



Thanks to radar data, the flooded area can be defined precisely. By draping the data on a digital terrain model, we can obtain an estimate of the level of water.

HYDROLOGY AND HYDRAULICS

As regards hydrology, the variable required to estimate the absorption capacity of a perimeter is soil moisture. This determines how much precipitation will infiltrate the soil and how much will run directly on the surface. In the field, this variable is extracted from measurements taken

Flooding of the River Dyle in Walloon-Brabant.

The ground penetrating radar instrument (or geological radar) is mounted on a quad for real-time soil moisture measurements.

using Ground Penetrating Radar (GPR). Regarding the catchment area, the necessary information is extracted from synthetic aperture radar (SAR) satellite data. The soil moisture values derived from the two types of sensors are then correlated in a completely innovative way.

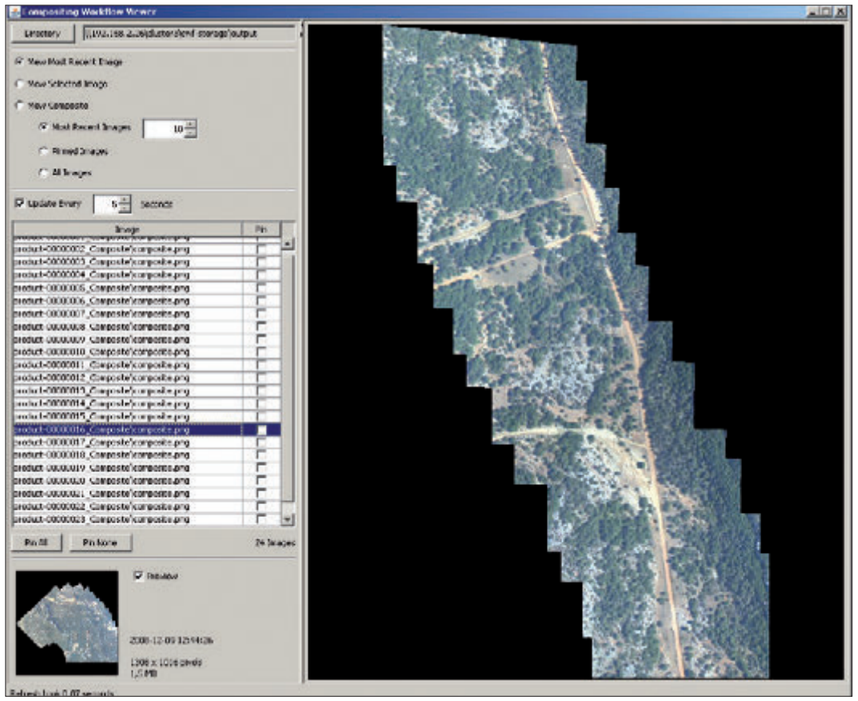
Concerning hydraulics, the important variable is the extent of the flooding. Up until now, it was very difficult (despite having SAR data) to map the outline of a flood within an urban area or under plant cover. By merging the SAR data with the high-resolution digital field models, a solution to this problem was found.
The extraction of these two variables – soil moisture and extent of the flooding – based on SAR data, is an important advance; their integration into the flood forecasting model does indeed make it more effective. At each of the stages, the model's calibration is improved thanks to the addition of updated data.

"LIVE" FORECASTING AND MONITORING OF FLOODS

Like all models, the flood forecasting models currently used produce errors. These are mainly errors concerning timing, the extent of the flooding or the height of submersion. The **FLOODMOIST** project focuses more on the interest of assimilating soil moisture observations and the extent of flooding in these models. Hence, the project studied the usefulness of the SAR data for the continuous surveillance of the water saturation level in the ground, on the one hand, and the precise localisation of areas actually flooded, on the other.

The researchers are mainly focusing on the flood maps' level of uncertainty resulting from SAR imaging. Indeed, depending on the mapping method implemented, the result can differ significantly. Therefore, they will begin by developing techniques to define this uncertainty and then integrate them into the data assimilation process. The results show that this integration improves the model's accuracy and its forecasts.

UAVs (unmanned aerial vehicles) or drones are remotely controlled aerial vehicles used for various applications. From ultralight aircraft to this octocopter, they can take different types of payload (imagers, GPS instruments, weather, ...). Their flexibility and responsiveness are the instruments of choice for disaster monitoring.



Thanks to radar data, the flooded area can be defined precisely. By draping the data on a digital terrain model, we can obtain an estimate of the level of water.

For now, the techniques developed have only been validated on events in the past; the next step is to test them by using SAR data recorded in real time (or near real time, if we take into account the short interval between acquiring, processing and transmitting). This would allow civil authorities to use models with a "live" supply of data to justify alert decisions taken before the disaster, and to organise aid during the crisis.

The European Space Agency has shown an interest in these two projects and their major methodological advances. In the framework of the EU Copernicus Programme, ESA developed a successor for the ERS-1 and 2 and Envisat satellites. This mission is called Sentinel-1 and is made up of two satellites carrying a synthetic aperture radar. The first satellite, Sentinel-1A, was launched in April 2014, and the images it has taken thus far have already shown their worth for numerous applications.

A PATCHWORK OF IMAGES IN REAL TIME

As regards disaster management, acting quickly and in the right place is essential. Having reliable and immediate information is often a major problem. The **RIMS** project is dedicated to this difficulty through its focus on unmanned aerial vehicles (UAV). From light drones to large stratospheric aircraft, these pilotless systems have many advantages: on the one hand, they offer a wide range of sensors and, on the other, they can be deployed on request, offering an unequalled flexibility and reaction time. In the monitoring of disasters, they are the missing link in all the remote sensing platforms. However, to obtain visualisation solutions in near real time, the complete and automated data processing chain must be optimised.

The researchers have elaborated a new geocoding method: this crucial stage consists of matching (i.e. "locking" and geo-referencing) superimposed images and vector layers of the same scene taken at different times, from different angles and by different sensors. This new approach reaches new levels of reliability, rapidity and quality. While such automatic geocoding techniques did already exist, the quality of their results wasn't always very high.

The method developed allows the best processing chain to be selected in near real time, based on the content of the scene observed and the external data available. This has led to the creation of a prototype software program that processes images directly on the UAV platform, assembling them in a patchwork and delivering a faithful geolocalised observation of the area flown over "live". This visualisation is broadcast online and can be used as such by the civil protection services. With the public authorities and the industrial world showing their interest in this operational tool, its development is continuing, in partner-ship with AGIV (Agentschap voor Geografische Informatie) and Belgian companies specialising in imaging products, such as Barco and Gatewing.

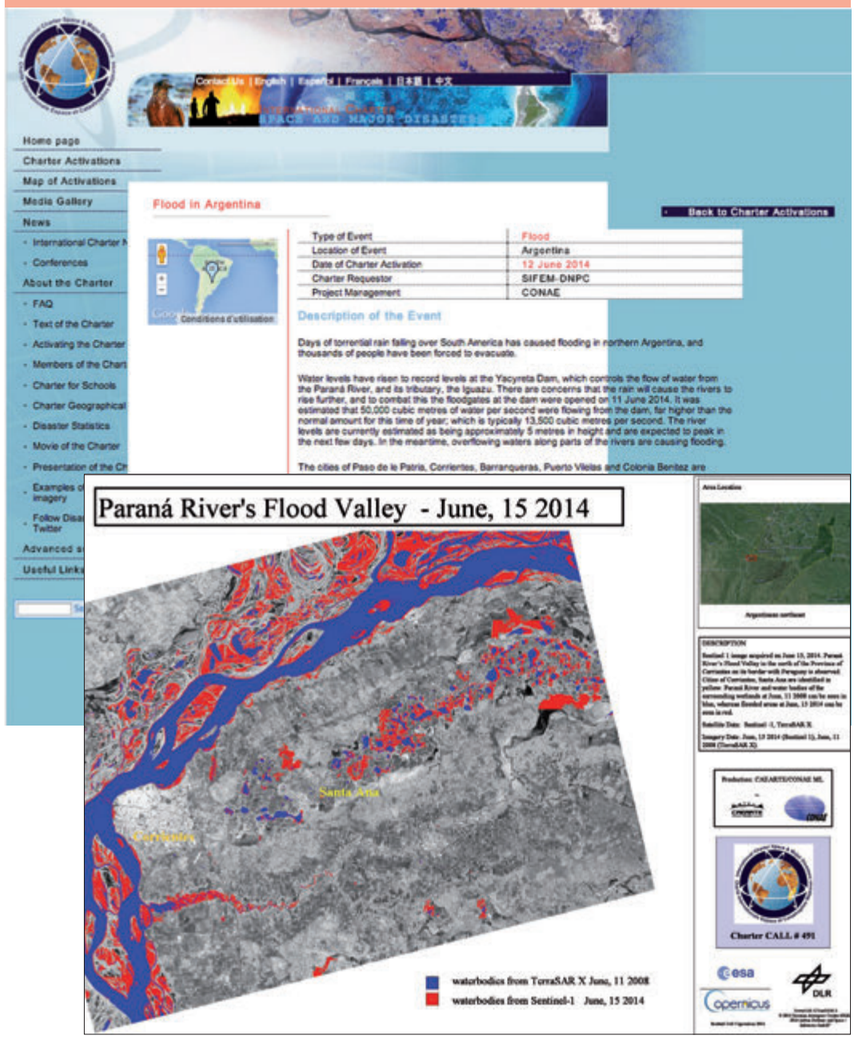
The Charter was activated during the flooding of the Paraná River in Argentina in June 2014. The Sentinel-1A data that were delivered were used to map the extent of the flood. Sentinel-1A is the first in a series of satellites of the European programme of Earth observation Copernicus. Data of Sentinel satellites will be available free to all. In emergency situations, they can even be delivered within an hour after acquisition.

The International Charter on Space and Major Disasters

Telecommunications, Earth observation, meteorology, geolocation: spatial resources are of major interest in risk management. To have access to these resources in case of a disaster, it was necessary to set up a centralised system focused on acquiring and delivering spatial data. The International Charter on Space and Major Disasters, which officially came into force on 1 November 2000, meets this need and helps to support the management of disasters and limit the repercussions on the population. All the agencies that are members of the charter commit to mobilising their resources to produce and distribute images and maps to disaster areas as a matter of priority.

Soon after the Charter's foundation by the European (ESA) and French (CNES) space agencies, it was joined by the Canadian Space Agency, followed by 15 or so major agencies and institutions worldwide over the years. The procedure is very simple: if a disaster occurs, every authorised user has access to a confidential phone line, available 24/7. Following the analysis of the request, a project leader prepares a plan for the acquisition of new data and a choice of archives, by using the available satellite resources. In collaboration with the operators capable of processing and analysing this data, it provides images, maps and all useful information as quickly as possible. Since its creation, the charter has been activated more than 400 times, to assist civil defence and security organisations faced with dramatic events, whether they are of human or natural origin (floods, storms, fires, earthquakes, eruptions, oil spills, etc.).

www.disasterscharter.org



MINEFIELDS SEEN FROM THE SKY

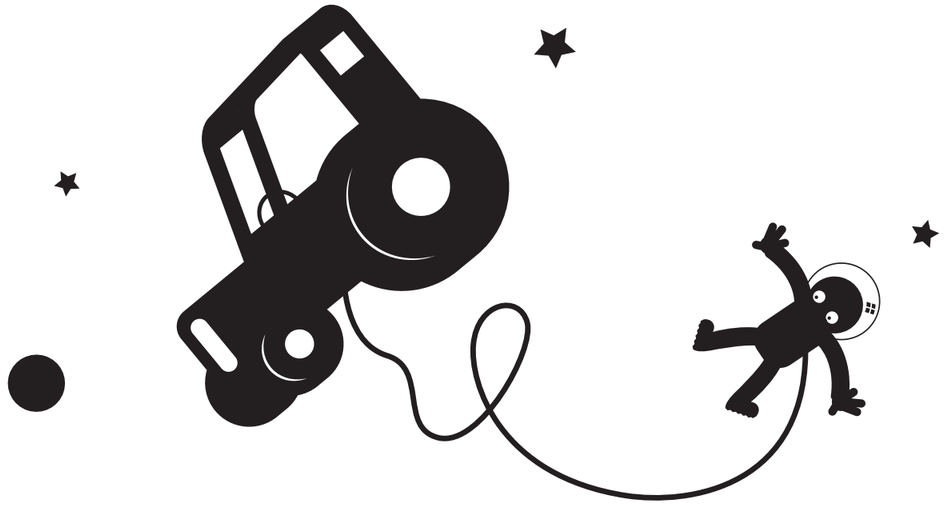
Despite the Nobel Peace Prize won in 1997 and a major international campaign banning landmines, this scourge is still widespread. In 2013 (year of the last census), there were no less than 3,308 victims, mainly civilians, the majority of whom are women and children. Nearly 70 countries are currently contaminated. Besides the actual mines, unexploded munitions also constitute a latent threat. The **SPRINT** project, conducted by the Belgian Royal Military Academy, is dedicated to this contamination of former war zones. The remnants of war are a major obstacle when it comes making the transition from a crisis situation to a genuine state of peace. They not only endanger the physical integrity of the inhabitants but also the possibility of reconstructing and reviving local development. Taking into account the disparity of the situations in the field, TIRAMISU, a vast European project, aims to provide all those actively taking part in humanitarian mine clearance with a global toolbox.

To improve the process to make land available again, TIRAMISU wants to develop an integrated geospatial system, capable of processing data that differs according to type (visual interpretations, historical data, multispectral satellite data, hyperspectral, radar, etc.), their resolution and their source (drone, airborne, satellite).

In support of this large-scale project, the **SPRINT** project researchers have developed a minefield localisation technique in Croatia based on radar data. The basic principle is that an area which is no longer frequented by the local population is likely to be dangerous. The study therefore aims to differentiate the areas where there is human activity from those where it has ceased. This information can be extracted from changes detected in the SAR radar image time series, based on an analysis of the interferometric coherence. This parameter provides information on variations in the ruggedness of the ground's surface between two shots. A previous study carried out on the border between Jordan and Syria, based on SAR data from the ERS satellites, did indeed show that human activity in a given place leads to a modification in the interferometric coherence; on the other hand, areas where human activity has declined continue to maintain interferometric coherence for a very long time and can actually be identified as high risk areas.

Mine clearance operation in Petrinja (Central Croatia). 90,000 landmines are still buried in the Croatian soil. Since the war ended in 1995, more than 500 people have been killed by landmines.

FOCUS ON AGRICULTURE



This article is based on the research projects:

GLOBAM
EVA-3M
ADASCIS
MOCA
SOC-3D
SENSAR
HYPERMIX

The agricultural sector lies at the centre of major challenges such as food security, respect for the environment and socioeconomic expansion. From a planetary level right down to the plot, remote sensing is used for the development of ever-more efficient monitoring and forecasting tools.

In just a few generations, the agricultural sector has undergone profound changes accompanied by a globalisation of its stakes. The first one is unquestionably food security for everyone. The world population will reach 9.6 billion by 2050. To guarantee food in sufficient quantity and quality by that year, global food production must progress by 70 % compared with the current volume, according to FAO forecasts! This is a considerable challenge knowing that rural labour is continuously in decline. Furthermore, agricultural production depends on climate conditions, which are subject to growing variability and increasingly common extreme weather conditions.
Secondly, farming practices lie at the heart of environmental issues. They have a direct impact on soil, air and water quality, but also on landscape and the habitats necessary for the preservation of biodiversity. And finally, agricultural produce is a leading economic tool, the volume of which is even the subject of speculation in financial markets.

To meet all these stakes, it is essential to improve farming practice monitoring tools and production forecasting tools. These tools were developed at the time remote sensing began to expand. Since the launch in 1972 of Landsat-1, the first civil satellite dedicated to the observation of terrestrial resources, many useful farming applications have seen the light of day. They provide information on the state of plants, allow cultivated surfaces to be mapped, help with the estimation of future yields or the assessment of damage after extreme events (drought, flooding, frost, storms, etc.). The constant improvement of the sensors' spatial and spectral resolution also benefits precision agriculture. This consists of adjusting the supply of water, fertilisers or other input according to the plot's actual needs. A 'precise' approach that optimises quality and yield while limiting the environmental impact.

Today, research projects are supported by a growing number of observation instruments that offer a great variety of scales, spectral ranges and acquisition frequencies. The volume of archived data is also considerable. For instance, we have more than 40 years of Landsat (resolution of 30 metres) and SPOT HR images (20 to 2.5 metres), 36 years of global daily images from the NOAA-AVHRR satellite (1 kilometre), 16 years of VEGETATION images (1 kilometre to 300 metres), almost 15 years of data from the MODIS sensor (1 kilometre to 250 metres) and 10 years from the MERIS sensor (approximately 300 metres).
By exploring the specific benefits of the different sensors and the most productive way to combine them, researchers have extended their possibilities and their sources of information in order to help the agricultural monitoring from a global level (thanks to worldwide agrometeorological models) to the level of the farms themselves.

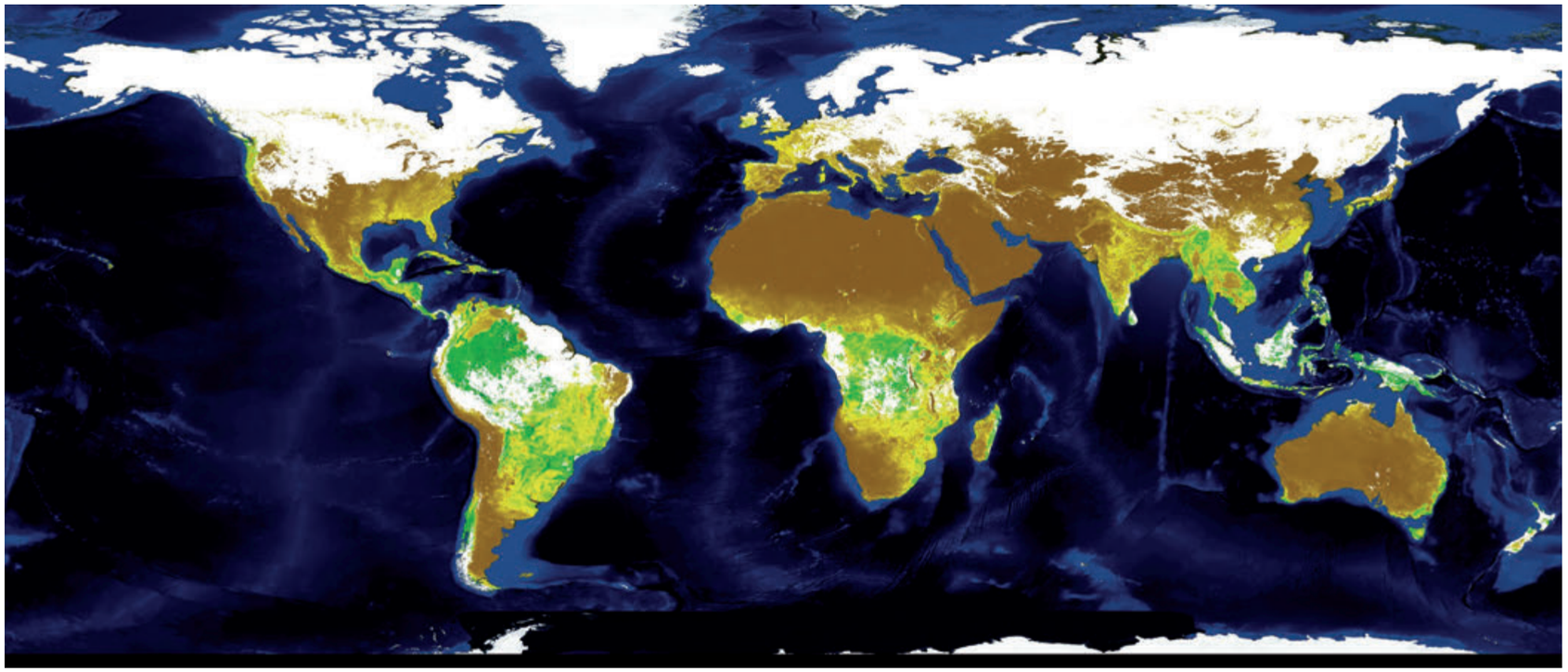
One of the goals of the Global Earth Observation System of Systems (GEOSS) is to strengthen the global agricultural monitoring to improve food security.

FEEDING NINE BILLION HUMANS IN 2050

Faced with global demographic pressure and the absolute necessity of an increased agricultural supply, the variability in production and yields has become a major concern. In order to ensure food security, authorities have joined forces on a local and global level to create monitoring systems. In 1988, the European Commission founded the MARS programme, aimed at making the link between the Earth's new observation capacities and agricultural forecasting techniques. It was followed by the GEO initiative (Group on Earth Observations), which works on building a global public observation service called GEOSS (Global Earth Observation System of Systems). These efforts are assisted by space agencies, major international organisations (World Food Programme, FAO, World Bank, etc.) and by a community of national and regional authorities that provide farmers with help and information.

Within this context, it is rather surprising to note that while technological progress in the domain of Earth observations has been remarkable since the end of the 1990s, operational monitoring systems haven't significantly evolved. Leading-edge scientific advances integrating remote sensing have indeed been made, especially in the modelling of crop growth, but they are under-used. The aim of these models is to generate detailed information on a regional, continental and global level. For this purpose, they must be provided with precise and reliable data, which relates to proper time slots, covering vast geographical stretches with very different conditions.

Within this context, the **GLOBAM** project combined local crop monitoring by Earth observation with the global growth models to best estimate farming production at all levels.



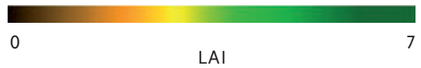
WHICH SENSORS FOR WHICH RESULTS?

The study concerned three sites measuring 300 x 300 km each – Northern Europe (including almost the entirety of Belgium), Asia (China) and Africa (Ethiopia) – in order to cover three radically different agro-ecological contexts. The growth seasons of winter wheat and corn were observed using field measurements and data from different types of satellite sensors and different spatial resolutions.
The properties and advantages of these different sensors were explored and combined in order to provide material for the global monitoring methods that take into account local particularities. Since field sampling is impossible on such a vast scale, the study chose to combine variables derived from remote sensing with various growth models, calibrated specifically to each of the sites.

The results of the project have opened up a series of methodological possibilities that will help improve the forecasting and monitoring of crop growth. For instance, the data from the SAR radar, whose active signal crosses the cloud layer, is very useful in places where the sky is often covered. If these images are acquired on a regular basis, they can be used to complete the information provided by the optical images. By innovatively correlating these two sources, the research has improved the extraction of the Leaf Area Index, an important parameter since it concerns the surface of green foliage per unit of ground surface.

An even more surprising result was the confirmation of the valuable contribution of the geostationary satellites. These satellites, which orbit at approximately 36,000 kilometres from Earth, are traditionally used for meteorological observations. Data from the MSG (Meteosat Second Generation) satellites however, can also be used to estimate the evapotranspiration for a precise type of crop. This parameter gives information on the plants' (and the soil's) water deficit and on its level of vulnerability, which influences its development and therefore the expected yield.

What is the resolution needed to identify plots in a given agricultural landscape? The GLOBAM project used data from low, medium and high-resolution sensors. Below you can see the same agricultural landscape seen by SPOT 5's HRV sensor (10 m) and the MODIS sensor (250 m).

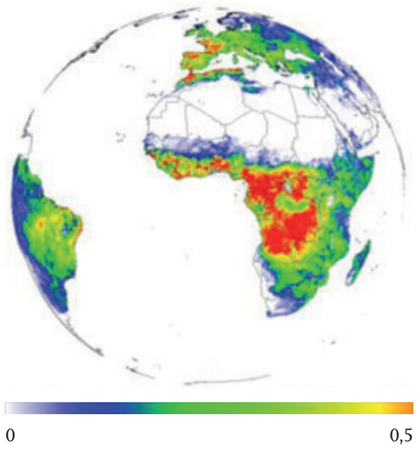


The Leaf Area Index (LAI) is derived from the global data of the VEGETATION sensor. Issued every ten days, it is one of the parameters to establish estimation maps of worldwide agricultural production.

Assimilated in growth models, evapotranspiration is valuable for the monitoring of plant growth.

MORE ROBUST METHODS

Towards the end of the project, two studies showed what the necessary evolutions should be for satellite images and extraction methods in order to meet future challenges, especially in terms of the spatial resolution required for several types of agricultural landscape representative of global diversity. In Ethiopia, for example, very high-resolution observation data is recommended in order to perceive the mountainous area in sufficient detail as well as the network of small plots often containing mixed crops of two or three species.



Evapotranspiration (ET), the sum of evaporation from land and sea surfaces and plant transpiration, is an essential component of the water cycle. Global maps of ET are produced every 30 minutes by means of Meteosat data.

The robustness of the methods to be developed is also highlighted. Indeed, it is not simply a question of elaborating monitoring techniques applicable to all geographic regions, but also in unstable meteorological and climate conditions. To face the planetary challenge of food security, it is now essential to have higher performance monitoring and forecasting tools integrating this variability.

Another project, **EVA-3M**, is endeavouring to develop a generic method in order to quantify the evapotranspiration process for different types of land use and different climate zones. The spatial and temporal resolutions must be sufficient to meet the needs of the agricultural sector: to estimate water needs, establish irrigation plans, better anticipate drought alerts or fine tune yield forecasts.

The project therefore studies how best to exploit, on a regional or sub-regional level, the evapotranspiration maps produced from the MSG geostationary satellites data. While the frequency of their observations is very high (every 15 minutes), the spatial resolution, on the other hand, is only three kilometres. The researchers are therefore trying to compensate this lack of spatial precision by combining this high temporal resolution data with polar satellite data, offering a spatial resolution of 300 metres.

The hailstorm that hit the country in June 2014 caused extensive damage to crops as well as infrastructure. If it is recognized as a natural disaster, the affected farmers will be eligible for compensation from the Disaster Fund.

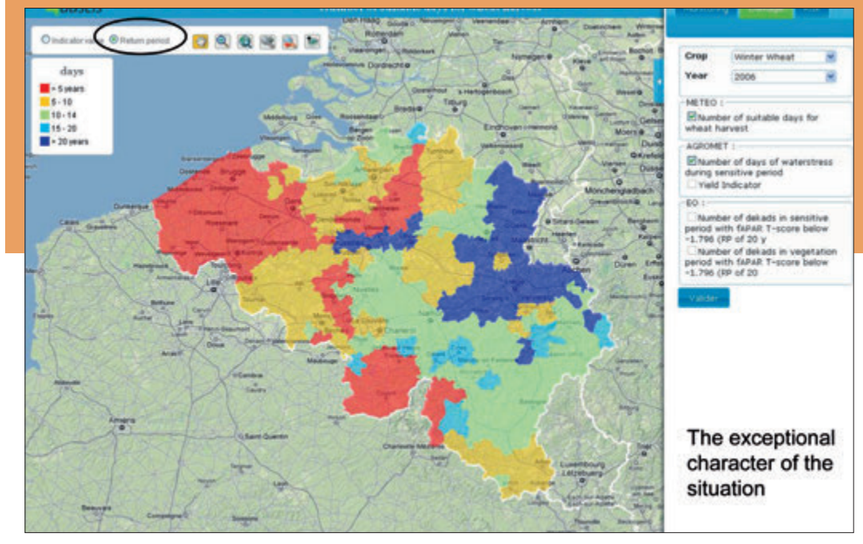
Crop insurance: from remote sensing to practical application

Every year, farmers in our regions face growing instability with regard to their income. On the one hand, they are confronted with fluctuations in market prices and a gradual reduction in the European Union's compensation mechanisms; on the other hand, they are faced with unpredictable weather conditions and increasing extreme meteorological events (drought, heatwaves, heavy rain, storms). For the agricultural sector, better management of natural risk is therefore sometimes a crucial necessity. In Belgium, agricultural losses due to a disaster are covered by the Fund against Natural Disasters. The services responsible for managing the fund are seeking to make the damage assessment process and follow-up of the damage more reactive and more efficient. The **ADASCIS** project has therefore studied how to support the decision support system on the basis of reliable and objective information.

The project began with a selection of relevant indices that take into account the damage suffered by the crops. These indices are derived from meteorological data, agrometeorological models and observations from low and medium-resolution satellite sensors. The index values are then compared to reference values established on the basis of historical data.
On a regional and community level, the calculation of indices has enabled the identification of areas with a recurring problem (late growth, low yield, low soil moisture) or at high risk of crop damage. At the level of the plots, a detailed study, using very high-resolution satellite images and SAR images, was carried out at two particular sites in order to validate the results obtained thanks to the medium-resolution data.

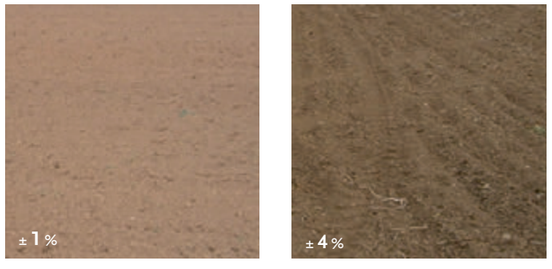
A pre-operational web application was developed to allow users to visualise and analyse their various damage and risk indices in the form of maps and graphs. The application was tested during the 2011 growth season to assess the extent and the intensity of the spring drought.
The tool developed allows the competent authorities to identify a disaster zone and to make a decision concerning the eligibility of the claims.

The project also concerns the evolution of crop insurance. Since 2006, extended cover against unpredictable weather conditions is recommended by the European authorities. In case of a disaster, the amount of European compensation paid out to farmers is directly linked to the insurance policy they have taken out. The project analysed the crop insurance systems in use in other countries and defined a procedure adapted to Belgium. For the regional farming authorities, the tool created can thus serve as an information base on nature and the frequency of the risks incurred. The composition of the project's steering committee reflects all these stakes; besides FPS Economy, it includes farming groups, representatives from the Flemish and Walloon Regions and stakeholders from the insurance sector (Assuralia).



With the web application developed by the ADASCIS project, users can visualise the exceptional nature of a situation. For example, the number of favorable days for wheat harvest compared to a reference year.

The extraction of an intact soil core of about 1 m long is done with a percussion corer. The vertical distribution of the carbon is then analyzed.



Both types of freshly plowed soil can serve as standards for organic carbon concentrations: the right one has an average carbon content, the left one scores rather low.

ORGANIC CARBON AT THE HEART OF MAJOR CHALLENGES

The soil organic carbon (SOC) is an essential factor in agricultural productivity. It fulfils a series of fundamental biological, physical and chemical functions which have an impact on the fertility, quality and stability of farmland but also on biodiversity or the toxicity of pollutants. It also plays a key role in carbon balance. Indeed, soil offers a significant carbon sequestration capacity. It has been shown that the implementation of certain farming practices optimises the amount of carbon captured in the soil, thus reducing the concentration of CO_2 in the atmosphere. The new Common Agricultural Policy programme (2014-2020) includes the protection of soil rich in organic carbon among its priorities and defines the reduction of organic matter as one of the main threats to soil resources.

Luxembourg was one of the first countries to take the initiative to systematically measure SOC concentrations in its farmland. The SOC estimation can be used directly for the implementation of the carbon credit granting mechanisms. It is also an indicator of the compliance with the "good agricultural and environmental conditions" established by the European Union. These conditions set out all the rules and practices to be followed in order to benefit from community aid (maintenance of land and grassland, controlling irrigation, diversified cropping systems, etc.).

The **MOCA** project studied how to develop an efficient and operational analysis and mapping method for SOC concentrations. The researchers endeavoured to determine whether the precision obtained was sufficient to allow farmers to assess the impact of new farming practices on these concentrations. Since obtaining the field data necessary for such an inventory using traditional sampling techniques is expensive and fastidious, airborne hyperspectral sensors are an ideal alternative. However, the researchers had to find a way to reduce the negative impact of factors that disrupt the signal, such as the level of humidity or shadows linked to the land's ruggedness. In the area studied in Luxembourg, characterised by different soil types and a high variability in SOC concentrations, five hyperspectral images captured by the AHS-160 sensor were processed, analysed and compared with field measurements.

In the majority of cases, the models developed provided sufficiently precise SOC estimations to meet the needs of extensive farming. The project's methodological advances directly benefit end users, such as the Luxembourg-based company Convis, which uses the results to establish fertilisation plans and soil quality reports.

CARBON'S 3RD DIMENSION

Continuing this research, the **SOC3D** project studied how to improve the estimation of the carbon stock by integrating its vertical distribution in the first metre of arable land into the spatial representation of the SOC.

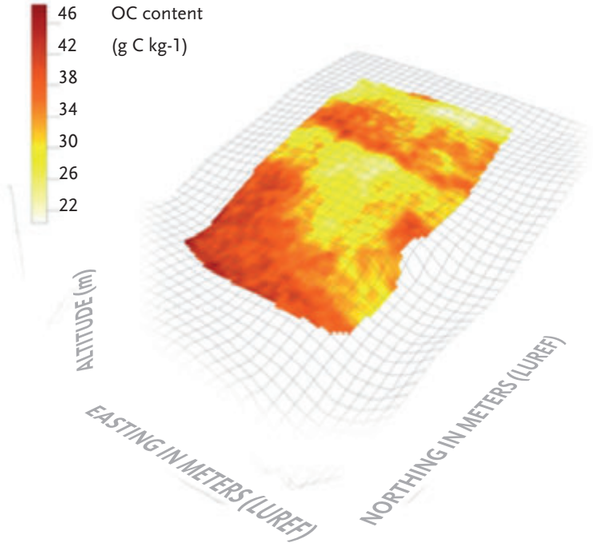
Regarding surface concentration, the APEX (Airborne Prism Experiment) hyperspectral sensor flew over a perimeter of 860 km² in Luxembourg. Its data was validated and compared with more than 150 soil samples taken from the study area. For the contents in the first metre of soil, core samples were extracted using a percussion gauge and every 10-centimetre intact layer was scanned by a laboratory spectrometer. The purpose of the experiments carried out on this "third dimension" is to obtain estimations of SOC concentrations that are closer to reality and to be able to extrapolate the carbon stock of the entire the perimeter studied.

For the estimation of surface concentrations, the best results were obtained by combining the hyperspectral data and geomorphological variables (slope, curvature). The maps obtained provide a good overview of within-plot variation and clearly show that the SOC content depends on the soil type and the geomorphological variables.

By putting these results in a Google Earth application, the user can very easily observe the spatial distribution of the SOC. This often reflects changes in farming practices that have occurred over the years or differences in the level of erosion.

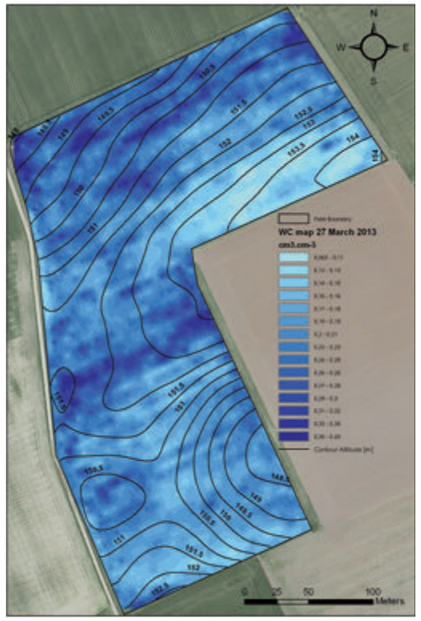
These detailed maps are useful on two levels: on the one hand, they inform farmers about the organic matter content in their fields, which allows them to take the appropriate conservation measures; on the other hand, they provide material for the national SOC inventories, which lie at the heart of the concerns and the new regulations of the Common Agricultural Policy.

Google Earth image of the southern Grand Duchy of Luxembourg, which was projected onto a map of the organic carbon content of plowed soil.



One of the factors that change the soil carbon content within a parcel is topography.

High-resolution soil moisture map of an agricultural parcel in Gentinnes, compiled using data from ground-penetrating radar and draped over the contours. The darker the blue, the higher the water content.



WATER, AT THE SOURCE OF EVERYTHING

Soil moisture is, of course, another essential parameter in plant growth, but it also plays a major role in numerous processes of the water cycle (infiltration, runoff, absorption by roots, evaporation), in energy exchanges with the atmosphere and, therefore, also in the climate system. Thanks to airborne or satellite remote sensing instruments, in particular radars, its estimation has become widespread at all levels, from the field to the drainage basin. However, soil moisture is by nature highly variable in time and space, and it is difficult to obtain sufficient field data to effectively calibrate and validate processing methods for Synthetic Aperture Radar (SAR) data.

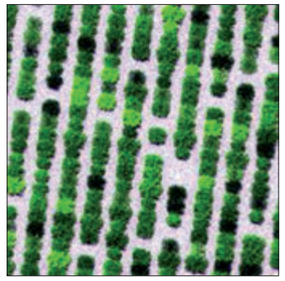
To reduce the continuing high level of uncertainty of these methods, the **SENSAR** project is seeking to integrate the contribution of a new type of radar, the Ground Penetrating Radar (GPR). This could indeed help to overcome the continuing difference in scale between remote sensing and traditional field samples. The perfecting of the SAR data processing methods will ultimately lead to the production of soil moisture maps that are more faithful to local variability. The project is examining several study zones located in Belgium with different types of soil and topography, with the aim of establishing maps that can be directly used by Belgian or international public services, or by private organisations such as insurance companies or farming associations.

HYPERSPECTRAL AND HYPERSPATIAL

The **HYPERMIX** project focused on a fundamental problem of remote sensing: when the engineers design a satellite sensor, they have to make a compromise between the spatial resolution and the spectral resolution, by optimising the signal-to-noise ratio (signal = useful information; noise = irrelevant data), which indicates the quality of the recording. For instance, the Hyperion satellite sensor currently offers the highest spectral resolution from space (220 spectral bands), but its spatial resolution is only 30 metres. On the other hand, sensors such as Pleiades, QuickBird or WorldView-2 offer a very high spatial resolution (approximately 50 centimetres in panchromatic and 2 metres in multispectral), but their spectral resolution is much lower (4 to 8 spectral bands). As for airborne hyperspectral sensors, such as APEX, they often combine the benefits of an unequalled spectral resolution and a very good spatial resolution (0.5 to 7 metres), but the field of vision is reduced.

Many applications, such as detailed land cover mapping, the study of the dynamics of vegetation or the assessment of its condition require spatially and spectrally precise information. The research team has therefore developed methods to merge the hyperspectral and hyperspatial data, in order to generate a product that combines their respective qualities. The test was carried out on citrus fruit orchards located in the region of Valencia in Spain and in Loksbergen in Limburg. An image with 215 spectral bands and two metres of resolution provided by the APEX sensor, and an image with three spectral bands and 20 centimetres of resolution provided by a microdrone were merged to generate an image with 215 spectral bands and 20 centimetres of resolution.

Thanks to this merged product, it was possible to extract more precise estimations from certain biophysical parameters (chlorophyll concentrations, water content, etc.) of fruit trees. It was possible to precisely map the water stress level of trees, a parameter that directly influences the quality of the fruit. Tests were also done on a virtual orchard located in an environment with simulated conditions. The methodological advances produced were made available to the community of remote sensing researchers.



High spatial resolution

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High spectral resolution

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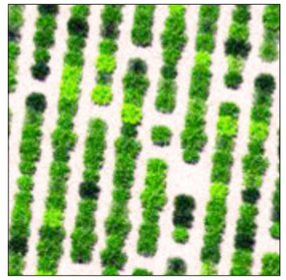
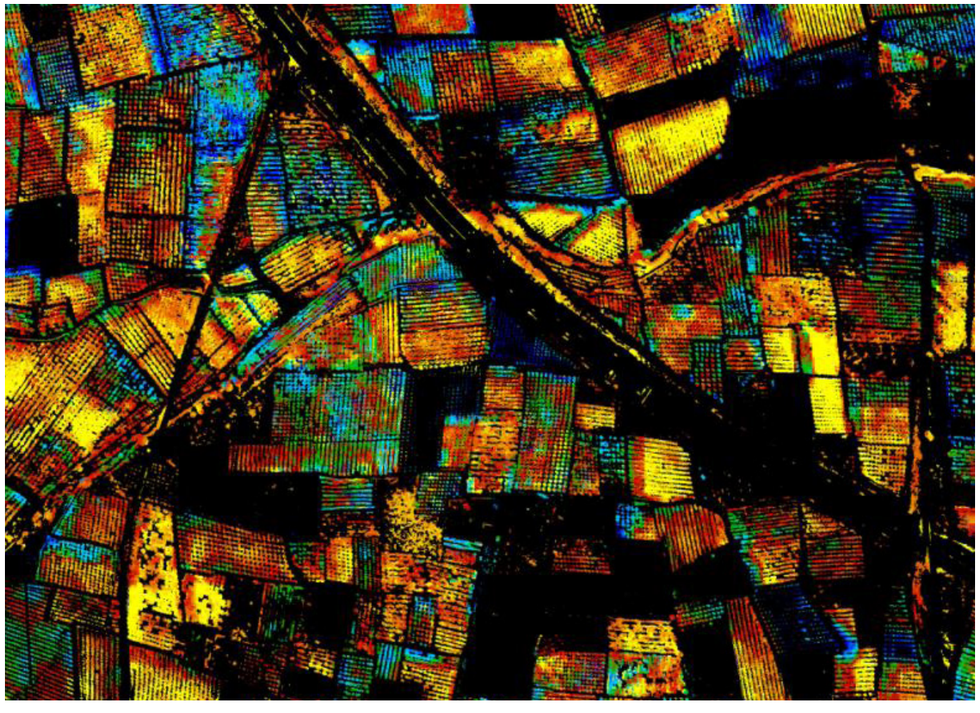


High spatial and spectral resolution



The Photochemical Reflectance Index (PRI) reflects the plant health variability between and within parcels, and helps for example to accurately determine water needs within each plot.

Citrus orchard in the area of Valencia, Spain, overflown by a UAV equipped with a hyperspectral sensor.

URBAN GROWTH AND HUMAN CHALLENGES

Towns and cities are increasingly complex and subject to numerous challenges. In response, remote sensing is used on all fronts: it helps to update necessary information, improve diagnostic tools and generate new quality-of-life indicators.

This article is based on the research projects:

MAMUD
ASIMUD
VALI-URB
BIOHYPE

In 2008, our planet reached the inflection point where the global urban population exceeded the rural population. The number of city-dwellers increased from one in ten in 1990 to one in two today. In 1970, Tokyo and New York were the only large cities with more than 10 million inhabitants. Since then, the number of megalopolises has increased tenfold and is continuing to grow, mainly in developing countries. As for cities with more than a million inhabitants, there are hundreds of them, notably in Western Europe, where more than two out of three inhabitants are city-dwellers. Towns and cities are therefore confronted with major sustainability stakes, at the intersection of social cohesion, economic development and protecting the environment. They are at the heart of continuously evolving management, for which remote sensing tools are turning out to be very useful.

BETTER DEFINING URBAN DYNAMICS

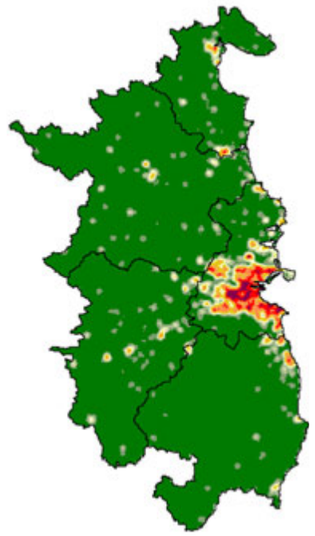
Towns and cities are almost constantly undergoing changes. Their external boundaries are incessantly being pushed back, and internally they are subject to successive phases of restructuring neigbourhoods, constructing new buildings and creating green spaces. These changes affect both the human and natural environment. To maintain the inhabitants' quality of life in the face of this process, it is imperative that the local authorities know the causes, the chronology and the effects. Several research projects have studied these parameters based on increasingly detailed spatial and temporal information provided by remote sensing.
Within this scope, the **MAMUD**-project used high-resolution images and medium-resolution time series to measure the impact of urban growth on the structure of the landscape and on residents' accessibility to green areas.

The methods were developed and tested for the cities of Dublin and Istanbul. Both have indeed been subject to considerable expansion: while Istanbul has been continually absorbing the rural exodus for almost half a century, Dublin was boosted by high economic effervescence from the beginning of 1990s up to the financial crisis in 2008. Another project, **VALI-URB**, explored how high and very high-resolution images can further improve the characterisation of the urban fabric and the changes it undergoes. The study related specifically to the evolution, in towns and their surrounding area, of built surfaces and vegetation, which both constitute a fragile balance that must constantly be monitored.

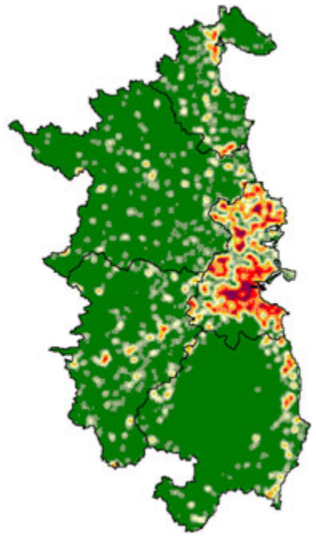
TOWARDS A MORE ACCURATE MODEL

Urban management is often achieved with the help of models that simulate the probable evolution of the situation. The European Commission and its major bodies, such as the European Environment Agency, use them to assess the impact of new directives and recommendations. By refining the extraction of information on urban land use based on satellite data, the **MAMUD** project was able to improve both the existing maps and the MOLAND urban growth model used since 2002.

2010

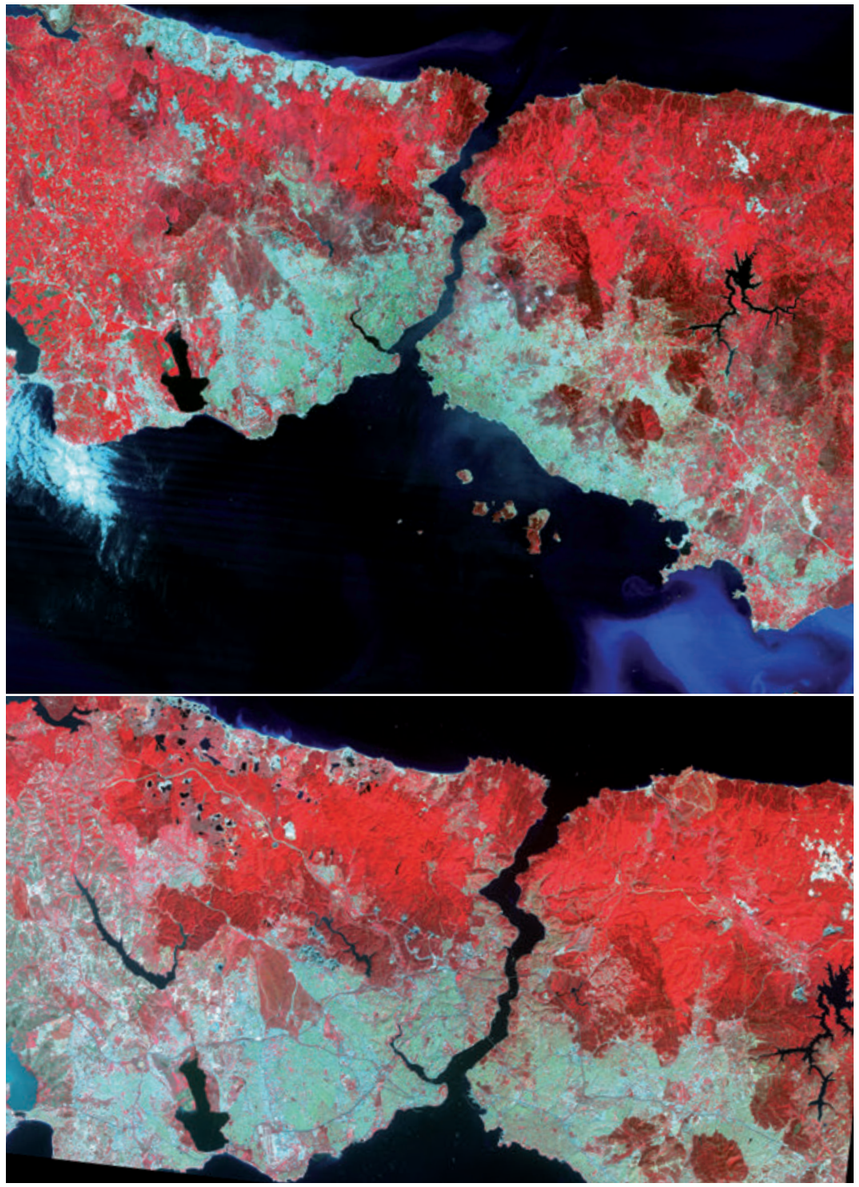


2050



Urbanisation level of Dublin in 2010 and prediction for 2050.

Satellite images of Istanbul in 1990 (above: Landsat 5 image with 30-metre resolution) and 2009 (below: SPOT 5 image with 10-metre resolution). On these false colour images the urban expansion is clearly visible in grey-green.



Besides parameters such as socioeconomic categories, topography and road infrastructure, a model such as this requires detailed spatial information on the occupation of urban spaces. In this instance, satellite images are very useful, even if urban land use can't be directly derived from spectral measurements. A method was therefore developed to deduce urban land use based on urban forms, thanks to maps derived from satellite images that take into account the structure and the density of buildings. This information can then be used to calibrate the MOLAND model, i.e. adjust its parameters to obtain an optimum balance between the planned urban land use and that actually observed by remote sensing.

ASIMUD, a second project, focused on the level of uncertainty of predictions. It depends on uncertainties associated with both the initial parameters and the reference data used for the calibration. The researchers developed an automatic method of calibration that integrates recent urban land use satellite data, at each stage of the simulation procedure. In very simple terms, the team showed that by assimilating certain real data into the simulation process, the model becomes even more effective: it validates the confirmed data and deletes the rest, thus reducing the level of uncertainty of the whole chain.

The algorithm developed was made available to potential users, in the form of scripts (written in Python scripting language) under an Open Source licence. These advances are particularly beneficial to the *RuimteModel Vlaanderen*, an urban land use model used as a tool to help decision-making in several Flemish organisations (Agentschap voor Natuur en Bos, Vlaamse MilieuMaatschappij, Instituut voor Natuur- en Bosonderzoek).

IMPERMEABLE PIXELS

The wide-scale **MAMUD** project also explored the impact of urban growth on hydrology. The construction of buildings or urban facilities (car parks, asphalted roads, etc.) significantly reduces soil permeability. This massive soil sealing restricts normal rainwater infiltration and accelerates runoff, which increases and exacerbates the risk of flooding in the case of very bad weather. Crossed by three rivers, the city of Dublin often suffers such episodes that endanger its inhabitants and cause major material damage.

In the north of the city, the river basin of the Tolka, which is particularly vulnerable, served as a study area. Assisted by Dublin City Council and Trinity College, the researchers were able to establish maps detailing the runoff coefficient in the river basin for 1988 and 2001, based on satellite image time series. Their comparison highlighted the significant increase in impermeable surfaces, with a high coefficient, thus giving a good indication of the urbanisation phenomenon during this period.

A flood prediction model was developed on this basis. It not only takes into account the rainfall-runoff data, but also the changes in the density of the different types of land use (residential, commercial, industrial, recreational, etc.).
For the authorities, such tools help guide development policies and decisions towards safer choices.

Pléiades, new possibilities for urban mapping

Shortly after their launch, the Pléiades satellites started providing images that could be directly used in numerous research projects. Launched in December 2011 and 2012 respectively, the twin Pléiades 1A and 1B satellites form a new generation constellation that completes the services offered by the SPOT satellites. In orbit at an altitude of 694 kilometres, the Pléiades satellites can take up to 1,000 shots a day with a daily revisit capability. Light and agile, they are capable of turning on themselves to vary the viewing angles, allowing them to acquire stereoscopic images, which helps measure terrain elevation. While they have a narrower field of vision than SPOT satellites, their spatial resolution is only 50 centimetres, which means they can really zoom into the observed areas. Precision, repetitiveness and stereoscopy: Pléiades images have all the assets to map the urban fabric, which is particularly heterogeneous and subject to frequent changes.

The Pléiades satellites were developed under the responsibility of the CNES, the French Space Agency, but among the programme's partner countries, Belgium holds an important place. In return for this participation, the Federal Science Policy can offer a quota of images at preferential rates to users established in Belgium who are involved in a public service mission, to accomplish tasks within the framework of this mission and for non-market services. It has therefore set up a distribution and archiving system for Pléiades data, called the Belgian Pléiades Archive.

To find out more, visit the ***Belgian Pléiades Archive*** portal at **pleiades.belspo.be**

A GREEN NETWORK WITHOUT ANY TEARS

While land planning requires good tools to aid decision-making, the same is true for the closely linked environmental policies. Adhering to the collective "green" and sustainable management efforts, towns and cities are committed to respecting a series of local and European enforcements (Habitats Directive, Pan-European Biological and Landscape Diversity Strategy, etc.). For instance, the Brussels Region is keen to preserve and maintain the green network that criss-crosses the city. In the urban environment, green spaces fulfil many functions: they regulate pollution and drainage, they provide a green lung for city-dwellers in a highly dense urban fabric and, when they are connected, they ensure the continuity of ecological corridors for animal and plant species allowing them to cross into surrounding green spaces.

To obtain updated information on these corridors, the **VALI-URB** project studied how to characterise and list all the green spaces in Brussels: those in the public space but also less accessible elements such as green roofs, private footpaths, gardens or parks within housing blocks. Satellite imaging offers a view of the entire urban surface area, including these out-of-reach green areas. Furthermore, latest generation satellites, such as Pléiades, provide images of vast stretches, with a resolution reaching 50 centimetres, allowing a precise cartographic inventory and an analysis of the changes.

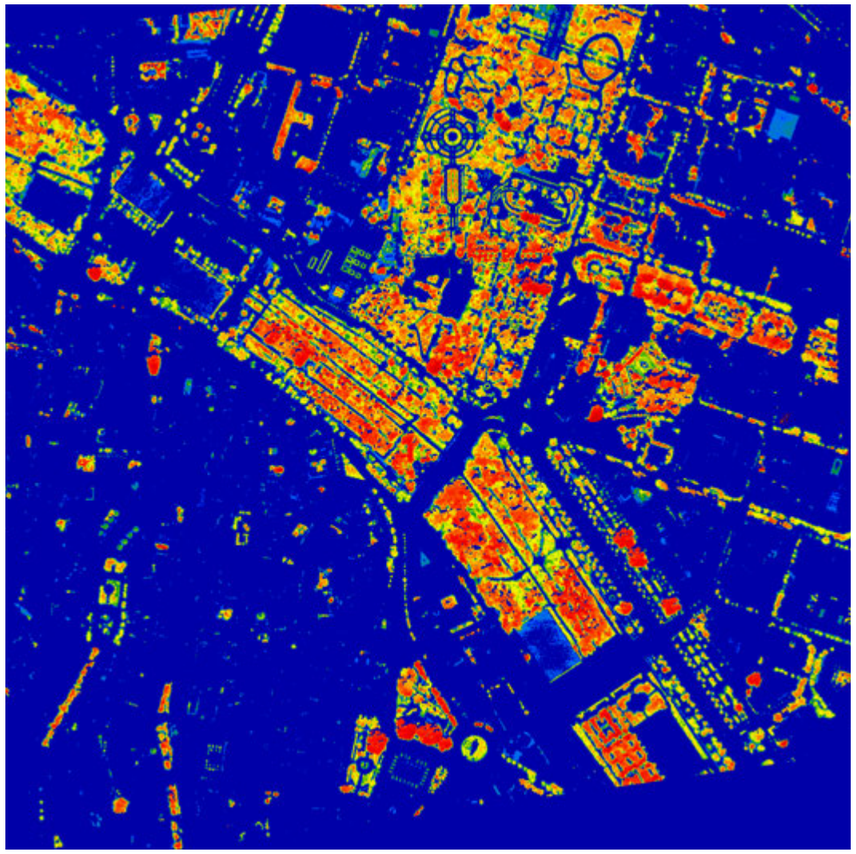
By combining the satellite data at different scales with the existing topographical maps, the researchers have developed a consolidated and reproducible method to map ecological corridors. Elaborated in Brussels, the method was transposed to and tested on two medium-sized French cities: Strasbourg and Rennes, in partnership with local universities and certain authorities interested in these results for the management of their area.

VEGETATION, THE SENTINEL OF AIR QUALITY

Air quality is another great urban challenge. It is influenced locally by the way streets are organised and the amount of traffic passing through. The air quality indexes, to which we are now accustomed, are calculated according to concentrations of several atmospheric pollutants, measured separately (CO_2, NO_2, SO_2, ozone, etc.).

In search of a more integrated approach, the **BIOHYPE** project focused on urban vegetation, which is continuously exposed to all pollutants. Polluted foliage, which has accumulated the various substances throughout its growth season, doesn't reflect the light in exactly the same way as healthy, unstressed foliage. Its observation by remote sensing could therefore be a good indicator of the level of pollution, just like canaries used in coal mines would sound the alarm of a lack of oxygen by suffocating.

Measurement of sun-induced chlorophyll fluorescence using a portable spectrometer.

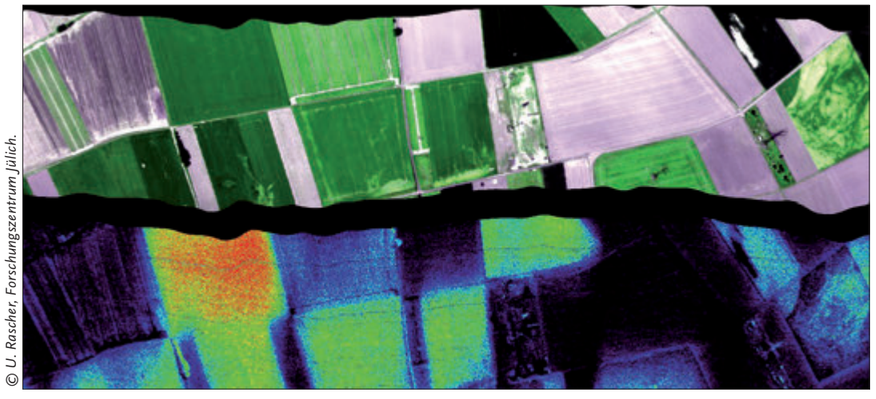


Vegetation index values (based on hyperspectral data) shown in colour help to visualize individual trees in the city of Valencia.

THE INDICATOR TO WATCH: FLUORESCENCE

Conducted in collaboration with the University of Valencia in Spain, the project was carried out at two study sites, in the cities of Ghent and Valencia. Four species of trees that are common in Valencia were selected; samples of trees based in areas of heavy traffic were observed and compared with others located in quieter areas.
A complete battery of reflectance measurements were taken either directly in the field, or using an airborne spectrometer. In addition to the reflected sunlight, plants emit a low level of radiation known as chlorophyll fluorescence.

Researchers were able to reveal that the latter actually varied in correlation with the intensity of urban traffic. Initial results therefore tend to show that fluorescence could ultimately become a valuable bio-indicator of pollution, for instance, to guide inhabitant protection policies and to assess the impact of the implemented measures. In fact, the European Space Agency is planning a mission specifically devoted to fluorescence, with the launch of the FLEX (Fluorescence Explorer) satellite.



Fluorescence of different vegetation types as seen by the airborne Hyplant sensor, in the framework of the preparation of ESA's FLEX mission.

FORESTS, A VITAL HERITAGE TO BE PROTECTED

How can we protect our forests?

How can we support international efforts to halt deforestation?

Which tools can we develop to sustainably manage forest resources?

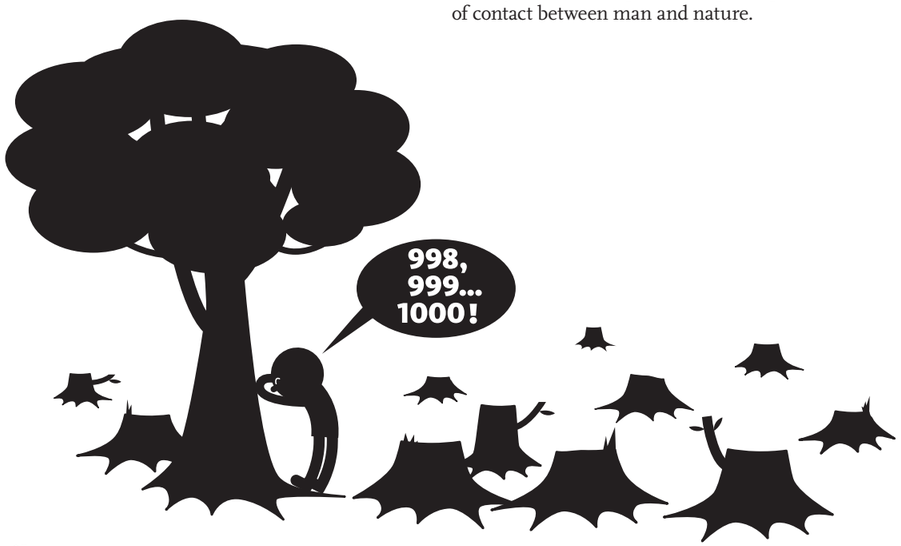
Remote sensing research explores these vitally important questions.

Forests cover more than 4 billion hectares, i.e. almost a third of the land on this planet. While only 300 million people live in them, more than a quarter of the world's population, i.e. 1.6 billion people, depend on forest resources to survive. This exceptional environment has numerous functions which have motivated the international community to set up the sustainable management of forest resources.

On an economic level, logging provides 3 billion m^3 of wood every year and sustains significant trade in non-timber forest products: fish, game, rattan, bamboo, cork, resin, nuts, mushrooms, spices, essential oils, honey, etc. Forests also play an important social role: used on a daily basis for leisure, recreational activities, tourism, education and the conservation of heritage, all of them provide a special point of contact between man and nature.

This article is based on the research projects:

VEGECLIM
UNESCO-WATCH
FOMO
GRAZEO
HYPERFOREST
ECOSEG



Finally, from an environmental point of view, forest ecosystems lie at the heart of fundamental processes. They help purify the air (extraction of dust, production of oxygen by growing forests), protect and stabilise the soil (protection against erosion), purify water (three quarters of accessible fresh water originates from forest catchment areas), and contribute to hydrological regulation (prevention of the risk of flooding thanks to their ability to retain water) and temperature regulation (humidification and cooling of the ambient atmosphere thanks to evapotranspiration). They also offer fauna and flora highly diverse habitats, thus providing a home to 80 % of the world's biodiversity.
Their crucial impact on climate (de)regulation has been highlighted since the 1980s. Forest ecosystems (including biomass, dead wood and soil) "sequester" more than 650 billion tons of carbon, i.e. more than all the carbon present in the atmosphere. Massive deforestation, especially in the great old-growth forests of the tropical belt (Amazonia, Central Africa, South-East Asia), release these carbon stocks and contributes to the increase in greenhouse gases in the atmosphere and, therefore, global warming.

The REDD imitative (Reducing emissions from deforestation and forest degradation) was set up in 2008, under the aegis of the United Nations, in an effort to incite the countries concerned to protect their tropical forests. Its principle is to give developing countries that abandon or reduce deforestation financial compensation to make up for the loss of income resulting from this abandonment. The REDD programme was quickly extended to REDD+ which includes the sustainable management of forests, as well as forest carbon stock conservation and growth measures through reforestation or new plantations.
These initiatives are part of a confirmed desire at international level to curb deforestation (approximately 13 million hectares on average every year, corresponding to twice the surface area of Ireland), and sustainably preserve all the benefits provided by our forests.

Earth observation research contributes to these efforts by allowing the development of the most effective estimation and monitoring tools, from a global scale (carbon footprint, vast changes in cover, productivity, etc.) to the most local level (extent, composition, structure or health of the stand).

CARBON SINKS OR CARBON SOURCES?

To support greenhouse gas reduction programmes, it is vital to be able to quantify and forecast the dynamics of the associated vegetation and carbon fluxes. Vegetation is an essential carbon sink. Through photosynthesis, it assimilates the CO_2 present in the atmosphere to produce organic matter and thus reduce the concentration in the greenhouse gases responsible for global warming. But human intervention is reversing the trend. Forest degradation and deforestation are the primary mechanisms responsible for turning the carbon sinks into carbon sources. It is estimated that deliberate fires, unsustainable logging and the conversion of forests into pastures, farmland and various infrastructures are responsible for approximately 20 % of global greenhouse gas emissions, i.e. more than the entire transport sector.

Besides having a decisive effect, these anthropic disturbances have, until recently, seldom been taken into account in carbon cycle modelling, such as the ORCHIDEE model. This global dynamic model of the continental biosphere includes biophysical, biogeochemical and ecological processes. It takes into account the CO_2 and energy fluxes between the soil and the atmosphere as well as certain hydrological components, and is employed in the large climate models used by the IPCC (Intergovernmental Panel on Climate Change) or the REDD programme. Besides anthropic disturbances, seasonal and interannual variability in the carbon fluxes in tropical regions is another parameter that needs to be accurately defined.

The goal of the **VEGECLIM** project is to improve the terrestrial carbon cycle forecast in tropical regions by dynamically integrating the characteristics of the continental surface into the global ORCHIDEE model, on the basis of 10 years of SPOT VEGETATION image time series (type of vegetation, seasonal and annual evolution, dry, cut, burnt areas, etc.). The main innovation of this vast five-year project is the implementation of a close collaboration between Earth observation researchers and land surface modelling experts.

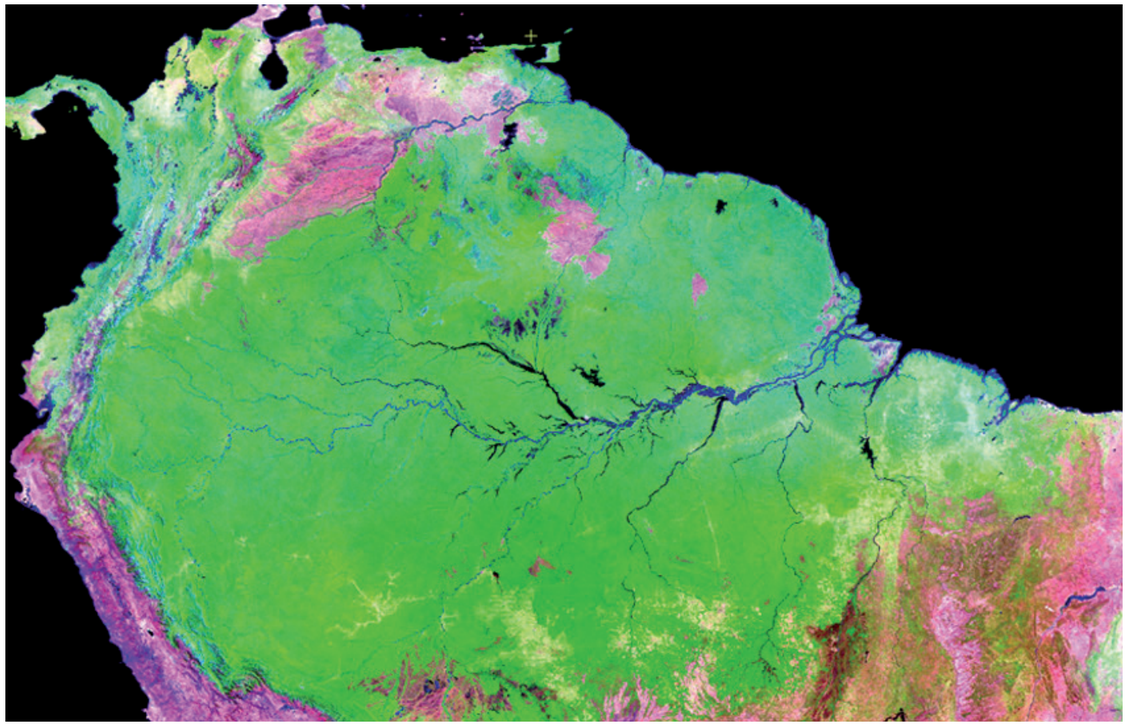
Traditionally, existing maps, ground surveys, climate data or low-resolution (4 kilometres) and static (at a given moment) satellite data provide the information for the global or regional models. By integrating the time dimension and the most precise soil classifications derived from SPOT VEGETATION (resolution of 1 kilometre) in the ORCHIDEE model, researchers have been able to improve the estimation of stocks and real carbon fluxes in the Amazon and Congo basins.

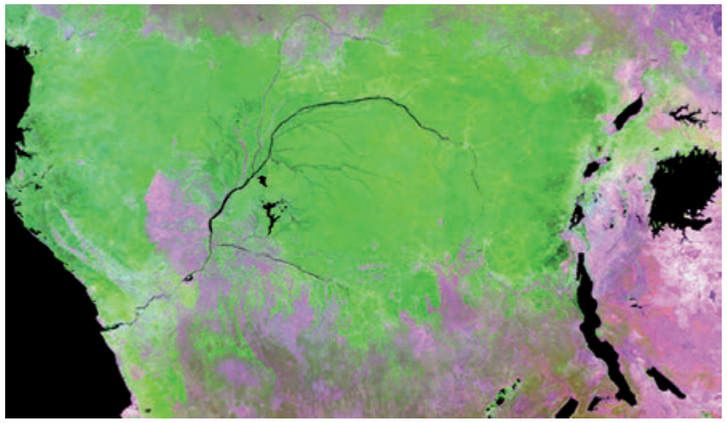
In particular, they tested the model with the deforestation simulation results in the Democratic Republic of Congo (DRC), in order to establish forecasts of the evolution in stocks and carbon fluxes until 2035, according to different climate scenarios. Based on the advances of the **VEGECLIM** project, it should be possible to determine whether the DRC's terrestrial carbon budget will remain negative or become positive, thus changing the DRC from a carbon sink to a carbon source.

Relatively preserved up until now, Central Africa's old-growth forest, the second largest tropical forest after the Amazon forest, is increasingly being threatened by degradation and deforestation, mainly owing to industrial exploitation. The results obtained will therefore help to define the most relevant policies to adopt within the framework of the REDD+ mechanisms or other strategies to mitigate climate change factors. The study could also extend to the whole of the Congo basin thanks to the optimised modelling of changes in land cover.

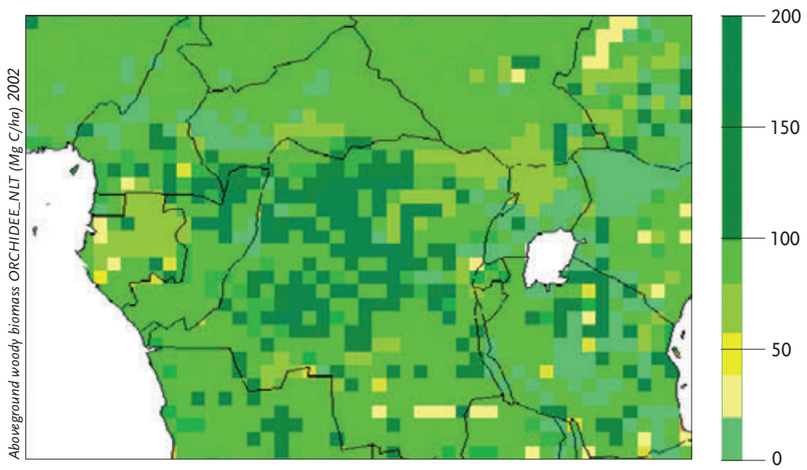
Besides these results, two global products have been made available to the scientific community: a multiannual map of land cover and a reference database on the phenology of foliage. Furthermore, a global map of the world's forests was created and used as a linchpin for a public exhibition aimed at drawing attention to the importance and the vulnerability of our forests.

Networks of "flux towers" measure the carbon amount exchanged between an ecosystem (here the Amazon Forest) and the atmosphere. By combining these measurements with other measurements, it is possible to continuously follow the CO_2 levels in a forest.





False colour composite of the Amazon and Congo basins based on daily SPOT VEGETATION images. In the Congo Basin, the map shows woody biomass (trunks, branches, leaves ...) in Mg C/ha, as estimated by the ORCHIDEE model.



Imaging the World's Forests EXHIBITION

In support of the International Year of Forests 2011, the Federal Science Policy, VITO (Flemish Institute for Technological Research) and the Université Catholique de Louvain joined forces to set up the travelling exhibition ***Imaging the World's Forests***. Its objective is to demonstrate to the general public the usefulness of Earth observation by satellite to manage and protect the world's forests. A series of remarkable satellite images highlight some of today's major stakes: deforestation and reforestation, savannah and forest fires, threatened mangroves, etc. A global map of the world's forests, classified into seven main types, has also been produced on the basis of SPOT VEGETATION images collected over 10 years (2000-2010). The exhibition was shown around Louvain, Brussels, Mons, Charleroi and in regional environment initiation centres in the Walloon Region, and can still be viewed at the Euro Space Center in Transinne, and online on the **eoedu.belspo.be/forests** website.

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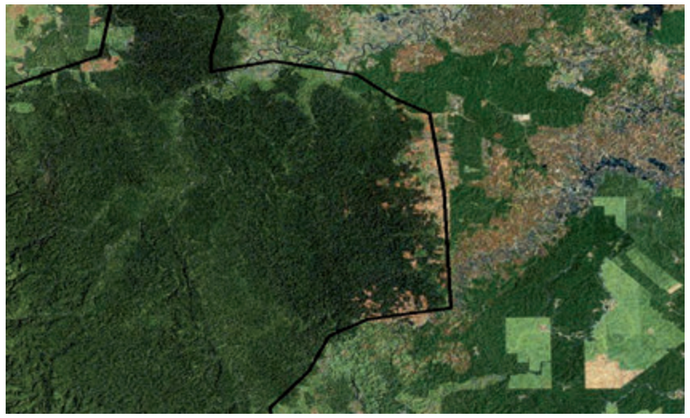


The tropical rainforests of Sumatra in Indonesia are part of the forest heritage sites in danger. This SPOT image clearly shows how deforestation, already important in the buffer zone, is starting to nibble at the borders of the site.

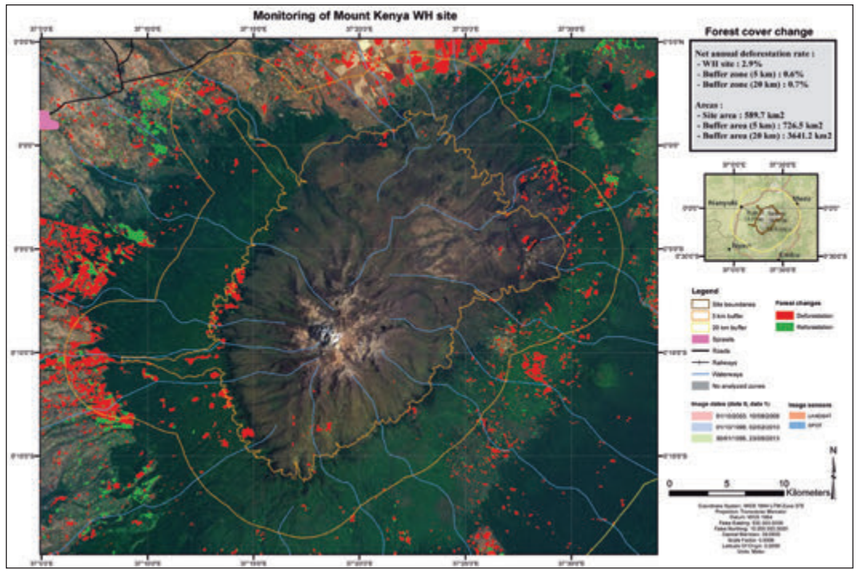
HELPING UNESCO MONITOR THE TROPICAL FORESTS

The tropical forests have an invaluable natural and cultural value. Besides their essential role in regulating the climate and the water cycle, they are an unparalleled reservoir of biodiversity. The tropical rain forests alone are home to more than half our planet's animal and plant species. In order to protect this exceptional wealth, UNESCO has already classified more than 80 sites, composed mainly of tropical rain forests, as world heritage.
While the World Heritage Committee decides on the classification of a site, it must also examine the state of conservation, in order to be able to take measures when the site is threatened. However, the annual assessment of the different sites' state of conservation is a difficult task owing to their vast surface areas and inaccessibility. For instance, only 18 % of the sites inscribed on the World Heritage List were assessed during the Committee's session in 2013.

To manage and thus protect this precious heritage as good as possible, UNESCO needs semi-automatic tools to detect changes. Consequently, the challenge of the UNESCO-WATCH project is to develop an operational method based on satellite imagery to assess, at regular intervals, the state of conservation of the tropical rain forests classified as world heritage.
In order to observe the external pressures exerted on these sites, a 20 kilometre buffer zone was established around the perimeter of the protected site. By monitoring this buffer zone, it is also possible to determine the impact of the protection measures in the areas directly surrounding the site in question.

The researchers selected 15 test sites with different types of vegetation (from mangroves to mountain forests), expanse (from 150,000 to more than 5 million hectares) and geographic location (spread across the entire tropical belt). In total, the surface area of the sites analysed corresponds to approximately five times that of Belgium.
The chosen sites share an exceptional biodiversity, some home to emblematic species such as the giant panda in Sichuan (China), the jaguar in Calakmul (Mexico) or the gorilla in Virunga National Park (DRC).
The study analysed a great number of Landsat images (resolution of 30 metres) and SPOT HR

Example of a clickable pdf file delivered to managers of heritage sites. For the site of Mount Kenya, the deforested areas are marked in red, reforestation areas in green, the perimeter of the heritage site in dark brown and the buffer zone (5 km) in light brown.



images (10 metres) covering three periods: 1990, 2000 and 2010. The originality of the image processing consists of grouping together neighbouring pixels with similar characteristics, known as objects. These objects have an average surface area of one hectare. The objects are used to detect changes allowing the visualisation of variations per entity and not per pixel. Using this approach, it is possible to take into account the context surrounding each pixel and contribute to a better characterisation of the change's dynamics.

As regards prototypes, maps of 12 of the selected sites were created in the form of interactive pdf files, in order to facilitate their use by UNESCO and local managers. These maps allow users to visualise changes in plant cover within the protected area, whether they are negative (deforestation, degradation) or positive (reforestation, regeneration), as well as identify potential threats that may appear along the borders (clearing, deforestation, expansion of farmland, etc.).

REVERSING THE MOVEMENT: REFORESTATION

Of crucial importance to all life forms, humans see forests as a seemingly inexhaustible source of ecosystem goods and services. While the global demand in food is accelerating the conversion of forests into farmland, in some parts of the world, however, forest cover is expanding. "Forest transition" describes the transition from deforestation to reforestation. Many industrialised countries have already tried out this transition, while in the majority of developing countries, it is only just beginning or has yet to happen.

The aim of the FOMO project is to assess the dynamics of these forest transitions, as well as their impact on ecosystem services. The study particularly relates to mountainous regions because farmland is most often abandoned and forests allowed to regenerate on marginal land that is unproductive and/or difficult to access. In order to make a comparative analysis, three sites were chosen in very different geographic contexts: the Carpathian Mountains in Eastern Europe, the Northern Andes in Ecuador and a valley in Bhutan in the Himalayas.

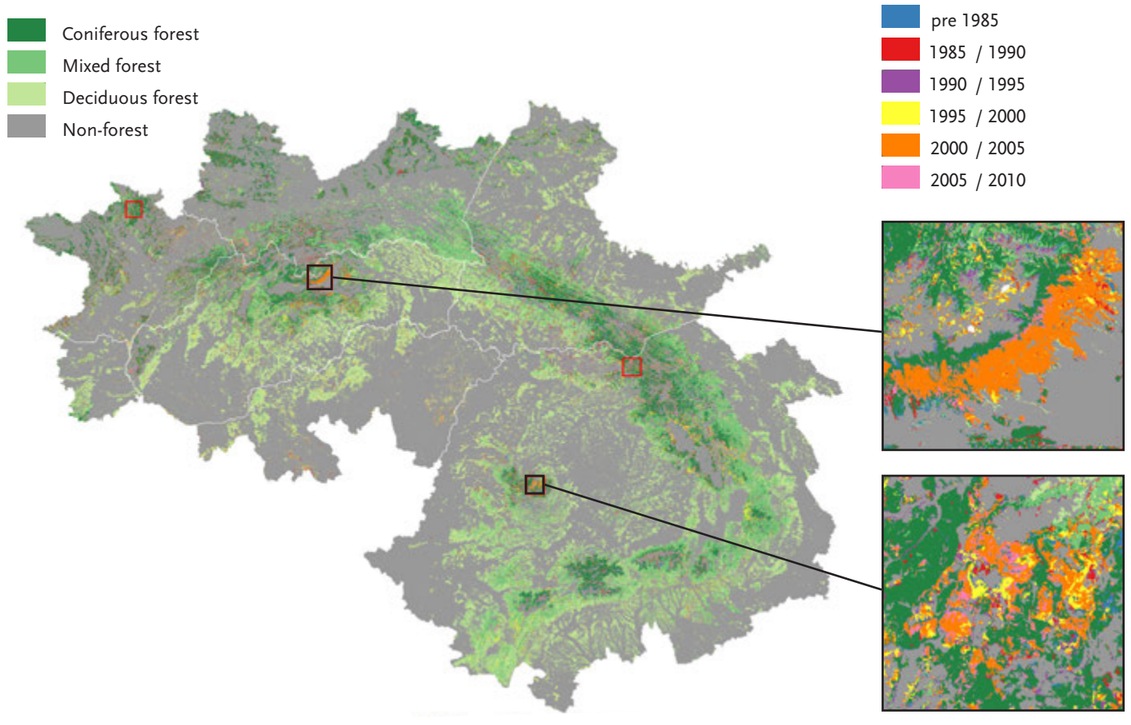
To develop tools to monitor changes in forest cover in mountainous regions, satellite imagery is the preferred source of information. It provides detailed, reliable, up-to-date and cost-effective data on relatively inaccessible areas. The five years of research led to important methodological advances:

- atmospheric and topographic correction techniques (shadow effects) were optimised for mountainous terrains. The steep, hilly landscape interferes with the images' "readability";
- an automatic large-scale forest cover mapping process was developed based on an assembly of Landsat images (resolution of 30 metres);
- innovative methods were developed to detect changes in forest cover over short or long periods.

Based on very high-resolution WorldView-2 images, these methods are sufficiently precise to allow tree species to be identified. For instance, in Ecuador, researchers were able to determine the presence of pine or eucalyptus copses, exotic species that were introduced to the detriment of the páramo, the natural ecosystem at this altitude. This reforestation is supported by the government to encourage wood production and take part in carbon sequestration efforts within the framework of programmes to combat global warming. These benefits are nevertheless counterbalanced by a series of negative effects such as the decline in biodiversity and a reduction in the capacity to store water. This leads to a disruption in water flow control and a potential threat to the stability of the slopes after the harvests.

On the one hand, the FOMO project has revealed the links that exist between changes in forest cover and the provision of ecosystem services and, on the other hand, it has produced detection and quantification tools for these links. These results are a significant help to decision-makers and managers of forest ecosystems, whether at local, regional, national or global level. They can indeed help them to adopt land-use strategies more adapted to a sustainable management of the resources supplied by the forests.

In the Ecuadorian Andes deforestation is clearly visible in the middle of this picture. A little higher we also see patches of pine and eucalyptus, exotic trees planted at the expense of the natural ecosystem.



Forest map of the Carpathian mountain chain made from a mosaic of Landsat images. The insets show details of forests disturbance between 1985 and 2010 (in green are the stable areas, other colours correspond to different periods of disturbances).

What is a forest?

According to the definition of the United Nation's Food and Agriculture Organisation (FAO), a forest is "a land area of more than 0.5 hectares, with a tree canopy cover of more than 10 %. The trees should be capable of reaching a height of 5 metres at maturity". As for primary forests, they are "naturally regenerated forests of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed".
As for the Ministerial Conference on the Protection of Forests in Europe, held in Helsinki in 1993, it defines the sustainable management of forests as "the stewardship and use of forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems".

THE SAVANNAH, A SPECIAL TYPE OF FOREST

Dotted with low-growth vegetation comprised of trees and shrubs, the savannah is a particular type of forest that requires specific monitoring tools. The GRAZEO project focused on Kruger National Park in South Africa, where the savannah covers more than two million hectares. The project's emphasis is on the structure, composition and quality of the natural vegetation, key factors of the habitat and behaviour of the large local herbivores.

The main objective of GRAZEO is to improve the models developed by the EPISTIS project (see Epidemiology section, page 70) to estimate the risk of the transmission of foot-and-mouth disease between the wild buffalo enclosed in the wildlife reserve and the livestock outside it. The abundance and the quality of the fodder are the determining parameters for the distribution of livestock and buffalos in the savannah's pastures. Their assessment, coupled with the risk of the destruction of the enclosures, allows the risk of contact between these two populations to be better defined.

Subsequently, GRAZEO explored the potential of WorldView-2 data to map tree species (solitary or in a copse), grassland, herbaceous biomass, as well as the nitrogen concentration, all indicators of the fodder's availability and quality.
These indicators are entered into adapted models and various scenarios are tested in order to determine their contribution to the estimation of the risks of contact.

By making use of the WorldView-2 sensor, researchers were able to develop new methods to produce detailed regional maps – generally unavailable up until now – for savannah environments. Thanks to the very high spatial resolution of the images (50 centimetres), it is possible to deal with the savannah's significant spatial variability (alternation between prairie grasslands and clumps of trees); at the same time, they are also compatible with the distances covered by the animals. The sensor also offers a specific spectral diversity: in addition to the usual spectral bands of what is visible and the near infrared, four extra channels are available, including yellow and red-edge, thus allowing users to better discriminate between trees and grass.

The principle aim of GRAZEO's results is to prevent the spread of foot-and-mouth disease around Kruger National Park. The objective is to provide park managers with the necessary information to adapt the fight against this highly contagious disease, by primarily allowing them to locate priority areas of intervention (vaccination, reinforcement of enclosures, etc.). But the results' reach extends beyond this case study.

The methodology and products developed can be used to monitor changes on a regional level in all of the savannah's ecosystems. They should help to better understand the impact on these special ecosystems of local environmental factors (soil use, livestock density and other animal populations, bush fires) or global ones (climate evolution).

The difference in vegetation cover inside and outside the Kruger Park is clearly visible on this image. Within the Park (left), managers maintain a savannah-like vegetation, while on the other side of the barrier, natural vegetation is intact.

The Wijnendale Forest seen by the hyperspectral APEX sensor in false colours and real colours. The false colour image is made up of three specific wavelengths in the near-infrared, red and blue. Vegetation looks red; the different shades of red indicate different stages of development or different species.

STANDS IN 3D

It is impossible to imagine the sustainable management of a forest without monitoring its general condition. Forest managers must have reliable and regularly updated data on important parameters such as the diversity of the stands, the species therein and the vitality of the trees. Once lengthy and fastidious, the task of gathering data in the field is now increasingly supported by different types of airborne remote sensing instruments. For instance, hyperspectral imagery is useful to identify tree species and assess the foliage's state of health. However, its observations only relate to the upper part of the forest, i.e. the canopy. LiDAR, an active sensor that emits a laser beam, provides 3D information on the structure of the forest (height of the trees, presence of understories) and its density. The HYPERFOREST project's objective was to determine whether the three-dimensional information provided by LiDAR could enrich the processing of hyperspectral images in such a way as to provide forest managers with more reliable and more detailed information.

The researchers selected three forest sites located in Flanders with a structure increasing in complexity: the entire Kersselaerspleyn reserve in the Sonian Forest, which has a homogeneous stand of beeches; Wijnendale Forest, one of the biggest forest areas in West Flanders, where the dominant species, oak, grows alongside maple, beech, hazel, larch, etc.; and Aelmoeseneiebos, the University of Ghent's experimental forest with mixed species (oak, beech, ash, larch, etc.) and a lush undergrowth.

Conducted over a five-year period, the project delivered concrete, widely documented and published results:

- improvement in the geometric correction of the hyperspectral images. The height of a tree causes its position on a hyperspectral image to move. Thanks to LiDAR, this vertical component can be taken into account and the position of the crown can be determined more precisely;
- supplementary information provided by LiDAR has also helped to improve the classification of tree species and determine more precisely the level of crown closure, which is an important indicator of the forest's state;
- LiDAR data was also shown to contribute in other ways. It particularly helps to determine whether part of the crown is exposed to the sun or not, since it is more difficult to identify the species in this case. It also helps to better define the tree crowns.

To fine tune the results still further, the HYPERFOREST project used two other sources of information at the same time as the airborne data. On the one hand, a LiDAR sensor placed on the ground, which helps to generate a clearer picture of the lower strata of the forest. On the other hand, a complex model called DART which links the recorded hyperspectral signal with the biophysical and biochemical properties of the vegetation, since the latter have a direct influence on the trees' state of health.

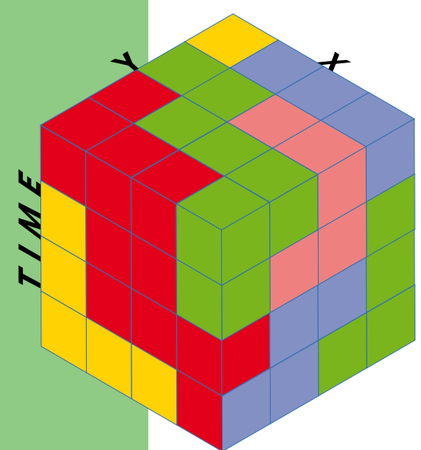
Through the intermediary of the Instituut voor Natuur- en Bosonderzoek (INBO), one of the project's partners, forest managers were involved in all stages of the study. Not only did they collect reference data in the field, they also assured of the research's relevance for end users. The types of products and applications to be developed were continuously discussed and adapted to real needs (for instance, the mapping of species and the level of crown closure). The final results were presented at a workshop held especially for users.

MAPPING THE DYNAMICS

Several studies have already explored the use of satellite image time series to monitor the vegetation's evolution. The majority of traditional techniques compare the spectral responses of a given set of pixels over a given period, for instance, every month over 10 years. But, in general, these approaches don't take into account either the spatial context (the value of the pixels or groups of neighbouring pixels), or the time context (the values of the same pixels at different periods). Furthermore, these procedures are rarely based on a hierarchical classification, i.e. one that groups together the data, from level to level, in similar segments. Hence, they don't succeed in showing the complex spatial-temporal mechanisms at work in nature, where the majority of ecological processes are spatially linked and organised hierarchically.

Consequently, the objective of the ECOSEG project was to develop an optimised method of classification which includes temporal information in the image's hierarchical segmentation. In an innovative manner, the project attempted to integrate the context of a pixel from the point of view of all its components (spectral, spatial and temporal) in order to be able to determine its classification at a lower hierarchical level.

Forests provide the ideal environment to validate such a method, owing to the complexity of their responses, on a spatial and temporal level, in relation to stress factors (for instance, insects and other pathogens, drought, fire). Time series of several biophysical parameters were therefore used as the key indicators of the forests' health. By the end of the project, the researchers had developed a methodology and an algorithm that should allow users to more precisely determine the dynamics of forest ecosystems and thus better understand how they function.



SEEING THE PAST THANKS TO TECHNIQUES OF THE FUTURE

A DIFFERENT TAKE ON ARCHAEOLOGY

Seldom used in the domain of archaeology up until now, remote sensing is not only poised as an interesting technique to find out more about sites and therefore better preserve them, but also as a means to discover remains from the past undetected through more traditional methods.

While agricultural management and land planning have already assimilated the use of remote sensing into their practices, it is a more recent approach in the domain of archaeology. Traditionally, information gathering is essentially based on countless surveys, patiently and laboriously carried out, with the help of maps and aerial photos which provide an overview. But now, satellite instruments offer spatial and spectral resolutions that are continuously improving. Research teams are therefore endeavouring to explore the added value they could offer through precision, speed and the extent of their observations.

THREATENED PYRAMIDS

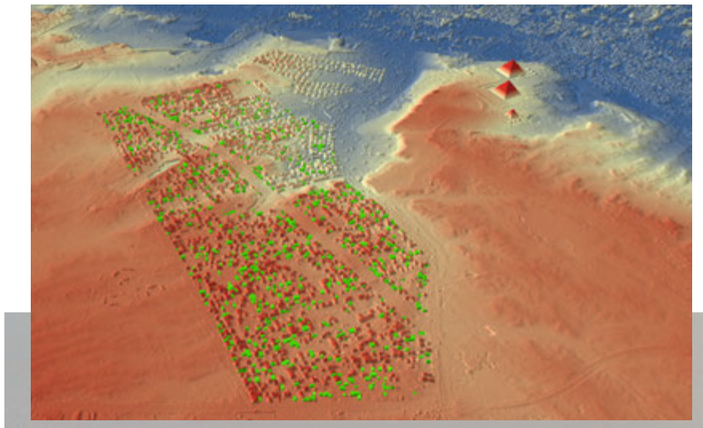
The **APLADYN** project focuses on the Nile valley and the pyramids of Giza, the archaeological site par excellence. Just like other large fluvial systems, the Nile is the axis of a mythical fertile valley, which was the cradle for the emergence and expansion of three thousand years of Egyptian civilisation. For the researcher, as for ordinary mortals, the cultural and natural heritage it harbours is priceless. A better understanding of the sites' dynamics, and the links woven between man and his environment, certainly provides the keys to studying the past. For instance, by determining where the old channels and the river bed passed, we can more accurately pinpoint the areas probably occupied by humans in ancient times.

Detailed observation of the landscape also provides the keys to the future, by defining the threats that weigh on these unique sites. New methods integrating remote sensing data have not only revealed the rapid growth of urbanisation in Cairo, but also the migration of the sand dunes which are advancing at an average of four metres a year. By comparing the Landsat images of the past 40 years, the scientific team has shown that this clear progression of the dunes still doesn't compensate for the continued expansion of farmland in the fertile plain into the desert. Remote sensing has therefore helped to quantify both the risk of the formation of sand dunes and anthropic pressure. Thanks to the methods developed, it is now possible to estimate the progression of these phenomena by extrapolating future changes based on past evolutions. Such models are essential for local managers so that they can take the necessary protective measures.

This article is based on the research projects:

APLADYN

ANAGHLIA



A digital elevation model can be created by comparing two sets of high-resolution stereoscopic images, clearly showing and quantifying the degradation of the Gizeh plateau by new housing developments. The buildings erected between 2009 and 2011 in the area called "Pyramid Gardens" (Hada`iq al-Ahram), located southwest of the archaeological site, appear in green.

THE HUNT FOR ARCHAEOLOGICAL TREASURE

Automatically identifying an area with a high archaeological potential, anywhere in the world, is, of course, one of the researchers' objectives. Human activity in the distant past has left traces in the composition of the soil, and this can be conveyed through modifications in the plant cover. Succeeding in characterising these traces is an exciting challenge, explored by the ANAGHLIA project.

Since archaeological wealth is closely linked to the contours of the landscape, it is important to obtain a detailed topography of the site being studied. This is why researchers integrate the LiDAR data into their methods: this airborne active system sweeps surfaces with its laser signal, even through clouds or vegetation. The return signal is intercepted and provides information on the position and altitude of thousands of points of contact on the ground, thus providing the (micro)topographical context necessary for the analysis and interpretation of the spectral signals.

Furthermore, the considerable amount of information provided by the hyperspectral data helps to reveal some of the ground's geophysical properties indicating that the site was probably occupied in the past: the presence of charcoal particles, tiny fragments of terracotta or an unusually high quantity of organic matter are just some of the elements sought after. By combining the two sources of information in an innovative manner, the researchers better understand how existing remains are distributed on the surface, and how elements of the landscape can expose them or, on the contrary, hide them.

For the ANAGHLIA project, two contrasting study areas were chosen. One of them is the watershed of the Raganello river in Calabria, where more than 150 archaeological sites were discovered, dating mainly from the Bronze Age and Hellenistic periods.

The drone: flexible, fast and inexpensive

Another technological contribution, that can help to validate these results with field measurements that isn't too time consuming, is the UAV (Unmanned Aerial Vehicle), which is turning out to be very useful. Better known as a drone, this remote-controlled machine takes a video or stills camera on board. It is easy to programme the parameters to be recorded as well as the course changes. The fact that it is easy to programme, easy to handle and relative inexpensive, explains the recent success of the drone. Nowadays it is no longer rare for academic research centres or private organisations to acquire their own observation drone.

BIODIVERSITY, A WEALTH TO BE PRESERVED

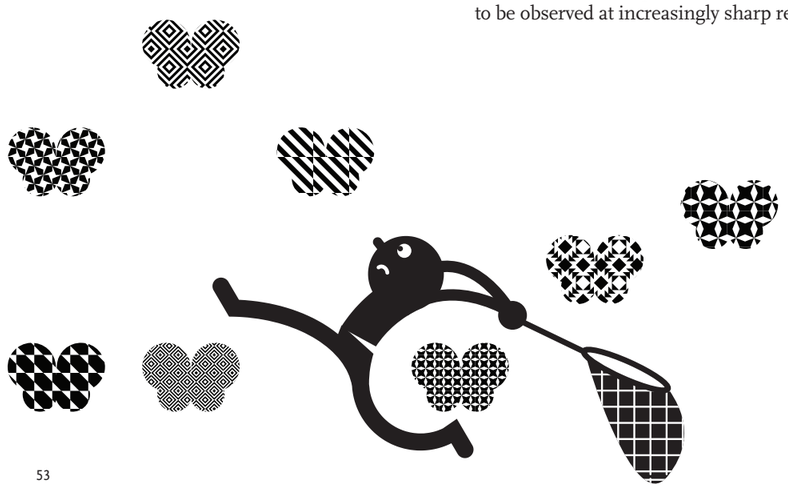
In an attempt to curb the decline of biodiversity, a new approach is being implemented. Multidisciplinary, large-scale and integrated, it aims to observe ecosystems in a global manner, in all their complexity. Serving this so-called ecosystemic approach, remote sensing is proving to be an excellent tool.

Biodiversity is continuing to lose ground, threatened by global warming and anthropic activities. The International Union for Conservation of Nature has announced alarming figures: nearly 30 % of the species listed are threatened with extinction. In the hope of stemming the phenomenon, conservation efforts must increase and become more efficient. With the Pan-American ecological network, the Australian climate corridor, the Alpine Convention, the French green infrastructure and the European Natura 2000 network, etc., wide-scale projects are on the increase.

As regards these major projects and more local initiatives, the global approach is now being given priority; the ecosystem is being considered in its entirety. From this point of view, satellite images have a role to play. Indeed, they have a number of important advantages concerning the monitoring of biodiversity: obtained through a non-invasive technique, they allow large areas to be observed at increasingly sharp resolutions.

This article is based on the research projects:

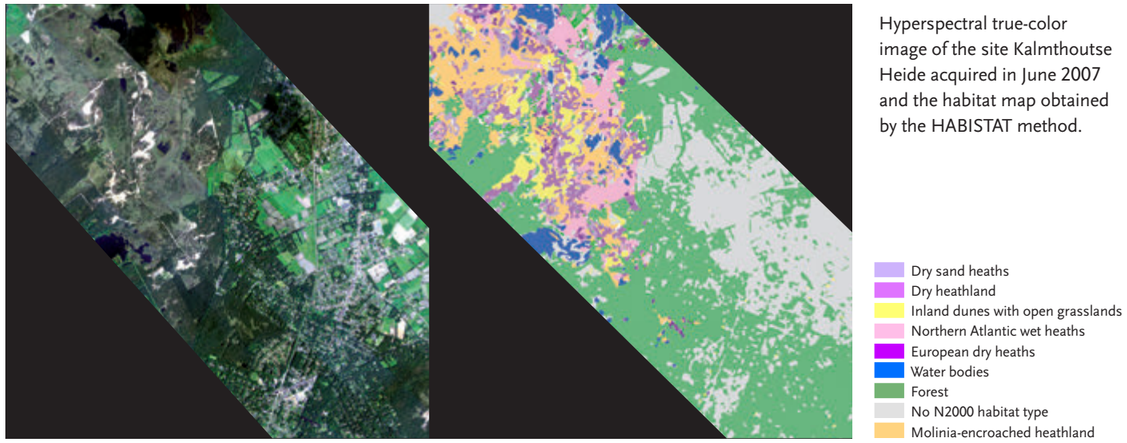
HABISTAT
RE-LEARN
ESSENSE
HEATHRECOVER
VEGEMIX
REMEDY



Furthermore, the repetitiveness of the shots allows researchers to have a range of information throughout the year and the seasons.
One particular method of acquisition, hyperspectral imaging, is the natural choice for the study of biodiversity. A true technological revolution, it offers researchers much more precise and extensive data than traditional multispectral imaging. This means scientists have an incredible mass of information available to them, but this also presents a real challenge when it comes to processing and storing it.
After many methodological explorations and the development of procedures to process and analyse hyperspectral images, researchers are now using them for applied studies. Belgian teams are providing us with concrete results in the field of biodiversity.

AN ASSESSMENT EVERY SIX YEARS

In Europe, protecting biodiversity has become a priority. In order to define a framework for joint action, the Natura 2000 network was established in 1992. Every country draws up a list of sites of interest and promises to continuously monitor their state of conservation. Every six years, the European Commission must be given an assessment report. This commitment involves a considerable amount of work in terms of collecting field data; it is both costly and fastidious. In an attempt to be more efficient, control bodies should ideally be able to rely on practical and reliable tools, such as detailed and recent maps, quality indicators of the identified habitats, or models linking types of precise habitat to areas of vegetation. The 18 Belgian and Dutch researchers of the **HABISTAT** project worked on the subject for more than four and a half years. Their objective: to develop a method allowing them to obtain a detailed map of the habitats and indicators of their quality, thanks to hyperspectral data.



Hyperspectral true-color image of the site Kalmthoutse Heide acquired in June 2007 and the habitat map obtained by the HABISTAT method.

Natura 2000, a large-scale project

The objective of the European Natura 2000 network is to identify, monitor and protect natural and semi-natural sites with a regional or community interest, owing to the exceptional character of the fauna and/or flora there. These sites, whether inland, on the coast or at sea, require increased protection and a special type of management. The stakeholders in the network are both numerous and varied: researchers, public services, farmers, citizens, etc. The Natura 2000 network is the very expression of the desire to adopt a more global approach regarding the protection of biodiversity. The animal and plant population have no borders. Extended knowledge of their needs is more than ever necessary to accelerate conservation and restoration efforts.

MAPPED HABITATS

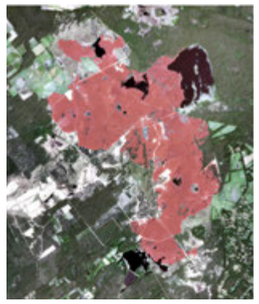
The project focused on three sites in the Natura 2000 network featuring a heathland ecosystem: Kalmthoutse Heide in the north of Antwerp, Ginkelse and Eder Heide in the Netherlands. The researchers' first challenge was to carefully classify the habitats present in this ecosystem. They are very diverse but their structure is only determined by a limited number of abundant plant species. Besides several exceptions, there is no one-to-one relationship between a species and a type of habitat, thus preventing any direct classification. The innovative approach therefore involved first mapping the dominant species at a highly detailed level, then rearranging them into habitats, taking into account their spatial distribution. The researchers were thus able to go from six broad categories of habitat (heath, grassy surface, dune, etc.) to 27 far more specific subcategories, which is far more useful for the management of the sites.

The method was successfully tested on the three sites studied. For Kalmthoutse Heide, the managers of the nature reserve had access to maps of unequalled precision. The resolution of the maps reached 2.5 m (one pixel on the map corresponds to 2.5 m² in the field), i.e., much better than the results obtained by traditional methods. Thanks to this, they were able to visually assess the effects of measures such as reaping, grazing, or mowing on the conservation of the ecosystem. They were also able to define zones where it was necessary to intervene to prevent damage to the site. Followed by many publications and two international workshops, the project raised a great deal of interest. The methodology can therefore be put to the test and applied to several other European sites.

AN ALTERNATIVE TO FIELD COLLECTION

Continuing on from the **HABISTAT** project, and keeping the Natura 2000 obligatory reporting in perspective, the **RE-LEARN** project has endeavoured to find out how to keep fieldwork to a strict minimum. One of the solutions put forward is to reuse existing reference data. Researchers are therefore working on the development of a tool that doesn't require an input of new reference data to map the vegetation. Two types of existing data can be used: either data collected in the past at the actual site, or data collected at a different site, but with similar vegetation. For instance, the technique has made it possible to classify a hyperspectral image that is normally unusable because it is largely covered by the shadow of a cloud.

One of the main advantages of this approach is the possibility of mapping regions that are difficult to get to, by combining satellite images and reference data collected at sites with similar ecosystems. The precious tool should be very useful for organisations responsible for monitoring the Natura 2000 network, but also the entire scientific community using remote sensing.



Aerial photo and map of burned areas of the reserve Kalmthoutse Heide, after the devastating fire in May 2011.

ECOSYSTEM SERVICES UNDER SURVEILLANCE

Since its appearance in the 1970s, the concept of an ecosystem service has established itself in the scientific and political arena. It works in perfect harmony with the holistic (or globalist) orientation adopted in the area of protecting biodiversity. In order to best protect the countless services rendered to man by ecosystems, the ideal solution would be to map them. The Belgian and Basque researchers of the **ESSENSE** project have developed an innovative approach that can specify the location, the area and the structure of the ecosystem services, using hyperspectral data.

Up until now, the mapping of these services was derived from land use and the emphasis was mainly on production services, such as the production of wood or farming yield. Here, researchers are interested in regulating and supporting services such as denitrification, the phosphorous cycle or carbon storage. Their study focused on two nature reserves in the Kempen: De Vennen in the basin of the Grote Nete and De Liereman around Turnhout.

To establish a link between the hyperspectral image and the service rendered by the ecosystem, the researchers made two premises. The first one is that the good working order of an ecosystem depends directly on the number of species in it; the greater the biodiversity, the higher the service rendered. The second premise establishes a link between biodiversity and the spectral signal visible on the images; the richer the biodiversity, the more heterogeneous the spectral signal. The researchers therefore correlated the ecosystem service and the spectral signal, through the intermediary of biodiversity. The Belgian-Basque project should provide new possibilities for conservation efforts.

AFTER THE FIRE

In April 2011, a huge fire devastated the Hautes Fagnes. The flames ravaged more than 1300 hectares of vegetation, i.e. nearly a third of

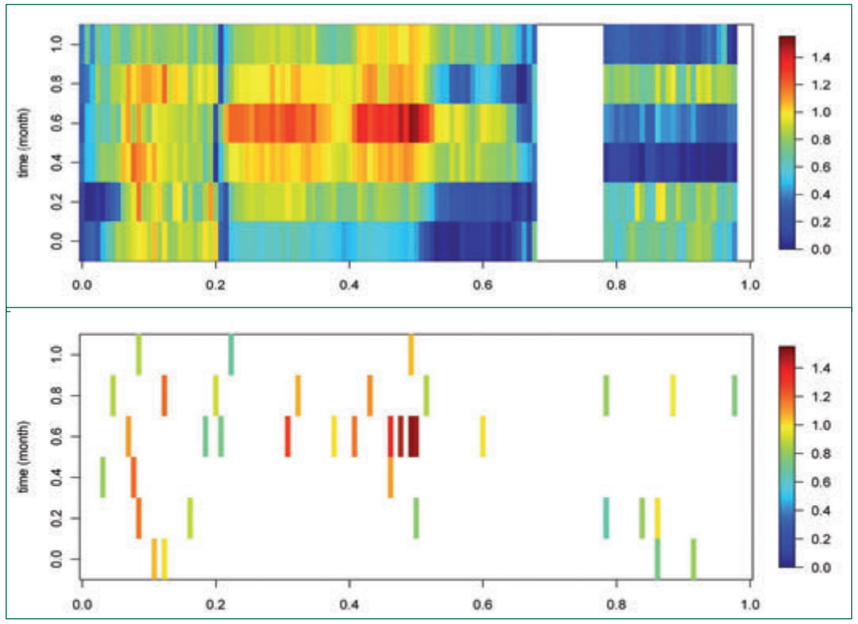
What is an ecosystem service?

An ecosystem service or ecological service is a service provided to us by an ecosystem. When an ecosystem is in a good ecological state and functions properly, it renders services to our human societies: maintaining air quality, purifying water (through denitrification, capturing nitrogen or phosphorous), trapping carbon, etc. As a result, the ecosystem has an economic value because its disappearance would lead to costs. A value that is difficult to quantify but that is the subject of much research. In 2005, the publication of the *Millennium Ecosystem Assessment* allowed the concept to leave the laboratory and establish itself on the political scene. The text aroused global interest in this notion, by illustrating the vital importance of these services in relation to man's well-being. The ecosystem services, often linked to extensive biodiversity, are threatened by our activities. The general aim is to better preserve them, which entails the identification of key areas, i.e. hotspots, that provide a high level of service.

the surface area classified as a nature reserve. A month later, the Belgian/Dutch Kalmthoutse Heide reserve was hit, and 600 hectares went up in smoke. These catastrophes revealed the lack of existing information on (dry or wet) heath and peat bog ecosystems.

Within the framework of the **HEATHRECOVER** project, Belgian and Dutch researchers and the American space agency (NASA) worked to overcome this gap in the system, and help the managers of such sites to restore the ecological balance in the damaged areas. Aid that is all the more critical since these vulnerable ecosystems are the subject of major conservation efforts.

Hyperspectral imaging has enabled us to better understand the complex interactions that exist between these ecosystems and fires. The team reached an interesting initial conclusion: to precisely assess the severity of a fire in the ecosystem of a heath, it is necessary to take into account the vegetation before the fire.
The estimation of the extent of the damage is more complex than for a "classic" forest, where a simple index is generally sufficient. The highly detailed maps obtained by the researchers have allowed the people in charge of restoration to have a more precise assessment of the areas affected and the ecological losses just after the fire. The Instituut voor Natuur- en Bosonderzoek (INBO) will continue this research in the mid and long term. By combining the maps obtained with the pre- and post-fire vegetation maps, the managers will be able to determine what types of management are the most efficient to restore the ecosystem.



To distinguish between invasive species and native species, the VEGEMIX project has developed a strategy of "unmixing" the overall and multitemporal signal. The best time and best spectral characteristics are determined to maximize the separability between species.

ALWAYS HIGHER... FROM PLANE TO SATELLITE

After the hyperspectral revolution, some scientists embarked upon a new route and went from airborne to satellite hyperspectral imaging systems. Compared with an airborne imaging system, satellite sensors allow larger areas to be covered, on the one hand, and on the other, data with a bigger frequency to be provided, and at a lower cost. Within this framework, studies have revealed the advantages of the Hyperion sensor, taken on board the NASA EO-1 satellite.

The **VEGEMIX** project explored how Hyperion data can help to map invasive tree species in Hawaii's tropical forest in order to be able to estimate their evolution and their impact on the tropical ecosystem. Since seasonal variation is a major parameter for the identification of these invasive species, the satellite option is clearly of interest, since the satellite passes over the same site several times during the growth period, when the tree canopy undergoes rapid changes.

The project was able to show that native species have unique spectral properties, different to those of invasive species. Moreover, it was easier to make the distinction between native and invasive species in summer than in winter. A simple explanation based on the fact that invasive, opportunistic species make the most of the hot season to greatly extend their canopy. By consolidating the spectral data obtained at different times in the summer, when the invasive species spread out, the difference between species can be seen more clearly, thus improving the precision of the classifications.

The results obtained were examined in depth and corroborated by the **REMEDY** spin-off project. The arguments put forward by these studies in favour of using satellites, suggest that they will be used in the future to monitor the flora. After the dramatic changes brought about by airborne hyperspectral imaging, new horizons are opening up to researchers.

Hyperspectral imaging: technology takes off

A given plant has a unique spectral profile: its colour, its structure, its exposure determining the way it reflects the different parts of sunlight. The more the spectral information obtained for a given object is detailed, the easier its identification will be. The hyperspectral sensors, carried by planes or satellites, record the radiation reflected by objects in hundreds of narrow, adjacent spectral bands that cover a very large window ranging from the visible to thermal infrared. Compared with multispectral data recorded in only three to ten bands, the quantitative and qualitative leap is considerable regarding the spectral information obtained from the surfaces observed. Researchers can determine physical and biochemical variables.

The technology is therefore valuable for a wide range of applications faced with the variety and complexity of the environments studied. In the field of biodiversity monitoring, hyperspectral imaging is therefore the natural choice; plant cover, the vegetation's state of health, soil composition, humidity level, eutrophication of surface water, sediment concentrations, etc., are all examples of parameters that can be studied with precision thanks to this method. The combination of these parameters allows researchers to obtain a more complete view of the biological, physical and chemical processes that interact and determine the state of a site at a given moment.

Rainforest on the slopes of Kīlauea in the Volcanoes National Park in Hawaii. On the left the native species, *Metrosideros polymorpha* (endemic shrub of the archipelago) and *Acacia koa*. On the right the invasive species *Psidium cattleianum* and *Myrica faya*.

SEAS AND COASTLINES, IN THE SPOTLIGHT

Over 70% of our planet is covered in water. The coastal areas that border seas and inland waters host ecosystems that are especially rich, but subject to extreme anthropic pressure. Remote sensing has become essential to better understand and safeguard precious aquatic and coastal resources.

This article is based on the research projects:

BELCOLOUR-2
GEOCOLOUR
BEL-GOYA
MICAS
SEASWIR
RE-COLOUR
BESST
HISEA
INSHORE
ALGASED
RESORT
JELLYFOR

Coastal regions are made up of a mosaic of terrestrial and aquatic ecosystems that very often have, by their very nature as transitional areas, crucial ecological value. They contain a distinctly greater biodiversity than inland regions and offer an exceptional variety of habitats such as coral reefs, mangroves, marshes, estuaries, etc.

But these regions are also highly sought after by the residential sector and often constitute major economic hubs, at the centre of transport, fishing, tourism and energy activities.

The anthropic pressure on coastal areas continues to increase.

Relevant figures

According to the United Nations Atlas of the Oceans, 44% of the world population lives less than 150 kilometres from the sea.

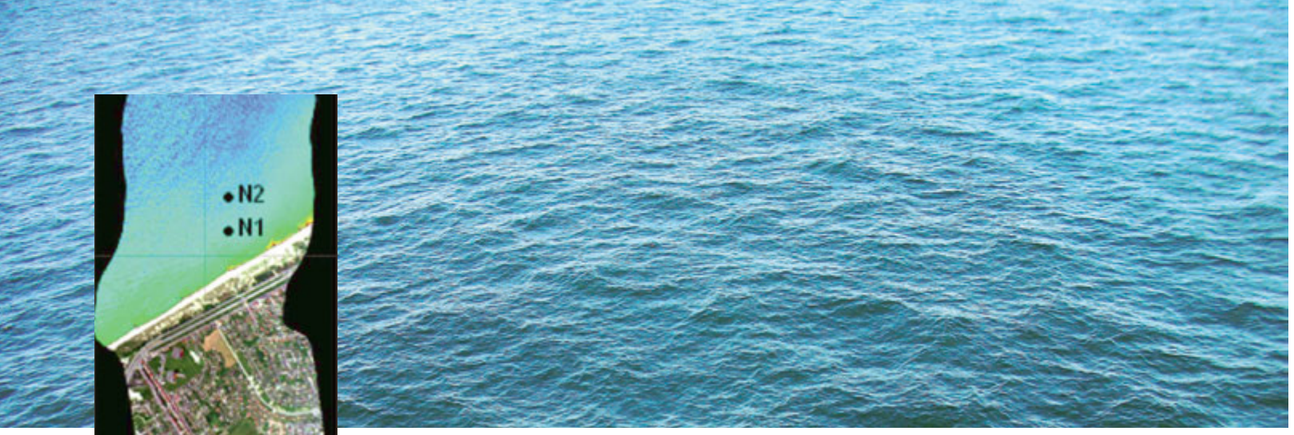
Over 90% of world transport of merchandise takes maritime routes.

Floating domestic waste is composed of 80% plastics.

According to the FAO, the activities of fishing and aquaculture provide the means of sustenance for 12% of the world population.

The latest report from the IPCC (Intergovernmental Panel on Climate Change) states that:
- there is an average increase in the temperature of the oceans of 0.1°C per decade for the first 75 metres of depth;
- the sea level is estimated to rise at 3.2 millimetres per year on average;
- the oceans have absorbed 30% of anthropic emissions of CO_2.

This night image of Earth gives an overview of the distribution of the world's population.



This aerial image covers a 6 km long strip east of Ostend. Coastal and inland water areas affected by adjacency effects are represented in red.

Intense maritime traffic leads to pollution of the oceans and coasts, in particular by hydrocarbons (sometimes accidental, but very often operational discharges). These are added to the urban effluents, industrial discharges, agriculture residues and domestic waste that constitute the main sources of pollutants. The consequences are twofold; on the one hand, toxic substances accumulate in the food chain, and on the other hand, the increase in nutrients (like nitrogen or phosphorus) alters the quality of the water, increasing the production of algae that exhaust the oxygen dissolved in the water.

Fishing is another vital sector: sea products constitute a significant share of the food supply of 3 billion people. For several decades, the total volume of fishing has increased continuously. As the rate of exploitation is more rapid than the rate of reproduction, there is an alarming decline in fishing reserves (fish, molluscs, crustaceans) on the global level. In addition, overfishing and its destructive techniques devastate sea beds and affect ecosystems essential for both the primary productivity of the oceans and for other marine species like dolphins, turtles and seabirds.

This drop in productivity is further exacerbated by the increase in temperatures and the acidification of the oceans. Climate changes also in fact have a major incidence on marine environments and coastal areas. Aside from the effect on fishery reserves, the expected consequences are an exacerbation of the impact of some hurricanes and cyclones as well as water expansion. Along with melting sea ice, this leads to an elevation in sea level. Moreover, surface water also has a significant capacity for absorption of CO_2, resulting in an acidification of the water that is harmful to the development of plankton and calcification (shells, skeletons, coral, etc.), which wreaks havoc on the equilibrium of the food chain and ecosystems.

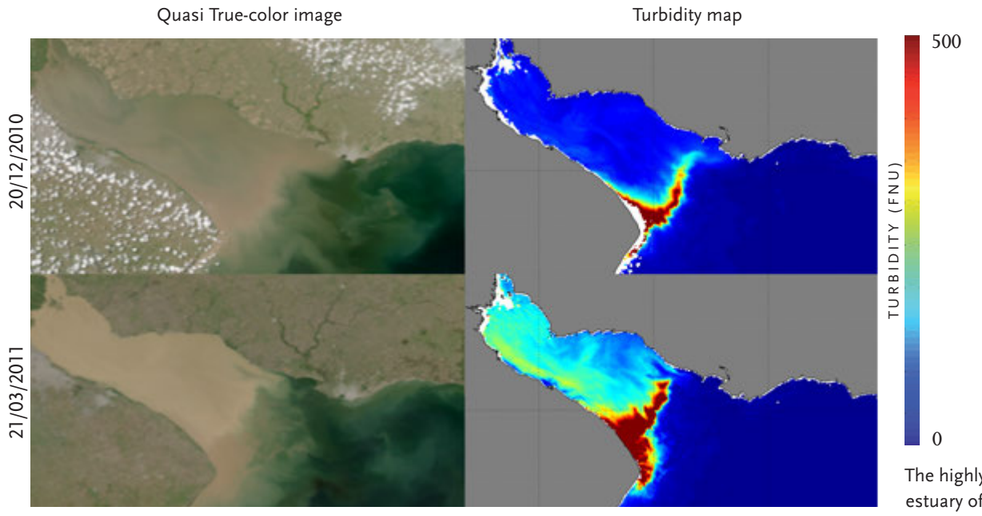
Land development, pollution and over exploitation, coupled with the consequences of global warming, thus lead to a disturbing degradation of marine and coastal habitats and rapid depletion of resources. In order to combat these direct and indirect effects in a concerted manner, it is necessary to be able to rely on more solid and more complete scientific data at all levels. Therefore, researchers observing the Earth are striving not only to take advantage of all the existing sensors, but also to prepare future instruments for improved monitoring of these highly sensitive marine and aquatic environments.

THE COLOURS OF WATER

Seawater can take on various nuances of blue, green or brown according to the types and concentrations of suspended particles and organic matter dissolved in it. If it contains few particles, it will be clear and blue; if it is full of phytoplankton (living or decomposing) and/or mineral matter, it will look rather green and cloudy. These ranges of colours are perceptible by optical sensors like our eyes.... or sensors onboard satellites. The aim of remote sensing is to extract quantitative information on the waters observed, like for example the chlorophyll concentration, from reflectance data recorded by these sensors. Such information, coupled with sampling in situ and/or information incorporated into models, can be used for numerous environmental and scientific applications: monitoring water quality, modelling ecosystems, the dynamics of algal bloom, monitoring eutrophication, following sediment transport, etc.

The **BELCOLOUR-2** project therefore sought to:
- improve the quality of certain existing products developed using optical remote sensing to study coastal and inland waters;
- develop new products for important applications like estimation of primary marine production and the flux of CO_2 between the atmosphere and the sea.

The researchers studied several optical phenomena, from the absorption and dispersion of light by phytoplankton and mineral particles on the submicron scale (less than 0.001 millimetres) to their impact on the colour of the ocean as seen by a satellite several hundred kilometres away.

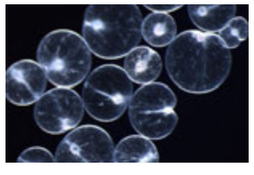


The highly turbid waters in the estuary of the Rio de la Plata between Argentina and Uruguay are visible on the MODIS images from the AQUA satellite (left). Processing of the images with the BELCOLOUR-2 methods produces turbidity maps (right), expressed as standard FNU units.
At 500 FNU, the underwater visibility is reduced to less than 1 cm, which is ideal for fish larvae that want to hide from visual predators.

The results gathered by this large-scale project conducted over five years are numerous and range from the theoretical basis, including image processing, to the development of finished products directly useful to numerous users:
- improvement in research in atmospheric optics to ensure that atmospheric effects do not contaminate the marine parameters;
- development of a method allowing the adjacency effects (the "surrounding influence") that creates blurring in the case of observations close to land to be avoided;
- development of new methods for detection of two important species of plankton present in the North Sea, *Phaeocystis globosa* and *Noctiluca scintillans*;
- notable progress in estimating suspended particles, turbidity, water transparency, primary production and CO_2 dissolved in seawater;
- advances in research on the evolution of predatory fish that hunt by sight and in which vision is genetically adapted as a function of the underwater light available;
- production of maps and images of sea surface temperatures (SST), concentrations of chlorophyll-a and total suspended matter (TSM) in quasi-real time;
- development of software that adapts the data from the SeaWiFS sensor for turbid waters.

To achieve these objectives, **BELCOLOUR-2** established a high-level multidisciplinary collaboration bringing together Belgian, French and Australian teams with expertise not only in aquatic optics and image processing, but also in physical and chemical oceanography, ecophysiology of phytoplankton and marine ecology.

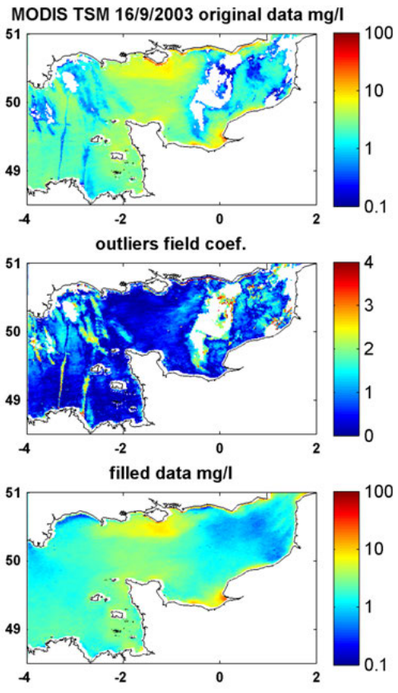
During the June summer days, brown-red colour patches sometimes appear in the North Sea. The BELCOLOUR-2 researchers could link these to a bloom of microscopic *Noctiluca scintillans* algae and developed a method to detect them by means of remote sensing.



The oceanographic research vessel Belgica.

The project results have been used in about thirty publications and a university training module. They still hold numerous challenges for a whole generation of researchers. In fact, in the field, end users are always awaiting still more complete information: more frequent data, finer spatial resolutions, more detailed parameters (for example, types and sizes of particles, in addition to their concentration)... and fewer clouds!

Map of concentrations of suspended matter in the water of the Channel, derived from MODIS data on the polar Aqua satellite.
Top: Original data with clouds in white.
Centre: Automatic identification of suspect data.
Bottom: Reconstructed data, with clouds replaced by the best DINEOF estimations.
This technique has been applied by the GEOCOLOUR project to data from the SEVIRI instrument on board of the METEOSAT satellites. Likewise, in the RE-COLOUR project, DINEOF has been successfully used to reconstruct SST and chlorophyll-a concentration maps.



GEOSTATIONARY SATELLITES TO AVOID CLOUDS

Most of the advances of **BELCOLOUR-2** on the spectral properties of ocean waters are based on data coming from sensors such as MERIS, MODIS or SeaWiFS, which are located in a polar orbit approximately 750 kilometres above the Earth. While their spatial and spectral resolution is adapted to the observation of seas and coasts, they provide on the other hand only a single image per day of the site studied, which is of course unusable if it is cloudy.

This is why researchers have turned their attention to geostationary satellites, which are in an equatorial orbit and orbit at the same speed as the Earth. Remaining "fixed" above a single point on Earth, they allow continuous observation of the North Sea throughout the day, generating dozens of images daily when the sky is clear. A windfall of data! But it is still necessary to extract from it information useful in studying the colours of the ocean.

Historically devoted to telecommunications and meteorology, geostationary satellites orbit 36,000 kilometres from the Earth. Providing sufficiently precise data from such a distance is a real technological challenge that has prevented oceanography researchers from envisaging geostationary satellites as sources of information until now.

The MUMM (Management Unit of the North Sea Mathematical Models) team is the first to have demonstrated the usefulness of geostationary platforms and existing meteorological sensors in mapping the suspended matter in highly turbid coastal waters. Under its auspices, the **GEOCOLOUR** project therefore aims to improve the quality and quantity of the products of marine observation using data from the SEVIRI sensor on board the Meteosat satellites. This sensor, designed to detect clouds, provides observations every 15 minutes. This research also constitutes a feasibility study for the development of future geostationary sensors specifically devoted to the colours of the ocean.

The researchers have developed SEVIRI image processing techniques to estimate the turbidity of the water and the quantity of underwater light available to phytoplankton in the North Sea. The data acquired during a two-year period have been processed, compared to the measurements made by sea buoys and combined with both the Aqua-MODIS data and the DINEOF statistical method which intelligently fills in the "holes" in the clouds with the most probable estimates. Data from the GOCI sensor, the first geostationary instrument devoted to the colours of the ocean (with a spatial resolution of 500 metres) was also used. GOCI was launched in 2010 by the South Korean Space Agency to monitor the coastal areas of the western Pacific.

The **GEOCOLOUR** project proved the advantages of using geostationary sensors to observe the colours of the ocean. The high frequency of image acquisition in particular allows the detection of variations related to tides, for example sediment transport (which is impossible with one image per day) and provides complementary data on days with sparse clouds.
The results obtained have already been incorporated into the design of a new generation of geostationary sensors flying over Europe and devoted to the colours of the ocean, a programme planned by the European Space Agency for 2020.

Another project, **BEL-GOYA**, has gone into depth on these matters by specifically evaluating the performance of polar and geostationary sensors in mapping the TSM in river plumes and very turbid estuaries. The results obtained are compared according to the characteristics of each sensor: frequency of acquisition, type of spectral bands, etc.
BEL-GOYA is part of a project of the French Space Agency (CNES) that is studying the

Jellyfish alert!

The term "jellyfish" covers a number of species of gelatinous zooplankton. Most of them are harmless, but some are harmful to fish and/or humans due to their toxic sting. This is the case for *Pelagia noctiluca*, a species that fortunately is not found in the Belgian part of the North Sea, but that is responsible for numerous stings in the Mediterranean each year; a massive invasion of them completely destroyed a salmon farm in Northern Ireland in 2007. The economic impact of these jellyfish on the aquaculture and tourism sectors has encouraged researchers to better understand their lifecycle in order to try to predict their appearance along the coasts. In this context, the **JELLYFOR** project sought to develop a warning service for arrivals of toxic jellyfish using satellite data as one of the sources for the model. The study regions chosen were Northern Ireland and Catalonia (Spain).

The satellite data processing methods already developed for the North Sea were extended and allowed automatic processing in quasi-real time (within 12 hours) of Envisat-MERIS and Aqua-MODIS data over the two study areas. Complete time series over 10 years of three parameters (SST, chlorophyll-a concentration, turbidity) were processed and analysed. The idea was to compare the occurrences of jellyfish and the values of oceanographic parameters for different periods so as to deduce the conditions favourable or unfavourable to development of jellyfish. The 10-year archive was therefore also incorporated into a jellyfish warning model.

While the steps of the project related to processing of remote sensing data were developed successfully, the model itself is not yet capable of producing reliable predictions. In situ measurements (on beaches and in the seas) and better validation of the model are necessary and currently being studied for certain species in Belgium.

Incorporated into a project of the European Union and the European Space Agency, **JELLYFOR** has improved the software that rapidly processes the voluminous archives of satellite data (for example, 10 years of daily data). It has been highly automated and can now be configured for any point on earth, delivering its conclusions in just a few hours and almost without human intervention. The software developed by the project could thus be useful for numerous other applications and regions.

The Gironde estuary as seen by Landsat 8.

dynamics of suspended particles in major estuaries where biogeochemical exchanges between the continent and the ocean take place.

The project test regions are the estuaries of the Gironde (France), the Rio de la Plata (Argentina, Uruguay) and the Yangtze (China).
The **BEL-GOYA** project has concentrated on this latter site, the extremely turbid waters of which can be observed by the South Korean GOCI sensor.

The project has allowed higher-performance algorithms for atmospheric correction and extraction of TSM for these extremely turbid areas to be developed and checked using the near infrared (NIR) bands of the sensors devoted to the colour of the oceans. These new algorithms also allow better detection of clouds above very turbid water and easier classification of pixels regardless of the quantity of TSM in the water. Thanks to the results obtained, researchers have been able to formulate valuable recommendations on the design of future sensors devoted to the colour of the oceans.

EXPLORING NEW SPECTRAL BANDS

While the better temporal resolution of geostationary satellites offers advantages for observation of marine environments, very high spectral and spatial resolution offers other advantages for better characterisation of the water and its constituents. The **MICAS** project used data from the APEX airborne hyperspectral sensor to map out the quality of coastal and inland waters. Starting with three study regions (Lake Constance in Switzerland, the Scheldt in Belgium and the Wadden Sea in the Netherlands) and in partnership with the University of Zurich, researchers developed a special algorithm that is incorporated into an automatic processing system for APEX images.

Designed to map out the concentrations of chlorophyll, coloured dissolved organic matter (CDOM) and suspended matter, it "corrects" certain errors that commonly occurred with previous methods (in particular errors related to atmospheric effects). Applied to the APEX images from the Wadden Sea, the algorithm allowed a complete mapping of the concentrations studied to be generated in a very short time. The airborne observations and derived maps are in addition perfectly correlated with field measurements. But while these latter are only occasional, the APEX images provide continuous spatial information on the water quality at a specific time.

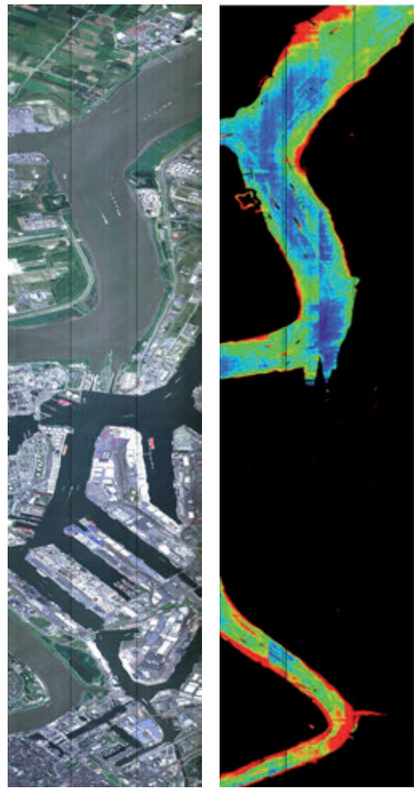
The **MICAS** project also revealed the potential of the spectral bands in the short wavelength infrared (SWIR) for characterising the turbid waters of estuaries and inland waters. Another project, **SEASWIR**, therefore concentrated on this channel, very little used at present in observation of surface waters (except for atmospheric corrections). In fact, clear water absorbs this part of the spectrum to a great extent. The spectral response of the constituents of water at these wavelengths is so weak in comparison with the responses in the visible and near infrared that it has been considered negligible up to the present, even for very turbid water. But during the **MICAS**, project, positive reflectance measurements in the SWIR were recorded for the Scheldt and related to the concentrations of suspended matter.

The **SEASWIR** researchers therefore postulated a spectral response of water in the SWIR and collected field data to determine the variability of this reflectance. As special measurement instruments for water did not yet exist, they used an instrument designed for land in three regions: the Scheldt near Antwerp, the Gironde and the Rio de La Plata. A clear signal could be recorded in these three cases, and for both the Scheldt and the Gironde, a relation could be demonstrated between the signal and the concentration of suspended sediments. The SWIR could thus prove to be very useful in measuring the quality of very turbid water, where the concentrations of sediments and algae are such that the signal detected at the shortest wavelengths often reaches saturation. The European Space Agency has moreover incorporated a SWIR channel into the new instrument devoted to the colour of the oceans onboard the future Sentinel-3 satellite.

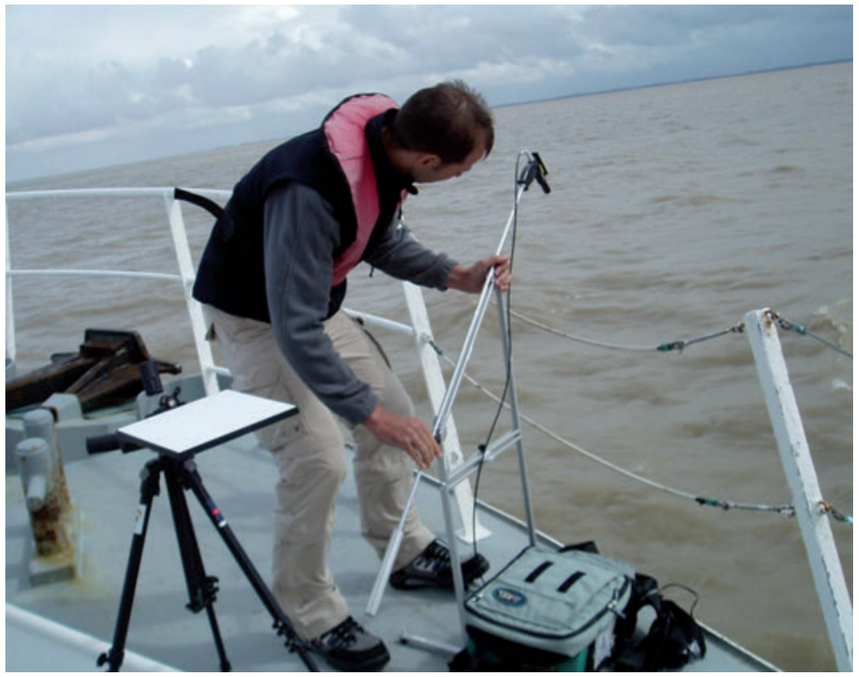
MAPS WITH HOLES

The marine environment is extremely dynamic. For many studies it is essential to have complete time series of images available covering the entire area observed. But these series often have gaps due to the presence of clouds, data of poor quality or the lack of acquisition at the desired time. The **RE-COLOUR** project sought to use the DINEOF algorithm (see above) to reconstruct the complete spatiotemporal information concerning three parameters (chlorophyll-a, TSM, SST) in the southern part of the North Sea over a four-year period.

The technique was applied successfully and complete series of data were produced for the three parameters, as well as the associated errors. Mean weekly and monthly values could be derived from the regular daily reconstructions. The technique also allows pixels that are "suspect" compared to the overall dynamics (pixels generally originating from imperfect detection of clouds) to be detected. The improved DINEOF algorithm as well as the reconstructed fields of TSM and chlorophyll-a have proven their usefulness in various types of environmental research. The results pave the way for other applications in processing and quality control of optical remote sensing data.



Hyperspectral image of the river Scheldt acquired by the APEX instrument and sediment concentration map.



WATER TEMPERATURE: NOT JUST FOR SWIMMING

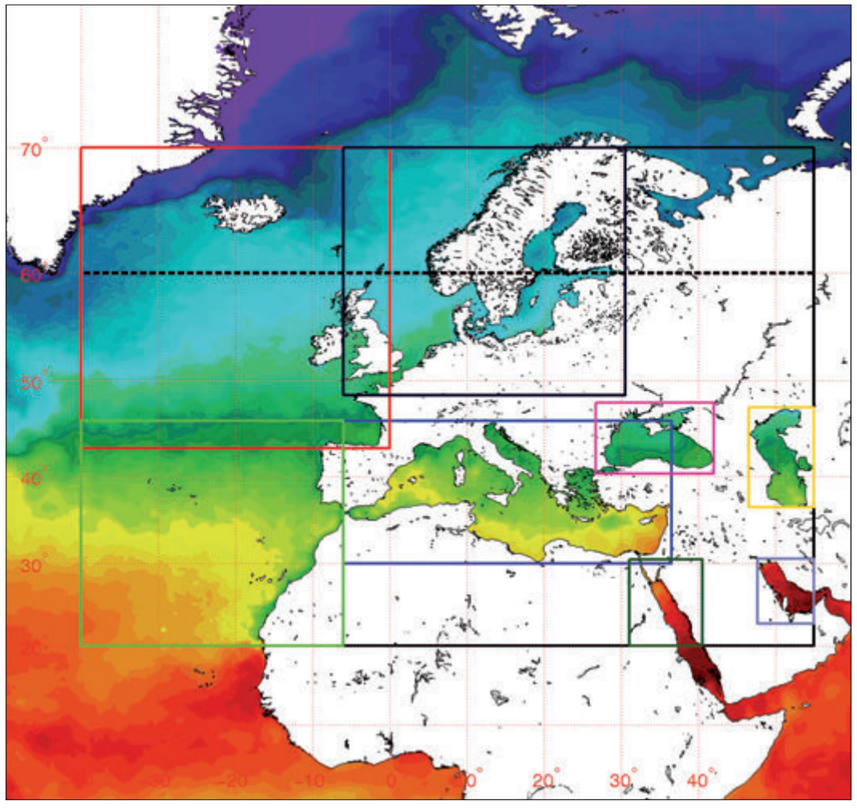
Sea surface temperature is a fundamental parameter in oceanography but also in meteorology and climatology. It characterises the exchanges of heat and moisture between the surface of the oceans and the atmosphere. Historically, as of the end of the 19th century the surface temperature was recorded from ships, and then by sea buoys, but since 30 years it is also being measured by satellite sensors capable of detecting the infrared (IR) and microwave radiation emitted by the surface of the water. These satellite measurements offer high spatial (on the order of a kilometre) and temporal (on the order of several hours) resolution, but difficulties remain; the IR radiation emitted by the sea surface is attenuated by atmospheric constituents, mainly water vapour, and useful data come from sensors with different characteristics and it is sometimes difficult to combine them.

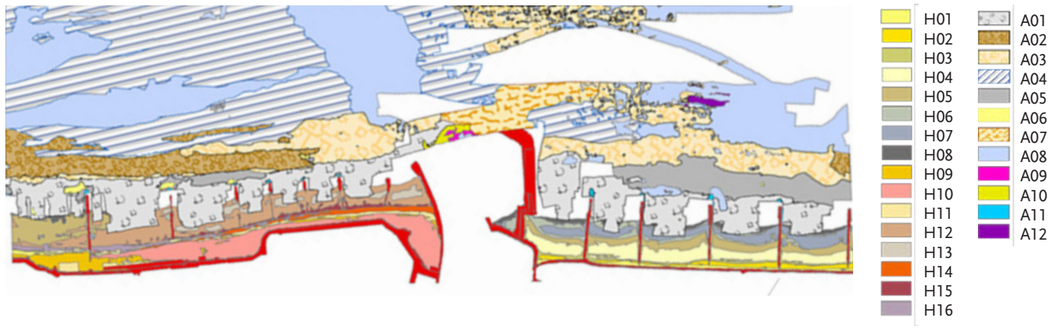
The AATSR sensor, which was onboard the Envisat satellite (decommissioned in 2012) recorded the radiation both at the nadir (vertically) and forward, allowing atmospheric corrections and therefore SSTs to be determined more precisely. On the other hand, as its field of vision was relatively narrow, the period necessary to cover the entire Earth was 2 to 3 days. Other IR sensors (like AVHRR on the MetOp-A satellite and SEVIRI on Meteosat) do not have this dual vision, but their distinctly broader scan width allows the Earth to be covered with a considerably higher frequency (twice daily for MetOp, every quarter of an hour for SEVIRI).

The **BESST** project researchers subsequently sought to standardise the data coming from these various sources. In partnership with the Centre for Space Meteorology of Météo-France, the team tried to combine the advantages of the different types of sensors by improving the precision of the SST measurements while maintaining broad coverage. The DINEOF reconstruction technique was adapted to produce corrected versions of the SST maps of the European seas. DINEOF fills in the missing data and areas of difference between the datasets by finding the spatiotemporal connections that relate them.

The innovatively developed method has allowed the disparities between the data from various sensors to be reduced at both the spatial and temporal levels. It is consequently planned to implement it in the procedures of Météo-France, a major supplier of SST maps in Europe and the world. These improved SST measurements will allow both weather predictions and climatological studies to be refined.

Sea surface temperature map and delimitation of the different study sites of the BESST project.





Final classification of the study area of the INSHORE project, containing both subtidal sediment classes derived from sonar data and beach sand classes derived from airborne data.

In the **HISEA**, project, the same team sought to produce SST data that combine the advantages of polar satellites (high spatial resolution) and geostationary satellites (high temporal resolution). An advanced version of DINEOF was developed and allowed data from the AVHRR sensor in a polar orbit (2 kilometres of spatial resolution, 2 images per day) and the SEVIRI sensor in a geostationary orbit (6 kilometres of spatial resolution, one every 15 minutes) to be merged. Tested in the Mediterranean, the method generated surface temperature estimates with better resolution, both spatial and temporal. These results allow the daily variation of SSTs, which are highly influenced by weather conditions (rain, clouds, sun and wind) to be understood, and their spatial variability to be better determined. The method has been successfully transposed to another variable, namely suspended matter in the North Sea, demonstrating its potential for other regions and for new parameters, for example surface salinity. A general code for the new DINEOF-OI algorithm, applicable to any parameter and any study area, has moreover been made freely available to the scientific community in order to promote its widespread use.

MAPPING THE COAST ALL AT ONCE

It is now common to use satellite imaging to study the dynamics of littorals. But study of the intertidal zone, the part of the littoral between the extreme limits of the highest and lowest tides, requires techniques different from those for other parts of the littoral. The **INSHORE** project therefore explored the possibility of mapping the coastal belt all at once so as to be able to study the morphology of the littoral and the dynamics of sediments. A field campaign was organised over 4 kilometres of coast in Ostend. To protect the city, the beach in Ostend received significant additional sand between 2004 and 2008; an overall map would allow the movement of the sand due to waves, tides and storms to be monitored.

The innovative approach of the project consisted of combining data from airborne (hyperspectral, LiDAR) and underwater (echo sounder, sidescan sonar) sensors. The detailed information provided by the hyperspectral data allowed 16 classes of sand on the beach to be distinguished (differentiated by grain size, water and iron content and mineralogical composition). By repeating the measurement campaigns, displacements of sand could be detected. To interpret them correctly, they had to be compared however to the topographical variations in the beach. These were derived from the LiDAR data regularly provided by the costal monitoring authorities.

Underwater, an echo sounder was used to determine morphological changes (degree of compaction, rugosity, etc.) while side-scan sonar allowed 12 classes of sand to be identified. The study gave priority to areas where the underwater acoustic and airborne optical data agreed. The maps produced have an unprecedented level of detail. They accord perfectly with the data from official biological monitoring studies or studies on the status of work on access to the port channel. The method developed in the project is therefore recommended for mapping coastal areas with strong dynamics and for the study of sedimentation when a high level of precision is required.

The ALGASED team in the field.
Right: hyperspectral image of the IJzermonding site studied by the project.

THE NORTH SEA MUD FLATS, A UNIQUE ENVIRONMENT

The coastal areas and estuaries around the North Sea are of vital importance. Not only do they constitute a barrier against floods and an economic development area, but the intertidal expanses also play a crucial role in the functioning of the ecosystems. Essential biological, physical and chemical processes take place in the mud flats, the riverbanks that are exposed at low tide. The erosion of these expanses can lead to a loss of productivity in this very rich environment and hinder navigation by accumulating sediment in the channels.

The stability of the mud flats is affected by external factors like waves and currents, but also by the biophysical properties of the sediments themselves. The **ALGASED** project studied how to better understand the variability in these biophysical properties at different spatial and temporal scales, using multispectral and hyperspectral data from satellite or airborne platforms.

In collaboration with Dutch and British partners, the researchers concentrated on two lines of research, characterisation and classification of sediments, and quantification of the microphytobenthos (MPB), the unicellular algae that form a biofilm several millimetres thick on the surface of intertidal sediments. Two sites of intertidal mud flats, The IJzermonding in Belgium and The Molenplaat in the Netherlands, were studied using hyperspectral, multispectral and in situ data.

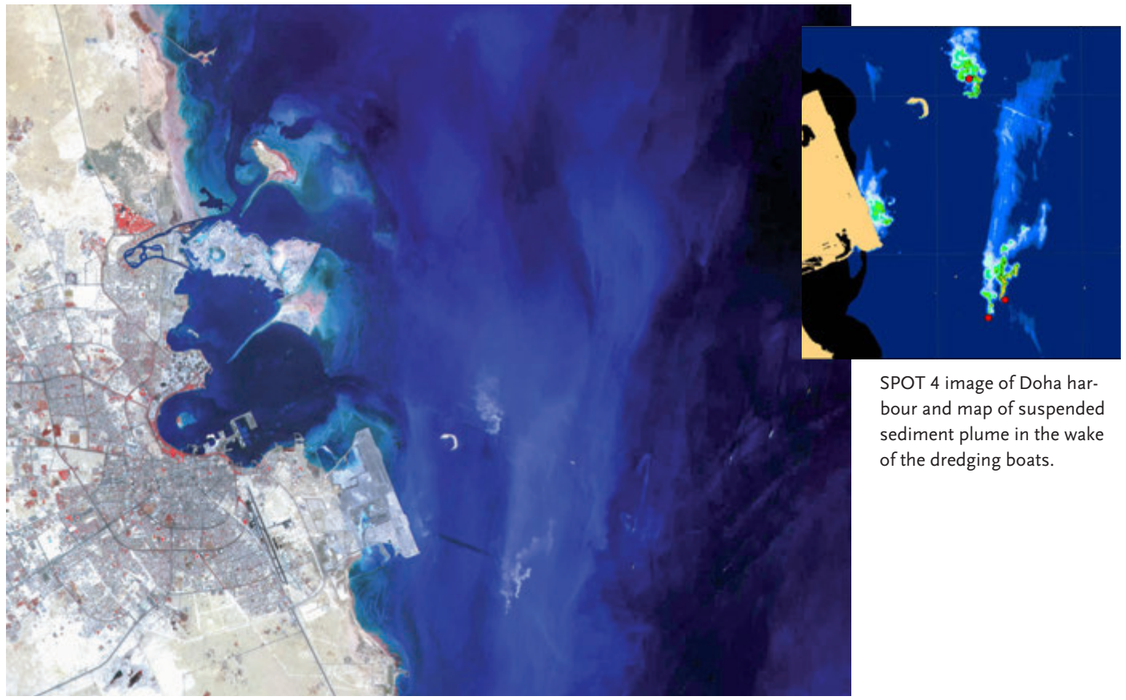
The project produced several advances:
- improvement in classification techniques (unsupervised and supervised);
- characterisation of sediments using multispectral imaging;
- quantification of the MPB biomass and modelling of the primary production using two indices (NDVI and Red Edge) that have proven to be high-performance, robust and applicable to both airborne and satellite imaging;
- finally, integration of all the types of data (field, airborne, satellite) using a multi-scale approach to produce complete maps of the biophysical properties of the sediments.

The project provided end users with classifications of images for all the hyperspectral data, sediment property maps and abundance maps of biophysical properties. The methods developed pave the way for additional studies dealing in particular with extrapolation to new data from the areas studied or other sites, so as to validate their general applicability to the ecosystem services of the estuaries.

MILLIONS OF M³ OF SEDIMENTS TO DREDGE

Every year, dredging companies remove over 2 million m³ of sediment from the estuary of the Scheldt, essential work so that larger and larger container vessels can access the port of Antwerp. One of the missions of the IMDC (International Marine and Dredging Consultants) company, based in Antwerp, is to advise dredging companies. It therefore needs precise and up-to-date information on spatial variations in the turbidity in order to calibrate and validate models of sediment transport and subsequently optimise dredging operations and the siting of structures in the harbour. In this context, remote sensing constitutes a source of valuable data to complement traditional extremely laborious sounding. The company already has software, developed on the basis of images acquired during a single flight campaign conducted in the spring, allowing the suspended sediments in the Scheldt to be mapped out. The **RESORT** project is continuing the research by evaluating the degree to which this software can be transposed to all seasons and to other regions.

From hyperspectral data, water samples and optical measurements recorded for the Scheldt, researchers have been able to develop an algorithm for mapping sediments that has proven to be robust throughout the year. The reproducibility of the method has been tested in the port of Doha (Qatar) in the Persian Gulf and in the Panama Canal, using satellite images. The SPOT high-resolution multispectral data allowed dredging boats to be identified, the plumes of sediments in suspension in their wake to be monitored and their size and direction to be determined. The advances of the project have convinced users (IMDC, dredging companies, and research laboratories) of the added value of remote sensing for calibration/validation of the models for sediment transport and for monitoring dredging operations.

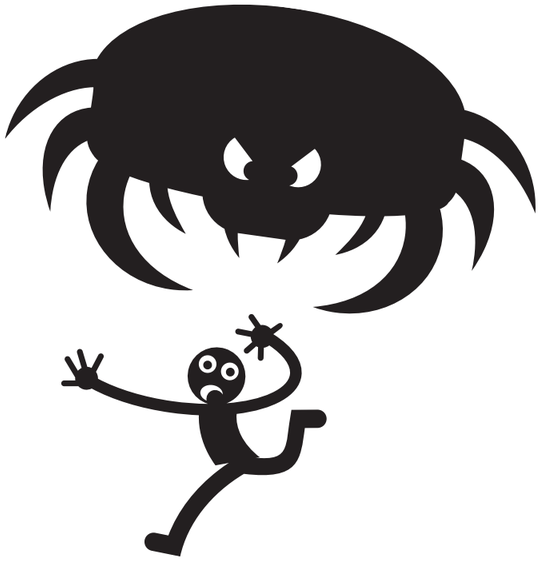


SPOT 4 image of Doha harbour and map of suspended sediment plume in the wake of the dredging boats.

SENTINEL-3: MANY APPLICATIONS

In the framework of the Copernicus programme, the programme monitoring the Earth for the environment and the safety of the European Union, the Sentinel missions of the European Space Agency include a marine monitoring component charged with providing reliable, frequent data with geographically extended coverage on the status and variation of the oceans and coastal areas. The Sentinel-3 mission will aim to establish a capacity for multi-instrument observation in order to generate important marine parameters like the colour of the ocean, the surface temperature and the surface height in a precise way. In accordance with the policy of free access to Sentinel data, these data will be made available free of charge to all users to fulfil the needs of the various applications specific to the marine environment:
- **Marine safety** (ship traffic, areas of piracy, hydrocarbon pollution, etc.);
- **Marine resources** (fishery resources, fossil energies, minerals, wind, tidal, wave, and thermal energies, etc.);
- **The marine and coastal environment** (affected by natural processes, human intervention and climate change);
- **Seasonal and climatic predictions** (climate fluctuations, seasonal conditions, impact on phenomena like El Niño, weather alerts in the event of extreme episodes, etc.);
- **Marine ice** (seasonal or permanent ice fields, drift ice).

FIGHTING DISEASE FROM SPACE



This article is based on the research projects:

MULTITICK
BUSHTICK
TICKRISK
EPISTIS
EPIDEMOIST
DYNMAP
SATHELI

Faced with the threat of spreading infectious diseases, epidemiology is becoming increasingly important. Tele-epidemiology collates the data collected in the field and satellite data to track down and prevent infection.

Malaria, Lyme disease, the common liver fluke, bluetongue disease, etc. These diseases gain more ground every year thus increasing the risk of epidemics. What do they have in common? They are all transmitted by small organisms, often arthropods (mosquitoes, flies, ticks, lice or fleas), which are called vectors because they transmit the infectious agent from one host to another. The distribution area of these vectors is gradually expanding, with climate change opening up altitudes and latitudes that were previously protected from them. New, sometimes vulnerable regions are thus seriously affected. Faced with this scourge, research is intensifying to decipher the space-time dynamic of the diseases and to obtain forecast maps of high risk areas in order to anticipate and contain epidemics more efficiently.

EPIDEMIOLOGY TURNS TO SPACE

Tele-epidemiology combines data sets from multidisciplinary areas (physical factors such as temperature or humidity, biological readings, health data, socioeconomic data, etc.) with satellite observation data (climatological, environmental, land use, etc.). This allows us to analyse the mechanisms of emergence, propagation and transmission of infectious diseases, firstly, by investigating the "climate - environment - health" relationships, and secondly, by updating the links that exist between the infectious diseases and the environment in which they develop, all with the help of space technology. The ultimate objective is to provide public health stakeholders with tools, risk maps for instance, allowing them to monitor and anticipate epidemics.
A great number of statistical and non-statistical products have been developed to facilitate the work of epidemiologists: quantification of the cases of disease, identification of the factors characteristic of the affected areas, definition of the high risk areas, forecasting models, prevention programmes, etc. Remote sensing is now involved in every step of this research.

TICKS MOVING WITH THE CLIMATE

Ticks travel. They move easily from one continent to another on the back of their host. Very sensitive to climate change and local modifications in temperature, exposure, humidity, etc., their distribution area is evolving and expanding. In Europe, the majority of vector diseases are transmitted by ticks. Several thousands of people are affected by Lyme disease every year and the number is increasing.

The **MULTITICK** study focused on the environmental factors that influence the distribution of tick-borne diseases in Europe. Researchers chose to concentrate on Lyme disease in Belgium and the Baltic states. Ticks and the host animals, which are essential to their survival, have a specific habitat, which they choose according to their needs and is linked to particular environmental characteristics. Therefore, the tick can be strictly associated with certain environmental factors (type of vegetation, temperature, etc.). Many of these specific factors can be derived from remote sensing data and then entered into models that allow us to identify which environments are most favourable to the appearance of the disease. The study's originality lies in the fact that several types of observable factors (environmental, human, etc.) were examined at a number of scales. The majority of studies carried out up until now have focused on one type of factor and one specific scale (land use data deduced from high-resolution images or climate data deduced from low-resolution images, for instance). The research team therefore combined the scales by using low- and high-resolution images and several statistical techniques to collate the data obtained. The results confirmed that the spatial distribution of tick-borne diseases is determined by a set of factors that operate at different scales. The project also showed that environmental factors don't explain everything; for example, the way in which humans develop and manage

© M. Madder

Rhipicephalus microplus, a tropical tick that recently arrived in Western Africa, threatens the growth and milk production.

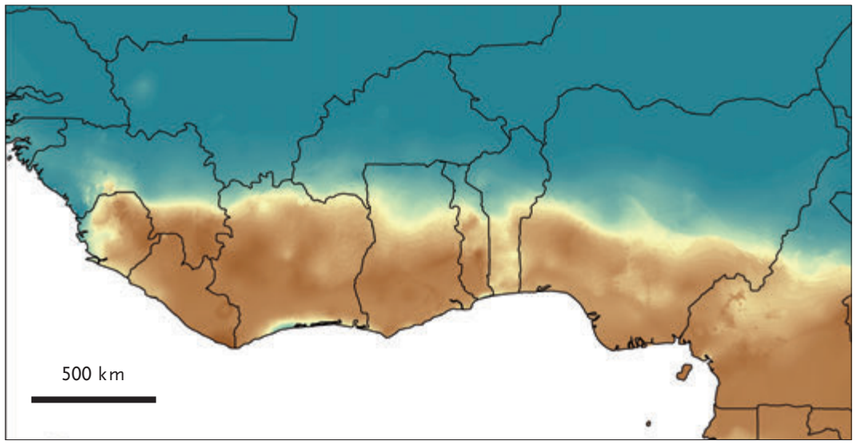
© S. Vanwambeke

At the entrance of Latvian forests hikers are notified of the risks linked to tick abundance.

Collection of ticks in an abandoned field in southern Norway for the BUSHTICK project.

their land must also be taken into account. The research carried out therefore provided a rather innovative integrated vision in the domains of the environment and the ecology of diseases. Continuing along the same vein, the team began work on the **BUSHTICK** project. This project studies the dynamics of abandoned farming areas in order to better understand the impact of land development and management changes on the risk of the presence of ticks and the occurrence of diseases. In the south of Norway, the project's study area, there is an increase in the ticks' area of distribution, along with an increase in tick-borne diseases among human and animal populations. To be exact, the researchers are examining "areas of bush", i.e. cultivated areas or pastures which have been abandoned and where nature has taken over. Indeed, while forests are well known for being a favourable habitat for ticks, we still have little information on these areas that have been left to return to their wild state. These unmaintained areas are less exposed to wind and or any type of disturbance, and are therefore more likely to contain ticks than a pasture or a field.

The aim of the project is to produce a map of the vegetation's evolution in the region during the past three decades in order to better understand the processes of abandoning grasslands and their return to a wild state. To be able to detect gradual changes in the vegetation's density, the researchers have to test several land use classification methods. For each of the methods used, they selected the most efficient components: some of them allow the structure of the landscape to be analysed thanks to the definition of classes of land use at a given time, while others deduce continuous information from time series, which is more useful for the observation of gradual processes. By combining the advantages of the different methods, the team hopes to be able to draw up maps of bush encroachment and define the impact of land use changes and land management on the risk of the presence of ticks and the appearance of the diseases associated with them. The ultimate goal is to be able to unravel the complex network of interactions that exist between environmental variables, land development and tick-borne diseases.



Risk map for the presence of *R. microplus* in Western Africa, created by determining the favorable climate zones for this vector.

TICK JUMP

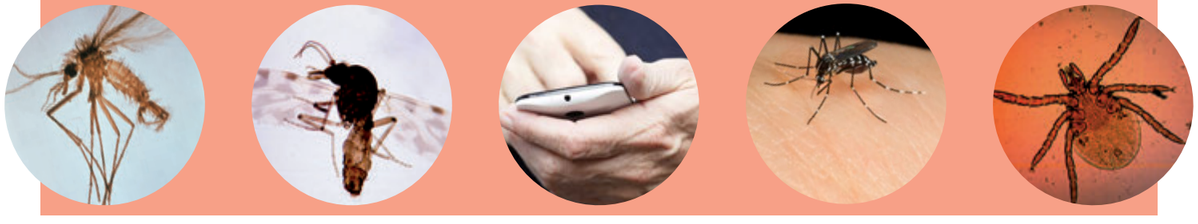
Rhipicephalus microplus, a tropical tick, appeared in Benin in 2006. It probably arrived on the African continent as a stowaway on the back of Brazilian cows. There is no trace of it in West Africa before 2007. This dangerous tick causes anaemia and skin and udder infections. It is also a vector for several particularly serious cattle diseases, such as babesiosis and anaplasmosis, which cause a high fever, weight loss, a reduction in milk production and sometimes death in animals. The cost of these diseases is considerable for the farmers.
Resistant to acaricides, the tick is very difficult to eradicate once it has been established. There is a great risk of expansion of the area occupied by the tick, which is encouraged by the farming system used in West Africa. The cattle aren't kept in closed pastures but are required to roam to find food and water. Therefore, they can transport the ticks over more than a hundred kilometres.

The fruit of a collaboration between UCL, the Institute of Tropical Medicine in Antwerp and the Spanish University of Zaragoza, the **TICKRISK** project worked on producing a map of potential habitats for the tick in West Africa, to help the authorities set up targeted monitoring. They developed the use of smartphones among the players in the field to facilitate the collection and centralisation of the data, via the VECMAP application. Thanks to the results of the tick collections in Benin, the researchers were able to establish which environmental conditions were favourable to them. On the basis of this information and satellite data, they were able to draw up a detailed map of the risk of invasion in West Africa. This map enabled them to show that very large areas of the land studied are indeed high risk areas.

VECMAP, A SMARTPHONE APPLICATION

Developed by the company AVIA-GIS with the collaboration of the scientific teams working on the **EPIDEMOIST** and **TICKRISK** projects, among others, VECMAP is a support service for the management of diseases transmitted by vectors such as mosquitoes or ticks (malaria, chikungunya, etc.).

From sampling to spatial modelling, the mobile application goes through all the steps leading to the mapping of high risk areas. It simplifies and improves field and laboratory work as well as the modelling of distribution thanks to satellite data. It facilitates data collection in the field thanks to the smartphones, and then combines these data with satellite data for the statistical modelling of the disease's distribution. The terrain allows the researchers to determine the distribution of the disease's vector while the remote sensing data provides indicators such as climatic seasonality or the vegetation index. The data collected can be transferred at any time to a centralised database to be stored there. Costly and laborious field work is thus facilitated and optimised.

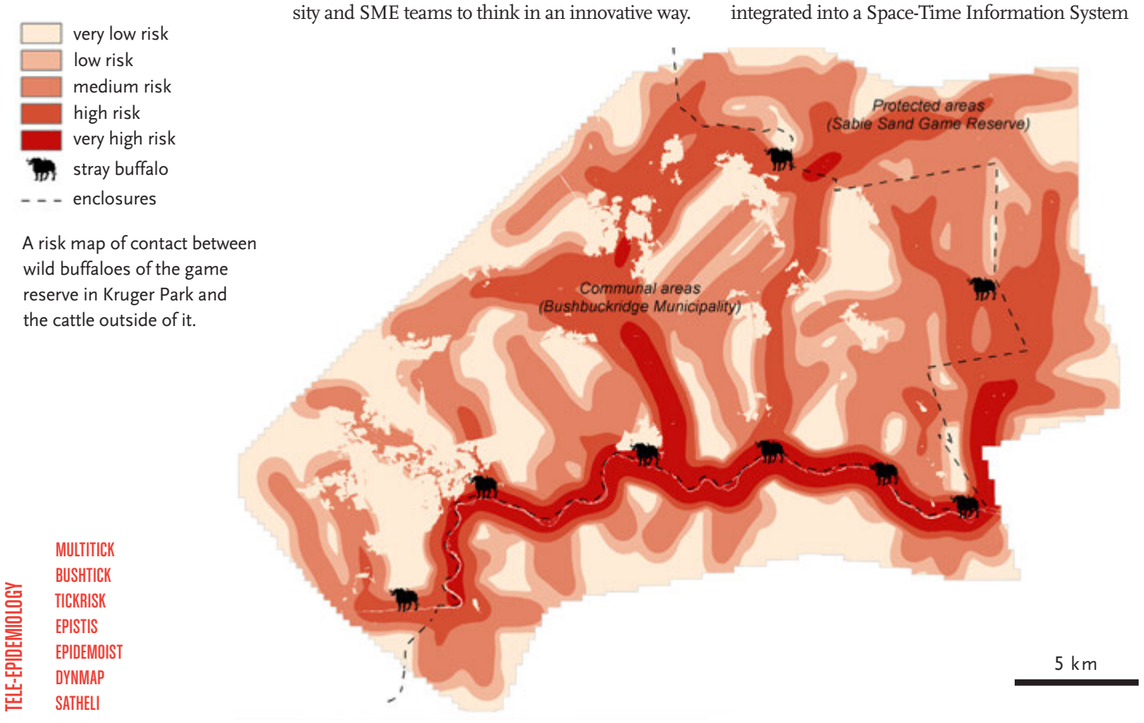


TAILOR-MADE MODELLING

Confirming Belgian know-how, the **EPISTIS** study began in 2006 and continued for four years. The project's goal was to create a network of expertise in the domain of space technology applied to epidemiology. The teams developed several tools using remote sensing in order to obtain a better analysis of the spatial-temporal dynamics of the transmission of diseases. Results which can help local managers and vets to take crucial decisions. Spatial epidemiology requires a multidisciplinary approach. The wide-scale **EPISTIS** project includes seven partners, specialised in complementary disciplines: the techniques and approaches of the remote sensing specialists complemented those of the specialists in epidemiology. A wealth that has led the university and SME teams to think in an innovative way.

Two case studies were selected. They are very different but complementary owing to their epidemiological characteristics and the specific control strategies associated with them. The first one deals with the presence and propagation of bluetongue, a vector-borne disease present in Belgium, Italy and the Mediterranean basin. The second one relates to the dynamics and the transmission of a highly contagious disease, foot-and-mouth, in Kruger National Park in South Africa. The major factors in a vector-borne disease are those that influence the dynamics and installation of the infected vectors. In the case of a contagious disease, attention is focused on the likelihood of contact between infected and uninfected animals; it is necessary to take into account the effectiveness of the fences erected to prevent contact as well as the factors affecting the dynamics of the infected animals.

While the subjects are specific, the innovative approaches developed are applicable to other diseases (even human) with similar characteristics. The study begins with an epidemiological analysis which compiles the information on the occurrence of the disease, the vectors, the potential hosts, wild animals, cattle and the human population. Extra data, such as soil maps or topographical indicators, are added to this. Low, medium, high and very high-resolution satellite data are integrated and used for different types of modelling, at different scales. It is therefore possible to create a distribution model on a national or regional scale, a model of local propagation, or a model based on very high-resolution for a detailed result targeting a precise area. All models are then integrated into a Space-Time Information System



A risk map of contact between wild buffaloes of the game reserve in Kruger Park and the cattle outside of it.

WorldView-2 image in false colours (near infrared, red, green) of the study site of the EPISTIS project in South Africa, acquired during the dry season (July 2012). Several burned areas are clearly visible.

(STIS) used as a decision-making support tool. The ultimate goals are to be able to estimate the risks of future propagation, to determine the fences' level of effectiveness and to improve the disease's management and control. **EPISTIS** has created a real network of Belgian expertise in tele-epidemiology and has set up a large number of innovative tools: the STIS information system, several new distribution and propagation models as well as additional land modelling approaches, which are based on data from high and very high-resolution sensors. The operational applications of the project's results go well beyond the laboratory activities involved in this research and can be useful for all tele-epidemiology researchers.

Similarly, the **EPIDEMOIST** project took a closer look at bluetongue disease in Italy. The team tackled a specific question: why is the density of midges (vectors of the disease) different in the north and south of Calabria even though the climate conditions seem similar? The project, initiated by the SME AVIA-GIS, in collaboration with the University of Ghent, aimed to improve the VECMAP application, and to fine tune the midge distribution models by integrating the type of soil and its level of humidity. The lifecycle of the vectors often has a development stage in the soil, which explains the decisive impact of this factor on their spatial distribution. In an effort to offer an alternative to fastidious and costly field measurements, the project sought to extract

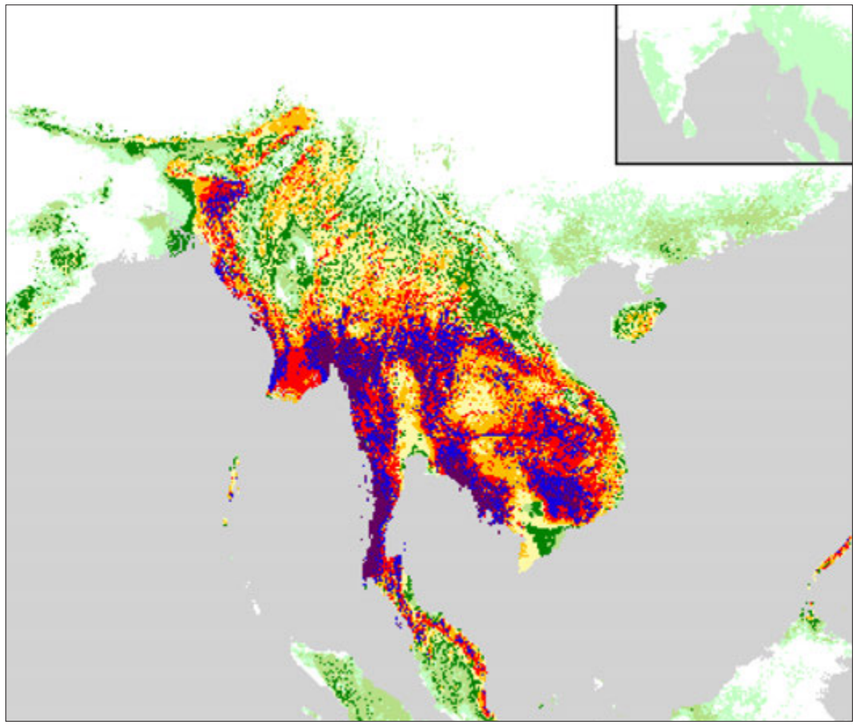
Above: probability map for the presence (red) or absence (yellow) of the midge *C. imicola*, vector of the bluetongue disease in Calabria.
Below: distribution map of sand (light) and moist clay soils (dark).

humidity indicators from the soil based on optical and radar satellite images. While optical images offer the advantage of being easier to process, they are however unusable when clouds are present. In this case, it is necessary to use radar images, but they require more extensive processing before they can be used. Thanks to these two types of images, it was possible to extract three interesting variables: apparent thermal inertia, the soil dryness index and the soil moisture index. These variables can be integrated into the spatial models of other vector-borne diseases. The results obtained are very promising but the methods still need to be fine-tuned before being operational. In particular, they aren't really suitable in the presence of abundant vegetation. Nevertheless, advances in the project already allow a better understanding of the impact of factors such as soil moisture or vegetative barriers on the propagation of a vector-borne disease, therefore justifying the implementation of more efficient and targeted control measures.

AUTOMATIC UPDATE

And what if the forecast maps were to become dynamic? If an easy update could be envisaged? This is the challenge that the DYNMAP project researchers set themselves. The idea is to merge the data from different sources and with different spatial resolutions to obtain dynamic predictive mapping. The research carried out endeavoured to develop such a tool for the habitat of the mosquito which is the vector for malaria in Asia. The method obtained allows the data from different resolutions to be combined, as well as allowing the high-resolution images to be updated almost automatically with the help of time series of low or medium-resolution images.

The globalisation of trade and the increase of passenger traffic by air, illustrated here by the map of the global aviation network in 2009, are important risk factors in the distribution of infectious diseases.



Probability map for the presence of the mosquito *Anopheles dirus sensu lato*, one of the vector species of malaria in South East Asia.

This application provides more detailed information on land use, such as the location of rice fields, thus allowing researchers to expand their knowledge on the relationship between the malaria vectors and environmental indicators. The project also confirms the hypothesis of a habitat in recession for *Anopheles dirus sensu lato*. during the dry season, as well as the influence of parameters such as land use and relative humidity on the presence of the mosquito. The project also validated the quantity of water contained in a leaf as a valid indicator to estimate this relative humidity.

The research has therefore yielded many results and numerous applications. DYNMAP has opened the way to the development of new products based on the use of remote sensing data that can be used in epidemiology.
This multidisciplinary project integrates perfectly into the philosophy of the STEREO II programme. It is the fruit of a close collaboration between two complementary sources of expertise: the Institute of Tropical Medicine's practical knowledge of the terrain and the diseases, and UCL's theoretical experience of data processing and classification.

SATHELI, A SNAIL UNDER SCRUTINY

EUR 8.2 million a year, that is the economic impact of the common liver fluke on the dairy sector alone in Flanders. The intermediary host of the common liver fluke is the *Galba truncatula* mud snail, which lives in ponds and puddles (Small Water Bodies – SWB).
The SATHELI study began in February 2012. The "tailor-made" technique developed by researchers to detect high risk areas (small bodies of water) combines WorldView-2 satellite data (up to a resolution of 50 cm) with even more precise data collected by a drone. The models forecasting the risk of infection that have been developed will allow farmers to make a better choice as to where and when their cattle should graze, in order to avoid infection as much as possible.

PRODUCTS AND SERVICES FOR THE AFRICAN CONTINENT

This article is based on the research projects:

ENDELEO
ENDELEO-OPS
MORECA
WWW
WWW2
POPSATER

Protecting fragile ecosystems, combating deforestation, preventing locust plagues, providing warning systems for food security or taking a census of populations... Satellite imagery allows researchers to develop operational applications that meet the priorities expressed by their African partners.

At the dawn of the third millennium, the planet's state leaders approved a global action plan in an attempt to eradicate poverty worldwide: the Millennium Development Goals.
They committed to mobilising their efforts to improve the living conditions of the most vulnerable populations and meet their needs in terms of food security, health, education and protection of the environment. As for the United Nations' major institutions and non-governmental organisations, their role is to relay local requests for support and to stimulate international cooperation in specific domains, such as food and agriculture (FAO), the environment (UNEP) or nature conservation (WWF).

In support of this ambitious project, detailed, regular and near instant information provided by the Earth's observation satellites are essential tools. It is therefore crucial to ensure that the remote sensing techniques and data are within everyone's reach, in order to perfect the planet's management and monitoring systems at all levels, from local to global. For instance, to meet precise needs in the field, many African countries would like easy access to satellite data and the creation of an exchange network with countries that are more advanced in space techniques.

One of the sections of the STEREO II programme meets this desire. It is a more practical section that is devoted to the transfer of knowledge and technologies with the aim of developing pre-operational products and services. In continuous interaction with African partners and international organisations, several projects are focusing on developing mapping, analysis and assessment tools that can be used directly in the field.

A SOUND MANAGEMENT OF KENYA'S ECOSYSTEMS

East Africa's natural ecosystems have suffered considerable modifications in the last few decades. Significant demographic growth, climate changes and economic pressure are among the main factors responsible for the overexploitation of natural resources.
The resulting degradation weakens the ecosystems making them increasingly vulnerable to

natural catastrophes such as the recurring drought that characterises the climate in this region. It is therefore essential to implement measures to curb the degradation of land and resources.

In Kenya, in particular, the natural ecosystems are a vital source of income for the country's most prosperous sectors such as tourism, agriculture and energy production. The public authorities are well aware that optimal management is essential if the country is to continue benefiting from all these resources in the future. Just like the environmental organisations and local managers, they want up-to-date information on the state and the evolution of the natural resources.

Satellite imagery is able to provide such a synoptic view of the state of the vegetation and changes in the ground cover over time. The **ENDELEO** and **ENDELEO-OPS** projects are working on providing simple tools that will help to improve the monitoring of the dynamics and, hence, the management of the fragile ecosystems in East Africa, and Kenya in particular. The goal is to make the information derived from the satellite images on the state of the vegetation available to the end-users, in the most accessible way possible. During the first stage, the team attempted to assess the efficiency of the conservation measures in vulnerable dry areas using image time series. An operational tool was then developed to help local managers (of rangeland ecosystems above all, but also of forests) to actively monitor the impact of their interventions.

RENDEZVOUS IN NAIROBI

In association with scientific teams from the University of Ghent and VITO, two of the project's partners are based in Nairobi: the African regional office for the United Nations Environment Programme (UNEP) and the Department of Resource Surveys and Remote Sensing, which is dependent on Kenya's Ministry of the Environment. At the beginning of the project, representatives from several NGOs, research institutes and governmental organisations attended a workshop to reconcile the various sectors' needs in terms of information with the means offered by remote sensing. Achieving this goal turned out to be a challenge in itself since, in the beginning; the users had no knowledge of the possibilities satellite imagery had to offer.

This consultation made it possible to define which quantitative indicators to provide the end-users with at regular intervals: the Normalized Difference Vegetation Index (NDVI), which is useful for the identification of episodes of drought; and Dry Matter Productivity (DMP), an index to estimate the production of dry biomass which is useful in the assessment

TOOLS FOR AFRICA

ENDELEO
ENDELEO-OPS
MORECA
WWW
WWW2
POPSATER

of the productivity of the prairies. These two indices are derived from low- and medium-resolution data obtained from sensors such as SPOT VEGETATION and MODIS. Their values, which are automatically updated every ten days, have been archived since 1999. These time series are essential to monitor the vegetation's dynamics. They help to show the long-term trends but also to reveal seasonal changes, by comparing the situations with a given period of the year for several consecutive years. Furthermore, to have a more concrete view of the modifications the ecosystems have undergone, Landsat, ASTER and SPOT HRVIR images, which have a higher resolution, were used to map land use changes and certain types of degradation.

BY AND FOR KENYA

Conducted over a period of almost four years, the project involved Kenyan users at every stage. Internet tools, already designed from the outset to meet their needs, were improved according to their recommendations, in order to create a tailor-made service that better corresponded to their expectations. The project therefore led to durable interactions between the users and the **ENDELEO** team. Local organisations that had never or almost never used satellite data until this point, are now aware of the possibilities offered by remote sensing and have a precious tool in terms of environmental monitoring and support for decision-making. The users are informed several times a year, through the **ENDELEO** newsletter, of the improvements and extensions made to the tools as well as new case studies presented on the site.
The products developed have demonstrated their usefulness in daily life in the implementation and assessment of protection processes. As a result, UNEP would like to export the concept to other countries in East Africa, such as Uganda, Ethiopia and Tanzania.

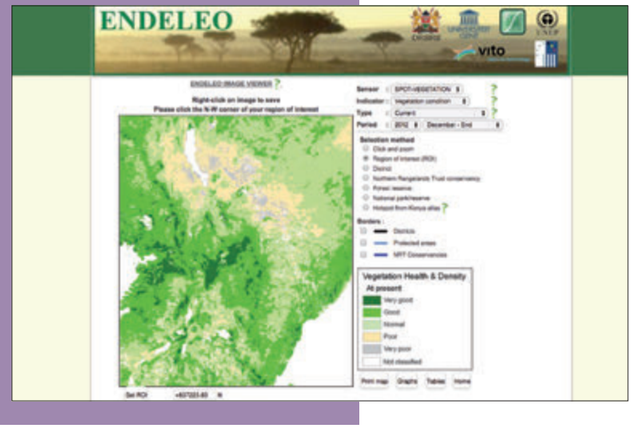
Monitoring vegetation in just a few clicks

Thanks to **ENDELEO**, Internet tools have been developed that allow users to visualise and analyse useful information in just a few clicks. In an effort to keep things simple, technical terms were avoided as much as possible. Substantial general documentation and a detailed user manual are nevertheless available for anyone who wishes to consult them. **ENDELEO** is therefore aimed at a target audience, i.e. organisations active in the protection of the environment, whose representatives have no background in terms of remote sensing, and don't have either specialised software or a significant download capacity.

The "Image viewer" tool allows the user to precisely map the state of the vegetation and study its evolution by comparing it, for instance, with the average over ten years, the previous year or the last ten days. The "Graphs" tool displays variations in the state of the vegetation during a growth season per region and per type of plant cover, in comparison with an average year. The "Tables" tool calculates the percentage of reduction or increase in the vegetation index of the year in progress compared with a reference year of choice. Finally, the "Focus Area" allows you to visualise the results obtained for certain specific cases (deforestation, fires, etc.) with the help of more detailed satellite images.

The site also includes several case studies that show, in concrete terms, the usefulness of the vegetation indices in the management of natural resources. In particular, these indices have served to study the influence of the state of the vegetation on the migration of wild animals. One study examined the behaviour of Grévy's zebra, an endangered species, and another, that of elephants. The latter can indeed cause considerable damage to natural vegetation and crops when their territory is too small.

Fires in the east of the great Mau Forest complex in 2009 and the extreme periods of drought that ravaged Kenya in 2005 and 2009 were also the subject of detailed studies. They demonstrated the usefulness of vegetation indices to assess the impact of natural catastrophes, to locate the areas most severely affected and determine the effect of environmental protection measures, such as banning grazing in certain areas of the Mau Forest. Furthermore, thanks to series of high-resolution images available since 1986, researchers have been able to map the deforested areas in several nature reserves selected by the users.



REFORESTING THE DEMOCRATIC REPUBLIC OF CONGO

Virunga National Park covers an area of 790,000 hectares in the east of the Democratic Republic of Congo, on the border with Rwanda and Uganda. It has a chain of volcanoes, two of which are active, and an amazing variety of habitats (lava plains, savannahs, steppes, tropical rainforest, lakes, marshes, etc.) that are home to exceptional diversity, represented by the emblematic mountain gorilla. Despite its inclusion on the Unesco World Heritage list, the park is subject to an alarming rate of deforestation, due to the extension of farmland and pastures, but also because of intense illegal logging (a huge amount of wood is cut down for firewood and charcoal production).

The province of North Kivu has been destabilised by wars and fighting for more than 20 years. Its capital city, Goma, has seen the arrival of countless rural families escaping the threats and its current population stands at more than a million inhabitants. Wood and charcoal (called makala) are the only easily accessible energy sources for this population. Eighty percent of these resources are extracted daily from the neighbouring national park. In 2007, the WWF, with the help of the European Union, started up the EcoMakala programme. It involves supplying the families of Goma with charcoal produced from plantations of fast-growing trees, an income-generating activity led by small farmers on land situated in the areas surrounding Virunga Park. This alternative system for the production of legal and sustainable makala offers the double benefit of improving the peasants/planters living conditions and protecting the park's forest resources. In total, more than 5,000 hectares of trees have already been replanted in all these small-sized farms (less than 5 hectares).

HOW TO BENEFIT FROM CARBON FINANCE?

Although very small, the EcoMakala plantations stock carbon, and help to reduce the deforestation of the National Park. Consequently, they are perfectly eligible for carbon finance. But proof needs to be provided that the plots meet the required criteria. Could satellite images be used for this purpose?

As regards reforestation in the DRC, the United Nations Framework Convention on Climate Change (UNFCCC) defined "eligible" forest as a plot of at least 0.5 hectares that hasn't been forested since 1990, covered with a minimum of 30 % trees, with a potential height of three metres at maturity. Although remote sensing is suggested in the Kyoto agreements and can be used to monitor large plots, no study has examined as yet the feasibility of detecting 30 % tree cover in a surface area of only 0.5 hectares. To explore this question and thus support the EcoMakala programme, the WWF initiated

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Financial Incentives To Reduce Carbon Emissions

In an effort to combat global warming, international agreements have seen the light of day. At the heart of these agreements, the Kyoto Protocol aims to reduce greenhouse gas emissions, in particular by combating the deforestation responsible for 20 % of these emissions on a global level.

To protect and reinforce forest carbon stocks, the sustainable management of forests and the reforesting of plots need to be encouraged. Two types of carbon finance mechanisms have consequently been set up: the Clean Development Mechanism's Afforestation/Reforestation system, which promotes the increase of forest surface area, and REDD+ certifications (Reducing emissions from deforestation and forest degradation in developing countries) aimed at reducing deforestation. Their principle is simple: industrialised countries support projects encouraging a reduction in carbon emissions in developing countries and in return, they benefit from credits that can be included in their own emissions balance.

© K. Holt / WWF-UK

Woman at makala market, Saké, DRC.

the **MORECA** project, in collaboration with the Catholic University of Louvain and the Free University of Brussels.

A VERY USEFUL ELIGIBILITY MAP

To establish the eligibility map of the plots, different classification methods applied to the high-resolution SPOT images (20 metres) were compared. The study showed that in the case of a mountainous, fragmented landscape, as is the case in the eastern DRC, a traditional classification method based on pixels (and not objects) gives very satisfying results. Moreover, it has the advantage of being compatible with the software already used at the local branch of the WWF in Goma and at the region's head office.

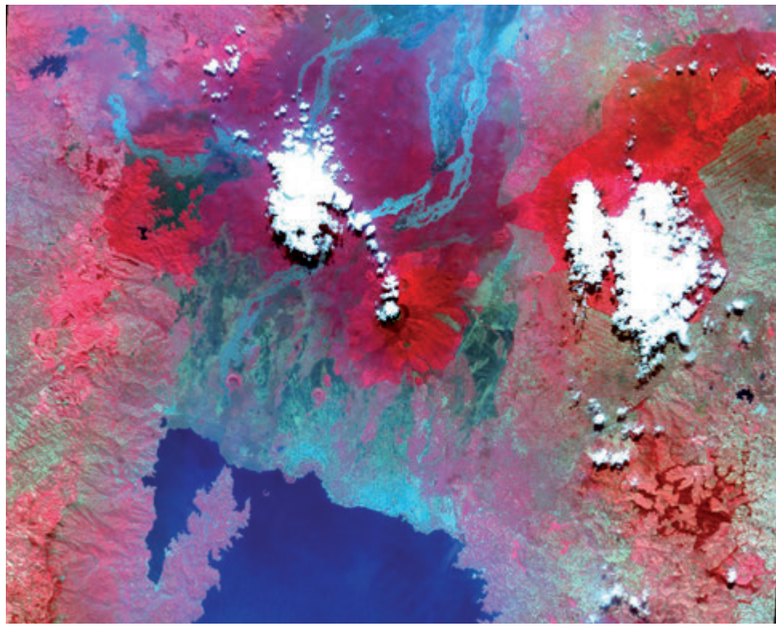
The maps produced allow users to calculate the forested surface for each plot, while taking into account classification and positioning errors. The eligibility map obtained allowed the WWF branch in Goma to provide the necessary proof to grant the financing for the EcoMakala plantations. Since the method developed has proved its usefulness, it could be reproduced to support funding requests for other regions with different eligibility criteria.

The second part of the **MORECA** project studied how to follow the evolution of reforested plots in a difficult geographic and social context. The plots are indeed small and not easy to access, owing to a poorly developed road network and recurring insecurity. To elaborate this monitoring tool, very high-resolution satellite images and radar images were used. GeoEye optical images with a resolution of 60 centimetres allow detailed mapping of forest cover. However, they are very expensive and their acquisition in a tropical area is often tricky owing to the extensive cloud cover. As for radar images, they can be obtained in all weather but they have a lower spatial resolution. Technological developments and increasingly competitive prices could facilitate the development of such tools in the future. The new possibilities offered by satellites such as Pleiades are very interesting in this respect.

BELGIUM PRODUCES WARNING SERVICES

The Copernicus Earth Observation Programme (formerly GMES) was initiated in conjunction with the European Space Agency and the European Union in order to provide Europe with an independent and operational monitoring capacity in terms of the environment and civil security, both on a local and global level. Belgium,

SPOT HRV false color image acquired in August 1996 showing the border between DR Congo and Rwanda north of Lake Kivu. In red, dense vegetation delineates the contours of the Virunga National Park (left, with the fumes emitted by Nyiragongo) and the Volcanoes National Park (right).



which is actively involved in the programme, is using its centres of expertise in remote sensing to develop new high-performance tools. They are intended to supply reliable, up-to-date, high quality information which is precisely adjusted to the expectations expressed by the end-users. Within this framework, the overall objective of the **WWW** et **WWW2** projects is to offer global operational services to certain specific communities of users. This is the Belgian contribution to one of the six thematic areas defined by the Copernicus programme, in this case, land monitoring.

The design and production phases of these new services are fully linked, with the Geomatics Units at the Catholic University of Louvain taking charge of scientific development, while VITO is implementing the processes in the operational processing chains. Three continuous global monitoring services, in near real time and on a continental scale, were thus proposed: "Desert Locust", "Agriculture Phenology" and "Pan Tropical Forest Watch".

They have been developed in close collaboration with their future users and favour a multi-sensor approach, in order to be able to produce applications that can benefit from the most suitable available source of information.

THE DESERT LOCUST, AN ANCIENT SCOURGE

The "Desert Locust" service has been set up in response to a request from the Emergency Centre for Locust Operations (ECLO) organised by the United Nations Food and Agriculture Organisation (FAO), in order to combat the devastating effect of plagues of this voracious pest. Inoffensive in its solitary form, the desert locust, under the influence of an increase in the insect population, transforms into the gregarious form which poses an extremely serious threat to agriculture. The desert locust becomes a fearsome creature owing to its voracity, the mobility of its swarms, which can cover up to 200 kilometres a day, and the vastness of the areas concerned. The areas extend over 29 million km², encompassing the south of Europe, the whole of Africa north of the equator, as well as the Arabian and Indo-Pakistani peninsulas.

During plagues, an adult locust can eat the equivalent of it bodyweight in fresh food a day, i.e. approximately two grams. Hence, a ton of locusts, just a small part of an average-sized swarm, can devour the same quantity of food as 2,500 people every day. Extremely polyphagous, the gregarious desert locust attacks both natural vegetation, depriving cattle of their food source, and food crops and plantations. Unfortunately, the loss of crops is considerable. If the situation continues, entire populations are threatened with famine and their survival is at stake. The great invasion of 2004-2005 in West Africa is still fresh in people's memories, with figures that speak for themselves: 26 countries affected, 6.5 million hectares destroyed, 13 million hectares treated with pesticides and crop losses estimated at USD 2.5 billion...

DYNAMIC MAPS OF THE DESERT LOCUST'S HABITAT

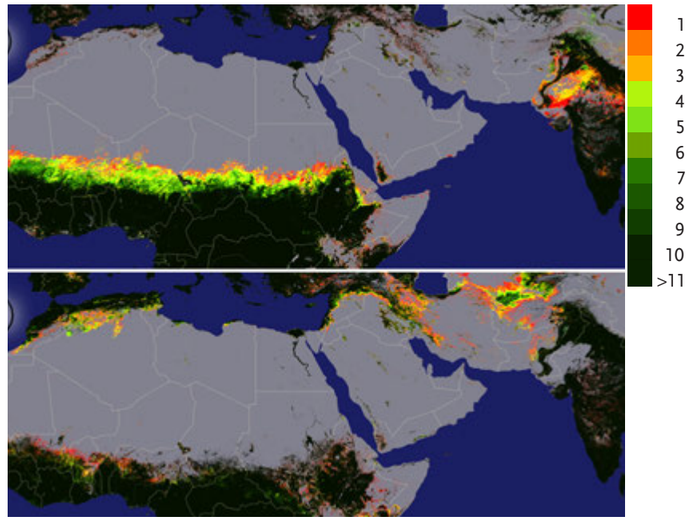
The **WWW** project has produced tools which help to improve monitoring of the vegetation and moisture conditions in arid and semi-arid areas, which are the natural habitat of the desert locust during its quiet periods of recession.
It is a question of reinforcing the action of local surveillance teams to prevent the reappearance of the locusts and the formation of huge swarms. Indeed, when the rains increase and the vegetation grows, the desert locust can multiply very rapidly and their density can reach dangerous thresholds.
To optimise the early warning systems, the project's team developed a new multi-spectral and multi-temporal image analysis method to automatically detect, in near real time, the vegetation in arid and semi-arid areas. The images used are SPOT VEGETATION and Aqua/Terra MODIS time series. The originality of the method consists of combining the multi-spectral and colorimetric analyses of the spectral signal. It is based on an innovative image pre-processing technique, the simultaneous use of three channels – red, infrared and mid-infrared – and on the transformation of the common Red-Green-Blue (RGB) colorimetric system in another better adapted Hue-Saturation-Value (HSV) system.

A complete automatic processing chain was developed which generates a dynamic map of the vegetation in the whole of the desert locust's recession area, on the basis of daily observations made by the MODIS and VEGETATION sensors. Delivered every 10 days by VITO, this map with a resolution of 25 metres summarises the spatial and temporal distribution of the vegetation in a single image file. Potential locust reproduction areas can therefore be identified more precisely and ground controls can be better oriented. For the teams in this project who are in charge of locust plague warnings at the FAO, this tool is a valuable aid for the prediction of reproduction times and areas, and the migration of the desert locust. The international community therefore has a more effective and faster warning system that is continuously in operation, in near real time and on a continental scale.

SECOND PHASE, MONITORING FORESTS AND CROPS

In the second phase of the project, **WWW2**, the "Pan Tropical Forest Watch" service was initiated in response to a request from the World Conservation Monitoring Centre, set up by the United Nations Environment Programme (UNEP-WCMC). To improve the warning systems, the service consists of automatically detecting, on a planetary scale, any changes within the tropical rainforests, especially deforested areas, fires, variations in stretches of water (overflowing and drying up), or the regeneration of the vegetation. The product is based on a series of low- and medium-resolution seasonal images from several sensors. The performance of a service such as this depends on the frequency of the acquisition of quality images, in the absence of clouds. In tropical areas, the cloud cover does of course make it difficult to obtain useable series. However, since the tropical rainforest is an environment with a low level of seasonality, image acquisition can be less frequent.

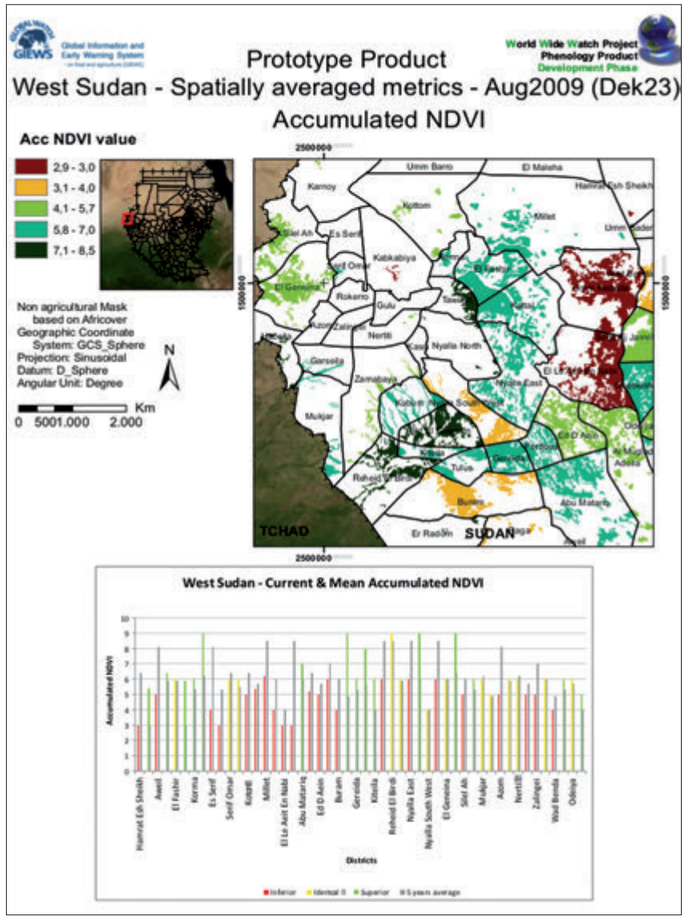
The "Agriculture Phenology" service was also developed in close partnership with an FAO body, the Global Information and Early Warning System (GIEWS). Dedicated to food security, GIEWS's mission is to continuously monitor the global supply and demand of farming products, and to provide early warning of food crises likely to affect certain countries.



The green vegetation dynamic map from 01/09/2008 (above) and 21/09/2009 (below). The colors represent the number of 10-day periods during which the area was covered with vegetation.

Through this service, it is possible to monitor the interannual variability of crops, on a regional or national scale. Their phenological parameters, i.e. the observation of their seasonal development phases, are of primary importance to characterise the agro-ecological zones. This type of information is essential for knowledge of the present situation and crop prospects but also to study the fluctuations due to climate change in the longer term.

Traditionally, the phenological data is extracted from a vegetation index such as the NDVI, with a frequency of 10 days, and independently from the type of ground cover and the agro-ecological context. Based on SPOT VEGETATION and MODIS multispectral image time series, the **WWW2** teams endeavoured to provide a more specific characterisation of the phenology of the agricultural vegetation and develop a method that takes into account the types of ground cover. The suggested algorithm can be adjusted according to the type of ground cover and therefore provide end-users with more relevant data. It is composed of a series of ten major phenological indicators, including the start and end dates of the vegetative period, the date of maximum development, the rate of growth and senescence, the duration of growth, etc. The "Agriculture Phenology" service is in the pre-operational prototype phase and will eventually be integrated into an optimised version of the GIEWS workstation, the internet platform that manages and distributes global information relating to food security.



Phenological prototype product illustrating the NDVI values accumulated over a given period in a region of western Sudan. These map data are supplemented by comparative statistics in graph form.

ESTIMATING POPULATIONS THANKS TO SATELLITE IMAGES

For the successful social and economic development of a country or region, it is essential to have precise knowledge of the state and the dynamics of its population. This information is also crucial to manage civilian displacements, caused by wars or catastrophes, in periods of crisis. Unfortunately, many countries, particularly in Africa, only have access to partial and approximate data on the real number of inhabitants and this data is all the less precise because the population is growing so quickly.

Since their emergence at the end of the 1990s, very high-resolution satellite images offer a unique opportunity to observe inhabited areas in detail. While not everything can be seen from space (for instance, the number of people living in a house), these images nevertheless allow us to measure other important parameters such as the number of dwellings or the typology of neighbourhoods, which can be directly linked to the number of inhabitants.

The **POPSATER** project attempted to develop a new demographic estimation method, both in urban and rural areas, based on the combined use of high and very high-resolution images completed by field surveys. It was initiated by a partnership between three Belgian entities grouping together their complementary expertise: a private company specialising in geographic information products, a research unit from the Free University of Brussels and a design office focused on the field collection and analysis of socio-demographic data.

With the very high resolution QuickBird images (60 centimetres), it is possible to distinguish dwellings and therefore count them manually or automatically if the contrast is high. To estimate the population, a direct approach can therefore be applied, by multiplying the number of dwellings by the average number of occupants; the last piece of information being extracted from a series of field surveys.

Lubumbashi, in the Democratic Republic of Congo, was selected as an urban environment test zone as there was a census available. The direct approach revealed different results between the town centre and the outskirts, where the population figures obtained were significantly closer to reality. Two factors explain this disparity: on the one hand, the small size and the density of homes in the town centre mean that it is impossible to automatically detect individual homes; on the other hand, the confusion between the roofs of homes (corrugated metal) and tarmac roads makes it difficult to extract data on developed areas. In order to solve this problem other methods were tested, in particular, on the basis of the estimation of the inhabited surface: in this case, it is no longer a question of counting the houses but the inhabited surface, i.e. the surface represented by the roofs of all the dwellings.

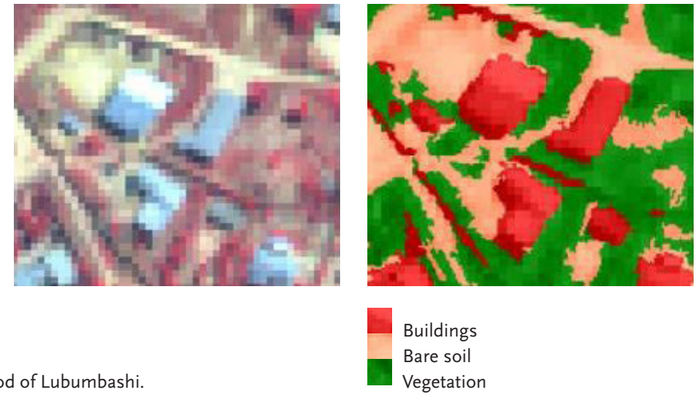
In this case, the estimation of the population is dependent on a zonal approach: the surface of the built-up area is measured and multiplied by the density of the sampled inhabitants in several blocks of houses. However, in Lubumbashi, it was difficult to find a unit of space where the density of occupants was constant. In the town, there is considerable diversity in the same housing block, with more wealthy homes sitting alongside slums.

In rural environments, the methods were tested on an area situated to the north of Benin. The results obtained from very high-resolution images turned out to be reliable, but considering the high cost of these images, the technique isn't ideal for covering large expanses. Tests were carried out using high-resolution (5 metres) SPOT 5 images, which are cheaper. With the latter, it is impossible to identify every dwelling but it is possible to estimate the built-up surface. Whilst the smallest hamlets aren't always detected, the zonal method turned out to be effective for average-sized villages because the density of occupants per dwelling is relatively stable.

Following **POPSATER**, new collaborations between the team of demographers and the remote sensing company were formed allowing them to win several bids concerning population estimations.

Automatic extraction of buildings on a very high-resolution satellite image (QuickBird).

Satellite image | Land use map



QuickBird image (60 cm resolution) of a neighborhood of Lubumbashi.

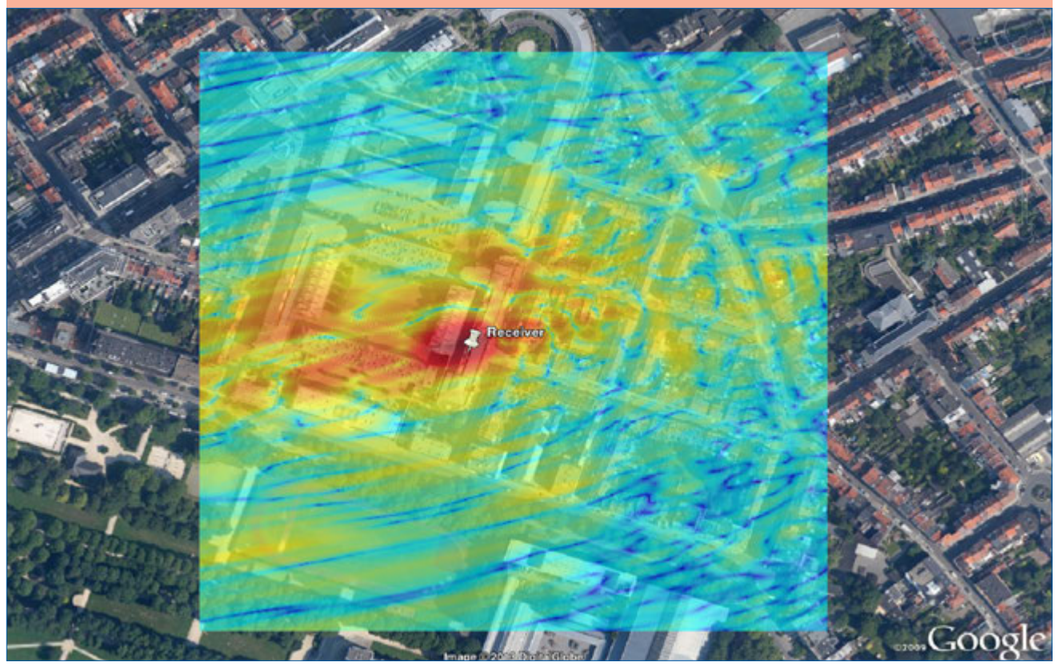
NOVEL APPROACHES & UNCHARTED DIMENSIONS

MUSAR A RADAR RECEIVER WITHOUT AN EMITTER?

Unlike passive sensors, that record the portion of the sun's radiation reflected or re-emitted by Earth's surface, a radar sensor is active: it sends out an electromagnetic signal itself that "illuminates" the terrain and then measures the echo backscattered by the target in its direction. Not being dependant on luminosity, it has the non-negligible advantage of being operational day and night. As the waves it emits can pass through clouds, the quality of its observations is ensured in any type of weather. Radar, SAR (Synthetic Aperture Radar) in particular, is a tool of choice for applications like soil moisture estimation and infrastructure monitoring (buildings, roads, etc.). The backscattering of the radar wave depends in fact on surface moisture; in addition, the interferometric technique allows very slight movements, displacements of bridges and dams for example, to be detected from space.

Most SAR instruments include both the emitter and the receiver. In a new approach, the **MUSAR** project has studied a "bistatic" configuration, where emitter and receiver are separate. In such a configuration, the emitter can be located onboard a satellite, while the receiver is installed on the roof of a building. It can thus capture signals from any emitter flying over its area. The advantages of the system are the increase in useful information, the reduction in the revisit time for the same site, and savings on the cost of the emitter. Research has dealt with the problem of synchronisation between the two entities and development of a new image reconstruction algorithm that differs from the standard methods.

Intensity of (direct and indirect) signals captured by opportunistic receivers, draped over an aerial image of Brussels.



WAVARS A BIT OF PSYCHOLOGY IN REMOTE SENSING

The perception and interpretation of a human operator often play an important role in the analysis of satellite images, even when image processing is largely computerised. But there are inadequate data on evaluating the performance of operators. The **WAVARS** project was concerned with this aspect of remote sensing, using tools from cognitive psychology. Over 300 participants, experts as well as novices, were called upon to perform a series of tasks in digitised image interpretation within a certain time period. The idea was to evaluate the extent to which the results obtained are subject to error and to reveal the criteria that help explain the differences in performance between people (age, gender, educational level, personality) and between tests (experimental conditions, allotted time, etc.).

The study showed that there was great variability in operator efficiency; almost 30% can be attributed to human or external factors, which is significant. Another incontestable result is the progressive decrease in performance after a certain working time, indicating the importance of taking breaks when working on long interpretation sessions. The project approach can serve to develop instruments for evaluation of the image analysis process, and can be incorporated into methods for training or professional selection.

Operators concentrated on the WAVARS questionnaire.

PROCESS A SINGLE PROCESSING SYSTEM FOR NUMEROUS SENSORS

The products of high-resolution remote sensing are appreciated and in demand by an increasingly broad circle of users, from the scientific community to the general public. Among observation systems, the latest-generation airborne sensors (like APEX, AVIRIS ou HyMAP) are therefore receiving growing interest. To provide high-quality products and services suited to the needs of the users, it is crucial to be able to process data reliably and efficiently. The VITO has already developed a high-performance processing system applicable to various single-shot or video, multispectral or hyperspectral imaging sensors. This processing system is implemented in the CDCP (Central Data Processing Centre).

The **PROCESS** project studied how to extend the existing processing system to two new sensors, a thermal sensor operated by the Public Research Centre - Gabriel Lippmann (Luxembourg) and the HYPLANT hyperspectral sensor of the Jülich Research Centre (Germany), devoted to observation of the fluorescence emitted by vegetation in sunlight. The general approach of the project is thus to optimise the flexibility of the algorithms implemented in the existing system so as to be able to generically and dynamically process data resulting from the largest possible number of airborne sensors.

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Mississippi river acquired by the OLI instrument on NASA's Landsat 8 satellite in February 2014 - ©NASA Earth Observatory image by Michael Taylor and Adam Voiland, using Landsat data from the U.S. Geological Survey.
False-colour image of Brussels acquired by the Spot-5 satellite on 28 September 2011.
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What's the link between
the volcanoes in the Virunga Park,
the orchards in the Valencia region,
the city of Istanbul,
the tropical forests of Sumatra,
the pyramids of Egypt,
the heathlands in the Belgian nature reserves,
elephants in Kenya,
jellyfish off the Irish coast,
mosquitoes in Southeast Asia
and locusts in the Sahel?

Each of them was the subject of research carried out in the frame of the Belgian remote sensing research programme STEREO II.
Almost 300 researchers tried to get a better understanding of how our environment functions by using satellite and airborne data.
Open and discover inside the 60 projects financed by the Belgian Science Policy Office during the programme's 8 year lifespan.