Geoinformation and Earth Observation for environment and territories
Agropolis International brings together institutions of research and higher education in Montpellier and Languedoc-Roussillon in partnership with local communities, companies and regional enterprises and in close cooperation with international institutions. This scientific community has one main objective—the economic and social development of Mediterranean and tropical regions.

Agropolis International is an international space open to all interested socioeconomic development stakeholders in fields associated with agriculture, food production, biodiversity, environment and rural societies.

Agropolis is an international campus devoted to agricultural and environmental sciences. There is significant potential for scientific and technological expertise: 2300 scientists in more than 100 research units in Montpellier and Languedoc-Roussillon, including 300 scientists in 60 countries.

Agropolis International is structured according to a broad range of research themes corresponding to the overall scientific, technological and economic issues of development:

- Agronomy and Mediterranean and tropical agricultural production sectors
- Biotechnology and food technology
- Biodiversity, natural resources and ecosystems
- Water, environment and sustainable development
- Societies and sustainable development
- Genomics and integrative plant and animal biology
- Food and health
- Food quality and safety

Agropolis International promotes the capitalisation and enhancement of knowledge, personnel training and technology transfer. It is a hub for visitors and international exchanges, while promoting initiatives based on multilateral and collective expertise and contributing to the scientific and technological knowledge needed for preparing development policies.
Development research and expertise on geoinformation and Earth Observation for environment and territories in Montpellier and Languedoc-Roussillon

Access to airborne and satellite technology for Earth Observation is a major methodological boon for researchers. This ‘altitude gain’ for monitoring has led to the development of a new approach to assessing territories, providing an overview of the target area and clarifying the distribution of elements within this area.

The quality and accuracy of the remote sensing tool are continually being improved. The increase in the number of spaceborne sensors and progress achieved in signal processing have generated new information that can in turn be used in a broad range of scientific fields as well as for decision support.

Moreover, as information can now be repetitively acquired over time at low cost, it is possible to draw up a historical record of changes instead of just having access to single images that have been captured at given times.

Alongside the development of information collection technology, information processing methods have also progressed substantially in conjunction with advances in computer technology. Collected information can thus be analysed by scientists, as well as users and decisionmakers.

Products obtained in this way have become demonstration tools that are highly effective for boosting stakeholders’ awareness, simulation, training and decision support. This technology has thus given rise to real communication products that—in addition to their scientific features—have evident artistic attributes.

This is the first Dossier devoted to a research and action tool. It presents research on improving this tool, along with examples of its applications to meet needs on different topics.
Demographic pressure, socioeconomic dynamics, climate change, ecosystem transformation, pandemic disease risks... Societies have to make rational choices with respect to human activities, land use, resource tapping and land development so as to mitigate their environmental impacts. These sustainable development strategies are based on an overall understanding of the system dynamics, joint formulation of management methods, the empowerment of citizens and implementation of assessment systems. Geoinformation and Earth Observation for environment and territories have a crucial role in these strategies. It is currently at the crossroads of three major challenges, i.e. knowledge, management and governance, and technological challenges.

The knowledge challenge may be met by gaining insight into ecosystems, territories and societies. The importance of spatial information in these approaches can be summed up in a single question: how can spatiotemporal information be acquired on a complex system and be analysed so that it is effective for revealing structures, processes and dynamics? The topics covered in this Agropolis International Dossier—ranging from snow cover on Andean glaciers to coral ecosystems in the Pacific, from temperate forests to Mediterranean agroecosystems, from changing rural areas to epidemiological events—highlight the research under way associated with the use of spatial information to address this knowledge challenge.

The management and governance challenge concerns the capacity to streamline management strategies, ensure effective collaborations and negotiations, while fostering the empowerment of stakeholders and citizens. The efficient use of spatial information has a pivotal role. It can boost the insight of different stakeholders and enable them to put forward their views, facilitate joint representation of territories, structuring of information systems, as well as sharing of information between individuals and between organizations.

The technological challenge encompasses telecommunications, computer and satellite remote sensing issues. It has an overwhelming role in fostering the development of innovative spatial information approaches involving geopositioning, distributed mobile sensors, virtual globes, etc. In addition to the economic benefits, these technological advances have major impacts on our societies. They have remodelled our vision of Earth, from a patchwork of local systems into a standalone system of interacting constituents, from local initiatives to global dynamics—climate, pollution, economics, biodiversity, epidemics, etc.

Geoinformation and Earth Observation for environment and territories is a research focus that spans many fields and has several specific features: obviously its spatiotemporal nature, along with its complexity, diversity and uncertainty. It must be dealt with through a multidisciplinary approach, including geography, mathematics, image and signal processing, computer science, cognitive science, humanities and social science, other specialised disciplines, etc. Thirty-one Agropolis International research teams collaborated in drawing up this Dossier, some in conceptual and methodological fields, others in thematic fields using these methods in specific settings.

The Dossier is structured in four chapters:

• The first three deal with methodological research on the acquisition of spatial information via satellite and airborne remote sensing (chapter 1), on spatial analysis and spatiotemporal modelling (chapter 2), and on designing information systems and observatories (chapter 3).

• Chapter 4 illustrates applications of this research in four fields, i.e. agriculture, environment, land-use planning and societies.

We all (often unconsciously) use spatial information to monitor the environment, get our bearings and take action. Agropolis International teams—along with their national and international partners—are striving to extend, develop and make effective use of this potential for the benefit of humans, society and the planet.

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General map of France, 092, [Montpellier], N°92, file 116
(drawn up under the direction of César-François Cassini de Thury) Source: gallica.bnf.fr / Bibliothèque nationale de France
Satellite and airborne remote sensing
In 2009, around 60 satellites are seamlessly monitoring the Earth’s atmosphere, oceans, and land surfaces. Satellite remote sensing has many advantages for environmental and territorial inventories and surveys as compared to conventional ground measurement systems (objectivity, homogeneity, repeatability, completeness, archiving, etc.). Acquired images and data are inputs for global surface process models while—on a more local scale—providing essential information for environmental and territorial resource management. The launching and development of new satellite and airborne systems has substantially enhanced the management of natural and agricultural areas. Specific innovative algorithms for image and signal processing are thus being developed in order to take full advantage of the technological potential of these systems.

- **Light aircraft systems:** So-called ‘light’ data acquisition systems are currently being developed as a complement to ‘heavy’ satellite and airborne systems. With these systems, images are acquired via drone or microlight aircraft equipped with commercial digital cameras that have been modified for acquisition of images in spectral bands other than red/green/blue. These inexpensive and easy-to-use systems can generate images that require specifically tailored techniques to preprocess and convert them into quantitative thematic maps.

- **Very high spatial resolution (VHSR):** Very high spatial resolution (metric and submetric) remote sensing systems first appeared around year 2000 for visible and infrared wavelengths (multispectral imaging) and 2008 for microwaves (radar imaging). Although initially limited to airborne acquisition, VHSR technology has radically changed satellite remote sensing and made it possible to map most landscape and urban environment constituents. Techniques implemented for object detection (extraction) and for splitting images into different entities (segmentation) are booming but, as the quality of the results may vary, adaptations may be required depending on the topic being investigated.

- **Very high temporal resolution:** The scientific community and users can have access to time series images in low (100-1000 m) and, recently, decametric spatial resolutions, with a repeatability of around 1-3 days. Extraction of information from time-series images is a major future remote sensing challenge. Such work requires analysis and debate on time (season, year, etc.) and space (plant, plot, region, etc.) scales at which dynamic functioning, evolution and change phenomena are perceived and detected, and on tailoring models to these new data sources.

- **Lidar techniques:** Lidar (light detection and ranging) is an observation technology system based on laser beam transmission-reception. Onboard range-finder systems determine the distance between the sensor and the target by analysis of the main lidar echo and may be applied to bathymetrical or topographical measurements. On the other hand, full wave form systems measure the entire reflected signal, thus providing access to the vertical structure of a target surface. They generate information that cannot be accessed by other remote sensing techniques, such as the digital terrain model in forested areas and 3D vegetation structure mapping.

- **Radar techniques:** An essential feature of radar is its capacity to acquire images irrespective of the meteorological and sunlight conditions through active microwave transmission and reception of their echo after interaction with a surface. SAR radar imaging thus provides information on the surface roughness, radar altimetry generates information on ocean surface and continental water levels, while radar interferometry can be used to measure relief (spatial interferometry), movements and deformations (temporal interferometry) in soil and water.

The expertise pooled at Agropolis International in the fields of satellite and airborne remote sensing is highly original. There is substantial potential for developing remote sensing methods that could be mobilized to help in dealing with issues concerning environmental and resource knowledge and management, at regional and local scales in Europe and developing countries. The research teams thus invest in data acquisition, image and signal processing. They conduct studies directly associated with thematic fields of research, with support from the technological research platform of the Remote Sensing Center in Montpellier (France) and its development via the GEOSUD project.

Agnès Bégué (UMR TETIS) & Frédéric Huynh (US ESPACE)
Harnessing geoinformation to enhance environmental and territorial knowledge and management

The joint research unit (UMR) Geoinformation and Earth Observation for Environment and Land Management (UMR TETIS, Cemagref, CIRAD, ENGREF/AgroParisTech) focuses on developing methods for acquiring and deploying geoinformation to enhance environmental and territorial knowledge and management. An integrated approach is thus implemented throughout the information flow channel, from the acquisition of data (mobilization) until the use of knowledge (appropriation), with the processing, production, management and pooling of geoinformation involved along the way.

The UMR TETIS research team conducts conceptual, methodological and thematic research to deal with the different components of this information flow channel, with four main lines of research:

- **Analysis of spatial structures and spatiotemporal dynamics.** This research line involves the analysis and mapping of spatial structures and spatiotemporal dynamics through a combined mathematical (geostatistics, spatial field reconstruction, spatial modelling of processes, etc.) and geographical (analysis of territorial dynamics, stakeholders’ viewpoints, pictorial symbolization) approach. The research is focused especially on problems of spatial resolution, scaling consistency, measurement quality, model sensitivity, indicator development, and adaptation of computer languages for territorial modelling.

- **Information system design.** This information management, exchange and pooling research line deals with the structuring of spatiotemporal knowledge and information through the development of observatories and information systems. Studies are focused specifically on information modelling as well as concepts and methods for capitalizing, managing, archiving and providing access to information to be shared between stakeholders (data infrastructures, interoperability between information systems).

- **Remote sensing, geoinformation acquisition and processing.** This research line is focused on satellite and airborne remote sensing methods applied to rural areas and territories in the domains of passive (visible, thermal) and active (radar, lidar) sensors. The research encompasses image and signal processing methods (classification, object detection, characterization of change, etc.). The UMR collaborates closely with CNES, space laboratories and industrial partners in this field, as well as with specialized research teams with the aim of adapting the methods to the specific features of the issues and systems under investigation.

- **Information and territorial development.** This research line is focused on processes that facilitate the appropriation of information by stakeholders in territorial governance and development approaches. It deals with the role of information and systems that provide access to this information. Case studies are conducted in settings in which information is generally shared asymmetrically between stakeholders. The research is aimed at developing methods for hosting, coaching and training on information management. The goal is to ensure that the viewpoints, objectives and
Constraints of different social groups will be clearly expressed and taken into account by all concerned parties.

A fifth line of activity is devoted to training (representing around 20% of the UMR’s activities): initial engineering training, MSc and PhD courses, continuing professional education, etc.

Approaches are developed in remote sensing, computer science, spatial analysis, geography, environmental science and territorial development. The UMR coordinates research projects and public policy support projects that concern agriculture, the environment, natural areas, forests, aquatic environments, animal health, territorial development and hazards.

Earth Observation, integrated management of environments and societies, information for territorial development in tropical environments

The overall goal of the Expertise et SPAtialisation des Connaissances en Environnement unit (ESPACE, IRD) is to develop and implement methods for the spatialization of knowledge through remote sensing and integrated approaches, from data acquisition to decision-making processes, with the aim of promoting sustainable territorial development in tropical environments.

The scientific and technological activities of the unit are organized in the framework of three methodological research programmes:

- satellite Earth Observation for monitoring tropical environments: remote sensing based spatial indicators, near real time environmental observation and monitoring methods
- integrated approaches to environment and society: landscape analysis and observatories for environmental management, spatialization of environment-health risks; territorial governance indicators
- integrated knowledge systems to enhance decision-making support: interoperable information systems for sharing mixed (spatial and in situ) data, modelling of dynamics.

Development of light airborne image acquisition systems (visible and thermal IR bands): the AgriDrone project

These new tools are based on aerial photographs taken with commercial digital cameras. These cameras are equipped with band-pass filters through which only the desired wavelengths pass (e.g. near infrared). A thermal camera is also used to measure surface temperatures. These cameras are mounted on small unmanned aerial vehicles or ultralight-type aircraft that are ready for service upon request. Maps are drawn up on the basis of geoinformation obtained from the images. Spectral information from the images is correlated with the field data (plant nitrogen and water contents, leaf area, biomass, etc.) in order to clarify the link between the measured radiometric signal and the surface parameters, and to develop relevant agricultural indicators for the agricultural subsector. The tools developed within the framework of AgriDrone will ultimately enable users to gain insight into the actual situation on target farms (planted area, average field slope, heterogeneity, etc.), and to monitor crop development and growth anomalies (germination, weed infestation, water and nitrogen stress, etc.).

A comprehensive operational service is now available based on the methods and tools developed through this project: a catalogue of mapping products, a tool for disseminating and handling digital maps and teaching material for secondary schools and technical services.

This project is carried out by CIRAD in partnership with Cemagref, Avion jaune and CERF. It is supported by the French Ministry of Agriculture and Fisheries and the Réunion Region.

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SEAS-Guyane: a direct satellite data receiving technological platform for Amazonian territorial monitoring

Considering the exceptional uniqueness of the Amazon Basin, it is essential to have a satellite programming and data receiving capacity to enable the programming, processing and development of indicators that could be used to assess the environment in this specific area and thus enhance its management. The SEAS-Guyane (Survey of Environment Assisted by Satellites) project was designed to set up a technological platform for the acquisition and processing of data on different spatiotemporal scales from high-resolution satellites (SPOT and ENVISAT) to be used for research, training and regional development.

Through this platform, users have access to quasi-daily data at a spatial resolution ranging from 20 to 2.5 m within a 5 000 km diameter circle focused on French Guiana and spanning the Guyana Plateau, West Indies and Amazon Basin. Over 14 000 images are acquired annually within this circle, and over 500 images are generated for selected and labelled SEAS-Guyane projects.

The technological platform operational policy was drawn up by a steering committee (Regional Council, IRD, CNES, French government, SPOT Image, ESA, Guyane Technopole, Pôle Universitaire Guyanais [PUG], Université des Antilles et de la Guyane [UAG]) headed by the French Guiana Region and IRD. The ESPACE research unit (IRD), the project coordinator, has established partnerships with SPOT Image (station installation and operation), UAG (joint research team, training), PUG, CNES, ESA, Guyane Technopole, local communities and French government services to develop an international research platform for spatial remote sensing and monitoring of the Amazonian environment. The overall objective is to set up environmental observatories to foster sustainable development in French Guiana, the Amazon Basin and the West Indies.

This project has given rise to many French, European and international research projects and pilot applications. For instance, the SEAS project has enabled France to work towards fulfilling its Kyoto Protocol commitments by acquiring an image mosaic to determine the state of its forests in this region in 2006 (Institut Forestier National, IRD, ONF, IGN, Cemagref).

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The unit develops training activities: participation in Master’s programmes, individualized training tailored to scientific network needs and management.

This service activity concerns:
- operational management of a network of low-resolution and high-resolution data direct receiving stations (French Guiana, Montpellier, Réunion, Canary Islands, New Caledonia) so as to facilitate access to satellite data for research in developing countries, while also contributing to environmental observatory operation
- access to spatial data infrastructures via a general interoperable information system platform in compliance with INSPIRE/OGC (Infrastructure for Spatial Information/Open Geospatial Consortium) standards.

The priority operational themes are:
- Sustainable management of ecosystems in developing countries: geoinformation and sustainable management
- Continental waters and coastal environments: resources and uses
- Health security, health policies: the environment and emerging diseases
- Development and globalization: enhanced governance for sustainable development
- Renewable energy and territorial development.

The unit’s research is based on permanent laboratories in France, in tropical French overseas regions and in other foreign countries and on a network of research platforms:
- Remote Sensing Center (Montpellier, France), in partnership with Cemagref, CIRAD, AgroParisTech/ENGREF and the University of Montpellier Sud de France
- French Guiana Campus (IRD-UAG-Pôle Universitaire de Guyane) in cooperation with Brazil on issues in the Amazon region
- Campus for the Indian Ocean Region, Réunion University
- New Caledonia (University of New Caledonia) for the South Pacific region.

International research is also carried out in collaboration with joint research teams and laboratories in Brazil and Africa. ***
Very high resolution remote sensing—which can generate images with up to sub-metric resolution—has boosted the potential for agricultural land use mapping and inventory. Crop types can thus be now distinguished on the basis of their spatial structure, no longer just according to radiometric criteria.

UMR LISAH carried out a study aimed at acquiring geoinformation on surface features in vineyards on the basis of airborne remote-sensing images obtained at 25 cm resolution. The vineyards were successfully detected and the plot distribution patterns characterized. Within the framework of the European BACCHUS project, UMR TETIS and ITAP have developed a software tool for automatic detection of vine plots through airborne or satellite imaging, without any prior knowledge of the plot distribution pattern.

The automatic recognition and characterization sensing principle is based on Fourier spectrum analysis of images in which vine plots, due to their periodic structure, are identified by marked amplitude peaks. The tool automatically detects these peaks, which each correspond to a spatial frequency and a specific orientation. A highly selective filtering process (Gabor filter) is applied around each thus-determined frequency and orientation value. Only target vine plots are highlighted, so the edges of these plots can therefore be determined. The frequency and orientation values associated with each plot provide a very accurate measurement of the interrow distance and row orientations, which are crucial parameters from an agricultural standpoint. The plot characterization process is also focused on the detection of grassy interrow strips (additional frequencies in the Fourier spectrum), and on estimating the number of missing plants (statistical radiometric comparison).

The tool was assessed in a 200 ha study area (La Peyne catchment, Languedoc-Roussillon, France) from a natural colour (red, green, blue) aerial image, at 50 cm resolution, which was acquired via a microlight aircraft (Société l’Avion Jaune). Around 80% of the vine plots were detected, or 84% in terms of surface area.

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Vine-plot mapping using very high spatial resolution remote sensing

Vine-plot detection via Gabor filtering.
Processing hyperspectral images containing spectral and spatial information

Hyperspectral imaging (HSI) can be used to produce and analyse images of the same scene at a series of wavelengths within the same spectral domain. Such images generate information on the chemical composition of objects, which means that objects of the same apparent colour but with a different chemical composition can be differentiated.

Most standard hyperspectral image processing methods analyse data without taking spatial information into account. Pixels are thus processed individually as a single array of spectral measurements without any particular spatial arrangement by using various classification methods (k-means, fuzzy-C-means, hierarchical classification, support vector machines, etc.).

The combined use of available spectral and spatial information for object detection, which has been promoted by the advent of high spatial resolution hyperspectral imaging devices, etc., now seems essential for many application domains (characterization of urban areas, agriculture, etc.).

This is especially useful for processing images with complex contents, where the objects to differentiate are very spectrally close while having different spatial features (e.g. in shape, compactness, etc.).

UMR ITAP is focusing on this issue and has thus developed a spectral-spatial cooperation scheme to split images into spectrally homogenous adjacent regions (segmentation). The two dimensions (spectral, spatial) are studied separately and simple tools designed for specific environments are used. These are chemometric tools (spectrum processing tools) for the spectral domain, and image segmentation tools for the spatial domain. These tools can be used to extract relevant spectral and spatial structures and are iteratively implemented to achieve optimal image segmentation.

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Results obtained with an HSI image of a natural vegetation scene (160 spectral bands, 400-1000 nm).
(a) Original image (multispectral).
(b) Result obtained with an approach that disregards contextual information (k-means, 5 classes).
(c) Result obtained with a spectral-spatial approach: the vegetation is clearly differentiated from the surrounding environment.

Development of sensors and decision-support systems

The joint research unit (UMR) ITAP Information and Technologies for AgroProcesses (Cemagref, Montpellier SupAgro) aims to develop equipment to enhance agricultural sustainability. The team conducts studies on sensors and decision support systems and on environmental technologies in agriculture. The main research topic, i.e. sensors and decision-support systems, includes proxy-detection remote sensing, traceability and information processing/modelling.

UMR ITAP conducts research to develop optical sensors (artificial vision, hyperspectral vision, UV & near-infrared spectrometry). It is striving to develop decision support systems to assess the status of different systems or to develop precision agricultural approaches. Different methods are thus studied and implemented: fuzzy logic, discrete event systems and geostatistics. The goal is to characterize agrosystems and agroproducts. Finally, it develops systems to ensure the traceability of agricultural operations, especially spraying, with the traceability data being subsequently used to improve such operations. Vine cropping is the main field of study, but other crops, including fuel crops, are also covered.

In the sensor field, research is conducted on new optical devices that could be used in harsh environments (outdoor and industrial environments). UMR ITAP has developed advanced know-how on portable or online near-infrared sensors that can be used for the analysis of organic product compositions. In addition to material sensor developments, the measurement problem also concerns robustness. UMR ITAP is recognized worldwide for its chemometric expertise, which is specifically oriented towards boosting measurement robustness. Finally, the focus is also on hyperspectral vision research and especially on designing innovative hyperspectral image processing methods that take advantage of the team’s image analysis and chemometry expertise.

UMR ITAP also concentrates on developing decision support systems for managing agricultural operations.
The unit is developing methods and adapted tools. The methods are based on fuzzy logic and enable users to come up with rules on the basis of data and/or expertise for mapping phenomena or building indicators, all of which may be spatialized or not. The methods also involve geostatistics, which are applied to high resolution viticulture data (precision viticulture). The aim is to delineate homogenous areas in which it would be appropriate to apply a specific operation. Finally, the formalization of decision processes is approached via discrete event systems.

The main research framework of UMR ITAP is precision viticulture. The VINNOTEC project (funded by FUI, FEDER, LR Region, labelled by the Q@LI-MEDiterranée competitive cluster) is highly emblematic, with Cemagref serving as the scientific partner. VINNOTEC fosters the contribution of information and communication technologies (ICTs) in developing vineyard products tailored to meet market expectations. UMR ITAP is involved in the development of portable, online or airborne sensors in near infrared spectroscopy, in artificial vision, along with the processing of data acquired through sensors with the aim of developing indicators and rules of conduct.

UMR ITAP also proposes different training on this topic. It is especially responsible for the specialized training programme ‘AgroTIC: ICTs for agriculture and the environment’ at the Master’s level at Montpellier SupAgro (France).

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Potential of L-band radar imagery for studying tropical forest dynamics: the international ALOS Kyoto & Carbon Initiative

Through the international Kyoto & Carbon Initiative, the Japan Aerospace Exploration Agency (JAXA) is backing an international scientific initiative aimed at developing reproducible forest ecosystem monitoring methods. These could, for instance, generate a quantitative database that could be tapped to help reduce carbon emissions due to environmental degradation and deforestation. It is essential to pre-evaluate forest parameters contributing most to the signal measured in images so as to be able to extract information on the distribution of plant biomass in the 3D space and to monitor potential changes under the forest canopy.

Following the launching of the Advanced Land Observing Satellite (ALOS)* in January 2007 and thanks to the availability of Phased Array type L-band Synthetic Aperture Radar (PALSAR)** data, it is now possible to reanalyse tropical forest structuring through a tailored instrumental configuration. First, surveying forests with L-band radar, i.e. with a 1.25 GHz signal (\(\lambda\) wavelength = 23.6 cm), enables more efficient assessment of forest dynamics, with radar signal saturation occurring at a 3-fold higher biomass level than with C-band radar (150 t/ha of dry matter as compared to 50 t/ha). Secondly, because of the high quality radiometric calibration of PALSAR data (<±1 dB), reproducible methods for characterizing forest resources may be developed on the basis of still images. Thirdly, having access to images that are unaffected by cloud cover will boost the operational potential for imaging in tropical regions. Finally, the estimation of tropical forest parameters on a regional scale by statistical inversion of properly calibrated L-band radar signals could likely be improved. Forest canopy texture could be analysed on metric resolution optical images in order to come up with estimations that could serve as benchmarks for forest stands as a supplement to field measurements.

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For further information: www.eorc.jaxa.jp/ALOS/en/kyoto/kyoto_index.htm

* A Japanese satellite that was developed for mapping, regional land-coverage observation, disaster monitoring and resource surveying.

** A radar system capable of acquiring data with up to 10 m resolution.

L-band ALOS PALSAR image of the coastline of French Guiana between Cayenne and the Oyapock estuary (colour composite image with HH and HV polarization): at low tide, the bare mudbanks (black) appear to be smooth at 20 cm wavelength; mangrove saplings (greenish-brown) can be distinguished from older mangroves and forests with more substantial biomass (grey).
Mapping and monitoring tropical plantations by remote sensing

The productivity of planted tropical ecosystems must be increased in the long term, while avoiding negative impacts on the environment, in order to meet growing market needs. Environmental and climatic conditions as well as current and previous cropping practices could, however, have a major lasting impact on the evolution of biophysical and biogeochemical components of planted tropical ecosystems. It is essential to quantify these factors.

The CIRAD internal research unit (UPR) Functioning and Management of Tree-Based Planted Ecosystems focuses research on characterizing and formalizing water, carbon and mineral cycling within tropical plantations. An ecosystem-based approach is implemented to gain insight into the relevant plant-soil-climate interactions.

Satellite imaging is an efficient tool for spatiotemporal monitoring of plantations. Specific sensors with suitable spatial, temporal and spectral properties are required for studying particular ecosystem features. The satellite information collected cannot be used without processing, i.e. different treatments involving geographic information systems (GIS) and complex models are required.

Some structural and physiological characteristics of plantations that can be estimated via satellite imaging are:
- leaf-area index (quantity of leaves on the plantation)
- vegetation biomass
- chlorophyll content
- productivity.

These characteristics can then be analysed spatially (differences between plots) and/or temporally (plot changes over time). For instance, information on temporal changes in the leaf-area index in plantation stands can reveal the duration and intensity of water stress (see above graph). Spatial information can highlight differences in fertility or the water storage capacity of the soil during the dry season.

All of this information can then be used to fit ecosystem functioning models on a plot scale or for a set of plots. These models can be implemented, for instance, to assess the sustainability of carbon or mineral stocks in plantations.

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Lidar mapping of vegetation, landscape and surface water

Lidar (light detection and ranging) technology involves an active remote sensing sensor based on a laser impulse transmission-reception principle. Lidar, which is conventionally used in topometry and meteorology, shows promise for characterizing continental and oceanic surfaces, especially from aerospace platforms. As lidar is capable of penetrating into environments such as water and vegetation, the information it generates can supplement other information obtained by radar and optical imaging. Signals from lidar sensors are processed on the basis of telemetry principles. This can generate accurate topographical data on natural environments, submerged or slightly submerged areas, along with a 3D description of the vegetation structure. A more complete form of the backscattered signal (a highly sampled waveform) can also be processed using suitable signal processing algorithms. Other target properties can then be extracted depending on the wavelengths used, e.g. the geometry and nature of the target (water turbidity, local slope, vegetation density, etc.).

Research carried out by UMR TETIS, LISAH and AMAP is focused on three thematic fields: vegetation characterization, hydrology and fine topography. The aim is to develop specific methods for processing lidar waveforms and lidar derived 3D point clouds and to qualify the data. Lidar signal modelling studies are also conducted in collaboration with CNES and commercial stakeholders to determine the specifications of sensors for future space missions. For vegetation studies, biomass is assessed and canopy and understorey structures are characterized since such information is crucial for sustainable management of forest environments (forest fires, biodiversity). In hydrology, altimetric monitoring and bathymetric assessment of continental waters are carried out to improve management of water resources and aquatic environments. Another aim is to make effective use of detailed descriptions of areas imaged by airborne topographical lidar (dams, drainage systems) in order to improve descriptions of surface flows and to predict associated risks such as erosion.

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Space agencies like the French Centre National d’Études Spatiales (CNES) and the European Space Agency (ESA) obtain support from the scientific community to develop concepts for satellite missions undertaken for scientific or operational purposes, to develop technologies upstream of sensors, to validate products derived from these missions, and to design methods that will enable operators to use these products for scientific or operational applications.

Researchers from the Remote Sensing Center (UMR TETIS, US ESPACE), based in Montpellier (France), participate in French, European and international scientific committees and initiatives:

- Science Programme Committee and Earth-Ocean-Continental Surface-Atmosphere Scientific Committee of CNES
- Earth Science Advisory Committee of ESA and GMES Programme of the European Commission and ESA
- International initiatives such as the Group on Earth Observation and the Integrated Global Observing Strategy.

Through this involvement, Agropolis International researchers strive to include concerns and challenges of agriculture, the environment, territories and sustainable development in strategies developed for satellite Earth Observation.

They have, in collaboration with laboratories and commercial stakeholders in France, elsewhere in Europe and other countries, helped to define and promote different satellite missions of CNES, ESA and the National Aeronautics and Space Administration (NASA):

- radar altimeter satellites (Topex Poseidon, Jason 1 and 2, ERS 1 and 2, ENVISAT) for measuring continental water levels
- the future PLEIADES satellite constellation for very high spatial resolution optical imaging
- the concept of the Surface Waters Ocean Topography mission for measuring continental water slopes by across-track spatial radar interferometry
- the concept of the OSCAR mission for measuring the surface velocity of rivers by along-track temporal radar interferometry
- the concept of the LVTH (lidar, vegetation, terrain, hydrology) mission for lidar measurement of 3D characteristics of forests, terrain and continental waters.

The Remote Sensing Center technology platform, and its development via the Geoinformation for Sustainable Development (GEOSUD) project, offers the scientific community and Agropolis International partners a suitable environment for research, training and knowledge transfer in the satellite Earth Observation field.

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Spatial analysis
and spatiotemporal
modelling methods

Unfragmented terrestrial natural areas in France classified according to size (50 km² and over) in 2000.
Spatial analysis and spatiotemporal modelling are geared towards formalizing the spatial characteristics and spatiotemporal dynamics of systems (ecosystems, agricultural systems, territories, etc.) on the basis of often incomplete and imprecise data and more-or-less indepth knowledge on the underlying processes. Once mapped and modelled in this way, researchers can gain insight into these systems to enhance their management.

It is essential to determine the spatial dimension of systems and take the presence of several partially interlinked levels of internal organization into account in order to understand their functioning. This may include environmental and socioeconomic dynamics and their interactions within territories. Spatial analysis and modelling are thus guided by both the space and the investigated issues, for which some structures and processes may turn out to be more relevant than others. The space is thus a ‘support’ and a ‘revealer’ of processes that have biophysical (disseminations, flows, ecological processes, etc.), technical (agricultural practices, management practices), human and social (stakeholders’ strategies, collective actions, exchanges, etc.) features.

Spatial analysis may be carried out to characterize the properties of different features (urban clusters, river systems, natural habitats, etc.) or ranges of variables (rainfall, population density, etc.). Each feature or range can be described by its position, footprint, morphology, topology, structure and internal variability. Spatial analysis is also aimed at determining the spatial organization of a group of features (e.g. individuals in a population) or the limits and interactions between different groups. Spatial analysis research encompasses a very broad range of methods adapted to different issues and types of system: sampling methods (in situ metrology, surveys, etc.), system description methods (geography, cognitive sciences, etc.), spatial and/or temporal field reconstruction methods (geostatistics, oversampling), environmental indicator construction, spatialization and mapping methods, and construction of spatial metrics and indicators.

Spatiotemporal modelling is aimed at drawing up representations of systems while taking their spatial and temporal dimensions into account. There are two separate but complementary aspects to this modelling: first the structural aspects with the representation of spatial structures and associated information and indicators and, secondly, the dynamic aspect with the representation of temporal sequences of spatialized information and even of the underlying processes. The dynamics can be portrayed by a series of system states or by a continuous spatiotemporal formalization of the processes—via these simulations, hypotheses can be tested by taking the spatial dimension into account, and scenarios can also be studied.

Spatiotemporal modelling research also involves a broad range of methods, including procedures for analysing correlations between spatial fields, pressure-state-response models, different spatiotemporal modelling approaches (deterministic to conceptual, distributed to aggregated, cellular automata, agent based models, etc.), parametering of distributed models and analysis of uncertainty propagation in these models.

When a variety of stakeholders or topics have to be managed within the same territory, it is essential to consistently overlap the different spatial structures relevant to each of them, which may each present a different spatial and temporal aspect. Spatiotemporal modelling can thus contribute to the modelling of complex systems.

The research carried out by Agropolis teams showcased in this chapter illustrates the methodological spatial analysis research conducted on the basis of remote sensing data or cartographic data derived from surveys or local observations. Reconstructing spatial fields by spatial interpolation methods, and taking the data quality into account from both spatiotemporal and semantic standpoints, are major challenges for all teams. Spatiotemporal modelling studies are focused mainly on coupling different models integrating spatial descriptions, and on the assimilation of geographical or remote sensing data. The modelling types also differ, ranging from mechanistic models designed to gain insight into processes, to indicator-based models that provide decision support in management processes.

Flavie Cernesson (UMR TETIS)
& Jean-Pierre Müller (UR GREEN)
Spatial analysis and spatiotemporal modelling methods

Geoinformation and modelling applied to botany and plant ecology

The joint research unit (UMR) Botany and Computational Plant Architecture (UMR AMAP; CIRAD, INRA, CNRS, IRD, UM2) conducts research on the characterization and analysis of diversity, and the organization and structure of plants and plant populations. Original methods are used such as the analysis of plant architecture and development, computer-assisted identification, mathematical and computer representation of organs, plants, populations and landscapes, and modelling of their growth and production. The UMR works in close collaboration with researchers specialized in various disciplines to assist in its cognitive (botany and ecology), methodological (applied mathematics) and targeted (agronomy, forestry, conservation) research projects. The team has substantial expertise in systematic and plant architecture, supported by several taxonomic platforms (herbarium collections based in Cayenne, Montpellier, Nouméa). It conducts field research in Europe, Africa, South America, Asia and Oceania.

Georeferenced or spatially explicit information is used in much of this research, e.g. plant organ distributions in 3D space, species distribution patterns, ecological descriptor maps, topologies of plants or habitat networks, and remote sensing images (optical, laser, radar). The methodological research is thus focused on geoinformation analysis and modelling via the application of mathematics or applied statistics (Markov chains, graph theory, point processes, geostatistics, wavelet and Fourier based image analysis, etc.) in botany or plant ecology studies. Remote sensing information is used in spatial analysis and modelling in three main thematic areas:

- spatial organization of species communities and plant biodiversity
- structure and dynamics of plant populations, especially mixed multistrata forests
- plant and landscape mosaics.

These three research themes respectively emphasize the diversity of groups of species and emerging structural properties on population and population-mosaic scales.

Considerable methodological debate is currently under way on remote sensing measures (optical, radar, laser) with respect to the two latter research themes. The focus is on interfacing dynamic models of the 3D structure of forests and physical measures produced by spatial sensors. The aim is to develop innovative approaches for large-scale assessment and monitoring of mixed forest resources and biomass. ***
Vegetation structure relates to the layout of constituent plants and organs in 3D space. This organization can be quantified on the basis of variables (density, tree height, biomass, profile, etc.) that are estimated by field procedures. Space observations are required for large-scale analysis of vegetation structures and for monitoring the underlying functional processes (exchanges with the atmosphere) or associated dynamics. This is a substantial challenge when attempting to assess forest stands with high biomass and a complex multistrata structure, such as natural forests in humid tropical regions. For such environments, the remote sensing techniques used over the last two decades have often been hampered by the problem of saturation of optical or radar signals from forests with intermediate to high biomass levels.

Recent studies based on metric resolution optical data have shown that the results of the analysis of spatial signal variations by texture and feature identification procedures (in partnership with EPI ARIANA of INRIA-Méditerranée) can be correlated with the field-based findings on structure variables with no saturation effect. Moreover, 3D characterization of forest cover structures can be further enhanced by the use of signals that are able to penetrate through the cover (lidar, radar). Multiscale coupling of forest structure models with physical models that can simulate electromagnetic signal diffusion (from optical to microwave) is necessary for the ‘inversion’ of remote sensing data into relevant thematic information. Concerning tropical forests, this coupling is dependent on the capacity to build ecologically realistic models of 3D structures in forest stands in order to simulate their electromagnetic signatures. Through this modelling, the aim is, for instance, to formally relate texture indices to a distribution of structural features (tree crowns, gaps), or to relate signal penetration to the vertical vegetation stratification. In turn, forest dynamics models could be enhanced by gaining greater insight into electromagnetic signatures of tropical forests.

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Spatial analysis and spatiotemporal modelling methods

Integration of spatiotemporal variability in rainfall and surface conditions for modelling West African water resources

There has been a substantial decline in rainfall throughout West Africa since the late 1960s, thus paving the way to an unprecedented period of nearly 40 years of persistent drought. Large West African rivers have suffered severely from the drought, with runoff deficits exceeding the rainfall deficit by twofold on average. Moreover, surface conditions were also modified as a result of the combined effects of climate change and human activities (expansion in croplands, deforestation, etc.), which may have led to major changes in runoff and infiltration conditions. In order to be able to assess the impact of these changes on flows, it is necessary to represent processes governing links between climatic (rainfall, evapotranspiration) or anthropogenic forcings, and river flow regimes in a spatially explicit way. UMR HydroSciences Montpellier thus develops hydrological modelling approaches that integrate spatiotemporal variability in rainfall and surface conditions.

This research theme is based on: (i) diachronic processing methods based on aerial photographs and satellite images to characterize and analyse long-term land-use changes; (ii) spatial analysis techniques to interpolate rainfall fields, for instance; and (iii) lumped and semidistributed conceptual models to simulate flows with different complexity (especially spatial) levels throughout large catchments. The aim is to gain further insight into flow phenomena and enhance the environmental risk prediction capacity in conditions where water resource access and availability are major factors limiting the socioeconomic development mainly based on agricultural production.

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Integration of spatiotemporal variability in rainfall and surface conditions for modelling West African water resources

Climatic and human impacts on water resources in Mediterranean and tropical environments

The joint research unit (UMR) HydroSciences Montpellier (CNRS, IRD, UM1, UM2) studies climatic and human impacts on water resources in Mediterranean and tropical environments. This research involves the analysis and modelling of underlying processes, the characterization of regional phenomena and the development of conceptual modelling approaches. The research activities of HydroSciences Montpellier encompass: (1) water in the environment, (2) water resources, and (3) links between hydroclimatic variability and water resources.

Two of the laboratory’s main research areas are concerned about addressing the ‘impact of climate change’ issue and implementing methods for the management, analysis and processing of spatiotemporal data through flow simulation models.

The first research area, i.e. ‘Hydrological variability: analysis, mechanisms and impacts on water resources’, is devoted to climatic and/or human induced hydrological changes in tropical and semiarid regions. Spatiotemporal data analysis is necessary for characterizing and understanding the structures and dynamics that prevail, for instance, in Sahelian regions where the environmental balance is weakened by drought, desertification and ever-increasing human pressure. Moreover, these approaches are essential for monitoring the evolution of tropical glaciers, which is a major water resource issue.

The second research area, i.e. ‘Hydrological risks associated with extreme hazards’, introduces the concept of risk, irrespective of whether it is associated with extreme hydroclimatic events or concomitant pollution flows. Substantial spatiotemporal data must be available and managed to be able to gain insight into and monitor parameters as divergent as spatial variability in rainfall, territorial organization, plant cover modifications, types of land use and associated water level variations.

Through collaborations with many partners, HydroSciences Montpellier...
also wants to strengthen its expertise in geoinformation management and develop a set of specialized databases in order to achieve its research goals in these areas.

**Supporting collective resource management processes**

The main goal of the Management of Renewable Resources and Environment research unit (UPR GREEN, CIRAD) is to develop and provide access to knowledge, methods and tools to: (i) gain insight into interactions between natural resource use and ecosystem sustainability, and (ii) support collective management processes. Sustainable environmental management depends on the conditions of interaction and tradeoffs between ecosystem conservation and development. The issues are significant in developing countries because the inhabitants are highly dependent on renewable resources. This situation also applies in developed countries due to the dispersal of decisionmaking centres pushed by globalization and decentralization. Research is focused on these issues so as to gain insight into and boost awareness on complex social and ecological processes. The aim is to enhance sustainability, provide support for management processes that integrate the environmental dimension over the long term, to take information asymmetry into account and promote the participation of concerned stakeholders.

The unit conducts broad-scope research on modelling spatialized biophysical and social dynamics. In the first phases of information acquisition and stakeholder collaboration, cartography, role playing games and surveys are essential for spatializing resources and their many uses. Pixelized or vectorial cartographic data is also used for simulations to delineate initial spatial configurations and to visualize temporal patterns. Spatial visualization of simulations is an essential tool for discussions with stakeholders with respect to appropriating the model or investigating scenarios.

Applications are developed within the research unit and in collaboration with other teams in the Agropolis network, as well as with partner universities in developing countries. The fields of application include land use management in the African Sahel and Réunion (see the DOMINO thematic research project, page 22), integrated management of coastal areas in Réunion (‘Integrated Coastal Management Support’ project), biodiversity in Brazil and Madagascar, agrodiversity in West Africa and Latin America, and catchment management in Asia.

**Development of models and indicators of water stress in the Mediterranean region using geostatistical methods and topoedaphic indices**

Terrestrial Mediterranean ecosystem dynamics and functioning are overwhelmingly controlled by the highly unpredictable rainfall regime. Water stress hampers transpiration, carbon assimilation, volatile organic compound emission and organic matter decomposition. This stress determines the extent of plant species’ survival or replacement and impacts the wildfire intensity and frequency. On landscape and regional scales, topoedaphic (soil and relief), climatic and biotic (species distribution) variability induces marked spatial heterogeneity in the water stress. Moreover, due to temporal irregularities in the water cycle, a daily resolution must be adopted to map these water stress dynamics.

The Centre of Evolutionary and Functional Ecology develops tools for modelling the functioning of soil-plant systems based on geostatistics and landscape ecology modelling methods. Daily water stress maps can thus be produced on different scales. The initial data are essentially derived from digital elevation models and soil maps from which a continuous spatial map of the soil water retention properties can be plotted. Vegetation maps, combined with remote sensing products, NDVI, or percentage tree cover, are used to model plant system functioning according to rooting depths, species’ maximum potentials for water extraction and leaf area. Finally an automatic method for spatial interpolation of daily climatic data, using data from weather stations and digital elevation models, was developed. This takes the fine scale topography into account to draw up continuous maps of climatic variables.

This method can be applied to actual meteorological data or that simulated by general circulation meteorological models based on increases in atmospheric CO₂, predicted by the Intergovernmental Panel on Climate Change (IPCC). The findings of this research have many different applications, especially to support wildfire hazard management, to gain insight into biosphere-atmosphere interactions (water and carbon fluxes, air quality) and to assess ecosystem vulnerability.

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DOMINO project: companion modelling to debate land allocation

Participatory territorial management involves interactions among different stakeholders with various views on social and ecological systems and their underlying processes. The DOMINO project was developed by UPR GREEN with the aim of enabling stakeholders to explain and share their views so as to facilitate the coordination of land allocation processes. The ‘companion modelling’ approach (as defined by the ComMod charter, www.commod.org) was tested in two different socio-institutional settings, in Réunion and in Senegal, thus providing an opportunity to assess its adaptability to different contexts.

In Réunion, the territorial planning documents of the Region, of the inter-communal bodies and of the municipalities were all under revision. The issue was to build a dynamic information system based on a consistent set of geographical data provided by different institutions. Development agents and researchers designed, hand-in-hand, an integrated simulation model that was used to illustrate the long-term impact on land-use patterns of the various prospective scenarios of the regional development scheme.

In Senegal, the emerging Guiers Lake management plan was on hold. Information on land is scarce, there is no coordination among stakeholders, and the local institutions struggle in carrying out their assigned tasks. An ad hoc users’ committee was therefore set up to work with the project, and trained on interpreting and producing cartographic data. Researchers developed dynamic tools ranging from role-playing games to economic models to address various land issues at different scales. Some tools were tested and validated by the user’s committee.

The DOMINO project showed that a ComMod approach can take into account a range of management levels and essential data to facilitate management of land allocation processes. It led to their effective integration in the tools, and to the implication of stakeholders at different levels of territorial management, from the tool design stage to the implementation phase.

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For further information on the open modelling platforms developed by GREEN, see http://cormas.cirad.fr and http://sourceforge.net/projects/mimosa and the ComMod companion modelling network website: www.commod.org.

Developing research and tools on the hydrology of cultivated environments

The Laboratoire d’étude des Interactions Sol - Agrosystème - Hydrosystème (UMR LISAH, INRA, IRD, Montpellier SupAgro) conducts research on the hydrology of cultivated environments, focused specifically on:

- enhancing knowledge on erosion, water and material transfers and the fate of pollutants (pesticides and metals) in soils and rural catchments as a function of their spatial organization and temporal variation patterns
- developing tools to assess and prevent risks induced by human activities (cultivated environments) and their impacts on hydrological systems and the evolution of water and soil resources
- contributing to the development of new sustainable management strategies for rural areas
- training students on analysis and modelling concepts and tools for hydrology and cultivated environments.

LISAH’s scientific approach is based on hydrological field studies and experiments, methodological research for the acquisition and processing of spatial data on soils and landscape and on the development of ‘distributed hydrological modelling’ approaches geared towards mapping the specific heterogeneous features of rural landscapes. LISAH manages an environmental research observatory (Observatoire Méditerranéen de l’Environnement Rural et de l’Eau, OMERE, see p. 32), which was set up to analyse the impact of human activities on the physical and chemical erosion of Mediterranean soils and on water quality. In terms of geoinformation for environment and territories, LISAH is currently focusing research on digital soil mapping, including the use of hyperspectral images, spatialization of linear elements in rural landscapes (see p. 11), spatialization of soil maintenance practices in vineyards in Languedoc region (France, see p. 39), digital mapping of agricultural landscapes for hydrological modelling (see p. 24), and spatialization of the water status of vine crops on the basis of thermal infrared images.

UMR LISAH is based at the Gaillarde agricultural research campus in Montpellier (France), and also in several Mediterranean countries (Morocco, Tunisia), within the framework of collaborations with agricultural research and higher educational institutions in these countries, including the Institut agronomique et vétérinaire Hassan II in Rabat (Morocco), the Institut national de recherche du génie rural et des eaux et forêts and the Institut national agronomique in Tunis (Tunisia).
Interdisciplinarity and spatial indicators to support sustainable development in developing countries

Sustainable development—a key concept that took shape and was promoted globally during the Earth Summit in Rio de Janeiro (1992)—integrates environmental, economic and social components. An interdisciplinary approach is essential to be able to take these three analytical dimensions into full account and participate in the evaluation and orientation of development policies.

In this setting, a multidisciplinary team (US ESPACE) studies the complexity of resource management and spatial distribution via the landscape, which is considered as: (a) a marker of economic, social and environmental dynamics in territories; and (b) a revealer of new local/global relationships inherent to globalization.

Methods developed in different territories within developing countries have been used to design spatial indicators of the state of territories and inhabitants’ living conditions, thus highlighting the importance of landscape in space/resource/use interactions. These studies were focused on the impact of public policies on biodiversity in Amazonian forests (BIODAM/IFB) and on coral reefs around Réunion (AGIL/VALSECOR), the risk of land degradation in dry areas in circum-Saharan Africa (ROSELT/OSS) and in the Pacific Island region (GERSA/FFEM-CI), as well as health risks in humid American forests (ROVERTA/CNRS, EDCTA/IRD-CNPq).

This team aims to highlight the complementarity of these methods in order to broaden the fields of application and stimulate joint involvement of social science, economy, biomedical and natural science researchers in an integrative spatiализation approach (multi-spatial and multi-temporal scales). The objective is to produce territorial diagnoses and forecasts at the interface between research, civil society and decisionmakers that could be used to guide development projects. This production will fuel environmental observatories devoted to sustainable development.

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Controlling floods and water erosion, assessing, preserving and restoring the quality of water and soil resources, and evaluating environmental risks associated with land use are key environmental and agricultural challenges in the current setting of high population growth and cropping intensification. Distributed hydrological models are essential tools for gaining insight into hydrological processes in catchments and for predicting the impact of changes on the response of these catchments.

To represent the transfer of water and waterborne substances in agricultural catchments, digital landscape maps are required that take all elements in the landscape that may have an impact on these transfers into account. Different sources of geoinformation (topography, soil maps, presence of water bodies, plot patterns, crop species, plot management strategies) must be combined in such representations, as well as natural (streams) and human-induced (earth banks, ditches, edges of crop fields) discontinuities that could have a major impact on water transfers.

As part of its research on modelling the hydrology of small cultivated catchments, UMR LISAH has developed Géo-MHYDAS, which is an original three-step procedure for agricultural landscape delimitation and characterization. In the first step, geographical features of potentially different natures and sizes (soil units, subcatchments, farming plots, ditch networks, etc.) are imported. In the second step, all of this geoinformation is combined to create uniform hydrological units, while preserving the initial features but remaining compatible with the water transfer functions of the hydrological model, and with the user maintaining control over the hierarchical order so as to be able to combine the features according to his/her specific objectives. In the third step, an application-oriented topology is created to be able to simulate water flows through the landscape during the actual hydrological modelling phase. The original feature of Géo-MHYDAS is that it can take a broad range of different agricultural landscape characteristics into account while not classifying them only on a topographical basis.

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Studies of many important issues that society faces today are based on a modelling approach. Insight is required prior to action—whether it concerns the emergence and spread of diseases associated with new environmental conditions, rapid transformations in urban areas, or the degradation of natural ecosystems and biodiversity loss. For a given issue: What are the key elements that make up the landscape? How do they interact? How does the landscape function and evolve as a system? As such systems can usually not be experimentally investigated in the field, studies often rely on computerized modelling, despite the inherent problems of spatial representation, time management and multiple spatial and temporal scales.

New tools are sought to solve these problems, such as a language specifically developed for modelling landscapes and for simulating their dynamics. The language elements should help scientists to accurately describe the composition of landscapes, to express the relations between their components, to specify how they evolve in time and to generate simulations according to different experimental scenarios (e.g. a change in land-use legislation). In addition to the language, by this approach landscape elements, called 'primitives', can be compiled in libraries. Users have access to these libraries and are able to assemble the primitives required for modelling a given landscape.

This research is being conducted within the framework of the Spatial, Temporal and Multi-scale Primitives for Modelling Dynamic Landscapes (STAMP) project (2008-2010) supported by the French Research Agency’s Programme Blanc (i.e. open to all disciplines). Researchers from UMR TETIS and AMAP, the Institut National de Recherche en Informatique et en Automatique (INRIA) and the University of Marne-la-Vallée, along with scientists from a range of disciplines (epidemiology, agronomy, ecology, etc.) are jointly involved in this project.

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Designing management and mapping systems (AGIL and SYSCOLAG projects).
An information system is a scientific, technical and institutional platform that binds links within a community (companies, public institutions, research groups, territorial associations, etc.) via information. The aim is to build knowledge and to participate in coordination and negotiation between stakeholders concerned about a specific territorial or societal issue. The system, which pools structured human and material resources, organises and integrates data acquisition, processing, management, sharing and dissemination via given reproducible protocols. These functionalities are tailored to specific needs, such as knowledge building, coordination or negotiation between stakeholders.

All information systems include managerial and organizational aspects which underlie their creation, along with computer technology aspects. A system may therefore be oriented according to two standpoints, i.e. depending on the typology and nature of the information circulating between individuals, or on the system's architecture, which facilitates information exchange and storage.

The typology of information systems is broad ranging. A few that are devoted to the environment are (but this list is not exhaustive):
- Technical information systems in which observation services supported by sensor networks may be classified
- Organizational information systems that enable some organizations to structure their information, such as environmental research observatories serving the scientific community
- Information systems that are supported by informal networks in which information circulates and which can provide support for territorial projects
- Information systems devoted to both monitoring and decision support, which could be called ‘observatories’.

Some Agropolis teams focus research on methods concerning resource management and environmental change issues. Information systems developed in this framework should account for the complexity of the issues in terms of the diverse range of stakeholders and spatiotemporal scales. In a multi-institutional setting, the representations that stakeholders have of the same system (e.g. a territory) and their motives for subscribing to a common information sharing objective are wide ranging, and data heterogeneity is high (nature, format, scale, etc.).

Observatories represent a specific instance of information systems. They are set up to observe (monitor, analyse, understand), within a spatial area representative of a territorial entity targeted for research, socio-environmental dynamics resulting from dynamic interactions of socioeconomic and biophysical systems. These are sites for the production, exchange and sharing of information and knowledge with a long-term scope. They thus require methods specifically adapted to the management of cumulative data processes (sustainability, replication, storage, etc.) and of knowledge building processes (sharing, exchange, interaction, etc.).

This chapter highlights—through a selection of representative examples—how the teams are involved in upstream and follow-up research activities to facilitate efficient operation of information systems and observatories in many areas throughout the world: needs analysis, specification and instrumentation. It also showcases the diverse range of uses, depending on whether the focus is on knowledge production, information management and sharing or supporting decisionmaking processes. It reveals the challenges faced with respect to successfully integrating the range of different stakeholders and their views, taking the different spatial and temporal aspects of information into account, representing its complexities, managing uncertain data aspects, mobilizing and combining many different data sources, etc.

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Information systems and observatories

Geological risk studies and prevention

Géosciences Montpellier (CNRS, UM2) pools Earth scientists and a broad range of research resources in a single laboratory. Geodynamics—from the nano to the plate scale—are pivotal to the research, which is conducted using tectonic, geochemical, geochronological, geodesic and sedimentological tools. Geodynamics concern the different Earth envelopes, from the deepest to the surface, through the lithosphere, and interactions with the mantle. The team’s expertise, derived from fundamental research, is utilized in studies carried out along several targeted research lines, in the fields of natural hazards (earthquakes, landslides, near-shore erosion, heavy rain storms), geological reservoirs (sedimentary architecture, fracturing, fluid transfer, mineral physics), environment and sustainable development (CO₂ sequestration, geothermal resources, subsurface hydrodynamics, water resources: stock assessment, transfer monitoring and quality). Most of these research topics require continuous or recurrent observation of physical parameters, in addition to laboratory analysis and modelling of the underlying processes. Most of the instrument-equipped Mediterranean sites monitored are located in Languedoc-Roussillon region (France).

In the laboratory, geoinformation is used to study and prevent geological hazards through, for instance, fault and landslide detection surveys. The techniques implemented include synthetic aperture radar interferometry (INSAR) and correlation of high resolution optical satellite and aerial images. The laboratory places priority on investigating hazard zones where earth movements can be measured continuously (interseismic deformations, slow landslides) or on a disaster-event basis (earthquakes, avalanches). It has a library of images on key sectors, so it is prepared to study ‘before-and-after deformations’ in natural disaster situations.

Géosciences Montpellier devotes research to enhancing knowledge in the internal and external dynamics of planet Earth, while also addressing societal issues through natural hazard assessment, management of mineral resources (geological fluids) and the environment.
Software engineering and information systems

The Montpellier Laboratory of Informatics, Robotics and Microelectronics (LIRMM, CNRS, UM2) offers a broad scope of expertise in the fields of information science and technology, communication and systems (STICS). The laboratory’s research is multifaceted, i.e. theory, tools, experiments and applications, in all of its specialized scientific domains. This research is carried out in three departments: Informatics (INFO), Microelectronics (MIC) and Robotics (ROB).

Data Object Components for Complex Systems is one of the project teams in the Informatics department. This team’s research involves cooperation in two fields, i.e. software engineering (components and objects) and information systems, while also being oriented towards modelling and engineering of complex systems in various application domains (chemistry, life science, environmental science, robotics).

The research is focused on the contribution of object modelling in developing highly expressive data and processing models, while also integrating the evolution concept. Because of the variety and volume of cumulated information, and beyond the problem of system continuity, scientists in these domains have to deal with the issue of information sharing and dissemination—to put it simply, relevant information must be ‘served’ to users. Designing mediation infrastructures is a challenge. Based on metadata and ontological concepts, the goal is to build real systems that integrate the semantics of the underlying data and processing domain. This topic concerns integration and mediation infrastructures tailored to the concerned domains. There are many mixed and distributed initial data sources. They can be located at a meta level that includes the semantic description of the domain (metadata and ontologies). These different research thrusts were developed through the involvement of LIRMM within the Geographic Information Systems, Methodologies and Applications (GDR SIGMA, CNRS) research group.

Environmental data sharing and dissemination infrastructures

Various international conventions (Rio 1992, Aarhus 1998, etc.) and, more recently, the Infrastructure for Spatial Information in Europe (INSPIRE) European Directive have confirmed the importance of providing public access to and exchange of environmental information between different sources in support of environmental management.

This illustrates the current increase in awareness on the importance of pooling environmental knowledge and providing public access to it for decision support. In order to enhance integrated territorial management, this access could be extended from being solely focused on environmental knowledge to include technical, social and economic aspects.

In order to respect the independence of organizations and their information production, collaborative knowledge building and data distribution and processing are broad areas of debate and the focus of research in the field of information and knowledge systems. This research generates operational solutions through the development of ‘building block software’ tools required to create data infrastructures.

Amongst all of the proposed solutions, the MDweb project is exemplary. MDweb catalogues and locates web information resources and is an essential operational tool for information pooling and sharing infrastructures. It was developed through a collaboration between several partners (IRD, LIRMM, Cemagref, CIRAD, CEPALMAR, Région Languedoc-Roussillon) within the framework of research projects (ROSELT desertification observatories, data libraries of Systèmes Côtières et Lagunaires du Languedoc-Roussillon [SYSCOLAG]). MDweb is an open source tool (CeCILL French royalty-free license). It is based on geographic information metadata standards (ISO 19115, CEN) for resource referencing, and on Open Geospatial Consortium communication standards. The integrated open source search engine offers multicriterion searches using spatial (cartographic interface) and thematic (thesaurus) reference bases.

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For further information: http://mdweb.codehaus.org
Online demo: http://demo20.mdweb-project.org
Methods for the design and analysis of territorial information systems

In an ever-changing rural world, sharing targeted, reliable, updated information tailored to specific issues is a key element for territorial development. This is true regardless of the aim, i.e. to gain insight into territorial dynamics, coordinate agricultural practices, characterize and manage flood hazards, control pollution or restore the ecological balance of rivers, etc.

The joint research unit (UMR) TETIS conducts research on information system concepts, formalisms, design and setup methods by implementing them using specially tailored computer tools. For instance, in collaboration with UMR G-EAU, it has developed a new participatory approach for building observatories in given territories to fulfil the needs of a collective action targeting a specific issue. Between 2005 and 2007, a test was carried out in two areas of France: Aume-Couture Basin (Charente region) where quantitative water management was the key concern to deal with, and Hien Valley (Isère region), where biodiversity and water quality were the issues. Concerned rural stakeholders’ organizations were queried to establish the base of an information system. There are four steps to this iterative approach: statement of requirements, representation of viewpoints, development of the computer application and use of the resulting information system.

Long-term representation and capitalization of knowledge used during the development of information systems is another example of the unit’s research. A case-tool, which was initially set up for the modelling and development of computer applications, was modified to focus on adding pictograms of spatial and temporal concepts used in observatories. The functions developed in this case-tool automatically enhanced the models developed during the analysis as a function of the spatial and temporal concepts introduced. Automation of model enrichment boosts the speed, traceability, quality, reliability and improves the efficiency of information system development processes.

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Role playing games used in preliminary analysis of a participatory GIS for concerted management

GIS tools have been substantially criticized for being inaccessible to citizens and mainly available for the use of public authorities. Over the last 15 years, research has been under way with the aim of designing participatory GIS that could bring together different partners (especially basic communities) for spatial decision-making. This concept is still relatively vague and methods for designing such systems have not been formalized.

In this new research field, CIRAD (UPR Forest Resources and Public Policies), in collaboration with the Malian forestry administration, launched companion research with the aim of building a participatory GIS with all stakeholders of the fuelwood supply subsector in Bamako.

There is a very high number of stakeholders in this subsector, sometimes with antagonistic goals, with marked differences in information access. This research is based on the hypothesis that GIS, which is considered as an intermediate tool that can be used to collectively build a shared vision of the Bamako wood energy supply area, could facilitate stakeholder coordination and thus enhance forest resource management.

The selected approach is based on a role playing game and is similar to a scenario-based needs approach. It is aimed at encouraging stakeholders in the profession to describe their views on GIS, thus to express their needs, goals and the pathway that should be taken to achieve them. The game enables different stakeholders to be full-fledged protagonists of a simulated information system. They are introduced to the situation in a structured area (room) as information users, vectors and producers. The experiment highlights the efficacy of the game with respect to explaining viewpoints, analysing needs and documenting information sharing strategies. It boosts the prospects for designing information systems in relatively unstructured organizations.

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Agricultural production must be managed at a larger scale than individual plots in order to be cost-effective and comply with regulations. Farmers are thus faced with the problem of overcoming many constraints to optimize their production. The internal research unit (UPR) Annual Cropping Systems (CIRAD) is striving to facilitate farmers’ task by developing support tools for the management of crop production on a regional scale based on geographic information:

- an information system, connected to models developed through research, containing administrative, agronomic, climatic and production data for a broad range of agricultural plots
- an online cartographic server that enables data restoration in the form of maps containing raster data (satellite images, orthophotos, etc., as well as crop growth or harvest monitoring maps), vectorial data (plots, roads, etc.) and attributary data (yield, harvest dates, area, etc.).

These tools are designed for:

- farmers wishing to more efficiently manage the growth of their crops on a plot level
- extension services to tailor their technical advice
- industrial stakeholders to enhance production system operation (supply, volumes to process, optimal dates for technical interventions, etc.)
- institutions so that they will have a more accurate idea of the production capacities per commodity channel and be able to calculate the amount of assistance needed (price guarantees, natural disasters, etc.)
- research organizations.

These tools are now integrated into a modular system that can be implemented by a broad range of users thanks to new information and communication technologies.

TSIGANE is an online information platform that combines different components specifically designed for:

- management of climatic information
- management and dissemination of agricultural data on a per-plot basis (GIS and web mapping)
- harvest forecasting
- crop growth simulation
- satellite image based mapping for harvest monitoring.

Other research-generated components could potentially be integrated into this scalable platform.

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For further information on the TSIGANE platform (Online technology and geographic information systems for crop management): [http://tsigane.reteendeteczione.fr](http://tsigane.reteendeteczione.fr)
ROSELT/OSS: an information system for monitoring desertification in sub-Saharan Africa

The service unit ESPACE (IRD) has designed, developed and implemented an information system (IS) within the framework of the Convention to Combat Desertification and the Long Term Ecological Monitoring Observatories Network of the Sahara and Sahel Observatory (ROSELT/OSS). This all-encompassing IS—from the collection of biophysical and socioeconomic data on specific territories (methodological guides) to the sharing and dissemination of generated information (MDweb), as well as integrated and spatial data processing—enables joint analysis of territorial dynamics. This local environmental information system (LEIS-ROSELT) is the product of a collective initiative, with substantial involvement of research institutions responsible for observatories in member countries of the network (Institute of Arid Regions, Tunisia; University of Alexandria, Egypt; Centre de Suivi Écologique, Senegal; ‘ROSELT team’ associated with the Ministry of Environment, Niger).

MDweb—an online environmental information cataloguing and search tool—is used for inventorying, describing and accessing information produced by all of the observatories.

LEIS-ROSELT combines GIS and generic models in the ArcGIS platform for the assessment of environmental vulnerability utilizing minimal data and calculating synthetic spatial indices of land degradation risks. The temporal results are comparable between observatories. The models are tailored to dry areas where there are marked nature/society interactions, with high spatial and temporal variability and where resources are simultaneously or successively tapped for various end uses. By changing the input parameters, long-term forecast maps may be produced to facilitate discussions with resource managers.

The thematic guides are open-ended scientific documents that are shared within the network. They are designed to enable users to gradually organize the streamlined monitoring system by topic (nature/societies), thus ensuring the synchronous and diachronous approach of ROSELT. The recommended sampling data collection and processing methods can be implemented to develop specific indicators for each topic and indicators adapted to the interdisciplinary spatial approach applied in the LEIS.

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For further information on MDweb: www.mdweb-project.org

Mediterranean environmental observatories

Systematic observation of the natural environment and its use by humans is essential for studying global changes and natural hazards. Observatories are collaborative structures supported by research units that define the features to be observed, implement the observation techniques and design the information systems. Autonomous flexible structures governed by all stakeholders through ad hoc committees ensure their sustainability and missions. These units are the main observatory developers and users. The observation products are sometimes also useful for other stakeholders (territorial communities, public and private partners). Many observatories are associated with these other stakeholders, or even developed in collaboration with them. This is a long-term approach (spanning more than 10 years).

The Mediterranean region is both a victim and witness of hazards and global changes. This area is marked by serious land instability, where water can be considered as both a hazard (extremely heavy rainfall, flooding) and a rare and hard to utilize resource, as well as a biodiversity hotspot. Several regional observatories are devoted to the observation of Mediterranean natural and man-made environments:

- The Observatoire Méditerranéen de l’Environnement Rural et de l’Eau (LISAH, HydroSciences Montpellier, etc.) focuses on Mediterranean cultivated systems that can be studied for many reasons: the hydrological setting, i.e. at the interface of arid and temperate environments, while being subjected to a broad range of hydrological processes (severe drought, extreme flooding, etc.); the social and human setting in which, after thousands of years of human activities, major changes are taking place as a result of rapid population growth.

- The Observatoire Hydro-Météorologique méditerranéen Cévennes-Vivarais is striving to boost knowledge and prediction capacities on hydrometeorological hazards associated with intense rain storms and flash floods by pooling the expertise of researchers in various fields. This observatory is managed by the Laboratoire d’étude des Transferts en Hydrologie et Environnement (Grenoble) in collaboration with many other laboratoires (Géosciences Montpellier, HydroSciences Montpellier, ESPACE, EMA).

- The Observatoire de Recherche Méditerranéen de l’Environnement (OSU-OREM) monitors the natural environment while mobilizing researchers from various complementary disciplines to assess the impact of global climate change and natural hazards on Mediterranean environments. Géosciences Montpellier, HydroSciences Montpellier, CEFE, ISEM, ECOLAG and CBAE are the main developers and users.

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Based on the successful experience of the Surveillance de l’Environnement Assistée par Satellites (SEAS) network, which was launched more than 15 years ago in the Indian Ocean region, the service unit ESPACE (IRD) has installed several environmental satellite receiving stations with wide field-of-view antennas and is using the received images in its own research programmes as well as partnership research programmes.

Receiving stations of IRD and its local partners (University of Las Palmas, Polynesian Fisheries Service) are set up throughout the intertropical region (Réunion, Canary Islands, New Caledonia, French Guiana, Tahiti). They belong to SEASnet and operate as environmental observatories. They continuously generate scientifically validated spatial thematic products (water surface temperatures and turbidity, vegetation conditions, etc.) that are available online.

There are many application fields (fisheries, coastal areas, turbidity in the Amazon River, etc.) concerning terrestrial, coastal and even pelagic oceanic areas. Over the last decade, this scientifically high value-added observatory activity has been carried out in partnership with space agencies (ESA, CNES, NASA). It is aimed at contributing to spatial environment monitoring initiatives on regional, European and international levels, including the Observatoire National sur les Effets du Réchauffement Climatique (ONERC), the African Monitoring of the Environment for Sustainable Development (AMESD) programme, etc.

This concept of a network with geographically dispersed expertise differs from regular centralized usage with single satellite data acquisition and global processing sites. Conversely, by allowing each station to build a regional borderless advanced technology area, SEASnet is complying closely with the recommendations outlined in the Rio Declaration. In 2006, a high resolution SPOT and ENVISAT satellite receiving station was set up in Cayenne on the basis of SEASnet concepts. A similar project is also under way in Réunion.

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For further information: www.seasnet.org and www.gobierno.decanarias.org
Spatial information applications in different fields

Agriculture, fisheries and forestry

Environment

Land-use planning, Risks

Populations and societies
As population growth, climate change and the impact of human activities on ecosystems increase, sustainable management of our environment and its renewable resources—especially food—is crucial. This requires being able to describe the past and current state of the environment, understand the underlying processes and simulate management scenarios by predicting how it could evolve under the impact of human pressure.

Continental surfaces form a spatially complex system resulting from a combination of features, including the geology, topography, soils, climate, fauna, flora and human land-use patterns. This extremely high spatial variability occurs on all scales: plant, farm plot, small region, country and continent. Besides this spatial structure, temporal changes also take place on different scales: daily cycle, meteorological event, season, and longer term climate change. This trend also applies to oceans, seas and continental waters, whose characteristics vary markedly on spatial and temporal levels.

It is essential to have access to methods for spatial description of the environment and also for organizing spatial information of different types and origins. Remote sensing techniques, geographic information systems (GIS) and spatial modelling techniques are favoured tools for this. Moreover, it is necessary to describe and gain insight into the evolution of these spatial variables—this is the focus of dynamic modelling studies supported by remote sensing data.

In the renewable resources field presented in this chapter—agriculture, forestry, ecosystems and fisheries resources—variables that characterize studied environments must first be determined spatially: topography, soils (mineralogy, humidity, surface state), vegetation (type, status, growth and development, height, solar radiation interception and albedo), landscape spatial organization (plot patterns, ditch networks), cropping practices (management strategies, tillage operations, pesticide treatments), water temperature, nutrients and plankton for fisheries resources. Furthermore, it is essential to gain insight into temporal changes that most of these variables undergo. In a number of these cases, this spatial information is used directly for management purposes (precise agricultural techniques, harvest management in cropping areas, controlling nonpoint source pollution). Moreover, this information is often used as parameters or inputs for models describing processes under way in target environments (crop models, hydrological models, surface-atmosphere exchange models).

Due to the complexity in the spatial organization of terrestrial environments—especially cultivated landscapes—there is an urgent need for spatial information representation and processing methods. GIS technology is widely implemented to combine spatial information of different types and origins in the fields of agriculture and ecosystem characterization. In addition to this conventional use, there are more specific needs, such as the application of spatial modelling to simulate an entire area based on information acquired in just a small part of this area, especially when other parts of the area are hard to monitor; for mapping purposes (spatial interpolation techniques, spatial stochastic simulations). Finally, substantial lateral flows run through these highly heterogeneous environments: water transfers via runoff, stream flow, groundwater movements, atmospheric gas and particle transport (pollen, pesticides, etc.). Spatial characterization of these environments and flow modelling are required to represent these flows—which is a current focus of active research.

Laurent Prévot (UMR LISAH)
& Jean-Baptiste Laurent (UPR SCA)
Monitoring sugarcane harvests in Réunion via satellite images

The regional productivity of the sugar industry is dependent on the sugarcane harvesting efficiency, i.e. regular supplies of sugarcane to sugar factories and effective geographical distribution of harvesting equipment and resources. In French overseas departments and many producing countries (South Africa, Vietnam, etc.), a large portion of sugarcane-growing areas is managed by thousands of small-scale farmers growing cane on barely a hectare of land. In such conditions, it is hard to obtain reliable and thorough information on harvestable sugarcane areas, their geographical distribution and harvesting progress rates.

To address this concern, the SUCRETTE (SUivi de la Canne à sucre par Télédétection) project, coordinated by CIRAD and SPOT Image, has developed a method for processing SPOT 4 and 5 images to generate maps of harvests in near-real time during harvesting periods.

The classification of sugarcane plots extracted from satellite images is based on the high spectral contrast between the standing plant cover, the crop-residue covered ground (after sugarcane harvesting) and bare soil (crop residue burnt, soil tilled for replanting). Statistical indicators of harvest areas and rates are thus calculated at different geographical scales (delivery centre, sugarcane-growing area, factory, region) in order to provide decisionmakers with elements that they require to adjust their production forecasts and harvest logistics.

In Réunion, CIRAD supplies its partners with four sugarcane monitoring maps per harvest season: a month after the beginning of harvesting, at mid-season, a month prior to the end of the season and postharvest. This enables them to estimate the annual unharvested sugarcane area.

An online information system (see TSIGANE system, p. 31) is being developed to support this type of tool, to automate treatments and to provide all stakeholders in this subsector with access to the results.

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Agricultural production forecasting is a keystone of early drought warning systems in Sudanian-Sahelian regions where climate change has a heavy impact. The aim of this project is to improve the production forecasting capacity by characterizing agricultural landscape variability via remote sensing. It addresses two questions:

- How can this variability be expressed on different scales?
- How can it be taken into account to improve yield estimations?

Agricultural landscape descriptions are based on the characterization of land-use patterns through the analysis of spectral, spatial and temporal information derived from remote sensing images. The data and methods should be tailored to semiarid environments and to their heterogeneous mosaic patterns (rangelands, crops, wooded savannas, etc.), while also being adapted to the economic conditions in these regions (low-cost monitoring). MODIS and SPOT VEGETATION images were used for this study.

Initial results have been obtained for Senegal (African Monsoon Multidisciplinary Analysis [AMMA] European Integrated Project, 2005-2009) by combining thematic information from different sources with time-series SPOT VEGETATION and MODIS satellite images. A first ‘stratification’ phase involves delimitation of homogenous agroecological zones by visual analysis of thematic maps (heterogeneous in terms of dates, media, etc.) describing the soil, relief, vegetation and climatic features. A second ‘classification’ phase is focused within each of these zones, and then photointerpretation of each class is done using SPOT set images (high resolution) and monitoring the normalized difference vegetation index (NDVI) on MODIS time series (NDVI is used to monitor plant phenology). Finally the crop land-use rates are mapped (classification at three levels: absence, >50%, >80%) by analysing, per pixel, decadal NDVI time series datasets derived from the satellite images.

Temporal changes in types of land use will be the focus of further studies.

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\[ \Delta \text{Cultivated area in Senegal in 2005.} \]
How geomatics information enhances knowledge on complex cropping systems

Many specific methodological problems arise when characterizing and assessing complex cropping systems established on smallholders’ plots and based on various crop associations, e.g. fruit trees (coconut, papaya, cocoa, banana, etc.) and vegetable gardens. Agronomists are thus adopting new tools, such as geomatics, to enable them to gain insight into these systems on different scales. Moderate spatial resolution studies facilitate quantification of structures and their temporal evolution on a regional level, whereas very high resolution imagery can be used to refocus studies on a cultivated crop level.

A preliminary study was carried out by a CIRAD team from the joint research units UMR SYSTEM and UMR TETIS on coconut-based Melanesian agroforestry systems. This involved the combined use of field data and very high spatial resolution satellite image information to gain further insight into the intra-plot structure of these systems. A QuickBird satellite image (processed at 0.65 m/pixel resolution, multispectral [green, red, NIR bands]) covering a 64 km² area on Malo Island (Vanuatu Archipelago) was thus acquired in 2003.

The results revealed that coconut plantations could be clearly identified on the images and classified according to age. The main agroforestry types were recognized and mapped using a texture-based classification, thus enabling preliminary analysis of their layouts and densities. A remote-sensing index was also developed to quantify the canopy closure of the vegetation cover in relation to the complexity of the associations present. However, this method was not suitable for assessing all agroforestry systems encountered in the field, especially highly complex structures in which associated plants were invisible under the main cover.

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Spatialization of vineyard weed control practices in Languedoc (France)

Vineyard weed control practices represent an important factor with respect to variations in flooding, soil erosion and pesticide nonpoint source pollution hazards. These practices are the result of decisions made by farmers on the basis of various constraints and opportunities on different spatial scales—from the plot to the production area—and at different time steps. This results in a complex spatial and temporal organization on a catchment scale, which must be monitored to be able to assess the hazards.

On large spatial scales (several tens of km²), data required for these risk assessments cannot be obtained by field surveys or in-depth monitoring. The joint research unit (UMR) LISAH thus decided to adopt another approach to analyze the spatial organization of these agricultural practices in the Languedoc vineyard region (France) so as to be able to locate and quantify them.

Surveys of 65 wine growers in the lower Peyne Valley (80 km²), representing 1460 vineyard plots, enabled the researchers to draw up a typology of weed control practices that accounts for herbicide treatment ranges and variations in the soil surface states that determine the extent of runoff.

Multivariate analysis of the determinants of these practices and their locations revealed a high spatial structure of practices related with the communal locations of the plots.

The vineyard inter-row widths was the second influencing factor of soil maintenance practices.

Finally, stochastic spatial simulations based on methods for classifying these determinants, some of which could be extracted by remote sensing (UMR TETIS collaboration), generated realistic maps of weed control practices on a plot scale for the entire lower Peyne Valley. These maps could be used as inputs for distributed hydrological models to enable risk assessment.

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GIS—a tool to understand the dynamics of Mediterranean tree agroecosystems: fig and olive orchards in northern Morocco

Trees and forest components are structuring elements of different types of Mediterranean agroecosystems, including chestnut orchards in the Cevennes (France), argan groves in southwestern Morocco, and orchards predominantly planted with fig and olive trees in northern Morocco. The extension and regression dynamics of these tree stands are associated with historical, socioeconomic and political factors. Spatial and temporal information analysis may be used to gain insight into these factors.

Northern Morocco (Tingitane Peninsula and Rif area) is a remarkable region with respect to the expansion of olive and fig orchards. An interdisciplinary research project involving geneticists and ethnobioologists from CEFE, the joint research unit (UMR) Développement et Amélioration des Plantes (INRA, Morocco) and Abdelmalek Essaadi University (Tetouan, Morocco), is focused on studying fig and olive tree domestication processes from two angles: the layout of wooded landscapes and the genetic structure of tree agrodiversity and associated ethnobiological knowledge.

GIS is an efficient analytical tool for comparing oral testimony (ethnohistorical data) with political and historical data and to gain insight into landscapes. The Spanish annexation of part of northern Morocco had a positive impact on the extension of these orchards (dissemination of new agricultural techniques, plants, etc.). Similarly, at independence in 1956, historical data suggests that inhabitants benefited from a transition period to extend their land rights by planting fig and olive orchards on large tracts of land. Aerial photos taken at different periods (pre- and post-independence) and old georeferenced military maps are used for this analysis.

The project is currently pooling substantial georeferenced data from the Rif area on intravarietal genetic variability in fig and olive trees with the aim of gaining insight into the underlying genetic structure. GIS will be used to facilitate comparisons with ethnobiological data.

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Modelling tools to understand and sustainably manage pastoral systems

Extensive nomadic livestock herding is a key economic factor in Sahelian countries and generally in other African countries south of the Sahara. This activity, which is practiced with a diverse range of livestock species, contributes to the food security of rural and urban households. There are many ambivalent interactions between herding and the environment. Herding has negative impacts such as extreme grazing pressure and health risks due to water pollution. It can also have positive impacts on ecosystems such as improving soil fertility through better organic matter recycling or increasing herbaceous biodiversity and landscape diversity through grazing pressure.

A multidisciplinary approach using substantial georeferenced data is required to characterize the potential of pastoral systems and analyse their functioning and spatiotemporal dynamics. Moreover, accurate updated information on the state of natural resources, their dynamics, many functions and uses by human and animal populations is essential for decisionmaking on planning, local development and rangeland safeguarding initiatives.

There is growing demand from stakeholders, territorial authorities and technical services for spatial data, information systems, indicators and simulation models. This is a challenge for targeted research on knowledge building processes and the utilization of information in decisionmaking tools.

To address this challenge, some research lines of the scientific programme of the international research unit (URP) Pastoralism (CIRAD, Dry Zone Pastoral Research Pole) are focused on accounting for information and relevant baseline data needs to be used in decision support and resource management tools, as well as on the participative construction of indicators and shared use of information systems.

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Participatory mapping workshop based on the interpretation of satellite images with herders.
Primary production in marine environments regulates fisheries catch levels in European waters

![Map showing ecoregions and chlorophyll concentration](image)

Positive linear and statistically significant relationships were documented between primary production and the small pelagic fish catch, as well as between primary production and the total catch. The results revealed that large-scale spatial variability in primary production determines the spatial gradients of fisheries production. This highlights the prevalence of a bottom-up trophic (nutrition) linkage in European seas, i.e. the consistent patterns (spatial structures) observed are associated with energy transfers from biomass–produced during phytoplankton photosynthesis activity–towards higher trophic levels by predation along the food chain.

The results are important with respect to promoting an ecosystem approach to fisheries, especially for estimating the capacity of ecoregions to support sustainable fisheries. Our findings are also relevant in the climate change framework as they facilitate the assessment of variations in high trophic level species and in fisheries as a function of potential modifications in plankton communities due to global warming.

Combining satellite information on biological production in oceans with global fisheries data was found to be especially useful for detecting large-scale ecological patterns and testing hypotheses on the structure and/or function of marine ecosystems.

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An information system to reduce pesticide pollution

As part of the European LIFE project ‘A Water Assessment to Respect the Environment’ (AWARE), Cemagref has developed new onboard equipment technology for monitoring and recording pesticide application data. With this system, treatments can be accurately monitored since it measures and records application parameters every second with GPS georeferencing. Collected traceability data (flow rates, tank volumes, meteorological data, etc.) are analysed and compared to declarative data so as to be able to propose wine growers ways to improve their cropping practices.

With this tool, wine growers can calibrate their equipment daily and monitor the meteorological conditions. Moreover, they can detect malfunctions by viewing the equipment operation parameters in real time.

A GIS enables collection and display of all data: catchment delimitation, vineyard plots, river system, relief, pesticides applied, etc., in order to produce maps and spatial analyses on the concerned catchment. Rows in vineyard plots can be accurately differentiated by GPS.

The system produces a set of objective data for automatic treatment sheet printouts, including a graph of the plot on which one of the measured parameters is displayed, along with a written summary of the different parameters: current sprayer settings, meteorological measurements, treated area, number of rows treated, dosages used, etc.

Moreover, hardcopy declarative data are compared with automatically recorded data, thus enabling operational feedback and facilitating discussions with wine growers. Potential ways for improving spraying methods are thus highlighted. Streamlining the techniques could lead to a reduction in application losses and in applied pesticide quantities.

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Environment management and biodiversity conservation are universally considered as priorities in the current setting of accelerating global changes affecting physical and biological resources on Earth. It is important to think before acting, but also to understand before managing. Understanding the functioning of continental and aquatic ecosystems is, however, an uneasy task. It requires substantial time, many observations, and experts from different scientific fields to explain the underlying phenomena as accurately as possible. Geoinformation is a keystone of this approach.

Several research teams based in Montpellier (France) are working on formalizing knowledge on all physical, biological and socioeconomic processes required for sustainable natural resource management. They are developing databases and models that bring together acquired knowledge and facilitate hypothesis testing. These have been initially designed as knowledge tools that reflect specific aspects of studied systems, but they can also guide resource managers in their initiatives. To an increasing extent, these tools are based on geoinformation acquisition and processing methods, including remote sensing and geographic information systems (GIS), in order to mobilize a diverse range of data and account for their spatial and temporal relationships. Remote sensing and GIS are thus widely used in environmental sciences as they provide efficient support for integrating information and cartographic analysis.

The examples presented in this chapter illustrate the close links between environmental data acquisition, management and representation techniques, as well as thematic research domains as broad ranging as water, forestry and plant and animal biodiversity in terrestrial and aquatic environments. Satellite image (low or high resolution, optical or radar) processing is widely used to characterize the distribution of research subjects at different spatial and temporal scales. For instance, this is the case in monitoring Andean glaciers, African plant covers, toxic algal blooms in the Mediterranean, environmental niches of disease-vector rodents in Asia, coral ecosystems and oceanic eddies in association with marine predator populations. Most of these studies are also based on geographical database management systems that enable mapping and analysis of spatial interactions between the physical environment, the living environment and climatic or human forcings. This meshing of environmental data gives rise to a different enhanced view of the underlying mechanisms by promoting an interdisciplinary approach via spatial dialogue. Researchers can thus gain insight into processes and their spatial and temporal distribution, and more effective explanatory models can be developed to guide management, restoration and conservation strategies to be implemented.

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Remote sensing and the biocomplexity of coral ecosystems

Remote sensing applied to coral reef ecosystem biocomplexity focuses on biodiversity quantification specifically using a habitat-based approach. The aim is also to gain insight into processes that control and depend on this diversity, and its interaction with human communities. This latter aspect includes sustainable use of biological resources and their conservation.

Passive optical remote sensing is an effective observation tool for coral reef ecosystems that are often located in tropical, shallow, hard to reach, clear-water coastal environments. Spatial and airborne imagery, often combined with field observations, can be used to develop multidisciplinary products and applications such as field sampling designs, multi-thematic habitat maps, geomorphological adaxes, bathymetric maps, water quality maps, multisensor temporal monitoring, etc. This first line of descriptive products provides decision support tools for managing communities of living organisms, delineating marine protected areas, assessing fisheries stocks, modelling hydrodynamic processes, monitoring reef systems impacted by high human pressure and global warming.

The research unit (UR) CoRéUs conducts research on several Indo-Pacific sites. The main sites are located in New Caledonia, French Polynesia, Wallis and Futuna, Reunion, Fiji, Vanuatu, Maldives and Madagascar. This research is carried out in close collaboration with local and international operators. In addition, as spatial data is routinely available for any site worldwide, the unit is a partner in scientific international research initiatives (Australia, USA) and for marine resource management programmes, with a regional (e.g. the Secretariat of the Pacific Community) and global scope (via the Millennium Coral Reef Mapping Project, Mora et al., 2006).

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Example of habitat maps drawn up within the framework of a regional study on marine turtles and seagrass beds in the Caribbean (extracted from Landsat images).
The Mozambique Channel (10°-30°S/30°-50°E) is a natural laboratory for research on oceanic mesoscale eddies (50-300 km dia., lasting from one week to several months) and their impact on top predator populations. Four to seven eddies (alternation of cyclonic to anticyclonic) pass through the Channel each year. These eddies are detected mainly by satellite radar altimetry (satellite measurement of local sea level heights). Spatial descriptors of eddies and associated structures (fronts, filaments) have been used to study their impact on tuna distributions.

Two types of tuna school indicators were used: tuna catch data and georeferencing of frigatebirds fitted with transmitters. Frigatebirds, which are unable to dive, follow tuna schools to feed on small animals hunted by these large marine predators, essentially on the edges of eddies: their feeding strategy is tailored to small-sized habitats where the probability of finding prey is high. These birds thus have a role as "sentinels enabling greater insight into the evolution of marine ecosystem health" (F. Marsac).

Direct tuna catch observations (associated with the location of fishing boats) are obtained at the periphery or core of eddies, where phytoplankton production is high. Analysis of the spatial distribution of tuna schools based on these two types of indicator revealed that these fish, just like other top predators (turtles, sea lions, etc.), can benefit from eddies (core and periphery) for hunting. Mesoscale eddies can thus serve as transient habitats for these large pelagic fish.

This example highlights the importance of detecting and characterizing oceanic eddy structures in order to improve knowledge on offshore marine habitats and, finally, to enhance the management of exploited fisheries resources.

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Monitoring blooms of the toxic alga *Alexandrium catenella* by satellite imagery at three Mediterranean sites (Thau, Tarragona, Olbia)

Toxic algal blooms occur in all oceans and seas worldwide, having major environmental and socioeconomic impacts (often adverse for aquaculture and recreational activities).

A project was thus set up to analyse the dynamics of these algal blooms and links with human activities, within the framework of integrated environmental management policies. Satellite imagery, which provides a synoptic spatial view of the phenomenon, is also used to effectively support current *in situ* measurement methods (water sampling and analysis). However, the spatial resolution of satellite sensors designed for such monitoring (i.e. Sea-viewing Wide Field-of-view Sensors [SeaWifs], with around 1 km resolution) is not sufficient to obtain accurate descriptions of local or regional bloom phenomena, especially on basin or lagoon scales.

The aim of the project under way, carried out by the joint research unit (UMR) ECOLAG in collaboration with IFREMER and the Nev@ntropic company, in partnership with SPOT Image’s collaborative Planet Action network, is to assess the benefits of high resolution satellite imagery at three pilot sites: Thau Lagoon (France), Tarragona Port (Spain) the Gulf of Olbia (Sardinia, Italy). These are sites where blooms of a toxic alga (*Alexandrium catenella*) occur regularly, and sometimes simultaneously, with a marked environmental impact. As a complement to *in situ* measurements, high resolution satellite imagery is used to specify and understand the factors determining bloom development through analysis of their spatiotemporal distributions and characterization of the species’ lifecycles. The patchy distribution of algal blooms (typically around 100 m long and wide) is a substantial challenge with respect to evaluating the total biomass of these toxic algae. Satellite imagery—which provides an integrated synoptic view of the phenomenon—is thus used to monitor the development of such blooms and their dissipation over time.

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Monitoring snow cover on Campo de Hielo Norte, Patagonia (Chile) from MODIS satellite images

Many members of the scientific community are now focusing on gaining greater insight into the impact of climate change on our planet. Melting of glaciers is one of the most obvious consequences. Information acquisition is, unfortunately, complicated by problems of access (steep reliefs) and the vastness of glaciated areas.

Satellite and airborne remote sensing is very effective for overcoming these complications since it enables remote monitoring and analysis of huge surface areas. The research advantages of these technologies are multiplying with the regular improvements being achieved in spatial and temporal resolutions.

South America hosts many glaciers in the Andes Cordillera, stretching from Colombia to Patagonia. In line with the global trend, these glaciers are retreating, especially in the Patagonian region of Campo de Hielo Norte (CHN), i.e. a 4 200 km² ice field, whose surface area is diminishing in conjunction with the accelerated retreat of glaciers that prevail in this region.

To get a clearer picture of the local climatic factors influencing CHN glacier variations, the evolution of snow-covered areas in this ice field was monitored over the 2000-2006 period based on the normalized difference snow index (NDSI) applied to MODIS satellite images.

The study highlighted the seasonality of the intra-annual evolution in the snow-covered area: in summer (December-March), this surface area retracted to 3 600 km² (corresponding to the accumulation zone), with very few inter-annual variations during this season, whereas the snow extension was much greater in winter (up to 11 700 km²), with high inter-annual variations.

This study suggested that snow cover on the western part of CHN could melt more rapidly in response to the milder temperatures, but the area could be quickly covered again with more frequent and abundant snow falls.

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Example of an application of the NDSI index on a MODIS image.
Since the Earth Summit (Rio, 1992), principles that promote ecologically sustainable management of tropical forest ecosystems are widely recognized. In Central Africa, sustainable forest management has become a key element of new forestry policies. Over the last 10 years, geographic information processing tools (GPS, image processing software and GIS) are widely used by professional stakeholders and GIS has become an essential tool for African forest managers.

Within the framework of companion research, CIRAD has been involved for over 15 years in the development of remote sensing methods to monitor forest cover and of GIS-based decision support tools.

Because of the complexity of the objectives (especially reconciling multiple uses), forest managers are hampered to an increasing extent by the problem of translating their objectives and potential management scenarios into a set of mathematical equations. This difficulty is partly due to the fact that foresters are unable to determine the state of a target system at any given time, and to the imprecise or even intuitive nature of the decisionmaking elements.

The research under way is geared towards the development of tools to support decisionmaking on planning forest trail networks, on creating plot layouts, on designing ‘reduced impact’ logging and on predicting stand growth. Because of the contextual limits (acceptance and adoption by stakeholders) of automated and mathematical optimization approaches, CIRAD aims to develop interactive and semiautomated management support tools. GIS software is a key tool for facilitating information integration and cartographic analysis, while also serving as an interface between users and automatic computation procedures.

Prototypes are currently being field tested in French Guiana, Central African Republic and Gabon.

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GIS tools are essential for tropical forest management

Since the Earth Summit (Rio, 1992), principles that promote ecologically sustainable management of tropical forest ecosystems are widely recognized. In Central Africa, sustainable forest management has become a key element of new forestry policies. Over the last 10 years, geographic information processing tools (GPS, image processing software and GIS) are widely used by professional stakeholders and GIS has become an essential tool for African forest managers.

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Satellite vegetation data as a tool for paleoecology research in Central Africa

Climate change and human activities can trigger flora and vegetation structure modifications. In the Central African forest region, paleoenvironmental research sites, where the evolution of the vegetation cover and associated forcings over the last millenia can be traced, may be represented by a few scattered dots on a map. To reconstruct a regional history of the range and nature of the forest, this point information should be interpolated via spatialization of functional models that are able to deduce the features of plant formations according to the climatic and pedological characteristics.

In Central Africa, outputs of these models can be interpreted in terms of the vegetation structure, e.g. by assessing the total biomass, the grass-tree cover distribution in savannas and the proportion of deciduous tree cover in forest areas during the dry season. This information on the actual vegetation status, which was for a long time limited to small areas, is now available on a large scale via remote sensing tools. These data (generally open source) are highly useful for the task set out by ISEM (Institute of Evolutionary Sciences, CNRS, UM2) of integrating ecological and paleoecological knowledge on Central Africa: i) they compensate for the lack of field measurements to calibrate paleoenvironmental indices required to trace the history of the vegetation structure; ii) they enable a regional comparison between the vegetation patterns and phytogeographical domains, i.e. the distribution of floristic associations on which current vegetation maps are based; iii) they provide a reference source for validating vegetation models; these latter could thus more accurately represent the current situation before being used to reconstruct or predict past and future changes.

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Map interface of a support tool for forest trail network planning.

A Map of the dry and humid rainforest region based on floristic associations (phytogeographical domains identified by White, black lines) or on the percentage deciduous tree cover (evergreen forest in dark green, semideciduous in pale green).

From the MODIS ‘Vegetation Continuous Field’ product
Georeferenced taxonomy databases on vertebrates (amphibians, reptiles, mammals) in the South of France

For three decades, the Ecology and Biogeography research team of the École Pratique des Hautes Études (CEFE-EPHE) has been centralizing information on vertebrates in southern France derived from point observations by professional and amateur naturalists. This information, which is now computerized and spatialized, can be used to answer many scientific and operational questions.

From a scientific standpoint, many issues can be addressed via these databases: How is biodiversity distributed in the Mediterranean area? What factors best explain the observed gradients? What changes have been underway in recent decades? Hence, it is possible to monitor the progression of invasive species (e.g., red-eared slider turtles, muskrats, painted frogs) and develop strategies to control them or, conversely, to monitor the fate of endangered heritage species that would warrant conservation initiatives: otter, ocellated lizard, European pond turtle, etc.

From a more applied standpoint, these databases can be utilized to fulfill many current biodiversity conservation requests: What areas would warrant biodiversity preservation initiatives? In what areas is there contention between economic development and environmental protection? These databases are therefore tapped by many French administrations and governmental agencies (Direction Régionale de l’Environnement, Agence Régionale de l’Environnement, general councils, etc.) responsible for the protection of natural environments: setting up the Natura 2000 network, inventories of natural areas of ecological, faunistic and floristic interest, acquisition policies for sensitive natural areas, development of a regional biodiversity preservation strategy, etc. They can also address wider scope requests such as monitoring biodiversity on a national or European basis. These databases should ultimately be merged with public databases that are being developed on a French (Système d’Information sur la Nature et les Paysages) and international (Global Biodiversity Information Facility) scale.

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Ecology of rodent communities and their pathogens in Southeast Asia

The high biodiversity that is known to prevail in Southeast Asia is currently threatened by the rapid economic development and rising impact of human activities on ecosystems. In this setting of harsh and radical environmental change, rodent populations, which account for most of the vertebrate animal biomass present, are emerging as major vectors of diseases (some of which can be fatal for humans, e.g., leptospirosis and scrub typhus) and as crop pests.

The CEROPATH project, funded by the French Agence Nationale de la Recherche ‘Biodiversité’, is focused on the impacts of environmental change on the evolution of rodent communities, their parasites (helminths, arthropods) and pathogens (microparasites). It groups different French and foreign laboratories in complementary fields, including population genetics (CBGP, ISEM), morphometry (ISEM, Muséum National d’Histoire Naturelle), spatial analysis (TETIS and the Laotian National Agricultural and Forestry Institute), as well as molecular epidemiology for research on viruses (Institut Pasteur, Cambodia), bacteria (Siriraj Hospital, Mahidol University, Thailand), fungi (Institut Pasteur, Lille, France) and blood parasites (Kasetsart University, Thailand).

This project, which is under way at eight research sites located in Cambodia, Laos and Thailand, is aimed at characterizing processes that contribute to observed host-pathogen associations, while also considering the environment and evolutionary histories of the interacting species. One of the key issues concerns the identification of rodent species and estimation of their spatial distribution and spatiotemporal dynamics. The study is based on GIS software integrating field data on rodents. This GIS utilizes satellite images on different scales, from the regional scale (to compare study sites and place them in their geographical context), to the local scale (involving high spatial resolution characterization of environmental niches). The project is thus aimed at building models to assess the spatiotemporal dynamics of populations and to forecast changes in host-pathogen communities associated with potential ecological changes.

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Potential distribution range of Rattus tanezumi in Nakhon Pathom province (Thailand) estimated by combining field capture data and satellite image analysis.
Geomatic research is carried out to gain further insight into areas utilized by humans and to enhance territorial management and governance. The results have been widely published through visual products such as maps (thematic, 3D, photomaps, etc.), as well as various images and photographs (orthophotomosaics, aerial photographs, satellite images, etc.). This broad range of constantly evolving and ever more accurate, exhaustive and diversified ‘images’ (‘animated maps’, web mapping, ‘virtual globes’) prompts researchers to reflect on choices to be made for stakeholders as a function of the knowledge collected, issues at hand and objectives to fulfill.

Mobilizing spatial information for land-use planning is a co-building and co-responsibility process. The project contributes to building a shared view of territory based on available tools, including: remote sensing, which enables information acquisition on large areas and targets of interest; and geographic information systems (GIS) and georeferencing of different information layers for spatial correlation of data of various origins. Geoinformation mobilization could be defined as the “implementation of an information process by an individual (or a group of individuals) in order to assess, or communicate on, a social area”. This approach thus combines technical and social aspects. The increasing dissemination of these many geographic tools and their use in a range of fields, especially land-use planning and risk management, nevertheless prompts us to re-examine the meaning of some concepts (e.g. ‘geoinformation’, ‘information system’, ‘complexity’, etc.), modifications in knowledge and its use, the status of territory with respect to geomatics (e.g. between real and virtual spaces), etc.

The research examples presented in this chapter highlight the broad range of different territories investigated and scales considered: from a national view, through the prevention of locust outbreaks in Madagascar; to an in-depth characterization of the vulnerability of a region (Ile de France) to accidents associated with dangerous material transport, but also through targeted objectives. The applications presented thus involve the characterization and assessment of territorial modifications (converting agricultural land into housing developments), monitoring the evolution of a phenomenon (coastal erosion), characterizing geological disasters (earthquakes). Integrated studies are also presented. They are aimed at building ‘applied’ geographic information systems, such as GIS RINAMED on natural hazards in the Mediterranean region, or ‘integrated’ GIS tools such as the SYSCOLAG project for global coastal zone management. Through their diversity, these studies illustrate the range of issues associated with the use of geoinformation. These problems are hinged on the uncertainty, the level of validity of spatial information used and their impact on associated models, as clearly illustrated by the study on the spatialization of the cost-benefit analysis of flood prevention projects.

Geoinformation enables studies on all topics associated with land-use planning and risks by providing key decisionmaking support elements, while also highlighting new scientific questions that will become research topics of the future.

Jean-Paul Bord (EA GESTER) & Pierre-Alain Ayral (LGEI)
Spatial analysis to prevent locust outbreaks in Madagascar

The Malagasy migratory locust, *Locusta migratoria capito* Sauss., is able to change phase according to its population density. The solitary and gregarious phases are characterized by specific behaviours with markedly different morphological, physiological and ecological traits. In the solitary phase, these locusts are dispersed and do not threaten crops. They migrate by flying in search of suitable conditions for their development. If such suitable areas are spatially reduced, the locusts form high density groups. They can then, through a few generations, switch to the gregarious phase, where they form hopper bands and swarms that are capable of destroying crops and pastures.

An operational research project carried out by EMPA (CIRAD), in collaboration with the Malagasy National Locust Centre, is aimed at improving locust forecasting and monitoring systems in order to control this plague. This involves combining monthly information on rainfall, habitats and the biology of the locust (density, phase and stage). Spatial data can also be used to delimit potential grouping areas where the high population densities could trigger phase transformation and subsequent outbreaks.

Spatial monitoring of pest locusts in Madagascar, and elsewhere, represents extremely targeted research. It requires in-depth field knowledge, effective management of spatial information and long-term partners in concerned countries.

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**BRGM - Service Géologique Régional, Operational services « Eau » et « Aménagement et risques naturels »** (BRGM Languedoc-Roussillon)
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**UMR LISAH - Laboratoire d’étude des Interactions Sol – Agrosystème – Hydrosystème** (see page 18)

**UMR TETIS - Geoinformation and Earth Observation for Environment and Land Management** (see page 8)

...continued on page 50

*Swarm of migratory locusts in Madagascar.
Crop damage associated with the last major outbreak (1996-2000) led to pesticide spraying of an area of over 4 million ha, thus highlighting the need for an operational warning network.*
This project is part of a European initiative aimed at raising awareness on natural risk prevention in the Mediterranean region (INTERREG RINAMED programme: a European interregional cooperation initiative ‘Natural Risks and Hazards in the Mediterranean’). It involves development of an interactive open-ended geoinformation platform (GIS and webmapping) on natural risks and disasters throughout the Mediterranean Basin. This is an exceptionally interesting area because it hosts a broad range of damaging natural phenomena (earthquakes, flash floods, volcanic eruptions, landslides, severe storms, etc.) while benefitting from a number of risk reduction initiatives.

The main difficulties encountered in this project concern the integration, synthesis, homogenization and critical analysis of the many sources of available data, and setting up a network of foreign correspondents. Moreover, the mapping production process requires the development of a graphic production line, a specific graphic charter, and an online interactive digital mapping tool.

The first applications derived from the database (GIS RINAMED) concern the production of maps for a future permanent atlas of natural risks and hazards in the Mediterranean Basin (RINAMED Atlas) and the development of composite indicators of risk on the NUTS3 scale (international classification equivalent to the French departmental level) for the Mediterranean Latin Arch (corresponding initiative entitled ‘RINAMED indicators’).

Current and future projects are focused on the development of an online interactive GIS software tool based on open source technology. It should enable clients, via Internet, to manage information layers, import data, make spatial requests, develop statistical analyses and produce maps. This work should ultimately lead to the development of an open-ended, top notch and efficient tool designed to enhance knowledge and promote geoinformation sharing on natural risks and hazards in the Mediterranean region.

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Integrated environment/society approach applied for the management and sustainable development of interface territories: coastal regions and islands

- developing and validating knowledge integration and management tools, such as the MDWeb tool for the management of metadata tailored to the needs of the SYstèmes Côtières et LAGunaires du Languedoc-Roussillon (SYSCOLAG) project by the ESPACE, LIRMM and TETIS research teams and regional stakeholders, i.e. the Centre d’Études et de promotion des Activités lagunaires et Maritimes du Roussillon (CEPRALMAR in Languedoc-Roussillon, France);

- proposing each of the three main types of territorial stakeholders, i.e. public authorities, economic decisionmakers and users, a description of the dynamics and dysfunctions of this system, while specifying their respective responsibilities in order to boost their awareness on the problems and encourage them to jointly come up with solutions.

The research unit ESPACE (IRD) has thus developed three methodological modules focused respectively on:

- modelling the impact of catchment dynamics on coastal areas;
- analysis of spatial and temporal agreements and disagreements in administrative territories with respect to institutional integration of public policies;
- assessment of the socioeconomic value of ecosystems.

All of these initiatives involve sharing, analysis and joint management of spatial information on territories, while contributing to enhanced governance of coastal areas and islands.

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Spatial imagery as a tool for research on geological hazards and their prevention

Of all the different categories of geological hazards, earthquakes have the greatest societal impact, with heavy human casualties. In the last 5 years, the only major earthquakes (Iran in 2003, Sumatra and Pakistan in 2005, Indonesia in 2006, China in 2008) claimed almost 500,000 victims (source: United States Geological Survey).

Satellite imaging is very useful for gaining insight into the mechanisms that control these geological phenomena, while also being an efficient means of obtaining quantitative measurements.

A new imagery method that was developed by the French Commission for Atomic Energy (CEA) and recently implemented by Géosciences Montpellier provides a way to supplement GPS point measurements and field observations following earthquakes. This technique, which is based on the correlation of high resolution optical satellite images (e.g. Ikonos, QuickBird or SPOT5) acquired before and after an earthquake, enables operators to identify faults where displacements have occurred and to accurately measure the horizontal constituents of land deformations over a broad region around the earthquake epicentre. These data are essential for understanding the behaviour of seismic faults and assessing associated hazards and risks.

Landslides are another major source of risk for inhabitants and infrastructures. They have a key role in the evolution of the topography of mountain ranges. Remote sensing techniques facilitate global monitoring of hazard zones while not being hampered by any field constraints. Radar interferometry (InSAR) is advantageous for quantifying, with centimetre accuracy, a landslide that has taken place between two image acquisitions. It enables the operator to accurately determine the spatial distribution of the surface deformation. Moreover, the temporal evolution of landslide activity can be studied to analyse the impact of tectonic or climatic forcings that could induce catastrophic landslides.

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Evaluation of the vulnerability to risks associated with the transport of dangerous goods

It is essential to understand and prevent hazardous events so as to ensure the safety of inhabitants in the concerned area. Methodological risk characterization research involves quantification of hazard sources and also on taking into account—in an organized and formal way—the stakes (people, goods and environment) and their vulnerability, and finally on aggregating all of this information to assess risk levels.

An analysis of risks associated with hydrocarbon transport throughout the Ile de France (IdF) territory focused on modifications in risk levels induced by shifting hydrocarbon depots from the petite couronne area (four departments adjacent to Paris) to the grande couronne area (four departments on the periphery of IdF).

The number of kilometres travelled to deliver fuels to Paris has increased substantially, but it is also crucial to quantify the associated risks. The risk 'level' is defined as a function that combines a hazard potential variable (quantified by a probabilistic and deterministic approach) generated by the source (hydrocarbon transport) and a variable of the vulnerability of stakes in a concerned area. The method was implemented with GIS software to map the risk relative to hydrocarbon transport in IdF.

Three categories of mapping information were obtained:
- mapping the hazard potential of hydrocarbon transport;
- mapping the vulnerability within a territory (human, natural, material stakes);
- and finally mapping the risk level relative to a hydrocarbon depot and associated hydrocarbon transport involved in the depot shift.

Based on all of this information, an analysis can be conducted on the risk of shifting a hydrocarbon depot and to predict the impact of a given scenario.

This project was funded by the French Direction Générale de l’Énergie et des Matières Premières (Ministry of Economy, Finance and Employment) and supported by the ‘crisis management preparation’ service of the Direction Régionale de l’Équipement d’IdF/Service Sécurité Défense (Ministry of Equipment).

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Mapping economic indicators and uncertainties for flood prevention projects

Cost-benefit analysis (CBA) is a public policy assessment method based on comparison of expected policy drawbacks and advantages. In the framework of flood prevention projects, the advantages are estimated on the basis of damage avoided via these projects. Spatial data is involved in calculating this damage: flood maps for a range of different flooding intensities (derived through a combination of hydrological, hydraulic and topographical models), and land-use maps. These data are correlated on the basis of vulnerability functions determined for each type of stake. Several research issues associated with the spatial dimension of CBA emerge through its implementation.

First, methods should be developed that take spatial relationships between systems into account for economic modelling of stake vulnerability. Stakes are often considered as elementary and independent spatial entities (e.g. a cooperative, farm) whereas the damage suffered by a stake also depends on the relationships with other stakes, e.g. an agricultural cooperative located beyond a flood zone is concerned because of the damage suffered by member farmers who live in a flood zone. Secondly, a sensitivity analysis is required to validate the approach. It should take the errors propagated during coupling of different models into account and enable identification of key CBA data. The imprecision of a digital field model, for instance, will be ramified in the measurement of the efficiency of certain local protections, e.g. temporary protective embankments.

A spatialized CBA can be conducted to generate a cartographic representation of different intermediate and final results: flood damage map; map summarizing damage for a flood range; map of damage avoided for a studied project. The extent of flood exposure of a territory can thus be qualified. In the last step in which the produced maps are correlated, it is essential to assess the accuracy of the maps used and produced, as well as their legends and the spatial scale of the analysis.

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A method for evaluating farmland consumption via urban expansion

Periurban development, housing development in rural areas and the expansion of transportation and tourism infrastructures generally occur to the detriment of farmland. This land is systematically taken over and utilized as a result of local patterns (population growth, economic issues, introduction of infrastructures and real estate at the expense of a few hectares of farmland) and landowners’ interests.

This trend of farmland consumption to benefit urbanization is considered marginal on a local scale, but it is a concern on regional and especially national scales when multiplied by the number of towns and cumulated over time. The risk is that this extinction of farmland could be irreversible. Indeed, it would be difficult and expensive (or even impossible or economically unrealistic) to try to reconvert this land back into fields for crop production. In the current international setting of food production and farm product and foodstuff trade, it is thus a strategically important heritage component that is being consumed for immediate economic profit, without regarding the medium- and long-term social utility.

In 2008, the joint research unit (UMR) TETIS, in partnership with UMR LISAH, developed, in a pilot area in Languedoc-Roussillon region (France), a method for quantification and qualification of the spatial and temporal dynamics of farmland consumption by housing developments. This method, which was designed for potential application throughout France, is based on the use of satellite images acquired over the last 20 years, recent land-use databases, and a soil mapping inventory.

The method is being applied in 2009-2010 for validation and to generate objective results on farmland consumption patterns in this region since 1989. A national farmland conservation strategy could ultimately be applied, in line with recognized strategies for the conservation of natural areas and aquatic environments.

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Maps, and more recently aerial photographs and satellite images, have long been used to support decision-making processes. These data are primarily aimed at ‘rebuilding’ an actual situation through projections, military maps, orthophotos, spatial maps and other maps. These information sources showcase the natural geographical area and, within it, highlight physical resources, human communities and their activities. Interpretation tools are obviously required to give meaning to the shapes, colours and symbols, etc. They can also provide support for the acquisition of many different types of information that could be mobilized in databases or via local know-how and testimony. They may be presented in the form of atlases and information systems.

With computer progress, it is assumed that unlimited power is available for data management. However, experience shows that the full potential of available geoinformation is only utilized when implemented for a targeted approach. This information thus simply serves as an ‘intermediate tool’ to support individual or collective analysis and debate. It can be used to model phenomena and put forward hypotheses on cause-effect relationships through the identification of key factors, indicators and criteria, whose relevance must then be confirmed. Exchange platforms facilitate data management to gain insight into relationships between activity systems, territorial footprints and impacts on resources. Once this work is done, the image and maps serve as communication tools that enable presentation of results in attractive and accessible forms.

Natural and sanitary risk maps, development plans, cadastral maps and models are all decision support tools. Online mapping can also fuel social discussions.

Geoinformation has thus enhanced the scientific process as well as project decision-making and management processes. This is the approach discussed and illustrated in the present chapter through many users and various applications.

Historians and geographers can analyse and understand changes in land-use patterns through studies on road networks or landscape dynamics. Political scientists use different sources of available geographical data to interpret territorial modifications highlighted by war and peace dynamics. Geographic information systems facilitate the analysis of heterogeneous multisource and multidayte data for such studies. Remote sensing images can also be used to enhance land management in Madagascar, for instance, where very high spatial resolution images are used as base maps—communities may trace the boundaries of plots on these maps and draw up cadastral maps at reasonable cost. Correlation of geographical data and health data enables epidemiologists to detect certain environmental or social factors responsible for disease distributions. Finally, land planners propose future scenarios in collaboration with different territorial stakeholders, and this process is facilitated by the use of information systems as communication tools.

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Differential exposure of riverside populations of Río Beni (Bolivian Amazon) to mercury contamination

In Bolivia, epidemiological research concerning the variability in methyl mercury contamination in riverside communities of Río Beni has raised a geographical problem, where the contamination level is an indicator of lifestyles and spatial practices. What nonbiological factors associated with territorial practices and resource management are responsible for inequalities with respect to this contamination?

Two surveys were jointly conducted in 15 riverside communities, i.e. an epidemiological survey of women and their children and a geographical survey to highlight contrasting areas in terms of contamination. The population studied was found to use many different resources, ranging from farming, hunting, gathering, logging and other income-generating activities (house and boat building, etc.). However, the relative importance of these different activities has created an imbalanced situation with respect to health risks. A classification of resource management and exploitation strategies was drawn up on the basis of the findings of a multidisciplinary cross-sectional survey. This revealed five specific groups, with heterogeneous levels of mercury contamination.

This study, which was carried out by the EPIPREV (IRD) team, revealed the influence of social practices on the health risk in riparian populations of Río Beni in distinctly separate areas. Fishing was found to have a role in the degree of exposure, but this was significantly influenced by the specialized or diversified resource exploitation systems in which the families were involved. Consequently it was found that the population’s main activity determined the contamination level more than the proximity to Río Beni.

Studies are currently under way to assess the structure of territories, inhabitants’ practices and resource availability. The aim is to reduce exposure risks through better environmental management.

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A database was built with ArcGIS® software on the basis of historical spatial information describing land-use patterns in the Grands Causses region (France) with the aim of analysing the role of human societies in landscape dynamics.

Cadastral maps and index maps mentioning land cover types were digitized in order to determine the landscape structures that prevailed in the 19th century. This information was matched with older written sources in order to get a clearer picture of the peri-Mediterranean limestone mountainous landscape during the 1700-1900 period, i.e. treeless areas with substantial cereal cropping. Information for the early 20th century highlighted the impact on the landscape of the transition to an economy based on sheep production, i.e. a decrease in cropping and an increase in semi-natural grasslands, with a slight increase in forests.

In addition to the land-use patterns, cadastral maps enabled an analysis of a number of social parameters, including land appropriation (private or public), evolution in property sizes, and location of owners’ residences.

Information describing recent land-use stages (late 20th century) was derived from photo-interpretation studies or remote sensing. They revealed major changes in the landscape structure, with a very marked increase in forest area. This was partly due to reforestation, but especially to spontaneous forest growth from old core forests. These changes should be correlated with the modernization of livestock production systems which utilize semi-natural grasslands resources to a much lower extent. The dynamics of the landscape transformation, which began when cereal cropping was abandoned in the late 19th century, were further strengthened by the reduction in grazing pressure.

These transformations are now socially considered as being problematic from biological (biodiversity loss) and cultural standpoints.

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Documenting the impossible: the development of a GIS for a territory of high strategic importance—
the Greek-Albanian border region

The Greek-Albanian border region is a stretch of land and sea located relatively close to the Italian coast. The forests and beaches of Corfu are visible from the tops of the rugged mountains. For almost 50 years, however, this Balkan sector was one of the most tightly sealed and guarded parts of the former Iron Curtain. The state of war declared in 1940 between Greece and Albania was only lifted in 1987. The high militarization in this zone and strict border control ‘froze’ activities in many villages and forced marginalized populations into exile. Since the early 1990s, despite the many conflicts affecting southern Albania, the situation has cooled off and relationships between Athens and Tirana have gradually returned to normal.

How did the transition from the opened Ottoman vilayet of Ioannina (which disappeared in 1912)—a hub of activity and trade—to such fragmented areas take place? How can the recent transformation of such seemingly opposed territories and landscapes be explained?

Different GIS and remote sensing tools were implemented to determine the successive territorial changes that have taken place. The initial project (CNRS, Ecole Française d’Athènes) was hampered by many factors, including the fact that access to all mapping information and images was prohibited until just recently. However, highly varied data was still collected during several field trips: Ottoman, Greek and Albanian statistics (population, agriculture land use) established over the last century, old aerial photographs, declassified documents from CORONA satellite data, Landsat MSS archives, SPOT 5 and QuickBird images of the towns of Gjirokaster and Ioannina.

This effective use and analysis of multisource spatial data by a stakeholder during his research (for potential publication of the findings) is an essential step in this physical and social geographical approach—for this work, the geographer had to be able to adapt to different spatial information processing methods.

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Remote sensing—a key land reform tool in Madagascar

The Malagasy land reform, which has been under way since 2005 with the support of different expert teams (including UMR TETIS and UMR INNOVATION*), is based on land management decentralization. Municipalities with a ‘land office’ can now manage untitled private land for which they can award land certificates (CF) after local land recognition commissions (CRL) have been held.

Very high resolution orthorectified and georeferenced remote sensing images provide mapping templates for drawing up, on a municipal level, local land-use maps (PLOF) that are listed in different land acts: titled private property, untitled private property, special status areas, etc. During CRLs, certificate requestors and their neighbours sketch out the boundaries of plots to be certified based on ‘land markers’ that are visible on the images (irrigation canals, bunds, trails, remarkable trees, buildings, etc.). The image thus serves as a base for local participatory and contradictory land mapping. Hardcopy versions of each CF includes a PLOF extract drawn on the image, enabling owners to view the boundaries of their plots and their neighbours’ plots. Remote sensing satellite (QuickBird and Ikonos) images and aerial images are used by local authorities and Malagasy land services.

The image resolution range is 0.5–1 m. They are projected in the Laborde Madagascar system and used at 1:2500 to 1:10000 scale.

Costs and times for acquiring such images for large surface areas are inevitable issues when archival images are considered insufficient.

In late 2008, 300 municipalities out of 1550 had a land office and a PLOF, which means that considerable investment would be necessary for acquisition of the corresponding images and training on their use for land management purposes.

Contacts: Pascal Thinon, thinon@supagro.inra.fr & André Teyssier, ateyssier@cirad.mg

* UMR INNOVATION: Innovation and Development in Agriculture and the Agrifoods Sector (Montpellier SupAgro, INRA, CIRAD)

▲ Delivery of an act of recognition for a property in the commune of Miadanandriana, Madagascar (November 2006).
Many problems are often encountered when striving to ensure the consistency of territorial public policies in France, especially the capacity of stakeholders to get organized to collectively address the issues within their territory. This challenge is substantial since all concerned parties and the local population must, by law, be involved in the development and implementation of territorial projects. In this new setting, collective learning capacities within networks of mixed stakeholders are dependent on the availability of information and communication tools.

The joint research unit (UMR) TETIS has been collaborating with other laboratories, and in close partnership with the Syndicat Mixte du Bassin de Thau and different stakeholders in Thau Basin, to develop and implement tools that will favour integrated sustainable development (territorial consistency and orientation scheme, water planning and management scheme, Agendas 21).

Information and communication tools implemented or being developed are highly varied and address different levels of stakeholder participation. A few examples are: the MDWeb tool for inventorying and making effective use of information resources available within the stakeholder network, ‘stakeholder-guided’ cartography that combines observatory data and local know-how, physical relief models to facilitate territorial dialogue, a cellular automaton combined with a geographic information system to represent the dynamics of urban sprawl from 1940 to 2020, new tools based on Web 2.0 and online mapping to support large-scale public debates (INTERnet pour la MEDiation project [INTERMED]). In addition to contributions towards the development and dissemination of these innovations, UMR TETIS is conducting an assessment of their uses to measure progress towards a form of territorial intelligence.

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For further information on MDWeb: www.mdweb-project.org

Contact: Pierre Gondard, pierre.gondard@ird.fr

Andean road networks: technical history and population geography

The spatial distribution of transportation and communication networks reflects the social, economic and political structure and technological resources of a society, while also being a key factor in its development. Historical and geographical approaches to these spatial networks are studied by the research unit (UR) Dynamiques socioenvironnementales et gouvernance des ressources (IRD).

During pre-Columbian times, the main route for the movement of people, linking local confederations, was via the Andes. The ‘Inca Road’ followed previous trails. There was technical progress in the quality of stopping-station construction, maintenance and organization because the empire needed roads to control their territories and populations. The Inca Road, spanning over 4000 km, ran straight over mountains, high plains (Altiplanos) and through valleys without difficulty. The slopes were not very important for pedestrian travel until the advent of the industrial revolution.

In Peru and Ecuador, most people now live on the coastal plain. The Panamerican route shifted accordingly. The initial project was based on a railway network, but discussions are now focused only on the development of a road system. ‘Road’ and ‘Panamerican’ are sometimes synonymous in popular language. Lorry transport overtook railway transport around the middle of the 20th century since trains are unable to climb slopes of more than 4%. Lorries nevertheless lose 10% of their power with every 1000 m elevation step. The choice of development between the Altiplano at 4000 m and the coastal plain is not as simple as it seems.

A new route is taking shape on the eastern side of the Andes. From Venezuela to central Peru, it is only disrupted and dangerous in the Amazonian foothills region due to violent situations. The population along the road is quickly increasing. Coca and opium poppies are not present everywhere. To travel from Caracas to La Paz, it would be faster to go via the inside of the Andean Arch than by the outside, as is currently the case. The direct route via Manaus and the Transamazonian highway already links the two most remote Andean capitals—this is and will be the fastest itinerary.

Contact: Pierre Gondard, pierre.gondard@ird.fr
Geomatics and epidemiology: satellite images to track midges

The distribution of vectors (insects and mites that transmit pathogens) and communicated diseases is shifting as a result of climate change and human activities. The AGIRs team and the research unit (UMR) TETIS are collaborating to study the key environmental factors determining the disease distribution.

The topics investigated concern the search for epidemiologically useful indicators that could be obtained from satellite images and the application of geomatic tools for the spatialization of health hazards. One thesis research project derived from this partnership, carried out in collaboration with the Université de Franche-Comté, is aimed at identifying suitable landscapes for Culicoides imicola, a small exotic midge that transmits bluetongue disease to sheep, on SPOT satellite images of Corsica combined with field information. The recent arrival (late 1990s) of this midge in the Mediterranean Basin led to a major epizootic (animal epidemic) of bluetongue disease. Following a large-scale midge trapping campaign in sheep herds in southern Corsica, environmental characteristics such as land-use and spatial vegetation patterns, and the altimetric and hydrographic features around sites where the midge was present, were compared with characteristics in the vicinity of sites where the midge was absent. The results indicated that the presence of this midge was associated with environments where the vegetation cover had low chlorophyll activity and where the land-use pattern was highly diversified. Hazard maps were drawn up on the basis of these results in order to target surveys of the disease and vectors in both infected and uninfected zones.

Contact: Hélène Guis, helene.guis@cirad.fr
This Dossier is structured in four chapters. The first three deal with methodological research issues associated with the development of methods. The fourth chapter is thematic and is divided into four subchapters that illustrate the use of remote sensing and spatial information in various specific research fields.

The different research units and teams mentioned throughout the text are listed on the following chart.

The main topics focused on by the research teams are represented by a triangle (▲) and secondary topics are shown with a circle (●). Red triangles (▲) indicate the chapter in which the team’s features are presented.

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This research unit was disbanded in January 2009.

1. Satellite and airborne remote sensing
2. Spatial analysis and spatiotemporal modelling methods
3. Information systems and observatories
4. Spatial information applications in different fields:
   4.1. Agriculture, fisheries and forestry
   4.2. Environment
   4.3. Land-use planning, risks
   4.4. Populations and societies
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<tr>
<td>Pascal Kosuth</td>
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</tr>
</tbody>
</table>

1 These research units belong to the Institut Languedocien de Recherche sur l’Eau et l’Environnement federative research structure (ILEE, IFR 123), Director: Pierre Chevallier, chevalli@msem.univ-montp2.fr ; www.ifr-ilee.org
2 These research units belong to the Montpellier Environnement Biodiversité federative research structure (MEB, IFR 119), Director: Nicole Pasteur, nicole.pasteur@univ-montp2.fr ; www.biodiversite-montpellier.org
3 These research units belong to the Observatoire des Sciences de l’Univers ‘Observatoire de recherche Méditerranéen de l’Environnement’ (OSU OREME), Director: Nicolas Arnaud, nicolas.arnaud@gm.univ-montp2.fr
4 These research units belong to GEOSUD (Geoinformation for Sustainable Development), Director: Pascal Kosuth, pascal.kosuth@teledetection.fr

Geoinformation and Earth Observation for environment and territories
Agropolis International proposes a complete training-education programme provided through its member institutions (universities and engineering schools, as well as vocational training institutions). The training-education programme includes more than 80 diploma courses (from Bac +2 to Bac +8: technician, engineering degree, Master’s, post-Master’s degree, PhD), as well as vocational training modules (existing or developed upon request).

The tables below outline the training-education courses related to the Geoinformation domain. They specify the diploma levels, a description of the training courses and the institutions in charge of the programmes.

### Education programmes

#### Programmes focused on the Geoinformation theme

<table>
<thead>
<tr>
<th>Level</th>
<th>Degree</th>
<th>Title</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bac+5</td>
<td>Master professionnel (Professional MSc)</td>
<td>Territories and societies, planning and development (TSAD) Specialization 'Information systems and geoinformation for land management and governance' (SIIG3T)</td>
<td>AgroParisTech/ENGREF, UM2, UM3</td>
</tr>
<tr>
<td>Bac+6</td>
<td>Mastère Spécialisé CGE (Master of Advanced Studies)</td>
<td>Geolocalized information systems for territorial management (SILAT)</td>
<td>AgroParisTech/ENGREF, Montpellier SupAgro</td>
</tr>
</tbody>
</table>

#### Programmes specialized on other themes with the main components focused on the Geoinformation theme

<table>
<thead>
<tr>
<th>Level</th>
<th>Degree</th>
<th>Title</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bac+3</td>
<td>Licence (BSc)</td>
<td>Geography and planning</td>
<td>UPVD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geography, Planning</td>
<td>UM3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Earth and environmental sciences</td>
<td>UM2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Earth and environmental sciences</td>
<td>UPVD</td>
</tr>
<tr>
<td></td>
<td>Licence professionnelle (BSc with professional scope)</td>
<td>Web-oriented geographic information systems</td>
<td>UPVD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Geographic information processing</td>
<td>UPVD</td>
</tr>
<tr>
<td>Bac+5</td>
<td>Ingénieur (Engineering)</td>
<td>Agricultural engineering - Specialization 'Information and communication technology' (AgroTIC)</td>
<td>Montpellier SupAgro</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agricultural engineering - Specialization 'Territories and resources: public policies and stakeholders' (TERPPA)</td>
<td>Montpellier SupAgro</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agricultural engineering - Specialization 'Water, cropland and environment management' (GEME)</td>
<td>Montpellier SupAgro</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agricultural engineering - Specialization 'Environmental engineering: water, waste and sustainable planning'</td>
<td>AgroParisTech/ENGREF</td>
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<tr>
<td></td>
<td></td>
<td>Forest engineering</td>
<td>AgroParisTech/ENGREF</td>
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<tr>
<td></td>
<td></td>
<td>Engineering at the École des Mines d’Alès</td>
<td>EMA</td>
</tr>
</tbody>
</table>
Over the last 20 years, Agropolis International institutions, especially AgroParisTech within the framework of the Remote Sensing Center (Montpellier, France), have developed a solid diversified training programme for professional stakeholders and research staff wishing to enhance their knowledge on geoinformation methods and tools and to implement them in different specific fields.

In addition to this ‘catalogue’ training package, other special training courses are offered in response to specific requests. These services are adapted to fulfill the specific needs of partner organizations and are accompanied by educational engineering initiatives aimed at formalizing training approaches and disseminating geomatic training methods and tools. Educational technology is used especially so as to be able to tailor training sessions to the constraints and to the diverse range of target trainees (open and distance learning, customization of learning processes).

<table>
<thead>
<tr>
<th>Institution</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgroParisTech/ENGREF</td>
<td>Operational GIS: methods and tools (ArcGIS) (5 d)</td>
</tr>
<tr>
<td></td>
<td>Operational GIS: methods and tools (MapInfo) (5 d)</td>
</tr>
<tr>
<td></td>
<td>Administration of geographic data (5 d)</td>
</tr>
<tr>
<td></td>
<td>GIS project management (4 d)</td>
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<tr>
<td></td>
<td>Images and orthophotos in GIS (3 d)</td>
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<tr>
<td></td>
<td>Digital terrain models (3 d)</td>
</tr>
<tr>
<td></td>
<td>Cartographic representation (3 d)</td>
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<tr>
<td></td>
<td>Webmapping and online GIS services (4 d)</td>
</tr>
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<td></td>
<td>Definiens Developer software familiarization (5 d)</td>
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<tr>
<td></td>
<td>UML: modelling and environmental applications (5 d)</td>
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<tr>
<td></td>
<td>MapServer/PostGIS in practice</td>
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<tr>
<td></td>
<td>Free GIS software: initiation (2 d)</td>
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<tr>
<td></td>
<td>Free GIS software: familiarization (2 d)</td>
</tr>
<tr>
<td></td>
<td>Spatial statistics (5 d)</td>
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<tr>
<td></td>
<td>Participative management of territorial projects: facilitation initiation (3 d)</td>
</tr>
<tr>
<td></td>
<td>Participative management of territorial projects: benefits of geomatic tools (3 d)</td>
</tr>
<tr>
<td></td>
<td>Territorial analysis (5 d)</td>
</tr>
<tr>
<td></td>
<td>Use of spatial representations to develop territorial action strategies (4 d)</td>
</tr>
<tr>
<td></td>
<td>Network analysis (5 d)</td>
</tr>
<tr>
<td>CIRAD</td>
<td>Observatories and geographic information systems for rural planning and environmental management (4 weeks)</td>
</tr>
<tr>
<td>CIHEAM / IAM.M</td>
<td>Multi-use approach to land-use planning – Fences as an educational tool (trainer training, semi-distance training, 7 d)</td>
</tr>
<tr>
<td>Montpellier SupAgro</td>
<td>Land-use planning tools (8 d)</td>
</tr>
</tbody>
</table>
A PhD diploma is obtained after 3 years of laboratory research. PhD students are de facto attached to a PhD institution. PhD institutions host research units and laboratories working on major themes. Their mission is twofold: 1) to ensure direct scientific support for PhD students; 2) to provide additional training throughout the 3 years.

The purpose of these modules is to improve the scientific education of the PhD students and help them prepare their professional future.

Three graduate schools focus on the ‘Geoinformation’ theme:

Graduate school ‘Systèmes Intégrés en Biologie, Agronomie, Géosciences, Hydrosciences, Environnement’ (SIBAGHE)

The SIBAGHE graduate school (integrated biology, agronomy, geoscience, hydrosience and environment research systems) is devoted to life and earth sciences. It has joint accreditation with AgroParisTech/ENGREF, Montpellier SupAgro, UM2 and the Université d’Avignon for Agricultural and Environmental Sciences, along with the universities UM1 and UPVD for genomics, botany, microbiology and parasitology.

In the geoinformation field, the SIBAGHE graduate school hosts PhD candidates focusing thesis research on spatial and airborne remote sensing, spatial analysis and modelling applied to water, agriculture, environment, risks, health, etc.

Graduate school ‘Territoires, Temps, Sociétés et Développement’ (TTSD, ED 60)

The TTSD graduate school (territory, time, society and development) is affiliated with UM3 and UPVD. It groups 14 research teams, 200 teacher-researchers and around 500 PhD candidates. It offers PhD degrees in 13 fields, including ‘Geography and land-use planning’. Some of the main lines of research are:

- relationships between society (human groups, institutions, companies, etc.) and the environment (territories, resources, etc.)
- rural area, sustainable development, risk prevention and conservation of natural areas
- physical features and resources (natural or technological) of rural or urban areas, etc.

In the geoinformation field, the
TTSD graduate school hosts PhD candidates focusing thesis research on the analysis of spatial and temporal territorial dynamics and on the importance of information in territorial development, both in terms of drawing up and implementing public policies and governance strategies and discussions between stakeholders.

Graduate school ‘Information, Structures, Systèmes’ (I2S)

The I2S graduate school (information, structures, systems) is affiliated with UM2, with the participation of UM1, UM3 and Montpellier SupAgro. INRA and CIRAD are associate institutions. This school provides PhD training in a broad range of hard sciences (mathematics, mechanics, physics, information science and technology), with substantial interaction with life sciences. It is supported by 17 host research units with recognized expertise in each discipline.

It pools seven PhD specialties: biostatistics, electronics, informatics, mathematics, mechanics and civil engineering, automated systems and microelectronics, and physics. It currently hosts over 440 PhD candidates.

In the geoinformation field, the I2S graduate school hosts PhD candidates focusing thesis research on designing spatially referenced information systems and on image and signal processing methods.
## List of acronyms and abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgroParisTech</td>
<td>Paris Institute of Technology for Life, Food and Environmental Sciences / Institut des sciences et industries du vivant et de l'environnement (France)</td>
</tr>
<tr>
<td>BRGM</td>
<td>Geoscience for a sustainable Earth (France) / Géosciences pour une terre durable</td>
</tr>
<tr>
<td>Cemagref</td>
<td>Agricultural and environmental engineering research institute (France) / Institut de recherche pour l'ingénierie de l'agriculture et de l'environnement</td>
</tr>
<tr>
<td>CEPRALMAR</td>
<td>Centre d'Études et de promotion des Activités lagunaires et Maritimes du Roussillon (France)</td>
</tr>
<tr>
<td>CERF</td>
<td>Centre d'Essai de Recherche et de Formation (France)</td>
</tr>
<tr>
<td>CEROPATH</td>
<td>Community Ecology of Rodents and their PATHogens in South-East Asia</td>
</tr>
<tr>
<td>CHEAM / IAMM</td>
<td>International Centre for Advanced Mediterranean Agronomic Studies – Montpellier Mediterranean Agronomic Institute / Centre International de Hautes Études Agronomiques Méditerranéenne - Institut Agronomique Méditerranéen de Montpellier (France)</td>
</tr>
<tr>
<td>CIRAD</td>
<td>Agricultural Research for Development (France)</td>
</tr>
<tr>
<td>CNES</td>
<td>French National Space Agency* / Centre National d'Études Spatiales (France)</td>
</tr>
<tr>
<td>CNPq</td>
<td>National Council for Scientific and Technological Development (Brazil) / Conseil National de Développement Scientifique et Technologique (Brazil)</td>
</tr>
<tr>
<td>CNRS</td>
<td>National Center for Scientific Research (France) / Centre National de la Recherche Scientifique</td>
</tr>
<tr>
<td>EA</td>
<td>Host team / Équipe d'accueil</td>
</tr>
<tr>
<td>ED</td>
<td>Graduate school / Ecole doctorale</td>
</tr>
<tr>
<td>EMA</td>
<td>Ecole des Mines d’Alès (France)</td>
</tr>
<tr>
<td>ENGREF</td>
<td>Ecole nationale du génie rural, des eaux et des forêts (France)</td>
</tr>
<tr>
<td>ENITA</td>
<td>Ecole nationale d'ingénieurs des travaux agricoles (France)</td>
</tr>
<tr>
<td>ENVISAT</td>
<td>Environment satellite (ESA)</td>
</tr>
<tr>
<td>EPHE</td>
<td>École pratique des hautes études (France)</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency / Agence spatiale européenne</td>
</tr>
<tr>
<td>ETP</td>
<td>Potential evapotranspiration</td>
</tr>
<tr>
<td>FRE</td>
<td>Formation de recherche en évolution</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic information system</td>
</tr>
<tr>
<td>GEOSUD</td>
<td>Geoinformation for sustainable development</td>
</tr>
<tr>
<td>GPS</td>
<td>Global positioning system</td>
</tr>
<tr>
<td>HH-HV</td>
<td>Transmitting-receiving polarization (radar) : H Horizontal, V Vertical</td>
</tr>
<tr>
<td>IFR</td>
<td>Federative research institute / Institut Fédéral de Recherche</td>
</tr>
<tr>
<td>IFREMER</td>
<td>French Research Institute for Exploitation of the Sea / Institut français de recherche pour l'exploitation de la mer</td>
</tr>
<tr>
<td>IGN</td>
<td>French National Geographic Institute* / Institut géographique national (France)</td>
</tr>
<tr>
<td>INRA</td>
<td>National Institute for Agricultural Research (France) / Institut national de la recherche agronomique</td>
</tr>
<tr>
<td>INRIA</td>
<td>French national institute for research in computer science and control / Institut national de recherche en informatique et en automatique</td>
</tr>
<tr>
<td>InSAR</td>
<td>Interferometric synthetic aperture radar</td>
</tr>
<tr>
<td>IRD</td>
<td>French Institute of Research for Development* / Institut de recherche pour le développement (France)</td>
</tr>
<tr>
<td>IUT</td>
<td>University Institute of Technology* (France) / Institut universitaire de technologie</td>
</tr>
<tr>
<td>LIDAR</td>
<td>Light detection and ranging</td>
</tr>
<tr>
<td>MODIS</td>
<td>Moderate Resolution Imaging Spectroradiometer</td>
</tr>
<tr>
<td>Montpellier</td>
<td>International Center for Higher Education in Agriculture Sciences (France) / Centre international d'études supérieures en sciences agronomiques</td>
</tr>
<tr>
<td>SupAgro</td>
<td>Centre international d'études supérieures en sciences agronomiques</td>
</tr>
<tr>
<td>MSS</td>
<td>Landsat multispectral scanner</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration (USA)</td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalized difference vegetation index</td>
</tr>
<tr>
<td>NIR</td>
<td>Near infrared</td>
</tr>
<tr>
<td>ONF</td>
<td>French National Bureau of Forestry * / Office national des forêts (France)</td>
</tr>
<tr>
<td>Radar</td>
<td>Radio detection and ranging</td>
</tr>
<tr>
<td>ROSELT</td>
<td>Network for long-term ecological monitoring observatories / Réseau d'Observatoires de Surveillance Écologique à Long Terme</td>
</tr>
<tr>
<td>SEAWifs</td>
<td>Sea-viewing Wide Field-of-view Sensor Project</td>
</tr>
<tr>
<td>SPOT</td>
<td>French Earth Observation satellite / Satellite Pour l’Observation de la Terre</td>
</tr>
<tr>
<td>SYSCOLAG</td>
<td>Coastal and lagoon systems of Languedoc-Roussillon region* (France) / SYstèmes Côtières et LAGunaires du Languedoc-Roussillon</td>
</tr>
<tr>
<td>TSIGANE</td>
<td>Technologies et Système d'Information Géographique pour l'Agriculture via Internet</td>
</tr>
<tr>
<td>UAPV</td>
<td>Université d'Avignon et des Pays de Vaucluse (France)</td>
</tr>
<tr>
<td>ULM</td>
<td>Ultra-light motorized aircraft</td>
</tr>
<tr>
<td>UM1, 2,3</td>
<td>Universités Montpellier 1, 2, 3 (France)</td>
</tr>
<tr>
<td>UMR</td>
<td>Joint research unit / Unité mixte de recherche</td>
</tr>
<tr>
<td>UPR</td>
<td>Internal research unit / Unité propre de recherche</td>
</tr>
<tr>
<td>UPVD</td>
<td>Université de Perpignan Via Domitia (France)</td>
</tr>
<tr>
<td>UR</td>
<td>Research unit / Unité de recherche</td>
</tr>
<tr>
<td>URP</td>
<td>International research unit / Unité de recherche en partenariat</td>
</tr>
<tr>
<td>US</td>
<td>Service unit / Unité de service</td>
</tr>
</tbody>
</table>

* unofficial translation