

Remote sensing: *a tool to monitor and assess desertification*



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and Company), **Professor E. Zakarin** (National Center for

Radio Electronics and Communications),

the POSTEL team (*Pôle d'Observation des Surfaces*

continentales par TELEdetection) as well as the authors

of the pictures shown in this report.

Design and production

Olivier Piau (Agropolis Productions)

Printed by *Les Petites Affiches* (Montpellier, France)

Translated by Catherine Tiné

Registration of copyright: on publication • ISSN: 1772-6964

1,500 copies • also available in French

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The French Scientific Committee on Desertification

The creation in 1997 of the French Scientific Committee on Desertification (CSFD) has met two concerns of the Ministries in charge of the United Nations Convention to Combat Desertification. First, CSFD materialises the will to involve the French scientific community versed in desertification, land degradation, and development of arid, semi-arid and sub-humid areas, in generating knowledge as well as guiding and advising the policy makers and actors associated in this combat. Its other aim is to strengthen the position of this French community within the international context. In order to meet such expectations, CSFD is meant to be a driving force regarding analysis and assessment, prediction and monitoring, information and promotion. Within French delegations, CSFD also takes part in the various statutory meetings of the organs of the United Nations Convention to Combat Desertification: Conference of the Parties (CoP), Committee on Science and Technology (CST), Committee for the Review of the Implementation of the Convention. It also participates in meetings of European and international scope.

CSFD includes a score of members and a President, who are appointed *intuitu personae* by the Minister for Research, and come from various specialities of the main relevant institutions and universities. CSFD is managed and hosted by the Agropolis Association that gathers, in the French town of Montpellier and Languedoc-Roussillon region, a large scientific community specialised in agriculture, food and environment of tropical and Mediterranean countries. The Committee acts as an independent advisory organ; it has neither decision-making powers nor legal status. Its operating budget is financed by subsidies from the French Ministries of Foreign Affairs and for Ecology and Sustainable Development. CSFD members participate voluntarily to its activities, as a contribution from the Ministry for Research

More about CSFD:

www.csf-desertification.org

Redaction, production and distribution of Les dossiers thématiques du CSFD are fully supported by this Committee through the backing of relevant French Ministries. Les dossiers thématiques du CSFD may be freely downloaded from the Committee website.

*With special contribution from
the French Space Agency (Centre National d'Études Spatiales, CNES)*



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Mankind is facing a world-wide concern, i.e., desertification, which is both a natural phenomenon and a process induced by human activities. Our planet and natural ecosystems have never been so much degraded by our presence. Long considered as a local problem, desertification now belongs to global issues that affect us all, whether a scientist, a decision-maker, a citizen from the South or from the North. Within such a context, it is urgent to mobilise the civil society and induce it to get involved. To start with, people must be given the elements necessary to understand better the desertification phenomenon and its stakes. Scientific knowledge must be brought within everyone's reach, in a language understood by the great majority. Within this scope, the French Scientific Committee on Desertification has decided to launch a new series entitled "*Les dossiers thématiques du CSFD*", whose purpose is to provide appropriate scientific information on desertification, its implications and stakes. This series is intended for policy makers and their advisers, whether from the North or from the South, but also for the general public and for the scientific journalists involved in development and environment. It also aims at providing teachers, trainers and trainees with additional information on various fields. Lastly, it endeavours to help spreading knowledge to the actors part of the combat against desertification, land degradation, and poverty, such as representatives of professional, non-governmental, and international solidarity organisations. A dozen reports are devoted to different themes such as biodiversity, climate change, pastoralism, remote sensing, etc; in order to take stock of the current knowledge on these various subjects. The goal is also to set out ideological and new concept debates, including controversial issues; to expound widely used methodologies and results derived from a number of projects; and lastly, to supply operational and intellectual references, addresses and useful websites.

These reports are to be broadly circulated, especially within the countries most affected by desertification, by e-mail (upon request), through our website, and in print. Your feedback and suggestions will be much appreciated! Redaction, production and distribution of "*Les dossiers thématiques du CSFD*" are fully supported by this Committee thanks to the backing of relevant French Ministries. The opinions expressed in these reports are endorsed by the Committee.

Hubert Curien⁺
Member of the French
Academy of Sciences

Since the dawn of time, the first hunters, and later the first shepherds and farmers, observed their environment with their eyes and brain. They thus conceived systems of interpretation that enabled them to know where to sow and plant, where to graze their animals, and where to build their villages. Then several big revolutions occurred, in particular during the 19th century: opticians invented telescopes and binoculars, Niepce and Daguerre invented photography, and the brilliant Nadar was the first ever to set up a photographic camera in the gondola of a balloon. Aerial photography was born.

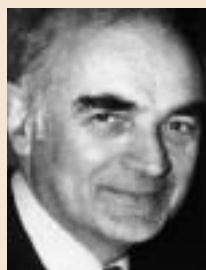
Initially much used during World War I to locate the enemy's position, this technique expanded out of the military field to become the essential tool of every cartographer and town and country planner around the world. At the beginning of the 60', the first meteorological satellites appeared, which have become essential to short-term forecasts. Earth observation satellites came out in 1972 with the US Landsat series, and the generation of high resolution satellites began with the French SPOT satellite in 1986. Today, a wide range of high, medium and low resolution satellites and sensors are available to monitor our environment, to make comparisons in time and space, and to model our ecosystems and planet in order to know them better.

Thanks to these means, lots of data are received daily, but they are too often the privilege of scientists and people highly skilled in their processing. Their use in developing countries, and especially in arid, semi-arid and sub-humid areas, began about two decades ago. The huge services that these new techniques could supply, in particular to assess degraded areas and try to forecast trends, were soon realised.

Considering that such techniques should not remain the prerogative of technicians of developed countries, many cooperative actions have been implemented and are still ongoing within bilateral or international frameworks. To allow development stakeholders and decision-makers to use the results obtained, it is necessary to popularise such results and to provide information regarding their limits and costs.

This is the aim of the current CSFD publication, and I congratulate the Committee and the authors on their efforts in making accessible to a wide audience the complex steps required to convert data recorded onboard satellites into useful information.

in memoriam



Hubert Curien redacted the preamble of this report in January 2005, little before departing this life on February 6th. We wish to pay him a special tribute, considering his constant concern to disseminate scientific and technological results to the greatest possible majority.

We will miss a great man who had been General Director of the French National Centre for Scientific Research (CNRS), President of the French Space Agency (Centre National d'Études Spatiales, CNES), Minister of Research, President of the French Academy of Sciences and President of the Cirad Ethics Committee.

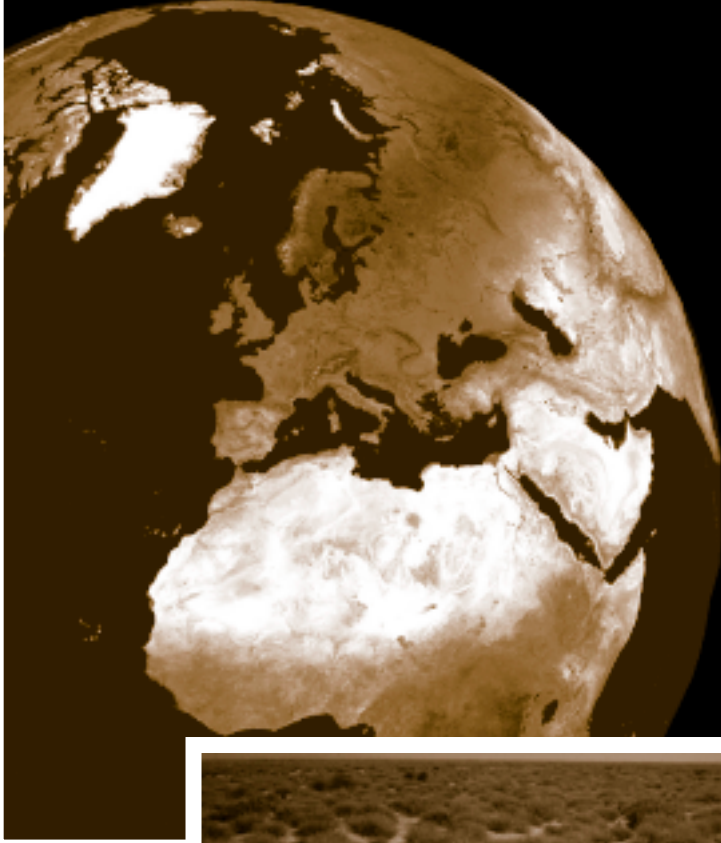


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To go deeper...

Remote sensing, a support to the study and monitoring of the Earth environment

Earth observation technologies play a major part in the study, modelling and monitoring of environmental phenomena, at various spatial and temporal scales, and on an objective, exhaustive and permanent basis. These technologies therefore open the way for the implementation of early warning systems, and capacitate policy- and decision-makers to set out relevant strategies for sustainable development.

Various national and international programmes for space-based Earth observation (LANDSAT, SPOT, IRS, ERS, ADEOS, RADARSAT, ENVISAT, TERRA, METEOSAT, MSG, etc.) have been implemented as soon as 1960 and are still ongoing. They evidence the degree of priority that States (among which France plays a prominent part) attach to this technology. Up to now, the progress achieved (satellite design, measurement instruments, etc.) offers increasing capabilities to study and monitor our environment as well as global change.

Remote sensing: both a science and a technology

Remote sensing is defined as “*all the knowledge and techniques used to determine the physical and biological characteristics of an object by measuring it without physical contact with it*” (From Journal Officiel¹, December 11th, 1980).

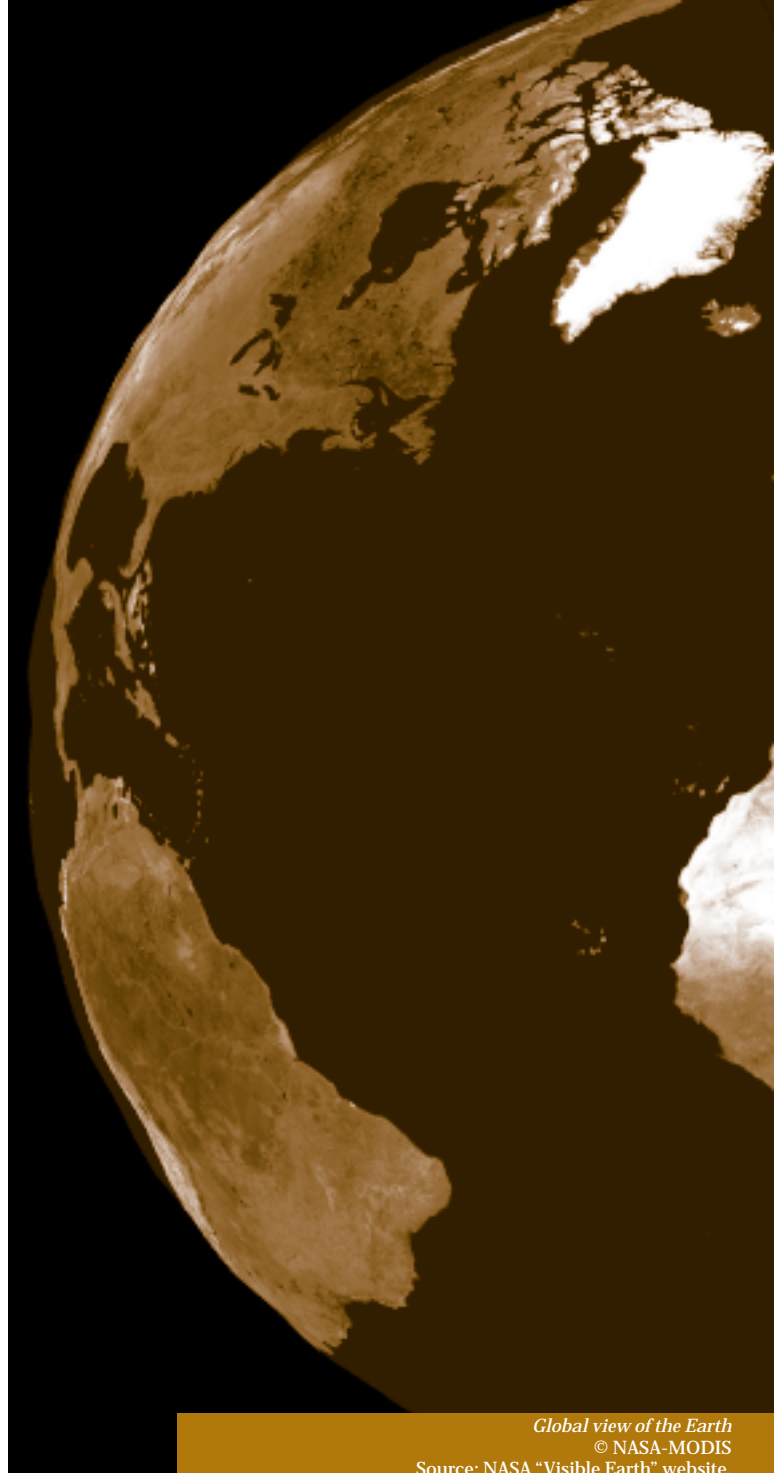
Instead of this quite broad definition, remote sensing is usually understood as a tool that allows to study phenomena involving only electromagnetic waves, mainly detected and recorded by **sensors** onboard planes or satellites². Remote sensing is consequently a way to define an object or group of objects on the Earth surface from its particular features:

- A **spectral signature**, i.e. a characteristic electromagnetic signal or set of electromagnetic signals in specific more or less narrow wavelength(s) of the electromagnetic range;
- A temporal variation in this spectral signature;
- A determined spatial distribution of this object;
- One or several relations of this object with the other objects that surround it, i.e. the so-called “neighbouring objects”.

Vegetation, lands, rivers, water-covered areas, buildings, and generally speaking, any element located on the Earth surface and interacting with an electromagnetic radiation, are considered as objects.

¹ Bulletin of official announcements issued by the French Republic (translator's note).

² This use is not universal; for instance, our Russian colleagues have a much wider definition of remote sensing.

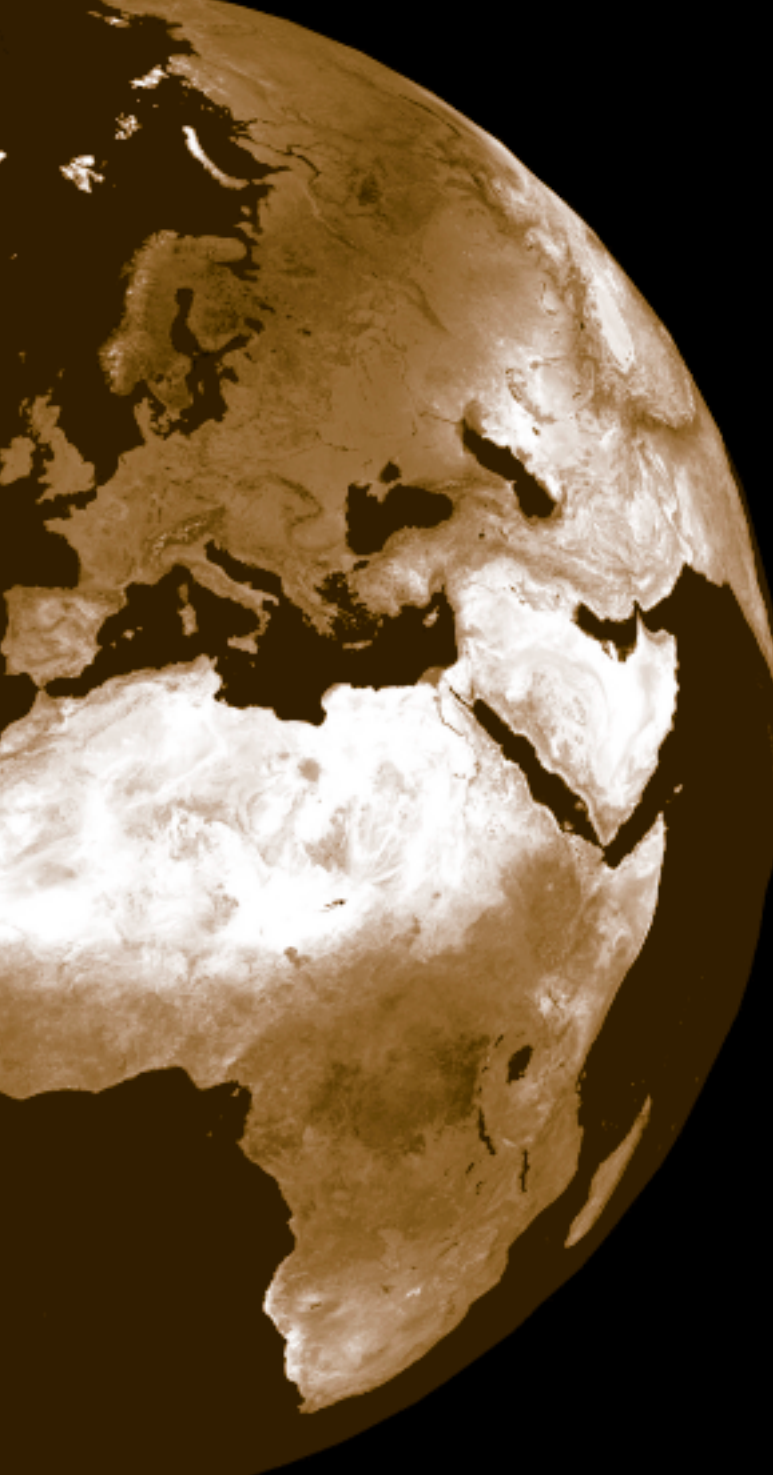


Global view of the Earth

© NASA-MODIS

Source: NASA “Visible Earth” website, consulted on January 11th, 2005. <http://visibleearth.nasa.gov>

Remote sensing is both a technology and a science that enables to observe and analyse our environment and subsequently to define, monitor and assess policies for natural resource management. Satellite-based remote sensing is currently one of the only tools that allow to collect detailed information (quite) anywhere on Earth, quickly and objectively, regularly and repetitively, thus enabling to monitor environmental events (pollution, forest fires, earthquakes, floods, desertification, etc.). It also allows to derive applications in many fields such as agriculture, forestry, hydrology and water resources, oceanology, geology, mapping, town planning, cadastre, as well as strategic information (most of remote sensing techniques were first developed for military purposes).



Brief history

Remote sensing was born with the first aerial black and white photograph taken by Nadar from a balloon above Paris in 1858. However, aerial photography, that allows to obtain a global vision of our environment, was actually developed during World War I. At first limited to the visible range (wavelength $[\lambda]$ between violet $[0.4 \mu\text{m}]$ and red $[0.8 \mu\text{m}]$), photography was then extended to the near infrared radiation (λ between $0.8 \mu\text{m}$ and $1 \mu\text{m}$). From the 60's, its until then military use was broadened to civilian applications such as vegetation study.

From World War II, airborne remote sensing techniques were enhanced, especially through the development of new instruments such as radars (the first imaging radars were made in England in order to improve the accuracy of night bombing).

Aerospace remote sensing appeared in the 60's, but was really developed at an international scale with the NASA (National Aeronautics and Space Administration) LANDSAT programme in 1972. A second key date was indisputably the launching of the SPOT satellite by France (with Swedish and Belgian contributions) in 1986.

A number of programmes and satellites have followed since then, and the design of satellites together with the conception and variety of measurement instruments have been substantially improved, thus enabling to collect a great variety of highly accurate top-quality data. Space-based remote sensing already offers considerable capabilities, but many studies remain to be undertaken in order to further enhance its use.

Remote sensing principles: the basics

Remote sensing uses the physical properties of objects, commonly called **targets**, to collect information on their nature and define them. It supposes an interaction between the energy that is transmitted by electromagnetic radiation coming from a natural (e.g. the sun) or artificial (e.g. microwave emission) source, and the target. This energy is then sensed by an observing system, the sensor (embarked onboard a satellite), that records it and transmits it to a receiving station, then transforming this signal into a digital image. Electromagnetic radiation interacts with the atmosphere a first time when it passes through from the source to the target, and then in the opposite direction, from the target to the sensor. These interactions induce modifications in the electromagnetic signal, which are used to characterise the object observed at ground.

Basic physical foundations

• *Electromagnetic spectrum and radiation sources*

The electromagnetic spectrum is divided into different ranges, from short to long wavelengths. Space-based remote sensing only uses part of the electromagnetic spectrum, on technological grounds and also because the atmosphere is not “translucent” in all the wavelengths. These ranges are mainly the following ones: visible (λ between 0.4 μm and 0.8 μm), near infrared (λ between 0.8 μm and 1.1 μm), middle infrared³, thermal infrared (λ between 10 μm and 12 μm , which is the radiation emitted under the form of heat by the Earth surface), and microwave range (radar remote sensing). There are two main types of remote sensing, **passive remote sensing** and **active remote sensing** (radar). Passive remote sensing resorts to passive sensors that measure the natural radiation reflected by objects on the Earth surface, whereas with active remote sensing, the system both emits and receives an electromagnetic signal.

Electromagnetic radiation may be transmitted by different sources:

- The sun (visible, near and middle infrared ranges): sensors record the solar energy reflected by objects on the Earth surface.
- The ground (thermal and microwave fields): remote sensing receivers record the energy emitted by the Earth from its surface temperature.
- A so-called artificial source, i.e. an active sensor (e.g. lasers and microwave radars).

• *Disturbances caused by the atmosphere on radiation*

Solar radiation, emitted or backscattered by objects at ground, is subjected to alterations or disturbances (**refraction, absorption, scattering, proper emission**) of various kinds when it passes through the atmosphere. Indeed, the atmosphere allows electromagnetic radiation to pass through in specific spectral bands only, the so-called “atmospheric windows”. Atmospheric influence must therefore be considered by modelling, in order to compute fluxes measured by space-based sensors⁴.

³ Middle infrared is usually limited to a wavelength range in which thermal emission is not significant ($\lambda < 5 \mu\text{m}$).

⁴ A computer displays each digital value of an image as light intensity.



Artist view of an ENVISAT satellite
© ESA-DENMAN Productions

The three types of electromagnetic radiation: reflected, emitted and backscattered radiation

• *Signal reflected by objects on the Earth surface*

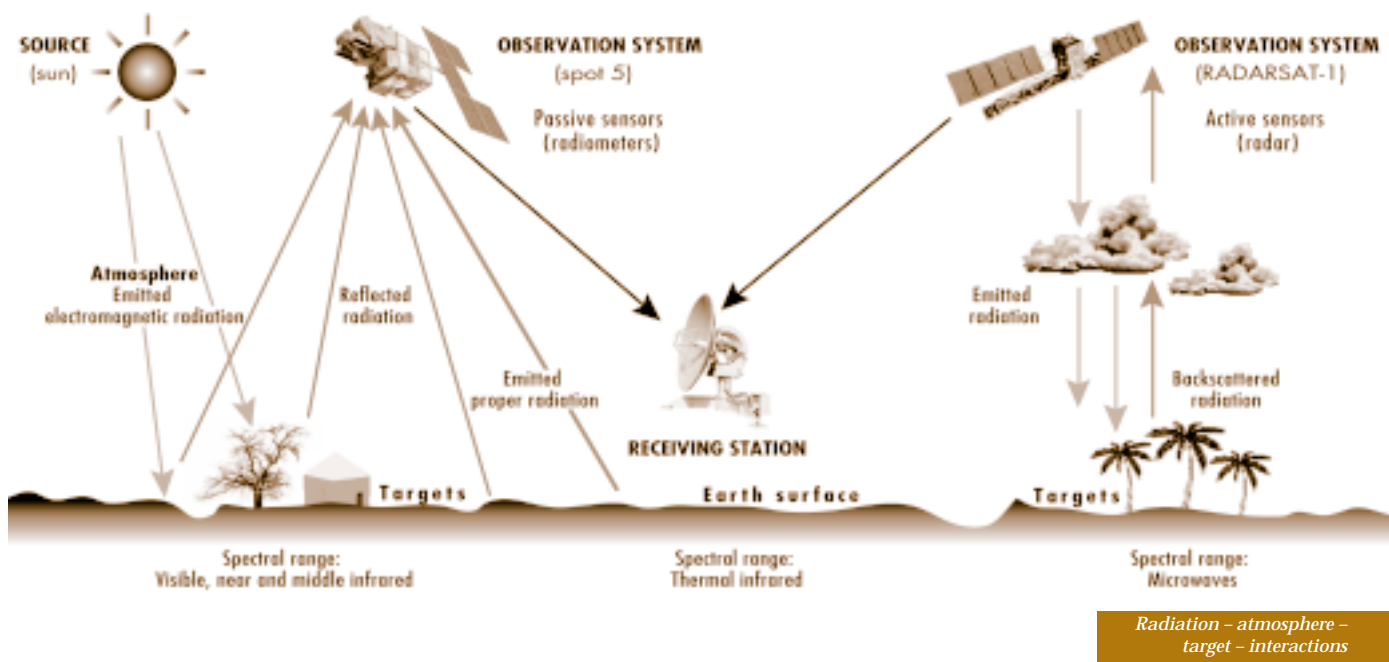
When solar radiation hits the ground, it is in part reflected to the atmosphere off the Earth surface and objects at ground. Signal reflection depends on the nature and properties of the surface and on its wavelength. On perfectly smooth surfaces, the whole solar energy is reflected in a single direction, whereas on rough surfaces, it is reflected in every direction (as usually occurs). In such case, the solar flux reflected mainly corresponds to the visible and near infrared ranges. Recordings are only possible during daytime and if the atmospheric transmission of electromagnetic radiation is good. With active remote sensing (radar), the energy reflected in the direction of the sensor is said to be backscattered.

• *Energy emitted by objects*

With passive remote sensing, sensors measure the energy directly emitted by objects, in the thermal infrared as well as microwave ranges. This energy is related to the temperature and surface state of objects. Contrary to the former case, the signal emitted can be measured night and day.

• *Energy backscattered by objects*

This concerns active remote sensing: the observing system includes both a transmitter (artificial source) and a receiver, usually located at the same place. The electromagnetic radiation that is emitted in the direction of the target interacts with its surface and is scattered in every direction. Part of the energy is consequently reflected in



the direction of the sensor: this is the backscattered signal. The basic principle of a radar is transmission and reception of pulses, which makes it sunlight-independent. Radars consequently allow night and day recordings, and are particularly useful in cloudy areas (microwaves do not depend on meteorological conditions), where it is often difficult to collect data in the visible or near infrared ranges.

Elements of remote sensing systems

A remote sensing system is a whole combination that includes a **platform**, one or several sensors, and various means of controlling the system and of processing the data collected.

• Platforms

They are aerial (plane or balloon) or spatial (satellite) vehicles that embark tools (sensors) to measure and record data collected on objects observed at ground. A satellite may be **sun-synchronous** or **geostationary**.



*Sun-synchronous orbiting satellite
(in white: ground track
and swath)*

• Sensors

They are measurement instruments that allow to collect and record data on objects observed on the Earth surface (in one or several given wavelengths) and to transmit them to a receiving system. There are passive sensors that only record the solar radiation reflected or the own radiation emitted by objects, and active sensors that both emit and receive the energy reflected by the target. Sensors are characterised by their:

- **Spatial resolution:** It corresponds to the size of the smallest element (**Pixel**) detectable on the Earth surface. The sharpness and details that can be distinguished in a remotely sensed **image** are a function of spatial resolution.
- **Spectral resolution:** It is defined as the width or wavelength range of the part of the electromagnetic spectrum the sensor can record and the number of channels the sensor uses.
- **Ground swath:** It is the surface observed at ground (the targeted scene).

Because of their high altitude (36,000 km), sensors of geostationary satellites observing large surfaces cannot supply detailed images of our planet. On the contrary, sensors onboard lower orbiting satellites (for instance, sun-synchronous satellites, from 750 km to 900 km height) provide detailed images but on smaller areas.

• Control and receiving facilities

A satellite remote sensing system is always associated with a mission (or programming) centre that regularly defines the tasks to be performed by the satellite, a control centre to pilot the satellite, data receiving and recording stations, one (or several) data pre-processing centre(s), and structures for data dissemination (distribution / marketing). Pre-processing centres (that are often combined with receiving stations) supply standard products of easier use.

Characteristics of the main current and future operational sensors and satellites – A non-exhaustive list

Satellite	Panchromatic Multiband	Spatial resolution	Spectral resolution	Ground Swath	Derived products (non-exhaustive list)
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Very high spatial resolution satellites

SPOT 5	Panchromatic Multiband	2.5 m and 5 m 10 m	Optical	60*60 km 60*120 km	Maps (geological, soil, land cover, vulnerability maps), satellite image maps, informative plans (river systems, road and railway networks), Digital Terrain Models (DTMs)
IKONOS 2	Panchromatic Multiband	1m 4 m	Optical	11*11 km	Maps, satellite image maps, informative plans, DTMs
QUICKBIRD	Panchromatic Multiband	0.60 and 0,7m 2.4 and 2.88 m	Optical	16.5 km	Maps, satellite image maps, informative plans, DTMs
ORBVIEW 3	Multiband	1 and 4 m	Optical	8*8 km	Maps, satellite image maps, informative plans, DTMs
HELIOS 2A		30 cm	Optical	Confidential	Defence
Pléiades (2008-2009)	Panchromatic Multiband	0.7 m 2.8 m	Optical	21 km	Maps, satellite image maps, informative plans, DTMs
EROS A	Panchromatic	1 - 1.8 m	Optical	12.5*12.5 km	Maps, satellite image maps, informative plans, DTMs
ROCSAT-2	Panchromatic Multiband	2 - 5 m 8 - 20 m	Optical	24*24 km	Maps, satellite image maps, informative plans, DTMs
IRSP6	Multiband	5.8 m 23 m 60 - 70 m	Optical	24 to 70 km 140 km 740 km	Maps, satellite image maps, informative plans
RADARSAT-1		3 to 100 m	Radar	20 to 500 km	Informative plans, DTMs, maps (soil moisture, flooded area maps)

Medium spatial resolution satellites

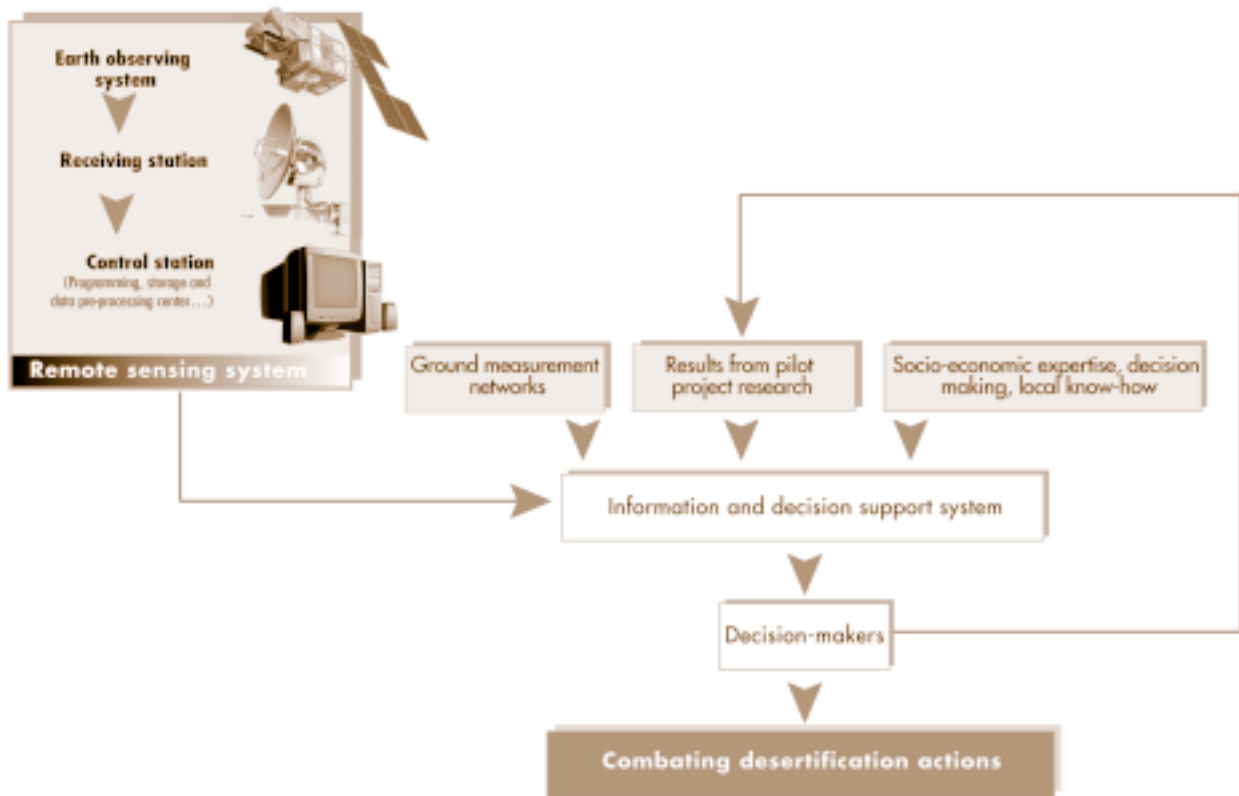
ERS 1,2		25 m	Radar	100 km	Coherence products that allow to derive land cover (especially in tropical areas) and geological maps. Soil moisture, flooded area maps. DTMs
SPOT 1, 2, 3 and 4	Panchromatic Multiband	10 m 20 m	Optical	60*60 km 60*80 km	Maps, satellite image maps, DTMs, informative plans
LANDSAT 7 (ETM)	Panchromatic Multiband	15 m 30 m	Optical	185*170 km	Maps, satellite image maps, DTMs, informative plans
LANDSAT 4, 5	Multiband	30 and 80 m	Optical	185 km	Maps, satellite image maps, informative plans
ENVISAT (ASAR)		10 to 1,000 m	Radar	15*5 km to 405*405 km	Maps (geological, topographical, soil moisture, flooded area, marine pollution, coastal dynamics, glaciology maps), informative plans, DTMs
TERRA (ASTER)	Multiband	15 to 90 m	Optical	60 km	Maps, satellite image maps, informative plans, DTMs

Low spatial resolution satellites

SPOT (VEGETATION)	Multiband	1 km	Optical	2*2 km	Synthesis products (daily, ten-day syntheses), NDVI (Normalised Difference Vegetation Index)
METEOSAT	Multiband	2.25 and 4.5 km	Optical	Hemisphere	Meteorological, oceanographic and geophysical products
MSG (Meteosat Second Generation)	Multiband	1 and 3 km	Optical	Hemisphere	Meteorological, oceanographic and geophysical products
ENVISAT (MERIS)	Multiband	300 m	Optical	1,150 km	Products derived from ocean colour measurements (carbon cycle, fishing area management, coastal area management...)
SMOS (Feb. 2007)		35 and 50 km	Radar	1,000 km	Maps (soil moisture, ocean salinity maps)
PARASOL	Multiband	6*7 km	Optical	2,400 km	Radiative budget maps, observation of clouds and aerosols

Correspondence between satellite image resolution and map scale:

1,000 m -> 1/1,500,000 • 30 m -> 1/80,000 • 20 m -> 1/50,000 • 10 m -> 1/24,000 • 5 m -> 1/12,000 • 1 m -> 1/2,000



Scope of a remote sensing system

What is the use of remotely sensed data?

A remote sensing system is not by itself self-sufficient to generate information directly usable by end-users. It is first and foremost a tool for data production. Such data are then analysed together with other data sources (field data, socio-economic data, etc.) in order to derive understandable useful information likely to be integrated into information and decision support systems (Geographic Information Systems).

A remote sensing system may be used in various contexts; it especially plays an essential part within the scope of the combat against desertification. Indeed, it allows to follow-up and monitor the environment in the long term, to detect risk areas, to determine desertification factors, to support decision-makers in defining relevant measures of environmental management, and to assess their impacts.

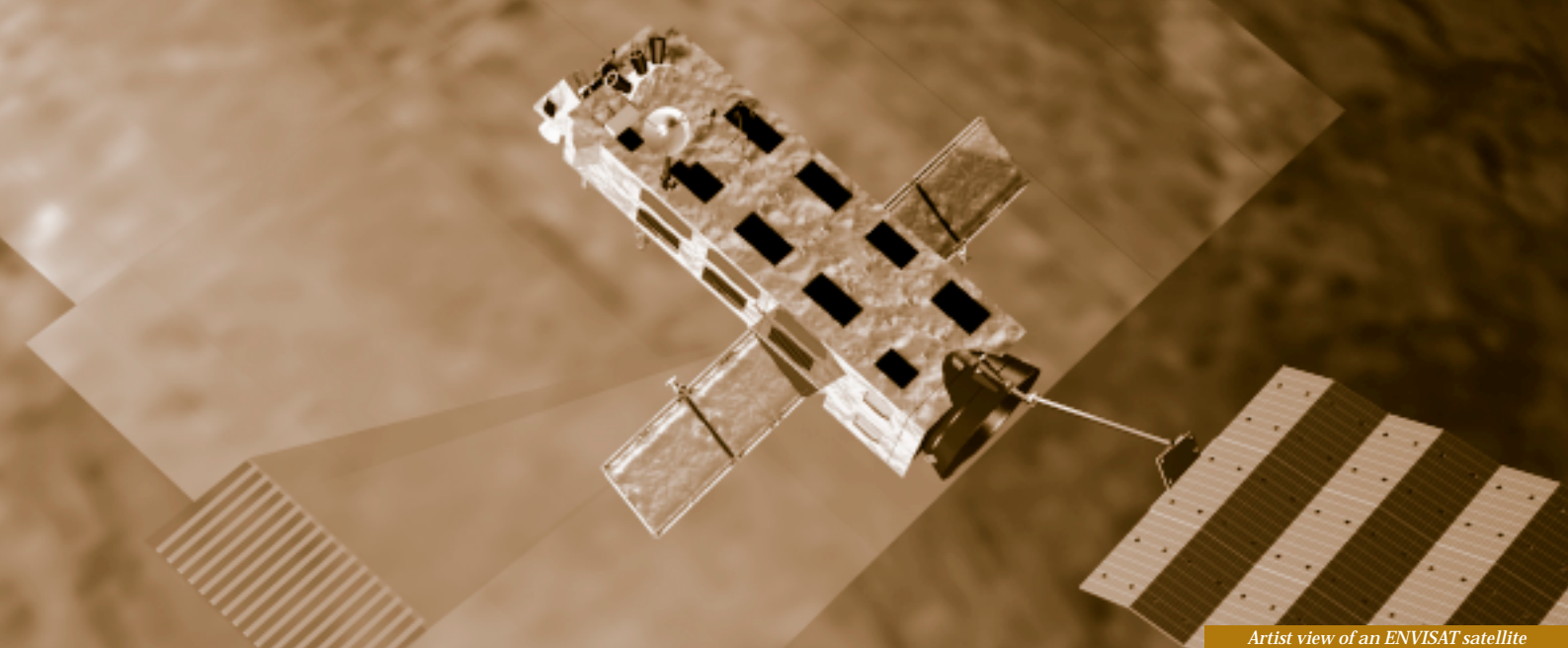
Various steps to get satellite images

Sensors record the spectral response of objects observed on the Earth surface. Such data are neither photographs nor direct images. A satellite image consists of a two-dimensional array of points (pixels). Each pixel has coordinates (a location address) and an intensity value

(represented by a digital number). The intensity value corresponds to the electromagnetic signal measured by the sensor, in a given wavelength range (named spectral band). Multispectral sensors record this physical measurement in various spectral bands (or channels); their number and type vary according to the sensor. Therefore, several radiometric values correspond to each image pixel; this is the spectral signature of an object at a given time.

Digital images are displayed by associating each spectral band with a primary colour (red, green, blue). Combining the various colours that correspond to the various intensity values of a given pixel generates a combined colour (additive colour synthesis). This is how colour composites are obtained; the most widespread process is called “false colour” by analogy with aerial infrared photographs (both use the same combination of spectral bands).

Images are generally pre-processed in two ways: **geometric corrections** (to comply with a system of **map projection** for instance) and **radiometric corrections** (that take into account the bias induced by the atmosphere and convert space-based measurements into “ground” values). Images may be further processed in order to improve their readability or to extract specific information related to a particular study.



Artist view of an ENVISAT satellite
© ESA-DENMAN Productions

How much do satellite images cost?

Prices vary a great deal according to the category and characteristics of a given image and to the different suppliers' policies.

Two major categories should be distinguished: archive images and programmed images. Archive images are scenes already recorded that are kept by imagery suppliers. They may be consulted and ordered. Since the launch of the first SPOT satellite in 1986, the Spot Image company has created an archive of more than 10 million images that may be consulted through the company's SIRIUS catalogue. Programmed images are future images to be collected according to the needs and characteristics defined by the customer. They are generally more expensive; their price also depends on the features of the image ordered (image resolution, type of satellite):

- **Very high resolution images** allow to detect objects of a size ranging from tens of centimetres to metres. They are widely used in defence and town planning sectors. They are supplied by military satellites (including Helios, confidential data) and in the civilian field, by the Quickbird and Ikonos commercial satellites.
- **Medium resolution images** (of about tens of metres) allow to classify lands and to locate and differentiate forest covers and agricultural lands. They are provided by the Landsat, Spot and ERS satellites.
- **Low resolution images** (ranging from hundreds to thousand metres) are used at the regional and global scales. When regularly repeated, they are used to monitor environmental phenomena, regarding for instance vegetation cover, coastal areas and ocean surfaces. Low resolution images are supplied by the SPOT-VEGETATION, ENVISAT-MERIS, TERRA-MODIS and NOAA satellites.

Geostationary satellites (METEOSAT, MSG, GOES) observe with a high temporal repetitivity the same area of the Earth surface.

- **Synthetic Aperture Radar (SAR) images** are used to measure the physical and geometric characteristics of the objects observed (structure, water content, biomass). They allow various applications: floods, forest fires, vegetation growth, soil moisture, ploughing, deforestation, etc. Such images are derived from ERS, ENVISAT and RADARSAT satellites.

A number of satellite images are freely displayed on specific websites, such as the site developed by VITO (Flemish Institute for Technological Research) that distributes SPOT-VEGETATION products (<http://free.vgt.vito.be>). However, to obtain a particular satellite image, it is usually necessary to apply to image providers. Such images are often expensive (from 1,600 to 13,000 euros), but several programmes of support to the scientific community, such as the French ISIS⁵ programme (*Incitation à l'utilisation Scientifique des Images SPOT*) grant special prices.

Within the scope of the ISIS programme, for instance, the price to be paid by laboratories for archive images (i.e. already recorded by SPOT satellites) range from 100 to 400 euros, and from 500 to 800 euros for programmed images. These rates should be put into perspective with the cost of a whole integrated application, and compared with prices for methodologies relying on different sources. Under the current economic circumstances, a well-considered use of remote sensing often proves to be cost-effective.

⁵ In 1999, the French Space Agency (Centre National d'Études Spatiales, CNES) decided to extend its ISIS programme to European scientists by granting them special prices (excluding VEGETATION products). Since this initiative, researchers have bought more than 2,500 SPOT images (including SPOT-5 high resolution products).

Glossary

Absorption: It is due to the various gases and particles composing the atmosphere that absorb the energy emitted by electromagnetic radiation. It varies in relation to the nature and properties of such gases, and according to spectral wavelengths.

Active remote sensing: A remote sensing system that both emits and receives electromagnetic signals (radar principle).

Energy flux: The power emitted, transported or received in the form of electromagnetic radiation.

Geometric corrections: They allow, on the one hand, to compensate for distortions due to satellite motion and on the other had, to transform an image so as to represent it as a plan (map projection).

Geostationary: Geostationary satellites use to have a circular, high (about 36,000 km above the equator) orbit; their position allows a non-stop monitoring of our planet because of the high repetitivity of their image collection. Meteorological (METEOSAT) or telecommunication (EUTELSAT) satellites are geostationary satellites.

Ground swath: It is the ground surface observed. According to the type of sensor, its width ranges from tens to hundreds of kilometres.

Image: A graphic representation of electromagnetic values measured and recorded in digital form..

Map projection: A method that consists in transforming and representing on a bi-dimensional (flat) surface, points located on the tri-dimensional spherical surface of the Earth.

Passive remote sensing: A remote sensing system that only records the energy reflected or emitted by objects on the ground surface.

Photograph: An image recorded on a photographic film (through the chemical action of light or other radiation on specially sensitised material).

Pixel: Picture element. The smallest homogeneous surface component of a recorded image.

Platform: An aerial or spatial vehicle carrying the mounting (also called itself a platform) where sensors and payload are set up.

Proper emission: The atmosphere sends back part of the incoming solar radiation, thus contributing to increase the electromagnetic radiation reflected or emitted by the Earth surface.

Radiometric corrections: They correct recorded measurements in relation to the specific characteristics of the viewing instruments and to the disturbances caused by the atmosphere in the transmission of the electromagnetic signal.

Refraction: A geometric distortion of the trajectory of electromagnetic waves travelling to the Earth surface, due to variations in the refractive index.

Satellite image map: A map drawn up from satellite images that are combined (tessellation) and geometrically corrected in a projection system and a standardised mapping division. A mapping product generated in digital form or in print.

Scattering: It results from the interaction of particles and molecules (water droplets, dust, smoke, aerosols) on the incident and reflected electromagnetic radiation. It is a function of the nature of wavelengths, and of the turbidity and thickness of the atmosphere crossed by radiation..

Sensor: An instrument that detects and records the energy coming from the targeted scene and that indicates the corresponding measurable electric signal.

Spatial or geometric resolution: It is the size of the pixel at ground. Its geometric dimension conditions the size of the smallest element detectable on the Earth surface. It may be likened to the distance that must separate two objects at ground for them to be differentiated. It is the essential parameter to recognise objects by their shape.

Spectral resolution: The sensor sensitivity to specific wavelengths of the electromagnetic spectrum. It characterises the accuracy of the radiometric measurement.

Spectral signature: The spectral response of an object, i.e. the amount of light energy reflected, absorbed by an object in various wavelengths.

Sun-synchronous: A satellite is said to be sun-synchronous when its orbit plane keeps the same orientation in relation to the Earth-Sun direction, and therefore receives the same light all year round. A sun-synchronous satellite always crosses the vertical line of a same spot at the same solar time. Most Earth observing satellites (SPOT, LANDSAT) are sun-synchronous.

Synthetic Aperture Radar (SAR): A coherent radar system that generates high resolution remotely sensed images.

Target: The surface or object observed (a major part of the vocabulary used in remote sensing derives from its military origin).

Remote sensing applied to desertification monitoring

It is an accepted fact that land degradation concerns our whole planet. **Desertification** is a typical process in arid and semi-arid areas. It also occurs in humid regions*, but is much less widespread there. When actually serious, desertification leads to an irreversible state of land degradation within a human generation (25 years). It is materialised by environmental changes, as land surfaces are affected by modifications in both vegetation covers and soils. Desertification factors may be natural or human-induced. Once they understand the processes that characterise this phenomenon, researchers attempt to find **indicators** associated with such factors, in order to assess the degree or possible risks of desertification in a given area. These indicators allow to warn and help local or national authorities in undertaking relevant actions of environmental management. Within this scope, remote sensing enables to assess such indicators (especially physical and ecological ones) through “derived variables”, thus allowing to determine desertification processes.

* In some tropical areas, for instance, deforestation followed by rain leads to soil loss and exposure of infertile bedrock.



Sudanian savannah during
the cold dry season - Autumnal landscape, Mali.
Vincent Robert © IRD

Focus

Desertification stems from an anthropogenic process and particularly affects economic production and consumption activities. The United Nations Convention to Combat Desertification, adopted in Paris in 1994 and ratified ten years later by 190 countries, is a Convention concerning both environment and development. It defines the desertification process at the local and regional scales as “*land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities*”.

Desertification consequently describes an irreversible decline or destruction affecting the biological potential of lands and their capacity to sustain or feed the populations. This process highlights the need to improve the standard of living of the most vulnerable societies by long-term supporting their activities, preserving land fertility or finding other activities that should alleviate pressure on lands. Desertification is an integral part of the issue of sustainable development in drylands. As evidenced by the Annexes to the Convention, this notion applies to every continent, mainly to dry areas where aridity and drought are two common climatic data.

From Requier-Desjardins and Caron, 2005.

Five derived variables to assess desertification indicators: roughness, albedo, surface temperature, soil moisture, vegetation index

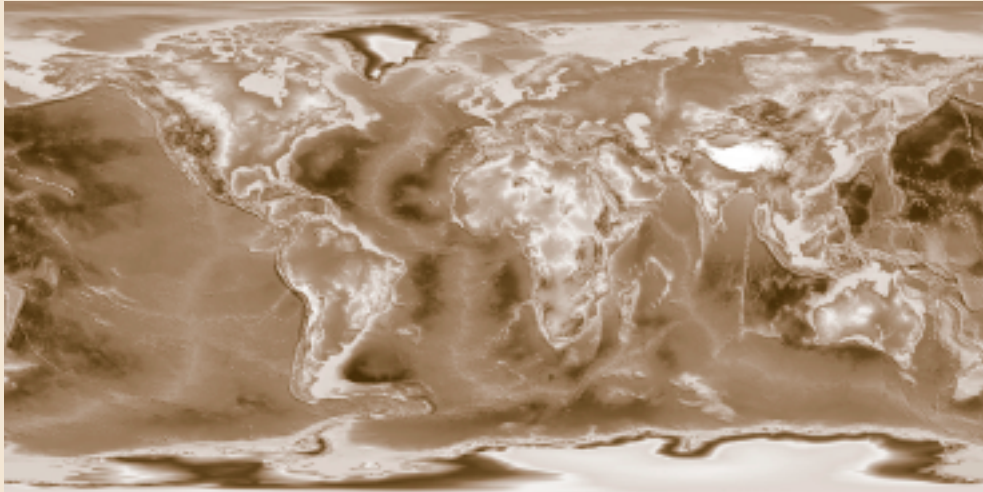
The part played by remote sensing consists in converting physical measurements of surfaces into information. Remotely sensed data must therefore be calibrated and transformed into derived variables, that are used to estimate desertification indicators. Information thus obtained includes in particular surface roughness, albedo, surface temperature, vegetation cover (coverage and phenological state) and soil moisture.

Roughness: quantifying the unevenness of a surface

Roughness is a parameter that allows to quantify the unevenness of a surface. The more uneven the surface, the greater is the roughness parameter. Roughness is generally measured by radar remote sensing. Radar emits micro-waves and measures the power with which an object reflects them back (backscattering). The more uneven the surface, the stronger is the backscattering.

Example

Use of the “roughness” parameter
The Earth seen from a radar altimeter:
land topography and ocean bathymetry



© ESA/ERS

This map is drawn out from data derived from the ESA (European Space Agency) ERS-2 European satellite.

See original picture in the colour supplement.

Albedo, i.e. the fraction of solar energy reflected from the Earth back into the atmosphere

Albedo is the ratio of the amount of light reflected by an object in relation to the amount of light that hits such object, i.e. the ratio of reflected light to incident light. Albedo is expressed by a number ranging from 0 (none of the light hitting the surface is reflected) to 1 (all the light hitting the surface is reflected), or by a percentage. Albedo plays a part in energetic balances and in the radiative budget since it controls the amount of solar energy sent back into the atmosphere.

For a same geographic area, albedo may vary during the year because of physical phenomena (or biases such as clouds in low resolution pictures). Interpreting this value with its temporal and spatial variations and considering them jointly with other observable variables supply information on desertification processes. Indeed, the albedo of a bare soil decreases when its water content increases. The albedo of a vegetated ground depends on its rate of vegetation coverage and its chlorophyllous activity.

Many works have intended to study the relationships between albedo and desertification (mainly the relationships between albedo and fluctuations in the vegetation cover of drylands, and between albedo and climate models). Such fluctuations have been evidenced at the continental scale, but the nature of their impact on climate is still being discussed.

Example

Relationships between albedo and vegetation in Mali

The two curves below show albedo fluctuations in the Sahel (Mali). Data are derived from the SPOT-VEGETATION satellite and concern two spots 400 kilometres away from one another. They illustrate a bare ground and a vegetated ground. In the former case, albedo decreases around July, during the rainy season. In the latter case, visible albedo decreases in July whereas NIR (near infrared) albedo remains steady. This is due to the development of vegetation during the rainy season, which absorbs visible radiation for photosynthesis.



Albedo fluctuation in the Sahel
© Médias-France

Data derived from VEGETATION1/SPOT4 and VEGETATION2/SPOT5 satellites (2002-2003).

Source: FP5/CYCLOPES project (INRA [French National Institute for Agricultural Research], Médias-France, CNES [Centre National d'Études Spatiales], Météo-France and Noveltis). CYCLOPES is a shared-cost project (Contract n° EVG1-CT-2002-00076) co-funded by the Directorate-General for Research of the European Commission within the Research and Development activities of the Environment and Sustainable Development sub-programme (5th Framework Programme).

Surface temperature varies according to land nature and cover

Surface temperature results from energy exchanges that occur above and below this surface. It is thus partly connected with albedo, air temperature and the efficiency of thermal exchanges. Surface temperature is assessed by measuring the emitted thermal infrared radiation (wavelength comprised between 10.5 and 12.5 μm – passive remote sensing). Its value depends on land nature and cover. Indeed, under the same conditions of light and climate, sandy or rocky grounds do not have the same balance point temperature, all other things being equal. Same applies to a bare or vegetated ground. Water conditions observed near the surface studied may also modify the surface temperature. The time of observation is relevant as well. Since the sun is the main warming source, an image collected in the morning usually indicates surface temperatures less high than an image collected in the afternoon. Consequently, thanks to geostationary satellites (e.g. meteorological satellites), it is possible to monitor the evolution of surface temperature and therefore to characterise the local thermal inertia.

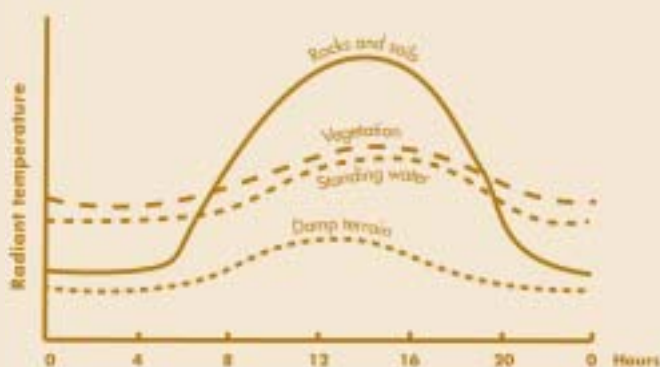
Soil moisture, a warning parameter for desertification

Soil moisture, i.e. surface water content, is defined by the amount of water contained in the top ten centimetres of soil. It may be estimated by radar (active remote sensing), and is connected with surface temperature. Soil moisture conditions exchanges with the atmosphere through the land surface energy budget (which significantly differs in a dry or wet area). It also governs the growth of the vegetation cover (seed germination, emergence, root striking, etc.). It is consequently a parameter well worth assessing for hydrology and agronomy, as well as a warning parameter for desertification.

Examples

Variation in surface temperature during a day according to surface type

Surface temperature varies according to land nature and cover. The time of the day is also relevant, with a peak of temperature at 2 P.M., i.e. when the sun, the main warming source, is at its zenith.



From: *Remote Sensing: Principles and Interpretation*. 2/e by F.F. Sabins.
© 1987 by W.H. Freeman and Company. Used with permission.

Use of the "soil moisture" parameter in Europe



Soil moisture in Europe – ERS satellite (January 2000)

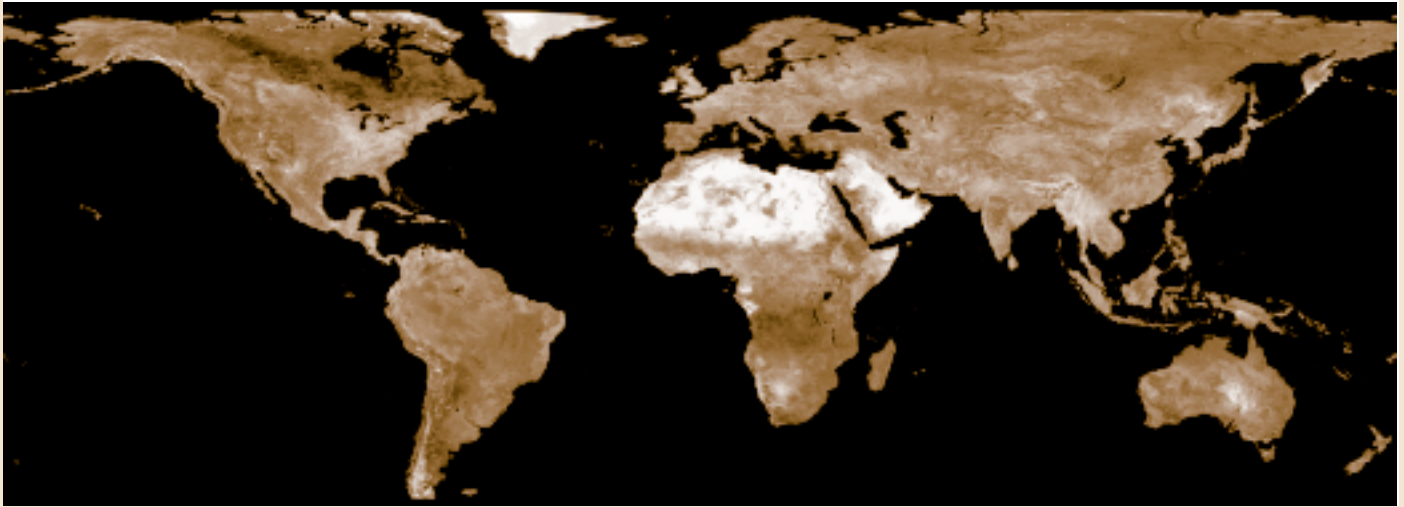
This soil moisture map is derived from measurements performed by the ERS satellite (January 2000) over Europe. Data are expressed comparatively, in percentage, with 0% representing dry lands and 100% very wet lands.

See original picture in the colour supplement.

Source: kindly provided by the Institute of Photogrammetry and Remote Sensing, Vienna University of Technology.

Example

Global scale vegetation indices



© CNES 2004

Image distributed by VITO

A global synthesis of vegetation indices made by EOworks from NDVI Spot-Vegetation data (03/1999). The colour range expresses increasing index values, from yellow to green.

See original picture in the colour supplement.

Which processes do these parameters allow to observe?

Desertification results from many natural and anthropogenic interwoven processes, whose underlying factors are often slow. Modelling such processes at various scales aims at early warning, designing mitigation measures and assessing their efficiency. Models rely on socio-economic and physical observations made at ground level as well as sensed from space, through the derived variables above described.

Two major processes are especially dealt with in this report, since several of their characteristics are easily observed thanks to space-based remote sensing:

- Vegetation cover monitoring (which is essential regarding food security and is a potential tracer of soil fertility);
- Land cover and surface composition changes.

Studying these processes from satellite images requires to take into account seasonal cycles and rain events*.

* Generally speaking, a wet surface is less reflective than the same dry surface.

Monitoring vegetation cover through three variables: green vegetation, tree density and biomass

• Green vegetation

Decreases in vegetation cover play a significant part in desertification processes. Many works are devoted to the monitoring of green vegetation, which is easily performed by satellite through vegetation indices. Low resolution images daily collected by satellites allow to compute mean 10-day vegetation indices, which in turn enable to detect risk areas and the state of vegetation resources. It is then possible, if need be, to issue a warning to try to prevent the further degradation of these resources.

Examples

Use of vegetation indices: a map of African drylands

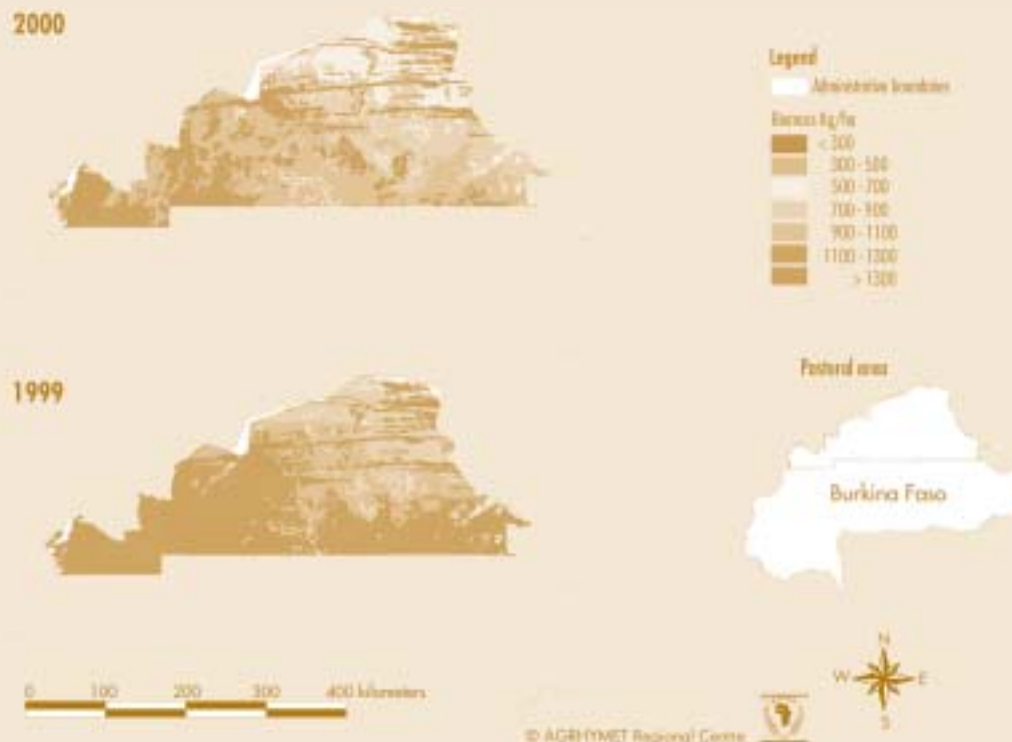


Vegetation indices (NDVI) for the first ten days of April 2004 are derived from NOAA/AVHRR satellite data. The higher the index, the more developed is the vegetation cover.

Source: Data from NASA GSFC (Goddard Space Flight Center), GIMMS (Global Inventory Modelling and Mapping Studies). Map issued by the FEWS-NET (Famine Early Warning Systems Network) project of the USGS EROS (United States Geological Survey – Earth Resources Observation System) Data Centre. A research funded by USAID (U.S. Agency for International Development).

See original picture in the colour supplement.

Monitoring of grass biomass in the pastoral area of Burkina Faso



Annual maps of grass biomass in the pastoral area of Burkina Faso in 1999 and 2000 (note the difference between the two annual situations).

In the Sahel, annual grasses that make up a large part of pastoral resources are the predominant vegetation cover. The AGRHYMET Centre (CILSS: Permanent Inter-state Committee for Drought Control in the Sahel) created in 1974 is currently monitoring grazing lands at the regional scale and is circulating information to national decision-makers. This allows to determine grazing lands at risk, and if need be, to issue a warning in order to reduce grazing in relevant regions and prevent their desertification. The state of pastoral resources is assessed by estimating biomass from cumulated vegetation indices. These data regarding the Sahelian region are also listed in the monthly report of the FAO (Food and Agriculture Organization of the United Nations) GIEWS (Global Information and Early Warning System).

Similar techniques may be applied to other semi-arid pastoral areas rich in annual plants, such as Central Asian regions.

Monitoring vegetation north of the Sahara is more difficult because steppes of small low woody bushes prevail. Moreover, during a large part of the year, vegetation is only weakly green, or even not at all during very dry periods. It is then quite impossible to use vegetation indices to estimate variations in vegetation cover.

© AGRHYMET Regional Centre
Source: AP3A (Early Warning and Agricultural Production Forecast) Project. AGRHYMET Regional Centre, Niamey, Niger

See original picture in the colour supplement.

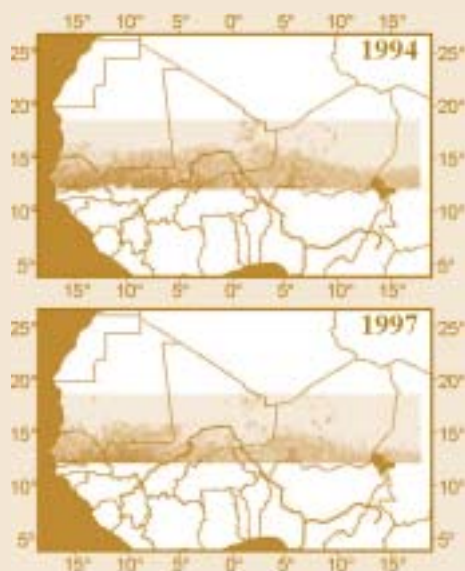


Camp of Fulani herdsmen in a reg (desert pavement) invaded by the sand of the previous erg (Inchirian period, 22000 BP). North Oursi, Burkina Faso. Jean-Claude Leprun © IRD

Example

Biomass monitoring in the West Sahelian region

Estimating above-ground plant biomass resorts to meteorological data combined with those derived from scatterometers (through modelling). In the Sahelian area subject of this study, biomass distribution is significantly different in 1994 (wet year) and 1997 (dry year). This method applied to the whole Sahelian belt shown in this figure has been submitted to ground validation in the Gourma region (Mali).



Above-ground vegetation production in the West Sahelian region ($-18^{\circ}\text{E}/18^{\circ}\text{E}$ and $13.5^{\circ}\text{N}/20^{\circ}\text{N}$) assessed by an ERS satellite scatterometer regarding these two contrasting years. © CESBIO 2003

Colour scale ranges from 0 (off-white) to 3,000 kg of dry matter per hectare. From Jarlan et al., 2003.

See original picture in the colour supplement.

• Tree density

This is a criterion used at ground level, especially in forested savannahs. Very high spatial resolution satellites now enable to detect individual trees and to monitor the evolution of a tree stand density. For instance, in arid areas of New Mexico, comparisons between current commercial images and old declassified pictures taken by military satellites have evidenced a high increase in the number of trees over a thirty-year period. A study of the same type (but using aerial photographs) has shown that tree stands were receding southwards in the West African Sahel. Nevertheless, this method cannot be applied to extensive areas because collecting and analysing high resolution images is quite costly.

• Biomass global monitoring

Vegetation indices derived from satellite-based optical sensor images allow to monitor the development of green vegetation in land surfaces. Nevertheless, other methods at the continental scale have been generated from micro-wave measurements. Measurements made by scatterometer sensors onboard ERS satellites (micro-wave range) relate to the water content of land surfaces. Its variations measured in the African Sahel are particularly significant between the dry and rainy seasons. These data allow to monitor seasonal variations in surface moisture and plant biomass.



*Herdsman driving his cattle to a watering place, Burkina Faso.
Marc Bournof © IRD*

Modification in sand surface composition and wind transportation: two processes observable through remote sensing

The primary production of a given environment mainly depends on rainfall and land states. Monitoring and modelling from remotely sensed data endeavour to obtain significant indicators such as ecological efficiency, growth balance and water consumption. A loss in land quality may thus be indirectly detected.

Modifications in ground surface composition may be observed in various ways, more or less easily remotely sensed, through variables such as **reflectance** and secondarily roughness.

Soil depletion due to unsuitable farming methods or overgrazing may reveal itself by slight changes in colour and/or albedo that should be interpreted cautiously. A severe soil impoverishment often induces a decrease in grass cover (grazing land or cultivated vegetation), which comes down to observing the process above described.

In determined areas where overgrazing is particularly severe (especially near watering places), massive shuffling may occur. This modifies the spectral signature and albedo (which usually increases) of the place. These localised areas may be quite easily identified through remote sensing, all the more that they often show a specific morphology (paths converging to watering points).

Land salinisation is also materialised by a loss in primary productivity and is therefore indirectly detected through the process above described. This phenomenon rarely modifies the spectral signature of a soil so much that it may be unequivocally identified by its spectral signature. However, there are extreme cases in which salt shows on the surface and may therefore be observed in high or medium resolution images. This occurs for instance in Central Asia where determined areas (usually former ponds) are now totally converted into a salt crust. Such crust is due to both the drainage of dissolved salt and the fact that water recharge does not offset evaporation any longer, and is very easily observed through remote sensing (white colour, high albedo).

Soils and rocks may be covered with materials deposited or in transit, often transported by wind (dust, silt, sand) or water (flooded areas). These materials are eroded and may also expose underlying materials of different composition. Wind transportation plays a significant part in the desertification process. In its most striking form, it may lead to form or move sand dunes, visible by their shape and spectral signature (SPOT, LANDSAT, IRS images). More subtly, wind transportation may occasion sand deposition likely to invade or cover fields, infrastructures and houses. This mechanism may therefore involve socio-economic damage beyond desertification itself. Wind erosion can be mitigated by vegetation (trees, grasses) that stabilises sand locally and contributes to slow down the wind by its aerodynamic roughness; vice versa, overgrazing and deforestation may speed up wind transportation processes.

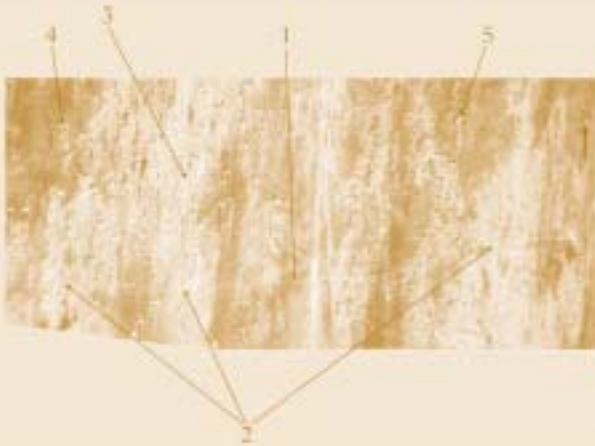
In this context, remote sensing is used at various scales. A global picture evidences the major wind currents that connect for instance the Sahara with the Sahel (example of Sahara-Sahel wind circulation). At the regional and local scales, it allows to observe sand invasion mechanisms likely to cause desertification by impoverishing soil quality, as well as damage affecting infrastructures and transportation networks. Nevertheless, it is essential to analyse aerial photographs in order to complete and refine the understanding of such phenomena.

Wind erosion is also detected by the frequency of dust winds that can be observed by systems such as METEOSAT, NOAA-AVHRR and VEGETATION. Since dust winds entail a loss in fine matter, a characterisation of soil degradation

may be inferred. Low resolution satellites also enable to observe the transportation of materials far away from their original areas. In such cases, studies of environmental modifications mainly rely on observing textures and structures. Such observations are performed visually by a researcher trained in these techniques. The computer processing widely used in remote sensing systems proves to be less reliable for the monitoring of environmental degradation in dry (sandy) regions. Whether due to erosion or sand accumulation, dunes have the same spectral signatures, and therefore cannot be differentiated by digital analyses.

Example

Space-based observation of wind processes and sand invasion in Mauritania



- 1- Railway of the "Société Nationale Industrie Minière" mining company (Nouadhibou-Zouerate)
- 2- Railway section threatened by sand invasion
- 3- Area of wind transit by saltation; sand veils and barchan-type structures*
- 4- Barchan dune*: its anticlockwise tip is longer due to the coastal wind current.
- 5- Barchan dune*: its clockwise tip is longer due to the harmattan.

*Editor's note: A barchan dune is a free crescent-shaped sand dune whose crests point downwind.



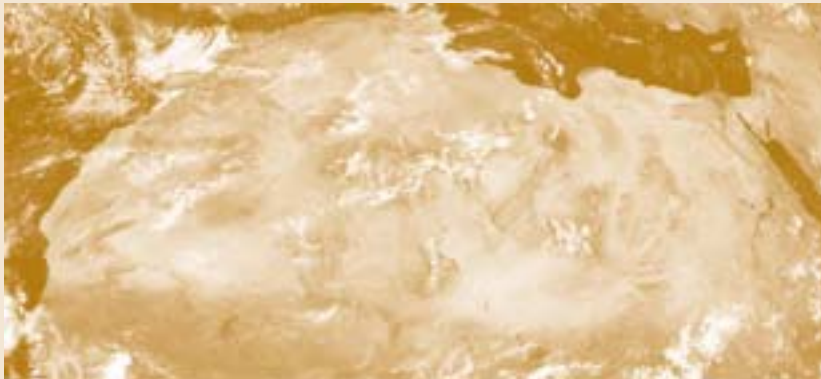
Because of the continuous sand deposition on the railway, rails wear out quickly: when they are not replaced in time, spectacular derailments occur.

Legend:

- Left picture: **View from space:** meeting place between the N/S oceanic current and NE/SW harmattan, Mauritania (from SPOT-1 P 021-313 image, 1:100,000). Kindly supplied by M. Mainguet and F. Dumay (LGZD - Laboratory of Zonal Geography for the Development).
- Right picture: **View at ground level:** Barchan-type deposition threatening the Nouadhibou-Zouerate railway, Mauritania. © Frédéric Dumay

Examples

Detection of wind erosion by observing dust and sand winds

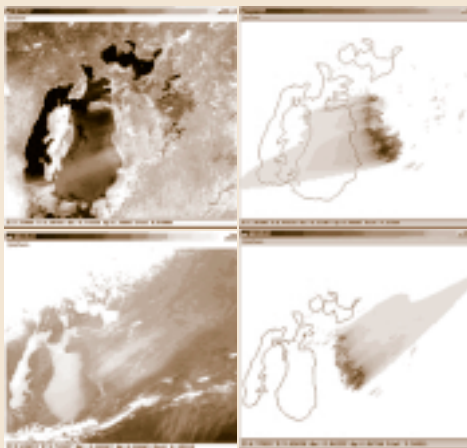


A : Ai	E : Kordofan
AD : Adrar des Doudi	E : Chad Lake
AI : Adrar des Ifoghas	M : Djebel Marra
E : Eghab	T : Tibesti
En : Ennedi	T.A. : Tassili N'Ajjer
H : Hoggar	

Thanks to its 1:26,000,000 scale, this infrared METEOSAT-4 image taken on January 3rd, 1992 (METEO-France CMS Lannion) allows the global scale observation of a dust and sand storm that stretches over more than 3,000 km, from the Qattara depression (27°N, Egypt) to the Gulf of Guinea (5°N) at the limit between forest and savannah. The connections that ensure continuity between the big Saharan and Sahelian ergs have been mapped from reflectance values, just like the role played by the various obstacles on the wind trajectory of sand particles.

From Mainguet and Dumay, 1995.

Detection of erosion and wind transportation: the Aral sea



Observations through low resolution remote sensing of the former bed, now dried-up, of the Aral sea (Central Asia) and of wind transportation episodes (19/09/1998 and 09/04/2002).

This figure illustrates the particularly serious case of the regions surrounding the Aral sea (Central Asia). Excessive water consumption for irrigation purposes and outdated technologies have led to a terrible shrinking of this lake. While evaporating, the Aral sea leaves an infertile salty deposition. The albedo of this totally desert area is very easily detectable on low, medium and high resolution images (NOAA-AVHRR or SPOT-VEGETATION satellites). This deposition is prone to erosion and wind transportation: both processes spread salt particles and make the soils affected infertile. This may be interpreted as an extreme case of local salt crusting in this region.

Kindly supplied by Pr. E. Zakarin,
National Centre for Radio-Electronics and Communication
of the Republic of Kazakhstan (NCREC)
within the scope of a cooperation with Médias-France.



Tagant plateau. This plateau populated from remote antiquity is a heterogeneous combination of cliffs, crests and massifs intersected by alluvial plains and defiles where oases and palm groves are located. N'Belka, Tagant plateau, Mauritania.
Jean-Jacques Lemasson © IRD

Glossary

Indicator: A synthetic parameter used to assess environmental changes connected with desertification processes. Indicators may be quantitative or qualitative.

Normalised Difference Vegetation Index (NDVI):
The ratio of: $(\text{Near Infrared} - \text{Red}) / (\text{Near Infrared} + \text{Red})$.

Reflectance: The ratio of the total amount of radiation reflected by a surface to the total amount of radiation incident on the surface (target).

A few examples of remote sensing used at various scales

Remote sensing is a space-based observing tool that allows the study and monitoring of spots at various scales. The present chapter illustrates this variety with two examples: The Menzel Habib test site in pre-Saharan Tunisia has been subjected to repeated observations since 1970, especially within the framework of the CAMELEO (Changes in Arid Mediterranean Ecosystems on the Long term and Earth Observation) project (1997-2001); The ROSELT (Long-Term Ecological Monitoring Observatories Network) project. This interdisciplinary initiative has been led at the regional circum-Saharan scale by the *Institut de recherche pour le développement* (IRD) within the scope of OSS (Sahara and Sahel Observatory) programmes.

Monitoring of a sandy steppe area: an example in pre-Saharan Tunisia

Among the places where research on desertification has been undertaken in Africa, the Menzel Habib spot in southern Tunisia has been continuously monitored since the 70's, especially by the French and French-speaking scientific communities and their pioneers in this field. This site, that belongs to the observatories of the ROSELT programme, has been the subject of space-based monitoring experiments and of a recent study on long-term ecological indicators.

The Menzel Habib observatory

The Menzel Habib area, located in southern Tunisia, is characterised by its highly irregular annual rainfall ranging from 100 to 200 mm and its sandy and sandy-silty soils covered with a low woody steppe, typical of the arid regions of the northern Saharan border.

Due to both a drought period and the cultivation of plots until then used as rangelands, this region was affected by particularly severe desertification phenomena during the 80's. A programme aimed at combating land degradation and sand invasion was consequently launched.



*Wadi El Akarit, located at some thirty kilometres north of Gabes, Tunisia.
Jean-Pierre Roset © IRD*

Space-based monitoring methods have been tested and developed in this region, in particular within the scope of Euro-Mediterranean research programmes such as the CAMELEO project, which is the source of the following information.

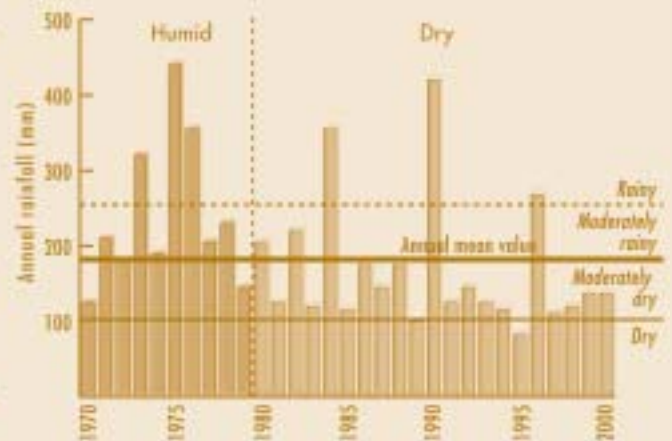
Immature soils covering hard sedimentary rocks are located only in the mountains that border the Menzel Habib plain. Quite all the other soils in the region have developed on wind-deposited materials, peridesert loess and fine sand, enriched with soluble elements originated from underlying gypsum and salt deposits. Organic matter is quite scarce, but a small quantity due to surface biological activity gives some cohesion to the sand (algal crust for instance).

Regarding natural vegetation, low woody bushes (chamaephytes) prevail; annual plants develop quickly after rain events that mainly occur in winter. Cultivated vegetation consists of annual crops (barley, hard wheat) and trees of poor planting density. Consequently, vegetation is green only during part of the year (generally the first months), and shows on the whole a poor coverage. At surface level, soils prevail.

Location and annual rainfall, Menzel Habib, Tunisia



Location map of the Menzel Habib test area, pre-Saharan Tunisia.
Map from Floret and Pontanier, 1982.



Variation in annual rainfall in Menzel Habib, Tunisia (1970-2000).

Over this thirty-year period, the mean annual rainfall amounts to 180 mm. Wetter years can be observed until 1980, then dryer years follow. They are interspersed with “rainy” years with rainfall exceeding 250 mm, as for instance in 1990.

From Jauffret, 2001.

Research approach regarding the monitoring of the Menzel Habib area

Remotely sensed images have been used to establish relationships between, on the one hand, the soil and characteristics of surfaces observed at ground level, and on the other hand, the spectral response of the same surfaces measured by satellite-based optical sensors. At ground level, the ecological description of surface states (soil composition and organisation, phenological nature, vegetation abundance) have been associated with reflectance values measured by portable devices. It was thus demonstrated that in this region, the vegetation index was ill correlated with the global vegetation cover. The rate of vegetation cover (a highly relevant indicator regarding desertification diagnosis, which accounts for the

abundance of woody perennial plants) globally affects signal intensity. Consequently, for a given soil, a denser steppe appears darker on satellite images (albedo-related link).

In addition, since the local vegetation generally provides little coverage, reflectance measurements are highly influenced by soil properties, and especially by their colour. A colour index derived from measurements made in the visible spectral bands was suggested: the higher it is, the more coloured are the soils (e.g. sand), while low values correspond to greyish soils (e.g. gypsum). Consequently, both albedo and colour criteria have been used to monitor the evolution of surface states over time, and to determine trends.

Monitoring soil and vegetation evolution

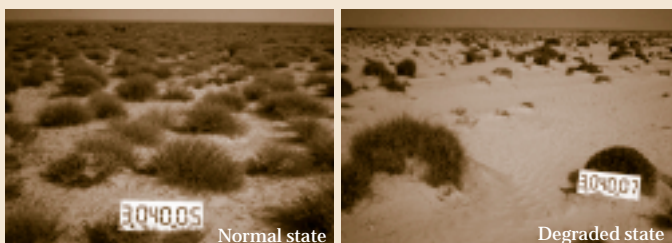
Studies bearing on a whole region require high resolution images. A Landsat image series was collected over the Menzel Habib sandy plain, on the basis of one image per year. Whenever possible, pictures were taken during the same season in order to minimise reflectance differences caused by variations in sun altitude. Spring images were preferred so as to photograph vegetation when it reaches its maximum. These images were processed with geometric correction (to make them superimposable pixel by pixel) and radiometric correction (to convert the pixel values of each image into ground reflectance), in order to make them comparable.

The pictures below display results obtained on four dates, when differences are particularly contrasted. Combining older Landsat MSS images with more recent Landsat TM ones allows to cover a 23-year period. Images are shown in standard colour compositions ("false colours"), in which green vegetation is displayed in red. Two photographs taken at ground level feature a sandy steppe in "normal" and degraded states, to complete this illustration. Degradation due to a decrease in vegetation cover is materialised in such case by the encroachment of moving sand (sand invasion).

Focus

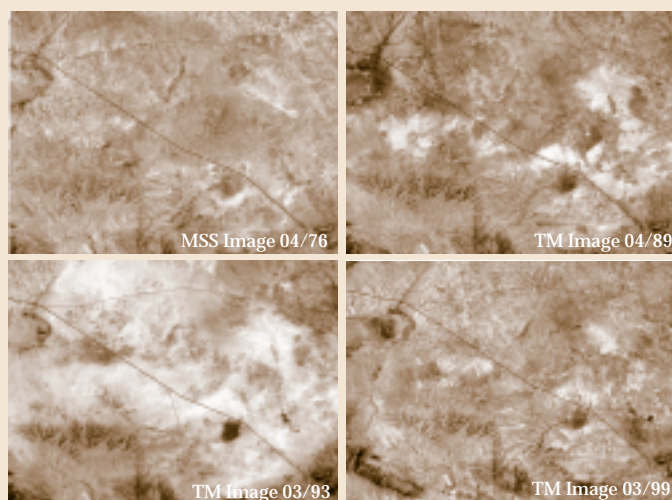
Degradation due to a decrease in the vegetation cover of the Menzel Habib sandy steppe, Tunisia

View at ground level



R. Escadafal © IRD

Satellite images



R. Escadafal © IRD

Four georeferenced and intercalibrated Landsat images of the Menzel Habib area (Tunisia) (1976, 1989, 1993, 1999)
Richard Escadafal © IRD

The differences evidenced correspond to modifications in surface states at ground level. Each picture covers a 30x24 km area.

- **Landsat MSS image dated April 1976**

The Menzel Habib plain in 1976: bordered in the South-East and South-West by mountains (in grey), a sandy steppe prevails (in beige in the centre). Annual crops (in red) are located at the periphery and in depressions (bright red spots).

- **Landsat TM image dated April 1989**

In 1989, drought leads to a decrease in crops and to the striking expansion of mobile sand (light yellow): the region is "desertified".

- **Landsat TM image dated March 1993**

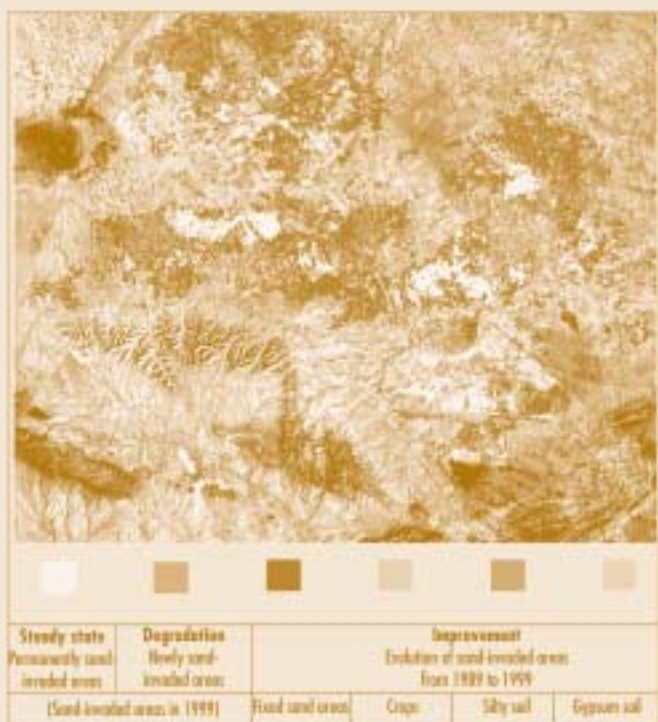
In 1993, i.e. four years later, the impacts of enclosure areas clearly show as dark trapezium-shaped spots among sandy areas, while annual crops intensify (red dotted lines).

- **Landsat TM image dated March 1999**

In 1999, mobile sand areas prove to have completely receded and the situation is apparently well controlled. The landscape appears to be fully parcelled out in plots of various uses, and new enclosure areas have been set up in the few remaining dune areas.

See original picture in the colour supplement.

Synthesis of sand invasion evolution in the Menzel Habib area (Tunisia) between 1989 and 1999



Richard Escadafal © IRD

This figure illustrates one of the syntheses obtained by analysing trends observed in images classified over five dates (between 1989 and 1999) and showing sand-invaded surfaces (unfixed moving sand, dunes, etc.). Sand-invaded areas (mobile dunes) have decreased in favour of fixed sand areas and farming lands.

Satellite images thus evidenced that the environmental state did improve between 1989 and 1999. Efforts undertaken in order to fix the moving sand that had invaded the region during the previous decade were successful. Space-based monitoring allowed to quantify these impacts over large expanses. Such good results were of course also observed locally on site.

See original picture in the colour supplement.

Map synthesis of environmental evolution

Observing image series makes it possible to design a sequence of the various surface states. However, it is not sufficient to define long-term trends, nor to identify environmental desertification or restoration. Analyses should bear on long enough series and derive trend syntheses while taking into account climate variations.

In order to define such long-term trends, many attempts to monitor desertification focus on biomass. Instead of this method, since biomass is too poor in the region studied for its variations to be easily detectable, surface states in general have to be monitored in the long run.

Such surfaces of sparse vegetation cover require the use of brightness and colour indices, as well as vegetation indices that help distinguish the most active covers. This method allows to classify each image according to a simple legend based on soil type and vegetation cover density. The percentage covered by each category has been monitored over time so as to determine environmental evolution (stability, degradation or improvement).

Application of this method to other contexts

This example in southern Tunisia illustrates the use of satellite images for the monitoring of a sandy steppe area. Desertification also causes havoc in other environments such as southern Sahara where it materialises differently, with an increasing scarcity of woody plants for instance. Satellite-based monitoring should consequently take into account the ecological features of the environments followed-up and rely on the knowledge of local processes. This is the necessary condition for being able to interpret changes in surface states and to identify land status: environmental degradation, stability or restoration. Thanks to the increasing number of satellites and sensors, denser and more diverse data are collected from space. The current challenge then consists in using them at best to obtain the most accurate monitoring at the lowest cost. The ultimate goal is to supply the information necessary for early warning systems, which are the actual concern of the managers of the regions affected.

Using satellite images for wildlife monitoring

Within the scope of the Long-Term Ecological Monitoring Observatories Network (ROSELT) of the Sahara and Sahel Observatory (OSS), ASTER images (NASA) have been used in the Oued Mird observatory (Morocco) in order to implement a wildlife monitoring system. Such system integrates the concepts and methods derived from landscape ecology and population biology (Baudat, 2003).

An integrated mapping of the natural environment has been designed to allow to work at various scales: from landscape to biotope, then to habitat. It is then possible to follow up landscape evolution, to sample animal populations as per **biotope** and to take into account the specific problems connected with habitats of particular species.

For biotope mapping, a plan has been defined and a stratified sampling method selected according to the animal population studied. Integrating such data into a Geographic Information System (GIS) allows to perform the necessary processing and spatial operations.

The Oued Mird observatory in Morocco

The Oued Mird observatory extends over 550 km² in southern Morocco (Saharan Anti-Atlas). This site is located at the Saharan bioclimatic stage, with warm winters (mean winter temperatures above 7°C and annual rainfall below 100 mm, Brignon and Sauvage, 1963). Altitude ranges between 637 and 1,243 metres, from the bottom of the Oued Mird valley to the crests of Jebel Tadrart. Plant communities consist of desert steppes and wooded steppes.

Besides, Oued Mird exemplifies a specific desertification problem, because there are still in this region well conserved *Acacia raddiana* woods. Such species is a key host from an ecological point of view. Together with access to water, it represents the socio-economic mainspring of human presence in this territory. Indeed, these trees supply firewood for heating and cooking, and are grazed by cattle (camels, goats).



*Erg Chebbi, the beginning of the Great Western Erg located south-east of Erfoud.
An example of sand encroachment:
dunes invading palm groves, Morocco.
Claude Dejoux © IRD*

This area is inhabited by about 1,500 people who live on extensive breeding and food-producing agriculture (cereals and henna). Out of 152 families registered, only 17 still practice nomadic breeding in the pre-Saharan rangelands of this area.

Drawing out a landscape map

The set-up of observation stations takes into account altitude and slope, if possible along toposequences. For every station, a vertical section has been drawn out: each one includes a systematic stratified description of environmental components, through 17 variables considered as ecological descriptors of desert environments (soil and vegetation). Two hundred and six stations that are geo-referenced by GPS (Global Positioning System, four weeks at ground level) have thus been depicted in more than 400 photographs. A typology of natural environments could then be drawn out with the help of statistical analyses (factor analysis of correspondences associated with a hierarchic ascending classification): 14 classes evidence an ecological gradient, from non-vegetated environments (regs and bare grounds) to *Acacia raddiana* woods.

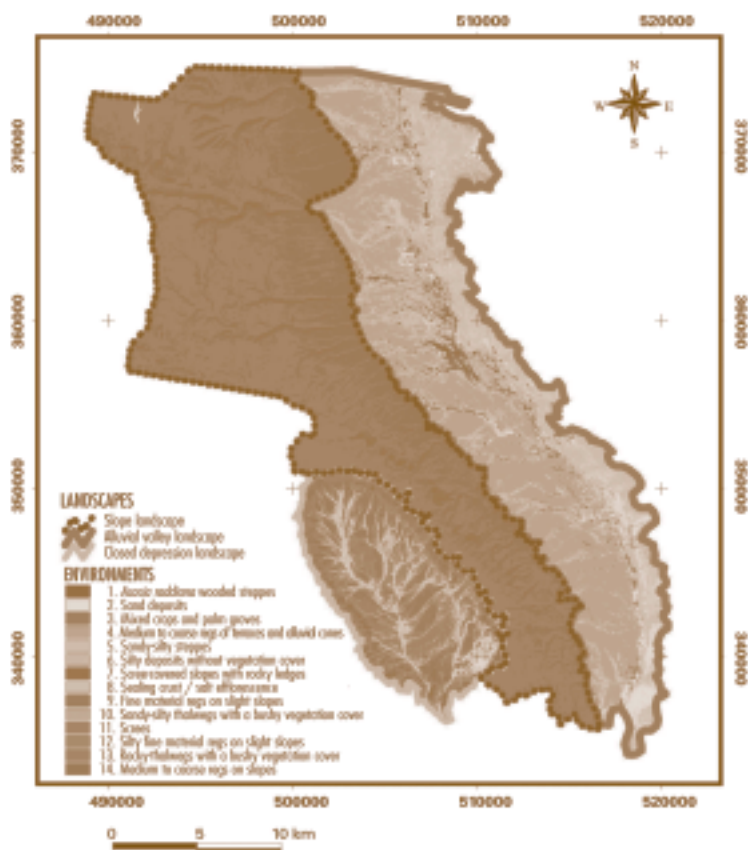


Two 15-m resolution (visible and near infrared) ASTER images, both taken on the same date (August 18th, 2001) were classified according to the so-called “maximum likelihood method” by using the typology derived from ground stations. However, only a poor overall accuracy of the classification was obtained (< 40%): ground classes were totally mixed together or not even classified. This is due to the fact that ecological classification (ground level) and radiometric classification (satellite image) did not match. In fact, the ecological variables that prevail in the definition of these classes are not detected in the 15-m resolution satellite image and/or are completely mixed up. In addition, the vegetation cover, which often does not even reach 10% in this area, could not be sensed properly.

Eventually, images have been visually interpreted according to ground typology, in order to correct the results of the maximum likelihood classification: the map of landscapes and natural environments therefore results from associating computer-aided classification with human expertise.

Three landscapes are defined on the map:

- *A slope landscape:* A long medium slope shows a monotonous aspect due to the prevailing reg and screes (environmental classes 14 and 11). Vegetation only consists of bushes along drainage axes (13). A matrix of much interconnected rocky environments can be identified. It is intersected by vegetation corridors as well as scree-covered slopes with rocky ledges (7 and 11). The whole combination forms a very homogeneous mosaic.
- *A closed depression landscape:* The Tafenna depression is a large oval basin with a quite flat bottom where fine material regs prevail (9 and 12), cut across by screes on the bare ground (11). Sandy-silty thalwegs are colonised by a well-developed bushy vegetation, interspersed with shrubs and isolated trees (10 and 5). Sand deposits (2) likely to reach a considerable size cover the sides of the basin that are characterised by steep slopes with coarse screes and rocky ledges (11 and 7). A fine reg gentle slope matrix can be spotted. It is divided by coarse screes and corridors of sandy-silty steppe and bush vegetation. Sharp sides with rocky ledges and screes constitute the transition with the slope landscape; they form a circle-shaped corridor that delimits the depression (orange line).



Landscape map, Oued Mird observatory, Morocco.

© ROSELT/OSS. From Baudat, 2003.

Lambert conformal conic projection / South Morocco II.

Merichich datum / 1880 Clarke ellipsoid (IGN).

Map derived from two 15-m (visible/NIR) Aster images.

Pictures taken on August 18th, 2001.

J. Baudat / Mastère SILAT (GIS applied to land use planning)

IRD-ROSELT/OSS, October 2003.

See original picture in the colour supplement.

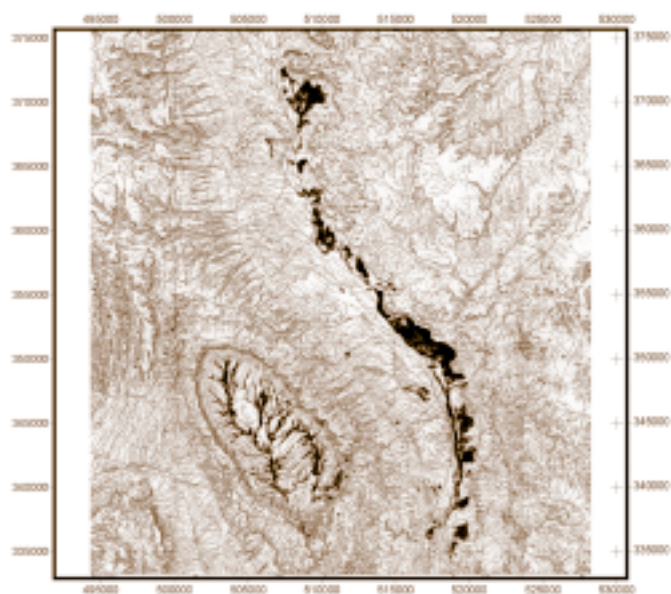
• **An alluvial valley landscape:** The Oued Mird valley has the most heterogeneous ecology in the observatory. This is due to the existence of water (outfall of the slope drainage system, near-surface groundwater) associated with human presence (crops). The matrix there consists of medium to coarse regs of terraces and alluvial cones (4) or of the association of silty deposits with very sparse vegetation cover and sandy-silty steppes (5 and 6). The other element characteristic of this alluvial valley landscape is the combination of heterogeneous spots of mixed crops and palm groves (3), sand deposits and areas (2), an *Acacia raddiana* wooded steppe (1) and bare grounds with sealing crust and salt efflorescence (8).

A landscape map may therefore be regarded as a meeting point for the various nature sciences, since a landscape may be considered as a collection of biotopes (Forman and Godron, 1986; Blondel, 1995; Burel and Baudry, 2001). This type of mapping product is a tool for interdisciplinary work and long-term ecological monitoring. For ROSELT, defining landscape units of this kind would allow to integrate wildlife monitoring from the study of populations sampled in the various biotopes.

Example of the houbara bustard

The houbara bustard is a quite big (about 60 cm) walking bird whose distribution area extends from Saharan arid areas to central Asia. The habitat of this species consists of xerophytic steppes, with fine reg sandy-silty ground and gentle slopes interspersed with small depressions. The diet of the houbara bustard is mainly vegetarian, including insects (Collar, 1996).

In Algeria, in the same biogeographical area as the region studied, Gaucher (1991) provided several indications regarding which plant species the houbara bustard eats (such as those of the genus *Farsetia* in Oued Mird), and regarding its foraging area (1 km/day within a minimum 400-m radius). A map of the houbara bustard habitat in the Oued Mird observatory has been derived from these criteria and the environmental map. A superimposition onto the topographic base allows for instance to plan a systematic research or to establish a baseline status of the habitat for monitoring purposes. Besides, the result tallies with the observation of an individual during the campaign of June 2003.



Location of the houbara bustard habitat (in dark orange) in Oued Mird. Modified topographic base: 1:100,000 (DFCTT, 1968). © ROSELT/OSS. From Baudat, 2003.

See original picture in the colour supplement.



*Wadi Dades valley, North of
Boulmane, Morocco.
Georges Grandin © IRD*

Glossary

Biotope: A localised region of uniform environmental conditions which constitutes the habitat of one or several plant and animal communities.

Georeferencing: The process of assigning map coordinates to image data in order to conform to a map projection system.

Remote sensing: successes, limits, open questions and outlook

An increasingly affordable, reliable tool for data collection

Satellites have the immense advantage of covering at a reasonable cost very large expanses in a repeated, homogeneous and systematic way, which cannot be done on site. Naturally, this notion of “reasonable cost” should be clarified. When resolution increases, the image size decreases - generally together with observation frequency - while collection and processing costs usually increase as well.

Consequently, the regular monitoring of large surfaces at a daily or weekly scale typically resorts to low resolution images. The dynamics observed in the evolution of such images then needs to be interpreted at a small scale. To make this easier, a few high resolution images may be used. These pictures, that are less frequently collected, concern representative sites selected according to their specific characteristics (vulnerability for instance) or to statistical rules (stratification and sampling), or else in view of inputting to long-term observatories networks.

Efforts are in progress to federate and improve in an integrated way research and the knowledge obtained up to now. In particular, the European Commission has taken such initiatives within the scope of the 6th research framework programme. When a seemingly unusual evolution appears in low resolution images (early warning), what is actually happening in such places can be observed more precisely by programming high resolution images and if need be, by undertaking on-site assessment.

A follow-up through both low and high resolution images also allows to monitor the efficiency of restoration and combatting desertification measures.

How to bridge the “digital gap”?

Between experts in remote sensing digital techniques and stakeholders of the combat against desertification, there is what is popularly called a “**digital gap**”, that scientists, engineers, decision-makers and their advisers are trying to bridge.



Young Fulanis, Ferlo, Senegal.
B. Devaux © IRD

Coupling remotely sensed data with *in situ* information

For a start, there is a long way between highly complex desertification processes, relevant indicators that allow to monitor them, variables observable through remote sensing, and the efficiency of methods that enable to extract these variables and to derive models. Some difficulties are partly constitutional (is it possible to determine the irreversible aspect of a degradation from remotely sensed information?), others may be solved by advances in research. Such advances often consist in associating remotely sensed data with data derived from other sources in models that improve the use and efficiency of these various data. The ROSELT project exemplifies a major effort to reduce this kind of gap in the circum-Saharan region. Indeed, many ecological diagnoses are based on the dynamics of different species, the extinction of some of them and appearance of new ones, and such information cannot be supplied by satellite (biodiversity aspect).

Only specific populations may be recognised by their particular structure, usually thanks to the phenological calendar that enables to differentiate easily annual plants from perennial vegetation, and even more easily deciduous species from evergreen ones. Progress consists in obtaining the most representative models based on remotely sensed information and ground data sources, such models being designed to be used in the long run.



Improving international aid targeting

The cost of remote sensing is reasonable in view of the advantages it offers compared with other techniques. Investments, operating costs and expenses for experts' training must be allowed for. However, countries threatened by desertification are poor nations that can hardly finance such investments and recurring costs, let alone keep specialised staff. Under these conditions, it is surprising to see that international aid generally concerns intellectual or material investments rather than recurrent operating costs, which might make fruitless the investments afforded by both parties (brain drain, obsolescent equipment).

Expanding the dissemination and appropriation by end-users of remote sensing techniques

Technology is developing faster than its use and experts' know-how. Nevertheless, comparatively simple products that do not match the highest standards of technological knowledge are available; e.g. warning bulletins are now common. For a start, the utilisation of this type of products should be enhanced. In particular, it is essential that end-users should get them and be able to interpret them. Thanks to the quick development of digital communication techniques, their dissemination that used to be a problem a few years ago is being considerably improved - even though end-users may be a long way

behind in the information distribution chain. The issue of training end-users in these new space technologies and the question of staff retention still remain pending. Without trained people, investment and operating costs would be spent to no avail.

The optimal and efficient use of remote sensing within the scope of the desertification combat is both successful and limited at the social, economic and environmental levels. To go ahead, it is essential to make progress in reducing the three types of gaps above mentioned. If voluntary participation lacks, new knowledge might be generated without any possibility to derive practical applications; or the methods applied by relevant stakeholders might unacceptably stagnate whereas technological advances would allow to forge ahead and ensure the sustainable development of the most vulnerable regions and populations of our planet.

Glossary

Digital gap: The gap regarding the access to information technologies.



Young people of the Kamadjan IRD youth club are making a flora inventory conducted by Moussa Karembé (researcher at IER). Mande region, Mali.
Thérèse Touré © IRD

List of acronyms and abbreviations

AGRHYMET	Regional Training Centre for Agrometeorology and Operational Hydrology and their applications / <i>Centre Régional de Formation et d'Applications en Agrométéorologie et Hydrologie Opérationnelle</i>
AP3A	Early Warning and Agricultural Production Forecast Project / <i>Projet Alerte Précoce et Prévision des Productions Agricoles</i>
AVHRR	Advanced Very High Resolution Radiometer
C3ED	Centre of Economics and Ethics for Environment and Development / <i>Centre d'économie et d'éthique pour l'environnement et le développement</i>
CAMELEO	Changes in Arid Mediterranean Ecosystems on the Long term and Earth Observation
CESBIO	Centre for the Study of the Biosphere from Space / <i>Centre d'Études Spatiales de la BIOSphère</i>
CILSS	Permanent Inter-State Committee for Drought Control in the Sahel / <i>Comité permanent Inter États de Lutte contre la Sécheresse au Sahel</i>
Cirad Emvt	Department of Animal Production and Veterinary Medicine of the French Agricultural Research Centre for International Development / <i>Département Élevage et Médecine Vétérinaire du Centre de Coopération Internationale en Recherche Agronomique pour le Développement</i>
CNES	French Space Agency / <i>Centre National d'Études Spatiales</i>
CSFD	French Scientific Committee on Desertification / <i>Comité Scientifique Français de la Désertification</i>
DTM	Digital Terrain Model
EROS	Earth Resources Observation System
ESA	European Space Agency
ETM	Enhanced Thematic Mapper
FAO	Food and Agriculture Organization of the United Nations
FEWS-NET	Famine Early Warning Systems Network
GIEWS	Global Information and Early Warning System
GIMMS	Global Inventory Modelling and Mapping Studies
GIS	Geographic Information System
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
INRA	French National Institute for Agricultural Research / <i>Institut National de la Recherche Agronomique</i>
IRD	<i>Institut de recherche pour le développement</i>
ISIS	Incentive for the Scientific use of Spot Images / <i>Incitation à l'utilisation Scientifique des Images SPOT</i>
LGZD	Laboratory of Zonal Geography for the Development / <i>Laboratoire de Géographie Zonale pour le Développement</i>
Médias	Regional Research Network on Global Change in the Mediterranean basin and subtropical Africa / <i>Réseau Régional de Recherche sur le Changement Global dans le bassin MEDIterranéen et l'Afrique Sub-tropicale</i>
MERIS	Medium Resolution Imaging Spectrometer Instrument
MODIS	Moderate Resolution Imaging Spectroradiometer
MS	Multispectral
MSG	Meteosat Second Generation
MSS	Multi Spectral Scanner
NASA	National Aeronautics and Space Administration
NCREC	National Centre for Radio-Electronics and Communications
NDVI	Normalised Difference Vegetation Index
NIR	Near InfraRed
OSS	Sahara and Sahel Observatory / <i>Observatoire du Sahara et du Sahel</i>
POSTEL	<i>Pôle d'Observation des Surfaces continentales par TÉLÉdétection</i>
ROSELT	Long-Term Ecological Monitoring Observatories Network / <i>Réseau d'Observatoires de Surveillance Écologique à Long Terme</i>
SAR	Synthetic Aperture Radar
SMOS	Soil Moisture and Ocean Salinity
UMR	Joint Research Unit / <i>Unité Mixte de Recherche</i>
USAID	U.S. Agency for International Development
USGS	United States Geological Survey
UVSQ	University of Versailles Saint-Quentin-en-Yvelines / <i>Université de Versailles Saint-Quentin-en-Yvelines</i>
VITO	Flemish Institute for Technological Research



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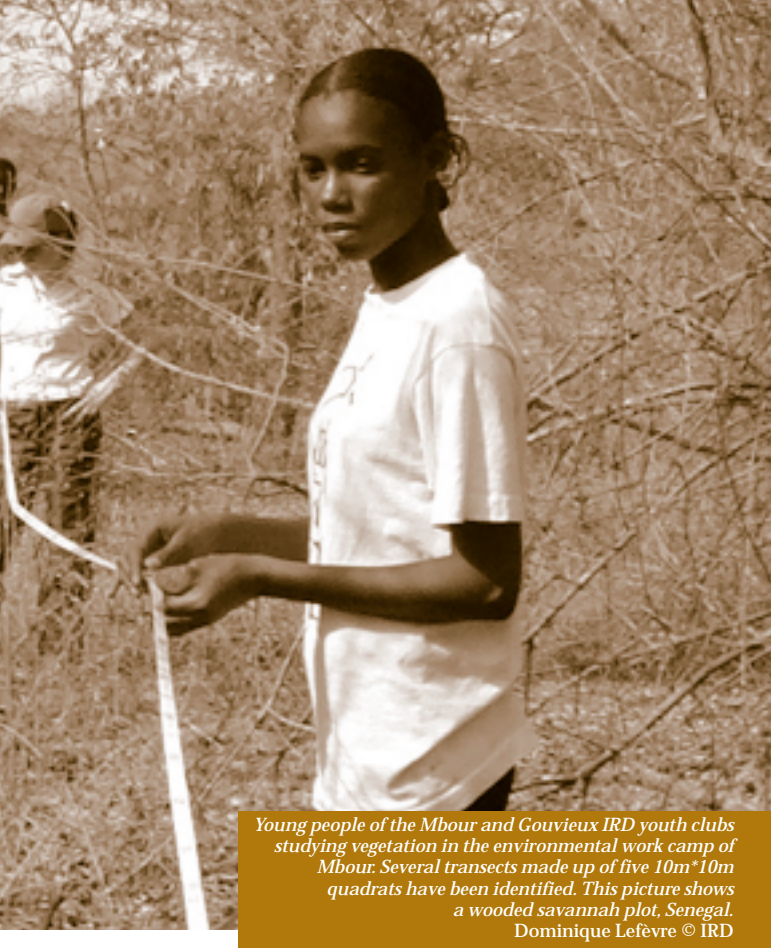
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Young people of the Mbour and Gouvieux IRD youth clubs studying vegetation in the environmental work camp of Mbour. Several transects made up of five 10m*10m quadrats have been identified. This picture shows a wooded savannah plot, Senegal. Dominique Lefèvre © IRD

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- **EUropean organisation for the exploitation of METeorological SATellites (EUMETSAT)**
www.eumetsat.de
- **French Scientific Committee on Desertification (CFSD)**
www.csf-desertification.org
- **Institut de recherche pour le développement (IRD)**
www.ird.fr
- **Laboratory of Zonal Geography for the Development (LGZD)**
www.univ-reims.fr
- **Long-Term Ecological Monitoring Observatories Network (ROSELT)**
www.roselt-oss.teledetection.fr
- **Regional Training Centre for Agrometeorology and Operational Hydrology and their applications (AGRHYMET)**
www.agrhymet.ne
- **Regional Research Network on Global Change in the Mediterranean basin and subtropical Africa (Médias)**
<http://medias.obs-mip.fr>
- **Sahara and Sahel Observatory (OSS)**
www.unesco.org/oss
- **United Nations Convention to Combat Desertification (UNCCD)**
www.unccd.int

Space agencies

- **Canadian Space Agency (CSA)**
www.space.gc.ca/asc
- **European Space Agency (ESA)**
www.esa.int
- **French Space Agency (Centre National d'Études Spatiales, CNES)**
www.cnes.fr
- **Indian Space Research Organisation (ISRO)**
www.isro.org
- **Japan Aerospace Exploration Agency (JAXA)**
www.jaxa.jp
- **National Aeronautics and Space Administration (NASA)**
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Satellite programmes and missions

- **ADEOS II**
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- **ENVISAT**
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- **ERS**
<http://earth.esa.int/ers>
- **IRS-P4 (OCEANSAT)**
www.isro.org/irsp4.htm

- **LANDSAT**
<http://landsat.gsfc.nasa.gov>
- **MODIS**
www.ga.gov.au/acres/prod_ser/modisdata.htm
- **MSG**
www.esa.int/msg/pag0.html
- **PARASOL**
<http://smc.cnes.fr/PARASOL/Fr>
- **RADARSAT 2**
www.radarsat2.info
- **SMOS**
www.esa.int/esaLP/smos.html
- **Spot 4**
<http://spot4.cnes.fr>
- **TERRA**
<http://terra.nasa.gov>

Satellite image providers

- **ESA (European Space Agency)**
<http://earth.esa.int/images>
- **EURIMAGE**
www.eurimage.com
- **GLCF (Global Land Cover Facility)**
<http://glcf.umi.acs.umd.edu>
- **Landsat**
www Landsat.org
- **Radarsat International**
www.rsi.ca
- **Space Imaging**
www.spaceimaging.com
- **Spot Image**
www.spotimage.fr
- **VITO (VEGETATION)**
<http://free.vgt.vito.be>

Education

- **Canada Centre for Remote Sensing**
www.ccrs.nrcan.gc.ca/ccrs/learn/learn_f.html
- **Institut national agronomique Paris-Grignon (INA-PG)**
<http://lacan.grignon.inra.fr/ressources/teledetection/vademecum.htm>
- **Institut national agronomique Paris-Grignon / National Institute for Agricultural Research (INRA)**
www.inapg.inra.fr/ens_rech/ager/ressources/supports/courteld/cours/couverture.htm
- **Remote Sensing Tutorial (NASA)**
<http://rst.gsfc.nasa.gov>

ISIS Programme / Incentive for the Scientific use of Images from Spot system

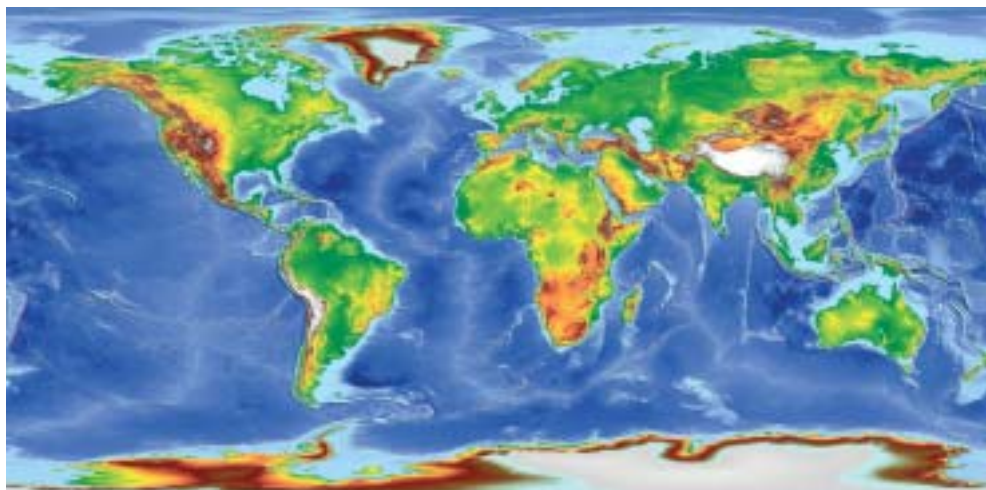
- <http://medias.obs-mip.fr/isis>
- <http://medias.obs-mip.fr/www/Reseau/Lettre/13/en/isis.pdf>



*Camp of Fulani herdsmen in a reg (desert pavement)
invaded by the sand of the previous erg
(Inchirian period, 22000 BP).
North Oursi, Burkina Faso.
Jean-Claude Leprun © IRD*

Example (page 13)

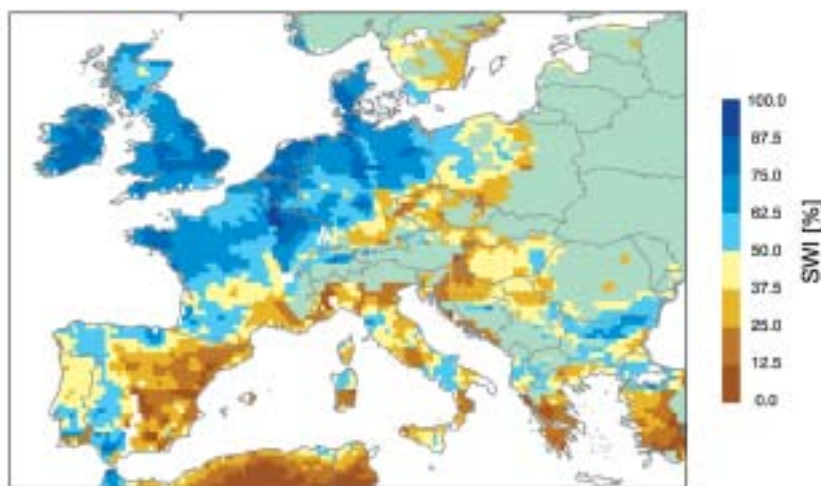
Use of the “roughness” parameter
The Earth seen from a radar altimeter:
land topography and ocean bathymetry



This map is drawn out from data derived from the ESA (European Space Agency) ERS-2 European satellite).

Example (page 14)

Use of the “soil moisture” parameter in Europe



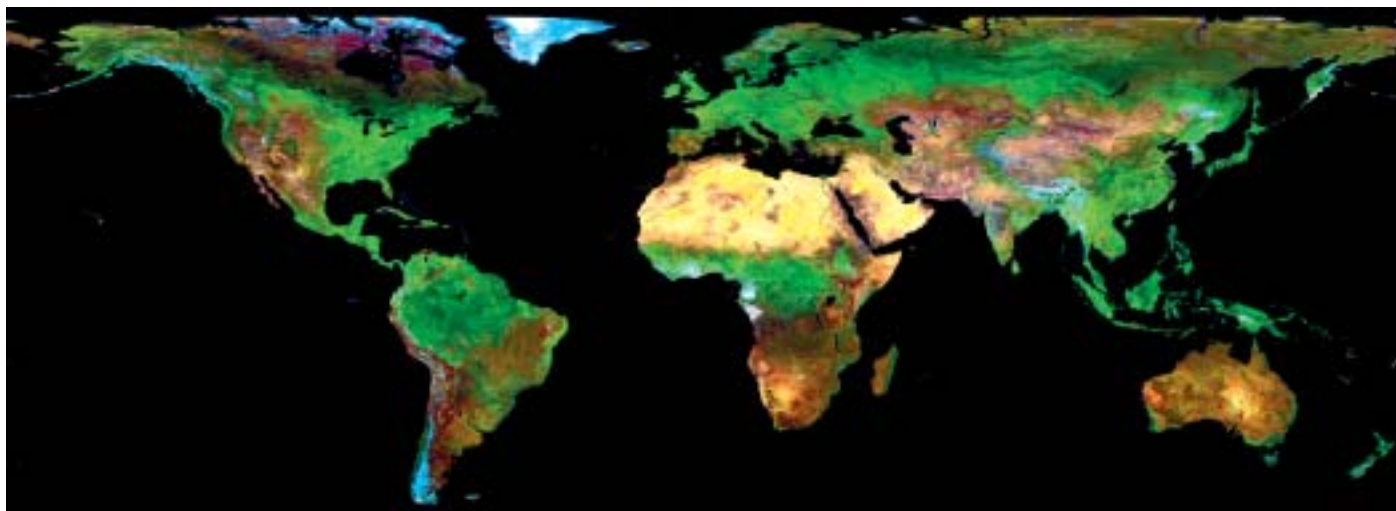
Soil moisture in Europe – ERS satellite (January 2000)

This soil moisture map is derived from measurements performed by the ERS satellite (January 2000) over Europe. Data are expressed comparatively, in percentage, with 0% representing dry lands and 100% very wet lands.

Source: kindly provided by the Institute of Photogrammetry and Remote Sensing, Vienna University of Technology

Example (page 15)

Global scale vegetation indices



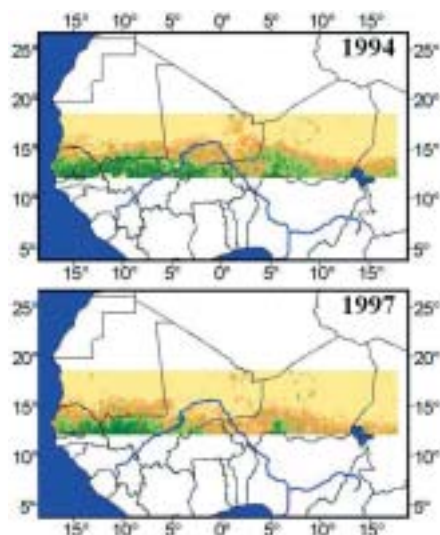
A global synthesis of vegetation indices made by EOworks from NDVI Spot-Vegetation data (03/1999). The colour range expresses increasing index values, from yellow to green.

© CNES 2004

Image distributed by VITO

Example (page 17)

Biomass monitoring in the West Sahelian region



Above-ground vegetation production in the West Sahelian region (-18°E/18°E and 13.5°N/20°N) assessed by an ERS satellite scatterometer regarding these two contrasting years.
© CESBIO 2003

Estimating above-ground plant biomass resorts to meteorological data combined with those derived from scatterometers (through modelling). In the Sahelian area subject of this study, biomass distribution is significantly different in 1994 (wet year) and 1997 (dry year). This method applied to the whole Sahelian belt shown in this figure has been submitted to ground validation in the Gourma region (Mali).

Colour scale ranges from 0 (off-white) to 3,000 kg (dark brown) of dry matter per hectare.

From Jarlan *et al.*, 2003.

Examples (page 16)

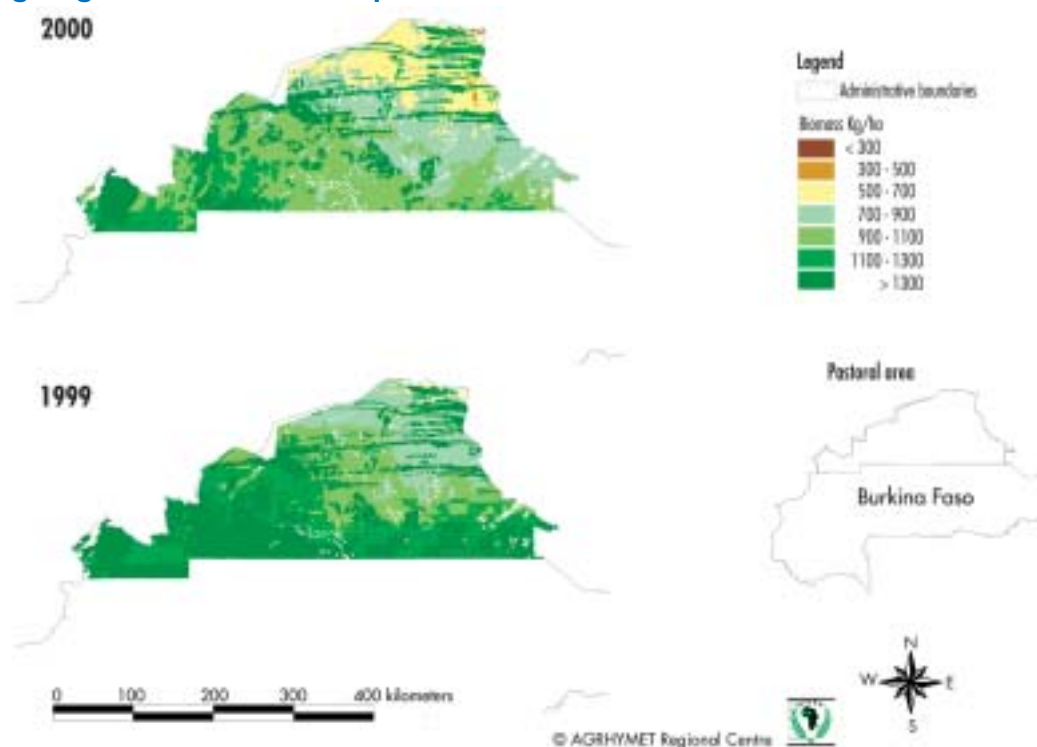
Use of vegetation indices: a map of African drylands



Vegetation indices (NDVI) for the first ten days of April 2004 are derived from NOAA/AVHRR satellite data. The higher the index, the more developed is the vegetation cover.

Source: Data from NASA GSFC (Goddard Space Flight Center), GIMMS (Global Inventory Modelling and Mapping Studies). Map issued by the FEWS-NET (Famine Early Warning Systems Network) project of the USGS EROS (United States Geological Survey – Earth Resources Observation System) Data Centre. A research funded by USAID (U.S. Agency for International Development).

Monitoring of grass biomass in the pastoral area of Burkina Faso



Annual maps of grass biomass in the pastoral area of Burkina Faso in 1999 and 2000 (note the difference between the two annual situations).

In the Sahel, annual grasses that make up a large part of pastoral resources are the predominant vegetation cover. The AGRHYMET Centre (CILSS: Permanent Inter-state Committee for Drought Control in the Sahel) created in 1974 is currently monitoring grazing lands at the regional scale and is circulating information to national decision-makers. This allows to determine grazing lands at risk, and if need be, to issue a warning in order to reduce grazing in relevant regions and prevent their desertification. The state of pastoral resources is assessed by estimating biomass from cumulated vegetation indices. These data regarding the Sahelian region are also listed in the monthly report of the FAO (Food and Agriculture Organization of the United Nations) GIEWS (Global Information and Early Warning System).

Similar techniques may be applied to other semi-arid pastoral areas rich in annual plants, such as Central Asian regions.

Monitoring vegetation north of the Sahara is more difficult because steppes of small low woody bushes prevail. Moreover, during a large part of the year, vegetation is only weakly green, or even not at all during very dry periods. It is then quite impossible to use vegetation indices to estimate variations in vegetation cover.

© AGRHYMET Regional Centre

Source: AP3A (Early Warning and Agricultural Production Forecast) Project. AGRHYMET Regional Centre, Niamey, Niger

Degradation due to a decrease in the vegetation cover of the Menzel Habib sandy steppe, Tunisia

View at ground level



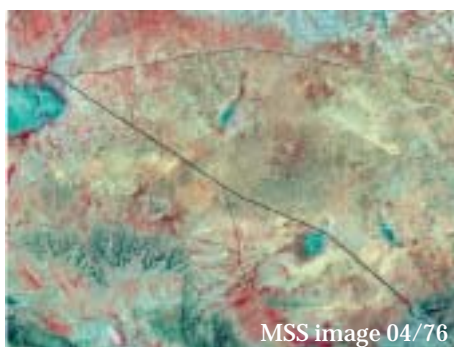
Normal state



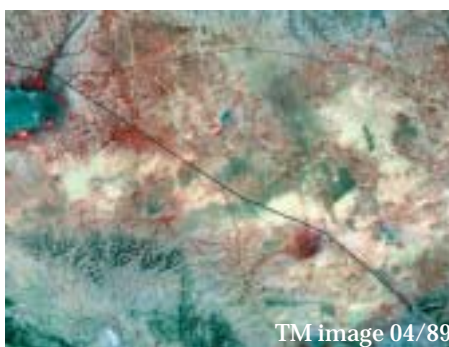
Degraded state

R. Escadafal © IRD

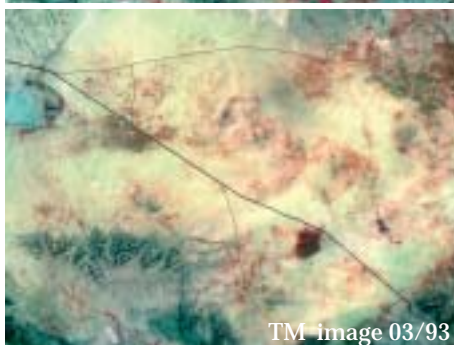
Satellite images



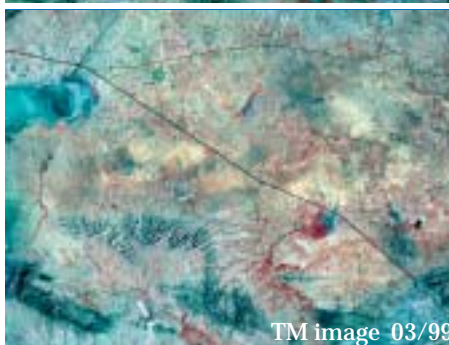
MSS image 04/76



TM image 04/89



TM image 03/93



TM image 03/99

R. Escadafal © IRD

Four georeferenced and intercalibrated Landsat images of the Menzel Habib area (Tunisia) (1976, 1989, 1993, 1999)
Richard Escadafal © IRD

The differences evidenced correspond to modifications in surface states at ground level. Each picture covers a 30x24 km area.

• Landsat MSS image dated April 1976

The Menzel Habib plain in 1976: bordered in the South-East and South-West by mountains (in grey), a sandy steppe prevails (in beige in the centre). Annual crops (in red) are located at the periphery and in depressions (bright red spots).

• Landsat TM image dated April 1989

In 1989, drought leads to a decrease in crops and to the striking expansion of mobile sand (light yellow): the region is "desertified".

• Landsat TM image dated March 1993

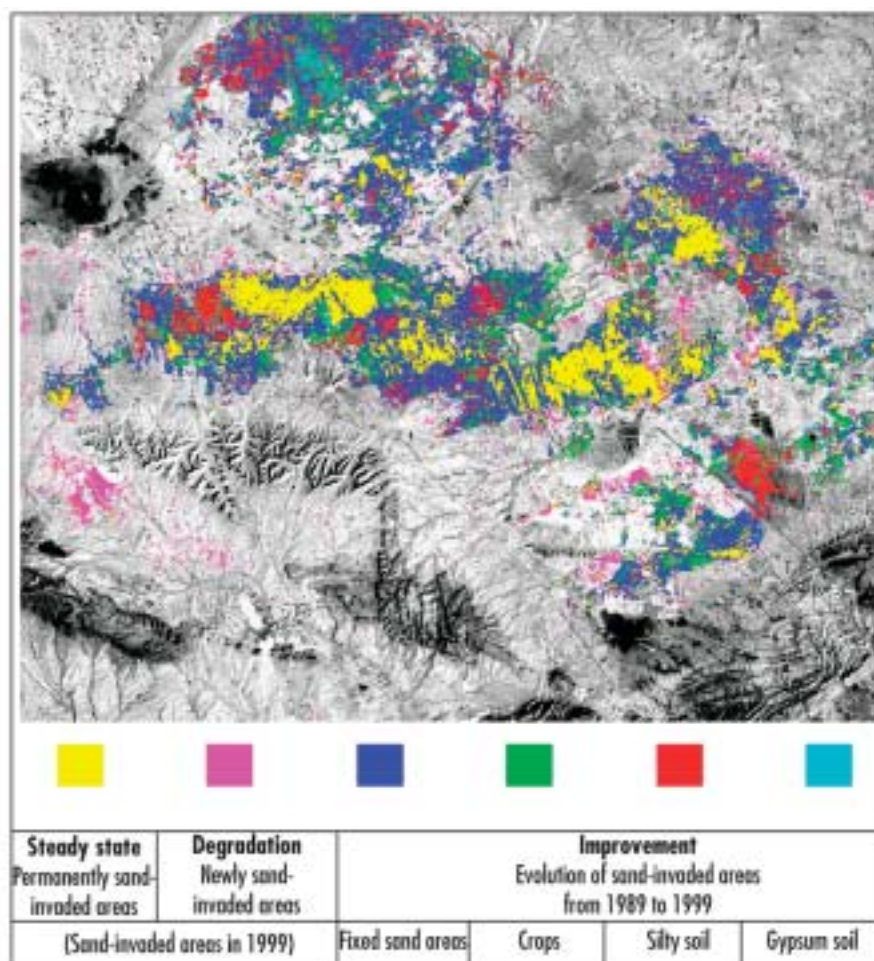
In 1993, i.e. four years later, the impacts of enclosure areas clearly show as dark trapezium-shaped spots among sandy areas, while annual crops intensify (red dotted lines).

• Landsat TM image dated March 1999

In 1999, mobile sand areas prove to have completely receded and the situation is apparently well controlled. The landscape appears to be fully parcelled out in plots of various uses, and new enclosure areas have been set up in the few remaining dune areas.



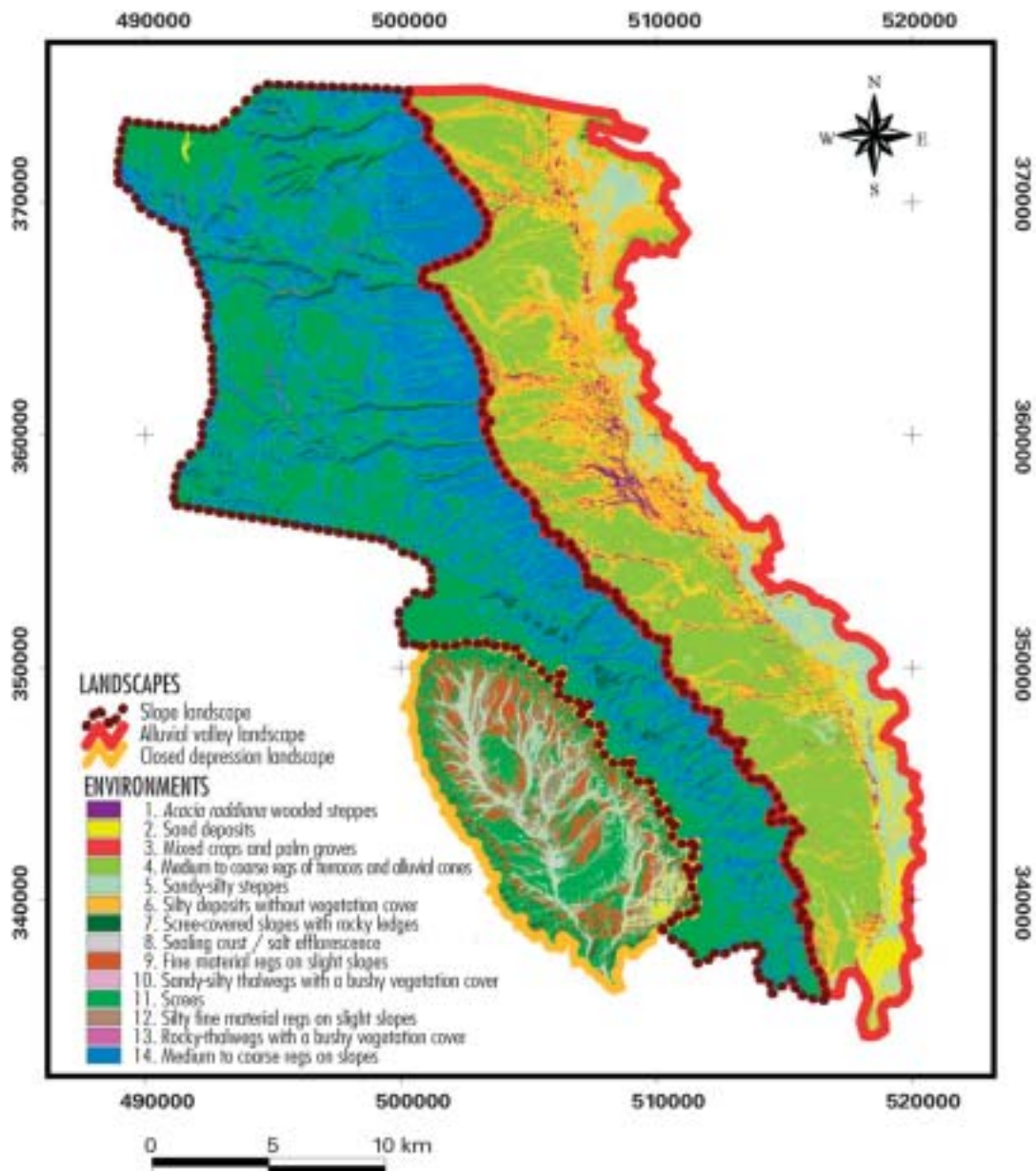
Synthesis of sand invasion evolution in the Menzel Habib area (Tunisia) between 1989 and 1999



R. Escadafal © IRD

This figure illustrates one of the syntheses obtained by analysing trends observed in images classified over five dates (between 1989 and 1999) and showing sand-invaded surfaces (unfixed moving sand, dunes, etc.). Sand-invaded areas (mobile dunes) have decreased in favour of fixed sand areas and farming lands.

Satellite images thus evidenced that the environmental state did improve between 1989 and 1999. Efforts undertaken in order to fix the moving sand that had invaded the region during the previous decade were successful. Space-based monitoring allowed to quantify these impacts over large expanses. Such good results were of course also observed locally on site.



Landscape map, Oued Mird observatory, Morocco.

© ROSELT/OSS.From Baudat, 2003.

Lambert conformal conic projection / South Morocco II.

Merchich datum / 1880 Clarke ellipsoid (IGN).

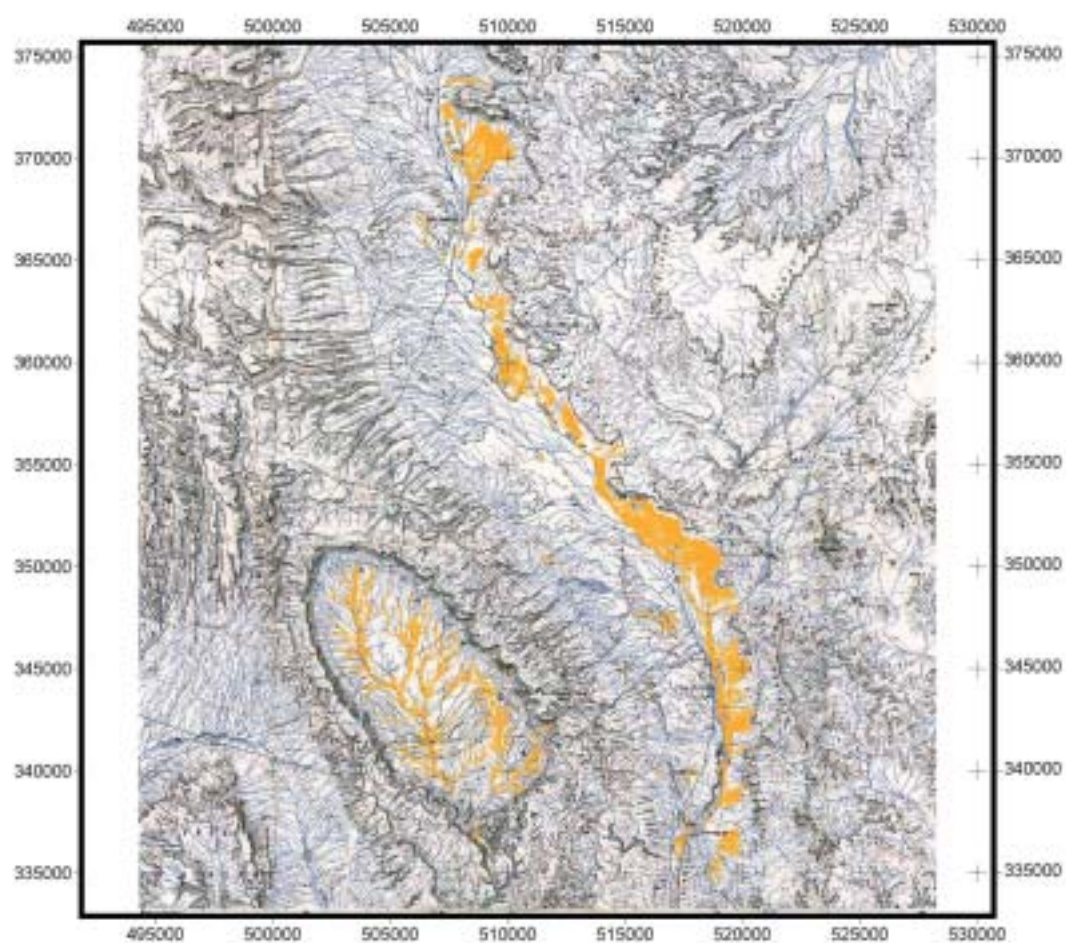
Map derived from two 15-m (visible/NIR) Aster images.

Pictures taken on August 18th, 2001.

J. Baudat / *Mastère SILAT* (GIS applied to land use planning)

IRD-ROSELT/OSS, October 2003.





*Location of the houbara bustard habitat
(in dark orange) in Oued Mird.
Modified topographic base: 1:100,000 (DFCTT, 1968).
© ROSELT/OSS. From Baudat, 2003.*

The colour supplement is printed on Cyclus Print chlorine-free de-inked recycled paper.



Abstract

Remote sensing is a technique that enables to observe the radiation scattered or emitted by the Earth surface. Satellite-based remote sensing allows regular, repetitive, accurate observations of nearly the whole planet, at various spatial and temporal scales, in several wavelength fields.

Such observations render the nature, state, temporal and spatial variations of the properties of the objects at the Earth surface. By way of example, water-covered areas, roughness, soil moisture, changes in the nature of land, density and phenological evolution of the vegetation cover, sand winds, are information included in these observations. Nevertheless, these observations usually combine together, making them more or less difficult to extract from the raw data transmitted by satellites. The science of remote sensing consists in interpreting and processing the series of spatial and temporal images in order to extract such parameters, qualitatively or quantitatively. Desertification is a phenomenon of irreversible land degradation. It results from complex processes linked to the coupled and joint evolution of natural and human-induced factors. The beginning, development and results of such processes are materialised by land surface states and their evolution.

Remotely sensed data consequently include information that the science of remote sensing allows to partly extract with more or less accuracy. Such information coupled with others are involved in various stages of the desertification process. Remote sensing provides useful data; some of them are essential information impossible to collect otherwise (especially in terms of homogeneity and spatial coverage and/or temporal monitoring) for early warning, monitoring the development of desertification phenomena and acknowledging a final state. Among others, remote sensing may allow to determine the impacts of policies to combat desertification. However, because of the mentioned limits regarding the extraction of useful parameters and the part played by the latter in the processes concerned, remote sensing turns out to be a tool among others - certainly a powerful one, but not a scientific, decisional or operational "miracle" solution.

After presenting in detail the technique and science of remote sensing and how it allows to monitor various elements of desertification processes, this brochure deals with the most important and significant cases and brings both aspects together. Several key parameters and processes are studied: roughness, albedo, surface temperature, moisture, vegetation indices on the one hand; vegetation cover monitoring, modifications in the land surface composition in dry environments, wind transportation on the other hand. Examples are developed: evolutions of specific sites, projects under way. Lessons taught by previous experiments are critically analysed, options for the future are designed.

Key words: Remote sensing, desertification, vegetation cover, land surface states, wind transportation, early warning, prevention policies, monitoring/assessment

Résumé

La télédétection est une technique permettant l'observation du rayonnement diffusé ou émis par la surface de la Terre. La télédétection par satellite permet des observations régulières, répétitives, fidèles, de la quasi-totalité de la planète, à divers pas d'espace et de temps, dans plusieurs domaines de longueur d'onde. Ces observations traduisent la nature, l'état, la variation spatiale et temporelle des propriétés des objets présents à la surface terrestre. À titre d'exemple, l'étendue des surfaces en eau, la rugosité, l'humidité des sols et leur changement de nature, la densité et l'évolution phénologique du couvert végétal, les vents de sable, sont des informations présentes dans ces observations.

Néanmoins, ces observations se combinent entre elles le plus souvent et il est plus ou moins difficile de les extraire des données brutes transmises par les satellites. La science de la télédétection consiste à interpréter et traiter les séries spatiales et temporelles d'images afin d'extraire ces paramètres qualitativement ou quantitativement. La désertification est un phénomène de dégradation irréversible des terres. Elle est le résultat de processus complexes liés à l'évolution conjointe et couplée de facteurs naturels et anthropiques. Le départ de tels processus, leur développement et leur résultat, se traduisent dans les états de surface du sol et leur évolution.

Les données de télédétection sont donc porteuses d'informations que la science de la télédétection permet partiellement d'extraire, avec plus ou moins de précision. Ces informations, couplées avec d'autres, interviennent dans diverses phases du processus de désertification. La télédétection apporte des informations utiles, parfois indispensables et impossibles à acquérir autrement (notamment en termes d'homogénéité et de couverture spatiale et/ou de suivi temporel), pour l'alerte précoce, le suivi du développement de phénomènes de désertification et le constat d'un état final. Elle peut notamment permettre de dresser des constats sur les impacts de politiques de lutte. Néanmoins, de par les limitations signalées sur l'extraction des paramètres utiles et le rôle de ces paramètres dans ces processus en jeu, la télédétection s'avère être un outil parmi d'autres, certes puissant, mais non une solution 'miracle' scientifique, décisionnelle ou opérationnelle.

Après avoir présenté de manière détaillée la technique et la science de la télédétection, et comment elle permet de suivre certains éléments des processus de désertification, ce dossier s'attache aux cas les plus importants et significatifs, en rapprochant les deux aspects. Certains paramètres et processus clés sont étudiés : rugosité, albedo, température de surface, humidité, indices de végétation d'une part ; suivi de la couverture végétale, modification de composition des surfaces en milieu aride et transport éolien d'autre part. Des exemples sont développés : évolutions de sites particuliers, projets en cours de développement. Des leçons d'expériences passées sont analysées d'un œil critique et des voies pour le futur sont dessinées.

Mots clés : Télédétection, désertification, couvert végétal, état des surfaces, transport éolien, alerte précoce, politiques de prévention, suivi/évaluation

Cover picture (photomontage):

Landscape: Irrigation in arid environment, Tunisia - (J. Pouget © IRD)

Man: Life of the Fulani ethnic group, Burkina Faso - (J.J. Molez © IRD)

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