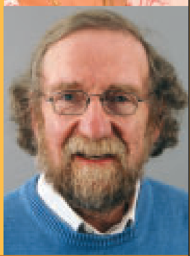
Observing Earth from space

Over the past few decades, our understanding of Earth's structure and how it evolved, and is evolving, has improved considerably thanks to satellite observations.



>>> Anny CAZENAVE, CNES engineer, researcher at LEGOS (joint UPS/CNES/CNRS/IRD lab) and Bernard Dupré, CNRS senior scientist, director of the Midi-Pyrénées Observatory, researcher at LMTG (joint UPS/CNRS/IRD lab).

Headline

Progress not only concerns solid Earth but also its fluid envelopes (atmosphere and oceans) as well as land surfaces. Two factors have played an important role here: observations of continuousl y improved quality, and modelling tools developed for simulating Earth's past, present and future structure. .

Satellites

Observations from space have played a crucial role. The importance of satellites for observing planet Earth is well known: satellites offer global coverage, high resolution and continuous or frequent measurements. Their data are well calibrated and, in general, easily accessible. Not to mention that observations from space have also helped improve model performance.

The technical center of the French National Space Agency (CNES) has been located in Toulouse since the mid-1970s. The centre has strongly contributed in enhancing regional development of space research, in particular in geosciences.

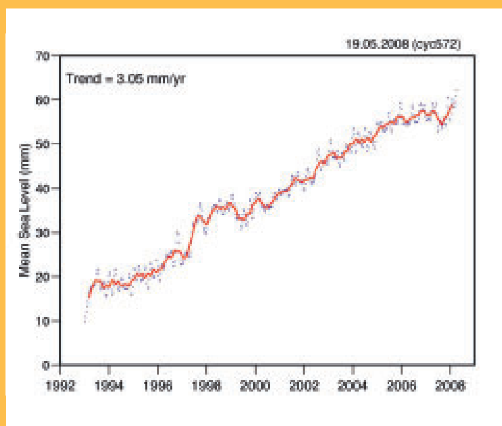
In the Toulouse region, Earth observation research using space techniques is mainly conducted at the Midi-Pyrénées Observatory (OMP), which is part of Paul Sabatier University. Five OMP laboratories are involved in space research to study the solid Earth, land surfaces, atmosphere, oceans and ice bodies. Two of them, CESBIO (Centre for Space Studies of the Biosphere) and LEGOS (Geophysics and Spatial Oceanography Study Laboratory) are partially sponsored by CNES. The other three (DTP –Terrestrial and Planetary Dynamics-, LMTG –Mechanism and Transfers in Geology Laboratory- and the Aerology Laboratory) also routinely use satellite observations. Let us also mention the pioneering role of the Groupe de Recherches en Géodésie Spatiales –GRGS-, a national institution created in 1971 for developing space geodesy in France, which includes several OMP teams.

High-precision oceanography

Although OMP is not the only French institution developing Earth-oriented space research, its teams are clearly world leaders in several areas. These include space oceanography, thanks to the development of a French program in satellite altimetry (Topex/Poseidon and Jason missions) by CNES. During the past 15 years, LEGOS, in collaboration with other Toulouse groups (for example, CLS –Collecte Localisation Satellite-, a CNES subsidiary, and MERCATOR) have made important contributions in several areas of space oceanography, such as ocean tides, ocean circulation, ocean-atmosphere interactions related to El Nino and sea level rise. Satellite altimetry data are also now routinely used by MERCATOR for forecasting the state of the ocean one or two weeks in advance, as is currently done in meteorology. Today, such a satellite altimetry applications are well integrated in the ongoing European project GMES (Global Monitoring for Environment and Security).

Land surfaces

CESBIO is also a leader in the domain concerning land surfaces and the terrestrial biosphere. In addition to contributions to fundamental research



>>> Average sea level rise since 1993 from space altimetry measurements (blue dots are raw data, red curve is smoothed data). There is an observed increase of 3mm per year over the last 15 years (Topex Poseidon and Jason-1 data)

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(for example, on the carbon cycle and land hydrology), numerous applications for society as a whole have been developed, such as in agriculture, for instance.

Crustal deformations

In the 1990s, scientists from the DTP, together with CNES engineers, were the first to use radar interferometry (a technique derived from "synthetic" aperture radar on satellites such as ERS, JERS and Radarsat) to measure crustal deformation in tectonically active regions, with unprecedented resolution. Such a technique is now routinely used worldwide to monitor co- and post-seismic deformations, volcanic deformations, ground subsidence, land slides and glacier motion. Another example concerns the use of precise positioning from space (for example, GPS, satellite laser ranging and DORIS) to measure large-scale tectonic plate motions.

Terrestrial waters

In recent years, several teams from OMP (at LMTG, LEGOS and CESBIO) have developed a new research area, hydrology from space. Space techniques such as satellite altimetry, space gravimetry (the GRACE space mission), radar and visible imagery, radiometry, active and passive microwaves can be used in synergy to measure key variables in land hydrology and their evolution in response to climate variability and anthropogenic forcing. Examples include soil moisture, lake water levels, rivers and floodplains, surface water volumes and total land water storage. This data is very valuable for better understanding the global water cycle. It is also highly useful for applications, such as water management, river navigation, agriculture and land use, flood and drought prediction and hydroelectric power production. The same techniques also yield information about the mass balance of the Greenland and Antarctica ice sheets in response to global warming and their impact on sea levels.

Atmospheric pollution

The use of satellite data in meteorology has been around for a long time but it is only recently that satellite observations have been used to study atmospheric pollution. The Aerology Laboratory at

OMP is now involved in such a field, providing information about atmospheric pollution on vast scales by combining space data with modelling approaches.

The examples mentioned here highlight the advantages of using space observations to study our planet. Important advances have been made over the last decade by OPM laboratories in studying oceans, solid Earth, terrestrial waters, land surfaces and atmospheric pollution. With existing space missions and those to be launched soon, future research in these areas is very promising. OMP will no doubt continue to play a leading role at both the national and international level.

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Congratulations!

Anny CAZENAVE, in charge of putting this headline together and member of the French Academy of Sciences, is now also a member of the American Academy of Science.

A satellite view of Earth's global water resources

Three laboratories at the Midi-Pyrenees Observatory are using satellites to measure the continental water cycle -- a new kind of research.

>>> Yann KERR, CNES engineer, director of CESBIO (joint UPS/CNRS/CNES/IRD lab) ; Nelly MOGNARD, CNES engineer and Frédérique RÉMY, CNRS senior scientist at LEGOS (joint UPS/CNRS/CNES/IRD lab), Frédérique SEYLER, senior scientist at IRD (LMTG, joint UPS/CNRS/IRD lab)

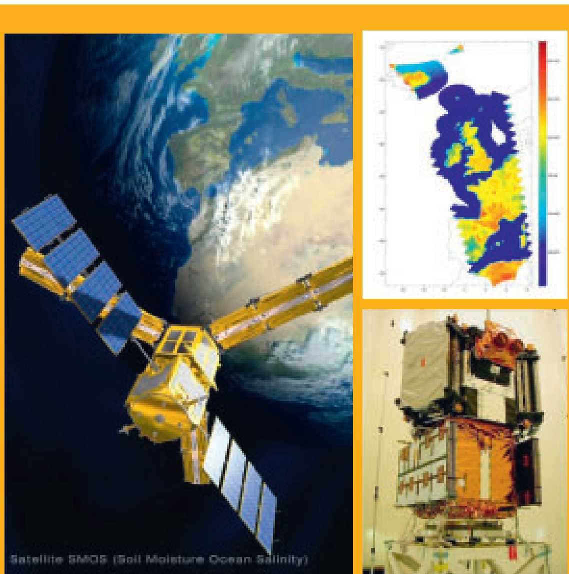
The interactions between precipitation and lateral transfer of energy and mass fluxes from the ground or "root zone" are being studied at CESBIO. Instantaneous satellite observations in the visible, infrared and near infrared wavelength have poor spatial resolution and require complex data processing. Soil moisture is estimated indirectly from active (radar) and passive (radiometers) microwave satellite measurements.

CESBIO is in charge of the AMMA/CATCH programme (African Monsoon Atmosphere and Water Cycle Coupling) and for soil moisture in situ and satellite measurements in Mali.

The water cycle

Variations of the gravity field derived from GRACE (Gravity Recovery & Climate Experiment) satellite measurements are used at LEGOS to quantify the spatio-temporal variability of continental water stock (surface and ground water, and snow), ice sheet and glaciers, which cannot be observed by any other means on a global scale.

To estimate surface water levels for large rivers, lakes and enclosed seas, LEGOS and LMTG use radar altimeter satellite data (Topex/Poseidon, ERS, Jason and Envisat) initially designed to measure ocean surface topography. These measurements are used for studying climate and anthropic processes. New results from altimeter estimates of water levels have been obtained by modelling river discharge, and calculating riverbed elevation using theoretical relationships between altimeter-derived water levels and slopes, and discharge. These measurements are used for hydrodynamic modelling. For large river basins, radar altimeters provide measurements of flood plains and estimates of the corresponding water volume used to model the dynamics of flooded regions. These studies are especially important for estimating the carbon cycle dynamics in tropical regions.



>>> Artist's view of SMOS, which will measure soil humidity and ocean salinity.

Suspended sediment

Recently, LMTG developed new methods to estimate the concentration of surface suspended sediment using visible and near infrared images (300 m resolution) from MERIS (on board the Envisat satellite) and MODIS (on board AQUA and TERRA satellites). The suspended sediments come from the erosion of continental surfaces and are carried away by large rivers. To validate and calibrate the satellite data LMTG uses networks of in situ measurements in the Amazon basin through official collaboration agreements with the different countries in this region.

Since 1979, LEGOS has been monitoring the dynamics of the high latitude snowpack, derived from passive microwave satellite measurements. Since the launch of the ERS-1 satellite in 1992, the surface topography of Antarctica and Greenland has been monitored with unprecedented precision from radar altimeter measurements. The combination of satellite radar altimeters with gravimetry shows that ice mass is decreasing in the western portion of Antarctica and globally over Greenland.

Future satellite missions

A new satellite mission SMOS (Soil Moisture and Ocean Salinity) was proposed by CESBIO in 1998 to estimate soil moisture and ocean salinity on a global scale. This new mission (whose interferometer functions at 1.4 GHz) will be launched in 2009.
LEGOS is also the lead for a new satellite mission SWOT (Surface Water Ocean Topography) for continental surface water hydrology and high resolution ocean topography. SWOT is a new wide swath interferometric altimeter (36 GHz) that will provide complete global coverage with 100 m resolution for continental surface water and 1 km resolution for oceanography studies. SWOT is a NASA-CNES collaboration and its launch is scheduled for 2015.

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Pluridisciplinary and multiscale approaches for vegetation studies

How is the terrestrial ecosystem adapting to global climate change? Is agriculture reducing greenhouse gas emissions? How can we optimize water resources? What are the risks for desertification? Work at CESBIO is helping to answer these other questions.

>>> Eric CESCHIA, assistant professor at UPS, researcher at the Centre for Biosphere Spatial Studies (CESBIO, joint UPS/CNES/CNRS/IRD lab).

Several approaches combining field work, remote sensing and terrestrial ecosystems dynamics modelling using conceptual models adapted to different study scales are being used to answer the above questions. Our research focuses on three region: the Sahel zone, the southern part of the Mediterranean sea and southwest France.

Vegetation dynamics (land-cover, leaf-area index and biomass distribution) can be analyzed in the field by sampling protocols. However, the sampling areas are limited and are sometimes difficult to access. On the other hand, large scale observation of vegetation characteristics can be carried out at daily to monthly intervals by remote sensing data through analysis of vegetation indices calculated form surface reflectance in different wavelengths: visible, infrared and radar can be used to obtain information on land use and vegetation biomass, height, leaf area and water status (figure 1). However, such remote sensing requires field calibrations and validation campaigns.

Water vapour (evaporation and transpiration) and CO_2 (photosynthesis and/or respiration) exchanges between vegetation and the atmosphere can be studied in detail in the field by infrared gas analyzers that can be either connected to small gas exchange cuvettes for leaf photosynthesis or transpiration measurements, or combined to 3D sonic anemometers analyzing eddies transporting H_2O and CO_2 for ecosystem net flux measurement at larger scales. Finally, the analyzer can be transported by tethered balloons to measure changes in vertical CO_2 or water concentration profiles at the frontier with the atmosphere. Such experiments have shown that wheat and rapeseed crops have a good ability to store carbon and that it is important to encourage intercropping to improving crop carbon budgets.

Since field campaigns are restricted in time and space, remote sensing is a good way to extend the zone studied and increase the frequency of operations. Remote sensing data can then be used as input data or to constrain vegetation models. These models use simplified descriptions of the processes driving vegetation dynamics. They are therefore used for monitoring yield estimates or for ecosystem management (including irrigation). In parallel, mechanistic models, some of which are being developed at CESBIO, are used to analyze sensitive ecosystem processes. They may be used at smaller scales to study how agrosystems respond to climatic and anthropic constraints in a global climate change perspective.

More generally, the tools developed at CESBIO can be used to analyze the relationships between carbon and water cycles, and to assess terrestrial ecosystems' response to climate changes.

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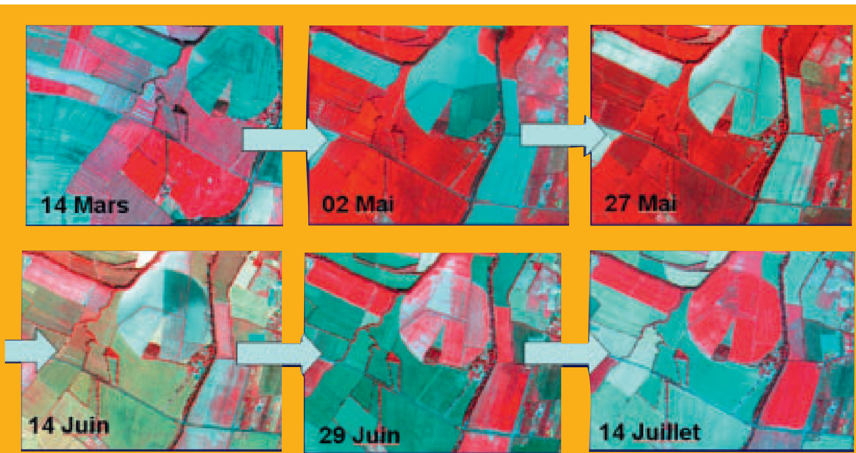


>>> Images from the Formosat satellite showing the seasonal evolution of vegetation photosynthetic activity (in red) in an agricultural landscape near Toulouse in 2006. For further details please contact Olivier Hagolle (hagolle@cesbio.cnes.fr) and Valérie DEMAREZ (demarez@cesbio.cnes.fr).

Remote sensing of Earth's Interior

>>> Alexis RIGO, CNRS scientist, head of Dynamic Terrestrial and Planetary Laboratory (DTP, joint UPS/CNRS lab), Sylvain BONVALOT, IRD scientist, head of the Bureau Gravimétrique International and researcher at the Study of Transfer Mechanisms in Geology Laboratory (LMTG, joint UPS/CNRS/IRD lab) and Richard BIANCALE, CNES engineer and researcher at DTP

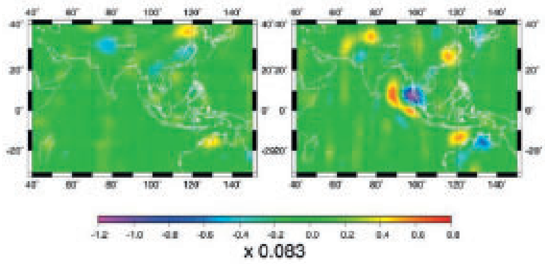
Dynamics, such as tectonic movements, affect the surface of our planet and can thus be observed by satellites from space. Surface phenomena, like volcanic eruptions and seismic events, can be spectacular but "hidden" phenomena like the gravity field and how it changes with time, can also be seen.

At the Midi-Pyrénées Observatory, two laboratories, the DTP and LMTG, are working with other French researchers to develop and exploit space technologies to observe Earth's surface so that processes occurring in the interior of the planet can be characterized.

The space gravimetry decade

Techniques to model Earth's gravity field advanced rapidly in the first half of this decade, essentially thanks to new space gravimetry missions, including CHAMP in 2000, GRACE in 2002, and GOCE (to be launched in 2008-2009). Using EIGEN models, these missions have improved our knowledge of the total gravity field by a factor of 100 to 1000. Moreover, the micron precision of GRACE measurements allowed scientists to measure how gravity varies on monthly time scales for the first time, at spatial resolutions of around 500 km. GOCE, a European Space Agency satellite, should extend this resolution to 100 km by the end of the decade.

The GRACE mission's main achievement was to produce temporal models showing that great mass variations could be detected from space, and that these variations are related to the hydrological cycle, to ice shrinking or to major tectonic events. In a few orbits, GRACE was effectively able to detect the consequences of the great Sumatran earthquake, which occurred in December 2004 and which generated a 8 mm depression of the geoid as well as a land rise in the east of Sumatra.



>>> Mean geoid variations detected by the GRACE satellite before and after the Sumatran earthquake of December 2004. The redistribution of masses in the crust and in the mantle induced by the earthquake generated a geoid anomaly detectable from space (from Panet et al., Geophys. Journal Int., 2007).

Continental deformation: small and great

Since the beginning of the 1990s, remote sensing has made significant progress in precisely measuring continental deformation and plate tectonics. The first geodetic measurements were carried out at the beginning of the last decade using the American GPS (Global Positioning System) composed of 24 satellites. Positioning on Earth's surface is now accurate to a resolution of centimetres in absolute terms and millimetres in relative terms. The resolution depends on the number of the measured points.

The European Space Agency, for its part, launched two aperture radar (SAR) satellites, which made it possible to quantify the deformation field at continental surfaces with millimetre precision using interferometry. This radar technique, the first images from which were the fruit of a collaboration between the CNES and DTP, opened up the possibility of observing geophysical phenomena with a hitherto unseen hectometric resolution without having to go on-site. Nevertheless, optical imagery is still useful because satellite sensors have increased in resolution (50 to 70 cm) and the correlation technique also allows deformation at the surface to be mapped with a good resolution.

The research undertaken in our laboratories mainly concentrates on the Mediterranean region and South America and makes use of these techniques, combined with other geological and geophysical observations. Thanks to developments in digital techniques, we are improving the precision for observing deformations to the millimetre scale to better characterize the dynamics of seismic and volcanic zones, and to quantify the associated risks.

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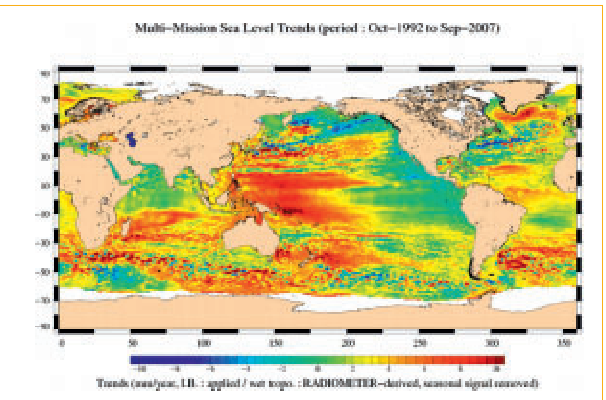
When satellites spy on the oceans

Altimetry and other observations are revolutionising our view of the oceans.

>>> Yves MENARD, CNES senior scientist and Roseamry MORROW, scientist at the Geophysics and Oceanography Studies Laboratory (LEGOS, a joint UPS/CNRS/CNES/IRD lab).

The oceans play a key role in moderating our climate and maintaining its equilibrium, by absorbing and damping out climate perturbations. The ocean responds to atmospheric forcing (wind, heat flux and precipitation changes) at scales of tens to thousands of kilometres. Oceanic time scales range from seconds to hours for surface waves and extreme events such as hurricanes or tsunamis, from days to months for large current systems and their eddies and meanders, and up to years and even centuries for deep ocean currents. Atmospheric perturbations can therefore invoke changes to the ocean circulation at both local and global scales, with significant repercussions on the climate. An example is El Nino, which is a strong ocean-atmosphere perturbation centred on the tropical Pacific, but which induces climate perturbations on regional and global scales.

Monitoring ocean changes over these wide range of space and time scales is now crucial for understanding and predicting climate change. Up until the 1980s, most oceanographic measurements were made “in situ”, either from ship-born observations or from moored instruments and analyzed every few months. In the 1980s and 1990s, the advent of satellites revolutionized oceanographic observations, allowing regular monitoring of the ocean surface, including sea surface temperature and sea level. For the first time, the wide range of ocean movements could be observed for all of the ocean basins over time periods of many decades.



>>> Global maps of sea level rise from Oct 1992 – Sep 2007 from satellite altimetry, showing a strong increase in the western Pacific. However, sea level has fallen in the NE Pacific over the last 15 years and the global sea level rise is 3 mm/yr (Lombard et al., 2007).

Since electromagnetic radiation cannot penetrate water, satellites are restricted to observing surface parameters. Satellite altimetry, measuring sea level variations, is the only instrument which detects deeper ocean currents. A warm deep current will induce a thermal expansion at depth, which in turn raises sea level. Wind can push water up against the coast, raising sea level by mass convergence. Local precipitation, river flow and polar ice melting can also raise sea levels and can be observed by satellite altimetry. Since 1992, a series of altimeters have provided global maps of sea level variations every 10 days.

At LEGOS, a number of different research groups use satellite altimetry to unveil the rich structure of oceanic dynamics, in collaboration with the CTOH, an observational service dedicated to altimetry observations. Among the new discoveries, the GOHS research group at LEGOS has used altimetry to determine increases in sea level, which have risen by 2-3 mm/yr over the last 15 years (figure 1), and to better understand the different factors contributing to this sea level rise (Lombard et al. 2007). The OLVAC group has observed how the ocean responds to El Nino and La Nina events in the tropical Pacific with altimetry, helping researchers develop new theories to explain these events and their global impact on climate (Bosc and Delcroix, 2008). The CTOH has developed new surface current products based on different satellite captors, and other products specifically adapted to monitoring coastal currents. For the first time we have been able to track ocean eddies, which move systematically across the ocean over many years, and which are an important mechanism for oceanic heat transport (Morrow et al., 2004).

In addition to the physics, LEGOS scientists use ocean-colour satellites to detect changes in the surface chlorophyll concentration, which is important for understanding the distribution of ocean biomass. Future satellite missions will provide new observations, such as sea surface salinity (for example, SMOS will be launched in 2009). Today, we use different satellite measurements, in combination with realistic numerical models, to better understand and predict the changing ocean and its affect on the climate.

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