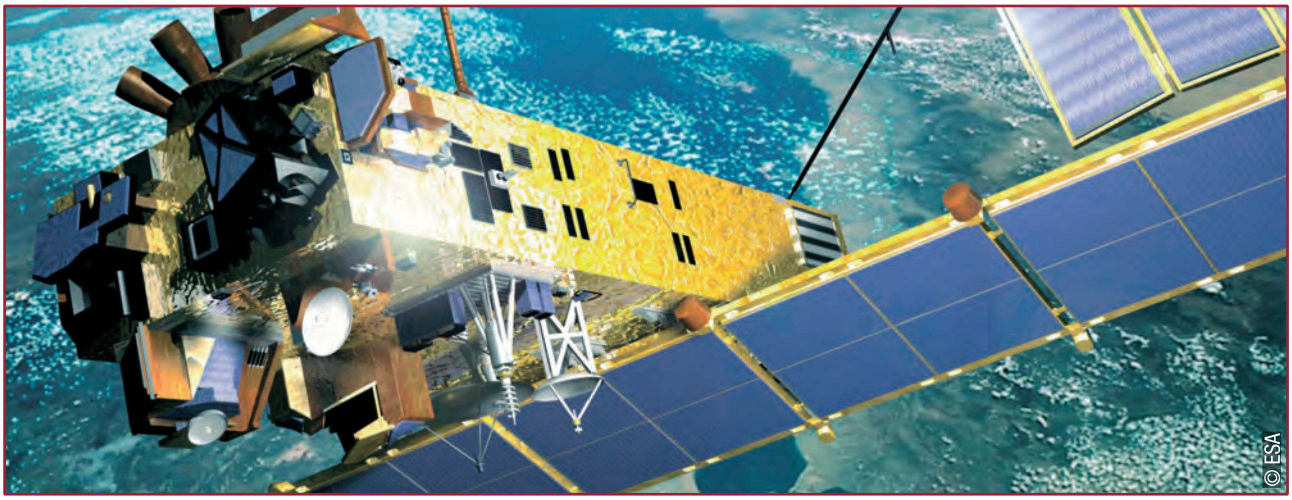
esa

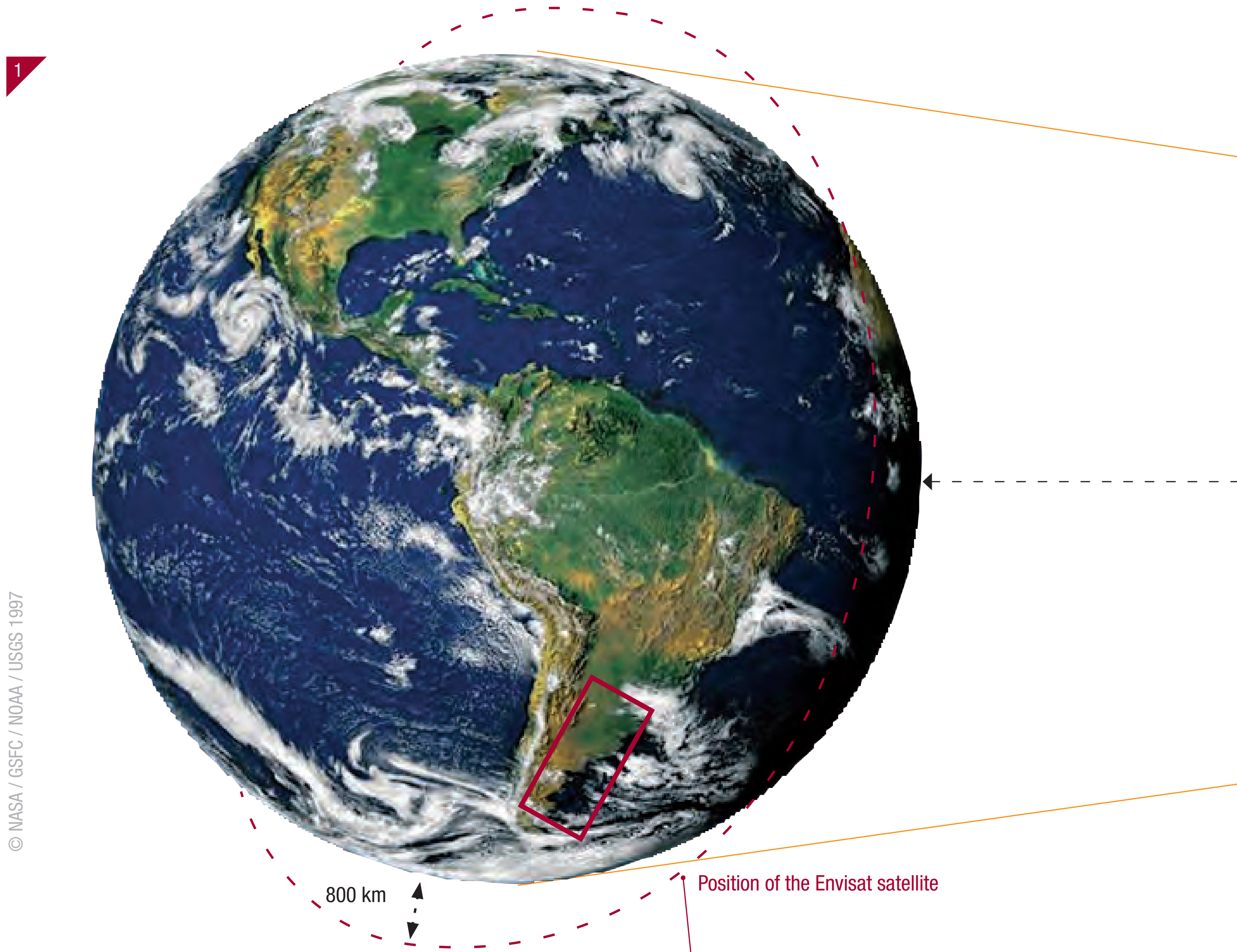
1- Earth observation satellites

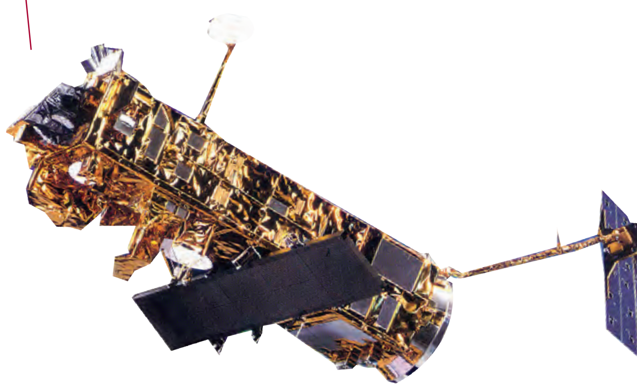


European Space Agency
Agence spatiale européenne

the Living Planet

There are several types of satellite: remote-sensing satellites such as Envisat and Meteosat, used to observe our planet’s surface and atmosphere, while other types are used for telecommunications or navigation (GPS, Galileo). Not all remote-sensing satellites occupy the same kinds of position in space. Their trajectories and distance from the Earth can vary. The picture below shows the positions and orbits of two different satellites – Envisat and Meteosat – in relation to the Earth.



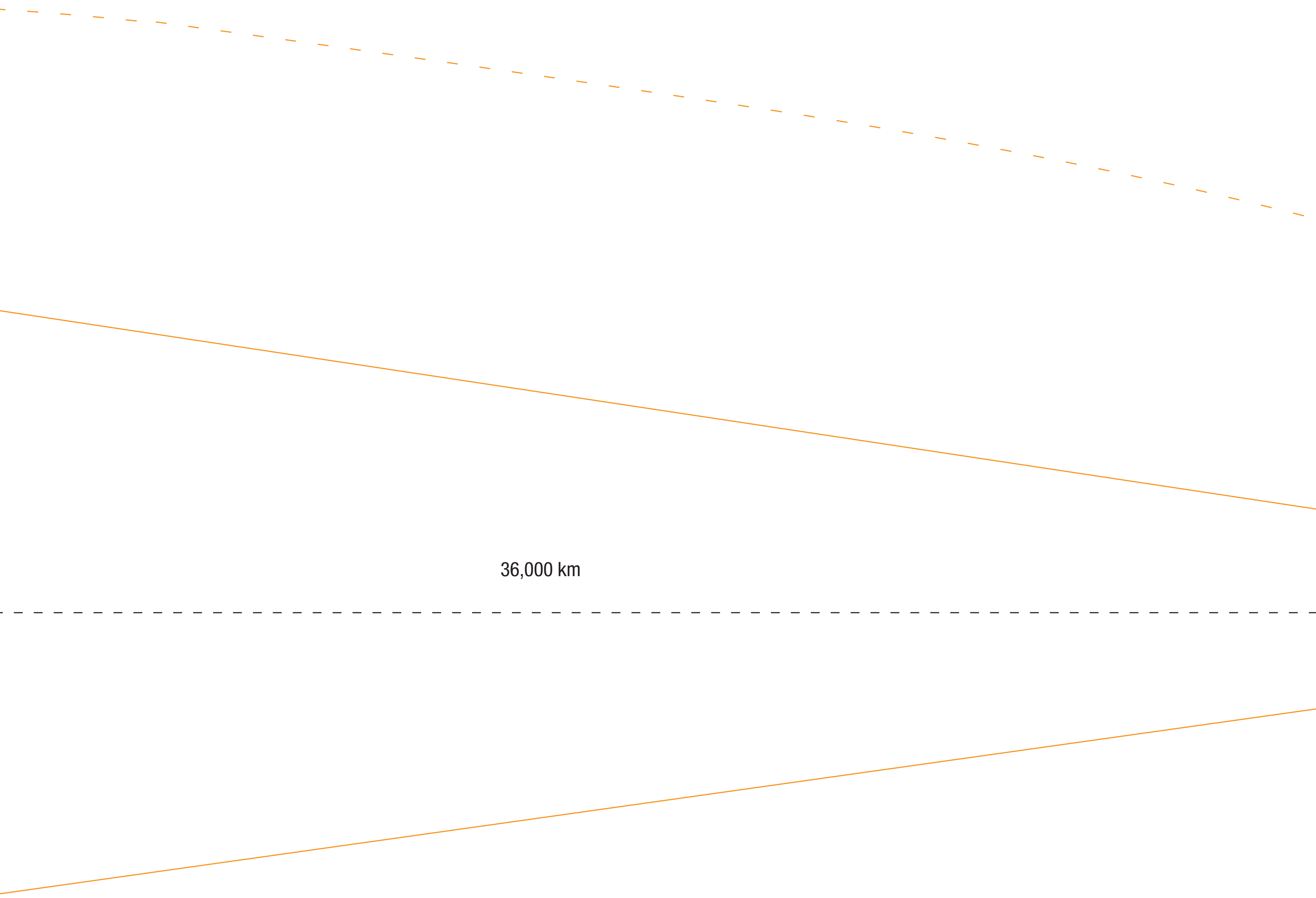


POLAR ORBITS

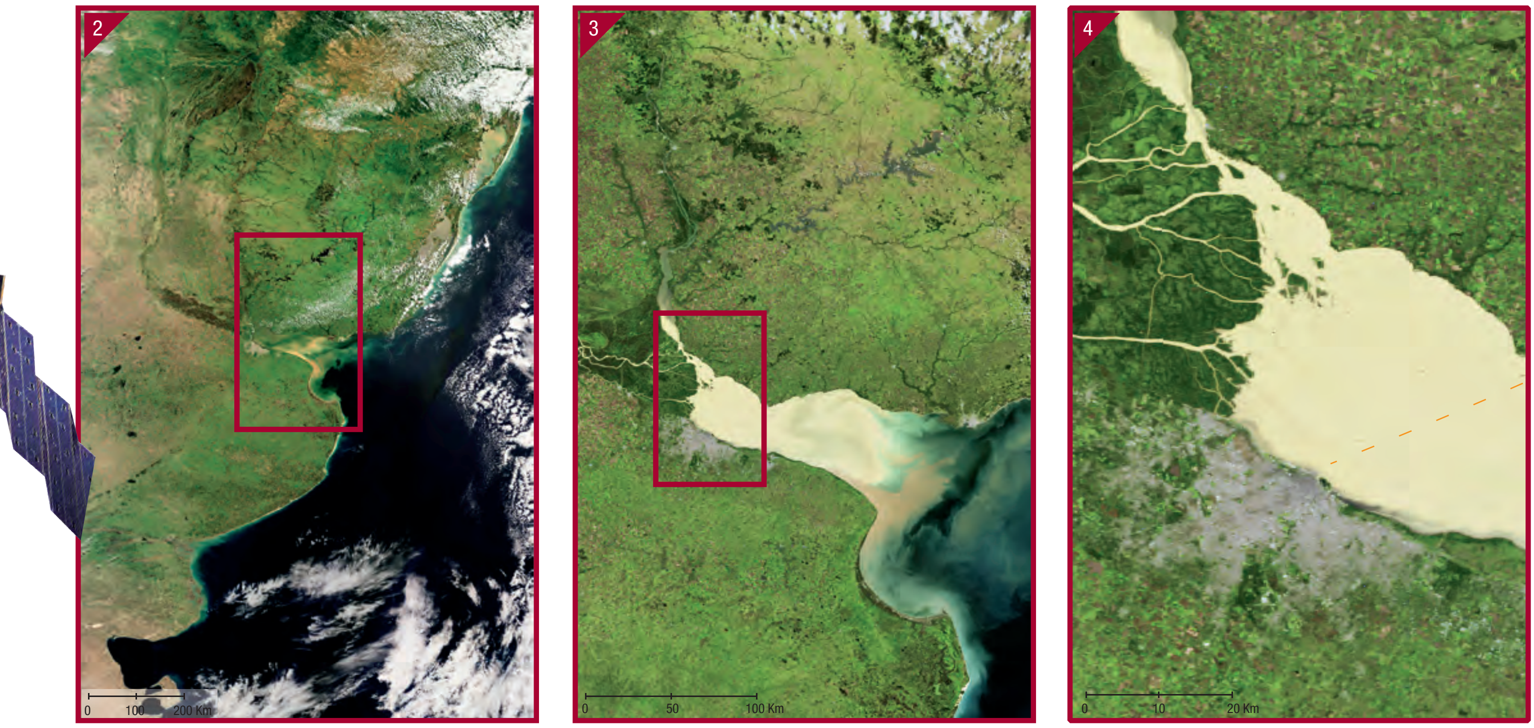
These are circular orbits performed at low altitude. For example, the European Space Agency’s Envisat satellite orbits the Earth at an altitude of about 800 km. With each pass, such observation satellites fly over a narrow zone (in the tens or hundreds of kilometres), thus allowing them, depending on the instruments on board, to obtain very detailed images.

In a 24-hour period, such satellites orbit the Earth several times, passing over the poles as they do so. The plane of their orbit has a set direction in space but because the Earth turns around its own axis, with each pass they fly over a different area.

Among their many applications they are used to produce very accurate geographical maps or to monitor variations in vegetation cover according to the season. They also help to locate and analyse clouds of atmospheric pollution or pollutant spills at sea.

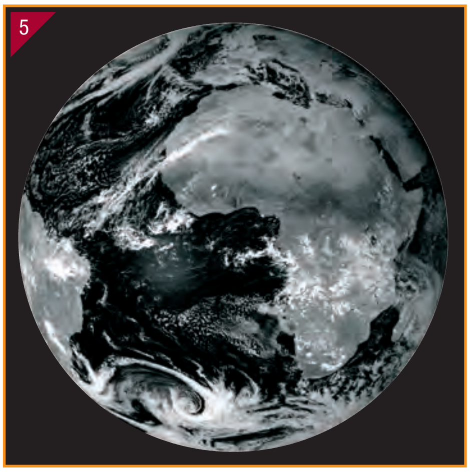


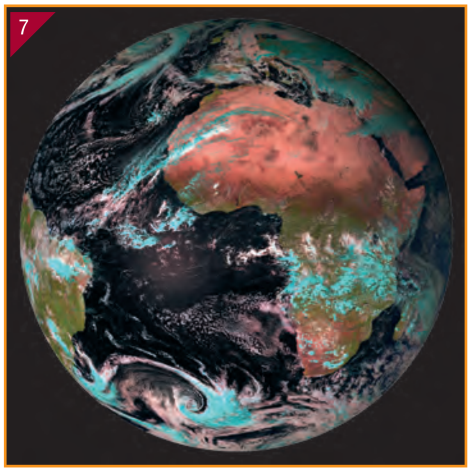
Example of a polar orbit: the Envisat satellite



Images from a satellite like Envisat can provide very detailed information. Here for example, zooming in on Argentina's Atlantic coast, we can clearly see the Rio de la Plata estuary, with Buenos Aires also visible in grey.

Example of a geostationary orbit: the Meteosat satellite





Geostationary satellites are very far from the Earth compared to satellites in low-Earth orbit. They therefore provide images with a very wide field of view but relatively lacking in detail. While the images obtained are in black and white, subsequent conversion into colour brings out different kinds of information such as variations in temperature or the location of cloud masses.

GEOSTATIONARY ORBITS

These are circular orbits located precisely in the equatorial plane and performed at altitudes of around 36,000 km. Such satellites' movements mimic the rotation of the Earth so that they can remain constantly above the same region. This "geostationary" positioning is vital if they are to observe changes in meteorological phenomena and monitor the movement of cloud masses.
In addition, they remain in constant direct contact with receiving stations on the ground so as to be able to transmit their data.

It is Europe's Meteosat satellites that supply the images we are used to seeing in TV weather forecasts. Most of the Meteosat satellites are stationed at 0º longitude (above the Gulf of Guinea) and thus are able to cover both Europe and Africa.

Remote sensing refers to the observation of an object from a distance without coming into physical contact with it. This is what satellites which observe the Earth from a distance do. Remote sensing has become a science in its own right, the main aim of which is to discover and observe what is happening on the Earth's surface.

Regardless of whether its field of view is broad or narrow, or whether it watches over a whole continent or focuses on the heart of a city, each satellite provides its own specific set of useful information.

VIEW OF EUROPE FROM THE ENVISAT SATELLITE

This image taken by Envisat shows the principal relief and variations in vegetation cover across continental Europe.

VIEW OF BUENOS AIRES FROM THE SPOT 5 SATELLITE

These images of Buenos Aires taken by the SPOT 5 satellite show precise details to within a few metres.

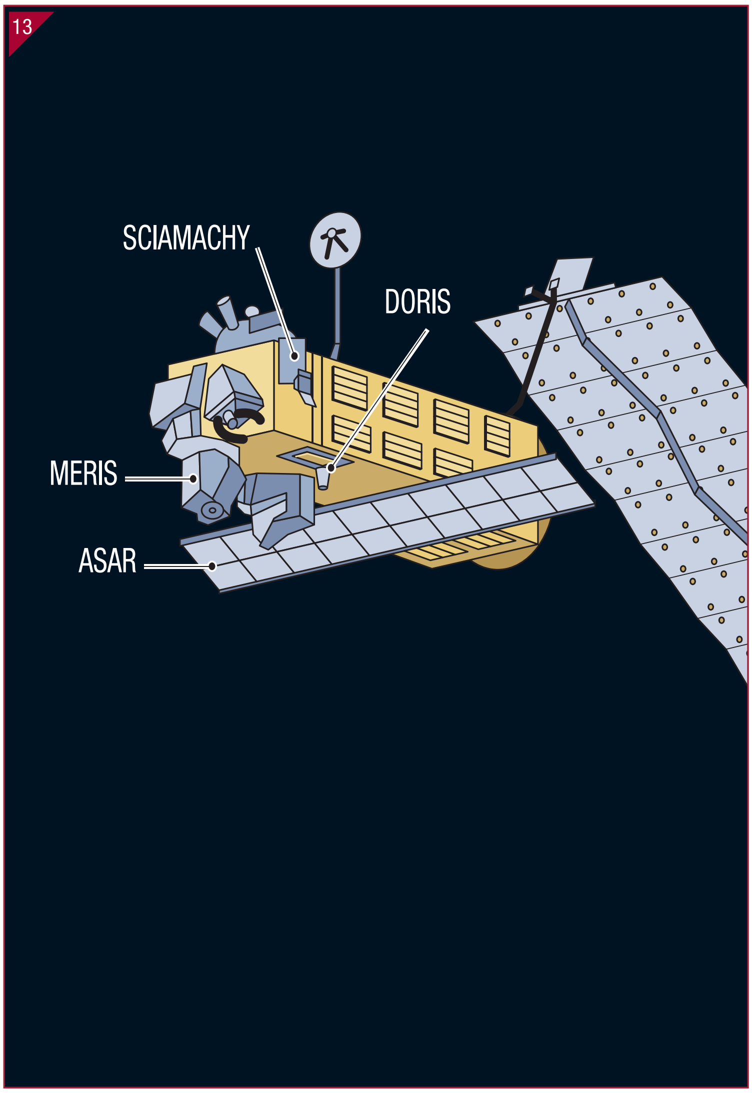
How do satellites work?

The example of Envisat

Envisat is a very large satellite. It has a mass of 8,200 kg, of which 2,050 kg is accounted for by its instruments, with dimensions – excluding solar panels – of 10m x 4m x 4m, making it roughly the size of a large truck.

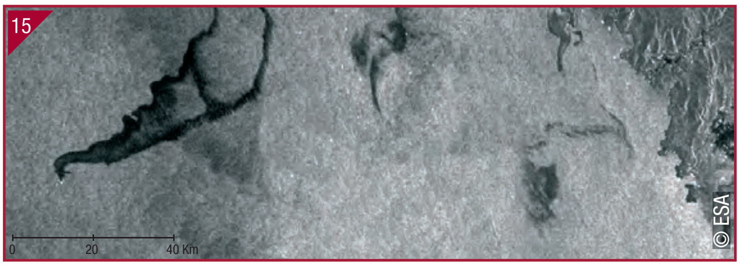
It carries ten scientific instruments on board, all used to gather specific information and each with a specific name (for example MERIS, ASAR, SCIAMACHY). The measurements from these instruments are used to produce images or graphs in a form suited to whichever phenomena are being studied.

Some Envisat instruments

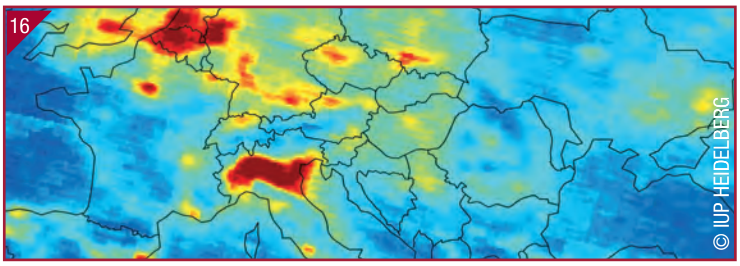


Envisat is made up of 10 instruments. Some capture images in the visible light range or using radar. Others, such as DORIS, are designed to produce altimetry measurements and control the satellite's positioning.

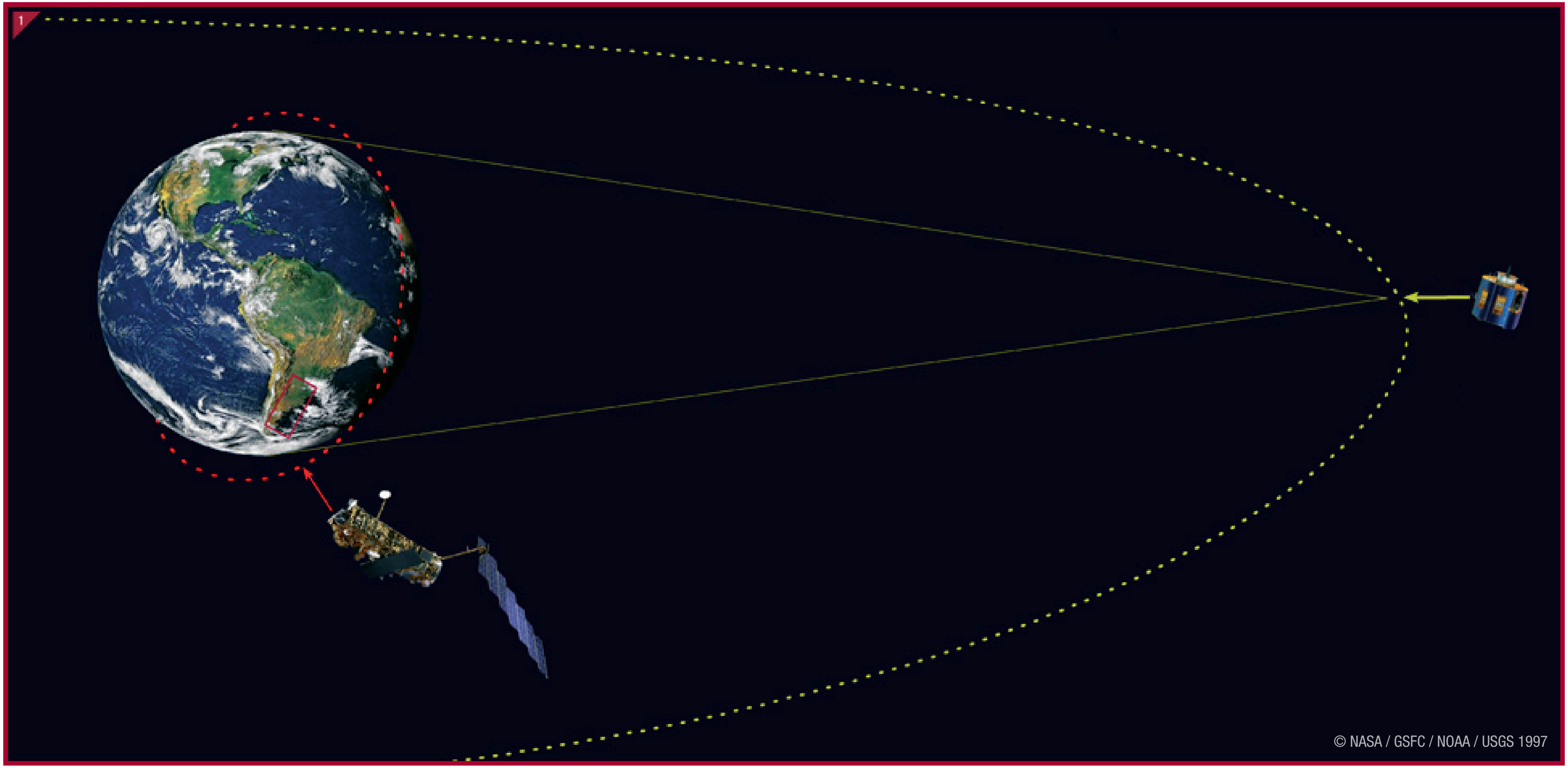
MERIS takes pictures by day of oceans and land mass. It also measures chlorophyll concentration in the sea or water vapour in the atmosphere.
Bloom off the coast of Brittany (15.06.03).



ASAR is a radar instrument that maps the surface of the land, ice and oceans and measures certain variations in them. It provides invaluable data on land use and land characteristics.
Spill from the tanker "Prestige" off the Spanish coast (17.10.02).



SCIAMACHY measures traces of gas, clouds and dust particles. It helps provide a better understanding of the consequences of industrial pollution, volcanic eruptions and forest fires.
NO_2 concentration in the atmosphere in Europe (2003 / 2004).



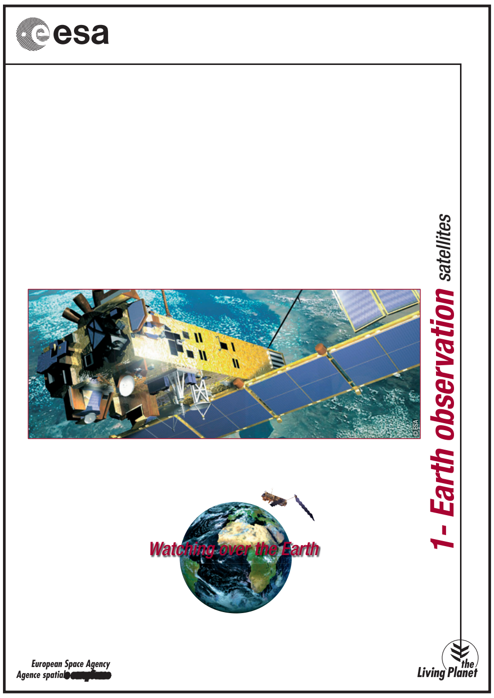
The Earth and the orbits of the Envisat and Meteosat satellites

This image belongs to the 'Watching over the Earth' teaching pack from the European Space Agency (ESA).
The Living Planet programme.

Information for teachers

The "Information for teachers" sheets are designed to offer assistance with the preparation of classes and complement the worksheets handed out to pupils. They contain useful information for the presentation of the subject, additional information relating to the satellite images, and a list of websites dealing with the subjects concerned.

Worksheet 1: Earth observation satellites



Worksheet 1 is an introduction to the main types of Earth observation satellites and the two main types of orbits: geostationary and polar. This worksheet is the first in the series, and explains some key information regarding Earth observation by satellite. It can be used as a supplement to the part of your teaching programme dealing with the Solar System and learning about the Earth.

This worksheet can be used to:
- present the concept of Earth observation;
- help understand distances in space (illustration in the worksheet inner pages shows satellite positions true to distance scales);
- discuss the variety of uses and data provided by satellites.

Satellite orbits

The movement of satellites around the Earth is one of the consequences of gravitation. The process of putting a satellite into orbit is subject to the fundamental laws of physics. The flight trajectory depends on the initial speed of the satellite: if the speed is too slow, the satellite falls back to Earth following a parabolic path; if the speed is too high, reaching approximately 11 km per second (escape velocity), the vehicle (a space probe for example) leaves the Earth's orbit and continues indefinitely towards outer space. In order for it to travel in a circular trajectory at an altitude of 800 km, the initial speed needs to be approximately 7.5 km per second.

A satellite can stay in the same orbit for a long time, as long as the Earth's gravitational pull counteracts the centrifugal force. Since satellites travel in orbit outside the Earth's atmosphere, they are not affected by air resistance so their speed remains constant. This results in a stable orbit with the satellite circling the Earth for many years. The satellite travels around the Earth using solely the Earth's gravitational force. The propellant reserves on board are only used to make small adjustments to the trajectory or the altitude.

Gravitational pull decreases as the vehicle travels further away from the Earth, while the centrifugal force grows with orbital speed. A satellite in low orbit is under the influence of immensely powerful gravitational pull and must therefore travel at great speed in order to generate sufficient centrifugal force to counteract gravitation. As a result, there is a direct link between the distance to the Earth and the satellite's orbital speed.

At a distance of 36,000 km from the Earth, the satellite takes 24 hours to complete the orbit, which is the same amount of time the Earth takes to turn on its own axis. At this distance, a satellite positioned above the Equator will remain stationary with respect to the Earth. Telecommunication and weather satellites use "geostationary" orbits. Three geostationary satellites, spaced out at 120°, cover the entire surface of the Earth.
Satellites in "polar" orbits fly above the poles at an altitude of 700 and 800 km and are able to observe the entire surface of the Earth in just a few days.

The satellite images

Cover page

Cover image: Artist's impression of the Envisat satellite

On 1st March 2002, the European Space Agency launched Envisat. It is an Earth observation satellite placed in a polar orbit to provide measurements of the atmosphere, oceans, land mass and ice. Data from Envisat is used to conduct scientific research into the Earth and to monitor changes to the environment and climate.

Core content

View of the Earth showing the Americas. This shows Meteosat's true position in relation to the Earth. Thus, the European geostationary satellite Meteosat – positioned directly above the Gulf of Guinea – can be seen in this image to the right of the globe. An observer in space "seeing" Meteosat in that position would necessarily be above the American continent.

Image 1: The Earth

This image of the western hemisphere was produced by combining data from several Earth observation instruments. The data on cloud mass comes from GOES (Geostationary Operational Environmental Satellite), which belongs to NOAA (National Oceanic and Atmospheric Administration). The data on the oceans comes from NOAA's SeaWiFS (Sea-viewing Wide Field-of-view Sensor) satellite, while that on vegetation is from POES (Polar Orbiting Environmental Satellite). Shown here, near the west coast of the United States, is Tropical Cyclone Linda (9 September 1997).

Images 2, 3, 4: Argentina - Rio de la Plata estuary - Buenos Aires (Envisat, 2004)

The city of Buenos Aires (12 million inhabitants) is located on the Rio de la Plata estuary, which forms the border between Argentina and Uruguay. Montevideo (1.3 million inhabitants), the capital of Uruguay, is located at the northern mouth of the estuary. Each year the currents of the Rio de la Plata carry 57 million cubic metres of sediment, notably from its principal tributaries, the Paraná and Uruguay rivers. The mouth of the estuary is 219 km wide.

Images 5, 6, 7: The Earth as seen by Meteosat

Solar rays striking the Earth can be absorbed or reflected as well as being visible to the human eye or a satellite. The albedo value of a surface indicates the percentage of solar light reflected.
Thus Meteosat satellites measure, in the visible and near infrared, the different albedo values of the surfaces observed. Clouds, snow and ice, which reflect light strongly, appear light grey. Dry, barren surfaces are also shown in light colours, while vegetation-covered regions have a slightly lower albedo and appear darker. Water surfaces have a very low albedo and are represented in very dark tones.

From all of these measurements it is possible to create black and white images which can then be processed to produce colour images of the globe (see centre image). Depending on which channels are used, it is also possible to produce images which reveal variations in temperature on the Earth's surface (see right-hand image).
The Meteosat satellite spins rapidly around its axis, which is parallel to that of the Earth, and performs 100 revolutions per minute. With each rotation it scans a 5-km wide strip (or swath) from east to west. The scanograph mirror is adjusted so as to allow a new swath to be scanned with each rotation, thus providing a complete image.

MSG (Meteosat Second Generation) generates multispectral images of the Earth's surface and cloud systems every 15 minutes by covering 12 channels of the spectrum. MSG's spatial resolution has also been improved compared to previous Meteosat satellites (1 km for the visible high-resolution channel and 3 km for the others). Eight of these channels are located in the thermal infrared range and provide – in addition to other information – permanent data on cloud, land and sea surface temperatures. By using channels that absorb ozone, water vapour and carbon dioxide, MSG also enables meteorologists to analyse the characteristics of air masses, thus constituting 3D views of the atmosphere.

Page 5 - Views of Europe and Buenos Aires

Image 8: Europe as seen by the Envisat satellite

Dozens of images, taken during part of 2004, were required to produce this view of Europe without cloud cover. This image was produced by the MERIS (Medium Resolution Imaging Spectrometer) instrument on board Envisat.

Images 9, 10, 11: View of Buenos Aires taken by the SPOT 5 satellite

The new HRG (High Resolution Geometric) telescopes on SPOT 5 record high-resolution images of the Earth: 10 m in colour and 2.5-5 m in black and white (a single image with a resolution of 2.5 m covering 60 km^2 on the ground represents 576 MB). It has a 60-km wide field of view.
These images of Buenos Aires complement the images of the Rio de la Plata region produced by the Envisat satellite and presented in the worksheet core content.

Page 6 – "How do satellites work?"

Image 12: Artist's view of the Envisat satellite

Envisat performs a full cycle every 35 days, before going on to trace exactly the same course again and again. By the end of this 35-day period, the satellite has described a certain number of orbits, while in that same time, the Earth has performed the same number of revolutions. Envisat's orbit is also heliosynchronous (or sun-synchronous), meaning that it flies over a given point on the Earth's surface at the same local solar time. Since the conditions for capturing images are virtually identical (except for seasonal variations), the information thus provided can be rigorously compared.

Image 13: The satellite and its principal instruments

Its data is gathered by 10 complementary instruments:

MERIS stands for Medium Resolution Imaging Spectrometer (300 m). It records 15 spectral bands in the visible and near infrared. One of its main tasks is to measure the colour of the water in the oceans in order to calculate the chlorophyll concentration contained within. This data is essential to the study of the oceanic carbon cycle.

ASAR (Advanced Synthetic Aperture Radar) uses radar signals to map land surfaces, the profile of waves and ice at sea or on land, to monitor land use and vegetation types and to measure certain surface properties.

GOMOS stands for Global Ozone Monitoring by Occultation of Stars. It carries out very precise measurements of the ozone in the stratosphere as well as the profile of the trace gases in the upper troposphere and mesosphere.

GOME stands for Global Ozone Monitoring Experiment. This instrument explores the solar radiation emitted by reflection from the Earth's surface vertical to the Earth (nadir mode).

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography) is the principal atmospheric sensor onboard Envisat. It uses several measuring modes. Its data can teach us about the distribution of gases in three dimensions in the troposphere and lower stratosphere.

MIPAS (Michelson Interferometer for Passive Atmospheric Sounding). This interferometer is used to measure gas emissions in the mid infrared. Its data can notably be used to determine the composition of gas emissions from industry.

AATSR (Advanced Along Track Scanning Radiometer). This instrument scans the surface of the land and oceans to measure sea temperature. It detects the "hot-spots" in forest fires and maps the extent of vegetation in different regions.

DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite) is a satellite radio system used to continuously calculate the satellite's position in orbit. This position is obtained to within a few centimetres using signals emitted by more than 50 ground beacons disseminated all around the globe.

RA-2 and **MWR** The RA-2 radar altimeter measures to within one nanosecond the time it takes for a signal to return and calculates its distance from the Earth accurate to within 4 centimetres. MWR is a microwave radiometer that measures the amount of water vapour in the atmosphere and is able to correct RA-2's signals to improve its accuracy.

LRR is a Laser Retro-Reflector system used to calibrate DORIS and RA-2.

Envisat is constantly scanning the Earth's surface and atmosphere. For two-thirds of its orbit it flies over the oceans. It is the moving mass of these oceans, the complexity of the thermal exchanges which bring them to life or which they conduct with the atmosphere that make them a major influence on the behaviour and evolution of the Earth's climate.

These three images demonstrate the variety of instruments carried on board Envisat:

Image 14: The English Channel to the north of Brittany (Envisat/MERIS)

Of particular interest in this image is the bloom (rapid development of phytoplankton) visible off the coast of Brittany and spread over a distance of 400 km.

Image 15: Image of an oil slick (Envisat/ASAR image, Nov. 2002)

The oil escaping from the tanks of the Prestige is close to the Galician coast. Radar images such as this show relief: the areas where the oil is concentrated are smoother than the sea surface and send back a weaker signal, which shows up as black in the image.

Image 16: NO_2 emissions in Europe (Envisat/SCIAMACHY)

This image, taken by the Heidelberg institute for environmental physics (IUP) was constructed from measurements taken by the SCIAMACHY instrument. This instrument records the spectrum of sunlight shining through the atmosphere. Very little data on such pollution is gathered by ground-based sensors; only sensors located in space are able to perform effective global monitoring.

Online resources

www.esa.int	ESA (European Space Agency) website
www.esa.int/SPECIALS/ESRIN_SITE/index.html	ESRIN (European Space Research Institute) website ESRIN is ESA's centre for Earth observation
www.esa.int/eo	ESA Earth observation website
earth.esa.int/earthimages	Gallery of ESA satellite imagery
www.esa.int/education	ESA educational website
www.eduspace.esa.int	Earth observation educational website (EDUSPACE)
www.cnes.fr	CNES (Centre National d'Etudes Spatiales) website Presentation of the French national space agency's missions and activities
www.cnes-edu.fr	CNES educational website
www.spotimage.fr	SPOT IMAGE gallery

ORBITOGRAPHY

www.eduspace.esa.int/subtopic/default.asp?document=297&language=en	EDUSPACE site: principles of remote sensing/satellite orbits
www.bnsc.gov.uk/content.aspx?nid=5956	BNSC (British National Space Centre) website: different types of orbit
www.cnes.fr/web/5004-geostationary-orbit.php	Geostationary orbit and space debris isssues
www.satcom.co.uk/article.asp?article=11	Geostationary, LEO, MEO and elliptical orbits
www.cnes.fr/web/1094-how-orbital-manoeuvres-work.php	Orbital manoeuvres
www.eoportal.org/orbits	Tracking the orbits of Earth observation satellites

ENVISAT

envisat.esa.int	Information on the Envisat satellite
www.esa.int/esaEO/SEMWYN2VQUD_index_0_m.html	Envisat overview
www.esa.int/esaEO/ESAXU0MBAMC_index_0.html	All about Envisat, including Envisat-related news
www.esa.int/envisat/instruments.html	Instruments onboard Envisat

METEOSAT

www.eumetsat.int	European organisation responsible for the exploitation of meteorological satellites
www.cnes.fr/web/1446-meteosatmsg.php	Europe's weather observation satellites
www.metoffice.gov.uk	Met Office website

Satellite images

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Original text/project oversight	Frédéric Létang	Illustrations	Philippe Bouillon - Illustratek
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Pedagogical advisors	Éric Janin / Jean Jandaly	Production	Europimages - Aliette Cremer

Worksheet N° 1 – Earth observation satellites

Once you have read and carefully examined the worksheet, please answer the following questions :

1 – What are the main functions of remote sensing satellites? Give two examples of remote sensing satellites.

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2 – What is the altitude of a satellite in a polar orbit? Why do we call this type of orbit “polar”?

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3 – What is the altitude of a satellite in a geostationary orbit? Why do we call this type of orbit “geostationary”?

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4 – What can you see on the three images taken by the Envisat satellite?

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5 – Which continents or parts of continents can be seen from the 3 images taken by the Meteosat satellite?

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6 – What is the main purpose of satellites in geostationary orbit?

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7 – Describe the details you observe in the three images of Buenos Aires. Which satellite took these images?

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8 – Give three examples of the kind of missions that the instruments on-board the Envisat satellite would be able to carry out.

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