11- Colours *in satellite imagery*

European Space Agency
Agence spatiale européenne

the Living Planet

VISIBLE LIGHT

To our eyes, visible light emitted by the Sun appears white. It is in fact composed of a mixture of primary colours, as is clear when we look at a rainbow or light passing through a glass prism. Each of these colours (red, orange, yellow, green, blue and purple) has its own specific wavelength.

Earth observation satellites can use their sensors to record the various waves emitted or reflected by the Earth's surface.
There are many types of waves, all differing according to their wavelengths.
The human eye is only able to perceive visible light, which represents only a very small fraction of the spectrum.

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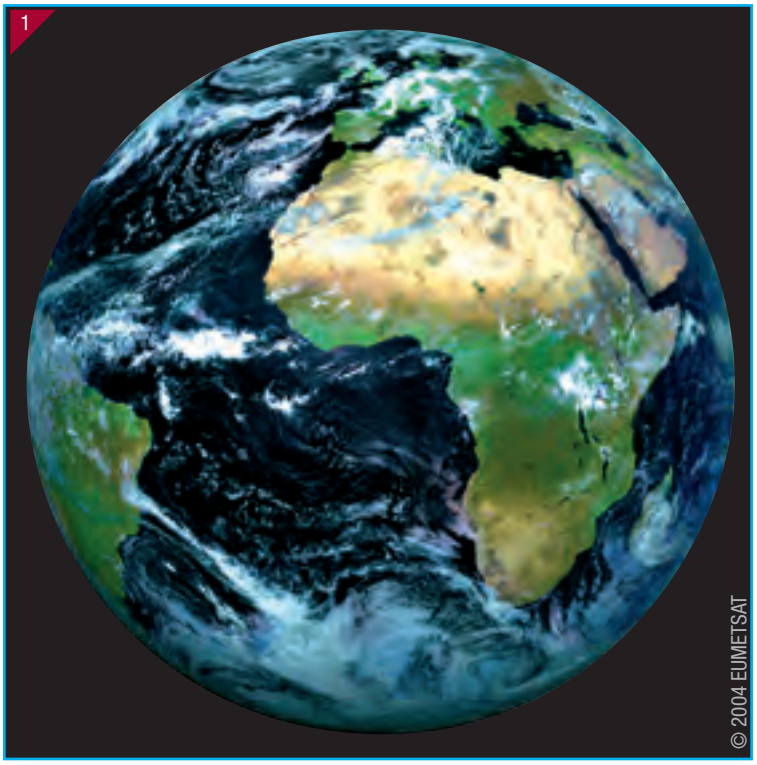

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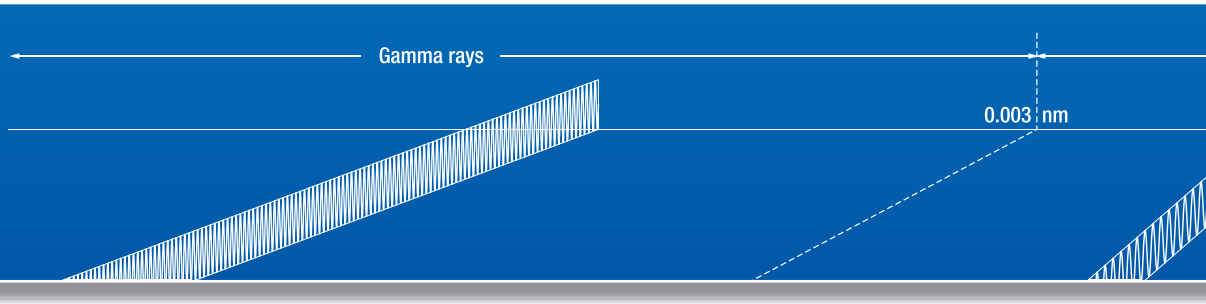
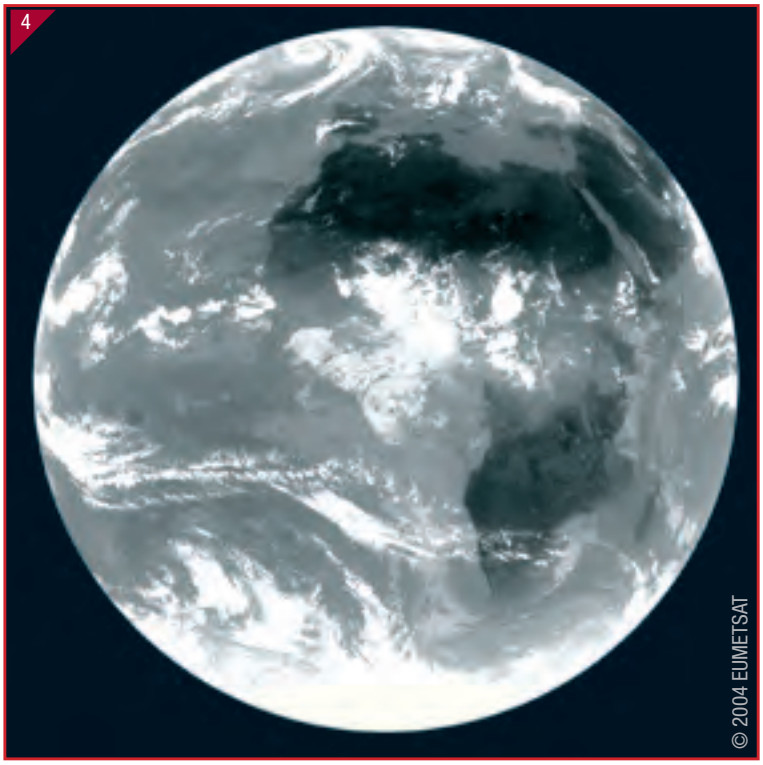
THE RADIATION SPECTRUM



INFRARED AND THERMAL IMAGING

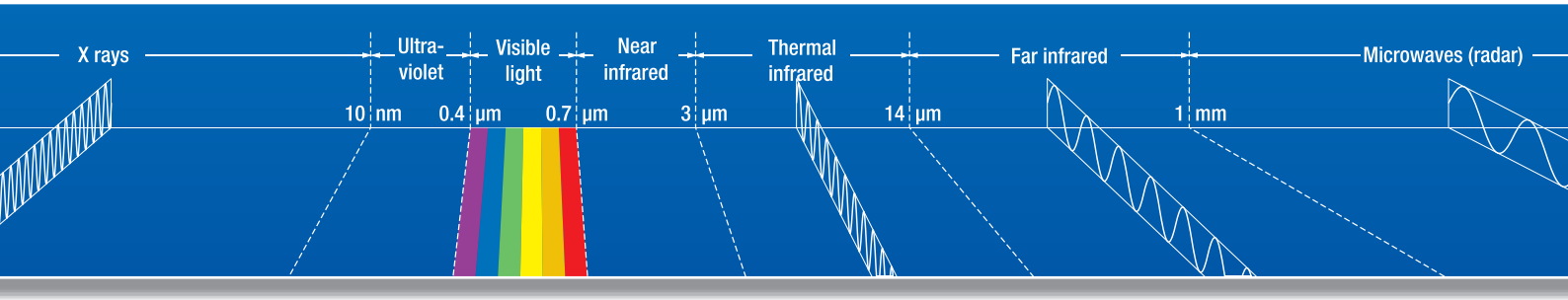
Thermal infrared images are in fact no more than a map of temperatures on the Earth's surface. This is why images taken at night are not necessarily black as is the case for images in the visible channel. Hot surfaces such as deserts produce strong emissions, whereas cold surfaces such as clouds and ice produce very few. The source images obtained, therefore, show cold cloud as black and deserts as white. These are then displayed in negative form (see below) to make the clouds show up as white, just as the public is used to seeing them. It is satellites equipped with a thermal channel such as Meteosat which make such observations possible. They provide important information on cloud temperature and water vapour in the atmosphere.



Optical images

Temperature measurements

Radar waves



RADAR IMAGES

A radar image is one which is taken by a satellite equipped with a radar instrument, which sends a signal and detects its echo as it bounces back off objects and relief on the ground. Radar images do not reflect reality as we see it. They are in black and white because all that they show is the intensity of the signal received as an echo. In general, if a surface is smooth, the signal bounces, yet does not bounce back to the radar with the result that the area shows up as black on the image. In contrast, if a surface is uneven with substantial relief, many rays bounce back to be recorded by the radar, producing grey or white areas depending on the intensity of the relief.

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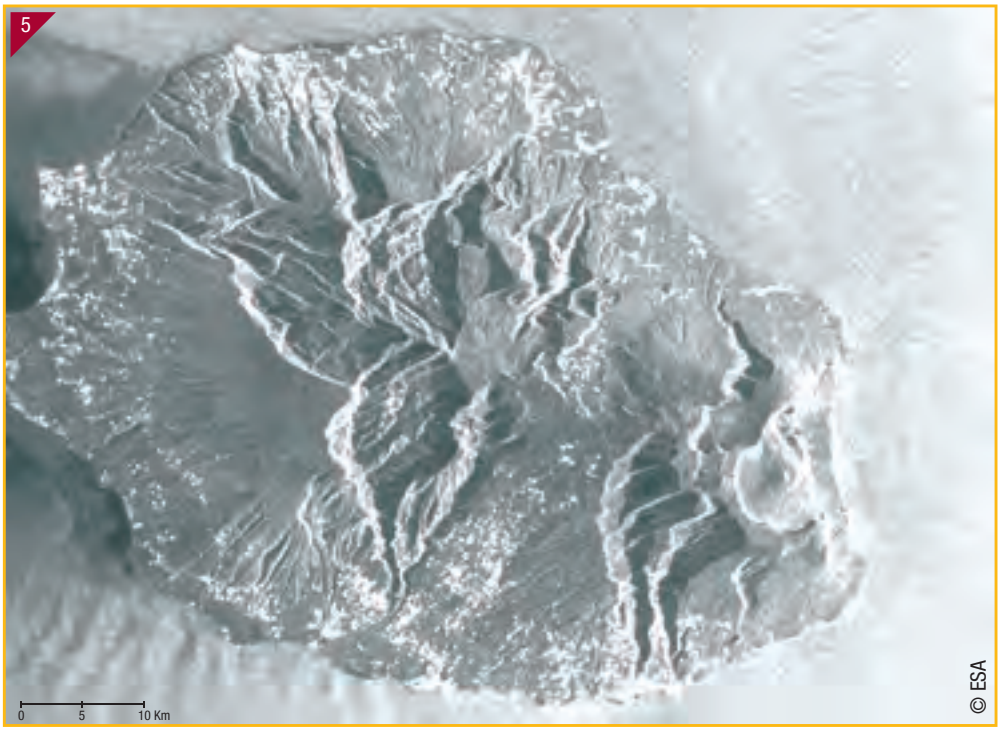

Certain animals, such as bats, emit ultrasonic waves and then pick up their echo, allowing them to represent the world around them in the form of a mental image reconstructing relief. The principle of this system is not unlike radar. There are other wavelengths, such as X-rays or infrared rays, for example, that we are not able to see. Given the right kind of instruments, however, we can record them to produce corresponding images. Such images are every bit as valid and real as those we are more used to seeing.

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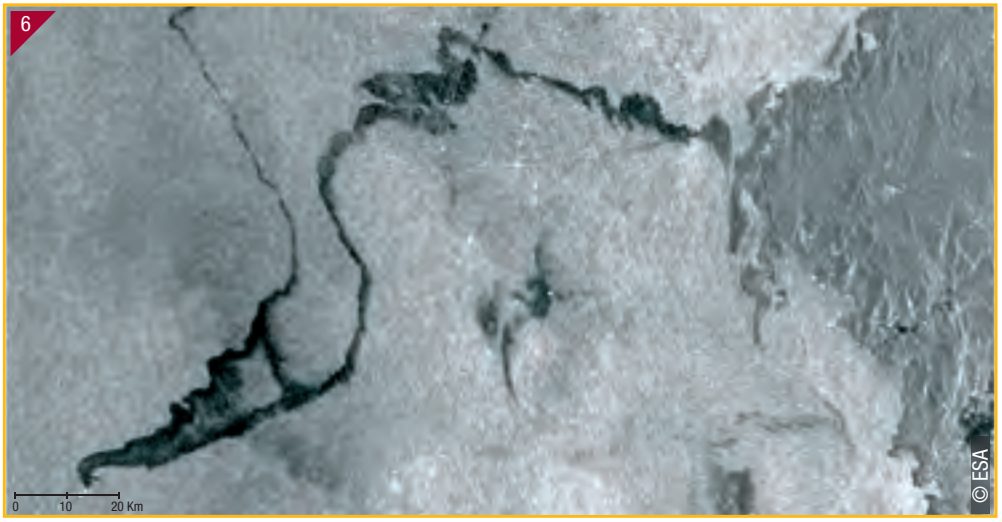
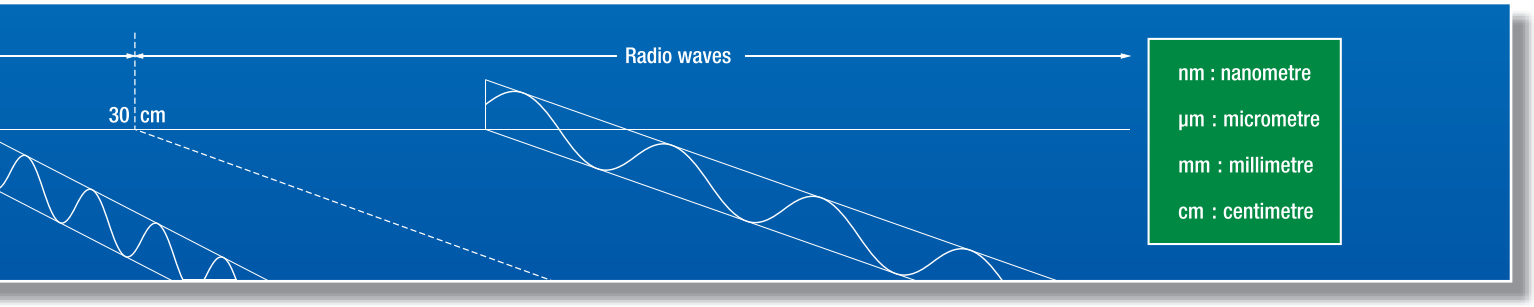


Radar images can also be used to monitor sea conditions: the rougher the sea, the lighter the image produced. This image clearly shows the extent of an oil spill. Crude oil, like any oil for that matter, maintains a very smooth profile on the surface of the sea, making it difficult for waves to form. Consequently, the area covered by the oil spill appears somewhat black.

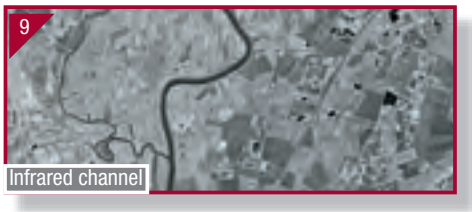


COMBINING CHANNELS TO FORM COLOUR IMAGES

Each colour channel is represented in black and white. Each indicates, in a scale ranging from black to white, that is from the weakest to the strongest, the intensity of reflection in each wavelength. It is by combining these three black and white images and giving each one its proper colour that the image can be reconstituted in natural colour.

Each channel is given its proper colour. The end result of combining the three images is an image in natural colour.

It is possible to artificially switch the colours chosen for each channel. When creating an image that includes information provided by the infrared channel (which is invisible to the human eye), by convention that channel is shown in red. The colour green is attributed to the red channel and blue to the green channel.



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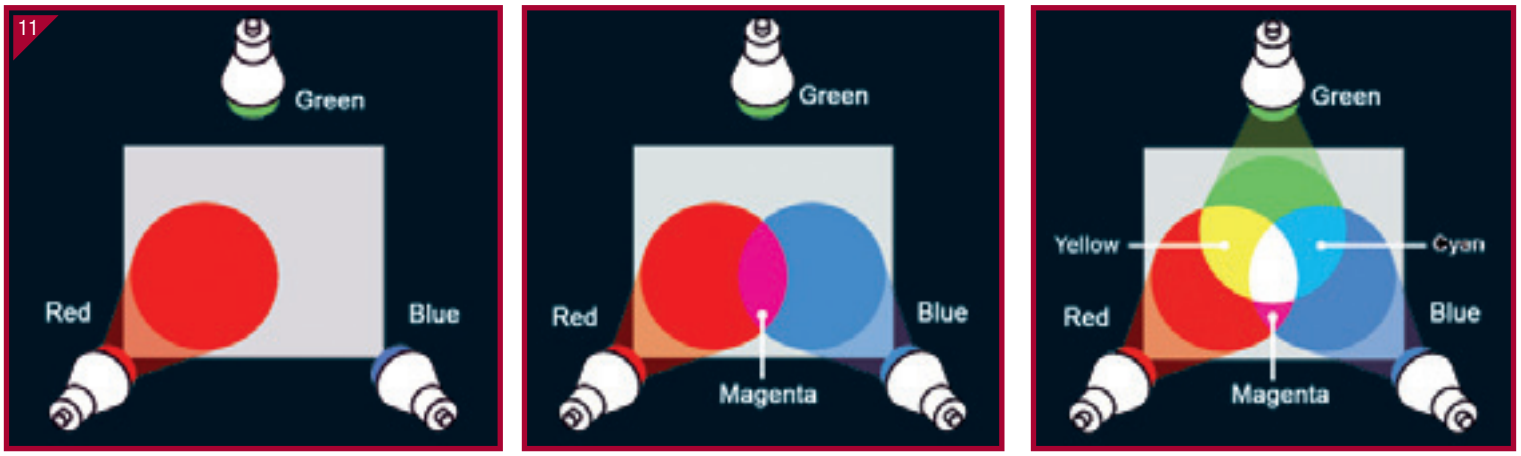
The colour red is attributed to the infrared channel, green to the red channel and blue to the green channel.

Vegetation reflects more energy in the infrared than in the green channel. This channel is therefore useful for identifying and revealing certain variations in vegetation. That is why many satellite images show vegetation in red.

How do satellites work?

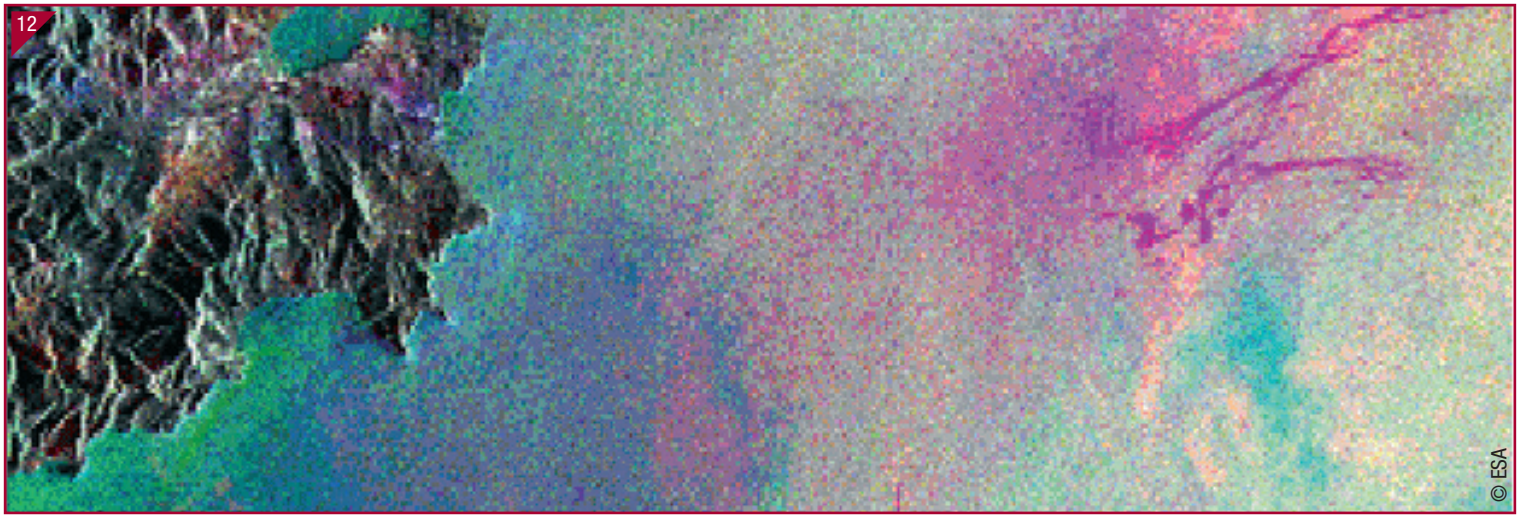
Additive colour synthesis



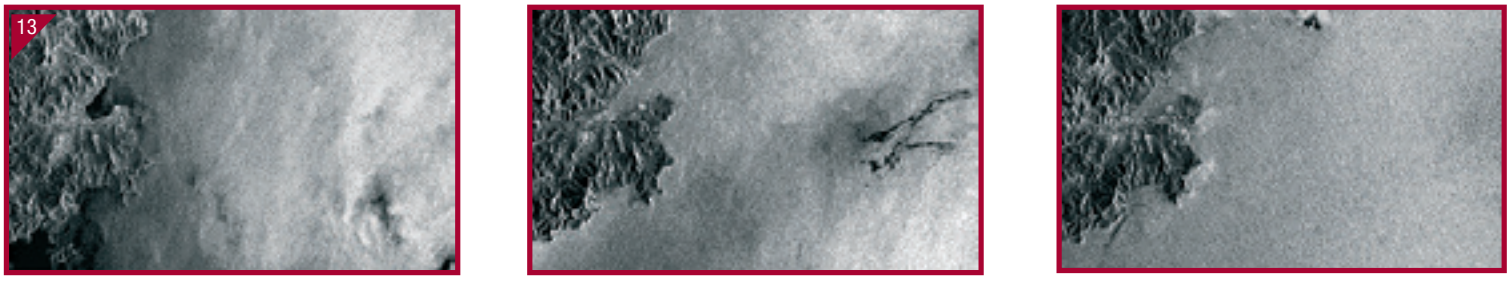
Images in photography, on television screens and computer monitors are all produced using 3 primary colours: red, green and blue. By combining these colours two at a time, one obtains either yellow, magenta or cyan. It is possible to obtain any shade by combinations of the three primary colours and adjusting the intensity of each.

Multitemporal radar images

By combining three radar images, taken on three different days and attributing a different primary colour to each, one can create a new image in colour revealing the changes which have occurred between the different days on which the images were taken.



Three superimposed coloured radar images.



Before the pollution occurred

Pollution off the coast

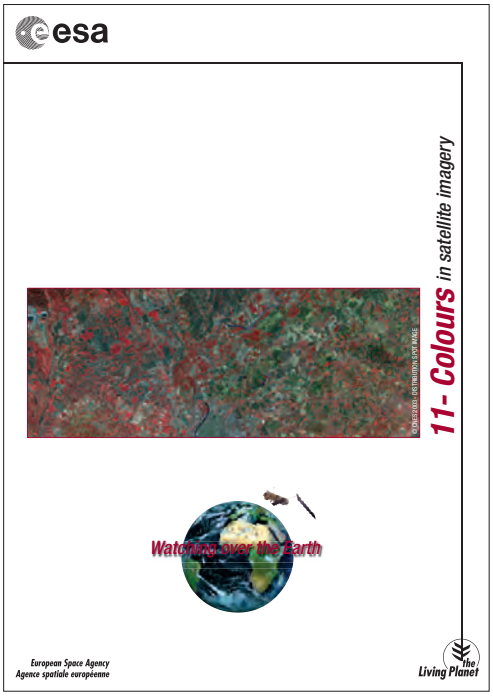
Pollution at the bottom near the coast

The oil slick has made the sea surface smooth so that the radar signal sent back to the satellite is very weak. Consequently, the area covered in oil appears black in these radar images.

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 11: Colours in satellite imagery



Worksheet 11 addresses the concepts of light and colour.

This worksheet can be used to:

- introduce students to the concept of wavelength, and to show where the visible light spectrum is situated on the electromagnetic spectrum, which spans from gamma rays to radio waves;
- discuss infrared radiation, radar waves, and additive colour synthesis;
- discuss the characteristics of satellite images and the different processing methods used.

Eyesight and the processing of colour

Light is radiation emitted by a body brought to a high temperature or excited by various forms of energy. The Sun emits numerous types of radiation, but only a minute part of it is visible to the human eye. Satellites are equipped with special instruments that allow them to detect radiation that is otherwise invisible to us, such as infrared waves or microwaves used by radar instruments. In order to produce an image, the wavelength measurements recorded by the different satellite instruments must be converted into a palette of colours that corresponds to human vision. The data recorded by these instruments are in fact a set of numbers indicating the intensity of the signal for each wavelength. This is why a complex process is required to translate this information into printed images using colours visible to the human eye.

What does seeing colours mean?

Light is an electromagnetic wave. It can be pure, "monochromatic" or "polychromatic", meaning composed of many colours, like the light coming from the Sun. A monochromatic wave is characterised by a number called the wavelength, measured in nanometres (abbreviated to nm: one billionth of a metre), and each wavelength value corresponds to a particular colour as it is perceived by the human eye:

Wavelength	← 420 nm →	← 470 nm →	← 520 nm →	← 580 nm →	← 600 nm →	← 650 nm →
Colour perception	← violet →	← blue →	← green→	← yellow →	← orange →	← red →

"Ultraviolet" waves, with wavelengths shorter than 380 nanometres, are invisible to the human eye. The same is true for "infrared" waves, with wavelengths greater than 750 nanometres, or microwaves (with wavelengths in the order of one to several dozen centimetres). When solar radiation reaches the Earth after being filtered by the atmosphere it consists of a wide range of wave types, from 300 nanometres to 22 micrometres in length (the optical window), and from 1 to about 1500 centimetres (the radio window).

Vision is one of the human senses. It is stimulated by the reception of light by the eye's retina. The human vision mechanism for colours is extremely complex. The retina consists of three types of cones, with maximum sensitivity at 420, 530, and 560 nm respectively. The brain uses a process of comparing stimuli sent by the different types of cones to produce an impression of colour.

How do satellites process recorded data?

Certain satellites, referred to as "passive" satellites, capture light from the Sun as reflected by objects on the surface of the Earth: these satellites work with the visible light spectrum and light close to infrared. Other satellites, referred to as "active", send their own electromagnetic waves towards the Earth and record the echo of the emitted signal: this is true for radar satellites which can send out signals that pass through cloud cover.

Satellites are equipped with sensors in a rectangular grid, each one corresponding to 1 pixel in the final image. They are sensitive to the intensity of light that reaches them for a given wavelength. Certain types of satellites are "monospectral", only working within a very narrow band of wavelengths. Other satellites are "multispectral"; this is the case with SPOT 4 and 5 which can process wavelengths from 0.55 µm (green-yellow), 0.65 µm (red) and 0.85 µm (near infrared). For each channel, a greyscale image is obtained which can be re-coloured with a different value of the sensor's wavelength: for example, the infrared channel is coloured red to make it artificially visible. Consequently, the other colours are displaced: infrared is coloured red, so red is shown as green, and green becomes blue. The three images, where each one corresponds to a single channel, are merged using additive colour synthesis. The final image is obtained displaying in "false colour".

A legend explaining the colour code makes it possible to interpret these images: vegetation, which absorbs little infrared radiation, appears in red, while urban areas, which absorb a lot of infrared light, appear as cyan-blue. The images obtained using the additive colour synthesis process can be viewed on a computer or television screen. To obtain an image on paper requires quadrichromic (four-colour) printing, a process which essentially involves subtractive synthesis.

The satellite images

Cover page

Cover image: Seville Region (SPOT 5 image, 2003)

In this image the infrared channel is shown in red. Resolution is 5 metres. The area represented constitutes a strip of approximately 70 km in width. The city of Seville is located in the middle, to the bottom of the image. One can just make out the Olympic stadium between the Alfonso XIII canal and the Guadalquivir river.

Core content

Image 1: The globe (Meteosat)

The visible channel is not the only one used to produce this image. Most of the Meteosat colour images we see are in fact derived from three black and white images taken at three different wavelengths in the visible and infrared channels. For each wavelength, the satellite produces a "greyscale" image. By subsequently combining these images through additive synthesis, it is possible to recreate a colour image highlighting various formations both on the ground and in the clouds.

Image 2: Seville region (SPOT 5 image, 2003)

This image is an enlarged detail of the general view of the Seville region shown on the cover page. The village in the meander loop in the centre of the image is La Algaba. The spectral channels of the SPOT satellite, which work at wavelengths of between 0.55 µm and 0.85 µm, are thus different from those used by Meteosat.

Image 4: The globe (Meteosat)

This view shows the image generated by just one of the satellite's channels: the thermal infrared channel. In this band (with a wavelength of around 10 mm), it is essentially the rays emitted by the Earth and clouds which are detected, and not the light emitted by the Sun and reflected by the Earth. These images provide information on temperature conditions and cloud cover since clouds form at altitude and are colder.
In this greyscale image, the areas of low intensity are white so as to match the representations to which the general public are accustomed (clouds thus appear as white).

Images 5 and 6 are radar images. They are produced by so-called "active" sensors, which emit an electromagnetic signal in the direction of the ground and then measure the intensity of that signal once it is reflected by the obstacles it encounters. Radar instruments, therefore, do not depend on sunlight and produce images by day and night regardless of cloud cover. Radar images are in black and white because they are acquired on a single electromagnetic wavelength of about 5.3 cm.

Image 5: Reunion Island (Envisat/ASAR - Advanced Synthetic Aperture Radar, 2003)

Reunion is a volcanic island located 645 km east of Madagascar. Visible to the south-east is Piton de la Fournaise (2631m), which has erupted about a hundred times in the last three hundred years. When the slope of some relief is greater than the incidence angle of the radar signal, this produces radar shadows that mask the geographical features on the slopes. This results in dark or black areas in the image, which give an impression of relief, but without using a stereoscope.

Image 6: The Prestige oil spill (Envisat/ASAR image, 2002)

The tanker spilled its cargo of oil as it was towed out to sea, away from the Galician coast. The white dots visible close to the point from which the oil slick extends are the Prestige and the emergency vessels at the scene.

The presence of heavy oil on the surface dramatically reduces wave intensity, creating a relatively flat expanse. These areas send back a very weak signal and thus appear black. Waves, due to their uneven surfaces, send a stronger signal back to the satellite so that the surface of the sea appears grey in the image. Ships, due to their very uneven profiles, form white dots.

Page 5 – Combining channels to produce a colour image

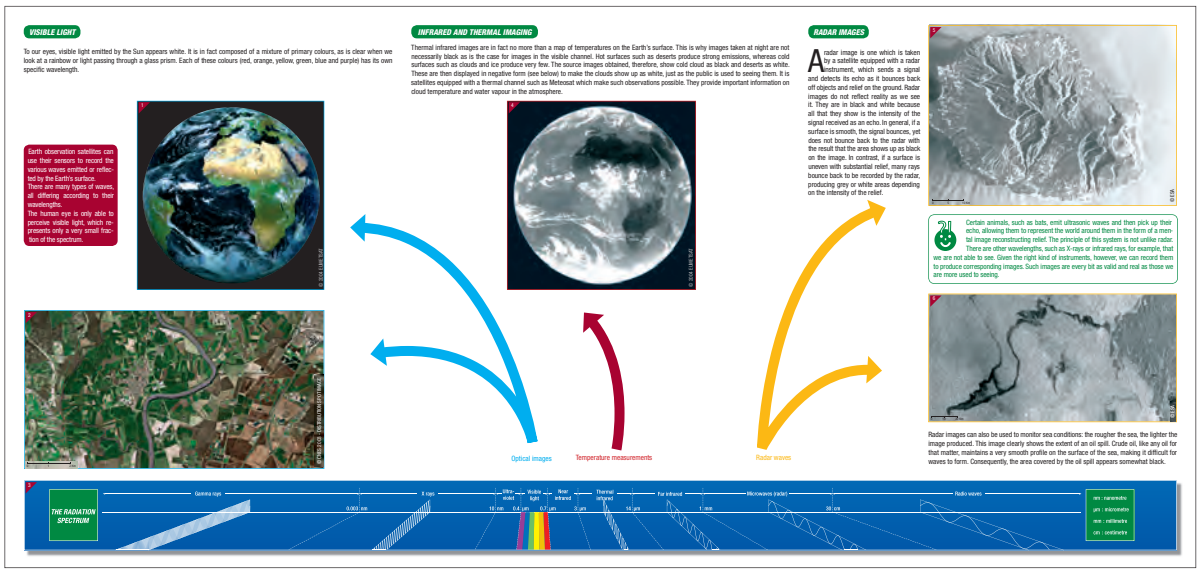
Images 7, 8, 9 and 10: Seville Region (SPOT 5 image, 2003)

Breaking down each colour image into three source images serves to illustrate how satellite sensors simply record in greyscale in each spectral band. SPOT 5 has one channel for infrared measurements but no blue channel.

Page 6 – "How do satellites work?"

Images 12 and 13: Radar images of an oil spill at sea

It is possible to produce radar images in colour (multitemporal composite images) by combining three images taken on different dates. Each date/image is displayed in one of three colours (red, green or blue) and these are then combined to produce a colour image. These images (in principle the most difficult to interpret) have the advantage of measuring the evolution of phenomena over time and potentially showing how they will evolve in the future. In the case of oil spills at sea, it is thus possible to observe a slick's movements and determine the course it is likely to take subsequently.



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

THE ELECTROMAGNETIC SPECTRUM

imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html	The electromagnetic spectrum: information from NASA's Goddard Space Flight Center

RADAR

www.eduspace.esa.int/subtopic/default.asp?document=323&language=en	EDUSPACE website: resources satellites/radar technology
telsat.belspo.be/beo/en/guide/index.htm	Telsat: guide to remote sensing (radar/image processing)

PRESTIGE OIL SPILL

www.disasterscharter.org/disasters/spain_e.html	Prestige oil spill: International Charter "Space and Major Disasters" website

Satellite images

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Worksheet N° 11 – Colours and satellite imagery

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

1 – What are the components of sunlight?

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……

2 – Name several types of waves that can be detected by satellites.

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3 – Which type of ray has the shortest wavelength: ultraviolet or infrared?

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4 – When looking at an infrared thermal image, what do the black and white areas mean?

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5 – What do black and white areas mean on a radar image?

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6 – Give an example of a specific application for radar images.

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7 – Satellites that take images using infrared technology are said to be “passive”, while satellites that take radar images are said to be “active”. Why?

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8 – Do radar images show “reality” the way traditional photographs do, or do they show what we humans can see with the naked eye?

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9 – Why does vegetation often show up in red on satellite images?

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10 – What colours can be obtained using additive colour synthesis with primary colours?

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