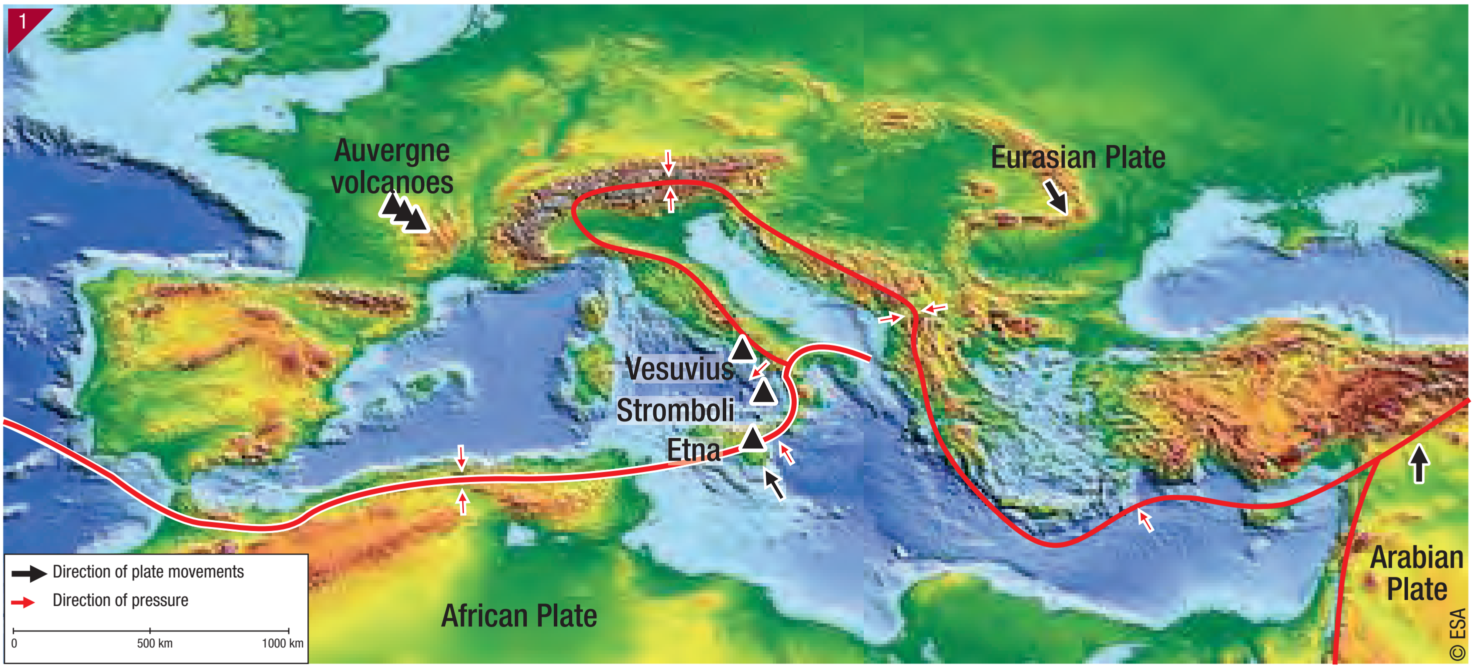
esa

9- Volcanoes: Mount Etna, a case study

European Space Agency
Agence spatiale européenne

the Living Planet

The Earth's surface is made up of huge plates which are constantly but slowly moving against each other. It is these movements that cause earthquakes and volcanic eruptions.



In this picture of the Mediterranean the satellite has recorded variations in sea bed levels and in surface relief. In it, it is possible to make out submarine mountain ranges, and also to see the continuous contours of the main plates more easily. When these plates move against each another, faults appear and molten rock in the depths of the Earth can suddenly move up to the surface. In such areas, notably in Italy, this causes volcanoes to form.

View of Sicily, in the heart of the Mediterranean, taken by the Envisat satellite in October 2002 during the eruption of Mount Etna.

The immense plume of smoke released by the October 2002 eruption, reaching heights of up to several thousand kilometres, is entirely visible from space. The plume is made up of gas, dust and ash. It contains carbon dioxide and sulphur and has an impact on the quality of the environment.
One can see the prevailing winds carrying the smoke towards the coast of Africa (Tunisia, Libya). Satellites are able to deliver constantly updated information on such phenomena.

From a human perspective, the sliding of tectonic plates, at barely a few centimetres per year, can appear very slow. Nonetheless it all adds up: India, for example, has shifted over 2,000 km nor-

MOUNT ETNA, EUROPE'S MOST ACTIVE VOLCANO

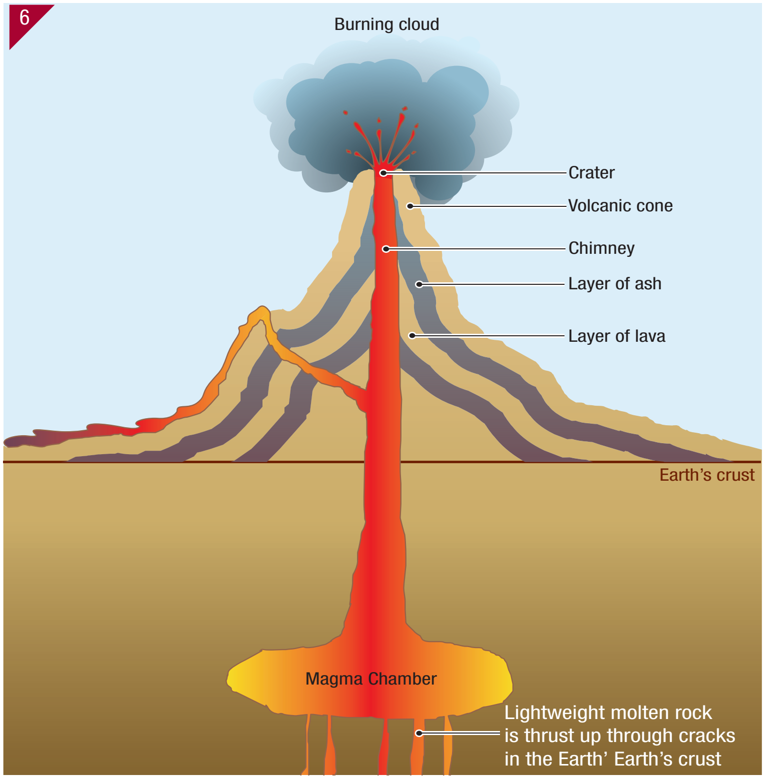
In this image taken during the July 2001 eruption, smoke can be seen escaping from Mount Etna's crater. Black lava flows left behind by previous eruptions are visible along the sides of the volcano. The town of Catania can be seen to the bottom of the picture on the coast. The land around volcanoes is extremely fertile and vegetation rapidly regains a foothold (image by SPOT 5).

The town of Catania at the foot of Mount Etna.

Active volcanoes such as Mount Etna are prone to frequent eruptions.

It is for that reason that volcanoes must be observed and monitored either by traditional ground-based methods or by satellite. In 1669, part of Catania was destroyed by a lava flow.

Night-time eruption of Mount Etna. Visible in the distance are the lights of Catania.



The smoke that escapes from the volcano is made up of gas and dust. But the volcano also spews out molten material (magma) as well as expelling stones or rocks of all sizes from the depths of the Earth. This molten material is stored in a kind of vast reservoir several dozen kilometres underground and is hurled outwards when the pressure becomes too great.
This pressure is such that it can even raise the volcano by several centimetres.

MEASUREMENTS TO WITHIN A CENTIMETRE

In this image one can see four series of concentric coloured bands. Each cycle represents a 2.8 cm elevation of the volcano in the direction of the satellite. This shows that the summit of Mount Etna has risen temporarily by 11.2 cm.

The instruments on satellites are able to detect tiny movements of the Earth's surface. By carefully combining radar signals, it is possible to measure relief with great accuracy.

The radar instrument emits a signal in the form of waves which bounce off the Earth's surface (a volcano, or mountain for example) and back to the satellite to be recorded. These waves are vibrations of varying speed and amplitude, and it is their echo which is picked up by the satellite.
To know whether the surface of the ground has moved, if only by a few millimetres, all that is required is to send two radar signals within the space of a few days. If the characteristics of the waves sent back to the satellite do not form a precise match, that means that the ground has moved by a few millimetres at that particular spot depending on the particular wavelength emitted by the radar.

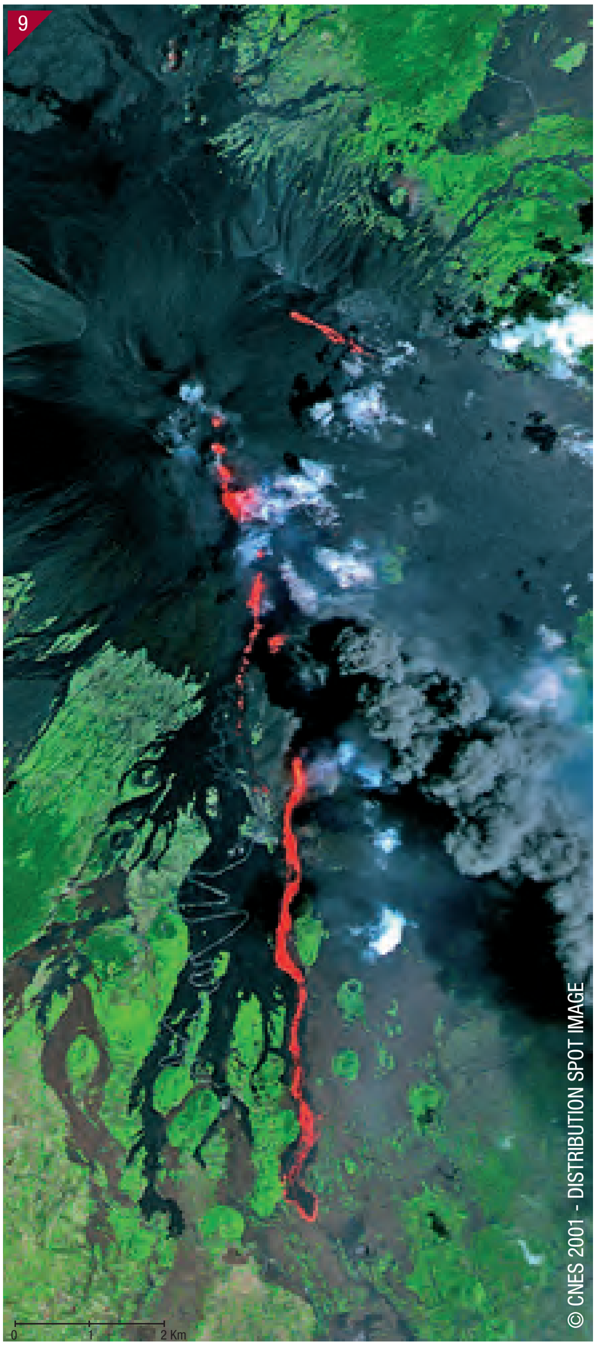
THE ERUPTION OF MOUNT ETNA IN 2001

Lava flows can move at great speed, destroying everything in their path.

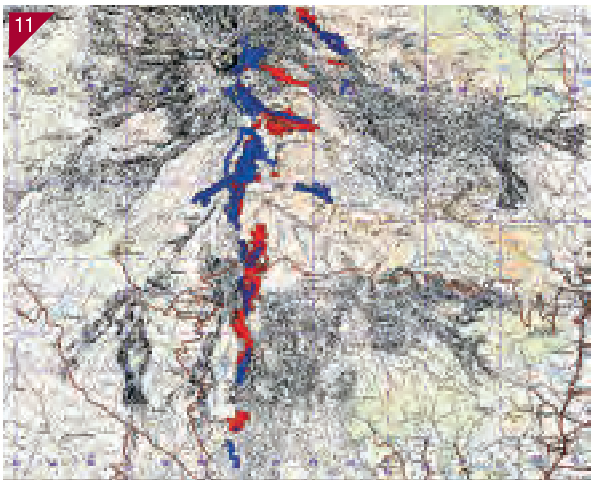
Lava flows can cause considerable damage. Satellites can be used to observe volcanic eruptions as they occur and notably to monitor the path of such flows. Sometimes satellites can also spot ground movements indicating that an eruption is going to take place.

Damage caused by an eruption of Mount Etna.

There is always some delay between the physical phenomenon itself (the volcanic eruption), the passage of the satellite over the area, transmission of the data, image processing, images being made available to local authorities and the implementation of alert procedures on the ground. For that reason, satellites are not the main tool of prevention, but they are very important when it comes to evaluating needs once disaster has struck and to planning the response of the rescue services. For example, they make it possible to form a precise picture of the state of access routes into the devastated areas.
The overall view they provide also helps to determine priorities should emergency intervention be required.



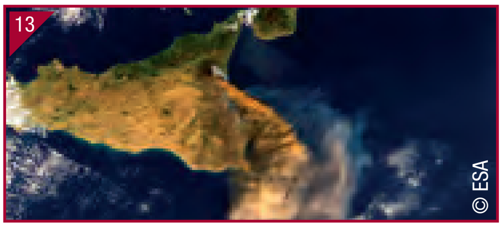
This satellite image shows where roads have been cut off by a previous lava flow from Mount Etna (SPOT image).

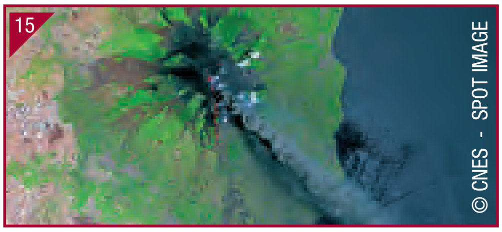


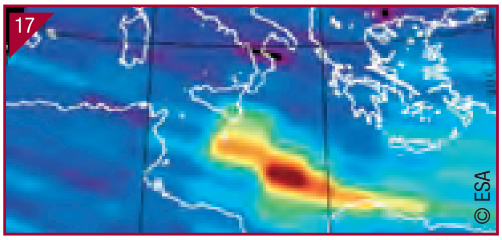
Satellite images provide information, which, when combined with maps, help local authorities to respond appropriately to the situation.

How do satellites work?

The International Charter - "Space and Major Disasters"







One satellite alone is not sufficient to provide all the information that can be of assistance when a disaster strikes. It could quite easily be on the other side of the planet when the event occurs. In addition, a satellite which only takes pictures in the visible domain is unable to operate if the area is in cloud or if the disaster occurs at night. In such cases, a radar-equipped satellite would do a better job.

The European Space Agency and a number of other space agencies have reached an agreement which enables them to pool and coordinate the satellite observation capabilities of several countries. This international "Space and Major Disasters" charter defines how these technical and scientific resources are made available to authorities in the event of a disaster.

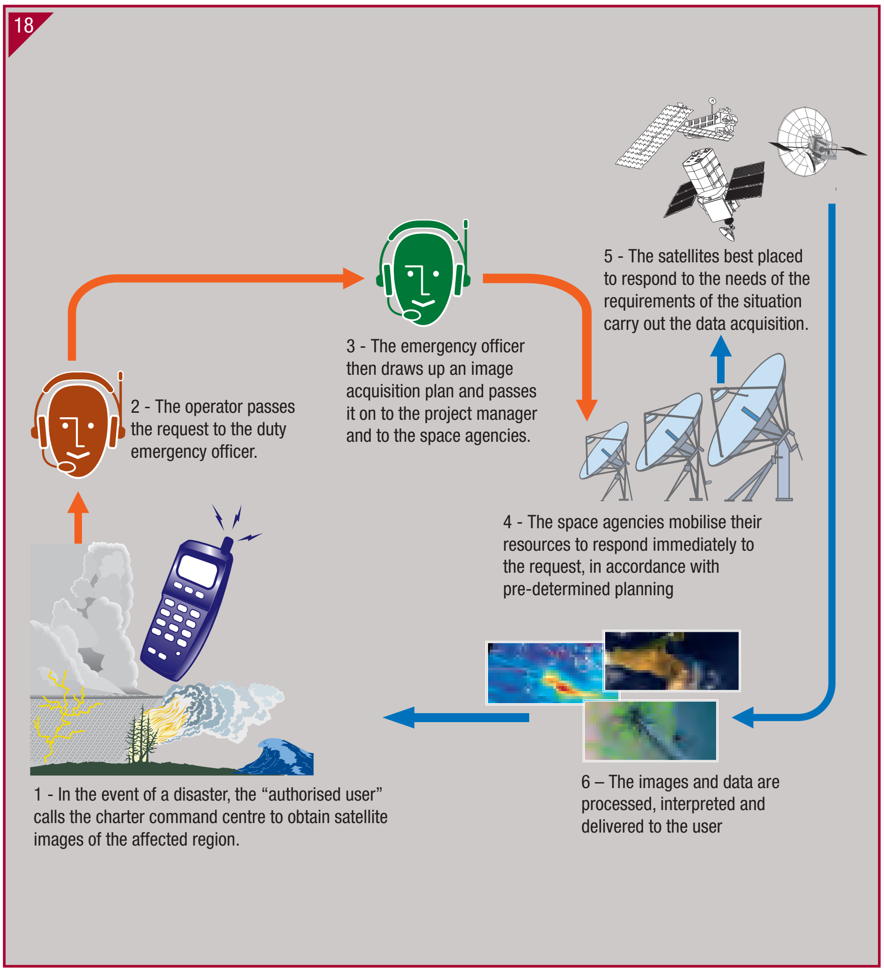
How the Charter works

In the event of a major disaster, this international charter organises, as a matter of the utmost urgency, the acquisition of images by satellite.

The charter is invoked at the request of emergency services in the event of a disaster which involves risk to human life or which causes considerable damage to property.

This international coordination is a European initiative, and, as at January 2007, involved the following organisations:

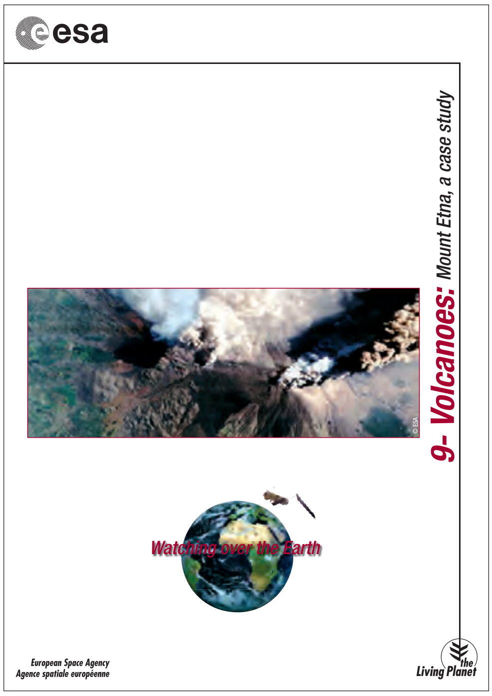
The European Space Agency (ESA)
The French space agency (Cnes)
The Canadian Space Agency (CSA)
The Indian Space Research Organisation (ISRO)
The National Oceanic and Atmospheric Administration (NOAA) - USA
The Argentinean space agency (CONAE)
Japan Aerospace Exploration Agency (JAXA)
The US Geological Survey (USGS)
DMC International Imaging / British National Space Center (BNSC)
The Chinese National Space Administration (CNSA)



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 9: Volcanoes: Mount Etna, a case study



Worksheet 9 is about volcanoes.

This worksheet can be used to:
- locate and identify the main volcanic phenomena, in Europe in particular;
- identify the different forms associated with these volcanic phenomena;
- analyse the relationships between human societies and volcanism.

Volcanism

Understanding and localising volcanic phenomena in the world is inseparable from the concept of tectonic plate movement. The top part of the Earth's crust, the lithosphere, is approximately 100 kilometres thick. It includes the continents and the ocean floors. It consists of the Earth's crust and the uppermost layer of the mantle, and is divided into six main tectonic plates and six secondary plates. These plates glide over the underlying viscous layer, the asthenosphere, under the influence of the convection movements resulting from the rise to the top of magmatic rock. This causes major fractures in the crust. There is a clear connection between volcanic activity and seismic instability (visible, for example, in the "Ring of Fire" in the Pacific) and so regions with active volcanism also have seismic activity.

Eruptions differ depending on the nature and form of the materials present in the magma chamber. The different types of volcanic eruptions include: Hawaiian (low lava dome, no explosions, few ejections, large lava flows), Strombolian (alternating lava flows and ejections deposited in layers on the sides of the domes), Vulcanian (copious ejections, impressive eruptions), and Pelean (explosions, glowing avalanches, formation of acidic lava needles). The eruptions are not always the same for a given volcano, and can change with the centuries. Volcanic activity is not always continuous.

The consequences of volcanism for human societies can vary. First and foremost, volcanoes represent a major natural risk for local populations. The dramatic examples of Vesuvius 2,000 years ago, and eruptions closer to our time, at Mount Pinatubo (Philippines), and Nevado del Ruiz (Colombia), and on the Island of Montserrat, remind us that volcanism constitutes a threat that is beyond our ability to control. But volcanism can also have positive economic consequences. Ash deposits on the slopes or at the base of the volcano can form fertile soil for use in agriculture. Spa treatments, tourism (as in the Chaîne des Puys province in Auvergne), and the mining of volcanic materials (pozzolan, andesite, basalt, etc.) are among the different ways human societies have learned to adapt to this natural phenomenon.

The satellite images

Cover page

Cover image: Mount Etna's crater (Proba/CHRIS)

Proba is a small experimental satellite launched by ESA in 2002. This platform, weighing only 94kg, can be used to test new automatic functionalities. In addition, it is equipped with a high-performance instrument (CHRIS), a multispectral high-resolution imaging device. The image was taken on the 30th October 2002.

Core content

Image 1: Digital Elevation Model of Europe and the Mediterranean

This Digital Elevation Model (DEM) image of Europe and the Mediterranean has been used to represent underwater relief.
The space sensors actually record small localised increases in sea levels. The accuracy and number of measurements taken enables us to recreate a map of the underwater landscape, having first incorporated this data into a digital model taking into account other sources (sonar measurements etc.) and other parameters (such as geoid knowledge and tidal effects). This one shows the continuity of the geological structures to be found on the continents.
Several laboratories collaborated in producing this map, using data from various satellites, notably ERS-1 and ERS-2.

Image 2: Sicily and an erupting Mount Etna (Envisat/MERIS image)

The aerosols and carbon particles ejected by the volcano will have a lasting impact in the atmosphere on both a local and global level, particularly sulphuric acid produced by sulphur dioxide, which can remain present for several years. Satellites enable us to monitor and analyse the evolution of such aerosols and their action in the atmosphere and cloud cover. Image taken on 28th October 2002.

Image 3: The eruption of Mount Etna (SPOT 5 image)

Mount Etna, which rises to 3370m, is the most active volcano in Europe.
The speed with which matter is thrown into the atmosphere can reach 450 meters per second: faster than the speed of sound. This image shows a lava flow from a secondary crater.

Image 7: Radar interferometry image of Mount Etna (Envisat)

Interferometry is a technique that enables us to accurately measure and detect ground movements to within millimetres.
This technique involves combining two radar signals from the same area taken at different times or from two different positions. If the signals are identical, the wave pattern of the combined signal will remain the same. On the other hand, changes (of geometric or temporal origin) produce wave patterns which are slightly different from one another and thus produce interference when they are combined. A precise measurement is made of the phase difference of the path of the outgoing and incoming signal of the two different recordings.

Analysis of these interference fringes is equivalent to a very precise measurement of the variation in distance (a fraction of the wavelength, i.e. measured in millimetres), but which is only known to within a whole multiple of the nearest wavelength. This image of the phase differences, composed of fringes, is what we call an interferogram.
If the ground changes in shape, this will directly affect the radar signals. The interferogram can therefore be understood as a map of earth movements to within millimetres, in which the fringes are lines of isodisplacement.
This complex technique is mostly used to detect ground movements—especially the expansion of volcanoes due to magma pressure—or signs of landslides or earthquakes. Also, it can complement recordings by seismographs on the ground.

Page 5 - The eruption of Mount Etna in 2001

Image 9: The lava flow from Mount Etna (SPOT 5 image)

This image is an enlarged version of the SPOT image in the worksheet core content. In this view it is possible to see a twisting road cut in half by the lava flow.

Image 11: Thermal flows on the slopes of Mount Etna

On 26th July 2001, the International Charter "Space and Major Disasters" was activated in the wake of the eruption of Mount Etna. The volcano was threatening Nicolosi, a village of 5,000 inhabitants situated in the path of the lava flow.
This map is an example of information Charter partners are able to provide with great speed: here the red and blue areas show the evolution in the thermal flows on 29th July compared to those on 21st July 2001. The map was created using Landsat imagery.

Page 6 – "How do satellites work?"

Image 18: The International Charter Space and Major Disasters

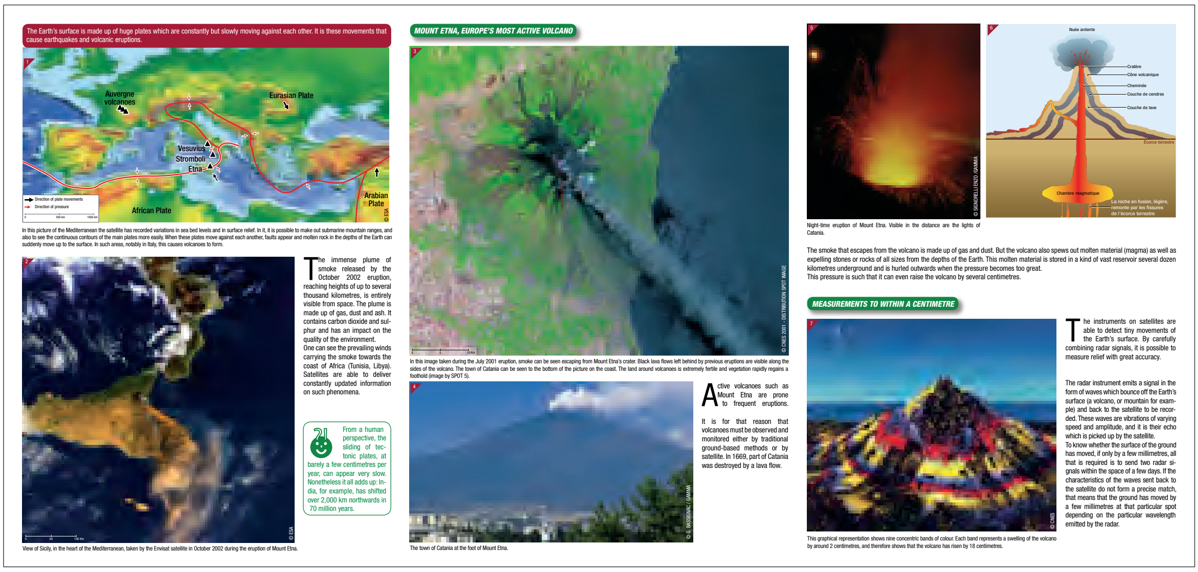
In July 1999, the French space agency, CNES and the European Space Agency decided to make their satellite systems available for the prevention and management of natural or industrial disasters. The International Charter officially entered into force on 1st November 2000 and, in January 2007, counted ten space agencies among its members.
Coordination and pooling of the space capability of several agencies is essential to guarantee monitoring and observation of a crisis-hit area.

By mobilising a large number of satellites, it is possible to guarantee that the moment a disaster happens, the nearest and most suitable satellites will immediately be able to take pictures of the disaster area. Other satellites in a low Earth orbit, which cover the entire globe every two or three days, will in turn be able to provide the necessary images to understand the scale of the disaster and its evolution, and provide accurate maps to help emergency units and deliver aid to victims.

Annex - The following are extracts from Article II of the Charter citing its objectives:

1- "...supply during periods of crisis, to States or communities whose population, activities or property are exposed to an imminent risk, or are already victims, of natural or technological disasters, data providing a basis for critical information for the anticipation and management of potential crises."

2- "participation, by means of this data and of the information and services resulting from the exploitation of space facilities, in the organisation of emergency assistance or reconstruction and subsequent operations."



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MOUNT ETNA, EUROPE'S MOST ACTIVE VOLCANO

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The town of Catania at the foot of Mount Etna.

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This graphical representation shows nine concentric bands of colour. Each band represents a swelling of the volcano by around 2 centimetres, and therefore shows that the volcano has risen by 18 centimetres.

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

VOLCANOES AND PLATE TECTONICS

www.eduspace.esa.int/subtopic/default.asp?document=277&language=en	EDUSPACE website: disaster monitoring-volcanoes
www.volcanoes.com	Website covering world volcanic activity, how volcanoes work
www.ucmp.berkeley.edu/geology/tectonics.html	History behind and mechanisms of plate tectonics
www.seismo.unr.edu/ftp/pub/louie/class/100/plate-tectonics.html	Plate tectonics: the cause of earthquakes
earth.esa.int/ew/volcanoes	ESA's "Earth Watching" website: includes case studies (Etna, Mt St Helens, Piton de la Fournaise etc.)

INTERFEROMETRY

www.space.com/scienceastronomy/astronomy/interferometry_101.html	Explaining interferometry

INTERNATIONAL CHARTER SPACE AND MAJOR DISASTERS

www.disasterscharter.org	Website of the International Charter "Space and Major Disasters"
www.bnsc.gov.uk/content.aspx?nid=5674	BNSC website: disaster monitoring and humanitarian relief

Satellite images

esa · SPOT IMAGE · International Charter Space & Major Disasters · cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

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Worksheet N° 9 – Volcanoes: Mount Etna, a case study

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

1 – What natural phenomenon causes earthquakes and volcanic eruptions?
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2 – How fast can a tectonic plate move?
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3 – What are some of the elements released into the atmosphere during a volcanic eruption?
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4 – What kind of damage can be caused by volcanic eruptions?
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5 – What similarities do you see between the satellite image taken of Mount Etna by the SPOT satellite (image n°3) and the photograph of Mount Etna below (image n°4)? What kind of information does the satellite image provide?
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6 – What are the main functions of remote sensing satellites which monitor volcano activity?
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7 – How accurate can satellite instruments used to observe ground movement be?
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8 – What agreement did the space agencies conclude in case of a natural catastrophe? What is the purpose of this agreement?
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