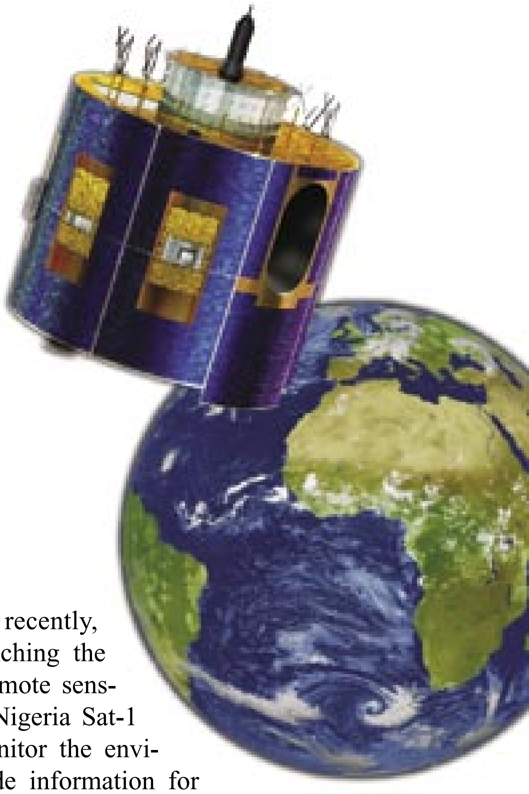
A system for **managing the planet** by 2015



On 25 April 2004, the second Earth Observation Summit in Tokyo (Japan) moved a step closer to a global information system for 'managing the planet' with the adoption by Ministers of the *Framework* for a 10-year implementation plan. While not legally binding, the *Framework* represents a strong political commitment by 47 governments and the European Commission to putting in place comprehensive, co-ordinated and sustained observation of the Earth by 2015 within a Global Earth Observation System of Systems (GEOSS).

On the face of it, this may seem like nothing new, since many international organizations and programmes are already working to sustain and improve co-ordination of Earth observation systems, such as within the Integrated Global Observing Strategy partnership. However, efforts have been hindered up to now by an ambivalent attitude on the part of governments. Even in the wealthiest countries, technical infrastructure has been eroding for want of a sustained commitment to Earth observation and space agencies have been feeling the pinch.

Times are changing. Governments are coming to appreciate the importance of Earth observation for planning sustainable development. This first became apparent at the World Summit on Sustainable Development in Johannesburg (South Africa) in 2002. The G8 meeting in France in June 2003 then went on to identify Earth observation as the highest scientific priority for the coming years. This in turn led to the first Earth Observation Summit in Washington (USA) the following month where 33 countries and the European Commission committed to preparing a 10-year implementation plan.

A technical Group on Earth Observations (GEO) was formed. Co-chaired by the USA, European Commission, Japan and South Africa, and joined by more than 21 international organizations including UNESCO and its Intergovernmental Oceanographic Commision (IOC), the GEO is to prepare the implementation plan. Now that the Framework has been approved, the next step will be for the GEO to translate this document into a detailed plan for presentation to the third Earth Observation Summit in February 2005.

GEOSS will build on existing systems, including those of individual nations, the joint Global Monitoring for Environment and Security of the European Union and European Space Agency, and initiatives within the United Nations system.

Half of the 47 governments at last April's Summit represented developing countries. This is logical because countries of diverse financial means have invested in Earth observation satellites, from the USA, Japan and France to India, China, Vietnam, Argentina, Brazil, Algeria, South Africa and, most recently, Nigeria. Since launching the Low Earth Orbit remote sensing micro-satellite Nigeria Sat-1 last October to monitor the environment and provide information for infrastructure development, Nigeria has been welcomed into the fold of the Disaster Monitoring Constellation grouping Algeria, China, the UK and Vietnam. Natural hazards being unpredictable phenomena, membership of the constellation multiplies each country's chances of being overflown by one of the five satellites at the 'right' moment and thereby of reducing reaction time.

It is also logical that countries which do not possess their own satellites should be part of GEOSS. For one thing, they are regularly overflown and remotely sensed by satellites yet currently have only limited access to the data collected, a situation obviously unsatisfactory for them but also for developed countries which themselves have a stake in making Earth observation more inclusive. If we are to understand the natural processes involved in such long-term phenomena as climate variability, desertification or natural hazards and improve prediction, this will demand comprehensive, sustained global observation both by satellites and *in situ* (on land and at sea) over several centuries. We know from instrumental records dating back to 1861, for example, that the increase in surface temperatures in the Northern Hemisphere during the 20th century surpassed that of any other century for at least 1000 years. But we are hampered in making a global assessment by the fact that insufficient records exist for the Southern Hemisphere.

'For GEOSS to achieve its objectives', Ambassador Ben Ngubane of South Africa told the April Summit, 'it is vital that membership include more representatives from developing countries [...] Integration of regional initiatives such as NEPAD into the development of GEOSS will be critical in this regard. It is ultimately essential for the GEO to interrogate and resolve issues such as the availability of Earth observation data to developing countries at minimum and affordable costs.'

An information management system for our planet

Ben Ngubane was outlining South Africa's expectations of GEOSS on behalf of Phumzile Mlambo–Ngcuka, Minister of Arts, Culture, Science and Technology. 'Over the past 20 years', he noted, [...] 'we have made strides in establishing credible political structures to promote compliance with science-based global sustainable development criteria. This [...] is exemplified by the phenomenon of the 'ozone hole', where detection, an understanding of causality and an effective remedy mandated by international political structures were separated by little more than a decade[9]. What is missing then? To avoid our successes being limited to a series of *ad hoc* examples such as that of the ozone hole, we need what the business world calls a management information system, [...] founded on broad global benefit principles and monitored according to internationally accepted indicators amenable to reliable and affordable scientific measurement. Our vision for GEOSS is that it should be the information management system for our planet'.

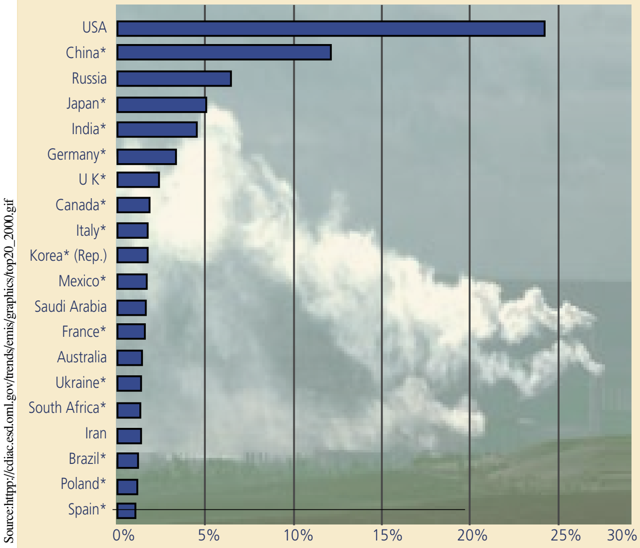
The current status of the Kyoto Protocol

Negotiated by over 100 countries for more than a decade, the Kyoto Protocol calls for the 38 largest industrial nations to reduce their emissions of greenhouse gases to 5.2% below 1990 levels by 2012.

As of April 2004, 122 countries responsible for 44.2% of the world's CO_2 emissions had ratified the Kyoto Protocol, the most recent additions being Israel (March 2004) and Ukraine (April 2004). Since the Protocol must be ratified by countries representing 55% of world CO_2 emissions before it can come into force, the Protocol's successful implementation will depend upon the ratification by one or more of the 12 remaining Parties to the UN Framework Convention on Climate Change.

For details of the Kyoto Protocol: http://unfcc.int

The top 20 CO_2 emitters (2000)



Source:http://cdiac.esd.ornl.gov/trends/emis/graphics/top20_2000.gif

* has ratified the Kyoto Protocol
N.B. All but Iran and Saudi Arabia are parties to the UN Framework on Climate Change

Furthering implementation of environmental treaty obligations

Besides improving understanding of dynamic Earth processes and enhancing prediction, the GEO has the stated ambition of furthering implementation of environmental treaty obligations. Examples in recent years are the Convention on Biological Diversity adopted at the Earth Summit in Rio in 1992, the Convention to Combat Desertification of 1994 or the Kyoto Protocol (*see box*).

As Eric Vindimian of the French Ministry of Ecology and Sustainable Development explains, 'the act of participating in the GEO does not imply a desire to ratify treaties. But the fact remains that the ambition of GEOSS is to develop tools which enable us to observe the planet and that these tools are designed to respond to the needs of the major users, in other words the governments; it is they who most need to know what state the planet is in, in order to sign and ratify international treaties. Even governments which have not ratified certain treaties are not averse to seeing GEOSS serve the implementation of international treaties. Obviously, the pressures on the environment are one parameter to observe and the manner in which the environment copes with these pressures is another.'

The Integrated Global Observing Strategy

Since the end of the Cold War, space agencies have increasingly focused on environmental security by launching an expanding constellation of satellites equipped with optical, infrared and radar sensors to monitor the Earth. These satellites are often the only way to obtain suitable data to understand and predict both man-made and natural changes to the atmosphere, land and oceans.

However, satellites are an expensive business and global *in situ* observation hardly less so. In 2002, Tillman Mohr of the Committee on Earth Observation Satellites (CEOS) remarked that, 'there are several global initiatives to observe the climate or the oceans, for example, but no single agency or organization can afford to implement one of these systems alone.'

Cost-sharing was one consideration in the decision to launch the Integrated Global Observing Strategy (IGOS) four years ago. A second consideration was the growing realization that land, atmosphere and the oceans were not separate systems but interlocking parts of a single Earth system and that research programmes would only be effective if bridges were thrown between the different global initiatives.

IGOS is made up of 14 partners, including CEO representing 23 space agencies, UNESCO, FAO, UNEP, WMO, the Global Terrestrial (GTOS), Ocean (GOOS) and Climate (GCOS) Observing Systems, ICSU, the World Climate Research Programme and International Geosphere–Biosphere Programme.

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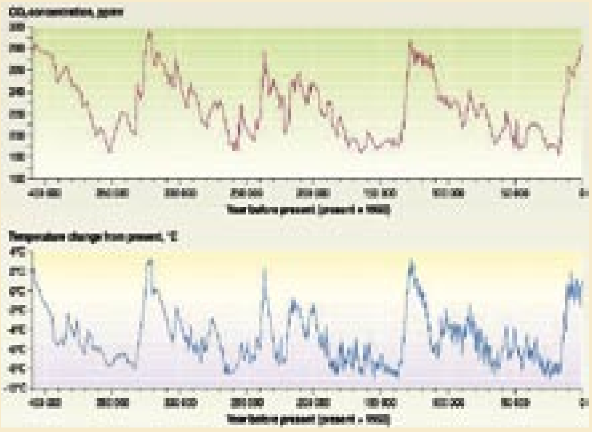
9. *Some 90% of ozone is found in the stratosphere (altitude of 11-30 km). At this height, ozone acts like a protective shield against UV radiation. The Montreal Protocol first reduced (1987) then banned (1992) chlorofluorocarbons in developed countries. The natural ozone production process should heal the ozone layer by 2050, although climate change could delay its recovery*

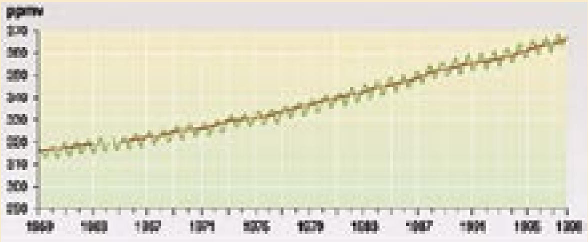
The *Framework* for the implementation plan of GEOSS recognizes the contribution of IGOS as one of a number of groups which have developed 'some important work and guidance for future action' in the area of co-operation in land, water, climate, ice and ocean observation'.

Among the anticipated socio-economic benefits listed by the *Framework* are reducing loss of life and property from natural and human-induced disasters, understanding environmental factors affecting human health and wellbeing, improving management of energy resources, understanding, predicting, mitigating and adapting to climate variability and change, improving water resource management and the protection of terrestrial, coastal and marine ecosystems, and biodiversity conservation. These are the very objectives of IGOS.

CO_2 concentration in the atmosphere



From the Vostok ice core. Note the correlation between change in temperature (bottom) and change in CO_2 concentrations (top) over the past 420 000 years. Each dip in the temperature curve corresponds to an ice age. The present CO_2 concentration (368 parts per million by volume (ppmv) in 2000) has not been exceeded during the past 420 000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20 000 years. The projected concentration of CO_2 in the year 2100 ranges from 540 ppmv to 950 ppmv. The variation results from uncertainties as to the persistence of present removal processes (carbon sinks) and the magnitude of the climate feedback on the terrestrial biosphere.



Before the industrial era (around 1750), atmospheric CO_2 concentration was 280±10 (ppmv) for several thousand years. It has risen continuously since then, reaching 368 ppm in 2000.

The IGOS 'theme teams'

Over the past four years, IGOS has identified several critical issues, including ocean observation needs and currents and climate change, the state of the world's water cycle, the global carbon cycle, atmospheric chemistry and geohazards such as volcanic eruptions and landslides. Scientists specializing in these areas have been working in committees to develop strategies in the form of reports, which begin by identifying the type and duration of satellite data which might fill the gaps in current knowledge.

So far, the IGOS partners have approved the strategies for five of the 'theme teams', as they are known. These concern the carbon cycle, water, the oceans, geohazards and the subtheme on coral reefs. The strategies for atmospheric chemistry and coastal observations are still under preparation.

Two further themes have been proposed, those of land cover and the cryosphere. Derived from the Greek word *kruos* meaning frost or icy cold, the cryosphere is the portion of the Earth's surface where water is found in a solid form, such as sea ice, freshwater ice, snow, glaciers and frozen ground (or permafrost). The land cover theme will focus on sustainable land use, natural ecosystems, soils, biodiversity and on monitoring changes in land cover.

Life inside the greenhouse

There are already fairly regular and accurate measurements of air-pollution levels for many capitals but air pollution goes unmonitored in most of the world's cities, despite exponential growth in motor vehicle use in even the poorest countries. Air pollution being both a health issue and an environmenta issue, we need a better grasp of the ways in which different chemicals affect the atmosphere. Satellites may very well provide a global monitoring system for this purpose.

Unlike stratospheric ozone which is beneficial, ground-level ozone (up to an altitude of 11 km) is the primary constituent of city smog. Ozone is created by sunlight acting on nitrogen oxides and volatile organic compounds emitted by motor vehicles and stationary sources. These emissions can be carried hundreds of kilometres and result in high ozone concentrations over great distances. An Airtrends summary in 1995 by the US Environmental Protection Agency cited scientific evidence that 'exposure to ozone for six to seven hours, even at relatively low concentrations, significantly reduces lung function and induces respiratory inflammation in normal, healthy people during periods of moderate exercise. It can be accompanied by symptoms such as chest pain, coughing, nausea and pulmonary congestion.' The report estimated that 'ozone is responsible for approximately \$1–2 billion of agricultural crop yield loss in the USA each year [...] and damages forest ecosystems in California and the eastern USA'.

Several reports published as recently as May 2004 note growing damage to health as a result of atmospheric pollution. One published by the French Environmental Health Agency (*Agence française de sécurité sanitaire environne-*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'Exposure to ozone for six to seven hours significantly reduces lung function and induces respiratory inflammation in normal, healthy people during periods of moderate exercise'

mentale) estimates that atmospheric pollution is responsible for 6500–9500 deaths every year (out of a French population of 60 million), or 3–5% of deaths in the population aged over 30. Another report published by the Harvard Medical School in the USA and cited by the medical journal *The Lancet*, entitled *Inside the greenhouse: the impacts of CO_2 and climate change on public health in the inner city*, lays part of the blame for more widespread childhood asthma at the door of fossil-fuel combustion. Inner-city children are described as being most at risk, since diesel particles are highly effective at depositing pollen in immune cells in the lungs, even as higher CO_2 levels are stimulating plants to produce more pollen earlier in the year. In the USA, childhood asthma rose by 160% between 1980 and 1994; in Europe, one child in seven is thought to suffer from the affliction today.

A decade of data just a drop in the bucket

The approved ocean theme report was published in January 2001. The adoption of this ocean programme led to an agreement between two research space agencies, NASA (USA) and the CNES (France), and two operational space agencies, NESOLS (USA) and EUMETSAT (Europe), to launch Jason-2 jointly in 2005. This satellite will follow in the footsteps of the Jason-1 and Topex/Poseidon, Franco-American satellites that revolutionized our understanding of oceanography.

Circling the Earth every 112 minutes, Topex/Poseidon (launched in 1992) was the first satellite capable of measuring the height of the height ocean surface with a precision of a few centimetres; this permitted scientists to infer the dynamics of the underlying ocean and temperature of sea waves, as well as related wind speed. This kind of data ables scientists to observe the major ocean currents that regulate our climate by shifting heat around the world. Topex/Poseidon has also provided an efficient method of monitoring the variation in global mean sea level in relation to global climate change.

The Topex/Poseidon mission was so successful that the USA and France launched a follow-up, Jason-1, in 2001. The satellite has been sending the most precise measurements of sea surface ever recorded, with an accuracy of 1cm. Jason-1 should be operating for about ten years.

Even so, a decade of data is just a drop in the bucket in scientific terms. 'We now know that events like El Niño and the North Atlantic Oscillation, an atmospheric see-saw driving winter storms west to east across the ocean, don't simply occur on a year-to-year basis but follow decadal cycles,' says Colin Summerhayes of the UNESCO-IOC. 'With longer-term data, weather forecasters might provide practical information for agricultural planning, especially in arid regions.'

Plugging the holes in our knowledge of the water cycle

IGOS has produced a similar theme report on the world's water cycle. We take for granted the satellite images shown by weather forecasters on television, which have been around ever since a string of meteorological satellites followed the first US mission launched in 1960.

However, there are still gaping holes in scientists' understanding of the basic water cycle. Precipitation is notoriously difficult to evaluate; it has been estimated that only 1–4% of the globe's area is covered at any one time by rainfall. Moreover, the intensity of that rainfall can vary widely in a matter of minutes or even seconds. Scientists will soon have an unprecedented quantity and quality of water-related data thanks to a new generation of satellites: Terra and Aqua (USA) and Envisat (Europe).

IGOS is weaving a global network to collect, compare and synthesize the data of the various satellites with land-based observations. The aim is to finalize the system in time for what promises to be a technological milestone. In 2007, the USA and Japan will be launching a constellation of nine Global Precipitation Measurement satellites which will be able to measure the rainfall at any spot on the globe every three hours.

Satellites alone won't provide all the answers

However, satellites alone cannot answer most of the critical questions facing scientists today. Satellites alone cannot measure the amount of CO2 absorbed by forests or the rate of coastal erosion. This is why IGOS is also developing strategies to integrate land- and space-based data. Satellite images of coastal erosion can transform the studies of a marine biologist.


© D.Roger/UNESCO

Rice paddies in Indonesia. Feeding the world's growing population will demand greater agricultural productivity, a goal better information on the water cycle will help us to achieve

At the same time, space agencies need information from the field to interpret the signals sent by satellites.

Understanding the carbon cycle to predict climate change

IGOS approved a strategy to study the impact of rising carbon dioxide CO_2 emissions in early 2004. CO_2 is responsible for more of the atmospheric warming than all other greenhouse gases combined, including methane, nitrous oxide and halocarbons. Part of the problem stems from the fact that CO_2 concentrations in the atmosphere take centuries to stabilize even after the level of emissions itself stabilizes. Concentrations of methane, on the other hand, a gas produced primarily by agricultural activity, waste disposal, coal mining and natural gas, will stabilize only decades after the level of emissions itself stabilizes.

To predict how atmospheric CO_2 levels and climate may change in the future, we must understand where and how CO_2 moves between the land, oceans and atmosphere in what is known as the global carbon cycle.

Within this cycle, the oceans will ultimately absorb approximately 90% of the anthropogenic CO_2 emitted to the atmosphere. However, the rate of absorption by the ocean's surface waters and its transport into the deep ocean, where it is out of contact with the atmosphere for thousands of years, is much slower than the rate of CO_2 emissions to the atmosphere. This leads to a build-up of CO_2 in the atmosphere. At present, the oceans are absorbing about 30% of fossil fuel carbon but understanding how this process works and may work in the future under a changed environment is problematic. The ocean removes CO_2 from the atmosphere in two ways. Microscopic plants, known as phytoplankton, convert CO_2 to organic matter by photosynthesis; this carbon is then transported into the deep ocean when the plants die and sink in a process called the 'biological pump'. Another mechanism, the 'solubility pump', results from the fact that CO_2 from the atmosphere is soluble in seawater. When surface seawater is cooled in the high latitudes, it becomes very dense and sinks to the deep ocean, carrying this dissolved CO_2 with it. The net ocean uptake of anthropogenic CO_2 appears to be controlled over long time-scales by ocean physics, specifically the transport of these surface waters saturated with CO_2 to the deep ocean. However, in many regions and over shorter time-scales, the biological pump can have a stronger control on the distribution of CO_2 in the oceans.

Through measurements of carbon in surface and deep waters and an understanding of the physical circulation of the ocean, scientists can begin to understand where, how and how quickly the ocean is removing CO_2 from the atmosphere. These measurements are made through a combination of samples taken on board research vessels or specially equipped commercial vessels and by using scientific buoys. By studying satellite images of ocean colour, scientists can gauge phytoplankton levels globally and begin to understand the processes controlling the spatial and geographic variability of the growth patterns. It is essential to combine these observations to develop models on how the

The eruption of the century

Courtesy of US Geological Survey

Mount Pinatubo wakes from 400 years of slumber

After lying dormant for four centuries, Mount Pinatubo in the Philippines erupted so violently in June 1991 that it spewed columns of more than 10 km^3 of pyroclastic debris and ash to an altitude of 40 km and flung a giant umbrella cloud containing 17 megatons of sulphur dioxide into the stratosphere. Volcanic ash hung in the air for months, some of it being scattered by the wind as far as Russia and North America.The eruption caused average temperatures in the Northern Hemisphere to fall by up to 0.6°C. The eruption buried more than 400 km^2 of countryside under hot ash flows and blanketed 7500 km^2 of the island of Luzon in ash. More than one million people were displaced and approximately 900 killed. Damage to property and infrastructure ran into hundreds of millions of dollars.

Courtesy of US Geological Survey

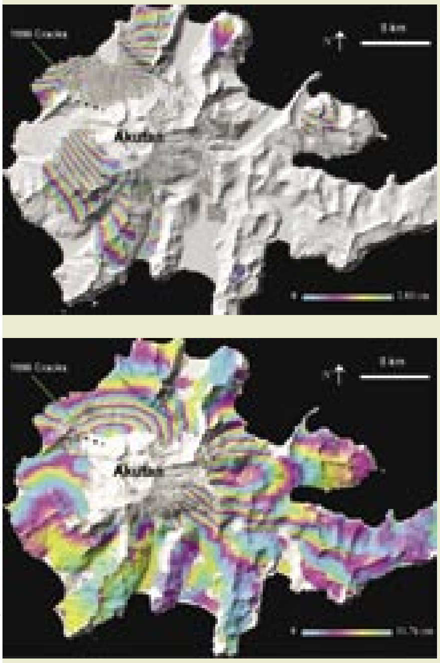
The eruption blanketed the Philippine iland of Luzon in ash and turned day into night

Courtesy of US Geological Survey

Children on the roof of their school in Bamban in October 1991

Volcanic activity is monitored regularly around the world. Computer-based data acquisition and processing have made great strides but not to the point of replacing the traditional cylindrical drum recorders you will still see at volcano observatories, where they record signals from seismometers that are strategically stationed around potentially active volcanoes.

A satellite study



Courtesy of US Geological Survey

These two interferograms show Akutan Volcano on a remote island in the Aleutians in Alaska (USA). In 1996, an intense earthquake swarm shook the sparsely populated island. Fearing the dormant volcano might erupt (which it did not), scientists used two pairs of satellite images produced from radar of different wavelengths to measure changes in the volcano's topography.

The C-band interferogram (top) on the shorter wavelength was constructed on the basis of images taken by a sensor onboard the European Space Agency's ERS satellite; the L-band interferogram (bottom) stems from the Japanese J-ERS satellite. To calculate an interferogram, you need a minimum of one pair of images of the same target taken at different times. Current satellites measure the same target about once a month. One image is then superimposed on the other to show where changes have occurred. The pairs of images used to produce the interferograms on the left reveal a deformation in the surface of the volcano caused by the intrusion of magma, which moved from under the volcano's summit to the east. This deformation has been 'captured' because one image was taken before the intrusion and the other afterwards.

C-band may be more sensitive to smaller deformations than L-band but it is not suited to monitoring deformations that displace the target more than a few centimetres between two observations.

The presence of vegetation and cloud variations alter the path followed by the wavelength. As most natural surfaces are not solid rock but include soils, rubble and so on (as in the case of this island), the longer L-band radar would appear to be much more useful than C-band for geohazards monitoring, even in the absence of vegetation.

No L-band missions are being flown at the moment, so observations like the one shown in the bottom picture are no longer possible. The Japanese Space Agency is, however, scheduled to send the (L-band) ALOS satellite into orbit. Several other satellites are flying with C-band interferometric capabilities: the Canadian RadarSat, the European ERS-2 and Envisat.

carbon absorbed and released by the ocean interacts with the atmosphere and land (*see also page 41*).

'Today, there are several models but the results they give can vary by as much as 50%', notes Philippe Ciais of the French Atomic Energy Commission, leader of the IGOS strategy for the carbon cycle. 'These models will probably improve. But if we don't improve our current observations, we won't have a reference point to measure the extent to which the carbon cycle has changed between now and the next decade.'

Taking the measure of geohazards

The geohazards strategy was published in April 2004 by the three leaders of the theme team, the British Geological Survey, European Space Agency and UNESCO.

Every year, volcanic eruptions, earthquakes and landslides claim thousands of lives, injure thousands more, devastate peoples' homes and destroy livelihoods. The cost in terms of damaged infrastructure runs into the billions in any currency, a cost pushed higher still by insurance premiums. Geohazards affect rich and poor alike but have a disproportionate impact on the developing world. As the human population increases, more and more people are living in hazardous areas, causing this impact to grow at an unsustainable rate.

Citizens need to know a hazard's location, timing, extent, likely behaviour and duration. It is not yet possible to give firm answers to any of these questions. This is because of critical gaps in topographic data, hazard inventories and geoscience maps, insufficient coverage of local GPS and seismic networks, inadequate geohazards models and a lack of continuity in C-band – and especially L-Band – radar interferometry (*see box*).

The goal over the next decade is to fill these gaps by integrating disparate geohazards research into global operational systems. This should enable the geohazards community to improve mapping, monitoring, forecasting, mitigation and preparedness, and thereby provide the agencies involved in disaster management with critical information. The strategy will fill key gaps in long-term observations and bridge issues not covered by the disaster response system set up under the international Charter on Space and Major Disaster or the UN Action Team on Disaster Management.

Into the political arena

Over the next decade, the IGOS partnership will bring us a more thorough understanding of how the planet's life support systems function and interact. In so doing, IGOS will be fashioning the tools decision-makers will need to plan sustainable development.

The ten-year Earth observation summit process brings the work of IGOS into the political arena. These parallel processes hold the promise of a potent cocktail blending scientific rigour and political commitment. The summit next February should design the architecture of an Earth observation system which will revolutionize the way we manage the planet.

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Robert Missotten[10] and Maria Hood[11]

To read the theme reports: www.igospartners.org

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