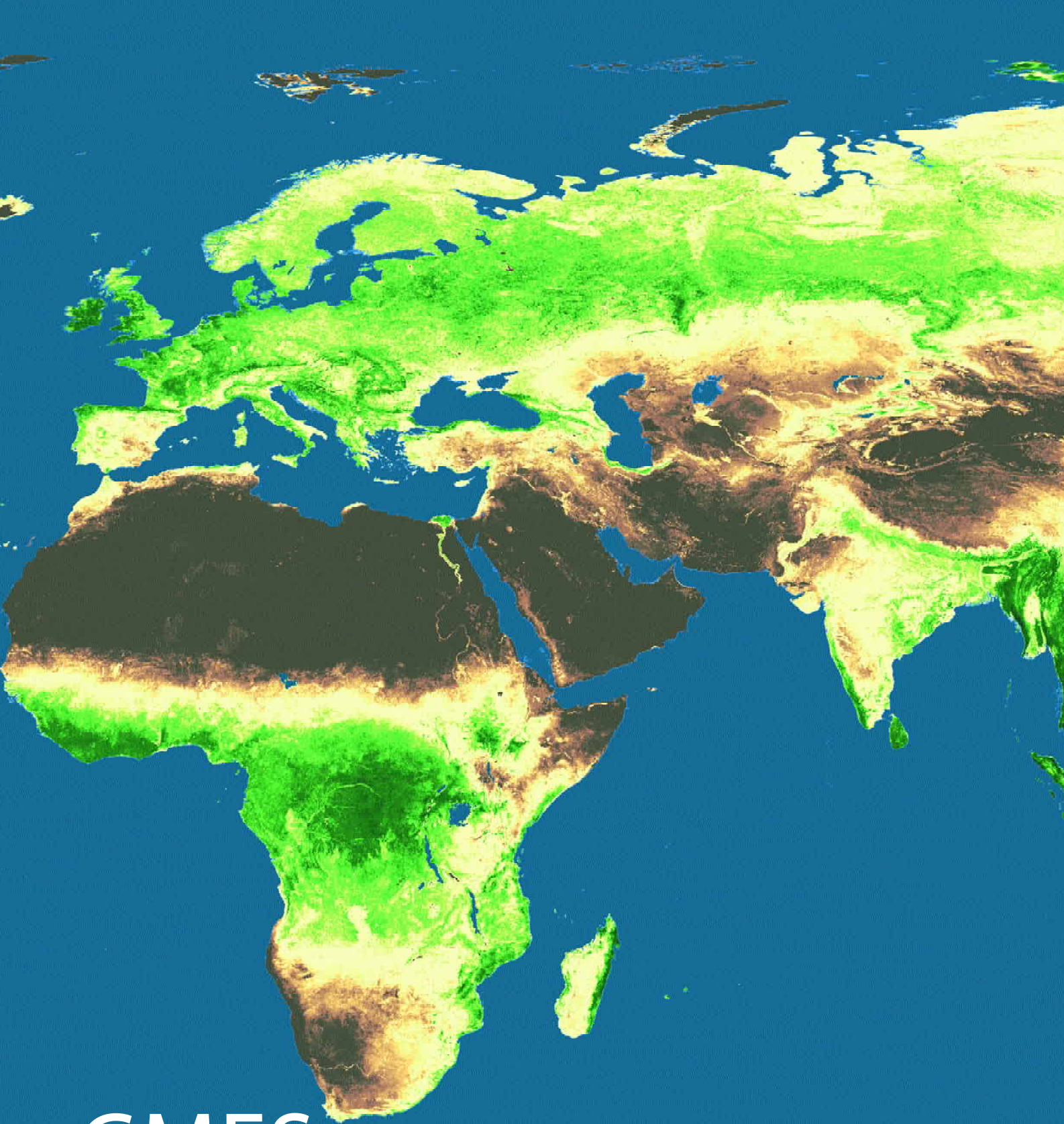
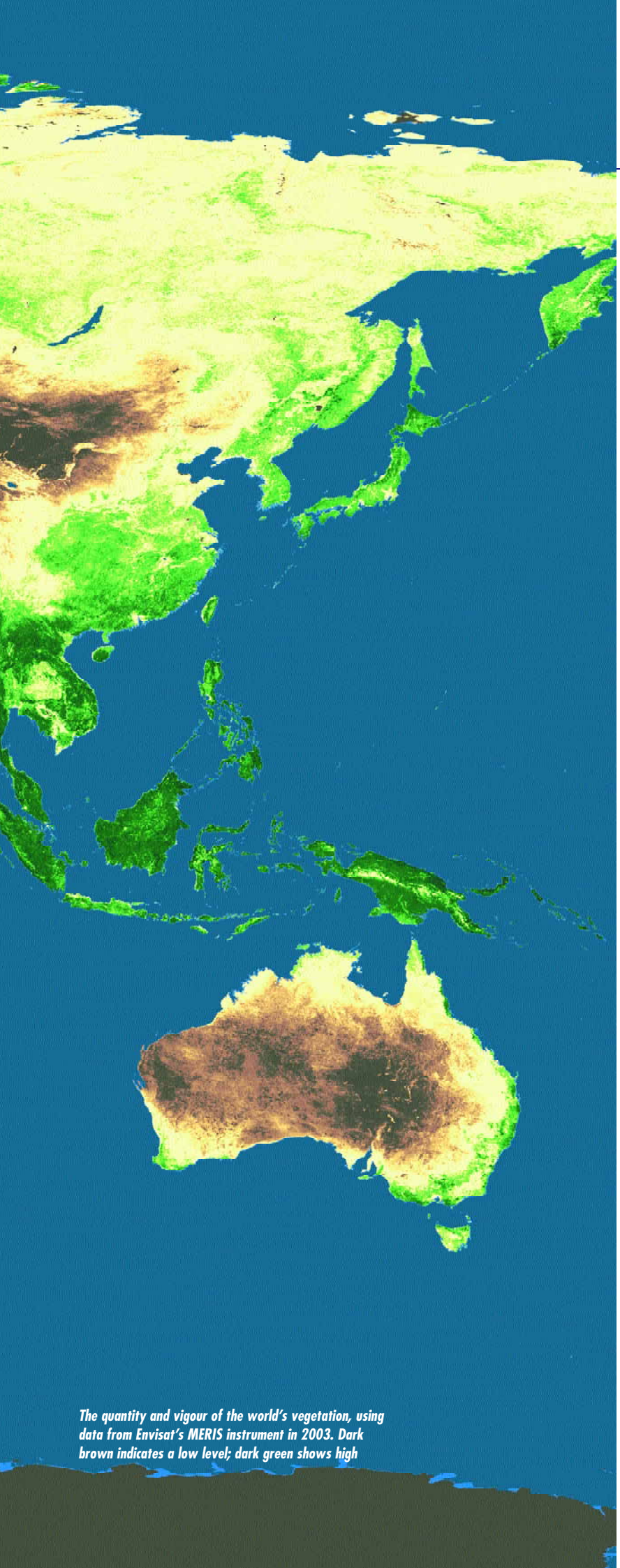


GMES

Global Monitoring for Environment and Security: The Second European Flagship in Space



The quantity and vigour of the world's vegetation, using data from Envisat's MERIS instrument in 2003. Dark brown indicates a low level; dark green shows high

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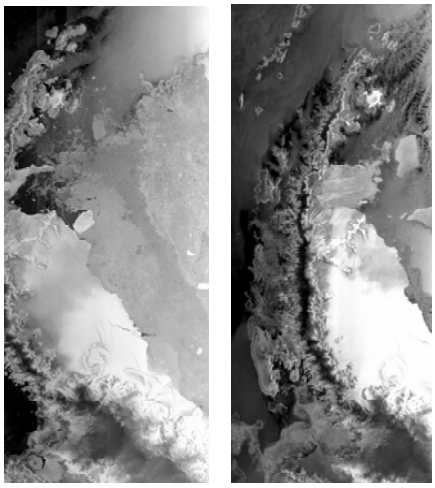
Directorate of Earth Observation Programmes, ESRIN, Frascati, Italy

Society and politicians are demanding operational information services in order to manage our planet's environment, understand and mitigate the effects of climate change, and ensure civil security for Europe's citizens. GMES can respond to these challenges by providing accurate, up-to-date and globally available information on an operational basis to European, national, regional and local entities. Important decisions are expected in the next two years on the future of GMES, including finalisation of the funding scheme for developing the infrastructure, and progress in setting up its long-term governance and funding. ESA's responsibility is to provide the GMES satellites, which includes developing a dedicated space infrastructure and coordinating the space contributions from all the partners.

GMES Political and Strategic Goals

The Intergovernmental Panel on Climate Change, at its recent meeting in Paris, concluded that global temperatures will increase by 1.7–4.4ºC and sea levels by 21–48 cm by the end of this century. Heat waves and tropical storms will likely intensify and Arctic summer sea ice will disappear in the second half of the century.



Captured by Envisat on 22 February 2007, this radar image (left) highlights changes in the Antarctic ice shelf since the image of 18 March 2002 (right)

Climate change will affect developing countries most. They are already under stress through large increases in their populations; the global population will rise from 6000 million today to 9000 million by 2050. Shortages of food and clean water will lead to conflicts and large-scale emigration to wealthier regions such as Europe and North America.

Environment and security are intimately linked and will become major political issues in the coming decades. The command of information has geostrategic implications. The political mandate for the Global Monitoring for Environment and Security (GMES) programme was expressed at the 2001 Gothenburg European Union (EU) Summit, stating the need to "*achieve by 2008 an operational and autonomous European capacity for global monitoring for environment and security*". This was transformed into an Action Plan 2004–2008, endorsed by the European Parliament. Further, the second Space Council, combining the EU Competitiveness and ESA Councils, stated that GMES will be the second flagship of EU space policy, after the Galileo navigation system.

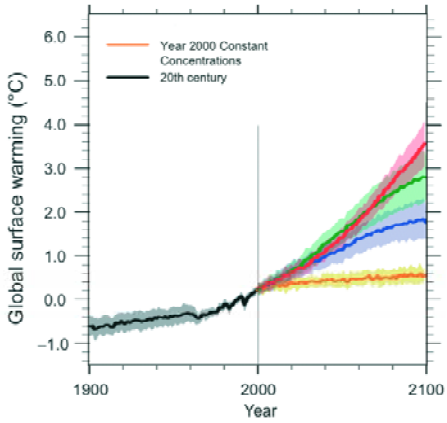
GMES will provide critical environment and security information to European and national policy-makers. Satellites will be a critical component, assuring autonomous, up-to-date and globally comparable information.

A secondary objective of GMES is to provide a coherent European contribution to international efforts such as the Global Earth Observation System of Systems (GEOSS), which was established in 2005 through an international Ministerial Summit. GEOSS is largely modelled on GMES in terms of overall objectives, but totally relies on participants' contributions. GMES will be one of the most significant contributors to GEOSS.

GMES: A European Project in the Making

GMES began in 1998 through the 'Baveno Manifesto', which states the need for a global satellite-based monitoring system for Europe. It attained political momentum in 2000 when it first appeared on the agenda of several EU Presidencies. In 2001, both ESA and the EC obtained approval for some EUR100 million each to initiate GMES services and build up a sustainable user community.

GMES comprises four main, interdependent, elements: services, space observations, *in situ* observations, and data management, integration and modelling. The last is particularly important because it allows forecasts of critical parameters for environment and security.

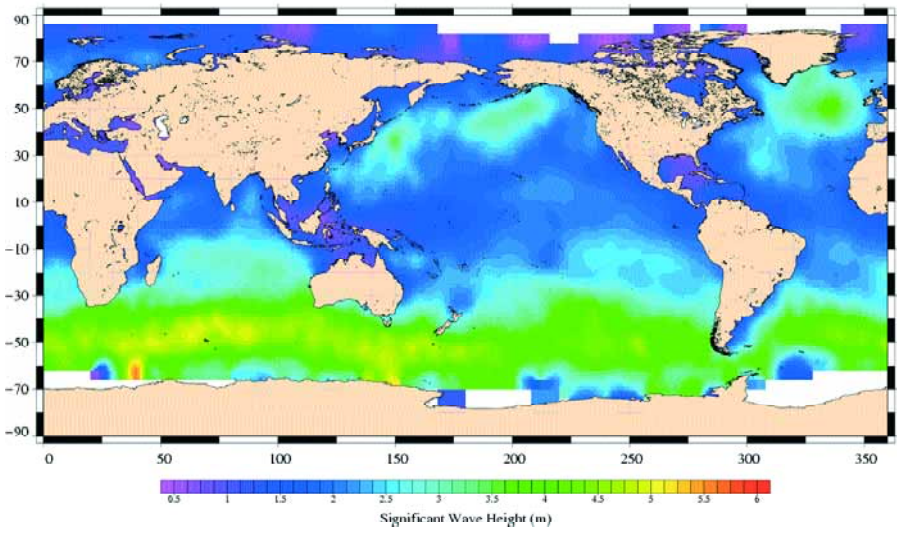


Predicted global warming, depending on different levels of greenhouse gases (red, green, blue). The orange curve predicts the increase if the levels did not rise after year 2000. (Adapted from the Intergovernmental Panel on Climate Change)

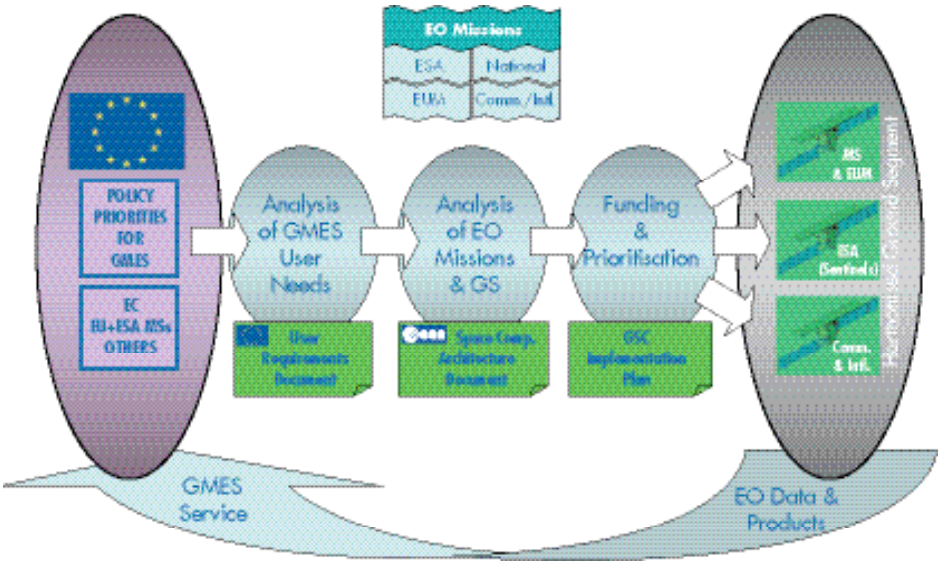
In 2005, the European Commission (EC) assumed political leadership of GMES and took responsibility for the development of services, including the definition and setup of a sustainable governance structure.

ESA is responsible for the space component. This role comprises two basic functions, confirmed by Member States, according to which ESA is responsible for:

– the end-to-end definition and implementation of the space component. Some of elements will be provided



Global wave height measured by Envisat's radar altimeter, 4 September to 10 October 2006. (CNES-CLS)



The process leading to the GMES satellites

through national entities or Eumetsat;
– the development of space and ground infrastructures through ESA programmes, complementing national and Eumetsat contributions.

The elements developed through ESA programmes – the Sentinel satellites and the ground segment and operations – complement Member State contributions.

Responding to User Requirements

GMES satellites are responding to user requirements. The Sentinels, approved at the Berlin Ministerial Council in December 2005, were defined by a 'gap analysis', which analyses user requirements based on policy needs, derives space observation requirements, and compares them with available and planned missions from EU/ESA Member States and Eumetsat.

The EC was closely involved in defining the specifications of these Sentinels. It provided an assessment of the Mission Requirement Documents (MRDs) of Sentinel-1, -2 and -3 through the GMES Fast-Track Implementation Groups on emergency management, marine and land monitoring. The recommendations led to design changes of these missions. The EC further prepared a synthesis report on space infrastructure needs, which endorsed the designs. The report also states that the Sentinel-1, -2 and -3 missions need two satellites each to meet the observation coverage and repeat cycle requirements.

GMES Services

ESA and the EC began developing GMES information services as early as 2002. Under the ESA GMES Service Element, approved in November 2001, ten service portfolios were developed. Each responds to user needs in a specific sector of environmental or security policy. They address domains such as polar monitoring, forest monitoring, marine and coastal monitoring, flood, fire and geo-hazard risk assessment, air-quality monitoring and forecasting, and land-cover mapping and urban development monitoring, as well as information services to support humanitarian aid and development and food security actions.

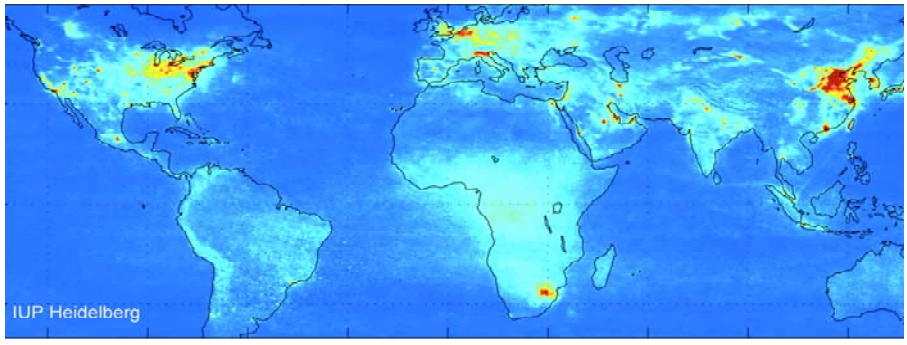
In parallel, the EC undertook a series of large integrated projects within its 6th Framework Programme to address the underlying research issues. Together, these activities engaged more than 300 organisations from 35 countries as end users of GMES. This enabled ESA and the EC to identify the key requirements for the GMES space element, and led to specifications for the Sentinels and access to national missions.

Building on this, the EC organised major consultations with user organisations in Europe and is now dedicating significant resources of the 7th Framework Programme to develop three Fast Track Services: The Land Monitoring Service; The Marine Service, and The Emergency Management Service. These will enter their pre-operational stage in 2008.

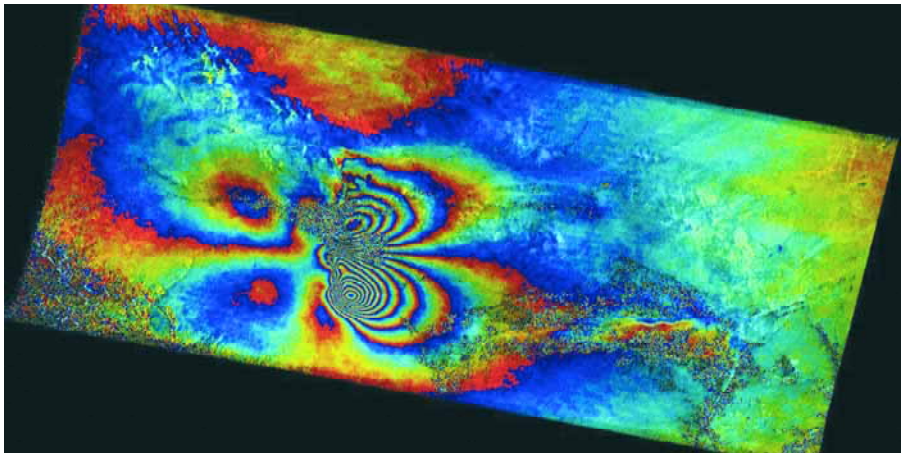
Two other pilot services are planned: the GMES Atmospheric Service, and a service dedicated to Security. A set of core, pan-European or global services will be established first. Later, more specialised services (at national, regional or local levels, for example) will be introduced.

National and Eumetsat Contributions

In line with the GMES Declaration, the space component comprises shared



Nitrogen dioxide pollution measured by Envisat's SCIAMACHY instrument from June 2003 to January 2004. (Univ. Heidelberg)



Envisat radar images of Bam (Iran) from before and after the Earthquake of 26 December 2003 are combined in this 'interferogram' to reveal the ground movement. (Polimi/Poliba)

infrastructure provided by national, European and other contributors as well as the dedicated Sentinel satellites developed by ESA.

Today, a number of national, Eumetsat and commercial Earth observation (EO) missions are being developed in Europe. They primarily serve their respective operator's strategic priorities but are also of interest to GMES.

The candidate EO missions listed in the GMES Declaration will be the starting point for determining these contributions. The list will evolve as new missions become available. Priority will be given to European data sources, to underline the principle of independent data access.

Currently, the missions identified as potential contributors are (in alphabetical order): Altika, Cosmo-SkyMed, DMC, EnMap, Envisat, ERS, Jason, Meteosat, MetOp, Pleiades, Proba, Radarsat, RapidEye, SeoSat, Spot, Tandem-X, TerraSar-X and TopSat.

In order to assure the sustainability of those national and multinational missions that are required for GMES (based on a formalised user endorsement process), a high-level coordination group, the GMES Space Component Partnership, will be set up by ESA with the stakeholders involved.

Sentinel-2 will provide high-resolution multispectral imaging. Shown here is the Barrax test site in La Mancha (E), imaged by Proba-2's CHRIS compact high-resolution imaging spectrometer in 19 of its 62 spectral bands

Sentinel Missions

Based on the gap analysis, five observation capacities have been identified that need to be developed for GMES, in addition to national and Eumetsat missions:

- Sentinel-1: high-resolution synthetic aperture radar (SAR) imaging;
- Sentinel-2: high-resolution multispectral imaging;
- Sentinel-3: global ocean and land monitoring;
- Sentinel-4: geostationary atmospheric monitoring;
- Sentinel-5: low-orbit atmospheric monitoring.

Sentinel-1 carries a SAR in a precise dawn-dusk Sun-synchronous orbit at 700 km altitude with an exact repeat of 12 days for multi-pass interferometry. With a SAR swath width of about 240 km, 12-day quasi-global coverage is ensured. The ground resolution of about 5 m exceeds that of the ERS and Envisat satellites in imaging mode. The 2.1 t satellite is built around the large SAR instrument, which features a phased-array antenna with 5 kW total radiated power. It is designed for launch on Soyuz and a lifetime of 7 years.

Sentinel-2 carries a medium- to high-resolution push-broom multispectral imager operating in the visible and near-

infrared and shortwave infrared in an Envisat-like orbit. The ground resolution is 10, 20 and 60 m, depending on channel. The swath width of the multispectral imager is about 280 km, which ensures systematic acquisition of all land surfaces every 10 days. The 850 kg satellite will fit a small launcher (Vega) and has a 7-year design lifetime.

Sentinel-3 carries a CryoSat-derived microwave altimeter (including a microwave radiometer and precise orbit-determination device) and two imagers, for ocean/land colour observations (MERIS-like) and for sea/land surface temperature observations (AATSR-like) into an Envisat-like orbit. The imager also provides continuity of the Spot/Vegetation mission. The 1.3 t satellite will use a small launcher (Vega). The design lifetime is 7 years.

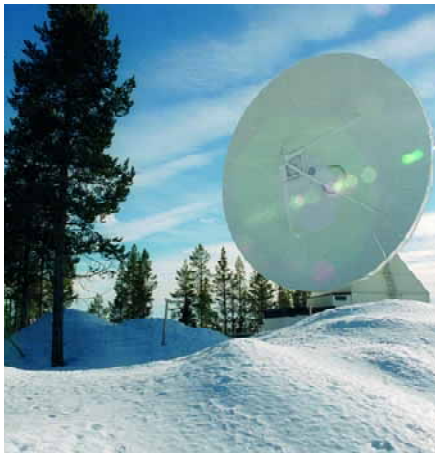
Sentinel-4 and -5 are atmospheric chemistry missions, details of which are being defined through pre-Phase-A studies. The baseline assumption is that they will be instruments aboard the Meteosat Third Generation (MTG) around 2017 (Sentinel-4) and on post-MetOp around 2019 (Sentinel-5). Their use, if confirmed in the above configuration, will be closely coordinated with Eumetsat, who will operate the MTG and post-MetOp satellites.

Long-term continuity of Earth observation data is a prerequisite for GMES services. It is therefore assumed that the baseline technology for the satellites will remain stable for a long period, such as 15 years per satellite generation, which is similar to operational programmes like Meteosat, Spot, Landsat and NOAA/AVHRR. This assumption does not exclude some evolutionary improvements in, for example, in-orbit performance. The ground segment will have shorter renewal cycles of technology to absorb better computing, telecommunication, software systems and user interface technologies.

The strategy and phasing of the procurement process will significantly influence the overall programme's financial profile and cost. The satellite deployment schedule, lifetime, overall funding and the use of new or existing technology are key parameters affecting global cost. For this reason, the technology should be chosen to keep the cost of the overall system low rather than to increase performance. Technology has to be mature before entering engineering and system development.

Replenishment of Sentinel-4 and -5 would follow the MTG and post-MetOp schedules if they are indeed carried by those satellites.

Sentinel-3 will provide ocean and land monitoring, similar to this image from Envisat's MERIS instrument, a dedicated ocean-colour sensor able to identify phytoplankton concentrations. On 6 June 2006 it found a plankton bloom (pale blue) stretching the length of Ireland in the Atlantic Ocean



An integrated network of receiving stations will ensure the operational supply of Sentinel data to users

Ground Segment and Operations

The ground segment will control and exploit the ESA Sentinels-1/2/3 satellites and manage, plan and monitor the overall GMES space component, including access to the other missions.

The Payload Data Ground Segment is distributed, reusing existing facilities, infrastructure and expertise. Furthermore, it will link and share the infrastructure already developed for national missions.

Sentinel operations and utilisation will have a higher degree of automation compared to, for example, ERS and Envisat, but near-realtime requirements and operational reliability will put higher demands on the development of the ground segment.

From 2008 onwards, pre-operational support of GMES services will start through coordinated and harmonised

EO data provision from national, Eumetsat and other third-party missions, all referred to as GMES Contributing Missions.

Routine operations cover all missions. These include mission planning, a distributed user service shared with all partners, coherent quality assessment and the monitoring and control of the end-to-end data provision for the entire GMES space element.

Socio-Economic Benefits of GMES

A consortium led by Price Waterhouse Cooper has analysed the potential socio-economic benefits of GMES over 2006–2030, following wide-ranging consultations with stakeholders and authorities in the policy sectors addressed by GMES.

The study demonstrated that GMES can lead to significant benefits in environment and security policies, because decision-making will be able to draw on better, more complete, consistent, timely and reliable information. Significant benefits were quantified in the following policy areas:

- Europe as a global partner (climate change adaptation, global environment protection, humanitarian response);
- preservation and management of natural resources (air quality, marine environment, forest ecosystem management, civil protection).

Significant benefits were also identified, but not allocated a monetary value, in the following domains:

- Europe as a global partner (climate change mitigation, development and aid);
- preservation and management of natural resources (urban and rural policy, agricultural policy, water quality, management of wetlands).

GMES strategic and political benefits were grouped as:

- *efficiencies in implementing existing policies.* These benefits could, in principle, be realised almost immediately. They represent a value of the order of EUR100 million per annum;
- *European policy formulation benefits.* Since they depend on future policy evolution, these benefits would accrue later, typically a decade hence. Price Waterhouse Cooper estimates the potential magnitude of these benefits to be at least ten times greater than the first category;
- *global action benefits.* Since they depend on new international policy agreements, these benefits would accrue later. The external dependencies and uncertainties in their realisation are greater. However, by virtue of their global scope, they hold the greatest potential benefits. These are estimated to be at least ten times greater than the previous categories.

The potential GMES benefits accumulated from 2006 to 2030 were estimated to be around 0.2% (about EUR80 000 million) of the EU's current annual gross domestic product.

The study highlighted the fact that the mere availability of information does not in itself produce benefit. The GMES benefits will materialise only when the information is used. Hence, during its implementation, major emphasis is being placed on integrating GMES information into future policy and decision-making processes within Europe.

Phased Funding Approach

Up to 2013

The funding required for the build-up of the GMES space component is being obtained in a phased fashion. ESA funds are complemented by EC funds.

Several funding steps are planned during the period 2006–2013. On ESA's side, the 2005 Ministerial Council provided EUR257 million for the first phase. This is expected to be complemented by EUR430 million in 2007 for Phase-2 and then, at the 2008 Ministerial Council, by the amount required to complete the build-up of the space component.

The EC foresees a total of EUR780 million through its 7th Framework Space Work Programme for 2007–2013. Future contributions will be necessary to cover the operational phase of GMES beyond 2013 and to complete the initial operational validation (IOV) of the current Sentinels (such as Sentinel-4/5, launched in 2017–2019). These figures are subject to negotiations with ESA Member States and the EC.

Long-term funding considerations

For the space infrastructure, the longer term funding sources have to move from research & development to infrastructure budget lines. The current share of the investment made via ESA Member States for the build-up of the GMES space component (the IOV) is expected to decrease, while the EC is expected to replace its R&D contributions increasingly through infrastructure budgets to support the operations (including recurrent spacecraft).

The goal should be to follow the example of meteorology, where ESA develops and finances (with a suitable contribution from Eumetsat) the prototypes based on the requirements defined by the users, who are responsible for funding recurrent units, operations and services.

Funding through ESA will focus on technology evolution and upgrades as well as the overall coordination of the space component.

The development of funding sources along these lines would allow GMES to become an operational system that provides critical information to support European policy.

Acknowledgements

The authors wish to thank the staff of the GMES Space Office, the EO Services & Exploitation Division and the Communications Department staff at ESRIN for their support in the compilation of this article and the provision of figures and diagrams.

Further information on GMES can be found at www.esa.int/gmes