→ EARTH OBSERVATION FOR GREEN GROWTH

An overview of European and Canadian Industrial Capability

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European Space Agency

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Background

The European Space Agency (ESA), Directorate of Earth Observation Programmes has more than 20 years' experience in executing activities that advance scientific research, develop applications and expand exploitation of Earth Observation (EO) information in both public and private sector user communities (for further information see www.esa.int/Our_Activities/Observing_the_Earth)

In the last 5 years, ESA has taken initiatives to raise awareness of the potential of EO-based information for improved planning, implementation and monitoring of activities and operations of International Financing Institutions (IFIs) / Multi-lateral Development Banks (MDBs) within the context of development assistance to reduce poverty and promote economic growth in low and middle-income countries.

Initial discussions began in 2008 with the World Bank, but have expanded to include the European Investment Bank (EIB), The UN International Fund for Agricultural Development (IFAD), the European Bank of Reconstruction and Development (EBRD), and recently the Asian Development Bank (ADB). The approach has been to identify on-going Bank projects (either in implementation or planning phases), work with the Bank staff to understand what types of geo-spatial information could bring benefit, and then to carry out small demonstrations with European specialist service providers (small companies) to produce and deliver EO-based information specifically in support of the selected projects.

To date, some 15 World Bank projects, 13 EIB projects and 8 UN-IFAD have (or are in the process) been supported. Interim progress reports are available for the World Bank and EIB activities, and a final report on the impact of EO within the World Bank projects is being finalised (for further details see www.worldbank.org/earth-observation).

This work has been carried out as part of a small ESA EO development programme called the Value Adding Element (VAE, see www.vae.esa.int). This programme aims to further strengthen the competitive position of the European and Canadian Value-Adding sector, both small companies and institutional suppliers of marketable EO services. All EO services in support to Bank projects were produced and delivered by specialised and experienced Value Adding companies in Europe selected by ESA through open competitive tender and under the management and technical oversight of ESA Directorate of EO Programmes. In addition, the European Association of Remote Sensing Companies (EARSC – the trade body representing the EO services industry) has been involved as a strategic partner with ESA in starting this initiative.

Based on these initial results, ESA and the World Bank have now agreed to pursue further the collaboration during the period 2013–15 with a view to 'mainstreaming' the use of EO information within the Bank activities. It is within this context of growing awareness within the IFI/MDB community, that this document has been drafted as a consolidated reference for the relevance of EO information to the international development environment.

Furthermore, the next few years will see Europe at the forefront of developing operational use of EO, through the ambitious, new European Earth Observation Programme; Copernicus (further details given later in this Introduction). This system will take Earth Observation from a research and development technology into becoming a long-term source for operational monitoring of the Earth's global environment (land, atmosphere, oceans, cryosphere), and open up further opportunities for the IFI/MDB community to make use of this new source of information.

Purpose

This document presents a summary of the main European EO-based information services available today with particular emphasis on their relevance to key development activities of International Financing Institutions (IFIs) / Multi-lateral Development Banks (MDBs). The aim is to help Bank staff understand broadly what kinds of information content are available, what are the accuracies/ limitations, what are the benefits/costs, and how this information could be used within their operational projects.

This document should be used by Bank staff within the framework of on-going cooperation between the European Space Agency (ESA), Earth Observation Programmes Directorate and a number of key IFIs/MDBs (i.e. World Bank, European Investment Bank, Asian Development Bank, European Bank for Re-Construction and Development, UN International Fund for Agricultural Development, plus others to follow). This document should serve as reference material to identify further opportunities for collaboration with ESA in order to mainstream EO-based information within Bank activities.

This document will evolve as the cooperation with the key IFIs/MDBs develops in time. This initial version has been produced to support a second phase of collaboration with the World Bank during 2013–2015, and (as such) contains many references to specific World Bank issues and initiatives. However, the material should still be of interest and relevant to the wider IFI/MDB community.

Scope/Content

This document focuses on European EO capabilities as Europe enters the operational phase of the new European Earth Observation Programme; Copernicus (further details given later in this Introduction).

These EO capabilities are divided into 3 groups as follows:

- **Basic EO Capabilities**
- **Customised Services examples**
- **EO Products/Data-sets currently available.**

All information presented has reached a sufficient level of technical maturity and validation such that it can be reliably produced and delivered, and it can be brought to the attention of IFI/MDB user communities with operational needs. Note that this document does NOT include information on the many and varied activities that ESA is conducting in the scientific research domain (i.e. still under development).

This document is not a comprehensive source of all EO capabilities. It is based largely on the ESA Earth Observation science, applications and exploitation development programmes and activities over the last 20 years, drawing together those elements and results that are most relevant for the international development environment. Further information on EO a broader overview of applications and complete description of EO missions see ESA-CEOS Earth Observation Handbook 2012 Special Edition for Rio+20 (www.eohandbook.com).

The three types of information (Basic EO capabilities, Customised Services examples, EO Products/ Data-sets) are presented in relation to the main thematic sectors in international development as follows:

- Agriculture & Rural Development
- Forestry
- Urban Development
- Disaster Risk Management
- Coastal Zone Management
- Marine Environment Management
- Water Resources Management
- Oil & Gas/Energy/Mineral Extraction
- Climate Change

This approach has the advantage that Bank staff specialised in one thematic area (e.g Agriculture & Rural Development) can quickly locate the main EO capabilities relevant to their specific domain. However, some EO capabilities are relevant to more than one single theme (e.g. Land Use / Land Cover Change is of interest to almost all terrestrial thematic sectors), and therefore Bank staff should focus on specific thematic sections where they will find the primary information, but are encouraged also to consult other sections of the document that may be of interest.

Basic EO Capabilities

The EO Services in this document are (mostly) as a result of a 10-year, 130 M€ ESA development programme (the GMES Services Element, see www.esa.int/Our_Activities/Observing_the_Earth/GMES/Services_overview
which is now completing and that has been developing information services to meet the requirements and needs of some 400+ European user organisations (mainly national Government Departments/ Agencies) in preparation of what Copernicus will soon deliver on a fully operational basis. These services have been developed together with many specialist service providers (companies) throughout Europe, collectively referred to as the European EO service industry (further details given later in this Introduction).

These consist of a set of 10 service portfolios as follows:

Each service portfolio consists of a number of individual information services with technical specifications for information content, accuracies, costs, etc. It is from these portfolios that the key information for some (not all) of the EO services presented in this document have been summarised.

For each basic EO capability described, this key information is given in a standard format/layout throughout the document.

- **Information content** A description of the main geo-information content supported with images/examples.
- **Resolution, Frequency and Availability:** Spatial resolution, temporal update possible, geographic availability, historical availability.
- **Accuracies and Constraints:** Comments on the information accuracy, geo-location accuracy, and any major constraints (e.g. cloud cover)
- **Benefits and Use:** Highlight of the main benefits, and description of how this information could be used within the context of international development.
- **Indicative Costs:** Rough order of magnitude for a 'unit' of service based on ESA development activities. NOTE: this is indicative only and is not to be considered as substituting commercial offers from individual service companies.
- **Future Prospects:** Brief description on the impact of Copernicus (considering mainly the ESA Sentinel missions) on the future availability / performances of this service.

Example of land motion monitoring product providing millimeter precision subsidence measurements at individual building level in Venice; background image: Image © 2009 Digital Globe, Google Earth. Credits: TRE Italy.

Customised Services Examples

The Customised Services examples are all using the basic EO capabilities described above, but are as a result of smaller ESA development activities targeted to the specific needs of individual users (both public and private sector) for specific applications. These examples give insight into how the basic EO capabilities can be tailored and applied to address particular issues (for additional examples and further information see www.vae.esa.int).

EO Products/Datasets

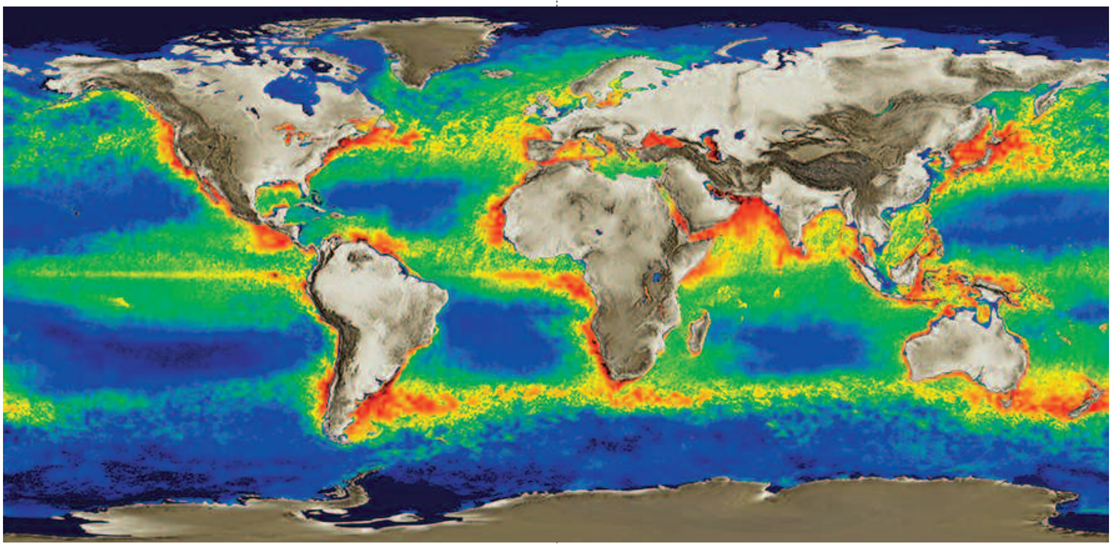
The EO Products/Datasets are (largely) as a result of smaller ESA development activities and produced in support of UN International Environmental treaties and conventions. They consist of global information products, with each product containing a specific type of information. All products are named with the 'Glob' pre-fix to indicate their global nature. Examples include GlobColour (water quality), GlobCover (land use classification), GlobEmission, GlobGlacier, Glob-Volcano, GlobSnow, GlobWetlands, GlobWave. All 'Glob' are available free of charge from ESA (see http://due.esrin.esa.int/projects.php).

Overview of Current EO Missions used in Support of Bank Projects

These EO services produced and delivered to date have made use of many existing EO missions; including those of ESA, European national and non-European missions to complement the range of observation parameters.

ESA's own Earth Observing satellites (the ERS-1&2 and ENVISAT missions) were widely used in the production. In addition, ESA provided access to satellites operated by organisations (public and private) other than ESA (both European and non-

Chlorophyll map of the Earth. © ESA



European) via the 'Third Party Missions' (TPM) scheme operated by ESA (for further details see www.esa.int/Our_Activities/Observing_the_Earth/Third_Party_Missions_overview). The ESA TPM scheme currently includes over 50 instruments on more than 30 missions serving a wide range of users globally, including Africa, Asia, and South America. These are often the missions to which ESA contributes financially (usually through sharing of Ground Segment facilities or operations) or for which ESA assumes a data distribution responsibility to a European scientific user community. The most prominent examples of ESA TPM used in the Bank projects to date are SPOT1-4, Landsat, Kompsat, ALOS, and Ikonos. This data can be provided by ESA (within limited quantities) at cost of reproduction.

Finally, a number of EO missions data was used which is not covered by the ESA TPM scheme, and which needs to be commercially procured by the EO service providers. These are mainly missions of high or very high spatial resolution and include RapidEye, SPOT5, SPOT DEM, CosmoSkyMed, TerraSAR-X, Radarsat, GeoEye, Quickbird and WorldView.

The European Earth Observation Programme: Copernicus

As the most ambitious Earth Observation programme to date, Copernicus (previously named Global Monitoring of the Environment & Security – GMES) is the next-generation European EO system for monitoring the Earth. It will provide, accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security.

The Copernicus programme is coordinated and managed by the European Commission. The development of the observation infrastructure is performed under the aegis of the European Space Agency for the space component and of the European Environment Agency and the Member States for the in situ component (for further details, see www.copernicus.eu).

The Copernicus Space Component, which is placed under ESA's responsibility, consists of two different types of satellite missions: the Contributing Missions, which are operated by national, European or international organisations and already provide a wealth of data for Copernicus services, and the Sentinels, which are currently being developed for the specific needs of the Copernicus programme.

The Sentinels will provide a unique set of observations. They will consist of five different families, the first of which is scheduled to launch in 2013:

- **Sentinel-1** will provide all-weather, day and night radar imagery for land and ocean services. The first Sentinel-1 satellite is planned for launch in 2013.
- **Sentinel-2** will provide high-resolution optical imagery for land services. It will provide for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2 will also deliver information for emergency services. The first Sentinel-2 satellite is planned for launch in 2014.
- **Sentinel-3** will provide high-accuracy optical, radar and altimetry data for marine and land services. It will measure variables such as sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The first Sentinel-3 satellite is planned for launch in 2014 with routine operations shared between ESA and EUMETSAT.
- **Sentinel-4** will provide data for atmospheric composition monitoring. Sentinel-4 will be a payload embarked on Meteosat Third Generation (MTG), which is scheduled to be launched around 2020 and which will be operated by EUMETSAT.
- **Sentinel-5** will also be dedicated to atmospheric composition monitoring. Sentinel-5 will be a payload embarked on a MetOp Second Generation satellite, also known as Post-EPS, to be launched in 2020 timeframe and which will also be operated by EUMETSAT.

Pléiades image of Hong Kong acquired on 16 February 2012. © CNES 2012. Distribution Astrium Services / Spot Image S.A., France, all rights reserved.

A satellite mission called Sentinel-5 Precursor is also planned to launch in 2015 in order to reduce data gaps between Envisat and Sentinel-5.

For further information on the Sentinel missions, see:
www.esa.int/Our_Activities/Observing_the_Earth/Sentinels_overview

Contributing Missions are missions from ESA, their Member States, EUMETSAT and other European and international third party mission operators that make some of their data available for Copernicus. There are around 30 existing or planned Contributing Missions. They fall into the following categories: Synthetic Aperture Radar (SAR), optical sensors, altimetry systems, radiometers and spectrometers. Even when the Sentinels are operational, the Contribution Missions will continue to be essential, delivering complementary data to ensure that a whole range of observational requirements is satisfied.

Copernicus Services

Following the initial development undertaken by ESA within the GMES Services Element programme (described above), the services are currently in transfer to the framework of the EC. In addition, some of the services developed by ESA have been transferred into sustainable operations by EU Agencies, including oil-spill monitoring for European waters with the European Maritime Safety Agency (EMSA).

Copernicus services address 6 main thematic areas:

- Land Monitoring
- Marine Monitoring
- Atmosphere Monitoring
- Emergency Management
- Security
- Climate Change

The services have reached different degrees of maturity. Some are already operational (land monitoring and emergency management) while others are still in a pre-operational mode (atmosphere monitoring and marine monitoring) or in a development phase (climate change monitoring and services for security applications). All are provided free of charge to European Government users (for further information on each of these services, see:
http://copernicus.eu/pages-principales/services).

The European EO Services Industry

Europe has a highly-skilled, dynamic and vibrant EO Services sector consisting of many small, specialised companies and a few institutional suppliers. The companies have developed mostly from the research sector (e.g. spin-off from Universities) and have established a growing volume sustainable revenue based on the sales of many diverse EO information services which is currently of the order of USD 1 Billion/year.

In particular, Europe has pioneered the development of EO information services based on radar data through the ESA missions of ERS-1, ERS-2 and ENVISAT, including precision land motion monitoring, ice mapping, oil-spill monitoring and ship detection. The initial ESA missions have been followed by European national radar missions operating at very high resolution (e.g. TerraSAR-X in Germany and CosmoSkyMed in Italy) and opening new opportunities for improved information services.

In addition, Europe has a strong heritage in Optical EO missions through the SPOT series, and is building on this heritage with a new generation of European National missions operating very high resolution (e.g. Pleiades in France).

The European EO services industry is represented by a trade organization: the European Association of Remote Sensing Companies – EARSC. For further information on the activities of the industry (including a directory of available services and suppliers), see: www.earsc.org.

→ AGRICULTURE & RURAL DEVELOPMENT

Related World Bank Programmes and Iinitiatives

World Bank related organisations, programmes and activities to which the following section is pertinent: Consultative Group on International Agricultural Research (CGIAR), Forum for Agricultural Risk Management in Development (FARMD) initiative, BioCarbon Fund, Climate-Smart Agriculture, Global Index Insurance Facility (GIIF), Global Agriculture and Food Security Programme (GAFSP) and Global Food Price Crisis Response Programme (GFRP).

The World Bank work program in Agriculture and Rural Development is based on the *World Development Report 2008: Agriculture for Development and synthetised within the Action Plans.*

Addressing Development Challenges

Main World Bank related topics against which EO capabilities are available:

- Raising agricultural productivity: reducing the gap between yields at farm level and overall national/regional values, improving water management, increasing adoption of improved technology and strengthening agricultural innovation systems, improving watershed management for rain-fed agriculture, developing standards on foreign investment in large-scale agricultural production
- Linking farmers to market and strengthen value addition: investing in infrastructure
- Reducing risk and vulnerability: innovative insurance products
- Facilitating agricultural entry and exit and rural nonfarm income: supporting regional clustering of economic activity, improving rangeland, watershed, forestry and fisheries management, linking improved agricultural practices to carbon markets
- Enhancing environmental services and sustainability

The Potential of EO Information Services

Agriculture has been one of the first areas where historically Earth Observation has played a role. A wide range of EO services are currently available/possible and the full framework of future satellite missions promises to tackle some of the major limitations affecting current EO agricultural monitoring services by improving sites revisit time and spatial resolution.

As a mirror of the wide variety of agricultural landscapes, several types of earth observation sensors are exploited, covering a wide range of spatial and temporal scales. There are ongoing initiatives aimed at sharing, at global level, operational methods and new research findings and develop best practices (e.g. GEO-GLAM).

BASIC EO CAPABILITIES

CUSTOMISED SERVICE

EO PRODUCTS/DATASETS

→ CROP LOCATION MAPPING

Information Content

This service provides crop mapping at country level, exploiting the temporal variation in vegetation greenness and specific changes of agricultural land during the growing season (field clearance, sowing, growth, senescence, harvesting, etc.) to derive the two cultivated land and non-cultivated land classes. This service has a global coverage and applies to large agricultural fields (> 25ha) with low crop diversity.

Resolution, Frequency and Availability

The primary data sources are multi-temporal fAPAR[1] (fraction of Absorbed Photosynthetically Active Radiation) medium resolution (250–300m) optical images, leading to a map scale of 1:500,000 / 1:1,000,000. Wide areas (whole country, continent) are typically covered once every ten days during the entire growing season, to produce one map per growing season. Data (MERIS/MODIS and SPOT VGT have been main data sources to date) are available in current and past archives and future continuity is expected using data from PROBA V and Sentinel-3 satellites.

Accuracies and Constraints

The product average thematic accuracy is about 75% for crop vs. no-crop classes. The processing method for this service may use, as additional input, a few 'training' high resolution maps for calibration. Accuracy of this auxiliary data might be a constraint to the overall product thematic accuracy.

Benefits and Use

Timeliness in production makes this product very useful for an early assessment of crop location changes with respect to previous years in support of early warning for food security purposes. In addition, its spatial and temporal consistency over wide areas proves the service useful as an indicator of favorable conditions for crops at country level and across different countries. In many countries (especially in Africa), information on the annually cultivated land is otherwise unavailable.

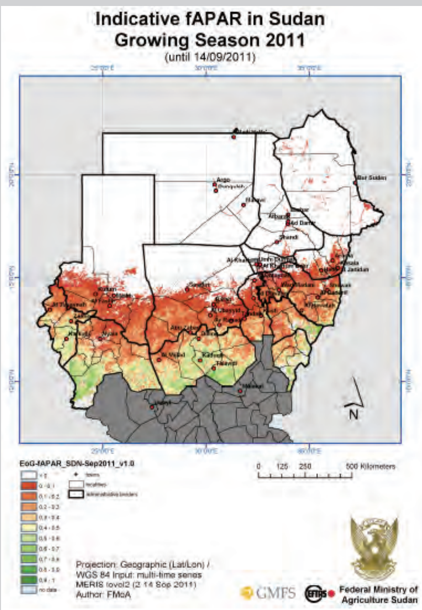
Indicative Costs

The service cost is between 100 and 120 kEuro per country (processing cost, the EO data being mostly available for free).

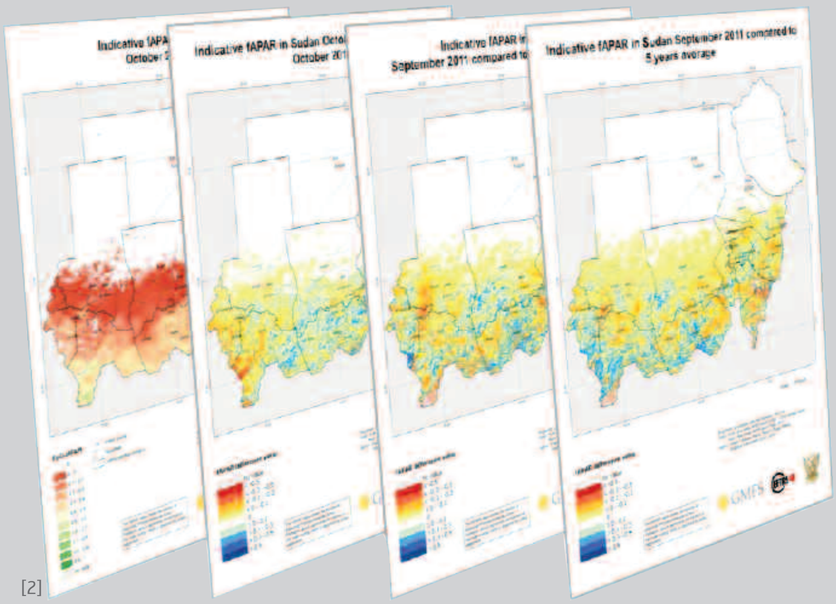
The Contribution of the Sentinel Missions

While continuity of this particular service is guaranteed in the future by forthcoming sensors, with similar characteristics to the currently used ones (e.g. Ocean and Land Colour Instrument (OLCI) aboard Sentinel-3 and PROBA V), future availability of new sensors providing more frequent global coverage at higher spatial resolution (e.g. Sentinel-2) promises an whole-new, advanced version of this service with much improved spatial resolution.

[1] The solar radiation reaching the surface on the 0.4-0.7 µm spectral region is known as the Photosynthetically Active Radiation (PAR). fAPAR refers to the fraction of PAR that is absorbed by a vegetation canopy. It is a primary variable controlling the photosynthetic activity of plants, and therefore constitutes an indicator of the presence and productivity of agricultural, forest and natural ecosystems, as well as of the intensity of the terrestrial carbon sink.
fAPAR estimates result from the analysis of multiple measurements with the help of a radiation transfer model in plant canopies using EO observations as constraints.



[1] The Indicative fAPAR Extent of vegetation Growth provides an inter-seasonal map of growth activities. It reflects the fraction of the solar energy which is absorbed by the green vegetation within each pixel. Credits: Federal Ministry of Agriculture Sudan, EFTAS



[2] Advanced fAPAR products comparing recent fAPAR with previous season (change map) and with a five year average (five year average map) processed by FMoAI. Credits: Federal Ministry of Agriculture Sudan, EFTAS

Information Content

The service provides information on acreages covered by main land use classes in irrigated arable land per administrative and/or hydrological units. Products generation is based on the inversion of crop phenological models with statistics of biophysical parameters computed from medium resolution optical EO data.
It is able to discriminate acreage for various groups of irrigated annual crops (e.g. summer herbaceous crops, fodder, rice, winter herbaceous crops).

Benefits and Use

Generally aimed to serve added value services such as water quality or water abstraction by irrigation, it is a basic piece of information to feed databases used for multi-purposes applications.

Resolution, Frequency and Availability

Based on 1 to 3 medium resolution optical data (MERIS) per month, a yearly update is operationally feasible on large areas. Minimum Mapping Unit should be at least 2 km².

Accuracies and Constraints

Cross-checking with statistical information demonstrated a very good fit, up to 90% of correct thematic accuracy in Europe.
Meteorological data (daily minimum and maximum temperatures measured on weather stations of the area, and geographic coordinates of weather stations) and agronomic data of local crops for each class of arable land use are needed for additional inputs.
The non-arable areas (artificial, forest and semi-natural, wetlands, water, agricultural non arable) are masked out on the map product. The mask is derived from a most recent high-resolution land use map (tentatively, maximum 5 years old, depending on the dynamic of land cover change over arable land).

Indicative Costs

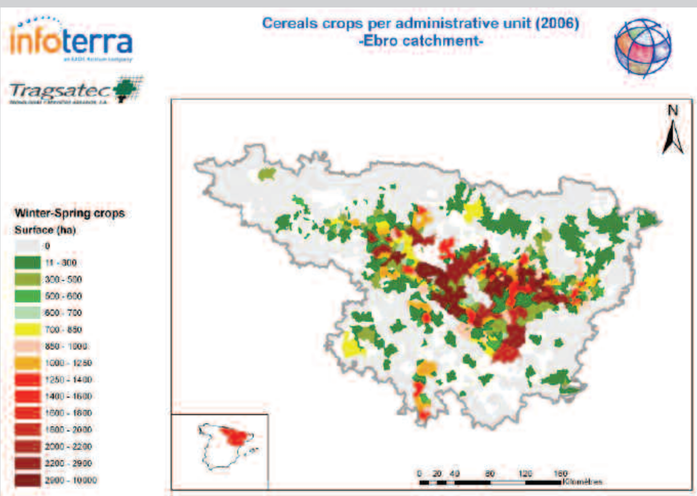
The service cost range is 0.5-1 Euro/km².

The Contribution of the Sentinel Missions

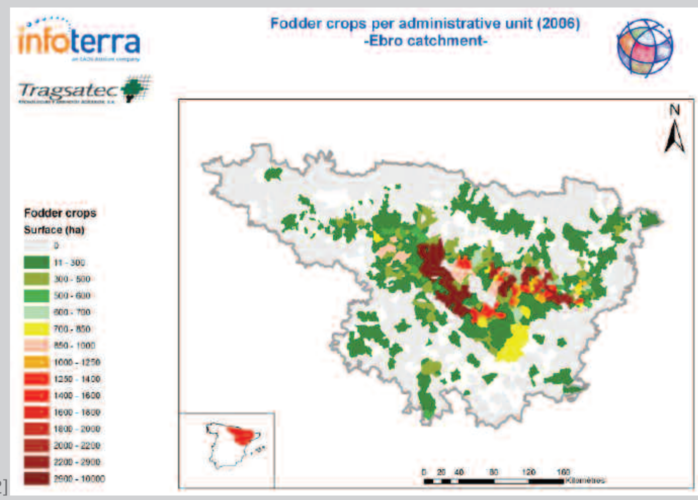
While continuity of this particular service is guaranteed in the future by forthcoming sensors, with similar characteristics to the currently used ones (e.g. Ocean and Land Colour Instrument (OLCI) aboard Sentinel-3 and PROBA V), future availability of new sensors providing more frequent global coverage at higher spatial resolution (e.g. Sentinel-2) promises an whole-new, advanced version of this service with much improved spatial resolution.

[1] Illustration of irrigation surface on Ebro basin: irrigated cereals crops map. (left). Credits: Tragsatec and Infoterra.

[2] Illustration of irrigation surface on Ebro basin: fodder crops map. Credits: Tragsatec and Infoterra.



[1]



[2]

→ CROP TYPE AND ACREAGE MAPPING

Information Content

The service provides maps of cultivated areas from local to national level (medium size crop fields, 1 – 25 ha) by mid or end of the crop season. Complementary features, derived from independent optical (spectral behavior) and SAR (temporal behavior) data sources, are used to delineate the cultivated area by crop type and emergence dates of the different cultures.

Multi-temporal acquisitions from optical sources allow mapping of different crop types, although these can hardly be distinguished when they have similar spectral and temporal characteristics (only crop clusters can be identified in those cases).

Imaging radar data are a very effective source to monitor main crops (e.g. rice) extent in tropical areas, characterised by very high cloud coverage. High frequency of observation and Near Real Time acquisitions make it possible to observe crop acreage and emergence dates.

Resolution, Frequency and Availability

The service makes use of multi-temporal optical and/or radar 10–20m resolution datasets and production is carried out on a yearly basis. (Data sources mostly include Landsat TM/ETM+, SPOT-4/5, ENVISAT ASAR-AP and ALOS PALSAR FM.)

Accuracies and Constraints

Cloud cover is a strong limitation to the optical component of classifier. Consequently, crop type and acreage from optical data cannot be mapped in rain fed agricultural fields where crop growth takes place during the rainy season. Thematic accuracy for the optical product is around 70–80%, depending on the completeness of the validation dataset (often ground survey points might be in areas of difficult access). Radar based product (rice) has a higher thematic accuracy, around 80–90%.

Benefits and Use

Crop inventory is essential for policy, food security programmes and other agro-environmental health investigations as well as an input to tools to support subsidies, certification systems, climate-smart agricultural practices. Often the basic crop type and extent is one of the input variables to production estimates and yield analysis models.

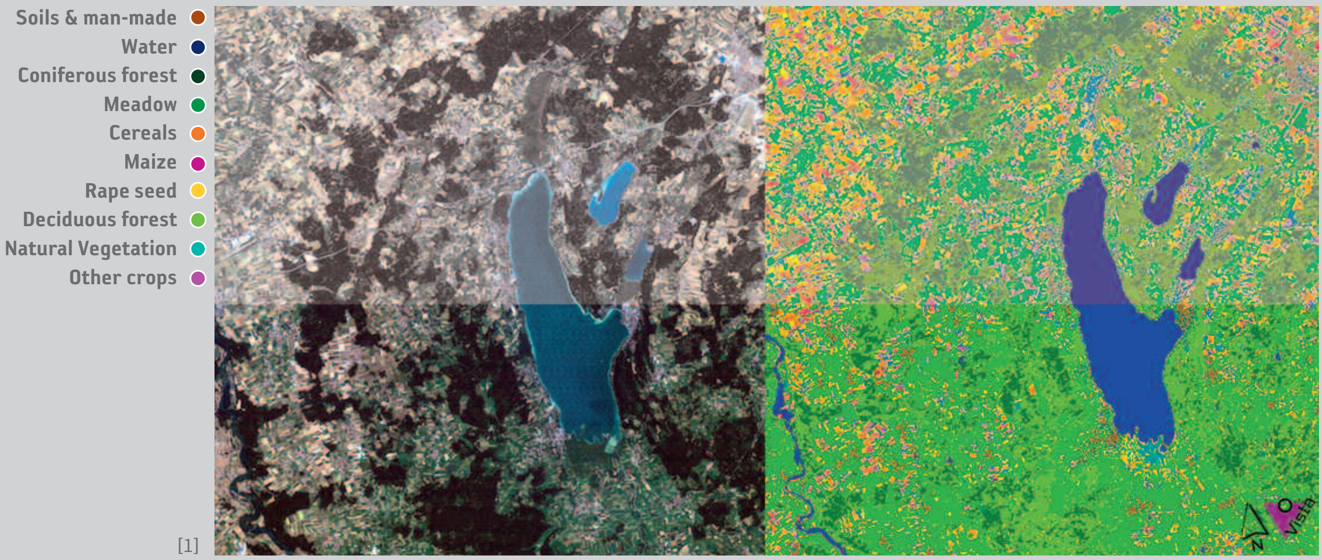
Though optical data have very strong limitations in rain fed agricultural areas, where crop growth takes place during the rainy season, and cannot be used to directly map crop types and acreage in such conditions, the data can provide an extremely efficient and cost effective support prior to and after field surveys, screening (by visual interpretation of data) the number of points to be surveyed and by validating survey results.

Indicative Costs

Service cost is between 1.5 and 2.5 Euro/km².

The Contribution of the Sentinel Missions

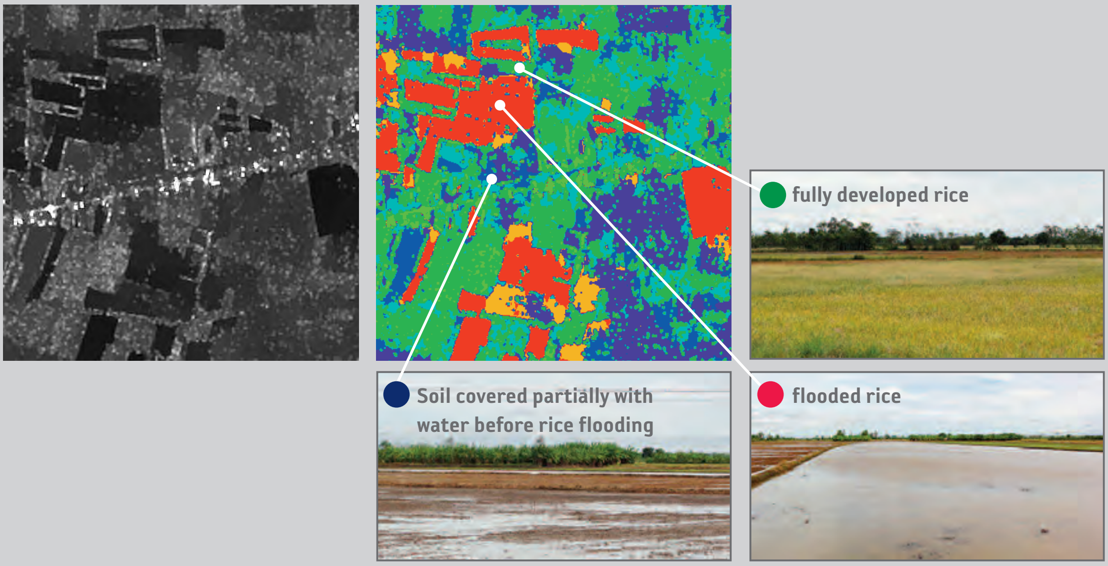
Forthcoming Sentinels-1,2 and other VHR optical and SAR satellites will provide continuity and further enhance this service both in terms of spatial resolution and of temporal revisit frequency.



[1]

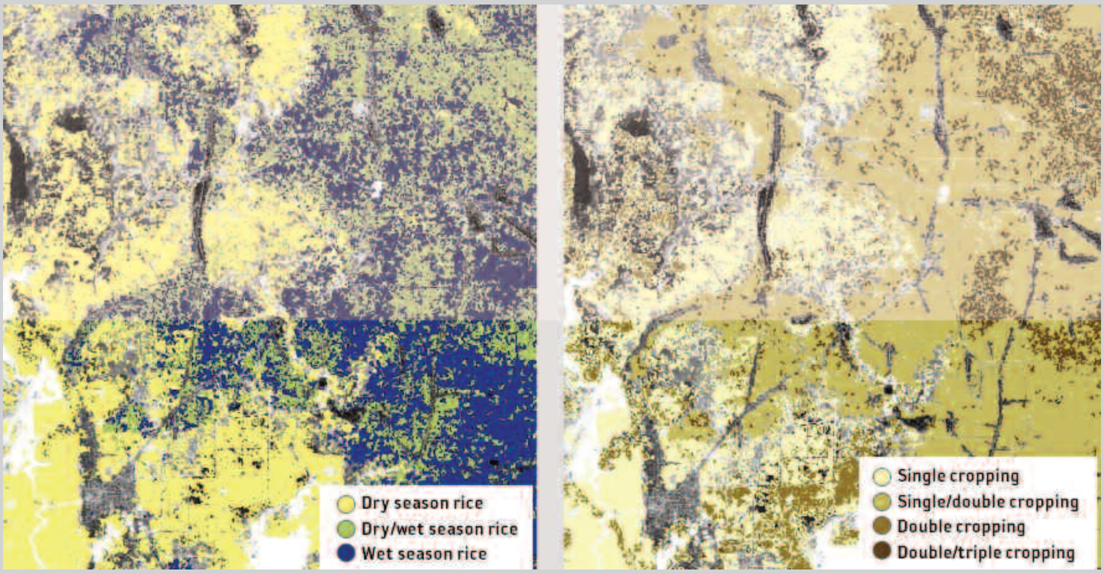
[1] Crop types/clusters from optical high resolution EO data (30m satellite image in false colours on the left with large-scale agricultural classification on the right). Credits: VISTA.

[2]



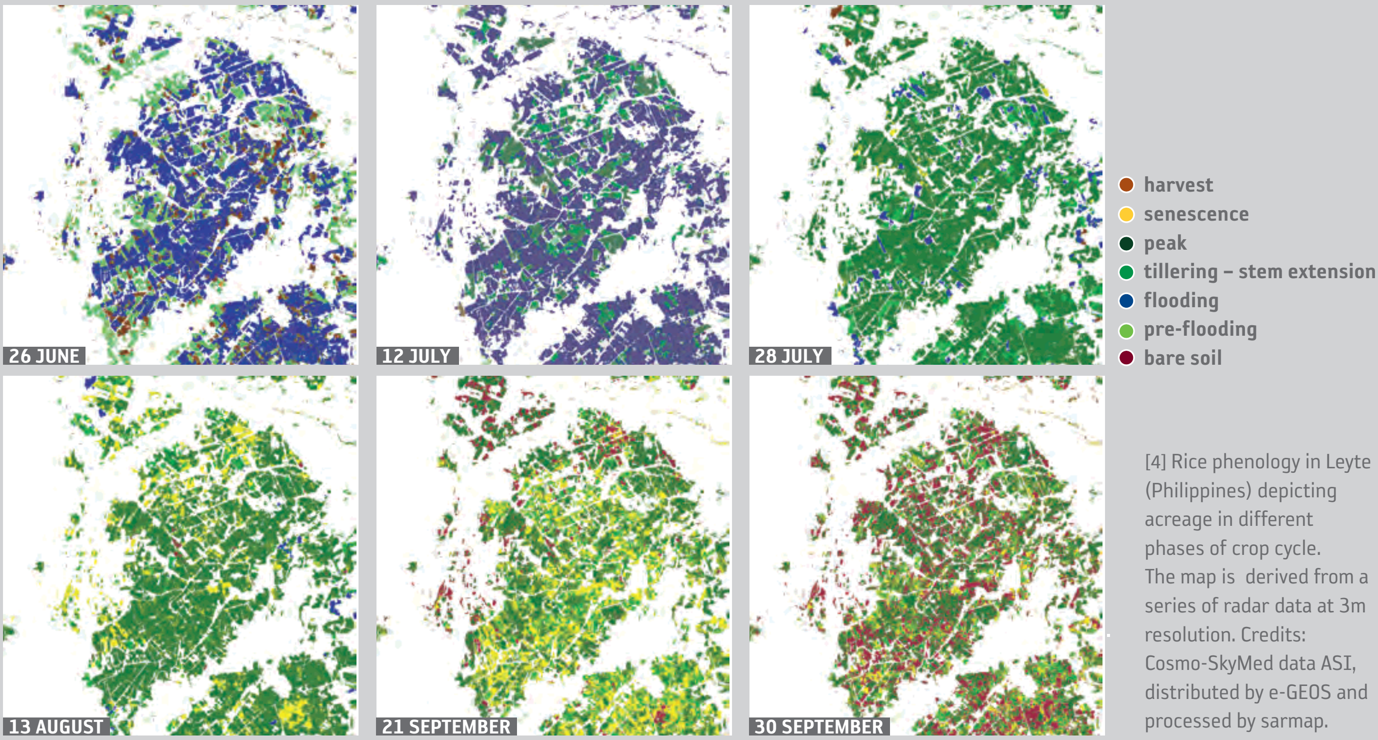
[2] Rice growth from a single radar dataset at 3 m resolution in Soc Tang Province (Vietnam), 6 September 2012. Credits: Cosmo-SkyMed data ASI, distributed by e-GEOS and processed by sarmap.

[3]



[3] Rice cropping system map (to the left) and crop cycle map (to the right) generated using multi-temporal ASAR imagery, differentiating major cropping systems and crop cycles in the Feb – Oct 2011 period, in the Cambodian part of the Lower Mekong River basin. Credits: Geoville.

[4]



[4] Rice phenology in Leyte (Philippines) depicting acreage in different phases of crop cycle. The map is derived from a series of radar data at 3m resolution. Credits: Cosmo-SkyMed data ASI, distributed by e-GEOS and processed by sarmap.

Information Content

The service provides vegetation health early warning. It makes use of a set of qualitative indicators and biophysical variables providing information on the status of vegetation with high temporal frequency over wide areas (country/ continental level) at medium spatial resolution. The indicators described represent the state-of-the-art, exploiting most advanced algorithms and taking advantage of the performance and characteristics of recent optical satellite sensors.

1. *VPI (Vegetation Productivity Indicator)*
   Its purpose is to identify drought affected areas. The VPI is used to qualitatively identify areas with potentially low agricultural productivity as compared to what can be expected based on the historical range. It's derived from a statistical analysis and gives probability ranges (categories) and can be calculated on the basis of either NDVI, fAPAR or DMP (see description below).

2. *NDVI (Normalized Difference Vegetation Index)*
   NDVI measures the relative presence (or absence) of healthy, green vegetation, exploiting spectral features in optical data. Over the course of a growing season, we first see a steady increase in the 'vegetation health and density' values as the young, green vegetation grows (the growth makes the surface appear more and more green). This increase reaches a maximum value just before it drops suddenly at harvest time or when the plants die naturally.

3. *fAPAR (fraction of Absorbed Photosynthetically Active Radiation)*
   The solar radiation reaching the surface in the 0.4-0.7 µm spectral region is known as the Photosynthetically Active Radiation (PAR). fAPAR refers to the fraction of PAR that is absorbed by a vegetation canopy: it is a primary variable controlling the photosynthetic activity of plants, and therefore constitutes an indicator of the presence and productivity of agricultural, forest and natural ecosystems, as well as of the intensity of the terrestrial carbon sink.

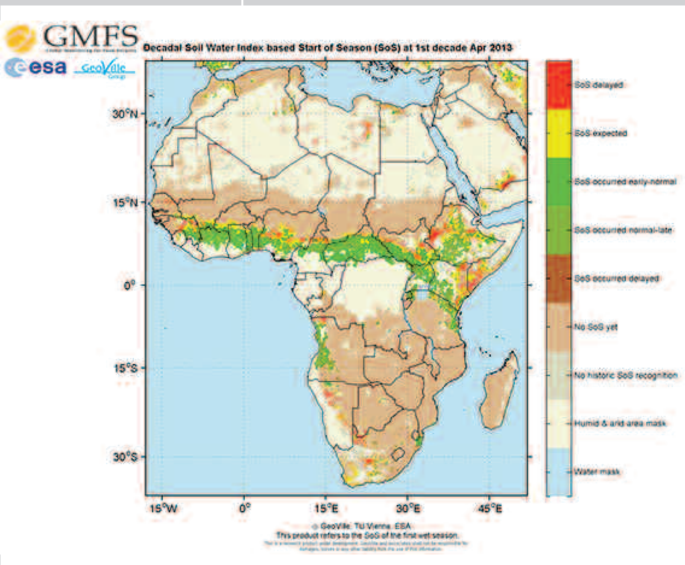
fAPAR estimates result from the analysis of multiple measurements with the help of a radiation transfer model in plant canopies using remote sensing observations as constraints.
In parallel to the optical indicators, the service provides soil moisture indicators for the start of the growing season (showing water availability to vegetation) as well as for monitoring drought and/or wet spells. These indicators are completely independent from the optical ones and as such work as a cross-validation source.
Information on the start date and progress of the growing season can be derived from these indicators, as well as derived products such as early estimates of crop yields and drought indices.

Resolution, Frequency and Availability

Optical indicators calculation is based on mostly medium resolution (300-500 metre to 1 km) multispectral data, with a very high temporal frequency (usually 10-days composites are used for a country/continental area map). Soil moisture indicators are based on a long time series of soil moisture measurements (1991-present) derived from the ERS scatterometer and ASCAT sensors.

Accuracies and Constraints

The service provides early warning indications which are timely, frequent and spatially consistent over wide areas. Validation is obtained by



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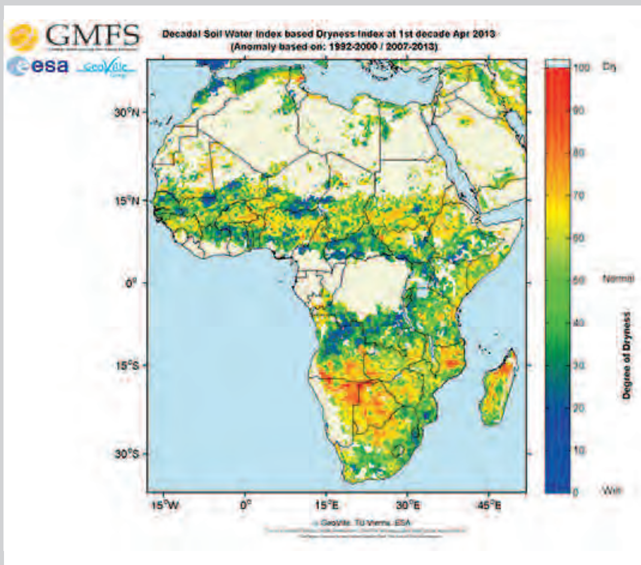


[2]

Sample Near Real Time products derived from the Soil Water Index (SWI) (soil moisture content in the first meter of the soil profile in relative units (0 – 100%) ranging between wilting level and field capacity). Both products are based on a time series of a decade up until April 2013.
[1] Start of Season - to steer agricultural practices and hint at potential production shortages.

[2] Dryness Index (relative to past values) - to support water management and drought monitoring - values higher than 50% indicate increasingly dryer conditions. Credits: Geoville, TU Vienna.

comparing the results from the two completely independent data sources (optical and radar scatterometer).
For early crop yield forecasts, one significant constraint is the reliability of historical yield values which are used to calibrate the service.

Benefits and Use

This service can support early warning for food security in relation to the effects of climate variability and change, or extreme events on agriculture productivity to adjust food-aid measures; it can qualitatively indicate crop areas affected by damages related to water stress/drought.

Indicative Costs

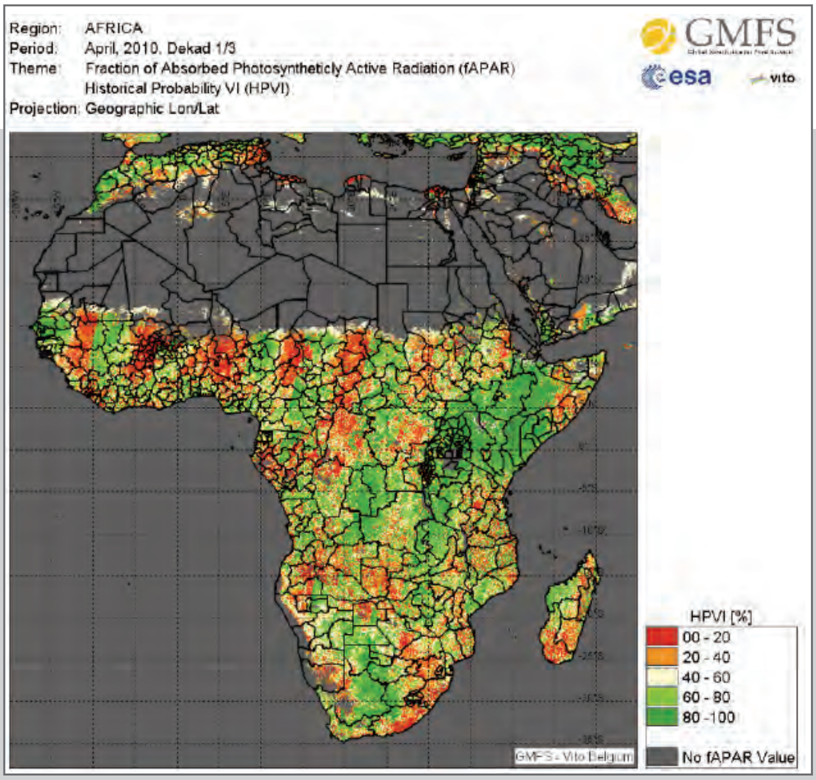
Annual continental coverage with a suite of early warning indicators, at 10-day update frequency ranges between 200 and 300 kEuro.

The Contribution of the Sentinel Missions

Forthcoming PROBA V, Sentinel-3 and meteorological satellites will provide continuity to the optical component of the service.
Data availability for soil moisture will also improve in the future. As a replacement for ASCAT, a Scatterometer Mission (SCA) on board the Post-EUMETSAT Polar System (Post-EPS) is planned, with a spatial resolution improved by a factor of 2. Furthermore, the Soil Moisture and Ocean Salinity (SMOS) satellite on orbit allows the establishment of more high-quality validation sites in different environments.

[3] Sample VPI based on fAPAR. The VPI percentages indicate the probability of getting a lower or higher fAPARvalue based on a historical analysis of the fAPAR values. Credits: VITO Belgium.

[4] Example of drought hazard mapping in Lao based on Standardized Vegetation Index SDVI measurements. Credit: Geoville.



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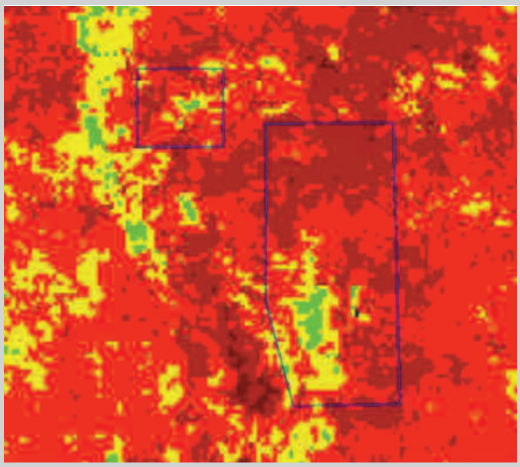


→ YIELD ASSESSMENT

The service provides operational crop yield estimates. When these values are multiplied by the cultivated area, this provides the crop production estimate at national/regional level. This service uses medium resolution optical satellite data.

Agricultural yields are traditionally estimated using Crop Growth Models or Agro-Meteorological Models (AMM) with different levels of complexity, using several data sources. Today, these crop growth models can be improved and also simplified by using EO data that can be input to various stages of the modeling process (parameters, input or driving variable).

Yield values for each crop are provided at sub-national level and then aggregated at country level, either post-harvest or a forecast during the growing season.

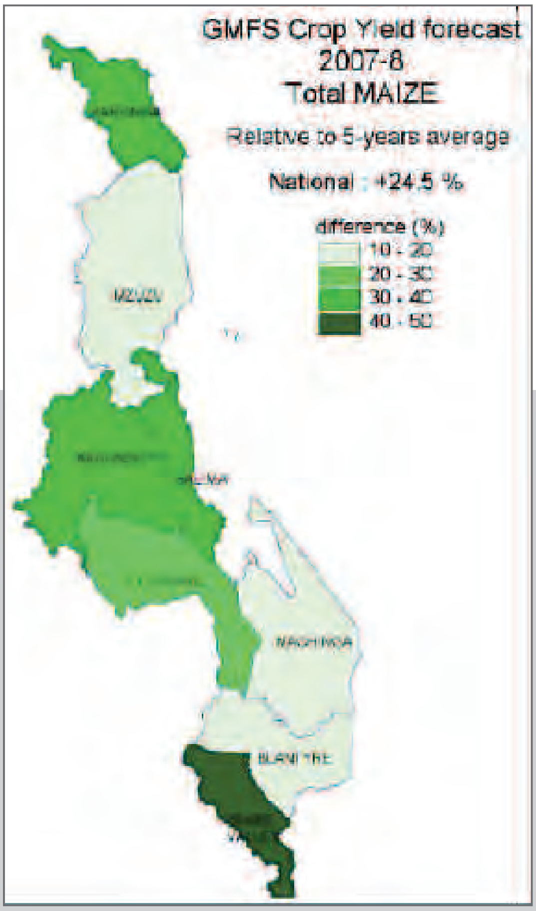
The model makes use of several input variables (e.g. phenological, meteorological), not all derived from EO sources. Availability of local data might differ among countries. Similarly to the Early Warning service, another constraint is associated, in some countries, with reliability of historical yield values provided by public authorities in charge of collecting such data. Such yield values are in fact used to calibrate the service.

Transparent and homogeneous data on agricultural production and estimates of agricultural output growth at country level are essential inputs to National Agricultural Statistics and Crop and Food Security Assessment Missions by the international donor community. Timely forecasted yield values are one of the key variables in early warning for food security. Moreover, they can assist agricultural subsidies control.

Yield forecast cost for 2–3 main crops over a 100.000 km² area ranges between 70 and 100 kEuro.

Country	WHEAT (t/ha)				
	2011	2012	Avg 5yrs	%12/11	%12/5yrs
BY	3,53	3,40	3,44	-3,8	-1,4
DZ	1,47	1,42	1,39	-3,1	+2,5
MA	1,95	1,31	1,55	-32,8	-15,5
TN	1,57	2,00	1,58	+27,1	+26,1
TR	2,69	2,38	2,41	-11,7	-1,6
UA	3,22	2,71	3,00	-15,8	-9,6
	BARLEY (t/ha)				
	2011	2012	Avg 5yrs	%12/11	%12/5yrs
BY	3,29	3,14	3,23	-4,4	-2,7
DZ	1,23	1,26	1,26	+2,7	-0,1
MA	1,15	0,90	1,04	-21,5	-13,6
TN	1,94	2,07	1,33	+6,8	+56,4
TR	2,65	2,56	2,33	-3,2	+10,2
UA	2,34	2,18	2,23	-7,0	-2,5
	GRAIN MAIZE (t/ha)				
	2011	2012	Avg 5yrs	%12/11	%12/5yrs
BY	5,37	5,83	4,89	+8,5	+19,3
DZ	-	-	-	-	-
MA	-	-	-	-	-
TN	-	-	-	-	-
TR	7,48	7,08	7,19	-5,4	-1,6
UA	4,85	4,64	4,60	-4,4	+0,9

[1]



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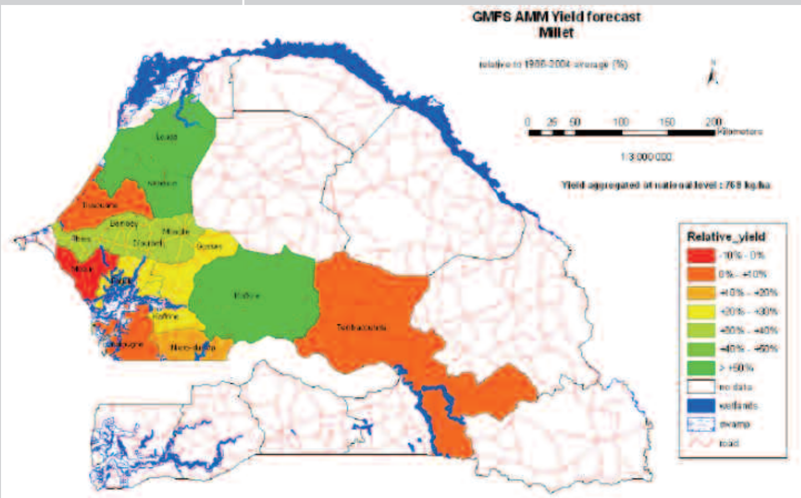


[2]

[1] Extract of MARS bulletin Vol20 No9 (http://mars.jrc.ec.europa.eu/mars/Bulletins-Publications) © European Union 2012. A pan-European crop monitoring and yield forecasting service based on satellite observations.

[2] Relative yield forecast for millet in Senegal. Credits: University of Liège.

[3] Maize yield forecast in Malawi. Credits: University of Liège.

This operational service provides management advice, for each plot at key stages of crop growth, as well as recommendations, and yield maps based on crop status maps. If used in synergy with a GPS system, an automatic adjustment of fertilizers /pesticides quantity at sub-plot level can be obtained.

Using high/very-high resolution satellite data, timely monitoring and effective management of crops at sub-field level can be achieved throughout the growing season. EO data help identifying inadequate irrigation or cultivation practices, assessing and optimizing agricultural treatments (e.g. use of fertilizers).

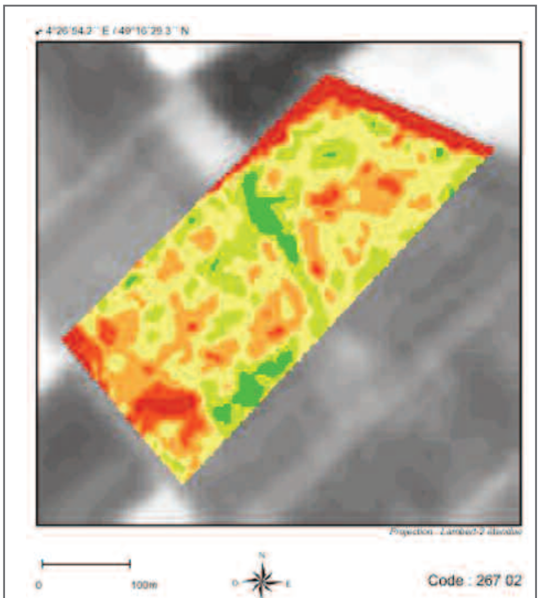
Products are available within less than a week from EO data acquisition, with sub-plot resolution, at planned critical points of the growing season.

In situ data are needed as additional inputs (such as crop variety, date of sowing, depth and type of soil, type of irrigation system). The service requires repeated (to cope with cloud coverage risk) programmed satellite acquisitions over specific areas, coinciding with important growth stages.

The service supports proper use of intensive agricultural systems, preventing damage to the field/farm (less fertile and more fragile soil) and to surrounding water resources (water pollution due to inputs – fertilizers, herbicides, pesticides – exceeding requirements) and land (health problems among the local population).

The service cost ranges between 10 and 15 Euro/ha.

Forthcoming and other VHR optical satellites will provide continuity and further enhance this service both in terms of spatial resolution and of temporal revisit frequency.



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Carte de préconisation

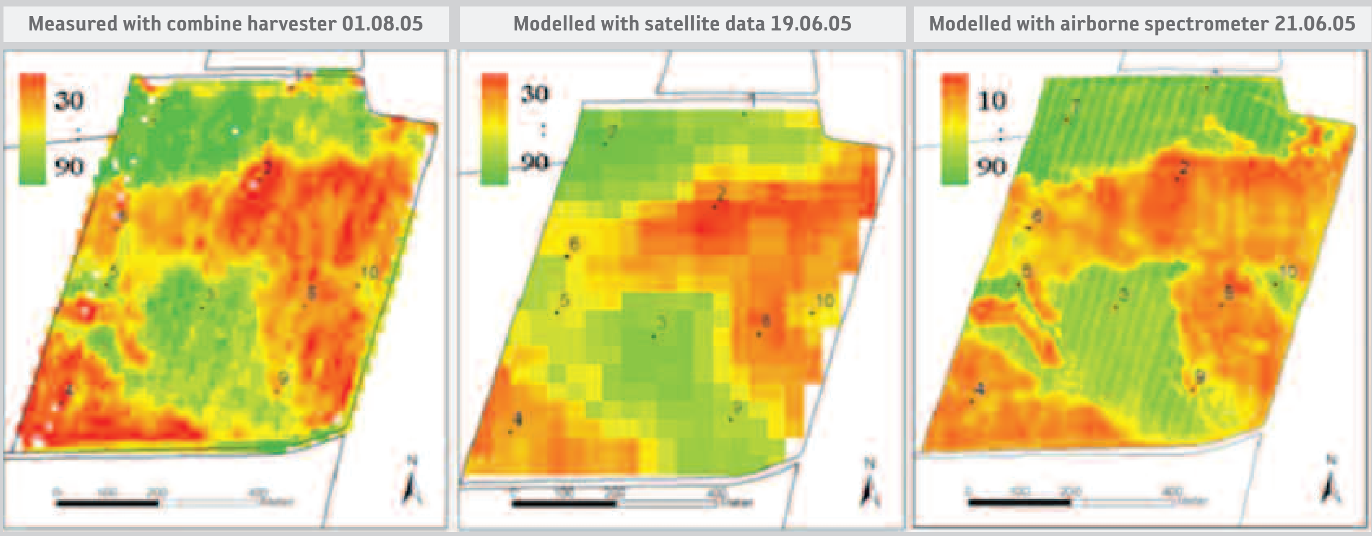
Interprétation au 13/05/2002

(date du vol)

Dose		% surface	% surface cumulée
(dark green)	< 30U	4.3	4.3
(green)	40U	17.9	22.2
(yellow)	50U	38.0	60.3
(orange)	60U	23.6	83.9
(red)	70U	6.1	90.0
(dark red)	> 80U	10.0	100.0

[1] Fertilizer use within a crop field. Credits: EADS/Astrium (Farmstar service)

[2] Yield estimation for winter wheat six weeks before harvest using airborne and satellite data in comparison to the yield map as measured with a combine harvester. Credits: VISTA.



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→ WATER ABSTRACTION BY IRRIGATION MONITORING

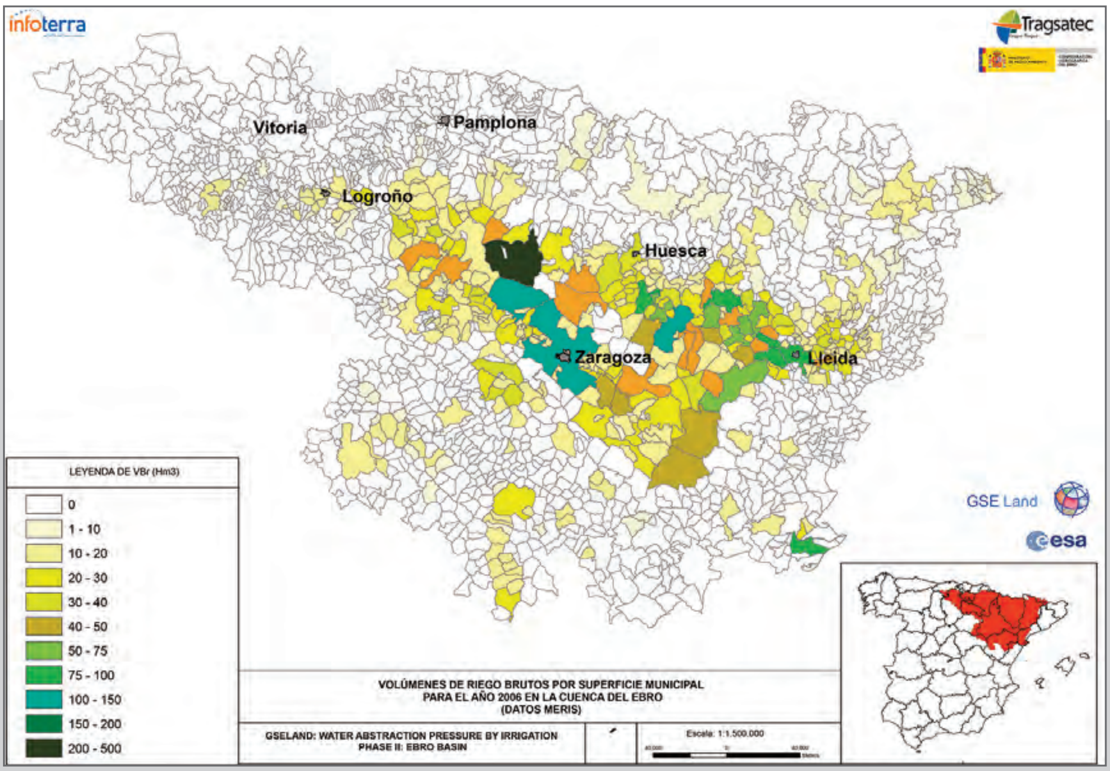
The service provides, per spatial unit of analysis (pixel or irrigation district), water height monitoring for irrigated crops per unit of time (irrigation season or month). In large irrigated areas where ground measurements are not available, the actual evapotranspiration is a good estimate of water consumption by irrigated crops. This provides an indication of the amount of water used by the crops irrelevant of its source (public irrigation networks, private wells, rain), and takes into account the local conditions (meteorological, water availability, plant phenology, plant stress, etc.).

Using a time series of satellite observations during the irrigation season, the seasonal evapotranspiration can be estimated. This represents the seasonal water use by the crops. With further geographic analysis, spatial statistics are derived to provide valuable information in tabular or map form to water managers.

The volume of water requested by the crops for |irrigation per unit of time (week, month, year) can then be obtained by multiplying the height of water by the irrigated crops area (as described above – see Irrigated crops acreage mapping).

The service outputs are made available at the end of the irrigation season.

The service offers to water catchments authorities and water suppliers (irrigation, hydro-electricity) a monitoring tool which provides means for a more efficient management of their water resources. This better management benefits users by supporting climate change adaptation measures (e.g. irrigation infrastructure upgrading) as well as assessment, monitoring and management of the reduction of water available to agriculture due to escalating demands for industrial, urban, and environmental uses.



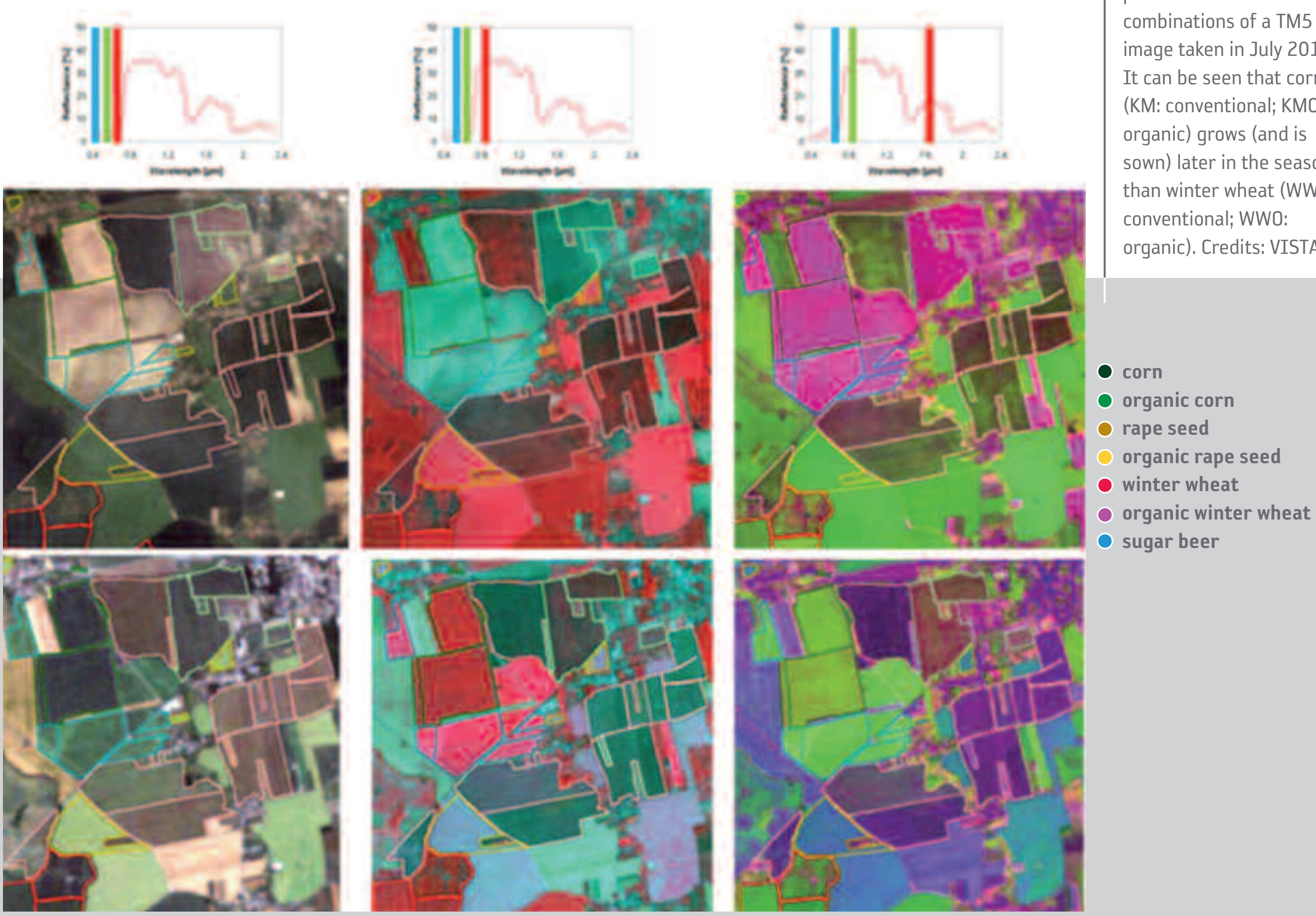
[1]

[1] Water volumes requested by irrigation by single municipalities in the Ebro basin (Spain) in 2006. Credits: Tragsatec.

Use of high to very high resolution multispectral, hyperspectral EO data has proven helpful in identifying a set of indicators characterising organic versus traditional crops: nitrogen content, yield, spatial heterogeneity, early ripening, presence of catch crops, crop rotation and detection and characterization of tractor traces in fields.

Monitoring organic crops along their development stages might be particularly relevant for certification purposes in countries where certain amounts of yield are certified for export before harvest and organic farmers might be tempted to 'fill up' any gaps in their own production due, for instance, to hail damage, with conventional crops.

Real-time yield estimation via EO can serve as a flag for these yield-influencing events by calculating a range for the possible yield, thus raising awareness to areas, where estimated and previously certified yield do not match the actual output.



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[1] Corn and winter wheat fields. Several band combinations of a Landsat TM5 image of the target fields in Germany. The upper row presents the band combinations of a TM5 image taken in June 2010. The lower row presents the same band combinations of a TM5 image taken in July 2010. It can be seen that corn (KM: conventional; KMO: organic) grows (and is sown) later in the season than winter wheat (WW: conventional; WWO: organic). Credits: VISTA

→ LAND DEGRADATION

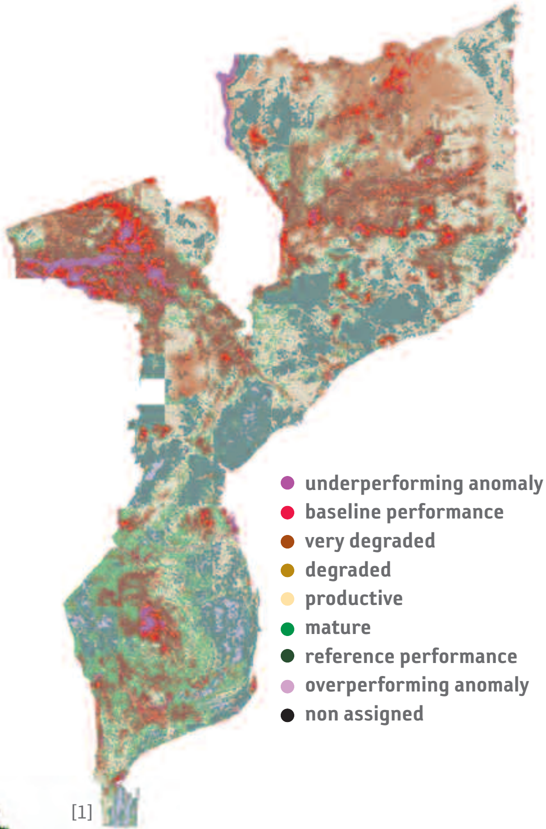
EO data provide synoptic, continuous and homogeneous views to monitor land degradation: from mapping land degradation drivers such as for instance land use and land use change, to assessing actual land degradation status, to identifying areas with higher susceptibility and land degradation. The service makes use of different resolution data in order to map land use and its changes at different scales to connect the regional dimension with national and local processes.

Land degradation conditions can be measured by a change in net primary productivity (NPP), whose EO proxies are vegetation indexes proportional to vegetation density, like the Normalized Difference Vegetation Index (NDVI). A Land Degradation Index can be obtained from a ratio of the NPP proxy (NDVI) to climate data (temperatures and precipitation) by exploiting a model (e.g. 2dRUE – Rain Use Efficiency).

Finally, identification of areas more prone to land degradation (Indicator of susceptibility to land degradation) takes into account soil degradation, land cover changes and climate dynamics over time.

[1] The Indicator of Susceptibility to Desertification (ISD) in the semiarid region of Brazil has shown that the areas susceptible to (or already within) desertification processes have seen a decrease in vegetation quality. This is due to an increase of agricultural activities and to more severe droughts. Credits: IST (Portugal), DesertWatch project team

[2] Land Degradation Index in Mozambique. Analysis from 1998 to 2006 detected 42% of land is degraded and 19% is undergoing active degradation (particularly in the provinces of Manica, Nampula, Sofala and Zambezia). Open deciduous shrublands are considered to be endangered while deciduous woodlands could be in the initial desertification stage. Credits: EEZA (Spain), DesertWatch project team.



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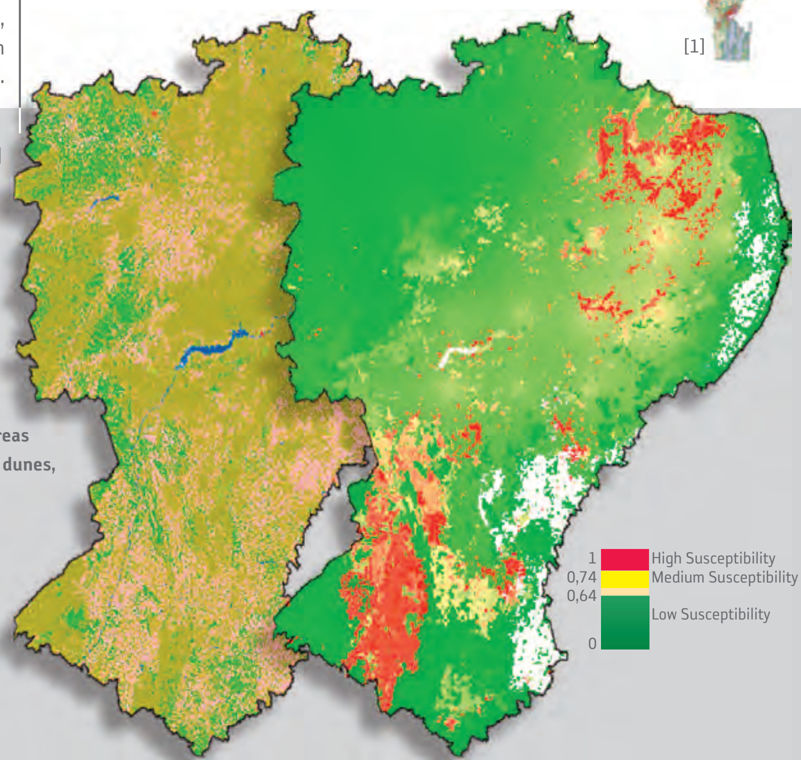
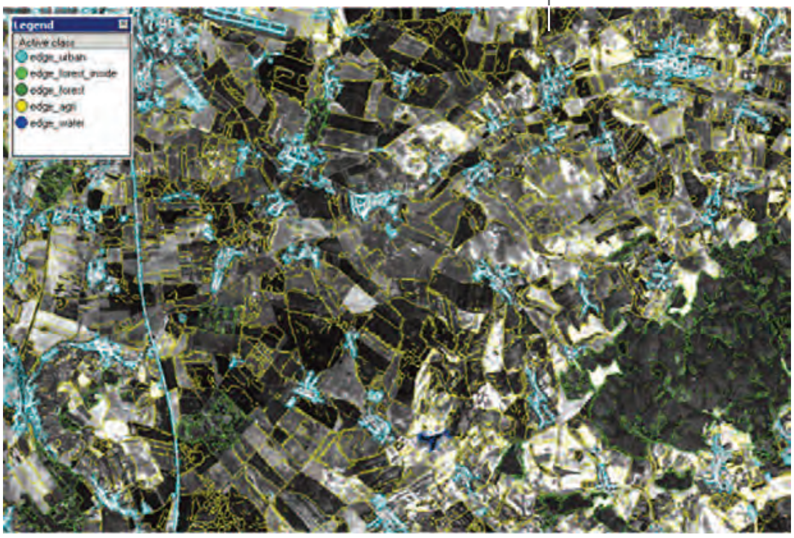


Agricultural productivity improvement can certainly leave an environmental footprint and impact on biodiversity. Biodiversity, in terms of species and habitats richness, is crucial to ecosystem productivity today and also in the future when it will more and more act as an insurance policy against changing climatic and other conditions. Maintaining biodiversity and ecosystem services can therefore be seen as a hedge to offset exposure to negative future developments and so underpin economic opportunities and societal cohesion.

Several EO derived products (at different spatial scales, from regional to local) can jointly provide indication of an area biodiversity trends and act as effective tools for proper land use planning:

- land cover and its changes
- landscape fragmentation by identification and classification of small linear features (either connectors, interfaces and habitats or barriers). This is currently being investigated together with the European Environment Agency (EEA) and they now plan to integrate this linear feature and habitat heterogeneity delineation capability into their ecosystem mapping and assessment (EU biodiversity strategy to 2020) as a proxy indicator of ecosystem quality.
- indicators of forest fragmentation and other characteristics (e.g. distance between forest patches).

[1] Example of small linear features (edges) highlighting fragmentation of land cover classes (different colour edges correspond to different land cover classes). It looks immediately clear how what appears as an homogeneous area within a land cover map is actually characterised by landscape infrastructures and fragmentation. Credits: Geoville



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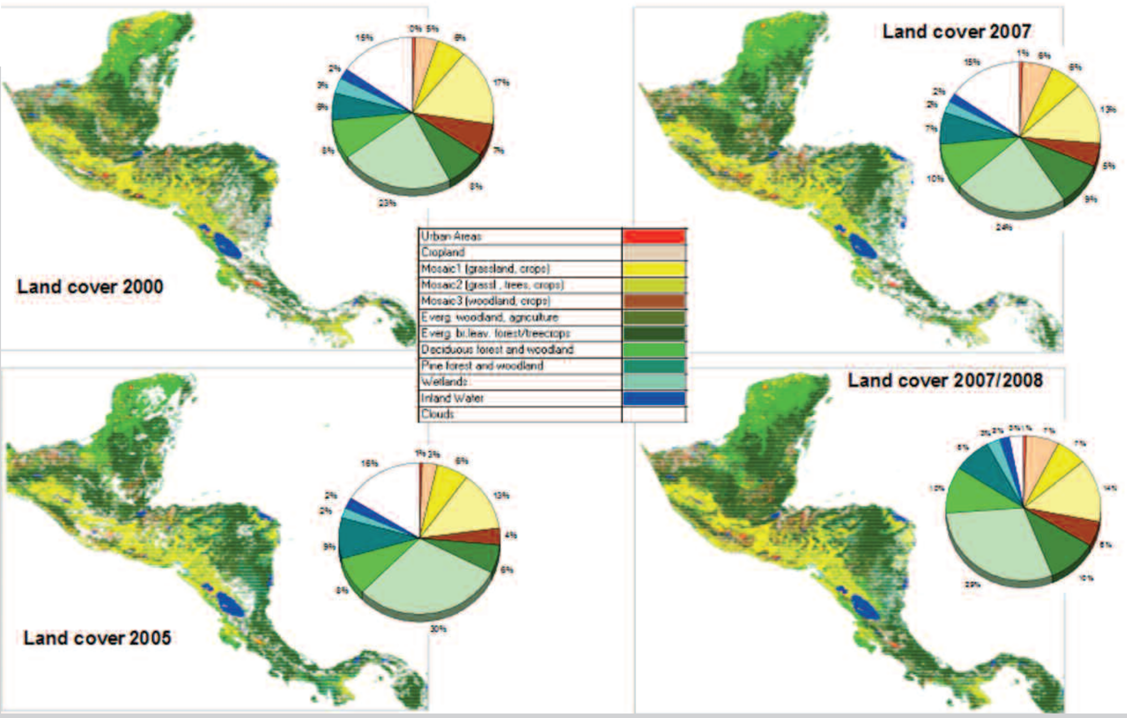


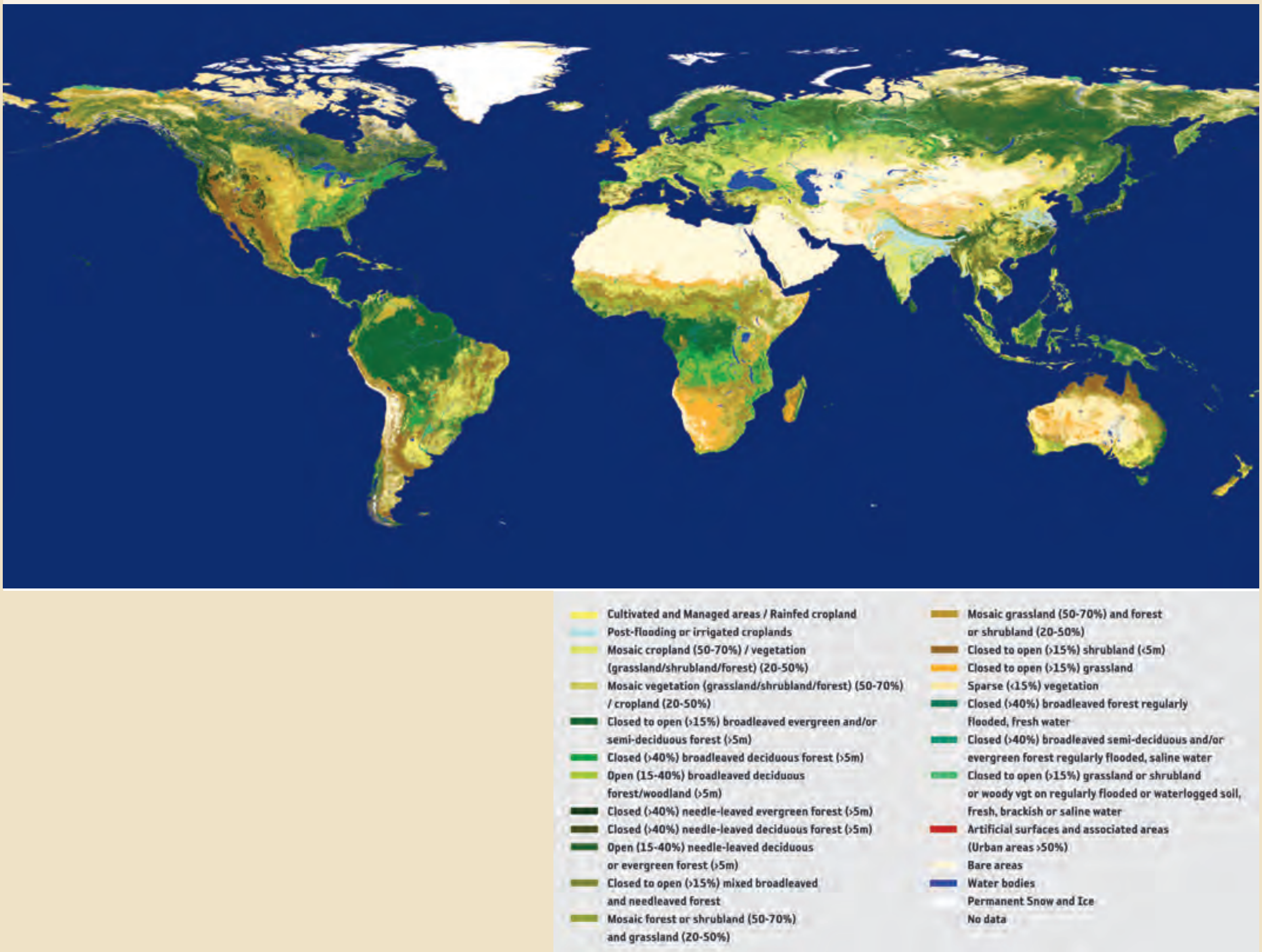
[2]

[2] Regional land cover maps in the Mesoamerican Biological Corridor for the years between 2000 and 2007/2008 based on MERIS (MODIS). Analysis of the land cover changes reveal a strong anthropogenic influence, with growth of urban areas, cropland and pine forest/woodlands. On the other hand, the change assessment shows a decline of wetlands and increase natural wood-lands and grasslands. Credits: Geoville

GLOBCOVER

Globcover provides global extent land cover maps covering two periods: December 2004 - June 2006 and January - December 2009. It is is an ESA initiative which began in 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. Globcover uses input observations from the 300m MERIS sensor on board the ENVISAT satellite mission.

Illustration of Globcover.
Credits: ESA 2010 and Université Catholique de Louvain;
source: http://due.esrin.esa.int/globcover



→ FORESTRY

Related World Bank Programmes and Initiatives

World Bank related organisations, programmes and activities to which the following section is pertinent: Forest Carbon Partnership Facility (FCPF) , Forest Investment Programme (FIP), Collaborative Partnership on Forests, Global Environment Facility Sustainable Forest Management (GEF-SFM), The Programme on Forests-PROFOR.

Addressing Development Challenges

Main World Bank related topics against which EO capabilities are available:

- Loss and depletion of forests; forest cover mapping & support assessment of deforestation, forest degradation and forest carbon tracking in emission reductions programmes
- Destruction of forest habitats and the loss of livelihood opportunities
- Support forest accreditation & certification to address the undermining of economic development opportunities that result from poor forest sector governance
- Integrating Forests into Sustainable Economic Development (Ecosystems service assessment and biodiversity assessment)
- Forest resource management; support to forest stock growth estimation
- Forest Law Enforcement and Governance

The Potential of EO Information Services

ESA has been working with forest mapping from space since the beginning of the satellite monitoring era in the early eighties. The ESA forest activities have ranged from R&D activities using new techniques and new sensors to large scale activities where the aim has been to set standards for and provide operational forest monitoring based on established techniques. The monitoring services and products include carbon stock information, forest disturbance data and standard products on land use/land cover as well as forest type mapping.

EO applications for forest managements are therefore among the most developed EO practices and provide many inputs to sustainable forest managements including ecosystems valuation, certification practices and natural resource mapping.

BASIC EO CAPABILITIES

CUSTOMISED SERVICE

EO PRODUCTS/DATASETS

Information content

In line with the launch of better satellite sensors and improvement in analysis methods the production of Land Use/Land Cover maps derived from satellite images has become a standard service of most EO companies. The maps typically provide information of basic forest types, major agricultural surface types, conservation areas, settlements, infrastructure, primary roads, bare soil, water bodies, rivers, wetlands following standard classification schemes according to CORINE or FAO LCCS.

Using the availability of satellite archive data Land Cover Change maps track and quantify developments in land use/land cover over time and can among other things be useful for M&E activities in international development projects.

Resolution, Frequency and Availability

Typically the maps reflect changes from one year to another and are usually provided with a resolution (spatial accuracy) of 10–30 metres. In tropical rain forest areas frequent cloud cover can be an issue for the production of the maps but may be mitigated by combing radar and optical satellite images.

Accuracies and Constraints

The accuracy of the maps are related to the annual/seasonal variability on ground as well as the possibility to use ground data to validate and update the map contents. The geometric accuracy is less than 1 pixel which in the case of land cover is on the order of 10-20 m and typically accuracies of 80–90% are reached for the classifications.

Benefits and Use

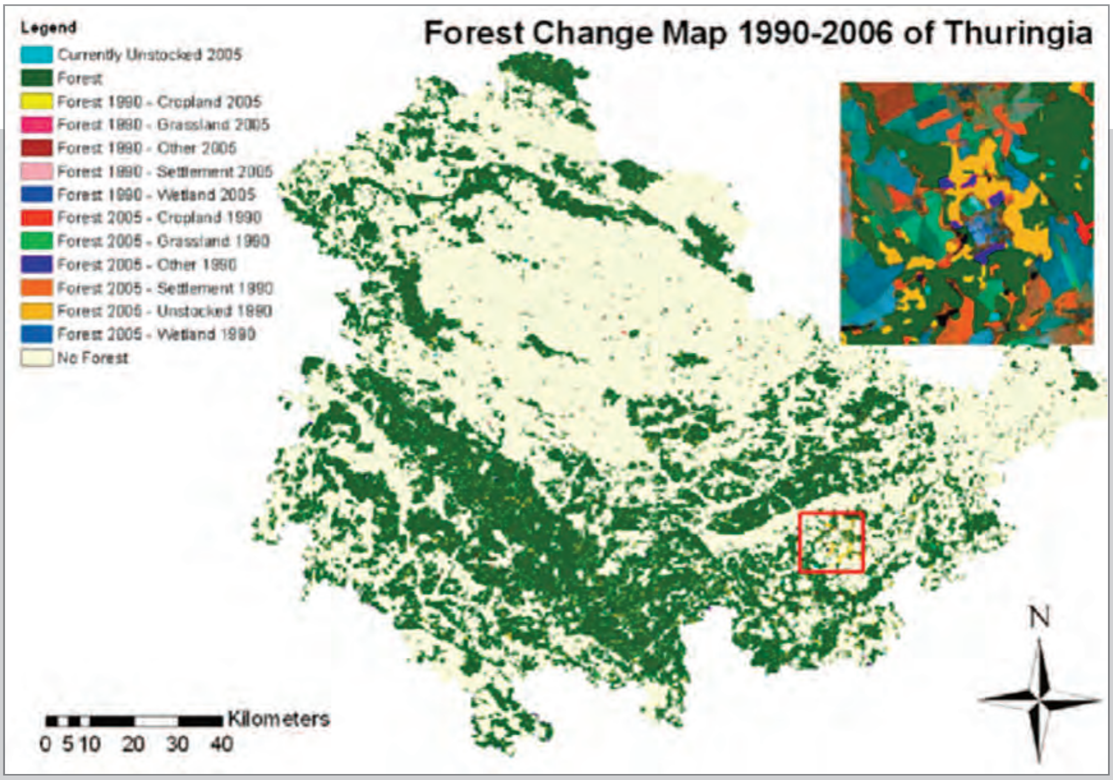
For forestry the land cover maps provide a visual overview of the area of interest. However, since the statistical information on the land cover can be extracted, they can also assist in more economic assessments of land use and change. The change detection maps can be used to track forestry logging activities and detect violations against regulations as well as natural changes caused by fires or storms.

Indicative Costs

Assuming a size of approx. 100 000 km2 the cost for commercial EO data procured for these kind of maps is about 1,5 Euro/km² which will become cheaper/free with the launch of new ESA satellites (Sentinel 2). The cost for the service production is 2 - 3 Euro/km2 for the land use maps and about 1 Euro/km2 for the land cover change maps. The prices vary from service provider to service provider and largely depends on specific needs, available in-situ data and number of thematic classes.

The Contribution of the Sentinel Missions

The Sentinels will provide high-resolution optical and radar images globally with a very high frequency (day to weeks). This will allow to produce Land Use/Land Cover/ Land Cover Change maps with high frequency, high thematic accuracy, high precision (down to 10m) at a lower cost due to the foreseen free data price.



Land Use/Land Cover and change maps from Thuringia, Germany of GSE FM (http://www.gmes-forest.info/). CREDITS: GAF AG

Information Content

Forest Type maps are in depth examination of the forests, subdividing forest inventories into different forest classes. For well-known & managed forests typically 2–4 volume classes within deciduous and coniferous forests can be distinguished. For tropical forest typically the classes are customised to the area of interest by distinguishing e.g. broadleaved forest, bamboo, palm forest, mixed forest or forest plantations on a case by case basis.

Resolution, Frequency and Availability

Maps are typically produced locally or regionally on a 3 to 5 year basis with a resolution (spatial accuracy) of 10–30 meters. In tropical rain forest areas frequent cloud cover can be an issue for the production of the maps but may be mitigated by combing radar and optical satellite images.

Accuracies and Constraints

The accuracy of the maps are related to the topography of the forests, the biodiversity of the forest as well as the possibility to use ground data to validate and update the map contents. The geometric accuracy is less than 1 pixel which in the case of forest type maps is on the order of 10–30 m and typically accuracies of 80–90% are reached for the classifications.

Benefits and Use

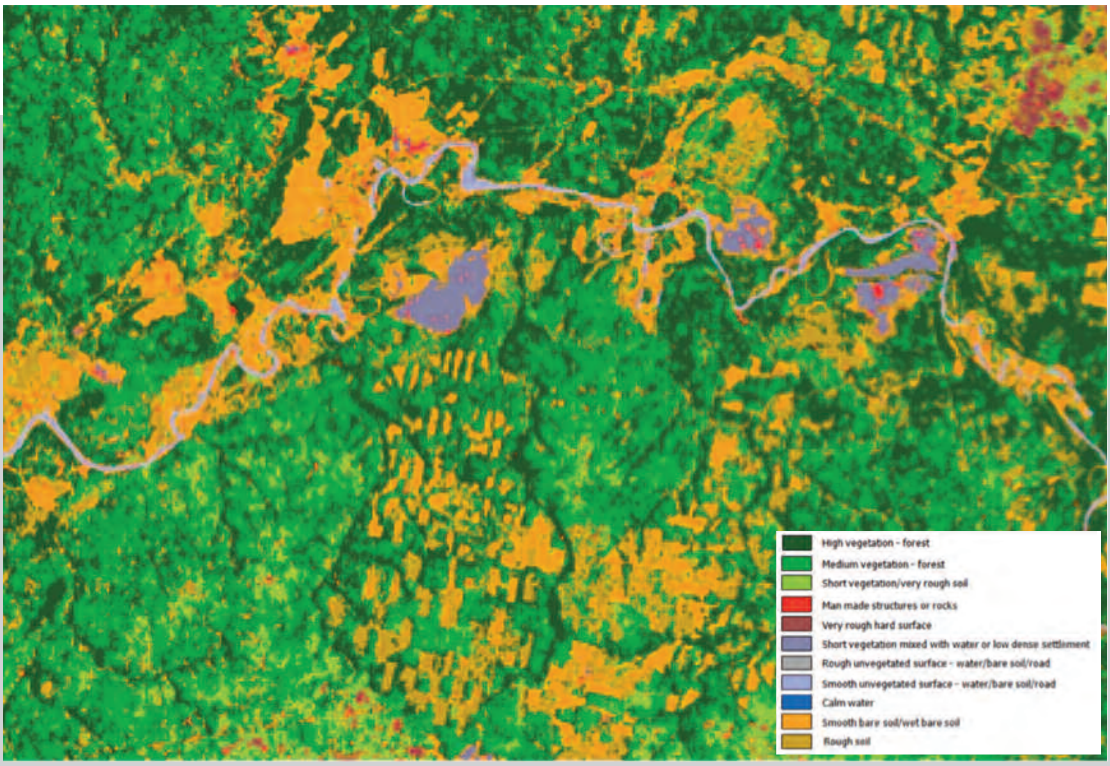
A spatial examination of forest types and forest density is useful for forest managers/natural resource managers for assessing the general state and biodiversity of the forest. A forest type map can be used for ecoystems valuation, forest certification/audit and general forest stock management.

Indicative Costs

Assuming a size of approx. 100 000 km² the cost for commercial EO data procured for these kind of maps is about 1,5 Euro/km² which will become cheaper/free with the launch of new ESA satellites. The cost for the service production is 2-3 Euro/km². The prices vary from service provider to service provider and largely depends on specific needs, available in-situ data and number of thematic classes.

The Contribution of the Sentinel Missions

Sentinel-1 and 2 will provide high-resolution optical and radar images of all global forests with a very high frequency (days to weeks). The spectral characteristics of the sensor are directly useful to forest type mapping and will allow to classify forests with high frequency, high thematic accuracy, high precision (down to 10m) at a lower cost due to the foreseen free data price.

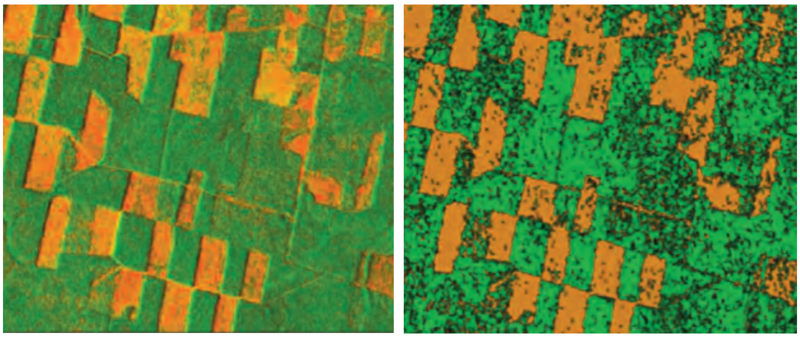


ALOS PALSAR Forest classification ~15 m resolution in Mondi Syktyvkar Russia. Credits: Sarmap

→ CLEAR CUT MAPS/BURNT AREA MAPS

Information content

Clear Cut Maps / Burnt Area Maps provide up to date information on afforestation, deforestation and reforestation. Minimum two time periods are analysed to track changes in the forests and derive information on clear cutting caused by burning, selective logging or storm damage. It is also possible to do similar analysis to identify canopy gaps, logging roads and log landings. This is a very established EO technology and many providers offer this service.

[1] 

[1] Clear cut product from CosmoSkyMed Radar, MondiSYK, Russia – 3m resolution. Orange patches are clear cuts with green seed trees visible. Credits: Sarmap

[2] Greece Stira Burnt Areas. Credits: DLR ZKI; ESA; International Charter; RISK EOS.

[3] Deforestation of the Amazon Rainforest USGS/Deimos Imaging

Resolution, Frequency and Availability

Clear cut mapping can be done frequently and on an operational basis depending on needs. The spatial resolution of this is typically of the scale of 10-20m. In tropical rain forest areas frequent cloud cover can be an issue for the production of the maps but may be mitigated by combing radar and optical satellite images.

Accuracies and Constraints

The accuracy of the maps are approx. 75-90% depending on cloud cover, seasonal fluctuations, topography and data availability. The geometric accuracy is less than 1 pixel which is on the order of 10-20 m and typically accuracies of 70-90% are reached for the classifications.

Benefits and Use

Clear Cut Maps / Burnt Area Maps can be used to monitor: canopy gaps, clear cuts, illegal logging, Log landings, burnt areas and regrowth. Considering the long term availability of historical data and the fact that aerial surveys can be expensive and difficult there is no other reasonable alternative to assess forest changes and logging patterns on larger spatial scales over time.

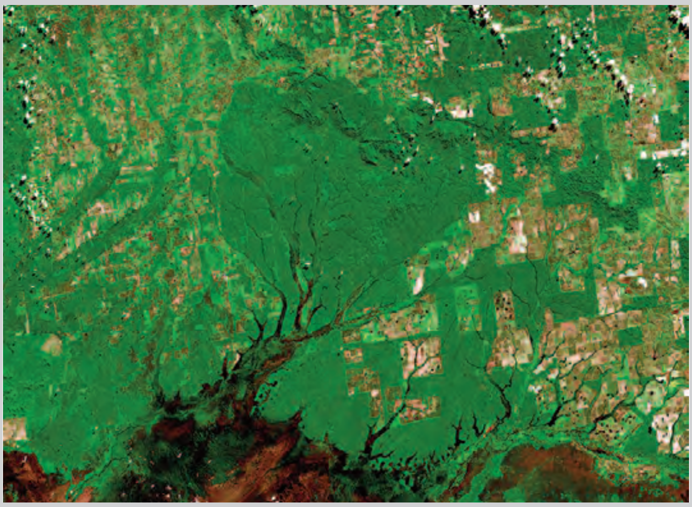
Indicative Costs

Assuming a size of approx. 100 000 km2 the cost for commercial EO data for these kind of maps is about 1,5 Euro/km² which will become cheaper/free with the launch of new ESA satellites. The cost for the service production is about 0,35-0.5 Euro/km². The prices vary from service provider to service provider and largely depends on specific needs, available in-situ data and number of thematic classes.

The Contribution of the Sentinel Missions

Sentinel 1 and 2 will provide high-resolution optical and radar images of all global forests with a very high frequency (days to weeks). The fact that clear cut mapping is possible both from radar and optical images will allow to map clear cuts and logging activities with high frequency, high thematic accuracy, high precision (down to 10m) at a lower cost due to the foreseen free data price.

[2] 

[3] 

Information Content

A number of different environmental indicators maps can be derived from the Land use / Land cover and Forest Type maps. These indicator maps address the spatial complexity and structure of the forests and can be used for environmental monitoring and assessment of forests ecosystems. Examples of these indices are:

- Area: The proportion of one land cover type in % per area.
- Core Area: The percentage of the inner central parts of patches in relation to the total patches. Related to the habitat quality for certain species.
- Diversity: The extent to which one or a few class types dominate the landscape index. E.g. is an area dominated by coniferous or deciduous trees.
- Edge: The amount of edges occurring between patches or classes.
- Nearest neighbour: The edge to edge distance of patches.
- Shape: A measure for the complexity of forest shapes.
- Patch: The total/relative number of patches in a given area.

Resolution, Frequency and Availability

The indicator maps can be produced both on a regional and national scale depending on the background maps that go into the production. The background maps also define how frequently the maps are produced which is usually on yearly scales (each 2-5 years) with a resolution (spatial accuracy) of 10-30 metres. Also up to medium resolution – e.g. 300m MERIS are useful on regional to continental scale.

Accuracies and Constraints

The accuracy of the indicator maps are linked to the accuracy of the background maps that go into the production. Typically accuracy values of 80-90% are reached.

Benefits and Use

Fragmentation of land due to increase in infrastructure have an effect on forest ecosystems and biodiversity. Habitats become isolated and animals can no longer roam freely. The indicator maps can help to address the status of the biodiversity of the forests and indicate stresses on ecosystems as well as on soil and water resources. These maps can support environmental agencies and forest managers on both regional and national levels.

Indicative Costs

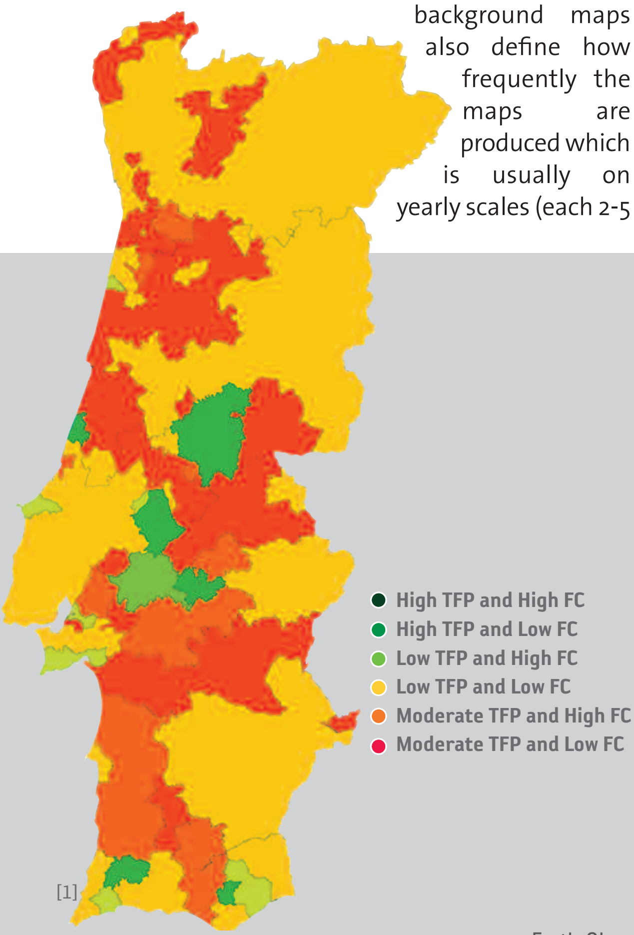
The costs vary from case to case and the products must be derived from either existing map products or from new productions of land use/ land cover and forest type maps.

The Contribution of the Sentinel Missions

The Sentinels will provide high-resolution optical and radar images globally with a very high frequency (day to weeks) which will allow to produce even better and more timely indices maps.

[1] Forest Fragmentation Index per Municipality 2004, Courtesy: Advanced Computer Systems A.C.S. S.P.A., Italy.

[2] Landscape indicator map of Austria with number of forest and non-forest patches per km². Credits: Joanneum Research.



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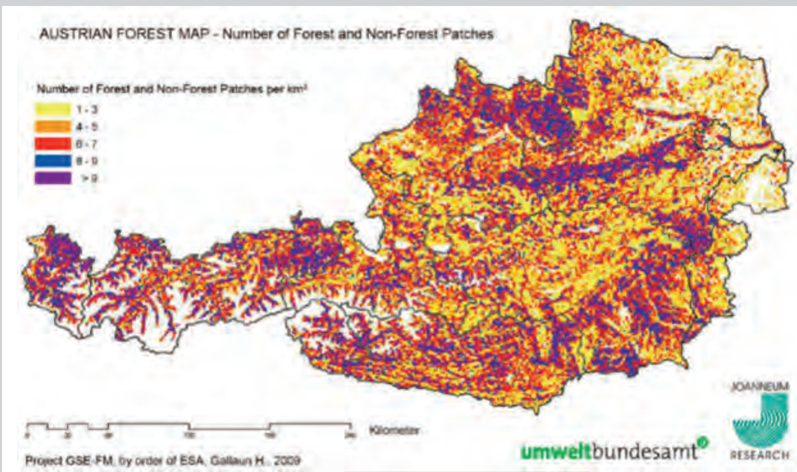


→ STEM VOLUME, BIOMASS AND CARBON STATISTICS

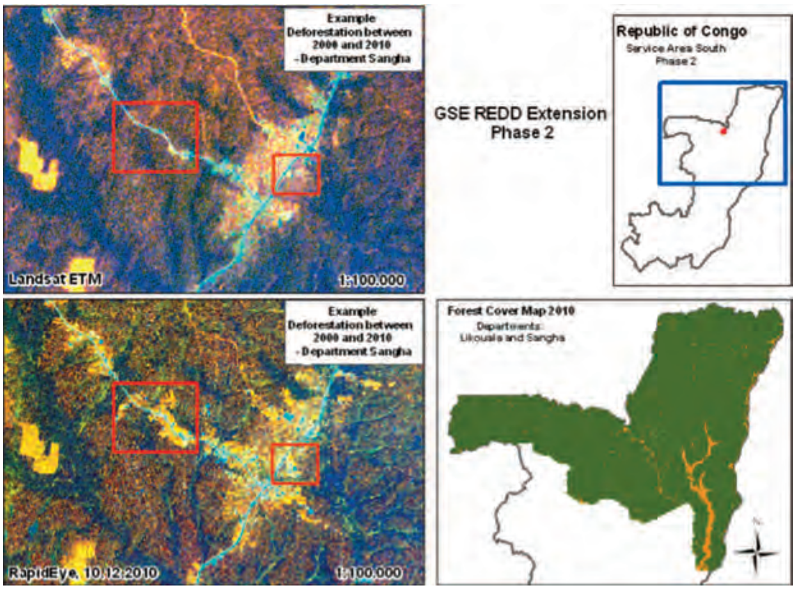
Determination of forest biomass and carbon stock has become increasingly more important in line with an increase in REDD and REDD+ activities[2]. At present this is mostly done from in situ measurements on tree types, volume and height estimates.

Customised EO products can be delivered on stem volume in tropical as well as boreal forests with typically 30 m resolution on a large spatial scale. The EO techniques use radar pulses to penetrate into the forest canopy where the return signal is used to derive information on stem volume. The EO derived stem volume can then be related to above ground biomass and carbon stock by calibrating and correlating with in situ data. In this way EO adds a spatial dimension to existing in situ estimates of biomass. Using EO change detection techniques, forest degradation by the decrease in forest biomass/diversity can also be estimated.

It should be noted that these services are customised solutions and accuracies must be estimated on a case by case basis. However, since few conventional methods can assess biomass on large spatial scales attention should be given to this product. The development of EO biomass estimations will be even more interesting to follow with the launch of the Sentinel-1 satellite which allows for more timely estimations of forest changes.

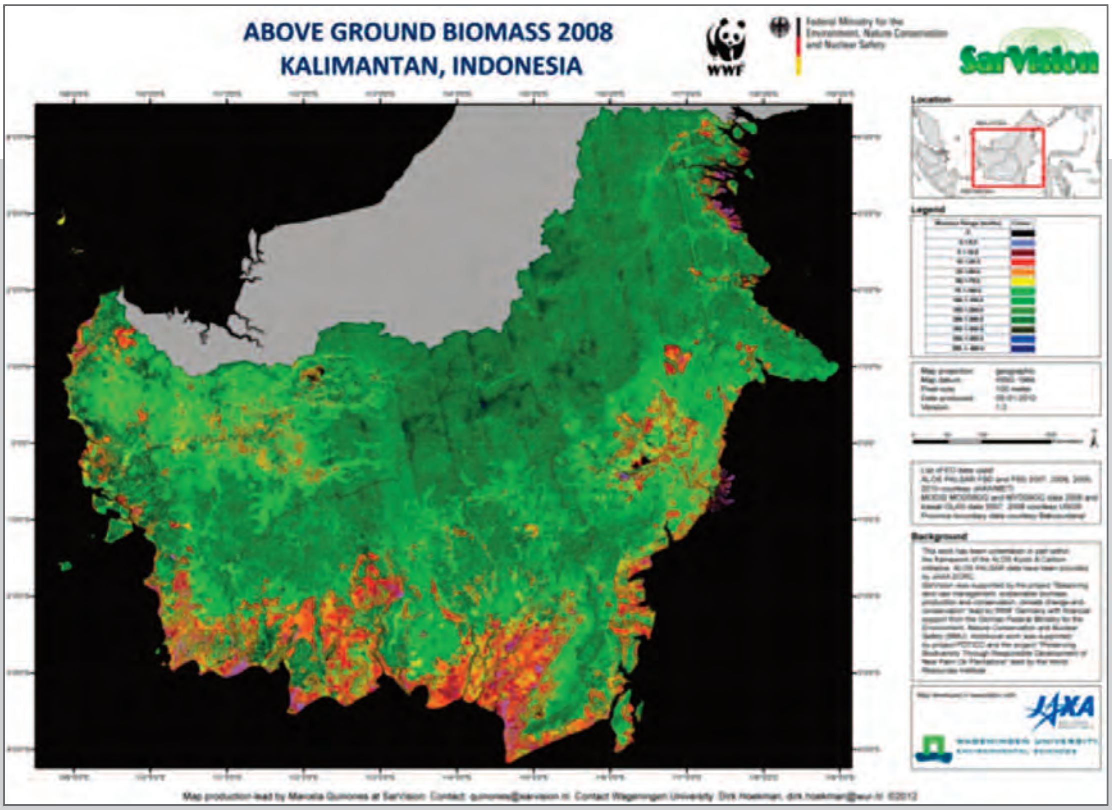
The price of biomass determination from satellite varies and is fully depending on in situ availability.

[2] REDD is the UN Collaboration on Reduction of Emissions from Deforestation and Degradation. ESA has been involved in a REDD Pilot Project in Cameroon in 2007 co-financed by ESA, the German Development Bank-KfW and GTZ providing deforestation/degradation assessment for the country based on forest maps for 1990, 2000 and 2006, and with capacity building/technology transfer to the national authorities. This pilot was a success and was extended to implement REDD services in the Republic of Congo and Gabon. http://www.redd-services.info/content/gse-fm-redd. ESA is furthermore an active member of the Forest Carbon Tracking (FCT) initiative which facilitates access to long-term satellite, airborne and in situ data, and provides the framework, tools and technical standards to assist countries in the development of national forest carbon tracking systems. www.geo-fct.org



[1]

[1] Deforestation in Congo between 2010 as part of a REDD trial project led by ESA and GAF AG. (www.redd-services.info/content/gse-fm-redd). CREDITS: GAF AG



[2]

[2] Biomass map over Kalimantan (Indonesia) for 2008. The resolution is 50m derived from a LIDAR and a radar sources ICESat-GLAS & ALOS PALSAR. Credits: SarVision.

An Ecosystem service is defined as the benefits that people derive directly or indirectly from a natural reserve. EO can provide input to the valuations of ecosystem services by establishing baselines, monitoring the compliance of standards, spot checks of sustainable management practices and support environmental reporting. Combining the geospatial information from the EO data with GIS ecosystems model tools as INVEST/ARIES it is possible to determine the economic value of the nature reserves.

In 2013 ESA is launching activities on how EO can be used for the assessment of Ecosystem services. Focus will be on establishing ecosystems trials in which EO information is given as input to the GIS tool INVEST and used to derive economic figures for the trial areas. Furthermore, based on inputs from a large user community an overall market study for the uptake of EO for ecosystem valuations will be carried out.

The EO capabilities suitable for Ecosystems service assessments are mainly forest and land use/land cover mapping but also carbon inventory mapping as well as topographical information on slope and elevation.

ESA worked with WWF on using EO for Ecosystems service assessments in Borneo – a project which was effective in changing policy makers view on land use in Borneo (www.heartofborneo.org).
[1] Water yield and water supply intakes for Kalimantan, Indonesia using land cover information, slope and elevation data from EO satellites.

[2] Projected Land cover and land use scenario for 2020 Business as Usual scenario, Kalimantan, Indonesia. Courtesy: Hatfield Consultants.

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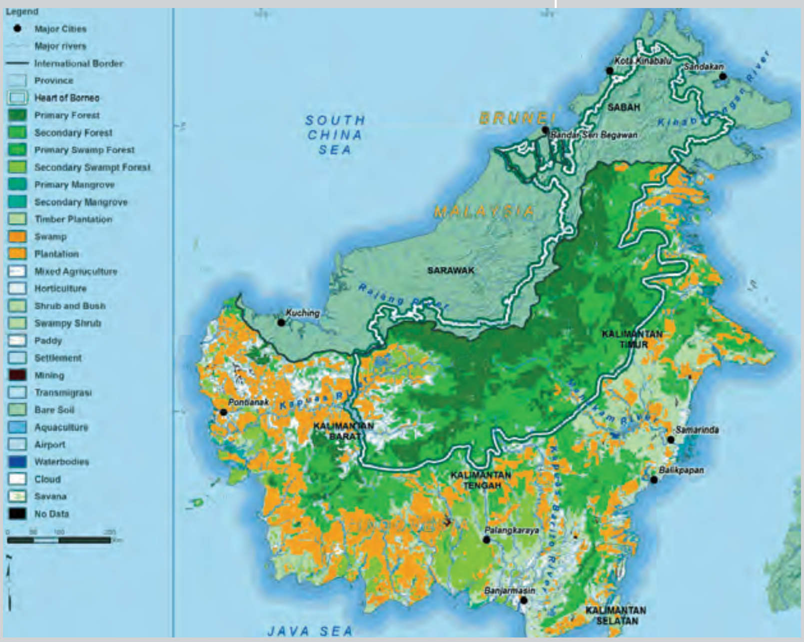


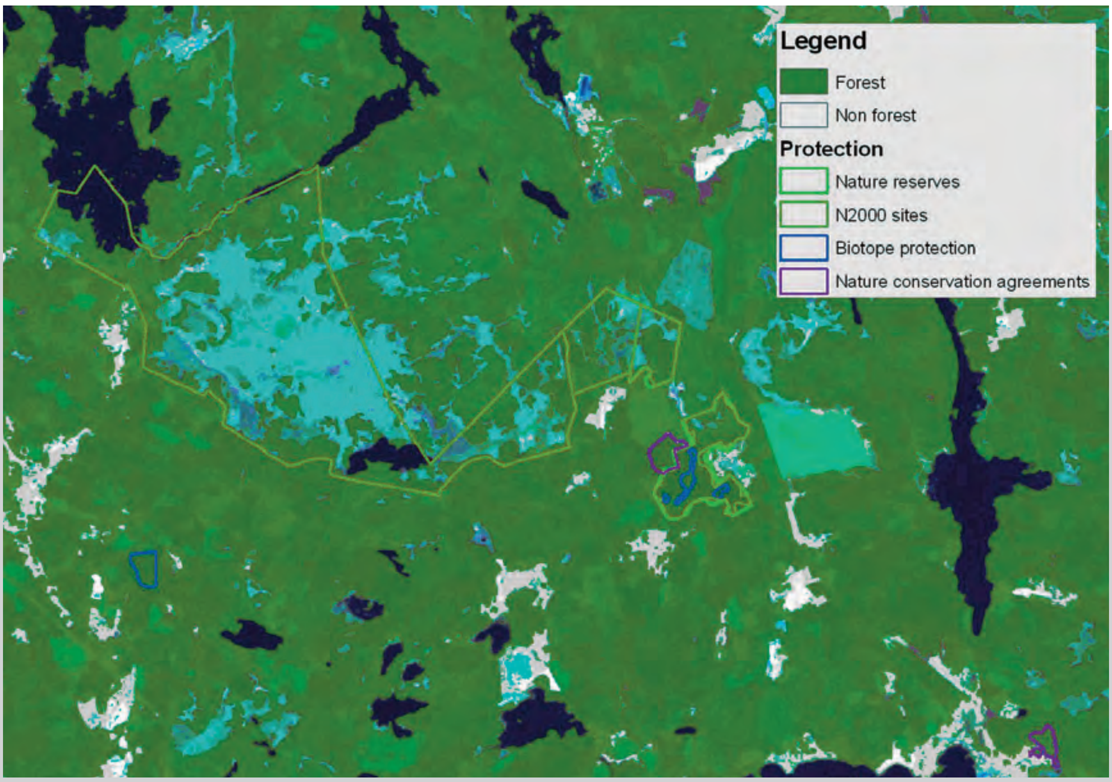
→ CERTIFICATION OF SUSTAINABLE FOREST MANAGEMENT

ESA has completed a number of projects together with the Forest Stewardship Council (FSC), to demonstrate the value of EO and GIS for forest certification and audit. The projects were mainly focused on assessing how EO can help in the FSC accreditation and certification process but also in the annual audit process.

The projects for FSC certification included assessment on all EO services (e.g. clear cut mapping, forest type and forest inventory mapping) and arrived to the conclusions that EO & GIS can:

- Make certification data and annual audits more transparent
- Increase data availability for all partners
- Standardise parts of certification process by using geospatial information
- Reduce the costs of certification and annual audits
- Identify forest areas where FSC standard prohibits logging

Read more about this at: http://ic.fsc.org/space-borne-earth-observation.206.htm



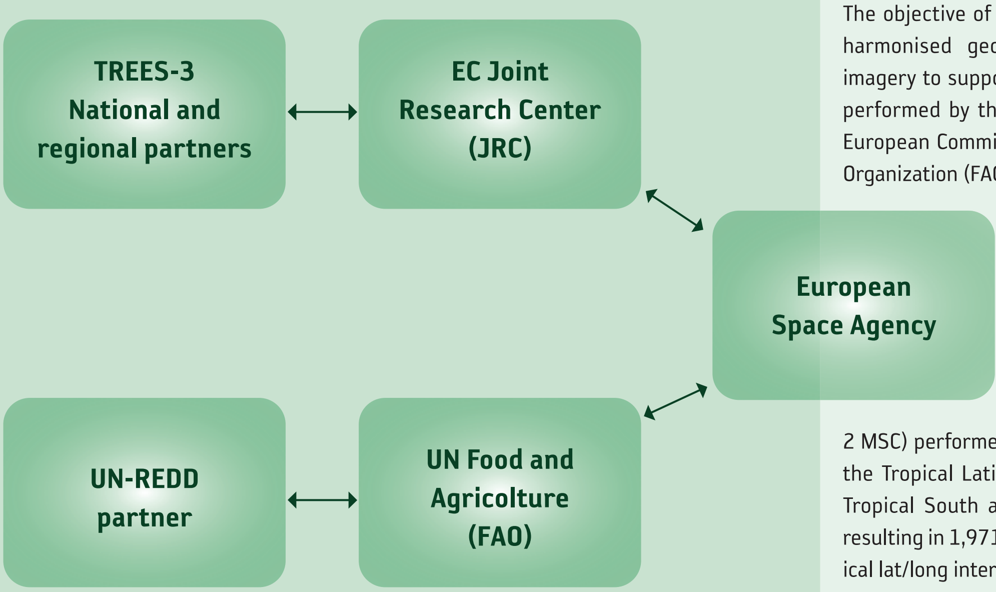
Forest mask with areas protected from forest management including key habitats within protected areas. Optical EO data (SPOT -5). Courtesy Metria

GLOBCOVER

The Global Forest Resources Assessment 2010 (FRA 2010) by the Food and Agriculture Organization (FAO is the most comprehensive assessment of forests and forestry to date. It examines the current status and recent trends for about 90 variables covering the extent, condition, uses and values of forests and other wooded land, with the aim of assessing all benefits from forest resources.

http://countrystat.org/home.aspx?c=FOR&p=ab

Illustration of Globcover. Credits: ESA 2010 and Université Catholique de Louvain; source: http://due.esrin.esa.int/globcover



The relationship between all partners of the TropForest

TROPFOREST

The objective of the TropForest project is to create an harmonised geo-database of ready-to-use satellite imagery to support the 2010 global forest assessment performed by the Joint Research Center (JRC) of the European Commission and by the Food and Agriculture Organization (FAO).

The TropForest project of the European Space Agency aims at addressing these needs by first creating an harmonised ortho-rectified/pre-processed imagery geo-database based on satellite data acquisitions (ALOS AVNIR-2, DEIMOS-1, KOMPSAT-2 MSC) performed during the years 2009 and 2010, for the Tropical Latin America (excluding Mexico) and for Tropical South and Southeast Asia (excluding China), resulting in 1,971 sites located at 1deg x1 deg geographical lat/long intersections.

http://www.tropforest.info

GLOBCOVER

GlobCover is an ESA initiative which began in 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The aim of the project was to develop a service capable of delivering global composites and land cover maps using as input observations from the 300m MERIS sensor on board the ENVISAT satellite mission. Land cover maps from 2 periods: December 2004 - June 2006 and January - December 2009 with a 300m resolution can be downloaded.

http://due.esrin.esa.int/globcover/

Lao People's Democratic Repubblic - Regional Map of Land Cover (from GlobCover regional) Map 2006. Courtesy ESA

GLOB BIOMASS

The European Space Agency together with the University of Jena and the Max Planck Institute for Biogeochemistry in Jena are organising user requirements to a global biomass product (Feb 2102). The project is coordinated with the GOFC-GOLD subgroup on biomass.

The goal of the GlobBiomass project is a better characteristic of the distribution and changes, and an improved quantification of regional and global biomass to help a reduction of uncertainties in calculations of carbon stocks and fluxes in the terrestrial biosphere based on today's available satellite data and techniques. The products aim mainly towards international programmes on climate research and modelling, but could have an impact as well on national GHG reporting. The programme is formally initiated in 2013.

http://due.esrin.esa.int/meetings/meetings283.php

ESA organised user consultation meeting 2012 in Jena, Germany bringing together over 80 users, scientists and experts in satellite biomass retrieval. Courtesy ESA

➜ URBAN DEVELOPMENT

Related World Bank Programmes and Initiatives

Examples of World Bank related initiatives to which this section is pertinent: Urbanisation Knowledge Platform; Inclusive Green Growth; Global Facility for Disaster Reduction and Recovery (GFDRR); Cities Alliance; Ecological Cities as Economical Cities (Eco2); Global Protocol for Community Scale Greenhouse Gas Emissions; Partnership for Sustainable Cities; Multi-Donor Trust Fund for Cultural Heritage and Sustainable Development.

Addressing Development Challenges

Main World Bank related topics against which EO capabilities are available:

- Global and national urban expansion trends, urban expansion at agglomeration level
- Sustainable growth (energy, transport, fragmentation)
- Urban resilience to natural hazards
- Urban public health, air pollution
- Urban public health, microclimates
- Urban water and sanitation
- Urban poverty and slum upgrading, illegal housing, informal settlements
- Ecosystem services for the cities, ecological cities
- Greenhouse gas emissions for the cities (cities 'metabolism' and carbon accounting)
- Sustainable urban mobility and transport systems development, periurban development and urban liveability
- Cultural heritage and sustainable tourism

The Potential of EO Information Services

Earth Observation using satellites has become a powerful technique for the study of urban areas. Typically, urban landscapes are spatially complex, consisting of an intricate combination of various land cover patterns, usually without any systematic geometric orientation. In addition to spatial heterogeneity, urban areas are typically a mosaic of many different materials, each with its own spectral signature. Depending on the desired mapping scale, imaging such areas may call for sensors with high spatial and spectral resolution. Recent advances in image classification, based on textures, have greatly increased the use of high and very high spatial resolution.

The last decade has seen an increasing number of successful launches of satellite systems providing data at spatial resolutions at or better than 1 m, thereby providing accuracies at the level of more traditional aerial methods. Remote sensing of urban environment is traditionally based on mapping of land cover types. However, the same satellite data used to assess urban composition can also contain significant bio-geophysical information: for example, information concerning green vegetation and the proportion of impervious surface material and exposed soil can contribute to the analysis of urban climate, the water cycle, etc.

BASIC EO CAPABILITIES

CUSTOMISED SERVICE

EO PRODUCTS/DATASETS

Information content

This capability provides mapping of urban areas in terms of type of land surface and the associated temporal changes (land cover and land cover change). Based on this, the services can provide various urban indicators, as well as infrastructure and building inventories based on construction classes. Typical artificial surface land cover classes used in the classification follow the established nomenclatures (CORINE, MOLAND, etc.), i.e. continuous and discontinuous urban fabric, industrial, commercial and public units, road and rail networks, port areas, airports, green urban areas, sport and leisure facilities, etc.

Resolution, Frequency and Availability

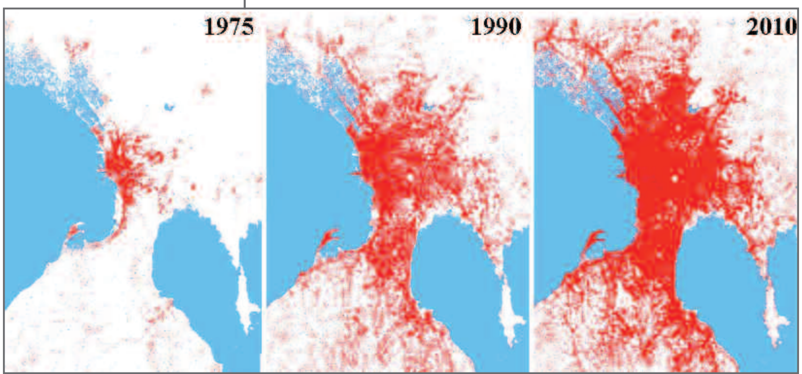
The spatial resolution of most products can reach a few meters depending on the input imagery resolution. Typically construction classes can be estimated at block level (MMU of 0.25 ha resulting in 1:10000 scale maps). Monitoring for the period from the late 1970s to the late 1990s relies mostly on medium resolution data which provide useful information to analyse spatial urban growth at regional level, for example differentiating between urbanised and non-urbanised areas.
The temporal resolution (update frequency) is usually once every 1–5 years, but is limited only by the availability of satellite data (available globally every few days/weeks, depending on geographic latitude, cloud cover and data acquisition schedule).

Accuracies and Constraints

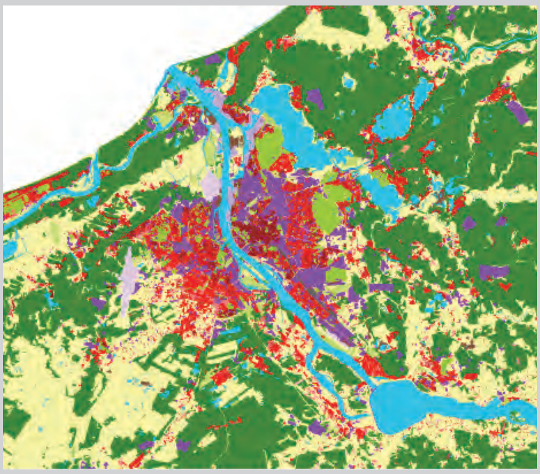
The geometric accuracy is usually comparable to the spatial resolution of the input satellite data, i.e. typically a few metres. The thematic (classification) accuracy is in the range of 80–90% depending on the quality of the EO data.
In the case of building inventories, only part of the building information can be captured, depending on the sensors used for data acquisition. Very high resolution optical sensor imagery makes it possible to estimate building footprints, building location, distance from building to building, building height classes (using stereo image pairs). Other features, such as building height as number of storeys, building material, structure type, load bearing structure system, construction technique, floor area, are more difficult to capture.

Benefits and Use

Basic urban mapping products offer a sound basis for spatial statistic calculations and revision of urban plans for urban planners, politicians, environmentalists and other public stakeholders for planning and management of cities. The service is particularly relevant for monitoring urban expansion / urban sprawl adjacent to cities. These areas are often the most dynamic, and have a large impact on city planning and development. Furthermore, the products serve as a starting point for a range of urban indicators for soil protection and management as well as the monitoring of crucial water supply systems, urban structures, and flood risk control. In general, the



[1] Example of an urban dynamics analysis product: urban sprawl analysis in Manila, Philippines using medium-resolution EO data. Credits: DLR-DFD.



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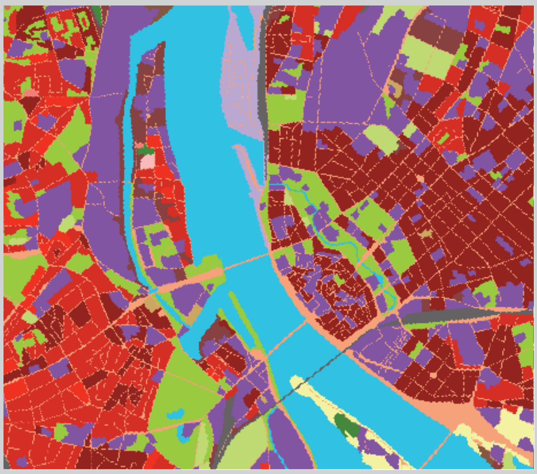


[3]

[2] Land cover product for the city of Riga, Latvia with a detail of the city centre [3]. Credits: Urban Atlas (see also "Existing Datasets and Products" later in this chapter)

products are independent and up-to-date, available practically around the globe. The products also are reproducible and thus consistent and comparable. Especially for urban areas in developing countries, EO information services and products often remain the only data source. While the EO products rarely achieve the accuracy of cadastral data, their accuracies are sufficiently high to form an objective basis for decision-making.

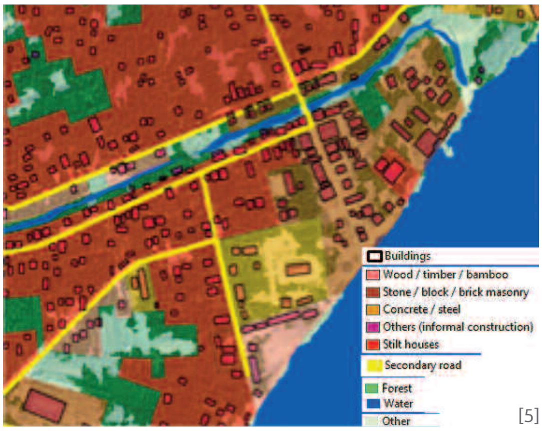
Indicative Costs

The total service cost is in the range 10–50 k EUR for an extent of 1000 km², depending on the EO data source. The cost of processing is relatively high compared to the data costs due mostly to a lack of fully automated classification procedures.

The Contribution of the Sentinel Missions

The Sentinel-2 mission will routinely provide high-resolution (10–20 m) optical images globally with frequent revisits (12 days). It is anticipated that the current number of space-based optical imaging sensors will keep increasing, and include relatively affordable small satellite systems with very high resolution sensors operated by a growing number of countries. Together with sensors like Sentinel-2, these will ensure the long-term continuity of medium-, high- and very high-resolution data, creating the possibility of urban studies across many decades.

[4]



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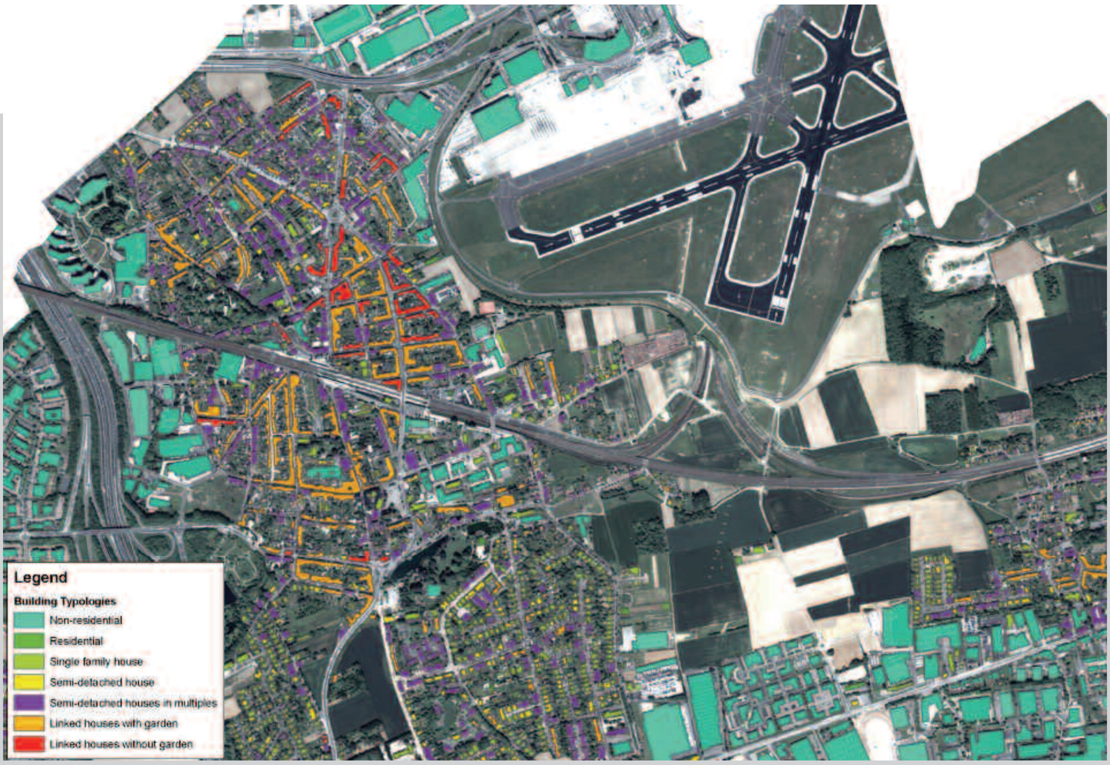


[6]

[4] Urban sprawl map of the Rome area showing 'hot spots' (in red) of new urbanisation between 1995 and 2000. The white colour indicates built-up areas existing in 1995. Credits: ACS.

[5] Land use map with building inventory on building block level in Laos. Credits: GeoVille.

[6] Map of building typologies for Zaventem (Belgium) derived from very high-resolution satellite imagery. Credits: GIM/EUSI.

Information content

High-resolution satellite images capture very detailed information of the terrain. Much of the imagery is at the resolution close to that of small-scale aerial photographs making it possible to apply photogrammetric methods to collect stereoscopic information about buildings and other urban objects using stereo pairs or multiple images. In addition to the cross-track (side-looking) stereo images acquired during different orbit overpasses, many sensors can acquire along-track (same-orbit) stereo images of the same region quasi simultaneously.

Successful solutions exist for semi-automated object extraction and modelling of built-up environments from satellite, aerial and terrestrial platforms. These allow modelling of not only buildings, but also terrain models and any other objects of interest which can be represented as a polyhedral model (bridges, industrial infrastructure and even ships or individual trees).

Resolution, Frequency and Availability

Space-based sensors provide high resolution (0.6–5.0 m) multispectral data and multiple-view terrain coverage along the same satellite orbit, enabling the multi-image matching approach, leading to higher measurement accuracies (reduced problems of occlusion, multiple solutions, surface discontinuities, etc.). The availability of data goes back to the last years of the 1990s, with frequency of coverage increasing in time.

Accuracies and Constraints

In general, the processing of very-high resolution satellite images poses a challenge for traditional photogrammetric algorithms. Processing methods need redesign and extension in order to accommodate the imaging geometry characterised by nearly parallel projection in along-track direction and perspective projection in cross-track direction.

Benefits and Use

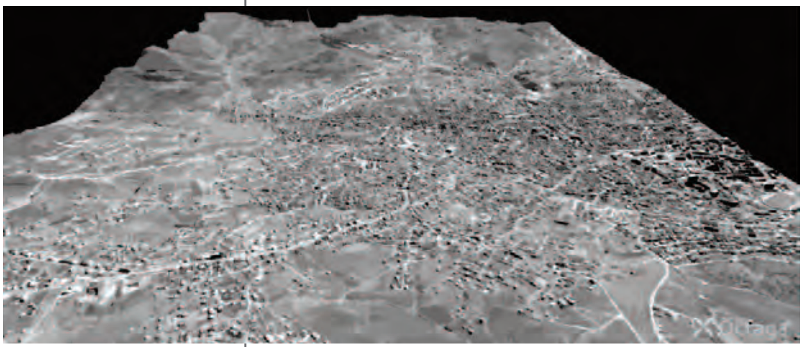
The benefits of satellite imagery as opposed to aerial photography lie in the possibility to consistently, frequently and efficiently map large areas at lower costs.

Indicative Costs

In the long term, the cost of satellite data acquisitions is only a fraction of the cost of organising aerial photography campaigns. Costs related to human supervision of the processing and error-checking are still the driver in most cases.

The Contribution of the Sentinel Missions

With very high-resolution satellite data becoming increasingly available, the positive future prospects of 3D-modelling from satellite imagery are guaranteed (see also the Urban Mapping section).



[1] 3D view of Pristina (Kosovo), generated from two panchromatic Ikonos satellite scenes (1 m resolution, 680 km altitude). Credits: ReVisitor AB (Sweden).

[2] A 3-dimensional view of the city centre of Beijing derived from very high resolution stereo satellite imagery. Credits: GIM/Epsilon/EUSI.

Information content

Soil sealing describes the covering of the soil surface by materials such as concrete thereby changing the nature of the soil into behaving as an impermeable medium. EO-based products describing impervious areas and sealing levels are oriented towards an inventory and monitoring of artificial surfaces in relation to other land cover types. Typically the products contain at least land cover information and degrees of soil sealing.

Resolution, Frequency and Availability

Typical spatial resolutions are 5–50 m (MMU of 0.25 ha for artificial surfaces and 1 ha for non-urban classes), resulting in scales of 1:25.000. Monitoring for the period from the late 1970s to the late 1990s relies mostly on medium resolution data which does not allow for much thematic detail, but provides enough information for a regional analysis.

The temporal resolution (update frequency) is usually once every 3–5 years, but is limited only by the availability of satellite data (available globally every few days/weeks, depending on geographic latitude, cloud cover and data acquisition schedule) and the ancillary, non-EO (demographic, economic) datasets.

Accuracies and Constraints

The spatial and thematic accuracies of soil sealing products depend mostly on the urban mapping products they are based on (see previous chapter).

Benefits and Use

Maps of the sealing levels of the soil help understand the impact on the environment of urban expansion and development of related technical infrastructures. Disturbance patterns with different intensity result from transport, noise, exploitation of natural resources, waste dumping and pollution. The products contribute to analysing and describing land take trends in relation to population development as well as the drivers, pressure, state and impact of land consumption. Various types of thematic analysis can be performed when combining these products with other data such as demographic and economic data, spatial indicators on the exposure to natural hazards, or climate change-related risks, policy-relevant indicators on essential spatial planning parameters (e.g. land consumption per capita, pressure on protected areas), etc.

Indicative Costs

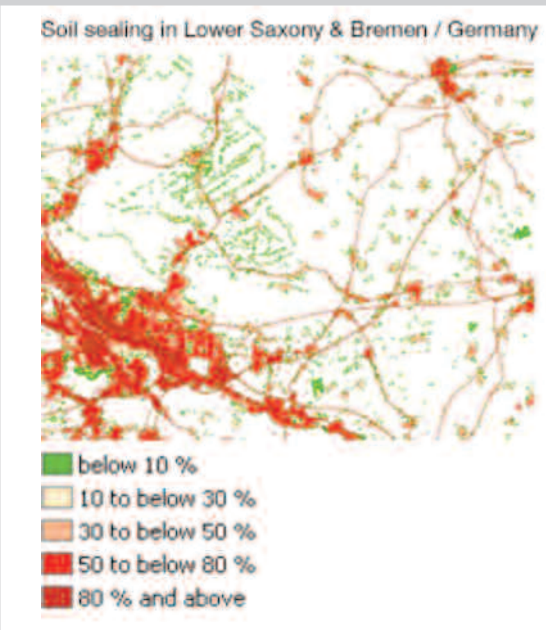
The service cost is in the range 1–5 EUR/km2 in addition to the cost of the basic regional land cover information.

The Contribution of the Sentinel Missions

Similarly to the basic urban mapping products, the ever-increasing amount of relatively affordable medium- and high-resolution data will ensure the continuity of this type of product long into the future. The benefits from the Sentinel-2 mission in particular are similar to those highlighted in earlier sections.

[1] Example of a soil sealing map

[2] Illustration of how the soil sealing map can be used in combination with socio-economic data and risk data to provide a map of the population exposed to flood hazard. For other EO-based risk services see the Disaster Risk Management section. Credits: GeoVille.



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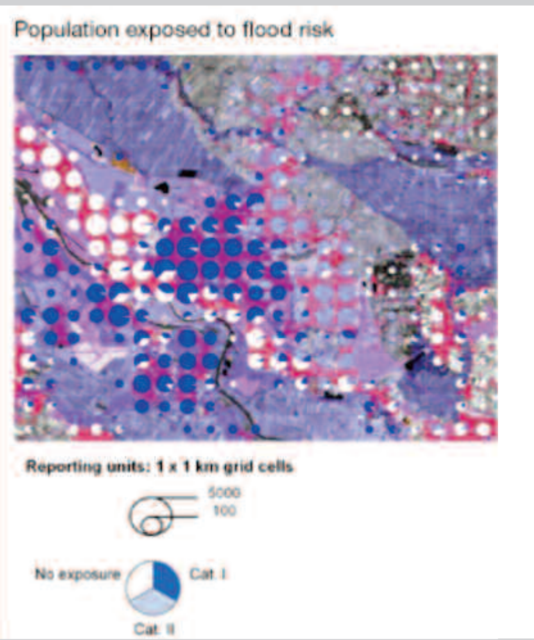


[2]

Information content

Traditionally, urban air quality has been monitored with networks of ground stations in conjunction with models that evaluate point-wise emissions and predict changes in air quality. EO data can provide complementary information to assess urban air quality at a local and regional scale, either in a monitoring or forecasting regime.

Typically, the contribution of EO for air quality monitoring services is by measuring either gas concentrations (e.g. tropospheric NO2, SO2, O3) or the aerosol thickness in the atmosphere (e.g. optical depth of PM10 and PM2.5, presence of dust), which is an indicator of the overall pollution of an area.

A typical air quality forecast delivers maps of air pollution in a region or local authority as a public information service. The products usually have a so-called "urban dispersion model" at their heart, driven by boundary conditions calculated by a model also assimilating satellite data. These complex models usually ingest information from weather forecasts, wide pollution forecasts and very detailed local pollution source data in a complex mathematical model. This means that the model doesn't account for the detailed effects of individual buildings or chaotic flows from strong winds, but it does include such effects as pollution build up along major roads with tall buildings – "street canyons" – and the diluting effect of rising warm air.

Resolution, Frequency and Availability

The most basic products usually have global coverage, with an improvement of both spatial resolution and accuracy when modelled at regional/local scale using both satellite and in-situ observations. Typical spatial resolutions range from 1 to 10 km on a daily basis, with local improvements down to street level when adequate in-situ information and/or modelling is available.

Accuracies and Constraints

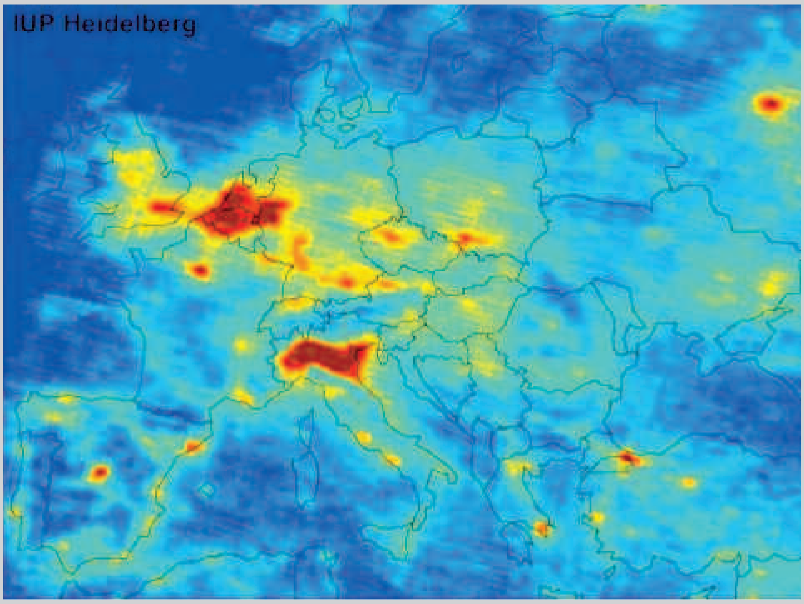
Apart from the availability of ground-based data for best accuracy and resolution, drawbacks associated with EO for air quality assessment are the spectral interferences caused by atmospheric components that are not pollution. Satellite observations are made only in specific wavelength ranges and the results of the observations are subject to the atmospheric conditions. Pollutants with a low concentration will usually not be detected. Another constraint is the need for highly qualified staff to supervise the process.

Benefits and Use

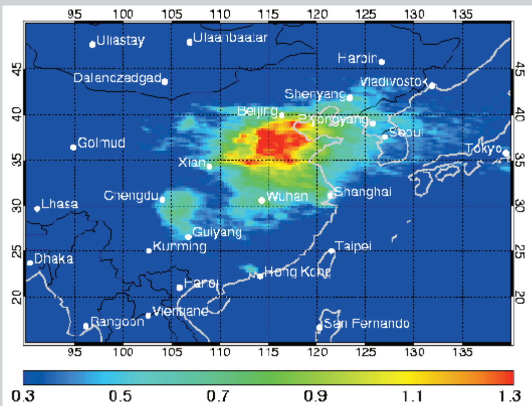
EO can provide a complete survey of a populated area, showing the major pollution sources and their distribution pattern. It can help in finding relationships between the city features and the air pollution distribution patterns. The key added value of air quality assessment services lies in the provision of satellite and model output which is complementary in space and time to existing data sources. Example uses of public citizen information services are vulnerable parts of the population limiting their exposure to air pollutants and taking precautionary medication when critical air quality levels are forecasted.

Indicative Costs

Overall service operation costs are to some extent scalable by the area, horizontal resolution, and the number of calculated parameters. Costs depend on the complexity of input data streams



[1] Measured mean tropospheric nitrogen dioxide (NO2) vertical column density (VCD) over Europe, between January 2003 and June 2004. Credits: Institute for Environmental Physics, University of Heidelberg.



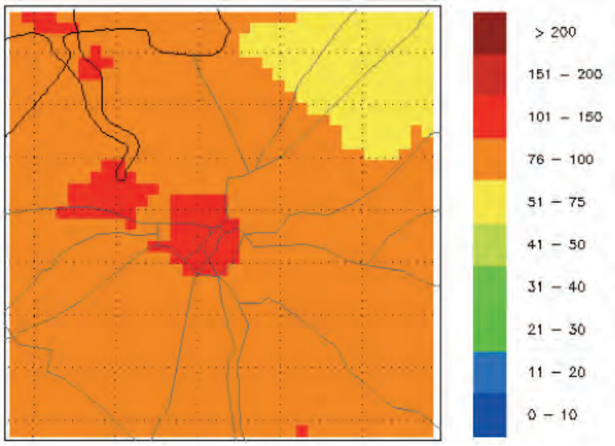
[2] Measured mean tropospheric SO2 (DU) for the period January 2005 up to December 2007 in Eastern China. Credits: BIRA-IASB, DLR, KNMI.

and algorithms which are determined by the user requirements (accuracy, timeliness, reliability). Forecast service costs are determined by operation efforts. For regional and city air quality forecasts implementation costs for new regions are also substantial (i.e. to obtain emission datasets). In general, the yearly cost estimate of producing one year of satellite and assimilation records is in the order of 100 kEUR for an entire continent (Europe), and the yearly cost for the forecast service (daily at regional/local level) being an additional approximately 100 kEUR for the setup and 30 kEUR for the operation.

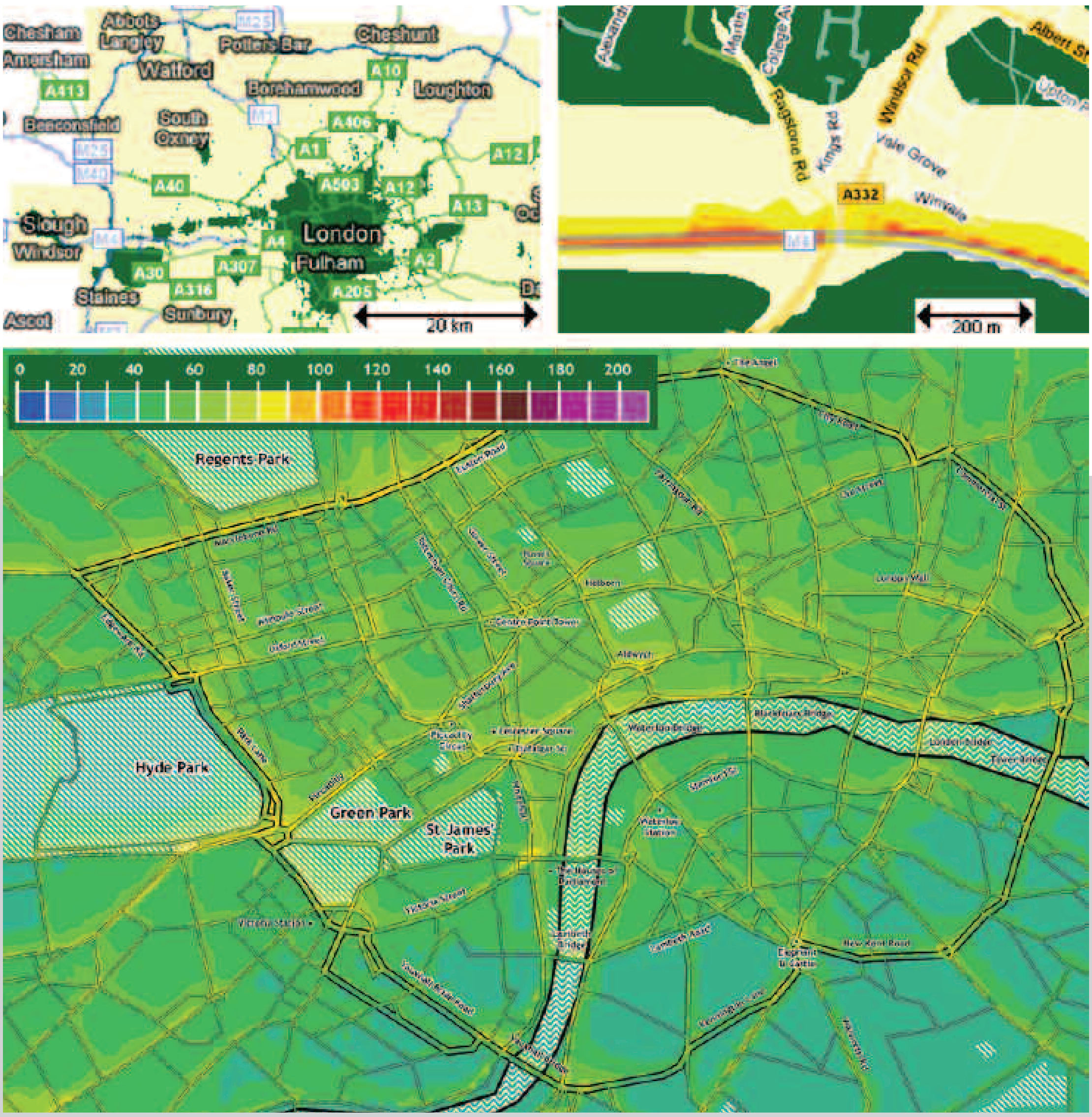
The Contribution of the Sentinel Missions

The continuity of urban air quality services will be guaranteed by the continuation of existing programmes like the EUMETSAT's Metop-A/B/C or future missions such as Sentinel-4 and Sentinel-5, both dedicated to monitoring the composition of the atmosphere.

[1]



[1] Daily mean PM10 forecast for 2008 February 20 for the Brussels area, at 1 km resolution. Credits: VITO Belgium (GMES GSE PROMOTE).



[2]

[2] Overview of a forecast ozone episode (left) and a detailed view of a forecast PM10 episode (right) and NO2 (µg/m3, bottom) for the city of London. Credits: Cambridge Environmental Research Consultants Ltd./ airTEXT (GMES GSE PROMOTE).

→ POPULATION DISTRIBUTION MAPPING

Population distribution mapping using EO data is very useful, particularly for fast-growing or developing countries, where urbanisation creates rapid significant changes in the geographical distribution of population. Population distribution and density are based on the spatial disaggregation of census data using EO-derived land cover information. When collected at various administrative levels, census data is often too coarse for direct analysis, but additional information inside each administrative division can be obtained by studying the spatial distribution of land cover types inside each division. Knowing the type of urban fabric (residential or non-residential) allows for more accurate spatial distribution of information and provides population estimates, for example, at night-time (home) periods, and, provided additional information is available, also for daytime (work) periods.

Other EO contributions to population mapping consist in the estimation of the population in informal settlements (e.g. refugee camps) by measuring their spatial extent in very high-resolution imagery.

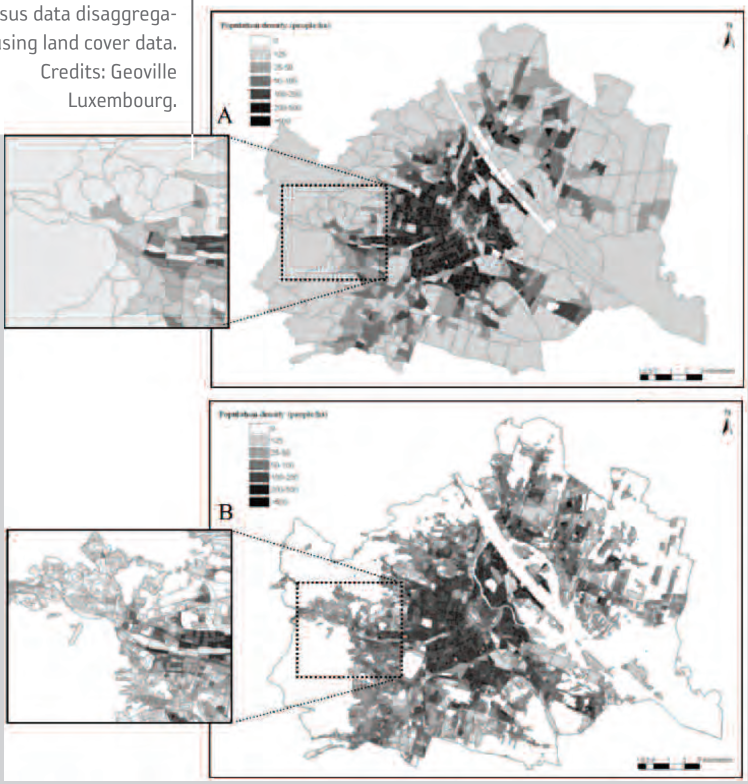
The spatial resolution, frequency and availability of the final products are directly linked to that of the input satellite products. Disaggregation using land cover information can be performed at various scales, from medium- to very high-resolution. Mapping of settlements requires very high-resolution data in the order of 1–5 m.

For the disaggregation technique using land cover, the accuracies and constraints discussed in the Urban Mapping section apply, and are naturally influenced by the accuracy of the input census data. The presence of high-rise buildings needs careful consideration, as the vertical component biases the outcome of the spatial disaggregation technique.

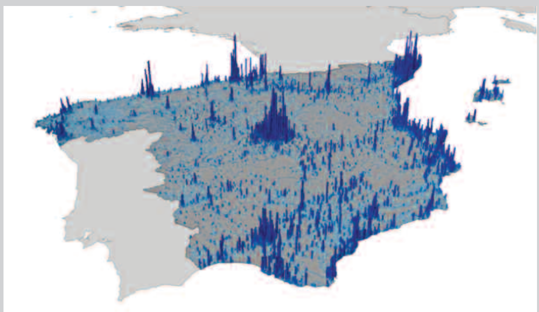
Population mapping using very high-resolution imagery still suffer from accuracy issues and a lot of detail is required in order to recognise and differentiate man-made structures and their extensions. No global solutions exist, many of the existing solutions apply only regionally and in an ad-hoc manner. Nevertheless, presently it is often possible to achieve better results than with existing GIS datasets, which are usually derived from much coarser or more aggregated sources.

Information about population distribution is important for planning purposes and geomarketing. Census data are often only available for large administrative units with arbitrary boundaries that convey a wrong impression of homogeneous population density leading to analytical and cartographic problems. EO data can contribute to refine census information to better reflect reality in terms of spatial distribution of population. The largest potential of the products is in regions and countries where limited information on population distribution is available.

The costs for these services are low. The most significant part of the cost relates to the degree of supervision needed in the production.



[1] Population density maps for the city of Vienna, Austria, based on census tracts (A) and based on disaggregation using land cover at building block level (B). The "sharpened" real-world population distribution is clearly visible in image B. Credits: GeoVille Austria



[2] Degree of population redistribution between daytime and night-time in Spain, derived based on census data disaggregation using land cover data. Credits: Geoville Luxembourg.

The temperature in densely urbanised areas can be several degrees higher than in nearby rural areas – a phenomenon known as the "urban heat island" (UHI) effect. These heat islands are particularly noticeable at night. During the day, cities accumulate solar radiation and release the energy after the Sun sets, city centres reaching temperatures up to 10°C warmer than surrounding rural areas.

In cold climates, the same EO-based continuous monitoring of thermal radiation emitted by urban surfaces can deliver useful maps of energy efficiency.

When integrated into urban meteorological and climate models, EO-based data together with ground truth data improve surface temperature forecasts, helping in mitigating the negative effects of UHIs (i.e. through maps of population vulnerability).

Typical UHI products are produced at mesoscale resolution (1 km). Forecast maps of surface temperature are typically produced at 0.25–3 km resolution up to 4 days into the future.

Due to the current characteristics of the satellite sensors, a regular and efficient monitoring of UHI at night is possible only at 1km resolution. Nevertheless, 1 km UHI products derived from satellite data in geostationary orbit can be delivered continuously several times per hour, thereby contributing to the monitoring of temperature anomalies in the summer period, during heat wave events.

Thermography products derived from satellite data at 100 m spatial resolution are sometimes too coarse for energy efficiency studies.

More research and development of suitable algorithms and models are required, especially at higher resolutions, i.e. modelling of urban canopy-level processes and inclusion of ancillary data such as street and building width/height, traffic heat release, etc.

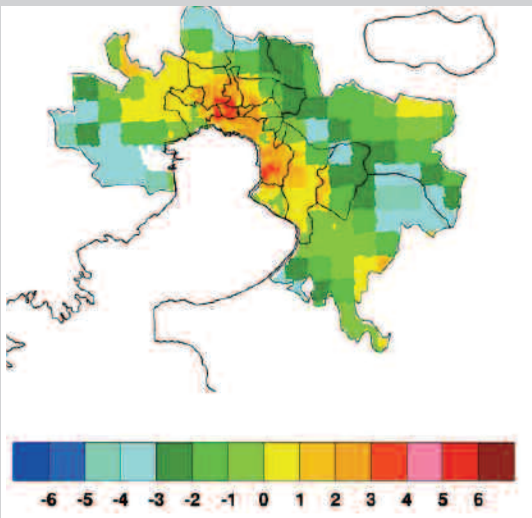
Over the last decade, heat waves have claimed an increasing number of casualties among the elderly, particularly in southern Europe. Prolonged periods of high temperatures also put a strain on medical and water resources, air quality, and place an additional financial cost to society as a whole. Another consequence of UHIs is that energy consumption rises with the increased use of air conditioners and refrigeration appliances. Satellite monitoring of UHIs can help mitigate these negative effects.

The cost of these monitoring services is typically low.

The Sentinel-3 mission will improve the quality of land surface temperature data and the revisit frequency (approximately daily acquisitions as a result of using two satellites). However, limitations in the spatial resolution of UHI products (1 km) remain.

[1] Urban Heat Island intensity forecast (°C) at 03:00 UTC, 2012 August 17 over the city of Thessaloniki, Greece. At night, the most vulnerable areas of city retained high temperatures, above 31°C. The small area within the urban centre both temperature and risk were expected to be low, corresponding to an open space with abundant vegetation cover. Credits: Laboratory of Atmospheric Physics Aristotle University Thessaloniki, National Observatory of Athens. Laboratory of Atmospheric Physics Aristotle University

[2] Mean air temperature in Paris, France at 22:00 CEST in summer 2003. During that summer, large portions of Europe were struck by a major heat wave. Paris was affected severely because the urban heat island effect prevented the city from cooling during the night, leading to thousands of heat-related deaths. Credits: VITO, Planetek.



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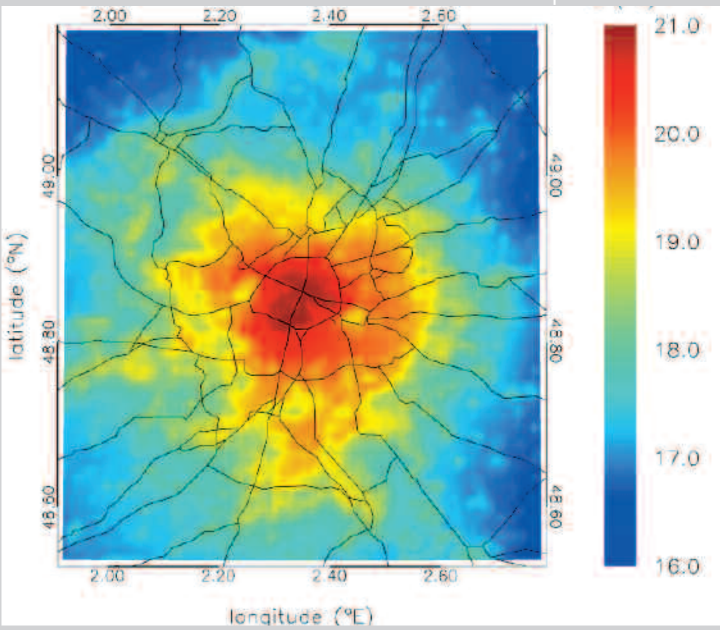


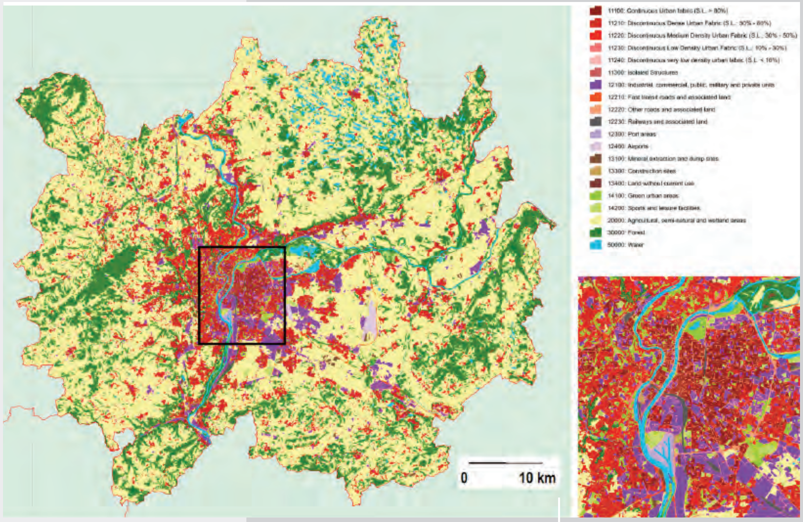
[2]

GMES URBAN ATLAS

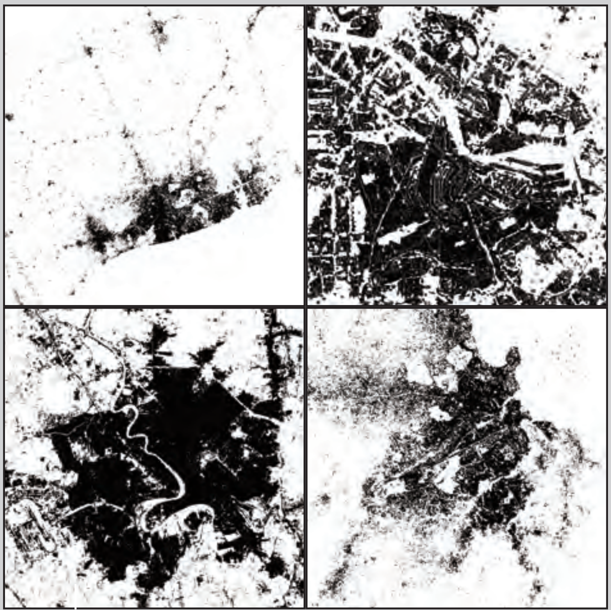
An operational example of consistent and large-scale urban monitoring effort is the GMES Urban Atlas, a GMES project funded by the European Commission (DG REGIO) presently providing reliable and inter-comparable detailed and cost-effective land use maps for 305 EU Large Urban Zones with more than 100000 inhabitants. It comprises 22 thematic classes, with a MMU of 0.25 ha for the urban areas and 1.00 ha for other surrounding areas. Because the Urban Atlas classifies urban functional zones, i.e. the dominant use of city blocks, it opens the way for fruitful inter-city comparisons on factors such as industrial or residential density, green areas, and urban sprawl.

Future editions of Urban Atlas are planned every three to five years, communicating on the evolution of cities. Maps, GIS data and metadata reports can be downloaded for each covered area at

www.eea.europa.eu/data-and-maps/data/urban-atlas



Urban mapping example for the city of Lyon, France. Credits: Urban Atlas.



Details of the DLR Global Urban Footprint product for, from left to right: Accra (Ghana), Dar es Salaam (Tanzania), Baghdad (Iraq) and Amsterdam (Netherlands). Credits: M. Marconcini (DFD-DLR).

GLOBAL URBAN FOOTPRINT

The Global Urban Footprint (GUF) is a dataset produced by DFD-DLR (German Remote Sensing Data Center of the German Aerospace Center). The fully-automated processing system detects and extracts built-up areas from very high resolution radar satellite imagery. The result is a global binary settlement mask that outlines urban and non-urban areas at the unprecedented spatial resolution of approximately 12 m. A public domain version of it will be made available at the resolution of 50–75 m. With its global coverage and the enormous spatial detail, this initiative represents a promising contribution to global analyses of urban and peri-urban areas.

→ DISASTER RISK MANAGEMENT

Related World Bank Programmes and initiatives

Examples of World Bank related initiatives to which this section is pertinent: Global Facility for Disaster Reduction and Recovery (GFDRR), GFDRR Post Disaster Needs Assessment (PDNA), Pilot Programme for Climate Resilience (PPCR), Catastrophe Deferred Drawdown Option (CAT-DDO), etc.

Addressing Development Challenges

Main World Bank related topics against which EO capabilities are available:

- Disaster response - natural hazards: support to Crisis Mapping/Damage Assessment
- Early Warning/Alert of natural hazards
- Disaster response - man-made disasters: support to Crisis Mapping/Damage Assessment concerning industrial accidents, chemical spills, etc.
- Critical infrastructure monitoring
- Post Disaster Needs Assessment (to support the evaluation of early and long-term recovery needs and priorities)
- Support to Recovery / Reconstruction / Rehabilitation (Natural Disasters)
- Exposure Mapping to support Preparedness/Mitigation, Early Warning & Response
- Risk Assessment (geo-hazards):
  Hazard Mapping to support Mitigation/Prevention / Preparedness
- Risk Assessment (hydro-meteorological hazards):
  Hazard Mapping to support Mitigation/Prevention / Preparedness
- Risk Assessment (climatological hazards):
  Hazard Mapping to support Mitigation/Prevention / Preparedness

The potential of EO Information Services

Actors involved in the Disaster Risk Management (DRM) process at local, national, regional and international levels have observation needs that can be divided according to purpose along hazards, exposure and vulnerability. Satellite based geo-information can contribute to the entire cycle of risk management including mitigation, warning, response and recovery. Currently much of the focus of the EO sector activity is on the immediate response phase, during which rapid action can save lives and properties. This is primarily the result of initiatives such as the International Charter Space and Major Disasters http://www.disasterscharter.org, Sentinel-Asia and Europe's GMES. Concerning other phases of the risk management cycle it is however widely accepted that increased efforts on risk reduction during the mitigation and warning phases of a disaster will save more lives and protect property by reducing the exposure of populations to the hazard. To reduce the severity of disasters EO can contribute to refined risk assessment by providing up to date localisation and characterization of the asset at risk; information to support prevention plan elaboration; supporting anticipation and early warning as well as crisis response and help better understand the resulting environmental damages and natural recovery mechanisms.

BASIC EO CAPABILITIES

CUSTOMISED SERVICE

EO PRODUCTS/DATASETS

→ BASIC MAPPING / REFERENCE MAPPING

Information content
Basic mapping products or background mapping products are generic terms designating maps elaborated using satellite EO data ex archive or recent acquisitions. Reference mapping products inform users on the state of an area before the crisis event e.g. using imagery acquired before the hazard impact for natural disasters (within 24 hours). They generally are supplied in a rapid fashion. Basic mapping products and Reference mapping products include as minimum information the distribution of roads, rivers, and highly populated urban/peri-urban areas, including height information and administrative boundaries.

Resolution, Frequency and Availability
The spatial resolution is in the range of a few meters. Typically Very High Resolution (VHR) Optical data allow to elaborate maps at 1:5000 to 1:10 000 scale and 1:25 000 to 1:50 000 using HR Optical. The date and update frequency of the map depends on the satellite observations used; typically recent and updated observations using Optical VHR and HR sensors are available globally depending on cloud coverage. Some regions have very frequent cloud coverage such as for instance in parts of the tropical belt. As a surrogate all weather SAR based basic mapping can be provided.

Accuracies and Constraints
The geometric accuracy depends on spatial resolution of input EO data, typically < 1 pixel i.e. a few meters. The absolute location accuracy depends on the sensor and can be of a few meters with most VHR sensors; combining SAR ascending and descending data using space triangulation can provide very accurate 'virtual GPS network' allowing geospatial surveying without in situ data in remote or inaccessible regions.

Benefits and Use
Basic mapping underpins almost all the mapping services provided in disaster management and humanitarian aid projects using satellite EO. It provides the base layer information as a standardised geographical reference dataset that users can utilise to determine key geographical attributes of a given area.

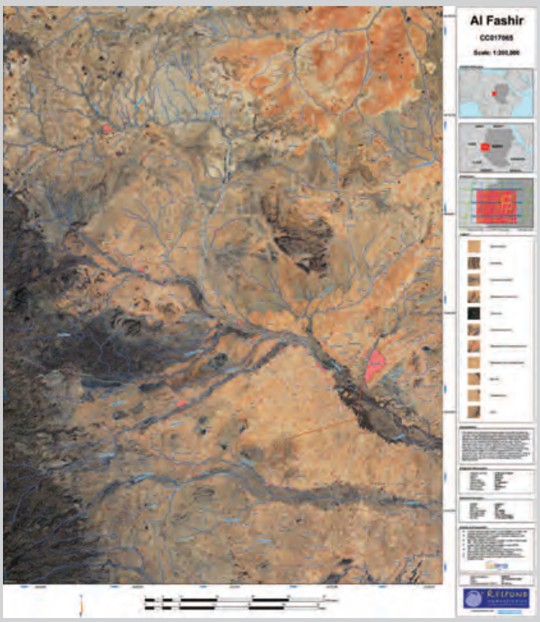
Indicative Costs
The service cost is in the range 1-15 kEuro (not including data) for a unit area within the size of a satellite footprint (typically a width less than a few tens of km), depending on the sensor class and site extent. The cost of the required data is in the range of 1-10 kEuro per scene depending on data type. Some of the data sources are at no cost (in the Medium Resolution to HR class).

The Contribution of the Sentinel Missions
Sentinel-2 will routinely provide 10 m resolution optical images globally with frequent 12-day revisits. Sentinel-2 aims at ensuring continuity of Spot- and Landsat-type data, with improvements. The spatial and spectral characteristics of the sensor are useful to mapping applications at scales up to 1:50 000.The Sentinel-2 Multi-spectral Instrument (MSI) features 13 spectral bands from the visible and near-infrared (VNIR) to the short-wave infrared (SWIR), featuring four at 10 m, six at 20 m and three at 60 m resolution.

[1] Example of Basic Mapping of Banda Aceh, Sumatra; following the December 2004 Tsunami; this city map was updated with in situ to help locate the min recovery infra-structure, medical centres and other humanitarian structures; thousands of hard copies of this map were distributed on the ground to the general public and to actors of the international humanitarian community. Credits: Keyobs.

[2] Example Basic Mapping of Al Fashir in Northern Darfur, Sudan - the map includes road networks, rivers, wadis and settle-ments. Credits: Astrium Geo-information Services.

[1]



[2]

Information content
Up to date mapping of urban areas, isolated buildings and infrastructure in risk prone areas.

Resolution, Frequency and Availability
The date and update frequency of the map depends on the date of the satellite observations used; typically recent observations using Optical VHR and HR sensors are available globally depending on cloud coverage. Some regions have very frequent cloud coverage. such as in tropical zones, making reliable Optical VHR coverage difficult to obtain. As a surrogate, all weather SAR based basic mapping can be provided in these areas.
The service can be delivered at various observation scales. By using high and very high resolution satellite imagery different levels of accuracy can be provided. For overview purposes, decametric products (5 to 10-meter resolution) are provided, where metric products with a resolution between one meter and five meters can focus on small areas.

Accuracies and Constraints
The absolute location accuracy depends on the sensor and can be of a few meters with most VHR sensors. Combining SAR ascending and descending data using space triangulation can provide very accurate 'virtual GPS network' allowing geospatial surveying without in situ data in remote or inaccessible regions.

Benefits and Use
These products provide up-to-date, synoptic and objective infrastructure information to maintain information concerning the asset at risk. They can be used to provide improved knowledge of the potential impact of natural hazards in areas at risk.

Indicative Costs
For coverage at national level the service cost is in the range 50-100 kEuro (not including data) depending on the sensor class and site extent. The cost of the required data is in the range of 1-10 kEuro per scene depending on data type.

The Contribution of the Sentinel Missions
As for the basic mapping product / background reference mapping service, Sentinel-2 will provide access to large volumes of high resolution (approx. 10-20 metres) and regular repeat acquisitions (every 12 days).

Example of Asset Mapping product over the Sure river basin (Luxembourg); the product is based on VHR IKONOS imagery and highlights areas prone to flood risk (yellow) and building with recent construction date (red). Credits: Luxspace, Institut Gabriel Lippmann, Risk-EOS, ESA.

Information content

Crisis mapping/damage assessment concerning natural & man-made hazards relate to a pre-defined group of hazard types (see right panel). The service includes rapid provision of hazard impact maps (e.g. flood extent, active fires, etc.) and hazard damage maps (i.e. damage zoning). The service provides an assessment of the state or availability of infrastructure in areas during humanitarian crisis situations or after catastrophic events. An overview of the different types of crisis mapping/damage assessment products is given in Table xxx, next page.

Resolution, Frequency and Availability

The service is available on any scale (local starting at 1:5000/1:10 000 to global) on a 24/7 basis. The spatial resolution is in the range of a few meters depending on the satellite data used. Typically Very High Resolution (VHR) data allow to elaborate maps at 1:5000 to 1:10 000 scale and 1:25 000 to 1:50 000 using HR data. The service is based on the programming of different VHR/HR missions for rapid and repeat observations over a short period (typically a few days to a few weeks). This includes 'rush' tasking of satellites to obtain VHR & HR imagery and SAR & Optical and systematic observations using MR imagery. The Service makes us of reference mapping/ situation mapping.

Earthquake	
	Reference Mapping (pre disaster)
	Zonal damage assessment
	Detailed damage assessment (building level)
Flooding	
	Reference Mapping (pre disaster)
	Water body extent (at flood observation time)
	Flood water extent (observed flooded waters)
	Temporal evolution: flood water extent (multiple observation times)
	Detailed impact assessment
	Flood traces extent (comprehensive flood traces)
Landslide/Mudslide	
	Reference Mapping (pre disaster)
	Detailed impact assessment (mudflow extents)
Severe Storms/Hurricanes / Tsunami	
	Depending on the effect of the specific event either landslide scenario products or flooding scenario products apply; moreover the impact of severe storms or Tsunami can lead to product types similar to the product types for the earthquake scenario
Wildfire	
	Reference Mapping (pre disaster)
	Fire (hotspot) detection
	Fire (hotspot) monitoring
	Burnt areas
	Detailed impact assessment
Volcanic Eruption	
	Reference Mapping (pre disaster)
	Lava flow extent
	Ash plume extent
	Volcanic ash residue and/or lava flow (temporal evolution)
	Detailed damage assessment

[1] Crisis and damage map showing the impact of the 2005 Asian Earthquake in the Muzzafarabad region in Pakistan; the white area in the centre of the large image indicates where the land has slipped into the river below. [2] The smaller inset image shows the same area before the Earthquake. Credits: DLR, IKONOS imagery Copyright © 2001-2012 Satellite Imaging Corporation.


[2]
[1]

Accuracies and Constraints

The geometric accuracy depends on spatial resolution of input EO data, typically < 1 pixel i.e. a few meters using VHR Optical and VHR SAR data and in the range 10 meter using HR Optical & SAR data. The ability of Satellite EO to support damage assessment depends on the hazard type and sensor type and options therefore programming scenarii are based on certain hazard types. Timeliness is a key parameter and typically a crisis or damage map is produced within hours or days following a disaster. Timeliness is dependent on the type and number of EO mission programmed. Many EO satellites can be used typically HR and VHR Optical (High / Very High Resolution Optical e.g. Landsat, DMC, ALOS AVNIR, DEIMOS, SPOT 1-4, KOMPSAT RapidEye, US VHRO, SPOT 5, Pléiades, etc.) and VHR SAR satellites (such as e.g. Terrasar-X, CosmoSkymed, Radarsat 2). Data sources and sensor options depend on the hazard type. For example the preferred source for flood monitoring is all-weather SAR, the preferred source for earthquake damage assessment is VHR Optical.

Benefits and Use

The service provides up-to-date geographic information and situation assessment to help better organise, direct and mobilise national disaster management resources during emergencies and the international relief community concerning situations where humanitarian assistance is required.

Indicative Costs

The service cost is in the range 15-30 kEuro (not including data) for a site of typically 50 square km depending on the sensor class. The cost of the required data is in the range of 1-10 kEuro per scene depending on data type and some of the data sources are at no cost (in the Medium Resolution to HR class).

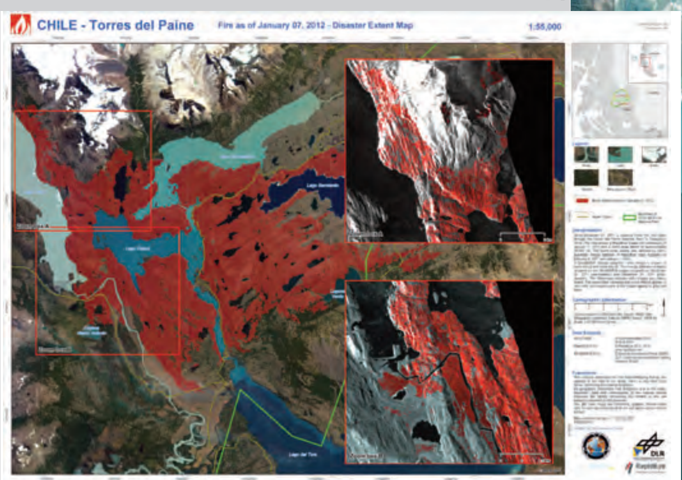
The Contribution of the Sentinel Missions

Sentinel-2 will provide access to large volumes of high resolution (approx. 10-20 metres) and regular repeat acquisitions. Sentinel-1 will provide access to large volume of all-weather C-Band SAR data at a resolution of around 20m. Both Sentinel-1 and Sentinel-2 will provide data at no cost that can be used for rapid and repeat observations of the impact of hydro-meteorological and geological hazards.

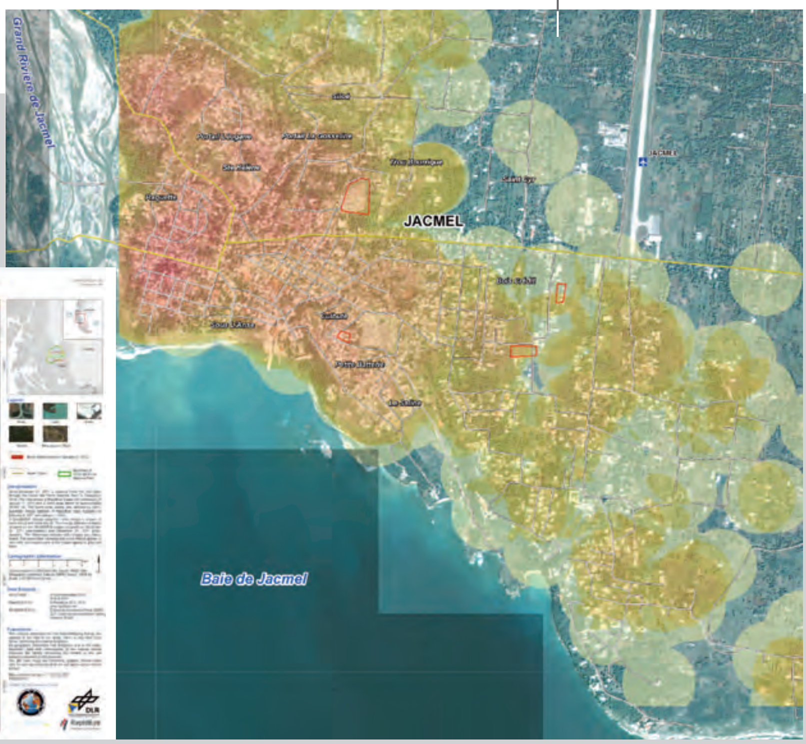
International Charter Space and Major Disasters

International Charter Space and Major Disasters

Globally the main mechanism to exploit space technology for response is the International Charter Space and Major Disaster (http://www.disastercharter.org), an international collaboration among Space Agencies to provide a unified system to access imagery for disaster response. With 14 members today the International Charter is able to provide rapid access to data from a virtual constellation of a series of satellites, optical and SAR, tasked in rush mode to help disaster management centres in relief actions. This activity is focused on hazards with rapid on-set scenarios, on the hazard impact, and aims to service operational users, not science users. EO data provided by the International Charter was for example invaluable for the emergency response and situational awareness during the 2010 Haiti earthquake.



[3] Example of a crisis and damage map showing the impact of the Torres del Paine wildfires in Chile in January 2012 using TerraSAR-X data and the change detection technique; Credits: DLR.



[4] Crisis and damage map depicting the damaged building density and gathering areas in Jacmel, Haiti, after the earthquake of 12 January 2010. The map was elaborated using Kompsat-2 imagery (1 m res.) acquired the 21st of January 2010. Credits: SERTIT, EC GMES SAFER project, International Charter Space & Major Disasters.

→ FLOOD RISK ANALYSIS

Information Content

The flood risk analysis service has the purpose to support risk assessment in the prevention/ preparedness phase. Mapping of past flood events and flood risk maps based on hydraulic simulation of flood potential damage assessment support flood risk management in the field and at decision making level. Typically a flood risk analysis service is produced outside the emergency-response phase and consists of producing and maintaining geo-information about areas potentially affected by floods. It comprises information about past and potential flood events and is composed of independent products such as flood inventory maps, flood duration per area, flood maximum extent, multiple flooding maps, maximum historical flood extent, flooding frequency per area, inundation depth, flood extent line, dike failure simulation, maps of estimates of return periods, flood simulation products, estimation of potential damages & losses, etc. The assessment of damages and losses is based on the correlation of flood extent with land use data and statistics. The assessment can be generated using actual (current or historic) or potential (simulated) flood events.

Resolution, Frequency and Availability

The spatial resolution is in the range of a few meters depending on the satellite data. Typically VHR data allow to elaborate maps at 1:5000 to 1:10 000 scale, 1:25 000 to 1:50 000 using HR data. The service historical requires collecting a large series of observation on flood events over the river basin. The preferred source for flood hazard mapping is the all-weather SAR although a range of EO sources can be used typically HR/VHR Optical and HR/VHR SAR sensors.

Accuracies and Constraints

The geometric accuracy depends on spatial resolution of input EO data. Typically < 1 pixel i.e. a few meters using Very High Resolution (VHR) Optical and VHR SAR data and in the range 10 meter using HR Optical or SAR data. To characterise flood pattern and estimate return periods requires frequent EO data collections with observations of flood phenomena over a long time scale.

Benefits and Use

The service provides information to support risk management and water resources management. Depending on input data and methodologies used, different types of information can be extracted, such as the classified distribution of the land cover and socio-economic units in areas at risk or hazard damage information based on measurements of water depth and/or flow velocity.

Indicative Costs

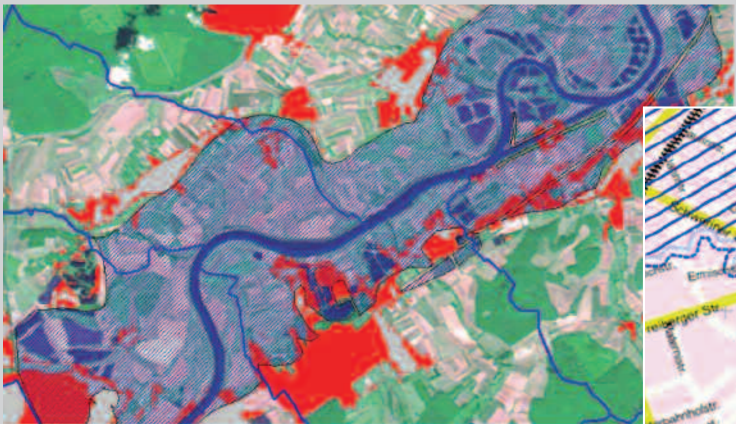
The service cost is in the range 25-80 kEuro (not including data) for a site of typically 50 square km depending on the sensor class and is in the range of 100-200kEuro for the extent covering a full river basin. The cost of the required data is in the range of 1-10 kEuro per scene depending on data type and some of the data sources are at no cost (in the Medium Resolution to HR class).

The Contribution of the Sentinel Missions

Sentinel-1 will provide access to large volume of all-weather C-Band SAR data at a resolution of around 20m. The mission will provide data at no cost that can be used for repeat observations of the impact of hydrological events to support risk analysis.

[1] Example of utilisation of flood extent data in combination with geographic information on urban land. Credits: SERTIT, VISTA.

[2] Overlay of historical flood extent on urban sprawl to help infer hazard risk; example showing the planned urban growth (blue); flood prone areas processed by SERTIT. Credits: SERTIT.



[1]

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Information Content

The historical terrain deformation mapping is a dense map of individual measurement points of land motion histories; it is precise (millimetric accuracy) motion data measured in the direction of the satellite (almost vertical) and at high resolution (typically 20 m in the horizontal plane). This historical product contributes to risk assessment (geo-hazards) to support Mitigation/ Prevention/ Preparedness and is based on High Resolution SAR data ex archive such as ERS and ENVISAT ASAR data.

Resolution, Frequency and Availability

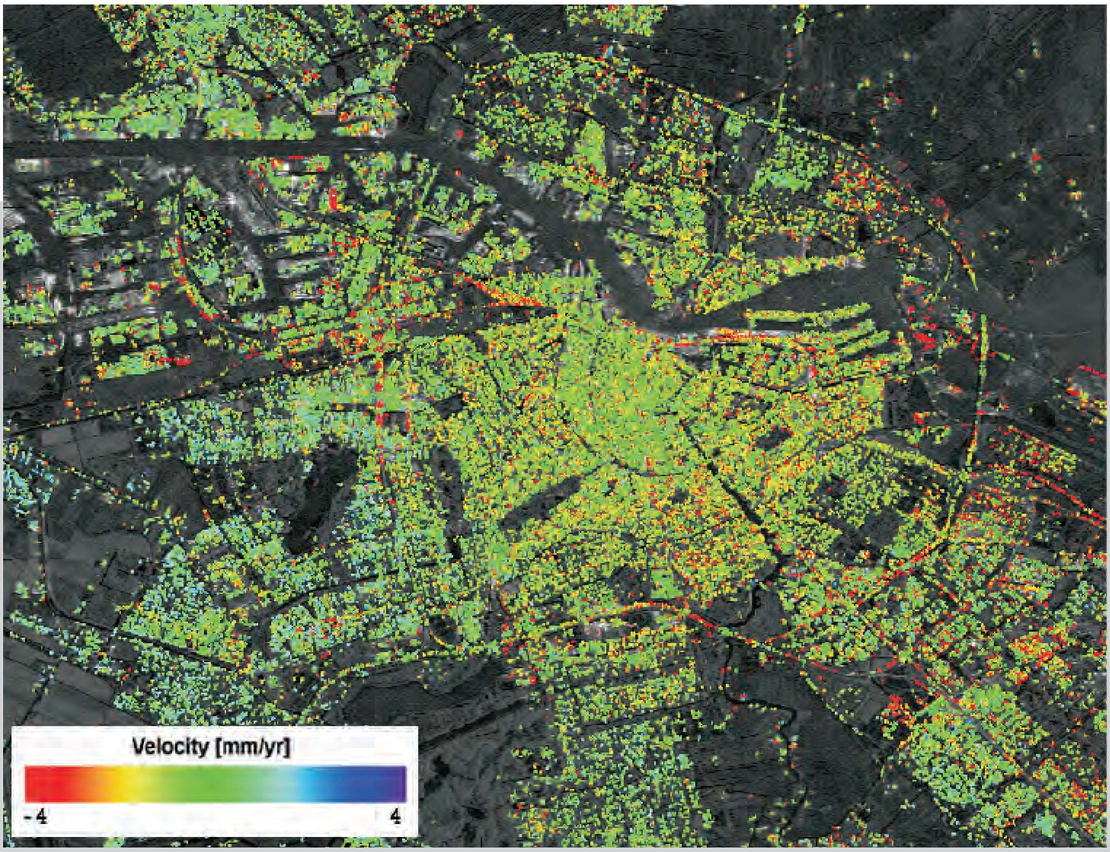
The period and update frequency depends on the SAR mission used. Typically the service is based on repeat acquisitions once every month approximately depending on the EO mission and a minimum of 20-25 scenes are required (typically several years). The product uses long time series i.e. last 15 years of interferometric SAR (INSAR) data. The time span is depending on SAR data available; for example thanks to their background mission strategies the ERS and ENVISAT missions provide all weather and high resolution radar data ex archive globally over more than 15 years.

Accuracies and Constraints

The geometric accuracy depends on the spatial resolution of input EO data, typically < 1 pixel. The Spatial resolution of the product has the following performances: High spatial resolution (better than 20 m), High absolute location accuracy (better than 20 m), High Relative planimetric accuracy (East-West better than +/-10m, North/South better than +/-5m). The land motion histories are calculated in the direction between the ground and the satellite i.e. with a dominant contribution from vertical deformation compared to horizontal. By combining ascending and descending passes it is possible to derive absolute 3D motion vectors of the terrain velocity points.

Benefits and Use

The service contributes to geo-hazard risk assessment to support Mitigation/Prevention/ Preparedness. There is a wide range of risk management policies for which terrain-motion information is of direct relevance. The applications for the service range from local policies on historical building inspection to flood risk mapping policies. Furthermore, a variety of users have expressed intentions to apply the service in different policies covering a range of applications that could not have been predicted previously. Today, terrain-motion data is being highlighted in a variety of different directives (i.e. Flood, Landfill and Critical Infrastructure Directives in Europe) as well as international climate change related policies. The service supports users such as civil protection agencies, disaster management organisations, and coastal, rail and motorway authorities in the process of risk assessment and mitigation. In conjunction with expert interpretation by geoscience organisations, the service can



Historical precise terrain deformation mapping product at high resolution over Amsterdam, NL; product generated by TRE (IT) using 10 years of High Resolution C Band ERS SAR data from 1992 to 2002; urban area including autonomous and spatially uncorrelated terrain-motion over the 9.5km route of the new N-S metro line. Credits: TRE (IT).

provide ground motion hazard information (see section Customised Services).

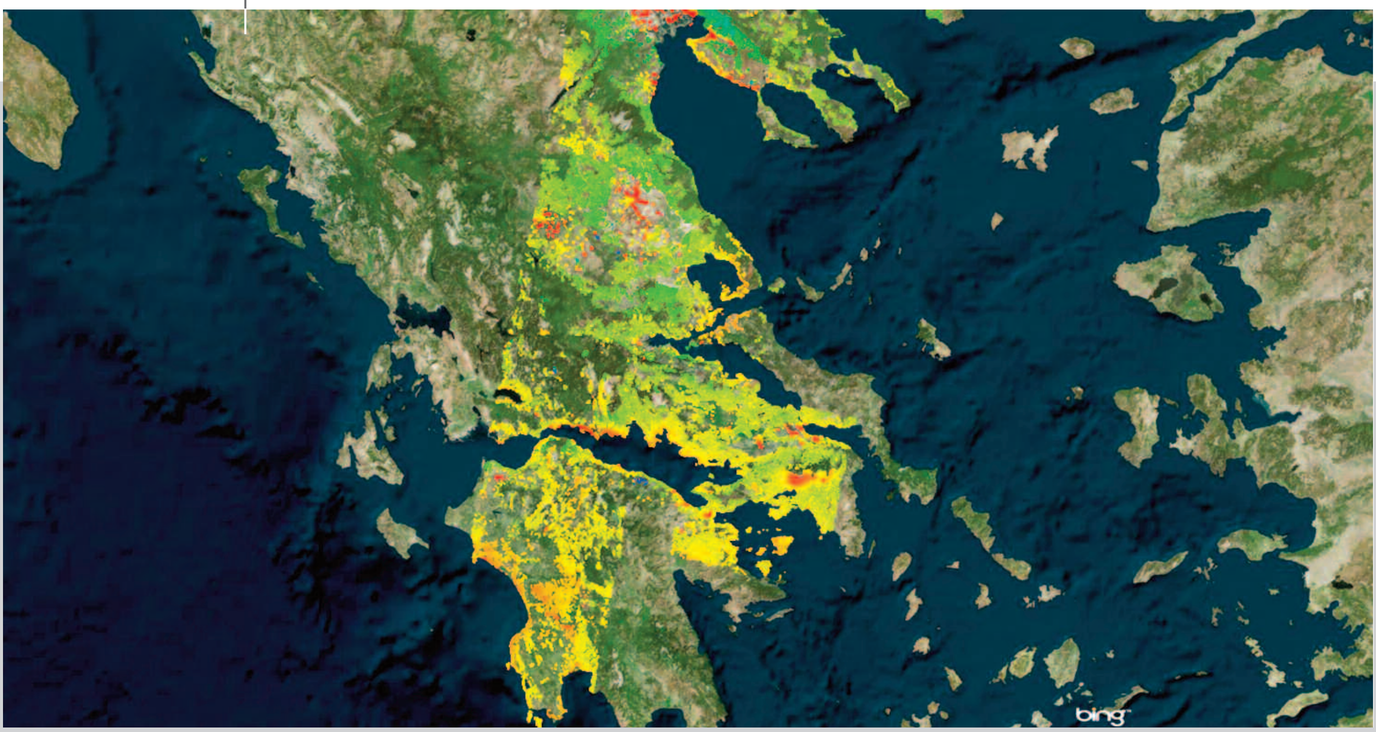
Indicative Costs

The service cost is in the range 20 kEuro (excluding data) for the terrain deformation measurements for a site of extent. The cost of the required datastack is in the range of 0-10 kEuro depending on data type and stack size (period covered, minimum 20 observations) and data includes data at no cost (e.g. ESA archive data).

The Contribution of the Sentinel Missions

Sentinel-1 will provide access to large volume of C-Band SAR data useful for terrain deformation mapping that will be used to obtain large extent terrain deformation assessment at a resolution of around 20m and at reduced cost. This is in continuity with the capability of C Band SAR missions such as ERS, ENVISAT and RADARSAT.

Two-dimensional example of wide-area mapping of terrain deformations over mainland Greece. This deformation map covers 65 000 sq km – approximately half of the country's territory. This map was created using 10 individual ERS-1/2 stacks, each stack being a time series of 58 to 76 SAR images acquired from 1992 to 2003 for a total of 671 images. Credits: DLR



Information Content

The current monitoring of terrain deformation service is a dense map of individual measurement points of land motion over a short time span (a few weeks or months); it is precise (millimetric accuracy) motion data measured in the direction of the satellite (almost vertical) and at very high resolution (typically 5m in the horizontal plane). This monitoring service contributes to geohazard risk assessment to support Mitigation/Prevention/Preparedness and crisis monitoring to support emergency response and recovery. Generally this service is based on Very High Resolution SARs such as for instance TerraSAR-X, Cosmo Skymed or RADARSAT-2.

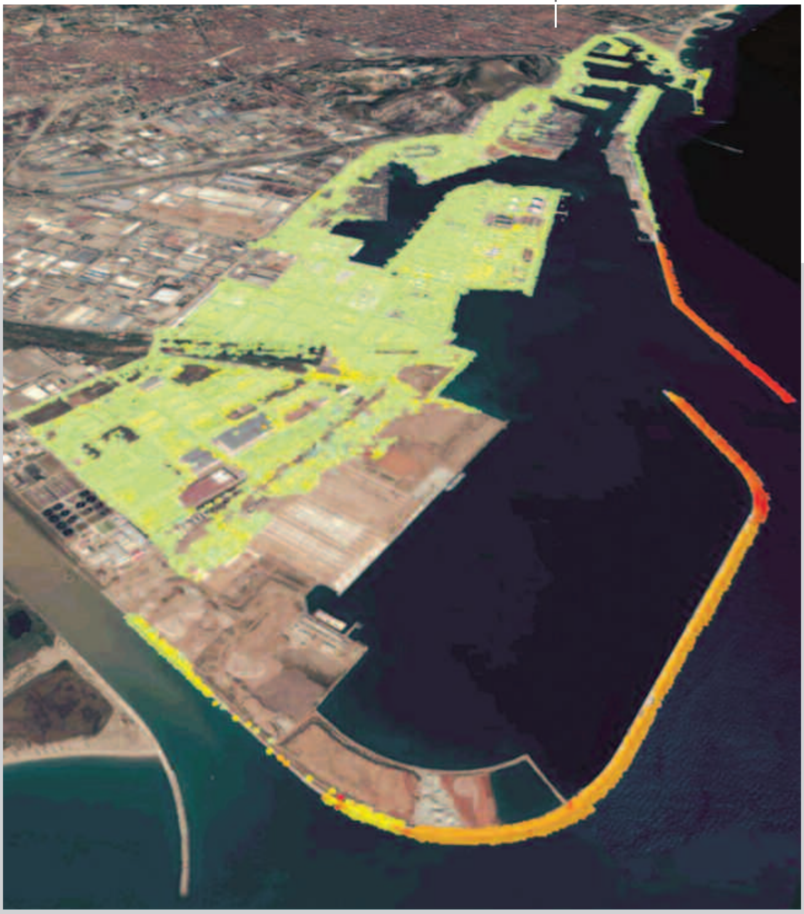
Resolution, Frequency and Availability

The period and update frequency depends on the Very High Resolution SAR mission used. The service is based on repeat acquisitions typically 1 to 4 times a month, depending on the EO mission, and a minimum of 20-25 scenes are required, typically a few months using current missions. Longer periods are generally used in order to have a strong displacement signal in the measurement dataset. The product either provides a single collection of measurements of terrain deformations over the covered period or it is supplied as monitoring service with regular updates of the measurements. The time span of the product is depending on SAR data available, typically limited and recent as Very High Resolution SAR missions generally do not provide dense stacks of data ex archive like High Resolution SAR missions as for the historical terrain deformation mapping product.

Accuracies and Constraints

The geometric accuracy depends on the spatial resolution of input EO data, typically < 1 pixel. The Spatial resolution of the PSI product has the following performances: Very High spatial resolution (around 5 m), High absolute location accuracy (better than 2 m), High Relative X, Y accuracy (metric in both East-West & North/South directions). The land motion histories are calculated in the direction between the ground and the satellite i.e. with a dominant contribution from vertical deformation compared to horizontal. By combining ascending and descending passes it is possible to derive absolute 3D motion vectors of the terrain velocity points. The motion estimation has an accuracy better than a few mm/yr. The density of measurement points depends on the type of area observed but can reach very high values over urban/peri-urban land (typically several tens of thousands of measurement points per km2). Generally the ability to produce measurement points and their density is related to the nature of targets on the observed area; for example, densely vegetated areas have few measurement points while there are many in urban/peri-urban land. To mitigate this constraint an alternative to the radar based terrain deformation monitoring product is the Corner Reflectors (i.e. CR-INSAR) technique that is using artificial point targets i.e. man-made reflectors anchored to or near the structure or region to be monitored

Example of precise terrain deformation monitoring product at very high spatial resolution: TerraSAR-X based terrain deformation map of Barcelona Port. Colour coding indicates subsidence rate measured over Jan-Nov 2009, where green indicates stable areas and red 15 cm/year. This product was generated using the PSI processing technique. Credits: Altamira Information; TerraSAR-X data: copyright Astrium Geo Information Services. Background image: Microsoft Bing Maps.



such as for instance a dam, tunnel, the flood defence system, landslide etc. Such reflectors and natural reflectors with stable radar response over time (with regard to the radar intensity and phase information) allow to apply interferometry over areas that normally suffer from coherence loss and measurement artefacts.
Generally the product is supplied with reference maps using Optical imagery and a DEM for visualization purposes.

Benefits and Use

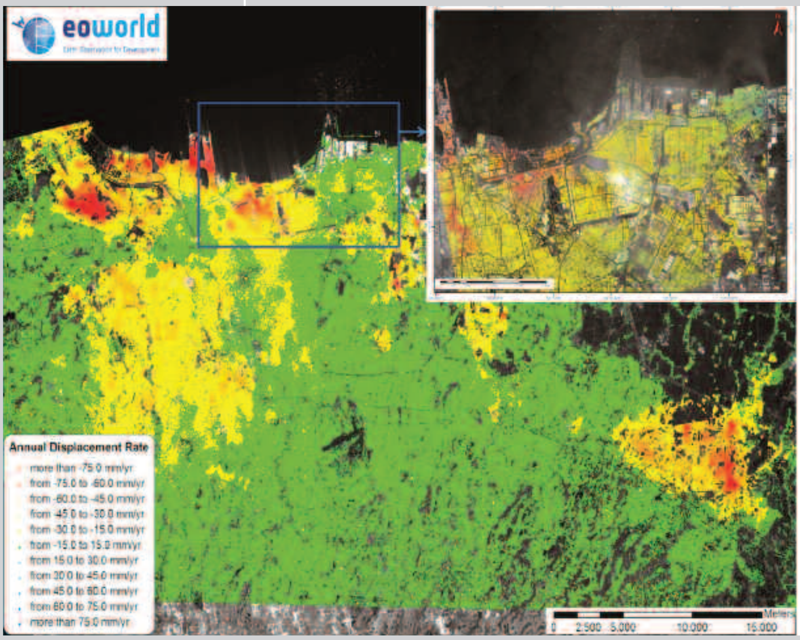
See description of 'Historical precise terrain deformation mapping product at high spatial resolution'.

Indicative Costs

The service cost is in the range 50-70 kEuro (excluding data) for the terrain deformation measurements for a site of extent 30x30km. The cost of the required datastack is in the range of 50-150 kEuro depending on data type and stack size (period covered, minimum 20 observations).
Very High Resolution SAR based products provide deformation mapping and monitoring at very high resolution and with a very high density of measurement points.

The Contribution of the Sentinel Missions

In continuity with the capability of C Band SAR missions such as ERS, ENVISAT and RADARSAT, Sentinel-1 will provide access to repeat acquisitions of C-Band SAR data useful for PSI based deformation mapping and allowing frequent monitoring of terrain deformation. In particular to expand from motion mapping to regular monitoring the planned constellation of two platforms Sentinel-1A and Sentinel-1B will provide interferometric capabilities with repeat observations every six days.
Sentinel-1 will provide SAR data at a resolution of around 20m and at reduced cost that will be complementary to Very High Resolution products providing wide extent historical measurements to characterise a site prior to very detailed measurement using Very High Resolution missions.



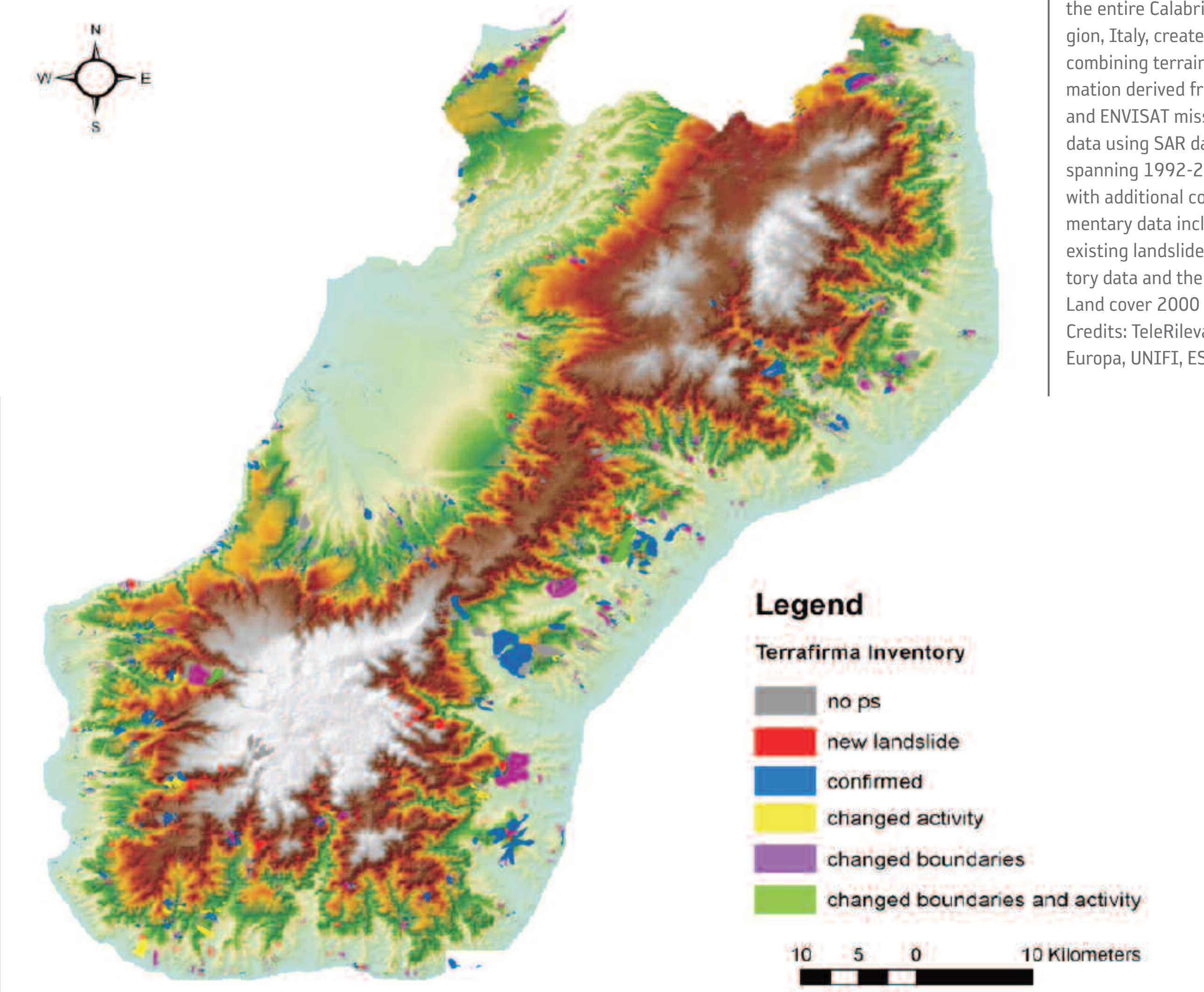
Coastal lowland subsidence monitoring service: historical precise terrain deformation mapping product at high resolution (central) and very resolution (top right insert) over Jakarta; scale of very high resolution product is 1:30.000 and based on the analysis of COSMO-SkyMed data acquired from October 2010 to October 2011. Credits: Altamira Information, Background image SPOT-5 copyright CNES distributed by Spot Image.

The thematic services derived from the historical precise terrain deformation monitoring product at very high spatial resolution and/or the precise terrain deformation mapping product at high spatial resolution are integrating generic terrain deformation with external data, expert interpretation and possibly modeling techniques. They contribute to risk assessment (geo-hazards) to support Mitigation/Prevention/Preparedness.
They are available for a number of application themes:

Hydrogeology (groundwater management, landslides and inactive/abandoned mines), for hydrogeological hazards affecting urban areas, mountainous areas and infrastructures. This is focusing on urban and mountainous areas, concerning the ground motion directly or indirectly connected with the hydro-geological systems. The expected causes of ground motion should be mainly linked to groundwater overpumping and recovery from pumping, mining, above ground and underground construction and slope instability. Landslide services comprise landslide inventory products, terrain deformation maps over large areas i.e. entire watershed basins, integrated into a pre-existing landslide inventory created using conventional geo-morphological tools, and the landslide monitoring product, terrain deformation maps across specific landslide events as identified within an inventory product and based on historical and up to date/continuous satellite observations.

Examples of EO service include:
- Landslide Inventory service
- Landslide Monitoring service
- Hydrogeology/Ground Water Management service
- Thematic Modelling service
- Abandoned/Inactive Mines service

Tectonic theme (fault creep mapping and soil vulnerability mapping); services that present information on seismic hazards and that are established by end-user needs. The services are customised to allow product integration into geo-information systems. There are two services: the first is the crustal block boundaries service, based on the analysis of terrain deformation



[1]

[1] Risk Assessment to support Mitigation/Prevention/Preparedness (Geo-hazards, landslides) – Example of a landlside inventory product over the entire Calabrian region, Italy, created by combining terrain deformation derived from ERS and ENVISAT missions' data using SAR data spanning 1992-2006 and with additional complementary data including existing landslide inventory data and the CORINE Land cover 2000 map. Credits: TeleRilevamento Europa, UNIFI, ESA.

measurements to investigate surface movements, and to discriminate different crustal blocks. It has the aim to help investigate major and local faults, to support analysis of the earthquake cycle and to assess vertical deformation sources in urban areas. The second is the vulnerability map service, based on very dense spatial data and detailed measurements of surface displacements, used as input to be added to in-situ measurements to compute vulnerability maps. It has the aim to contribute to the investigation of possible causes of surface movements as well, providing the discrimination between primary tectonic displacements and seismically induced movements.

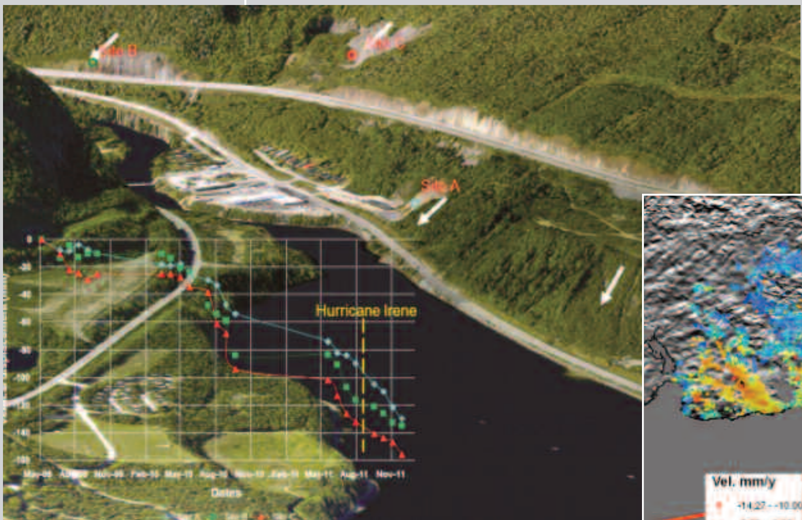
Examples of EO service include:
- Tectonic/Crustal Block Boundaries service
- Tectonic/Soil Vulnerability service

Coastal lowland theme (coastal lowland subsidence mapping and flood defense structure monitoring). These services support mitigation of flood risk in coastal urban lowland by providing geo-information related to the hydraulic network and investigations of possible land subsidence and the flood defense system (i.e. dykes, sea wall, etc.). They comprise the basic wide area service, that is the combination of terrain deformation measurements over extended regions prone to flood risk using multiple scenes; the flood plain subsidence mapping service, that is the integration of the deformation measurements with ground truth data, notably leveling data and GPS, and geological data and information to develop a service which enables users to interpret subsidence maps within their geodetic reference system of use and to assess mechanisms of subsidence risk; the flood defense monitoring service, a focused application of terrain motion monitoring and evaluation of coastal defenses and flood protection systems.

Examples of EO service include:
- Basic Wide Area service
- Flood Plain Subsidence Mapping service
- Flood Defense Monitoring service

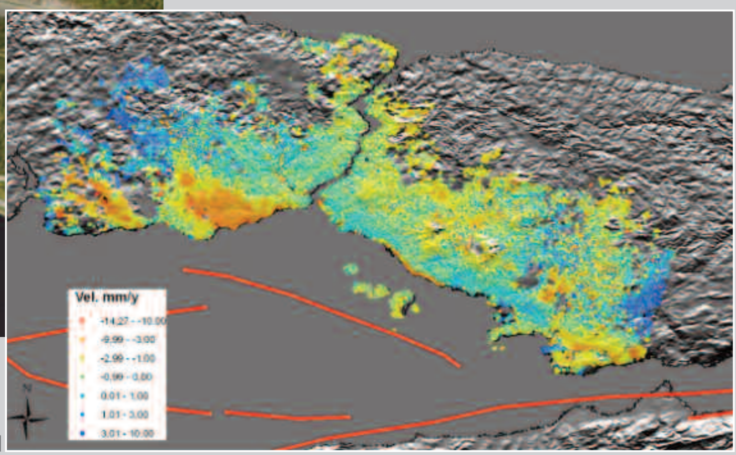
Benefits and Use

Such products can be used to further elaborate risk assessment information for example:
Multi-hazard vulnerability mapping concerning the risks of climate and disaster impacts (primarily coastal/ flood-plains) to provide quantitative and standardised metrics for cities to use in benchmarking risk over time and relative to peers.
Risk assessment based on methods to estimate hazard, exposure and vulnerability providing objective, uniform and inter-comparable assessments.
A high resolution DEM with a vertical accuracy better than a few meters (relative) and better than 10 meters (absolute) and a horizontal grid spacing better than 10 meters (X, Y). Precise DEMs derived from European EO sources such as VHR Optical SPOT-5 and VHR SAR (e.g. Tandem X data if available) may be pertinent. It is to be noted that the vegetation cover in Guyana is a limiting factor concerning most DEM generation techniques (both INSAR and stereo-optical).
Mapping of the stability of the flood defense system (sea defenses consisting of dikes, drainage canals, seawalls, sluices, etc.)
Accurate estimation of the effective rate of sea level rise for flood defense Estimates of sea level rise have been prepared using historical measurements provided by Guyana, but an accurate estimate of subsidence could be used in combina-



[2]

[2] Example of landslide monitoring product in the area of highway routes, Corner Brook, Newfoundland, Canada following the impact of Hurricane Irene. INSAR measurements using RADARSAT-2. Credits: Singhroy and Li (CCRS 2011), EO data: MacDONALD, DETTWILER & ASSOCIATES LTD. (2012), Canadian Space Agency, 2012 / Agence spatiale canadienne, 2012.



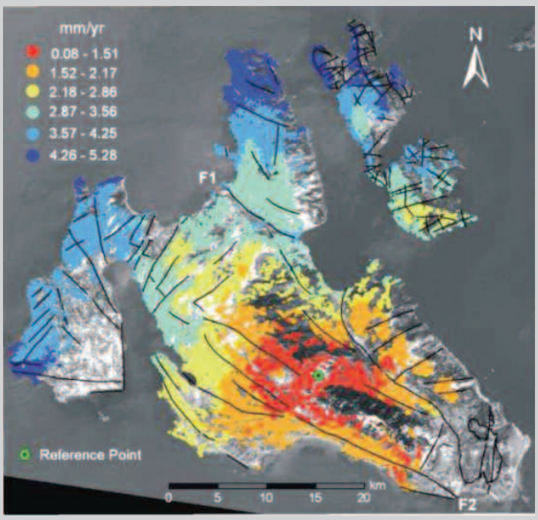
[3]

[3] Precise Terrain-Motion product to support Soil Vulnerability analysis over Istanbul, Turkey. PSI velocity map showing average annual ground movement in mm per year using SAR data (period: 1992-2001). Negative sign indicates subsidence (orange and yellow), green and turquoise are stable and there is indication of some small uplifting (darker blues). User organisation: Bogazici University, Kandilli Observatory and Earthquake Research Institute (KOERI). Credits: Tele-Rilevamento Europa, ESA.

tion with these estimates to calculate an overall combined rate to help planners know more accurately when the defenses would be regularly overtopped and hence effectively overwhelmed.

[4] Precise Terrain-Motion product to support Crustal Block Boundaries analysis over the Cephalonia Island, Greece, Standard Deviation of Velocity Field using ENVISAT Descending (2003 – 2008), Credits: NKUA, ESA.

[5] Terrain Deformation Mapping along the Netherlands' IJsselmeer dikes, Envisat's radar detected subsidence of 5 mm per year (in red) during 2003–10. Credits: GMES/Terrafirma/ Hansje Brinker; Envisat ASAR data: ESA.



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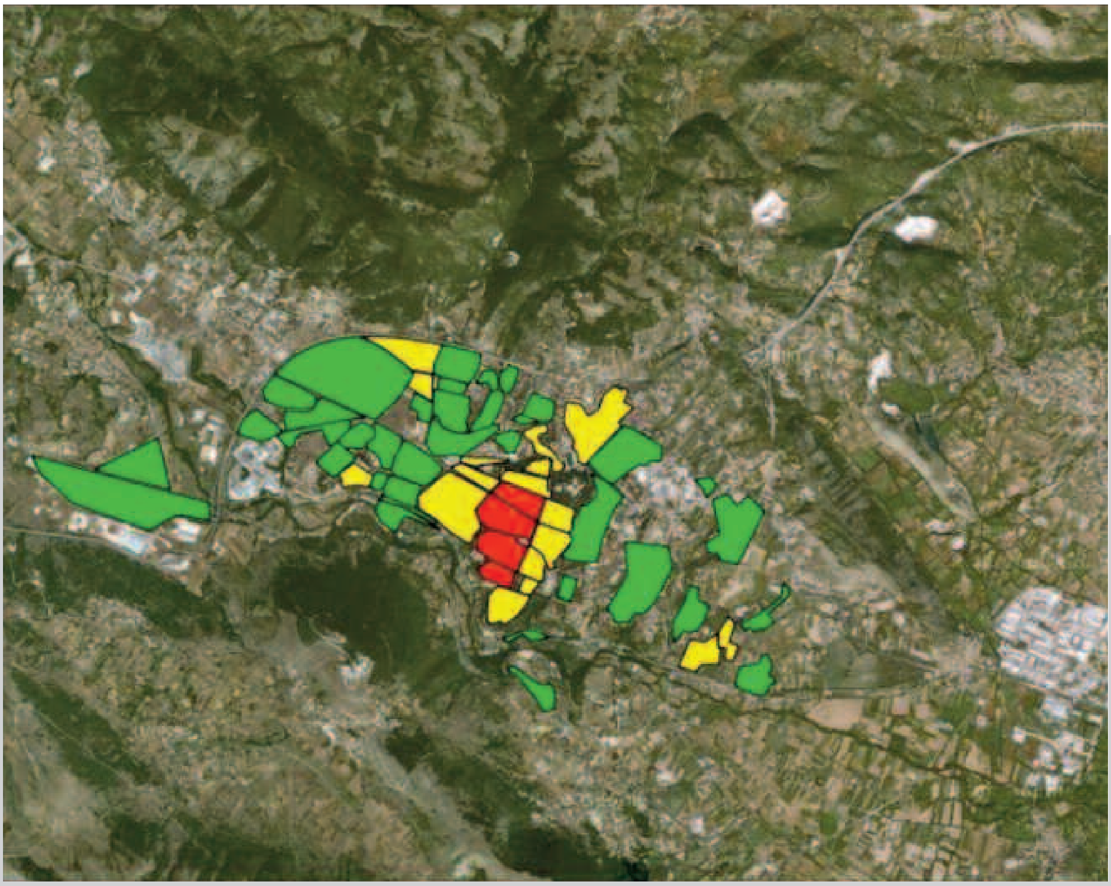
→ DETAILED DAMAGE MAPPING

The detailed damage mapping service has the purpose to support needs assessment in the recovery phase. It provides up-to-date geographic information concerning damage estimation to support PDNA in the phase following the immediate emergency response. Typically a damage assessment map is produced within days or weeks.

The service provides a detailed assessment of the hazard impact and is available on any scale (local to global) on a 24 hrs/7 days a week basis. The service is comprised of either damage zoning or precise damage mapping. The precision of the latter generally is limited, compared to airborne mapping, due to the spatial resolution of current satellites. The geometric accuracy depends on spatial resolution of input EO data, typically < 1 pixel i.e. a few meters using VHR Optical and VHR SAR data. The spatial resolution is in the range of a few meters depending on the satellite data. Typically VHR data allow to elaborate maps at 1:5000 to 1:10 000 scale, 1:25 000 to 1:50 000 using HR data. The service provides a detailed assessment of the hazard impact and is available on any scale (local to global) on a 24 hrs/7 days a week basis and is based on the programming of specific VHR missions for precise observations. Satellite mapping does not require authorizations to fly and provides objective information at a limited cost but the precision of airborne and ground based damage mapping methods is superior.

Many EO sources can be used typically VHR Optical (i.e. KOMPSAT RapidEye, US VHRO, SPOT 5, Pléiades, etc.) and VHR SAR sensors (such as. Terrasar-X, CosmoSkymed, Radarsat 2). Data sources and sensor options depend on the hazard type.

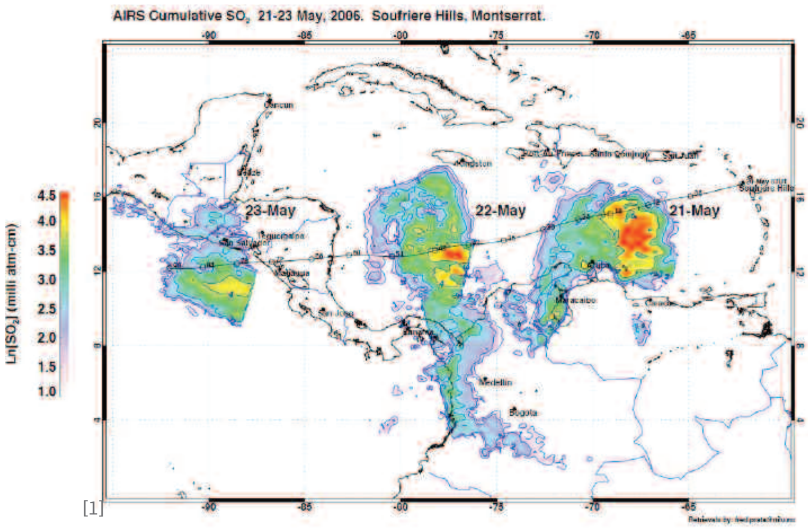
The service cost is in the range 20-60 kEuro (not including data) for a site of 50 square km depending on the sensor class. The cost of the required data is in the range of 1-10 kEuro per scene depending on data type and some of the data sources are at no cost (in the Medium Resolution to HR class).



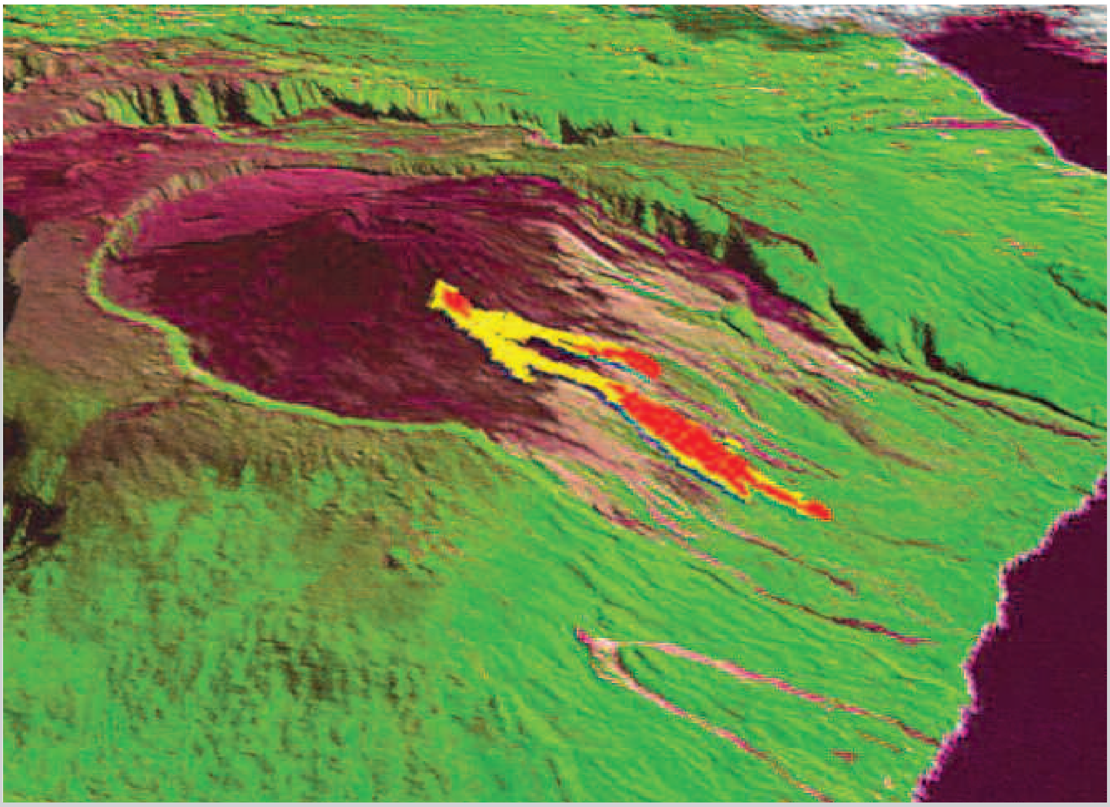
Satellite EO-based earthquake damage mapping to support post disaster damage assessment; GIS layer produced by the European Centre for Training and Research in Earthquake Engineering (EUCENTRE) for the Italian Civil Protection Department. The coloured polygons represent an estimate of the seismic damage level in three categories of damage intensity (up to 10% damage, greater than 10%, greater than 30%). The estimate is based on damage-related statistics from spatial features in a post-event very high resolution COSMO-SkyMed image of the area. Credits: EUCENTRE, ASI.

The volcanic hazard monitoring service has the purpose to support Early Warning & Emergency Response. By nature, a volcanic eruption is a local event that may turn into a trans-boundary one. Consequently, there are two categories of major, potential, systematic users of space-borne information on volcanic activity (monitoring and early warning) and volcanic hazards in general (risk exposure assessment and mapping). The first category is national, and is selected on a case-by-case basis by those responsible for disaster and risk management, or for giving scientific advice to those who make decisions to protect lives and property. Typically, the former is a Ministry or a mandated National Agency, whereas the latter is a volcano observatory, a geological survey or their equivalent. The second category is trans-national and, as such, has no authority over the territory containing the volcano. Typically represented by the Volcanic Ash Advisory Centres (VAACs) within a Meteorological Watch Office (MWO), the VAAC is an intermediate link between the World Meteorological Organisation (WMO), the International Civil Aviation Organization (ICAO) and individual airlines. Timely warnings from volcano observatories –where they do exist– on major ash and gas emissions are required.

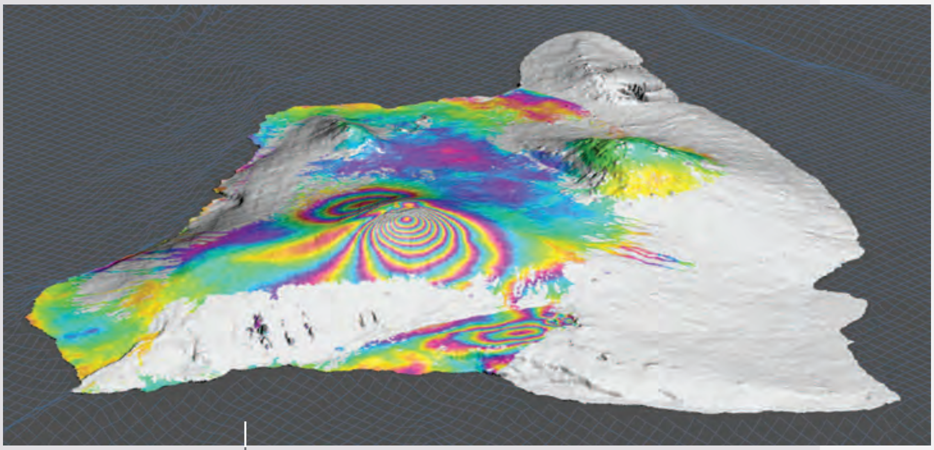
Satellite EO data are used for different facets of risk management concerning volcanoes and volcanic ash. Historical analysis using EO data can help identify and characterise eruption types and their probability of occurrence. EO-based monitoring is used to support the characterisation of the state of a volcano. This includes terrain elevation measurements and terrain deformation monitoring using space borne SAR data. Interferometry is now a recognised technique in the early detection of magma injection and in monitoring the stability of the underlying structure of a volcano. In addition infrared and multispectral sensors are useful for observations of the thermal output of an eruption and estimates of the height and behaviour of the eruption column and observations of the movement and extent of the ash cloud. In particular, thermal anomalies and estimates of gas and aerosol composition (source: Monitoring Volcanic Ash from Space, ESA-Publication STM-280. Doi:10.5270/atmch-10-01, C. Zehner, Ed., 2010).



[1] Soufrière Hills volcano, Montserrat, following the eruption of 20 May, 2006. The image shows SO2 retrievals on 7 consecutive days, from the Atmospheric Infrared Sounder (AIRS on board EOS-Aqua), to measure atmospheric profiles of temperature, moisture and trace gases for climate and weather prediction applications. Trajectories from an atmospheric dispersion model overlaid on the plot confirmed a high, stratospheric SO2 cloud. Cloud behaviour was monitored every 15 minutes using MSG-SEVIRI data. Credit Fred Prata, NILU, Norway.



[2] High-temperature thermal anomalies on the ground, Reunion Island, France. Lava flowing Piton de la Fournaise November 8, 2000, imaged by ASTER, Landsat-7 overlay. Credits: B. Hirn, IES Consulting.



Interferogram of the island of Hawaii derived from CSA's RADARSAT-1 mission. It shows ground deformation owing to the arrival of new magma under the Mauna Loa volcano.
Credits: University of Miami/CSA

THE GEOHAZARD SUPERSITES

In 2007, ESA and GEO convened the 3rd International Workshop on Geohazards in Frascati, Italy, which addressed geophysical risks and the contribution of EO to geohazard research. As a result, the Geohazard Supersites and Natural Laboratories (GSNL) were created and remain the premier contribution of satellite EO to geohazard research. The GSNL are an initiative of the international geohazard scientific community, providing access to spaceborne and in-situ geophysical data over selected sites prone to geohazards.

For the supersite areas the GSNL promote free exchange of all relevant data, including in situ, airborne, and space-borne observations, and the availability of the data for scientific studies. The GSNL provide access to space-borne and in-situ geophysical data of selected sites prone to earthquake, volcano or other hazards. The GSNL are supported by numerous partners including GEO, ESA, JAXA, NASA, DLR, ASI, CSA, NSF, UNAVCO and EPOS. Earthquake supersites exist in Istanbul (Turkey), Tokyo (Japan), Los Angeles (USA), Vancouver/ Seattle (Canada/USA) and Hawaii (USA). In addition, "event supersites" have been established after significant earthquakes. The GSNL were selected for scientific reasons but also to maximise the visibility of the project. They are not intended to be global in their reach, but to provide data for type examples of hazardous systems or natural laboratories.

http://supersites.earthobservations.org

THE SANTORINI CONFERENCE

Following the International Forum on Satellite Earth Observation for Geohazard Risk Management (the Santorini Conference), a joint ESA-GEO publication was released: the Scientific and Technical Memorandum of The International Forum on Satellite EO and Geohazards, 21-23 May 2012, Santorini Greece. doi:10.5270/esa-geo-hzrd-2012.

This publication provides the result of the assessment and discussions with users and practitioners concerning the contribution of satellite EO for risk management concerning geohazard themes such as volcanoes, landslides, seismic hazards, coastal subsidence and flood defence and inactive mine hazards.

http://esamultimedia.esa.int/docs/EarthObservation/Geohazards/esa-geo-hzrd-2012.pdf

→ COASTAL ZONE MANAGEMENT

Related World Bank Programmes and initiatives

Examples of World Bank related initiatives to which this section is pertinent: Global Partnership for the Oceans (GPO); Global Facility for Disaster Reduction and Recovery (GFDRR), Critical Ecosystems Partnership Fund (CEPF), Wealth Accounting & the Valuation of Ecosystem Services (WAVES), Pilot Programme for Climate Resilience (PPCR). In addition, some of the capabilities presented here are of relevance to activities within the Agriculture and Rural Development and Global Fisheries sectors

Addressing Development Challenges

Main World Bank related topics against which EO capabilities are available:

- Global Fisheries & Aquaculture
- Sustainable growth (energy, transport, fragmentation)
- Urban water and sanitation
- Natural/Cultural Heritage and Sustainable Tourism

The potential of EO Information Services

Information derived from satellite Earth Observation has been demonstrated to be of significant benefit and impact for enhanced coastal management. The capability to acquire imagery anywhere at a variety of spatial scales enables the systematic monitoring of changes in coastal conditions over periods of up to 20—25 years with new data every few days. Furthermore, these changes are observed consistently over a wide area due to the coverage of satellite imagery. This provides improved characterisation of coastal processes and consistent regional analyses, models and monitoring systems.

Over three decades of research guarantee that the extraction of coastal information parameters from satellite imagery is now considered scientifically mature and available on a fully operational basis. These include environmental parameters (chlorophyll concentration, transparency, sediment concentration, algal bloom occurrence), coastal metocean parameters (sea surface temperature, surface wave parameters, coastal currents, sea level variations such as storm surges) and hydrographic information such as coastal bathymetry, coastline location and changes in coastal morphology (e.g. erosion, deposition) over time. Satellite imagery also support assessment of coastal habitats such as sea grass beds, coastal mudflats, mangroves and coral reefs. Finally, satellite monitoring can detect pollution events to support timely cueing of response assets and the compilation of pollution statistics.

More complex analysis is also possible using customised versions of information sets described elsewhere in this report. Two of the most relevant examples are:

- climate change related coastal flood risk assessment can be supported through a combination of coastal subsidence measurements, coastal bathymetry change mapping and coastal ocean dynamics information (including storm surge risk. and changes in parameters such as sea surface temperature, sea surface height and surface wave statistics)
- climate resilience for new coastal infrastructure (e.g. new port developments) can be assessed using customised urban information for coastal areas together with the different satellite based coastal change mapping and coastal ocean information parameters identified above.

BASIC EO CAPABILITIES

CUSTOMISED SERVICE

EO PRODUCTS/DATASETS

Information Content

Two classes of information are available:

• Routine monitoring of water quality parameters to detect anomalies (e.g. algal blooms, temperature anomalies etc.) for coastal management and management of coastal facilities (e.g. aquaculture sites, desalination plants, water treatment facilities etc.

• Analysis of longer term trends and indicators (e.g. for assessment of climate resilience, environmental impact assessment etc.)

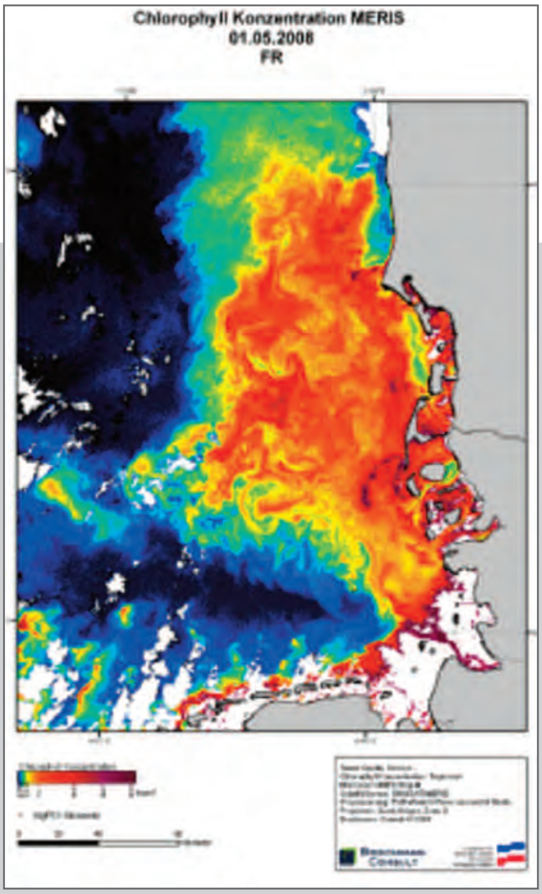
Any selection of the following parameters can be provided, depending on user priorities:

• Chlorophyll-A concentration in µg/l
• Transparency (or turbidity if required) in m-1
• Sediment concentration in µg/l
• Algal bloom detection and delineation
• Sea surface temperature in K
• Other customised parameters are available such as the delineation of the boundaries between different coastal water bodies including the boundary between turbid coastal waters and the more transparent open sea as well as frontal structures linked to river outflow, upwelling/downwelling and coastal currents

The information parameters are available in the following modes:

• For monitoring purposes, information can be daily samples or maps showing the values of the paramters averaged over a representative time period (typically weekly, monthly or seasonal). In addition to average values, p90 values (ie the measurement value below which 90% of the measured values fall) are also used in many monitoring or analysis activities

• For trend analysis and historic baseline assessments, information can be provided as maps of the average or p90 value where the statistics are compiled over appropriate time periods.



[1]

[1] Example of a daily chlorophyll concentration product based on data from the ESA MERIS sensor. This example is from 1 May 2008 for the Wadden Sea. The capability to detect fine scale current and frontal structures within the higher resolution (300m) imagery is evident. Changes in frontal structures are of increasing interest to understand climate change induced evolution of coastal processes. Credits: Brockman Consult.

Resolution, Frequency and Availability

Information can be provided at a range of resolutions depending on the measurement objective and with some constraints for time periods after March 2012. For the time period 2003–2012, all information parameters except temperature can be provided at 300 m resolution. Outside of this period, information parameters are provided at 1 km resolution.

Sea Surface Temperature is provided at 1km resolution for all time periods.

In some cases, monitoring and reporting may be structured around a set of identified water bodies. In such cases parameters can be provided as a spatial average over the water body. However, it is recommended that the highest spatial resolution available is also analysed to maximise the quality of the information

Update frequency can be daily for low resolution information over a restricted area (typically 1000km by 1000km) but there is anassociated risk of cloud contamination within the data. In most situations today, operational users do not require daily data except where heightened monitoring is in place (eg during periods of algal bloom). Instead, they typically request update times as follows:

• For routine monitoring, information is updated every week/10 days as a running average over

the previous 7/10 days. If particular processes are detected (e.g. algal bloom formation) then the update frequency can be shortened. Note that even where 7/10 day or monthly merged products are being generated, these still rely on data being collected as often as possible, preferably daily
- For statistical analysis and trend monitoring, updates are usually provided on a monthly, seasonal or annual basis comparing the most recent values of water quality indicators with the historic trend.

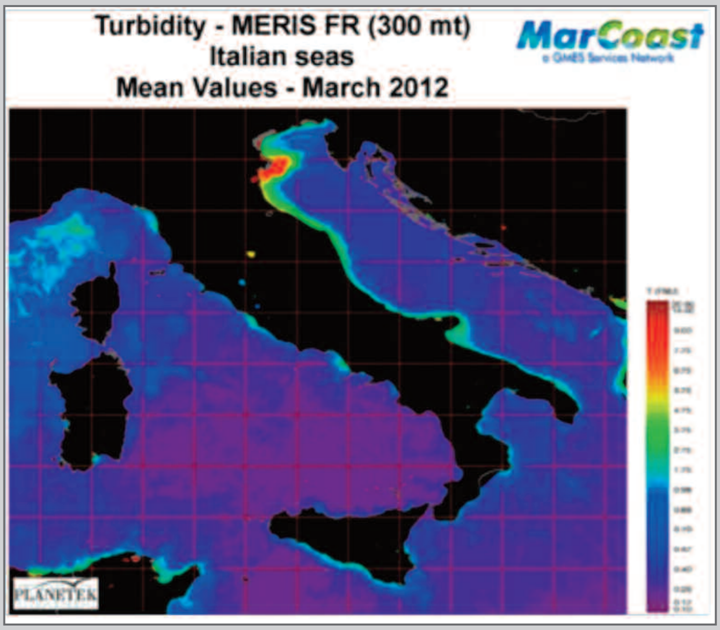
Satellite based water quality monitoring information is available in theory for any coastal region world wide. However in some areas (e.g. West Africa), cloud cover may hinder data collection for large portions of the periods of interest. In such situations, a reduced quality information service would be provided.
With respect to historic time series of data, satellite based water quality information products are available for most areas for the time period 1998 to the present.

Accuracies and Constraints
Absolute accuracies are regularly demonstrated to be of the following orders of magnitude:
- Sea surface temperature – better than ±0.5K
- Chlorophyll concentration - ±20-30% for coastal waters

However in most cases, the absolute accuracy is not a priority as users are interested in relative measurements (e.g. spatial variation in sea surface temperature or transparency or time series trends in indicators). This means that long term consistency in instrument properties is highly desirable. Most organisations providing satellite derived information maintain dedicated teams tasked with monitoring and reporting on the performance and status of the satellite instruments. This ensures that the quality of satellite derived information (eg chlorphyll concentration, transparency) can be continuously assessed. There is also a continuous activity by many satellite operators, in particular ESA, to ensure that data are processed using state of the art algorithms. Once an improved algorithm becomes accepted by the scientific community then these are incorporated into the satellite operators data processing infrastructure both for new measurements and also (after a delay due to the processing effort required) for archived historic data also.

Benefits and Use
Traditional methods for water quality monitoring involve taking in-situ samples and conducting laboratory tests such as laser fluorescence to measure parameters such as chlorophyll concentration. This is time consuming and requires considerable effort and cost. The sampling itself requires a dedicated cruise or collection of water samples at specific coastal locations and the laboratory analysis requires certified equipment.
Satellite derived information are available over a wide area, relatively quickly and the data processing ensures consistency in estimated parameter values over the entire image area.
Satellite derived information is used primarily to complement limited in situ measurements by enabling an extrapolation of the in-situ measurements to entire areas or to provide data outside the in-situ data collection time periods. Examples include:
- Monitoring activities required by local environmental agreements or legislation
- Assessing changes in particular areas as a result

[1] Monthly mean value for turbidity for Italian waters for March 2012 based on data from the ESA MERIS instrument. These measurements are obtained at a spatial resolution of 300 m and averaged on a pixel by pixel basis over all images acquired during the month of interest. Credits: Planetek / MarCoast.

[2]


of engineering activities, infrastructure development etc, eg changes in sediment load, increase in temperature etc

- Monitoring areas with aquaculture operations, tourist activity or desalination activities for the presence and evolution of algal blooms
- Compilation of baseline historic reference conditions for coastal water bodies in support of environmental legislation
- Elaboration of indicators to support the identification of potential new sites for activities such as aquaculture operations
- Assessing long term stress on sensitive coastal ecosystems (eg coral reefs, mangroves, sea grass beds , coastal wetlands etc)

The primary benefits reported are lower cost and increased spatial coverage for collecting water quality information. In cases where organisations also conduct dedicated in-situ measurement campaigns, the small additional cost of the satellite derived information results in several benefits:

- increased confidence in the data collected by the in-situ measurements
- an understanding of the context of the conventional measurements (e.g. the degree to which the sampled point is representative of the area of interest)
- the capability to extrapolate the limited duration in-situ measurement to monthly, seasonal or annual intervals.

In addition the satellite derived information provide a homogeneous baseline against which different measurements in different locations can be related to each other

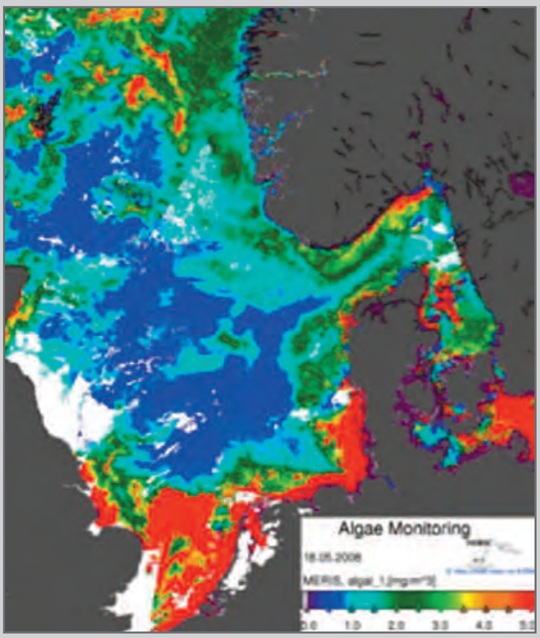
Indicative Costs

Typical monitoring costs for national coastal waters depends on factors such as the geographic extent of the coastal areas and the complexity of the coastal processes. However in most situations national waters can be monitored on a routine basis for an annual budget of between 50000 and 150000 Euro.

For historic data, depending on the size of the area of interest, the complexity and the density of the sampling (both spatially and temporally) a trend analysis for a coastal area over a 10 year period would cost approximately as an annual monitoring service. If very high resolution information in restricted estuaries is required, this may be more expensive, as this may require the use of high resolution (1-5m) optical data which require more processing effort and the payment of commercial licence costs.

The Contribution of the Sentinel Missions

Sentinel-3 data will ensure long term continuity of the high quality data originally provided by the MERIS and AATSR instruments on board ENVISAT. Other lower quality systems have been available to cover the gap in data from 2012 to 2014 between the ENVISAT and Sentinel 3 missions and these, if properly combined with historic ENVISAT data can ensure consistent (but slightly lower resolution) time series of coastal water quality parameters.



[3]

[3] Algal Bloom detected in the North Atlantic and forecast to cause potential problems for aquaculture operators in southern Norway, North West Scotland and Northern Ireland. Environmental Protection Agencies in each country as well as aquaculture associations and regional organisations were alerted. Credits: NERSC

Information content

Satellite imagery can support the generation of several information layers. Information products have been validated for mangroves, coastal mud flats, sea grass beds and coral reefs. Information content for these habitats includes:

- Spatial extent of the coastal habitat
- Level of fragmentation of the coastal habitat in a particular area of interest
- Delineation of sub-species within the habitat
- Delineation of elements of the habitat subject to degradation or improvement (this can include identification of multiple levels of degradation if these have been characterised in advance)
- Delineation of elements of the habitat subject to change with respect to a defined reference year (e.g. loss of habitat area, encroachment of transport infrastructure in to the habitat)

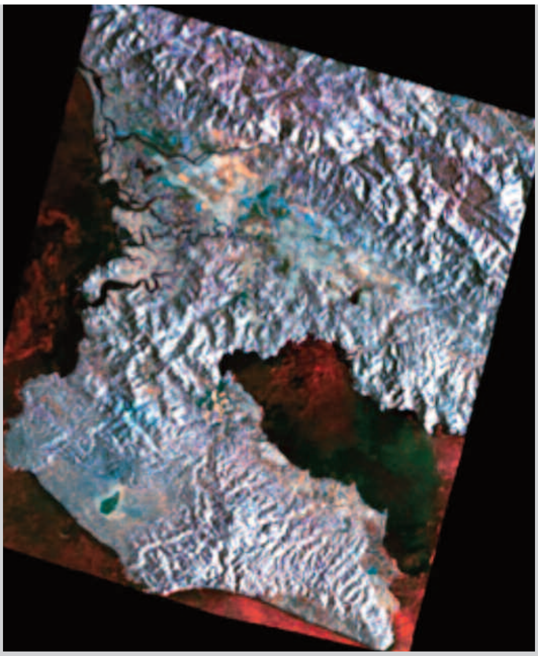
There are some specific considerations related to the assessment information products for the different habitat types:

- Analysis of evolution in habitats, eg for mangrove systems, is based on the analysis of a time series of images to delineate changes. This requires consideration of the phase of the tidal cycle at the point when the images were acquired. In addition to basic changes in coverage, more detailed analysis can be generated including fragmentation, degradation etc.
- Sea grass habitat maps are based on the use of high resolution multi-spectral imagery with spatial resolution of between 1 and 5 metres. It is important to note that such high resolution data have been available only since 1999 which places a strong constraint on the time period over which time series can be elaborated.
- For inter-tidal habitats, imagery can be acquired only at certain points of the tidal cycle due to the requirement for the inter-tidal zone to be exposed. If high resolution optical imagery are used then it may be possible to provide both classifications of the sea bed as well as mapping pressures on particular inter-tidal habitats
- For Coral Reef ecosystems, two types of information are collected based on very different classes of satellite imagery:
- Environmental stress information linked to bleaching and reduced coverage is based primarily on sea surface temperature, and transparency measurements. Mechanical stress due to wave and current conditions can also be assessed. Stresses are typically characterized along two dimensions: chronic and acute. This enables an assessment of the vulnerability to different pressures such as climate change related temperature change or changes in sediment load due to coastal infrastructure expansion.
- Habitat element change is based on very high resolution optical imagery to detect changes in the status of coral elements or reduced coverage on an annual or multi-annual basis. In most areas, sufficiently high resolution imagery is available only since 2000.

Each of these information products can be integrated with the coastal water quality information product to analyse environmental stress on a particular coastal habitat and the habitat response

More general coastal land cover change maps are also available on a reliable basis for coastal areas world-wide. These are similar to standard land cover change maps described elsewhere in this report but with customised classification keys. They are not further described in this section.

[1] [2] The characterisation of changes in a mangrove area based on analysing differences in radar images of the area acquired during different time periods. Credits: GeoVille Information Systems



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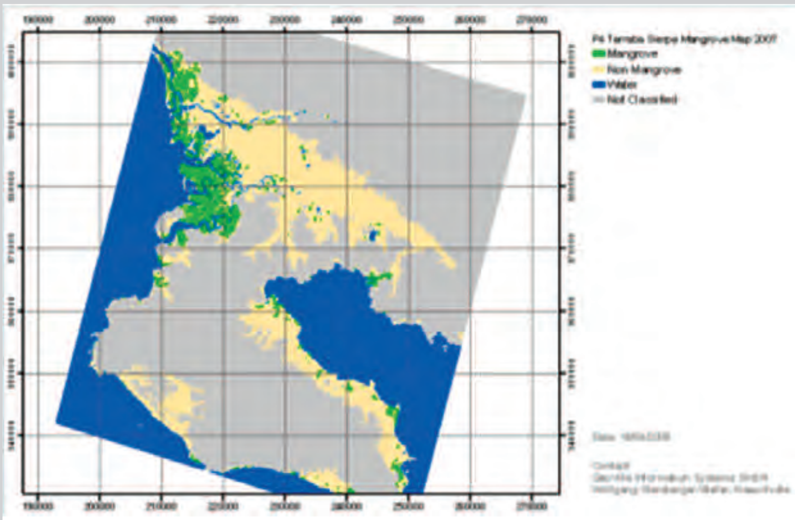


[2]

Resolution, Frequency and Availability

Experience within the various verification exercises conducted indicates that a spatial resolution of 0.5 to 2 m is necessary for effective delineation of the different units within a habitat and to support a sufficiently robust classification analysis. However basic habitat extent for mangroves can be performed with lower resolution imagery (10-25m).

Frequency of update can be monthly although in most cases annual or multi-annual assessments are sufficient to characterise change processes or the impacts of environmental stress such as pollution or climate change induced evolution in surrounding conditions (e.g. temperature, pH, sediment load). In the case of sea grass beds, the attainable update time may be longer. This is due to the limitations on accurate sea bed observation in moderate to high wind conditions where the rough sea surface scatters the sun-light reflected off the sea bed. However most assessments of sea grass habitats are conducted every 5—10 years so this is not a significant blocking factor. Excessive cloud coverage in certain regions (e.g. West Africa) may be a limiting factor in update frequency also, in particular if seasonal monitoring is required. Heavy sediment loads may also impact on viewing possibilities for sea bed maps.

These information products are available World-wide subject to the constraints identified above on cloud cover constraining the attainable update times.

Accuracies and Constraints

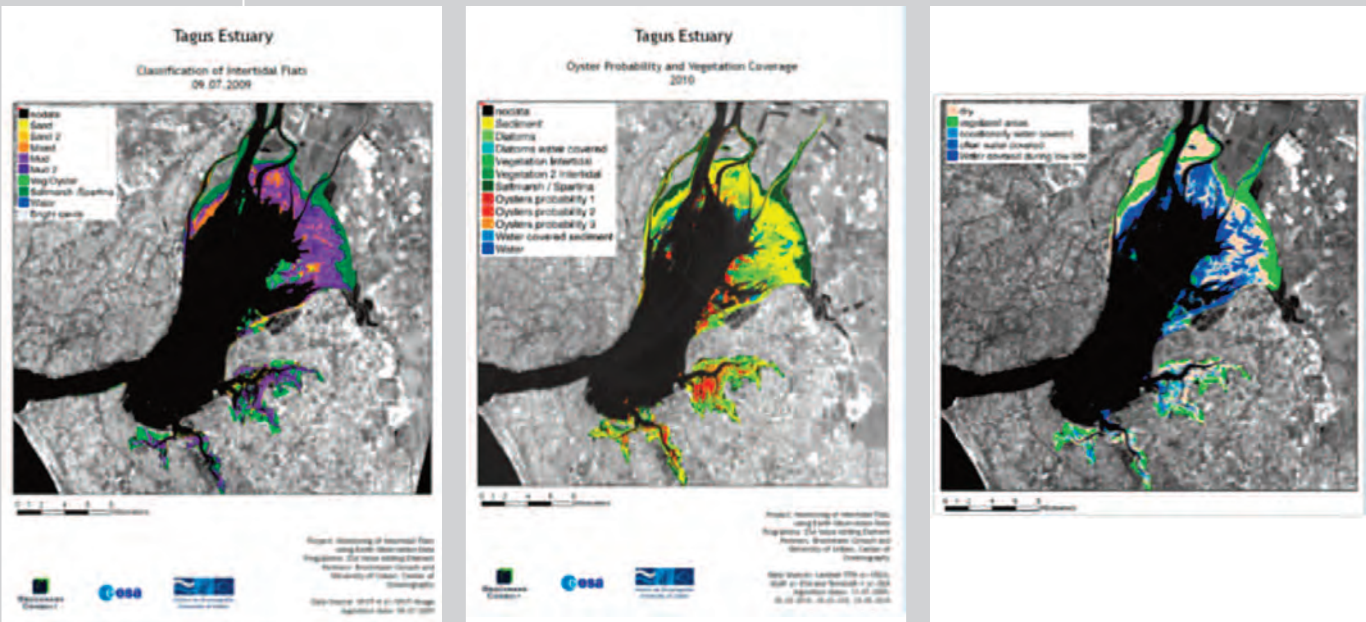
Classification accuracy of the habitat compared to surrounding region depends on how abrupt is the border between the habitat of interest and the surrounding region (e.g. for mangroves, a gradual reduction in mangrove density results in a boundary being delineated that depends on a definition as to what density of mangrove forest constitutes "mangrove" and below what level constitutes "non-mangrove"). Taking this potential for subjective definitions into account, the location accuracy for delineation of habitat boundaries and boundaries of sub elements within the habitat is better than 1 pixel of the image (i.e. the spatial resolution of the image).

Within the habitat, classification of the different sub-units is typically of the order of 80-85% accuracy.

Benefits and Use

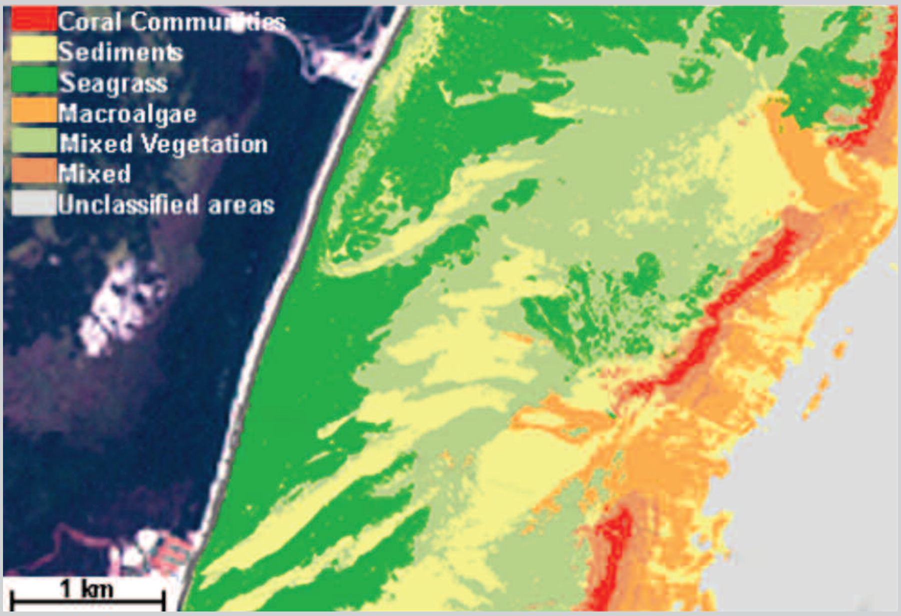
The habitat characterisation information products are typically used in the following situations:

- Support to regularly updated assessments of the coastal and marine environment conducted by national or regional environmental protection agencies
- Baseline analysis of habitats in areas where new infrastructure or commercial activity (e.g. oil and gas production, mineral extraction, increased maritime transport, water treatment facilities, desalination plants) is planned. Identification of optimal locations for new commercial activities (e.g. aquaculture, mineral extraction). In addition, environmental impact assessment conducted once such activities have started will use the same capabilities
- Monitoring the response of key habitats to the stress of climate change (e.g. increased sea temperature, salinity or acidity)
- Assessing the capability of coastal habitats to provide ecosystem services, including support to fisheries resource management

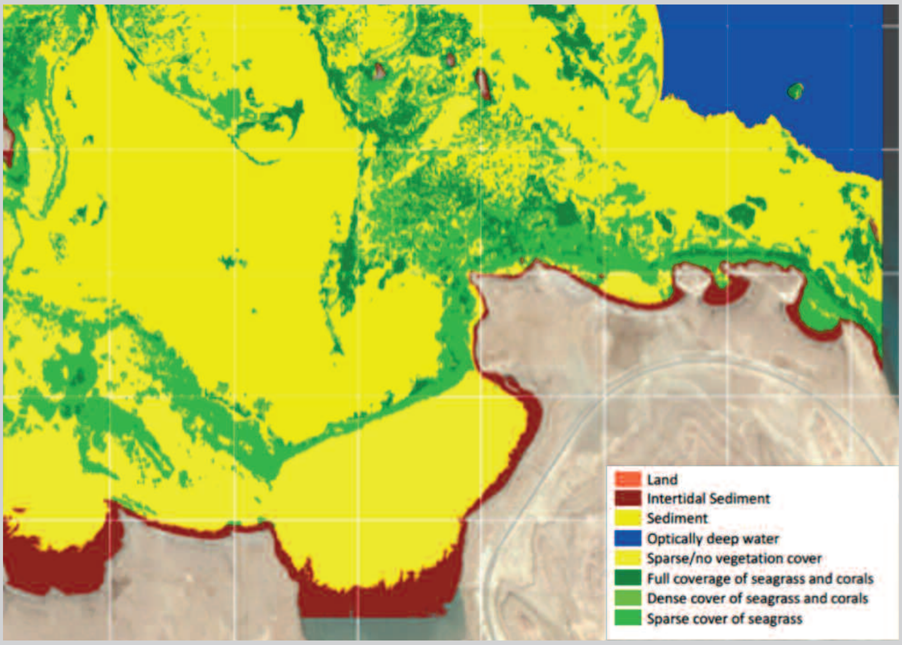


[3] The example below shows the main habitat types in the Tejo estuary in Portugal. Credits: Brockman Consult

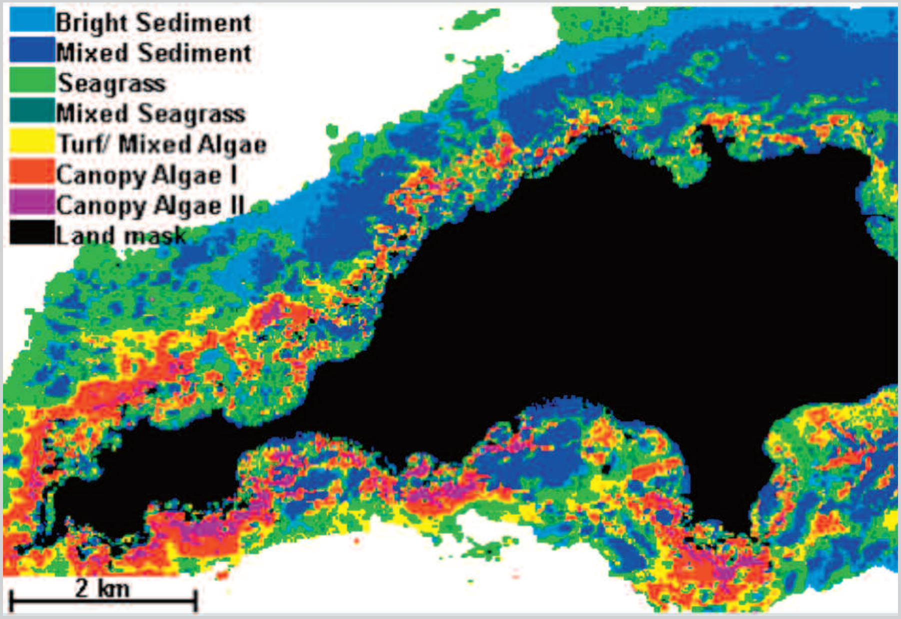
[3]



[4] This example is part of the Yucatan coast in the Gulf of Mexico where a mixture of different habitats including sea grass and coral communities is found. Habitats are mapped out to a depth of 20 to 25 metres. In this case, satellite imagery with a spatial resolution of 4m was used for the mapping. Credits: EOMAP



[5] This example is from high resolution optical data that have also been used to generate a local coastal bathymetry map. It shows a coatal habitat classification in Qatar. Credits: EOMAP



[6] Sea grass is the dominant habitat mapped in this example for the sea areas around Rottnest island, off Western Australia, close to Perth. Sea grass is clearly delineated against the surrounding sediments. Credits: EOMAP

A number of operational benefits have been cited in relation to the use of satellite derived information. These include:

With respect to all types of habitat:

- The time taken to generate analysis and change maps for the habitats is significantly reduced compared to traditional in-situ surveys. In addition, archive historic data can support enhanced characterisation of change processes with a shorter separation in time between different reference years. Satellite derived analyses also have a lower associated cost
- A homogeneous approach to characterising habitats over an extended area (e.g. mangroves over different coastal states) or similar habitats subject to a degree of separation (e.g. coral reefs)

With respect to benthic and inter-tidal habitats

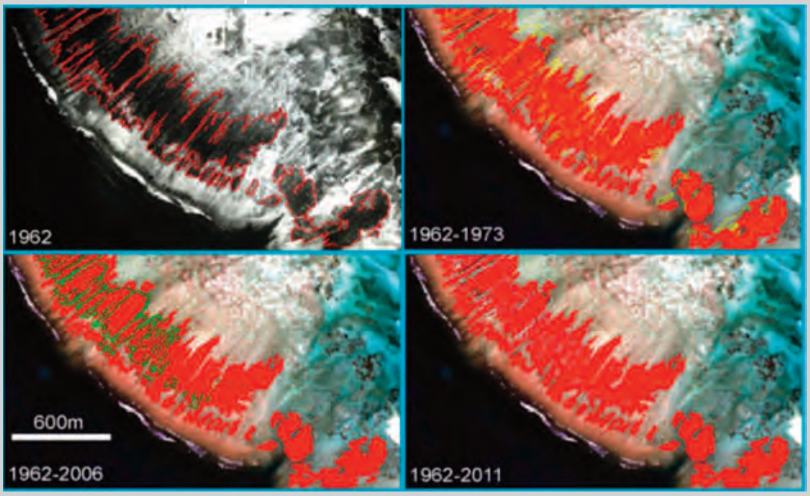
- Location accuracy of habitat boundary for benthic habitats is significantly improved compared with traditional mapping techniques performed by in-situ inspections such as divers
- The capability to undertake monitoring analyses more frequently in dynamic areas (e.g. where there is significant sediment transport) or areas with difficult access conditions (as is the case for most inter-tidal zones) is considered an important benefit

Indicative Costs

Fine scale analysis requiring very high resolution (i.e. better than 2m spatial resolution) are, in general, more expensive than analysis using imagery with a spatial resolution of the order of 10m. Mangrove monitoring costs are of the order of 10—150 KEuro depending on the number of reference years to be included, the extent of the coastal area under consideration and the complexity of the habitat. Finer scale analysis such as coral reef, sea grass and inter-tidal mudflat ecosystem assessments will be in general 2-5 times more expensive per square km.

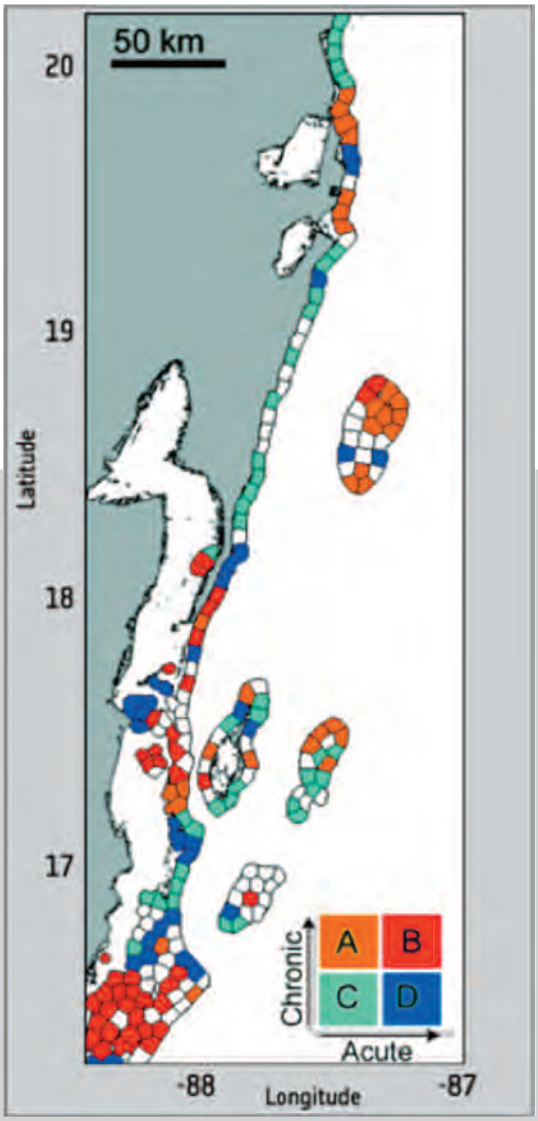
The Contribution of the Sentinel Missions

Continued improved performance of high resolution optical satellite imagery will ensure the capability to provide coastal ecosystem information services. In addition, the availability of Sentinel 2 data from 2014 will ensure low cost capability to conduct lower resolution analyses (e.g. for mangrove systems). In parallel, development in low cost small satellites over the next 5 years will result in wider availability of high resolution (1 m) imagery and a corresponding reduction in price for such data.



[7]

[7] Examples show the use of historic high resolution imagery to monitor changse and degradation of coral reefs over an extended time period. Credits: Institut de Recherche pour le Developpment (F).



[8]

[8] Thermal stress map for coral reef systems off Belize. This demonstrates the joint consideration of "chronic" stress (measured as the climatological summer temperature average), and the "acute" stress (measured as the frequency of degree heating weeks) induced by prolonged elevated temperatures leading to bleaching events. Credits: University of Exeter (UK)

Information Content

Two categories of information are available:

- Coastal bathymetry maps and coastal bathymetry change maps
- Coastline maps and Coastal Erosion/Deposition characterisation

Coastal bathymetry maps provide depth information in coastal waters for depths up to 30-40m. In addition, through regular surveys, maps highlighting changing seabed conditions (e.g. movement/ migration of sea bed dune structures) can be generated.
Coastline maps provide delineation of parts of the coastline and the capability to monitor erosion and deposition dynamics between reference years. Due to phenomena such as storm surge and tidal signal variations, the most stable reference point is the dune crest line (shown in the schematic illustration) which is sufficiently distant from the high tide line so as to be unaffected by short time scale variations. Any change to this location clearly represents systematic erosion or deposition.

Optical imagery compiled for selected reference years can be used to track movements in the dune crest location. Typically at least 10-20 years of data should be used. Spatial resolution of the imagery is an issue – for coastal areas with many fine scale bay structures, higher resolution imagery will be required to ensure a sufficiently precise location of the dune crest and this may limit how far back in time an analysis can cover as high resolution imagery has been available only since 1999-2000. In addition, such data sets tend to be more sparse. For more slowly varying coastlines, lower resolution (20-30 m) imagery can be used and these provide both longer time series as well as a denser coverage of acquisitions.

Resolution, Frequency and Availability

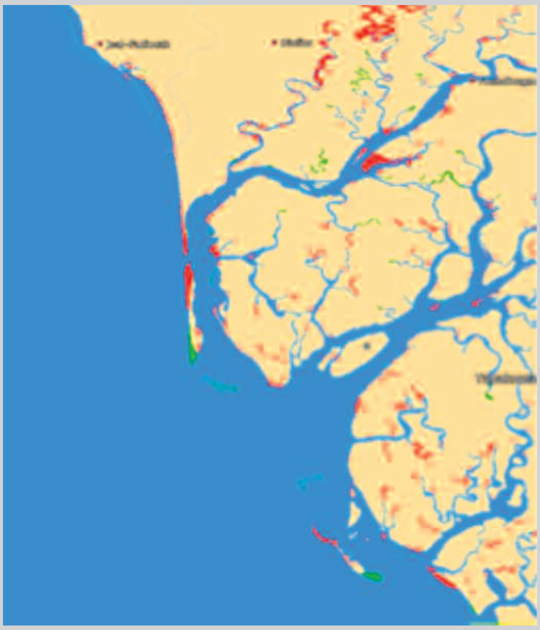
For bathymetry mapping, spatial resolution is of the order of 1 – 5m to ensure that all sea bottom structures within the area of interest can be detected. For coastline change mapping, the spatial resolution required depends on the length scale of the coastal morphology. Depending on typical length scales, spatial resolution can be 0.5 m to 20 m (although worse than 10 m is not recommended in most situations except for very slowly varying coast lines).
Update frequency can be as fast as monthly for most areas except regions subject to heavy cloud cover where data acquisition on such timescales may be problematic. Typical update times have been of the order of every 2-5 years, depending on how dynamic the area of interest.
Depth maps are available in most areas unless there is heavy sediment load covering the area of interest. Coastline change maps are available for all coastal areas.

Accuracies and Constraints

Location accuracy of features is typically of the order of 1 pixel.
Depth measurement accuracy for coastal bathymetry maps in sufficiently transparent waters are of the order of ±0.2 – 2 m. This measurement is the instantaneous water depth and is not corrected for the tidal cycle variation and is not relative to reference water depths (therefore the measurement is a different quantity from a hydrographic chart).

Several constraints apply to these information products:

[1] The example shown here is for the Senegal coastline. Credits: Geoville.
[2] The example here shows coastline erosion and deposition for a different part of Senegal over the period 1990–2010. The red colour depicts areas that were identified as land in the original data (1990) but are now covered in water while green indicates areas that were originally covered in water in 1990 but are now land. Credit: Geoville


[1]

[2]

- For both products, heavy cloud cover will limit the capability to generate products with fast update time (i.e. less than 1 year). This primarily refers to extreme northern regions and certain equatorial regions such as West Africa.
- For coastal bathymetry maps, heavy sediment concentrations in the water column limit the capability to generate depth maps. This is mainly limited to the estuaries of sediment laden river outflows such as the Amazon and Yellow River.
- Coastline maps and Coastal Erosion/Deposition characterisation may be more difficult in areas where very slow changes are occurring.

Benefits and Use

Both products are used in the following situations

- Characterisation of coastal areas for new infrastructure planning (e.g. ports, transport infrastructure), marine highway planning and maintenance and new economic developments (e.g. tourism, aquaculture)
- Impact assessment for coastal engineering developments
- Coastal flood risk assessment and climate resilience characterisation
- Monitoring changes in coastal sea bed evolution in coastal shipping lanes

The primary benefit is the reduced cost of satellite derived information compared to more expensive conventional methods. It should be noted that satellite derived information is less precise than conventional mapping methods. In particular for depth mapping, satellite derived information are not compliant with International Hydrographic Organization charting standards such as S-57 or S-100 although it is significantly cheaper and faster to updated and in many cases is of sufficient quality for planning and monitoring purposes.

Satellite derived information is also faster to produce than traditional methods hence updated are easier to implement.

Finally, the capability to combine both depth maps and coastline change maps from the same data enables a homogenous and optimised approach to be adopted for general coastal change mapping and for customised purposes such as coastal flood risk assessment.

Indicative Costs

Typical costs will be of the order of 2—10 Euro per square km depending on how many reference years are to be included in a change analysis.

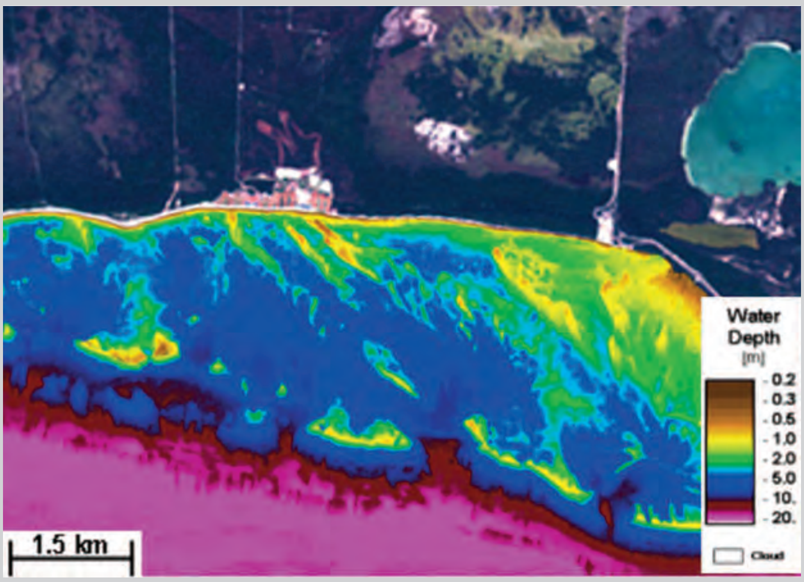
The Contribution of the Sentinel Missions

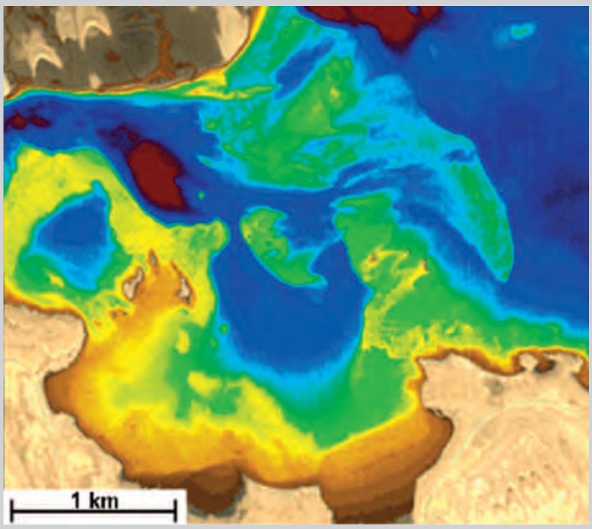
Increased availability of high resolution multi-spectral imagery will ensure that prices for accessing these data will become more competitive. The availability of Sentinel 2 data from 2014 will ensure a global reference baseline at 10 m resolution. In addition, by combining Sentinel- 2 and Sentinel- 3 data, improved characterisation of coastal processes, in particular linking sediment load and coastal erosion dynamics will be possible over more coastal regions than was previously possible.

The examples below show example bathymetric charts generated for different regions.

Water depth in the coastal zone off Cancun, Mexico - Credits EOMAP

Water depth around Qatar using the same dataset as was used to generate a coastal habitat map - Credits EOMAP





Information Content

Satellite Earth Observation derived information can be used for planning and for monitoring and management in relation to aquaculture operations.

For planning purposes, information content includes statistics on local environmental conditions (e.g. chlorophyll concentration, sea surface temperature, wave height, current velocity, probability of algal blooms) and habitats (extent and status for nearby habitats such as mangroves, coral reefs, coastal mud flats etc.). Coastal bathymetry, land cover and topography are also of interest.

For monitoring purposes, nowcasts and forecasts of local conditions are required to support a timely response to potentially hazardous conditions such as algal blooms, temperature anomalies, low oxygen concentrations, salinity etc. that could result in fish kills or ingestion of toxins by the stock. In addition, environmental impact assessments are supported by regular updates of the status of surrounding habitats. In particular, the characterisation of changes and the analysis of their causes.

Satellites can also support enhanced monitoring of aquaculture activities - Information includes detection of changes in the spatial extent of a site and changes in coastal infrastructure (transport routes, processing plants etc.).

Many of the information products to support aquaculture operations are described elsewhere in this report. These include:

- Monitoring of coastal environmental conditions (Sea Surface Temperature, Chlorophyll concentration and front delineation). Jelly fish bloom prediction (described under the section on customised services) is also of significant interest
- Environmental impact assessment – including the detection of changes in surrounding mangrove, coral reef and coastal mud flat habitats described previously in this chapter
- Characterisation of surrounding habitats prior to establishing new coastal aquaculture operations as a planning tool. This uses habitat characterisation over a set of reference years to consider the effects of waste products, transport infrastructure and also the exposure of the site to hazards such as algal blooms and temperature variations.

Resolution, Frequency and Availability

Environmental conditions assessments are available at spatial resolutions of between 300 and 1000 m.. Monitoring products are available at spatial resolutions of 1000 m and available every 2—3 days.

Habitat status assessment is available at a resolution of 10-20 m for reference years back to 1990 and at a resolution of 1-4 m for reference years back to 2001. Habitat change monitoring is available at 1-4m resolution and can be generated every few months.

Monitoring aquaculture operations is available at spatial resolutions of 1-10 m and can be generated every few days if necessary although every few months would be more usual.

All products are available world-wide

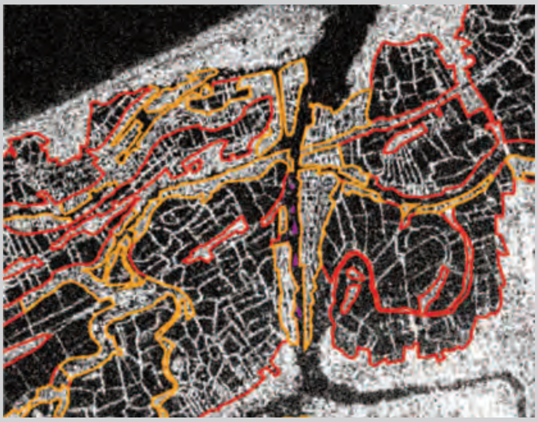
Accuracies and Constraints

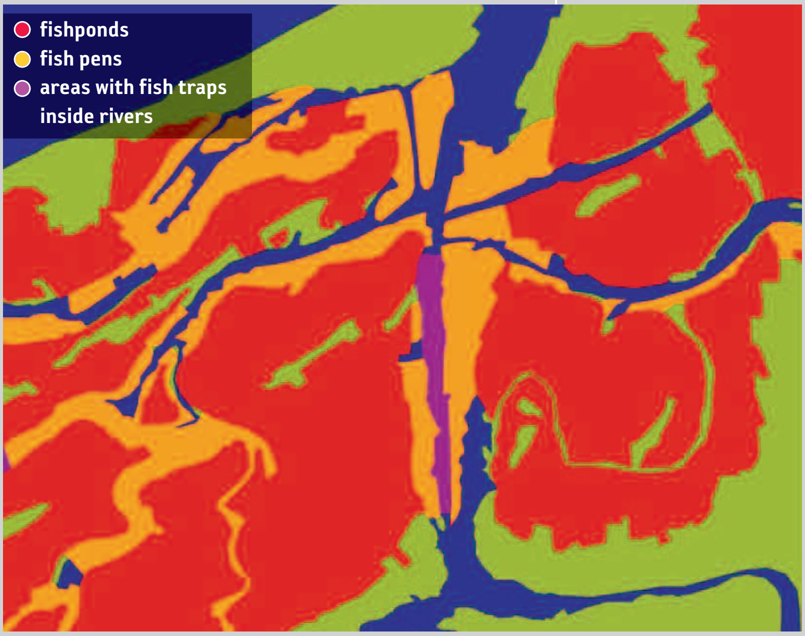
Location accuracy of features is typically of the order of 1 pixel.

Accuracies for many of the parameters are described elsewhere in this section. Detection accuracy for extent of aquaculture operations is very high (i.e. close to 100%)

Several constraints should be taken into

Use of SAR imagery to map extent of fish pens and traps in coastal areas of the Philippines. This image was acquired as part of a case study by FAO to demonstrate the utility of satellite data for aquaculture management. Credits C. Travaglia, G. Profeti & J. Aguilar-Manjarrez, FAO Fisheries Department





consideration. These include:

- Marine environment conditions (temperature etc.) must avoid the presence of land in a pixel contaminating the signal
- Coastal bathymetry information (sea bed characterisation and mapping) requires very low wind conditions and cloud free observations.
- Detection of algal blooms is effective only for species where there is a pigment related signature. For some low biomass toxic blooms, there is no pigment signature – however in these cases it may be possible to delineate the water masses containing these blooms and track these water masses.

Benefits and Use

The primary uses of these products are:

- Improved information for planning new aquaculture operations, to minimise exposure to environmental risks and the impact on surrounding habitats
- Enhanced monitoring of aquaculture operations and ensure that facilities are managed in compliance with local environmental legislation. In addition, routine monitoring provides timely warning of the onset of potentially hazardous environmental conditions such as algal blooms.

Benefits for aquaculture operators are primarily related to enhanced management of aquaculture sites, including timely warning on local environmental conditions so that appropriate mitigation measures can be taken (e.g. stock harvesting or movement of cages)

Benefits for national environment and fisheries authorities are enhanced sustainability of aquaculture operations within their areas of jurisdiction due to better, more comprehensive information being taken into account in the planning process. In addition, the capability to routinely monitor operations and environmental conditions ensures higher levels of food safety for local aquaculture products.

Indicative Costs

Historic analysis of environmental conditions costs a few thousand Euro per region.

Routine monitoring is also not expensive for a monitoring service subscription and many aquaculture operators are already making use of such products on a commercial basis in Europe.

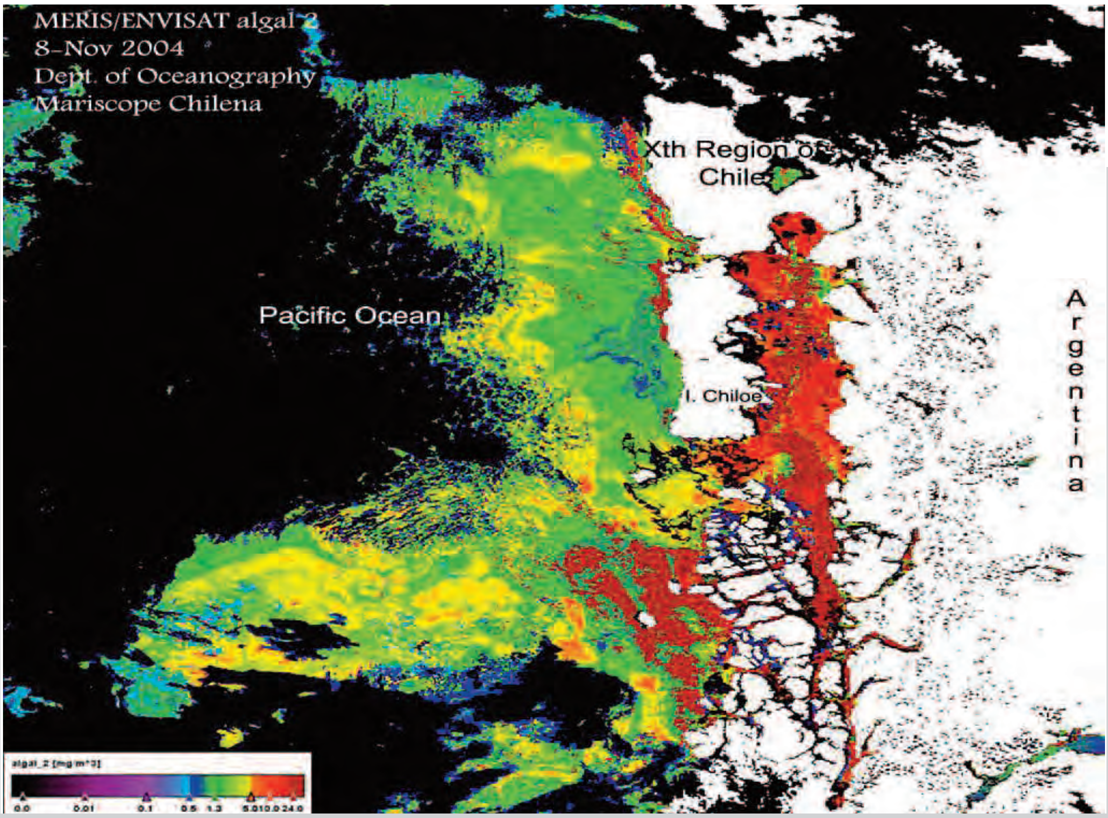
The Contribution of the Sentinel Missions

Sentinel-1 will ensure the long term routine capability to generate coastal environment information (e.g. surface currents, water mass delineation).

Sentinel-2 will ensure the capability to provide land cover change assessments for coastal areas

Sentinel-3 will ensure the long term capability to provide coastal environment conditions.

The example shown here is an algal bloom detected of the coast of Chile in 2005. CREDIT Mariscope In addition, more specialised products are routinely used for planning and monitoring. The main additional information service is Aquaculture Operations Mapping



Initial work has been undertaken to verify the capability to make limited levels of bloom predictions for Spanish, Irish and French waters close to areas of intense aquaculture operations. The work performed so far is valid only for a limited range of species but initial results indicate the capability to use neural net based analysis techniques on time series of satellite observations (temperature, ocean colour etc.) to predict jellyfish concentration levels with sufficient advance notice to enable aquaculture operators to pre-empt stock loss.

At present the system provides a forecast of the probability that jellyfish presence is above a defined threshold for a particular date up to 2—3 days in advance

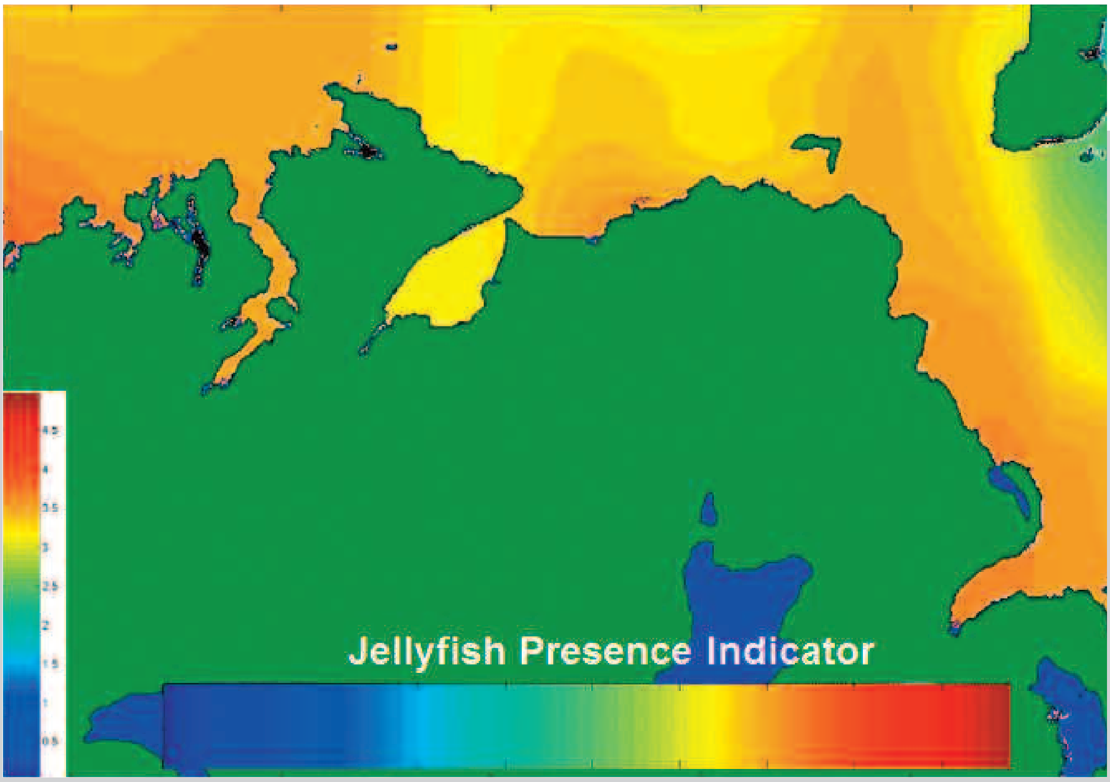
Information is updated every 2—3 days during seasons when jellyfish blooms may occur. Information is usually provided in 1km by 1km cells although lower resolution may also be preferred. At present, the system has been tested in the North East Atlantic and Western Mediterranean. Roll-out to other areas is under discussion

Full characterisation of accuracy is still on-going. Current constraints are the requirement to set up separate neural net training sets for each species of jellyfish and each geographic area

The main usage is expected to be for aquaculture operators (where jellyfish kills can cause total loss of stock) and both public and private sector organisations in the tourism sector (e.g. holiday villages, local authorities)

The primary benefit is the capability to predict presence of jellyfish blooms in areas close to activities that are sensitive to their presence (e.g. aquaculture sites, tourism areas). This enables appropriate mitigation measures to be put in place. At present, areas where jelly-fish warning services are in place rely completely on in-situ observations which is costly and time-consuming. Furthermore, the level of advance notification in such cases may be less than a few hours leaving little time to execute mitigation measures.

With the availability of Sentinel-3, long term continuity of the key data sources for this service will be ensured. In addition, further development of this service for other coastal areas is under discussion. Improved links to jelly-fish observation networks are also under investigation to improve accuracy of the product for different species of jelly-fish.



The example shows a prediction for northern Irish waters for September 2010. Credits: Techworks and Starlab.
5 = strong likelihood of jellyfish bloom
0 = very low likelihood of jellyfish bloom

→ RESOURCE EXTRACTION MONITORING

Sand extraction from coastal areas represents a risk for coastal flooding as well as potentially negatively impacting on other economic activities such as tourism and aquaculture. High resolution imagery can support the following information components for monitoring sand extraction:

- Change detection along sand and gravel beaches
- Detection of vehicles on sand and gravel beaches

Reliable detection of vehicles on the beach area requires imagery with a spatial resolution of better than 2m. Detection of the removal of sand resources requires a spatial resolution of better than 1m. Assuming cloud free conditions, information can be updated for most regions on a daily basis.

Delivery times at present are of the order of 24 hours as very few regions have the possibility for near real time (less than 3 hours) access to optical satellite imagery. It may be possible to use high resolution radar imagery to detect vehicles on beaches, in which case, information could be available within 1 – 2 hours for most coastal areas world-wide (and faster in many areas). However the reliable identification of vehicles involved in resource extraction may have a higher error rate when based on radar imagery due to the difficulty of image interpretation.

In areas where sand or gravel is removed from below the high water mark then the detection of removal may be problematic Also, in cases where sand or gravel removal does not generate abrupt variations in surface slope, then the detection may not be possible. The latter situation may be related to slower rates of removal and therefore a lower priority issue.

The major constraint for the detection of vehicles on the beach area is that the high resolution optical satellites pass over the area of interest between 10:00 and 12:30 local time – outside of this window, no observations are possible due to the orbit phasing of the different satellites. Therefore vehicles operating only outside this time window will not be detected

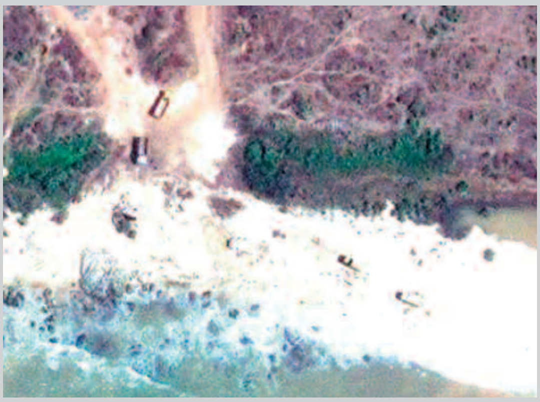
The additional constraint on the timeliness of information availability may create difficulties for users planning to intervene.

This activity is at present a technical feasibility analysis. It is not clear what the operational costs would be.

Sentinel-2 data will enable the detection of the coast-line erosion associated with the sand extraction activity. However the main data to detect unlicensed operations is likely to be high resolution imagery.

Continuous improvement in spatial resolution and wider availability of high resolution optical imagery could result in lower service costs for such monitoring. Also if sufficient structure is visible on the satellite imagery, it may be possible to construct digital elevation models on a regular (e.g. 6—12 monthly) basis to monitor areas subject to excessive extraction

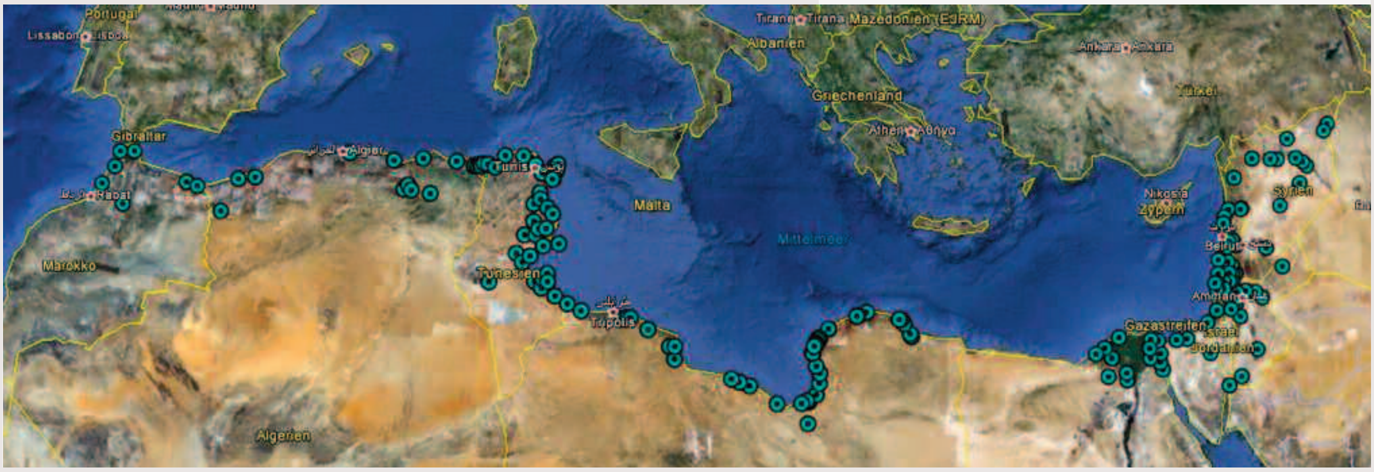
Satellite imagery showing lorries accessing sandy beach in Sierra Leone CREDIT: Digital Globe



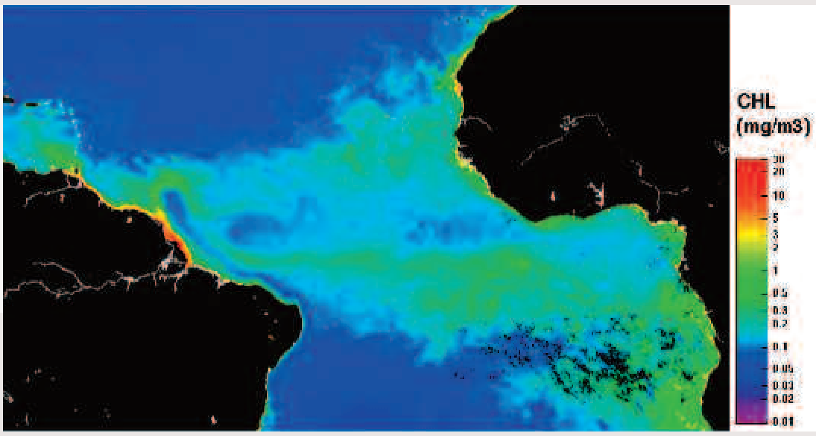
GLOB COVER

- **GlobCover** Under this project, an archive of global composites and land cover maps have been developed. This uses as input observations from the 300 m MERIS sensor on board the ENVISAT satellite mission. ESA makes available the land cover maps, which cover 2 periods: December 2004 to June 2006 and January to December 2009. These products are available online - For more information, see **http://due.esrin.esa.int/globcover**

- **GlobWetlands** – This project is intended to contribute to the set-up of a Global Wetlands Observing System (G-WOS) as per the strategy 1.2 of the Ramsar Strategic Plan 2009–2015 for the areas shown in the map below. The project has generated a set of Wetland Information Maps and Indicators (WIMI) for 3 points in time (1975–76, 1990–91, 2005) at 1:50000 scale for each of the wetlands of interest. For more information, see **www.globwetland.org**

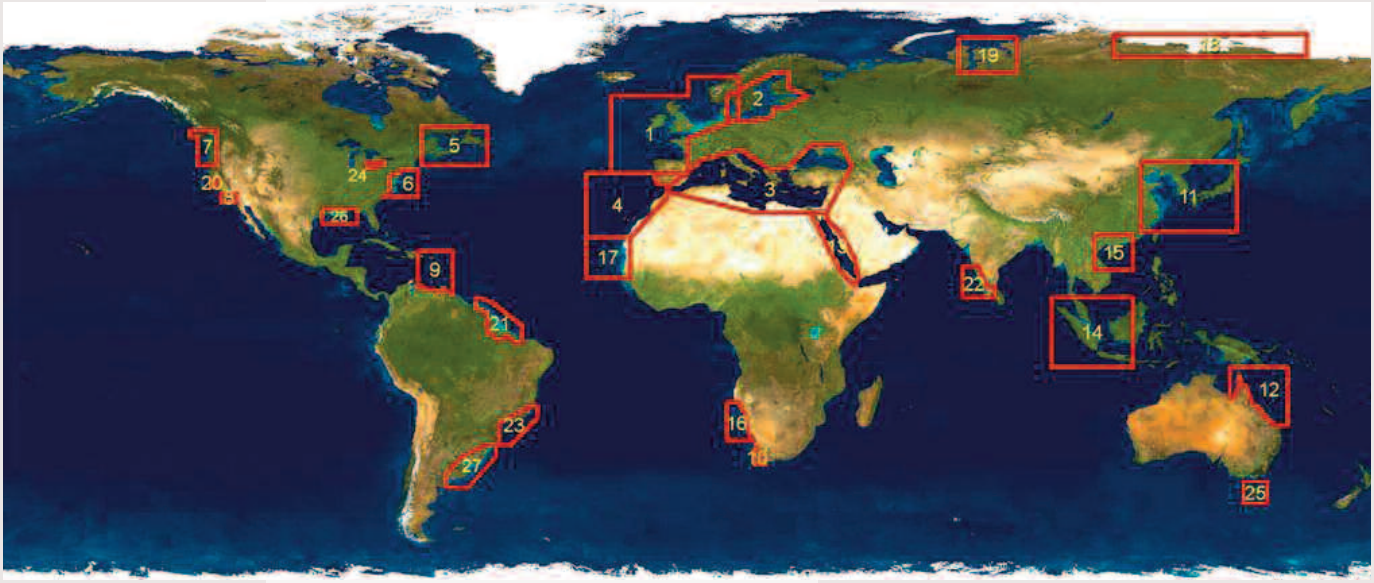


- **GlobColour** – a 10 year datasets covering all oceans worldwide has been compiled by fusing different ocean colour sensors. The main focus is so called "case-1 waters" where optical properties are dominated by plankton. An example of the monthly chlorophyll concentration product is shown below. For more information on the products available from the project see **www.globcolour.info**



- **CoastColour** – this project has generated an archive of customised ocean colour based products for the time period 2005 to 2011 for the test sites shown in the map.

  Products include basic water quality parameters such as chlorophyll concentration, transparency etc. but also engineering products related to measured water leaving radiances in the different spectral channels. For more information on the products and how to access them, see **www.coastcolour.org**



- **GlobWave** – Under the Globwave project, a comprehensive database of wave height and wave period measurements extracted from satellite radars has been compiled. The data cover the time period 1991 – present and are available for all ocean areas world-wide. Note that there are some limitations with the extraction of measurements in shallow waters and in coastal areas. For more information on the products and how to access them, see **www.globwave.org**

In addition, two projects recently started are compiling datasets for storm surge characterisation in areas of high risk (e.g. the Northern Indian Ocean) and global ocean currents at higher resolution than previous analyses. These projects are:

- **eSURGE** – This project is intended to improve the modelling and forecasting of storm surges through the increased use of advanced satellite products such as scatterometry and coastal altimetry. These will feed into a database to bring together the available satellite and in situ data for a range of surge events.
  For more information see **www.storm-surge.info**
- **GlobCurrent** – this project will start in 2013 and will provide global high resolution surface current measurements. This will include both nowcast and historic analyses and climatologies and statistics.

→ MARINE ENVIRONMENT MANAGEMENT

Related World Bank Programmes and initiatives

This section is pertinent to the following World Bank Initiatives: Global Partnership for the Oceans (GPO); Critical Ecosystems Partnership Fund (CEPF), Wealth Accounting & the Valuation of Ecosystem Services (WAVES), Pilot Programme for Climate Resilience (PPCR). In addition, some of the capabilities presented here are of relevance to activities within the Global Fisheries and Maritime Transport sectors.

Addressing Development Challenges

Main World Bank related topics against which EO capabilities are available:

- Sustainable growth (energy, transport)
- Food Security (Fisheries and Aquaculture)
- Ecosystem services
- Climate Resilience

The Potential of EO Information Services

Collecting information at sea is difficult and costly due to the remoteness of many regions and the harsh conditions under which data collection systems operate. However, many activities rely on effective and timely information on marine conditions or reliable and comprehensive analyses and assessments of changes in the marine environment. Examples include fisheries management and marine pollution control as well as assessments of climate change inducted evolution of ocean conditions or timely detection of regional phenomena such as the onset of El Nino events.

Satellite sensors represent a unique ocean observing capability. They provide homogeneous wide area measurements of ocean conditions as well as supporting timely detection and tracking of vessels (including fishing vessels, oil tankers etc.) and illicit discharges at sea. When combined with other data (e.g. transponder data for vessel detection and tracking, in-situ measurements of ocean parameters), satellite derived information enables complex analyses to be performed including detection of anomalous vessel behaviour and forecasting of ocean parameters.

At present, satellite based pollution information supports operational pollution control in European waters. Fisheries inspections are also increasingly making use of satellite derived information both to optimise interventions during time periods when fishing activity is permitted as to monitor the activity taking place outside of the permitted fishing seasons.

Time series of satellite derived measurements are also providing reference climate quality information on the trends in ocean parameters – at present mature products are available for sea level, sea surface temperature and ocean colour with additional products such as salinity under development. In addition, satellite derived information can be used to monitor shorter time period phenomena such as El Nino events, providing timely warning of the onset of such phenomena.

BASIC EO CAPABILITIES

Information Content

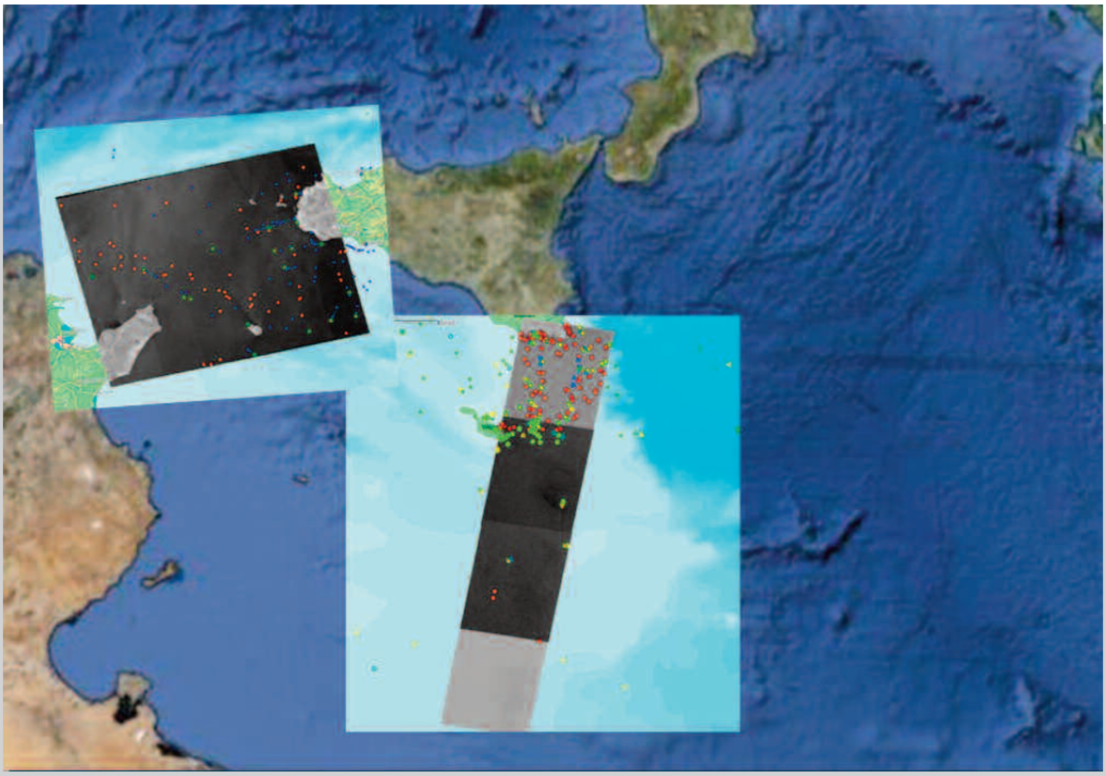
Satellite derived information provide different information layers customised to the requirements and operational working practices of the different users involved. The main information layers are:

- Detection, characterisation and tracking of vessels in a defined area of interest. In this case the information content is location, heading and speed of all detected vessels together with an initial classification (estimated length, vessel type). This is usually based on a combination of satellite imagery to detect the vessels and transponder data from vessels operating legally. The transponder messages are used to filter out known vessels from the satellite imagery. This leaves vessels detected for which no transponder information is available. These are usually of considerable interest to authorities.
- Extended tracking of a vessel of interest. In this case, the information content is a track containing the behaviour of the vessel of interest over the time period of interest. This includes time history of location, heading speed, as well as any anomalies (e.g. exit from shipping lanes, stopping, loitering etc.). Again this is based on a combination of transponder data and satellite imagery
- Anomalous behaviour identification. In this case the information content for a given area of interest is the notification and location of pre-agreed anomalies within a certain time cut-off from the satellite acquiring the imagery. Typical anomalies include presence of vessels with no linked transponder signals, proximity of vessels to each other, presence of vessels in restricted areas and vessels executing abnormal manoeuvring (e.g. stopping and starting for no reason, loitering, unexplained deviation from standard routes).
- Monitoring of coastal areas to characterise fishing assets is also possible. In this case, high resolution optical data are used to count the number of vessels or characterise the distribution of vessels over different geographic areas
- In addition to the monitoring of vessels, in certain fisheries activities (e.g. Blue-fin tuna), once fish are caught they are placed in cages. There is usually strict legislation in place related to the movement and management of these cages (e.g. vessels are in general prohibited from approaching the cages as this is considered a suspicious activity linked to clandestine transfer of illegally caught tuna). Such anomalies can be detected through routine monitoring of the cages based on satellite imagery and transponder data of the various fishing vessels in the area.

Resolution, Frequency and Availability

The resolution of the imagery depends on the typical size of the vessels of interest. Typically, spatial resolution is chosen to optimise the coverage of the imagery while ensuring several pixels on the vessels of interest:

- For open ocean areas, the spatial resolution for monitoring larger ocean going vessels is between 10 and 50m (due to the larger size of the vessels of interest)
- For coastal areas where also smaller vessels are



[1] These radar images were acquired during the 2012 Blue Fin Tuna Inspection campaign in the Mediterranean – green dots indicate identified vessels. Red dots indicate vessels detected on the satellite radar imagery for which no identification transponder data are available. CREDITS e-GEOS (I)

being monitored, spatial resolution is between 3 and 20m. Resolutions finer than 3m are not often used due to the radar imaging mechanism being corrupted by the motion of the vessels under the influence of sea surface waves

For most geographic areas, new information can be acquired every 12 hours. However, for many operational users, update times of 24 hours are typical. Satellite data acquired each evening is used to cue surface patrol vessels on inspection cruises while satellite data acquired each morning are used to cue airborne surveillance (as most countries patrol aircraft operate during daylight hours).
The information services are available for all areas World-wide although some degradation of delivery time may be experienced in certain areas (e.g. parts of the Pacific Ocean). This is due to the lack of a local ground station with a fast image processing capability. In these situations, the data must be downlinked at a later time, generating an additional delay of between 30 and 60 minutes in information delivery.

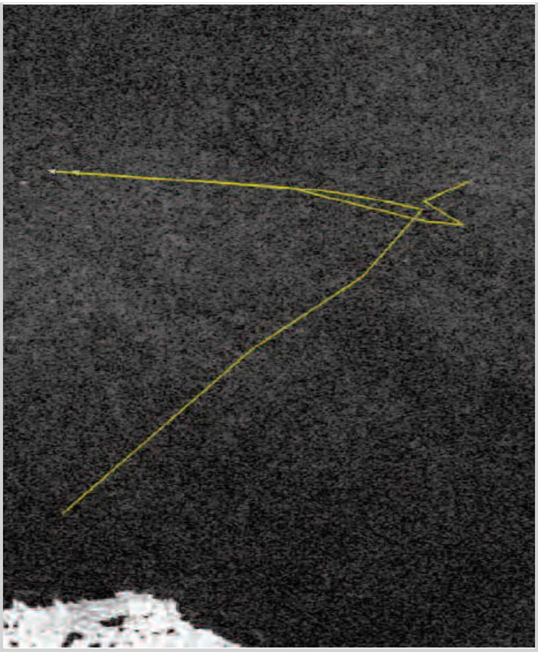
Accuracies and Constraints

The main constraint to take into consideration is the limited time windows during which satellite derived information can be provided. Due to orbit constraints linked to the satellite power requirements, radar imagery can be provided only for two time windows – early morning (typically 03:00 – 06:30 local time) and late afternoon (typically 15:00 to 18:30 local time). Depending on the typical size of the vessels of interest, images with a swath of order 400km can be provided. This represents many hours transit time for vessels travelling at typical speeds (e.g. 18 hours at 12kts) so track formation is possible through regular acquisition of satellite imagery over a given area of interest or along the track of a vessel of interest. Probability of detection of vessels depends on the vessel size, its composition (metal, wood fibreglass etc.) and the sea conditions as well as the spatial resolution of the satellite imagery. Typically, in open ocean, fishing vessels are metal and larger than 20m and are detected in satellite imagery in sea states up to sea state 4-5. Smaller non-metallic vessels are more difficult to detect reliably in rough seas.

Benefits and Use

Several benefits have been identified from using satellite derived information in fisheries control. These include:

- Satellite imagery detects all vessels (above a certain size) in a given area. Unlike cooperative transponder systems such as the Vessel Monitoring System or the Automatic Identification System, there is no action required on the part of the vessel crew to facilitate detection. This means that combining satellite derived information with transponder information allows authorities to rapidly locate vessels that should be transmitting information but are not
- Satellite derived information can cover all marine areas. There is no range limitation and only marginal tasking delays to acquire data over new areas of interest. Conventional systems such as maritime patrol aircraft may require redeployment of crew and support logistics if areas of interest are radically different from those currently monitored
- Satellite derived information enables optimisation of the deployment of conventional patrol assets such as ships or aircraft. Areas where no vessels are present and areas containing vessels of priority interest can be notified to the



[2]

[2] Fusion of Satellite SAR imagery with AIS tracks (in yellow). This shows that two vessel are detected on the SAR image (white dots) but only one vessel is reporting its position by AIS. Given the proximity of the two vessels it is possible that these vessels are engaged in transfer of catch. CREDITS Kongsberg Satellite Services (N)

surveillance planning teams enabling more efficient use of the available patrolling time. In larger marine areas this benefit becomes even greater due to the time taken by aircraft or surface vessels to reach their patrolling station.

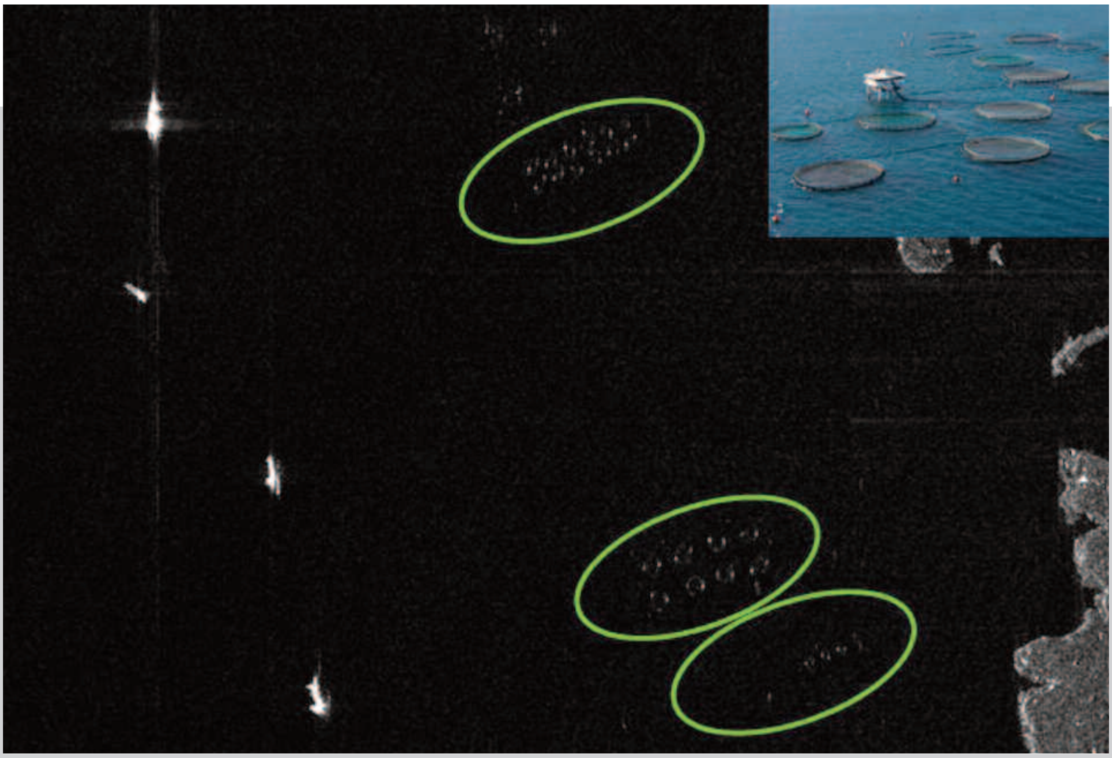
Indicative Costs

Costs depend very strongly on the resolution of data (driven by the typical size of the vessel of interest), the geographic area of interest and the time within which information must be delivered to the relevant authorities. Some typical scenarios are elaborated here:

- Detecting vessels larger than 12m over wide areas within 60 minutes of the satellite overpass with an update every 24 hours. Typical costs for this service would be 500 – 2500 Euro per day
- Detecting anomalous behaviour in an offshore area within 60 minutes of the satellite overpass. Typical costs of this service are 3000 – 6000 Euro per day
- Following a contact of interest over an extended period of time – typical costs of this service are 2500 – 5000 Euro per day

The Contribution of the Sentinel Missions

Sentinel-1 will ensure long term continuity for the availability of basic radar imagery in support of global fisheries monitoring. When used in combination with national missions such as Cosmo-Skymed, TerraSAR/Tandem-X, Radarsat 2/Radarsat Constellation and the new Paz mission which combines radar imaging with AIS message detection, this will support the detection of a wider range of anomalous behaviours.



[3] Satellite monitoring of tuna cages in the Mediterranean, including detection of unauthorised movements of cages and anomalous proximity of fishing vessels. The figure is based on a radar image from the Italian Cosmo-Skymed system. CREDITS: e-GEOS (I)

[3]

Information Content

Two types of information service based on satellite data are available:

- Routine monitoring of a defined area of interest for the occurrence of oil slicks. In this case, the information provided includes a notification of the occurrence of an oil pollution event, its location and extent. In addition, the locations of vessels and the metocean conditions around the slick can also be provided. Finally, by fusing the oil slick information with AIS transponder information, potential polluters can also be identified
- Compilation of statistics on the occurrence of oil slicks in a defined area. This provides a characterisation of the spatial variation in oil slicks based on historic data. Information can be compiled on inter-annual and interseasonal variability

Resolution, Frequency and Availability

TTypically satellite radar imagery with a spatial resolution of 30 – 150m is used for oil slick detection. This ensures the widest possible coverage for a reliable detection of an oil slick.

Due to constraints associated with the use of the service and the fact that large oil slicks move only as a result of forcing by environmental conditions, a daily update frequency is usually sufficient.

This service is available world-wide although in some areas there may be a degradation of the information delivery time due to the lack of a suitably equipped ground station in the vicinity.

Accuracies and Constraints

Detection of large oil slicks is almost 100% accurate. In some cases (e.g. accidents involving spillage of very heavy oils), the oil may float below the sea surface and be difficult to detect. In areas prone to sea ice formation, it may also be difficult to detect illicit discharges.

False alarms are an issue in oil slick detection. Naturally occurring surfactants such as algal blooms or natural seepage can create the same effect on the sea surface as an illicit discharge and be falsely reported as pollution. Similarly areas of low wind may appear similar to oil. For large slicks, false alarms are quite rare when the image analysis is performed by an interpreter with appropriate experience of the region of interest.

As for fisheries control, the issue of the restricted times of day at which radar satellites pass over a given area of interest constrains the update times. As most organisations use the satellite derived information to optimise deployment of airborne surveillance, it is often the case that only the morning acquisitions are used as many surveillance aircraft operate during daylight.

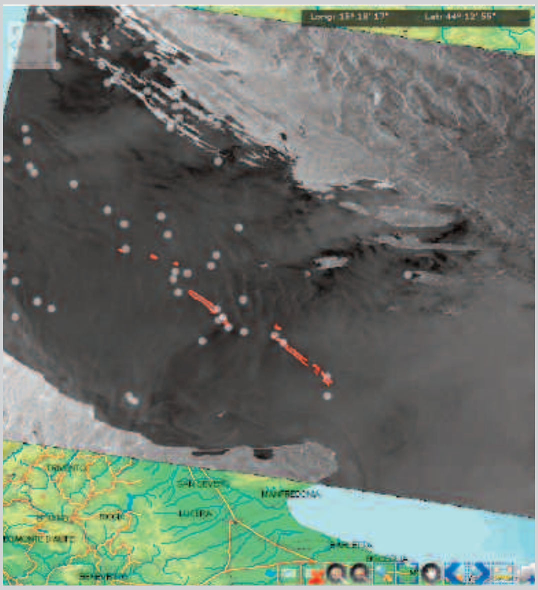
Benefits and Use

Satellite derived information provides an initial notification of the occurrence of a pollution event within 20-30 minutes of the satellite passing over a given area. It also provides an analysis of the presence of potential polluters and an estimate of wind conditions.

National authorities use this information to cue patrol aircraft to make an on-site inspection and also to complement airborne surveillance in regions where airborne operations are more difficult or costly. In addition, if an oil discharge is detected and a possible source vessel identified on the basis of AIS data then the national authority can request a

[1] Detection of an illicit discharge and identification of potential polluter in the Adriatic Sea. This demonstrates the operational interface to the EMSA CleanSeaNet service. Oil is delineated in red.

[2] Example of the fusion of ENVISAT ASAR imagery showing a detected oil slick (the long black line running north-south) with AIS data to identify potential polluters. By matching the tracks of the vessels to the trajectory of the oil slick, the potential polluter can be identified. This is now fully operational within the EMSA CleanSeaNet service.



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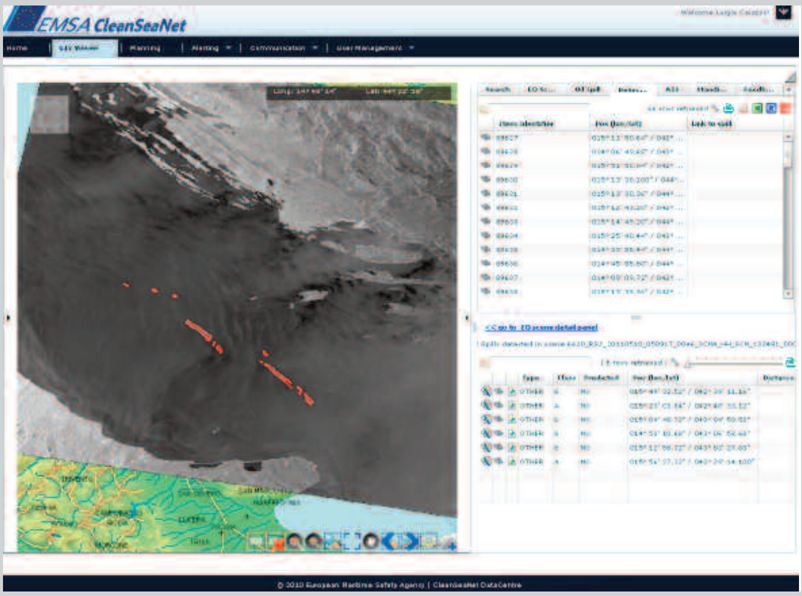


[2]

Port Inspection at the next destination of this vessel. This represents an increased level of deterrence to ship masters against making illicit discharges. All of these capabilities are fully operational within the European Maritime Safety Agency (EMSA) CleanSeaNet system provided to EU Member States. This covers national waters and adjacent high seas areas subject to international environmental protection agreements.

This gives rise to the following benefits:

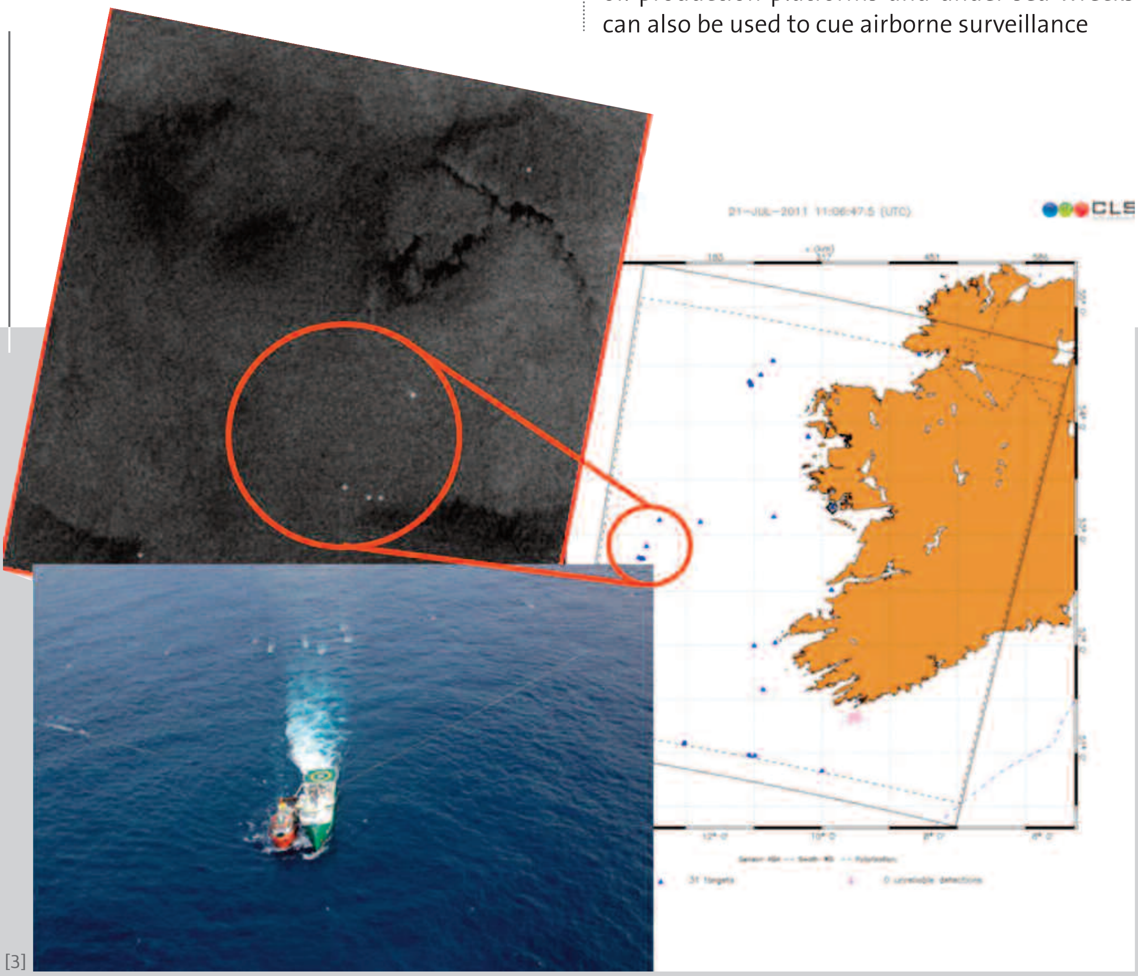
- Optimisation of the deployment of conventional patrol assets. Authorities can be notified of areas identified as being clear of oil and areas where possible oil slicks have been detected, enabling flight hours to be targeted on the areas where they make the most impact
- Extension of the surveillance coverage beyond the immediate vicinity of patrolling assets. Limited airborne surveillance can be complemented by satellite overpasses, in particular for areas far away from the aircraft base.

There are also benefits associated with offshore oil and gas production and exploration for new reserves – for example:

- Offshore oil and gas producers must ensure that an effective pollution detection system is in place but this can be costly and limit interest in more marginal basins. By using satellite based surveillance, costs are reduced, generating wider interest in operating licences for new production areas
- Seismic survey is time consuming and the survey vessel must be refuelled every few days. If this is done in port, it results in increased operations costs due to the associated down-time. Many operators request permission to refuel at sea but there is a strong associated risk of significant harm to the marine environment from leakage. In addition, such a process requires the presence of a representative of the national pollution control authority. By using satellite based monitoring, even small amounts of leakage can be detected and the requirement to transfer an observer to the refuelling vessels is avoided. This represents significant cost savings for the pollution control authority as well as requiring less time commitment from the monitoring personnel.

Finally satellite based detection of pollution from oil production platforms and under-sea wrecks can also be used to cue airborne surveillance

[3] Using ENVISAT ASAR data to monitor at-sea refuelling of a seismic survey vessel. The radar image shows the vessels in close proximity to each other and the surrounding area clear of pollution. CREDITS: ESA, CLS and Irish Coast Guard



[3]

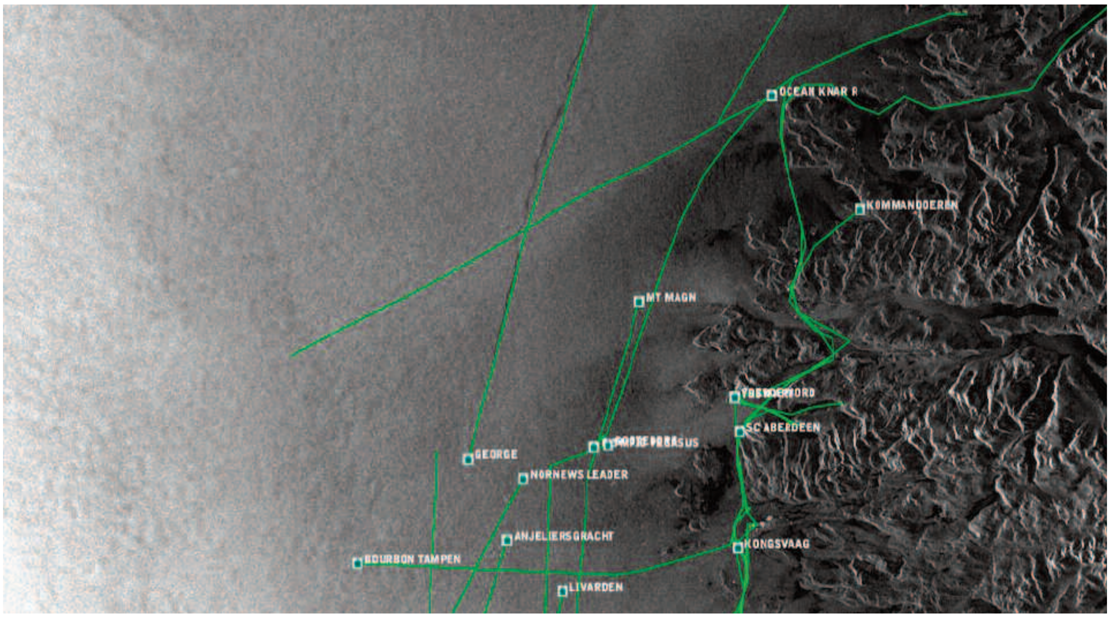
Indicative Costs

Costs depend on the update frequency requested for a particular area of interest. For daily sampling of national waters over an extended period, typical costs would be 500 – 7500 Euro per day depending on the extend of the area of interest and the data used.

The Contribution of the Sentinel Missions

Sentinel-1 will provide routine coverage of most maritime areas world-wide, enabling cost effective pollution surveillance. When combined with national missions such as Radarsat 2/Radarsat Constellation, TerraSAR and Cosmo, updates every 12 hours over most marine areas will be possible.

Sentinel-3 will provide the highest resolution ocean colour data enabling improved characterisation of naturally occurring surfactants and reducing false alarms for oil slick reporting.



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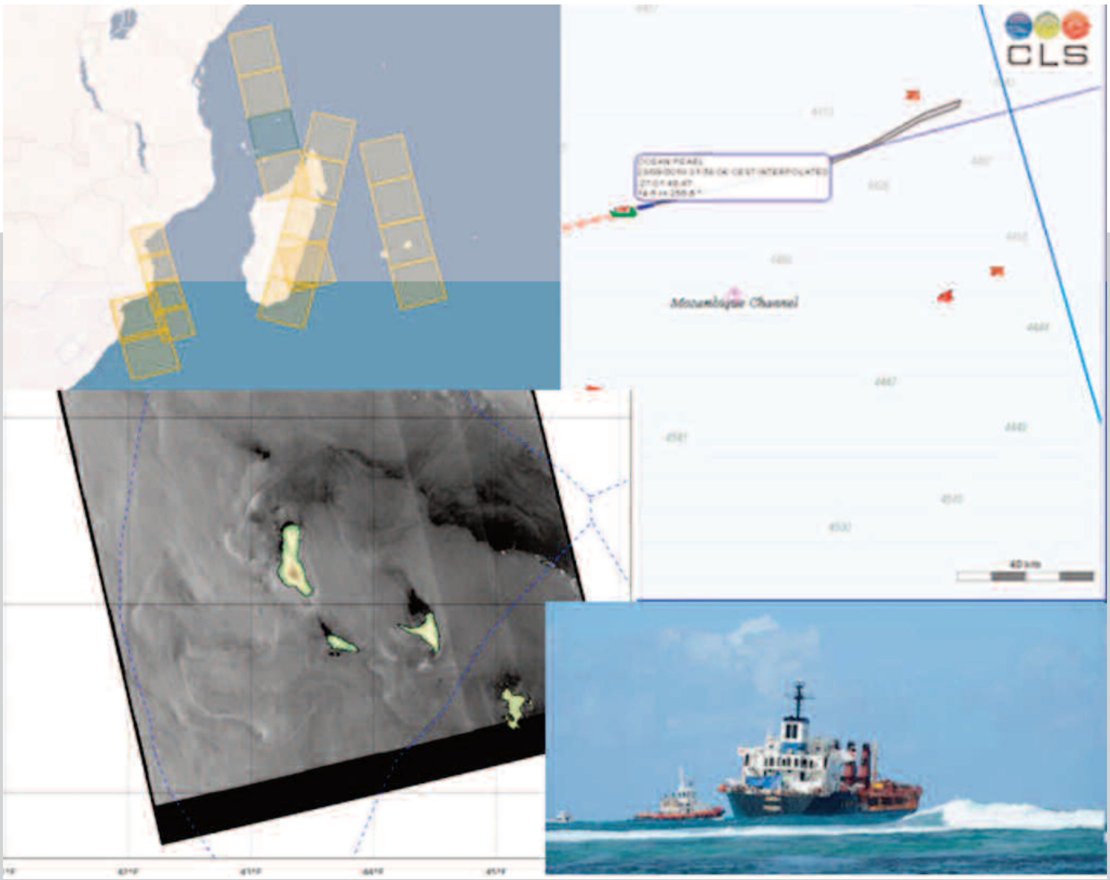


[5]

[4] Example of the fusion of ENVISAT ASAR imagery showing a detected oil slick (the long black line running north-south) with AIS data to identify potential polluters. By matching the tracks of the vessels to the trajectory of the oil slick, the potential polluter can be identified. This is now fully operational within the EMSA CleanSeaNet service.

[5] An ESA financed prototype oil slick detection and polluter identification system covering the Western Indian Ocean. The prototype was operated by CLS and based primarily on ESA Envisat data. In addition to routine surveillance, the system was also used to support emergency response such as removal of fuel from a rice carrier grounded on a coral reef. CREDITS: CLS, ESA and Mauritius Coast Guard

→ OCEAN ANALYSIS AND FORECAST

Information Content

EO derived information provide a range of information parameters to support the analysis and forecasting of ocean conditions and the compilation of long term trends. These include:

- Sea surface temperature
- Chlorophyll concentration
- Transparency
- Sea level height
- Sea surface currents
- Surface wave height, period and propagation direction
- Surface wind speed and direction

These information products are provide as 10 day and monthly composites for temperature, chlorophyll concentration transparency. Other parameters are available as instantaneous measurements or monthly composites

Resolution, Frequency and Availability

Sea Surface Temperature, chlorophyll concentration and transparency and sea surface currents are available at spatial resolutions of 1km Sea level height and surface wave conditions are available at a spatial resolution of a few km. Surface wind parameters are available at 25km resolution. Global composites of these parameters are available every few days (with gaps), with complete coverage available on at least a monthly basis. Information parameters are available on a global basis.

Accuracies and Constraints

Temperature measurements are accurate to ±0.5K Chlorophyll concentrations and transparency are accurate to approximately 30%
The relative error in sea level height is of the order of a few cm. Absolute error is being reduced through the use of a new reference geoid built up from the data acquired by the ESA GOCE mission.
Surface wave height is accurate to ±10% or 50cm, whichever is the larger
Surface wind speed is accurate to ±10%

Benefits and Use

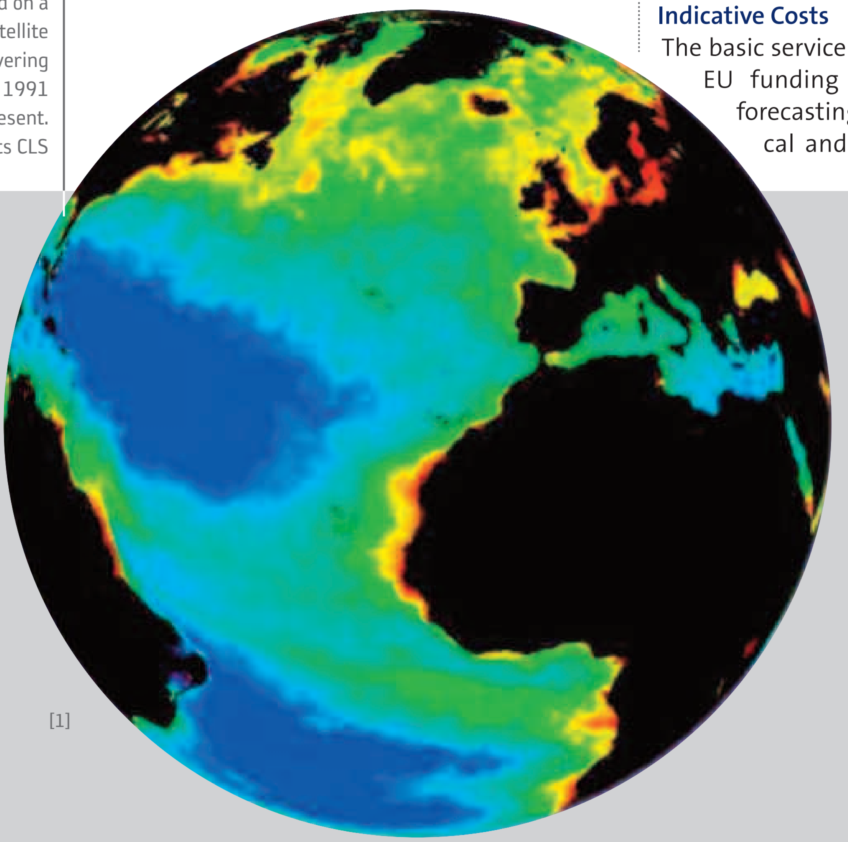
EO derived information provide consistent measurements over wide areas and extended periods of time. They provide a framework for combining different in-situ measurements in a dynamically consistent manner and as such improve the overall accuracy of the characterisation of the ocean conditions.
By providing wide area boundary conditions on the ocean surface, they enable the modelling of sub-surface behaviour of temperature, salinity, currents and chlorophyll conditions which improves the overall understanding of ocean conditions and the dynamics of key processes that drive the Earth system, including air-sea interactions and heat and salinity transfer. In addition, the accurate characterisation of regional and local trends in all ocean areas is of critical importance for assessing possible resource management and economic development policies and infrastructure investment options.

Indicative Costs

The basic service costs are at present covered by EU funding for generic nowcasting and forecasting information services. Statistical and trend analyses are being put

[1] Global chlorophyl concentrations and transparency measurements are available at 4km and 10km resolution based on the fusion of all available ocean colour sensors. Information can be provided as 10 day or monthly composites as well as seasonal or annual mean values and long term time series.

[2] Combination of different radar altimeter systems enable reduction of measurement errors and the generation of precise sea surface height measurements. This can support both regional sea level rise characterisation and also monitoring of shorter term processes. The figure here shows the extraction of the Indian Ocean regional mean sea level trand based on a time series of satellite measurements covering the time period 1991 to present. Credits CLS

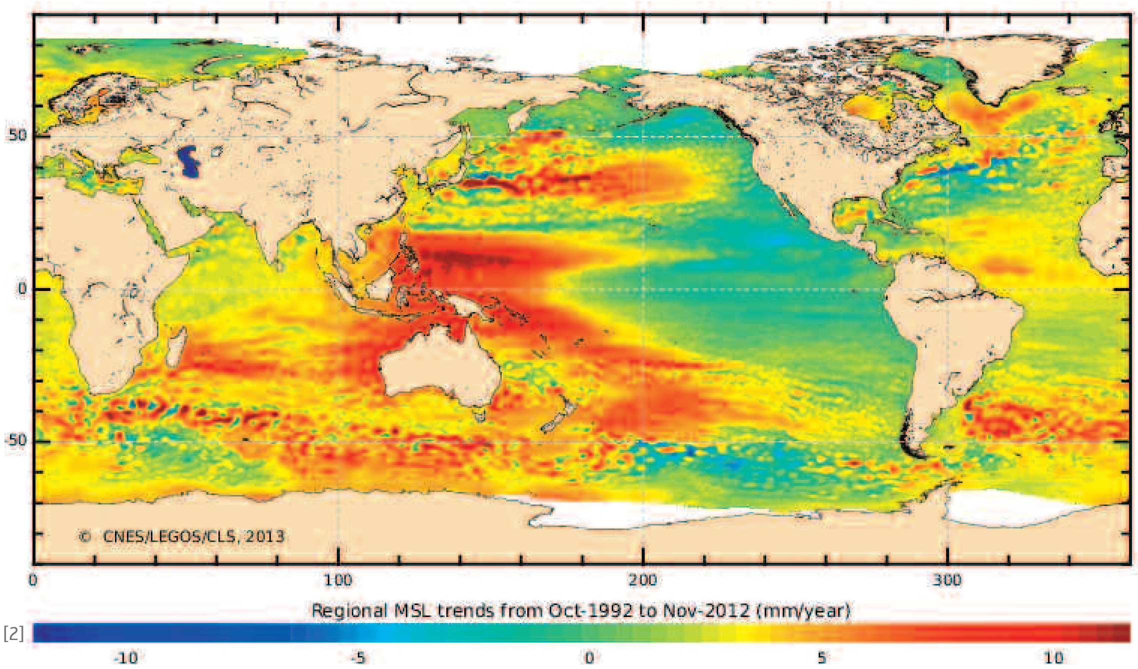


[1]

together under ESA funded initiatives and will be made freely available

The Contribution of the Sentinel Missions

Sentinel-1 and Sentinel-3 data provide long term continuity for all datasets except the surface wind data which are already guaranteed as a result of the Eumetsat Polar System.



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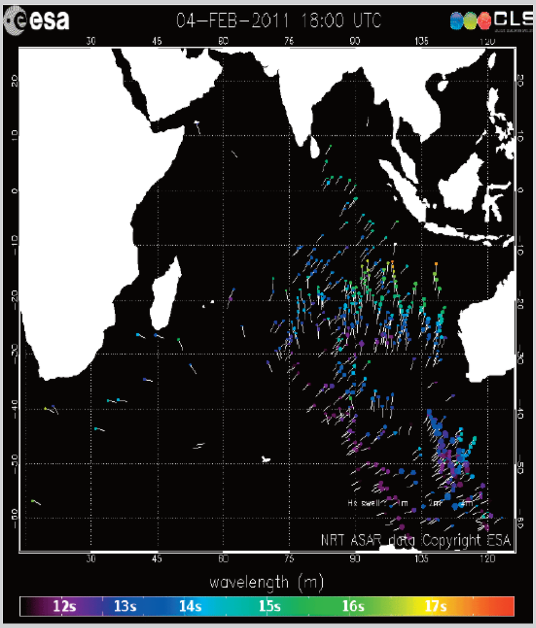

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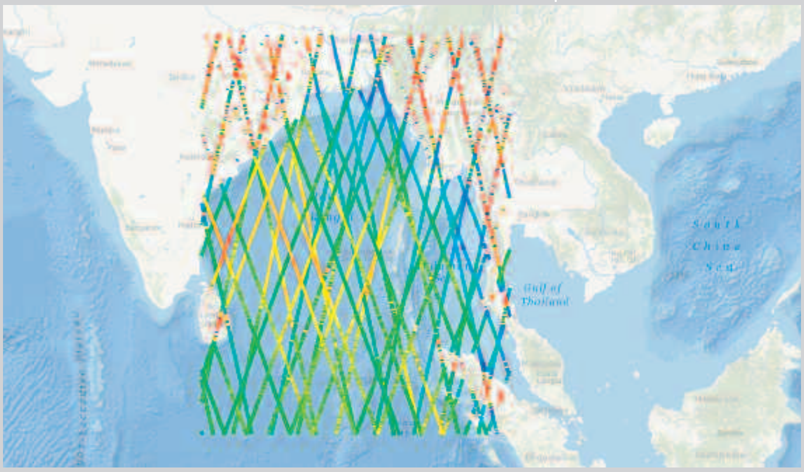

[4]

[3] Global Wave Models provide nowcasts and forecasts of average wave height for all oceans world-wide at a resolution of 10s of km based on the routine assimilation of satelite altimeter measurements of wave height. However other wave parameters such as wave period and propagation direction are also important. A compilation of all satellite wave measurements has been put together under the ESA Globwave project and is freely available.
For more information see http://www.globwave.info
Credits: GLOBWave project

[4] In addition, shorter term assessments can be compiled in support of applications such as storm surge characterisation. The image shows a composite of altimeter measurements over a XX (TBC) hour period, with colour denoting the height of the sea level above a 10 year average.
Credits: eSURGE project

[5] For many of these datasets, routine analyses, nowcasts and forecasts of ocean parameters are available at both regional and global level via the European Marine Core Service,. financed. Information products cover temperature, salintiy, current, sea ice and ocean colour parameters. See http://www.myocean.eu CREDIT: MyOcean project.

[6] Propogation of sea level and sea surface temperature anomalies from the western coast of South America towards Australia results in the El Nino which generates a wide range of negative and positive impacts. Expoitation of positive imapcts and mitigation of negative impacts requires timely information on the status of the temperature anomaly and the point at which it appears that an El Nino is forming. Data from ESA missions including ERS and Envisat have been contributing to El Nino observations since 1991. Sentenel 3 data will ensure long term continuty of these observations.

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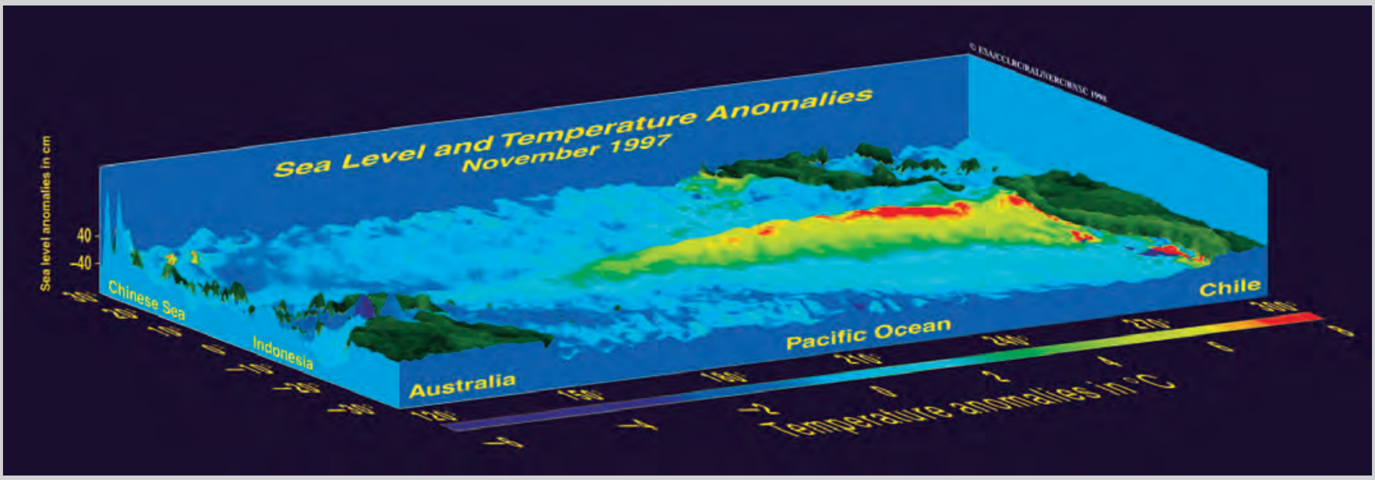


[6]

→ WATER RESOURCES MANAGEMENT

Related World Bank Programmes and Initiatives

Examples of World Bank related initiatives to which this section is pertinent: The Water Partnership Programme (WPP), the Nile Basin Initiative (NBI), Nile Equatorial Lakes Subsidiary Action Programme (linked to NBI) and Regional Coordination on improved water resources management and capacity building project. The World Bank's vision for the water sector was initially articulated in the 2003 Water Resources Sector Strategy. The implementation progress report "Sustaining Water for All in a Changing Climate" (2010) reaffirms the strategic directions for the World Bank Group's approach to supporting water resources management. It emphasises a water development agenda that is integrated with energy, climate, agriculture, land use, and overall economic development and the importance of tackling institutional reforms along with infrastructure upgrades.

Addressing Development Challenges

Water quality and access is essential for socio-economic development and for maintaining healthy ecosystems. Properly managed water resources are a critical component of growth, poverty reduction and equity. The livelihood of the poorest are critically associated with access to water services.

The key topics concerning water resources management in World Bank activities include:

- Water Supply and Sanitation (Quality and availability of surface -rivers and lakes, Groundwater management, Urban sanitation, Management of Industrial wastewater)
- Irrigation and drainage (Drought control, Food security, River networks management, Erosion and land degradation, Energy Security, Development and management of hydropower facilities Environmental services)
- Environmental services (Sustainable development of watersheds, Ecosystems management, including wetlands)
- Industry (Freshwater fisheries and aquaculture – plus agriculture and fresh water supply/sanitation).

The Potential of EO Information Services

The concept of Integrated Water Resource Management (IWRM) is seen as an opportunity to mitigate the wide spread water scarcity in developing regions such as Africa. One blocking key component of IWRM is the limited knowledge of the available extent and quality of water resources at basin level. Earth Observation (EO) technology can help to fill this gap by assessing and monitoring water resources at the regional scale. Currently a portfolio of EO products relevant to IWRM, such as water reservoir inventory, catchment characterization or water quality monitoring - has been developed and demonstrated in dedicated projects. Furthermore the wide spatial coverage of satellite images has proven to be of specific relevance for trans-boundary basins where consistent information between countries is needed for sustainable water resource management.

BASIC EO CAPABILITIES

CUSTOMISED SERVICE

EO PRODUCTS/DATASETS

→ INLAND WATER QUALITY

Information Content

The service provides information concerning inland water quality, both regarding chlorophyll content and suspended matter. Total suspended matter (TSM) and/or turbidity maps is provided in the unit milligram per litre [mg/l]. Chlorophyll a is one essential pigment included in phyto-plankton cells and therefore a measure of phyto-plankton. The common unit of chlorophyll is [µg/l]. Products of the different satellite sensors can be used, like MERIS, MODIS Aqua/Terra, to provide consistent, simultaneous measurements within a range of 0.1-0.2 mg/l for suspended matter and 1 µg/l for Chlorophyll.

Resolution, Frequency and Availability

The period and update frequency depends strongly on cloud-cover for the lake in question. Normally for this type of this service, the satellite sensor MERIS is used as baseline to generate 300m resolution products up to 10-20 times per year. This baseline service can be complemented with more high-resolution satellites like Rapideye to provide a spatially high resolution product (down to 5 meters) but with less frequent updates (3-5 times per year).

Accuracies and Constraints

The final quality of the satellite water quality products will depend heavily on the availability of in-situ ground measurements in order to validate the EO based products due to the different nature of individual lakes and their height above sea level (for atmospheric corrections). Having available in-situ measurements one can achieve accuracies of both chlorophyll and suspended matter in the order of 90%. The geometric accuracy depends on the spatial resolution of input EO data, typically < 1 pixel. Historical data sets can be obtained from the archives to provide for trend analysis of water quality, and to monitor impacts over time of corrective actions to improve the lake ecological situation. Typically datasets from MERIS can be obtained globally for the last decade, but not all data pass the quality control due to strong haze, sun glint or problems with the satellite raw data.

Benefits and Use

Several factors threaten the ecological state of lakes, including issues relating to harmful algae, toxic chemicals, dis-charges from vessels, aquatic invasive species, habitat degradation, and the effects of climate change. Monitoring these issues is critical for local sustainable management of lakes and satellites are particularly suitable for observing relevant water quality parameters like phytoplankton and total suspended matter.

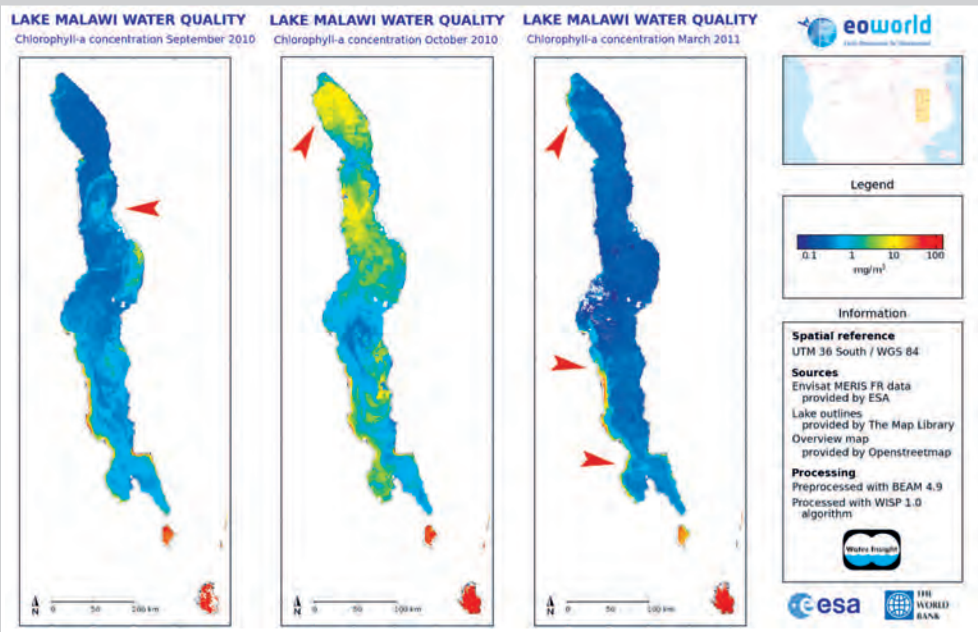
Indicative Costs

The cost for these products is very roughly 10k€ for multi-annual time series of one inland lake.

The Contribution of the Sentinel Missions

Colour Instrument (OLCI) is based on heritage from Envisat's Medium Resolution Imaging Spectrometer (MERIS). With 21 bands, compared to the 15 on MERIS, a design optimised to minimise sun-glint and, a resolution of 300 m over all surfaces. The pair of Sentinel-3 satellites will enable a short revisit time of less than two days for OLCI and less than one day for SLSTR at the equator.

Red arrows points to chlorophyll-a plumes caused by riverine influx. Credit: WaterInsight.



Information Content

The service can include baseline land use mapping of forest, major agricultural surface types, conservation areas, settlements, primary roads, bare soil, water bodies, rivers, wetlands (FAO LCCS classification system). Land use change can then be monitored for these classes over time for trend analysis with the corrective actions undertaken to improve the sustainable management of the watershed.

Resolution, Frequency and Availability

Geometric accuracy will depend on spatial resolution of input EO data, typically < 1 pixel. The Spatial resolution will depend on the satellite sensor used, but 5-30 meter resolution is typically sufficient for the relevant land use classes. The period and update frequency depends strongly on cloud-cover for the region in question but using different satellites, it is often possible to have good quality information of land use up to a monthly frequency if required although an annual update will be sufficient in most cases. The update frequency will also depend on the resolution required for the observations. Normally for this type of this service, a satellite sensors like Spot 4/5, Landsat or RapidEye are used as baseline for the monitoring.

Accuracies and Constraints

The accuracy of the derived land use information will depend on the quality of the EO data, but typically be in the order of 80—90 %. The presence of ground truth data will improve the classification process and normally increase the overall accuracy of the EO derived product.

Benefits and Use

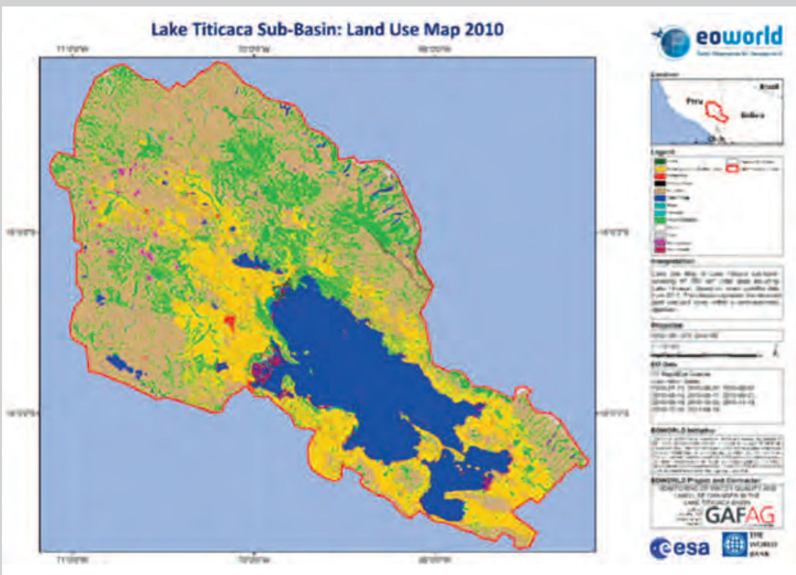
Activities related to agriculture and industry can have big impacts on water quality in a watershed and therefore need to be monitored. Changes in land use from forest to agriculture can dramatically increase the nitrate fertilizer run off from the farmland and impact water quality. Likewise, urbanization in regions of the watershed, can also lead to increased wastewater run off in the watershed. By monitoring the surroundings of lakes and rivers, one can identify land use hotspots with potential that could have impact on water quality.

Indicative Costs

The cost for these products is in the order of 50-100k€ to cover one catchment area (one time step, at 5-10 meter resolution). Costs vary significantly depending on the resolution, thematic accuracy and required numbers of temporal observations.

The Contribution of the Sentinel Missions

Sentinel-2 will routinely provide high-resolution (10-20) optical images globally with frequent revisits tailored to the needs of GMES land services. Sentinel-2 aims at ensuring continuity of Spot- and Landsat-type data, with improvements to allow service evolution. The first launch is expected in 2014. The Sentinel-2 Multi-spectral Instrument (MSI) features 13 spectral bands from the visible and near-infrared (VNIR) to the short-wave infrared (SWIR), featuring four at 10 m, six at 20 m and three at 60 m resolution.



Land use map of the Lake Titicaca sub-basin. Credits GAF

Information Content

The service provides information concerning freshwater run-off from snow covered areas and glaciers relevant as important contributions to hydroelectric capacity within a hydropower project. Obtaining run-off estimates from these sources is important both during the project development phase and as part of the hydropower day-to-day operations planning. Satellites can map the snow-covered areas and provide baseline glacier outlines, changes to surface area, velocities and mass balance.

Resolution, Frequency and Availability

Satellite based snow covered area products can reliably be provided down to a spatial resolution 500 meters. Global coverage is possible and updates can be provided on a weekly basis. In addition, historical data sets can be made available for the last 30 years to assess how the evolution of snow conditions in the watershed. Glacier information can be provided at sub-meter resolution to the scale of hundreds of meters, depending on the glacier size and the accuracies required for run-off model input. Annual updates will often be sufficient to follow glacier evolution.

Accuracies and Constraints

Both the snow and the glacier products can be provided with a geometric accuracy of less than a pixel. It has been demonstrated that having both satellite snow and glacier information can improve catchment run-off modelling and even reduce in-situ observations without significant impact in model output accuracy.

Benefits and Use

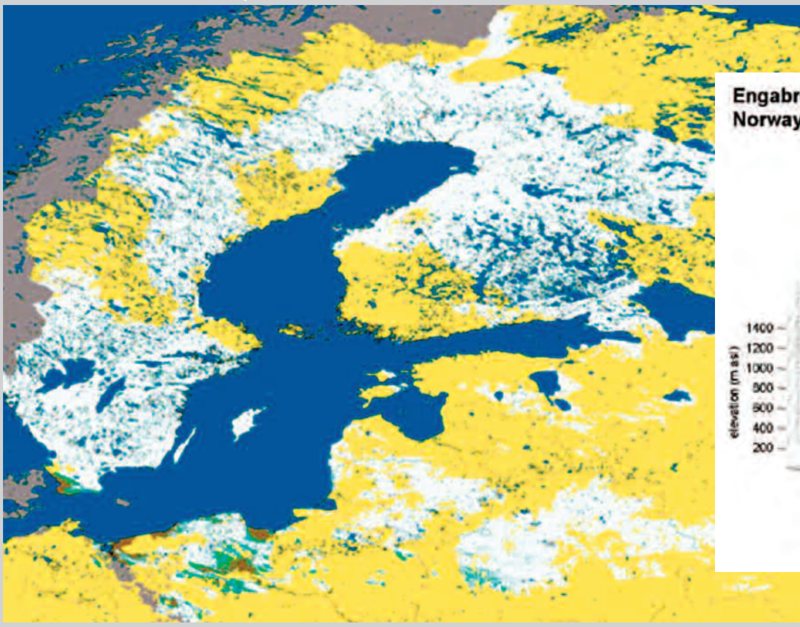
As demand grows for clean, reliable, and affordable energy, the role of hydropower has increased over the past decade as developing nations move to harness their resources. Hydropower reservoirs are often built for multiple purposes, such as irrigation and drought protection that drives poverty alleviation and sustainable development. Currently, the World Bank Group is engaged in hydropower projects in all its regions. The activities include both construction of new projects and rehabilitation of old projects. Earth observation services can play a vital role in all phases of a hydropower project, from estimating the environmental impact on ecosystems to providing potential water run-off from snow and glaciers. Glaciers can also represent an important run-off potential for hydropower reservoirs. A number of countries are highly dependent upon its glaciers and glacial runoff for energy production, for example in the Andes region, hydropower supplies 81% of Peru's electricity

Indicative Costs

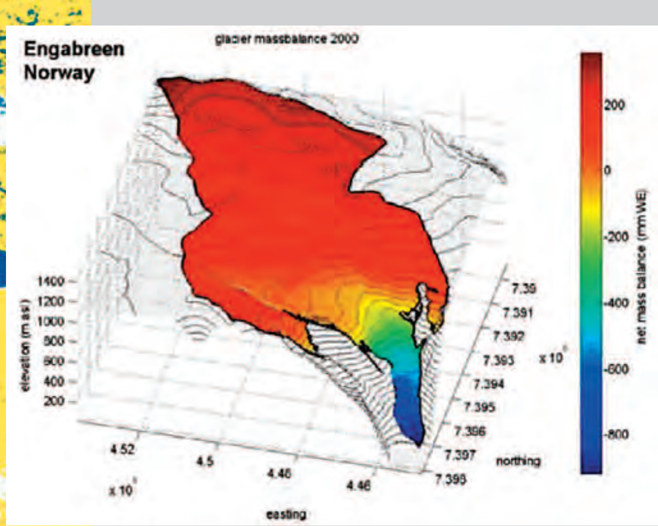
The cost for the snow monitoring products are roughly 100-200k€ for annual monitoring of a catchment, and about 20-50k€ for a glacier baseline product.

The Contribution of the Sentinel Missions

The Sentinel 1, 2 and 3 satellites will both provide continuity with respect to monitoring of snow covered area and glaciers. Sentinel 1 will be of particular importance for glacier monitoring due to its day and night radar and the possibility of using radar interferometry to derive glacier velocities.



[1] Snow Monitoring Baltic Region during melting period. Credits: Syke



[2] Glacier mass balance of Engabreen, Svartisen, modeled using an energy-balance model validated with EO data. Credits: Regine Hock/Thomas Schuler.

Information Content

The service provides information concerning wetlands and their adjacent uplands. With wetlands often made up of difficult and inaccessible terrain, satellites can provide information on local topography, the types of wetland vegetation, land cover and the dynamics of the local water cycle. A single satellite image can often cover a wetland's entire catchment area and the surrounding landscape that drains into a wetland. Radar imagery is of particular interest being able to differentiate between dry and waterlogged surfaces, and in combination with optical data deliver multi-temporal data showing how wetlands change across seasons.

Resolution, Frequency and Availability

The Spatial resolution will depend on the satellite sensor used, but 5-30 meter resolution is typically sufficient for this application.

Accuracies and Constraints

Geometric accuracy will depend on spatial resolution of input EO data, typically < 1 pixel. The accuracy of the derived land use information will depend on the quality of the EO data, but typically be in the order of 80—90 %. The presence of ground truth data will improve the classification process and normally increase the overall accuracy of the EO derived product.

Benefits and Use

EO products also function as a useful tool for wetland managers and scientific researchers. The thematic content of these EO products comprises baseline mapping of wetland boundaries (e.g. size and variation), land cover/use of the wetland site and corresponding catchment area, digital elevation model of the wetland site and the corresponding catchment area, water regime (e.g. periodicity, extent and flooding) and water chemistry (e.g. colour and transparency). In addition continuous monitoring can identify changes in biological, physical and chemical conditions of the wetland site. Potential threats (overgrazing, urban expansion, agriculture activities and industrial pollutants) in the wetland site and the corresponding catchment area can also be identified.

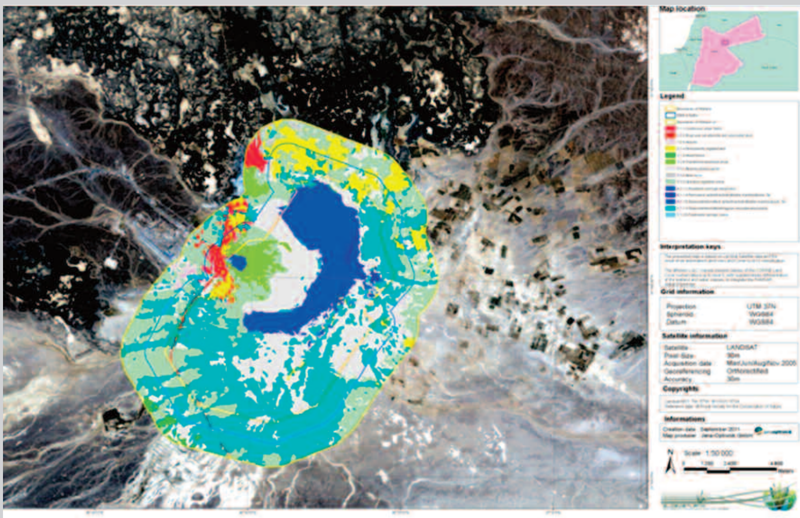
Indicative Costs

The cost of this service is roughly 20-50k€ for yearly seasonal monitoring of one wetland.

The Contribution of the Sentinel Missions

The Sentinel 1, 2 and 3 missions will provide continuity with respect to monitoring of wetlands. Sentinel 1 will be of particular importance for due to its capability to detect water, Sentinel 2 will provide the land use information and Sentinel 3 can provide for water quality measurements.

Wetlands Land Use and Land Cover map of Azraq in Jordan 2005. Credits: Regine Hock/Thomas Schuler.



→ WATER RESERVOIR MAPPING

Information Content
The service provides information concerning small water reservoirs. Water reservoirs baseline maps and their evolution over time can be reliably generated, providing both water surface and volume.

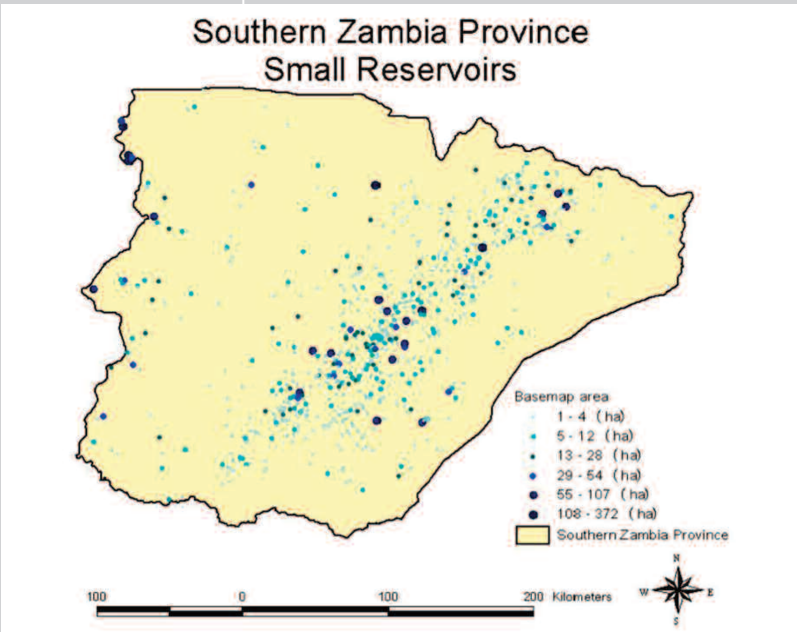
Resolution, Frequency and Availability
The period and update frequency depends on the satellite sensors used, but using only Landsat data one can have monthly updates at a global scale for reservoirs larger than 1 hectar. In cloudy areas SAR observations are mandatory to ensure a sufficient temporal coverage.

Accuracies and Constraints
Optical sensors like Landsat and Spot can easily identify reservoirs of size down to one hectar. In cloudy conditions radar sensors can provide the same level of detail, but with slightly reduced accuracy under certain local environmental conditions (wind with waves on the reservoir surface). The final product can be provided with accuracies of better than 90% for both the water surface and volume.

Benefits and Use
In semi-arid areas of the developing world, rural water supply is increasingly insufficient. Supplying the rural population in semi-arid developing countries with water requires spatially distributed sources of different qualities and quantities of water. Access to clean drinking water is being improved with borehole programs, but the equally important large volume demand for non-drinking purposes is currently not addressed sufficiently.
One of the key advantages of small reservoirs is their existence in large numbers, greatly improving the water availability at village level. They are often the only adequate and economically feasible source of large volume water supply for non-drinking purposes and important for economic development and the reduction of poverty. While their small size, existence in large numbers, and widespread distribution leads to many desirable socio-economic effects, the same characteristics make hydrological impact assessments and scientifically sound development difficult.
EO products can be used for planning construction and maintenance of small reservoirs at regional/national scale, as well as the need for irrigation oriented extension services. In addition, it is possible to derive important hydrological indicators from reservoir storage, which may feed into hydrological models and/or famine early warning systems/harvest predictions.

Indicative Costs
The cost for these products is very roughly 0.75 € per km^2

The Contribution of the Sentinel Missions
Sentinel-2 will routinely provide high-resolution (10-20) optical images globally with frequent revisits with the potential of replacing the Landsat 5 data. Sentinel-2 aims at ensuring continuity of Spot- and Landsat-type data, with improvements to allow service evolution. The first launch is expected in 2014. Sentinel-1 will provide temporal coverage in areas of high cloud coverage.

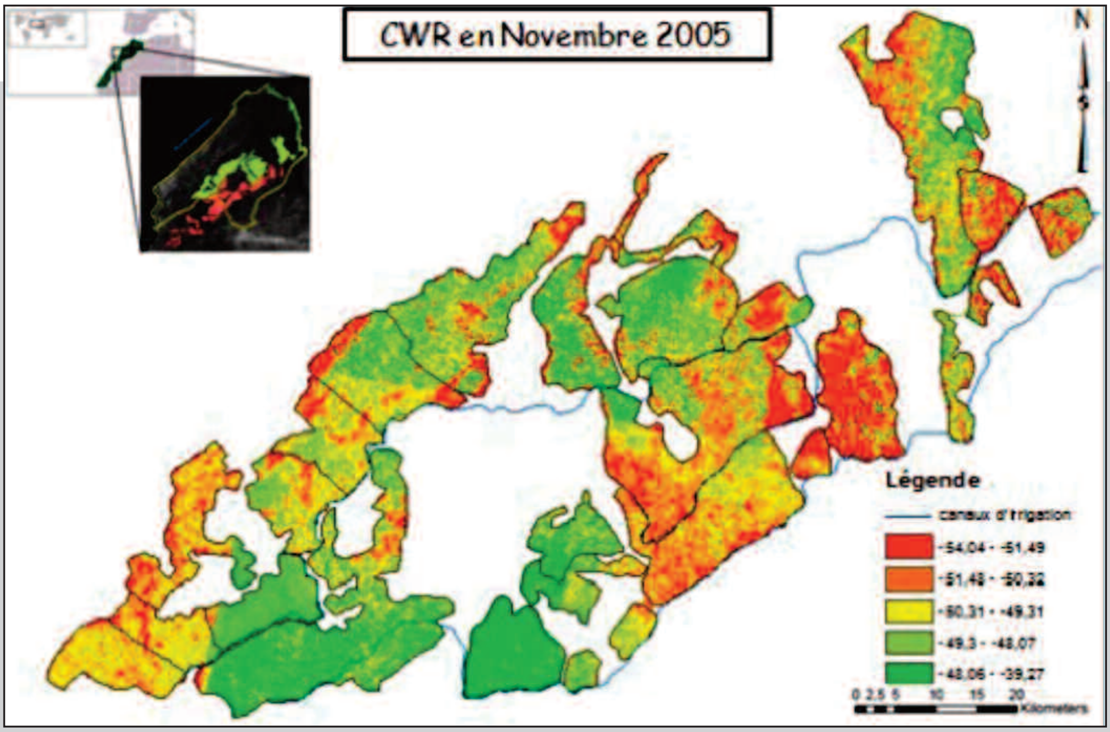


Small reservoir base map of the Southern Province of Zambia. Credits NEO

The service provides information to estimate the amount of water actually needed by crops. Irrigation water management is based on the water used by a specific type of crop balanced against natural precipitation and irrigation as well as the soil water holding capacity. Crop type(s) are needs to be explored in relation to specific water needs as well as cropping patterns and agronomic and market practices.

Canopy cover is a direct driver of crop water use and hence allows a direct relationship to be developed between NDVI satellite derived values and crop coefficients which take into consideration specific agronomic and management conditions for individual crops. This allows a specific crop water requirement indicator to be derived on an area as small as 30 x 30 m when data from the commonly available Landsat satellite is used.

The EO based irrigation water management service can support sustainable water management practices. Irrigation water management by satellite helps irrigators to determine how much water their crop has used and how long they need to run their pump or drip system for each day using the latest in remote sensing techniques and mobile phone based delivery services. This approach also allows irrigators to benchmark their water use, in real time, against other irrigators. By viewing a web page irrigators can see how much water they have applied and compare against other users at any time through the season.



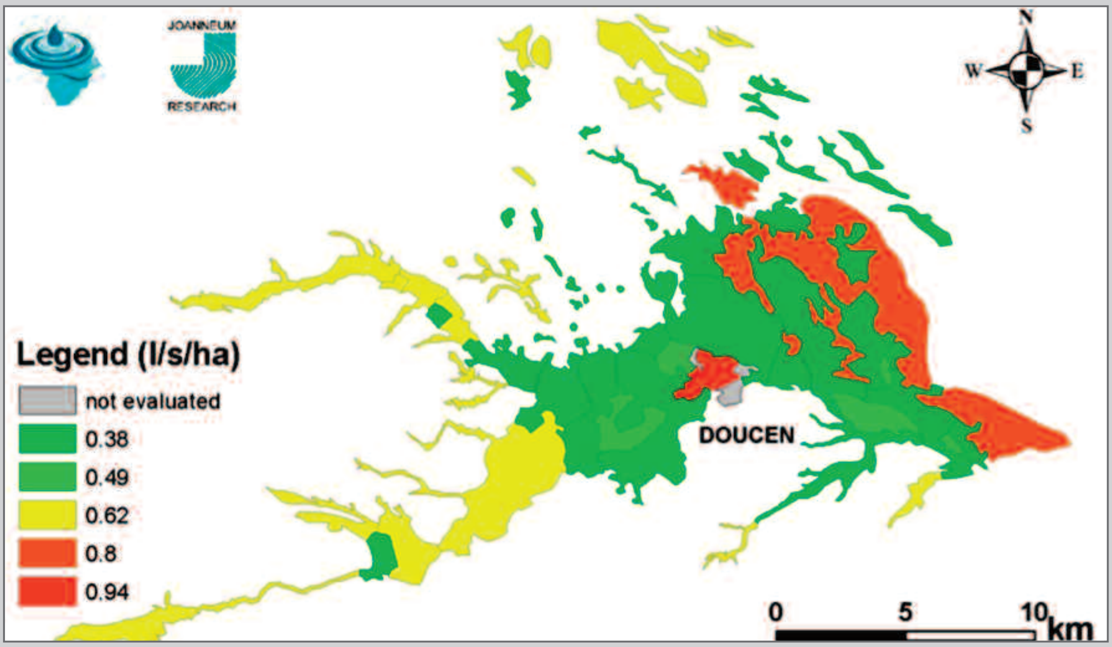
SPOT-4 satellite based map used to assess the water needs of crops in the agricultural region of Doukkala, Morocco in November 2005. Credits: University El Jadida

→ AQUIFER MONITORING

EO based indicators of ground water may provide important data where practical alternatives are not available. Predicting hydrologic behavior at regional scales requires heterogeneous data that are often prohibitively expensive to acquire on the ground. As a result, satellite-based remote sensing has become a powerful tool for surface hydrology. Subsurface hydrology has yet to realise the full benefits of remote sensing, even though surface expressions of ground water can be monitored from space. Remotely sensed indicators of ground water may provide important data where practical alternatives are not available.

The relevant EO based products include, vegetation and water monitoring maps at basin-wide level, rainfall estimates and evapotranspiration and water balance maps, land use / land cover maps and their changes, water abstraction estimation and crop water consumption, digital terrain models and derived products, subsidence mapping and monitoring.

The EO based aquifer monitoring service can improve the management of internationally shared water resources and aquifers. Improved and sustainable management will contribute to improving the living conditions for the people depending on the groundwater for drinking water and irrigation.



Water abstraction estimate map for the oasis of Doucen, Algeria. Credits: Joanneum Research

Recognizing the utility of satellite data for Integrate Water Resource Management (IWRM) and responding to the urgent need for action in Africa stressed by the Johannesburg World Summit on Sustainable Development (WSSD), the European Space Agency (ESA) launched the TIGER initiative in 2002. The overall objective of the initiative is to assist African countries to overcome problems faced in the collection, analysis and use of water related geo-information by exploiting the advantages of Earth Observation (EO) technology. It follows four major action lines to realize its objective:

- Facilitating Access to EO data
- Capacity Building & Training
- Knowledge and Information Network
- Development of EO Information Services

The TIGER initiative has established and supported capacity building activities and development projects in over 42 African countries, reaching more than 150 African water authorities and research institutes.

The TIGER Partnership

The TIGER initiative is a demand driven process, where the main focus is on the needs and requirements, in terms of water related information, of water authorities and other stakeholders involved in IWRM in Africa (i.e., Ministries of water and river basin authorities, African technical centres and universities).

TIGER is an international endeavour that has been endorsed by the African Ministerial Council on Water (AMCOW), contributes to the strategy of the Group on Earth Observations (GEO) and involves as partners the UNESCO-IHP (the UN Educational, Scientific and Cultural Organization), UN-ECA (UN Economic Commission for Africa), the African Water Facility, the African Union Commission, the Canadian Space Agency (CSA) and most recently Cap-Net of UNDP as well as the World Bank on project level.

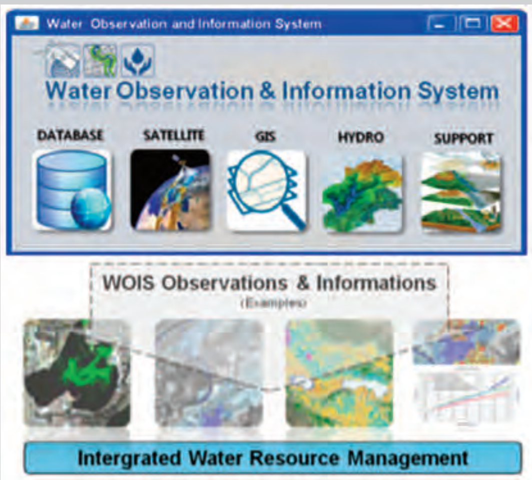
Capacity Building & Training:

The main focus of TIGER is on training and capacity building activities to support African partners (water authorities, technical centres, universities) to advance them towards independent capacity to exploit EO technology for improving knowledge on water resources management. TIGER's goal is to support the consolidation of a critical mass of technical centres in Africa with the skills and capabilities to derive and disseminate space-based water relevant information for scientific research and management at regional, national and local scales.

Besides conducting EO training courses TIGER supports through its TIGER Capacity Building Facility (TCBF) currently 20 research projects lead by African scientists and 6 research fellowships for young African scientists. The TCBF works closely together with its Regional Offices RCMRD (Kenya), AGHYMED (Niger), Water Research Council (South Africa) and OSS (Tunisia) to reinforce their training capacity in Earth Observation with Training of Trainers in partnership with the UNDP Cap-Net programme. Most recently the TCBF developed and started a three years EO training programme with the World Bank for the Zambian government.

Finally TIGER develops and demonstrates currently a water observation information system (WOIS) in direct partnership with African national water authorities and transboundary river basins commissions.

The WOIS, based on open-source source software, will enable the African water authorities to produce and exploit a range of satellite earth observation based information products for monitoring and managing their own water resources.

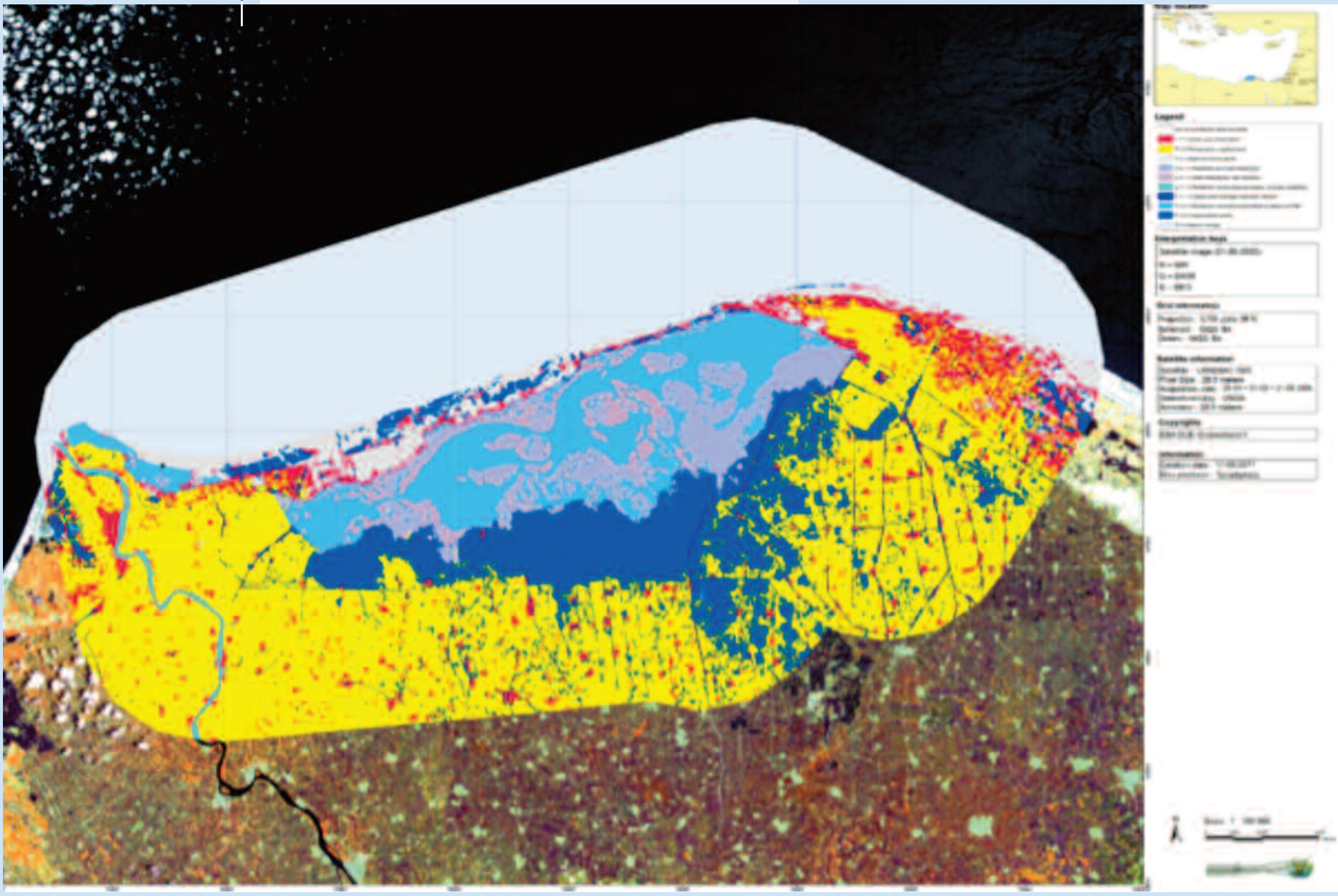


GLOBWETLAND

Information content:
The service provides information concerning wetlands at a global scale. The GlobWetland Information Maps include; Land Use / Land Cover maps (including wetland typologies), change detection maps for long-term change and trends analysis and water cycle maps for the analysis of the annual variations of the water table. Globwetland cover 200 wetland sites and surrounding areas, which have been selected over the coastal catchment areas of the Southern and Eastern part of the Mediterranean basin, extending from Morocco to Syria (less than 100 km from the coastline). The wetlands Information Maps and Indicators will be provided for 3 points in time (1975-76, 1990-91, 2005), taking full advantage of the time series of Landsat data (MSS, TM and ETM). The maps will be produced at a geographical scale of 1:50.000.

Benefits and Use:
These products are intended to serve the needs of many wetlands conservation practitioners from the wetlands managers up to the stakeholders of the Ramsar Convention. The targeted user communities of the project are the Ramsar Administrative Authorities and National Focal Points of the subject countries and their supporting conservation agencies, the MedWet partnership and its MWO, the international organisations member of the Ramsar STRP, intergovernmental environmental organisations, international environmental and conservation NPOs/NGOs, and partnerships of conservation organisations.

Globwetland Land use and land cover of Lake Burullus (Egypt) in 2005. Credits ESA DUE Globwetland 2. Credits: ESA DUE Globwetland 2



→ ENERGY AND NATURAL RESOURCE EXTRACTION

Related World Bank Programmes and initiatives

World Bank initiatives in the area of energy and extractive industries include:

Mining (Mine Closure, Mining & Environment, Mining & Local Economic Development, Mining & Poverty Reduction and Small Scale Mining),

Energy Access & Renewables (Renewable energy generation and energy efficiency, Clean Energy & Climate Change and Power Sector Reform),

Environment (Environmental Assessment, Corporate Responsibility and Biodiversity)

Addressing development challenges

- Governance of the petroleum, natural gas and mining sectors, including environmental management and infrastructure investment including both transport logistics (e.g. pipelines) and regulatory authority processes and tools
- Renewable Energy and Energy Efficiency
- Clean Energy and Climate Change
- Small scale mining
- Natural/Cultural Heritage

Extractive industries are key components of many developing countries' economies. When managed effectively, mineral and hydrocarbon resources offer a real opportunity for such countries to achieve sustainable economic growth and reduce poverty. Extractive industry and oil and gas production are not the only sources of external revenue - renewable energies represent an area of significant potential growth and many developing countries have the possibility to become significant suppliers of renewable energies such as hydropower, wind, wave, tide, current and solar energy. In addition, there is increasing interest in biofuel production, which would involve many developing countries. However, many of these sectors risk significant detrimental effects on the natural environment and adjacent habitats and ecosystems.

The potential of EO Information Services

Information derived from satellite Earth Observation has been demonstrated to be of significant benefit and impact for characterising new resources, planning new operational infrastructure, sustainable management of extraction and energy generation operations and the optimised rehabilitation of production sites once the operational activity has ceased.

By using satellite derived information over all stages of an extraction or energy generation activity, from preliminary planning to post closure site remediation, facility operators and government regulators can ensure that the operations are implemented, operated and closed down such that the negative impacts on natural capital and ecosystems are minimized while the economic benefits of the operation are maximized.

This is also the case for renewable energy developments - there has been extended discussion on the impact of hydropower related dam construction while coastal energy developments can result in severe impacts on coastal ecosystems and economic activity such as aquaculture. In addition, there is increasing concern with respect to preservation of cultural heritage in areas where natural resource extraction is taking place.

CUSTOMISED SERVICES

→ GEOLOGICAL MAPPING

Information Content

Satellite based geological mapping provides the following information layers:

- Delineation of different lithological units (important to understand the geological history of a particular area of interest and the possible presence of minerals or hydrocarbons)
- Delination of boundaries between different lithological units
- Classification of lithological elements
- Classification of visible soil types and relationships to standard lithological classifications
- Classification of vegetation types and relationships to identified soil types

A satellite based geological map enables the geological interpretation of a particular region without the requirement for extensive field surveying in this area

In addition to these standard geological map products, satellite data are routinely used to generate customised geological information products. These include:

- Uplift probability mapping. By combining lithological classification using optical satellite imagery with structural geological markers from radar imagery such as ERS or ENVISAT, it is possible to delineate features associated with the surface expression of geological processes (i.e. the uplift and subsequent weathering) that create hydrocarbon traps. By reliably detecting such features, it is possible to identify areas of high potential for hydrocarbon extraction within a given licence block.
- Seepage slick mapping for offshore oil exploration. Sub-sea oil and gas deposits are often located due to the seepage of these hydrocarbons into the sea where they float to the surface. Under calm wind and wave conditions, these "seepage slicks" can be identified on Synthetic Aperture Radar images as dark areas (due to the damping effect on small scale surface waves) with characteristic shapes (usually either "dog-leg" or "spot" like). By analysing areas over an extended time period, persistent slicks can then be correlated with new sub-sea oil and gas deposits by combination with available geological maps.

Resolution, Frequency and Availability

Resolution depends on the lengthscale of the geological process of interest in the region being analysed. Typical resolutions vary from 0.5 m to 50 m resulting in a map-scale of 1:2000 to 1:250000 although coarser scales may also be used. Typical geological interpretation will include the following elements:

- Interpretation of surface geological structure at 1:100 000 – 1:250 000 scale
- Identification of major lithostratigraphical units at 1:250 000 – 1:500 000 scale
- Capture of major drainage channels and water bodies

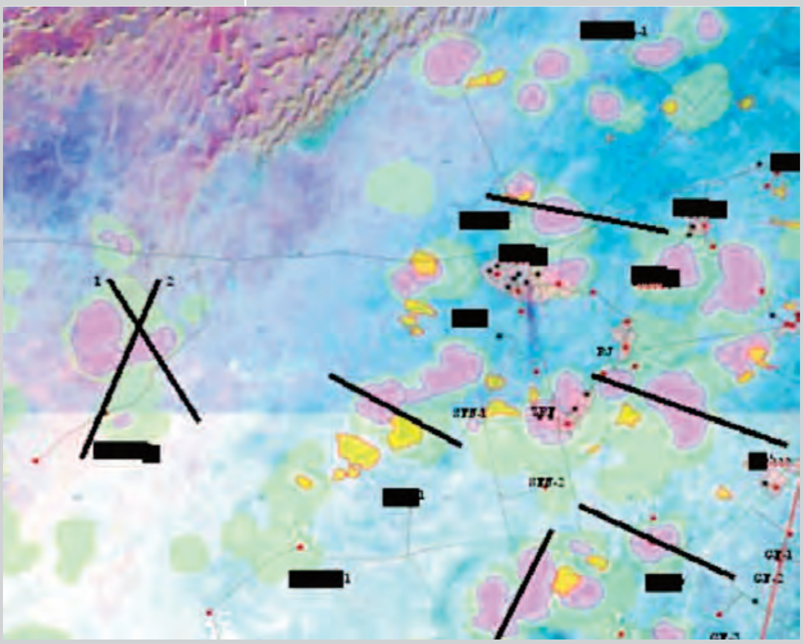
Update frequency is typically not an issue for geological maps given the timescale of geological processes.

Satellite based geological maps are available for all land-surfaces world-wide

Seepage slick maps are available based on a comprehensive archive of SAR imagery from the ERS and Envisat missions. It has resulted in multiple images in low wind conditions being available for almost any potential offshore oil and gas production area, world-wide.

[1] Illustration of the use of combined radar and optical data to delineate surface features associated with the geological processes that create hydrocarbon traps. Reliable characterisation of such features makes possible the identification of areas of high potential for hydrocarbon extraction (pink and yellow areas). These were verified by seismic surveys (black lines). Image CREDIT – GAF (D)

[2] Geological Map of the East Africa Rift System derived from satellite data. CREDITS Astrium Geoinformation Services The interpretation is based on 15m Landsat 7 ETM+ imagery combined with a 90m SRTM digital elevation models. CREDIT: Astrium Geoservices



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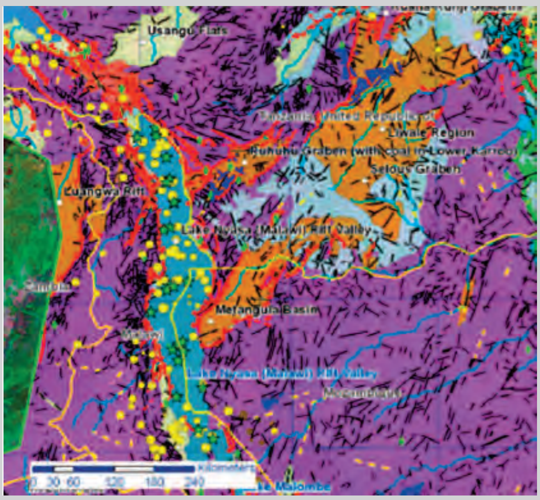


[2]

Accuracies and Constraints

Accuracy depends on the extent to which in-situ validation data are available. Typically:

- Lithological boundaries are characterised to better than 1 pixel resolution (assuming imagery is geocorrected)
- Lithological classification is characterised to better than 90% accuracy unless the area of interest contains different lithological units in close proximity without well delineated borders and having similar spectral response characteristics over the visible and near infra-red spectrum.

Uplift probability products are available for all arid regions of the world. Detection of uplift structures in heavily vegetated areas or areas with significant surface ground water dynamics is more complex.

Benefits and Use

Satellite derived maps provide rapid low cost assessments of the geological structure of a given area of interest and enable optimised approaches to field mapping and deployment of conventional mapping techniques. Typically they provide higher resolution assessments of the geology for a given region of interest than the baseline assessment. In addition, in many cases the customised approach for identification of structures associated with particular deposits (e.g. oil, gold) can result in a re-evaluation of the value of concessions and the optimised deployment of conventional exploration resources (e.g. seismic surveys, airborne geophysical surveys) for new concession areas

Indicative Costs

Typical costs are 3-4 times the cost of the input data set, i.e. 2 – 16000 Euro for an area of 20 x 20 km

The Contribution of the Sentinel Missions

Sentinel-1 will provide robust delineation of lithological boundaries although much of this information will also be available from archived ENVISAT and ERS imagery.

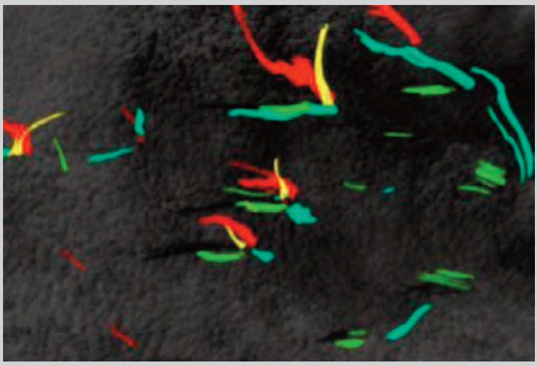
Sentinel-2 will ensure coverage of any gaps in the acquisition plans of previous SPOT missions to support the lithological classification

Other missions will also be of interest, in particular when combined with the Sentinel data. Examples include:

The ALOS 2 mission which also carries a synthetic aperture radar. This instrument operates at a longer wavelength than Sentinel 1 and therefore can penetrate soil cover to a depth of up to 20-30 centimetres, depending on moisture conditions. This can provide additional insight on the local geology in arid areas

The EnMAP mission carries a hyper-spectral sensor which will enable improved identification and discrimination of lithological classes, in particular with respect to mineral exploration.

[3] Analysis of persistent slicks in the Gulf of Mexico. CREDIT NPA (UK)
[4] Seepage slicks on the Caspian Sea as part of a systematic assessment of the exploitation potential of new licence blocks CREDIT – Astrium Geoservices



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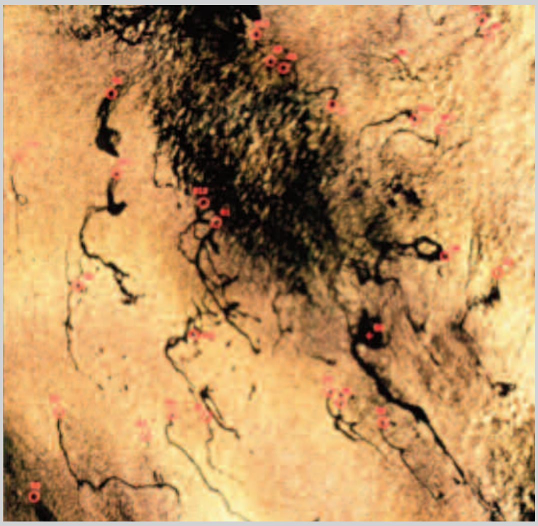


[4]

→ HABITAT ASSESSMENT MAPS

Information Content

Habitat assessment maps based on satellite derived information are used at all stages of mining or on-shore oil and gas production. It includes baseline assessment for planning of new operations, monitoring the environmental impact of on-going mining and on-shore oil and gas production activities and also ensuring that post activity remediation is implemented successfully. It is based primarily on the following parameters:

- Extent and fragmentation of habitats of interest
- Vegetation stress in habitats of interest
- Water distribution within habitats of interest
- Presence of contaminants within ground waters of relevance for habitats of interest

Habitat extent and fragmentation is based on the delineation of habitats within satellite imagery. That is usually based on a classification approach that typically permits 2-3 different levels of habitat degradation to be characterised.

Vegetation stress is based on the computation of a vegetation index. This is compiled as a ratio of the vegetation response in different optical and infra-red channels and is a direct indicator of stress or contamination of the plants. Chemical contamination shows up as an altered vegetation index.

Water distribution concerns primarily delineation of surface waters and changes in surface extent.

The presence of contaminants can be detected directly for situations where there is an observable signature (eg leakage of gold extraction by-products is usually detected in optical imagery due to the distinctive colours) or inferred where there is an impact on the surrounding vegetation.

Resolution, Frequency and Availability

Information is available at a range of resolutions depending on the scale size of the habitat structures. Resolutions can vary from better than 1 m to 20 m.

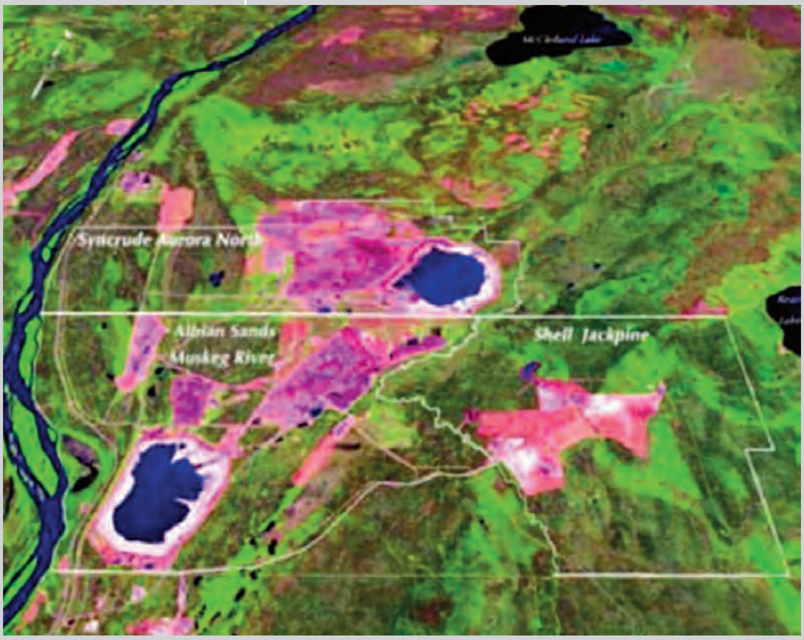
Typical requirements for update frequencies are between 6 months and 3–5 years. Update times for collection of new imagery is every few days, possibly every few weeks when cloud cover constraints are taken into consideration

In many cases for a new mining operations site, the initial environmental appraisal is required quickly (ie a few weeks). Such analyses are generally based on recent acquisitions. There may be some difficulties in accessing recent data for areas subject to heavy cloud cover (eg parts of West Africa) but in most cases, reliable data archives are available.

Accuracies and Constraints

Several accuracies should be taken into account:

- Location accuracy for delineation of the boundaries and fragmentation levels of habitats, mine waste storage and ground water areas. This is addressed by correction of the satellite imagery using local topographic data
- Classification accuracy. Land cover classification must be performed using an appropriate classification key. To ensure accuracy, the land cover classification is usually performed on different images to compare the results. The resulting baseline information can then be used as a reference map against which changes can be detected
- Detection accuracy for areas contaminated with heavy metals and other toxins. In some cases the contamination may not result in a visible signature in the vegetation response over optical and infra-red spectra.



[1]

[1] Regular monitoring of the vegetation status using multi-spectral optical/near infra-red imagery enables early detection of chemical contamination of the surrounding habitats and ecosystems. The example here shows a vegetation stress map for the area surrounding an shale-oil plant in Canada. Credit: Hatfield Consulting

Heavy persistent cloud cover may strongly constrain the response times for acquiring imagery . For example, regions of West Africa and South America. In these cases, validation of the capabilities of radar imagery are on-going. For most other regions, satellite imagery can be acquired on timescales consistent with the required response time for the service.

Benefits and Use

Habitat assessment is used prior to initiating a new mining development and then regularly updated during the mining operations to detect negative impacts resulting from the mining activity:

- Prior to starting a new development, the habitat assessment is one of the primary inputs into the planning of waste management and extraction logistics. Site selection for waste management represents one of the most important aspects in the initial phase. Information on vegetation cover and human activity in the neighbourhood of the site is used to assess potential constraints on waste storage. It is also used to support planning of rehabilitation operations, taking into account sensitive environmental elements in the site vicinity.
- Once operations have started, routine monitoring of surrounding habitats is conducted, including both surface and ground water circulation and vegetation. At the border of the mine waste storage, it is important to detect potential water seepage which may result in acid mine drainage. Detection of vegetation stress provides an early indicator of possible contamination of soils adjacent to the operations site.

The primary benefits resulting from the use of satellite based habitat maps are:

- Less time is spent doing in-situ sampling and the resources deployed on in-situ sampling are optimized to cover areas of priority interest
- Sampling areas are selected to ensure they are statistically representative
- Logistics associated with transporting analysts to the areas to be assessed are optimized

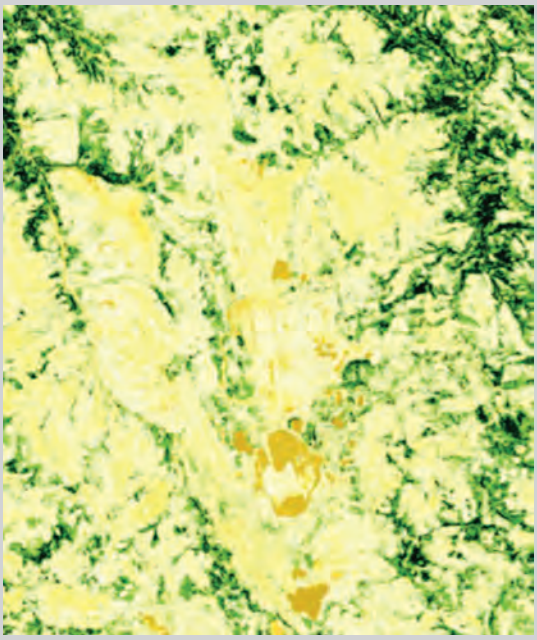
As a result, the habitat assessment is of higher quality and the cost and timescales for the assessment are significantly reduced. In addition, any contamination that may occur is detected more quickly, thereby minimizing the consequences on the surrounding habitat.

These information products are also increasingly used to support remediation monitoring for end of life mines. Once mining activities have ceased, companies are usually required to implement a remediation plan. This plan is increasingly based on an initial analysis using satellite derived information. Monitoring of the remediation may include several components, for example:

- Monitoring remediation progress against the original plan and detection of anomalies
- Assessment of vegetation expansion and health
- Monitoring areas where waste materials have been stored for structural integrity and contamination
- Detection of illicit mining activities that may result in contamination of surrounding habitats prior to completion of the remediation

Indicative Costs

Typical costs depend on the extent of the area of interest, the complexity of the habitat and the volume of in-situ sampling that is required. Considering solely the costs of the EO derived information, these are driven by the number of very high resolution images required. Key



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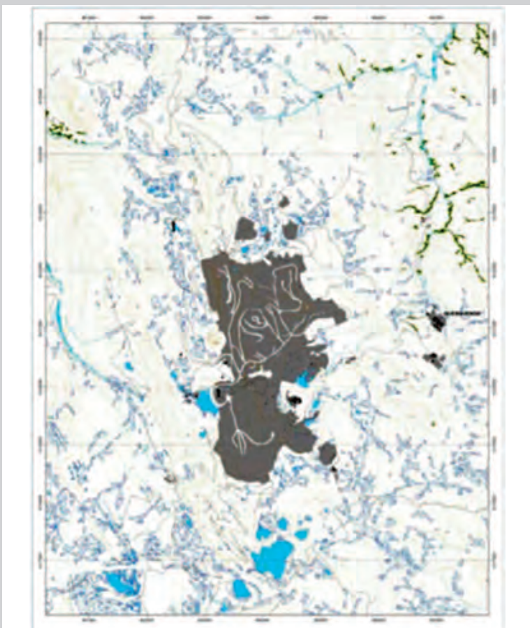


[3]

A combination of vegetation index [2] and ground water status [3] for a forest area surrounding a mining site. In this case the imagery demonstrate that no contamination has taken place. CREDIT: Effigis Geosolutions considerations include:

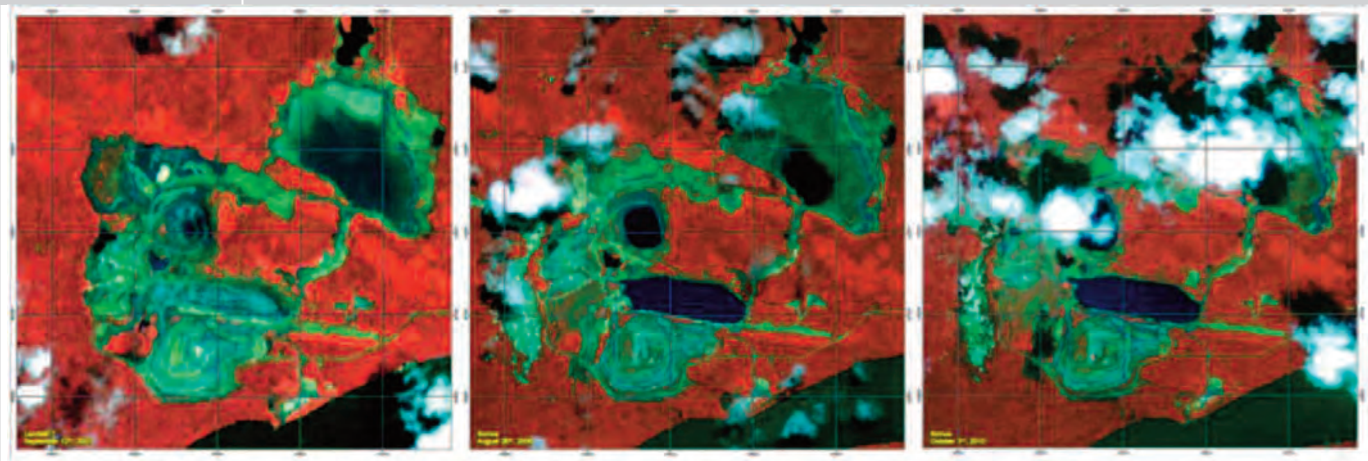
- Whether the habitat status can be characterised by a single set of images or whether monitoring over a number of seasons is required
- The difficulty in obtaining images due to cloud cover and the requirement for fusing optical and radar imagery
- The complexity of the analysis to be conducted

Typically a habitat assessment for a mining operation will cost a few 10 KEuro depending on the actual data acquired.

The Contribution of the Sentinel Missions

Sentinel-2 will be capable of generating imagery over the total Earth land surface at 10 m resolution every 12 days thereby providing a robust data source for basic habitat assessments. The availability of the German EnMap mission will provide an additional monitoring tool with greater sensitivity.

[4] A series of multi-spectral images used to monitor the remediation of a gold mining site in Guyana and the progressive expansion of vegetation cover. CREDIT Effigis Geosolutions



[4]

Information Content

Different planning proirities can be supported. The information provided includes the following: For planning of mine waste storage and management facilities, information content includes slope stability characterisation, drainage network delineation, vegetation, topography and soil cover.

For planning of network infrastructure such as power cables or road/rail transport connections to the mine or energy plant, information content may also include characterisation of habitats further from the operations site, domestic constructions in the region of interest and existing transport infrastructure.

In general, these parameters are presented as follows:

- Slope stability characterisation is presented as an index combining slope angle, soil cover and presence of vegetation with the extent of each slope delineated. In addition, if required, slope movement can be characterised over an extended period of time based on differential InSAR techniques although there may be some variation in precision for the more extreme slopes or for slopes oriented perpendicular to the viewing angle of the radar.
- Drainage networks are presented as maps of the drainage channels, with different sub-units separately delineated. If necessary, slope indications can also be included
- Vegetation and soil cover presented as a classification of land cover over the area of interest
- Topography is presented as a contour map or height classification map

Resolution, Frequency and Availability

In general, information is provided with a spatial resolution of between 0.5 and 10m depending on the extent of the area of interest and the degree of spatial variation

Logistics support maps tend to be one-off products generated during the planning period for new infrastructure although routine impact monitoring or incident investigations can also be generated. In case there is a need for an investigation, an analysis product can be generated within 1—2 months of the request. In emergencies (eg slope stability following prolonged rainfall), the analysis can be performed faster, assuming suitable imagery can be acquired.

Accuracies and Constraints

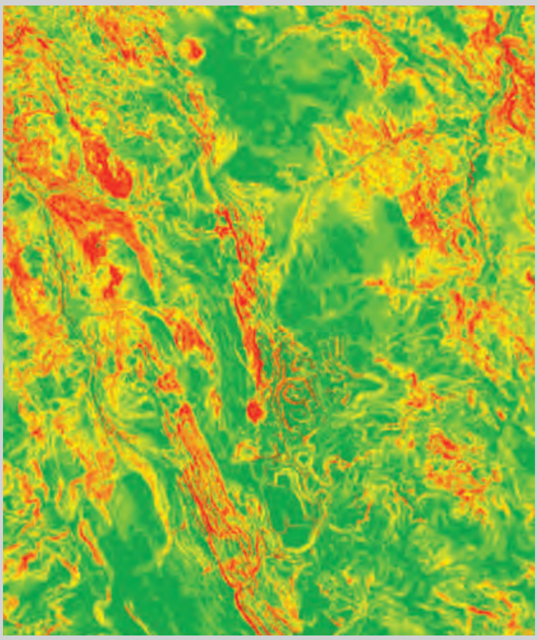
Location accuracies for delineation of slope edges, drainage network elements and boundaries of vegetation and soil types are better than 1 pixel, assuming that appropriate correction of the satellite imagery has been implemented

Topography horizontal location accuracy is better than 1 pixel, again assuming that appropriate correction of the satellite imagery has been implemented. Vertical height accuracy depends on the technique used to generate the height value. If stereo techniques based on optical data are used then the height accuracy is better than the spatial resolution (i.e. typically 0.5–1 m). If SAR Interferometry is used then the height accuracy depends on the variability of the slopes.

The main constraint is cloud cover. Reliable acquisition of new imagery in areas subject to heavy cloud cover may require more than 12 months although recent archive imagery are often available as a temporary solution to support the generation of the required information.

[1] Slope Stability Index map for the region surrounding the mining operations in Lagunas Norte in Peru. In this product, slopes are colour coded from green (very stable) to red (stability risk). CREDIT Effigis Geosolutions.

[2] A drainage map showing the different catchments in separate colours and the inclination of the run-off. In addition, the different channels within each sub-network are delineated in white. CREDIT Effgis Geosolutions



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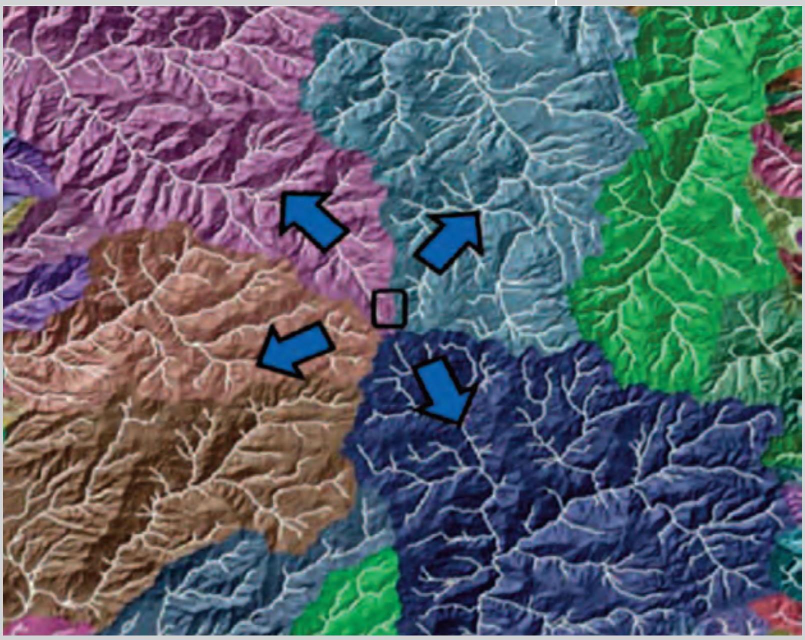


[2]

Benefits and Use

Geo-technical assessment of mining operations areas are important to ensure stability of waste materials and the retaining structures as well as in support of initial planning to complement the environmental assessments for waste siting, logistics planning etc.

Drainage maps are used to characterise ground water flows in areas surrounding mining operations sites in order to plan where waste storage facilities should be sited and to optimise the location of in-situ chemical monitoring instruments to maximise their effectiveness in timely detection of any leakage or contamination.

Slope stability maps are used to plan the construction of waste retaining structures and to monitor the structural stability of waste materials to minimise the probability of movement of waste materials into areas where they would impact on local habitats.

The primary benefit of using satellite derived information is the reduced time associated with generating the map products and the comprehensive overview provided. In addition, the reduced cost of the monitoring due to optimisation of traditional monitoring techniques has been cited by several users as a benefit of interest. In some cases (eg elaboration of drainage networks), the satellite derived information can be generated at a higher resolution than existing baseline information. This enables more robust planning in decisions such as siting of waste storage. The more frequent update possibilities when compared with traditional information collection methods are also important. For example, monitoring erosion within drainage networks is an important consideration in safe mining operations to ensure that waste storage facilities do not interfere with local flow of rainwater. In particular, following periods of heavy rainfall when there is increased erosion and risk of landslides for tailings piles and regions surrounding waste storage sites, EO based information can give a timely assessment of the location of the main risk areas. This enables effective intervention that may otherwise have been impossible, in particular for adjacent habitats that may be difficult to access.

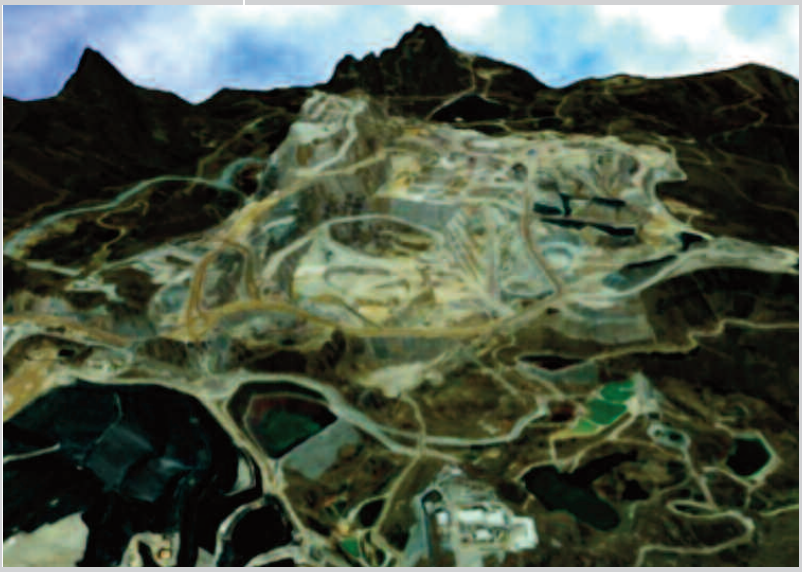
Indicative Costs

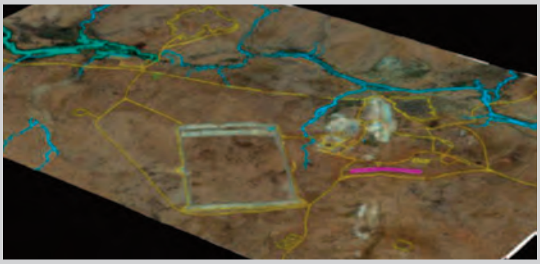
In general, costs are driven by the commercial prices of the very high resolution satellite imagery. Depending on the number of acquisitions required to cover the area of interest, information may be available for between 10000 and 50000 Euro.

The Contribution of the Sentinel Missions

Sentinel2 will ensure global availability of 10 m resolution data, enabling initial baseline lower resolution assessments to be conducted. These can then be improved using very high resolution imagery or new hyperspectral data from national missions such as the German EnMap satellite to be launched in 2014.

[3] Three dimensional projections of two different mining sites to support the planning of transport logistics and waste management over the operations lifetime. CREDITS: Effigis Geosolutions





[3]

Information Content

Mine waste monitoring information includes:

- Delineation of extent and topographic structure of the waste structures
- Status of water discharges from tailings structures
- Characterisation of water movement through tailings structures
- Vegetation stress and soil status in areas adjacent to tailings structures
- Slope stability over tailings structures
- Stability of tailing retaining walls

Resolution, Frequency and Availability

Spatial resolution of the majority of analysis maps is at least 1 m. Slope stability is for individual slope units with boundaries delineated with a location accuracy of approximately 1m. Stability of tailings retaining walls is measured using using the precision land motion service and the separation between measurement points will depend on the structure of the retaining wall. Typically at least one measurement point each 10 m is expected when high resolution radar imagery is used and one measurement point each 50 m when systems such as ENVISAT are used. Analysis is usually conducted every few months and it is possible for EO based services to support this update frequency for most areas unless they are subject to very heavy cloud cover. Stability of retaining walls is monitored every few weeks.

Accuracies and Constraints

Location accuracy is better than 1 pixel assuming effective correction of the satellite imagery. The accuracy of contaminant detection depends on the material. Many of the by-products from gold mining contain complexes with distinct optical properties. Their detection is therefore quite straightforward. Detection of vegetation stress depends on the nature of the stress. Often chemical contamination leaching into the soil or water table is detectable after low levels of exposure. Slope stability characterisation is currently undergoing validation as the number of test cases remains limited at present. Stability of tailing retaining structures is a similar analysis to geotechnical risk assessment and land motion discussed in Chapter 4.

Benefits and Use

Monitoring the extent of mine tailings as well as the evolution of slopes and movement of water within the tailings pile ensure that the risk of contamination to surrounding habitats can be minimised In particular, routine monitoring can help prevent the catastrophic failure of tailings retaining structures observed in Hungary in 2010 and Baia Mare, Romania in 2000.

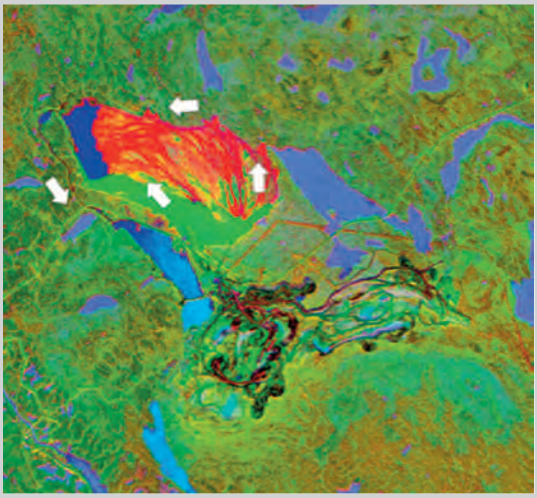
Indicative Costs

Typical costs depend on the extent of the area of interest and are driven by the commercial price of the high resolution imagery. An analysis using one or two images twice per year would typically cost between 20-50000 Euro per annum. The annual cost of stability analysis would also be within this range.

The Contribution of the Sentinel Missions

Sentinel-1 will support greater medium resolution (i.e. 20 m) monitoring of retaining wall stability. Most of the other products depend primarily on high resolution optical or radar imagery.

[1] An assessment of mine tailings– green areas illustrate stable waste, blue areas illustrate ponds and red areas indicate areas of potential instability to be monitored – the arrows indicate the direction of water flow through and over the tailings piles.
[2] Structure of the tailings pile combined with a Digital Elevation Model for the area around the tailings piles. The most recent height contours for the tailings piles are overlaid on the DEM. CREDITS: Effigis Geosolutions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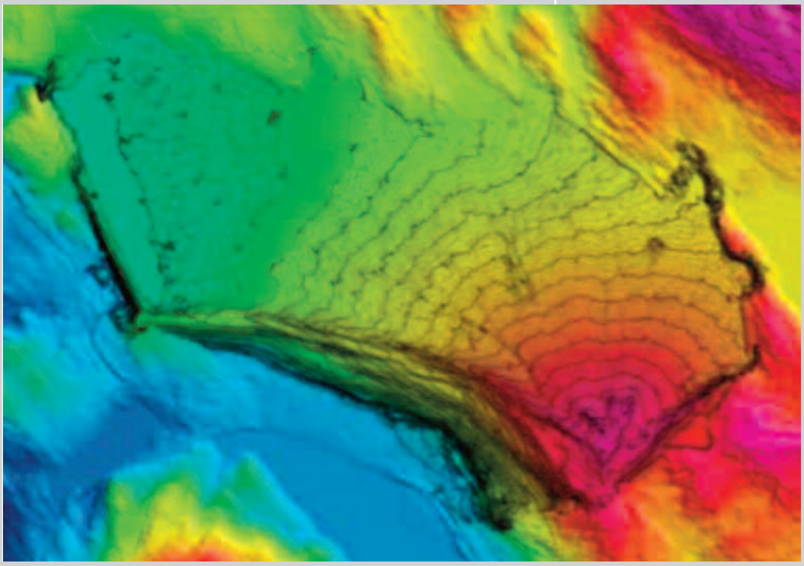

[2]

→ OIL & GAS PRODUCTION OPERATIONS SUPPORT

[1] As operations move into deeper waters and make greater use of floating structures, environmental conditions become even more important – for example, in the North Atlantic, strong currents and high sea states impact on deep water drilling while current eddies in the Gulf of Mexico can create strong shearing forces on subsea infrastructure such as moorings and riser pipes connected to sea bottom pumps. Other phenomena such as subsurface internal waves (or solitons) can be significant in regions such as West Africa and South East Asia. In all these areas, national authorities may also require to monitor local conditions to ensure compliance with local safety regulations.

Information Content

A range of information products are available to support the monitoring and management of oil and gas production operations. These include:

- Marine environment statistics, products for offshore operations. These information products may contain time series and statistical properties of wave height, wave period, wave direction, surface wind speed, sea surface temperature and ocean current velocity
- Marine environment nowcast and forecast products for offshore operations. These information products may contain any or all of the following information layers (depending on user priorities)
  - Nowcast and forecast of wave height, period and propagation direction
  - Surface current velocity nowcast and forecast
  - Current velocity nowcast and forecast at defined depths
  - Surface wind velocity nowcast and forecast
  - Internal wave location
  - Location of frontal structures
  - Sea surface temperature nowcast and forecast
- Reservoir movement monitoring for on-shore horizontal drilling. The information content comprises regularly updated map of the spatial variation in land surface motion over the reservoir. This can be linked through a geological model of the reservoir to generate the updated status of the reservoir itself
- Gas flare detection for compliance with local emissions legislation. The information product includes the location of all detected gas flares in the area of interest as well as the identification of areas of known gas flaring where no flaring is taking place during the satellite overpass. Gas flares can be detected in the infra-red channels of geostationary meteorological satellites as well as by several low earth orbit satellites. These systems provide an instantaneous snapshot of the occurrence of gas flares as they pass over a given area of interest. Due to the temperature at which the gas combusts, the flares are always detected whenever there are cloud free conditions.
- Detection of discharges into the marine environment. The information provided includes the occurrence (or not) of a discharge as well as the extent of the discharge at the time of the satellite overpass.

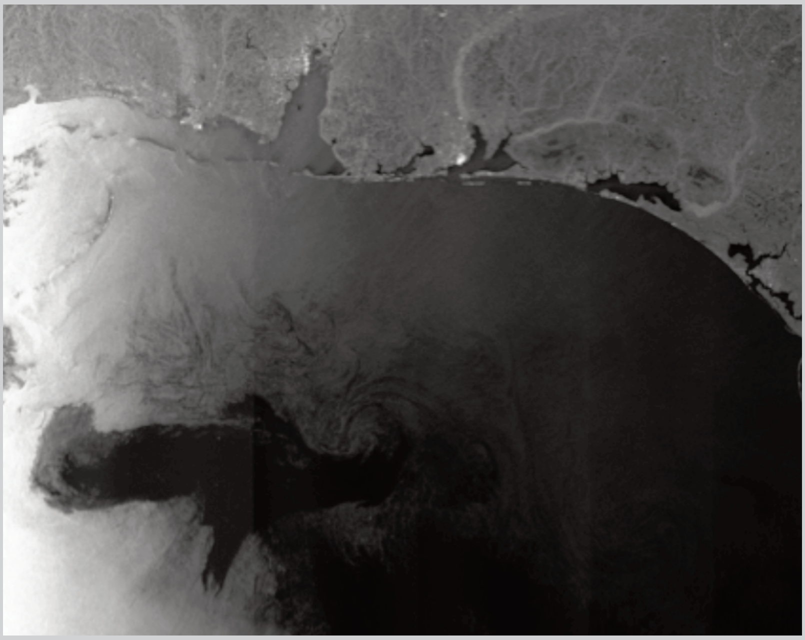
Resolution, Frequency and Availability

Metocean data:

- Wind and wave data are available on grids of approximately 10 km by 10 km. Higher resolution wind speed can be provided for limited areas at a resolution of 1 km by 1 km.
- Surface current over limited areas can be provided on a grid of 1 km by 1 km but wider area ocean current data are available only at a lower resolution. Sea Surface Temperature is available over limited areas at 1 km by 1 km and over wider areas at a resolution of approximately 10 km by 10 km
- Location of marine frontal structures was possible up to a resolution of 300 m based on MERIS data although a resolution of 1km is more widely available.
- Metocean data can be provided on a daily basis and statistics are available as monthly, seasonal or annual products or as time series.

Reservoir movement measurements are available at a resolution of approximately 30m and can be updated on a monthly basis

Gas flares are detected typically on a grid of between 1 and 4km resolution. Update frequency depends on location. Areas within the central



[1]

portion of the visibility disc of a geostationary meteorological satellite can be imaged several times per day (depending on cloud cover) while other areas are imaged typically once per 24—48 hours. Discharges into the marine environment are detected with a resolution of between 50 and 150m and can be updated on an almost daily basis for most regions. Availability of timely information (i.e. within 60 minutes of the satellite overpass) depends on the area of interest being within the coverage mask of a suitably equipped ground station. Many areas are now within these coverage masks.

Accuracies and Constraints

Wind and wave measurements are typically accurate to within ±10%.
Land motion measurement is typically a few mm per year.

With respect to monitoring gas flaring, at present the capability is limited to detecting the occurrence or absence of gas flaring. However research is underway to link the detected properties of the flare to estimates of the volume of gas being flared. It is important to bear in mind the various limitations:

- Flaring that takes place towards the edge of the visible disk of geostationary satellites will be heavily distorted
- Flaring is detectable by higher resolution satellites only at the time of overpass (typically from 10:00 and 12:00 local time)
- Flaring is detected only in cloud free conditions.

In addition, in hot arid regions such as the Middle East, false alarms be reported due to the high daytime temperatures for some parts of the exposed land surface.

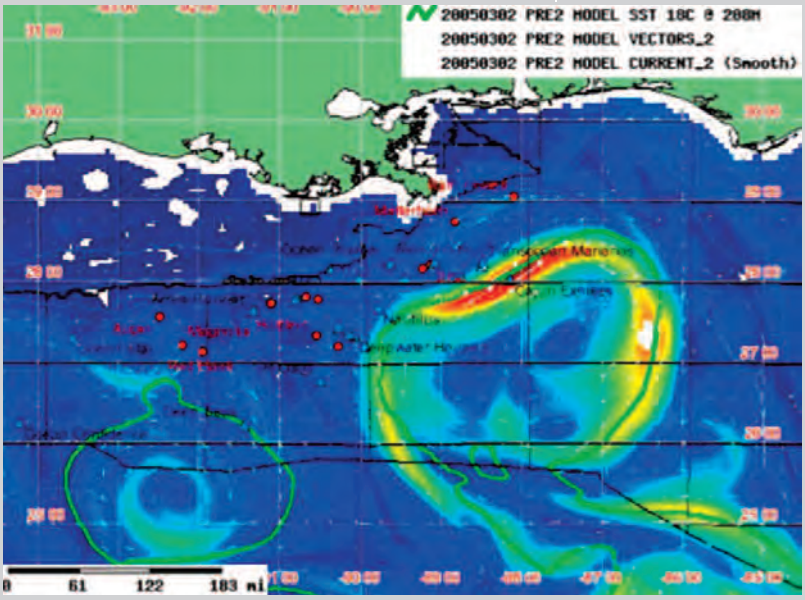
Operational discharge detection is close to 100% for discharges extending over more than a few hundred square metres and wind speeds between 3 and 15m/s.

Benefits and Use

Marine environment statistics are used to plan offshore operations such as engineering operations (liftings, installations, towing etc.) and to certify particular structures for operation in a specific area of interest.
Marine nowcasts and forecasts are used to support operations planning in deep water operations where heavy wind/wave/currents may cause damage to surface or sub-sea infrastructure (e.g. riser pipes) or represent an unacceptable risk to on-board personnel
The main benefits from using satellite based metocean data are the improved accuracy on location and timing of potentially dangerous conditions and optimised operations management as a result.
Land motion is used to model the status of a particular reservoir where horizontal drilling is taking place. This enables effective management of processes such as CO_2/steam injection to maintain the internal pressure and ensures the structural integrity of the reservoir (and hence minimises the risk of damage or loss of the drill). In addition the data can be used to optimise reservoir management to reduce the risk of damage to surface infrastructure such as pipelines. The main benefit is a reduced cost when compared to traditional time lapse seismic techniques as well as an improved capability to characterise the surface motion.
Gas Flare detection is used to monitor compliance with local regulations on the volume of gas being flared at production sites.

[2] Gas Flare Detection and Assessment - Routine monitoring for compliance with emissions regulations. Examples of satellite detected gas flaring in the Persian Gulf region during August 2008 (left) and the Khanty-Mansiysk region of Russia during 2009. CREDITS: AMEC and RSS

[3] Example of a loop current nowcast for the Gulf of Mexico. The location of current/frontal boundaries enables platform managers to understand their exposure to such phenomena more precisely. CREDITS Fugro-GEOS, CLS, Nansen Environmental and Remote Sensing Research Centre.



[3]

Monitoring operational discharges is used to ensure compliance with local environmental protection regulations and provide early warning to optimise the response to any potential contamination threat to surrounding habitats. The main benefits are the independent source of information and the lower cost of routine monitoring as compared to traditional monitoring systems such as aircraft.

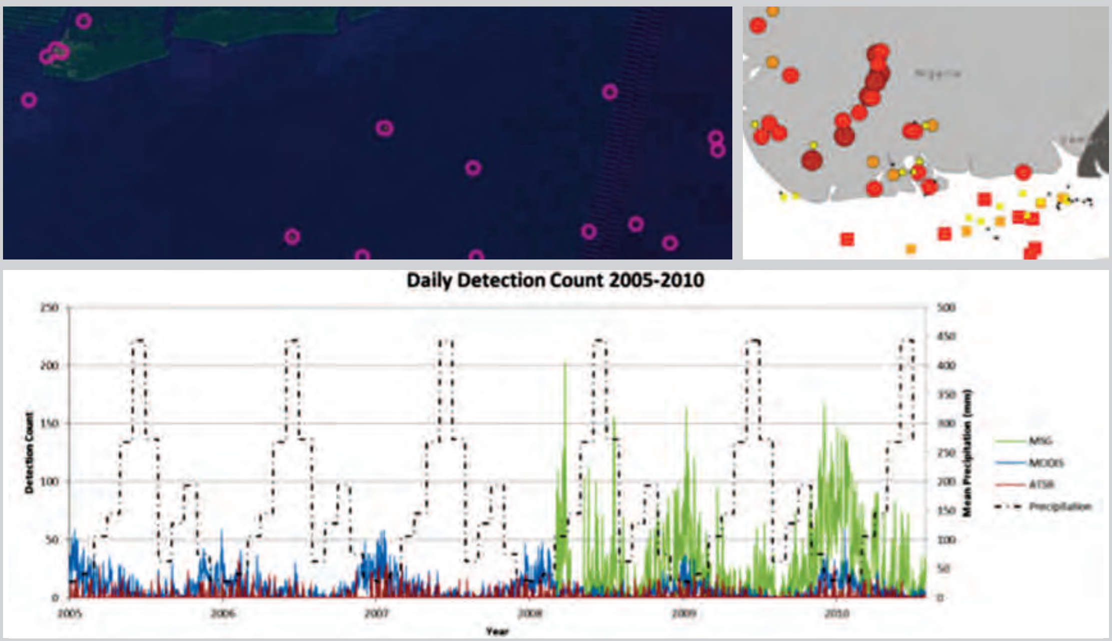
Indicative Costs

Typical costs are as follows:

- Metocean nowcast and forecast – these are provided as a service over a period of time (usually at least one year) and cost a few 10s of thousands of Euro per annum
- Metocean statistcs depend on the level of detail requested but may be as little as 50—100 euro for a single assessment extracted from a database, to a few thousand Euro for a more detailed analysis
- Reservoir motion assessment is available for approximately 10—30 KEuro per month
- Gas flare detection is available for a few thousand Euro per month
- Oil discharge monitoring is usually provided as a routine service over an agreed period of time (typically at least 1 year as a minimum) and is usually provided as an overall pollution surveillance service rather than monitoring specific facilities. Cost depends on the desired update intervals but an update every couple of days would typically be available for a price of the order of 100—200 KEuro per annum depending on the extent of the area of interest.

The Contribution of the Sentinel Missions

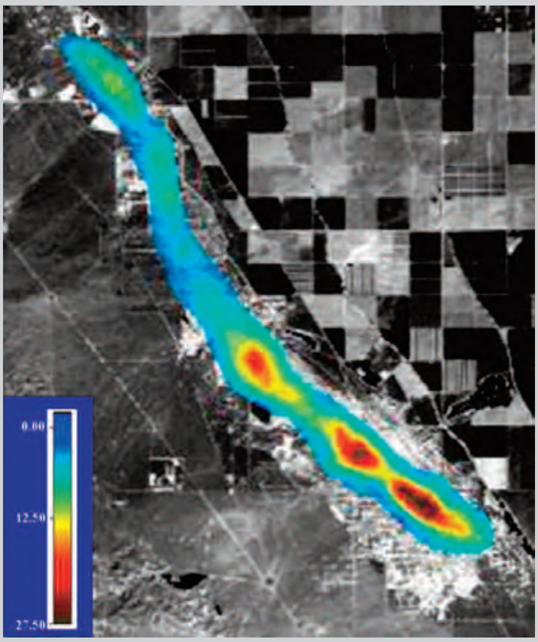
Sentinel-1 will ensure long term availability of the interferometric capability required to support reservoir evolution monitoring. For marine areas, Sentinel-1 will be the main focus of services to detect operational discharges into the marine environment from production platforms. In addition, the SAR data will ensure the continued capability to monitor surface currents and high resolution wind fields in ocean and coastal areas. Sentinel-3 will ensure the long term capability to detect gas flaring as well as providing marine environment information such as sea surface temperature, surface wave conditions and sediment concentrations which are regularly required for operational production decisions by both the platform operators and contractors providing support logistics.



[4]

[4] Elaboration of cumulative statistics for gas flaring for Nigeria based on multiple satellite overpasses. Credits: AMEC and RSS

[5] A land surface motion map based on data from the ESA ERS-2 satellite for part of the Belridge oil field showing the effect of oil extraction on part of a reservoir.
CREDIT: MDA
[6] The leak from the Deep Water Horizon facility detected by the ENVISAT ASAR: Gulf of Mexico, 2010. Credits: ESA



[5]

Information Content

As already mentioned in the Ocean Analysis and Forecast service (Chapter 6), EO can support the long-term monitoring and forecasting of ocean surface conditions. Specifically for offshore wind speed and direction, information to assess wind resources is available from a combination of different radar satellite data. The globally-available long-term, frequent but coarse-resolution wind statistics derived from scatterometers and altimeters and can be enhanced locally (near the coasts) by higher-resolution but less frequent SAR data. The sea state (roughness) information contained in SAR imagery can also be refined in such a way to obtain specialised products for wave resource assessment, e.g. wave frequency, propagation direction and height. For tidal energy assessment (tidal level variations, tidal currents and currents in general), information can obtained from long-term observations by radar altimeters. These are usually integrated into models operated at various spatial resolutions, together with data from tidal stations (e.g. buoys) and bathymetry information.

The use of EO services to support hydroelectric potential assessment (runoff from snow-covered areas) and the management of water reservoirs have already been introduced in the Snow and Glacier Monitoring and Water Reservoir Mapping sections respectively (Chapter 7).

An important function of meteorological satellites such as METEOSAT is detecting cloud fields and monitoring their evolution in time over extended regions of the world. Clouds being the main modulator of daily and hourly solar irradiance, it is obvious that radiance measurements from space are a unique data source for geographically continuous assessments of the solar resource at the earth's surface. Typical products are hourly, daily, monthly or yearly averages of global and direct irradiances.

Resolution, Frequency and Availability

Scatterometer-derived surface wind speeds and directions at 25 km spatial resolution are available globally up to several times per day since the early 1990s. At locations close to an offshore site of interest it is possible to increase the level of spatial details by using less frequent but higher-resolution SAR imagery (usually in the order of tens of metres once every few weeks or months). Wave and tidal information is typically delivered as instantaneous measurements or monthly composites.

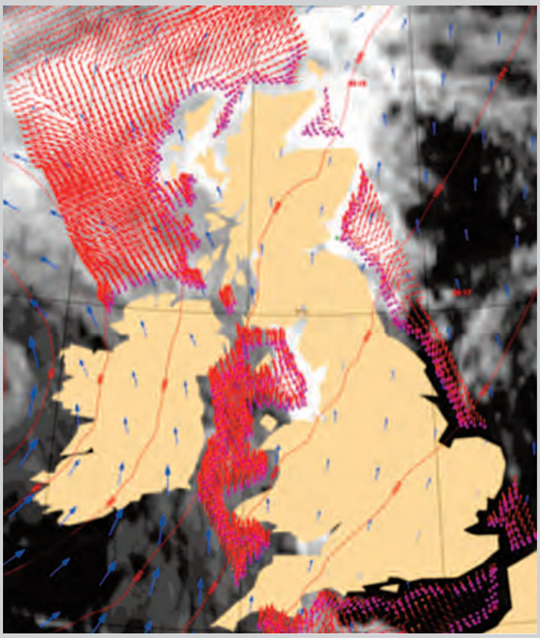
For solar irradiance products, spatial resolutions of up to one kilometre and temporal resolutions up to 15 minutes are possible. Data is available since the mid-1980s.

Accuracies and Constraints

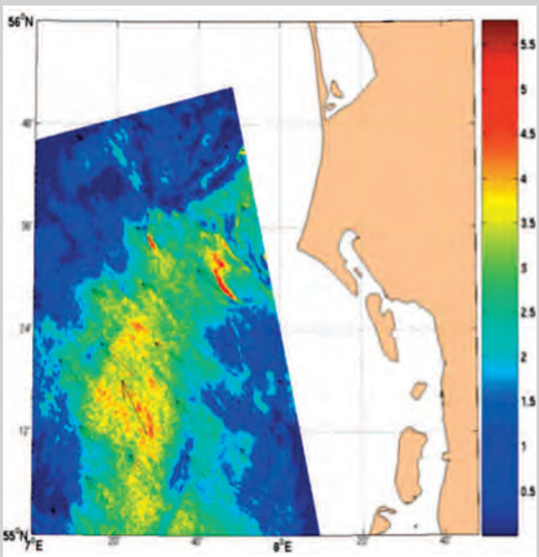
Typical wind product accuracies are approximately 2 m/s or ±10% in speed and 20° in direction, while wave height data is accurate to 50 cm or ±10%.

The relative error in sea level height is of the order of a few cm. Absolute error is being reduced through the use of a new reference geoid built up from the data acquired by the ESA GOCE mission.

Satellite-derived solar irradiance data is more accurate than ground measurements if the distance between site and weather station is more than approximately 20 km. In addition, for many solar applications like photovoltaic power grid interaction studies or larger solar energy systems, pinpoint irradiance readings are much less relevant than irradiance integrated over a pixel-size ground area (e.g., 5x5 km). Satellite data may thus prove considerably more useful and



[1] Wind speed and direction around the British isles on 2013 April 15, 20:17 UTC. The red wind arrows are derived using data from the ASCAT scatterometer onboard the Metop-A satellite. Blue arrows represent numerical weather prediction model winds. A magenta marker denotes land presence. Credits: KNMI/EUMETSAT OSI SAF



[2] Wind speed (in m/s) derived from ERS SAR off the western coast of Denmark. Credits: NERSC/EOWIND project

accurate than the conventional 15-20% RMSD estimate for hourly values might suggest.

Benefits and Use

EO-derived services can support site assessment through historical assesment of renewable energy resources (wind, solar, hydro) allowing the investor to find the best site for a planned power plant and to optimise the financial yield. The financing of offshore wind parks and solar power plants is often based on loans, and financial institutes and insurers expect precise audits in the planning stage.
At the same time, EO can contribute to the monitoring and operations planning of power plants, helping to reduce costs and risks and optimise the benefit from the infrastructure.

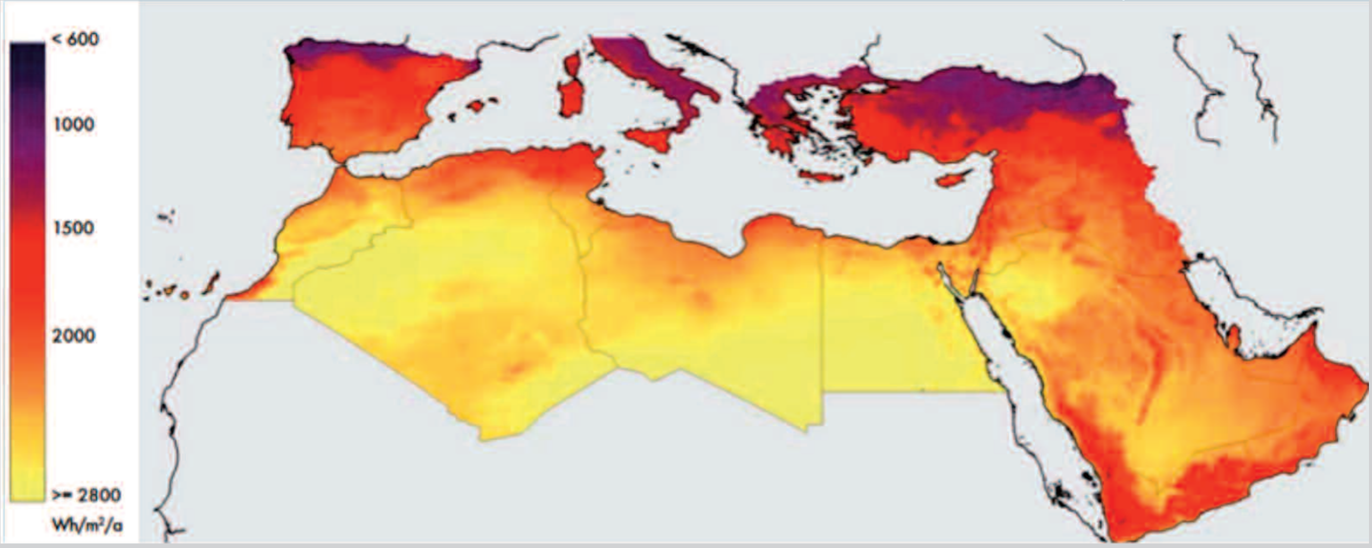
Indicative Costs

Typical costs will be of the order of 2— 10 euro per square km depending on how many reference years are to be included in a change analysis.

The Contribution of the Sentinel Missions

Sentinel-1 data provide long term continuity for the high-resolution radar-based components of the marine energy and hydropower-related services. Sentinel-3 will provide for the continuity of the optical component of the hydropower-related services. The scatterometer component of marine energy services are already guaranteed as a result of EPS (EUMETSAT Polar System), with a future extension through the EPS-SG (Second Generation) system. Solar energy services based on geostationary satellite data will continue through the present MSG (Meteosat Second Generation) and planned MTG (Meteosat Third Generation) programmes.

[4] Satellite-derived annual sum of direct normal irradiance for 2002. Credits: DLR/ENVI-SOLAR project



[4]

→ DETECTION OF ILLICIT MINING

[1] Detection of irregular mining using TerraSAR imagery. This shows unlicensed activity close to an existing mining operation. The small ponds in the centre left of the image are caused by illicit mining activities which can cause leakage from the larger ponds (containing toxic waste products) into the surrounding ground water. Credits: GAF, ASTRIUM

[2] These small digs can also be routinely detected on optical imagery as show in this example from an area adjacent to a gold mine. Tailings (visible as light coloured features) resulting from these irregular mining activities are also visible. The photo below shows a ground based view of these illicit mining activities. Credits: GAF, Digital Globe Inc.

Satellite imagery can be interpreted manually to characterize the extent to which illicit or unregulated mining is taking place in a defined area of interest. Information content includes:

- location and extent of features related to illicit or unregulated mining
- characterisation of features close to illicit mining sites that may represent a potential hazard (e.g. chemical tailings)

Features associated with illicit mining are quite small scale (a few metres in diameter) hence reliable detection and characterisation requires very high resolution imagery. In addition, reliable detection of contextual features such as waste products from illicit mining may have colour signatures so multi-spectral imagery at very high resolution (i.e. 1-2.5 m or better) is of interest. In some areas, very high resolution radar imagery can also be used to detect features associated with illicit mining (e.g. for gold mining) – again resolution of at least 1m is necessary.

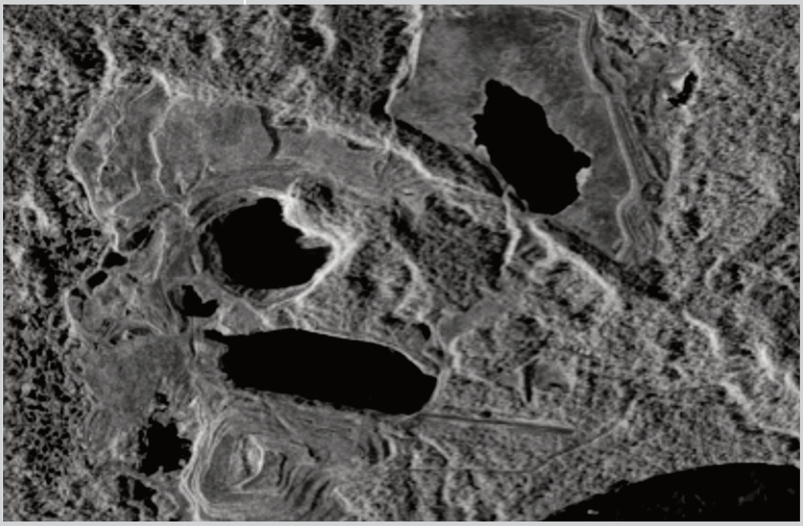
Update frequency is driven by the orbit dynamics of the satellites. At present there are three different satellites capable of providing very high resolution optical imagery and six different high resolution radar systems and it is expected that this number will expand over the coming years. Between the different optical systems it is possible to obtain an image at least once per month over a defined region of interest although cloud cover may limit the number of analyses that can be performed with these data.

Images are geocoded so location accuracy is better than 1 pixel. Detection accuracy depends on the mineral being extracted and the scale of the illicit mining operation.

The main utilisation is for central monitoring of remote regions where law enforcement or environmental protection personnel may be exposed to risk from local populations while conducting on-site inspections and surveys. In addition, the satellite derived information can be extended backwards in time to compile longer term assessments of the evolution of the illicit mining activity.

Costs are driven by the commercial price of acquiring new very high resolution optical imagery – typically 5 – 10 K Euro per analysis should be expected.

Availability of national hyper-spectral missions such as the German EnMAP system may also contribute to an improved capability to detect and characterise different types of illicit mining.



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→ CLIMATE CHANGE

Related World Bank Programmes and Iinitiatives

Examples of World Bank Group related initiatives to which this section is pertinent: The Climate Investments Funds (CIF), the Adaptation Fund (AF), the Energy Sector Management Assistance Programme (ESMAP), the Clean Technology Fund (CTF), the Pilot Programme for Climate Resilience (PPCR), the Clean Energy Investment Framework, the Strategic Framework on Development and Climate Change, the Global Facility for Disaster Risk Reduction (GFDRR), and the Climate Risk Program together with the Climate Business Group led by the International Finance Corporation (IFC).

Addressing Development Challenges

The recent '4-degrees briefing' to the World Bank prepared by the Postdam Institute for Climate Impact Research (PIK) have clearly illustrated the dramatic consequences of a world without an adequate climate policy. The need to systematically account, within development projects, for the risks as well as opportunities induced by climate change, has now been widely recognised by multilateral development agencies (World Development Report, 2010).

The climate change 'environmental issue' is now being addressed as a true 'development issue' through a risk-based approaches in order to foster adaptive capacity and resilience to climate change impact, progressively moving towards the concept of 'climate-proofing' (Managing Climate Risks, WB, 2012). Key sectors affected by climate change include health, water supply and sanitation, energy, transport, industry, mining, construction, trade, tourism, agriculture, forestry, fisheries, environmental protection, and disaster management.

The Resilience Dialogue Series launched by the World Bank Group / International Monetary Fund Annual meeting of 2011, is testimony to the increasing emphasis on making disaster and climate resilience a priority in development planning, also in the post-2015 Development Framework. In addition resilience to global risks is a theme that runs through the 2013 edition of the Global Risks report of the World Economic Forum, with 'runaway' climate change identified as one of the 5 emerging game-changers.

The potential of EO Information Services

Global data are needed to address Global problems, such as climate change. Polar regions are the most sensitive indicators of climate change. ESA has missions which offer unique opportunities to monitor this environment, measuring ice thickness and extent. They indicate that ice loss is far worse than current IPCC model predictions. However, the issue of climate change goes far beyond the use of Earth Observation (EO) information alone, and involves the use of complex Earth System models for climate projections which are developed and operated by leading European government institutes (mainly Meteorological offices). For this reason, only a brief introduction of these wider aspects (climate services) is given in this chapter, as this report focuses on the contribution of EO. Nevertheless, EO information is a key input to support climate research, enact measures for climate adaptation and mitigation, and enhance climate resilience.

→ CLIMATE SERVICES

Climate Services provide decision-makers with tailored "climate information" on the state of climate, how it is changing and impacting our environment. This is vitally needed by development practitioners to better mitigate climate changes, prepare and adapt to their impact, thereby increasing the climate resilience of developing countries.

A Global Framework for Climate Services (GFCS) is currently being set-up through the World Meteorological Organisation (WMO) to coordinate the development of climate services and its delivery to users in developing countries. In parallel, Europe is building new observational, modelling and computational capabilities, in particular within Met offices (e.g. ECMWF, UK Met, MeteoFrance, DWD), to deliver the next generation climate services.

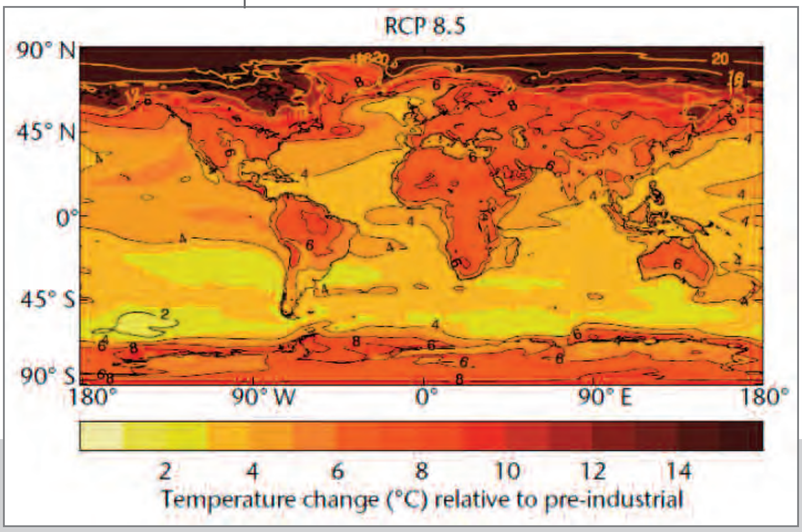
In order to provide credible scientific advice to policy makers, Earth system models are being improved to include key elements of the biosphere (biology of the land surface and ocean), and atmospheric and ocean chemistry. Important Earth system processes being addressed include: the Carbon Cycle (Land carbon uptake, Ocean carbon uptake), Greenhouse Gases (Methane, Ozone), Aerosols (windblown atmospheric dust, dimethyl sulphide from ocean plankton, 'black carbon' from combustion).

Examples of the resulting types of climate services include : long-term century climate reanalysis (European Reanalysis of Global Climate Observations ERA-CLIM, see: www.era-clim.eu), regional climate impact (e.g. Coordinated Downscaling Experiment CORDEX, see: www.euro-cordex.net), attribution, and seasonal-to-decadal prediction. While the science of climate projection is advancing, it is still far from being complete. The longer-term aim is to provide 'seamless forecasting' services that cover the complete range of spatial and temporal scales necessary to fully support climate change adaptation, mitigation, vulnerability assessment and resilience measures (see Fig. 3).

EO data from space underpin the information needs of climate services, delivering accurate and consistent data on our changing environment at the global scale, even in the most remote or difficult to access regions. Such wide-area information directly contributes to support decision and early warning systems within National Meteorological Hydrological Services (NMHSs), resulting in major socio-economic benefits (Hallegatte, A Cost Effective Solution to Reduce Disaster Losses in Developing Countries NMHSs, Early Warning, and Evacuation, 2012).

These climate services will become significantly enhanced and made available to users on an operational basis within the framework of the ESA-EU Global Monitoring for Environment & Security (GMES) / Copernicus (copernicus.eu).

[1] [2] Global temperature rise and precipitation change at the end of the century (relative to pre-industrial average) for the Met Office model and the 'business as usual' scenario RCP 8.5 (credits UK Met Office).
[3] Seamless forecasting schema. Credits: UK Met Office)



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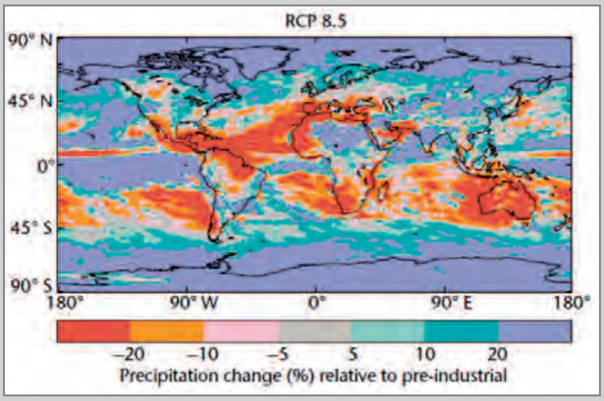

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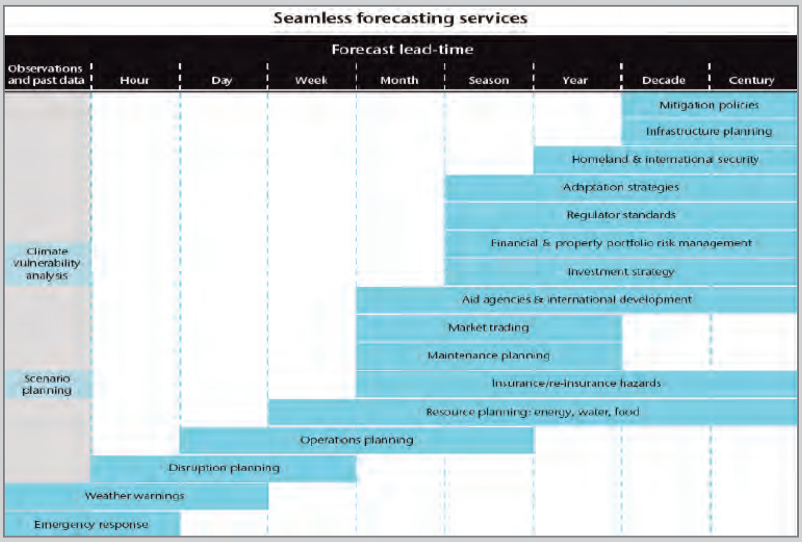

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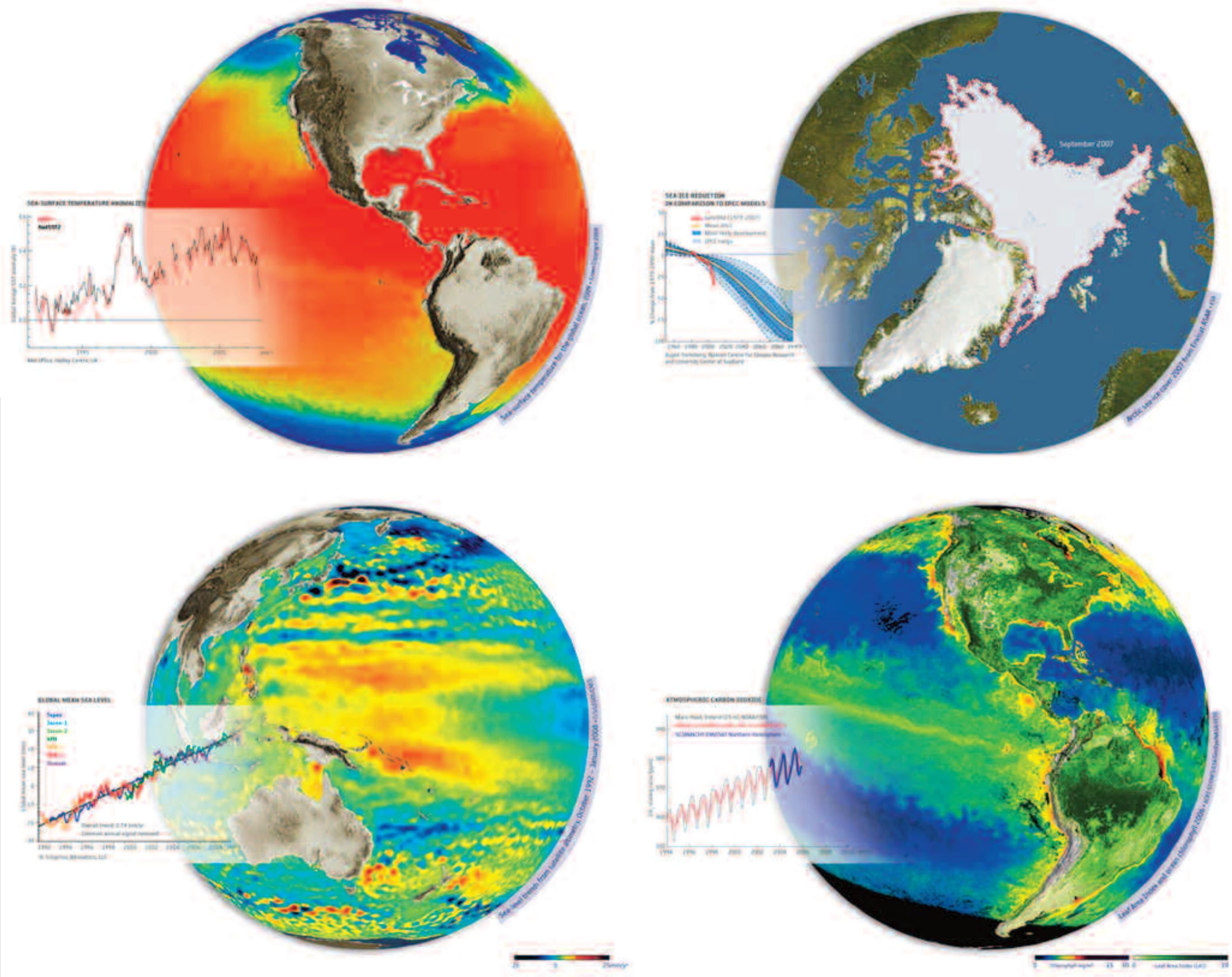
ESA's Climate Change Initiative (CCI) is making full use of Europe's Earth observation space assets to exploit robust long-term global records of essential climate variables. Through this programme, ESA is generating a Climate Data Record of a set of 13 Essential Climate Variables (ECVs) quantifying the state of our climate and its forcing by constantly re-processing long-term EO data archive (see www.esa-cci.org). The specific ECVs include : Sea Surface Temperature, Sea Surface Height, Sea Ice, Ocean Colour, Land Cover, Aerosol, Clouds, Greenhouse Gases, Ozone, Fire, Glaciers, Ice Sheet, Soil Moisture (see Fig. 4 for examples). Such climate-quality data sets are produced mainly to support climate research but also form the foundation of climate services.

Essential Climate Variables (ECVs) as measured from Space, including global field and time series of (a) Sea Surface Temperature, (b) Sea-Ice concentration, (c) Mean Sea-Level Height, (d) Evolution of atmospheric Carbon Dioxide and map of Leaf-area index and Ocean chlorophyll.



Climate change adaptation and mitigation and have been defined simply as (J. Holden, Harvard University):

- **Adaptation**: Managing the Unavoidable
- **Mitigation**: Avoiding the Unmanageable

These definitions, together with assessing climate vulnerability and resilience point to a need for information about the Earth's environment; past, present, and future. EO is a key source of information for the first two requirements, and is an important input to the third.

Regarding the first two requirements, many examples are given in the previous sections of this document (the reader is encouraged to consult these sections). Most of these applications are strongly related to climate, in particular those linked to extreme weather-induced disasters (i.e. adaptation) and clean energy production (i.e. mitigation). For example, EO data can help better quantify the flood risks in coastal cities, resulting from the combined effect of sea-level rise, coastal erosion, and subsidence/uplift (resulting from human activities such as water pumping). Long-term archive of EO data also provide useful information on natural resources, such as offshore wind, solar irradiance, met-ocean conditions, which provide renewable energy managers with a first assessment of the amount of potentially available renewable energy.

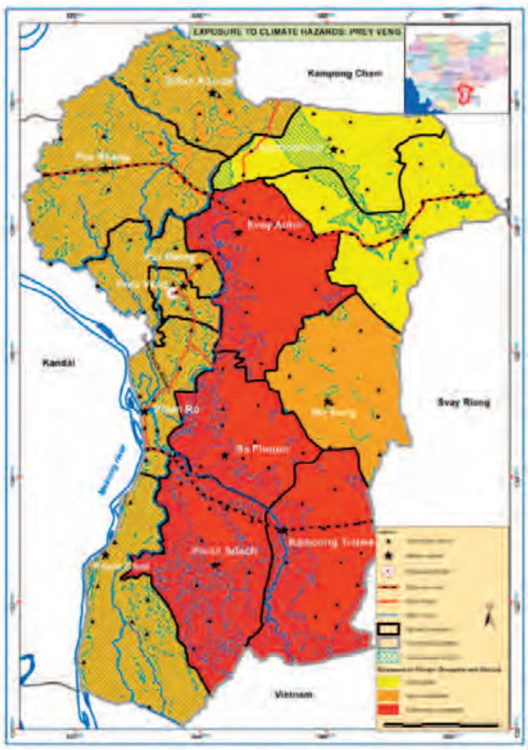
A few further examples of how EO information is customised and exploited to support climate change assessment and the green economy are given below.

Current climate hazards and long-term climate change have been identified as significant environmental and developmental issues in Cambodia. Climate variability and extremes are projected to increase, causing floods, droughts, storms, increased coastal erosion, heat waves, and outbreaks/intensification pests and diseases. Increase in temperature, rising of sea level, and changes in rain patterns pose significant risks to the already vulnerable agriculture and fisheries sector as well as rural livelihoods.

This activity (carried out for Asian Development Bank and World Bank) integrated EO information (land cover, land use) together with existing vulnerability and assessment literature, combined with consultations with government agencies (at the national and provincial levels). In-depth assessments were conducted in four target provinces (Battambang, Kampong Thom, Prey Veng and Stung Treng) to obtain an understanding of sub-national levels of climate change vulnerability (see Fig. 5 & 6).

The analysis provides a scientific, evidence-based assessment of climate-related vulnerability, and recommendations for enhancing adaptation to climate variability and change in key sectors (agriculture, water resources and infrastructure development).

[1] Exposure map to climate hazards for the province of Prey Veng.
[2] Adaptive capacity map to climate hazards for the province of Prey Veng



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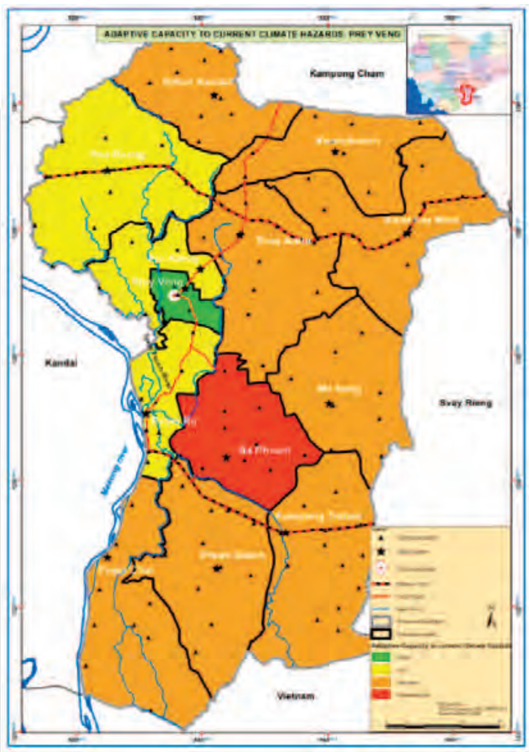

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→ MODELLING THE GREEN ECONOMY IN THE HEART OF BORNEO

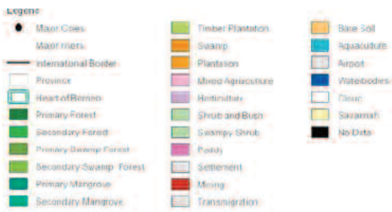
Home to approximately 6% of the world's biodiversity, the Heart of Borneo (HoB) is one of earth's richest biological treasure troves. HoB's forests cover upstream and midstream portions of 29 river basins and provides important ecosystem services across an area of 54 million ha, more than 70% of Borneo, benefiting over 11 million people. HoB's natural capital has tremendous social and economic value at local, national and global levels. Over 40% of HoB is allocated to palm oil, forestry and mining.

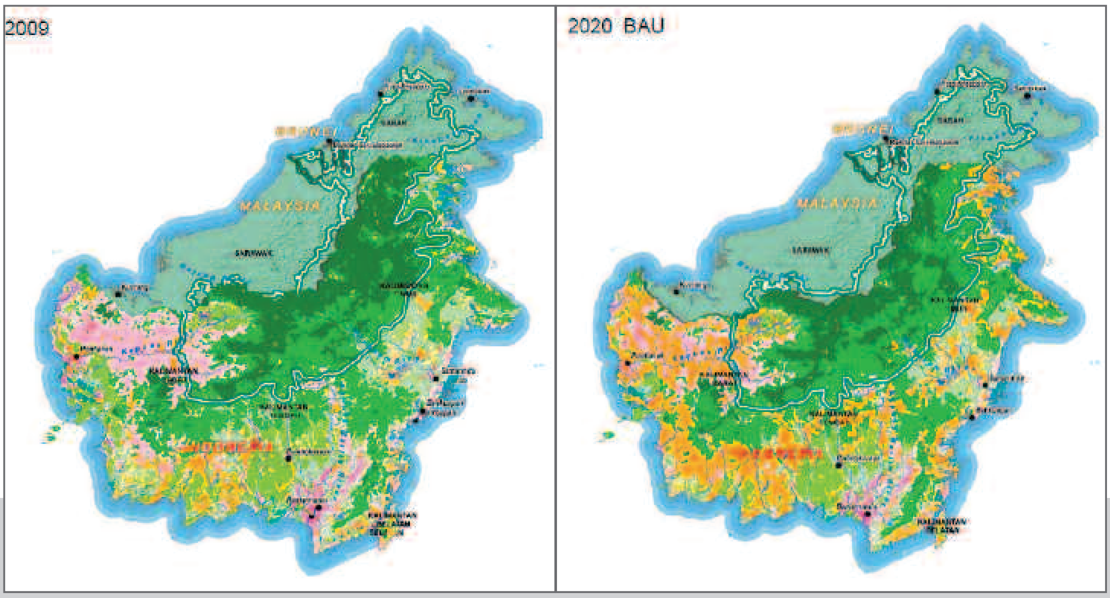
In this activity (carried out in partnership with WWF), EO information (land cover, land use) was produced and used to characterise ecosystems services as of 2009 and map and their likely evolution to 2020 under two scenarios (see Fig. 7) Refer to www.hobgreeneconomy.org for more information.

Business As Usual (BAU: an economy heavily reliant on non-renewable, high carbon, primary industry), and Green Economy (achieving sustainable growth while valuing natural capital and providing for food, water, climate and resource security).

The specific ecosystem services investigated were: carbon storage & sequestration, avoided reservoir sedimentation, water purification/nutrient retention, and open-access harvest. An example of likely nutrient pollution under BAU is given in Fig. 8.

This information (current status and projections) was used together with a suite of valuation techniques (i.e. InVEST: Integrated Valuation of Environmental Services and Tradeoffs) to put a monetary value on ecosystem services and assess the financial impact of their evolution that goes beyond the conventional market-prices approach for goods and services.





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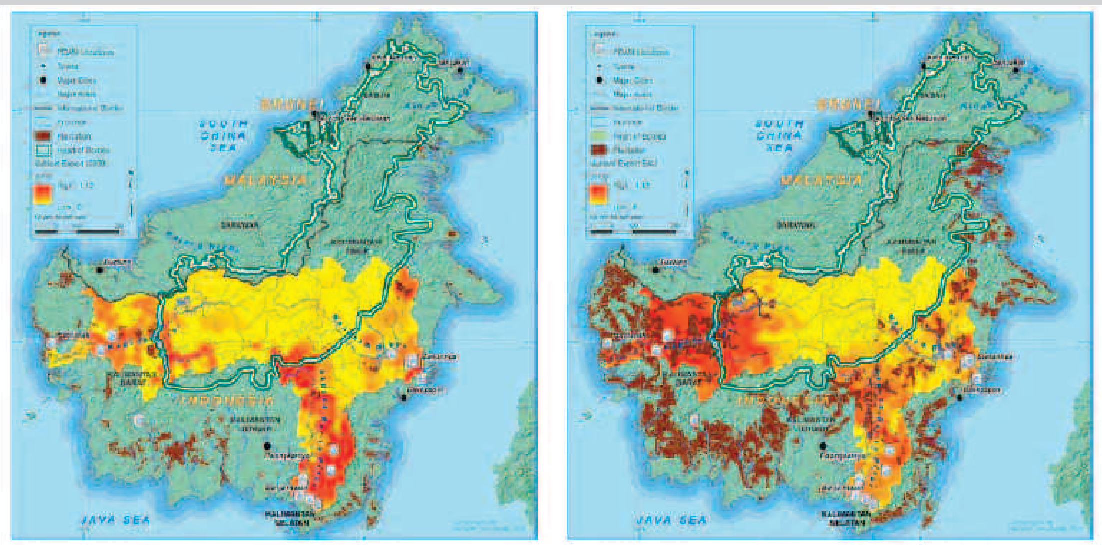

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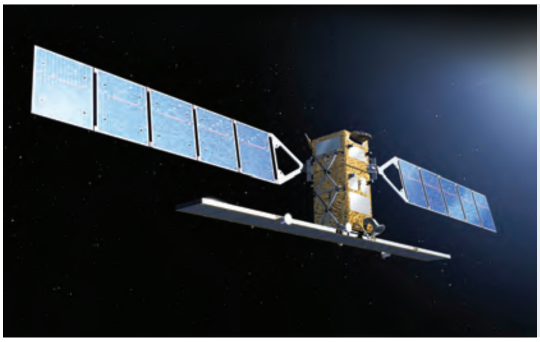
[1] Map of Land use projection form 2009 status to 2020 Business as Usual (BAU) scenario. The BAU scenario for forest cover projects a loss of 3.2 million ha of primary and secondary forest cover between 2009 and 2020, primarily due to palm oil expansion, mining and unsustainable forestry practices (credits: WWF Indonesia and Hatfield Consultants).

[1] Maps of nitrogen exports, where red is high and yellow is low, for three watershed that originate in HoB. Left map shows the nutrient pollution in 2009 affecting drinking water utilities. Right map shows the likely distribution of nutrient pollution and affected drinking water utilities under BAU in 2020 (credits: Hatfield Consultants).

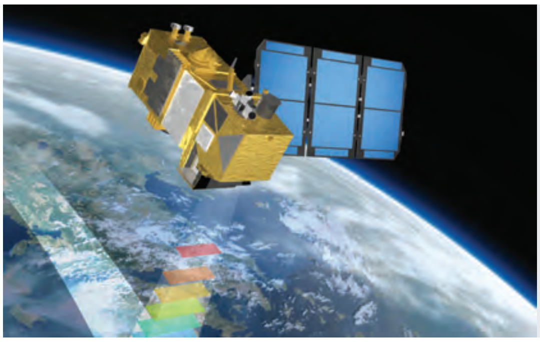
The Sentinel missions

As the most ambitious Earth observation programme to date, Global Monitoring for Environment and Security (GMES) will provide, accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security. GMES provides a unified system through which vast amounts of data, acquired from space and from a multitude of in-situ sensors, are fed into a range of thematic information services designed to benefit the environment, the way we live, humanitarian needs, and support effective policy-making for a more sustainable future. These services fall into six main categories: services for land management, services for the marine environment, services relating to the atmosphere, services to aid emergency response, services associated with security and services relating to climate change.

The programme is headed by the European Commission (EC) in partnership with the European Space Agency (ESA) and the European Environment Agency (EEA). Managed by ESA, the Space Component is in its pre-operational stage, serving users with satellite data currently available through the GMES Contributing Missions at national, European and international levels. GMES will become operational after launch of the first Sentinel mission. ESA is developing five families of Sentinel missions specifically for GMES:

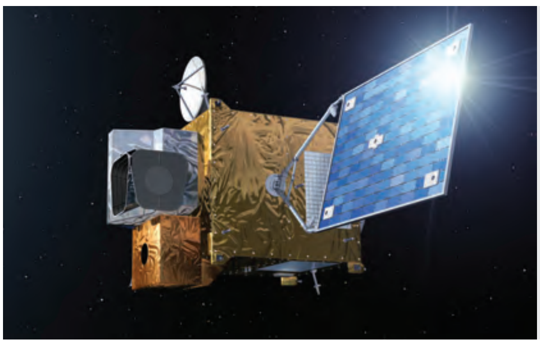


Sentinel-1 is a polar-orbiting, all-weather, day-and-night radar imaging mission for land and ocean services. The first Sentinel-1 satellite is planned for launch in 2013.



Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring providing, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2 will also deliver information for emergency services. The first Sentinel-2 satellite is planned for launch in 2014.

Sentinel-3 is polar-orbiting, multi-instrument mission to measure variables such as sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability. The first Sentinel-3 satellite is planned for launch in 2014



Sentinel-4 is a payload that will be embarked upon a Meteosat Third Generation-Sounder (MTG-S) satellite in geostationary orbit scheduled to be launched in 2019. Sentinel-4 is dedicated to atmospheric monitoring.

Sentinel-5 is a payload that will be embarked on a MetOp Second Generation satellite, also known as Post-EPS, to be launched in 2020. Sentinel-5 is dedicated to atmospheric monitoring.

Sentinel-5 Precursor satellite mission is planned to launch in 2015, thereby reducing data gaps between ENviSAT (Sciamachy data in particular) and Sentinel-5. This mission will be dedicated to atmospheric monitoring.

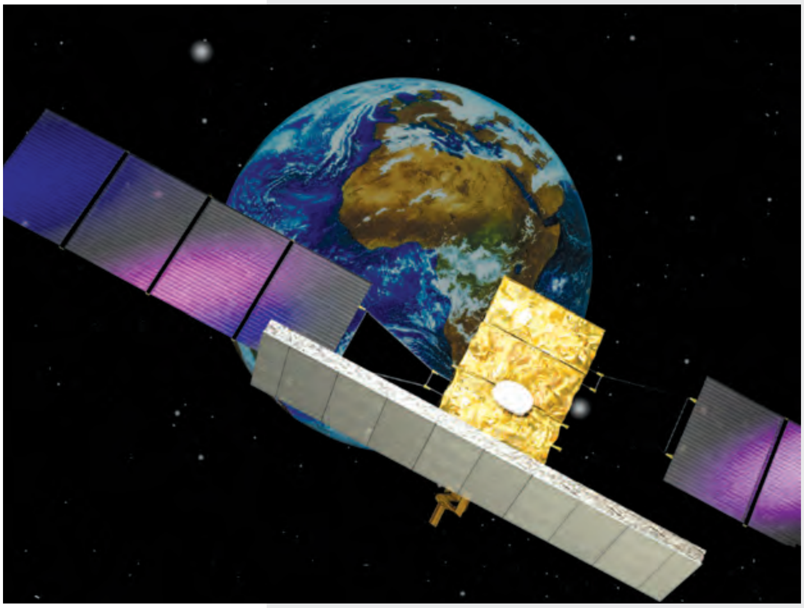
Other EO missions of the European Space Agency

ENviSAT (ESA) Launch date: 2002 Type: Optical (300 m res) and radar (25 m res) ENviSAT is the largest Earth Observation spacecraft ever built. The instruments address four major areas: (i) radar imaging, (ii) optical imaging over oceans, coastal zones and land, (iii) observation of the atmosphere, and (iv) altimetry. The ENviSAT data are used in many fields of Earth science, including atmospheric pollution, fire extent, sea ice motion, ocean currents and vegetation change, as well as for operational activities such as mapping land subsidence, monitoring oil slicks and watching for illegal fisheries. **www.esa.int/esaEO**

ErS 1-2 (ESA) Launch date: ERS-1 (1991-2000), ERS-2 (1995-2011) Type: Radar (25m res) ESA's first Earth Observation satellites carried a comprehensive payload including an imaging Synthetic Aperture Radar (SAR). Both ERS satellites (ERS1&2) were built with a core payload of two specialised radars and an infrared imaging sensor. The two spacecraft were designed as identical twins with one important difference - ERS-2 included an extra instrument designed to monitor ozone levels in the atmosphere. **www.esa.int/esaEO**

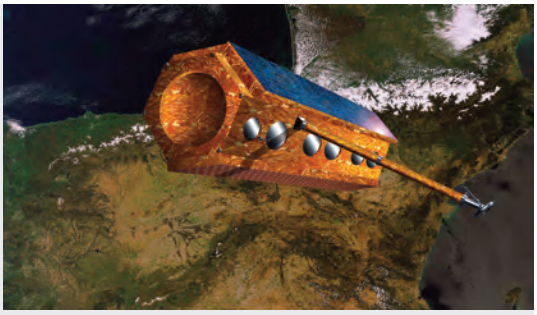
National EO missions from Europe & Canada (using SAR sensors)

COSMO SkyMEd (ASi - IT MoD, data distribution: egeos) Launch date: Jun-2007, Dec-2007, Oct 2008, Nov-2010 Type: VHR Radar (up to 1m res) COSMO-SkyMed (Constellation of Small Satellites for Mediterranean basin Observation) is a 4-spacecraft dual-use constellation, conceived by ASI (Italian Space Agency) and funded by the Italian Ministry of Research and the Italian Ministry of Defence. Each of the four satellites is equipped with a X-band SAR instrument operating at 9.6 GHz, capable of operating in all visibility conditions (all-weather and night/day conditions) at high resolution and with interferometric/radargrammetry capability. The primary mission is to provide services for military and civil (institutional, commercial) community for land monitoring, territory surveillance, management of environmental resources, maritime and shoreline control, law enforcement, topography as well as scientific applications. Plans for expansion: COSMO SkyMed Seconda Generazione, with launch date: 2016 (foreseen) Type: VHR Radar (up to 0.8 m res) COSMO-SkyMed Seconda Generazione is a dual-use constellation that will gradually replace the First Generation one with two additional satellites and an improved ground infrastructure, providing in this way operational continuity to the mission at least until 2024. Each satellite is equipped with a fully polarimetric X-band SAR instrument capable of operating in all visibility conditions and with interferometric and radargrammetry capability. The system will provide increased performances with respect to the current generation in terms of resolution, acquisition modes, satellite agility, system capacity and programming and processing capabilities. CSG main civilian applications concern Risk Management, Scientific and Commercial Applications with a focus on monitoring of natural disasters and on their consequences on environment and man-made structures in continuity with the service offered by CSK. **www.asi.it - www.egeos.it**



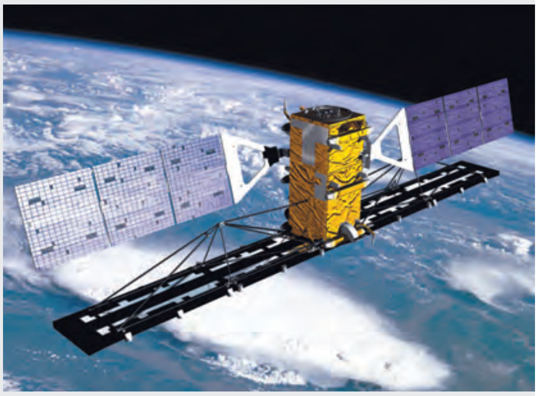
TERRA SAR-X (DLR / ASTRIUM GEOINFORMATION SERVICES) Launch date: 2007 Type: VHR Radar (up to 1 m res) TerraSAR-X Earth Observation satellite system was designed by the German space agency (DLR) and is operated by Infoterra GmbH. TerraSAR-X acquires high-resolution all-weather SAR (Synthetic Aperture Radar) data in the X-band for research and development purposes as well as scientific and commercial applications. A second sister satellite, TanDEM-X launched in early 2010, makes the two satellites acting as a pair and producing a Digital Elevation model featuring a vertical accuracy of 2 m (relative) and 10m (absolute), within a horizontal raster of approximately 12x12 square meters. Global Digital Elevation Model (DEM) of an unprecedented quality, accuracy, and coverage will be soon available for the Earth's complete land surface. Plans for expansion: DLR's TerraSAR Next Generation planned for 2016 will guarantee continuity with the current system. **www.infoterra.de**

PAZ (HISDESAT) Launch date: 2013 Type: SAR (6 m res) PAZ is the first Spanish radar observation satellite. It will be capable of providing images in any type of weather conditions, day and night, and will primarily fulfil the security and defence needs of the Spanish government. The PAZ satellite will be equipped with an X-band synthetic aperture radar (SAR) instrument, mounted on a TerraSAR-X recurrent platform. It will be designed to offer different modes of operation, with different swath widths, and various resolutions of up to a metre. PAZ is designed as a dual-use mission to meet operational requirements, mainly of a defence and security nature, but also high-resolution civil applications.



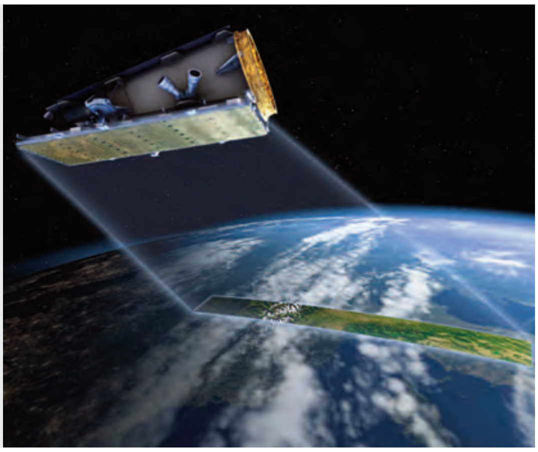
The polar orbit of PAZ was specifically optimised to improve temporal resolution over key areas of interest when operating TerraSAR-X and PAZ as a constellation.
www.hisdesat.es/eng/satelites_observ-paz.html

RADARSAT 1-2, RADARSAT CONSTELLATION MISSION (CSA / MDA) Launch date: Radarsat-1 (1995), Radarsat-2 (2007) Type: VHR Radar (up to 2 m res). Equipped with a powerful synthetic aperture radar (SAR) instrument Radarsat satellites acquire images of the Earth day or night, in all weather and through cloud cover, smoke and haze. The system has three main uses: maritime surveillance (ice, wind, oil pollution and ship monitoring), disaster management (mitigation, warning, response and recovery) and ecosystem monitoring (forestry, agriculture, wetlands and coastal change monitoring). The system is operated by the Canadian company MDA. Radarsat-2 is an ESA Third Party Mission. Plans for expansion: The RADARSAT Constellation is the evolution of the RADARSAT Program with the objective of ensuring data continuity, improved operational use of Synthetic Aperture Radar (SAR) and improved system reliability. The three-satellite configuration will provide complete coverage of Canada's land and oceans offering an average daily revisit, as well as daily access to 95% of the world to Canadian and



International users. The mission development has begun in 2005, with satellite launches planned for 2018. The RADARSAT Constellation is the evolution of the RADARSAT Program with the objective of ensuring C-band data continuity, enhanced operational use of Synthetic Aperture Radar (SAR) data and improved system reliability over the next decade.
www.gs.mdacorporation.com,earth.esa.int/TP-MDAG/radarsat_sar.html

NOVASAR (SSTL, UK) Launch date: 2015 Type: SAR (6 m res) NovaSAR-S is a small Synthetic Aperture Radar (SAR) mission designed for low cost programmes and providing radar imaging globally, day or night and through clouds. It is using a constellation of three satellites operating S-band Synthetic Aperture Radar sensors, will be complementary to optical satellites and will support a range of thematic applications such as flood monitoring, disaster response, crop monitoring, forestry, land cover & land use, ice monitoring and maritime applications. **www.sstl.co.uk**

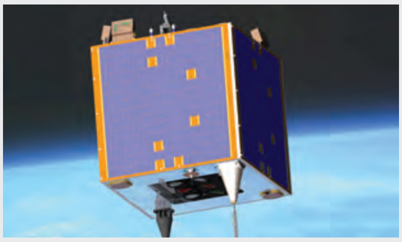


National EO missions from Europe & Canada (using Optical sensors)

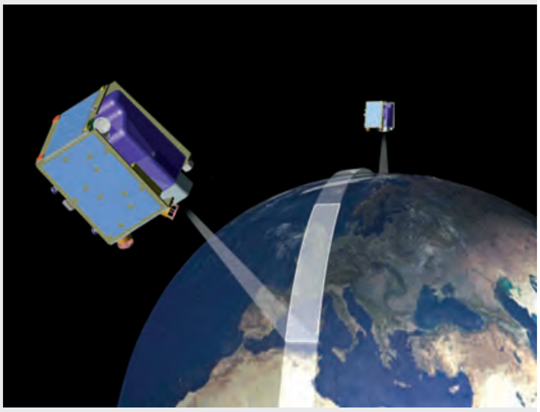
Pleiades- 1A, 1B (CNES/ ASTRIUM GEO-INFORMATION SERVICES) Launch date: Pléiades 1A (17 December 2011), 1B (2 December 2012). The Pléiades system, with its two satellites in orbit, will be fully operational by the 2nd quarter of 2013. The two satellites will be phased opposite one another to enable daily revisits to any point on the globe. Type: VHR Optical (panchromatic 0.7 m and multispectral 2.8 m at nadir). The Pléiades system was designed under the French-Italian ORFEO program (Optical & Radar Federated Earth Observation). The Pléiades programme was launched in October 2003 with CNES (the French space agency) as the overall system prime contractor and EADS Astrium as the prime contractor for the space segment. It is operated by Astrium GEO-Information services. Pleiades imagery comes in a full range of resolutions from 2 m down to 0.5 m (Panchromatic) for work on local scale for mapping the densest urban areas and for other precision applications (monitoring disaster areas, mining or oil exploration, maritime surveillance, agriculture, etc.). Pléiades' stereo and tristereo capability makes it possible to generate DEM products with a 1-metre or 4-metre posting, ideal for 3D modelling of urban areas and relief. **www.astrium-geo.com**

SpOT 1-7 (CNES / ASTRIUM GEOINFORMATION SERVICES) Launch date: SPOT 1 (1986-1990), SPOT 2 (1990-2009), SPOT 3 (1993-1997), SPOT 4 (1998-2012), SPOT 5 (since 2002), SPOT 6 (launched in 2012), SPOT 7 (2014) Type: VHR and HR Optical (1,5 m — 20 m res) The SPOT system was designed by the French space agency (CNES) and it is operated by Astrium GEO-Information services. SPOT imagery comes in a full range of resolutions from 20 m down to 2,5 m, for work on regional or local scales (from 1:100 000 to 1:10 000). Thanks to the constellation of SPOT satellites and their revisit capabilities, it is possible to obtain an image of any place on Earth, each day. A SPOT DEM is a digital elevation model produced by automatic correlation of stereo-pairs acquired by the HRS instrument on SPOT5 with 10 to 20m vertical accuracy. To provide continuity with the SPOT 1-5 missions EADS Astrium has decided to provide the SPOT 6 and SPOT 7 satellites providing 1.5m res optical imagery. **www.astrium-geo.com**

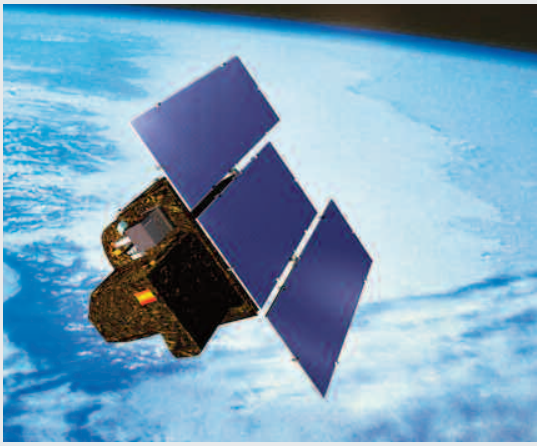
Disaster Monitoring Constellation – DMC (DMCii) Launch date: 2002 (first generation) Type: HR Optical (22 m res) The DMC is an earth observation resource that enables high frequency imaging globally from a constellation of multiple satellites providing Optical multispectral imagery to support precision agriculture, forest mapping, land cover, disaster monitoring classification, change detection. The constellation is coordinated through DMCii to achieve seamless commercial earth imaging services whilst each satellite is independently owned and controlled by a separate nation/operator. Operational satellites include Nigeriasat-NX (Nigeria), UK-DMC2 (UK), Deimos-1 (Spain) and Nigeriasat-2 (Nigeria) that provides enhanced capabilities with 5 m res. in multispectral mode and 4m res. in panchromatic alongside with Beijing-1 (China) that provides 32 m res. in multispectral mode and 4 m res. in panchromatic mode. **www.dmcii.com**



RAPIDEYE (rapidEye AG) Launch date: 2008 Type: HR Optical (5 m res) RapidEye - a German constellation of five identical EO satellites at 5 m spectral resolution - provides multispectral optical data since 2009 with five spectral bands, including the near infrared, which is very valuable for land use/ land cover applications. Other main areas of applications is agriculture, forestry, energy & infrastructure, environment and security & emergency management. Together, the 5 satellites are capable of collecting over 4 million km² with a revisit date of 1 day. The system is operated by RapidEye AG. **www.rapideye.de**

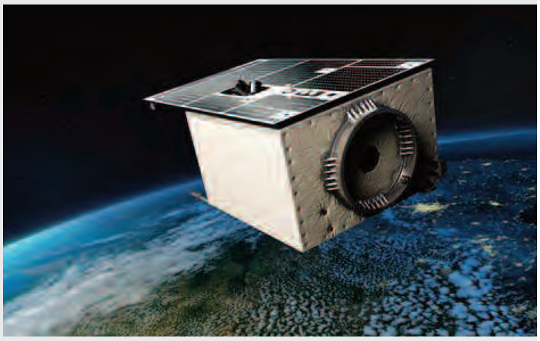


INGENIO (CDTI / HISDESAT) Launch date: 2014 Type: HR Optical (2.5m res) INGENIO is a Spanish optical Earth observation satellite, which will mainly serve a civil purpose. The mission will provide high-definition panchromatic and multispectral ground imaging for various applications that can be used in mapping, monitoring borders land changes, urban planning, agriculture, water management, environmental monitoring, and risk and safety management. The mission will last for a minimum of seven years following launch. This will offer the capability to provide a supply of data which will be the basis for operational services, facilitating the decision-making of the Spanish government and the GMES users, when necessary.



www.hisdesat.es/eng/satelites_observ-ingenio.html

EnMAP (dLr) Launch date: 2016 Type: Hyperspectral imaging (30m res) The instruments on Germany's hyperspectral Earth observation satellite, Environmental Mapping and Analysis Programme (EnMAP), will observe the sunlight reflected from Earth across a wide range of wavelengths from the visible to the short wave infrared. This will make it possible to accurately study the condition of Earth's surface, and the changes affecting it. EnMAP will carry a 'hyperspectral instrument' – essentially a spectrometer that depicts Earth's surface by contiguous spectra assembled by about 250 narrow bands. This will provide detailed information about vegetation, land use, surface rocks and waterways. The data can be used to provide information about the mineralogical composition of rocks, the damage to plants caused by pollution and the degree of soil pollution, among other applications. **www.dlr.de**



PRISMA (ASi) Launch date: 2014 Type: Hyperspectral imaging (20-30 m (Hyp) res and 2.5-5m (PAN) res) PRISMA is an earth observation system with innovative electro-optical instrumentation which combines a hyperspectral sensor with a panchromatic, medium-resolution camera. The advantages of this combination are that in addition to the classical capability of observation based on the recognition of the geometrical characteristics of the scene, there is the one offered by hyperspectral sensors which can determine the chemical-physical composition of objects present on the scene. This offers the scientific community and users many applications in the field of environmental monitoring, resource management, crop classification, pollution control, etc. Further applications are possible even in the field of National Security. **www.asi.it**

AATSR	Advanced Along-Track Scanning Radiometer (ENVISAT)
AIRS	Atmospheric Infrared Sounder (Aqua)
ALI	Advanced Land Imager (NASA's EO-1)
ALOS	Advanced Land Observing Satellite (Japan)
ASAR	Advanced SAR (ENVISAT)
ASI	Italian Space Agency
ASTER	Advanced Space-borne Thermal Emission and Reflection Radiometer (Terra)
ATSR	Along-Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CEOS	Committee on Earth Observing Satellites
CIESIN	Center for International Earth Science Information Network
CSA	Canadian Space Agency
DEM	Digital Elevation Model
DORIS	Downstream Observatory organised by Regions active In Space - Network
DGGT	Deutsche Gesellschaft für Geotechnik (Germany)
DRM	Disaster Risk Management
ENVISAT	ESA's Environment Satellite
EO	Earth Observation or Earth Observations
ERS	ESA's European Remote Sensing Satellite
ESA	European Space Agency
ETM	Enhanced Thematic Mapper (Landsat)
EWS	Extra Wide Swath mode (Sentinel-1)
HRG	High Resolution Geometrical (SPOT-5)
GEO	Group on Earth Observations
GEOSS	Global Earth Observing System of Systems
GMES	Europe's Global Monitoring for Environment and Security programme
GNSS	Global Navigation Satellite Systems
GOES	Geostationary Operational Environmental Satellite
GOME-2	Global Ozone Monitoring Experiment
GPS	Global Positioning System
HH	Horizontal/Horizontal – polarizations for SAR
HV	Horizontal/Vertical – polarizations for SAR
InSAR	Interferometric Synthetic Aperture Radar
IWS	Interferometric Wide Swath mode (Sentinel-1)
HR	High Resolution
LDCM	Landsat Data Continuity Mission (Landsat-8)

LiDAR	Light Detection And Ranging
LOS	Line of Sight
LSM	Landslide Monitoring
LSMd	Landslide Modelling
MIR	Mid Infra red
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Next Generation
NIR	Near Infra Red
NOAA	National Oceanographic and Atmospheric Administration (USA)
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	National Polar-orbiting Operational Environmental Satellite System Preparatory Project
OMI	Ozone Monitoring Instrument
PSHA	Probabilistic Seismic Hazard Assessment
PSI	Persistent Scatterer Interferometry
RCM	Radarsat Constellation Mission (Canada)
SAR	Synthetic Aperture Radar
SENTINEL	Europe's EO missions multi-satellite project developed by ESA under the GMES programme
SEVIRI	Spinning Enhanced Visible and Infra Red Imager (MSG)
SPOT	Satellite Pour l'Observation de la Terre (France)
SWIR	Short wave Infra Red
TIR	Thermal Infra Red
TMPA	Multi-satellite Precipitation Analysis
UAVSAR	Uninhabited Aerial Vehicle Synthetic Aperture Radar
UN	United Nations
UNAVCO	University Navstar Consortium (Boulder, Colorado)
UNIFI	University of Florence (Italy)
USA	United States of America
USGS	United States Geological Survey
VAACs	Volcanic Ash Advisory Centres
VHR	Very High Resolution
VIR	Visible Infra Red
VIIRS	Visible Infrared Imager Radiometer Suite
VV	Vertical/Vertical – polarizations for SAR
WOVO	World Organisation of Volcanic Observatories
WMO	World Meteorological Organisation

satellite image
The Okavango River, northern Namibia and southern Angola.
The Korea Multi-purpose Satellite (Kompsat-2) of the Korea Aerospace Research Institute acquired this image on 3 January 2013. Credit: KARI/ESA

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Credits: IFAD/Mwanzo Millinga