



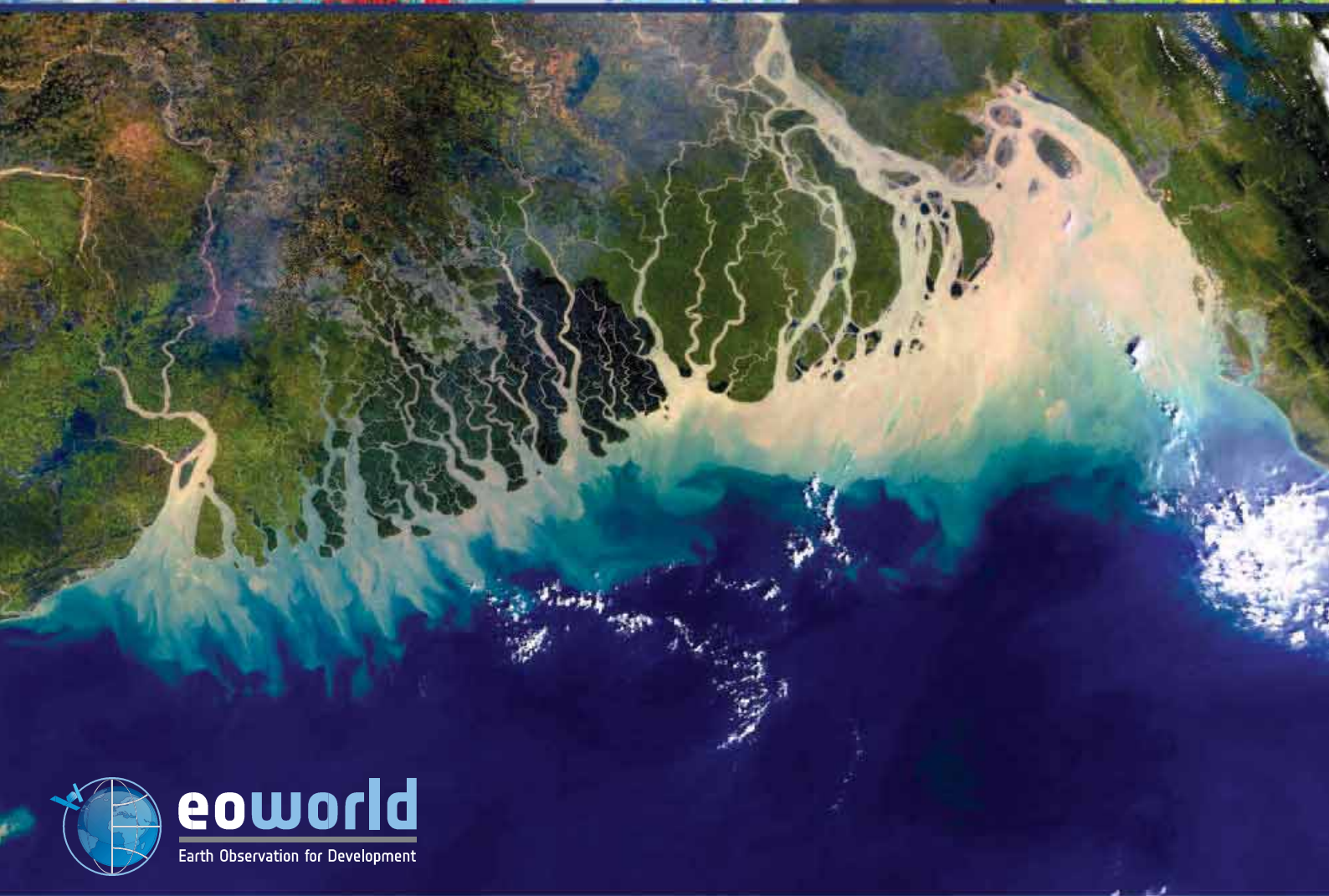
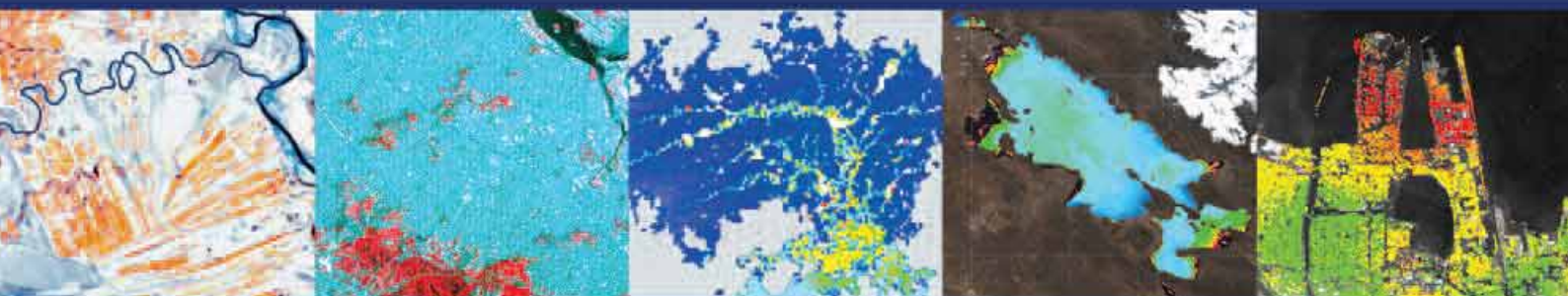
World Bank



European Space Agency

→ EARTH OBSERVATION SUPPORT TO WORLD BANK PROJECTS

Progress Report | November 2011



eoworld

Earth Observation for Development

Acknowledgements

This Progress Report was prepared by Anna Burzykowska, ESA Earth Observation Project Specialist, with the collaboration of Henry Jewell, Geospatial Analyst of the World Bank. Valuable contributions were made by the Team of the Service Providers. ESA Technical Officers and World Bank Task Team Leaders provided advice and guidance. The ESA Earth Observation Graphic Bureau produced the design of the layout of the Report.

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ESA-ESRIN | Frascati , Italy



www.worldbank.org/earthobservation
www.esa.int/eomd

FOREWORD

Earth Observation (EO) is increasingly used in development work and has become a valuable tool to help achieve the mission of the World Bank. EO-based services can be undertaken at varying spatial scales from local to global and they allow to generate information in a non-intrusive, objective and consistent manner around the world.

*The World Bank and the European Space Agency (ESA) have partnered for the purpose of mainstreaming the use of EO in the World Bank's lending operations, across all of the Sustainable Development Network's sectors. ESA's Directorate of Earth Observation Programmes, and the World Bank's Finance, Economics and Urban Department have therefore launched **eoworld**.*

*The aim of this initiative is to establish a stable connection between the specific information needs of the World Bank projects and the new developments in Earth Observation programmes and services. In particular **eoworld** gives the World Bank the opportunity to benefit from ESA's 30 years of experience in collecting and distributing Earth Observation (EO) data to users around the world, and in developing innovative information services for various applications to be used by public organizations, national authorities and private sector operators in their development projects. With the start of the EU-ESA flagship space program - GMES (Global Monitoring for Environment and Security) and the emergence of new national space missions in Europe and Canada, EO technology is moving towards a long-term sustainable data flow, forming the basis for its operational use.*

In order to demonstrate the utility of EO techniques to the World Bank Group activities, ESA and the World Bank agreed to conduct a set of pilot projects in the following domains:

- Disaster Risk Management
- Urban Development
- Agriculture and Forest Management
- Water Resources Management
- Coastal Zones Management
- Marine Environment Management
- Climate Change Adaptation

This Progress Report provides an overview of the World Bank–ESA collaboration to date, and an insight into the services contents. The collaboration began in 2008 with initial, small-scale EO demonstrations for three Bank projects. Based on these results, it was decided in 2010 to initiate more extensive demonstrations for a wider range of Bank activities. Twelve Bank projects are currently benefiting from the initiative. Their initial results are presented in this Progress Report, while the final delivery and review are planned for the first quarter of 2012.

We look forward to the continuing collaboration between our two institutions in the pursuit of sustainable development.

Zoubida Allaoua

Director of the Finance, Economics,
Urban Department
Sustainable Development Network
The World Bank

Volker Liebig

Director of Earth Observation Programmes
European Space Agency

Introduction by the European Space Agency

I have spent the last 20 years of my professional life working in the area of Earth Observation (EO) at the European Space Agency (ESA). During this time, the ESA facility where I work (ESRIN, located just outside of Rome, Italy) has grown dramatically in size, and is now the ESA Centre for Earth Observation. That growth is also a reflection of just how much this technology has developed and matured over the last two decades.

Since the launch of ESA's first Earth Observation satellite (ERS-1 in July 1991), we have been working at ESRIN with the world's leading scientific groups in order to develop the methods and techniques that turn basic satellite data into higher-level information that can be used in operations and decision-making for a wide range of organisations that are monitoring and managing the environment. This has been followed in the last 10 years by cooperation with more than 400 of these user organisations at national level in Europe (eg. ministries of environment, forestry, water resources, civil protection, etc) and at international level (eg. UNFCCC environmental treaties and conventions) to assess exactly what benefits (and limitations) Earth Observation information can bring into their operational practices. In addition, we are exploring with private sector industry (eg. oil & gas, insurance) how this information can be integrated into business processes (environmental impact assessment, risk assessment, corporate social responsibility).

Based on these experiences, Earth Observation can now be taken into new user communities and we began focussing on the information needs of Multi-lateral Development Banks. The **eworld** initiative recently set up between the World Bank and ESA is leading the way forward in this domain. It is clear that for the planning, implementation, monitoring and completion of large investments in developing countries around the world, there is a need for both historical and current reliable geo-spatial information. Earth Observation has the potential to supply some (but not all) of this information in a *global* and *consistent* manner, including regions where it is difficult to access information by conventional means.

The aim of activities described in this report is to work closely with World Bank Task Team Leaders and local users on a first set of Bank projects to assess the utility of Earth Observation information within the context of project aims and goals. The objective is to promote greater

awareness and better understanding of European and Canadian Earth Observation capabilities – both of EO satellites (ESA and national missions), and of information service providers (mainly SMEs). In Europe, this sector is strong and growing with more than 200 small companies offering a wide range of innovative and leading-edge information services based on Earth Observation. The information is being produced and delivered not by ESA, but by specialist service providers from across Europe, selected through a process of open competition. ESA is managing the activities of these specialist companies and providing independent technical oversight to ensure that the work is carried out as specified.

The stage is now set for Earth Observation to move from a research and development technology, to becoming a source of data for operational monitoring of all aspects of the Earth's environment (land, atmosphere, oceans, cryosphere). ESA currently operates the world's largest Earth Observation satellite, Envisat (with 10 separate instruments), which is opening up new scientific applications (especially in atmospheric monitoring). But, more importantly, ESA is now developing a fleet of new satellites (the Sentinels) together with the European Union under the joint initiative of GMES (Global Monitoring of the Environment and Security). The first in this series (Sentinel-1) is scheduled for launch early 2013. In total, this system of satellites will generate more data in 5 months than Envisat has generated in 5 years. Furthermore, the plan is to maintain and replenish the space segment in order to ensure long-term (decadal) continuity of observations, which is a key element for user organisations in order to adopt this source of information in working practices.

ESA looks forward to continuing the collaboration with the World Bank over the next years in order to expand the understanding of Earth Observation, prepare for the capabilities that GMES will soon bring and establish the use of this information in the Bank's operations on a sustainable basis.

Stephen Coulson

Head of Industry Section

Directorate of EO Programmes,
European Space Agency
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Introduction by the World Bank

While an urban planner by training, and having always produced visuals and maps to nourish my project work, I only encountered directly the potential of Earth Observation when in 2009 I was offered some support by ESA to investigate land subsidence in some cities for which I was conducting urban risk assessments. The results were so powerful, detailed and incontrovertible, that their contribution to the analytical work became essential.

The World Bank's Finance, Economics and Urban development Department, to which I belong, engaged in consultations and reached a high-level agreement with ESA in 2010 to carry out a larger set of projects to prove the real potential of Earth Observation for the Bank's development work. An internal Call for Proposals was conducted and twelve projects were selected from thirty proposals from across the Sustainable Development Network. They concern a wide range of sectors, themes, and parts of the world, from Africa to Oceania.

The interest elicited by this program, the inquiries received from across the institution, and the early results from the implementation of the twelve projects, have convinced us further that so many Bank investment operations, whether in the early design and identification stage, during preparation, or under implementation and supervision, can benefit from the intelligent use of Earth Observation to achieve greater development impact. Colleagues from across the institution are quickly realizing this potential, and more initiatives of this kind are taking shape. In 2010 the Bank launched its "Open Data, Open Knowledge, Open Solutions" policy reforms, aimed at making most of the information assembled or generated directly by the Bank available openly and publicly. It is more than a conventional disclosure policy, as it entails the sharing of information and databases that can be used by researchers, decision-makers, opinion-makers and by the public in general to produce their own analyses, and come to their own conclusions about a wide range of development topics. The use of spatial analysis has also greatly increased within the Bank, with the "Mapping for results" initiative which generates and makes available spatial data about the location of World Bank investments worldwide.

In 2011, the World Bank published its first ever Knowledge for Development report, tracking the increasing role of knowledge services across the institution and the

increasing demand for such services from partners and clients. Knowledge generation and sharing requires ever greater use of and access to Information and Communication Technology and is based on reliable, consistent data, of which Earth Observation is a natural component. In April, the Bank announced the winners of the "Apps for development" competition for software developers who tackled some of the world's most pressing development problems by creating digital applications using data collected by the Development Economics Data Group of the Bank.

This environment of open data, spatial thinking and an increased thirst for knowledge is the context in which the **eoworld** initiative takes place. This has been made possible thanks to the generous financial and technical support of the European Space Agency. ESA has taken the selected Bank projects through a process of technical refinement and definition of the Earth Observation applications needed, competitive selection of service providers, contracting, and supervision.

Throughout this process, the importance of interacting with the end users of the EO services, which are the national and local agencies directly involved in the Bank operations, has become clearer. Beyond the technical contribution of the EO services to achieve the development objectives of each project, there is real value in demonstrating how this rapidly evolving technology can improve the ability of local institutions to track changes on the ground.

In September 2011 ESA, JAXA and NASA held a joint event in Washington DC on international cooperation for long term Earth Observation from space, demonstrating how it is important for the global community and how international space agencies are working together for it. As a global institution, responding to a Board of Governors hailing from (nearly) all the countries of the world, the World Bank is ready to expand its outreach in this promising area of work, and deepening its successful partnership with the European Space Agency.

Anthony G. Bigio

Senior Urban Specialist

Earth Observation Coordinator

FEU, The World Bank

Washington, DC

Setting up the Projects

The European Space Agency and the World Bank have agreed to increase their collaboration for the purpose of mainstreaming the use of Earth Observation (EO) in the identification, preparation and supervision of Bank operations and related studies. Within this framework ESA is providing the capacity (financing and technical supervision) to produce and deliver EO information services tailored to the requirements of the World Bank projects based on pro-bono support. This work is being carried out under the Value Adding Element (VAE) of the ESA Earth Observation Envelope Programme (EOEP).

In June 2010 ESA and the World Bank jointly launched a Call for Proposals and invited submissions from the World Bank Task Team Leaders to specify types and content of geographic information needed in their projects. On this basis, 12 proposals which were most relevant to on-going or planned Bank operations and were feasible in view of the existing and validated EO capabilities were selected for implementation.

Following this selection, the ESA team has closely interacted with the World Bank teams in order to better understand the complete geo-information requirements associated with each individual project. On the basis of this information, ESA identified technical specifications for EO information products required and in November 2011 issued an Invitation to Tender to the European and Canadian EO service industry to deliver the services. The total value of the Tender was approximately €1,3 mln (or €100.000 per project). In addition, ESA is supporting this work by providing the access to EO data from 15 different satellite missions for a total value of approximately €1 mln.

The World Bank teams have been supporting this work by:

- Assisting ESA and the service providers in the final definition of services to satisfy their user requirements,
- Facilitating access to suitable in-situ data and any other ancillary data available to the World Bank and the local stakeholders in order to help implement and validate the required products,
- Providing a users' assessment of the service. Specifically, providing feedback on the quality and benefit of the projects results,
- Capturing and communicating the projects outcomes to

the broader network of international development practitioners.

In March, contracts were finalized for the provision of the services, and in April 2011 the World Bank and ESA jointly conducted a kick-off meeting in order to set up the baseline for the production and delivery of the services. This Services Readiness Review meeting, held at the Bank's Washington, DC Headquarters, was aimed to present in detail the types of information products to be delivered, to agree on the division of roles between the stakeholders and to schedule the implementation phase. As a result, the technical specifications for each of the projects were finalized following the establishment of the working contacts between the service providers, the World Bank teams, and the end users in developing countries.

The services are currently in their production phase which involves the collection of EO and in-situ datasets, their processing, value-adding analysis, followed by quality checking, validation and delivery planned for Q4 2011. During that time the dialogue with Bank teams and end users is being maintained to ensure that the work is fully in line with any evolution or refinements of geo-information requirements associated with each of the projects.

The Involvement of the Local Stakeholders

In addition to the World Bank project teams, the primary recipients of the **eoworld** final products are the national and regional, public agencies involved in the World Bank projects' countries. The involvement of the local stakeholders in the EO projects implementation (i.e. through the collection of the in-situ data, interpretation of the satellite-based findings, evaluation of causal processes) and their participation in the assessment of the utility of the services is critical to reaping all the benefits of the on-going collaboration.

The Bank as one of the world's largest sources of development assistance can catalyze and support the flow of the specialized EO know-how to the end-users in developing nations, thus helping to build local capacity in utilizing Earth Observation technology. Capacity-building and user training in the **eoworld** projects was highlighted by ESA's active involvement in the "Western Indian Ocean Marine Highway Development and Coastal and Marine Contamination Prevention project" Steering Committee

meeting in Johannesburg in June 2011. The objective was to set up the operational early warning system for real-time oil spill detection in the Mozambique Channel. As a result, representatives of the eight participating countries (South Africa, Seychelles, Comoros, Mauritius, Madagascar, Mozambique, Kenya, Tanzania and Réunion (France) were given full access to the oil spill information portal and were trained on the portal's usage and the transfer of this information to their respective national operation centres. The early warning system is triggered automatically, providing the marine polluter's non-ambiguous identification, and it is receiving a very positive feedback from the African national maritime authorities.

In this case, ESA contributed to the World Bank operation with its more than 10 years of operational experience in working together with multiple European national Coast-Guard agencies. This is the first time such system has been introduced to the Africa region, the Western Indian Ocean being currently the only marine area besides European waters where such state-of-the-art satellite tools are being implemented.

The Utility Assessment

The EO services being applied to the 12 Bank projects are examples of currently available, mature and previously well validated information products with known, documented performances and constraints.

The final phase of the **eoworld** projects will focus on the assessment of their utility based on the users' feedback regarding the ease of use, fitness for purpose, and direct benefits and costs in comparison to alternative sources of information. The objective is to evaluate the availability, usefulness, reliability and affordability of the EO services as delivered, to gather recommendations for improvements, to capture additional requirements and to estimate prospects for wider use of EO across a greater number of Bank operations in these and other sectors.

Each of the projects will be concluded with the delivery of the complete portfolio of its outputs, followed by a Final Report describing main activities and results achieved. In addition, ESA and the World Bank will produce a joint overall World Bank-ESA report meant for wide circulation to record in detail the outcomes of all of the twelve projects, assess their results and lessons learned,

in view of establishing the baseline for the wider adoption of EO services in World Bank operations.

Moving Forward

The World Bank with its global programs on sustainable natural resources management, agriculture, food security, ecosystems services, urban development, energy, water, disaster risk reduction, climate change and so on, can obtain significant benefits from the stream of comprehensive EO-based information for better informed decision-making.

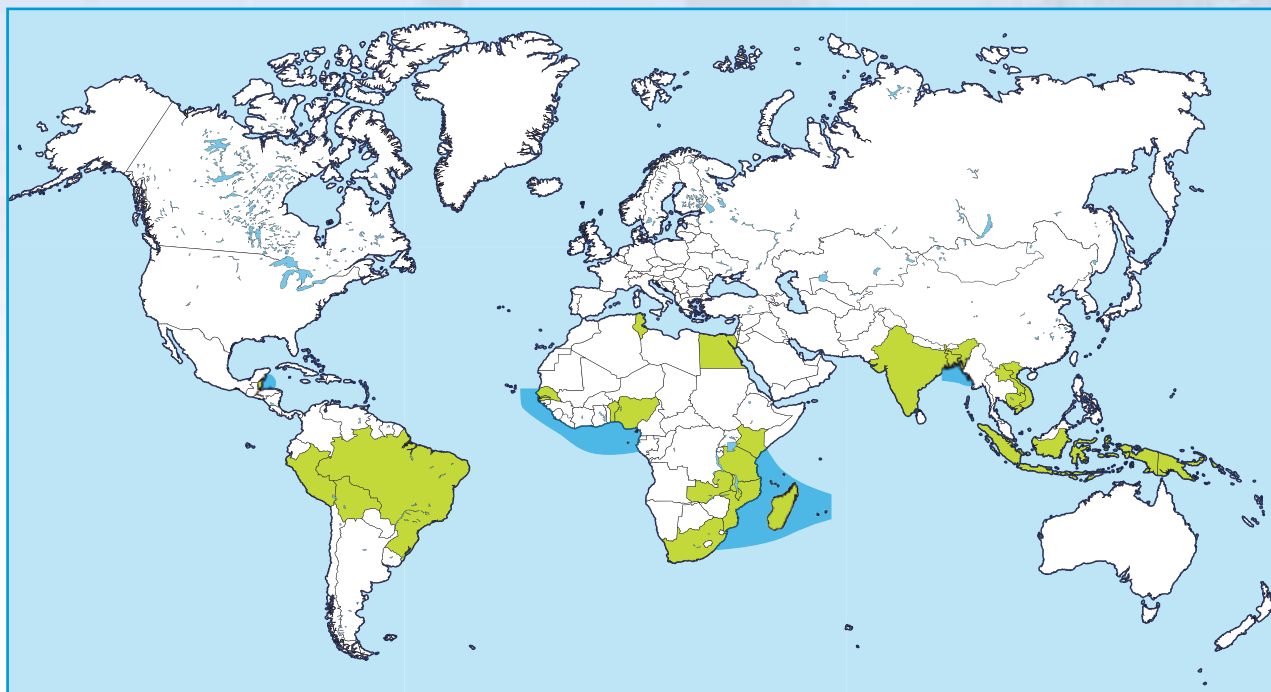
For the period of 2011-2013 ESA and the World Bank agreed to work together with the purpose of consolidating this EO information delivery network beyond the initial technology demonstration phase. A range of capacity-building and awareness raising activities is being planned, including sharing know-how and relevant technical expertise, facilitating access to existing ESA EO tools (EO data and products) and launching a dedicated dialogue in the disaster risk management and climate change adaptation domains.

The next ESA-World Bank event is planned to take place during the World Bank Sustainable Development Network Week in February 2012. More information on the program can be found at www.worldbank.org/earthobservation.

Table 1: World Bank projects description

Theme	Region	Project Title	E0 Products/Services
Urban risk management	Latin America Caribbean	Assessing Vulnerability in the Metropolitan Area of Rio de Janeiro	DEM-derived slope maps, Urban mapping of infrastructure & buildings, Flood risk analysis, Land motion mapping and analysis
Urban risk management	Latin America Caribbean	Building Flood Defence Systems in Guyana	Land motion mapping, Urban mapping of infrastructure & buildings
Urban risk management	East Asia Pacific	Multi-Hazard Vulnerability Assessment in Ho Chi Minh City and Yogyakarta	Land motion mapping and urban mapping of infrastructure & buildings, geo-hazard risk analysis
Disaster risk management	East Asia Pacific	Building Exposure Maps of Urban Infrastructure and Crop Fields in the Mekong River Basin	Urban mapping of infrastructure & buildings enhanced by in-situ data collected in the field, Crop mapping (crop type and acreage)
Urban risk management	East Asia Pacific	Analysis of Land Subsidence in of Jakarta	Land motion mapping and analysis
Water resources management	Africa	Watershed Mapping for Water Resources Management in the Zambezi River Basin	Small water bodies mapping, Water quality, Temperature & water level, Soil erosion analysis
Water resources management	Latin America Caribbean	Monitoring of Water Quality and Land Use Changes in the Lake Titicaca Basin	Water quality monitoring, Land use & land change mapping
Coastal zone management	Africa	Monitoring of Coastal Vulnerability and Coastal Change Trends in West Africa	Coastal change maps, Sea-level height & ocean currents
Marine environment management	Africa	Monitoring of Environmentally Sensitive Areas in the Mozambique Channel	Oil spill detection & polluter identification, Coral reef health status & evolution
Urban development	South Asia	Historical Assessment of Spatial Growth of the Metropolitan areas of Delhi, Mumbai and Dhaka	Land cover mapping
Agriculture and Rural Development	East Asia Pacific	Sustainable Oil Palm Production in Papua New Guinea	Forest mapping, Land cover mapping
Forestry	Africa	Forest Resources Management in Liberia	Forest mapping, Land cover & terrain mapping and analysis
Climate Change Adaptation	Middle East and North Africa	Climate Change Adaptation and Natural Disasters Preparedness in the Coastal Cities of North Africa	Land motion mapping and analysis
Climate Change Adaptation	Latin America Caribbean	Adaptation to Climate Impacts in Coastal Zones in the Caribbean: Monitoring of Coral Reefs in Belize	Coral reef health status & evolution
Climate Change Adaptation	South Asia	Monitoring of the Coastal Change Trends in Bangladesh	Coastal change maps

World Bank projects: geographic location



Sustainable Development Network themes, World Bank regions and Country Offices involved

Sustainable Development Themes

- Disaster Risk Management
- Urban Risk Management
- Urban Development
- Water Resources Management
- Environment and Natural Resource Management
- Agriculture and Rural Development
- Forestry
- Marine Environment & Coastal Zone Management
- Climate Change Adaptation

World Bank Regions

- Sub-Saharan Africa (AFRICA)
- Middle East and North Africa (MENA)
- South Asia (SA)
- East Asia and the Pacific (EAP)
- Latin America and Caribbean (LAC)

World Bank Country Offices

- South Africa (Pretoria)
- Indonesia (Jakarta)
- Liberia (Monrovia)
- Papua New Guinea (Sydney)
- Zambia (Lusaka)
- Senegal (Dakar)

Assessing Vulnerability in the Metropolitan Area of Rio de Janeiro

Users

World Bank Unit:
Urban, Water and Disaster Risk
Management Sector Unit, Latin
America and the Caribbean Region

Local Stakeholders:

- Rio de Janeiro State, Secretariat of Public Works (SEOBRAS)
- Fundação CEPERJ Centro Estadual de Estatística, Pesquisa e Formação de Servidores Públicos do Rio de Janeiro)
- Fundação GEO-RIO for landslides (Instituto de Geotécnica do Município do Rio de Janeiro)
- Rio-Águas for floods (Subsecretaria de Gestão das Bacias Hidrográficas)
- Geological Survey of Rio de Janeiro State (DRM/RJ)
- Rio State Institute of Environment (INEA)

EO services provided

DEM-derived slope maps, urban mapping of infrastructure & buildings based on VHR Optical data (1:10 000 scale) complemented with Digital Elevation Model (DEM) generated using VHR Optical data

Additional analysis:

- 1: Flood simulation product based on land use data, DEM and historical meteorological data
- 2: Landslide susceptibility mapping based on interferometric terrain deformation technique using Synthetic Aperture Radar (SAR) data

Service Providers

Flood risk:

- Critical Software (Portugal)
- NOA (Greece) • Hidromod (Portugal)
- INPE [Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)] (Brazil)

Landslide risk:

- NEO (The Netherlands)
- Hansje Brinker (The Netherlands)



Context

The World Bank's Rio de Janeiro Metropolitan Urban and Housing Development Program is currently supporting the State Government of Rio de Janeiro (GORJ) in the strengthening of its policies for planning and managing territorial growth in the Rio de Janeiro Metropolitan Region. Rio de Janeiro is at a critical juncture of its urban development. Multiple, large scale investments in transportation systems and infrastructure are currently being planned to prepare the city for the 2014 World Cup and the Summer Olympic Games of 2016. At the same time Rio has been found increasingly vulnerable to rainstorm-related disasters aggravated by urban and illegal sprawl. In 2010 the heavy rain combined with a tidal surge resulted in catastrophic floods and devastating mudslides affecting low-lying neighbourhoods and slums built on steep, unstable hillsides. Over two hundred people perished while Rio suffered significant economical losses. Right now, one of the World Bank Program's priorities is to address the need for planning, preparedness and risk reduction measures concerning hydrological and geological hazards.

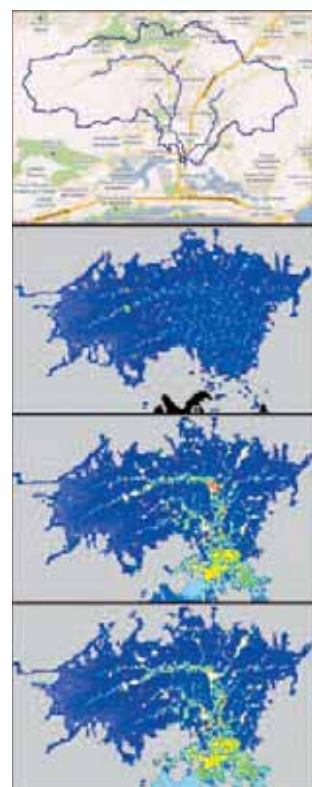
EO contribution

The aim of the EO services provided in this project is to contribute to disaster risk management in the Rio Metropolitan Region. They are focused on three elements:

- detailed and up-to-date land use information concerning Rio's infrastructure and housing, including slope maps,
- landslide susceptibility analysis through interferometry techniques which allows for monitoring of millimetre and centimetre scale deformations in sloping terrain that can be an early indicators of a landslide threat, and
- flood scenarios based on selected past flood events occurring in Rio.

The products can be used to delineate vacant lands and under-utilized spaces as well as industrial areas that can be redeveloped or used for infill. This will allow for new housing development while mitigating risk of settlement pressure in hazard prone areas.

The urban mapping service is primarily based on the exploitation of Very High Resolution (VHR) satellite imagery - SPOT5 optical data at 2,5m resolution - and existing orthophotomaps. Slope maps are based on High Resolution Digital Elevation Model (High Resolution SPOT 3D DEM) derived from SPOT5 stereoscopic acquisitions. The flood scenarios are based on land use maps combined with historical meteorological data, information about past flood extent and inundation levels and rainfall-runoff/water intrusion models based on SPOT 3D Digital Elevation Model.

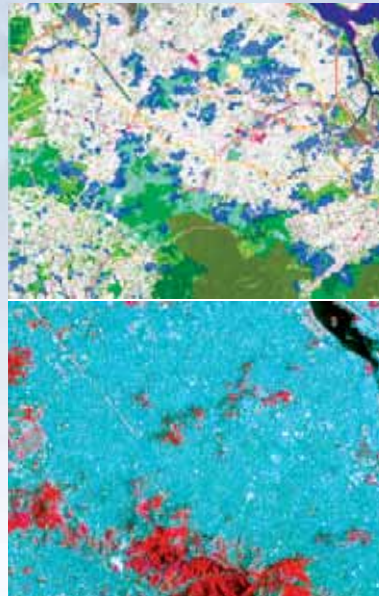


First results

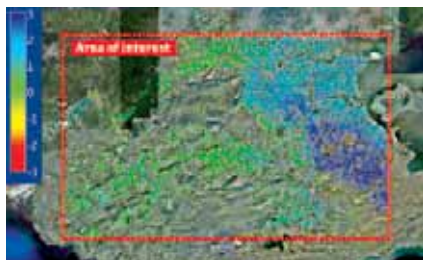
The historical flood scenario showcased in Figure 2 is based on the flood event which occurred in southern part of Rio on the 24th of December 2001. The flood simulation within the Rio Grande and Rio Anil watersheds were computed for three different situations: for a pristine situation (where there are no urban areas), for the current land cover, and for the hypothetical scenario where there are more urban areas added up the stream of the watersheds (e.g. to the lower parts of the hills).

These scenarios (provided by the consortium led by Critical Software) allowed for a better understanding of the different impacts of the same flood event when facing different land cover status. For example, the consortium took into consideration the possible introduction of a new legislation by the Brazilian authorities concerning land cover, which defines which areas at hilltops must remain forested. Moreover, the data provided by these simulations allows for an immediate understanding of the consequences of land cover changes when assessing the amount of people affected by the floods and the amount of time available for the civil protection authorities to respond to the emergency. This information can be extremely useful in formulating disaster prevention strategies i.e. by adding green and recreational areas where the most vulnerable assets are located.

The consortium has also found that 9% of the analyzed area is covered with isolated structures, mineral extraction, herbaceous vegetation or bare soil. After analyzing other constraints such as flood and landslides risks, it was concluded that these areas could possibly be converted to other land uses (new housing development, redevelopment, etc.).



3



4

The images in Figure 3 and Figure 4 represent preliminary results of the land use and land motion mapping product to be provided by the consortium led by NEO. The landslide susceptibility mapping product will be based on the combination of the DEM-derived slope map, urban map (Figure 3), soil data and an additional layer of land motion information generated using a Persistent Scatter Interferometric (PS-InSAR) technique by processing of the archived Synthetic Aperture Radar (SAR) data, such as ENVISAT, ERS and ALOS (Figure 4). After initial processing of the SAR images, the results indicate clear seasonality of land movement which has to be resolved before other deformations (such as landslide threat) become visible. For this reason a time series of ALOS images will be used in addition to ESA's ENVISAT data.

Urban risk management

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 America and the Caribbean Region
 The World Bank Group

Fig.1 The slopes on a hills where a landslide occurred in Nova Friburgo and Tersepolis, north of Rio de Janeiro, Brazil, on January 13, 2011
 © AFP Getty Images.

Fig.2 A snapshot of a flood scenario simulation in the southern part of Rio de Janeiro.
 Credit: Critical Software.

Fig.3 Land use classification,
 Credit: NEO, SPOT5 image data
 © CNES/Spotimage.

Fig.4 Preliminary results of the terrain deformation.
 Credit: Hansje Brinker, ENVISAT
 image data © ESA

Users

World Bank Unit:
Urban, Water and Disaster Risk
Management Sector Unit, Latin
America and the Caribbean Region

Local Stakeholders:
Guyana national disaster preparedness
and emergency management sector

EO services provided

- PS-InSAR mapping/monitoring of
historical terrain deformations based
on VHR SAR data
- Urban mapping of infrastructure &
buildings based on VHR Optical Data
(1:10 000 scale)

Additional analysis:

- 1: High resolution Digital Elevation
Model (DEM) based on VHR SAR data
- 2: Sea level height
- 3: Past Flood Analysis

Service Providers

- Altamira Information (Spain)
- Eurosense (Belgium)

Building Flood Defence Systems in Guyana

Context



1

The World Bank is currently implementing a Conservancy Adaptation Project with the objective to reduce the vulnerability to catastrophic flooding in Guyana's low-lying coastal areas. Guyana has repeatedly experienced a number of damaging floods in the past: frequent and violent storm surges and the threat of sea level rise brought to light the need for strengthening of the national sea and flood defenses consisting of dikes, drainage canals, seawalls, and sluices.

The main objective of the EO services incorporated into this World Bank project is focused on the estimation of a potential land subsidence in the coastal lowland of Guyana, in particular the state of the old dyke system along the East Coast Demerara

and the stability of the seawall located in the capital city - Georgetown. The terrain deformation study is complemented with up-to-date digital urban reference mapping.

EO contribution

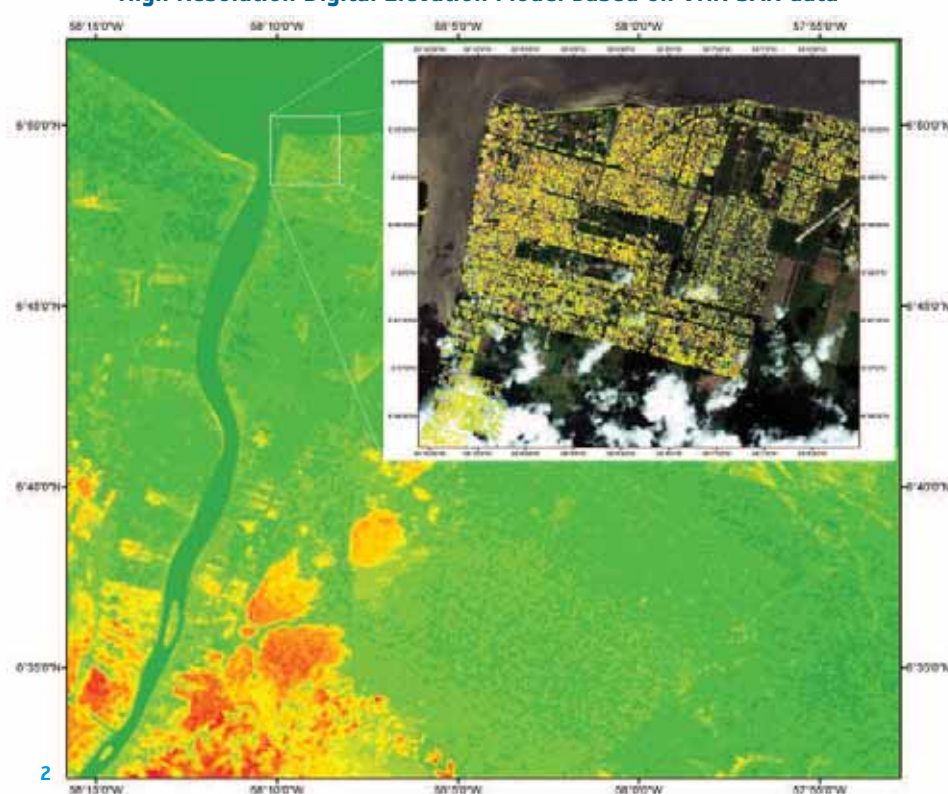
Land motion mapping is conducted using SAR interferometry which allows the detection of terrain movement rates of a few millimetres per year. Good spatial coverage and high density of measurement points is ensured by exploiting Very High Resolution (VHR) TerraSAR-X radar data. These measurements are complemented with an urban mapping product which is built on existing ancillary and VHR Optical Data at the scale of 1:10 000. The urban map will give an up-to-date spatial view of the distribution of urban infrastructure and can be used to support urban planning. An additional input product is a high-resolution

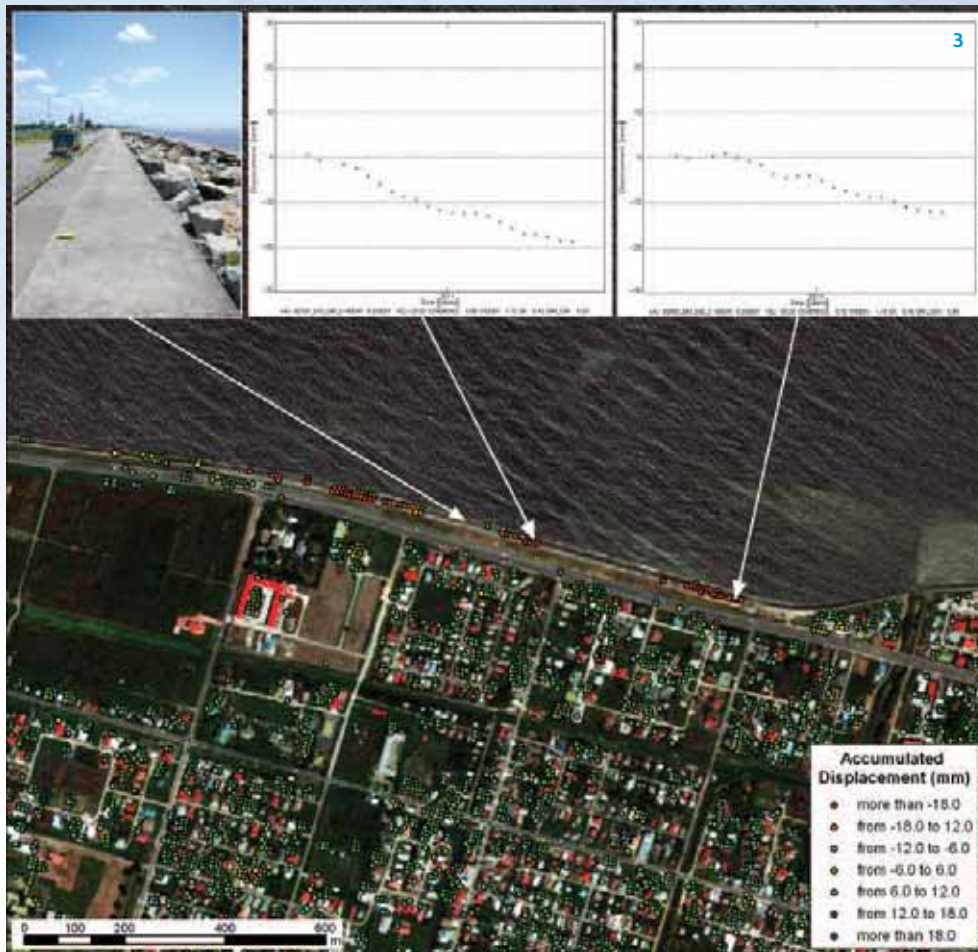
Digital Elevation Model based on VHR SAR data which can later contribute to rainfall-runoff/water intrusion modelling (Figure 2).

Urban mapping is based on data acquired between November 20th, 2009 and September 29th, 2010 over the Guyana's coastline spreading from Georgetown to Enmora and covering a total area of 402 km². It provides fourteen thematic classes including water supply infrastructure, sea walls and flood defences treated as individual thematic class (such as dams, dikes, irrigation and drainage canals, ponds, breakwaters, piers, jetties, including the roads, embankments and associated land) (Figure 3).

The land motion measurement points are overlaid on the urban map, measuring the accumulated displacement rates (in mm) over the 8 month period of project implementation, as shown in Figure 2.

High Resolution Digital Elevation Model based on VHR SAR data





Urban risk management

ESA Technical Officer

Philippe Bally

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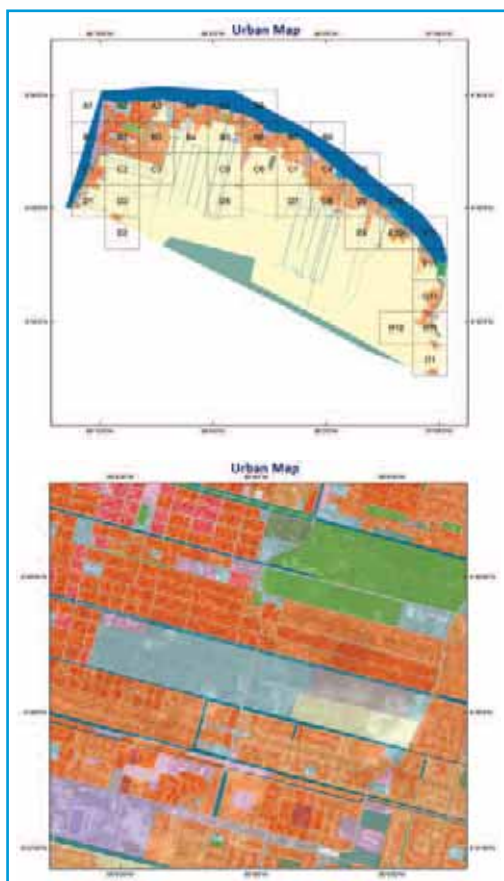
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 The World Bank Group



First results

The study area is quite stable as a whole and does not show any large scale deformation. However the eastern part of the Georgetown seawall shows some instability with accumulated motion up to 20 mm over the 8 month time period. Some other parts of infrastructure also show motion of varying magnitude. Some large-scale deformation patterns have been detected in rural areas. However those areas show zones of fast motion and sudden changes where EO techniques have limitations.

The complete PSInSAR/urban mapping analysis will be available to the World Bank in the Q4 2011 timeframe.

Fig.1 Seawall in Guyana

© World Bank

Fig.2 The maps represent a high resolution DEM generated combining SRTM and the precise height information derived from the PSI analysis of the TerraSAR-X data. In Georgetown and along the Demerara the map has a pixel size of 9x9m and provide vertical height precision of 2m.

Credit: Altamira Information, TerraSAR-X data

© DLR/Infoterra 2011, SRTM DEM 90 m © USGS 2011

Fig.3 Preliminary result of the accumulated terrain deformation derived from the analysis of TerraSAR-X data acquired over 09/2010/ - 04/2011.

Credit: Altamira Information, TerraSAR-X data

© DLR/Infoterra 2011

Fig.4 The inventory of urban functional areas within the 30 km strip of the Guyana's coastline. Difference is made between industrial, commercial, residential and other infrastructure types. The product is derived from GeoEye and Ikonos data.

Credit: Eurosense, EO data

© GeoEye

Users

World Bank Unit:
Urban, Water and Disaster Risk
Management Sector Unit, East Asia
and the Pacific Region

EO services provided

- Urban mapping of infrastructure and building inventories based on Very High Resolution (VHR) Optical data (1:10 000 scale)
- Historical mapping of terrain deformations based on interferometric technique using Synthetic Aperture Radar (SAR) data

Additional analysis:

- 1: Precise Digital Elevation Model (DEM) generated using VHR Optical data providing building height for an enhanced urban mapping
- 2: Multi-hazard vulnerability mapping addressing the risks of subsidence and flooding
- 3: Flood risk analysis (past flood mapping, flood hazard mapping and flood risk assessment)

Service Providers

- Altamira Information (Spain)
- Eurosense (Belgium)
- Center for Environmental Engineering (Vietnam)

Fig.1 HCMH false colour SPOT5 imagery (2,5m) taken on 14/02/2011 © CNES/Spotimage

Fig.2 Urban maps of Ho Chi Minh City based on false colour SPOT5 imagery (2,5m) taken on February 14th, 2011. Credit: Eurosense, Image data © Spotimage

Fig.3 Digital Surface Model of Ho Chi Minh City (input data SPOT5 stereo pair (5m resolution) acquired on 10/03/2008 and 16/03/2008). The high-rise buildings can be clearly identified from the preliminary DEM results (illustration at scale 1:10000). Produced area: 660 km². On going work includes manual corrections and filtering. DSH data © Spotimage

Multi-Hazard Vulnerability Assessment in Ho Chi Minh City and Yogyakarta

Context

The World Bank is currently performing a study to better quantify the exposure of East Asian cities to climate change and disaster risks. The project aims to build a Multi-Hazard City Risk Index (MHCRI) with the objective to help local policymakers to assess their cities' susceptibility to climate change and other disasters' impacts over time and relative to other cities. While contributing to this study the project team looks in particular at hydro-geological hazards (such as subsidence) in two South East Asian cities: Ho Chi Minh City in Vietnam and Yogyakarta in Indonesia.



EO contribution

The EO contribution is based on four products:

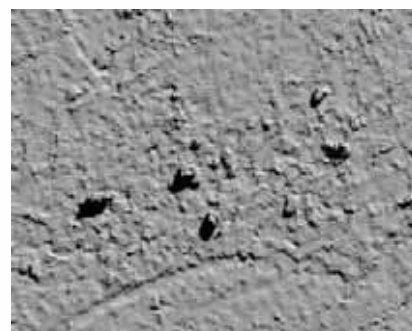
- up-to-date urban mapping of infrastructure and building inventories based on Very High Resolution (VHR) Optical Data,
- historical mapping of terrain deformations based on interferometric technique using Synthetic Aperture Radar (SAR) data,
- 3D Digital Elevation Model, Digital Terrain Model and Digital Height Model based on High Resolution SPOT5 stereoscopic acquisitions exploring SPOT5 imagery, and
- EO-derived Flood Risk Analysis on the basis of historical events.

Figure 2 shows an overview map of Ho Chi Minh City based on false colour SPOT5 imagery (2,5m) acquired on February 14th, 2011. The total area covered by the service is 660km².



Precise land subsidence mapping products are provided by exploiting long-time span data from ENVISAT and ALOS satellites using Persistent Scatterer InSAR (PS-InSAR) (Figure 5 and Figure 6). In addition, the team is providing a Past Flood Analysis combining information concerning past flood events (including information on maximum flood extent, water depth, water direction and velocity based on archived radar ERS and optical SPOT4 data) with risk scenarios supported by the up-to-date urban inventory (Figure 3).

Flood risk analysis will be done for Ho Chi Minh City, based on the flood event of 2001. 3D Digital Elevation Model exploring SPOT5 imagery will contribute in both cases to rainfall-runoff/water intrusion modelling (Figure 3). For Yogyakarta a flood simulation will focus on to the eruption of the Merapi volcano in October 2010 which combined with a rainfall intensity of more than 50mm/h during a La Niña occurrence caused a subsequent mud-flow of debris, called cold lava floods (lahars).



Urban risk management

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The World Bank Group

First results



The map in Figure 5 represents the evolution of terrain deformation in HCMH between 1996 and 2010, derived from the analysis of ERS and ENVISAT data. The results are overlaid on a SPOT 5 image acquired on February 14th, 2011. Motion is mainly visible at the location of the water pumping stations and wells. District 1, at the center of the image, is affected by annual subsidence rates of more than 20mm/year as a consequence of the rapid urbanization and high rates

of ground water exploitation. District 6, in the south west of HCMC, shows high magnitude subsidence patterns, they are also the results of the rapid increase of the ground water use in industrial districts.

The agglomeration of Yogyakarta shows relative stability (snapshots of the map in Figure 6). Nevertheless the south of the city is affected by a low magnitude large scale subsidence pattern (up to -7.0 mm/year). This subsidence is related to the earthquake that affected the area on May 27th, 2006 causing heavy damages in terms of buildings and other in-

frastructure, especially in the sub-districts of Kotagede, Umbulharjo, Mergangsan, Mantrijeron, and Gondokusuman. In the period from 2007 to 2011, the measurements have been also extracted in the rural areas surrounding Yogyakarta City. In particular, landslides of more than -7.0 mm/year have been detected in the Pleret sub-district.

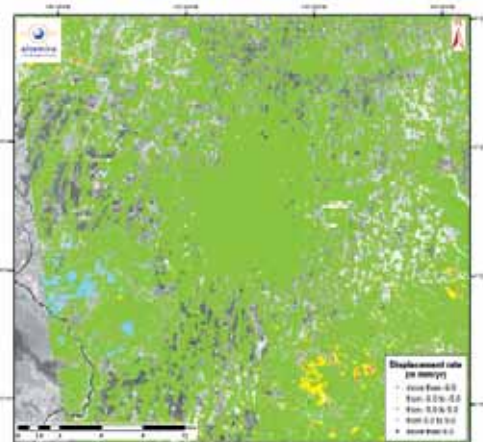
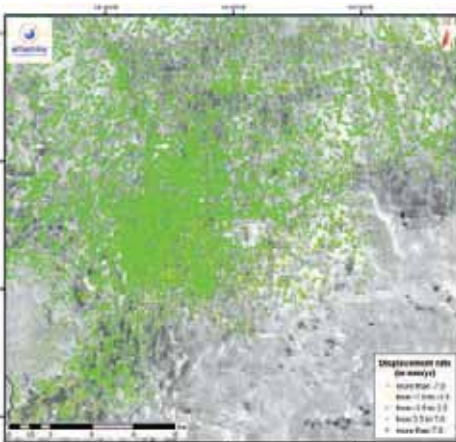
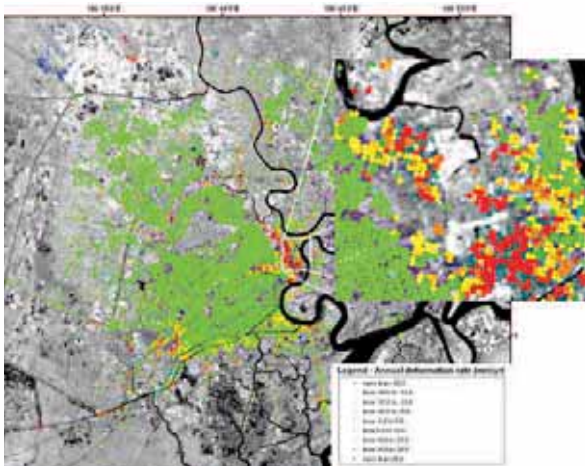


Fig.4 Example of a past flood map.
Credit: Eurosense.

Fig.5 Terrain Deformation measurements in HCMH City based on the PSI analysis of ERS and ENVISAT ASAR data (1996-2010). The results are overlaid on a SPOT 5 multispectral image acquired on Feb. 14th, 2010.

Credit: Altamira Information, ENVISAT ASAR image data © ESA

Fig.6 Terrain Deformation measurements in Yogyakarta based on the PSI analysis of ALOS (2006-2011) and ENVISAT ASAR data (2003-2009). The results are overlaid on a SPOT5 multispectral image acquired on May 18th, 2008. Credit: Altamira Information, ENVISAT ASAR image data © ESA, ALOS data © JAXA

Users

World Bank Unit:
Urban, Water and Disaster Risk
Management Sector Unit, East Asia
and the Pacific Region

Local Stakeholders:

- Mekong River Commission
- Cambodia's National Committee for
Disaster Management (NCDM)

EO services provided

- Urban mapping of buildings and
infrastructure based on Very High
Resolution (VHR) Optical data and
enhanced by in-situ data collected in
the field
- Crop types and acreage mapping
based on Synthetic Aperture Radar
(SAR) data

Additional analysis:

Historical flood and drought hazard
mapping

Service Providers

GeoVille (Austria)

Building Exposure Maps of Urban Infrastructure and Crop Fields in the Mekong River Basin

Context

For many years the World Bank has played a major role in the development of integrated water resources management (IWRM) in the Mekong River basin and administered several WRM projects in the region. One objective of the ongoing Mekong IWRM initiative at the Bank is to build national and regional capacities for managing the risks associated with natural disasters, such as floods, flash floods and droughts. An open-source multi-hazard modelling tool is planned to be developed for risk assessment in the Lower Mekong River Basin. It would be used in planning, disaster preparedness and emergency management by the Basin national stakeholders as well as by insurance and financial institutions involved in reducing the impacts of disaster risks. As a contribution to this initiative EO techniques can provide objective and synoptic observations of elements at risk (exposure data) including buildings and infrastructure, and crops (primarily rice).

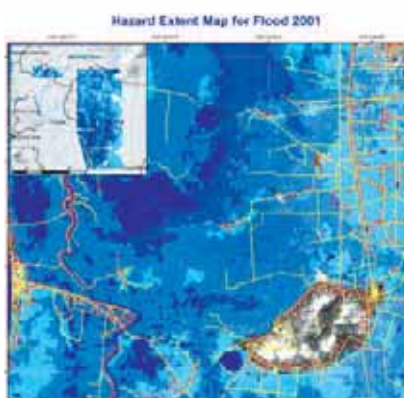
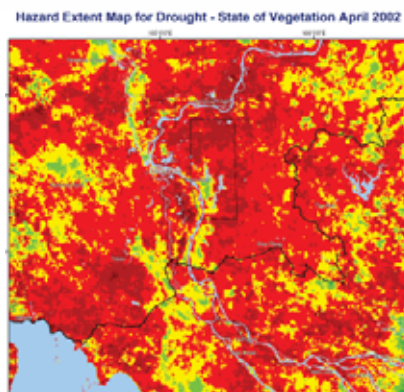
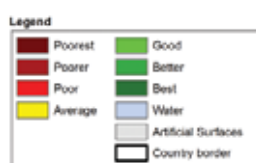


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EO contribution

To characterize at-risk elements, the service integrates data from satellite imagery, field surveys and local knowledge. The fusion of space-based and in-situ data is expected to fill in the gaps of EO observations, enhance accuracy of the service and validate results.

Very High Resolution (VHR) optical data from SPOT5 (2,5m), Kompsat-2 (1m) and Quickbird (1m) are used for mapping and classification of buildings and infrastructure potentially exposed to risks (residential, commercial, industrial buildings, main infrastructure, other public assets). Figure 2 represents sample results of this classification showcasing land use patterns and building types.



1

A key input to this work is data collected by the project team in the field with the purpose of scoping information about buildings including footprints, material, location, height (number of stories), structure type, load bearing structure system, construction technique, floor area, distance from building to building as well as building count. High Resolution SPOT-based Digital Elevation Model is additionally generated to provide surface elevations of vegetation and man-made objects with a vertical accuracy of 10m. By using this methodology thousands of buildings and infrastructure features are mapped clearly indicating the location and characteristics of the assets.

EO is also used to provide information concerning crop type and acreage. This involves mapping of rice cultivation areas, identification of rice cropping system (wet-season vs. dry season), crop cycles (single /double / triple crop per year), date of emergence/harvest and the distinction between rice planted under intensive (SRI) vs. regular rice cultivation techniques. Figure 3 is an example of rice acreage and seasonal cultivation patterns mapping where the dense temporal sampling with all weather radar imagery allows for continuous monthly moni-

Fig.1 Mapping of historical flood and drought events. Credit: Geoville, data © SPOT and NOAA

toring of rice cultivation areas. Crop mapping is mainly based on ENVISAT-ASAR acquisitions programmed to cover a period of 9 months in 2011, complemented with optical SPOT5 and ALOS-AVNIR data. New satellite data from TerraSAR-X satellites will also be integrated to demonstrate the utility of Very High Resolution (VHR) radar sensors.

Exposure maps will be complemented with the analysis of historical flood and droughts using ERS-2 scenes concerning historical flood events alongside with vegetation index data from SPOT VEGETATION or NOAA-AVHRR concerning drought events (Figure 1).

First results

The service provided a comprehensive building and infrastructure inventory with over 110,000 buildings and 3,200 km of road network mapped. The first results indicated the predominant rural settlement structure of the project area.

More than 80% of the area is cropland and other vegetated land. Only 5 % of the area used for settlements and 1% of land for transport infrastructure. 86% of the buildings are small structures with a ground area of less than 100m², and 90% of the settlement area is characterized mainly by low-density stilt-houses with 2 stories and a distance of less than 100m distance to a road to prepare for regular floodings.

79% of the settlement area and 88% of the road network are threatened by high-water levels in case of a severe flood similar to the 2001 event. More than 90% of the cropland would be threatened by high water levels. 99% of the cropland was exposed to the 2002 drought for a period of at least 1 month, and almost 50% of cropland was under heaviest drought conditions at the drought peak in April 2002.

The team has also documented a doubling of rice cultivation areas from dry- to wet-season based on the bi-weekly monitoring of cropland.

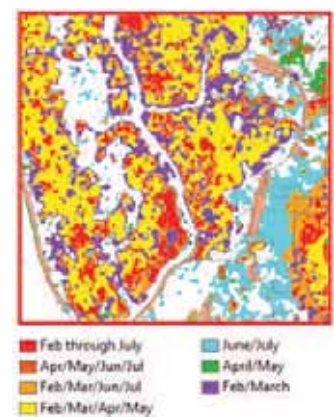
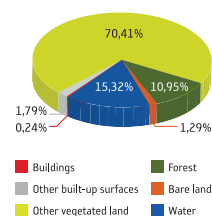
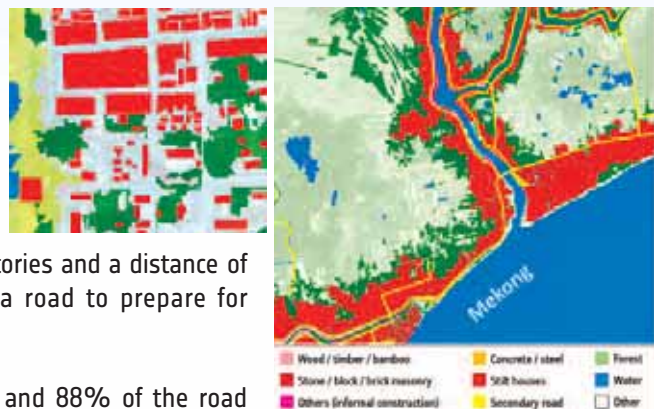


Fig.2 Mekong - Urban land use and building types – Preliminary results.

Credit: GeoVille, EO data
© CNES/Spotimage

Fig.3 Mekong - Rice acreage and seasonal cultivation patterns – Preliminary results.

Credit: GeoVille, ENVISAT ASAR image data © ESA

Disaster risk management

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Users

World Bank Unit:
World Bank, Indonesia Country Office
(Jakarta)

Local Stakeholders:
DKI local government of Jakarta

E0 services provided

PS-InSAR mapping/monitoring of
historical terrain deformations based
on VHR SAR (Cosmo-SkyMed) and
other SAR data (ALOS PALSAR)

Additional analysis:
Thematic analysis of the causes of
possible land deformation over
Jakarta

Service Providers

- Altamira Information (Spain)
- ITB Bandung Institute of Technology
(Jakarta - Indonesia)

Analysis of Land Subsidence in Jakarta

Context

World Bank studies conservatively estimate that land subsidence in Jakarta is occurring at an average rate of 5 cm per year. Other recent studies found that subsidence rates can reach 7.5-10cm a year and that in localized areas of north Jakarta, terrain deformation occurs at even greater rates. If sustained this would result in some areas of Jakarta sinking to 4 to 5 meters below sea level by 2025.



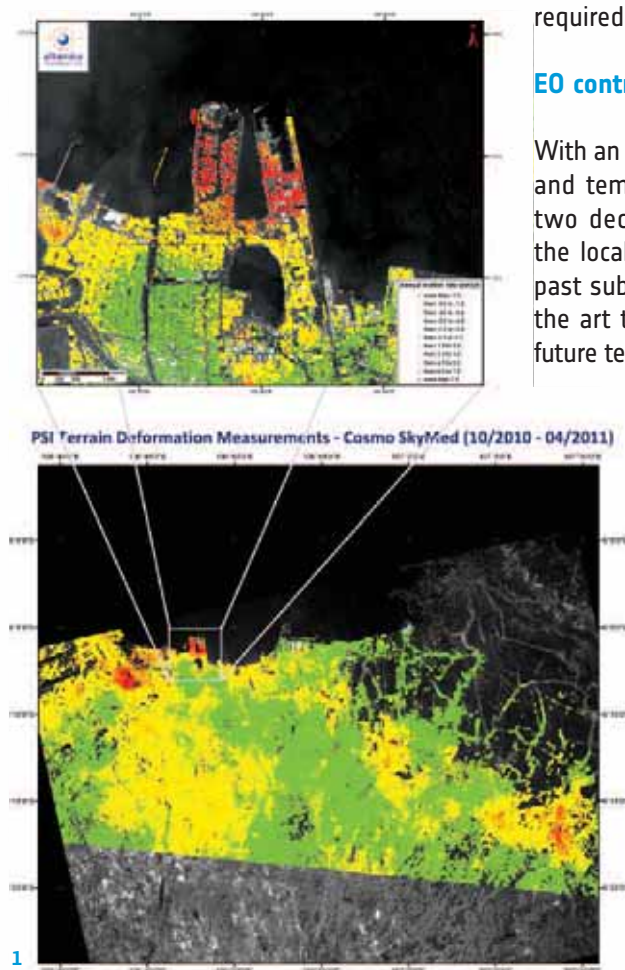
© World Bank

The prevalence of land subsidence patterns is causing serious concern to local government. Terrain deformation threatens local communities with increased flooding by distorting gravitational flow capacity. Moreover, the risk of increased sea water intrusion and tidal flooding puts Jakarta's population in a very vulnerable position since 40% of Greater Jakarta's area (which is inhabited by 28 million people) lies below the sea level. To remedy this situation some major interventions are currently being considered by Jakarta Provincial Government (such as increased pumping, dikes revitalization and introducing major new infrastructure investment for sea defense). In this context the World Bank is preparing the Jakarta Urgent Flood Mitigation Project (JUFMP) which is aiming to contribute to the rehabilitation and maintenance of Jakarta's flood management system. However, while impacts of the land subsidence phenomena in Jakarta are known to the public, there is still a need to better understand its causes and patterns to more accurately plan the required mitigation measures.

E0 contribution

With an archive of imagery with good spatial and temporal coverage spanning the past two decades, Earth Observation can offer the local government a unique insight into past subsidence trends as well as state-of-the-art tools for monitoring of present and future terrain deformations. Satellite imagery provides higher motion accuracy in comparison to traditional survey methods (e.g. leveling surveys, extensometer measurements, ground water level observations, GPS data) and a larger monitored area, which corresponds to the satellite image (40x50km² for Cosmo SkyMed and 70x100km² for ALOS PALSAR used in this project).

This project provides precise terrain motion mapping using Very High Resolution (Cosmo SkyMed) and High Resolution (ALOS PALSAR) radar sensor data through the Persistent



1

Scatterer Interferometry (PS-InSAR) technique. Figure 1 represents the map of deformation rates over Jakarta derived from 24 Cosmo-SkyMed images acquired over 6 months, between October 2010 and April 2011. While Cosmo-SkyMed allowed the detection of more PSI points with higher resolution, ALOS PALSAR (in Figure 2) measures motion of higher magnitude in case of stronger deformation patterns over the period of 4 years (2007-2010).

The second part of the project concerns the thematic analysis of the causes of land deformation (interpretation of the PSI results). This will be conducted in cooperation with the Bandung Institute of Technology, which has studied and analyzed land subsidence in Jakarta for more than 20 years.

First results

There are many subsidence patterns visible in Jakarta (i.e. Cengkareng), Jakarta Bay and the industrial zone of Cikarang.

The detected deformation rates in the subdistrict of Cengkareng in the west of Jakarta reach a subsidence of about -15 cm/yr, with accumulated subsidence of more than -60 cm over the 4 years. In the Jakarta Bay district of Penjaringan, where water draining channels, canals, and water reservoirs protecting the land from sea flooding are located, the maximal subsidence rate detected is more than -15 cm/yr, resulting in a deformation of more than -60cm over the period of 4 years. In Cikarang, the capital of Bekasi Regency and one of the biggest industrial estates in Southeast Asia, the detected deformation reaches -7.5 cm/yr. Those preliminary results demonstrate that SAR data is suitable for the detection and monitoring of ground motion in Jakarta.

A digital height model using Cosmo SkyMed interferometric data (with 5 m vertical and 9 m spatial accuracy) will be generated to enhance the analysis output and to support the modeling of rainfall-runoff/water intrusion.

Urban risk management

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PSI Terrain Deformation Measurements - ALOS PALSAR (2007-2010)

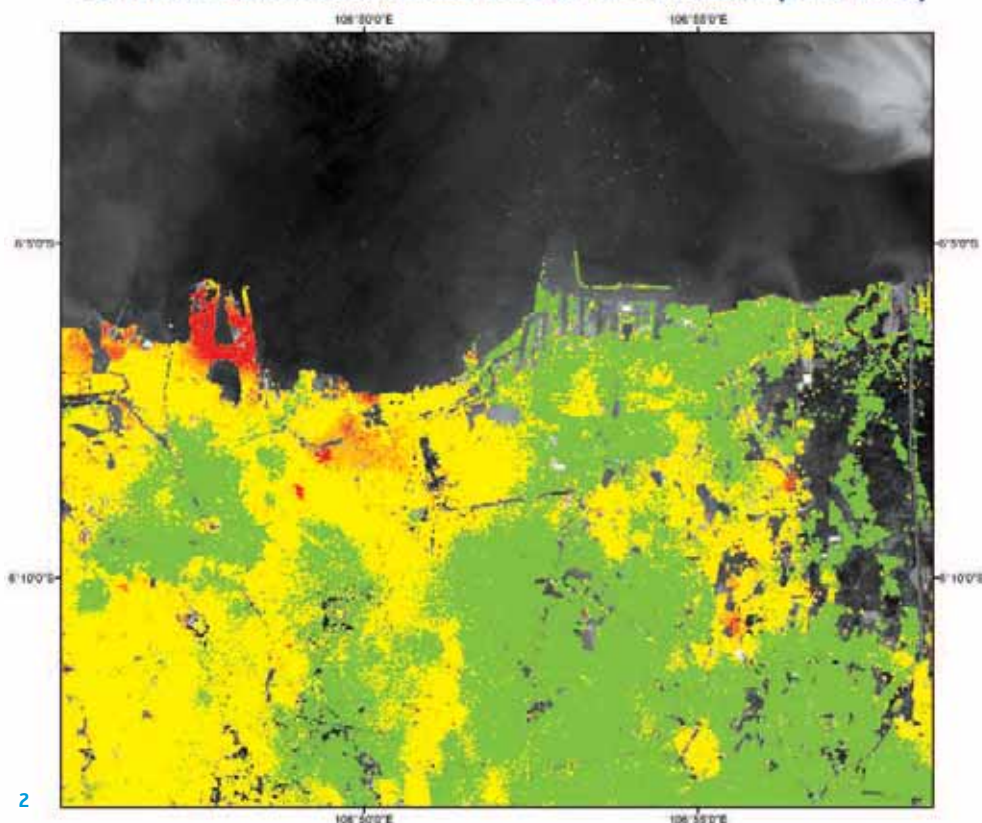


Fig.1 Terrain Deformation measurements using Cosmo-SkyMed data at 3m resolution (10/2010–04/2011-Preliminary results.

Credit: Altamira Information, Cosmo-SkyMED SAR data.

© ASI/e-GEOS.

These annual terrain velocity measurements results are overlaid on the SPOT5 multispectral image acquired on May 15, 2010. EO data

© CNES/Spotimage

Fig.2 Terrain Deformation measurements using ALOS PaALSAR data at 20m resolution (2007-2010) – Preliminary results: Credit: Altamira Information, ALOS PALSAR data © Jaxa. These annual velocity measurements are overlaid on the SPOT5 multispectral image acquired on May 15, 2010, EO data © CNES/Spotimage

Users

World Bank Unit:

- Environment and Natural Resources Management Unit, Africa Region
- Water Resources Management Unit, Africa Region

Local Stakeholders:

- World Bank Country Office in Lusaka, Zambia
- World Bank Country Office in Maputo, Mozambique
- World Bank Country Office in Lilongwe, Malawi

EO services provided

- Small-scale water bodies mapping based on SAR (Synthetic Aperture Radar) data to identify small (minimum 1ha) water bodies, reservoirs and lakes extensions and evolution over time
- Lake Malawi water quality products, including lake surface temperature as well as historical water level records
- Soil lost and erosion estimation using VHR Optical data (SPOT5)

Service Providers

- NEO (The Netherlands)
- Technical University of Delft (The Netherlands)
- Water Insight (The Netherlands)

Watershed Mapping and Water Resources Management for the Zambezi River Basin

Context

The World Bank has a diverse portfolio of investments supporting water resources planning and management in the Zambezi River Basin (ZRB). The Zambezi Basin plays a central role in the economies of eight countries—Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe. However, recent studies by the Bank indicate significant opportunities for increased productivity of the basin's resources through improved coordination and cooperative water resources management among all of the stakeholders. Moreover, the Zambezi River, which is one of the most diverse and valuable natural resources in Africa, is characterized by extreme climatic variability and is subject to a cycle of floods and droughts that have devastating effects on the people and economies of the region, especially the poorest members of the population. In this context the World Bank voiced the need for geo-spatial information to support sustainable watershed management activities and sees EO products as one of the solutions in seeking an innovative approach to prioritize its investments. This is particularly pertinent in Malawi, Zambia, and Mozambique where the Bank is involved with a significant upstream work.



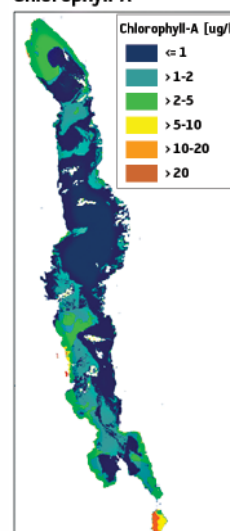
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EO contribution

The EO contribution to this project is focusing on:

- Supporting the development and management of water resources, such as through the promotion of smallholder irrigation, by mapping of small water bodies in the Southern Province of Zambia using combined satellite SAR (Synthetic Aperture Radar) and optical capabilities to provide a comprehensive overview of small reservoirs and their storage evolution over time,
- Supporting sustainable Lake Malawi/Nyasa/Niassa management by providing water quality monitoring based on full resolution multispectral data (i.e. ENVISAT-MERIS and AATSR; MODIS) including chlorophyll concentration, Total Suspended Matter (TSM) and Coloured Dissolved Organic Matter (CDOM), lake surface temperature as well as historical water level records,
- The assessment of environmental and anthropogenic stresses in Malawi's Shire river basin by providing soil erosion estimations using high-resolution imagery generated using VHR Optical data (SPOT5).

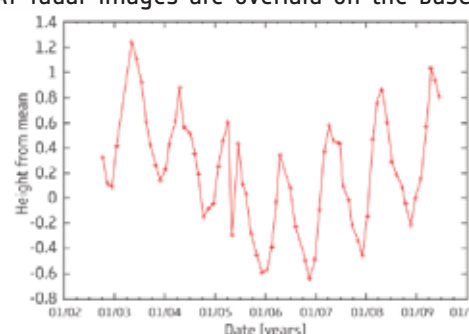
Lake Malawi Water Quality Chlorophyll-A



2

For small-scale reservoir mapping, the service explores the EO capabilities in evaluation of available water resources for 0.5 hectare reservoirs and higher. In order to be able to follow the development of the reservoirs' water storage over time, ESA's ENVISAT radar images are overlaid on the base map generated using optical imagery collected over the Southern Province of Zambia.

The main advantage of radar imagery is that it is not affected by cloud cover, thereby ensuring that frequent (>monthly) observations are possible. The disadvantage of radar imagery is that they are relatively "noisy", which makes delineation of small reservoirs more



3

Water resources management

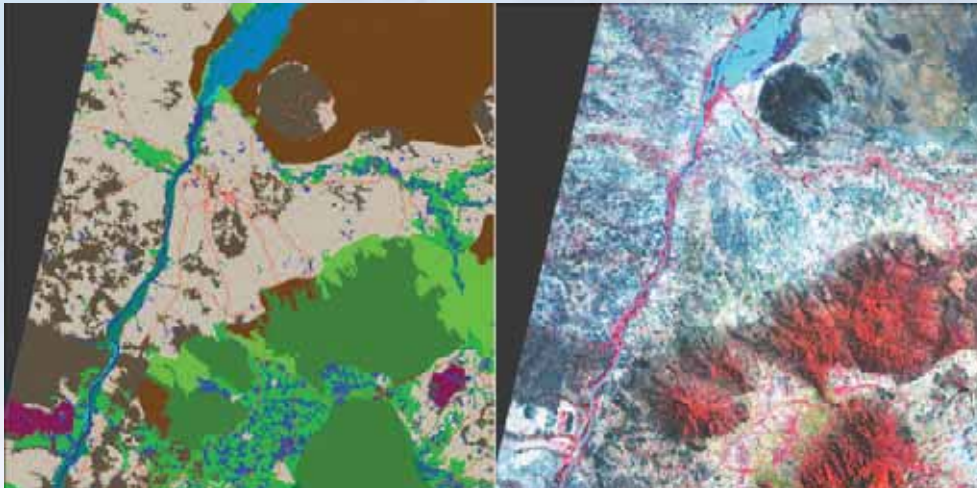
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 Senior Environmental Specialist,
 Africa Region
 The World Bank Group



difficult than with standard optical imagery. The solution provided to mitigate this problem is to use the base map to extract classification seeds as starting points for the extraction of reservoir outlines from the radar. The image in Figure 4 shows this methodology as applied to mapping of small-scale reservoirs with irrigated fields.

First results

For the mapping of water quality parameters of the Lake Malawi/Nyasa/Niassa, the service is focused on providing timely (twice per week) information about spatial and temporal distribution of nutrients and sediments flow into the Lake as well as water surface temperature (Figure 2). Near-real time information on the Lake water level using satellite-based altimetry with 10 cm vertical accuracy (based on ERS 2 ATSR SST data) is integrated into the final outputs (Figure 3).

The estimation of soil lost and erosion within Malawi's Shire river basin is done using SPOT5 acquisitions from the period 2005 to 2010. Satellite images are used to study the erosion hazards resulting from deforestation and exploitation of lands for pasture and agriculture, and their impact on the sediments load discharged to the Shire River. Resulting maps, as shown in Figure 4, will be used to determine erosion hazards due to land use changes.

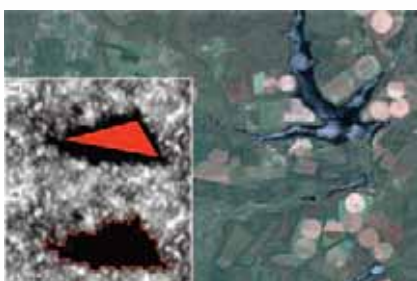


Fig.1 Image of a small water reservoir in Zambia © World Bank

Fig.2 Lake Malawi/Niassa water quality - Preliminary results.
 Credit: WaterInsight

Fig.3 Time series of water level variation (m) in the Lake Malawi/Niassa around the mean for one of the altimetry points.
 Credit: TUDelft

Fig.4 Preliminary classification of land use in the mountainous areas of the Shire River basin.
 Credit: NEO, SPOT5 image data.
 © CNES/Spotimage

Fig.5 Small-scale water resources mapping. Small scale reservoirs can be delineated automatically by using seeds (a) or by using SignalEyes software (b).
 Credit: NEO

Water resources management

Users

World Bank Unit:
Urban, Water and Disaster Risk
Management Sector Unit, Latin
America and the Caribbean Region

Local Stakeholders:

- Autoridad Binacional Autónoma del Lago Titicaca (ALT) in Bolivia
- Ministerio de Culturas in La Paz, Bolivia

EO services provided

- Water quality monitoring using medium resolution imaging spectrometers, primarily Medium Resolution Optical data sources (ENVISAT MERIS and RapidEye)
- Land use and land change with a special focus on wetlands/crop type derived from high to very high resolution imaging optical sensors

Service Providers

- GAF (Germany)
- EOMAP (Germany)

Monitoring of Water Quality and Land Use Changes in the Lake Titicaca Basin



Context

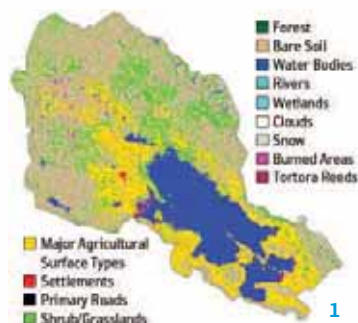
This EO demonstration is implemented under the umbrella of the World Bank's Lake Titicaca Sustainable Development Project, the objective of which is to elucidate the state and dynamics of the Lake Titicaca ecosystem. Lake monitoring is essential for the improved understanding of the regional aquatic ecosystems and for managing pollution hot spots by local authorities and policy makers. The central concern is to reduce the flow of nutrients and pollutants into the lake waters, and reverse some of the adverse environmental developments of the past. EO techniques can offer reliable mechanisms for systematic observation of temporal and spatial dynamics of the Lake, which is possible based on the fusion of water quality and land use data spanning the past decade. The overall objective is to contribute with this information to the key documents for guiding the management of Lake Titicaca in Bolivia and to provide important inputs to various watershed planning and management tasks (i.e. tourism development and cultural protection, waste water treatment, sanitation, etc.).

EO contribution

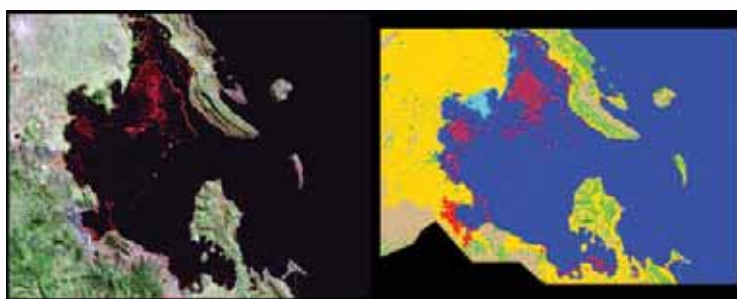
The land use and land change maps are based on high to very high resolution imaging optical sensors and will cover the entire Titicaca sub-basin (the Bolivian and Peruvian side) identifying the most critical land use classes such as conservation areas (treated as a separate class), forest, major agricultural surface types, settlements, primary roads, bare soil, water bodies, rivers, and wetlands (Figure 1). EO techniques can serve as a thematic and geometric reference for the production of further maps for change detection and spatial analysis of the region.

Gathering detailed information on the characteristics of the lake waters and its quality is possible thanks to the use of a time series of ENVISAT MERIS data from 2003 to 2010. This data can be analysed for annual variations and trends with the aim of identifying important hotspots such as nutrient concentrations, pollution, turbidity, sediment and phosphorus flows as well as water plants.

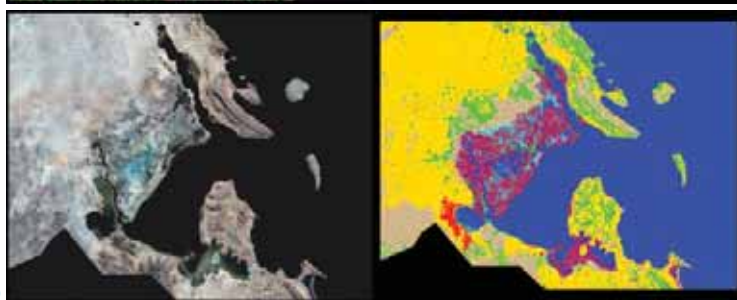
Using EO it is possible to verify the trends in land use and water quality as well as the effectiveness of the applied environmental protection measures. An interpretation of the satellite-based findings and evaluation of causal processes however requires an interchange and collaboration with the national authorities. Therefore this work is largely supported by a



2 (a)



2 (b)



Water resources management

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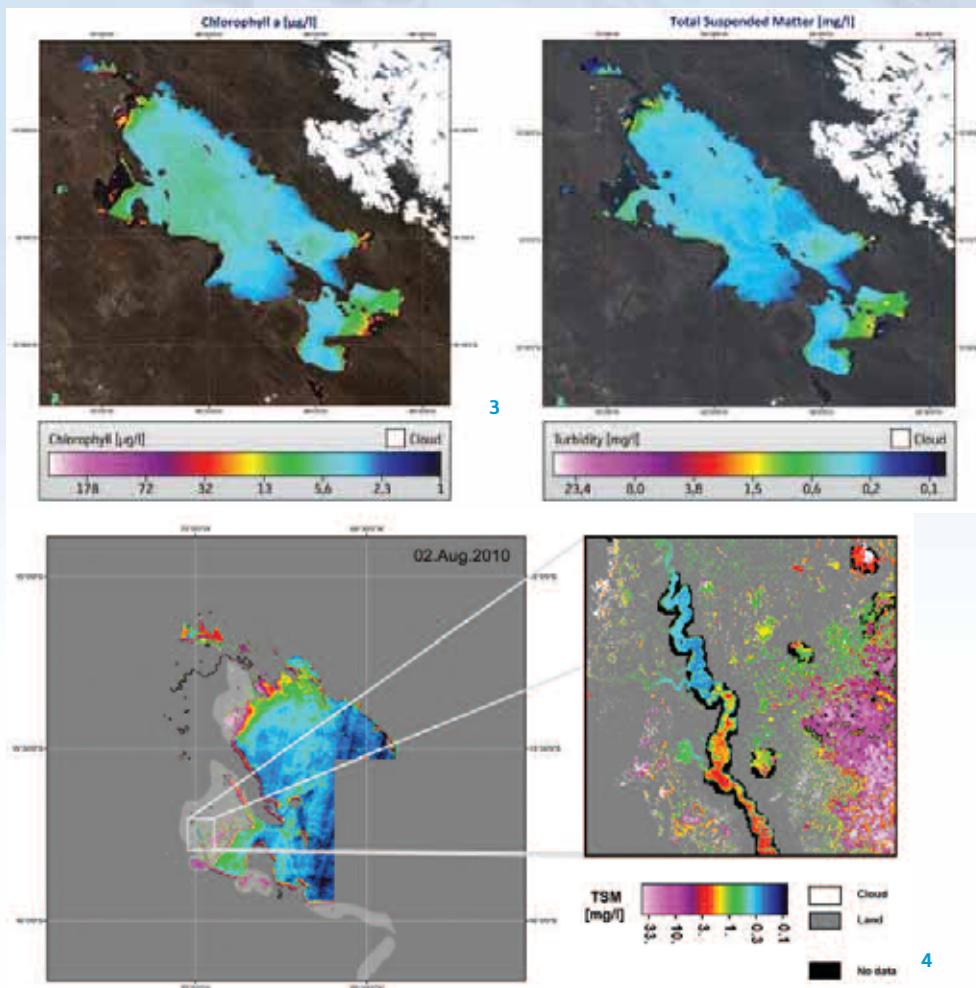
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John Morton

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range of in-situ data collected in partnership with the World Bank and in cooperation with local partner and the user of this information services - Autoridad Binacional Autónoma del Lago Titicaca (ALT) in Bolivia.

First results

The size of Lake Titicaca has visibly decreased during the observation period of 7 years (Figure 5). For example, in Puno Bay, Peru, the increase of the reeds growth caused the significant change of the shoreline as visualised in Figure 2 (a) and (b) (Totora reeds coloured in purple). In other regions the results show that the areas covered with reeds in 2003 have been displaced by areas which are used for agricultural production in 2010. First results from the observations of Lake Titicaca water quality indicated sources of increased chlorophyll and suspended matter distributions (Figure 3 and Figure 4). For example, at several areas and bays, i.e. parts of Lago Huiñaymarca, in the Bay of Puno, near the Ramis River Delta as well as in the Golfo de Achacachi, increased nutrient concentrations are frequent, originating from the river inflows. In the South Eastern part of the Lake (Lago Huiñaymarca) some differences in water quality can also be observed as compared to the central part of the Lake, possibly because of the prevalence of the shallow water areas and re-suspension effects. The results are provided in 5m, 50m (Figure 4) and 300m resolution (Figure 3).

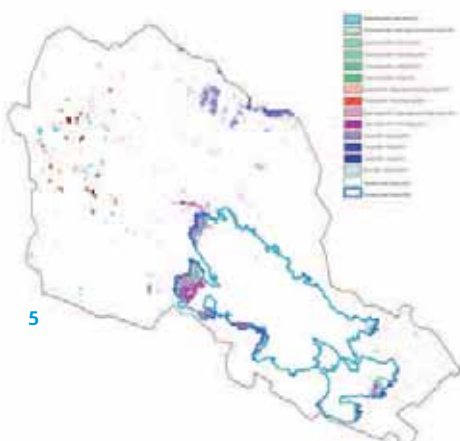
Fig.1 2010 Land use classification based on RapidEye data.
 Credit: GAF

Fig.2 (a) 2003 Landsat-based land use classification. Credit: GAF
 Fig.2 (b) 2010 RapidEye-based land use classification. Credit: GAF

Fig.3 Chlorophyll concentration and Total Suspended Matter. The data were processed at 300m pixel resolution using ENVISAT MERIS acquired on in November 2006. The full service will provide annual variation of water quality parameters for the period of 2003-2010. Credit: EOMAP, Envisat MERIS image data © ESA

Fig.4 Total Suspended Matter in 50m (left) and 5m (right) resolution for the Northern part of Lake Titicaca. Credit: EOMAP, RapidEye data © RapidEye

Fig.5 The changes in the Lake Titicaca basin and shoreline between 2003 and 2011. Credit: GAF



Coastal zone management

Users

World Bank Unit:
Environment and Natural Resources
Management Unit, Africa Region

Local Stakeholders:

- World Bank Country Office in Dakar, Senegal
- World Bank Country Office in Lusaka, Zambia

E0 services provided

- Coastal change maps
- Sea level height and ocean currents

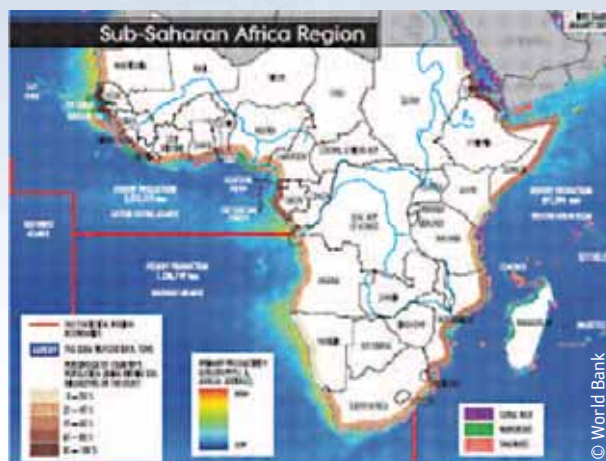
Service Providers

- CLS (France)
- GeoVille (Austria)

Monitoring of Coastal Vulnerability and Coastal Change Trends in West Africa

Context

Coastal ecosystems in Africa are very varied - Estuaries, coral reefs, mangroves, wetlands etc, and these support a wide range of economic activity. However, overfishing and habitat degradation threatens the often poor coastal communities, directly dependent on the services provided by these coastal and marine ecosystems. Moreover, climate change is expected to create additional impact on these ecosystems, due to sea level rise, ocean warming, subsidence, flooding and mangrove/ coral reef habitat alteration.



Coastline map 2010
Senegal / Gambia



Coastline change map 1988 - 2010
Banjul area / Gambia



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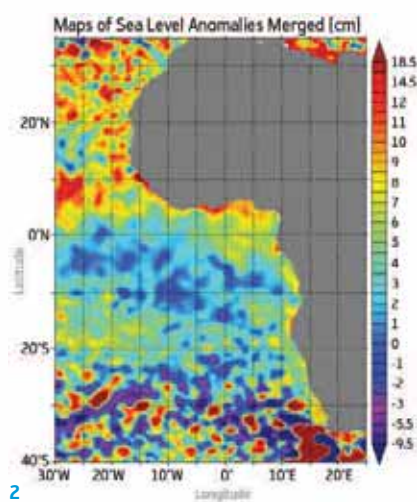
According to the 2007 report by the UN International Panel on Climate Change, global warming is causing sea level to rise at a global average of approximately 3mm per year over recent years. However the extent of sea level rise in different geographic regions is forecast to diverge considerably from this global average. Furthermore, the impact of such sea level changes on developing countries also depends on additional factors such as coastal morphology and dynamics, distribution of urban centres and the sensitivity of key habitats and ecosystems to pressures and change. This in turn will cause a diverse set of economic impacts in sectors such as fisheries, transport, energy and resource management.

ESA and the World Bank are collaborating to estimate coastal changes and coastal vulnerability in critical coastal areas of West Africa, with the focus on the islands of Sao Tome and Principe, the coastline of Gambia and Senegal, Cotonou (Benin) and Lagos (Nigeria). Gathering together an adequate dataset to assess the extent of coastal changes is extremely difficult-factors such as unknown measurement accuracy, difficulties in extrapolating point measurements to nearby areas of interest and lack of comprehensive systematic measurements in some areas create considerable obstacles in elaborating a reliable estimation of underlying drivers such as sea level rise and coastline change.

EO contribution

The EO-based information services will help to improve the accurate measurement of trends in marine and coastal environments in West Africa. In particular, it will provide accurate regional level measurements of changes in sea level height and distribution of major current systems. It will also generate historical maps of the extent and rate of coastal degradation and erosion over different regions at an unprecedented level of accuracy over the last 10-20 years.

First results



Shoreline change caused by natural or human induced factors is a serious issue for West African countries, and predicted climate change scenarios will further exacerbate the vulnerability of coastal areas. The knowledge on exactly where and how fast these changes will occur will contribute to establishing cost estimates for implementing building and rehabilitation measures.

Initial results confirm land loss and shoreline retreat in wetlands and mangrove systems of The Gambia and other countries, but also show considerable changes in developed areas such as the capital area of Banjul. (Figure 1)

Coastal zone management

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Fig.1 Coastal change map in Senegal/Gambia. Credit: GeoVille

Fig.2 Map of Sea Level Anomalies in West Africa. Credit: CLS

Marine environment management

Users

World Bank Unit:

- World Bank, South Africa Country Office (Pretoria)
- Environment and Natural Resources Management Unit, Africa Region

Local Stakeholders:

- South African Maritime Safety Agency (SAMSA)
- National maritime institutions and port authorities from:
 - Seychelles
 - Mauritius
 - Mozambique
 - Madagascar
 - Tanzania
 - Kenya
 - Comoros

for the oil spill surveillance service as well as Indian Ocean Commission for the coral reef monitoring service.

EO services provided

- Real time oil spill detection and polluter identification
- Coral reef health, status and evolution observation

Service Providers

- CLS (France)
- IRD (France)

Monitoring of Environmentally Sensitive Areas in the Mozambique Channel: Real time oil Spill Detection and Polluter Identification



1

Context

The World Bank's GEF Marine Highway Development and Coastal and Marine Contamination Prevention Project is a cooperation project between Western Indian Ocean states (South Africa, Seychelles, Comoros, Mauritius, Madagascar, Mozambique, Kenya, Tanzania and France (Reunion) funded to implement improved navigation, port state control and marine environment protection around the heavily trafficked main shipping routes between Southern Africa, the Gulf States and South East Asia. This includes up to date hydrographic surveying for the main maritime routes, enhancing maritime surveillance capabilities in the region and monitoring sensitive mangrove and coral ecosystems for contamination and pollution due to maritime transport. Earth Observation services contribute in two important areas – the timely detection of pollution by maritime traffic (together with available information on vessels in the area for possible polluter identification) and the rapid assessment of the status and health of priority coral ecosystems to detect deterioration caused by marine pollution.

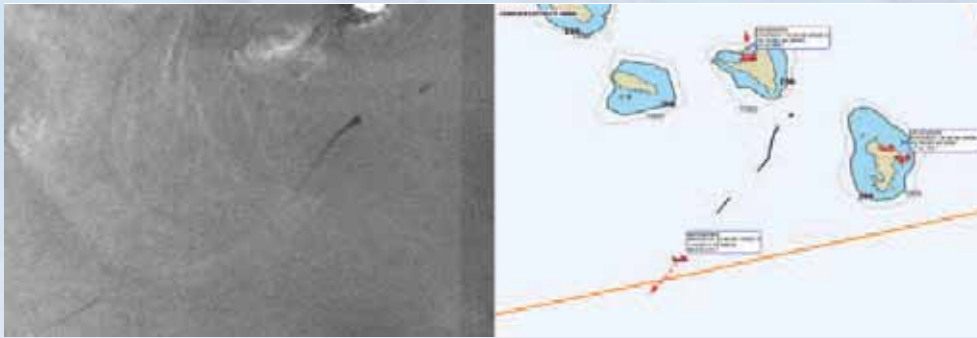
EO contribution

Timely oil slick detection enables national authorities to either dispatch interception assets to collect evidence and prosecute vessel owners responsible for illicit discharges (which are banned in this area under the MARPOL international treaty) or request that the destination port authority inspects vessels suspected of being responsible for discharges when they arrive. Oil spill information is based on the use of satellite based Synthetic Aperture Radar (SAR) imagery (e.g. Envisat-ASAR, Radarsat) which is fused with vessel identification data from satellite source (satellite-based Automatic Identification System or AIS).

In addition, the Coral Reef Status and Health Assessment service will be provided to address potential threats to ecosystems by combining available in-situ sampling and analysis information with recently acquired very high resolution optical data. Given the proximity of shipping lanes to such sensitive habitats and the impact of even small volumes of mineral oil on marine ecosystems, the combination of the two services (oils spill detection and coral reef observations) provides a valuable and easily accessible addition to conventional monitoring and surveillance capabilities in the area.

2





3

First results

During the month of August, some 20 Envisat radar images were acquired over the area of interest. Each image covers an area of at least 400x400 km². The images were received and analyzed in near-real time and each analysis report was disseminated to the end user roughly one hour after the satellite pass (Figure 2).

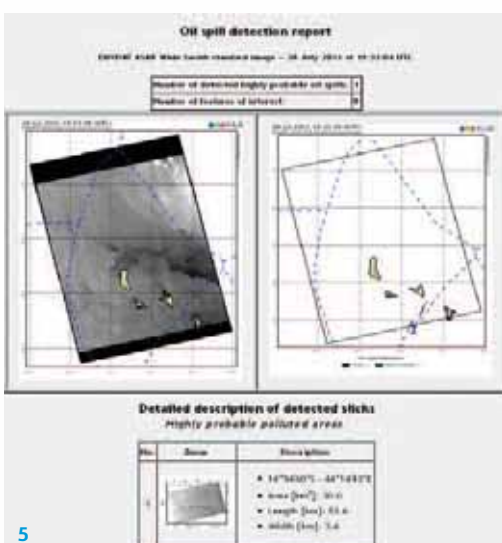
Within only one month three oil spills were detected: around Comoros, Aldabra and Mauritius. The spills' extents were quite significant (from 17 to 30 km²) and two of them could be clearly associated with the passing vessels. The images represented in Figure 3 show the case of the spill detected between Mayotte and Comoros on July 28th at 19:32 UTC. A large oil spill (more than 50 km long) is clearly visible and could be detected and associated with a potential polluter as the AIS message broadcasted by the vessel and collected by the satellite allowed its non-ambiguous identification.

The local authorities were alerted and flew on-site to check on the situation.

The entire service has been visualised via a user-friendly, comprehensive web interface providing a description of the event (image footprint, acquisition time, slick location and extent, environmental conditions, polluter identification) (Figure 5).



4



5

"This product is being developed for the first time in our project in the Western Indian Ocean. The WIO is the only area other than Europe where such state of the art is currently being piloted [with the support of ESA.]

The above developments are very important since the identified polluters have been very surprised about the far reach of the technology [...] it will start acting as a deterrent and hopefully this will even further the project development objectives"

Juan Gaviria,
eoworld project Task Team Leader
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Marine environment management

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Fig.1 The tanker MV Jolly Roger spilled oil into the sea, on September 2002, after running aground on reefs off the UNESCO World Heritage Site of St Lucia, 150 miles north-east of Durban on South Africa's east coast.

Fig.2 Images acquired by August 2011 over the area of interest. Credit: CLS

Fig.3 Screenshots of the visualization system which shows an oil spill detected between Comoros and Mayotte (using radar imagery) and its connection to the polluter vessel (as identified by its AIS message signal collected by satellite). Image on the left shows oil slick as observed on the SAR image and mapping of the slick and associated AIS track collected by satellite. Credit: CLS; ENVISAT ASAR data © ESA

Fig.4 The Panamanian registered rice carrier, MV Angel 1 ran aground on coral reefs off the coast of Mauritius in August 2011. An extended salvage operation was required to transfer the rice and 1000 tons of fuel oil aboard. Satellite imagery were used to support the National Coast Guard in ensuring no pollution resulted from the transfer operation. Credit: National Coast Guard of Mauritius

Fig.5 The extract of the oil spill detection report sent to the users. Credit: CLS

Users

World Bank Unit:
South Asia Sustainable Development Department, Urban Development Unit, South Asia Megacities Improvement Program

Local Stakeholders:

- Dhaka: municipalities & local engineering department
- Mumbai: metropolitan development agency
- Delhi: several state governments including main capital planning board

E0 services provided

Accurate historical land cover/use mapping by exploiting the High Resolution (HR) Optical data archive: providing a sequence of land use datasets monitoring urban growth in 1992, 2003 and 2011.

Service Providers

GISAT (Czech Republic)

Historical Assessment of the Spatial Growth of the Metropolitan Areas of Delhi, Mumbai and Dhaka

Context

Within the frame of the South Asia Megacities Improvement Program the World Bank is currently conducting a number of studies to better understand the patterns and impacts of the extensive urban growth in the metropolitan areas in South Asia, including the mega-cities of Delhi and Mumbai in India, and Dhaka in Bangladesh. These metropolitan areas are an example of the development challenges related to urban rapid expansion as a result of high natural growth and population migrations. Bank's studies have found that while urbanization is

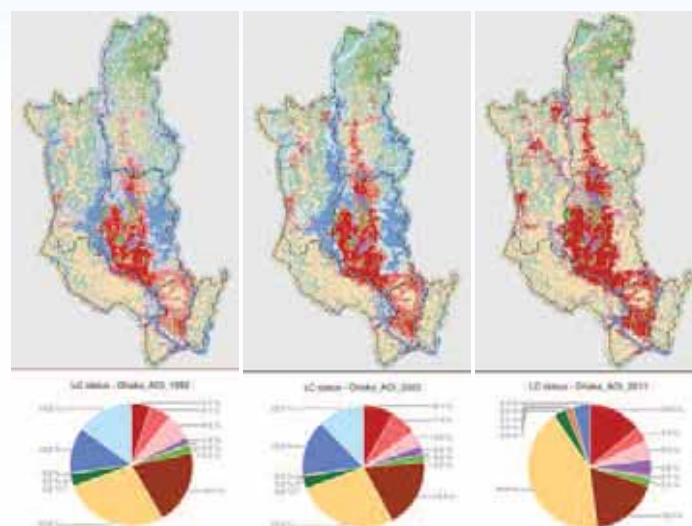


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an integral part of economic development, in many developing countries, including India and Bangladesh, housing opportunities and infrastructure accessibility is rarely keeping up with the fast pace of urban growth. As a result both in India and Bangladesh as much as a quarter of all urban housing is located in slum-like neighbourhoods with no or little access to modern infrastructure.

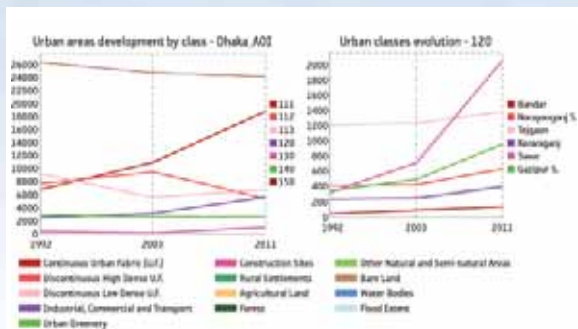
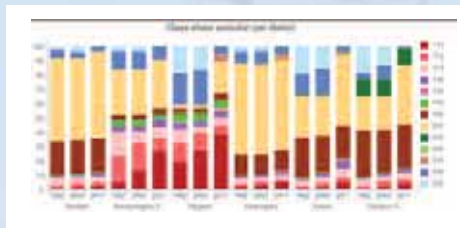
Mumbai and Delhi - which are some of the most populous cities in the world - despite their dynamic economic development still have more than half of their population living in slums. In Mumbai many of them are situated near employment centers in the heart of

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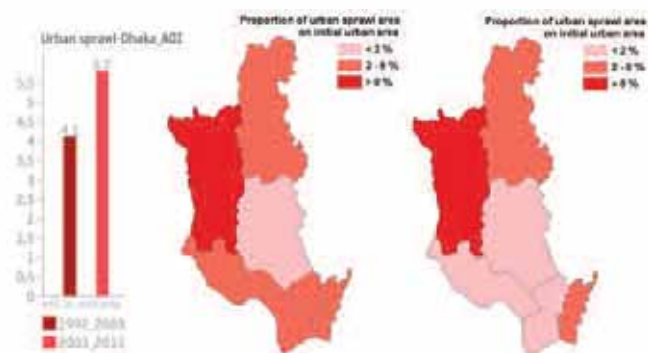




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development in three decadal sequences: 1990's, 2000's and 2010/11.

EO contribution



5

potential of EO techniques and the ability to derive statistical results for selective administrative units, which are comparable in spatial and temporal scales. Sensors used are mainly SPOT5 (2,5m/10m/20m resolution) and RapidEye (5 meters resolution). Using EO data the only feasible approach to provide harmonized retrospective information on the cities spatial growth for such large areas (total of ~18 000km²).

First results

Figure 2 represents the first results of the high resolution land cover / land use mapping product extracted for Dhaka using up-to-date satellite images. This baseline information allows to identify and assess changes in land cover / land use area within individual sub-districts/sub-regions for 2011 and back to 2000 and 1990 and to extract summary statistics for overview. Data for three pilot cities (Delhi, Dhakka, Mumbai) can be further explored and analyzed using the user-friendly web based tool developed in the frame of ESA Urban Atlas project.

the town, unlike in most other developing countries. In view of these developments local urban managers and planners are challenged to implement sustainable and inclusive urban growth policies, housing policy reforms, slum upgrading and other infrastructure improvements. The insight into the patterns of urban spatial growth, its structure and foresight into the future is expected to help better prioritize those investments as well as as prepare for future World Bank involvement in the region. In this context, the EO service aims to provide the analysis of the spatial growth of Delhi and Mumbai in India, and Dhaka in Bangladesh spanning 20 years of urban

Urban development

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Earth Observation services represent a particularly efficient method to deliver quality results to measure urban growth which are harmonised in a consistent manner across different geographical locations.

The service highlights the retrospective mapping po-

Fig.1 Dhaka, Bangladesh. © World Bank

Fig.2 Land cover/ land use, Dhaka for 1992, 2003 and 2011. Credit: GISAT, EO data, Landsat © USGS, SPOT2-5 © Spotimage, RapidEye © RapidEye

Fig.3 Screen shot of a user-friendly tool to explore and analyze the data. Credit: GISAT

Fig.4 Evolution of urban development over 20 years by land cover class for the total of Dhaka city and single districts. Credit: GISAT

Fig.5 Urban sprawl indicator for Dhaka - proportion of sprawl on initial urban area. Credit: GISAT

Sustainable Oil Palm Production in Papua New Guinea

Context

The Smallholder Agriculture Development Project (SADP) funded by the World Bank and PNG Sustainable Development Program Ltd (PNG SDP) is being implemented in Oro and West New Britain provinces. The Project is implemented by the Oil Palm Industry Corporation (OPIC) in collaboration with the PNG Oil Palm Research Association and with the

Users

World Bank Unit:
Pacific Islands Sustainable Development Department, East Asia and the Pacific Region

Local Stakeholders:

- PNG Sustainable Development Program Ltd.
- Oil palm smallholders
- Palm oil milling companies
- Provincial government of the PNG Oro and West New Britain provinces
- Oil Palm Industry Corporation (OPIC)
- PNG Oil Palm Research Association (PNGOPRA)

EO services provided

- Forest mapping for three points in time 2005-2009-2011 using High to Very High Resolution (HR/VHR) Optical sensors
- Land cover mapping for 2011 using High to Very High Resolution (HR/VHR) Optical sensors

Service Providers

- SarVision (The Netherlands)



1

support of the provincial governments and palm oil milling companies in the Project areas. The main objective is to increase, in a sustainable manner, the level of involvement of targeted communities in their local development through measures aimed at increasing oil palm revenue and local participation. Some components of this work include infill planting areas (planting of 9,000 hectares of new smallholder village oil palms along existing access roads) and the upgrading and maintenance of provincial access roads facilitating better access to markets (that involves rehabilitation and reconstruction of 550km of roads). The SADP incorporates various environmental control measures and monitoring programs in order to ensure that the project activities do not impact high conservation value habitats, forests and wild life habitation areas. Some measures are planned to support the existence of adequate buffer zones along rivers, springs and streams and to prevent smallholders from displacing their food gardens into protected lands or primary forests. The EO services address the need for the monitoring any deforestation activities as well as encroachment to forest/conservation areas in relation to the expansion of smallholder village oil palm plantations under the project. The overall objective is to contribute to the project's environmental impact assessment, audits and planning.

EO contribution

2



The thematic context for the forest mapping service is based on the distinction between primary and secondary forest areas in the parts of Oro province. 2011 was set as the baseline for the production of the maps but the temporal coverage of the service extends to three points in time (2005-2009-2011) and covers respectively: primary forest between 2005-2009 and 2009-2011, and deforestation of secondary forest between 2005-2009 and 2009-2011. The requirement to differentiate between primary and secondary forests is necessary to comply with the Bank's safeguards policies and with the Round Table on Sustainable Palm Oil (RSPO) Principles and Criteria, where identification and protection of primary forest and other areas containing high conservation values are a requirement. The second part of the service—land cover

mapping—is aiming to provide up-to-date information about land use in selected parts of Oro and West New Britain provinces in view of establishing the baseline for project monitoring prior to the commencement of new investments. As such it can be used as the benchmark for future compliance verification in view of project bi-annual reporting.

The service is largely enabled by RapidEye operating system providing images at 5 meters resolution. With five satellites constellation and frequent revisit time (daily) RapidEye imagery mitigates cloud cover limitations typical to equatorial regions (usually pertinent to VHR satellites operating singly). To this end the service additionally integrates data from variety of other sources: Landsat (30m), SPOT4-5 (2,5-10-20m), and ALOS (AVNIR/PALSAR 10-15m). This approach is expected to demonstrate EO capability to provide bi-annual coverage (for environmental and social audits) with a potential to map features at a minimum mapping unit of 0.1 hectares. As the land use mapping component requires a substantial in-situ support to fully satisfy user requirements, complementary field surveys and collection of ancillary data will be undertaken in partnership with the World Bank in course of the project implementation.

Agriculture and Rural Development

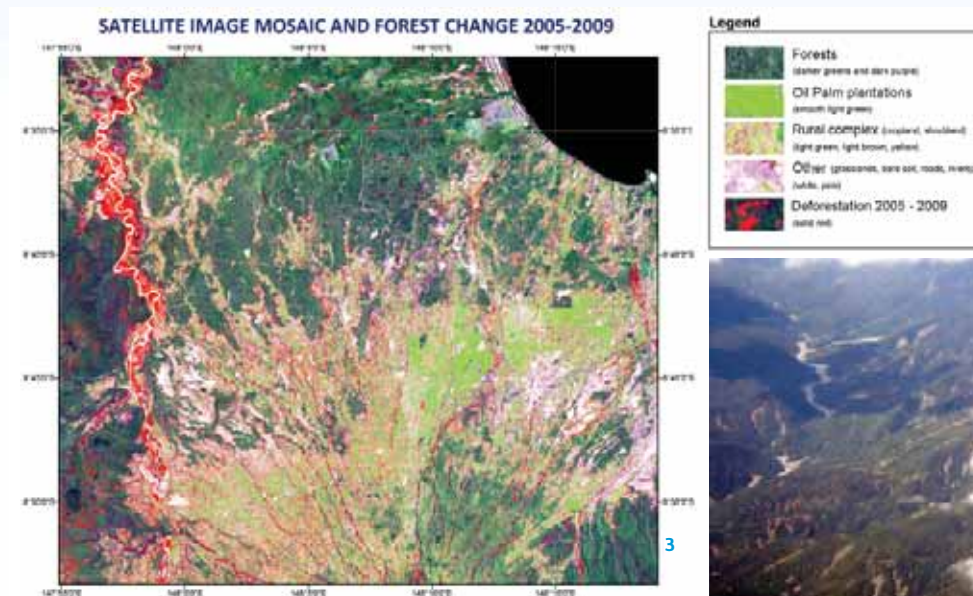
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First results

The first results confirm the feasibility of EO to conduct land use change and deforestation analysis. As illustrated in Figure 2, using high-resolution RapidEye data makes it possible to distinguish patches of forest and some large individual trees, small agricultural fields and grasslands, small scale oil palm plantations managed by local communities, individual houses as well as industrial oil palm plantation estates.

Figure 3 shows some preliminary results of the wide area forest cover mapping in Oro Province created using Landsat 5 and Landsat 7 images. The image displays an overlay of preliminary deforestation 2005-2009 and the processed 2005 image composite (atmospheric correction, cloud removal and gap-filling have been applied). Forest cover loss between 2005 and 2009 is indicated in red. On the left part of the image one can see the damage to forests after the cyclone Guba that hit PNG in 2007. Torrential rains decimated forested areas by spawning landslides, causing rivers to change course and villages to disappear off the map due to floods, only to reappear rebuilt somewhere else. One can also detect new logging roads as well as small clearings due to agricultural expansion for subsistence agriculture. Planted oil palm areas are also clearly visible. The detailed forest mapping as well as thematic land use classification will be completed by the end of 2011.



Fig.1 Oil palms - Higaturu Oil Palm, Popondetta (Papua New Guinea)
 © Wakx

Fig.2 RapidEye (5m) image over Oro province. Credit: Sarvision, RapidEye data © RapidEye

Fig.3 Satellite image mosaic and forest change for 2005-2009 derived from Landsat 7, SPOT5 and ALOS PALSAR imagery for the year 2009. Credit: Sarvision

Fig.4 Landslides and massive siltation of a local river caused by the December 2007 cyclone that hit Papua New Guinea © Wakx

Forest Resources Management in Liberia

Users

World Bank Unit:

- Environment and Natural Resources Management Unit, Africa Region
- Liberia Forestry Program

Local Stakeholders:

- Liberian National Forestry Development Authority (FDA)
- Liberian Environmental Protection Agency
- Ministry of Planning and Economic Development
- Ministry of Lands, Mines and Energy Financial Controls

Other stakeholders:

- FAO's Liberia Forest Initiative (LFI) Partnership
- UNDP
- various NGOs

EO services provided

- Forest mapping in North-Western Liberia (Gbarpolu and Gbarpolu & Grand Cape Mount) for 2002, 2006, 2011
- Land cover and terrain mapping for 2011

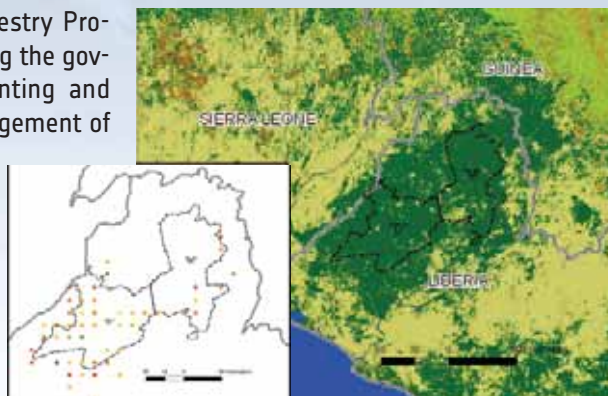
Service Providers

- Metria (Sweden)
- GeoVille(Austria)

Context

In the context of its Liberia Forestry Program the World Bank is supporting the government of Liberia in implementing and monitoring the sustainable management of Liberia's commercial, conservation and community forestry. These activities have been guided by the FAO's Liberia Forest Initiative (LFI) since 2004. The need for adequate geo-data for the forestry sector in Liberia is immense. After the uncontrolled logging activities

taking place in 1990's and early 2000's, knowledge about the Liberia forests was drastically reduced. To bridge that gap the LFI has initiated mapping and survey efforts using satellite data from 2002 to 2004, and 2005-2006. However the existing forest inventory has been found to be outdated. A lot of forestry activities have been taking place since 2007 and more recent forests volume assessments are needed in view of ongoing and future World Bank supported actions. The overall objective of this project is to improve the knowledge about a large forest area in North-Western Liberia (Gbarpolu (D) and Gbarpolu & Grand Cape Mount (M)) with a special focus on the mapping of areas planned for nature conservation purposes and future REDD (Reducing Emissions from Deforestation and Forest Degradation) activities.



1

EO contribution

The services will demonstrate the suitability of validated EO services for independent forest monitoring and the support of land-use planning for sustainable forest management. The most up to date satellite datasets are being utilized in combination with in-situ data collected by the project team in the field to evaluate the accuracy of the measurements and validate results. Forest classification service will delineate the present forest extent and classify the forest in different density classes for three points in time 2002, 2006 and 2011, and conduct change detection between these years. The land cover service will provide the overview of the 2011 land use with 15 thematic classes and revealing primary roads. EO data used for this project are based on Landsat TM (30m), SPOT5 (2,5m-20m) and RapidEye (up to 5m) datasets. Forest map will be enhanced with terrain mapping using Digital Elevation Model (ASTER-GDEM exploited together with the SRTM DEM at 15m vertical resolution) to assess available forest area.

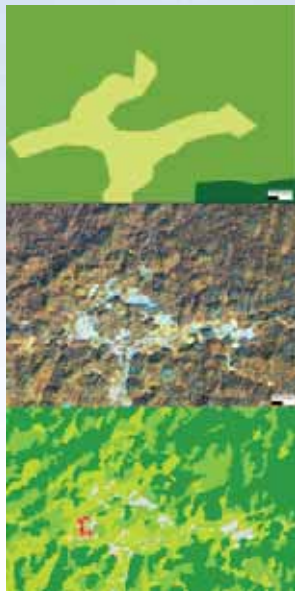
First results

With a monitoring system based on a combination of field data collection and EO data analysis, the control of forest resource utilisation is much improved. For mapping of the forest resources for the baseline year 2011 the project is making use of the most recent satellite datasets, integrating semiautomatic methods for classification, including segmentation structural analyses and statistical methods. The first results show a significant enhancement in the forest area classification and discrimi-

2

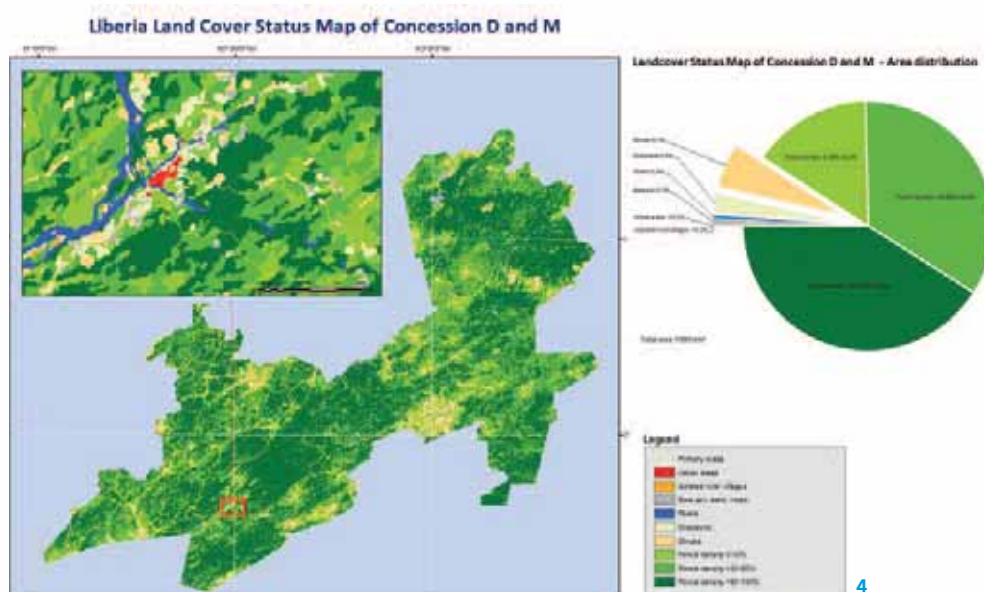


nation between forest types (i.e. areas with different densities and crown sizes) and better accuracy as the minimal mapping unit (MMU) comes down to less than 1 ha, as compared to the previous 1000 ha (Figure 3). The recent forestry activities are easily distinguished based on analysis of RapidEye data from 2011 (Figure 5).



About one tenth of the observed area of the Forest Monitoring Concessions D and M is covered with other land cover types than forest (Figure 4). Even though this is only a small proportion of the overall land cover, it is considered that the impact to the forest cover caused by housing and farming activities is remarkable. The status map of 2010 gives valuable information on the current status of larger populated places, isolated rural villages and open land and in combination with DEM it can be used to support forestry management activities in Liberia, including commercial, conservation and community forestry.

3



4



5

Forestry

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Fig.1 The areas in North-Western Liberia selected to be mapped. Left: The surveyed points of the NFI in relation to the M and D areas. Green dots have ~10 trees with dbh > 50 cm in 2005/2006 and red dots ~1. © Metria

Fig.2 The team's field trip to Liberia early June, 2011 facilitated discussions with a wide range of the local stakeholders such as World Bank Country Office, FDA, Department of Agriculture, USAID, Ministry of Lands Mines & Energy, LISGIS (Liberia Forestry GIS laboratory) and Liberfor (SGS). Photo © Metria/GeoVille

Fig.3 Land cover mapping from 2004 with a MMU of 1000 ha, compared to the EO services provided in this project. The RapidEye image in the middle was used as a reference. The Legend is displayed in figure 4. Credit: Metria/GeoVille, RapidEye data © RapidEye.

Fig.4 Land cover status map and area distribution of Forest areas D and M. Credit: Metria/GeoVille

Fig.5 Left: Landsat image from 2002 (30 m) shows the evident timber roads, but no evident recent logging. Middle: Rapid Eye (6 m) from 2010 with less visible roads and no signs of logging. Right: Rapid Eye from 2011 recent logging activities in FMC C in central Liberia. Credit: Metria/ GeoVille, Landsat data © USGS, RapidEye Data © RapidEye.

Users

World Bank Unit:
Urban and Social Development Unit,
Middle East and North Africa Region

Marseille Center for Mediterranean
Integration

Local Stakeholders:

- In Egypt:
 - Egyptian Environmental Affairs Agency
 - Arab Academy of Science, Technology and Maritime Transportation
- In Tunisia:
 - Ministry of Environment and Sustainable Development
 - Ministry of Development and International Cooperation
 - Municipality of Tunis

EO services provided

- Historical mapping of terrain deformations in Alexandria (Egypt) based on interferometric technique using Synthetic Aperture Radar (SAR) data
- Historical mapping of terrain deformations in Tunis (Tunisia) based on interferometric technique using Synthetic Aperture Radar (SAR) data

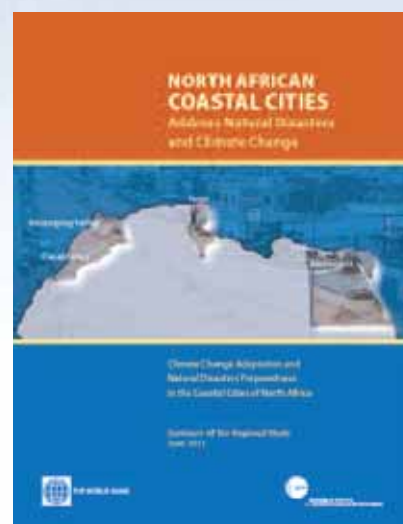
Service Providers

- TRE (Italy)
- Altamira Information (Spain)

Climate Change Adaptation and Natural Disasters Preparedness in the Coastal Cities of North Africa

Context

This project was conducted in the framework of the World Bank study on “Climate Change Adaptation and Natural Disasters Preparedness in the Coastal Cities of North Africa” which aims to identify and assess natural risks and vulnerabilities in some of the main North African countries. The contribution of EO data was primarily focusing on terrain deformation mapping to provide precise indications on the location of subsidence and uplift zones in Alexandria in Egypt and Tunis in Tunisia in support to surveys on land stability and seismic issues. This monitoring generated valuable information to the users and is considered an excellent example of the added-value of EO technology to disaster risk reduction policies.



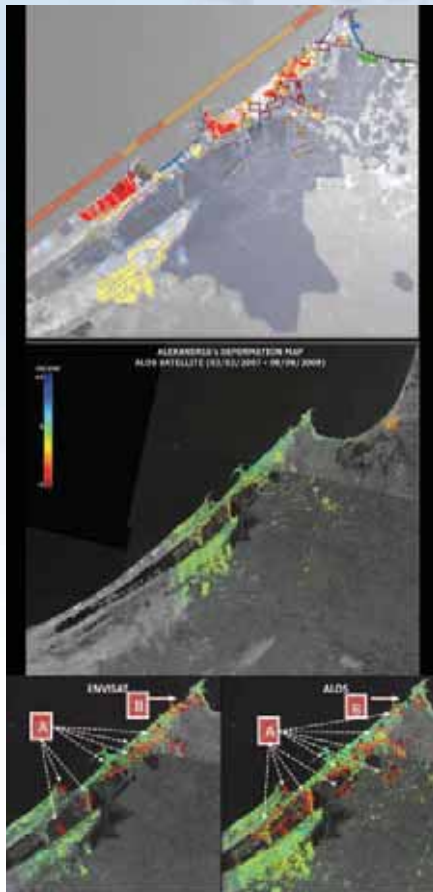
EO contribution

In Alexandria, Altamira Information applied InSAR technologies for the reconstitution of the monthly historical ground displacement in the urban and rural areas of Alexandria during the period 1992 to 2009. The results of ALOS data process covered 30 months (from March 2007), ERS data covered 9 years (from May 1992 to December 2000) and ENVISAT data covered 5 years (from July 2003 to November 2009). In Tunis, TRE applied an upgraded InSAR technology, called SqueeSARTM. It is an advanced second generation PSInSAR analysis, exploiting both “point wise” (permanent scatterers) and spatially “distributed scatterers” (DS).

The study analyzed potential ground movements in Alexandria and Tunis between 1993–2000 and 2003–2009, the periods for which respectively ERS and ENVISAT satellite data were available over this area. A large advantage of EO is to give indications on the location of subsidence and uplift zones over a long time span. The land movement data derived from EO technology usually has to be further analysed in combination with other data, i.e. in-situ measurements from levelling /Differential GPS to provide reliable evidence of subsidence/ uplift in the area. The results of both EO services have been integrated in the analysis performed by a consortium of French consulting companies in the framework of the World Bank project (headed by Egis-BCEOM International and including IAU-RIF and BRGM).

Results

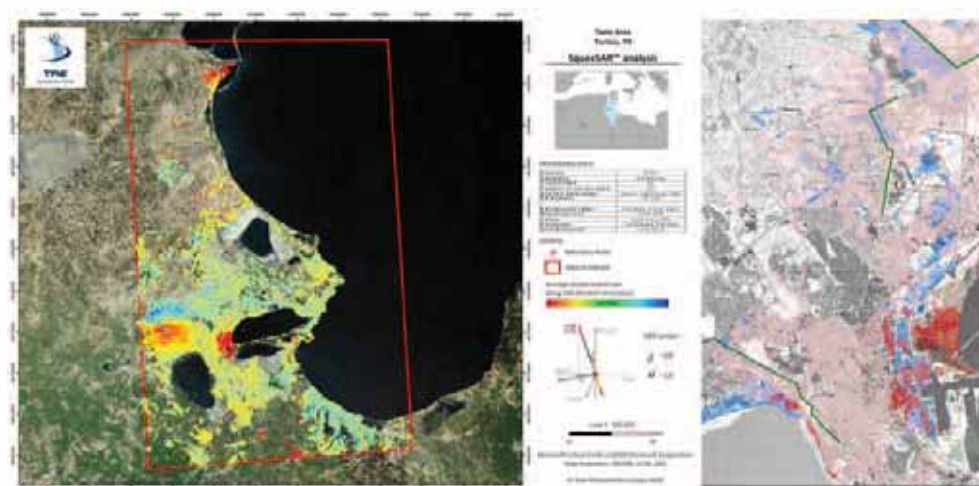
Figure 1 showcases the multi-risk map created for the World Bank “Coastal Cities” report which highlights Alexandria’s critical vulnerabilities. The large shaded area indicates low-lying, flood-prone lands; red represents high-density residential areas; yellow shows slums and informal settlements; blue shows areas most subject to marine submersion. The diagonal line of the coast represents different degrees of coastal erosion risk. Historically, the region of Alexandria was affected by geological hazards such as seismic activity, tsunamis and offshore subsidence. Satellite data was used to reconstruct monthly



historical ground displacement in the urban and rural areas of Alexandria over the period 1992 to 2009. The PSI analysis found that the terrestrial ground uplifting and ground subsidence in the urban and rural zone of Alexandria and Idku regions were ranging from maximum of -3 cm/year (ALOS) via -1.5 cm/year (ERS, ENVISAT) to maximum uplift of 0.9 cm/year (ALOS) via 0.5 cm/year (ERS, ENVISAT). The maximum of this ground motion is mainly located in the northern border of the Al Bouhayra and Mariut lakes located in the south of the city and in the central area of Idku city.

In the study of Tunis it was found that in central part of the city, former and present industrial areas on the southern shore of the lake and port of Rades have experienced significant subsidence patterns undermining city's resilience to storms, seismic risks and extreme weather events. This finding implies the need for infrastructure strengthening to better manage water levels, and upgrading of sewage and drainage structures as illustrated in Figure 2.

1



2

Climate Change Adaptation

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Fig.1 Upper map highlights Alexandria's critical vulnerabilities identified by the World Bank "Costal Cities" project. Credit: World Bank. The lower images indicate Alexandria's historical terrain motion patterns provided by Altamira Information as a contribution to World Bank study. ENVISAT ASAR image data © ESA 2003-2009

Fig.2 The findings of the World Bank study. In economically important central Tunis, subsidence indicated in red combines with flooding risks indicated in blue to multiply potential impacts. Major storms overwhelm the center-city drainage, inundating streets and buildings. Left: SqueeSAR analysis of ERS ascending data identified more than 70000 measurement points, with a density of about 70 PS/km². For each point, the average rate of deformation and time history of movements were estimated. Positive values (blue) suggest uplifting movement, while negative values (red) indicate a subsidence phenomena affecting the area. Credit: TRE, ERS ASAR data © ESA

Adaptation to Climate Impacts in Coastal Zones in the Caribbean: Monitoring of Coral Reefs in Belize

Users

World Bank Unit:
Sustainable Development Department,
Environment and Water Resources
Unit, Latin America and the Caribbean
Region

Local Stakeholders:
Caribbean Community Climate Change
Center, Belmopan, Belize

Other Users:
GEF Coral Reef Targeted Research &
Capacity Building for Management
www.gefcoral.org

EO services provided

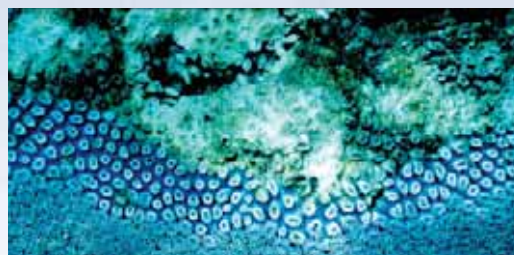
Coral Reef monitoring using remote
sensing techniques to assess thermal
stress regimes, wave exposure areas
and reef connectivity (for larvae
dispersion)

Service Providers

Marine Spatial Ecology Lab, University
of Exeter (UK)
<http://msel.ex.ac.uk/gis/belize>

Context

The World Bank is a founding member of the International Coral Reef Initiative (ICRI) and has remained actively engaged in development of the ICRI Partnership since its inception in 1995 investing more than US\$235 million since the early 1990's in activities involving coral reefs and associated marine environments protection including transboundary environmental issues.



This service trial was developed in support of the World Bank coral reefs initiatives in the Latin America Region, specifically in the context of the "Regional Project on Adaptation to Climate Impacts in Coastal Zones in the Caribbean" carried out through the Caribbean Community Climate Change Center, located in Belmopan, Belize. The central theme of the trial focused on monitoring of the stressors acting upon coral reefs off the Belize coast where coral ecosystems are exposed to number of threats. Chief amongst these are coral bleaching, the whitening of corals due to stress during periods of exceptionally warm sea temperature, and overfishing of herbivorous fishes, which are now the most frequently caught fish group in Belize.

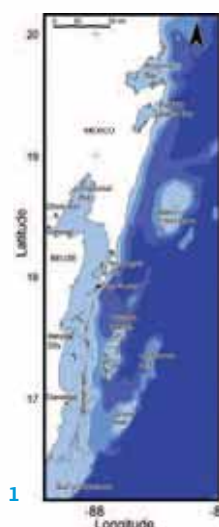
EO contribution

The service integrated data from a variety of satellite sources: sea-surface temperature data from the Along-Track Scanning Radiometer and the Advanced Along-Track Scanning Radiometer on ESA's ERS-2 and Envisat satellites, wind speed and direction data from the Active Microwave Instrument (AMI) on ERS-2 and imagery from Landsat (30m) and Quickbird (2,6m) to identify coastline and reef-crest areas.

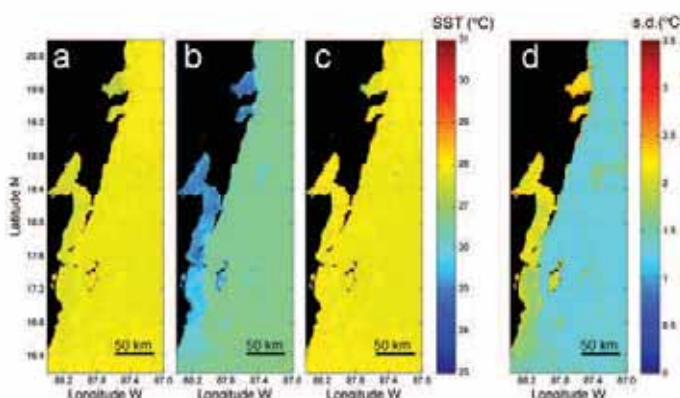
The study confirmed that remote sensing techniques provide a good alternative to field-surveys by addressing many of the caveats highlighted for in situ monitoring programs. The EO is cost-effective, offers a synoptic view, and allows for the simultaneous evaluation of several putative stressors for the establishment of causative links. However while satellite remote sensing can be used to map the locations of reef habitat and communities it requires substantive in-situ support to measure the health of the system directly.

Results

EO data can be used to map the locations of reef habitats and to understand better what regions are more vulnerable and likely to experience coral bleaching. Satellite monitoring of sea surface temperature is remarkably effective



1



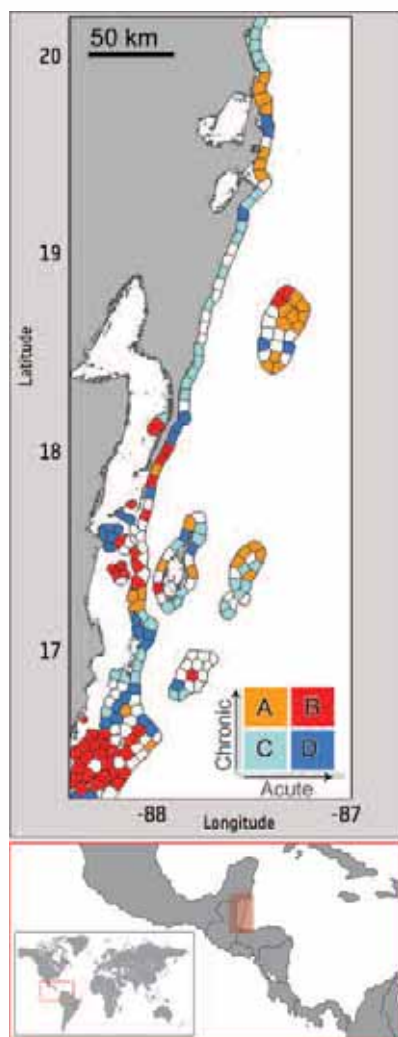
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at predicting where and when bleaching, one of the main sources of stress, will take place. However further research is needed to predict the outcome of such events; i.e., the extent to which the corals recover or die.

In this EO demonstration the project team:

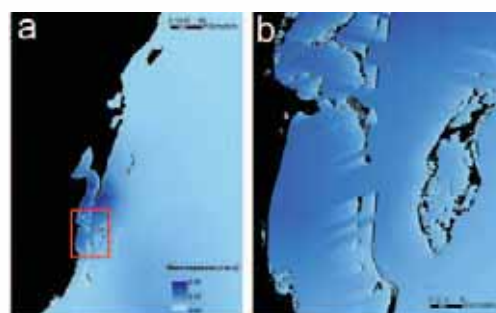
- reviewed how state-of-the-art remote sensing capabilities support the monitoring of coral reefs, their health and quantify stress,
- mapped reef habitats at two selected locations within the barrier reef system (the central section of the barrier reef, Turneffe Islands and Lighthouse Reef, and the southern section of the barrier reef) (Figure 1), and
- explored extrinsic factors that can improve reef resistance and recovery from disturbances in the northern Mesoamerican barrier reef system by mapping four important factors influencing the establishment of monitoring and management priorities in the region, namely: sea surface temperature patterns, chronic and acute thermal regimes, wave exposure, a proxy for potential seaweed growth, if grazing fishes (herbivores) are absent, and coral connectivity among reefs (Figure 2 and Figure 3).

As a result the services contributed to assessment of vulnerability of reefs to coral bleaching and vulnerability of reefs to experiencing a phase shift, changing from a coral-dominated to a macroalgae-dominated state, if herbivores habitats are absent. Results showed that those areas predicted to fare better under climate change (from a thermal perspective) are rare and scattered across the study area (Figure 4). Also, if over-fished, some areas are more vulnerable to becoming dominated by seaweed with a resultant loss of corals (for example, north of the barrier reef and the seaward side of the atolls). Finally, the reefs are in general well connected, facilitating the dispersion of larvae.



3

The project also commenced a pilot research activity has been included to promote the restoration of coral populations affected by increased sea surface temperatures and lower sea pH. Overall, the information generated by this service fostered the use of EO data within the World Bank and its relevant departments, and fed into relevant research activities at the Bank, in particular GEF funded Center for Coral Reef Targeted Research & Capacity Building for Management.



4

Climate Change Adaptation

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The World Bank Group

Fig.1 Study area: northern Mesoamerican barrier reef system (NMBRS 16.2-20.2°N 87.0-88.4°W)

Fig.2 Sea Surface Temperature patterns for the study area (a) average, (b) minimum monthly mean (c) maximum monthly mean (d) standard deviation. Credit: MESL,ERS, ENVISAT data © ESA

Fig.3 Left: (a) Exposure map for the study area. Land and reef crest are black. Relative exposure measures ranges from 0 to 0.3 J/m³ (b) detailed region showing shading effects. Regional variations in wave exposure are characterised by higher exposures at the north of the barrier reef, between Ambergris Cay and Belize City, where the winds are strongest within the study area. At a local scale, the seaward side of the atolls and the barrier reef (unless shadowed by a reef structure to the east) experience higher exposures, and are thus the most vulnerable to algal blooms if the reefs are depleted of herbivorous fishes. Credit: MESL

Fig.4 Areas that are predicted to fare better under future climate change (a) are rare and scattered across the study area, mainly on the barrier reef and the atolls. Areas with high selection pressure (b) are located in shallow sheltered areas with slow water flow. Credit: MESL

Users

World Bank Unit:

- Environment and Water Resources Unit, South Asia Region
- Agriculture and Rural Development Unit, South Asia Region

E0 services provided

- Mapping of the development of the coastal zone in the Ganges Delta (long term trends and change zones, interannual change zones, and single event change zones) using medium and high resolution optical imagery
- Monitoring of a coastal change using long range of EO data (Landsat archives from 1962 to 2007)

Service Providers

- GRAS (Denmark)
- planquadrat Geoinformation (Germany)

Monitoring of the Coastal Change Trends in Bangladesh



1

Context

In the context of changing climate many projections estimate a rise in sea level of around 1 meter by the year 2100 in Bangladesh. This would mean an inundation of approximately 18% of the land surface of the country. However, what these estimates fail to recognize is the extremely dynamic and changing nature of the river delta. The river morphology is constantly changing, depositing over a billion tons of sediment a year into the delta. These processes are crucial for renewing the fertility of the flood plain – Bangladesh's backbone for economical and societal stability.

This service was aimed at contributing to the scientific debate on the net result of high accretion and deposition rates which add land surface, against the erosion and compaction rates which reduce the land surface.

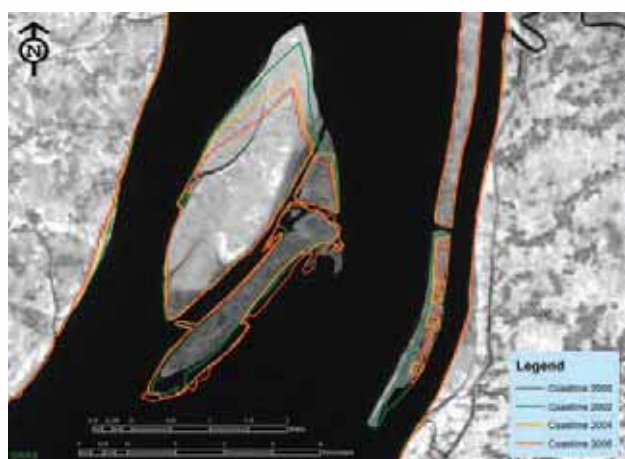
E0 contribution

In principle the rates of loss or gain of land are calculated by the comparison of satellite images acquired at different points in time. The difficulty with applying this approach to the study lies in the existence of strong tidal range (difference between water levels at

low tide and high tide) which in combination with flat coast morphology in the Ganges Delta could result in misinterpretation of the extended tidal flat areas as land loss or gain. Therefore the project was a proof-of-concept to develop two new methodologies.

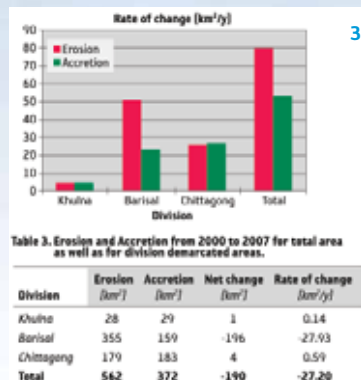
planquadrat Geoinformation developed a nearly automatic method based on the analysis of time series (1990, 2000, 2009) of more than 160 satellite images of freely available Landsat data, 90% of which were at the high tidal water level. These were further used to derive Land/Water masks using the mid-infrared spectral band (5) of the Landsat ETM+ satellite sensor. Those Land/Water masks were combined to time series data sets and classified into trend zones for erosion, accretion and tidal flats.

2



GRAS analyzed the impact of geometric resolution and very long time comparisons on the results. Data of different pixel resolution from 0,6m to 32m were tested. The time span of the EO imagery ranged from 1962 to 2007. Semi-automatic object-based segmentation and classification methods were applied as well as visual interpretation of the imagery.

Results

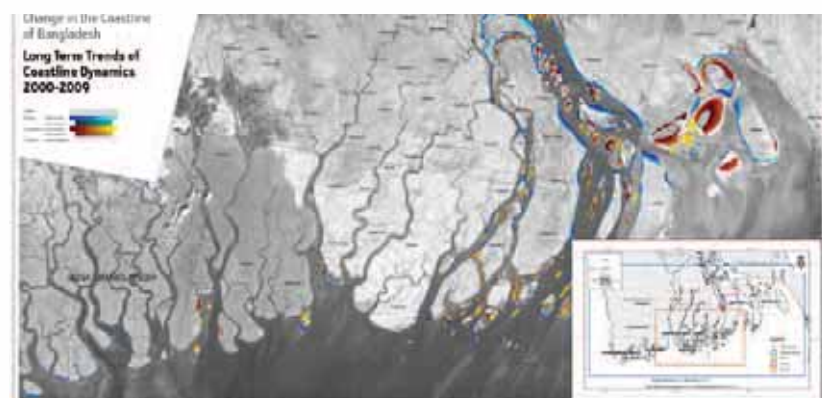


The results of this pilot project highlighted the added value of the analysis of EO data for the monitoring of coastline dynamics. For a large study area, the method provides useful baseline information on (i) locations with tendency to erosion and (ii) locations with tendency to accretion (Figure 3 and Figure 4). Additionally it provided robust and reliably annual average rates of erosion and accretion for the period of decades (Figure 5).

The analysis confirmed however that the level of the tide, i.e. the water level at time of data acquisition by the satellite sensor, has a significant impact on the results.

Semi-automatic methods can be applied to multi-spectral data while panchromatic data should be visually interpreted (Figure 2).

For more detailed information on rates of erosion and accretion, higher resolution EO data combined with detailed and exact digital terrain data of the coastal area and the tidal zone, as well as the exact tidal water levels along the coastline at the various points in time of the EO data acquisition would be required.



Climate Change Adaptation

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 The World Bank Group

Fig.1 The World Bank estimates that Bangladesh and the Netherlands are among the countries most exposed to rising sea levels. This is a colourful view of the Bangladesh coastline seen by Envisat's Medium Resolution Imaging Spectrometer (MERIS) © ESA

Fig.2 Coastline migration from 2000 to 2006 identified by manual interpretation. Credit: GRAS

Fig.3 Erosion and accretion trends from 2000-2007. Credit: GRAS

Fig.4 Annual coastlines on land-water mask backdrop of 1990. The 11 annual coastlines were attributed a color range from orange (2000) to dark blue (2009), plus red for 1990. Credit: planquadrat Geoinformation

Fig.5 Long term trends in the coastal dynamics. Classification of the study area is done using the slope intercept approach. Colour scheme according to the slope-intersect matrix provided in the study: blue and blue-green areas are erosion areas, brown to yellow areas are accumulation areas, mid gray areas are tidal flats. Credit: planquadrat Geoinformation. Smaller image on the left shows the location map of Bangladesh and division boundaries and areas of interest covered by the service. Credit: GRAS

Service providers

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Service providers

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Earth Observation satellite missions used in the eoworld projects

The **eoworld** initiative took the opportunity to showcase the capabilities of European and Canadian satellites, ESA and national missions, and also harnessed a variety of other missions' datasets. The plethora of data used reflected the needs of the ESA-World Bank projects which relied on a combination of EO data from different sources, both to increase sustainability of services provision and to complement the range of observation parameters. In addition, ESA have been early in discussions with mission operators to anticipate new data acquisition for the majority of the twelve ESA-World Bank projects.

The services are largely based on ESA's own Earth observing satellites – the ERS-1&2 and ENVISAT missions. Moreover, ESA provided access to the so-called 'ESA Third Party Missions' (ESA TPM) - satellites operated by organizations (public and private) other than ESA, both European and non-European. 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 or worldwide user community.

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. The most prominent examples of ESA TPM used in the framework of the **eoworld** initiative are SPOT1-4, Landsat, Kompsat, ALOS, and Ikonos. The service providers were granted a Category 1 user status, which allowed them to access TPM data at cost of reproduction.

Concerning EO data not covered by the ESA TPM scheme, these were procured commercially by the service providers (i.e. RapidEye, SPOT5, SPOT DEM, Cosmo SkyMed, TerraSAR-X, Radarsat, GeoEye, Quickbird and WorldView). In case of the European national missions



ESA was in a fruitful dialogue with the operators concerning planning, programming and acquisition of new data to stimulate their active involvement in data procurement.

Data Policy

European Space Agency's Earth Observation Data Policy is based on free and open access principles and it was defined by the ESA Member States with the objective of maximizing the beneficial use of ESA and of TPM data and to facilitate balanced development of science, public utility and commercial applications.

ESA is moreover dedicated to advancing international trends for full and open access to EO data, in line with inter-governmental Group on Earth Observation (GEO) data sharing principles, setting the context for future data policies. In case of non-ESA missions used in the framework of eoword projects, the underlying image data licensing conditions vary. This is in particular relevant to the data available commercially for which data licenses usually depend on the applicable Terms and Conditions (rights and obligations of the users).

Future ESA Missions: GMES Sentinels

With the start of the European flagship space program-GMES (Global Monitoring for Environment and Security) European Union and ESA provide the framework for the development of the operational Earth Observation system of a new generation.

ESA is developing five families of new Sentinel missions specifically for the GMES programme, the first of which is scheduled to be launched in 2012. The Sentinels will provide a unique set of observations, starting with the all-weather, day and night radar images from Sentinel-1 to be used for land and ocean services, followed by Sentinel-2 which will deliver high-resolution optical images for land services, Sentinel-3 for services relevant to the ocean and land and Sentinel-4 and Sentinel-5 for atmospheric composition monitoring from geostationary and polar orbits, respectively. Sentinel missions will provide worldwide carpet coverage resulting in an unprecedented increase in the amount of Earth Observation data available to the users while guaranteeing a long-term continuity of observations for future decades (25+ years).

Along with the Sentinels, there are around 30 existing or planned missions contributing to the GMES programme. These include missions from ESA, their Member States, Eumetsat (European Organization for the Exploitation of Meteorological Satellites) and other European and international TPM.

Sentinel Data Policy Principles includes full and open access to Sentinel data to all users. Overall, with GMES operations in place ESA is aiming for maximum availability of data in support of increasing demand of EO data in context of climate change initiatives and for the implementation of environmental policies, also resulting in many humanitarian benefits to international development community.

GMES is all about delivering products and services to manage and protect the environment and natural resources, and ensure civil security. The GMES 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, including downstream sector providing information based on these core thematic areas and offering tailored solutions to specific regional or local needs, as well as the needs of the specialized global users. The monitoring capacity of GMES will be used for the benefit of the international community with the objective to support effective environmental policy-making for a more sustainable future.



ENVISAT (ESA)

Launch date: 2002

Type: Optical and radar

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

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



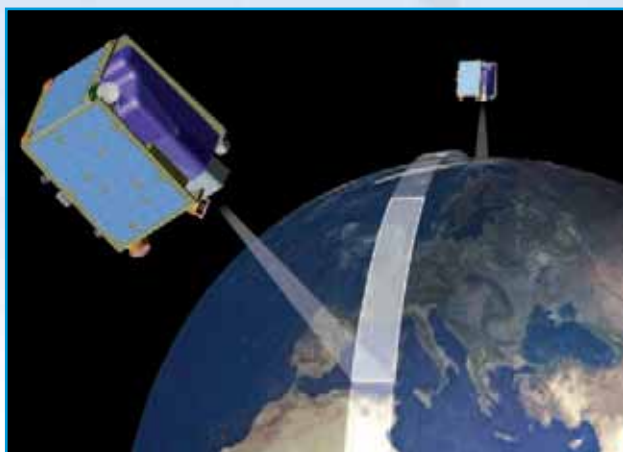
SPOT 1-5 (CNES / Spotimage)

Launch date: SPOT 1 (1986-1990), SPOT 2 (1990-2009), SPOT 3 (1993-1997), SPOT 4 (since 1998), SPOT 5 (since 2002)

Type: VHR and HR Optical (2,5m – 20m res)

The SPOT system was designed by the French space agency (CNES) and it is operated by Spot Image. SPOT imagery comes in a full range of resolutions from 20m down to 2,5m, 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 stereopairs acquired by the HRS instrument on SPOT5 with 10 to 20m vertical accuracy.

www.spotimage.com



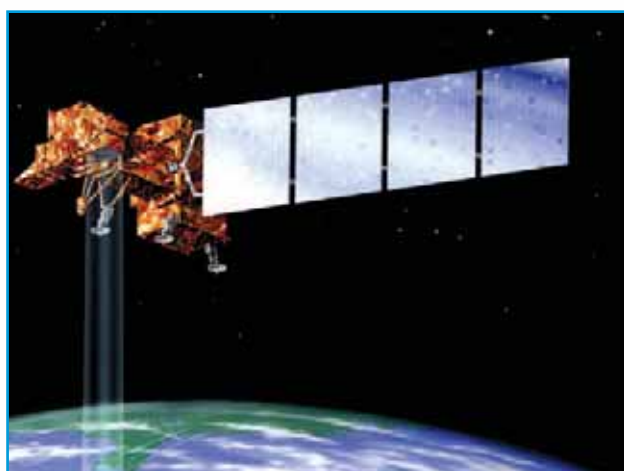
RAPIDEYE (RapidEye AG)

Launch date: 2008

Type: HR Optical (5m res)

RapidEye - a German constellation of five identical EO satellites at 5m 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



LANDSAT (NASA)

Launch date: 1972

Type: Optical (30m res)

Landsat imagery accounts for the largest parts of Earth's surface displayed on web mapping services. NASA-owned the vast majority of Landsat data is made available free of charge for any use by different web services like the USGS Landsat archive. Landsat is ESA's Third Party Mission.

<http://earth.esa.int/TPMDAG/landsat.html>



Kompsat-2 (KARI)

Launch date: 2006

Type: VHR Optical (1m res)

Kompsat-2 was developed in South Korea by KARI (Korea Aerospace Research Institute). The main mission objectives of the KOMPSAT-2 system are to provide a surveillance of large scale disasters and support disaster response, acquisition of independent high resolution images for GIS (Geographic Information Systems), composition of printed maps and digitized maps for domestic and overseas territories and survey of natural resources. Kompsat is ESA's Third Party Mission

www.esa.int/esaEO



COSMO SkyMED (ASI / e-geos)

Launch date: 2007

Type: VHR Radar (up to 1m res)

COSMO-SkyMed (Constellation of Small Satellites for Mediterranean basin Observation) is a 4-spacecraft constellation, conceived by ASI (Italian Space Agency) and funded by the Italian Ministry of Research (MUR) and the Italian Ministry of Defence (MoD). Each of the four satellites is equipped with the SAR-2000 instrument operating in the X band and is capable of operating in all visibility conditions at high resolution and in real time. 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.

www.egeos.it



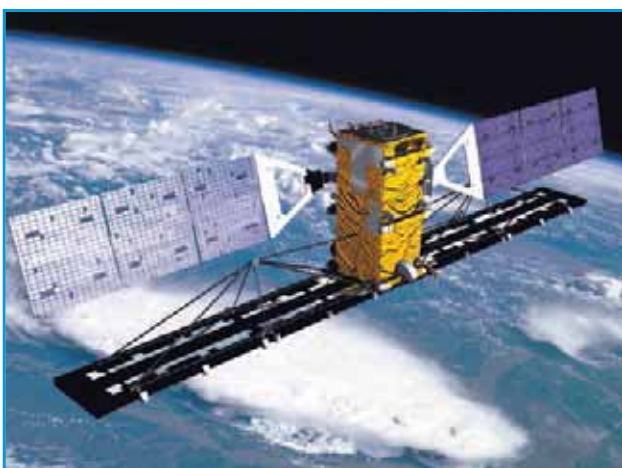
TERRA SAR-X (DLR / Infoterra GmbH)

Launch date: 2007

Type: VHR Radar (up to 1m 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 2m (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.

www.infoterra.de



RADARSAT 1-2 (CSA / MDA)

Launch date: Radarsat-1 (1995), Radarsat-2 (2007)

Type: VHR Radar (up to 2m 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 ESA's Third Party Mission. www.gs.mdacorporation.com | http://earth.esa.int/TPMDAG/radarsat_sar.html



ALOS (JAXA)

Launch date: 2006-2011

Type: VHR Optical (2,5-10m res), HR Radar (up to 20m res)

The Advanced Land Observing Satellite "DAICHI" (ALOS) has been developed by the Japanese Space Agency - JAXA - to contribute to the fields of mapping, precise regional land coverage observation, disaster monitoring, and resource surveying. ALOS is ESA's Third Party Mission.

http://earth.esa.int/TPMDAG/alos_palsar.html



Ikonos (GeoEye)

Launch date: 2000

Type: VHR Optical (0,8m res)

The world's first commercial satellite able to collect black-and-white (panchromatic) images with 82-centimeter resolution and multispectral imagery with 4-meter resolution. Imagery from both sensors can be merged to create 1-meter colour imagery (pan-sharpened). It is being used for national security, military mapping, air and marine transportation, and by regional and local governments. Ikonos is ESA's Third Party Mission.

<http://earth.esa.int/TPMDAG/ikonos.html>



GEOEYE 1 (GeoEye)

Launch date: 2000

Type: VHR Optical (0,4m res)

GeoEye offers unprecedented spatial resolution by simultaneously acquiring 0,41-meter panchromatic and 1,65-meter multispectral imagery allowing for a number of applications in every commercial and government sector.

www.geoeye.com

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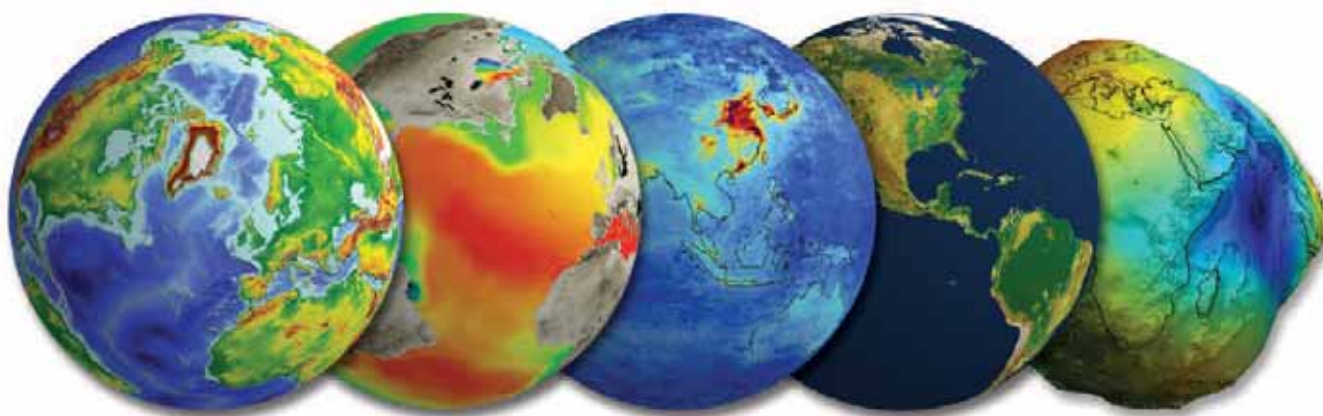
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