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EARTH observation SERVICES today

METOCEAN

USING RADAR FROM SPACE

the Living Planet

THE NEED FOR BETTER INFORMATION

Safety, environmental security and operations cost reduction in the marine engineering, offshore exploration and shipping industries depend critically on accurate information on wind, wave and ocean current conditions. For example, stresses generated by eddies and other current features can damage riser systems and other deep water oil production equipment, and wave generated impact forces cause structural fatigue on vessel hulls and operations platforms. Wave-induced motion can easily cause collisions and capsizes as some operations involve the coupling of structures and unevenly distributed loadings. As a result, two categories of metocean information are required on a systematic basis:

Forecasts of local wind, wave and current conditions

Lifting oil production platforms on to their foundations, towing large and complex structures, recovering sunken vessels and connecting to riser buoys all require winds and waves to be lower than certain thresholds and the absence of specific propagation directions or wave numbers.

Pipeline-laying operations, for example, can only be carried out in conditions where waves are less than 3 metres. Drilling operations must be suspended when current shears exceed levels that cause unacceptable stress on drilling and riser infrastructure. For coast guard authorities, high-resolution wind, wave and current information is required for Search and Rescue operations, while ship operators require forecast wind and wave conditions to optimise fuel consumption and voyage times and racing yacht operators are increasingly reliant on customised metocean forecasts for tactical route planning.

Local and regional wind and wave statistics

Coastal protection agencies require environmental information as inputs for oil spill preparedness and response systems. Survey, dredging and salvage companies need to assess the likely downtime due to bad weather when estimating costs for a particular job. The establishment of design criteria such as limits on operations deck weights and materials selection for offshore production platforms and coastal defence structures is based on statistics of expected average and extreme wave conditions. Planning when to undertake particular activities such as lifting and installation operations requires seasonal or monthly statistics. Insurance companies require average and extreme statistics when certifying ships and production facilities for operations in specific locations and periods.

"accurate and timely information on wind, wave and ocean current conditions is critical for marine operations"

SPACE-BASED
and TRADITIONAL METHODS
to BETTER MEET **USER NEEDS**

THE LIMITATIONS OF TRADITIONAL TECHNIQUES

Several national meteorological organisations operate regional or global wave forecasting models and use these as the basis for commercial or operational services. However, these provide wave forecast information on a low spatial resolution grid and hence fine scale variations may not be fully represented. Furthermore, these models cannot fully account for phenomena such as long wavelength swell propagation generated by storm systems. Increasingly, metocean instrumentation such as wave radar and acoustic doppler current profilers (ADCP's) are being installed on offshore oil and gas platforms to support customised 12-24 hour forecasts for short term operations planning and management. These instruments cover only local conditions however and many operators admit that there is room for improvement in these forecasts. Coastal radar installations can measure surface currents (e.g. using Over the Horizon techniques originally designed to detect low flying aircraft) but the resolution is poor and the coverage is highly dependent on the set up of the radar station.

For statistical wind and wave information, historical records are a low cost source of metocean information, however the quality of the data is often difficult to assess and these data are usually confined to measurement stations and ship routes. Where local information is required, moored buoys are deployed for fixed time periods but these provide point measurements and may be difficult to extrapolate up to regional level statistics.

THE BENEFITS OF SPACE-BASED MONITORING

Satellite based measurements of ocean conditions offer a range of benefits, which complement conventional data collection systems. Examples include:

> **Wide area coverage.** Earth Observation instruments enable retrieval of wave height and period, wind vectors and ocean current velocity at global and regional scales. This provides a more synoptic view of mesoscale processes that will affect local conditions and which in-situ instrumentation may not be able to identify.

> **Homogeneity.** EO data offers extensive archives of consistent, quality-controlled data in an homogenous format. A typical satellite operational lifetime is between 5 and 10 years, with a series of identical instruments such as radar altimeters and scatterometers launched on a regular basis. This guarantees consistency within a long time series data set, allowing higher

quality statistical inferences to be made. Similarly, satellite based measurement of metocean conditions over large regions are performed by the same instrument, minimising difficulties in cross calibration and integration of data.

- **Comprehensive time series.** Satellite based instruments measuring wind, wave and current conditions are operating near continuously, so that the time-space density of measurements is more complete than networks of in-situ measurement systems.
- **Rapid turn-around.** Satellites provide global coverage while specially designed ground station processors ensure that the data are processed and disseminated extremely rapidly. Wind and wave data from the ERS mission were available on a systematic basis to national meteorological offices and commercial metocean service providers within three hours of the satellite acquiring the measurements. For historical data, satellite operators maintain complete archives of their metocean measurements and support rapid access to these datasets via internet requests.
- **Accessibility.** Due to their global coverage, satellites gather data from remote or harsh environments that are far offshore and inaccessible or infrequently visited by ships. Satellite based measurements from such areas can be compiled without the need to leave your desk.

While in-situ measurements remain an extremely important source of metocean information to offshore engineers and operators, EO data offers a powerful source of complimentary information, especially when combined with the in-situ point measurements through appropriate models and data assimilation techniques.

THE INTEGRATION OF EO IN EXISTING GEO-INFORMATION SERVICES

For wave and current forecasting and nowcasting, EO derived measurements are combined with buoy, ship and platform measurements by assimilation into regional and global models. In the case of wave conditions forecasting, radar altimeter derived significant wave height measurements are assimilated into wave forecasting models such as WAM. Organisations such as the UK Meteorological Office provide wave forecast services to offshore operators based on the output of these models.

These models are run every 6 hours and each measurement is assigned a weight based on the time of observation, the confidence in the measurement and the location compared with the model grid point. The assimilation procedure combines the different measurements (including the initial values calculated by the model) so that the most likely value is generated at each point and then propagates the forecast forward so that the most realistic conditions are obtained at each forecast step. To ensure this procedure is effective, it is crucial that all available measurements arrive in time for the assimilation - in response to this requirement, fast delivery wave height measurements from ERS and now Envisat are injected into the data exchange network of the national meteorological agencies (called the Global Telecommunications System or GTS) within 3 hours of the measurements being acquired by satellite. Similarly for wind information, wind vectors at 10m altitude, measured by the ERS scatterometer, were systematically injected into the GTS within 3 hours of acquisition.

"EO data offers a powerful source of complimentary information, especially when combined with in-situ point measurements through appropriate models and data assimilation"

Assimilation into ocean current models is more complex given the wider range of measurements that are ingested. For example, EO measurements of sea surface temperature and current vectors are combined with in-situ measurements of salinity, density and temperature as well as forecast and weather station estimates of surface wind stress. In some cases consideration of ice conditions, sediment load and biomass concentrations need to be taken into account. In addition, different models have to be combined in a dynamically consistent manner so that global coverage low-resolution models provide boundary conditions for local and regional coverage finer scale models nested inside.

Given the time scales on which ocean currents evolve, the access times for the EO measurements are more relaxed and data are delivered within 24 hours. This includes precise correction of the altimeter measurements to correct for factors such as atmospheric effects delaying signal propagation time (and hence implying a lower sea surface level) and precise orbit correction. In some cases, measurements from different altimeters are combined into an integrated high-resolution dataset before being assimilated into ocean current models.

In addition to altimeter derived currents, imaging sensors such as SAR and thermal radiometers can be used to derive sea surface current conditions. These instruments provide a much finer resolution of the current structure. These images are presently used as analysis charts in the same way as a meteorological forecaster uses analysis charts to understand present atmospheric conditions. This enables more precise delineation of eddy and frontal boundaries and hence a more accurate estimate of the potential impact on offshore operations.

EXPLOITING NOVEL EO-BASED TECHNIQUES

Radar altimeters measure the height above a surface by the time taken by the radar pulse to travel to its target surface and return. By knowing the precise position of the satellite, variations in the height of the sea surface can be detected as variations in pulse travel time. The degree of modulation of this returned pulse gives a measure of the sea surface roughness, which provides an estimate of local wave height averaged over the footprint of the pulse.

Retrieval of ocean current information from sea level anomaly measurements is similar to generation of wind speeds from atmospheric pressure data. These height anomalies can reach several tens of centimetres over major current systems such as the Gulf Stream. Clearly the radar altimeter height measurement must be very precise to ensure an accurate geostrophic current is generated - at present the Jason and Envisat altimeters measure sea level height anomaly to an accuracy of around 3cm.

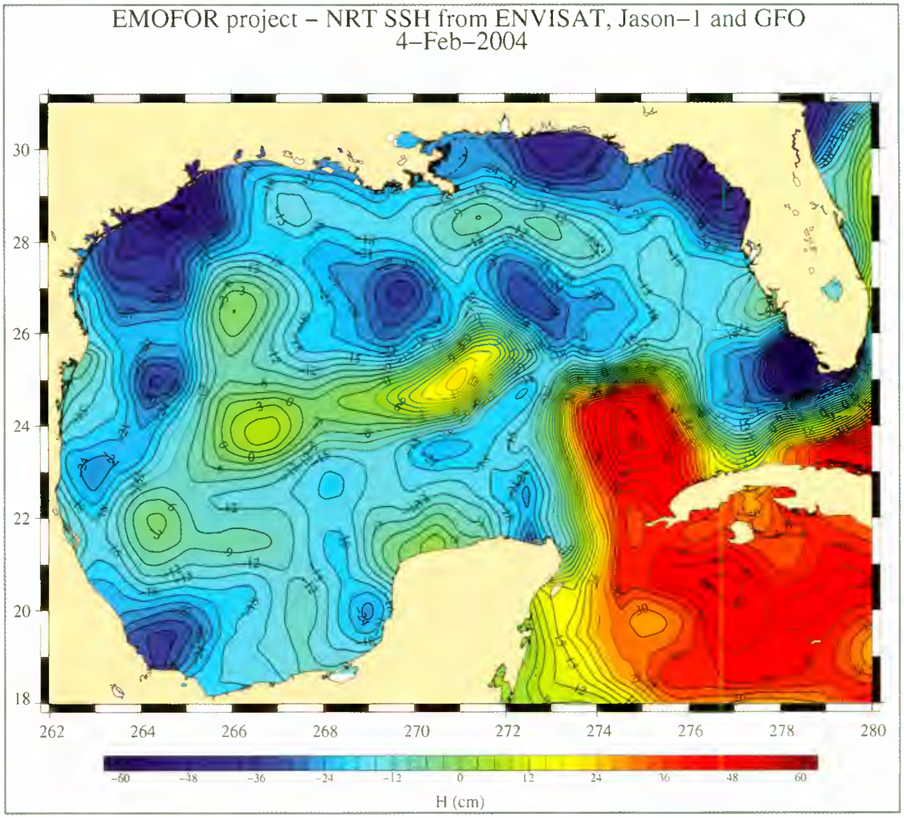
By generating maps of the ocean current structure, eddies and loops can be identified and their propagation monitored on a regular basis. Marine operators likely to be affected by these currents can then be notified well in advance.

Scatterometer instruments measure fine scale sea surface roughness generated by local wind conditions. For very small wavelengths there is a defined relationship between the observed surface roughness and the wind speed and direction, enabling the retrieval of wind vector data from the scatterometer. At present, the main impact of scatterometer data is in the detection of atmospheric depression structures. By assimilating the scatterometer measurements, the location of these structures can be corrected so that the forecast information is more accurate.

In addition, scatterometer data provide a higher resolution representation of the wind vector close to the sea surface than conventional atmospheric models, enabling local forecasters and operations managers to make better decisions based on more precise local data.

Satellite based Synthetic Aperture Radar (SAR) instruments measure the intensity of radiation scattered back to the satellite from the oceans surface which is strongly related to surface roughness properties. This allows retrieval of wave direction and wavelength, as well as the detection of mesoscale features such as ocean currents, fronts, eddies and internal waves. The Advanced Synthetic Aperture Radar (ASAR) instrument on Envisat has a wide area coverage (up to 405km swath width) and multi mode (polarisation and incidence angle) imaging capabilities, further enhancing the ability of the instrument to detect ocean features.

Thermal infrared instruments such as the AATSR (Advanced Along Track Scanning Radiometer) on Envisat, enable the derivation of Sea Surface Temperature at scales of approximately 1km and with an accuracy better than 0.5°K.



Near real time sea surface heights for the Gulf of Mexico, using altimeter data.
© CLS/Ocean Numerics

Monitoring and forecasting services for the offshore industry

The offshore oil and gas idustry requires metocean information to support the design of offshore structures, and also for use in routine operational planning. For design purposes, estimates of extreme metocean criteria, based on analysis of available long-term datasets, are required to facilitate engineering solutions that are both safe and cost effective. For operational planning activities such as exploration drilling, installation of structures, and operation of production facilities, the requirement is for characterisation of present metocean conditions, and, ideally, reliable short-term forecasting.

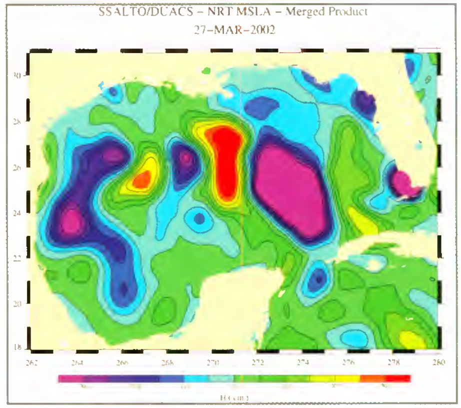
Ocean Numerics, a partnership between FugroGEOS, NERSC and CLS, is offering EO based products and services to support deep-water exploration and field development and operations for the offshore industry. The products and services on offer can be tailored to specific customers depending on requirements, and include historical statistics for design and operational purposes, monitoring for ocean feature recognition, including eddy structures and currents, and near real time drilling support, as well as site specific and regional forecasts.

A standard service involves regular reporting (twice weekly) describing the ocean processes and features appearing at the clients' location of interest with forecasts of magnitude and timing of periods of strong currents. Telephone support and access to specialised forecasters offshore are also provided on request.

Feature analysis charts are constructed using all available EO data and in-situ data. Near real time processing of altimeter data provides maps of sea level anomalies and geostrophic currents, which give an estimation of the strength of oceanic eddies and allow the monitoring and propagation of eddies and fronts on the sea surface. These near real time products can be updated with a time delay of 48-72 hours. They give a synoptic view of near real time sea level variation as well as information on current velocities and strength. The hind cast products give a statistical view of current variability over a much longer time period. Sea surface temperature data (e.g. from AATSR on Envisat) and Ocean colour data products (e.g. from MERIS on Envisat) identify the extent of oceanic fronts and eddies.

Numerical modelling techniques provide 3-D forecast information on currents, temperature and salinity at selected depths in the form of vector time series plots. Hindcast modelling outputs can be used for the derivation of current extreme statistics, criteria required for support of design and production activities. In addition

SERVICE **EXAMPLES**



Top Mean sea level anomalies from the Gulf of Mexico, using altimeter data. Maps of sea level anomalies and geostrophic currents, give an estimation of the strength of oceanic eddies and allow the monitoring and propagation of eddies and fronts at the sea surface.

© Ocean Numerics

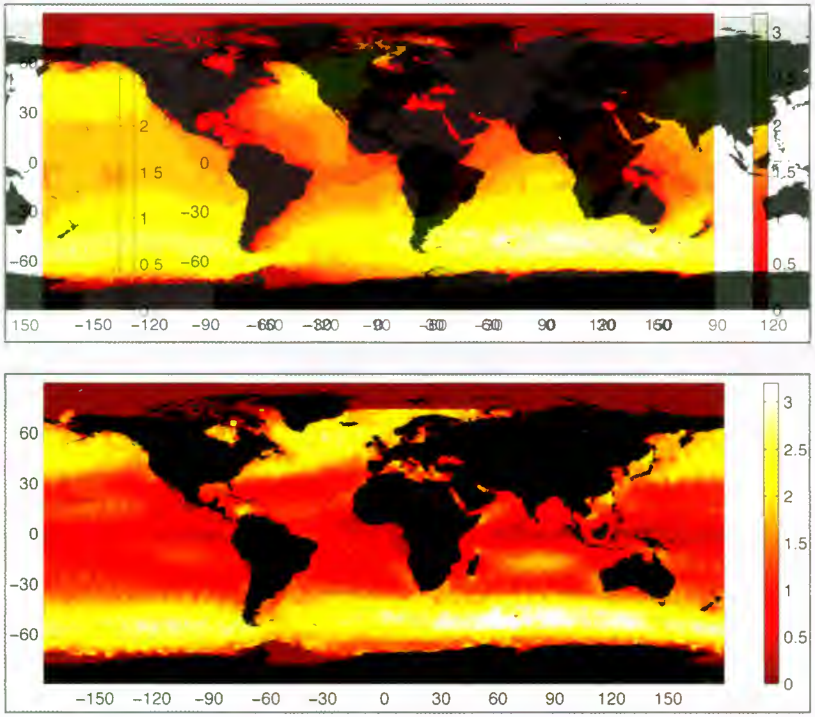
numerical modelling systems (such us HYCOM operated by Ocean Numerics) are easily located to any area since they are based on general circulation equations.

On line wind and wave information

Wave Climate is an on-line wind and wave climatological service offered by ARGOSS. Wave Climate is based on an extensive database of satellite derived wind and wave data derived primarily, but not exclusively, from ERS radar altimeter, scatterometer and SAR wave mode data. It has been further developed to include spectral ASAR data from Envisat.

The service covers all of the world's oceans and seas to a resolution of approximately 200 km^2. Wave Climate allows one to query the database online, via the Internet, and retrieve information on wind speed and direction, significant wave height, mean period and direction of the entire sea state, and also separately of wind sea and swell. The data set of significant wave height dates back to 1985, with data of other parameters generally being available from 1993 onwards.

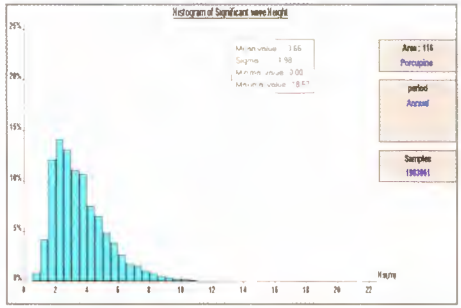
ANNUAL MEAN SIGNIFICANT HEIGHT OF GLOBAL SEA SWELL, AND GLOBAL WIND-SEA IN METERS.
© ARGOSS

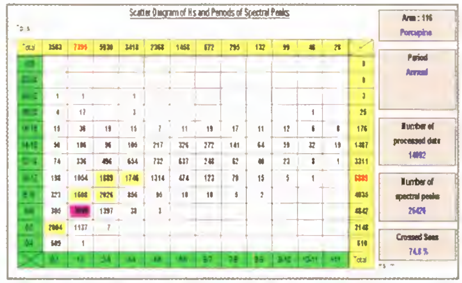


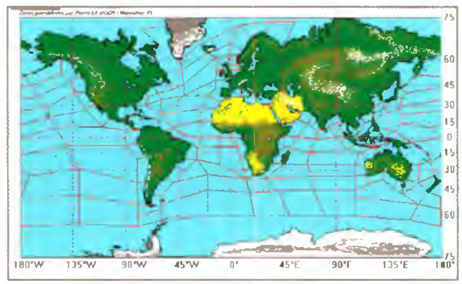
ARGOSS also offers an on line voyage-planning tool, Route Climate, for the maritime transport industry. Route Climate, is based on the same database as Wave Climate, and provides ship operators with information on the climatic conditions on their voyage, as well as the probability of meeting critical wind and wave conditions and a selection of optimal routing options. Both Wave Climate and Route Climate services have been extensively validated against marine data buoys and the accuracy limits are clearly stated in the product specifications.

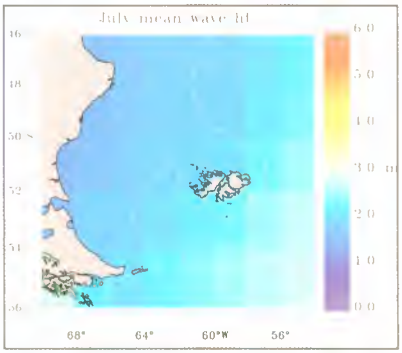
In partnership with IFREMER, (Institut Français de Recherche pour l'Exploitation de la Mer), MétéoMer have developed CLIOsat, a wind and wave climatological service based solely on satellite data. CLIOsat provides information on significant wave height, wave peak periods and directions, wind speed and direction and scatter diagrams of spectral parameters of waves, from wind and wave satellite measurements and covers 170 global sea areas on a quarterly and annual basis. MétéoMer also have considerable expertise in marine weather analysis and forecasting and offer a maritime forecasting service providing oceanographic information in near real time to maritime operators.

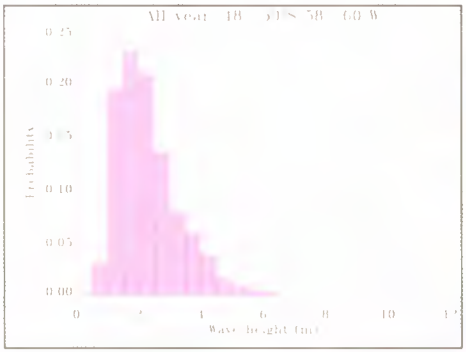
Satellite Observing Systems (SOS), maintains the WAVSAT database, containing continuous satellite observations, which provide global wave statistics of wave height and surface wind speed. Monthly average and extreme values can be calculated along a given route for any location. The Sea State Alarm service from SOS provides access to global wind and wave fields measured over the previous 24 hours by the ERS-2 radar altimeters.

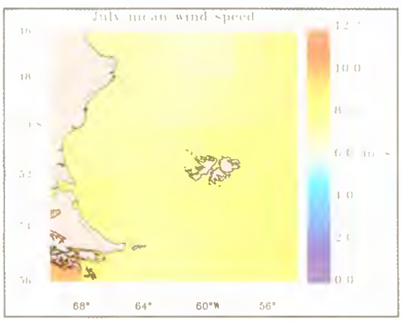












Mean significant wave height and wind speed around the Falkland Islands in the austral winter month of July, together with a histogram of wave heights, with a mean wave height of 2.3 m (Altimeter data from Geosat, ERS and TOPEX).
© SOS Ltd for FugroGeos Ltd

CLIOSat product from MeteoMer provides information on significant wave height, wave peak periods and directions, wind speed and direction for 170 global sea areas.
© MeteoMer

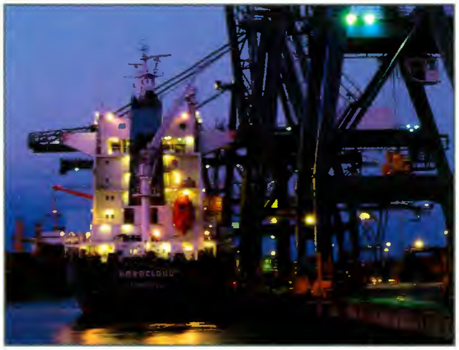
FUTURE OUTLOOK

Growing Markets

Demand for customised metocean data is expected to evolve in terms of both volume in demand and complexity of information requirements. Some highlights are summarised below.

Offshore exploration will continue to expand into new frontier areas, especially into deeper waters off the Continental Shelf. This will drive industry demand for both statistical products to support structure design and operations planning and for more complex environmental forecasting services in areas with extreme wave or current conditions.

Marine construction, towing and salvage activities are becoming increasingly complex both as a result of the nature of systems to be moved or recovered and due to heightened concern over environmental safety as a result of construction or recovery operations (the priority in many emergency interventions is to remove the harmful or noxious elements of the cargo before they can escape into the marine environment). These activities are therefore reliant on accurate and timely metocean information to a much greater extent than was the case previously.



Within Europe, improved transportation of goods and people is seen as one of the foundations of economic growth. In parallel, improved transport links are seen as vital to support effective cultural and economic integration with the mainstream European economy. An important component of future transport policy is increased utilisation of short shipping routes and so-called fast ferries. However, many of these vessels are considerably more sensitive to local wind and wave conditions than older longer haul shipping, generating a requirement for improved accuracy and higher resolution, short and medium term metocean forecasting.

Navy operations are increasingly being conducted in the littoral environment where complex oceanographic processes can strongly impact on the performance of surveillance and targeting systems and drive choices for support ship location and landing strategies. For example, internal wave and sediment load conditions strongly influence acoustic propagation conditions affecting sonar detection capabilities while the presence of specific algae can cause bio-luminesence in submarine wakes, rendering them easily visible to maritime patrol aircraft.

Coast Guards and other marine rescue agencies have basic systems in place today to support planning and execution of Search and Rescue activities. Examples include use of local fine-scale hydrodynamic models to identify priority areas for investigation and define appropriate search patterns. As confidence grows in the capabilities of models presently under development, this will drive increased demand for both global metocean measurements as boundary conditions and local and regional scale measurements to drive the model forecast runs.

As part of the European ratification of both the MARPOL convention and the Oil Spill Preparedness and Cooperation Convention, national and regional authorities must implement more effective emergency response and counter pollution systems and ensure these are coordinated for European coastal waters. Present systems provide a basic risk assessment but have strong limitations - for example, no operations system was able to reproduce the double slick pattern observed as a result of the Prestige accident. To support these requirements, improved oil spill drift models are under development and these will require state of the art oceanographic models driven by operational sources of wind, wave, current and temperature measurements.

"Demand for customised meteocean data is expected to evolve in terms of volume of demand and complexity of information requirements"

New EO systems

Until recently the impact of using EO data for metocean applications has been hindered by poor revisit times and limited spatial coverage of the sensors. One important example has been the single swath scatterometer aboard the ERS mission from which data were assimilated into wind and wave models on an operational basis, but which could generate only a limited impact on regional and local models. With the launch of Metop however, the dual swath Advanced Scatterometer (ASCAT) will continue the heritage of C-band measurements and result in a significant improvement in model forecast accuracy. The Metop mission series also guarantees the long-term availability of these datasets.

Numerical Modelling & Data Assimilation

A wide range of ocean measurement instrumentation, data assimilation techniques and models presently exist and for the most part these are not connected in any coherent fashion. Various efforts are underway to rectify the situation under international cooperation programmes such as GOOS (Global Ocean Observing System) and the Ocean Observing Panel for Climate Change. One key element of this development is the Global Ocean Data Assimilation Experiment (GODAE). This is the basic initiative driving present European activities to integrate different regional and basin scale ocean models and upgrade data gathering and assimilation. GODAE has defined a practical demonstration of real-time global ocean data assimilation to provide a regular, complete depiction of the ocean circulation at time scales of a few days and space scales of several tens of kilometres, consistent with a suite of space and direct measurements and appropriate dynamical and physical constraints. Although largely driven by the research community, operational institutions such as national meteorological offices and naval operations support organisations, together with a number of private oceanographic information companies, are closely involved and in a position to spin out the resulting capabilities into the operational and commercial domains.

ACKNOWLEDGEMENTS >>

This booklet provides descriptions of EO services available today from specialist providers for the marine environment e.g. CLS (Collecte Localisation Satellites) and NERSC (Nansen Environmental and Remote Sensing Centre), Ocean Numerics, ARGOSS, MétéoMer and Satellite Observing Systems (SOS). For their work in market development these companies have been supported by ESA's Earth Observation Programme.

For further information on the EO service industry

CLS Jean Yves Le Bras • FRANCE
http://www.cls.fr

Mercator Pierre Bahurel • FRANCE
http://www.geos.com

MeteoMer Pierre Lasnier • FRANCE
http://www.meteomer.fr

NERSC Ola Johannessen • NORWAY
http://www.nersc.no

Ocean Numerics Robin Stephens • UK
http://www.oceannumerics.com

SOS Tom Allan • UK
http://www.satobsys.co.uk

For further information on EOMD activities and ENVISAT Program

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A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE

Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.

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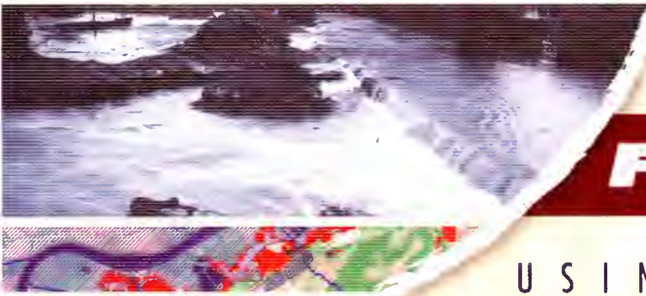

FLOOD MAPPING

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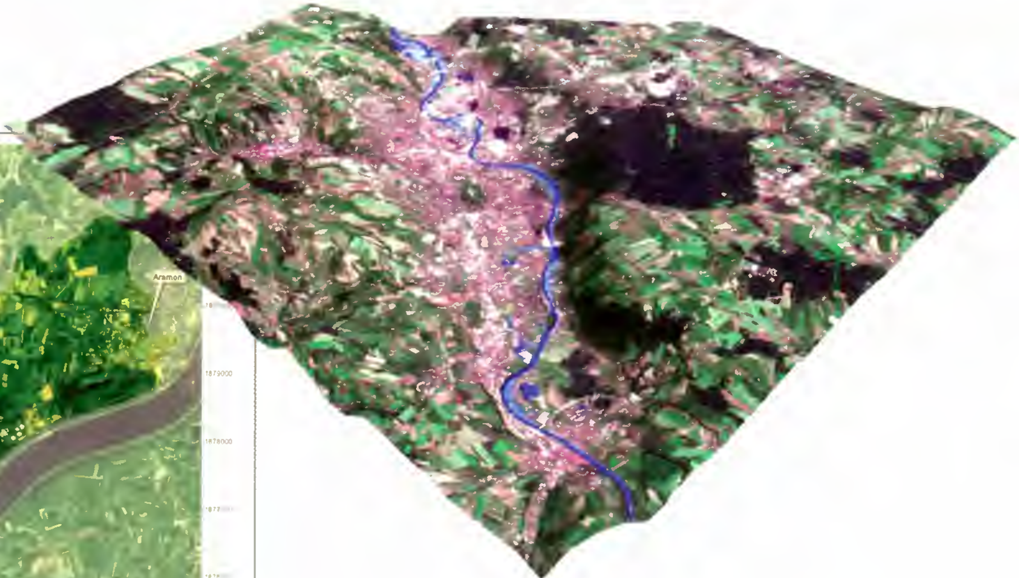


Oblique aerial ... 1995 ... aerial ... R ... M ... Wa ... A ... M ... D ... A ... 19 ... 2002 ... ENVISAT ASAR ... SPOT-2 ... R. A ... the S... 2002 ... in France ... SPOT5 ... P... by SERTIT. Processed by SERTIT. Envisat images ©ESA, 2002. Spot images ©CNES, 2002. *Distributed by Spot Image. Courtesy of P.Y Valantin of the Service of the Navigation, Nancy, France.*

THE NEED FOR BETTER INFORMATION

Flooding is a major hydrological hazard with a high frequency of occurrence. During the last decade floods have affected approximately 1.5 billion people. This is more than 75% of the total number of people reported as affected by natural disasters worldwide. There is an annual average of about 150 serious floods around the world, with significant rises in water level ranging from severely overflowing streams, lakes or reservoirs to major ocean-driven disasters in exposed coastal regions. Like droughts, floods are catastrophic events, following to a certain extent an often-predictable natural cycle. Timely information concerning the flood phenomena, which may provide strong indicators of a forthcoming disaster, can often help to track and identify potential flood zones that may be hardest hit.

Flooding events develop on a variety of time scales, sometimes over several days (plain floods) but in some cases in just a few hours (flash floods). The resulting damage affects people, property, road and rail links, agriculture and last but not least wildlife and the environment.

It is essential then to support prevention measures by estimating flood risk, which takes into account both vulnerability and hazard, the first being a measure of the degree of human and property loss, which would result from the disastrous event, and the second the probability of occurrence of critical conditions, which would trigger the crisis start.

Efficient monitoring is thereafter a fundamental necessity during the crisis and post-crisis phases of the flooding event in order to minimise and evaluate its impact in terms of human safety and damage to property. In addition, monitoring is also a necessity in the prevention and alert phases in order to support the zonation and risk assessment in areas subjects to flooding. This includes the characterisation of the impact of flood events together with the analysis of vulnerability exposed in these areas

[illegible] 1999 [illegible] 200 years in South Germany. [illegible] VISTA GmbH

THE LIMITATIONS OF TRADITIONAL TECHNIQUES

Current conventional methodologies supporting a flood crisis do not offer a complete real-time view of the threatened area since they cannot show spatial trends and are mainly model-based.

Hydrologic and meteorological in-situ measurements provides frequent and updated data on river height and rainfall situation only at a limited number of locations. According to guidelines provided by the World Meteorological Organisation, the density of water level measuring stations should be selected in order to moni-

SPACE-BASED and TRADITIONAL METHODS to BETTER MEET USER NEEDS

tor a maximum area of 1000-2500 km^2 within plains and 300-1000 km^2 when areas are characterised by a more complex topography. But this is not usually the case.

In addition, flood extent is usually derived from historical analysis of maps of past events or model calculations based on previously mentioned in-situ measurements, with in some cases, inputs from satellite-derived meteo information. Refinement regarding the "real-time" situation may only occur through expensive aerial-photo campaigns, which require favourable meteorological conditions and demanding material and human resources logistics.

In the post-crisis phase, quantification and characterisation of damaged areas is currently obtained using conventional data collection methods (population statistics, administrative documents consultation, damage claims, etc.) and, in a few rare cases, by classical geo-information analysis based on river network databases associated with simplified hydraulic models.

THE BENEFITS OF SPACE-BASED MONITORING

Space techniques such as navigation, telecommunications and in particular Earth Observation can greatly improve flood management during all stages including:

- risk assessment, prevention
- preparedness, forecasting, alert
- crisis management, extent mapping
- post crisis phase, damage assessment

Prevention	Forecasting & Alert	Crisis & Post-crisis
• River Basins Characterisation: - Vulnerabilirty Maps - Risk Maps - DTM - Vegetation Cover - Land Use - Geology • Catalogue of Reference Scenarious	• Forecasting Model • Data Collection • Telecommunication • Forecasting Integrated System - Rain Forecasting - Flooded Area - Terrain Integrated System - Real-time	• Mobiles Localisation • Navigation • Crisis Images - Crisis Management - Post-crisis Analysis
• Local Communities • Ministry of Environment	• Flood Announcement Service • Civil Protection • Local Communities	• Civil Protection • Insurance

The figure shows the information needed for each stage of evolution of a flood event for the different actors concerned with risk management.
Courtesy of the PACTES* project, which is under the responsibility of the French Ministry for Research and CNES, lead by ASTRIUM and jointly conducted by a team of scientists, government agencies and industry players.

*Prévention et Anticipation des Crues au moyen des TEchniques Spatiales

These techniques therefore have a large applicability both in support to decision makers and for the insurance sector - for risk assessment and planification - and for the actors involved with emergency operations such as Civil Protection Authorities (CPAs) and other actors involved with flood defense - in the crisis and post-crisis phases.

This is especially the case for all-weather space borne SAR. Thanks to the availability of a number of programmable sensors on orbit, SAR (Synthetic Aperture Radar) systems ensure the provision of timely information (at scales up to 1:50 000) during a plain flood, when the event develops over a period of several days. The radar signal is not affected by meteorological conditions, as would happen in the case of an optical sensor, allowing timely and updated delineation of flooding, even through a single acquisition, thanks to the synoptic view of the sensor.

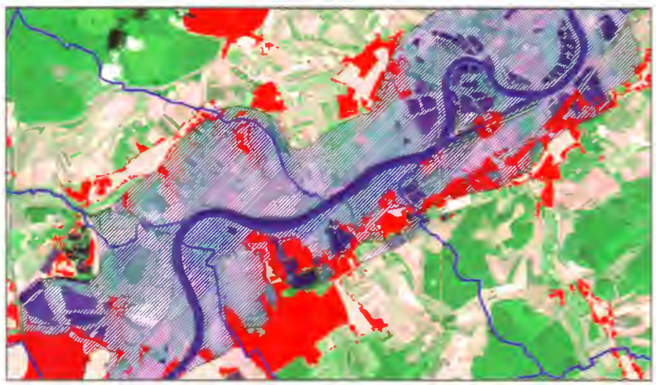
SAR derived flood extent measurements may be integrated with optical high or very high-resolution images, acquired in normal conditions before the event, exploited to describe land use and assess vulnerability. The combination of radar and optical data provides useful information for flood damage assessment as well as for flood risk zonal mapping.

[illegible] PROCESSED BY SERTIT.

THE INTEGRATION OF EO IN EXISTING GEO-INFORMATION SERVICES

Using such EO-derived information provides a valuable tool when integrated within the operational activities of people involved in the different phases of flood defence.

An up-to-date knowledge of land use and urban sprawl, joined with characterisation of river basins, contributes to mapping of (economic and human) vulnerability. Combined with a historical events database, spatial trends of risk are obtained to support the prevention phase, when all needed measures to limit flooding events consequences are established.



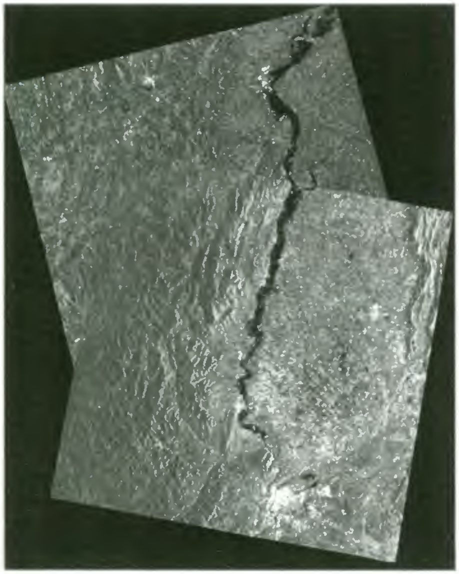
During a crisis, Civil Protection Authorities need up-to-date global information on flooded areas. Periodic analysis of a complete scenario, following the progress of the flood event taking into account the location of infrastructures and means for support relief operations, contribute to a more efficient decision making process. This information supports elaboration of emergency plans and allows visualisation of events at emergency headquarters thus helping to anticipate the event's evolution.

Once the emergency is over, Civil Protection authorities require an assessment of the extent of the flood as well as of particular features related to potential damage (communication networks, urban infrastructure, cultivated fields, etc) in order to help plan recovery actions.

Less stringent temporal requirements characterise the needs of insurance companies, interested in geo-information for calculating insurance premiums and compensation. The analysis of EO-based maps of flood extent help improve damage assessment for loss estimation. The identified areas are then combined with information on economic vulnerability in order to establish insurance fees. In the aftermath of a crisis, quantification of damages is made more efficient overall by jointly analysing the spatial trend of the flooding event, land use within the affected area and the company insurance contracts with their customers.

EXPLOITING NOVEL EO-BASED TECHNIQUES >>

ERS-2 SAR mosaic (radiometric and geometric corrections applied). The Saône river is the clearly [illegible] dark feature within the covered area. ERS images ©ESA, 2001.



As demonstrated by numerous European and international projects, EO-derived information based on current space borne missions can play a key role in natural risk management. The SAR can easily detect water-covered areas, characterised by a much lower intensity than any other feature in the surroundings. The main limitations are induced by the presence of nearby vegetation cover or the presence of wind, but change detection techniques using SAR acquisitions from different dates (in the normal conditions and during the flood), prove to be a robust way to overcome these difficulties.

The Envisat ASAR instrument, in continuity with ERS, is a C-band instrument that can observe details with a 30 m spatial resolution. Nonetheless it provides new advanced features enhancing flood monitoring: the Wide Swath acquisition mode (at 150m resolution, with 405km swath width) enables a higher temporal repeat and is suitable for medium to large basins, the steering incidence angle increases the revisit frequency at higher resolution. Moreover the alternate polarisation of Envisat ASAR combined with high incidence angles provides enhanced detection capabilities for flood monitoring. Today, used in conjunction with ERS and RADARSAT SARs the frequency of observations is significantly increased, to approximately once every 24-36h, to provide an operational flood mapping service.

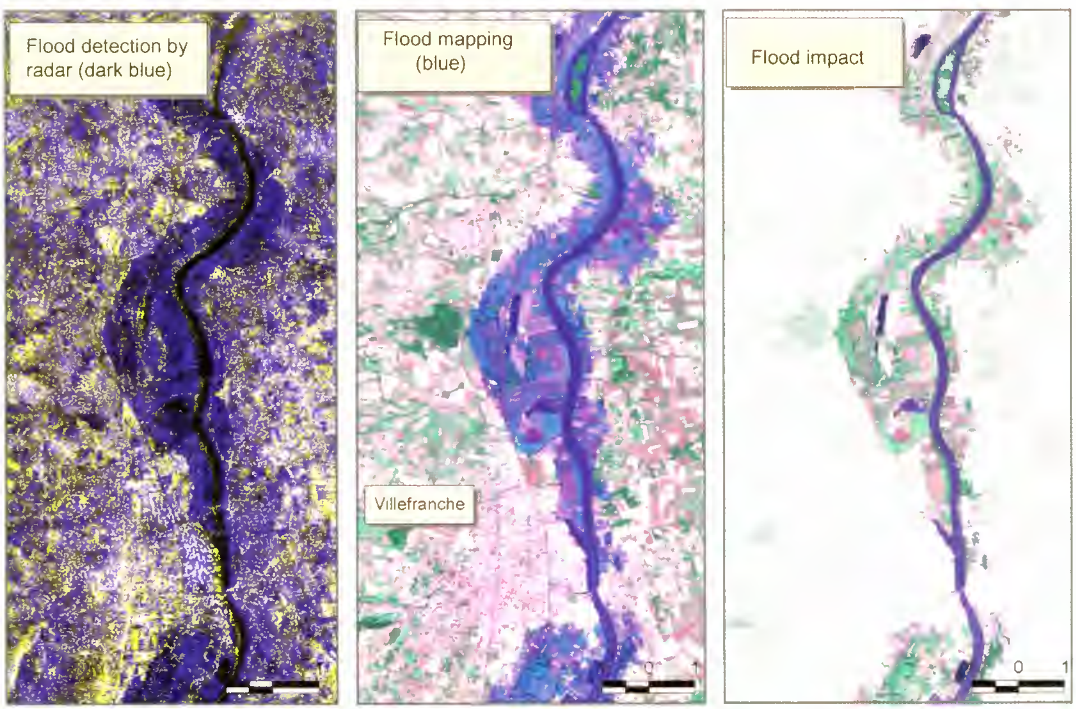
Optical sensors with high (~20m) spatial resolution eg. Landsat, SPOT 1-4, to very high (~1m) eg. IKONOS, QuickBird, SPOT 5, are a useful data source in clear sky conditions and/or when no flood event is ongoing. They are used as an input to analyse and update land use periodically.

All information layers derived from EO data can be easily integrated into Geographical Information Systems (GIS), which are also fed by other sources (i.e. administrative and socio-economic data, GPS measurements). The GIS then becomes a unique tool to support, during normal hydrological regimes, land management or planning and preparation for crisis management and, after a crisis, assessment of damages caused by the flood event. Moreover, advances in internet-based GIS services and faster communication routes, allow sharing of common information among different actors involved in management also during the flood crisis phase.

Nevertheless there are various limitations to EO based monitoring techniques in the case of flooding. In most situations Optical sensors are very difficult to exploit because of cloud cover. Meanwhile using a single space-borne SAR sensor does not generally provide the right frequency of acquisitions for flash flood events. Meeting temporal sampling requirements of a few days or better, implies to combine today's all-weather SAR sensors. Moreover although SAR imagery is an appropriate source of information, the effect of wind over inundated areas sometimes decrease detection capabilities and, secondly, in the absence of an accurate Digital Elevation Model, relief leads to geometric distortions of radar images wich can result in measurement errors. For all these reasons present solutions based on SAR and Optical EO data are generally applied to the the case of plain flood monitoring and for risk modelling and prevention, and still not considered mature for flash-flood monitoring purposes in an operational context.

[illegible] M. 27 2001) [illegible] ERS SAR [illegible]

Processed by SERTIT.
ERS images ©ESA, 2001.
Distributed by Eurimage.
Spot images ©CNES, 2001.
Distributed by Spot Image.



SERVICE **EXAMPLES** >>

SERVICE TO CIVIL PROTECTION AGENCIES

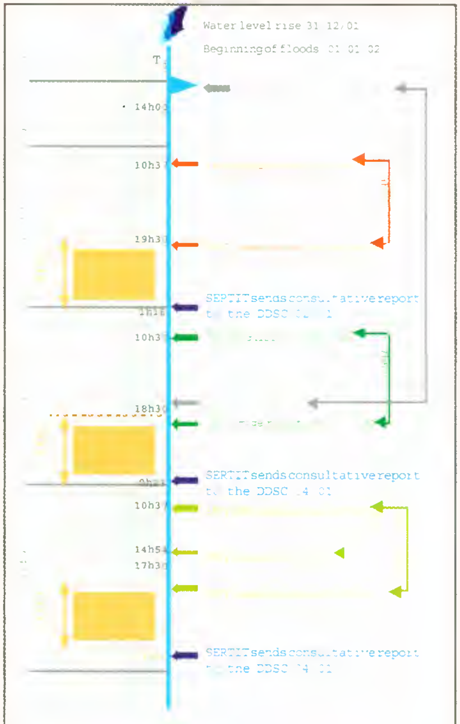
The measurements made at hydro-meteorological stations placed along the Meuse River, in the north east of France, started an alert on 31st December 2001. Rain and snowmelt from the Vosges Mountains had suddenly raised the water level threatening the population and infrastructures in the Champagne-Ardennes Region, from Verdun down-river to Charleville-Mézières. It was the start for an intense week of tight cooperation among the EO service provider, the ERS-2, SPOT and RADARSAT operations managing units and the crisis managing authorities.

The alert message passed through CIRCOSC of Metz, operational aid cell of civil protection local authorities, reaching SERTIT, the EO service provider.

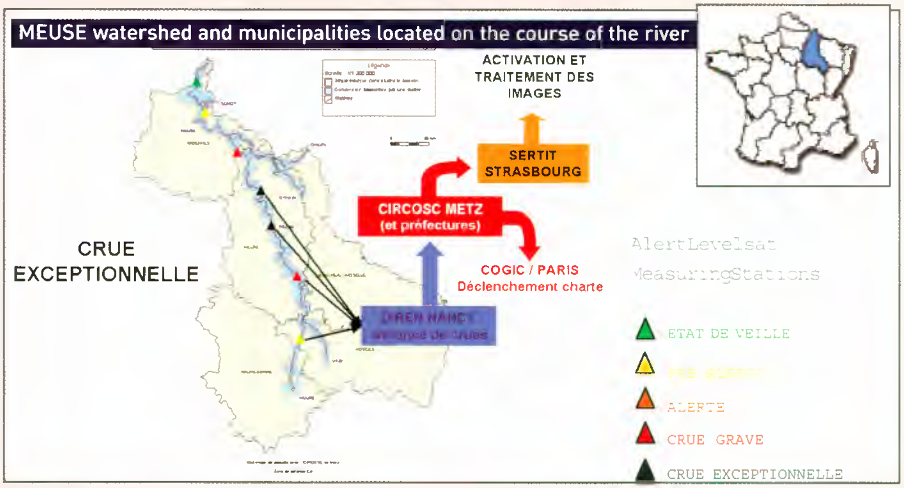
EMZ-CIRCOSC is the heart of the civil protection organisational structure. It coordinates at a defence zone level (1/4 of France, 5 regions, 18 departments) the actions of all operational services related to flood crisis management and is closely related to all government agencies responsible for civilian risk who operate before, during and after a flood crisis and to government administrations in charge of water resources management and environmental management.

During the emergency, EMZ-CIRCOSC operated 24 hours a day, collecting information, analysing the scenario and issuing directives for operations.

The same working rhythm applied to satellite operations and for data processing allowed delivery of daily updated EO-derived flood extent maps covering the whole affected area.



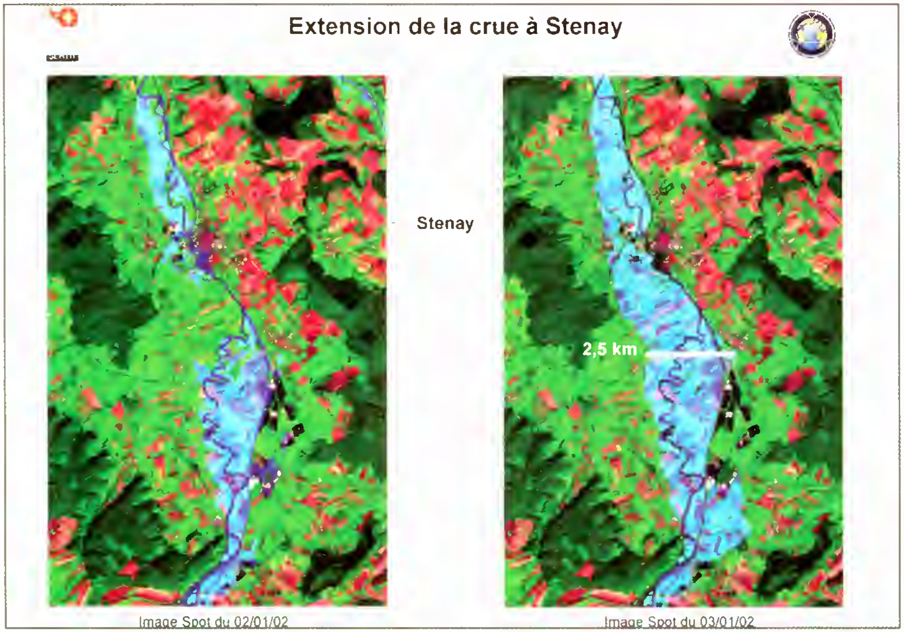
Timeline of EO-service provided by SERTIT during the flood.

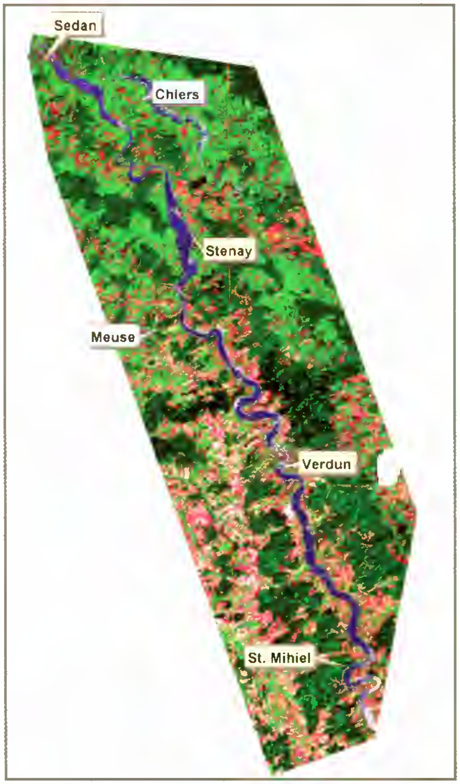


Thanks to favourable weather conditions, both radar (ERS-2) and optical (SPOT) data were rapidly acquired and pre-processed (ortho-rectified, mosaicked). They were then compared to an existing reference "normal state" image in order to extract relevant change information. Flood dynamic mapping was produced with a complete coverage of the Meuse area, highlighting changes in most critical locations, as shown in the Stenay case. The flood increased in extent until the 4th of January when, though very widespread, it posed no more immediate threat due to the freezing of the floodwaters in extremely low temperatures (-5 °C at midday). The flood's rate of descent was quite fast until it froze. Thanks to low temperatures, the flood impact over the area Charleville-Mezieres was therefore relatively limited.

At the end of the disastrous event, CIRCOSC authorities acknowledged the following issues as crucial contribution to crisis management and preliminary assessment provided by EO:

> Availability of a periodic and synoptic view of the situation easily comparable with previous data
> Capacity to perform identification and preliminary characterisation of areas





CUMULATED MEUSE FLOODING FOR THE PERIOD 2-4 JANUARY DERIVED FROM COMBINING THE THREE RAPID SPOT ACQUISITIONS.
AS A BACKGROUND, A NATURAL COLOUR RGB COMPOSITE OF THE REFERENCE IMAGE.
PROCESSED BY SERTIT.
SPOT IMAGES ©CNES, 2002.
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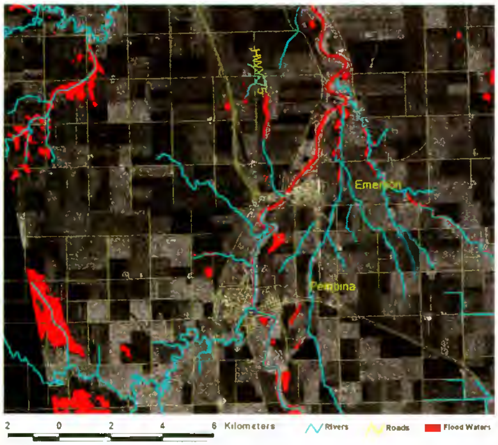


EXAMPLE OF CHARTER ACTIVATION TRIGGERED BY THE OFFICE OF CRITICAL INFRASTRUCTURE PROTECTION AND EMERGENCY PREPAREDNESS (OCIPEP), CANADA. MANITOBA, NORTH DAKOTA BORDER JUNE 15, 2002. SATELLITE DATA IN BACKGROUND PERMITTED IDENTIFICATION OF FLOODED AREAS (IN RED), INTEGRATED WITHIN A GIS TO HIGHLIGHT INFRASTRUCTURES (STREETS IN YELLOW) INVOLVED IN THE DISASTROUS EVENT. RADARSAT DATA © CANADIAN SPACE AGENCY, 2002. PROCESSED BY VANTAGE POINT INTERNATIONAL INC.

affected by flooding

> Compatibility with aerial data, acquired at the end of the flood and available long after, "filling the gaps" and producing a consistent mosaic
> Capacity to refine forecast models through cross-check of outputs
> Provision of additional information about land use along the river basin, to be exploited in flood risk prevention plans set up
> Availability of a historical event database supporting new crises management plans development.

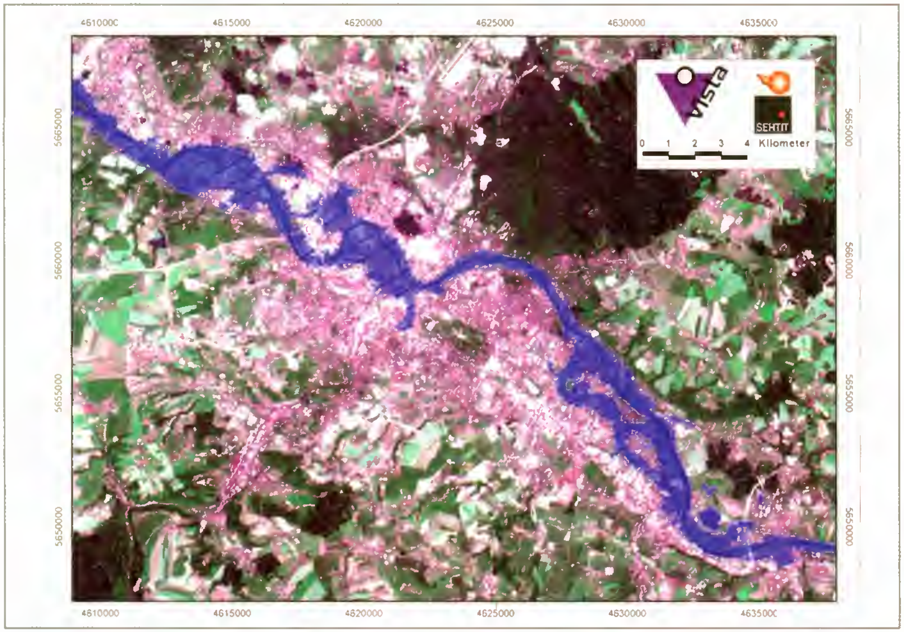
The demonstrated service is part of the "Operational Centre for Plain-Flood Monitoring" set up by SERTIT together with EMZ-CIRCOSC of Metz. For this example of service supply, the International Charter "Space and Major Disasters" has been activated in order to supply EO data to EMZ-CIRCOSC. The centre is intended to provide a 24-hour service delivery, in France and neighbouring eastern countries, supplying products like those delivered during the Meuse event. Civil protection authorities may obtain rapid flood dynamic extent - within 6 hours processing - and flood impact on specific landscape features - within 12 hours processing.

THE INTERNATIONAL CHARTER

The European and French space agencies (ESA and CNES) initiated the International Charter "Space and Major Disasters", with the Canadian Space Agency (CSA) signing the Charter on October 20, 2000. In September 2001, the National Oceanic and Atmospheric Administration (NOAA) and the Indian Space Research Organization (ISRO) also became members. Recent additional members now include Brasil (CONAE) and since July 2003 the United Nations (through UN OOSA). The International Charter aims at providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through an authorised users' system. Authorised users can be a civil protection, rescue, defense or security body from the country of a Charter member. They can now call a single number to request the mobilization of the space and associated ground resources (RADARSAT, ERS, SPOT, IRS, POES, GOES) of the five agencies to obtain data and information on a disaster occurrence. A 24-hour on-duty operator receives the call, checks the identity of the requestor and verifies that the User Request form sent by the Authorised User is correctly filled up. The operator passes the information to an emergency on-call officer who analyses the request and the scope of the disaster with the User, and prepares an archive and acquisition plan using available space resources. Data acquisition and delivery takes place on an emergency basis, and a project manager, who is expert and qualified in data ordering, handling and application, assists the user throughout the process.

Since 1st November 2000, official opening of the Charter's operational activities, a total of 16 flooding emergencies have been supported by means of EO-derived information, tailored to specific event's user requirements.

More information available at: http://www.disasterscharter.org/disasters_e.html



THE MAX[illegible]M[illegible] F[illegible]OD [illegible]XT[illegible]N [illegible] E[illegible]B FLOOD [illegible] D[illegible]ES[illegible] B[illegible]A[illegible]NED [illegible]ROM A SPOT-4 [illegible]MAGE [illegible] A[illegible] 17TH 2002 [illegible] SED ON A SPOT-2 BASED SATELLIT[illegible] MAP.
PROCESSED BY SERTIT AND VISTA GMBH.
SPOT IMAGES ©CNES, 2002. *DISTRIBUTED BY SPOT IMAGE.*

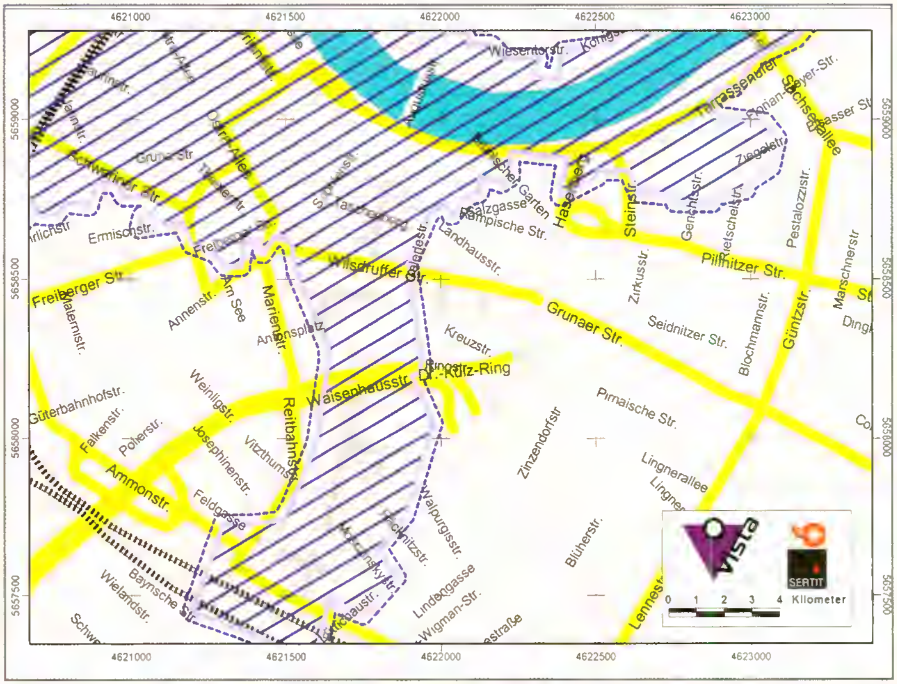
SERVICE TO THE INSURANCE COMPANIES

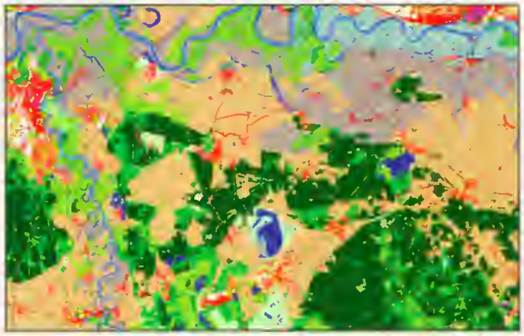
Systems with capabilities equivalent to those demonstrated in the case of the "Operational Centre for Plain-Flood Monitoring" can also be utilised to meet the specific needs of insurance companies. The latter take advantage of EO based products like flood maximum extent and impact assessment based on detailed land use maps, which can be regularly updated e.g. every 5 years.

During the summer 2002 Elbe flooding event, the advantages of flood mapping products and the potential of GIS integration were demonstrated. Swiss Re, an insurance company covering most of the insured flood risk in East Germany was interested in a fast assessment of the flooded area as an information source for damage assessment a few weeks after the event.

Dresden was one of the Cities in Germany most seriously affected. During the maximum flood extent a SPOT acquisition was programmed and evaluated. The maximum flood extent was classified and superimposed in a GIS system of Dresden. The insurance company was interested in obtaining a street map where the flooded area was clearly highlighted. These maps were handed over to the local insurance advisors in order to optimise loss assessment.

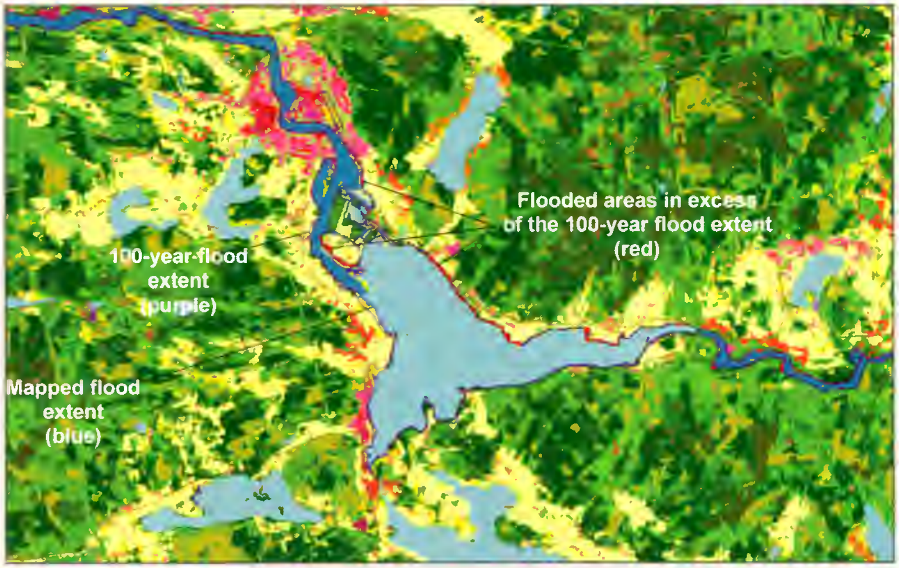
Right Maximum flood extent derived from SPOT analyses superimposed onto a street map of Dresden for aiding local insurance advisors during damage assessment. **Courtesy VISTA GmbH and SERTIT.**





Above: Flood extent map during the August 2002 Elbe River flooding in the area of Dessau (Saxony-Anhalt, Germany). The flood extent map, derived from Landsat 7 ETM imagery (20 August 2002), is overlaid i[n] light blue on the Infoterra's German 25m Land Cover Map 2002. **Courtesy: Infoterra GmbH (Germany)**

Right: Another example of flood extent map during the July 2000 Ljungan River flooding (Sweden). With the aid of ERS-2 SAR imagery, the flood extent was mapped out and superimposed upon the Swedish La[n]d Cover Map, constructed from Landsat imagery at a resolution of 25m, with a minimum mapping area of 1-4 ha and 62 separate classes. The figure puts in evidence the flooded areas outside the 100year flood boundary. **Courtesy: Metria (Sweden)**



The threat of flooding is projected to increase in the future as a result of rising sea levels and the changing climatic conditions accompanying global warming. The disasters they cause are the results of rapid population growth, excessive concentration of populations and property in flood-prone areas, and changes in upstream land use that lead to greater, more rapid run-off. Flood monitoring services based on Earth Observation allowing a quick overview of the affected areas would then become more and more useful tools in managing the crises.

The potential offered by the innovative features of the ENVISAT ASAR instrument are currently being explored and some are being extensively tested to verify their performances for flood monitoring purposes, in terms of quality, robustness, timeliness and affordability.

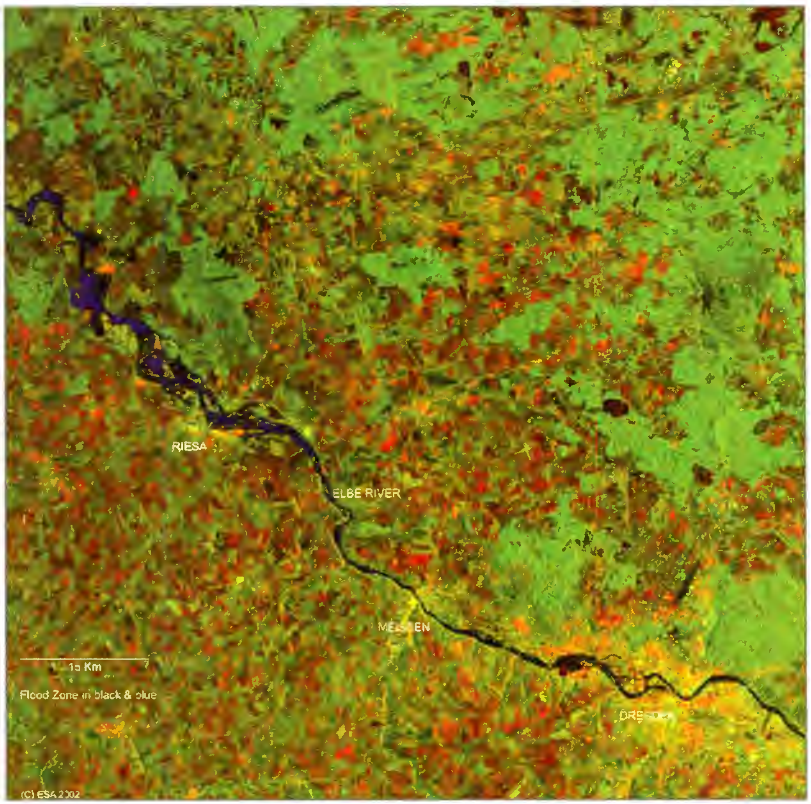
The alternate polarisation and the steerable beam of ASAR appear to provide enhanced capabilities for better discrimination of land cover, which can be used to refine methods for the distinction of vegetation from water. NRT data transmission capabilities are enhanced by the communication link between the Envisat and Artemis satellites, and by the direct transmission links from the satellite to the Kiruna and Svalbard ground stations.

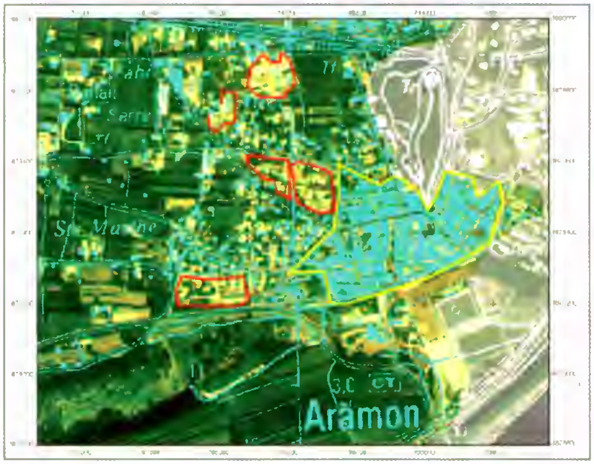
Meeting near real time delivery requirements means on-line delivery of not only EO data but also the final added value information obtained after post-processing and analysis. New techniques to meet those requirements are being tested in the operational environment of authorities involved with risk management for flood monitoring. They are based on web-mapping tools using the Internet to supply the needed thematic information over a user-defined area of interest in digital and cartographic format.

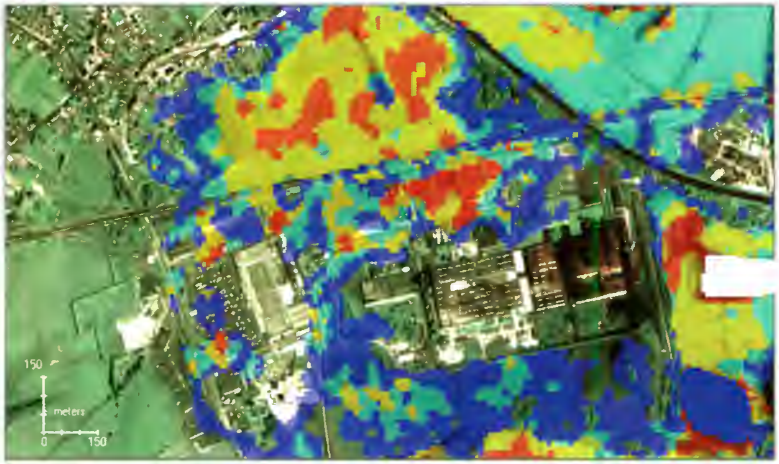
Meanwhile new and very accurate damage assessment products are being developed taking advantage of high-resolution optical imagery provided by SPOT-5 and IKONOS.

<< FUTURE OUTLOOK

ENVISAT ASAR [illegible] 2002 [illegible] (Red HH, [illegible] HV, [illegible]) [illegible] ASAR data ©ESA, 2002.







Left. [illegible] SPOT 2 AND [illegible] SPOT 5 [illegible]. PROCESSED BY SERTIT. ©CNES, 2002. *DISTRIBUTED BY SPOT IMAGE.*

In addition, Envisat ASAR will soon be accompanied by new SAR spaceborne sensors such as for instance RADARSAT 2, ALOS, Cosmo SkyMed and TerraSAR. These will help increase all weather monitoring capabilities with improved temporal sampling on a global basis. Generations of Very High Resolution (VHR) optical satellites are now ready (e.g. QuickBird with 60cm resolution) or under preparation. This includes constellations of Optical VHR sensors such as Pleiades combining a suite of sensors with a spatial resolution better then 70 cm. Overall the planned Optical and Radar EO missions do promise continuity for operational plain flood monitoring services a key requirement for risk management.

ACKNOWLEDGEMENTS >>

This document provides descriptions of EO based services supplied by SERTIT and VISTA. For their work in market development these companies have been supported by ESA's Earth Observation Programme.

This document also includes contributions from Astrium, Infoterra Gmbh, Metria, Vantage Point International and Spot Image who are gratefully acknowledged.

Right. [illegible] SAR [illegible]. PROCESSED BY SERTIT. ERS IMAGES ©ESA, 2002. *DISTRIBUTED BY EURIMAGE.* IKONOS IMAGES ©SPACE IMAGING, 2002. *DISTRIBUTED BY SPACE IMAGING.*

For further information on the EO service industry

INFOTERRA GmbH Marek Tinz • GERMANY
http://www.infoterra-global.com/

METRIA Michael Ledwith • SWEDEN
http://www.lantmateriet.se/

SERTIT Paul de Fraipont/Kader Fellah • FRANCE
http://sertit.u-strasbg.fr

TELESPAZIO s.p.a. Carlo Coretti • ITALY
http://www.telespazio.it/

Vantage Point International Ron Saper • CANADA
http://www.vantpoint.com

VISTA GmbH Heike Bach • GERMANY
http://www.vista-geo.de

For further information on EOMD activities and ENVISAT Program

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A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE

Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

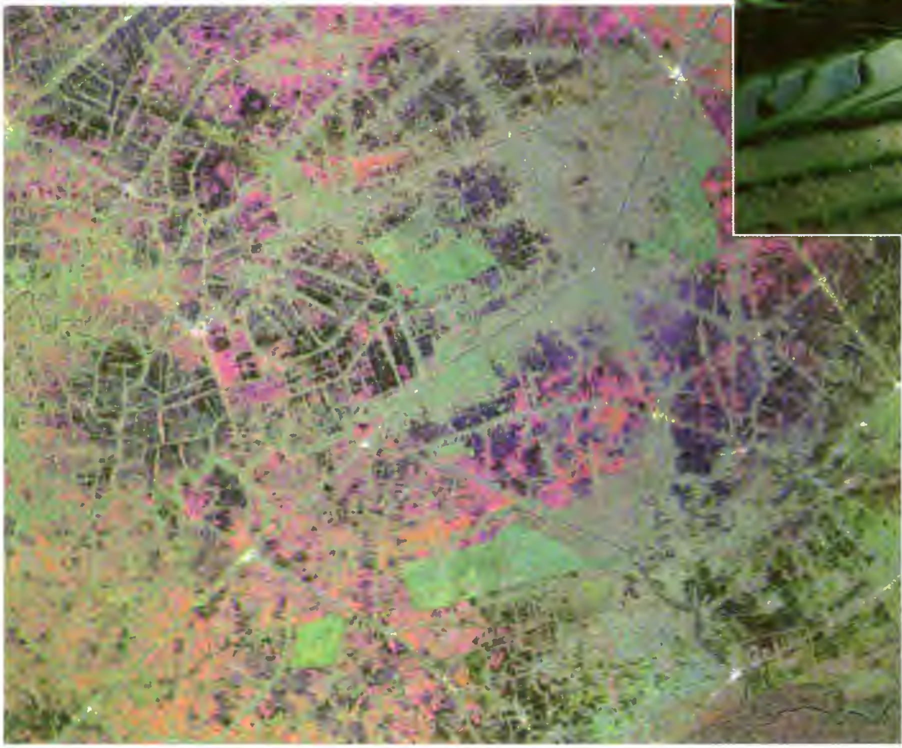
For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.

EARTH observation SERVICES today

RICE MAPPING

USING RADAR FROM SPACE



M[illegible] ASAR A[illegible] P[illegible] S[illegible] 21 [illegible] 24 [illegible] 2002) [illegible] V[illegible] HH [illegible] HV [illegible] the green [illegible] VV [illegible]
Processed by sarmap, ENVISAT images ©ESA 2002, *Distributed by Eurimage*

THE NEED FOR BETTER INFORMATION

Rice is the most important food crop in developing countries. Rice now provides 29% of the total calorie intake of developing countries, down from 31% in the 1970s. 91% of he world's rice is produced in the Asia and Pacific Region. Recent projections made by he International Food Policy Research Institute show that the demand for rice will ncrease by about 1.8% per year over the 1990-2020 period. This means that over the next 30 years, rice consumption will increase by nearly 70%, and Asian rice production must ncrease to about 840 million tons by the year 2025, from the present level of about 490 million tons, if rice prices are to be maintained at current levels.

Increase in rice yield in the past was due to public and private sector investment in irrigation, flood control and drainage that converted rainfall into irrigated ecosystems to facilitate the adoption of modern rice varieties and improve farming practices. Theoretically, the potential for further increase in rice yield with irrigation is still large, as only 55% of Asian rice land is irrigated. The scope for further conversion of rainfall into irrigated ecosystems is, however, becoming limited. Water is becoming a scarce resource with increasing demand for human consumption, industrial use, and for generation of power. The cost of irrigation has ncreased substantially, as easy options for irrigation development have already been exploited. Many environmental factors, some natural, some the consequence of human activities, can limit agricultural potential. Besides human factors such as pollution and landmines, other factors include extremely dry or cold climates, poor soil, erratic rainfall, and severe land degradation.

During the 1980s attention was focused on the production side of food availability, and increased agricultural production in particular. The need for increased production remains, but the focus is now on access to food, with social and health issues indicating the need for targeted interventions. The availability of, and the access to, accurate and timely information on food and especially on the rice crop is vital. In this sense, access to objective information on food resources is a global issue and food production and trading are a key elements in achieving world food security.

According to rice market analysts, during the next twenty-five years it is expected to see the following forces at work

> The volume of rice traded will continue to climb steeply over the next 5 years or more

> The eventual spread of "super rice" varieties developed by IRRI (International Rice Research Institute) will be uneven with the result that Africa's share of world trade will increase further

> Exportable supplies will also be increased from developing Asian countries for example Burma and Cambodia

> Exports out of the U.S. and Europe will decline as tightened world trading rules will result in reduced subsidies

> Market transparency will continue to increase and trading margins will be further eroded

> Increasingly driven by consumer preferences as markets are freed of artificial controls, the trade in special varieties and special qualities (likely branded) will grow.

THE RICE CROP'S GROWTH CYCLE

Depending on the climate, there are generally one to three growing seasons per year in South East Asia. In many cases rice is rotated with a different crop to preserve or enhance soil fertility. The rice crop's growth cycle (and consequently the yield obtained at harvest) depends on whether the plants are growing in the irrigated areas (usually low-lying land) or the more remote upland areas, which depend on rainwater for irrigation.

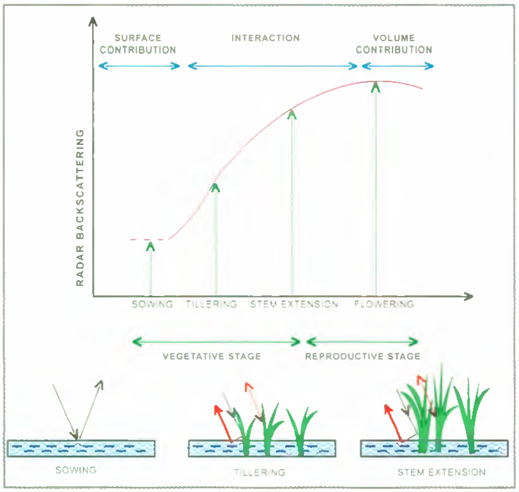
Flooded fields – at the onset of the rains or the arrival of irrigation water, fields are flooded to a depth of between 2 and 15 cm. The rice plants are sown in nurseries and transplanted after 25 to 35 days to the flooded fields in clusters of 1 to 10 plants.

Vegetative phase – the duration of this phase depends on the rice variety being grown. It is characterised by the increase in the plant's height, the development of leaves, and the development of secondary and tertiary stems, each with the possibility of producing a panicle. The soil remains under water during this stage and the plant structure remains vertical.

Reproductive phase lasts about 25-35 days. During a complete growth cycle, a rice plant will produce a total of 10 to 20 leaves, but with only 5 to 10 in place at any one time. Once the last leaves have formed, the plant flowers and distorts to allow the panicle to rise. Complete panicle formation and flowering takes about 17 to 24 days. Ripening lasts about 25-35 days. In some areas irrigation is stop-ped during the ripening period, but in others the fields remain flooded. At the end of this phase, depending on the availability of labour, the crop is harvested. Thereafter the paddy fields are characterised by bare dry soil. There are several issues associated with efficient rice growing, including the maintenance and improvement of the productive functions of the crop, crop health and vitality, soil fertility and the prevention of damage due to diseases, droughts, etc. A major source of increase in rice yield in the past was flood control and drainage that converted rainfall into irrigated paddy fields to facilitate the adoption of modern rice varieties, and improved farming practices. But water is becoming a scarce resource, the costs of irrigation have increased substantially and environmental concerns regarding adverse effects of irrigation such as methane emissions and flood control are growing. All countries involved in rice production therefore share a critical need for accurate and up-to-date information throughout the crop's growth cycle in order to forecast rice yields early in the season and to use the resources more economically.

THE LIMITATIONS OF TRADITIONAL TECHNIQUE

In many countries there is no suitable infrastructure for the implementation of programmes to monitor rice production. The conventional method of compiling statistics on rice-crop acreage is for staff from the appropriate Government Ministry to make ground surveys, during which selected farmers or village offi-cials are interviewed regarding their crops. By comparison with the results of pre-vious years, this information is then extrapolated to generate data and predictions on a regional basis. The principal difficulty associated with the collection of ground data in this way is the remoteness of many of the farming areas, especially for the upland varieties of rice. This means that these traditional surveys are both time-consuming and expensive. In addition, the information collected is often imprecise and unreliable, leading to inaccurate crop-yield forecasts and subse-quent difficulties for agricultural planners and managers on both regional and national scale.



During the early growth stages, flooded paddy fields exhibit very low backscatter levels (as measured using radar imagery). The backscatter keeps on increasing with plant development during the vegetative phase. This increase is typically due to wave-plant-water multiple interactions. At the end of the vegetative stage, the radar response reaches a plateau corresponding to the reproductive phase. No other crop types display a comparable range of backscatter values over such time periods.
Courtesy of CESBIO

THE BENEFITS OF SPACE-BASED MONITORING

Earth Observation allows regular and timely monitoring of rice cultivated areas and provides accurate information about the rice growth status.

Traditionally, Earth Observation meant optical imagery. Nonetheless, satellites carrying high resolution (10 to 30 m; scale 1:50,000 to 1:100,000) optical sensors cannot acquire data regularly in tropical regions during the rainy season due to the often persistent cloud coverage. The usefulness of space borne optical images from the Landsat and SPOT missions for rice monitoring has indeed proved to be limited.

In this situation operational, weather independent systems utilising high resolution microwave sensors such as Synthetic Aperture Radar (SAR) offers an effective alternative. SAR data allow the determination of the rice extent, the monitoring of the rice growth, and the detection and mapping of crop damages deriving from meteorological events, as illustrated.

A basic requirement for monitoring rice growth is that the satellite overpass and the flooding of the paddy fields temporally coincide. Practically, images are required at planting date or during the sowing-transplanting stage. This can be fulfilled by the joint utilisation of multiple high resolution spaceborne SAR sensors such as those on-board Envisat and RADARSAT-1. In this context, five key features of the Envisat ASAR instrument are of importance for rice mapping and monitoring. These are:

> Envisat's compatibility with RADARSAT-1 improving the temporal frequency of acquisition and allowing optimisation of the temporal sampling of rice fields.

> The selectable SAR instrument look angle playing an important role in isolating the radar response of the vegetation canopy from that of the underlying soil allowing at the same time a rapid access to target areas and a higher spatial resolution for data acquired with large incidence angles.

> Alternate Polarisation Mode improving significantly the identification of different growth stages during the crop season even with respect to ERS and RADARSAT-1 data.

> The possibility to avoid wind related effects during the paddy field flooding period, which typically makes it difficult to discriminate water bodies from surrounding land areas on SAR imagery, by properly setting incidence angle and polarisation mode.

> Wide Swath Mode enabling large scale rice monitoring, (400 x 400 km) with a repetition frequency of 3 to 4 days, over extended rice cropping regions.

SARI (SATELLITE ASSESSMENT OF RICE IN INDONESIA)

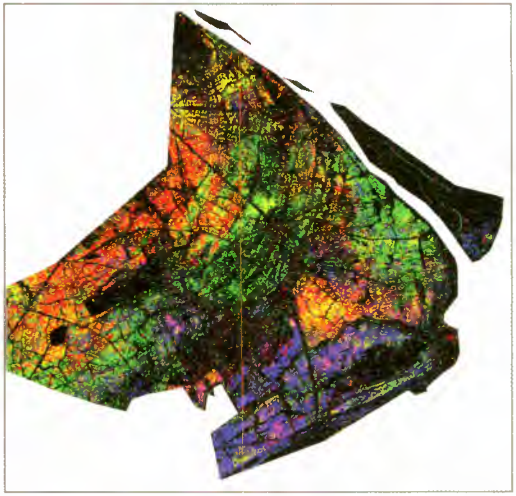
A precursory example of a rice monitoring system is given with the service prototype designed and implemented in Indonesia by Synoptics in the framework of the European SARI project following underlying research work performed in France by CESBIO. The goal was the optimisation of rice production and distribution for the major rice producing regions, by means of designing and implementing an information system to provide accurate and timely information on rice acreage and production.

Traditionally, rice production figures in Indonesia (and throughout Asia) are collected and processed by governmental agencies using a sampling system at village level. This system is often prone to subjectivity and thus inaccuracies. This has prompted the Government of Indonesia to set up a collaboration with the European Union to develop and make operational an objective and efficient rice monitoring system, based on experience gained during the Monitoring of Agriculture using Remote Sensing (MARS) project using remote sensing techniques over Europe.

A prototype service has been developed using a combination of ground survey sampling techniques in combination with SAR time-series images. Rice yield predictions (ton/ha) at sub-district level are estimated using a sampling technique where random samples were measured with fieldwork on a 2-month basis, covering rice cycles throughout the year. Rice acreage (ha) at sub-district level was estimated through classifications of ERS-2 SAR time series images. Rice transplanting and harvest dates have been identified using SPOT-Vegetation time-series, through the analysis of 10-days NDVI composites. A combination of yield and acreage figures leads to rice production predictions (tons per sub-district), available usually 2 months before the harvest time.

The statistics were disseminated through a dedicated web site. Users could query on rice yields (tons/ha), acreage (ha), production (tons), transplanting and harvest dates up to sub-district level, for the current and past rice seasons in Java. Statistics were continuously updated with new satellite acquisitions and ground surveys. The variability (mean error) of the rice statistics is within 3% at province level. In order to ensure continuity of the on site service, an extensive training program has been carried out during the project.

SERVICE **EXAMPLE**



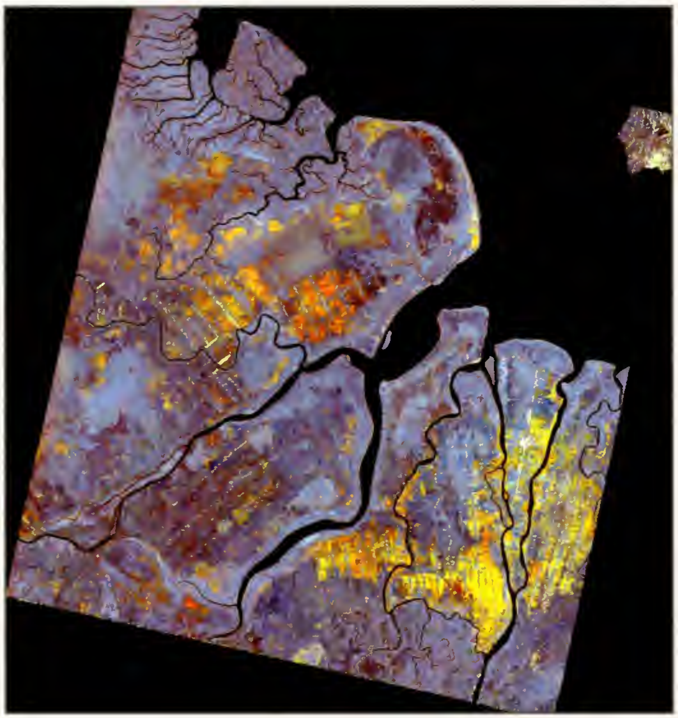
Map of rice crop system in the Province of Soc Trang, Mekong Delta, South Vietnam, using multitemporal ERS-2 images, acquired over the period from August 1997 to April 1998. Blue corresponds to areas cultivated with a single rice crop per year; green corresponds to double crop, and red to triple crop. Magenta indicates single crop and yellow is undetermined double or triple crop. Note. the overall proportion of cultivated areas, corresponding to three crops per year, have increased over the last twenty years as a response to local socio-economic pressure and relying on modern rice species and cultural practices.

Courtesy CESBIO, ERS data

A SERVICE TO SUPPLY RICE INFORMATION: IRIS

Internet Rice Information Service (IRIS) is a collaborative response to the vagaries of the rice market. In essence, approximately 90% of the world's rice is produced in Asia. Because an estimated 45% of the Asian crop is not irrigated, the delicate balance between world rice supplies and demand depends crucially on the performance of the Asian monsoon. The bulk of the harvest is largely consumed in the region where it is produced and very little of the surplus is marketed outside the growing region - only 5% of the harvest enters world channels. As such, a production variation in one or two important markets can have a significant impact on world demand and, consequently, world rice prices. Because rice is a subsistence crop in most countries, production shortfalls or surpluses are somewhat tempered by changes in on-farm consumption.

The colour composite image acquired over Palembang (Indonesia) shows three synthetic channels extracted from a time series of 9 ERS images (acquired from September 1998 to September 1999). Red corresponds to standard deviation, Green corresponds to maximum value, blue corresponds to minimum value. Rice cultivation areas are represented in reddish-brown and yellow colours.
Courtesy Synoptics, ERS images
© ESA 1998-1999, *Distributed by CRISP*



Accurate statistics within each rice cycle are generated by analysing space borne Earth Observation data to determine rice acreage and transplanting / emergence moment, while rice yield, production and harvest time are estimated in a predictive way using a hybrid approach based on Agro-Meteorological and a Statistical Models. An easy-to-use web application provides clients with predictive statistics in form of tables, graphs and/or maps for any sub-district and any rice season in Asia.

The goal of IRIS is to contribute to the transparency of information concerning the production, management and distribution of rice in the world, starting in Asia in a first step, in order to help the rationalisation of the agricultural and insurance-related policies. This rationalisation leads to a better flow of information, enabling nations to better manage the main staple food of the planet – and transfer the risks associated with price volatility from the farmers to the traders and financial institutions.

The technology at the foundation of IRIS is well developed and accessible to groups and organisations participating in the rice market. The basic concept is that all users can obtain up-to-date information to make the appropriate investment decisions. At the heart of these decisions is the larger issue of food security.

IRIS provides an operational rice information service to re-insurance companies, rice industries, national and international institutions, and food traders supplying timely and reliable information on:

- acreage
- transplanting (or emergence) moment
- growth status
- losses due to meteorological events
- yield and production
- harvest time

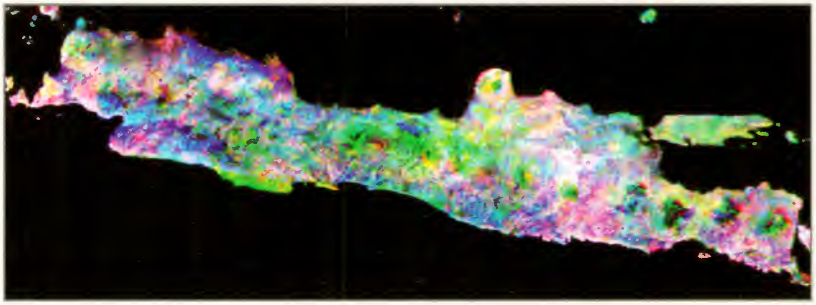
in the rice growing regions of Asia.

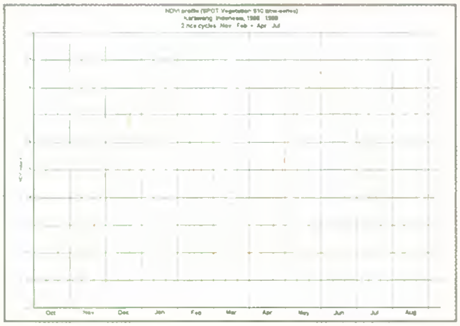
RICE ACREAGE AND TRANSPLANTING DATES

Acreage and transplanting dates are two key parameters to accurately determine rice production. Conventional methods for rice mapping and currently available rice crop calendar information are not reliable enough to estimate the beginning and duration of the rice crop cycle over large areas. Multi-temporal spaceborne high resolution (scale 1:50,000 to 100,000) active microwave sensors – such as Synthetic Aperture Radar (SAR) – integrated with low resolution (scale 1:6,000,000) optical data, offer an effective solution today. This multi-source methodology enables a continuous and precise transplanting moment detection and rice acreage determination at both regional and local scale.

The basic idea behind the generation of rice acreage statistics at large scale, using SAR techniques, is the analysis of changes in the radar signal backscatter recorded all along the rice growth cycle. Measurements of temporal changes of radar response due to the rice plant phenological status – an increase in the SAR backscatter corresponds to a growth of the rice plants – lead to the identification of the transplanted areas. To date the service is based on the utilization of SAR data (large scale) acquired from the Envisat ASAR and RADARSAT-1 instruments and SPOT-Vegetation decade images (small scale).

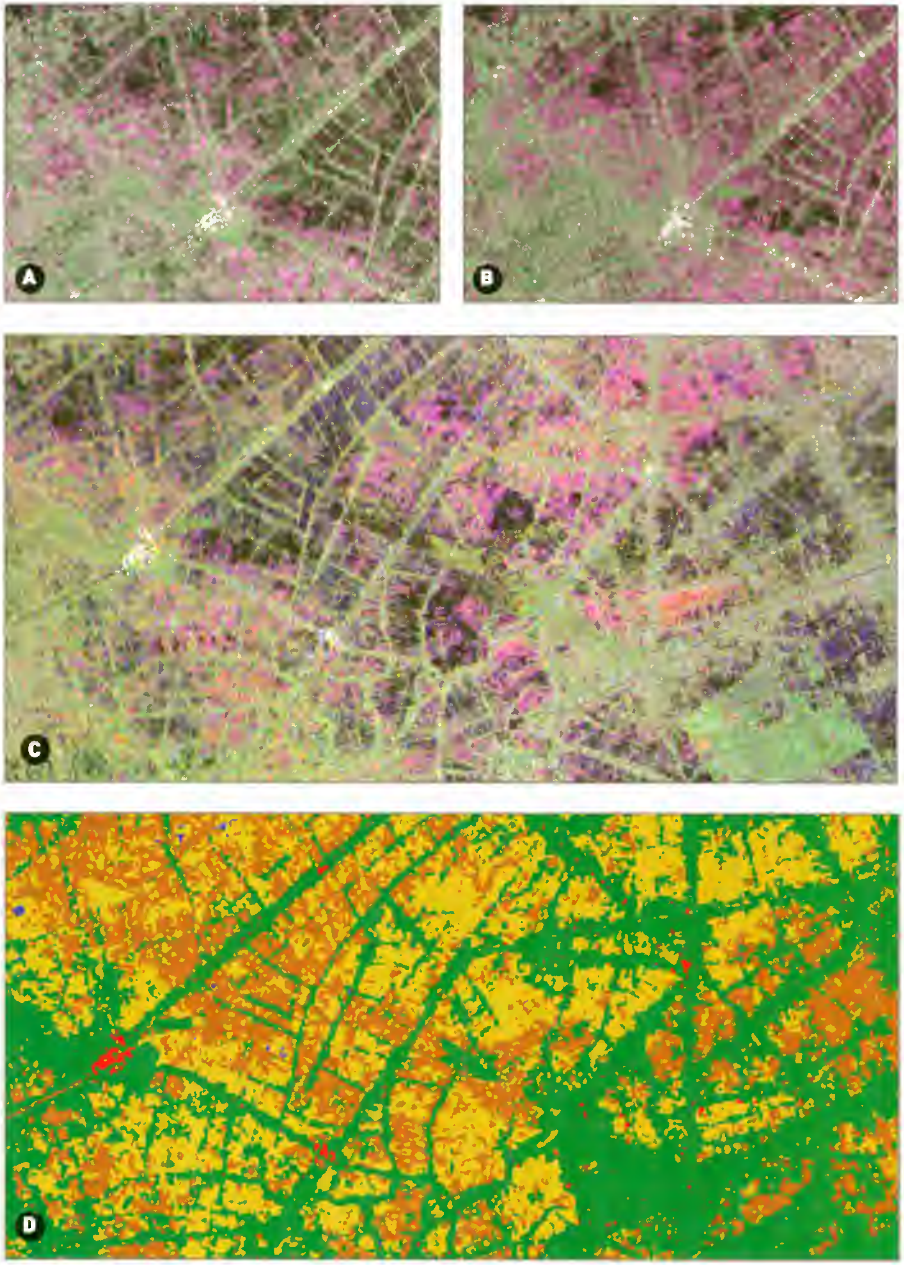
IRIS products are deeply interfaced with a customised Earth Observation (EO) data processing chain, which is based on the use of SARscape® software for determining rice acreage and transplanting moment from SAR data. In order to process the large amount of EO data in an efficient way, the processing is carried out using PCs in parallel, coordinated by an EO server, which supervises the whole





SPOT-VEGETATION 10 DAYS IMAGE (FROM 1 TO 10 JUNE 2002) OVER JAVA (INDONESIA), AND BELOW, NDVI PROFILE RELEVANT TO THE PERIOD APRIL-SEPTEMBER 2002. THE PROFILE EMPHASIZES THAT THE TRANSPLANTING MOMENTS CORRESPOND PRECISELY TO THE ABSOLUTE MINIMUM OF THE NDVI VALUE.

data handling and stores the computed rice acreage statistics into the Central Database. Prerequisite for an automatic processing is a continuous update of the Central Database. The rice acreage statistics are stored in the form of maps showing the rice acreage and, in the form of numerical tables, quantifying the dimension of cultivated areas on each transplanting date. These products are generated at administrative level – typically village unit. Since these data are integrated into a dedicated Geographic Information System, statistics over larger portion of territory – district, region, province and country – can be gathered.



(Mekong River Delta, Vietnam) - a) Colour composite of Envisat ASAR Alternating Polarisation: HH-HV (red), HV (green), HH (blue). Data acquired on 21 September 2002; b) Colour composite of Envisat ASAR Alternating Polarisation: VV-VH (red), HV (green), VV (blue). Data acquired on 24 September 2002; [illegible]; c) Multi-temporal colour composite of Envisat ASAR Alternating Polarisation: HH 21 September 2002 (red), HV 21 September 2002 (green), VV 24 September 2002 [illegible]; [illegible]) Supervised cla[illegible] f[illegible] rice type 1 in yellow, rice type 2 in [illegible]rk brown, rice [illegible] 3 in light brown, water in blue, urban settlement in red, [illegible]rse [illegible]on in green. Rice types 1, 2 and 3 [illegible]pond [illegible] three different rice [illegible] which [illegible] characterised b[illegible]erent temporal signat[illegible] of the [illegible]gna[illegible]

Processed by Sarmap
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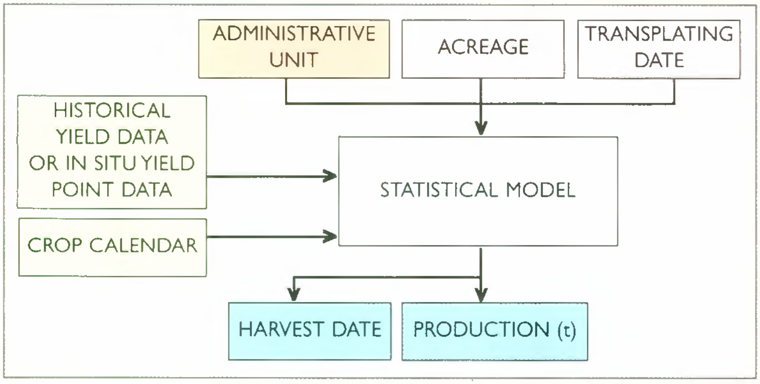
RICE YIELD, PRODUCTION AND HARVEST DATES

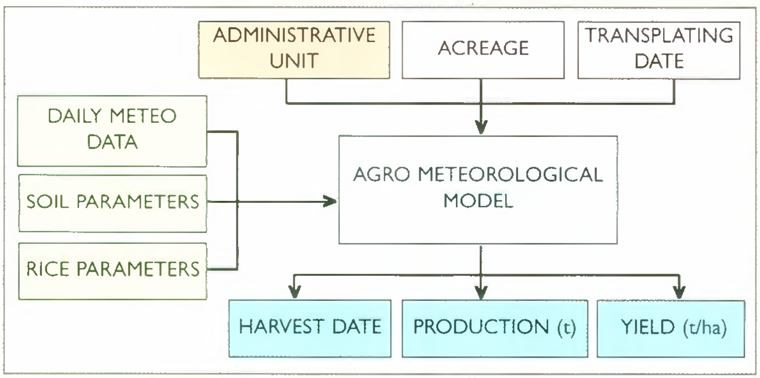
A service is robust and reliable only if complementary and/or redundant solutions are available. For this reason, the IRIS system foresees two independent methodologies to determine harvest date and related yield and production figures depending on what historical and in situ information is available. In both methods acreage measurements and transplanting dates are extracted from space borne SAR data.



OVERVIEW OF THE STATISTICAL MODEL.

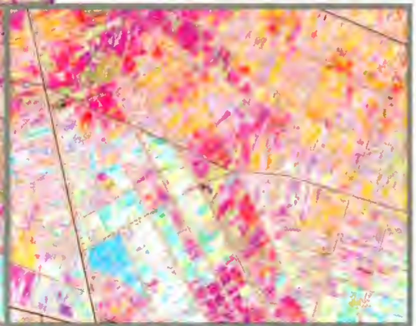
Statistical method: this approach is followed in order to get **a)** rice production estimates by combining historical yield figures or in situ measurements and acreage measurements; **b)** harvest date estimates by integrating crop calendar information and actual transplanting dates. In situ sample measurements are additionally considered to validate, at harvest time, the predicted production figures.

Agro Meteorological Model (AMM): this approach is applied to predict and update, on a daily basis, rice yield, production and harvest dates. The AMM, which is built around a crop growth model developed at the DLO institute in Wageningen, The Netherlands – is a quantitative deterministic model that simulates rice growth, based on sets of rice parameters, daily meteorological data, and soil characteristics. The daily meteorological data – minimum/maximum/average temperature, sun radiation, relative humidity, wind speed, sun illumination hours, precipitation – are used to predict the rice crop growth.



OVERVIEW OF THE AGRO-METEOROLOGICAL MODEL.

The AMM determines yield (t/ha) based on the starting parameters for soil characteristics and the rice crop variety, a full series of daily meteorological data and the transplanting dates based on EO data. Initially, the daily meteorological values are "standard" averages of the last 5 years, to be able to complete a full "run" of a rice season and generate yield figures. With each newly received set of daily actual meteorological data, the average values are replaced by the actual ones received on-line, and the system is run again to produce a new set of estimations, each more accurate than the previous one.



<< Example of a typical output of IRIS for the Mekong River Delta (Vietnam) showing RADARSAT-1 Fine Beam data and derived rice figures.

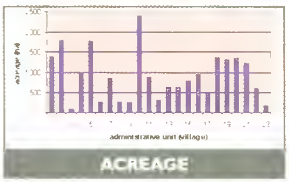
Examples of a geographical and temporal selection on rice statistics for Indonesia

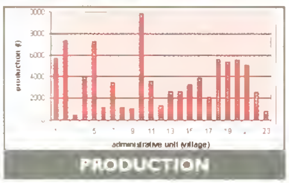
Country: **INDONESIA** Province: **WEST-JAVA** district: **KARAWANG** subdistrict: **CIBUAYA**

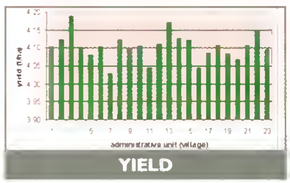
Year and Cycle	Tons	Hectares	Tons per Hectare	Transplanting date	Predicted harvest date
2002, Second rice season (first dry season) Only district of karawang	26375,0	4507,0	5,85	2002-07-06	2002-10-10

Country: **INDONESIA** Province: **NORTH-SUMATRA**

Year and Cycle	Tons	Hectar	Tons per Hectar
1996, Year statistics	3136760,0	790051,0	3,97
1997, Year statistics	3212208,0	797545,0	4,03
1998, Year statistics	3321049,0	823749,0	4,03
1999, Year statistics	3451430,0	838626,0	4,12
2000, Year statistics	3441848,0	826780,0	4,16







Relevant rice figures:
1) acreage (ha),
2) production (t),
3) yield (t/ha).
The figures, generated at administrative level (village units in this case), are provided on a daily basis from the IRIS service.

Production is simply calculated by combining yield estimation and the acreage. Harvest dates are automatically generated and updated by the AMM based on the evolution of the meteorological data.

The rice statistics, which are updated on a daily basis, are made available through the Internet. Clients can access the IRIS information service on the IRIS website (www.iris-rice.org). A dedicated and easy-to-use web-application provides clients with predictive data in the form of tables, graphs and/or maps for any sub-district and any rice season in Asia.

FUTURE OUTLOOK

Improved methods for rice production and management strategies are crucial. Indeed, an important theme in the context of Sustainable Development (as seen at the World Summit in Johannesburg 2002) is the creation of conditions for sustainable agriculture and rural development. One of the key ways to reach this objective is through land resources planning. Therefore, the use of integrated farm management technologies, combining collections of land resources information (including space-borne monitoring) will become relevant to a greater extent.

Today, the use of Earth Observation in rice mapping and monitoring, has been mainly limited to the identification and mapping of rice-fields. Earth Observation contributes to a large extent to progress in this area, for example with Envisat due to the new features of ASAR (dual polarisation, steerable acquisition capability and the Wide Swath Acquisition mode). In the years to come, rice mapping and monitoring will further improve thanks to the development of further technologies through new missions – such as TerraSar, ALOS and the next generations of RADARSAT. The combined use of various observing systems will increase temporal coverage and will allow a greater use of the synergy between the different SAR frequency bands (X, C and L). Earth Observation technology, integrated with other reliable data – such as accurate field surveys, GIS, predictive models, etc. – within Global User information systems, will help to supply complete and accurate information of predicted rice harvest volumes, within one month of planting (or transplanting) for all or a selection of major rice producing countries.

The investigation of farming techniques to reduce methane emissions from rice crops - possible contributors to global warming - is another area where research will be of significant importance. Although research in this domain is still in its early stages; it could play a more important role in the coming years. Here again, new EO technologies for agriculture show a strong potential.

ACKNOWLEDGEMENTS

This document provides descriptions of EO based services supplied by Synoptics, Radarsat International, Bolton Associates and SARMAP. For their work in market development these companies have been supported by ESA's Earth Observation Programme.

This document includes contributions provided by the IRIS consortium and CESBIO, which are gratefully acknowledged.

For further information on the EO service industry

Sarmap	Francesco Holecz • SWITZERLAND http://www.sarmap.ch	
Synoptics	Eric van Valkengoed • THE NETHERLANDS http://www.synoptics.nl	
RADARSAT International Inc.	Pierre Engel • CANADA http://www.rsi.ca	

For further information on EOMD activities and ENVISAT Program

The ESA Earth Observation Missions Help and Order Desk Team
tel: +39 06 94180777 • fax: +39 06 94180292
e-mail: eohelp@esa.int
http://earth.esa.int

EOMD e-mail: eohelp@esa.int
http://www.eomd.esa.int

A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE

Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

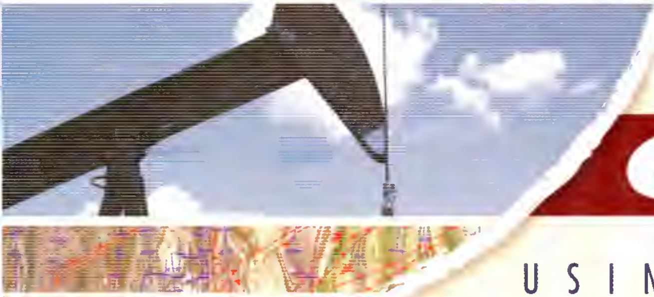
In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.

esa

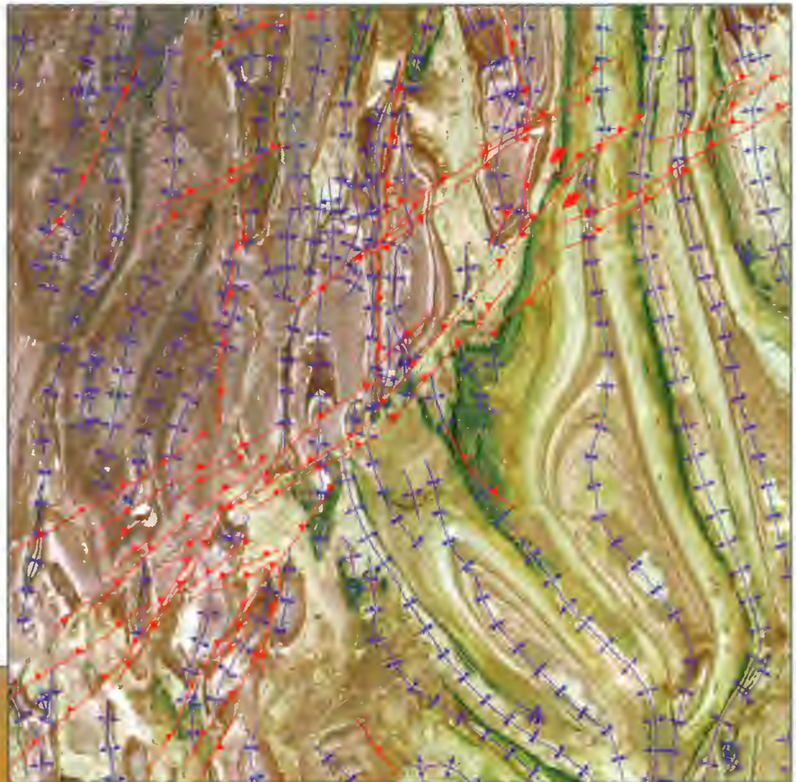
EARTH observation SERVICES today



GEOLOGY

USING RADAR FROM SPACE

the Living Planet



Right Derived Geology map from Landsat ETM and ERS, overlaid on the Landsat image. Exploiting satellite imagery is a useful aid in preliminary geological exploration before more extensive ground based techniques proceed. © Infoterra

below Satellite imagery can then aid the logistics of a hydrocarbon extraction facility, providing information on how and where to situate surface operations

THE **NEED** FOR BETTER **INFORMATION**

Oil, gas and minerals are vital raw materials on which the world economy depends. Ensuring an adequate supply means continuously exploring frontier regions for new supplies. Often, this implies conducting mapping surveys in remote or inhospitable regions with little or no existing reliable data to provide indicators on investigation priorities. In addition, inhospitable environments, where much of today's exploration is focussed (such as Arctic or desert regions), require careful planning and optimisation for logistics support. These factors combine to generate a constant need for reliable access to suitable data for these areas.

In parallel to the opening up of new regions in response to new government licencing, technology developments are ensuring that existing reserves can be extracted more effectively. Examples include horizontal drilling and improved reservoir modelling to optimise oil extraction from oil fields with a more com-

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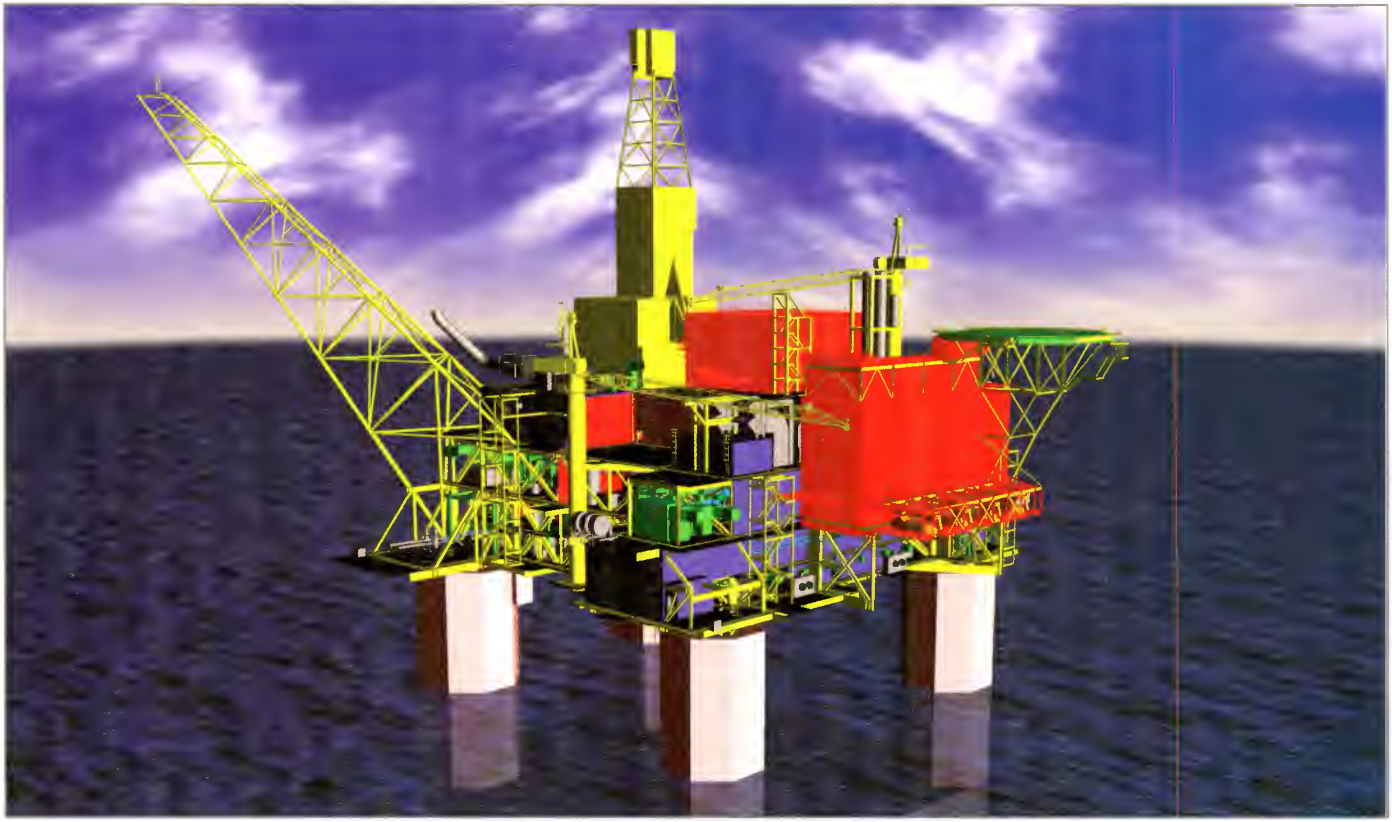
FROM AMEC



plex structure. Such developments generate demand for new and more comprehensive data to drive models used to manage these techniques (eg precise surface motion measurements). Although conventional mapping and surveying technologies can provide much of the required data, this may not be the most cost effective solution or there may be ways of reducing the risks associated with decisions based on incomplete information.

SPACE-BASED and TRADITIONAL METHODS to BETTER MEET **USER NEEDS**

THE LIMITATIONS OF TRADITIONAL TECHNIQUES

There are a wide range of data sources available to support exploration activities. These provide a valuable decision support function but there are many limitations. For example:

- Existing geological maps may be of limited value due to the scale on which the mapping was undertaken (eg 1:250000 is typical in many areas) or the accuracy of the analysis, if compiled using out of date, less accurate techniques than those available today. Lack of reliable basic geological information for planning new exploration activities adds to the risk of requiring additional survey time and the possibility of misinterpreting data once it has been gathered.
- Traditional field geology mapping is a slow process and in inhospitable regions can be conducted only at certain times of the year.
- Gravity and magnetic anomaly mapping provide information on the presence of particular structures and lower resolution data may be obtainable relatively inexpensively. However, the data cannot be used effectively alone and interpretation requires additional information on geological structure and even then can be ambiguous.
- Seismic mapping ensures detailed information but costs are high and turnaround times are very slow. Data are still subject to dropouts and other processing problems which may not be identified until after the data gathering campaign has been completed. Significant logistics support is also required (eg earth moving equipment) to ensure proper functioning of the instrumentation.
- Test drilling is the only method of reliably sampling a specific location although this is the most costly technique of all and requires a very high degree of logistics support both on and offshore. In general, test drilling is the last stage of analysis once all other datasets have been collected and analysed.

Although each of the above datasets have limitations, they also have significant value. If the cost effectiveness of these methods could be improved, this would ensure a realisation of a range of benefits including cost reductions, improved accuracy and faster turnaround times.

THE BENEFITS OF SPACE BASED MONITORING

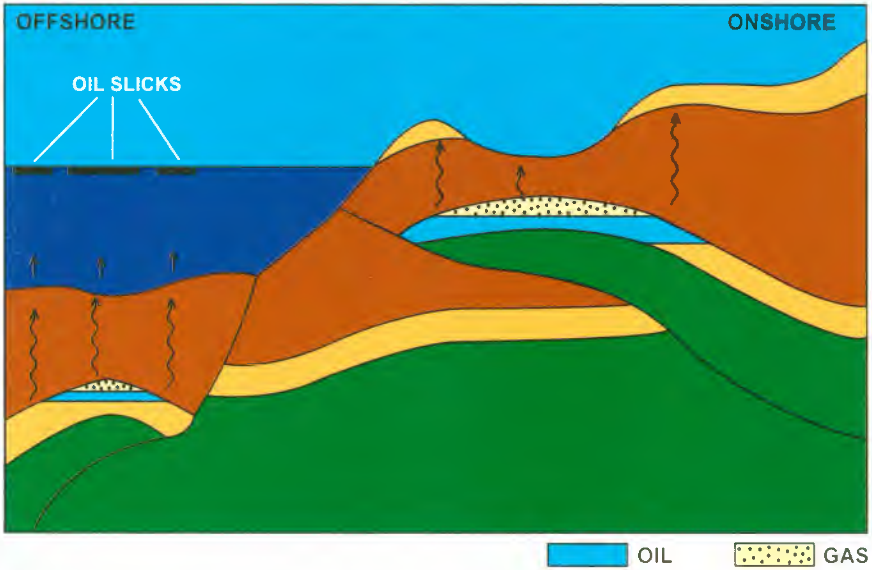
Today, services based on Earth Observation (EO) data gathered by a range of satellites are making a significant contribution in geological exploration. The main benefits of these services are:

- **Lower total data gathering costs** - use of EO based services can optimise the amount of more costly traditional data required for a given field area, enabling more competitive prices to be charged by consultancies
- **Faster turnaround of mapping and surveying projects** - EO based geological information services can use archived historic data for just about any area of the Earths surface. These data can be obtained very rapidly, often in just a few days. Extracting the necessary information obviously adds to the total turnaround time but this is still significantly more rapid than conventional techniques. Where the EO derived data are used to optimise the deployment of conventional technologies, the time savings can be considerable.
- **Lower risk** associated with identifying sites for detailed seismic survey or test drilling - the more information layers to which decision makers have access, the better the interpretation through cross-validation and removal of ambiguities. EO based services offer extra information layers in a cost effective manner to support improved decision making.
- **Improved logistics support** to field operations - more accurate characterisation of potentially difficult areas for geophone coupling ensure that field crews can effectively plan data gathering campaigns and have the required resources to hand. Areas of potentially poor data quality can be compensated for during the campaign through alteration of sites for vibroseis trucks and geophone arrays. Where extensive earth moving is required, support crews can be used in the most efficient manner.

THE INTEGRATION OF EO IN EXISTING GEO-INFORMATION SERVICES

EO based services ensure the benefits described previously due to their unique cost structure, the wide geographic coverage and the range of different classes of information that can be gathered. EO derived information can be combined with traditional data gathering techniques in a number of different situations. Some of the main examples are listed here.

Seepage slick mapping for offshore exploration support



Offshore seepage slicks can be reliably identified by expert interpreters using satellite based Synthetic Aperture Radar (SAR) images. The technique is effective under a well understood range of environmental conditions (surface currents, winds and waves). For a given region, archives of historic SAR images enable statistical analysis of these slicks which can be combined with traditional gravity and magnetic anomaly mapping techniques to better characterise particular basins when bidding for exploration licences against tight deadlines or for prioritising the deployment of costly seismic crews.

The quality of the analysis depends directly on the amount of data analysed so larger SAR archives ensure more reliable interpretation

The technique works due to the fact that hydrocarbon deposits can seep through the overlying strata and through the sea bed into the water column. These small amounts of oil and gas then rise to the surface where the gas is lost to the atmosphere and the oil forms a slick. These slicks can then be observed in SAR imagery over the ocean. This seepage process is already exploited in offshore oil and gas exploration although prior to the availability of EO data the only effective analysis tool was in-situ chemical sampling followed by laboratory analysis.

Geological structure mapping

Structural mapping exploits the fact that surface geology and geomorphology are coupled to subsurface structure. At present, SAR imagery is used to identify changes in surface roughness and to detect faults, joints and fractures to improve delineation of lithological boundaries and characterise drainage networks.

In parallel, multi-spectral data in the optical and infra-red bands are used to improve the characterisation of specific lithology units. In addition, multi-spectral data can be used to detect areas with spectral anomalies that indicate chemical alteration of the local strata caused by proximity to hydrocarbon or mineral deposits. For example, iron rich alteration products caused by hydro-carbons seeping through and reacting with over-lying sediments have specific spectral signatures (or ranges) that can be traced using multispectral sensors.

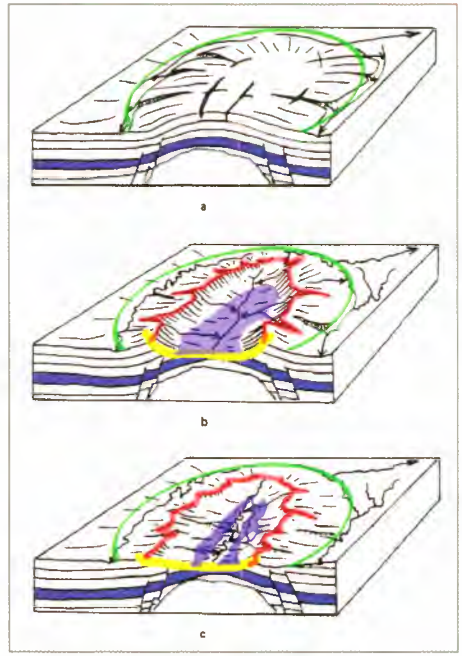
Digital Elevation Models based on SAR interferometry are also used to provide geomorphological indicators for possible hydrocarbon traps.

Linear features such as, folds, faults and lineaments, can be easily traced using SAR imagery. The Geologist studies these surface features in order to work out what is happening to the strata below. With continuous extension more rock beds become exposed such as the blue rocks at the surface in 'c' (see illustration) the different composition of the rocks have different spectral characteristics which can be picked up on multispectral data, and the textural differences can again be distinguished with SAR.

Thus by interpreting the different indicators within the context of the inferred tectonic and erosion processes for a given area, an independent analysis of the local geological structure can be derived. This information is integrated with conventional geological information (eg low resolution maps) as different layers within a GIS to enable substantially improved interpretation and analysis. By combining the different datasets, geological maps of between 1:50000 and 1:100000 scale can be generated.

Logistics support planning

Seismic surveys over a wide area require an array of geophones to be deployed to ensure accurate processing of the seismic signals. To ensure precise signal measurement by each geophone, they should be in direct contact with bedrock. Material between the bedrock and the geophone can alter the seismic waves or corrupt the measurement, thereby degrading the detected signal. Specifically, the presence of complex mixtures of rock and unconsolidated sediments close to the surface can cause data loss, multiple reflections or other propagation and scattering problems, each of which makes signal inter-



ABOVE These three diagrams show an extensional fault system at different stages of development (a-c). They show the surface expressions, faults, folds and lineaments of subsurface processes, in this case, uplift and the formation of extensional faults, a typical environment where a hydrocarbon trap could exist.
Courtesy GAF, modified from Berger and Aghassy, 1980.

pretation more difficult.

By analysing land cover, drainage patterns, DEMs, lineaments, morphological interpretations and textural patterns obtained from EO data it is possible to help identify areas liable to cause problems for seismic signal quality before a seismic acquisition campaign is started. This means that campaigns can be structured to avoid areas likely to generate such problems or appropriate support for particular areas (eg earth moving equipment to remove loose surface materials along the acquisition line) can be organised with suitable advance warning so that the campaign experiences minimum disruption.

Vibroseis Truck,
vital equipment for seismic data collection.
Image - Courtesy of Industry Vehicles International.
http://www.indvehicles.com

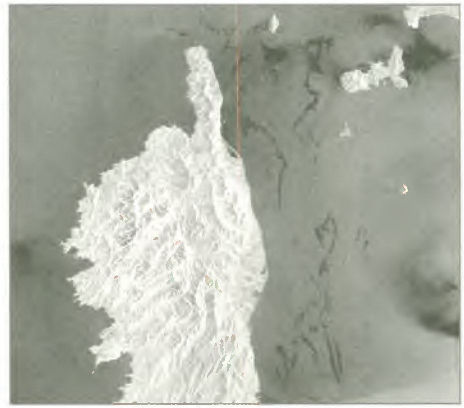
EXPLOITING EO-BASED TECHNIQUES

How can EO data provide useful information that can be integrated beneficially within the exploration process? This depends on the specific features being mapped.

In the example of seepage slick detection, the presence of thin oil films on the sea surface reduces the local sea surface roughness and hence the intensity of energy backscattered in the direction of the SAR. Slicks therefore appear as dark areas within a SAR image, usually with a characteristic shape. Specific features associated with oil seepage are used by specialist interpreters to distinguish these slicks from other phenomena (eg pollution). A characteristic of oil slicks opposed to those formed by other means is their duration, natural slicks have a constant source of oil therefore remain and evolve in one place over time, therefore studying images over time is an essential part of oil slick detection. The ERS mission operated by the European Space Agency has been collecting imagery over ocean basins world-wide since July 1991 and the Radarsat mission has been collecting imagery since 1995. In March 2002, Envisat was launched to ensure continued SAR observations for at least the next five years.

For mapping geological structures, satellite based sensors enable the detection of a range of physical parameters such as lineaments, surface roughness, elevation and lithospectral response which can be related to well understood geological and geomorphological indicators. In particular, the intensity of backscattered radiation measured by a SAR instrument depends on the surface roughness properties - changes in the scale of the roughness cause identifiable variations in the observed texture. Linear features stand out in SAR imagery due to the side viewing geometry and the increase in radiation reflected directly back to the satellite by such structures. With its systematic coverage, the ERS SAR archive is a valuable resource to support exploration geology although expert interpreters are required. In addition the Radarsat and J-ERS missions have both collected substantial archives of SAR imagery in all areas of interest to geologists.

SAR Interferometry (InSAR) can be used to generate Digital Elevation models (DEMs) over areas with moderate relief, while radargrammetry can be used to generate DEMs over more complex terrain. The ERS SAR archive provides a comprehensive coverage of all areas for interferometric applications, with over 10 years of data. Data from the so-called tandem phase of the mission (when ERS-1 and ERS-2 were operated together) were collected specifically in support of DEM generation. In parallel, InSAR processing has matured consid-

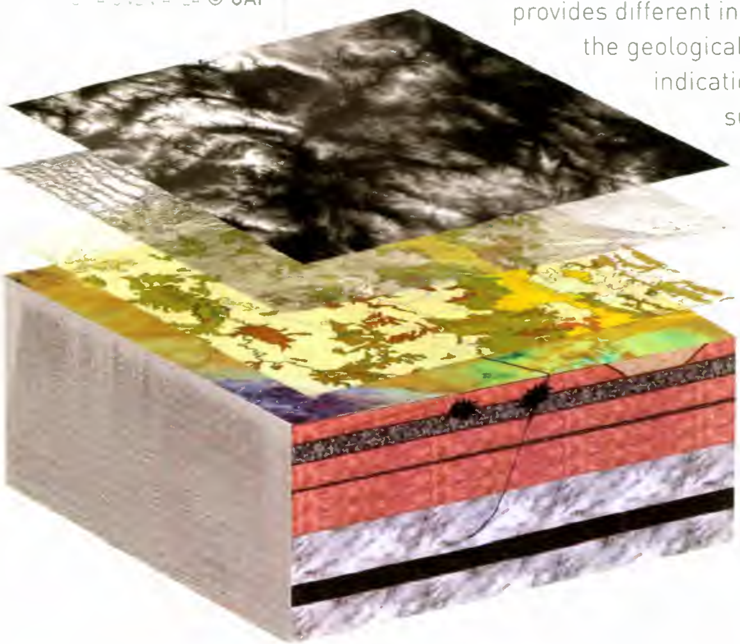


Above [illegible] © ESA 2002

erably and is now a standard capability offered by several service providers. With the availability of variable incidence angle, the Envisat ASAR offers a complementary capability to Radarsat in the generation of DEMs based on radargrammetry.

In the case of multi-spectral sensors, spectral reflectance in a range of different bands can be related to known properties of particular minerals and rock types. Both Spot and Landsat missions have extensive cloud free archives while newer missions such as ASTER provide a wider range of spectral bands at a similar spatial resolution.

Below: Combining data sets from numerous techniques, both traditional - field mapping, seismics etc, and Satellite - Optical, Radar, DEM, in a GIS in order to gain a better understanding of a given area © GAF



By combining the different information layers derived from the techniques listed above, a more accurate understanding of the underlying geological structure can be built up in a cost effective manner. Each layer provides different indications and constraints with respect to the geological history of a region (eg SAR data provide indications of drainage channels, DEMs indicate subtle surface variations associated with folding events while multi-spectral data indicate intrusion and oxidation processes.)

In the following sections, specific examples are given of how EO derived information layers are combined into a total service package.

Synergistic geology maps are already being produced for certain areas of the globe, combining remotely sensed Optical and Radar data. They are being generated and made available to a number of oil and gas companies by service providers such as Infoterra, NPA (both UK) and GAF (Germany). The data can also include known ground data, seismic, magnetic and gravity survey data, if available, in order to meet their client's specific information needs.

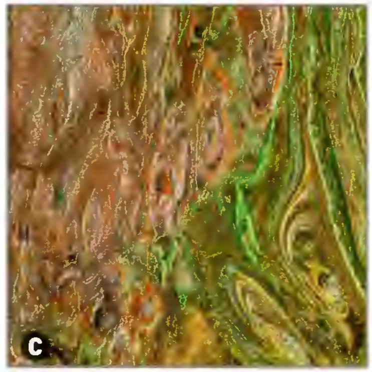
Working with IMC Group Consulting Ltd., a US based mining development company, Infoterra is supplying detailed geological maps derived from geo-referenced satellite imagery. The geological interpretation is integrated in a GIS structure with a range of ancillary geological data supplied by IMC, in this case, field reports, geological and geotechnical data (such as magnetic, gravity and

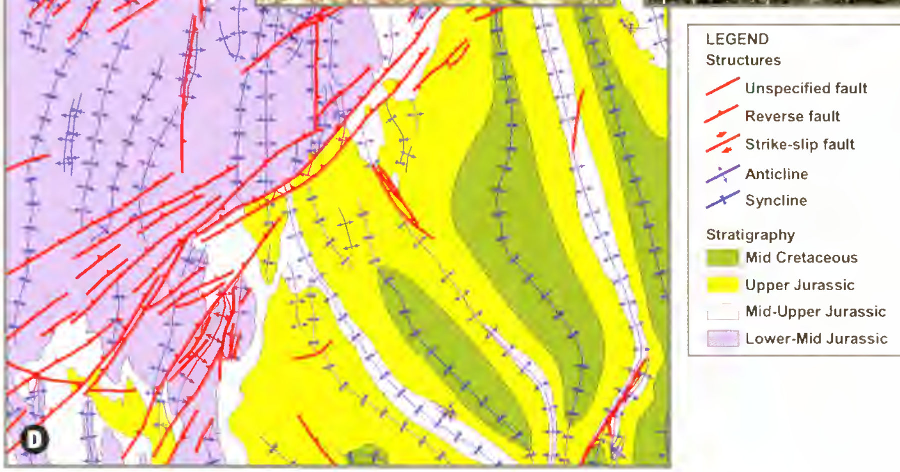
SERVICE EXAMPLES

Geological Interpretation by Data Integration.

A. Optical Landsat ETM+ image sub-set of the Tabas Coal Field, Iran. Bands 7,4,2 (R,G,B) merged with Landsat panchromatic band for intensity.

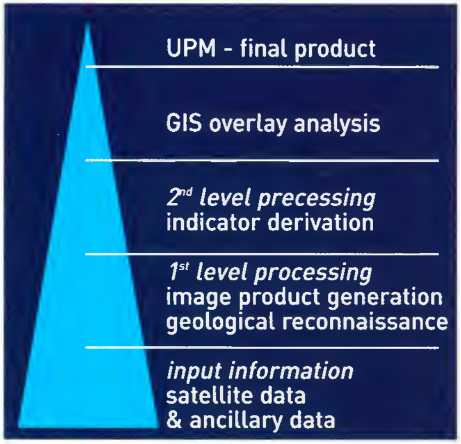
B. Radar ERS image of the same area, the radar image has been enhanced using a sharpening filter.





C. Synergy Image merge of the Optical and Radar data, the image highlights the different lithologies characterized by differing spectral attributes, along with textural differences and detailed lineaments picked up by the ERS data.

D. Geological Map of the Tabas Coal Field, using an integration of the given datasets.



THE ANALYSIS IS BASED ON INTERPRETATION OF BOTH SAR AND MULTI-SPECTRAL IMAGERY IN WHICH FEATURES SUCH AS CIRCULAR STRUCTURES, DRAINAGE NETWORK ANOMALIES, MARKER BEDS, TOPOGRAPHIC ANOMALIES, BRAIDING ZONES AND SPECTRAL ANOMALIES ARE IDENTIFIED AND DELINEATED WITHIN SEPARATE INFORMATION LAYERS IN A GIS.

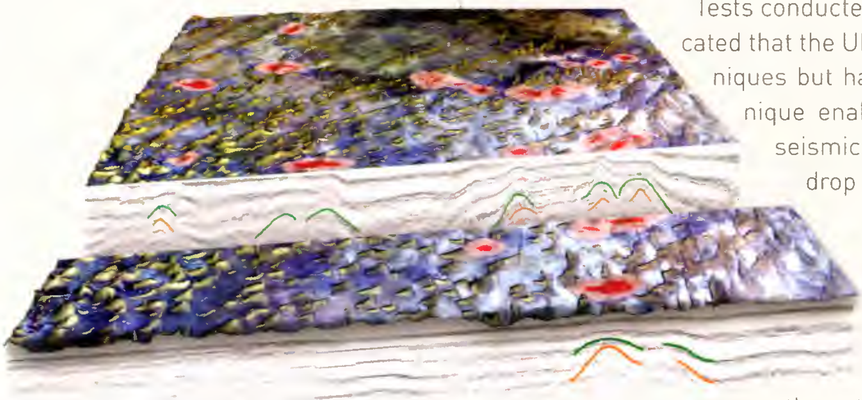
seismic data), to enable the identification and characterisation of areas of potential leads for future mineral exploration.

GAF are using a combination of optical and radar imagery to identify uplift signatures associated with possible subsurface hydrocarbon traps. The service is called Uplift Probability Mapping (UPM) and the underlying workflow is structured to retain the maximum possible flexibility to ensure that the techniques work under a wide range of geological conditions.

This information is then combined to generate a measure of probability that an uplift structure associated with the presence of oil or gas is present at a specific location.

In terms of the actual product delivered to clients, the UPM is a map of weighted probabilities for subsurface uplift structures. This is a multi-layer compilation of each data-set generated during the analysis process formatted as:

- Processed image products in GeoTiff format
- Vector layers as thematic maps in shape file format

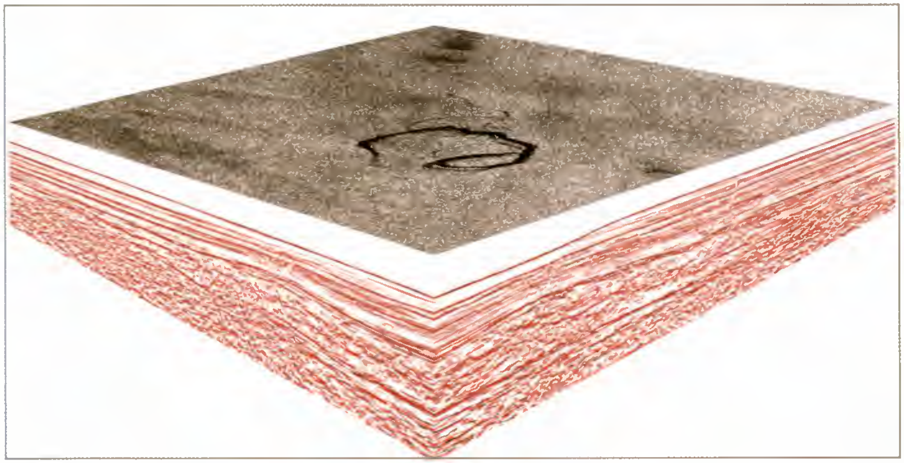


WHEN COMBINED WITH CONVENTIONAL DATA (EG UPLIFT FROM SEISMIC PROFILES OR KNOWN OIL/WATER CONTACTS), THIS IMPROVES THE FINE SCALE ANALYSIS OF A GIVEN REGION. IN THIS SCHEMATIC MAP RED INDICATES HIGHER PROBABILITY OF AN UPLIFT STRUCTURE © GAF

Tests conducted by a major Middle Eastern oil company indicated that the UPM method is consistent with traditional techniques but have a much lower cost. In addition, the technique enables improved interpretation of areas where seismic data may provide ambiguous signals or where drop outs may prevent any useful analysis.

Offshore seep detection, or basin screening, is presently purchased by a number of companies working in the Oil and Gas Exploration sector. The service is based on the extensive archive of SAR imagery from the ERS mission operated by ESA as well as Radarsat imagery. Both the NPA Group and Infoterra offer this service based on rapid access to the ERS data archive as well as Radarsat and now Envisat data.

Using a minimum of two scenes per location and looking at repeat acquisition NPA and Infoterra are able to cost effectively screen basins to provide recommendations for future oil and gas exploration. In practice a larger number of scenes are used within the analysis to guarantee the quality of the analysis. Typical products offered include analysis reports for a given basin containing a characterisation of all seepage detected in the area of interest and customised analysis combining seepage slick data with customer proprietary data and potential field data such as gravity anomaly maps



This schematic diagram shows a seepage slick observed in the Southern Caspian in ERS SAR imagery overlain above the underlying subsea geological structure. © ESA/Infoterra

FUTURE OUTLOOK >>

There is a necessity for more efficient and cleaner practices within the Oil and Gas industry and to monitor long term effects on the environment. This is one of the topics highlighted during the Johannesburg World Summit on Sustainable Development (WSSD)

Many observers agree that the Kyoto protocol will increase demand for gas as a clean fuel before cost effective methods for alternative energy generation are mature. This means continued requirements for exploring new frontier regions and re-analysis of existing concessions. In both cases, EO based services can ensure this is undertaken in the most cost effective manner. The Johannesburg World Summit on Sustainable Development (WSSD) also illustrates the commitment to adopt cleaner industry practices, highlighting the needs for environmental impact and monitoring in the Oil and Gas industry. This means more and more such companies are using EO data to not only search the prospective sources but also to assess logistics and the scale of environment impact such exploration will cause.

Advances in seismic techniques ensure higher resolution sampling of the subsurface but require an improved characterisation of the properties of the local environment to be taken into account in a more systematic way. More precise maps of local geological conditions are required and EO based information is an obvious source.

Additional SAR systems are also under development including Cosmo Skymed and TerraSAR. ESA is also acting as a data node for the ALOS satellite which carries the ALOS L-band SAR instrument. This will enable greater levels of penetration within land surface cover. Meanwhile, full polarimetry will provide improved distinction capability between different types of surface cover.

ACKNOWLEDGEMENTS >>

This document contains descriptions of EO based services supplied by GAF, Infoterra and NPA, and also includes contributions from Atlantis Scientific.

For their work in market development these companies have been supported by ESA's Earth Observation Programme.

For further information on the EO service industry

Atlantis Scientific Inc. Bob Dams • CANADA
http://www.atlantis-scientific.com

BRGM Christine King • FRANCE
http://www.brgm.fr

Era Maptec Martin Critchley • IRELAND
http://www.era.ie

GAF Tobias Wever • GERMANY
http://www.gaf.de

GEOSENSE Martin Tocher • UNITED KINGDOM
http://www.geosense.co.uk

Infoterra Global Martin Insley • UNITED KINGDOM
http://www.infoterra-global.com

Nigel Press Associates (NPA) Nigel Press • UNITED KINGDOM
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For further information on EOMD activities and ENVISAT Program

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A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE

Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

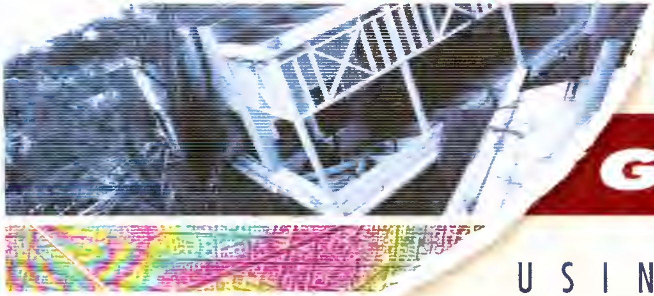
In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.

esa

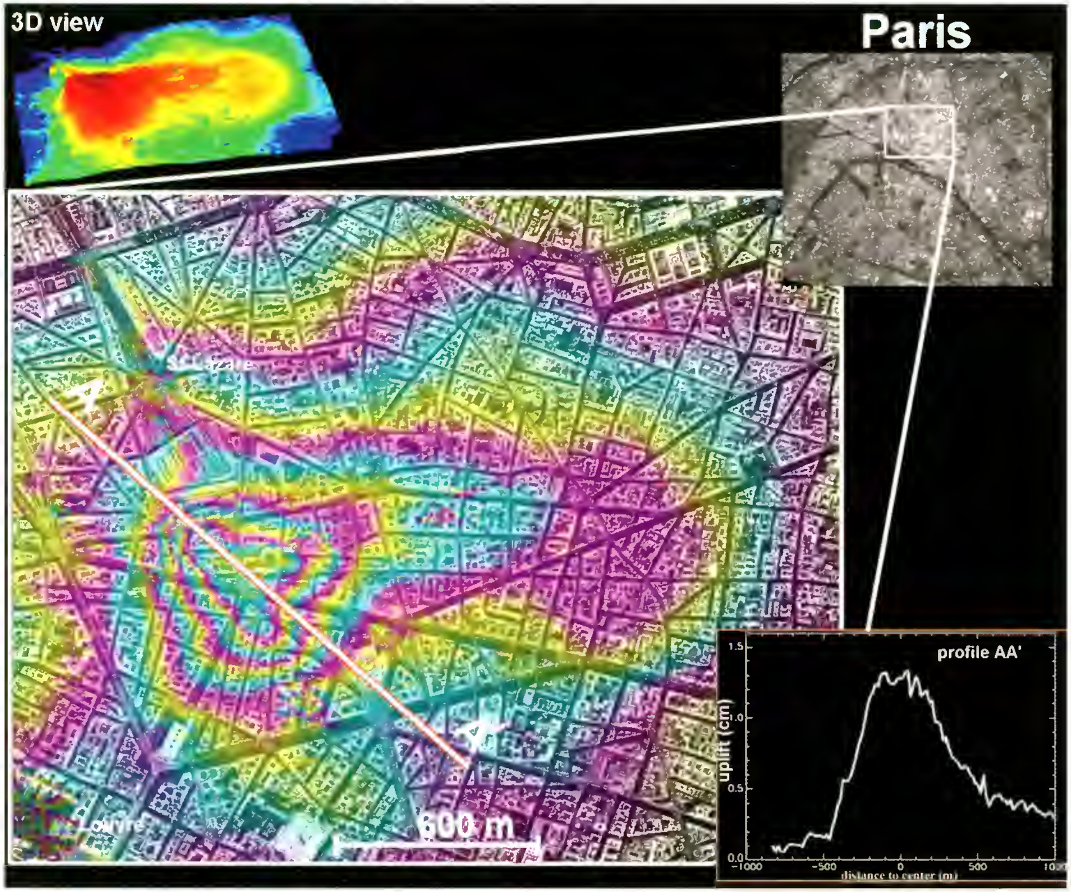
EARTHobservation SERVICEStoday



GROUND MOTION

USING RADAR FROM SPACE

the Living Planet



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THE NEED FOR BETTER INFORMATION

Ground motion is the surface expression of different physical events: subsidence, mass movements, earthquakes, volcanic activity, etc. In many situations human activities play an increasingly important role in triggering or accelerating the phenomena: slopes undercut by roads and infrastructures or overloading by buildings may induce changes in the natural equilibrium and cause ground instability; removal of fluids or solids performed through mining or pumping may result in consolidation phenomena, hence in subsidence.

According to the World Bank, over the last 18 years fossil fuel consumption has increased by almost 30% with an implied increase in the extraction rate, resulting in ground motion phenomena. Moreover, more than 80% of the subsidence identified world wide is a consequence of human exploitation of underground water. Both the rate of movement and the magnitude of deformation depend on local geology, and for instance, in the case of subsidence caused by mining or pumping, are related to size and depth of the layers being compacted or exploited and the extraction-rate.

Ground motion endangers public and private property and poses safety (and legal) issues, making the need for identifying and monitoring natural or human-induced ground deformations progressively more important. The overall increasing development of land and water resources threatens to aggravate existing ground motion problems and initiate new ones.

Environmental laws force oil, gas and mining industries to monitor the subsidence caused by extraction activities. Timely identification of deformations and assessment of their trends helps to plan mitigation activities and reduce economic losses. Knowledge of the areas affected by ground motion phenomena enables better corridor-planning for new infrastructures, avoiding unstable areas. Customers of a ground motion service can therefore be identified in different environments such as: public institutions (local/regional governments, civil protection, environmental offices); the oil, gas and mining industry; the insurance sector; engineering companies and utility operators, environmental organizations as well as the geophysical research community.

SPACE-BASED and TRADITIONAL METHODS to BETTER MEET USER NEEDS

THE LIMITATIONS OF TRADITIONAL TECHNIQUES

Current practices for monitoring ground motion are based on field surveys. Specifically planned campaigns are carried out to gather data offering discrete point information over restricted portions of the territory in a defined time-interval. Information is acquired by means of different tools and techniques such as optical levelling, Global Positioning Systems (GPS), total stations, bore-hole observations, extensometers, etc.

The accuracy of the ground-based motion measures range from mm to cm, depending on atmospheric conditions, unimpeded line of sight, availability of good benchmarks and reference points. In the case of GPS, measurements along the vertical axis have a lower accuracy than along the horizontal axis; therefore vertical ground motion such as subsidence cannot be analyzed with high accuracy.

Temporal sampling of the ground-derived data can be very high, but data must be acquired through dedicated campaigns and no previous information is generally available in absence of an archive.

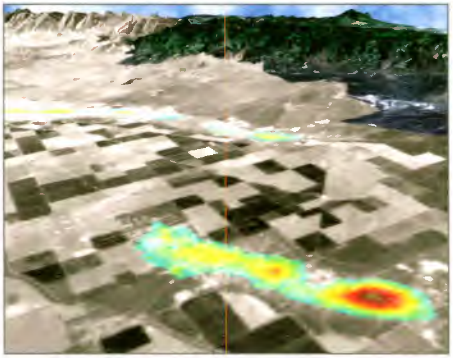
In a typical levelling network, the distance between benchmarks is in the order of 1 km, but may decrease to some 200 m in critical areas. When large areas need to be surveyed with a dense network of measures, the techniques become time consuming and expensive. Where an area is particularly wide, remote or inaccessible, aerial surveys, using photogrammetry or the light detection and ranging technique (Lidar) can be planned, but may be limited by cost restraints whenever repeated observations in time are required.

THE BENEFITS OF SPACE-BASED MONITORING

Space-based monitoring, as opposed to airborne and ground-based surveys, is possible day or night independent of weather conditions; this means that synoptic, 2D views of displacements can be periodically obtained at very low costs and over large areas.

In addition, techniques based on space borne radar imaging instruments (such as SAR Synthetic Aperture Radar) provide the capability to map past and on-going displacements in absence of ground networks, making possible the identification and monitoring of previously unknown ground-movements.

Monitoring of land motion can be achieved with Earth-Observation satellite data via the technology that employs a SAR instrument that scans the ground in successive passes and determines the difference in distance between the satellite and stable natural reflectors (i.e. buildings, engineering structures, rocks etc.). It is possible to measure the difference in position of the reflectors by combining two radar images that have been acquired over the observation period. With this method - Differential radar interferometry, or D-InSAR - differences of distance as small as a fraction of the radar wavelength can be measured, providing millimetric accuracy in the case of current space borne SARs. The technique has been applied to different Earth Observation (EO) missions including ERS-1 (1991-2000), ERS-2 (1995-), JERS (1992-98), Radarsat (1995-), Envisat (2002-) and will be applicable to future EO SAR missions such as Alos (2005) and Radarsat2 (2004). Today the availability of the world's largest and most dense EO archives, spanning over more than one decade, makes ERS data an invaluable and unique input for the creation of historical deformation maps.



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THE INTEGRATION OF EO IN EXISTING GEO-INFORMATION SERVICES

Users interested in deformation monitoring need to know the location of the area prone to motion (reconnaissance) and to quantify land motion over time. Standard differential interferometry directly results in deformation maps; in other cases point measurements of deformation are plotted in a graph so as to get the temporal evolution of the deformation (useful to forecast its trend), point information is then interpolated to get either raster or vector deformation maps. The products of interferometric processing are generally expressed in a geographic coordinate system, enabling ingestion into Geographical Information System (GIS) and comparison with other information layers.

Site selection, geo-technical risk analysis, exploration control or damage assessment are among the practices where integration of displacement maps derived from space borne SAR data with other parameters may help analysis, understanding and eventually prevention or mitigation of the causes of deformation. Services are developed aiming at the regular updating of displacement maps. Delivery frequency of such products depends on the type of motion: man-induced subsidence is in general much faster than natural subsidence.

Services associated to oil and gas pumping include deformation monitoring over the areas where extraction is on-going and provision of displacement maps to be used by specialists as an essential input to understand/forecast relationships between rate of extraction and induced subsidence. Understanding of this relationship enables better planning of extraction activities as well as preservation of the structures from unwanted damage in the extraction area and in the neighborhood.

Services associated to mining activities account for deformation monitoring for active mining, location of subsiding area associated to active mining and delineation of residual subsiding areas after the end of the excavation.

Services associated with engineering works focus on the reconnaissance of ground motion areas where creation of structures or infrastructures should be avoided and on monitoring of structures or infrastructures to prevent buckling and shearing of pipelines and railways, structural damages to bridges, dams and roads, or losses in gradient of canals and drains.

The information provided by EO data and associated techniques provides a cost-effective contribution to all these services and the availability of new satellites with interferometric capabilities in the future will bring continuity to these systems.

EXPLOITING NOVEL EO-BASED TECHNIQUES >>

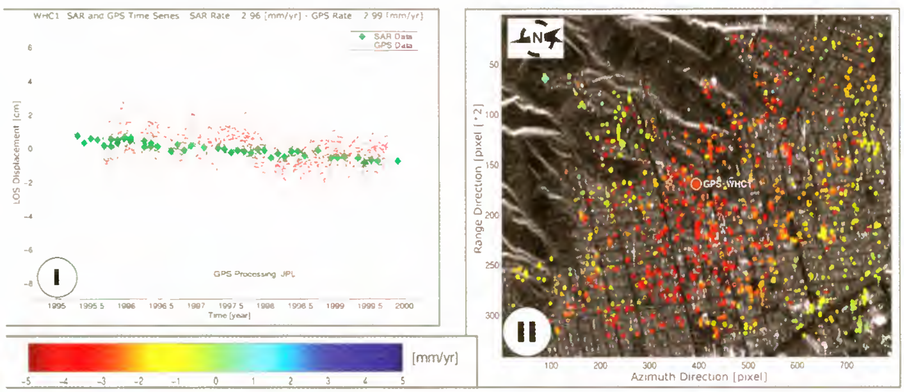
The ESA ERS missions have been acquiring C-band images of the world since 1992, which has led to the creation of a unique archive of valuable information for users of geo-information. This archive allows the study of past ground movements that can provide the means to forecast/model ongoing and future deformations in the case of deformation monitoring. The ASAR sensor, onboard the Envisat satellite provides continuity of C-band SAR data, building on ERS SAR archives, hence further consolidating the EO-based services. ASAR has enhanced viewing capabilities as compared to its SAR predecessor: the variable incidence angle makes it possible to achieve an overall better imaging geometry in hilly and mountainous terrain, with much less geometric distortions (so called "layover").

The availability of larger incidence angles also results in increased spatial resolution in ground range and a slightly reduced sensitivity to vertical deformations (being an advantage in case of large deformations). The 7 possible image swaths of ASAR also increase the possibility of identifying natural reflectors not available with the fixed swath of ERS SAR. In addition the on-board recorder of Envisat and the rapid data transmission capability to ground segment thanks to the ARTEMIS communication satellite guarantees faster and more reliable access to data worldwide. The ground resolution of the imagery ranges from 4m along the direction of movement of the satellite (so called "azimuth") and 25m in the direction perpendicular to the azimuth ("range").

Besides their unique performance, conventional D-InSAR techniques show some limitation in those areas where land-cover undergo changes between different acquisition dates ("coherence loss") and where the transmission of the radar signal is being modified by interaction with atmospheric effects ("atmospheric artefacts"). The applicability of interferometric techniques to monitor deformations is also influenced by the magnitude of the deformation that must not be bigger than a fraction of the radar wavelength along the satellite's line of sight. In the case of a C-band SAR (ERS or Envisat) the wavelength is 5.6cm, in the case of a L-band SAR (J-ERS) the wavelength is 23.5cm. Revisit time of the satellite is another key-issue, since the ERS and Envisat satellites pass over the same spot once every 35 days, which is often not enough particularly in those cases where frequent updates are needed (e.g. alert systems).

Recent advancements in differential interferometry have demonstrated the robustness and precision of new methods and techniques to overcome some of the limitations of conventional INSAR. These techniques are based on artificial point targets (passive receivers or Corner Reflectors as well as active transmitters or Transponders) as well as natural reflectors with stable radar response over time - with regard to the radar intensity and phase information.

By using artificial targets (man-made reflectors anchored to or near the structure to be monitored) it is possible to apply interferometry over areas that normally suffer from choerence loss and measurement artefacts. The pioneering works of Politecnico di Milano in the late nineties showed that natural or artificial targets can be identified in time-series of images, and allow the removal of disturbances created by atmospheric effects by reconstruction and analysis of the deformation history of each identified target. For example such techniques e.g. the Permanent Scatterers by T.R.E., Interferometric Point Target analysis by Gamma, Stable Point Network by Altamira and Coherent Target Monitoring by Atlantis Scientific, have proved extremely valuable for ground motion measurement in the built environment such as in urban regions, as demonstrated through intensive testing and validation.



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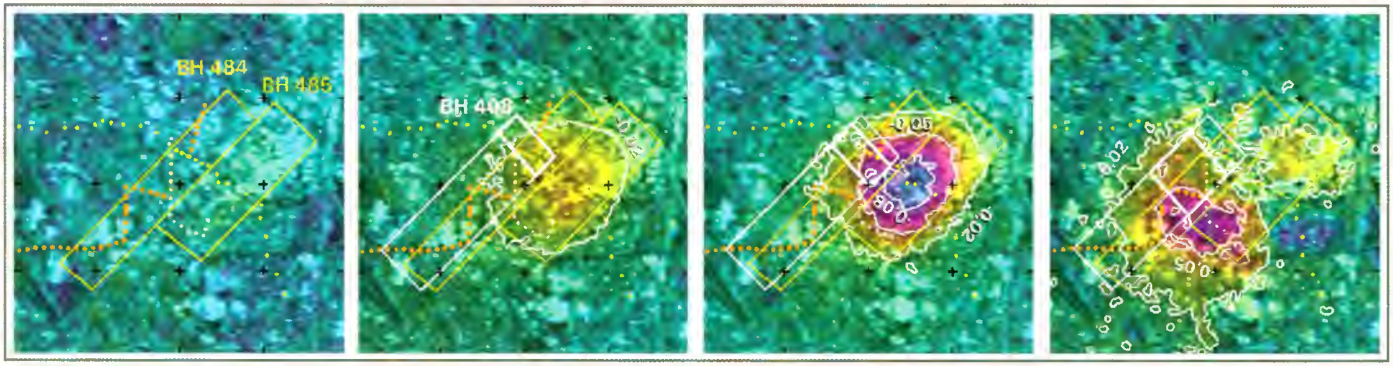
SERVICE **EXAMPLES** >>

Routine ground based monitoring of ground deformations through a GPS network maintained by the German coal company DSK has been integrated with a space borne SAR monitoring service to study subsidence associated to coal mining in Ruhrgebiet (Germany). Time series of deformations were elab-



17.02.2000 - 01.06.2000 01.06.2000 - 14.09.2000 10.08.2000 - 19.10.2000 4.09.2000 - 28.12.2000

Monitoring of underground coal mining induced surface deformation with differential SAR interferometry. The absolute subsidence values are indicated in colour (one color-cycle from blue to red to blue corresponds to 12,8 cm vertical subsidence) and by isolines (2 cm, 5 cm and 8 cm contour-lines); an overlay with production panels (BH484 Jan. 98 - Dec. 98; BH485 Apr. 99 - Nov. 99; BH408 Jul 00 - Jul. 01) and levelling lines 1 (orange), 2 (yellow) and 3 (white) is shown. ERS data © ESA, 1998-2001. *Distributed by Eurimage.* SAR and interferometric processing by GAMMA Remote Sensing, mining panel information DSK.

orated by GAMMA, a Swiss based value-adding company providing consulting services and software, and supplied to the user as geocoded layers. The interferometry based deformation information is integrated into the users geo-database together with standard measurements, enabling the analysis of the correlation between subsidence and the coal-production panels. Radar interferometry, with its very high sensitivity to height changes appears to be extremely well suited to identify subsiding areas and especially to quantify and map residual deformations after the end of the excavation process.

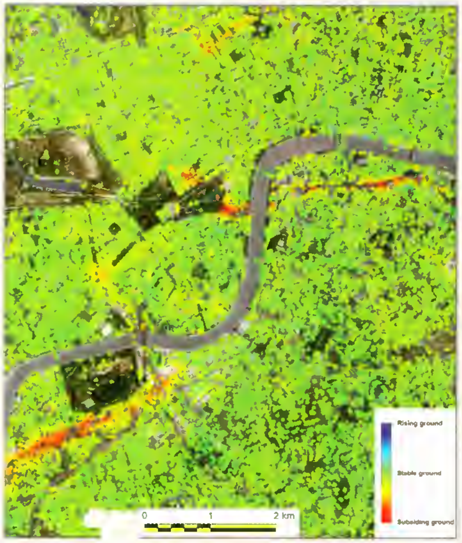
In the Belridge Oil Field (U.S.A.), the removal of fluids from the 3rd largest oil field in the U.S. has led to substantial reservoir compaction, causing surface subsidence and well failures costing millions of dollars per year and having a major impact on the economic viability of oil production.

Since the late 1980s a network of level survey measurements has been used by SHELL to monitor subsidence in the attempt to find a model for it. Radar data were acquired over the area by the ERS-1 and ERS-2 satellites of the European Space Agency in such a way that a quasi-continuous subsidence monitoring service could be guaranteed on a monthly basis for a period of 1 year. Additionally, ESA provided baseline values (a parameter characterising the "stereo" effect of a pair of interferometric images) within 3 days after the acquisitions in order to allow the most suitable data to be identified and the resulting service to be rapidly provided. The time required for the provision of the end- to- end service was systematically shorter than 2 weeks (1-2 weeks in average). In this example the products provided by Atlantis Scientific Inc., a Canadian company specialised in providing products and services based on radar satellite imagery, contributed to a better understanding of the relationship between injection, extraction, subsidence and oil-well failures, which coincide with high subsidence gradients: this forms critical input for assessing the impact of the density of oil wells in the planning of oil production. Moreover, the frequent and rapidly supplied subsidence maps by Atlantis are now an effective management tool for monitoring production and injection operations. They are also used in the form of well failure risk maps by engineers in the field during oil well maintenance activities. As a consequence of this activity, the customer has discontinued their conventional in-situ measurements, and placed a further follow-on contract for continued provision of this EO-based service. Deformation maps are delivered routinely within 2-3 days after SAR data acquisition.

In Southern California C-CORE a global research and development company based in Canada providing engineering solutions to clients in the natural resource sectors, used SAR data in a blind test to monitor ground motion of an oil field traversed by a series of gas pipelines. The results compared favorably with the concurrent in situ surveys. In related work C-CORE used archive data to identify possible subsidence features and generate a ground movement risk map for an area where very little ground motion information previously existed.

A series of passive corner reflectors are installed on slopes supporting buried gas pipelines maintained by TransCanada Pipelines Ltd in order to monitor, by means of D-InSAR, incremental small movements whose cumulative effects may affect pipeline integrity. In these regions of Canada pipeline corridors are cleared of trees for a width of 10 to 20m hence the study by C-CORE uses Radarsat fine mode data, providing higher horizontal geometric resolution. Monitoring is conducted from spring until fall and detected motion (ranging from 1 mm to 35 mm) are in accordance with field data. Information gained through SAR processing, coupled with geotechnical analysis, enabled understanding of mechanical behavior of the

Operational D-InSAR monitoring for Bart Heart Creek, Alberta. The photo shows obvious signs of slope instability.
© C-CORE.



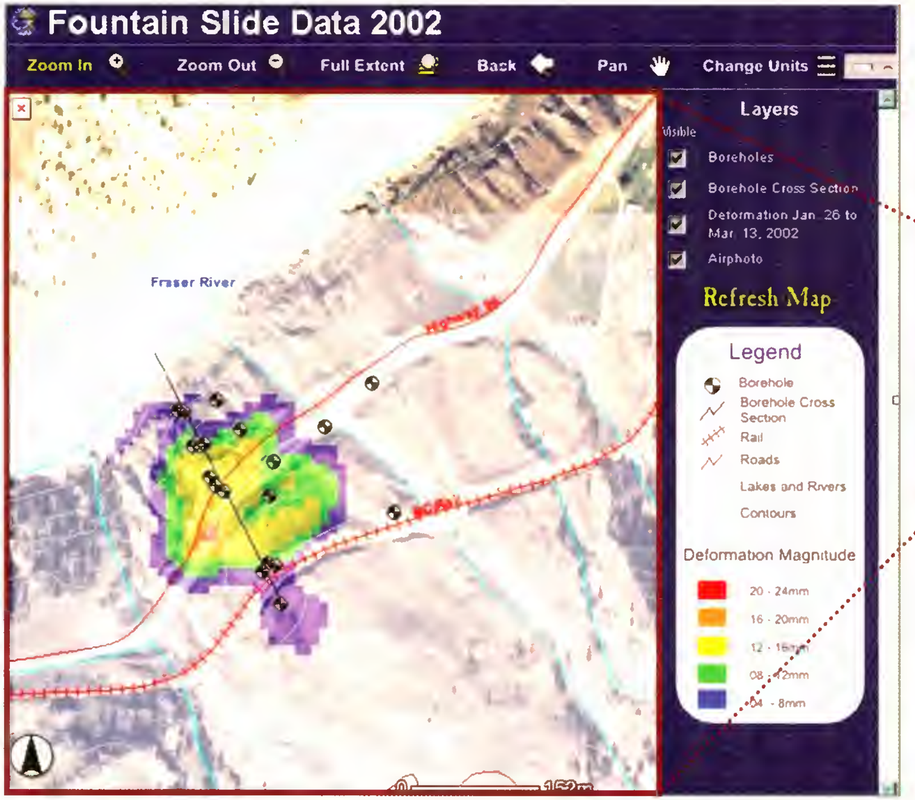
^^ Georeferenced and interpolated average annual displacement map over London. Results reveal areas of subsidence (red) corresponding to underground tunnelling activity for the extension of London's Underground Jubilee Line. This magnitude of subsidence was expected and the amount revealed by INSAR closely compared to that measured by in-situ equipment. © NPA, 1992. ERS Data © ESA, 1995-2000. *Distributed by Sarcom.*

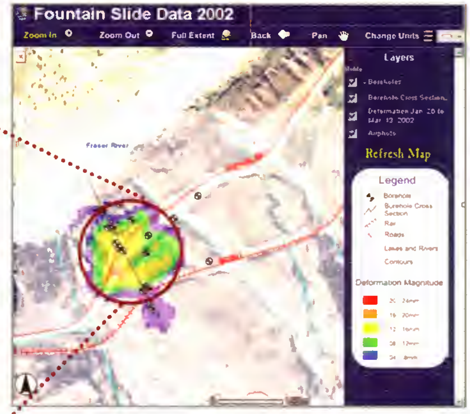
>> Radarsat imagery of a London reservoir shows an array of radar reflectors which were deployed around the perimeter of the reservoir allowing millimetric measurements of stability. The inset images show the eflector responses from the reflectors, one of which is shown in the lower left hand corner of the image. Processed by NPA with TRE software. Radarsat data © Canadian Space Agency, 2001. *Distributed by Radarsat International (RSI).*

slope, the impact of rainfall events, and resulting pipeline stress.

Tunnelling activity for the Jubilee Subway Line extension in London triggered ground displacement phenomena, affecting also Thames Water's infrastructures. Detection and monitoring of deformation has been performed by NPA -a company providing expertise in remote sensing and digital cartographic information- together with their Italian based partner TRE on archived SAR scenes by means of the Permanent Scatterers technique. From the analysis of the georeferenced and interpolated PS velocity field combined with Thames Water's Ordnance Survey land-line vector data it was shown that the subsidence started occurring at the beginning of 1996; the spatial distribution of subsidence correlates well with the tunneling works.

Thames Water needed to monitor in an effective way the integrity of a water reservoir, west of London. Traditional measurements carried out by means of GPS to measure the stability of reservoirs retaining walls have been coupled to InSAR processing performed by NPA. Corner reflectors have been installed on the retaining walls and any millimetric movement of the structure between two consecutive

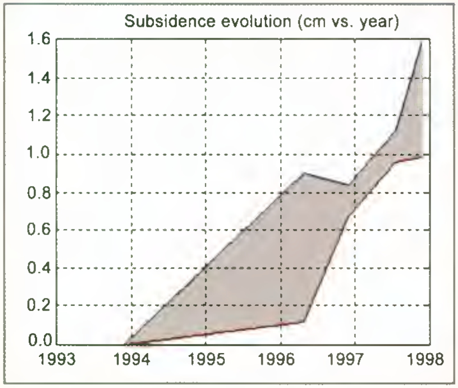




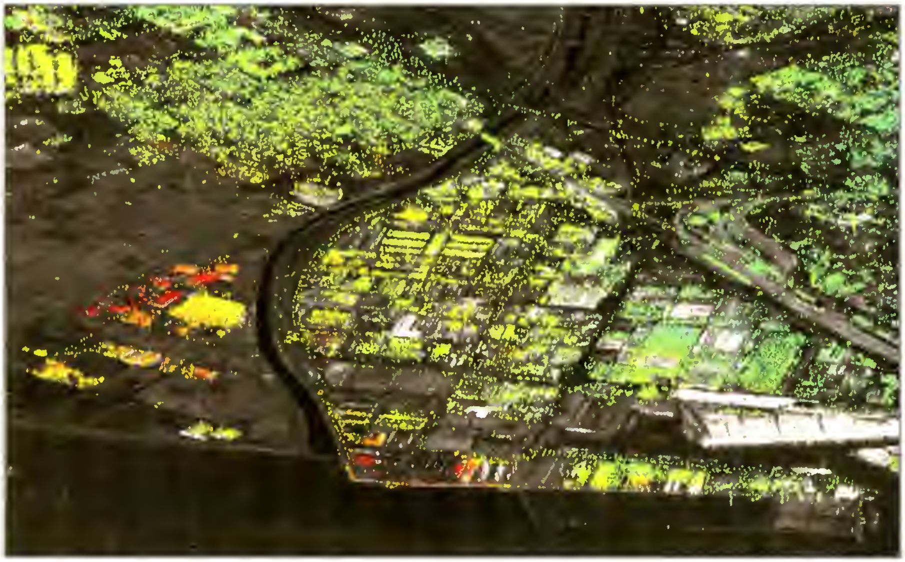
The image shows the GIS used by the BC Ministry of Transportation: different layers (elements at risk, boreholes, Radarsat derived deformations) are displayed. It is evident that the ground network of measurements is not extensive enough to monitor the overall extent of the Fountain landslide (active since 1970). Processed by Atlantis Scientific Inc. Radarsat data © Radarsat International (RSI), 2002. *Distributed by RSI.*

passes of the SAR sensor are routinely detected and monitored. The excellent results provided by this technique resulted in the extension of the monitoring service to another reservoir located in Turkey.

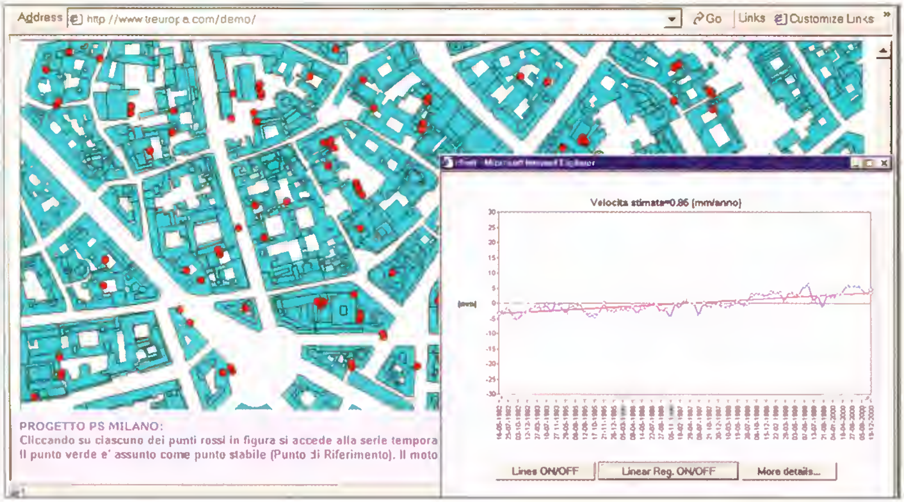
BC rail and highway 99 in Canada are endangered by the deep-seated Fountain slide. In the past 10 years, engineering works on the slopes and remedial works on the highway have been performed without the expected results. In order to analyse ongoing deformations and to plan mitigation interventions, BC Ministry of Transportation has asked Atlantis Scientific Inc. to analyse with InSAR extension, magnitude and direction of the landslide movements. The produced information was ingested in a GIS and successfully compared with geotechnical information. From the exploitation of the ERS archives it has been possible to delimitate, follow in time and understand the evolution of the landslide since 1995.



Arica is a city of some 170000 inhabitants located in the Norte Grande province, Chile. Salt lenses alternated with sandy sediments characterise the underlying geology. The growing urban area over the soft sediment causes stress on the soft lenses provoking their dissolution. The consequence of this dissolution is ground subsidence, quantified in the order of 2 to 15 cm/year. Interferometric processing of 7 SAR archive scenes acquired between 1993 and 1997 was done by INDRA and enabled the identification of subsiding areas with a non linear evolution of subsidence in time. The picture shows urban subsidence and the rate of subsidence in time.
Processed by INDRA. ERS data © ESA, 1993-1997. *Distributed by Eurimage.*

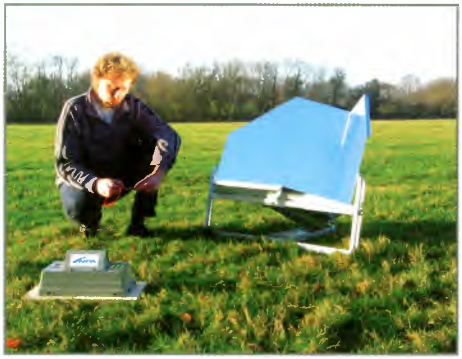


Example of mean subsidence estimation in an industrial area of Barcelona Harbour over an 11 year period measured by ERS and ENVISAT obtained with the Stable Points Network (SPN) technique. Built on the old delta of the Llobregat river, this area experiences subsidence at rates of up to15 mm a year.
The displacement is measured with an accuracy better than 1.0 mm/year.
Processed by Altamira Information.
ERS and ENVISAT data © ESA.
Distributed by Eurimage.



Amministrazioni Immobiliari Beretta and Consorzio Provinciale per il Risanamento Idra[illegible] Nord-Est Milanese are concerned about ground movements in the city of Milan that may result in damage to their assets. Information about temporal and spatial distribution of the deformation might also be used in legal procedures for damage claims. The PS technique was used by TRE to locate and quantify time series of subsidence in the area. A Web GIS has been developed coupling a georeferenced map of the city and point information about the deformation evaluated in the time-span 1992-2000. Prototype radar reflectors have been produced and deployed for monitoring purposes on those buildings of specific interest to the customer, not showing a natural permanent scatterer behavior. These reflectors (mirrors) are a low cost, easy to install and environmentally friendly (non-intrusive) solution with a high mechanical stability.
Processed by TRE.

FUTURE OUTLOOK >>



CRInSAR is an InSAR technology appropriate for measuring and monitoring the stability of specific structures, e.g. water reservoirs, dams, bridges and other buildings. These artificial reflectors can be deployed in areas lacking natural reflectors, in order to monitor such areas or structures for displacements. NPA is currently developing the 'Compact Active Transponder' which in some circumstances will replace metal corner reflectors and provide enhanced features for site-specific monitoring. © NPA, 2003.

Further work to integrate ground data acquired through GPS or levelling, and information derived by interferometric techniques will help to offer complementary information for the creation of full 3D deformation vectors models, thus providing even more effective and reliable tools to analyse deformations.

In addition, enhanced monitoring potential is expected thanks to the Envisat ScanSAR mode: the possibility to image areas 4 times wider than in image mode will enable "low resolution interferometry" and a more frequent revisit time.

Deployment of Compact Active Transponders, with their reduced size will help in the future to fill the gaps in low-coherence areas and to better correlate ground measurements with satellite-derived information. Furthermore their portability will enable the re-utilization of the instrument, reducing the costs needed to monitor with artificial targets and hence enabling provision of even more affordable services.

Future EO SAR missions are taking into account interferometric applications such as with TerraSAR and RADARSAT-2 in the years to come. This is also true for the Japanese ALOS mission scheduled for 2005 that will include L-Band SAR to guarantee better coherence in vegetated areas and provide reliable information (but with lower accuracy) to allow monitoring of land motion in areas with subsidence rates > 3 mm/day.

ACKNOWLEDGEMENTS >>

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This document also includes contributions from Altamira Information and BRGM who are gratefully acknowledged.

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A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE

Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.

esa

EARTHobservation SERVICEStoday

SATELLITE MAPPING

USING RADAR FROM SPACE

the Living Planet

FROM LEFT TO RIGHT

Extract of an ASAR image acquired in AP Mode over Amsterdam and surrounding area, Envisat data © ESA 2002.

Overview of the radar based digital map of French Guiana, *Courtesy of DGA/CEGN/IGN Espace/UPMC/STAT*, ERS data © ESA 1992-1994.

THE NEED FOR BETTER INFORMATION

Many remote areas of the World are now being opened to exploration and development, generating a growing demand for up-to-date knowledge of topography, land cover and other geo-spatial information. Such knowledge is of great importance for the management and planning of activities including land-use development, natural resource exploitation and engineering projects. And yet statistics provided in 1987 by a United Nations Secretariat Survey show that more than 40% of the World's land surface is still not mapped at a scale of 1:100 000. 1:50 000 scale maps cover just over 50% of the land area, but only 20% is mapped at 1:25 000 or better.

The mapping industry worldwide is currently experiencing rapid technological and organisational change. By using as many data sources as possible, a more complete and accurate knowledge of a landscape can be obtained. Therefore, users are seeking to integrate a multitude of spatially referenced information into their management and decision-making systems, a step that is facilitated by the standardisation of digital formats and the rapidly expanding market of Geographical Information Systems (GISs).

Today's mapping projects rely increasingly on Earth Observation (EO) techniques capable of providing high-resolution data using different types of sensors' data sets over wide geographical areas. Thus, map producers are making use of the latest, least time-consuming and most efficient methods to ensure their products are of the highest quality whilst minimising the cost.

THE LIMITATIONS OF TRADITIONAL TECHNIQUES

SPACE-BASED and TRADITIONAL METHODS to BETTER MEET USER NEEDS

Aerial surveys and ground measurements are the conventional means of producing maps and, for small area mapping, remain the most accurate. Triangulation/levelling and Global Positioning System (GPS) measurements in the field establish a network of precisely located benchmarks, whilst photogrammetric analysis of aerial photographs adds topography and surface features. These traditional map-making techniques are labour intensive and demand highly skilled operators. The production of maps covering large geographical areas (i.e. entire regions) is particularly time consuming. Therefore, mapping projects often become obsolete within five years because they cannot be up-dated often enough. Furthermore, products are frequently incompatible with the modern computer-based decision-management systems employed in many application sectors.

THE BENEFITS OF SPACE-BASED MONITORING

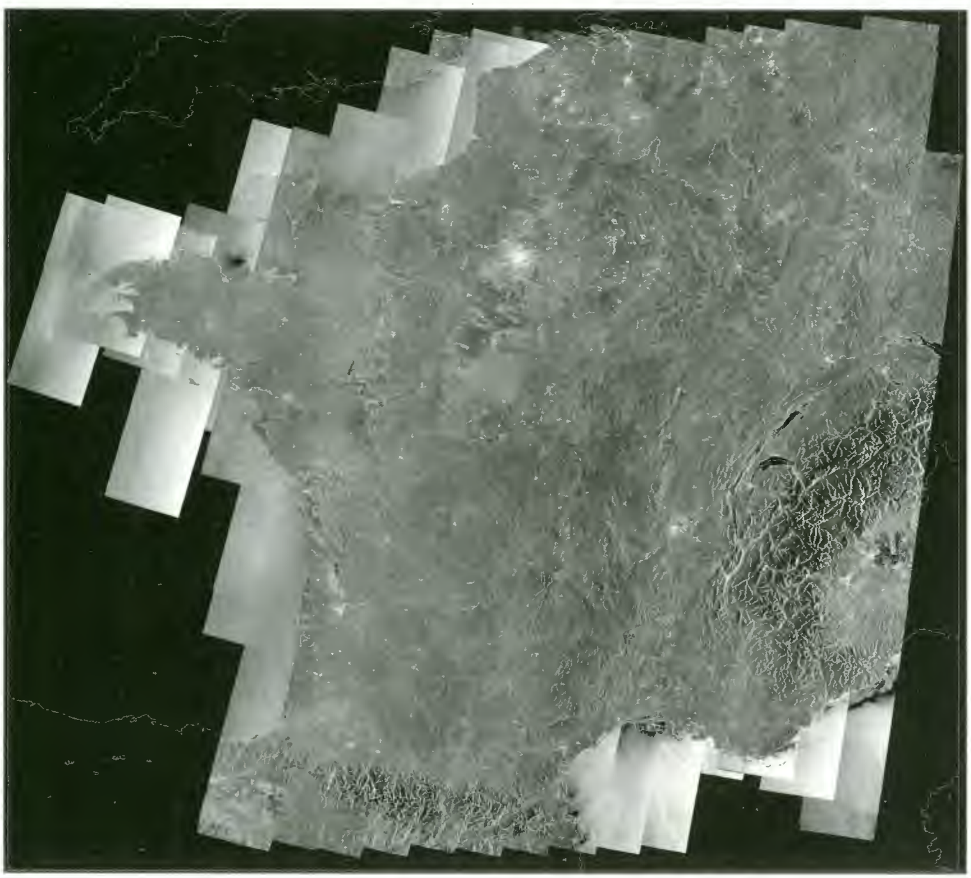
Because of its ability to provide up-to-date information quickly over a large area, spaceborne imagery is increasingly being adopted by the mapping industry. Unlike airborne platforms, satellites provide regular, systematic and synoptic views of all areas of the globe with a consistent geometry and at a contained cost per square kilometre, thus enabling effective land monitoring practices and repeatable cartographic analysis. Problems of access to remote and restricted areas are also overcome.

Optical remote-sensing data products (such as those from the Landsat SPOT and US very high resolution systems) are used to produce space maps (geo-referenced, annotated images) on a wide range of scales. Those with the highest resolution (e.g. from Ikonos and Quickbird) facilitate detailed delineation and identification of surface features for map compilation. Such space maps serve in particular the needs of mapping agencies, exploration outfits and telecommunications companies.

The primary limitation of optical imagery for mapping purposes is its dependence on virtually cloudless skies. In areas of the world where cloud cover persists for much of the year (as in the tropics) - regions where base mapping could typically benefit from space-based solutions - this precludes the use of optical data. Radar imagery has all-weather, day-night capability enabling it to overcome this limitation.

The SAR (Synthetic Aperture Radar) instrument carried by the European Remote Sensing satel-

THIS MOSAIC OF ERS SAR IMAGERY OVER FRANCE, ASSEMBLED USING 21 STRIPS OF REDUCED RESOLUTION DATA, DEMONSTRATES HOW EASILY THE RIGID IMAGING GEOMETRY OF SAR ENABLES ADJACENT SWATHS TO BE COMBINED TO PRODUCE LARGE-COVERAGE MAPS.
© ESA



lites ERS-1 and ERS-2 has proved extremely valuable in markets dependent on large-coverage maps. The archive of SAR data has been growing since the launch of ERS-1 in July 1991 and continues to be augmented with new acquisitions, making it the largest database of global imagery in existence. Such a resource is invaluable for historical change mapping and space map image quality improvement by means of multi-temporal filtering.

Courtesy of SERTIT.
Map extract © IGN, SPOT extract © CNES 1996, *Distributed by Spot Image.*
ERS extract © ESA 1992-1996.

THE INTEGRATION OF EO IN EXISTING GEO-INFORMATION SERVICES

Geo-information is, by definition, spatially related and therefore reliant on mapping. Some sort of base map is the foundation upon which every GIS or geo-spatial service is built. Hence, cartography can be seen as a horizontal element of the geo-information service industry, supplying an input to every processing and application-based chain and for a broad range of thematic applications.

Cartographic production chains that exploit both SAR and optical data exist and operate in both the civilian and security sectors. Topographic mapping services can be provided using a number of techniques and EO data sources. The conditions under which these services can be provided, and the technical specifications of the resulting topographic products are well understood.

Satellite mapping offers improvements in terms of localisation accuracy, height determination and level of feature detail that benefit the whole spectrum of service providers and users. As an alternative source of data, satellite mapping is established and, in some sectors, has become the preferred choice. It has now become a recognised source of topographic information for a range of applications including Telecoms and Security.

EXPLOITING NOVEL EO-BASED TECHNIQUES >>

Synthetic Aperture Radar is an active system that produces images under all weather conditions by analysing the echoes (C-band) transmitted from the satellite and scattered by the Earth's surface. Because of the specific interaction between the radar wave and the ground surface, the information content of SAR images is different from that of optical images. An image product from the ERS and Envisat SAR sensors typically covers an area of approximately 100 km by 100 km and has high geographical location accuracy.

ASAR on-board Envisat will continue and enhance the legacy of the ERS family with enhanced capability in terms of coverage, range of incidence angles, polarisation, and modes of operation. The new Wide Swath Mode offers improved coverage for large area mapping, affording a synoptic view of a 400km swath of the Earth's surface.

SAR image maps can be exploited for various types of applications:

> **cartographic mapping and Digital Elevation Model (DEM) generation**: for compiling and updating map products by taking advantage of the thematic information they contain, and of the capabilities to extract topographic information from them

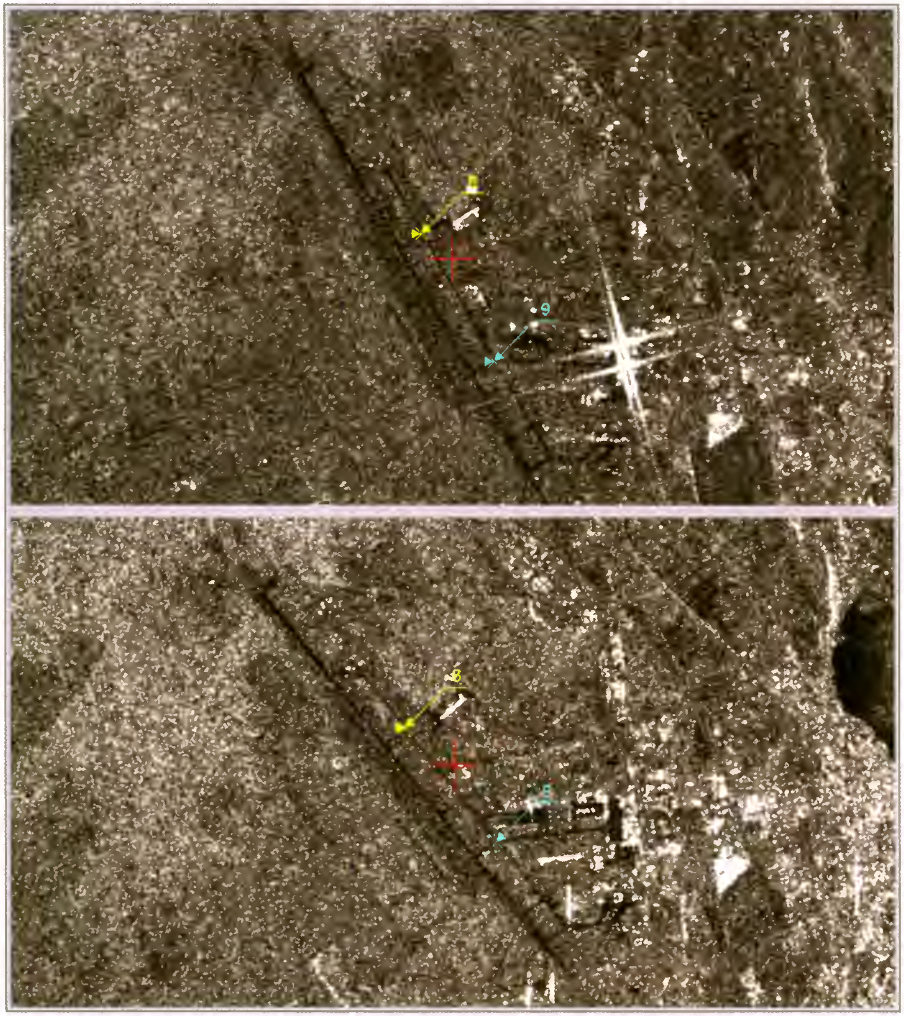
> **localisation**: to detect or identify control points and localise targets on the ground surface in remote areas, as a complement to GPS measurements

> **rectification**: to rectify old or inaccurate maps, space maps generated using remote-sensing data with inaccurate localisation accuracy, or even to rectify a Digital Elevation Model (DEM).

The capabilities of SAR for generating image maps have been well-established thanks to the experience gained using ERS.

The space triangulation technique allows the precise modelling of a SAR acquisition based on orbit and instrument parameters. Envisat's DORIS instrument helps by providing rapid access to very accurate orbit information for imagery acquired simultaneously by the ASAR sensor.

By using space triangulation, it is possible to generate SAR-based image maps over large surfaces and with high geometric quality and to extract very accurate topographic information with the minimum of external data. When images acquired in opposite viewing geometries (with ascending and descending orbits) are combined, the geolocalisation technique allows the absolute position of a feature on the ground to be derived as part of a Ground Control Point (GCP) network. Previous studies led by various EO service suppliers in Europe have demonstrated the operational capabilities of ERS SAR for geo-localisation; independent feasibility analyses have established that with this technique it is possible to locate targets on the ground in three dimensions with average RMS errors in x, y and in z better than 25m. In the case of Envisat ASAR, the antenna is able to vary the incidence angle between 15 and 45 degrees, thus achieving even greater geo-localisation accuracy.



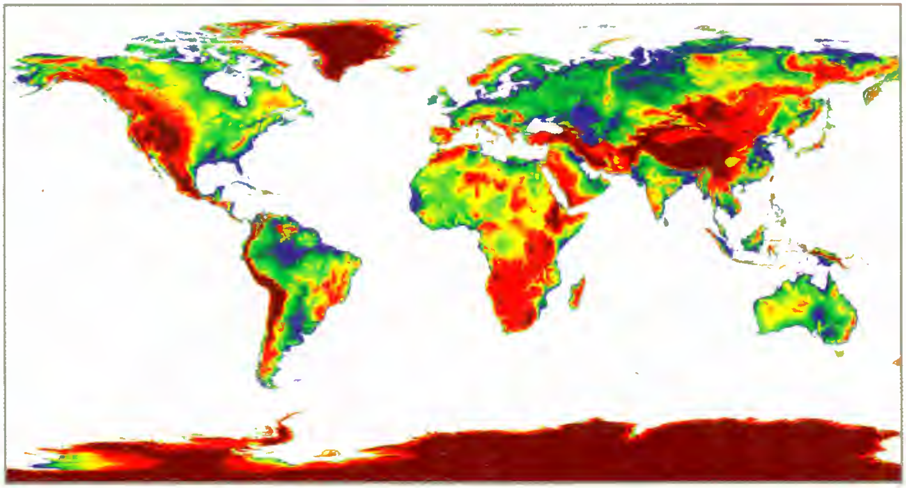
[illegible] COURTESY OF THALES. ERS DATA © ESA 1998.

A three-dimensional view of an area south-east of Aix-en-Provence, France. The elevation data was derived from a multi-baseline interferometry technique which uses several pairs of ERS SAR Tandem data. Atmospheric distortions were eliminated using permanent scatterer analysis to achieve planimetric accuracy of 17m and altimetric accuracy of 8m. The DEM is draped with SAR reflectivity data averaged from 40 ERS 1&2 images. Presented in this form, the data can be effectively visualised for improved topographic analysis and navigation purposes.
INSET: The same multibaseline InSAR elevation data presented as a map product, including 50m contour lines, relief shading and other map annotation.
Courtesy of POLIMI/Alcatel.

By combining optical images with stereoscopic qualities, geo-location information can also be extracted. GCP networks derived from these geolocalisation techniques can be used to rectify other spatial data, where high geometric accuracy is required, such as in navigation and location based systems.

Radargrammetry is based on the correlation of amplitude SAR images using the same principle as stereoscopy in photogrammetry. Contrary to the geo-localisation technique, this method provides continuous measurements (a DEM, not a sparse network of points) derived from stereoscopic SAR pairs acquired from either two ascending or two descending passes, with different incidence angles. Thanks to Envisat's pointable beam, pairs of ASAR images with different viewing angles over the same area can be obtained to generate DEMs. The typical vertical accuracy of such DEMs is in the order of a few 10s of metres, slightly coarser than those derived from high resolution stereo optical data (e.g. SPOT) but unaffected by cloud cover.

In addition, SAR data products can be used for topographic mapping using interferometry (INSAR) to generate DEMs. INSAR is based on the combination of two SAR images acquired with slightly different geometric configurations. The technique exploits the phase component of complex SAR data to make a precise measurement of the separation between target and antenna and build up a



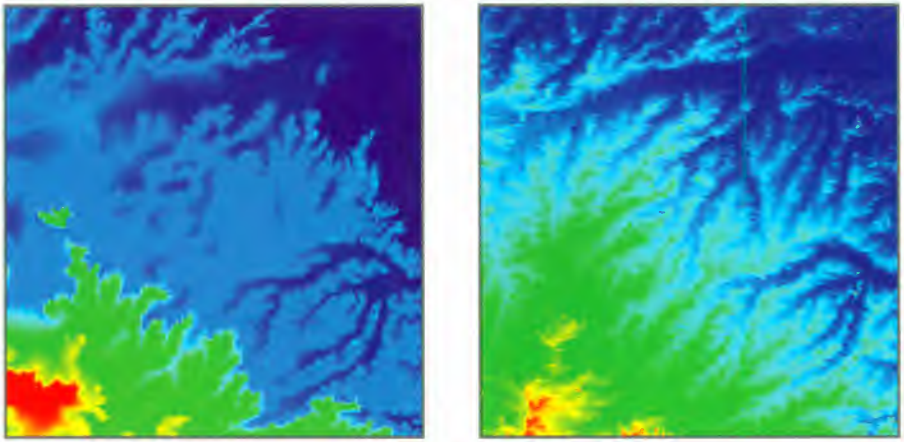
[illegible]

Courtesy of DMU. ©ESA

highly accurate DEM over an entire scene. However, the performance of this technique depends on surface conditions, which may give insufficient interferometric correlation (this is the case for areas of dense vegetation) and atmospheric artefacts - a known limitation that can only be overcome using specific processing such as the Permanent Scatterer (PS) Technique, invented and implemented by POLIMI and TRE. Nevertheless, using the PS technique, altimetric accuracy has been measured in the order of a few meters RMS only.

The synergy between SAR and optical data for cartographic mapping increases the quantity of extractable information and the ability to detect, identify and characterise thematic features of interest for cartographic mapping. Thematic and topographic maps compiled using SAR data allow the detection and identification of specific features such as hydrographic networks. Additionally, SAR-derived elevation data may be used to orthorectify optical data such as that from SPOT or Landsat, thereby reducing geometric distortions due to relief.

The SPOT5 satellite, launched in 2002 by CNES, is equipped with two High Resolution Geometry (HRG) sensors with four times the resolution (2.5m) of their predecessors (whilst maintaining a swath width of 60km), and a new High Resolution Stereoscopy (HRS) instrument designed to acquire 'simultaneous' image pairs along the flight track for generating DEMs without using external control points. Both will contribute to improved satellite mapping capabilities in relatively cloud-free regions of the globe.



These two [illegible] maps show representations [illegible] Amazon basin. On [illegible] GLOBE DEM. On the right, the ACE-DEM [illegible] 100 [illegible] -derived in this area. N[illegible] increase in detail of the [illegible] network. Both images use the same [illegible] fairness of comparison.
Courtesy of DMU.
ERS Altimeter data © ESA.

On the largest scale, the use of height data from the Radar Altimeter combined with available conventional map products (e.g. GLOBE) to refine global DEM accuracy has been effectively demonstrated. The resulting 1km-resolution ACE (Altimeter Corrected Elevations) DEM demonstrates radically improved performance and quality over large parts of the globe where existing maps were inaccurate or biased. This technique has proved particularly effective for improving detail in areas of low relief and for correcting discrepancies between neighbouring regional DEMs. The value of every cell is qualified according to its likely accuracy by means of a complementary quality assessment map.

SERVICE **EXAMPLES**

SPACE MAP OF FRENCH GUIANA

Except on the coastal plain, where its population is concentrated, French Guiana is dominated by rain forest. For the central and southern parts of the territory, the existing cartography is old, inaccurate and incomplete, consisting of 1:100 000 and 1:200 000 scale maps in the form of sketches. Only the coastal plain is mapped at 1:25 000 scale. Because of the inaccessibility of the terrain and almost permanent cloud cover, it is virtually impossible to conduct ground or airborne surveys.

A project to accurately map the whole territory at a scale of 1:200 000 using ERS SAR data was initiated by the French Ministry of Defence and IGN, the

An extract of the French Guiana 1:200 000 space map generated by the Institut Français [illegible] Géosciences using ERS SAR imagery from 1992 and 1993-94 with complementary information from existing maps. It represents the only precise and homogeneous map of Southern French Guiana. Ge[illegible] positioning is achieved using space triangulation, combining ground reference points and [illegible] orbit information.

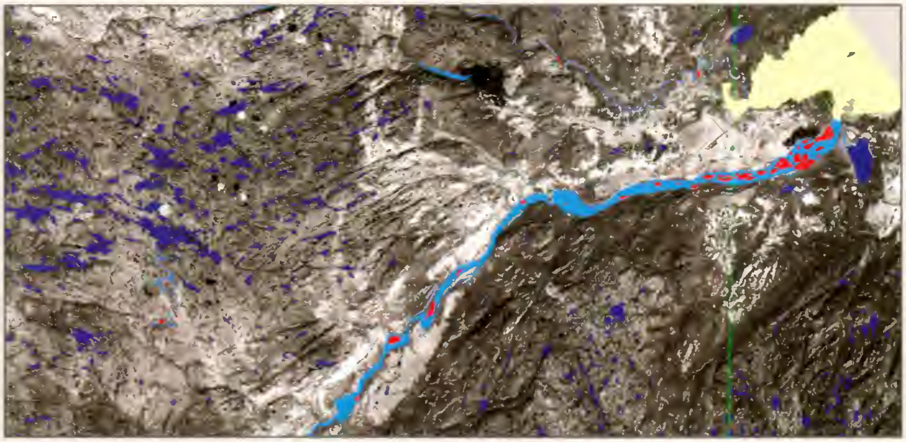
Courtesy DGA/CEGN/IGN Espace/UPMC/STAT.

ERS data ©ESA 1992-1994.

French mapping agency. The project was developed by IGN-Espace (part of IGN, France) in cooperation with CEGN (the geographic research department of the French armament agency) and the University Pierre et Marie Curie (UPMC), Paris. The resulting space map is the only complete, homogeneous and geometrically correct example of cartography for the region.

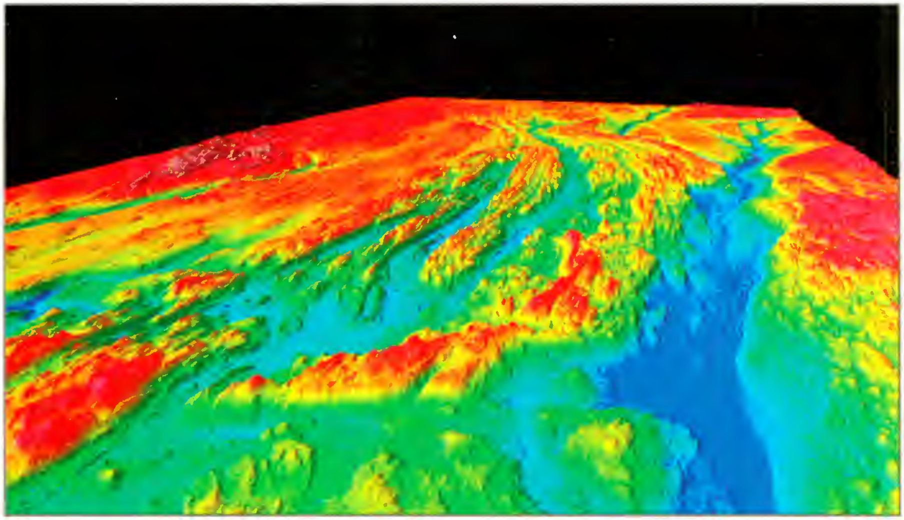
A DEM was generated using the contour lines and spot heights from existing cartography, augmented with GCPs obtained by processing ERS crossed-orbit data using the geo-localisation technique. It was used with a geometric acquisition model to rectify and geo-reference ERS SAR images, which were then mosaicked and filtered to increase their information content. GPS surveys on the ground confirmed absolute planimetric accuracy of the resultant space map to be around 15m RMSE.

The success of this pilot project demonstrates that the geometric quality of ERS SAR data products is sufficient to allow map production in many equatorial areas.



Vector layers derived from orthorectified Landsat 7 data (shown in black and white in the background) in Labrador, Newfoundland, Canada, to identify water bodies in an ERS InSAR-derived DEM for 'cleaning' as part of ASI's DTED-2 finishing process. Super imposed to the image map are the lake or river masks (dark and light blue), the river/island mask (red) and the salt water mask (white)

The optical data was acquired in summer for optimal contrast between water and land. *Courtesy of ASI.* Landsat data ©EarthSat.



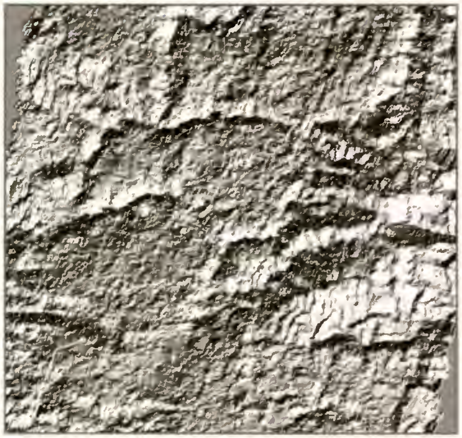
Three-dimensional rendering of a finished cell of the DTED-2 elevation product showing Goose Bay, Labrador, Newfoundland, Canada. The DEM was generated from ERS SAR Tandem data using ASI's EarthView InSAR software; the CDED (Candian Digital Elevation Data) low resolution DEM was used to reduce atmospheric effects. In this representation, flattened water bodies appear in homogenous colours. Courtesy of ASI. ERS data © ESA 1998

DTED-2 CERTIFICATION OF INSAR DEMS FOR TOPOGRAPHIC MAPPING

Atlantis Scientific Inc. (ASI) is a Canadian company involved in SAR-based services including the generation of DTED-2 (Digital Terrain Elevation Data) elevation products. In order to achieve acceptance in both the civilian and security markets, these must meet certain standards, as set out in requirements of national mapping agencies such as those of the US (NIMA) and Canada.

ASI uses software created in-house to derive DEMs from ERS SAR tandem data taken from the large ESA archive. The technique is limited mainly by the stability of the observed surface, atmospheric effects that attenuate the radar signal and errors in areas of shadow and layover. The resultant products also exhibit problems common to other DEM creation technologies such as inaccurate surfaces in the vicinity of lake and ocean shorelines and wide drainage channels.

An end-to-end supply chain has been devised to reduce and control the impact of these deficiencies and ensure the certification of ERS-derived InSAR DEMs to accepted topographic standards. At the beginning of the chain, selection of appropriate archived data is carefully qualified. During interferometric processing an ancillary low resolution DEM is used to filter low frequency atmospheric effects. The resulting geocoded DEM is 'finished' using tools for



EXAMPLE OF A RADARGRAMMETRIC DEM (IN SHADED VIEW) OVER A SOUTH OF FRANCE SITE, GENERATED USING ENVISAT ASAR DATA IS-3 & IS-7 ACQUIRED ON 25 AND 15 JULY 03. THE ESTIMATED ALTIMETRIC ACCURACY OF THIS PRODUCT IS 56M RMS WITH AN ERROR MEAN OF 17.4M. PRODUCT GENERATED USING THE DIGITAL MAP PRODUCTION SYSTEM (DMPS) OF THALES COMMUNICATION.
COURTESY OF THALES.
ENVISAT DATA © ESA 2003

the semi-automatic flattening of water bodies and drainage channels and the elimination of spikes and wells. Shadow and layover areas are identified and filled using SAR acquisitions from the opposing viewing angle.

The quality and integrity of the full processing chain and the reliability of the source data have been proved sufficient to meet the required standards of key mapping agencies (such as in Canada, where Canadian J2 has evaluated ERS InSAR DTED) and hence validate the processing of large quantities of archived ERS Tandem data. On-going evaluation by NIMA may also result in the endorsement of ERS InSAR for DTED-2 mapping as a complement to SRTM (Shuttle Radar Topographic Mission) data, particularly for high latitudes not covered by the latter.

DIGITAL GEOGRAPHY FOR INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE

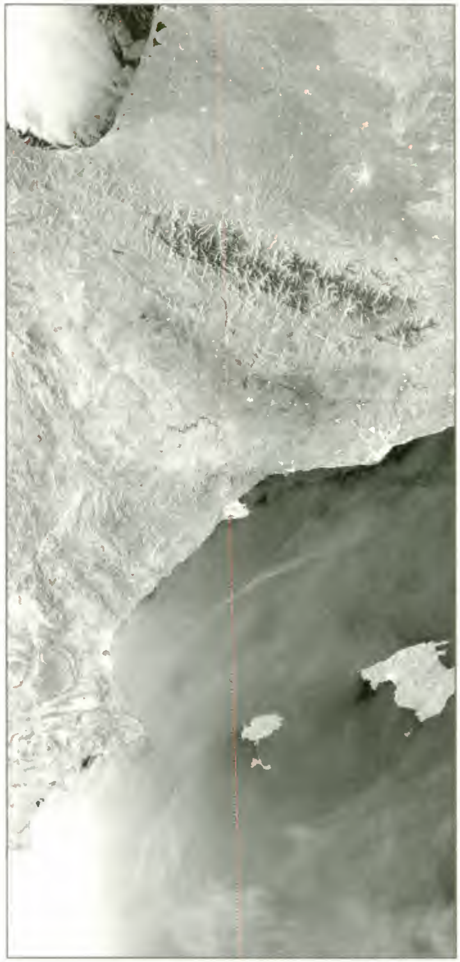
THALES Communications is a French aerospace company specialising in geomatics in the security sector. The services supplied by THALES Communications comprise space-based services for cartography, tools and data necessary for building customised geo-information systems. In the market segments in which they operate customers require reliable digital elevation data of vast, inaccessible and potentially cloud covered areas for simulators, live navigation systems and mission planning. The Digital Map Production System (DMPS) is a multi-source, modular and interoperable system for generating and updating value added geographic products such as raster and vector maps, space-maps, Ground Control Points and DEMs. The system, combining digital photogrammetry with Computer-assisted Design (CAD) techniques, offers the capability to generate 3D databases at a variety of scales from airborne and space-borne (Optical & Radar) imagery in order to faithfully reproduce real environments. A network of accurately determined GCPs is the foundation for a more comprehensive DEM. In the absence of any other external (ground) information, the DMPS performs geo-localisation of ERS SAR data with RMS precision around 18 metres in planimetry and better than 10 metres in altimetry. Results are used to geo-reference and refine a wide range of geospatial datasets (such as Optical imagery), eliminating the need for ground surveys which are time consuming and often anyway impossible. Comprehensive evaluation of the operational needs of end users has confirmed that using SAR data for geo-localisation does meet customer driven reliability criteria. In parallel using the radargrammetric technique based on Radarsat and/or Envisat ASAR data, DEM precision ranges from 10 to 50 metres RMS (40 metres standard deviation) depending on relief. Following the so-called '3D fusion' approach, independent and complementary techniques like Optical stereoscopy, SAR geo-localisation, SAR radargrammetry and SAR interferometry enable improved accuracy and reliability of cartographic production systems and ensure that they meet the stringent quality specifications of government and defence agencies, even when ground data are unavailable.

MAPPING SERVICES FOR HUMANITARIAN AID AND INTERNATIONAL DEVELOPMENT

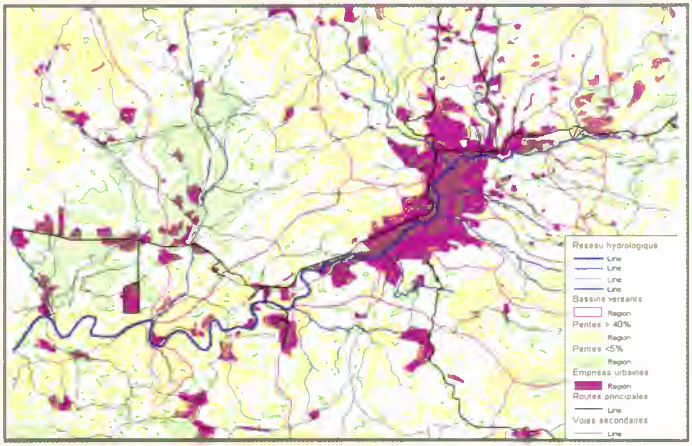
The United Nations Office for Project Services (UNOPS) is developing a service infrastructure called UNOSAT to encourage, facilitate and accelerate the use of accurate geo-information derived from satellite imagery amongst the humaniatrian community (for instance UN agencies and NGOs) involved in the implementation of humanitarian aid and international development projects. It endeavours to overcome the difficulties of access to diverse satellite imagery and related value adding services that end users really need.

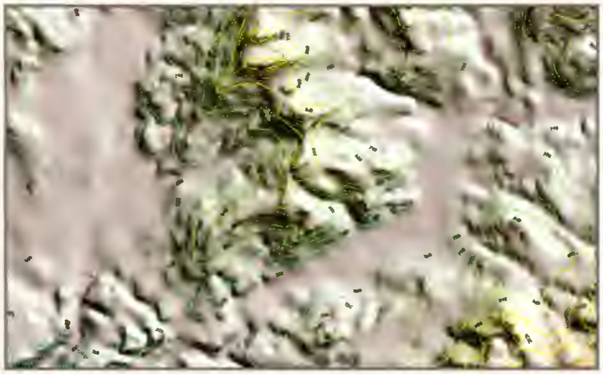
Set up during 2002, the centralised web portal of UNOSAT enables non-specialist users to interact with a partnership of EO service providers interfacing with UNOPS to deliver information services. The portal is available to facilitate the identification, preparation, management and purchase of EO-derived products and services. To achieve this, UNOSAT is developing and continuously consolidating service capabilities that use a wide range of EO data (both optical and radar) and non-EO data (e.g. digital maps).

As far as Envisat data are concerned the UNOSAT portfolio of services comprise services exploiting the ASAR and MERIS sensors. In particular UNOSAT provides the ASAR based radargrammetric Digital Elevation Model based on ASAR stereo data, and, in the Optical domain, a suite of thematic mapping products derived from the medium resolution sensor MERIS. A large operational project has now been completed to deliver geo-information services to local actors of the humanitarian community for territorial management purposes in Nicaragua. An operational GIS has been established to identify and characterise the optimal zones in and around the city for development



A section of an ASAR Wide Swath image (405 km wide by 1235 km long) covering in a single acquisition the east of Spain, the west of France and a part of north Africa, demonstrates the capability of the Wide Swath Mode to cover more than 400 km in range using the ASAR beam steering in elevation and the ScanSAR technique. ENVISAT data © ESA 2003





Examples of GIS based products supplied by UNOSAT in the framework of a UN based project in Matagalpa, Nicaragua. **Left**: very high resolution colour image over the town and environs, displayed in true colour; **Centre**: Digital Elevation Model of the area, annotated with colour-coded contours; **Right**: Derived thematic map showing hydrological features and urban areas for flood risk management purposes. Such information are used to help better appreciate the relationship between terrain, land cover and drainage for planning and development in the region. *Courtesy of UNOSAT. SPOT data © CNES 2002, Distributed by Spot Image, IKONOS DATA © Space Imaging 2002, Distributed by Inta Space Turk*

with particular reference to risk assessment and taking into account social and economic integration issues in territorial management. It also contributes to sustainable urban development by providing planning information and tools (such as aerial imagery) suitable for monitoring urban growth. The GIS incorporates basic reference mapping, thematic and historical geospatial information that includes information concerning hazards for risk management purposes.

UNOSAT enlarges the opportunities for UNOPS to implement project activities in the earliest stages of a crisis, whilst giving users reliable and timely access to information products. It also promotes the use of EO data to a wide market segment, thereby increasing demand for related data and products.

<< FUTURE OUTLOOK

The continued adoption of GIS in government and industry augurs well for the integration of satellite mapping services. So too does the spread of Internet Map Servers, making digital geographic information available at the click of a mouse. These technologies are enabling service providers and value adding companies to penetrate all areas of society. At the same time they continue to expand the range of products and customisation possibilities offered to professional users.

Fulfilling many of the resolutions arising from the Johannesburg World Summit on Sustainable Development (WSSD) in August 2002 certainly requires better utilisation of cartographic solutions as well as other geo-information solutions to monitor key bio-geo-physical processes. For instance, land resources management as well as environmental monitoring are two examples for which EO data represent a viable and cost effective tool for mapping and thematic mapping purposes, particularly in remote areas of the world that presently have poor maps or Geographic Information Systems.

ESA's environmental satellite, Envisat, provides data that can be exploited for mapping purposes in many diverse application sectors. ASAR's new operating modes are of particular use for accurate satellite mapping; in addition it is expected that many new applications will be developed in the coming years using SAR and combining SAR and optical data, as evidenced by research going on at present.

There are a series of other future missions with potential to improve satellite mapping. Among them, the PRISM instrument onboard ALOS (NASDA) will provide 2.5m panchromatic along-track stereoscopic optical data for global topographic mapping at 1:25 000 scale. RADARSAT 2 will continue its predecessor's legacy with additional innovative features such as improved resolution and location accuracy. The French and Italian Pléiades and Cosmo Skymed constellations will both provide Very High Resolution data (Optical and Radar) with high temporal sampling that have a strong potential for cartography and thematic mapping, whilst the TerraSAR initiative has identified 'focus products', including topographic maps, regional planning aids and environmental planning tools, to be generated from SAR data.

In the Value Adding sector, the combined use of data from a variety of EO data sources - the so-called '3D Fusion' methods - promises to enhance dramatically the accuracy and reliability of topographic information required in the sector of cartography. By modelling several independent acquisitions and from different sensors, using all available data (including platform parameters and ephemeris data), a complex space triangulation can be achieved to improve the density, accuracy and reliability of information in the final map product. In this way, the relative merits of Radar geolocalisation, of radargrammetry and interferometry, as well as of Optical stereoscopy can be brought together.

Based on the scope and capabilities of both existing and planned EO platforms, the map-making industry is likely to make ever-greater use of remote sensing data in the years to come, as an indispensable complement to traditional techniques.

ACKNOWLEDGEMENTS >>

This document provides descriptions of EO based services supplied by Atlantis Scientific Inc., THALES Communications ISR, Alcatel ASPI, POLIMI, the UN Office for Project Services (UNOPS) and De Montfort University. For their work in market development these companies have been supported by ESA's Earth Observation Programme.

This document also includes contributions from SERTIT, CEGN, IGN and IGN - Espace, who are gratefully acknowledged.

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For further information on the EO service industry

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Eurosense André Jadot • BELGIUM • http://www.eurosense.com

Gamma Remote Sensing Urs Wegmuller • SWITZERLAND • http://www.gamma-rs.ch

Hugin Christoph Boehm • GERMANY • http://www.hugin-gmbh.de

Infoterra Global Nick Veck • UNITED KINGDOM • http://www.infoterra-global.com

Joint Research Centre Daniele Ehrlich • ITALY • http://www.jrc.cec.eu.int

KEYOBS Herbert Hansen • BELGIUM • http://www.keyobs.be

METRIA Michael Ledwith • SWEDEN • http://www.lantmateriet.se/

Nigel Press Associates (NPA) Ren Capes • UNITED KINGDOM • http://www.npagroup.com

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SPOT Image Francoise Axes • FRANCE • http://www.spotimage.fr

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UNOPS/UNOSAT Alain Retière • SWITZERLAND • http://www.unosat.org

A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE

Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.

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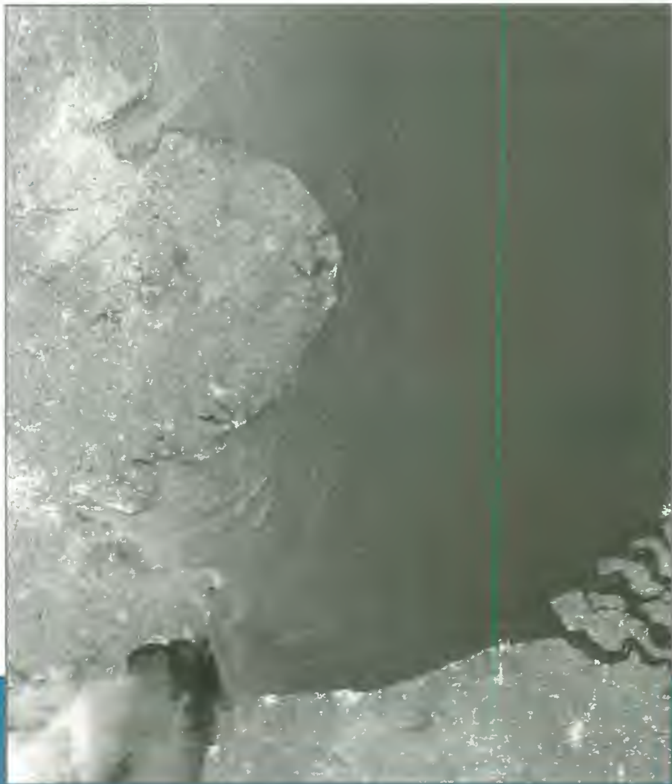
BATHYMETRY

USING RADAR FROM SPACE

the Living Planet



Envisat ASAR image of the North Sea, 21 August 2002.
This ASAR Wide Swath image shows the part of the coastlines of the Netherlands, Belgium, France and England bordering the North Sea. The brighter land areas are major cities. Radar instruments can detect changes in the roughness of the water's surface caused by seabed topography, such as sand banks. The sea-surface expression of these features can be seen off the northern coast of Belgium parallel to the coastline, and also extending from the Thames Estuary. The bright flecks in the sea in the English Channel between Dover and Calais are ships. The volume of traffic in this waterway shows why it is the busiest in the world. A weather front at the northern end of the Channel is reducing the surface roughness of the sea, causing the image to appear darker.

THE NEED FOR BETTER INFORMATION

Up-to-date depth information on the bathymetry (sea floor depths) of shallow coastal waters is a pre-requisite for safe navigation and for some offshore engineering activities, as well as for effective coastal zone management, yet this information is typically costly and time consuming to acquire.

For example, bathymetric charts are required for engineering works in the offshore construction industry and for offshore activities such as for cable laying. Information on changes in bathymetry over time is also required by coastal engineers for the planning and design of coastal defence structures as well as by environmental and fisheries managers. Port Authorities need to know the positions of sand bars and other navigational hazards in order to keep shipping lanes clear for safe passage in and out of port. Moreover, large commercial vessels demand more reliable knowledge of the available depth of water in relation to their draughts, in order to navigate safely whilst taking full advantage of their maximum cargo capabilities.

Conventional ship-borne surveys are time consuming with relatively high cost and long delivery-time. Nowadays newer Earth Observation (EO) techniques can help to assess the depths of shallow water in a much more cost-effective way.

"new EO techniques can help to assess the depths of shallow water in a cost-effective way"

SPACE-BASED and TRADITIONAL METHODS to BETTER MEET USER NEEDS

THE LIMITATIONS OF TRADITIONAL TECHNIQUES

Traditional Hydrographic Charts are based on data that were accumulated during decades of official surveying operations and are updated periodically. They are inexpensive and available for most areas of the world, however their depth accuracy is variable. Hydrographic charts are used primarily for safe navigation purposes and as a reference for marine traffic control in coastal waters.

Bathymetric information is typically gathered from dedicated survey vessels using single or multibeam sonar systems. Depths are calculated from the travel time of the return echo from the seabed to the ship, with many corrections for tidal height, and ship movements. The multibeam echosounder provides nearly 100% coverage of a given area (the very shallow water is inaccessible to a vessel) and has the capability to detect very small objects on the seafloor. The main limitation of ship-borne surveys is the time and thus the expense involved in conducting the survey and in data post-processing, particularly in shallow coastal areas. Delays due to factors such as weather related down time, or logistics, such as faulty instruments, mean operational costs

> *EO based depth charts can be used as a tool for planning, monitoring and management*

can soar. This is an important issue in shallow waters where sonar beam geometries mean track lines must be close together therefore increasing the survey time. Operating close to the shore limits the manoeuvring options for survey vessels and therefore increases the risk of damaging expensive under-water survey equipment.

In recent years airborne bathymetric surveys have gained considerable commercial success in the mapping of shallow waters. Hyperspectral imagery such as CASI (Compact Airborne Spectrographic Imager) has been used to map clear shallow coastal waters of up to 20m.

In addition, airborne laser systems can chart shallow areas (40metres at most) in clear coastal waters. Airborne Laser systems such as LIDAR (Light Detection and Ranging), SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) developed in Canada, and LADS (Laser Airborne Depth Sounder) developed in Australia, are all used for shallow water bathymetry. While maximum penetration is heavily dependent upon water clarity, measured depths up to 25 - 30m in clear waters are common.

While these airborne systems perform very well, their main limitations are the high costs of conducting the surveys as well as the logistics involved in getting the aircraft to the survey site. The waiting time required to produce a chart may also be prolonged, for example due to bad weather, causing unfavourable flying conditions or unacceptable water clarity.

THE BENEFITS OF SPACE-BASED MONITORING

New advances in Earth Observation (EO) technology now offer the possibility to use Synthetic Aperture Radar (SAR) data from satellites, for the creation of bathymetric charts for shallow water areas (< 30m deep). Bathymetric charts generated in this way do not comply with International Hydrographic Office (IHO) standards and therefore cannot be used for safe navigation. In addition they cannot detect objects on the sea floor, for which multi-beam sounders are far more suitable. Nevertheless, these EO based depth charts are a new type of bathymetric chart, which can be used as a tool for planning, monitoring and management. It is possible to compile these charts in a short time and at low cost. In addition the generation of these charts can be repeated periodically for an affordable price and being in digital format t hese charts can be integrated with other information within a GIS (Geographical Information System).

While EO radar based techniques can never fully replace conventional ship surveys or even airborne hyperspectral or laser scanning for bathymetric measurements, these systems give significant advantages in terms of operational flexibility, data collection rates and savings in time and resources, when compared with other techniques

ERS SAR [illegible] © ESA

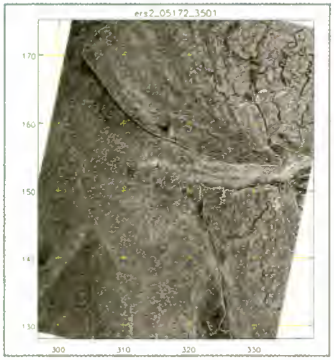
THE INTEGRATION OF EO IN EXISTING GEO-INFORMATION SERVICES

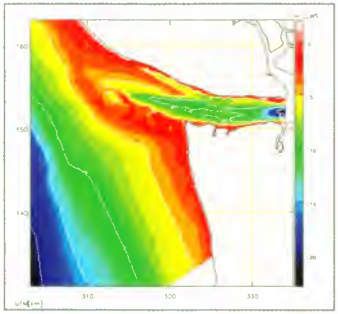
The bathymetric charts generated from EO radar data are excellent for planning, monitoring and coastal management and for engineering applications such as cable and pipeline laying. A global, archive of SAR imagery, from the ERS -1 and 2 missions of the European Space Agency (ESA), is available at a relatively low cost. This image archive provides an historical record of past seabed topographies and may be accessed rapidly to provide a suitable survey method especially for remote areas or where the deployment of an aircraft is logistically problematic.

With the launch of ESA's Envisat in 2002, continuity of access to relatively low cost radar data from ASAR (Advanced Synthetic Aperture Radar) is set to continue until at least 2007. The new selectable polarisation ability of the ASAR instrument will improve the acquisition of bathymetry-related information in the radar image. Envisat's ASAR beam steering capability will mean improved coverage is now possible, also on board data storage capabilities with later transmission to an active reception station gives better global coverage than available on the ERS mission.

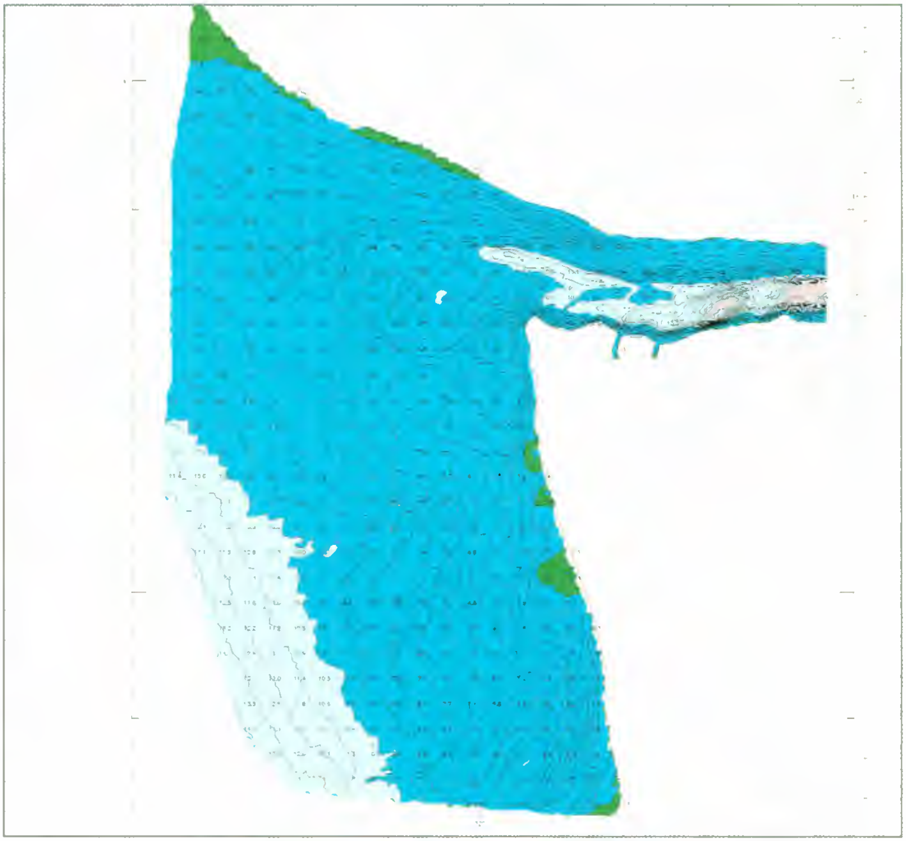
How it works

When wind speed is between 3 and 8 m/sec and the magnitude of the tidal current is sufficiently large (> 0.5 m/sec), satellite based SAR can detect changes in sea surface roughness caused by the underwater bottom topography modify-





SEA [illegible] BATHYMETRY F[illegible] N[illegible] [illegible] ERS SAR DATA.
© ARGOSS/ESA 2003



ing local currents. This results in changes in surface flow velocity that interact with short surface waves. These short surface waves then interact with the radar signal creating a backscatter intensity pattern. To retrieve actual water depth values, the SAR data must be further analysed, which requires accurate models of the local hydrodynamics and wave evolution. By using suitably tuned inversion models the sea surface variations can be inverted to generate bathymetry maps. Information on local metocean conditions is required, in addition to a small number of actual depth measurements to initialise the models.

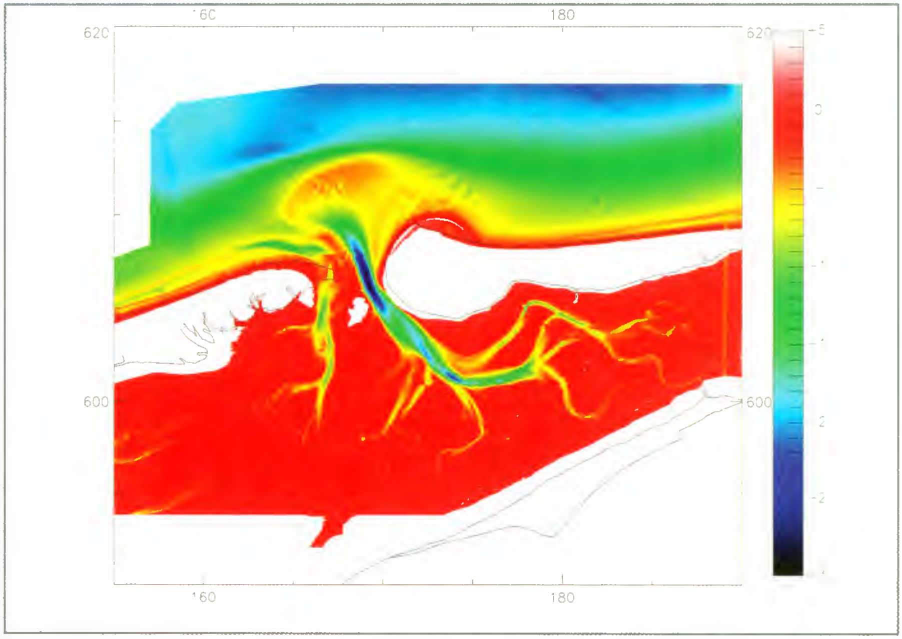
Bathymetric mapping of shallow waters from space: A Global service for non-nautical applications

SERVICE **EXAMPLES**

The Dutch company ARGOSS has developed the Bathymetric Assessment System (BAS) for estimation of the bathymetry of shallow water using satellite radar imagery. This technique allows the creation of large area bathymetric maps (non-nautical) of shallow and coastal waters, for depths of up to 30m. Various map products can be produced at different resolutions, and accuracy varying with required delivery times. The cost of the service can be between one third and one tenth of conventional survey methods.

The system consists of a suite of numerical models that calculate a synthetic SAR image from first-guess bathymetry using a much-reduced set of in-situ measurements. The difference between the synthetic image and the actual

GEO-REFERENCED ERS SAR IMAGE OF THE BORNRIF AREA IN THE WADDENZEE, THE NETHERLANDS. © ARGOSS/ESA 2003



Depth changes in the Waddenzee, the Netherlands. © ARGOSS 2003

image is minimised in such a way as to generate an update of the bathymetry and this process is repeated until the depth values converge.

Other inputs needed for the system are tidal data, wind speed and direction related to the acquisition time of the SAR image. The main restriction of the BAS is the need for moderate tidal currents (0.5 m/sec). A spatial resolution of approximately 20m is available which makes the BAS ideal for use in macro scale surveying and regular monitoring rather than for strategic navigation. This limitation in spatial resolution would also limit the ability of these systems to detect small underwater objects, which is required to satisfy the requirements of higher order surveys. The BAS maps therefore can be used as a reconnaissance tool for shallow waters, for instance to identify where strategic surveying for nautical surveys or for coastal engineering works are required. For example the system is useful for tracking movements of large sub-tidal sand-waves and sand dunes as movements due to changing prevailing tides/currents can ultimately lead to the development of hazards to shipping.

FUTURE OUTLOOK

Satellite radar data is already being successfully used in many parts of the world, offering an alternative, faster and lower cost way to map large areas of shallow waters. In developing countries in particular, this technology has many possibilities, as it is often the case that large areas of coastal bathymetry are unmapped and conventional mapping techniques are far too costly.

The demand for low cost shallow water bathymetry maps is also growing in Europe. For offshore engineering these maps are used for initial planning of cable and pipeline lay and preliminary design of coastal infrastructure as well as for reconnaissance surveys.

Increasing interest in offshore or near shore renewable energy farms in Europe is also creating a growing requirement for shallow water bathymetry, especially if the bathymetry is changing over time e.g. for identification of a suitable location for siting wind farms.

the demand for low cost shallow water bathymetry maps is growing

Coastal zones are facing serious problems of habitat destruction, water contamination and resource depletion. Erosion of Europe's coastline continues despite the development of a wide range of measures to protect shorelines from erosion and flooding. As Coastal Zone Management becomes an increasingly important issue for many authorities, requirements to map coastal areas are growing. Coastal managers need information on bathymetry for feasibility studies, for dredging and for beach nourishment activities as well as for coastal resource mapping.

New sensors such as the ALOS (Advanced Land Observing) Satellite has an advanced array type L-band Synthetic Aperture Radar (PALSAR) which will be a valuable new source of radar imagery for coastal bathymetry mapping.

The legal implications inherent in the use of EO data for chart and map updating is an area under investigation. Currently there are no professional standards at the IHO (International Hydrographic Organization) for these kind of spatial information products. In the future with the advent of Electronic Nautical Maps and increased use of GIS for marine applications, new standards will be developed for Gridded Bathymetries, thereby opening further opportunities for new EO based bathymetric charts.

ACKNOWLEDGEMENTS >>

This booklet provides descriptions of EO services available today from specialist service providers for the marine environment e.g. ARGOSS (Advisory and Research Group on Geo Observation Systems and Services). For their work in market development these companies have been supported by ESA's Earth Observation Programme.

For further information on the EO service industry

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http://www.argoss.nl

For further information on EOMD activities and ENVISAT Program

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USING RADAR FROM SPACE

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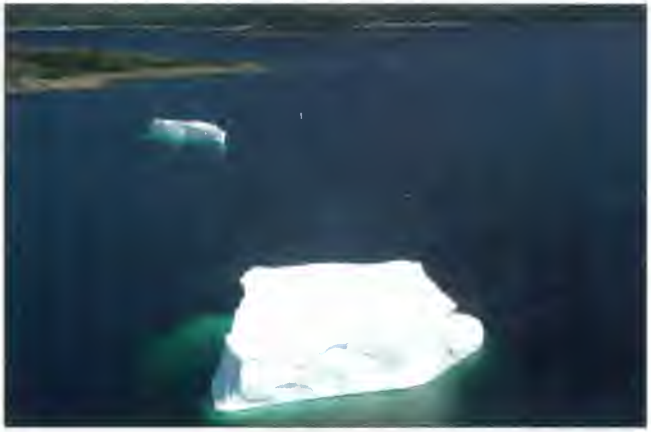
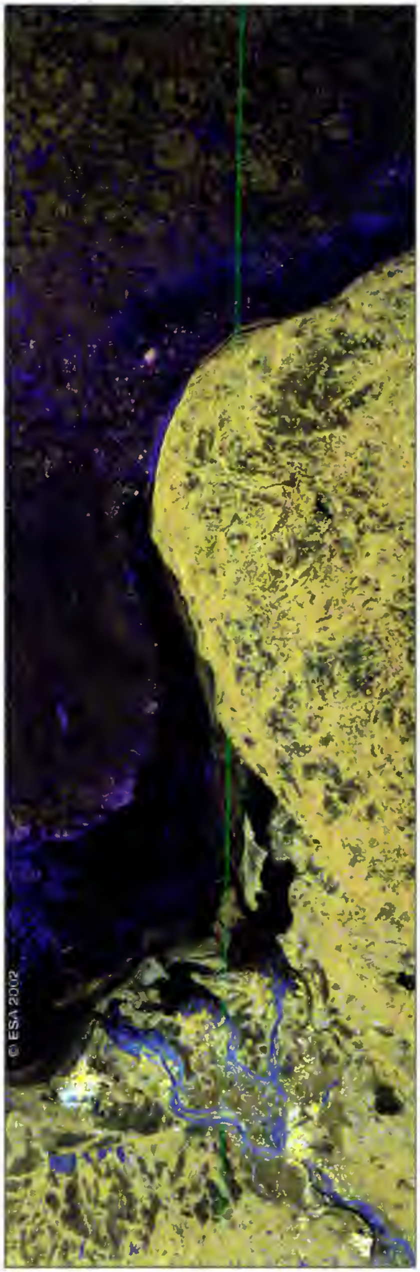




The ASAR AP image displays an ice-laden segment of the White Sea on Russia's northern coast and the port of Archangel. To the north is the peninsula of Kolskiy Poluostrov, Russia's northwestern extremity. Since the 1600s, Archangel has been considered the cradle of Russian shipbuilding and is of major strategic importance as a port, from where lumber, cut from the surrounding forests, is exported throughout the world. This image illustrates that during early April the sea that surrounds the port is still heavily infested with ice floes. The ASAR AP mode provides two simultaneous images , or channels, of the same scene taken with different radar polarisaton options. AP mode can help define the boundaries between sea ice and water © ESA2003; © C-CORE (top image)

THE NEED FOR BETTER INFORMATION

In Northern regions today there is an increased level of fisheries activity, mineral extraction and hydrocarbon exploration and production, mainly due to a combination of technology advances and non-viable alternatives. This is leading to an expansion in transport levels and associated logistics support in close proximity to fragile and sensitive Arctic ecosystems. In addition the volume of international sea borne trade is growing steadily.

Oil production managers need information on pack ice movement to assess risks of damage to fixed drilling and production platforms. Oil tankers insurance is valid only for particular sets of ice conditions and hence their operators need to ensure that local conditions are consistent with their classification ranking. Icebreaker operators use detailed information on open water location, ice concentration and ice type to ensure the most effective support to local shipping, e.g. by identifying the optimal ice-breaking route to reach a given port. The presence of multi-year ice of any thickness is a significant hazard even to many icebreakers and should be avoided.

Many countries that are dependent on shipping in ice-affected regions operate regular airborne patrols and icebreaker support services. Russia and the Baltic States, China, the USA, and Canada all have public agencies providing ice-monitoring services in regions where ice impacts marine operations. In Europe, operational ice-monitoring services are maintained in Demark, Finland, Sweden, Poland, Iceland, Norway and Germany. Typically, these consist of daily surveys in the form of ice type and concentration maps, text bulletins and regional seasonal forecasts.

Further south in the Atlantic basin, sea ice is not a problem but icebergs pose a hazard for transport in the busy North Atlantic sea lanes and offshore oil production in the Grand Banks. In response to the sinking of the Titanic in 1912 there was an unprecedented and extensive international effort to set up an iceberg monitoring system. This is now the International Ice Patrol, which operates under the auspices of the International Maritime Organisation. Iceberg patrols are operated by the US Coast Guard , the Canadian Ice Service and the Canadian fisheries patrol aircraft, but this has limited coverage and bad weather often hampers patrol flights. Offshore oil operators require more systematic surveillance coverage and maintain their own detection systems although these cover only the immediate vicinity of a platform. Additional wide area information on iceberg location is needed for effective iceberg management and operations planning.

SEA ICE AND ICEBERGS

Sea ice is any form of ice that is formed by the freezing of seawater. Sea ice itself can be classified into different categories, such as new ice, young ice, first year ice and old ice, which broadly reflect its different forms, thickness and stages of development. Icebergs meanwhile, are massive pieces of glacial ice, which result from detachment of an ice sheet or after having broken away from a glacier, and thus they are made from freshwater.

Courtesy of Canadian Ice Service

SPACE-BASED and **TRADITIONAL** METHODS TO **BETTER** MEET **USER REQUIREMENTS**

"accurate and timely information on sea ice conditions and iceberg location is vital for all these activities"

The Limitations of traditional techniques

National ice services have an operational responsibility for the generation and dissemination of standard ice information products for their area of jurisdiction. These include ice charts presented in a WMO (World Meteorological Association) standard format, which contain information on ice edge, ice concentration and the main type of ice at any location, and may include maps of sea surface temperature. Ice reports are text bulletins describing ice conditions and expected short-term evolution. These are distributed to all users operating in the affected areas (e.g. ship masters, fishing vessels, icebreaker operators etc) through standard marine telecommunications

Ice services presently use a variety of data sources to generate their standard ice charts. These include airborne reconnaissance, with SLAR (Side Looking Aperture Radar), cameras and reports by the flight crew, as well as reports from icebreakers, weather stations and shipping operators.

Airborne radar is costly and cannot provide complete coverage of an entire region. Many ice services make systematic use of low-resolution satellite data such as the Special Sensor Microwave Imager (SSM/I) instrument on the U.S. Defense Meteorological Satellite Programme (DMSP) and the NOAA Advanced Very High Resolution Radiometer (AVHRR). The latter is particularly useful due to its capability to measure sea surface temperature. However, both the SSM/I and AVHRR have constraints that limit their overall utility for ice chart products. SSM/I is of relatively coarse resolution. AVHRR has a spatial resolution of 1km but cloud cover and darkness limit operational effectiveness of these data. More recently NASA MODIS imagery is also being used.

Such information on a coarse grid is by definition aggregated and there may be significant variation in ice conditions (e.g. ridges, leads etc) on scales too fine to be resolved in the standard information products, but which impacts on operations safety. The main element missing with respect to utility for operations support is ice structure information on scales of between 50 and 1000m over a wide area (several hundred kilometres) on a reliable all-weather basis. Ice services therefore need to respond to growing requirements for more fine scale information, within their operational budgets.

For many customer groups (e.g. oil and gas operations, shipping), these limitations often mean that specialist ice personnel must devote considerable effort to analyse the standard ice information products and supply operations management with customised decision support information.

Iceberg surveillance, on the other hand, is presently much more limited in extent. The US and Canadian patrols are funded by the International Ice Patrol to conduct regular airborne surveillance of regions threatened by icebergs. This information is fed into standard iceberg reports that are distributed to all marine operators in the affected areas. These data are also incorporated into the charts issued by the Canadian Ice Service to the offshore oil industry operating in the Grand Banks area. Unfortunately, present airborne surveillance does not provide a systematic coverage of the areas of interest and the complex ocean currents in the area can make prediction of iceberg track evolution prone to error. Coastal fixed radar can be used but this again has limited coverage and detection probability is limited at the edge of the coverage zone in high sea states (which are very common).

The Benefits of Space-Based Monitoring

Satellite based Synthetic Aperture Radar (SAR) can offer more accurate, fine scale information with wide area surveillance coverage independent of cloud cover and weather conditions. With the advent of RADARSAT, and the Advanced Synthetic Aperture Radar (ASAR) on ESA's Envisat, systematic coverage of Polar Regions, with updates approximately every 12-24 hours is possible. SAR instruments support spatial resolutions of between 10m and 150m with a spatial coverage of around 400km for the lower resolution (ScanSAR) operating mode.

Typical benefits accruing from this improved information content include:

> Improved iceberg management capacity for offshore oil and gas production.
> Improved ice edge location accuracy enabling fishing operators to remain longer in highly productive areas close to the ice edge without the risk of becoming stranded in dangerous ice conditions.
> Safer and more efficent routing of vessels, either around ice, or through only the thinnest and lower concentrations of ice. Effective ship routing reduces the need for ice breaker support to non-ice strengthened vessels and optimises the efficency of the breaking resources.
> More cost effective data gathering for the national ice services. Since 1996, RADARSAT with the support of the Canadian Space Agency, have been providing the Canadian Ice Service with SAR imagery to fulfill their wide area ice

"satellite based SAR can offer accurate, fine scale information on sea-ice conditions, over a wide area day and night"

surveillance requirements. Reduction in the cost of traditional aircraft and ship based resources have resulted in cost savings of $6 million dollars per year for the Ice Service, while increasing surveillance coverage 15 times.

The Integration of EO in Existing Geo-Information Services

The integration of SAR imagery within ice service operations is critically dependent on time. Rapid reception of the imagery from a ground station equipped with a suitable fast delivery processing chain is required. Imagery is then transmitted over a wide bandwidth channel and can be available to ice analysts within 40 minutes of the satellite acquiring and downlinking the raw data. Once received on the ice analyst workstation, the image must be geocoded to the appropriate projection system. The analyst can then delineate different ice classes within the image and this information is then combined within a GIS environment into the ice analysis derived from other sources of data.

Iceberg detection also depends on rapid access to data from a ground station with a fast delivery processing chain. In this case however, full resolution imagery is needed rather than the reduced resolution ScanSAR data used for mapping of sea ice conditions. This means wide bandwidth connections to an appropriate ground station are critical to effective operations given the large file sizes being transmitted on a regular basis under strict deadlines.

For iceberg monitoring, SAR based iceberg information is used to improve surveillance coverage on icebergs entering zones close to shipping lanes or offshore production activities. The images are geocoded and an automatic classification identifies and locates probable icebergs. This analysis is then confirmed by an iceberg analyst. In general, this focuses on separating ship targets from icebergs around the zone of interest. A table of iceberg characteristics is then generated as both a text file in a standard internationally agreed format and as a datafile for automatic assimilation into the management support system that enables regular evaluation of the level of threat posed by a particular iceberg and identification of the nature and timing of any intervention activity to be conducted.

EXPLOITING NOVEL
EO-BASED **TECHNIQUES**

Different ice types have different typical surface structures and variations in properties such as salinity. These generate different intensities and characteristic variations in backscattered radiation in SAR imagery, that enable ice analysts to identify the presence or absence of a specific ice type. Typical ice information that can be extracted from a SAR image includes the identification and location of open water, and different ice types such as grease ice, first year ice and multi-year ice.

National Ice Services were well aware of the potential utility of satellite based SAR imagery, but have taken some time to adapt and become accustomed to working with this type of information. SAR data represent a means through which information products and services provided by national ice mapping agencies can be better tailored to a wider range of customer requirements. In addition, many Ice Services already have appropriate high bandwidth telecommunications links in place through which they can ensure rapid access to fast delivery SAR imagery from the appropriate ground station.

The launch of ERS-1 in 1991 provided the R&D community with the opportunity to develop and validate operational concepts for the use of satellite based SAR imagery within national ice information services. Icebergs are identifiable within full resolution SAR images as intense bright points surrounded by lower backscatter returns from the sea surface. The bright returns are generally caused by a corner reflector resonance effect caused by the steep angles between the sides of the iceberg and the sea surface. Iceberg detection algorithms isolate bright returns and then determine the probability that this is in fact an iceberg (ships, surface clutter and small islands can cause effects that could be mistakenly identified as an iceberg). Examples include size, shape, presence or absence of a wake and the distribution of bright returns over the probable iceberg.

Due to their freshwater composition, SAR radiation can penetrate to a sufficient depth inside the iceberg so that some degree of volume scattering takes place. This is recognised within the SAR data by using cross polarisation data and is one important factor enabling separation of iceberg targets from ships and surface clutter. The timeliness constraint also requires a suitable processing chain within the appropriate ground station – many ground stations set up for fast delivery of SAR data operate ScanSAR processing chains whereas iceberg detection and tracking requires a processing chain capable of generating full resolution imagery on short timescales.

“SAR based iceberg information is used to improve surveillance coverage and maintain tracks on icebergs entering zones close to shipping lanes or offshore production activities”

SERVICE **EXAMPLES**

Ice berg surveillance for Offshore Exploration & Production

During the ice season on the Canadian East Coast, vessels passing near the Grand Banks, through one of the world's busiest shipping lanes, are forced to detour south to avoid icebergs. C-CORE, in cooperation with Provincial Airlines Limited (PAL) both based in Canada, have implemented a multi satellite SAR surveillance system using RADARSAT and Envisat data for operational iceberg management services.

There are two notable examples of the types of services offered. C-CORE provided iceberg surveillance services with RADARSAT-1 to the International Ice Patrol and PetroCanada (who manage the Terra Nova oilfield) via Provincial Airlines Limited. Approximately 50 SAR scences were acquired and processed in near real time during the time frame of March - June 2003. In June, satellite surveillance was switched over to Envisat ASAR to test its operational capabilities. With the success of the 2003 programme, satellite surveillance continues through 2004 and onwards.

AMEC a global civil engineering company, provided ice management planning and operational ice services for Statoils Summer 2000 Fyalla Bank Exploration programme in the Davis Strait, 130km southwest of Nuuk, Greenland. On arrival of the drilling ship at the drill site, 20 icebergs were detected within visible range. The frequency and rapid drift of the icebergs made it particularly difficult for ice management.

230 icebergs were tracked during the three-month programme. Of these, in excess of 70 icebergs were prevented (deflected) from drifting too close to the drill site. Iceberg size ranged from small 'growlers' to a massive 4 million ton berg that was over 250m in length and which was successfully towed out of the path of the drill site. RADARSAT imagery provided by the Danish Meteorological Institute (DMI) was used to determine large-scale patterns of the icebergs in the area, together with vessel radar and support vessel reconnaissance for tracking of icebergs. The ice management project was successful in minimising the downtime for drilling operations.

Iceberg monitoring services in Canada (this page and following page) © C-CORE

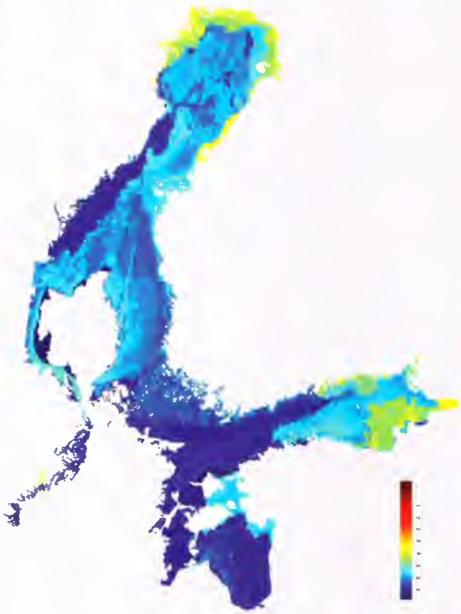
combining RADARSAT and Envisat data enables a better update rate for a given area

Sea Ice Monitoring Services in Europe: The Finnish Institute of Marine Research (FIMR)

Operating as part of the Finnish Institute of Marine Research, the Finnish Ice Service is tasked with the collection, processing and subsequent distribution of sea ice information to all operators in the Baltic Sea. Some 80-90% of Finnish export and import is carried out via merchant vessels. Thus, the country is entirely dependent on sea borne transport. The volume of Finland's international sea-borne trade is growing with winter navigation growing faster than summer transport, at roughly 5% a year. In 2002, sea-borne trade exceeded 87 million tonnes.

Finland is one of the few countries on the world where all harbours are ice-bound during normal winters – some of them for as long as six months. This means that during the winter, transport is possible only with support of the Finnish Maritime Administration icebreakers. Twenty-three of Finland's 50 commercial ports are kept open throughout the year so that provision of accurate and timely ice information is an issue of national economic importance.

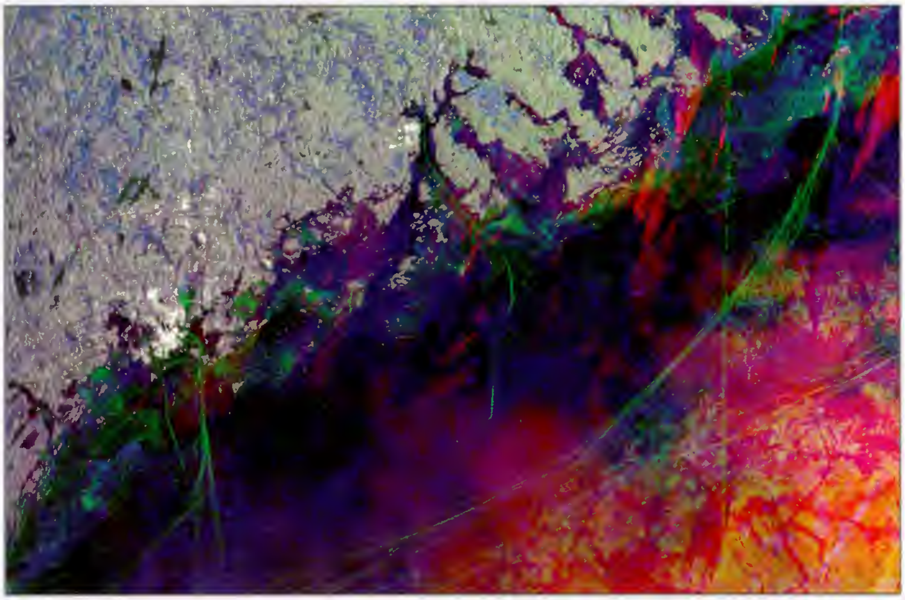
AUTOMATICALLY PRODUCED HIGH-RESOLUTION ICE THICKNESS MAP OVER THE BALTIC SEA. THE MAP (CREATED IN COMBINATION WITH GROUND TRUTH DATA/ALGORITHMS) IS A MOSAIC OF THREE RADARSAT SCANSAR WIDE IMAGES FROM THE 6-7 JANUARY 2003. © FIMR, 2003.



During the last ten years marine traffic has increased by 30%, and this trend is expected to continue. In the same period, however, the number of operating icebreakers has not increased. This increase in traffic has been made possible due to more efficient ice monitoring for vessel navigation and route planning, where the use of EO data has become increasingly important.

The ice season normally begins in October-November and lasts until May-June. The annual maximum ice extent occurs between January and March. The ice covers, on average, almost half of the total area of the Baltic Sea. Daily reporting of ice conditions in the region continues for the duration of the ice season. Ice charts, ice reports and coded reports are broadcast, and processed satellite images (AVHRR from NOAA and SAR from Radarsat) are sent to the active Finnish and Swedish icebreakers via a dedicated joint communication system (IBNet). Ground information is collected from fixed stations, pilots, coastal guard, vessels and icebreakers and data is also exchanged with other ice services.

Since 1992, FIMR's ice service has extensively used SAR data (1992-1997 ERS SAR, 1998 onwards RADARSAT SAR and since 2003 Envisat ASAR in demonstration mode). EO data, and especially SAR data, has become so important to



ICE COVERED GULF OF FINLAND. © ESA 2003
THIS ADVANCED SYNTHETIC APERTURE RADAR (ASAR) MULTITEMPORAL COLOUR COMPOSITE IMAGE SHOWS AN AREA OF 100 KM SWATH WIDTH CENTRED OVER THE ICE-COVERED GULF OF FINLAND. THE IMAGE IS MADE OF THREE ASAR IMAGES ACQUIRED ON DIFFERENT DATES AND ASSIGNING A COLOUR (RGB) TO EACH DATE (RED: 1 JULY 2003, GREEN: 7 JANUARY 2003, BLUE: 22 APRIL 2003). VISIBLE LANDMARKS ARE THE CITY OF HELSINKI. (BRIGHT WHITE AREA, CENTER LEFT). ICE IS VISIBLE ON THE BAY AS YELLOW AND BLUE GREEN PATCHES.

the Ice Service that it has almost completely replaced reconnaissance flights.

FIMR have also been using ScanSAR data from RADARSAT to generate ice classification maps from the Baltic Sea area. Data are acquired from the Tromsoe ground station fast delivery processing chain, and is geo-referenced and assimilated into the FIMR anal,sis environment. In the latest version, an automatic classification routine then combines ground truth data with algorithms producing high-resolution ice thickness maps. These special maps have been delivered in near real time to the users at sea. FIMR has also been verifying the capabilities of Envisat ASAR data to generate similar sea ice information for incorporation into the operational service.

The Canadian Ice Service

The Canadian Ice Service (CIS) provides three main categories of sea ice and iceberg services; ice analysis and iceberg charts, ice and iceberg bulletins and Model based forecasts of ice conditions for periods of 24 to 48 hours in the future.

Due to the annual variation in ice cover, the focus of Ice Service operations changes during the year. In Spring, the main effort is devoted to the Labrador Coast and East Newfoundland waters, the Gulf of St. Lawrence, the Great Lakes and the St. Lawrence River. In summer, the main ice cover of interest is the Arctic and Hudson Bay area and then attention turns back to the Labrador Coast and St Lawrence areas with the onset of winter.

Daily ice analysis charts are intended to support both strategic (day-to-day) or tactical (longer-term) planning and operational purposes. These Ice analysis charts represent the best estimate of daily ice conditions at the time of issue, based on analysis and integration of data from sources such as shore, ship- and aircraft-based visual observation together with airborne and satellite based remote sensing data.

They are prepared daily during the ice season and delivered to users in time for planning the next day's activities. The charts are generated at a standard scale of 1:2 Million and describe ice conditions by predominant ice type, stage of development and form of ice. They also include a 24-hour forecast of the drift of freely moving ice. Customers for these services include the Canadian Coast Guard, port and harbour authorities, offshore oil and gas operators, marine insurance companies and fishing fleets in Canadian waters.

RADARSAT data have been integrated into CIS operations since 1996 and is now a standard data source – indeed justification for government funding for the mission was based to a considerable extent on the benefits envisaged from subsequent improvements in ice information.

A dedicated processing chain has been set up in Canada to ensure rapid Ice Service access to Envisat ASAR data to enable faster update times and improved identification of ice conditions – as ASAR can operate in more than one polarisation, combination with single polarisation RADARSAT data improves ice classification and thickness estimation.

At present, RADARSAT data are processed to a spatial resolution of 100m, and ASAR to a resolution of 150m and then transmitted over a fibre optic link to the Canadian Ice Centre where high performance ice classification techniques are applied. Time from data capture by the satellite to image reception at the ice centre can be faster than 60 minutes. The output ice classifications are then assimilated into the integrated Ice Analysis Chart or distributed as analysis products in their own right.

Sub scene of an ENVISAT ASAR Wide Swath image. The image shows the sea ice at the entrance to Jones Sound in the Canadian Arctic. The Southern tip of Ellesmere Island is in the upper left of the image and the Northeastern portion of Devon Island is in the lower left. The sea ice is in the process of freezing up and consolidating for the winter. To the left of Jones Sound, refrozen leads (open water) appear as dark toned areas while ridged and rubbled first year ice appears brighter. On the right side of the image , the sea ice is still dynamic and moving. The brighter round ice floes are thicker multi-year sea ice. © ESA 2003. Image received and processed by the Canada Centre for Remote Sensing (CCRS).

<< FUTURE OUTLOOK

The Arctic basin is gaining a higher level of political visibility due to factors such as increased levels of resource exploitation and support logistics in the region (e.g. oil and gas production off the Northern coasts of Alaska, Canada and Russia as well as Russian Far East), the evolution of a viable "Northern Sea Route" transport corridor between Europe and Eastern Asia and the changing security environment engendered by ice free oceanic areas developing from previously impassible ice locked northern coastlines. The following specific areas will require increased systematic availability of sea ice information:

Increased transportation of oil and gas products around the Northern Russian coastline and into Europe around the Kola peninsula mean movements of oil products through ice infested seas close to a large number of extremely sensitive ecosystems

The possibility of reduced voyage times between Europe and East Asia by transiting around the North coast of Norway and Russia will result in increased ship traffic levels close to environmentally sensitive areas.

The US Energy industry has been lobbying for expansion of oil production areas off the Northern coast of Alaska. Transport to market is proposed via a dedicated pipeline but production operations will depend on adequate sea ice information in areas where there is presently little commercial traffic.

Away from the Arctic, sea ice in the Caspian and Black Sea areas is likely to become a greater concern for oil and gas production and transport operators in these regions. Sea ice in the Northern Caspian represents an operations hazard in a uniquely fragile environment. Transport by tanker would increase shipping levels in the Black Sea at a time when a major international effort is being called for, to clean up high levels of pollution.

In parallel, environmental concerns are priorities for European citizens while corporate environmental responsibility is an area that many oil, gas and transport companies are enthusiastically attempting to use in an effort to reassure potential customers of their environmental performance. Many of these factors are expected to drive demand for sea ice information over the coming decade that can be satisfied only through an increased reliance on satellite measurements, both near real time monitoring and statistical planning information.

The need for better sea ice information will continue to drive technical developments in new sensor technology, data processing and communications. There is still no standard system for retrieving ice parameters from SAR automatically so there is a continuing need for improved automatic ice classification algorithms. Ice centre operations are still mainly based on visual interpretation, with limited, short term, forecasting services available. New modelling and improved forecasting techniques are giving us the ability to fill the gaps between observations and to extend observations into the future in a consistent manner. In addition the greater assimilation of EO data into regional ocean/ice/atmosphere models for sea ice monitoring and forecasting is an important area undergoing development. New techniques in advanced radar data processing, such as recent developments in the field of SAR Polarimetry and Polarimetric Interferometry (POL-inSAR) are increasing the information content and the value of SAR data for Sea Ice monitoring.

ACKNOWLEDGEMENTS >>

This booklet provides descriptions of EO services available today from specialist service providers for the marine environment e.g. C-CORE. For their work in market development these companies have been supported by ESA's Earth Observation Programme.

This document also includes contributions from the Canadian Ice Service, the Finnish Institute for Marine Research, the Canadian Centre for Remote Sensing and RADARSAT International Limited who are gratefully acknowledged.

For further information on the EO service industry

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http://www.c-core.ca

Canadian Ice Service Mike Manore • CANADA
http://www.ice-glaces.ec.gc.cd

Danish Meteorological Institute Henrik Steen Andersen • DENMARK
http://www.dmi.dk

Finnish Institute for Marine Research Ari Seina • FINLAND
http://www2.fimr.fi

Noetix Research Inc Tom Hirose • CANADA
http://www.noetix.ca

Norwegian Meteorological Institute Helge Tangen • NORWAY
http://www.met.no

SMHI Bertil Hakansson • SWEDEN
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For further information on EOMD activities and ENVISAT Program

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A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE

Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.

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MARINE SURVEILLANCE

USING RADAR FROM SPACE

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OIL SLICKS IN THE MEDITERRANEAN ASAR, 26 JUNE 2002

Envisat ASAR image acquired over the Islands of Corsica, Sardinia and the Italian peninsula.
The area covers several major shipping lanes including the main route to Genoa.
The long thin dark structures are due to oil dumped illegally by shipping in the area.
The presence of oil or natural films damps out the surface waves and reduces the observed backscatter levels. ASAR wide swath imagery will make a major contribution to improved monitoring of marine areas to prevent such dumping.
The image was acquired at approximately 0930 hence most of the dumping probab occurred during the hours of darkness. Due to the operating wavelength, ASAR is able to detect illegal dumping both day and night.

THE NEED FOR BETTER INFORMATION

Regular surveillance of territorial sea areas is increasingly important for coastal nations. Signatories to the United Nations Convention on the Law of the Sea (UNCLOS) can establish a territorial sea out to 12 nautical miles from the coastline and an Exclusive Economic Zone (EEZ) of up to 200 nautical miles. These marine areas are then an economic resource for a coastal state (e.g. for fisheries or oil extraction) but that state must then take responsibility for the administration, law enforcement, environmental protection and sustainable management of this frontier. Development, implementation and enforcement of policy and legislation require systematic surveillance of these areas but this is very costly and logistically cannot cover all areas all of the time. Priority monitoring and surveillance requirements for coastal nations are:

> *systematic surveillance of these areas is very costly and cannot cover all areas all of the time*

Oil and chemical pollution detection and prevention

The main sources of oil pollution are accidental leakages from offshore oil production platforms and illegal cleaning and discharges from shipping operators.

Offshore oil production has been expanding steadily over the last 15 years and this trend is expected to continue. Furthermore, many new licences are in areas with sensitive ecosystems (e.g. recent developments in the UK-Faroes region). In response, offshore operators must demonstrate the effectiveness of their internal control systems to ensure early detection of spills, leakages and other sources of contamination, to be awarded new licences in the waters of many European states.

90% of the EU's external trade and 43% of its internal trade goes by sea. More than 1 billion tons of feight a year are unloaded in EU port's. Many vessel operators discharge oil contaminated ballast waters and lubricant wastes at sea instead of using specially designed port facilities. Recent oil spills such as the Prestige off the Atlantic coast of Spain in November 2002 and the Erika off the Atlantic coast of France in December 1999, have raised public awareness of the risks that oil transportation poses to the coastal environment. However, illegal discharge of ballast and engine residue are estimated by the WWF to have an impact at least 20 times greater than a Prestige type incident each year. International agreements preventing such discharges exist (e.g. MARPOL, OSPARCOM, the Barcelona Convention and HELCOM) and appropriate national legislation is in place in all European coastal states. However, effective enforcement of these agreements requires extensive surveillance of territorial waters beyond the levels presently implemented by coastal states.

Fisheries protection

The European Common Fisheries Policy requires regional fisheries monitoring centres to enforce strict controls on fishing activity in their waters. Information on the numbers and distribution of national and non-national vessels, as well as fishing activities is essential for management of the stocks and for controlling illegal, unreported and unregulated fishing. Timely detection of incursions into exclusion zones by unauthorised vessels helps ensure that patrol ships can be rapidly deployed and illegal fishing activities stopped.

Transport of illegal cargoes

Navies and coastguards are also responsible for detection and interception of those involved in the illegal transportation of goods and people. However, the present sampling strategy for EEZ surveillance adopted by many coastal states means only a fraction of the area of interest is covered on any particular day. Clearly this limits the scope for successful interception by surface vessels.

SPACE-BASED >> and TRADITIONAL METHODS TO BETTER MEET USER REQUIREMENTS

THE LIMITATIONS OF TRADITIONAL TECHNIQUES

Today the predominant strategy for monitoring an EEZ is a combination of coastal radar and airborne surveillance. This is backed up with patrol ships for interception and the majority of European coastal nations have dedicated marine surveillance programs operated by national navies and coastguards. Although very effective, the deterrent effect of these systems is based on sampling a sufficient fraction of a given area to guarantee a high probability of detection for any illegal activity conducted within an EEZ. Continued oil pollution, fishing incursions and smuggling of illicit cargoes are testimony to the fact that a certain amount of illegal activity continues. The limited coverage of both airborne and land based surveillance systems means that substantial investment in new surveillance infrastructure is required, but this is beyond what is currently affordable today.

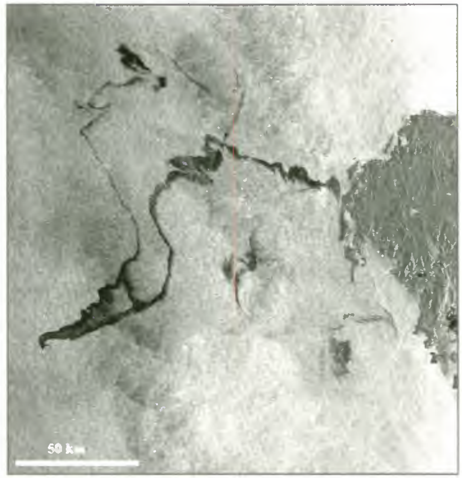
THE BENEFITS OF SPACE BASED MONITORING

Satellite based Synthetic Aperture Radar (SAR) can offer wide area surveillance coverage day and night, independent of cloud cover and weather conditions. The system can detect ships and can be used to identify pollutants such as crude-oil emulsions from leaking ships or drilling fluids from offshore oilrigs. When used to complement current surveillance strategies, this results in:

> Maximising the impact of a fixed number of conventional surveillance assets - satellite based SAR systems can identify areas free from pollution or incursion so that airborne or surface vessel investigation is not required. In addition, space-borne SAR can be used to cue airborne or surface vessels to collect more detailed information on potential slicks and illegal vessels detected during the satellite overpass

> Increasing the area covered in a given period leading to more effective deterrence. This can support a move to a more co-operative implementation of environmental protection measures (e.g. in Norwegian waters, offshore oil operators and the government tightly coordinate monitoring and surveillance for pollution prevention and impact mitigation)

> Improving the timeliness with which a particular activity is detected and intercepted. The increased volume of satellite SAR imagery now available means improved revisit times that can dramatically shorten the time between the start of an incursion or dumping incident and its detection, thus enhancing the chances of effective prosecution of offenders by coastal states. This is particularly useful for night-time overpasses when many illegal discharges and incursions take place and when very few nations operate maritime patrol aircraft.



ASAR IMAGE OF OIL SLICK FROM THE WRECKED TANKER PRESTIGE OFF THE NORTHWEST COAST OF SPAIN, 17 NOVEMBER 2002

THE HUGE OIL SLICK IS CLEARLY VISIBLE AS A DARK PLUME EMANATING FROM THE STRICKEN SHIP AND STRETCHING TO THE COAST. THE ASAR WAS OPERATING IN ITS WIDE-SWATH MODE COVERING AN AREA APPROXIMATELY 400 KM BY 400 KM. STRONG WINDS IN THE AREA RESULTED IN LIGHTER OIL COMPONENTS BEING BLOWN OFF WHILE HEAVIER CONSTITUENTS HAVE BEEN MOVED AROUND ON THE SEA SURFACE, LEAVING CHARACTERISTIC DARK FEATHERY TRAILS. THESE WINDS ALSO CAUSED SOME DEGREE OF MIXING BETWEEN THE OIL AND THE SURROUNDING SEA, REDUCING THE LEVEL OF OIL AT THE SURFACE AND MAKING IT MORE DIFFICULT TO DETECT.

THE INTEGRATION OF EO IN EXISTING GEO-INFORMATION SERVICES

In Europe today some coastal states are starting to use positional information, typically from satellite navigation services such as from GPS, in combination with satellite based radar data and satellite communication services, providing a geo-information service to support traditional ship or aircraft based surveillance activities.

For example oil spill monitoring using satellite radar data has been operational since the mid-nineties over Northern Europe. Satellite SAR data is used to complement conventional surveillance aircraft capabilities, by providing information for large-scale surveys with unbiased spatial sampling and through direction of aircraft flights towards slicks identified in the SAR imagery.

For operational fisheries monitoring activities positional information from on board Vessel Monitoring Systems (VMS), which provide GPS location for individual vessels, is integrated with on-board radar detection equipment as well as logistics support from aircraft and vessel observers. Satellite SAR data can provide complementary information on vessel location activities to fisheries monitoring centres and to the enforcement authorities. In a number of EC studies it has been demonstrated that improvements in aircraft and vessel patrol effectiveness, with potential savings in costs, may be gained by using satellite based SAR for routine wide area surveillance, and using aircraft only when suspicious activities are identified in a particular area. In this way any illegal fishing operations can be more easily detected and intercepted without disruption to licensed fleets.

EXPLOITING NOVEL EO-BASED TECHNIQUES

"satellite based SAR can offer wide area surveillance, independent of cloud cover and weather conditions"

A number of factors contribute to make SAR particularly suited to marine surveillance activities. The ASAR (Advanced Synthetic Aperture Radar) instrument on Envisat (ESA) has the ability to steer its beam in different swath positions and widths. For example, ASAR can operate in Wide Swath (ScanSAR) mode with a swath width of 400 km. If higher resolution for a smaller area is required, there is a choice between 7 image mode swaths at 56-100 x 100km. ASAR has the flexibility to offer co and cross-polarised data, which improves detection abilities for vessels and for natural and artificial slicks. Selectable incidence angles from 15 to 45 degrees, also improves detection capabilities for different features.

By combining ASAR capabilities on Envisat with SAR data from RADARSAT, a given area can be monitored at least every 12 hours. When combined with airborne and surface vessel capabilities this represents a significant improvement over aircraft and ship based monitoring alone.

Detection of ships using SAR

Ships act as corner reflectors and are identified as high intensity pixel groupings within a SAR image. Automated threshholding analysis can highlight all targets with a detected backscatter higher than the threshold level, enabling a level of confidence to be assigned to a given vessel detection (the higher the measured backscatter intensity, the greater the confidence in a positive detection). Locations of potentially suspect vessels can then be notified to the surveillance organisations for follow-up verification and interception. Detection probability varies with factors such as wind speed and vessel size. Furthermore, different SAR operating modes can affect the detection of the vessel. In general, ships are more easily detected when swath is at shallower incidence angles. In addition the multi-polarization modes of the radar instrument are expected to make a useful contribution to ship detection although this is still an area of research at present.

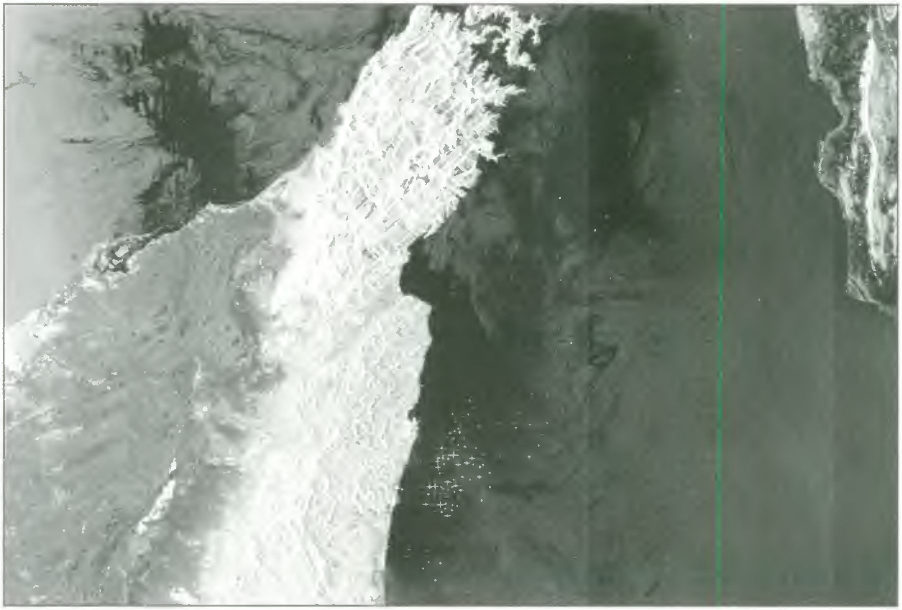
Detection of slicks using SAR

The presence of a film on the sea surface damps out small waves due to the increased viscosity of the top layer. This reduces the measured backscattered energy and results in darker areas in SAR imagery thus allowing the detection of a slick. However, many oceanic and atmospheric phenomena can cause low

backscatter areas. Examples include natural surface films (e.g. plankton or oil seepage slicks), cold upwelling increasing the air stability at the sea surface and hence reducing the wind speed and surface roughness, and wind shadowing close to coastal areas where land areas block the action of the wind on the sea surface or even rain cells. Trained operators are therefore required for accurate identification of pollution slicks. The operators can rapidly access SAR imagery for slicks within a few hours of satellite overpass. The parameters associated with each possible slick (e.g. location, extent, etc) can then be transmitted to the appropriate national authorities.

"operators can rapidly access SAR imagery for slicks and ships within a few hours of satellite overpass"

Imaging of the slicks may be affected by the type of the oil discharged and wind speeds. Under very high wind speeds the pollutant may mix rapidly leaving no surface effects visible. Similarly, heavy oil may sink below the surface after the initial spill, resulting in no detectable modulation of the surface roughness. However, in these cases the performance of airborne surveillance systems also suffers. In summary, within a well characterised range of environmental conditions and discharge situations, slicks as small as 0.1 km^2 in area can be detected reliably with operationally acceptable false alarm rates.



Ships off the Arabian Peninsula ASAR, 22 June 2003
This wide-swath radar image (400km wide) shows the Arabian Peninsula. The group of small white dots off the coast of Oman indicate the presence of ships and oil rigs. © ESA 2003

OIL SPILL MONITORING AND SHIP DETECTION SERVICES

A number of commercial services for surveillance of European waters using EO data are available today.

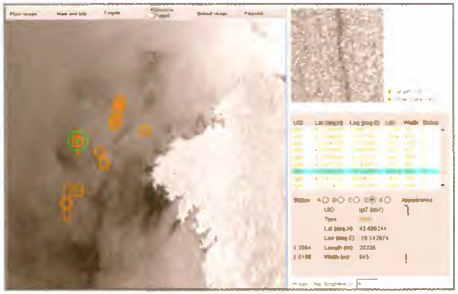
QinetiQ, based in Farnborough, U.K., have developed the Maritime Surveillance Tool (MaST), which forms the basis for a near-real time ship detection service and OilWatch, an oil spill detection service. MaST uses SAR data from the RADARSAT, ERS and Envisat satellites. Results can be supplied to the customer in approximately two hours (allowing for data transfer and processing). A variety of products can be generated, including details of slick location, extent and close-up image chips of the slicks themselves.

MaST has supplied near-real time ship detection reports directly to operational fisheries monitoring centres, to help them optimise the use of their existing patrol craft. The ship detection process is performed automatically by MaST and the results sent directly to the customer (via fax, email or via the Internet) or post-processed e.g. incorporated into a GIS environment, dependent upon the customer's specific requirements.

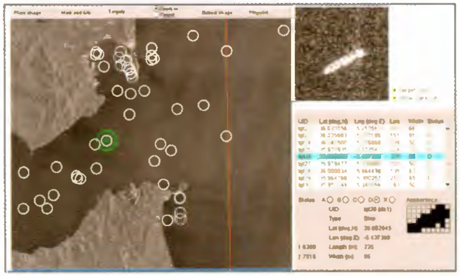
Kongsberg Satellite Services (KSAT) based in Tromsø, Norway, is also a provider of near real-time earth observation services for marine surveillance. KSAT offer an oil spill monitoring and ship detection service, based on satellite SAR data from RADARSAT, supported by ERS and Envisat, with a service area extending over the North Sea and the Norwegian, Baltic, Barents and Karah Seas south to 50 degrees latitude. Information on possible oil spills (position and estimated size of polluted area) and ship position can be made available to the end users within 2 hours of data acquisition.

KSAT is operational 24 hours a day, and both day and night passes are analysed and notified upon. SAR data are downlinked and analysed at the Tromsø Receiving Station and the relevant national authorities are notified when a possible oil spill has been identified. Clients include the Norwegian Pollution Control Authority, whose surveillance-aircraft operations are planned and co-ordinated based on the timings of the satellite overpasses. The Tromsø Station operators are in direct contact with the aircraft crew, which allows flight-path deviations to be made to verify satellite-detected slicks.

SERVICE EXAMPLES



DETECTION OF OIL SLICKS OFF THE COAST OF SPAIN AND PORTUGAL. INFORMATION ON OIL SLICK LOCATION AND SIZE ALONG WITH AN ESTIMATION OF SLICK EXTENT PROVIDED THROUGH THE MAST/OILWATCH SYSTEM. © QINETIQ 2003



SHIP TRAFFIC IN THE STRAITS OF GIBRALTAR. SHIP TARGETS ARE CIRCLED. INFORMATION ON THE SHIP POSITION AND ESTIMATED VESSEL LENGTH AND WIDTH ARE PROVIDED THROUGH THE MAST SYSTEM. © QINETIQ 2003

ENVISAT ASAR image
of the Gulf of Finland (off shore Estonia)
from 16 September 2003.
An oil slick, loop and the polluting
ship can clearly be seen in the image.
The length of the spill
is approximately 100km.

<< FUTURE OUTLOOK

The value of satellite based SAR as part of an operational EEZ surveillance and monitoring system has been demonstrated over the last decade. Extrapolating from present trends indicates that demand can be expected to grow over the next 5-7 years.

For example.

- Offshore oil and gas operations are expanding but environmental protection is high on the European agenda. When combined with industry commitments to sustainable and environmentally responsible business practices this results in oil companies working together with authorities in order to ensure the safe operations and transport of oil resources.
- The ambiguity over responsibilities for some recent major accidents involving oil pollution is encouraging certification agencies to increase their mon-

itoring and control efforts for shipping under their responsibility. This is expected to result in increased monitoring requirements in which space based systems could play a major role.

> The establishment of the European Maritime Safety Agency will provide the EC with the necessary means to act effectively to enhance overall maritime safety and environmental protection. In addition, it is expected that the Agency will be involved in the implementation of surveillance infrastructure as part of the EC directive for the establishment of a Vessel Traffic Monitoring System (EC directive 2002/59/EC). This represents a significant advance in the establishment of a European wide monitoring infrastructure

and is expected to strongly influence demand for coordinated surveillance, including the integration of satellite SAR capabilities into operational monitoring systems.

> Port authorities and regional environmental protection organisations within Europe are often responsible for pollution control in holding areas and approach channels. Increased availability of a common surveillance infrastructure based on satellite SAR is expected to encourage wider uptake of these capabilities and their integration within local scale GIS and Decision Support Systems.

> Reforms in Fisheries Policy in the EU have led to increased monitoring requirements for fishing vessels for the identification of illegal and unreported fisheries activities. Many organisations are presently investigating how to integrate such information with airborne and satellite based radar surveillance within a GIS environment to ensure that both legal and illegal activities can be accurately and effectively traced. Spaceborne SAR imagery can complement VMS and other advanced technologies, such as satellite communications and electronic logbooks, in providing operational support to Fisheries Monitoring and Control Centres in near real time and at a low price.

> New satellite missions will ensure continuity and improvements to present radar surveillance and monitoring capabilities. For example, Cosmo-Skymed will provide a constellation of 4 X-band SAR systems, RADARSAT-2 is planned for launch in 2005 and TerraSAR is expected to be launched soon after. In addition, the Japanese ALOS satellite will carry an L-band SAR.

These and other drivers ensure that requirements for surveillance and monitoring of the EEZ and international waters will continue to increase and that satellite SAR will have a crucial role to play in this sector. However, present capabilities do not yet meet the full spectrum of user requirements for such information on a systematic basis. Present development priorities therefore focus on guaranteeing effective, transparent combination of satellite based information services with conventional surveillance activities together with current telecommunications and positioning technology. The key to the adoption of these new technologies by the responsible organisations at local, regional, national and European level is to ensure that the resulting information is provided in an understandable way that brings the benefits inherent in space based monitoring into day to day operational procedures.

ACKNOWLEDGEMENTS >>

This booklet provides descriptions of EO services available today from specialist service providers for the marine environment e.g Kongsberg Satellite Services AS (KSAT) and QinetiQ. For their work in market development these companies have been supported by ESA's Earth Observation Programme.

For further information on the EO service industry

KSAT Line Steinbakk • NORWAY
http://www.ksat.no

QinetiQ Robert Ringrose • UNITED KINGDOM
http:www.QinetiQ.com

RADARSAT International Adrian Bohane • CANADA
http://www.rsi.ca

Telespazio Marcello Maranesi • ITALY
http:www.telespazio.it

For further information on EOMD activities and ENVISAT Program

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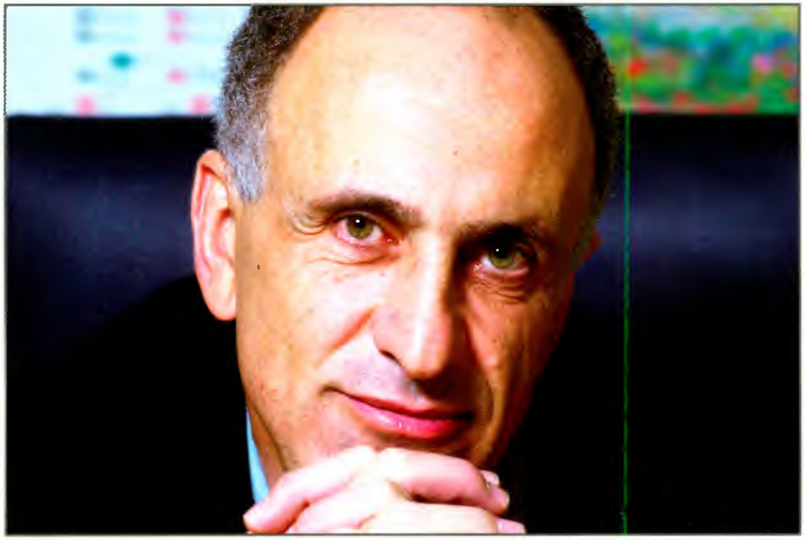
A few words from the ESA Director of Earth Observation Programs, Prof. J. ACHACHE



Services, whether commercial or public, are about the provision of the right information at the right moment to the proper person. The optimistic forecasts of the early 1990's regarding the growth of commercial exploitation of EO missions have not been realized. The EO service industry has remained small, dispersed, fragile and heavily dependent on income from government programmes.

In the short-term, ESA is working with small Value-Adding Companies (VACs) in order to attract customers for the specialized EO services available today. These services make primary use of radar data (ERS and ENVISAT), together with non-ESA missions and cover a range of Land and Ocean applications, as described in these booklets. The basic approach is to engage larger (non-EO) companies from a range of industrial sectors (eg On-shore/Off-shore Oil & Gas, Civil Engineering, Mining, Insurance, etc) to evaluate 'hands-on' whether the type of EO services available now are of value to their business or operational needs. Over 50 small Value-Adding companies are testing out how EO services need to be tailored, packaged, supplied, delivered and supported in close partnership with these larger industries.

For the longer term, a new strategy is required in order to build up the necessary momentum, rationale and resources for the definition, deployment and operation of the next generation of European operational satellites. A shift from the current technology-pushed to a market-pulled, user-oriented approach is needed. This new strategy is described in my paper of 2003 - A New Perspective for Earth Observation: The Oxygen (O_2) Project.

A first, important step in implementing this new approach is already underway with the joint initiative of ESA and the EC; Global Monitoring for Environment and Security (GMES). This is aimed at evolving to the provision of self-sustainable, operational EO services that deliver benefit to European citizens, governments, industry & scientists impacted by policies in the domains of environment and security.