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ERS AND ITS APPLICATIONS

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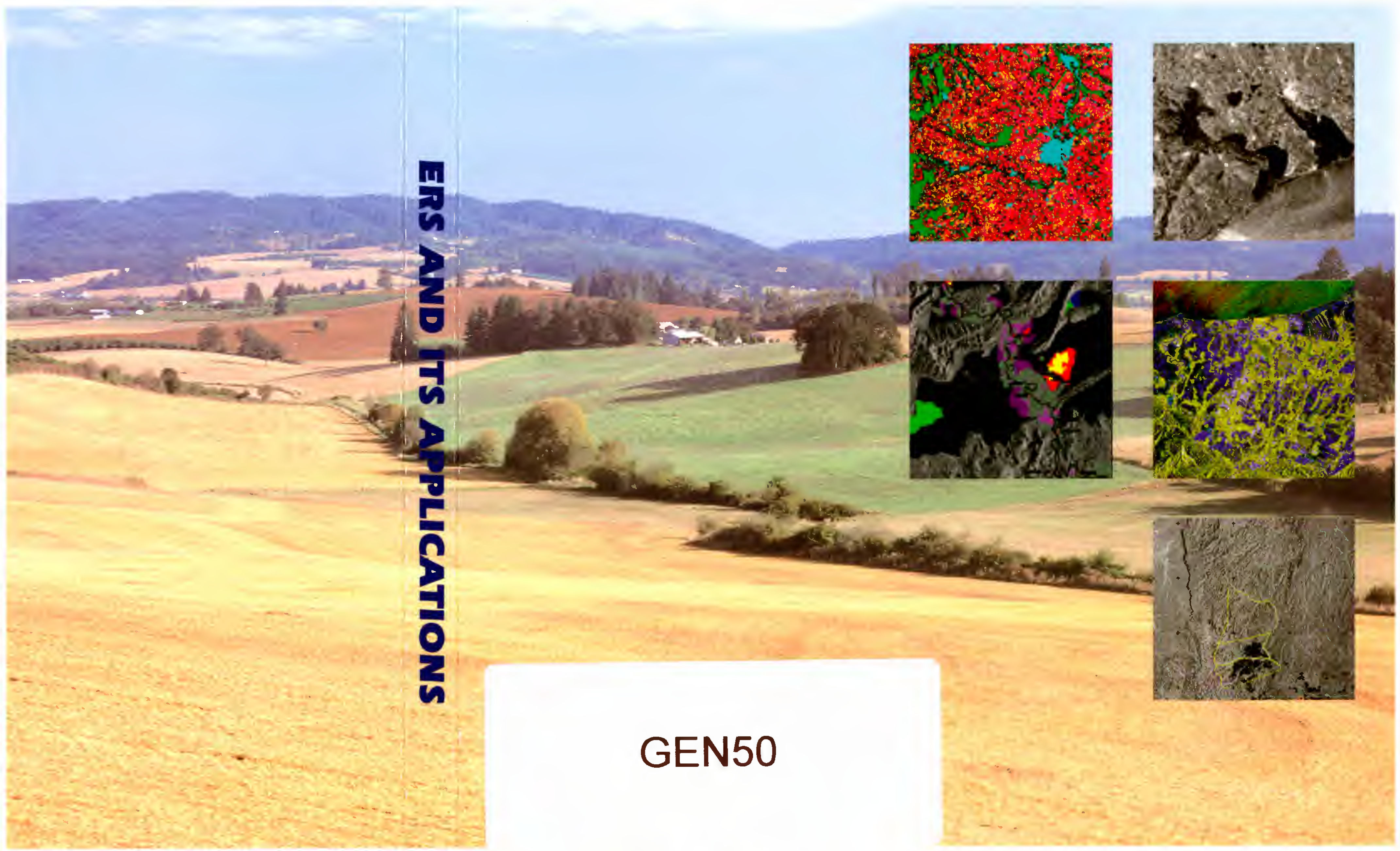

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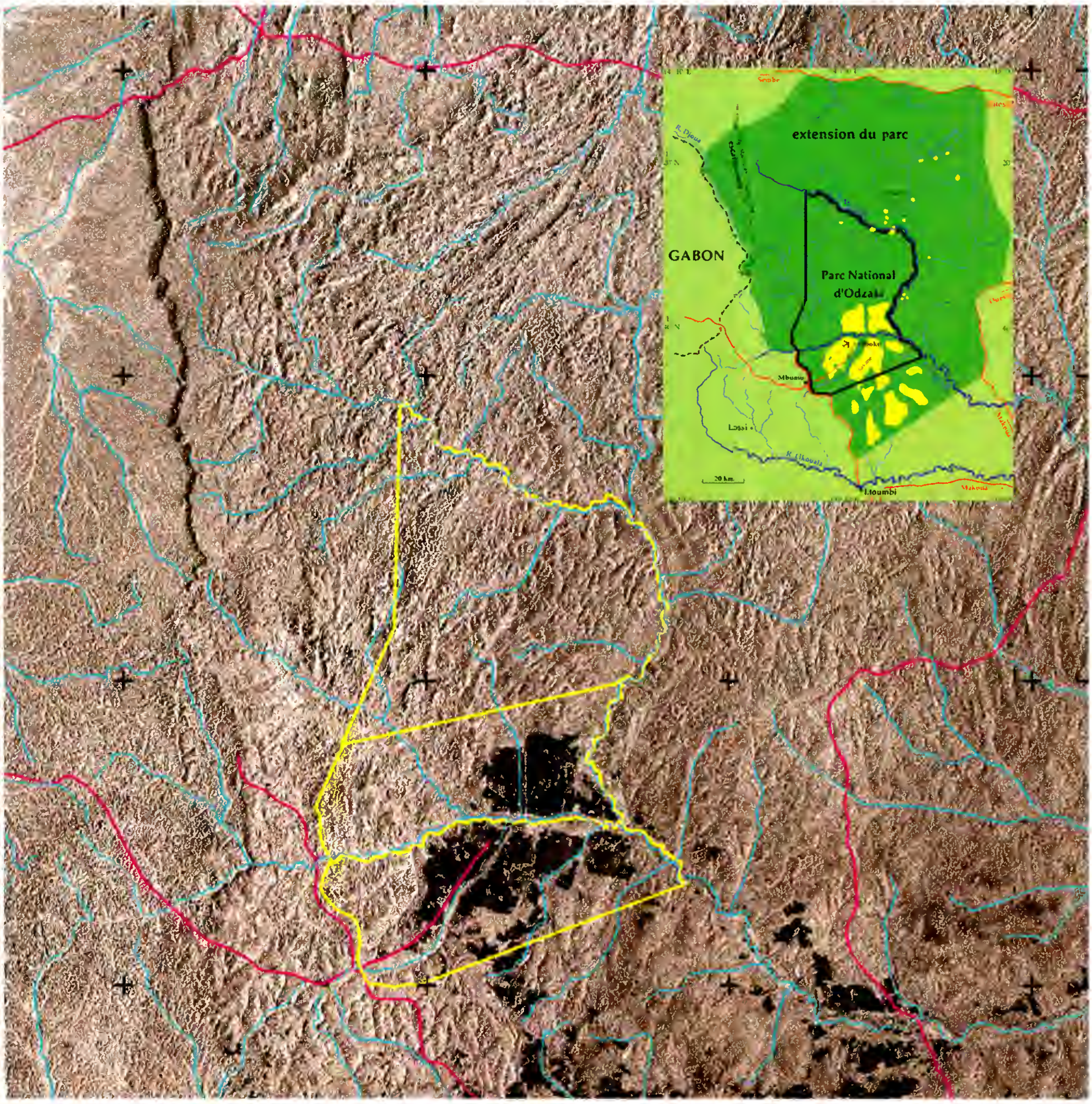
SATELLITE MAPPING



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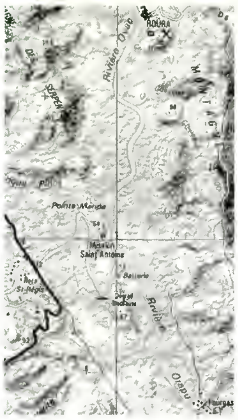


SATELLITE MAPPING

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 maps of land topography, land-use and other information products. Such maps are of great importance for activities ranging from managing and planning land-use development, to natural-resource management and engineering studies. In this context, more and more users have started to integrate cartographic and thematic mapping products into their management and decision-making systems.

The mapping industry worldwide is currently experiencing rapid technological and organisational change. A prerequisite for obtaining a complete knowledge of any landscape is to rely on as many data sources as possible. Today's mapping projects are therefore relying more and more on multi-source remote-sensing techniques capable of providing high-resolution data sets over wide geographical areas. In addition, map products available in digital format are of a great value in the rapidly expanding market of Geographical Information Systems (GISs). These are now used extensively to integrate data from different sources in domains like land management, monitoring and planning. Moreover, map producers are looking to the latest and least time-consuming methods to ensure the best product quality at the lowest cost.

The Limitations of Traditional Techniques

Aerial surveys and ground measurements are the conventional means of producing maps. These traditional map-making techniques rely on scanning and digitising processes for their updating and injection into modern decision-management systems. However this type of process does not allow the fast and cheap production of maps covering large geographical areas such as entire regions. Consequently, there is a lack of regular

information updating and many maps quickly become obsolete and are therefore of little practical use.

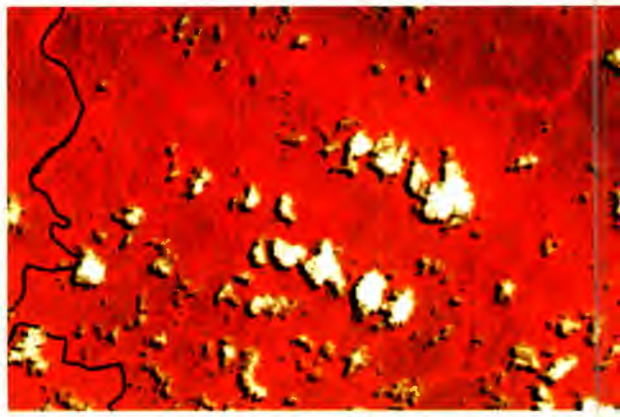
Furthermore, statistics provided in 1987 by a United Nations Secretariat Survey showed that more than 40% of the World's land surface is still not covered by 1:100 000 scale maps. Almost 50% is not covered by 1:50 000 scale maps, and 80% is not covered by 1:25 000 scale maps.

The Benefits of Space-Based Monitoring

Because of its ability to provide fast, up-to-date information and wide spatial coverage, spaceborne imagery is being used more and more by the mapping industry. Optical remote-sensing data products are used to produce space maps on a wide range of scales to serve many different needs. These include 1:50 000 scale (one of the standard scales) map compilation and map updating, as well as Digital Terrain Models (DTMs) based on stereoscopic imagery. Space maps are geocoded products, annotated in the same way as traditional maps.

Although optical remote-sensing information is widely used particularly in remote regions, it has two major limitations:

- excessive cloud cover often precludes its utilisation, and
- the location accuracy of individual points within a space map is sometimes not sufficient for some applications.



(a)

(b)

The Contribution of ERS SAR

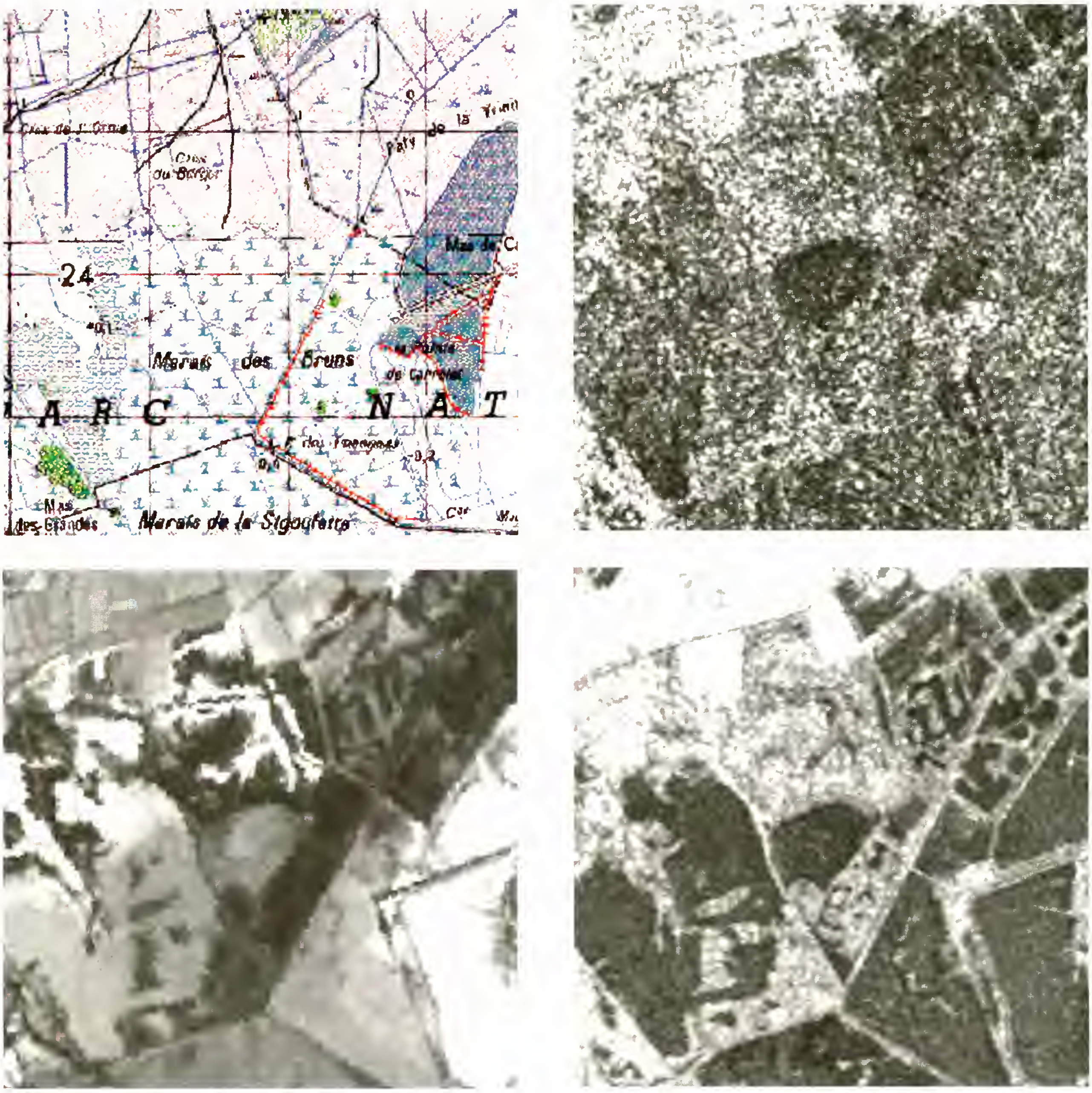
The Synthetic Aperture Radar (SAR) instrument carried by the European Remote Sensing satellites ERS-1 and ERS-2 has proved extremely valuable in developing markets dependent on large-coverage maps on scales ranging from 1:1 000 000 to 1:50 000. A large archive of SAR data has been constructed since the launches of ERS-1 and ERS-2 in July 1991 and April 1995, respectively, and this database is continually being updated with new acquisitions.

The SAR is an active instrument that produces images under all weather conditions by analysing the echoes (C-band and VV polarisation) transmitted from the satellite and backscattered by the Earth's surface. An ERS SAR scene covers an area of 100 km by 100 km and has a high geographical location accuracy. 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.

The accompanying figures show a sample image-map product extract over French Guiana derived from SPOT optical imagery (a), and the equivalent image-map based on ERS-1 SAR data (b). Ground visibility is much improved in the latter thanks to the radar's cloud penetration, while the topographic features stand out clearly as a result of the SAR's oblique viewing angle. Both images have been post-processed and geo-referenced by CEGN (Cellule d'Etudes en Geographie Numerique), the geographic research department of the French armament agency.

The synergy between ERS SAR and optical images, for both cartographic map generation and updating, increases the ability to extract thematic information. Thematic and topographic maps compiled using ERS SAR data allow one to detect and identify specific features such as hydrographic networks and structures, which are particularly important in geomorphologic analysis and geology.

In regions such as the tropics, where optical satellite information is either unavailable or not usable due to excessive cloud cover, space maps generated from SAR data are a precious tool, and sometimes represent the only solution. SAR images can be a unique source of information for compiling high-resolution space imagery at a continental scale, and for providing highly valuable thematic information as the sensor can



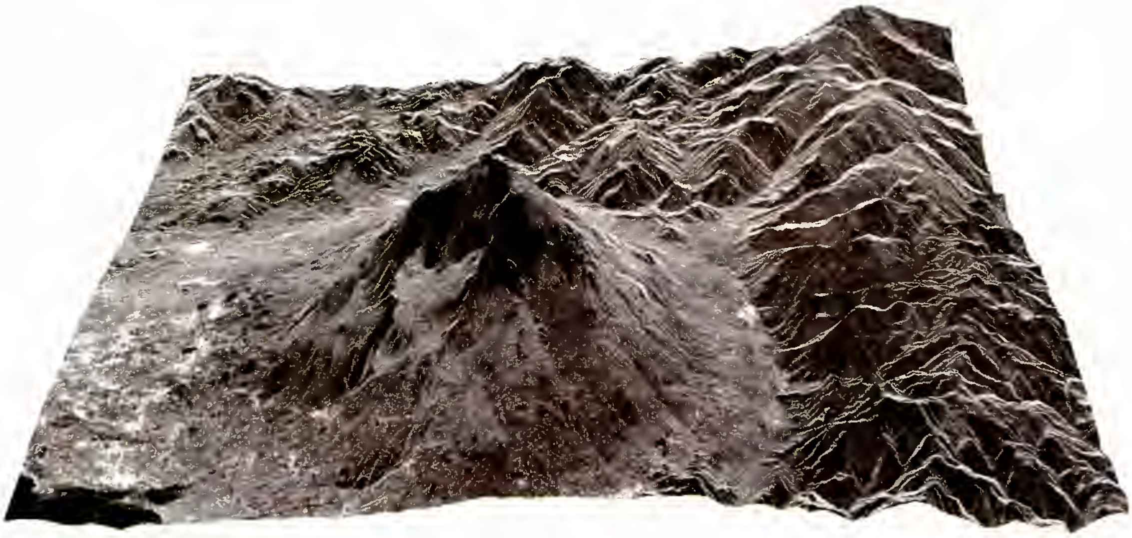
also discriminate between a wide variety of land-cover types.

The capabilities of ERS for large-coverage image mosaicing and thematic mapping worldwide are well-established. They are based on state-of-the-art processing techniques which allow improvement of both the radiometric and geometric quality of the data. For example, the speckle induces alterations in the radio-metric resolution of SAR data. This effect, which is inherent in the SAR system and due to the coherent nature of the SAR signal, gives a noisy effect in the images.

Filtering techniques applied on the SAR image can reduce this noisy effect, and thereby enhance image quality.

The example shows how multi-temporal filtering techniques have been applied to SAR data by the French company SERTIT, specialised in image processing and GIS systems, in order to reduce the speckle and thus tobe able to use enhanced radarimagery as an input to Geografical Information System. The informat on content of ERS temporally filtered image is highly valuble in this context and facilitates the interpretation

Extract of IGN map sheet over a test area (top left); subsets of ERS SAR PRI (top right) and SPOT XS (bottom left) images acquired over the same area; temporal filtering of ERS SAR PRI data (bottom right)



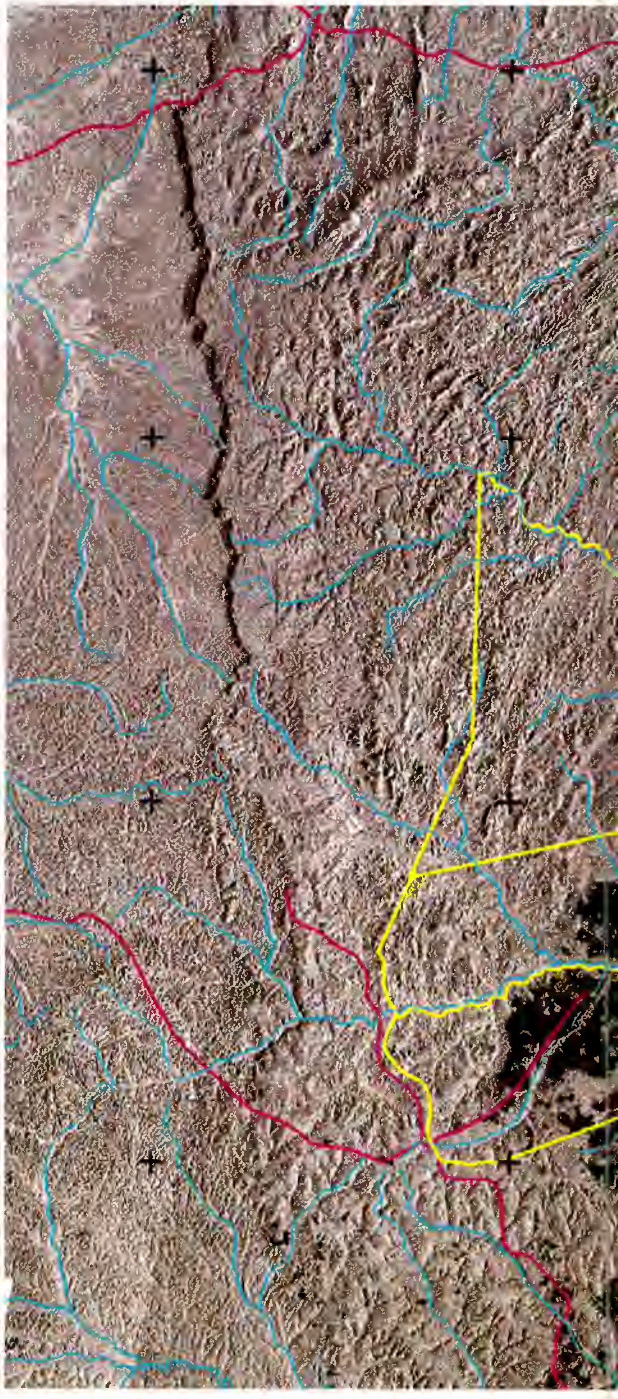
An ERS SAR image overlaid on an ERS-SAR-derived DTM of the Mount Etna volcano, Italy

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

- cartography: for map compiling and updating taking advantage of the thematic information provided by the radar for broad applications and its capabilities to extract topographic information.
- localisation: to detect or identify control points and localise targets on the ground surface, as a complement to GPS measurements for remote areas.
- rectification: to rectify old or inaccurate maps, space maps generated using remote-sensing data with inaccurate localisation accuracy, or even to rectify a Digital Terrain Model (DTM).

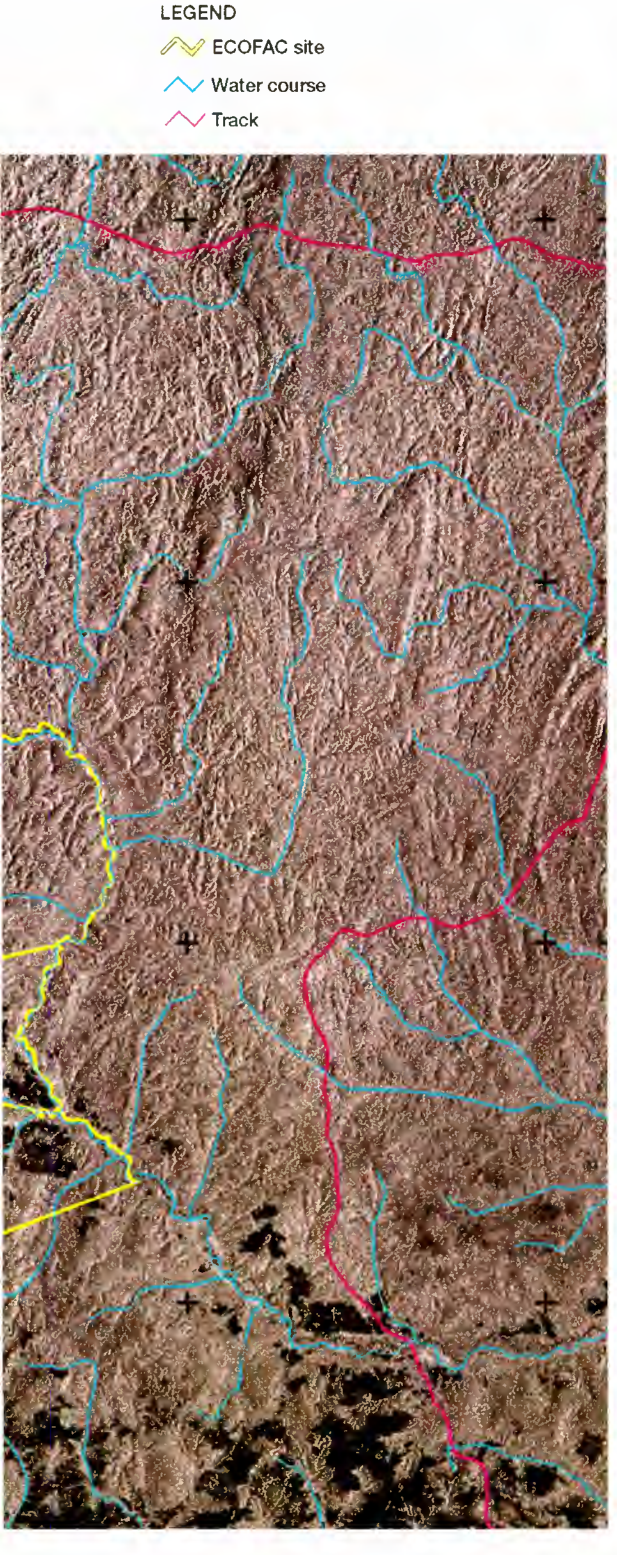
In addition, ERS SAR data products can be used for topographic mapping as Digital Terrain Models can be provided using techniques such as radargrammetry and interferometry (INSAR). Radargrammetry allows one to generate DTMs using stereopairs of radar images with different viewing angles, as for optical stereo imaging.

INSAR is based on the combination of two ERS SAR images acquired with slightly different geometrical configurations. Using INSAR, highly accurate DTMs can be produced, depending mainly on the stability of the observed surface over time with respect to radar signal phase and atmospheric effects that may affect the phase information during the acquisitions. Under favourable conditions, the altimetric accuracy achievable can be a few metres.



ERS-1 SAR mosaic extract over the Odzala National Park, a major biosphere reserve in Central Africa (Republic of Congo). An important sanctuary for birds and large mammals (gorillas, chimpanzees, forest elephants), the park's vegetation is a complex of lowland rain forests, swamp forests, open forests with marantaceae and savannah. An extension of the park is planned to include a wider spectrum of forest types. The Odzala Park is currently managed through the ECOFAC (ECOsystemes Forestiers d'Afrique Centrale) Programme of the European Union (DG VIII), dedicated to the conservation of the Central African ecosystems. The mosaic was produced to help the ECOFAC team delineate the park's future boundaries. The Central Africa Mosaic Project (CAMP) is part of a novel approach for continental-scale mapping of the tropical forest using radar remote sensing. The new approach calls for the rapid assembly of a vast amount (approximately 470 images) of high-resolution ERS-1 SAR imagery in order to obtain thematic information over the whole rain-forest domain of Central Africa at several scales and with unprecedented completeness, spatial resolution and quality. The CAMP imagery consists of a multi-resolution pyramid of products with different spatial scales, generated using a wavelet representation. Both the so-called smooth images (approximations at that scale) and the detail images (texture measures) are generated at each resolution level.

This mosaic was assembled in the framework of the TREES Project (EU-JRC, Ispra)



Differential interferometry allows one to measure surface movements with a sensitivity of the order of a few centimetres over large surfaces. This technique can be applied for subsidence monitoring and in the observation of active volcanoes, earthquakes and faults.

Moreover, interferometry can be used to extract thematic information from ERS SAR data for land-use mapping. By computing the correlation of the SAR signal between the two images, valuable thematic information is obtained. The interferometric correlation, or coherence, mainly depends on radar wave interactions with the target, and its temporal stability. Such derived imagery is used as an additional channel allowing the generation of multi-band radar products (i.e. colour composite products combining coherence image, amplitude image, and amplitude change between the two images).

Space-Based Services for Cartography

Today, more and more specialised companies are offering services including value-added products like those mentioned above. The contribution of ERS SAR has proved fundamental in meeting precision mapping requirements.

In the generation of geocoded products (rectified to a particular map projection), ground control points are needed to define the geometric models and improve the location accuracy. Generally, ground control points are identified on maps, or surveyed during field work when no maps are available. It is often necessary to use old and inaccurate maps, e.g. at 1:250 000 or 1:500 000 scales. When no geographic information (maps or GPS points) is available, the geocoding accuracy is often driven by the SPOT satellite's absolute positioning accuracy, which is in the order of several hundred metres for most optical data (e.g. SPOT).

Thanks to the high positioning accuracy of the ERS platform, and using the geometric properties of SAR imagery, a new methodology has been developed recently for localisation purposes. Such a methodology proposed and implemented by IGN-Espace allows the extraction of networks of ground control points (GCPs) using a combination of ascending and descending images. The methodology is based on a space-triangulation technique, and uses ERS as a passive positioning system. The following results can be achieved:

- absolute accuracy of localisation better than 50 m in X,Y,Z (planimetric errors around 27 m and altimetric errors around 34 m)
- estimated r.m.s. precision around 15m for planimetry and 10 m for altimetry when combined with Global Positioning System (GPS) data.

The adoption of such a methodology proves particularly useful when generating value-added products based on satellite images such as: stereoscopic DTMs, ortho images, or space maps.

Moreover, this technique can help substantially in reducing the field work needed to determine GPS points, with consequent cost and time savings. A good example is when those networks of reference points are used to geocode SPOT data in remote regions.

The use of a similar technique has been investigated by ISTAR to improve the absolute positioning accuracy of SPOT products. It combines the geometric model of both ERS and SPOT satellites, and it is based on ERS SAR images acquired in the same mode (ascending or descending). Such a methodology allows one to reduce the number and the level

ERS SAR mosaic image of French Guiana based on data acquired in descending mode. It was generated by merging two groups of 18 PRI ERS images in descending mode, acquired at two different time periods, in 1992 and in 1993-94, respectively. In addition, a strip of five scenes acquired in ascending mode has been used for localisation purposes, including height references

of accuracy of ground control points required to geocode SPOT data.

An Example of Spaceborne Mapping

The French-Guiana Space Map

French Guiana is a territory in South America, located between 2°N and 6°N. Its population is concentrated in the coastal plain, the rest of the territory being covered by rain forest. Rivers provide the only communication links with the hinterland. For the central and southern parts of the territory, the existing cartography is old, inaccurate and incomplete, due mainly to the inaccessibility of the terrain and the almost permanent cloud cover. It is virtually impossible to conduct ground or airborne surveys, and to utilise spaceborne optical data extensively.

The available cartography includes 1:100 000 and 1:200 000 scale maps in the form of sketches. Indeed, only the hydrographic network is present, without any altimetric information except some very rare spot heights. Moreover, the planimetric accuracy of such sheets is poor, ranging from 100 to 200 m or worse. There is a tourist map at 1:500 000 scale available, but with poor elevation information and a low geometric accuracy.

The coastal plain is the only region mapped at 1:25 000 scale, according to the cartography produced by the French National Geographic Institute (IGN). Each one of these maps contains contour lines with adequate geometric accuracy. An acceptable 1:50 000 map sheet series has then been derived over the coastal zone comprising the northern regions of the country. It shows adequate contour lines and a dense network of spot height measurements.

A project for the cartographic coverage of the whole territory, at a scale of 1:200 000, based entirely on ERS SAR data has been undertaken, through an initiative of the French Ministry of Defence, and IGN, the French mapping agency. The project has been developed by IGN-Espace (part of IGN, France) in

A 1:200 000 scale map of an area in southern French Guiana, on which an ERS SAR map product has been superimposed. This example shows how geometric distortions in old maps can be corrected using ERS SAR data

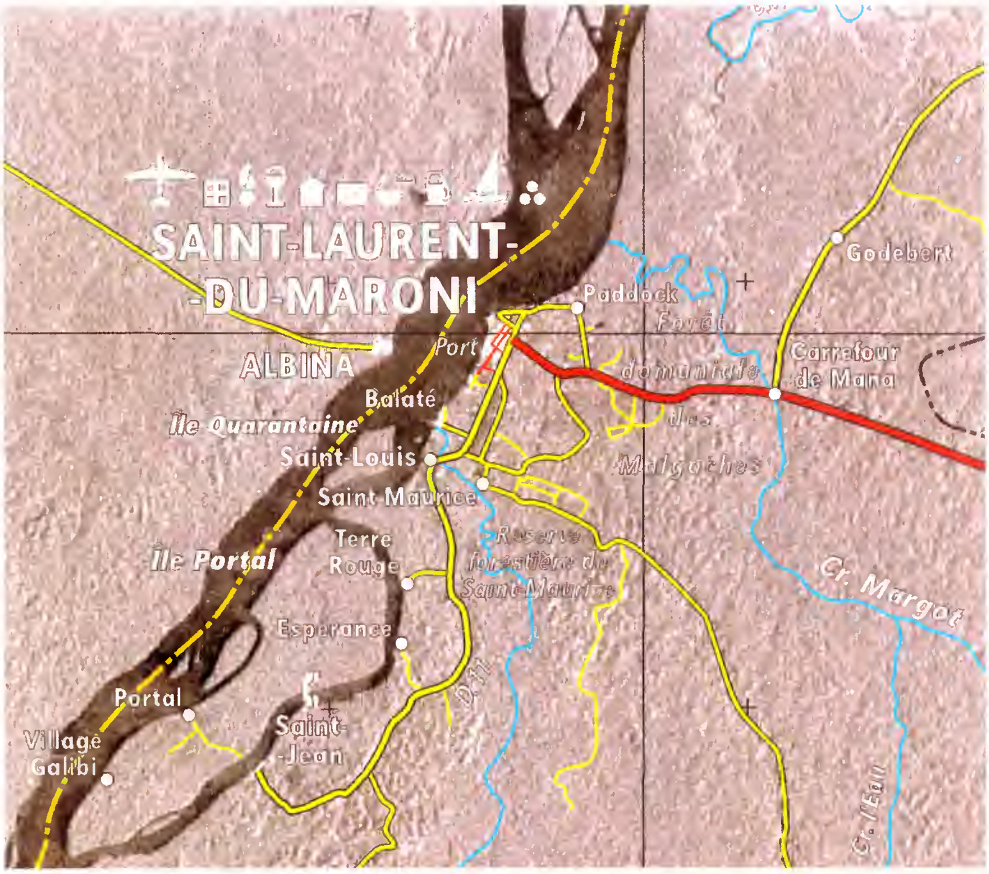
cooperation with CEGN (the geographic research department of the French armament agency) and the University Pierre et Marie Curie (UPMC), Paris. The resulting space map is the only global, homogeneous, complete and geometrically correct example of cartography for the region, resulting from ERS radar imagery and space triangulation techniques. Derived products have grids with geographic and cartographic coordinates as a reference. They are specially suited for medium- to small-scale map coverage (1:100 000 to 1:1 000 000).

The space triangulation techniques developed by IGN-Espace allow relative and/or absolute geo-referencing of a large number of image products using Ground Control Points (GCPs) and a geometric model of the acquisition.

A DTM was produced by IGN-Espace to rectify ERS SAR images in the local geodetic and projection systems as no DTM covering the entire country was available. The only altimetric data sources available were an IGN DTM over the coastal plain derived from the 1:25 000 map sheet coverage and the "Digital Chart of the World" (DCW). The latter, however, covers only a small region at the border of Surinam. The existing cartography has therefore been used to generate the missing DTM, including features such as contour lines and spot heights.

SAR images acquired in ascending mode combined together with SAR descending passes provided stereo pairs that allowed the calculation of series of ground control points (X,Y,Z) which have been used to locally "densify" the DTM. After mosaicing and geo-referencing the SAR images, multi-temporal filtering techniques were developed and applied by CEGN to increase the information content.

The success of this project has demonstrated that the geometric quality of ERS SAR data products allows one to complement the incomplete and uncertain conventional cartography data sets that exist in many equatorial areas. Although no ground control point information was available for southern French Guiana, the space triangulation



Example of a remote-sensing cartographic product derived from the mosaic. Marginal information, such as contour lines derived from the DTM, toponyms selected on the 1:200 000 map series and roads from the 1:50 000 map series, has also been integrated into the map. This does not bear the hydrographic network reference, as the main river channels can be easily detected. Here, the contribution of SAR is evident: land cover and topographic relief information can be extracted; forest areas, clearings, agricultural fields and settlements can all be identified

technique was sufficiently reliable to allow map production.

Surveys undertaken by French-army troops in August 1995 provided GPS observations both in the coastal region and close to the eastern and western borders, along the Oyapock and Maroni Rivers. The absolute planimetric accuracy of the space map was checked and found to be around 15 m r.m.s. error.

Further applications of ERS SAR in the region include geological interpretation and planning, as well as the definition of strategies for urban settlements and infrastructure development.

Future Outlook

Further developments of remote-sensing techniques for mapping require the full exploitation of ERS SAR capabilities, including an increased use of techniques such as interferometry. The latter has shown high potential for the generation of products especially tailored to topography and thematic-cartography requirements. Moreover, thanks to the SAR instrument onboard Radarsat and to the C-band ASAR instrument that will be flown on ESA's Envisat mission at the end of 1999, wider spatial coverages as well as additional polarisation modes will also be available.

Based on the scope and capabilities of both existing and planned Earth-observation 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.

Acknowledgement

The cooperation and contributions from IGN-Espace, CEGN, ISTAR, SERTIT and SPOT Image in the production of this fact sheet are gratefully acknowledged.

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AGRICULTURAL MONITORING

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AGRICULTURAL MONITORING

The Need for Better Information

Since its inception, the Common Agricultural Policy (CAP) has been the European Community's biggest single budgetary item. More than 60% of the Community's agricultural output is regulated by mechanisms that determine internal prices and incomes to producers and processors using agricultural products emanating from the Community. In 1995, this activity absorbed about 48% of the European Union's total budget. Major goals include increasing productivity and stabilising internal markets whilst adapting European agriculture to an increasingly competitive international environment and to the enlargement to the east. Control of agricultural expenditure is therefore a key objective of European Union policy.

The European Commission has identified the following needs for information for agricultural monitoring:

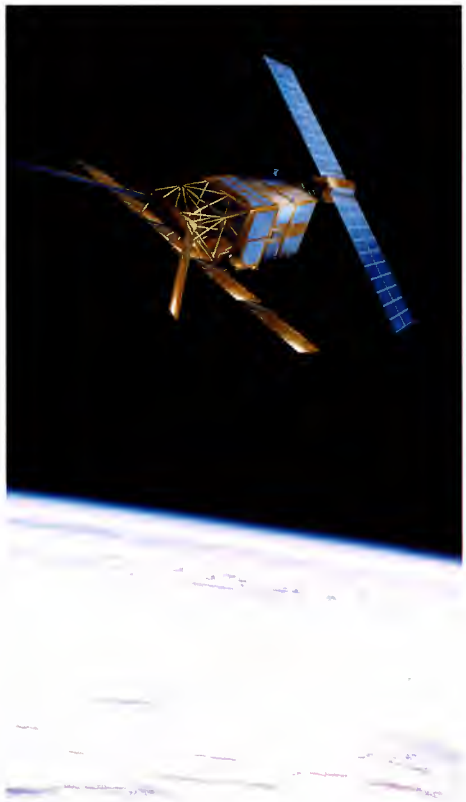
- distinguish, identify and measure the areas of important crops in Europe
- estimate production early in the year
- check the validity of farmers' applications for EU subsidies.

The primary information need for expenditure control is to determine before harvest time what a farmer is growing, in order to predict yields, anticipate the market and estimate the support needed. There is a major time constraint in that the relevant information has to be gathered in the period between crop emergence and crop harvesting, which is just a few months.

The Limitations of Traditional Techniques

The Common Agricultural Policy programme currently depends on the timely gathering of information via field and aerial surveys, i.e. operational systems that provide accurate data but have a number of inherent drawbacks, including:

- difficulties in comparing statistics and validating information collected by the various European countries, which currently use different methodologies for monitoring and measuring their agricultural production
- availability of production estimates only close to harvest time
- time-consuming and expensive nature of frequent field trips and airborne surveys.



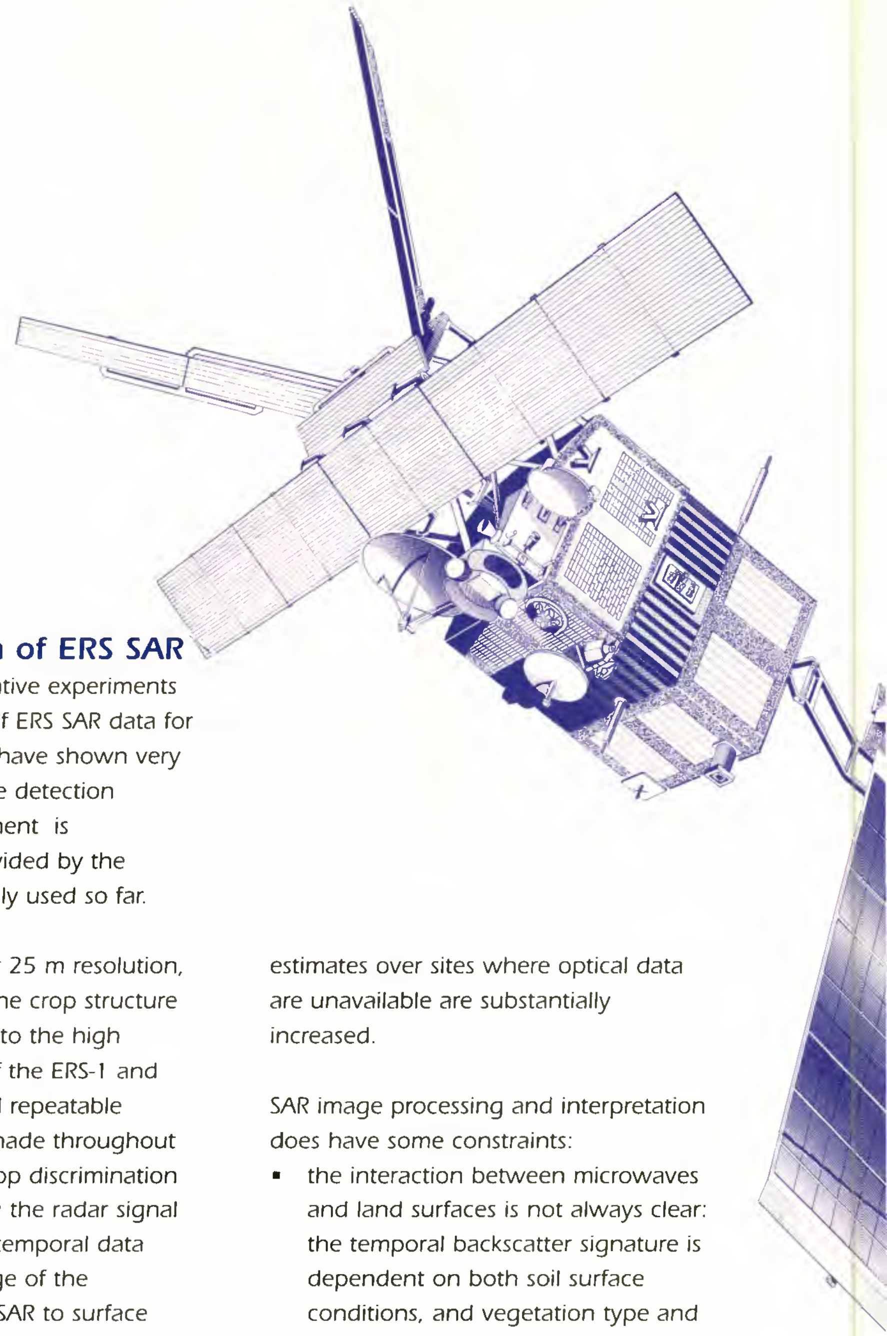
The Benefits of Space-Based Monitoring

Satellite-gathered Earth-observation data offer a significant improvement in the European Commission's ability to reduce expenditure by providing a new, cost-effective tool for agricultural monitoring and management. With the advent of the ERS (European Remote Sensing Satellite) missions in particular, Synthetic Aperture Radar (SAR) data are now available over all European countries.

The application of remote-sensing techniques for accurate crop identification and crop-area estimates requires multi-temporal series of data, as each single image has to be acquired within a key time-window for optimal target discrimination. SAR data also complement optical data available from other operational observation systems. This is particularly true for Northern European areas, where the SAR's weather- and day/night-independent imaging capability is an essential factor in raising the likelihood of surveying all crops from sowing to harvest at all test sites.

The introduction of satellite data as an additional information source has several immediate advantages:

- adoption in all European countries of a unique method of measuring agricultural production, with subsequent storage of the information in a common database
- generation and availability of accurate predictions several months before harvesting
- objective control of farmers' declarations.



The Contribution of ERS SAR

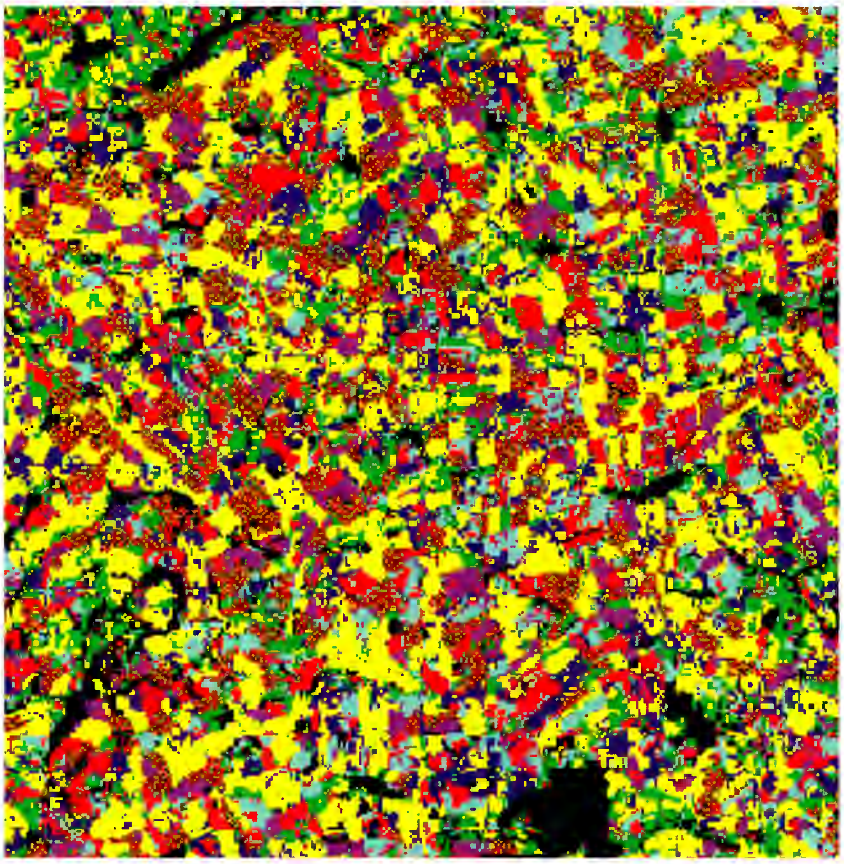
Qualitative and quantitative experiments to assess the potential of ERS SAR data for agricultural monitoring have shown very encouraging results. The detection capability of this instrument is comparable to that provided by the optical sensors commonly used so far.

ERS SAR data, with their 25 m resolution, supply information on the crop structure as it grows and, thanks to the high accuracy and stability of the ERS-1 and ERS-2 SARs, precise and repeatable measurements can be made throughout the growing season. Crop discrimination is achieved by analysing the radar signal backscatter using multi-temporal data sets. By taking advantage of the particular sensitivity of SAR to surface roughness, additional information about soil preparation can be collected and analysed during the winter months to provide early estimates for major crop types. Indications of generic crop classes, such as grassland, winter crops (smooth seedbeds at the onset of winter) and spring/summer crops (rough fields) can also be derived. With the multi-temporal approach, one can also monitor changes in surface roughness, which are indicative of soil tillage and crop-class-specific activity. Still better crop-type discrimination can be achieved by the combined analysis of the reflectance and backscatter, respectively, of the optical and radar data sets. By using ERS SAR data, the chances of obtaining both early estimates of crop production and crop estimates over sites where optical data are unavailable are substantially increased.

SAR image processing and interpretation does have some constraints:

- the interaction between microwaves and land surfaces is not always clear: the temporal backscatter signature is dependent on both soil surface conditions, and vegetation type and development stage. Directional effects also have an influence on backscattering. Therefore, temporal backscattering profiles tend to be highly variable, especially early in the season. Ancillary data, such as soil, meteorological and crop knowledge, need to be used as a support to signature interpretation;
- strong geometric and radiometric distorsions of the image due to local relief have to be removed before analysis; and
- speckle noise needs to be reduced by applying filtering techniques.

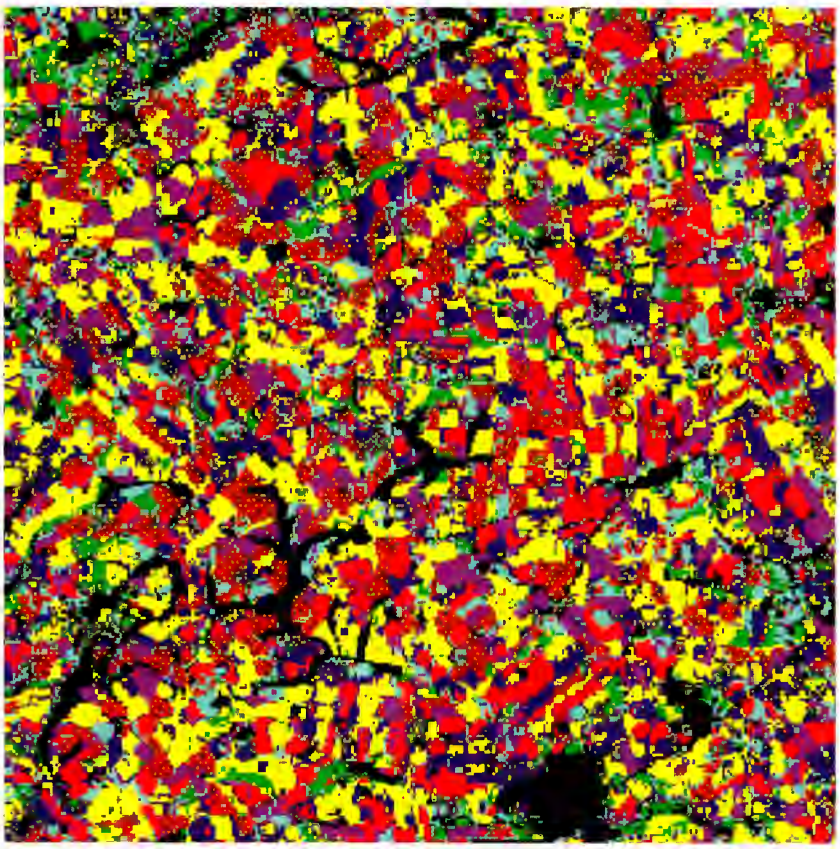
These issues have been addressed through Pilot Projects in 1996 and 1997.



Colour-coded classification results from the MARS project's Great Driffield site in the United Kingdom, using an optimal four-date composite (spring and summer images). Several distinct classes are discriminated including: oil-seed rape, spring barley, grassland, winter barley and winter wheat.
Left: Knowledge-steered classification (analysis of ERS SAR byte composite in combination with optical satellite imagery results, meteorological data, soil data, DEM, agronomic information and ancillary site information) with a classification accuracy of 69.9%.
Below: Unsupervised isodata classification with a classification accuracy of 66.3%

LEGEND

- Mask
- Summer Crops
- Winter Rape
- Peas/Sugar Beet
- Spring Cereals
- Grass Land
- Winter Barley
- Winter Wheat
- Other



Examples of Space-Based Applications

The MARS-STAT pre-operational project

In 1988, the European Commission approved the creation of a ten-year pilot R&D project known as MARS (Monitoring Agriculture with Remote Sensing) to pursue the application of remote sensing to help upgrade and unify its agricultural statistics system. The project, the aims of which were defined jointly by the Commission's Agriculture Directorate (DG VI) and the Statistical Office of the European Communities (EUROSTAT), is run by the EC's Joint Research Centre (JRC) in Ispra, Italy. The MARS-STAT element of the project is aimed at developing methods for improving agricultural statistics. Its results will form part of the "Advanced System of Information on Agriculture" which, in addition to data from conventional sources, will employ remote-sensing information collected with both high- and low-resolution space sensors. The system will incorporate sophisticated interpretation techniques as well as agro-meteorological models.

The agricultural crops targeted are those with high market potential, but excluding farm fodder crops. Representativeness is sought not only at the Community level, but at national and regional level also. A quick estimation of crop areas is derived from an analysis of high-resolution remote-sensing data sets acquired from the SPOT or Landsat (Thematic Mapper) missions. The system operations are based on:

- definition of a sample of representative sites (60 for the whole of the European Community)
- acquisition, processing and interpretation of satellite images over the test-site areas
- extraction of the information needed by means of computer-aided image-interpretation techniques.

The first reliable crop-area estimates are produced at the end of April using optical imagery. Each month from April to October, a single estimate of the yearly percentage change for each crop and for the whole of Europe is derived and forwarded to the EC's Directorate General for Agriculture within 10 days of the satellite image acquisition.

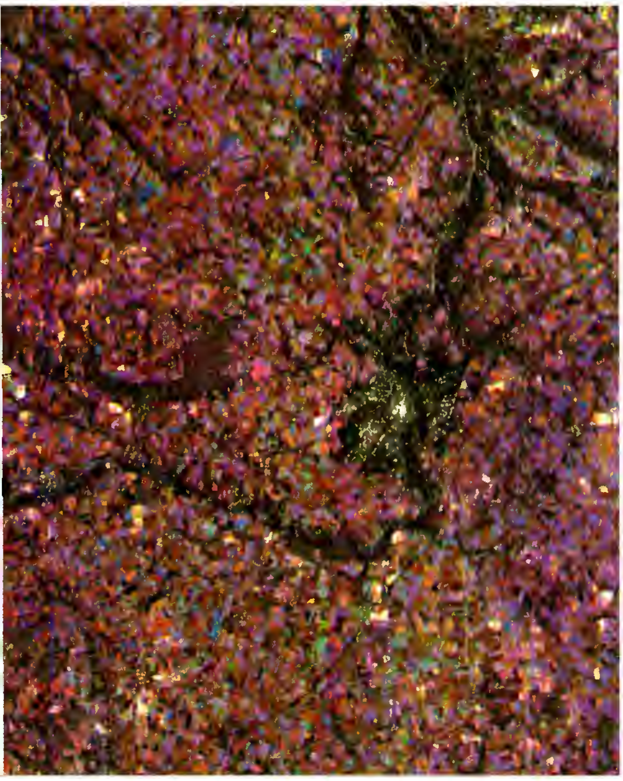
The timeliness and quality of such information derived from passive optical systems alone is subject to several constraints, not least those due to cloudiness and haze, which result in a reduced sampling of the area. This problem of data unavailability due to cloud cover can be overcome by using microwave sensors such as the ERS SAR.

The feasibility of using SAR data to derive crop estimates was tested in several studies in 1994 and 1995 at JRC with the support of the University of Stuttgart (Germany) and Synoptics (The Netherlands). The continuity in such studies was ensured in 1996 by a Pilot Project aimed at analysing the feasibility of SAR data operational use within MARS. Initiated by DG VI, the work was carried out by the Space Application Institute at JRC in cooperation with GAF (Germany), NRSC (UK) and Synoptics.

Twenty project sites were selected mainly on the basis of historical data availability and frequent cloud cover. Three ERS SAR images were acquired over each site and submitted to a classification analysis after the application of image-processing techniques such as geometric and radiometric correction and filtering. Optical satellite images from the previous year were used to produce masks indicating non-arable land.

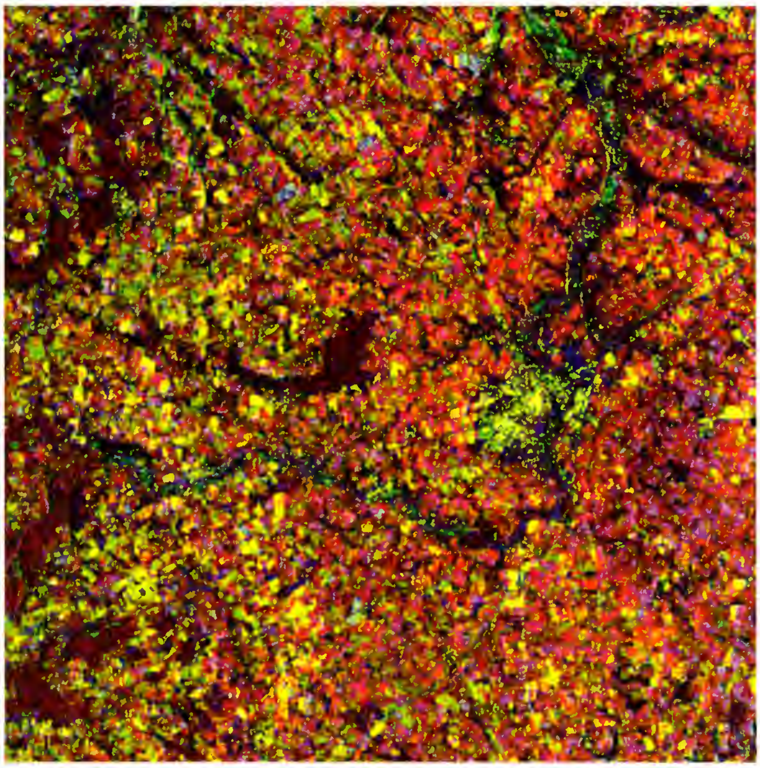
The classification was based on the use of decorrelated synthetic channels computed from the multitemporal data sets. This method was tested on three test sites of the MARS-STAT Project, within an experimental study carried out in 1995(Nezry et al., 1995).

A higher accuracy can be achieved by using more data sets and further specific processing. A new method was then developed and tested, based on byte-slice composition of scaled images (Lemoine et al., 1997). Significant results were



Multitemporal ERS SAR image of the Chartres test site in France (28 November 1994 in red, 4 January 1995 in green and 10 February 1995 in blue)

Synthetic channel composite for the Chartres (F) test site, with the mean backscatter amplitude channel in red, the range-radar cross-section variation for the time series in green and the date of maximum backscattering in blue. From the first two channels, it is possible to separate urban, forest, grassland/bare soils and agricultural themes. From the third channel, crop identification is possible by comparing the backscatter signal and the field preparation and the crop calendar



obtained at several test sites and could be satisfactorily compared with the existing information. The method was also adopted in the generation of classification products over selected test sites, based on long time series of data.

By using autumn and early spring imagery, it is possible to separate crop groups such as "winter crops", "spring/summer crops" and "permanent grassland".

A more sophisticated degree of separation can be achieved through the use of additional SAR data sets, alone or combined with optical sensor data, if possible together with the application of statistical methods and with the integration of ground-truth information.

In 1997, autumn and early spring SAR data were applied to 60 test sites within the framework of a second Pilot Project. The main objective of this project, carried out with the support of NRSC (UK), Synoptics (NL) and SOTEMA (F), was to test the time series interpretation of data in an operational context, with special emphasis on such aspects as SAR data timeliness and reliability, and project costs. These were drastically reduced compared with those in the MARS-operational project. Five SAR images per site were analysed and estimates were generated which are presently undergoing a thorough validation process.

Crops (areas in ha)	ERS, 4 dates 28 Nov. - 10 Feb.	SPOT, 2 dates 4 Mar. - 5 May
Non cultivated	14 225	11 499
Winter wheat	68 178	70 622
Other cereals	5357	10 015
Rape seed	12 834	11 360
Summer crops	24 368	25 784
Non agriculture	35 038	30 720

Comparison of early surface estimates for the Chartres (F) test site using ERS (results obtained in March 1995) and SPOT (results obtained in May 1995) data. The SPOT-based accuracy is estimated at 85%

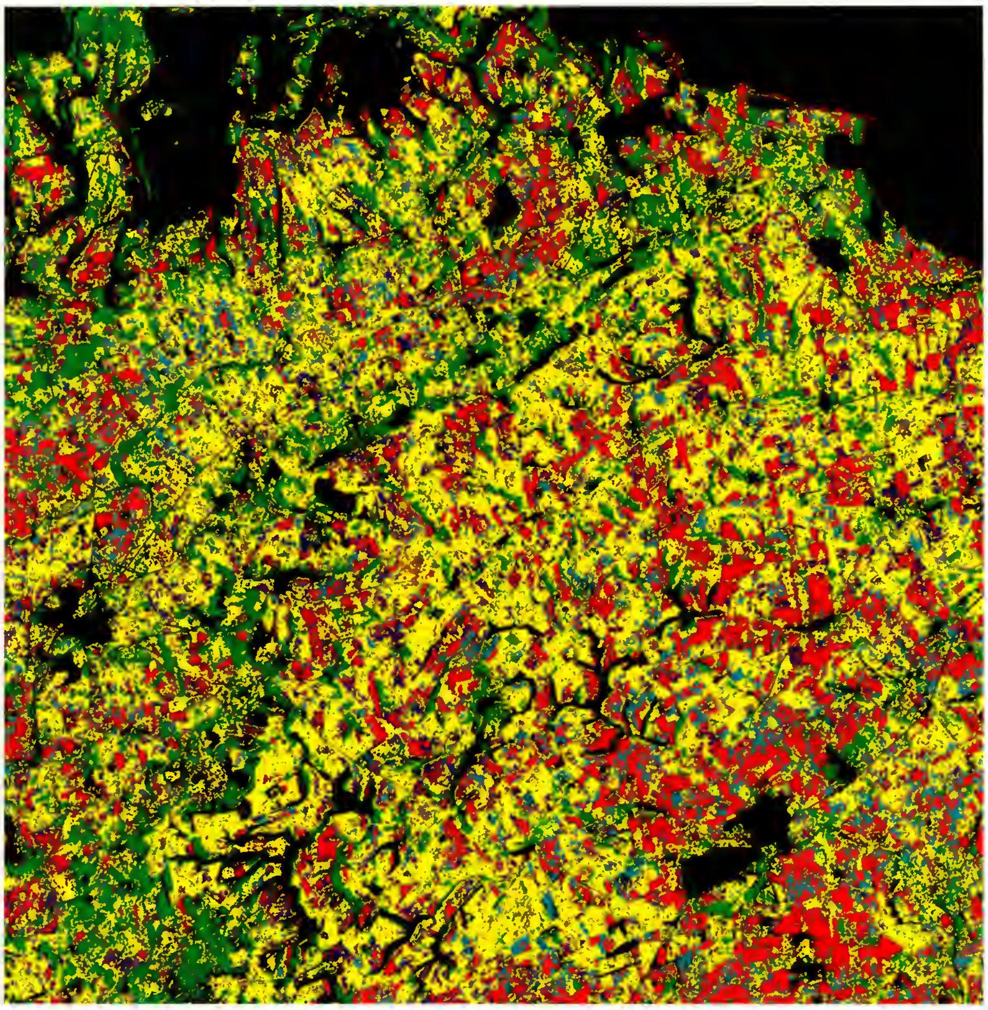
Final classification for the Chartres (F) test site. Non-cultivated, bare soils and natural vegetation low in winter appear black, forest is green, winter wheat on soils prepared before November appears in red, winter wheat on soils prepared early in November appears in pink, other winter cereals appear in light grey, rape seed appears in yellow, soil prepared in February for summer crops, as well as field peas and fodder beets are dark grey, urban areas and roads appear in light blue

Controlling farmers' declarations

MARS-CAP (Common Agricultural Policy) is a programme of activities conceived to support DG VI in controlling farmers' crop declarations. Every year, some 17 billion European Currency Units (ECUs) are paid out in subsidies by the European Commission directly to farmers complying with the CAP's objectives and regulations, on the basis of farmers' requests. To help verify such crop declarations, new methods involving the use of remote-sensing data have been unde˜ test since 1991. They have proved to be useful at both the regional and field level.

Based on the analysis of multi-temporal remote-sensing data, the operational system set up for the Commission and the Member State Administrations determines the individual crop classes related to specific farms on a field-by-field basis. The results are compared with a digital map in which the candidate applications for subsidy are listed. An accurate validation is then obtained on a "per-farm" basis.

Great Driffield (UK): one of the test sites of the MARS (Monitoring Agriculture with Remote Sensing) Project. The image derives from a classification utilising data from the SAR (Synthetic Aperture Radar) instrument onboard ERS-2. It shows preliminary results obtained in early spring 1997 from the interpretation of four images acquired in the time frame between October 1996 and February 1997. Four distinct classes can be discriminated, namely: winter crops (yellow), spring crops (blue), summer crops (red) and grassland (green)



Another example of the useful contribution that remote-sensing information can make is the Pilot Project set up in 1995 by the UK National Remote Sensing Centre on behalf of the Ministry of Agriculture, Fisheries and Food. The objective was to test the operational use of ERS SAR data collected over a particularly cloud-prone site. A combined optical and radar (SAR) automatic classification, optimised on per-field signature characteristics, was performed after full correction of the geometric and radiometric effects of the terrain. The main project deliverables were reports on a "per-farm" basis indicating whether or not the application for subsidies was justified. The classification accuracy obtained using ERS SAR data was comparable to that of optical satellite data, and accuracy improved considerably when the optical and radar data were combined. The project demonstrated conclusively that SAR can be used operationally for the successful control of area aid declarations.

In 1996, most of the EU States verified their farmers' crop declarations using either satellite imagery or aerial photography, thereby significantly reducing the number and cost of field inspections. The work was organised such that each Member State arranged to have the highly specialised photo-interpretation work performed by external contractors on satellite imagery - including radar images - purchased by the EC (at a cost of approx. 0.54 ECU per hectare, compared with 0.57 ECU for aerial photographs).

Future Outlook

Further research into SAR data use needs to be conducted by taking advantage of all of the information already gathered. There are now ample SAR data sets - thanks to ERS - and corresponding ancillary data (ground surveys, agricultural practices) available for such studies, which need to focus on the optimum combination for long-term agricultural applications of the radar data being provided by ESA's present ERS satellites and forthcoming Envisat mission, as well as Radarsat. In the short term, the integration of the radar data with optical datasets, as well as the improvement and automation of the interpretation cycle and the testing of wide-area sampling, are important objectives.

An additional key factor could be the implementation of quick image dissemination systems, in order to ensure the transmission via electronic networks of not only "browse" imagery, already operational today, but of customised, full resolution SAR products referring to small geographical areas and tailored to specific user requirements.

Acknowledgements

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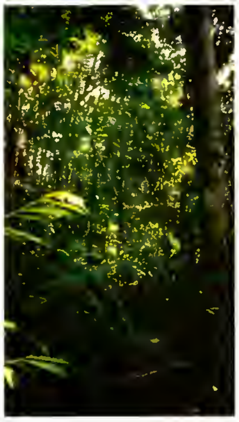
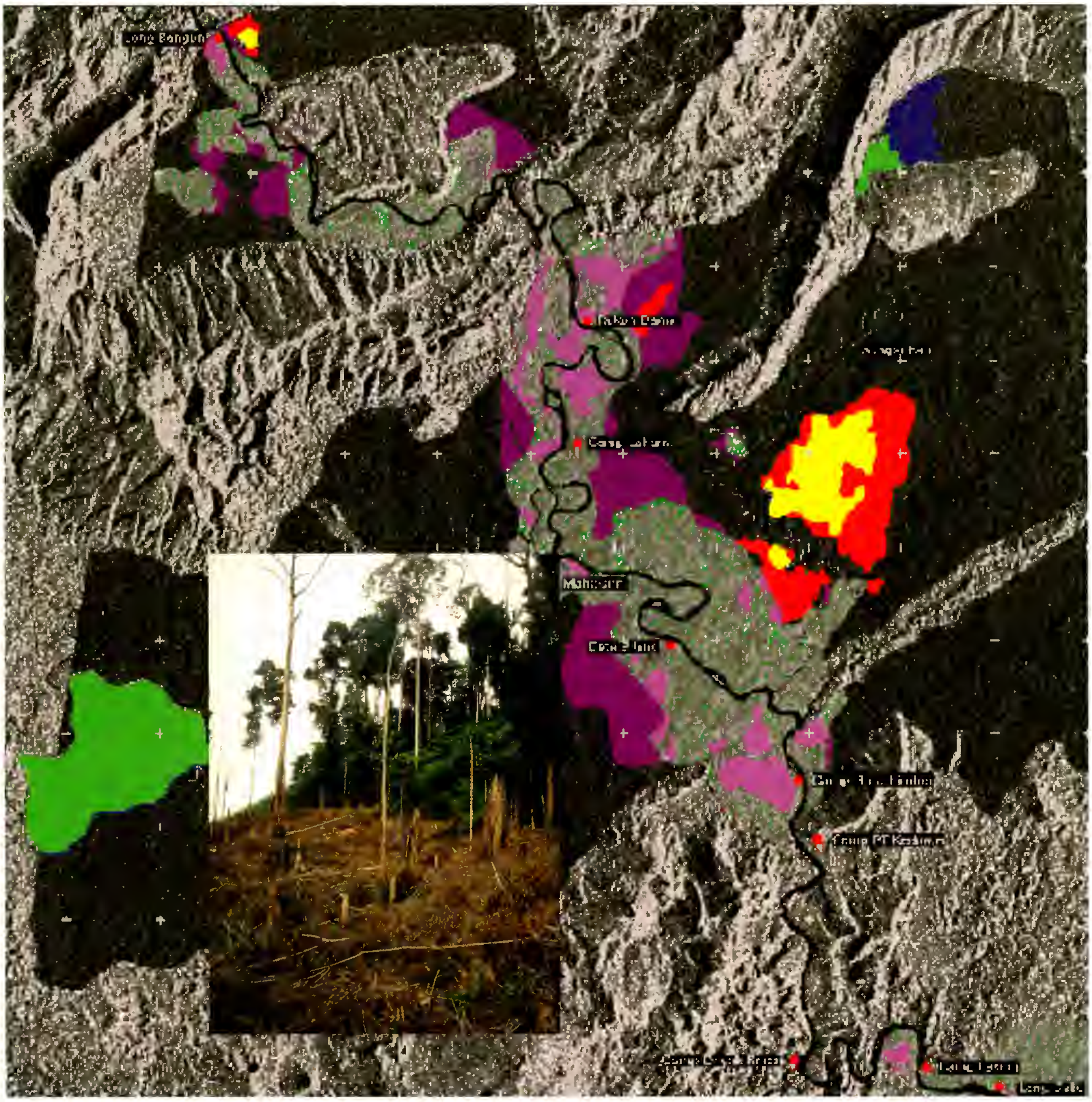


TROPICAL FOREST MONITORING



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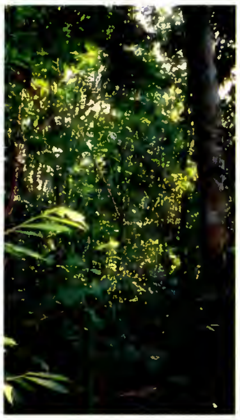


TROPICAL FOREST MONITORING

The Need for Better Information

Tropical rain forests constitute the most diverse ecosystem on our planet, as more than 80% of all known species of plants and animals live in the tropics. In addition, they are home to millions of people and comprise a natural resource so rich that their exact value is impossible to quantify in financial terms.
Uncontrolled deforestation is estimated to be resulting in the extinction of several species each day. In addition, as tropical soils are often extremely susceptible to degradation and erosion, any economic exploitation must be carefully planned, implemented and managed. In order to monitor these unique tropical-forest regions adequately, accurate and up-to-date information on forest characteristics and forest health is required. This means that the appropriate national agencies must regularly conduct land-use surveys, leading to a continual demand for the sort of information that is difficult and expensive to obtain with conventional land-based surveying expeditions.

An increasing number of politicians and decision-makers are recognising the importance of sustainable development for the tropics. A pre-requisite for such development is the availability of reliable, complete and up-to-date information, especially in Developing Countries. Often, however, the only maps available in those countries are 30 years old. A number of states and international organisations have decided to set up monitoring infrastructures capable of identifying and controlling deforestation activities, which can have a serious impact on the environment, with heavy financial consequences. These monitoring infrastructures require timely and accurate data on: the location and extent of clearing-cutting activities; burning of forest areas; settlement patterns; land-use practices, such as shifting and permanent cultivation; differences in logging intensities within particular regions; etc.

A complete knowledge of logging operations is essential. Statistics are needed to estimate the extent of the areas involved, as well as areas subject to selective logging, in order to be able to monitor restocking and to assess the damage caused to the forest structure in addition to the timber's removal.

The Limitations of Traditional Techniques

Current practices include field and aerial surveys that collect information on the areal extent of forests, timber volumes, afforestation and deforestation levels, and the impact of storm and fire damage. In tropical regions, however, regular field surveys are expensive and time-consuming, so that only limited areas can actually be covered in the time available. In addition, many areas are hard to access. Traditional airborne surveys do provide wider coverage, but the costs are extremely high.

The Benefits of Space-Based Monitoring

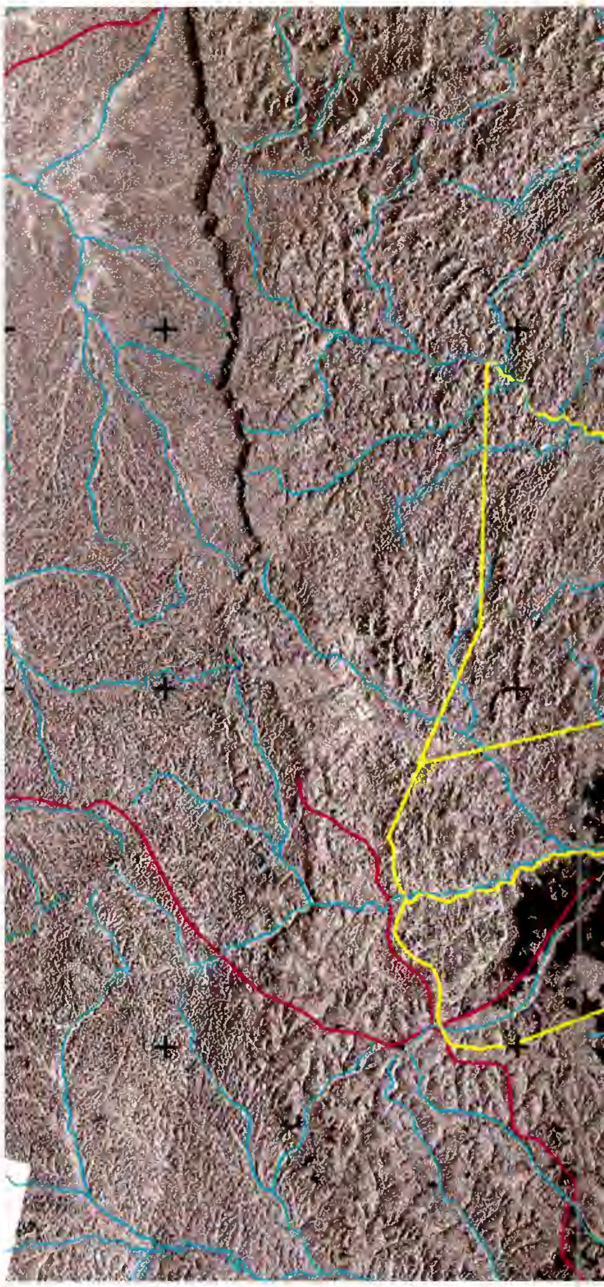
Earth-observation satellites in general, with their ability to monitor large geographical areas repeatedly at relatively low cost, can help in overcoming the difficulties of keeping inaccessible regions of rain forest under constant supervision. However, remote-sensing information derived from optical sensors is often of very limited use for monitoring forest canopy and land surfaces in the tropics because of the almost permanent cloud cover. Synthetic Aperture Radar (SAR) instrumentation of the sort carried by ERS-1and ERS-2 is ideal for such regions due to its unique ability to operate unhindered day and night and in all weather conditions.

The Contribution of ERS SAR

SAR has proved itself to be the only realistic source of geographical information in such regions as the Kalimantan Islands (Borneo, Indonesia), Papua New Guinea and the Amazonian Forest, where the mean annual cloud cover can reach 90%. The instrument's high radiometric accuracy and stability allow one to make precise and repeatable backscatter measurements in such environments. Each forest type has a different backscatter behaviour, i.e. specific value and variation of the return signal, so that by analysing time series of SAR images it is possible to both map and monitor forested areas. In addition, the uninterrupted data flow from space-based SAR's since the launches of ERS-1 and ERS-2, in July 1991 and April 1995, respectively, provides for a consistent and continually updated archive.

ERS-1 SAR mosaic extract over the Odzala National Park, a major biosphere reserve in Central Africa (Republic of Congo). An important sanctuary for birds and large mammals (gorillas, chimpanzees, forest elephants), the park's vegetation is a complex of lowland rain forests, swamp forests, open forests with marantaceae and savannah. An extension of the park is planned to include a wider spectrum of forest types. The Odzala Park is currently managed through the ECOFAC (ECOsystemes Forestiers d'Afrique Centrale) Programme of the European Union (DG VIII), dedicated to the conservation of the Central African ecosystems. The mosaic was produced to help the ECOFAC team delineate the park's future boundaries. The Central Africa Mosaic Project (CAMP) is part of a novel approach for continental-scale mapping of the tropical forest using radar remote sensing. The new approach calls for the rapid assembly of a vast amount (approximately 470 images) of high-resolution ERS-1 SAR imagery in order to obtain thematic information over the whole rain-forest domain of Central Africa at several scales and with unprecedented completeness, spatial resolution and quality. The CAMP imagery consists of a multi-resolution pyramid of products with different spatial scales, generated using a wavelet representation. Both the so-called smooth images (approximations at that scale) and the detail images (texture measures) are generated at each resolution level.

This mosaic was assembled in the framework of the TREES Project (EU-JRC, Ispra)



Examples of Space-Based Applications

The Central Africa Mosaic

The Central Africa Mosaic is a good example of how ERS SAR information can be a real "database/catalogue" in itself. Compiled by the Joint Research Centre (JRC) of the European Commission within the framework of the TREES (Tropical Ecosystem Environment Observations by Satellite) Project, a joint initiative of the EU and ESA, the Mosaic represents the preliminary coverage of a 3 000 000 km^2 area within the tropical belt. It can also be "navigated" to extract specific information for further processing for particular applications. Approximately 470 ERS SAR Precision Processed Images (PRIs) were collected, selected and processed to build up the Mosaic. Being able to rely on acquiring such widespread coverage on short time scales allows one to compile high-resolution imagery quickly on a continental scale to monitor and discriminate between a variety of vegetation-related features like deforestation fronts, savannah, and forest.

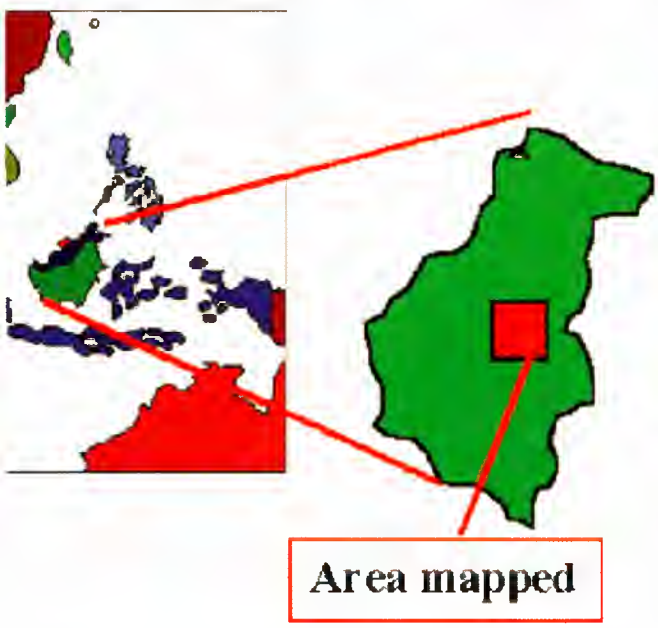
Mapping land-cover changes in Indonesia

In Indonesia, the National Land-Use Planning Agency (BPN) has used ERS SAR data to successfully identify areas subject to deforestation and alert the Government to the extent of the problem. This was done in the context of the "Tropical Rainforest and Use of Land Investigation" (TRULI) Project, coordinated by Kayser-Threde GmbH and the Zoology Department of the University of Munich. The primary aim of the project was to develop an operational forest-monitoring and management system for remote regions of Indonesia.

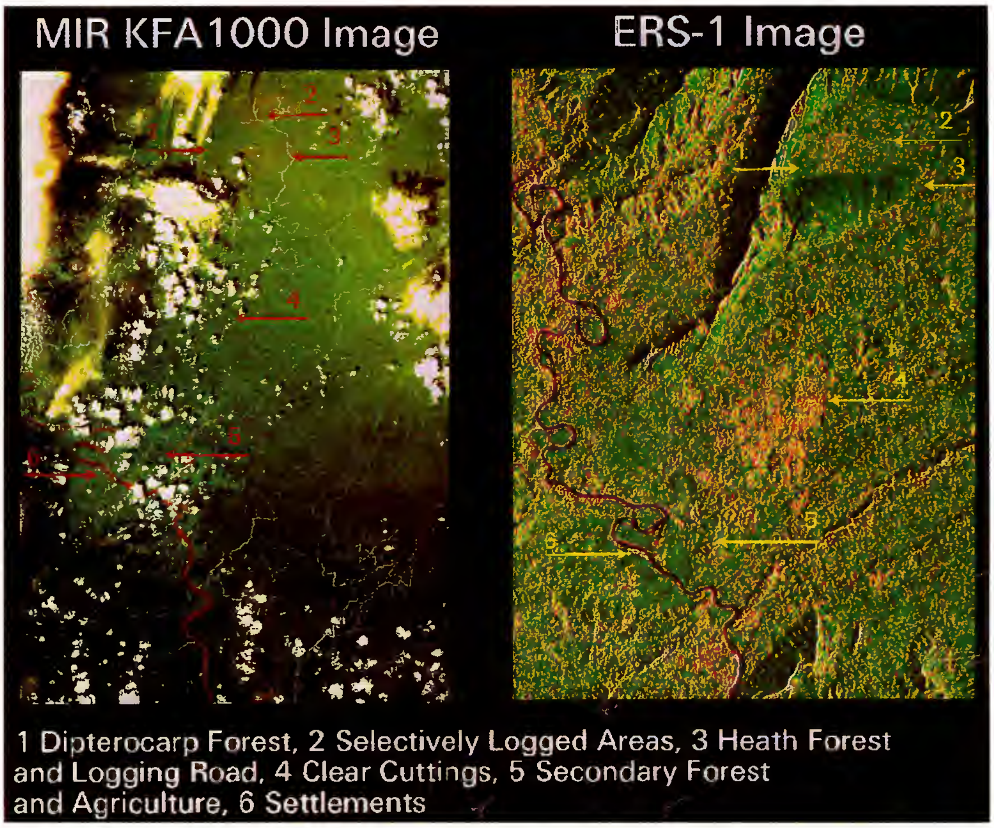
The primary source of information was geocoded SAR (SAR GEC) images derived from data acquired at the Bangkok ERS ground receiving station in Thailand between July 1993 and September 1994. High-resolution optical data from the KFA-1000 instrument (7m ground resolution) on Mir were also used as a reference. Speckle-reduction, variance-filtering and texture-analysis techniques were applied to enhance and analyse the radar imagery's content in order to delineate different land-cover classes, namely:

- undisturbed forest
- logged forest with different logging intensities
- newly regenerated forest
- clearings due to fires or deforestation
- logging infrastructure such as roads and settlements and agriculture.

Two field surveys were conducted at three locations within the area imaged by the SAR for the preliminary identification of the land-cover classes that would have to be detectable from the space-acquired data.



TRULI project test area along the Mahakam River in the province of Kalimantan Timur on the island of Kalimantan (Borneo), Indonesia. The terrain is relatively flat with altitude differences seldom exceeding 50m. The main issues of interest are the extent of the logging activities, the expansion of settlements and the encroachment of shifting cultivation on forested areas. There are two principal forest types within the area monitored: the original dipterocarp forest, the region's main timber resource, and heath forest which grows on poor soil unsuitable for agriculture



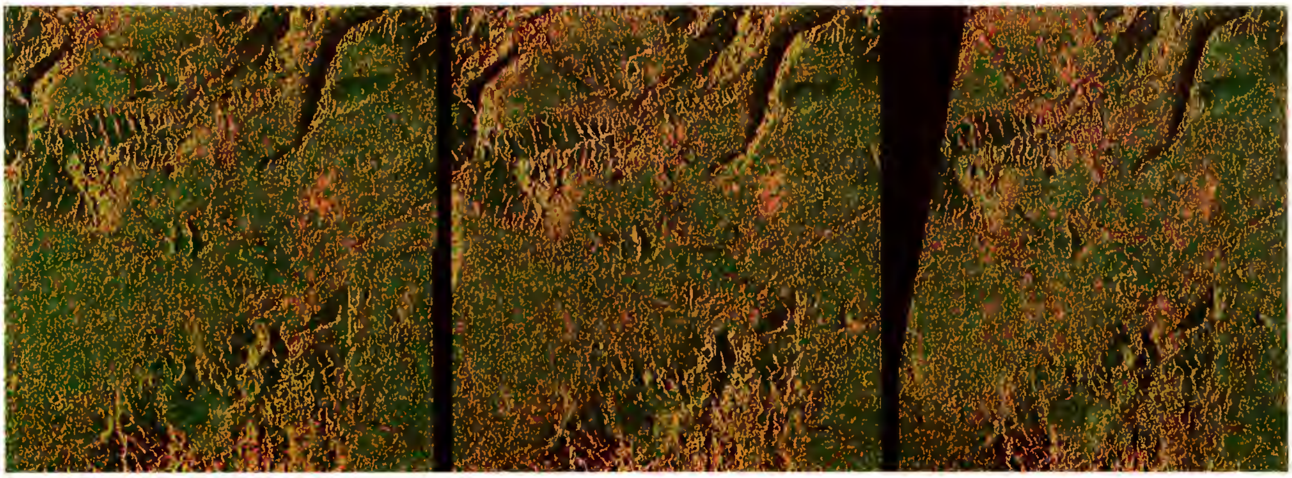
An enhanced SAR image and the corresponding KFA-1000 image. Several vegetation classes can be detected in both data sets. The KFA-1000 data are well-suited for the detection of such tell-tale features as small roads and agricultural crops associated with logging activities. The optical data together with any in-situ observations available form a basis for the interpretation of multi-date SAR images and the extraction of forest-health parameters

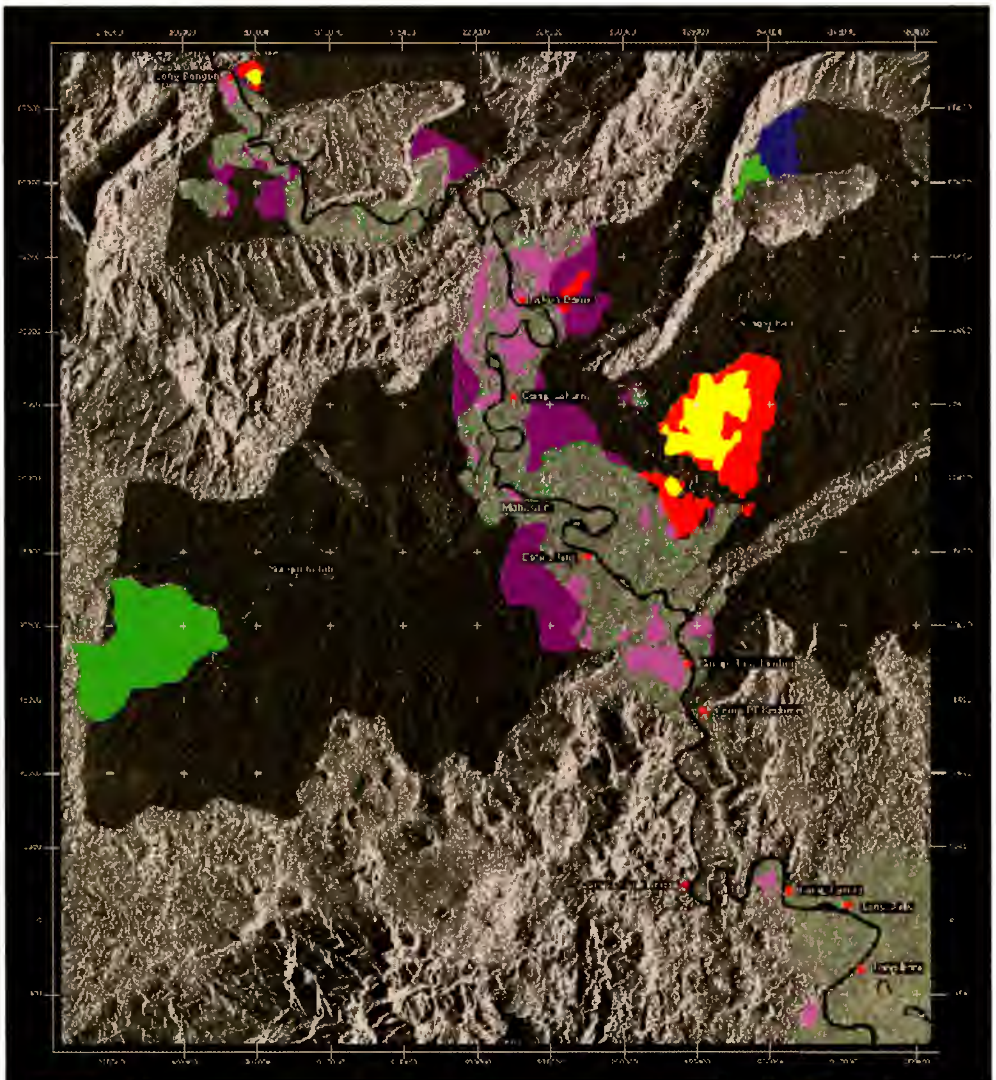
Using multi-temporal SAR data and applying principal-component analysis, it was possible to determine the extent of land-cover changes within the test region, particularly in terms of forest cutting, agriculture, logging, etc. This method also improved on the accuracy of the initial classification scheme for the area, which had been derived from single-date imagery.

As BPN's experience has confirmed, the availability of land-cover change maps is a key issue in forest monitoring as they allow the authorities to identify exactly where illegal deforestation is occurring and then to implement suitable mechanisms for its control or prevention.

The so-called "demonstration change map" shown here was compiled from three SAR images acquired on different dates. In some cases, selectively logged forest can be distinguished from virgin forest due to a change in backscatter. Most of the logging road infrastructure cannot be detected in an ERS SAR image, unless the roads happen to be oriented perpendicular to the radar beam. Nevertheless, SAR is a useful tool for detecting clearing-cutting and a number were identified, corresponding to government-sponsored resettlement programmes and to pulp-related reforestation. Many small villages can be identified close to the Mahakam River, both in single and multi-temporal SAR images, as well as new fields in the vicinity of those villages.

Hill-based rice crops and other vegetation types could not be distinguished. SAR is normally well-suited for detecting wet rice-crop growth, but multi-temporal data need to be acquired on suitable dates during the growing process. Newly burnt forest areas can also easily be identified in the SAR images, allowing an estimation of the extent of illegal settlement activity along former logging roads.





Conversion of second forest to shifting cultivation

Conversion of selectively logged forest to shifting cultivation

Conversion of selectively logged forest to clear cuts

Conversion of dipterocarp forest to selectively logged forest

Mountainous region

Virgin dipterocarp forest

Clear cuts

Demonstration change map for the Mahakam River region produced from three images (shown above) acquired on 12 July 1993, 29 November 1993 and 15 September 1994

An inspection of the change map clearly shows a situation typical of shifting cultivation and, to a lesser extent, clearing-cutting for plantations. In addition to the change map, several land-use maps of the same site were generated. Together, they represent the first map products generated for the region for many years and BPN was able to rely on accurate and updated forest-health information for the first time.

The National Land-Use Planning Agency's plans foresee continuation of the experiment in the form of a more detailed analysis of land-use change, once these map products, together with all available ground-truth data, have been incorporated into a Geographical Information System (GIS). The programme's ultimate goal at present is to transfer the mapping technology to the end-user organisations in Indonesia. In addition, BPN will operate a GIS currently being set up for the Kalimantan region. From the study and research point of view, the TREES programme has been extended to include Kayser-Threde's and the University of Munich's work in the TRULI project.

Forest monitoring on the island of Sumatra

Tropical rain forest constitutes one of Indonesia's major natural resources, covering about 60% (110Mha in 1990) of the total land area. Most of the existing forests have been destroyed, mainly by shifting cultivation, by logging and, above all, by the growing number of people involved in agricultural activities. Three regions were selected for analysis in South Sumatra - where the main characteristics are a fair-to-medium topography, a super-humid climate with just a few dry months - as being representative of varying degrees of forest exploitation and re-conversion:

- Kotabumi, a site largely covered by tree plantations and subject to extensive exploitation, where existing secondary forests are being over-logged
- Baturaja, a region whose eastern part has been extensively exploited. Secondary forests remain in the central part, whereas plantation forests occupy the western part
- the Ranau Lake area, comprising primary forest coverage in mountainous and sub-mountainous regions where secondary growth and a mosaic of secondary forests and grassland represent important coverage.

The general land-use/land-cover classes comprise:

- primary forests, subsisting only on mountainous or sub-mountainous areas and representing very marginal coverage at the three test sites

- secondary forests, including shrubs and thickets
- low forest, Schima forest, and Melaleuca in swampy areas.

In addition, the deforested areas have mostly been converted into tree plantations, with rubber, oil palm, coconut and fruit trees. Agricultural crops include mainly paddy fields, and in some instances sugar cane, cassava, and corn.

Some interesting results have been achieved by CESBIO, a French institute involved in the TREES Project which is running an experiment to assess the utilisation of ERS SAR data in South Sumatra. It worked with ERS-1 data over an area covered by eight SAR frames, each 100 km x 100 km, acquired between September 1993 and September 1994.

The accuracy and repeatability of the ERS SAR's backscatter measurements made it possible to analyse temporal variations for a variety of forest and land-cover classes. Other parameters like surface type, time of the year and topography were also taken into account. A land-cover map derived from Landsat data and verified by a field trip in January 1994 was also used.

In ERS SAR images, the forest backscatter corresponds to the volume scattering from the foliage of the upper canopy. Rain forest shows backscatter values of -7 or -8 dB, whereas temperate coniferous species have lower responses, around -8 or -9 dB. Less dense canopies show a temporal variation, especially between the dry and wet seasons, caused mainly by changes in soil moisture and underlying re-growth conditions. For low canopies such as crops, the backscatter results from both volume and surface scattering, leading to variable radar backscatter and variable temporal change. Consequently, three categories of canopy could be distinguished in South Sumatra:

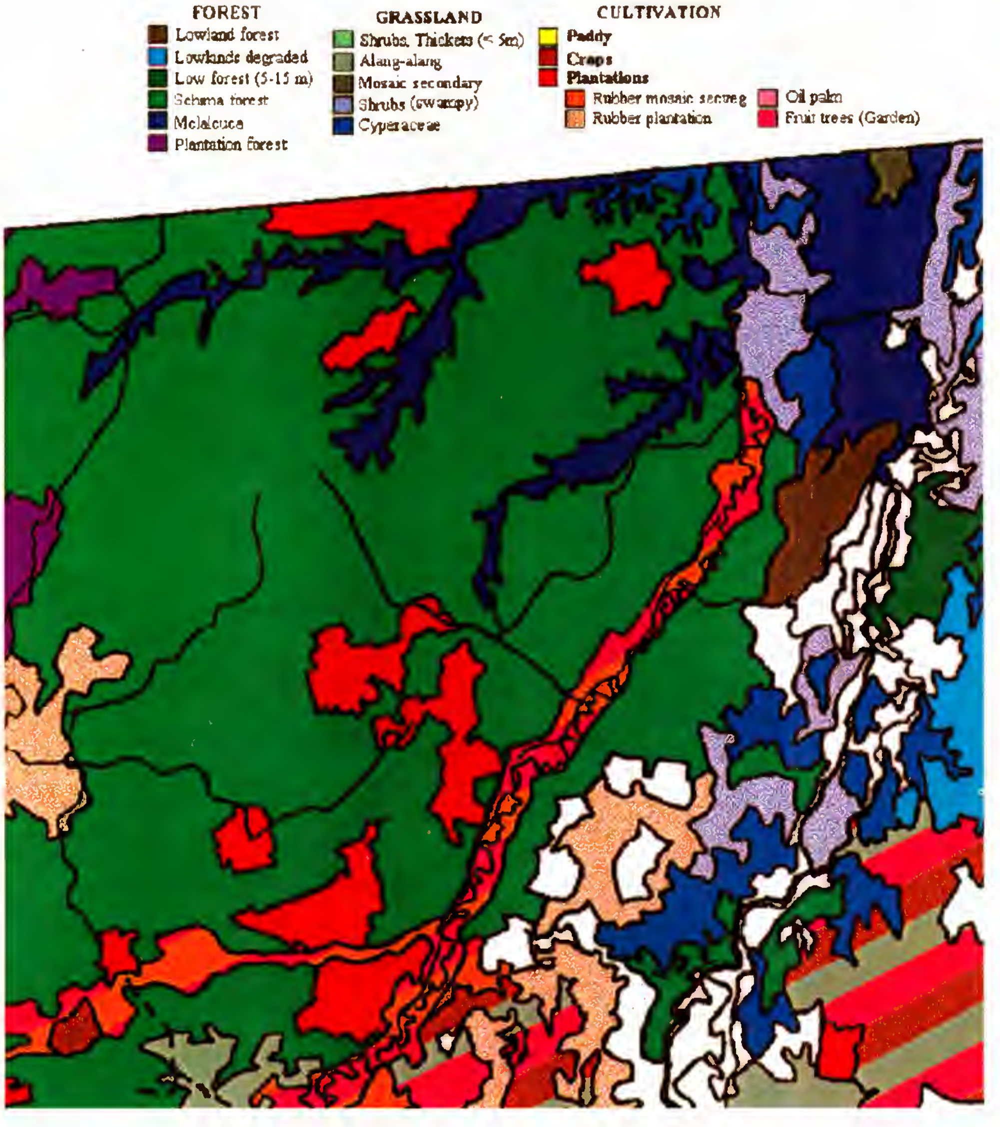
- Dense canopy, characterised in terms of biomass (of order 50 ton/ha) by stable radar backscatter values (except in mountainous areas) and small temporal changes. It includes closed primary forest, secondary forests and "older" tree plantations.

- Less-dense canopy (< 50 ton/ha), characterised by small temporal changes (± 2 dB) and variable backscatter values. It includes shrubs, thickets, over-logged forest and young tree plantations.
- Low canopy. It is characterised by highly variable radar backscatter and their temporal change (agricultural crops, clearing-cut areas, young forest regrowth, new tree plantations, etc.).

Other non-temporally stable land covers include swamps, savannahs and water bodies. Urban areas are characterised by high backscatter values and no temporal variation.

Based on the above observations, it is possible to develop unsupervised methods to discriminate a land-cover category with stable radar backscatter and small temporal change, corresponding to a particular forest class (primary forest, secondary forest, mature fruit tree plantation, etc.). In mountainous areas where only the temporal change can be used as a classifier, the temporally stable classes will include all other mature tree categories such as plantations and oil palms, and mineral and urban areas. A method has been developed that is based on the temporal variations of the radar backscatter, using the ratios of the backscatters between two images.

This method includes spatial and temporal speckle filtering of multitemporal data sets of ERS SAR images, temporal image ratioing and change-detection techniques to extract



The Baturaja region forest/non-forest map (far left) derived from ERS SAR data and the land-cover map (left) derived from Landsat TM data

forest classes. As a result, forest features are generally classified correctly (70 to 80% success rate confirmed by comparisons with reference maps). Intermediate tree canopies, such as over-logged forest, shrub and fruit-tree plantations, are classified partly as forest and partly as non-forest, depending on their biomass values. Crops are identified as non-forest and grassland for 75%. The results have to be treated carefully as the land-cover map has been derived from the interpretation of Landsat TM imagery.

An important issue raised by the proposed method is the saturation level of the ERS radar signal in vegetal features whose biomass is 50 ton/ha or more. Selective logging can hardly be distinguished where the biomass remains high.

Forest/non-forest mapping based on ERS SAR data appears to be very promising, despite the complexity of the land-cover distribution and the relief effects. Supervised methods can be used to discriminate more classes for tree plantations (coconut, oil palm, certain fruit trees, etc.) characterised by the differences in their backscatter levels from those of the main forest. A strategy for deforestation monitoring will involve regular updatings with new ERS imagery for regions of active deforestation. The boundaries of deforested areas can be easily detected because the contrast between the temporal changes of the forest and that of clearings, bare soil or agricultural fields are significant.

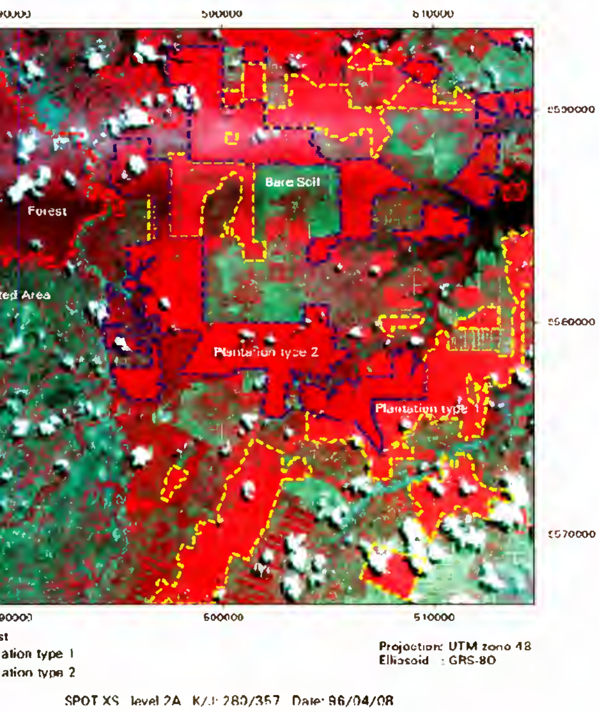
The above figure shows an ERS-1 SAR scene in which the geometrical shapes of deforestation features are clearly visible. In addition, the identification of different re-conversion classes based on their backscatter values appears possible, which means that deforestation monitoring can be achieved using just two ERS data acquisitions each year, one during the wet and one during the dry season.

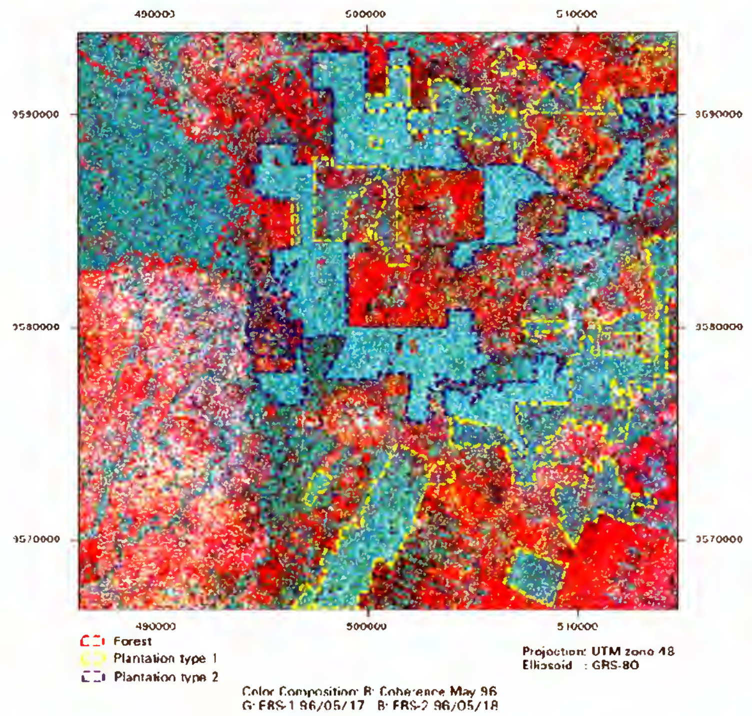
A region in South Sumatra, Indonesia, where important logging activities take place. The left-hand image is a Spot XS product acquired on 8 April 1996 and used as a reference for the interpretation of the INSAR product. In this original image, five land-use classes were defined and marked: bare soil, deforested area, primary forest, and two classes of plantations at different growth stages. The ERS INSAR-derived image on the right is a colour-composite with the coherence component shown in red. The amplitude images of ERS-1 (acquired on 17 May 1996) and ERS-2 (acquired on 18 May 1996) are shown in green and blue, respectively. Clearings and bare ground appear in red, with a high coherence level. Two types of plantations - namely old and young oil-palm plantations - can be distinguished, as blue/green areas. Darker blue areas relate to rain forest ▼

The Contribution of ERS SAR Interferometry

ERS SAR Interferometry (INSAR) techniques represent an additional tool that is likely to be used increasingly in the future in the tropical (and even non-tropical) forestry domain. To extract the thematic information needed, ERS SAR data acquisitions from two satellite repeat passes over the same area are processed together. The interferometric correlation - coherence - computed from the image pair is used as a discriminator for land-use classification. The degree of coherence depends mainly on the changes in target geometry that have occurred between the two acquisitions. Forest areas show low coherence due to significant variations in the volume backscatter of the canopy layer, whilst bare soils or built-up areas have higher coherence levels.

Most of the ongoing projects in forest monitoring and mapping make use of INSAR-derived colour composites showing coherence, in conjunction with the two radar amplitudes of the relevant acquisitions. Although still at an experimental stage, these INSAR techniques are showing enormous potential in domains like forestry, where the use of SAR imagery alone might give only partially satisfactory results.

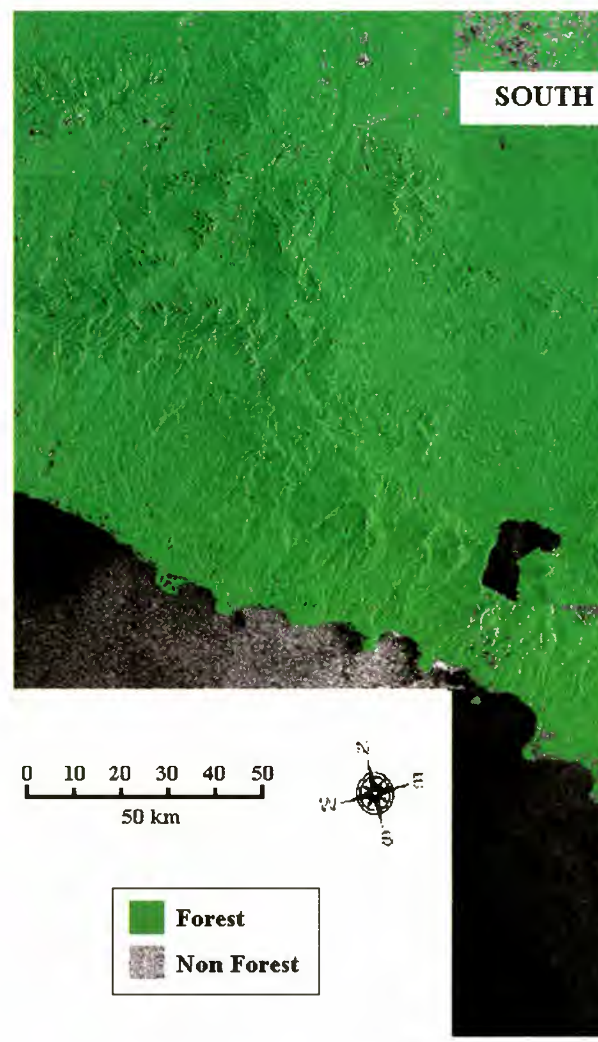




Future Outlook

On the regional scale, the strategy for using ERS SAR data for annual deforestation monitoring involves producing mosaics of the forest/non-forest segmentation by processing the wet/dry-season image pair, perhaps employing data-compression techniques such as spatial averaging to reduce data volumes and allow speckle reduction.

In addition to the generation of operational techniques for tropical-forest monitoring, adequate methods now need to be developed to cope with mountainous regions, where a digital elevation model is needed. Work is also in progress to quantify the cost/benefit aspect of using ERS SAR data for routine forest mapping and monitoring compared with more conventional high-resolution optical data (SPOT, Landsat) and low-resolution data such as NOAA/AVHRR. Envisat, the forthcoming ESA mission due for launch at the end of 1999, and equipped with a payload that includes an Advanced SAR instrument, will guarantee continuity of SAR data availability.



Mosaic of forested/non-forested areas for a large region of South Sumatra (200 km x 300 km) based on multitemporal ERS SAR images, as processed by the Centre d'Etudes Spatiales de la BIOsphère (CESBIO). The pixel size of the output product is about 150 m

Acknowledgements

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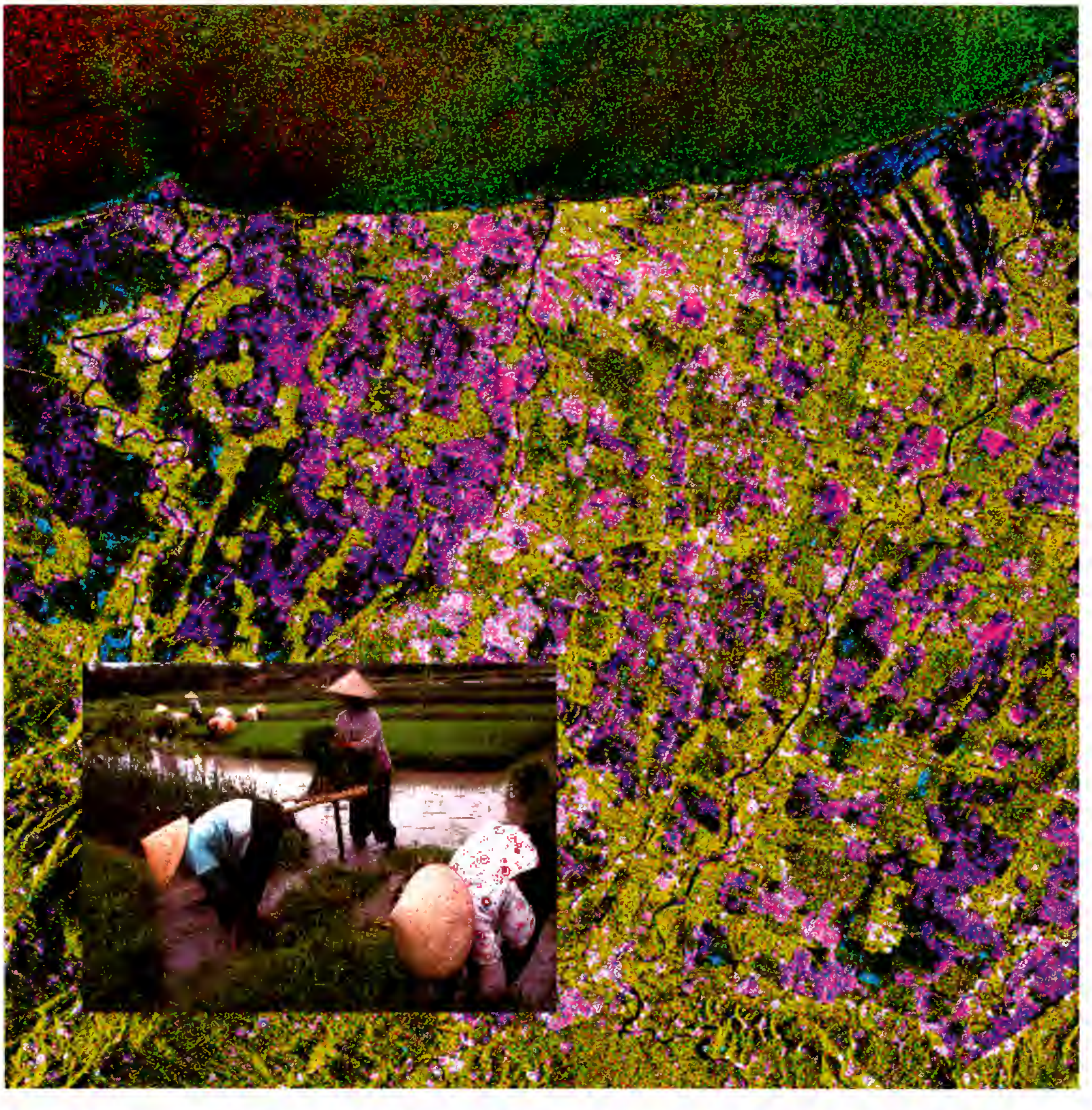
BR-128/II

RICE MAPPING AND MONITORING



Rice Mapping and Monitoring

The Need for Better Information

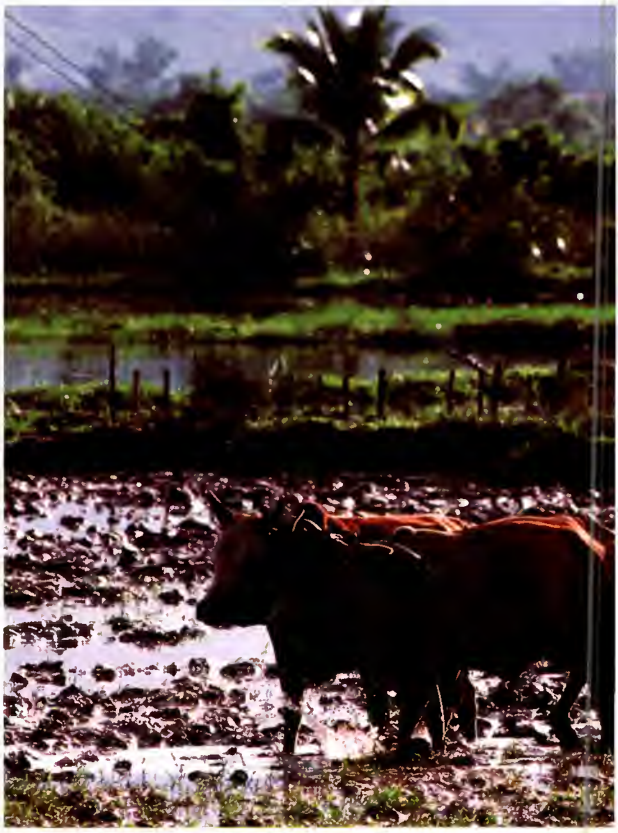
Two thirds of the rice-growing areas in the World are in South East Asia and hundreds of millions of people depend on rice as their staple food source. For countries such as Indonesia, Thailand and China, regular monitoring of the crop is necessary for both economic and political reasons. In particular, accurate yield predictions early in each growing season allow better planning and more efficient management of harvesting, storage and distribution systems or, in the case of a crop failure, the timely implementation of measures to mitigate the effects of such a disaster.

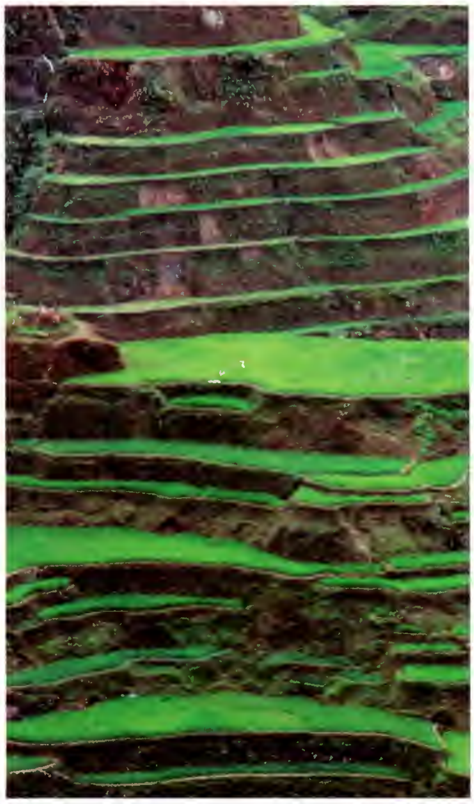
There are many issues associated with efficient rice growing, including the maintenance and improvement of the productive functions of the crop, crop health and vitality, soil fertility and the prevention of damage due to droughts, etc. All countries involved in rice production therefore share a critical need for accurate and up-to-date information throughout the crop's growth cycle.

There are generally two growing seasons per year in South East Asia, although in many cases rice is alternated with a different crop to preserve or enhance soil fertility. The rice crop's growth cycle 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.

The basic difference between cycles is the amount of the time that the plant spends in flooded soil. Upland rice crops are not drained during the ripening phase, whereas lowland crops are. The paddy-field conditions vary widely during the growth cycle, depending on local climate, environmental conditions and agricultural practices (such as transplanting or direct sowing).

The following main stages can be identified in the rice-growing cycle in many parts of Indonesia:





- **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:** this 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:** this also lasts about 25-35 days and is characterised by a decrease in stem and leaf moisture content and a reduction in the number of leaves. In some areas irrigation is stopped during this 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.

The Limitations of Traditional Techniques

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 officials are interviewed regarding their crops. 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 inaccurate and unreliable, leading to inaccurate crop-yield forecasts and subsequent difficulties for agricultural planners and managers on both a regional and a national scale.

The Benefits of Space-Based Monitoring

The requirement for inexpensive, synoptic information on crop acreages in remote regions lends itself to the use of satellite imagery, which has traditionally meant optical imagery. Unfortunately, satellites carrying optical sensors cannot acquire data regularly in tropical regions during the rainy season. The usefulness of optical satellite imagery from the Landsat and SPOT missions for rice monitoring has therefore proved to be limited, as the main rice growing takes place during the rainy season when there is typically 90% cloud cover. In this situation, the all-weather monitoring capability and particular instrument characteristics of Synthetic Aperture Radar (SAR) can provide a unique and timely source of data.

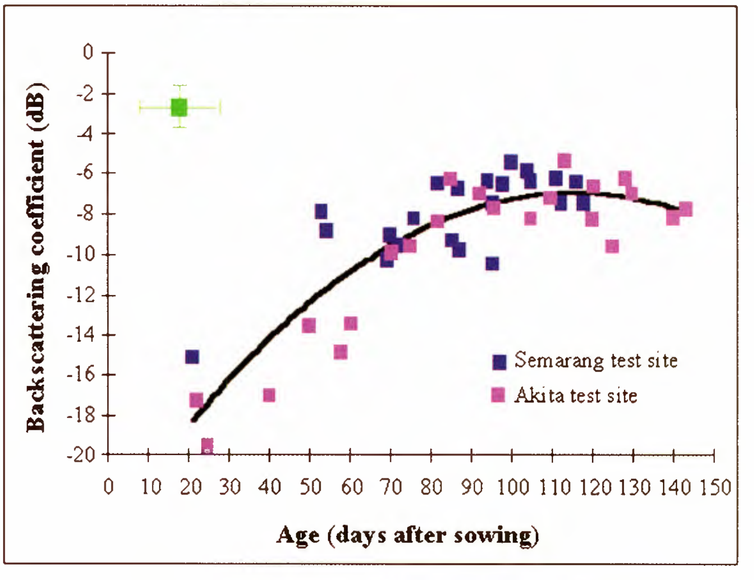
Test sites in Thailand, Indonesia, Malaysia, Japan and the Philippines have already been used to demonstrate the potential of SAR data for providing rice-crop information.

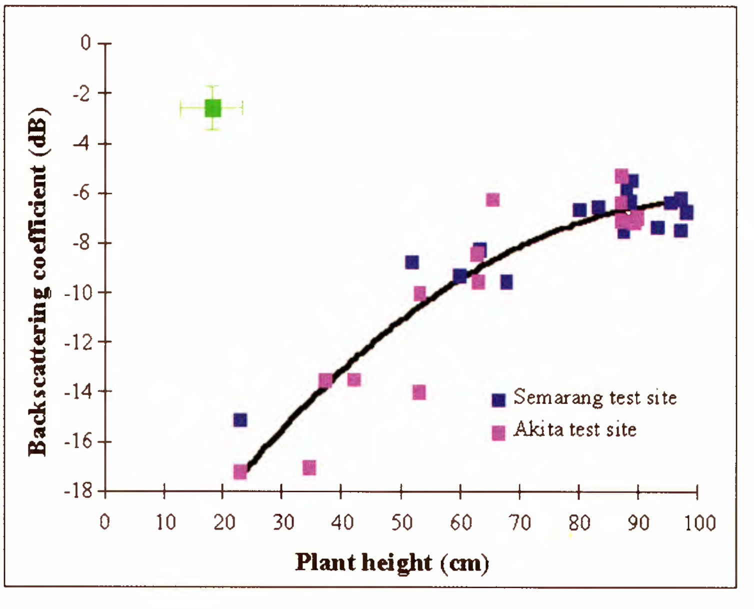
The Contribution of ERS SAR

Rice is one of the agricultural crops most suited to monitoring with the SAR instruments on the European Remote Sensing Satellites (ERS-1 and ERS-2). The particular interactions between the radar beams and the rice crop in the presence of underlying water during the various stages of the growth cycle give rise to a characteristic temporal variation in backscatter response, which is a parameter that is measured by the SAR. Because the ERS SAR instruments have a particularly high radiometric accuracy and stability, precise and repeatable measurements can be performed. When analysed over a growing season, the temporal variations in the backscatter from each growth stage allow one to delineate rice-growing areas within multi-date images. The backscatter results from multiple interactions between the radar beam, the plant and the water and is influenced by various biophysical parameters, including the structure and biomass of the plant and the structure of the canopy.

Combined analyses of SAR measurements and ground surveys have demonstrated unique characteristics in the radar measurements:

- the backscatter is strongly correlated to rice crop parameters such as height and biomass
- the backscatter of a rice field varies strongly with time, as the crop grows
- the backscatter of rice fields varies widely from a field to another, depending on the crop calendar.





During the early growth stages, paddy fields exhibit very low backscatter levels, whereas at the end of the vegetative phase, when the plants have typical canopy heights of 1 m, backscatter levels are relatively high for agricultural vegetation. The increase in the backscatter is typically due to wave-plant-water multiple interactions, which increase with the plant's growth. No other crop type displays a comparable range of backscatter values over such time periods (from -18 to -6 dB over 100 days).

Location of the Semarang test site in Indonesia. Cultivated areas within the region are mainly rice fields (typically 1000 to 2000 m²) within a flood plain. The main rice variety (IRS64) has a short growth cycle (~120 days). Rice production within the area can be classified into two categories:
- irrigated sawah where water is supplied artificially and one, two or even more rice crops per year are produced, depending on the area (in some regions five crops over a two-year period are common)
- rain-fed sawah where fields irrigated by rainfall and in some cases with additional run-off collection provide one rice crop per year together with a secondary crop such as vegetables.

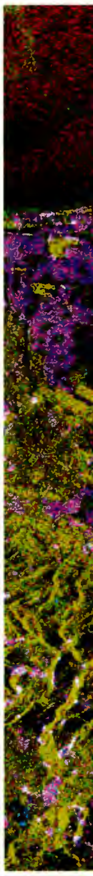
Examples of Space-Based Applications

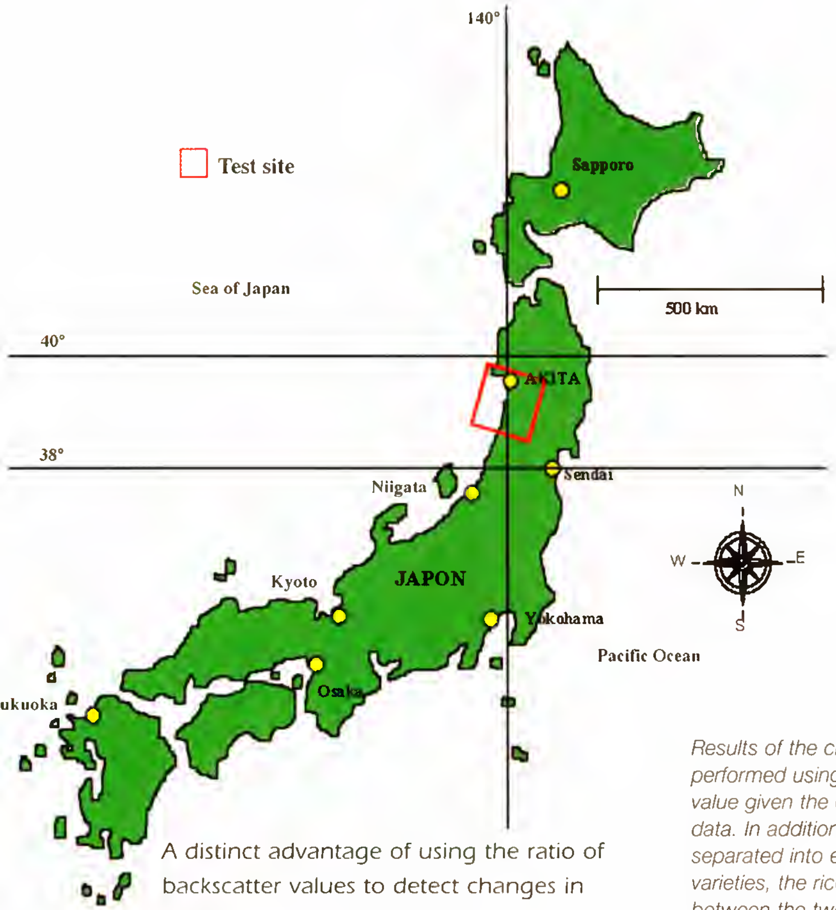
The Satellite Assessment of Rice in Indonesia (SARI) Project

Agriculture, together with forestry and fishing, represents an important sector of the Indonesian economy, accounting for 21% of GDP and occupying over 50% of the labour force. The staple crop is rice. Once the World's largest rice importer, Indonesia is now nearly self-sufficient. In order to manage their rice crops efficiently, however, the Indonesian authorities need reliable crop-acreage information, in particular the Ministry of Agriculture which is responsible for providing rice-acreage statistics for the Government.

A project entitled Satellite Assessment of Rice in Indonesia (SARI) was therefore set up with the objective of providing accurate and timely acreage measurements on an operational basis using ERS SAR data. To this end, a high degree of involvement of the relevant Indonesian authorities was necessary and various training programmes were conducted alongside the investigation of the infrastructure required for the task. An additional consideration was the use of standard computer hardware and image-processing software products in order to simplify the implementation of the system as an in-house service operated by the Ministry. The SARI project was initiated, with European Union support, early in 1997. However, back in 1994 a so-called Phase-1 of the project had already been conducted as a cooperative enterprise between Scot Conseil and CESBIO in France, and the Agency for Technology (BPPT) and Ministry of Agriculture in Indonesia. Funded by the French Centre National d'Etudes Spatiales (CNES), the SARI Phase-1 was an ESA ERS Pilot Project intended to demonstrate the feasibility of using ERS SAR for rice-acreage estimation and, to a lesser extent, for monitoring growing conditions. Based on the experience acquired in the framework of SARI Phase-1, and using additional experimental data sets over a test site in Japan, CESBIO has since conducted a further project geared to developing rice-mapping and rice-monitoring methods.

A rice-mapping method has been established that is based on the temporal change of the backscatter - the so-called "change index" - at the field scale. The value of this change index depends on the points during the growing cycle at which the SAR data are acquired, i.e. whether the change is over the growing season when the backscatter is increasing, or between harvesting and the beginning of the next cycle when the backscatter is descreasing. In order to apply this method, these changes need to be accurately quantified. This is made difficult because of speckle, a well-known effect in SAR imagery that gives a noisy aspect to images and introduces errors in the measurements of the backscatter. A rice-field mapping algorithm has therefore been developed that enables one to reduce speckle, derive a suitable change index, and finally separate rice and non-rice areas.

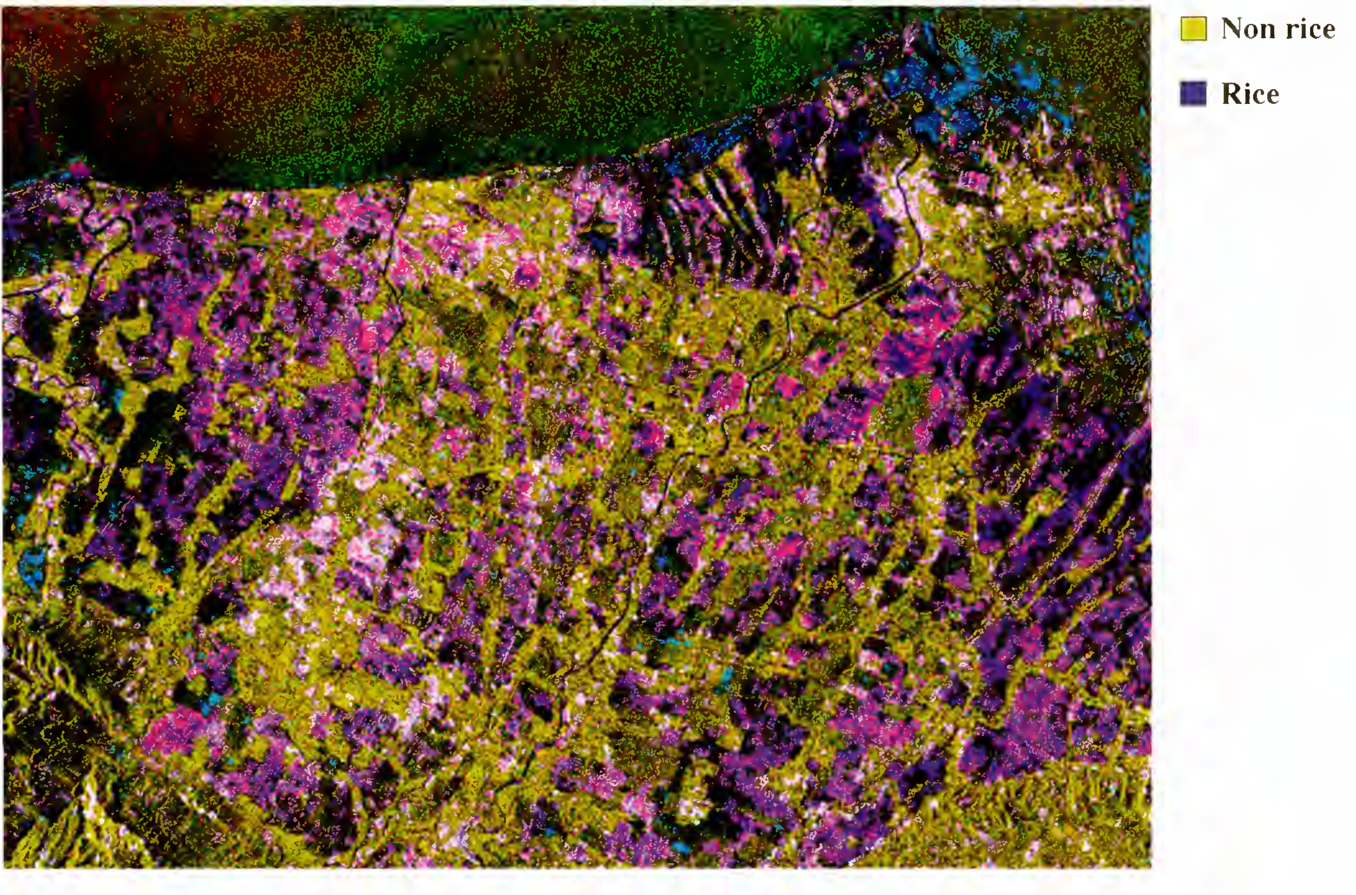




Location of the second test site, at Akita in Japan, where data were gathered in the framework of a rice crop-monitoring experiment carried out in 1992 and 1993. The targetted rice field is about 300 m long by 1 km wide, divided into 20 subsections of 140 m by 90 m. The rice variety grown, which is adapted to the site's relatively high latitude, has a comparatively long growth cycle of 150 days. The experiment was carried out during the entire rice-growth cycle, from June to October in 1992 and 1993, during the 35-day repeat cycle of ERS-1

A distinct advantage of using the ratio of backscatter values to detect changes in SAR images is that the radiometric effects due to relief are removed. This is important since the precise digital elevation models needed in order to correct for the effects of sloping terrain (terrain geocoding) are often not available in such regions.

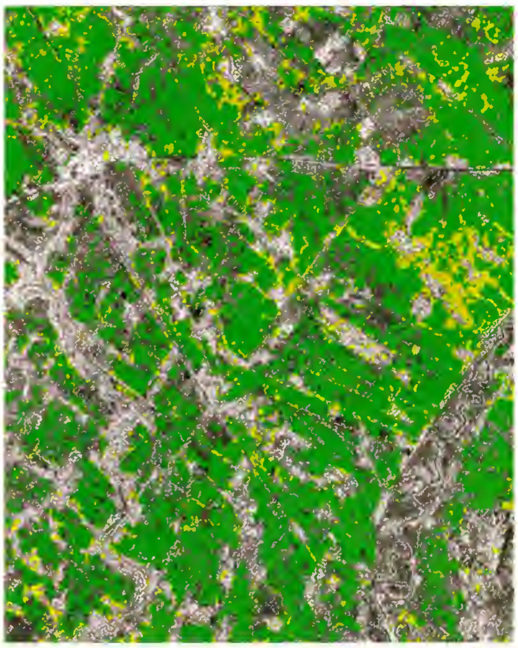
Results of the classification of rice fields. Rice/non-rice segmentation has been performed using a threshold of 3 dB, which was identified as being the optimal value given the constraints in terms of test-site conditions and available SAR data. In addition to the rice/non-rice classification, the rice fields could be separated into early and late varieties, depending on the ratio value. For late varieties, the rice had not been harvested leading to an increase in backscatter between the two image acquisitions and a negative ratio in dB. For early varieties, the rice had been harvested between acquisitions resulting in a drop in backscatter and a positive ratio in dB. Rice fields at the end of the cycle corresponding to late rice crops are shown in dark blue, whereas rice fields that were at the end of the cycle when the first image was acquired and are at the beginning of the cycle for the second are visualised in magenta. Non-rice areas are shown in light green. Ground surveys confirmed that all the sites at which rice parameters were measured were correctly identified as rice crops by this method. The calculation of rice coverage is then possible from the classification.



The ERS SAR measurements have been interpreted using a theoretical model which is based on a detailed description of the structure of rice plants and which takes into account the interactions between the radar wave and the ground surface, including the contribution from stems and leaves, as well as the effects of attenuation by the canopy of the wave propagation. The model indicates that the dominant scattering mechanism is that of the vegetation, followed by a reflection on the underlying water and vice-versa. Good agreement has been obtained between experimental data and theoretical results. In addition, simulations using the validation model indicate that the increase in the temporal radar response remains predictable with good accuracy for different rice growth conditions and different rice varieties.

In addition to rice-acreage maps, agricultural planners need forecasts of the levels of crop production. This can be calculated from the crop acreage and a forecast of the crop yield. Whilst satellite SAR data are well-suited to providing the crop-acreage information needed, the crop-yield information is somewhat more difficult to extract, requiring the use of complex models which are susceptible to local environmental perturbations. One of the principal inputs required for such modelling is more detailed data on crop height and biomass parameters.

MAPS OF HEIGH



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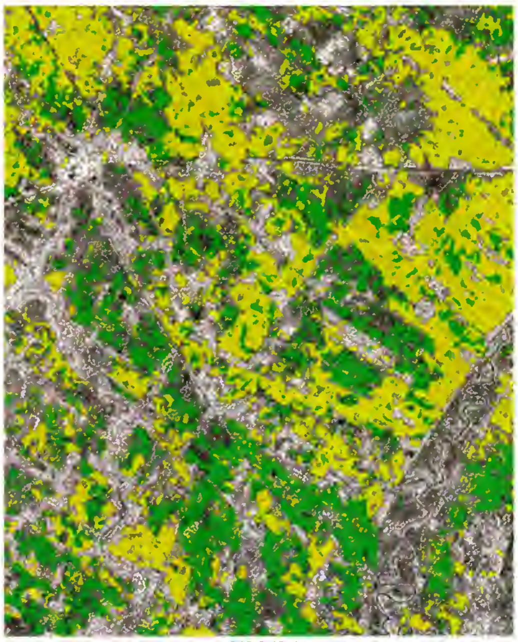

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Vegetative stage (< 80 cm) Re

Mapping of rice fields in a vegetative stage (green) and a reproductive stage (yellow) at different dates, allowing one to follow the evolution of the different rice fields (late and early) which have distinct growing cycles. Based on the relation between the backscattering coefficient, as measured using a data set of four ERS acquisitions, and the rice height or biomass, it is possible to derive a map of the rice fields at different heights and/or different levels of biomass. The map was derived from images of plant heights calculated for each of the four dates in order to relate each value of the backscatter to a plant height using the experimental relationship derived from SAR measurements.
A segmentation is performed using the height images so as to separate the rice fields that still are at the vegetative stage and those at the end of the cycle (reproductive stage). The beginning of the reproductive cycle appears when the plant is about 80 cm high.
A segmentation was performed to separate the rice fields with a biomass threshold of 2200 g/m^2. This value corresponds to the saturation point of the relationship between the backscatter and biomass, indicating the beginning of the reproductive cycle. The fields with a biomass below 2200 g/m^2 are displayed in green and those with a biomass exceeding 2200 g/m^2 in yellow in the next figure. Accuracy of the plant-height retrieval using ERS SAR corresponds to a standard deviation of ±9 cm.

CLASSES

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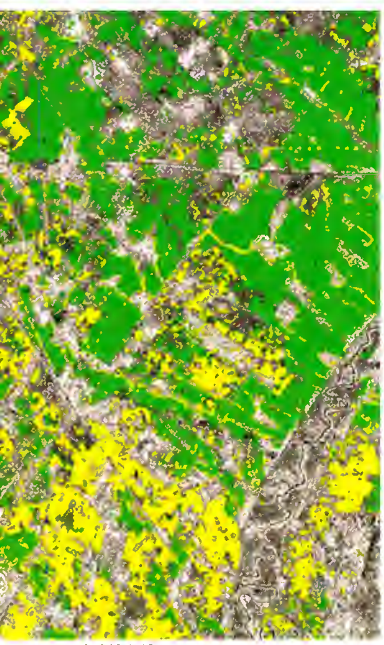

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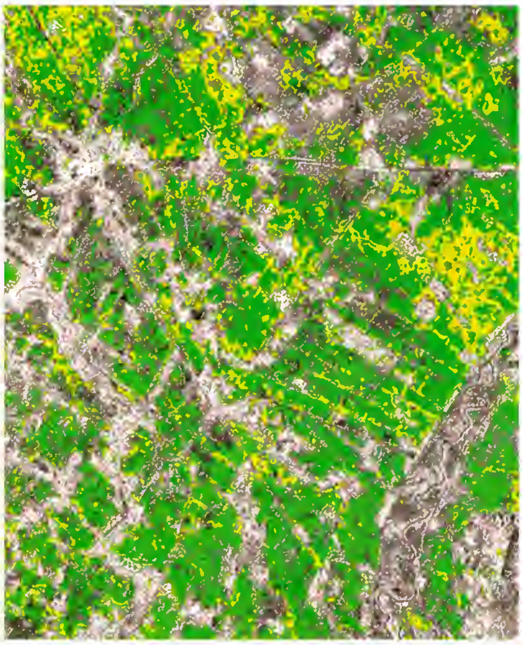
ductive stage (> 80 cm)

MAPS OF BIOMASS CLASSES



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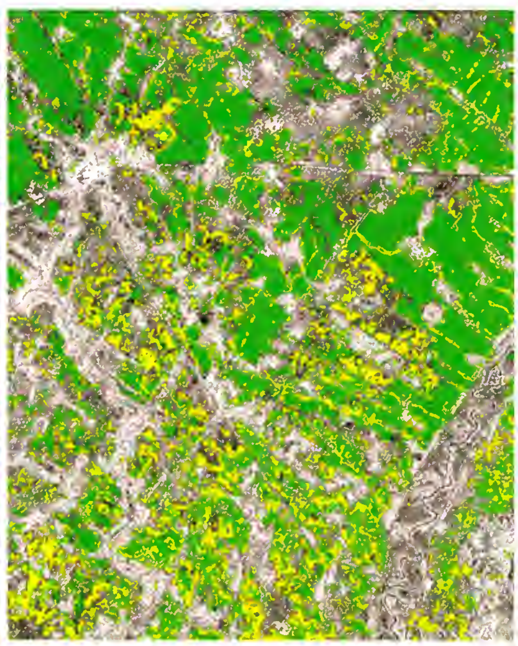

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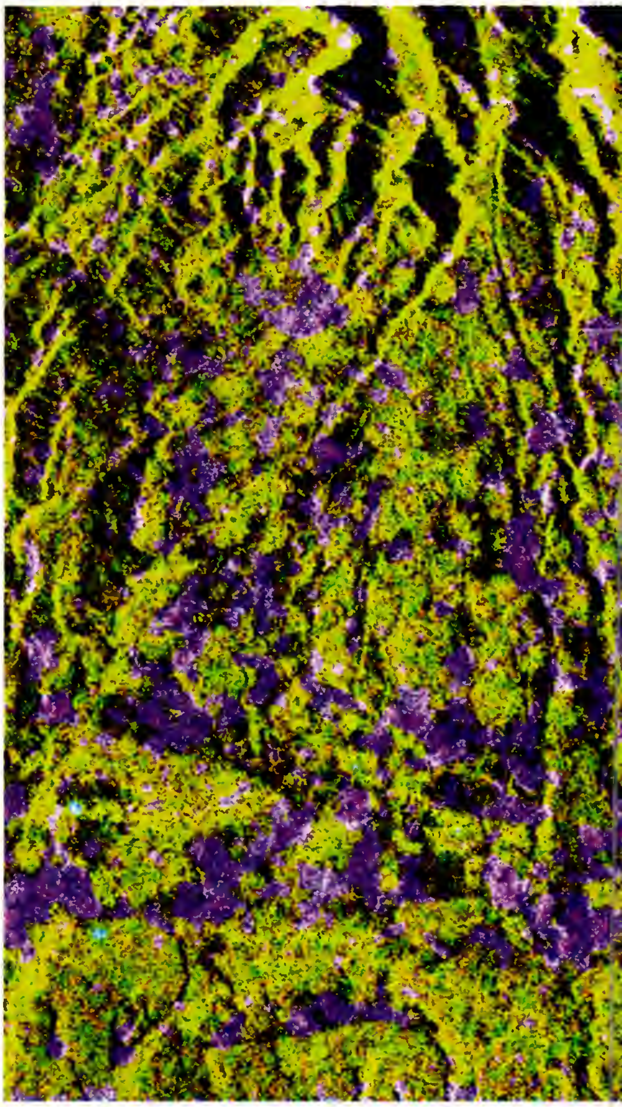
< 2200 g/m² **> 2200 g/m²**

Map of rice fields in a mountainous area

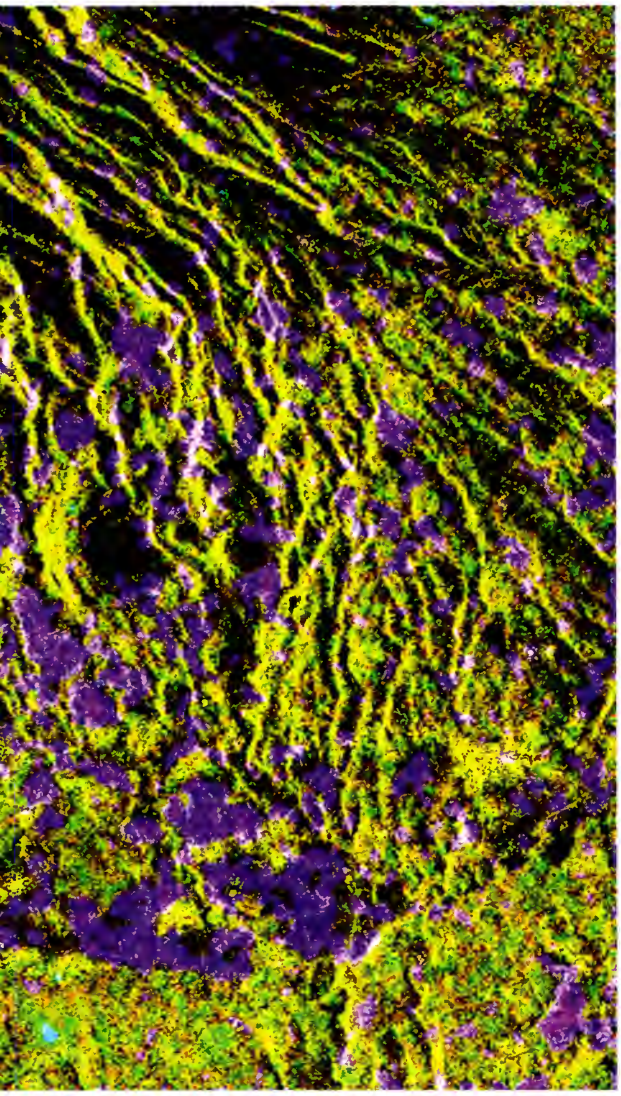


Prospects for a SAR-based Rice Monitoring System

Based on the above studies performed at two different sites with different geographical and rice-growth conditions, and using a theoretical backscatter model, methods using ERS SAR data have been developed that allow the identification of rice crops, the calculation of rice acreages and the monitoring of specific rice-growing parameters. The results are in good agreement with the existing crop maps of both areas. Application of the method calls for the availability of at least two SAR images recorded within the same growth cycle, or during consecutive cycles. The time interval between the two acquisitions should not be more than 80 to 100 days in order to maximise the variation. Potential confusion between rice fields and other types of land cover is minimised since no other land-cover type undergoes a backscatter-change similar to that of paddy fields.

For rice-growing areas with non-uniform crop calendars (e.g. varying numbers of crops per year from one area to another, or delays in the start of the growth cycle due to water-supply or manpower-availability problems), three to four ERS SAR acquisitions per year may be necessary. However, the exact number of SAR data acquisitions must be refined according to the particular characteristics of a site. Other limitations stem firstly from wind effects which increase the radar backscatter from the water surface of newly flooded rice field, and secondly from alternative cultural practices involving direct crop sowing on non-flooded fields, both of which cause variations in the radar backscatter characteristics during the rice's early growth stage.

Future refinement of the methods should include testing over a variety of rice-growing areas in Indonesia, taking account of different terrain types (coastal, alluvio-colluvial hills, transition and mountainous regions), the type of water supply, the crop-management practices and the cropping patterns.



Non-rice

Rice

It is already clear that SAR data have important potential for providing regional, national and international organisations with the information that they need to make comprehensive and reliable crop growth and yield predictions. Two key parameters in this respect are the total area prepared for wetland rice cultivation and the harvested area, which depend on the number of growing cycles per year. By applying the temporal-change approach with four well-scheduled SAR acquisitions, it should be possible to determine the number of cycles per year for a given field.

Future Outlook

When the project presented here is considered in the context of similar projects in South East Asia and elsewhere, it becomes clear that the ERS and Radarsat SARs have an important role to play today as a complement to optical sensors in managing the food economies and agricultural practices of the region. The benefits to be derived from applying a more tailored approach to the use of existing satellite data in these regions needs to be investigated, and the next generation of SAR systems need to be analysed in terms of the further opportunities for, and refinements in crop monitoring that they will bring. One such possibility is the combination of images obtained with two different polarisations (horizontal and vertical), which promises good discrimination between plant species with different characteristic structures. The Advanced SAR instrument carried by ESA's Envisat platform, due for launch at the end of 1999, will have the ability to operate with these two different polarisations.

Acknowledgement

The cooperation and participation of CESBIO (F) is gratefully acknowledged.

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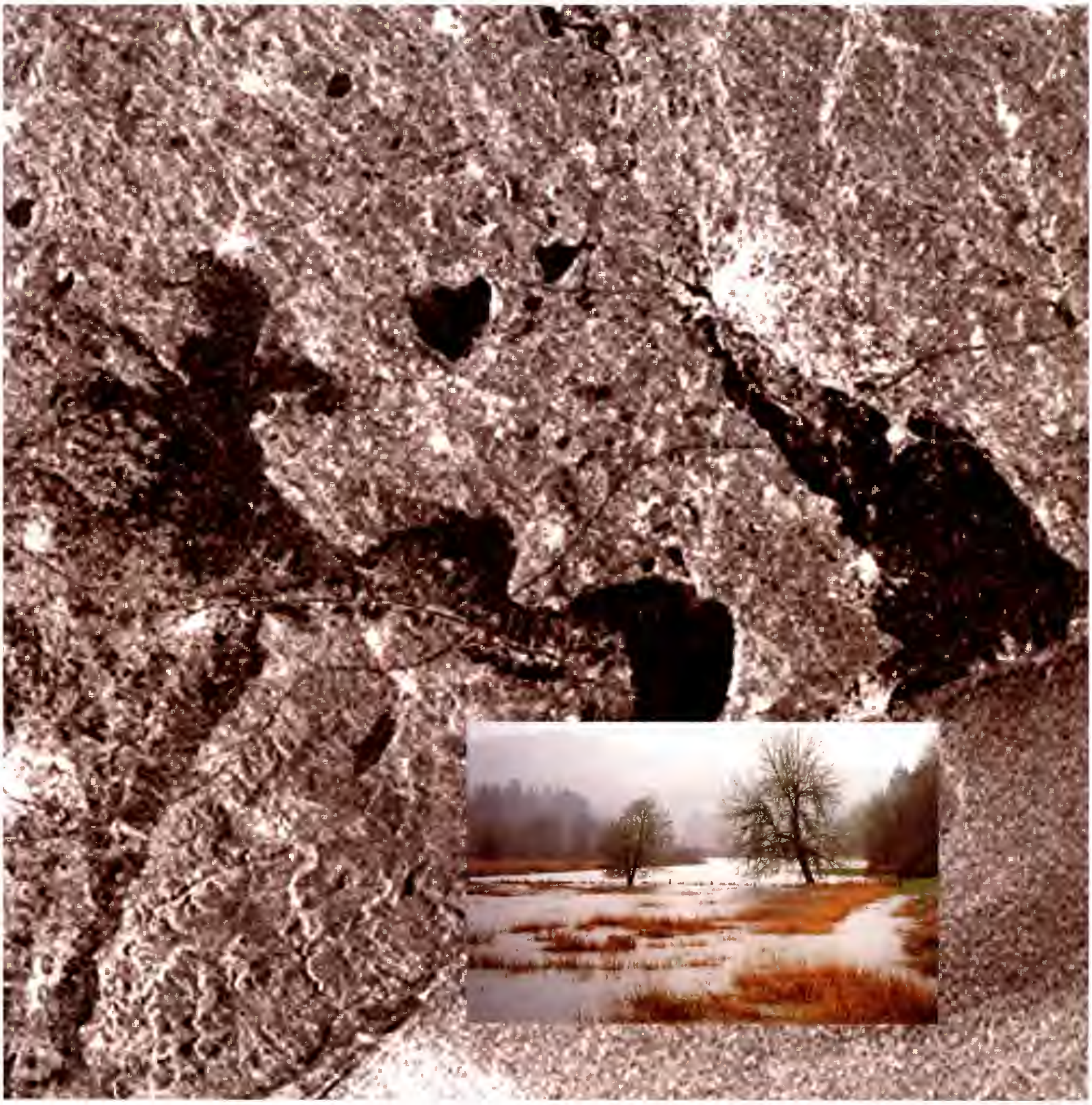
BR-128/II

FLOOD MAPPING



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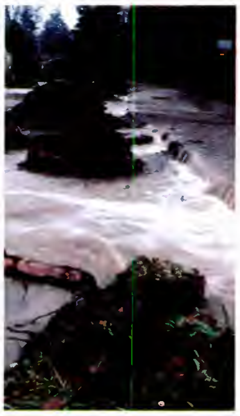
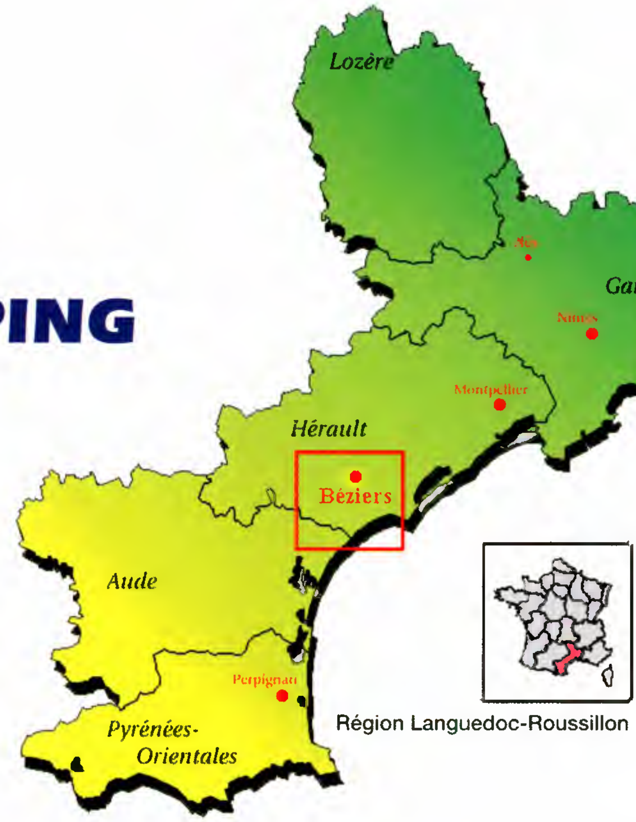


FLOOD MAPPING



Région Languedoc-Roussillon

The Need for Better Information

Flooding is a major hydrological hazard with a high frequency of occurrence, with an average of about 100 serious floods each year around the World. These significant rises in water level range from severely overflowing streams, lakes or reservoirs to major ocean-driven disasters in exposed coastal regions.

Like droughts, floods are catastrophic events which follow a "natural cycle" to a certain extent, involving phenomena that can be foreseen and predicted in many instances, given access to up-to-date information. Flooding events develop on a variety of time scales, sometimes over several days but in some cases in just a few hours. The resulting damage affects people, property, road and rail links, agriculture and last but not least wildlife and the environment.

Efficient monitoring is therefore a fundamental necessity during all three phases of a flooding event - before, during and after - in order to minimise its impact in terms of risk to human life and damage to property. Access to better information is paramount, as it is not always possible to map extensively flooded areas quickly enough or homogeneously enough using traditional means such as aerial photography or ground-based measurements. The combination of satellite remote-sensing data with the more traditional techniques within a user-friendly Geographical Information System (GIS) environment would seem to offer the best solution.

The Role of ERS SAR

The identification and monitoring of inundated areas during severe floods is of great relevance for damage assessment and the minimisation of risk. The radar imagery provided by the ERS satellite can be invaluable in this respect, given the all-weather operating capability of its Active Microwave Instrument (AMI) and its ability to map flooded areas on a regional as well as a local scale. In fact, flood mapping is one of the most promising applications of ERS SAR data in the context of natural-hazard monitoring.

Several studies and projects that were carried out between 1992 and 1995 in conjunction with significant flooding events in Europe clearly demonstrated that SAR flood-extent maps represent a unique disaster-mitigation tool when put into the hands of the authorities that have to deal with such catastrophic events.

SAR can contribute to all three phases of such events:

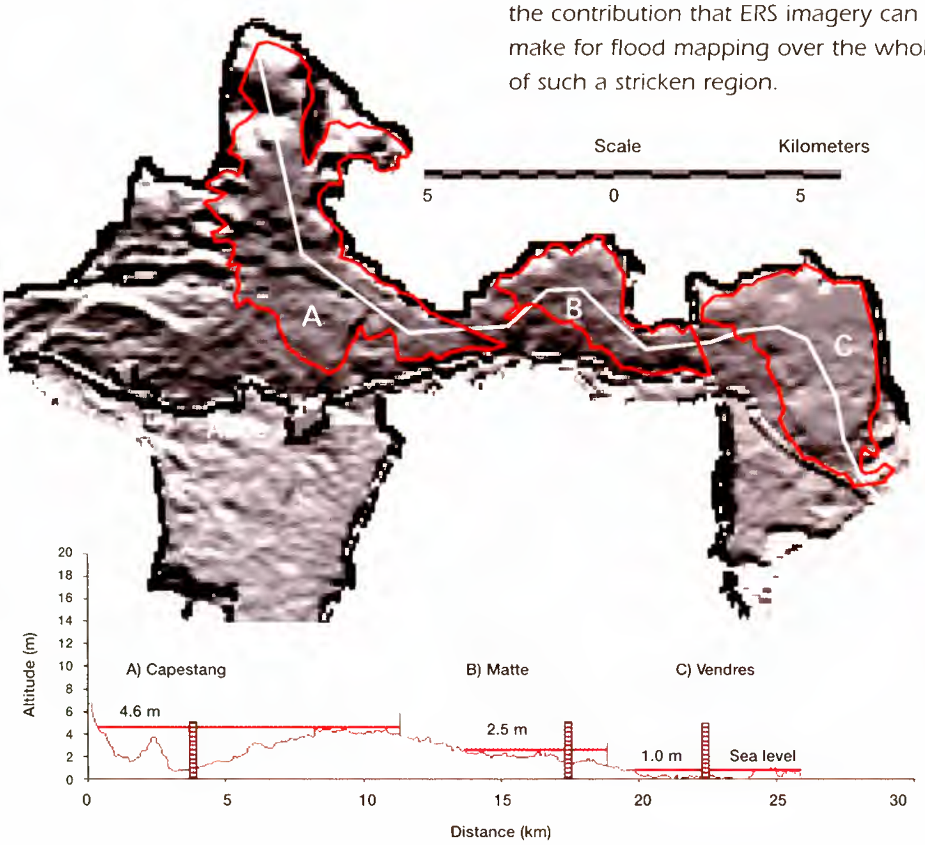
- prevention, through modelling of river-basin dynamics for future planning
- monitoring, through the mapping of flooding events to facilitate the quick delivery of emergency aid
- relief, through timely damage assessment and the identification of risk areas.

Example of Space-Based Applications

The Hérault Floods in France in January 1996

After a very rainy autumn and early winter in 1995, further intense rainfall (> 200 mm in 24 hours) affected the area around the city of Béziers, in the Hérault département, on 28 and 29 January 1996. The Aude and Orb Basins were particularly badly affected (see accompanying map). The peak flow rate of the Orb River exceeded 2000m^3/s at Béziers, causing major flooding and heavily inundating the Orb Valley all the way down to the sea. The lowlands of the Aude Basin were also flooded to exceptional levels and the whole region was declared a disaster area, with material damage totalling many millions of Francs.

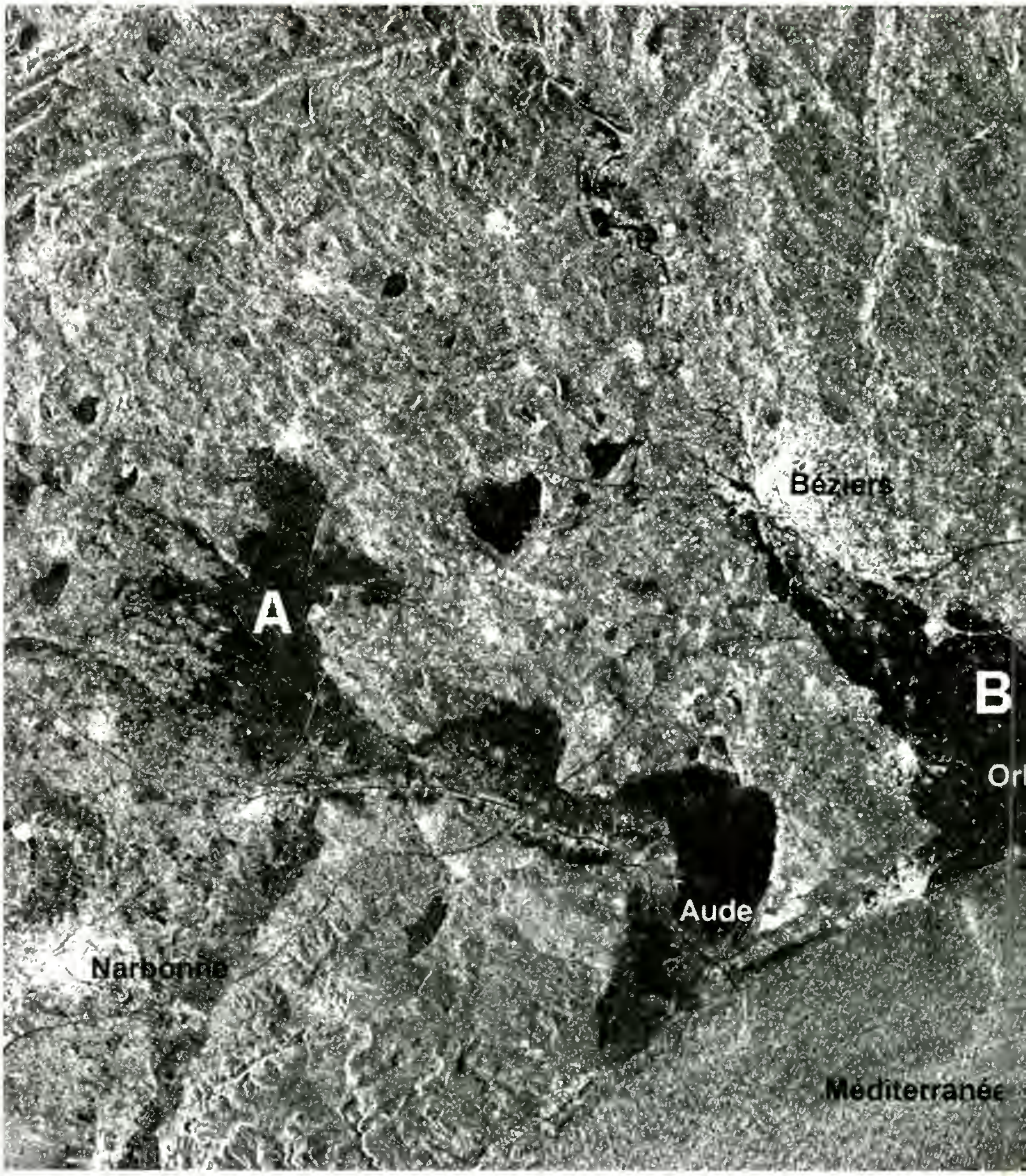
In an attempt to try to protect the Aude Basin lowlands against flooding, detailed surveys have been performed for many years, including a detailed topographic survey (1cm precision, 100m grid), to which an hydraulic model describing the run-off dynamics has been coupled. In addition, the maximum water levels during the 1996 floods were carefully registered within the area. This groundwork provided a very good opportunity to assess and demonstrate the contribution that ERS imagery can make for flood mapping over the whole of such a stricken region.

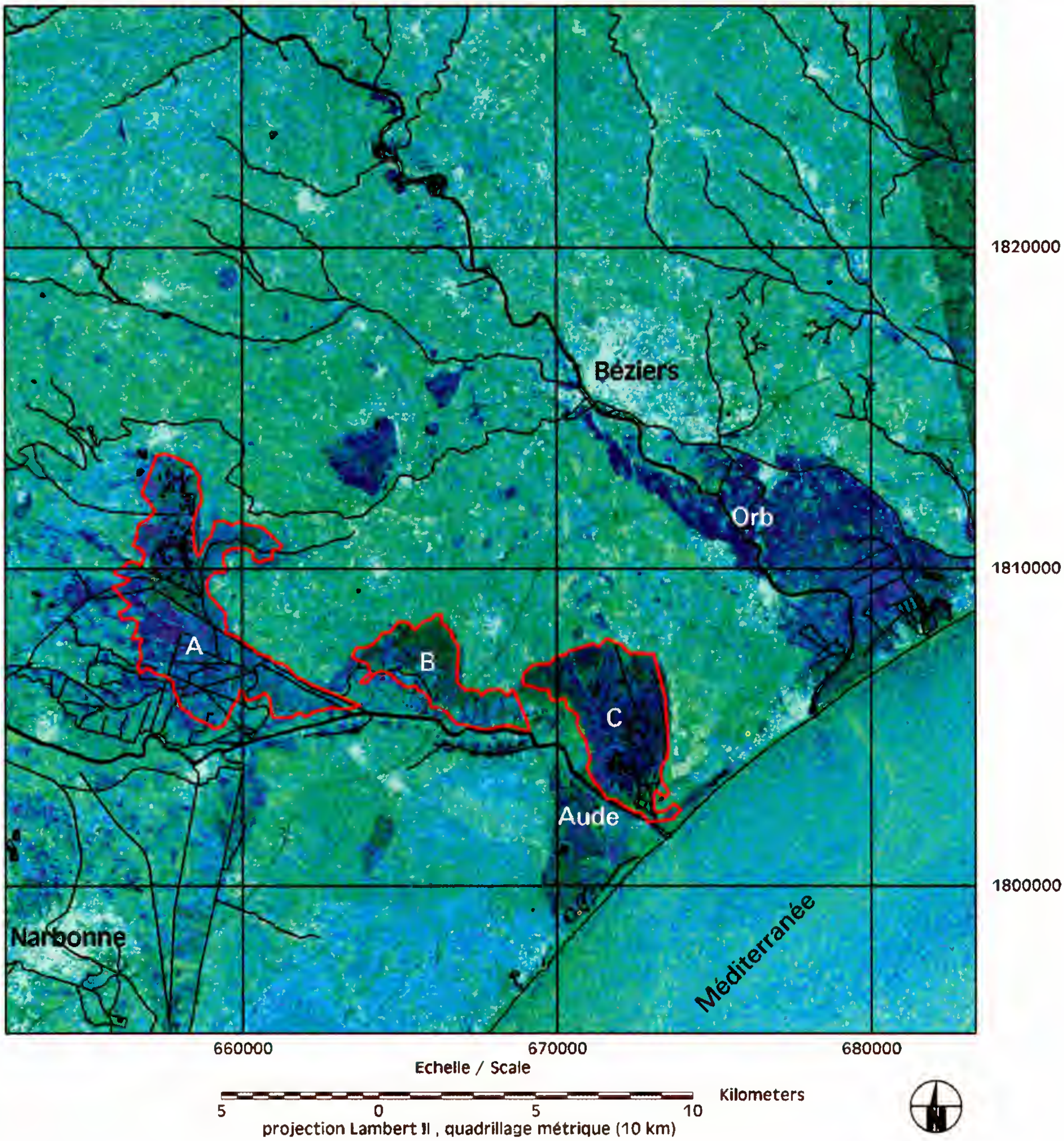


Survey in the Aude Basin lowlands:

- *black & white: topography as shaded relief*
- *white line and plot: profile and water stages*
- *red polygons: estimated flooded areas.*

ERS-2 SAR image acquired on 29 January 1996 at 23:00 hours local time





ERS SAR's contribution

The ERS-2 SAR image shown here (left) was acquired at night during bad weather conditions, less than 24 hours after the heavy rainfall that occurred on 28 January. Flooded areas appear as very dark patches, and large areas of lowlands and ponds were filled to an exceptional level (A).The vicinity of Béziers was flooded, as well as the valley running down to the sea (B).

By combining the image taken on 29 January with an image taken earlier in the year during summer conditions, on 7 August 1995, as a reference (at low water), and applying both radiometric (speckle filtering and reduction of relief distorsion) and geometric (geocoding) processing, it was possible to produce the SAR "space flood map" shown above. The flooded areas which are delineated in dark-blue hues in this map are in excellent agreement with those obtained from ground-based modelling.

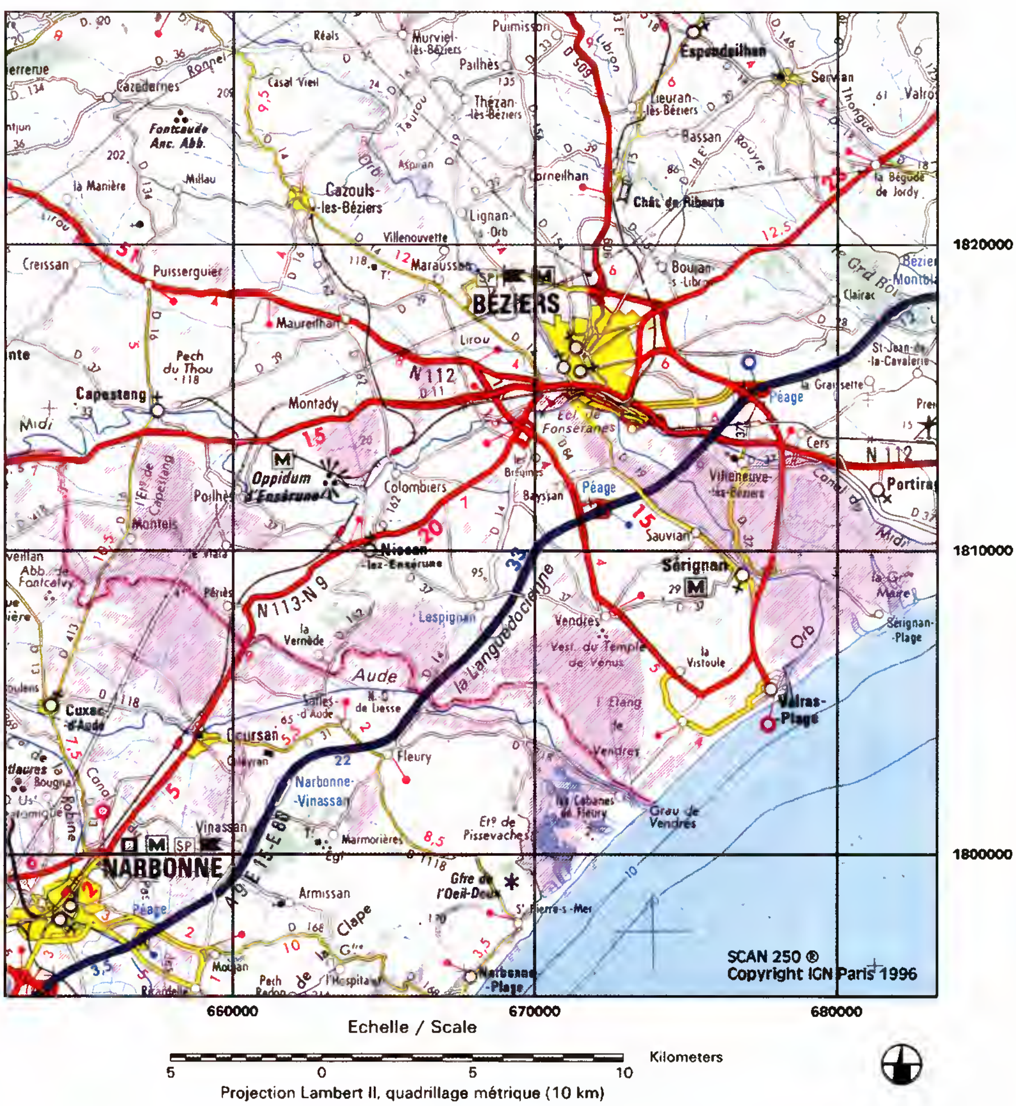
The ERS SAR space flood map:

- *channels :* *green 29 January 1996, blue 7 August 1995*
- *red polygons:* *flooded area from modelling*
- *black lines:* *main drainage network*

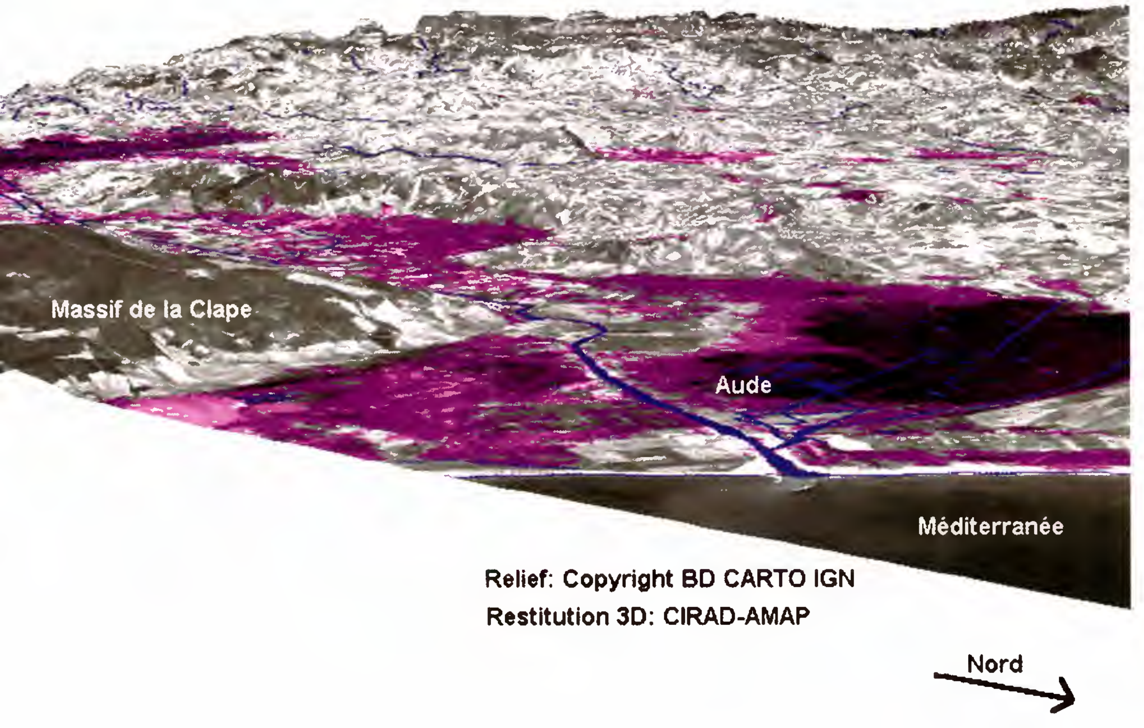
A final step taken with this ERS SAR map was to apply an image classification process in order to extract flooded areas, which can be combined via a Geographic Information System (GIS) to provide:

– a scanned traditional topographic map
– other remote sensing data, a digital elevation model and the drainage network
– land cover, soil types, administrative boundaries, networks, socio-economic data, etc.

as shown in the accompanying figures.



Conventional map including flooded areas (purple) mapped from ERS SAR images



Three-dimensional view of the Aude Basin lowlands:
- *flooded areas from ERS SAR (purple)*
- *SPOT panchromatic data (black & white)*
- *main drainage network (blue)*

Future Outlook

These various flood maps and associated space-derived data can be used for two main types of application:

(i) flood monitoring at a scale of less than 1: 50 000:
- estimation of flooded areas and volumes, within administrative or geographical limits
- flood damage caused to communication networks, agricultural and urban areas
- help in financial compensation.

(ii) prediction of flood risks: assessment of hydraulic models simulating the area liable to flooding, which are presently validated mainly by aerial photography and ground-based water-level measurements. Both of these approaches have many limitations that can be largely overcome by employing ERS SAR imagery acquired before, during and after the peak of the flooding.

Whilst SAR data cannot drastically improve flood warning/monitoring services if used in isolation, its proven synergy with meteorological, hydrological and soil-characteristic information from other sources means that it can be of great help not only for monitoring purposes, but also in the improvement of models. Moreover, by exploiting ERS-1/ERS-2 tandem-mode type SAR data, one can achieve a close to real-time flood detection and monitoring capability.

In terms of continuity, the launch at the end of 1999 of ESA's Envisat mission, equiped with a complex payload that includes an Advanced SAR, will make a further substantial contribution in terms of the availability of radar data for flood-related applications.

Acknowledgements

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- Ms M. Vinje, Young Graduate, ESTEC.

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