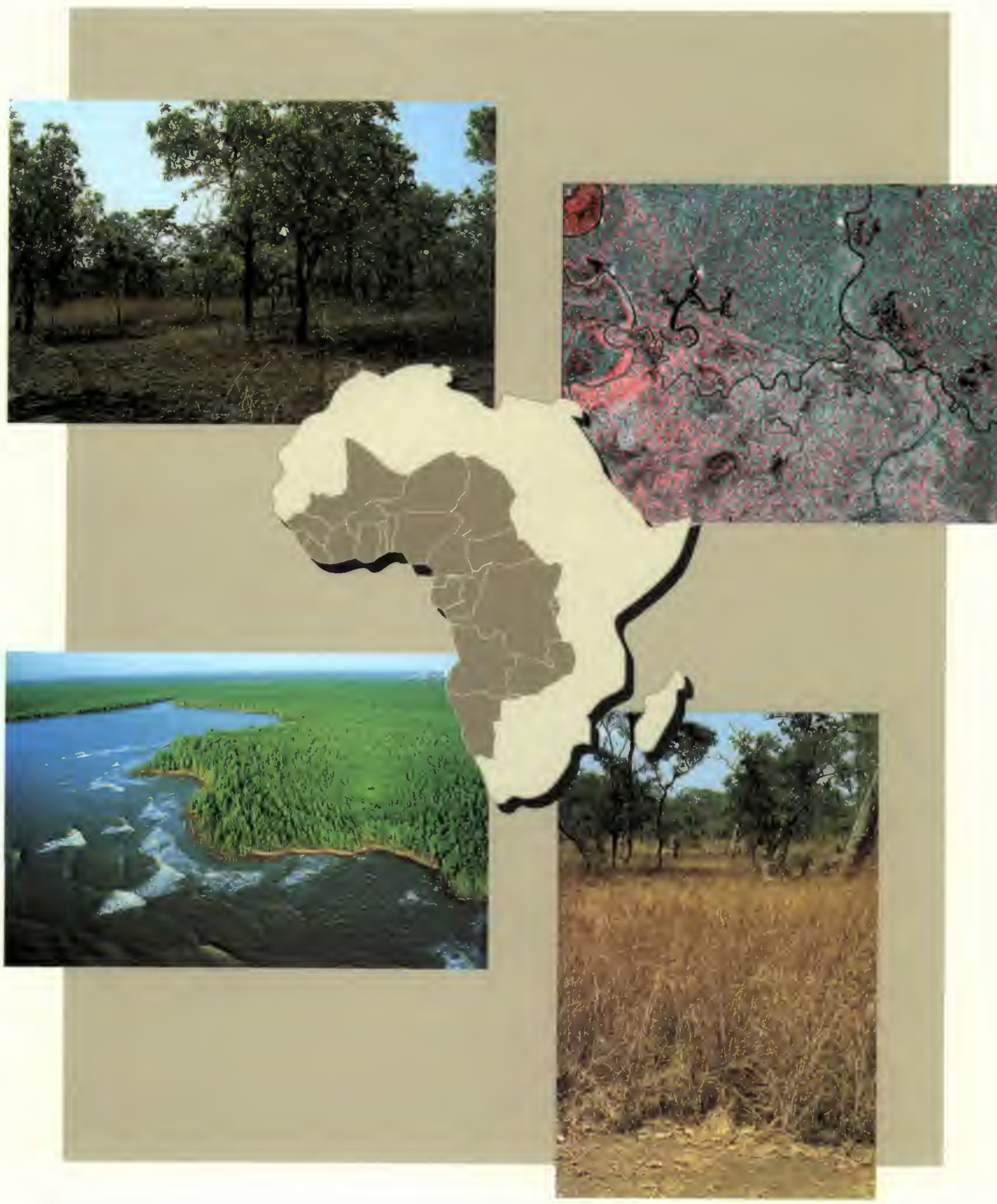
SP-1199

THE ROLE OF ERS-SAR DATA FOR CENTRAL AFRICAN COUNTRIES



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The Role of ERS-SAR Data for Central African Countries

A. Husson & J. Harms
Scot Conseil

European Space Agency
Agence spatiale européenne

Prepared by:

SCOT CONSEIL

in cooperation with

Laboratoire de géologie-géomorphologie

structurale et télétection (LGGST)

Technical coordinator:

K. Bergquist,

ESA International Relations Division

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I INTRODUCTION

1.1 Background to and objectives of this publication

Since 1972, when the first ERTS (Earth Resources Technology Satellite) better known under the name Landsat-1 was launched, remote sensing from space has evolved towards more operational oriented applications. Nevertheless, one of the limiting factors in the use of remote sensing for the majority of applications has been the problem of the availability of data over a certain area for a particular time period. This problem was partly resolved by the launch of Spot in 1986 and its off-nadir viewing capabilities. Nevertheless, in tropical areas there has always been a pronounced lack of data due to the almost continual cloud cover in these regions.

With the launch of ERS-1 in 1991, and the recent launch of ERS-2 in 1995, to be complemented by the scheduled launching of a further satellite (RADARSAT I) of the same type by Canada in late 1995, a remote sensing tool with new characteristics has been made available to the users of various Earth observation data related applications.

This availability of data over a longer time span will ensure that projects using radar data in an operational way will not suffer from a lack of spaceborne information well into the next century.

With this in mind, the European Space Agency (ESA) decided to launch a campaign aimed at making potential radar data users aware of the availability and capabilities of ERS-SAR images for various applications. This publication on the use and role of ERS data for Central African countries is part of the campaign and is also part of the joint ESA and UN effort to support sustainable development in developing countries with remote sensing techniques. The installation of a mobile ERS receiving station by DLR (German Aerospace Establishment) in collaboration with ESA in Libreville (Gabon) in June 1994 finally created the means for acquiring ERS-SAR imagery of Central Africa. These images are shown in the following chapters and emphasize the great potential of SAR data as a very useful tool for sustainable development in Central African countries.

1.2 Potential users of this publication

Since the launch of the first remote sensing satellite about 25 years ago, satellite images have played a considerable role depending on the application. The speed of satellite data integration has not only been different from application to application, but also from region to region. While meteorological forecasting applications started to integrate satellite data very early in their operational activities, other fields of potential spaceborne image use remained «underdeveloped» for a longer time. This is not surprising, as hardware and software capabilities, necessary for the processing of a high resolution data set occupying for instance 70 megabytes, were not affordable for a «normal user» even ten years ago. Thus, current developments in computing, through the speedy increase of computing power coupled with falling prices are also allowing a certain «democratization» of satellite imagery use. Ten years ago, a potential user interested in the processing of images paid 10,000 US $ for hardware and about the same amount for software. Now, image processing hardware can be obtained for about 5,000 $. The necessary software (e.g. GRASS) can be obtained free in the public domain directly via Internet.

Consequently, this publication is not intended for a specific user group (either scientific or operational), but rather for the general information of users interested in the processing of high resolution imaging radar. However, as the examples given in this report are primarily related to land applications, the target group may be described as follows:

- National and regional bodies in the fields of cartography, planning, environment, agriculture, forestry, geology or hydrology which are in charge of the management of natural resources.
- Universities and other scientifically oriented institutions responsible for adapting remote sensing techniques to national or regional needs (although this report is not a scientific publication). The aim is to demonstrate the general capabilities of radar images and not the scientific analysis of a specific case.
- Private companies in charge of the exploitation, management and renewal of natural resources or construction activities for government agencies (roads, railways, etc.).

The importance of transnational activities as, a priori, very promising for satellite data applications should, in particular be mentioned here. The use of radar imagery for the mapping, monitoring and assessment of natural resources is not only of interest for the sustainable development of a particular region (e.g. the African Development Bank) but can also help to reduce territorial conflicts between neighbouring countries and increase mutual trust.

In order to provide those users who are not familiar with remote sensing in general nor specifically with the interpretation of radar data, with a better understanding of the potential of SAR imagery, the following chapter explains some basic principles. For more detailed descriptions, a bibliography related to this issue is given in the Annex.

2 GETTING STARTED WITH ERS-SAR DATA

2.1 Some basic radar principles

Radar systems (Radio Detection and Ranging) were developed in the 1950s mainly by the armed forces. Radar is an «active» remote sensing system which means that it provides its own source of energy to produce an image. Thus, it does not require sunlight (as do optical systems) and data can be acquired either by day or by night. Furthermore, due to the specific wavelength of radar (for the microwave spectrum see Figure 1) cloud cover can be penetrated without any effect on the imagery[1].

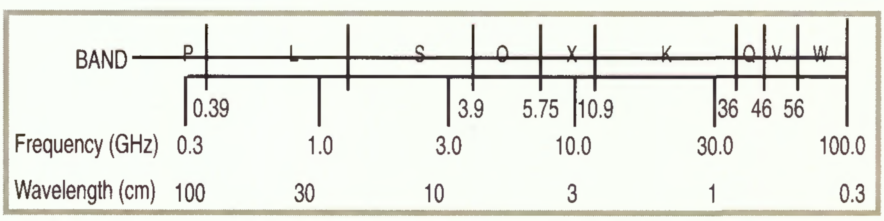


Figure 1: Band designation of the radio spectrum and designation of the microwave range

Radar is based on the transmission and reception of pulses in a narrow beam in the cm bands of the electromagnetic spectrum; the returning echoes are then recorded, taking into consideration their strength, time interval and phase. The power received by the antenna on board from each radar pulse transmitted is directly connected with the physical characteristics of the target through the backscattering coefficient. The value of this backscatter coefficient (corresponding to grey values in optical images) is basically dependent on three factors:

- the surface roughness,
- the surface humidity,
- the wavelength of the radar.

A surface is considered as being rough in the radar sense if its structure or shape has dimensions which are an appreciable fraction of the incident radar wavelength. For example, gravel surfaces exhibit stronger scatter than smooth

1) This chapter has been based on the ESA/FAO publication «Principles of Radar Imagery», Roma 1989 clays. Another example of the effect of surface roughness can be observed when looking at the difference between water surfaces with and without waves. Over water surfaces which are not moved by wind effects, almost no energy is scattered back to the antenna, which means that this area appears dark. Land surfaces are usually rougher (higher backscatter) than water surfaces as they contain structures with vertical faces and corners.

Moisture content influences the electrical properties of a target (soil, vegetation, etc.) and the backscatter increases with humidity. A wet ground surface is characterised by a stronger backscatter than a dry one having the same roughness.

The importance of both factors is also dependent on the chosen wavelength. A given surface may appear smooth at a wavelength of 25 cm (S band) and rough at 5 cm (C band). Furthermore, the longer the wavelength the higher the penetration capabilities. Thus, a 100 cm wave (P band) penetrates vegetation better than a 3 cm (X band wave) one.

Furthermore, a distinction can be made between active systems (radar) and passive systems (radiometers), as well as non-imaging systems (scatterometers, altimeters) and imaging systems (synthetic or real aperture radar, scanning scatterometers). For example, the radar instrument mounted on ERS is a SAR (Synthetic Aperture Radar) which means that the antenna is made to appear longer than it really is by exploiting the relative movements between the platform and the Earth with complex processing. Through this, a higher resolution can be achieved. Moreover, both the polarization and the incidence angle play a very important role in the detection of a target with the radar instrument.

More detailed information on radar principles can be found via the bibliography given in the Annex.

2.2 Technical Features of the ERS-SAR

The first satellite in the ERS series was launched in June 1991, and its successor (ERS-2) in April 1995. Since 1991, an almost global coverage of the Earth's surface has been attained with the satellite's SAR (Synthetic Aperture Radar) instrument.

The ERS satellites have Sun-synchronous, near polar, quasi-circular orbits with a mean altitude of 785 km and an inclination of 98.5°. Most of the ERS-1 mission has been performed with a 35-day cycle. ERS-2 only operates in a fixed repeat cycle of 35 days, which means that a particular site is covered every 16 days (figures for Equator latitude). Day and night orbits can be used to obtain a higher temporal coverage.

The coverage of one ERS-SAR image is 10,000 km^2 (100 x 100 km). A wide range of products has been made available by ESA through its Processing and Archiving Facilities (PAF's). Among these products, the PRI (Precision Image) can be considered to be the most adapted for general use in application fields such as agriculture, forestry or cartography. The pixel size of this product is 12.5 x 12.5 m. One can obtain the data either on Exabyte or CCT. However, Exabyte is the most widely used medium as Exabyte drives are now very cheap and can also be used for saving work following data interpretation. The size of one data set is basically 120 megabytes, which corresponds to an image size of about 8,000 x 8,000 pixels. Data are packed in BSQ (band sequential blocks). There are normally four files on one band, the third one corresponding to the data file.

2.3 Loading ERS-SAR PRI data into an image processing system

Using for example an ERDAS image processing system, SAR PRI data may be loaded by taking the following major points into account:

a use the BSQ or BIL option,

b skip two files,

c there is an additional line on the top of the file, but you can remove it later-on (see point i),

d the number of columns is 8 006 (the first six bytes are zeros). The image record length is 16 004 (the double of the column number),

e blocking factor is 1,

f data are packed into 16 bits,

g if you have a workstation or PC do not reverse bytes; this is only necessary when a mainframe is used,

h there is only one band in the data set,

i start loading data from input with co-ordinates 7, 2,

j the maximum number of lines is 8 200,

k do not forget to check your available disk space (min. 135 megabytes) before loading an ERS-SAR image.

A smaller subset of the data set can easily be loaded. When choosing the right portion within a map, you have to take the necessary «reflection around an axis» into account, which means that the original image is always wrong-sided (more details in Chapter 2.4.2).

2.4 Radar image processing and interpretation

Two different processing and interpretation approaches can be distinguished. These are basically the more scientific method based on radar backscatter evaluation and the application-oriented way of dealing with the interpretation of grey values. Although each of the methods has its advantages the latter one has been applied for this report because the user group targeted consists mainly of operation oriented users. In addition, the methods described and applied to the ERS images shown in this report have been chosen in such a way that even less experienced users who are not familiar with radar data should be able to process and interpret the images for their applications.

2.41 Conversion from 16 to 8 bit data sets

The first step of converting the original 16 bit data set to an 8 bit one is mainly disk space dependent as a complete scene takes up 135 megabytes, while an image, reduced to 8 bits only occupies about 60 megabytes. In addition, the visual displays, as well as a large number of filters and classification algorithms, are currently only available as 8 bit versions. The transfer itself can be performed by the division of each count (grey value) by a number (for example 7, 11, 13, 17, 19). The division value should be dependent on the range and the target to be detected. This means for instance that, within an agriculture application, taking a range of 100 - 20,000 grey values within a «normal» ERS-SAR image into account, 13 could be a good division value. In the case of a multitemporal approach, all images should be divided by the same value, in order to keep the grey level range on the same level. This processing step is of particular importance in view of the reflection around an axis.

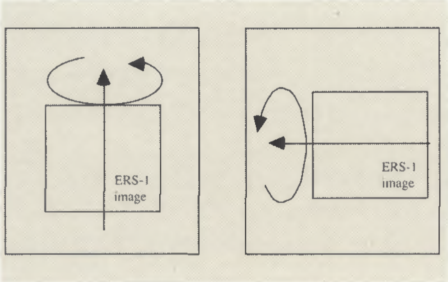


Figure 2: Reflection around an axis

2.42 Reflection around horizontal or vertical axis

Reflection of the ERS-SAR data is necessary due to the lateral viewing (to the right) of the satellite. For data taken during the descending orbit, the reflection has to be made around a vertical axis and for ascending orbits around a horizontal axis (see also Figure 2). Image processing software currently on the market does not provide a simple reflection function, but performs a resampling of the image (similar to the rectification). Unfortunately, although this process is not very complex, the processing through a «nearest neighbour» function may take several hours and a large amount of disk space. However, this phase is inevitable.

2.43 Superposition of different ERS-SAR images

A direct superposition with the help of a simple shifting is only possible for data having the same frame and track parameters (ascending or descending). This shift is due to the lateral displacement of the satellite of only a few hundred metres between the different orbits, which shows the high stability of the spaceborne platform. For the superposition of data, taken from different frames in descending and ascending orbits, this approach is not suitable. These images have to be rectified with the help of a normal rectification procedure (see below). The superposition can be performed by taking a few ground control points only (3 to 5).

2.44 Rectification to geographic basis

The rectification of ERS-SAR images taken under different orbit conditions to a common geographic basis starts with the choice of a certain number of ground control points in two images (road and river networks). Highly reflecting points like houses have to be treated with more care as the displacement of the objects taken from different view points (orbits) can be very important. Following this, a rectification matrix is calculated. This matrix is a set of numbers that can be plugged into polynomial equations (choice of order from 1 to 10). The polynomial equations are used to transform the coordinates from one system to another. Afterwards, the rectification is performed with either nearest neighbour, cubic convolution or other, more complex, algorithms. Major problems occur in areas with relief distortion. These areas cannot be successfully rectified without a digital terrain model (DTM). It is therefore recommended that when possible these areas should be interpreted using monotemporal data sets.

2.45 Mosaicking

Cartography can be considered as one important application of ERS-SAR data. Two approaches are possible - either data sets are interpreted separately or data are mosaicked before interpretation. In the following, examples illustrate the second possibility. In this case, two images over the south of Nigeria were mosaicked using the geo-referencing procedure described above. The resulting image 1 shows the limits of this processing as data were taken on different dates from different orbits. Therefore, the radiometric calibration cannot be similar.

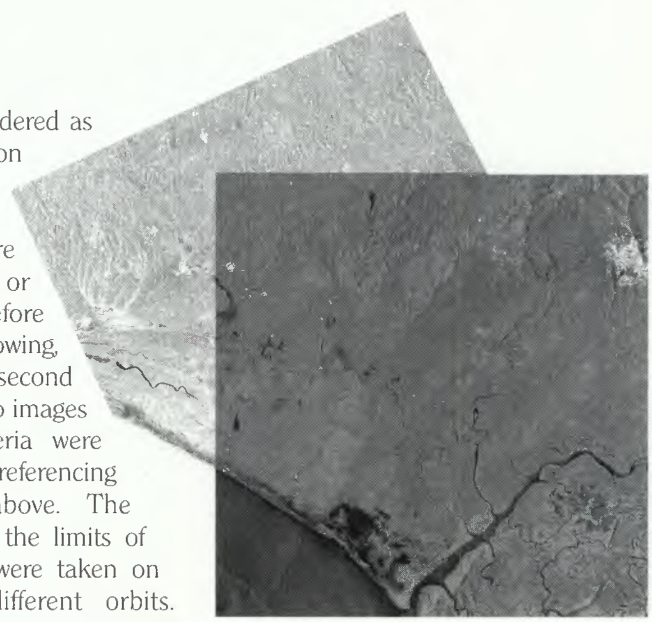


Image 1: Mosaicked data sets
(without any further radiometric processing)

In image 2, a radiometric correction algorithm has been applied and land surfaces are visible with almost the same grey levels. Only the sea surface differences are so great that radiometric correction does not work sufficiently well to reduce the effect.

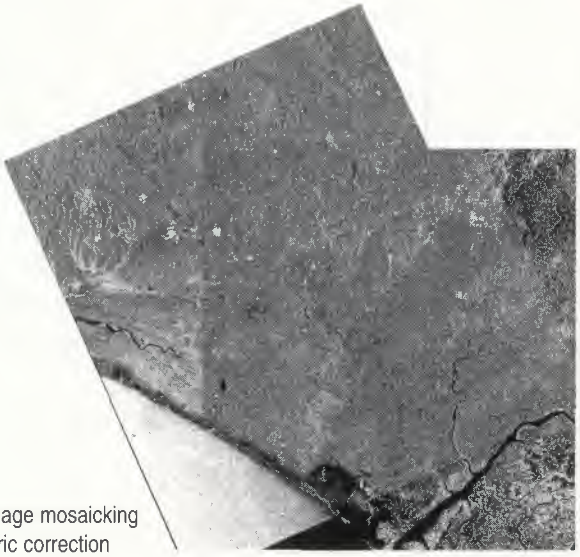


Image 2: ERS image mosaicking with radiometric correction

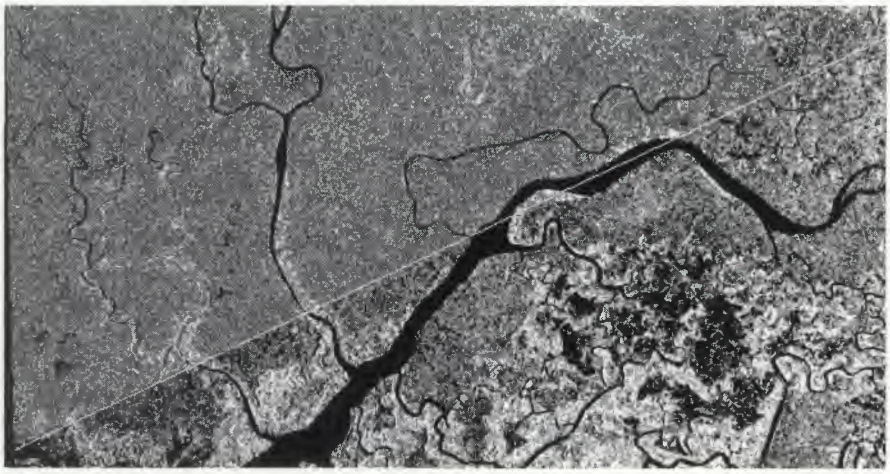


Image 3: Detailed view of mosaicking results

In order to control the output of the radiometric correction better, a subset of the boundary area was made.

In image 3, one can see on the right and left of the white line that some differences can still be detected, but the interpretation can now be performed without any risk of mixing classes.

2.46 Filtering

In contrast to the optical data of for example Spot or Landsat, the ERS-SAR images show a granular aspect, with important grey level variations that may occur between adjacent resolution cells. These variations create a grainy «salt and pepper» texture, the so-called «speckle effect», and might make interpretation of the image difficult. This phenomenon, induced by the coherence of the radar signal, is of particular importance for homogeneous surfaces (for example agricultural fields) where the random changes due to the noise «speckle» the homogeneous background. This noise can be explained by the fact that each pixel of the radar image corresponds to a surface which is much bigger than the wavelength (16 - 20 m to 5.7 cm).

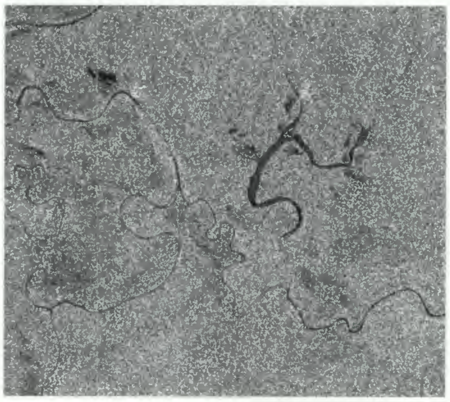


Image 4: ERS image subset

Therefore, one pixel contains many scatterers which contribute to the final reflection. The random combination of these elementary contributions yields a darker or brighter pixel in the image. As this phenomenon greatly hiders visual interpretation and specifically the automatic classification of radar images, its reduction by the so-called «speckle filters» is useful. A number of filters have recently been developed for this purpose. They are either statistical filters (LEE, FROST, SIGMA, MAP), geometric filters (ASF), multi-temporal filters or filters based on wave theory. Currently, only the statistical filters are used in a more or less applied way and included in commercial image processing packages. In the majority of cases a simple averaging can be considered to be sufficient for visual interpretation.

However, since some objects might disappear through this processing, the technique is not recommended for urban application. In general, it can be said that the larger the scale of application, the larger the filter (averaging) that can be chosen. On the other hand, the larger the window (box) chosen, the longer the processing takes. Two image subsets (see image 4 and image 5) demonstrate the usefulness of filters. Image 4 is not filtered while image 5 was processed with a 6 x 6 pixels average filter. One can see that certain objects (here rice fields) indicated in dark tones became visible only after filtering the data.

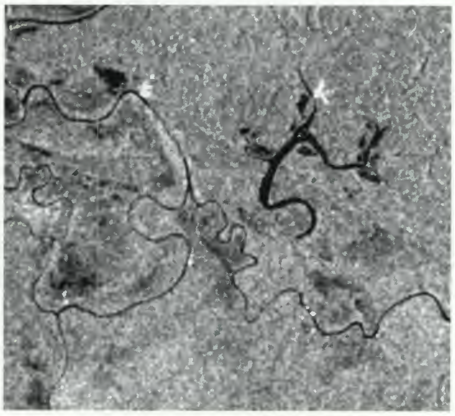


Image 5: Filtered ERS image subset

2.47 Specific further application-related processing steps

In general, two processing or classification methods can be distinguished for the thematic interpretation of satellite data. These are visual interpretation and automatic classification. Visual interpretation can either be performed on paper prints of the images or directly on the screen (then called computer-aided visual interpretation). Automatic classification is done either by using a pixel-oriented approach, or with the help of recently developed field classifiers based on image segmentation. All methods and approaches can be applied to one image (monotemporal) or a multiple of images (multitemporal). Very often, a combination of the different approaches (e.g. first a visual interpretation for overview purposes followed by an automatic, pixel based approach) gives the best results.

3 ERS-SAR APPLICATIONS

A first and very important step that each remote sensing related project should take is to evaluate the adequacy of a satellite sensor for a given application.

Thus, a number of applications were investigated in order to identify those which might profit greatly from the use of information obtained through the interpretation of ERS-SAR data. The following criteria were applied:

- the economic value of the application (e.g. the detection of mineral resources),
- the environmental value (e.g. information on the degradation of forests),
- the political value (e.g. information on the availability of food resources),
- the technical feasibility,
- the existence of reliable processing methods to be applied by the institutions of the countries concerned.

In general, the following applications can be considered when talking about the use of high resolution satellite data:

- monitoring of forest,
- monitoring of agriculture,
- monitoring of urban areas,
- geological mapping,
- cartography,
- monitoring of coastal zones,
- monitoring of the maritime environment.

Whereas mapping is defined as the evaluation of a relatively stable situation (map up-date every 10 years), monitoring is defined as the evaluation of a dynamic process (deforestation detection on an annual basis).

The requirements for the different applications can vary depending on the climatic zone of the area of interest. Therefore, three major zones were identified: sub-arid regions (e.g. North of Nigeria), sub-tropical regions (e.g. Cameroon), tropical regions (e.g. Gabon).

In the following pages, different applications are briefly described with the help of the above criteria. These short descriptions aim at giving a flavour of what could be done with remote sensing, and readers are invited to test them for themselves. A subset of the applications has been chosen for more detailed image interpretation. This does not mean that those which are not explained in the later chapters cannot benefit from the use of ERS-SAR data, but rather that the results are perhaps less impressive than for the key applications selected. In addition, this publication does not aim to give a comprehensive picture (see literature list) of the application potential of ERS-SAR, but rather tries to help the user to identify the most useful data sources, the related interpretation methods and some potential results.

APPLICATION I

Tropical and sub-equatorial forest management and deforestation evaluation

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Forestry	**Gabon, Equatorial Guinea**	**Tropical and sub-tropical regions**

ECONOMIC VALUE

Tropical forests are one of the major sources of income for countries like Gabon or the Congo. Forested regions have enormous potential, but are not covered by regular topographic mapping. Thematic maps are also lacking. Effective management of these forest ecosystems is essential, in particular to limit uncontrolled clearing.

ENVIRONMENTAL VALUE

Part of the forests were classified as "biosphere reserve" by UNESCO in 1988. For example, the Mayombe forest in the Congo has very high botanical value.

POLITICAL VALUE

More and more governments in Central Africa tend to give clearing permits to private companies in order to reduce their deficits. For both parties an evaluation of the resource before, during and after exploitation is of great importance.

TECHNICAL FEASIBILITY

Forest monitoring with radar data (ERS-SAR) in tropical areas has always remained a «dream» for the remote sensing community due to the heavy cloud cover in the regions concerned. Current results indicate that forest detection is mainly dependent on the topography (the stronger the relief, the less chance of working with ERS-SAR). Good interpretations could be achieved for selected regions in South America and West Africa.

RELIABLE PROCESSING METHODS

In various studies (e.g. TREES) it could be shown that, a priori, the identification of forested areas is possible. The interpretation mainly relies on the detection of forested areas in contrast to non-forested areas.

REMARKS

APPLICATION 2

Rice monitoring

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Agriculture	**Cameroon, Nigeria**	**Tropical and sub-tropical regions**

ECONOMIC VALUE

Rice is one of the most important crops in this region. The supply of «basic food» by the domestic agriculture (self-sufficiency) is very important for the political stability and the independence of the countries. Good management of the rice area (irrigation control) is necessary to ensure stable production. Monitoring of the surface and the production allows the government to plan exports and imports in the event of over- or underproduction.

ENVIRONMENTAL VALUE

No direct environmental value, but good management of the actual rice growing areas might avoid their spreading into regions that do have a high environmental value. Specifically, humid areas are endangered, due to favourable growth conditions for rice.

POLITICAL VALUE

The maintenance and extension of food supply is the major task of the FAO (Food and Agriculture Organisation). The Commission of the European Union is currently investigating the possibilities of financing a rice monitoring system with ERS-SAR data in Indonesia.

TECHNICAL FEASIBILITY

Within different ERS-SAR pilot projects, the feasibility of using radar data for rice monitoring could be shown (e.g. FAO-Thailand, SCOT CONSEIL-Indonesia). Projects to test the operational application of radar data are underway.

RELIABLE PROCESSING METHODS

Although the processing methods currently applied have to be seen as more experimental than operational, development of the necessary reliable and simple techniques seems possible.

REMARKS

Due to the physical appearance of the different growth phases of the rice plants/fields, easily identified within ERS-SAR images, the demonstration of this application issue is extremely interesting for Central Africa.

APPLICATION 3

Oil spill detection/water pollution and ship detection

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Oceanography	**Gulf of Guinea**	**All**

ECONOMIC VALUE

Oil is the major export product of several West African countries (e.g. Nigeria). Oil pollution of the Gulf of Guinea may however destroy, in the long run, the second export sector, namely the fishing industry. Knowledge of the major pollutors (ships and platforms) might help to protect the areas of major risk. The problem of over-fishing by ships of other nations is known and is endangering the export capabilities of the region.

ENVIRONMENTAL VALUE

The environmental impact of oil spills in the Gulf of Guinea is presently unknown. Changes in the biological activities within the area are however possible. The direct danger of over-fishing is less an environmental than an economic factor.

POLITICAL VALUE

Knowledge of oil spills in the region (oil exploitation by international companies) might be of great interest to the surrounding countries as the Gulf of Guinea is one of the richest fishing areas in the world (reimbursement for damages). The surveillance/control of trawlers of other nations is potentially of great interest to avoid international over-exploitation. The area is under investigation within the MAST Programme (JRC) using NOAA/AVHRR data.

TECHNICAL FEASIBILITY

The detection of oil spills with ERS-SAR has been demonstrated in various projects. A major problem for monitoring is the low temporal resolution (specifically in tropical regions).

RELIABLE PROCESSING METHODS

Visual and automatic processing and interpretation methods have been developed only recently. The detection of oil spills in rough sea conditions with wind speeds higher than 10m/s is still a problem. The difficulty of distinguishing between oil spills and certain natural phenomena might hamper the interpretation.

REMARKS

The use of radar data for oil spill and ship detection can generally be regarded as one of the major applications.

APPLICATION 4

Lake Chad extension

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Hydrology	**Area around Lake Chad (Cameroon, Chad, Nigeria, Niger)**	**Sub-tropical regions**

ECONOMIC VALUE

The capture of part of the waters of the Lake Chad basin by the Niger basin has considerable consequences for the economy of the regions concerned in terms of fishing, agriculture and stock farming.

ENVIRONMENTAL VALUE

During the rainy season, the overflow of the rivers Logone and Chari into the river Benoue (affluent of the Niger) is a matter of concern to the countries bordering Lake Chad (Chad, Cameroon, Nigeria, Niger). These countries fear a progressive drying up of the lake.

POLITICAL VALUE

An international Commission known as CBLT (Commission of the basin of Lake Chad), set up by the countries bordering the lake, with headquarters in N'Djamena, has drawn the attention of the scientific community to this little known problem.

TECHNICAL FEASIBILITY

Recent results from the interpretation of ERS-SAR data over the flooded Camargue (France) and Mississippi (USA) areas indicate the feasibility of using radar images for this application.

RELIABLE PROCESSING METHODS

The major techniques to be used for this application issue are filters and visual interpretation. Filtering techniques are under development and show reliable results.

REMARKS

Additional important applications related to lake management include the cartography of river networks (river basins) and flood mapping.

APPLICATION 5

Coastal environment of Guinea Bissau

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Sedimentology, hydrology, forestry, management of coastal zones and aqua-culture (cultivation of shrimps)	**Coast line of Guinea-Bissau and the archipelago of Bijagos**	**Sub-tropical regions**

ECONOMIC VALUE

A significant programme for coastal planning, funded by the UICN, has been set up in Guinea-Bissau. This programme covers projects aimed at developing forestry, tourism, fishing, aquaculture and transport in the region. It also includes the setting-up of ecosystem protection areas and nature reserves. The World Bank has recently granted a loan to the Guinea-Bissau government in order to carry out a national action plan for environmental purposes.

ENVIRONMENTAL VALUE

The only active delta of West Africa is located within the coastal area and islands of Guinea-Bissau and constitutes a natural area of high diversity and richness. This active delta causes a rapid evolution of the coastal zone (sediment deposition, swell effect, etc.). An area of the Bijagos Archipelago is being classified as a "biosphere reserve" by UNESCO.

POLITICAL VALUE

The decision-makers of Guinea-Bissau, and more particularly the Ministry for Rural development and Agriculture and the National Institute for studies and planning (INEP), would be very interested in the use of data from ERS-SAR.

TECHNICAL FEASIBILITY

Different projects have shown the potential of using ERS-SAR data for coastal zone monitoring. However, the potential of radar for the gathering of detailed information still has to be demonstrated.

RELIABLE PROCESSING METHODS

To be evaluated.

REMARKS

The advantage of carrying out this project is also based on the long-term availability of ERS-SAR data via the Maspalomas receiving station. This area is, however, not within the visibility circle of the mobile Gabon station.

APPLICATION 6

Management of urban agglomerations

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Urban area	**Lagos (Nigeria), Libreville (Gabon)**	**Tropical regions**

ECONOMIC VALUE

The population increase in the third world accompanied by strong rural desertification has led to an entirely uncontrolled growth of the main urban agglomerations in several African towns (i.e.: Libreville/Gabon; more than 1 million inhabitants). The monitoring of this fast urban growth is an important economic factor for the countries in order to provide the necessary services to the population.

ENVIRONMENTAL VALUE

Impacts of urban growth on the environment can be identified in the areas of air and water quality.

POLITICAL VALUE

Eurostat is currently undertaking a number of pilot projects in order to establish a methodology for monitoring European cities on an operational basis. The aim of this information gathering is to predict potential regional developments (fast growth or rural desertification) in order to implement the necessary actions. The monitoring of changes in urban agglomerations not only in Europe but also in the potential investment country is of major importance both for the receiver and the donor of funds (i.e. transportation network).

TECHNICAL FEASIBILITY

The technical feasibility of monitoring urban areas with ERS-SAR data has not yet been established. First attempts have been made for Seville, Tunisia and Barcelona, with very different results.

RELIABLE PROCESSING METHODS

No reliable processing methods have yet been developed. The filtering of radar data, seen as essential for urban detection, should in particular investigated.

REMARKS

The use of the complementarity of optical and radar data seems to be important for urban management.

APPLICATION 7

Pipeline location and planning/environmental impact assessment

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Geology, cartography, hydrology	**Between Lake Chad and Duala**	**Tropical regions**

ECONOMIC VALUE

The design of a pipeline from the south of Lake Chad to the Douala harbour is a project for tapping a recently found petroleum deposit. This petroleum deposit is of major interest for Chad since the country has few natural resources.

ENVIRONMENTAL VALUE

The pipeline might cross or pass close to several nature reserves. An impact study is absolutely necessary.

POLITICAL VALUE

See economic value.

TECHNICAL FEASIBILITY

The feasibility of using ERS-SAR data as the unique source for an environmental impact study has not yet been established. However, information from radar data can be considered as very important.

RELIABLE PROCESSING METHODS

Visual interpretation for land-cover class identification and DTM creation from interferometry.

REMARKS

APPLICATION 8

Map updating

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Cartography	**Gabon**	**Tropical regions**

ECONOMIC VALUE

Reliable maps are obligatory for the economic development of a country. Since the end of colonial times, almost no new maps have been produced which reflect the changes of the last 40 years. Although there are recent map editions (i.e. IGN for Gabon), they have mainly been produced on the basis of 50 year old information.

ENVIRONMENTAL VALUE

Incomplete cartography has no direct impact on the environment.

POLITICAL VALUE

A reliable cartographic base is of major importance for the countries themselves, but also for potential donor or investor nations or institutes. Major political and economic decisions are based on current maps.

TECHNICAL FEASIBILITY

Different ERS-SAR pilot projects have shown the feasibility of using radar data for cartographic purposes. Therefore, map up-dating on the basis of an existing information base would probably result in greatly improved accuracy.

RELIABLE PROCESSING METHODS

Processing methods have been developed by the national cartographic institutes (i.e. IGN).

REMARKS

APPLICATION 9A

Mapping and management of non renewable resources

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Geological mapping	**Central African Republic**	**Sub-tropical**

ECONOMIC VALUE

A national master plan is being prepared with the financial support of the World Bank. Geological maps are to be made at a scale of 1:200,000 and 1:1,000,000. ERS-SAR data could be used to save financial resources. As mineral resources are a major source of income for Central African countries, their detection is of a great economic value.

ENVIRONMENTAL VALUE

Geological and geomorphological information are important data sources for impact studies and environmental protection plans.

POLITICAL VALUE

Very high political value, as many countries depend on mineral exploitation and exports.

TECHNICAL FEASIBILITY

The investigations depend on the availability of ERS-SAR data over the selected region, which can almost be guaranteed today, and on the availability of maps (geological) in order to validate results obtained.

RELIABLE PROCESSING METHODS

Visual interpretation is the most adequate method. Lineaments and other features are difficult to detect with other methods.

REMARKS

Method to be applied to all countries in Central Africa.

APPLICATION 9B

Volcano monitoring in Cameroon and Zaire

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Geology - volcano surveillance	**Cameroon and Zaire**	**Tropical zone**

ECONOMIC VALUE

In 1986, hot CO_2 gases killed 1 800 persons in the region of the volcano Lake of Nyos (Cameroon). Yet, nobody knows whether the source of the gases was the crater itself or lateral fissures. Similar phenomena killed 37 persons in 1984. In order to save lives in the future, it is extremely important to gather geological information on the volcano.

The Niragongo volcano in Zaire is one of the world's three volcanos that have a permanent lava lake. Studies carried out over 40 years have shown that the level of lava in the lake varies widely. A lava overflow was observed some years ago. Apart from the scientific missions no direct observation station has been installed in the region and satellite imagery has not yet been used to study the area of the volcano.

ENVIRONMENTAL VALUE

See economic value.

POLITICAL VALUE

See economic value.

TECHNICAL FEASIBILITY

SAR data have proved to be extremely useful for geological mapping. Interferometric analysis with ERS-SAR can be considered a unique tool for the observation of the changing heights of surfaces.

RELIABLE PROCESSING METHODS

Geological mapping by visual image analysis is an operational method. Reliable interferometric processing methods have been developed by CNES, France and the University of Stuttgart, Germany.

REMARKS

APPLICATION 10

Protection of mangrove forests and coastal erosion

APPLICATION AREA	GEOGRAPHIC ZONE (EXAMPLE)	CLIMATIC ZONE
Coastal areas, sedimentology, forestry	**Gabon, Nigeria**	**Tropical region**

ECONOMIC VALUE

The coastal zones of Gabon and Nigeria are currently being eroded by about 10 m per year. The mangrove forests are the most important protection against coastal erosion. This material, washed out from the coasts, forms sediments along shipping routes which have to be dredged more and more often in order to maintain the possibility of exporting the oil.

Monitoring of the mangrove forests and an understanding of the coastal sediment transport patterns are therefore necessary in order to control the sedimentation process and dredging efforts. The coastal erosion itself might have a negative influence on specific areas.

ENVIRONMENTAL VALUE

The destruction of the mangrove forests can be considered as very negative for the coastal environment.

POLITICAL VALUE

Knowledge and monitoring of the mangrove forest size can be seen as vital for potential investors or donor countries in order to ensure the exportation of goods produced in the country.

TECHNICAL FEASIBILITY

The technical feasibility of using ERS-SAR data as the unique source of information for identifying mangrove forests could be established. Further data on sediment transport patterns can only be obtained through direct measurements (bathymetry, etc.).

RELIABLE PROCESSING METHODS

Current techniques are mainly based on the visual interpretation of enhanced (filtered) data. Automatic classification techniques are under development.

REMARKS

All eleven of the forgoing applications are considered to be very important for Central African countries and ERS data can certainly provide very useful information. It was not possible to investigate all of them in detail, however, and therefore six were selected as being representative examples for more in-depth study. The areas investigated were located in different countries in order to demonstrate the usefulness of ERS-SAR for the whole Central African region.

1. Tropical forestry management in Gabon, the Congo and Equatorial Guinea (Application 1).
2. Agriculture (rice) monitoring in Nigeria (Application 2).
3. Hydrology and water resource management for Lake Chad in Cameroon (Application 4).
4. Cartography (including urban management) in Nigeria and Gabon (Applications 6, 8).
5. Geological cartography in the Central African Republic (Application 9a).
6. Mangrove forest management in Gabon (Application 10).

Those applications which are not described in detail in Chapter 4 are, however, included in the general evaluation of the ERS-SAR application potential in the last chapter. More details about these applications can also be found via the bibliography in the Annex.

4 SELECTED INTERPRETATION RESULTS

The following interpretation results are divided into sub-chapters by country. The coverage area over which images were acquired by the mobile receiving station of Gabon is shown in Figure 3. The visibility circles of Maspalomas and Johannesburg are also indicated. Figure 4 on the next page shows the locations of the scenes that were interpreted.

Figure 3: Coverage of ERS-SAR over Central Africa

Figure 4: Location of interpreted images

For the work discussed here a small number (12) of data sets was interpreted. Generally two images have been used for each application, to demonstrate the capabilities of radar. Using more images over a certain area not only increases the possibility of detecting more objects, but also makes it possible to identify changes in the object, e.g. where a forested surface becomes an agriculture surface.

Data for this current project was only available for one acquisition period, between July and October 1994.

The strong potential of ERS-SAR for multitemporal applications has already been demonstrated by different research and application teams for other regions of the world (more information on this item can be found through the bibliography in the Annex).

The results of image interpretation for certain applications may have been duplicated in some cases through the choice of a country-related approach. On the other hand, this duplication strongly highlights the use of the data for all Central African countries.

Finally, it should be remembered that the image interpretation presented here has been performed without any field verification. Some features might not have been fully understood therefore, and the reader is kindly requested to excuse any such, hopefully minor errors.

4.1 Nigeria

The Federal Republic of Nigeria is the 30th largest country in the world (923,768 km^2) and is 9th largest in terms of population, which amounts to about 115 million inhabitants (information from 1991).

These figures already hint at the importance of spaceborne information for the sustainable development of Nigeria.

The country's major resource lies in the exploitation of offshore oil fields. Due to its fast growing population, the management of agriculture as well as the development of forest resources are a major challenge for the national and regional administrations. The availability of accurate and appropriate topographic maps can be considered absolutely essential for the country. As far as expertise in remote sensing is concerned, Universities (e.g. Lagos, Ile-Ife) have been able to increase their capabilities through cooperative programmes with different countries.

The «Regional Centre for Aerospace Surveys» in Ile-Ife has been successfully employed as the «motor» behind this development of earth-observation activities. In addition, Nigeria has recently created a national remote-sensing centre in its new capital, which shows the increasing involvement of the Nigerian government. Besides national administrations, private companies (national and foreign) are very much interested in information about the development status of a particular region.

The availability of a land cover map and its introduction into a GIS (Geographic Information System) can be considered as one basis for the sustainable planning and management of the resources of a particular country or region. The best scale for such a land-cover map depends on the particular application and the availability of data to be interpreted. For information needs at a national level, a scale of 1:500,000 should be sufficient, taking the size of Nigeria into account. The class requirements (nomenclature) depend first of all on the specific needs of a particular administration. However, a number of «basic land cover classes» should be included in all maps (e.g. rivers, lakes, roads, agriculture, forests, urban areas). In this respect, the topographic and land-cover maps carry very similar information (except for the height information of topographic data sets).

Regional land cover maps should give a more detailed view and a scale of 1:50,000 to 1:100,000 is therefore more appropriate. Again, the number of classes needed depends on the goals of the work (e.g. planning a road) but data used to archive the class resolution has to be investigated very carefully. Not all of the desired classes can be detected from space.

Therefore, a certain compromise between the requested resolution and the detectability of a particular object sometimes has to be made.

The ERS SAR can be used to produce land-cover maps at national level and with a scale of 1:500,000 without any problem while taking the above described «broad classes» into account. Image 6 is a full ERS-SAR image (100 x 100 km) taken over the coastal zone in the south of Nigeria. For visual interpretation purposes, it has been filtered with a 10 x 10 pixel moving box average filter.

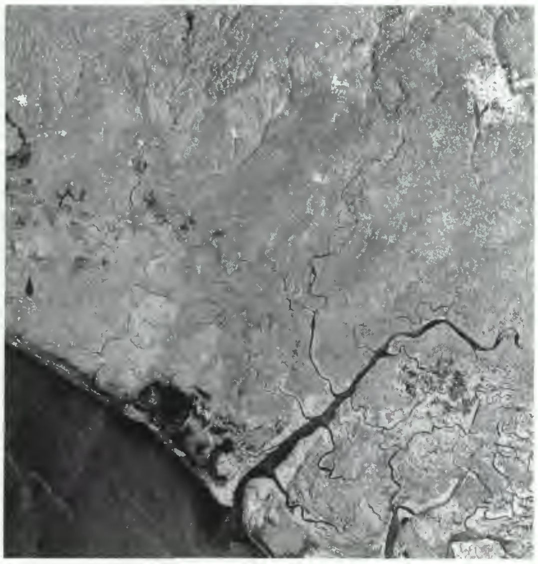


Image 6: ERS-SAR image over the south of Nigeria of August 14, 1994

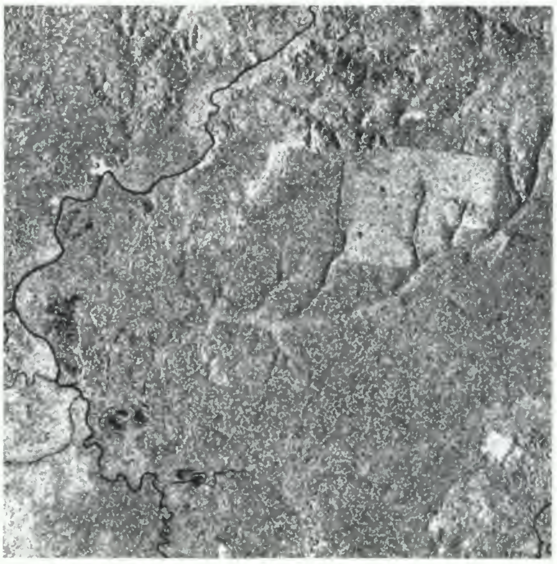


Image 7: ERS subset with forest cutting visible on the right side of the image

The most important and most visible features in the image are certainly elements of the hydrologic network such as rivers, streams, lakes and lagoons, which can be detected and mapped very easily. The coastline is also clearly visible.

Urban areas can be distinguished as white spots, like the town of «Benin City» in the upper right corner. Smaller villages and towns can be seen by increasing the screen resolution (image 6 has been reduced by a factor 12, in order to display the full data set on the screen).

In the upper centre a square surface with a different grey level can be seen. Looking at a subset, one can identify this feature as a forest cutting (see image 7 right side).

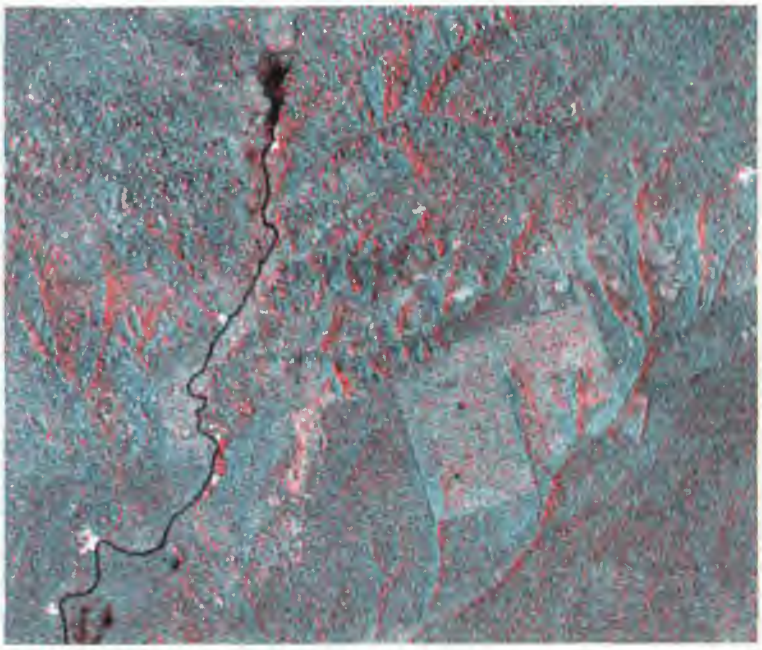


Image 8: Terrain disturbed multitemporal image

Image 8 shows the same feature in a multitemporal data set taken from different orbits. Although the river appears in black (a sign of successful superposition), red and blue lines can be observed and interpreted as a sign of a bad superposition. This low georeferencing quality is caused by the mountainous terrain conditions affecting the upper part of the image. In this case, georeferencing with the help of a DTM (Digital Terrain Model) would give a better result.

However, even with the distortion, the forests and forest cuts are clearly visible on the image. As these surfaces were also observed in other images, ERS-SAR can be seen as an appropriate tool for the management of forest concessions (clear cuttings) for the whole of Nigeria.

Improved image interpretation capability through the multitemporal approach can already be seen in image 8. This technique is even more valuable for agriculture as features change more quickly than in forestry or cartography.

Image 9 is an example of ERS-SAR data's potential for monitoring rice. Areas in dark red are surfaces under rice. Due to the rice-cycle, the areas are flooded and therefore easily detectable. The transverse line (upper left to lower right) which divides the image into a more bluish and a more reddish area is probably the boundary between cultivated (lower part) and forested land. As the individual fields are smaller than the resolution of the ERS-SAR data, the boundaries between them cannot be detected.

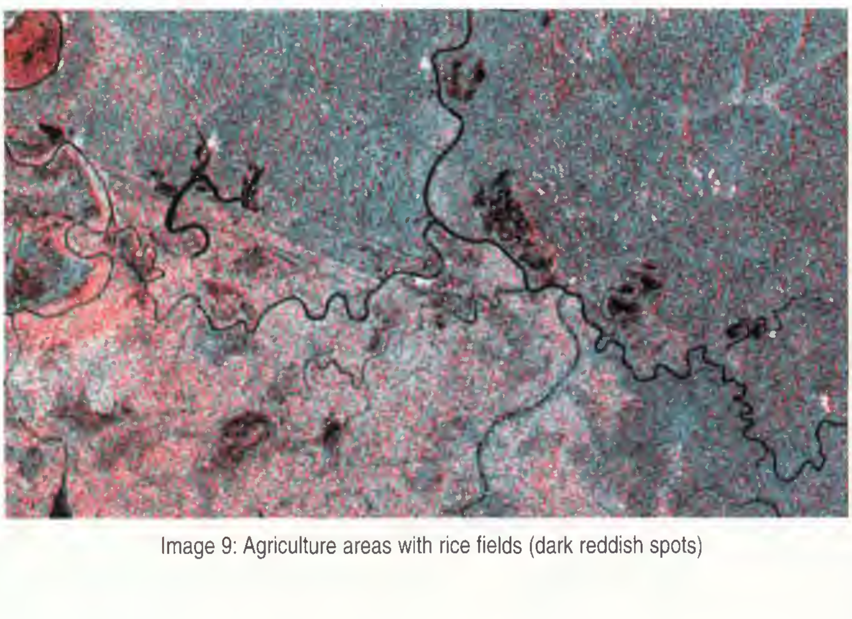


Image 9: Agriculture areas with rice fields (dark reddish spots)

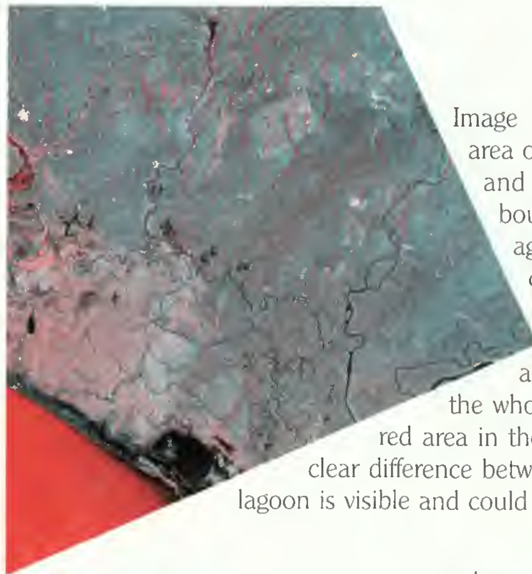


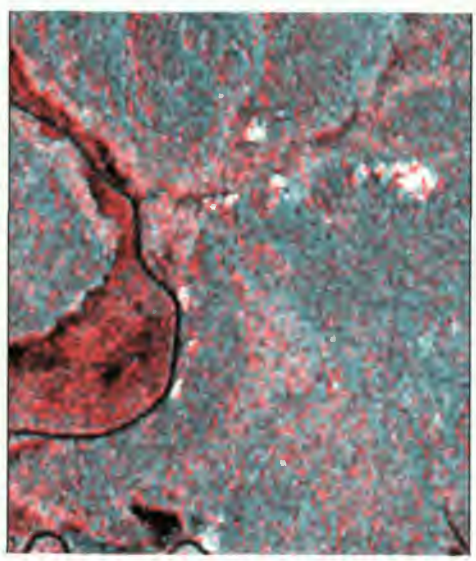
Image 10:
Multitemporal data set of images acquired on August 2 and 14, 1994

Image 10 shows the total overlapping area of two images from a descending and an ascending orbit. The boundary between the forested and agricultural land can again be clearly identified, whereas the reddish coloured surface corresponds to the cultivated area. White spots distributed over the whole image are small villages. The red area in the lower left part is the ocean. A clear difference between open water and the coastal lagoon is visible and could be mapped.

Image 11: Area before flooding

Besides the ERS-SAR's potential for mapping the hydrological network of a country or region, flooding phenomena can also be monitored with its data on a regular basis, as the next example shows. Whereas the first image (11) was acquired before the event on August 2, the second subset (image 12) was apparently taken during the event or shortly afterwards (August 14); the black colour shows that the area is under water.

Image 12: Area during or shortly after flooding



The multitemporal data (image 13) set gives a good view of the original river bed and its extension during the flooding event.

Image 13:
Synthesis by multitemporal approach

4.2 Cameroon

The republic of Cameroon has a surface area of 475,442 km^2 and a population of 12,1 million. Its major income is derived from the exploitation of oil fields and forests. Crops are only cultivated for the country's internal needs. Selected food products are imported. Figure 6 shows an overview map of Cameroon. As the use of ERS-SAR data for coastal zones will be demonstrated over Gabon and Cabinda, Cameroon has been chosen to demonstrate the SAR's potential for the management of hydrological resources. Together with Nigeria, Niger and Chad, Cameroon shares the resources of Lake Chad, which is listed as the fourth largest lake in Africa at between 10,000 and 25,000 km^2 by different literature sources.

Figure 6: Geographic map of Cameroon

One can immediately see that the simple spread of Cameroon across different climatic zones calls for very sophisticated regional planning and management. Both have to be adapted to the different climatic zones, from the humid and almost tropical South (ocean) to the very dry North (Lake Chad). In the North, desertification is an important issue and is also one of the major factors in the decreasing size of the lake that has been observed in the past 20 years. For this reason, a lake commission was funded by the different countries involved to coordinate work to re-establish the lake's level or, at least, to deal with the new economic and ecological situation. The most important need is therefore for up-to-date maps and information that show the changes in the lake's level and size from one year to the next.

Through these observations, trends can be established and used for medium- and long-term planning for infrastructure items such as roads, etc.

Turning to the environmental issue, the smaller the lake surface becomes, the higher will be the salinity of the lake (through evaporation of the water). This leads to lower amounts of fish (fish normally adapt to a certain level of salinity; changes in these conditions lead to their death). In addition, the original lake bottom which emerges when the lake is decreasing and which is saturated by salt, is blown away and «pollutes» the surrounding agricultural area.

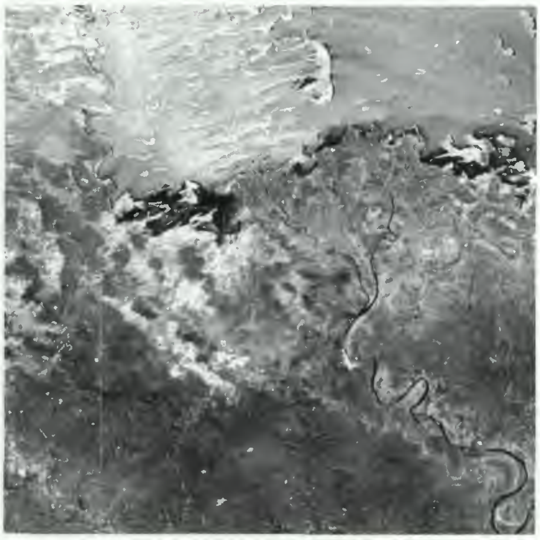


Image 14: ERS-SAR scene acquired on August 1, 1994

This desertification effect is very difficult to overcome (recultivation of fields) as the salt needs to be washed out or kept below the fertile soil. This is a very expensive and not always successful process.

Image 14 shows the southern border of Lake Chad in a light grey. Some parts of the coastal zone, being in the wind shadow of islands, appear black, due to a flat water surface (no waves). On the left hand side of the image one can see the river Chari. The white spot on the left of the river is a smaller city. Grey level differences over the land surface are due to changes in the composition of the vegetation.

Images 15 and 16 show the gains that can be achieved through the use of a multitemporal approach and image filtering.

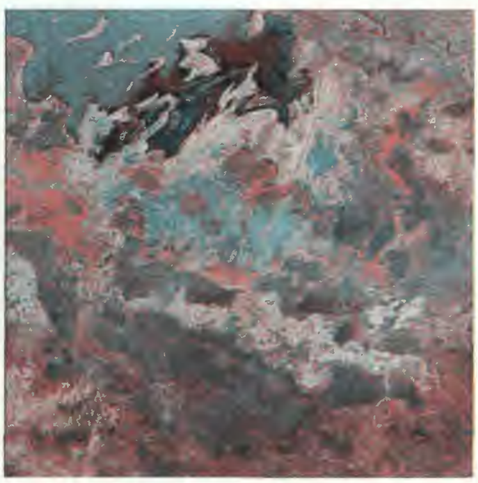


Image 15: Multitemporal subset (non-filtered)

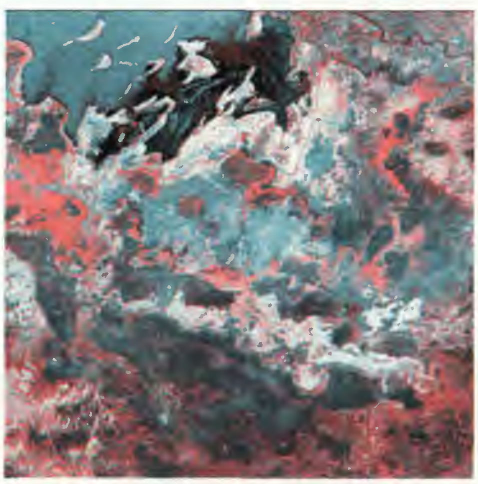


Image 16: Multitemporal subset (filtered)

A number of simple rules can be applied for the interpretation of these multitemporal data sets. First of all, one can see that some areas are black or white, which means that the surface did not change from one image to the next (difference of 20 days). As the agriculture surface changes very quickly due to the growth of plants or the increase or decrease of humidity in the soil, those areas which tend to keep their grey level can be considered to be stable and covered by material which does not change its spectral properties very quickly.

Different investigations have shown that forests generally appear in a darker colour in ERS-SAR images. Therefore these areas in the lower part of the images must be interpreted as wooded surfaces. White areas are probably sand dunes. Those areas with different grey values between the first and second dates are potentially cultivated.

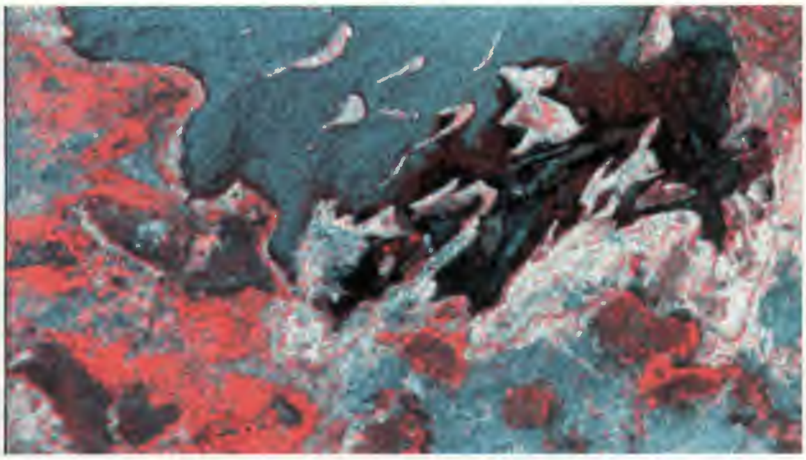


Image 17: Multitemporal subset showing the shoreline of lake Chad

Image 17 shows a full resolution filtered multitemporal subset of the coastal zone. This example demonstrates that it is possible to map the shoreline of the lake. One needs to apply the multitemporal approach as, depending on the wind speed and direction on a particular date, land surface and large water bodies like Lake Chad tend to exhibit similar grey levels.

Image 18 shows a phenomenon which is probably due to the extension of the lake's surface. Apparently, the lake has been growing in the past year and sand dunes (former land) have been submerged by it. Only the peaks of these dunes can still be seen.

Image 18: Submerged sand dunes in lake Chad seen from ERS-SAR

Image 19, covering an area south of the lake, was acquired in order to study the potential of ERS-SAR for the monitoring of different land-cover classes and general topographic mapping in this semi-arid zone.

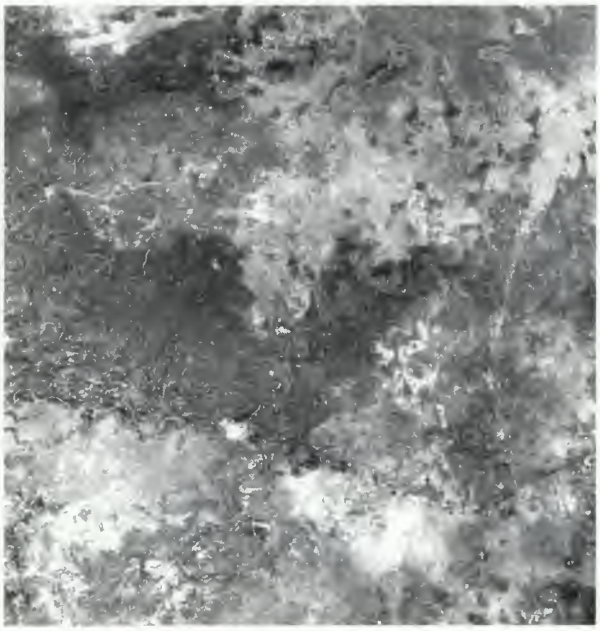


Image 19: Full image (processed with average filter) acquired on August 12, 1994

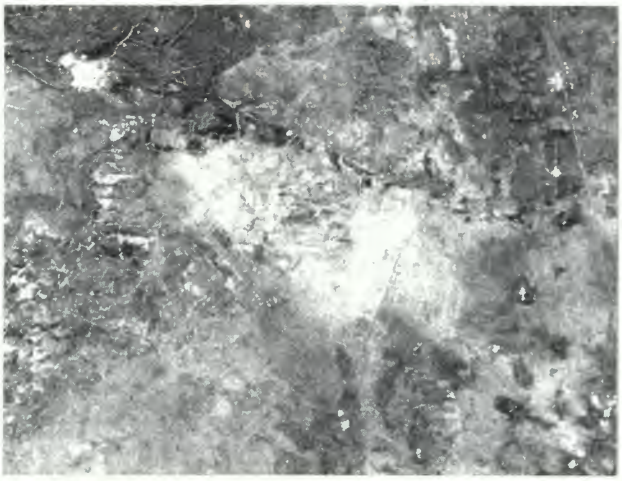


Image 20: Subset of an ERS-SAR scene over a cultivated area south of lake Chad

Features that can be interpreted in the image include a large number of grey lines on the left side which correspond to the old river beds. The feature in the lower region expressed as a large number of black spots can be explained by metallic deposits which are less eroded than the surface. As the lake surface is reported to have been much larger in former times and these «hills» were considered to be above flood level, the housing areas on these «hills» (white spots) can be explained and easily mapped. A more detailed interpretation of cultivated areas is possible from images 20 and 21. On image 20, one can see a number of smaller fields on the left side which are probably enclosed by bushes in order to reduce wind erosion. The large white area in the middle of the image potentially corresponds to a dry field (smooth surface). Small white spots in the lower part are houses or villages located on the small hills described above.

Image 21 shows another subset of the scene with some agricultural fields visible as well as a road with villages to the side, which probably leads to the lake located in the north of this area. This subset clearly demonstrates that cartographic map updates can be performed with ERS-SAR data. New housing areas as well as roads can be easily detected. For the mapping of agriculture, one should have at least two images of the same area (multitemporal approach).

The images shown above demonstrate very impressively the capabilities of ERS-SAR data for basic cartographic mapping in this climatic zone. Specifically this will consist of mapping the lake extension and the river network. Changes in surface area and the drying-out or flooding of river beds can be quickly identified. The low price of the images and the need for relatively limited processing software and hardware might be a further advantage and argument for the integration of these data into the operational cycle of map updates. Of course, the images also show that very precise cartography from «scratch» is very difficult to perform with radar data. Assuming that a much higher level of expertise on local phenomena is available in each country, then mapping at a scale of 1:100,000 to 1:500,000 should be feasible. Studies requiring a larger scale (e.g. 1:50,000) are possible, but class affiliation to land cover types will become more difficult to handle.

Image 21:
Subset with road and housing features

4.3 Gabon

The Republic of Gabon covers 267,667 km^2 and has a population of 1,3 million (information 1991). Its capital is Libreville (352,000 inhabitants - information 1987). The major sources of income are the exploitation of forests and oil fields on the coastal shelf.

Besides the natural resources of the tropical forests, large coastal areas of Gabon are covered by mangrove forests, an ecosystem of particular importance for the diversity of marine and land fauna and flora. Together with the tropical forests, which are normally exploited by clear-cuttings, mangrove forests play an important role in the stability of the global climate. Pressure on this ecosystem has recently increased through the growth in shrimp farming, which uses the coastal zones for their cultivation and for which the mangrove forest has to be destroyed.

In order to ensure a sustainable development of the mangroves by reducing the effect of «wild cutting», a permanent mangrove forest surveillance system could be envisaged. Such a system would also provide the opportunity to regularly update the cartographic maps of the country (or at least the sensitive coastal regions).

The next ERS-SAR image (image 22) was acquired on July 28, 1994 over an area to the south of Libreville.

Figure 7: Geographic map of Gabon

The river estuary (upper left) appearing in black is that of the river Ogooué. The white area along the river can clearly be identified as mangrove forest. The black spots in the lower part correspond to lakes, one of which is lake Azingo. The grey area, covering almost the whole image, is tropical forest.

Image 22:
ERS-SAR scene acquired on July 28, 1994
region in the south of Libreville, Gabon

Image 23:
Subset - ERS-SAR for mangrove mapping
(processed with an 8 x 8 pixels moving average filter)

A further subset (image 23) shows more details of the mangrove forest, the boundaries of which can easily be detected and mapped. The hydrological network can also be seen and mapped in detail. For this cartographic approach, a scale of 1:50,000 is sufficient.

In order to test the consistency of the detectability of mangrove forests, a second image was interpreted, acquired on August 14, 1994. This subset (image 24) showing the border region between Gabon and Equatorial Guinea shows the same results.

Image 24: ERS-SAR subset (filtered) at the border between Equatorial Guinea and Gabon

The mangrove forest is easy to detect and map as a white area. In this case, the forest around the estuary of the rivers Noya and Temponi is more oriented towards the land surface. The grey areas in the estuary correspond to a coverage of reed which might, in some cases, hinder ship traffic.

Image 25 gives an overview of the northern coast of Gabon. One can see the estuary/mangrove area already shown in image 24. In the southern part, another mangrove forest is visible which is close to the capital of Gabon, Libreville, which borders the ocean and appears as a white area. The black line above Libreville is the airport. Light grey areas, covering the majority of the land surface, correspond to tropical forests.

Image 25:
Overview scene acquired on
August 14, 1994
(Libreville in the lower part)

Looking in more detail into the urban area of Libreville (image 26), one can clearly differentiate the airport to the upper left as well as a number of roads within the city.

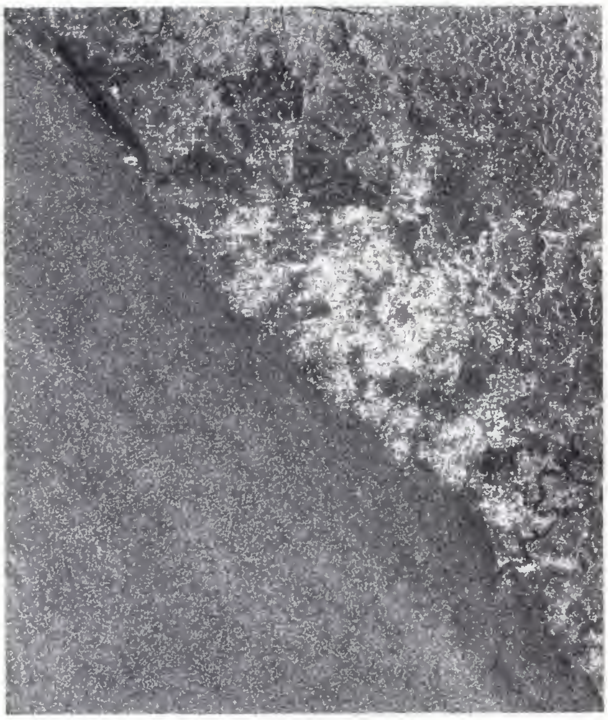


Image 26: Libreville

However, the image also shows the limitations of ERS-SAR data for urban applications.The boundary of the urbanization can be identified but inside the city it is difficult to distinguish different subgroups. One can see a few towers (white crosses) and a zone with denser housing, but the data does not fully meet the needs of town planners.

Oil terminals, visible in image 27, however, indicate the usefulness for regional planning. The distance of these terminals from housing areas might be important in the event of further development of this infrastructure, as well as for the planning of access roads. The white square visible in the southernmost part of the land surface probably corresponds to a lighthouse or a surveillance tower constructed for the guidance of ships entering the harbour area (white line left of the point).

The images below have not been filtered in order to preserve the contours in urban areas, which tend to disappear during the average filtering process.

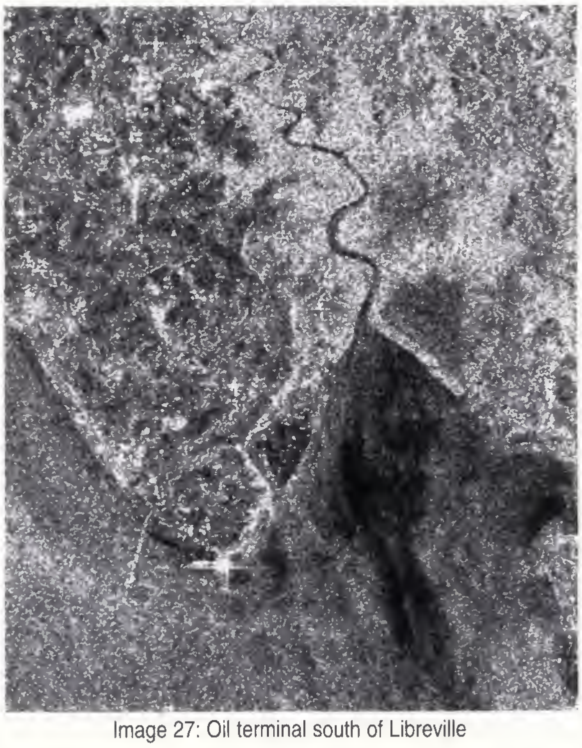


Image 27: Oil terminal south of Libreville

A further example over Gabon once again clearly indicates the usefulness of ERS-SAR data for regional cartography. Images 28 and 29 are from east of the estuary shown in image 22. In the very upper left of the image a bridge is visible as a white line crossing the river. When looking in detail at image 22 one can see that this is the only bridge that crosses the river for the next 20 km. A road runs parallel to the mountain chain to the south. On image 29 this road is visible as red line.

Image 28: ERS subset

Image 29: Simple cartographic interpretation of road network

The visible interpretation of these two images over Gabon provides a clear demonstration of the usefulness of ERS-SAR data for cartographic purposes on regional or national levels.

The SAR sensor could equally demonstrate its unique capabilities for the detection of mangrove forests in coastal zones and river estuaries. Specifically this unambigious identification of mangrove forests, which cannot be achieved with any optical sensor, should be further exploited in an operational system for mangrove management. The example of Libreville shows the limits of the SAR for local (urban) planning. The current and expected future maximum resolution of this type of sensor means that it can only be used to identify trends for urban developments.

4.4 Equatorial-Guinea

The Republic of Equatorial Guinea covers 28,051 km^2 and has a population of 360,000. Its major income comes from the exploitation of its forests.

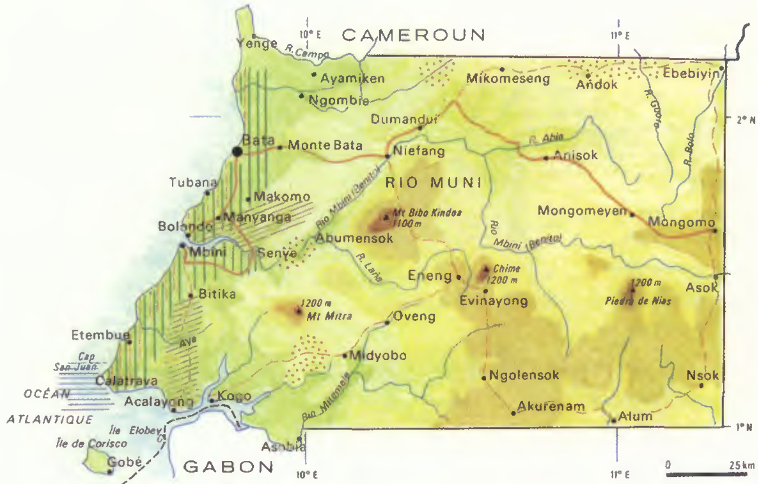


Figure 8:
Geographic map of Equatorial Guinea

The mangrove forest application of SAR has already been described for the border region between Gabon and Equatorial Guinea. Image 30 shows an area inside Equatorial Guinea which is completely covered by tropical forest. For overview purposes, a simple filtering enhances the visibility of the different features on this large scale. The second basic feature (besides the grey coverage corresponding to tropical forests) is the mountain chains on the left and right of the river that crosses the scene from the upper left to the lower right. The location of the mountain chains and their internal structure is of major interest for geological purposes such as the exploitation of minerals. This application is described in detail in Chapter 4.7.

In general, images with only one type of feature (here tropical forest) are much more difficult to interpret than images with a number of different features. In addition, georeferencing is often almost impossible because it generally tends to be difficult to match satellite data with ground control points on large scale maps. In such cases, rivers are often the only way to match image and map. In areas where these problems are encountered, it is recommended to limit scales to above 1:500,000 in order to avoid location errors which are too great. Often, it may be useful to mosaic a few images with the same orbit conditions (ascending or descending), as georeferencing points might be identifiable on the multitemporal image with greatest precision.

One should however not overestimate this problem as basic features can also be extracted from the original data set through visible interpretation followed by a digitalization of the result, which is finally georeferenced with less difficulty than the original image. In case almost no points are found in the image, it is very useful to look through the data set in detail with a full screen resolution. Image 31 shows an example of what additional features can be seen when such «browsing» is performed. In this image one can not only detect the river bed in great detail, but also see a small village which can provide a new reference point.

Image 30: ERS overview image (100 x 100 km) not filtered

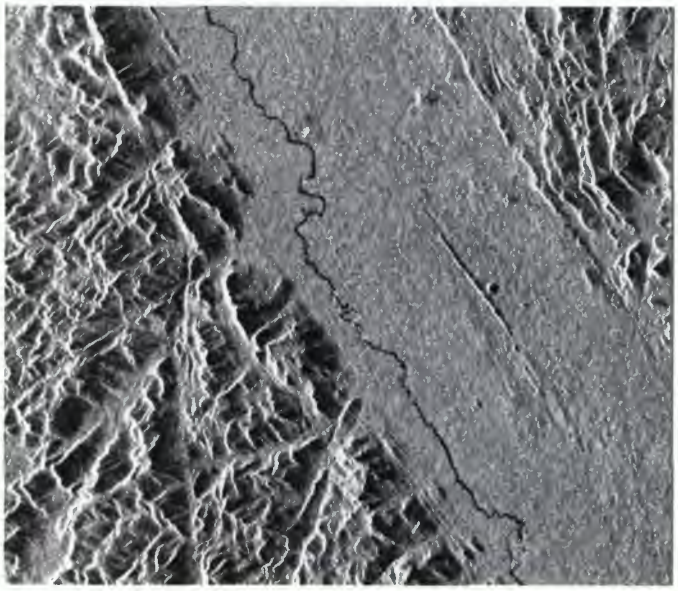


Image 31: Subset with almost full screen resolution

4.5 Cabinda (Angola)

Cabinda is part of the People's Republic of Angola, separated from it by a small area around the river Congo which secures Zaire's access to the ocean.

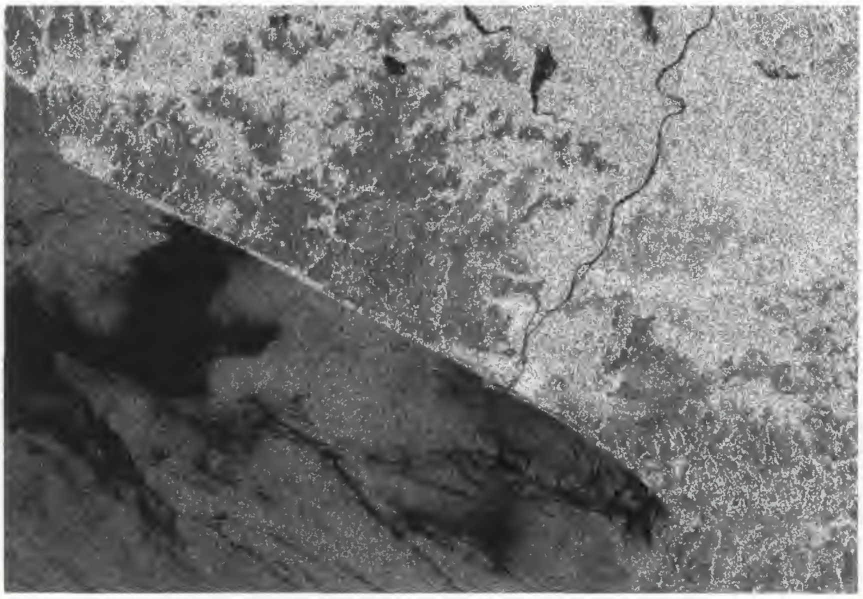
Figure 9: Geographic map of Cabinda

The major income in this part of Angola comes from the exploitation of forests. Agricultural products are only used for national food supply. Oil prospecting is underway on the continental shelf .

Image 32 provides an overview of the coastal zone of Cabinda. Different grey levels indicate a certain variability of the land cover. A coherent grey surface (as, for example, in Equatorial Guinea) cannot be detected. For detailed interpretation of the different land use patterns, a multitemporal approach would be very valuable as assessment via a mono-temporal approach without any terrain knowledge is very difficult.

One can however speculate that the dark areas are likely to correspond to wooded areas (also due to the fact that this area encloses some mountain ridges visible in the lower left side of the image). The light grey area is possibly covered by savanna.

Image 32:
Coastal zone of Cabinda (Angola) seen from ERS-SAR (Image acquired on August 14, 1994)



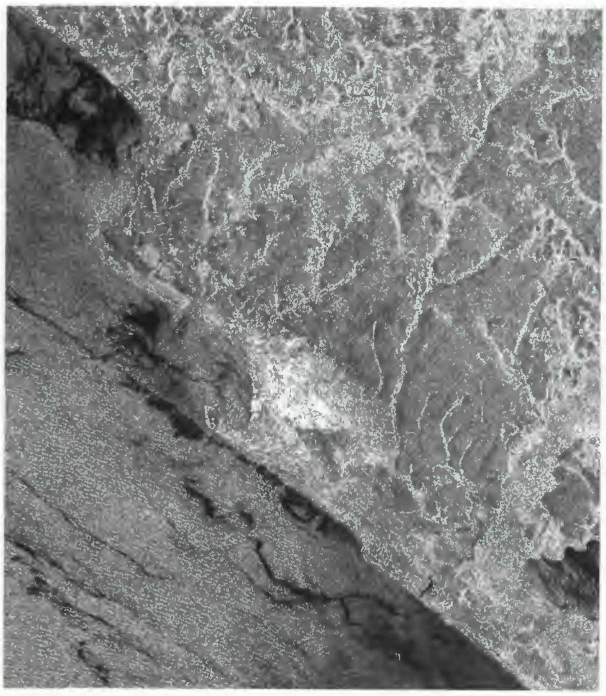


Image 33: Town of Cabinda

Image 33 shows the town of Cabinda (white in the image) which is located in front of a hilly terrain cut into smaller areas by valleys (visible in light grey).

4.6 Central African Republic

The Central African Republic has a surface area of 622,984 km² and about 2,9 million inhabitants. Its major income comes from the exploitation of minerals. Figure 10 is a geographic overview map of the country.

Figure 10:
Geographic map of the Central African Republic

The mapping of geological features related to the potential exploitation of minerals can be considered as very important for the economies of Central African countries that are not industrialized.

Radar data have been used for the mapping of geological features. These data were acquired during airborne campaigns and interpreted for detailed geological surveys aimed at the preparation of mineral exploitation. The availability of large scale (compared to aerial photography) ERS-SAR data is very much complementary, as a first survey can be made with satellite data in order to identify areas of major interest, which can then be mapped from aircraft in more detail. This complementarity of methods can save a lot of money.

An ERS-SAR image of the Carnot region acquired on August 8, 1994 during a descending orbit was analysed in detail by the LGGST (Laboratoire de géologie-géomorphologie structurale et télédétection, Université Pierre et Marie Curie, Paris) in order to evaluate and demonstrate the general interest of using radar data for geological purposes in Central Africa.

For this analysis, two geological maps provided by Barbet (1939) and Gérard (1950), being the most recent products, were used as reference data. Image 34 clearly shows three major fractions: NS, NE-SW and NW-SE. It is difficult to define the chronological relation between the different directions, but one could imagine that the NS structures were disturbed by the NE-SW fracture.

Image 34:
Full ERS-SAR image of the Carnot region (Central African Republic) acquired on August 8, 1994 principal structural direction are indicated with white arrows

Image 35 : ERS-SAR subset

In images 35 and 36, a distinction between the gneisic bedrock formation (Gn) and the above lying standstone formation (Gr) can be made. This sandstone (Carnot) has a smooth texture, disturbed by a network of thalwegs and drainages all located within 2 to 3 kms.

The gneisic formation, characterized by higher retrodiffusion values (visible in a light grey), shows a rougher texture and a denser hydrological network (1 km). Thus, one can locate the boundary between the two formations with an accuracy of about 1 km. Within the bedrock formation, a number of lithological units can be distinguished, but boundaries are very difficult to find. The two different types of gneis (indicated in the map) can also be separated.

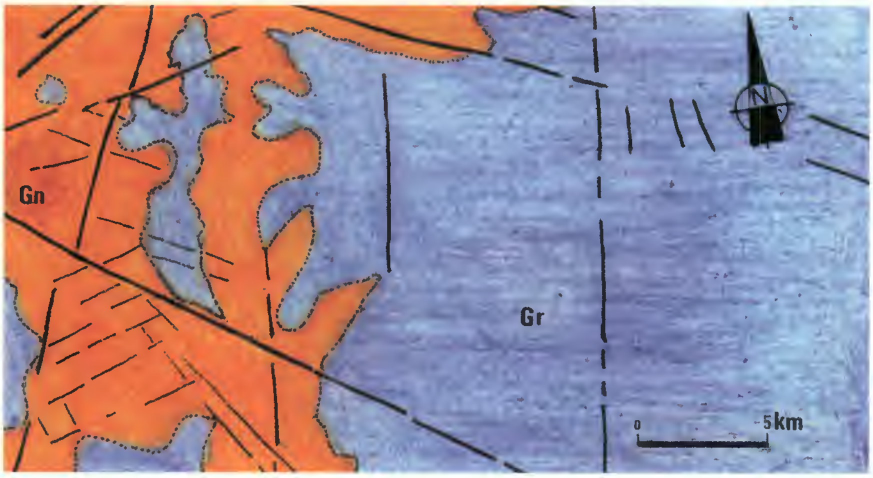


Image 36: interpreted geological map - Gn: Gneiss, Gr: Sand stone

Image 37: ERS-SAR subset

Images 37 and 38 show the difference between the underlying quartz schist (Qs) and the covering sandstone formation (Gr). The underlying formation has a very specific texture of turned lines due to quartz banks that form small slopes oriented towards the West. These different lithological units can be mapped by taking into account mainly the texture and the hydrological network.

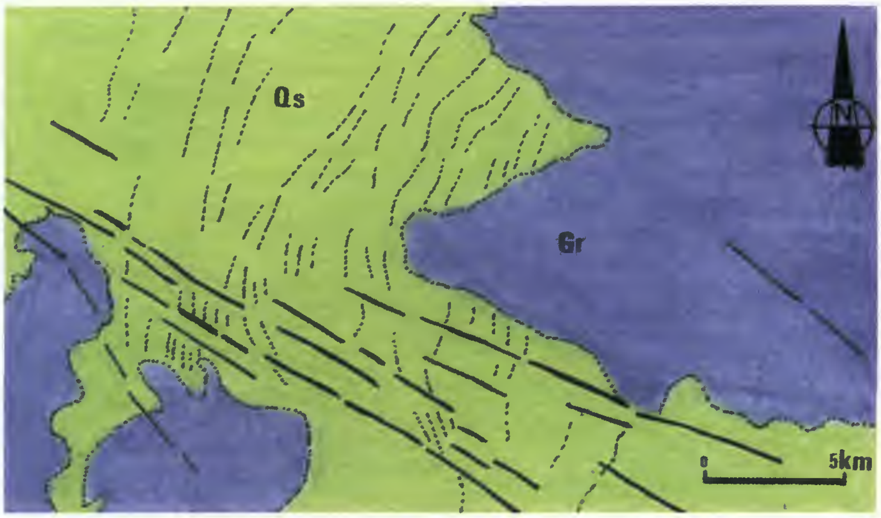


Image 38: interpreted geological map Gr: Sand stone, Qs: quartzid

Image 39: ERS-SAR subset

Image 40: interpreted geological map
A: Amphibolites, Rg: rocks

Within images 39 and 40 a large number of folds (east-west oriented) can be observed in the bedrock formation. These folds, not indicated at all on the reference maps, should be studied in more detail in the field.

Even this short analysis of the ERS-SAR imagery over the Central African Republic shows the high potential of radar data for geological mapping, providing new information not shown on existing maps. Based on the radiometric and geometric characteristics of the ERS-SAR (sensitive to surface roughness and relief variations, type of hydrological network, etc.), a number of new geological and geomorphological units can be identified. The different rock types can be distinguished, as well as the different fractions and folds. Thus, ERS-SAR images provide new information that complements the available maps. Although the general texture observed in the image can also be found in the map, details vary a great deal. Specifically, the extension and boundaries of the different features seem to be identified much less accurately on the map. These differences should, however, be validated by a field trip.

In a region mainly covered by dense vegetation (like the region studied), the identification of lithological units is possible by mapping the texture expressed by the hydrological network. This mapping can easily be performed by a visual interpretation of a georeferenced image. If a more sophisticated approach is to be applied, one can use programmes extracting textures in an automatic way, followed by a segmentation that recognizes homogeneous forms.

In conclusion, it can be underlined that geological applications in Central Africa can benefit greatly from the use of ERS-SAR data. The above images and their interpretations show that spaceborne radar data is the only practical way of complementing existing geological maps, as the almost permanent cloud cover does not allow the use of optical sensors. In addition, large areas can be covered at relatively low cost by exploiting satellite images, which favours their use in Third World countries.

5 CONCLUSIONS & RECOMMENDATIONS

Through the above description of ERS-SAR image interpretation, a number of advantages and limitations to the use of radar data for mapping, monitoring and management of natural resources have become evident. The most important are:

- Cartographic maps and land cover maps can be considered one of the basic needs in African countries, to ensure their sustainable regional and national development. The scales of 1:500,000 for evaluations at national level and 1:100,000 for regional planning can be considered as most adequate, containing a relatively small number of classes. This reduced number of land cover classes should be considered at least for those countries that extend geographically over more than one climatic zone.

  ERS-SAR data fulfil these basic mapping requirements. Scales of 1:100,000 to 1:500,000 can be achieved without any major problem while taking the reduced number of classes into account. In order to better identify the different land cover classes, the multitemporal approach has been shown to be the best solution. However, it is not necessary to acquire a large number of images, but only 2 to 3. The images analysed above were taken in July and August, which seems to be a season when a large number of features can be identified. Images taken in other seasons should equally be investigated.

  The processing of the data has been reduced to mandatory step reflection around an axis and the (not mandatory) transfer from 16 to 8 bits. This latter step is specifically recommended as the size of the original data set (120 megabytes) makes it difficult to handle when using less sophisticated hardware. To reduce speckle, an averaging filter, available in almost all image processing software packages currently on the market, was used. The size of the moving box should be chosen based on the image size. For a full scene, a 10 x 10 box is useful for overview purposes. For the interpretation of the images, a computer-aided visual approach was preferred (through digitalization on the screen). Currently available methods for automatic classification were tested for certain images but did not produce any significant improvements.

- Within the application area of «Forestry», the capabilities of ERS to detect mangrove forests have to be specifically emphasized. The highly valuable results obtained through a visual inspection of the images allow us to state that mangrove forests can be identified with almost one hundred percent accuracy. Thus, monotemporal data sets seem to be a sufficient support. Confusion in radiometric terms only appears with towns that have a similar grey level (very bright). The identification of tropical forests is more difficult to achieve. Four cases are possible:
  - The region of interest is almost completely covered by forest - the data will show up in an uniform grey. When there are some mountains or hills they can be seen in a quasi-three-dimensional way. Beyond the identification of these forests, no further distinction between different types is possible. It has to be assumed that the mountain ranges are also covered by forests.
  - There are clearings within the forests; in the majority of cases, these clearings can be identified when they are large enough and not covered by bushes. Cuts through shifting cultivation are very difficult to identify as trees normally remain in the fields.
  - Forested areas remain in a region used for agriculture. The identification of the forests largely depends on the crop types cultivated. The higher the crops (bananas, etc.), the lower the chance of distinguishing the forests from the crops (similar reflectance).
  - Forests only remain in some remote locations which are normally mountain ranges. Due to the reflection of the radar signal in hilly terrain, the detection of forests is very difficult. The use of DTM's has been shown to give some good results. One should, however, analyse the benefits as the generation of DTM's is generally very expensive and forest interpretation results are not automatically improved.
- The mapping and monitoring of hydrological phenomena can be considered one of the most adequate application areas for ERS-SAR data. Monitoring of lake levels and extensions as well as flood monitoring have given very good results. Visual interpretation of the images is recommended and sophisticated image-processing equipment is not mandatory.
- Tropical agriculture is very difficult to monitor as crop signatures tend to be confused with the surrounding natural vegetation. The monitoring of rice with ERS-SAR is the only but very important exception as certain stages (flooded fields) give a unique reflection. Swampy areas might be classified as rice. Also here, no complex image interpretation equipment is necessary for the processing of data. Automatic classifications are possible, but algorithms are still under development.
- The use of radar data for urban applications should be assessed very carefully. Due to the resolution of the images (about 20 m), their capabilities for the detection of inner-city roads and distinction of different housing areas is of less interest. An adequate application was, however, found in terms of mapping remote villages and housing areas, which clearly appear as white spots in the radar data.

- The detection of geological features to be used for general purposes as well as the later exploitation of minerals can be considered very worthwhile. Images can be used for overview mapping accompanied by field surveys. Scales around 1:500,000 are considered the most valuable.

In addition to the above points related to selected applications, a number of advantages of a more general nature should not be forgotten. First and foremost, one should consider the ERS-SAR's ability to penetrate cloud cover. With ESA's current and planned missions (ERS-1, ERS-2, Envisat...) this implies the long term availability of data acquired with each satellite pass (every 15 days in general). Unfortunately, the availability of ERS-SAR data over Central African countries is more problematical as no receiving station (apart from the mobile station of DLR) can cover the whole region. The area between the South African station and the one at Maspalomas will remain uncovered (in terms of ERS acquisitions) until a receiving station has been installed in the area or a satellite is capable of recording data on-board (Radarsat and Envisat will have this capacity).

Until then, users in Central Africa will have to rely on data which were acquired in 1994 and 1995. For a large number of the applications described above, this is however not a limitation (at least to start with). Among these applications, regional cartography could easily use the already acquired data sets for a first updating of maps. This also applies to forestry and mangrove issues where ERS-SAR data could demonstrate its usefulness. Existing radar images can therefore be used extensively to prepare for the future operational availability of SAR imagery over Central Africa.

However, one of the major necessary prerequisites is further support to co-operative projects between European and African institutions in order to better introduce the new technique into national plans and adapt it to their particular needs. A number of pilot projects of national, regional or even global interest could be carried out for this purpose:

- **A west African mangrove mapping project:** ERS's capabilities for mangrove forest detection and mapping were impressively demonstrated in Chapter 5. Knowledge of the current mangrove status (location, pressure, etc.) on a regional scale would allow the countries to manage their development better. Precise data could be introduced into global databases on climate change and bio-diversity.
- **A cartography demonstration project:** FAO is currently carrying out a project called Africover dealing with the description of the available cartographic bases in Africa. The ultimate goal is to create a general map for regional and national scale applications. It should be re-emphasized here that the availability or otherwise of topographic maps over a particular country or region strongly influences its development.
- **A Lake Chad Observatory:** This is aimed at long-term study of the lake's level. Projects are currently underway, but radar data have not yet been introduced due to their non-availability in the past. In addition, by exploiting the specific capabilities of ERS imagery in relation to hydrological applications, flooding or in more general terms projects dealing with the operational observation of rivers and lakes, could be investigated. Strong interest on the part of scientific groups dealing with the global hydrological cycle can be expected, in addition to that from national and regional institutes.

Annex

The purpose of this Annex is to provide the interested, potential user with useful addresses from which to obtain more information and support should problems occur during the processing of ERS-SAR images. It also provides bibliographic information.

Data can be ordered through the consortium (Eurimage, Spot Image and Radarsat International) which ensures the global marketing of ERS data. The French company Spot Image is responsible for the distribution of data over Africa:

Spot Image
5, rue des Satellites
BP 4359
F-31030 Toulouse cedex - France
Tel.: (33) 62 19 40 40 - Fax: (33) 62 19 40 11

Eurimage distributes data in Europe, while Radarsat covers America.

Several organisations in Europe offer specific training courses on the use and interpretation of radar data. Users unfamiliar with the detailed interpretation of remote sensing data are recommended to participate in one of these courses, which are given several times per year by:

GDTA
18, avenue Edouard-Belin
F-31055 Toulouse cedex - France
Tel: (33) 61 27 42 90 - Fax: (33) 61 28 14 98
or
ITC
350 Boulevard 1945
PO Box 6
NL-7500 AA Enschede - The Netherlands
Tel.: (31) 53 874 444 - Fax: (31) 53 874 400

More specific problems concerning image interpretation can be resolved by contacting:

ERS Data Utilization Section
ESA/ESRIN
Via Galileo Galilei
I-00044 Frascati - Italy
Tel. (39) 6 941 80 626 or 625- Fax: (39) 6 941 80 622

ESRIN also organizes training courses, in collaboration with Eurimage. Information about these can be obtained from the ERS Help Desk at ESRIN: Tel.: (39) 6 941 80 666 - Fax: (39) 6 941 80 272/292

The ERS Help Desk also provides information on ERS missions, available products and prices, etc...

Several documents have already been published by ESA concerning the basic features and applications of ERS data:

- ERS-SAR System (SP-1146).
- ERS User Handbook (SP-1148).
- ESA ERS-SAR Product Specification (SP-1149).
- The CD Guide to ERS-SAR (SP-1155).
- SAR Ocean Feature Cataloque (SP-1174).
- Land and Sea - ERS-SAR Applications (BR-109).
- News Views of the Earth (SP-1176/Vols. I & II).
- Satellite Radar in Agriculture (SP-1185)

Additional documents are currently being prepared. All of these publications can be obtained at nominal cost from:

ESA Publications Division
Keplerlaan 1
NL-2200 AG Noordwijk
The Netherlands
Tel.: (31) 71 565 3400 - Fax: (31) 71 565 54 33

The Proceedings of the ERS-1 Pilot Project Workshops in Cannes (1992), Hamburg (1993) Toledo (1994) and London (1995) can also be obtained from ESA Publications Division.

This short bibliographic list may be useful, but does not pretend to be comprehensive:

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Contact: ESA Publications Division
c/o ESTEC, PO Box 299, 2200 AG Noordwijk, The Netherlands
Tel (31) 71 565 3400 - Fax (31) 71 565 5433