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REPORT ON THE UNITED NATIONS/EUROPEAN SPACE AGENCY TRAINING COURSE ON THE USE OF ERS-1 DATA FOR THE MAPPING AND INVENTORY OF NATURAL RESOURCES IN AFRICA

(Libreville, Gabon 15-19 May 1995)

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INTRODUCTION

A. Background and objectives

1. A mobile receiving station which is capable of receiving data from the ERS-1 and ERS-2 radar satellites has been operational at Libreville, Gabon, since late 1994. The coverage of the station is a roughly circular geographical zone centred on Libreville which extends, to the north-west, as far as eastern Mali, and to the south-west, as far as the western regions of Zambia. The territories of 23 African countries, of which 17 are francophone, are either wholly or predominantly covered by the Libreville station. The near-equatorial location of the receiving station and the cloud-penetration characteristics of radar render the station particularly useful to those countries whose exploitation of conventional optical remote sensing data has been severely hampered due to the presence of heavy cloud cover, which often obstructs observation of the ground in equatorial zones.

2. The objective of the training course was to provide participants with the knowledge and skills necessary to use radar data in a number of application areas that correspond with major regional and national interests, in particular those pertaining to agriculture, forestry, geology, mineral exploration and land use. Knowledge of radar image interpretation is becoming increasingly important because of the growing number of operational and planned radar satellites (e.g. ERS-1, ERS-2, JERS-1, Radarsat) and the attendant increasing use of spaceborne radar as a tool to monitor tropical regions. The training course was co-sponsored by the European Space Agency (ESA) and the United Nations. It was held at Libreville, Gabon, from 15 to 19 May 1995, for the benefit of francophone countries within the region served by the receiving station. The course was conducted as part of the 1995 activities of the Space Applications Programme of the Office for Outer Space Affairs, which is mandated to promote the awareness of advanced technologies and greater cooperation in space science and technology between developing and developed countries as well as among developing countries.

3. The present report includes descriptions of the organization of the training course and enumerates the recommendations for follow-up action. In particular, it details plans for a number of projects of regional interest and scope which were elaborated by the participants themselves. The report has been prepared for the Committee on the Peaceful Uses of Outer Space and its Scientific and Technical Subcommittee. Participants are expected to report to the relevant authorities in their countries.

B. Organization and programme

4. Application forms and information on the training course were sent out in September 1994 by the United Nations to offices of the United Nations Development Programme (UNDP) for onward transmission to national authorities in 13 countries within the region: Angola, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Gabon, Mali, Niger, Togo and Zaire.

5. The training course was attended by 25 participants, 12 of whom were from Gabon. The other 13 participants were from the following nine countries: Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Congo, Gabon, Niger and Senegal. Other participants were from the Office for Outer Space Affairs, ESA, German Aerospace Research Establishment (DLR), Scot Conseil and Groupement pour le développement de la télédétection aérospatiale (GDTA).

6. Funds for the participation of the 13 international participants from developing countries were obtained from budgetary allocations of the United Nations and from financial support received from ESA. The Government of Gabon provided secretarial support and local transportation for the benefit of the participants.

7. A high official of the Ministry of Water, Forests, Post and Telecommunications, and the Environment, Mr. O. Mboulamatari, gave an address on behalf of the Government of Gabon at the opening ceremony. Addresses were also given by the representatives of ESA, UNDP and the Office for Outer Space Affairs. The Minister of Water,

Forests, Post and Telecommunications, and the Environment received the representatives of ESA and the Office for Outer Space Affairs together with nine high-ranking ministry officials. This ceremony as well as those of the opening and closing of the training course were covered by the local radio, newspaper and television media.

8. The programme of the training course (see annex I) was developed by the United Nations in consultation with ESA. The course was conducted through a series of lectures and practical exercises which emphasized the use of ERS data but did not exclude discussion of other satellite radar systems. On the last day of the training course, formal presentations were made followed by discussion of regional projects prepared by the participants in working groups for which access to and the use of ERS data would be a key element. One of the highlights of the course was a visit to the Libreville ERS receiving station, which was conducted by Mr. K. Reiniger of DLR, and followed a visit to the Ariane tracking station, conducted by Mr. Audegean of the Centre national d'études spatiales (CNES), the French space agency.

9. The principal instructor of the training course was Mr. M. Fea of ESA. Supplementary technical presentations were made by the representatives of DLR, GDTA, Scot Conseil and the Office for Outer Space Affairs. A concise summary of the major topics presented during the training course is given in section I, below. This is followed, in section II, by a presentation of the recommendations of a number of working groups. In addition to informal comments communicated to the United Nations during the course, a formal course-evaluation session (see section III, below) was held on the last day of the training course to gather input which would be useful for identifying future activities which would respond best to the needs of countries in the region. The proposed plan of follow-up activities is presented in section IV, below.

I. SUMMARY OF PRESENTATIONS

A. European remote sensing satellites and instrumentation

10. There are currently two ERS satellites in operation, ERS-1 and ERS-2, launched in July 1991 and April 1995, respectively. Both satellites are equipped with microwave (radar) instrumentation which penetrates cloud cover and darkness and provides information 24 hours a day. The satellites measure many parameters which are not currently measured by existing satellite systems. ERS data, when used either alone or in conjunction with other data, are particularly useful in the following applications: oceanography, glaciology, meteorology, forestry, soils, agriculture and hydrology.

11. The principal instruments on board the satellites include (a) an Active Microwave Instrument (AMI), which comprises a synthetic aperture radar (SAR) and a wind scatterometer; (b) a radar altimeter (RA); (c) an along-track scanning radiometer (ATSR), which comprises an infrared radiometer (IRR) and a microwave sounder (MWS); (d) precise range and range-rate equipment (PRARE), presently functioning only on ERS-2; and (e) a laser retroreflector. In addition, the ERS-2 mission contains the global ozone monitoring experiment (GOME), which provides atmospheric chemistry measurements (ozone and other gases) and an improved ATSR instrument that includes three visible channels.

12. SAR permits the acquisition of all-weather images of ocean-, ice- and land-surfaces and it facilitates the monitoring of coastal zones, polar ice, sea state, geological features, vegetation, land surface processes and hydrology. It also allows the derivation of digital elevation models (topographic maps). In wave mode, SAR is used to measure ocean-wave spectra and wave direction, while in scatterometer mode, AMI is used to measure wind direction and speed at the ocean surface. The radar altimeter permits the measurement of wind speed, wave height, sea-surface elevation, ice profile, land and ice topography, and sea-ice boundaries. ATSR is used to measure the surface temperatures of the sea, land and clouds. It is also used in the measurement of cloud cover, aerosols, vegetation, atmospheric water vapour and liquid water content. PRARE on ERS-2 provides precise corrections of

altimeter measurements. The laser retroreflector is a passive optical device used as a target by ground-based laser ranging stations in order to determine the accurate position of the satellite.[1]

13. The participants from countries in the equatorial regions of Africa showed the greatest interest in the terrestrial applications of images obtained using the SAR instrument. In image mode, the SAR instrument acquires strips of images 100 km in width to the right of the satellite track. The ground spatial resolution is 25 m. It is different from optical sensors in that it operates within a frequency range, designated C-band, at a nominal frequency of 5.3 GHz with vertical transmission and vertical reception of radar signals (VV polarization) and a look angle of 23 degrees.

14. ERS-1 has a sun-synchronous, near polar, quasi-circular orbit with a mean altitude of 785 km and an inclination of 98.5 degrees. It has a 35-day repeat cycle with a re-visit period of 16-18 days. Its orbital cycle is 101 minutes. The data transmission rate for the SAR instrument is 105 megabits per second. On-board recorders cannot be used to store SAR data, which can only be transmitted to receiving stations when these are in sight. ERS-2 is similar in operation to ERS-1. Following the commissioning phase of ERS-2, the two satellites will operate in tandem with ERS-2 following ERS-1 at a separation time of 1 day. This time of separation is subject to change. It is planned to maintain the ground track between the two satellites at 50-600 metres in order to improve opportunities for interferometric applications.

B. Interpretation of European remote sensing satellite data for applications of national interest

15. Radar remote sensing from space has a number of advantages over airborne radar. Unlike spaceborne radar where the incidence angle changes very little, in airborne applications there is a large change in incidence angle across the image swath, which causes difficulty in distinguishing whether changes in backscatter are related simply to changes in incident angle or to changes in the geometry and/or the materials themselves. The look angle for the ERS satellites is 23 degrees (the local angle of incidence on the ground is slightly greater than this due to the curvature of Earth). At this look angle, radar backscatter is strongly influenced by topographic slope. Hence, surface features which give rise to changes in topography, e.g. geological lineaments which may indicate mineral occurrences, are more easily interpretable using spaceborne imagery. Nevertheless, effects such as radar shadowing, layover (relief displacement) and foreshortening can complicate the visual interpretation of imagery of areas of rugged terrain.

16. Radar backscatter is dominated by the geometrical and electrical properties of surface materials, a fact which must be taken into account during the interpretation of radar images. Materials of varying roughness - a factor which is dependent on the particular radar wavelength being used - reflect the radar signal in different ways. Rough surfaces cause diffuse reflections in all directions and a significant portion of the signal is returned to the sensor. Smooth surfaces result in specular reflection with practically all of the signal being reflected away from the sensor. Very high return signals occur when adjacent smooth surfaces form right angles, which cause a double reflection and hence high return signals to the sensor. This occurs naturally, for example, in the case of tree trunks standing in swampy, water-logged areas.

17. The electrical character of surface material, as indicated by its complex dielectric constant, is also critical in the interpretation of radar images. Radar reflectivity is considerably increased in the presence of water, which has a dielectric constant greater than 10 times that of dry materials. This characteristic makes radar imagery especially useful in differentiating areas of dry from moist soil and in the identification of vegetated zones often characterized by high humidity that would give rise to a strong radar response.

18. Radar reflection from vegetation is also influenced by the type of polarization. In general, like-polarized signals, such as the VV polarization of the ERS instruments, are better at penetrating vegetation than crossed-polarized signals. While ERS and Radarsat satellites operate in the C-band, JERS-1 operates in the longer L-band. Radar penetration of vegetation - forests and agricultural crops - is influenced by the wavelength of the signal. Shorter wavelengths may be scattered by the tree canopy, however, longer wavelengths tend to penetrate it and be reflected by the underlying soil. The use of radar images of multiple wavelengths from multiple space platforms (e.g.

ERS/Radarsat, JERS-1, Shuttle Imaging Radar/Seasat) can therefore provide more information and allow for better differentiation in certain land-cover and forestry studies.

19. In general, through a knowledge of the interdependence of the factors which have a major influence on radar response (e.g. incidence angle, moisture content, surface roughness, geometry and slope orientation), ERS imagery corresponding to a single date can be interpreted for a variety of terrestrial applications. These applications can be placed in one or more of the following categories: (a) feature identification, (b) determination of the spatial extent of a feature of interest, (c) detection of change, e.g. deforestation, and (d) quantitative determination of biogeophysical parameters, e.g. soil-water content.

20. The interpretation of ERS imagery can be facilitated by digital enhancement procedures (filtering, colour coding etc.) that serve to highlight particular features of interest. Radar images are often characterized by speckle, which appears as a salt-and-pepper pattern. This effect is due to random constructive and destructive interference of radar waves that results in a random pattern of light and dark areas on the imagery. Speckle can be reduced by application of appropriate digital filtering or multi-look processing procedures. The reduction of speckle is a necessary precursor to computer classification of radar imagery as well as to visual interpretation since it tends to mask fine details.

21. In addition to the various possible enhancement of imagery from a single date, images from multiple dates can be exploited to yield new information, e.g. change detection. A single image from a given date may not be sufficient to differentiate several different crop types. However, two or more images acquired at different times during the growing season may allow differentiation of crop cover. In addition, colour composites of radar images of the same area taken at three different times can allow some differentiation of tree species and thereby avoid the difficulties of interpretation of tones and textures on a single image which may be due principally to variations in topography and not of tree species. Soils whose moisture content evolves differently during the year may be differentiated using multiple-date images.

22. In instances when both optical and radar satellite images are available, the two can be merged to exploit the complementarity that exists between the two data sets. Techniques for merging optical and radar data, such as the construction of colour composites and intensity-hue-saturation (IHS) transformations, can be employed to emphasize or de-emphasize surface features while retaining information from both data sets. Such merging operations must overcome difficulties of image co-registration, i.e. the accurate matching of common features appearing on both images when these are superimposed. For this reason, in areas of appreciable relief, a digital elevation model is used during registration to correct for relief displacements.

23. The technique of interferometry, by which the "phase" difference associated with a given pixel from two SAR images is analysed, allows for precise determination of elevation. The preparation of precise topographic maps from SAR images is therefore possible. Differential interferometry also allows for the monitoring of volcanic eruptions and earthquakes.

C. Data access and processing

24. Information on the availability of processed ERS data collected at the Libreville station and archived at the DLR facility at Oberpfaffenhofen, Germany, is readily available using a software program called DESC developed by ESA. The program allows interactive searching of a database to find and identify image frames which correspond to a geographic region of interest. This database is periodically updated by ESA and distributed to registered users. Updates can also be obtained electronically via the Internet.

25. The high volumes of data associated with digital processing (e.g. geocoding, enhancements) of ERS images necessitate access to fairly powerful PC-based systems with software capable of processing and displaying 16-bit ERS images. In addition, the production of high-quality prints of the digitally enhanced images would require access to large-format printers. The high costs inherent in the acquisition of these items of equipment may put digital image

processing of radar data out of the reach of some African institutions. However, the preparation of large-scale photographic prints of ERS images may be more cost-effective if it is initially left to service companies in Europe and elsewhere.

II. RECOMMENDATIONS OF THE WORKING GROUPS

26. Based on the potential usefulness of satellite radar data as presented during the training course, the participants identified a number of projects which could benefit from the radar data collected at the Libreville receiving station. Some of these projects are already ongoing and involve the institutions to which the participants are attached. The remainder are newly conceived project proposals. Summaries of the various projects are presented in tabular form in annex II. The tables regroup projects by theme, namely, (a) agriculture and forestry, (b) land use and landcover, and (c) mineral resources. The projects listed represent the output of three working groups, corresponding to each of the three application themes. These groups were constituted specifically to discuss national and regional development issues and to identify specific target activities which can benefit from the exploitation of ERS data. The working groups also made a number of recommendations which aim at enhancing the use of ERS data by countries within the region. These recommendations are aimed at all relevant entitites, including the United Nations, Governments and space agencies, whose timely interventions may serve to improve the present situation. The recommendations have been synthesized and are as follows:

(a) Participants should have access to more in-depth training on detailed radar image interpretation. In general, while a one-week training course is good for a general introduction to radar, a course lasting approximately three weeks is needed to develop the technical confidence needed to use the data on an operational basis;

(b) A follow-up training course should be organized to share operational experiences on applications of ERS data and to consolidate technical concepts introduced during the present course;

(c) Countries within the region should have access to the ERS images collected by the Libreville station;

(d) Cooperation between South-South and North-South in matters related to ERS data should be promoted and strengthened;

(e) Training should be given in Geographic Information Systems (GIS) technology and the integration of radar and other remote sensing data in GIS systems;

(f) Countries within the region should have access to technical assistance in matters related to the exploitation of radar images within an operational setting;

(g) National and regional institutions should be invited to participate in the demonstration studies of ERS data from the Libreville station.

27. There is as yet limited experience on the use of satellite radar images in tropical regions. For this reason, the operational usefulness of ERS data in African countries needs to be demonstrated. Necessarily, such a demonstration should involve African institutions and professionals who are knowledgeable of ground conditions and can attest to the usefulness and applicability of the radar data under their local conditions.

28. As illustrated in annex II, the problems which have already been encountered in existing projects or those that are envisaged in proposed ones concern the presence of heavy cloud cover on conventional optical satellite images. Thus, a principal need is adequate access to the radar images which have been collected by the ERS station at Libreville.

29. Only a few of the participants came from institutions which possessed the computer hardware and software needed for digital processing of voluminous ERS radar. Consequently, there was considerable discussion on ways in which to gain immediate access to the paper prints of digital images which would be suitably enhanced so as to highlight particular features of thematic interest, e.g. geology, land use and land cover, agriculture and forestry. In that regard, it appears that private companies in Europe which already have experience in the digital processing and enhancement of ERS data as well as in their photographic reproduction may be used to create large-scale photomaps. Such maps could easily be used at the present time by all of the countries represented at the training course. An eventual progression towards the digital processing and printing of ERS images is, however, highly desirable, particularly by participants from those national institutions which already have several years of experience in digital image analysis.

III. COURSE EVALUATION

30. Suggestions abstracted from the evaluation sheets filled in by the participants are as follows:

(a) Access to more detailed training (lasting at least 10 days) is highly desirable, in association with national or international entities experienced in the specific area of application;

(b) The course should devote more time for practical exercises;

(c) French documentation on ERS radar applications in all themes of interest should be made available;

(d) A wider distribution of information concerning training courses should be made available well ahead of their scheduling;

(e) Consideration should be given in order to avoid problems of distribution, to making direct contact with the national agencies or contact persons concerned, perhaps using electronic means, in addition to the normal official channels;

(f) The United Nations and ESA should maintain contact with the participants after the course in order to keep them abreast of developments in satellite radar technology;

(g) A follow-up meeting should be held in one or two years;

(h) Access should be given to training on digital analysis of radar images.

IV. PROPOSED FOLLOW-UP PLAN OF ACTION

31. The Office for Outer Space Affairs together with ESA propose to respond to the recommendations of the working groups and the various comments made during the course evaluation by undertaking the following activities:

(a) A number of projects will be selected from among those already proposed by the participants for possible assistance. In this regard, more detailed proposals than those elaborated during the course will be solicited from the participants in order to evaluate properly the relative merits of the various proposals and to facilitate the selection, on a competitive basis, of a number of projects worthy of support;

(b) Subsequently, arrangements will be made for supporting the selected projects within the framework of an assistance programme currently being developed jointly by the Office for Outer Space Affairs and ESA. As envisaged, this programme will provide limited support (e.g. training, access to satellite images and selected items of equipment needed for image interpretation) for ongoing activities;

(c) Expansion of the distribution of information related to the scheduling of the various training programmes and workshops organized each year by the Office for Outer Space Affairs will be made progressively to include selected national institutions whose activities may benefit from the application of space technology. Priority will be given to information distribution by electronic means (e.g. e-mail);

(d) Access to information pertaining to ERS applications will be improved. (Some action has already been taken by ESA in this regard. Specifically, the names of all course participants has been put on the ESA mailing list to receive the *Earth Observation Quarterly*. In addition, ESA has mailed copies of the DESC software program to all participants.);

(e) A follow-up advanced training course/seminar will be held involving participants who will have used ERS data from the Libreville station in an operational setting.

Notes

[1]European Space Agency, *Committee on Earth Observation Satellites: Coordination for the Next Decade*, 1995 CEOS Yearbook (United Kingdom, Smith System Engineering Limited, 1995) and European Space Agency, *ERS-1 User Handbook*, Louis Proud and Bruce Battrick, eds. (ESA SP-1148) (Noordwijke, Netherlands, 1992).

Annex I

PROGRAMME OF THE TRAINING COURSE

Time	***Subject***	***Speaker***
Monday, 15 May		
	Opening ceremony	
0930-1030	Addresses by the following:	
	• Representative of the United Nations Office for Outer Space Affairs	Hubert George
	• Resident Coordinator of UNDP	Toon Vissers
	• Representative of the European Space Agency	Karl Bergquist
	• Minister of Water and Forests, Post and Telecommunications and the Environment	Martin Fidèle Magnaga
	Basic concepts of radar remote sensing	
1130-1215	Remote sensing based on different regions of the electromagnetic spectrum	M. Fea, ESA
1215-1300	Theory and concepts of SAR	M. Fea, ESA
1430-1500	ERS: Space and ground segments	M. Fea, ESA
1500-1730	Practical exercises on satellite images	M. Fea, ESA
Tuesday, 16 May		
	Access to data and products	
0900-0945	Radar activities of GDTA	R. Nadal, GDTA
0945-1045	ERS: Data and products	M. Fea, ESA
1045-1130	Improvement of access to the information required for development: an initiative of the Office for Outer Space Affairs	H. George, OOSA
1130-1200	Access to and query of ERS databases: Demonstration of the DESC software	M. Fea, ESA

Time	*Subject*	*Speaker*
	Basic concepts of radar remote sensing (cont'd.)	
1200-1300	The complementarity between optical and radar data	R. Nadal, GDTA
1430-1530	Image quality, filtering, colour coding	M. Fea, ESA
1530-1730	Practical exercises on radar images	M. Fea, ESA
Wednesday, 17 May		
	Applications based on ERS radar data	
0900-0945	ERS data applied to problems of development in central Africa	P. Puyot-Lascassie (Scot Conseil)
0945-1130	Applications related to (a) land-use, (b) geology and mineral exploration, and (c) agriculture and forestry	M. Fea, ESA
1130-1300	A recent application of ERS data: radar interferometry	M. Fea, ESA
	Practical thematic exercises and group work on the analysis and the interpretation of ERS data within an African context	
1430-1630	Thematic exercises: the processing and interpretation of radar images	M. Fea, ESA
1630-1730	Group work on projects related to: ● Land cover and land use ● Geology and mineral exploration ● Agriculture and forestry	
Thursday, 18 May		
0900-1100	Visit to the mobile ERS satellite receiving station	K. Reiniger, DLR
1100-1200	Operation of the ERS satellite receiving station	K. Reiniger, DLR
1200-1300	Group work (continued)	
1430-1730	Group work (continued)	
Friday, 19 May		
0900-1300	Group work (continued)	
1430-1730	Presentation of group projects	
	Course evaluation and closing ceremony	
1700-1730	Course evaluation	
1730-1800	Closing ceremony	

Annex II

PROPOSED PROJECTS

Projects already in progress or for which funding is being sought – Agriculture and Forests

Title of project (Country)	Objective	Present status	Difficulties	Needs
Land use planning: (Benin)	Rational use of land in rural areas	Project finalized; funding being sought	Access to satellite images	Technical support from ESA
Land-cover mapping: (Burkina Faso)	Restoration of protected areas	Not specified	Insufficient photographic images	Acquisition of supplementary radar and optical satellite images
Study of crop systems: (Central African Republic)	Crop monitoring; land cover mapping	In progress (World Bank 1993-1998)	Significant cloud cover on SPOT images used for land use/land cover mapping	Access to paper prints of ERS radar images to complement SPOT images
(a) Crop monitoring: (b) Study of natural resources: (Chad)	Crop monitoring using NOAA images Update information on natural resources	In progress In progress	None specified	Use radar images to complement existing sources of information
(a) Agricultural map: (b) Forest-Environment (c) Forest stratification: (Gabon)	Updating maps on land use and natural resources Assure the sustainable development of the GAMBA complex Map of forest production areas (5 million hectares)	Funding being sought In progress Funding being sought from OIBT	Cloud cover on optical images Available IGN maps are out of date causing slow progress Cloud cover on optical images (SPOT and LANDSAT)	Access to radar and optical satellite images Access to appropriate satellite imagery Access to ERS images to complement existing information
Management of Natural Resources: (Niger)	Creation of updated maps	About to start	Cloud cover in SPOT and LANDSAT images	Access to ERS images to complement existing data

Proposed projects – Land use and land cover mapping

Title of project (Country)	Objective	Anticipated technical difficulties	Needs
Land use/land cover mapping of two test zones covering forested and degraded areas: (Burkina Faso)	Integrated land planning and management; monitoring of migrations	Poor availability of optical images (cloud cover greater than 30 per cent during the rainy season)	Access to prints and digital satellite images; computers, software, training
Remote sensing and image processing of radar images: (Cameroon)	Advanced research on radar image processing for regional and international applications related to littoral zones, hydrology, geology and geomorphology, human impacts	Heavy cloud cover in optical images of zones of interest	Access to a wide range of data including ERS satellite images
Monitoring of lakes using remote sensing: (Chad)	Mapping of lakes at 1:200,000 using SPOT and ERS images	Not specified	Technical assistance, equipment, training
Forest cover mapping: (Congo)	Update 1:200,000 maps of forested zones (e.g. "Mayombe" forest) using ERS and SPOT images	Heavy cloud cover	Technical assistance, equipment, training, documentation
Forestry management Urban planning: (Gabon)	Monitoring the exploitation of forests Establish plans for each town	Heavy cloud cover	Access to ERS and SPOT data; training

Proposed projects – Mineral resources

Title of project	Objective	Anticipated technical difficulties	Needs
Inventory of mineral resources (For countries in the geographic region covered by the ERS receiving station at Libreville)	*Medium term* Preparation of geological maps *Long term* Preparation of thematic maps	Heavy cloud cover	Access to ERS data Documentation, collaboration with institutions experienced in geological applications; equipment for radar image interpretation, training Access to topographic applications of satellite radar data