TREES ERS-1 Study '94 Final Workshop

AGENDA

ABSTRACTS

South East Asia Study Area

Latin America Study Area

Africa Study Area

LIST OF PARTICIPANTS
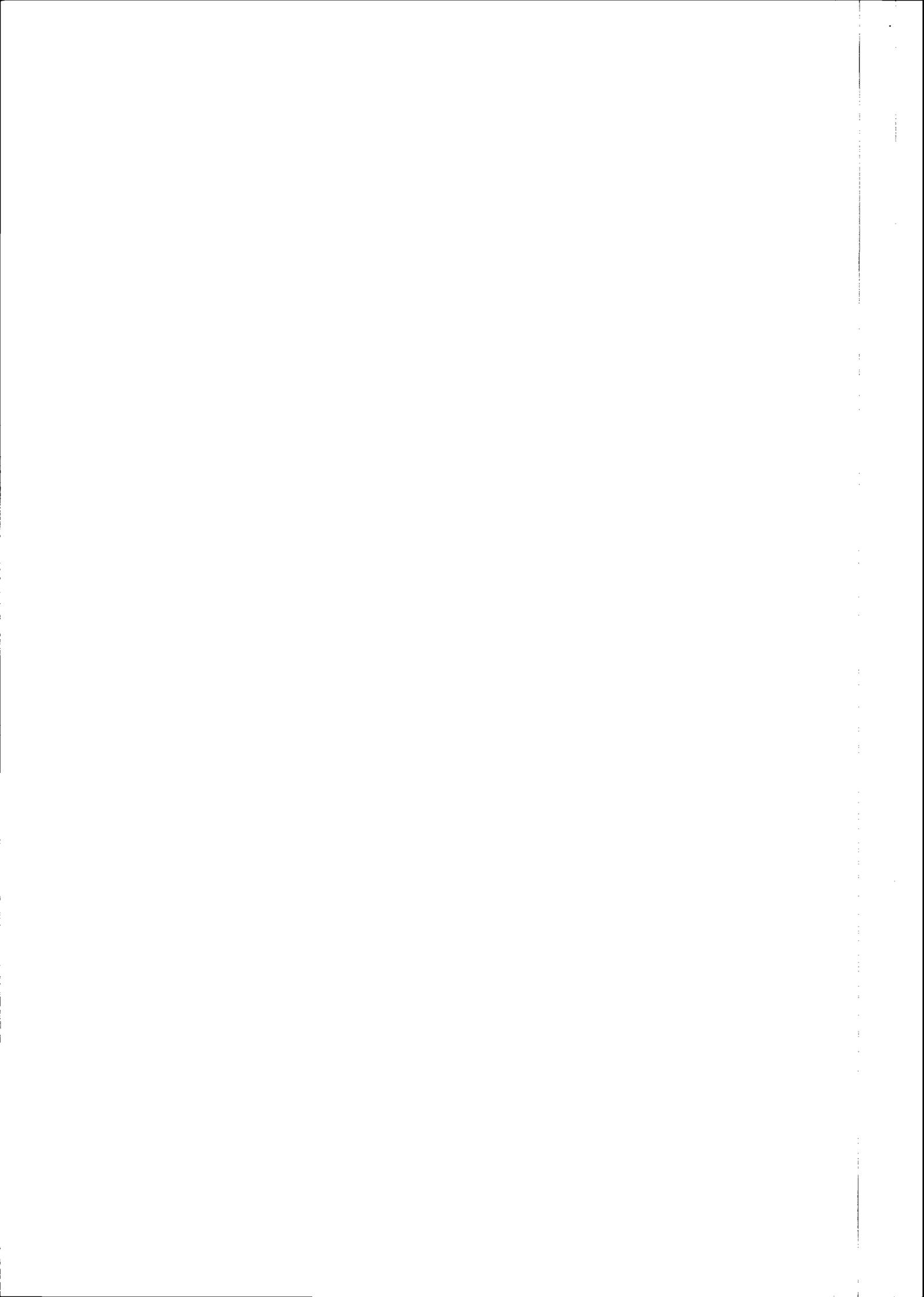
Thursday 23rd February 1995 (continued)

14.45 - 17.00: Investigations in Latin America
Chairperson: Alan Belward, JRC

LAM-6	Colombia-Araracuara:	Dirk Hoekman Agricultural University of Wageningen, NL
LAM-1	Panama/Costa Rica:	Guido Lemoine SYNOPTICS, NL
LAM-2	Brazil-Acre :	Jacquie Conway JRC Manfred Keil DLR, D
LAM-3	Brazil-Manaus:	Christoph Corves University of Edinburgh, UK
LAM-4	Brazil-Rondonia:	Mike Wooding RSAC, UK
LAM-5	Brazil-Tapajos :	Shaun Quegan University of Sheffield, UK
LAM-7	Guyana:	Joost van der Sanden Agricultural University of Wageningen, NL
LAM-8	Colombia-Guaviare:	Wiske Bijker ITC, NL

17.00 - 17.30: Latin America Synthesis: Dirk Hoekman, scientific coordinator
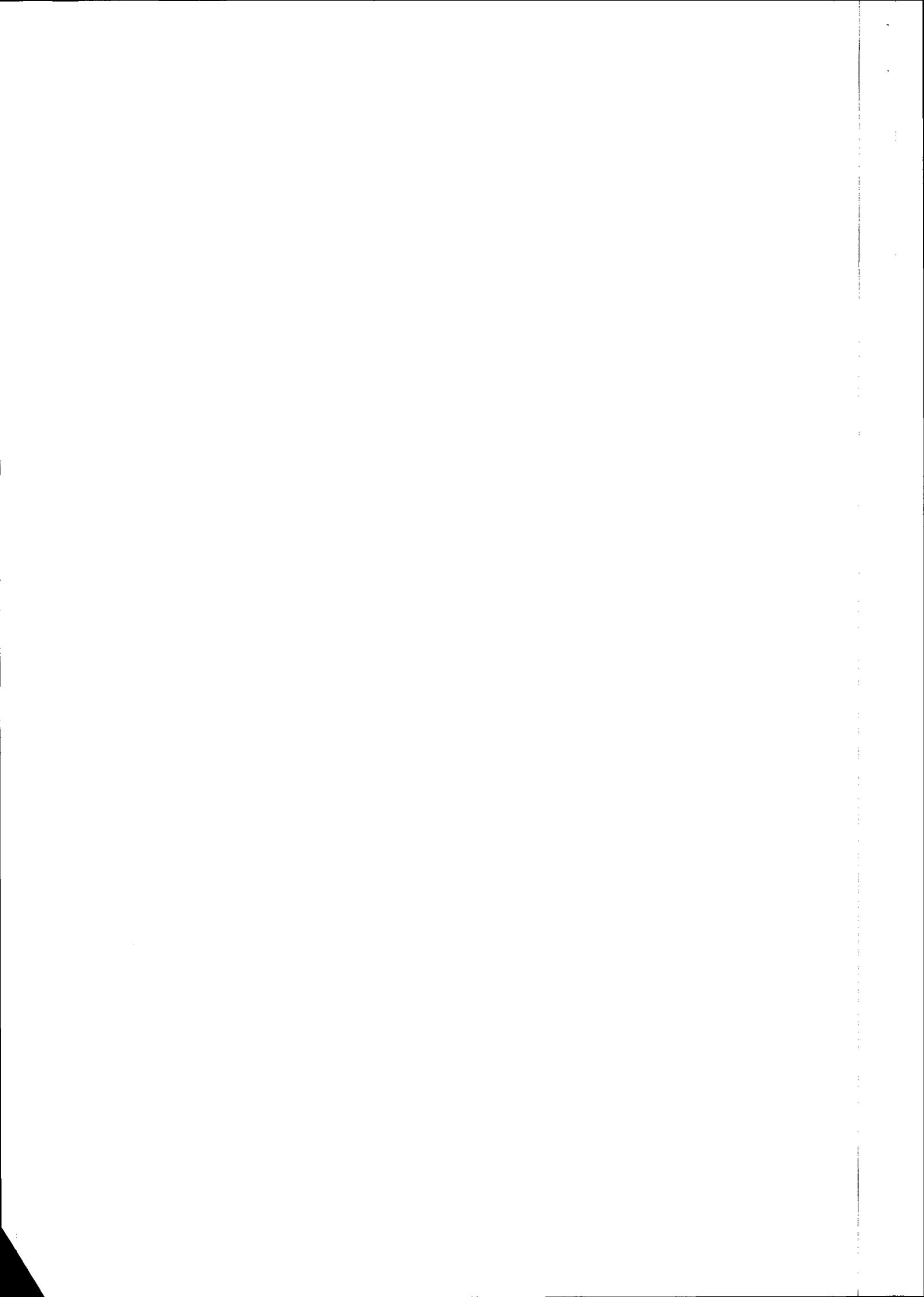
Friday 24th February 1995

09.00 - 09.45:   Investigations in Africa
Chairperson: Günther Kohlhammer, ESA

AFR-1   Ivory Coast study area: Marc Leysen, JRC

The ERS-1 Central Africa Mosaic: Franco De Grandi, JRC

10.15 - 12.15:   Technical Synthesis of the TREES ERS-1 Study '94
Rappoteur: Josef Aschbacher, JRC

10.15 - 10.45   Thematic synthesis: Dirk Hoekman & Thuy Le Toan

10.45 - 11.15   ERS-1 SAR processing synthesis: Franco De Grandi

11.15 - 12.15   ERS SAR and TREES: Jean Paul Malingreau

Lunch

14.00 - 15.30:   Round Table: ERS SAR Perspective for TREES 2

Moderator:
Participants: Guy Duchossois (ESA), Evert Attema (ESTEC),
                     ESRIN representative, Jean-Meyer Roux (JRC),
                     Jean Paul Malingreau (JRC), Alan Cross (EC-DGXII),
                     Gilberto Camara (INPE), Rudolf Winter (DLR),
                     Steffen Kuntz (Kayser-Threde).

15.30 - 15.40:   Closing address: Guy Duchossis, ESA

15.40 - 16.00:   Meetings of Proceedings Committee (JRC, ESA and RSAC)
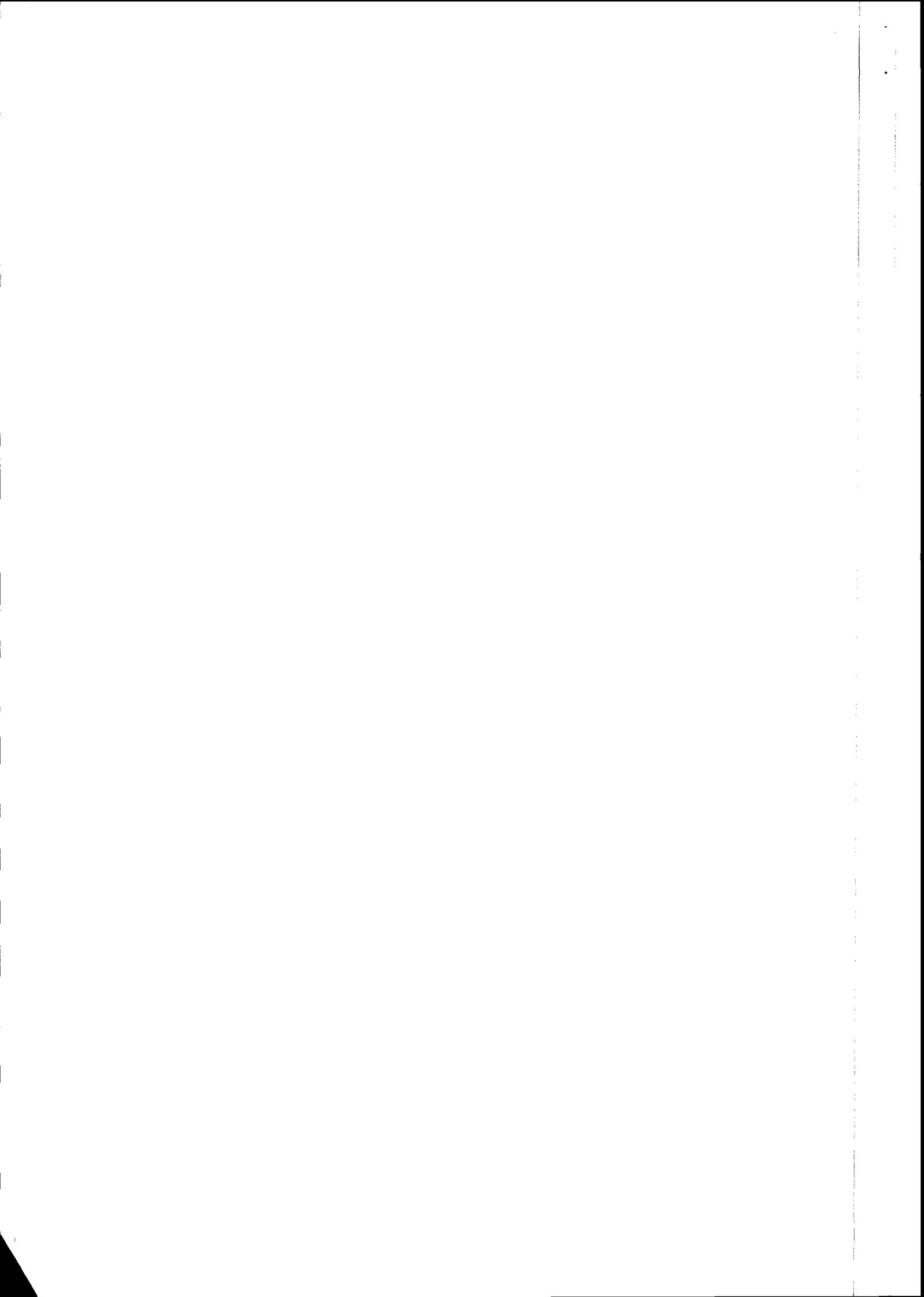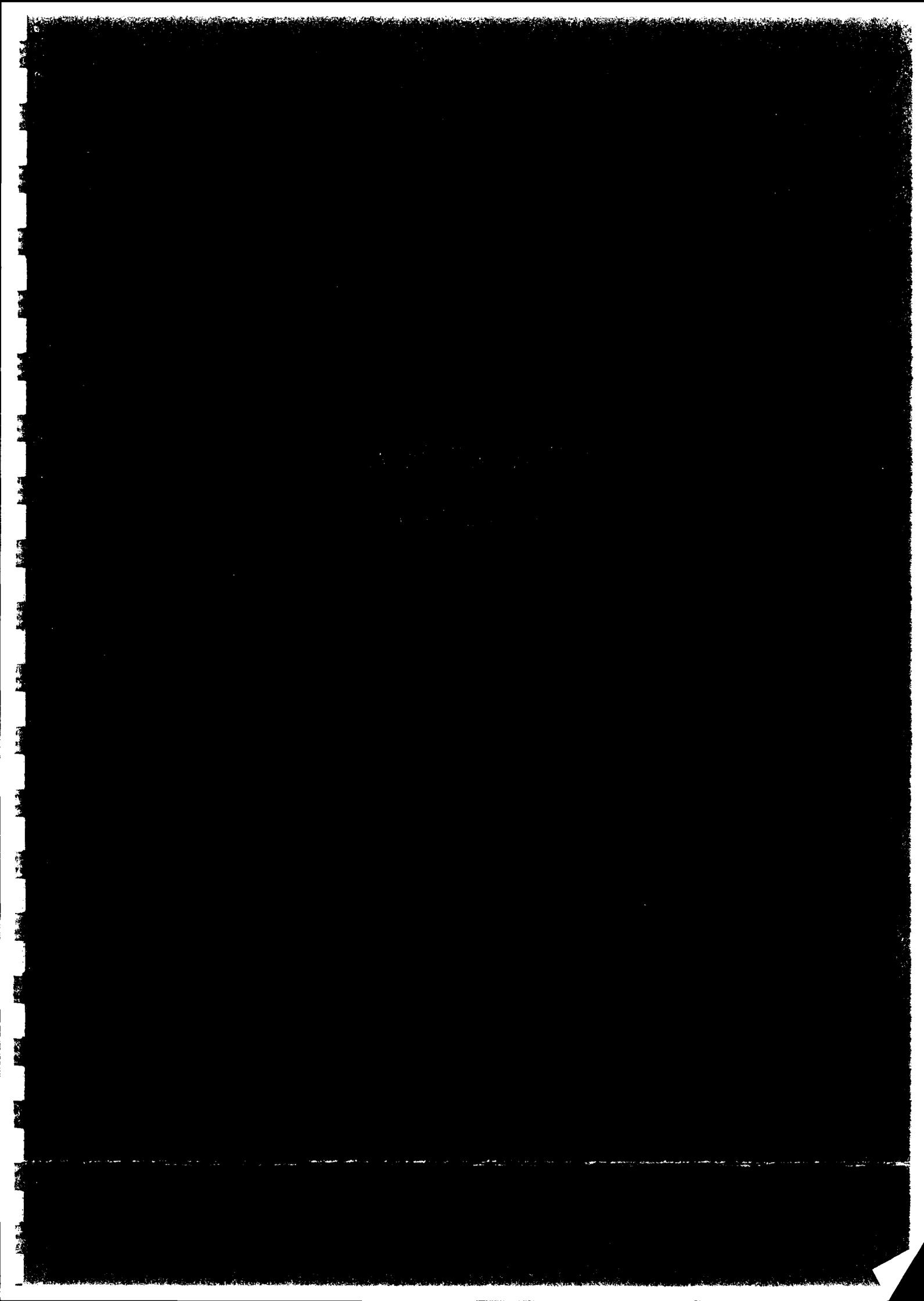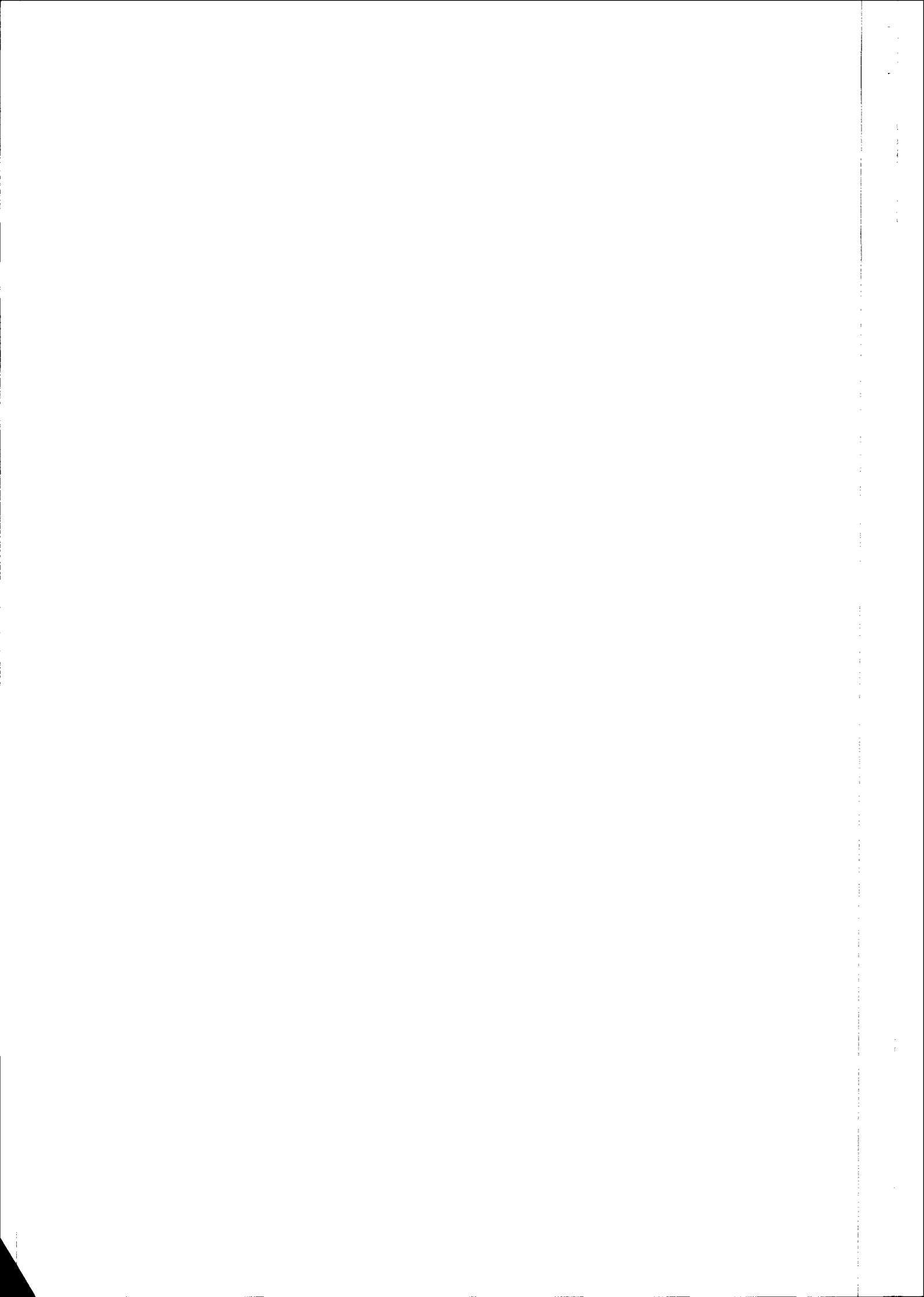
ANALYSIS OF MULTI-TEMPORAL ERS-1 SAR DATA
FOR FOREST MAPPING OVER MOUNTAINOUS TERRAIN
A CASE STUDY IN YUNNAN PROVINCE OF THE P. R. OF CHINA
(TREES ERS-1 STUDY '94 - SEA-1)

Zengyuan Li[1] and Marc Leysen[2]

[1] Chinese Academy of Forestry, Beijing, P.R. China
[2] CEC Joint Research Centre , Ispra, Italy

In the framework of the TREES ERS-1 Study '94, the study site situated in the Province of Yunnan (South China) was primarily chosen for its pronounced topography. The application of SAR imagery for land cover mapping poses specific problems over mountainous areas. The study presented was therefore initiated in order to assess the potential and limitations of ERS SAR data for major land cover type discrimination in mountainous terrain and the analysis of data processing techniques for compensation or correction of SAR data distortions induced by topographic relief.

In general, the mountains in the area are covered with tropical evergreen forest. The two main valleys around the cities of Mengla and Menglun are under agricultural cultivation. A considerable part of the agricultural land is irrigated for rice cropping. Up to a certain altitude limit, rubber plantations have replaced the original forest on the slopes around the valleys. This woody crop is considered an important land use type in addition to forest and agriculture, and is therefore included in the first level classification scheme.

Three ERS-1 SAR images acquired at consecutive overpasses during the multi-disciplinary phase of the satellite operation were obtained as standard PRI format products. The acquisitions cover the transition period of late rainy season to early dry season.

The Refined Gamma-Gamma Maximum A Posteriori filter was applied in order to reduce the speckle noise in the original PRI scenes. Second, images of 100 meters pixel size were derived from the original PRI scenes by means of block averaging. The radiometric resolution and class separability are compared quantitatively between the original images and the images with 100 meters pixel size. The temporal signatures of forest and non-forest classes are analysed, and ratio images are evaluated for detection of relative back scattering changes.

Preliminary results show that the temporal behaviour of forest is more stable than that of non-forest. Block averaging to a pixel size of 100 meters enhances the radiometric resolution of ERS-1 SAR images and the class separability.

A georeferencing exercise using a high resolution DEM has been initiated aiming at the evaluation of techniques for correcting geometric and radiometric distortions in the SAR image products. Preliminary results indicate that the S/N ratio in the DEM is an important, although often underestimated factor. Noise filtering techniques in the frequency domain have been investigated.
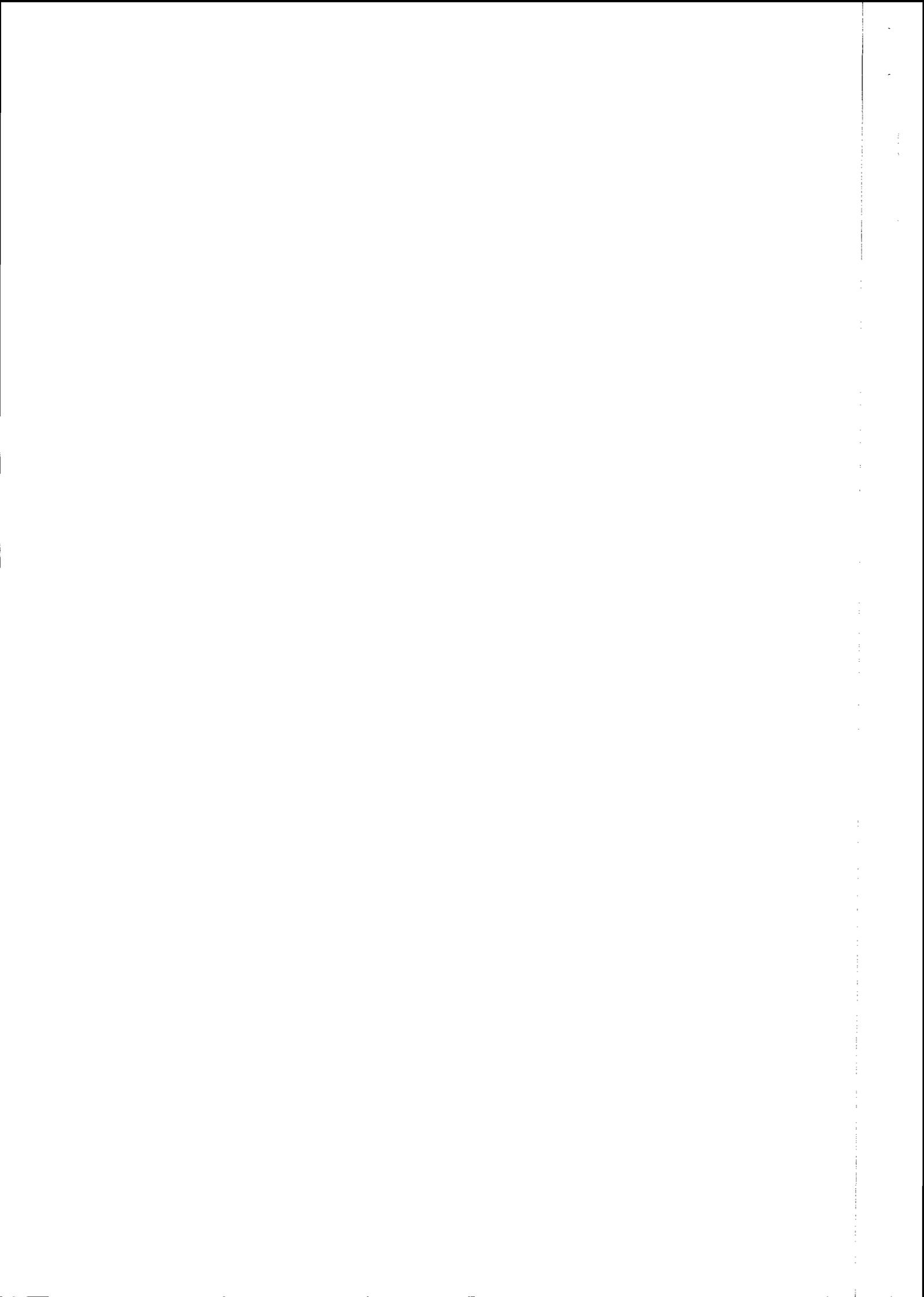
ASSESSMENT OF MULTI-TEMPORAL ERS-1 SAR DATA
FOR TROPICAL FOREST DISCRIMINATION AND MAPPING IN WESTERN THAILAND
(SEA-2)

Dipak R. Paudyal[1], Peter N. Tiangeo,[1]
Josef Aschbacher [2] and Yian Kwan Ang[1]

[1]Remote Sensing Laboratory, Natural Resources Program
Asian Institute of Technology
GPO 2754, Bangkok, Thailand
Tel: +66-2-524-5577, Fax: +66-2-524-5597
e-mail (correspondence): dipak@emailhost.ait.ac.th
[2] EC Joint Research Centre, IRSA-MTV, Ispra (VA), Italy

ERS-1 SAR is assessed for its potential in forest/non-forest discrimination over two test sites in West Thailand. The primary objective of this study being to investigate the usefulness of ERS-1 SAR data for identifying forested areas from agriculture and clear cut areas in the Western part of Thailand close to the Myanmar border.

It is found that the evergreen, mixed and bamboo types of forest show similar radar backscatter. However, scrub forest type in the area show lower backscatter and is well discriminated from other forest types. The clear-cut in the forested areas can be easily separated and mapped. However, the complete discrimination of agricultural areas from the forest areas require optimum combination and timing of image acquisitions. Agricultural areas are easy to discriminate from the forest areas if ERS-1 SAR is available from three well timed acquisitions. Best classification results are obtained using all the three imaging dates for one of the test sites. But for the other test site, where data from only two imaging dates are available, inclusion of the improves classification accuracy.
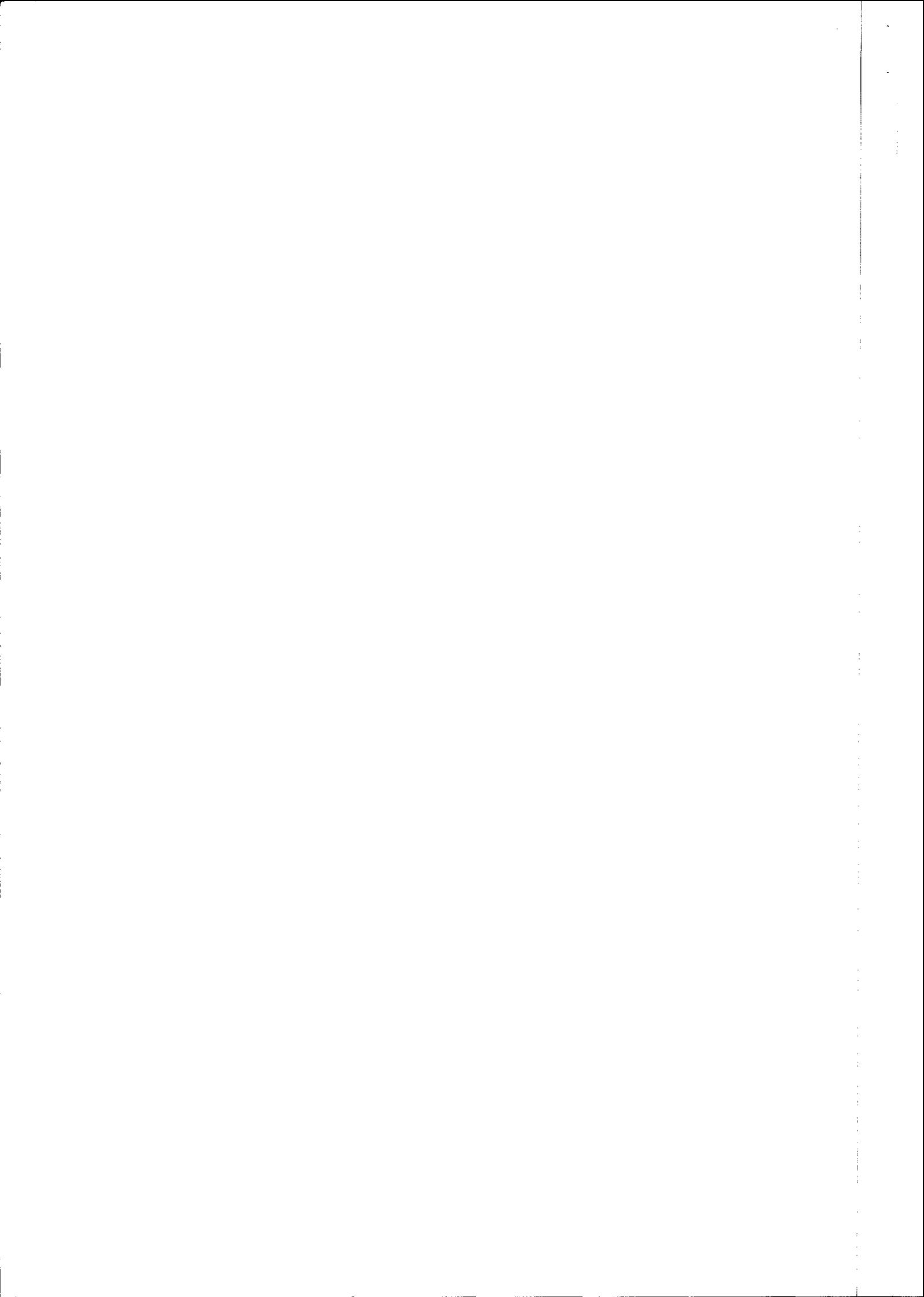
ASSESSMENT OF MULTI-TEMPORAL ERS-1 SAR DATA FOR TROPICAL FOREST DISCRIMINATION AND MAPPING IN SOUTHERN THAILAND (SEA-3)

Dipak R. Paudyal[1], Peter N. Tiangeo,[1] Josef Aschbacher [2] and Yian Kwan Ang[1]

[1]Remote Sensing Laboratory, Natural Resources Program
Asian Institute of Technology
GPO 2754, Bangkok, Thailand
Tel: +66-2-524-5577, Fax: +66-2-524-5597
e-mail (correspondence): dipak@emailhost.ait.ac.th
[2] EC Joint Research Centre, IRSA-MTV, Ispra (VA), Italy

ERS-1 SAR data is assessed for its potential in forest/non-forest discrimination over a test site in South Thailand. The primary objective of this study being to investigate the usefulness of ERS-1 SAR data for identifying coastal mangrove and inland evergreen forest, around the coastal areas of South Thailand.

It is found that the mangrove forest areas show within class variation of the order of 2 dB which can be attributed to tree height and density. However, there is considerable difficulty in using this information in an automatic classification process. This is attributed to the very similar radar response between agricultural and forest areas. Majority of the inland forest which lie in the mountains are affected by pronounced foreshortening. The forested areas on the backslope of the mountains exhibit lower response and are confused with wind roughened sea surface. This difficulty is however easily overcome by using a DEM. Best classification accuracies are obtained using the combined tone and texture bands derived from the gray level concurrence matrices. The serious limitation of this study is the unavailability of data from a third imaging date. Also highly desirable is a dry season date which may provide the greatest discrimination between forest, agriculture and marshland areas.
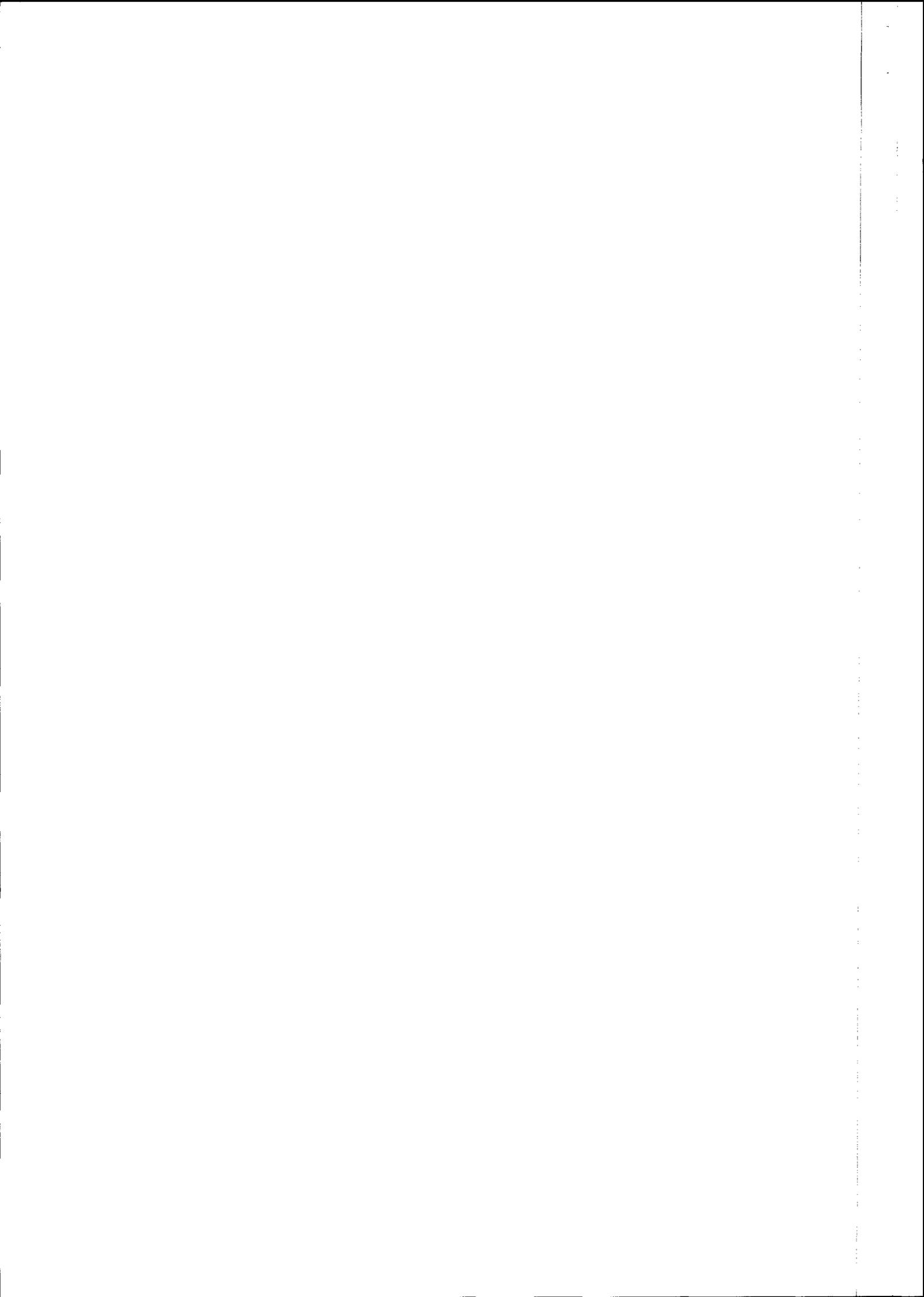
USE OF MULTI-DATE ERS-1 SAR IMAGES FOR TROPICAL FOREST STUDIES
(SEA-4)

J. P. Gastellu-Etchegorry[1], J. Bruniquel[1,2], A. Lopes[1], Y. Laumonier[3]

1: CESBIO, bpi 2801, 18,Av. Edouard Belin, 31055 Toulouse Cedex, France
Tel: (33) 61-55-61-30, Fax: (33) 61-55-85-00, E-mail: gastellu@cesbio.cnes.fr

2: Alcatel Espace, 26, Av. J-F Champollion, 31037 Toulouse Cedex, France
Tel: (33) 61-19-60-84, Fax: (33) 61-19-61-63

3: ICIV, 13, Av. du Colonel Roche, BP 4403, 31045 Toulouse Cedex, France
Tel: (33) 61-55-85-43, Fax: (33) 61-55-85-44

The test site is located in the Riau archipelago along the east coast of Sumatra (Rangsang Island, 1°N-103°E). It is a flat area that comprises patches of undisturbed peat swamp forest, large tracks of logged-over forest and mosaic of rubber plantations and secondary regrowth. Logging activity and clear-cutting for agricultural purposes are the main causes of deforestation. A persistent cloud cover is a critical constraint for the monitoring of forests with optical data. This study relies on the use of five SAR images acquired at different dates in 1993 and 1994. They are PRI (Precision Image) products without phase information.

With only one SAR image, only a very small number of features allow the discrimination of land surfaces: these are essentially the mean radiometry and the spatial heterogeneity. There is no spectral information and speckle noise corrupts the measurements. In this context, the combination of multi-date acquisiotns provides a unique opportunity for improving the information content of mono-date acquisitions.

This paper presents a methodology developed with this objective in mind. The first step consists of an efficient filtering of the available ERS-1 images. For that purpose, a weighted temporal summation of the five images was computed, followed by a spatial filtering with a Kuan filter. This greatly reduced speckle noise and, therefore, led to more accurate radiometric information.

The second step is a classification procedure based on the detection of radiometric change variations, with the hypothesis that tropical forests have radiometric responses that do not change with time. The method relies on the computation of mean neighbourhood radiometric values R_j; for each filtered image No j (here $j \in [1, 5]$). Pixels associated to a large time variability, i. e. with at least one ratio R_j/R_j larger than a threshold value, are classified as non-forest. This led to a pretty good discrimination of forest areas. However, some confusion between forest/non-forest zones still remained. Finally, comparison of the resulting forest map with another one derived from a 1989 Landsat image clearly stressed the potential of the ERS-1 SAR as a potential gap filler between optical acquisitions.
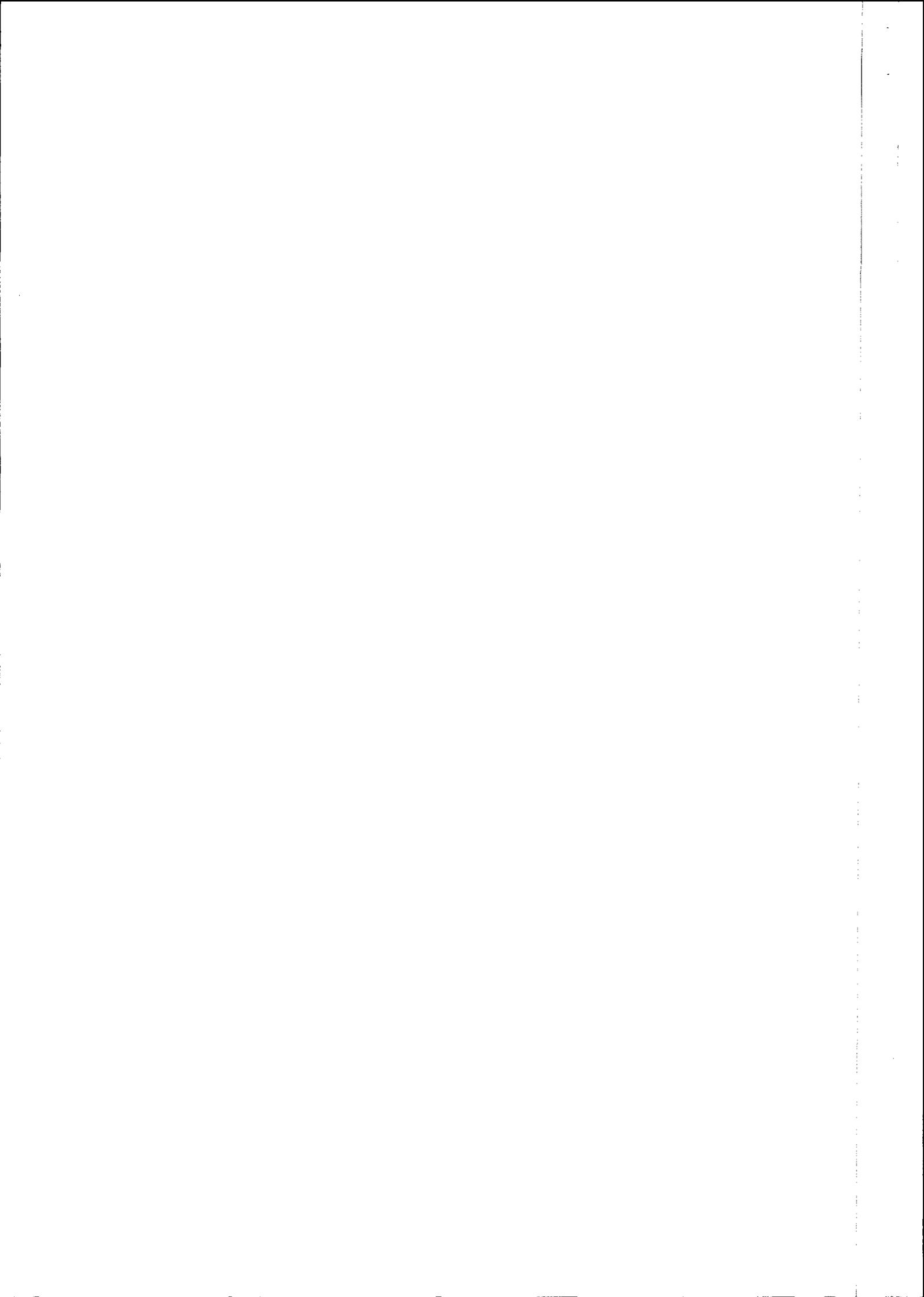
ASSESSMENT OF MULTITEMPORAL ERS-1 DATA FOR DEFORESTATION MONITORING IN SOUTH SUMATRA (SEA-5)

Thuy Le Toan, Thomas Hahn, Nicolas Floury, Florence Ribbes, Jerome Bruniquel,
Armand Lopes

Centre d' Etudes Spatiales de la Biosphere
CNES, CNRS, UPS - Toulouse, France
Tel: 33 61 55 66 71   Fax: 33 61 55 85 00

Upik Rosalina Wasrin
Seameo-Biotrop, Bogor, Indonesia
P. O. Box 116, Bogor
Tel: 62 251 323 848 Fax: 62 251 326 851

The South of Sumatra is characterized by the rapid depletion of the rain forest, mainly due to forest logging and permanent or semi-permanent settling of transmigred population. The deforested land is either allocated to transmigration or to industrial plantation of palm tree and rubber. The remaining forests are located mainly on hilly or mountainous terrain, with various degradation stages due to access roads and logging.

During the course of the TREES ERS-1 project, ERS-1 data have been acquired on the site with a maximum temporal coverage of 3 dates on 2 southern scenes.

In this paper, we investigate new methods of discriminating forests from deforested areas. The methods are based on the temporal change of different forest and land cover types. The results are interpreted as a function of the land-use types and conditions. The overall objective of the study on this selected site is to derive conclusions on the feasibility of the algorithms using ERS-1 data to monitor forest in hilly terrain with strong fragmentation in a diversity of land-use types due to an important transmigration programme.
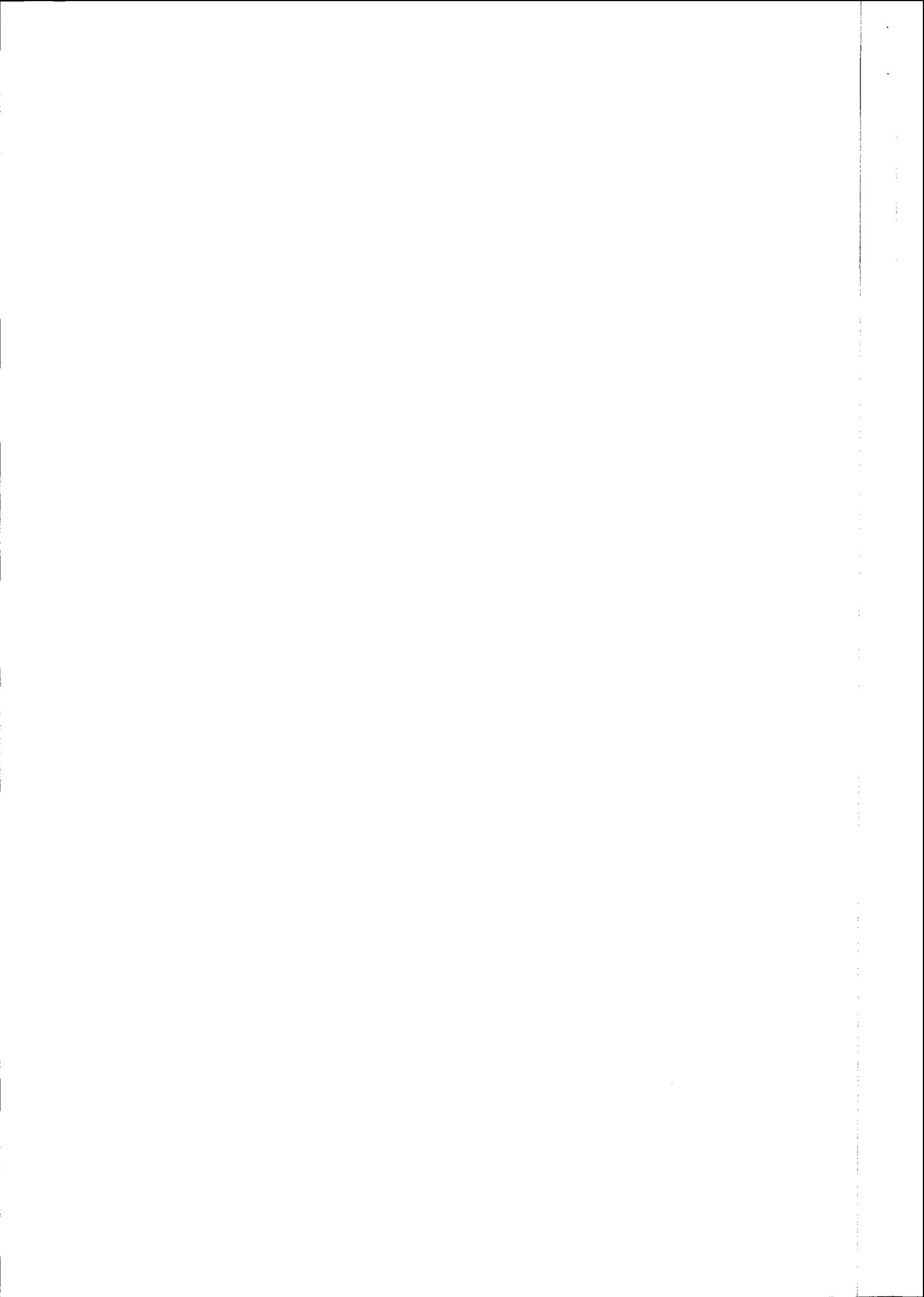
TREES ERS-1 STUDY '94 WORKSHOP: - SEA-6 PAPUA NEW GUINEA

Jaquie Conway

Monitoring Tropical Vegetation Unit
Institute of Remote Sensing Applications
Joint Research Centre, Italy

In the frame of the joint ESA-CEC TREES project, ERS-1 SAR data over a test site situated in Papua New Guinea are evaluated on their information content for mapping tropical forest ecosystems. The backscatter characteristics of specific vegetation types are evaluated, with firstly the aim of assessing the feasibility of discriminating between forest and non-forest using both mono-and multi-temporal ERS-1 SAR data, and secondly with the aim of assessing and indicating optimal time periods and numbers of acquisitions with respect to tropical forest mapping in the geographical area.

Two test areas were chosen in the Western Province, one situated near Lake Murray and the other situated south of the Fly river. These sites, were chosen for their relevance for observing seasonal features and different vegetation formations dependant on periods of flooding. Detailed and localised ground data were collected during a field campaign which took place in July 1994.

For the first site, nine ERS-1 SAR images were acquired between May 1992 and December 1993. For the second site twelve images were acquired between May 1992 and December 1993. Precision (PRI) images of each date were used in the analysis. Pre-processing of the imagery consisted of calibration, co-registration and block-averaging to a pixel size of 100m which reduced the speckle and increased the number of looks to approximately 70.

Temporal signatures of the vegetation types present in the imagery were examined. These vegetation types were visually identified in the imagery with the aid of ground data. These signatures show the separability of the classes on each specific date and also the temporal evolution of each vegetation type. The signatures showed the temporal stability of the forest backscatter coefficient compared to the other vegetation types and that all the vegetation types have lower backscatter coefficients in the months corresponding to the dry season.

Two techniques were investigated and compared for the classification of this data. One being the supervised classification approach (K-K' nearest neighbour classifier) using both the tonal and textural information present in the SAR imagery. The other being a classifier based on the exploitation of the information content of ratio images together with the tonal information. At the first level classification into forest and non-forest was performed using different multi-temporal combinations. At the second level a more detailed classification was attempted. In the Lake Murray test site, these classifications were quantitatively compared with a classification derived from Landsat TM data.

The classification results showed that reasonable classification accuracies could be achieved with the ratio based classifier using just two dates, one acquired in the wet season and one acquired nearing the end of the dry season in order to maximise the probability for change in the non-forest vegetation types. The classification accuracy achieved using this classifier increased as the acquisition of the dry season imagery became closer towards the end of the dry season.

TREES ERS-1 STUDY 1994
STUDY AREA : SOUTH EAST ASIA, VIETNAM
(SEA-7)

H. Jeanjean[1], T. Le Toan[2], A. Lopez,[2] J. Bruniquel, [2]

N. Floury[2], Nguyen Huy Phon[3], Prof. Dr. Tran An Phong[4]

[1] SCOT Conseil, Parc Technologique du Canal, 1 rue Hermès, 31526 Ramonville Cedex, France
tel.: (33) 61 39 46 24 fax: (33) 61 39 46 10
E-mail: hjj@scotc.cnes.fr

[2] Centre d'Etude Spatiale de la Biosphère (CESBIO),BP 4346, 31029 Toulouse Cedex, France
tel: (33) 61 55 66 70 fax: (33) 61 55 67 01

[3] Forest Inventory and Planning Institute (FIPI), Ministry of Forestry, Thanh Tri, Hanoi, Vietnam
tel.: (84 4) 61 55 11 fax: (84 4) 61 28 81

[4] National Institute of Agricultural Planning and Projection (NIAPP)
Ministry of Agriculture and Food Industries,
61 Hang Chuoi, Hanoi, Vietnam
tel: (84 4) 26 34 52 fax: (84 4) 25 30 93

Located in Vietnam, in the province of Dac Lac, nearby the border with Cambodia, extending from latitudes 12° to 13° N, and from longitudes 107° 30' to 108° 15'E. the study site is characterized by high plateaux at an average altitude of 500 m, with surrounding mountains rising up to 1500m. The main road crossing the study area (road 14) is connecting Kon Tum in the North to Ho Chi Minh City, passing through Buôn Ma Thuôt, the main city in the area.

The main eco-floristic zone is characterized by a moist climate (mean annual rainfall over 1500 mm) with a dry season (4 to 5 months) at low elevation below 800 meters. The climax is the dense semi-deciduous Dipterocarp forest, with locally dense deciduous forest and dense evergreen Dipterocarp forest. Forest fires and shifting cultivation practices have led to the creation of extensive open woodlands. Tree savannahs and bamboos are sometimes encountered. Agricultural activities can be described by upland crops, rice fields to a limited extent, coffee plantations and rubber plantations.

Four ERS-1 PRI scenes have been received, with dates of acquisition ranging from November 1993 to August 1994. Preliminary processing on the images coded in 16 bit include: (i) mean value in sliding window 4 x 4 pixels, (ii) geometric correction and superimposition, (iii) extraction of the area of particular interest (50 x 50 Km). The backscattering coefficient σ° was derived from the images using the standard procedure proposed by ESA. Temporal variation of σ° was then analysed on some major land-covers such as evergreen forest, mixed deciduous forest, shrubs, crops, rice fields, rubber plantations. The location of the sampling points for retrieving σ° was conducted on the basis of ancillary data (land cover map and forest map provided by the Vietnamese co-investigators).

Further developments are tested on the speckle filtering. A multitemporal addition was performed on the 16 bit images, followed by a 9 x 9 Kuan filter. A change index was then computed between the images, which seems to be an efficient way of tackling the effect of topography without Digital Elevation Model (DEM). Some attempts of segmentation were performed to assess the potentialities of delineating rapidly the forest/non forest boundaries.

TROPICAL FOREST MAPPING WITH ERS-1 SAR DATA
IN A HILLY REGION IN EAST KALIMANTAN, INDONESIA
TREES ERS-1 REPORT FOR SEA-8

Ralph -M. Ridder

DLR (German Aerospace Research Establishment) & University of Munich,
Department of Land Use Planning.
e-mail: ralf@oe.dlr.de
fax: +49 8153 28 1444

1. Abstract

In the frame of the ESA-JRC TREES ERS-1 study, ERS-1 SAR data from the DLR test site Bukit Suharto in East Kalimantan, Indonesia, were evaluated on their information content for tropical forest mapping.
Two ERS-1 SAR PRI datasets, recorded on 22 October 1993 and 26 November 1993 at Bangkok station, were visually interpreted and computer aided classified into the two classes, forest and non-forest.
The results were compared to the multispectral classification of the TM scene 116-061 from 28 February 1992, which was accuracy checked by a GPS field campaign.

2. Introduction

Rapid changes in forest cover take place in the tropical belt of our planet. This causes severe problems to the fragile tropical ecosystems, up to global climatic changes. The consequences for the economy and politics will be dramatic if the deforestation continues at the same velocity as took place during the last decades.

Therefore international effort on tropical forest inventory, mapping and change monitoring is necessary.
Satellite remote sensing offers the most cost and time effective tool for mapping large inaccessible areas on a regular basis.

For analysing the possibilities of remote sensing techniques, the ongoing DLR-ESA pilot project: *Monitoring of tropical rain forest in East Kalimantan, Indonesia,* was initiated at the end of 1992. Multitemporal and multisensoral ecosystem monitoring, within a geographical information system, for a representative test-site in East Kalimantan is under way.
The results of the classification of optical and SAR satellite data will be combined with additional information like planning maps and DEM's for the generation of new information, e.g. fire-risk maps.

The project was supported by LAPAN and MoF, and is carried out in co-operation with the BPN-GTZ-LUPAM project, BPK-DFS-ITTO and others.

The objectives are:

* development of an operational tropical forest monitoring system by evaluation of satellite data for Indonesian agencies.
* support of national authorities involved in spatial planning by demonstrating the possibilities of GIS as a management tool.

In 1994 the DLR test site in Indonesia was included in the global tropical forest monitoring initiative TREES by JRC and ESA. Several research institutes from tropical and European countries were invited to join the TREES ERS-1 study.
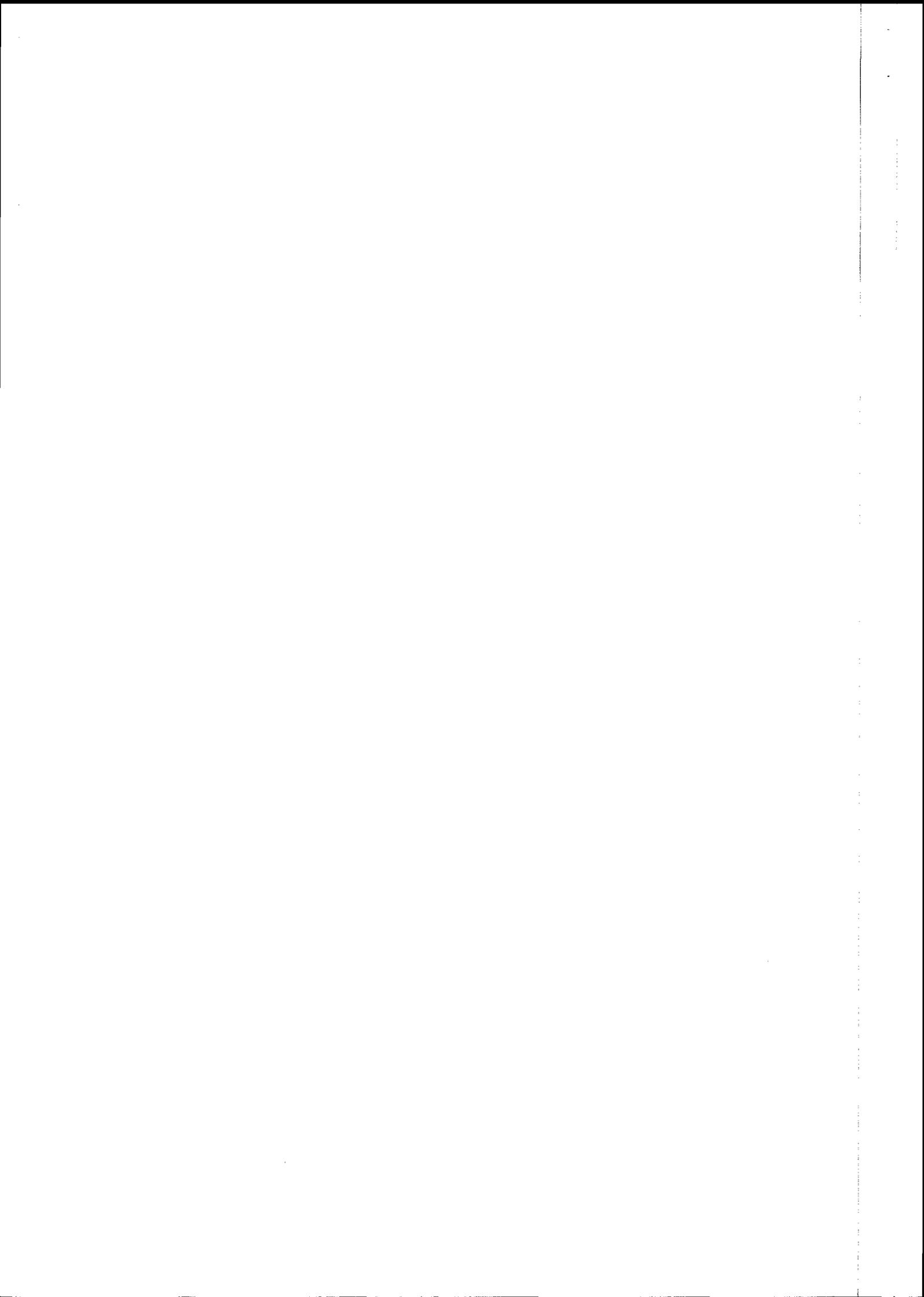
The advantage of using SAR data for forest mapping is the independence of data acquisition of day and night time and the independence of weather conditions. This is especially useful for monitoring tasks in tropical regions with persistent cloud cover.

The objectives of using ERS-1 SAR data for TREES study is:

- Forest non-forest discrimination
- Forest type classification
- Operational deforestation monitoring

3. Conclusions

The available ERS-1 data are significantly influenced by terrain caused SAR specific pattern, which caused difficulties in classification. The evaluation results can be summarized as follows:

- Forest non-forest areas can be separated by visual interpretation and maximum likelihood classification within certain limits. Both classes are disturbed by SAR specific pattern and bush/shrub vegetation, which is not separable from forest.
- Dipterocarp and mangrove forest can be separated by DEM supported classification.
- With continuous evaluation of ERS-1 SAR data every half year or every year, forest clearing activities can be mapped and monitored at least on a pre-operational base.
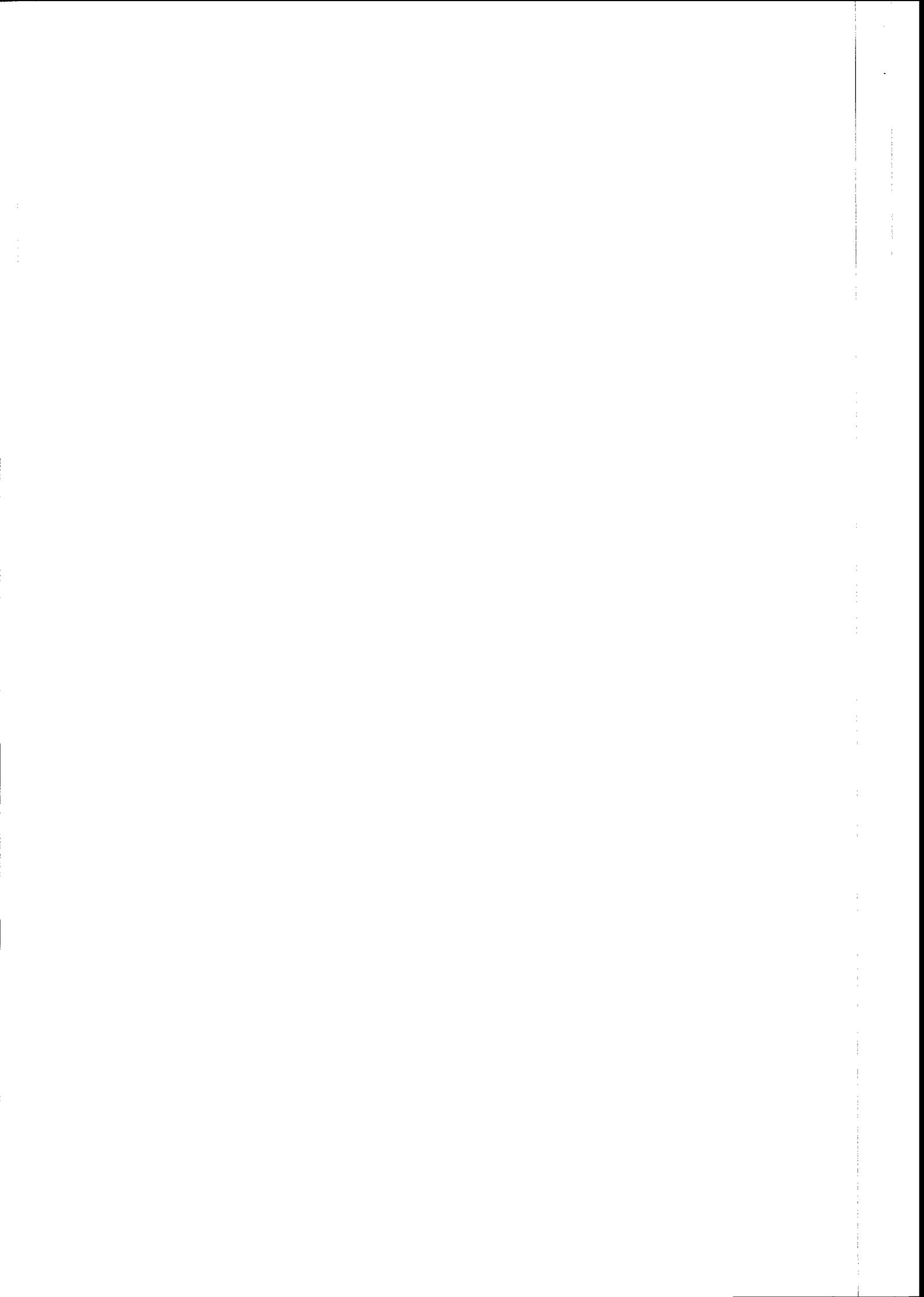
TROPICAL RAINFOREST AND USE OF LAND INVESTIGATION (TRULI)

S. Kuntz, F. Siegert, & C. Streck

Kayser-Threde GmbH, Wolfratshauser Str. 48,
81379 München

The ESA pilot project TRULI (Tropical Rainforest and Use of Land Investigation) was aimed at investigating the potential value of ERS-1 SAR data as a tool for monitoring rainforest conversion and land use planning. Final goal was to develop an operational system for ERS-1 SAR image interpretation which is suitable for conditions found in many countries of the tropical belt. Thus commercial software and established procedures only were used for the data analysis

KFA 1000 images from the Russian MIR Space Station offering high ground resolution and information acquired during an intensive ground truth campaign served as a reference. The analysis showed that major land use classes and different forest types can be identified, even in a single ERS-1 scene in tropical rain forest environment in Kalimantan, Indonesia. Texture analysis allows the discrimination of 1) undisturbed forest in two different natural types, 2) logged forest, 3) clearings by fire and clear cutting, 4) settlements and major roads. The results obtained so far establish the use of ERS-1 data as a tool to monitor deforestation processes and for land use planning tasks. Unfortunately we received a second data set which will allow multitemporal data evaluation in December 1994 only (after one and a half years after project kick off). It is expected that multitemporal analysis will increase the quality of results significantly.

In September 1995 we will execute our ground truth campaign in Kalimantan to finally check our results achieved so far. This will also offer the opportunity to disseminate our results towards our Indonesian colleagues during a one week workshop in Jakarta.
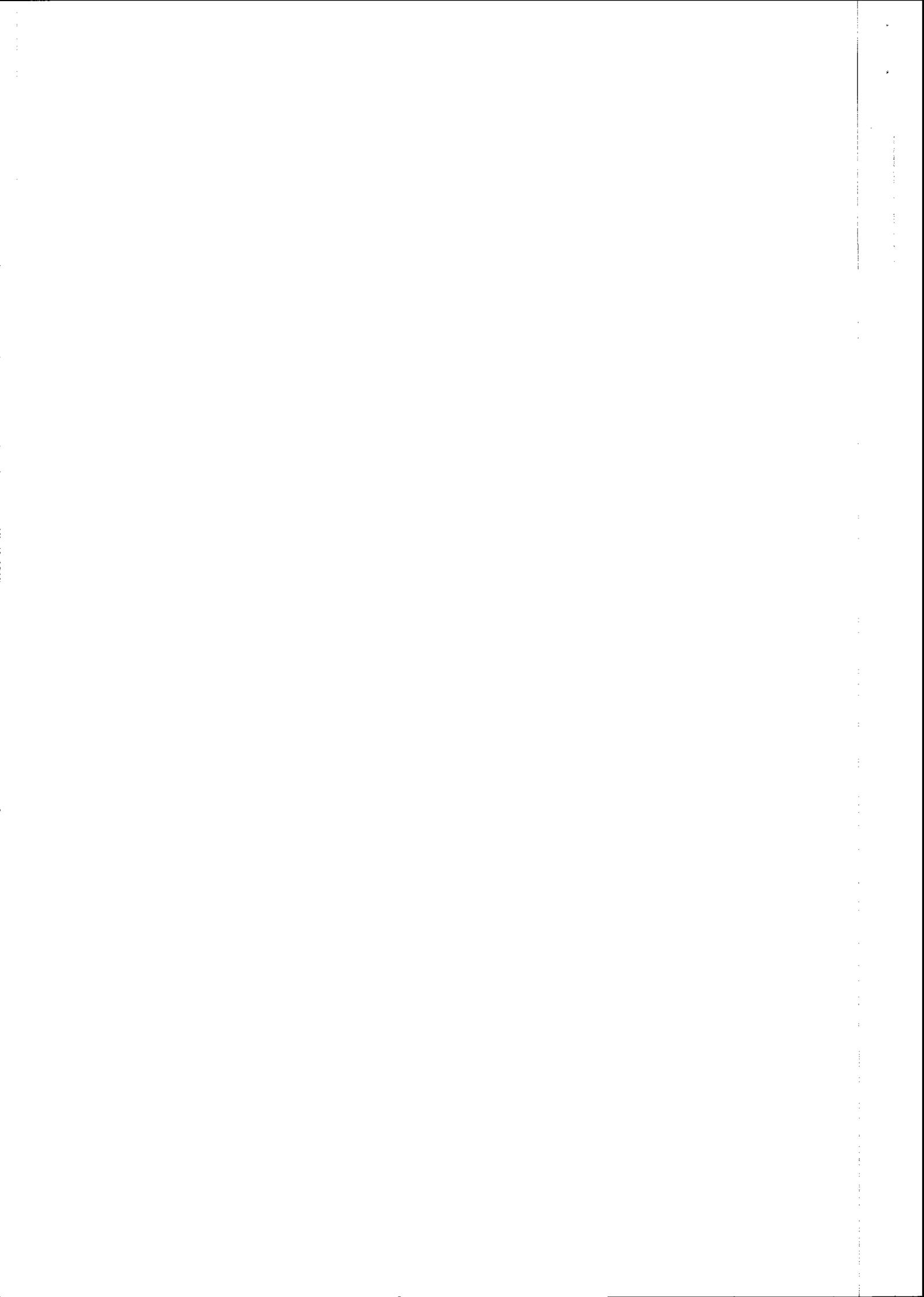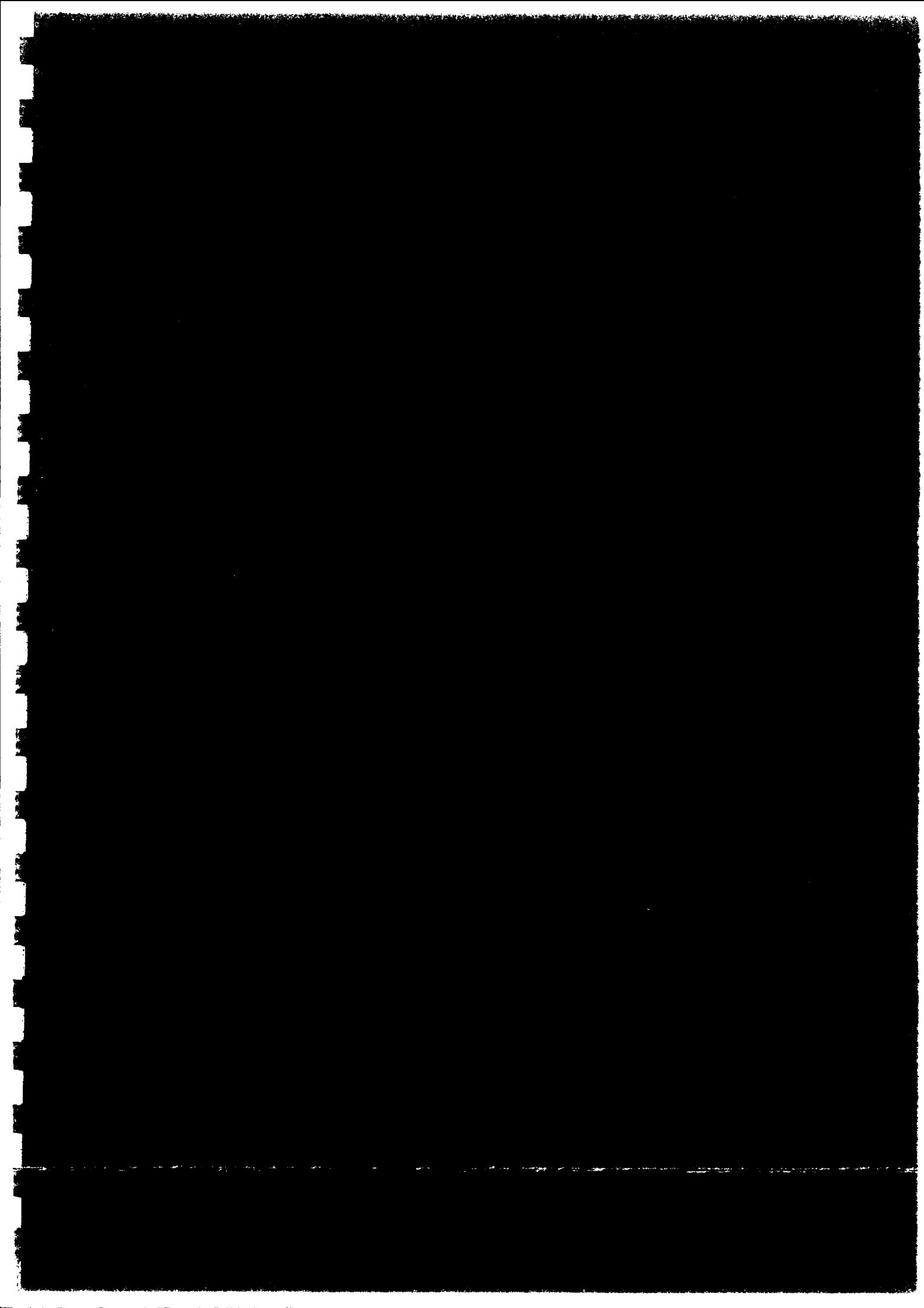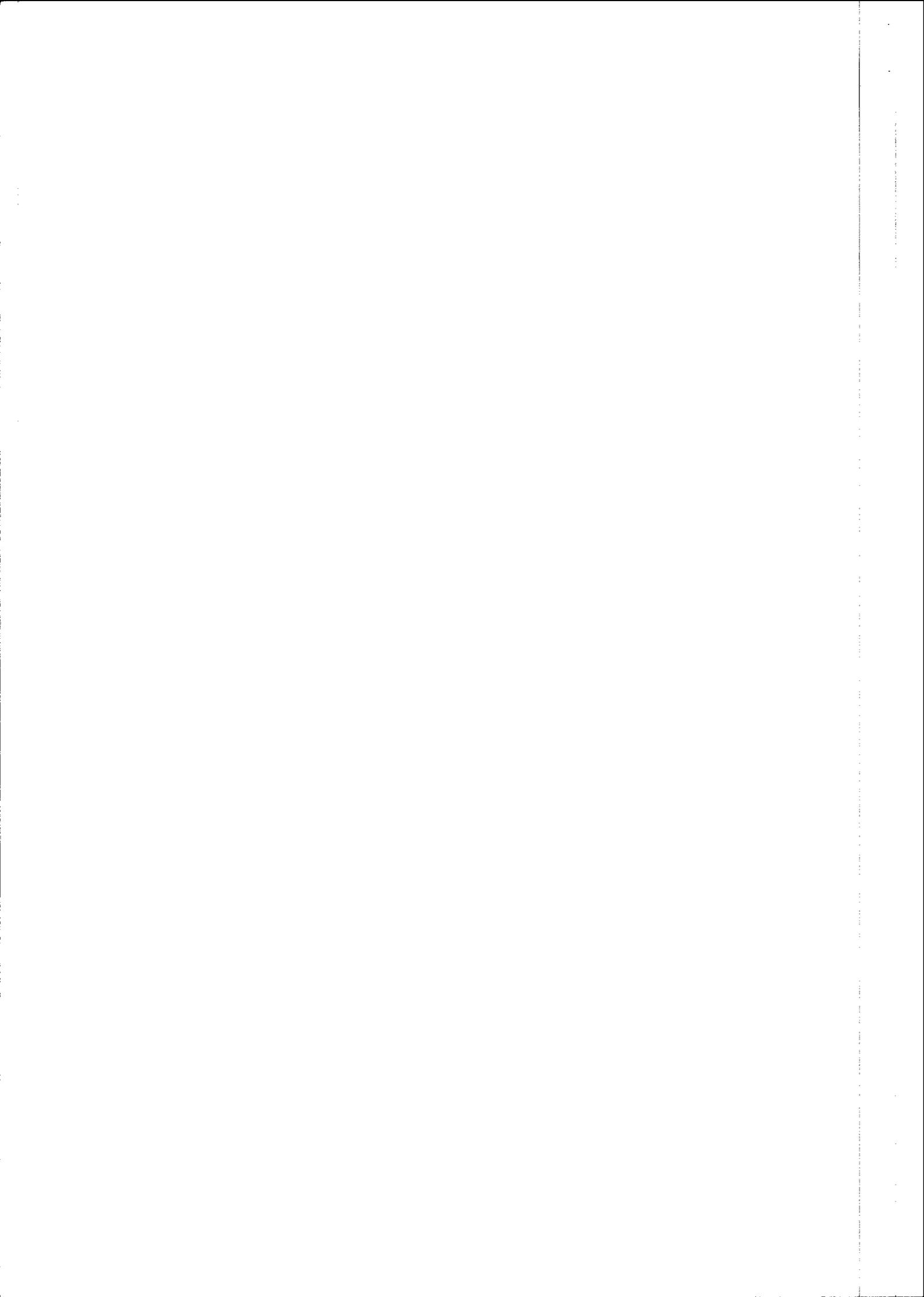
TREES COSTA RICA ERS-1 DATA ANALYSIS
(LAM-1)

E. J. Huising & G. G. Lemoine

SYNOPTICS
Integrated Remote Sensing & GIS Applications
PO Box 117
6700 AC Wageningen
The Netherlands
Tel: +31 8370 26936
fax: +31 8370 25705
e-mail: xsynoptics01@rcl.wau.nl

The TREES project aims at getting an overview of well founded classification results for monitoring land cover change in the tropical belt. The innovative use of ERS-1 imagery for these purposes is thought to be of importance since conventional remote sensing techniques using optical instruments are unsatisfactory because of prevailing weather conditions in the study areas (near permanent cloud coverage).

The study carried out under this study contract pertains to data of the Costa Rica test site. The study is oriented towards 'forest non-forest discrimination' in the first place and in the second to 'ERS for operational deforestation monitoring'.

The thematic study objectives (defined at the Paris kick off meeting, April 28-29th 1994) supported by this investigation are:

1.1	Forest/non-forest discrimination
1.2	Classification accuracy of a forest/non-forest map
2.1	Discrimination of forest types
2.3	Retrieval of biophysical parameters
3.1	Potentials of ERS-1 for assessment of deforestation
3.2	Proposal of a strategy for operational deforestation monitoring

Technical issues addressed are:

4.2	Analysis and processing techniques
4.3	Minimum analysis procedure required and optimum techniques for forest/non-forest discrimination
4.4	Pixel size and radiometric dynamic range for data volume reduction
7.1	Comparison of ERS-1 classification results with high resolution optical data

Based on results the following conclusions can be given:

1. Forest and non/forest can well be discriminated on the basis of ERS-1 data.
2. Land cover classification accuracies are 75% and higher.
3. Discrimination of forest types is difficult and requires more study. Discrimination between general cover classes like forest and secondary forest is good.
4. Retrieval of biophysical parameters is difficult on the basis of ERS-1 data alone. Ancillary data has to be used and more study is required in this respect.
5. Clear cuts are readily detected also if these are in small;; patches.
6. ERS-1 can be used for deforestation assessment at large as well as small scale with satisfactory accuracy in both cases. The first inflicts higher costs.

TROPICAL RAINFOREST INVESTIGATION WITH ERS-1 SAR DATA IN THE REGION OF SENA MADUREIRA, ACRE/BRAZIL (TREES STUDY AREA LAM-2)

M. Keil, D. Scales, W. Semmt, R. Winter
DFD/DLR, D-82234 Oberpfaffenhofen
H. Hönsch,
(GAF), Leonrodstr. 68, D-80636 Munchen
G. Lohmann
Technische Universitat Munchen, I
nstitut fur Informatik, Orleansstr. Munchen

Introduction and orientation of the assessment.
The TREES ERS-1 study contribution in the tropical rainforest region of Sena Madureira, state of Acre/Brazil, is based on several remote sensing investigations, especially ERS-1 investigations, of the study team. In 1989, a cooperation between the German Aerospace Research Establishment (DLR) and the National Institute of Space Research (INPE) was started to study remote sensing abilities for controlling the environmental impact by deforestation in the Amazon region and for mapping of rainforest formations and anthropogenic land use. The study site was defined in the south-western part of the Amazon basin near Rio Branco/Acre. Mainly Landsat MSS and TM data of the period between 1975 and 1990 have been used (Hönsch 1991). Based on these studies and within this cooperation, an ERS-1 pilot project (PP2-D3) started in June 1993, funded by DARA, in order to test C-band SAR data for forest monitoring purposes. This pilot project will be finished in June 1995.

In the context of the TREES ERS-1 study objectives, the following two tasks were investigated:

-forest/non-forest discrimination by ERS-1 data,
-ERS-1 for operational deforestation monitoring.

The information content of ERS-1 SAR data was investigated also for the differentiation of forest types (dense and open rainforest) and different landuse classes, for the influence of seasonal changes and for the dependence of surface topography.

Target of the specific studies
The study contribution is to be seen as a complement to other studies in the Acre area performed by a TREES team at JRC (Conway 1993). A special classification approach has been used, the approach of EBIS, the evidence based interpretation of satellite images (Lohmann 1991). EBIS is based on multinomial distribution functions for the description of the classes; no special pre-processing like special filtering is necessary for that approach. After having applied a version using local histograms for a window based classifier, a new version could be tested also including a texture classification approach (Lohmann 1994).

Monotemporal as well as multiseasonal/multitemporal datasets have been used, Landsat TM data of 1990 and 1992 and field data of a field campaign in June/July 1994 were available for comparison. The application of ERS-1 for AVHRR validation was not part of the investigation, that field was covered by the JRC study team (Malingreau et al. 1994).

Conclusions
Under the situation of the Acre testsite, ERS-1 SAR data can successfully be applied to forest/non forest classification, and monitoring of the deforestation development of most of the areas. The large pasture areas for cattle farming are readily detected. There remains a partial overlapping of rainforest and shrubby regeneration areas, and also of different types of plantations which deliver similar backscatter in C-band. In multiseasonal data an additional information content can be used, responding to the different vegetation development of pastures, regrowth and primary/secondary rainforest.
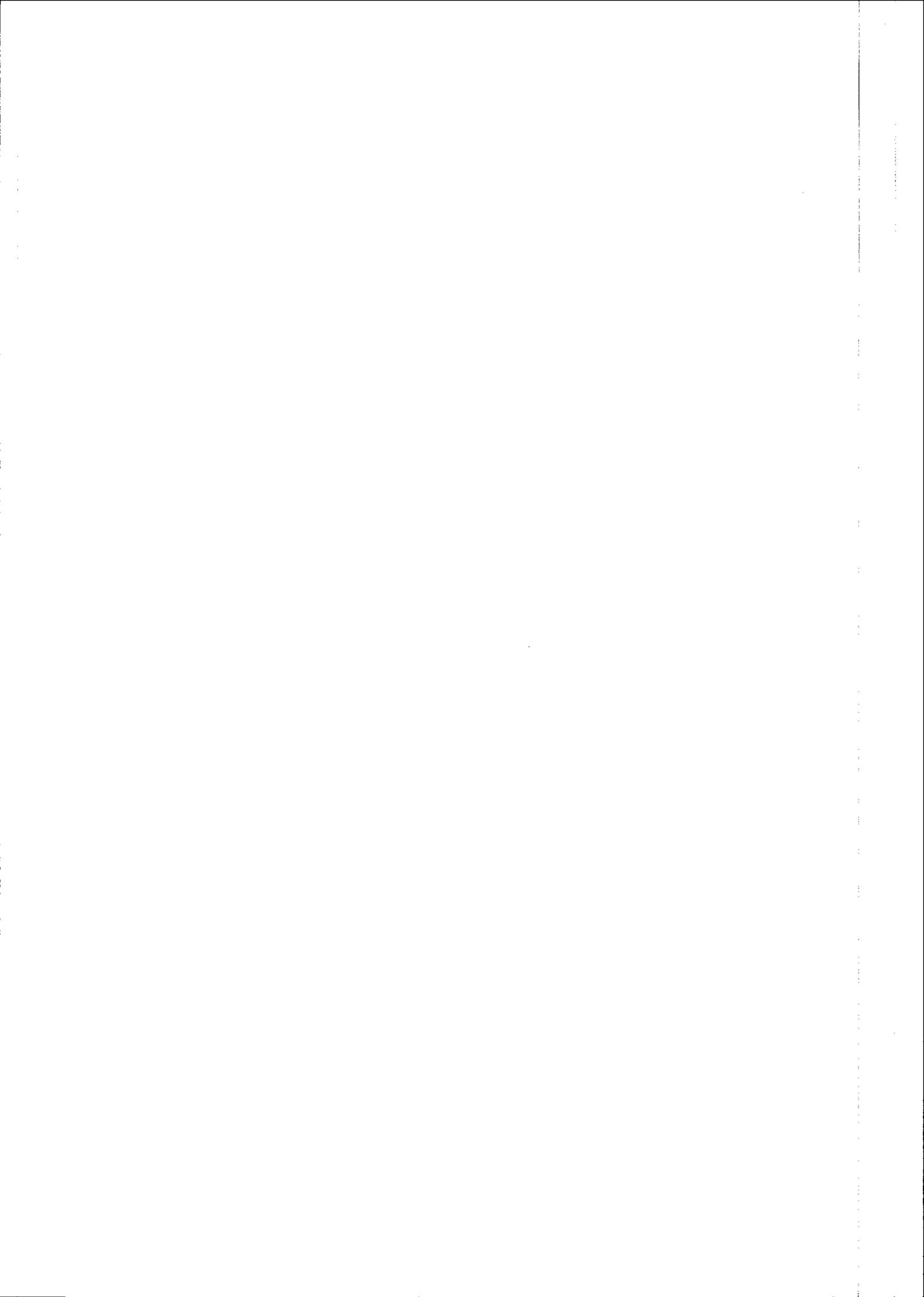
TREES ERS-1 STUDY '94 WORKSHOP: - LAM-2 ACRE

Jaquie Conway

Monitoring Tropical Vegetation Unit
Institute for Remote Sensing Applications
Joint Research Centre, Italy

In this study ERS-1 SAR data over a test site in the state of Acre in Brazil are evaluated on their information content for mapping tropical forest ecosystems. The study is split into two parts. The first being the discrimination of forest and non-forest over a relatively large spatial area using a mono-temporal ERS-1 SAR data set (sub-site A). This classification result is then compared with both high and low resolution optical data in order to assess the feasibility of using the ERS-1 SAR data as an alternative to high resolution optical data for the validation of the coarse resolution optically derived forest/non-forest maps produced within the TREES project. The second part being the classification of a smaller area (one ERS-1 SAR frame) using a multi-temporal dataset (sub-site B) with the aim of investigating the multi-temporal aspects of the data set and to investigate different techniques for processing and classifying the SAR data.

For sub-site A four ERS-1 SAR precision (PRI) images consisting of two consecutive frames from two consecutive ascending orbits (acquired on the 30th May 1992 and 15th June 1992) were used. For sub-site B five images acquired on the 15th of May 1992, 19th June 1992, 11th December 1992, 4th June 1993 and 9th July 1993 were used.

Pre-classification processing algorithms used included further calibration to remove the effects introduced due to the change in incidence angle over the image swath, for sub-site B, co-registration of the multi-temporal data set, block averaging to a pixel size of 100m, and for sub-site A, filtering using the GMAP filter. The four filtered images covering sub-site A were then manually mosaiced together into a single image.

Classification techniques compared within the scope of the study included the supervised non-parametric K-K' nearest neighbour classifier, a classifier based on the information content of ration images and a classification produced by thresholding a segmented image produced from an iterative multi-scale edge detection/segment growing algorithm at the University of Sheffield.

For sub-site A, a comparison of non-forest features extracted from the classified mono-temporal mosaic and the classification of Landsat TM data were undertaken. From this analysis it could be seen that both the classification results yielded very similar non-forest area estimates for the type of non-forest features present in this test-site where the main deforestation practice is the formation of cattle ranches. Classification results obtained from the pixel based K-K' nearest neighbour classifier and the segmentation approach proved to be very similar, however, the segmentation approach was computationally heavier. Within this study the non-forest area estimates from the ERS-1 SAR classification were also used as a reference for the comparison of non-forest area estimates derived from NOAA AVHRR and ERS-1 ATSR-1 classifications.

For sub-site B the backscatter signatures of the forest and several non-forest features were compared. From this analysis it was found that the forest signature was temporally stable and the backscatter coefficient varied by less than 1dB for all forest samples measured, both spatially and temporally. Classifications produced from different temporal data set combinations using both the ratio based classifier and the K-K' nearest neighbour classifier were compared in conjunction with the classification produced from the TM data set. This analysis showed that reasonable classification accuracy's could be obtained with a single ERS-1 SAR image acquired in the dry season (mid June to September) using the K-K' nearest neighbour classifier, and with the ratio combination of one image acquired in the dry season and one in the wet season using the ratio based classification approach.
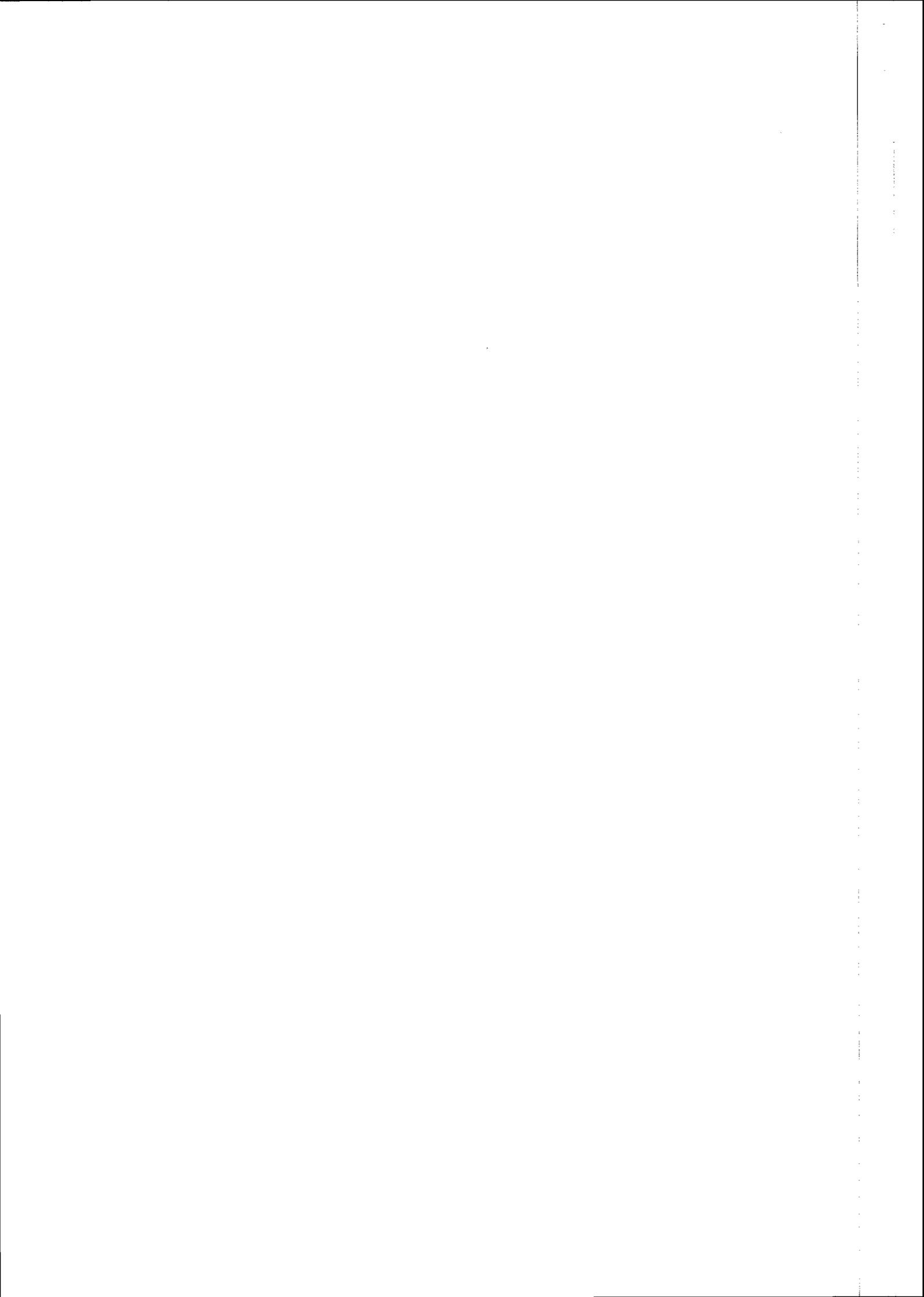
In conclusion, it was found for geographical areas having similar deforestation practices to this test site and thus characteristically regular block-shaped deforestation patterns that ERS-1 SAR data can be used as a viable and in some respects better alternative to high resolution optical data both for mapping forest and non-forest features and for the validation of AVHRR derived forest/non-forest maps due to the capability of ERS-1 to acquire SAR images day and night and independent of cloud conditions.

EVALUATING MULTI-TEMPORAL ERS-1 SAR DATA FOR MAPPING FORESTS AND DETECTING FOREST CLEARING IN THE MANAUS REGION OF BRAZIL (TREES/ERS-1 TEST SITE LAM-3)

Christoph Corves[1], Ron Caves[2], Sean Quegan[2],
Franco De Grandi[3], Edmond Nezry[3]

[1] Department of Geography, University of Edinburgh,
Edinburgh EH8 9XP, Scotland-UK (corresponding author)

[2] School of Mathematics and Statistics, The University of Sheffield,
PO Box 597, Sheffield S3 7RH, UK

[3] Commission of the European Union,
Joint Research Centre,
Institute for Remote Sensing Applications, 21027 Ispra (VA), Italy

1.   Study objectives

The study has concentrated on the following issues:

- Which vegetation types are distinct in terms of backscatter amplitude?
- To what extent do seasonal changes in backscatter exist?
- Can the forest/non-forest boundary be detected on ERS-1 SAR data?
- Which dates of imagery are most suitable to detect deforestation in the Manaus region?
- What are likely obstacles to mapping deforestation in the Manaus region through the digital classification of ERS-1 SAR data?
- Identification of a likely approach for detecting deforested areas.

2.   Results

(a)   Vegetation mapping

On level terrain of terra firme, two classes existed in terms of backscatter amplitude: (a) vegetation with woody elements, and (b) vegetation without woody elements (i.e. grassland). Neither secondary forest nor early secondary regrowth could be differentiated from primary forest. Backscatter from woody vegetation targets in the floodplains was not (or, at most, only very marginally) influenced by sub-canopy flooding. Backscatter amplitude from predominantly herbaceous vegetation in the floodplains was strongly influenced by seasonal changes in flooding conditions and vegetation structure.

(b)   Mapping the forest/non-forest boundary on terra firme

Digital mapping of the forest/non-forest boundary on terra firme areas in the Manaus region would have to overcome the following obstacles:

- Relief-induced distortions: Relief-induced distortions in backscatter are pronounced in the Manaus region. In particular, forest on slopes facing away from the satellite exhibit low backscatter values that are very similar to grassland on level terrain.
- Highly variable backscatter from open water surfaces: Backscatter from open water surfaces varies strongly depending on wind conditions.
- Highly variable backscatter from herbaceous vegetation in the floodplains: Backscatter from herbaceous vegetation in the floodplains varies depending on seasonal flooding conditions.
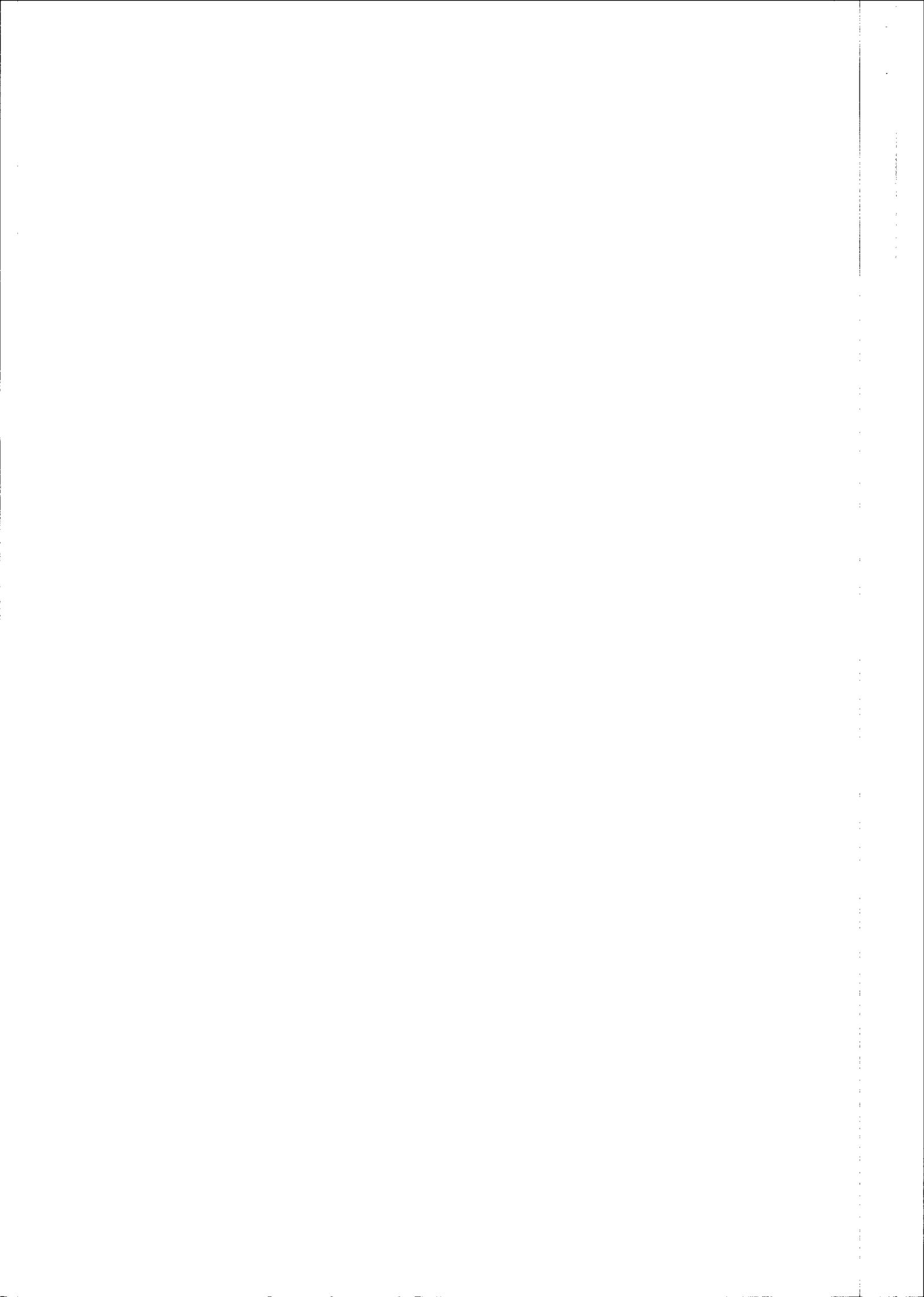
During the high water season, herbaceous vegetation in the floodplains exhibits backscatter levels similar to woody vegetation.

Even if these problems could be solved, it appears that the potential of mapping the true extent of cleared areas from ERS-1 SAR data would still be limited by the low capability to discriminate forest from areas of early secondary regrowth or secondary forest.

(c)   Detecting forest clearing

Dry season imagery (June-early November) provided the highest contrast in backscatter level between woody vegetation and grassland. Deforested areas remained detectable for several months, however, possibly for less than a year. October and September appeared to be the months most suitable for detecting newly cleared areas on single date imagery. The use of one image from the late rainy/early dry season (May-June: before forest clearing starts) and one image of the end of the dry season (late October/early November) allowed for the detection of forest clearing between image acquisition dates.

(d)   Potential use of ERS-1 SAR data

ERS-1 data appeared to be useful for the updating of existing vegetation maps for recent forest clearing in terra firme regions. This would probably require at least two images per year: (a) late rainy/early dry season, and (b) late dry season. This study suggests that a promising approach to the automated detection of forest clearing might involve the following elements: (1) multi-temporal segmentation of ERS-1 SAR data, and (2) segment classification by matching the temporal backscatter profiles of the resulting segments with reference profiles in spectral libraries.
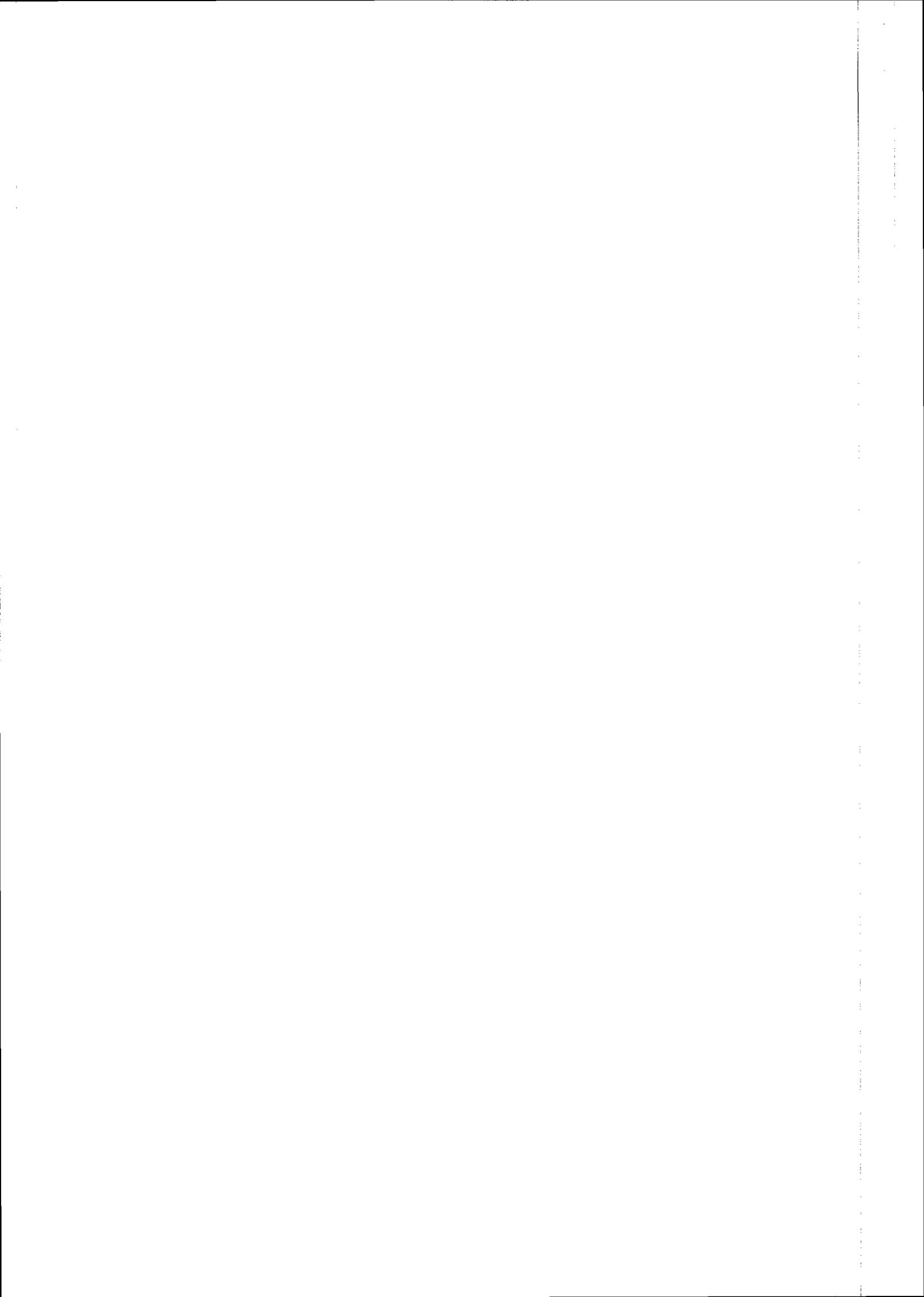
ASSESSMENT OF ERS-1 SAR FOR MONITORING DEFORESTATION LAM-4 RONDONIA, BRAZIL

M. G. Wooding & A. J. Batts

Remote Sensing Applications Consultants,
Mansfield Park, Medstead,
Alton, Hampshire, GU34 5PZ, UK

The potential of ERS-1 SAR data for monitoring deforestation is evaluated in the context of an area which has been severely affected in the state of Rondonia, Brazil.

A total of 15 ERS-1 images have been used in the study. Initially there is a comparison of a single date ERS-1 image with a Landsat TM image which provides an excellent visual separation of forest and non-forest areas. Forest areas have light tones on the ERS-1 images and many cultivated deforested areas have a darker tone appearance. The main problem concerns separating areas of scrub/grass from forest because these areas have a similar light toned appearance.

Image enhancement techniques are then used to optimise the visual identification of deforestation on ERS-1 images. Speckle filtering and multi-temporal analysis significantly improve the discriminatory potential of the images, but there are still some problems in accurately separating forest and non-forest on the best multi-temporal colour composites produced during the study.

Attention is then directed specifically towards the potential of ERS-1 SAR images for updating forest maps prepared on earlier dates from Landsat TM images. The basis of an analysis strategy for monitoring deforestation is demonstrated using ERS-1 images to monitor deforestation against a baseline map derived from optical satellite data.

ERS-1 OBSERVATIONS AND POTENTIAL FOR USE
IN TROPICAL FOREST MONITORING
(LAM-5)

K. D. Grover[1], S. Quegan[1], L. V. Dutra[2], C. C. F. Yanasse[2],
P. Hernandez[2], F. and S. S. Sant'Anna[2]

[1] University of Sheffield, England.
[2] INPE, Sao Jose dos Campos, SP, Brasil.

The area of interest for this study is the Tapajos National Forest (FLONA Tapajos), in Brazilian Amazonia. Three ERS-1 PRI images from the 35 day repeat cycle are examined; seven others are available although their coverage of the test area is not complete. A sequence of relatively cloud-free Landsat TM images (one for each year between 1986 and 1992), airborne C band HH and VV data from the SAREX-92 campaign, fieldwork results and daily rainfall data are also available.

Models have been used in interpretations of multi-temporal differences in backscatter observed in the ERS-1 imagery. Fieldwork established that the areas showing dynamic behaviour were predominantly areas of bare soil, pasture or similar low vegetation. However some areas of pasture and bare soil did not exhibit this multi-temporal signature. The inputs to the small perturbation, Kirchhoff and Michigan empirical surface scattering models were systematically varied in order to find the conditions which gave best fits to observations from two pasture areas showing large and small seasonal variation. All predicted a decrease in soil moisture between the two dates, in agreement with the daily rainfall data. All three models also predicted that the region showing less dynamic behaviour was rougher than the area showing fluctuations in backscatter.

Backscatter from the forest canopy was modelled using MIMICS. Observations of SAREX wide swath data and ERS-1 indicate both lie on the same cosine curve, as predicted by the model. The first stages of forest regeneration were simulated by omitting the trunk layer from the MIMICS model. Even a small amount of regrowth causes the backscatter to tend towards that for a full canopy, especially at high incidence angles. At 23° there is less than 1 dB difference between the modelled backscatter from a 2 metre vegetation layer and a complete forest canopy. Modelling also showed that a rough surface would be practically indistinguishable from forest, whatever the soil moisture, in accordance with observations.

A quantitative comparison of change detection algorithms was carried out using an area of farmland (which showed large dynamic change across the dates of imaging), surrounded by primary forest. Four pre-processing techniques to enable change detection were investigated, based on simple averaging, filtering using the gamma maximum a posteriori (GMAP) filter, simulated annealing and image segmentation. Automatic classification was achieved by thresholding images prepared from differencing pre-processed images from two of the dates used. The performance of GMAP is badly affected by speckle. Annealing and image segmentation found a similar proportion of pixels falling above a threshold, although there are differences between the two when examining thresholded images. Typically, annealing finds much more small scale structure (possibly due to errors in registration of the sub-pixel levels). Several small segments away from the main areas of change also occur in the segmented image. Their correspondence to ground features is unknown at present. Simple averaging of large blocks of pixels produces results comparable to those using more sophisticated methods for large areas but fails to locate small areas of change.

A qualitative analysis of the suitability of using different sensors (ERS-1, Landsat TM and SAREX) for discriminating different types of land cover was also carried out. This implied the expedience of using optical images for this task, if cloud-free data is available. ERS-1 backscatter was found to be weakly sensitive to secondary forest age (using a forest age map derived automatically from a time series of Landsat imagery); a change of approximately 1 dB between regeneration ages of 2 years and 6+ years was noted. This would be hard to detect unless large homogeneous areas were used.

CONCLUSIONS

Forest/non-forest discrimination is possible using two images acquired under different soil moisture conditions, as long as the soil surface is not too rough; rough soil appears to give similar response to primary forest under all reasonable soil moisture conditions. The important condition needed is a change in soil moisture; this is **not** a seasonal effect (in our data the **dry** conditions occurred during the **rainy** season, but the **wet** conditions occurred during the **dry** season). Even a small amount of regrowth gives similar backscatter to primary forest.

Change detection by thresholding the difference of pre-processed log images can automatically detect non-forest areas. Pre-processing by averaging blocks of pixels to reduce speckle produces results comparable to those using simulated annealing or segmentation, if only large areas are of interest, at a fraction of the computational cost.

An automatic monitoring system to detect changes in forest boundaries would therefore need to acquire images soon after deforestation and before significant regrowth could occur. Since images under wet and dry conditions are also required it seems likely that images need to be acquired on a monthly basis (this approximate figure needs proper analysis based on RCS saturation time for regrowth, rainfall probability as a function of season and seasonal likelihood of forest clearing).

ERS-1 TROPICAL RAIN FOREST
STUDY IN ARARACUARA, COLUMBIA
TREES ERS-1 '94 STUDY: LAM-6

Dirk H. Hoekman

Wageningen Agricultural University,
Department of Water Resources
Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands
tel: +31-8370-92894, fax: +31-8370-84885
e-mail: dirk.hoekman@users.whh.wau.nl

1. Introduction

The Araracuara test site is located in the central part of the Colombian Amazon. It comprises undisturbed primary forests as well as savannahs. This site is one of the three Amazonian test sites where the Wageningen Agricultural University (WAU) and the International Institute for Aerospace Survey and Earth Sciences (ITC), in consultation with the Tropenbos Foundation, carry out a systematic research program to study the utility of remote sensing techniques for tropical rain forests.

1.1 Orientation of the study within the general TREES ERS assessment

1. Forest non-forest discrimination.
Deforestation in the Araracuara is limited to some (very) small clearings for shifting cultivation, mainly along the rivers. Natural non-forest vegetation types are present on isolated hard rock hills. These cover large areas in the   western part of the test area.

2. ERS-1 for operational deforestation monitoring.
There is almost no deforestation in this area. Available ERS-1 images cover the year 1992 only.

3. ERS-1 for AVHRR validation.
The area is suitable to validate the usefulness of the AVHRR instrument for the discrimination of savannahs from primary forest types. However, this study was not executed (yet).

4. ERS-1 as gap filler.
Cloud cover is very persistent in this area. The usefulness of ERS-1 as gap-filler, though, is low, because the location of non-forest areas are known and   deforestation is absent.

1.2 Target of the specific study
(numbering according to the "Proposed study objectives" document, Paris kick-off meeting)

Thematic issues
1. Forest non-forest discrimination.
The detectability of small areas of shifting cultivation in ERS-1 images was studied and compared with results for SAREX-92 and AIRSAR images.

2. Forest typology.
Detailed landscape-ecological maps, covering vegetation types and biophysical characterisation at an appropriate scale are available for the test area. Temporal backscatter signatures for 14 vegetation types and textural properties have been studied.

<u>Technical issues</u>
4. ERS-1 data products and analysis techniques.
Selection of the most appropriate times of observation and the usefulness of some analysis and processing techniques (e.g. texture, speckle filtering, backscatter modelling) have been studied. So far, only PRI products have been used.

8. R & D Issues: Backscatter models.
The radiative transfer model of the University of Texas at Arlington (Karam et al., 1992) was modified to handle the complex structure of tropical rain forests and tested.

<u>Optional issues</u>
AIRSAR
The utility of AIRSAR polarimetric C-, L- and P- band data for classification and biomass and forest structure estimation was studied.

1.3 Conclusions

From a temporal analysis of four ERS-1 images acquired in 1992, covering the seasonal cycle well, it can be concluded that three groups of vegetation types can be differentiated on the basis of backscatter level. These are (1) vegetation types on hard rock forms: a complex of savannahs and low forests, (2) low biomass forests of the alluvial plain and (3) high forests and palm swamp forest of high biomass. The total number of vegetation types that may be differentiated on a combined analysis of backscatter level and texture may be five.

Detection of small areas of shifting cultivation is difficult with ERS-1. Only in time-averaged product some small areas show up because of the effect of radar shadow.

AIRSAR data shows the high utility of larger wavelengths. Many forest types can be differentiated well. Inundated forest can be detected by dominance of the double bounce scatter mechanism. In Guaviare land cover types and, thus, forest non-forest types, can be discriminated easily through combination of C- and P-band. Here relations between biomass, forest structure and backscatter level are apparent.

ANALYSIS OF ERS-1 SAR DATA FOR MABURA HILL, GUYANA (TREES '94 STUDY: LAM-7)

Joost van der Sanden

Wageningen Agricultural University,
Department of Water Resources
Nieuwe Kanaal 11, 6709 PA Wageningen, The Netherlands
tel: +31-8370-82778, fax: +31-8370-84885
E-mail: sanden@rcl.wau.nl

Introduction
The TREES ERS-1 '94 study for Mabura Hill, Guyana evaluates the capacity of ERS-1 SAR data to discriminate between tropical forest and non-forest cover types. The studied forest types include: a number of primary forests, secondary forests and selectively logged forests. The non forest class consists of a mixture of agricultural crops, bare soil and grassland. The study aims to contribute to the TREES ERS assessment with regards to forest/non forest discrimination and the use of ERS for global deforestation monitoring.

Target of study
The main goal of the study is to evaluate the potential of both the ERS-1 SAR Precision (SAR.PRI) and SAR Single Look Complex (SAR.SLC) data for the classification of the mentioned cover types based on either radar backscatter or texture. In addition, the study assesses the value of a multi-temporal radar data set for the same purpose. The potential of ERS-1 PRI images for the monitoring of human interaction (e.g. road construction and selective logging) is evaluated on the basis of a visual image interpretation.

Conclusions
ERS-1 SAR PRI images can be said to offer little or no opportunities for the classification of tropical forest types based on either radar backscatter or grey level co-occurrence textural features. However, based on backscatter there do seem to be possibilities for the discrimination of forest and non forest cover types. The use of textural features derived from ERS-1 SAR.SLC images proves to greatly enhance the possibilities for tropical forest type classification.

The use of multi-temporal SAR.PRI data cannot be expected to improve the results for a backscatter (or textural) based classification, as none of the forest types seem to exhibit a very specific seasonal backscatter behaviour, and as the seasonal backscatter changes are small in comparison to the within class backscatter variations. The latter conclusion is also supported by a visual interpretation of a time series of ERS-1 PRI data. This interpretation, in addition, leads to the conclusion that a priori (field) knowledge is required to visually detect selectively logged areas and that the detection of logging roads requires the use of two or more SAR scenes.
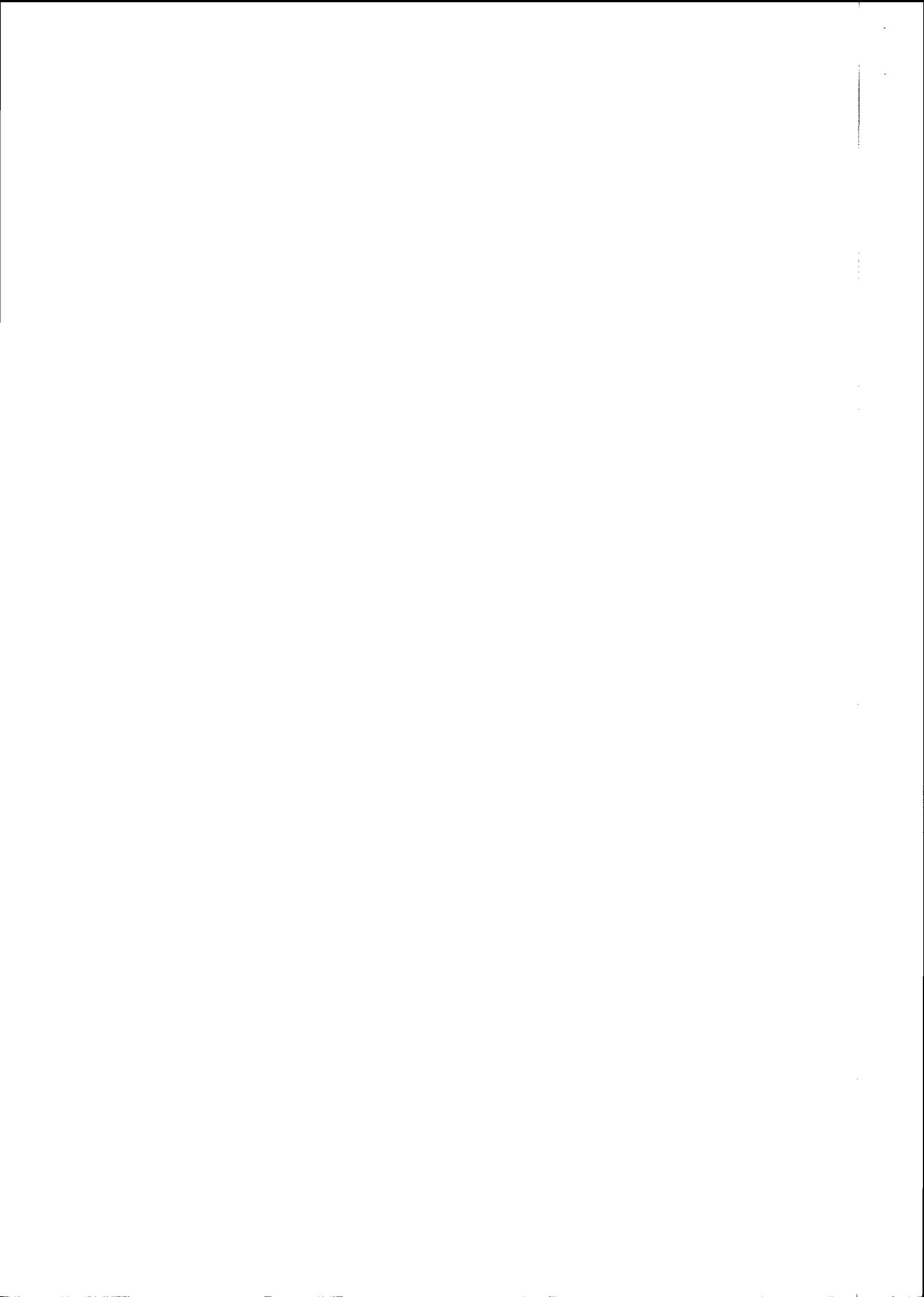
MONITORING OF TROPICAL RAIN FORESTS
AND PASTURES WITH ERS-1
(TREES '94 LAM-8)

W. Bijker

ITC, 350 Boulevard 1945, P. O. Box 6,
7500 AA Enschede, The Netherlands

Orientation with the general TREES ERS assessment
This study covers themes 1 (forest/non forest discrimination) and 2 (ERS for operational deforestation monitoring) of the TREES ERS assessment.

Target of this study
Many areas in the Amazonian basin experience a rapid change in land use and hence in land cover, as settlers move in. The area around San José del Guaviare, on the fringe of the Colombian Amazon is such an area. The forest is replaced by crops, secondary forests and ultimately by pastures. In the course of time , these pastures degrade seriously. In order to plan and guide the development of the area towards a sustainable land use, planners and decision makers need up-to-date information on the rapidly changing land cover. For this reason, a land cover monitoring system, based on (radar) remote sensing, is being developed for the area. Within this development, the use of multi-temporal composites of ERS-1 images has been studied.

Conclusions
As a single image did not give the information needed for monitoring of forests and pastures, a composite has been made of three ERS-1 images of different seasons of the same year. The information content of this composite is very high: forests stand out clearly from non-forest areas, savannahs can be discerned from pastures. Also changes in the river are visible.

With digital processing of the multi-temporal image land cover types can be distinguished by their typical curves for the change of backscatter with time within the same year. Crops and secondary vegetation show much heterogeneity and hence no typical backscatter curves have been found for these land cover types.

Land cover can be monitored by comparing multi-temporal composites of different years.
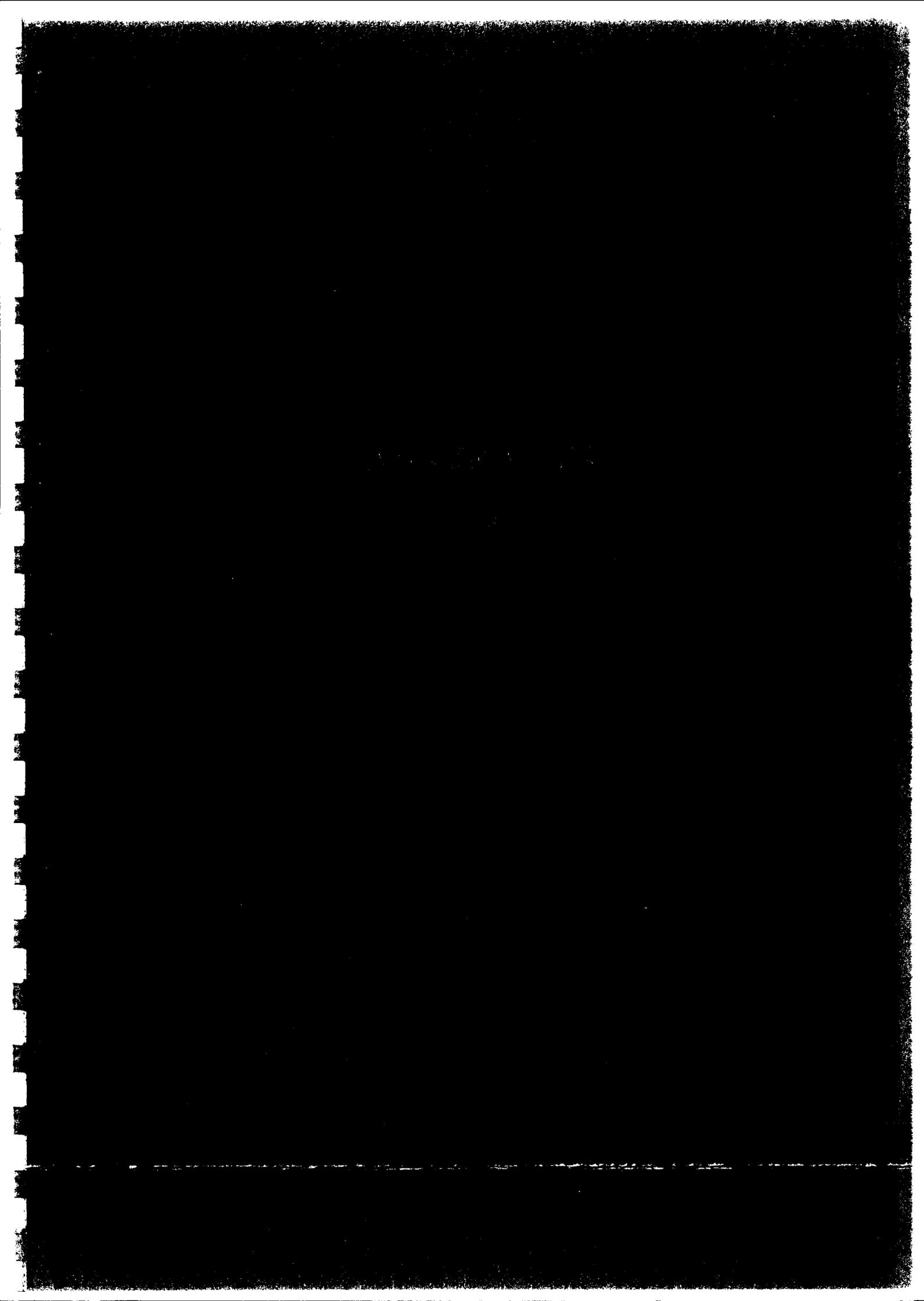
ANALYSIS OF MULTI-TEMPORAL ERS-1 SAR DATA FOR FOREST MAPPING AT THE FOREST-SAVANNAH INTERFACE A CASE STUDY IN COTE D'IVOIRE (TREES ERS-1 STUDY '94 /AFR-1)

Marc Leysen & Gianfranco De Grandi

CEC Joint Research Centre, Ispra, Italy

In the overall framework of the TREES project, transition issues in terms of spatial arrangement and temporal variation of vegetation types play an important role. The NOAA/AVHRR images used as basic remote sensing data layer in the tropical forest mapping effort show clear limitations in both spatial and temporal domain. The exploitation of the all-weather capacity of the ERS-1 SAR sensor enables the study of temporal variations of tropical vegetation types through high spatial resolution observation of the land cover at regularly spaced time intervals.

In this respect, the West-African study site of the TREES ERS-1 study '94 (AFR-1) offers a unique opportunity to study the temporal behaviour of the back scatter dynamics of a range of vegetation types thanks to the availability of a data set covering more than a full vegetative cycle. Nearly two years of 35 day interval ERS-1 SAR observations acquired throughout the multi-disciplinary phase of the satellite operation were made available. For the study presented here, 18 coincident ascending node scenes were used with standard PRI products as the base material.

Due to the combination of the natural climatic gradient and historic forest management practices, a range of forest types is covered in the study site. Some major blocks of closed forest considered relics of the natural high forest are clearly marked. In the North West a partly forested mountain range emerges, while towards the North East intrusions of edaphic savannah alternate with semi-deciduous woodlands. The remainder of the site is characterised by a mixture of agricultural land, patches of fragmented forest, fallow and secondary vegetation types.

The main objective of the study is to explore the temporal variation of the radar returns for a number of vegetation types representative for the transition zone between the given natural biomes. Methods to exploit these variations for characterising vegetation types and for mapping purposes are evaluated. Issues relating to the physical meaning of derived back scatter change parameters and the relative validity of image combinations of specific sets of imaging dates are discussed. Satisfactory results in the context of the TREES objectives can certainly be gained using an optimised selection of imaging dates extracted from the available coverage.

In a second section of the study, the potential and limitations of ERS SAR data for land cover type discrimination over mountainous terrain are assessed. Processing techniques for both compensation or correction of SAR data distortions induced by topographic relief are evaluated. A georeferencing exercise using a high resolution DEM aiming at the evaluation of techniques for correcting geometric and radiometric distortions of the SAR imagery is elaborated. The results gained with relief effect compensation techniques through image combination are compared with those resulting from the geocoding effort. The issue of operational application of these techniques is addressed with respect to the TREES objectives and geographic target zone.

Keywords: ERS-1 SAR, Tropical forest mapping, Multi-temporal Classification, Georeferencing
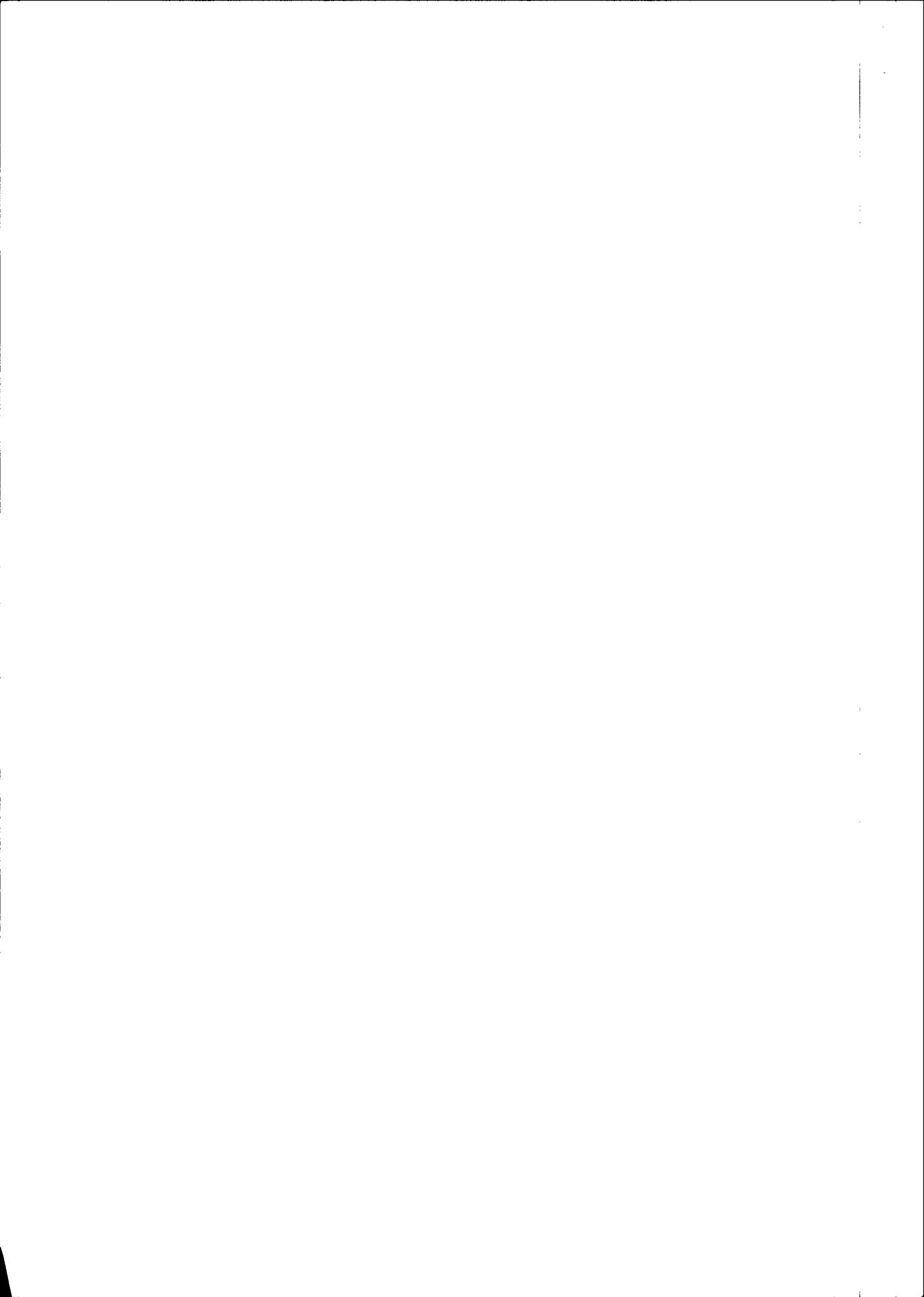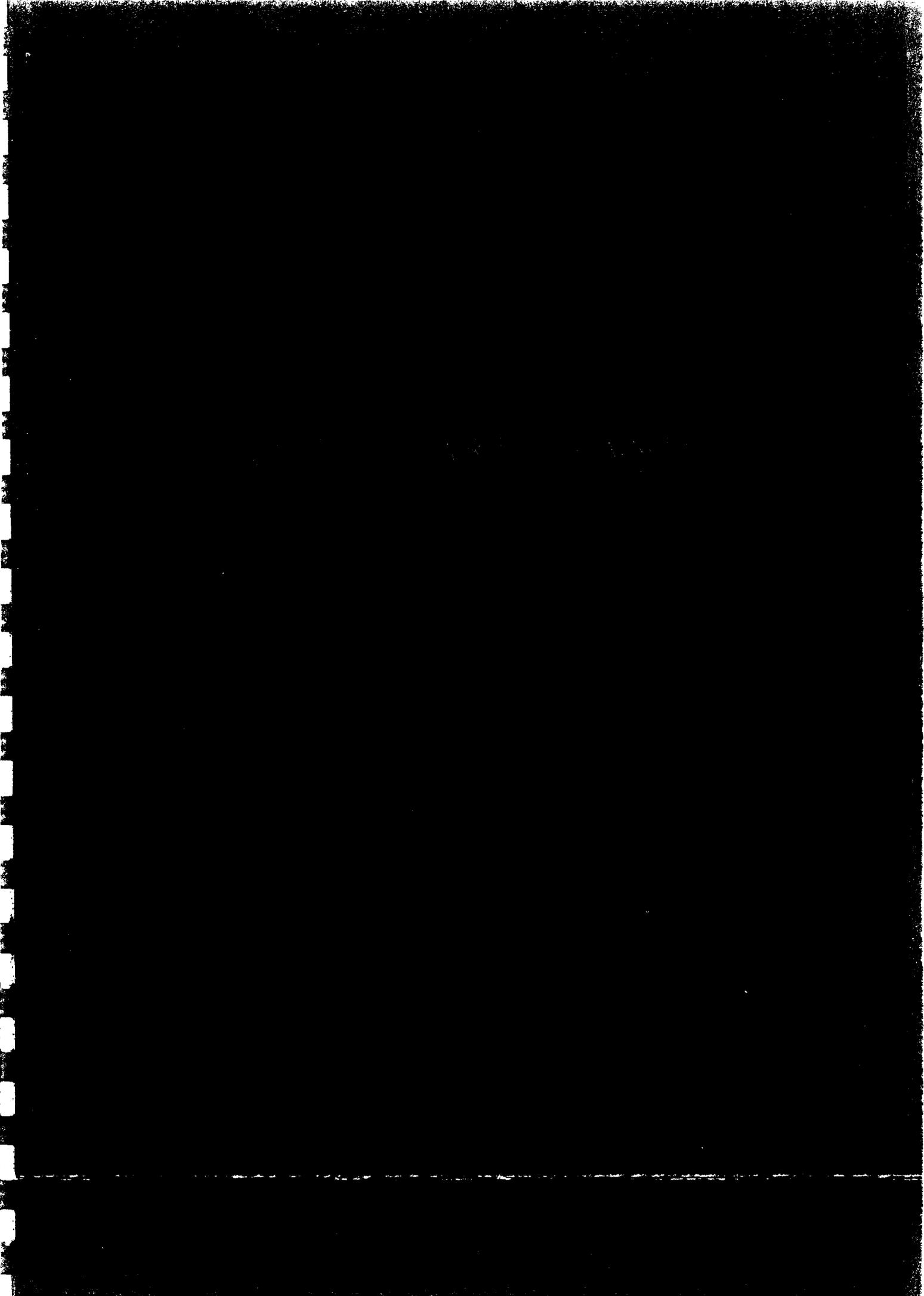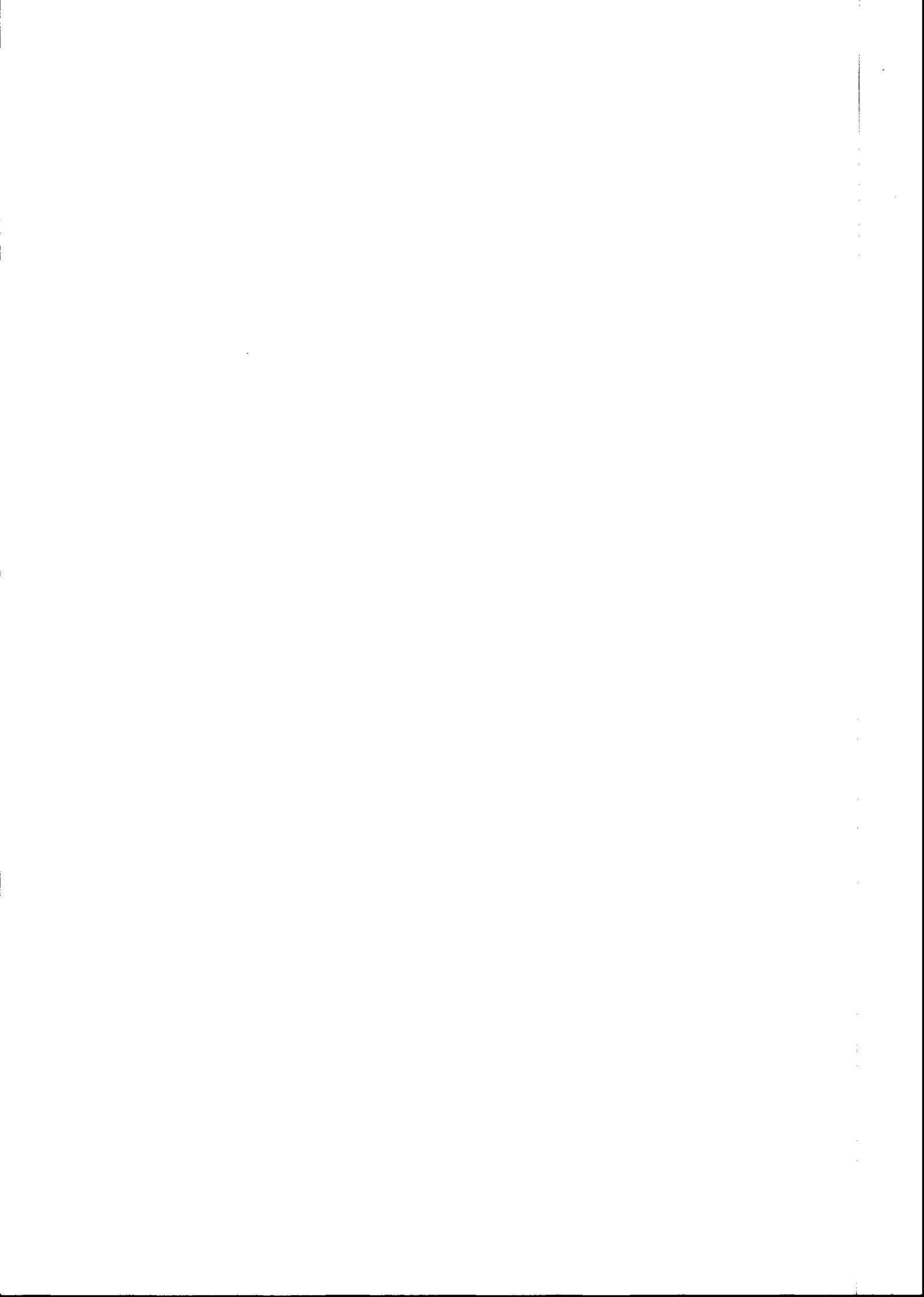
Frederic Achard
JRC
IRSA/MTV, TP440
21020 Ispra (VA)
ITALY
T +39-332-78-5545
F +39-332-78-9073

Yian Kwan Ang
Asian Institute of
Technology
RSL Manager
GPO Box 2754
Bangkok 10501
THAILAND
T +66-2-524-5582
F +66-2-524-5597

Dr. Josef Aschbacher
c/o JRC
IRSA/MTV, TP440
21020 Ispra (VA)
ITALY
T +39-332-78-5545
F +39-332-78-9073

Evert Attema
ESTEC
Postbus 299
Noordwijk NL-2200 AG
THE NETHERLANDS
T +31 1719-84461
F +31-1719-85675
E attema@estere.jw.estec.es
a.nl

Dr. John Baker
BNSC/RSADU
Monks Wood
Abbots Ripton
Huntingdon, Cambs.
PE17 2LS
UNITED KINGDOM
T +44-1487773381
F +44-1487773277
E JRB@WPO.NERC.AC.U
K

Olivier Barois
ESA/ESRIN
Data Utilisation Dept.
Via Galileo Galilei -
C.P.64
00044 Frascati
ITALY
T +39-6-941801
F +39-6-94180361

Alan Belward
Institute of Remote
Sensing Applications
Joint Research Centre
CEC
Ispra (VA) I-21020
ITALY

W. Bijker
ITC
350 Boulevard 1945,
PO Box 6,
Enschede 7500 AA
THE NETHERLANDS
T +31-53-874203
F +31-53-874399

Steve Boardman
Earth Observation
Sciences Ltd.
Broadmede
Weydon Lane
Farnham, Surrey GU9
8QL
UNITED KINGDOM
T 01252 721444
F 01252 712552

Dr Gilberto Camara
INPE/DPI
Avenue de Astronautos
1758-CP 515
12201 Sao Jose dos
Campos-SP
BRAZIL
T +55-123-418977
F +55-123-218743

Thongchai Charuppat
Survey & Mapping
Royal Forest Department
THAILAND

Jaquie Conway
JRC
IRSA/MTV, TP440
21020 Ispra (VA)
ITALY
T +39-332-78-9706
F +39-332-78-9073

Christoph Corves
University of Edinburgh
Department of
Geography
Edinburgh, Scotland EH8
9XP
UK
T +44-31-650-2523
F +44-31-650-2524

Alan Cross
Commission of the
European Communities
DG XII/D/4 Space Unit
Rue de la Loi 200
(SDME 3/7)
Brussels B-1049
BELGIUM
T +32-2-9541-60
F +32-2-9605-88

G. De Grandi
Joint Research Centre
IRSA/AT, TP27
Commission of the
European Communities
Ispra (Varese) 21020
ITALY
T +39-332-78-9823
F +39-332-78-5469

Dr. Hugo de Groof
Institute for Remote
Sensing Applications,
Agriculture Information
System
Joint Research Centre
I-21020 Ispra (Varese)
ITALY
T +39 332 785048
F +39 332 789074
E hugo.de-groof@cen.jrc.it

Guy Duchossois
European Space Agency
8-10 rue Mario-Nikis
75738 Paris Cedex 15
FRANCE
T +33-1-5639-7284
F +33-1-5639-7674

K. D. Grover
University of Sheffield
Dept. Applied &
Computational Maths
Sheffield
S10 2TN
UNITED KINGDOM

M. C. Imberti
GEOSYS
3, Rue Hermes
Parc Technologique du
Canal
31526 Ramonville
FRANCE
T +33-61-75-1210
F +33-61-75-8722

Manfred Keil
DLR Oberpfaffenhofen
DFD
Muenchner Strasse 20
Oberpfaffenhofen
D-82230
GERMANY
T 49 (0)8153-281377
F 49 (0)8153-281445
E keil@dfd.dlr.de

B. De Roover
University of Gent
Laboratory of Remote
Sensing and Forest
Management
Coupure Links 653
Gent B-9000
BELGIUM
T +32-92-64-6109
F +32-92-64-6240

Peter Fletcher
Remote Sensing
Applications Consultants
Mansfield Park
Medstead
Alton, Hants GU34 5PZ
UK
T +44-1420- 561377
F +44-1420 -561388
E peter@rsac.demon.co.uk

Louis-Francois Guerre
Spot Image
5 rue des Satellites
BP 4359
Toulouse Cedex F-31030
FRANCE
T (33) 62 19 40 88
F (33) 62 19 40 53

Herve Jeanjean
CIRAD-Foret/CESR
9 Avenue du Colonel
Roche
BP4346
Toulouse F-31029
FRANCE
T +33-61-273-441
F +33-61-556-701

Werner Kirchhof
DLR
Muenchner Strasse 20
Oberpfaffenhofen
D-82230
GERMANY
T +49-8153-28-2331
F +49-8153-28-1444

Michel Deshayes
ENGREF Centre de
Montpellier
648 Rue
Jean-Francois-Breton
Domaine de Lavalette -
BP 5093
Montpelier Cedex 1
34033
FRANCE
T +33- 67-04-7114
F +33-67-04-7101

Dr Jean-Philippe
Gastellu-Etchegorry
CESR-BP 4346
Paul Sabatier University
9 Avenue du Colonel
Roche
Toulouse F-31029
FRANCE
T +33-61-55-61-30
F +33-61-55-67-01

Dr. Dirk Hoekman
Agricultural University of
Wageningen
Dept of Water Resources
Nieuwe Kanaal ll
Wageningen 6709 PA
THE NETHERLANDS
T +31-8370-82894
F +31-8370-84885
E VISSERS@RCL.WAU.N
L

S. Karnchanasutham
N.R.C.T.
196, Phahonyothin Road
Chatuchak
Bangkok 10900
THAILAND
T 662-579 0345
F 662-561-3035

Guenther Kohlhammer
ESRIN
Via Galileo Galilei
00044 Frascati
Rome
ITALY
T +39-6-94180-356
F +39-6-94180-361
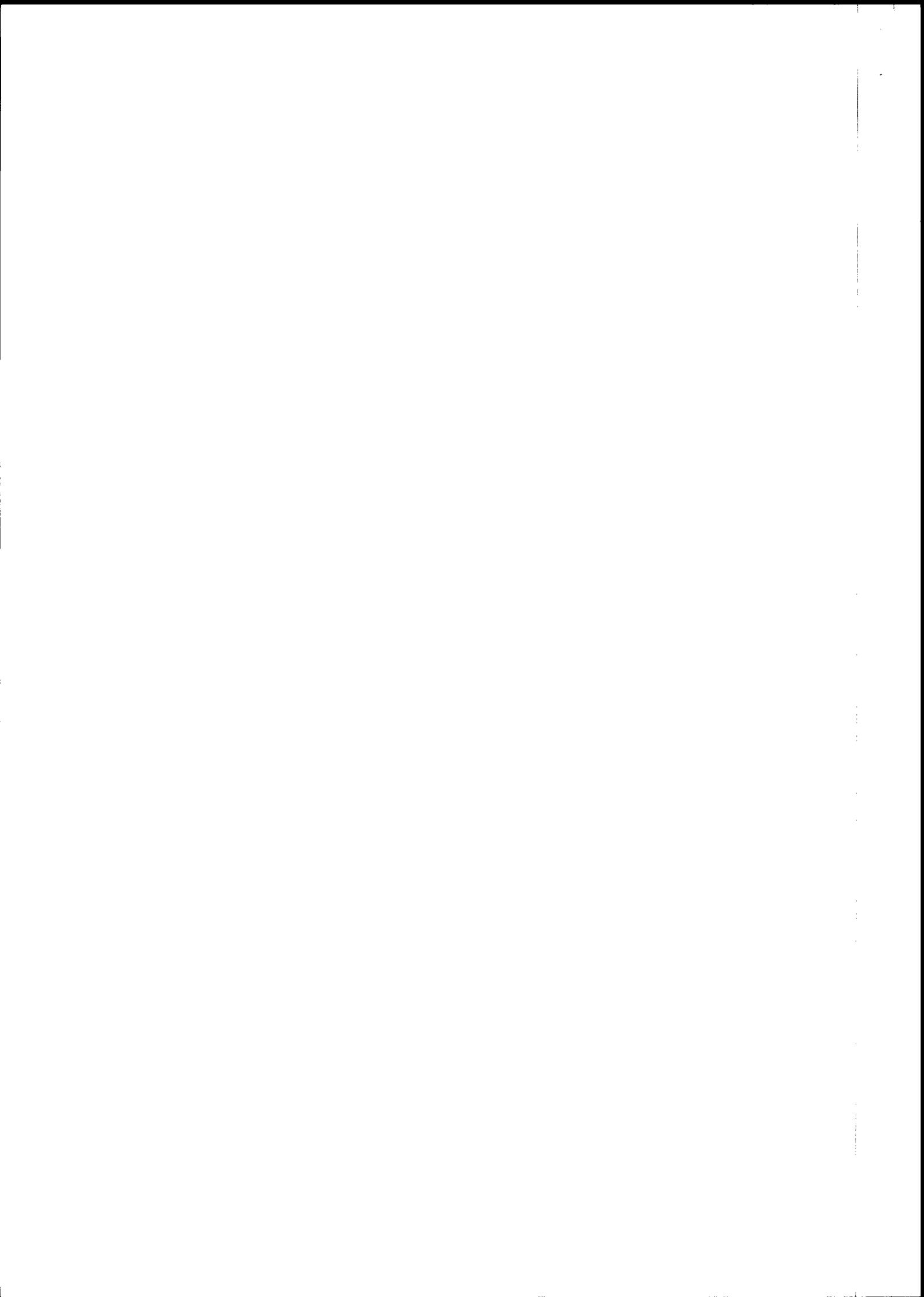
Dr. Steffen Kuntz
Kayser-Threde GmbH
Wolfratshauser Str. 48
D-81379 Munich
GERMANY
T +49-89-72495119
F +49-89-72495291

Dr. Thuy Le Toan
CESR
9 Avenue du Colonel
Roche
BP 4346
Toulouse F-31029
FRANCE
T +33-61556671
F +33-61556701

Guido G. Lemoine
Remotely Sensible
Kreuzgasse 20,
3860 Meiringen
SWITZERLAND
T +41 36 714995
F +41 36 714995
E LEMOINE@clients.switc
h.ch

Marc Leysen
Joint Research Centre -
TP440
IRSA/MTV-TREES
21020 Ispra (VA)
ITALY
T +39-332-78-9706
F +39-332-78-9073

A.J. Luckman
BNSC
RSADU
Monks Wood
Abbots Ripton,
Cambridgeshire PE17
2LS
UNITED KINGDOM
T +44-1 487 773 381
F +44-1 487 773 467

Jean-Paul Malingreau
c/o JRC
IRSA/MTV, TP440
21020 Ispra (VA)
ITALY
T +39-332-78-5545
F +39-332-78-9073

G Mariet
GDTA
18 Avenue Edouard Belin,
31055 Toulouse Cedex
FRANCE
T 33-612-746-28
F 33-612-814-98

J. Meyer-Roux
Institute of Remote
Sensing Applications
Joint Research Centre
CEC
Ispra (VA) I-21020
ITALY

Edmond Nezry
Institute for Remote
Sensing Applications,
Agriculture Information
System
Joint Research Centre
I-21020 Ispra (Varese)
ITALY
T +39 332 785048
F +39 332 789074

Guido Paci
ESA/ESRIN
Data Utilisation Dept.
Via Galileo Galilei -
C.P.64
00044 Frascati
ITALY
T +39-6-941801
F +39-6-94180361

P. Pasquali

Dipak R. Paudyal
Asian Institute of
Technology
Remote Sensing
Laboratory/Natural
Resources Program
GPO Box 2754
Bangkok, 10501
THAILAND
T 524-5575/524-5576
F (66-2) 516-2126

Dr. Shaun Quegan
University of Sheffield,
Dept. Applied &
Computational Maths.
Sheffield S10 2TN
UNITED KINGDOM
T +44-1142-768555 x4432
F +44-1142-739826
E s.quegan@sheffield.ac.uk

Paul Reichert
FAO
Via Terme Di Caracalla
00100 Rome
ITALY

S. Remondiere
ESA/ESRIN
Data Utilisation Dept.
Via Galileo Galilei -
C.P.64
00044 Frascati
ITALY
T +39-6-941801
F +39-6-94180361

CENTRAL AFRICA MOSAIC PROJECT: AN OVERVIEW

Franco De Grandi - TREES ERS-1 Coordinator

J.P. Malingreau - TREES Coordinator

M. Leysen - TREES ERS-1 Investigator

MTV Technical Note

1.0 Primary Scientific Goal

The primary scientific goal of the Central Africa Mosaic project (CAMP) is to explore the possibility of extending to a semi continental scale the intended functions of the ERS investigations, which are so far validated only on a smaller scale. The intended functions are the ones defined as objectives of the TREES ERS-1 Study 94 [MAL94], and in particular the usefulness of ERS for operational deforestation monitoring is of relevance here.

Simple extrapolation of the results from a smaller to a larger scale is in principle not possible because:

- A snapshot of the extended target is acquired in a time frame which is not negligible with respect to the dynamics of the ecological system; therefore spatial and temporal variations are contained in the same mosaic, and ways to discriminate them must be eventually found.

- The sensor is tailored to high resolution detailed studies; the passage to a global monitoring function requires a careful assessment of the spatial sampling, compromising between signal to noise ratio, natural features detectability, and data volume (important in view of an operational system).

- Most of the local area results are based on the use of sensor stability to improve the signal to noise ratio, or the discriminants for forest non-forest through multiple acquisitions in time. This concept must be revisited when talking of semi-continental multiple acquisitions, and possibilities explored to exploit either the intrinsic within image time variations, or entirely new avenues that work on single acquisitions (e.g. filters working on second order statistics [NEZ94]).

- Since the global coverage product has different radiometric and statistical properties with respect to the local area ones, the performance of an algorithm can change when applied in one situation or in the other.

Therefore the project has a well defined scientific connotation that makes it fit into the guidelines of the TREES ERS 94 study and steers it away from the general purpose problem of mosaicking remote sensing images, as the title could mistakenly suggest.

2.0 Technical and Engineering Goals

In order to achieve the above described main scientific goal, a waterfall of technical and engineering problem have been solved. These can be grouped into the following areas:

1. Computational aspects
- processing chain design
- intermediate and final product definition
- data volume (compression)
- throughput
- archive policy
- history and threading mechanisms
- undo and recover
- presentation, visualization
2. Radar Science
- calibration
- compression and signal enhancement
- geometric registration
- mapping to a cartographic reference frame
3. Image Processing
- framelets stitching
- feathering

The solutions of these problems has relied on a consolidated ground of knowledge in the respective areas, but also innovative solutions tailored to the particular sensor, imaged target, data sets and computational environment have been explored, and will give added value to the project.

3.0 Project Organization

The project is organized in the following way, as far as the functional decomposition and resources are concerned:

1. Science and algorithm team.

    J.P. Malingreau (JRC MTV): coordination, thematic science plan, evaluation

4.0 Project Flowchart

In the following diagram the major functional blocks are shown with their current status, dependencies, and allocated staff members

---

FIGURE 1. Project Organization Diagram

TREES ERS-1 1994
Central Africa Mosaic
Project Organization Diagram

Concept ML
ERS frames JPM
D

Calibration EN
Comp FDG
D

Geolocation HDG
Registration FDG
P

Software Eng. GP
P

Interface FDG
D

Seam Search FDG
D

Interfaces GP
FDG
P

Control Shell GP
CISI
P

Database GP
Journaling FDG
P HDG

Early protos D

Test Set (100 PRIs)

Mosaic Machine P

Final Set (435 PRIs)

HR Database

Products

LR Database

Status:
D done
P in progress

CENTRAL AFRICA MOSAIC PROJECT: AN OVERVIEW

G. De Grandi (JRC MTV): project management, radar science

Marc Leysen (JRC MTV): project definition, evaluation, thematic interpretation

Hugo De Groof (JRC AIS consultant): framelets registration, mapping

Edmond Nezry(JRC AIS consultant): calibration, compression

2. Computational aspects team

Giorgio Perna (consultant): software engineering, processing chain control and housekeeping.

Elisabetta Franchino (CISI) Luigi Maggi (CISI): software development and operation.

6.0 Software Project Highlights

Distinctive features of the software project are:

- Contrary to the conventional approach in mosaicking software, the main objective here is not to realize a monolithic processing chain that generates a unique final product (e.g. the assemblage of a set of related images), but rather an environment to support the interpretation of ERS data on a semi-continental scale.
- The environment will consist mainly of a number of engines to generate different products, a database to keep the relationships between the products, and services that allow the user to manipulate and represent graphically the products.
- Due to the vast amount of data that must be handled in this context, a new paradigm is introduced, which is called processing on demand, and is similar to the classical paging mechanism in an operating system; this means that more specialized products, such as high resolution speckle filtered images, are generated only when a specific processing step, such as spatial zooming, is invoked; and they are kept on line only until the request rate is above a certain threshold.

In the design phase of the software life cycle we have taken a number of strategic decisions, which are here summarized:

- The mosaicking software will have to run as much as possible in a automated way
- The main structure of the software is based on a control shell (written in IDL) where algorithmic and house-keeping modules are plugged in.
- This will give flexibility in changing the control flow and the algorithms, in order to tailor the software machine to different target products.
- A database is built incrementally to keep track of the life cycle and the characteristics of each sub-product.
- Before the bulk processing is started a survey is made on the raw incoming data to assure proper consistency in the auxiliary parameters and integrity of the data.
- At any point of the processing chain a checkpoint can be made by the software operator to assess the status of the system.
- The archive function on the Epoch machine is de-coupled from the mosaic processor.
- Disaster recovery is implemented to restart the system at any point after failure.
- The mosaic is built at first in the PRI images reference frame, and warped into a cartographic frame only in the final stage. This will extremely simplify the stitching and registration algorithms, and provide an intermediate product which is more amenable to automatic geophysical processing.
- Early prototyping will be used to assess potential problems and fine tune the algorithms.
- SCCS will be used to control the software generation by the software engineering team.

The concepts behind the mosaicking environment are depicted in Figure 2 on page 7. The flow of the main operations in the mosaicking machine is shown in Figure 3 on page 8.

5.0 Scheduling

The major milestones and the scheduling of the project are reported next.
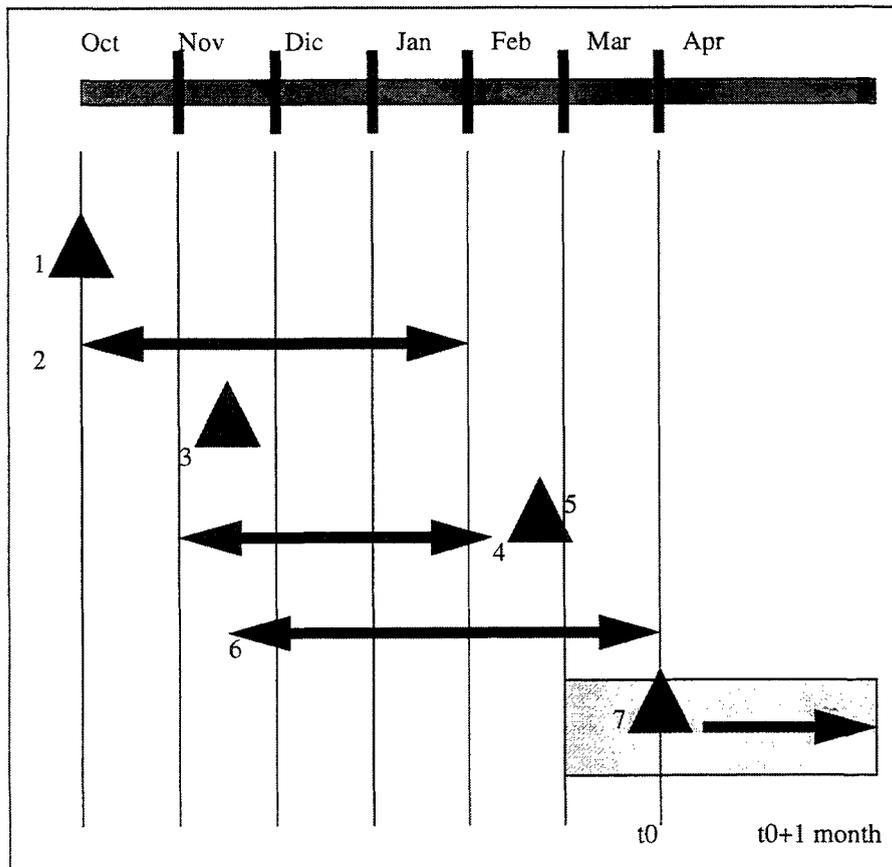
1 - Project Start
2 - Design and algorithms test
3 - First data batch delivered to the JRC IRSA (100 PRI)
4 - Prototype and demostrator
5 - TREES ERS-1 final meeting
6 - Operational processing chain development
7 - Production phase (from time t0 of data delivery)

FIGURE 2.   Mosaicking Environment
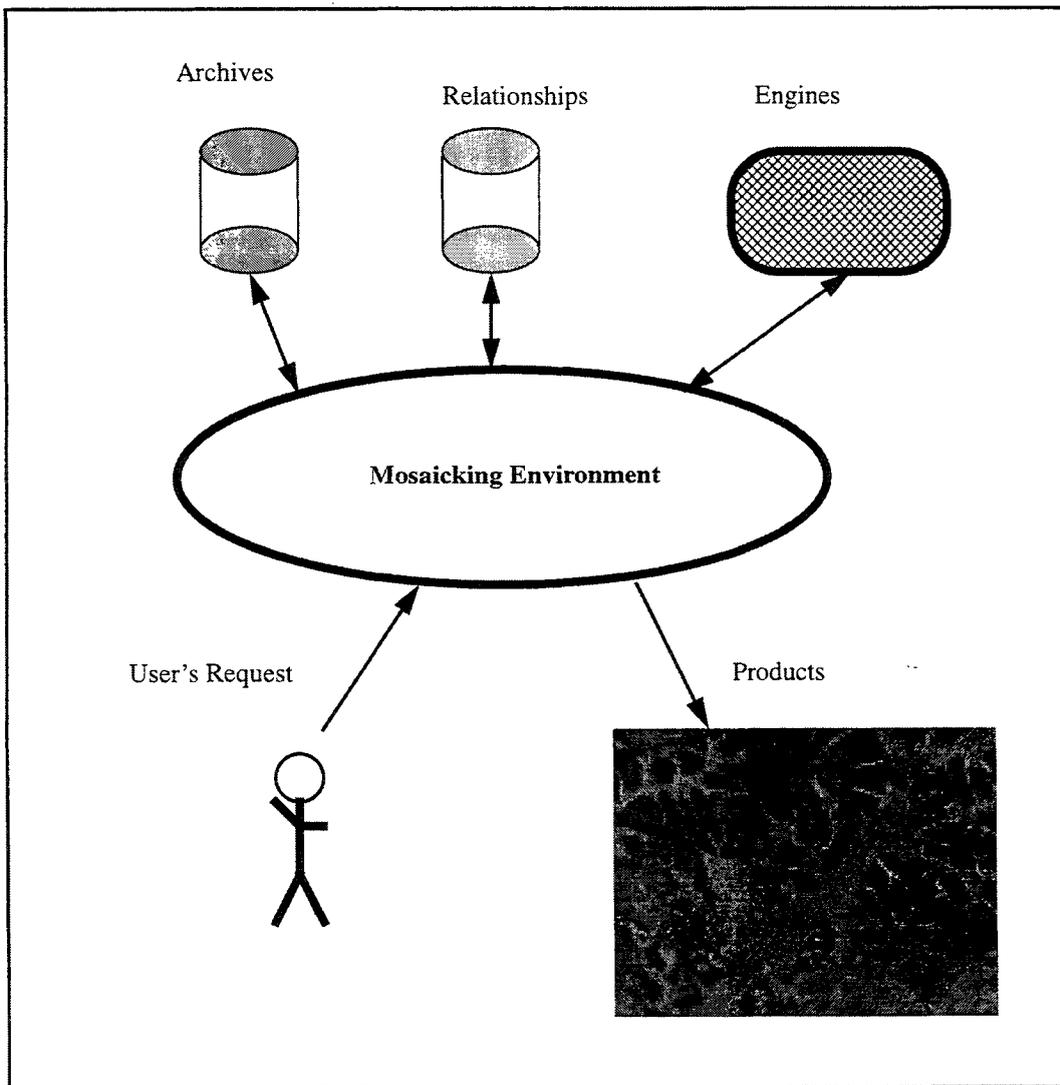
FIGURE 3.   Mosaicking Software Flowchart
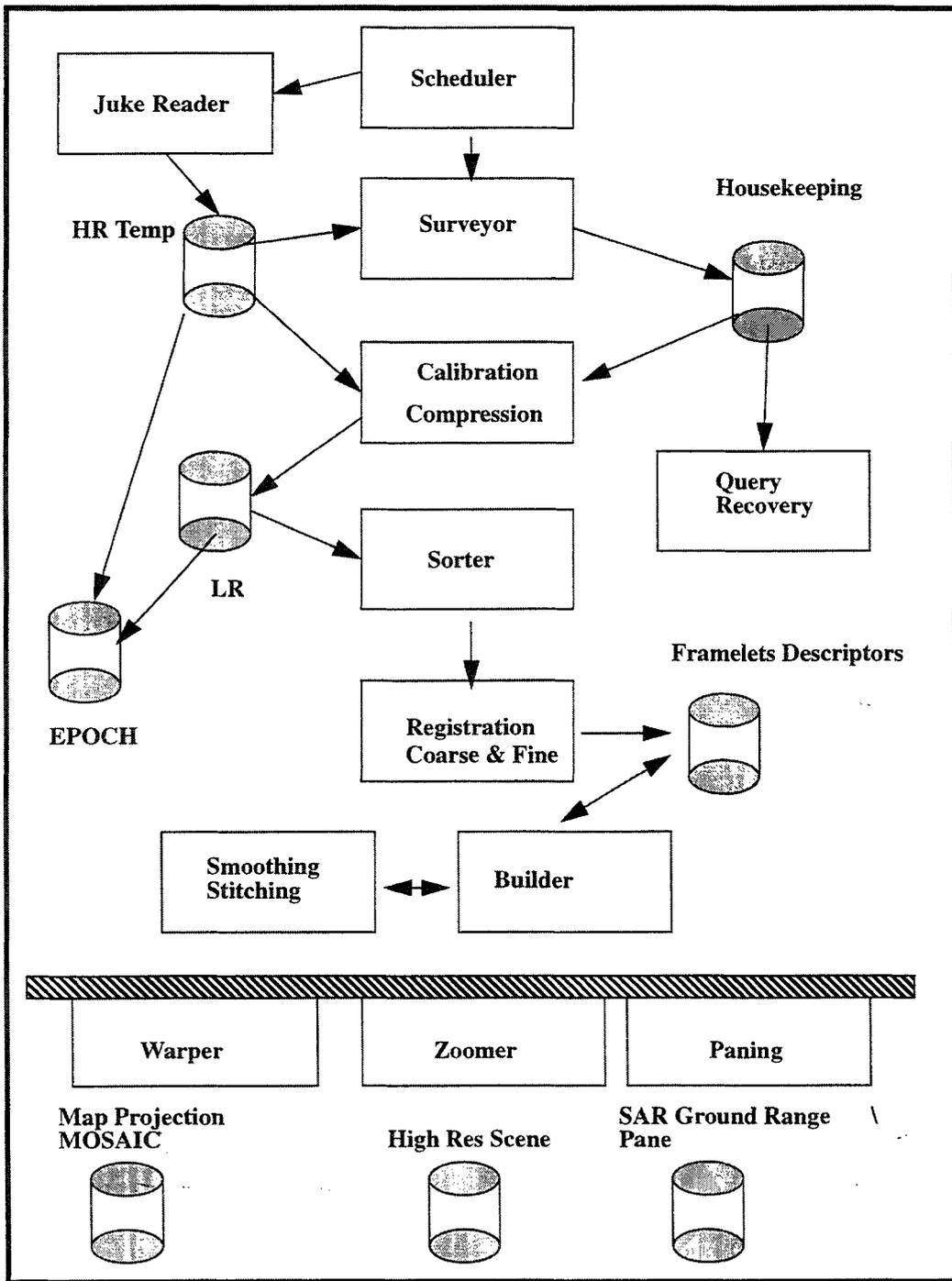
microwave approach. It is possible to refine the positioning of the southern boundary of the Central Congo rain forest using the mosaic material.

- the boundary between the rain forest and the mixed savannah - gallery forest formations is also well marked in the northern parts of the Congo basin examined so far; this is rather surprising since acquisitions have been obtained in the middle of the rainy season (July-August). Further to the north the open dry forest shows particular texture patterns which make them rather distinct (Figure 7 on page 15). These points need to be further investigated.

- deforestation fronts, a major focus of interest in the TREES approach, are not frequent in the Central Congo Basin. Yet one example in Southern Zaire (Figure 5 on page 13) shows features associated with the dynamics of those fronts in an unmistakable manner. Geometric forms typical of an organized exploitation pattern as well as more diffuse clearings probably associated with the accompanying agricultural expansion are visible at the southeastern edge of the rain forest. This area provides a good demonstration of the ERS-1 SAR discrimination capabilities.

- unexpectedly, the ribbon of secondary formations following the older road network of Zaire is visible in the SAR microwave return signal by contrast with the surrounding primary forest (Figure 6 on page 14). These forest "galleries", correspond to the pattern of land management which since colonial time has essentially followed the road communication system. The vegetation is formed here by secondary regrowth, plantations, gardens, etc.. Some small openings with lower radar return are seen at the edge of the galleries; they may indicate active agricultural expansion in the forest domain. With the assistance of a road map it is possible to follow many of those forest galleries from one town to the next. Image enhancement can be applied to reinforce the image contrast. The results reported here are in contrast with the first pass TREES AVHRR analysis of the same area.

- in the rain forest domain itself the range of visible features is rather limited. This maybe due to compounded reasons. Lack of recent deforestation activities, diffuse patterns of agricultural expansion or the inability to separate primary forest and older secondary regrowth with no clear geometrical patterns, are possible explanations.

The results of this preliminary and still partial investigation are encouraging on several grounds:

- at first they indicate that, contrary to what is commonly expected, the ERS-1 SAR coverage may represent a unique source of data on vegetation at continental and global scales. The assemblage of more than 400 images foreseen in the Central Africa Mosaic will undoubtedly tell us a lot about this very new perspective on SAR coverage.

- second, the items of relevant information derived from the present analysis must be considered as starting points for further research on a wide range of issues. The mosaic is helping to formulate a more relevant research agenda in view of operational tropical forest monitoring.

- third, while the processing of such a large amount of data and their assembling into a mosaic needs major investments in terms of expertise and equipments, it appears possible to establish operational processing chains which can feed the analysts with highly usable products. The global coverage aspects of the exercise is therefore fur-

7.0 Preliminary Processing Results

Some of the processing blocks have been implemented and tested to date at a prototype level; these are:

- Calibration compression
- Registration
- Stitching
- Control shell

Some preliminary results obtained by the prototype software are reported in the next section. A number of frames acquired over orbits 15846 and 16133 and processed by the German PAF (see coverage map Figure 9 on page 17), were calibrated, compressed to the low resolution (LR) product [SOL93] (ENL=80, pixel spacing= 100m.), registered and mosaicked into two stripes.

Some of the LR frames are shown, to give a flavor of the quality achieved, which looks quite promising in terms of the thematic goals (see next section).

Finally the results of a test on the stitching algorithm are shown (Figure 8 on page 16). The algorithm is based on a bi-directional seam point search algorithm [SHI89]. The algorithm was modified to take into account the boundary conditions and the horizontal edge at the border of the overlap area.

8.0 Thematic Results: a Preliminary Analysis

A first coarse analysis of four strips of ERS-1 SAR images included in this Central Africa Mosaic (CAMP) reveals a series of features which are of most relevance in the framework of the TREES project objectives. The preliminary results are also of high interest for global vegetation monitoring, a major objective of the International Global Change Research Program (IGPB). The mosaic represents, indeed, a unique and uniform cross section of important tropical biomes from the savannah and dry forest in the north, through the entire rain forest domain and again through seasonal formations south of the equator (savannah and edge of the Miombo Woodland). The design of this Central Africa mosaic is such that, since it crosses the equator it contains at the same time dry and rainy season acquisitions with a gradient of wetness in between. This allows a range of observations to be made with respect to the occurrence or to the lack of seasonal contrasts between various vegetation formations. The scale, resolution and biowindows offered by the 1994 Central Africa Mosaic qualifies it as a truly global product, which satisfies a series of important conditions related to vegetation monitoring.

A few items of information derived from the visual analysis of the 200m. pixel spacing products generated by the above described processing chain are presented here. The analysis has been conducted on print-outs assembled in continuous strips.

- the boundary between the rain forest - or in this case, more likely, a mix of evergreen/semideciduous mesophyllous forest formations - and the mixed seasonal - savannah formations to the south is extremely well marked (Figure 4 on page 12). This being a dry season (July-August) the contrast between the evergreen cover and the more deciduous (trees) or senescent (grass) cover is well detected using the

**FIGURE 4.**   ERS LR Product - Orbit: 15846 Frame: 3681 July 27,1994

ther reinforced by the advances made in the streamlining of all the necessary operations.

The TREES project is planning to pursue this large scale effort in ERS-1 SAR data analysis.

FIGURE 5.   ERS LR Product - Orbit:16133 Frame: 3681 Aug 16, 1994

FIGURE 6.   ERS LR Product - Orbit: 16133 Frame: 3645 Aug 16, 1994
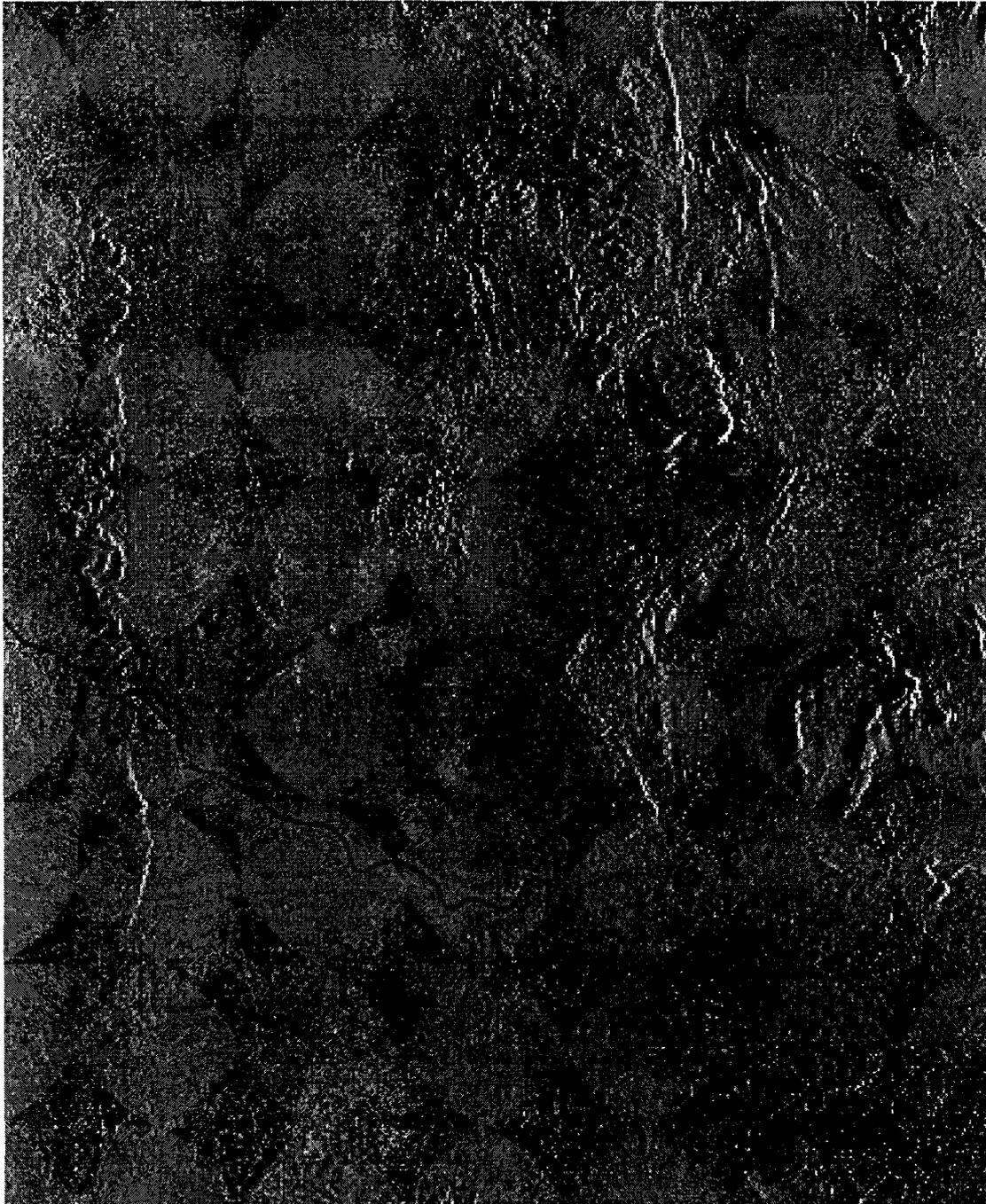
FIGURE 8.   Seam Point Search Algorithm
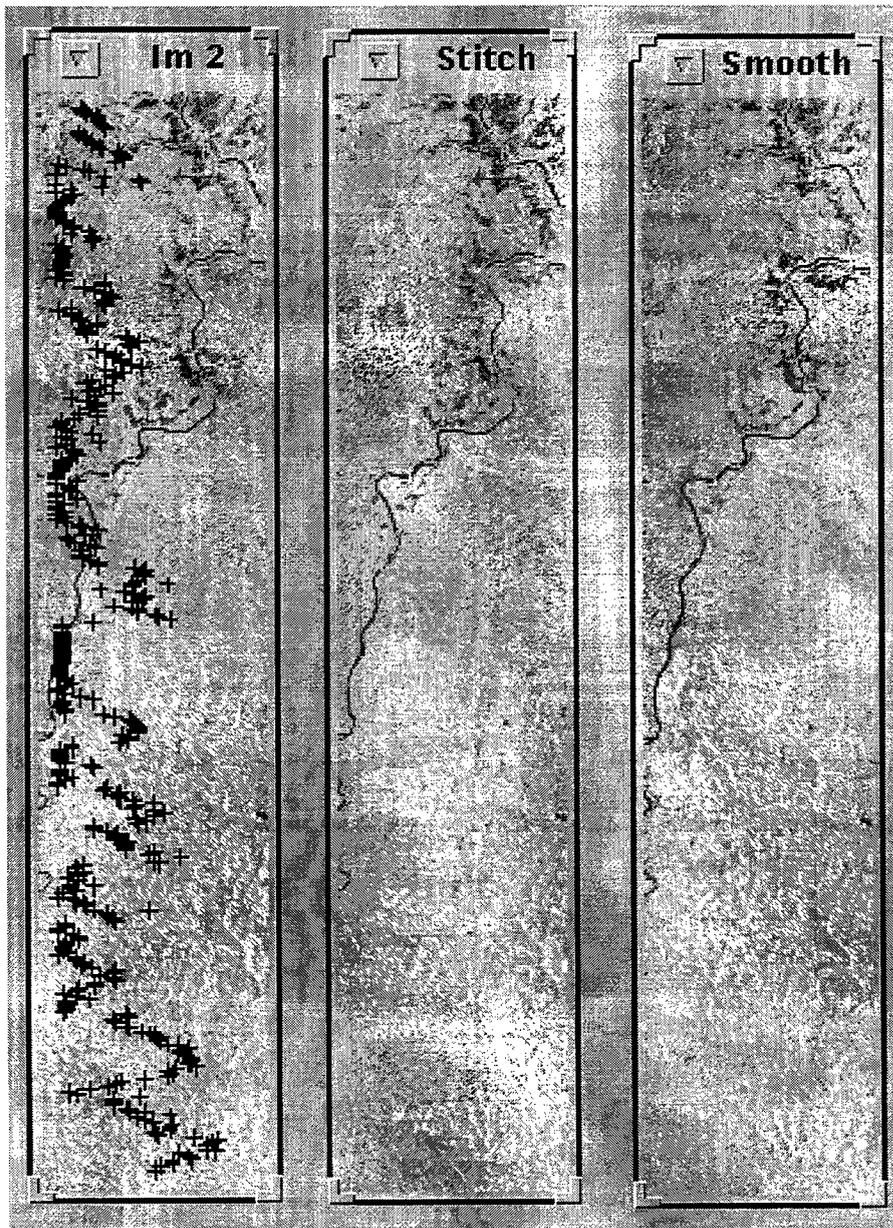
FIGURE 7. ERS LR Product - Orbit: 15846 Frame: 3537 Jul 27, 1994
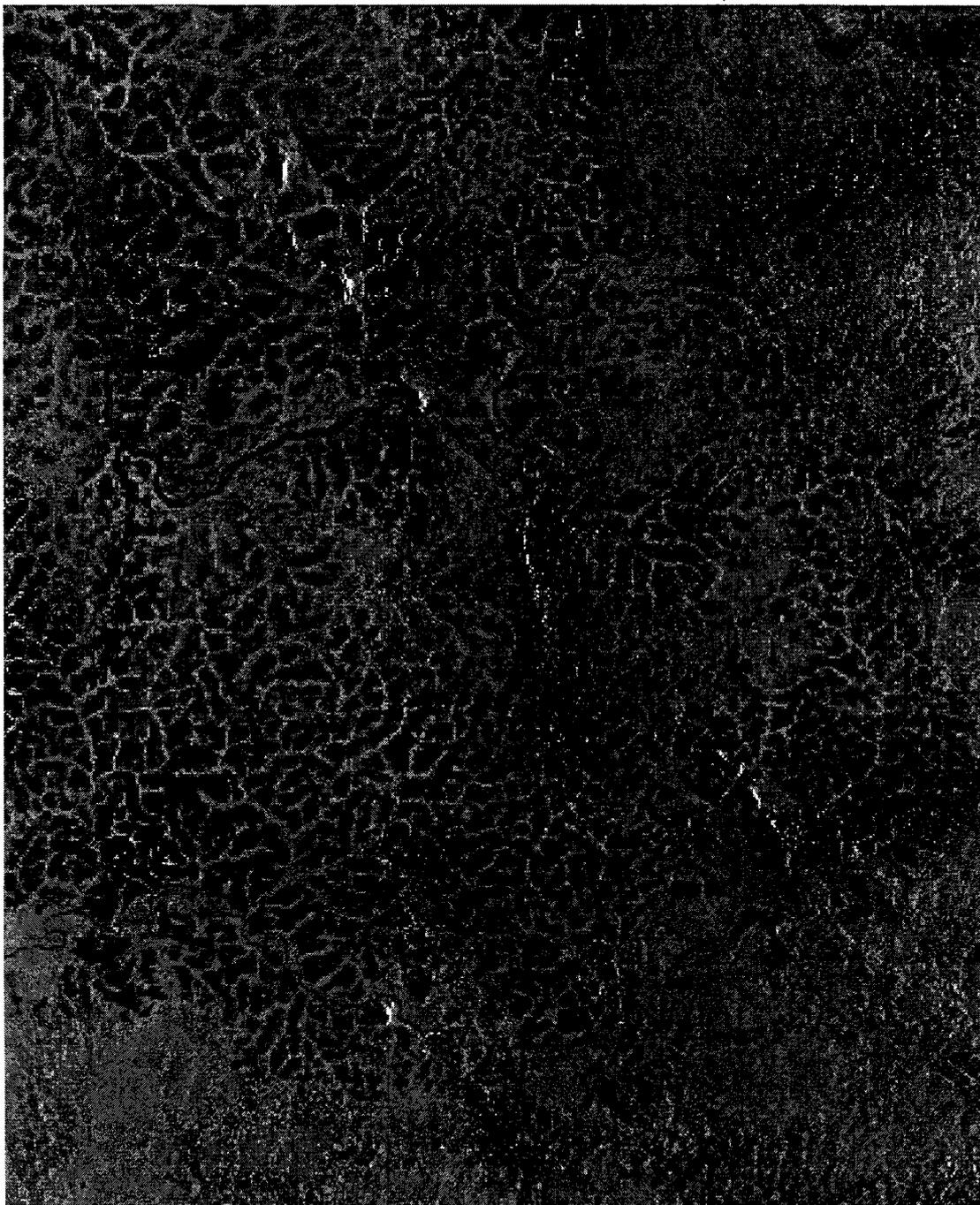
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[SHI89] Yang Shiren, Li Li, Gao Peng, "Two-Dimensional Seam-Point Searching in Digital Image Mosaicking", PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING, vo. 55, No. 1, Jan 1989, pp. 49-53.

[SOL93] G. Solaas, H, Laur, "An Assesment of ERS SAR Low Resolution Imagery", ESA technical note ES-TN-DPE-OM-GS01.

FIGURE 9.   Central Africa Mosaic ERS Coverage
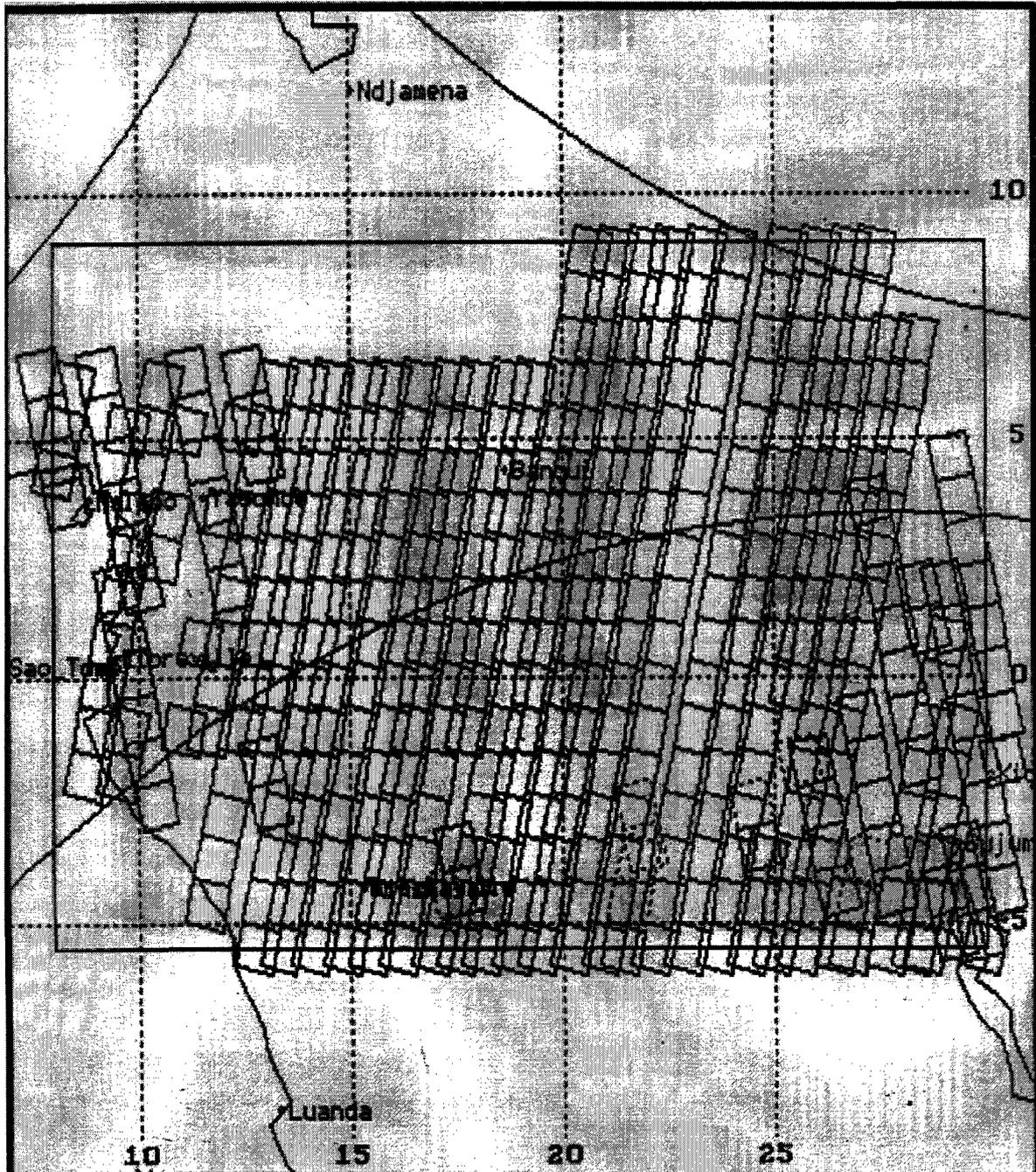
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TREES

TROPICAL ECOSYSTEM ENVIRONMENT OBSERVATIONS BY SATELLITES

TREES ERS-1 Study 94 Final Workshop

JRC Ispra, 23 and 24 February 1995
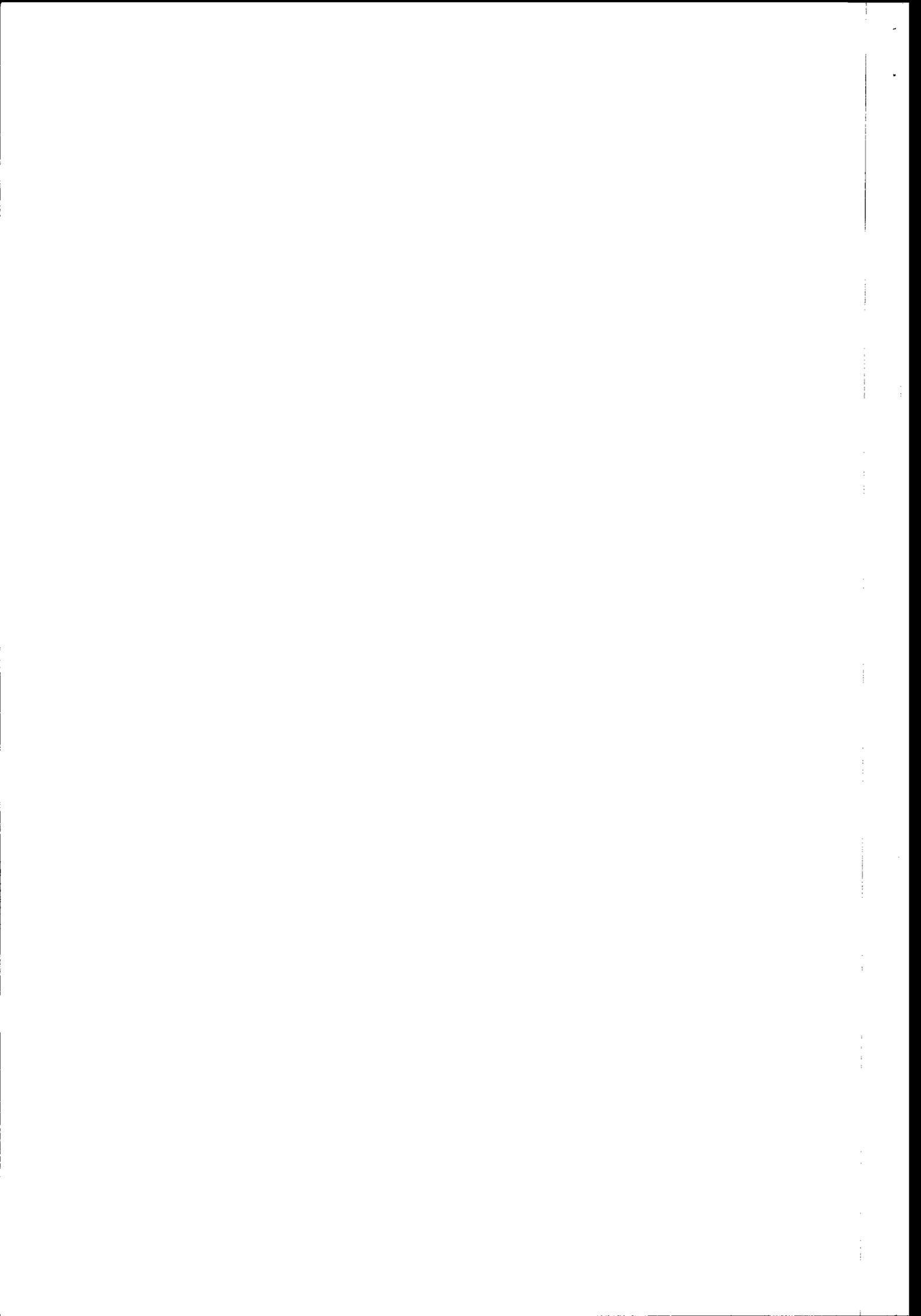
Thursday 23rd February 1995

09.00 - 10.00: General presentations

Welcome Address: Jean-Meyer Roux, JRC

Background and Objectives of the Workshop: Jean Paul Malingreau, JRC, & Guy Duchossois, ESA

10.15 - 12.30: Investigations in South East Asia
Chairperson: Evert Attema, ESA

SEA 5	South Sumatra:	Thuy le Toan CESBIO, F
SEA-1	South China:	Li Zenguyan Chinese Academy of Forestry
SEA-2	Thailand/Cambodia:	Dipak Ram Paudyal Asian Institute of Technology, Thailand
SEA-3	Peninsular Thailand:	Yian Kwan Ang Asian Institute of Technology, Thailand
SEA-4	Central Sumatra:	Jean Philippe Gastellu-Etchegorry CESBIO, F
SEA-6	Papua New Guinea:	Jacquie Conway JRC
SEA-7	Cambodia/Vietnam:	Herve Jeanjean SCOT-Conseil, F
SEA-8	East Kalimantan:	Ralph-M Ridder DLR, D
TRULI Project:		Steffen Kuntz Kayser-Threde, D

Lunch

14.00 - 14.30: South East Asia Synthesis: Thuy le Toan, scientific coordinator