ANNUAL·REPORT·89

Institute
FOR
Remote Sensing Applications

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EXECUTIVE SUMMARY

Introduction

The Institute for Remote Sensing Applications was created in November 1988 as the result of the decision taken by the Council of Ministers on the restructuring of the Joint Research Centre.

The principle objectives of the Institute are:

- to evaluate and demonstrate possible applications of remote sensing techniques in support of sectorial policies of the Commission in areas such as the Common Agricultural Policy (agricultural statistics, land use), Environmental Policy (Land and Sea Protection), Development (food resources and environmental protection in developing countries), Fisheries (resources evaluation and conservation) and Regional Aid.
- to undertake research on advanced methods for the interpretation and utilisation of satellite data including their integration with geographical data (geographical information systems).
- to help stimulate the scientific community in the use of European satellites (complementary to the mission of the European Space Agency) such as ERS 1, SPOT, Polar orbiting Platforms. This is carried out through collaborative programmes (joint air campaigns for advanced sensors such as, microwaves, high resolution imaging spectroscopy etc.), pilot projects of European significance where the collaboration of many national laboratories or industries is essential due to the scale of the effort required.

Nineteen eighty nine saw the initiation and consolidation of a number of application oriented projects such as Agricultural Statistics, Land Use in European Marginal Regions, Monitoring of Vegetation in Tropical and Subtropical Areas of West Africa and Surveillance of Marine Environment and Resources.

The year was also characterised by the beginning of research in the area of microwaves, especially in view of the launch in the near future of the European satellite ERS-1. Studies on the application of laser fluorescence have led to the construction of an airborne LIDAR fluorosensor instrument which will be flight tested during 1990. Investigations of laser spectroscopy to vegetation (green matter) have culminated in a EUREKA project "LASFLEUR" in which the Institute will actively participate.

Two airborne measurement campaigns have been organised in collaboration with the European Space Agency and with the participation of many European laboratories. The first, named MAESTRO 1, used a polarised Synthetic Aperture Radar (SAR) with three frequency bands (C,L,P,) the other, named EISAC, used two different high resolution spectrometers. Areas over which these new sensors were flown included forestry, agriculture and oceanographic test sites.

During the year the Institute reinforced its research teams with the recruitment of specialists in agronomy, statistics, image processing and microwaves. An important effort was equally made for grantholders, visiting scientists and seconded national experts.

An important number of initiatives were undertaken in the framework of international collaboration: a mixed working group European Space Agency - Commission was created on the theme "Environment and Earth Observation"; the Institute was accepted as an associated member of the Space Agency Forum of the International Space Year (SAFISY) and participates strongly in activities for the International Space Year (ISY); similarly the Institute participates in the United Nations Environmental Programme (UNEP) and the International Geosphere-Biosphere Programme.

The programme of the Institute is divided into three main areas: specific programme, exploratory research, and scientific and technical support to community policies.

Programme Objectives: Specific Programme

Monitoring of Land Resources and their Use. This research activity is aimed at the:

- development of methods integrating satellite earth observation and conventional data to provide information for the monitoring and management (development and/or conservation) of the marginal (less favoured) areas of the European Community.
- investigation of approaches, using artificial intelligence techniques, to improve the classification of remotely-sensed images. The objective is to develop a knowledge-based (or expert) system which is able to store and process information about selected test areas and integrate this system with image processing and geographical information data bases.

The project has been developed as a contribution to the implementation of the Common Agricultural Policy and of the Environmental Policy.

Monitoring of the Marine Environment

Sea Pollution Surveillance

The aim of this project is to carry out a series of remote sensing exercises at sea under near operational conditions in order to demonstrate and optimise airborne instrument packages. The instrumentation is essentially composed of active and passive microwave sensors for the evaluation of oil spills under all-weather conditions.

Coastal Pollution Dynamics

This research concerns the study of coastal transport of pollution in the northern Adriatic Sea using largely sea colour data obtained from the Coastal Zone Color Scanner (CZCS), as well as relevant sea truth measurements and hydrodynamic modelling. Work has also been undertaken in the Gulf of Naples using the Thematic Mapper sensor.

A joint proposal has been prepared by the JRC and ESA for a CZCS data archiving organization and exploitation network with the objective of obtaining an improved understanding of the European marine environment.

Advanced Techniques:

As a part of its long-term research, the Institute evaluates a number of advanced sensor techniques which will become important in the future as new observations systems are developed (e.g. ERS1, polar orbiting platforms, airborne remote sensing).

Microwave Remote Sensing

This project is aimed at the development of remote sensing by microwaves. The objective of this activity is to help prepare the European scientific and user community to use the data that will be available from the ERS-1 satellite which will be launched by the European Space Agency in 1991. Microwave sensors are attractive through their all weather, day and night sensing capability. However the information content of the data is not sufficiently understood at present to allow a full range of practical applications. Initial areas foreseen for study relate to agricultural crops and forests.

The microwave project is thus being developed to respond to these issues including: an important effort in understanding radar signatures of vegetation through the development of a radar signature laboratory; undertaking airborne remote sensing campaigns; the promotion of a European Airborne Remote Sensing Capabilities (EARSEC) etc.

Laser Fluorosensing

The Joint Research Centre has been developing over a number of years a time resolving laser fluorosensor which can simultaneously measure the spectral and temporal fluorescence response of remote targets under the excitation of a laser beam.

Current applications are in the field of characterization of oil spills on the sea surface, the measurement of selected water quality parameters (chlorophyll, yellow substances etc.) and the monitoring of land vegetation (this activity is undertaken under the heading of Exploratory Research). The development of a prototype airborne system is being investigated.

Imaging Spectroscopy

This is a new project for the Institute and is seen as an extremely important technique in the future development of remote sensing. The technique splits visible to shortwave infra-red light into high resolution channels. The choice of the number and positions of the bands depends upon the application requirements. During 1989 the JRC and European Space Agency organized an imaging spectroscopy airborne campaign using aircraft equipped with two different imaging spectrometers.

Scientific and Technical Support to Community Policies

External Affairs (DG 1): Study of the Northwest African Upwelling Area

The aim of this study of coastal upwelling off the North Atlantic coast of Marocco is to demonstrate how knowledge of upwelling dynamics, obtained by remote sensing and complemented with other types of data, can be used to evaluate resources and thus identify stock conservation requirements.

Common Agricultural Policy (DG VI) and Statistics Office (EUROSTAT)

Pilot Project Application of Remote Sensing to Agricultural Statistics
The objective of the Pilot Project is to demonstrate a methodology by which remote sensing could supplement, integrate and standardize data provided by more classical techniques. It will develop an operational use of remote sensing and agro-meteological modelling for agricultural inventory and monitoring. The project started with limited staff in 1987, has considerably developed and has been divided into four main actions and three support actions. The plan covers a period of ten years but is at present funded for five years (until the end of 1993). The Institute has responsibility for the project. Most actions are carried out by contractors to the JRC in Member States of the Community.

Development Policy (DG VIII): Monitoring of Vegetation in Tropical and Subtropical Areas

This project is concentrating on the development of remote sensing approaches for the monitoring of vegetation changes over large areas in West Africa. This choice has been guided by requests for specific information on the evaluation of tropical environments as well as by the need to develop new methodologies which can address problems at more global levels. Three main fields of application are being investigated: use of satellite data for improving agricultural sampling framework, and for assessing rainfed cereal yields at the regional and national level; the study of vegetation conditions in large watersheds by the analysis of low resolution satellite data time series; and the investigation of tropical deforestation and biomass burning.

Exploratory Research

Applications of Laser Spectroscopy to the Characterization of Green Matter

The objective of this research is to use methods of laser-induced chlorophyll fluorescence for remote characterization of the healthy state of vegetation. In a first phase vegetation in known physiological

state will be described by plant characterization (net-photo-synthesis, transpiration, stomata conductance and potential photosynthetic activity) and by time resolved chlorophyll fluorescence measurements. The final goal of this phase is to correlate the physiological parameters with those obtained by the analysis of the fast fluorescence decay.

Summary of results

Monitoring of Land Resources and their Use

The program deals with land use mapping and land cover statistics over the department of Ardèche by automatic processing methods using mainly Landsat Thematic Mapper data (30 m resolution). A geometric registration method has been developed, which includes the use of a digital elevation model to correct for the relief displacement effect. The average superposition accuracy is within one pixel over the whole image. An atmospheric correction method starting from scene based target reflectances (and not from additional on site measurements) has been also set up with success in order to derive physically calibrated temporal features to characterize the vegetation categories.

A first test of multitemporal classification was performed on a reduced area (512x512 pixels) using multitemporal data compression techniques. The average mapping accuracy for 9 main vegetation classes including agriculture, orchards, forest and natural vegetation is in the order of 80%, this percentage will increase when applied over the Ardèche department.

Work has begun on developing artificial intelligence approaches to improve the classification of the images by making use of ancillary contextual knowledge about the geographic area. The overall goal is to build a knowledge based (or "expert") system able to store and process facts and heuristics about the area and to integrate them with the image processing environment. One important component of this "image understanding" system is near to completion: the evidential reasoning system, the purpose of which is to combine in a realistic way all available evidence about a pixel (or segment).

Monitoring of the Marine Environment

Sea Pollution Surveillance: The ARCHIMEDES project was considered generally successful by operators and research institutes. During the last North Sea campaign the 90 GHz Passive Microwave Radiometer (PMR) succeeded in measuring thickness of thin oil spills, where SLAR and SAR appeared to offer some potential of discriminating between mineral oils and biogenic films. A report on the ARCHIMEDES exercise has been completed.

Coastal Pollution Dynamics: the Coastal Zone Colour Scanner-CZCS has been used to study the coastal transport of pollution by the analysis of sea colour data. Forty nine consecutive maps of Chlorophyll for the North Adriatic basin have been correlated with Po rivers run offs for the most significant months. Discharge rates correlate well with points for the area near to the estuary. Peaks of Chlorophyll follows peaks of run off with a time lag of 3-5 days.

Implementation of CZCS data processing using new "transputer" technology on Personal Computer was adopted in view of providing high rate production for the numerical modelling group. A factor of 150 was gained and the processing time decreased substantially.

Updating and extension of analysis of Thematic Mapper performance versus in-situ experiment has continued in the Gulf of Naples, yielding an improvement of algorithms for Chlorophyll and sediment retrieval and a new algorithm for atmospheric correction accounting for horizontal aerosol variation.

Microwave Remote Sensing Activity

Emphasis is put on the development of all-weather remote sensing techniques; in both operational applications and scientific investigations related to land and sea.

In 1989 the major elements of this programme have been significantly developed and can be summarized as follows:

a) Microwave Signature Laboratory: This facility received the approval of an international group of experts in October 1988. On the basis of this a contract has been placed in November 1989 to construct and install the laboratory for completion by December 1990. In the meantime an Interim Laboratory has been designed, constructed and installed in order to test components and measurement techniques.

b) Promotion of Airborne Campaigns: In August 1989 an airborne microwave campaign (MAESTRO 1) was undertaken over four forestry and agricultural European test sites using the NASA/JPL three frequency (C-, L- and P-band) polarimetric SAR. This was the first opportunity for European scientists to evaluate this new technology.

c) Implementation of EURACS: During 1989 the European Radar Cross Section Database (EURACS) has been designed and implemented at the JRC, and is currently in its validation phase. In addition the scope of EURACS has been extended from agricultural applications into the field of forestry.

d) Implementation of Microwave Signal Processing System: A processing system has been installed in 1989 based upon SUN running under UNIX. This links the various elements of the microwave programme, and also incorporates significant developments in the field of radar dedicated software data analysis.

e) EARSEC: In September 1989 JRC/ESA organized a "hearing" of European groups interested in providing an input into the

European Airborne Remote Sensing Capabilities (EARSEC). Five groups attended this meeting from the Netherlands, Spain, Denmark and West Germany. On the basis of this a 3 year plan was defined to install EARSEC by 1991.

Lidar Fluorosensing

Recent work has consisted in:

a) a control and support activity for the construction by the firm CISE of the airborne "Time Resolved Lidar Fluorosensor" (TRLF) and the preparation of the validation campaigns;

b) the equipment of the support ground laboratory with the same type of instruments as those used in the airborne system with the main objective of improving the time resolution and the extension of the water column simulation capabilities.

The results of a first series of reception tests in October 1989 are encouraging; in particular, remote measurements on oils have shown that the full spectro-temporal characteristics of the fluorescence can be obtained from one single laser shot.

The transformation of the support laboratory has been centered on the conversion of the previous 4.5 ns Q-switched Nd-YAG laser in a mode-locked one with pulse durations down to 20 ps and the installation of a streak camera system as detector. The laboratory is now finally operating and the new instrumentation allows measurement of decay times as short as 100 ps. This can be done on a remote target or in the laboratory by using a recently constructed optical delay line for the exciting UV pulse.

Exploratory Research

Application of Laser Spectroscopy to the Characterization of Green Matter

The objectives for 1989 were to perform vitality tests on vegetation using classical instrumentation for plant physiology work and to build up a system for time resolved fluorescence measurements. First results on green leaves show, that at room temperature, time resolved measurements of the chlorophyll fluorescence decay can be analyzed.

The overall decay is characterized by lifetimes of approx. 10-40 ps, 80-140 ps, 400-450 ps and 700-900 ps. By blocking the photosynthetic electron transport system with herbicides, the lifetimes of the two slowest components increase by a factor of 4. To correlate these results with physiological parameters, a biological laboratory with the possibility to monitor net-photosynthesis, transpiration, stomata conductance, the potential photosynthetic activity and the water potential of the plants has been developed. ·

S/T Support to Community Policies

External Affairs (DG I) - Study of the Northwest African Upwelling Area

The study of coastal upwelling along the Northwest African coast of Morocco relies on remote sensed sea colour, and surface temperature data. The objective is to demonstrate how knowledge of upwelling dynamics obtained by remote sensing and complemented with other types of data can be used to evaluate resources and thus identify stock conservation requirements.

A descriptive study of the Northwest African upwelling area has been carried out using a series of NOAA AVHRR images. They have been processed into maps of sea surface temperature (SST) (where SST is used as an indicator of upwelling) and are interpreted with respect to upwelling variability and eastern boundary circulation. Analysis of daily wind fields are consistent with the large scale spatial and temporal variability of coastal upwelling as seen in the SST images.

Variability issues have been further investigated in a study of simultaneously acquired CZCS and AVHRR images, which have been processed into maps of chlorophyll (CHL) and SST. The spatial and temporal relationship between these parameters is highly variable in the upwelling area. Images acquired during a well developed upwelling event demonstrate a consistent degree of relationship while images acquired after relaxation of upwelling show very different distributions of CHL and SST.

Common Agricultural Policy (DG VI) and Statistics Office (EUROSTAT)

Pilot Project "Application of Remote Sensing to Agricultural Statistics"
Action 1: Regional inventories
The inventories of the five regions were followed up with the same contractors as in the previous year. The ground surveys and the automatic classifications of satellite data were analyzed; SPOT and LANDSAT provided almost complete coverage of 100,000 km^2 and allowed to increase significantly the accuracy of the ground survey. An effort has been made to improve the rapidity with which results are released. We are testing the possibility of estimating yield. Internal research is aimed at improving the registration and digitization of the segments recorded by enumerators, in order to accelerate the automatic classification of satellite images.

Action 2: Vegetation conditions and yield indicators
Seven contractors are studying methods to monitor vegetation with low-resolution (AVHRR) satellite data. Intermediate reports for all the studies have been received and final reports from three of the contractors will be available by the end of the year. In parallel with these thematic studies, the Institute for Remote Sensing Applications (IRSA) is collaborating with the European Space Agency (ESA) to provide a user service for AVHRR data.

Action 3: Yield prediction models
Currently the work involves setting up a reliable data base containing historical agronomic climate and agro-meteorological information. Intermediate reports have been obtained on:

– agro-meteorological characteristics of the main crops
– standard estimation of evapotranspiration at a European scale
– analysis of atmospheric pollen loadings for yield prediction of grapes and olives and determination of flowering stages.

All of this information is necessary for the creation of yield prediction models at the European scale.

Action 4: Rapid estimates of changes in areas and potential yield at a European scale
A single consortium is executing a three-year contract to interpret high-resolution imagery of sample sites. Software specifically designed for image interpretation of crop characteristics is almost completed and in parallel a methodology for estimation of changes in areas is ready for initial testing ground work has continued at thirty of the sample sites.

Monitoring of Vegetation in Tropical and Subtropical Areas (DG VIII)

The current data set consists mainly of archives of low resolution satellite data (AVHRR) since 1982, daily, over the whole continent of Africa and of the current production by the Maspalomas station covering most of West Africa.

Three main fields of application have been investigated; they relate to a specific aspect, role or functioning of the tropical ecosystems.

Technical developments in the use of Landsat data for the elaboration of a sampling frame adapted to rainfed crops have been completed.

The results are being used by the national statistical services. The yield of the main crops (millet, sorghum) has been estimated using time series of vegetation index measurements by the NOAA satellite. It has been shown that, empirically, two thirds of the yield variability can be described using such satellite data. A deterministic yield model linking the primary productivity process to the vegetation index measurement has also been tested and evaluated.

The study of the vegetation conditions in the large watersheds is based on the analysis of time series of satellite data at low resolution. These were assembled for each major basin of the region and then characterized in terms of dynamics of land cover. Two parameters were used to characterize surface parameters: the vegetation index and the surface temperature. An interpretation of fire patterns is included in the methodology. The insertion of such information in existing hydrological models is currently investigated. This work is guiding the selection of priority basins for intervention by the FED regional programme.

Tropical deforestation activities have first focussed on West Africa where it has been shown that the regional views provided by the NOAA satellite can be used to study the dynamics of vegetation at the interface between the tropical forest and other vegetation types. Biomass burning which is a major biosphere atmosphere linkage is being intensively studied using thermal data of the AVHRR. A preliminary investigation, using a similar methodology, has also shown the possibility of characterizing tropical deforestation at the regional level in Southeast Asia.

The investigations carried out provide new information on the use of remote sensing for characterizing dynamic phenomena over large regions. The results are increasingly interpreted in the framework of the study of global changes in terrestrial ecosystems.

MAIN ACHIEVEMENT AND MILESTONES

SPECIFIC PROGRAMME

Monitoring of Land Resources and their Use

The objective of the activity is the establishment of a methodology, using mainly high resolution earth observation satellites together with collateral data and information for the monitoring and the management (development and/or conservation) of the marginal (less favoured) areas of the European Community.

During the year 1989 the activity proceeded along five main lines.

a) Land use mapping and land cover statistics of the test area "Ardèche" (France) with Landsat TM and SPOT data.

The Ardèche department was chosen because its geographic position and structure characterize it as a typical Mediterranean marginal and less favoured area of the European Community.

The previous experience demonstrated that for obtaining accurate enough statistics and mapping precision (at least 80% on the average) in such a difficult area, multitemporal analysis and processing of a series of satellite images over the vegetative cycle is mandatory. This in turn leads to an effort to solve two challenging preprocessing problems:

- Superposition of the series of images with sub-pixel accuracy and registration with topographical maps.
- Correction of the data from variable atmospheric effect in order to derive meaningful time varying features for characterizing different vegetation categories.

Geometric registration method including the use of a digital terrain model

It has been demonstrated that Landsat 4 and Landsat 5 TM data are of exceptionally good geometric quality which, over rather flat terrain, allowing geodetic rectifications to subpixel accuracies with as few as 5 ground control points (GCP's) for a full scene. The rectification of system corrected CCT's should preferably be performed with first degree polynomials, and users can expect rectified Landsat TM to conform to 1:50.000 to 1:100.000 scale maps.

In mountainous areas, however, the geometry of optical satellite data, such as TM or SPOT, is considerably deteriorated by horizontal displacement of ground features which is due to high elevation at off-nadir scene areas. This effect (relief displacement) is known to cause local distortions to true geodetic position and misregistration of multi-temporal overlays. Its dimension is not negligible since terrain features at an altitude of 2.000 m will be misplaced by as much as 9 pixels at each end of a TM scan line. This horizontal pixel displacement will not cause problems as long as two or more scenes from the same orbit (path/row) are involved. However when TM frames from adjacent orbits need to be registered as in the present case, the complementary view directions at a given pixel position lead to cumulative pixel offsets which already exceed 1 pixel even at medium altitudes. Without applying a suitable correction, the field size configuration in the Ardèche area would not allow multi-temporal analysis.

The correction of relief displacement effects cannot be achieved by the use of GCP-based polynomial models only, since the satellite data must be adjusted on a pixel by pixel basis which requires the use of local altitude information during geometric registration. Therefore a rectification method has been implemented which corrects this type of geometrical distortion by using commercially available digital elevation data of moderate spatial resolution (250x250 m).

The rectification process first involves the use of polynomials of the form:

$$X = a_0 + a_1x + a_2y + a_3x^2 + a_4xy$$

$$Y = b_0 + b_1x + b_2y + b_3x^2 + b_4xy$$

where X and Y are the map coordinates, x and y the known image coordinates in the respective line (x) and pixel (y) system. The numerical values of the coefficient vectors A and B are estimated by a Least Squares solution of the polynomial equations using a set of GCP's being scattered throughout the data set.

Since system corrected TM data are already corrected for panoramic distortions and earth curvature effects, such scanner imagery can be assumed to form geometrically a series of near orthogonal projections in along-track direction, and across-track, a series of parallel perspective projections. The correction of relief induced displacements can therefore be limited to a correction of the pixel position within the respective scan line (figure 1).
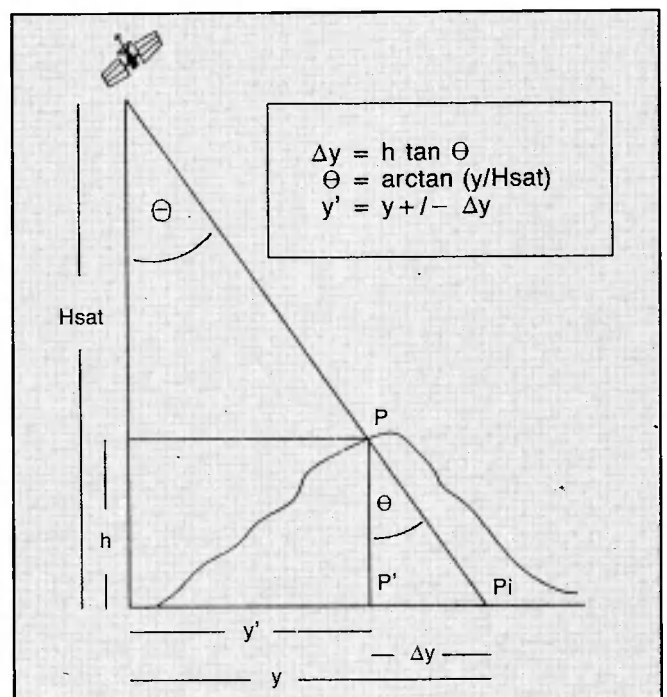

$$\Delta y = h \tan \Theta$$
$$\Theta = \arctan (y/Hsat)$$
$$y' = y +/- \Delta y$$

Fig. 1: Geometrical derivation of the horizontal offset Δy.

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The horizontal offset Δy between the location of a terrain point P_i in the image and its respective position P' in an orthogonal projection is calculated according to:

$$\Delta y = h \tan \theta$$

with h as the elevation of P at its true map position. The scan angle θ is the angle at which the point is observed from the satellite. For each pixel position, it is given by the relation:

$$\theta = \arctan(y/H_{sat})$$

The terrain altitude h is obtained from the topographic map or, during the rectification process, from digital elevation data. The satellite altitude H_{sat} is known from the ancillary data which are provided with each CCT, and the distance y is readily obtained from the scene itself once the satellite nadir position within each image line has been identified.

The correct location of the terrain point P in the image is then found by shifting P_i for the distance Δy towards the respective line nadir (figure 1). In case of SPOT data, the observation angle θ must be corrected for respective sensor tilt angle ϖ.

This relief correction, however, must first be applied to the image coordinates of the GCP's in order to define a transformation which is not further affected by terrain induced pixel displacements. It is found that after correction, error vectors are significantly reduced, especially those which were originally oriented along scan direction. During the actual rectification of the image it becomes a straightforward operation to find the geometrically correct position of a map coordinate in the image by combining the affine transformation and the correction of terrain depending distortions. The method results in subpixel accuracy and provides map compatible image data which are free of local distortions. See fig. 2 for illustration.

Atmospheric corrections

Ideally, a comparison of several satellite scenes from the same area would show changes in their intrinsic property and be invariant to other effects. Since the sensor measurement results from the interaction of several factors, the effects of surface material (reflectance factors) must be separated from the effects of topography, illumination, shadows, viewing directions and atmospheric path phenomena. With the increased use of multi-temporal and multi-sensor data sets in thematic classification and change detection, it has become increasingly important to compensate for such radiometric errors of satellite imagery. Therefore radiometric correction methods form an essential part of any image analysis system.

A radiative transfer model has thus been implemented which is derived from the one developed by Tanré et al. (1985). For a uniform Lambertian surface, ρ^* can be conveniently expressed as a series of radiation interactions in the ground-atmosphere system

$$\rho^* = t_{o3} \left[\rho_{at} + \frac{T(\mu_0)\,[t_d\,(\mu)\,\rho_t + t_s(\mu)] <\rho>}{1 - <\rho>s} \right]$$

ρ_t is the target reflectance, $<\rho>$ the background contribution to the apparent reflectance of the target, and s gives the spherical albedo. ρ_{at} denotes the intrinsic atmospheric signal component, μ and μ_0 are the cosines of the zenith angles of the direction vectors towards the satellite and the sun respectively at the pixel. They indicate upward (μ) or downward (μ_0) direction of the various atmospheric transmission coefficients, where T is the total, td the diffuse and t_s the scattered transmittance; t_{o3} gives the ozone transmittance. The target reflectance ρ_t depends on the photometric properties of the surface and the distribution of the illumination which is a complex combination of the attenuated solar irradiance, diffuse sky light and reflected ground radiance from the target's surroundings.

The precision of this scene-based atmospheric correction method for Thematic Mapper data has been evaluated with respect to a set of contemporary radiometric ground measurements taken in 1988. The results from this campaign emphasize that the proposed atmospheric correction scheme is a valid procedure for the calculation of reflectance factors from TM imagery (Hill & Aifadopoulou, 1989)

Under operational conditions, surface reflectance factors were retrieved from system corrected TM data within + 0.02 reflectance units.

The method has proven to be a valid tool for operational scene-based atmospheric corrections of Thematic Mapper imagery over land sites. All required parameters can be derived from scene data provided that reference targets with sufficiently known ground reflectance can be identified. Therefore the correction scheme seems to be well suited for operational radiometric preprocessing of time series which might then be used in a more quantitative analysis of remote sensing data for landscape monitoring (land use dynamics, soil erosion assessments, landscape degradation, desertification and vegetation mapping).

The method applies especially well to Thematic Mapper data, but can also be used for Landsat MSS and SPOT imagery. In this context it should be mentioned that its use will facilitate long-term studies using Landsat MSS data (available for a period of 17 years).

Comparison of TM and SPOT data for multiple sensor approaches

Multi-temporal approaches to monitoring, classification and mapping of agricultural crops and natural vegetation in Central Europe are often hampered by the lack of suitable imagery due to the frequent cloud cover. The joint use of Landsat 5 Thematic Mapper and SPOT data in multiple sensor approaches can help solve this problem.

The analysis has thus been carried out of the geometric and, in particular, the radiometric accuracy of SPOT HRV-1 data in comparison to Landsat 5 TM imagery using concurrent TM and SPOT

Fig. 2: Correction of relief induced distortions on the localisation of a lake (altitude 1150 m). The white contour corresponds to the exact topographic location. The displacement occurs to the right or to the left when the satellite is viewing from the West or from the East.

images which have been recorded almost simultaneously in September 1986 (table 1) over the study site in the southern Ardèche region.

The TM and SPOT scenes could be registered to map projection with sub-pixel accuracy, while a common pixel size of 30x30 m was maintained. The mountainous character of the study region, however, required the use of digital elevation data for the compensation of relief induced distortions.

Table 1: Tm and SPOT scene characteristics.

	TM	SPOT
Acquisition date	29 September 1986	29 September 1986
Acquisition time	9.49	10.47
WRS frames	197/29	47/260&261
Scene location	44.6 N	44.2 N
	3.72 E	3.85 E
Sun elevation	37.42	42.20
Sun azimuth	145.92	163.95
Instr.tilt	—	R2.4

The radiometric comparison of TM and SPOT uses the apparent reflectances of more than 40 reference targets representing a wide range of vegetated and non-vegetated cover types. The calibration of both sensors was found to be in rather good agreement, which confirmed not only the SPOT Image in-flight calibration but also the validity of known TM calibration assessments. It was demonstrated, that TM and SPOT data permit a quantitative analysis in terms of ground reflectances once suitable calibration data are provided for each sensor.

Field experiments have shown that important parameters such as leaf area index, absorbed photosynthetic active radiation and wet and/or dry biomass, are related to the normalized difference vegetation index (NDVI).

Since atmospheric conditions may introduce additional variability in the vegetation indices obtained from different sensors, the TM and SPOT scenes were corrected for atmospheric absorption, scattering and pixel adjacency effects.

For each of the reference targets, SPOT and TM vegetation indices were calculated based on the retrieved ground reflectance in the corresponding channels of the visible red and the near-infrared. The comparison was based on vegetated and bare soil targets only, and revealed a significant linear relation (r=0.998) between the NDVI of SPOT and TM

NDVI spot = -0.0054 + 0.9904 NDVI tm

It is demonstrated that practically identical index values are obtained, once suitable calibration data are provided. These results agree completely with existing evaluations of vegetation indices for simulated Landsat 5 TM and SPOT 1 data.

Therefore, a wide range of applications in agricultural monitoring and vegetation observation can be investigated by using multiple sensor data sets which involve TM and SPOT imagery.

Multi-temporal land use mapping

In 1984, a collaborative project between JRC and the Statistical Service of the French Ministry of Agriculture (SCEES) was initiated in order to evaluate the suitability of TM and SPOT data for agricultural

inventories and natural vegetation mapping in the Département Ardèche in the south of France. It is a mountainous area with a large variety of natural vegetation types. The agricultural land is mainly characterized by its strong fragmentation and small parcel dimensions (0.5 -2 ha).

In an initial experiment, one TM data acquisition from 5 July 1984 was used to classify and map the ground cover classes of interest. An acceptable accuracy was found for the global inventory, but there were indications of bad precision in local cover mapping. This is due to the fact that spectral information from single-date imagery contains a high level of spectral confusion between cover types. As already said better mapping accuracy can be achieved with multi-temporal approaches which, however, require precise geometric and radiometric corrections of the satellite data.

For this case study (Hill & Mégier, 1989), a test area has been selected for which an almost complete coverage with aerial photographs is available. The area includes a complex mixture of natural vegetation and agricultural cover types. Deciduous and coniferous forests extend over varying morphological units; low wood- and shrub lands are mainly found within the sub-mediterranean "Garrigue" and abandoned areas of agricultural terrace cultivations. The agricultural land includes cereals (mainly winter wheat), rape seed, maize and sorghum, sunflowers, alfalfa and, mainly in the Rhone valley, various orchard cultivations.

The multi-temporal data set includes four TM scenes from the year 1984 (25 April, 5 July, 30 July and 31 August), all of which have been corrected for atmospheric absorption, scattering and pixel adjacency effects. Geometric registration was completed with sub-pixel accuracy.

The classification of multi-temporal data sets involves techniques for spectral feature extraction and data reduction. Greenness and brightness features (vegetation indices, Tasseled Cap features) have proven their suitability to emphasize important object characteristics for crop and vegetation monitoring, they also provide a valuable reduction of data dimensionality.

A green leaf's chlorophyll pigment strongly absorbs sun radiation at wavelengths between 0.5 and 0.70 μm (visible red) and the reflectance factor is normally below 0.1. In the near-infrared region (0.75-1.35 μm), multiple scattering occurs due to the leaf's internal mesophyll structure and the reflectance tends to be in the range of 0.4 to 0.6 This physiological relationship has been used to estimate the greenness of plant canopies through the use of various ratios i.e. simple ratio NIR/R, or the normalized difference (NIR-R)(NIR+R).

The Tasseled Cap transformation of Landsat TM data is a linear transformation the resulting features of which are known as "Brightness", "Greenness" and "Wetness". Tasseled Cap transformations preserve euclidean relationships in the data space but capture typically 95% or more of the total variability in its three features. The transformation matrix is derived with respect to physical scene characteristics and is invariant to the spatial structure of individual scenes. It is therefore possible to compare quantitatively the derived features from

different scenes, once the data have been normalized for external effects such as haze level, viewing and illumination geometry.

In agricultural zones with a limited variety of crop types, good classification results have been achieved by using only the multi-temporal NDVI. Time series of NDVI and Tasseled Cap features have been analysed for important cover types, and it was found that the multi-temporal vegetation index alone does not provide sufficient information for the classification in complex landscape units as the Ardèche. Tasseled Cap features, however, are considered a more efficient compromise between data reduction and the preservation of relevant image information. They are especially suited for unsupervised approaches since the principle of this transformation is related to physical concepts of optical remote sensing.

Classification was performed by using simple parametric techniques such as minimum euclidean distance class mapping. It is demonstrated that the multi-temporal approach leads to distinctly improved results and allows detailed ground cover mapping even in structurally complex landscapes. The overall accuracy is 79.1%, which is the summation of the accuracy of each class weighted by the number of pixels occurring in each class (table 2). The comparable single-date classification performed were clearly less satisfactory (table 3).

Multi-temporal thematic mapping of the natural vegetation types was examined in comparison with the existing aerial photographs and topographic maps (Fig. 3). This evaluation indicates a good mapping accuracy for extended areas of deciduous forest, wood- and shrublands, and permanent grasslands. The acreage of coniferous forests is slightly overestimated in areas of cast shadow, but the mapping seems to be more precise than in the case of single-date analysis. It is believed that, in mountainous terrain, distinct improvements will be only achieved by applying modelistic corrections of terrain illumination prior to the classification.

b) High Resolution Imaging Spectroscopy

In relation to this year's "European Imaging Spectroscopy Aircraft Campaign" (EISAC '89), a pilot study has been initiated in the southern part of the Département Ardèche. An overflight with the GER 63 - channel airborne scanner took place in June 1989. These high resolution spectroscopy data will be used to assess possibilities of mapping areas affected from soil erosion and vegetation degradation, and to explore the feasibility of deriving indications for the actual development status of soils by using mineral-specific absorption features detectable with this instrumentation. The results are also

Table 2: Error matrix comparing ground reference segments and unsupervised multi-temporal classification, expressed in number of pixels.

Classification	Ground observations								
	1	2	3	4	5	6	7	8	Tot
0 Unclassified	8	3	2	—	48	2	—	—	63
0 Bare soil	—	6	3	—	—	—	3	8	20
1 Dec. Forest	131	—	—	—	6	3	6	12	158
2 Grains	4	207	5	1	17	1	0	5	240
3 Maize	4	—	666	4	—	—	9	27	710
4 Sunflower	—	—	6	72	—	—	—	1	79
5 Alfalfa	2	—	5	3	311	—	—	1	322
6 Grasslands	45	13	5	0	23	93	32	31	242
7 Shrublands	20	5	5	1	17	—	95	12	155
8 Orchards	25	3	26	11	3	2	3	271	344
Total	239	237	723	92	425	101	148	368	2332
Well class. pixels %	54.8	87.3	92.1	78.3	73.2	92.1	64.2	73.6	79.1

Table 3: Error matrix comparing ground reference segments and unsupervised single-date classification.

Classification	Ground observations								
	1	2	3	4	5	6	7	8	Tot
0 Unclassified	—	—	22	1	11	2	1	—	37
0 Bare soil	1	—	135	—	—	—	3	13	152
1 Dec. Forest	132	—	—	—	16	3	3	23	177
2 Grains	24	115	33	4	8	2	35	68	289
3 Maize	4	21	409	28	10	—	3	91	566
4 Sunflower	2	—	25	20	9	—	8	1	65
5 Alfalfa	4	—	11	17	299	1	7	1	340
6 Grasslands	50	25	27	16	57	60	23	90	348
7 Shrublands	15	19	1	2	1	1	10	19	68
8 Orchards	7	57	59	4	14	32	55	62	290
Total	239	237	723	92	425	101	148	368	2332
Well class. pixels %	55.2	48.5	56.6	21.7	70.4	59.4	6.8	16.8	47.5

expected to provide valuable information for the potential use of operational satellite systems as Landsat and SPOT.

Ground data acquisition campaign

A ground data acquisition campaign was organized which included land use mapping during the GER overflight, contemporary radiometric field measurements of soil and vegetation targets, the collection of numerous soil samples for spectral measurements and X-ray diffractometer analysis in the laboratory, and the detailed (scale 1:10.000) mapping of the geologic, pedologic and vegetation conditions in the test area. This task could only partly be accomplished by JRC staff and contracts were thus passed to the German Aerospace Research Establishment (DLR), and the Universities of Trier - Germany (geologic mapping, x-ray diffractometer analysis of rock and soil samples for the identification of the mineral content) and Utrecht – The Netherlands (soil and vegetation mapping, physical analysis of soil samples).

Radiometric measurements

Radiometric measurements have been carried out at ground level by a team from the Institute for Remote Sensing Applications of the JRC in the Ardèche test site in June 1989. Reflectance measurements of selected targets were performed from June 20 to June 22. Measurement of the incoming solar irradiance was undertaken coinciding with the overflight of the GER imaging spectroradiometer on June 28.

The reflectance measurements included areas with and without vegetation with special emphasis on areas where soil erosion was particularly significant. In the latter areas, the targets were mainly composed of bare rock with some sparse vegetation. In the vegetated areas, the targets included the main agricultural crops of interest (e.g. vines, wheat, barley, orchards, tomatoes, sugar beet; alfalfa and sunflower). A spectroradiometer (Spectron Engineering SE590) was used for reflectance measurement in the 400-1100 nm region, supplemented by a TM compatible radiometer (Barnes 12-1000) for the visible and near IR region. The measurements were made at a height of about 1.5 m above the target under generally good weather conditions.

Due to a last minute change in flight plans, the overflight with the GER imaging spectroradiometer was performed one week later than expected. However, it was possible to measure the incoming solar irradiance by means of two Exotech radiometers and consequently to estimate the atmospheric transmittance at certain wavelengths on the day of the overflight (June 28). The ground measurements are presently being analyzed.
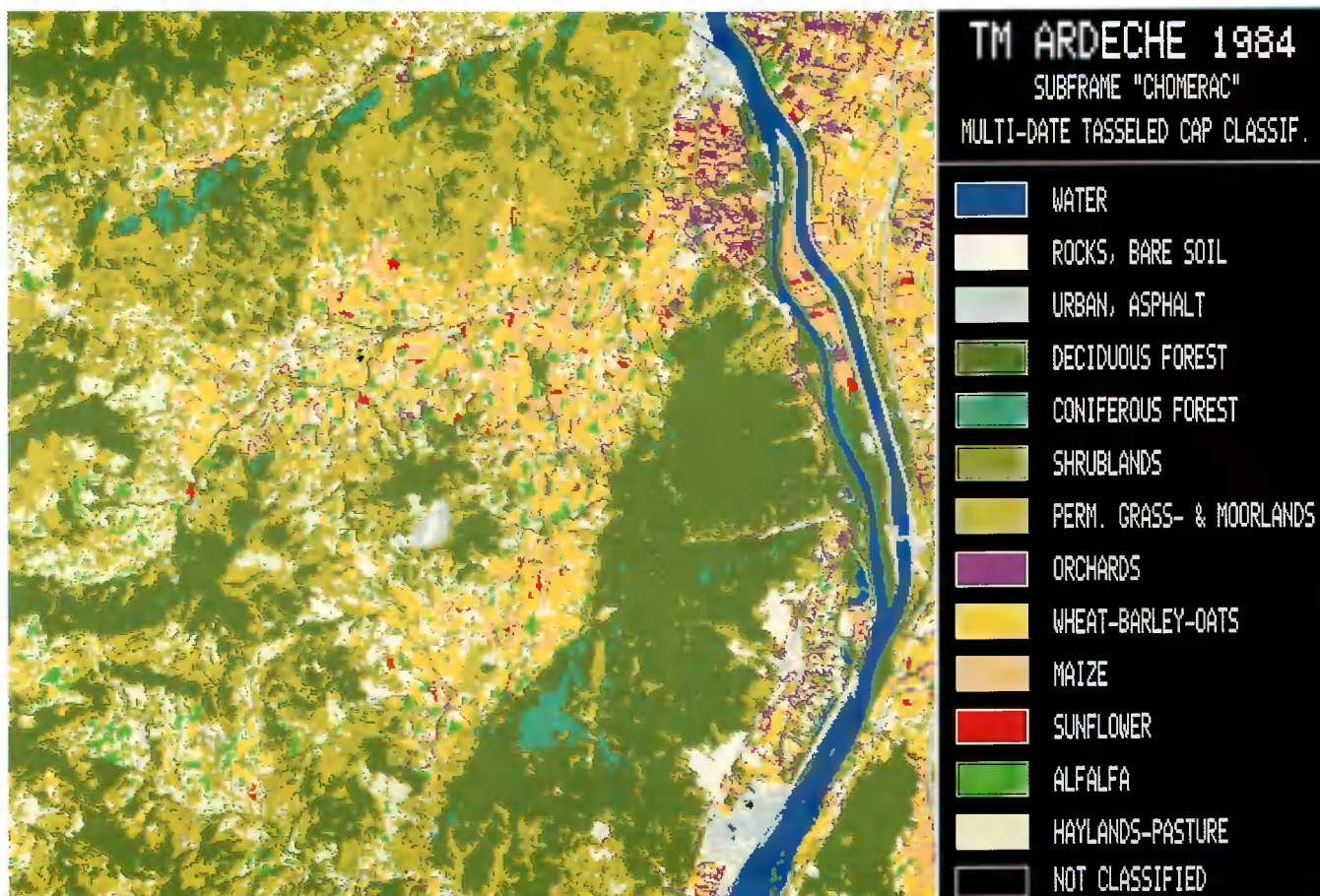
Fig. 3: Multi-spectral classification over the sub-area of Chomérac showing the mapped results (512x512 pixels).

c) Expert systems and artificial intelligence in image processing

Work has begun on developing artificial intelligence approaches to improve the classification of remotely-sensed images. The motivation for this research is the general awareness that in principle imagery can be interpreted much more effectively by making use of ancillary contextual knowledge about the geographic area from which the satellite scene has been taken. In past work it has been shown that in some experimental test areas the classification does not always produce totally unambiguous ground cover classes - this is a well-known problem in remote sensing which becomes more significant with high resolution satellite imagery. There is therefore a requirement to improve the performance of classifiers for high resolution imagery by making use of information extraneous to the data. Some initial work has demonstrated that the use of terrain altitude is a useful parameter for resolving ground cover ambiguities; however we wish to extend this approach to include much more local

geographic knowledge and expertise in order to extract maximum possible information from the imagery - this approach may be regarded as "image understanding".

The overall goal is to build a complex knowledge-based (or "expert") system which is able to store and process facts and heuristics about selected image test areas and to integrate this system totally with our image processing system and a geographic information database. The approach should be as general and flexible as possible in order that it might lead to the development of operational ground cover mapping methodologies which can be readily adapted to new geographic test zones.

The first stage of the work was to define an advanced image understanding system architecture (see figure 4). This is to include the existing multi-channel Landsat TM image data obtained in the Ardèche test area together with software to integrate thematic datasets with the imagery and with an integrated geographic information system (IGIS). The image understanding system will then combine data extracted
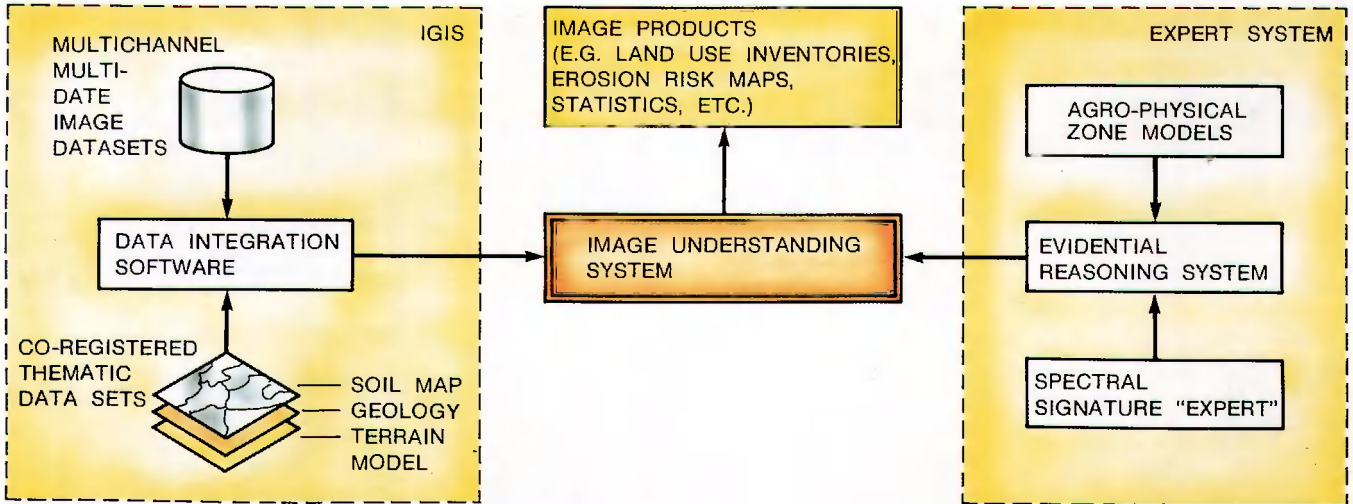
Fig. 4: A prototype image understanding system to exploit ancillary data.

from the IGIS with expert system rules and agro-physical zone models to generate improved image products.

A considerable amount of background research was undertaken on appropriate software packages to implement such a system. It was decided to use a frame language (FLEX) in combination with the logic programming language PROLOG to encode the main knowledge rules of the expert system.

Much of the overall image understanding system is still at the development stage, although one of the main components - the evidential reasoning system has been brought near to completion. The purpose of this system is to combine in a realistic way all available evidence about a pixel or segment classification coming from diverse sources and to assign an optimal class to the pixel or segment from that combined evidence. The procedure must weigh-up output from a variety of image classifiers, contextual expert system rules and local geographic information to yield an optimal pixel or segment classification. These sources may give supporting information or disconfirming information about the pixel or segment class. The reasoning system therefore has to combine both positive and negative evidence in establishing an optimum classification taxonomy. For example, some of the rules in the expert system may refer to high-level concepts such as "agricultural land" or "non-agricultural land". Other rules (and especially classifiers) may refer to low-level singleton classes such as "wheat", "barley", "bare soil". The reasoning system has to cope with all taxonomic levels. The approach chosen for this was the Dempster-Shafer theory of evidence. The full Dempster-Shafer algorithm for evidential reasoning in a hierarchy is computationally intractable for large numbers of classes. We have therefore implemented a tractable approximation to this theory known as the Gordon-Shortliffe algorithm. This algorithm was developed for the
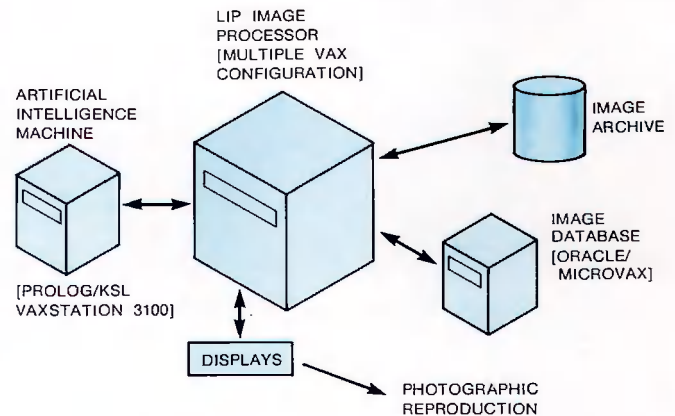

Fig. 5: Image understanding computer environment on Ethernet network.

medical field and is computationally manageable for classification hierarchies which are strictly tree data structures (i.e. members of one level of the classification hierarchy only have one ancestor at a higher level - for example wheat would be a member of the cereal crop class and not also of the root crop class). This algorithm has now been implemented and is currently undergoing extensive testing. Some preliminary results will be available in the near future.

Steps have also been taken to set up an appropriate machine environment to host such a system (see figure 5). A high-power DEC VaxStation 3100 has been obtained as a dedicated artificial intelligence machine to host both the evidential reasoning system and the contextual expert system. This machine is linked via an Ethernet to a VaxCluster containing the main image processing "engine" and image archive, database and display machines.

d) Collaborative Programme with European institutes and laboratories on remote sensing in the management of European Less Favoured Areas and Marginal Land.

The "Collaborative Programme" consists of a network of different application oriented research projects involving 25-30 participating institutions and laboratories coordinated by the JRC, Ispra. It is aimed at the promotion of application of Remote Sensing and at R/D of Remote Sensing integrated in Geographical Information Systems in the management of land use in European marginal areas.

Following the decision agreed on during the plenary meeting in July 88 R/D contracts have been given to some institutes concerning themes found to be of importance to reaching the main goals of the Programme:

– University College, Dublin (IRL): Development of a microcomputer software based Geographical Information System for both image and map data with particular application in forestry.
– Department of Geography, Reading (UK): Establishment of Land Information Systems in Nomos of Messinia, Greece.
– Laboratory for Regional Geography and Landscape Studies, State University of Ghent (B): Analysis of landscape structures and dynamics in relation to soil, land use and settlement in Messinia using SPOT data.
– Department of Geography and Climatology, Athens (GR): Evaluation of Geographical Information Systems and Second Generation Earth Observation Satellite data for land use planning in south Peloponesos.
– Institut fuer Geologie, Muenchen (D): Reconnaissance and evaluation of natural risks and disasters in mountainous regions.
– Department of Geography, Socioeconomic Analysis and Computer Science, Roskilde (DK): Mapping of SGEOS data and management of marginalized agricultural land.

One contracted project has been finalized and reported: "Uses of SGEOS data in the implementation of forestry management models". Main responsible of the project was Bureau of Land Data, Vejle (DK) - the four subcontractors were: University College, Dublin - Forestry Department; Department of Forestry and Environment, Thessaloniki; Department of Environmental Planning, Berlin; CSATI, Bari.

In April Newsletter no. 5 was distributed. A brochure describing the projects for a non specialized audience has been produced. A workshop entitled: "Integration of Remote Sensing and PC-based Geographical Information Systems in the management of European marginal land" was held at JRC - Ispra, September 6th and 7th. Forty persons participated in the Workshop. Besides colleagues from the programme some external experts were invited. Sixteen papers were presented and the role of RS and GIS in future activities was discussed extensively; the Workshop defined a set of recommendations for the next plenary meeting.

e) Application Software

Development of an image display program (PCDIS) and an image coloring program (TINT) for personal computers (PC) display units

Both programs are PC versions of programs already existing for a DEC-VAX environment. They feature full compatibility with the image processing software of the Laboratory for Image Processing (LIP) and ERDAS.

The main advantage of PC-based display and colour programs is the flexibility of such an approach in a network environment. The concept of PC-based Image Display Units will allow to simply add low cost Image Display Units as soon as there are additional needs.

The scope of PCDIS is the displaying of untreated or treated imagery residing either locally at the PC, or remotely on VAX or other discs, through network transmission. The aim is to provide an inexpensive means of local interactive image display, while freeing the larger machines for more suitable applications. PCDIS is menu driven and provides the most important display features: zoom, pan, contrast stretching, colourtable load, coordinate and pixel value readout, etc.

The scope of TINT is the colouring of pseudocolour imagery where colours are used to distinguish different classes or quantities. The aim of the application software is to allow a user to apply interactively colour to his imagery in an easy and convenient way. TINT features are divided into five different menus.

Development of an image archiving system

A relational database using ORACLE RDBMS software has been designed and developed to follow through the various stages of the image ordering and archiving cycle, on the request of the Agriculture project. The database is divided into two logical parts, the Archive database and the Fiancial database.

Archive database: To date, SPOT and TM images have been archived for the Agriculture and the Land Use projects.

The information that has been stored for each image has been extracted directly from the header and ancillary records that accompany the scene. It was decided to store all the information that could be of interest to any potential user, and not only the scene identifying data.

The previous archive of CZCS images has been loaded onto the database as a temporary measure and can be accessed via ORACLE. Extracts from the BRAMS (Spotimage catalogue) and the LEDA (Esrin catalogue), of interest to the various projects, are also stored on ORACLE and can be accessed.

The data stored on the financial database concern contract and price details, programme details, supplier details and order details. They can be accessed by authorized personnel only.

Monitoring of the Marine Environment

a) Sea pollution surveillance

As a conclusion of the ARCHIMEDES project a workshop was organized on 22-23 February 1989 at the JRC-Ispra to discuss the results of the ARCHIMEDES IIa campaign held in the Southern North Sea in April 1988 with the participation of DVFLR (microwave airborne flights) and Rijkswaterstaat (sea operations). The Passive Microwave Radiometer (90 GHz) used to measure the thickness of thin hydrocarbon spills provided satisfactory results (see Fig. 6); a second one (1.4 GHZ) meant to measure very thin spills and biogenic films, essentially failed due to strong interferences from radar and radio signals. A SLAR and a SAR operated quite satisfactorily and showed that there was still a substantial margin for amelioration for detection, characterization and distinction between hydrocarbon spills and biogenic films, in particular the SAR (see Fig. 7).

This experiment was considered generally successful by the EC member state operators and research institutes attending the workshop and it was felt worthwhile to repeat the experiment using 1.4 GHZ Passive Microwave Radiometer.

Two Working Groups were formed to draw up a report of all experiments done and the results obtained during the entire course of ARCHIMEDES project and to agree on recommendations for future work.

During this meeting and subsequent contacts held with European operators responsible of the protection of the marine environment and research bodies, interest was expressed for investigation into detection, characterization and individualization of chemicals in sea waters and into RS techniques that can be used for environmental monitoring and law enforcement.
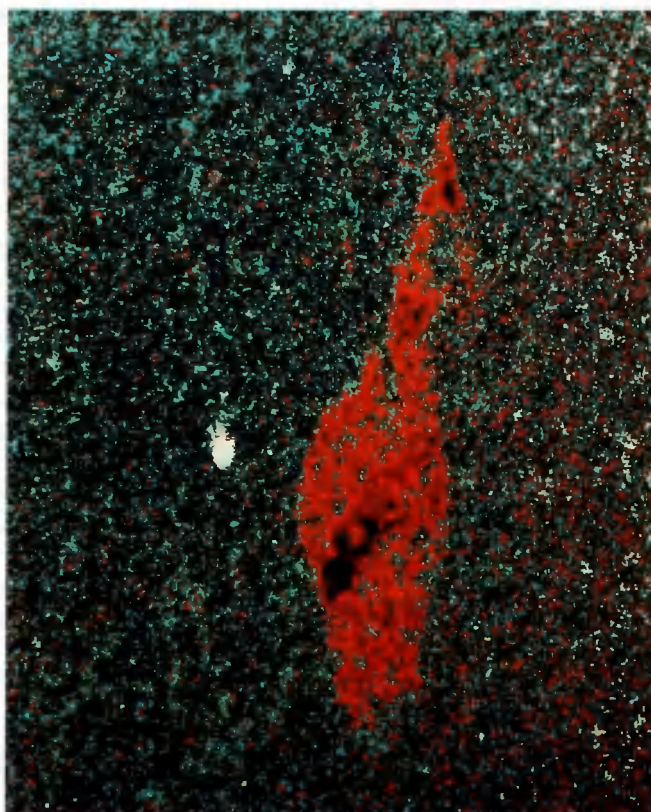

Fig. 6: Passive Radiometer (90 GHZ) image of Crude Oil. Flight altitude is 2500 ft.

Fig. 7: SLAR (X-band 9.4 GHZ) image of Crude Oil Flight altitude is 1350 m. Off-line elaborated and geo-corrected.

b) Marine pollution dynamics

The OCEAN Proposal: an ESA/JRC Initiative for the Reappraisal of CZCS Satellite Data

A joint proposal has been prepared by the JRC-Ispra and the ESA/Earthnet-Frascati for a CZCS data archive organization and exploitation with the objective of obtaining an improved understanding of the European marine environment.

A considerable amount of multi-annual ocean colour data, covering all the major European basins, has been collected by the Coastal Zone Color Scanner (CZCS) aboard the satellite Nimbus-7 from 1978 to 1986 and stored at Maspalomas, Frascati, Dundee and Ispra. Only limited efforts have been made in Europe to fully exploit the considerable wealth of this information. This has been due to the fact that while the CZCS was in operation:

– the algorithms and analysis techniques for exploitation of these data were still in preparation;
– there was no perspective, in the potential user community, of continuity for the operational collection of such data;
– the ecological problems of coastal pollution had not surfaced to the extent that it is perceived today.

The growing public and political concern on marine issues, particularly to the European regional seas and coastal areas requires that all resources available are effectively used to help in a sound management of the marine environment.

It has been proposed:

1) to compile a catalogue of all CZCS data available in Europe;
2) to pre-process all suitable level 0 data (i.e. receiving station raw format data) to level 1 data (image data, integrated with geometric parameters and atmospheric pressure and ozone information);
3) to identify and assemble a user oriented software package relying on established methodologies to extract relevant information contained in the CZCS level 1 data; use the same software for the processing of all suitable level 1 data to level 2 (i.e. Rayleigh and ozone corrected radiances, water temperatures, derived parameters, etc.);
4) to create a well documented, easily accessible archive on optical disks for long-term conservation and retrieval of data of various levels;
5) to carry out demonstration programmes related to the production and application of CZCS level 3 data (time sequences of image on equatorial Mercator grid, composite and statistical imagery, etc.). This could include the systematic assessment of spatial and temporal patterns related to marine processes and variabilities in the field of primary productivity, pollution and sediment transport;
6) to make an Announcement of Opportunity aimed at broadening the user community and to identify new proposals for a comprehensive use of the products of various levels.

The JRC and ESA have analyzed in a document entitled OCEAN: (Ocean Color European Archive Network) specific objectives (bio-geochemical and global scale processes, sediment transport, air sea interaction, open ocean and coastal dynamics, pollution of coastal waters, etc.), and a number of important topics which may be selected for the Demonstration Programme. Within the spectrum of the application phase of OCEAN, some main topics can be singled out as the generation of long-term ocean colour time scenes in specific areas to monitor spatial patterns of coastal and river runoff, the production of composite seasonal images for the description of phytoplankton pigment field over large scales and the development of methodologies for direct use of ocean colour data in numerical modelling.

Development, cost and time analysis for three groups of working packages have been performed with regard to generation, archiving, cataloguing and distribution of products of different levels, including the Demonstration Programme. The document reports in detail on present European CZCS data availability, types of CZCS quick-look state of national facilities and information on other European programmes.

The proposed exploitation of CZCS data should be of great scientific and operational value: it is foreseen that it will complement various other projects being carried out at European level (e.g. MAST, EUREKA/EUROMAR, EROS 2000, JGOFS, TOGA/WOCE, etc.,) and will provide the European oceanographic community with useful training for developing the know-how needed in view of future missions planned for advanced ocean colour instruments (e.g. MODIS-T, MERIS, OCTS, etc.).

The project proposal has been presented to the Directorate General for Environment (DG XI) and has been accepted by Division of Water Quality as a subject of support activity to the Commission Services.

Water Quality Studies in the Gulf of Naples

This activity was continued as an updating and extension of the analysis of TM performances in coastal application of marine Italian waters. The interpretation of the sets of data collected in the in-situ campaign carried out in June 1988 in collaboration with the Zoological Station "A. Dohrn", Naples, has been completed, yielding:

– TM algorithms of better quality than previously available on spectral reflectance for chlorophyll and sediment retrieval (Fig. 8);
– an optical model accounting for absorption scattering by chlorophyll, suspended sediment and yellow substance and specific to the considered water body, which allows to compute water upwelling radiance corresponding to a given water composition.

The results were both satisfactorily tested against experimental data. An agreement within a factor of 1.5 with in-situ measurements was generally found for chlorophyll retrieval up to 5 mg/m^3.

During 1989 no in-situ campaign took place. This was due to the very regrettable fact that the Oceanographic vessel "Posillipo" sank in
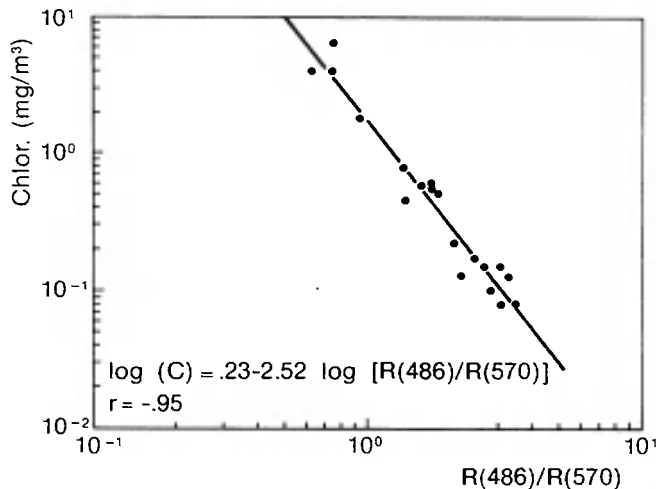
Fig. 8: Chlorophyll retrieval algorithm for the Thematic Mapper (dots are in-situ measured values).
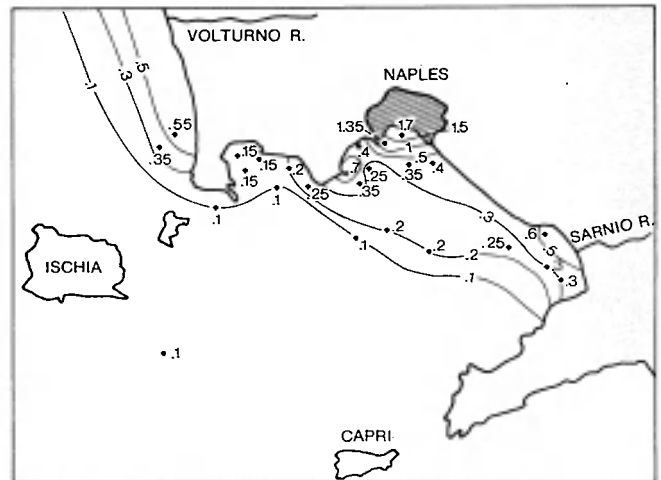

Fig. 9: Map of yellow substance absorption (standard value at 375 nm in m^{-1} derived from in-situ measurements).

December 1988, so that a planned campaign in January 1989 had to be cancelled. This activity may possibly be resumed with a new vessel in spring 1990.

A new algorithm for the atmospheric correction of TM data, accounting for horizontal variation of the aerosol type has been developed and positively tested versus experimental data. Retrieved chlorophyll has been found in agreement within 30% with measured values, for TM scene of June 22, 1988. The "Yellow Substance" samples collected during the June 1988 campaign have been analyzed by improved fluorescence/absorption measurement procedures, yielding a map of the "Yellow Substance" absorption in the Gulf which shows the high pollution of the Naples harbour (Fig. 9).

An optical model for the Gulf of Naples has been used to evaluate the influence of the "Yellow Substance" optical signature on remote sensing of water quality. The results of this computation, besides being of general interest, permitted to improve the reliability of the retrieval algorithms.

Elaboration of an Annual CZCS Data Series and Correlation with Po river's run-off

The activity on the systematic elaboration of CZCS scenes relevant to the Adriatic Sea has continued. From the forty-nine consecutive scenes of the year 1981 which were processed into quantitative maps of concentrations of Chlorophyll (CHL) and Total Suspended Substance (TSS), monthly averages and standard deviations have been calculated for the most significant months (May to September) (Fig. 10).

Averaging images is a means of obtaining cloud free composites. The comparison of the averages shows a tendency of increasing chlorophyll concentration. The standard deviation images allow the discrimination of areas with high variability (i.e. around the Po delta) from those with rather constant productivity conditions (i.e. off shore of Northern Adriatic). A comparison has been performed of the Po discharge rate with chlorophyll concentrations of selected marine coastal areas (Figs. 11 and 12).

The study has shown that a correlation exists between discharge rates for the areas near to the estuary while the far-away area seems not to be affected by the river run-off. The peaks of CHL follow the peaks of run-off with a time lag of about 3-5 days.

It should be noticed that this application study could be considered as an interesting example of retrospective CZCS data utilization within the spectrum of the OCEAN demonstration programme.

Modelling of Marine Transport Processes

The work developed in 1989 for mathematical-numerical purposes at the Institute for Safety Technology, with the participation of personnel of the Institute for Remote Sensing Applications, concerns the development of computer models for linking remotely sensed surface concentration patterns of bio-geophysical parameters (chlorophyll, sediment, etc.) to marine transformation and transportation processes.

The activity of the group started at the beginning of 1989. Work is being performed under two activities:

– in-depth analysis of the numerical properties of several 3D computer models available at JRC; systematic evaluation of the application limits of model simplifying assumptions; comparative assessment of sub-models for describing the turbulent transport properties;
– comparative application of the available computer models for simulating typical situations in the Adriatic Sea and confrontation with in-situ measurements and with remotely sensed data.
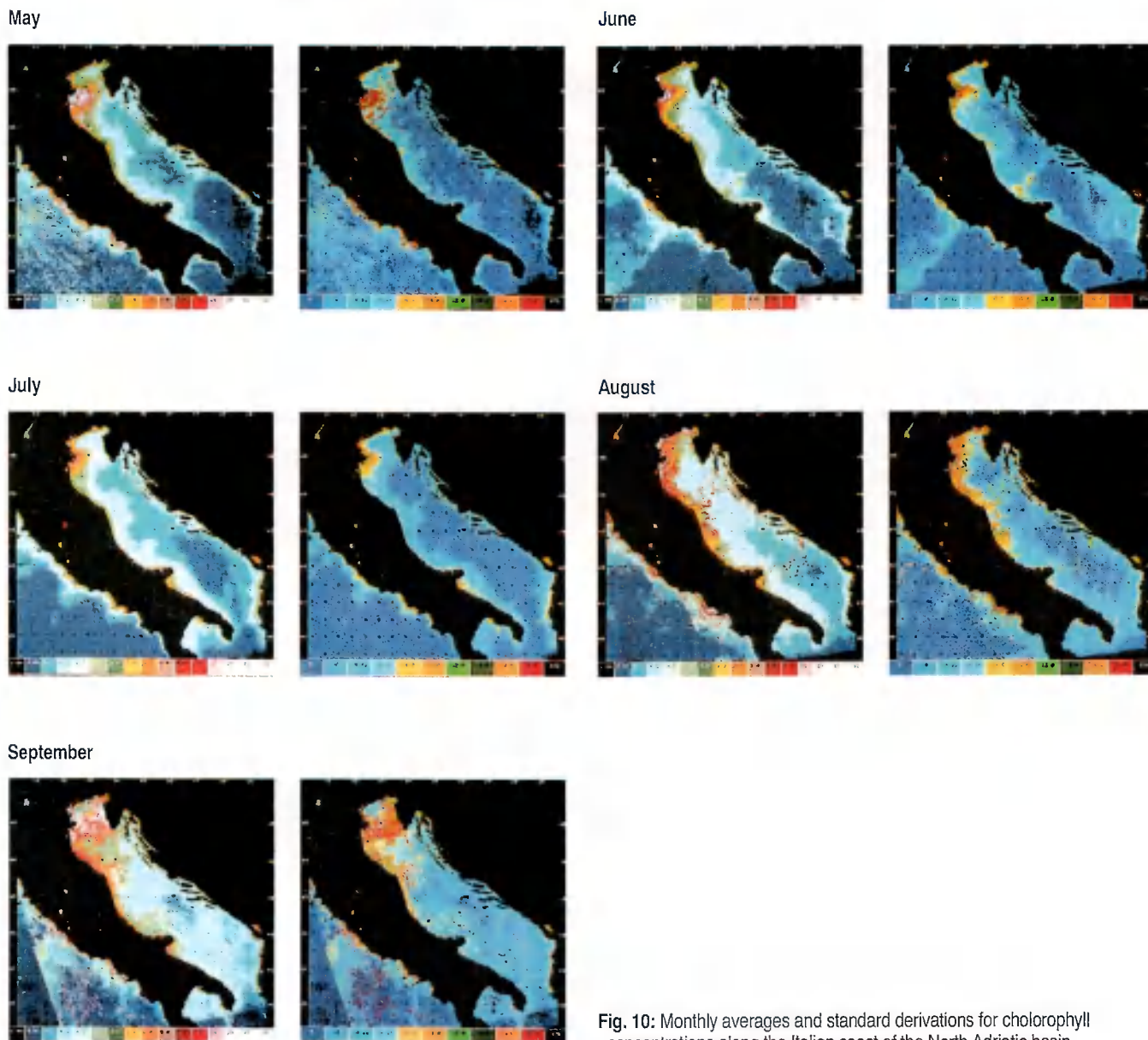
May

June

July

August

September

Fig. 10: Monthly averages and standard derivations for cholorophyll concentrations along the Italian coast of the North Adriatic basin.

Presently three models of different origin are available at the JRC. Under the first activity, an extended study has been performed dealing with the vertical diffusion of momentum in a homogeneous sea of an infinite horizontal extent. Under the second activity, the three computer models are being used to simulate the circulation pattern in the Northern Adriatic during a winter- typical episode of a strong NE wind (bora), characterized by essentially homogeneous water. Work is underway for coupling a Lagrangian tracer model with the hydrodynamic models for visualizing the flow pattern, especially the Po plume. The results will be compared with RS images.

CZCS Data Processing on PCs. Implementation Using New "Transputer" Technology

CZCS data processing for obtaining synoptic maps of chlorophyll- like pigment concentration and other derived products has still not become a commonly practiced approach due to the rather heavy "number-crunching" required for atmospheric corrections. Progress in computer hardware development is such that PCs running under MS/DOS and using transputer technics can reach computing speeds comparable with big mainframe computers.
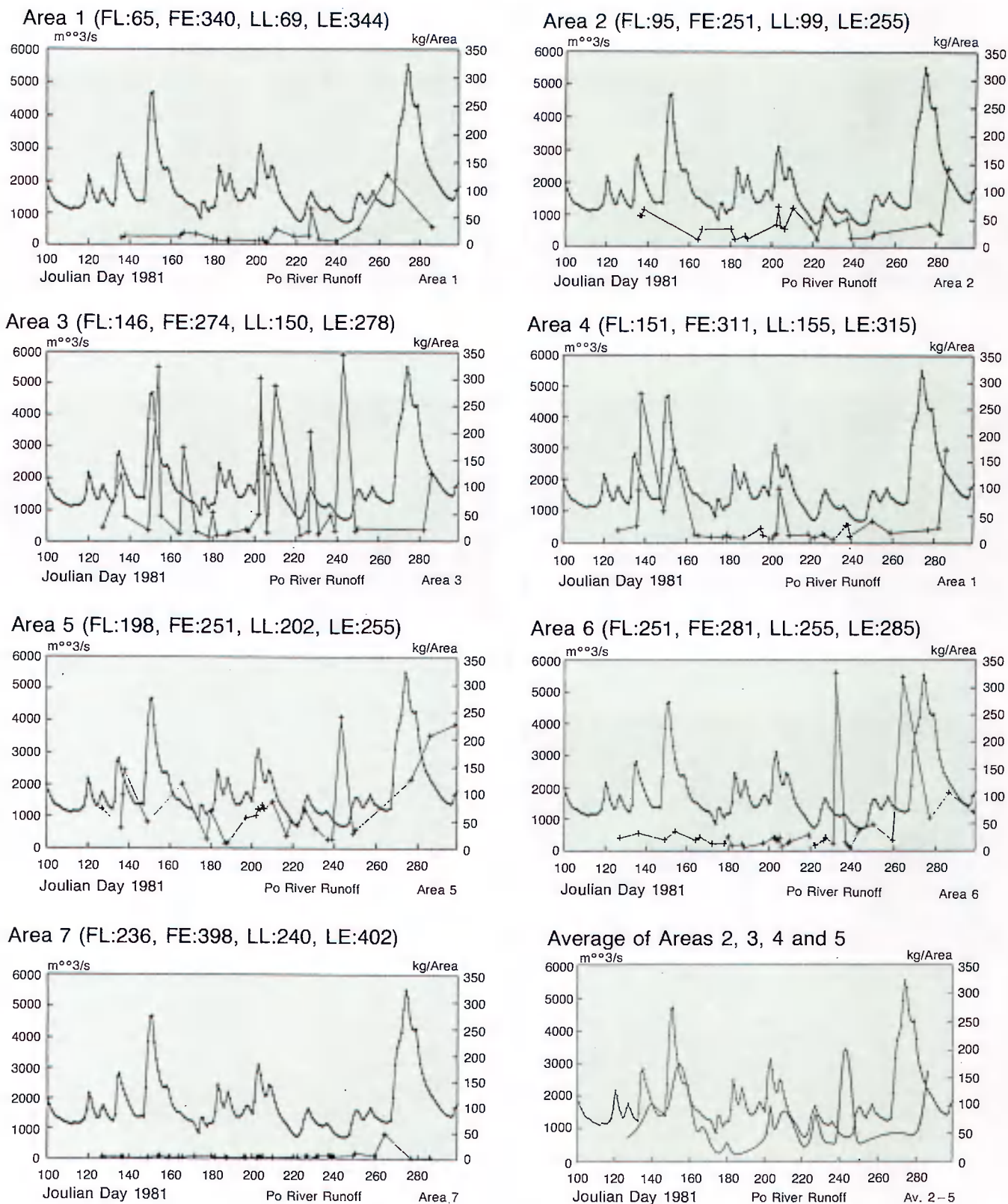
Fig. 11: Various areas of the North Adriatic, which have been considered for the study. The far away area 7 seems not to be affected by river's run-off.
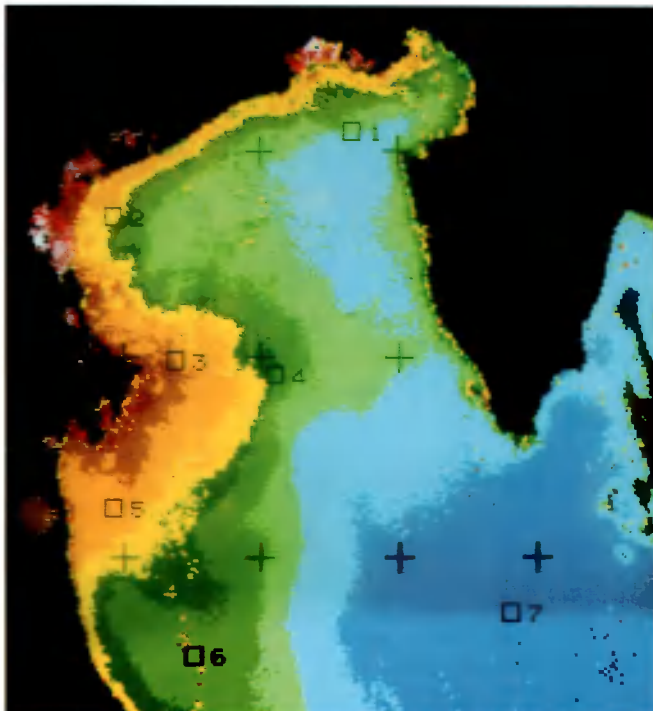
Fig. 12: Time correlation exists of chlorophyll concentrations in selected areas and the Po discharge rate. In Fig. 11 the flow discharge is correlated with the average of areas 2-5 which are the nearest ones to the estuary.

Fig. 13: Performance of transputer compared to sequential processing.

In view of this development, a minor part of the CZCS software was experimentally oriented towards PCs. As a first step software was developed for CZCS data processing on a normal PC-AT with numerical co-processor and EGA colour display. It was written in Turbo Pascal Vs.4.0. Typical processing times were of the order of 20 to 40 hours for a 400x300 pixel scene (six bands).

A transputer board with 8 T 800 processor chips each with 1 Mbyte DRAM was then installed into the PC and the processing software was translated into 3L Parallel-C using the "farming" technique: a factor of 150 was gained in speed and the processing time decreased to some minutes (Fig. 13).

A transputer station is planned to be ready in 1990. The aim is to obtain high rate production of images which will enable modellists to set up atlas of maps of surface concentration patterns of typical parameters to be compared with results of model simulations.

Water Quality Laboratory

As far as physical and optical measurements are concerned, the modernization of the PC equipment has advanced as planned. With the purchase of the Data Acquisition Package A-SYST, some application programs have been written, so that real time data acquisition and screen presentation is now possible for measurements with the CTD sonde of Meerestechnik Kiel and the EOS radiometer.

A special application of DB III-plus is under development for the creation of a standard database system of all in-situ data until now collected by the team. The final programme will allow for the extraction of:

– specific data sheets for each campaign, whose choice is based on data definable by the user;
– summary data sheets for future campaigns, whose selection is based on criteria definable by the user (e.g. the extraction of a summary of chlorophyll measurements against optical data relevant to several consecutive campaigns on the same marine area).

A study on "Monitoring of Primary Productivity of Algae Culture" by means of the PAM fluorometer has been conducted. This study continues with research on oxygen production of algae.

The Water Quality Laboratory participated in the following in-situ measurement campaign:

– Goro, Po delta area, Italy (May 1989), "sea truth" for the EISAC project. Bio-physical measurements (chlorophyll, nutrients, yellow, salinity, water temperature, etc.), biological investigators to establish the type of living material present in water and chemical measurements for the characterization of suspended sediment (nature and composition, and quantities of trace metals associated and/or dissolved in sea water).

Instrument Development and Design

The preliminary design phase of an image system for the in-situ measurement of the spectral and geometrical distribution of solar radiance in the sea and atmosphere has been pursued. Some

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problems have been encountered. Typical is the required large dynamic range going from the very high local radiance of the sun to the low diffuse radiance of sky in the same image. Antiblooming devices for the CCD image system or neutral density filters in the optical path of the instrument have to be foreseen.

The extremely high cost of fish-eye optics, made to customer's specifications, suggested further consideration and experimentation with less sophisticated devices such as a commercial CCD camera and fish-eye.

Microwave Remote Sensing

The overall programme puts a significant effort in developing applications of all - weather remote sensing techniques. Specifically this effort aims to demonstrate and validate methodologies for the practical use of data from space- and airborne sensors in both operational applications and scientific investigations related to land and sea.

In undertaking this task, the role of the JRC Microwave programme is complementary to that of ESA and national agencies. It is intended to stimulate an effective use of remote sensing data emanating from on-going space missions and to identify the needs for and the specifications of future missions based on prime application areas.

The development of future sensor technology is the responsibility of the European Space Agency (ESA) together with industries in the member states. However, no coordinated application oriented research programme over land exists in Europe.

The JRC proposes to develop a microwave remote sensing programme which is based on:

- in-house research,
- scientific and technical cooperation with external experts, users and industries in the EEC member states,
- project oriented cooperation with ESA, but also a
- scientific cooperation with non-EEC and non-European leading institutions.

The major elements of this microwave programme are:

- implementation of a microwave signature laboratory which will be used for in-house research and which will be open for use to researchers primarily from all EEC member states;
- implementation of a European Airborne Remote Sensing Capabilities (EARSEC) together with ESA;
- promotion of application oriented airborne experiments in joint cooperation with ESA and national institutions;
- improvement of a standard data base for characteristic target parameters and calibrated radar signatures (EURACS);

- development of application oriented radar data interpretation algorithms;
- promotion of application based pilot projects, e.g. in forestry;
- training of users.

a) Microwave Signature Laboratory

On the basis of the results of the Feasibility Study which was concluded at the end of 1988, the technical specifications of this installation have been defined. These specifications provided the technical support for the launch of a project concerning the detailed design, the construction and the installation of the Laboratory. (see section on construction of Large Installations)

b) Promotion of Airborne Campaigns

The JRC Ispra has placed considerable emphasis on the organization and implementation of airborne microwave campaigns. This is evidenced by the past activities of the JRC when, in conjunction with the European Space Agency (ESA), the JRC organized the first European microwave campaign (SAR 580, 1981), followed by the AGRISAR and AGRISCATT (1986 and 1987) campaigns.

However, as Europe moves towards the era of spaceborne SAR sensors with the first European microwave based spacecraft (ERS-1), there is a requirement to begin to give airborne campaigns a set of clearer, more specific objectives. These have been formulated upon the basis of the lessons learnt in the past campaigns, and against a background of application requirements; these objectives can be summarized as follows:

- the development of applications (and in particular renewable resources applications such as forestry and agriculture);
- the development and evaluation of new sensors;
- the validation of space borne sensors (such as ERS-1);

In 1989 the first implementation of these objectives was undertaken via the MAESTRO 1 polarimetric airborne SAR campaign. The JRC Ispra, in collaboration with ESA, supported and organized an airborne microwave campaign using the National Aeronautics and Space Administration (NASA) and Jet Propulsion Laboratory (JPL) three frequency (C-, L-, and P-Band) polarimetric SAR. Four major objectives were defined for this campaign:

- development of forestry and agricultural applications;
- evaluation of the potential of polarimetric SAR data;
- sensor evaluation;
- cross-calibration of the NASA/JPL SAR with other microwave sensors.

These objectives were developed in line with the overall campaign objectives set out previously. In particular the MAESTRO 1 campaign presented the the first opportunity for European scientists to evaluate

the capabilities of polarimetric SAR data over European test sites. In addition the objectives of the campaign were firmly based on the requirements of proven applications. Specifically the agricultural application objectives of the campaign were based upon the requirements for agricultural statistics as stated by Directorate General VI and EUROSTAT (Luxembourg). The forestry application objectives were defined by the requirements of an international forest experiment, whose major objective is to monitor global forest ecosystems.

On the basis of these objectives four test sites were selected: Flevoland (The Netherlands), Freiburg (Germany), Landes (France), Thetford (United Kingdom).

For each of these test sites JRC supported the SAR sensor operation and data processing for three scenes per test site, whilst ESA supported the flight operations. In addition, JRC/ESA arranged with the national agencies responsible for the Flevoland (BCRS), Landes (CNES) and Thetford (BNSC) test sites to define a set of flight lines, to support SAR data calibration, to provide (where appropriate) underflights by complementary systems and to support ground data collection. The JRC took responsibility for the Freiburg test site.

Overflights by the NASA/JPL SAR successfully took place during the period 16 - 18 August 1989. Initial results indicate that the SAR data collected were of good quality, and that the flight campaign was a success. In addition a large amount of ground data were collected, and will be compiled in preparation for input into the EURACS.

In order to maximize the participation of European institutes in the MAESTRO 1 Campaign a Call For Experiments has been distributed throughout CEC and ESA member states. Those institutes who respond to the Call For Experiments, and whose proposals are accepted by JRC/ESA, will become MAESTRO 1 investigators and will receive data (ground and SAR) derived from the campaign free of charge.

The Maestro 1 Campaign is now proceeding with the data processing and data analysis phases. The next steps in the campaign will involve the selection of the scenes for full processing to the level of high resolution complex one look data. These data, or the compressed version of these data, will then be distributed to MAESTRO 1 investigators for data analysis. These analyses will be undertaken on a European wide basis, and will be undertaken in such a way as to maximize cooperation. The cooperation will be assured via a number of workshops to be held at the JRC Ispra, and also by inviting a number of European experts to come to the JRC.

The MAESTRO 1 Campaign is due to conclude in mid-1991 with a final workshop to discuss the results of the campaign, accompanied by a final report.

c) Implementation of the European Radar Cross Section Database (EURACS)

As has been briefly discussed earlier a number of microwave campaigns and experiments have been undertaken in Europe using a variety of sensors and platforms, resulting in the generation of a large amount of microwave and associated ground data. However much of these data are currently disparately located, and consequently inaccessible to a wide range of users, and incompatible, due to the data collection technique applied.

In order to begin to overcome these problems the JRC Ispra initiated the development of a central store of microwave and associated data; the European radar cross section database, EURACS. This development began in 1986 with the European airborne microwave campaign, AGRISAR. For this campaign preliminary work was undertaken in the definition and implementation of standard collection methodologies for agricultural ground data. This work was further developed in the 1987 and 1988 during the AGRISCATT campaigns when data collection methodologies were refined.

Concurrently methodologies for data recording and data quality checking are being developed. The data recording has been undertaken using a standardized data format on floppy disk. This formalization of the data recording format has permitted the necessary quality checks of the data to be undertaken.

During the year 1988-89 the development of EURACS has significantly progressed. The actual design and implementation at Ispra of EURACS was initiated, and completed. This was based upon a number of objectives:

− data should be of the highest quality; it is therefore essential that all data must be fully quality checked before entering into the database;
− data contained within EURACS must have defined limits of validity; all parameters must be defined, and mean values alone are not permitted;
− parameters contained within the database must recreate the campaign/experiment they are related to as completely as possible, as they will be used by experimenters who have no experience of that particular campaign/experiment;
− access to EURACS will be undertaken by a wide range of users, therefore the database must be flexible.

During 1988-89 the scope of EURACS was also expanded. In preparation for the MAESTRO 1 Campaign standard ground data collection methodologies, and a data recording of the same type used for agricultural campaigns, were defined for forestry. Both of these innovations were applied and tested during the MAESTRO 1 Campaign in the summer of 1989.

EURACS has now entered its validation phase; during this phase the database will be fully tested. It is also planned to significantly increase the amount of data held within EURACS. The database currently holds a limited data set from the AGRISCATT 1987 campaign, however it is

planned that for the next year this data set will be significantly added to, in particular with data from the AGRISCATT 1988 and MAESTRO 1 campaigns.

d) Microwave Signal Processing System

Starting in the second half of 1988, the MW Team defined an architecture and the specifications for the Microwave Team data processing system. The analysis was performed as follows:

- definition of the environments: a set of functional specifications, related to a target activity,
- identification of common requirements,
- definition of computational resources that must be allocated to support the environments and, of an architecture to thread together the resources and make them cooperate to satisfy the intended goal. The environments identified for the processing are the signature laboratory, algorithm and software development for radar data processing and post processing, the hosting and management of the European Radar Cross Section Database and technical office automation, including desktop publishing and electronic mail.

These environments share a set of requirements ranging from high performance in terms of data throughput, large amounts of data, numerically intensive algorithms, high interactivity, flexibility for a variety of data types and multiple cooperating applications, homogeneous user interface, manageable and controlled software environments and a smooth migration path towards future extensions.

These requirements suggested an architecture based on the paradigm of a distributed system of computing resources, with servers and task oriented clients, and based on a consolidated foundation of international standards, such as:

- operating system - UNIX,
- communications - TCP/IP, NFS, X.25, IEEE 802.3,
- windowing systems - X.11 NEWS,
- graphics - PHIGS.

Based on a call for tender a system was procured from a pool of companies and it is now fully operational.

The system architecture is based on a networked system of workstations (Fig. 14). The backbone of the system is a LAN (Local Area Network), whose physical and link layer are compliant with the IEEE 802.3 standard (commonly referred to as "Ethernet") with a theoretical bandwidth of 10 Mbit/sec.

The heart of the system is a SUN4/280s workstation, which acts as a file server for a number of diskless and dataless client workstations. 3.6 Gigabytes of magnetic disk storage is available to all stations as well as 10 gigabytes of on-line WORM (Write Once Read Many times) optical disk systems. This data storage is shared through the paradigm of SUN's NFS (Networked File System) running under UNIX (SUNOS)
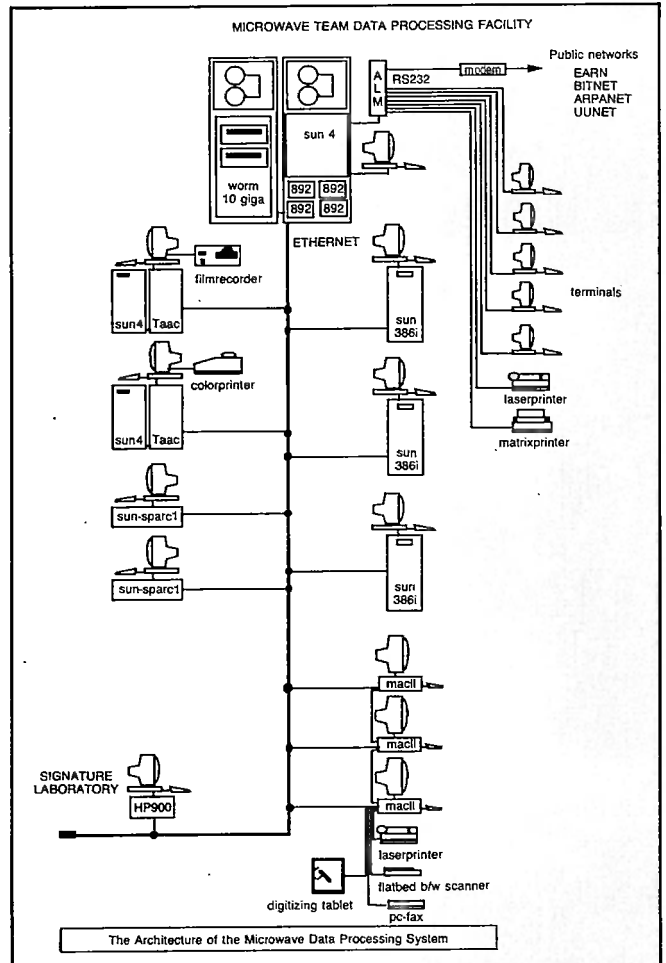

Fig. 14: The Architecture of the Microwave Data Processing System.

which turns the network into a distributed system of shared resources and computing power.

The Microwave team has developed a number of software tools that will be used for its internal research purposes and also made available to external institutions in the frame of cooperation agreements. A list of the tools available are as follows:

1. POLTOOL - multipolarization SAR data analysis and presentation (Fig. 15).
2. DISTOOL - raster - and vector data display and manipulation.
3. SIMSAR - a SAR simulator.
4. TAPEAN - tape analysis.
5. COMPRESS - JPL full resolution complex data to compressed Stokes matrix.
6. QLOOK - JPL full resolution complex data quick look.
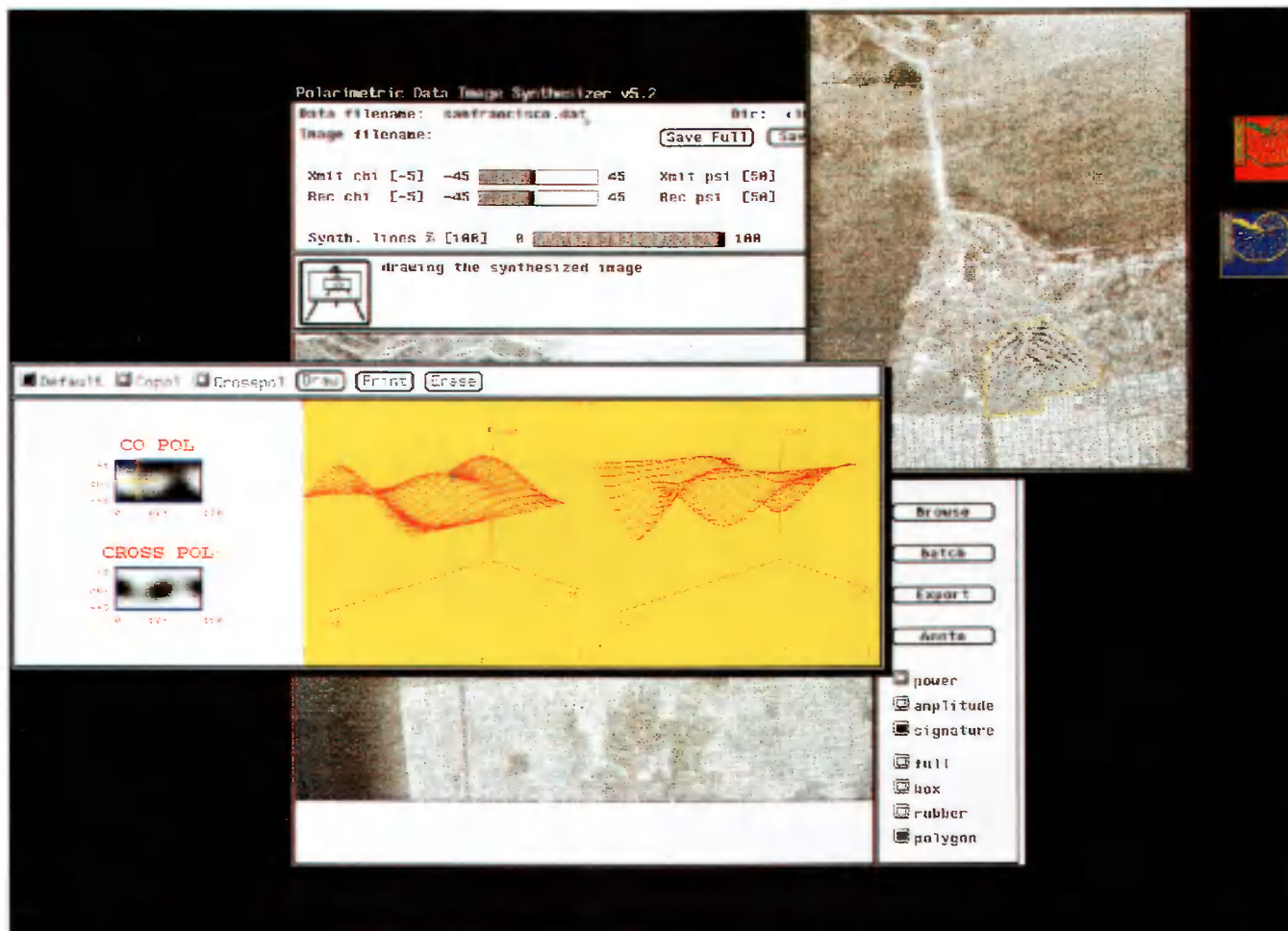7. CHAMELEON - multipolarization synthesis on the TAAC.

Fig. 15: POLTOOL a Software Tool for Radar Polarimetric Data Processing.

e) European Airborne Remote Sensing Capabilities

In response to the various presentations of JRC/ESA plans to promote and eventually have installed a European Airborne Remote Sensing Capabilities (EARSEC), different groups contacted JRC and ESA indicating their interest in EARSEC and their "readiness" to provide such a facility. JRC took the initiative, in agreement with ESA to arrange for informal meetings with the key groups in Europe. The series of separate discussions took place in Ispra from September 20 to the 22nd. JRC and ESA received presentations on plans and projects for an airborne C-band SAR, by:

1. The PHARUS Project in the Netherlands,
2. The EUROSAR Project, by a company with the same name under the leadership of the Spanish group GDS-Tecnogestion, S.A.
3. The KRAS Project by the Technical University Denmark,

4. The E-SAR Project by the Institute for Radio Frequency Technology, DLR, West Germany,
5. The DO-SAR Project by the German Company Dornier System, Friedrichshafen.

Since the optical sensor type (multispectral scanner) is a standard product no special effort with regard to it was included in this series of meeting. All the teams presented technical description of their sensors, the sensor status and future plans, their interest in the JRC/ESA EARSEC concept and preliminary cost and budgetary considerations. Most of the teams provided to JRC/ESA detailed technical hand out material.

In summary these presentations provided new elements to ESA/JRC. The groups have used different base lines for their design, e.g. experimental versus operational, flexible versus professional quality assurance, low swath width versus large area mapping.

To be able to provide JRC/ESA with comparable ground for further decisions more details were requested from all teams.

Lidar Fluorosensing

For some years, the Lidar group has been working on the development of advanced time resolved fluorescence measurement techniques with the purpose of applying them to sea pollution monitoring.

In a first phase, the effort has been focused on the problem of pollution by crude oils. The fluorescence properties (spectral and temporal) of the crudes have been extensively studied in the laboratory. The decay times have been measured in two different ways. A first series of measurements was performed with a pulsed nitrogen laser (50 μJ, 0.1ns duration), a monochromator, a fast PM and a transient analyser. These measurements were later repeated in a configuration which simulated to some extent the "in field" conditions: the sample was placed in a tower 100 m away from the laboratory. In this case, a more powerful frequency tripled, Q-switched Nd-YAG laser (50 mJ, 4.5 ns) was used as the exciting source and the fluorescence light was collected by a 25 cm aperture telescope. The detector was a gated Optical Multichannel Analyser.

The study has included 10 different crude oils which were supplied by the "Stazione Sperimentale dei Combustibili" (San Donato Milanese, Italy) as representative of the oils normally transported on European waters.

These experiments have been reported in detail in the EUR report "Remote Characterization of Mineral Oils by Laser Fluorosensing: Basic Diagnostics and Simulation Experiments" (EUR 11781 EN, 1988).

The most important conclusion was that the various types of oils could be identified on the basis of the spectro-temporal characteristics of their fluorescence. A practical fingerprinting method was proposed which is based on the fluorescence decay times measured in five spectral bands.

a) The airborne "Time Resolved Lidar Fluorosensor"

An airborne instrument has been designed to implement the fingerprinting technique in practice. To obtain the high temporal resolution, of which the simulation experiments had shown the importance, the design has used a number of advanced techniques: the exciting source is a mode-locked Nd-YAG laser delivering one-nanosecond pulses and the detection system is based on a streak camera coupled to a polychromator. This combination offers the unique possibility of acquiring the entire spectro-temporal information from a single laser shot.

The construction of the instrument was entrusted under contract to the CISE SpA (Milano, Italy) (Fig. 16). The delivery of the instrument has been delayed several times due to difficulties encountered in the

development of the laser and repeated failures of the streak camera system.

However, these problems now appear to have been mastered and preliminary reception tests were performed in October 1989 to check some important characteristics of the system:

– the laser has now reached the normal operative energy of 270 mJ at the fundamental wavelength, delivered at 10 Hz in one-nanosecond pulses; this corresponds to 35 mJ at 355 nm after the output optics;

– the collection efficiency of the telescope coupled to the 19 m, 0.4 mm diameter optical fiber (which creates the delay needed by the streak camera) has been measured to be 24% at 532 nm; this value was obtained by using a standard Lambertian diffuser as the target and by measuring the optical power at the fiber output;

– the temporal accuracy and the dynamic range were tested with good results by measuring the fluorescence of quinine bisulphate which presents a well known mono-exponential decay with a time of 19.2 ns; it was however found that the correct value could only be obtained by correcting irregularities in the streak camera sweep speed;

– remote (at 110 m) measurements on three different oils have shown that the single shot capability of the instrument has been achieved (Fig. 17) shows the single shot measurement on a medium-light napthenic oil); the fingerprinting signatures obtained on the "slow" samples are in agreement with the laboratory measurements while shorter decay times have been measured on the "fast" samples;

– the data acquisition and on-line display on the VAX workstation has been tested with good results; however, it was found necessary to

Fig. 16: The "Time Resolved Lidar Fluorosensor" under construction at CISE S.p.A. (Milano). The top right structure contains the laser, the telescope and the streak camera.
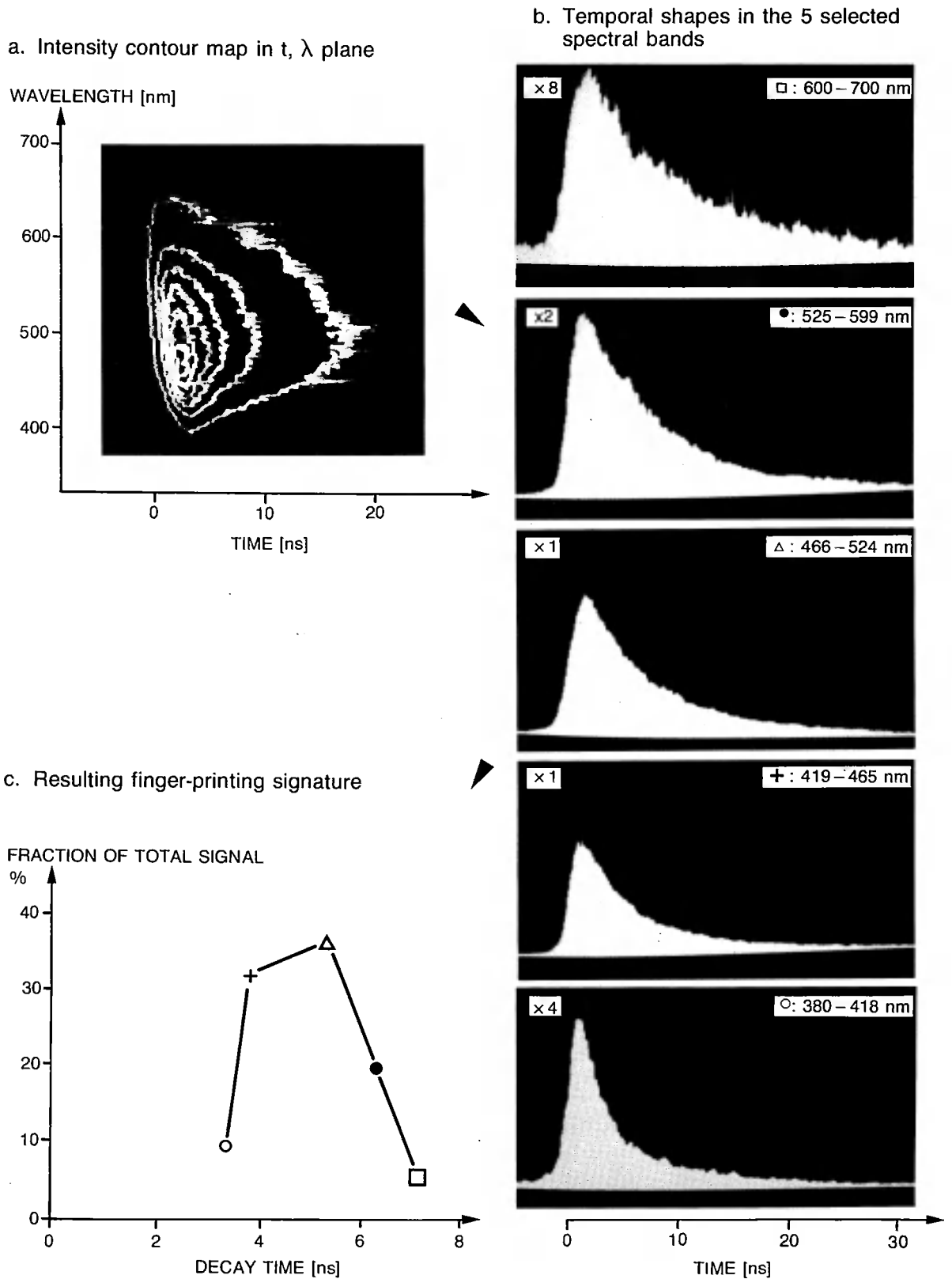
a. Intensity contour map in t, λ plane

b. Temporal shapes in the 5 selected spectral bands

c. Resulting finger-printing signature

Fig. 17: Single shot spectro-temporal measurement of an oil fluorescence (FORCADOS, medium-light napthenic).
This measurement was performed with the sample at 110 m from the instrument during the preliminary reception tests of the TRLF.

make a slight modification in the display of the spectrum in order to compensate for the chromatic dispersion of the fiber;

- due to the limitations of the water column simulation carried out at CISE, no conclusion could be reached on whether the system can be triggered by the return signal from the water surface.

These results show that the basic technical objectives have finally been achieved. The operability in field conditions is still to be evaluated. A first indication will be obtained when the instrument is tested under vibration in the specially adapted motorvan of the JRC, just before its transfer to Ispra in February 1990. The work foreseen to be done in Ispra comprises additional study of the triggering problem, calibration work and the constitution of the fingerprinting data base.

As for the future validation campaigns from an aircraft, the mechanical aspects of the installation of the instrument aboard a G222 aircraft of the AERITALIA have been studied and the project for the interface platform has been defined.

Contacts have also been maintained with several Italian ministeries in order to better define the campaign program. Our proposal is first to undertake a series of flights over coastal and deep waters in order to assess the operability of the instrument. The organization of the campaign in which the instrument is to be tested with oil slicks as targets is, for the moment, encountering legal obstacles.

In order to reduce the delays in case of failure, part of 1989 budget has been dedicated to the purchase of spare parts for the most critical components of the TRLF.

b) Upgrading of support laboratory

In order to better understand future results of the TRLF and to further develop the applications of these ultra-fast fluorescence measurements, an effort has been made to upgrade the Ispra laboratory. The objectives were to improve the temporal resolution and to enlarge the capabilities of simulating the water column.

Laser source

A transformation of the Q-switched Nd-YAG laser into a mode-locked one with shorter pulse duration was ordered at the end of 1987.

The transformed laser was delivered in September 1988; it nominally emits pulses with a duration ranging from 500 ps to 20 ps and with corresponding energies from 70 mJ to 6 mJ at 355 nm.

A series of problems rapidly occurred due to the successive failures of various optical components. After several interventions by the manufacturer in the course of which both harmonic generators, the dye cell (twice), a Nd-YAG rod and a lens have been substituted, the laser has reached a usable condition in September 1989, at least for pulse durations of 100, 200 and 500 ps.

At the same time, the laboratory is being progressively equipped with high energy optics able to sustain the high instantaneous power developed in these very short pulses.

Detection system

The Optical Multichannel Analyser, still useful for precise spectral measurements, is to be paralleled by a streak camera system offering a much higher temporal resolution.

Extensive tests performed on the streak camera during August and September 1988 have shown that the unit was suffering from an impressive series of defects among which: a very low gain, a high dark signal, a 20% distortion of the temporal scale, large spatial non-uniformities of the response, defective CCD chip and A/D converter, a very restricted dynamic range, an inoperative DMA interface, etc. Under these conditions, the instrument was completely unusable for fluorescence measurements. These findings led to long and difficult discussions with the manufacturer finally resulting in the company's chief engineer coming to examine the instrument in December 1988. It was then agreed that the entire system would be sent back to the factory and that the problems would be solved within two months. In fact, the instrument finally returned to the JRC at the beginning of September 1989, after substitution of about half of its components. The tests conducted so far have shown a definite improvement, though not all the problems have disappeared.

The study of the instrument has in fact demonstrated that, precise decay time measurements would require a special calibration procedure to correct the irregularities in the sweep speed and spatial non-uniformities. A characterization procedure has been devised to acquire the correction matrices. To perform this, it was necessary to obtain a constant intense light flux during the time scale of the streak. A solution has been found by feeding a green LED with 1A, 1µ s current pulses. This is now being incorporated in the revised instrument.

Another difficulty in using a streak camera arises from the necessity of triggering the streak tube with a precise delay before the arrival of the optical signal. When a moderate time resolution is required, an optical fiber can be used to delay the optical signal; the fiber modal dispersion limits the resolution to 100 ps and its chromatic dispersion introduces an inconvenient delay of several ns between the red and blue components of the signal. To overcome this, it was necessary to construct an optical delay line for the exciting UV pulse. The delay line has two basic lengths of 26 and 44 m, with a fine adjustment over 3 cm in order to center the signal on the streak camera scale; it is entirely constructed with high energy UV optics.

Other work carried out to implement the new instrumentation are:

- installation of two new optical benches;
- construction and installation of a dedicated polychromator coupled to the streak camera;

– equipment of the laboratory with the various accessories needed by a streak camera system such as ultra fast photodetectors to generate the trigger signal and precision digital delay generators.

The very high temporal resolution provided by this arrangement has been recently demonstrated though the measurement of the shape of laser pulses as short as 26 ps. An example of such a laser pulse is illustrated in Fig. 18.

The difficulties encountered in implementing the streak camera led to the analysis in detail of the limitations of this technique and to consider alternative solutions such as single photon counting. However, it was concluded that the streak camera technology should be used as in the field of remote sensing it offers the unique possibility of acquiring simultaneously the spectral and temporal information contained in the optical signal (in the sub-nanosecond range). In view of the fact that any further failure of instrument would provoke again a prolonged paralysis of the laboratory activity, it was decided to order a second instrument. After a careful study of the market, an instrument was selected showing improved characteristics, in particular very high gain, high S/N ratio and sweep regularity.

In relation to the streak camera, a program has been written to perform the multi-exponential analysis of temporal decays. It is based on a weighted least-squares fitting technique and takes into account such factors as the finite laser pulse width, the instrumental resolution, the electronical noise of the streak camera and statistical fluctuations. It has been successfully tested on simulated data.

c) Water column simulation facility

The TRLF has been constructed for the monitoring of oil slicks but it is susceptible of other applications related to signals generated in the water column (Fig. 19). These are: fluorescence of gelbstoff (dissolved organic materials) and phytoplancton, scattering by suspended matter
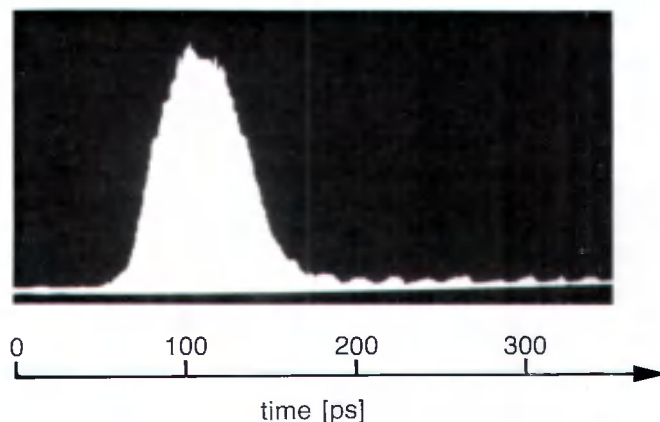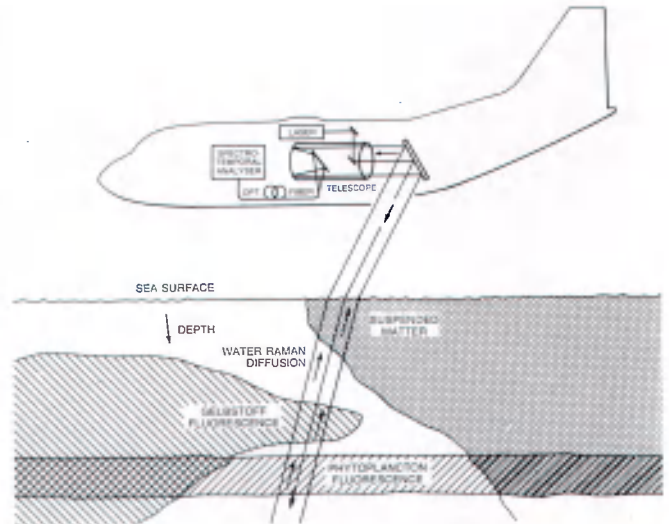
Fig. 19: The TRLF in its possible use to probe the water column.

and Raman diffusion by the water itself. In fact, one of the most important applications of existing marine LIDARs is the establishment of detailed maps of the phytoplancton distribution; in this application, the Raman signal has been shown to be very useful for normalization.

In this case the temporal resolution of the TRLF will allow the measurement of the distribution in depth of the various substances. The simple model intend for use in the temporal analysis of the return signals has been presented in a paper entitled "Problems related to time-resolved fluorosensing of an extended aquatic medium" (8th EARSeL symposium, May 1988).

Using the small facility installed for studying oil films on water (Fig. 20), the instrumentation used in the TRLF has been shown to be capable of detecting the weak return signals from the water column. Fig. 21 shows the spectrum obtained from a 3 m high tap water column placed at a distance of 100 m from the laboratory.

The result of detecting the Raman diffusion has led to the construction of a facility specifically dedicated to water column studies. This 7 m high, 2 m in diameter cylindrical tank now awaits the installation of the deflecting mirror to be operational. The purpose of the first experiments will be to assess the validity of the above mentioned model.

In summary it may be concluded that after a difficult initial development period, the airborne Time Resolved Lidar Fluorosensor has finally yielded positive indications on its performance. In particular, during the first reception tests, the remote measurements performed on several oils have shown that the full spectro-temporal characteristics of the fluorescence can be obtained from one single laser shot.

The support ground laboratory has been re-equipped and the first tests show that decay times as short as 100 ps can be measured. The
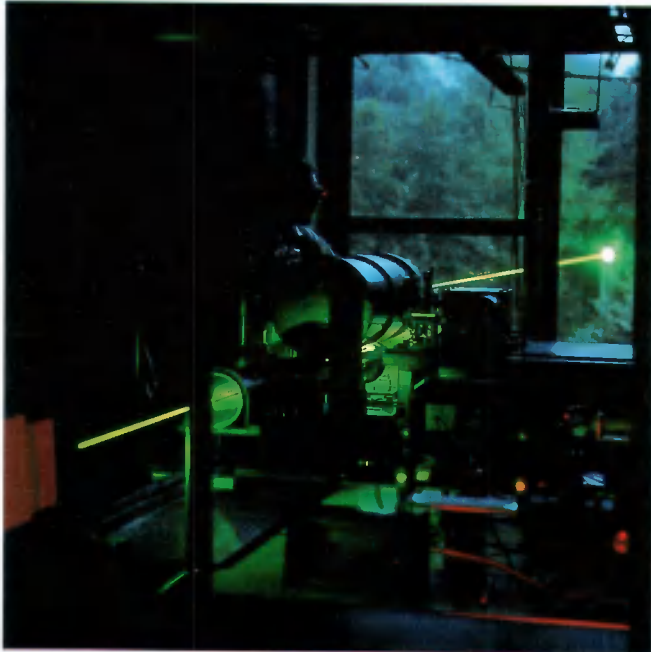

0   100   200   300

time [ps]

Fig. 18: Example of laser pulse measurement performed using the streak camera and the recently constructed optical delay line. This particular pulse was found to have a 74 ps duration FWHM.

Fig. 20: Remote measurements on the water column from the ground support laboratory.

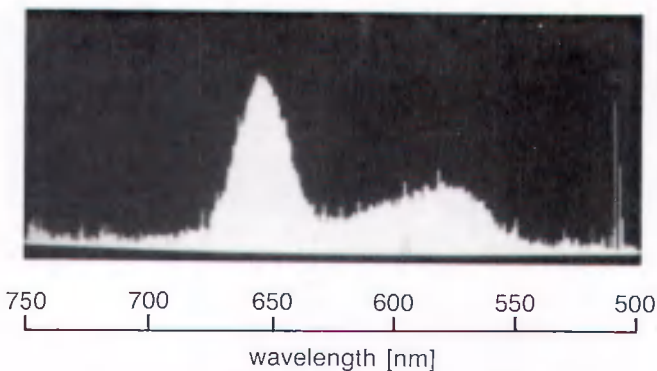| 750	700	650	600	550	500

wavelength [nm]

Fig. 21: Spectrum of the return signal from a 3 m high tap water column. The peak at 650 nm is due to the water Raman diffusion, the broad background fluorescence is attributed to dissolved organic material. Here, the much more intense scattering signal at the excitation wavelength (532 nm) has been cut off with a coloured filter.

planned studies on the oils will concern weathering processes such as evaporation and emulsification. A new facility has been installed to simulate the signals of the water column. This completes the instrumentation for studying the distribution at depth of the substances present in the water column.
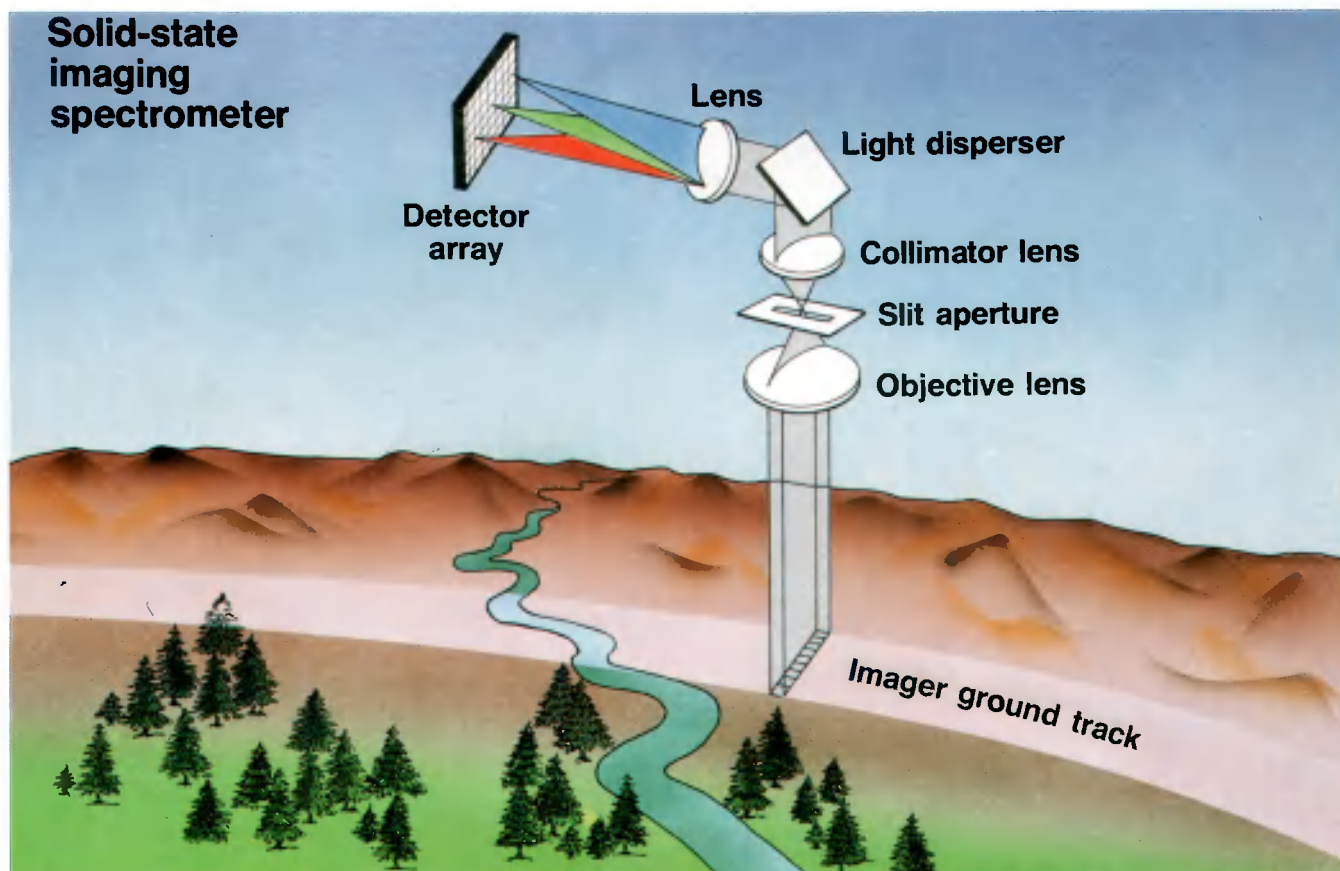
European Imaging Spectroscopy airborne campaign – EISAC 1989

Imaging spectroscopy represents a further step in the continuing development of new ways to obtain more accurate information of the physical properties of the Earth's surface from remote platforms. Originally developed to obtain geochemical information of not accessible planetary surfaces in the solar system, it becomes of increasing importance throughout many application areas in Earth observation.

The definition of imaging spectroscopy is the acquisition of image data in many contiguous spectral bands. The ultimate goal is to produce laboratory-like reflectance spectra for each pixel of an image.

Most natural Earth surface materials have diagnostic absorption features in the 400 nm to 2500 nm range of the reflectance spectrum. Since these diagnostic features are typically of a very narrow spectral appearance, direct identification can be made for these surface materials, if the spectrum is sampled at sufficiently high resolution which becomes possible using the new technique.

During the last years a new generation of optical remote sensing systems has evolved under the name of "imaging spectrometers" (Fig. 22).

This new type of sensor which can provide image data with detailed spectral resolution up to more than 200 spectral bands can be considered to be a powerful tool for future optical earth observing remote sensing because the availability of such data promises a diagnostic surface differentiation by evaluation of spectral signatures (Fig. 23). Research from recent experiments with high spectral resolution airborne spectroradiometers indicated and confirmed that significant advances can be achieved over Landsat-TM and sensors of similar spectral coverage. With increasing emphasis being placed upon global measurements in an effort to understand global change, more sophisticated techniques must be developed and applied to provide the kind of information that are important to the development of predictive models.

Against this background and regarding the recommendations resulting from the Frascati workshop on imaging spectroscopy, held by ESA in April 1988, the European Space Agency (ESA) and the EC Joint Research Center Ispra (JRC) jointly decided the organization of the European Imaging Spectroscopy Airborne Campaign 1989 (EISAC) scheduled to be flown during the period from May 15th to June 15th 1989.

The principal objectives of the EISAC campaign were:

– the development of imaging spectroscopy for the purposes of agriculture, forestry, soil science and marine biology aiming at the development of future spaceborne systems
– the familiarization of a broad community of European remote sensing users with imaging spectrometer data.

Solid-state imaging spectrometer

Lens

Light disperser

Detector array

Collimator lens

Slit aperture

Objective lens

Imager ground track

Fig. 22: Schematic diagram of an imaging spectrometer.

To optimally meet these demands and with a view to the restricted time window available for the campaign, the decision was taken to cover several flight lines over six test areas, determined by an international expert group, using two different instruments. Extensive ground data sampling and atmospheric measurements, an absolute necessity for the scientific evaluation of the airborne data, were planned to be executed simultaneously to the flights by local test site coordinators supported by ESA and JRC. The sensors and test sites were chosen as follows:

Sensors and aircrafts:

a) GER Airborne Scanner flown in a 63 band mode, covering the spectral range from 450 - 2500 nm. The following bandset was used: 31 bands 450 - 865 nm, bandwidth 12,3 nm
4 bands 1440 - 1800 nm, bandwidth 120,0 nm
28 bands 2000 - 2500 nm, bandwidth 16,3 nm
Aircraft: PIPER ATZTEC of Geophysical Environmental Research Corporation (GER)

b) Moniteq PMI (FLI) Programmable Multispectral Imager covering the spectral range from 400 - 805 nm in two different modes.

Spatial Mode: 8 selectable bands, bandwidth 2,6 nm
Spectral Mode: 288 bands, bandwidth 2,6 nm

c) Metric Camera device RMK 15/23 with false colour infrared film.
Aircraft: b) and c) on a DO 228 of Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt (DLR).

Test sites:

a) Oceanography:
North Sea (FRG, N, UK) - Waddensea, Helgoland, Skagerrak
Northern Adria (I) - Venice Lagoon, Sacca di Goro

b) Land applications:
Somerset Levels - Agriculture (UK)
Upper Rhine Valley - Forestry, Agriculture (F, FRG),
Almaden - Soil Science, Vegetation (E)
Ardèche - Soil Science, Land Use (F, JRC experiment)

To meet the minimum requirements on sea- and ground truth data the
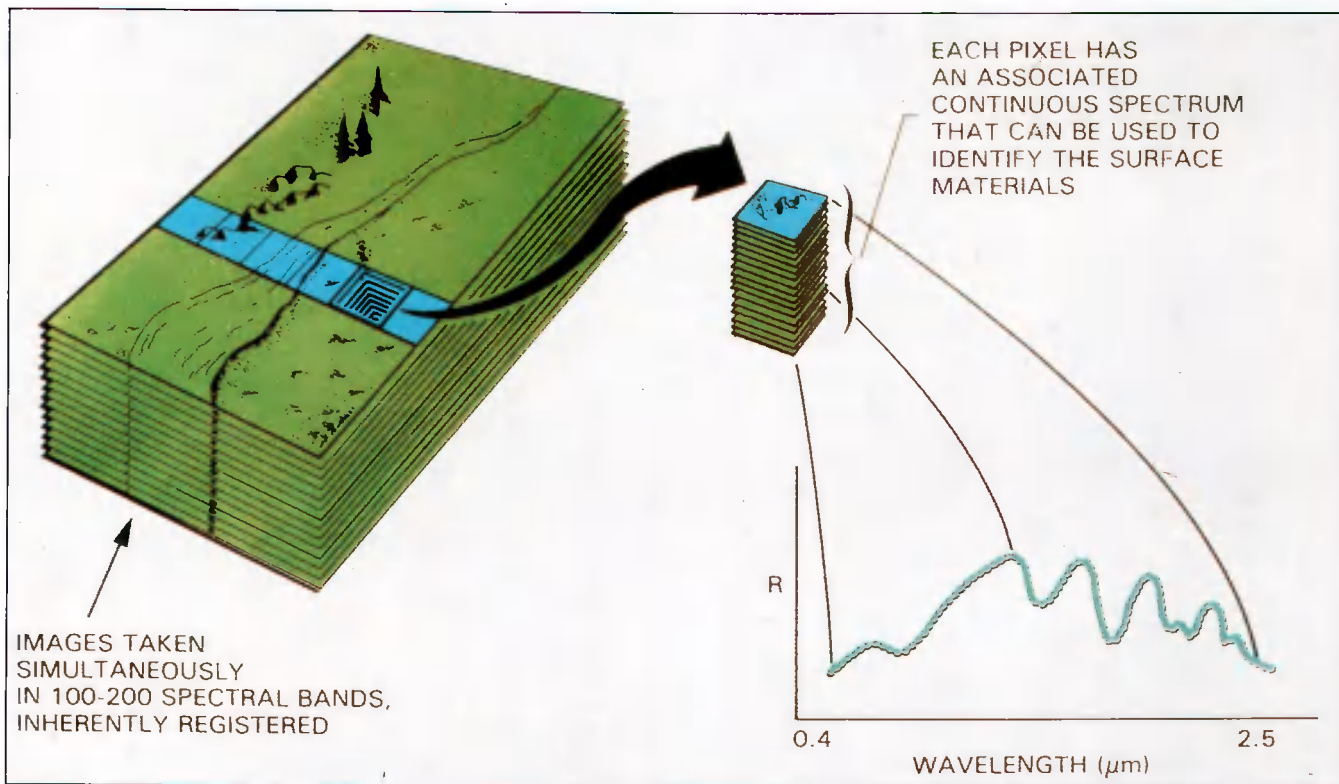
Fig. 23: Spectral signature generation.

following parameters were investigated for each test site, to report and provide, with geographical references, information on:

a) for Land Applications:
   - typology of the test-site and land occupation
   - agriculture practice where relevant
   - ground spectral signature measurements of some reference surfaces within the test site

b) for Oceanography:
   - measurements of Secchi depth, CTD (conductivity, temperature, density) profiles, chlorophyll, TSS (total suspended substance), yellow substance attenuation coefficient and up/downwelling ratios in 5 - 6 narrow bands

c) for both Land Application and Oceanography:
   - monitoring of the incoming irradiance during the overflight
   - measurements of atmospheric parameters such as horizontal visibility, surface meteo data (T,P,RH,wind), cloud cover and if possible, total optical thickness.

Upon this basis ESA and JRC invited all EARSeL institutes and expert groups to participate in the EISAC campaign in terms of forwarding proposals for utilizing the data in the following tasks:

- processing the spectrometer data
- spectral signature modelling
- data analysis in terms of applications in agriculture, forestry, soil science and oceanography.

Execution of Flight Operations and Data Acquisition:

The EISAC flight campaign was executed successfully between May 11th and June 14th 1989. During this period the extensive ground measurement programme was performed on each test site.

The following airborne data were acquired:
FLI: The FLI instrument was flown in spatial as well as in spectral mode over all test sites, except the Ardeche.
Length of flight lines: ca. 300 km (for each mode)
Number of acquired CCTs: 77 (1600 BPI)

GER: Except the Helgoland and Somerset site, the GER instrument acquired data from all test sites as follows:
Length of flight lines: ca. 250 km
Number of acquired CCTs: 24 (6250 BPI)

MC (RMK 15/23): 683 IR false colour photographs have been taken over all test sites, except the Ardeche.

Call for Experiments:

In April 1989 the "Call for Experiments" has been sent to all Remote Sensing institutions in Europe attached to EARSel. Conceding that the first deadline (12.05.89) for forwarding proposals might have been too short-termed ESA and JRC decided in May to postpone the deadline to June 16th in order to give all interested institutions the possibility to participate in the EISAC data evaluation.

Up to June 16th JRC received about 50 enquiries concerning the "Call for Experiments" amongst which 30 proposals were selected that met the minimum requirements of the AO.

The 30 proposals came from the following countries: Belgium (2), France (3), Germany (7), Italy (6), Netherlands (3), Switzerland (1), Sweden (1), United Kingdom (7).

Test site requirements:
21 proposals require data from one test site only.
9 proposals require data more than one test site.

The test site requirements are shown in table 4:

Additional local experimenters are collaborating with the responsible coordinating investigators of the Spanish and Norwegian test site.

EISAC data evaluation programme:

The coordination of the EISAC data evaluation programme was entrusted to JRC Ispra. The first phase of data evaluation is scheduled to last one year and will be concluded with a campaign analysis workshop which should result in a "pool of experiences" in the application of imaging spectroscopy. On the basis of the experimenters' and of the test site coordinators' EISAC proposals, an extended evaluation programme for imaging spectroscopy data was defined in order to assess the suitability of this technique for the needs of European remote sensing and to define the requirements on future spaceborne instruments. In this context JRC will lay its main emphasis on the following topics:

– Radiometric correction of data
– Atmospheric correction of data
– Spectral signature modelling
– Definition and evaluation of relevant surface parameters to be received by future spaceborne instruments with a special regard to the modelling of spectral band combinations for the final definition of a combined vegetation and ocean bandset (i.e. midband frequency, band width, number of bands) for the MERIS instrument on the first ESA Polar Platform Mission.
– Data analysis in terms of applications in agriculture, forestry, soil science and oceanography.

Table 4: Test site distribution.

Test Site	B	CH	D	F	I	NL	S	UK	*
Waddensea	—	—	1	—	1	1	—	2	5
Skagerrak	—	—	—	—	—	1	1	1	3
Helgoland	—	—	2	1	—	—	1	2	6
N-Adria	—	—	1	3	3	—	—	2	9
Almaden	1	—	1	—	1	1	—	3	7
Up-Rhine	1	1	6	—	2	—	1	2	13
Somerset	—	—	—	—	—	1	—	4	5

Application of Laser-Spectroscopy to the Characterization of Green Matter

a) Application areas

Present applications of different existing remote sensing techniques are oriented towards agriculture and forestry. They include land use, crop type classification, early warning of plant stress, assessment of crop photosynthesis and prediction of yield. The results obtained by all these techniques suffer from the fact they are not only sensitive to vegetation response but also to the optical properties of the surrounding environment.

A new technique for remote detection of plant stress, due to biochemical and physiological changes, is based on the detection of the light induced chlorophyll fluorescence. Since chlorophyll fluorescence is only due to emission of green vegetation, it can be considered complementary to existing techniques.

In a photosynthetic system light energy is absorbed by a large array of light harvesting chlorophyll protein complexes and transferred to the reaction centers of Photosystem I and Photosystem II. Due to the absorbed energy the chlorophyll of the reaction center reaches an excited state:

$$ChL + h \cdot \nu \longrightarrow ChL^*$$
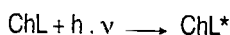
The excited molecule can release its energy by different pathways:

$$ChL^* \begin{cases} ChL + ChL^* & \text{Energy transfer} \\ ChL + Heat & \text{Non radiative} \\ ChL + e & \text{PSII-Photochemistry} \\ ChL + h \cdot \nu & \text{Fluorescence} \end{cases}$$
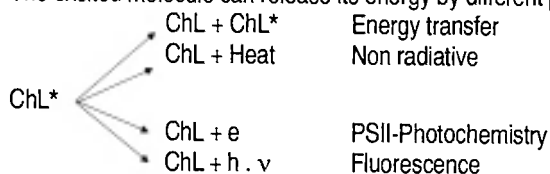
In a full functioning system, the greater part of the absorbed energy is used for photosynthesis. The remainder is lost as heat and re-emitted as chlorophyll fluorescence. If the de-excitation pathway via PSII photochemistry is blocked the heat production plus fluorescence emission increases. Due to this inverse relationship between in-vivo chlorophyll fluorescence and photosynthesis, the detection of the fluorescence emission can be utilized to describe the potential photosynthetic activity of the sample.

The Institute for Remote Sensing Applications is investigating the energy transfer processes in photosynthetic systems by time-resolved chlorophyll fluorescence in regard to remote characterization of the vegetation by this fluorescence technique.

In future this work will be performed in cooperation with national institutes from France, Germany and Italy in the LASFLEUR project (EUREKA).

b) Results

Time-decay measurements of the chlorophyll fluorescence (LURE, JRC - Ispra)

Figure 24 shows the instrumental response function to scattered light and the decay of the chlorophyll fluorescence of a spinach leaf,

measured at 684 nm, following excitation at 645 nm. Four exponential decay components were required to fit the overall decay. The four individual decay components have lifetimes in the order of 10-40 ps, 80-140 ps, 400-450 ps and 700-900 ps. These values were independent of the place on the same leaf; similar results were found with different identical looking leaves from the same and from different plants.

By blocking the photosynthetic electron transport, via the application of the herbicide DCMU, the lifetimes of the two slowest components increase by a factor of 4.

Figure 25 and 26 show the time-resolved emission spectrum of a spinach leaf before and after the application of DCMU. The spectrum at steady state conditions of photosynthesis show one main peak at 684 nm and a depressed peak at 730 nm. It can be seen that the two slow components with lifetimes of 404 ps and 844 ps have emission maxima around 684 nm while a fast component (100 ps) exhibits a broad peak around 724 nm and a shoulder at 688 nm. The shape of
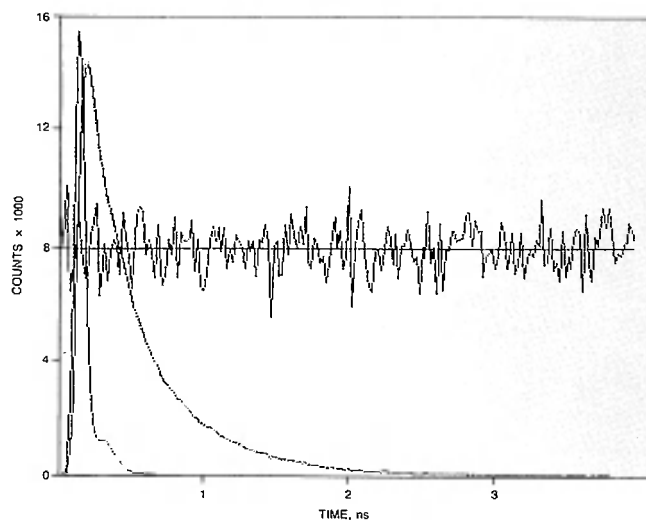
Fig. 24: Room temperature chlorophyll decay of a spinach leaf measured at 684 nm at steady state fluorescence level. The excitation profile shown has a width of 70 to 80 ps (FWHM). The best fit of a quatroexponential model is superimposed with the experimental decay. The weighted differences between the measured and fitted curves are shown in the center of the plots.

the fastest component (24 ps) indicates two maxima, one around 690 nm and one at 720 nm.

The emission spectra of the DCMU incubated leaf is characterized by a peak at 686 nm and a shoulder in the 730 nm region. With the four component analysis, it can be seen that the two slowest components with lifetimes of 1.6 ns and 3.0 ns have an emission maximum at 686 nm, while the two fast decays (28 ps and 196 ps) show a maximum emission at 720 nm.
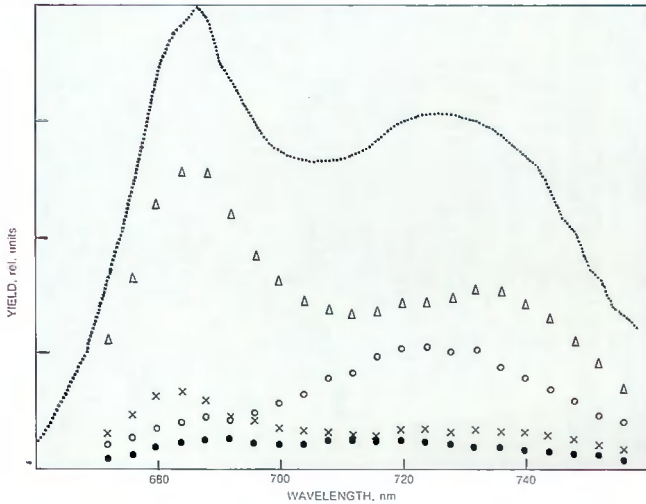
Fig. 25: The time-resolved fluorescence emission spectra of the individual decay components of leaves of spinacea oleracea (control) using a free running exponential model (x 0.884 ns; Δ 0.404 ns; o 0.1 ns; ● 0.024 ns).
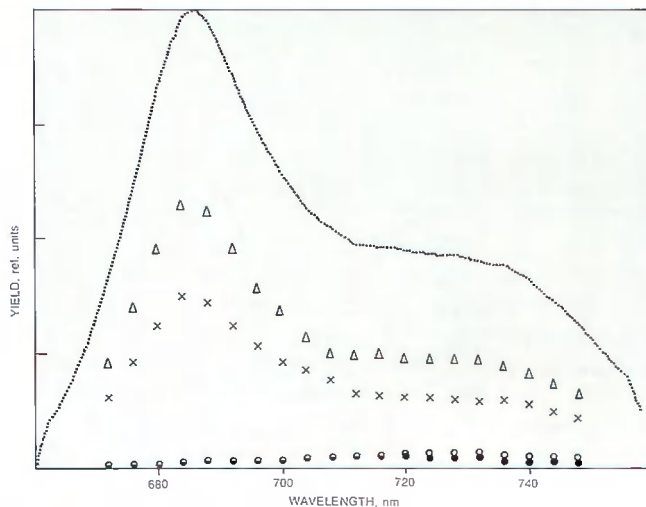
Fig. 26: The time-resolved emission spectra of the individual decay components of leaves of spinacea oleracea after blocking the photosynthetic electron transport by application of DCMU (x 3.011 ns; Δ 1.609 ns; o 0.196 ns; ● 0.028 ns).

From these results and those of a literature study it can be concluded

that the two fastest components are attributed to PSI while the two variable components are associated with PSII.

The first time-resolved fluorescence measurements on water-stressed and photo-inhibited leaves indicate that these selected stress conditions create an increase of the slowest lifetime component.

Time decay measurements on the blue fluorescence emission

Additional information about the physiological state of vegetation has been observed in the laboratory by investigation of the "blue" fluorescence, excited by UV light. A combination of these blue emission bands (λ EM = 450 nm and 535 nm) with the red chlorophyll emission was successfully applied to plant type identification and to differentiate between spruce needles of high and low damaged trees.

The first measurements about the origin of this blue emission has been investigated by means of time-resolved fluorescence measurements with the storage ring of SuperACO (Orsay, LURE, France). The work shows the heterogeneity of the blue emission of fluorescence in leaves and green algae. At least three different components (177 ps; 744 ps and 2.2 ns) with different emission spectra are present in leaves. Future work will concentrated on measurements of different plant components in order to find the origin of the different decay times of this blue emission.

Development of systems for time-decay measurements (JRC Ispra)

The system for time-resolved fluorescence measurements will mainly be based on ps-laser excitation and a streak camera detection system. Due to a delay in delivering both the excitation and detection sources, it was not possible to perform any measurements this year The system will be ready to work in 1990.

In collaboration with French colleagues it was decided to perform direct decay time measurements by use of a fast photomultiplier, associated with a storage oscilloscope having Gigahertz bandwith. At the moment this is being assembled in the laboratory of the JRC in cooperation with LURE.

For the calibration of the above mentioned techniques a laser diode based single photon counting system is being developed. The single photon counting technique has been extensively used in the past decade and defined deconvolution techniques have been developed, based on the known type of poissonian noise. This system should be set-up at LURE by the end of this year. After a check of the system and of the deconvolution programme (non-linear least-square programme using the Marquardt algorithm), the system will be assembled at the JRC.

Plant physiology

In order to interpret the time-resolved fluorescence the vegetation has to be described in terms of physiology. Therefore it was necessary to build up a laboratory for plant physiological work.This new laboratory should allow:

a) Production of plants under controlled conditions by installation of a phytotron with the possibility to regulate temperature, light intensity and relative humidity.

b) Vitality tests of the vegetation: (Fig. 27). The potential photosynthetic activity will be monitored via fluorescence induction kinetics, using the PAM-fluorometer. A gas exchange measuring system (CO_2/H_2O porometer) will be used to determine net photosynthesis, respiration, transpiration and stomatal conductance. These data will give the

complementary information about the actual photosynthetic activity of the sample. For an evaluation of the internal water potential, a Scholander pressure chamber will be used.

The different members of the LASFLEUR group agreed to install this instrumentation in each laboratory to have the possibility of comparing the results. For the JRC Ispra, all the instrumentation is available and will be equipped with additional hardware and software for a direct data acquisition and data handling. The overall laboratory will be completed at the end of this year.

Fig. 27: New Biological Laboratory for the definition of the physiological state of vegetation.

A part of the instrumentation was used in 1989 for the MAESTRO I campaign (Scholander pressure chamber) and for productivity studies on green algae (PAM-Fluorometer).

c) Design of an in-field instrumentation

For the definition of an in-field instrumentation it was necessary to quantify the emitted amount of the light which is absorbed by the plant and which is partly re-emitted in far-red chlorophyll fluorescence between 650 nm and 800 nm. The images that have been obtained for these quantities are represented in Fig. 28. The observed global saturated fluorescence in leaves of tobacco and philodendron is in the range of 0.2 : 0.3% at an absorption rate of 80-95%.

Development of a video computerized image analysis method

A system has been developed for non-distructive chlorophyll fluorescence measurements on attached leaves (Fig. 29). The system is based on an intensified CCD video camera, with which it is possible to record the intensity changes of the induced chlorophyll fluorescence emission (known as Kautsky-effect). The first recordings have been performed on tobacco plants.

Fig. 28: Image of transmission, reflectance and the emitted fluorescence of a philodendron leaf after excitation with a He/Ne laser (=632.8 nm).

Software to analyse these transients pixel by pixel is now being developed. The advantage of this technique is the possibility to obtain information about a whole leaf/plant without detachment. This method of recording the fluorescence induction kinetics was successfully applied in research in Germany and the USA on forest decline. These fluorescence parameters were used to measure the potential photosynthetic activity of the sample. With the new developed computerized video system it is possible to describe the whole leaf/plant. The system will also be tested for remote measurements.

Fig. 29: Layout of the video computerized image analysis system, developed at the JRC Ispra.

S/T SUPPORT TO COMMUNITY POLICIES

External Affairs (DG I): Study of the Northwest African Upwelling Area

a) Introduction

Coastal upwelling off Northwest Africa can be studied by remote sensing since the changes in surface temperature and pigment concentration caused by coastal upwelling are easily observed from space. The sensors of primary use are the Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA series of satellites and the Coastal Zone Color Scanner onboard NIMBUS-7. The latter has been inactive since 1986, however hundreds of scenes have been recorded and are waiting for scientific evaluation in the archives.

With the installation of AVHRR-HRPT equipment on the Maspalomas receiving station, a complete coverage of the Northwest African upwelling area with AVHRR data has been achieved since 1986. Since the NOAA satellites will be in orbit for several years to come, the AVHRR represents a very reliable and convenient data source for the study of the coastal upwelling phenomena.

The methodology for processing NOAA AVHRR images into maps of sea surface temperatures (SST) has been established during 1987 and 1988, and several time series of SST images are now available for analysis. During 1989 a series of SST images from 1987 have been analyzed with respect to upwelling and eastern boundary circulation. Included in the analysis are images of chlorophyll- like pigment concentration (CHL) and wind data. The analysis is summarized in section b) below.

Another activity that was carried out in 1989 was the comparison of simultaneous SST and CHL images, where the SST images were derived from NOAA GAC data and CHL images from CZCS data. This study is described in section c). Finally, section d) summarizes some data processing and software development activities that were executed during 1989.

b) Seasonal Distribution of Upwelling and Winds During 1987

As an example of the data material used in this study, Fig. 30 shows the SST on 27 February 1987 and Fig. 31 the corresponding map of the wind field.

In Fig. 30 coastal upwelling appears to be most intensive around latitudes of Dakhla (approximately 24°N). Between Cape Yubi and 25°N upwelling is moderate. The Banc d'Arguin southeast of Cape Blanc is considerably warmer than seen in other images during winter 1987. A warm water mass originating from the bank moves away with the coastal flow over the continental shelf. South of 20°N, Fig. 30 suggests no or only weak local upwelling activity at this time. Instead warm surface water with temperatures in the order of 22°C spreads over a large offshore area in the south and partially onto the shelf as well.
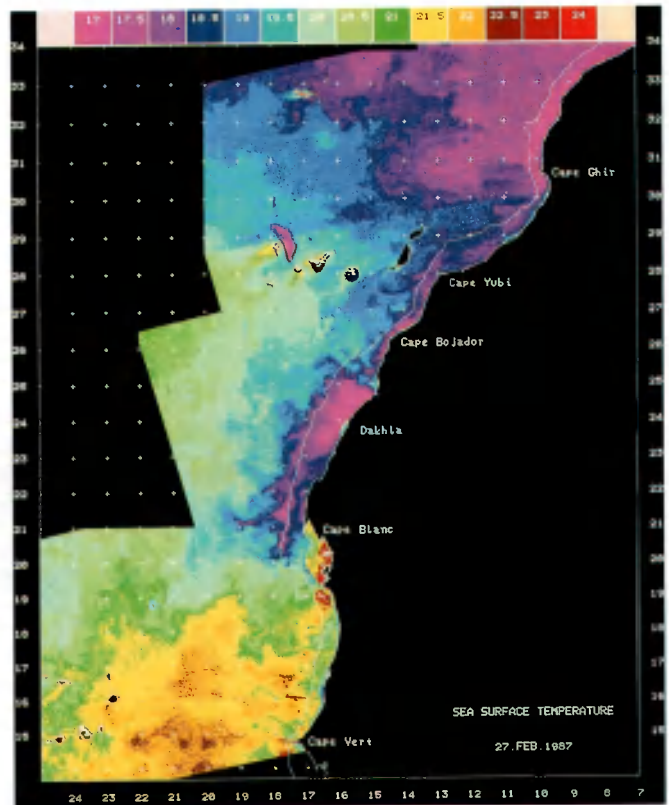
Fig. 30: Sea Surface Temperature (SST) on 27 February 1987.

It is observed that the trade winds (Fig. 31) are well developed south of Cape Yubi and accordingly upwelling should be expected along the whole coast including the shelf south of Cape Blanc. The absence of appreciable upwelling south of Cape Blanc on 27 February and the warming of surface waters inshore and offshore is apparently caused by advection from the south and southwest. The reason for this advection of relatively warm water, which moves oppositely to the trades towards the north and evidently encroaches upon the shelf, lies outside the upwelling are in the open tropical Atlantic. Most likely the spreading of the warm surface waters is a manifestation of the North Equatorial Counter Current which has advanced to the north at this time.

Similar interpretations have been carried out on images from spring, summer and autumn of 1987. The SST images clearly show the upwelling variability along the coast of Northwest Africa. The analyses of the daily wind fields are consistent with the spatial and temporal variability of upwelling as observed in the SST images. Additionally, several mesoscale patterns which have not been described in the existing literature are noticed in the images. This applies to the long warm water trails found in the wake of the Canary Islands and to the filaments of cool coastal water extending far offshore between 31°N and 32°N. Other unusual heating patterns are found on the shelf in the shadow zone of winds and currents south of Cape Ghir and in the bay
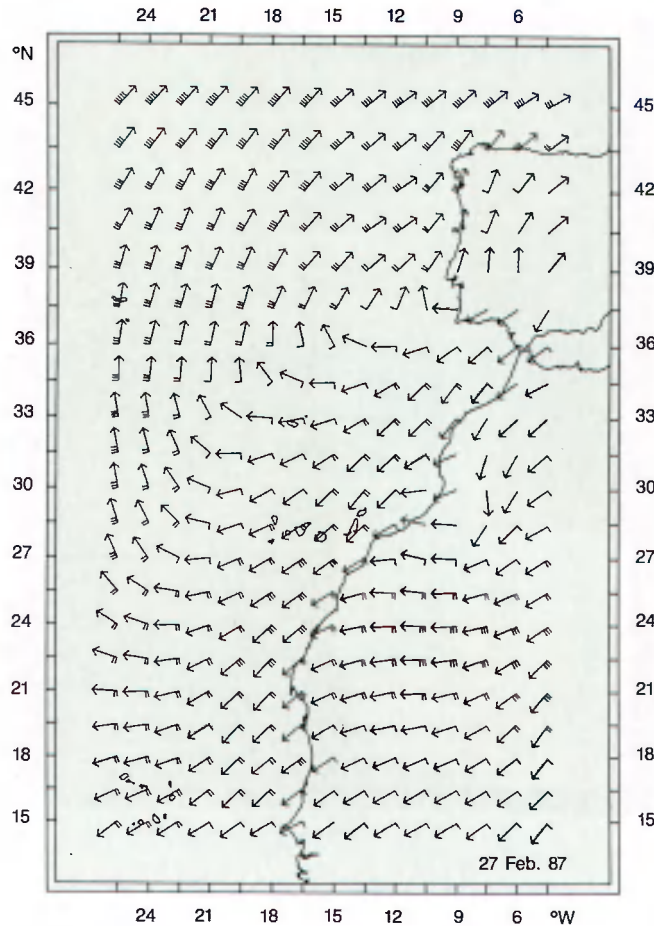
Fig. 31: Wind field on 27 February 1987.

inshore of the peninsula of Rio de Oro at approximately 24°N. Finally, the special hydrographic conditions on the shallow and mostly sheltered Banc d'Arguin are confirmed in the SST images by the particular temperature patterns observed.

c) Comparison of Simultaneous SST and CHL Images

Ten simultaneous CZCS and NOAA GAC images have been collected and processed into maps of chlorophyll-like pigment concentration (CHL) and sea surface temperature (SST), respectively. The images are analyzed with respect to:

– describing the relationship between SST and CHL in terms of similarities, discrepancies and spatial variability;
– identifying different water masses through the relationship between SST and CHL;
– interfering concepts of upwelling events based on the SST/CHL relationship.

The main results are most easily visualized from two sets of images, which probably represent two opposite situations during an upwelling event.

The 12 April 1984 images (Fig. 32): These images and the following ones, for 18 April 1984, are partly covering the same area and separated by only 6 days. However, the images show quite different SST/CHL relationship. On 12 April the CHL image is characterized by relatively high CHL at 26°N spreading offshore and ending in two phytoplankton-rich eddies. Assuming geostrophic balance in the eddies the rotational direction is cyclonic, maintaining the high pigment concentrations in the centre of the eddies. The diameter of the eddies is of the order of 100 km. Eddies of this diameter might have a lifetime of several weeks. The patterns in the SST image are very different. The eddies in the CHL image do not have an equivalent in the SST image, neither are there any signs of coastal upwelling in the CHL image. Just east of the Canary Islands very warm water is dominating, for which no obvious explanation is found.

On 18 April 1984 the CHL image (Fig. 33) still shows the offshore extension of relatively high pigment concentration, and additionally somewhat higher CHL in the near coastal region. The SST image shows coastal upwelling with SST at about 17°C thus an upwelling favourable situation must have developed in the 6 days since the previous image.

These two couples of images for 12 and 18 April 1984 illustrate very well the non-linear behaviour of the changes of pigment concentration and temperature in the surface. The 12 April images may represent a situation several days after the relaxation of upwelling, i.e. the SST of the previously upwelled water has been heated to the same temperature as open ocean water while CHL may continue to grow and may decay slowly in the upper layer. This represents indirectly the fact that the change of SST in the surface after cold water is brought to the surface is a function of time and the satellite tracks the "age" of the upwelled water, while CHL is a much more complicated function of environmental factors such as the availability of nutrients, light, grazing and the stratification of the water column.

The changes in upwelling conditions between 12 April and 18 April 1984 can be demonstrated from existing wind data. Fig. 34 shows the Ekman transport at 27°N, 15°W (location 3 in the map) calculated from the wind data from The European Centre for Medium-Range Weather Forecasts (ECMWF). The direction of the arrows must be compared to the orientation of the coastline for a correct interpretation of onshore/offshore transport. The first six days of April are characterized by upwelling favourable winds and Ekman transport. In the five days prior to 12 April the Ekman transport is directed onshore, thus unfavourable for coastal upwelling. The surface signature of coastal upwelling in the SST image is therefore absent. On 14 April the winds turn upwelling favourable and remain upwelling favourable for four days up to
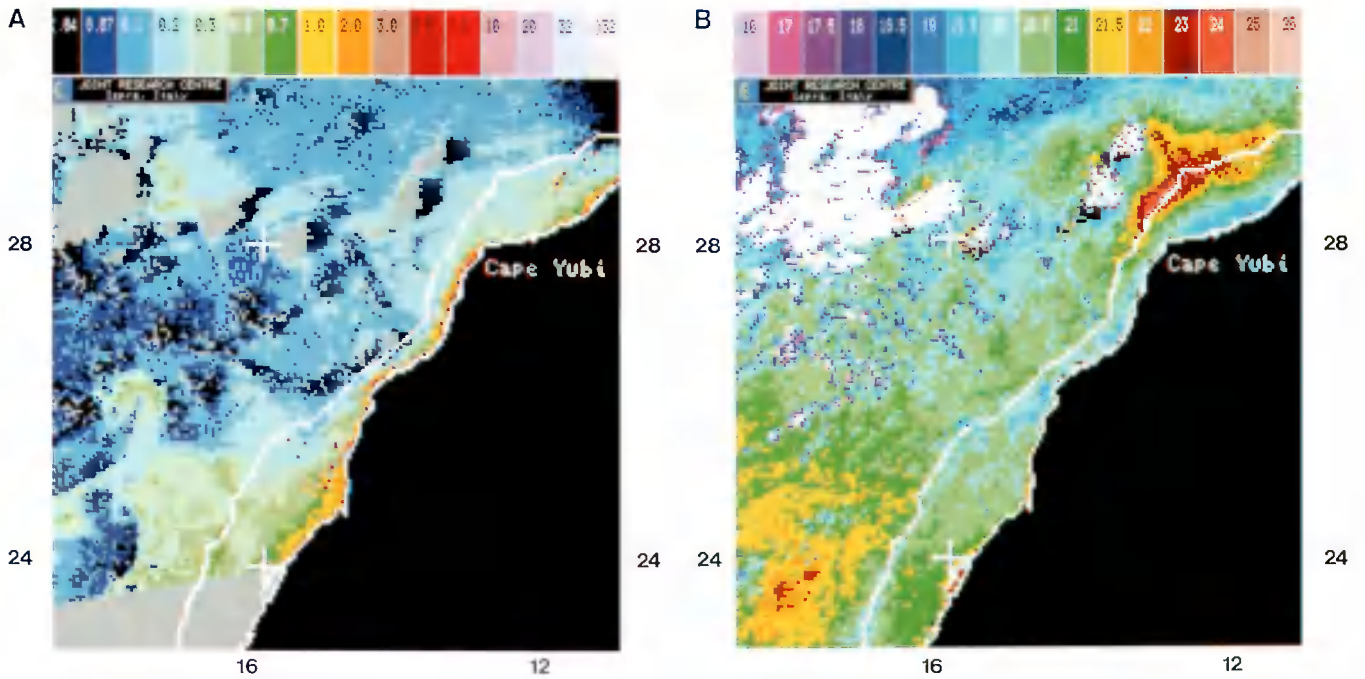
Fig. 32: Chlorophyll like pigment concentration and Sea Surface Temperature on 12 April 1984.
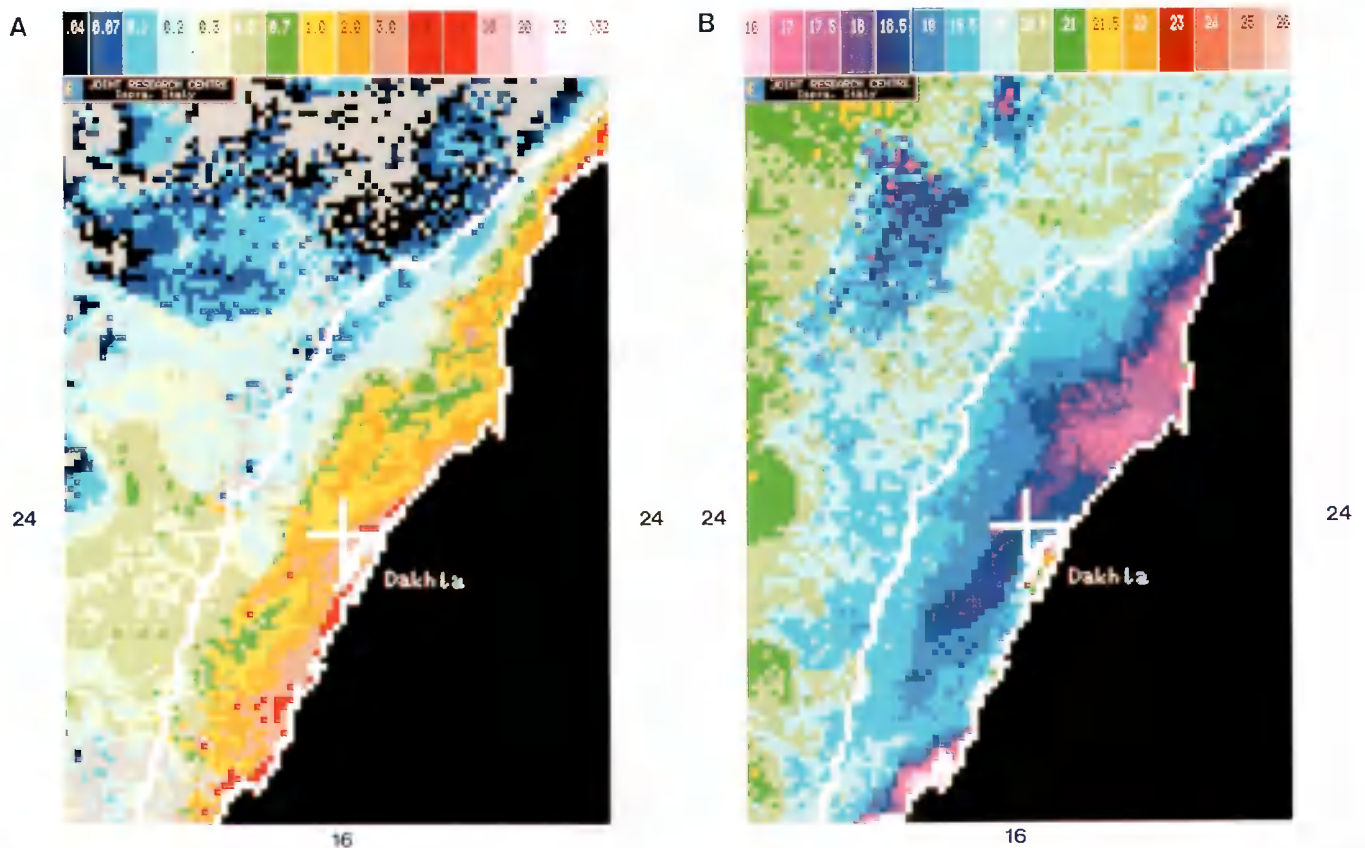

Fig. 33: Chlorophyll like pigment concentration and Sea Surface Temperature on 18 April 1984.
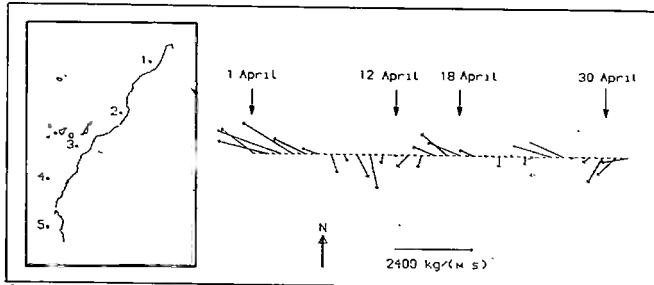
Fig. 34: Ekman transport at 27° N, 15° W, for each day of April 1984..

16 April. Therefore, the image from 18 April shows a well developed coastal upwelling situation.

d) Other Activities

The software for processing NOAA AVHRR images in the ERDAS environment has been finalized and is now in use.

The German research vessel Meteor was operating in the Atlantic Ocean off Northwest Africa from 12 January to 25 February 1989. As a part of an agreement between the University of Kiel and the JRC, NOAA AVHRR images were collected and processed for the study area simultaneously with the cruise to provide the scientists onboard the research vessel with near real time images of sea surface temperature. Apart from the near real time aspect, the collected images are presently used for a comparative study with the in-situ data collected by the scientists from the University of Kiel.

The processing of bimonthly AVHRR images has been carried out during 1989, continuing the image series which has been developed since 1987.

Likewise, the year 1989 has been covered with daily wind and pressure maps derived from the data from the European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, UK. This type of meteorological data has become increasingly important for understanding the manifestation and variation of coastal upwelling as seen in the satellite images. Notice, for example, the use of the wind data in sections b) and c) of this report.

A separate study has been carried out under contract with the Nansen Remote Sensing Center in Norway. The study provides a comprehensive overview of the application of remote sensing to fisheries worldwide, both for research and for operational purposes.

Common Agricultural Policy (DG VI) and Statistics Office (EUROSTAT) Pilot project "Applications of Remote Sensing to Agricultural Statistics"

In order to implement the Common Agricultural Policy the Commission of the European Communities must be able to monitor and control agricultural production.

It needs an informatic system which can:

- identify and measure, as fast and with as much accuracy as possible, areas under different crops (especially those which are subsidised by area);
- estimate regional production;
- estimate foreign production.

The principal arguments for applying remote sensing to the problem are that the technique:

- is insensitive to national boundaries and can thus provide objective information over the entire territory of the member nations;
- can provide information, using exactly defined methods, both on a continental scale and for much smaller areas;
- is based upon readily available space data.

The decision to launch the Pilot Project of Remote Sensing applied to Agricultural Statistic was formally adopted by the Council of Ministers on 26 September 1988. This pilot project is to demonstrate a methodology by which remote sensing could supplement, interpret and standardise data provided by classical techniques. The pilot project will develop the operational use of remote sensing and agro-meteorological modelling for agricultural inventory and monitoring. The key word for the project is "operational": the project is intended as a programme for putting known techniques into operation. By the time the project was formally launched the JRC had already been instructed by the Commission to take preliminary steps towards the project, and work started in April 1987 with limited staff.

The crops of interest to the pilot project were determined by the requirements of DG-VI (Agriculture)

Winter-Spring crops: Hard and Soft Wheat, Barley, Rapeseed, and Dried Pulses (which is also a summer crop);

Summer crops: Sunflower, Maize, Cotton, Tobacco, Sugar Beet, Potatoes, Rice and Soja.

The plan covers a period of ten years but is funded for five years (until the end of 1993). The Joint Research Centre has responsibility for the project but most actions are carried out by contractors in the Member States.

During the course of 1988, as the team has grown, (it now consists of 9 JRC scientific staff and two national experts), the main themes of the project were put into motion and during 1989 have developed rapidly.

The work of the project has been divided into 4 main and 3 support Actions.

The seven Actions are:

Action 1: regional inventories of crop acreage using a combination of ground observations and high-resolution satellite data;

Action 2: monitoring condition and development of vegetation on a continental scale using low-resolution satellite data;

Action 3: forecasting yield using **agrometeorological models** on a regional scale;

Action 4: rapid estimates of change in acreage and potential yield using high-resolution satellite data at sample sites throughout Europe;

Action 5: integrating data from remote sensing, modelling and conventional surveys to establish an **advanced agricultural information system;**

Action 6: a unified **system for collecting ground** data for the classification and interpretation of satellite data;

Action 7: long-term research into new systems (e.g. micro- waves) or software (e.g. expert systems) and the application of existing systems to agricultural monitoring through G.I.S. (e.g. the combination of image processing and spatial data bases).

a) Regional Inventories (Action 1)

The objective of this action is:

– to estimate areas under important annual crops in selected regions of the EEC
– to assess the possibilities of improving, both in cost and efficiency, a method that could be used by national or regional organisms.

The first activities of the project started with Action 1.

Using a feasibility study as a guide, five regions in Europe were selected for the project, the criteria being:

– reasonably flat terrain;
– high percentage of agricultural land use;
– wide differences in agricultural practices between regions;
– geographical dispersion;
– each region to be a contiguous area of some 20,000 square kilometres - corresponding to a regional scale equivalent to NUTS II. The five pilot regions in fact cover between 18,600 Km^2 and 26,200 Km^2.

At the end of 1987 a call for proposals was published for a study using high resolution satellite data, superimposed on classic ground data, to improve the estimates of the areas on which economically important crops are produced. The methods to be used in the field work and analysis were defined by the JRC. The contractors started work in the field in 1988.

The regions and contractors were:

Name	Areas concerned	Contractor
Bayern	Oberbayern Niederpfalz	GAF
Castilla y Leon	Valladolid Zamora	Hunting Aurensa
Makedonia	Kentiki Ditiki	BDPA BRGM ADK
France-Centre	Eure-et-Loir Loire-et-Cher Loiret	Aquater Sodeteg
Emilia-Romagna	Emilia-Romagna	Aquater

Methodology: Ground data

Within each region the land is stratified by criteria chosen by the contractor. The criteria used depend on the information available in each region, and typically include soils, slope, and principal land use. The sources include existing topographic and thematic maps and official statistical data. The number of strata developed by the contractors varied between 6 and 10. Within each stratum sample sites, or "segments", are chosen by stratified random sampling.

In detail, the method of locating the segments (known as area frame sampling) consists of conceptually dividing each stratum into a grid of cells whose size (700x700m or roughly 50Ha) corresponds to that of the segments. The grid itself is then considered as a set of contiguous square blocks of 16 cells by 16. Within the first such block a number of cells (usually 4) are selected at random. These 4 cells represent the first 4 segments. The identical pattern of 4 cells per block is then repeated over the whole stratum. A different pattern of 4 segments is repeated in each of the other strata in the region. The segments therefore cover just over 1.5% of the land surface of the region. The boundaries between strata are located so that no sample sites straddle any border.

The segments of the sample are then drawn on maps and aerial photographs, and ground teams visit each of the segments during the growing season. In Emilia-Romagna (Fig. 35) the segments were visited twice per year. In every segment in the sample the enumerator outlines on transparent paper the field or plot boundaries, roads, rivers and other features that he finds. He also notes the type of crop or other use made of each plot. About 10% of the segments are visited again by supervisors to check the quality of field work.

The area of each crop type is calculated in each of the segments. The area of that crop type in the region can then be estimated by an expansion estimator. The precision of the estimates, measured by the coefficient of variation (standard error divided by the estimate), is about 3% for the most dominant crops, and ranges between 5 and 10% for most of the important crops in each region.

Fig. 35: Thematic Mapper image Emilia Romagna (Action 1).

In theory, stratification of the area should increase the precision of the results, because it accounts for the natural variation in the percentages in the crops that one might expect to find as one goes from one stratum to another. In practice, the efficiency of the stratification can be calculated by comparing the variance found after stratification with that obtained without stratification.

The efficiencies of stratification for 1988 turned out to be lower than expected, which suggests that the strata do not correspond to local variability in agricultural practices. The images acquired in 1988 and the land use classifications that can be derived from the interpretation of the 1988 results will be used in future stratification of the regions.

Image Analysis

For each region the JRC requested complete satellite coverage of high-resolution satellite (SPOT and Landsat TM) data during the most appropriate period of each year.

Since satellite data acquired by different sensors or at different dates are not directly comparable, the boundaries of each image determine the boundaries of a new satellite-dependent stratum which cuts across the existing strata. Areas for which no imagery was acquired (as a result of cloud cover, for example) are considered to belong to a separate satellite- dependent stratum. This new stratification has a different efficiency (which one would expect to be lower) from the original one.

Within each of the segments the crop types are known from the ground work. In order to use the satellite data, at least 5 fields of a given crop type are selected within each stratum. The fields must be large (being represented by at least 150 pixels) and well separated. The radiometric characteristics of the various crops are determined using discriminant analysis and the entire image can then be classified on the basis of these characteristics. It is now possible to examine the relationship between the radiometric classification of the image with the ground data for the fields that were checked. Firstly, a confusion matrix can be established on the basis of correctly and incorrectly classified pixels, secondly for each segment it is possible to regress the proportion of pixels classified radiometrically as belonging to a given crop type against the number classified in the ground survey as belonging to that type.

For a given crop in a given stratum, the variance of the estimates from the regression is smaller than that from the ground survey. The ratio between them is called the efficiency of regression, which is equal to $1/(1-r2)$, where r is the correlation between ground-based and satellite-based estimates. An efficiency of 2 means that the same precision would have been obtained in the absence of remote sensing by sampling twice the number of segments. The efficiency of remote sensing is the combined efficiency of regression and the efficiency of the satellite-based stratification. This makes it possible to evaluate in economic terms the improvement brought about by remote sensing.

Results

Some crops are present in too few of the segments to estimate areas using remote sensing. Some crops, although present in many segments, were not on the list of crops of interest. Finally, for some crops it was possible to use remote sensing estimates only in some of the strata, and the ground survey estimates are used for the remaining strata.

The quality of the regression correction depends on the date of image acquisition much more than on which of the two sensors collected the satellite data. Landsat TM has more channels including one in the middle infra-red, and the scene size is greater (and hence there are fewer satellite-derived strata). On the other hand, SPOT has better

spatial resolution, which in the context of European field sizes, proves to compensate for the advantages possessed by TM.

For the contribution of remote sensing to be economically worthwhile, its efficiency must exceed a limit set by the costs of ground survey and image analysis. In general, even in the first year of operation of Action 1, these thresholds were reached over much of the regions studied.

For the forthcoming years, national or regional statistical offices will be more closely associated. This will help to optimize the methodology and to reduce the costs.

Conclusions

The results for this first year of semi-operational study show that agricultural surveys based on area frame sampling are feasible for medium-size regions in Europe. The methodology can be used anywhere, given aerial photographs and topographic maps of the area (at scales of 1:50000 or more).

The results are accompanied by a measure of precision, and based on objective observations. The use of remote sensing to increase the precision of ground surveys appeared economical in most cases but it will have to be tested for at least 2 or 3 years.

Several improvements are foreseen:

- more rapid results
- information on yield will be provided
- sampling strategy will be improved
- faster digitization
- clustering before supervised classification
- training fields from outside the segments to be used for the less common crops.

Internal research at JRC is addressing the problem of digitization and clustering.

b) Vegetation conditions and yield indicators (Action 2)

The project supplements the detailed data that it receives from high-resolution satellites with broad information from low- resolution satellites originally designed for meteorological applications. Action 2 depends largely on data from the Advanced Very High Resolution Radiometer (AVHRR) on board the National Oceanographic and Atmospheric Administration (NOAA) meteorological satellites in order to monitor the development of the vegetation during the course of an agricultural season (Fig. 36). The coarse spatial resolution of the AVHRR largely prohibits the monitoring of specific crops, but the data provide a frequent and synoptic view of growing conditions (Fig. 37). The AVHRR covers a swath 3,000 kilometers wide, and can provide data on almost any given target in Europe once or twice a day, cloud-cover permitting.
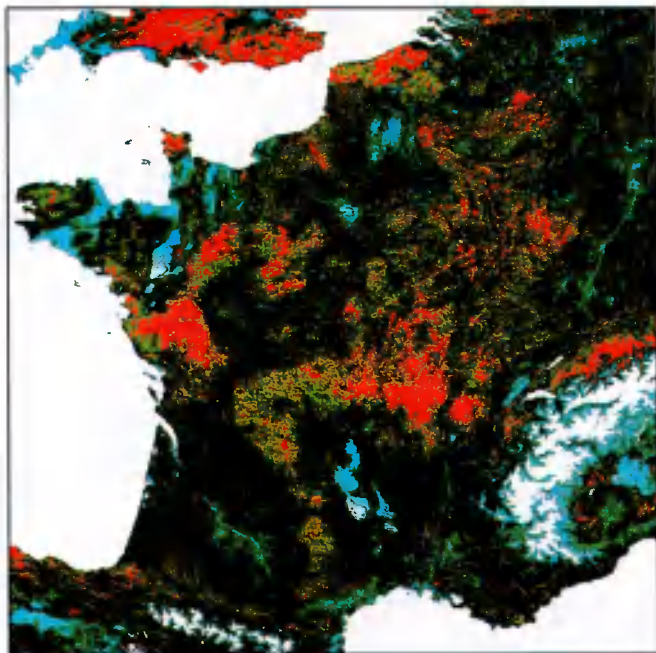
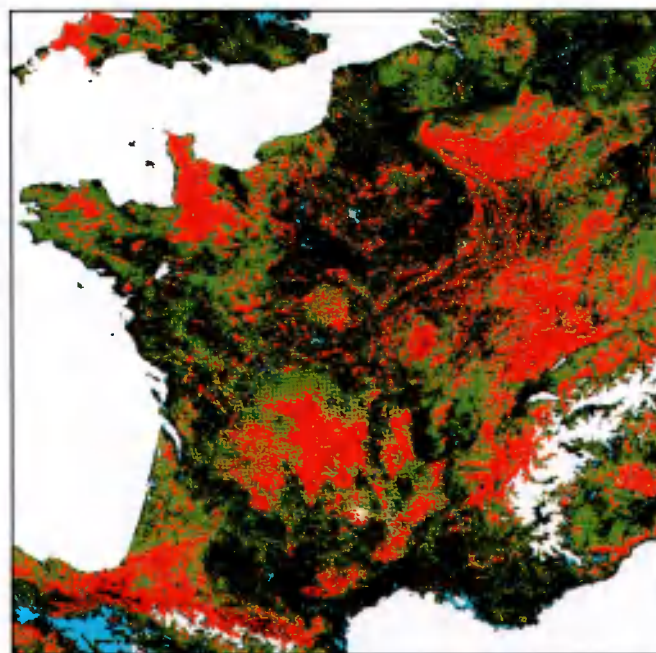**Fig. 36:** NOAA multi-temporal image analysis (March 1989).

Fig. 37: NOAA multi-temporal image analysis (July 1989).

In order to cope with this volume of data, and in view of the project's mandate to develop an operational monitoring system, the chain of

processing from raw data to final product must be as automated as possible. Since the project is to apply remote sensing to agricultural statistics, the final product is not images but statistics; images may be produced as illustrations of the spatial nature of the statistics, but it is not in any way the aim of the project to develop an image-production factory.

In February 1988, an Invitation To Tender (ITT) was published calling for studies using low-resolution satellite data for monitoring the condition of vegetation and for providing indicators of crop yield. Among other topics, the ITT included studies on:

- the use of low-resolution satellite data for monitoring crop development and providing early warning of unusual growing conditions;
- the use of such low-resolution data in conjunction with high-resolution data or with data from external sources;
- the application to agricultural monitoring of estimates made of surface temperature through data received from meteorological satellites;
- the possibility of using low-resolution data for land-use classification.

Seven contractors were selected to carry out the work:

INRA (F)
Silsoe (UK)
DHV (NL)
Logica (UK)
Hunting (UK)
INMG (P)
Telespazio (I)

None of the contracts has yet come to term, but results are expected in November and December of 1989.

A second ITT was published in October 1988 to define algorithms for preprocessing of AVHRR data and to provide a study leading to coefficients for the calibration of successive AVHRR instruments. Two contractors were chosen:

Tecnodata (I)
LOA (F)

The first meetings with these contractors took place in May 1989.

Acceptance of proposals for a third ITT ended on 22 March 1989. This led to a second contract with

Tecnodata (I)

which will provide the JRC with functioning software for AVHRR preprocessing. This contract started in October 1989.

The Institute for Remote Sensing Applications (IRSA) has agreed with the the European Space Agency's Earthnet Programme Office (EPO) that the latter will acquire AVHRR data at their receiving stations, and transform them by applying algorithms provided by

IRSA for calibration and for geometric and atmospheric corrections. EPO will then be responsible for distributing the product to all third parties except for the Services of the Commission, for which IRSA is the point of contact. IRSA will also provide specialized products.

The software used to transform the raw data to a distributed product is called the "Station HRPT Archiving and Reprocessing Kernel" (SHARK) and its several products are all in "Standard- family HRPT Archiving and Request Product" (SHARP) format. The corrections applied to the data by the SHARK software will be carried out by the ISRA's routines. The SHARK software will be distributed to the EPO "family" of ground receiving stations. Data leaving the stations will be catalogued at EPO's Frascati offices and will be in SHARP format. Various levels of pre- processing are envisaged for the distributed product.

c) Models of Yield prediction (Action 3)

Although the project does not contain the word "model" or "modelling" in its name, the prediction of agricultural yield using models is highly relevant to the project. Such models will be modified in such a way that remote sensing can be used to validate the results.

Purely statistical models function on the observed statistical relationship between yield and a variety of input data. This input data includes agriculturally important information such as rainfall and temperature, but the functional relationship linking yield to these parameters is not necessarily questioned. They work best when large areas and long time periods are considered .

In purely deterministic models, the detailed functioning of the plant is modelled in all its components - including root growth, biomass production, redistribution of nutrients within the plant, evapotranspiration etc. in order to predict, with given growing conditions, what yield might be expected. These highly detailed models work best on the single plant, or on a scale of one single homogeneous field of one single crop. Since they depend on a quantitative understanding of the minutae of the crop's reaction to any given input, and of precise details of the input itself, they are not suitable for modelling production over regions or nations, where it is impossible to collect all the necessary input data.

The models to be developed under the aegis of the Project are neither purely statistical nor purely deterministic, but are a third group containing some elements from both types and might be called "semi-deterministic"

The semi-deterministic model uses a third approach, for which the level of detail is in some ways a mixture of both the other approaches. For input it takes agriculturally important information, applies general, but scientifically sound causal rules relating crop growth to environmental conditions, and finally relates the result to yield - usually, although not necessarily, through statistical

relationships. The sort of input normally required by these models includes general water- balance, stress-degree-day, sum of temperatures, cumulative radiation, relationship between day-length and flowering, etc.

According to their design, semi-deterministic models can be well-suited to regional or national modelling.

In August 1988, a call for tender was published, intended to provide the project with a reliable data base containing historical crop, climatic and agro-meteorological information, to be used in creating a semi-deterministic model.

The project will also aim at the improvement of existing models and at their adaptation to more accurate operation on a regional scale using remote sensing. This will result in models which:

– are not crop specific in their analysis of the growing season;
– are crop specific in their quantitative forecasts of yield;
– take into account soil and meteorological data;
– use agronomically important variables as input;
– may use statistical techniques to validate results;
– lead to estimates of yield;
– operate on a regional scale.

These models should be flexible enough to accommodate:

– abnormal growing conditions, which should be flagged to allow the project team to issue warnings when necessary;
– a wide variety of climatic conditions, soil types and farming practices;
– adjustments to input parameters during the season, to reflect changing environmental conditions or, possibly to correct initial values chosen for the planting date, the length of crop cycle (probably expressed as a relationship between day-length and flowering), or other initial values.

The following major topics are being addressed by the contractors:

– potential evapotranspiration:
 University of East Anglia (UK)
 SGS-QUALITEST (F)

– agrometeorological inventories of main crops:
 Faculté des Sciences
 Agronomiques de l'Etat (B)
 I.N.R.A. (F)
 Scottish Crop Research Institute (UK)
 University of Edinburgh (UK)
 Association Generale des Producteurs de Mais (F)
 Meteorological Office (UK)
 Aquater (I)

– pollen capture for forecasting wine production:
 CEMAGREF (F)

– introducing fruit and wine forecasts into the OSCE's statistical model:
Faculté de Sciences Agronomiques de l'Etat (B)
The first results of these studies are expected during the autumn of 1989.

A second ITT was published in the second half of 1989. This ITT concerns non-crop-specific models. Contractors are being chosen at the time of writing.

d) Rapid estimate of areas and yield (Action 4)

One of the main action of the project is the installation of a system in which high-resolution satellite data is received at a pre-selected station, rapidly processed and analysed by a combination of computer and human expertise and the results published in a bulletin. Not only will this bulletin contain a quantitative measure of the degree of change and potential yield in an area by comparison with the situation at the same time the previous year, but also a qualitative statement concerning the condition and trend of the vegetation.

The project has designed a sampling strategy which will start with a few sites scattered over Europe, which by 1993 will have grown to 50 sites (Fig. 38).

This gradual increase is intended to allow the contractor to move from a brief introductory phase in which he establishes his methodology using a handful of sites, to a first interim phase (in which the sample will increase to about 20 sites) to enable him to improve the practical aspects of the operation, followed by a final interim phase (of 30 sample sites) in which he will become, to all intents and purposes, operational.

The choice of the sample sites was made in collaboration with a contractor (Aquater). The sample sites, each of 40x40 kilometers were located so as to:

– provide sample sites in each Member State;
– be located so as to be covered by Landsat on two separate orbits, to give the highest possible chance of obtaining cloud-free imagery;
– be located such that the number of occasions on which SPOT can view the target is maximised, bearing in mind that SPOT is able to view a target obliquely.

The first 10 sites were chosen to be in the U.K., Spain and Denmark. The second 10 are located in Spain, Portugal, Eire, Germany and Benelux.

Work has began in 1988 in the U.K., Denmark and Spain, (Fig. 39 and Fig. 40) to collect ground data in 16 "segments", or sub-samples within each sample site. This work consists of identifying the crops in all the fields in each segment, and getting estimates of yield in 25 fields within each segment. Each segment covers roughly 50 hectares, sides being 700 metres in length.

test region in 1988
test sites
test sites which should be analysed in 1988 (10)
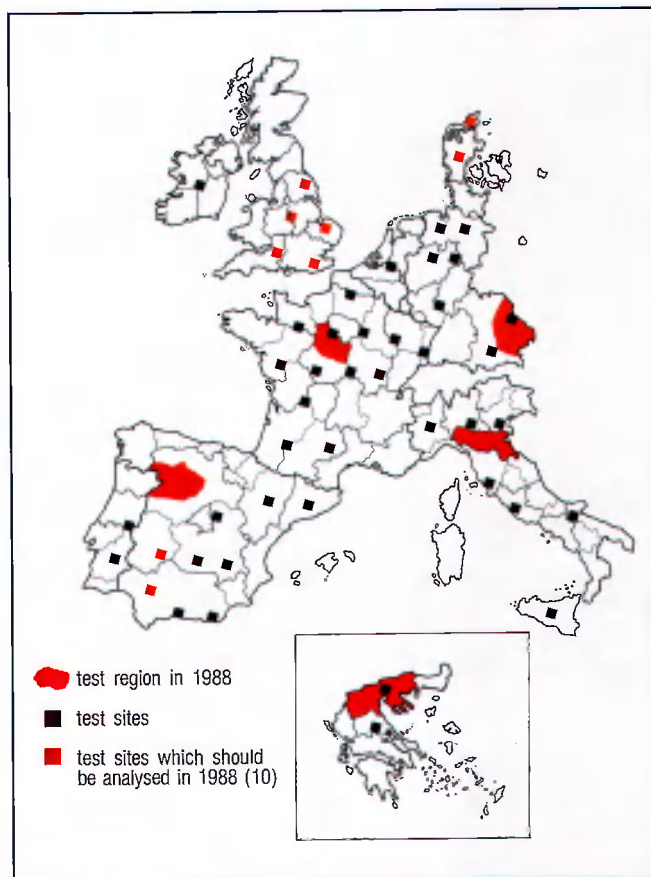
Fig. 38: Test sites for Actions 1 and 4.

The data gathered in the field sites will deliberately not be made available to the remote sensing contractor in time for his interpretation of the images, because in the operational phase of the work, the ground data will inevitably be acquired and interpreted too late for such comparison. Instead, the ground data will be used as an "a posteriori" check on accuracy, and will also enable the contractor to improve his technique as he gains experience.

The remote sensing part of Action 4 was the subject of an invitation to tender published in late September 1988. In this ITT the accent is on the rapidity of the assessment - it must be delivered to Brussels within a few days of the passage of the satellite - and on the lack of contemporaneous ground data to help in the interpretation of the imagery. The single successful bid was that of a French consortium led by SCOT which was chosen to carry out the three-year contract concerning the interpretation of the high-resolution imagery over the sample sites. Phase 1 of the contract, in which the contractor was to develop a methodology in close association with the JRC, started in January 1989 and came to an end in October 1989. Phase 2 is currently under way.
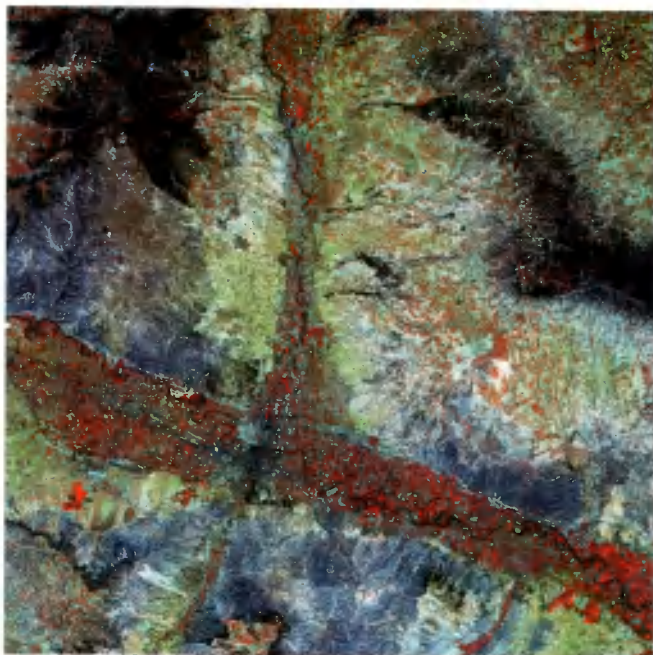
Fig. 39: SPOT high resolution image Zaragossa.
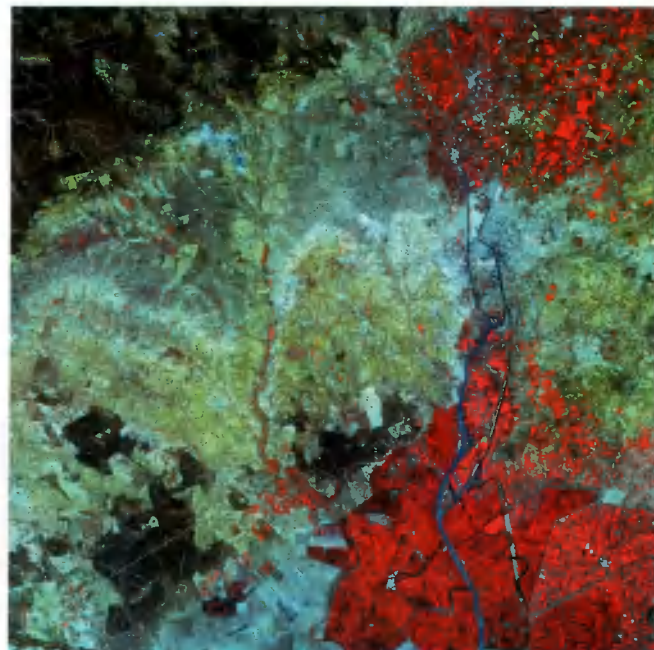
Fig. 40: SPOT high resolution image Sevilla.

e) Support Actions

Action 5: The aim of Action 5 is to test the degree with which the various methods complement each other: thus it may be that remote sensing of early spring helps in the determination of areas under spring wheat, while modelling provides a more accurate estimate of the yield of the crop, and both are made more precise by a judicious visit to one or two ground sites at a particular moment in the growth cycle. By its nature, the results of Action 5 cannot be anticipated until the project has gained considerable experience in all of the other Actions.

However, the Project will clearly have to move towards a fully operational Action 5 if it is to fulfill its mandate. This operational and integrated mechanism is called the "Advanced Agricultural Information System", and is the main aim of the Project.

Action 6: Each of the other Actions depends in part on getting data from the field, either because the Action needs the data as part of its input (1 and 5) or in order to check the estimates given by the technique (2, 3 and 4). Most of the ground work is carried out under Action 6 with the aim of standardizing methodologies. Most of the ground data will be collected using "Area Frame Sampling". In statistics, the term "Frame" is used to mean a list, possibly making up the entire population of objects of interest, for which some measure is to be estimated. The frame is therefore the list from which the sample is to be drawn. When one is sampling areas, rather than objects, it is possible to divide the target zone into as many sub-zones as one likes. The zone is then sampled by making an inventory within a selected set of the resulting sub-zones. This is area frame sampling. The number (and hence size)

and shape of the sub-zones into which the zone is divided influences the the precision of the result, and the number of sub-zones selected for sampling influences not only the precision of the result but also the amount of work required for the sample.

Action 7: Long-term research is needed to ensure that the Agriculture Project, with its preoccupation with rapid accession to operational capacity, is not left behind by advances in the related sciences. One obvious example it the problem posed by cloud, and the ability of radar to penetrate to the ground in all weather. Unfortunately the interpretation of radar signals from agricultural targets is still a matter of skill and insight, and it is obviously in the interests of the Agriculture Project to ensure that this interpretation is placed on a more objective footing. Similarly, many of the techniques used by the Project are based to a great extent on the educated decisions of experts and should therefore be susceptible to automation in an expert system. A third example of a technique that will rapidly benefit the Project is the Geographic Information System, which will be needed in Actions 3 and 5. The GIS will be adapted to receive remotely sensed data and turn it to agricultural needs.

The project has also been active in:

- implementing software to enable ground data collected in the converted rapidly into statistics;
- initiating discussions with other projects in the JRC with the aim of cooperating in developing the application of remote sensing to a agricultural statistics;

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– contributing to research into the use of radar and passive microwave techniques for agricultural remote sensing.

Development Policy (DG VIII): Monitoring of vegetation in tropical and subtropical areas

The Vegetation Monitoring Project has concentrated its research activities on the development of remote sensing approaches for the monitoring of vegetation changes over large areas. This choice has been guided by requests for specific information on the evolution of tropical environments as well as by the need to develop new methodologies which could address problems at more global levels than those currently investigated. New concepts for the preparation of the data thus had to be investigated. They mainly relate to the issue of scale.

The problem in regional or global studies is to reach an acceptable compromise between the scale (or resolution) at which the data are made available and the scale at which the phenomena under study are taking place. The practical ability to cope with large data sets of the kind currently required by the project also depends upon finding an answer to this scale problem. Given the growing size of satellite data banks it is increasingly relevant to raise the issue of the minimum data set providing the required information. The applicability of extending the results to large geographical scales (i.e from a site to the region, the continent and, eventually, the tropical belt) has also been an overriding concern of the project. This bias toward broadening remote sensing investigations toward the analysis of large changes in the terrestrial biosphere will hopefully provide new perspectives on earth observations.

a) Satellite Data Archive

Within the framework of the cooperative project "NASA-JRC AVHRR Remote Sensing Collaboration" the JRC has acquired daily 4km resolution satellite sensor data (NOAA AVHRR GAC) for the whole African continent from July 1981 to August 1989. These data are held on over 900 computer compatible tapes. Alternative storage media, such as optical disk, are being investigated.

The African continent is imaged by three or four part orbits running from 40°S to 40°N, and between 30°W and 65°E. Each orbit covers a ground swath 3000 km wide. Initially data from a window over west. Africa are being processed (3°N to 21°N, 1°E to 18°W), Fig. 41 shows an example from the dry season 1988. The processing involves the re-mapping of the raw data and the calculation of geophysical parameters.

Data from all five sensor channels are processed for each days cover. The data are re-mapped to a classical Mercator projection, using a cell size of 4 km. The daily five channel re-mapped product forms the basis of the processed data archive. The red and near infrared channels from the processed data are then used to create

Fig. 41: Geometrically corrected AVHRR GAC image for West Africa.

thenormalized difference vegetation index (NDVI). This has been shown to be a good estimate of photosynthetic activity, green-leaf area and green-leaf biomass, and is thus of considerable value in vegetation monitoring. The daily NDVIs are then composited over a ten day period by keeping the highest value at each geographic location. This has the effect of minimizing cloud contamination. Both the daily NDVIs and composites are added to the processed data archive. Data from 1st July 1981 to 3rd January 1985 have already been processed. Work on the 1988-1989 period is just beginning.

Preliminary analysis shows that strong seasonal patterns and inter annual change can be detected from the time series. Specific themes under investigation are the use of the NDVI composites as indicators of vegetation change related to rainfed crop production and vegetation condition as an indicator of the hydrological status of major river basins. The thermal channels of the time series are being evaluated as a means of monitoring bush fire activity and for identifying fronts where rapid change is taking place in vegetation cover. The same data set will be used in the framework of a global tropical deforestation assessment.

Full 1 km resolution data (High Resolution Picture Transmission HRPT and Local Area Coverage LAC) for West Africa have only been available on a regular basis since late 1986 when the Maspalomas ground receiving station opened in the Canary Islands. The coverage has just been extended with the opening of the Niamey facility in the République du Niger, but Southern and East Africa will remain uncovered until the Harare, Nairobi and Réunion receiving stations are fully operational (expected in 1990). In comparison 4 km (Global Area Coverage GAC) data for the whole African content are available

on a near daily basis from mid July 1981 to present. There is a need therefore, to determine the relative value of data availability, ease of handling and information content of the GAC archive against the loss of spatial resolution.

Fig. 42 shows contemporaneous 1 km (left side of the figure) and 4 km (right side of the figure) data from the southern border of Sierra Leone to the northern border of Guinea. The forest areas show as dark green tones and the savanna as yellows and pinks; the very bright red areas are indicative of active bush fires. Note how the general patterns observed in the HRPT image are preserved in the GAC image. Fig. 43 and Fig. 44 are north south transects obtained from these data. The main ecological zones can clearly be seen from both graphs.The transect runs from forest in the south (0 - 20 km) to the boundary of a recent fire (25 - 45 km), through the burned area (46 - 90 km) to the northern active burning front (95 - 110 km), then through open woodland (115 - 140 km) and into bushland savanna (141 - 250 km). The forest/fire boundary is clearly seen as a sharp fall in NDVI and a rise in the thermal channel (Ch 3), the burned area is characterized by low NDVI, and the northern woodland/fire boundary is clearly seen by the very high thermal channel values associated with active fires.

Note that the same basic trends for each graph appear in both the 4 km GAC and 1 km LAC data. This suggests that the GAC data are of considerable value for environmental studies of a regional nature, even though the NDVI at GAC resolution lacks the detail of the LAC data. Regional scale features are preserved, providing information on vegetation dynamics over important cover types like the savanna - forest transition zone. GAC resolution data provide a synoptic view of the entire West African region in a single 512 pixel by 512 line window.

Fig. 43: South to North transect from registered AVHRR (NDVI) 4 km GAC and 1 km LAC data; Sierra Leone Guinea, West Africa.
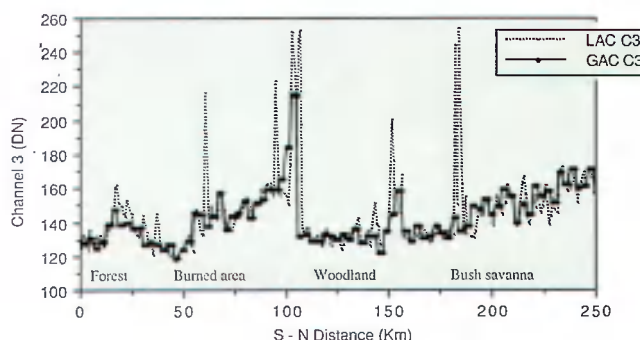
Fig. 44: South to North transect from registered AVHRR (Channel 3) 4 km GAC and 1 km LAC data; Sierra Leone Guinea, West Africa.

This combined with the existence of good time series, make these data well suited to environmental monitoring on a regional to continental scale. The increased spatial resolution of the 1 km data is of value in providing more accurate spatial information, but the 16 fold increase in data processing volume plus the lack of good time series may, in some cases, restrict its practical usefulness.

b) Monitoring of Agricultural Production

This theme of investigation is carried out in cooperation with the CILSS-EDF project "Monitoring of Renewable Natural Resources in the Sahelian Countries" located at the AGRHYMET Centre, in Niamey, Niger. Four countries are covered by the project: Senegal Mali, Burkina Faso and Niger. The objective is to develop remote sensing-based methodologies for improving statistical surveys, monitoring and forecasting of rainfed agricultural production. Two separate components are investigated; one for assessment of agricultural surfaces, and one for yield estimates.

Fig. 42: AVHRR 1 km (left side) and 4 km (right side) imagery; Sierra Leone Guinea, West Africa.

Agricultural Area Assessment

The JRC has made technical proposals to the CILSS "Monitoring" Project for the use of remote sensing techniques in the elaboration of a sampling frame adapted to the specific conditions of the Soudano-Sahelian agricultural production. These methods are now being evaluated on a region of about 300,000 km² in Mali. A PC-based software is being developed to allow the analysis of statistical significance of observations based on the proposed methodology. It will help statistical sampling by giving a priori assessments of surface measurement accuracy with respect to the number of field observations, the spatial organisation of the landscape and the size of the remote sensing sample.

Yield Monitoring

Special attention has been devoted to the application of remote sensing data for yield assessment. The method under development is applied to the whole study area, that is all parts of the four countries where rainfed agriculture is found.

1) Empirical Approach

Yield information for millet and sorghum, the main foodcrops of the region, was collected from the official agricultural surveys for 1984. This year was characterised by poor growing conditions due to bad weather, but it was the only one for which data were available for all countries. Production figures are provided by administrative units whose size is about 10,000 km² in size. At that geographical scale, no difference was observed between millet yields and sorghum yields. It was thus justified to use average regional values.

Weekly vegetation indice derived from AVHRR GAC data were obtained for each of the 85 selected administrative units. The comparison between observed 1984 yields and NDVI showed a strong statistical relationship (Fig. 45) from mid August and to the end of September. During this period about two-thirds of the grain yield variability in the four countries can be described by the NDVI alone, either integrated since the start of the growing season or considered as a quasi-instantaneous measurement. The best correlation appeared more or less four to six weeks before the
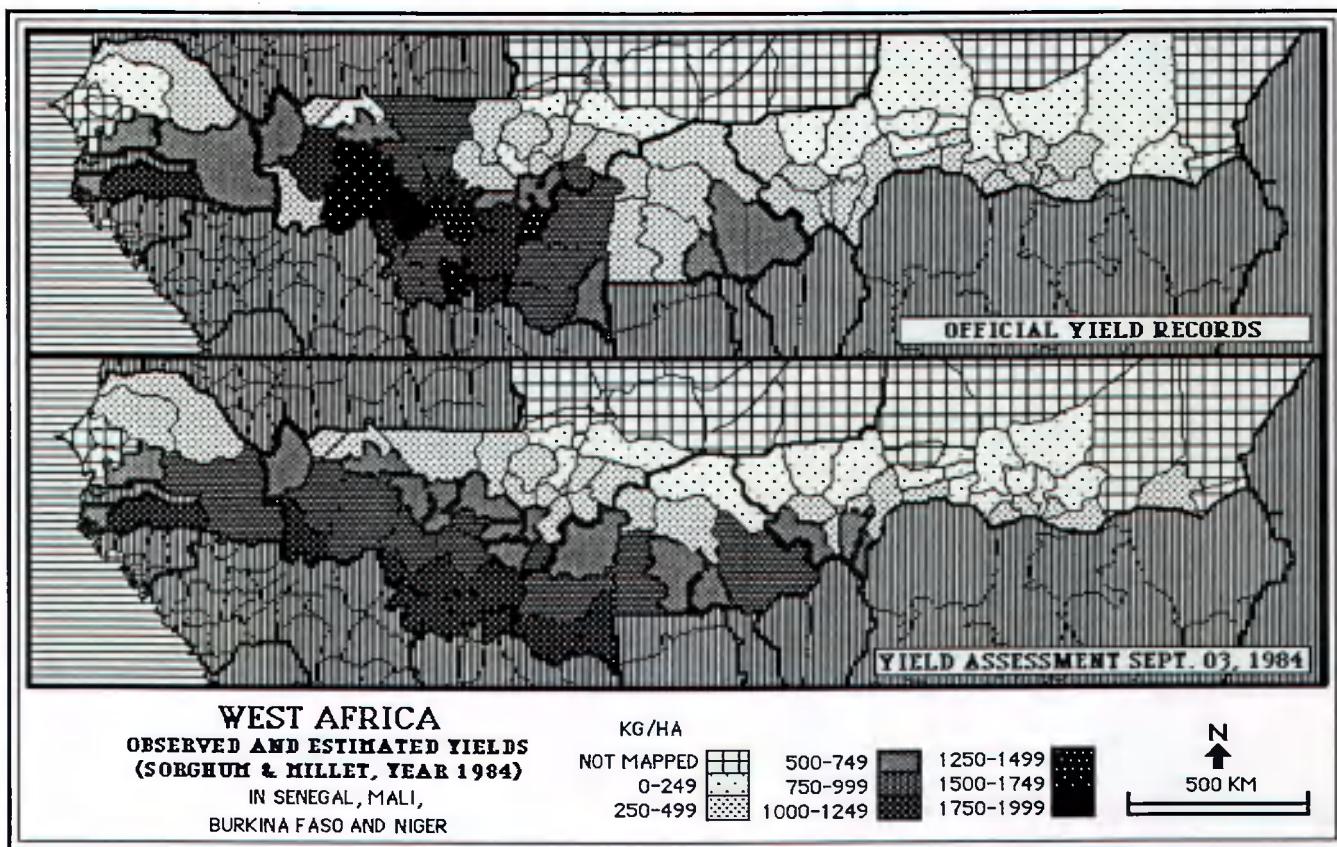
Fig. 45: Comparison of observed yields in 1984 according to official production figures with assessed yields from an empirical regression model.

beginning of the harvest. Data are now being collected to check the year-to-year variability of the relationship.

2) Deterministic Approach

The possibility of using a modellistic approach in establishing the relationship between NDVI and yield has been investigated. The model used in this study basically considers the NDVI as a measurement of the photosynthetic activity of the vegetation. It takes into account the amount of incoming solar radiation useful for photosynthesis, a coefficient of transformation of the energy into biomass, and the ratio between grain and that part of the biomass actually able to intercept the light for photosynthesis.

The analysis of SPOT data together with crop cover measurements made with large scale air photographs taken from ultralight aircraft showed that it is possible to calibrate remote sensing NDVI values in terms of amount of light intercepted by the vegetation without use of specific ground measurements (Fig. 46 and Fig. 47).
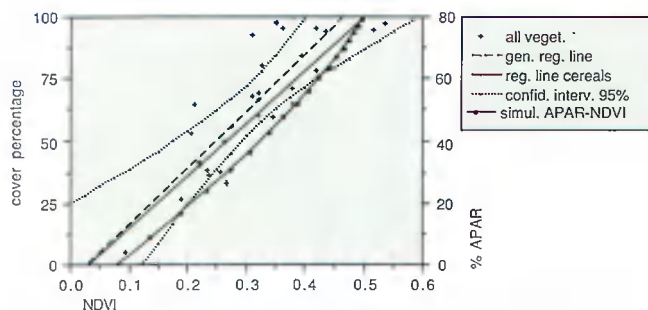
Fig. 46: Relationship between NDVI, cover percentage and percentage of light absorbed by plants for photosynthesis (APAR.) NDVI is derived from the SPOT image shown in Fig. 47, cover percentage was obtained for a series of fileds from enlargments of air photographs. APAR was estimated using Kumar's model (1988).
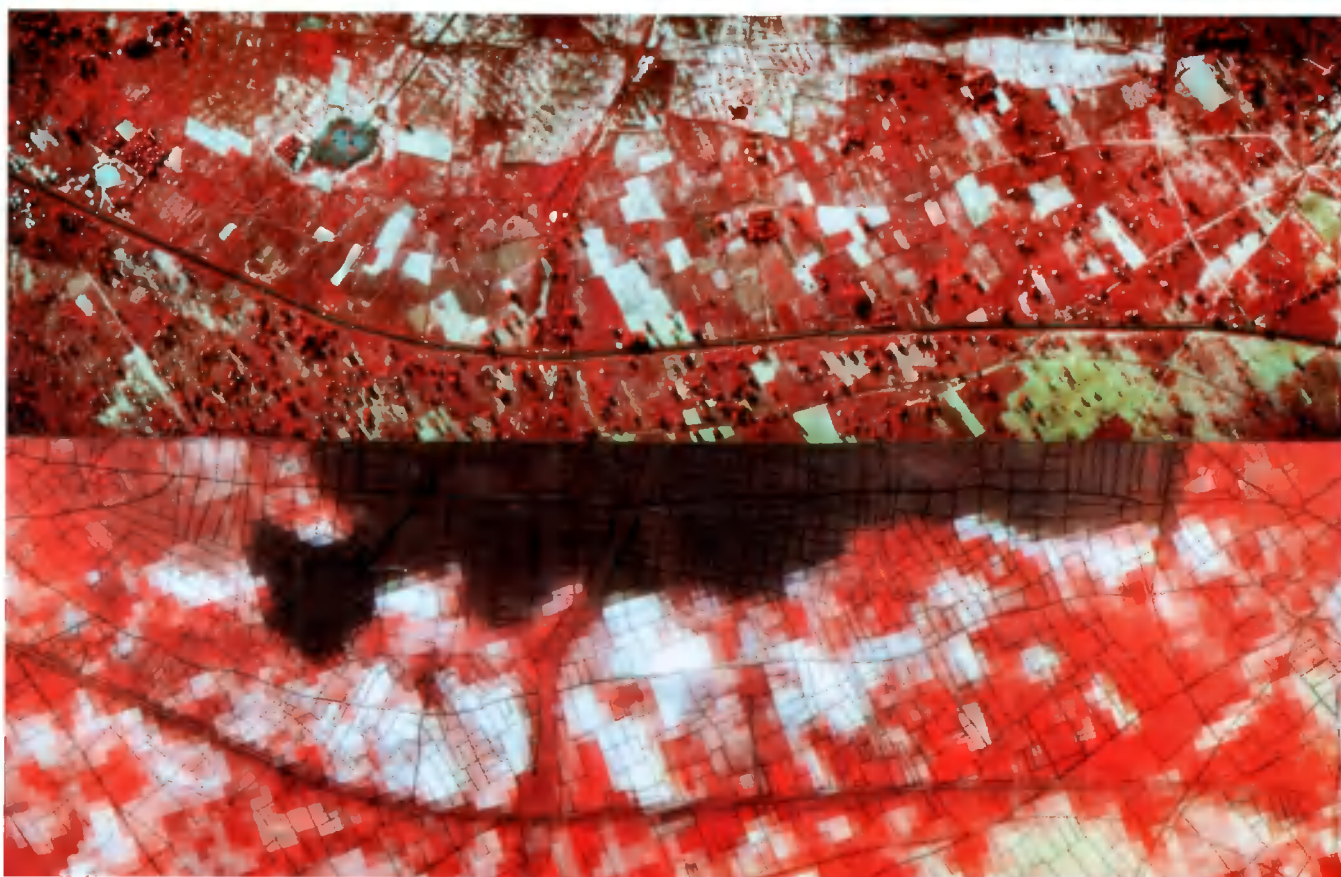
Fig. 47: Mosaic of infra-red false colour photographs taken with a 70 mm camera mounted on an ultra-light aircraft. Original scale: 1/3750.
Below: SPOT image of the same area and same period (9 Oct. 1986).
The cadastral map derived from the photomosaic was superimposed to the SPOT image to allow extraction of digital values on selected fields.
Total lenght of the area: + 3 km.

The incoming global solar radiation has been found to be sufficiently stable during the two main phenological stages of the growing season (vegetative and reproductive phases) and between sites to be considered as a constant factor in the equation.

The straw-to-grain ratio has been found to be equivalent for millet and sorghum, and poorly sensitive to the site (soil and topography). An average value has been defined. The year-to-year variability is now being analysed.

The application of the model to the NDVI data was reasonably successful (Fig. 48) The average yield value was correctly assessed. The discrepancies which appear for extreme values are linked both to specific ecological conditions and to the poor spatial resolution of the remote sensing data. In some regions where the agricultural fields are limited to small area with good water conditions, the average NDVI under-estimates the state of the crops. In others, where the natural vegetation is denser and has a longer growing period than the crops, the cultivated area often shows a lower biomass density than natural vegetation, and the average NDVI over-estimates the state of the crops.

The analysis of one-kilometer AVHRR data showed a slight, but significant, difference between NDVI measured on agricultural and non-agricultural surfaces. In the Sudanian zone the agricultural area NDVI s are usually lower than in the non-agricultural areas, but this trend may change during the season, especially at the very beginning of the dry season, when fires can appear in the savanna, while some vegetation is still green in the fields. Also, during that period, apple-ring trees (Acacia albida) start greening in the agricultural domain, while tree foliage is usually senescent in the savanna.
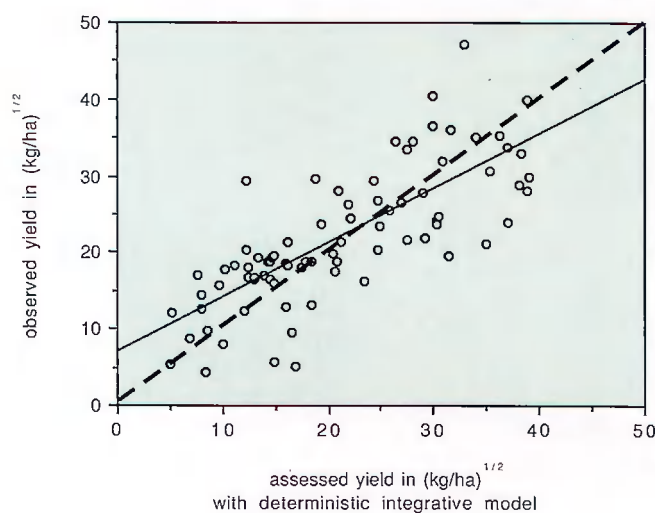
c) Monitoring Environmental Conditions in Large Watersheds of Western Africa

The constant degradation of West African watersheds has important consequences for the water resources of the region. Vegetation conditions represent a major determinant of the status of hydrological basins in terms of water yield. Previous work, based on the analysis of Landsat-MSS imagery, has allowed an assessment to be made of the state of the vegetation cover of several sub-basins of the Upper Niger river in Guinea. Areas where the evolution was critical have been identified; such sub-basins have been proposed as priority areas for the Commission Programme "Aménagement des bassins versants types en Guinée: Fouta Djalon et Hauts bassins du Niger". This work has shown that in order to have a real impact, the monitoring of environmental conditions of river basins has to be done 1) on a regional basis 2) at a time interval which is incompatible with the availability of Landsat or SPOT imagery. In order to be able to monitor seasonal changes of the vegetation canopy of large river basins of West Africa, the work has been oriented towards the analysis of NOAA-AVHRR data. The thermal data of the AVHRR sensor have also been used for evaluating the dynamics of bush fires, one of the main agents of vegetation degradation in this part of the world.

Study Area and Data Processing

In order to take into account the wide range of ecological situations found in the area, five windows (250.000 km^2 each), have been selected in the transition zones between the soudanian, sahelian and tropical environment (Fig. 49). These areas include watersheds of rivers flowing North towards the Sahelian region and South towards the humid tropical area on the Atlantic Ocean. The 21 watersheds selected for the study contribute to the water resources of the following countries: Sénégal, Mali, Guinée,

Fig. 48: Comparison of observed yields in 1984 according to official production figures with a deterministic model. The general average is correctly estimated, but bias appears for extreme values.
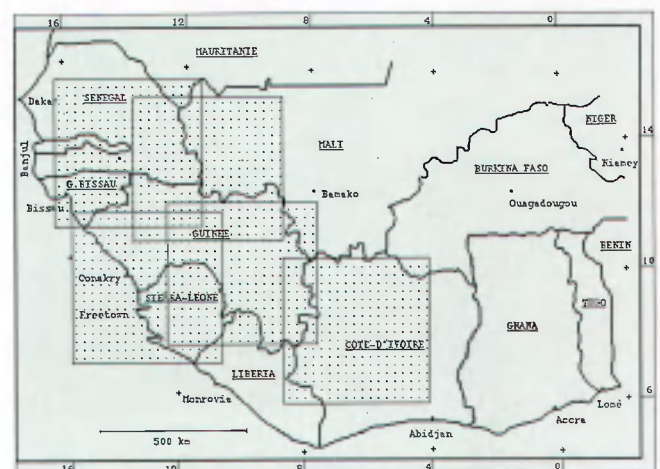
Fig. 49: Location of the five HRPT (High Resolution Picture Transmission) 512*512 pixels windows selected for the watershed-study.
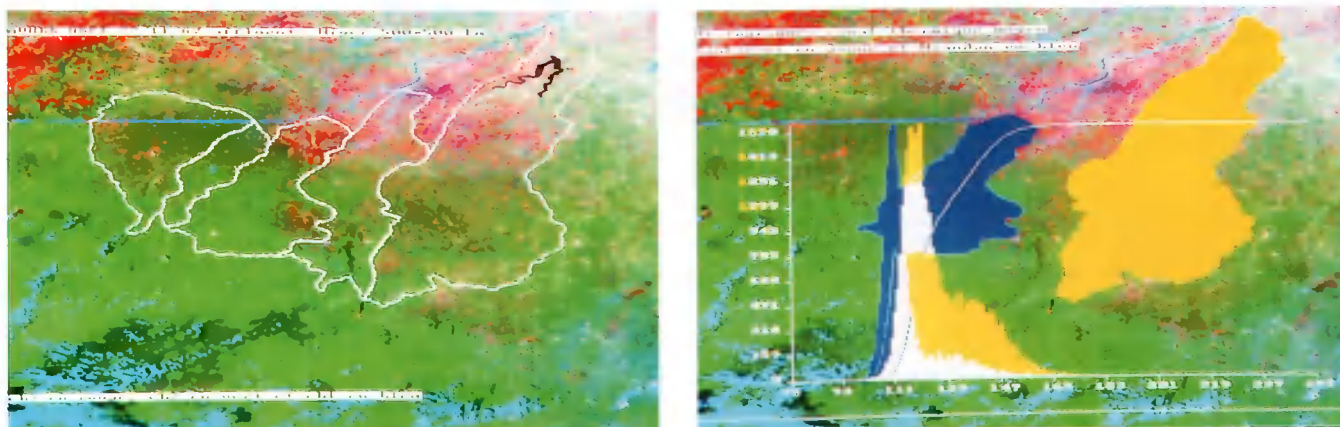
Fig. 50: Image 1: Limits of the five basins contributing to the Niger river, at the border between Guinea and Mali.
Image 2: Histogram distribution of DN value in AVHRR ch. 3 for two tributaries of the Niger river in Guinea.

Guinée Bissau, Gambia, Sierra Leone and Ivory Coast. The limits of the 21 river basins were extracted from a 1 to 1,000,000 topographic map, digitised and divided into five data sets corresponding to the five AVHRR windows. Each graphic file was then registered to the corresponding AVHRR window using manually defined ground control points. (Fig. 50). The first AVHRR data set used for this regional monitoring covered the 1987/1988 dry season, with a monthly scene from November 1987 to April 1988.

Monitoring the impact of the dry season on the vegetation cover of the studied river basins:

1) General trend of the vegetation canopy status
This trend has been characterised using two indicators: the spectral behaviour in the thermal domain and the changes in NDVI.

The first thermal channel of the AVHRR sensor (Ch 3: 3.55-3.93 μm) is sensitive to radiation emitted by the surface (linked to the radiative temperature), and to a lesser extent to reflected radiation. This double sensitivity is very useful for discriminating between vegetated and non-vegetated surfaces, and for the detection of localized heat sources such as bush fires. These characteristics make channel 3 well suited for studying the effect of the dry season on the vegetation canopy. Moreover, the NDVI, as derived from channels 1 and 2, is recognized to be a very good indicator of vegetation density and vigour.

During the dry season there is, with time, a shift in the distribution of the histograms in AVHRR channel 3 toward high levels of radiance, (expressed here in DN values) and a progressive increase in the number of saturated or near saturated pixels (D.N. 255) (Fig. 51). This evolution reflects a generalized warming of the river basin surface. The tendency is related to the progressive drying of the environment. Changes are marked in three different ways: 1) decrease in green

vegetation density and thus disappearance of evapotranspiration cooling 2) increase of bare soil surfaces with a consequent increase in air temperature near the surface 3) decrease of soil surface humidity. A more quantitative analysis would require calibration of the thermal data in order to obtain surface temperature, or at least brightness temperature; ongoing work is oriented towards this calibration process.

The appearance of saturated values in AVHRR channel 3 is also partially linked to bush fire activity. The interest of such observations is not so much related to the evolution of the drying process (such an evolution was expected even without access to remote sensing data), but in their regional dimension. Such a dimension allows us to take into account a wide range of environmental conditions.

It is possible to discriminate, within the general trend observed, specific evolutions from one watershed to another. These are due to the combined effect of vegetation type and climatological zoning. Finally, interannual monitoring of the basin should allow the detection of major changes in vegetation type and will therefore improve the "interception-evapotranspiration" module of existing hydrological models.

Two points must be stressed in the observed evolution of the vegetation index:

− The NDVI values, computed from the AVHRR data, are very low; most of the time lower than 0.25 in the wet tropical area, 0.20 for the Niger tributaries which are in the soudanese zone and 0.15 for the Senegal tributaries, in the sahelian part of the studied area. The possible interference of aerosols in the atmosphere must be seriously considered. Here again, the main interest is in the effective regional dimension of the monitoring approach.
− With time, the shift in the distribution of the histograms toward high levels of radiance in the thermal channel is coupled to a shift

61
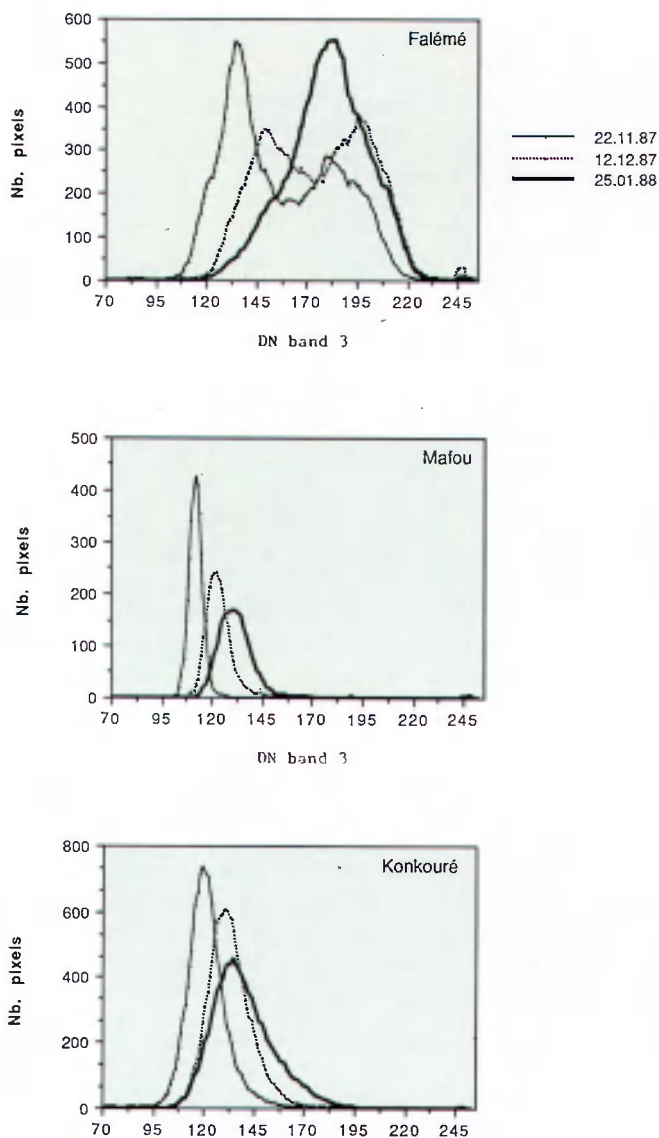
Fig. 51: AVHRR band 3 histograms for the Faleme, Mafou and Konkoure river basins.

towards low NDVI values. As already mentioned above, the rapid warming is due in large part to the decrease in vegetation density and evapotranspiration activity with a consequent decrease in NDVI values.

2) Bush fire activity

The warming of the environment, detected via the thermal data, is accompanied by a progressive increase in saturated, or near saturated pixels (DN >255 in AVHRR channel 3). Such occurrence of

saturated values is partially linked to bush fire activity. The analysis of AVHRR data has shown the possibility of monitoring:

- the intensity of bush fires and their spatial/temporal dynamics;
- the specific burning calendars of the watersheds according to the main climatological zones (soudanian, tropical and sahelian).

The ability to characterize such an important agent of environmental degradation will be a major step towards effective environmental monitoring for the river basins in this part of the world.

The work performed during the reported period clearly shows that the monitoring of seasonal changes of the vegetation canopy status of large river basins of West Africa is feasible. The regional dimension of the monitoring process makes it usefull for providing input data to hydrological and climatological modelling.

At this stage of the work, three actions or research lines are investigated:

- choice and test of criteria to quantify the degradation process. The temporal changes in spatial variability, as seen on the NOAA-AVHRR documents, could be one of these criteria
- building of a regional data base geographically referenced to river basins for West Africa
- introduction in hydrological and climatological models of the data derived from the analysis of the NOAA-AVHRR time series, in order to give a hydrological meaning to the changes occurring in the environmental conditions of some large river basins.

Support to the DGVIII Regional Programme

In parallel to the specific research, scientific and technical advice has been given to General Directorate VIII of the Commission for the Regional Programme "Aménagement de bassins versants types du Fouta Djallon et des Hauts Bassins du Niger en Guinée".

d) Tropical Deforestation

Under the pressure of an expanding population and of a growing demand for timber the tropical forest domain is submitted to intense pressure leading to its sometimes radical transformation. The phenomenon is general throughout the tropical belt and even if it is evident that some regions are being deforested faster and more intensively than others the process will eventually affect the whole biome. Given the trend observed during the last ten years, and barring drastic changes in forestry policy, it can be said with some certainty that the tropical forest biome will not long continue to exist in its age old ecological integrity. The implications are numerous and far ranging. Impacts will be felt at local (i.e soil degradation, habitat destruction) to global scales (i.e climate change). The evaluation of those possible impacts is, however, still fraught with difficulties. They stem mainly from the lack of understanding of the physical linkages between the

forest cover and other parameters of the environment; in particular, we have to recognize our inability to expand the knowledge acquired at local scales to processes taking place at more global scales.

There is, therefore, a need to develop remote sensing approaches to cope with the various scales of the deforestation process. At local scales, research has established that accurate assessments of land cover changes can be obtained. At the other end of the spectrum, it has been shown more recently that low resolution and global data of the type provided by the AVHRR instrument of the NOAA satellites can also be used to carry out regular assessments of tropical deforestation. The research of the Vegetation Monitoring Project has concentrated upon this last objective. The perspective has been to improve upon methodological approaches for monitoring tropical forests, to link this research with efforts carried out by other research teams and to develop an overall procedure for carrying out a truly global tropical forest monitoring exercise.

The current research has concentrated on West Africa and also in a more preliminary fashion, on Southeast Asia.

The main results of the analysis of West Africa are summarized as follows:

– A regional stratification of the West African subcontinent has been achieved using the AVHRR vegetation index and thermal patterns.

The large zones identified correspond closely to biogeographical units as reported on vegetation maps. The seasonal movement in the transition areas identify the regional ecotones. One of the objectives of the research is to produce methods which can be applied throughout the tropical belt, a stratification based on similar criteria has been attempted for Southeast Asia.

– An image based classification of vegetation is proposed to link the gap between standard vegetation classification and remote sensing information. The vegetation index, thermal data and fire patterns contribute to the definition of the retained classes. As large scene variability is a characteristic of the AVHRR data, a blanket classification algorithm cannot be envisaged. Two alternatives have been considered: selection of a "best date" for classification and, second, temporal compositing of classification results obtained on series of images. The work will lead to a map of forest-non forest formations at the subcontinental level (Fig. 52 and Fig. 53). The verification of such a regional map obviously present enormous difficulties.

– Secondary forest formations are dominant in the so-called "forest domain" of west Africa and they are the site of most of the human disturbances. The transition between the original moist forest and the surrounding secondary formations has been studied in a seasonal perspective in order to identify the optimal period (=period of higher contrast) for forest identification. The characteristic
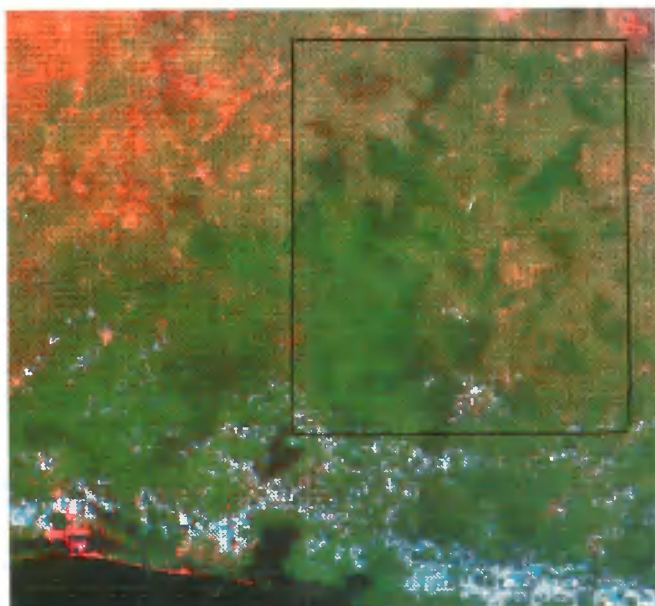
Fig. 52: Subset of an HRPT AVHRR image of 13-1.87. The color composite prepared using the CH3, 2 and 1 (printed in red, green and blue, respectively) shows in dark green the remaining forest blocks of Ghana. The drier savanna as well as intensive land occupation areas are shown in orange to red color because of their warmer surface temperature (see Abidjan in the lower left corner). Clouds are in white and are found, as usual, over the coastal strip.
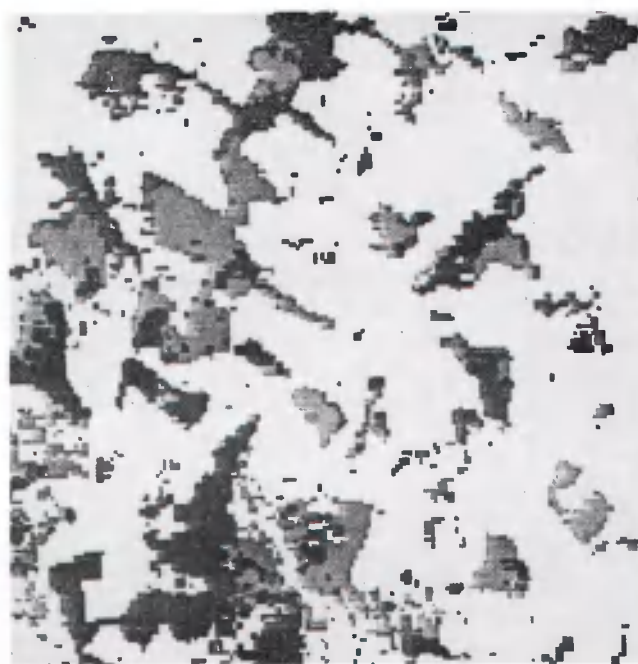
Fig. 53: Results of an unsupervised classification (automatic clustering) of a subset of the scene above for forest - non forest land cover mapping. The undisturbed forest is represented in grey, disturbed forest is in black. The remaining of the area is occupied by a mosaic of secondary regrowth, degraded forest and agricultural fields.

decrease in vegetation index (because of strong near infrared radiation capture) over the original forest canopy is used as a first criterion of discrimination (Fig. 54.). Thermal contrasts are seen to appear only much later in the dry season when the seasonal manifestations of the secondary vegetation phenology is at its peak.

– The appearance of fire in the secondary vegetation surrounding the forest blocks has been monitored. The data currently available (87,88,89) show the occurrence of burning late in the dry season or early in the rainy season. Annual patterns are established in order to assess if such a trend is related to the current intensification in land utilization.
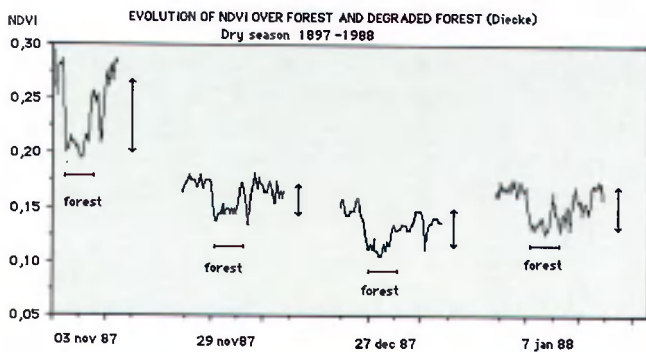
Fig. 54: In West Africa, the discrimination of primary forest blocks from the surrounding secondary vegetation can be done using the visible and near infrared data of the AVHRR. The highly structured forest canopy shows a distinctly lower reflectance in the near infrared (and thus a lower vegetation index) than the other tree formations. The amplitude of the spectral contrast between the forest and its surrounding depends upon the season and the quality of a particular image, as shown in this figure.

– It had been found that the difference between channel 4 and 3 can be used to detect fires and assess the presence of green vegetation in the savanna forest transition area which at the peak of the dry season present a uniform high temperature background. It is also found that a strong correlation exists between the NDVI and the difference channel 4 - channel 3; this offers the possibility of using thermal channels instead of the vegetation index when this latter is affected by adverse atmospheric conditions (Fig. 55).

– Temporal series of AVHRR data have been analyzed for the 1982-88 period. While such "long" time series are to be further explored for studying the functioning of the ecosystems and particularly their response to yearly and interannual climatic cycles, they have been first examined here to assess the degree of forest seasonality. This character is indeed important in evaluating the impact of deforestation and in assessing the susceptibility of the ecosystem to degradation; the hypothesis being that the seasonality increases with the intensity of degradation. Monthly vegetation index curves are described in Fig. 56 (the GAC data from which the time series have been
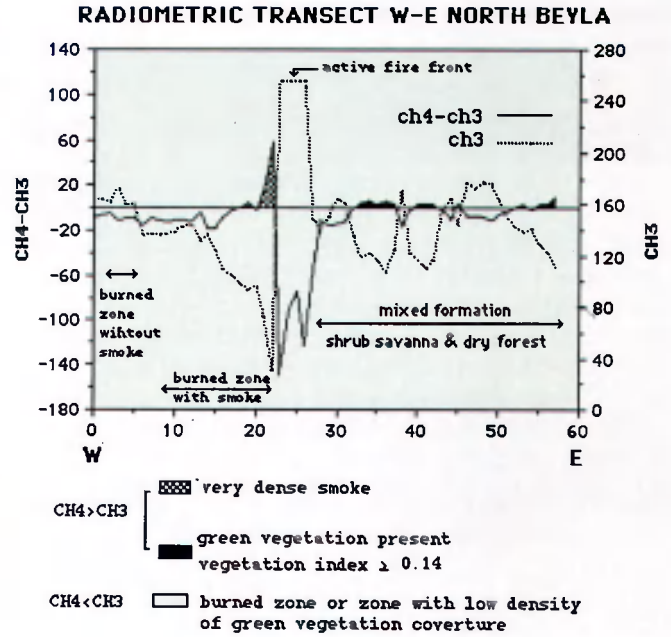
Fig. 55: West-East transect across guinean savanna during the burning period.
The transect drawn on the AVHRR image of 13.1.87, shows the differential response of the thermal channel 3 and 4 over a series of land and atmospheric features. The 3.7 micron channel 3 is very sensitive to active fires (signal saturation) and records lower "brightness temperature" over active vegetation as compared to warmer bare and dry ground. These vegetation features are also marked by positive values of the Ch4-Ch3 difference. The presence of a smoke plume is indicated by low Ch3 values (cool plume at high altitude) and by a negative Ch4-Ch3 difference.

extracted have been made available in the framework of the NASA JRCscientificcollaborationagreement).

Southeast Asia

The analysis of a 1983 AVHRR data set covering southeast Asia has been initiated. The objective of this analysis was to verify if the approach developed in other parts of the tropics could be accommodated to monitor deforestation in the particular conditions of that part of the tropics. The data were obtained from the Bangkok receiving station and cover all of the Southeast Asian subcontinent down to Singapore.

The three dates (6/2-28/3-5/4/1983) cover the end of the dry season during the extreme 1982-83 El Nino episode. The contrast between evergreen or semi deciduous formations and annual vegetation (i.e. agriculture, savanna) is thus very high on the images. The outstanding quality of the data set (despite a noisy thermal channel 3. allows a delineation of the forest - non forest cover (Fig. 57.). A search for a multispectral classification rule did again point at the difficulty of using

Fig. 56: Vegetation index development curve for two forest formations of West Africa (data are derived from selected sample points of the GAC 8 km time series). The two samples are geographically close. One sample covers a primary moist forest and the other a mix of secondary regrowth (with plantations and some agriculture). The two curves depicted here follow similar seasonal patterns but it is noted that the secondary formation has a higher amplitude of NDVI values (with higher maxima and lower minima) than the primary forest only for the dry 1982-84 period. In 1986 the two types of vegetation behave differently with, this time a shift in the peak period. The comparison illustrates the importance of selecting appropriate time windows for discriminating between tree cover formations in the tropics. Time series of this kind represent a unique. and little analyzed source of information on vegetation dynamics.

machine classification when scene variability is so high (angulars and atmospheric effects). Nevertheless it appears possible using two channels classification with threshold values adjusted to the local environment to separate forest from non-forest cover. In addition, the relationship between channel 3 and 4 appears, like in the case of West Africa, to give some unambiguous indication of the presence of a tree cover. Channel ratioing has the advantage of rendering the classification fairly independent from imaging conditions (Fig. 58). Observations have now been made over the three dates available over Myanmar (Burma), Thailand, Cambodia and Laos. Areas of intense fire concentration are being mapped (Fig. 59). The analysis was carried out mainly to identify the range of AVHRR features related to tropical deforestation present in the data set; results will also provide a base for comparison with the 1988 or 89 data which will hopefully be acquired soon.

The experience gained in the course of this research is being integrated with the one obtained otherwise and by other scientists. A methodological document for global tropical deforestation assessment is being prepared as a contribution to the UNEP-FAO Tropical Forest Assessment Project.

Fig. 57: AVHRR HRPT data of 28-3-83, covering Myanmar (Burma) and a portion of northwestern Thailand. The image combines the spectral Ch4, 2, and 1 and allows the clear identification of the remaining forested areas as well as of openings in their midst.

Fig. 58: Radiometric transect across Burma (West-East a 18º North) in Ch3, 4 and Normalized vegetation index of the AVHRR (Bangkok receiving station). The graph shows the strong correlation between the surface response in the thermal channel and the presence of a forest cover. The three forested ranges (Arakan, Pegu and Kayak) are marked by a sharp decrease in Ch3 and, to a lesser extend, in Ch4. Furthermore, the cross over from forest to dry agricultural land is always marked by a change in the sign of the Ch4 - Ch3 difference (positive for forest, negative for dry land). The vegetation index profile, on the other hand, misses the dry seasonal forest of the central Pegu Range; This is probably due to a conjunction of seasonal and atmospheric effects.

Fig. 59: The intense shifting cultivation activities taking place in the dry decidous forest of Southern Laos are marked by the presence of numerous fires as shown on this AVHRR Ch3 image. On the 1983 data set, this region of southeast Asia showed, together with northern Thailand and the Miso-Maripan Hills of India, among the most dense fire distribution patterns seen on AVHRR throughout the tropical belt.
Such data are now studied in terms of impact of biomass burning on atmospheric chemistry.

ASSOCIATED LABORATORIES

Land Use Collaborative Programme

The Collaborative Programme consists of a network of different application oriented research projects involving around 30 participating institutions and laboratories. It is aimed at the promotion of application of Remote Sensing and integration of Remote Sensing data in Geographical Information Systems in the management of land use in European marginal areas.

Following the decision agreed on during the plenary meeting in July 88 six contracts have been given in 1989 concerning themes ranging from establishment of Land Information Systems to evaluation of natural risks and disasters in mountainous areas. Newsletter no. 5 of the Programme was distributed (April). A brochure describing the projects has been produced and a Workshop on Integration of Remote Sensing and Personnel Computer based Geographic information Systems was held at Ispra (September).

Ocean Colour European Archive Network

A joint JRC/ESA initiative has been proposed to archive large scale, long term ocean colour data such as those of CZCS (1978-86). The project would produce general scientific and operational benefits to other European programmes and is aimed: 1) to compile a general catalogue and an easily accessible and available archive on optical disks, 2) to establish proper sets of methodologies and user friendly software 3) to identify and carry on a demonstration programme to exploit historical series of CZCS data and 4) to make an "announcement of opportunity" in order to broaden the user community.

Microwave Programme

As already explained the Institute is also collaborating with ESA and other European organizations in the frame of the microwave remote sensing research activity.

European Space Agency (ESA)

In accordance with the outcome of the meeting between President Delors and the Director General of ESA, Prof. Luest in February 1989, an ESA/CEC Environment and Earth Observation Working Group (EEO-WG) has been set up. The objective is to prepare joint initiatives. to cover a wide range of aspects related to the field of environmental research and monitoring and the Earth Observtion. The EEO WG is co-chaired by the Director General of JRC and the ESA's Director of Earth Observtion. Two meetings of EEO-WG were held in Paris (April) and at Ispra (October).

LARGE
INSTALLATIONS

CONSTRUCTION OF NEW INSTALLATIONS: MICROWAVE SIGNATURE LABORATORY

The Microwave Signature Laboratory, as a part of the Microwave Remote Sensing Programme was presented at the end of October 1988 to an international group of high ranking experts. The positive and encouraging opinion of the expert group resulted in an approval of the project by the Board of Governors of the JRC and the Director General of the JRC.

On the basis of the results of a Feasibility Study which was concluded at the end of 1988, the technical specifications of this installation have been drawn up. These specifications provided the technical support for the launch of a "Call for Tender" concerning the detailed design (Fig. 60), the construction and the installation of the Laboratory.

The selection process was concluded by August with the proposal to award a contract to a large European company, recognised world-wide as a leader in the electric and electronic field. The contract has been signed in November 1989 and the installation should be completed by the summer of 1991.

Preparatory activities have been also undertaken in order to make available within the Ispra Establishment the area suitable for the installation of the Laboratory. A portion of an existing building has been restructured to comply with the requirements of the new facility. The relevant works were started in October 1989.

The operation of the Microwave Signature Laboratory at its full potential will represent a complex task; expertise and practical experience will be essential. For this reason an Interim Laboratory has been implemented in order to undertake preliminary tests and to acquire such experience.

The microwave equipment, available in the Centre since spring 1989 has been arranged in a flexible configuration using a small anechoic chamber realised in a normal room by means of microwave absorbing panels (see fig. 61).

The Interim Laboratory has been designed using minimum costs and re-use of components as main requirements. This facility permits a number of objectives to be achieved including the practical implementation of different calibration procedures and verification of radar measurements providing real data to the processing tools under development.
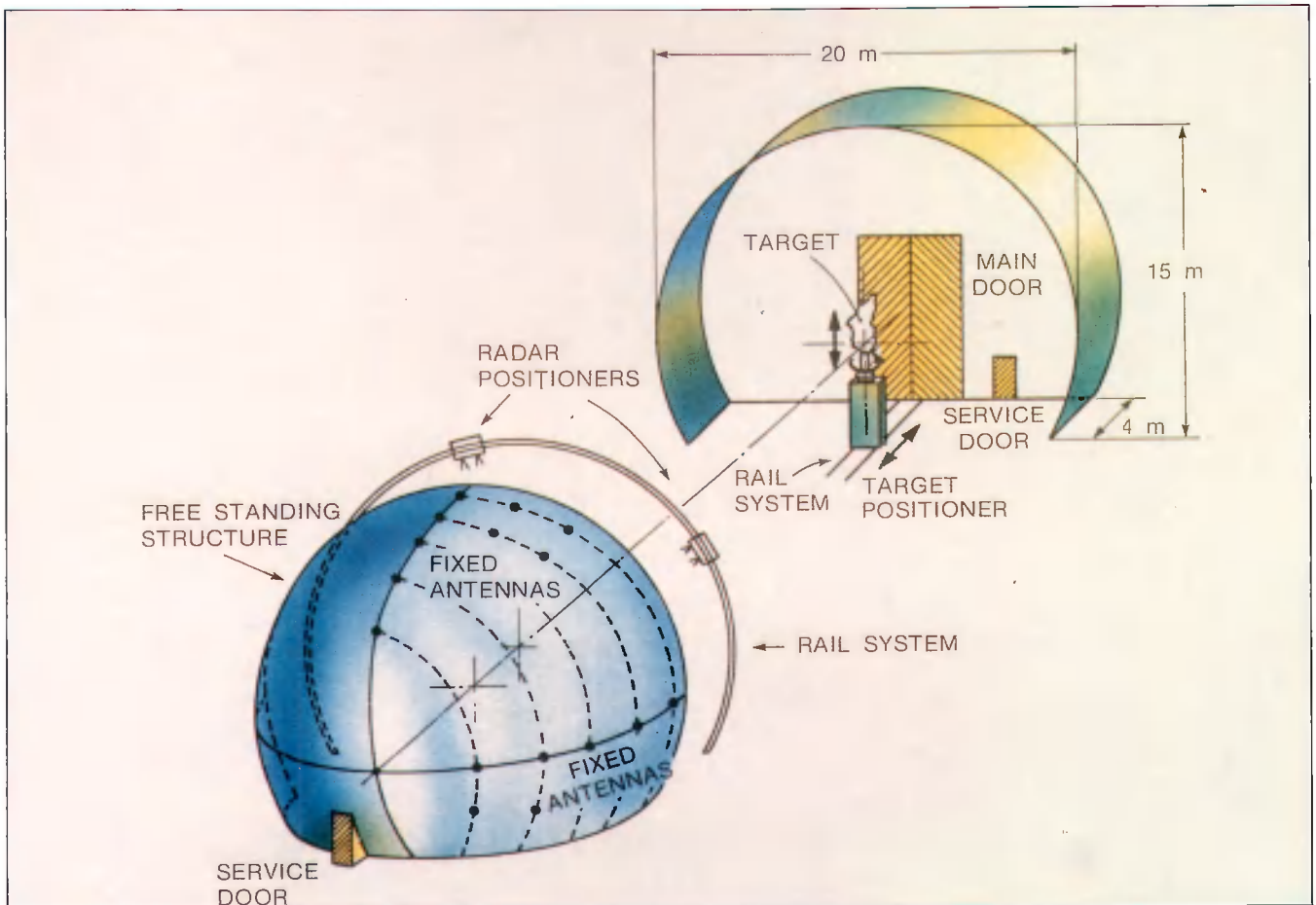
Fig. 60: Overview of the Microwave Signature Laboratory layout (exploded view).

Fig. 61: Works in progress for the implementation of the Interim Laboratory.

Preliminary calibration measurements were started in September 1989. The Interim laboratory will be fully functional by the end of 1989.

Good opportunities for undertaking research activity have been developed through the collaboration with external Institutions, namely the University of Karlsruhe (awarded by the JRC of a Study Contract on the Unfolding of Scattering Components) and the University of Texas at Arlington (responsible of the Imaging Mode design in the Feasibility Study).

In particular a member of the Microwave Team joined the Wave Scattering Research Centre at Arlington for six weeks with the opportunity to use the facilities of that Centre for gaining experience on radar measurements and microwave imaging techniques.

In house research has been essentially devoted to the evaluation of the performances of the Microwave Signature Laboratory and to the development of calibration techniques suitable for practical applications in laboratory measurements.

HUMAN RESOURCES

INSTITUTE STAFF

In 1989 the Institute for Remote Sensing Applications had a total of 75 staff shown as follows in table 1

Category of staff	A	B	C	Total
	39	23	13	75

VISITING SCIENTISTS AND SCIENTIFIC FELLOWS

In table 2 is shown the number of fellows by categories

Category of fellows	Post-graduate	Post-doctoral	Visiting Scientist	
	11	2	1	14

SECONDMENT FROM AND TO OTHER LABORATORIES

During 1989 the Institute hosted three national experts on secondment from member countries.

ANNEXES

ANNEX A

Publications

Monitoring of Land resources and their Use

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ANNEX B

Organisation Chart of Institute for Remote Sensing Applications

A.   Directorate   R. Kiersy

B.   Division of Advanced Technologies   G. Bertolini

- Laser Fluorosensor, High resolution   G. Bertolini
  spectrometry
- Microwave   A. Sieber

- Applications in the Marine   S. Galli de Paratesi
  Environment

C.   Specialised Services
- Agricultural Statistics   J. Meyer-Roux

- Land Use Planning   J. Mégier

- Aid to Development   J.P. Malingreau

Laboratory for Image Processing   J. Mégier

ANNEX C

Fig. 53 Results of an unsupervised classification (automatic clustering) of a subset of the scene above for forest - non forest land cover mapping.

The undisturbed forest is represented in grey, disturbed forest is in black. The remaining of the area is occupied by a mosaic of secondary regrowth, degraded forest and agricultural fields.

Fig. 54 In West Africa, the discrimination of primary forest blocks from the surrounding secondary vegetation can be done using the visible and near infrared data of the AVHRR. The highly structured forest canopy shows a distinctly lower reflectance in the near infrared (and thus a lower vegetation index) than the other tree formations. The amplitude of the spectral contrast between the forest and its surrounding depends upon the season and the quality of a particular image, as shown in this figure.

Fig. 55 West-East transect across guinean savanna during the burning period.

The transect drawn on the AVHRR image of 13.1.87, shows the differential response of the thermal channel 3 and 4 over a series of land and atmospheric features. The 3.7 micron channel 3 is very sensitive to active fires (signal saturation) and records lower "brightness temperature" over active vegetation as compared to warmer bare and dry ground. These vegetation features are also marked by positive values of the Ch4-Ch3 difference. The presence of a smoke plume is indicated by low Ch3 values (cool plume at high altitude) and by a negative Ch4-Ch3 difference.

Fig. 56 Vegetation index development curve for two forest formations of West Africa (data are derived from selected sample points of the GAC 8 km time series). The two samples are geographically close. One sample covers a primary moist forest and the other a mix of secondary regrowth (with plantations and some agriculture). The two curves depicted here follow similar seasonal patterns but it is noted that the secondary formation has a higher amplitude of NDVI values (with higher maxima and lower minima) than the primary forest only for the dry 1982-84 period. In 1986 the two types of vegetation behave differently with, this time a shift in the peak period. The comparison illustrates the importance of selecting appropriate time windows for discriminating between tree

cover formations in the tropics. Time series of this kind represent a unique, and little analyzed source of information on vegetation dynamics.

Fig. 57 AVHRR HRPT data of 28-3-83, covering Myanmar (Burma) and a portion of northwestern Thailand. The image combines the spectral Ch4, 2, and 1 and allows the clear identification of the remaining forested areas as well as of openings in their midst.

Fig. 58 Radiometric transect across Burma (West-East a 18° North) in Ch3, 4 and Normalized vegetation index of the AVHRR (Bangkok receiving station). The graph shows the strong correlation between the surface response in the thermal channel and the presence of a forest cover.

The three forested ranges (Arakan, Pegu and Kayak) are marked by a sharp decrease in Ch3 and, to a lesser extend, in Ch4. Furthermore, the cross over from forest to dry agricultural land is always marked by a change in the sign of the Ch4 - Ch3 difference (positive for forest, negative for dry land). The vegetation index profile, on the other hand, misses the dry seasonal forest of the central Pegu Range; This is probably due to a conjunction of seasonal and atmospheric effects.

Fig. 59 The intense shifting cultivation activities taking place in the dry decidous forest of Southern Laos are marked by the presence of numerous fires as shown on this AVHRR Ch3 image. On the 1983 data set, this region of southeast Asia showed, together with northern Thailand and the Miso-Maripan Hills of India, among the most dense fire distribution patterns seen on AVHRR throughout the tropical belt.

Such data are now studied in terms of impact of biomass burning on atmospheric chemistry.

Construction of Microwave Signature Laboratory

Fig. 60 Overview of the Microwave Signature Laboratory layout (exploded view).

Fig. 61 Works in progress for the implementation of the Interim Laboratory.

ANNEX D

Glossary of Acronyms and Abbreviations

AVHRR	Advanced Very High Resolution Radiometer
BRAMS	Spot-Image Catalogue
CCT	Computer Compatible Tape
CZCS	Coastal Zone Color Scanner
DEC	Digital Equipment Corporation
EPO	Earthnet Programme Office
ERDAS	Earth Resources Digital Analysis System
ESRIN	European Space Research Institute
GAC	Global Area Coverage
GCP	Ground Control Point
GIS	Geographic Information Systems
HRPT	High Resolution Picture Transmissions
HVR	High Visible Resolution (Sensor)
IGIS	Integrated Geographic Information System
ITT	Invitation To Tender
LAC	Local Area Coverage
Landsat TM	Thematic Mapper
LEDA	ESRIN Catalogue
LIP	Laboratory For Image Processing
MSS	Multispectral Scanner
NASA	National Aeronautic And Space Administration
ORACLE	Relational Data Base Management System
PCDIS	Personal Computer Display System
SAR	Synthetic Aperture Radar
SGEOS	Second Generation Earth Observation Satellite (SPOT and TM)
SHARK	Station HRPT Archiving And Reprocessing Kernal
SHARP	Standard Family HRPT Archiving And Request Product
SLAR	Side Looking Aperture Radar
SPOT	Systeme Probatoire pour l'Observation de la Terre
TINT	Software programme name
VAX	Computer type

The Institute for Remote Sensing Applications was created in November 1988 as the result of the decision taken by the Council of Ministers on the restructuring of the Joint Research Centre.

1989 saw the initiation and consolidation of a number of application oriented projects such as Agricultural Statistics, Land Use in European Marginal Regions, Monitoring of Vegetation in Tropical and Subtropical Areas of West Africa and Surveillance of Marine Environment and Resources.

The year was also characterised by the beginning of research in the area of microwaves, especially in view of the launch in the near future of the European satellite ERS-1. Studies on the application of laser fluorescence have led to the construction of an airborne LIDAR fluorosensor instrument which will be flight tested during 1990. Investigations of laser spectroscopy to vegetation (green matter) have culminated in a EUREKA project "LASFLEUR" in which the Institute will actively participate.

Two airborne measurement campaigns have been organised in collaboration with the European Space Agency and with the participation of many European laboratories. The first, named MAESTRO 1, used a polarised Synthesis Aperture Radar (SAR) with three frequency bands (C,L,P) the other, named EISAC, used two different high resolution spectrometers. Areas over which these new sensors were flown included forestry, agriculture and oceanographic test sites.

During the year the Institute reinforced its research teams with the recruitment of specialists in agronomy, statistics, image processing and microwaves. An important effort was equally made for grantholders, visiting scientists and seconded national experts.