USE OF ERS-1 SAR DATA FOR AGRICULTURAL, FORESTRY AND ENVIRONMENTAL APPLICATIONS IN CENTRAL-EASTERN EUROPE

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This Workshop on "Use of ERS-1 SAR data for Agriculture, Forestry and Environment Applications in Central-Eastern Europe" was organized and funded by European Space Agency, Food and Agriculture Organization of the United Nations, Commission of the European Communities and Telespazio. The Workshop took place at ESRIN-Frascati from 8 to 12 November and was attended by 16 participants from 6 Central and Eastern European countries. These proceedings include papers on remote sensing cooperation, SAR principles, applications development and remote sensing data distribution. The proceedings were edited by J.F.Dallemand (ESA/FAO consultant) and J.Lichtenegger (ESRIN-ESA, Frascati). Thanks are due to H.Palmer (FAO Remote Sensing Centre) and C.Lieber (FAO Remote Sensing Centre) for their assistance in the report preparation.

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An effort of coherence has been pursued by the Agency in trying to coordinate closely, on one hand, with its Member States, and on the other, at European level with organisations active in Central and Eastern Europe like OECD, the CEC, EBRD and EUTELSAT. Furthermore, ESA is closely associated withe the activities of the Science and Technology Group of the Hexagonal Initiative. Two Members of ESA, Austria and Italy are full members of the Hexagonal Initiative.

Any cooperative effort, due to scarce manpower and financial resources, will produce their results if coordinated with these partners.

ESA signed in April 1991 an agreement with the Republic of Hungary for cooperation in the field of exploration and the use of outer space for peaceful purposes and a similar one with the Government of Rumania in December 1992. The signature of a similar agreement with the Republic of Poland is expected shortly. Contacts have been established also with the Czech-Slovak Academy of Sciences but no agreement has been so far negotiated and the new political situation in these countries will not speed up the process in this direction.

These umbrella cooperation agreements cover all areas of space activities from space science to applications such as telecommunications and remote sensing. Through their general character they permit the establishment of close links between relevant space institutes in West and East, encourage the utilisation of European developed technology and help to avoid the dispersal of intellectual potential in countries of Central and Eastern Europe. The agreement while not granting a status of associated member or a status comparable with that of Canada with the Agency, still provides a forum for discussion, definition of pilot projects, exchange of information and assist countries to organise themselves internally.

ESA's cooperation activities with countries of Central and Eastern Europe have produced best results in the field of earth observation due to a number of reasons.

Central an Eastern European Countries attach high priority to problems such as environmental pollution, redistribution of land, agriculture activities and assessment of available natural resources.

These areas of activities represent objective priorities and need solutions in a relatively short term period. So even if space does not represent a priority in this phase of political re-organisation, financial difficulties and economic reconversion, specific applications of remote sensing technologies re certainly a useful key tool in contributing to solving main issues of concern for these countries.

This situation is well reflected in some of the major projects for support to Central and Eastern European countries, which have been defined by European entities. The PHARE programme of the European Commission that intends to support the economic re-organisation of countries of Central and Eastern Europe has allocated part of its consistent budget to project in the fields of space applications such as telecommunications or environment.

The field of remote sensing has emerged as an important one in the cooperative activities between ESA and Central and Eastern European Countries. The cooperation started at the time when ESA launched its ERS-1 satellite (European Remote Sensing Satellite-1). The ERS-1 programme is the first European programme in remote sensing, developed within the ESA framework and is an experimental satellite of high value in the field of advanced technology. It carries a radar instrument on-board able to monitor the earth in all weather conditions, during day and night.

Many signs of interest for the use of the ERS-1 data have been expressed by the scientific community of countries of Central and Eastern Europe.

Contacts between ESA/Earthnet Network and various institutions in Central and Eastern Europe have existed for numerous years as some centres in these countries have been designated national Points of Contact for Earthnet and this has facilitated cooperation.

ESA's actions in the field of remote sensing with Countries of Central and Eastern Europe are focused mainly in three directions:

- the definition of joint pilot projects for the utilisation of remote sensing data,
- the organisation of training activities in the field of remote sensing,
- the support of experts to attend main European conferences and events.

Due to its mandate and its limited financial human capabilities, ESA cannot play a major role to support the reinforcement of remote sensing infrastructures in Central and Eastern Europe through provision of hardware but a limited effort has also been made in this direction.

ESA organised its first regional training course for experts in remote sensing with the United Nations Food and Agriculture Organisation (FAO) and the support of Telespazio in Budapest (Hungary) in September 1991. The course focused on environmental and agricultural applications of remote sensing. A follow up of this successful event was organised October 1992 in Nitra (Slovakia). The second course included the extended co-sponsorship and active participation of the Commission of the European Countries through its Joint Research Centre.

High level decision-makers in the field of environment and agriculture representing all countries of Central and Eastern Europe attended the workshop. A presentation of the various remote sensing satellites (Landsat, Spot, ERS-1) was combined with lectures on potential practical environmental and agricultural applications of the data and case studies.

In the field of training the Agency has identified, through contacts with its partners in Central and Eastern Europe, a specific need for support in the area of management of remote sensing projects and also in the definition of proposals for projects for financial support or simply with the management of remote sensing projects. It is with this view of support to the managerial aspect of remote sensing activities that ESA and CNES have jointly organised, in December 1991, a regional Seminar on "Remote Sensing in the Development of Central and Eastern European Countries: benefits, management and funding".

ESA also organised a Workshop on ERS-1 on the occasion of the EARSeL 92 Symposium in Eger (Hungary) in September 1992.

In the field of training no specific programme nor funds exist and delegations within ESA's Member States recognize the need for an action but have not managed yet to find a consensus.

A few scholarships have though been granted to experts for training at ESA's establishments or other European organisations.

A Polish expert in meteorology spent, in 1991, 6 months on ESA's premises at the Joint Research Centre of the CEC.

A fellowship of 6 months has been granted to an Hungarian expert in geodesy to work at ESA's establishment in ESOC.

A number of pilot projects have been defined and are being carried out with various centres of excellence in remote sensing in Central and Eastern Europe. Two ERS-1 pilot projects on forestry applications have been selected and are presently being carried out with the Polish Institute of Geodesy and Cartography in Warsaw.

ESA has provided ERS-1 data sets for the pilot project led by France and conducted by Scot Conseil for the definition of an operational tool for the monitoring of the environment in the Danube Delta region in Rumania.

ESA is present in working jointly with FAO on a project on the assessment of the potential of ERS-1 SAR Data for natural resource mapping and environmental monitoring in countries of Central and Eastern Europe.

The project will select a number of test sites in countries of Central and Eastern Europe and the results of the work will be presented at the occasion of a training session to be organised at ESA's ESRIN establishment in autumn.

ESA'S ERS PROGRAMME: A SUMMARY STATUS REPORT ON SAR DATA DISTRIBUTION AND APPLICATIONS

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By now ERS-1 is in operation for almost 2.5 years with its systems available for more than 95% of the time. By the end of March 1994 almost 700.000 SAR scenes have been acquired of which 5% have been processed into image data.

The SAR data processing volume within Europe and West Africa (ESA stations and processing facilities) was low in the months following the launch. It is now well established with potentially more than 100 scenes per day of high resolution scenes and full swath near real-time processing to low resolution at the Norwegian National Receiving Station Tromsoe. The Canadian and the Alaskan station guarantee a good and fast data availability while stations in Latin America, India and Southeast Asia often do not report regularly and tape shipment to Europe is unsatisfactory slow. It has to be understood that the agreements between ESA and those station owners are on a "best effort" basis.

SAR data applications currently developed are mostly based on the results obtained by Principal Investigators and Pilot Project Team Leaders and are closely monitored and partly guided by ESA. The official data distributor, the ERSC consortium, in particular EURIMAGE are involved in this process as well.

Summarizing the outcome from the investigations reported in this proceedings as well as from papers presented at the 2nd ERS-1 Symposium in Hamburg, 11^{th} to 14^{th} October 1993, it can be stated that SAR data applications has not yet reached the operational character of optical data, but is well on the way. Although there is confidence in the new information source and its usefulness has been proven, there is still a lack of understanding of at least some of the physical interactions between microwaves and the sensed targets. The other issue hampering a smooth transition to operational use of SAR data, is its inherent character of a much higher noise level compared to conventional optical data. New and adapted tools for image post-processing need to be developed. This has been recognized by the industry, but is realized rather cautiously, perhaps too cautiously with respect to the wealth of data that is acquired.

ERS-1 is primary an ocean monitoring satellite, based on its Low Bit Rate Data Instruments, namely Scatterometer, Wave mode SAR, Altimeter and ATSR. The high resolution SAR image has only limited use in the open ocean because of its relative narrow swath of 100 km. This has been recognized. Already the next generation of space borne SAR, the Canadian Radarsat will provide a large swath allowing full coverage also in lower latitudes within few days. In a similar way but with much more options the Agency's ENVISAT will monitor the oceans and the land masses later in this decade.

SAR images of the ocean are used to study current/wind interactions and atmospheric effects producing particular roughness pattern on the sea surface. Seatruth campaigns proved that low to medium wind conditions enhance sea current features and sea surface/atmospheric interaction as well as meteorological phenomena "touching" the sea surface.

Under these conditions current shears become visible as long bright or dark linear features. The same phenomena is found in AVHRR sea surface temperature data: strong gradients perfectly match the linear features of current shears in SAR images. On other occasions wind fronts could be observed as an abrupt change in microwave backscattering.

The effect of unstable air layers, caused by temperatures lower than sea surface temperature can also be investigated since they produce a scheme of up and down winds which becomes visible in SAR image as a regular pattern, so-called wind streaks.

Footprints of raincells can be identified on the sea surface because of the roughening effect of strong downwind and the smoothening of the small wind waves by rain hitting the surface. Tropical thunderstorms on sea are revealed in a similar way, but due to the larger dimension the features are more pronounced.

For coastal monitoring, SAR can be used to detect current shears and wave deflections which locally can result into a dangerously high sea state. SAR can be used effectively as high resolution scatterometer to measure the wind field. For the Norwegian coast such data applications are being developed for use in forecasting models and also as synoptic observation and for sea and weather hazard warnings.

Sea ice monitoring is another objective of the ERS-1 mission. Campaigns in the Arctic and Antarctic and in inland seas as the Baltic Sea have confirmed the usefulness of SAR data. Different qualities of ice can be distinguished and qualitative information on the thickness retrieved. With this information low resolution images or image derived ice maps are produced and sent directly to ships by fax or file transfer. This service can be considered semi operational in the acquisitions zone of Tromsoe/Norway (European Arctic and Baltic Sea).

Oil pollution monitoring in Norway and the Netherlands is similarly well established. End-users are the pollution control authorities. Image interpretation is based on the fact that in low to medium wind conditions any type of oil is very effectively dampening the small wind waves, and radar backscattering is largely reduced. A skilled interpreter can in most cases distinguish between a man-made oil slick and a natural features. The obstacle to fully integrate space borne SAR in coastal monitoring system is the requirement of a very frequent coverage, therefore a larger swath width. Radarsat, to be launched 1995 and Envisat from 1998 onwards will provide this.

Most land applications take advantage of the fact that on SAR data availability is regular and reliable and therefore objects highly variable with time, as crops and in some cases forest, can be observed. After 2 years of SAR observations typical backscattering characteristic for most crops have been identified and visual image classification is possible. The high spatial resolution also permits surface estimations for each crop type. Accuracy achieved is comparable to the results obtained when using optical data. Automatic classification however is still in a development stage. Good results were obtained using segmentation technics and field-based instead of pixel-based classifications.

For forest mapping, SAR was successfully applied to separate younger from older stands and fire-damaged wood could be identified. A draw-back is that forest often persists in mountainous regions with steep slopes. In this case the peculiar image geometry of SAR has to be considered. By applying rigorous geometric corrections using a digital terrain model and ascending and descending passes, not usable data (layover, shadowed area) can be minimized.

The high expectations put into ERS-1 with respect to soil moisture assessment has been fulfilled. The basic problem is how to separate the two main components responsible for the strength of backscattering: the surface roughness and the dielectric constant which depends on the water content. Based on ground measurements it was concluded that in most cases roughness can be estimated and consequently soil moisture quantitatively assessed. It was reported that for bare soil or little vegetation coverage the penetration depth can be as much as 5 cm.

Interferometry has been rediscovered with ERS-1 SAR. Because of the precise orbit of the satellite and the high data quality it is possible to achieve coherence between complex data of two subsequent passes on the same orbital track. Precise matching of two data sets makes it possible to link phase differences to either relative elevation of the observed point or, if the target position is known in all 3 dimensions, it can be used to determine small relative movement, in the order of centimetres, or a physical change (growth). Promising results have been obtained regarding the production of digital elevation models, earth quake, glacier and land slide observation and forest and crop classifications.

SAR has been successfully used for flood monitoring by applying "change detection" technics comparing a normal situation with a catastrophic one in order to highlight the affected area. The reference image does not have to be a SAR image. Through a high resolution historical optical image additional information can be included such as the landuse of the area under consideration, with the data from the ERS-1 SAR serving as up-to-date information in the absence of conventional optical satellite or other data, due to bad weather conditions that often prevail during catastrophic events, e.g. floods.

The data merge of "historical" data from optical sensors (Landsat, Spot satellite) with latest SAR data acquisitions can be achieved by a conventional procedure forming the basis for thematic maps of high actuality and of a quality that equals or even surpasses the original optical data.

In Figure 1 a LANDSAT TM scene of 11th May 1993 was superimposed geometrically to an ERS-1 SAR scene acquired during the flood period in December 1993 in Germany. For the merge TM channels 4,5 and 3 (2 infrared 1 visible) were chosen and a conventional IHS (intensity/hue/saturation) colour transformation performed. Subsequently the intensity channel was replaced by the Lee-filtered SAR data and the reverse transformation into RGB (red/green/blue) was computed.

The SAR data now determines the intensity of the colours in the scene e.g. dark areas, with individual objects still visible, represent the flooded areas, concentrated along the Rhine river Very bright spots are mainly industrial plants, while a granular light bluish tone would indicates residential areas and light brown woods. Each image element or pixel represents an area of 30m x 30m allowing to measure the extent of the flooded area. In the agricultural zone a separate assessment for grassland and cereals (red) and other crops (bluish) can be made.

This wealth of information may contributes to the management of catastrophic events and allows an independent and differentiated assessment of the extension of the affected area.

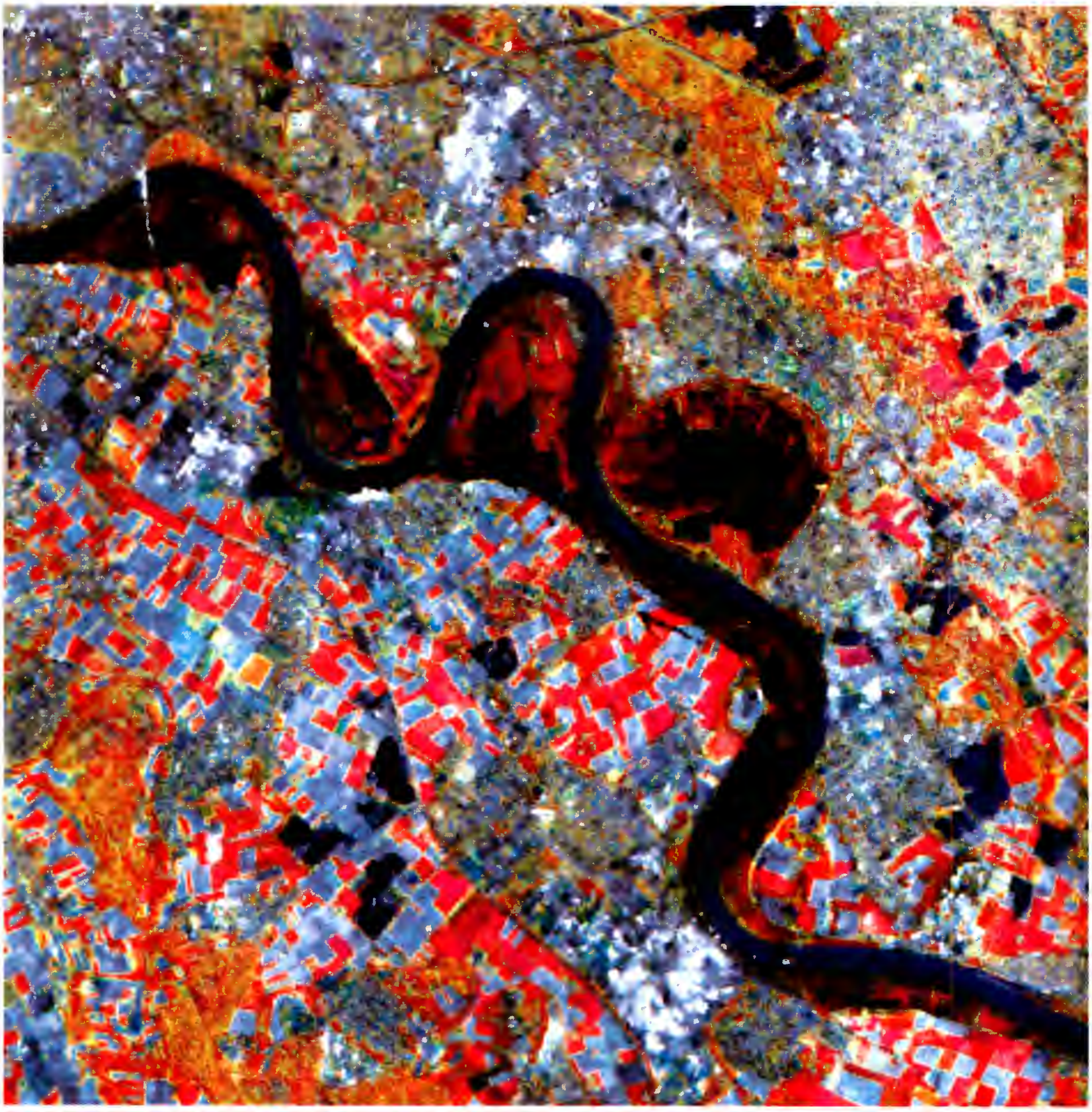

Figure: 1
ERS-1 SAR / LANDSAT TM data merge combining ERS-1 SAR of 25th December 1993 and Landsat TM of 11th May 1993.
Area: Rhine Valley between Düsseldorf and Cologne

red:	Intensity of ERS-1 SAR
green:	Hue of Landsat TM 453 ,
blue:	Saturation of Landsat TM 453.

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OPERATIONAL INTEGRATION OF ERS-1 SAR AND OPTICAL DATA FOR THEMATIC MAPPING AND ENVIRONMENTAL MONITORING: NEEDS OF COST-BENEFIT ANALYSIS

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1. INTRODUCTION

ESA and FAO have been collaborating since 1987 on the combined analysis of optical and microwave data for renewable resources studies. The first part of this cooperation was performed in Tunisia (1988-1991), before the lauch of ERS-1, aiming at land use/land cover mapping. This study was based on the analysis of spaceborne SAR data (Seasat, SIR-A) and optical data (Spot and Landsat TM). Several interesting points appeared such as:
- usefulness of low-cost image to image registration without SAR geocoding in flat zones,
- strong potential of visual interpretation of optical and microwave data at 1:100 000 scale,
- limitations of statistical classifications of unfiltered SAR data,
- limitations of vegetation mapping on SAR images, even after SAR geocoding.

After the launch of ERS-1 in July 1991, ESA and FAO started a cooperation in a tropical savannah zone of Guinea. This land use study stressed:
- usefulness of ERS-1 SAR data (combined to Spot or Landsat TM) for rice identification and monitoring,
- usefulness of the combination of dry season optical data and rainy season radar data for land use mapping, especially considering wetlands, temporary ponds, flood plain,
- necessity of adaptive SAR filtering.

Presently 4 technical studies are being executed in Central/Eastern Europe countries with ESA and FAO support:
- Poland (soil moisture assessment),
- Romania and Hungary (cartographic support to land privatization),
- Slovenia (agriculture statistics).

In addition to the technical studies, ESA and FAO participated in:
- Training Courses in Tunis (ESA/FAO/CNT, 1989) and Conakry (ESA/FAO/MARA, 1992),
- Microwave Workshops in Sao José dos Campos, Brazil (ESA/UN/FAO/INPE, 1990), Maspalomas (ESA/UN/FAO/INTA, 1991) and ESRIN/ESA Frascati (ESA/FAO/CEC/Telespazio, 1993).

Two points should be noted:
- the difference between "Training Course" (for non-specialized participants) and "Workshop" (exchange of experience between specialists)
- the desire to associate Training or Workshop activities to ongoing technical studies executed with national participation.

2. METHODOLOGY AND COSTS

Considering that FAO Remote Sensing Centre is not a Research Institute but a Service Unit for Agriculture, Forestry and Fisheries Departments, FAO Remote Sensing Centre radar activities aim a development of operational applications in the field of mapping or monitoring activities. It is worth discussing the meaning of operational applications. Many different professionals, each with a specific task, work in remote sensing, from the signal acquisition to the map production for example. These persons with different daily activities and different technical backgrounds may have different definitions of an operational remote sensing mission. For example, is a remote sensing satellite mission operational when it provides good quality data on a regular basis? Or is a remote sensing satellite mission operational when in addition to routine data supply it is the source of concrete applications in the field of renewable/non renewable resources ? In the case of projects, it should also be stressed that operational activities are not necessarily permanent. For example, in the case of thematic mapping at 1:50 000 scale i.e. at project level, activities are obviously interrupted when the map is completed. Such a project, even of short duration, may have been very successful. On the other hand, some monitoring activities are sometimes considered as operational mainly because they are long-term activities executed for 5 or 10 years periods; such activities should only be considered operational if their funding is assured (by users support for example) and only pre-operational if they depend on an external funding limited in time (case of donors contributions). French Spot Aval Programme is in our view a model of a useful and successful programme in the sense that it created a link between previous technical/scientific activities of the PEPS Projects ("Preliminary Evaluation of the Spot data") and operational activities sometimes executed on a commercial or industrial basis.

Seasat (1978), SIR-A (1981), SIR-B (1984) are examples of successful microwave experimental missions while Landsat (since 1972) and SPOT (since 1986) are examples of successful optical operational missions. In order to separate experimental missions from operational missions, we think the following criteria have to be investigated:
- information content of the data with respect to thematic applications,
- data availability in terms of spatial coverage of the earth,
- data availability in terms of access to historical data and continuity of the data supply,
- data availablity in terms of temporal resolution
- data delivery delay between order of the images and their reception by the users.
- price per km^2 and data distribution policy. The relevant price for the users is not the raw data cost but it should also include the necessary pre-processing and post-processing costs.

In the case of data delivery delay, programming period must also be taken into account. Data delivery delay must be clearly distinguished from processing time. It should be noted that the useful information for the users is not the minimum delivery delay that can not be used during mapping projects formulation but the maximum delivery delay that is one of the inputs required to define a project time table. It can also be noted that from Seasat (1978) to ERS-1 (1991) the processing time has been considerably reduced but that it is more difficult to reduce delivery time after acquisition.

Remote sensing data users in the field of natural resources mapping can work mainly on the extraction of thematic information and make recommendations about data availability and data delivery delay. In addition, they may compare the cost of execution of a mapping project based only on optical data with the cost of a project based on complementary optical/microwave data. Such a comparison was done considering the Land use/Land Cover Map of Afghanistan (FAO Remote Sensing centre, 1992/1993) and is thus based on real figures.

The objective of this project presently under execution is to produce a full Land Use/Land Cover Map of Afghanistan (647.451 km^2) at 1:100 000 scale, and also to produce 82 spacemaps at 1:100 000 scale. This area is covered by 43 Landsat TM scenes.
The cost of the remote sensing component, including map printing and 10 copies of 82 spacemaps, is US$ 1.486.000, i.e. US$ 2.2/km^2. The total cost of the project, including the remote sensing component and the creation of a digital data base is US$ 2.200.000, i.e. US$ 3.3/km^2.
The manpower associated to the project activities is 22.5 person/month for the analysis and interpretation of satellite data, 24 person/month for the cartographic work and 25 person/month for the data base creation.

Additional costs related to a hypothetical integration of ERS-1 SAR data in such a mapping project were computed. The methodology chosen for this estimation consists of visual interpretation at 1:100 000 scale of Landsat TM images and ERS-1 Precision images (2 dates). The following costs were considered:
- ERS-1 data, 800 Ecus/scene of 100 km x 100 km, i.e. US$ 0.19 per km^2,
- ERS-1 filtering and ERS-1 registration, 2 computer days (US$ 500/day) per scene, i.e. US$ 0.10 per km^2,
- ERS-1 film production (US$ 380) and photographic enlargement (US$ 120), i.e. US$ 0.05 per km^2.

The total additional cost related to the use of ERS-1 data is thus US$ 0.34 per km^2. For a country like Afghanistan, if we consider that high mountains and deserts should not be covered by ERS-1, and that SAR acquisitions should only cover half of the country, the additional cost is then US$ 110.160, i.e. 5.5% of the project initial budget.
It should be noted that these figures were computed assuming the cheapest methodology i.e:
- no terrain correction of SAR data using a Digital Elevation Model,
- no mosaïquing of ERS-1 scenes.
It appears nevertheless with this example that the present level of cost of ERS-1 SAR data is not a limiting factor for an operational use of spaceborne radar imagery in renewable resources studies. Nevertheless, we feel that presently ERS-1 SAR data are to a large extent underutilized.

Figure 1 shows in a simplified way the required methodological steps to be followed from ERS-1 SAR data acquisition to environmental information provision. The important part of this Table is the distinction between data, of interest only for the very limited remote sensing community, and environmental information which is of interest for a much wider community and sometimes for the society. Figure 2 shows methodological steps focusing on the SAR data interpretation. Figure 3 presents the 1993 costs of ERS-1 SAR data.

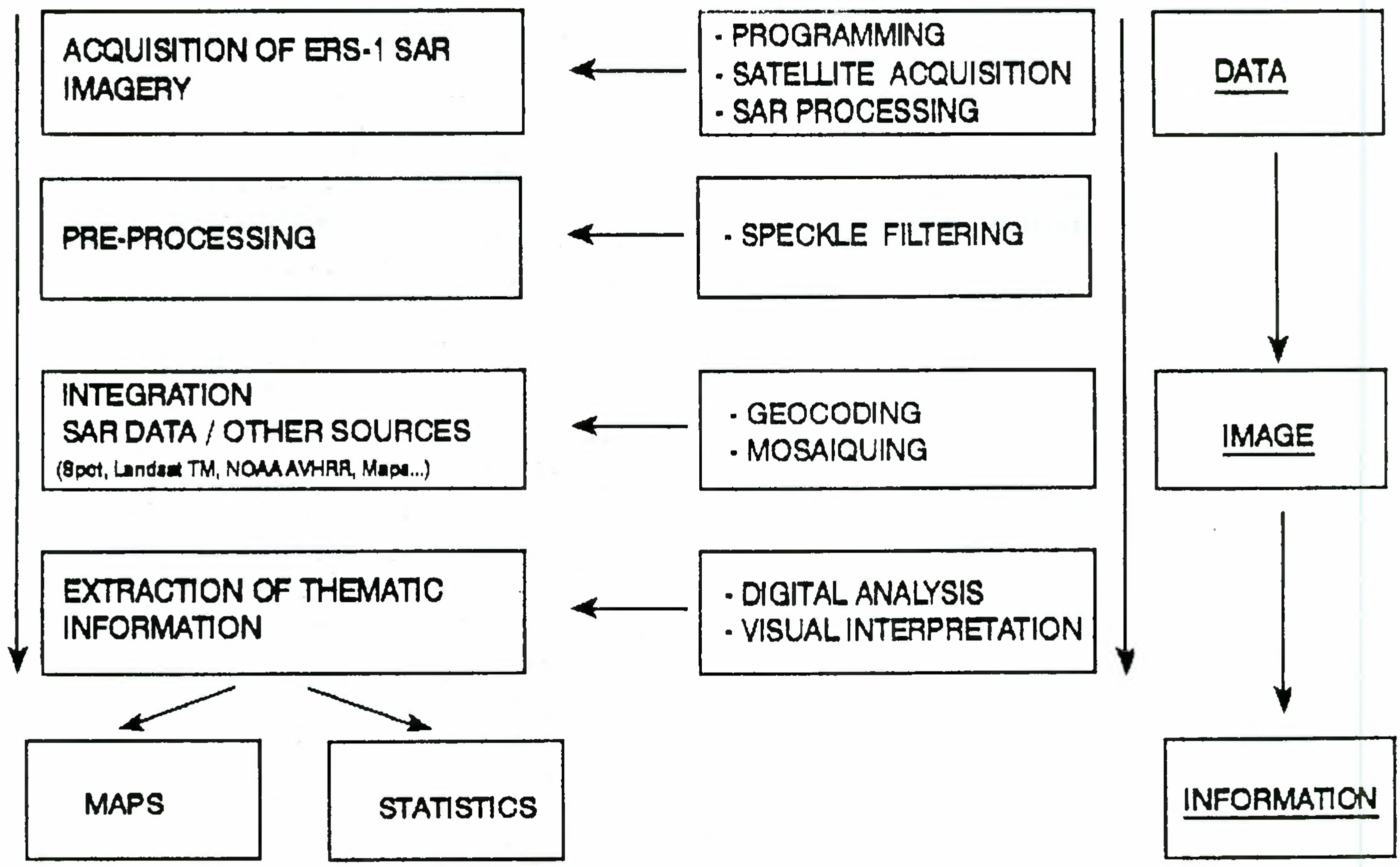

Figure 1: From ERS-1 SAR data to Environmental Information

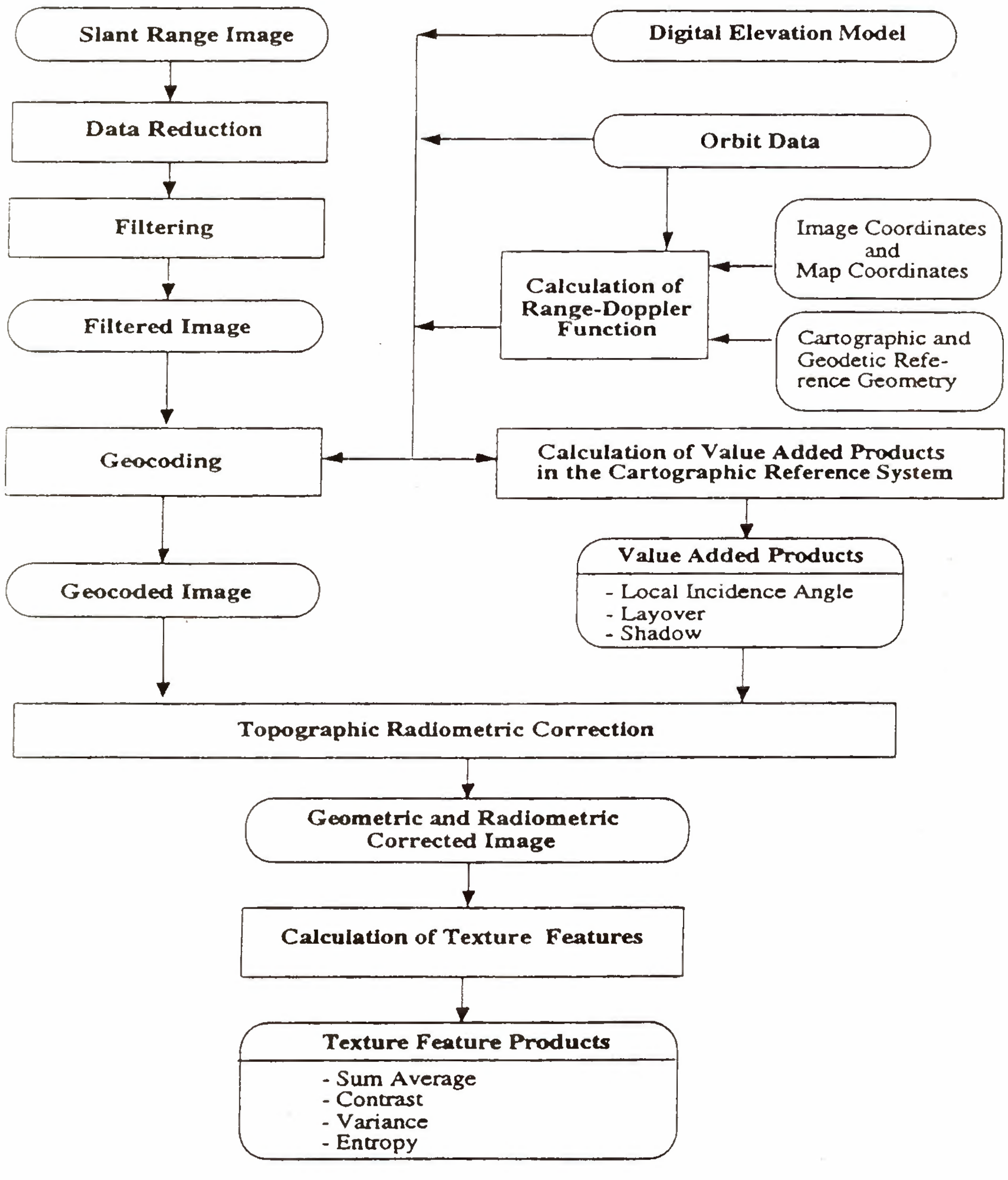

Figure 2: Example of a SAR Processing and Analysis System
(From Schmidt, Zurich University)

ERS-1 SAR Product	Image cost (Ecu)	Cost/km^2 ($ US)	Delivery time
Fast Delivery Product (SAR.UI16)	400	0.045	< 24 hours*
Precision Image (SAR.PRI)	600	0.067	1-3 weeks
Ellipsoid Geocoded Image (SAR.GEC)	1000	0.112	1-3 weeks
Terrain Geocoded Image (SAR.GTC01)	2000	0.224	2-4 weeks**

Table 3: Cost of ERS-1 SAR products (Reference 1993).

* If satellite communication station available **If Digital Elevation Model provided

- The image costs refer to ESA countries. In the case of non-ESA countries, the cost increase is 200 Ecus/product.
- Each SAR image covers 100 km x 100 km = 10.000 km^2.
- Delivery time does not include necessary programming period that should normally be 35 days minimum in the case of SAR products.
- The mentioned costs are the same in the case of SAR digital or SAR photographic products.
- Production cost of a Digital Terrain model is not included in the case of Terrain Geocoded Image price.
- Most thematic mapping projects will not require one but two or three SAR acquisitions.

3. PERSPECTIVES OF COMBINED USE OF OPTICAL AND SAR DATA

Based on the results of ESA ERS-1 pilot projects and of ESA/FAO cooperation, pespectives now exist of an operational use of ERS-1 SAR data combined with high resolution optical satellite data such as Spot and Landsat Thematic Mapper. Considering only temperate regions and renewable resources (Agriculture, Forestry, Environment) we can mention the following promising fields of application:
- **soil moisture assessment and monitoring**.
- **land use/land cover mapping**. All-weather multitemporal SAR data provide information about the dynamic elements of the terrain, such as agricultural fields and deforested zones. This information can be combined with information on vegetation extracted from previously acquired Visible/Infrared data.
- **forest fire damage mapping**.
- **agriculture statistics**. Activities of crop identification, crop monitoring and acreage estimates can provide earlier results thanks to the integration of all-weather SAR data with other sources (Maps, optical satellite data).

- **irrigated crops monitoring** due to the strong temporal variations of backscatter of irrigated crops during the growing season.
- **oil spill detection on the sea**. Fast Delivery products are required for this application.
- **flood mapping and flood extent measurement**, due to the limitations of optical data acquisition during flood periods.

4. CONCLUSIONS

In conclusion we would like to formulate the following remarks:
- The cost of the satellite data is often presented by users as a limiting factor. The cost of the satellite data is only one of the costs related to an operational project, the other items being personal, hardware/software, training, field check, etc..The cost of satellite data may be a problem in the specific conditions of some countries but it should also be stressed that we often observe a lack of of communication between Remote Sensing Units and Environment, Agriculture or Forestry Groups. If it is commonly accepted that remote sensing is only a tool, the obvious consequence is that remote sensing units (at organisation or country level) need a close link with potential thematic users. If for one reason or another this link fails, the access to existing budgets becomes impossible and data costs, as well as other items, can not be funded. Activities then remain at research-development level only without starting real applications.
- Training activities are important in the case of microwave/optical data applications development since a large part of the remote sensing users community is familiar with Visible/Infrared multispectral data and not necessarily with monospectral radar data. Nevertheless, especially in the case of low-income countries, we feel there is an unbalance between training courses, workshops and operational projects effectively executed. A greater association between training programs and national projects seems desirable.
- Pilot projects often refer to totally different activities and often thus do not meet their objective. It should be clear if a given pilot project deals with preliminary assessment of the information content of the data, radiometric or geometric quality assesment, test of the use of satellite imagery for a given thematic application, definition of conditions of operational execution. Without a clear separation between these different objectives and the expected outputs, pilot projects often provide limited results in terms of project formulation and implementation.
- In the case of optical satellite data, storage and conservation costs are increasing. It would be useful to have past data distribution at reduced price.
- At the beginning of satellite remote sensing in the seventies many multidisciplinary groups played an important role in the development of space remote sensing. We feel now that it would sometimes be useful to have a more precise definition of the activities of groups or sub-groups: for example, research/research-development/application promotion/operational mapping and monitoring activities.
- If it is relatively easy to compute the costs of execution of a mapping project (satellite data, manpower, equipments), it is extremely difficult to quantify the long term benefit for the country of map production activities. In order to convince Government authorities to undertake remote sensing projects, it is very important to present a quantification not only of the costs but also of the benefit. A major integration of agro-economists in remote sensing groups is thus desirable.

- The concept of sustainable agriculture is now well accepted and so it is now up to us to create "sustainable" remote sensing, i.e. investing enough in technology developments so that future sensors will be ready to face future challenges but at the same time investing enough in the development of environmental-oriented applications so that remote sensing activities are useful to resolve today's problems.

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HIGH RESOLUTION DETECTION, MONITORING AND ANALYSIS OF CHANGES USING ERS-1 SAR DATA

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ABSTRACT

Since the launch of the first European spaceborne SAR ERS-1, radar remote sensing is now entering the era of operation. Indeed, during the commissioning phase of ERS-1, SAR data were acquired on a regular basis over various test sites of the Commission of the European Communities, ensuring monitoring of the sites, regardless of cloud cover conditions.

The purpose of this paper if twofold. First, we present a processing strategy for detection of changes occurring to the scene in an ERS-1 time series acquired during several months. Then, careful analysis of the detected changes, related to environmental survey data (meteorology, phenology, land-cover and land-use knowledge, ...) gives some insights into the origin and nature of short and medium term changes in radar backscatter detected by ERS-1. Backscatter changes of different land-cover over the time series are finally exploited for better discrimination between surfaces, through a comprehensive multitemporal ERS-1 SAR data discriminant analysis.

Keywords: ERS-1, SAR Images, Change detection, Vegetation, Discriminant analysis.

1. INTRODUCTION

Background

In the framework of the IFI (International Forest Inventory), the Institute of Remote Sensing Applications of the Joint Research Center selected the area of Freiburg (Black Forest) as test site for ERS-1 SAR and several airborne campaigns held in the past and planned in the future (Lavalle & Sieber 1993).

The European ERS-1 satellite, which entered operational phase in 1992, now provides the scientific community with an all weather microwave sensor, actually able to cover a given site every 35 days. During the ERS-1 commissioning phase in 1991, SAR data were acquired over this test-site every 3 days (Section II).

Compared to the multispectral capabilities of optical spaceborne sensors the information content of a single frequency SAR like the ERS-1 AMI for land and forestry applications may be limited. However, continuous spaceborne SAR coverage may provide more information than can be obtained with single or limited optical spaceborne observations. ERS-1 SAR data will actually allow the filling of eventual temporal gaps of optical coverage, as well as ensuring throughout the year radar cost-efficient coverage of the site, with the purpose to continuously both refine and/or correct forest and crop surfaces estimates.

To profit from this advantage it is necessary to investigate the information content in ERS-1 SAR data under a variety of scene related and environmental conditions (Lavalle et al. 1993).

Objectives

The objective of this study is to exploit multidate ERS-1 observations and the available rich ground truth data set in order to assess the forestry information content of ERS-1 SAR data, the potential for improved information extraction from multitemporal C-band SAR data and techniques for change detection and monitoring purposes. We first try to establish qualitative short term relationships between backscatter and meteorological conditions, as well as longer term (seasonal) relationships between backscatter and forest/land-use evolution. Our final purpose is then to exploit the resulting influence of these external factors acting on the backscatter, in order to gain insight into optimal use of multitemporal ERS-1 data for land-use/land-cover (and especially forest) analysis.

Data processing and analysis

Computer image understanding tasks are often divided into low-level and high-level (processing). In the particular case of SAR data, low level processing or processing, includes image adaptive speckle filtering, in order to reduce problem complexity by enhancing desirable image properties as signal to noise ratio, reliable estimate of the radar reflectivity, structural features and textural properties. For this purpose, a standard data low-level processing chain was established in section III.

In the high-level processing, meaningful descriptions of the physical objects observed by the SAR sensor include the geographical identification of changing areas, as well as type of change. This high level processing will be treated in sections IV, V and VI.

2. DESCRIPTION OF THE TEST-SITE, ERS-1 SAR TIME SERIES AND GROUND TRUTH

In a relatively small area, the Freiburg-Black Forest test-site in southwest Germany uniquely represents landforms as well as geographical and climate units, typical of temperate Central European landscapes. The study area (about 30 x 30 km) stretches from France over the fertile Rhine valley with its sub-mediterranean climate and its variety of agricultural crops, vineyards and forests to the city of Freiburg in the centre of the area. From there it passes the western slope of the Black Forest up to a height of 1 414m with elevation differences of more than 600 meters, mostly covered with forest. Therefore, it is possible to investigate a variety of environmental conditions and also multitemporal vegetation aspects in one ERS-1 acquisition due to the phenological difference of around three weeks between the low altitude Rhine valley and the high altitude Black Forest. The study area contains a variety of forest communities with predominantly deciduous species on the lower regions, whereas conifers dominate at higher elevations.

ERS-1 acquisitions (Single Look Complex (SLC) data) from the commissioning phase in 1991 and from the following multidisciplinary phase in 1992/93 (c.f. Table 1) were selected to cover a variety of seasonal and therefore phenological stages and different meteorological conditions. Data were delivered either by the D-PAF or by ESA/ESRIN, with an original pixel size of 3.9m in azimuth and about 16m in range. All data were acquired during ascending passes of the ERS-1 satellite.

Meteorological data (e.g. precipitation, temperature, relative humidity) were compiled continuously from July 1991 on, by three meteorological stations (Freiburg in the Rhine Valley, Feldberg and Freudenstadt in the Black Forest) of the Deutschen Wetterdienst. A DEM from the Landesvermessungsamt Baden-Württemberg was also available for the whole area.

For selected forests in the Rhine valley and on the western slopes of the Black Forest a GIS data base containing forestry information from the regular forest taxation performed by the Landesforstverwaltung Baden-Württemberg in 1990 was available.

Data analysis was made by selecting a wide range of well documented ground samples. Therefore, 40 test areas (forest, agriculture, grassland, built-up areas, water bodies), each a size greater than 2.5 ha. were selected on flat terrain within the test site.

3. A PROCESSING CHAIN FOR CHANGE DETECTION IN MULTITEMPORAL ERS-1 SAR DATA

The overall processing chain (Fig.1) detailed in the following is especially dedicated to monitor the changes occurring to the scene at high spatial resolution. In developing this processing chain, emphasis was put on efficiency in terms of computation time and data storage. Every acquisition was processed as follows:

Data co-registration:

Data co-registration was performed by shifting the frames in range and azimuth. This proved very accurate for the commissioning phase data, but less efficient for the 1992/93 data (maximum error of 2 pixels on the edge of the test-site), because of the slight change in ERS-1 orbit inclination. Nevertheless, accurate individual co-registration of each of our 40 test areas was also performed.

Data calibration

We did take into account the changes in calibration constants introduced in the ESA/ESRIN and DPAFERS-1 SAR processors, in April and November 1992 (calibration constant K=-48.13 dB, for the data processed after 15 November 1992, K=-52.27 dB for the data processed from 6 April 1992 to 15 November 1992). Recent work shows that uncertainties in ERS-1 calibration are within $\pm$ 0.8 dB (Laur et al. 1993, Lavalle 1993). Antenna pattern and range spreading loss corrections (Laur et al. 1993) were also performed using JRC developed software (Lavalle 1993).

Spatial multilooking

The multilooking operation is done spatially by averaging the intensities of 5 consecutive pixels in the azimuth direction, then converting the resulting pixel value in amplitude by taking its square root. An overlapping of 1 pixel in azimuth is introduced, in order to introduce a spatial correlation between adjacent pixels in the multilooked image, and then to preserve thin features present in the 1-look SLC data.

The final equivalent number of looks (ENL) after this operation is L=4.8 looks in the resulting image. The pixel sampling is then about 16 x 16 meters, with a spatial resolution comparable to that of PRI data, but with much better speckle prefiltering. This pixel size corresponds also to an appropriate sampling rate with regard to the nominal ERS-1 spatial resolution of about 22 x 22 meters.

Data compression

Data compression is made by storing the multilooked image on 8-bit amplitude data. The amplitude rescaling is performed linearly (simple division of the amplitude values). The scaling factor, which is kept for further treatment in order to conserve data calibration, is determined using global statistics on the strong scatterers. This way, saturation occurs only for very strong scatterers, mainly located within the urban areas which are not of interest for our study. Given the low values of these scaling factors (of the order of 1.5 for SLC data), the loss of radiometric accuracy during this operation is negligible, within natural areas.

Restoration of the radar reflectivity

The next processing step consists in adaptive speckle filtering by means of the Gamma-Gamma Maximum A Posteriori feature retaining speckle filter, using 11 x 11 processing window size for structures detection and 9 x 9 processing window size for speckle filtering (Lopes et al. 1993). This operation allows a drastic speckle reduction from L=4.8 looks to an ENL of about L=300 looks. It restores the radiometric information with an error not exceeding, with 90 percent confidence level, $\pm$ 0.35 dB in homogeneous (textureless) areas of the scene. As a consequence, the filter preserves the radiometric accuracy of ERS 1-SAR measurement.

As the filter adapts to variations in scene heterogeneity, and includes feature retaining enhancements, scene texture and structural scene features like edges, lines and strong scatters, are preserved, leading to very limited loss in the useful spatial resolution, as shown in earlier studies (Lopes et al. 1993).

Monitoring of changes

The following preprocessing step is the development of change detectors, some of them designed for ERS-1 time series. The change indices were computed, using the 17 August 1991 acquisition as a reference point for change analysis.

For every other acquisition, we computed the following quantities, already extensively used in a number of previous studies concerning either optical (Singh 1989) or SAR (Villasensor et al. 1993) change detection:
- radiometric difference to reference data;
- ratio of radiometries between actual and reference data;
- comparison of structures detection, by adaptive threshholding of the locally computed coefficient of variation.

4. CHANGES IN RADAR BACKSCATTER WITH ENVIRONMENTAL PARAMETERS

Since some observational data suggest (Dobson et al. 1991, Moghaddam et al. 1993, Way et al. 1993, Pulliainen et al. 1993) that the variability of SAR backscatter is related to changing environmental conditions, a simple analysis was undertaken by calculating correlations between mean backscatter of test areas and meteorological parameters. In Table 2, results of correlations between precipitation measurements and mean backscatter values of three vegetated areas (grassland, agriculture and forest) and an urban area are presented. Precipitation measurements were averaged for time frames of 2, 4, 6, 8, 10 and 20 days before each ERS-1 acquisition, in order to characterize wet and dry periods before the acquisitions. This should allow the study of the influence of varying moisture conditions on backscatter behaviour of different kinds of land-use classes.

These correlations show that the three vegetated areas seem to react generally with an increase of backscatter (coefficients of correlations around 0.8 for precipitation averaged for 20 days) whereas the unvegetated urban area shows no significant correlation with precipitation. There is possibly also a difference in the time response of backscatter to increasing available moisture, as can be seen from the higher correlation of agriculture for average precipitation of 2 or 4 days compared to the grassland and the forested areas.

5. VEGETATION AND FOREST DYNAMICS

Grassland, agriculture and forest-vegetated areas mainly characterizing a landscape -were used to study phenological and seasonal influences on backscatter evolution, from which typical examples are presented in the following.

As can be seen from Fig.2, discrimination of grassland (in this case natural vegetation) and agriculture is possible from October onward. From our knowledge of the local agricultural practice, the increase of backscatter for the agriculture area can be attributed to harvesting and soil treatment resulting in bare soil conditions during the winter period. The same is also valid for the differentiation of forest and agriculture (Fig.3), also if test areas are considered with a mixing of signatures during the summer period.

Surprisingly, there is no clear indication of any effect of leaf fall on backscatter of deciduous trees, as can be seen in Fig.4, which shows the comparison of a mixed deciduous and a coniferous (spruce) stand. Similar results have also been found by other authors (Pulliainen et al. 1991, Ahern et al. 1993). Also, a decrease of conifer backscatter during the winter period (Fig. 4) was observed by other authors (Ahern et al. 1993), who attribute this to seasonal dependent differences in dielectrics of conifers, but an explanation for this backscatter behaviour is not obvious without further investigation involving controlled experiments and theoretical calculations.

The comparison of a young 10 year old stand, and an old 110 year old stand in Fig. 5 shows a possible rough discrimination of age classes in mixed deciduous forests. This indicates a certain sensitivity of C-band SAR to forest biomass or related parameters (Lavalle et al. 1993) which needs to be confirmed by further investigation.

To summarize the above observations for all vegetated test areas, Fig. 6 shows a plot of the backscatter range, defined as the difference between maximum and minimum measured backscatter of all acquisitions, versus the average backscatter value of all measurements. Generally different target groups, i.e. different combinations of high or low average backscatter and high or low dynamic range can be distinguished. Woody plants/forests form a group with high backscatter and a relatively low dynamic range of backscatter over the seasons. In this group, conifers show the highest dynamic range, while young stands show the lowest average backscatter. The remaining category contains herbaceous vegetation (grassland) with a low average backscatter and medium dynamic range, and agriculture with the highest dynamic range of backscatter due to man-made influences. A separation of woody and herbaceous vegetation and also of different accumulations of biomass seems to be possible using this representation.

Combining this information and calculating principal components, it is possible to focus on the statistics of land use classes of interest. Principal component analysis (Fund & Le Drew 1987, Eklund & Singh, 1993, Gong 1993) shows that discrimination uses different backscatter behaviour of land use/forest classes due to environmental and seasonal and in terms of agricultural areas, man-made influences.

Fig.7, the first three principal components of a sub-frame of the test site calculated using the statistics of a forested area, allows a clear discrimination of forested and non forested areas and also differentiations inside the forest in terms of young (dark blue-green tones) and old (brighter green tones) stands. Using this approach, information on forest structure is elaborated for further digital or visual interpretation. Although the principal component analysis was not optimized for agricultural themes, this colour representation also allows discrimination between different agricultural surfaces.

It should be mentioned that these first three principal components only contain about 45 percent of the overall variance of the full data set and that about 5 percent of the variance is still present in the 10. principal component. That means that each acquisition adds new information about the land use class of interest due to the combined meteorological, phenological and seasonal influences on backscatter.

Some definite trends in examples of consecutive ratio images (all referenced to 17 August 1991) were observed. Depending on the time of the year, backscatter increases or decreases occur in the forests, agriculture fields or grasslands. This indicates the potential to detect and monitor dynamic evaluation in the environment/landscape if the general temporal behaviour of processes and related changes of backscatter in a specific area are known.

6. CHANGE IN TEXTURAL PROPERTIES AS A SOURCE OF STRUCTURAL INFORMATION

The efficiency of surface characterization using textural information derived from first (scene coefficient of variation) and second order statistics (scene auto-correlation function) has been stated by former studies conducted on SAR (Ulaby et al. 1986, De Grandi et al. 1993) and optical data (Pulz & Brown 1987, Briggs & Wellis 1991). In this study, only scene first order statistics were investigated.

These statistics are estimated in the restored image, making use of a mask of the structural features (edges, lines, strong scatterers). These features are detected in the original SAR data using a shape-adaptive processing window, determined using ratio detectors (Lopes et al 1993). This allows the local statistics to be computed for a large neighbourhood around the pixel under consideration, with a great accuracy within extended areas. Along an edge or a linear feature, or in the presence of strong texture, the sample on which these statistics are estimated reduces to the set of pixels, which are statistically similar to the pixel under consideration (Nezry et al. 1993a). When the local scene coefficient of variation is computed on a small processing window (3 x 3 pixels), it can be used as a very efficient edge detector.

Only the main structural elements of the scene (the Rhine, built-up areas ...) are readily detected at every date. Nevertheless, as faint forest structures and borders of agricultural fields are not always seen by the SAR, systematic detection of scene structural elements can only be achieved using several acquisitions under different conditions, as already pointed out by Blom (1988).

7. SUMMARY AND CONCLUSIONS

The ERS-1 time series processing chain we developed at JRC is designed to reduce computation time as well as data storage in a concern for operational efficiency. It includes data archiving, antenna pattern and range spreading loss corrections, data multilooking, data compression, speckle reduction, and texture analysis for each ERS-1 acquisition. As a result, change detection can be performed without losing the useful spatial resolution provided by the ERS-1 SAR system, and at high radiometric resolution.

Data analysis was made by selecting a wide range of well documented ground samples (forest, agriculture, built-up areas) and correlating the detected changes with meteorological and phenological survey data.

Findings

i) The changes in backscatter observed by the ERS-1 SAR are fairly well correlated with the variation of meteorological parameters (i.e. precipitation) for different land-use. In fact, the temporal evolution of the C-band reflectivity of vegetated areas measured by ERS-1 appears to be sensitive to changes in moisture conditions, as already stated by Hsu et al. 1993.

ii) Long-term variations due to phenological and seasonal effects can then be used to discriminate land use classes. Temporal backscatter profiles show that a good discrimination of vegetated areas (grassland, agriculture, forest) is achieved from October to May.

iii) Concerning mixed deciduous forests, a differentiation of young (about 10 years) and old (more than 100 years) stands should be possible throughout the year. A possible separation of deciduous and coniferous species during winter should be confirmed by more detailed investigations.

iv) Discriminant analysis of time series allows the identification of different vegetated areas and forest structures taking profit of their different temporal evolution in terms of radar reflectivity.

v) Temporal variation in scene textural properties is also a useful discriminant since scene structural elements not apparent at a given date are identified on another date.

In conclusion, high spatial resolution monitoring of vegetated surfaces, forest conversion into cultivated or bare soils, or agriculture management is possible using multitemporal ERS-1 data. The method, validated on the well documented Black Forest site could also be adapted to the case of different European sites under the effect of different climatic conditions.

Future works

At this point, trends of changes observed in ERS-1 SAR data can be interpreted in terms of physical phenomena occurring within the scene. In the near future they should be better exploited using multiple source data, e.g.:

- incorporation of the change detection results into a GIS, which will provide the ancillary data needed for their detailed interpretation;

- establishing a link between the parameters introduced in backscattering models, forest/crops water balance models and predictive agro-meteorological models, and the change detection results, in order to make both easier change interpretation and adjustment of the model's parameters;

- undertaking additional efforts in relating changes occurring in ERS-1 time series to other optical monitoring data (SPOT, Landsat) in order to establish further strategies for complementary use of both microwave and optical sensors (Nezry et al. 1993b), with the twofold scope of improving comprehension of both radar and optical data, and to reduce monitoring costs.

8. ACKNOWLEDGEMENTS

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DATE	ORBIT	PAF
30/07/91	191	ESRIN
14/08/91	406	DPAF
17/08/91	449	DPAF
20/08/91	492	DPAF
23/08/91	535	DPAF
19/09/91	922	ESRIN
28/09/91	1051	ESRIN
19/10/91	1352	ESRIN
31/10/91	1524	ESRIN
06/11/91	1610	ESRIN
15/11/91	1739	ESRIN
18/11/91	1782	ESRIN
30/11/91	1954	DPAF
06/12/91	2040	DPAF
03/05/92	4175	DPAF
07/02/93	8183	ESRIN

Table 1: Selected ERS-1 data set

Averaged on	2 days	4 days	6 days	10 days	20 days
FOREST	0.20	0.39	0.58	0.64	0.70
GRASSLAND	-0.05	0.46	0.44	0.62	0.69
AGRICULTURE	0.36	0.58	0.62	0.69	0.83
URBAN	-0.18	0.00	0.14	0.38	0.32

Table 2:Correlation coefficients between backscatter and precipitations averaged on various time frames before acquisition

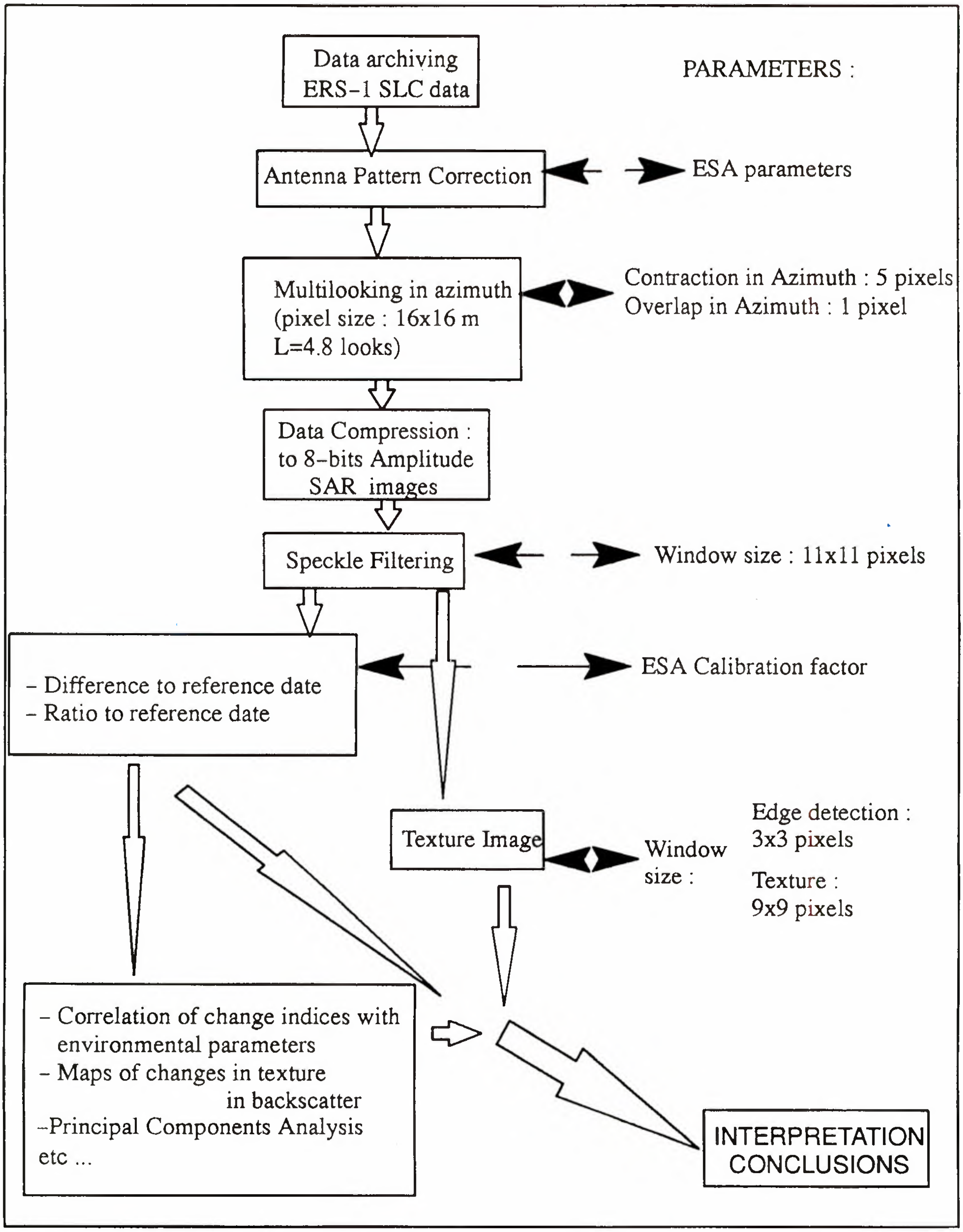

Figure 1: Change detection processing chain for ERS-1 SLC SAR images.

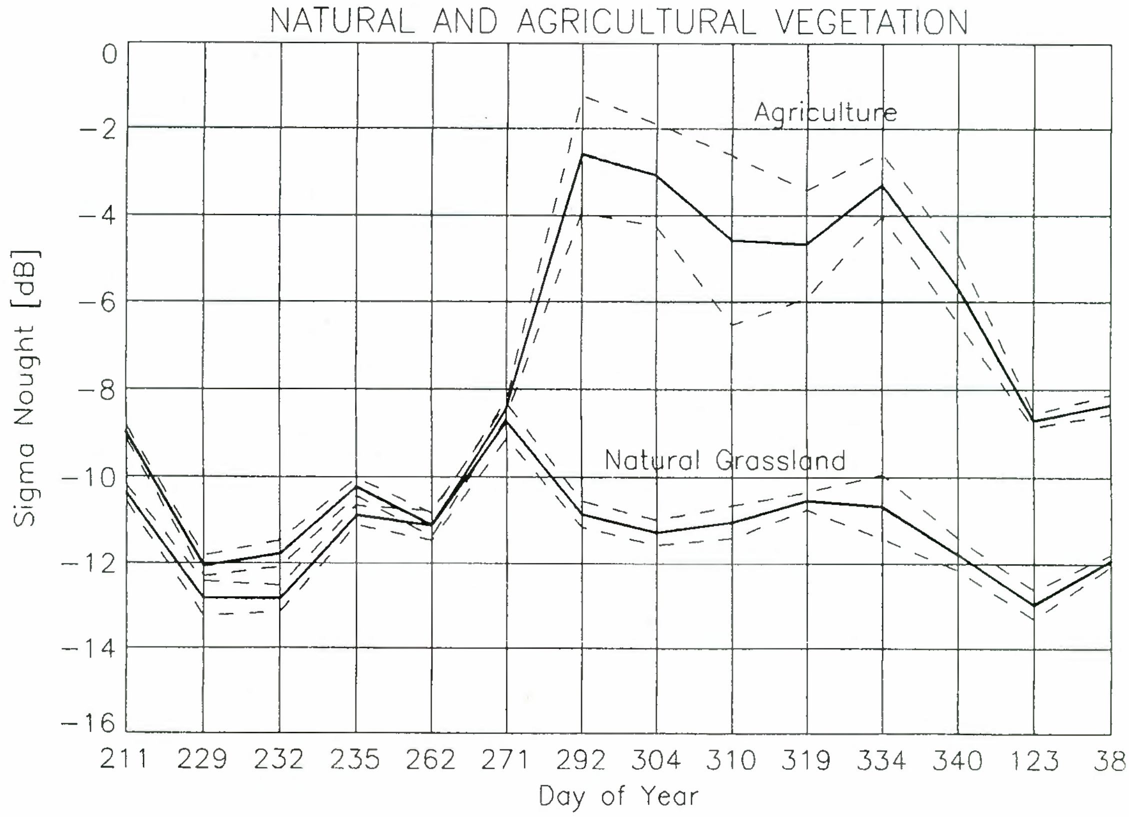

Figure 2: Temporal evolution of backscatter for agriculture and grassland test areas.

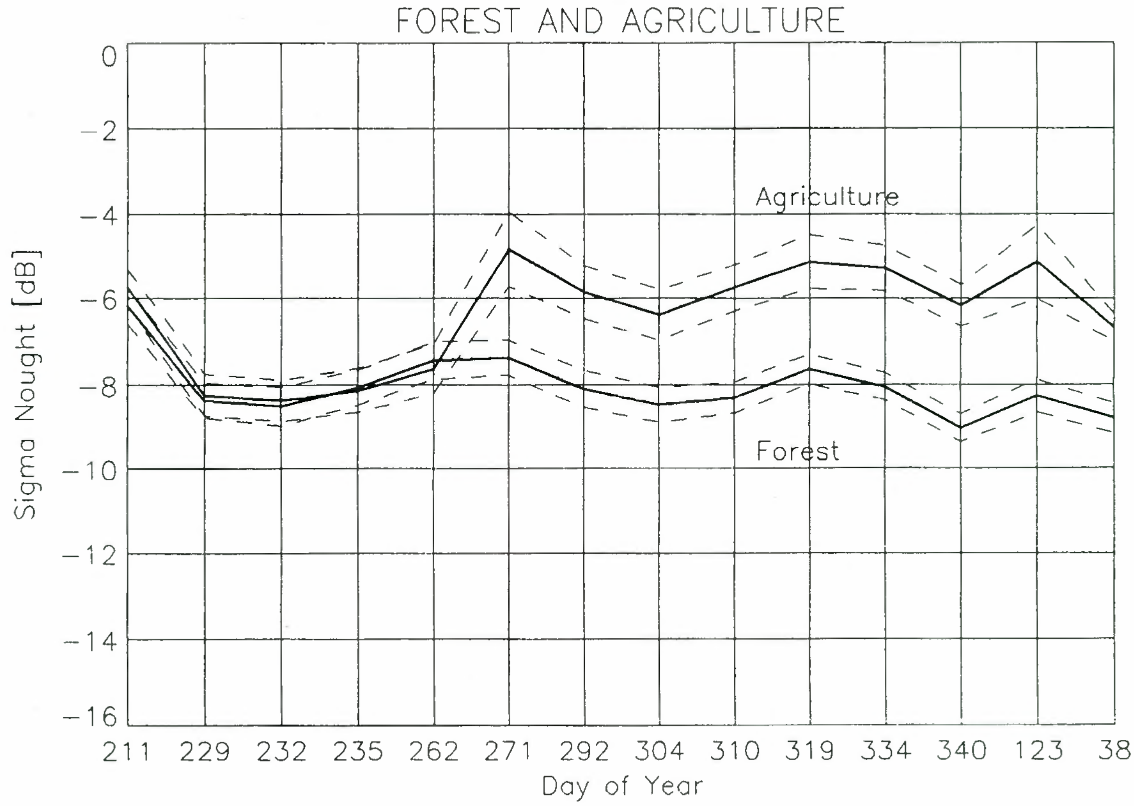

Figure 3: Temporal evolution of backscatter for forest and agriculture test areas.

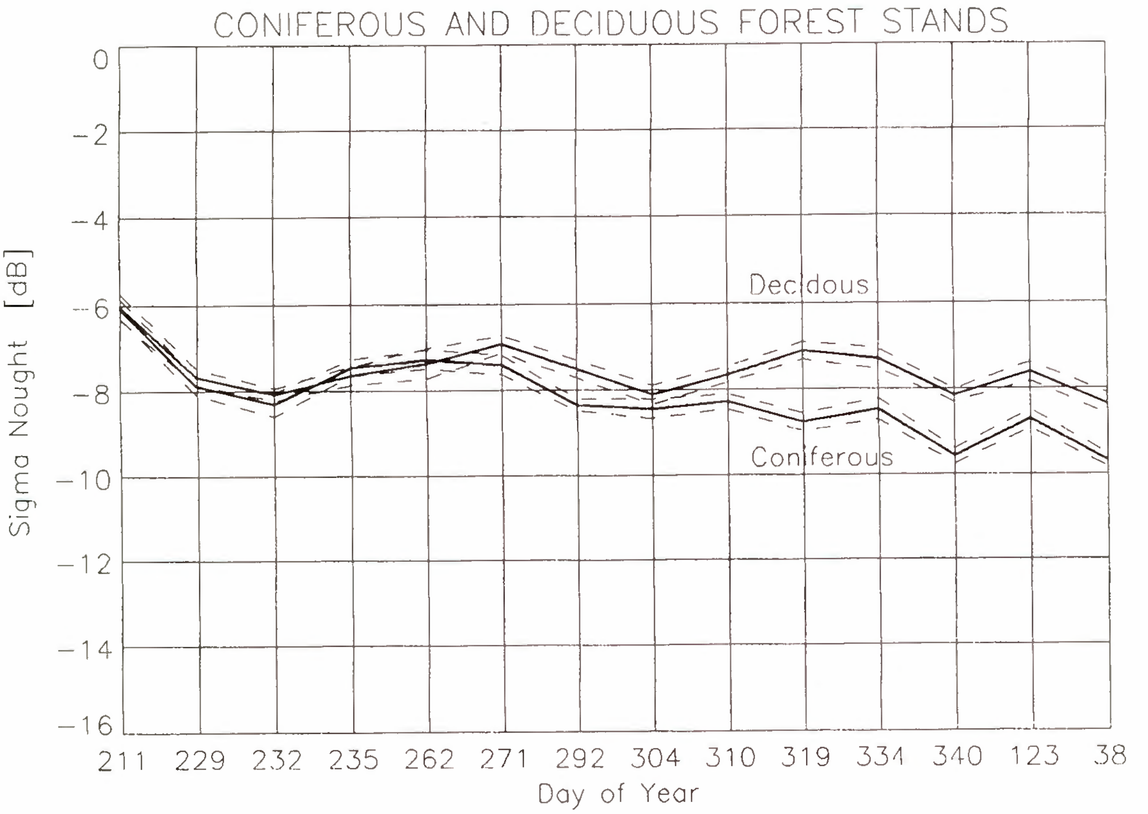

Figure 4: Temporal evolution of backscatter for deciduous and coniferous forested test areas.

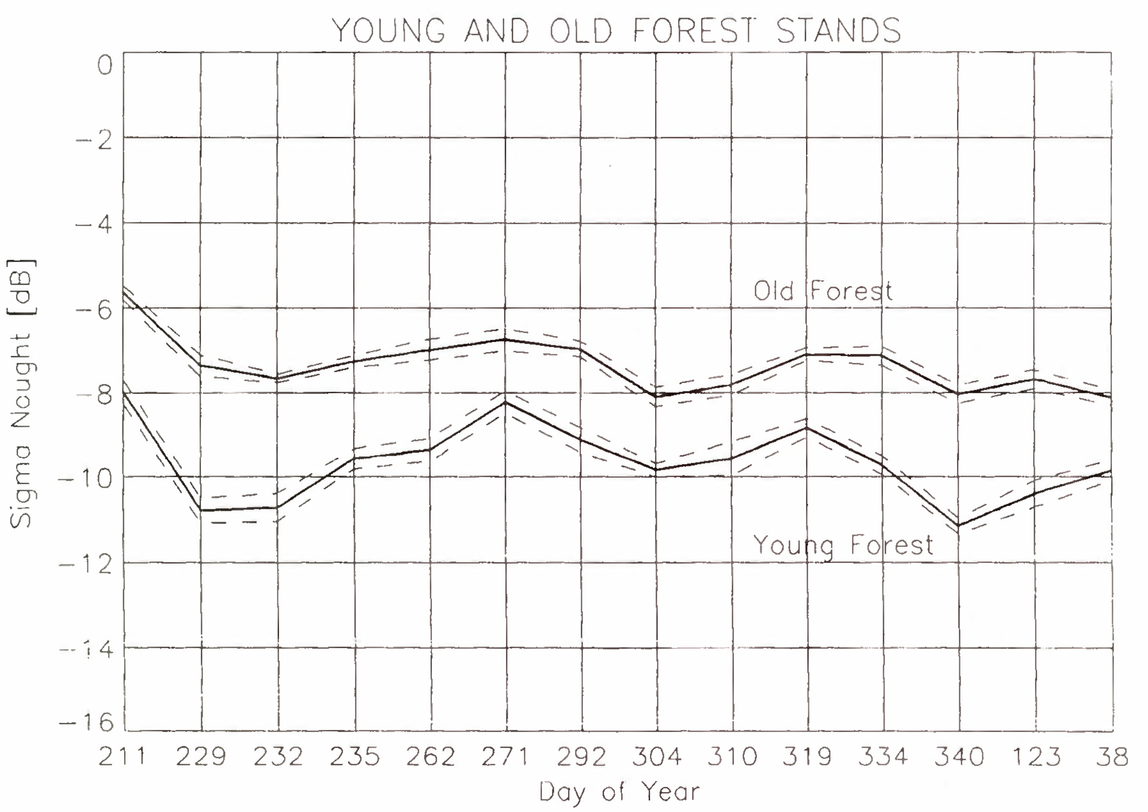

Figure 5: Temporal evolution of backscatter for old and young mixed deciduous stands.

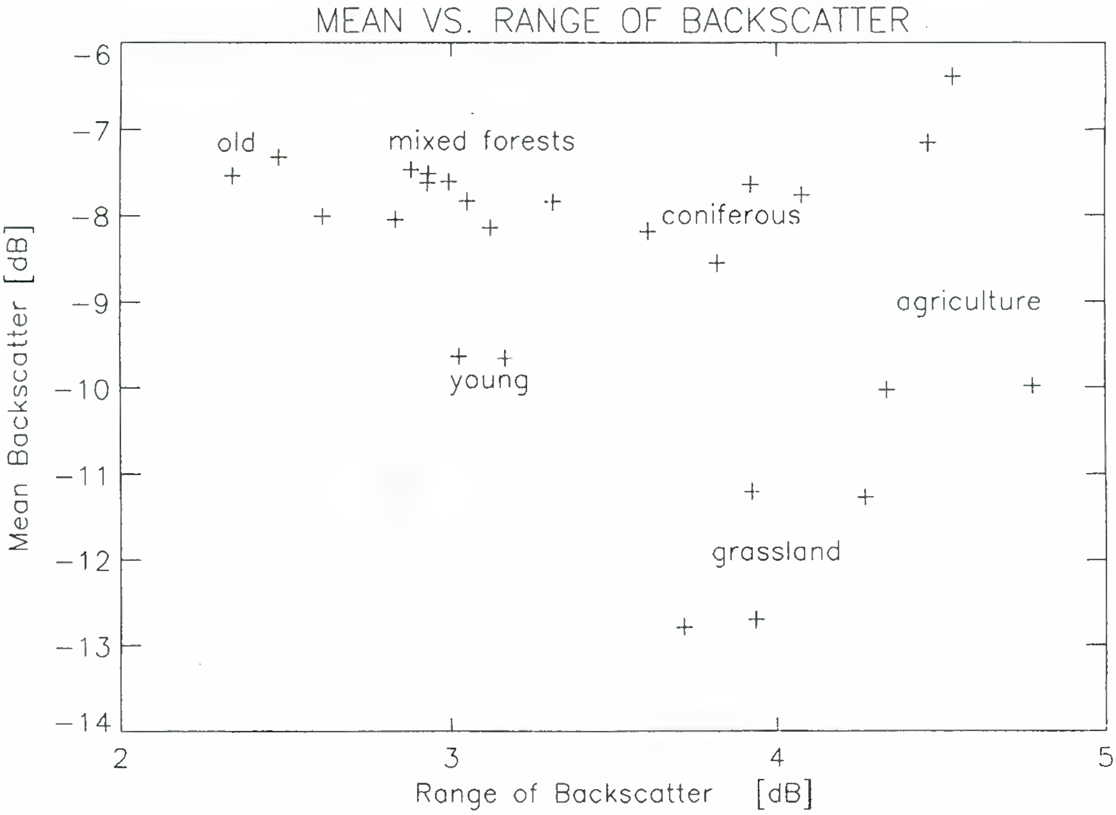

Figure 6: Average backscatter versus seasonal range of backscatter of all ERS-1 acquisitions for different vegetated areas.

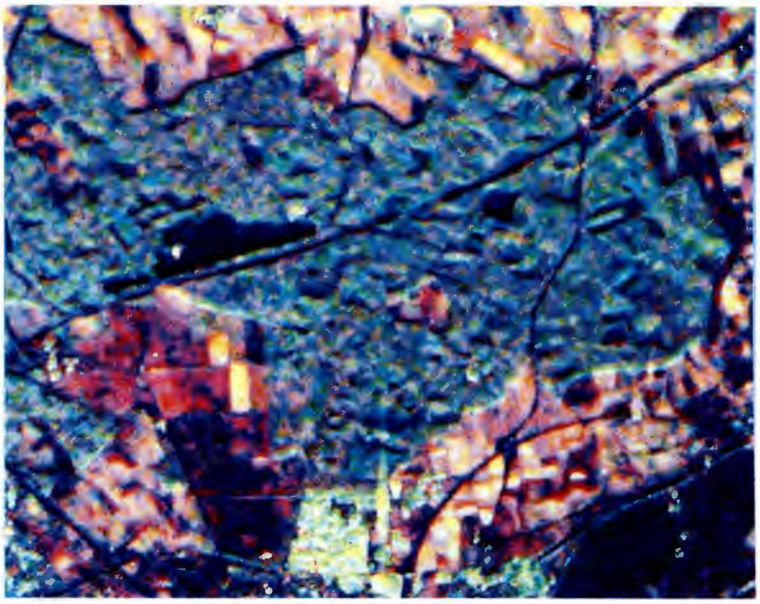

Figure 7: First three Principal Components of a subframe of the test-site in RGB-presentation (3. PC, 1. PC, 2. PC).

AN EVALUATION OF ERS-1 FDC DATA FOR THE RAPID ESTIMATION OF CROP ACREAGE IN EUROPE

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ABSTRACT

The paper describes the work performed by JRC on the Seville (Spain) test-site. Six ERS-1 Fast-Delivery (FD) scenes acquired in the period between April 22 and Dec.23, 1992 over the Seville test-site were analyzed. The information content extracted from these scenes has been evaluated with regard to a four-date SPOT-XS data-set, acquired during the agricultural season in 1992 and the results of a ground survey carried out in May 1992. The preprocessing of the FD-data consisted of 16- to 8-bit conversion, speckle reduction using G-MAP and Texture/Mean filter and geometric registration of the images. Two ERS-1 scenes were considered as being unsuitable for classification purposes. The comparison with AVHRR-imagery and meteorological measurements suggested that this is most probably due to rainfall events and related moisture effects on the ground. Maximum-Likelihood-Classifications (MLC) for 22 land use/ cover classes based on five-date ERS-1, combined three-date ERS-1/ single-date SPOT and single-date SPOT showed a significant increase in classification accuracy of the combined ERS-1/ SPOT data-set in comparison to either ERS-1 or SPOT alone.

Keywords: land-use classification, multi-date ERS-1 FD-data, combined SPOT/ERS-1 data-sets, speckle filtering, NOAA-AVHRR.

1. INTRODUCTION

The Pilot Project for Monitoring Agriculture by Remote Sensing (MARS) includes a specific action aimed at crop acreage estimating and forecasting (Action 4). For 53 European sites optical imagery from TM or SPOT is nominally acquired four times during the growing season. This data is successively analyzed by computer aided photo interpretation techniques. Within 10 days after data reception an updated forecast bulletin for the main crops is published and sent to the General Direction VI (Agriculture) of the EC at Bruxelles.
Due to unfavourable weather conditions in Northern Europe image acquisition is problematic for optical sensors. For 1993, for example, it was not possible to acquire even only one scene over our Irish (Kilkenny) site.

The above described time and weather constraints emphasize Action 4's strong interest in the operational use of ERS-1 FD-data. With regard to the operational approach taken by Action 4 that is mainly based on photointerpretation, the aims of this study have been defined as follows:

- Development and implementation of a preprocessing chain to provide the photointerpreters with images that can be readily integrated into the interpretation process,

- Evaluation of multi-date ERS-1 FD-data in comparison to SPOT-XS for land-use classifications.

The following paragraphs will describe in more detail the work that JRC is carrying out on its Seville test-site. As work is still going on, it can only describe the results obtained so far.

2. TEST SITE

The Seville test-site is an agricultural area located in the South-West of Spain at approximately 37.4° North and 5.8° West. The area is slightly undulated with altitude differences of some 300 meters. It is characterized by an extreme variety of crop types, approximately 30 after the ground surveys and a very irregular field pattern. The main crops are wheat, sunflower, rice, cotton and olives. The rice and cotton growing areas are situated in the flood plain of the river Guadalquivir. Wheat and sunflower fields are found in the Northern, more hilly region generally grown under rainfed conditions, but also on irrigated fields. Olives and various fruits, e.g., Citrus fruit, are cultivated in the central part. The field size ranges from 0.5 to 7 hectares for fruit plantations and wheat fields, respectively.

3. DATA-SET

For this study that has been performed from May to September 1993, the following data-sets were available:

- DEM, grid cell 20 by 20 m, derived from a SPOT panchromatic stereo couple,
- Ground survey, 30 land-use/cover classes from May 1992,
- 2 NOAA-AVHRR from May 27 and October 10, 1992,
- 6 ERS-1 FD-scenes, descending orbits, from April to December 1992,
- 4 SPOT-XS, 40 by 40 km subsets from March to August 1992.

At the present stage, the DEM has only been used to terrain correct tie-points during the geometric correction process, but in the future it will be used to model the radar backscatter for relief induced variations.

The geometry of the SPOT image subsets delivered to Action 4 is corrected for topographic effects and their radiometry has been normalized by transforming the digital numbers to reflectances at the top of the atmosphere.

From the ERS-1 images, the December scene did show a good separation between forest and non-forest, but it had to be discarded from the further analysis, because it did not seem to be relevant for the 1992 agricultural season. However, there are indications that such images of the very early (1993) agricultural season might increase the discrimi
nation of agricultural crops based on the field preparation practices of the farmers and not based on the spectral characteristics of the plants.

The ERS-1 images of May and October did show a sequence of dark and light patches distributed over the scenes. A comparison with NOAA-AVHRR and meteorological data of the same date made it at least plausible, that these effects were related to rainfall events of the same period, probably causing moisture differences on the ground [FIG.1]. The result of a five-date ERS-1 classification demonstrated to be clearly effected by these phenomena, so that the results given for this data-set are only indicative.

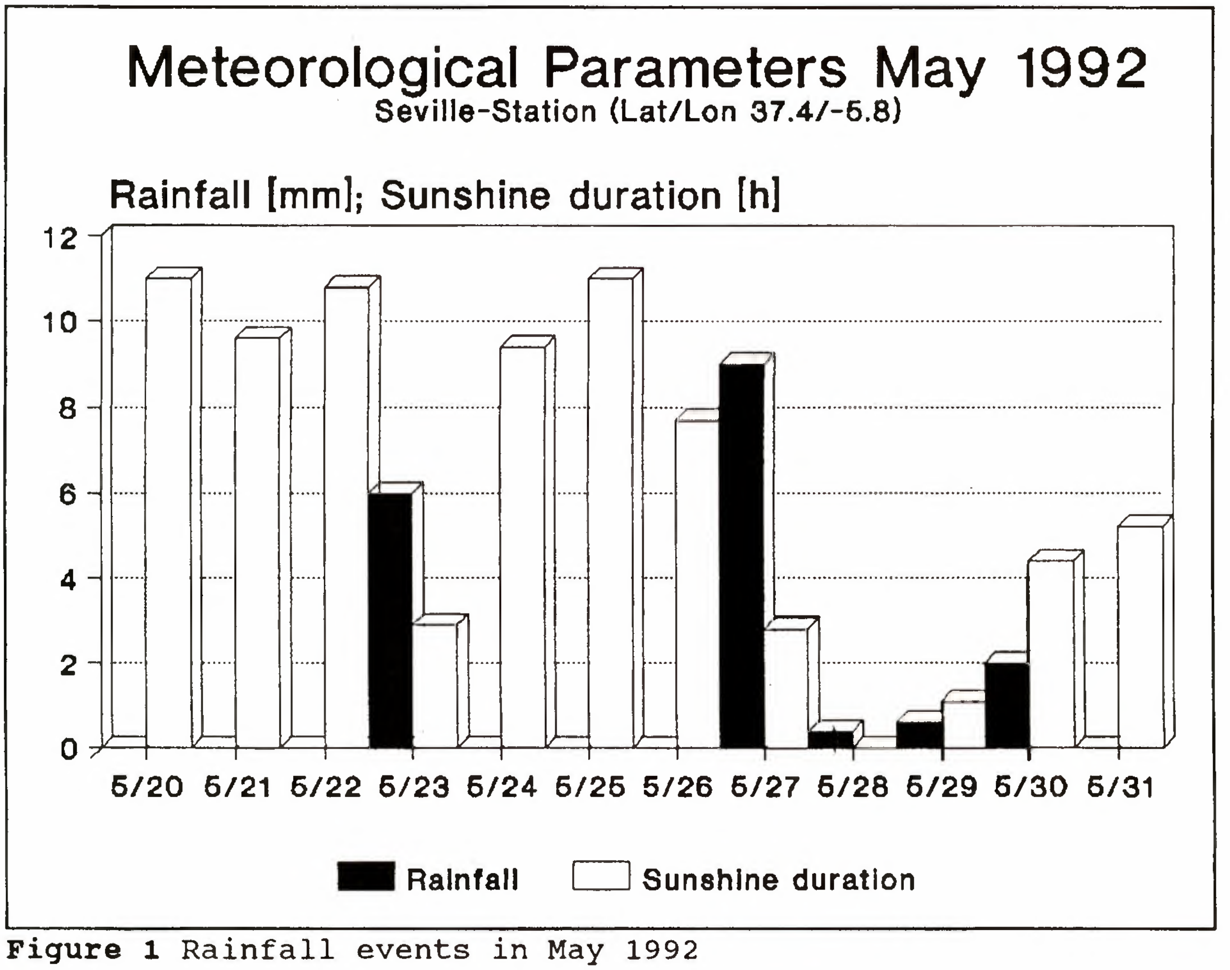

Figure 1 Rainfall events in May 1992

4. CLASSIFICATION

4.1 Filtering

To reduce the speckle effect of the Radar data to be used for visual photointerpretation, the GMAP-filter co-developed by E. Nezry of IRSA's Advanced Technology (AT) unit was used. Special care was taken not to "over"-filter the images and to maintain the inherent texture. In a second step a texture/mean filter, with a 5x5 filter size was applied [1].
The combined GMAP and texture/mean-filter processing shows a significant visual improvement and provides images apparently better suited for Action 4's approach based on photointerpretation.
Additionally, a signature separability index calculated from class means and covariance matrices, did also show an average increase in the order of 64% in comparison to the original data. Despite a slight blurring of the images, it was therefore decided to use these derived channels in the classification process.

4.2 Maximum-Likelihood Classification (MLC)

The 1992 ground survey did provide land-use information on 17 ground segments of 49 ha each. This corresponds to 0.5% of the total area. The segment information was used to train

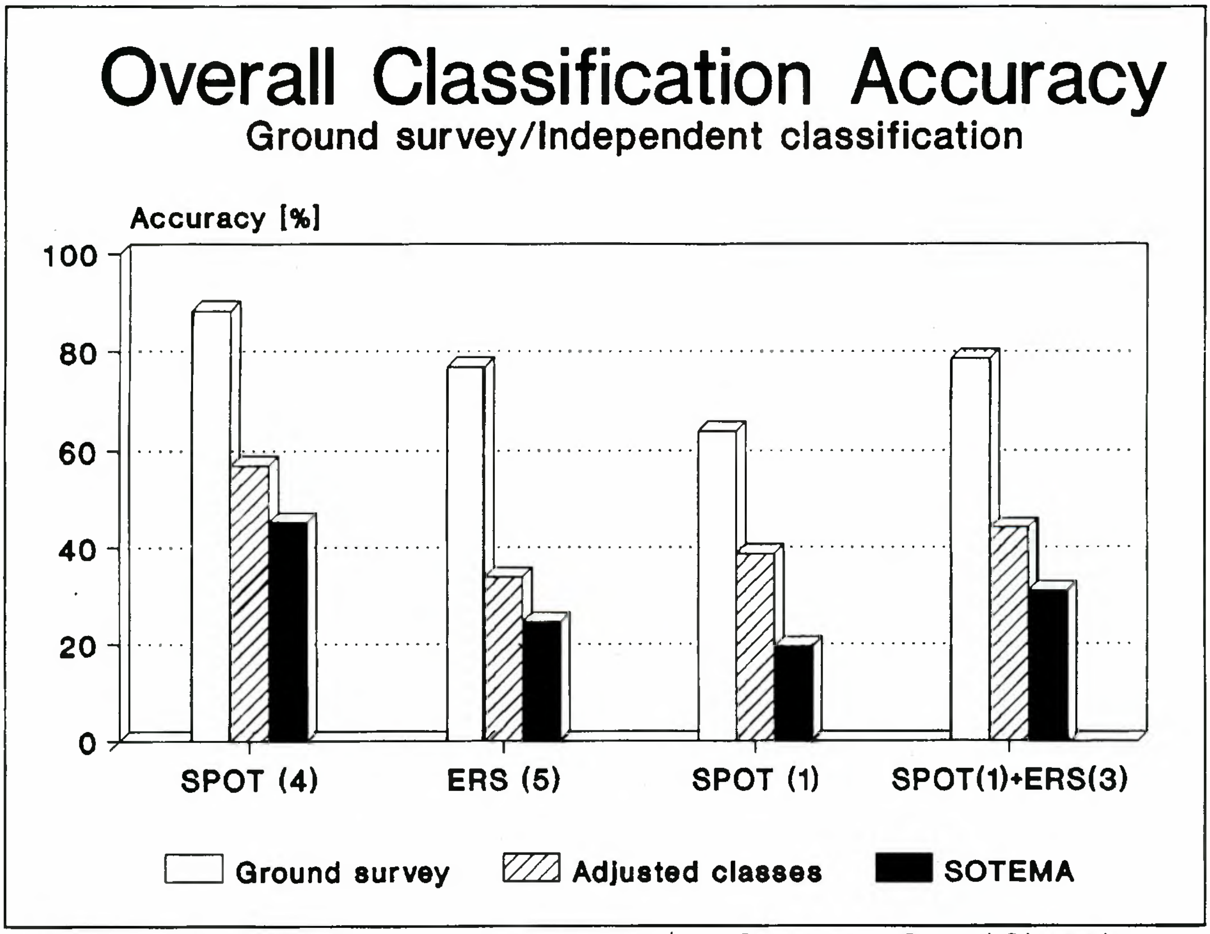

Figure 2 Comparison ground survey / reference classification

the classifier. For the classes water, forest and urban, which could be easily identified in the imagery, additional training areas were delimited. The classification results were checked using the ground survey again, which means that training and verification areas were identical. To overcome this drawback, the figures were also checked against the classification results independently performed under contract by SOTEMA.
The following ML-classifications using various sensor combinations have been performed:

- four-date SPOT-XS (SPOT 4) (23 03, 08 06, 01 07, 26 08 1992),

- five-date ERS-1-FD (ERS 5) (22 04, 27 05, 01 07, 05 08, 14 10 1992),

- single-date SPOT-XS (SPOT 1) (01 07 1992),

- combined three-date ERS-1 (April, July, August) and single-date SPOT (July) (SPOT (1) + ERS (3)).

Figure 2 illustrates that the classifications give generally good results, if compared to the

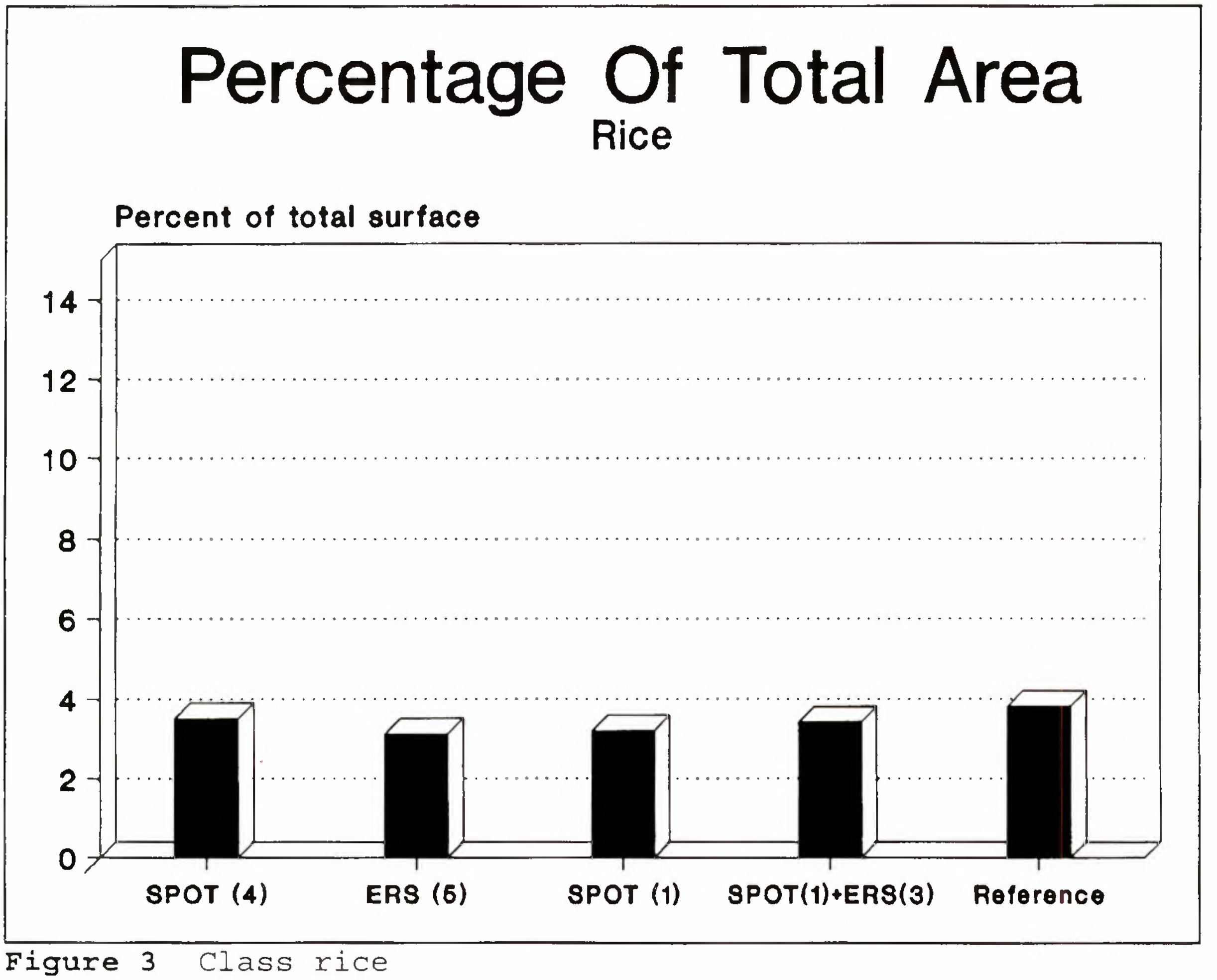

Figure 3 Class rice

ground survey data. The combination of ERS-1 and SPOT gives an accuracy in the order of 80% against 63% of the single-date SPOT alone. This is also the case for the ERS (5) data-set (78%), but this result can only be considered as a first approximation for the above men-

tioned reasons.
However, if compared to the reference classification, the results are very poor. It is important to notice, that the general tendency is still the same, i.e., a relative gain in accuracy between ERS-1/SPOT and SPOT alone. As the reference classification (14 classes) is not directly comparable to the others (22 classes), because it contains certain merged

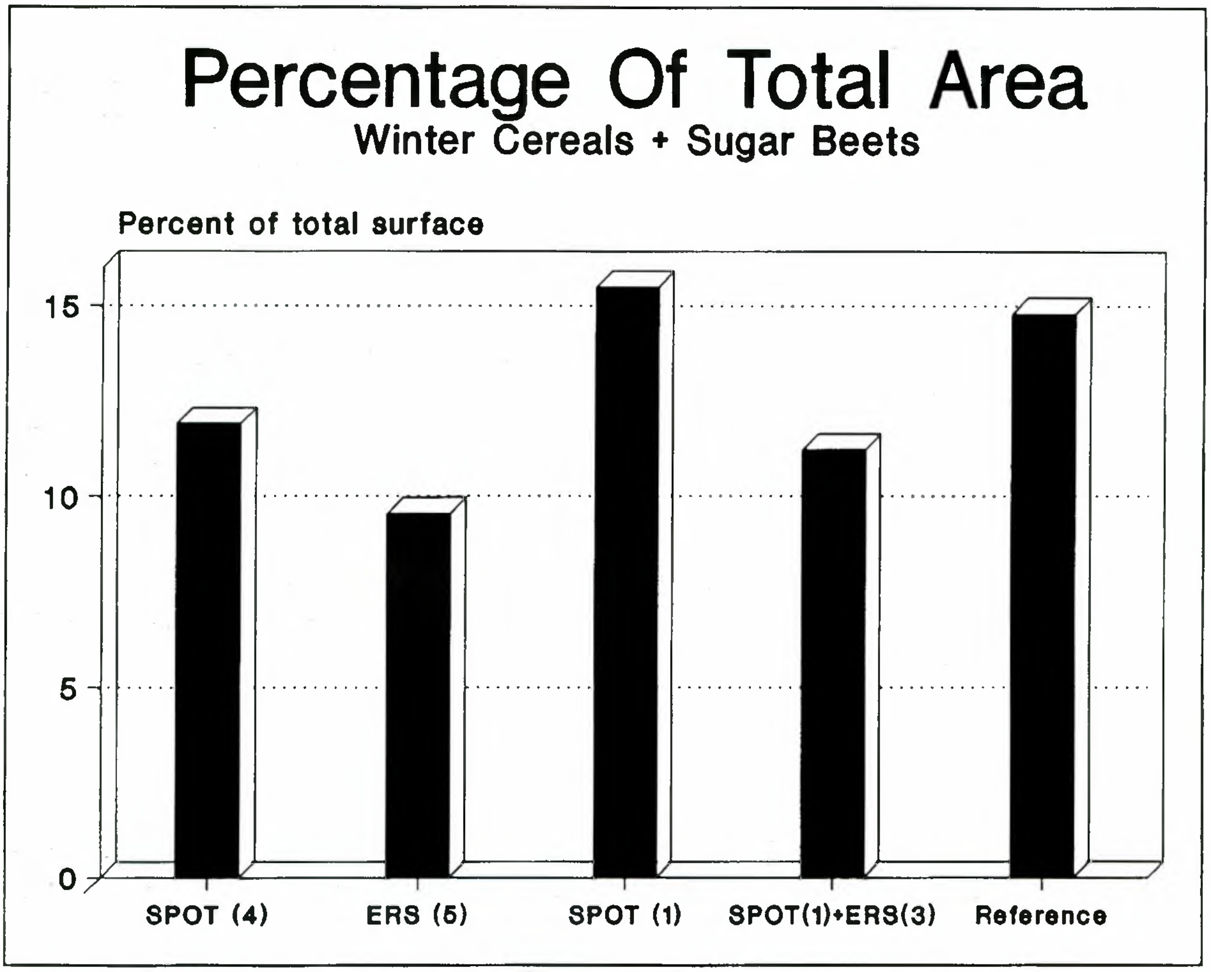

Figure 4 Class winter cereals + sugar beets

classes, i.e., winter cereals and sugar beets are one class, the following figures (Fig.3, Fig.4) allow a better comparison, because they compare only single classes.

For winter cereals and sugar beets the SPOT (1) is closest to the reference. The multi-date classifications give lower, but comparable results, with the combined ERS-1/SPOT close to the multi-date SPOT. For rice all the results are good and ERS-1/SPOT is again close to the SPOT (4).
For further analysis a class merging of the classification results with respect to the reference, even if being difficult, will have to be performed. This should improve the interpretability of the results by the calculation of proper confusion matrices.

5. DISCUSSION OF THE RESULTS ON SEVILLE

As work is still continuing a final discussion of the results is not possible yet. Due to the low sampling rate (0.5%) of the ground survey, a consistent accuracy check could not be performed. A comparison of the results obtained so far to the classification provided by our contractor SOTEMA proves to be difficult because of not congruent classes.
However, there are strong indications, that the accuracy of the ERS-1/SPOT based classification can satisfy the needs of Action 4. High dimensional, multi-date ERS-1 data seem to have good potential too, but this aspect needs further investigations.

6. CONCLUSION

The study on Seville did show the high potential offered by combined ERS-1 and SPOT data-sets for land-use classifications.
The work on the Spanish site led to the implementation of filtering algorithms (GMAP, Texture/Mean), resulting in images better suited for visual interpretation. A combined single-date SPOT, three-date ERS-1-FD data-set performed well in a ML-classification compared to SPOT alone.
There are also strong indications that the SAR-images are affected by rainfall events; at least for land use applications this is a problem. At present, further on-going studies on this subject are carried out at IRSA/AIS.

7. ACKNOWLEDGEMENT

Thanks to E. Nezry from IRSA's AT-unit for assistance with the GMAP filter and helpful discussions. The NOAA-AVHRR processing has been performed by J. Vogt and P. Loopuyt, both from IRSA's AIS-unit.

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USE OF ERS -1 SAR DATA FOR SOIL MOISTURE ASSESSMENT

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ABSTRACT

This project has been carried out for grassland and some agriculture crops in the western part of Poland. ERS-1 SAR data obtained from ESA/FAO for the growing season of 1993 were compared and analysed in relation to volumetric soil moisture, soil water potential, gravimetric vegetation moisture, biomass and other variables collected over the test site. The possibility of applying backscattering coefficient averaged for different blocks of pixels for soil moisture estimates was examined. The results obtained from AVHRR/NOAA data were compared with those obtained from ERS-1 data.

Key words: soil moisture, grassland, arable land, backscattering

1. INTRODUCTION

Investigations into the application of satellite remote sensing data to assess and monitor various soil/vegetation variables over large agriculture areas have been undertaken in the Remote Sensing and Spatial Information Centre - OPOLIS, of the Institute of Geodesy and Cartography, from 1987. The work has resulted in revealing several relationships between information derived from satellite images and the stage of vegetation development. The information about soil moisture is essential to predict the yield of green fodder and other crops. The method which has been developed was based on the use of AVHRR/NOAA data. Due to cloud cover, it was very difficult to get frequent AVHRR/NOAA observations. The first European Remote Sensing Satellite (ERS-1) gives the opportunity to continue the investigation independently of weather conditions. In order to estimate the utility of ERS-1 SAR data for soil moisture assessment in the root zone of vegetation, soil moisture values were compared with backscattering coefficients from grassland and various crops. An ERDAS image processing system was used to locate on radar images points of ground measurements collected simultaneously to ERS-1 overpasses. The study covered the 1993 growing season. The results and discussion are presented below.

2. TEST SITE DESCRIPTION, MEASUREMENTS AND ANALYSIS

The selected test site is located in western Poland, in the Obra Valley, approximately 80 km south-west of Poznañ. The area is covered by large areas of grassland flooded in the spring and agricultural fields with the following dominant crops: wheat, rye, barley, rape, corn, potatoes, sugar-beet. Some parts of the high areas are covered by coniferous or mixed forest. There are also a number of small villages at the test site. Soils throughout the arable land are generally loam and sandy loam and throughout the grassland soils are peat sometimes covered with muck.

During the ERS-1/SAR overpasses measurements of soil/vegetation variables were carried out at the 15 grass and 15 crop ground points. These were: soil moisture specified at the laboratory as volumetric, soil water potential (pF),wet biomass, dry biomass, LAI, height of the vegetation.

ERS-1 SAR data were obtained for 27 May, 12 June, 1 July, 17 July, 5 August and 21 August 1993. Two multitemporal composites were created on which the ground measurement of different size, of 3x3 up to 11x11 pixels. The points for the ground observations were located in the middle of each block.

The relationship of soil moisture at 0-10 cm depth and backscattering coefficient, σ^0, of each block has been statistically elaborated. The backscattering coefficient of an average of 8 x 8 pixels gave the best correlation with soil moisture. However the correlation coefficient for 42 grass points of 5 SAR observations of 1993 was low, 0.53 (Fig.1).

From six SAR images two succesive registrations were chosen, May 27 and July 1 1993. These were data from the same frame where the incidence angle was similar. The correlation of σ^0 with soil moisture from grassland was higher, $r = 0.72$ (Fig. 2). With increasing soil moisture the backscattering coefficient also increases. For these dates, soil moisture values ranged from 10 to 75 % and the range of σ^0 was from -13.5 to -9.5. It seems that for a high differentiation of soil moisture values the backscattering coefficients values did not vary significantly. Information about soil moisture in the root zone of vegetation, which is from 0 to 30 cm depth, is essential for agricultural purposes. As it is shown in Figure 3, there is a strong correlation for the soils at the test site between 0-10 cm and 0-30 cm. Figure 4 presents the relationship between volumetric soil moisture from the 0-30 cm depth and σ^0 for grassland.

The grassland was surrounded by agricultural fields where the influence of soil moisture from the 0-10 cm depth on backscattering coefficient σ^0 was examined for different crops. It was found that the best relationship occurs for winter rye. Figure 5 presents this relationship. Soil moisture mesurements were carried out for 3 plots of winter rye. Backscattering coefficients were calculated for 27 May, 12 June, 1 July, 17 July, 5 August and 21 August SAR data. The backscattering coefficients calculated for these dates for two plots of winter rye were examined. For the 12 June and 1 July the values of the backscattering coefficients were similar, while for 17 July the difference was 1 dB. The difference in gravimetric vegetation moisture for this date was the largest at 500g/m² (Fig.11). The ground data set for other crops from the statistical point of view was to small to examine relationships with backscattering coefficient.

The second part of the investigation was to extend the block of the pixels to the size of NOAA pixels and to examine how the averaging of backscattering coefficient for the area of 1.1 km^2 (88 x 88 pixels) influences the results. The grid of NOAA pixels was overlaid on an ERS-1 image (date 23.05.92). To get one value of soil moisture for each block of 88 x 88 pixels the values of point measurements of soil moisture were averaged against density surfaces on aerial pictures.

Figure 6 shows the relationship between soil moisture and the averaged backscattering coefficient for the blocks of 88 x 88 SAR pixels. For the test area, for each NOAA pixel evapotranspiration was calculated as a residual from the energy budget equation:

$$LE = Rn - H - G$$

With higher values of evapotranspiration, backscattering coefficient σ^0 is lower, which corresponds to the values of biomass (Fig.8). The range of evapotranspiration values was from 160 to 360. The range of σ^0 is narrow, -13.5 to -10.8 (Fig.7). Correlation of backscattering coefficient averaged over the block of 88 x 88 pixels and the mean of ground measurements values gave unexpectedly good results comparing to one ground measurement corresponding to the average σ^0 of 8 x 8 pixels (Fig.9) and (Fig.6).

3. CONCLUSIONS

It has been shown that grass-covered surfaces are easily distinguished by ERS-1 SAR from forest and from drier arable land because the backscattering coefficient from grassland is dominated by surface roughness, biomass and gravimetric vegetation moisture. Generally, backscatter from grass is lower than from arable land due to its specular reflection (Fig.10) which is seen as dark grey tones on SAR images.

These first results show that soil moisture influenced backscattering coefficient value when originating from the same frame of the images (with a similar incidence angle). The average of σ^0 from a small number of pixels did not give as good results as from 8 x 8 pixels. For better results several ground measurements for each block of SAR pixels should be taken. The range of vegetation backscattering coefficients was narrow compared to the range of soil moisture values. Further work is needed to test the utility of ERS-1 SAR data for estimation of soil moisture in the root zone for other crops. Additional work is also needed to verify these results using satellite JERS data.

4. ACKNOWLEDGEMENTS

Assistance of our colleagues from the Remote Sensing and Spatial Information Centre: Z.Bochenek and R.Jankowski in processing of ERS-1/SAR data is greatly acknowledged. We also wish to thank A.Kijowski (DEDAL s.c. Remote Sensing and Environmental Control) for soil moisture and soil water potential measurements.

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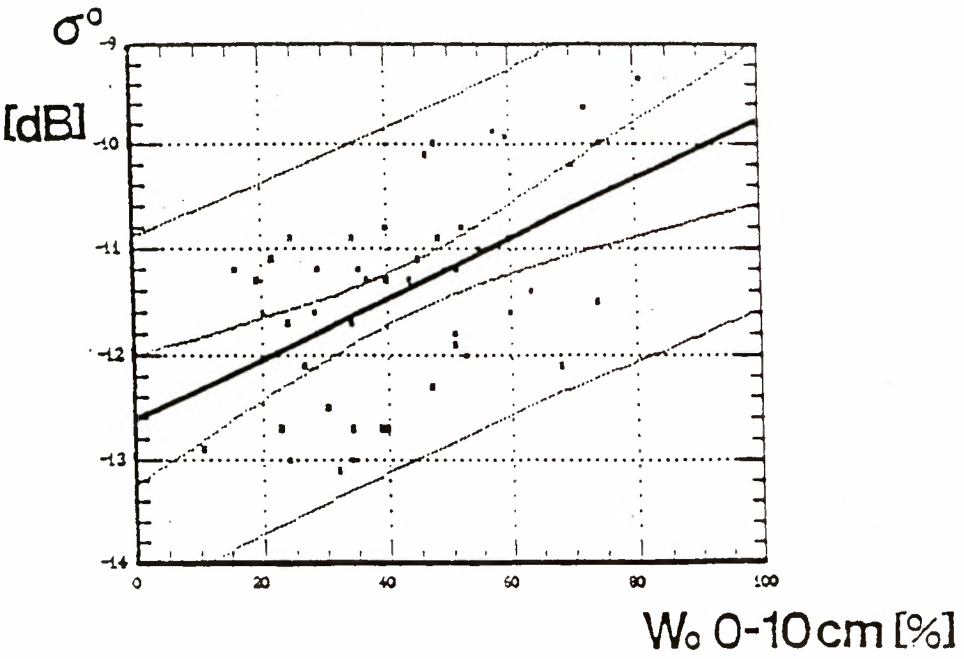
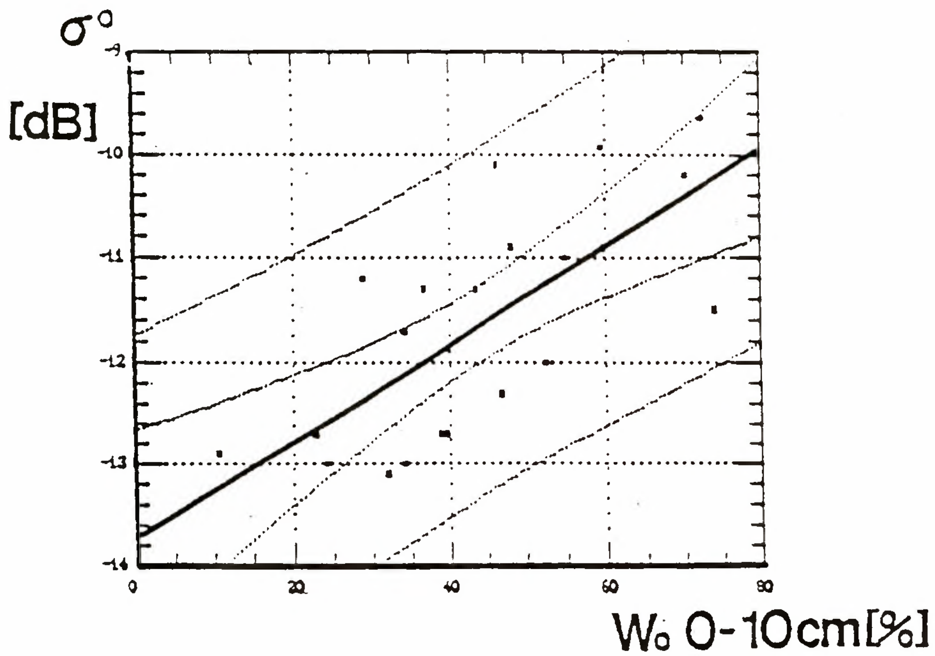


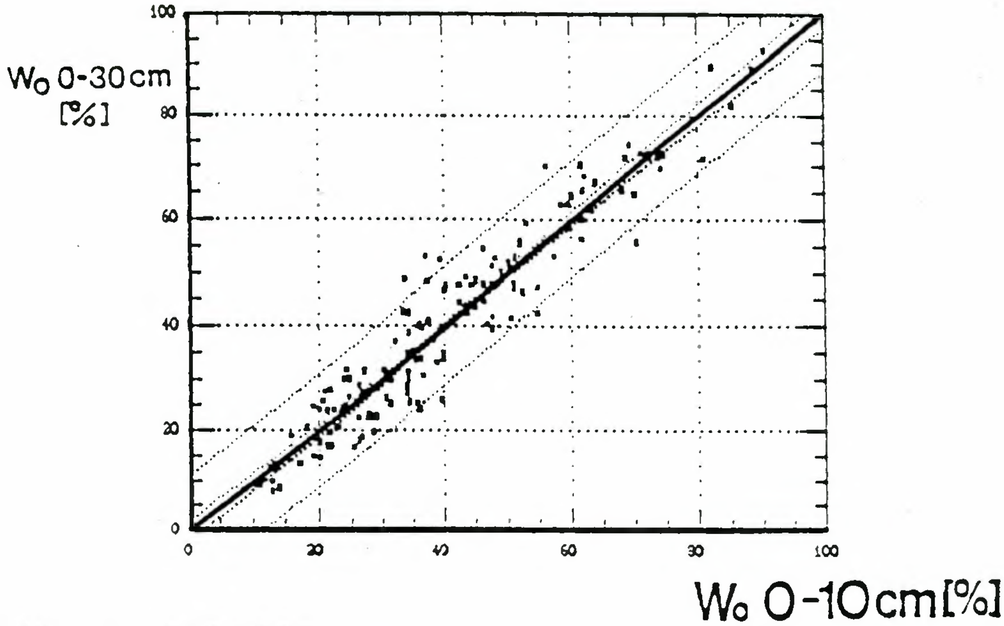
$\sigma^0 = 0.03\ Wo - 12.62$ $\quad r = 0.53$
all observations for 1993

Fig.1: Relation between volumetric soil moisture W_0 [%] from the 0-10 cm depth and backscattering coefficient σ^0 [db]



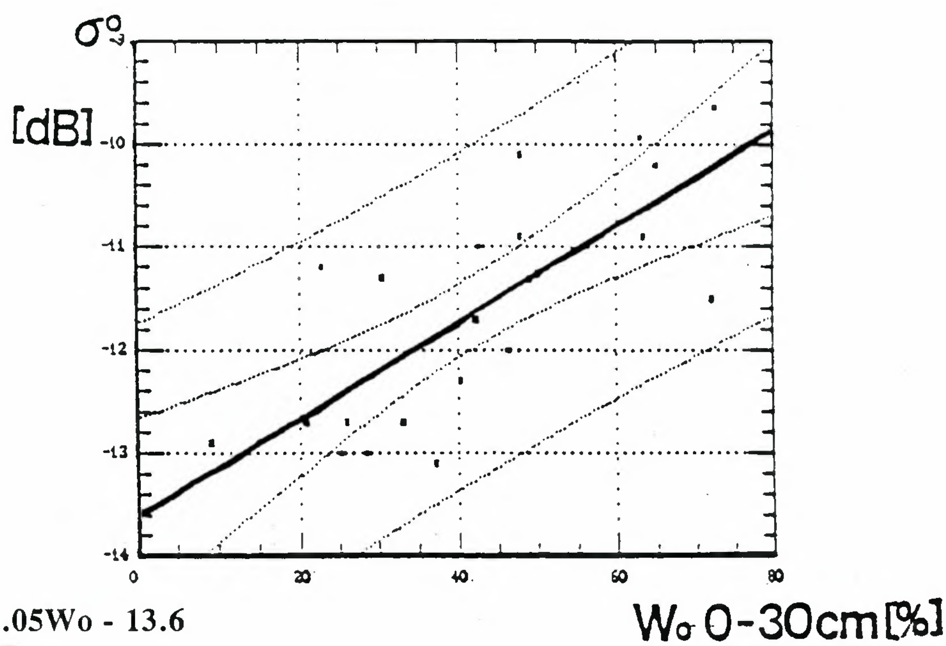
$\sigma^0 = 0.05\ Wo - 13.71$ $\quad r = 0.72$
observations for 27 May and 1 July 1993

Fig.2: Relation between volumetric soil moisture W_0 [%] from the 0-10 cm depth and backscattering coefficient σ^0 [db]



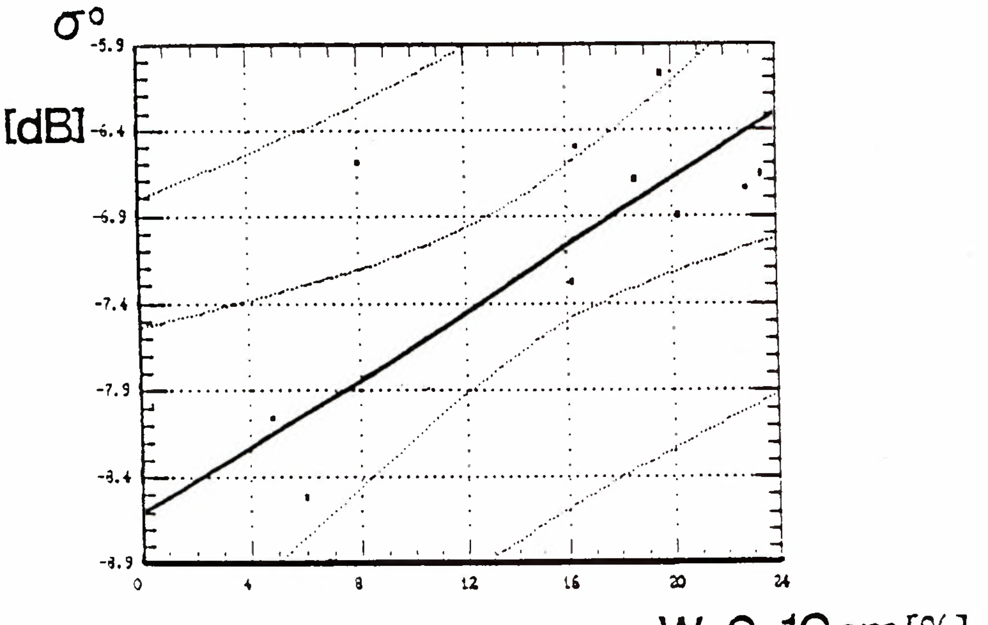
Wo 0-30 = Wo 0-10 - 0.27
r = 0.96
all observations for 1992 and 1993

Fig.3: Relation between volumetric soil moisture Wo [%] from the 0-10 cm and 0-30 cm depth



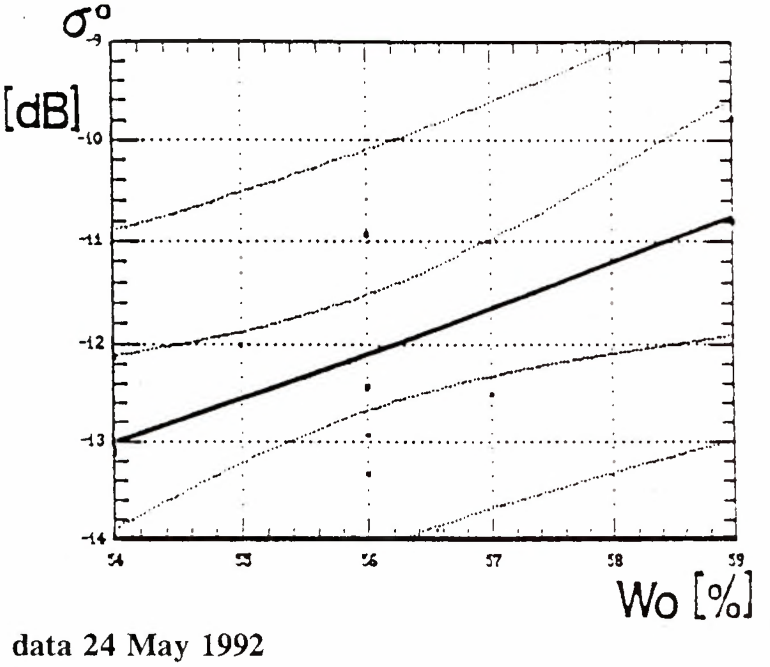
σ^0 = 0.05Wo - 13.6
r = 0.7
observations for 27 May and 1 July 1993

Fig.4: Relation between volumetric soil moisture Wo [%] from the 0-30 cm depth and backscattering coefficient σ^0 [db]



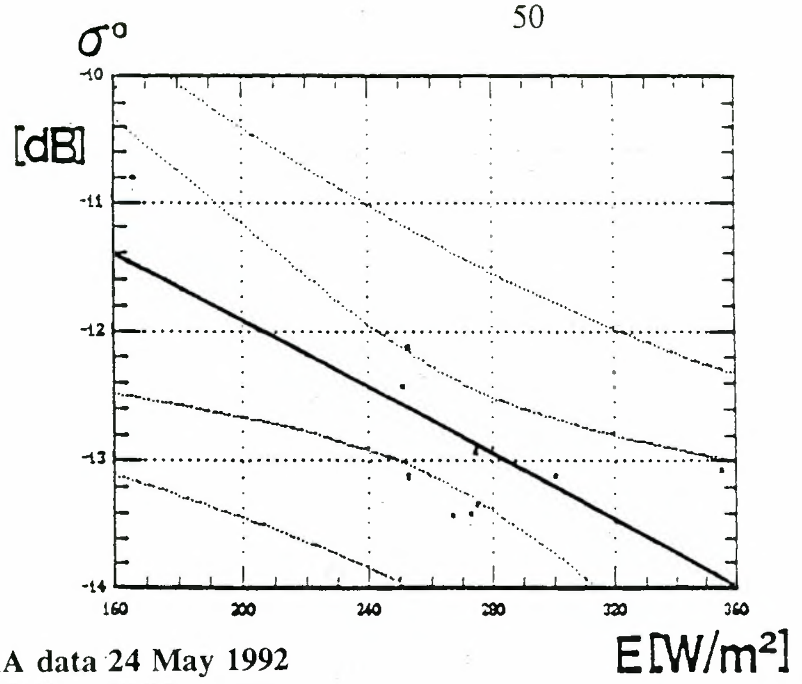
σ^0 = 0.1Wo - 8.6
r = 0.74
all observations for 1993

Fig.5: Relation between volumetric soil moisture Wo [%] from the 0-10 cm depth and backscattering coefficient σ^0 [db] for winter rye



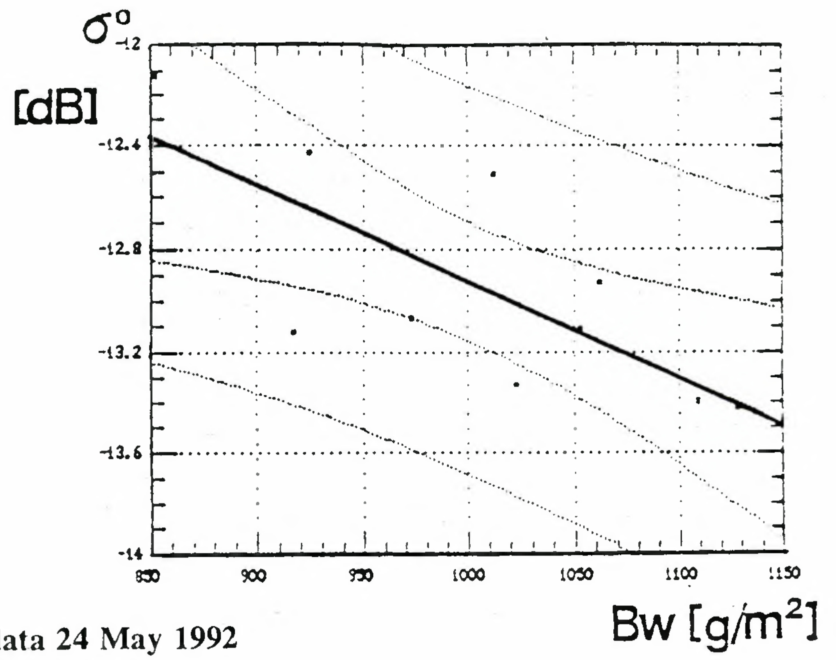
NOAA data 24 May 1992
ERS-1 data 23 May 1992
σ^0 = 0.45Wo - 37.2
r = 0.71 for 10 NOAA pixels

Fig.6: Relation between volumetric soil moisture Wo [%] from the 0-10 cm depth and backscattering coefficient σ^0 [db] averaged for NOAA pixels



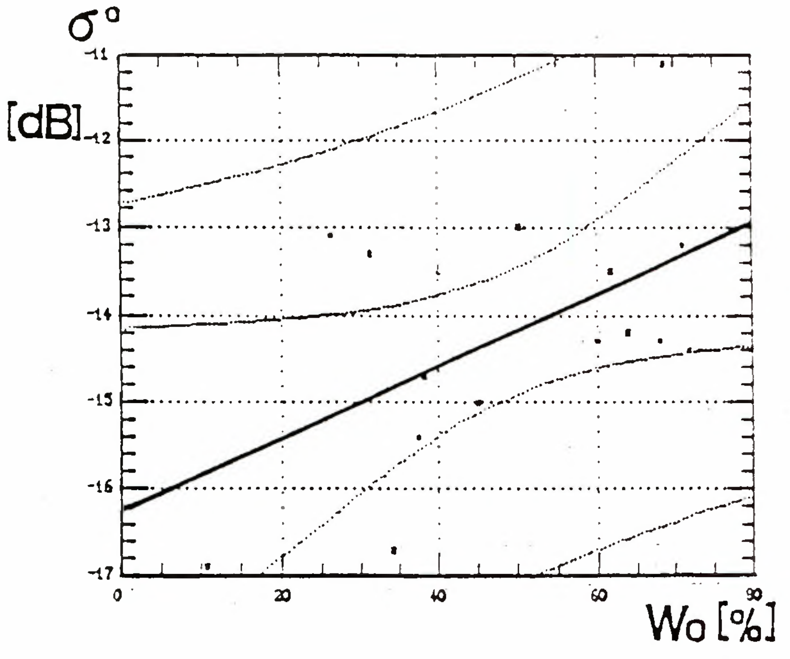
NOAA data 24 May 1992
ERS-1 data 23 May 1992
$\sigma^0 = -0.013E - 9.3$
r = 0.75 for 10 NOAA pixels

Fig.7: Relation between evapotranspiration E [W/m^2] and backscattering coefficient σ^0 [db] averaged for NOAA pixels



NOAA data 24 May 1992
ERS-1 data 23 May 1992
$\sigma^0 = -3.76Bw - 9.2$
r = 0.75 for 10 NOAA pixels

Fig.8: Relation between wet biomass Bw [g/m^2] and backscattering coefficient σ^0 [db] averaged for NOAA pixels



$\sigma^0 = 0.04Wo - 16.2$
$r = 0.53$

Fig.9: Relation between volumetric soil moisture Wo [%] from the 0-10cm depth and backscattering coefficient σ^0 [db] for 23 May 1992

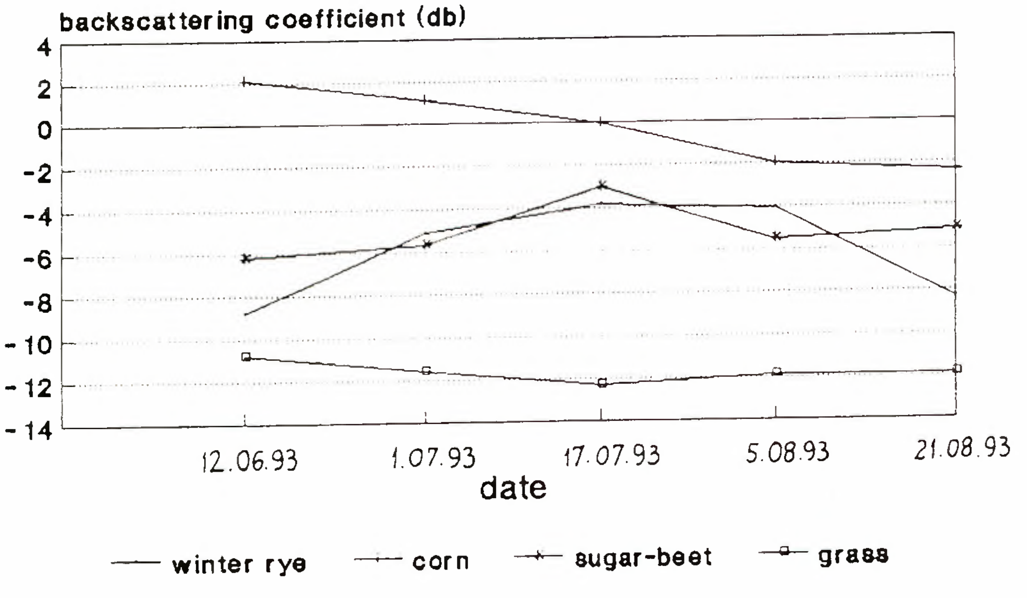


Fig.10: Backscattering coefficient for different crops

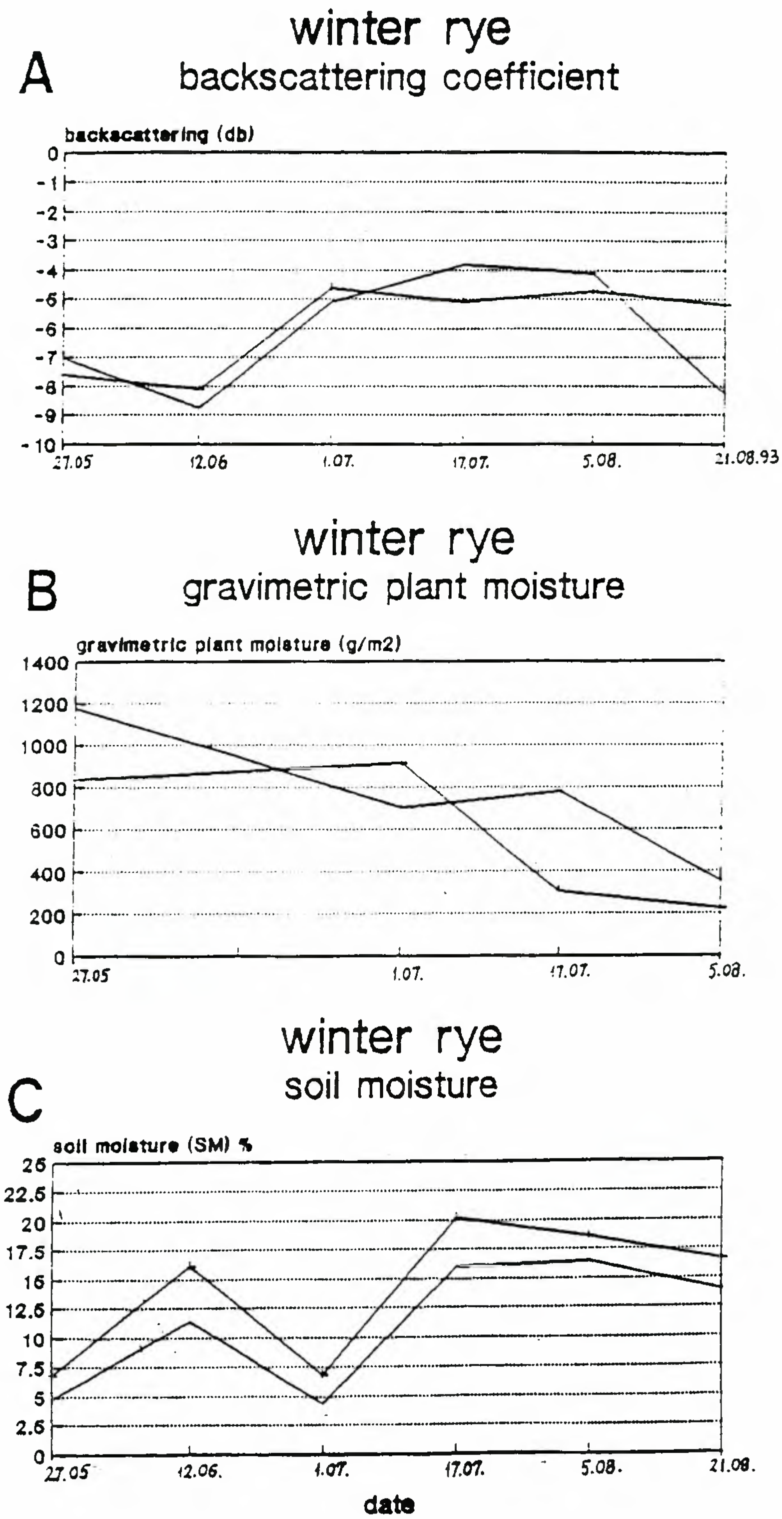


Fig.11:Backscattering coefficient (A), gravimetric plant moisture (B) and soil moisture (C) for winter rye.

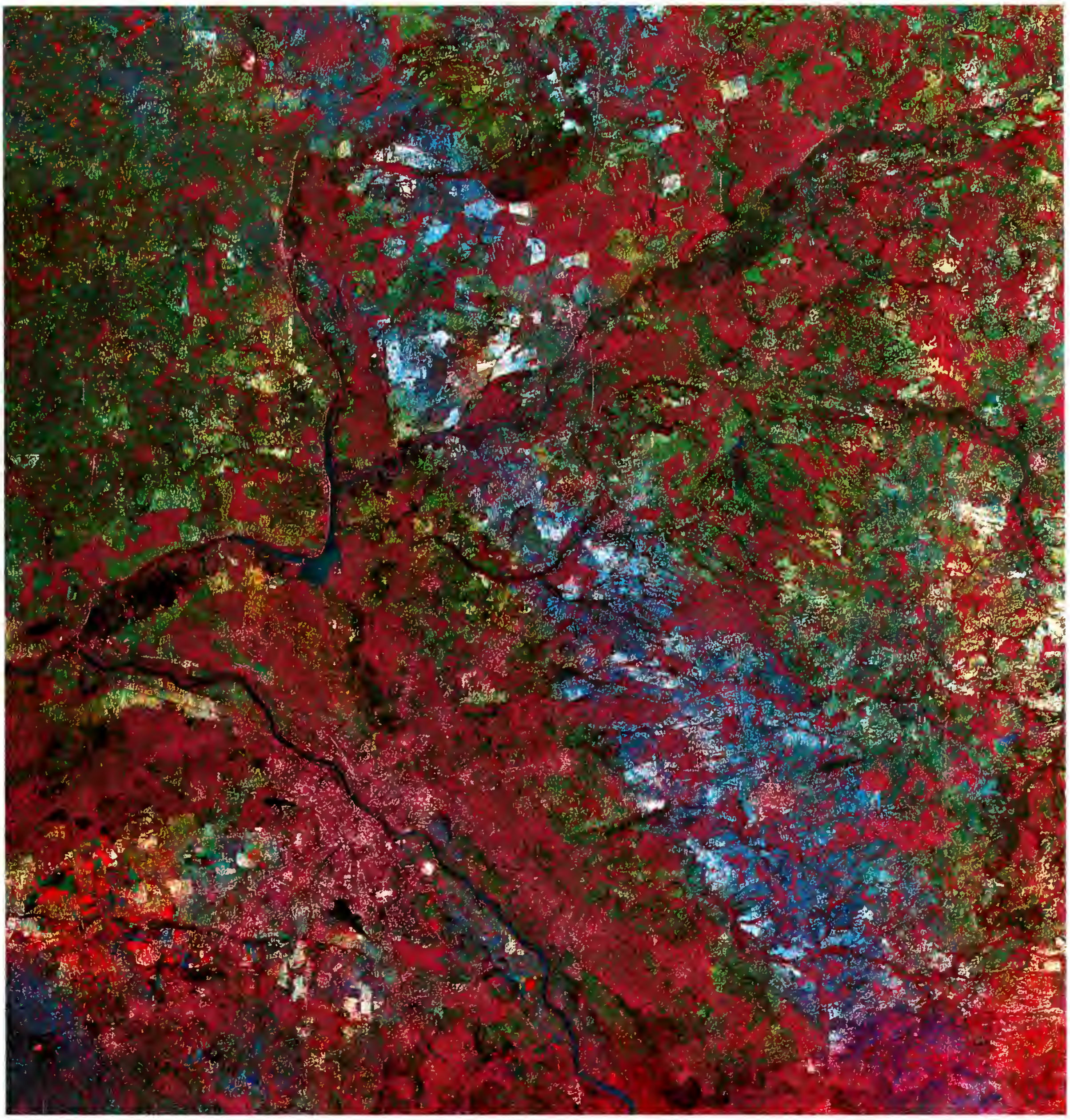


Fig.12: ERS-1 SAR multitemporal image of Warsaw region (18 June 1992, 27 August 1992, 1 October 1992 as Red/Green/Blue - Scale 1:625.000) Acquired by Fucino Station, processed by the Italian Processing and Receiving Station, Matera

USE OF ERS-1 SAR DATA FOR AGRICULTURAL STATITICS IN SLOVENIA

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1. INTRODUCTION

The Republic of Slovenia lies in the southern part of Central Europe and covers 20 255 km^2 with 1 974 839 inhabitants (Census data 1991).

From a geographic aspect, Slovenia is a very heterogeneous country. It comprises the Littoral, the Alps, the subalpine and Pannonian regions. The western and northern areas of Slovenia lie in the Alpine and Subalpine region, the central area consists of tectonic-created and later eroded basins and valleys. The southern part belongs to the Dinaric Karst, while the north eastern part of Slovenia extends into the Pannonian basin.

The Alps, which are the part of the Eastern Alps, (i.e. part of Southern Limestone Alps) are intensively dissected with the highest peak 2864 m above sea level. The possibilities for intensive agriculture production are poor in this region. The main activities are silviculture and cattle breeding for milk and meat production.

Most of the Alpine region is composed of subalpine hills and mountains which do not reach the upper timber line (1550-1900m). Valleys, ridges and basins prevail; of the latter, Ljubljana basin is the largest and is densely inhabited. On the Quaternary fluvio-glacial soils, wheat, corn, potato and oil seed crops are grown.

In the southern part, the subalpine hills merge with the Dinaric Karst region, which represents the northwestern corner of the Dinaric Mountains and extends to the Trieste Bay and Friuli lowland, being under the influence of the submediterranean climate. They are composed of carbonate rocks, called the Dinarski kras (Dinaric Karst) with shallow soil. Most of the plateaus lie at an altitude of more than 450 m and the upper line for cultivating corn for grain is approximatelly 500-600 m. Corn, wheat, pastures, orchards and vineyards are the predominant agricultural activities of this area.

In the Subpanonian, Slovenia Tertiary hills with peaks up to 180 m above the valley bottom prevail and are interrupted by fluvioglacial valleys and basins and some isolated mountains. As this region offers the most favourable natural conditions for agriculture in Slovenia, it has the highest average population density. The main crops cultivated in this region are: wheat, barley, corn for grain and fodder, and sugar beat (Pak, M. 1992; Gams, I. 1992).

The heterogeneous geographic structure of Slovenia is highly correlated with climatic diversity, ranging from submediteranian to alpine and moderate continental climate, which together with the pedological diversity results in a very heterogeneous land use pattern with 50 % of the total area being under forests, 43 % under agricultural land and the remaining 7% being barren land.

In 1990, Slovenia had a total of 652 667 ha of cultivated land, with the field sizes ranging from 0.5 ha to over 6.0 ha. The number of owners is now hard to estimate as denationalization is still in process.

The intensity of agriculture differs from region to region, depending on relief, pedology and climatic conditions, with the main crops on 228 504 ha arable land being:

wheat .... 25 % of arable land
maize .... 29 % of arable land
potato .... 13 % of arable land
ind.crops ...... 4 % of arable land
forage plants .. 30 % of arable land

For the needs of the Statistical Office, the estimates of land use, field acreage and crop forecasting are based on the reporting service, where 280 reporting agents estimate the mentioned items on 307 statistical units, called cadastral estimating areas. The principal disadvantage of the existing method is its susceptibility to subjective bias and the lack of geographic coordinates for acreage data. The latter makes it impossible to merge these data with other ground information, raises the costs and decreases the reliability of incorporating these data into an agricultural GIS (Zdjelar, J. 1992; Statistical Yearbook of the Republic of Slovenia, 1991).

In order to develop a methodology of collecting agrostatistical data that would result in timely, objective, accurate and georeferenced data the project "Application of digital remote sensing techniques for agricultural statistics" was initiated in 1982 and has been supported by FAO in the period from 1985 to 1987 (Tretjak A. et al 1987). In 1990, the Statistical Office purchased the required hardware and software: SunSparc1+ graphic station with the UNIX based ERDAS and ARC/INFO and peripheral units: printer, plotter and digitizing table.

In autumn 1991, the project "Compilation of an agricultural GIS for the needs of agrostatistics, case study Kranj " was initiated with its goal being to merge the existing databases of Slovenia with classified satellite scanned data into a GIS suitable for monitoring land use and agriculture changes, and having the capability of studying the influence of sociodemographic changes on the spatial distributed pattern of agricultural data (Tretjak A. and Sabic D., 1993).

2. APPLICATION OF ERS-1 SAR DATA

At the beginning 1993, our planned work presented in a draft project description was positively evaluated by various European and International organizations (among them FAO and ESA), who, in addition, supported our work by giving us a set of three ERS-1 SAR tapes acquired in 1993, covering the central part of Slovenia. The tape specifications are:

Acquisition date	Orbit	Frame ID		Processed	Received
12 June 1993	9972	2673	1P	UK NRSC	20 July 1993
17 July 1993	10473	2673	1V	UK NRSC	26 Aug. 1993
21 Aug. 1993	10974	2673	1V	UK NRSC	05 Oct. 1993

The ERS-1 SAR data had to be transfered to a Unix OS readable format. Due to the obsolete installation of the file transfer function for each band it took 7 days to accomplish the transfer of the 132 645 584 bytes/tape. Due to the North-South flight direction of the radar the image had to be rotated 180^0 from left to right. The rotation was performed by using the four corner pixels as four GCP points for the rectification function. The 16-bit format of each tape has been transformed to the 8-bit format.

On each of the three bands two working windows were selected: the central area covering the Celje basin where hops is the main crop and the the area north of Ljubljana where wheat and maize are the main crops.

3. CELJE BASIN CASE STUDY

The analysed area of Celje basin is approximately 35 x 20 km. Half of the area is hilly terrain, gradually changing into a flat basin. The basin is sourrounded by mixed forests and natural grasslands. In the basin on the sandy brown-clay soils, intensive agriculture is developed; the main crops being hops (Humulus lupulus), maize (Zea mays), wheat (Triticum aestivum) and grassland.

On the June data, a working window covering the area of Celje basin was selected. On the starting pixel UL: x = 3051, y = 2286 4271 columns and 2986 rows were taken. Using the maps of scale 1:25 000, 23 GCPs were identified and the window was rectified into the Gauss-Kruger projection with the total RMS error not exceding one pixel. In addition, the pixel size was transformed from 12.5m x 12.5m to 10m x 10m. The same procedures were applied to the July and August data. A subset covering only the Celje basin was selected and a new file generated with the multitemporal bands:

Data	Band	Colour
12 June	1	Red
17 July	2	Green
21 August	3	Blue

As hops is the main crop of the area under study, visual interpretation of ERS-1 SAR data was primarely concerned with these fields. Visual interpretation was also performed for wheat and maize fields for which ground truth data was available.

In the Celje basin, hops is grown on large, rectangular shaped fields of an average size of 4 to 8 hectares. In many places these fields are clustered, thus hops covers areas of 150 hectares and more. The clustered fields are separated by cart tracks of 3m to 5m width.

Hops is a climbing plant reaching a height of approximately 7m and is planted in rows beside wires that are fixed to concrete pillars/poles. The between-rows distance is approximately 3m and the between-plant distance approximately 1m. The rows are slightly elevated, and the area between the rows is cleaned to bare soil in spring. After harvest, the plants are cut and covered with soil. Hops is a perennial, being removed every 10-15 years, but prior to replanting the field is sown either with wheat or maize for one year. In the first year of the renewed plantation, when plants are small, wheat is grown underneath.

The obtained multitemporal ERS-1 SAR image of the Celje basin was visually interpreted using the following auxiliary information: ground truth data collected in June 93; b/w aerophotos of 1: 17 500 scale dating from June 93; maps of 1: 25 000 scale. The radar intensities reflected from hops fields, wheat and maize have been visually interpreted separately in each band, classifying the backscatter intensity into three classes: bright, medium, dark, where

Bright: vertical (south-north) direction of elevated rows and pillars.

Medium: approximately 45° left or right declination from the vertical direction of the elevated rows and pillars.

Dark: more than 45° declination up to perpendicular direction to the south-north direction of the elevated rows and pillars.

On the first band (12 June 93), the hops plants were not fully developed but had already reached the maximum height. The stems were not fully branched and lacked leaves. The soil and pillars were visible thus causing secondary backscatter, especially having the same direction of rows as the satellite flight direction. These fields have intensive bright backscatter.

Nearly the same brightness appeared on those grasslands that were growing on the east exposition, i.e. were perpendicular to the radar beam. They could be distinguished from hops field only by their irregular shape.

The medium brightness class includes all those hops fields with more or less 45^{0} deviation from the north/south direction and the maize fields. At this phenological stage of development, larger rectangular maize fields can not be distinguished from hops fields with medium backscatter intensity.
The dark brightness class includes all fields under wheat and grass. Wheat fields can be separated from grass only when grown on rectangular fields.
On the July ERS-1 data, the brightness values of hops and the east-exposed grass fields decrease while the backscatter values of wheat and maize increase. Only grass remains constantly dark. The same direction of decrease or increase of reflected values was observed on the August data, resulting in an average faint expressed or nearly-none differences in

brightness values among the different cultivations under study.

The multitemporal image shows the following visual separability:

Hops and to east-exposed grassland: red/yellow
Wheat: dark blue
Grass (and water): black/dark brown
Maize: brown/reddish

To verify the backscatter pattern of wheat, maize and grass on the three acquisition dates a cluster of 22 fields of the mentioned cultivations in the test site in Ljubljana basin was chosen; 13 fields were under maize, 7 fields under wheat, 1 under cultivated grass, 1 under grass surrounding the farm-buildings. The average field size was 250 ha.

All three radar images were rectified into Gauss-Kruger projection and a multitemporal image was compiled. The same pattern of the intensity of reflected values has been observed as those in the Celje basin with the exception of maize, which in two fields had extremely bright values in the June data. The intensity of brightness disappeared in the July and August data and was the same as on the other maize fields. The bright values of maize on the June data were the result of an earlier planting date of these two fields. The plants were already 1/2 m high and with well developed leaves on the first acquisition date. This conclusion has been reached by field inspection of the test site on 21 September. Only these two maize fields had been already harvested and stubble remained.

The visual analysis of the multitemporal data reveals the same colour pattern for the cultivations under study those as in the Celje basin:
Wheat: dark blue
Grass: black/dark brown
Maize: reddish/brown

In the next stage of our work, the cadastrial boundaries will be used in order to obtain teritorial units which can be classified and compared with official statistical data, as well as using interpreted airphotos taken in June 1993. In addition, the centroids of buildings will be used as a buffer to mask the built up areas and individual buildings which contribute to speckle.

The follow-up of the work will be oriented to the statistical classification of the data which will be merged with Landsat TM and SPOT XS data scanned this year. We believe that the geometry of the radar and different brightness intensity of cultivations within a three month span will contribute considerably to an improved statistical separability among the agricultural classes under study.

4. AKNOWLEDGEMENTS

We would like to thank Z.D.Kalensky, Chief of the FAO Remote Sensing Centre and J.F.Dallemand, Technical officer at FAO RSC and coworker of ESA for all the support and professional advice during our work. We would like to express our thanks to ESA who by giving us the three ERS-1 SAR tapes and high quality paper print of one ERS-1 SAR scene, enabled us to prepare this study. It is Dr. J. Lichtenegger who guided us over phone and by fax on the first steps of the elaboration of the radar data and we acknowledge this help.

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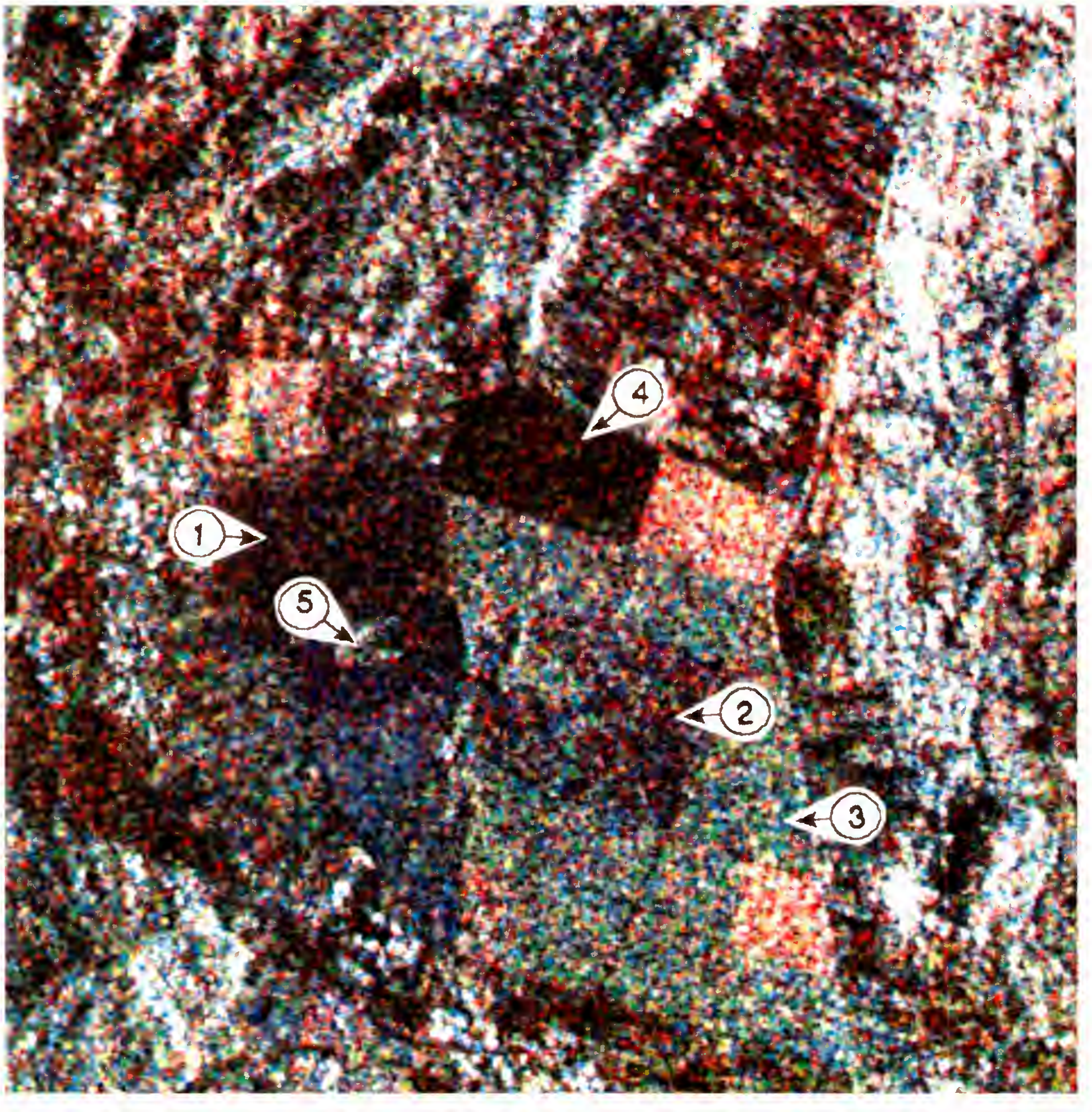

Fig.1: Multitemporal ERS-1 SAR image of the Kamnik Area (12 June 1993, scale 1:40.000).
Field data collected 3rd and 4th June 1993

1 Wheat with awns
2 Wheat
3 Maize
4 Grass
5 Dumpsite/Yard

ROMANIA CASE STUDY: USE OF ERS-1 SAR DATA FOR LAND USE MONITORING, CONTRIBUTIONS TO MONITOR THE PRIVATISATION PROCESS IN TERRITORIAL PROFILE

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1. INTRODUCTION

The existence and availability of ERS-1 (European Remote Sensing Satellite) SAR data have given new possibilities for remote sensing for our country, making available to us a working tool complementary to those already existing in the visible domain.

The area selected to be the pilot project zone is representative of our Romanian Plain, beginning with the Danube and its meadows and ending with the hill region, having an altitude varying between 10 m and approximately 300 m. The pilot project zone includes typical ecosystems, which have several management systems, from natural cropping, to irrigated systems, from small individual farms to big farms - ex-estate properties - worked in association. In this zone there are no steep valleys, with hidden slopes, or slopes opposed to the SAR ERS-1 system observation direction.

Reviewing the advantages of SAR ERS-1 recording system for this zone, the following should be noted:
- Independence from the atmospheric conditions (cloud cover), recording possibilities by day and by night. Even for this zone, already advantaged, the average number of cloudless days is 70 (which is also the average for the entire country), but this average is less than 50 in the May-October period, which is the period of phenological growth, thus of great interest.
- Possibilities to obtain satellite data during the ascendant orbit, as well as during the descendant orbit (day time or night time),

- Possibility to obtain ERS-1 SAR images in the optimum period for distinguishing between different types of crops, even though the observation period is reduced; the satellite image taken in the Visible-Infra Red domain can provide the mask for the areas where different types of crops occur while the SAR image allows the separability of the crop types.
- Possibility of sensing soil moisture content.

The difficulties/limitations are mainly in the structure of the data and are of a technical nature:
- monospectral and monopolarised data are of course less rich in information, compared to the data obtained using the "classical" sensors;
- the use and exploitation of the data obtained from the "classical" sensors is based on methodologies and procedures verified by years of practice; the SAR radar data are geometrically and radiometrically different from "classical" data. They require elimination of speckle noise and registration with the visible and Infra Red data (mainly Landsat and SPOT).

As users, we are experiencing the lack of possibilities to obtain SAR.GEC ERS-1 data (SAR Ellipsoid Geocoded Image) compatible with the Landsat and SPOT data and also SAR.GT001 ERS-1 data (Terrain Geocoded Image).

2. TEST AREA PRESENTATION

Different types of measurements and observations were performed in the test zone during a ground truth campaign, supported by thematic and topographic maps. These measurements were not oriented towards our experiment but were very useful for our goals.

The area has been studied by the MARS (Monitoring Agriculture with Remote Sensing) program of the CEC. This zone has almost 200 sampling sets of intensive measurements, regarding crop management on the ground, periodically inventoried, with positioning on conventional maps and on spacemaps (1991 edition). These samples are 2 km x 1 km (longitude/latitude) in size, specific for the MARS program.

In the test zone there is a ICCPT research and experiment station at Fundulea (Research Institute for Cereals and Industrial Crops), a subunit of the Agricultural and Forestry Academy (ASAS). For the design and the implementation of a LIS (Land Information System) of a cadastral type, the Frumusani Village was chosen. This region is the object of a collaboration between ISPIF and IGN-International leading to the elaboration of an adequate software for land privatization monitoring. The test site also includes the experimental photogrammetric polygon Albesti-Paleologu that can be used for geometrical correction of the satellite data, as well as a geophysical measurements station at Caldarusani.

Measurements were made for determining the roughness of the land surface, based on the analysis of closely sampled spectral profiles. To highlight the roughness - a spectrogram was used, from which the characteristic frequency is extracted; then the separation phase is done by a frequency filtering, using the Butherworth filter, followed by an inverse Fourier transform. These roughness measurements will be used for the assesment of the level of noise in the SAR data in order to reduce it.

On the same profiles on which the roughness was determined, realization of the radiometrical profiles is conceived by coupling the Exotech 100AX radiometer with a computer micro-processor PC 386SX; the radiometer is equipped with respective filters for the spectral bands of the Landsat MSS and TM (minus the thermal Infra Red band). A further step will consist of equiping the radiometer with the respective filters for the spectral bands of the SPOT satellite.

The zone is covered by 3 ERS-1 SAR PRI (Precision Image) images taken on 30 April, 9 July and 13 August 1993. It is also partly covered (about a half of it) by a Landsat TM, taken on 27 March 1989. Five spacemaps at 1:50 000 scale (July 1992) covering the entire test area are also available. The test area is covered by repetitive aerial photographs in the panchromatic mode, and also partly by some aerial multispectral photographs taken with the MSK4(6) camera.

3. METHODOLOGY

There were several difficulties in reading the magnetic tapes CCT 6250 bpi format of the ERS-1 SAR.PRI product type as format description was not included; it must be mentioned that the tapes that came from I-PAF have different format than those provided by UK-PAF or D-PAF.

Taking into account that very few of the computers available in Romania can operate directly with 6250 bpi magnetic tapes, the conversion and transfer of the information had to be done onto 1600 bpi CCT tapes. Reading and primary processing of the ERS-1 SAR data and of the Landsat TM images were done using a TITAN 1500 computer, with 2 RISC 2000 microprocessors and 128 MBytes internal memory. The monospectral and multispectral processing was partly done by using the AVS (Application Visualization System) program, and also in-house software of the Institute of Optoelectronics, Department of Remote Sensing, Bucarest.

Processing, analysis and interpretation were initially made using analog products, then a hybrid system was used and the main, detailed analysis of the selected zones were made by digital processing.

By zooming with the Rectimat the ERS-1 SAR image (image recorded on 30 April 1993, film received at the end of September) at 1:100000 and 1:50000 scale , we made up the working base for analog, hybrid and digital processing, by tracing on these zoomed photos the map geographical grid. The other two ERS-1 images were received only on 20 October 1993. The following processing, done by adding and subtracting the sequential recordings in different ways, and also the color composite product realization were rendered more difficult due to scale differences and deformations, visible at a glance.

Monospectral processing of each SAR ERS-1 image (displaying, histogram drawing, densitometric profiling, density slicing, contrast stretch, area calculations etc.) were done to observe specific phenomena over soil and vegetation.

Registration of the 3 ERS-1 SAR images has been initially performed using a relative registration, the base image being the one recorded on 30 April 1993. Before registration, filtering techniques were applied to attenuate and eventually eliminate speckle. Mean, median, Gaussian, Laplacian filters were tested; the median filter was found to be useful. For a better contrasting image several algorithms and especially those of the edge detection type (Sobel filter) were used. An attempt at registering ERS-1 SAR image of 9 July 1993 with the July 1992 spacemap and with Landsat TM image of 27 March 1989 is being made in order to monitor the evolution of the land administration.

For the test zone bi- and three-dimensional histograms are produced to apply a multivariate analysis. Principal components are extracted from the Landsat TM spectral bands.

Two methods of colour composite production were tested i.e. RGB (Red, Green, Blue) and IHS (Intensity, Hue, Saturation), in the following combinations:
(a) using the 3 sequential ERS-1 SAR images (called I, II, III), the II component being kept on green and the I and III components alternating on blue and red.
(b) using the same 3 SAR ERS1 images, but using the IHS components for the 3 images as I, II and III, in this order.
These color composites (RGB and IHS) are useful for determining the OIF (Optimum Index Factor) specific for thematic differentiation, necessary for providing data for a seasonal satellite data bank.

In the future, SPOT and Landsat TM spectral bands, accordingly to their availability, will be included. We will also try to process sequential SAR data (SIR-A, SIR-B, Almaz) to be correlated with 1993 ERS-1 SAR data.

The registration between ERS-1 SAR and SPOT (or Landsat TM) data, together with testing of the entire set of processing techniques, must highlight the complementarity of the two types of sensors, and also increase the information effectively provided by the ERS-1 SAR.

Supervised and unsupervised classifications were executed and the confusion matrix computed and used for establishing the effective accuracy of the classification.

4. SOME ACHIEVEMENTS; RESULTS OBTAINED AND EXPECTED

The program of this pilot project is rather large and ambitious. Nevertheless, we managed in the short time period we had at our disposal (less than 30 days) to obtain or approach some of the general and specific objectives:
- familiarization with the nature and the processing techniques of ERS-1 SAR data, beginning with magnetic tape reading, attempts to reduce the speckle, multispectral and monospectral processing, analysis and interpretation,
- increased possibility to discriminate between different types of vegetation/crops by using ERS-1 SAR data had been verified with the field mask provided by the visible images, mainly SPOT and Landsat TM.

Using adequate sequences of ERS-1 SAR data, it was qualitatively and, until now, only partially quantitatively possible to highlight the possibility to measure moisture, and to watch its evolution, in the complex soil/vegetation conditions, mainly in the irrigated areas.

5. FURTHER DEVELOPMENTS

- Examining moisture differences, correlated with the roughness of the land surface, mainly found in the Danube's Plain;
- Obtaining some windows of SPOT or Landsat TM images, over our sample areas, taken at convenient times (seasonal data would be most convenient). These images will be analysed and interpreted with the ERS-1 SAR data, altogether with positioning of radiometric profiles, measured with the Exotech 100AX radiometer, linked with a PC 386SX computer, for reducing to a minimum the number of satellite images needed. This aspect is of great importance for Eastern European countries and Romania.
- Testing and utilisation of the differences between ERS-1 SAR data, taken on the descending orbit and the data taken on the ascendant orbit. The 3 SAR images of this study were taken on the descendant orbit.
- Correlation with SIR-A, SIR-B and eventually Almaz data.
- Extraction after registration of 256 x 256 pixels windows from the CCT tapes, transfer on floppy disks for PC use.
- Testing and processing of the ERS-1 SAR Flevoland data due to some similarities with the Danube Delta.
- Familiarisation with the SAR Image Mode data and also with the Wave Mode data in order to test this new sensor type in the Black Sea remote sensing programme.

Difficulties met:
(a) The SAR ERS-1 tapes were received at the end of September 1993. The first film at the end of September and the other two on 20 October 1993.
(b) Important geometrical distortions (with respect to cartographic data) were found in the 3 ERS-1 SAR images leading to difficulties in local registration.
(c) Lack of SPOT data of the test zone at convenient periods.
(d) The time periods between the 3 images are not adequate for a series of objectives.

6. ACKNOWLEDGEMENTS

- The 3 SAR ERS-1 tapes were received in the framework of a ESA/FAO pilot project.
- In particular, we must thank the institutions and organisations which contributed to the satisfactory outcome of the pilot project, and in the first instance the Department of Remote Sensing of the Institute of Optoelectronics; we must emphasise the fact that the team worked in "a race against the time"!
- The Division of Remote Sensing of the Romanian Space Agency elaborated and published on this occasion a "Remote Sensing Bulletin" dedicated mainly to the SAR ERS-1 System.

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Fig.1: ERS-1 SAR image of Bucarest region
(30 April 1993, scale 1:1:500.000) Acquired by Kiruna recieving Station, processed by Italian Processing and Archiving Station, Matera.

ASSESSMENT OF THE POTENTIAL OF OPTICAL AND MICROWAVE SATELLITE REMOTE SENSING TECHNIQUES FOR LAND SURFACE MONITORING OF THE IMPACT OF LAND REFORM

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1. INTRODUCTION

The objective of the study: development of basic land surface spatial analysis methods based on multiplatform (ERS, Landsat, Cosmos, airborne) and all-weather multitemporal satellite and airborne remote sensing data for impact assessment of the privatization, compensation and other activities related to land reform.

In Hungary, after the collapse of the so called "socialist system" in 1990, the freely elected new parliament and government had decided to change not only the political, but also the economical structure of the country. This means - among other things - that the previous "socialist properties" should be privatized, e.g. many citizens, who, before World War II had any property, can get back his ownership under certain circumstances determined by the new law. This privatization would effect the structure of the Hungarian agriculture land use as most of the large agricultural cooperatives will be privatized. During the previous regime, the average size of agricultural fields was about 50-80 ha. After privatization the average size of agricutural fields will be very similar to the Western-European systems, where the fields are 3-5 ha.

During the last 14 years of activities of the FÖMI Remote Sensing Centre, we have developed technologies to use remote sensing techniques for land use mapping, vegetation status assessment, monitoring of cultivated area, change detection, environmental monitoring etc. based on Landsat MSS, TM, SPOT and airborne data.

In the frame of this project we would like to establish how we could use our already existing technologies and the ERS-1 data for the detection of landscape changes due to privatization.

2. AVAILABLE DATA

2.1. Selection of the test area

The test area had been chosen with the active participation of our potential users, experts from the Ministry of Agriculture and the Ministry for Environmental Protection and Regional Planning, taking into consideration the following factors:
- progress of privatization
- the area should be a characteristic agricultural region
- environmental considerations
- availability of different types of data from earlier investigations and surveys
- the knowledge to be gained could be useful to other national and international projects (CORINE, MARS, etc)
- the test area should be easily reached (due to a limited budget)

On the basis of the above considerations we had chosen a test area which is located in Pest county, about 50 km in the south of Budapest and has the following corner coordinates (geographical coordinates): N47.6/E19.0 N47.6/E20.0 N46.6/E19.0 N46.6/E20.0. This area corresponds to the 1:100000 scale topographic map sheet Number 55 in the Hungarian National Unified map projection system.

In the frame of ESA/FAO cooperation we received three ERS-1 SAR images of this area, acquired on the 8th July, 12th August and 16th September.

2.2. Reference materials

The following materials were available for the test area:
- a "COSMOS" satellite image that covers the eastern part of the test area (it is a panchromatic image made in 1979 and has a resolution of 5m)
- a LANDSAT TM composite (band 2, 3, 4) made in 04. 04. 1985
- a LANDSAT TM composite (band 3, 4, 5) made in 09. 14. 1986
- a LANDSAT TM composite (band 2, 3, 4) made in 08. 18. 1988
- a LANDSAT TM composite (band 2, 3, 4) made in 03. 17. 1990
- black and white air photos of 1:10 000 scale, made for soil mapping
- soil maps of 1:10 000 scale, made by the Soil Mapping Group of the Remote Sensing Department of FÖMI RSC
- colour infrared air photos of 1:22 000 scale from July 1992, covering the whole Pest county
- results from the interpretation of an environmental study of 1:100 000 scale, with 19 classes, covering the whole Pest county (made by the Hungarian-German program-office and sponsored by the Ministry of Environmental Protection in Germany)
- 6 m resolution airborne SAR images (X-band), covering part of the test area, acquired by INTERA (Canada) in the frame of the "Open Sky"
- 1:100 000 scale topographic map
- 1:100 000 scale agrotopographic map
- 1:10 000 scale topographic map
- agrometeorological data (including measurements of rainfall, wind and temperature in six different places in the test area from the time of the three overpasses of the ERS-1 satellite).

2.3. Field data collection

In possession of the available data we went to the test area five times to collect field data. In the field we tried to localize those parts of the test area where the privatization had already started and the size of the fields was no more than 1-2 ha. We had chosen such fields that could be used as training sets in the course of computer processing. We mapped the boundaries of regions with different land use coverage, and on the agricultural territories we marked the boundaries of the fields with different crops.

As the result of the field data collection we can conclude the following:
- Agriculture is the dominant activity in the region of the test area.
- The most important plants are: winter cereals, different types of maize, sunflower and alfalfa.
- In the fields already privatized a mixed cultivation is found. The new owners grow vegetables (for example cabbage), grapes, fodder-plants as well as such industrial crops such as sunflower and potato.
- The test area consists of part of the National Park of Kiskunság which is a natural grass land.
- Forests can also be found on smaller parts of the test area.
- The important surface waters of the area are the Danube and mine lakes.
- In the neighbourhood of the mine lakes we can find gravel hills that were extracted from of the lakes.
- There is sand production by surface mining in one of the villages of the area.
- On the the test area the density of the roads and railways corresponds to the characteristic Hungarian circumstances. Highways, roads, smaller roads with different surface materials as well as railways and railway junctions are found in the region.
- One of the most important field objects for identification was the previous military airport, located in the south-eastern part of the area.

3. IMAGE PROCESSING

The software used was not optimized to radar image processing. The system includes a MicroVAX II with software including the in-house written Remote Sensing Package for image processing, an IBM PC with the ERDAS 7.5 image processing software package, and a Pericolor 2000 image processing computer for displaying the images. The processing steps were as follows:

1) on the MicroVAX:
- reading the tapes containing the images

2) on the PC:
- cutting out a sub-image that contains the test area
- reflecting it around its vertical axis due to the reversed position of the subimage

3) on the MicroVAX and the Pericolor:
- reduction from 16 bits to 8 bits
- filtering
- image to image registration
- interpretation

We will describe in detail only the filtering method and the image to image registration.

3.1. Filtering

Filtering is an essential step in processing radar images, as SAR images contain speckle noise even after multilook processing. Many filters have been decribed by different authors which take into account the specific properties and statistical characteristics of radar images and speckle noise, the best known among them are the Sigma filter and the Local Statistics filter by Lee, the Frost and the MAP filter.

We implemented one of the simplest of the different speckle specific filters, the Lee Sigma Filter (Lee, 1986). Its main features can be summarized as follows:

a) It uses the multiplicative model for the speckle noise, on the base of which the following equation can be derived (valid for homogeneous, flat areas only):

$$\sigma_v = \frac{\sqrt{var(z)}}{\bar{z}},$$

where σ_v is the standard deviation of the noise, var(z) and z are the variance and the mean of the observed values on different homogeneous areas, respectively. We will see the significance of this equation in point b).

b) The Lee filter is a spatial filter in the sense that it uses a moving window of variable size for filtering the image, and replaces the central pixel with the average of certain pixels in the window. The selection of the pixels included into the averaging is based on the sigma probability of the Gaussian distribution, which can be summarized with the following term:

$$(1-C\sigma_v)z_{cp} < z_{i,j} < (1+C\sigma_v)z_{cp},$$

where z_{cp} is the grey value of the central pixel, $z_{i,j}$ is a pixel in the window, σ_v is the standard deviation of the noise, and C is a user-defined constant ($1 <= C <= 2$). In this inequality we have already made use of the simple equation in a), which tells us that the standard deviation of the pixel values in the window, σ_z can be expressed by the product of the mean, z and the standard deviation of the noise, σ_v.

For determining what filter parameters should be used, we chose a subimage of 256x256 pixels (Figure 1) to which we applied the Sigma filter with different parameters. We had to determine the window size, the value of σ_v and the value of the C constant. For determining the value of σ_v, we calculated the mean and standard deviation of pixel values on homogeneous areas, and delineated them in a coordinate system. The value of σ_v is equal to the tangent of the line we fitted onto the discrete points (Figure 1 shows the result for the July image).

After the calculation of the value of σ_v, we determined the other two parameters (C and window-size) by running the filter on the subimage several times with different parameters and evaluated the results both numerically and visually. Table 1 shows how the window-size influences the mean and standard deviation of the pixel values considering both the whole subimage and different fields within the subimage.

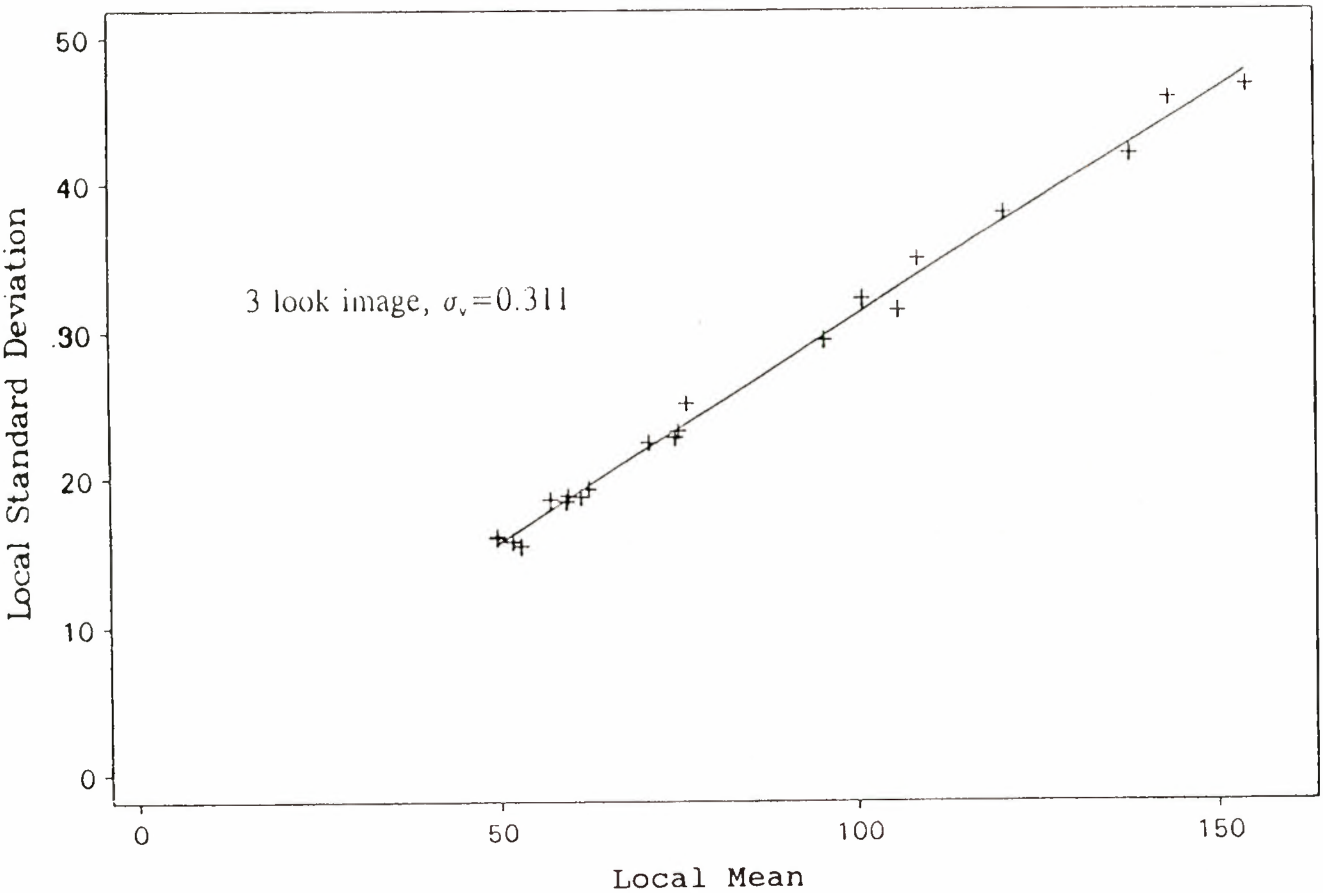
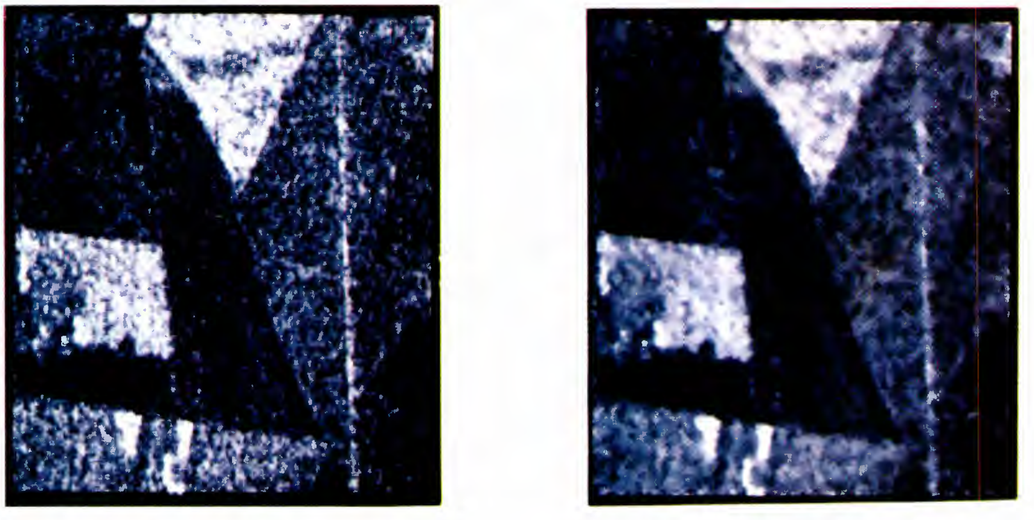


Figure 1: ERS-1 SAR speckle noise characteristics

Names	Filters	Mean	Stand. Dev
Subimage	Original	81.0	36.9
	5x5	78.8	28.7
	7x7	78.8	27.6
	9x9	78.5	27.1
	11x11	78.3	26.8
	7x7 and 3x3	78.9	26.9
Sunflower	Original	127.3	44.3
	5x5	124.4	28.4
	7x7	124.4	25.9
	9x9	123.8	24.8
	11x11	123.3	24.2
	7x7 and 3x3	124.5	24.3
Wheat	Original	60.3	18.7
	5x5	58.9	10.2
	7x7	58.9	8.8
	9x9	58.8	8.6
	11x11	58.8	8.3
	7x7 and 3x3	59.0	7.8

Table 1: Effect of window size on mean and standard deviation

We found that considering both the effectiveness of the filters with different parameters and the computational time, we can reach the best result by filtering the images in an iterative method, first applying a window 7x7 with C=1.5, then using a window size 3x3 with C=1. This way we can preserve the mean value quite well, while reducing the standard deviation significantly.



a) b)

Figure 2: The result of the applied filtering method on the subimage.
a) unfiltered b) filtered

3.2. Image to image registration

In order to make a multitemporal image from the three SAR images acquired on different dates, we had to first register the images. We found that there was no need for the usual calculations using second or higher order polynomials to make the registration; a single shift between the images was enough to bring them into a total correspondence (Figure 3, blue-July, red-August, green-September).

By resampling the radar images to have a pixel size characteristic to the Landsat TM imagery, we also registered the three images to a TM image acquired in 1990, with the aim that we could observe the changing field sizes due to privatization and that we could find out what additional information can be retrieved from the radar images by comparing them to a Landsat TM (Figure 4, merged Landsat TM and SAR July image: red-band 4, green-band 5, blue-SAR July image).

4. INTERPRETATION AND CONCLUDING REMARKS

The purpose of the interpretation we have done so far was twofold: 1) we tried to assess the possibility of using the ERS-1 and Landsat TM images to monitor the changes in the size of the agricultural fields due to privatization and 2) we investigated to what extent we are able to distinguish between the different types of crops.

4.1. Monitoring changes in the field sizes

The TM image was acquired in 1990, when privatization had not yet started and the SAR images date from 1993. We expected that by comparing TM to SAR images as well as the SAR images we would be able to detect changes in the field size. But, as distribution of the fields to the new owners has not yet begun exept in a few places, our aim to follow the process of the privatization could not be achived. However, we succeeded in obtaining some results concerning the size of the fields. By visual interpretation we can conclude that we can differentiate small parcels of land in some places depending on their cultivation and vegetation cover. Based on our field visits the smallest field size we were able to detect was 50m by 200m, approximately 1 ha. This is a promising result for future considerations since recent field sizes are about 80 ha.

4.2. Separation of different crops

Using the multitemporal SAR image, we tried to identify the crops. There are five main crops in this area: wheat, sunflower, alfalfa, maize and sugar-beet. In addition to these crops, we also observed orchards, vineyards, potato fields, pastures and on small areas vegetables such as cabbage and cauliflower. Table 2 shows mean values homogeneous fields from different dates.

On the basis of these numerical results and visual interpretation we can conclude the following:
a) Water bodies can be recognized on the image by their characteristic dark violet colour. This can be explained by the fact that in July they gave high backscatter due to the strong wind observed at the time of the overpass.
b) Wheat has not got a characteristic trend in the change of the mean values from the different dates, and can be observed with different colours on the multitemporal image. This can be explained partly by the different date of the harvesting of the wheat (in many places wheat has already been harvested by the beginning of July, so these fields give a low backscatter) and partly by the difference in the date of starting the autumn ploughing of the fields. The extremely high values from September can be due to the effect of the ploughing that was parallel with the orbit of the satellite.
c) Sunflower has a characteristic change in mean values from the three different dates and can be easily recognized on the image by a bluish-pink-violet colour. The high backscattering in July can be explained by the fact that sunflower canopy has a very rough surface for the incoming radar waves and thus gives high backscattering. By August the sunflower fields have partly dried out which is why it gives lower backscattering.

Names	July	August	September
Sunflower	131.9	111.5	137,6
	145.9	118,1	135.8
	129.5	93.6	86.2
	140.2	121.5	119.3
	143.4	125.9	124.3
Maize	123.3	103.2	96.3
	118,1	137.0	112.0
	86.5	84.7	68.5
	97.2	104.1	146.6
Sugar-beet	119.6	143.8	99.3
	110.4	135.6	108.6
	105.2	120.3	104.7
	104.4	115.8	104.4
Wheat	59.1	71.6	74.1
	74.3	73.4	101.2
	124.7	112.8	221.3
	70.0	78.1	95.1
	94.9	78.1	82.0
	53.7	83.1	77.5
	60.7	68.5	67.5
Alfalfa	43.2	44.9	54.7
	54.3	54.4	68.0
	40.2	40.0	47.0
	64.7	64.1	63.4

Table 2: Mean Values of Homogeneous Fields

d) Sugar beet also has a characteristic change in the mean values and therefore it can be recognized on the image by a greenish colour. It gives the highest backscattering in August.
e) Alfalfa gives low backscattering in all of the three dates and therefore has a dark, almost black colour. It can be confused with pasture which has the same law backscattering.
f) Maize, as wheat, does not have a characteristic colour. This can be explained by the fact that there are different types of maize and they are harvested at different dates.

Considering these results we can claim that for recognizing the different plants these three dates are not good enough, and we would need at least two, but rather three, images from the growing season. The images even after filtering were still too "noisy" for making an automatic classification, so the images were interpreted only visually. We can also claim that for our aim a single-date, black and white radar image is not sufficient, a multitemporal image for visual interpretation is necessary.

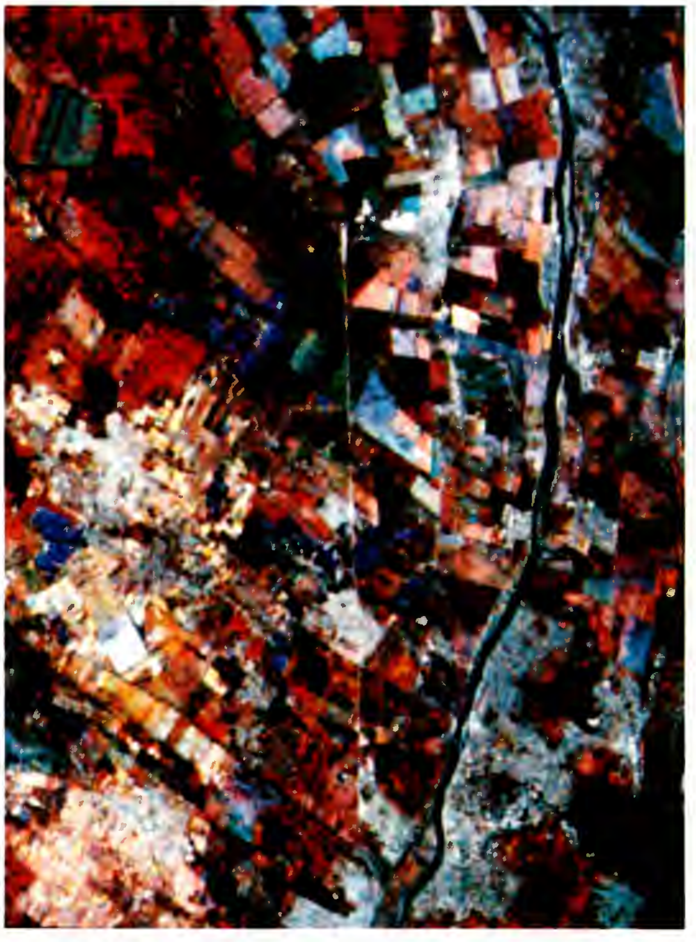


Figure 3: Multitemporal ERS-1 image

Figure 4: Registered Landsat image and ERS-1 July image

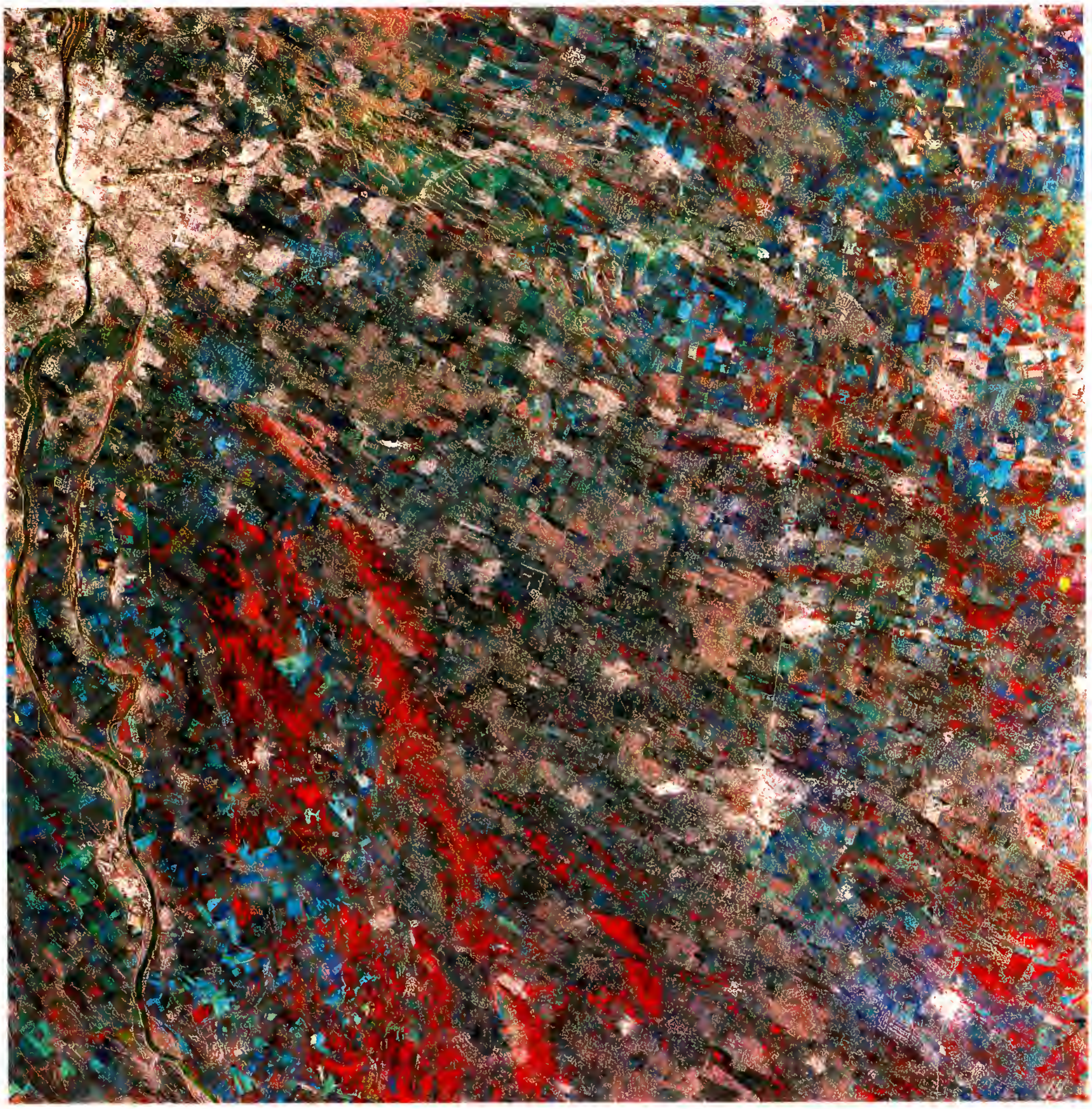


Figure 5: Budapest and Surrounding Areas. Multitemporal ERS-1 SAR image (Red 29 April 1993, Green 8 July 1993, Blue 12 August 1993 - Scale: 1:625.000) Acquired at Fucino recieving Station, processed at Italian processing and archiving Station, Matera.

USE OF RADAR DATA IN GEOMORPHOLOGICAL MAPPING (EXPERIMENTAL RESULTS FROM THE WEST CARPATHIAN REGION)

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1. REMOTE SENSING IN THE INSTITUTE OF GEOGRAPHY OF THE SLOVAK ACADEMY OF SCIENCES

Remote sensing (RS) together with cartography and Geographic Information Systems (GIS) are the methodological instruments utilised in our Institute of Geography for the collection, processing, analysis, presentation and storage of spatial data. In the case of cartography and RS, the basic research carried out by the workers of the Institute also contributes to the promotion of the knowledge in selected areas of the mentioned disciplines. The mentioned activities are carried-out in the Department of Cartography and Geoinformatics (established February 1, 1992), whose predecessor was the Department of GIS and RS (since 1989) and the Department of Thematic Cartography (since 1980).

The first Remote Sensing activities started in the Institute in 1979. From an extensive series of techniques for obtaining and interpretating RS data, analogue and digital interpretation of photographs and images are applied and developed in our Institute, for which two laboratories were established: Laboratory of Analogue Interpretation (equipped by a multispectral projector MSP-4, interpretoscope, ZT-4V Zoom Transfer Scope and other instruments), and Laboratory of Digital Interpretation of RS and GIS data (DIAD 32 image processing system, GIS SPANS and IDRISI with equipments for data input and output (Fig.1). These systems make it possible to obtain information on various objects and landscape properties using RS data, and to utilise these in the solution of environmental problems, spatial organisation of landscape and creation of thematic maps.

The following subjects are of special interest:

- analysis and mapping of land use/land cover,
- analysis and mapping of water content in surface soil layer,
- analysis and mapping of selected terrain characteristics,
- analysis of landscape changes,
- identification and analysis of forms of soil sheet erosion.

The following institutes in the Slovak Republic are involved in the Remote Sensing:

- Slovak Environmental Agency, subordinate to the Slovak Ministry of Environment: has a responsibility for the Czech-Slovak-Canadian RS and GIS Project in the Slovak Republic; in May 1993 the Canadian remote sensing hardware and software, PCI Easi/Pace Image Analysis Software, IBM RISC 6000 workstation under Unix Operating System and peripherals,were delivered, installed and implemented. Several projects are being prepared at the present time.

- Soil Fertility Research Institute, Bratislava. National Focal Point for the MARS and Environmental Related Applications Project in Slovak Republic (the proposals on the hardware and software equipments and contract for this project were prepared and submitted to the JRC Institute for Remote Sensing Applications).

- Forest Research Institute, Zvolen, Participant in the MARS and Environmental Related Applications Project. The Institute has installed the PERICOLOR 3400 image analysis system with interactive graphic station SUN and peripherals and GIS ARC/INFO version 6.1).

2. USE OF RADAR IMAGES IN GEOLOGICAL MAPPING

The aim of our work was to test the use of information obtained by analogue interpretation of radar images in geomorphological mapping. The work was carried out in four chosen regions of the Slovak Carpathians with different types of terrain: parts of Slovenský kras Karst, the Laborecká vrchovina Mts, the Polana Mts. and the Malé Karpaty Mts.

2.1 Data used

Radar images were obtained by the Russian radar system TOROS (SLAR), which operates on the wavelength 2.5 cm in autumn 1986. Its azimuth resolution is 15-40 m and range resolution is 20-200 m. The original black and white negatives are of 1:100 000 scale and the swath width is approximately 15 cm (therefore on the surface the swath width is 15 km). The whole territory of Slovakia was imaged.

2.2 Interpretation of radar images

Analogue interpretation techniques were used. Obtained results show the spatial arrangement of crest lines and valley lines, linear and non-linear dividing marks. These results were compared with geomorphological field work. The results were also compared with identified crest lines and valley lines patterns extracted by traditional way from the topographical maps.

2.3 Obtained results

In the area of the Slovak Karst, with its typically developed plateau-like karst, three groups of the linear dividing marks, indicating fault structures differing in age and type were distinguished. It is possible to distinguish the different regions according to the different types of geological structure (tectonic movements and quality of limestones) (Fig. 2).

Radar images of the research area in the Laborecká Vrchovina Mts. show the basic morphostructural plan and arrangement of a network of crest lines and valley lines, dependent on the geological structure. They reflect very distinctly the contrasting structural and lithological quality of flysch rocks. In addition, the typology of valley, according to its transverse profile, can be reliably distinguished (Fig.3).

Stratovolcanic structure is very distinct on the radar image of the Polana Mts. The formation of the crest line bordering the central depression allows a better interpretation. Using radar images, parallel morphostructural dividing marks corresponding to block structure were identified (Fig. 4).

Radar images of the Malé Karpaty Mts. revealed that there is a pronounced non-linear boundary line in the form of an amphitheatre in the drainage basin of the river Gidra. Non-linear boundaries identified using radar imagery correspond to the slopes dividing two systems of leveled surfaces on the map; but the map does not represent the slopes as being a coherent spatial system with an amphitheatre form. It is easy to identify the mentioned slopes on the map but not as a amphitheatre-like slope system. This whole unit will not be found either in a geological map. Radar imagery show the total shape (form) which would otherwise not be identified (Fig.5).

3. CONCLUSION

Obtained results showed that the use of radar TOROS images in geomorphology is justified mainly in the areas with mountainous terrain. Every dividing mark identified by radar images should be seen as an indication of certain morphostructural quality in that area. They can be the result of morphostructure, but it is not always the case. Elimination of the incidence of accidental arrangement of terrain elements can be made only after comparison with the results of other partial morphostructural analyses and field research. Radar images provide such information as large spatial compositions, linear and non-linear boundary lines and various terrain patterns; this information is not generally found in geomorphological or geological maps.

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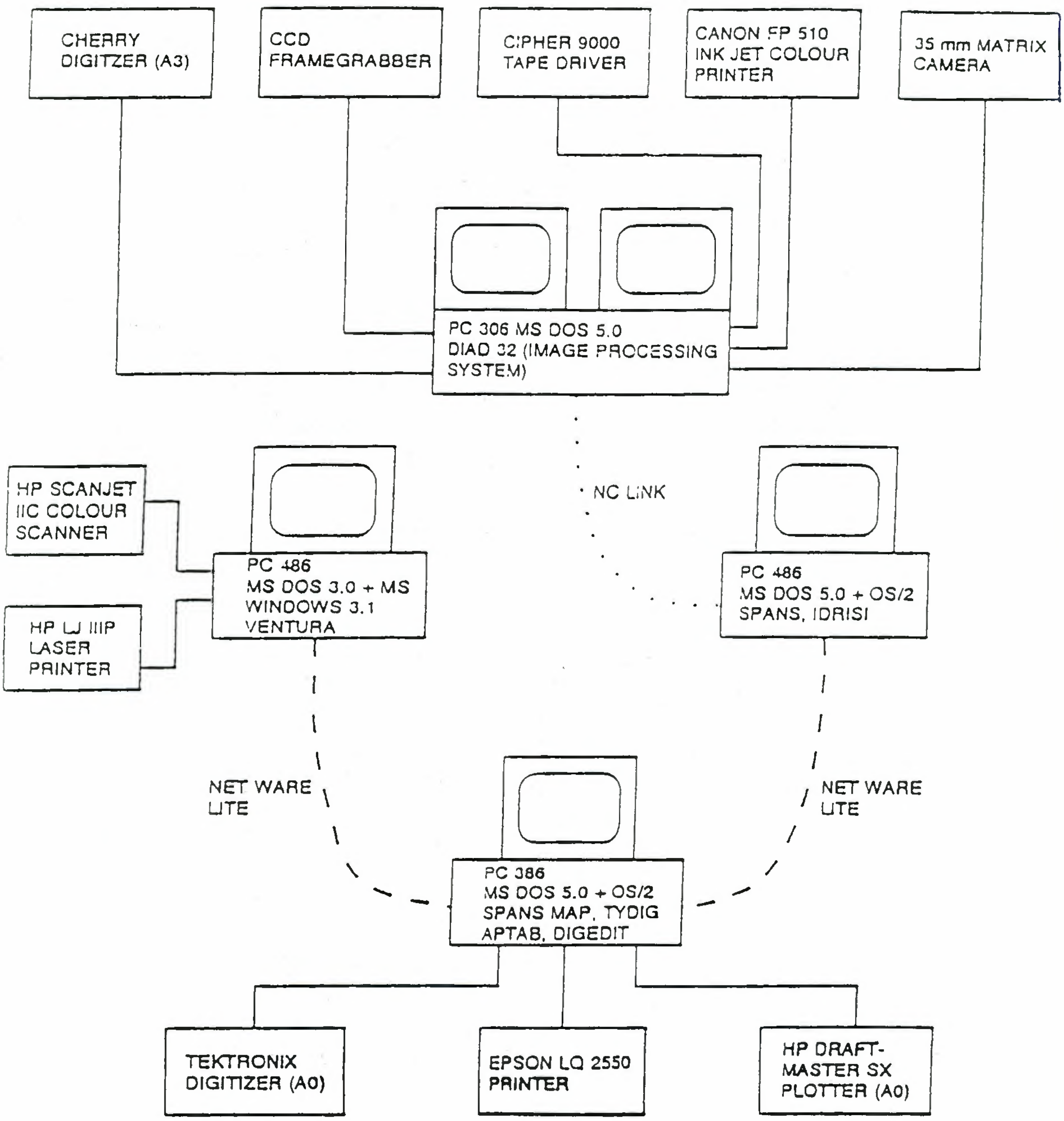

Figure 1: Hardware and software means of the Institute of Geography of the Slovak Academy of Sciences for digital interpretation of Remote Sensing data, technology of GIS and preparation of maps based on computer processing.

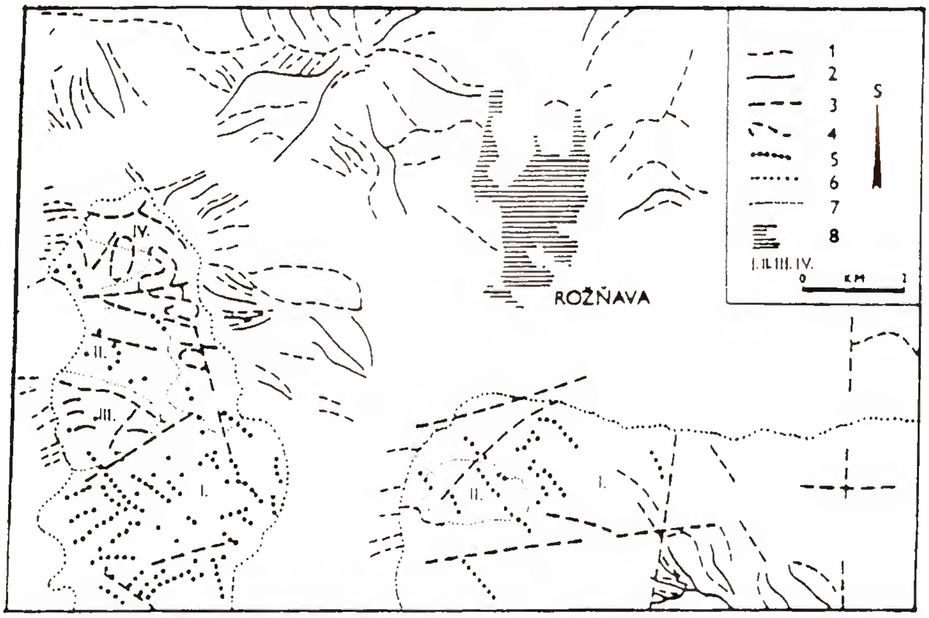

Figure 2: Interpretation scheme of the Slovak karst. 1-crest lines, 2-valley lines, 3-linear dividing marks, 4-non-linear dividing marks, 5-karst dolines, 6-edges of plateaus, 7-boundaries of patterns, 8-settlement, I,II,II,IV-patterns.

Figure 3: Interpretation scheme of the Laborecka vrchovina Mts. 1-crest lines, 2-valley lines, 3-linear dividing marks.

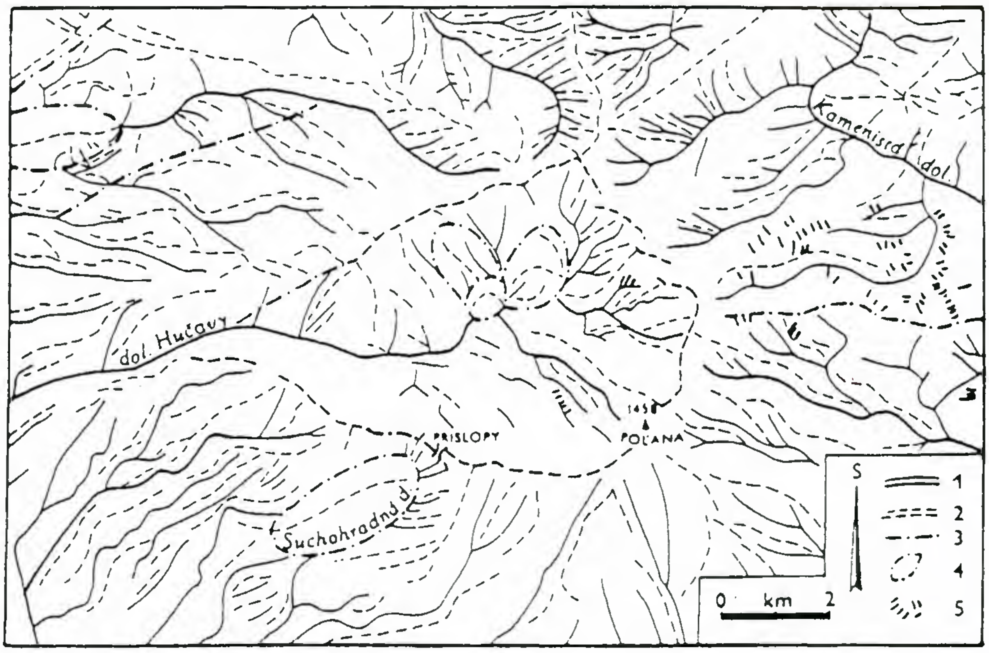

Figure 4: Interpretation scheme of the Polana Mts
1-valley lines, 2-crest lines, 3-other linear dividing marks,
4-non-linear dividing marks, 5-micro dividing marks

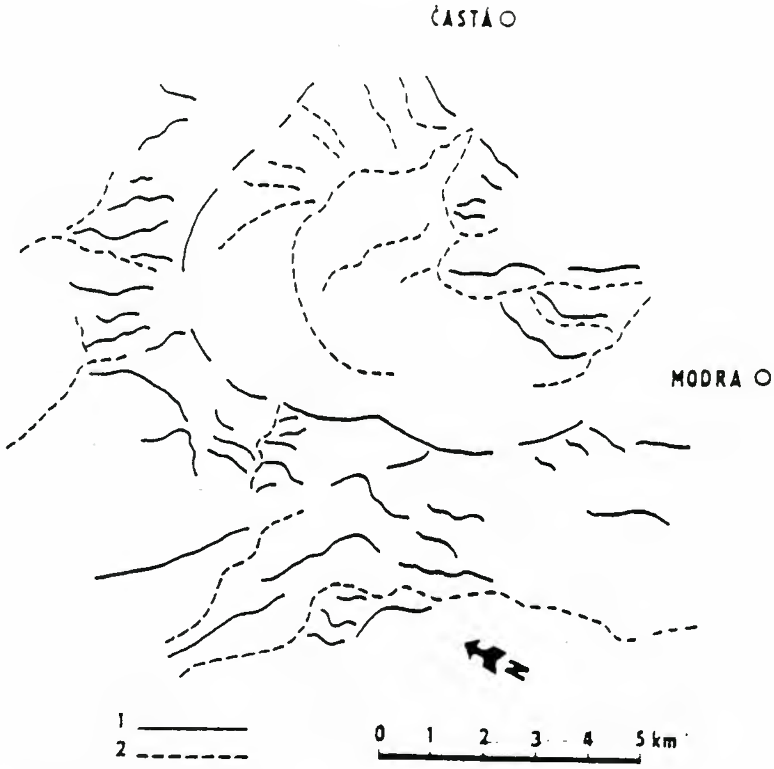

Figure 5: Interpretation scheme
1-crest lines, 2-valley lines.

CLASSIFICATION OF ERS-1 DATA FOR AGRICULTURE APPLICATION

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1. SATELLITE DATA IN AGRICULTURE

Satellite remote sensing has become more operational in various fields where monitoring of land surface is necessary. Agriculture profits from remote sensing technology by using satellite data for purposes of agricultural statistics and to develop agrometeorological models to allow forecasting of yields. Nevertheless, the problem of data availability is a key factor limiting an operational use of satellite remote sensing in agriculture. Due to cloud cover, the use of satellite data is often impossible.

Radar techniques offer monitoring of the planet surface independently of solar illumination and atmospheric conditions. This makes it a very important and potential mean of data collection for all countries with moderate climate conditions. Experimental processing of two data sets of ERS-1 satellite has been accomplished in central Slovakia to test this type of new technology.

2. AREA AND DATA USED

This study has been implemented in the test area located approximately 75 km northeast from Bratislava, capital of the Slovak Republic. A rectangular area of 20 km x 18 km has been centered around the point of 18 deg 05 min E, 48 deg 25 min N near the city of Nitra. Multitemporal ERS-1 data were used in this study. Two SAR images were obtained during the 1992 harvest season: 10 July and 18 September. The frame number was 2637 for both dates, orbit number 5148 and 6150 respectively. Data were written in PRI 16 bit format. Image size was 7671 pixels by 8176 lines (July data) and 7669 pixels by 8164 lines (September data). Both data sets represent files of about 125 Mbyte each. To make a comparision of radar and optical satellite data possible SPOT and TM data were also used during the study. SPOT XS scene containing multispectral data from 20 July 1992 together with a one quarter TM scene (path/row 186-26) acquired on 16 May 1992 were available.

Basic ground survey oriented towards agricultural applications has been accomplished by the staff of the Institute of Geography, Slovak Academy of Sciences in Bratislava. It took place one month after the ERS-1 second data set acquisition. Therefore it was impossible to define with certainty the land cover of the training fields at the time of data acquisition was impossible. This is valid only in the case of wheat and barley which were identified according to the residue of the stubble or ploughed soil surface. Other plants were not cut at the time of field checking. In all 14 fields located in different parts of the test area have been checked during the field survey. Land cover categories recognized in the fields are summarized in the Table 1.

Field No	Date 10/7/1992	Date 18/9/1992
1	vineyard	vineyard
2	barley	stubble-field
3	corn	corn
4	sunflower	sunflower
5	barley	ploughed soil
6	corn	corn
7	wheat	stubble-field
8	corn	corn
9	sunflower	sunflower
10	corn	corn
11	sugarbeet	sugarbeet
12	wheat	stubble-field
13	corn	corn
14	sugarbeet	sugarbeet

Table 1: Land cover/land use categories recognized on the surveyed fields during autumn term of ground control and derived categories for summer period of time.

To cover other main types of land cover additional training segments have been identified on the map corresponding to forest (3 sites), water bodies (2 site) and towns (3 site). It makes a total number of training sites used for interpretation and data processing equal to 22, which have been separated into 7 classes.

3. SATELLITE DATA PROCESSING

Digital processing of the data has been accomplished on the Silicon Graphics Indigo 4000 workstation using EASI/PACE image processing software product of PCI, Inc.(Canada).

3.1. Geometric corrections

To ensure spatial identity of all image data used in the study geometric transformations were performed. The SPOT image has served as a master image to which ERS-1 data and the TM data were registred. Polynomial transformation was applied using ground control points(GCP) specified in the respective images. Selection of GCPs is easier on images of the same physical origin, either both optical or both radar type of data. Therefore, the registration of radar images has been done first and is followed by fitting both radar images to the SPOT data. Spatial identity of two radar images of the same frame has been found satisfactory, nevertheless, transformation was needed. A total of 12 GCPs have been selected for the 1st order transformation using the 10 July image as a master image. Relative spatial accuracy of the two images after transformation was an average of 0.3 pixel.

To register radar data with SPOT data, 13 GCPs were identified and used for the 2nd order polynomial transformation. Average error in matching of both data sets has been 1.42 pixel in row direction and 1.33 pixel in column direction. The reason for applying the second order transformation was that the RMS errors were smaller for 0.3 pixel than for the 1st order polynomial transformation. Corrected radar data have been obtained by resampling radar pixel to 20 m using the cubic convolution method. In the final step of geometric correction the TM data was registred with SPOT image. Here, 11 GCPs were used for the 1st order polynomial transformation and with cubic convolution resampling to 20 m pixel size. Three sets of spatially registered satellite data have been created for thematic agricultural classification. Every data set has been multichannelled when optical data were monotemporal and multispectral while the radar set was multitemporal. All sets were of the same size, 1024 pixels and 934 lines.

3.2. Classification and data interpretation

ERS-1 data have been analyzed using two methods commonly used in satellite data processing. The first one is visual interpretation of displayed data and the second one is a digital classification.

3.2.1. Visual interpretation

The multitemporal SAR data set was visualized in the form of a two-color composite image. In this case, data of 10 July has been shown in red and data of 18 September in green. Color pictures have been printed on hardcopy at a scale of approximately 1:100000 for visual interpretation. Visual analysis followed the first results obtained during FAO/ESA/CEC Regional Workshop in Nitra, Slovakia, 1992 (Ref.1). The color assignments used were:

black:	low reflection in both dates
green:	low reflection in July and high reflection in September
red:	high reflection in July, low reflection in September
yellow:	high reflection in both dates.

Yellow sites in the lower part of the image indicate permanently high reflection targets such as urban areas and houses in villages as well as hill slopes faced towards the SAR antenna. Black corresponds to small lakes and river and roads. A key for the identification of agricultural classes is shown in Tab.1. Results of visual comparision are shown in Table 2.

Field No	Final color	Red component 10/7/1992	Green component 18/9/1992
1	yellow	vineyard	vineyard
2	yellow	barley	stubble-field
3	green/yellow	corn	corn
4	orange/yellow	sunflower	sunflower
5	red	barley	ploughed soil
6	green	corn	corn
7	orange	wheat	stubble-field
8	green	corn	corn
9	orange	sunflower	sunflower
10	green	corn	corn
11	red/green	sugarbeet	sugarbeet
12	black	wheat	stubble-field
13	green	corn	corn
14	red/green	sugarbeet	sugarbeet

Table 2: Color key for multitemporal ERS-1 image interpretation

Wheat and barley had not yet been harvested in July but by September fields had been fully harvested which resulted in red-tone colors in the image. Ploughed fields give low backscatter and so they are presented by more reddish tones compared to the higher reflectivity of stubble-fields which results in a more yellow color in the image. Corn is easily distinguished as green targets corresponding to its maturity in September. Sunflowers and sugarbeet are similar in color presentation, giving a fine texture of mixed green and red color mixture.

3.2.2. Automatical classification

Standard algorithms for supervised maximum likelihood classification has been used to recognize given categories in the SAR multitemporal data set. A training set was created based on ground survey data. Training pixels for every class were chosen interactively inside fields listed in Table 1. Their location was checked visually to assure availability of the training set for classification of the radar as well as the optical data. Due to a small shift of already corrected radar data in comparison to optical data , two to three pixel strips along boundary of every field were cut off from the training set, and so only one training set (see Table 3) could be used for classification of all data sets.

Code	Name	No of pixels
30	vineyard	356
60	corn	4371
90	sunflower	2862
120	sugarbeet	1539
150	leaf forest	2703
180	wheat	886
210	barley	2050
230	urban area	1691
250	water	263

Table 3: Composition of the training set

Results from the two-band multitemporal data set are presented in the form of a confusion matrix in Table 4. Training sets have been used to check the accuracy of the classification and to compute the number of pixels assigned from each class to other classes and vice versa.

Code	0	30	60	90	120	150	180	210	230	250
30	0.6	52.2	15.4	13.8	4.8	0.3	1.4	5.6	5.6	0.3
60	0.1	9.4	25.4	8.9	27.1	11.1	13.8	0.9	0.3	3.0
90	0.0	6.3	12.9	23.1	32.5	8.1	5.2	8.5	0.2	3.2
120	0.0	1.2	14.1	15.6	38.9	11.6	11.8	2.5	0.0	4.3
150	0.0	0.2	0.9	1.0	9.8	23.3	45.9	0.2	0.0	18.6
180	0.0	0.0	2.3	0.0	3.3	15.7	69.5	0.0	0.0	9.3
210	1.8	6.4	3.6	17.8	19.4	7.9	4.0	33.5	1.8	4.0
230	2.4	9.7	9.7	9.3	19.0	11.1	22.4	4.2	5.1	7.0
250	0.0	0.0	1.5	1.5	9.9	10.3	19.0	1.5	0.0	56.3

Table 4: Contingency table of the ERS-1 multitemporal data set classification.
Percent Pixels Classified by Code. Code 0 belongs to unclassified pixels.
Average accuracy = 36.36%
Overall accuracy = 28.23%
Kappa Coefficient = 0.19016
Standard Deviation = 0.00404

The best accuracy of 69.5% has been achieved for wheat. A similar result could also be expected for barley but this was not the case. Only classes of water and vineyard had a classification accuracy better than 50%. However, more then 45% of forest pixels have been included with wheat. Moreover almost one third of the sunflower pixels and a large proportion of the corn class have been classified as sugarbeet. In the second classification, forest and water classes were masked out of the image. Information about those two categories can be obtained from existing maps and thus used to decrease intrinsic complexity of the classification process. In this case, the mask of forest and water was obtained using classification of the SPOT and TM data. Results from the second classification are presented in Table 5.

Code	0	30	60	90	120	180	210	230
30	0.6	52.2	15.9	13.5	5.2	1.7	5.5	5.5
60	0.1	9.5	25.3	9.1	33.9	20.9	1.0	0.3
90	0.0	6.3	13.2	23.3	39.1	9.4	8.5	0.2
120	0.0	1.2	14.8	15.9	46.7	18.8	2.6	0.0
180	0.1	0.0	2.3	0.1	7.0	90.2	0.0	0.3
210	1.8	6.4	3.9	17.9	26.6	8.2	33.4	1.8
230	2.1	9.7	10.6	9.5	26.1	32.4	4.0	5.5

Table 5: Confusion matrix for classification of masked ERS-1 data
Percent pixels classified by Code
Average accuracy = 39.50%
Overall accuracy = 31.09%
Kappa Coefficient = 0.19684
Standard Deviation = 0.005

The application of the mask improved the classification accuracy for both wheat and sugarbeet but it left all other classes intact. As seen in Table 5, the confusion among classes of sunflower, corn, barley and sugarbeet remains.

4. EFFECT OF FILTERING

A much improved classification result has been obtained after texture filtering. A type of Frost filter was used which primarily filters speckled SAR data, smoothing image data, without removing edges or sharp features in the images. The filter uses an adaptive filtering algorithm which is known as the Frost filter. It is an exponentially damped convolution kernel which adapts itself to features by using local statistics. The adaptive filter computes a set of weighted values for each pixel within the filter window surrounding each pixel. The filter dimensions must be uneven. The damping factor depends on the non-filtered image and may require trial-and-error experiments to determine the best value. This value defines the extent of the exponential damping (the smaller the value, the smaller the damping effect).The implementation of this filter consists of defining a circular symmetric filter with a set of weighting values (M) for each pixel.

$$M = \exp(- A \times T)$$

where:

$$A = DAMP \times (V^2/I^2)$$

and T is the absolute value of the pixel distance from the centre pixel to its neighbour in the filter window; DAMP is the exponential damping factor; V^2 is the grey-level variance in filter window and I^2 is the square of the mean grey level in the filter window.The resulting grey-level value R for the smoothed pixel is:

$$R = (P1xM1 + P2xM2 + \ldots + PnxMn) / (M1 + M2 + \ldots + Mn)$$

where:

P1 ... Pn are grey levels of each pixel in filter window

M1 ... Mn are weights (as defined above) for each pixel.

All pixels in the image are filtered. In order to filter the pixels located near the edges of the image, edge pixels values were replicated to give sufficient data. The original multitemporal SAR data set was filtered using this filter for 5 by 5 pixels size with DAMP value equal to 1. Results of this classification are described by the confusion matrix presented in Table 6.

Code	0	30	60	90	120	180	210	230
30	1.1	82.9	9.3	0.6	0.0	0.0	0.0	6.2
60	0.0	7.8	73.3	3.6	14.7	0.1	0.2	0.3
90	0.0	1.3	2.9	61.3	29.7	0.0	2.0	2.8
120	0.0	0.0	9.7	12.6	77.7	0.0	0.0	0.0
180	0.0	0.0	0.7	0.0	0.0	98.3	0.0	1.0
210	0.3	3.7	0.1	28.3	3.1	0.0	52.4	12.0
230	3.3	2.2	37.8	13.5	22.4	4.6	0.9	15.3

Table 6: Confusion matrix for classification of filtered and masked ERS-1 data
Percent Pixels Classified by Code
Average accuracy = 65.87%
Overall accuracy = 62.89%
Kappa Coefficient = 0.54248
Standard Deviation = 0.00497

As has been shown, the classification accuracy improved dramatically with more than 98 % for wheat down to over 15 % for urban areas. Low accuracy for barley classification is probably due to the uncertainity of ground survey data. When devided into two classes, - one for barley stubble-field and one for barley ploughed soil - their particular accuracy reached 73.4 % and 90.1 % respectively.
Comparision of the classification of SPOT and TM data sets has been accomplished. The average accuracy of TM classification was 88% and the Kappa coefficient 0.74. Using the same parameters for SPOT classification these were 98.2% and 0.97, respectively. Classification of merged TM and ERS-1 data gave a slightly better accuracy but combination of SPOT and ERS-1 data resulted in a slight deterioration of accuracy compared to pure SPOT data classification.

5. CONCLUSIONS

Results of visual interpretation of ERS-1 SAR multitemporal data were encouraging and promissing for the automatic classification. However, classification results were not as successful as had been expected. Reasons for this could be the still large difference between interpretation capabilities of man and the rather simple algorithms of statistical classification. Two "channel" multitemporal radar data are less suitable for standard classification processes than are multispectral optical data sets. The main reason for this is due to radar data not fulfilling a presumption of the Gauss distribution and having a Rayleigh type of distribution. After application of the adaptive filter, the noise of the data is lowered and the data distribution becomes more Gaussian. Therefore, the classification results in terms of the overall accuracy are much better than in the case of unfiltered images. Nevertheless, the main advantage of radar is that it allows data acquisition independently of clouds, which makes radar a unique source of data, available during different stages of crop development and at a period of time which is important for agricultural statistics. Experience gathered in this study shows that ERS-1 data can be of significant help for some crop identification and acreage estimates, particularly during cloudy growing seasons. Radar data could be considered as an efficient means of extrapolating basic crop information obtained by optical sensors. After necessary investigations, radar data will be able to be used in already existing operational projects such as the MARS project. More research work is needed to improve our knowledge about the right parameters to be investigated during ground checking, about radar radiation backscattering of different crops and to examine more fully the use of multitemporal radar data sets.

6. ACKNOWLEDGEMENT

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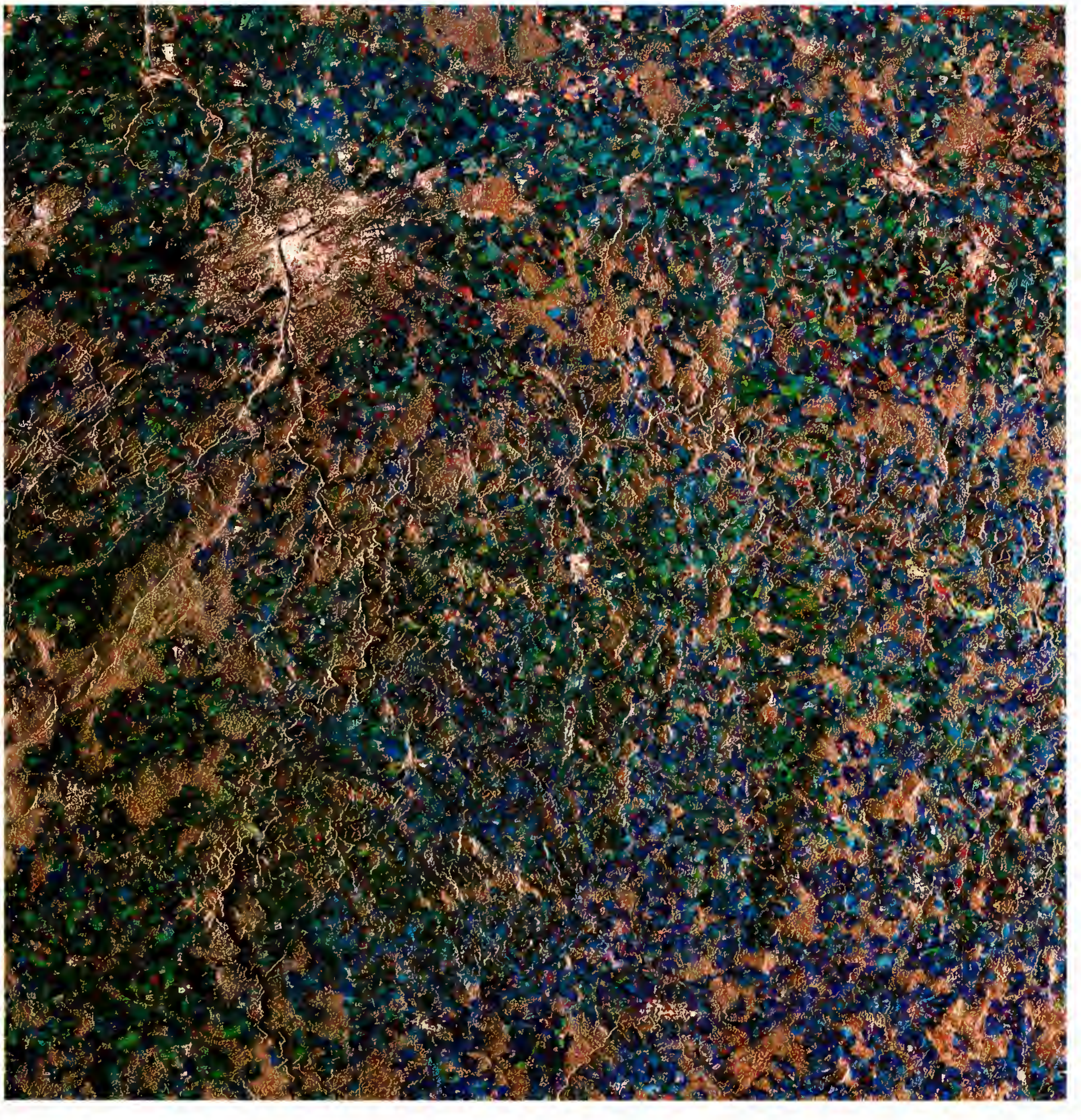

ERS-1 SAR multitemporal image of Prague region (26 May 1992, 30 June 1992, 8 September 1992 as Red/Green/Blue - Scale: 625.000) Acquired at Fucino recieving statio, processed by Italian processing and archiving facility, Matera.

THE APPLICATION OF ERS-1 IMAGES FOR FOREST DAMAGE ASSESSMENT

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ABSTRACT

Multitemporal ERS-1 images collected over the Sudety Mountains have been used to assess damage to spruce forest in this ecologically deteriorated area. It has been found that this type of image has serious limitations in detection of forest classes, which is why they may play a role only as auxiliary data. The ERS-1 images have also been used to monitor burnt areas within forests. It turned out that they can be very useful in forest fire management.

Keywords: forest damage assessment, monitoring.

In the early seventies, the problem of deterioration of environment emerged in Poland. It occurred in several places in the Southern part of the country; firstly in highly industrialised Upper Silesian Region as well as in the Sudety Mountains. A large number of investigations aiming at the assessment of threats and damage to the environment were undertaken. The majority of them were concentrated in the Sudety Mountains, where the problem of damage of various components of environment was most serious. A part of the Sudety Mountains has been even recognised as a region of ecological disaster. Since that time, in order to detect damaged trees and stands false colour aerial photographs have been used.

A thousand of hectares of forest covering the Sudety Mountains have been photographed. The acquired aerial photographs have been then used for elaboration of maps showing the state and extent of damage to coniferous stands. This investigation was accompanied by comprehensive ground measurements to facilitate the interpretation of aerial photographs and to increase the reliability of results.

By the end of seventies, the area of damage of spruce stands, predominant in the Sudety Mountains, extended over such large areas that it became possible to use satellite images to detect and classify the degree of damage to these coniferous forests. A number of Landsat MSS and TM as well as SPOT and Cosmos images were used for mapping forest conditions in that region.

After several years of investigations a large volume of information has been collected. This collection of data and information, and also the need of acquiring satellite data at the right time, which is very often difficult in the case of Landsat, SPOT and Cosmos, have induced us to undertaking the new investigations on application of microwave images to recognize of spruce stands and their state in the Sudety Mountains.

The proposal of such investigations has been approved by ESA as Pilot Project PL-3. ESA has provided a series of ERS-1 images for this project. The work on analysis of images was conducted in two ways. First of all a relationship between a backscattering coefficient and parameters characterising various stands were investigated, and at the same time interpretation of single and composite images have been performed using visual and computer assisted methods.

Special attention was paid to define a relationship between information derived from microwave images, ground measurements and information derived from Landsat TM images. Landsat images were used as a reference data because they were found to be the most valuable source of remotely sensed information for assessment of forest condition.

The following parameters of forest stands, determined in the course of field work, were analysed in the study: age, breast diameter ($D_{1.3}$), height of tress (H), height of crown base (H_K), crown diameter (O_K), crown length (L_K), canopy closure (Z_W), number of trees per unit area (N), number of dead trees per unit area in the main stand (NM_G) and number of trees in the secondary stand (NM_p), defoliation (D_f), needle discoloration (D_f), stand quality (D_m) and slope. Defoliation and discoloration were evaluated according to ICP-Forest instructions (International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests) and quality of trees was assessed on the basis of state of assimilatory apparatus, height increments and vigour of trees (Dmyterko & Grzyb, 1990).

Studying relations between ERS-1 and TM images, covering the Sudety test site, the following areas were analysed separately:
- full-scene areas, comprising different forms of land use (forest, arable land, build-up areas, water, etc.)
- sub-scene areas, comprising the Karkonosze forests (all spruce stands, clear-cuts and different levels of forest damage)
- areas covered by spruce and mixed beech-spruce stands (3rd class of age and higher)
- areas covered by stands with 80% spruce contribution (3rd class of age and higher).

The relationships between ERS-1 backscattering coefficient and Landsat TM spectral data were examined and moreover, in the case of forests areas, different transformations of original TM data were also considered: TM5/4, TM4/3 ratios, NDVI, brightness index, and principal components (PC1,2,3).

The results of these analysis, presented in Table 1, reveal low correlation between ERS-1 and TM data. Correlation coefficients, obtained only for forest areas are lower than those for the whole scene; they do not exceed a value of 0.1.

In the case of all forest stands, the highest correlation coefficient was obtained for TM6 band, but its value is still low (0.17). A slight increase of these values is observed, when only spruce stands are analysed, especially for visible bands, as well as for TM7, PC, TM5/4, TM4/3 ratios, NDVI and brightness index, but still the correlation between ERS-1 and TM data is not strong (the highest correlation coefficients reach a value of 0.29). Therefore, this analysis proved that there is not significant relation between radar and optical data. That result led us to the conclusion that the use of ERS-1 data can support information derived from optical bands, as both types of images give different information about environmental conditions.

Examination of relations between backscattering coefficient and stand parameters was the second stage of analysis of ERS-1 images covering the Sudety Mountains. This analysis was conducted for the following stands:
- spruce stands (over 80% spruce);
- spruce stands covering slopes with NE, E and SE aspects (most favourable, considering direction of radar beam);
- spruce stands with canopy closure higher than 0.8
- spruce stands with canopy closure higher than 0.8, covering slopes with NE, E and SE aspects.

Results of the examination, presented in Table 2 reveal that relations between radar images of forests and their terrain parameters are not significant. When studying all spruce stands the highest correlation coefficient of 0.34 was obtained, showing the relation between backscattering coefficient and crown diameter. In some cases, correlation coefficients increase when only forests on favourable aspects are considered. However, these relations are distinct only for crown diameter and breast diameter ($r = 0.76$), height of trees (0.72), age (0.61) and crown length (0.54).

For the next study, considering spruce stands with full canopy closure, the highest correlation was found for crown diameter (0.36) and for breast diameter (0.33). Also, in this case, while taking into account only NE, E and SE aspects, correlation coefficients increase for some parameters, such as breast diameter, height of trees, crown diameter, age, crown length, defoliation and index of damage, reaching the highest value of 0.71 for breast diameter. It is worth mentioning that the relation between backscattering coefficient and slope increases when the analysis includes only slopes illuminated by radar beam. It proves that values of radar response are dependent on the incidence angle of the radar beam.

For the selected spruce stands, attempts were made to find relations between backscattering coefficient and leaf area index (LAI) and mean tip angle (MTA) for needles. The data for this analysis were collected in the Sudety Mountains with the use of a Plant Canopy Analyser, (Zawila-Niedzwiecki et al., 1993). There was no correlation found between backscattering coefficient and LAI ($r = 0.08$), while a slightly higher correlation was observed for MTA ($r = 0.43$), although it is still too weak to draw valid conclusions. This analysis should be treated as a pilot study as only 17 stands were considered and the ERS-1 image was collected one year after field measurements.

Besides simple regression, multiple relations between stand parameters and SAR signals have also been investigated. The highest correlations were found for spruce stands with full canopy closure, covering slopes with NE, E and SE aspects; the regression equations are as follows:

(I) $\sigma^0 = 17.33 - 0.07\ \mathrm{Age} + 0.34\ D_{1.3} + 0.75\ O_K$ $\qquad R^2 = 0.83$

(II) $\sigma^0 = 13.35 + 0.33\ D_{1.3} - 0.07\ N + 0.71\ NM_G$ $\qquad R^2 = 0.64$

(III) $\sigma^0 = 3.99 + 1.11\ O_K - 0.09\ N + 7.6\ D_m$ $\qquad R_2 = 0.62$

Thus the variability of the backscattering coefficient can be mostly explained by changes in stand age, breast diameter, crown diameter, number of trees per unit area, number of dead trees in the main stand and quality of trees characterised by index of damage.

High relief in the Sudety Mountains makes analysis of radar images more difficult, as many stands are located in a shadow or at low incidence angle, which shows its influences with decreasing correlation coefficients. However, the results are better when only NE, E and SE slopes are taken into account. It can be concluded that in order to determine correlation characteristics, it would be more useful to analyse stands illuminated by radar beam, i.e. located only on eastern slopes (E). Unfortunately, it was not possible in this study as the number of stands would have been too small. Thus, for this analysis, a visual interpretation of radar images of the Sudety Mountains and a comparison with forest maps and aerial photographs was carried out.

While visually interpreting radar satellite images it was found that speckle ("salt-and-pepper effect") makes analysis of single images much more difficult. Visual analysis of colour composites, formed from multidate images, gives more interesting information, which is not easy to derive from individual images. In order to create colour composite for the Sudety Mountains, three images collected on Sept. 24, 1992, Dec. 3, 1992 and April 6, 1993, were utilised. They were projected using green, blue and red beam respectively, which gave rendition of forests in different shades of green colour, facilitating interpretation.

Non-uniform snow cover recorded on December's image made recognition of particular terrain objects more difficult. But it did not make a problem in case of colour composite; on the contrary, snow cover facilitated the analysis of this composite.

Particular components of colour composite should include complementary information, so they should be different as much as possible. This was the case in our study where colour composite was formed from images collected during three seasons (early autumn, winter and early spring). Results of visual interpretation reveal that the following forest classes can be distinguished on ERS-1 images; older stands, thickets, clear-cuts and stands with very loose canopy closure. The boundary between forest and arable land is clearly visible. On the other hand, delineation of species is not possible. Moreover, interpretation of dwarf mountain pine, high mountain grasses and bare rock, due to relief and high radar response from rocks and dwarf mountain pine, is much more difficult, being sometimes impossible. These difficulties do not exist on flat area where interpretation of colour composite is more easy to perform.

Snow and ice covers have a great influence on intensity of backscattering radiation. It is well visible in the case of water surface, forests with loose canopy closure and arable lands. The intensity of backscattering from these objects, registered on the satellite image acquired in December is much higher than on the image taken in September. The clear cut areas covered with grass have darker tone on images taken in December and April then on the image taken in September. The difference in signal response is due to amount of water in the root zone of soil.

It should be emphasised that analysis of ERS-1 images covering highlands, without using DTM, is extremely difficult and needs a comprehensive knowledge of terrain being under investigation. Distortion of the images as well as radar shadows are the main obstacles in interpretation of the images and make the computer-assisted classification more difficult and less reliable. It was found that low pass filtering and image segmentation help very much in the analysis of the objects registered in microwave images.

In the case of the test site located in lowlands there were many problems with varying illumination of stands. That is why the analysis of that image was limited to visual interpretation. Also in this case it was possible to recognise on the ERS-1 image old pine stands, thickets, clear cuts and stands with very loose canopy closure. The distinction between species is still impossible.

The huge burned area (about 8 000 ha) was an object of analysis on ERS-1 image from Kuznia Raciborska Forest. Due to significant changes in response of the signals from alive and burned stands it was possible to recognise that area without any problem. SPOT image was also used for the same purpose. Comparison between results of analysis revealed that the accuracy of delineation of the burned forest on this two types of images is similar.

In summary, it should be said that ERS-1 images have a very limited application in analysis of forests. They can serve only as the auxiliary source of information about forest located in lowlands. Recognition of species, as well as state of damage to the forest cannot be done on the basis of these images.

TM bands	**Entire screens**	**Forested area**	**All stands**	**Spruce stands**
1	0.10	0.06	-0.27	-0.30
2	0.09	0.06	-0.28	-0.32
3	0.08	0.07	-0.30	-0.36
4	0.08	0.03	-0.12	-0.01
5	0.10	0.07	-0.27	-0.25
6	0.10	0.03	0.02	0.14
7	0.08	0.08	-0.31	-0.35
5/4			-0.27	-0.40
4/3			0.15	0.24
NDVI			0.28	0.39
BR			-0.17	0.06
PC1			-0.23	-0.17
PC2			-0.19	-0.41
PC3			-0.04	

Table 1: Correlation coefficients characterizing the relationships between ERS-1 SAR and TM channels.

Parameter	Spruce stands	Spruce stands on NE,E,SE slopes	Spruce stands with close canopy	Spruce stands with close canopy on NE,E,SE slopes
Age	0.03	0.09	-0.18	-0.08
$D_{1.3}$	0.12	0.01	-0.15	-0.16
H	0.20	0.03	-0.12	-0.05
H_K	0.22	0.18	-0.03	0.17
$Ø_K$	0.13	-0.10	-0.09	-0.34
L_K	0.04	-0.22	-0.18	0.45
N	0.10	0.18	0.08	0.30
NM_G	-0.09	0.17	0.13	0.06
NM_P	-0.09	0.02	0.30	0.28
D_f	0.05	0.04	-0.02	-0.02
D_c	0.06	0.42	0.16	0.35
D_m	0.02	-0.16	-0.12	-0.24
Slope	-0.09	-0.23	-0.02	-0.25
Canopy closure	0.29	-0.06	--	--

Table 2: Correlation coefficients between ERS-1 SAR data and stand parameters.

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REMOTE SENSING AND GIS IN FIRE MANAGEMENT OF POLISH FORESTS

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ABSTRACT

For several years the number of fires in Polish forests has been increasing. It has been suggested that in some regions in Poland a new category of forest fire risk has appeared. Forest fires are a result of the simultaneous existence of at least three unfavourable phenomena: long-term drought, effects of air pollution (decline and decay of trees, formation of loose forest canopy, lush growth of grasses, all resulting in large amount of inflammable material) and high tourist traffic in forests.

Due to this situation, forestry has started to apply new techniques and technologies for forest protection, e.g. remote sensing and GIS, which can be considered within three aspects:

-fire risk prediction for particular regions and for the whole country,

-fire monitoring,

-inventory of fire damage to forests, assessment of losses and monitoring of regeneration/afforestation.

Several techniques have been used in these activities: aerial photographs, SPOT, Landsat TM and NOAA satellite imagery, and recently ERS-1 data. Comprehensive work on creating descriptive and spatial data bases, which enable forest fires inventory and assessment of losses, as well as monitoring of forest regeneration, has been carried out.

Four types of forest fires are recognized in Polish forestry, corresponding to forest storey affected by fire: underground fires (peat-boggy), fires of soil surface (75% of all forest fires in Poland), fires of the whole stand and fires of individual trees. The majority of these fires is not larger than 1 ha, but at the same time a distinct increase of large forest fires can be observed. In 1992, 9305 fires were recorded in Poland (3 times more than in previous years); they covered 37 000 ha of forest (12 times greater than in 1991). A long period of dry weather and high air temperatures were the main reasons for such a great number of fires. There is an opinion that there is a new category of fire risk in Poland; it results from the simultaneous overlap of at least three phenomena: long-term drought, high touristic traffic and effects of air pollution (decline and decay of trees, loosening of canopy closure, lush growth of grasses, hence large amount of inflammable material).

In this situation, characterized by increasing fire risk and greater number of large fires, it is necessary to apply new techniques and technologies for forest prevention, e.g. remote sensing and GIS. There are three aspects of their application for fire management in Polish conditions:
- fire risk forecast for the whole country and for particular regions,
- fire monitoring,
- inventory of fire damages to forests, assessment of losses and monitoring of regenerations.

Remote detection and monitoring of forest is possible due to radiation emitted by objects where the intensity is correlated with temperature. Spectral curves of blackbody radiation reveal variations of its emission according to temperature. Maximum object radiation at temperature 25°C is about 10 μm with a shift towards shorter wavelengths with increasing temperature. Emission by fire is characterized by radiation distribution similar to blackbody radiation at temperature 500°C. According to Arcybaszew (1983) and Calabri (1984) the temperature of flames oscilates between 275°C and 420°C, while a mean temperature of flames of 900° C was determined as a result of studies conducted by the Forest Research Institute in Warsaw (Karlikowski, 1992). Comparison of these data with the distribution of blackbody radiation allows the assessment of optimum spectral range for detection of forest fires, i.e. 1.8-14.0 μm (infrared band). There is quite strong absorption of radiation in this range, caused by ozone, carbon dioxide and water. Only two spectral bands within this range, 1.8-5.3 μm and 7-14 μm, enable radiation to be transmitted with negligible absorption.

The middle infrared band, i.e. 3-5 μm is especially important for fire analysis, as the maximum emission for fire temperature is in this range. It is located in the third atmospheric window, where low solar and Earth radiation are observed. Due to that fact, the main signal is not disturbed by signals coming from other sources, contrary to the 2.2-2.5 μm range, where a strong signal is emitted by fire but where high noise level makes usefulness of this radiation range very limited.

These rules of emission of electromagnetic radiation by fire sources are the basis for using remote sensing for forest fire management. Two types of data, aerial photographs and satellite images are applied for this purpose.

Satellite images can be used for detecting forest fire in large forest areas. Even geostationary meteorological satellites of the GOES system (Geostationary Operational Environmental Satellite) and Meteosat can be used for this purpose. Meteosat images recorded in three spectral bands (0.4-1.1 μm, 5.7-7.1 μm and 5-12.5 μm) are transmitted to receiving stations every 30 min; their ground resolution is 2.4 km in the visible band and 5 km in the infrared band. As can be seen from this description, images collected by geostationary satellites, located at 36 000 km orbit, are characterized by high temporal resolution and low ground resolution; it enables only very generalized analyses, so usefulness of these images for fire management in European conditions is very limited. Two other groups of satellites, collecting data with higher ground accuracy, are placed at lower orbits (700-800 km), such as NOAA meteorological satellites and earth resources satellites. Each polar orbiting NOAA satellite collects images of the same part of Earth's surface every 12 hours and mutual arrangement of satellites in space allows observation of the selected area every few hours. The AVHRR (Advanced Very High Resolution Radiometer) scanner is installed on board of the NOAA satellites; it collects images with 1.1 km resolution in five spectral bands. Three bands, i.e. AVHRR 3 (3.55-3.93 μm), AVHRR 4 (10.3-11.3 μm) and AVHRR 5 (11.5-12.5 μm) are useful for fire detection.

One pixel of a NOAA satellite image covers an area of 121 ha at the nadir point. However it was found that the AVHRR scanner can record a fire covering only 1 ha area (100 times less than pixel size). It results from a great intensity of radiation emitted by fire, which dominates the spectral response of the whole area covered by the pixel. Thus a satellite sensor is able to detect the source of a fire, but the acreage of the fire cannot always be assessed on the basis of the image (Ciolkosz and Kesik, 1989).

Due to low resolution, NOAA images are not especially useful for direct detection of forest fires in Polish conditions characterized by small forest areas, high urbanization and industrialization. High-resolution images collected by earth resources satellites are more applicable to fire management. The Landsat satellite with Thematic Mapper scanner, which records middle infrared bands (1.55-1.75 μm and 2.08-2.35 μm) with 30 m resolution and thermal infrared band (10.4-12.5 μm) with 120 m resolution, is the most suitable for fire studies.

While for fire detection the application of middle/thermal infrared band is advisable, smoke can be interpreted on panchromatic/near infrared images (0.5-1.1 μm). Meteosat and NOAA images can be used for this purpose, but Landsat TM images (30 m resolution) and SPOT images (10m and 20m resolution) give a much higher precision of fire mapping.

Due to high ground resolution, Landsat TM and SPOT images are the best for inventory of areas damaged by fires. Panchromatic SPOT images with 10m resolution can be especially recommended. Criteria of high ground resolution are also fulfilled by Cosmos images. These images are recorded in panchromatic and colour-infrared mode; lately they have extremely high 2m ground resolution. However, Cosmos satellites are not operational, compared to GOES, NOAA, Landsat and SPOT satellites. Nevertheless their high precision, exceeding accuracy of digital data collected by other systems, should be emphasized.

The collection of satellite images in optical bands is sometimes difficult in our latitudes due to cloud cover obscurring Earth's surface. Thus, there is ongoing research on using microwave region. Radars working at this range enable the collection of images in all-weather conditions. Currently there are two satellites equipped with radar systems: ERS-1, constructed by European Space Agency and the Japanese JERS-1. There will be soon a new series of satellites with microwave sensors: Canadian RADARSAT, the second European ERS-2 satellite and the Russian ALMAZ 1B following ALMAZ 1, which was used in 1990-92.

Temporal resolution is the crucial aspect limiting the usefulness of Landsat, SPOT, ERS-1 and JERS-1 images (on average from ten to twenty days). Even in the case of SPOT, which enables recording of the same area from several orbits, only about 15 images can be collected for the same area during fire risk months.

Research on using remote sensing for fire management is quite difficult in Poland, due to the spatial distribution and structure of forests. Moreover, the majority of forest fires occur at the soil surface and cover areas less than 1ha (on the average 1.5 ha). The strategy of fighting fires, accepted in our country, is based on assumption that only forest fires smaller than 10 ha can be effectively suppressed. Thus, in order to delimit acreage of fires, continuous ground and aerial monitoring of forest areas is carried out during the period of fire risk. Moreover, airplanes and helicopters are properly equipped and so are able to alarm immediately fire brigades and to begin fire extinguishing.

Considering the mean area of forest fires in Poland, application of satellite images for their detection is limited. Aerial thermal remote sensing is also not often used as a dense, dispersed settlement network in Polish forests and high touristic traffic make automatic air monitoring difficult. However, there are remote sensing methods which were verified in our conditions.

In 1992 the Forest Research Institute (IBL) in Warsaw applied panchromatic aerial photographs for evaluating the extent of fire in Lubsko Forest division. Thermal aerial images were used by Remote Sensing Centre (OPOLiS) of the Institute of Geodesy and Cartography for detecting underground fires. Thermograms recorded by AGA Thermoprofile THP-1 scanner and colour equidensity thermograms, produced with the use of an electronic-analogue viewer, allowed the determination of the distribution of soil temperature and hence fire location. OPOLIS has experience also in utilizing colour-infrared aerial photographs for assessing quality of forest; that experience can be used for evaluating stands damaged by fires at soil surface, which cause decline and decay of trees.

Research work on using satellite images has continued for several years. In 1992, the largest forest fire in Poland (9000 ha), located in Upper Silesia region (Kuznia Raciborska) was observed on satellite images. The way the fire, which started on August 26, 2 p.m. spread was exceptional in Polish conditions. It was evidenced by very rapid increase of burnt area:

26.08 6 p.m. - 600 ha (fourth hour of fire)
26.08. 10 p.m. - 2200 ha
27.08. 1 a.m. - 3500 ha
27.08. 9 a.m. - 5500 ha
27.08. 7 p.m. - 5700 ha
28.08. 8 a.m. - 6000 ha
30.08. 6 p.m. - 8500 ha

The extent of the fire was so large that increasing burnt area and smoke could be observed on NOAA AVHRR images at a distance of 100 km. SPOT XS and P images acquired in September 1992 and in May 1993, as well as ERS-1 images acquired in July 1993 present clearly the extent of the fire.

ERS-1 images and SPOT XS images of Kuznia Raciborska forests enable the determination of a burnt area with the same accuracy (Ciolkosz et al., 1993). However, small clumps of trees which survived could be better distinguished on SPOT image, due to high near-infrared reflectance. Speckle characteristic for microwave images makes discrimination of these clumps on ERS-1 images more difficult.

The location of the fire outbreak, located in southwestern part of forest area, close to Dziergowice-Kuznia Raciborska railway, is clearly visible on satellite images. The burnt area consists of two complexes: southern and northern part, divided by Kedzierzyn-Kozle - Knurow railway line, Kedzierzyn-Kozle - Gliwice road and sand mine. Fire was transferred from southern to northern part in the surroundings of Kotlarnia, where two forest complexes were joined by a 1 km strip. It can be assessed from satellite images that the maximum extent of the burnt area is: in the southern part: 7700 m - NS, 10700 m - EW; in the northern part: 10500 - NS, 7500 m - EW (Zawila-Niedzwiecki et al., 1993).

According to ground assessment, the acreage of the burnt forest is 9060 ha (Karlikowski, 1992), while a figure of about 8000 ha was obtained on the basis of analysis of ERS-1 and SPOT images. That discrepancy (10%) can be partly caused by generalization, resulting from ground resolution of satellite images, especially by "mixels" effect which appeared along the limits of the living and burnt stands. Overestimation of ground assessment is also possible.

Irregularities in the shape of the burnt area, as well as small clumps of surviving stands, can affect the accuracy of assessment, due to spectral values of mixed pixels at the edges, which aggregate different spectral response, causing underestimation of the burnt area. However, similar results obtained from measurements made on ERS-1 and SPOT images imply that ground evaluation was overestimated.

Forecast of forest fire risk is the next application of remote sensing for fire management. This risk is determined at present in Polish forests dayly during the period of inflammability, comprising 200-240 days. It is done through measuring moisture of forest litter at permanent terrain stations according to a method prepared by Forest Research Institute in Warsaw (Karlikowski, 1981).

New studies revealed that there is a relation between soil moisture, vegetation state and evapotranspiration, inferred from NOAA data (Dabrowska-Zielinska, 1987; Dabrowska-Zielinska et al., 1992). As a result of these studies it was decided to test the usefulness of NOAA AVHRR images for evaluating fire risk in Polish forests. Temporal resolution and real-time acquisition are the great advantages of applying NOAA images for fire risk assessment. The AVHRR scanner, accompanied by a system of high resolution picture transmission - HRPT, is characterized by operational features. It records in a broad spectral range and its high temporal resolution allow the acquisition of several images during 24 hours. A large field of view enables imaging of the whole country, while ground resolution (1.1 km) allows the aggregation of spectral response, thus avoiding disturbances caused by local changes of reflectance and emission. Thus a new idea of fire risk assessment was based on the assumption that indices derived from NOAA images can be correlate with parameters which determine susceptibility of forest to fire.

Current research work is concentrating on deriving radiation temperature, evapotranspiration and vegetation indices of stands from NOAA data, as well as on finding relations between these remotely sensed parameters and terrain parameters, which describe stand imflammability.

Reasons for forest fires are multiple and have various implications. Therefore, work on modelling fire risk, its origins, development and consequences has been recently started. Spatial information systems are of great help in creating these models; they enable analysis of the different data which influence fire risk and its consequences. The main elements of the models are: types of stands and species composition for particular forest storeys, archive forest data, topographic data, relief, climatic conditions, one of the most important elements of the system. In Poland this system is being built on the basis of Forest Fire Database-FFD (Karlikowski et al., 1993). FFD stores 32 types of information about forest condition of burnt stands, meteorological conditions existing during fire, type and acreage of burnt area, characteristic of fire and fire-extinguishing action. These data are used for analysis of forest susceptibility to fire and analysing reasons for their occurence, depending on natural conditions. This information, assembled with forest maps, already partly entered in the database, are the beginning of GIS for fire management purposes.

In 1992, joint works on creating a spatial information system for the Kuznia Raciborska burnt area and for surrounding forests have been started by OPOLIS, IBL and Laboratory of Remote Sensing and Forest Management-University of Gent (Belgium). This area is particularly important in the highly industrialized and polluted Upper Silesia region, as it formed a natural protection against industrial pollutants. An information system will be used for monitoring fire effects. It will be composed of several information layers, with information derived from archive forest maps, soil-site maps, topographic maps, as well as from aerial and satellite images and digital terrain models. Relational database, besides FFD, will contain archive taxation descriptions of stands and updated information, characterizing reclamation works and results of monitoring environmental changes.

Analyses of data already stored at FFD allow the derivation of the following acreages of particular forest classes within the Kuznia Raciborska burnt area:

- clear-cuts and openings - 358 ha
- stands at 1st class of age - 1254 ha
- stands at 2nd class of age - 1672 ha
- stands at 3rd class of age - 1706 ha
- stands at 4th class of age - 1676 ha
- stands at 5th class of age and older - 2394 ha

The other parameters of the burnt area are as follows:

- canopy closure: 7% - full, 30% - moderate, 48% - broken, 6% - loose canopy closure,
- stand density: 16% - density 0.5, 31% - density 0.6-0.7, 3% - density 0.8 and higher.

Total loss of timber caused by fire is 1 357 776 m^3; pine - 93%, spruce - 3% and alder - 3%. Analysis of multisource materials allowed the assessment of financial loss, which is about 250 millions US$, including losses due to burnt timber, as well as due to costs of fire-extinguishing action and clearing activities.

As it can be seen from the presented examples, remote sensing and GIS techniques are useful for forest fire management in Poland. It is planned to connect spatial information layers (containing forest maps updated with the use of remotely sensed data) and the existing relational databases (describing taxation features of particular stands) with the system of fire risk forecast and with fire alarm system. These information files, stored in spatial and relational databases, equipped with models of fire spreading in different natural and weather conditions, will allow the operational use of GIS for fire prevention and fighting.

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SAR INTERFEROMETRY WITH ERS-1

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An exciting and promising technique for the application of remote sensing data to emerge in recent years is that of Synthetic Aperture Radar (SAR) Interferometry, or INSAR.

Using the INSAR technique, it is possible to produce directly from SAR image data, detailed and accurate three-dimensional relief maps of the Earth's surface. In addition, an extension of the basic technique, known as Differential INSAR, allows the detection of very small (centimetre-scale) movement of land surface features.

Both of these possibilities open up many new potential application areas of space borne SAR data in the areas of cartography, volcanology, crustal dynamics, and the monitoring of land subsidence.

An Interferometer is a device that superimposes or mixes wave phenomena from two coherent sources. A SAR Interferometer typically consists of two SAR antennae separated by a fixed distance, or baseline. Both antennae measure the backscattered signal of the Earth's surface from a single microwave source (one of the two antennae). The backscattered signals received at each antenna can then be mixed or interfered.

The ERS-1 platform is flying a single SAR instrument. However, a SAR Interferometer can be 'synthesised' with ERS-1 by ingenious use of the repeat feature of the ERS-1 orbit.

After a fixed number of days (in the initial mission phases, 3 days), the orbit is such that the satellite ground-track repeats with an accuracy of +/- 1 km within latitudes of up to +/- 60 degrees. Therefore, any given area of the Earth's surface can be imaged on two passes separated by a multiple of the repeat cycle. The corresponding images are superimposed (or interfered) as though they were from a single SAR Interferometer. The orbit cross-track separation forms the Interferometer baseline. This use of the orbit repeat feature is known as multi-pass INSAR.

The INSAR technique exploits the phase information in SAR imagery in the following way: Firstly, the two SAR images are registered (or matched) with each other to identify pixels corresponding to the same area of ground.

Then, for each pixel, the phase values are subtracted to produce the phase difference image known as an Interferogramme. This phase difference is a measure of the difference in path length from a given pixel to each antenna of the SAR Interferometer.

Using a knowledge of the orbit parameters, the phase interferogramme can be related directly to the altitude on a pixel by pixel basis to generate a Digital Elevation Model (DEM) of the terrain surface. Theoretically, the INSAR technique applied to ERS-1 SAR data should produce terrain heights with an accuracy of less than 10 metres.

There are constraints on the repeat orbit separation in applying the INSAR technique. At ESRIN, the complete set of ERS-1 orbits to date have been processed and an INSAR orbit listing has been produced. Using this listing, one can identify those repeat orbit combinations for which the INSAR technique is possible. This INSAR orbit listing is available both in hard copy and also on-line for interactive acess using the world-wide web. Full details are available from ESRIN ERS-1 Help Desk (Tel + 39 6 94180 600 or 656).

All ERS-1 INSAR activity is co-ordinated within the framework of a mission-dedicated Working Group, called FRINGE, set up by ESA/ESRIN at the beginning of 1992 and currently comprising about 40 groups world-wide.

A number of designated Test Sites are supported within the framework of FRINGE for which data is provided to groups who can offer specialist expertise in data validation (DEM generation, comparison with precision DEMs, local geophysical knowledge, in-situ ground truth data, etc).

Figure 1 is an ERS-1 SAR Interferogramme of the region surrounding the Bay of Naples and has been produced by Polytechnic of Milan (POLIMI)

Lines of constant colour correspond to constant phase difference and therefore constant terrain altitude; i.e. height contours. The phase difference is coded on a colour wheel corresponding to approximately 40 m of altitude. One can clearly identify areas of tightly packed contours around Vesuvius which correspond to rapidly varying terrain topography. Note that no phase differences are given over the sea as total de-correlation of phase occurs between passes due to the motion of the sea surface.

In addition, a variety of geological areas are under study. Groups have recently reported the generation of interferogrammes for forested areas in Scandinavia and over ice in the Antarctic Ice shelf.

Figure 2 is an example of a DEM computed by POLIMI from ERS-1 SAR data via the INSAR technique. This DEM is a section of the FRINGE INSAR reference data set of Gennargentu (Sardinia). The area consists of vegetated peaks rising rapidly from the coastline to a height of about 1 200 m.

A first quantitative estimate of the height accuracy associated with ERS-1 INSAR has come from a comparison with Global Positioning System (GPS) measurements. These initial results are very encouraging and show excellent agreement with differences in terrain height of approximately +/- 5 m.

To demonstrate the capability of ERS-1 to measure small (centimetre-scale) terrain movements, a carefully controlled experiment (BONN Experiment) was conducted during March 1992. The BONN experiment made use of Corner Reflectors (CR's) which are man-made artificial targets that produce an extremely bright point response in the SAR image and are easily identified.

Two of the Corner Reflectors were raised by 1 cm in between a sequence of ERS-1 SAR acquisitions. The INSAR technique correctly identified which corner reflectors had been moved and when the movement took place. Furthermore, the computed movement of the two CR's was estimated as 9 mm and 7 mm.

Following this, there has recently been a spectacular validation of small terrain movement measurement by the ERS-1 SAR for the region of the Landers Earthquake, which occurred in California in the summer of 1992. Working with SAR images acquired both before and after the earthquake, groups at the French Space Agency (CNES) and at Jet Propulsion Laboratory in the USA have produced an Interferrogramme which measures directly the terrain surface displacement field across the fault line. Each fringe of the interferrogramme corresponds to movement of 28 mm. These measured displacements are in excellent agreement with both in-situ field measurements and the predicted motion from an elastic dislocation model of the Earth's surface for that region.

Current actvity within the framework of FRINGE includes two further experiments to detect small terrain movement in the areas of Naples (Italy) and Cefalonia (Greece). Results are expected shortly.

In conclusion, ERS-1 delivers the overall performance in terms of platform, SAR instrument and orbit maintenance, required for the application of the INSAR technique.

INSAR provides accurate values of surface height with high spatial resolution and independent of cloud cover. These are significant advantages when compared with the conventional techniques of aerial photography or space borne optical stereo photogrammetry. Preliminary results indicate terrain height errors of less than 10 metres appear achievable with ERS-1.

The capability of ERS-1 to measure centimetre-scale movement of surface features through Differential INSAR has been clearly demonstrated in the BONN Experiment. Furthermore, the terrain motion observed with ERS-1 for the Landers Earthquake is the first positive validation of the use of INSAR for measurement of co-seismic displacements. Further experiments are underway.

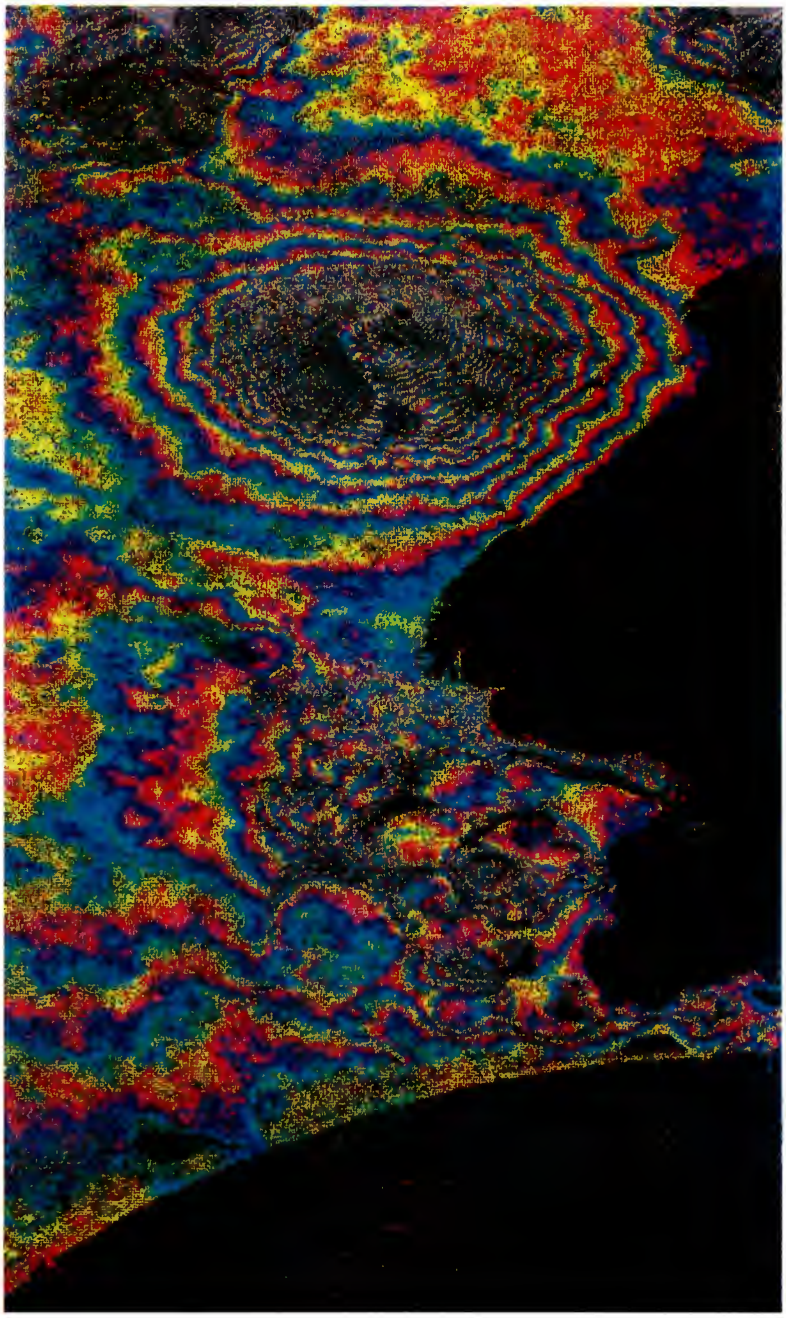

Figure 1. ERS-1 SAR Interferrograme of the Naples area (Italy).

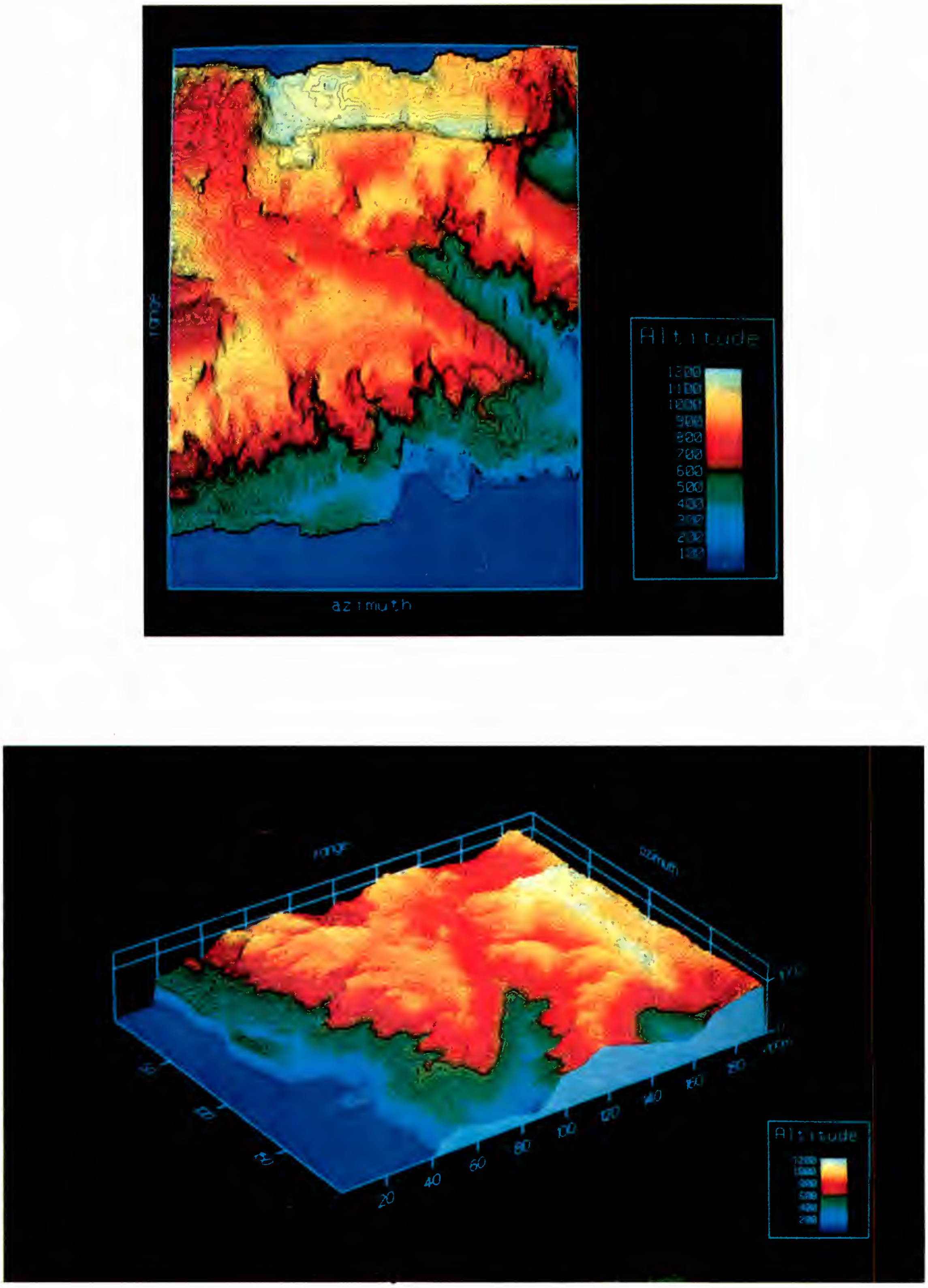

Figure 2: Digital Elevation Model (DEM) of Gennargentu (Sardinia) produced from ERS-1 INSAR.

EURIMAGE ACTIVITIES

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Since early 1992, the ERS Consortium, comprised of Eurimage, Radarsat International and Spot Image, has been the European Space Agency commercial distributor of the data from the ERS-1 Satellite. This international consortium brings together three major Companies representing the most extensive world-wide experience in the promotion, marketing and distribution of satellite Earth Observation data.

Each member of the Consortium is responsible for marketing and distribution of the data in specific territories, defined as follows:
- Eurimage: Europe, North Africa and the Middle East
- Radarsat International: Canada and the United States
- Spot Image: all other countries

Eurimage also provides data from other satellite missions (e.g. Landsat, AVHRR). It operates a multimission data distribution network in Europe, North Africa and Middle East, through a network of 40 distributors in 28 countries, and direct links with international organizations (e.g. FAO, EEC). In Europe, Eurimage has 35 ERS-1 distributors in 23 countries. In Eastern Europe Eurimage has currently distributors in 5 countries (Poland with IGC, Romania with Geodata, Hungary with Fomi, Czeck Rep. with GISAT, Croatia with GIS DATA) and it is planned to appoint others in the near future.

MARKET DESCRIPTION

The commercial distribution of ERS-1 has seen a rapid increase in the last 2 years. European sales in particular have more than doubled in 1993 reaching about 400,000 Ecu. New applications have been developed,and in some cased these are now becoming operational. Near-Real time applications in North Sea have proven to be successful in ice monitoring, ship routing and oil spill detection,and new Geology and Land mapping applications have also been developed based on radar techniques.

In 1993, agriculture applications have bene improved and in 1994 will become a very useful complementary tool to optical sensors for the operational monitoring projects funded by EEC.

In very cloudy areas the need of complementing or even substituting optical sensors has emerged as a very critical one, particularly for monitoring projects. The main future trend of ERS-1 commercial development can be summarized as follows:
- Growing market for both land and ocean/ice applications for SAR products
- Combined use of optical and SAR data in operational/monitoring projects
- Increasing use of multi-temporal SAR images
- Improvement in the SAR interferometry operational capabilities

COMMERCIAL AND PROMOTIONAL ACTIVITIES

Together with ESA, Eurimage is working on promoting ERS-1, improving general knowledge of radar techniques and the creation of tools to access the catalogue and the data.

Eurimage has collaborated with ESA in the development of the quick look browsing system (DESC) which allows users to directly access to archived images. Eurimage is also disseminating through its distribution network all the promotional materials.

Eurimage is also co-operating with ESA by organizing training courses specifically designed for radar image processing analysis.

Application articles and issue of press releases to the media is part of the promotional plan to improve the ERS-1 recognition in a market, traditionally used to optical techniques.

Eurimage has attended numerous international conferences/exhibitions with a stand and documentation and has also shared a stand with ESA. Particular emphasis has been place on ERS-1 SAR images and several multi-temporal posters were produced and distributed at these exhibitions.

A demonstration of Near Real Time data from Tromso Satellite station was set up at the recent ESA/Hamburgh Symposium. A similar demonstration showing commercial applications will be shown on the ESA stand at oceanology 94, a large International Conference to be held in Brighton, UK, in March 1994.

ESCORENA AND REMOTE SENSING

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The ESCORENA research networks (European System of Cooperative Research Networks in Agriculture) have since 1974 provided a special forum for the information exchange and coordination of applied research efforts in special fields of common interest. Many a collaborative program has been initiated, Europe-wide investigations and surveys have been coordinated and standardized and over 30 volumes in the REUR Series (Regional Office for Europe) and many other special bulletins have been published. Many of the 12 currently active networks are increasingly concerned with the inclusion of environmental issues in their activities.

Traditionally, most of the network members were from western Europe and four interregional networks also included Near-Eastern countries. Participation from Eastern and Central European countries is increasing and much of the financial support from FAO/REUR for regular workshops and symposia is to permit participation of scientists from those countries. The opening of the same countries brings with it a new focus of research interests and needs and thus the opportunity for additional cooperation. Many of the new interests are already included through active participation in f.e. the rice, cotton and pasture networks as well as the game farming ad hoc working group. The network on Sustainable Rural Environment and Energy (SREN) is preparing some activities with particular focus on needs of special areas in Eastern, Central and Southern Europe such as animal power, biodiesel, decentralized energy sources, etc.

Preparations for a Network for Agricultural Policy Analysis and Advice for Governments of CEE Economies in Transition, which however is not part of ESCORENA, are very much advanced.

In all these activities the common focus remains the development of agriculture systems or practices which are efficient, non-destructive, can support the farming community (preferably with less subsidies) and are integrated in the closer and larger European economic and environmental context. Since, however, even the best research results remain useless if they cannot be implemented, the connection of research to planning, policy development, economics and training are very important.

Remote sensing as a tool for planners and policy makers has been gaining importance through its increasing precision and versatility. The addition of radar imagery appears to have further increased availability of images and their precision and information content, particularly when combined with other imaging methods and geographic information systems. Thus remote sensing as a whole becomes more and more suited as an information and monitoring system for environmental and agricultural decision making in planning, policy and research development.

No other data collection system is so uniformly applicable across political and ecological boundaries. Yet, at the same time, due to the wide ecological diversity, data interpretation still requires a high degree of ground verification. Once established it appears as one of the most useful tools for regular data collection and predictive modelling of production and production requirements, but also for comparing infrastructural and environmental changes over time. In view of the large and very immediate benefit that the application of this tool can produce in economies in transition, ad hoc working groups or even regular network activities can be complementary to ongoing activities in basic research, uniform ground data collection as well as to application in policy and planning development. The uniformity in data acquiring is also an opportunity to increase efficiency and reduce costs of interpretation through close international cooperation.

In recognition of the potential of remote sensing as a planning and monitoring tool and the need of international cooperation, FAO/REUR has sponsored periodically participants of international meetings and workshops on remote sensing. There still appears to be ample room for collaboration between different institutions, government and non-government, and activities already carried out and supported by other organizations. However, no requests have been brought forward to REUR to establish a regular network cooperation in this area.

"JRC ACTIVITIES IN THE FRAMEWORK OF THE PHARE PROGRAMME"

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ABSTRACT: Since 1991, the MARS Project (Monitoring Agriculture with Remote Sensing), is extending some of its techniques into Central and Eastern Europe. In those Countries where the agricultural structure is rapidly changing, consistent and updated agricultural statistics are required. That is why Regional Inventories have been implemented, using an area frame sampling complemented by high resolution satellite data. Statistics on acreage and yields for the main agricultural crops have been obtained, as well as information concerning ownership and exploitation structure of the land. For the past two years, results have been available in an operational way in two of those countries- Rumania and the Czech Republic.

In the framework of the PHARE programme, the activities are planned to be extended to four more countries in 1994. Yield forecasting, using an agro-pedo-meteorological model to run in a GIS environment will start to be implemented in the six countries covered by the PHARE 92 Regional Programme. Together with MARS activities, Environmental Related Applications are also included in the PHARE Programme. They refer to Forest Ecosystems and Land Degradation mapping, which will be studied by the six countries concerned.

1. INTRODUCTION

Despite the fact that the title refers specifically to the PHARE programme, some general information on JRC activities in Central and Eastern Europe is also included. To understand the context of the project defined by JRC and supported by PHARE, a short explanation of the MARS Project is fundamental.Precise and up-to-date information on agricultural production is a vital component in running a common agricultural policy, which is one of the principal aims of the European Community. Such a policy relies also on agricultural statistics. Since the national systems of agricultural statistics differ, both in their approach to conventional surveys and the resources available, an homogenisation of data sources and methods was important. Remote sensing seems to be the most promising technique for upgrading the agricultural statistics system. To obtain rapid improvements, the Commission has set up a Project to introduce remote sensing into the European agricultural statistics. On September 1988, the Pilot Project of Remote Sensing Applied to Agricultural Statistics was approved and the Joint Research Centre is in charge of it. This Project, also known as MARS (Monitoring Agriculture with Remote Sensing), had its first phase from 1989 to 1993, during which several Actions were undertaken: - Regional Inventories which aims to estimate crop acreage and to forecast productions each year, at regional (or national) level. For that, both ground surveys and high resolution satellite images are used.

- Crop monitoring and yield indicators use NOAA-AVHRR data to obtain qualitative results to be compared and used with data coming from other Actions.
- Models of yield forecast are being developed based on agronomic, meteorological and pedological data. A network of 450 stations has been set up in Europe, from which meteorological data from the past 20-30 years has been collected, as well as current data.

- Rapid estimates of acreage and potential yields in Europe, based on high resolution satellite observations of 53 sites, around 4 times a year.
- An area frame sampling, together with a specific method for ground survey were implemented for all the actions in which ground survey is necessary.
- Data coming from all those Actions should be integrated in an advanced agricultural information system for Europe.Some of those Actions are now operational and others are pre-operational. Member States, or even regions, are taking on the responsibility of the inventories. DG VI will manage directly the rapid estimates; MARS in the JRC keep still provide the technical support and is in charge of the full operationalization of the remaining actions.

Having achieved the aims set down, the JRC is available for new actions, whether it involves developing new themes or extending the methods already tested to countries outside the Community, in particular to Central and Eastern Europe.
Once the methods and systems developed by MARS Project were implemented in an operational way in the E.U., requests for similar activities in the Central and Eastern European countries started to be formalised.
In order to prepare these activities, ministries of agriculture, statistical institutes, various technical organisations and remote sensing laboratories have been making contact with IRSA. Together, a pre-programme of co-operation started to be discussed and implemented according to the specific conditions in each country. The main constraints is the fact that MARS in its present phase does not cover countries outside the E.U. and does not include budget lines for the extension of its activities into eastern Europe. This has been taken into account when defining the amount of activities.

2. MARS ACTIVITIES IN CENTRAL AND EASTERN COUNTRIES

Since 1991 contacts have been established, either to immediately initiate a pilot project, or to prepare a co-operation to be implemented later on.

Regional Inventories, based on the area frame sampling technique, was the first to be implemented in the 1991/92 agricultural campaign, in Romania and the Czech Republic. The results on agricultural statistics then obtained were accepted by the National Authorities and considered of economic importance for the agricultural policy. This justified the interest of those countries in carrying out the same activities in 1993. The Romania zone covered by this project was 55 000 km^2, i.e. 25% of the national territory. Crop acreage figures were provided for wheat, corn, sunflower and sugar beet. The comparison with official figures was extremely useful in this period of land redistribution, characterised by rapid changes in agricultural structures, which makes it difficult to obtain reliable information from the traditional methods. In addition to the agricultural statistics project and with the same methods applied in the Agriculture Information Systems, the Unit also supported a land redistribution monitoring project, within a ISPIF-IGN collaboration.

In the Czech Republic, the Regional Inventory has been performed in the entire territory (78864 km^2) by GISAT (Prague). The second year of activity permitted the improvement of the adaptation of the method to the national conditions and the monitoring of the evolution of the agriculture structure.
In Slovenia, MARS co-operation started with the National Statistical Office of Ljubljana. A

Landsat Thematic Mapper satellite images coverage of the whole country was provided by IRSA for the stratification, in order to prepare the 1994 campaign. These Landsat images were also used for comparison with ERS-1 SAR data, in order to assess the usefulness of radar data for crop identification in Slovenia.

A technical co-operation with the Russian Institute of Land and Ecosystem Monitoring (RILEM, Moscow) started in the specific fields of agro-meteorological modelling, crop yield monitoring and forecasting. After a comparison between the methodologies used by CIS and MARS, a combined approach was suggested and a test proposed in the Krasnodar region. Furthermore, technical support was provided to formulate an agricultural statistics project (Regional Inventory and Agrometeorological modelling).

AIS Unit is also participating in a research project with Telespazio (Rome), Poland, Hungary and the Czech Republic, funded by Directorate General XII. The objective of this project is to integrate low resolution satellite data (NOAA AVHRR) with other types of data in order to monitor vegetation condition and hydric stress at regional level.

The extension of MARS Project to Central-Eastern countries had a strong development in 1993, due to the growing requests from other countries that are often faced with an urgent need to improve the agricultural statistics and land use information in this phase of economic transition. It is in this country that MARS supports DG I through the PHARE Programme.

PHARE Environment Regional Programme: Within the framework of this Programme, IRSA gives technical support to DG I. The project MERA (MARS and Environmental Related Applications) was defined, including the soil erosion monitoring and forest mapping components carried out by the EMAP Unit of the IRSA. MARS activities (Regional Inventory and Agro-meteorological modelling) were technically defined and planned with the National Focal Points of the six countries involved (Poland, Hungary, the Czech Republic, the Slovak Republic, Rumania and Bulgaria), which were designated by the respective Ministries of Agriculture. After the identification of suitable partners and co-operating agencies in each country, projects were finalised and submitted to DG I (External Relations). The technical specifications of computer equipment (hardware/software) to be provided to the recipient countries were also prepared in order to increase local capacity in the fields of Image Processing, Geographic Information Systems and Relational Data Bases Management. It included the transfer of IRSA dedicated software (TTS, AIS-STIM).
Co-operation was established with the CORINE Land Cover Project of DG XI EEA-TF, to share satellite data and to co-ordinate common activities.

"Use of ERS-1 SAR Data for Agricultural, Forestry and Environmental Applications in Central and Eastern Europe"

Workshop sponsored by:

- **European Space Agency (ESA)**
- **Food and Agriculture Organisation of the United Nations (FAO)**
- **Commission of the European Communities (CEC)**
- **Telespazio**

ESRIN, Frascati, Italy, 8-12 November 1993

Programme

Monday 8 November

Morning

9.00-9.30	Registration
9.30-10.00	Opening Ceremony (ESA, FAO, Telespazio)
10.00-10.30	Presentation of programme and participants
10.30-11.00	Coffee break
11.00-11.30	ESA cooperation with Central and Eastern European countries (E.Loeffler, ESRIN/ESA)
11.30-12.00	Remote sensing in Central and Eastern European countries (P.Winkler, FOMI)
12.00-12.30	Presentation of ESA and ESRIN activities (E.Loeffler, ESRIN/ESA)
12.30-13.00	Presentation of Information Retrieval Service IRS (J.Brinkmann, ESRIN/ESA)

Afternoon

14.00-15.10	Overview of optical and microwave remote sensing (J.Lichtenegger, ESRIN/ESA)
15.10-15.30	Radar remote sensing video
15.30-16.00	Coffee break

16.00-17.00 Principle of radar imagery (J.Lichtenegger, ESRIN/ESA)

17.30 Cocktail in ESRIN canteen

Tuesday 9 November

Morning

9.00-10.30 Radar image characteristics, processing, analysis and retrieval of backscattering coefficients (H.Laur, ESRIN/ESA)

10.30-11.00 Coffee break

11.00-12.50 ERS-1 mission presentation, status and data access (J.Lichtenegger, ESRIN/ESA)

12.50-13.00 Presentation of FAO Regional Office for Europe (REUR) activities: Research networks (R.Krell, REUR/FAO)

Afternoon

14.00-14.45 FAO activities in radar remote sensing (J.F.Dallemand, ESA/FAO Radar Project)

14.45-15.30 Hands-on demos on PC (J.Lichtenegger/J.F.Dallemand)

15.30-16.00 Coffee break

16.00-17.00 Hands-on demos on PC (J.Lichtenegger/ J.F.Dalllemand)

Parallel to the hands-on demos, visit of the ERS-1 help desk and order desk in small groups.

Wednesday 10 November

Visit to Fucino receiving station.

14.30-15.00 Telespazio microwave activities (A.Fiumara, Earth Observation Division, Telespazio)

15.00-15.30 Speckle filtering (M.Cantoni, Earth Observation Division, Telespazio)

15.30-16.00 Field experiment (Soil moisture)

Thursday 11 November

Morning

9.00-10.00	Use of ERS-1 SAR data for soil moisture assessment. (K.Dabrowska, Institute of Geodesy and Cartography, Warsaw)
10.00-10.30	Presentation of NITRA case study (J.Kolar, GISAT, Prague)
10.30-11.00	Coffee break
11.00-12.00	Use of ERS-1 SAR data for monitoring of the impact of land reform. (P.Winkler, FOMI Budapest)
12.00-13.00	Use of ERS-1 SAR data for agricultural statistics (D.Sabic, Statistical Office of Slovenia).

Afternoon

14.00-14.45	CEC activities in Central and Eastern Europe (V. Perdigao, Ispra JRC)
14.45-15.30	An evaluation of the potential of ERS-1 SAR data to rapid estimation on crop acreage and yield in Europe. (H.G. Kohl, Ispra JRC)
15.30-16.00	Coffee break
16.00-17.00	Multitemporal analysis of ERS-1 SAR data and environmental applications, (G.Kattenborn, Ispra JRC)

Friday 12 November

Morning

9.00-9.20	ERS Consortium and ERS-1 data distribution (F.Lombardi, Eurimage)
9.20-10.00	Speckle filtering and soil moisture experiment (M.Cantoni, Earth Observation Division, Telespazio)
10.00-10.30	Use of airborne radar data in geomorphological mapping: Experimental results from the West Carpathian region. (J. Feranec, Academy of Science, Bratislava)

10.30-11.00	Coffee break
11.00-12.00	Romania ERS-1 SAR case study (N.Oprescu, Romanian Space Agency)
12.00-13.00	Interferometry (S.Coulson, ESRIN/ESA)

Afternoon

14.30-16.00	Round table discussion, conclusion, recommendations (S.Cheli, ESA and Workshop participants)

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