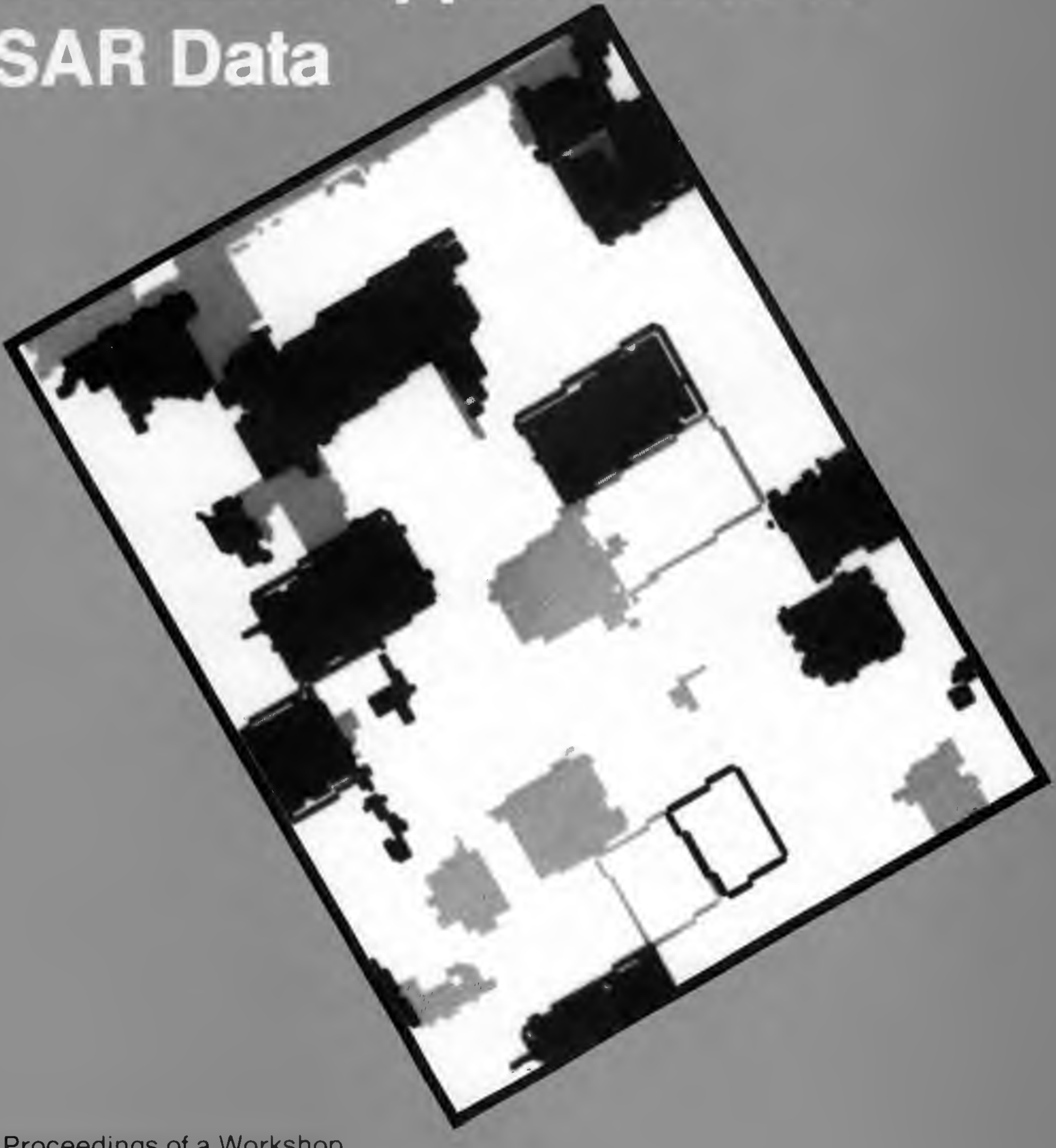
esa SP-257

Thematic Applications of SAR Data



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CONTENTS

OVERVIEW OF ESA EARTH OBSERVATION OBJECTIVES AND PROGRAMME

G. DUCHOSSOIS, ESA, Paris

The ESA long-term plan (ESA/C-M(85)2) proposes for Earth Observation the following specific programme objectives:

- Prepare the establishment, by the mid-1990's, of operational systems in polar orbit tailored to needs in the field of ocean, ice, coastal zones and meteorological applications;
- Initiate the development of satellites for experimental/preoperational use in remote sensing land applications, with emphasis on all-weather microwave instrumentation;
- Contribute to the development of a second generation meteorological satellite to be launched in 1994/95 to ensure continuation of the Meteosat operational system;
- Provide research tools for scientific and meteorological communities of studies of fields such as solid earth, climatology;
- Prepare potential future missions by advanced system and instrument studies and carry out pre-development of instruments.

It is proposed to achieve the objectives through the following main new programme elements:

- An ERS-2 Satellite for launch in 1992-93;
- An ERS-1/2 follow-on mission on operational oceanographic and meteorological applications;
- An "Advanced Land Applications" satellite for launch in the period 1994/1995;
- A solid earth research and applications missions;
- A climatology and atmospheric sciences programme;
- An Earth Observation Preparatory Programme with studies, measurement campaigns, instrument development and critical technology developments.

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Of particular interest for SAR oriented studies, the Earth Observation Preparatory Programme for Advanced Land Mission is concerned with:

- Review/update of user requirements in terms of mission objectives, measurement/performance requirements for sensors, ground processing and data distribution aspects.
- Analysis of existing data sets.
- Preparation of airborne campaigns.
- Organisation of specialised workshops.

SELECTED APPROACHES TO THEMATIC SAR STUDIES

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The preparation of the utilisation of ERS-1 SAR data and the definition of the advanced land application mission requires a major effort to improve our understanding of the SAR data potential applications. To this end, a number of coordinated actions have been undertaken since 1984 and one of the basic objectives of this workshop is to get a presentation of the main results from these studies and above all, to allow for an appreciation of these results.

Three types of efforts will be presented:

- studies aimed at establishing what SAR system parameters (e.g. frequency, angle of incidence, polarisation, etc.) are most suited to a number of thematic applications;
- studies aimed at defining optimal information extraction schemes by assessing the statistical properties of required parameters and developing decision tools (e.g. Bayes estimators, maximum likelihood estimators, etc.), the ultimate goal here being the automatic derivation of quantitative values related to geophysical phenomena, from SAR images;
- studies of analysis tools of interest for any application, such as radargrammetry (correction of the geometry of the SAR images), extraction of land features (e.g. roads, buildings, etc.).

It is worth noting that the three studies on using SAR for agriculture and forestry, result from the same ESA Call for Tender. For funding reasons, they have not been performed at the same time and they are concerned with different applications in the agriculture field (e.g. potato crops in the Netherlands, corn in France, etc.
This workshop brings the first opportunity to the three teams involved to compare their approaches and their results.

Whatever the application under consideration, all SAR studies are faced with the same basic difficulties: the presence of speckle and how to filter it, the need to identify homogeneous areas (image segmentation) for the sake of classification, the need for compensating for SAR system effects such as antenna pattern, relief effect, and last but not least, identify the information content of the SAR image (e.g. not only pixel intensity but maybe texture).

This workshop offers a suitable forum for establishing the state of the art in these areas. The discussions will also benefit from the diversity of the data set used in the various studies: SLAR data in the Netherlands, SAR 580 data in France, Seasat data in the United Kingdom, etc.

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SAR FOR AGRICULTURE AND FORESTRY

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ABSTRACT

The data-handling, system engineering and information extraction necessary for a land-use SAR are discussed in this paper. Data-handling requires techniques for change detection and interpretation; in both areas present knowledge is inadequate. The lack of multi-temporal SAR data and coordinated plant parameter data are a severe hindrance to the development of techniques and physical understanding. Our present state of knowledge does not permit clear definition of the parameters for a land-use SAR sensor, nor the requirement for ancillary data. Image interpretation is argued to be best carried out on a land-unit rather than pixel-by-pixel basis. Texture is shown to be a potential source of information independent of mean backscatter for some land-cover types. Human and machine measures of texture can be shown to correspond.

Keywords: SAR, Change Detection; Surface and Volume Scattering, Texture, Land Use, Forestry, Agriculture.

1. INTRODUCTION

Work undertaken by Hunting Technical Services Limited (HTS) and Marconi Research Centre (MRC) in the study of a land use orientated Synthetic Aperture Radar (SAR) system is reviewed in this paper. It is a condensed version of the full report to ESA (ESTEC) (Contract No. 5778/83/NL/MS, 'Study of a Land Use of Synthetic Aperture Radar', September, 1984) which will be referred to below as HTS/MRC. Its theme is the information relevant to land use contained in a time-sequence of SAR images. Very early in the study it was recognised that there is very little multi-temporal SAR data available, and that it would only be possible to elucidate the requirements for using such data, without a comprehensive demonstration of how these requirements could be met. In Section 2 we discuss the handling of multi-temporal SAR data. Section 3 discusses the empirical and theoretical bases on which sensor design relies, and shows their inadequacy to provide a clear specification of sensor parameters. Section 4 is a discussion of the forms of information in a SAR image, with a major emphasis on human and machine perceptions of texture in the presence of speckle. In Section 5 we draw some very large conclusions, whose main message is that a major coordinated effort is required if a SAR is to be feasible as a useful tool for land-use monitoring.

2. THE USE OF MULTI-TEMPORAL SAR DATA

The all weather capability of a SAR presents the opportunity of acquiring timely multi-temporal data. It is therefore considered that the principal land use oriented applications for which a SAR should be employed are those that require a succession of timely data, either data acquired within one growing season or for between season comparisons. Four specific land use applications may be defined.

i) Monitoring Land Use Change

ii) Monitoring Crop State

iii) Monitoring Crop Yield

iv) Monitoring Crop Type

An operational SAR system will present the interpreter with a time series of microwave backscatter measurements, corrupted by speckle. These measurements may be multi-dimensional, with components in several frequency bands and polarisations, and possibly variable depression angles and look directions. Available also to the interpreter will be ancillary data sets, such as maps, weather information and possibly imagery from other sensors.

The temporal evolution of the microwave signature will only be useful if:

i) Important changes in plant state affect this signature;

ii) There exists a known correlation between the signature and the plant state;

iii) The range of variation of the interpretative criteria (estimators) about a mean for normal crop development is known.

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ii) Changes in plant moisture content which will effect the dielectric constant.

d) Management Practice: Management practices vary considerably throughout Europe. Variations occur in a fundamental way, for example in terms of field size and the variety of crops. More particularly variations occur on a local, national and international basis in terms of the following ways:

i) plant spacing and density

ii) cultivation practice (bed or ride for potatoes?)

iii) germination success

iv) variety of species

v) level of management (fertiliser applied? weeded?)

vi) timing of the crop calendar for the same crop with latitude and altitude.

The means by which these effects can be included in the interpretation have yet to be defined.

3. SYSTEM ENGINEERING

The problem of defining sensor parameters can be approached by theoretical or empirical means. The former approach, as noted above, is still under development; the latter requires concerted and sustained measurement campaigns, with guidance from theory so that the relevant plant and soil state measurements are made. An extensive literature review of such empirical studies was carried out as part of HTS/MRC (for a full bibliography see that report); its findings are now summarized.

3.1 Forest Applications of SAR:

It is apparent that forestry and woodland have not been extensively studied by investigators using active microwave remote sensing. Little work has been undertaken to ascertain the form of the interaction of microwaves with woodland or to analyse the ability of SAR to undertake more detailed species, age, yield or crop state determinations.

Conclusions concerning the optimum system parameters for the analysis of woodland remain unclear due to the general lack of multi-temporal, multi-frequency imagery of test areas in different locations; the definition and constitution of woodland varies considerably throughout the world. Further, optimum radar parameters tend to vary depending on the application that is required (table 1). There is, however, a general requirement from investigators for shorter wave-length, like polarised and multi-temporal imagery, preferably with multi-incident angles and look directions.

It has been demonstrated (see Churchill et al, 1984) that by using SAR it is possible to delineate woodland from non-woodland; to delineate species groups (coniferous, broadlead and mixed); on some occasions to make finer species classifications (for example Scots Pine and Corsican Pine); and to determine broad age groups within single species stands. It is also apparent that the exact extent to which this might be undertaken, and extended into yield and crop state determinations has yet to be investigated. Further, other variables that might affect the backscatter response from woodland, such as diurnal effects, weather effects (solar radiation, precipitation and wind) and management practice have as yet received very little attention from investigators.

3.2 Cropland Applications of SAR:

A greater degree of research has been undertaken into the analysis of the interaction of microwaves with cropland than with forestry. Much of this work, however, has been undertaken utilising ground-based and airborne scatterometry, and many of the results have yet to be tested utilising imaging radar. Also, despite the increased amount of analysis many unknowns exist, and many of the conclusions that have been drawn have been tested on experimental sites only.

Conclusions regarding the optimum system parameters for the analysis of cropland tend to be variable and determined by the crop type, the sensor and the locations of the test area (table 2). Thus the optimum frequency for crop type classification varies considerably from L - Ku band. In terms of polarisation and grazing angle there is general agreement that like-polarized at 40° - 60° is optimum. The requirement for multi-temporal imagery is accepted by the majority of investigators in order that crop evaluation, crop state and crop yield studies might be more fully understood.

3.3 Theoretical Models

Parallel with the empirical study of the backscattering properties of soil and crops has been an effort to understand the physics underlying the various backscatter signatures. This has involved the development of appropriate theories of surface and volume scattering. There have been excellent reviews of these theories by Fung (1981 (a), 1981 (b)), and we here restrict ourselves to a few comments (for further discussion, see HTS/MRC).

(a) Surface scattering: The theory of surface scattering from Gaussian random surfaces is well-developed under two approximations, viz, the small perturbation and Kirchhoff models (and their combination into two-scale surfaces). Both models have been shown to be applicable to radar data in their appropriate regimes. Fung (1984) has also shown that using a combination of sensor characteristics these theories can be used to define a procedure for extracting the surface structure parameters and surface permittivity (with the proviso that surface, rather than volume, scattering is known to be the dominant effect).

(b) Volume Scattering The basic first-order theoretical models for volume scattering are the dielectric slab model (Attema and Ulaby, 1978), the lossy scatterer model (Lang, 1981, Lang et al, 1982, Lang and Sidhu, 1983), and the random media model (Fung and Fung, 1977; Fung, 1979). An account of the assumptions underlying these models is given in HTS/MRC. While all these models give much insight into the physics of the scattering, they are by no means fully-developed for interpretation of backscatter measurements. Use of the dielectric slab and random media models requires fitting of constants from an experimental data set. The inputs necessary to drive the models may be difficult (or impossible) to measure directly, and are certainly not readily available. None of the models can be regarded as adequately validated against extensive datasets. There appears to be no comparison of different models in the literature (indeed, it is not clear how such a comparison can be accomplished, since different models require different inputs which are not easily translated into each other). Where published results have been comparable, different authors predict different values for the mean backscatter. The 'invertibility' of the backscatter signature has not been investigated for any of the models (here invertibility is used in the sense defined by Fung (1984) as maximising the sensitivity of the sensor configuration to the parameters of interest). It is also unclear whether any of the models can be applied to the study of woodland, since the geometric structure is not adequately represented.

Conclusions about sensor parameters are not clear, apart from the obvious remark that shorter wavelengths are perferred (we wish to image the crops, not the soil), and angles off nadir are necessary (thus increasing the path length through the vegetation). The optimum frequency is not well-defined, since different crops have structures with different characteristic lengths; sensor response is dependent on the ratio between this length and the emitted wavelength. Polarization is not currently included in the formulation of the models, and hence no theoretically-preferred configuration is defined.

4. TEXTURAL INFORMATION IN SAR IMAGES

Scattering models deal with mean backscatter as a function of surface type and microwave radiation parameters. However, mean backscatter is only one potential source of information within a SAR image. Interpreters define four information-bearing elements in an image, which are:

a) Tone, defined as the mean backscatter over a land-use parcel;

b) Texture: defined as variations in tone within a land-use parcel;

c) Contexture: defined as data inferred from surrounding features;

d) Interpreter experience: this relates each of the pre-stated estimators to each other.

None of the above estimators are exclusive, indeed each can only be fully utilised in relation to the others.

Context and experience clearly require a high level of knowledge about the world and are not easily quantified. However, several automatic measures of texture have been proposed, and a selection was used in this study to address the following questions:

(i) Are tone and texture independent?

(ii) How do we distinguish texture from speckle?

(iii) Do human and machine perceptions of texture correspond?

The automatic texture measures considered were inertia, absolute difference, correlation and inverse difference (Haralick et al, 1973), with special emphasis placed on inertia because of the ease of analysis. For Rayleigh-distributed speckle, such as would be expected in independent amplitude samples of an extended uniform target, it can be readily shown (HTS/MRC) that

$$\sqrt{I} \sim 0.74\mu \qquad (1)$$

where I = inertia and μ = mean backscatter. Therefore texture can only be considered present as an independent source of information if the the relation (1) is not obeyed. More general expressions for multi-look images can be derived (HTS/MRC), and also predict a linear relationship between √(inertia) and mean.

4.1 Manual Evaluation of Texture

In order to compare human and machine measures of texture, a manual interpretation was first undertaken on X-band HV polarised SAR 580 data of Test Area GB6, Thetford Forest, England. The Test Area incorporated a wide range of land uses including Forestry Commission managed coniferous and broadleaf woodland, semi-natural woodland, arable land, grass and heathland and urban areas. The topography of the Test Area is relatively flat with a gentle southerly slope towards the valley of the River Little Ouse.

After initial manual segmentation five classes of image tone and five classes of image texture could be successfully delineated (table 3).

Figure 1 shows a selection of regions of different texture (on this image no very rough regions are present). By applying these tone and texture classes to the image on a multi-channel basis it was established that ten classes of land use could be delineated, as described in Table 4.

4.2 Automatic Evaluation of Texture

The inertia measure for each of the areas within the test image selected by the human interpreter as representative of the various classes of texture was then calculated. The results are depicted in Figure 2, showing √inertia vs mean for each of the selected areas. The clear conclusions from Figure 2 are that:

(i) Only those textures perceived as rough by the human interpreter carry information independent of the mean value. Below rough, apparent texture is an artefact of the speckle, which can be restated as 'no texture is really detected'.

(ii) The textural classification carried out by the interpreter can be emulated by the machine. For textures below rough, the perceived texture is perfectly correlated with mean intensity value, and it is simply necessary to partition the correlation line according to mean intensity. Points off the line can be assigned a rough texture.

(iii) All agricultural crops and some coniferous woodland display no texture in this data. Mixed woodland, young conifers and urban areas display texture.

It has also been established that:

(iv) The presence of texture significantly increases the standard deviation/mean ratio (Churchill and Wright, 1984).

(v) Directional and scale size properties of the speckle are detectable by automatic means (HTS/MRC; Klein, 1985).

5. CONCLUSIONS

This paper has reviewed the requirements for a land use SAR, in terms of the data-handling, the system engineering and the information content of a SAR image. Many conclusions can be drawn from this study (see HTS/MRC), but we here note a few major points.

(i) The techniques necessary for detecting and interpreting change in a sequence of SAR images are presently not well-developed, but are essential for the effective utilisation of SAR data gathered over land. It is vital that multi-temporal SAR data be gathered to allow the development of realistic useful methods.

(ii) The presence of speckle argues for interpretation methods based on land-use units rather than pixel-by-pixel methods.

(iii) The collation of comprehensive datasets of important physical properties of crops and soils should be undertaken. This effort should be guided by an understanding of the essential physics, as embodied in theoretical models, and used to validate (or invalidate) these models. Known model deficiencies should be attacked.

(iv) Present knowledge does not clearly indicate the optimum sensor parameters, beyond short wavelengths and incidence angles well off nadir.

(v) The need for other data is still unknown. It seems likely that weather and slope data must be input into the interpretation, but the means to do this are not defined. Crop classification must also be carried out, which may require optical or census data if the radar signature is to be interpreted early in the growing season.

(vi) Texture has been shown to be a potential source of information about land-use, though this conclusion may be a feature of the particular data set used. Human and machine measures of texture have been shown to be directly comparable.

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USE OF A SAR IN AGRICULTURE AND FORESTRY

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ABSTRACT

Under contract with ESA (nr. 5777/83/NL/MS) a study on the use of a SAR for agriculture and forestry was performed by the National Aerospace Laboratory NLR together with the Physics Laboratory TNO and the Microwave Laboratory of the Delft University of Technology. In the first part of this study the present state-of-the- art with respect to theory and experiment was reviewed. Specific applications were identified and estimators determined. Algorithms were developed for both segmentation and classification. Since SAR data of adequate quality were not available the algorithms were tested on specially processed SLAR-data.

Keywords: SAR, agriculture, segmentation, speckle, classification

1. APPRAISAL OF PAST EXPERIMENTS

From a review of the relevant literature the following conclusions can be drawn with respect to past experiments. The backscatter coefficients of objects in agriculture and forestry fall in a relatively narrow range. Therefore highly accurate (1dB) radar systems are necessary. The variation with frequency and incidence angle is smooth. The general behaviour is known for several agricultural crops. Very little is known about forests. The backscatter is dependent on polarisation; the effects seem to be related to plant geometry. Polarisation effects are dependent on time and incidence angle.
Temporal variations in backscatter coefficient are strong for most agricultural crops during the growing season. The general behaviour is known for some crop types.
Classification of agricultural crops is possible with high accuracy especially with data obtained at different incidence angles or at various times during the growing season.
Soil moisture, biomass and surface roughness (slaking) can be measured under specific circumstances (frequency, polarisation, incidence angles).
Experiments using image texture both for classification of crops and forests and for determination of slaking were not conclusive. The relation between visual texture and mathematical/physical texture measures is not yet established.

2. REVIEW OF MICROWAVE INTERACTION MODELS

The present status with respect to radar models was reviewed. With the present theories, a radar system designed to image a land target can be conveniently simulated. Such a simulation can satisfy the requirements for application development as well as for detailed system design.
The inverse problem, how to derive target parameters from the image intensity cannot be easily solved. Since there are many unknown target parameters for one single intensity measurement, the method can only be successful in special cases where one single target parameter is dominant over all others. In general, several independent observations have to be done, such as multi-frequency, multipolarisation, etc.
The available models can be used with some confidence to study the sensitivity to target parameters. In this way the radiometric resolution requirements and the enhancements expected from multi-dimensional (-frequency, -angle, -polarisation, -temporal) measurements can be determined.
No models exist to describe the relation between the temporal variation of the radar backscatter coefficient and the relevant processes that take place within the targets (monitoring of growth, erosion, etc.).

3. IDENTIFICATION OF APPLICATIONS IN AGRICULTURE AND FORESTRY

From discussions with experts an inventory was made of possible applications of radar. The quantities that have to be measured were identified. The measurements that are possible with radar were analyzed as to their applicability. In this way estimators could be determined for several applications. The additional information that can be derived when dealing with data in the form of an image was analyzed. The possible use of texture measures was studied.
Monitoring was investigated because it is a unique capability of radar. Other applications, like crop type classification, forest inventory, etc. can also be served by other remote sensing techniques, but

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identified with test fields. "Area error" is the area that was either under- or overestimated by the segmentation program relative to the total area of the test fields. "Area found" gives the area of the largest segment in a field relative to the total area of the field averaged over all test fields.

The data set of 5 SLAR images with 2, 4, 7.5, 15 and 30 looks was segmented with five different sets of parameters (significance levels, variance) each. An example of a segmentation is given in figure 5. The outcome of these 25 tests is the following. The number of fields found by the segmentation increases with the number of looks from 50 % to over 90 %. The area error is always very large (over 100 %) and decreases slowly with increasing number of looks. The area found is over 70 % and not very dependent on the number of looks. The difference in segment averaged and field averaged pixel value is small (less than 1 count on a scale of 0-256) and decreases with the number of looks.
One Seasat image of the same area (orbit 891) was segmented with four different sets of parameters. The results obtained for the 4-look SLAR image and the (4-look) Seasat image are compared in table 2.
A way to improve the segmentation is the use of multi-temporal images. A second series of experiments was thus performed with 30-look and 8-look SLAR images of the same area obtained in April, May and July 1980.
For one set of parameters table 3 gives a comparison between the monotemporal (July only) and multi-temporal case. As can be seen, the additional information from the other dates gives a drastic improvement.

4.2 Crop rotation detection

4.2.1 Classification strategy. For the detection of potatoe fields a classifier was devised based upon the use of field averages and multi-temporal data. Field averaged values are less influenced by speckle than are single pixel values. Moreover, it are the potatoe fields that have to be detected, not the potatoe pixels. Multi-temporal data can be easily obtained from an operational spaceborne SAR. The 8-look SLAR data of April, May and July that were used in the segmentation experiment were also used for the classification experiment. The same test fields served as ground truth with an additional 40 others. The averages of the pixel values in the largest segments were used for the design and test of the classifier. A scattergram of the April and July values for all fields is shown in figure 6. It can be seen that the classes sugarbeets (B), beans (b) and wheat (T) can easily be separated from potatoes (A).
In this way the classification problem is simplified to three classes only, viz. potatoes, peas and onions. Only for these classes a Bayes classifier is used.
In order to compare this classification strategy with conventional ones, three experiments were performed: 1) a Bayes classifier for all 7 classes, 2) a Bayes classifier for 7 classes combined with the thresholds, and 3) the preferred strategy. The results are shown in table 4. In the column potatoe fields two numbers are given: "wrong" gives the fraction of non-potatoe fields in the potatoe class, "correct" gives the fraction of true potatoe fields classified as potatoes. The experiments were performed with the Bayes classifier applied to either April and July or May and July. The preferred strategy which is simpler to apply than a full Bayes classifier compares favourably with the others.

4.2.2 Classification of potatoes in the multi-temporal SLAR image. The classifier design was based upon 83 segments only. Following the strategy of figure 7, a multi-temporal SLAR image was classified to detect potatoes. After segmentation all segments were classified and the area of correctly classified potatoe segments was determined. Figure 8 shows these potatoe segments in grey (actual image is much larger than shown in figure 8). For the potatoe test fields, 68 % of the area was found by the segmentation, whereas 83 % of the area was correctly classified. This result shows that the (low) accuracy of the segmentation alone is much improved upon by the subsequent classification. Note that in this and the previous experiment evaluation for the other classes is not possible because the classifier was optimized for potatoes at the expense of other classes.

5. CONCLUSIONS AND RECOMMENDATIONS

The study results were presented by the studyteam for members of the ROVE-team during a workshop. The following conclusions and recommendations were reached.

5.1 Conclusions

For the study of most applications in agriculture and forestry the presently available SAR imagery is inadequate.
Estimators can be developed for several applications. For the estimators that were tested in this study, we have the following results.
The segmentation algorithm 1) is a bad estimator for field size, 2) gives satisfactory results for field identification, and 3) leads to accurate determination of field averaged pixel value. The performance improves when the number of looks is increased. The use of multi-temporal data gives more improvement.
A classifier was devised based on segments rather than pixels. This special classifier for one class gives a good result with a smaller training set than is usually required. The area determination is better than in the case of segmentation only.
Monitoring is an important application of a spaceborne SAR because 1) images can be obtained under most weather conditions and by night, 2) the chain of: illumination-sensor-atmosphere can be calibrated.

5.2 Recommendations

The recommendations can be divided into two groups.

- object-sensor-interaction
  Experiments should be performed to investigate the dependence of the radar backscatter of agricultural crops and forests on frequency, polarisation, time and incidence angle.
- information extraction
  Integration of microwave data with data from other sensors and geographical data bases should be pursued to improve segmentation and classification. The problem of sampling should be studied especially in the context of monitoring in order to cope with the data volume.

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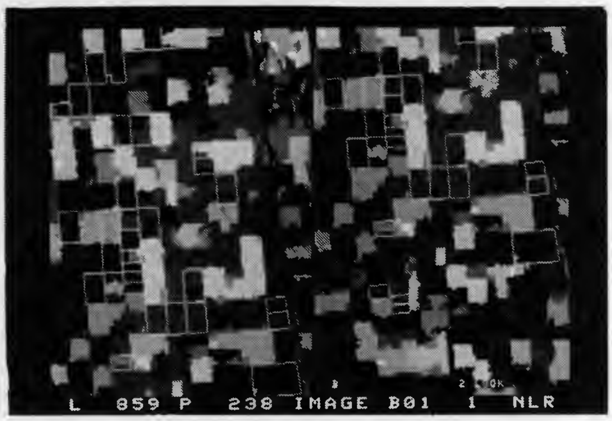

Fig. 5 Segmented (case B) 2-look image

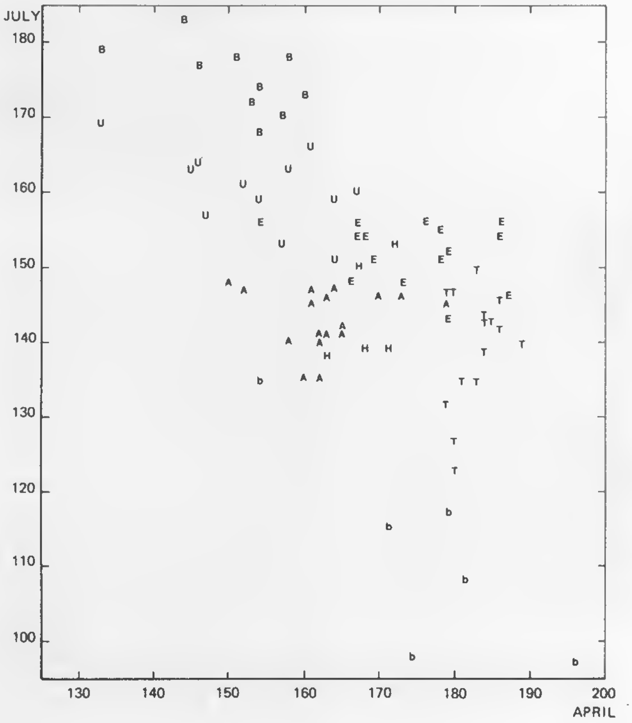

Fig. 6 Scattergram of 8-look July and April data. Fields are indicated by crop:
A-potatoe B-sugarbeet b-beans E-peas
H- oads T-winterwheat U-onions

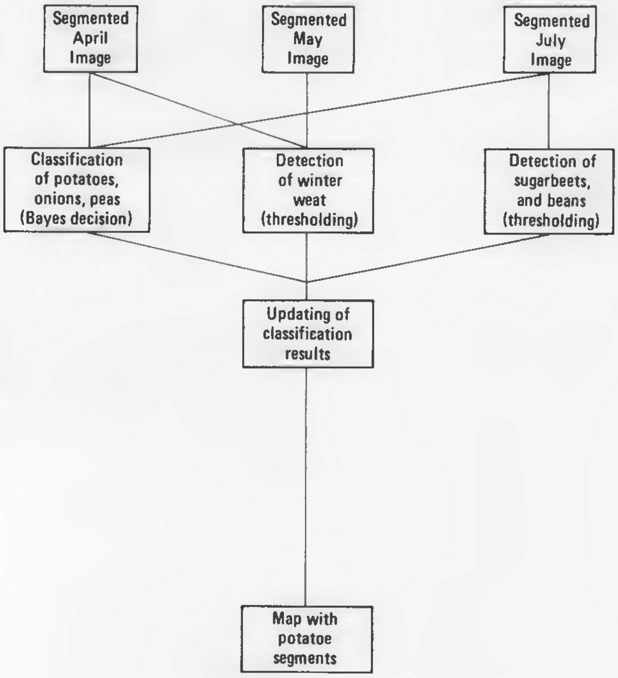

Fig. 7 Classification strategy for potatoes using segmented, multi-temporal radar images

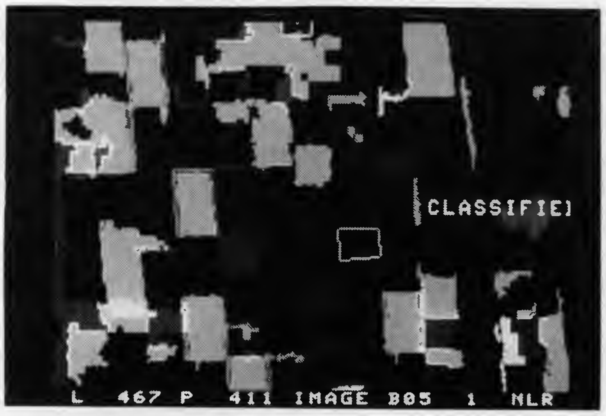

Fig. 8 Final classification result for potatoes (grey) of the multi-temporal SLAR data after segmentation and classification according to figure 7

SEA ICE PARAMETER RETRIEVAL FROM SAR DATA

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ABSTRACT

Automatic parameter retrieval methods for SAR data are needed because of the large volume of data acquired by an operational SAR. Two methods have been investigated: a pixel-by-pixel classification scheme for sea ice type determination, and a spatial segmentation scheme for studies of sea ice dynamics. Before these schemes may be applied, the inherent speckle must be reduced, and non-coherent averaging and adaptive filtering (Frost and Lee filters) have been applied. The Lee filter seems to give the best results. The performance of the classification method was surprisingly good, with mean classification accuracies of about 80%. Three segmentation algorithms were investigated: pyramid segmentation, edge-based segmentation, and region growing, with the second scheme considered to be the best one.

Keywords: Sea Ice, SAR,Parameter Retrieval, Ice Type Determination, Ice Dynamics, Segmentation, Speckle Reduction, Adaptive Filtering.

1. INTRODUCTION

Atmosphere-ocean-ice interaction is a key problem in polar ocean research. The present trend is to apply numerical modelling with meteorological, oceanographic and remote sensing data to describe the dynamics of the ice conditions in polar waters. It may be expected that this research may lead to methods of prediction not only for climate studies but also for navigation and off-shore activities in these waters. Due to the fact that microwave remote sensing is largely independent of light and weather conditions this technique will prove of very great importance in these regions. In particular, the synthetic aperture radar (SAR) is essential due to its fine spatial resolution capability which enables detailed imaging of the scenes of observation.

The numerical modelling referred to above requires a series of parameters including ice parameters such as extent of an ice field, ice concentration or fractional ice cover, ice thickness and ice velocity. These sea ice parameters may be supplemented by other related parameters including lead directions, floe size distribution, ridge statistics etc. These parameters may be derived from SAR data with accceptable accuracies in most cases.

The majority of work reported on the determination of ice parameters from SAR data have been carried out by simple photo-interpretation-like methods and very interesting observations have been made (e.g. Refs. 1-7). However, considering the very great amount of data that become available in the future - and already with ERS-1 - it is essential to study methods by which the interpretation may be facilitated, possibly by (semi-) automatic analysis methods, and this paper describes attempts in this direction.

Following this introduction, Section 2 of the paper outlines the occurrences and characteristics of sea ice. Section 3 considers the preprocessing needed before the parameter retrieval algorithms are applied. In Section 4 a simple ice type determination algorithm is presented, and in Section 5 some methods of determining the ice velocity are considered. Finally, conclusions and recommendations are given in Sections 6 and 7.

2. SEA ICE

2.1 Sea Ice Occurrences

Every year very large quantities of sea ice are formed in polar waters with great variations from year to year. The most important areas on the northern hemisphere are the Arctic Ocean, including the Barent Sea, the Beaufort Sea and Chukchi Sea, the Greenland and Bering Sea but also the Baffin Bay, the Labrador Sea and the Davis and Denmark Straits. In fact more than 10% of the oceans of the northern hemisphere is covered by ice every winter with the corresponding figure for the southern hemisphere, i.e. the oceans surrounding the Antarctic continent, being 13%.

There is a distinct difference between the ice conditions on the northern and southern hemispheres. Whereas about 90% of the ice formed during the austral winter melts in the following summer only 50% will melt during the arctic summer whereby ice which has survived one summers melt (second-year and multiyear ice) effectively will be encountered in the Arctic Ocean and in the East Greenland Current passing through the Fram Strait (between Greenland and Svalbard) and the Greenland Sea. In other Arctic waters all ice will melt except for smaller quantities along the coasts of Ellesmeres and Baffin Islands.

3. PREPROCESSING

Before the parameter retrieval algorithms are applied to the SAR data some preprocessing must take place to correct for radiometric variations across the swath, geometric distortions, and the inherent noise phenomenon called speckle.

3.1 Radiometric Correction

The radiometric properties (the mean and standard deviation for a target class) may vary across the swath due to e.g. system errors (e.g. the mal-positioned sensitivity time control (STC) in the SEASAT SAR), the antenna pattern, the incidence angle dependence of the target backscatter coefficient, or atmospheric-related distortions. A radiometric correction can be based on a model of the distortion, or it can simply be based on a curve fitted to the mean variation of the intensity across the swath. The latter method is used here, though some information might be lost.

3.2 Geometric Correction

The imaging geometry, the topography of the area imaged, the curvature of the surface of the earth, and the pertubation of the satellite orbit result in a geometric distortion of the image. This distortion must be corrected for, especially if ice drift maps are to be produced. Various geometric correction algorithms which have been published (Refs. 4,9) may be applied.

3.3 Speckle Reduction

SAR images are disturbed by speckle, a fading phenomenon arising when an area-extensive target, i.e. an area consisting of many small point scatterers, are imaged by the mono-chromatic radar. If the radar only obtains a single independent sample from each target cell (1-look SAR image), the backscatter signal will have a Rayleigh distribution after detection when the voltage of the backscatter signal is considered and an exponential distribution, when the power is considered. The inherent signal variation due to speckle is very large, e.g. the 90% range (i.e. the ratio of the signal exceeded 5% of the time to that exceeded 95% of the time) is 17.7 dB for both distributions (Ref. 9). Speckle reduction is therefore necessary to obtain a reliable estimate of the backscatter coefficient essential for the subsequent feature extraction.

3.3.1 Non-coherent Averaging. A simple and commonly-used speckle reduction method is averaging in either the voltage or the power image. This method is optimum (in a maximum likelihood estimation sense) in the power image but not in the voltage image, because the maximum likelihood estimator of the mean in the voltage image is the square-root of the second moment which is different from the average. The estimation of the backscatter coefficient is indeed improved by the averaging, e.g. the 90% range is reduced to 4.6 dB, when 10 independent samples are averaged in the power image (Ref. 9).

3.3.2 Adaptive Filtering. A serious drawback of the above-mentioned speckle reduction technique is that the fine, inherent spatial resolution of the SAR is also reduced. Two adaptive filters, the Lee and the Frost filter, have been investigated (Refs. 10,11). The filters try to avoid the deterioration of the resolution by computing the filter coefficients from the local statistics. Both filters compute the linear minimum mean-square error estimate of the intensity (power) assumed to be interferred with multiplicative noise. The Lee filter computes the estimate as a weighted sum of the pixel under consideration and the mean in a window surrounding the pixel, whereas the Frost filter computes a weighted sum of all the pixels in the window. In both cases the weighting is determined by the ratio of the variance to the squared mean in the local window, whereby edges are preserved. Both filters give a poor estimate near the edges, and a refinement of the Lee filter has been proposed (Ref. 12). When an edge is present in the window, only the pixels on the inner side of the edge are used in the estimation.

The Lee filter (11 x 11 pixel window) and three iterations by the Frost filter (5 x 5 pixel window) as well as averaging by a 5 x 5 pixel window have been applied to the 1-look SAR-580 image, shown in Fig. 1. Image profiles for the three filters and the 1-look data are shown in Fig. 3. The Lee filter has the best performance with a fine preservation of edges and a considerable averaging in the homogeneous areas. The averaging blurs the edges, and the Frost filter gives a good estimate in the homogeneous areas, but near the edges the estimate is poor and some edge blurring also occurs. The computational load of the two adaptive filters is almost the same, with the Lee filter runs being slightly slower (1.1 x) than the three iterations by the Frost filter. Averaging is by far the fastest algorithm being six times faster than the Frost filtering. The two filters assume, that the image consists of homogeneous areas separated by relative sharp edges. However, this is not the case here with individual floes being a composition of a number of smaller floes frozen together. This may be the reason for the modest results obtained and other types of adaptive filters should be studied.

4. ICE TYPE CLASSIFICATION

An investigation has been carried out to get an idea as to what extent a simple pixel-by-pixel classification technique based on the backscatter level alone could be used to determine ice types from SAR data. This method has proven to be succesful with multichannel visible/infrared data, but already at the outset it was clear that the performance would be inferior in the SAR case. This stems from the fact that SAR systems normally are one-band systems in contrast to the visible/infrared multispectral systems.

The classification procedure used in this investigation was the simple minimum distance classification method. This method can be described as follows: Appropriate ice areas are picked manually and assigned to different ice classes (Figs. 1 and 2). The mean pixel values of these ice classes are determined. For each pixel in the image the euclidian distances between the pixel value and the class means are computed. The pixel is then assigned to the class with the minimum distance. A set of test areas is also picked, so the classification accuracy can be estimated. The ice classes and the test areas are picked on the basis of the experience of the investigator, and no ground reference data were available.

The small differences in the backscatter level between some of the ice classes cause ambiguities between the classes (Section 2.3). In the SAR-580 image multiyear ice and the new ice with strong return are confused. The strong return from the new modelling, e.g. the floe size distribution, the lead and ridge structure, and the ice concentration.

The automatic algorithm may run in a number of steps: preprocessing (Section 3), floe delineation, floe recognition, and ice drift calculation. The last three steps will be discussed in some details below.

5.1 Floe Delineation

Before the mapping can take place, the image must be divided into areas corresponding to fairly uniform areas in the input image, which can be identified and accessed one by one at later steps in the processing. The standard method in digital image processing is to carry out an image segmentation. Three different image segmentation methods have been investigated and applied to SAR data: pyramid segmentation, edge-based segmentation, and region growing.

5.1.1 Pyramid Segmentation. This algorithm creates a pyramid-like structure by consecutive averaging with a 2 x 2 pixel window and after a linking of pixels which are alike in consecutive levels has taken place, values from one of the higher levels are backtracked to the bottom level through the links (Ref. 13). This results in an image, where fairly uniform areas have been assigned the same value, and after a thresholding bright uniform areas are separated from the background, i.e. a segmentation has been performed.

The pyramid segmentation has been applied to the SEASAT SAR image in Fig. 2 and the result is shown in Fig. 4. The segments represent mainly multiyear floes, due to the stronger backscatter from multiyear ice. However, due to the ambiguous strong backscatter from wind-roughened water also segments representing wind-roughened water appear. The thresholding is a complicated task because of the low radiometric resolution of the image. A great number of floes have been lost in the segmentation process, especially in the lower half of the image, and some of the floes have been merged into irregular shaped segments. Small holes within the segments are caused by the speckle effect, and larger holes probably represent melt water ponds or small leads, with a low backscatter level. The performance of the algorithm is marginal, mainly because of the noisy nature of the SAR image, but also because of the ambiguous backscatter level. Used in connection with visible/infrared data from the NOAA satellites this method of segmentation proved very succesful (Ref. 13).

5.1.2 Edge-Based Segmentation. The edge-based segmentation algorithm creates a segmented image on the basis of an edge-detected image. The edge-detection algorithm takes advantage of the statistics of the multiplicative noise in SAR images, and an edge is detected when two areas with different radiometric properties are found in a window (Ref. 14). The performance of this algorithm is rather encouraging, it produces fairly well-defined edges and only few false alarms in the interior of floes. A distance transform is applied to the edge image, and circular discs inserted at local maxima constitute region kernels. Finally, all non-disc pixels are linked to the regions (Ref. 15).

The result of the algorithm is a region labelled image, in which each label corresponds to a single connected, fairly convex area in the input image. The advantage of the method is its ability to segment in case of incomplete edges, on the other hand, its major drawback is its sensitivity to false alarms within the floes.

The result of the edge-based segmentation applied to the SEASAT SAR image is shown in Fig. 5. The algorithm works fairly well in the upper half of

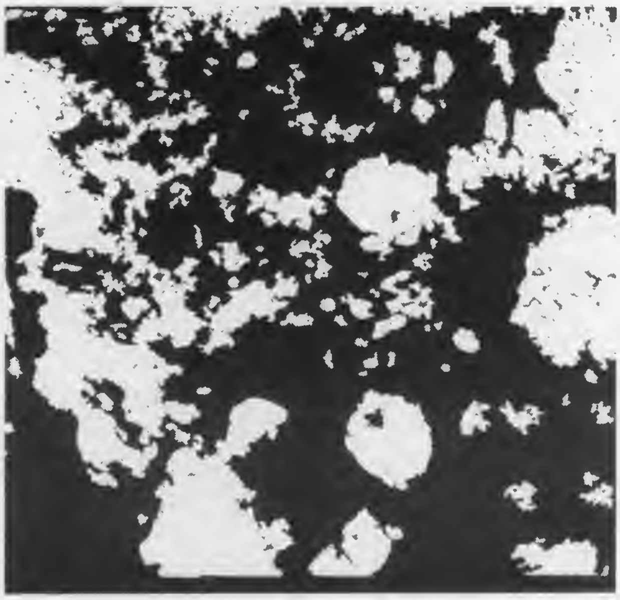

Figure 4. The result of the pyramid segmentation applied to the SEASAT SAR image in Fig. 2.

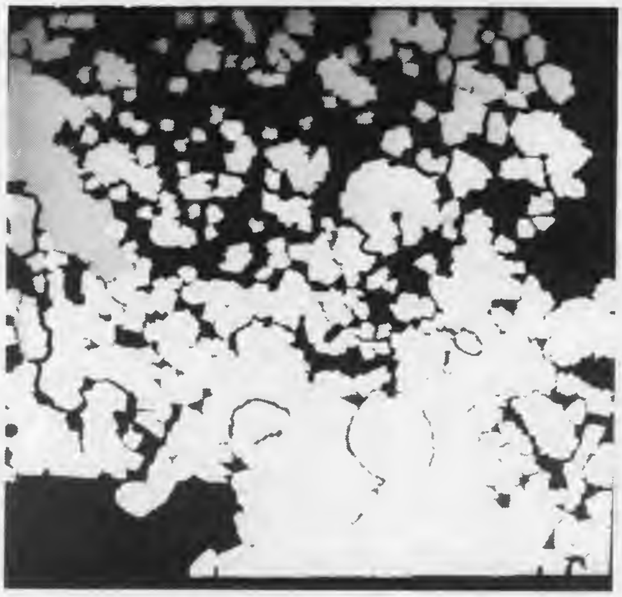

Figure 5. The result of the edge-based segmentation applied to the SEASAT SAR image in Fig. 2.

Old floes have normally rounded edges, due to the action of waves and to their bumping and jostling together, whereas the new ice is rather irregularly shaped. Measures of the shape of the segments may therefore be used in the characterization of the segments and some measures which can be suggested are: various moments with respect to the principal axes, and heuristic "non-ellipticity" measures. These measures have shown encouraging results when applied to visible/infrared images of sea ice (Ref. 13), however, their performance with SAR is yet to be investigated.

5.3 Ice Velocity

When the segmentation and evaluation of the descriptors have been carried out for two successive images the floe recognition process is going to take place. A weighted difference is calculated for a floe in the first image and all candidate floes in the subsequent image. If the difference is minimum and less than a threshold for one of the floes in the subsequent image, the floe has been recognized and the corresponding drift vector is simply the difference in the positions of the "centre of mass" for the two appearances of the floe.

The above-mentioned algorithm for automatic ice drift mapping using pyramid segmentation and shape descriptors has shown succesful results in mapping ice drift from visible/infrared sensors onboard the NOAA satellites (Ref. 13), but has not been applied to SAR images, so far. The slant-imaging geometry of a SAR may however create troubles for the ice floe recognition process, because the imaging of floes is dependent upon the aspect angle.

No automatic algorithms for ice drift mapping derived from SAR images has been reported, yet some interactive algorithms are described (Refs. 4,17, 18). Homologous ice features are picked interactively in successive images, and the computer calculates the translation vectors and draws an ice drift map. These methods are cumbersome and time consuming and may prove impractical for analysis of the large amount of data.

6. CONCLUSIONS

In an introductory section a brief description of the occurrence and characteristics of sea ice is given, and important parameters are discussed. The sea ice parameters, which may be derived from SAR data, are: sea ice boundary, ice concentration and leads (fractional area and orientation), ridges (orientation and fractional area), ice motion, and ice type (new ice, first-year ice, and multiyear ice).

Before the parameter retrieval algorithms are applied to SAR data, the data must be radiometric and geometrically corrected, and the inherent speckle must be reduced. Two methods for speckle reduction have been considered: non-coherent averaging and adaptive filtering with Lee and Frost filters respectively. The Lee filter seems to have the best performance but further studies are required to improve the performance of adaptive filters. In general, adaptive filtering is very suitable for these purposes because they modify the spatial resolution only to a limited extent in contrast to the non-coherent averaging, for instance.

A straight forward method of analyzing remote sensing images is a supervised classification pixel-by-pixel in the form of a minimum distance classification. This is applied on the basis of the backscatter levels to one channel (X-band) of the SAR-580 and to SEASAT SAR data (L-band). In order to reduce the influence of speckle non-coherent averaging was applied, and the classification was improved very much by this filtering. Mean classification accuracies of up to about 80% were obtained. Using adaptive filtering the edge smoothing will be less than in the case investigated, and this will extent the classified areas to the edges, so that classified data eventually could reveal data on ice concentration.

The other parameter retrieval algorithm is related to determination of the floe velocity on the basis of consecutive images. This parameter is very important for sea ice modelling. Furthermore, the techniques may also be useful for derivation of other parameters (e.g. the floe size distribution, the lead and the ridge structure, and the ice concentration). The technique is fundamentally based on recognition of floes in two (or more) consecutive scenes in question. This may be performed by visual inspection of the images involved, but automatic methods may be necessary to be able to cope with the large volume of data. Some methods have been investigated to perform floe delineation and characterization of the floes as a basis for determination of the ice movement, i.e. translation and rotation of individual floes. An important part of the process is the geometrical correction of the images involved using ground control points (if available) or satellite orbit data or a combination of both, but this is a relatively trivial process, and it is therefore not considered here.

Floe delineation is related to image segmentation and three methods have been investigated: pyramid segmentation, edge-based segmentation and region growing. None of these methods are ideal but applied to the same scene it is found that the edge-based segmentation seems to have the best performance and is the one which is best suited for automatic analysis. Naturally, the performance of any of the methods depends on the radiometric resolution and there is a strong indication that the edge-based segmentation may perform better than in the case investigated. The performance of the pyramid segmentation depends on a carefully selected thresholding and suffers in the cases investigated from the relatively small radiometric resolution. The region growing method is an interesting one but depends upon interactive selection of a number of parameters and is therefore less suited for automatic analysis.

In the visual analysis of a satellite image of a sea ice scene one uses the shape and some sort of surface feature in combination to recognize a floe for instance. Literature studies show that various texture measures, i.e. moments of the pixel intensity distribution, may be useful descriptors of the inner structure of the floes. More work has been devoted to shape descriptors although floe shapes may vary very much. However, great many large floes and multiyear floes in particular often have an approximate elliptical shape which may be described by the major and minor axes, by symmetry properties and non-ellipticity measures. This technique has been investigated in connection with satellite images from visual sensors with good re-

TOWARDS A SAR SYSTEM FOR SNOW AND LAND ICE APPLICATIONS

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ABSTRACT

The paper summarizes the main results of a study which was carried out in order to determine the characteristics of a SAR system for snow and land ice monitoring and to identify possible applications. Characteristics of backscattering from snow and ice are discussed. Examples are given for radar image simulations which provided information on required antenna look angle and spatial resolution for snow cover monitoring. Preliminary specifications are given for a SAR system for snow and land ice monitoring and promising applications are discussed. Recommendations are made for further investigations and experiments required for the final definition of a snow and ice monitoring system.

Keywords: Synthetic Aperture Radar, Snow, Land Ice, SAR System Specifications, Radar Image Simulation, Radar Backscattering.

1. INTRODUCTION

Due to the all-weather capability and the high spatial resolution synthetic aperture radar (SAR) systems offer unique possibilities for snow and ice monitoring. In order to determine the characteristics of a SAR system for snow and land ice monitoring and to identify possible applications, a study was carried out for the European Space Agency (Ref.1); this paper summarizes main results of this study.

The study was concerned with the cryosphere (the snow and ice masses) of the land surfaces which includes following elements:

1. seasonal snow cover
2. mountain glaciers
3. ice sheets
4. permafrost
5. lake and river ice.

The main ice masses are concentrated in the ice sheets of Antarctica and Greenland, while the largest areal extent is observed for the winter snow cover of the Northern Hemisphere (Ref.2). The seasonal snow cover with its great temporal variability has the strongest impact on human activities. It may cover at its maximum extent as much as 62 percent of the Eurasian continent and virtually all of America north of 35 deg. The seasonal snow cover, but also the mountain glaciers though comparatively small in size, are vital water resources for irrigation, hydroelectric power generation, agriculture, and other purposes. With the increasing world population and demand for fresh water the optimum management of these resources is getting more and more important.

Almost 20 percent of the land surfaces are classified as permafrost regions. Considering the increasing construction and exploration activities in high latitudes, knowledge on occurence and properties of permafrost bodies is of great economic importance. Permafrost is also a very sensitive indicator of climatic variations.

The other cryospheric elements, in particular the ice sheets and glaciers, are also highly sensitive elements of the global climate system. The time scale of ice sheets in equilibrium is in the order of thousands to ten thousands of years. However, this scale might be drastically reduced in case of major climate changes, as we learned from quaternary research. The elements of the cryosphere have the potential to amplify climatic fluctuations. For the unterstanding of the feedbacks between atmosphere, cryosphere, and oceans and its impact on climate, continuous monitoring of the snow and ice masses is essential.

Main application fields of snow and ice remote sensing are

- operational use in water management, hydrology, ship traffic, and construction;
- climatology
- glaciology
- hazard control including flood forecasting and glacier related hazards.

The requirements of these applications in time, space, and accuracy can be met only partly by existing satellites. Weather independent sensors are needed to fulfill the stringent temporal requirements for water management and hydrology.

2. MICROWAVE INTERACTION WITH SNOW AND ICE

2.1 Scattering from snow covered terrain

A radar beam incident on snow covered ground is scattered at the air/snow boundary, in the snow volume, and - in case of sufficient penetration -

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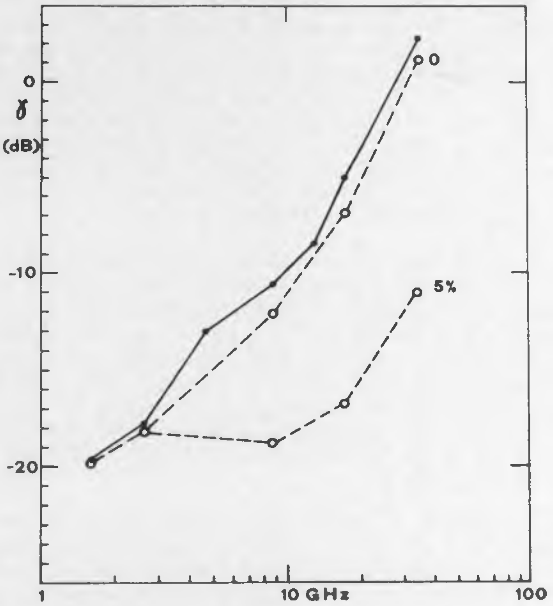

Figure 3. Backscattering coefficient at θ = 50° versus frequency derived from measurement data. Solid line and dashed line (0): dry snowpacks; dashed line (5%): wet snow, 5% liquid water content.

ground excludes discrimination of snow in winter situations, at least at X-band and lower frequencies. A possible exception could result when a nadir looking instrument such as an altimeter is used on flat terrain.

Considering the spectral behaviour of backscattering there is only little information available about absolute values of backscatter coefficients of snow at other frequencies than X-band. At low frequencies problems are caused by the high transparency of dry snow which is a medium with little intrinsic backscattering. Nevertheless the snow medium may modify the backscattering properties of the underlying ground. At high frequencies the increase $\sim(f^4)$ according to Rayleigh scattering becomes effective, and the penetration depth decreases.

Stiles and Ulaby (Ref.10, 11) reported on backscatter measurements in the range from 1 to 35 GHz, showing a clear increase of the backscattering coefficients with frequency. However, for dry snow it is not clear which contribution is due to scattering from the snow medium and which part is returned from the underlying ground.

Figure 3 illustrates the frequency dependence derived from data of Stiles and Ulaby. As the frequency increases the curves get steeper approaching a spectrum proportional to f^a with $a \approx 2.5$ for dry snow. For wet snow the increase with frequency is less distinct. These spectra can be explained by the superposition of two effexts: (1) surface scattering - either from the snow-ground interface (dry snow) or from the snow surface (wet snow) - that is not strongly dependent on frequency, and (2) volume scattering that increases with frequency. According to this interpretation volume scattering is certainly important above 10 GHz.

For snow mapping the backscatter contrast to the snow-free terrain is of main importance. For wet snow good discrimination is possible in the 8 to 15 GHz range, because wet snow reveals lower backscatter values than most snow-free surfaces; an exception are water surfaces and swamps.

Mapping of dry snow is more problematic and more experiments are needed to decide on the capabilities of radar. At frequencies < 15 GHz backscattering from soil covered with dry snow is clearly dominated by the soil contribution. At higher frequencies the snow contribution may be significant, and the strong increase of backscattering with frequency may enable the discrimination of dry snow using a dual frequency radar. However, because of technical problems spaceborne SAR systems at these high frequencies are not yet in view.

2.3 On the backscattering behaviour of land ice and permafrost

Information on backscattering properties of land ice (glaciers, polar ice sheets, lake and river ice) and of permafrost is rather limited; no systematic backscatter measurements on these targets have been reported. However, spaceborne and airborne SAR images have been acquired providing at least qualitative information on backscattering. In many cases the lack of adequate ground truth data is a limiting factor for interpretation of backscattering features. Another source of information on scattering is theory, in particular for considering effects of roughness and dielectric properties.

The mountain glaciers:
Glacier surfaces include snow cover, ice areas, and areas covered with debris (surface moraines). For ice and moraines scattering at the surfaces is the dominating factor for the radar return. Consequently the surface roughness in relation to the wavelength is of main concern. Generally the ice surfaces on glaciers are fairly rough. At angles off nadir this results in radar returns which are usually significantly higher than for wet snow. Low backscattering intensities are observed for glacier ice if the surfaces appear smooth in relation to the wavelength; this will occur primarily in L-band, and in other frequency bands in exceptional cases (e.g. superimposed ice).

The accumulation areas of glaciers include the soaked zone, where the snowpack is thoroughly wet, and - at high altitudes - the dry snow zone. In the Alps the dry snow zone is found at elevations above about 4.000 m. In the cold season the wet firn is covered with dry snow. Compared with the seasonal snow cover on ground, differences in backscattering are due to the great depth of the snow in the glaciers' accumulation zones. For wet snow this is of no relevance because of the small penetration depth. In dry snow the dielectric losses are small. Therefore the radar return of the dry accumulation zone originates from volume scattering of a deep layer which is in the order of 10 m at X-band and increases with the wavelength. This results in comparatively high return signals at all radar frequencies. For the separation of snow and ice areas on glaciers dry snow return is of

ERIM and CCRS. Data on the seasonal snow cover have been acquired in X-, C-, and L-band at test sites in Austria and Switzerland during the European SAR-580 experiment in 1981 and have been processed by optical and digital correlation.

For the study on a SAR system for snow and ice monitoring (Ref.1) the SAR-580 data of the Alpine test sites, Seasat SAR data on glacier areas in Iceland, in the Western Alps and in Greenland, and SIR-A data on glaciers in the Karakoram mountains (Pakistan) have been investigated. The analysis included quantitative studies of backscattering properties and image interpretation. Results of SAR data analysis on snow and glaciers are also reported in the Refs. 9, 13-16. In this paragraph only the main conclusions from investigations of the SAR data are summarized.

Conclusions from the analysis of SAR data:

1) In X- and C-band at like and cross polarizations wet snow areas reveal lower backscattering coefficients than most snow-free surfaces. Therefore wet snow can be clearly discriminated at surface incidence angles between about 25 and 80 degrees at like polarizations. At cross polarizations good discrimination at angles $< 25^\circ$ is also possible, but low return power may in practice limit the usefulness at higher incidence angles.

2) Differences in radar return of wet snow areas and snow-free surfaces are decreasing from X-band towards lower frequencies. In L-band a variety of surfaces (e.g. soil, meadows, alluvium) appear smooth and show low return similar to snow.

3) Ambiguities may result also in X- and C-band when wet snow appears together with open water surfaces, both showing similarly low returns. This problem can be solved by using a complementary sensor or a-priori information.

4) Snow and ice areas on glaciers can be clearly separated by backscattered power in X-band. The discrimination by return power is decreasing towards lower frequencies, but textural information enables the separation in most cases.

5) Glacier boundaries, features of glacial morphology, and glacial landforms are enhanced in the radar images. The optimum antenna incidence angle depends on the roughness of the relief.

6) Antenna look angles between 40 and 65 degrees (from the vertical) are adequate for appliactions in Alpine terrain.

7) Digitally processed SAR data are preferable for applications in mountain regions because they cover a wide dynamic range and enable optimum enhancement in respect to the targets of interest as well as quantitative analysis of backscattering.

4. A SIMULATION STUDY

Methods of radar simulation were applied to derive additional information for the definition of a spaceborne SAR system. The simulations were based on synthetic images as well as on real images.

Synthetic images were generated to investigate
- effects of various look angles for two different terrain types
- target discriminability and methods for SAR data analysis by including thematic information in the simulations.

The simulations based on real SAR images were aiming at
- effects of resolution and system noise.

The simulations focussed on the seasonal snow cover as main target of interest. For other cryospheric elements the available information for the simulation and comparative data were not sufficient to generate realistic synthetic images.

The simulations of synthetic images were based on an "Image Space Algorithm" (Ref.15) which starts from equidistant image coordinates of the output image. Input to the simulation are:
- a digital elevation model (DEM)
- optional: thematic information
- flight and imaging parameters
- backscatter functions

4.1 Simulations regarding incidence angle effects

Two types of topography were selected for the simulations: one site located in flat and hilly terrain (Leibnitz, Styria), the other site in a high mountain area. The mountain area includes the Austrian SAR-580 test site, which is shown in Figure 4. This enables the verification of the simulated images by comparison with the real image. The two model areas can be considered representative for many other sites for which snow cover data are required. In this paper the simulations for the Oetztal site are shown, which are based on a digital elevation model in 30 x 30 m raster.

The simulations were carried out for a flight altitude according to the ERS-1 orbit and for 3 different incidence angles, flight direction 51.5

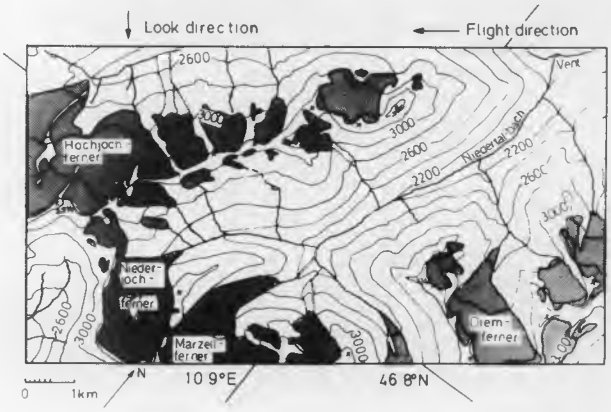

Figure 4. Sketch map of the SAR-580 test site Oetztal, Austria. Glaciers are dotted.

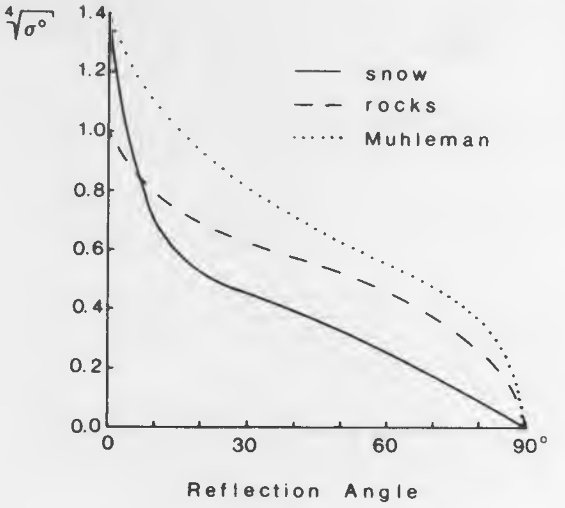

Figure 6. Angular dependence of backscattering: fourth root of σ^o for snow and rocks according to Equ.4 and Muhleman's backscattering function.

where A, C, and Φ are constant values for each surface class and Θ is the incidence angle of the radar beam. The term in brackets represents the fourth root of σ^o and was used for the backscattering calculations in the simulated images. This enables a good comparison with the real images which are provided in terms of signal amplitude (square root of power) and which were enhanced with a square root function for the display.

The following constants were used:

	A	ϕ	C
wet snow cover	0.90	7°	0.50
moraine and rock	0.35	11°	0.65
grassland	0.55	10°	0.55

Figure 6 shows the fourth root of σ^o according to Equation 4 for two backscattering classes (snow and rock) in dependence of the incidence angle. Muhleman's backscattering function is also shown.

Figure 7. Simulated radar image of the Oetztal site with thematic information.

Figure 8. Display of the digitally processed SAR-580 data of the Oetztal site, 5x5 pixels averaged.

Figure 7 shows the simulation for the Oetztal site, based on SAR-580 flight parameters and with 3 surface classes (snow, rock, grassland). For comparison the real X-band SAR image after 5 x 5 pixels averaging (resulting in 15 m spatial resolution) is shown in Figure 8. Differences between the real and the simulated image can be explained by the following effects: i) More small scale features appear in the real image due to the higher spatial resolution compared to the digital elevation model. ii) The thematic map does not include the small scale features (e.g. small snow patches). iii) The brightness decrease in the real image towards near range and far range is caused by decreasing antenna gain; uniform antenna gain was assumed in the simulation. iv) Speckle is not included in the simulation.

5.4 Simulations based on real SAR images

Digital airborne SAR data with high spatial resolution can be used for realistic simulation of spatial resolution by coherent degradation. This was applied to SAR-580 data of the Oetztal and Davos sites, with the aim to decide on the acceptable limits in sensor resolution for snow mapping in mountain regions.

Because the investigations were aiming at the detection of distributed targets (snow fields), a comparatively simple algorithm could be applied for the generation of the various image resolutions. Based on 3 x 3 m single look images the spatial resolution was coherently degraded by taking only every n-th line and every n-th pixel. In this case the speckle statistics (the Rayleigh distribution) was retained as checked by statistical analysis. However, for investigations on point and linear targets, this method would not be adequate.

In addition to speckle noise the effect of system thermal noise on image interpretation was investigated by comparing X- and C-band SAR-580

Table 1: SAR capabilities for land cryosphere monitoring

Cryospheric element	Parameter derived by SAR	Required repetition	Main application
SEASONAL SNOW COVER	area ⎫ of wet snow		hydrology and water management
	snowline ⎭	1 - 7 d	
	extent of dry snow?		
MOUNTAIN GLACIERS	area	7d(1), 1y(2)	(1) hydrology and hazard control
	boundaries	7d(1), 1y(2)	
	snow/ice area	7d(appl.1)	(2) glaciology
	flow features	1 m	
GLACIAL LANDFORMS	moraines	1 m	hazard control and glaciology
	glac. dammed lakes	1 - 3 d	
	meltwater streams	1 - 3 d	
	erosion forms	7 d	
ICE SHEETS	boundaries	1 m	climatology and glaciology
	snowline	1 m	
	icebergs	1 - 7 d	
	flow pattern	1 m	
PERMAFROST	landforms	1 y	exploration
	river aufeis	1 - 3 d	hazard control
RIVER AND LAKE ICE	boundaries	12 - 24 h	navigation, hazard control and hydrolgoy
	concentration	1 - 3 d	
	ice type	1 - 3 d	
	river ice jams	12 - 24 h	

discrimination of open water (swamps) and wet snow, both targets show low return. Large variability is also found in surface roughness and backscattering of glacier ice and of lake and river ice. For lake ice certain thickness information can be derived indirectly from SAR images.

Considering Table 1 it is evident that a number of key parameters cannot be acquired by SAR systems. Among these are the water equivalent of the snow cover and several parameters of the ice sheets and the permafrost regions. It is also not sure whether dry snow cover can be mapped with SAR; further investigations are needed to answer this question. This shows clearly that a system for cryosphere monitoring cannot be based on SAR as single sensor.

5.2 Preliminary SAR system specifications

According to the availability of the spaceborne and airborne SAR data the investigations were mainly concerned with the seasonal snow cover and mountain glaciers. Detailed ground based scatterometer data are available only on the snow cover. But even in this case additional experiments are needed, because not all aspects (e.g. frequency-dependence) are sufficiently covered.

Technical specifications for SAR system for snow and glacier monitoring are given in Table 2. For

Table 2: SAR characteristics for snow and glacier monitoring

Frequency single	X-band	(for wet snow)
dual	X and ≥ 18 GHz	(for dry snow, prel.)
Polarizations	hh or vv	
Incidence angle	40 to 50 degrees	(off nadir)
Spatial resolution	15 to 20 m, 1 look	
Range of σ°	-25 dB to 0 dB	(for X-band hh, vv)
	-20 dB to +5 dB	(at 20-30 GHz)
Radiometric resolution	3 dB for 15 m x 15 m	(at -25 dB)
Radiometric accuracy	1 dB (mean)	
Image localisation	200 m	
Swath width	wide swath	
Date turnaround	6 h - 24 h	

is questionable, and further studies should be conducted on this problem. Such a study should be based on a multitemporal experiment with a dual frequency SAR or scatterometer, operating at X-band and K-band (> 18 GHz) frequencies.

6. Absolute calibration of SAR sensors is important for applications in geoscience and would also improve operational data analysis. Studies on calibration methods should be carried out.

7. Two special tasks of SAR over Antarctica have been identified and should be studied in more detail:
   - the use of homogeneous areas (blue ice fields and ice shelves) for external calibration of SAR and scatterometer,
   - the relevance of SAR derived information on the ice surfaces for the analysis of radar altimeter data.

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THE USE OF SAR SYSTEMS FOR GEOLOGICAL APPLICATIONS

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This paper summarizes the experiences made by applying radar imageries for geological mapping purposes. Based on an extensive literature review the high significance but also the restrictions are outlined. The results of investigations in 4 test sites (Southern Iceland, Straubing/lower Bavaria, Sardegna/Italy, Egypt) clearly underlines that the different radar data available enables an improved identification of lithological units and structural features. In spite of this, the necessity of further experiments is obvious. Geologists need additional experiences on the information content of simultaneously collected X-, C- and L-band data. The application of radargrammetric correction is of great importance, however, also additional experience is necessary.

KEYWORDS: Radar; SIR-A; SEASAT; SAR-580; lithological/structural mapping; superposition of radar and optical data;

1. Introduction and Brief Literature Reviev

Geologists have made extensive use of radar imagery in the past primarily for purposes of terrain analysis and structural mapping. Thereby, Synthetic Aparture Radar (SAR) has proven its high potential for regional investigations. Linear features such as faults and fractures are easily delineated on radar imagery. Imaging radars have a remarkable capability to detect subtle variations in topography. These variations can, in turn, be related to the presence of underlying structures such as folds and faults.

The utility of radar data alone for discrimination of lithological units has been poor to moderate. Variations in lithology of surficial rocks and soils have been successfully detected on both airborne and spaceborne imagery. Analysis of Seasat and SIR-A data has tentatively suggested that orbital radar imagery can be used to detect lithologic boundaries between different geological materials in certain types of environments.

To better understand the characteristics of radar systems and to effectively exploit the imagery produced by them the need has become evident to integrate such data with the large body of other observations and earth science data currently available. Particularly important is the combination of radar image with other types of remotely sensed data with different spectral information and spatial resolution. Imaging radar is not a competing but a complementary technique to other remote sensing systems. Radar senses in a different portion of the electromagnetic spectrum and therefore provides different but additional information.

The practical application of SAR imagery, both airborne and spaceborne, as a supplementary data source for engineering feasibility studies has been demonstrated by several investigators.

Extraction of geologic information from a SAR imagery of a certain terrain is highly dependent both on the type of terrain and the radar system parameters. The choice of depression angle and look direction for a radar survey is of prime importance. Future radar experiments with variable systems parameters such as selectable look directions and depression angles (also for stereo) and multiple frequency and polarization will considerably increasethe utility of radar imagery for geological studies.

The independence of weather and illumination makes SAR indispensable for regional mapping in many different regions of the world.

Application of radar technology to earth resource sensing is still in an active state of advancement and our experience with radar as a geologic reconnaissance tool is quite limited compared to photographic or scanning systems. Limited as this experience might be, the outlook for extensive application of microwave sensing is an extremely promising one.

The geologist in the field was not replaced with the first availability of aerial photographs, but his job was made easier and his data became more understandable and meaningful. Similarly, radar is not a panacea for geological reconnaissance, but the interpretation of radar

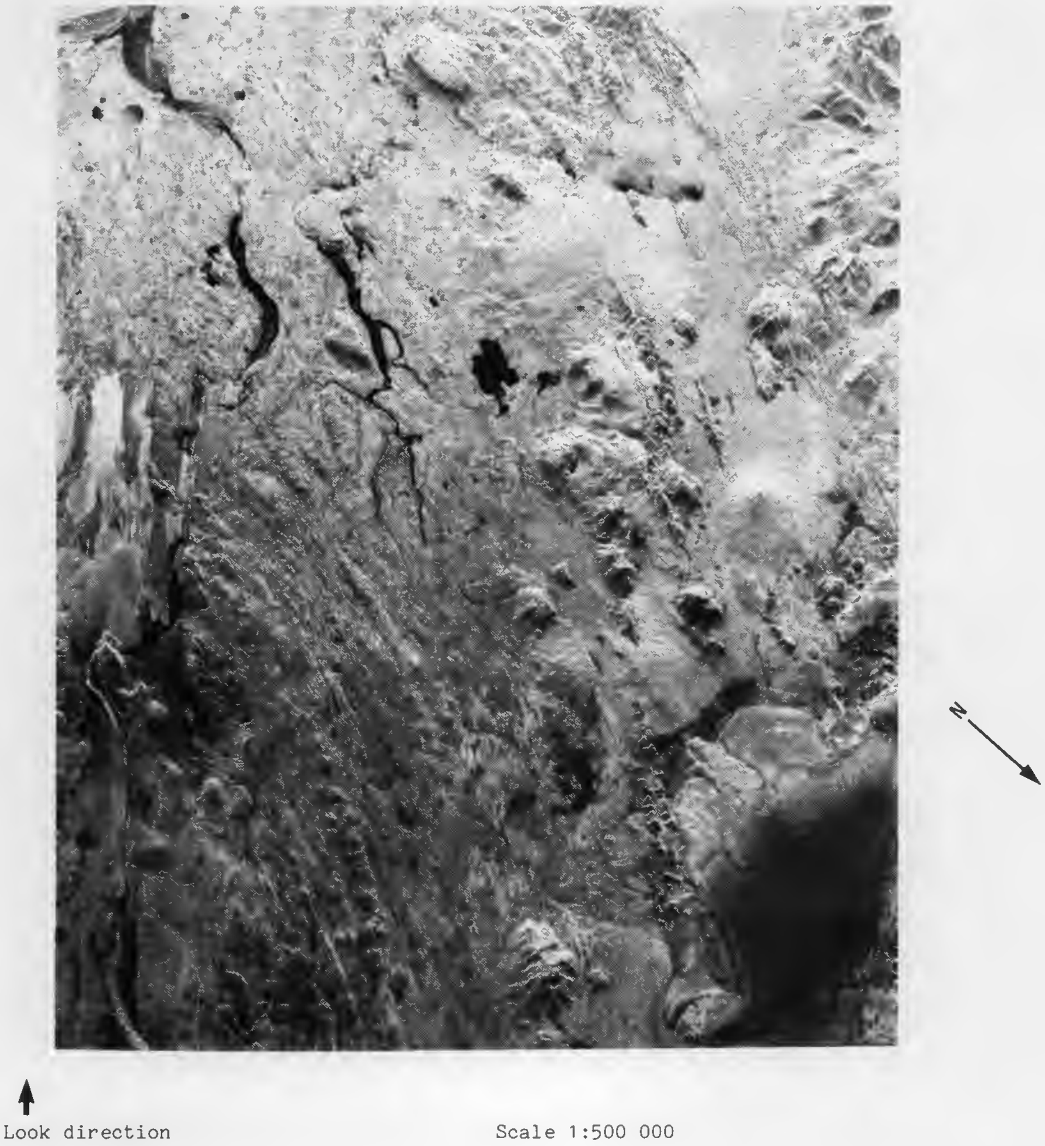

Fig. 1: The neovolcanic zone and the adjacent glacially eroded Plio-Pleistocene series.
The neovolcanic zone runs across the image from top middle to the bottom right corner, where it disappears under an ice cap. Prominent volcanic features such as table mountains, shield volcanoes and elongated palgonite ridges are easily recognized. Also smooth textured lava flows, numerous parallel fissures and faults and even small craters can be identified within the zone. Left-central part of the image: Area of intensive aeolian soil erosion. The exposed underlying lava flows which are rough appear brighter than the smoother uneroded areas.

3. Some Significant Results of the Investigations

It is obvious, that within the volume and intention of this contribution a detailed discussion of the results is impossible. Therefore, in the following some highlights of each test site will be presented.

3.1. Results of the Investigations in the Test Site Iceland

The four stratigraphic series of Iceland can be distinguished on the SEASAT-SAR imagery, mainly because of their different morphological expressions. Except for the neovolcanic zone the boundaries of the series are mostly not distinctive and in some parts impossible to delineate.
The volcanic and volcano-tectonic characteristics of the neovolcanic zone are well expressed. Features such as postglacial lava flows and ash fields, various types of volcanoes, craters, crater rows and palagonite ridges, linear and circular tectonic fractures and faults are readily distinguishable on the radar imagery (fig. 1). Various glacio-morphological features are also recognized . Many of these features are more easily discerned on the radar imagery than on LANDSAT images. This is because of the higher resolution of the digitally processed

Concerning the looking angle only potatoe fields show significant differences in grey tone level, due to their surface geometry (rows, furrows).

Due to the homogeneous soil type coverage and the nearly constant and dry soil conditions (3 - 5 vol. % H_2O), there could not be expected large differences in reflectivity. There are some small differences in grey tone level, going down from the higher Riss-glacial terraces to the region around Danube River. The areas where the Riss-glacial terraces are cut by little valleys are showing significant changes of average grey tone level. Some structural information (small structures like ancient field boundaries) are detectable, using X and L-band-data with different looking angles. Information concerning relief as well as lithologic phenomena (in this case slightly changing of soil condition) can be detected by use of L-Band-data (different looking angles).

At the beginning of the investigations it was assumed that the broad variety of radar data available enables the differentation of some relevant geological phenomena (detectability of structures and soil moisture variations due to system characteristics). Restricting factors, however, decreased the interpretabilty significantly. Nevertheless, the investigations within this test site characterized by humid climate, intensive agricultural land use and relatively homogeneous geological and soil parameters, clearly points out, that the impact of radar data for geological purposes has to be evaluated very carefully.

3.3. Results of the Investigations in the Test Site Sardegna / Italy

The SAR imagery of the Test Site Sardegna is valued of being of high use, mostly for structural and lineament studies. For other geologic purposes, such as lithological mapping, the possibilities are limited, even if lithological units proved to be of good detectability (e.g. granits/shists/carbonates; see table 2). Besides this, SAR imagery is characterized by a ready visibility of topographic features. So, the images also have a certain utility in regional physiographic acquirements. For geologic studies, the highest utility factor of SAR is primarly in cloud prone areas, where all other recording systems cannot acquire information. The high effort of SAR systems for terrain monitoring and especially for the detection of structural details is obvious. Thereby, for any requirements in SAR technology, depression angle and look direction have to be considered with high priorities in order to express the interesting features. The advantage of the SIR-A and SEASAT images in comparison to the LANDSAT system are the variability of depression (illumination angle), the look direction and the independency of atmospheric influence. Although the ground resolution of SAR is similar to other passive recording systems, this three advantages open the way to more detailed terrain surface information. Conjuncted with other information, derived from aerial photography and satellite systems, the SAR technology will undoubtedly guarantee a further way to terrain surface investigation.

- The evaluation comparing MSS and SIR-A delivered a not unexpected different lineament orientation which may lead back to geometric distortion.
- It has to be investigated to what extent digitizing of optical SAR data or low pass filtering influences the detectability of tectonic structures.
- Inspite of this, the geometric corrected models show nearly the same results as the basic information source. This is very important, because it proofs that radargrammetric procedure does not produce artifical structures. Anyhow a displacement of main maxima in SIR-A imagery (330°, 350° + 30° - 50°) can be determined comparing them with MSS data (350° - 10°, 60°). Due to partial suppression of lineaments oriented parallel to look direction the 350° - 10° orientation of MSS cannot be found in SAR imagery.
- The geometric correction does not meet a success in obtaining additional or improved information in comparison to original or digitized data. Summarizing during the interpretation of digital models interesting aspects figured out. They may not be estimated too good because of unsufficient data quality. The quality of SAR data as input to radargrammetric models has to be improved for further investigation to draw fair comparisons with other sensors.

Unfortunately, a comparison with SEASAT-SAR could not be carried out because of too little overlapping of the different data sets available.

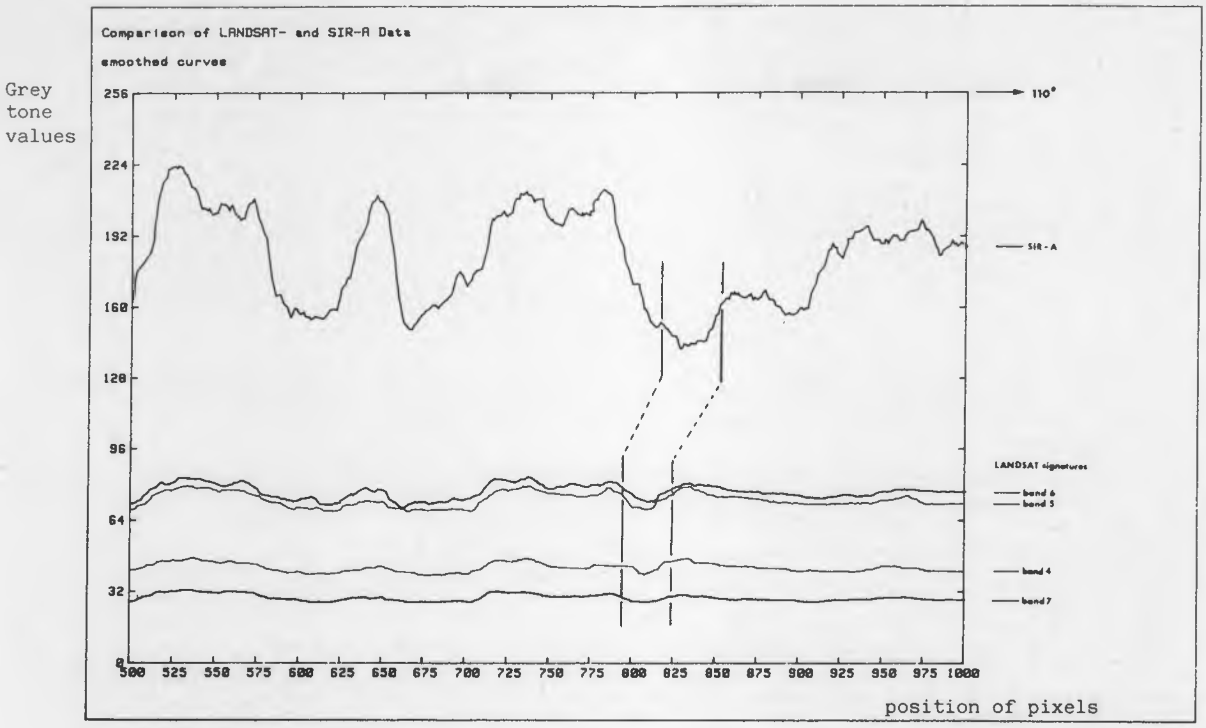

Fig. 2: Comparison of grey tone profiles of LANDSAT and SIR-A data of the Test site Egypt

Starting from approximatly point 800 to the east, remarkable differences can be observed between LANDSAT and SIR-A data. As indicated in the diagram, a reflection minimum is shifted to the east within the radar data in contrary to LANDSAT. This may be caused by typical radar reflection effects like foreshortening generated by cuestas due to flat lying sediments. More distant to the east, LANDSAT signatures are characterized by a relatively unique level, while SIR-A data are significantly differentiated. This can be explained by small variations on the thickness of sand coverage, which are penetrated by the radar signal. Therefore, the radar image shows more detailed gradations; however, this is not related to lithological differentiations.

4. The necessity of Superposition of Multistage Remote Sensing Data

4.1. General Remarks

Complementary to the classic processing of digital synthetic aperture radar, additional digital image processing techniques will become an indespensabel tool. They can enclose as well "cosmetic procedures" (e.g. contrast enhancement) as the superposition and color coding of multistage remote sensing data.

An intensive study of the literature on applications of remote sensing data in geology, impressively is documenting that the different types of data often are describing similar ground phenomena by different physical parameters. An excellent example is given by soil moisture variations which causes varying thermal radiation due to different temperatures and modulations of the backscattered radar signal due to the variation of the dielectric properties. Therefore it can be expected that a meaningful combination of adequate data sets can improve the geological interpretation. As crucial point, it has to be guaranteed that the combination occurs in a "meaningful way", which finally shall express that the critical and desirable criteria are preserved. In the following we present two procedures, which have been implemented by Dr. Haydn. Within different investigations of our institute, they have proven their suitability for geological application.

4. 2. Proposal for Data Combination

It was already described, that the preservation of the information content of the different remote sensing data set should be guaranteed. That means that the processing product has to enable a clear interpretation of the influence of the single input parameter. Therefore, 3 procedures seem to be adequate

- Merge via I-H-S approach

- Synthetic Stereo and

- Digital Classification Algorithm.

Concerning digital classification algorithms, it was already mentioned, that they must fail concerning geological purposes (mainly caused by the significant influence of textural parameters on the detectability of surface phenomena and the insufficiency of computers for their

by the example of the test site "Egypt", the variations of the product must not be controlled by the lithological parameters only; specially considering radar, surface parameters like roughnes significantly influence the appearance; although they are important for geological purposes, it is very hard to distinguish those effects;
- due to this consideration a ground check will be an indispensible requirement; in addition, this was demonstrated impressively by the investigations of Mc CAULEY, et. al., which elaborated astonishing results - however only by incorporating results of an intensive ground check.

Radar systems and the data produced offer important applications for geological purposes. Beside the improved possibilities of observations without dependancy of weather and illumination, there are geometric and radiometric aspects which will push forward geological remote sensing.

However, numerous investigations will be necessary to clarify the real impact. Specially the results of radargrammetric processing techniques have to be a crucial point because of their huge importance due to the missing geometric distortions.

5. Recommendations on futher SAR activities

The following recommendation on further European SAR activities is basing on our experiences on the applicability of SAR data for geological tasks as it was demonstrated briefly in chapter 3 and taking into account the projected capabilities of technologies that are 5 years in the future.

5.1. Requirements on an airborne SAR mission

In preparation of a future european spaceborne SAR system for land application the realization of a well prepared airborne SAR mission is of crucial importance. Taking into account the experiences of different european remote sensing campaigns (SPOT simulation, SAR 580) it is proposed to realize an extensive campaign within only a few test sites. These have to be well-selected, so that experts of different fields of application can cooperate and a most efficient information selection is guaranteed. It is our opinion that, all together, there shouldn´t be more than 3 test sites within Europe. Of course, this is not the right place for a presentation of well defined test sites - however, we can briefly put to the discussion the following regions:

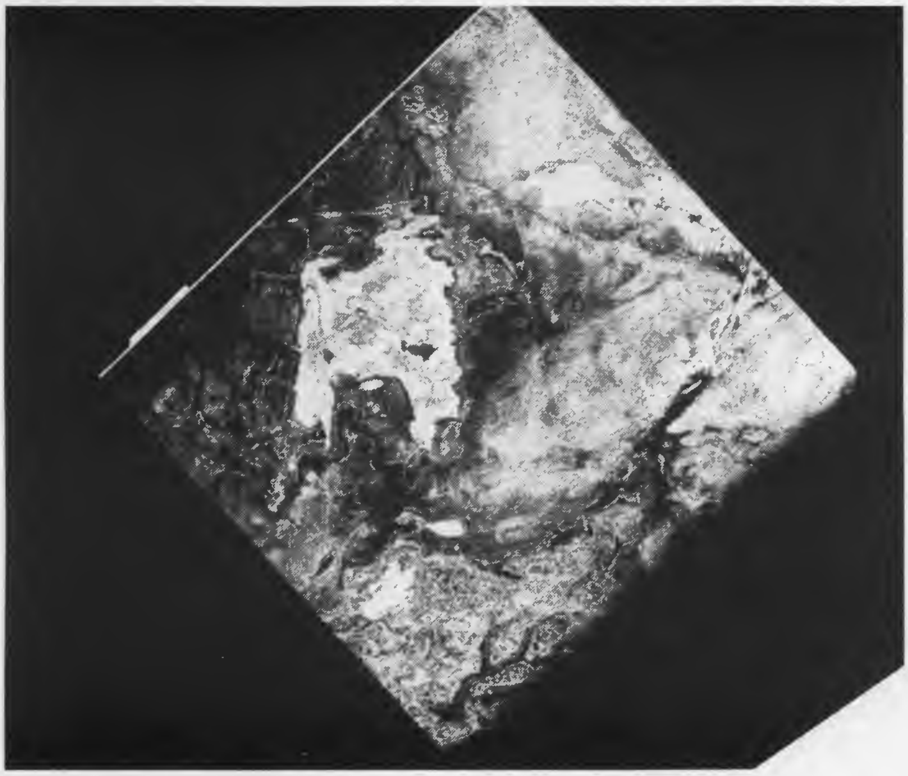

Fig. 3: Superposition of LANDSAT-MSS-Data and digitized SIR-A-Data of the Test-Site Egypt

LAND FEATURE EXTRACTION FROM SAR IMAGES

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ABSTRACT

Results of the reliability and precision with which land features can be extracted from airborne and satellite borne SAR's are reviewed. Similarly a review of the results of the application of automatic feature extraction techniques, particularly image to image correlation techniques, are presented. Finally, the ability to overlay imagery from airborne SAR and airborne thematic mapper is tested and the results presented

Keywords: SAR, Feature-extraction, Image correlation, multi-senor composites.

1. INTRODUCTION

This paper describes the work carried out by Hunting Technical Services Limited (HTS) and Marconi Reseach Centre (MRC) on the extraction and identificaiton of features on radar images.[3]

Features had been defined as distinctive point targets and linear targets which have significant form. The latter may include roads, railways, rivers, boundaries exhibiting particular corners, bends or junctions and items such as edges of fields, trees, and geographic features. In general the items are identifiable units which relate to comparable data on maps or other simiar data sources (air photos, Landsat imagery etc).

Feature extraction from SAR images is fundamental to the use of such imagery for two major reasons. Firstly, it is necessary to know the type of information which can be reliably extracted from a SAR image, and the types of targets which can successfully be discriminated. Secondly, most uses of imagery will require the referencing of that imagery to another data source, be it a map, another SAR image, imagery from another sensor or a geographical information system. Such referencing may be necessary to correct or modify the image, to merge data sources or to place the information into a widely-accepted reference frame.

The referencing of SAR images to other data sources is almost certain to require geometric transformations of the SAR images to fit the other data source since the processing of SAR data only partially corrects an image and inherent system distortions can be expected in the SAR imagery. The standard corrections are usually based upon platform ephemeris and attitude data and are of insufficient accuracy, therefore accurate geometric correction of the imagery will require accurate location of known control points to allow fitting algorithms to be applied. The recognition of what types of control points can be reliably extracted is important for manual interpretation, but even more so for systems which will look to automatic methods of feature recognition and image referencing.

A greater part of this study has been directed towards this latter aspect of feature extraction, i.e. the ability to define useful and identifiable control points. This is a more stringent requirement than simply knowing what features can be seen, since ground control points (GCP's) must possess several characteristics. These characteristics are defined by the need to compare two (or more) geographically organised data sets, probably over an extended period of time. As such, a useful GCP must have the following characteristics:

- it must be detectable and accurately locatable in both data sets
- it must be geometrically stable
- it must be radiometrically stable

For automatic purposes it is necessary to add two further considerations:

- it must have a good correlation function, with a high peak and rapid fall-off in all directions - here the correlation procedure must be defined:

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qualitative assessment demonstrated that digitally processed imagery permitted more features to be delineated than optically processed imagery, particularly in the case of field boundaries.

2.2. Coordinate Transformation

For the purposes of this study, an eight term polynomial transformation, as described by Ali (1982) was utilised. This comprises scale change, rotation and other independant translations in order to transform the measured image points into terrain coordinates and from these computer the residual errors.

The same range of features were studied for this section as were for the Feature Plotting.

For this study the following Test Areas were used:

1. SAR 580 Test Area GB4 of Norfolk, England, with X and L-band HH SAR 580 imagery
2. SAR 580 Test Area GB6 of Thetford Forest, England, with X and C-band HH and HV SAR 580 imagery and Seasat imagery.
3. SAR 580 Test Area 18 of Tuscany, Italy with X-band HH SAR 580 imagery.

From this study, for SAR 580 data, the following conclusions were drawn:

- for data of Test Area GB4 distortion effects within and between DFVLR and RAE processed data would not permit a successful multi-channel composite to be constructed
- the X-HH and the C-HV channels provided the most accurate results
- median filtering was found to improve accuracies
- colour compositing was found to degrade accuracies
- variations in accuracies were noted due to the location in the swath; near and far range features provided poor results
- the best accuracies overall were found to be for woodland/arable boundaries and field corners
- comparisons between processing techniques tended to prove inconclusive, except for the greater available range within the swath on the digitally processed channels. The results were also inconclusive in the case of the comparison between radiometrically balanced and full resolution imagery.

For Seasat imagery the following conclusions were drawn:

- woodland/arable boundaries provided the most accurate results
- comparisons between optically and digitally processed imagery proved inconclusive.

3. SPECKLE REDUCTION

3.1. Effects and Benefits of Speckle Reduction to Feature Extraction:

Investigators have noted the detrimental effect speckle has on the ability to delineate features. Conversely it has also been noted that in removing speckle the spatial resolution is also decreased, thus impairing the abiilty to delineate some features. The conclusions of investigators are that:

- a balance needs to be struck between these two facets;
- speckle reduction is not necessarily required for manual interpretation in areas of strong targets, but is required for the enhancement of targets in a noisy background;
- the use of techniques such as the "spatial-grey-level-volume" can result in the detrimental effects of speckle reduction, such as decreased resolution, being compensated for.

3.2. Testing Speckle Reduction Methods:

The following filtering techniques were tested in order to assess their effects on the ability to delineate features:

- Average Filter
- Median Filter
- Frost Filter
- PRSMT Filter
- Lee Bias Filter
- Lee 2 Sigma Filter

Of these the Frost 5 x 5 with = 2.2. σ/μ and the PRSMT with thresholds 7,5,3,0,0 provided the best result.

The Average provided the most unsatisfactory result.

4. AUTOMATIC FEATURE EXTRACTION

Very little literature exists on automated feature extraction, however there are a few reports of algorithms specifically considering SAR data which have been developed in the USA. There has also been some discussion in the literature of methods for the registration of Seasat SAR imagery with Landsat MSS data. These techniques are discussed in the final report (HTS/MRC, 1984a).

Automatic feature extraction is essentially concerned with the answers to two questions:

(i) What features can be recognised after automatic segmentation of the image?

(ii) What types of correlation algorithms are useful for matching features within images, and is it better to correlate raw, smoothed or segmented images?

The MRC segmentation procedure has been used on both spaceborne (Seasat) and airborne (SAR-580) image data for various test sites in the UK. After smoothing with a 3 x 3 window, using an

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RADARGRAMMETRIC ASPECTS OF SAR DATA EVALUATION

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ABSTRACT

The present paper results from a number of recent studies which make clear that radargrammetric concepts and processing methods are of considerable importance for the generation of radar data which display a satisfying geometric accuracy.

Besides, current issues of radargrammetric image analysis are discussed with emphases on the applicability for geology and land snow and ice mapping. The results of these application studies lead to conclusions for future radar satellite missions.

A method to create digital elevation models from radar stereo-images is outlined. Moreover, some remarks on radar stereo viewability are given.

Keywords: Side-Looking Radar, Rectification, Product Simulation, Stereoscopy, Geology, Snow/Ice, Digital Elevation Model

1. INTRODUCTION

One of the important systems for satellite remote sensing is side-looking imaging radar (SLR). Today, there exist satellite radar data sets from the Apollo 17 Lunar Sounder, SEASAT, SIR-A and SIR-B missions for use in scientific work. Additional imagery is scheduled to become available through the European Remote Sensing Satellite program (ERS-1) and the Japanese ERS as well as the Canadian Radarsat experiment.

One may well state that the availability of radar data for application studies is still rather limited when only considering satellite systems. This is different from the situation with aircraft side-looking radar. Since the early 1960's ongoing aircraft activities have led to the coverage of areas in the size of several hundreds of thousands of square kilometers.

The increased thoroughness of SLR research has led to a need for better image geometry for the comparison of radar images to other remotely sensed data acquired by different sensors, to topographic maps and to radar images taken at different times. While early radar mosaics have been compiled with comparatively little attention to geometric accuracy, there is now an increasing interest in techniques of "radar photogrammetry", i.e. "radargrammetry".

For an increasing number of applications analyses of radar imagery require proper consideration of image geometry and the development of procedures to convert the image into map-type products.

A basic task of radargrammetry is to define a mathematical model for relating an object point in any three-dimensional cartesian x, y, z coordinate system to the time and range coordinates t and r, measurable from the radar image. Numerous authors have thus formulated rigorous radar projection equations. In Ref. 7 a comprehensive review on the topic is given. On the other hand, various models describe how the raw electronic signal acquired by the antenna is converted into image points (Ref. 3).

However, a rigorous mathematical model of the imaging process and the electronic signal processing may not be able to reconstruct the entire chain of physical events leading to the image. Therefore, in radargrammetry supplementary interpolative methods, which use geometric ground control data, have been developed and are successfully applied when it is required to relate image and object space.

For reviews of the basic radargrammetric principles and existing algorithms for radar image data processing the reader is kindly referred to Refs. 1 and 8.

This paper discusses concepts and methods where radargrammetry substantially contributes to improved utilization of radar imagery and evaluation of specific parameters relevant for radargrammetric applications.

2. APPLICATION ASPECTS

Radargrammetric processing of radar images is required as a preparatory step in a multitude of subsequent applications and as a research object of its own. Among the various radargrammetric aspects the following are of major importance:

- Geographic "referencing" which may result in the computation of ground coordinates from given image coordinates or in the production of a geometrically rectified image, a so-called "radar ortho-image";

To produce simulated imagery of realistic appearance ground truth information, thematic data and speckle noise have to be included in the simulation. All over the world considerable efforts were made to generate comprehensive backscatter data bases for this purpose.

2.2 Radar-Stereoscopy

Many of the aircraft- and satellite radar missions yielded overlapping strips of radar images. Like in photogrammetry, on the one hand stereo-images are useful to improve image interpretation; on the other hand the reconstruction of three-dimensional models of an imaged object by using stereo-evaluation is possible.

For the human interpreter who wants to exploit radar stereo-images visually, stereo-viewability is of basic relevance. The stereo-partners should be similar in image brightness, whereas they have to be different in geometry to show distinct parallaxes for height perception. Stereo-radar data, however, are obtained by illuminating the terrain from at least two different sensor positions, which besides the differences in image geometry, also implies differences in the grey value distribution of the stereo-partners. Therefore, good stereoscopy in terms of its geometric definition in a way conflicts with good stereo-viewability.

A study on radar stereo-viewability with real radar data is presented in Ref. 9. In general, only a limited number of real data sets with varying stereo-configuration is available. Therefore, to support a more comprehensive viewability analysis, stereo-images of arbitrary configurations have been generated by image simulation. Results on this subject are given below and more detailed in Refs. 4 and 6.

Methods to compute object coordinates from radar stereo-image coordinates are reviewed in Refs. 7 and 8. In an operational mode radar stereo-mapping became possible with the employment of computer-controlled photogrammetric instruments, the analytical plotters. For the analytical plotter Kern DSR-1 a software system for mapping from single or stereo-radar images has been described in Ref. 12. It uses rigorous radargrammetric relations for the reconstruction of the orientation of the images within a radar bundle adjustment. Parallax-free stereo-models are obtained by the intersection conditions of homologue image-coordinate measurements. So the analytical plotter can be used for real-time contouring or digitizing of spot heights, polygons or a raster of object points in the stereo-model.

3. RESULTS OF RECENT INVESTIGATIONS

Recent research activities addressed a variety of application topics for radargrammetric processing and analysis (Refs. 6 and 14). Table 1 summarizes some facts on the performed studies.

The data sets available for a thorough radargrammetric assessment of the use and characteristics of SAR in the various geo-scientific fields are rather limited. For the investigations carried out synthetic images were generated by again employing the above mentioned simulation software. These images turned out to be important supplements.

The interpretation of radar imagery is influenced by sensor parameters like elevation angle and flight direction, and target parameters, e.g. the electrical and other physical properties of the imaged objects. There exist no generally approved guide-lines for the optimal sensor parameters with respect to specific applications. Therefore, elevation angle and flight direction have been selected to be the most relevant parameters for more in-depth investigation. Target reflectance and backscatter data have been included for simulation of thematic properties.

3.1 Antenna Elevation Angle

The elevation angle is defined as the angle between a vector from the sensor position to the nadir and the line connecting sensor position and terrain point. Depending on this geometric parameter, in non-flat terrain one has to cope with the characteristic radar effects of foreshortening, layover and shadows. For any type of terrain foreshortening and layover are relatively

Table 1: Test-sites, radar data and study objectives, which yielded the presented results

Test-Site	Radar Data	Procedure Applied	Evaluation of Applicability
Sardegna, Italy	SIR-A, SEASAT	Simulation Rectification	Geologic Information Extraction Stereo-Viewability
Ithaka and Cephallonia, Greece	SIR-A	Simulation Rectification	Derivation of DEM from Radar Stereo-Data Stereo-Viewability
Mt. Shasta, USA	SIR-B	Stereo-Restitution	Derivation of DEM from Radar Stereo-Data
Ötztal, Austria	SAR CV-580	Simulation	Land Snow and Ice Analysis Simulation with Thematic Contents
Leibnitz, Austria	-	Simulation	Land Snow Analysis

3.4 Simulation of Thematic Contents

For the radiometric rectification a homogeneous backscatter model determined by the standard Muhleman function (Ref. 5) has been chosen.

Furthermore, the available simulation algorithm was extended by the introduction of different surface cover types (wet snow, grassland, snow free moraines and rocks) and measured backscattering functions (Ref. 13). For the Ötztal site a thematic map based on aerial photography and ground surveys, which shows the snow coverage on the day of the SAR CV-580 overflight, was available.

In order to demonstrate the difficulties in providing realistic simulations, difference images of the real SAR CV-580 image and the image simulated using thematic backscatter functions were calculated.

3.5 Viewability of Same-Side Stereo-Radar

In Refs. 4 and 6 evaluation results of stereo-viewability for same-side stereo-image pairs were discussed for the test-sites of the Greek islands Cephallonia and Ithaka and of the Italian island Sardegna (cf. Table 1). In both cases a set of simulated radar images with assumed elevation angles ranging from very steep (10 degrees) to very shallow (80 degrees) was used. Without taking into consideration the different surface-cover types, homogeneous backscatter curves were used to obtain similarity in the thematic contents of the stereo-partners.

Each combination of two stereo-partners was judged for its intensity of the stereo-impression by several test-persons and ranked with numbers from 1 (no stereo-fusion) to 10 (excellent stereo-viewability).

Due to the topography of the investigated test-sites intersection angles of up to about 25 degrees were found to be best. For larger intersection angles the difference in the geometric contents of the two images would be too large for a good stereo-impression. In the case of very steep look angles (high amount of overlays) or of very shallow look angles (high amount of shadows) the stereo-fusion is rather poor, even with small intersection angles. For the Greek test-site the elevation angles of the best-ranked image pairs were 70 and 50 degrees respectively, i.e. an intersection angle of 20 degrees. For the Sardegna test-site 55 and 30 degrees respectively, i.e. 25 degrees intersection angle, were best.

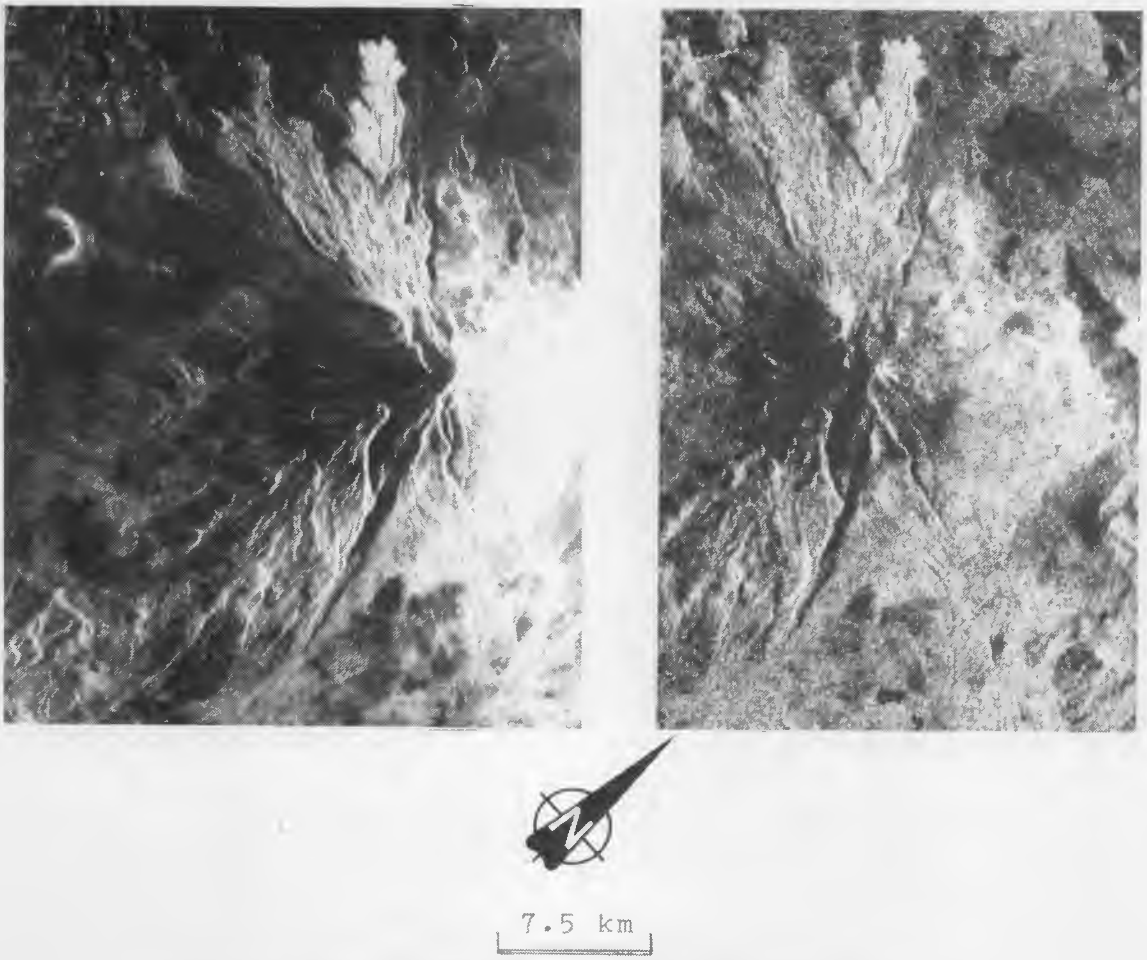

Figure 2: SIR-B radar stereo-pair of Mount Shasta, California, USA, in ground range presentation. Resolution 25 meters, flight altitude 230 km, elevation angles 60 and 29 degrees respectively, wavelength 25 cm. The images are mounted for stereoscopic viewing.

3.6 DEM Derived from Radar Stereo-Pairs

In a case study the software package referenced in section 2.2 was used together with a programm system for DEM generation (GTM package) in a case study to create a digital elevation model of the Mount Shasta test-site (see Table 1) with actual SIR-B satellite radar data. In Figure 2 the stereo-partners used for the study of this area are shown. By means of the stereo-radar software estimations of the restitution accuracy can be made. It amounts to approximately 80 meters in planimetry and some 50 meters in height.

Contour lines and break lines were digitized in real-time and subsequently entered into the GTM program system for interpolation into a height raster. An axonometric view of the generated DEM is shown in Figure 3. Moreover, using the GTM system, a digital elevation model of this very test area was created by scanning the contour lines of the 1 : 62 500 map sheets and additional interpolation of the raster heights. For comparison this DEM is also shown in an axonometric presentation in Figure 4.

As can be seen in Figures 3 and 4, the radar- and the map-derived elevation models correspond very well. In comparison with previous stereo-models of SIR-A radar images of the Greek islands Cephallonia and Ithaka (given in Ref. 12), which were evaluated for a first demonstration of the capabilities of DEM generation with stereo-radar images on the analytical plotter Kern DSR-1, the result is obviously to better. This mainly refers to the kind and quality of data digitized at the stereoplotter. In the SIR-A study polygons (drainage and ridge lines and quality) were digitized with a point density of about one point per square kilometer, while for the SIR-B stereo-model contour lines were selected with a density of digitized terrain points some ten times higher.

4. PROSPECTS

Geometric and radiometric rectification of SLR imagery is a valuable processing step for evaluation and information extraction. The solution of various problems connected with this processing turned out to consume more resources than anticipated, but most investigators have been unaware of these problems.

As shown in this paper, a number of algorithms and procedures have already been developed, most of them, however, still being in an experimental or prototype state. In many cases, where the radargrammetric approach could provide a reliable basis for subsequent investigations, applicability suffers from insufficient accuracy in geometry, navigation parameters or signal processing quality.

At present, besides others, the preparatory program for ERS-1 will catalyze the installation of facilities for operational processing of radar data to deliver high precision products. To meet the requirements of operationality, which also mean a high throughput of products, possibilities to speed-up image rectification procedures need to be identified and materialized. Algorithms, which will dispense a time-consuming involvement of human operators, have to be developed and realized in fully automated processes. Easy and quick access to DEM data bases will essentially improve the procedure's performance.

Operational aspects of radar stereoscopy might also be decisive for future efforts. In this context the possibility to derive DEMs directly from digital radar imagery without analogue processing steps is one of the challenging goals.

On the other hand, the assessment of characteristics and use of SLR image data for various application fields has not yet fully given evidence of the major capability of this remote sensing technology. However, recent research results are conclusively pointing to the fact, that with the availability of sufficiently accurate data its applicability will rise. The effects of the essential radar parameters, for instance those examined from the perspectives of the performed studies, will still need thorough investigations. Until present, many of the study results have been achieved only for one specific test-site, one single data set or one particular sensor system. Hence, extension of expertise in these fields is required and should be subject of further research.

Fortunately, an increasing number of data acquisition concepts takes into account the needs of the geo-scientific community of researchers. Application studies which up till now were only possible with simulated data sets become more and more interesting and important. Within the forthcoming years, e.g., spaceborne radar data of the same site acquired from the Space Shuttle with different elevation angles will become available.

As to the thematic contents of radar images, the existing simulation software has to be improved by including models for variation of geometric resolution and speckle generation. The process should consist of three steps which will be described in the following.

Out of the relative grey values computed from the slant range presentation for each DEM cell derived from the respective incidence angles and backscatter curves, a weighted sum is computed over these grey values corresponding to a particular image pixel. The weight function is a normal distribution in both range and azimuth direction. As a last step speckles are added using specified random number generators.

The result of this process will be an inhanced image simulation that permits one to consider resolution and speckle as parameters in analysis studies.

An effective evaluation of SLR data will require the employment of techniques, which are capable of including in the analysis not only image but also ancillary data from other sources, especially digital maps. Algorithms for automated image correlation, map-to-image correspondence and feature extraction will have to be developed. An increased involvement of adequate image processing techniques will enhance clearness of data contents.

SAR PRODUCT SIMULATION

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ABSTRACT

After a short discussion of the needs for radar simulation, the existing radar product simulators are reviewed. None of the simulators meets all the features required for the study and preparation of an advanced SAR mission. Furthermore, it turns out, that the various types of input data for the simulator characterizing the topography and the backscatter features of the targets are not available with the quality necessary for realistic simulations. The overall frame for a new SAR product simulator is presented. The development of a European RCS data base is recommended. It is also stated, that ESA should initiate in cooperation with EC, the build-up of a DTM for Europe.

This paper represents the summary of a study "SAR product simulation" conducted under ESA contract ESTEC No. 6188/85.

1. INTRODUCTION

Only a future Advanced ERS (AERS) can meet the ambitious expectations of land oriented applications of SAR, due to the fact, that both the technology as well as the fundamental knowledge on the information content of backscattered radar signals are not sufficiently advanced up to date.

Up until now, it is not clear how to specify an "optimal system" for various applications. The user has not yet enough experience to transform his basic interests into properly defined technical specifications. He will only be able to do this on the basis of image products, which show various feasable alternatives and allow in this manner to choose the best compromising versions. Such compromises will be necessary for financial reasons and will concern the geometric and radiometric resolution and the repetition rate, the numbers and types of polarization and frequency channels, the incidence angles and the illumination geometry.

As all these questions can only be answered by considering the consequences, i.e. the final products, the contained information, the benefits and shortcomings, it is necessary to show such products to many different users and for many mission alternatives. The users can reflect on the image data from the interpretation point of view rather than the technical specifications, which they are based on. This helps to understand the users' needs and to identify constraints for technical designs. The optimal specifications of land missions could then be specified.

Image data can of course, only be gained to the necessary extent by means of product simulation. To some degree, it can be complemented by real products, such as aircraft and shuttle flight images. However, the large number of scenes for the various disciplines, areas and alternative technical parameters cannot be gained by experiments. This would be too expensive as well as extremely time consuming.

2. REVIEW ON SAR PRODUCT SIMULATORS

There are several simulation models documented in the literature. Some years ago, W. MacCandles /1/ prepared a survey of eight such simulators and analysed which parts of an end-to-end data system are covered by these packages; fig. 1. If one assumes that the space and ground data links are properly taken care of by means of high quality PCM-transmission (which was not the case for SEASAT, but will be generally the case in all future missions), then a typical end-to-end product simulator is the RSL/University of Kansas simulator, which is called "RIS" (Radar Image Simulator) in the following.

Another survey was provided by Marconi Research Centre in a study for ESA /2/. It dealt mainly with RIS as a typical product simulator and the Ferranti SARSIM /3/ as a more system oriented one.

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2.6 Sensor Simulator SATSAR

For the early phase design studies of a spaceborne SAR sensor, the SATSAR Fortran program was developed by Braun /11/. It allows to optimize the system design parameters for various criteria and constraints. So, it is not a product simulator, but can only become a subroutine of it.

2.7 Radargrammetry

Due to the sensitive response of radar imaging to the terrain topography, exploitation of the stereo pair images seems to be an interesting topic to be studied for future application. Promising results /12/ have been achieved, in particular by the Graz and the JPL research groups. In the study report /4/, a short review is given concerning the SIMRISA/SIMROSA simulation program of Graz, which allows to study the geometric distortions and the practical use of these simulation programs for single-SAR and stereo-SAR images.

3. END-TO-END-PRODUCT SIMULATOR

Fig. 5 shows the general structure of an end-to-end product simulator, which meets all the requirements requested for the AERS-preparatory activities. It shows three data blocks for the flight data, sensor data and target data respectively. In the study /4/, the interdependencies between them and their segments is discussed and used for the definition of the individual tasks of the set of programs required to build-up the general purpose simulation software. It should be applicable to

- satellite-mounted and air-borne radars,
- arbitrary radar characteristics and motions,
- a wide range of allowable target inputs.

In the study it became apparent, that it is not only the processor as such, but also the input data, i.e. the geocoded data base, which needs further developments. This will be shortly explained in the following.

4. GEOCODED DATA BASE

The radiometric and geometric properties of simulated SAR images are defined by the backscatter data bases and the digital terrain model (DTM). For this reason, the various elements comprising the input files had to be analysed in the study. In the following, a short review is presented.

4.1 Existing DTM-Data Bases

A DTM describes the features of an area in digital form. It comprises the information of the surface geometry as well as of the codes for land use and other characteristics, such as vegetation canopy, geological and soil parameters, etc.

Very often, the term DTM is used in a more limited way, namely in the sense of the Digital Elevation Model DEM, which contains only the information of the geometric part of the generalized DTM-term from above. We will also use it in the restricted form, because it is in many cases such, that the DEM is assumed to be given as an input to remote sensing and the land use information is to be extracted from the remote sensing data of a mission. Of course in the simulation process, one has to have both the DEM and the land-use data base.

4.1 Digital Elevation Models

There are various programs and activities going on in the construction of digital terrain models. For most countries no DTMs, or for only small fractions of the areas, DTMs exist. For some countries DTMs exist, but are only available to military organisations or to a restricted community. They are very often of modest quality. The build up of a DTM for a large area is expensive. It is in particular, the collection of the digital values of the point coordinates, which is very time consuming. The interpolation process is then relatively easy to perform. Various program packages exist in Europe and elsewhere. However, for the DTM generation of large regions only a few program packages have been used. One of them is SCOP /13/, the Stuttgart Contouring Program, which is implemented at many institutes and for many computers. A review is given in the stuy /4/ about the present state of DTM generation.

From this review, one can conclude that a co-ordinated effort is needed and a harmonisation of the data processing as well.

It would also be necessary, to start a new action, which allows to first generate a DTM for a large area with modest accuracy as a frame and then to complement the data by stepwise improvement of the accuracy for the various countries and regions. Satellites can be used for that purpose (Radargrammetry /8/ and SPOT and the Metric Camera) in combination with high flying aircrafts.

DTMs are not only needed for the future remote sensing program of ESA, but are as important for many other purposes. They should be at least of great interest to the European Community and to national organisations. It is therefore, recommended to start a co-ordinated action of ESA and the EC in this direction.

4.2 Backscatter Data Base

The electromagnetic presentation of target parameters is very often described by the term "backscatter data base" or the signature catalogue. Such signatures are the radar cross sections RCS of the targets or the normalized backscatter data.

A careful analysis of imaging and non-imaging scatterometer data indicates, that the statistical distribution of the RCS values is not "just noise like". This means, that higher moments of the RCS itself are significant in the electromagnetic characterisation of the targets. Only recently, various experimentors started to include these statistical parameters into the evaluation.

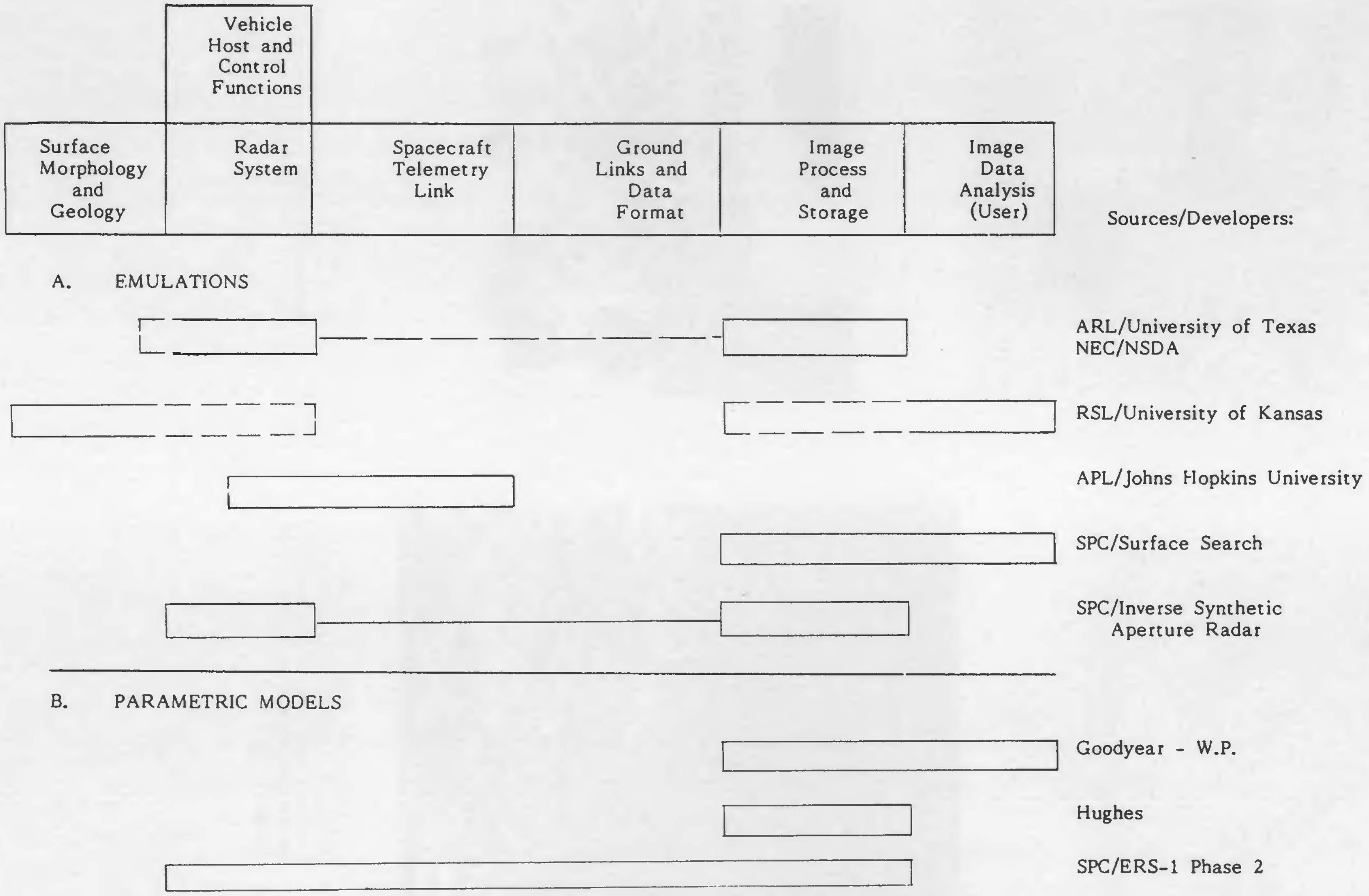

Figure 1: End-to-end SAR data system functions (McCandles, 1983)

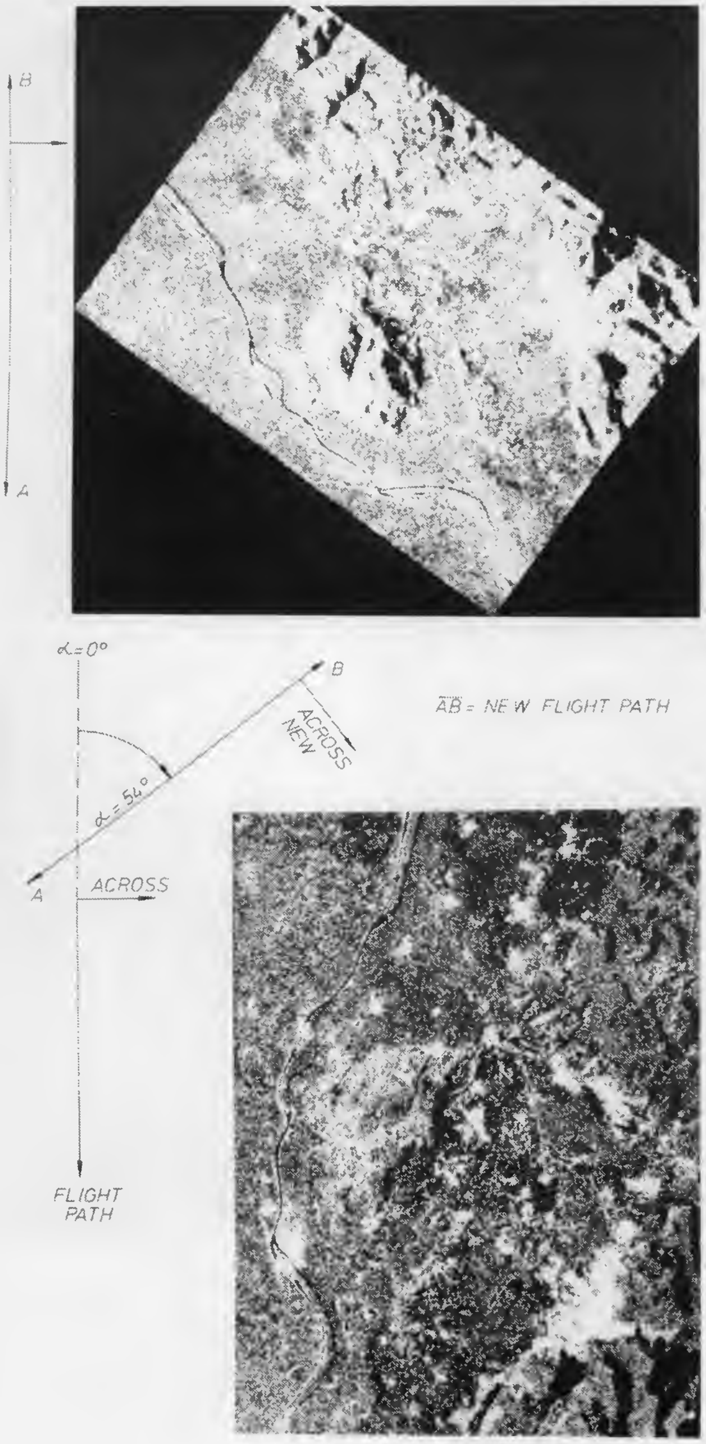

Figure 4: KU Upgrade DFVLR /INS; Imaging at arbitrary heading angle.

STUDY OF THE POTENTIAL OF SAR FOR CROP IDENTIFICATION AND MONITORING

presented by Thuy LE TOAN

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ABSTRACT :

In the framework of the ESA contract 6153/NL/MS, investigations have been done in order to evaluate SAR data for some specific applications in agriculture.

This paper presents a summary of the present results obtained.

Keywords : SAR - crop classification - crop monitoring.

INTRODUCTION

Today agricultural information system is expected to be improved by the use of remote sensing techniques in the following main objectives :

- **early acreage determination of the main crops,**
- **early yield prediction,**
- **evaluation of the effects of crop stresses and quantification of the effects of disasters.**

In summary, early identification of vegetation covers and timely monitoring of vegetation state remain the principal concerns for applications in agriculture. For Europe and many other parts of the world, radar systems are the only sensors which can provide adequate temporal coverage in a reliable manner.

The objective of this study is to investigate :

1) the capability of the physical content of SAR data to provide estimators for vegetation cover classification and for extraction of useful information needed in monitoring programmes. This will be done by examination of theoretical and experimental results.
2) the validation of some specific results by processing available and suitable SAR images.

PART I : Potential of the physical content of radar data for agriculture

I-1 Theoretical studies :

The first model for vegetation was developed for grass by Peake (1957) who modeled it as a collection of vertical thin cylinders. In 1979 another attempt was made to model vegetation as a collection of sparsely distributed cylinders and discs which may have a specified angular and size distribution (Sedghi and Fung 1979). Further studies on this discrete modeling concept have been carried out using the distorted Born approximation (Lang 1981).

These are single scattering models which can not adequately account for cross polarized backscattering and do not account for the irregular soil vegetation interface.

A different approach assumes that a vegetation layer can be modeled as a continuous random medium characherized by a varying permittivity function (Fung and Fung 1977, Fung 1979, Zuniga et al, 1979, Tsang and Kong 1981). Besides the fact that the model parameters which are the variance and correlation length of the fluctuating permittivity function are difficult to measure, a other disavantage of the continuous medium approach is that multiple incoherent scattering cannot be easily accounted for.

To overcome this difficulty radiative transfer theory has been used along with a scattering phase function computed for a small ellipsoid (Tsang, Kubacsi and Kong, 1981; Karam and Fung, 1983a). The ellipsoid may be specialized into a circular or elliptic disc (Karam and Fung, 1983b) or a thin needle. Then by solving the radiative transfer equation numerically (Tsang and Kong, 1976; Fung and Chen, 1981) or by using the matrix doubling method (Eom and Fung, 1984) it is possible to include an infinite collection of multiple scattering terms and hence provide the best theoretical estimate for cross polarized backscattering.

From the above studies, it was found that vegetation parameters used in the models are not always adequate given that plant geometry is often considered in a simplified manner. In the same order of idea, in most existing models leaves are considered as the only contributors to scattering.

It is clear that a model closer to reality must include adequate consideration of vegetation and soil parameters and this should be based on careful observations in experimental programmes.

From observation, it is also clear that a vegetation layer is intuitively a discrete collection of scatterers rather than a continuous inhomogeneous medium. In addition, it is desirable to considerer scatterers comparable to the incident wavelength and not just in the high or the low frequency limits.

In this report, to study the sensitivity of radar to vegetation parameters, the model developed by Fung and Chen (1985) which completes the one by

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As a conclusion, significant results have already been obtained from scatterometer ground measurements. Optimum radar parameters for specific applications are determined. Temporal responses of a certain number of crops are known. Due to the strong temporal variation of σ° for a given crop multitemporal observations are then necessary for identification purposes. Three or four different dates have been indicated.

Similar results have been obtained at two places concerning the determination of biological parameters such as volumetric water content (and consequently leaf area index). But in order to generalize the results, knowledge of the structural effects must be extended to a greater number of crops and at various climatic conditions. It would then be advisable to conduct ground based scatterometer measurement campaigns at different places. The scatterometers should be intercalibrated and ground data collection should be harmonized.

I.3 Conclusion :

Based on theoretical and experimental results reported to date, two following conclusions can be drawn :

1) Angular, spectral and temporal behaviour of radar backscattering coefficient is affected by changes in canopy geometry and plant water content. Crop classification using multitemporal, multispectral or multipolarisation data is then possible.

2) For plants with such a structure that volume scattering is dominating, σ° can be related to one of the biomass parameter of the plant. Once the condition on the plant structure is well established it is expected that the biomass parameter - which is here the volumetric water content - can be extracted from the values of the radar backscattering coefficient.

The above results need then to be validated on SAR images.

For classification purposes multitemporal SAR data are desired. Complete ground data are also necessary to ensure adequate conditions for supervised classification methods as well as for the understanding of the results.

For extraction of a vegetation parameter, the first step consists in establishing the relationship between σ° derived from SAR images to the selected vegetation parameter. Detailed ground measurements are thus essential.

For these reasons, we have to select a set of SAR images that is accompanied by simultaneous ground data including measurements such as the canopy volumetric water content or leaf area index.

SAR580 data acquired over la Beauce in France on July 23, 1981 are then chosen. Unfortunately, only one flight with X and C bands at polarization HH has been obtained. Potential of SAR images for crop classification will not be fully demonstrated by using these data. Nevertheless, an attempt is made to quantify the performance or a classification method applied on X and C SAR images.

PART II : Investigations on SAR images

II.1. Generalities

Relating SAR image pixel value to the radar backscattering coefficient is not an easy task. Quantitative analysis of SAR image is only possible when SAR system is calibrated and furthermore, speckle and texture on the images must be understood.

II.1.1 Calibration :

The output image value I is related to radar backscattering coefficient as follows :

$$\sigma^\circ = k_1 I$$

where k_1 is an overall system transfer function. In general, k_1 depends on the angle of incidence due to antenna elevation pattern and remains the same for a flight or a digital tape.

Accurate determination of k_1 required knowledge of the whole system from data acquisition preprocessing. Numerous sources of radiometric distortions can be identified :

- SAR data acquisition :
  - transmitter (power, waveform),
  - antenna pointing, gain,
  - platform ground speed and attitude,
  - data digitisation.

- Image processor :
  - processor gain azimuth and gain compression,
  - data projection error,
  - noise : electrical noise, A to D conversion...

II.1.2 Speckle :

Fading is an important problem with radar systems. The effect of the random fluctuations of the return signal observed from an area-extensive target is to produce speckles on the image. If only a single look is obtained at each pixel, the brightness will have a Rayleigh or exponential distribution depending upon the properties of the receiver (linear or square law detection).

To obtain an estimate of the backscattering coefficient for a target type, one can average over the various pixels within the target. Good estimates of the backscattering coefficient are obtained only if enough pixels are averaged.

II.1.3. Texture :

Variations on the scale of the resolution cell are in large part due to the fading of the return signal and are not indicative of actual ground texture.

When the terrain is associated with a texture significantly above the scale of the resolution, averaging a great number backscattering coefficients of the various homogeneous components of the terrain units.

Texture which is produced by spatial inhomogeneities on the order of several resolution cells shows for instance emergent species in a forest adjacent to shadowing. Discrimination by texture is then possible and moreover is less affected by the lack of calibration.

is preferable if one desires to apprehend the slightest difference in radar response of different crops. In this case, the physical content of the information is fully preserved. However, one difficulty can raise from the different angular variations of different surface types. When the incidence range is limited e.g. on spaceborne SAR image the angular variations of the radar backscattering can be considered as constant. On airborne images to identify the same cover types located from near to far range assumes that the angular variations of every cover type are known. This condition is not met at present.

An alternative approach can be used : instead of the radiometric calibration, an equalisation of the pixel values in both azimuth and transversal directions is performed. It assumes that all the cover types within the images have no angular variation and that the mean values computed from any line or column in the image are the same.

II.2.2.1. Training samples :

The training samples have been selected from 29 fields of different types located in a incidence range from 55° to 65°. Figure 6 shows distributions of X and C mean values for the different crop types. It can be seen that the 68% distributions of most crop types (materialized by the cross) cover nearly the whole dynamic range.

Furthermore, the same ranking in radar return is observed at X and C band : increasing responses are found from bare soil to bean, barley, tender wheat, grapeseed, corn and sugar beet. The exception is noted for wheat where the responses are higher at C band for wheat varieties with bearded ears. The explanation of this result is that at incidence angle beyond 55° major contribution to the radar return is that of the vegetation layer in both X and C bands. In this case the responses follow the increase of plant biomass. Bearded ears of wheat with a length of about 6 cm can act as antenna and a resonance effect can be possible.

From the above examination, contribution of C band allows mainly discrimination of different varieties of wheat. The expected result of a classification using X and C bands will not be very demonstrative compared to multitemporal classification. Nevertheless, application of classification methods on these available data will illustrate the methodology use.

From the above sections, it is clear that estimators for agricultural crops in this case should derived from spectral information, as no texture but that of speckles can be observed for a 3 m resolution cell SAR images.

Field-by-field classification is the most desirable, once the segmentation problem solved. Todate segmentation methods applied to SAR images remain a research field and progresses are to be made before their use in an operational manner.

The method presented in the following will consist to filter the image to reduce the effect of speckles, then to apply classification methods to the filtered data.

II.2.2.2 Filtering techniques :

Different filtering methods have been developed and tested on the available SAR 580 image. The efficiency of the method is evaluated first in terms of improvement of the signal to noise ratio for homogeneous areas. Then, an overall choice of the methods will be based on the performance of classification methods applied to filtered images.

The filtering methods are adaptive using two main categories of filters :

- non linear filters applied to non additive, non stationary and non linear noise.
- linear filters applied to additive noise. For multiplicative speckle noise, this hypothesis can be assumed by taking the logarithm of the image before filtering.

The following methods have been used :

- maximum likelihood filter,
- median filter,
- filter using linear local statistics,
- filter using non linear local statistics,
- Wiener filter.

In order to perform a quantitative comparison between the selected filters, 18 parcels (wheat and sugar beet) have been located in the area under study, then the mean and the standard deviation σ have been computed for each field.

The three following filters have been retained : maximum likelihood filter, linear local statistics and non linear local statistics filters. Figures 7 shows the 256 x 256 pixel original image compared to the filtered image. Figure 8 presents the distributions of X and C responses after filtering. A comparison with figure 6 shows that standard deviations of different classes are significantly reduced by filtering.

II.2.2.3 Classification methods :

The training farm including 29 fields is selected. Five classes are finally defined : bare soil, wheat (variety Fidèle), wheat (other varieties), corn, sugar beets.

Maximum likelihood classification is then applied to the filtered image on a pixel by pixel basis. A smoothing method is then performed on the classified image. To the central pixel of a 3 x 3 window is assigned the most frequent class encountered.

From the performance matrix performed on training samples, the following is obtained : 28,8 % resp. 62,2 % of well-classed percent are obtained on non filtered and filtered images. When an a- priori probability is used in maximum likelihood method, the well classed percentage from classification of filtered image is improved to 66%.

Figures 9 and 10 show classification results obtained from non filtered and filtered images.

The conclusion drawn from these results is that a pixel by pixel approach can be used on filtered images. The method should be tested on more adapted image sets, especially on multitemporal data and should be compared with methods combining segmentation and field by field classification.

Relationship between estimated σ° and m_v

σ° of the canopy can be considered as follows :

$$\sigma^\circ \text{ canopy} = \sigma^\circ \text{ vegetation} + \tau\sigma^\circ \text{ soil}$$

where τ is the two way transmission factor of the canopy.

When the soil contribution is negligible compared to the vegetation contribution, σ° canopy $\simeq \sigma^\circ$ vegetation. In most cases, this can be assumed at X band and the angles of incidence of interest (higher than 55°).

When the vegetation contribution results mainly from volume scattering, the cloud model can be applied (Attema and Ulaby, 1976).

$$\sigma^\circ_{\text{canopy}} = A m_v \cos\theta\,(1 - \tau)$$

where A is a constant for a given canopy at given frequency, polarisation and incidence.

$$\tau = e^{-2\alpha . h/\cos\theta}$$

with h = the canopy height
α = the extinction coefficient at given frequency, polarisation and incidence, which depends on the canopy moisture and structure.

Thus, at a given frequency and a given polarisation

$$\sigma^\circ_{\text{canopy}} = A(\theta)\ .\ m_v\ .\ \cos\theta.\ (1 - \tau)$$

The expression can be simplified if $\tau << 1$, then

$$\sigma^\circ_{\text{canopy}} = A(\theta)\ .\ m_v\ .\ \cos\theta$$

To determine the conditions which permit this simplified relation between σ° and m_v, a study is currently performed by the CESR to evaluate the transmission factor of crops. In particular, experimental results on wheat canopies have indicated the following :

- before flowering, τ values at 9 GHz, HH, 40° of incidence are not negligible (typically $\tau = 0.35$ to 0.45). At VV, τ is significantly lower for wheat with vertical structure (typically $\tau = 0.01$).
- after flowering, wheat heads appear to be the main contributors to radar backscatter. The transmission factors of the head layer depend also on the crop variety. Experimental values are typically 0.1 to 0.3.

During the SAR 580 campaign, the canopy volumetric water content has been determined for the following crops : Wheat (varieties Fidèle, Capitole, Anjou), sugar beet, corn, barley, bean, at a training farm. All the cereals were at maturity (after flowering). Thus the volumetric water content used should be the one measured on the head layer.

Current work at CESR consists in studying the transmission factor as a function of the plant structure. The expected result will be a) to specify the conditions which allow the simplified relation between the radar backscatter and the plant volumetric water content, b) to determine the range of the transmission factor values for the main crop types at specific phenological stage. Partial results will be provided in the final report of this project.

It is to be noted that the present state of the art permits only to deal with the direct problem, i.e. relating estimated σ° to a crop parameter in well known conditions. The inverse problem remains an objective for the future.

PRELIMINARY CONCLUSIONS

The aim of this study is to investigate the potential of radars for crop classification and crop monitoring. The conclusions obtained at present are the following:

1) Classification of vegetation covers with SAR data is possible by the use of spectral and, to a lesser extent, textural information. To fully demonstrate this potential for a wide range of cultural and climatic conditions, the following requirements can be identified:

- Adapted SAR data sets must be available. They should be mainly multitemporal, multipolarisation (HH and VV) and/or multifrequency SAR images associated to detailed ground data.
- Progress in processing techniques must be made, in particular in filtering, segmentation methods.

2) Extraction of vegetation parameters is potentially possible. Important investigations are to be developed :

- Theoretical studies should be conducted, based on reliable experimental observations.
- Validation of specific experimental and theoretical results on adequate SAR data. Strong requirements will concerne the radiometric image quality and the relevance of vegetation and soil parameters.

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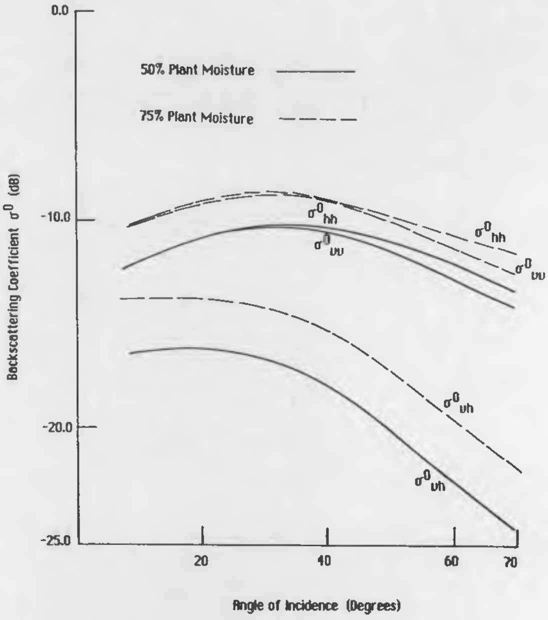


Fig. 2 Effects of change in the plant moisture on the backscattering coefficients σ°_{vv} σ°_{hh} and σ°_{vh}.

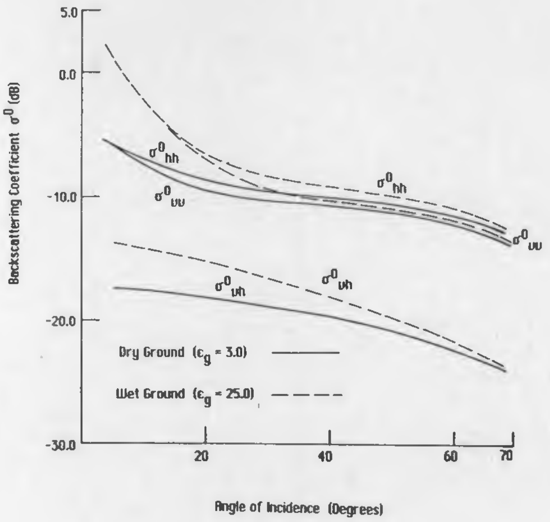


Fig. 3 Effect of soil moisture on radar backscatter

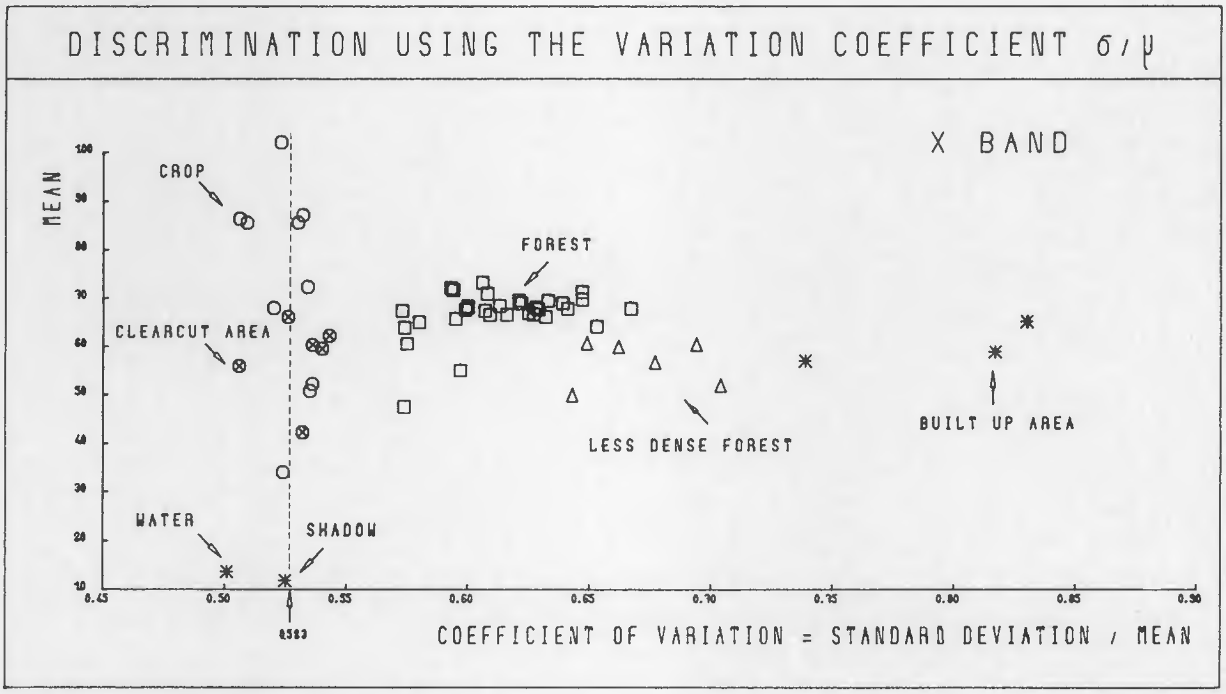
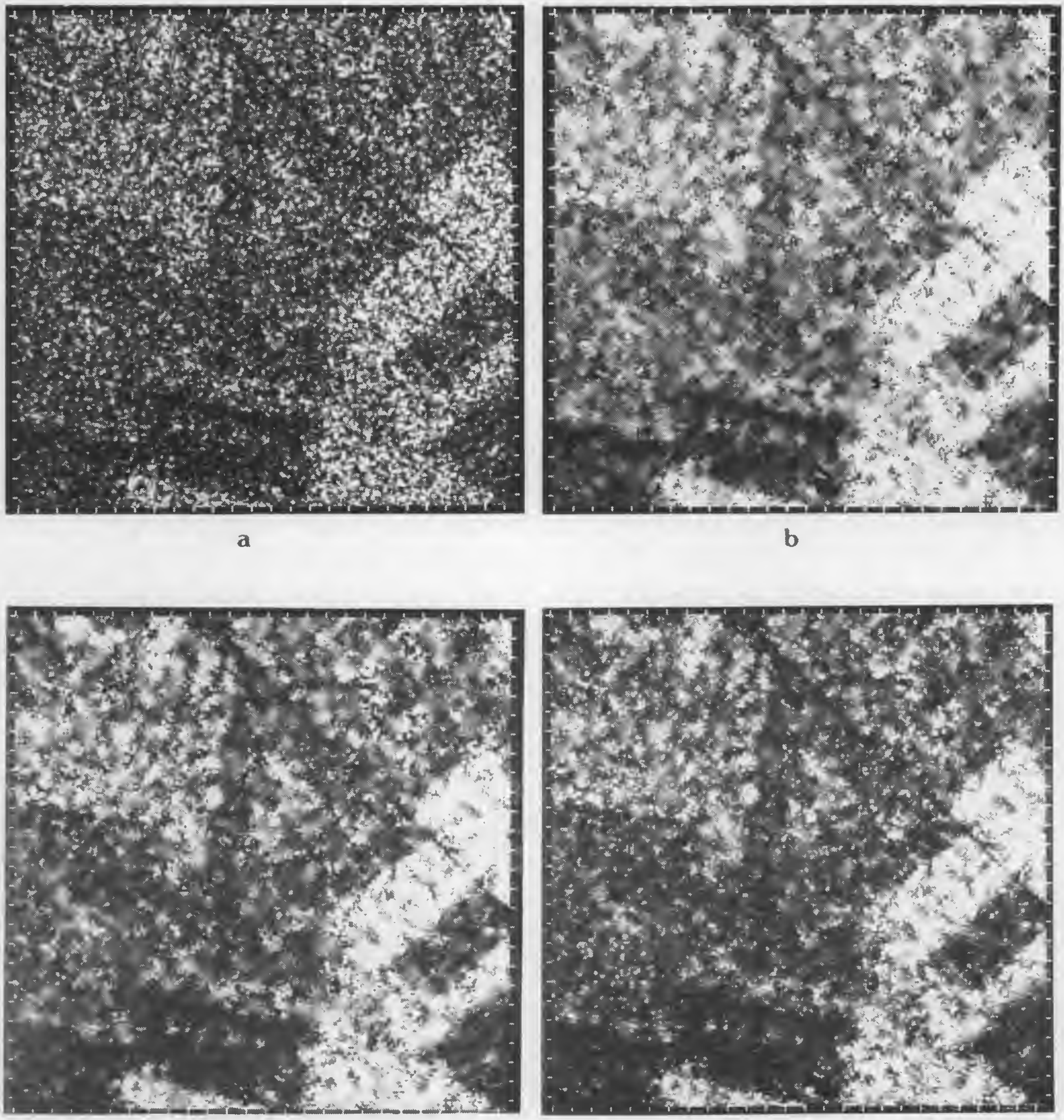


Fig. 4 Discrimination of several cover types using the mean and the coefficient of variation (SAR 580 - X - HH image)



a

b

c

d

Fig. 7 Comparison of original image (7a) and result of filtering by maximum likelihood (7b), linear local statistics (7c), non linear local statistics (7d).

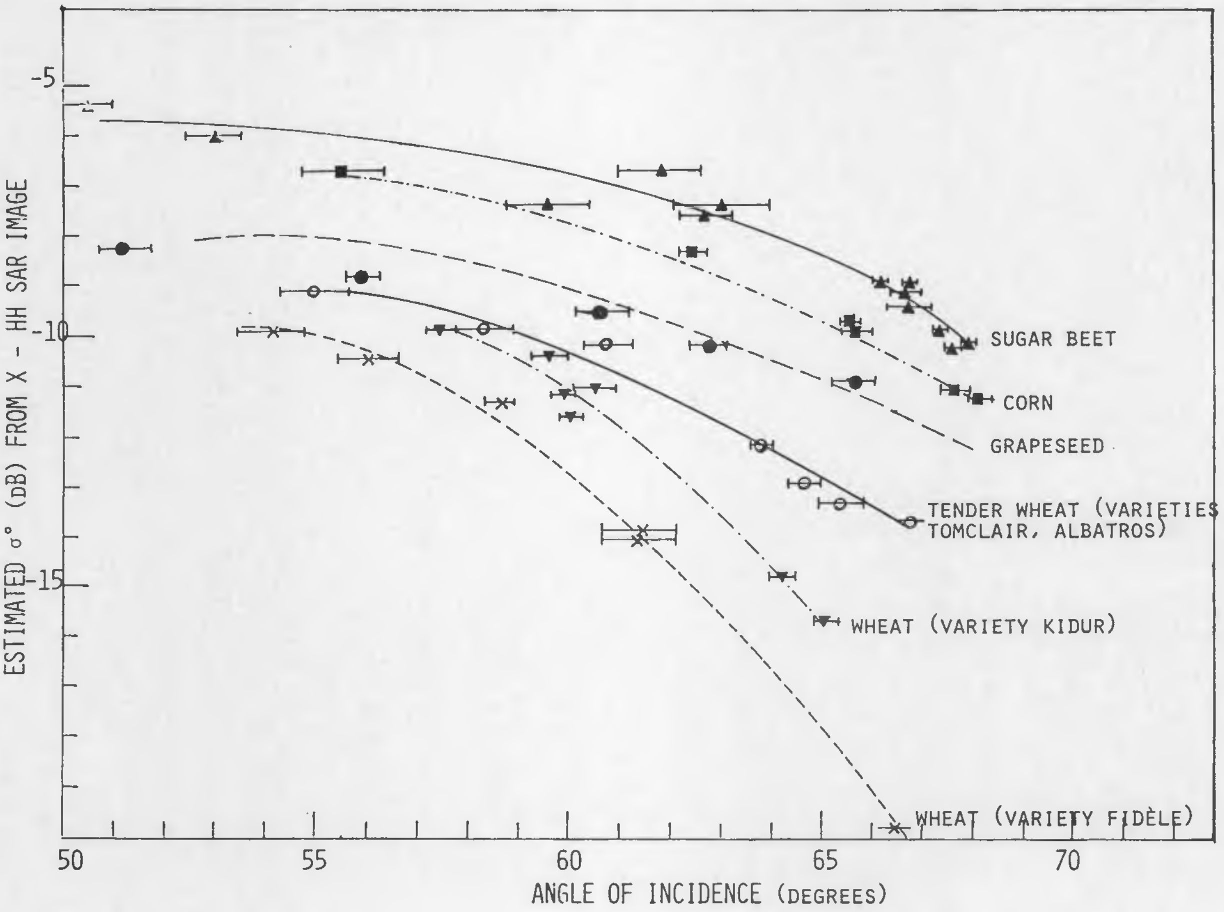


Fig. 12 Responses of the main crop types in the SAR image under study.

SUMMARY OF DISCUSSIONS ON THE PRESENTATIONS

From the discussions which followed the various presentations, some key points are reported hereunder:

1. Land Use - MRC/Huntings

It is stressed that distributed targets lead to Rayleigh distribution for the speckle, and therefore texture can be defined only in terms of departure from this distribution. Various participants (Le Toan, Nuesch) insist on supposed but unclear relationship between radar spatial resolution and identification of texture. In particular, aircraft systems (e.g. 3-m resolution) and spaceborne SAR's (e.g. 25-m resolution) are very different as far as texture is concerned. E. Attema pointed out the difficulty of defining geophysical calibration and the intrinsic relation to modelling.

2. Agriculture - NLR

Ph. Hartl pointed out the accuracy of the segmentation algorithm versus the size of the field. A minimum size in the order of 7-10 ha is required.

Various speakers discussed the interrelation between segmentation and classification and the possible distortion of the information content. The difficulty was mentioned but no definitive conclusion could be drawn at that time.

3. Land Feature Extraction - MRC/Huntings

The importance of comparing with/using Landsat TM data was highlighted.

The minimum number of ground control points used in the study was 10; the most efficient ones were crossing roads. The conclusions reached in the study will depend on the data set used (SAR 580) over flat areas. The comparison was made with existing maps.

4. Polar Ice - TUD

The discussion concerned:

- The fact that speckle filtering implies that the information of which the speckle consists is of no interest (Nuetsch);

- The performance of the speckle filter depends on the filter parameters and the values used in the study (from Frost) which are not the most suitable ones (S. Quegan). Ph. Hartl mentioned studies in DFVLR and ISPRA aimed at improving the performance of the Frost filters.

7. Radargrammetry

The possibility of using DTM data before SAR preprocessing was mentioned (Vidal Madjar), although still at an experimental stage (at JPL).

Stereo effects were under discussion (A. Haskell): it was shown that geometric corrections tend to decrease human stereo information.

8. Geology - University of Munich

The need for L-band or C-band rather than X-band is stressed for geology purposes.

The observation frequency can correspond to one repetition per year.

ROUND TABLE AND WORKSHOP RECOMMENDATIONS

1. INTRODUCTION

The last part of the workshop was devoted to those topics which were addressed in most applications studies, namely: speckle filtering, image segmentation, relief correction (terrain slopes), classification, modelling of earth-microwave interaction and calibration.

Also, preliminary thoughts were given to SAR system parameters for various types of applications.

A large number of people (52) were involved in the discussions so it is not intended to quote each participant but rather to sum up the conclusions at which they arrived.

2. SUMMARY OF THE WORSHOP DISCUSSIONS

2.1 Speckle Filtering

Firstly, it was stressed (S QUEGAN) that performance analysis methods do not exist to compare various filters (e.g. Lee, Frost, etc.) so the interest of speckle filtering is difficult to assess. Moreover, applications are using a cascade of operations (filtering, segmentation, classification) so all the operations are inter-related and more work is needed to validate the whole processing. It is also noted that so far, filter parameter values are guessed rather than derived so any conclusion would be premature.

2.2 Image Segmentation

Again, the lack of procedures to evaluate/compare segmentation algorithms is stressed.

Many speakers pointed out the interest of using external information (e.g. optical data) when available. However, Mrs Le Toan noted that often external information is more or less obsolete (e.g. cadastral data) and therefore their use can prove misleading.

It is clear from the discussion that if the use of the segments is application dependent, the type of segmentation procedure adhered to (e.g. starting or not from edge detection) also has to depend on the application.

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2.6 Desirable SAR System Parameters

Mr K Lenhart presented various tables of desirable parameters versus the applications under consideration. Four typical applications were selected, namely:

a) Inland snow and glaciers
b) Sea and Polar Ice
c) Geology
d) Land use (agriculture and forestry).

For a), b) and d), rather similar requirements exist with respect to frequency range (X-band, 8 to 16 GHz) polarisation incidence angles between 20° to 55° and comparable resolutions. The application geology however requires different frequency (C and L) higher geometric resolutions (10m) and a variable incidence angle. All four applications would require polar orbits because of either global coverage needs or because of the interest in polar regions (cryosphere). The typical swath width requirement ranges from about 150 to 300km. Some of the system requirements appear very demanding, particularly with respect to resolutions (geometric and radiometric), but this evaluation is only the first approach to a definition cycle.

In conclusion, it appears that a dual frequency SAR system (X-band and possibly C-band) with wider swath and variable incidence angles in a polar orbit could satisfy most of the applications.

The four attached tables (Tables 1 to 4) show the specific requirements and related comments.

Mr. Bolle pointed out that such tables are too much instrument design oriented. It would make more sense to specify the practical feasibility of certain applications such as soil moisture.

For Mr Vidal Madjar, tables of this type can be highly misleading as what is desirable tends to be mixed with what is possible from a technology viewpoint.

The discussion clearly showed that such tables have to be considered as indicative of users' needs only and this is exactly what was intended when they were established.

2.7 Calibration

The requirement for absolute calibration was discussed first. For Mr Vidal Mdjar, absolute calibration of spaceborne SAR data is essential in view of comparing to airborne SAR data and also in order to allow for correlation of data from various satellite systems.

For Mr Haskell, geophysical SAR products do not exist so only radiometric and geometric calibrations can be attempted. Mr. Hartl stressed the criticality of the required additional instrumentation (e.g. measure of transmitted power, measure of antenna gain, corners reflectors, etc.) to allow for correlating data from various satellites. His point was to call for international cooperation in that respect.

PARAMETERS FOR A SAR OBSERVING SYSTEM

APPLICATION	INLAND SNOW/GLACIERS		
PARAMETER	Wet Snow (8-15)	Dry Snow (dual)	COMMENTS
FREQUENCY	X	X plus > 18	Detailed frequencies need more study
POLARISATION	HH,VV		Cross polar of interest, but sigma nought very low
INCIDENCE ANGLE	40 - 50		(Higher value for mountainous terrain)
LOOK DIRECTION	-		
SPATIAL RESOLUTION	15-20m		
NUMBER OF LOOKS	1		
RADIOMETRIC RESOLUTION	3dB		For 15 x 15m
PRECISION	Same		
ACCURACY	1dB		Long-term stability required
IMAGE REGISTRATION	200m		High accuracy within image required
RANGE OF SIGMA NOUGHT	-25 to 0dB	-20 to 5dB	(Second value for higher frequency)
COVERAGE: SWATH	300 km		)Wide swath required for high repetition
AREA	Snow covered areas		)rate, high resolution only for selected
FREQUENCY	Varies (1-7 Days)		)areas required
STEREO	Not important		Except for glacier studies
COMPLEMENTARY DATA	High resolution VIS, radiometer altimeter		
IN FLIGHT CALIBRATION	For monitoring long-term stabilities		Ground control programme required
DATA DELIVERY	6-24 Hours		

Table 3

PARAMETERS FOR A SAR OBSERVING SYSTEM

APPLICATION	GEOLOGY	
PARAMETER		COMMENTS
FREQUENCY	C & L (perhaps X)	
POLARISATION	HH, HV	
INCIDENCE ANGLE	20-70 (variable)	
LOOK DIRECTION	Variable	E.g. due to orbit geometry (several passes)
SPATIAL RESOLUTION	10m	
NUMBER OF LOOKS	-	No specific requirements
RADIOMETRIC RESOLUTION	)	) Important is the stability of the system
PRECISION	) 3dB	) during its lifetime
ACCURACY	) 1dB	)
IMAGE REGISTRATION	2 pixels (relative in image) 100-200m	Image to image?
RANGE OF SIGMA NOUGHT	40 dB	
COVERAGE: SWATH	150km	
AREA	WHOLE GLOBE (Land)	
FREQUENCY	Four/year (seasons)	Depending on application several passes
STEREO	Yes	(E.g. by variable incidence angle)
COMPLEMENTARY DATA	VIS + IR sensors	(VIS same aorder of resolution 20 to 10m)
IN FLIGHT CALIBRATION	Not necessary	
DATA DELIVERY	Week(s)	On digital tape, including radargrammetry corrections

Table 4

h) on simulation:

- promote development of a modular SAR product simulator applicable to the various needs of airborne and spaceborne sensors:

i) it is necessary to promote coordinated measurements, through the various European groups, of radar cross sections; collecting the data in an ESA maintained database;

j) - develop cooperation with the EEC and national bodies for identification of DTM sources, existing models and accuracies, and harmonise standards;

- produce high accuracy DTM for test sites.

3.2 Workshop Final Recommendations

At the end of the workshop, the attention of the participants was drawn to the fact that upon ESA request, the delegates of all countries involved with the remote sensing (i.e. Programme Board on Remote Sensing), expressed their interests and priorities, as far as applications of SAR data are concerned.

The analysis of the replies show that studies of applications of SAR data, have to be carried out, in the following order of priority:

- agricultre;
- land use and land feature extraction
- radargrammetry
- SAR product simulation
- sea-ice
- land ice and snow.

These anticipated actions were presented to the workshop participants, who, on the basis of the presentations endorsed the approach.

They insisted on bearing in mind the following key elements:

1) Ensure that any theoretical work is supported by proper measurement campaigns and that conversely, measurement procedures are related to parameters used in models.

2) Develop performance/assessment algorithms to evaluate results from candidate algorithms in the fields of speckle filtering, segmentation and classification.

3) Develop a European data base of scattering coefficients by coordinating the measurement procedures and formats.

4) Ensure collection of new SAR data, particularly at C-band but spanning a large range of frequencies (typically 1 to 90 GHz).

5) Ensure the use of multi sensor data (namely multispectral scanners and SAR's) is properly addressed (e.g. co-registration) and develop multi-sensor analysis tools (classification).

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