ACQUISITION, VALIDATION, SIMULATION, CALIBRATION

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ABSTRACT

A survey of some recent developments in acquisition, validation, simulation, and calibration is made. Particular reference is made to synthetic aperture radar data. The paper refers to the continuing activity of Earthnet at ESRIN. This activity has involved the SEASAT, and European SAR-580 campaign data sets as a test of procedures directed towards the pre-operational ERS-1 radar.

1. INTRODUCTION

The Earthnet Programme Office, at Frascati, Italy, is responsible within the European Space Agency for the acquisition, processing and distribution of remote-sensing data. The problem of controlling, monitoring, and validating data has been anticipated, and methods to implement quality monitoring have been developed for some sensors. Synthetic aperture radar (SAR) data presents special problems. For the ERS-1 satellite, an efficient and effective quality control of the SAR data is being developed.

Two large data sources are available at ESRIN. The first set has been acquired from the SEASAT satellite, having been recorded at the Oakhanger ground station. The second set has resulted from the airborne multifrequency, multipolarization radar belonging to the Canadian Centre for Remote Sensing. The radar is carried by a Convair-580, and is referred to in this paper as SAR-580. These data sources have been utilized to develop some of the techniques described below.

The need to handle image data from many sources has determined that objective properties of the image should be measured when assessing quality. It is preferred that these measurements should use natural features and not specially constructed reflectors, for example, since only then can operational quality control procedures be set up.

This paper describes some of the activities that have been carried out by Ethernet in the field. The paper includes reference to Earthnet associated work on calibration and simulation.

2. ACQUISITION

2.1. The Requirements:

The general requirements for acquisition, recording and archiving of data from a spaceborne SAR, are not different from those imposed by any high data rate sensor, e.g. Landsat thematic mapper. In particular, the requirements are dictated by the attempt to solve the following problems:

a. The high data rate on the downlink from the spacecraft imposes:

  - use of high speed recorders
  - use of high density media.

b. The processing systems, normally incapable of accepting the data stream at the real speed require:

- playback of recorded data at reduced speed
- bit error rate between recording and playback of at least 10^{-6}.

c. The archiving medium and system must offer a guarantee of data preservation in the long term (up to 10 years) with a bit error rate between input and output to the archive of at least 10^{-6}. Depending on the duration of the mission, the archiving system must tackle problems of:

- data volume
- retrieval time
- data quality (monitoring and logging)
- catalogue and data access

2.2. Recording During Acquisition

Data rate in input varies between 118 Mbit/sec (SEASAT), 100 Mbit/sec (ERS-1), 46 Mbit/sec (SIR-B). The other radar missions foreseen in the next 10 years (e.g. Radarsat) fall within this range.

Landsat thematic mapper data rate is 85 Mbit/sec. Landsat-3 return beam vidicon camera was 45 Mbit/sec.

High density digital recorders (HDDR) have been the solution to remote sensing data acquisition since the start of the Landsat missions.

For the high bit rate instruments, the trend is to use 28 track recorders with error correction, or 42 track recorders (Table 1). The different densitites to be used in recording account for the choice of one or the other solution. Table 2 shows the different relationship between recording speed and playback speed.

Type	28 Track	42 Track
No. of Data Tracks	26	40
Packing Density	28,000 BPI	25,000 BPI
Error Correcting	NO	YES
Overhead (related to electronics input and error correction)	3%	23%
(Nom. Max. Data Rate (120IPS)	84.8 Mbit/sec	97.6 Mbit/sec
Nom. Min. Data Rate (3.75IPS)	2.7 Mbit/sec	3.0 Mbit/sec
Ext. Max. Data Rate (150 IPS)	106 Mbit/sec	122 Mbit/sec
Bit Error Rate	10^{-6}	10^{-8}
7200 Ft. Tape: Capacity Playtime (84 Mbit/sec)	 5.6 x 10(10) Bit 11.1 Min.	 6.4 x 10(10) 12.7 Min.
9200 Ft. Tape: Capacity Playtime	7.1 x 10(10) Bit 14.1 Min	6.4 10(10 16.7 Min
Archive Cost (9200 Ft. Tape)	3.7 US$/GBIT	3.1 US$/GBIT
Access Time (12 Min Passage, 84 Mbit/sec)	151 Sec	134 Sec
Relative Mean Time Between Maintenance	0.8	1.02
Relative Mean Time to Maintain	1.04	1.42

Table 1: Comparison of HDDR Configuration

Table 2

Storage Capacity and Input Rates for the Schlumberger 42 Track ML2601 (without error detection and correction).

Track Packing Density KBit/s (KPBI)	Tape Storage Capacity MBits/M	Nominal Input Data Rate MBit/s*	Simulation Reproduction Ability Input Range* MBit/s	Range of Input Data Rate MBit/s++
656	16.6	25.3	70 TO 84	45 TO 105
724	18.4	28.1	77 TO 94	54 TO 118
815	20.7	31.6	87 TO 105	60 TO 132
931	23.7	36.1	99 TO 121	66 TO 154
1087	27.6	42.1	115 TO 140	92 TO 154
1304	33.1	50.5	140 TO 154	109 TO 154
1630	41.4	NOT USED		

The only possible conclusions to date for the acquisition and recording of data is the range of 100 Mbit/sec are:

- recording with high density digital tape recorders does not present any problem from a technologival viewpoint
- recorders with 42 or 28 tracks can be used.

Parameters to be considered are:

- density: 28 track recorders have to work at much higher density. Error correction devices are recommended in order to guarantee the required bit error rate.

- capacity": 42 track recorders will store a larger amount of data. This is influenced anyway by the average and maximum pass duration to be recorded, and by the archiving and playback approach selected (e.g. one pass per tape, data compression, elimination of bad data sets, etc.).

Table 3

ERS-1 HDDR Configuration for SAR

Recorder	Speed	Tape Used (Ft.)	Tapes/Year
42 Track	120IPS	6000 (10 Mins.)	3650

Other more advanced technologies are not envisaged: rotary head recorders (Ampex) do not appear to be ready for operational use. Digital optical discs (Thomson-CSF) in the versions available at present do not have the capacity beyond 1-2 minutes of data, and in the foreseeable future do not seem likely to achieve the required transfer rates (4.1 Mbit/sec at present).

2.3. Playback for Processing

The playback of the data, after initial recording, has to be performed in order to input data to a processing system, either for reformatting or for preprocessing. Current input data rates to processing systems vary between 1 and 10 Mbytes/sec, including the cases where high speed parallel access disc subsystems (CDC, FUJITSU) are used for data input. This means that the recording media used for acquisition has to be played back at reduced speed, or that some demultiplexing of the data, according to some logical scheme (e.g. spectral channel, I/Q) has to be performed in order to input lower data rates on reduced capacity channels.

In the first case, playback speed not lower than a factor 16 of the recording speed is recommended if bit rate is to be kept to the specifications. The presence of an error detection and correction system may allow the limit to be exceeded.

3. VALIDATION

System validation can have two purposes:

i) monitoring of intermediate and final data quality to ensure that the system performs to a specification, and

ii) validating the system capability to derive geophysical data which agrees with measurable ground truth.

Techniques of performance monitoring are reviewed with specific reference to the work on SAR data sets being carried out at the Marconi Research Centre, and at Earthnet, ESRIN. An example of the validation of geophysical data extraction is presented where the technqiue involves correction for the sensor transfer function.

3.1. Techniques for Performance Monitoring

The products from seven processors were assessed using SEASAT data [1]. The assessment was based on:

- point target related measurements
- distributed target related measurements.

Generally, assessment procedures were developed for targets of opportunity, and test sites were not necessarily required.

In the case of point target related measurements, a point target detector was set up to determine features that were point-like. The procedure was not automatic, a local search being made in the neighbourhood of a target determined initially by visual inspection. The detector searches for a high peak-to-background ratio over a local window, which can be adjusted to cope with different image parameters, when a point-like feature passes the detector test, then the target response is interpolated between image points, and measurements of response width, usually between points 3 dB down on the peak, are made in two orthogonal directions. This procedure is now improved to include the full 2-dimensional interpolation around the target. This will often allow sidelobe structure to be discerned close to the main response, further confirmation of the presence of a point target.

For measurements of radiometric resolution, a detector is used to test statistically that an area selected has the characteristics of a uniform distributed target. The detector calculates the rank correlation coefficients between rows and columns of a rectangular area of the distributed target. When the target area is oversampled in the image, nearest neighbour correlations are omitted. The probability distribution of the rank correlation coefficients can be shown to be approximately Gaussian for the number of rows and columns greater than, say, 10, for a distributed target having no discernible structure or correlation. Hence, the test can be used to select the distributed target areas from the chosen areas. Clearly, the form of the test is not unique and alternatives are available.

The distributed target intensities are then used to calculate the quantity:

$$\gamma = 10 \log_{10} \frac{(\mu + \sigma)}{\mu}$$

where μ and σ are the mean and standard deviation of the observed distribution. γ is an estimate of the radiometric resolution, expressed in dBs, of the system.

The SAR-580 data set has been used for further measurements within this facility [2]. With this data, the interest has not been in comparing processing, but in a comparative evaluation of the image quality from the three radars used on the Convair-580.

3.2. Evaluation of Geometric Quality

More recently the problem of the assessment of geometric quality has been considered. The matching of a SAR image to a map presents difficulties because the radar locates a target in a fundamentally different way from a cartographer or optical sensor. In a SAR, systems imperfections can cause subtle, unpredictable and time-varying changes in the image geometry. The aim of this phase was to develop a technique of characterising distortion which embodied the physics of the general SAR system, and provides measures which give insight into the causes of any distortion.

Geometric distortion has three basic causes

i) terrain variation,
ii) uncorrected platform motion and system instability, and
iii) processing algorithms

Much work has been carried out on correcting for terrain effects, and systematic distortion, apparently little on time-dependent distortions.

As the main guiding principle, the range-azimuth image coordinate system provides a natural frame in which to work, and this should be reproduced in the measurment frame to allow range and azimuth effects to be treated separately. In addition, measures of distortion should be insensitive to small operator errors in target location.

The following indicates the main steps in the procedure:-

1. Locate a set of targets, spaced in azimuth, in bands at near and far range of the image, and locate them on a map;

2. Use the near range points to define a mean flight direction;

3. Transform map into coordinate system defined by mean flight direction;

4. Fit the image to map points by local scaling and translation only, at both near and far range in transform image.

Four scale factors are set up which relate to the dimensions of an image pixel at near and far range. These scale factors are used to calculate mean terrain slope, azimuth dependent skew of image lines, and an overall skew, for example.

Software generated to carry out this scheme has been incorporated into the image analysis package at ESRIN.

3.3. Validation of Geophysical Data Evaluation

The mechanism whereby a SAR images ocean waves is a topic of considerable interest (for example [3]). As a consequence of long imaging times for the formation of the synthetic aperture and motion of the sea surface during this interval, the sea image is often confused. Other factors such as resolution effects and coherent speckle can contribute to make extraction of geophysical data, ocean wavelength and direction, more difficult.

In order to provide an experimental tool for the data user, a procedure has been developed by Marconi Research Centre for the analysis of sea images generated by SAR. The theory is well developed [4].

The procedure has been incorporated into a software package which is now installed at ESRIN. The package corrects the image for:

- resolution effects,
- speckle, and
- system modulation transfer function.

The corrections are applied in the frequency domain of the image. After correction the image can be transformed back into the time domain, or measurements can be made on the sea wave spectrum in the frequency domain.

The applied corrections are described briefly. After transforming the image into the frequency domain, because of resolution effects, the spectrum is generally dome shaped. This shape is calculated by reference to an image where no structure is visible. The spectral form is then the static system transfer function, denoted by $Q_o(\underline{k})$.

A version of the function $\tilde{Q}_o(\underline{k})^2$, smoothed to reduce the effects of speckle and noise, is then used to divide the image power spectrum.

The next stage is to determine the mean speckle background, which shows as a flat noise background over the signal spectrum. The speckle is removed by thresholding, but alternatives are being sought.

The final stage, before inversion, is to correct for the dynamic modulation transfer function. This function takes account of the different scattering mechanisms for the SAR, and their dependences on the directional motion of the wave patterns.

Current work involves the comparison and validation of direct sea truth with data extracted from SAR images using the package above. A recent paper [5] provides further examples of the technique.

This example provides an excellent illustration of the need for total validation, where before deriving the geophysical data, full compensation is made for the sensor. The example emphasises the need for users to be fully aware of the sensor imaging process before geophysical measurement from the image.

4. SIMULATION

4.1. Introduction

Simulation is an important aspect of any remote sensing mission, from the early development phase, where simple computer programs can be used to establish basic system parameters, through to post-launch validation exercises, where simulated and real images of terrain can be compared. The simulation can take many forms, from analytic approaches using computer based techniques of varying degrees of complexity, to empirical methods utilizing antennas mounted on towers or aircraft.

In the particular instance of spaceborne synthetic aperture radar systems, there is a need to make potential users aware of the quality of the expected products in order to create a wider market for these products as and when they become available. The SEASAT experiment was a good advertisement for such systems (despite its brief operational life), but differences in altitude and particularly radar frequency precludes use of SEASAT images to demonstrate the products from, say, a C-band satellite system. Aircraft overflights such as the SAR-580 compaign are of importance, but the large discrepancy between the platform heights for aircraft and satellite systems leads to substantial differences in the nature of the two sets of images, primarily due to the range of incidence angles covered by the different systems.

The use of computer based tools therefore appears most attractive, although the approach taken depends on which aspects of the system are of prime interest. Two types of simulation tool can be readily identified: those seeking to model the SAR process, including pulse transmission and reception, the radar subsystem and data processing, and those which simulate typical SAR products directly. A brief discussion concerning each type of simulator is expanded below.

4.2. SAR System Simulation

An end-to-end SAR system simulator aims to faithfully reproduce the entire SAR process, through raw signal generation to the final processed image, in some instances including aspects of data storage and telemetry. The basic theory for such an approach is well known given certain assumptions governing the transmitted waveform and imaged target, but the implementation is by no means a simple task, if only in terms of the massive amount of computer memory and excessive running time a typical simulator consumes. However, if these problems can be overcome, the benefits are severalfold. System simulators can be used to study the effects of variations in radar parameters on image quality, to investigate the tolerance of the system to errors and to test processing algorithms. Furthermore, by generating the raw SAR video corresponding to simple test patterns, the performance of dedicated processing devices can be evaluated. Thus they provide an important analysis tool throughout all the phases of a SAR mission, from early system design and definition, through to pre-launch 'fine tuning' and post launch validation. Several companies have developed such simulators and the programs available from Ferranti, U.K. [6], the University of Texas [7], [8] and Analytic Sciences Corporation, Massachusetts [9] are well established.

The fundamental principle on which system simulators are based is the response of a SAR to a point target within the illuminated swath since, by correct use of such simulated responses, all desired types of target can be represented to some extent. For example, by randomly placing ten or more point scatters in each resolution cell (achieved by phase perturbation), it is possible to simulate the constructive and destructive interference seen as the speckled nature of SAR images of uniform distributed targets.

Taking the European Remote Sensing Satellite, ERS-1, as an example, the system design and definition phase is complete and hence, regarding simulation of the actual radar system, only fine tuning and validation activities may be required. However, processing options such as the use of different weighting functions to trade-off spatial resolution against energy distribution could still be investigated, and the use of simulated data sets to test dedicated processors if of paramount importance. MacDonald, Dettwiler and Associates (MDA) of Canada have produced a set of test procedures for their software SAR processor [10] in which measurements of spatial resolution, radiometric resolution, peak sidelobe levels and image fidelity are made from images of simulated point targets. However, the measurements are not particularly linked to the Phase B ERS-1 SAR image quality specifications given by ESA [11] and a recent study conducted by the Marconi Research Centre for ESA has identified aspects of the processor which are not tested by the MDA procedures [12]. These include flexibility of processing operations, handling of full scenes, arrangement and alignment of image blocks and processor operation with rapid update of reference patterns, together with tests of auxiliary data processing routines (should these be employed). Test data sets for use in assessing the processor performance in these areas have been proposed but their simulation using a program such as SARSIM has still to be verified.

4.3. SAR Product Simulation

The simulation of SAR products, i.e. the simulation of the SAR image and in some cases the image spectrum, is beginning to receive a good deal of attention. The inherent difference between a product simulator and any of the system simulators previously discussed is that, whereas the system simulator aims to accurately model the physical aspects of the SAR image process in order to generate a raw SAR data stream for subsequent processing, the product simulator merely derives a synthetic image for a given area of terrain. To achieve this end, a radar return-power map of the area is constructed (using the standard Radar Equation), speckle is added and an image of the required resolution produced. The most widely publicised program of this type is that available at the University of Kansas ([13], [14], [15]). Such a simulator can incorporate effects due to system parameters such as radar wavelength and look angle but, if aspects such as radar layover and shadowing are to be adequately represented, a highly accurate digital database of terrain coordinates is required, coupled with a reflectivity category (and hence scattering model) for each point in the database. Local incidence angles and backscatter power can then be calculated and realistic simulated scenes can be used to determine optimum system parameters for a particular mission and to develop scene-related processing algorithms. Despite the simplicity of this approach when compared with the system simulators, there is no substantial saving in computer time since local characteristics must be calculated for a large number of regularly spaced points prior to image generation. For adequate modelling of a satellite SAR image (resolution $\sim$ 30 m), the University of Kansas simulator requires a database accurate to 3 m and hence a simulated image of six 18 km square ($\lambda\ 10^6$ pixels spaced at half the resolution distance) requires a database of around 10^8 individual values. Typical run times are therefore of the order of several hours (assuming the database to have already been set up in the correct format).

The Kansas simulator has been used to good effect in developing SAR image processing algorithms, investigating optimum incidence angle and radar frequency configurations for soil moisture determination and in preliminary analysis of target detection and discrimination within SAR scenes. On a more fundamental level, the simulated images can be used to generate interest within the user community (particularly if realistic images of areas covered by other sensors can be produced for comparison) and in training personnel in the interpretation of SAR imges, i.e. recognition of the effects of shadowing and layover and the basic differences between this form of image and a simple photograph.

Returning to the example of ERS-1, there is a need to make potential users aware of the potential of a C-band spaceborne imaging radar particularly in light of the proposed land applications satllite which forms a later mission in the ERS series. However, the problem within Europe is the lack of digitized terrain information comparable to that available in the United States (and on which the current Kansas University simulations are based). The need is, therefore, for a simulation program to develop the necessary digital databases, including classification of the digitized areas into terrain types and the derivation of realistic scattering models. The first area is the domain of cartographers and mapping establishments whilst the latter is the realm of industrial and University research organisations. The area of land classification may be achieved by aerial (photographic) surveys or by use of data from overflight companies such as the Daedelus Airborne Thematic Mapper owned by Hunting Technical Surveys in the U.K. (which has produced very impressive images over areas of Europe and for which land classification algorithms are in existence.) The derivation of C-band scattering models demands a co-ordinated plan, making use of past and future measurement campaigns over Europe, with the empirical measurements being used to validate theoretically-developed models.

5. CALIBRATION

5.1. Introduction

The purpose of this section is to provide, after a short review of techniques applied in the past to the calibration of synthetic aperture radars, some considerations for the organisation of calibration for future SAR missions.

The previous missions considered here are those which have contributed to the formation of European microwave user community: the spaceborne Seasat SAR and the airborne Convair-580 multifrequency, multipolarisation radars. The focus is on digitally recorded and processed data: optically recorded and/or processed data are not suitable for calibration since they are affected by multiple non-linearities. Therefore the SIR-A mission is not discussed here.

5.2. Objectives of Calibration

For a synthetic aperture network the objectives of calibration can be summarized as follows:

1) To restitute, on an absolute scale, an accurate estimate of the backscatter coefficient of the sensed area or target.

2) To restitute, on an absolute scale, an accurate estimate of geophysical parameters which can be derived from the radar data:

   Examples are:

   - Soil moisture
   - Canopy water content
   - Wave number
   - Wave direction
   - Wind speed

3) To allow multitemporal comparisons of measurements/ estimates of both the backscattering coefficient and the derived geophysical parameters.

The third objective stresses the importance, from a user viewpoint, of designing systems which allow an easy and reliable relative calibration of the desired products.

It is important to underline that the purpose of a calibration exercise within the framework of a mission with specific application objectives is not to calibrate the sensor, but, as stated in the above three points, to calibrate a set of well defined products. Calibration of the sensor itself is therefore a necessary step but not the final goal of the activity.

5.3. Review of Two Calibration Exercises

5.3.1. Seasat SAR

Calibration of Seasat was achieved using two aspects:

- the pilot tone, a continuous wave signal in the data stream.
- a set of corner reflectors in the Goldstone area, of various return cross-sections.

In addition, thoughout most of the mission, a sensitivity time control device was employed, which applied a time varying gain to the analogue signal to compensate for the antenna pattern in range.

The pilot tone was not originally intended for calibration, but its use allows compensation of variations in the gain of the analogue data link and of daily variations in the gain of the ground receiving systems (from antennas to digital recorders).

The corner reflectors, carefully selected and distributed over a flat terrain area, had stated calibration objectives (to allow reconstruction of the antenna pattern on the ground, as a function of range), and they have been extensively used for comparison of different digital correlators (which could be called relative calibration to some extent). The parameters analysed in this comparison were related to the impulse response of the system (peak value, 3 dB width, shape of response, sidelobe presence and relative value, peak to background ratio) and were only indirectly useful for calibration [16]. Nevertheless the exercise was important: the present remote sensing environment allows, or forces, the user to collect his data sets from a number of different sources and comparison of data from these sources becomes a difficult exercise if proper parameters have not been defined.

5.3.2. Convair 580 Experiment

This multifrequency/multipolarization radar was flown over 39 European test sites for a total of 190 passes in the summer of 1981, and, at the outset, had ambitious calibration goals.

- A calibration loop had been set up on board based on a calibration signal generator (CALSIG). The signal was inserted into the receiver, and then passed through the data handling chain, to be recorded at the beginning and at the end of each flight both digitally and optically.

- An extensive set of corner reflections (e.g. Figure 1) was deployed on two test sites, which were overflown many times during the whole campaign. These test sites were overflown at different directions and at different heights, with the radar operating in all frequencies and polarizations.

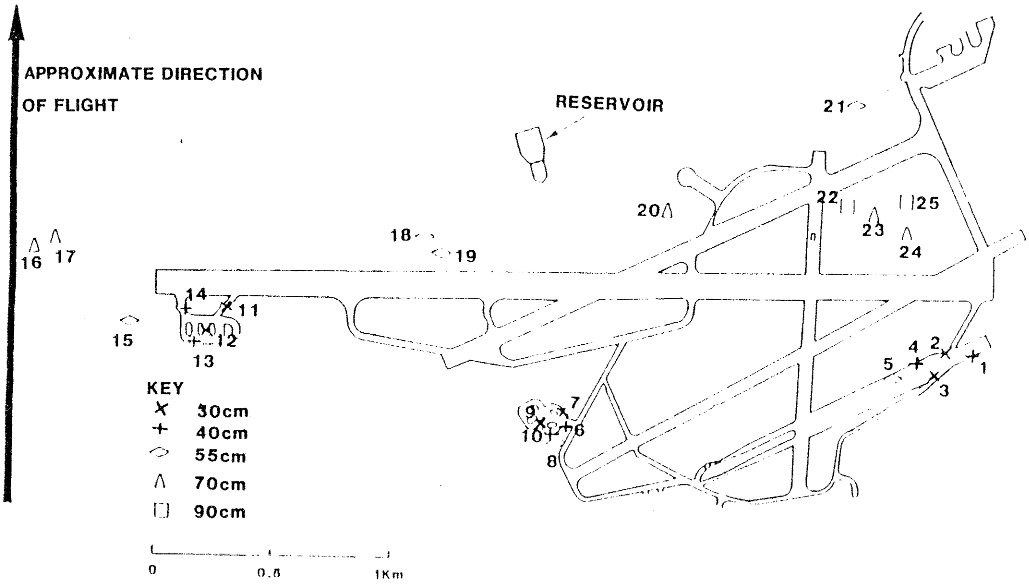

Figure 1: Bedford Calibration Site

- Auxiliary data was recorded on-board on a stripchart; other parameters were reported on log sheets. (The inadequency and inaccuracy of the auxiliary data logging and recording organisation proved to be one of the major drawbacks of the system.)

A small project was run in parallel to the data processing activities in order to assess the achievable extent of calibration, and perform calibration of a restricted data set; the main results were:

- Reconstruction of the antenna pattern from CALSIG data and corner reflector data.

- Definition of a procedure to calibrate a scene in terms of σ_0 (assuming the CALSIG from that scene is available and using the derived antenna pattern).

Figure 2 give examples of the derived antenna pattern. The main result of this activity was the acknowledgement of the problems related to calibration in a practical case, of the methodology to be followed for data collection, and the importance of accurate and reliable auxiliary data.

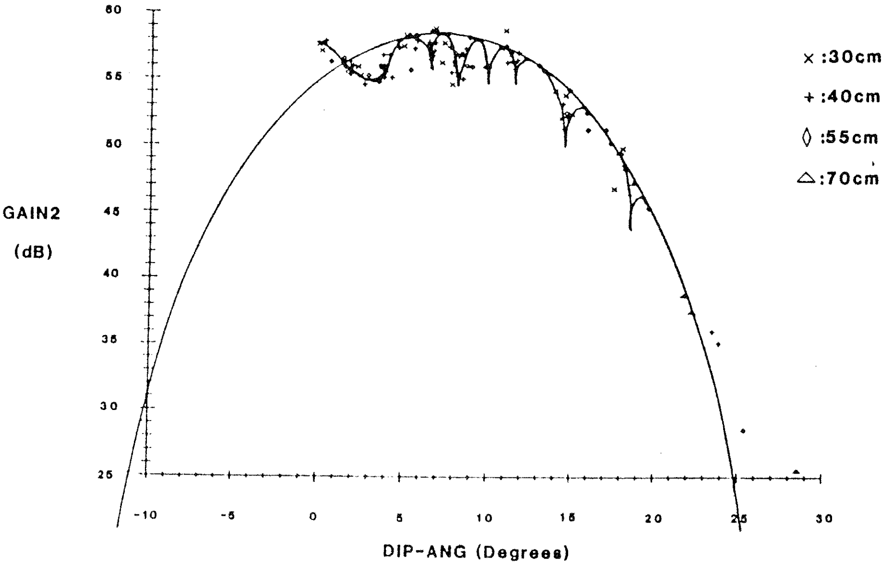

Figure 2: X-Band Data with Fitted Response and Nominal Envelope

5.4. Comments on the above Experiments

The experiments described in the previous section did not achieve, or fully achieve, their calibration objectives. Valuable information was collected during these activities, contributing, if carefully analysed, to the characterisation of parts, or subsystems, of the end-to-end chain.

The analysis of the corner reflectors in [2] and [17] characterises the processor performance.

It is important to decide whether the above results constitute a "calibration" in the sense of Section 1. In general, the answer is "no" - at best, they allow comparison of some scenes where reference signals and/or targets are available.

In both cases, to a different degree, the calibration has been an "a posteriori" exercise. In the CV580 experiment, where more precautions were taken, there was no stated objective in terms of the accuracy and precision of the derived σ_0 value.

5.5. The Calibration Strategy

In order to fulfill the objectives declared in Section 1, and from the discussion of the two cases presented, a set of actions must be undertaken at sensor design level.

1. The objectives must be stated quantitatively.

2. If, in answering point 1, it is established that calibrated products are one of the mission outputs, then the sensor and platform design must be performed accordingly to include recording of all sensor parameters and monitoring of gain variations.

3. The same type of close monitoring of system performance must be performed at the ground stations or processing facilities, including

   - Antenna gains
   - Receiving chain gains
   - BER monitoring during recording and playback from archiving media
   - Saturation conditions at the various steps
   - Processor set-up

All the monitored parameters should be logged or recorded, to be associated with any subsequent operation on the data set.

4. The establishment of "calibration" sites with artificial targets of known characteristics, passive and active, is certainly an important feature, for periodical monitoring of system characteristics.

In order to achieve this some additional steps are required:

5. Data related to backscattering coefficients of natural objects (targets) in a variety of conditions must be collected.

The data can be collected by scatterometers (both airborne and ground-based) and SARs (both airborne and spaceborne). It must, however, be collected in such a way that models can be developed to relate microwave scattering properties to variations in parameters such as frequency, polarization and incidence angle of the transmitted energy. Furthermore, local conditions related to the atmosphere, vegetation or sea state must be accounted for (and recorded).

6. Models must be designed and verified, based on the measurements suggested under point 5.

This set of measurements is by no means easily collected. Therefore a major part of mission planning, coordination, reorganisation will have to deal with the collection and the handling of these data sets. At best, a centralised database will have to be built. The database will accept data from:

- The mission specific SAR system
- The selected sensors (both airborne and spaceborne) used for data collection and model development before and during the mission
- The ground and sea truth campaigns organised before and during the mission
- The on board instruments used for spacecraft and sensor monitoring
- The calibration sites and targets

The database will have to be organised well in advance and will have to set standards for data collection and formatting throughout the mission preparation and operation.

The database must allow temporal and geophysical referencing of the data sets, and will have to include the most recent model for creating the calibration information.

Examples of such databases do not exist. Their use in the global calibration of a sensor has been proposed. Their structure should resemble those proposed as "geographical information systems" [18] and "geocoded databases" [19]. The classifications for these databases are described in the references above, and Figure 8 shows two typical structures. Depending on the specific calibration application, some other classifications will have to be considered: target types, coverage type, σ_0 categories, etc.

6. SUMMARY

Problems related to the acquisition, validation, simulation and calibration of remote-sensing data have been considered, with particular reference to synthetic aperture radars. Work in these areas is continuing at the Earthnet Programme Office in Italy as part of the build-up to the ERS-1 mission.

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