AIRBORNE MICROWAVE REMOTE SENSOR CAPABILITIES IN THE NETHERLANDS *

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ABSTRACT

Groundbased scatterometry in The Netherlands has proven to be essential in studying the scattering of microwaves by vegetation and sea. The results of groundbased measurements were among others used for the development of suitable models and for the design of a digital and calibrated airborne X-band SLAR system. Among others the multitemporal crop classification could be demonstrated with this system. There are however some limitations set to the groundbased measurements. The limitations led in the 1980's to the design and the use of the DUTSCAT system. The DUTSCAT is an airborne scatterometer system operating at six frequencies simultaneously between 1 and 18 GHz. The dataset from this system form the basis for the knowledge that is necessary to evaluate new applications in the field of remote sensing. The next step is the development of an airborne polarimetric SAR system in the C-band, called PHARUS The choice of the parameters for this system are based on the experience gained with the previous programs. The frequency used for the PHARUS is the same as for the ERS satellites. This paper will give an overview of the airborne microwave remote sensing capabilities in The Netherlands and some results obtained with these systems.

1 . 0 INTRODUCTION (Krul and de Loor, 1992)

The major advantage of radar over other observation systems is its independence of the weather. Although the absorption of microwaves by the atmosphere increases when going to the higher microwave frequencies, it remains small as compared with the visible and thermal infrared part of the spectrum. At the end of the fifties and in the early sixties in the United Kingdom the Royal Radar Establishment (RRE), now the Royal Signals and Radar Establishment (RSRE), and the Electrical and Musical Instruments (EMI) company developed two Side Looking Airborne Radar (SLAR) systems for the Tactical, Strike, Reconnaissance (TSR-2) aircraft then under development in the United Kingdom. One system, an X-band SLAR, was intended for navigation, the other, a Q-band high resolution system, for reconnaissance purposes. Both systems were flown extensively over the United Kingdom and the Netherlands. Due to the cancellation of the TSR-2 program only some prototypes of the X-band SLAR system were made. The Q-band system came to production: the EMI P391 reconnaissance SLAR. Most of the imagery collected with these two systems was declassified in 1968. One of the prototypes of the EMI X-band SLAR, on loan to the Dutch Department of Water Control, flew in the Netherlands until 1980 and was successfully used in several experiments over land and over sea.

A scatterometer is a non-imaging calibrated radar specially designed to measure accurately the normalized radar cross section (NRCS or σ^0) as a function of incidence angle. The instrument principle of a

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scatterometer is basically the same as of a radar: pulse modulation and frequency modulation for stationary targets and Doppler shift for a continuous wave in the case of moving targets. Ground-based scatterometers are usually of the FM-CW type, since range discrimination is relatively easy to implement, but the isolation between transmitter and receiver needs great care and can be solved by using separate antennas. There are however some limitations set to the ground-based measurements. In the first place the limited number of test sites, secondly the illuminated area in ground-based measurements is relatively small and in some cases even too small and in the third place only X-band or higher frequencies can be used for ground-based systems due to far-field restrictions. The mentioned limitations can be overcome with an airborne instrument.

Synthetic Aperture Radar (SAR) has proven to be an extremely useful tool for air- and spaceborne earth observation. Typical applications are in the fields of geology, environmental monitoring, agriculture, cartography, surveillance, verification, and others. Compared with optical sensors SAR offers the potential of day and night operation, long range performance, and penetration of clouds, fog and dust. Polarimetry, Doppler analysis and interferometry are additional dimensions for target detection, imaging and classification. While the principle of SAR was invented in the early 1950's the final breakthrough occurred in the recent past, driven by the dramatic progress in semiconductor technology. Large bandwidth and digital processing yield geometrical resolution comparable to optical systems. The next SAR generation will incorporate polarimetric active phased array antennas, thus providing high efficiency, reliability, flexibility, and the potential of multi-dimensional signal processing.

2.0 THE X-BAND SLAR SYSTEM (Hoekman, 1990)

The Dutch digital SLAR is a joint development of the Delft University of Technology (TU Delft), the Physics and Electronics Laboratory TNO (TNO-FEL) and the National Aerospace Laboratory (NLR). It is installed in the NLR Metro II laboratory aircraft and operated by the NLR. The SLAR has digital recording facilities for radar and flight data. In 1985, the sampling frequency was changed from 20 MHz to 50 MHz. A 50 MHz sampling frequency is more appropriate considering the receiver bandwidth of 20 MHz and transmitted pulse length of 50 ns. The range resolution of the SLAR improved from 15 to 7.5 m and, as a consequence, the number of independent samples per unit area was doubled. Also an internal calibration circuit was added and the antenna support construction was changed. With a new mechanical antenna support construction, one of two predefined settings of the antenna could be selected. It became possible to keep the antenna in the usual position or to tilt it 17.5° to nadir. With the second option, good image quality was obtained up to ≈65° grazing angle. This is a significant improvement over the 1982 and 1983 images which yielded useful data up to only ≈40°. The total increase of ≈25° resulted from a combined effect of improved range resolution (in 1984) and the antenna tilt to nadir (in 1985). It may have become evident that these modifications had a major impact on the system performance The pulse repetition frequency (PRF) is selectable within a wide range, but normally used at 200 Hz. Decorrelation of the backscatter signal in azimuth (or flight) direction theoretically occurs at approximately 1.0 m intervals (the effective half-antenna length). The nominal speed of flight (relative to the ground) is fixed at 180 knots (92.6 m/s). With a PRF of 200 Hz, a displacement length in azimuth direction of slightly less then 0.5 m between two successive lines follows. Since sampling in azimuth is ample within the decorrelation length, averaging of samples can be considered to be done effectively over the theoretical maximum number of independent samples (i.e. ≈1 per m).The spatial resolution in range direction is ≈7.5 m (corresponding to a system bandwidth of 20 MHz). It can be shown (using the sampling theorem) that a maximum of two independent samples per range resolution length (≈7.5 m) can be obtained when the range signal is adequately sampled. The sampling frequency of 50 MHz, every 3 m in range, is ample to obtain, effectively, the theoretical maximum number of independent samples in range (≈2 per 7.5 m).

During data processing, the samples corresponding to a 7.5 m square area are averaged to form a slant range pixel. The number of independent samples per (slant range) pixel thus becomes ≈15 (≈7.5 in azimuth times ≈2 in slant range). Averaging 15 independent samples theoretically results in a standard deviation of 1.14 dB for the speckle at the logarithmic dB scale for Rayleigh fading homogeneous object. The system transmits horizontally polarized waves and receives the horizontally polarized component of the backscattered signal; hence the system is called HH polarized.

During the period June 1982 to May 1983 another four flights were performed with the system on two selected forested areas in the Netherlands. To study seasonal effects of vegetation structure on radar backscatter and their impact on (multitemporal) classification, the periods in which the vegetation is stable are of principal interest. In forestry these periods are found in winter and in summer. The employment of temporal dependence to obtain multidimensional observations yielded good classification results for the main species (Hoekman 1985). Another interesting forest-related study was performed later (Hoekman 1988). This experiment concerned the extraction of small scale spatial information from a raw SLAR data set. The flight was conducted in July 1985, after the implementation of an internal calibration facility in the X-band SLAR. The information obtained by this internal calibration is used to improve the accuracy of the radar data. The experiment was designed in such a way that the radar was flown perpendicular to the tree row direction. As a result it may be expected that the small scale backscatter signature in azimuth will match the periodic tree row structure in that direction, even when the row spacing is smaller than the spatial resolution of the system. Since the autocorrelation function of a periodic function, in this case the small scale backscatter signature, is also periodic it is expected that the corresponding power density spectrum will have periodic features. A typical example that clearly shows the expected periodicity is reproduced in figure 1. Spectra of this type were found to be characteristic for forest stands that do not have a flat upper surface: in the example, a poplar stand. The relative maxima in the power spectrum are located at multiples of 14 Hz which corresponds with the 6.2 m row spacing.

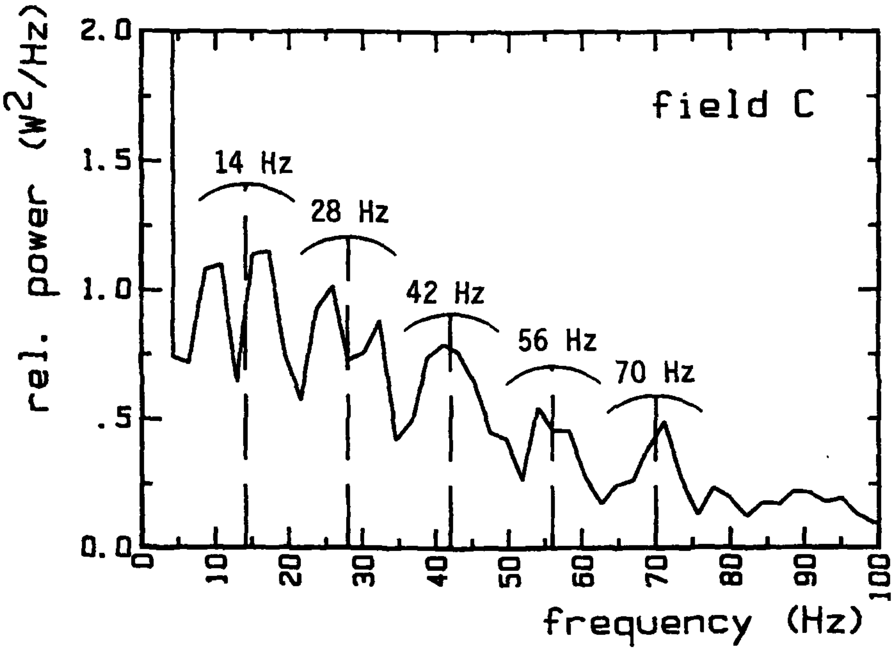

Figure 1. Averaged power density spectrum of popular stand showing row spacing

3 . 0 THE DUTSCAT SYSTEM (Snoeij and Swart, 1987)

Accurate measurements of the radar backscattering coefficient are generally performed with ground-based or near-ground-based (helicopter-borne) systems, and these systems are usually of the FM-CW type. A scatterometer which measures over a wide range of frequencies is known as a spectrometer. Aircraft motion must be used to achieve independent samples. The antenna beamwidth should be narrow to minimize variations in σ^0 and range over the illuminated area or a sufficient range resolution must be used. In the case of an airborne spectrometer operating over a large range of frequencies, a dual-antenna system cannot be used in a small aircraft, this limits also the modulation to the pulse type. A pencil-beam system is preferred over of a fan-beam system, to facilitate measurements of small agricultural fields with a well defined illuminated area. The measurements at all frequencies involved should take place virtually simultaneously to ensure measurements of the same target at different frequencies. To obtain VV- HH and VH- (or HV) polarizations a dual-polarized feed must be used.

The DUTSCAT uses as antenna a single parabolic dish with a dual polarized broadband feed. The diameter of the dish was limited to 0.9 meter due to mounting restrictions under the aircraft. The six operating frequencies are located within the major bands between 1 and 18 GHz allocated for spaceborne remote sensing. The DUTSCAT scatterometer was installed in the Beechcraft Queen Air research aircraft of the National Aerospace Laboratory NLR. The antenna is mounted on a support structure and protected by a radome. In the support structure the RF parts of the radar are mounted. The whole system can be tilted between 0° and 80°, looking to the left. The antenna pointing angle is selected by the operator inside the aircraft.

Figure 2. DUTSCAT system mounted under the Queen Air airplane

The six frequencies are time-multiplexed to increase the isolation between the different transmitters and receivers and to minimize the number of cables between the RF and IF sections. The system operates with a pulse repetition frequency of 78.125 kHz. If six frequencies are selected, ten pulses of frequency one are transmitted. The received signals are digitized by an 8 bits analog-to-digital converter with a sampling rate of 40 MHz and accumulated. After coherent integration the power of the 512 range samples are calculated and the results are placed in a memory. For the next frequency ten pulses are transmitted, until all six frequencies are transmitted. The power samples of a frequency are 256 times accumulated and the results are recorded on tape once every 200 ms. The coherent accumulation is a function of the number of selected frequencies. For six frequencies ten subsequent pulses are averaged and in the case that the system is operated with one frequency 60 subsequent pulses are coherently averaged.

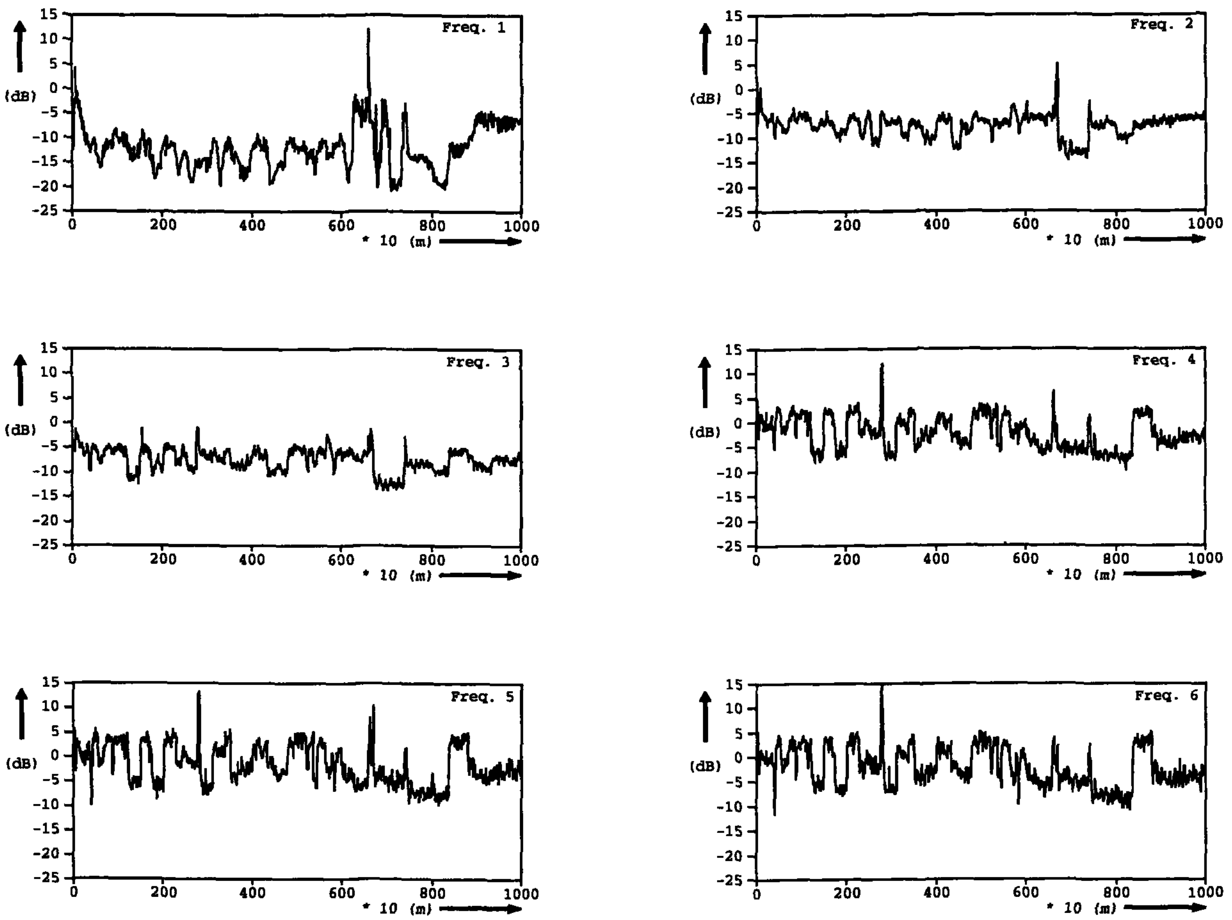

Figure 3. Agriscatt-88, sortie 5, Feltwell area, HH polarization, 40 deg. incidence angle.

In view of the lack of sufficiently comprehensive historical data sets, ESA took the initiative for a series of multi-temporal radar observations using primarily multi-frequency, dual polarization (HH/VV) and multi-incidence angle airborne scatterometers (DUTSCAT and ERASME) and supporting imagery taken by C-band and X-band airborne SAR systems (VARAN-S and IRIS). In analogy with the AGRISAR project, where the emphasis was on imaging radar, this project was named AGRISCATT. It was carried out in 1987 and 1988. The European airborne scatterometer ESA/JRC campaigns Agriscatt-

87 and Agriscatt-88 are preparatory data collection campaigns devoted to land applications as a part of ESA's EOPP. Ground data collection is supported by JRC aiming at standardization of measured parameters and database development to store ground data and absolute σ^0 values (EURACS). During the Agriscatt campaigns a number of test sites in Europe were measured by DUTSCAT. On each test site several tracks were flown with different incidence angle and polarization settings. In total over 4,000 km were measured, with six measurements at different frequencies every 10 meters along-track, a total of more then 2.4 million observations.

The Agriscatt sigma nought values are calculated using a 'standard' processing based on surface scattering. While this processing can be used for the case of agricultural fields it may lead to wrong results for forested areas because of relevant height differences of scatterers in a forest volume. Preliminary results indicate that forest stands, with a large height (30 m), measured at small incidence angles result in higher sigma nought values (1 dB) for the changed processing compared to the standard processing, as expected. An example is given in figure 3 (Snoeij and Swart, 1992)

4 . 0 THE SAR DEMONSTRATION SYSTEM PHARS (Snoeij et. al., 1991)

In the framework of the PHARUS project a SAR research system has been constructed. The system was necessary to study general problems of aircraft SAR and to study the coherent integration processes which in the end determine the system sensitivity. On one hand this research system can be considered as a simple SAR system, with a limited range, on the other hand it is a state of the art technology testbed, designed to test modern technology for the PHARUS system.

The aircraft used for the PHARS system is a Swearingen Metro II, a twin engine business plane, and in use as a laboratory aircraft by the NLR. The aircraft is equipped with various sensors to acquire aircraft attitude and position. Among others an inertial navigation system, using lasergyro's is available.

The second test flight with the research system PHARS resulted in good quality data over a mixed sea/urban/rural area in the surroundings of The Hague in The Netherlands. The measured resolution turned out to be close to 3 m in alongtrack direction and 5 m in crosstrack direction (Hoogeboom et. al., 1992)

After this testflight it was decided to participate in the international ERS-1 calibration/validation campaign carried out off the coast of Norway in the end of 1991. PHARS flew three missions and recorded 14 ocean scenes, from which directional ocean wave spectra were calculated. These spectra were, with good results, compared to spectra that were derived from simultaneous measured data by the the ERS-1 SAR and other radar sensors and by buoys. During later flights, several scenes like the cities of Amsterdam Amersfoort and of the North Sea locks near IJmuiden were recorded. Since then, PHARS has acquired data for many purposes, including bathymetric map production, ship traffic detection, land use and infrastructure mapping, and comparatory studies between PHARS and other systems such as the NASA JPL AIRSAR and the ESA ERS-1.

On February 1, 1995, PHARS was flown over some of the flooded areas in the Netherlands. The image (fig 4) shows the river Waal near Tiel, dark areas indicate water, the width of the river is tripled. Remark the brick works now surrounded by water, the Tiel bridge and the entrance of the Amsterdam-Rhine channel. It was recorded at an altitude of 4300 m, imaging a swath of 6 km, starting at 5700 m range. The image was processed to 6 meter resolution with 6 independent looks. During the flight the weather was cloudy but dry. The extent of the flooding is quite apparent when the radar image is compared to a topographic map.

Figure 4. PHARS image of a flooded area near Tiel, The Netherlands on February 1, 1995.

5.0 THE PHARUS POLARIMETRIC SAR SYSTEM (Snoeij et. al., 1995)

The selected configuration of PHARUS is capable of realizing high resolutions over long ranges in the single polarization mode. In dual and quad polarization (polarimetric) mode, the range is reduced. Alternatively, the resolution can be reduced in any of the modes. The antenna is configured as 2 x 24 elements (elevation x azimuth). A module is composed of a Transmit/Receive (T/R) module, a microstrip patch antenna and both are connected via a ratrace or hybrid ring. Every module can be replaced without disassembling a major part of the antenna. The modules are connected to a combiner/splitter network with the RF-generator, Local Oscillators, mixers, AD-converters etc. The antenna shall have an azimuth scan range of +/- 20^{0} and an elevation scan range of +/- 15^{0}. With a center frequency of 5.3 GHz ($\lambda = 56$ mm) this results in an element spacing of respectively 41 and 44 mm. These are also the cross-section dimensions of the T/R-module. The necessary miniaturization is reached by using MMIC-technology where ever possible. The T/R-module contains two MMIC vector modulators (4 bit amplitude control, 7 bit phase shifter), a 20W (peak) Power Amplifier (PA) and two Low Noise Amplifiers. In the transmit mode, the PA is connected by a diode switch to either the horizontal or the vertical channel, in the receive mode both channels are received and recorded simultaneously. The radiator is a microstrip patch because this is a flat and light weight structure. For a good polarimetric operation a polarization decoupling of at least 20 dB is required. To achieve this, the feeding should be as symmetric as possible. A ratrace (also called hybrid ring) appeared to be the solution to this and some other problems. Using one port of the ratrace, the two patch connectors will receive their signals in phase, the other port results in anti-phase feeding. On the patch this yields two orthogonal fields. The ratrace isolates the ports connected to the T/R-module on a natural way and the same applies for the two connectors to the patch. The ratrace also matches the patch impedance to the 50 Ohm impedance of the T/R-module. Couplers are used to implement a monitor/calibration channel. In the transmit mode a small part is coupled out (about -40 dB) and can be used for monitoring. In the receiving mode a signal can be injected to check both the receiving channels. Mutual coupling of other patches and modules is of no influence because the monitor/calibration port is isolated from the radiator. The two channels of the received analog radar data are digitized at a maximum speed of 100 MHz in 8 bits. The resulting high bitstream cannot be handled by single channel digital circuitry. Therefore the data is split up and treated in parallel. Four presummers are available to process the data of one or two channels. Four output channels are needed in the polarimetric modes, but in single polarization mode only one output channel is needed. To comply with these varying needs, the data streams can be configured as necessary in a matrix switch.

The aircraft which is used for the PHARUS system is a Cessna Citation II, a twin jet engine business plane, and to be used as a laboratory aircraft by the NLR and TU Delft. The aircraft will equipped with various sensors to acquire aircraft attitude and position. Among others an inertial navigation system, using lasergyro's and GPS will be available. This aircraft is much more suited for high resolution SAR imagery due to the high speed, between 150 and 250 m/s, and the maximum altitude of 14 km, which allows large swath widths to be recorded.

Figure 5. The PHARUS system mounted under the Cessna Citation II

The first test flights have so far demonstrated achievements for a number of the design criteria. All four polarimetric channels have been used, and the multi-look resolution goal of 4 m has been reached. One particular aspect that worked according to expectation was the limited pre-summing, resulting in the relatively wide Doppler spectra over the full swath. The Doppler filter needs to be wide because the Doppler centroid is a function of range, due to the fact that the electronic beam steering takes place in a other plane then the aircraft motion. In the near future an extensive test and familiarization program will start, in which PHARUS will be tried at numerous applications, ranging from crop classification to sea bottom topography imaging. Extensions are foreseen toward interferometric capability and higher resolutions.

6 . 0 CONCLUSIONS

Groundbased scatterometry in The Netherlands has proven to be essential in studying the scattering of microwaves by vegetation and sea. The results of groundbased measurements were among others used for the development of suitable models and for the design of a digital and calibrated airborne X-band SLAR system. Among others the multitemporal crop classification could be demonstrated with this system. There are however some limitations set to the groundbased measurements. In the first place the possible number of test fields is limited, therefore the statistical spread of the radarsignature for different fields with the same crop type cannot be investigated. Secondly the illuminated area is relatively small and in some cases even too small, which leads to differences in scatter values between groundbased and airborne measurements. In the third place groundbased scatterometers use normally only X-band or higher frequencies. The mentioned limitations led in the 1980's to the design and the use of the DUTSCAT (Delft University of Technology SCATterometer) system. The DUTSCAT is an airborne scatterometer system operating at six frequencies simultaneously between 1 and 18 GHz. The dataset from this system form the basis for the knowledge that is necessary to evaluate new applications in the field of remote sensing. Apart from studying the behavior of targets as a function of frequency or angle of incidence, the polarization dependence can be studied, which becomes of growing importance as the interest in polarimetry increases. The next step is the development of an airborne polarimetric SAR system in the C-band, called PHARUS (PHased ARray Universal SAR) The choice of the parameters for this system are based on the experience gained with the previous programs. This means that special attention will be paid to the data accuracy. In the end the system will have to deliver radarbackscattermaps: calibrated images with a high level of geometric and radiometric accuracy. The frequency used for the PHARUS is the same as for the ERS-1 satellite. The "universal" aspect of the PHARUS system is found in its twofold application: both military and civil programs in The Netherlands will benefit from it.

7 . 0 REFERENCES

D.H. Hoekman, "Radar backscattering of forest stand'. *International Journal of Remote Sensing*, Vol. 6, pp. 325-345, 1985.

D.H. Hoekman, "Extraction of small-scale spatial information from SLAR raw data of forests through an analysis of speckle, In *International Geoscience and Remote Sensing Symposium on Moving Towards the 21st Century*, edited by T. D. Guyenne and J. J. Hunt, Paris: European Space Agency, SP-284, pp. 1257- 1262, 1988.

D.H. Hoekman, *Radar remote sensing data for applications in forestry*, Ph.D. Thesis, Department of Land Surveying and Remote Sensing, Wageningen Agricultural University, Wageningen, October 1990.

P. Hoogeboom, P. Snoeij, P.J. Koomen and H. Pouwels, "The PHARUS project, results of the definition study including the SAR testbed PHARS", *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 30, No. 4, pp. 723-735, July 1992,

L. Krul and G.P. de Loor, "Experiments with microwave sensors", *International Journal of Remote Sensing*, Vol. 13, Nos. 6 and 7, pp. 1201-1216, 1992.

P. Snoeij and P.J.F. Swart, "The DUT airborne scatterometer", *International Journal of Remote Sensing*, Vol. 8, pp. 1709-1716, 1987.

P. Snoeij, P. Hoogeboom, P.J. Koomen and H. Pouwels, "PHARUS: the design of an airborne polarimetric C-band SAR, results of the definition study including the SAR testbed PHARS", In *Proceedings of CIE 1991 International Conference on Radar (CICR-91)*, Beijing, China, pp. 286-289, 22-24 October 1991.

P. Snoeij and P.J.F. Swart, "Processing and calibration of the DUTSCAT data during the AGRISCATT campaigns", In *Proceedings of the MAESTRO-1/AGRISCATT Final Workshop, Radar Techniques for Forestry and Agricultural Applications*, Noordwijk, The Netherlands, ESA WPP-31, pp. 160-164, 6-7 March 1992.

P. Snoeij, H. Pouwels, P.J. Koomen and P. Hoogeboom, "The PHARUS Airborne SAR concept", In *Proceedings of the European Symposium on Satellite Remote Sensing II, Conference on Synthetic Aperture Radar and Passive Microwave Sensing*, Paris, France, SPIE Vol. 2584, pp. 84-493, 25-28 September 1995.

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