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INTRODUCTION

The European satellite ENVISAT, following the previous ERS-1 and 2 will hold out some new features. Among those, the RA-2 altimeter will work, as previously, at 2 frequencies, but, if the Ku-band will still remain, the C-band will change for the S-band. The OSCAR project [1] concerns the use of the ENVISAT altimeter for exploring the potential of the nadir looking S-band for studying the ice sheet, sea ice, forestry, desert, canopy, hydrology or for planetology applications. The different elements of OSCAR consist in using :

(i) the backscattering as an additional information for studying the scattering mechanisms, for forest and cold regions
(ii) the S-band penetration capacity for sounding medium like snow or forest
(iii) the S-band for in situ terrestrial test of Magellan
(iiii) the dual frequency for ice or hydrology.

Therefore, the OSCAR project proposes to extend altimetry to continental surfaces and intensively exploit the S-band altimeter capacity. The radar altimeter is a strong tool providing topography, nadir looking backscattering, waveform shapes related to surface roughness and medium penetration, and temporal histogram of backscattered energy. While the classical on-board tracking and Ku-band gain yield to a major limitation of altimetric measurements above surfaces with slope up to 0.5, the ENVISAT on-board tracking and S-band antenna pattern gain will allow observations for surfaces slopes up to 3, strongly increasing the potential on continental surface. Moreover, S-band frequencies yields to a better penetration depth in most of the natural medium.

If some topics are quite heuristic, some others like (i) or (ii) are exploratory. Among those topics, the remote sensing of forest canopies by means of radar altimetry represents a new unexplored way at a spatial scale.

The information used up to now in radar remote sensing of forests was the return power related to biophysical vegetation parameters. More recently, radar interferometry has given a new interest, nevertheless, some other difficulties in interpreting the interferometric data arose, linked to the decrease of coherence of the signal, due to the low rigidity of the trees. That is why, space borne radar altimetry applied to forestry should be a new way of investigation and a complementary one of SAR measurements.

In the framework of the OSCAR project (forest sounding studies), we have proposed a remote sensing experiment at a small scale, using the polarimetric helicopter borne radar so-called René over the French Forest "Les Landes", which will take place during the ENVISAT commissioning phase. This paper deals with a presentation of the general scientific objectives, a description of René, the proposed campaign and the signal analysis.

SCIENTIFIC OBJECTIVES

At a global scale, forest ecosystems, which represent approximately 90% of the standing biomass, play an important role in hydrologic and biologic cycling in forests. Monitoring natural and antropogenic changes can have a major impact in understanding exchanges between the Earth surface and atmosphere as well as in surveying the good health of the vegetation. Remote sensing SAR techniques may have the potential of monitoring the forest canopies and possibly inferring important structural parameters, because of their high resolution, all weather day and night operational capability, and sensitivity to vegetation geometry and moisture. However, interpretation of the return signal is not straightforward and the use of a complementary technique such as altimetry could improve structural parameter retrievals.

The altimetric geometrical measurement consists in a signal sampling "in depth" instead of a sampling "in swath" (SAR technique) due to the capability of microwaves to penetrate the forest canopy at S-band, and the altimeter operates as a vertical sounder of the vegetation. In that sense, a space borne altimeter seems a promising tool to investigate the vertical structure of forests at a large scale.

This new way of investigation will be based on the experience already acquired in the domain of altimetric observations of the ocean or the ice sheet in Antarctica. Space borne altimetry was in fact firstly designed to observe the ocean surface and this instrument acts as a powerful tool to estimate the height of the illuminated surface thanks to its high range resolution (about 46 cm in the case of ENVISAT S-band altimeter), but also to quantify backscattering mechanisms at a vertical incidence and provide a temporal histogram of the return energy from the surface and possibly the underlying volume [2-7]. It has been shown, in particular, that analysis of the Antarctica altimetric waveforms can lead to separate the ground echo and the volume echo. Also roughness characteristics at the large scale altimeter footprint can be retrieved , information on surface and volume scattering as well as on wave penetration depth.

The methodology developed for ice sheet studies will be adapted to the analysis of altimetric waveforms acquired over forested areas and will enable us to evaluate the contribution of altimetry techniques in the improvement of forest remote sensing and to estimate the potential interest of using S-band instead of C and or Ku bands.

In that context of study, a CAL / VAL experiment is proposed in order to build a radar nadir looking database at a smaller scale than that of RA-2 for both calibration purposes and validation of the methodology leading to reach the scientific objectives described in the previous paragraph.

A calibration step of the airborne altimeter is important for modeling and inversion process. The validation step will consist in testing and validating the backscattered signal analysis. At a spatial scale, the altimetric waveform is the convolution of three terms, the average flat surface impulse response, the surface elevation probability density function of scattering elements and the radar point-target response [8]. The waveform analysis in order to get the backscattering properties (scattering + attenuation) of the underlying volume in terms of the penetration depth, consists in a deconvolution of the S-band signal by the Ku-band (less capacities of penetration at this frequency). At a small scale of observation such as René scale, the altimetric waveform is directly related to the scattering properties in terms of horizontal successive layers (see Fig.1). A comparison between the deconvolued spatial signal and the René signal will provide a validation test of this inversion technique

RADAR DESIGN AND SIGNAL PROCESSING

The radar system involved during the experiment will be the polarimetric radar René. A polarimetric radar is a radar designed to measure the amplitudes and phases of the electric fields transmitted and scattered along 2 orthogonal polarization. The complex scattering matrix [S] that links the electric fields backscattered by the target with the transmitted one can be derived from radar measurements, leading to the classical radar cross section retrieval in the co and cross-polar configurations as well as phase information used in a polarimetric processing.

Radar Design

René is a FM / CW side looking polarimetric radar. Its main characteristics are summarized on table 1. The signal is successively transmitted on two orthogonal polarization while the backscattered signal is simultaneously received on each of these polarization thanks to two separate receiving channels. The transmitted signal modulation is a saw tooth modulation and is synthesized through a direct numerical synthesis system. Transmitted and received signals are supplied to a mixer and low-pass filter and the resulting video is digitized .A FFT is then applied in real time in order to obtain a complex signal . Flight parameters (pitch and roll) and ancillary data (time and channel of transmission) are simultaneously recorded.

Table1 Main characteristics of René

René S-band polarimetric radar	
Type	FM/CW
Central frequency	3.2 GHz
Wavelength	9.4 cm
Transmitted power	63 mW
Sweep frequency B	200 MHz
Saw tooth period	3 ms
Frequency-range relationship	509.1 Hz/m
Antennas	
Transmitting antenna (H or V) 3 dB beam width	60°
Cross polarization isolation	30 dB
Gain	10 dB +/- 0.1
Cross polarization isolation	30 dB
Receiving antenna (H or V) 3 dB beam width	10°
Gain	20 dB +/- 0.2
Flight characteristics	Helicopter
Flight altitude	300m
Incidence angle	0° up to 80°
Signal acquisition	
Digitalization frequency	2 MHz
Frequency resolution	488 Hz
Range resolution	0.96m

The ground resolution varies with the flight altitude and the incidence angle and depends on the range resolution. As a matter of example, for a typical flight altitude of the order of 300 m and a range resolution of the order of 1 m, the ground resolution varies from 11,6 m at 10° of incidence up to 2 m at 80° of incidence, values compatible with the size of the surface to be observed with René (agricultural fields, forest, bare soils, etc…).

Antenna Design

The antenna system includes a dual polarization corrugated horn (60° at 3 dB) as transmitting antenna and one dual polarized parabolic receiving antenna (10° at 3 dB). These apertures lead to a swath width of about 100 m for an average flight altitude of 300 m. Obviously, the swath width can be modified by changing the flight altitude in order to be compatible with the observed surface inhomogeneities and the resolution of space borne instruments.

Calibration and Signal processing

Very precise calibration measurements are required in order to estimate with a great accuracy the amplitude and phase distortions that inevitably occurs in the transmitting and receiving chains. This point is of great importance for the polarimetric signal post processing [9]. Calibration measurements are conducted from the helicopter, following a classical procedure of flight over trihedral and dihedral corner reflectors. In addition, measurements from a tower are also in progress. Because helicopters are unstable, the orientation of the antennas mounted on the helicopter frame may vary significantly during a single measurement of several seconds. That is why, it is needed to correct errors due to pitch, roll and drift angles, either in the case of measurements made on dihedral corner reflectors (for calibration purposes) or on natural surfaces. These corrections are done all along the radar signal processing.

The signal is post processed in two different ways, depending first on the incidence angle, and secondly on the sensed surface.

In the case of side looking observation, the relevant parameters in order to analyze the polarimetric signal backscattered by natural surfaces as agricultural fields, forest or bare soils are the elements of a matrix, so-called the Mueller matrix which can be derived from the scattering matrix in averaging over many independent samples. The matrix elements describe the correlation between co-polarized and cross-polarized responses. The diagonal terms of this matrix are real and simply related to the classical radar cross section in hh, vv, vh and hv polarization. The other terms are complex and useful to study cross-polarization correlation. The polarimetric processing is complex, and will not be described here [9], [10].

In the case of nadir looking observation, which is the main objective of the experiment described in the next section, the signal processing differs from the previous one, because there is no polarization diversity in this case. Either the signal is processed in a classical way, leading to derive the radar cross section, by solving the radar equation, or the waveform are analyzed in terms of parameters related to the geometrical measurements.

EXPERIMENTAL CAMPAIGN AND SIGNAL ANALYSIS

Campaign

The proposed experiment must take place during the commissioning phase of the ENVISAT satellite and involves the small helicopter borne scatterometer, René, operating at S-band in a nadir looking configuration, as mentioned previously. The geometry of the measurement is shown on Fig. 1

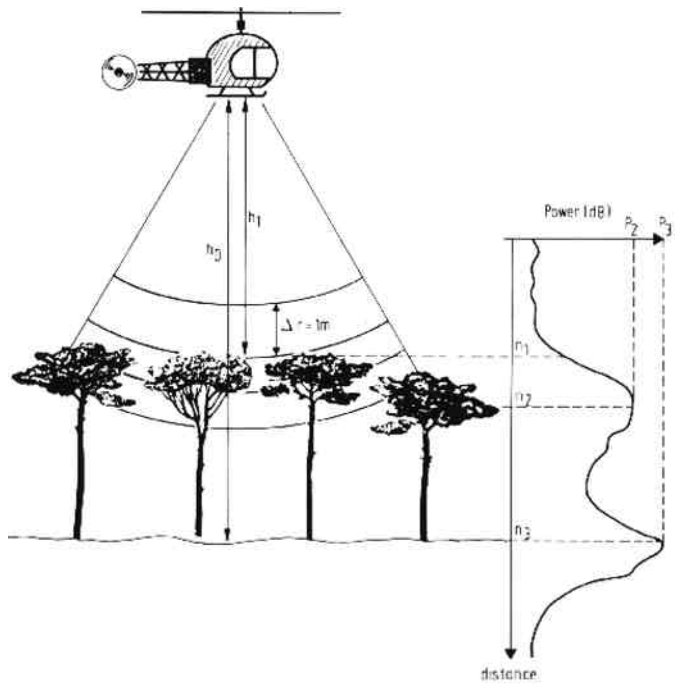

fig. 1 : The René radar is mounted on an helicopter and is looking towards the nadir in an altimeter like configuration. The first vegetation echo occurs in the radar bin n_1 corresponding to the distance h_1 from the radar. The flight altitude is h_0 corresponding to the radar bin n_3

The waveform represents the power return in terms of the radial distance from the radar, and it is roughly composed of two humps. The first echo corresponds to the top of the trees and the first hump to the power backscattered by the vegetation. The second one corresponds to the ground. Each point of the waveform is related to a specific distance from the radar, the distance between two points is about 1 m, corresponding to the range resolution.

The test sites will be located in “Les Landes” forest composed of maritime pine stand, the flight axis will be defined later. Measurement campaigns will be composed of several passes in different directions over the satellite swath. In addition thanks to the angular agility of the radar, several side looking flights are forecasted and will be performed on the same test sites. Comparison between nadir looking and side looking mode measurements will permit to quantify and understand the contribution of each of them. The side looking configuration will enable us to process the signal in a polarimetric way.

The René flights must be conducted at the same time as the RA-2 pass, or a few days before or after, but at the same local time. It can be assumed that structural forest parameters do not vary in that interval of time and that the biophysical parameters are quite the same from one day to another at the same local time.

Simultaneous ground measurement must be obviously carried out during the René campaign in order to build a ground database that will be correlated with the radar database. The parameters to be acquired are of two kinds : structural parameters with a low temporal evolution (height of trees, lengths, diameters, and orientation of branches,…) and parameters with high temporal evolution (branch and leave moisture,…).

Signal Analysis

We briefly describe here the signal analysis we want to carry out, apart from the radar cross section retrieval. An original pattern recognition method to study nadir looking ranging scatterometer observations over forests has been developed in the recent past [11]. The main objective was to propose a method of classification based on the study of the waveform shapes. A possible aim of this study is to detect how many significant classes of waveforms are prevent within a forest like "Les Landes". So, an helicopter borne sounding radar, coupled with such an a posteriori signal processing method, could provide an automatic diagnostic tool for forest monitoring The method will be first validated on this new database. In addition, we hope to apply this new methodology to spatial altimetric data. For example, comparison between typical waveforms corresponding to the classes present in a given forest and actual measurements would lead to a fast large scale detection of unusual terrain, like deforested or clear cut areas, expanding tree sicknesses, non typical low density areas, etc…

On the other hand, the waveforms provides a description as explicit as possible of the terrain observed, and several waveform characteristics will be derived and related to the vertical structure of the vegetation. One of the straightforward application is the tree height measurements [12]. Methods derived from ice sheet studies will be applied. At the end, a comparison between RA-2 and René waveform will be done for the calibration and validation objectives, as previously described.

At the end, a full polarimetric analysis will be performed on side looking radar data, in order to exploit the polarimetric capabilities of René and get more insight in the microwave remote sensing of forest.

CONCLUSION

We have proposed in the frameworks of the OSCAR project (forest sounding) and RA-2 ENVISAT calibration and validation a remote sensing experiment over forests by means of a small polarimetric helicopter borne nadir looking radar. At this scale of observation, the waveform provided by René is directly related to the scattering properties of the volume in terms of horizontal successive layers. We really hope that these measurements will help to validate inversion techniques of spatial altimeter data as well as give more insight in the knowledge of microwave scattering mechanisms.

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