THE PYLA'01 EXPERIMENT: FLYING THE NEW RAMSES P-BAND FACILITY

Ph. Paillou
Observatoire Astronomique de Bordeaux, BP 89, 33270 Floirac, France
Tel: +33 5 57 77 61 26 Fax: +33 5 57 77 61 10 E-mail: paillou@observ.u-bordeaux.fr

Ph. Dreuillet
ONERA, 91761 Palaiseau Cedex, France

and the PYLA'01 team

INTRODUCTION

In less than ten years, microwave remote sensing techniques have provided unexpected insights in the Earth surface structure and processes, and triggered the development of entirely new research fields. Using space-borne Synthetic Aperture Radar – SAR (SIR-C/X-SAR, JERS-1, ERS-1/2, RADARSAT), three characteristics of the Earth surface can in principle be observed: the slope (topography), the surface roughness (vegetation, geology, ocean surface), and the dielectric properties (nature of soils, moisture content). Using interferometric techniques, one dynamical parameter, i.e. centimeter-scale displacements of the ground related to subsidence or tectonic movements, can be accessed.

Low frequency SAR (L and P-bands) represent a promising future for remote sensing, since it allows us to investigate the sub-surface down to several meters and penetrates the vegetation cover. In particular, P-band radar can achieve penetration capabilities that could be used for accurate mapping of sub-surface characteristics such as moisture content or geological structures.

The Pyla region near Bordeaux in France was chosen as a suitable laboratory site for fieldwork validation of P-band SAR potentials. ONERA developed a multi-frequency, full polarimetric, and high resolution airborne SAR facility named RAMSES, which disposes of the P-band (435 MHz) since the end of 2000. Several RAMSES flights were performed over the Pyla region during April and May 2001: This experiment was performed within the "low frequency radar working group" set up by CNES and will explore potentials of the low frequency domain for sub-surface moisture detection (Pyla sand dune), biomass evaluation (Nezer forest), mapping of the ocean bathymetry and salinity (basin of Arcachon, estuary of the Gironde), and archaeology (S^t Germain d'Esteuil, Dignac, Moulin du Fâ). A dedicated P-band calibration site was set up in order to fully exploit the polarimetric information.

We present first results of the PYLA'01 airborne campaign. They will be used to promote a future P-band RAMSES flight foreseen in Egypt for the end of 2003, which will validate potentials of low frequency SAR in an arid context. This work should in particular lead to innovative Earth observation systems for hydrogeology and sub-surface mapping in desert regions.

THE RAMSES AIRBORNE SAR

RAMSES is an airborne SAR developed by ONERA for several years. It disposes of a wide range of frequencies available (W to P band, cf. Table I), and the P-band is operational since the end of 2000. RAMSES is flying onboard a Transall C160 aircraft which proposes high accuracy GPS for trajectory monitoring (cf. Figure 1).

The P-band operates at 435 MHz using a 1.3 x 0.8 m patch antenna, and is full polarimetric with an incidence angle ranging from 40 to 80 degrees. A high bandwidth of 70 MHz allows a range resolution of 3.5 m, and the emitted power is more than 600 W. Several operation modes are available (direct chirp, deramping chirp, step frequency) and onboard calibration is performed. The P-band capability can be combined to another frequency band such as S, C, or X-band.

Figure 1: The RAMSES SAR (right) flying onboard a Transall C160 (left).

Band	P	L	S	C	X	Ku	Ka	W
Frequency (GHz)	0.435	1.6	3.2	5.3	9.6	14.3	35	95
Bandwidth (MHz)	70	200	300	300	600	300	800	500
Transmit Pol.	V/H	V/H	V/H	V/H	V/H	V/H	V	L/R
Receive Pol.	V/H	V/H	V/H	V/H	V/H	V/H	V	L/R

Table I: Frequency bands available within the RAMSES system.

THE PYLA'01 EXPERIMENT

A multi-purpose test site was chosen in the region of Bordeaux in France (cf. white dots in Figure 2 left). A dedicated calibration site was set up in the Nezer forest, with specific reflectors developed for the P-band (cf. Figure 2 right). Four RAMSES P-band flights were performed during April and May 2001, under good meteorological conditions, corresponding to more than 50 acquisition paths.

Several application fields of low frequency SAR are addressed taking advantages of specific sites: sub-surface moisture detection (Pyla sand dune), biomass evaluation (Nezer forest), mapping of the ocean bathymetry and salinity (basin of Arcachon, estuary of the Gironde), and archaeology (sites of S^{t} Germain d'Esteuil, Dignac, and Le Fâ).

Sub-surface moisture detection

We investigate the penetration capabilities of P-band SAR for the mapping of sub-surface moisture. The experiment site is the Pyla dune, located Southern of the basin of Arcachon, which is a bare sandy area allowing high signal penetration and presenting large sub-surface wet structures (paleosoils) at varying depths. Previous studies conducted with RAMSES L-band data allowed to estimate a radar penetration depth of 4 m by inverting a scattering model for which the sub-surface structure geometric and dielectric properties are determined by GPR data analysis. We expect that a P-band airborne SAR will be able to detect sub-surface moisture down to at least 12 meters. Such capabilities could be applied to the sub-surface mapping of moisture and geological features in desert regions, such as North Africa and Middle East.

Biomass evaluation

The Nezer forest is part of the Landes forest and is located in the South of the basin of Arcachon. It is a well-know test site managed for several years by INRA. Several parcels of pine trees are present and the geometry of trees is accurately measured and described. It has been shown that the correlation between the radar backscattered signal and the forest biomass increases significantly as the radar frequency decreases, low frequency radar being able to estimate larger values of biomass. The combination of high resolution and polarimetry should allow discriminating between various growing stages of pine trees. Large incidence angle RAMSES images will be combined to vertical sounding radar data acquired from helicopter.

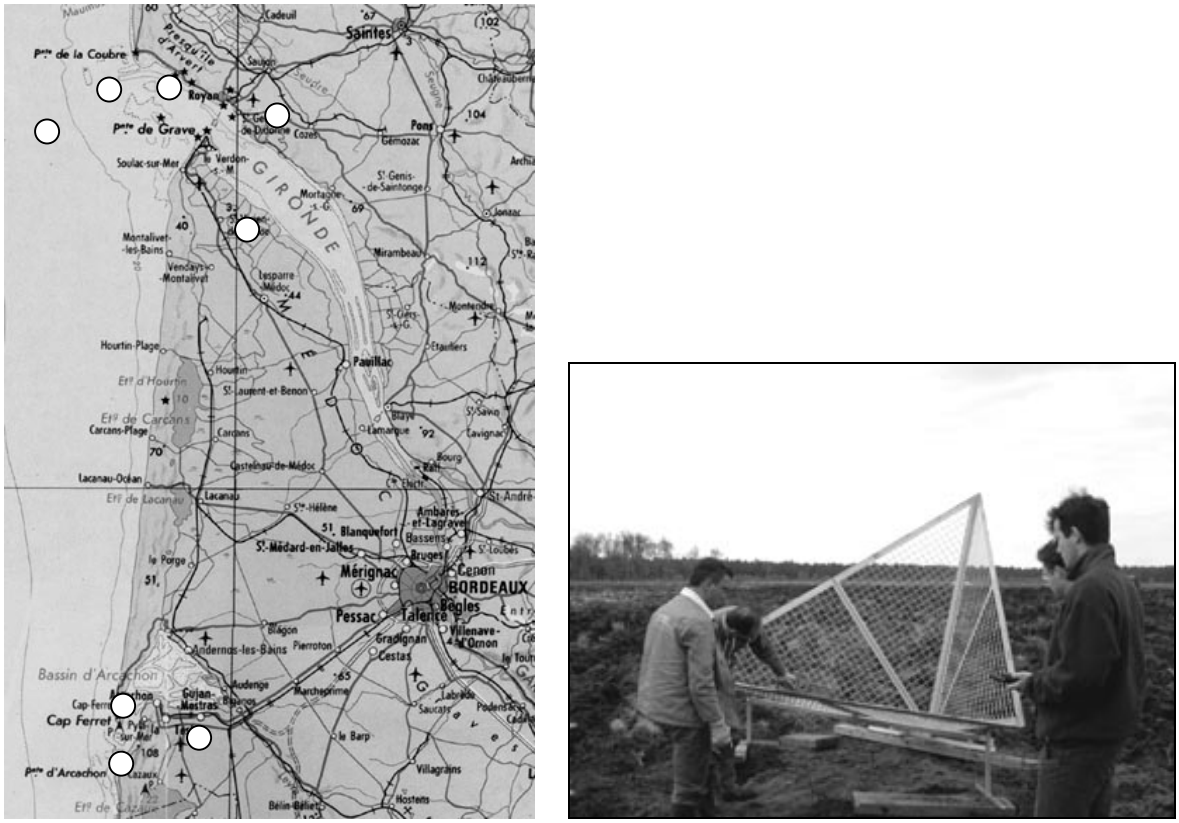

Figure 2: Map of the experiment zone (left) and picture of a P-band reflector (right).

Ocean bathymetry

C-band SAR was used to map the ocean bathymetry near the coasts, taking advantage of the radar sensitivity to surface roughness and using signal inversion techniques. The channel of the basin of Arcachon is an ideal test site for such bathymetry mapping, since it corresponds to a low ocean floor depth and a strong current zone. A low frequency P-band radar should allow to access the lower frequency roughness in order to derive some information strongly correlated to the ocean floor (and less correlated to surface patterns due to wind). We expect to build better bathymetry maps than the ones obtained using C or L-band SAR.

Ocean salinity

The P-band frequency domain is in principle more sensitive to the permittivity gradient due to water salinity changes, and less sensitive to roughness patterns due to wind. We chose to perform RAMSES P-band acquisitions in the estuary of the Gironde, where a high salinity gradient occurs. In situ salinity measurements were performed to allow SAR data calibration, and theoretical modeling of the Gironde plume was performed to define the best acquisition zones. We expect to show that active polarimetric P-band radar can be used to map the water salinity in the coastal regions.

Archaeology

Although penetration capabilities of low frequency radar are higher in arid areas, three bare fields were selected for archeological mapping purposes. The sites of S^{t} Germain d'Esteuil and Dignac in the Northern Medoc, and the so-called Moulin du Fâ site in the Charentes were selected since they present gallo-roman or medieval vestiges at depth ranging between a few centimeters to one meter. Previous geophysical prospecting was performed on these sites, and we dispose of ground truth maps that will guide the interpretation of SAR data. We expect that the combination of high resolution P-band data to the polarimetric capabilities of RAMSES will allow the detection of sub-surface vestiges, leading to archeological applications of low frequency SAR in temperate regions.

PRELIMINARY RESULTS

We present here preliminary results of the PYLA'01 experiment, since a huge amount of data still has to be processed and calibrated. Final results of the airborne campaign are expected for the end of 2002.

Figure 3 presents a P-band quick look (40 MHz bandwidth) of the Pyla sand dune (the dark structure in the middle of the image). The ocean surface is visible on the lower part of the image, while the Landes forest is on the top part of the scene. The quality of the RAMSES data appears to be excellent, with a signal dynamic range of more than 70 dB and very rich polarimetric information.

Figure 3: RAMSES P-band quick look of the Pyla dune.

Figure 4 presents a RAMSES P-band quick look (50 MHz bandwidth) of agricultural fields located near the Moulin du Fâ site in Charentes. Again, the quality of data is very good, with no UHF interferences, and the various types of vegetation covers can be easily discriminated from the large dynamic range of the signal.

Although main results are still to come, the PYLA'01 experiment already proved that the P-band capacity of RAMSES is operational. High resolution, full polarimetric and multi-incidence data can be acquired at 435 MHz, and the French scientific community disposes now of a competitive sensor. As a lot of technical challenges are still to solve for an orbital P-band radar (frequency allocation, ionospheric effects, antenna technology), we believe that an airborne P-band facility will be of first importance for the radar community in the next years. The PYLA'01 experiment was a validation campaign for the RAMSES sensor, and we foresee now to fly the Transall over arid areas in Egypt. Preliminary fieldwork and orbital L-band data studies were performed in order to prepare a P-band RAMSES flight over Egypt by the end of 2003. Several test sites will be selected for various low frequency radar applications: mapping of sub-surface moisture and geology in the Southern Egyptian desert, mapping of vegetation along the Nile, salinity and bathymetry mapping near the Nile estuary, and archeological vestiges detection in the Alexandria and Louxor regions.

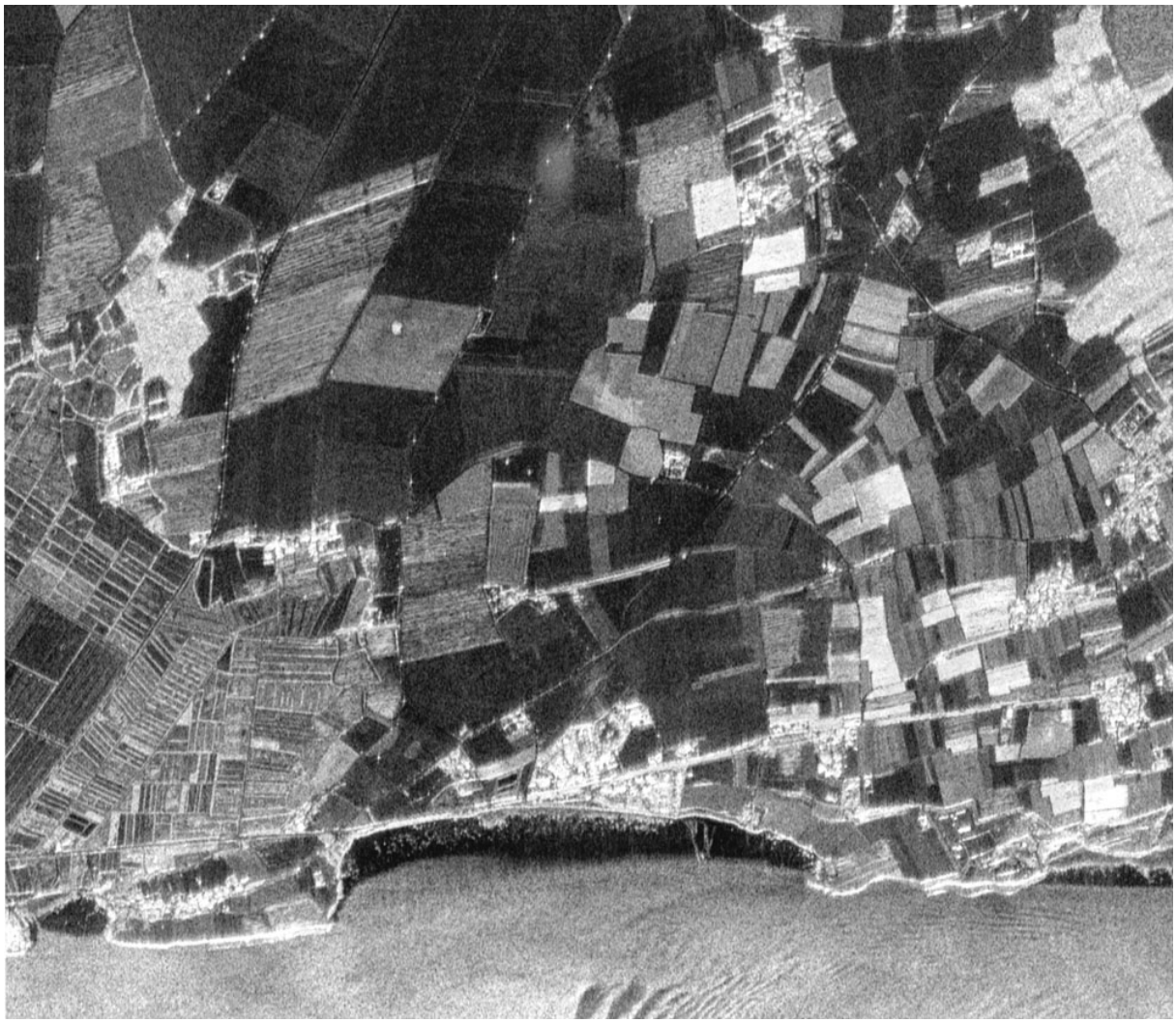

Figure 4: RAMSES P-band quick look of agricultural fields in the Charentes.

REFERENCES

Ph. Paillou, G. Grandjean, J.-M. Malézieux, G. Ruffié, E. Heggy, D. Piponnier, P. Dubois, J. Achache, "Performances of Ground Penetrating Radars in Arid Volcanic Regions: Consequences for Mars Subsurface Exploration", *Geophysical Research Letters*, vol. 28, no. 5, pp. 911-914, 2001.

G. Grandjean, Ph. Paillou, P. Dubois, T. August-Bernex, N. Baghdadi, J. Achache, "Subsurface structures detection by combining L-band polarimetric SAR and GPR data: Example of the Pyla Dune (France)", *IEEE Transactions on Geoscience and Remote Sensing*, vol. 39, no 6, pp. 1245-1258, 2001.

N. Baghdadi, Ph. Paillou, G. Grandjean, P. Dubois, M. Davidson, "Relationship between profile length and roughness parameters for natural surfaces", *International Journal of Remote Sensing*, vol. 21, no 17, pp. 3375-3381, 2000.

G. Grandjean, Ph. Paillou, Ph. Dreuillet, P. Dubois, J.-C. Souyris, N. Baghdadi, J. Achache, "Radar penetration in soils: Towards a new system for Earth subsurface observation", *CEOS SAR Worshop*, Toulouse, France, october 1999.

I. Champion, R. Dewar, D. Loustau, D. Bert, F. Danjon, "Coupling SAR data with Forest Growth Models", *International Journal of Remote Sensing*, vol. 21, no. 8, pp. 1763-1766, 2000.

I. Champion, D. Loustau, D. Bert, A. Porte, M. Guédon, F. Jean-Courdier, F. Lagane, C. Lambrot, A. Lardit, M. Sartore, "Trees architecture determination for theoretical modeling in remote sensing : The Bray experiment - first results", *International Journal of Remote Sensing*, 2001, in press.

A. Porté, A. Bosc, I. Champion, D. Loustau, “Estimating the foliage area of Maritime pine (*Pinus pinaster* Aït.) branches and crowns with application to modelling the foliage area distribution in the crown”, *Annals of Forest Sciences*, vol. 57, no. 1, pp. 73-86, 2000.

M. Bourdeau, M. Dechambre, “Observations of forests using an helicopter-borne nadir looking radar : a new methodology for morphometric purposes”, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 37, no. 4, pp. 2080-2091, 1999.

P. Bonneton, S. Vincent, H. Dupuis, R. Pedreros, “Modelling of wave transformation across the inner surf zone and swash oscillations on beaches”, *Proc. of the 4th Int. Conf. on Computer Modeling of Seas and Coastal Regions*, pp. 77-86, 1999.

V. Lafon, J.-M. Froidefond, F. Lahet, P. Castaing,, “SPOT shallow water bathymetry of a moderately turbid tidal inlet based on field measurements”, *Remote Sensing of Environment*, 2000, submitted.

N. Senechal, H. Dupuis, P. Bonneton, H. Howa, R. Pedreros, “Irregular wave transformation in the surf zone over a gently slopping sandy beach”, *Journal of Coastal Research*, 2000, submitted.

J.-A. Ródenas, R. Garello, “Detection and Characterization of Internal Wave Signatures from SAR Ocean Images”, *IGARSS’99*, Hamburg, Germany, 1999.

J. Inglada, R. Garello, “Volterra model for the imaging mechanism of ocean surface currents by synthetic aperture radar”, *IGARSS’99*, Hamburg, Germany, 1999.

M. Martinaud, F. Madani, “Resistivity vertical filtering for horizontal prospecting. Physical basis and archeological case histories”, *Proceedings of the 3rd International Conference on archaeological prospection*, Munich, Germany, 1999.

M. Martinaud, V. Bonnet, “Specific properties of the pole-pole array for depth investigations in geoelectrical mapping”, *Proccedings of the 4th meeting of the Environmental and Engineering Geophysical Society*, Barcelone, pp. 755-758, 1998.

M. Martinaud, R. Chapoulie, “Sur quinze profils radar réalisés sur un bâtiment enfoui de l’agglomération antique de Brion à Saint Germain d’Esteuil (Radar GSSI 500MHz du BRGM)”, Rapport remis au Service Régional de l'Archéologie, 1991.

J.-M. Boutry, “ONERA airborne SAR facilities”, *2nd International Airborne Remote Sensing Conference*, San Francisco, USA, June 1996.