Scene Characterization Using Sub-Aperture Polarimetric SAR data Analysis

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Abstract- **In this paper is introduced a fully polarimetric sub-aperture analysis method. A deconvolution technique is developed in order to decompose synthesized SAR images into sub-aperture data sets which correspond to the scene global response observed under different azimuthal look angles. A polarimetric variation analysis is achieved, using pertinent parameters, to determine the nature of the non-stationary scattering mechanisms. A statistical analysis of the polarimetric parameters permits to clearly discriminate the media showing a varying behavior during the SAR integration. Decomposition and analysis techniques are applied to data acquired by the DLR airborne E-SAR sensor at L band.**

1. INTRODUCTION

The decomposition of a SAR image in sub-apertures permits to analyze the variations of the scattering behavior of the observed media during the SAR integration. Even if such variations may not be detectable within full resolution images, they generally affect the scattering phenomenon. A description of the decomposition method is given in the first paragraph. This technique decomposes synthesized images into azimuthal sub-spectra and requires then the use of a deconvolution procedure in order to compensate the effects of weighting functions and antenna pattern. Sub-aperture images are then created using an inverse Fourier transform. In a second part, the decomposition technique is applied to data acquired by the DLR E-SAR sensor over the Alling test site, Germany, in the frame of the Surface PArameter Retrieval Cooperation (SPARC) project. An analysis of the sub-aperture data in terms of polarimetric descriptors variation is led. Some anisotropic media polarimetric responses are studied and a variation segmentation technique is introduced.

2. SUB-APERTURE DECOMPOSITION

2.1 Decomposition principle

In the case of a chirp signal composed of a linear frequency modulation, the SAR signal received from a point target can be expressed as the product between two terms representing the delayed chirp envelope and the antenna pattern, a third term associated to the frequency modulated signal and a last expression consisting in a phase delay function and representing the azimuth modulation. When the radar observation direction is orthogonal to the flight direction (squint angle equal to 0), the Doppler frequency derived from the SAR response simplifies to the following expression :

$$f_d(t) = \frac{2v^2}{\lambda_0 r_0} t \text{ with } -\frac{v\Delta Y}{\lambda_0 r_0} \le f_d(t) \le \frac{v\Delta Y}{\lambda_0 r_0} \qquad (1)$$

where ΔY is the swath width in azimuth. Signals backscattered from targets located at a range distance r_0 have, for a given radar position along the azimuth, a similar Doppler frequency.

The application of a Fourier Transform in azimuth permits to handle data in the range-Doppler domain. In this domain, a data subset selected around the Doppler frequency f_d, contains the global SAR response of the scene observed with an observation angle ϕ_d with respect to the range direction. This angle is given by the following relation :

$$\phi_d = \operatorname{atan}\left(\frac{vt}{r_0}\right) = \operatorname{atan}\left(\frac{f_d}{2F_0}\frac{c}{v}\right) \qquad (2)$$

It is then possible to study the angular behavior of specific media or targets during the integration by selecting different sub-spectra or sub-apertures and applying an inverse Fourier transform. Some artificial targets or anisotropic natural media present a non-stationary response during the SAR aperture. These variations may be due to different reasons :

- Targets having a specific orientation due to their structure or to the local topography are seen under incidence angles which vary with the sensor position.
- Some complex targets appear on a SAR image under the form of a set specific points which result from the coherent summation of a large number of responses. As the orientation of such targets varies respectively to the sensor position, the phase terms resulting from the wave interactions change and may modify the bright points intensity and location.

2.2 Application to synthesized SAR data

Sub-aperture SAR images are generally obtained by selecting a Doppler sub-spectrum from a raw data set acquired by the sensor and by processing the corresponding image using a synthesis algorithm. There are two disadvantages to such an approach :

- Raw data are seldom distributed by the organizations taking in charge the SAR data collection.
- The processing of SAR data generally requires a large amount of complex corrections and improvements that

are highly dependent on the sensor intrinsic characteristics and on the acquisition configuration.

It can be shown that an equivalent result is obtained by sampling a Doppler sub-spectrum within an already processed SAR image. This alternative approach allows any kinds of users to deal with high quality synthesized data that can be obtained from SAR image distribution organizations.

2.2.1 Spectrum deconvolution

SAR data spectra are generally convolved, with weighting functions aiming to reduce the side lobe amplitude of point target impulse responses or with non uniform antenna diagram patterns. The estimation of the Doppler spectrum requires a deconvolution of such non linear functions which is performed in two steps : the general weighting function amplitude is first estimated in the Doppler domain and an inverse normalized correction function is then computed and applied to the spectrum. The deconvolution is based on the usual assumption that backscattered power over the whole scene is uniformly distributed in the Doppler domain. The weighting function is estimated from the Doppler spectrum amplitude envelope averaged over the range direction. An example of this amplitude pattern is plotted in Figure 1 -a-. The Doppler spectrum amplitude follows a characteristic raised cosine like shape, surrounded by low-level zones containing no useful signal. A statistical analysis of this function using a variation coefficient, CV, is applied in order to delimitate the useful signal spectrum borders as can be seen in Figure 1 -a-. The correction function estimated between these limits is displayed in Figure 1 -b-. It is important to note that this function is normalized in order to preserve the original spectrum maximum amplitude after correction. In Figure 1. -c- are presented the amplitude corrected Doppler as well as sub-aperture spectra.

2.2.2 Decomposition of Polarimetric SAR data

The sub-aperture decomposition technique introduced in the former paragraph is applied to POLSAR images acquired by the DLR E-SAR. The original image resolution is (1.5m×3m). Each polarization channel is corrected and decomposed with a resolution divided by 4. In Figure 2 is shown the color coded polarimetric images corresponding to the full resolution data. The observed scene is mainly composed of agricultural fields and forested areas. Surface scattering is the dominant polarimetric behavior among the different kinds of crops. The full resolution and the sub-aperture images globally look similar. The polarimetric response from forest remains very stable as the look angle varies. Changes in backscattered intensity and polarimetric properties may be noticed when observing the evolution of some agricultural crops response. Examples of such areas are presented in Figure 2.

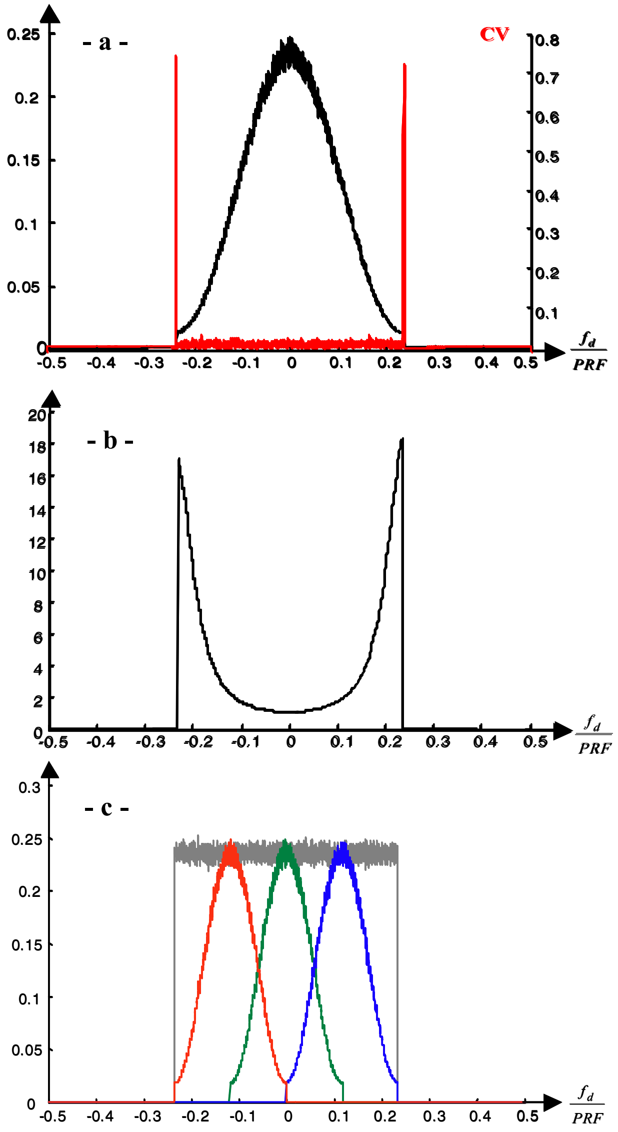


Fig. 1 *-a- Average Doppler spectrum amplitude and variation coefficient*
-b- Normalized correction function,
-c-Corrected spectrum and sub-apertures

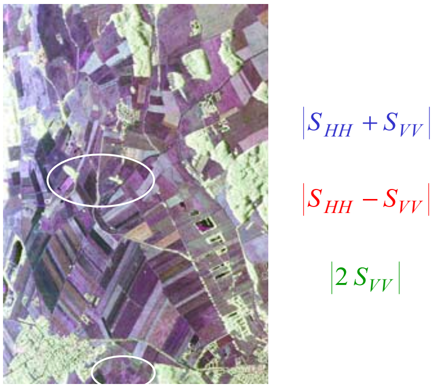


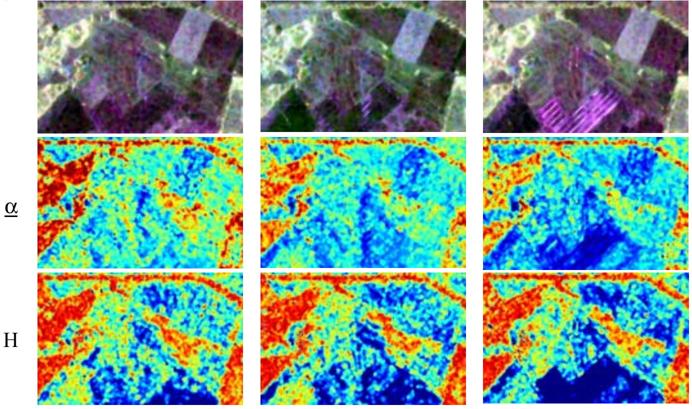
Fig. 2 **:** *Full resolution color coded POLSAR image*

3. AZIMUTH VARIATIONS ANALYSIS

The polarimetric variations observed in the color coded images in Figure 2 are analyzed using two parameters, H and $\underline{\alpha}$, widely used in natural target properties inversion [1] as well as in polarimetric classification procedures [2].

3.1 Anisotropic polarimetric behavior

An eigenvector/eigenvalue based decomposition theorem presented in [3] permits to split a distributed matrix, $\langle \mathbf{T} \rangle$, into a weighted sum of three orthogonal unitary matrices representing each a pure scattering mechanism. Two main parameters , $\overline{\alpha}$, the indicator of the nature of the mean scattering mechanism and the entropy, H, which indicates the random behavior of the global scattering, may be extracted from this decomposition. These parameters are calculated for each sub-aperture data sets and show to efficiently relate changes in the backscattering phenomenon properties.



$\phi_d = \phi_{\min}$ $\phi_d = \frac{\phi_{\min} + \phi_{\max}}{2}$ $\phi_d = \phi_{\max}$

Fig. 3 : *Polarimetric properties of an anisotropic medium as the look angle varies.*

It can be observed from the color coded images at the top of Figure 3 that a sudden variation of the backscattering mechanism occurs as the look angle reaches it maximum value. For such an angle the varying area presents a textural characteristic of a Bragg resonance over a periodical rough surface which may occur as the roughness period equals a multiple of the incident wavelength value. The high dependence of this coherent constructive scattering mechanisms can be verified on the sub-aperture images corresponding to other look angles which do not show such a behavior. From the polarimetric point of view, the Bragg resonance corresponds to a minimal value for $\underline{\alpha}$ and H which depict an almost pure reflection over a flat surface. One can note that the entropy parameter is more sensitive to polarimetric variations and Bragg resonance than the $\underline{\alpha}$ parameter.

3.2 Non stationary target segmentation

An unsupervised segmentation method aiming to discriminate non stationary areas was developed in [4] . This technique is based on the use of a Principal Component Analysis applied to the set of sub-aperture images. A reduced dimension polarimetric representation is obtained and is shown to follow a complex Wishart probability density function. A k-mean clustering algorithm using a Maximum Likelihood distance permits to segment the observed scene and to separate the non stationary targets. The efficiency of such an algorithm can be improved by taking into account in a direct way the information associated to the variations of the polarimetric parameters H and $\underline{\alpha}$. Figure 4 shows variations coefficients of the $\underline{\alpha}$ and H parameters computed over the sub-apertures. The entropy variation coefficient represented on the right hand side of figure 4 shows a good sensitivity to changes in backscattering properties occurring during data acquisition along the azimuth axis. The anisotropic fields can clearly be detected while the forested areas with a constant behavior correspond to low variation values.

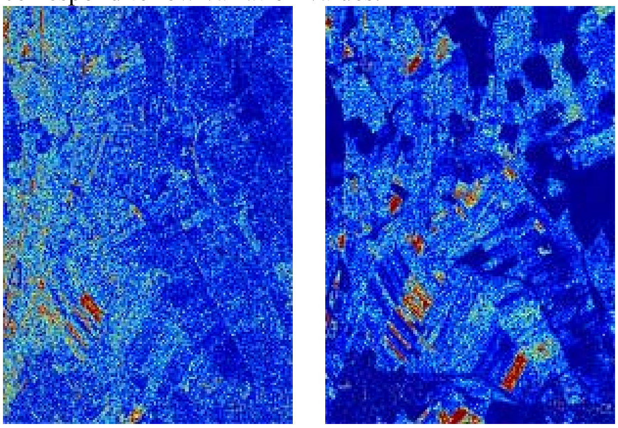


Fig. 4 *Variation coefficients of $\underline{\alpha}$ (left) and H (right)*

4. CONCLUSION

This paper presents a method to decompose synthesized images into azimuthal sub-apertures and proposes an analysis of the polarimetric variations encountered during the SAR integration. Some polarimetric indicators are shown to be well suited for segmenting and characterizing anisotropic media. This approach permits to highlight areas were the inversion of physical parameters from the polarimetric information may lead to unsatisfactory results. The localisation of such artefacts in the Doppler domain can be used to correct the data by forming an image composed of stationary sub-spectra.

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