Investigation of Multiple CSs inside a Resolution Cell by means of PolInSAR

Koichi Iribe, German Aerospace Center, Germany
Rafael Zandona Schneider, German Aerospace Center, Germany
Kostantinos P. Papathanassiou, German Aerospace Center, Germany
Irena Hajnsek, German Aerospace Center, Germany

Abstract

Recently, the *coherent scatterers* (CSs) technique has been introduced in order to detect scatterers with a deterministic point-like scattering behavior in SAR images. Although the majority of the detected CSs show the typical properties of point-like scatterers, e.g., high amplitude, high interferometric coherence and low polarimetric entropy, some CSs present medium or even high polarimetric entropy. In this paper we study such cases by investigating the possibility that more than one Cs are present insides the resolution cell. We exploit not only the interferometric coherence but also the sublook coherence as a function of polarization states using the PolInSAR formalism and experimental data. For the case that the presence of more than one CS inside the resolution cell is found, the separation of CSs is implemented using a interferometric coherence model. In this work, airborne experimental datasets acquired at L-band by E-SAR system of the German Aerospace Center over the city of Munich in Germany are used.

1 Introduction

Recently, the *coherent scatterers* (CSs) technique has been introduced in order to detect scatterers with a deterministic point-like scattering behavior in SAR images, by using their spectral correlation properties [1]. In many cases, point-like scatterers have several advantages when compared to distributed (extended) scatterers, due to their deterministic response. It has been shown that such scatterers (CSs) are mainly present in urban areas, and their polarimetric and interferometric characterization has also been presented [1]. Confirming the expected characteristics of point-like scatterers, CSs were shown to have, in their majority, high amplitude, high interferometric coherence and low polarimetric entropy.
The polarimetric entropy is related to the number of different scattering mechanisms present inside a resolution cell. Low values of entropy indicate one (or few), while high entropy values indicate many scattering mechanisms inside the same cell. Although the most of the CSs were shown to have low polarimetric entropy, a considerable amount of CSs are characterized by medium or high entropy values. As discussed in [1], a possible reason could be the presence of more than one CS inside the same resolution cell, having different polarimetric properties. In this way, by detecting a CS using a certain polarization channel in a given resolution cell, other CS(s) inside the same cell may not be sensed due to their different polarimetric characteristics. This would result in the detection of a CSs (in the used polarization channel), but the cell would nevertheless have a high entropy value (due to the presence of other CSs), what can explain the above observation.
The main topic of this work is to investigate such cases, i.e., the cases for which CSs exhibit high polarimetric entropy values.

2 The concept of Coherences as a Function of Polarization States

Due to the random nature of SAR images, coherence is frequently used to evaluate the degree of similarity between two images. Recently, a whole formalism has been developed, in the frame of PolInSAR (Polarimetric SAR Interferometry) to perform changes of the polarization states in the interferometric coherence [2], [3], [4].
Interferograms from two SAR images can be generated by using not only the linear polarization states, but also any other combination between arbitrary elliptical polarization states. All the elliptical polarizations can be synthesized by applying a change of polarization basis to transform the frequently measured scattering vector $\underline{k} = \begin{bmatrix} S_{hh} & \sqrt{2}S_{hv} & S_{vv} \end{bmatrix}^{\mathrm{T}}$, expressed in (H,V) basis, into another scattering vector $\underline{k}^{'} = \begin{bmatrix} S_{xx} & \sqrt{2}S_{xy} & S_{yy} \end{bmatrix}^{\mathrm{T}}$,expressed in any other general orthogonal basis (X,Y). For the polarization basis transformation, a transformation matrix $\mathbf{U}_{(\tau,\phi)}$, which is a function of the ellipticity and orientation angle τ and ϕ, respectively, is used:

$$\underline{k}' = \mathbf{U}_{(\tau,\phi)}\underline{k} \qquad (1)$$

$$\mathbf{U}_{(\tau,\phi)} = \frac{1}{2}\begin{bmatrix} \cos 2\tau + \cos 2\phi - j\sin 2\tau \sin 2\phi & \sqrt{2}(\sin 2\phi + j\cos 2\phi \sin 2\tau) & \cos 2\tau - \cos 2\phi + j\sin 2\tau \sin 2\phi \\ j\sin 2\tau - \sin 2\phi \cos 2\tau & \sqrt{2}j\cos 2\phi \cos 2\tau & \sin 2\tau - \cos 2\phi - j\cos 2\tau \sin 2\phi \\ j\sin 2\tau + \sin 2\phi \cos 2\tau & \sqrt{2}(-\sin 2\phi + j\cos 2\phi \sin 2\tau) & \cos 2\tau + \cos 2\phi + j\sin 2\tau \sin 2\phi \end{bmatrix} \qquad (2)$$

Physically, by changing the polarization state, different properties of the inherent scatterer's scattering mechanism can be sensed which could not be in other polarization state. In interferometric measurements, the polarization information of both SAR images are contained in two different scattering vectors $\underline{k}_1$ and $\underline{k}_2$ from image 1 and image 2, respectively.
After the transformation of the two scattering vectors, the interferometric coherence in the new polarimetric channel can be calculated:

$$[\Gamma]_{(\tau,\phi)} = [\Omega_{12}]_{(\tau,\phi)} \Big/ \sqrt{[\mathbf{T}_{11}]_{(\tau,\phi)} \cdot [\mathbf{T}_{22}]_{(\tau,\phi)}} \qquad (3)$$

Where,

$$[\mathbf{T}_{11}]_{(\tau,\phi)} = \left\langle \underline{k}_1' \underline{k}_1'^{*\mathbf{T}} \right\rangle \qquad (4)$$

$$[\mathbf{T}_{22}]_{(\tau,\phi)} = \left\langle \underline{k}_2' \underline{k}_2'^{*\mathbf{T}} \right\rangle \qquad (5)$$

$$[\Omega_{12}]_{(\tau,\phi)} = \left\langle \underline{k}_1' \underline{k}_2'^{*\mathbf{T}} \right\rangle \qquad (6)$$

Expanding all the polarization space by changing τ and ϕ, the coherence for the whole polarization space is achieved and can be analyzed.

2.1 Sublook Coherence as a Function of Polarization Channel

In the detection procedure of the CSs technique, the sublook coherence γ_S, i.e., the coherence between two sublook images, is employed, where the resolution cells with high sublook coherence are associated to CSs. In this way, the sublook coherence evaluates the spectral correlation between both sublooks derived from one original full image spectrum. One can then aim to track further CSs by exploiting the sublook coherence at different polarization channels using full polarimetric data. The scattering vectors $\underline{k}_1$ and $\underline{k}_2$ can be defined as the scattering vectors of sublook 1 and sublook 2, respectively. Applying the transformation matrix $\mathbf{U}_{(\tau,\phi)}$ for both vectors in the way described in the previous section, the sublook coherence γ_S can be obtained for different polarization. As well as the interferometric coherence in the PolInSAR formalism, an infinite number of sublook coherences γ_S corresponding to different polarization channels can be synthesized when full polarimetric data are available. Note that in contradiction to the interferometric coherences, the phases of the complex sublook coherences γ_S do not include interferometric information.
Using this procedure, the sublook coherence γ_S is analysed as a function of polarization states in order to investigate the resolution cells in which CSs have been detected and have high polarimetric entropy. Particularly, we search not only the maximum value of sublook coherence γ_S but also secondarily maximum values in the whole polarization space. The scattering mechanism corresponding to each maximum are also analysed.

2.2 Interferometric Coherence as a Function of Polarization Channel

Using polarimetric and interferometric SAR data, the interferometric coherences of the resolution cells are also investigated. The behavior of the interferometric coherence map (the coherence for the whole polarization space) is discussed and compared to the sublook coherence one.
For this, the scattering vector $\underline{k}_1$ and $\underline{k}_2$ are defined from the fully polarimetric SAR image 1 and image 2 data acquired with an interferometric baseline. Note that the phase of the complex coherences includes the interferometric information of scatterers inside the resolution cell and is exploited in a PolInSAR frame work.

3 The PolInSAR Model of Interferometric Coherence

Finally, for the cases where the presence of more than one scatterer inside the resolution cell is arisen, a PolInSAR model for the interferometric coherence is used to identify the different scattering phase center of each scatterer inside a cell. The model used in this work, for the case of three scatterers A, B and C, is given by [5].

$$\gamma_i = \frac{e^{jk_z z_A} + \frac{\sigma_B}{\sigma_A} e^{jk_z z_B} + \frac{\sigma_C}{\sigma_A} e^{jk_z z_C}}{1 + \frac{\sigma_B}{\sigma_A} + \frac{\sigma_C}{\sigma_A}} \qquad (7)$$

where k_z is the effective vertical interferometric wavenumber, σ_A, σ_B and σ_C are backscattering intensities of the three scatterers. z_A, z_B and z_C are the heights of each scatterer inside the resolution cell. Eq. (7) describes the polarization channel *i* complex interferometric coherence model and assumes the case that the three kinds of scatterers locate inside a resolution cell. Acquired information regarding the number of scatterers and the polarimetric and interferometric characterizations of scatterers inside the resolution cell would be embedded into the model to solve the unknowns of Eq. (7), namely the height of the scatterers z_A, z_B and z_C.

References

[1] R. Z. Schneider, K. P. Papathanassiou and I. Hajnsek, A. Moreira: Polarimetric *and Interferometric Characterization of Coherent Scatterers in Urban Areas*, IEEE Trans. Geosci. Remote Sensing, vol. 44, no. 4, pp. 971-984, Apr. 2006.

[2] S. R. Cloude and K. P. Papathanassiou: *Polarimetric SAR Interferometry*, IEEE Trans. Geosci. Remote Sensing, vol. 36, no. 4, pp. 1551-1565, Sept. 1998.

[3] S. R. Cloude and K. P. Papathanassiou: *Three-stage inversion process for polarimetric SAR interferometry*, IEE Proc.-Radar Sonar Navig., Vol. 150, No.3, June 2003.

[4] L. Sagues, J. M. Lopez-Sanchez, J. Fortuny, X. Fabregas, A. Broquetas and A. J. Sieber :*Indoor Experiments on Polarimetric SAR Interferometry*, IEEE Trans. Geosci. Remote Sensing, vol. 38, no. 2, pp. 671-684, Mar. 2000.

[5] R. Z. Schneider, A. Liseno, K. P. Papathanassiou and I. Hajnsek :*Polarimetric SAR Interferometry over Urban Areas: First Results*, in Proc. EUSAR2004, Ulm, Germany, May 2004.