POLARIMETRIC COHERENCE FOR LAND COVERS CLASSIFICATION

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INTRODUCTION

Synthetic Aperture Radar (SAR) data is extensively used in recent decades for Earth surface monitoring. Advantages of SAR are well-known: good resolution, all-weather, day-and-night etc. SAR Interferometry (INSAR) is a well-established technique which has a lot of applications, e.g., topography mapping, change detection, estimation of surface displacements, thematic mapping. Repeat-pass interferometry is a useful tool for natural processes monitoring. There are a lot of applications of it in different spheres: forestry, glaciers, earthquakes, landslides, agriculture etc. Interferometric coherence shows a level of signal decorrelation between the first and the second acquisitions. SAR polarimetry concentrates at the relations of the backscattered signal for different polarizations. Polarimetric SAR Interferometry (POLINSAR) [1] uses the vector coherence, which is a product of “polarimetric” and “interferometric” coherence. In the case of identical signal polarization for the both images of the pair the “polarimetric” multiplier is equal to 1. Consequently, for this case vector coherence coincides with usual scalar coherence with fixing of signal polarization. The proposal to visualize the POLINSAR coherence as a function of polarization ellipse parameters is the key idea of the present paper.

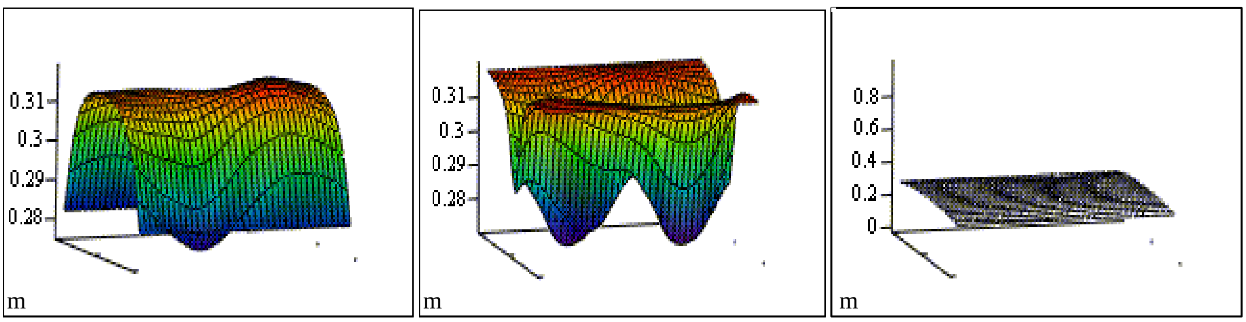
The coherence signatures were introduced in [2,3]. This paper gives material illustrating the application of coherence signatures for natural land cover classification. In addition, we analyze the shape of coherence region in the complex plane for forested and non-forested areas.

The experimental data used in this study are full-polarimetric interferometric pair of images acquired by the SIR-C sensor on October 7 and 9, 1994, over southeastern shore of Baikal Lake, Siberia. Both C- and L-band were processed. The study is focused on the left side of the Selenga River delta. The scene includes Bailkal shoreline, small lakes, the Selenga delta, a mixed forest near Istomino settlement, a number of agricultural fields, pastures, marshlands, meadows. Ground truth data collected during field trip in August 2002 was used for validation and interpretation of SAR data processing results.

CONCEPT OF COHERENCE SIGNATURES

Full-polarimetric interferometric data allows introducing the vector coherence [1], which uses an ensemble of pairs of scattering matrices. Using this type of data, one can calculate a conventional coherence map for any combination of polarizations on receive/transmit for both images. At the same time one can associate each pixel of the co-registered images with a plot of coherence magnitude as a function of orientation and ellipticity angles. By analogy with standard terminology of polarimetric SAR, we name this plot “a polarimetric coherence signature”. Examples of co- and cross-polar coherence signatures are in the Fig. 1.

As the coherence values on the different polarization for the same pixel are not independent (see, e.g., a model of the interferometric coherence in [4]), coherence magnitudes take also the neighbor values. Consequently, in the scale of [0,1] coherence signature looks like a plane (Fig. 1c). L-band signatures show light variations of the coherence magnitude even in full-scale representation, especially for non-forested land covers: coherence slightly decreases from linear to circular polarization. The possible explanation lies at the fact that the cross-section decreases also from zero ellipticity angle to 45° for a given orientation angle.



a) b) c)

Fig. 1. Polarimetric coherence signatures for field: a) co-polar, b) cross-polar, c) co-polar in scale [0,1].
Horizontal axes: orientation angle (from left to right, from 0° to 180°)
and ellipticity angle (across the page plane, from –45° to +45°)

Study discussed in this paper is based on the following key observation: in a small scale the coherence signatures have a similar shape for the same type of cover, and different types of cover show different signatures. The term "shape" means here the positional relationship of global and local maxima and minima in the plot. As in the case of conventional polarization signatures, where radar cross section is the function of polarization ellipse parameters, analysis of a coherence signature shape gives an additive information on the scattering surface.

COHERENCE SIGNATURES FOR DIFFERENT TYPES OF LAND COVER

In this paper we investigate coherence signatures for non-forested land, forest, and water surfaces.

Mean value of the coherence for non-forested land is about 0.3 for C-band and 0.8 for L-band. The shape of the signatures is almost the same, but for L-band the coherence variance is larger. Typical example of co- and cross-polarized coherence signatures for field is presented in Fig.1a,1b. Coherence magnitude is a measure of decorrelation in SAR interferometry. Let us examine the shape of co-polar signatures. Common property of all co-polarized signatures for non-forested covers is an almost ruled shape: profiles of constant ellipticity are very close to straight line for small ellipticity angles and for other angles profiles are only slightly deformated. This form allows drawing the following conclusion: as the zero-ellipticity profile of a convenient polarization signature shows different levels of radar cross-section for horizontal and vertical polarizations, these σ_0 variations do not affect the coherence. Hence, the variations of the coherence magnitude because of SNR can be neglected. Volume decorrelation is not essential for this type of cover because of poor vegetation. Independence of the coherence magnitude from the orientation angle indicates a surface type of the scattering. This conclusion is confirmed by other polarimetric methods (e.g., H-alpha classification [5] by S.R. Cloude and E. Pottier applied for this region [2]). Temporal decorrelation affects the mean value of the coherence, but there is no preferential direction in elementary scatterers' orientation: all orientations are equally stable for the period of 2 days. A profile of an arbitrary constant orientation angle is arc-shaped with a maximum at zero ellipticity. Decreasing of the coherence from linear to circular polarization is the consequence of the signal depression from linear to circular polarization. Nulls of radar cross-section at the circular polarization explain the form of constant orientation profiles.

Forested territories are the most interesting objects for investigating their coherence signatures. In contrast to the situation at bare areas, signatures for L-band and C-band differ from each other for the same forested region. L-band co-polarized signatures have the same shape for any part of forest. It looks like a saddle: maximum of the zero ellipticity profile lies at the horizontal polarization (0° and 180° orientation), minimum lies at the vertical polarization, and there is usual depression of the coherence from linear to circular polarization (Fig. 2a). Coherence mean value is a little bit lower than for the fields as a result of volume decorrelation. If vegetation is modeled as a cloud of random oriented elementary scatterers [1], volume decorrelation does not influence on the shape of the signature, because it does not depend on the polarization. Consequently, the source of coherence shape variations is temporal decorrelation. Maximum at horizontal polarization indicates that horizontally oriented elementary scatterers (branches, twigs, leaves) are more steady than others. C-band signatures show a diversity of coherence signature shapes. Most of them have maximum also at the linear horizontal polarization. But a considerable part of signatures have maximum at the vertical polarization, and there is mixed type of signature with local maxima at both horizontal and vertical polarization (Fig. 2b,c,d).

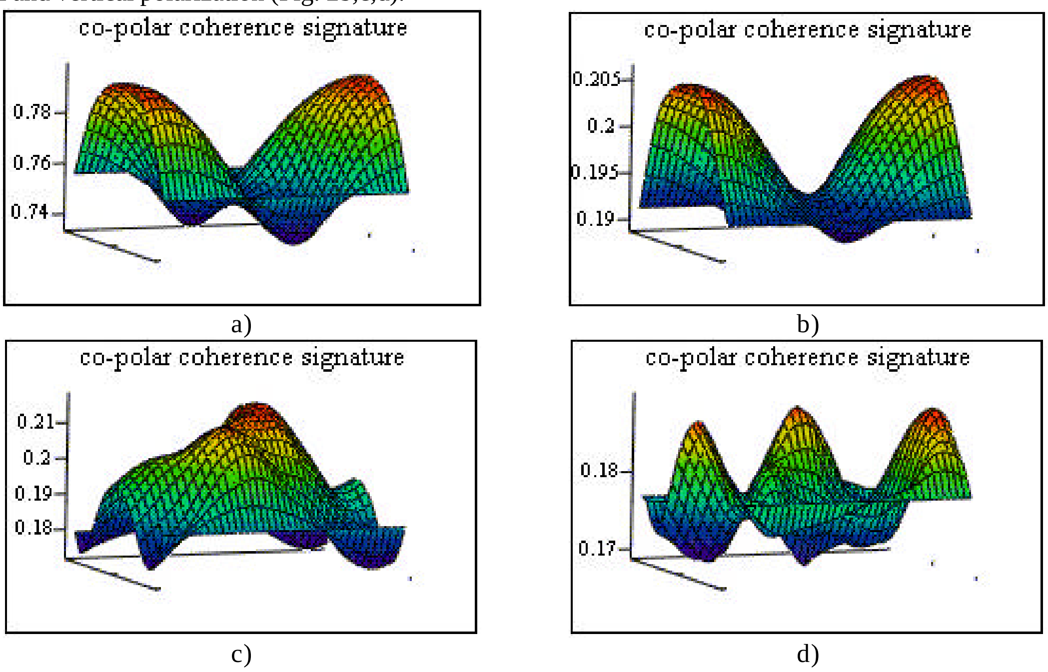


Fig. 2. Co-polar coherence signatures for forest: a) L-band; b),c),d) forest 1, forest 2, forest 3 in C-band.

Hence different parts of the forest have different temporal stability patterns: they have vertically or horizontally oriented elementary scatterers as the most stable objects. Coherence mean value is lower for the forest than for bare areas irrespective of signature shape. On the basis of this observation one can perform forest classification (see below).

As water surfaces show the total decorrelation in the situation of repeated-pass interferometric scheme, the magnitude of coherence is about zero. This fact and the random character of the coherence signature plot indicate water surfaces as the most unstable objects on the image. As usual, the same properties are expected for the shadowing regions. In the case of such irregular shape of the coherence signature for non-shadowing land surface one should suppose some event between the observations that changed strongly the microrelief of the surface. In our case one of the fields has a chaotic signature. It means that it was ploughed of flooded.

SHAPE OF THE COHERENCE REGION IN THE COMPLEX PLANE

In previous sections we regarded magnitude of the interferometric coherence, but interferometric coherence is complex. The set of complex values corresponded to different polarization composes a region in the unit circle. The shape of this region for non-forested terrain was investigated in [6].

Fig. 3 presents typical shapes of complex coherence regions for the field and forest. Red and blue points correspond to co- and cross-polar coherence, respectively. L-band is selected for illustration because of larger square of the region. (See C-band forest pattern in the Fig.3a for comparison). Forest coherence regions can be divided into two main types. The first type has a prolate form (Fig. 3b), according to linear model of the complex coherence [4]. But another type of coherence region (Fig. 3c) shows that requirements of linear model sometimes do not meet. The region is compact and has almost round shape. In that case the algorithm for finding terrain phase under vegetation cover works incorrectly. Field patterns demonstrate significant magnitude diversity (Fig. 3d) Near-radial orientation illustrates the effect of coherence decreasing from circular to linear polarization (mentioned above).

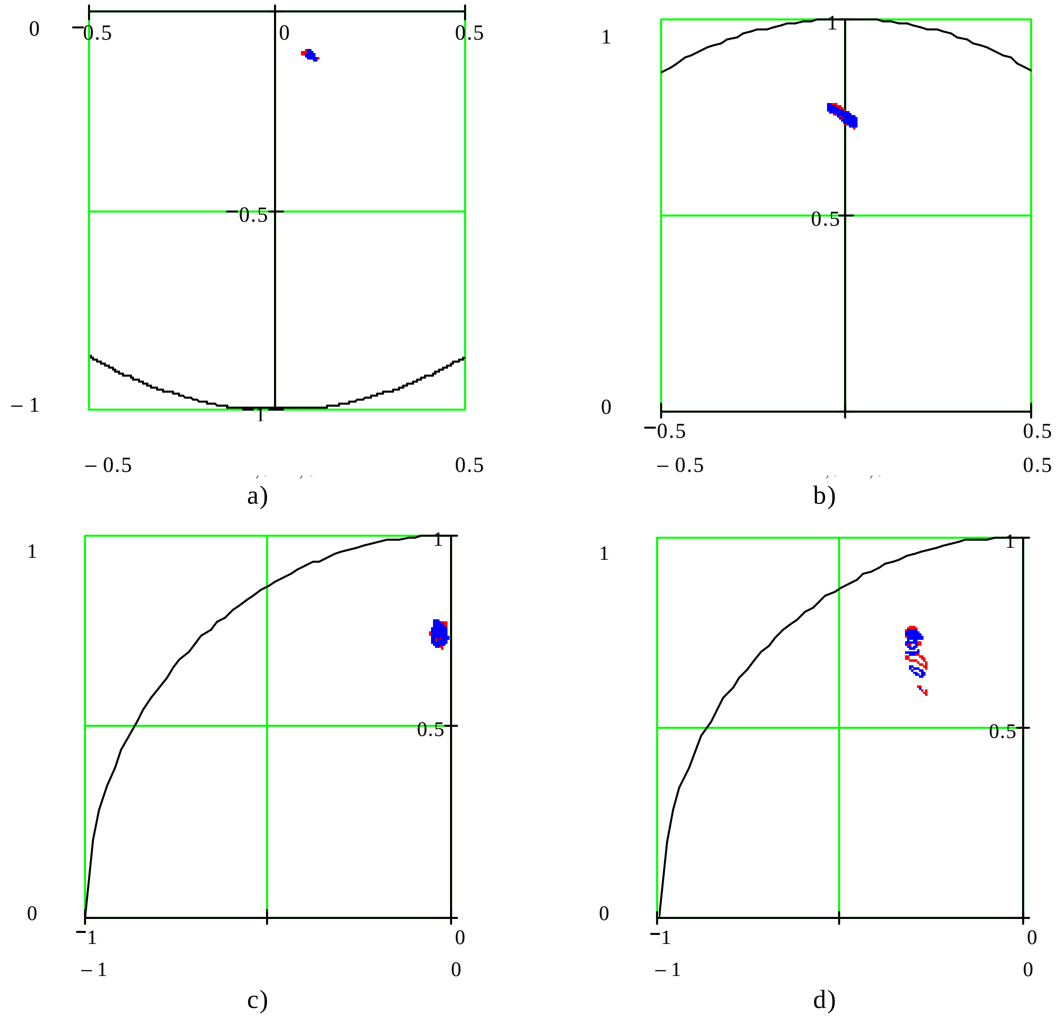
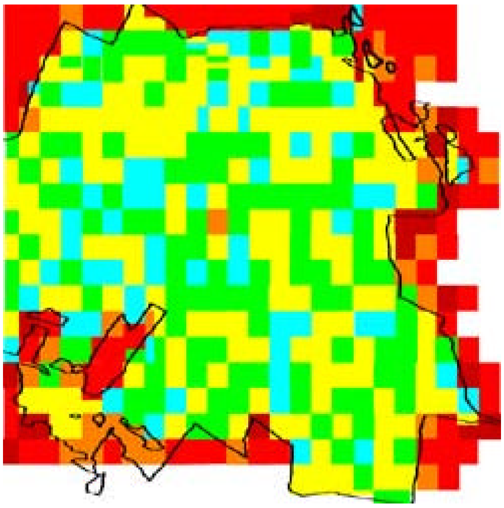
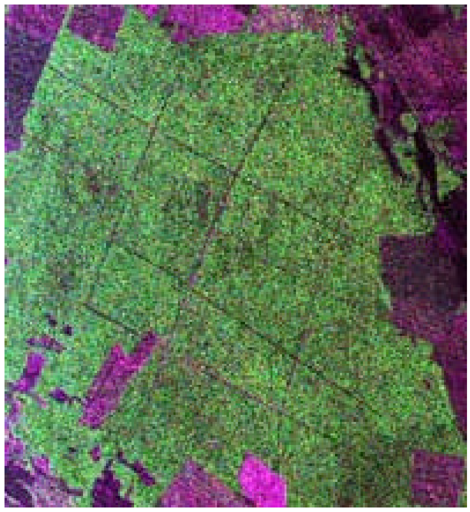


Fig. 3. Shape of the coherence region:

a) forest, C-band;
b) the first type of forest, L-band;
c) the second type of forest, L-band;
d) field, L-band



a)



b)

Fig.4. Istomino forest classification map and SAR image:
a)forest classification map: red – field, yellow – forest 1, blue – forest 2, green – forest 3, orange – sparce forest
b) RGB image 07.10.1994. Red – HH, Green – HV, Blue – VV polarization.

FOREST CLASSIFICATION BACED ON COHERENCE SIGNATURES

As we have some different types of coherence signature shape, we can create a "map" of forest (Fig. 4a) in terms of coherence signatures. Mixed forest near Istomino settlement on the left side of Selenga delta was chosen for classification (Fig. 4b). The image of this forest and its surrounding was divided into great number of parts with size 25x100 pixels, and a coherence signature for each part was calculated.

There are three basic types of the signatures for the territory: field-type signature, signature with maximum at the horizontal polarization (forest 1), and signature with maximum at the vertical polarization (forest 2). Also we have several mixed types of signatures: field-looks shape with a smooth maximum (at horizontal or vertical polarization) and forest-type signature with both vertical and horizontal local maxima, where any of them can be the global maximum (forest 3). The result of classification one can find in the Fig. 4a. Red cells correspond to the signature in Fig.1. Forest 1, forest 2, forest 3 colored cells correspond to signatures in the Fig. 2b,c,d. The forest border is evidently detected in the figure as a red band of field-type signatures enclosing the forest. This band follows the forest border (black contour) obtained from amplitude image (Fig. 4b).

The interpretation of the coherence signature map uses crown structure of the forest. Comparison of signature types and forest photos suggests that a signature maximum points out a dominated orientation of stable scatterers. Forest areas of the first type (forest 1 in Fig.4) have high thin trunks and medium crown density without undergrowth, first segment consists of pine-trees, and the second one is covered by birch and aspen. The second type of signature (with maximum at the horizontal polarization, Fig. 2a,b) corresponds to an alter forest pattern. These forest segments are mixed, with pronounced undergrowth and thick crown. It looks that vertical oriented scatterers in this type of forest crown are more stable and show a local maxima at the vertical polarization in the coherence signature. What about forest3 in Fig.4, it should be a compound type of the forest.

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