CHANGE DETECTION IN POLARIMETRIC SAR DATA OVER SEVERAL TIME POINTS

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ABSTRACT

A test statistic for the equality of several variance-covariance matrices following the complex Wishart distribution is introduced. The test statistic is applied successfully to detect change in C-band EMISAR polarimetric SAR data over four time points.

1. INTRODUCTION

A test statistic for the equality of two or several variance-covariance matrices following the real (as opposed to the complex) Wishart distribution with an associated probability of finding a smaller value of the test statistic is described in the literature, [1]. In 2003 we introduced a test statistic for the equality of two variance-covariance matrices following the complex Wishart distribution with an associated probability measure, [2]. In that paper we also demonstrated the use of the test statistic to change detection over time in both fully polarimetric and azimuthal symmetric SAR data, [3]. In [4] we used it for edge detection.

To detect change in a series of $k > 2$ complex variance-covariance matrices the pair-wise test described in [2, 4] may be applied to either consecutive pairs or to all possible pairs. The former would lead to a lack of ability to detect weak trends over time, the latter to an increase in the probability of false negatives and/or false positives. Therefore we need to test for equality for all time points simultaneously.

In this paper we generalize the test statistic for the equality of several variance-covariance matrices from the real to the complex Wishart distribution and demonstrate its application to change detection in truly multi-temporal, full and dual polarimetry SAR data.

In the early and mid 2000s not many workers had access to polarimetric SAR data. Today several spaceborne polarimetric SAR instruments are available which makes this contribution highly relevant and timely.

2. THEORY

In this section we first describe the covariance representation of multi-look polarimetric SAR data. We then give the test statistic for the equality of several complex Wishart distributed matrices.

2.1. Synthetic Aperture Radar

A fully polarimetric SAR measures the two by two complex so-called scattering matrix at each resolution cell on the ground. The scattering matrix relates the incident and the scattered electric fields, [3]. If S_{rt} denotes the complex scattering amplitude for receive and transmit polarization ($r, t \in \{h, v\}$ for horizontal and vertical polarization), then reciprocity, which normally applies to natural targets, gives $S_{hv} = S_{vh}$ (in the backscattering direction using the backscattering alignment convention) [3]. Assuming reciprocity, the scattering matrix is represented by the three-component complex target vector $\boldsymbol{s} = [S_{hh}\ S_{hv}\ S_{vv}]^T$, ^{T} means transpose.

The inherent speckle in the SAR data can be reduced by spatial averaging at the expense of spatial resolution. In this so-called multi-look case (below n is the number of looks) a more appropriate representation of the backscattered signal is the covariance matrix in which the average properties of a group of resolution cells can be expressed in a single matrix formed by the outer products of the averaged target vectors. The average covariance matrix is defined as [3]

$$\langle \boldsymbol{C} \rangle_{full} = \begin{bmatrix} \langle S_{hh}S_{hh}^* \rangle & \langle S_{hh}S_{hv}^* \rangle & \langle S_{hh}S_{vv}^* \rangle \\ \langle S_{hv}S_{hh}^* \rangle & \langle S_{hv}S_{hv}^* \rangle & \langle S_{hv}S_{vv}^* \rangle \\ \langle S_{vv}S_{hh}^* \rangle & \langle S_{vv}S_{hv}^* \rangle & \langle S_{vv}S_{vv}^* \rangle \end{bmatrix}$$

where $\langle \cdot \rangle$ denotes ensemble averaging and * denotes complex conjugation. Reciprocity results in a covariance matrix with rank three.

Spaceborne instruments often transmit only one polarization, say horizontal, and receive both polarizations giving rise to dual polarization data, S_{hh} and S_{hv}. In this case we have the components $\langle S_{hh}S_{hh}^* \rangle$, $\langle S_{hh}S_{hv}^* \rangle$ and $\langle S_{hv}S_{hv}^* \rangle$ only.

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The resulting covariance matrix

$$\langle \boldsymbol{C} \rangle_{dual} = \begin{bmatrix} \langle S_{hh} S_{hh}^* \rangle & \langle S_{hh} S_{hv}^* \rangle \\ \langle S_{hv} S_{hh}^* \rangle & \langle S_{hv} S_{hv}^* \rangle \end{bmatrix}$$

has rank two. (We could also transmit vertical polarization only and receive both, S_{vv} and S_{hv}, or even transmit and receive both, S_{hh} and S_{vv}.)

2.2. Test for Equality of Several Complex Covariance Matrices

To test whether a series of $k > 2$ complex variance-covariance matrices $\boldsymbol{\Sigma}_i$ (p by p) are equal, i.e., to test the so-called null hypothesis

$$H_0: \; \boldsymbol{\Sigma}_1 = \boldsymbol{\Sigma}_2 = \cdots = \boldsymbol{\Sigma}_k$$

against all alternatives, the following test statistic applies (for the real case see [1]; for the case with two complex matrices see [2])

$$Q = \left\{ k^{pk} \frac{\prod_{i=1}^{k} |\boldsymbol{X}_i|}{|\boldsymbol{X}|^k} \right\}^n$$

or

$$\ln Q = n \left\{ pk \ln k + \sum_{i=1}^{k} \ln |\boldsymbol{X}_i| - k \ln |\boldsymbol{X}| \right\}.$$

Here the $\boldsymbol{X}_i = n\hat{\boldsymbol{\Sigma}}_i = n\langle \boldsymbol{C} \rangle_i$ follow the complex Wishart distribution, i.e., $\boldsymbol{X}_i \in W_C(p, n, \boldsymbol{\Sigma}_i)$, and $\boldsymbol{X} = \sum_{i=1}^{k} \boldsymbol{X}_i \in W_C(p, nk, \boldsymbol{\Sigma})$. Also (if the hypothesis is true, "under H_0" in statistical parlance), $\hat{\boldsymbol{\Sigma}} = \boldsymbol{X}/(kn)$. $Q \in [0, 1]$ with $Q = 1$ for equality.

For full polarimetry data $p = 3$, for dual polarimetry $p = 2$, and for single band (HH, HV or VV) data $p = 1$.

3. CASE STUDY

Fully polarimetric C-band EMISAR [5, 6] multilook, covariance data from

- 21 March (called C62),
- 20 May (called C64),
- 16 June (called C65), and
- 15 July (called C68),

all from 1998, covering mostly agricultural fields near Foulum in Denmark, are available. The images have 5 m pixels, 1024 lines and 1024 samples. Number of looks is $n = 13$.

Figure 1 shows RGB combinations of the diagonal elements of the fully polarimetric covariance matrix for C62 (a), C64 (b), C65 (c), and C68 (d). $S_{hv} S_{hv}^*$ (red) is stretched linearly between –36 dB and –6 dB, $S_{hh} S_{hh}^*$ (green) between –30 dB and 0 dB and $S_{vv} S_{vv}^*$ (blue) between –24 dB and 0 dB.

Figure 2 shows $-\ln Q$ for full polarimetry data for all four images C62-C64-C65-C68 simultaneously, and pairwise for the three consecutive pairs, C62-C64, C64-C65 and C65-C68. No-change regions (here mostly woods, some agricultural fields, and built-up areas) are associated with low values of $-\ln Q$ (i.e., dark areas in the image) and are immediately identified. Change regions (here mostly some of the agricultural fields with crops developing over the growing season and near-shore areas in the lake in the upper left corner) are associated with high values of $-\ln Q$ (i.e., bright areas in the image) are easily spotted also.

It is clearly seen, that the result for all four images simultaneously (Figure 2(a)) contains all the changes that are detected in the individual pairwise results (Figures 2(b), (c), and (d)). Also, it is clearly seen, that the regions with no-change during the acquisition period, e.g., the forest area, stand out much more clear in Figure 2(a) than in the pairwise results. It is difficult from the images in Figure 2 to assess whether the new test statistics is able to detect weak trends over time, that are not picked up by the pairwise results. This requires further detailed analysis of the results.

4. CONCLUSIONS

No-change regions (the low values of the test statistic, i.e., the dark areas in the $-\ln Q$ image) are immediately identified by this method. For change regions more work on identifying when change occurred is needed. This is especially relevant for longer time series.

Ongoing work comprises finding the probability for obtaining a lower value of the test statistic, and establishing when a change event occurred.

5. REFERENCES

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(a) 21 March, C62.

(b) 20 May, C64.

(c) 16 June, C65.

(d) 15 July, C68.

Fig. 1. RGB images of diagonal elements of the original data.

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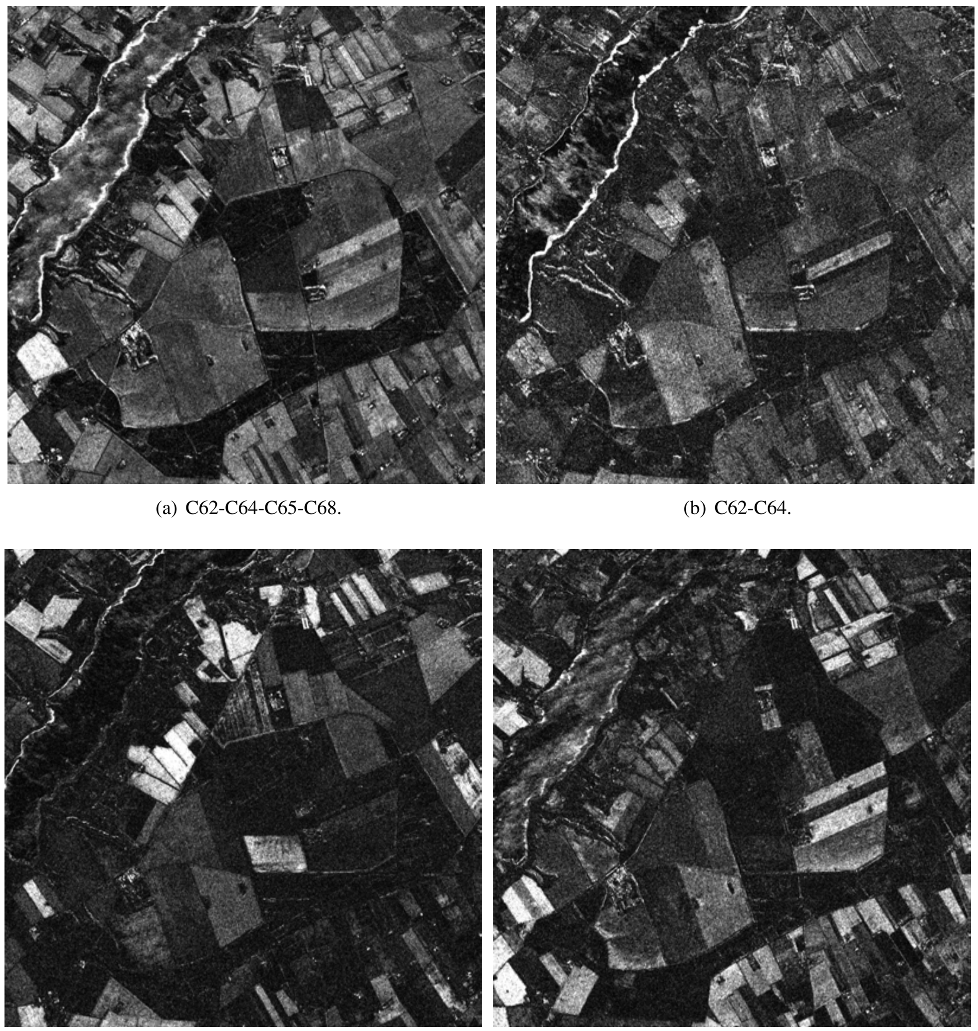

(a) C62-C64-C65-C68.

(b) C62-C64.

(c) C64-C65.

(d) C65-C68.

Fig. 2. $-\ln Q$ for full pol data; all images are stretched linearly between the 1% and the 99% fractiles. No-change regions are dark.