QUASI-SCATTERING MATRIX REGISTRATION IN REPEAT PASS MODE

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ABSTRACT
Full scattering matrix registration assumes four data channels (for HH, HV, VH, VV polarizations combinations at transmit/receive). Repeat-pass mode with registration of two channels allows reducing the number of data channels and getting a quasi-scattering matrix consisted of two lines mapped in different passes (e.g., HH and HV in the first pass and VH and VV in the second pass).

The paper contains the analysis of sources of errors of quasi-scattering matrix registration, modeling the polarization signatures by using such matrices, a method for errors compensation and reliability estimation. The experimental data of SIR-C SAR were processed for demonstration of potential of the introduced method.

1. QUASI-SCATTERING MATRIX
In the case of two dual-pol measurements, when the first one gives polarization channels HH and HV and the second one provides VH and VV, we can formally join them into quasi-matrix $S^q$:

$$ S^q = \begin{bmatrix} S^1_{HH} & S^1_{HV} \\ S^2_{VH} & S^2_{VV} \end{bmatrix}. $$

Certainly, it differs from the usual scattering matrix

$$ S = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix}. $$

So, some questions have arisen: can $S^q$ be used instead of $S$ or not? What kind of difference is there? Can we anyhow correct $S^q$ in order to make it appropriate enough for the role of scattering matrix $S$?

The paper offers investigation of the problems listed above.

2. DISTORTION MODELING
Let us examine our quasi-matrix $S^q$. Because of temporal and spatial decorrelation its second line is distorted in comparison to the second line of the scattering matrix $S$. Firstly, their initial phases are different. Therefore we may suppose a phase distortion term $e^{i\phi}$. Secondly, the scattering conditions may be different, especially for long time interval between observations, so we need a radiometric correction, too.

Let us introduce the error in the second line as a multiplier in the form $Ae^{i\phi}$. The number of parameters (two: $A$ and $\phi$) we will discuss later.

Extensively-used Pauli basis gives a suitable material for simple modeling distortions and comparing with the reference (non-distorted) matrices. Pauli basis matrices with distortion factor $Ae^{i\phi}$ introduced in the second line are:

$$ \sigma_0(A, \phi) = \begin{bmatrix} 1 & 0 \\ 0 & Ae^{i\phi} \end{bmatrix}, $$

$$ \sigma_1(A, \phi) = \begin{bmatrix} 0 & 1 \\ Ae^{i\phi} & 0 \end{bmatrix}, $$

$$ \sigma_2(A, \phi) = \begin{bmatrix} 0 & -i \\ Ae^{i(\phi+\pi/2)} & 0 \end{bmatrix}, $$

$$ \sigma_3(A, \phi) = \begin{bmatrix} 1 & 0 \\ 0 & -Ae^{i\phi} \end{bmatrix}. $$

Polarization signature plots [1] give a convenient tool for investigation of distortion effect: the plot shows the radar cross section as a function of polarization ellipse parameters. Let us concentrate at copolarized signatures, where the polarization of transmitting and receiving signals are identical.

Substitution the terms $S_{HH}$, $S_{HV}$, $S_{VH}$, $S_{VV}$ from each Pauli matrices in the formula

$$ S_{xx} = \frac{1}{1+\rho^2} \left(S_{HH} - \rho^* S_{HV} - \rho^* S_{VH} + (\rho^* \rho)^* S_{VV} \right) $$

of changing polarization basis from (HV)-basis to any orthogonal (XY)-basis [2] (where $\rho$ is a polarization ratio) results in formulae 7–10:

$$ S_{xx}(\rho) = \frac{1+(\rho^* \rho)^* Ae^{i\phi}}{1+\rho^2}, $$

$$ S_{xx}(\rho) = -\frac{\rho^*(1+ Ae^{i\phi})}{1+\rho^2}, $$

$$ S_{xx}(\rho) = \frac{i\rho^*(1- Ae^{i\phi})}{1+\rho^2}. $$
\[ S_{XX}(\rho) = \frac{1 - \left(\rho^2\right) A e^{i\phi}}{1 + \rho^2}. \]  

(10)

The first Pauli matrix corresponds to rough surface scattering mechanism, the second one models the scattering from diplane with horizontally oriented edge, so we focused at formulas (7) and (8) for our modeling. It is worth noting that the sum of the first and the third basis matrices represents the dipole scattering mechanism, but the second line of this sum is zero, so the distortion in the multiplication form will not influence on this type of matrix.

2.1. Amplitude effect

The reference polarization signature of the first basis matrix (which is a unit matrix with no distortions) is in the Fig.1. All polarization signatures below have the horizontal axes of orientation angle (from left to right) and ellipticity angle (to the reader) and the vertical axe of radar cross section value.

Figure 1. Reference polarization signature for the first Pauli basis matrix \( \sigma_0 \).

While keeping the parameter \( \phi \) equal to zero, let us vary the parameter \( A \). Figure 2 shows the distorted polarization signatures for two \( A \) values, greater and less than 1.

One can see that decreasing of \( A \) values leads to a gap at the vertical polarization, and increasing of \( A \) results in elevation in the plot at vertical polarization.

Figure 2. Polarization signatures of distorted matrix \( \sigma_0 \), \( A=0.5 \) (left) and \( A=2 \) (right).

Figures 3 and 4 present the reference and distorted polarization signatures for the second basis matrix \( \sigma_1 \). There is general decreasing/increasing of the mean level of the surface plots because of amplitude distortions in accordance of the value of \( A \).

2.2. Phase effect

The effect of phase distortions differs from the previous one. Let us fix \( A \) value equal to 1. Fig. 5 and 6 show the distorted polarization signatures for matrices \( \sigma_0 \) and \( \sigma_1 \), respectively. The phase term is equal to \( \pi/3 \).

As for the first matrix, \( \sigma_0 \), the distortion looks like warping.

Figure 5. Polarization signature of distorted matrix \( \sigma_0 \). \( \phi=\pi/3 \).
The effect of the phase distortion for the second matrix results in general decreasing of the plot surface level without change of the shape (Fig. 6).

2.3. Joint effect

The most natural situation is the dual influence of the phase and amplitude distortion terms. Figures 7 and 8 show the distorting effect on the polarization signatures for matrix $\sigma_0$.

3. QUASI-MATRIX CORRECTION

Now we can offer the way to correct the distorted matrix. If the distortion effect is a factor of the second line $Ae^{i\phi}$, the correction procedure is the multiplying by the inverse value $A^{-1}e^{-i\phi}$. The question is: how to calculate $A$ and $\phi$, if we have 4 values of a quasi-matrix $S_q$?

The reciprocity condition gives an answer. Under this condition the scattering matrix should be symmetric, i.e., $S_{HV}=S_{VH}$. Consequently, the correction multiplier should symmetrize the matrix, and the corrected matrix becomes the following:

$$
S_q^{ corr} = \begin{bmatrix}
S_{HH}^1 & S_{HV}^1 \\
S_{HV}^1 & S_{VV}^1 \\
S_{HH}^2 & S_{HV}^2 \\
\end{bmatrix}.
$$

In the case of zero cross-polar term in the second observation and non-zero $S_{HV}$ in the first term we state that correction is impossible. Fortunately, it is not the case.

3. DATA PROCESSING

For illustration of the correction method we use SIR-C L- and C-band quad-pol data, October 7 and October 9, 1994 over Baikal Lake coastline, Siberia.

Quasi-matrices were generated by joining together the first line of scattering matrix from October 7 observation, and the second line of scattering matrix from October 9 observation, with time difference of 2 days, after the accurate co-registration of the images.

Figures 9–11 give a view of polarization signatures of the mixed field area for L-band: quasi-matrix, corrected matrix and reference matrix, which is the real scattering matrix from the first observation (October 7). One can behold in the Fig. 9 both effects from the Fig. 2 and 5.
The corrected matrix (Fig. 10) is much more similar to the reference scattering matrix in the Fig. 11. The situation for the forest area is about the same: the correction procedure works perfectly.

Figure 10. Polarization signature of corrected matrix for field, L-band.

Figure 11. Polarization signature of the reference scattering matrix for field, L-band.

For the C-band data both types of surface show worse correction results (Fig. 12, 13, 14). Although the amplitude effect was partly corrected, the real shape of the reference signature (Fig.14) was not obtained. The reason of the fact lies in the greater level of temporal decorrelation for C-band in comparison with L-band.

Figure 12. Polarization signature of quasi-matrix for field, C-band.

Figure 13. Polarization signature of corrected matrix for field, C-band.

Figure 14. Polarization signature of the reference scattering matrix for field, L-band.

Fig. 15 and 16 show classification results (ISODATA algorithm of 3-channel intensities: HH, HV, VV). The territory includes a mixed forest near Istomino settlement and its surroundings.

The forest in Fig.15 is clearly seen as a large magenta-cyan-yellow integration of three main classes. Fields are in red, green and blue. Classification results are almost the same for the real scattering matrix (observation on October 7, left part of the Fig.15) and for corrected quasi-matrix (right part). Total number of classes is 8.

Figure 15. Classification results (ISODATA algorithm of 3-channel intensities: HH, HV, VV). The territory includes a mixed forest near Istomino settlement and its surroundings.

Figure 16. Classification results (ISODATA algorithm of 3-channel intensities: HH, HV, VV). The territory includes a mixed forest near Istomino settlement and its surroundings.
C-band classification result differs from the reference much more, but we can see that unsupervised classification is not good for our C-band data: unlike L-band case, the border of the forest is unseen in the classification result at all.

4. RESUME

We can summary our main results in the following list:

•Two-pass registration of scattering matrix does work even for 2-days time interval.
•Distortions of scattering matrix can be modeled as a factor \( Ae^{j\phi} \) of the second line.
•The correction procedure is a symmetrization of a quasi-matrix.
•L-band demonstrates better results of correction than C-band because of lower level of temporal decorrelation.

5. REFERENCES
