Fusion of Evidences for Edge Detection in PolSAR Images

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October 19, 2019

TENGARSS 2019

Statistical Modeling

Statistical modeling for PolSAR data (1 - Look)

- The complex scattering matrix **S**:

$$\mathbf{S} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vv} & S_{vv} \end{bmatrix}. \tag{1}$$

- The medium of propagation of waves is reciprocal

$$\mathbf{s} = [S_{hh}, S_{hv}, S_{vv}]^T.$$

Statistical Modeling

Statistical modeling for PolSAR data (1 - Look)

- The probability density function (pdf):

$$f_{\mathbf{s}}(\mathbf{s};\Sigma) = \frac{1}{\pi^3|\Sigma|}\exp(-\mathbf{s}^H\Sigma^{-1}\mathbf{s}), \tag{2}$$

  - $|\cdot|$ is the determinant,
  - H denotes the conjugate complex number,
  - Σ is the covariance matrix of $\mathbf{s}$ such that $\Sigma = E[\mathbf{s}\mathbf{s}^H]$,
  - $E[\cdot]$ denotes the expected value.
  - The distribution of $\mathbf{s}$ is assumed to be Gaussian circular complex multivariate with zero mean $N_3^C(0,\Sigma)$.

Statistical Modeling

Statistical modeling for PolSAR data (L - Looks)

- The estimated sample covariance matrix:

$$\mathbf{Z} = \frac{1}{L}\sum_{\ell=1}^{L} \mathbf{s}_\ell \mathbf{s}_\ell{}^H, \tag{3}$$

  - $\mathbf{s}_\ell$, $\ell = 1, \ldots, L$;
  - L independent samples of complex vectors distributed as $\mathbf{s}$.

Statistical Modeling

Statistical modeling for PolSAR data (L - Looks)

- Multilooked Wishart distribution with probability density function:

$$f_{\mathbf{Z}}(\mathbf{Z}; \Sigma_s, L) = \frac{L^{mL}|\mathbf{Z}|^{L-m}}{|\Sigma_s|^{L}\Gamma_m(L)} \exp(-L\,\mathrm{tr}(\Sigma_s^{-1}\mathbf{Z})), \tag{4}$$

  - $\mathrm{tr}(\cdot)$ is the trace operator,
  - $\Gamma_m(L)$ is a multivariate Gamma function

$$\Gamma_m(L) = \pi^{\frac{1}{2}m(m-1)} \prod_{i=0}^{m-1} \Gamma(L-i),$$

  - $\Gamma(\cdot)$ is the Gamma function,
  - $m = 3$,
  - $\mathbf{Z} \sim W(\Sigma, L)$,

Edges detection

Method

The following procedure is proposed to detected edges in the hh, hv and vv channels:

- identify the centroid of a region of interest (ROI) in an automatic, semi-automatic or manual manner;
- cast rays from the centroid to the outside of the area;
- collect data around the rays using the Bresenham's midpoint line algorithm, ideally the size of a pixel;
- detect points in the data strips which provide evidence of changes in their statistical properties, i.e., a transition point that defines edge evidence;
- use the Generalized Simulated Annealing (GenSA) method, Ref. [1], to find maximum points in the functions of interest;
- fuse the evidence of detected edges in the hh, hv and vv channels.

Edges detection

ROI Flevoland Example

Figure 1: Edges detection example (hh channel).

Edges detection

Maximum Likelihood Estimator (MLE) for two regions A and B

- The estimates for the covariance matrices can be found using the maximum likelihood estimator denoted by $\widehat{\Sigma}$, Ref. [2]:

$$\widehat{\Sigma_I}(j) = \begin{cases} j^{-1} \sum_{k=1}^{j} \mathbf{Z}_k & \text{if} \quad I = A, \\ (N-j)^{-1} \sum_{k=j+1}^{N} \mathbf{Z}_k & \text{if} \quad I = B. \end{cases} \tag{5}$$

- log-likelihood function

$$\ell(j) = \sum_{k_1=1}^{j} \ln f_{\mathbf{Z}}(\mathbf{Z}_{k_1}; \widehat{\Sigma}_A, L) + \sum_{k_2=j+1}^{N} \ln f_{\mathbf{Z}}(\mathbf{Z}_{k_2}; \widehat{\Sigma}_B, L). \tag{6}$$

Edges detection

Maximum Likelihood Estimator (MLE)

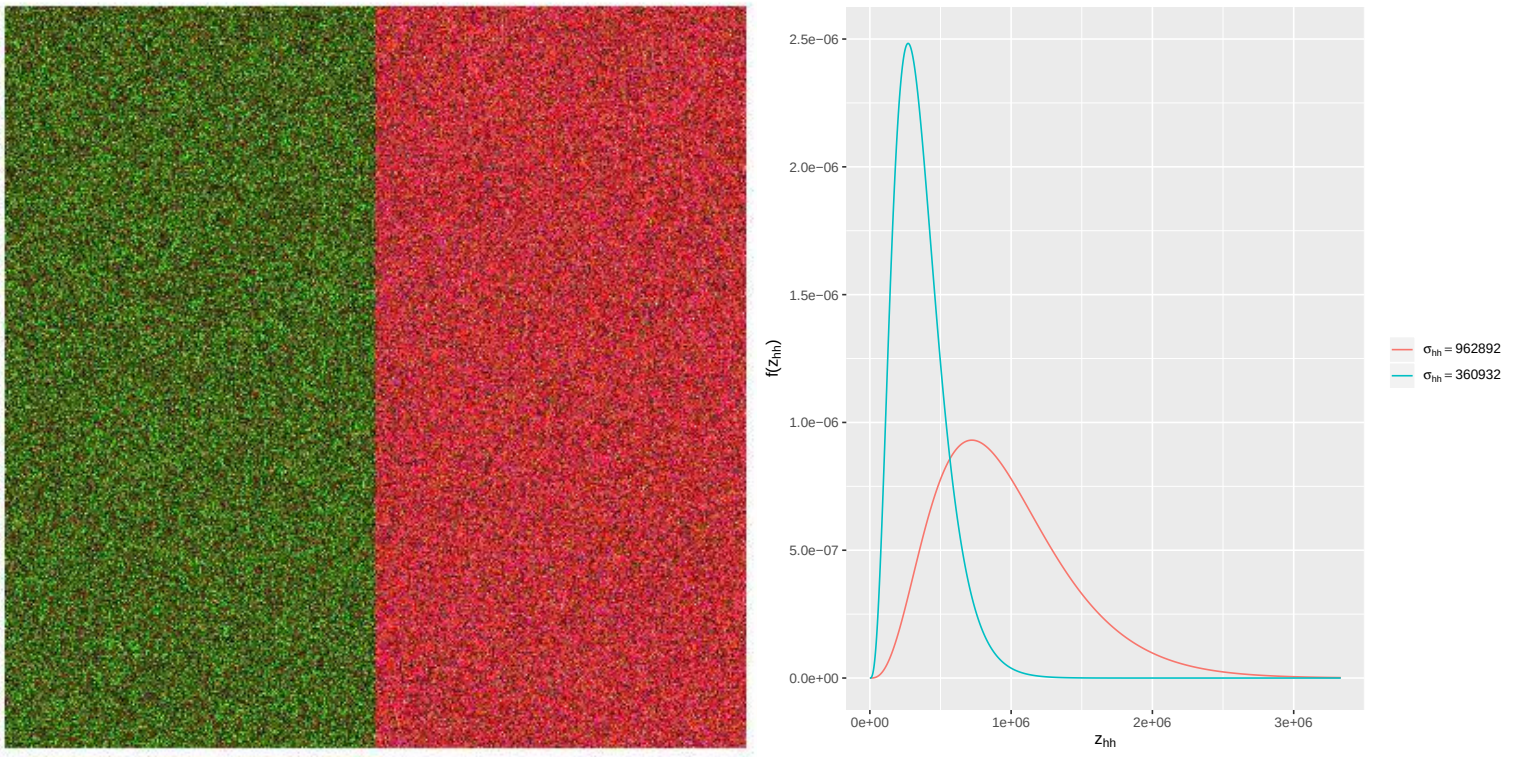
- After algebraic manipulations on each term of the summation, it is obtained:

$$\begin{aligned}\ell(j) = N\left[mL(\ln L - 1) - \ln \Gamma_m(L)\right] \\ - L\left[j \ln |\widehat{\Sigma}_A(j)| + (N-j) \ln |\widehat{\Sigma}_B(j)|\right] \\ + (L-m)\sum_{k=1}^{N} \ln |\mathbf{Z}_k|. \end{aligned} \tag{7}$$

- The argument of the maximum $\widehat{j}$ is the edge evidence that will be used in our fusion methods.

Edges detection

Application in simulated images



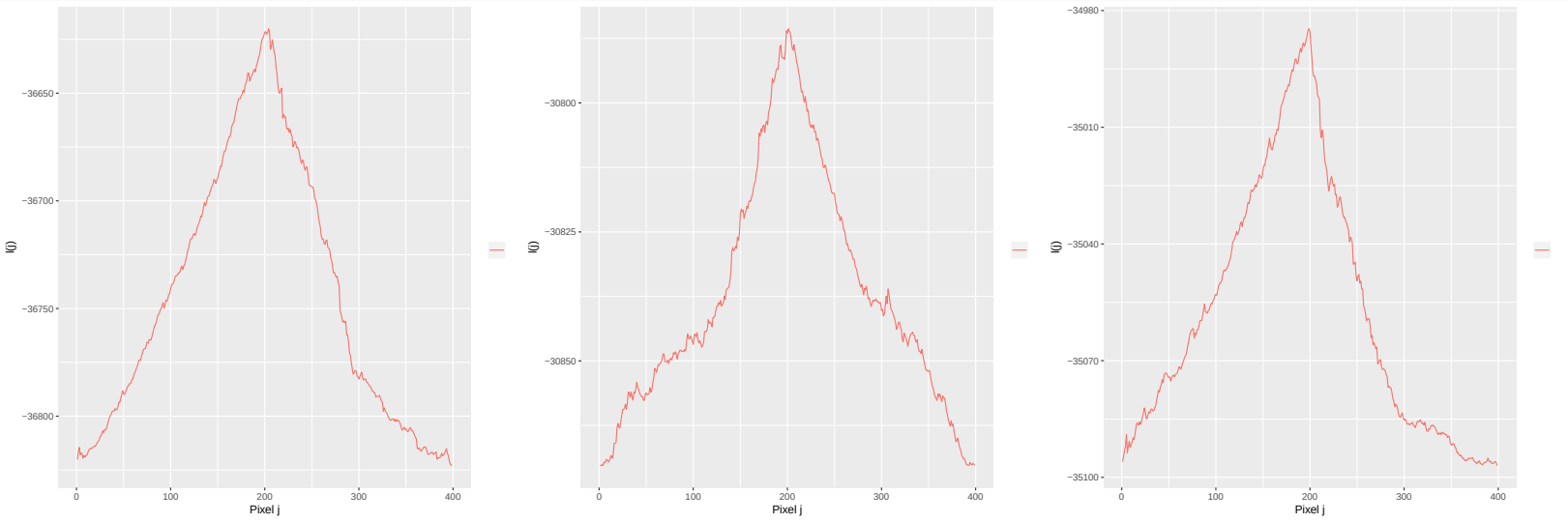
(a) Pauli decomposition

(b) Marginal densities of the hh channel

Figure 2: Model and observations

Edges detection

Application in simulated images



(a) Channel hh (b) Channel hv (c) Channel vv

Figure 3: $l(j)$ log-likelihood function

Edges detection

Application in simulated images

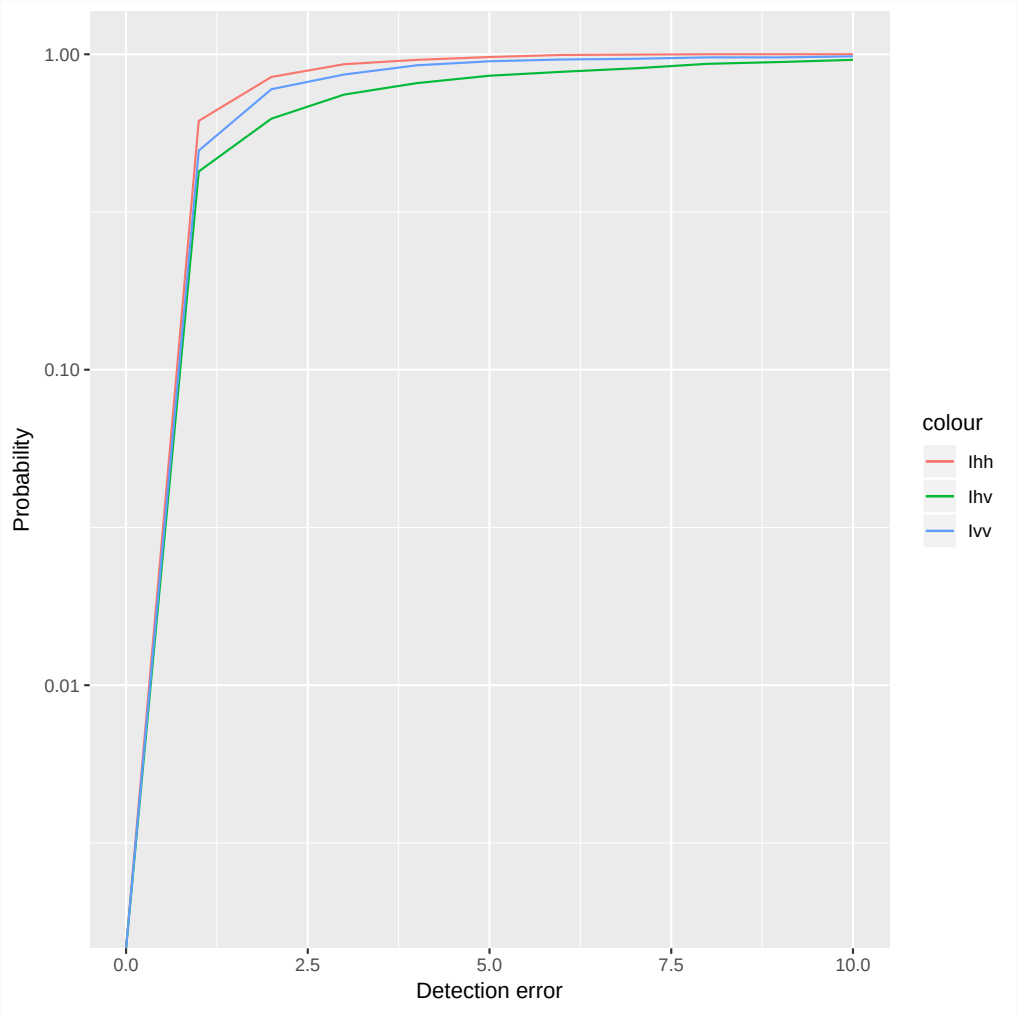


Figure 4: Probability of detecting edges evidences.

Average Fusion

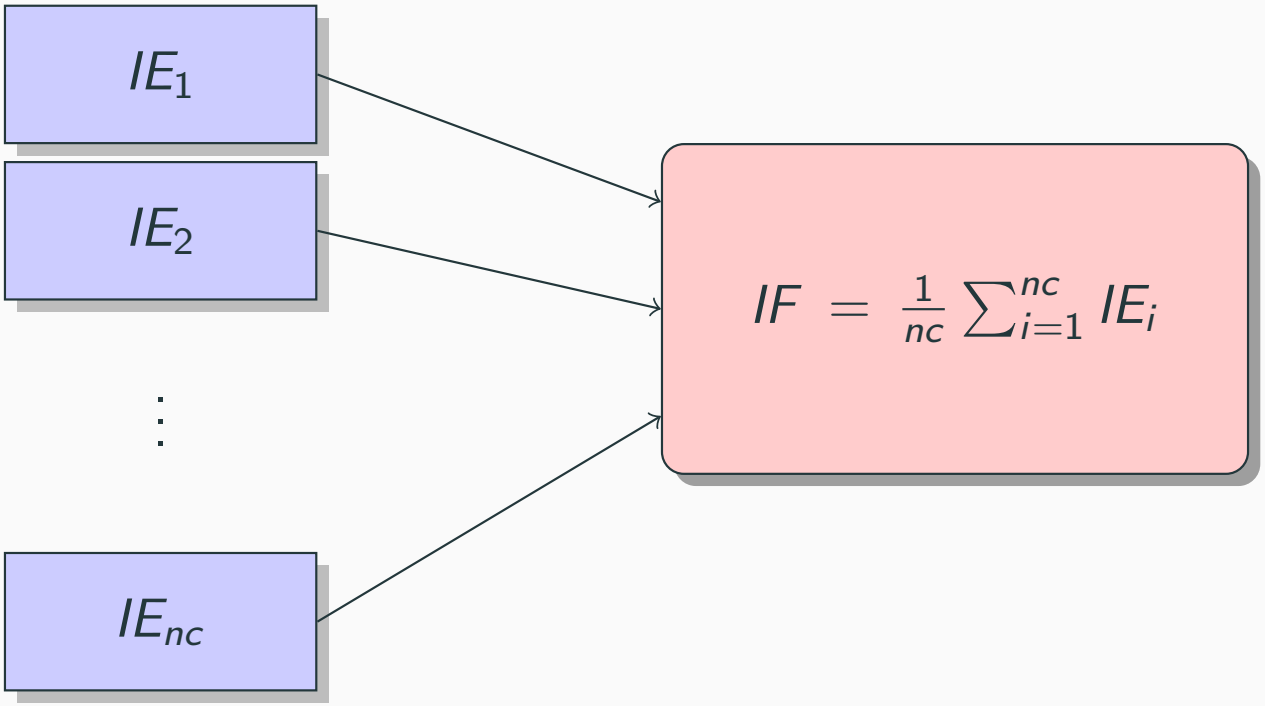


Figure 5: Average Fusion.

Evidence Fusion

PCA Fusion

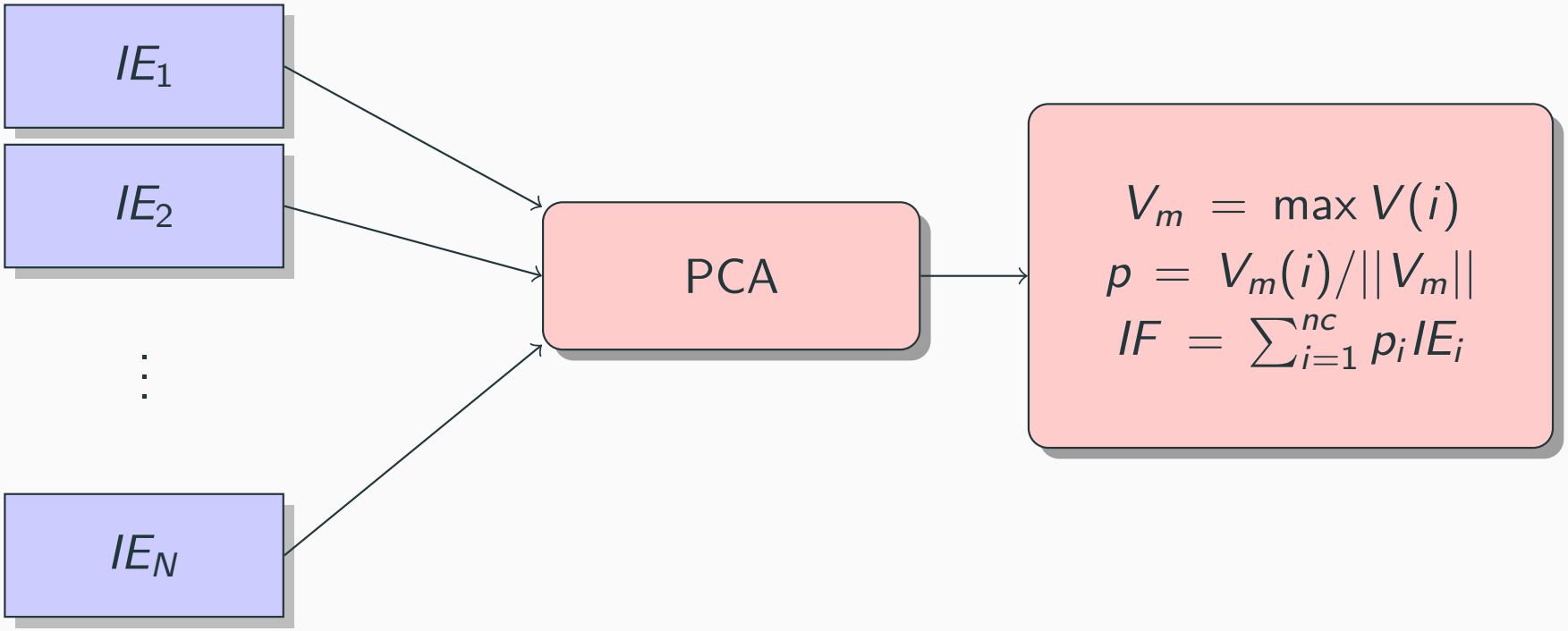


Figure 6: PCA Fusion.

Evidence Fusion

Stationary wavelet transform – SWT Fusion

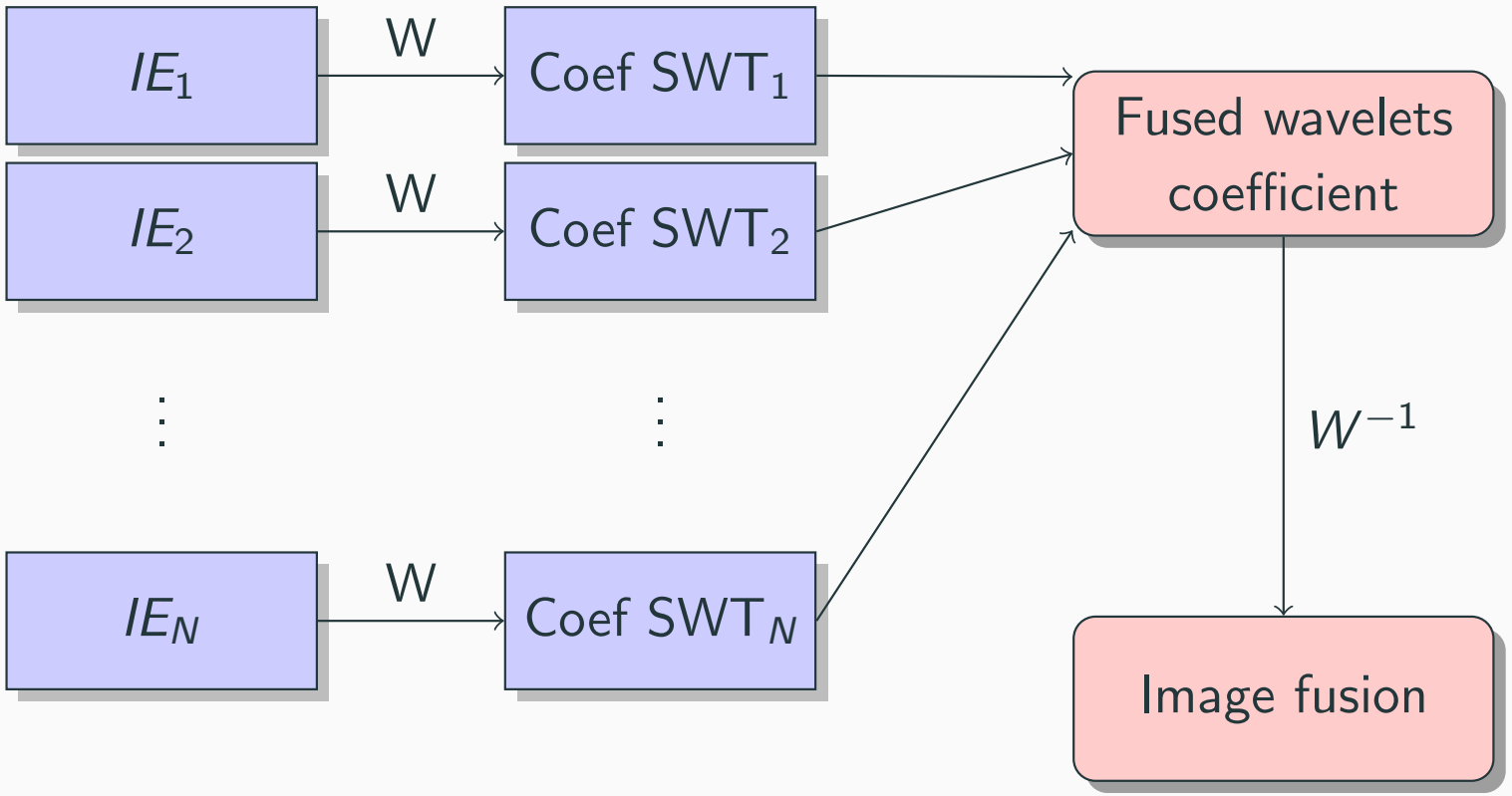


Figure 7: SWT Fusion.

- W is wavelet transformed.

Evidence Fusion

ROC statistics Fusion

- Part I

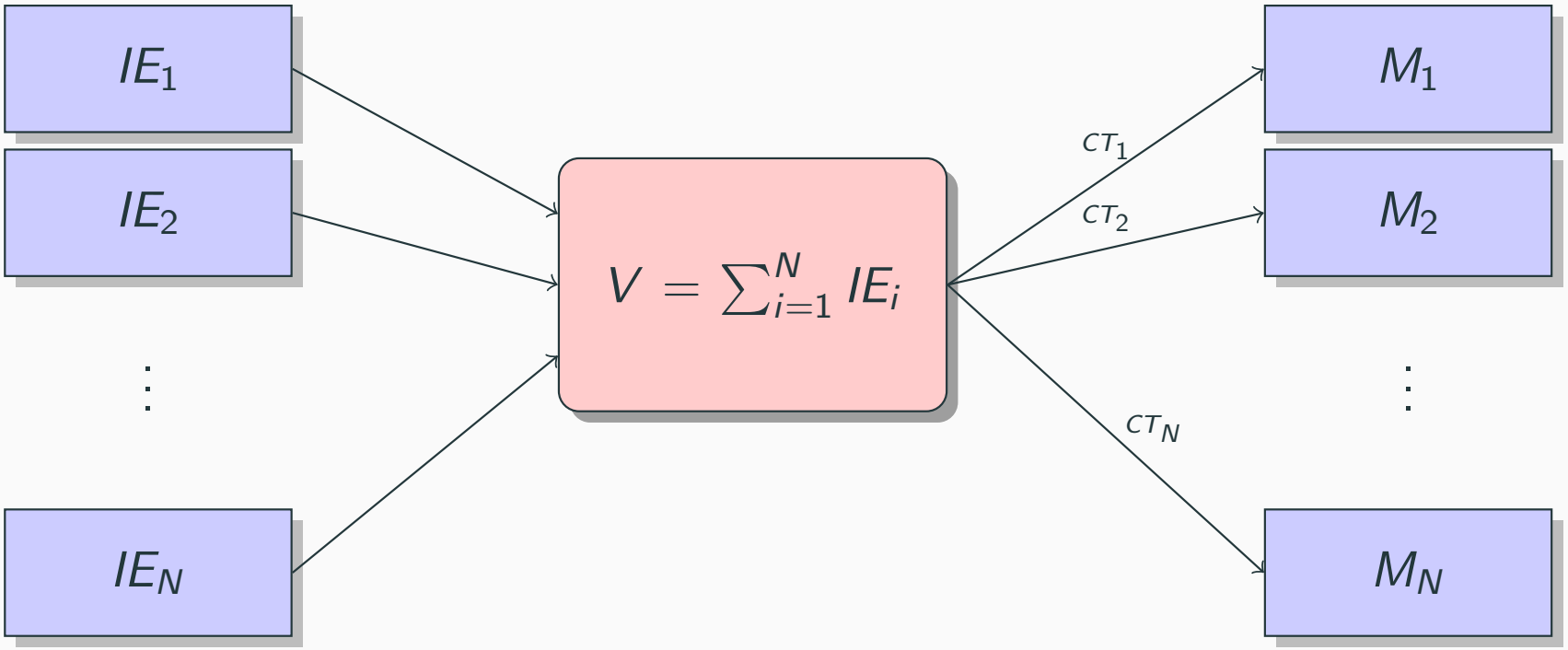


Figure 8: Fusion based in ROC statistics - Part I.

- CT_i is a threshold.

Evidence Fusion

ROC statistics Fusion

- Part II - for each M_j

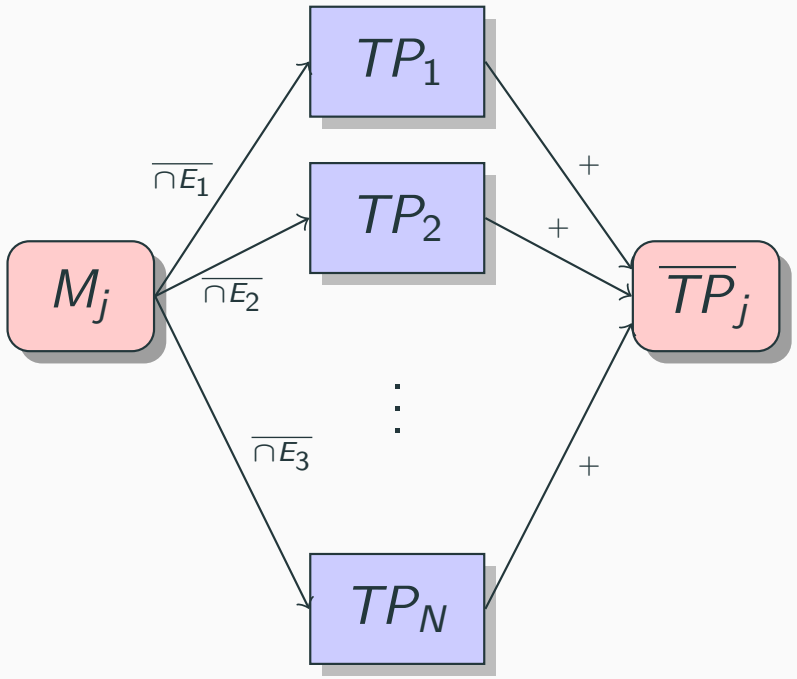


Figure 9: ROC Fusion for each j. It is true to $\overline{TN}_j$,$\overline{FP}_j$ and, $\overline{FN}_j$.

- To generate the confusion matrix, and calculate the ROC statistics.

Results

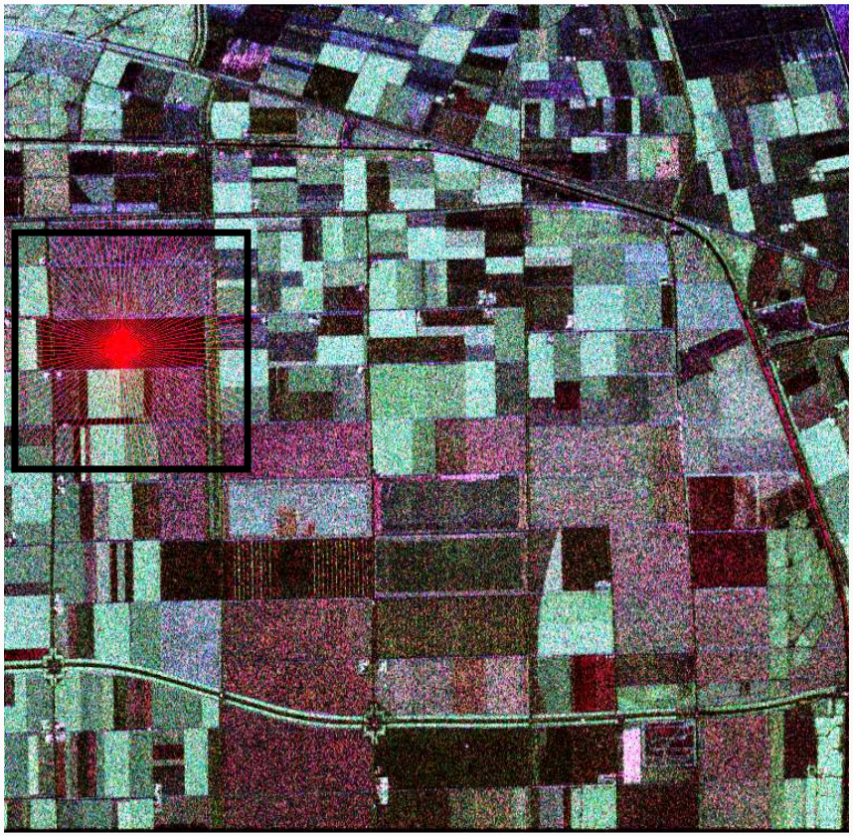
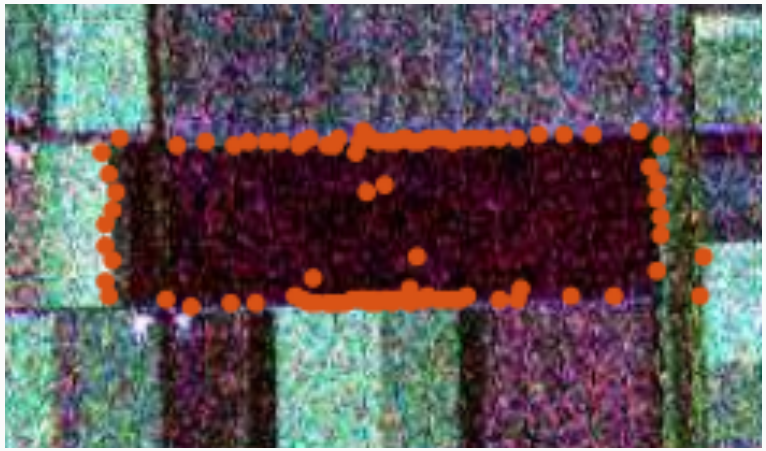


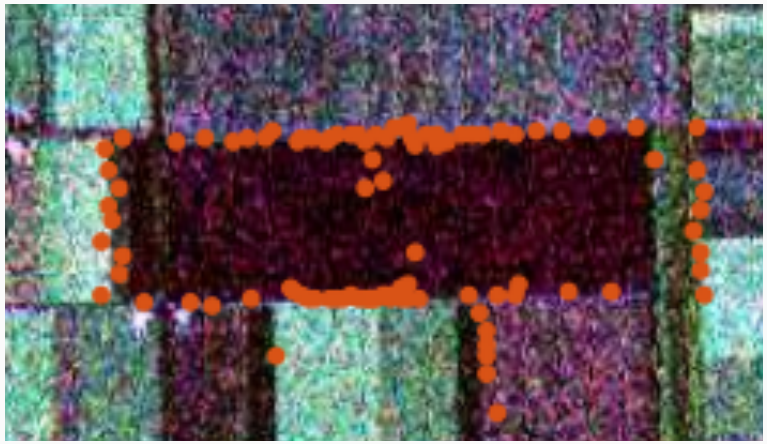
Figure 10: Region of interest (ROI) in the image of Flevoland.

Results



(a) Evidences in channel hh

(b) Evidences in channel hv



(c) Evidences in channel vv

Results

(a) Average Fusion

(b) PCA Fusion

(c) SWT Fusion

(d) ROC Fusion

Figure 12: Evidence after fusion

Conclusion

Conclusion

- Simulated Annealing works very well in non differentiable function. Figure (4) shows the probability of detecting edges evidences;
- The method to detect edges evidence in each channel works very well. See Figure (11). Similar ideas can be found in Refs. [3, 4];
- The fusion of evidence in intensity channels shows that these channels can be complementary and, therefore, suitable for edge detection in PolSAR images. See Figure (12).
- The article shows the viability of these methods and your extension to more channels.

Future researches

- Increase the number of channels to improve the fusion;
- Investigate new fusion methods.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