Seven-Category Model-based Segmentation for Polarimetric SAR Data

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Outline

- Idea of this work
- Details of the solution
- Experimental Results & Observations
- Conclusion

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  - Review of the model-based decomposition
  - Unsuitable requirement on the data
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Conventional Model-based Decomposition Algorithm

- Conventional model-based decomposition algorithms decompose the coherency/covariance matrix into three components
  - Surface Scattering (Bragg scattering)
  - Double-bounce Scattering
  - Volume Scattering
- The representative algorithms, to name a few, are
  - The well-known Freeman-Durden Decomposition
    - Reflection Symmetry Assumption
    - Negative Power Problem
  - Van Zyl Decomposition [1]
    - Reflection Symmetry Assumption
    - Orthogonality of Surface and Double-bounce target vector
  - Arii Decomposition [2]
    - Orthogonality of Surface and Double-bounce target vector

The Problem with Conventional Model-based Decomposition Algorithm

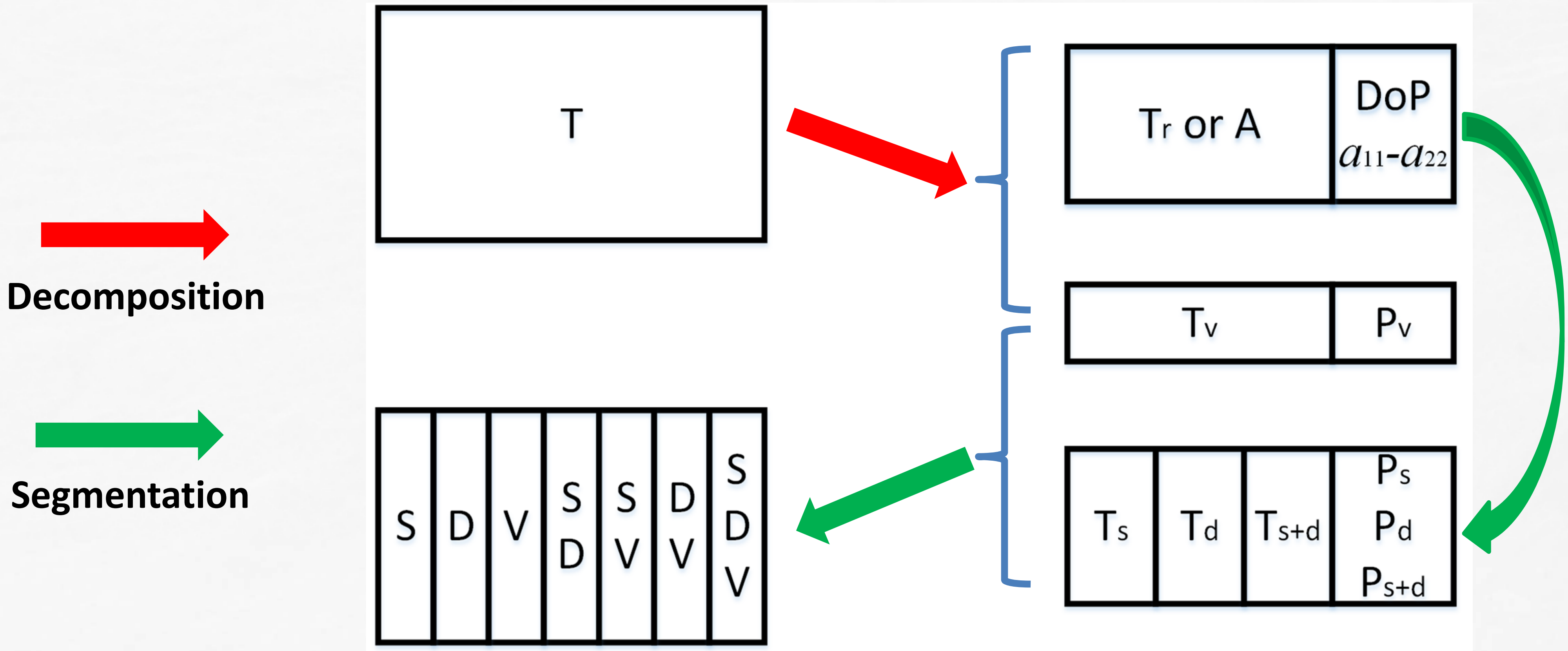
- The prerequisites for these algorithms to work well
  1. Proper volume scattering model is used;
  2. Assumptions are met;
  3. One of the three scattering components is dominant. ← Problem
- In a word, the relative strength between each scattering mechanism determines whether the conventional algorithms work well or not.
- Solution:
  – New scattering categories should be defined to cope with the situation when no dominant scattering presents;
  – New algorithm should be devised to estimate the relative strength between each scattering mechanism.

New Scattering Categories

- S: surface scattering dominates;
- D: double-bounce scattering dominates;
- V: volume scattering dominates;
- S+D: surface and double-bounce hybrid scattering;
- S+V: surface and volume hybrid scattering;
- D+V: double-bounce and volume hybrid scattering;
- S+D+V: triple hybrid.

Relative Strength Estimation

- Model-based decomposition algorithm combined with rule-based segmentation are used to estimate the relative strength.



Arii's Three Component Model

- Surface Scattering (Bragg scattering)
- Double-bounce Scattering
- Volume Scattering

$$\mathbf{T}_s = \frac{1}{1+|\beta|^2}\begin{pmatrix} 1 & \beta & 0 \\ \beta^* & |\beta|^2 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\mathbf{T}_d = \frac{1}{1+|\alpha|^2}\begin{pmatrix} |\alpha|^2 & \alpha & 0 \\ \alpha^* & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\mathbf{T}_v(\theta_0,\sigma) = \mathbf{T}_\alpha + p(\sigma)\mathbf{T}_\beta(2\theta_0) + q(\sigma)\mathbf{T}_\gamma(4\theta_0)$$

$$\begin{cases} \mathbf{T}_\alpha = \frac{1}{4}\begin{pmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \\ \mathbf{T}_\beta(2\theta) = \frac{1}{4}\begin{pmatrix} 0 & -\cos 2\theta & \sin 2\theta \\ -\cos 2\theta & 0 & 0 \\ \sin 2\theta & 0 & 0 \end{pmatrix} \\ \mathbf{T}_\gamma(4\theta) = \frac{1}{4}\begin{pmatrix} 0 & 0 & 0 \\ 0 & \cos 4\theta & -\sin 4\theta \\ 0 & -\sin 4\theta & -\cos 4\theta \end{pmatrix} \end{cases}$$

The expression for function $p(\sigma)$ and $q(\sigma)$ can be found in [2].

Arii's Three Component Decomposition:

$$\mathbf{T} = P_s\mathbf{T}_s + P_d\mathbf{T}_d + P_v\mathbf{T}_v(\theta_0,\sigma)$$

1). The volume scattering component estimation in [2] does not relies on the azimuth symmetry assumption.
2). The volume scattering model can be applied to general vegetation.

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Details of The Solution

1. Refined Lee filter -> multiplicative noise;
2. Hajnsek filter [3] -> additive noise;
3. Estimate $\mathbf{T}_v(\theta_0, \sigma)$ and P_v using Arii's decomposition algorithm;

$$\mathbf{T}_v(\theta_0,\sigma) = \mathbf{T}_\alpha + p(\sigma)\mathbf{T}_\beta(2\theta_0) + q(\sigma)\mathbf{T}_\gamma(4\theta_0) \begin{cases} \mathbf{T}_\alpha = \frac{1}{4}\begin{pmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \\ \mathbf{T}_\beta(2\theta) = \frac{1}{4}\begin{pmatrix} 0 & -\cos 2\theta & \sin 2\theta \\ -\cos 2\theta & 0 & 0 \\ \sin 2\theta & 0 & 0 \end{pmatrix} \\ \mathbf{T}_\gamma(4\theta) = \frac{1}{4}\begin{pmatrix} 0 & 0 & 0 \\ 0 & \cos 4\theta & -\sin 4\theta \\ 0 & -\sin 4\theta & -\cos 4\theta \end{pmatrix} \end{cases}$$

The expression for function $p(\sigma)$ and $q(\sigma)$ can be found in [2].

1). The volume scattering component estimation in [2] does not relies on the reflection symmetry assumption.
2). The volume scattering model can be applied to general vegetation.

Details of The Solution

4. Segmentation of the remainder matrix $\mathbf{T}_r$

$$\mathbf{T}_r = \mathbf{T} - P_v\mathbf{T}_v(\theta_0,\sigma) = P_s\mathbf{T}_s + P_d\mathbf{T}_d$$

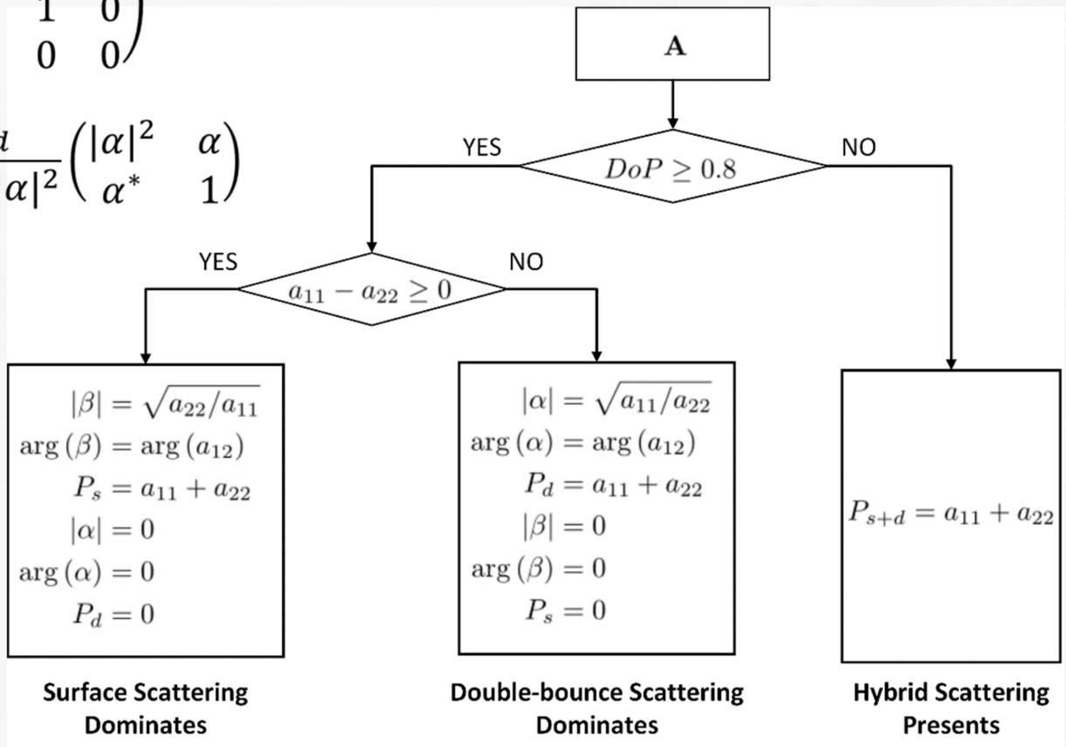
$$= \frac{P_s}{1+|\beta|^2}\begin{pmatrix} 1 & \beta & 0 \\ \beta^* & |\beta|^2 & 0 \\ 0 & 0 & 0 \end{pmatrix} + \frac{P_d}{1+|\alpha|^2}\begin{pmatrix} |\alpha|^2 & \alpha & 0 \\ \alpha^* & 1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} \\ a_{12}^* & a_{22} \end{pmatrix} = \frac{P_s}{1+|\beta|^2}\begin{pmatrix} 1 & \beta \\ \beta^* & |\beta|^2 \end{pmatrix} + \frac{P_d}{1+|\alpha|^2}\begin{pmatrix} |\alpha|^2 & \alpha \\ \alpha^* & 1 \end{pmatrix}$$

$$DoP = \sqrt{1 - \frac{4(a_{11}a_{22} - |a_{12}|^2)}{(a_{11}+a_{22})^2}}$$

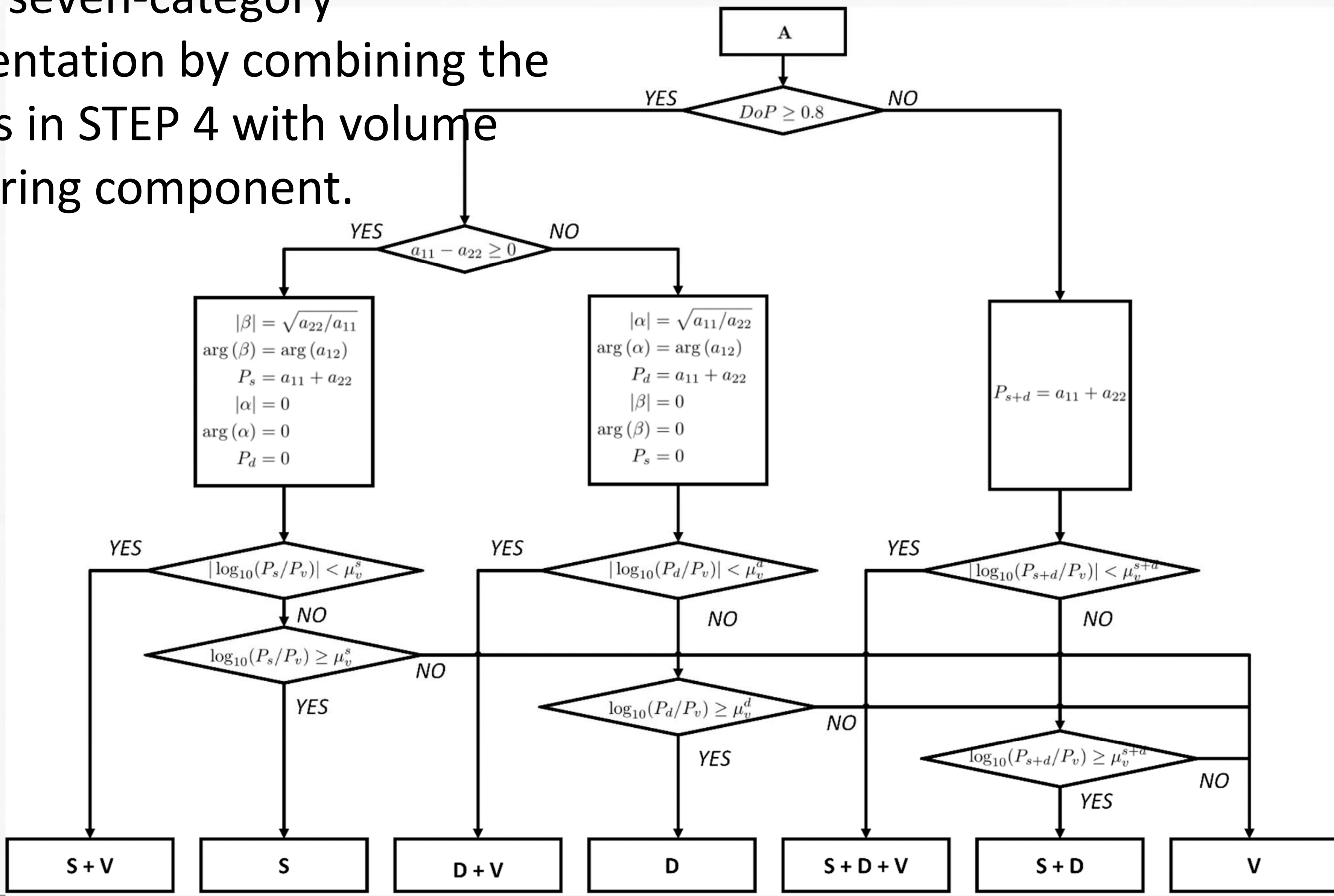
$$Dop \to 1 \quad if \quad |\log_{10}(P_s/P_d)| \to Inf$$

$$Dop = 0.8 \Leftrightarrow |\log_{10}(P_s/P_d)| = 1$$



Details of The Solution

5. Doing seven-category segmentation by combining the results in STEP 4 with volume scattering component.



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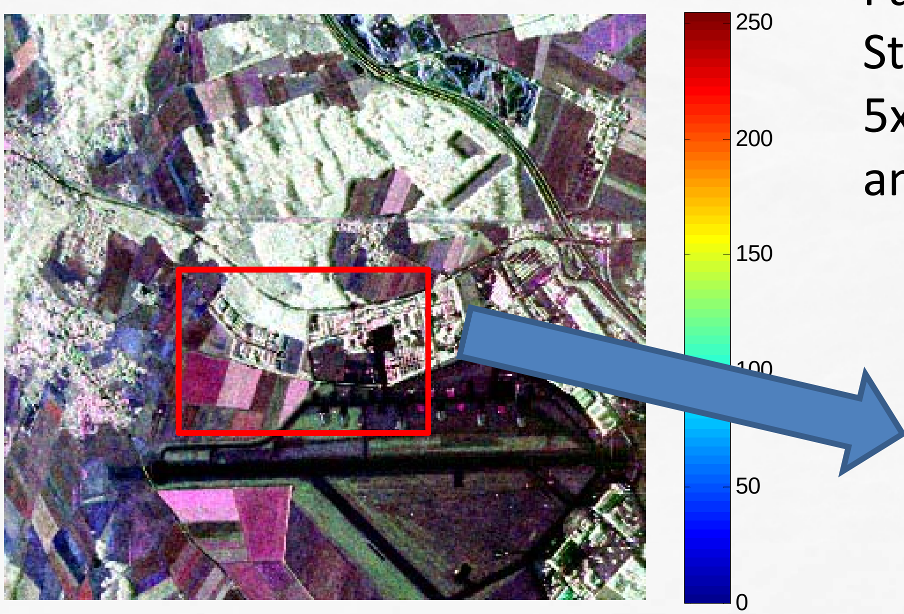
Experimental Results
Dataset Description & Filtering

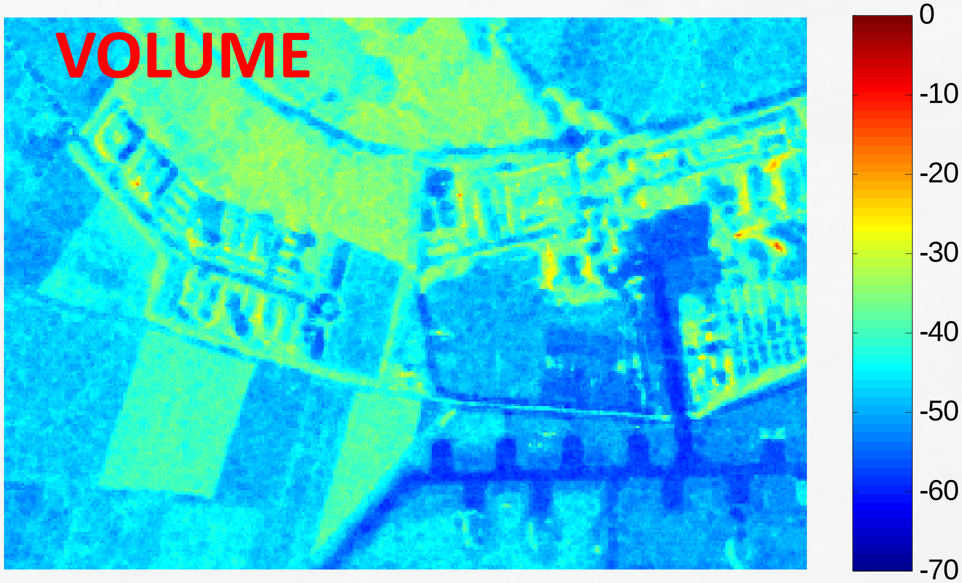
- DLR ESAR L-band image of Oberpfaffenhofen
  - Original Size 2816x1540 [**T4**]
  - 2-look along azimuth to make the pixel square [**T4**]



Pauli RGB Image of the Test Data.
Step 1 and 2 have already been applied.
5x5 and 1x1 windows are used in Step 1 and Step 2 respectively.

A 383x556 subarea is extracted for the demonstration.

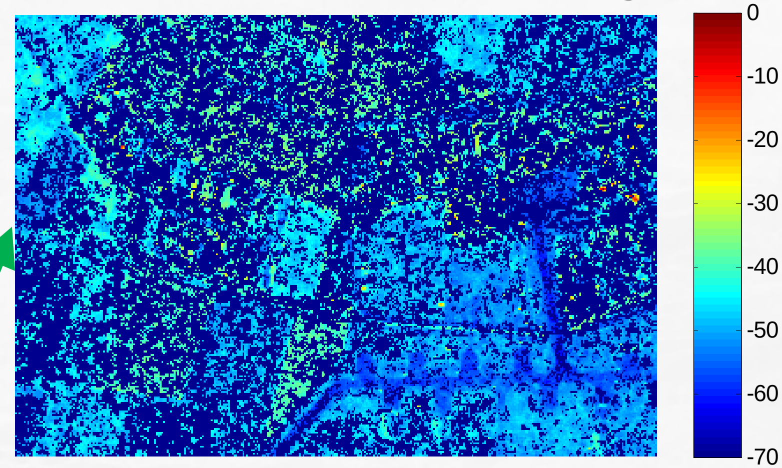
Experimental Results
Step 3. Volume Scattering Extraction



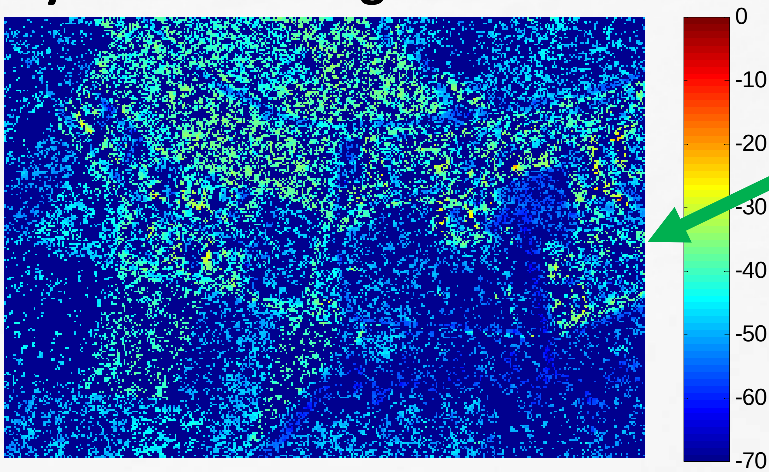
Experimental Results

Step 4. Segmentation of Remainder Matrix

Surface Dominant Scattering

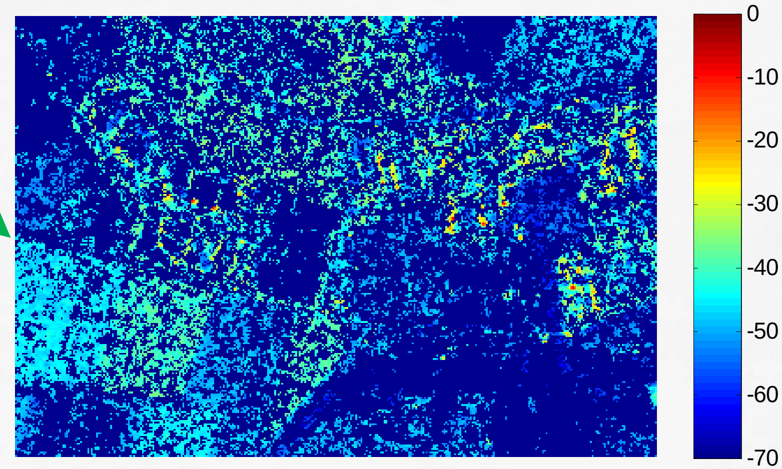


Surface and Double-bounce Hybrid Scattering



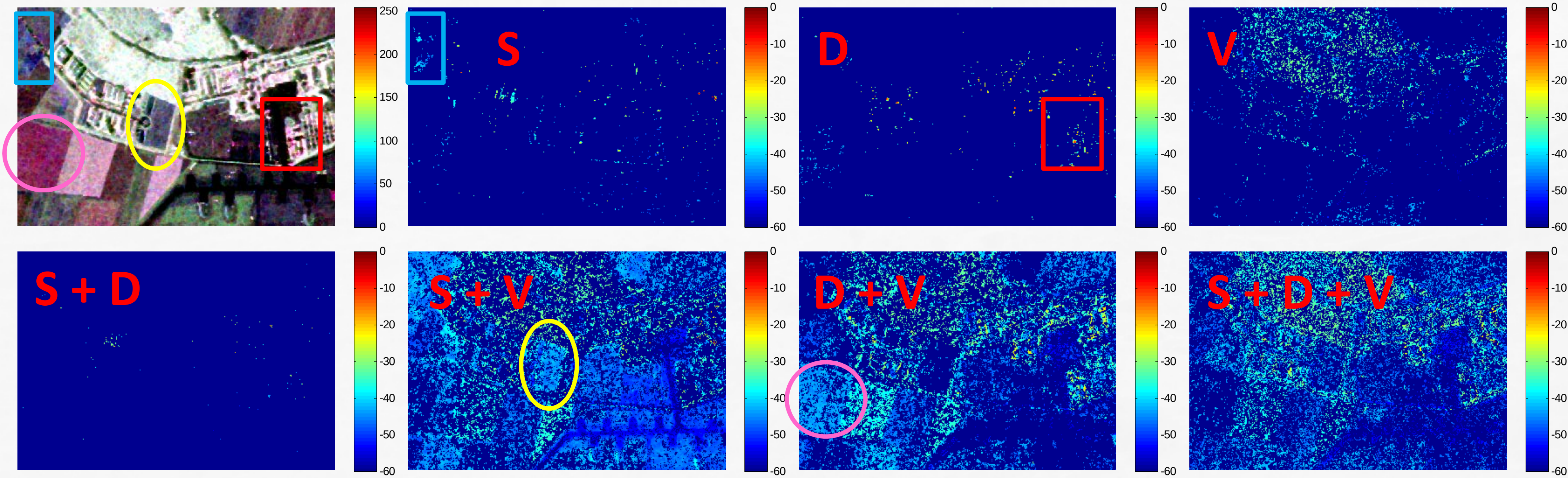
$\mathbf{T}_r$

Double-bounce Dominant Scattering

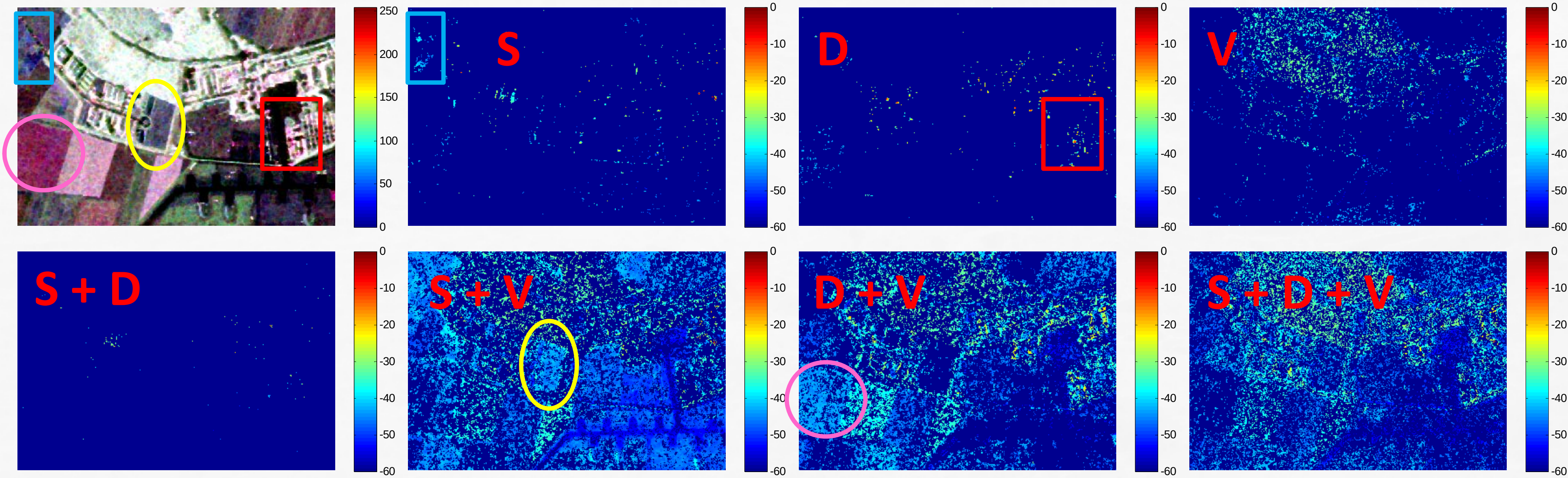


Experimental Results

Step 5. Seven-Category Segmentation

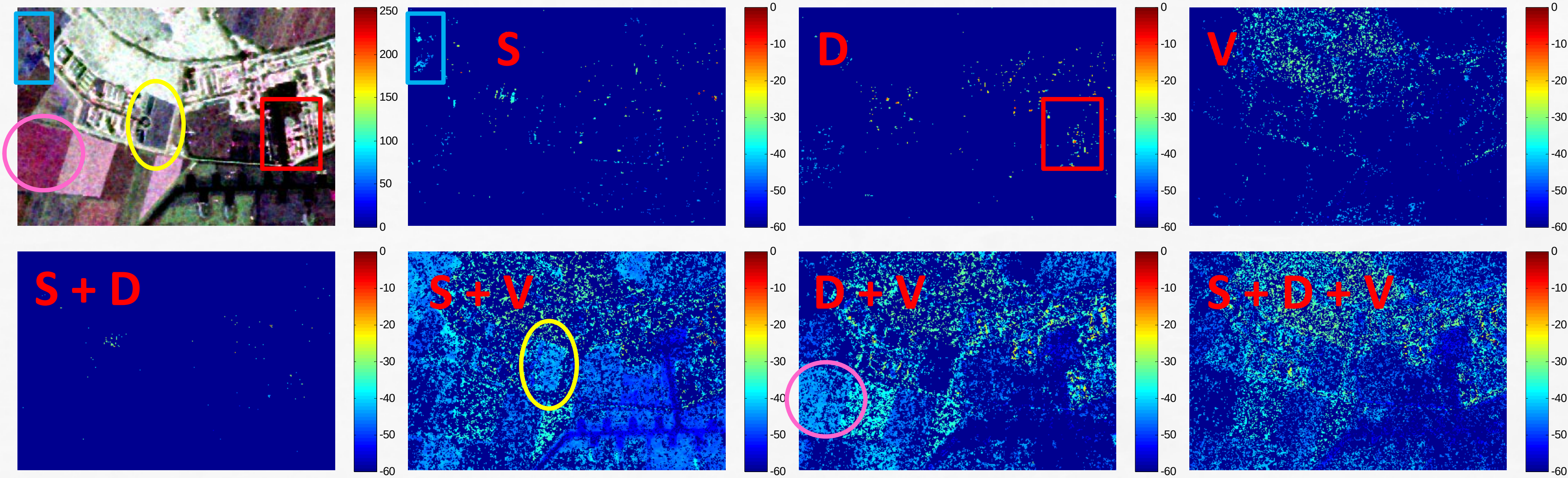


Observation (1/3)



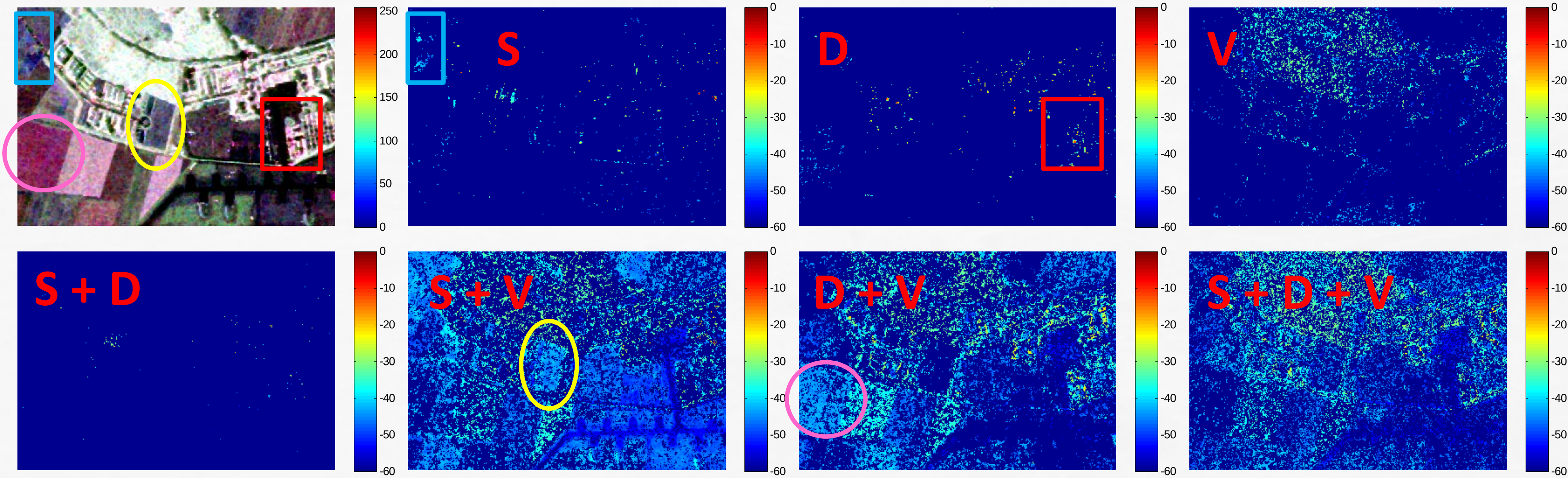
This segmentation algorithm enables direct access to area where pure surface or double-bounce scattering is present as shown in the blue and red rectangular.

Observation (2/3)



Considerable amount of pixels exhibit hybrid scattering mechanism. These new defined scattering categories enable better characterization of the underlying complex scattering process as shown in the ellipse.

Observation (3/3)



The forest area are mainly labeled as "S+D+V" category. Significant number of "holes" are present in the forest area of "S+D+V" image. These may caused by improper selection of the thresholds in Step 5.

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Conclusion

- Hybrid scattering is very common in POLSAR data due to the complex interaction between the EM wave and nature media. The conventional decomposition algorithm will result in unreliable results in those area where hybrid scattering presents. These unreliable results may be misleading if not interpreted with caution.
- The experimental results and observation have preliminarily demonstrated the effectiveness and usefulness of this seven-category segmentation.

Future Work

- Clustering step should be added to avoid the “hole” problem. A good clustering algorithm can soften the impact of the improper thresholds .
- The classification algorithm using this segmentation in the initial clustering step will be developed in the future work. This classification is believed to be capable of preserving scattering mechanisms.

Reference

[1] J. J. van Zyl, M. Arii, and K. Yunjin, "Model-Based Decomposition of Polarimetric SAR Covariance Matrices Constrained for Nonnegative Eigenvalues," IEEE TGRS, vol. 49, no.9, pp. 3452-3459, sept. 2011

[2] M. Arii, J. J. van Zyl, and K. Yunjin, "Adaptive model-based decomposition of polarimetric SAR covariance matrices," *IEEE TGRS*, vol. 49, no. 3, pp. 1104-1113, march. 2011.

[3] I. Hajnsek, K. P. Papathanassiou, and S. R. Cloude, "Removal of additive noise in polarimetric eigenvalue processing," IGARSS 2001, vol. 6, pp. 2778-2780

Thanks!

Questions & Answers