2017 DRAGON 4 SYMPOSIUM

Feature Extraction on PolSAR Images for Detection of Anthropogenic Extents

Meiqin Che,Andrea Marinoni,Gianni Iannelli Cristian, Paolo Gamba

Università degli Studi di Pavia

Italy

Outline

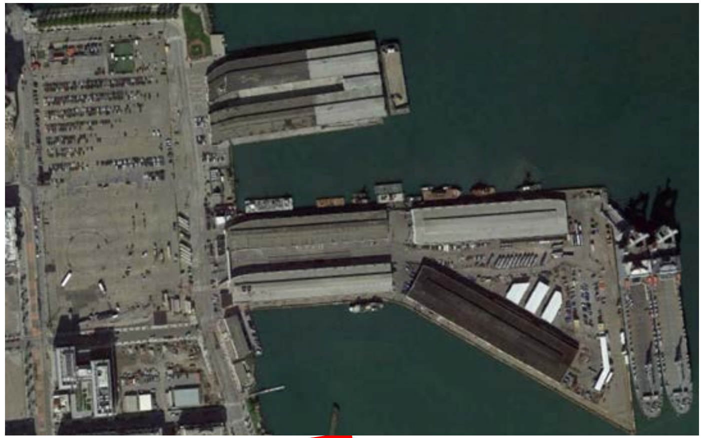
- **Understanding roll-invariance**
  1. Polarization orientation angle shift and depolarization
  2. Roll-invariant polarimetric parameters
- **Handle multivariable pattern of Quad PolSAR data**
  1. Ensemble optimizing on feature selection
  2. Hierarchical hybrid decision tree (HBDT)
  3. Data driven feature extraction(DDFE)
- **Conclusion and discussion**

Introduction

Urban areas are crowed with buildings, squares, streets, stadiums and special man-made targets like…

Sunset Reservoir, San Francisco

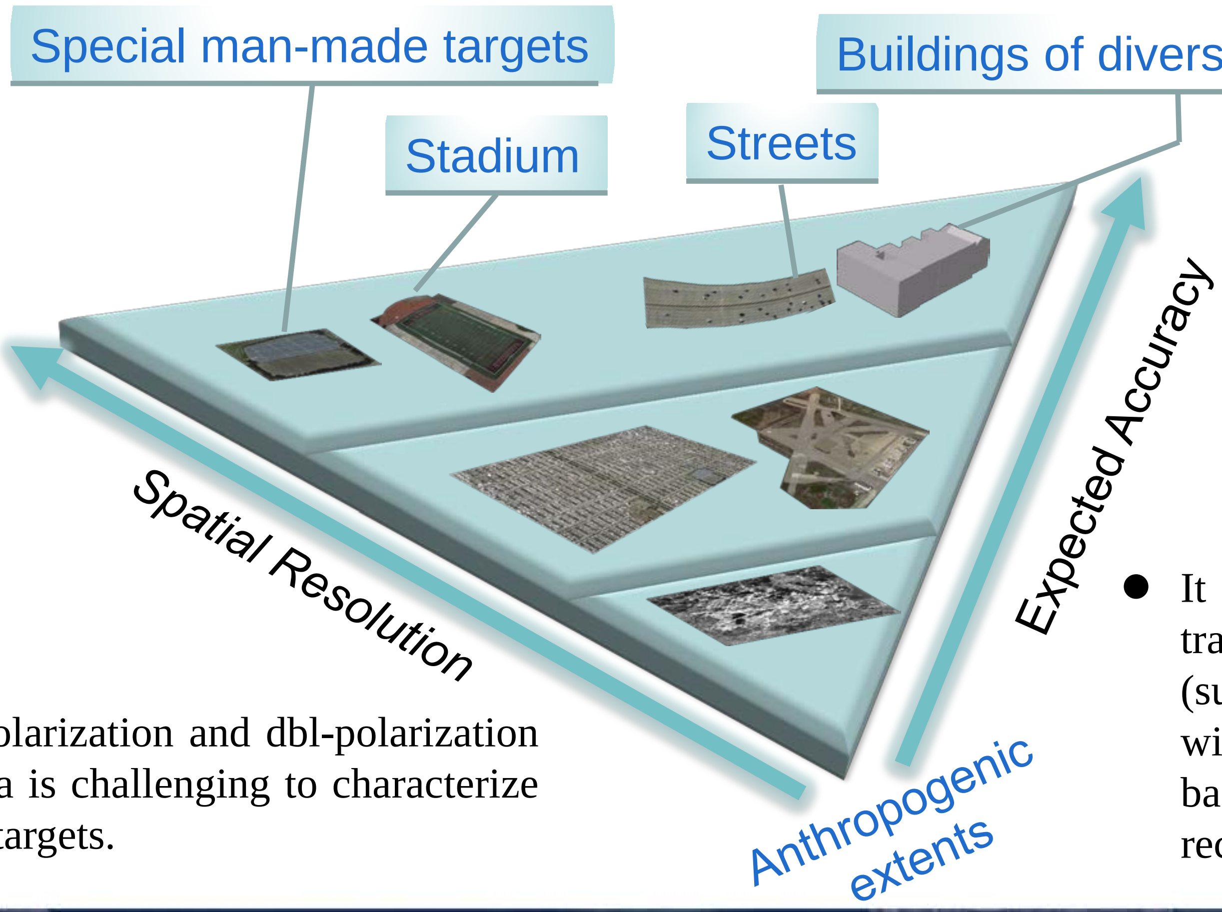
Ericsson Globe, Stockholm



Mission Bay, San Francisco

The back-scatterings from the SAR image are very diversified due to the complexity and diversity of man-made structures

Challenges in Urban Radar Remote Sensing using MR SAR and HR SAR



- At finer spatial resolution,more complex and detailed content of urban targets is collected,but with very different scattering effects
- It is not easy to describe these targets with traditional physical scattering models (surface,double and volume scattering) even with Quad-PolSAR data. Some wake backscattering signals are still hard to recognize
- Single-polarization and dbl-polarization SAR data is challenging to characterize detailed targets.

We are going to...

- **Explore new and useful polarimetric parameters**
  - Roll-invariance of polarimetric scattering
- **Characterize targets using suitable properties by selected polarimetric parameters**
  - Ensemble feature selection
- **Utilize multivariable dataset to detect anthropogenic extents using unsupervised and supervised strategies in the feature space**
  - Hierarchical binary decision tree (HBDT）
  - Unsupervised data driven feature extraction (DDFT)

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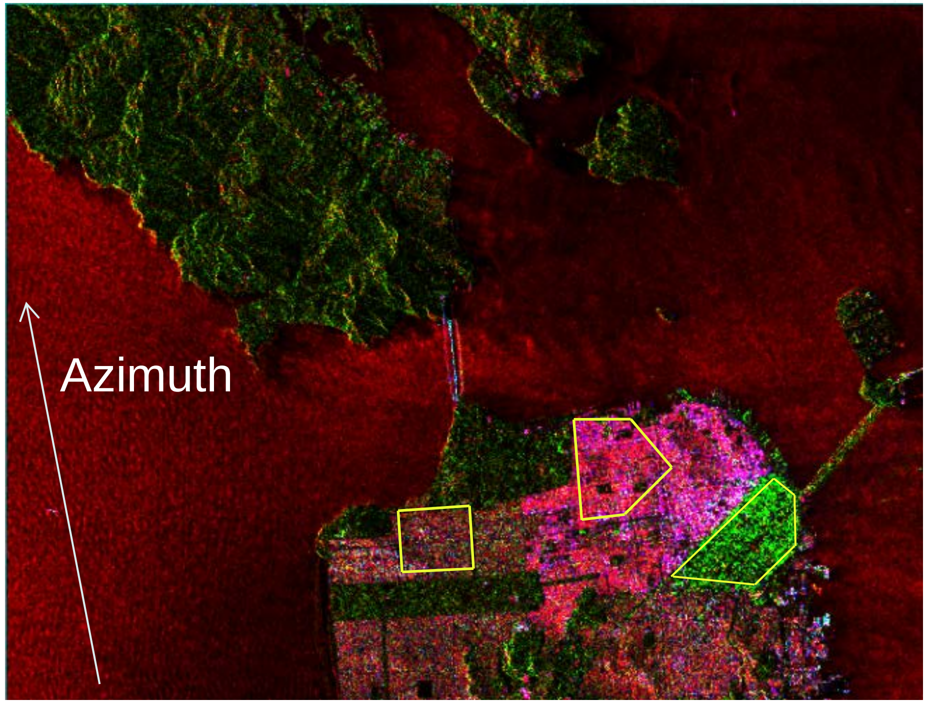
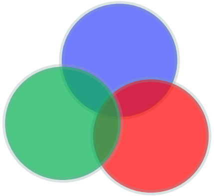
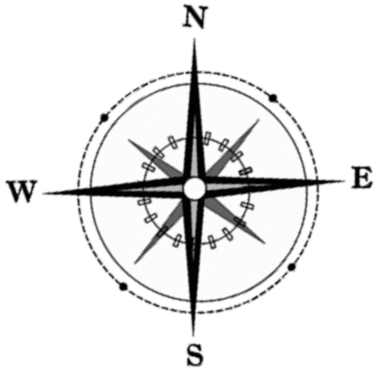
Study Case: San Francisco



Yamaguchi four-component decomposition of Radarsat-2 PolSAR(San Francisco)

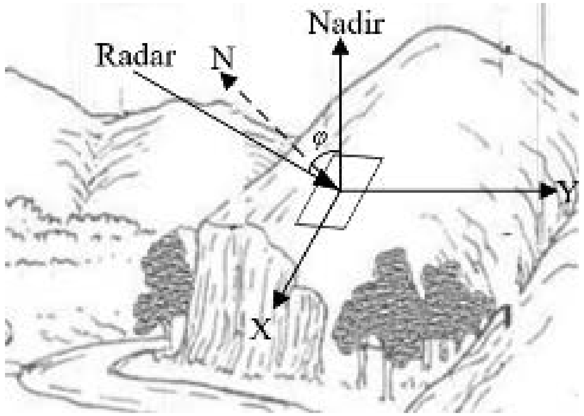


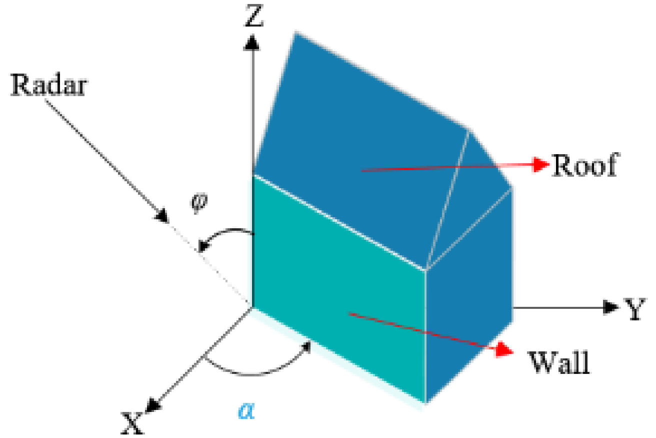
Odd-bounce scatters
Volume scatters
Double-bounce scatters



Understanding roll-invariance

Polarization orientation angle(***POA***) shift in mountainous area and in built-up area with variously orientated buildings





$$\tan\theta = \frac{\tan\alpha}{-\tan\gamma\cos\varphi + \sin\varphi}$$

$$\tan\theta = -\frac{\tan\alpha}{\cos\varphi}$$

φ——radar look angle

α——azimuth slope

γ ——range slope

Buildings with diverse orientation also cause ***POA shift***

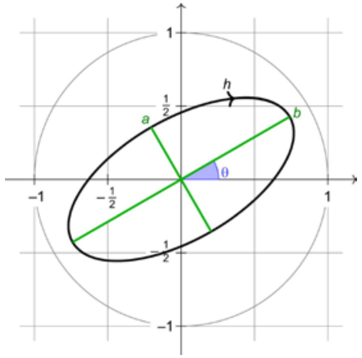
Lee J S, Schuler D L, Ainsworth T L. Polarimetric SAR data compensation for terrain azimuth slope variation[J]. IEEE Transactions on Geoscience and Remote Sensing, 2000, 38(5): 2153-2163.

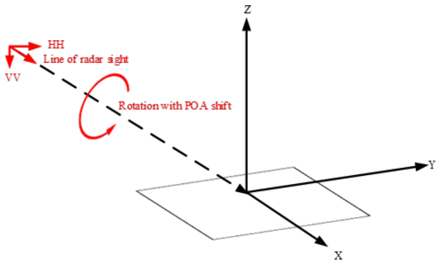
Kimura H. Radar polarization orientation shifts in built-up areas[J]. IEEE Geoscience and remote sensing letters, 2008, 5(2): 217-221.

Understanding roll-invariance

How can we handle with POA shift?

- **POA compensation**





$$S^{new}=\begin{bmatrix}\cos(\theta) & \sin(\theta)\\ -\sin(\theta) & \cos(\theta)\end{bmatrix}\cdot S\cdot\begin{bmatrix}\cos(\theta) & -\sin(\theta)\\ \sin(\theta) & \cos(\theta)\end{bmatrix} \qquad \boldsymbol{S}=\begin{bmatrix}S_{hh} & S_{hv}\\ S_{vh} & S_{vv}\end{bmatrix}$$

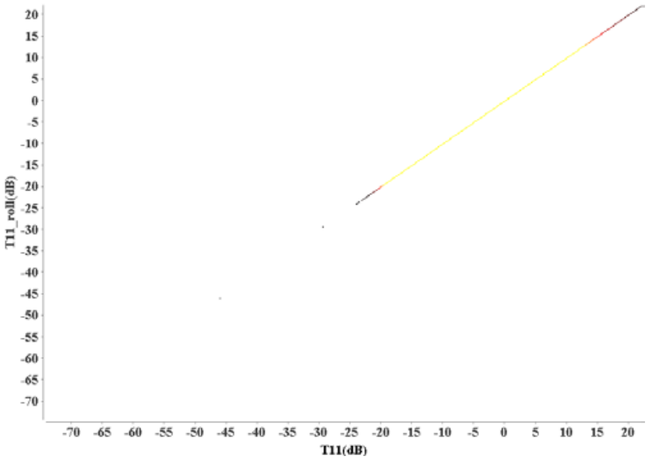
$$T^{new}=\begin{bmatrix}1 & 0 & 0\\ 0 & \cos 2\theta & \sin 2\theta\\ 0 & -\sin 2\theta & \cos 2\theta\end{bmatrix}\bullet T\bullet\begin{bmatrix}1 & 0 & 0\\ 0 & \cos 2\theta & -\sin 2\theta\\ 0 & \sin 2\theta & \cos 2\theta\end{bmatrix} \qquad T=\begin{bmatrix}T11 & T12 & T13\\ T21 & T22 & T23\\ T31 & T32 & T33\end{bmatrix}$$

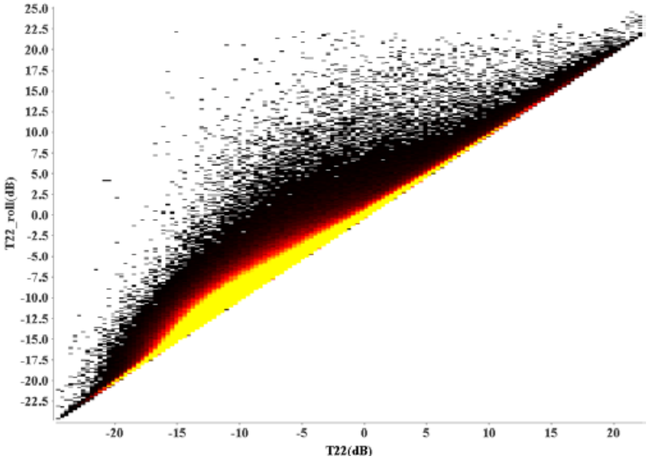
Rotate the scattering matrix about the radar line of sight

- **Roll-invariance**

Certain polarimetric properties are independent from polarization orientation angle or remain unchanged when rotating the polarimetric matrixes(e.g. scattering matrix, coherent matrix) with shift of polarization orientation angle

Understanding roll-invariance



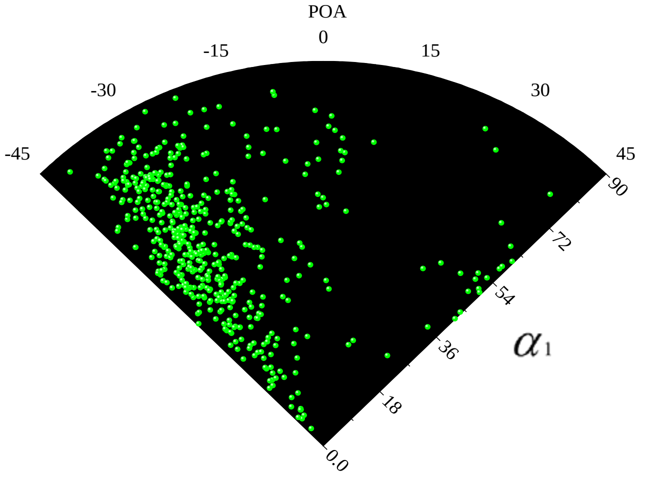


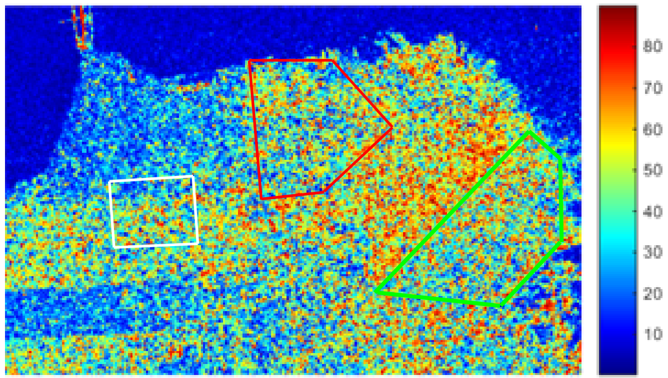
$$\boldsymbol{S} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$ → Huynen Parameters(1972) → $\tau_{m}i, mi$

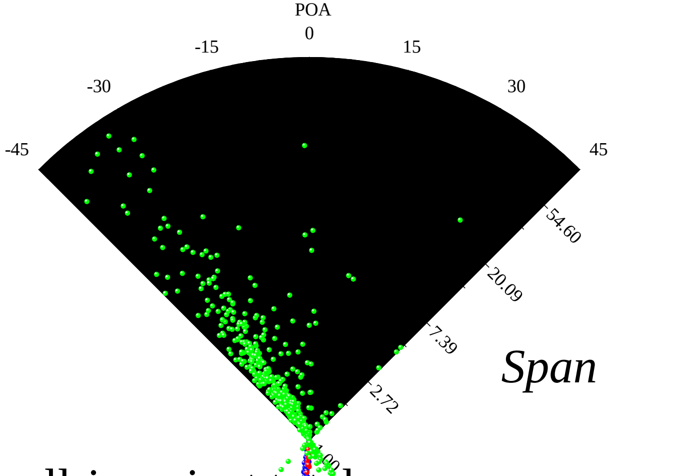
$$\boldsymbol{T} = \begin{bmatrix} T11 & T12 & T13 \\ T21 & T22 & T23 \\ T31 & T32 & T33 \end{bmatrix}$$ → $$\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & \sin 2\theta \\ 0 & -\sin 2\theta & \cos 2\theta \end{bmatrix} \bullet T \bullet \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\theta & -\sin 2\theta \\ 0 & \sin 2\theta & \cos 2\theta \end{bmatrix}$$ → *T11* and *T22*+*T33*

$$\boldsymbol{T} = \boldsymbol{U}_3 \bullet \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \bullet \boldsymbol{U}_3^{-1}$$ → *H/A/α* Polarimetric Decomposition(1997) → $\lambda 1, \lambda 2, \lambda 3 \cdots$ $\bar{\alpha}, \alpha 1, \alpha 2, \alpha 3, H, A, P$

$$e_T^{SV} = m \left(\frac{\left| e_T^{SV} \right|}{m} \right) e^{j\Phi} * \boldsymbol{R}(2\varphi) * \begin{bmatrix} \cos\alpha_s \cos 2\tau_m \\ \sin\alpha_s e^{j\phi_{\alpha_s}} \\ -j\cos\alpha_s \sin 2\tau_m \end{bmatrix}$$ → TSVM Decomposition (2012) → $\alpha_s i, \tau_m i, \Phi_{\alpha s} i, mi$

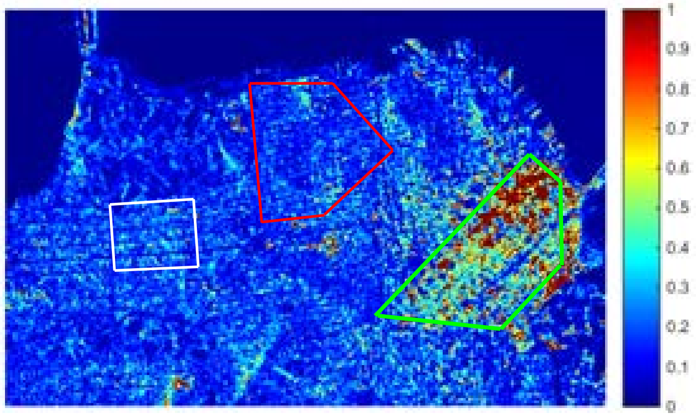


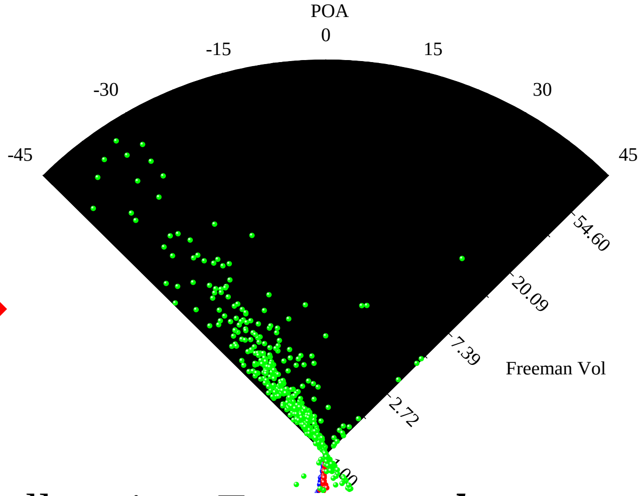


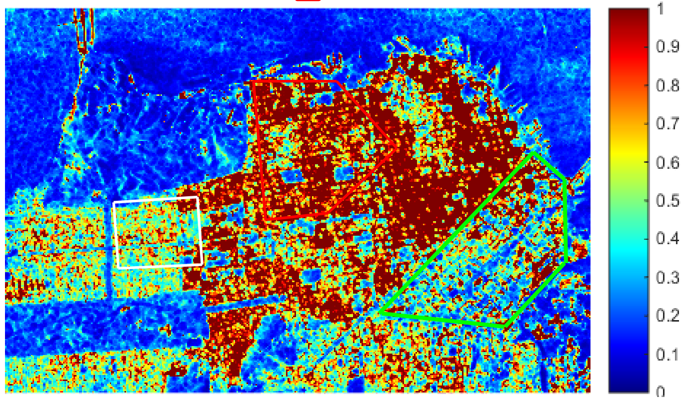


roll-invariant α_1

roll-invariant total power——***span***







roll-variant ***Freeman volume scattering***

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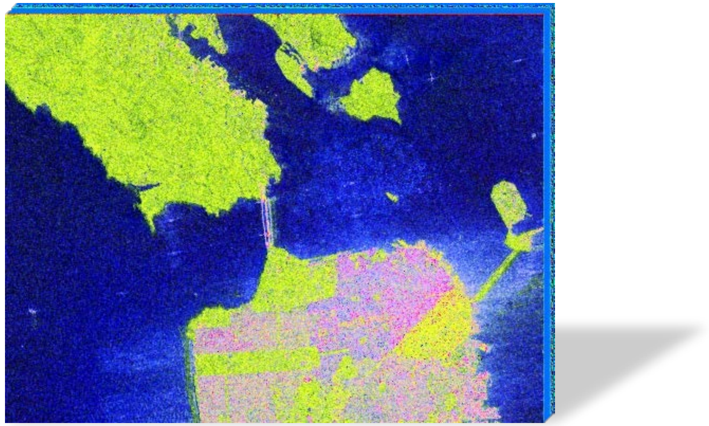
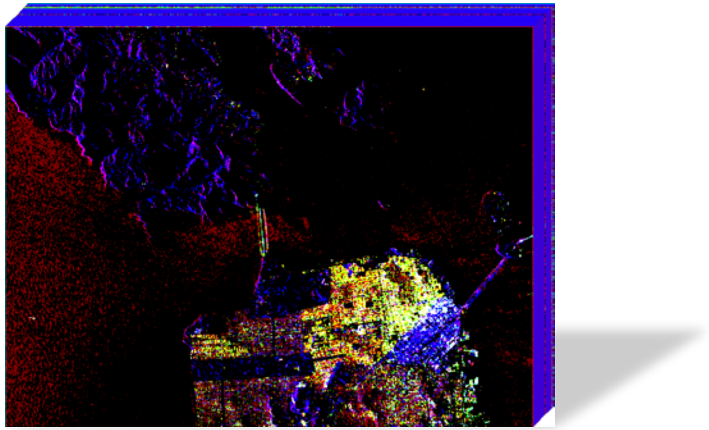
Multivariable Pattern PolSAR Dataset

Two polarimetric datasets in multivariable pattern are collected from Quad-PolSAR image



Roll-invariant data of 28 bands

- Coherent matrix ***T***:T22,T22+T33
- Eigenvalues of coherent matrix ***T*** and derived para**.**
- Total power of backscattering
- Polarimetric decomposition: H/α/A Dec.; TSVM Dec.

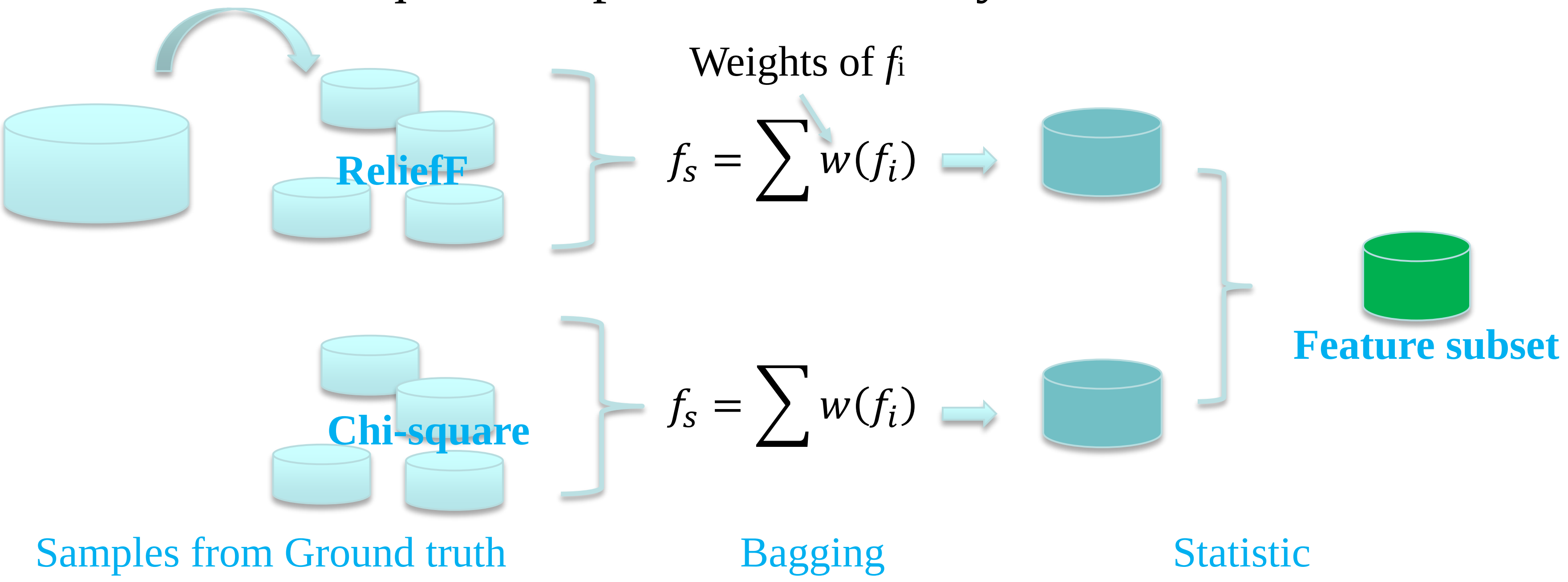


Collection of almost all polarimetric parameters——113 bands

- Coherent matrix ***T*** /covariance matrix ***C***
- Backscattering σ_{ij}: σ hh, σ vv, σ hv
- Polarimetric decomposition: Pauli Dec. ;H/α/A Dec. Huynen Dec.; Free-man Durden Dec.; Yamaguchi Dec. et al
- Other polarimetric parameters…

Ensemble Feature Selection

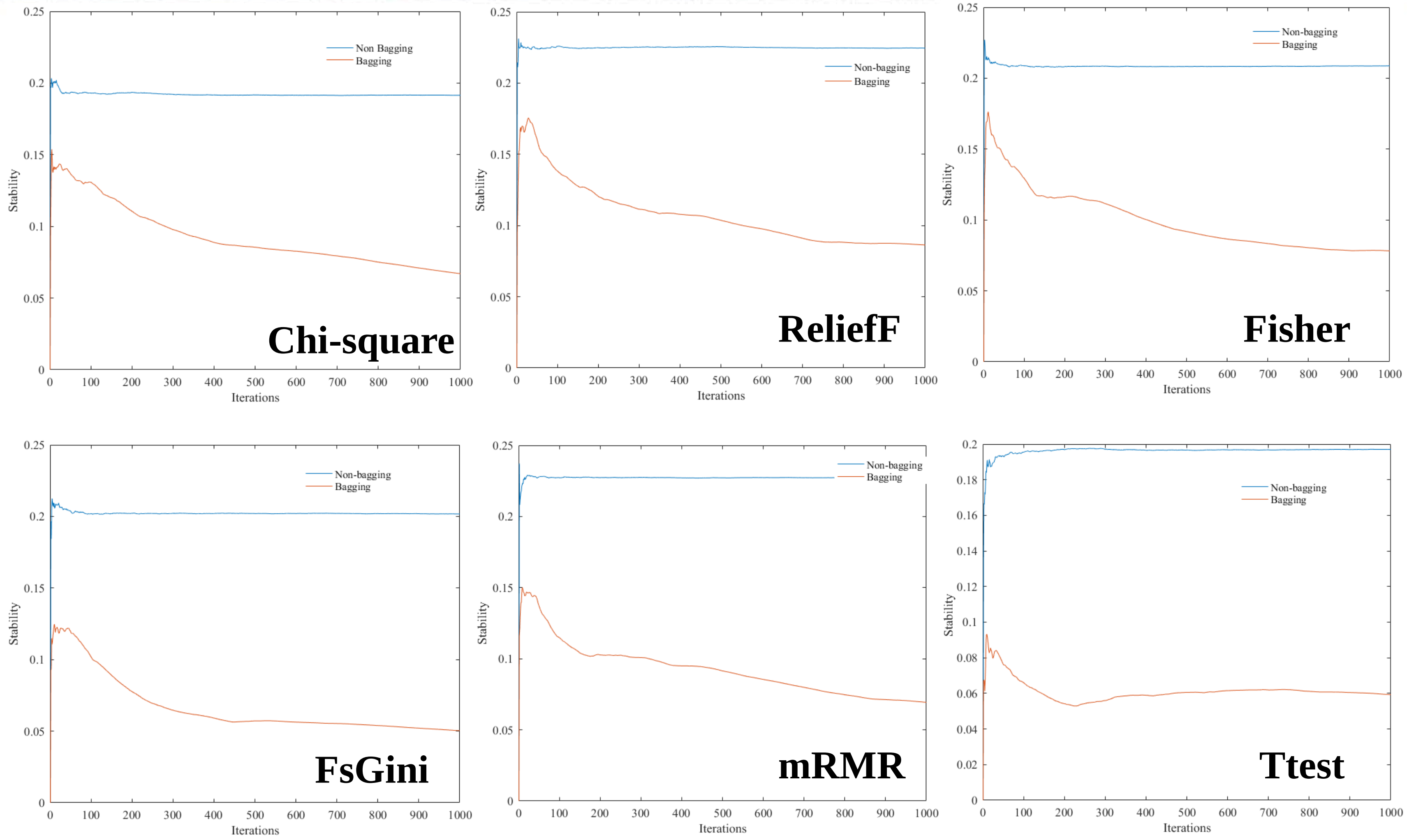
Selection result always changes with random training samples, it is not stable. Here we use an ensemble technique to improve the stability of selection



The stability between selected feature rank-order *Ri* and *Rj* can be measured by cosine distance

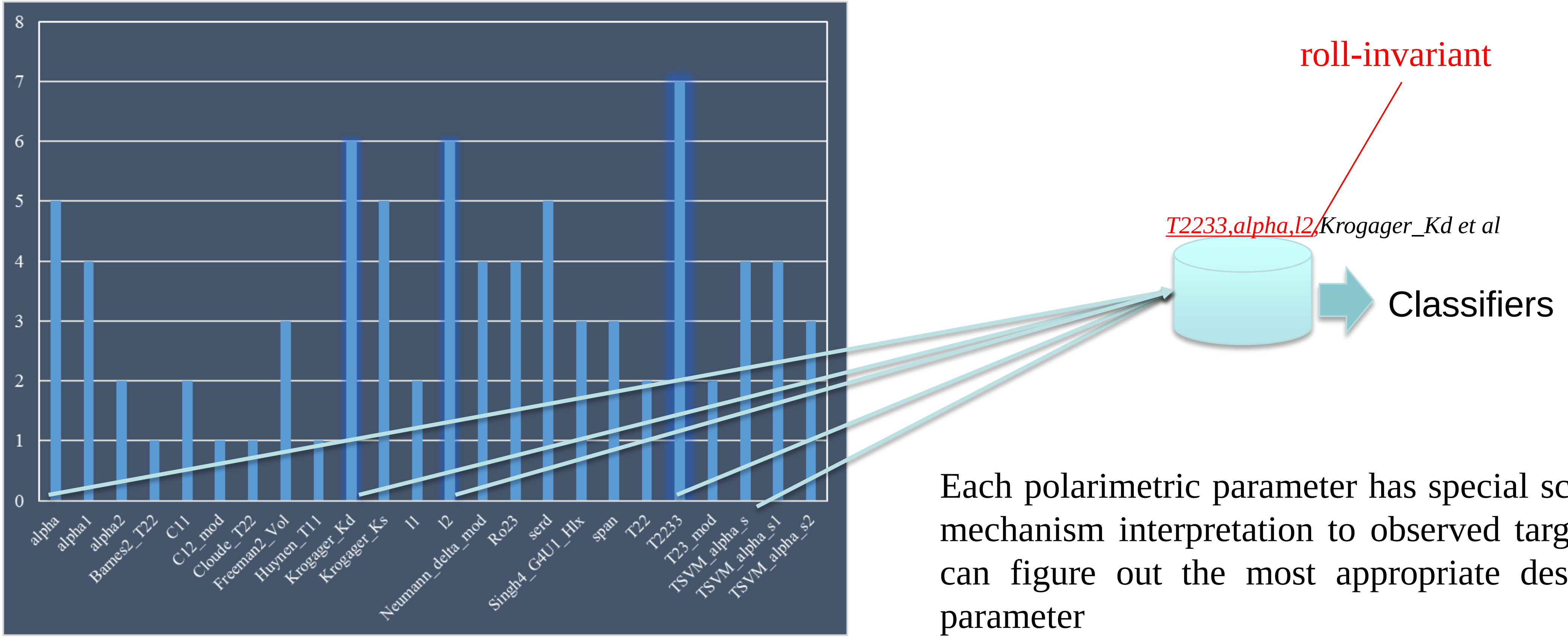
$$distance = 1 - \cos\theta = 1 - \frac{R_i \cdot R_j}{|R_i||R_j|}$$

Ensemble Feature Selection



After combining all these strategies, then we can get an optimized feature subset

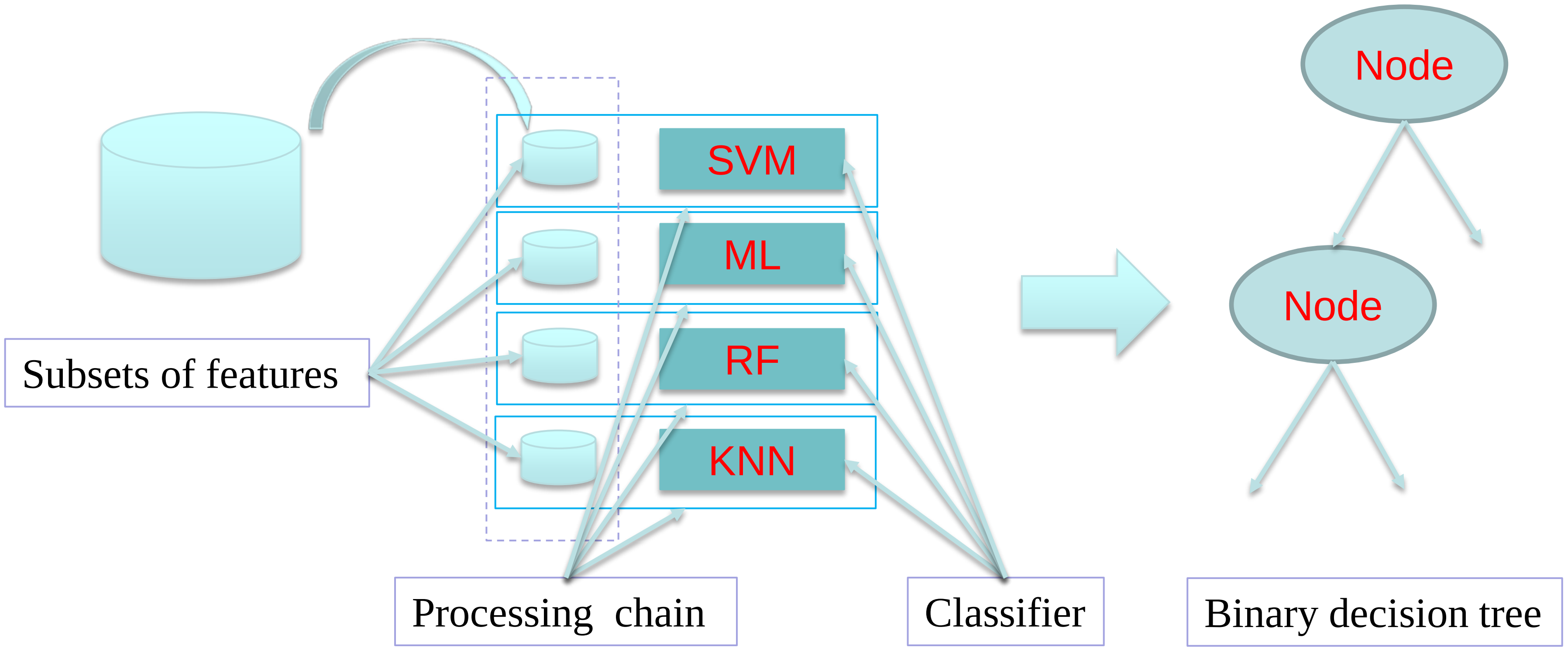
Ensemble Feature Selection



Each polarimetric parameter has special scattering mechanism interpretation to observed targets. We can figure out the most appropriate description parameter

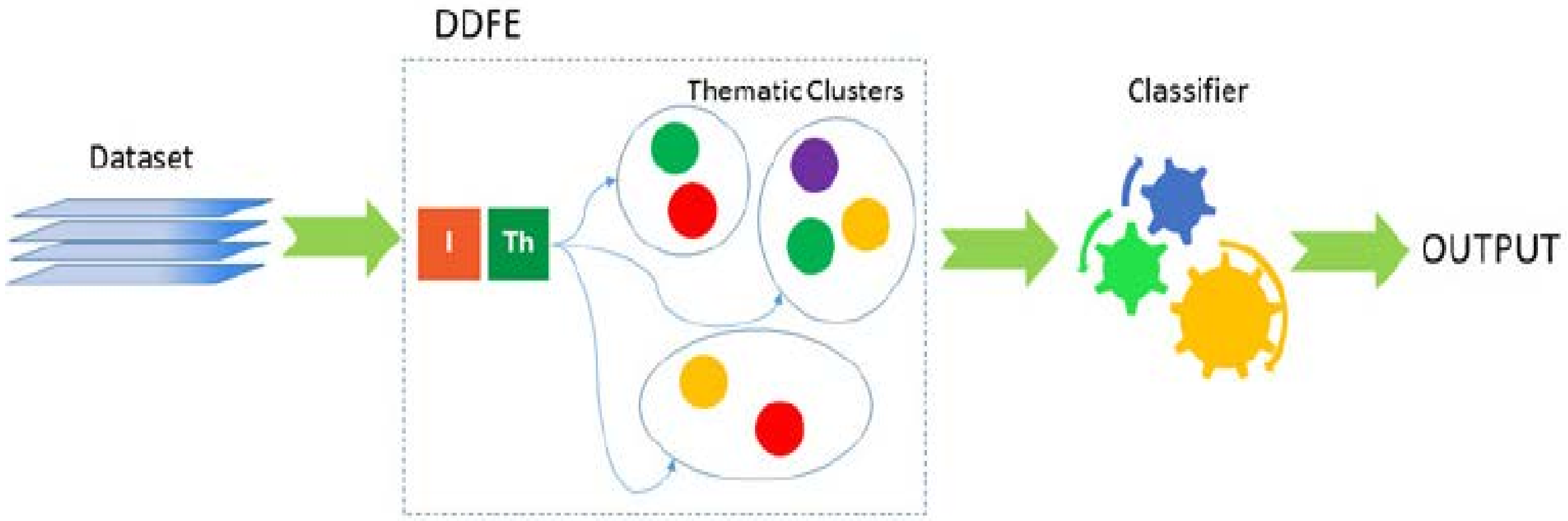
Hierarchical Hybrid Decision Tree

Combining feature set and classifier into hierarchical binary decision tree (HBDT) and select most useful "processing chain" is considered for each class on its node.



G.C. Iannelli and P. Gamba. "Hierarchical hybrid decision tree multiscale fusion for urban image classification." Geoscience and Remote Sensing Symposium (IGARSS), 2016 IEEE International. IEEE, 2016.

Unsupervised Data Driven Feature Extraction



- The dataset is explored by an information theory-based data driven discovery approach
- The data patterns which maximize the mutual information among samples are identified as ***thematic clusters***
- These significant clusters are used to classify the samples

A. Marinoni and P. Gamba, "Unsupervised data driven feature extraction by means of mutual information maximization," IEEE Trans. On Computational Imaging, 2017

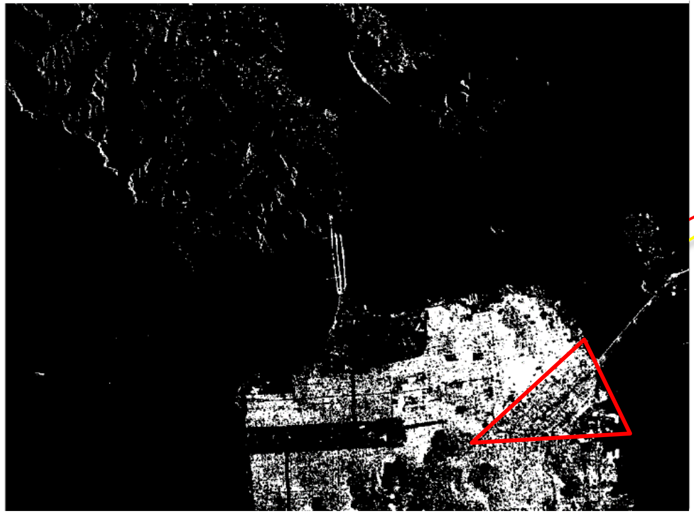
Detection mapping with 113-band data with HBDT

roll-invariant

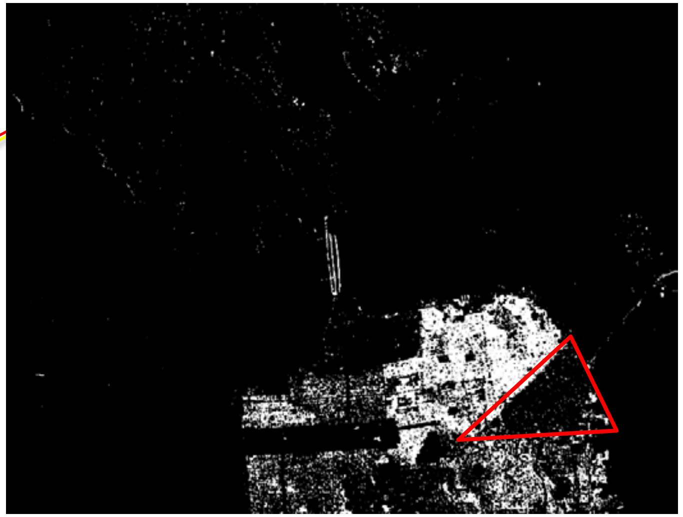
Detection mapping with 28-band data with HBDT

Method	113-bands		28-bands		Secleted first 5-bands		Secleted Last 5-bands	
Accuracy	OA(%)	Kappa	OA(%)	Kappa	OA(%)	Kappa	OA(%)	Kappa
HBDT	90.47	0.8	89.71	0.78	85.42	0.69	74.61	0.48
DDFE	**95.933**	**0.9541**	**95.912**	**0.9538**	85.77	0.73	75.999	0.55
SVM	87.73	0.748	86.723	0.7263	84.8831	0.6878	75.0289	0.4986
Bagging Tree	90.45	0.8036	89.46	0.7828	85.91	0.7099	74.65	0.4822
Boosted Tree	89.66	0.7872	89.04	0.7736	86.02	0.7124	75.04	0.4924
KNN	85.67	0.7067	84.1	0.6746	81.86	0.63	69.84	0.3877
Linear Disc	83.29	0.6615	**83.62**	0.6651	84.82	0.6845	73.75	0.4626
RUSboostTree	89.28	0.78	88.56	0.7648	85.94	0.7114	74.15	0.4825
SimpleTree	86.32	0.7174	**86.75**	0.7224	83.31	0.6554	74.37	0.4845
SubspaceDisc	87.58	0.7433	85.54	0.7007	84.8	0.6853	73.26	0.4471

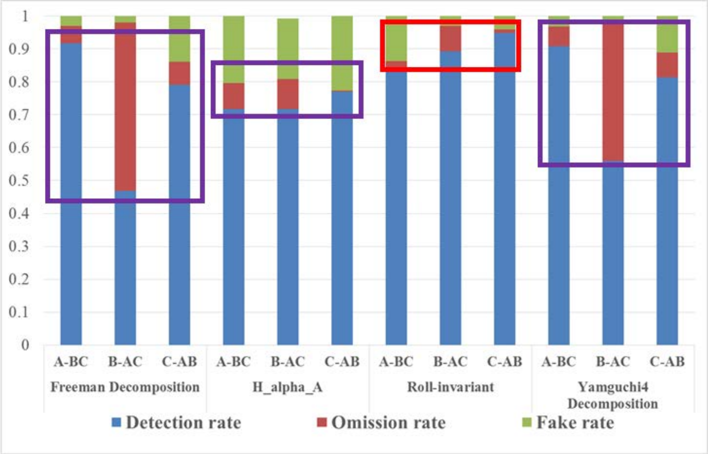
- HBDT shows the best performance when compared to other classifiers apart from DDFE.
- DDFE optimize the feature space and use the most relevant parameters to classify
- The roll-invariant parameter set almost have the same accuracy of 113-band feature set



Roll-invariant feature set



Roll-variant feature set



Roll-invariant parameters have advantage in supervised classification as it balance in sampling regardless of POA shift effects.

CONCLUSIONS AND DISCUSSION

- Three different strategies are introduced to handle two polarimetric multidimensional parameter datasets and the results show the advantage of combining of feature and classifier as well as unsupervised optimization of feature space. However, it does not mean that the feature selection is not appropriate, it mainly helps to understand special meaning of certain parameter for descripting targets.
- Parameter extracted from Quad-PolSAR image contaion speckle noises ,the Unsupervised feature extraction method DDFE may eliminates the parameters that contain noises and presents the outstanding performance in optimizing feature space and obtained the highest classification accuracy.
- Roll-invariance can be another way to handle with POA shift and this kind of parameters have good description on buildings with diversity orientation. Also these parameters can be used in other fields like terrain correction for forest recognition

Thank you

meiqin.che01@universitadipavia.it,
Andrea Marinoni:andrea.marinoni@unipv.it,
giannicristian.iannelli@unipv.it
paolo.gamba@unipv.it,