Exploitation of SAR image time series

Journée des doctorants 15/01/2019

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Context of the Ph.d

Problem under study and applications i

Recent years have seen a **huge** increase in the number of SAR images (Sentinel-1, TerraSAR-X, UAVSAR, etc).

Problematics

- Reliable automatic Unsupervised Change Detection.
- Taking into account the nature of the data (High-resolution and Multivariate).

Change Detection is useful for:

- Land cover monitoring
- Assesment of disaster
- Measure growth of city or forest

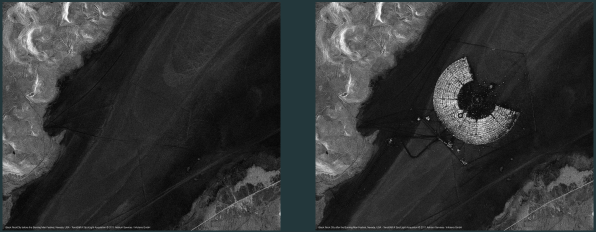


Figure 1: TerraSAR-X Images Burning Man festival

Problem under study and applications ii

Long time-series: **When** does the change occurs ?

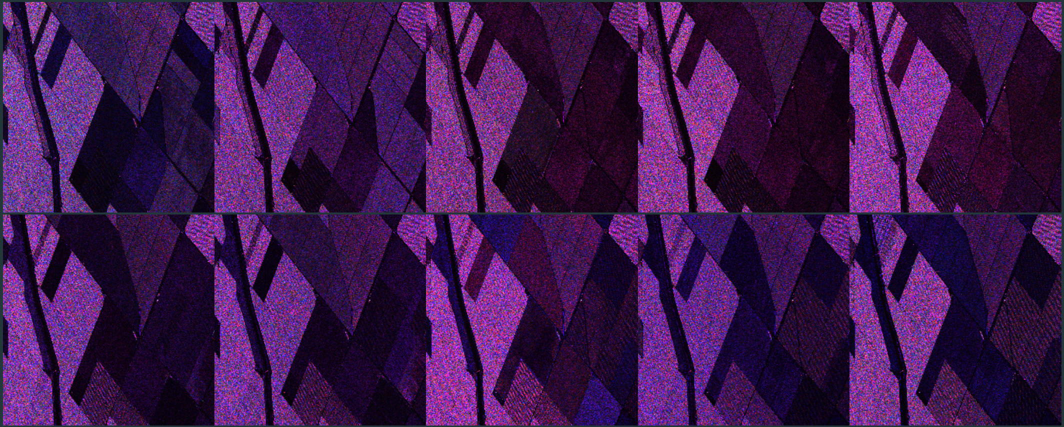
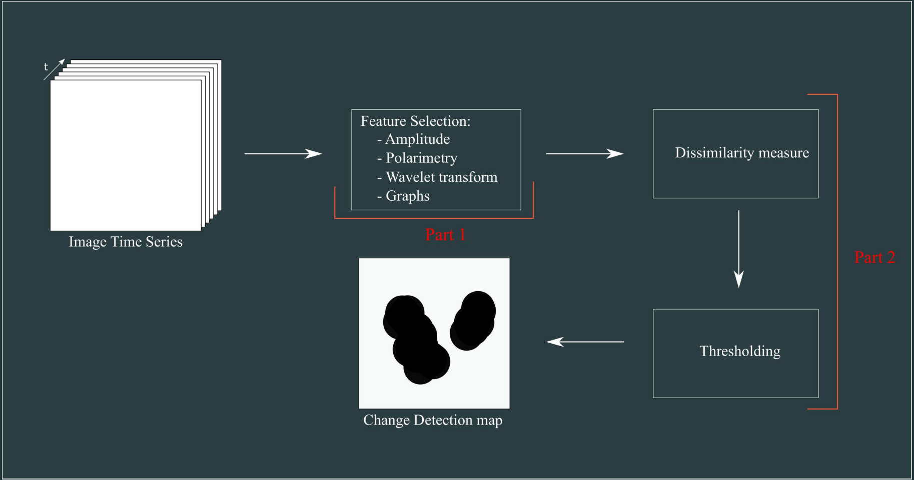


Figure 2: Example of UAVSAR/JPL image time-series between 2008 and 2018 over California

Unsupervised Change Detection Framework

Pixel-based techniques [Hussain et al., 2013]:



Spectro-angular diversity using Time-Frequency tools

Feature selection: The concept of diversity and its usefulness

When comparing data between two dates, more useful information (diversity) is better:

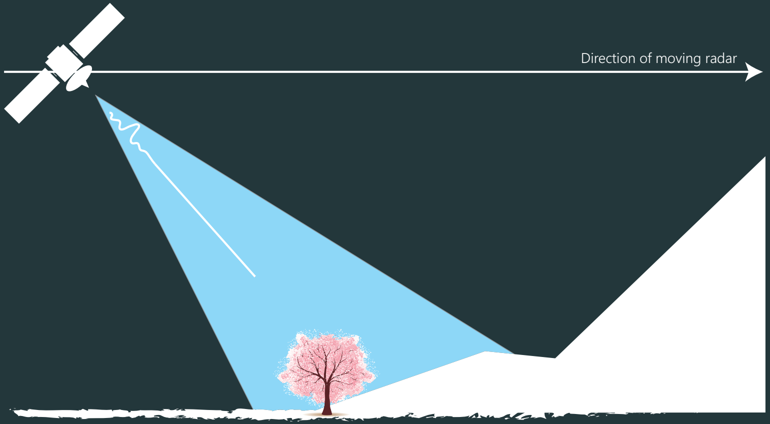
1-dimensional data   2-dimensional data

For SAR images, the diversity can come from:

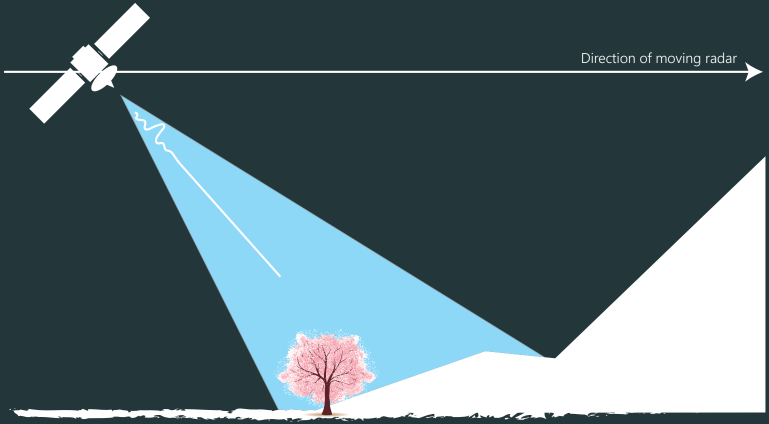
- Polarimetry
- Looking angles (interferometry)
- Spectro-angular behavior of scatterers

$\rightarrow$ For change detection, obtaining a good source of diversity is of importance.
Uninformative data may decrease performance !

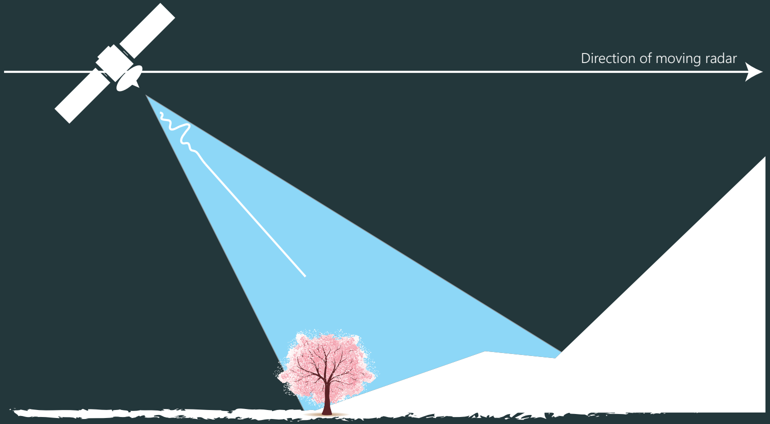
Principle i



Principle i



Principle i



Principle ii

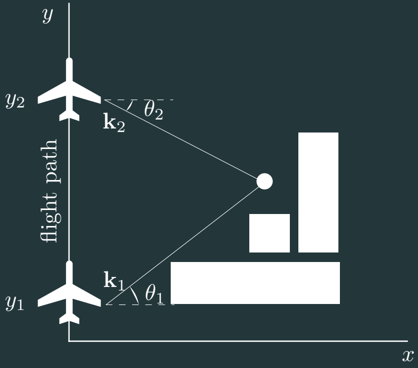


Figure 3: SAR acquisition geometry. A reflector is viewed at two different angles of illumination θ_1 and θ_2.

Bright points model (white and isotrope):

$$I(\mathbf{r}) = \sum_k h_k \delta(\mathbf{r} - \mathbf{r}_k)$$

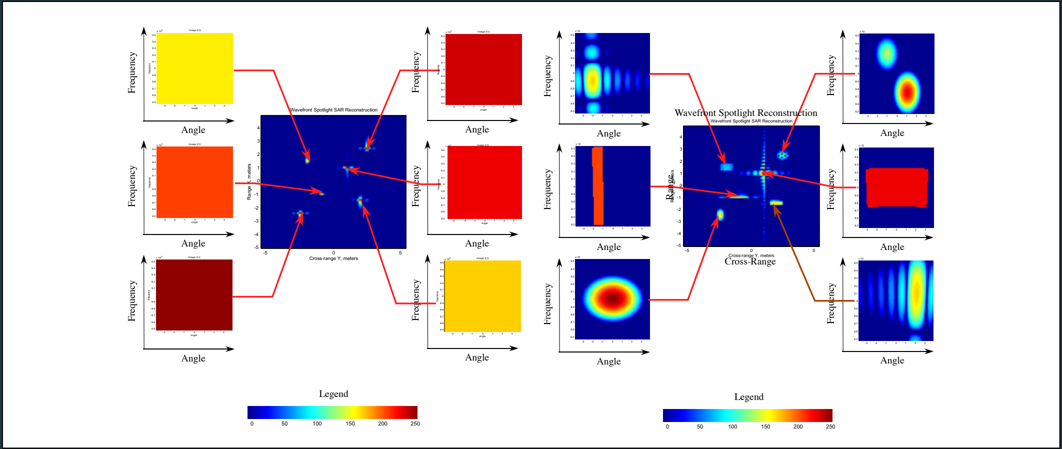
$\mathbf{r} = [x, y]^T$: scatterer position.
h_k: Backscattering coefficient.

SAR image construction [Soumekh, 1999]:

$$I(\mathbf{r}) = \int_{\mathcal{D}} H(\mathbf{k}) \exp\left(2\, i\, \pi\, \mathbf{k}^T\, \mathbf{r}\right) d\mathbf{k}\,,$$

$\mathbf{k} = [\mathfrak{K}\cos(\theta), \mathfrak{K}\sin(\theta)]$: wave vector.
H: backscattering coefficient for each $\mathbf{k}$.
$\mathcal{D} = [\mathfrak{K}_0 - \mathfrak{K}_B/2, \mathfrak{K}_0 + \mathfrak{K}_B/2] \times [-\theta_B, \theta_B]$: frequency and angular support of H.

High-resolution SAR images and scatterers' behavior



Behaviour studied in [Ovarlez et al., 2003, Tria et al., 2007, Duquenoy et al., 2010]. How can we retrieve this information ?

Time-Frequency analysis for SAR images

Definition

$$\Psi^{\mathbf{S},\measuredangle}_{j,[m,n]}(\mathfrak{K},\theta) = R^{j/2}\, L^{j/2}\, \mathbb{1}_{\Delta_{j,\mathfrak{K}_m}\times\Delta_{j,\theta_n}}(\mathfrak{K},\theta)\,,$$

where

$$\begin{aligned}\Delta_{j,\mathfrak{K}_m} &= \quad \mathfrak{K}_0 - \mathfrak{K}_B + \left[\frac{m\mathfrak{K}_B}{R^j}, \frac{(m+1)\mathfrak{K}_B}{R^j}\right],\\ \Delta_{j,\theta_n} &= \quad \left[\frac{n\theta_B}{L^j}, \frac{(n+1)\theta_B}{L^j}\right].\end{aligned}$$

Computation of coefficients

$$\mathbf{C}^{\mathsf{S},\measuredangle}_{j,[m,n]}[p,q] = \mathcal{F}^{-1} V_{j,[m,n]}(R^j\, p, L^j\, q)\,,$$

where $V_{j,[m,n]}(\mathfrak{K},\theta) = H(\mathfrak{K},\theta)\,\Psi^{\mathbf{S},\measuredangle}_{j,[m,n]}(\mathfrak{K},\theta)$.

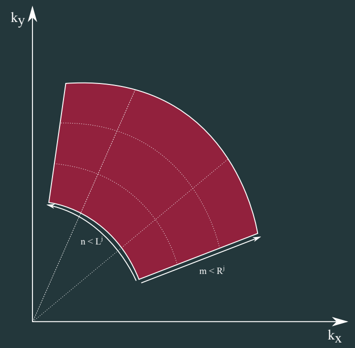
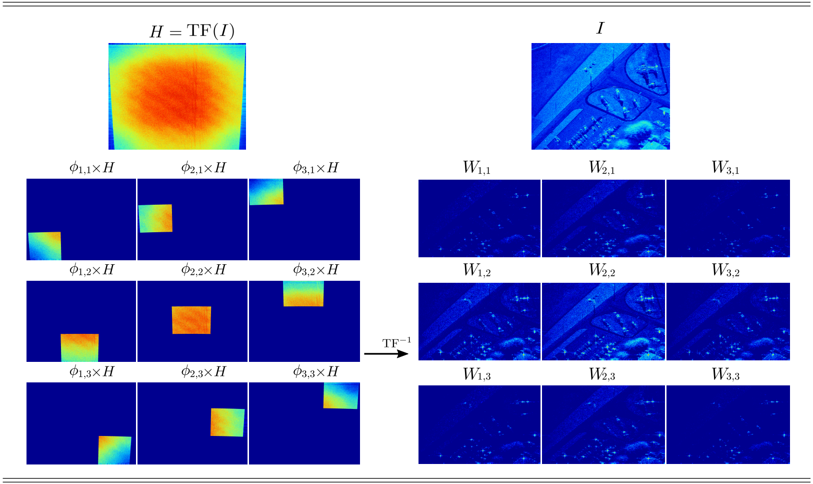


Figure 4: Illustration of decomposition

Example of decomposition

[Ovarlez et al., 2017]



Sidelobes problem

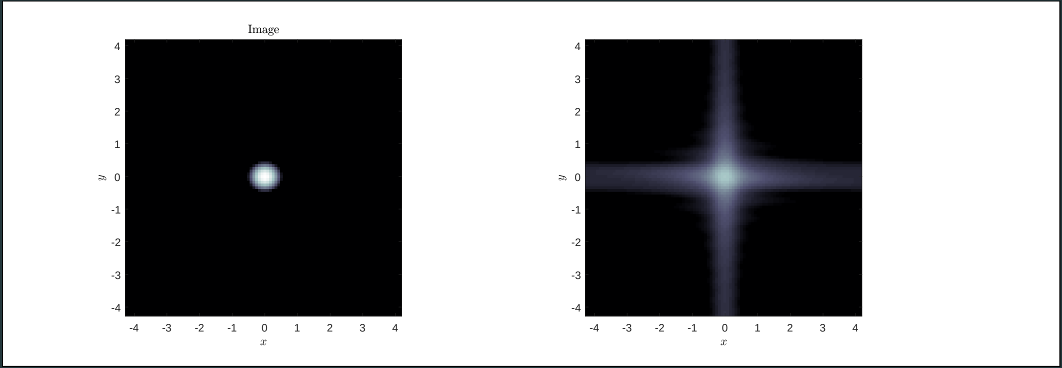


Figure 5: Left: Original Image. Right: Wavelet coefficient [1,1]

Definition

$$\Psi_{j,[m,n]}^{[d_1,d_2],\measuredangle}(\mathfrak{K},\theta) = R^{\frac{j}{2}} L^{\frac{j}{2}} H_{j,m}^{d_1,\measuredangle}(\mathfrak{K})\, H_{j,n}^{d_2,\measuredangle}(\theta)\mathbb{1}_{\mathcal{D}}\,,$$

where

$$H_{j,m}^{d_1,\measuredangle}(\mathfrak{K}) = g^{\mathrm{Bell}}_{\frac{\mathfrak{K}_B}{2R^j},d_1,\mathfrak{K}_0-\frac{\mathfrak{K}_B}{2}+\frac{(2m+1)\mathfrak{K}_B}{2R^j}}(\mathfrak{K})\,,$$

$$H_{j,n}^{d_2,\measuredangle}(\theta) = g^{\mathrm{Bell}}_{\frac{\theta_B}{L^j},d_2,-\theta_B+\frac{(2n+1)\theta_B}{2L^j}}(\theta)\,.$$

$\rightarrow$ Proposed in [Mian et al., 2019b] with a theoretical analysis (convergence, completeness).

$$g_{a,b,c}^{\mathrm{Bell}}(x) = \frac{1}{1+\left|\dfrac{x-c}{a}\right|^{2b}}\,.$$

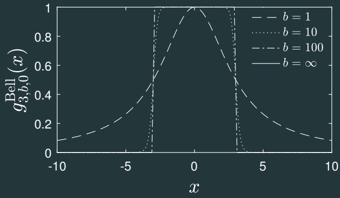
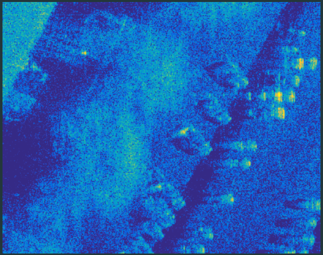


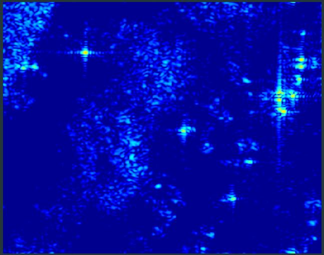
Figure 6: Bell function

Contribution: Design of a new wavelet packet ii

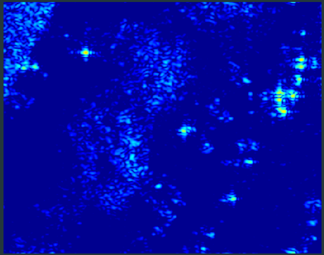
Sandia Image



Shannon Wavelet
Sub-Band 1

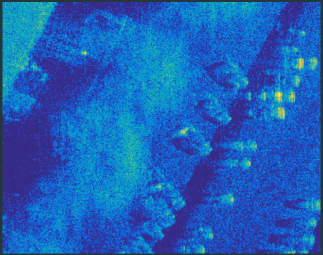


Bell-shaped Wavelet
Sub-Band 1

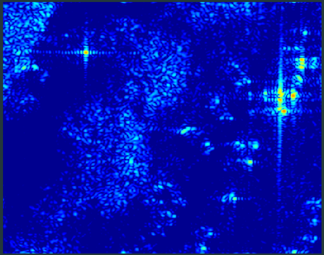


Contribution: Design of a new wavelet packet ii

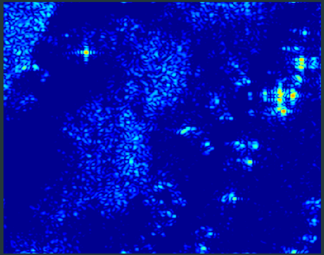
Sandia Image



Shannon Wavelet
Sub-Band 2

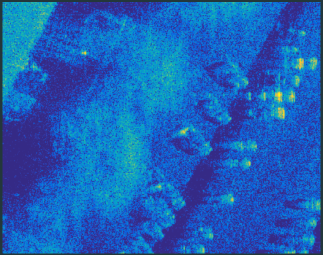


Bell-shaped Wavelet
Sub-Band 2

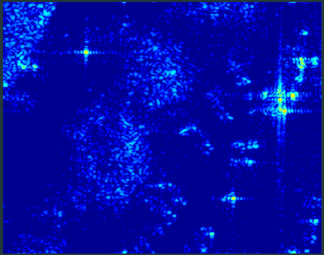


Contribution: Design of a new wavelet packet ii

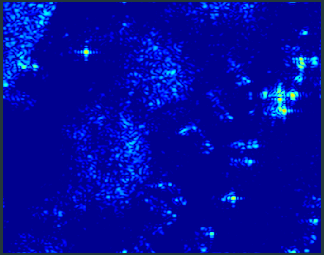
Sandia Image



Shannon Wavelet
Sub-Band 3



Bell-shaped Wavelet
Sub-Band 3



Detection based on Multivariate Statistical Analysis

Some definitions

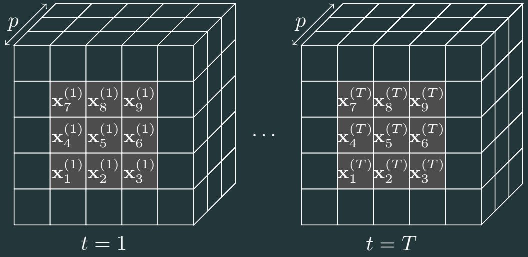


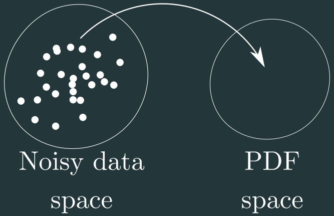
Figure 7: Illustration of local data ($N = 9$, $p = 3$). The central pixel ($\mathbf{x}_5^{(t)}$) is the test pixel.

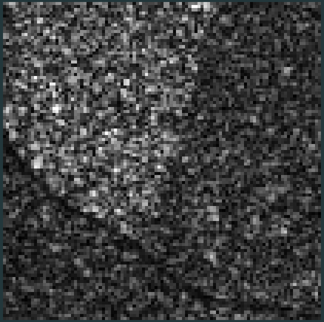
Distance design: Probabilistic modelling and underlying problems

- SAR images are subject to the **speckle** which is modelled using a probability distribution:

$$\mathbf{x}_k^{(t)} \sim p_{\mathbf{x}_k^{(t)};\boldsymbol{\theta}}(\mathbf{x}_k^{(t)};\boldsymbol{\theta}), \text{ where } p \text{ is the PDF}$$

- **Idea:** Compare the observed distributions of the data locally to detect changes.





→ Two issues: chose a realistic model and design a distance between distributions.

Background: Approaches under Gaussian model

Objective: design a dissimilarity measure taking into account the noise for change detection.

Litterature on the subject:
[Ciuonzo et al., 2017, Nielsen et al., 2016, Nascimento et al., 2018]

- Assume a zero mean Gaussian model for the observed data, which is parametrised by a **covariance matrix** $\boldsymbol{\Sigma}_t$.
- Estimate the covariance matrix at each date using spatial neighborhood.
- Design a distance using statistical tools such as Kullback-Leibler divergence or hypothesis testing.

Problem: For high-resolution SAR images, the Gaussian assumption is a poor approximation. [Greco and Gini, 2007] proposed to use the Complex Elliptical Symmetric (CES) model.
$\rightarrow$ We designed a new distance using this model [Mian et al., 2019a].

Contribution: Exploring non-Gaussian distributions

We considered a non-Gaussian model, **better suited to heterogeneous images**, and developed a new distance.

Non-Gaussian Change statistic [Mian et al., 2019a]

$$\hat{\Lambda}_{\mathrm{MT}} = \frac{\left|\hat{\mathbf{\Sigma}}_0^{\mathrm{MT}}\right|^{TN}}{\prod_{t=1}^{T}\left|\hat{\mathbf{\Sigma}}_t^{\mathrm{MT}}\right|^{N}} \prod_{k=1}^{N} \frac{\left(\sum_{t=1}^{T} \mathbf{x}_k^{(t)\,\mathrm{H}} \{\hat{\mathbf{\Sigma}}_t^{\mathrm{MT}}\}^{-1} \mathbf{x}_k^{(t)}\right)^{Tp}}{\prod_{t=1}^{T}\left(\mathbf{x}_k^{(t)\,\mathrm{H}} \{\hat{\mathbf{\Sigma}}_0^{\mathrm{MT}}\}^{-1} \mathbf{x}_k^{(t)}\right)^{p}} \underset{\mathrm{H}_0}{\overset{\mathrm{H}_1}{\gtrless}} \lambda, \text{ where :} \tag{1}$$

$$\hat{\mathbf{\Sigma}}_t^{\mathrm{MT}} = \frac{p}{N} \sum_{k=1}^{N} \frac{\mathbf{x}_k^{(t)} \mathbf{x}_k^{(t)\,\mathrm{H}}}{\mathbf{x}_k^{(t)\,\mathrm{H}} \{\hat{\mathbf{\Sigma}}^{\mathrm{MT}}\}^{-1} \mathbf{x}_k^{(t)}} \text{ and } \hat{\mathbf{\Sigma}}_0^{\mathrm{MT}} = \frac{p}{N} \sum_{k=1}^{N} \frac{\sum_{t=1}^{T} \mathbf{x}_k^{(t)} \mathbf{x}_k^{(t)\,\mathrm{H}}}{\sum_{t=1}^{T} \mathbf{x}_k^{(t)\,\mathrm{H}} \{\hat{\mathbf{\Sigma}}^{\mathrm{MT}}\}^{-1} \mathbf{x}_k^{(t)}}$$

Contibution: Theoretical Analysis

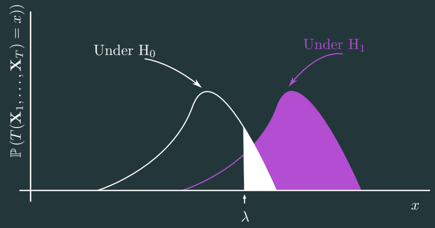
The following points have been studied through a theoretical analysis:

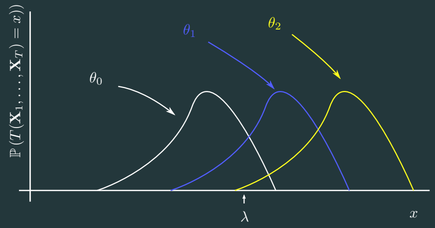
Convergence of fixed point estimates

$\hat{\mathbf{\Sigma}}_t^{\mathrm{MT}}$ and $\hat{\mathbf{\Sigma}}_0^{\mathrm{MT}}$ are solution to a fixed point equation. An iterative algorithm will always converge to the solution with any initialisation point.

CFARness of proposed statistic

The proposed statistic has the Constant False Alarm Property which means that under CES model, the distribution of the statistic is independent of the parameters.

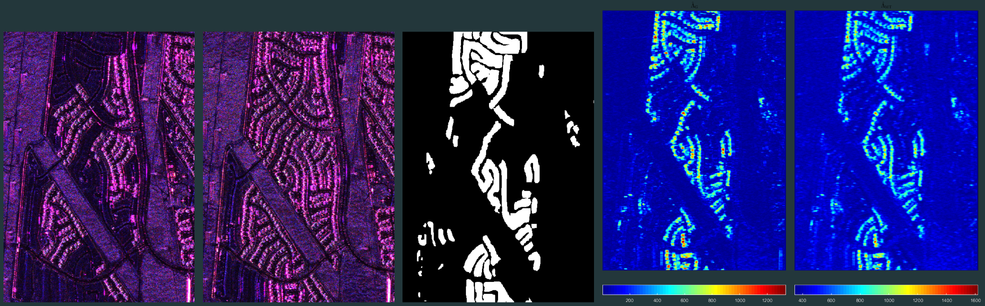




Application to Change-point detection on real data

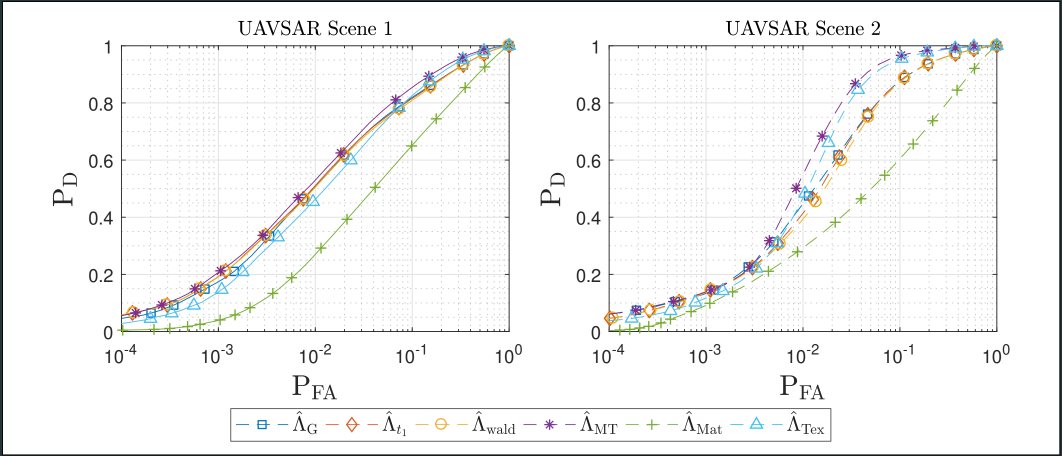
Example on UAVSAR (NASA) dataset [Mian et al., 2019a] i

- Polarimetric data: $p = 3$
- Dimensions: 2360px 600px
- Resolution: 1.67 m (Range) and 0.60 m (Azimuth)



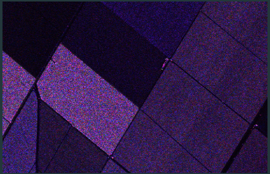
April 23, 2009 | May 1, 2011 | Ground Truth | Gaussian | Proposed

Example on UAVSAR (NASA) dataset [Mian et al., 2019a] iii

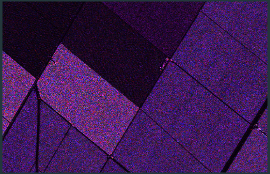


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

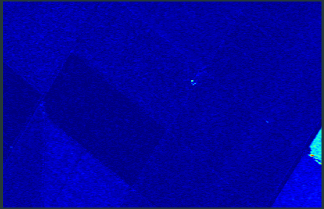


t =May 29, 2013

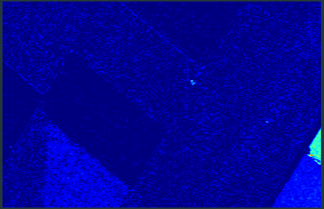


t =Jul 19, 2013

Gaussian



Proposed



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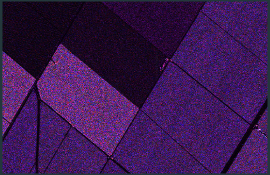
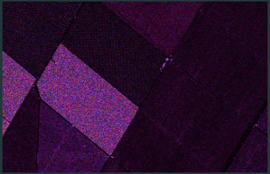
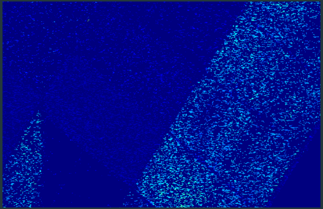


t =Jul 19, 2013

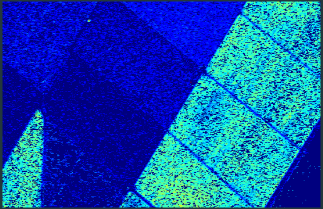


t =Oct 31, 2013

Gaussian



Proposed



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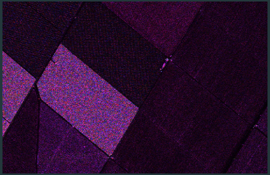
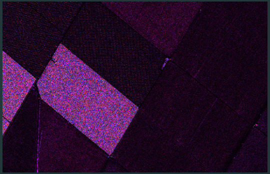
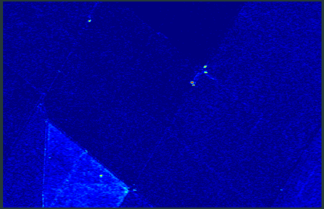


t =Oct 31, 2013

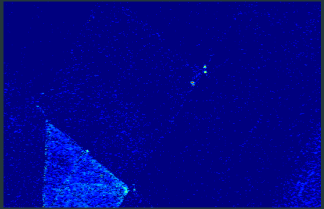


t =Jan 17, 2014

Gaussian



Proposed



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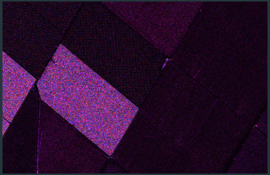
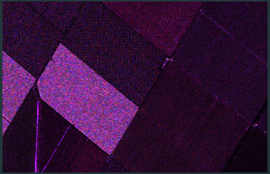
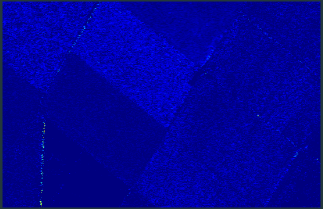


$t =$Jan 17, 2014

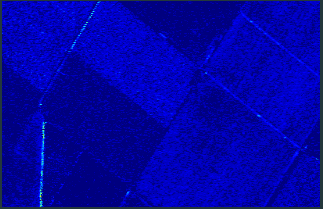


$t =$Apr 2, 2014

Gaussian

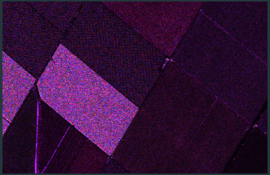


Proposed

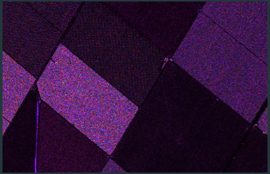


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

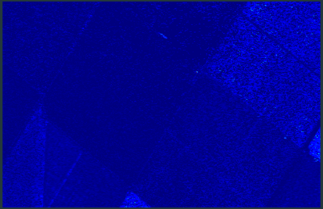


t =Apr 2, 2014

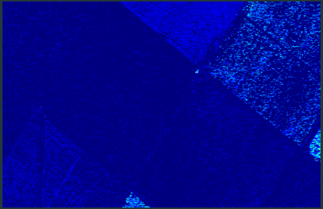


t =May 29, 2014

Gaussian

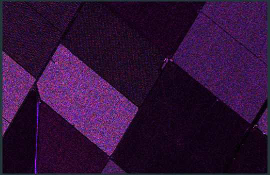


Proposed

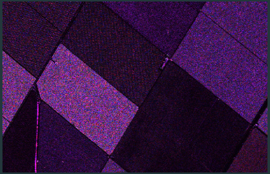


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

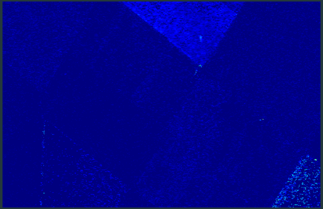


t =May 29, 2014

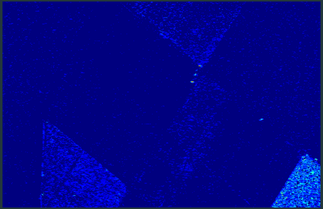


t =Jun 16, 2014

Gaussian

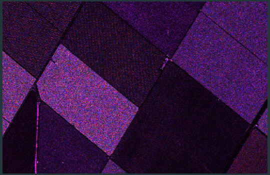


Proposed

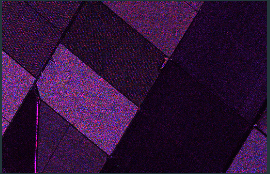


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

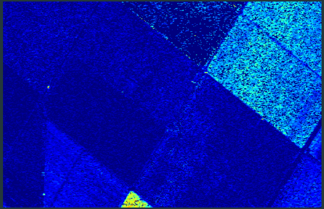


t =Jun 16, 2014

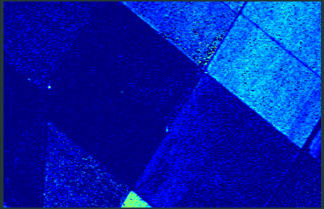


t =Aug 14, 2014

Gaussian

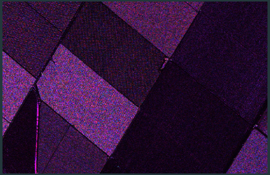


Proposed



Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.



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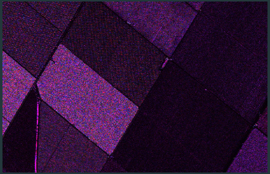
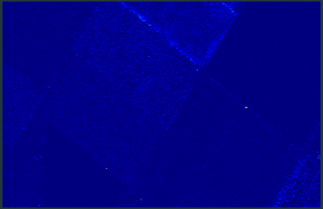
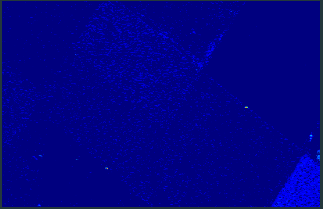


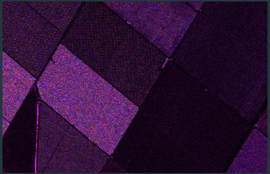
t =Oct 6, 2014





Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.



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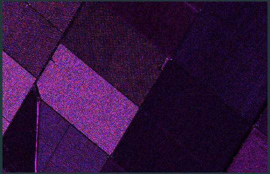
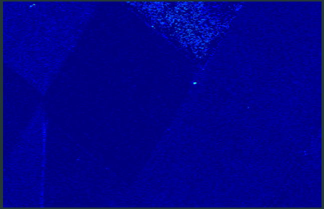
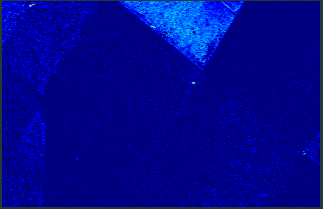


t =Nov 13, 2014

Gaussian

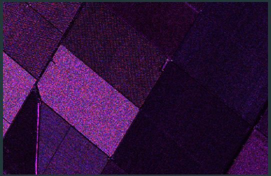


Proposed

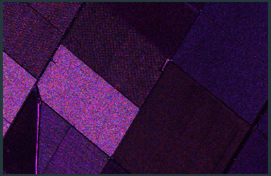


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

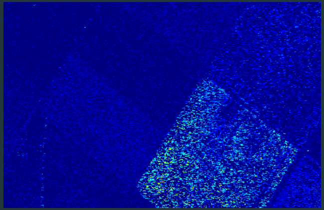


t =Nov 13, 2014

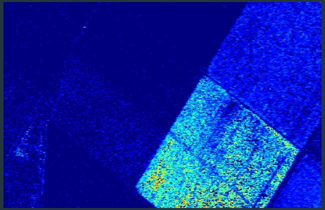


t =Jan 7, 2015

Gaussian

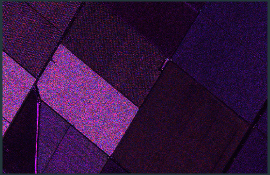


Proposed

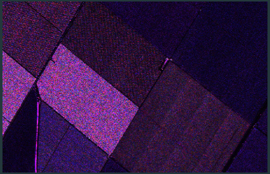


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

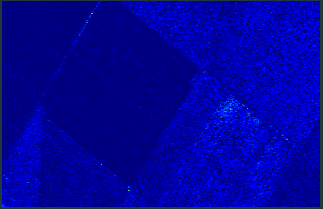


t =Jan 7, 2015

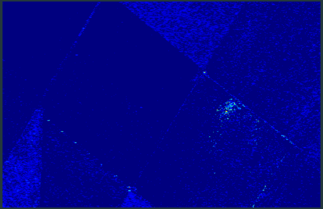


t =Mar 10, 2015

Gaussian

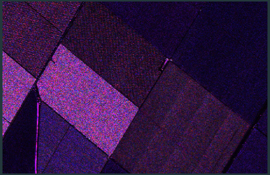


Proposed

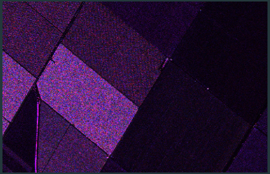


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

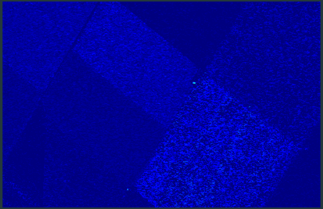


t =Mar 10, 2015

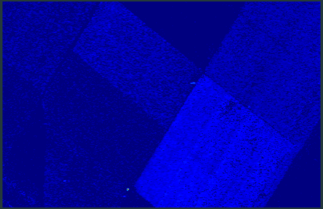


t =Apr 27, 2015

Gaussian

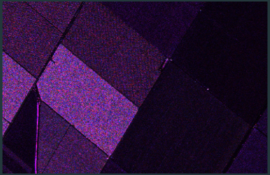


Proposed

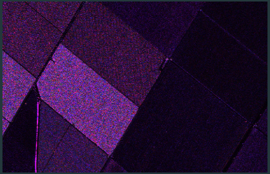


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

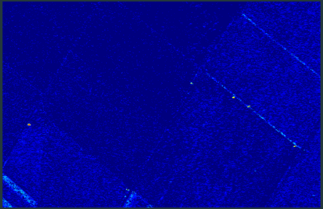


t =Apr 27, 2015

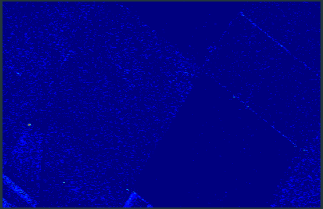


t =May 16, 2015

Gaussian

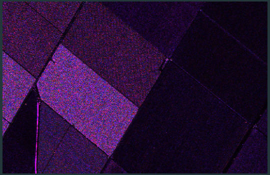


Proposed

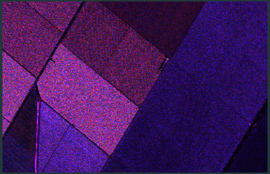


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

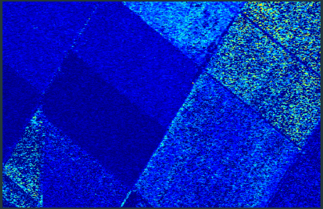


$t =$May 16, 2015

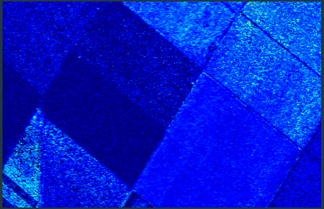


$t =$Feb 19, 2016

Gaussian

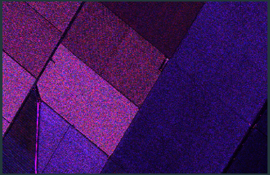


Proposed

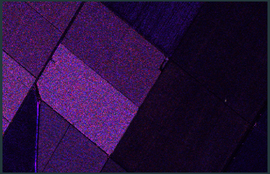


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

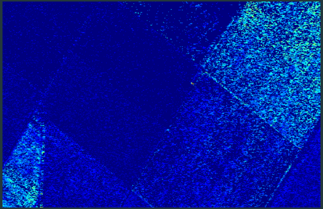


t =Feb 19, 2016

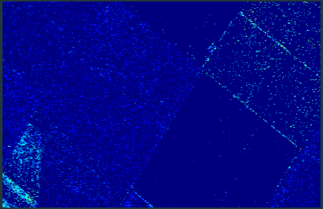


t =Jun 14, 2016

Gaussian

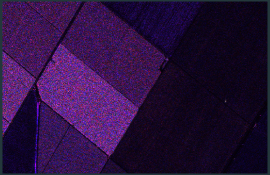


Proposed

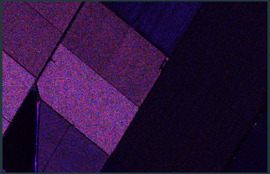


Test on another UAVSAR dataset

Change point is estimated using algorithm developed in [Mian et al., 2018], which exploits the proposed statistic.

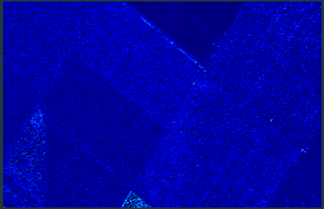


t =Jun 14, 2016

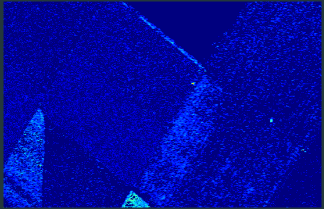


t =Oct 24, 2016

Gaussian



Proposed



Conclusions

Conclusions

What we have done:

- Designed a new wavelet packets that allowed to keep the benefit of Time-Frequency analysis of SAR images while controlling sidelobes.
- Designed a new distance under non-Gaussian model, better suited to heterogeneous images, and studied its performance theoretically.
- Developed an algorithm taking previous contributions into account to detect and estimate change-points in SAR image time series.
  → The proposed method leads to an improvement in false alarms and detection.

Perspectives:

- Collaboration with Alexandre Renaux and Lucien Bacharach (L2S, CentraleSupélec) on Lower-Bounds on change-point estimation (conference submitted and a journal paper will be written).
- Collaboration with Arnaud Breloy (LEME, Université Paris Nanterre) on Low-rank change detection (a conference paper has been submitted and an extension can be done for a journal).
- Clustering of changes types (slow change/impulsive/periodical): some ideas based on Riemannian geometry.
- Write my Ph.d thesis.

Scientific production

Scientific Production i

Journals:

- **A. Mian** and J. P. Ovarlez and G. Ginolhac and A. Atto, *New Robust Statistics for Change Detection in Time Series of Multivariate SAR Images*, *IEEE Transactions on Signal Processing*, (2019).
- **A. Mian** and J. P. Ovarlez and G. Ginolhac and A. Atto, *On Wavelet-based Time-Frequency Analysis for High-Resolution SAR Images*, *IEEE Transactions on Geoscience and Remote Sensing*, (2019).
- R. Ben Abdallah, **A. Mian**, A. Breloy, A. Taylor, M. N. El Korso, D. Lautru, *Detection Methods based on Structured Covariance Matrices for Multivariate SAR Images Processing IEEE Geoscience and Remote Sensing Letters*, (2019).

Conférences:

- **A. Mian** and J. P. Ovarlez and G. Ginolhac and A. Atto, *Multivariate change detection on high resolution monovariate SAR image using linear time-frequency analysis*, *2017 25th European Signal Processing Conference (EUSIPCO)*, pp. 1942-1976 (Aug 2017).
- **A. Mian** and J. P. Ovarlez and G. Ginolhac and A. Atto, *Détection de changement sur images SAR monovariées par analyse temps-fréquence linéaire*, *GRETSI 2017 XXVIème colloque*, (Septembre 2017).
- **A. Mian** and J. P. Ovarlez and G. Ginolhac and A. Atto, *A Robust Change Detector for Highly Heterogeneous Multivariate Images*, *2018 IEEE International Conference on Acoustics, Speech and Signal Processing*, (April 2018).

Scientific Production ii

- **A. Mian** and J. P. Ovarlez and G. Ginolhac and A. Atto, Robust Detection and Estimation of Change-Points in a Time Series of Multivariate Images, *2018 26th European Signal Processing Conference (EUSIPCO)*
- **(Submitted) A. Mian**, L. Bacharach, G. Ginolhac, A. Renaux, M. N. El Korso and J.-P. Ovarlez, Designing SAR Images Change-point Estimation Strategies using an MSE Lower Bound, *2019 IEEE International Conference on Acoustics, Speech and Signal Processing*, (April 2019).
- **(Submitted) A. Mian**, A.Breloy, G. Ginolhac, J.-P. Ovarlez, *Robust Low-rank Change Detection statistic and its Application to SAR Change Detection*, *2019 International Geoscience and Remote Sensing Symposium*

Talks:

- Ecolé d'été du GRETSI, Peyresq, July 2017
- Séminaire Laboratoire LISTIC, Annecy July 2018
- French-Finnish Workshop, Aalto university, December 2018

Others: Supervision of an internship on Clustering for SAR image time series.

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On multiple covariance equality testing with application to SAR change detection.
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IEEE Transactions on Geoscience and Remote Sensing, 45(3):566–575.

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Mian, A., Ginolhac, G., Ovarlez, J., and Atto, A. M. (2019a).
New robust statistics for change detection in time series of multivariate sar images.
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Mian, A., Ovarlez, J.-P., Ginolhac, G., and Atto, A. M. (2018).
Robust detection and estimation of Change-Points in a time series of multivariate images.
In *2018 26th European Signal Processing Conference (EUSIPCO) (EUSIPCO 2018)*, Roma, Italy.

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Tria, M., Ovarlez, J. P., Vignaud, L., Castelli, J. C., and Benidir, M. (2007). **Discriminating real objects in radar imaging by exploiting the squared modulus of the continuous wavelet transform.** *IET Radar, Sonar and Navigation*, 1(1):27–37.