PolTimeSAR:
The new benefit of Polarimetry for Urban areas

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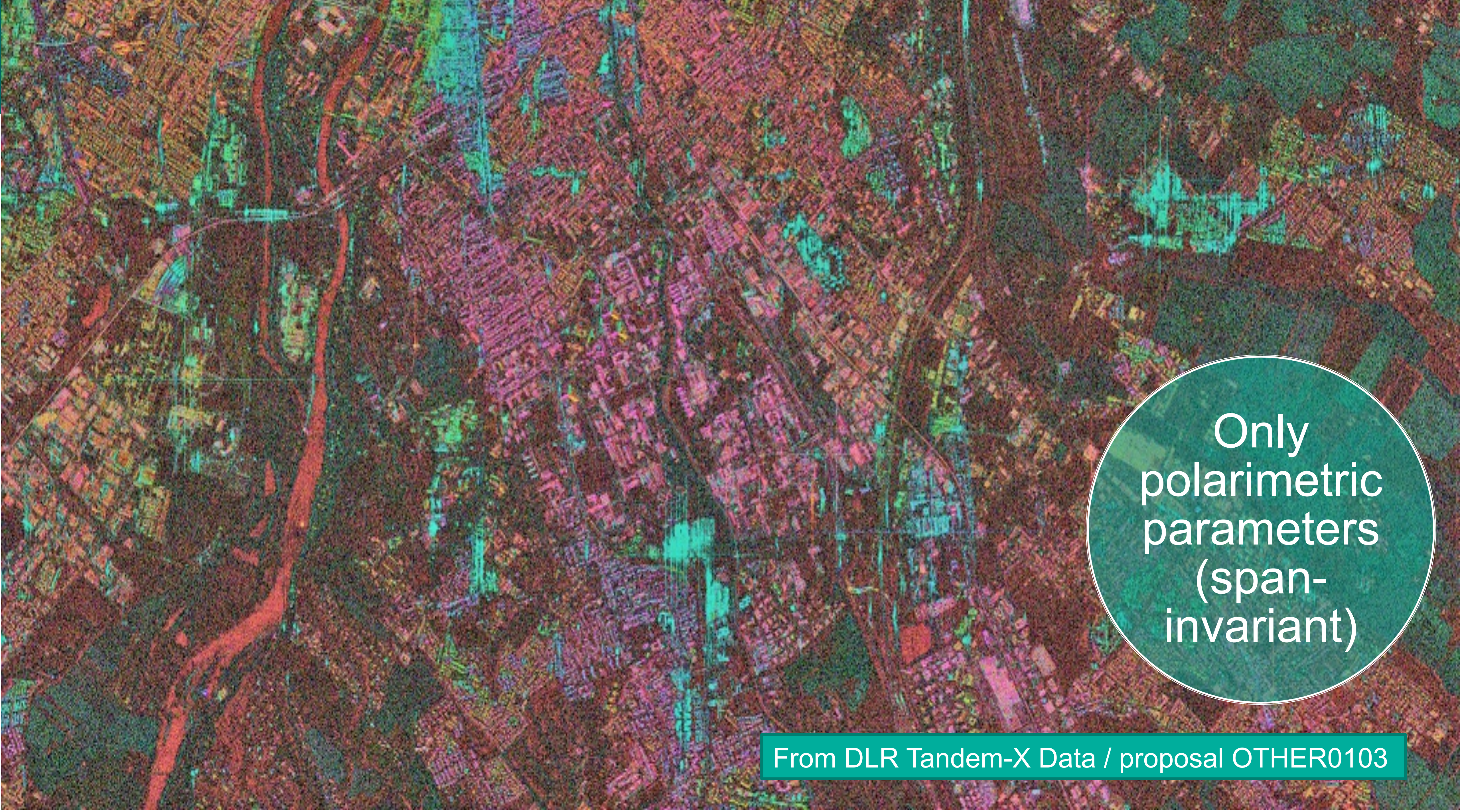

Only polarimetric parameters (span-invariant)
From DLR Tandem-X Data / proposal OTHER0103

Why time-series are a chance?

In polarimetry, there are :

- ❑ **first order** parameters: |HH|, |VV|, |HV|, |HH-VV| …
- ❑ **second order** parameters

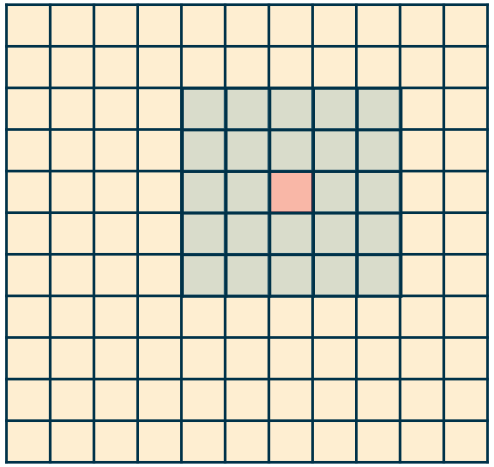
$$\gamma = \frac{< HH.HV^* >}{\sqrt{< HH.HH^* >< HV.HV^* >}}$$

$$k = \frac{1}{\sqrt{2}} \begin{pmatrix} S_{hH} + S_{vV} \\ S_{hH} - S_{vV} \\ 2S_{hV} \end{pmatrix} \Rightarrow T =< k\, k^H >$$

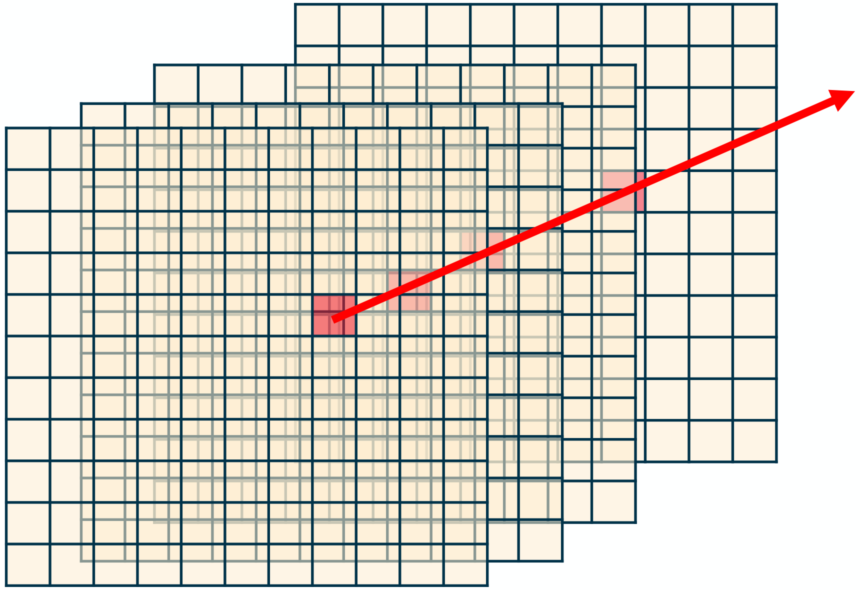
Polarimetric entropy
Incoherent decomposition

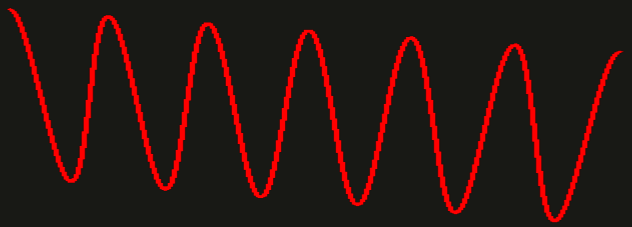
The second order parameters involve ESTIMATION

classically spatial averaging: loose of resolution

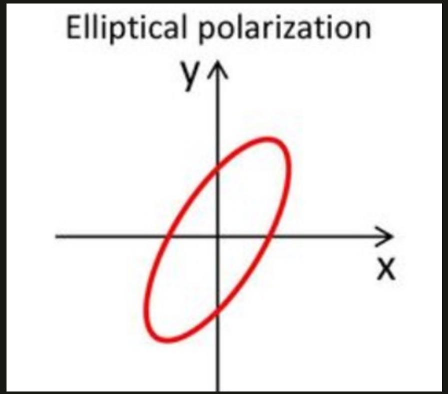


How dealing with temporal estimation instead of spatial estimation in polarimetric time-series ?

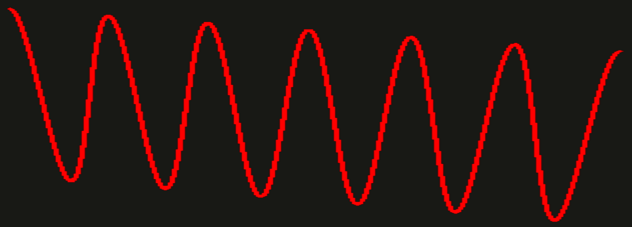




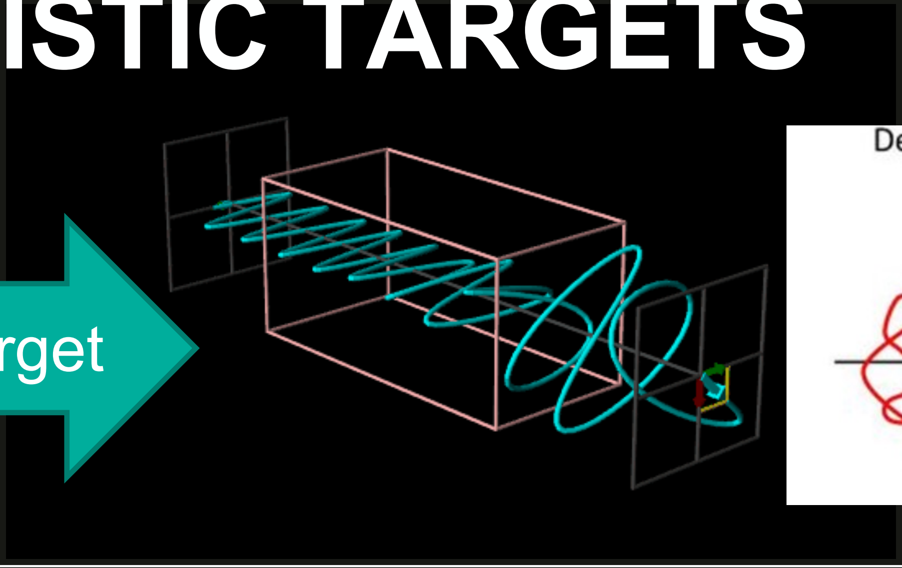
Deterministic target

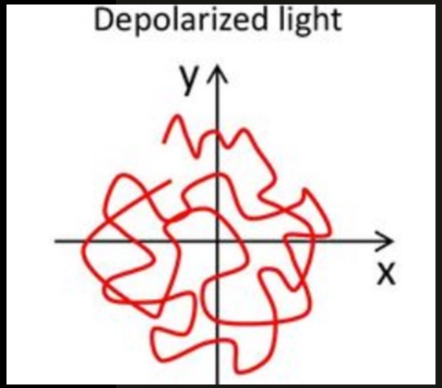


HIGHLIGHT DETERMINISTIC TARGETS



Non deterministic target



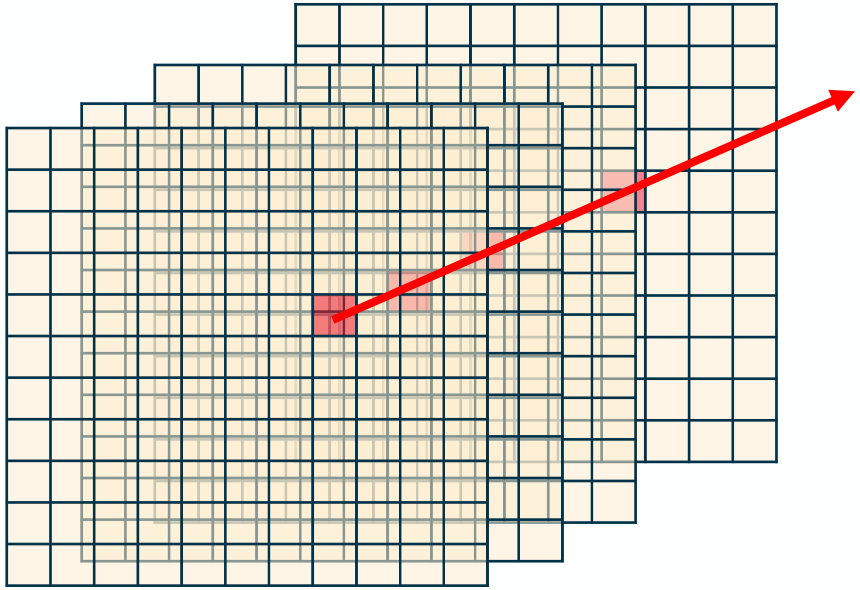


How to handle (HH,HV OR VH,VV time-series)

Each acquisition can be considered as a Jones vector

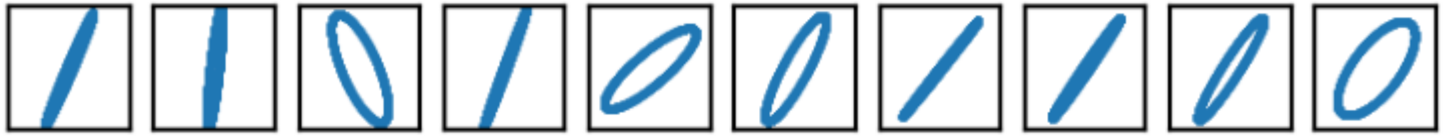
$$\mathbf{P} = \left(\mathbf{p}^1, \quad \dots \quad \mathbf{p}^k \quad \dots \quad \mathbf{p}^N\right) = \begin{pmatrix} E_\mathrm{x}^1 & E_\mathrm{x}^2 & \dots & E_\mathrm{x}^k & \dots & E_\mathrm{x}^N \\ E_\mathrm{y}^1 & E_\mathrm{y}^2 & \dots & E_\mathrm{y}^k & \dots & E_\mathrm{y}^N \end{pmatrix}$$

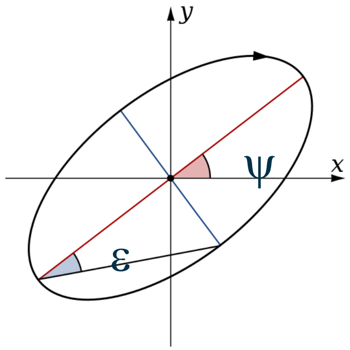
$$\begin{pmatrix} E_x = E_{\mathrm{Hh}} \\ E_y = E_{\mathrm{Hv}} \end{pmatrix} \quad \text{OR} \quad \begin{pmatrix} E_x = E_{\mathrm{Vh}} \\ E_y = E_{\mathrm{Vv}} \end{pmatrix}$$



Emitted Wave:  OR 

Received Wave:





$$\tan(2\psi) = \frac{2|E_\mathrm{x}||E_\mathrm{y}|}{|E_\mathrm{x}|^2 - |E_\mathrm{y}|^2} \cos\delta$$

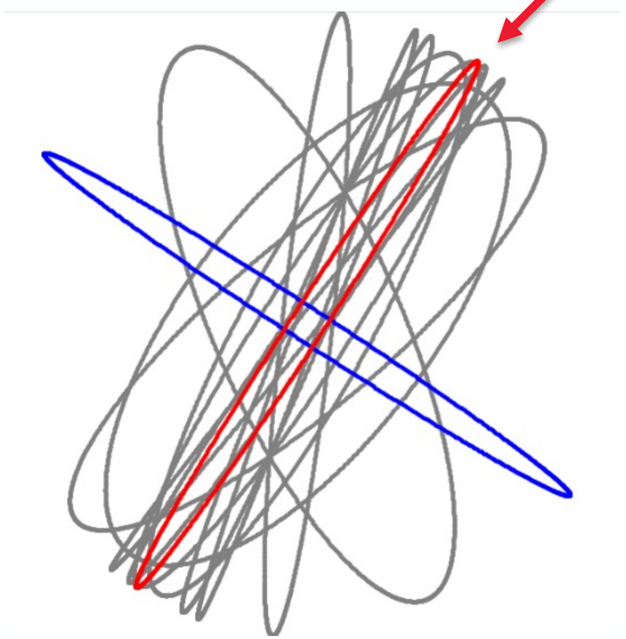
$$\sin(2\epsilon) = \frac{2|E_\mathrm{x}||E_\mathrm{y}|}{|E_\mathrm{x}|^2 + |E_\mathrm{y}|^2} \sin\delta, \qquad \delta = \arg(E_\mathrm{x} E_\mathrm{y}^*)$$

Covariance-coherence matrix, and Stokes vector

This two mathematical tools contain the same « second order » information:

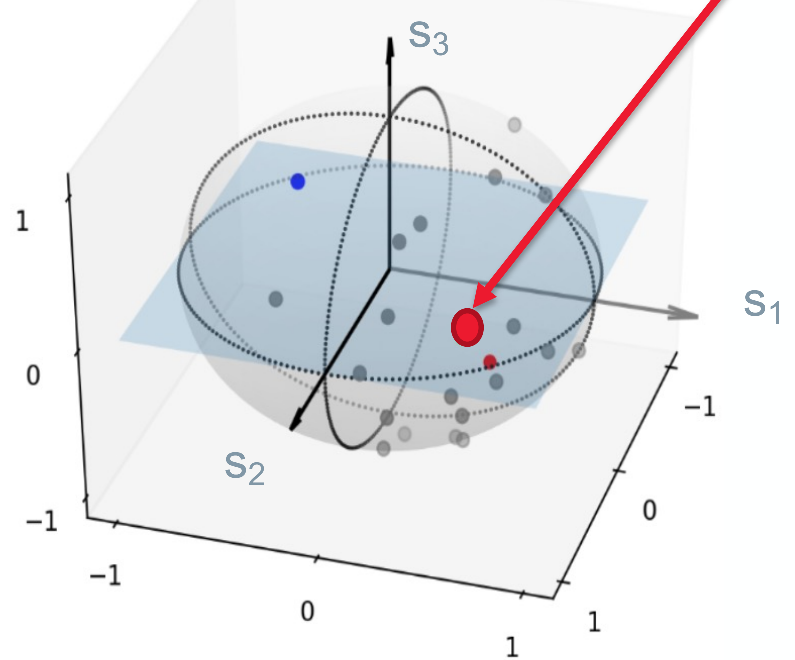
$$\mathbf{C} = \frac{1}{N}\sum_{k=1}^{N}\mathbf{p}^k\mathbf{p}^{k\dagger} = \begin{pmatrix} <|E_\mathrm{x}|^2> & <E_\mathrm{x}E_\mathrm{y}^*> \\ <E_\mathrm{x}^*E_\mathrm{y}> & <|E_\mathrm{y}|^2> \end{pmatrix} = \begin{pmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{pmatrix}$$

Covariance-coherence matrix
of Jones vector



$$\mathbf{S} = \begin{pmatrix} <|E_\mathrm{x}|^2+|E_\mathrm{y}|^2> \\ <|E_\mathrm{x}|^2-|E_\mathrm{y}|^2> \\ <2\Re(E_\mathrm{x}E_\mathrm{y}^*)> \\ <2\Im(E_\mathrm{x}E_\mathrm{y}^*)> \end{pmatrix} = \begin{pmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{pmatrix}$$

Stokes vector

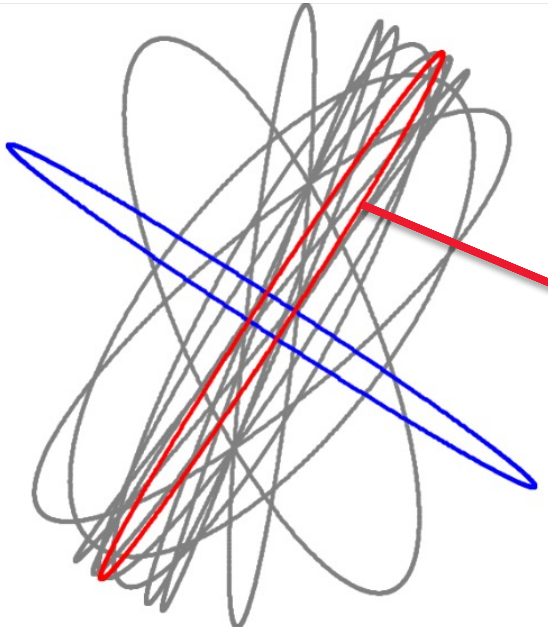


How to compute temporal coefficients

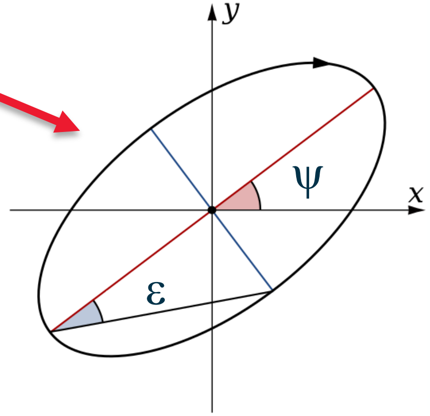
Degree of Polarisation

$$doP = \frac{2 < |E_{XX}E_{XY}^{*} >}{\sqrt{< |E_{XX}|^2 >^2 + < |E_{XY}|^2 >^2}}$$

$$\mathbf{C} = \frac{1}{N}\sum_{k=1}^{N}\mathbf{p}^{k}\mathbf{p}^{k\dagger} = \begin{pmatrix} < |E_{\mathrm{x}}|^2 > & < E_{\mathrm{x}}E_{\mathrm{y}}^{*} > \\ < E_{\mathrm{x}}^{*}E_{\mathrm{y}} > & < |E_{\mathrm{y}}|^2 > \end{pmatrix}$$



Main eigenvector (a,b)



Main polarization orientation

Main polarization ellipticity

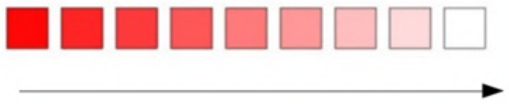
Applications to TerraSAR-X time-series (HH,HV)

Colored representation of second order parameters in HSV domain

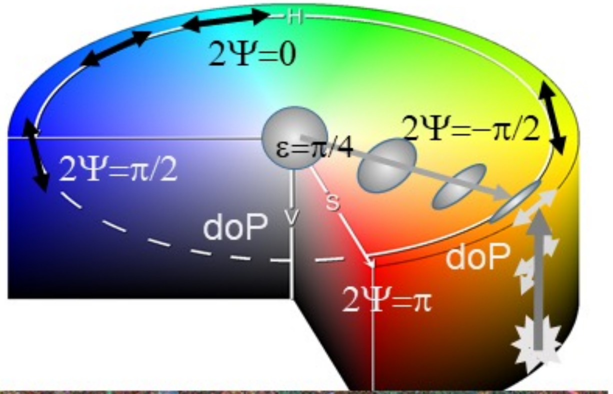
Degree of Polarisation

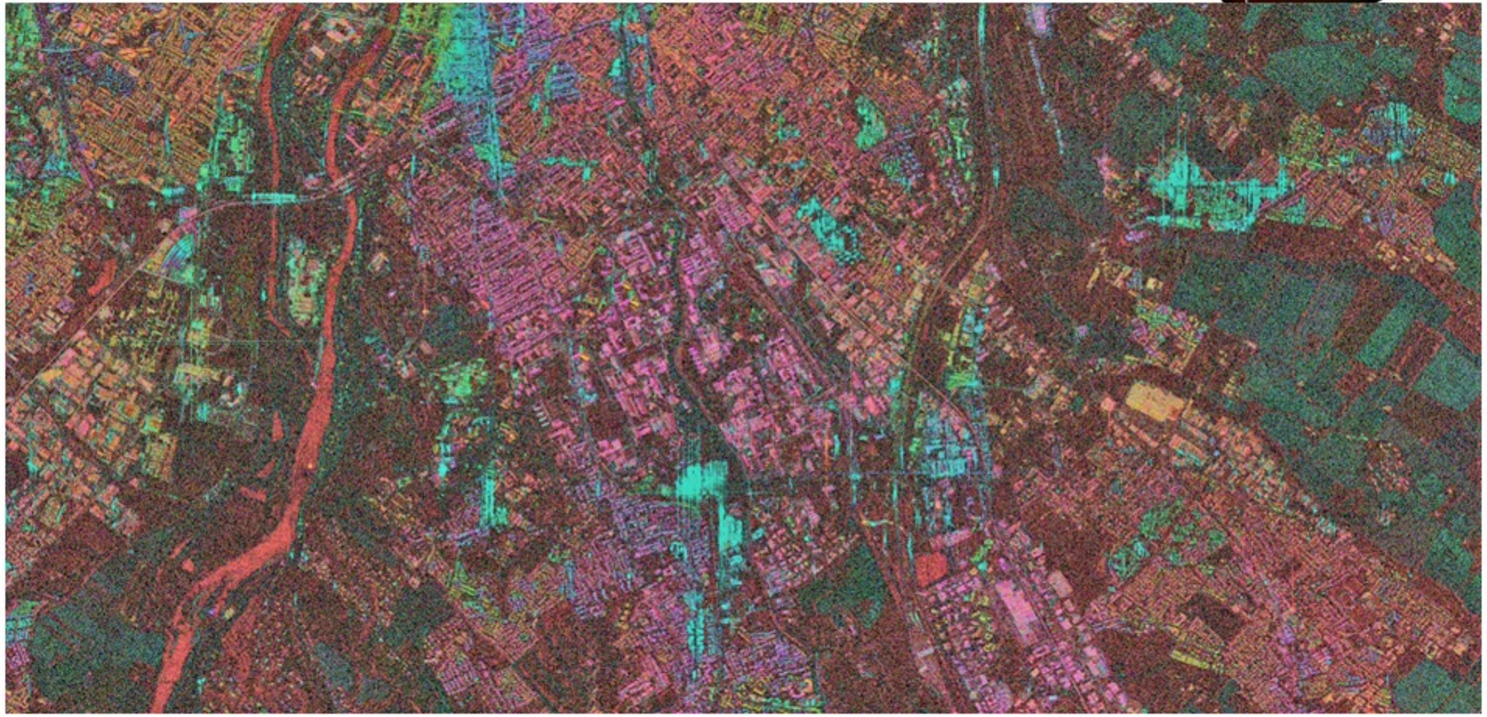
Main polarization orientation

Main polarization ellipticity

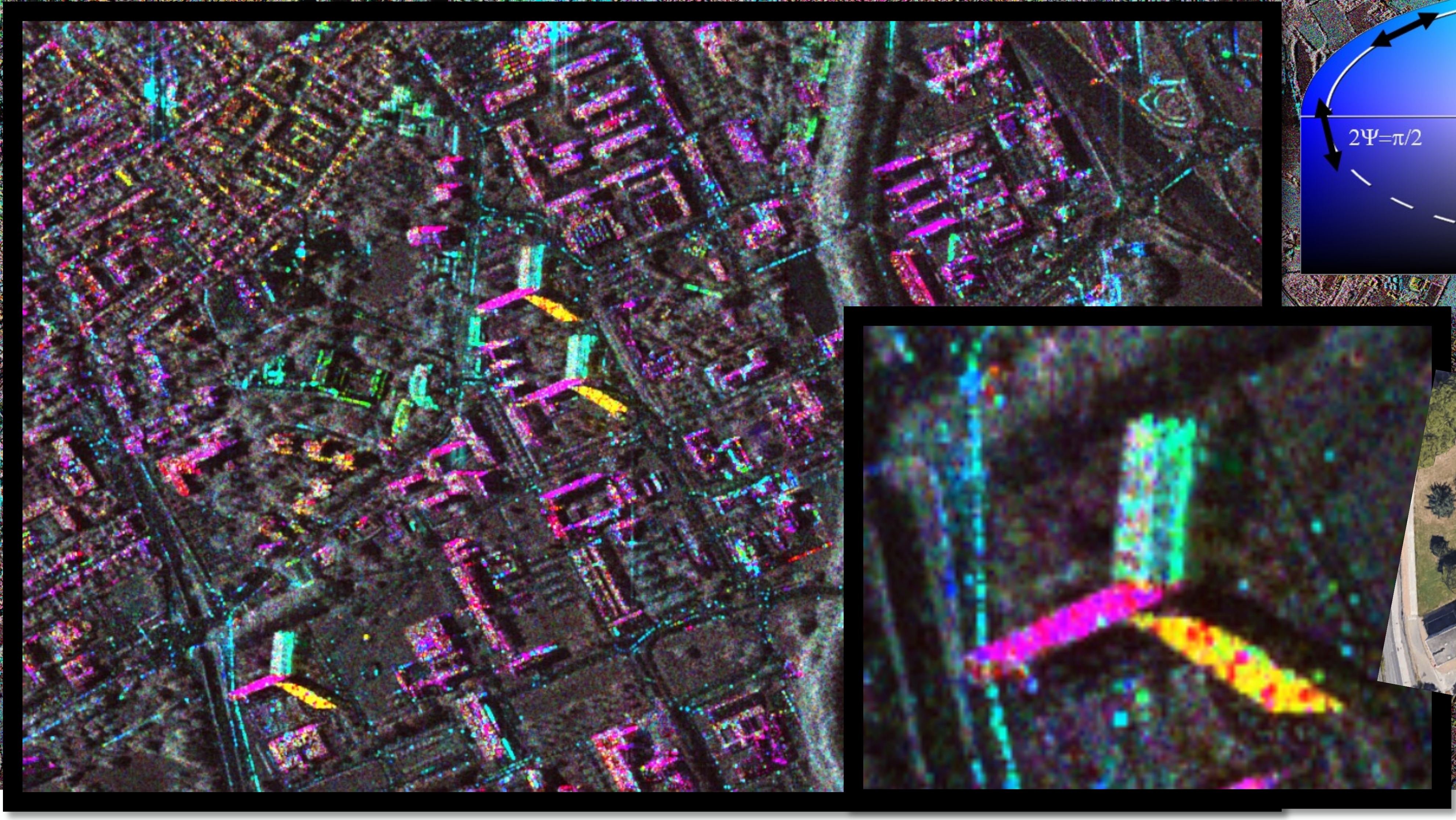


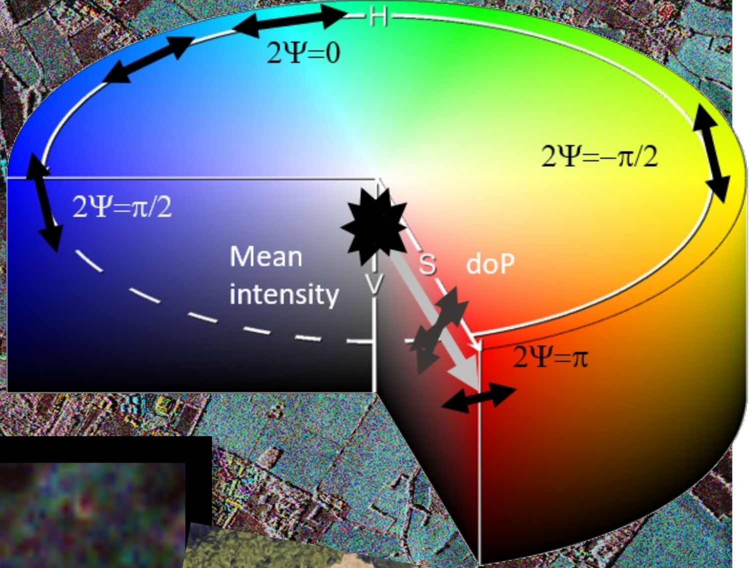
2Ψ

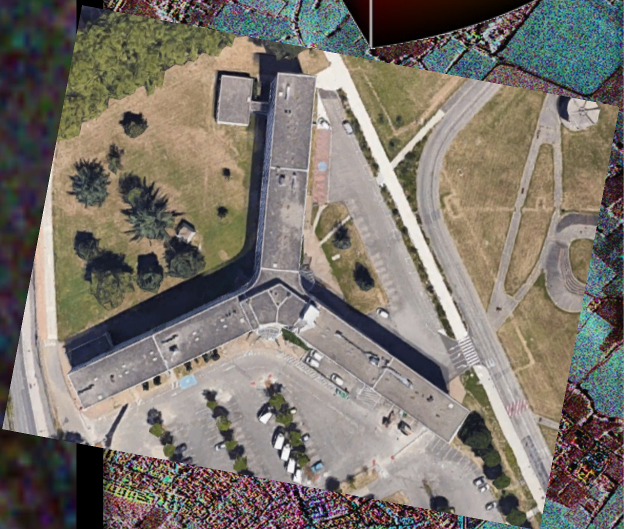




Applications to TerraSAR-X time-series (HH,HV)



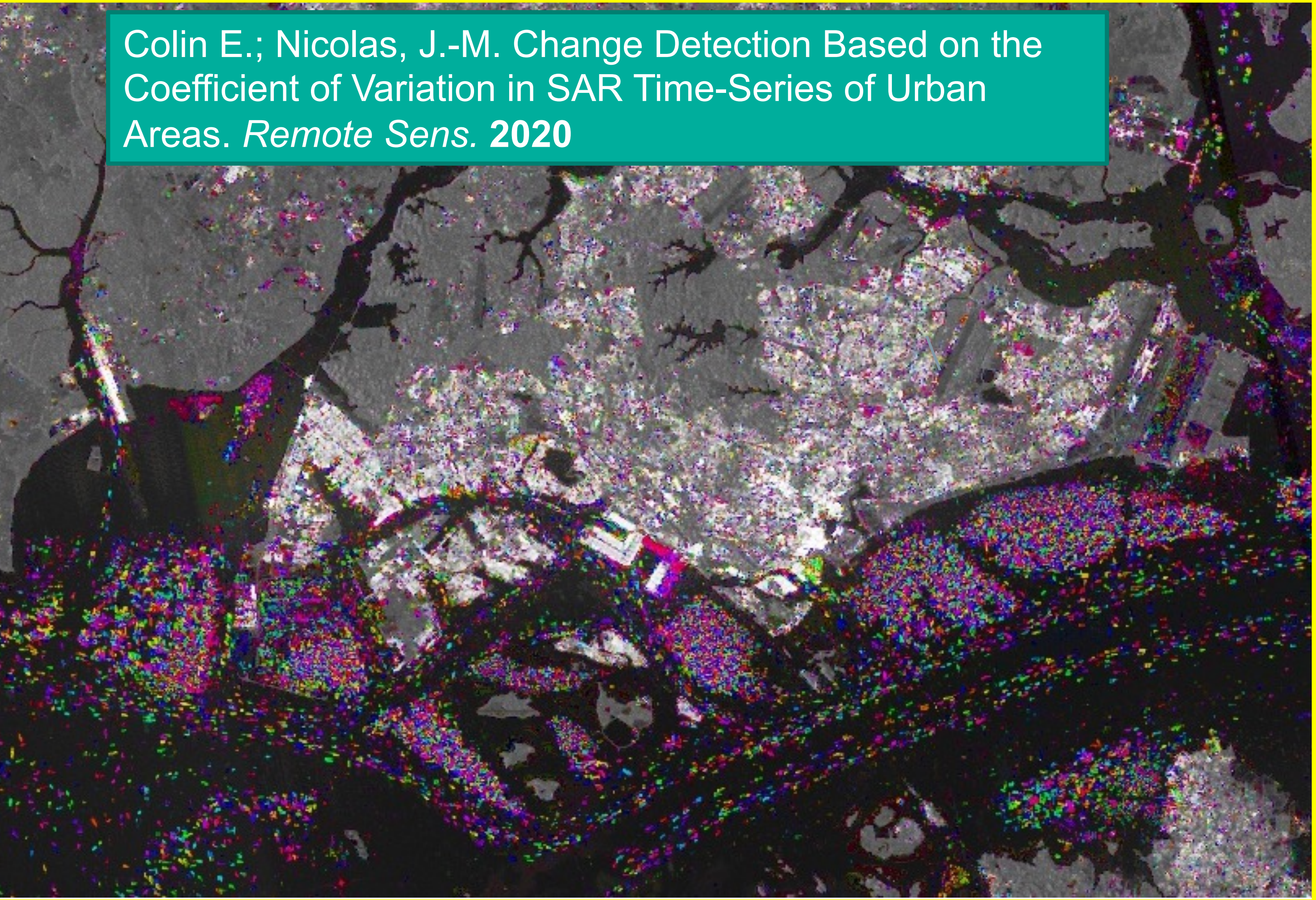




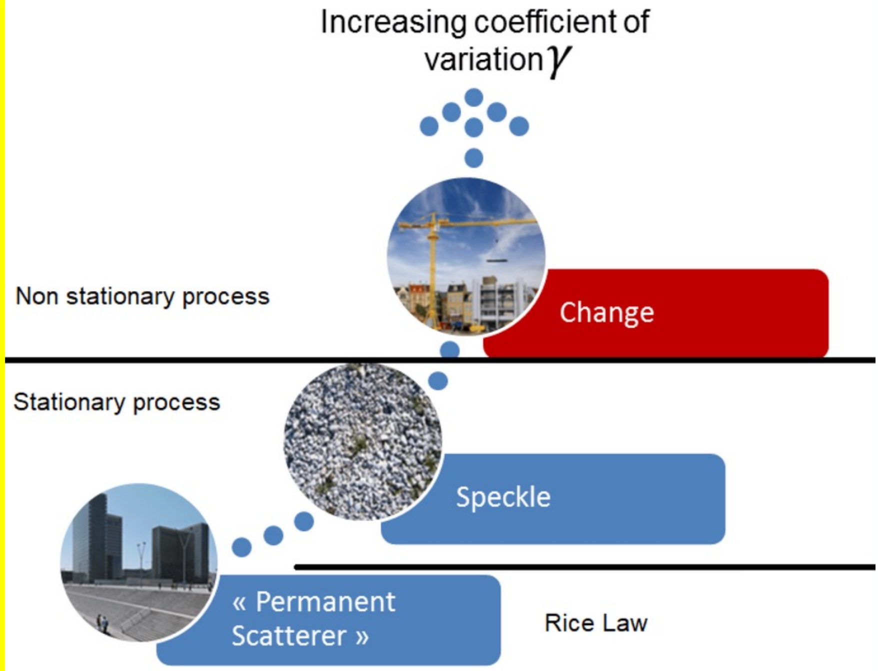
DETECTING CHANGES

Coefficient of variation and applications

Colin E.; Nicolas, J.-M. Change Detection Based on the Coefficient of Variation in SAR Time-Series of Urban Areas. *Remote Sens.* **2020**



$$\gamma = \frac{\text{standard deviation}}{\text{mean}}$$



Extensions to the multivariate cases

Extension to the multimodal case: $\mathbf{P} = (\mathbf{p}^1, \quad ... \quad \mathbf{p}^k \quad ... \quad \mathbf{p}^N)$ $\quad \mathbf{C} = \frac{1}{N}\sum_{k=1}^{N} \mathbf{p}^k \mathbf{p}^{k\dagger}$ $\quad \boldsymbol{\mu} =< \mathbf{P} >$

P is real component !

$$\gamma_{\mathrm{R}} = \sqrt{\frac{\det(\mathbf{C})^{1/p}}{\boldsymbol{\mu}^\dagger\boldsymbol{\mu}}},$$

Reyment [1960]

Sensitive to « zeros » (singular matrix C)

$$\gamma_{\mathrm{VV}} = \sqrt{\frac{\mathrm{trace}(\mathbf{C})}{\boldsymbol{\mu}^\dagger\boldsymbol{\mu}}},$$

Van Valen et al. [2005]

Does not take into account intercorrelation

$$\gamma_{\mathrm{VN}} = \sqrt{\frac{1}{\boldsymbol{\mu}^\dagger\mathbf{C}^{-1}\boldsymbol{\mu}}},$$

Voinov and Nikulin [2012]

Sensitive to noise
Requires matrix inversion

$$\gamma_{\mathrm{AZ}} = \sqrt{\frac{\boldsymbol{\mu}^\dagger\mathbf{C}\boldsymbol{\mu}}{(\boldsymbol{\mu}^\dagger\boldsymbol{\mu})^2}}$$

Albert and Zhang [2010]

Last alternative

Application to the polarimetric time-series

OR

$$\begin{pmatrix} E_x = E_{\mathrm{Hh}} \\ E_y = E_{\mathrm{Hv}} \end{pmatrix} \begin{pmatrix} E_x = E_{\mathrm{Vh}} \\ E_y = E_{\mathrm{Vv}} \end{pmatrix}$$

Solution 1

$$\mathbf{P} = \begin{pmatrix} |E_x| \\ |E_y| \end{pmatrix}$$

→ **Does not take into account cross-correlations**

Solution 2

$$\mathbf{S} = \begin{pmatrix} < |E_{\mathrm{x}}|^2 + |E_{\mathrm{y}}|^2 > \\ < |E_{\mathrm{x}}|^2 - |E_{\mathrm{y}}|^2 > \\ < 2\Re(E_{\mathrm{x}} E_{\mathrm{y}}^*) > \\ < 2\Im(E_{\mathrm{x}} E_{\mathrm{y}}^*) > \end{pmatrix} = \begin{pmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{pmatrix}$$

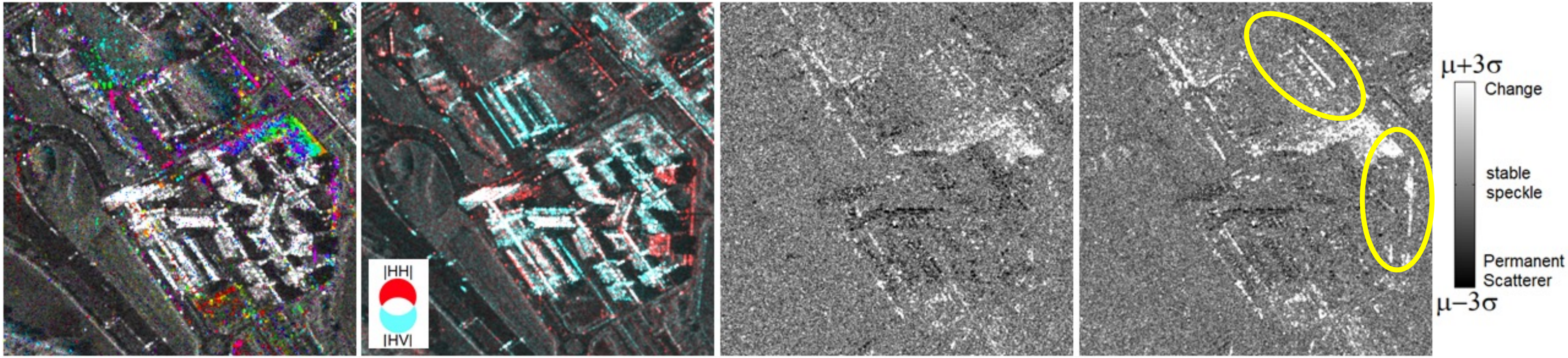
→ **Covariance includes cross-correlations**

Results on TerraSAR-X time-series (HH,HV)

considering $\mathbf{P} = \begin{pmatrix} |E_x| \\ |E_y| \end{pmatrix}$

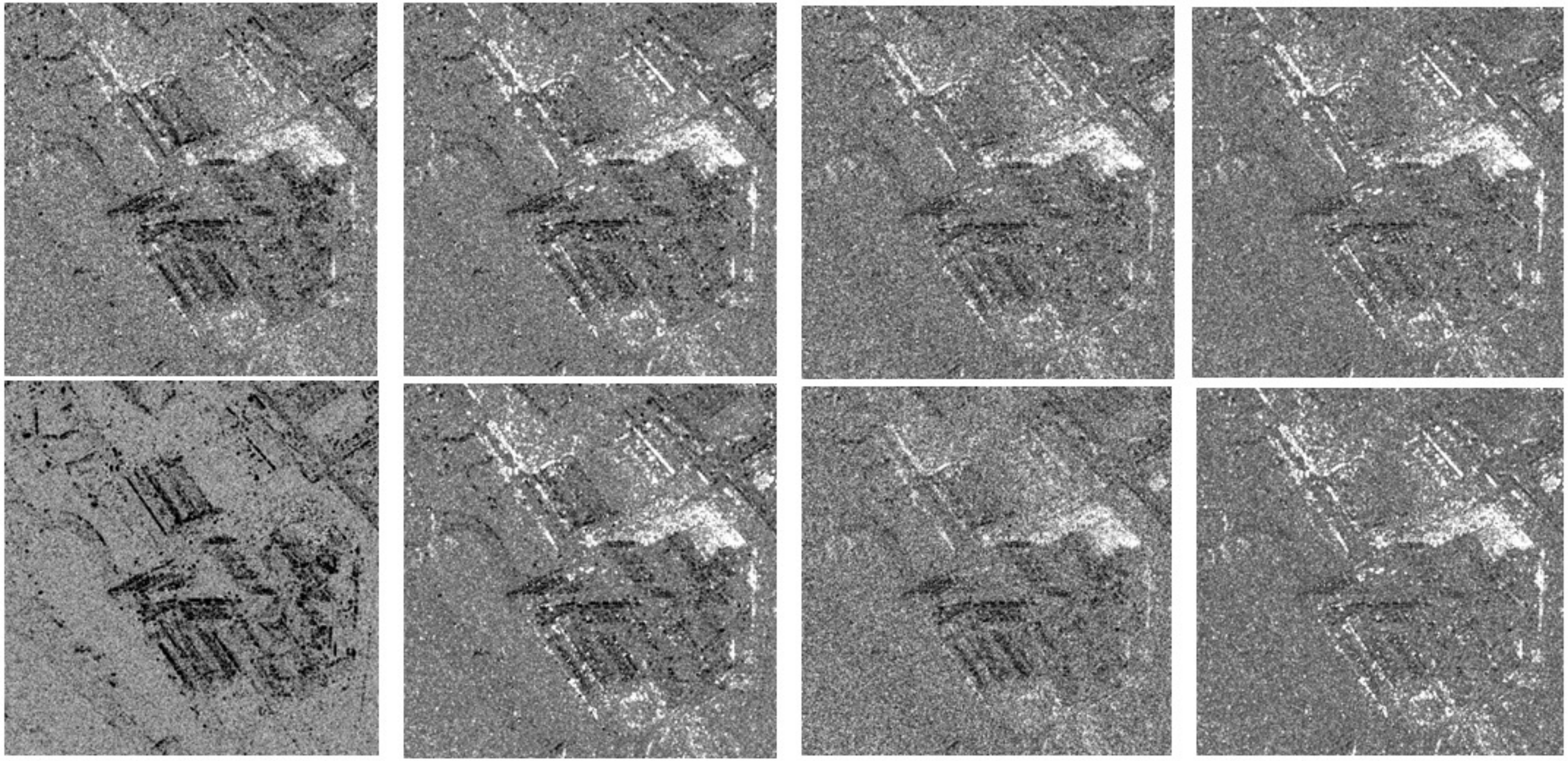
Classical Coefficient of variation in VH

$$\gamma_{AZ} = \sqrt{\frac{\boldsymbol{\mu}^\dagger \mathbf{C} \boldsymbol{\mu}}{(\boldsymbol{\mu}^\dagger \boldsymbol{\mu})^2}}$$



a) b) c) d)

Results on TerraSAR-X time-series (HH,HV)

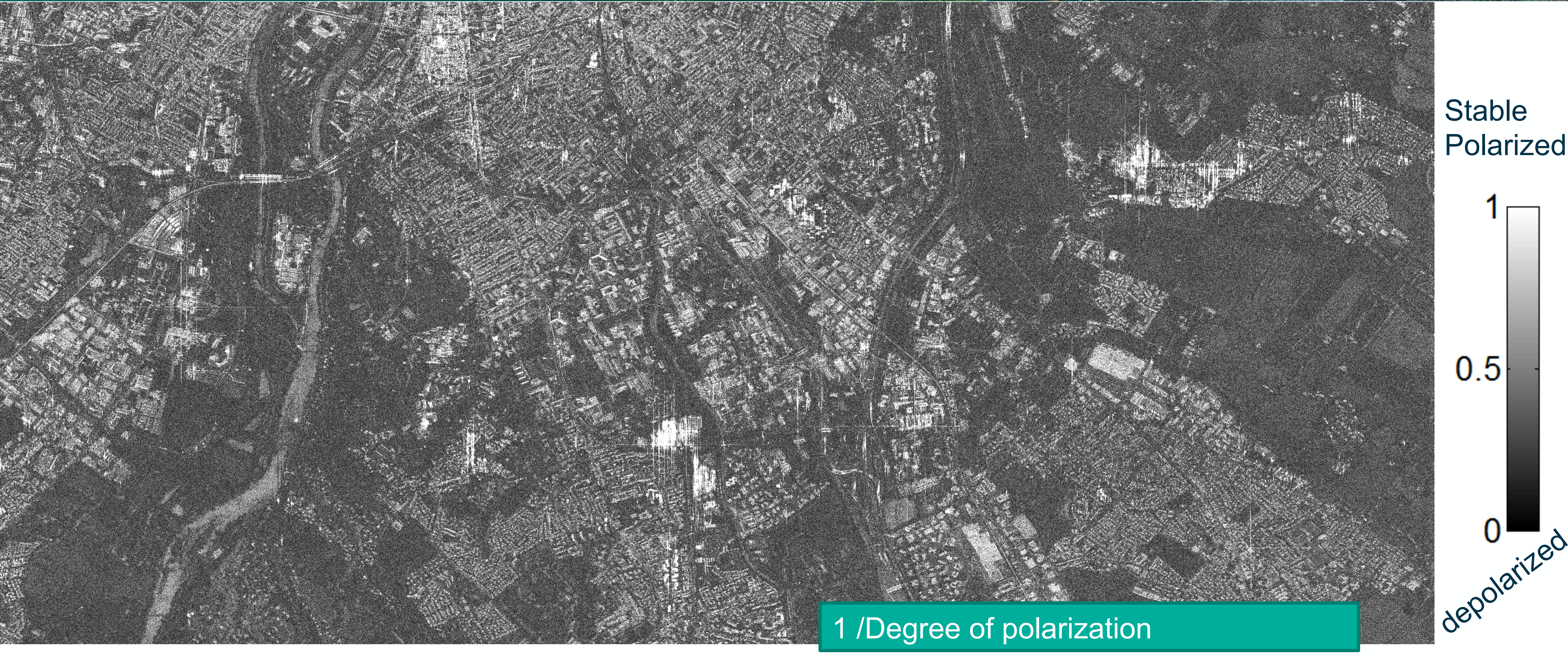


$$P = \begin{pmatrix} |HH| \\ |VH| \end{pmatrix}$$

$$S = \begin{pmatrix} |HH|^2 + |HV|^2 \\ |HH|^2 - |HV|^2 \\ 2\,Re\,(HH.HV^*) \\ 2\,Im\,(HH.HV^*) \end{pmatrix}$$

$$\gamma_{\mathrm{R}} = \sqrt{\frac{\det(\mathbf{C})^{1/p}}{\boldsymbol{\mu}^\dagger \boldsymbol{\mu}}}, \quad \gamma_{\mathrm{VV}} = \sqrt{\frac{\mathrm{trace}(\mathbf{C})}{\boldsymbol{\mu}^\dagger \boldsymbol{\mu}}}, \quad \gamma_{\mathrm{VN}} = \sqrt{\frac{1}{\boldsymbol{\mu}^\dagger \mathbf{C}^{-1} \boldsymbol{\mu}}}, \quad \gamma_{\mathrm{AZ}} = \sqrt{\frac{\boldsymbol{\mu}^\dagger \mathbf{C} \boldsymbol{\mu}}{(\boldsymbol{\mu}^\dagger \boldsymbol{\mu})^2}}$$

Link between multimodal coefficient of variation and depolarisation



Link between multimodal coefficient of variation and depolarisation

Conclusion

From dual polarimetric time-series (HH,HV) or (VH,VV), you can:

- compute a polarimetric degree of polarization or depolarization, **without loss of resolution**
- compute a mean « orientation angle » and ellipticity, **without loss of resolution**
- extend change detection to polarimetric case, **without loss of resolution**
- consider link between polarimetric depolarization effect, and temporal stability studies.

For all that, we need **to keep the phase between HH and HV or VV and HV**

Lack of a Sentinel-1 tool to handle SLC time-series on sub-parts of the whole footprint

Conclusion

esa

HAL open science

PolTimeSAR: why we need full polarimetry to detect changes in a SAR time series

Elise Colin

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Elise Colin. PolTimeSAR: why we need full polarimetry to detect changes in a SAR time series. 2023. hal-04011052

Polarimetry plays a major role in time-series, especially concerning changes

Proposition of formalism for (HH,HV) or (VH,VV) data computation of temporal depolarization

HAL open science

PolTimeSAR: Link between the measurement of a time series of N Jones vectors, and the measurement of a single Stokes vector integrating all these measurements. Application to (HH,HV) or (VH,VV) SAR time series

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Elise Colin. PolTimeSAR: Link between the measurement of a time series of N Jones vectors, and the measurement of a single Stokes vector integrating all these measurements. Application to (HH,HV) or (VH,VV) SAR time series. 2023. hal-04045501

THE SPECKLE CONTRAST EXTENDED TO THE POLARIMETRIC CASE: APPLICATIONS TO RADAR AND LASER IMAGES

A PREPRINT

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Multimodal coefficient of variation

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