Temporal Coherence of Multitemporal and Polarimetric SAR Data: Application To Agricultural Event Detection Using Sentinel-1 Data

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Summary

I Context

Crop monitoring

- Improving production by identifying the best farming practices
- Monitoring of the state of a field (flowering, disease control, irrigation management…)
- Logistics for farm silos, which fields to harvest

UE interest

- New common agricultural policy
- Agricultural subsidies
- Forecasting and managing agricultural or environmental crises

Existing methods at Capgemini

- Optical data used for this detection ➔ problem due to cloudy days (from 50% to 60% in France) for precise dating
- SAR coherence ➔ problem due to low-coherence area studied

Scalability

- Actual method is to send agents note the state of a field by visiting it ➔ outdated for new common agricultural policy
- Need an easy-to-use method for non-radar experts

II Theory
1 dataset and ground truth

Dataset:

- 8 SLC IW Dual-Pol VV/VH Sentinel-1 acquisitions over France, between 22/06/2022 and 25/08/2022, processed using SNAP, with a pixel spacing of 2.3m in range and 13.9m in azimuth
- 7 coherences have been calculated using a 15x3 window as spatial averaging, i.e 34.5m x 41.7m
- Different variables have been looked at in order to try to increase the event detection

Ground truth:

- Graphical Parcel Registers (RPG) data provided by the National Institute of Geographic and Forest Information (IGN) of 2022
- Campaign : 63 fields visited over 178897 fields the 28th August in our Sentinel-1 acquisitions footprint

Fig. 1: VV Coherence displayed over France

II Theory
2 Reinterpreted Temporal Coherence

Mono-polarisation:

The Interferometric Coherence between two acquisitions 1 and 2 is defined by :

$$\rho = \frac{\langle S_{1XY} S_{2XY}^{*} \rangle}{\sqrt{\langle S_{1XY} S_{1XY}^{*} \rangle \langle S_{2XY} S_{2XY}^{*} \rangle}}$$

Where $\langle \dots \rangle$ indicates the expectation value, S_1 and S_2 are the complex backscatter coefficient for the images 1 and 2, XY a chosen polarisation and * the complex conjugate.

Dual-polarisation (Sentinel-1 VV/VH polarisations):

We define the coherent scatting vector $\underline{k} = [S_{VV}, 2S_{VH}]^{T}$ and three matrices :
$[T_{11}] = \langle \underline{k_1} \underline{k_1}^{*T} \rangle$ and $[T_{22}] = \langle \underline{k_2} \underline{k_2}^{*T} \rangle$ the coherency matrices and $[\Omega_{12}] = \langle \underline{k_1} \underline{k_2}^{*T} \rangle$ the temporal PolInSAR matrix

The Polarimetric Interferometric Coherence is then defined by :

$$\rho = \frac{\langle \underline{w_1}^{*T} [\Omega_{12}] \underline{w_2} \rangle}{\sqrt{\langle \underline{w_1}^{*T} [T_{11}] \underline{w_1} \rangle \langle \underline{w_2}^{*T} [T_{22}] \underline{w_2} \rangle}} \quad [1]$$

Where $\underline{w_1}$ and $\underline{w_2}$ are unitary complex vector that are linked to the scattering mechanisms.

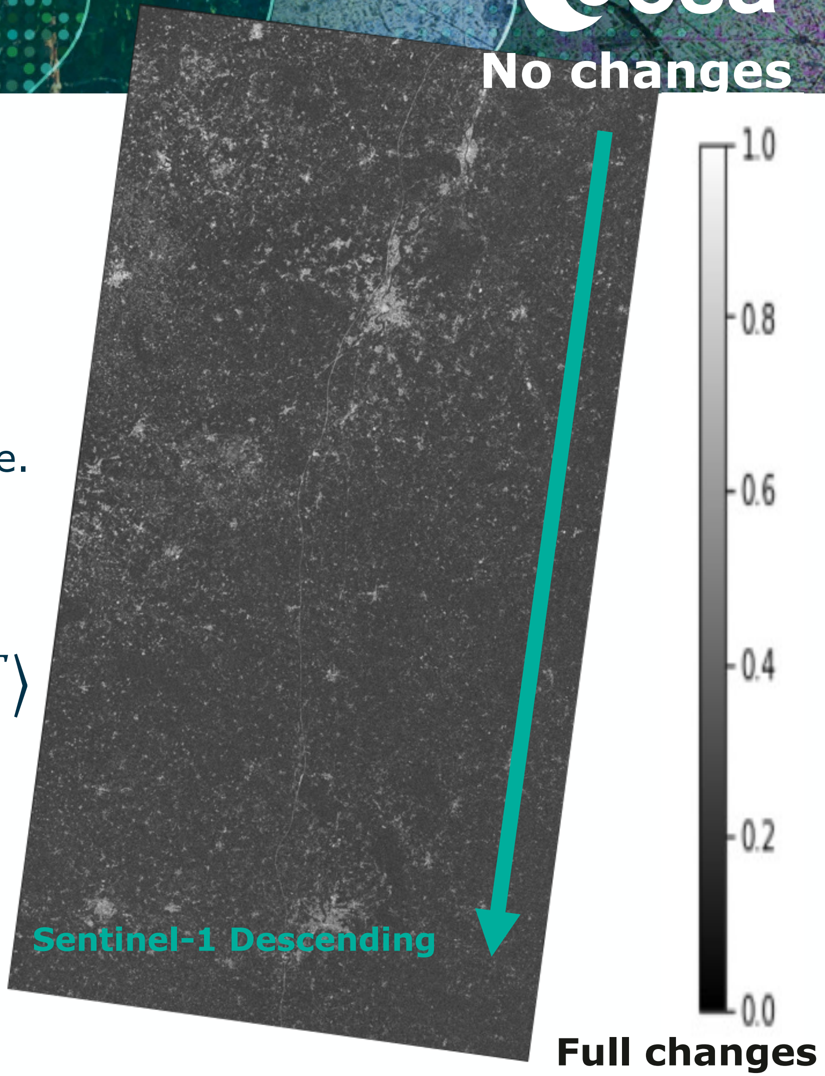


Fig. 2: VV Coherence

[1] S. R. Cloude and K. P. Papathanassiou, "Polarimetric SAR interferometry," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 36, no. 5, pp. 1551-1565, Sept. 1998, doi: 10.1109/36.718859.

II Theory
2 Reinterpreted Temporal Coherence

The Polarimetric Interferometric Coherence can be divided in two terms: $\rho = \rho_{sym}\rho_{asym}$, and using $[T] = \frac{[T_{11}]+[T_{22}]}{2}$ we obtain:

- $\rho_{sym} = \rho_{temp}\rho_{SNR}\rho_{rg}\rho_{vol}\rho_{other} = \frac{\langle \underline{w}_1^{*T}[\Omega_{12}]\underline{w}_2 \rangle}{\langle \underline{w}_1^{*T}[T]\underline{w}_2 \rangle}$ which account for changes under the equal scattering mechanism assumption between both acquisitions.
- $\rho_{asym} = \frac{\langle \underline{w}_1^{*T}[T]\underline{w}_2 \rangle}{\sqrt{\langle \underline{w}_1^{*T}[T_{11}]\underline{w}_1 \rangle \langle \underline{w}_2^{*T}[T_{22}]\underline{w}_2 \rangle}}$ which account for noncoherent changes between both images.

This second term is interesting as it allows characterisation of PolInSAR data for low-coherence scenarios, the idea is therefore to maximise it.

It has been demonstrated in [2] that it is maximised for $\underline{w}_1 = \underline{w}_2 = \underline{w}$ and when the following real eigenvalue problems is solved:

$$\begin{cases} [T_{11}^{-1}][T_{22}]\underline{w} = \nu_\tau \underline{w} \\ [T_{22}^{-1}][T_{11}]\underline{w} = \nu_\tau{}^{-1} \underline{w} \end{cases}$$

Therefore, using these eigenvalues ν_τ or corresponding $\rho_{asym,opti}$ values allows to study low-coherence scenarios.

[2] J. Ni, C. López-Martínez, Z. Hu and F. Zhang, "Multitemporal SAR and Polarimetric SAR Optimization and Classification: Reinterpreting Temporal Coherence," in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, pp. 1-17, 2022, Art no. 5236617, doi: 10.1109/TGRS.2022.3214097.

II Theory
3 Reinterpreted vs Classical Temporal Coherence

Reinterpreted Temporal Coherence

Advantages:

- Can be used in low-coherence scenarios
- Creation of new useful variables characterising the target
- Optimised values calculated to facilitate studies

Drawbacks:

- Loss of physical meaning for optimised values
- Much longer calculation times and need for more computing power for the optimised values (41,1Go RAM used, 25 minutes, parallelised on 20 processors)

Classical Temporal Coherence

Advantages:

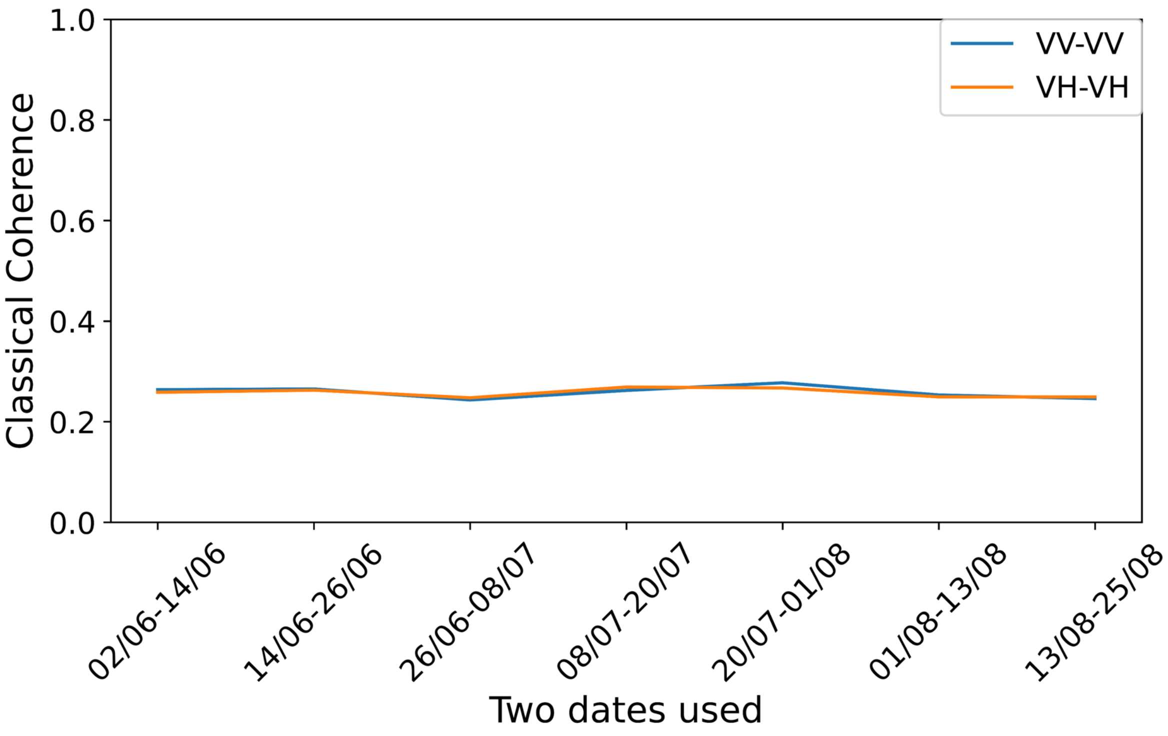
- Easy to understand
- Easy to calculate (12.1Go RAM used, 198 secondes)

Drawbacks:

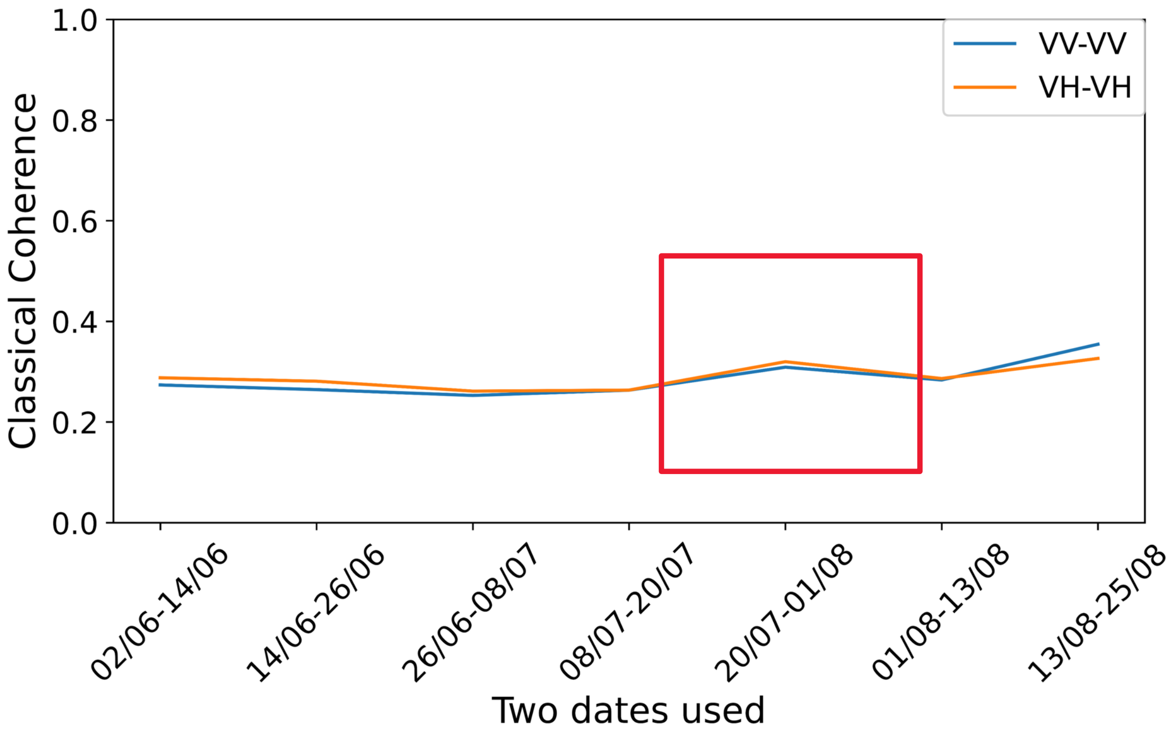
- Can not be used in low-coherence scenarios

III Results
1 Reinterpreted vs Classical Temporal Coherence

Classical Temporal Coherence



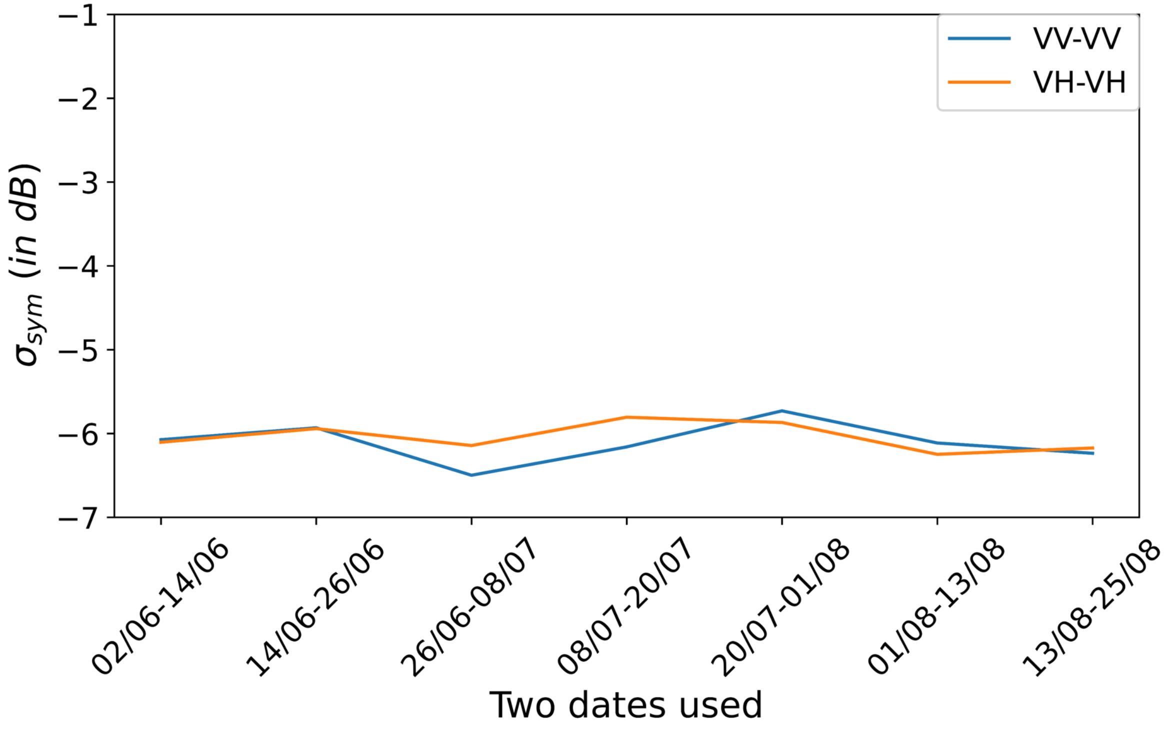
Noisy area : Water

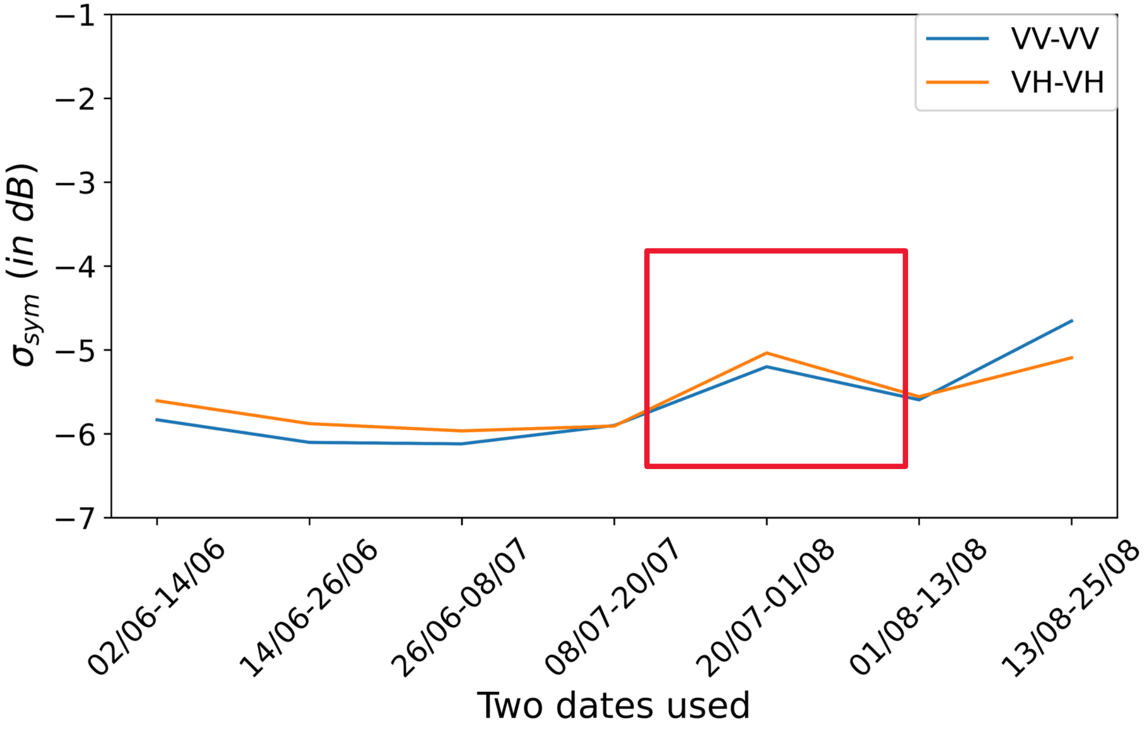


Stubble ploughing for wheat 25/07

III Results
1 Reinterpreted vs Classical Temporal Coherence

Reinterpreted Temporal Coherence: ρ_{sym}



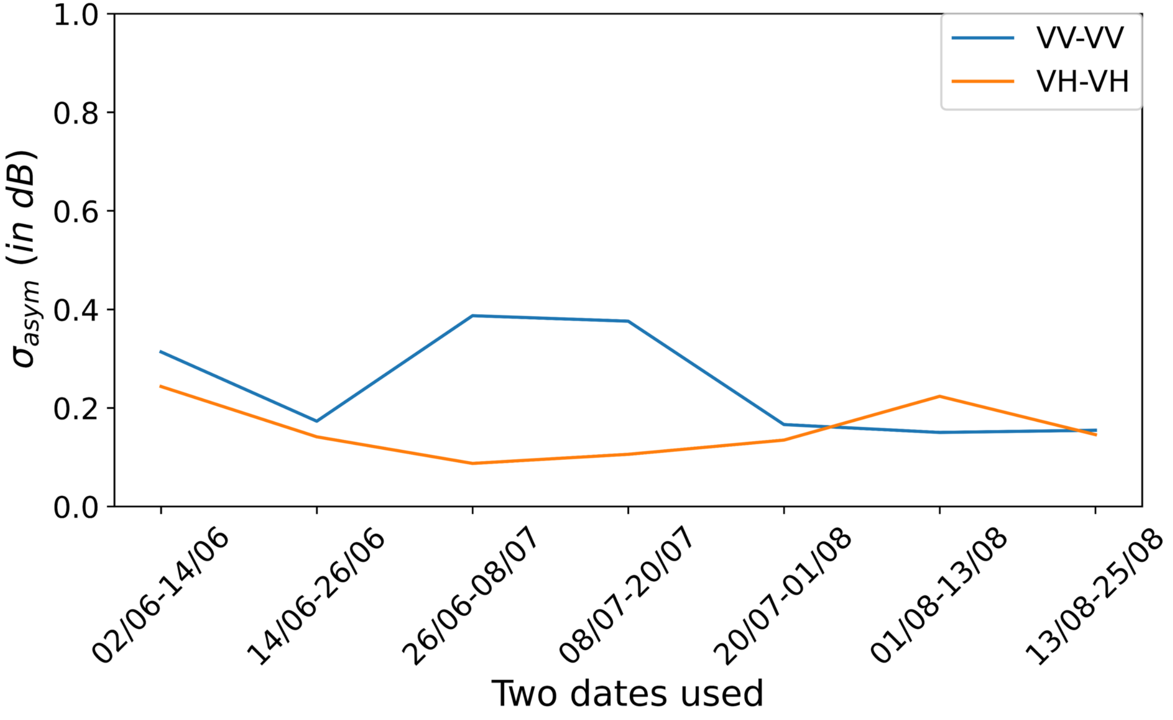


Noisy area : Water

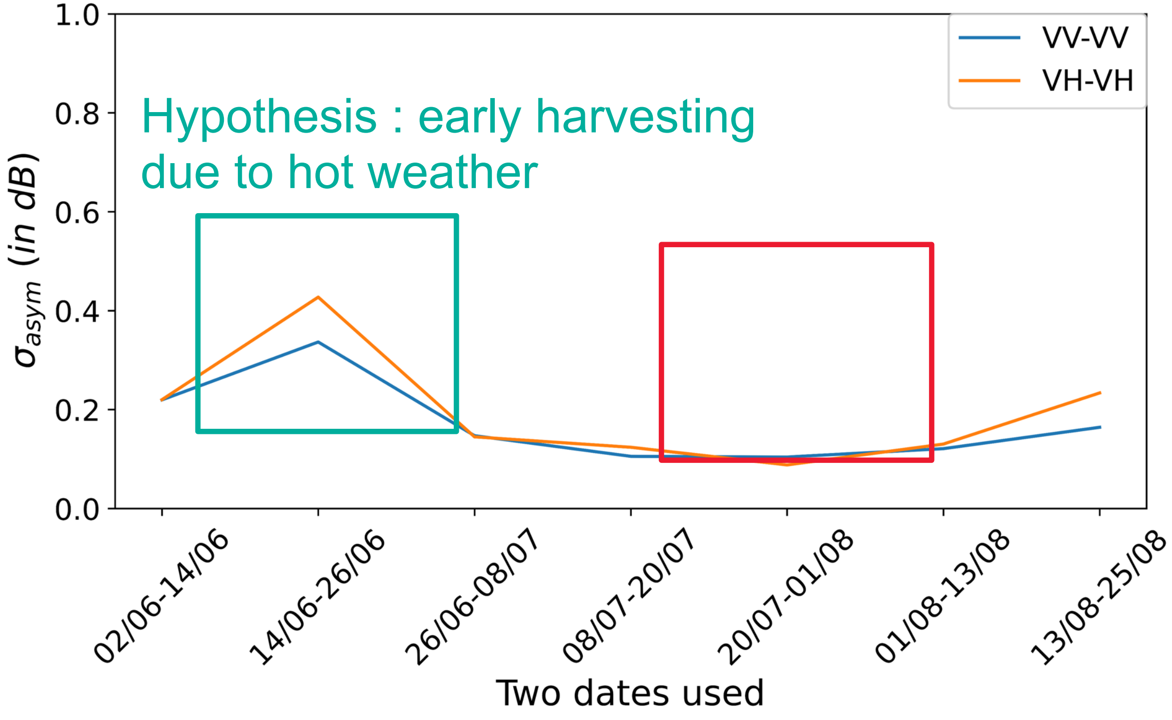
Stubble ploughing for wheat
25/07

III Results
1 Reinterpreted vs Classical Temporal Coherence

Reinterpreted Temporal Coherence: ρ_{asym}



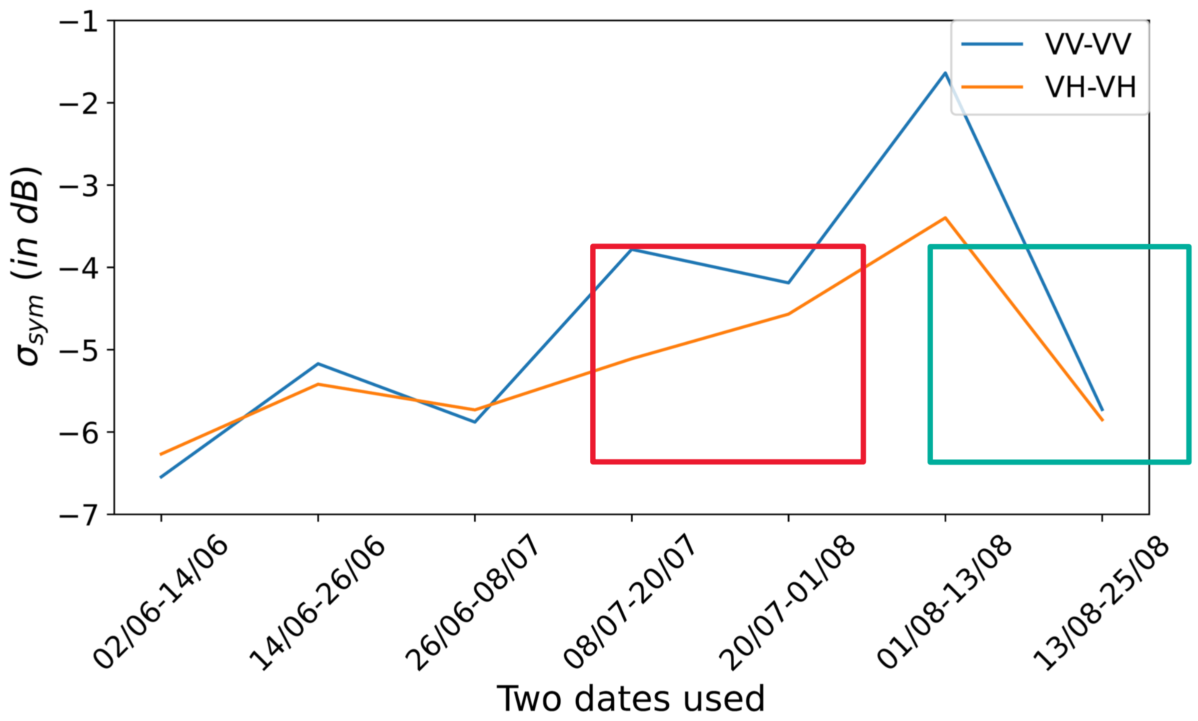
Noisy area : Water



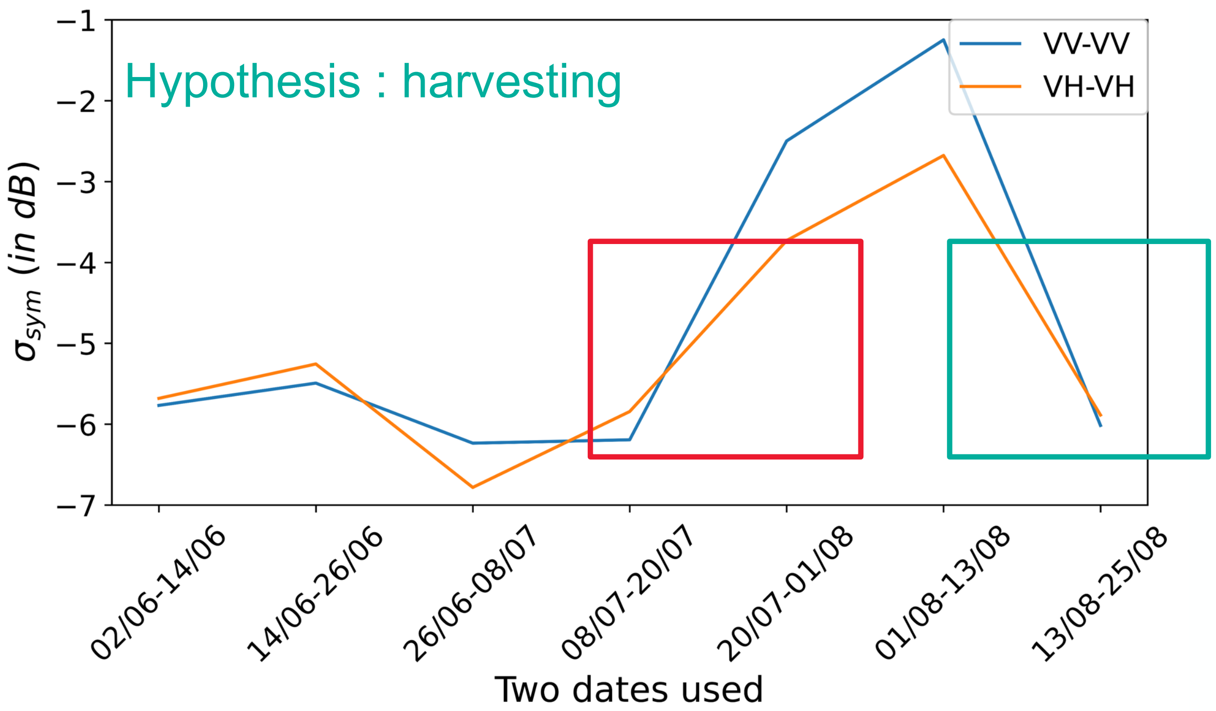
Stubble ploughing for wheat 25/07

III Results
2 Promising results

Reinterpreted Temporal Coherence: ρ_{sym}

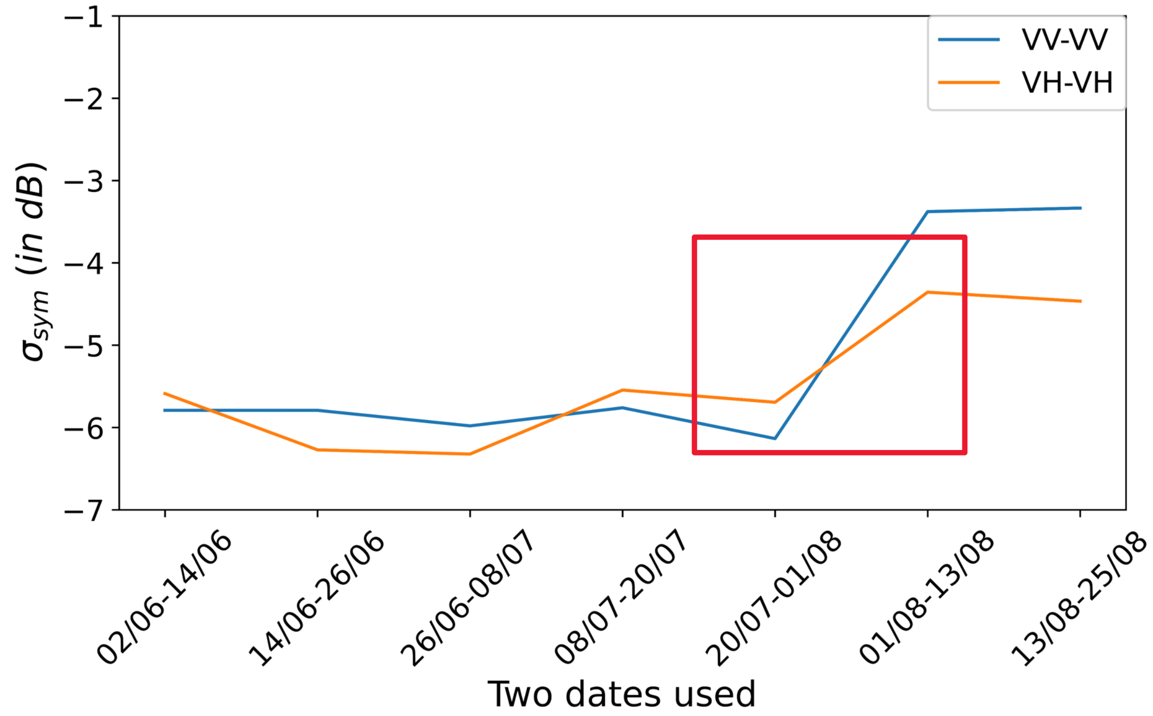


Corn flowering ROI 46
18/07



Corn flowering ROI 55
18/07

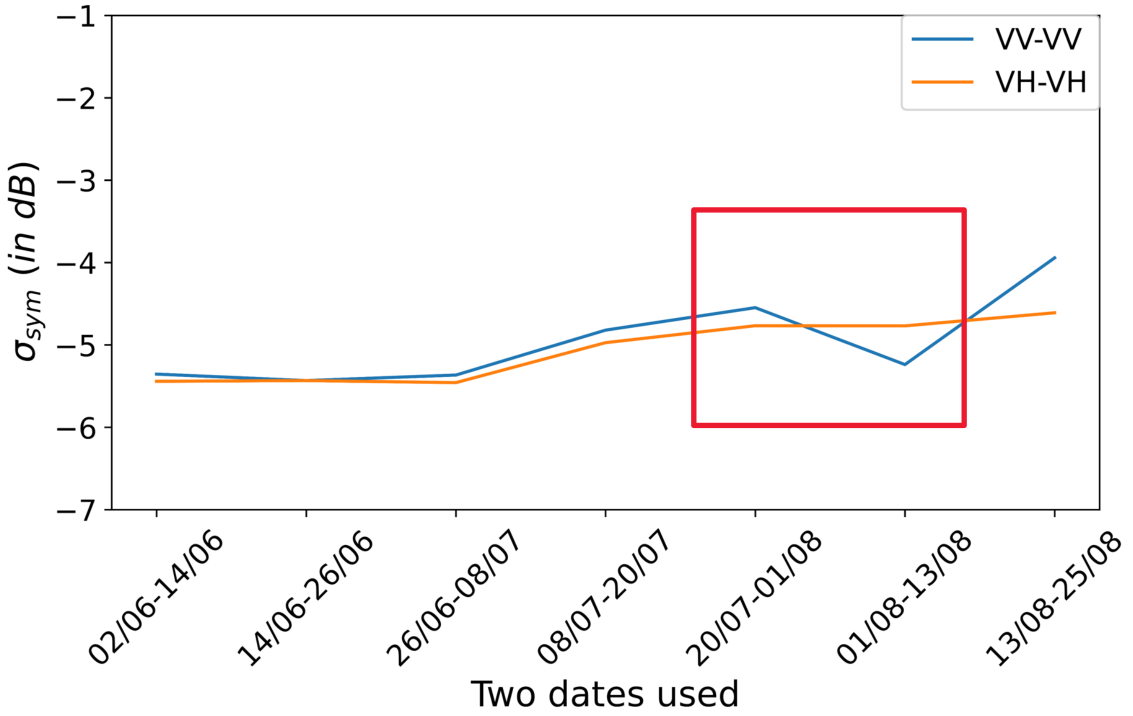
Reinterpreted Temporal Coherence: ρ_{sym}



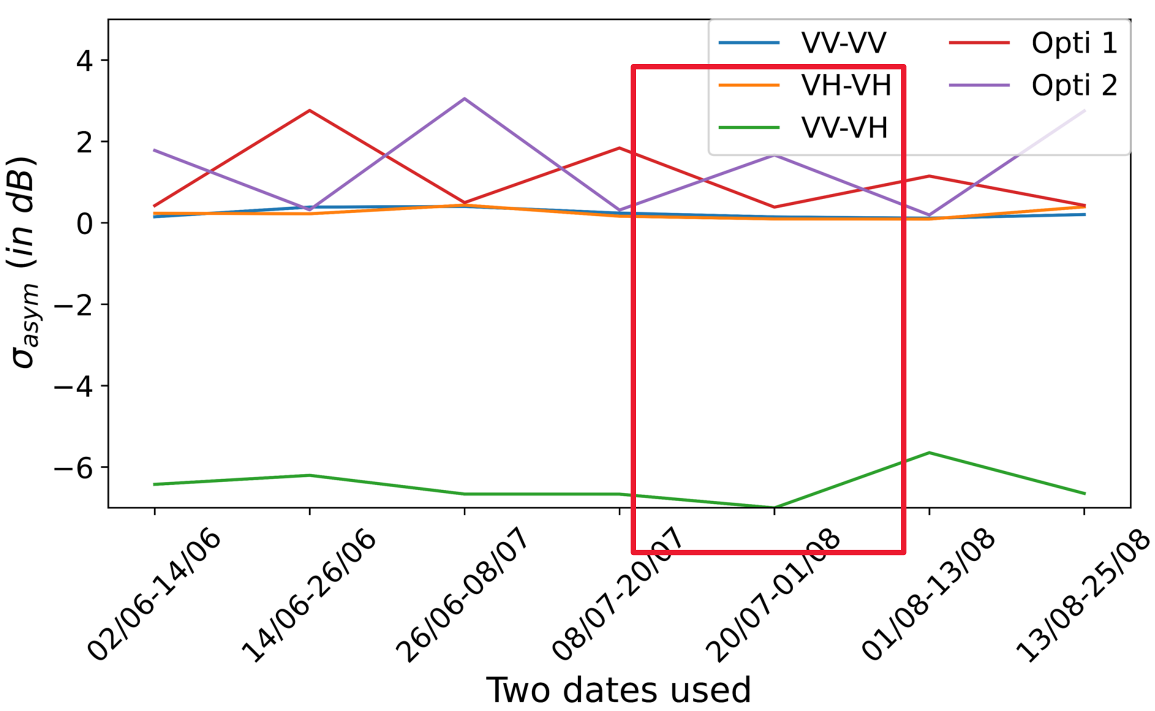
Wheat heading ROI 46
19/07

III Results
3 Issues

- No results based on ρ_{asym} matching our ground truth
- For some fields, non-consistant results
- Weird results for $\rho_{asym,opti}$



Corn flowering ROI 65 ρ_{sym} 18/07



Corn flowering ROI 55 $\rho_{asym,opti}$ 18/07

IV Leftovers and perspectives

Further researches

- Investigate the negative results where the detection failed : Small fields ? Sensor path ? Crop Orientation ? Other reason ? => Need for more ground truth : SinCohMap ?
- Study $\rho_{asym,opti}$ results, as they are in theory promising but did not gave any good results for now

Global application

- Develop an easy-to-use application on MAAP once results are confirmed
- Reduce processing time

New use cases

- Forests in C-Band
- Sand areas
- Any further ideas ?

Conclusion

- Innovative use case
- Further researches to improve our results
- Lot of possible applications
- Ambition to create an application to share with non-expert users
- Scalability

Thank you for your attention !

Do you have any questions ?

Annexes
1 w averaging

The Polarimetric Interferometric Coherence is then defined by :

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$$\begin{cases} [T_{11}^{-1}][T_{22}]\underline{w} = \nu_\tau \underline{w} \\ [T_{22}^{-1}][T_{11}]\underline{w} = \nu_\tau{}^{-1} \underline{w} \end{cases}$$

obtained making the assumption $\langle \underline{w}_1^{*T} [X] \underline{w}_2 \rangle = \underline{w}_1^{*T} \langle [X] \rangle \; \underline{w}_2$