Sentinel-1 coherence for agricultural statistics

**Keywords:** synthetic aperture radar, SAR, coherence, land cover, agriculture, farming events

# Introduction

First Copernicus satellite was launched in 2014 and by 2018 the Sentinel-1 and -2 systems have reached their operational status with nominal data production volumes. Despite the numerous outreach and promotional events, the data is still underused in the public sector and there is remarkable potential to be employed. Main factors limiting the use are:

1. lack of awareness about the capabilities and limitations among the end users;
2. lack of knowledge how to process the data and retrieve reliable information out of it;
3. insufficient applied research / piloting projects to test the academic research results in large scale (e.g. country level) real life conditions to discover and fix the possible problems not evident in the small scale research projects.

Agricultural statistics is one of the areas where Copernicus data can help to raise the current methods to the next level. Instead of field surveys sampling based indirect estimates it is now possible to directly measure whole geographical coverage and get virtually total representation. Despite the high resolution satellite data has been available for decades its usage has been limited due to high price, sparse temporal and spatial coverage. Copernicus addresses both of the shortcomings with free and open data policy and unprecedented spatial and temporal coverages. Largest improvements are expected for the applications, which need dense time series, fast updates and temporal process monitoring, where static once a year imaging has not been sufficient. Agricultural statistics seems to be a model example here.

Thanks to the long traditions, large and established user community of optical remote sensing the uptake of Sentinel-2 data has been relatively rapid. The reason that optical satellite imagery is easy and intuitive to interpret should not also be underestimated.

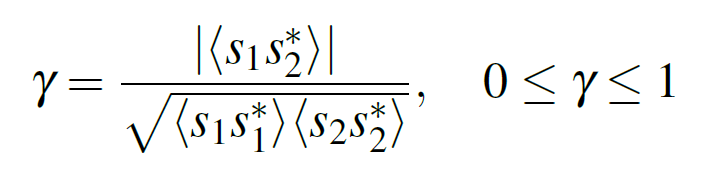
The usefulness of Sentinel-1 data has been so far undeservedly underestimated, which is best illustrated by the fact that large satellite imagery processing cloud environments like Google Earth Engine and Amazon Web Services don’t even provide Sentinel-1 SLC format data, despite that they are the most information rich data products of Sentinel-1. The reasons behind the very limited usage Sentinel-1 SLC data are likely higher technical complexity, not so intuitive data interpretation and smaller community of radar remote sensing experts among the universities and companies. Still Sentinel-1 is a very valuable complement to Sentinel-2 as it is virtually weather independent (no gaps in the time series due to cloud cover) and it is directly sensitive to the water content of the soil and vegetation cover, which is very important for describing the state of the agricultural landscapes.

The abstract introduces Sentinel-1 repeat pass coherence as an important parameter for describing agricultural landscapes. Methods section describes the coherence computation and its meaning for interpreting the resulting coherence images. Results section describes coherence for grasslands mowing detection and discusses its usage and limitations beyond, for other agricultural applications and statistics computation. Conclusion underlines the main benefits with potential applications and gives recommendations for applied research projects to pave the way for operational use.

# Methods

## Sentinel-1 repeat pass coherence

Coherence [1] is an established and universal synthetic aperture radar (SAR) parameter with multiple applications. It is defined with the following formula:



where s1 and s2 are the input complex SAR images, |…| denotes absolute value, <…> spatial averaging in a local neighbourhood and \* the complex conjugate of the original image. It can be computed e.g. with the SNAP software [2] developed by the European Space Agency and used as an interferogram phase info quality estimator, but also as an independent data layer for land cover classification or other applications. For Sentinel-1 case s1 and s2 have to be different images from the same relative orbit separated with 6, 12, 18, … days. In this case it is called the repeat pass coherence as opposed to the single pass coherence of the TanDEM-X or SRTM missions with slightly different information content.

## Interpretation of coherence images

After some deeper analysis of the coherence formula above it is clear that it is the normalized similarity measure of two complex images. Coherence is 1 in the areas, where the images are exactly the same. Coherence is 0 in the areas, where there is no correlation between the images and the pattern variation is completely random pixel by pixel. In case there is correlation between the input images s1 and s2, but it is not ideal, coherence has intermediate values between 0 and 1.

It is important to notice that for similarity just amplitude correlation is not enough, but the correlation of the complex valued pixels including the phase info – that is the phase difference of images s1 and s2 in the neighbouring pixels needs to be close to constant for the coherence to be high. Previous studies have shown that coherence is much more reliable and stable parameter for land cover classification than a single SAR image backscatter, which is often too random in nature and ambiguously dependent on too many variables. On the other hand coherence is yet simple enough and has much more straightforward physical meaning than the numerous decomposed polarimetric SAR parameters, which often lack a direct physical meaning.

In the context of land cover classification Sentinel-1 coherence is dependent on the amount of vegetation cover. Due to temporal decorrelation it is the lower the denser it the vegetation cover, for bare soil coherence can be very high. As a first approximation it can be thought as an inverse parameter to NDVI (see Figure 2 below for details).

# Results

Coherence is shown to be useful for detecting mowing events of grasslands [3] and lately also for crop type verification [4] for distinguishing grasslands from corn and other major crop type classes. Figure 1 presents coherence and NDVI behaviour respect to grassland mowings, the black lines indicate the medians of >1000 mowing events in Estonia during vegetative season 2017. It is visible that after mowing coherence typically increases by >0.1 and NDVI decreases by ≈0.2 units.

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Figure 1. Left: Sentinel-1 6 day coherence behaviour respect to mowing event. Right: Sentinel-2 NDVI behaviour respect to mowing event. Solid line is median, grey upper line the 75% quartile and lower line 25% quartile.

The potential of Sentinel-1 coherence is however much higher than just a parameter for mowing detection. Figure 2 shows and agricultural area in Estonia on 10th of May on a Sentinel-1 coherence and Sentinel-2 NDVI image. It is evident that the parameters behave roughly the same, but inversely – low coherence means high NDVI and vice versa.

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Figure 2. Agricultural area in Lääne-Virumaa, Estonia. Left: Sentinel-1 6 day coherence based on 10th May and 16th of May IW mode interferometric pair, scaled from 0.2 (black) to 0.7 (white). Right: Sentinel-2 NDVI on 10th May, scaled from 0.1 (brown) to 0.8 (dark green).

Still when interpreting the coherence and NDVI images one needs to keep in mind that their underlying physical meaning is different and the two parameters don’t fully substitute, but complement each other. While Sentinel-2 NDVI is sensitive to the amount of chlorophyll and green biomass, Sentinel-1 radar data is sensitive to water. Coherence is low when there is a significant amount of water containing biomass on an area. In case the vegetation water content is low, coherence can still be very high despite the presence of vegetation. Moreover coherence is always measuring the change between two images. It is low when there is a lot of water containing biomass on the field, which moves in time due to wind and growth resulting the loss of complex correlation. But coherence can also be low on bare fields, when the change is caused by something else – e.g. recent rainfall before the acquisition of either of the SAR images or a ploughing event between the data takes.

# Conclusions

Coherence is highly promising and thanks to Copernicus programme widely available land cover and vegetation status describing parameter. It has been shown to be useful for mowing detection, but it also has remarkable potential for producing agricultural statistics e.g. in crop type mapping, yields modelling, farming events’ detection and elsewhere. Temporal signatures of coherence are generally more unstable than the ones of NDVI, but thanks to the weather independence Sentinel-1 coherence measurements are very regular and it can complement and cover the time periods when Sentinel-2 optical data is not available due to cloud cover.

Smooth and reliable operational use of Sentinel-1 coherence for agricultural statistics needs still additional applied research, large scale testing and piloting projects. The reasons of temporal instability of Sentinel-1 coherence should be better understood. The effects of coherence saturation due to the presence of man-made metal containing scatterers (such as tractors or power-line poles) in some parcels should also be investigated. Comparison and complementation with weather data, farming events and other existing GIS data layers such as soil maps is needed.

# References

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| [1] | J. Lee ja E. Pottier, Polarimetric Radar Imaging - from Basics to Applications, 1st toim., New York: CRC Press, 2009. |
| [2] | European Space Agency, „Sentinel Application Platform,“ 2018. [Võrgumaterjal]. Available: http://step.esa.int/main/toolboxes/snap/. [Kasutatud 12 10 2018]. |
| [3] | T. Tamm, K. Zalite, K. Voormansik ja L. Talgre, „Relating Sentinel-1 Interferometric Coherence to Mowing Events on Grasslands,“ *Remote Sensing,* kd. 8, nr 10, 2016. |
| [4] | R. d’Andrimont, G. Lemoine ja M. van der Velde, „Targeted Grassland Monitoring at Parcel Level Using Sentinels, Street-Level Images and Field Observations,“ *Remote Sensing,* kd. 10, nr 8, 2018. |