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SENTINEL-1 INSAR COHERENCE AS AN INDICATOR OF MONITOR FARMING ACTIVITIES

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ABSTRACT

Reliable crop monitoring is paramount to achieve the objectives of the Common Agricultural Policy (CAP) and Food and Agriculture Organization. Synthetic Aperture Radar (SAR) provides high-resolution imaging and all-weather data acquisition capabilities for crop monitoring. This study investigates the sensitivity of parcel-level Sentinel-1 interferometric coherence to farming activities (e.g. planting, emergence, harvest and tillage) and weather events. A methodology to detect activities was developed and validated using ground-truth data from four crop types, collected over four years. The proposed approach was able to detect over 60% of all nine different farming activities. The results show that interferometric coherence is a reliable indicator for farming activities that can be considered as events resulting in a clear structural change (e.g. tillage 100%), but less reliable for gradual changes (e.g. Emergence 40%).

Index Terms— Agriculture, Catch Crop, Emergence, ERA5, Harvest, Interferometric Coherence, Sentinel-1, Tillage

1. INTRODUCTION

Monitoring crop development and farm management practices is important to support policy changes and to achieve sustainability goals set by the European Commission, CAP and other global agencies. Policies, regulations, and farmer practise need to be adaptive in order to achieve sustainable development goals objectives. For large-scale mapping of crop management practices, it is not feasible to rely on in-situ observations. Thus, the most practical solutions are based on remote sensing, which allows for frequent and spatially consistent observations.Studies have demonstrated the potential of optical and radar satellite observations for monitoring crop dynamics, e.g. emergence and harvest dates [1] [2]. These studies highlight that the influence of weather conditions, such as heavy precipitation and clouds, make it challenging to derive farming activities and crop dynamics in their right timing.Considering these constraints, many studies have been researching the potential of interferometric coherence as a potential signature to monitor crop development and indicate its sensitivity to biomass and structural changes [1] [2][3]. Other studies show the potential to use coherence to monitor ploughing and mowing events over grassland as well as an input for vegetation and land cover classification [3–8]. All these studies show the responsiveness of the coherence signal to the whole crop growing-harvesting cycle but also individual farming activities. Still, none of the studies investigated further to monitor and label all additional farming activities, which include field preparations, seeding, cover/catch crop rotations, planting next crop cycles, ridging and tillage. This pilot study addresses this research gap by developing a method to derive the "Day Of the Year" (DOY) regarding all mentioned farming activities using ground truth data from four different crop types in a four year time frame (2017 - 2020). Detecting field activities and their correct timing can be directly used to create additional input for crop growth simulations and land surface models, as well as to provide support for agricultural services and CAP regulations.

2. STUDY AREA AND DATA

This study uses data from the Agricultural SandBoxNL database which provides annual crop parcel boundaries, crop type information and fully processed parcel-level Sentinel-1 GRD backscatter and Sentinel-1 interferometric coherence [9]. The study area is Flevoland, the Netherlands, where ground truth information on crop management activities is openly available [10]. Ground data were collected from 2017 to 2020 in five individual parcels, with a record of all field activities since 2017 for four different crop types (onion, winter wheat, potato and sugarbeet). The following farming activities were documented on an annual basis: *Field preparation, Planting, Ridging, Emergence, Harvest preparation (e.g. haulming), Harvest, Cover/Catch Crop, Planting Next Crop, Tillage.* Skin Temperature, rainfall and snowfall data from the ERA5 Reanalysis database [11] were used to account for environmental influences on backscatter and coherence.

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3. METHODOLOGY

The basis of the monitoring methodology is the change in coherence between pairs of consecutive SAR images. For this study, only the VV polarization (relative orbit 88) was considered to calculate the interferometric coherence. Interferometric coherence is affected by many factors. However, many studies have shown that changes in coherence can provide information on agricultural dynamics [2, 3, 5, 6]. In this study, the change in temporal decorrelation was exploited to better understand this relationship in the context of several different farming activities. In order to derive and quantify the mentioned changes in magnitude, in-situ labels were used to relate changes in coherence to individual farming activities. ERA5 data was used to identify and flag changes caused by weather conditions. In order to establish the optimal coherence thresholds (positive and negative changes) the F1-Score, a product from recall and precision, was estimated to find the most sensitive and robust coherence change thresholds. The thresholds were varied between +/-0.5 using +/- 0.01 increments to find the optimal pair with the highest F1-Score. The F1, Recall and Precision Score are defined as follows (TP = True Positive, FP: False Positive, FN: False Negative) [12]:

Recall: $\frac{TP}{TP+FN}$

Precision: $\frac{TP}{TP+FP}$

F1-Score: $\frac{2*Recall*Precision}{Recall+Precision}$

At last, the established threshold method was extrapolated over Flevoland (7000 parcels) to derive large scale emergence and harvest dates.

4. RESULTS AND DISCUSSION

4.1. Time series assessment of a four year crop rotation

Figure 1 shows the multi-year crop rotation over one example parcel of the study site in Dronten (municipality in Flevoland). This parcel is chosen because the four dominant crops in the region were all grown in rotation (Sugarbeet, Winter Wheat, Onion and Potato). Backscatter follows the crop growing cycle and increases with biomass. VV and VH backscatter shows a high inter-annual variation due to its sensitivity to soil moisture, crop physical structure and fresh biomass/vegetation water content [1]. The cross-ratio (VH/VV) mitigates the influence of soil moisture. However, it may also reduce the impact of variations caused by farming activities. Overall, the sensitivity to soil moisture and associated rain events makes it difficult to attribute backscatter changes directly to farming activities. Interferometric coherence, on the other hand, shows a very strong response to all observed farming activities. In general, coherence is high in bare soil and decreases with increasing biomass during the growing season [1, 2]. Farming activities can cause an increase or decrease in coherence depending on the event. In Figure 1, precipitation causes only minor coherence changes compared to snow (blue) and sub-zero skin temperatures. Coherence changes of up to 0.5 are observed during snow and frozen conditions, which is comparable to the changes in coherence associated with field activities.

4.2. Optimizing the interferometric coherence threshold

The highest F1-Score (0.55) was achieved for a threshold $>$0.27 and $<$-0.19 in coherence. Figure 2 shows the timeline of all detected events, using the best thresholds, together with the farming practice labels for each crop annually. The width of the detected events is defined as a 12 day window due to the nature of estimating coherence changes covering three consecutive SAR observations. In the following, each field activity is discussed separately and indicated by a simple success detection rate *"[Detected / Ground Truth]"* (excluding False Positives).

Field Preparation (Pr 75%) events have been successfully detected. In one field (2020 Sugarbeet) the field preparation event was registered before the label. This could be due to an additional unregistered farming activity or a sub-optimal coherence threshold. Weather events can be ruled out because there was no event detected in the other surrounding parcels.

Most *Planting (Pl 75%)* events were observed for all crop types and years. Some additional events were observed before the planting period, which could not be classified. This could be due to unreported activities or due to the threshold sensitivity.

Emergence (E 42%) dates were observed but seldom on the date associated with the label. This highlights the sensitivity of coherence on the development of the emerging plant. If the emergence is very slow then the coherence will gradually decrease but will not show a sudden drop. Only if plants are sprouting fast the change will be significant enough to show a jump decorrelation. Thus, the identified event after planting is most likely related to growth sprout rather than the exact date of emergence. This observation is also valid for winter wheat as the emergence happened already the year before but the growing sprout happened around March.

Harvest Preparation (HP 0%) events were not detected. The nature of harvest preparations is to apply anti-sprouting substances (e.g. haulming [1]) to stop further development. This process causes the decay of the plant resulting in structural changes. These changes cause a gradual decorrleation but depending on the speed of the decay the drop of coherence may or may not be large enough to be captured by the threshold.

For *Harvest (H 33%)*, the method failed mainly for sugarbeet and winter wheat, in terms of timing. In the case of sugarbeets, harvesting was labeled over multiple days by the farmer. This limits the DOY estimation as coherence change happens in steps and hence is difficult to observe with a set coherence threshold. In the case of winter wheat, a poor

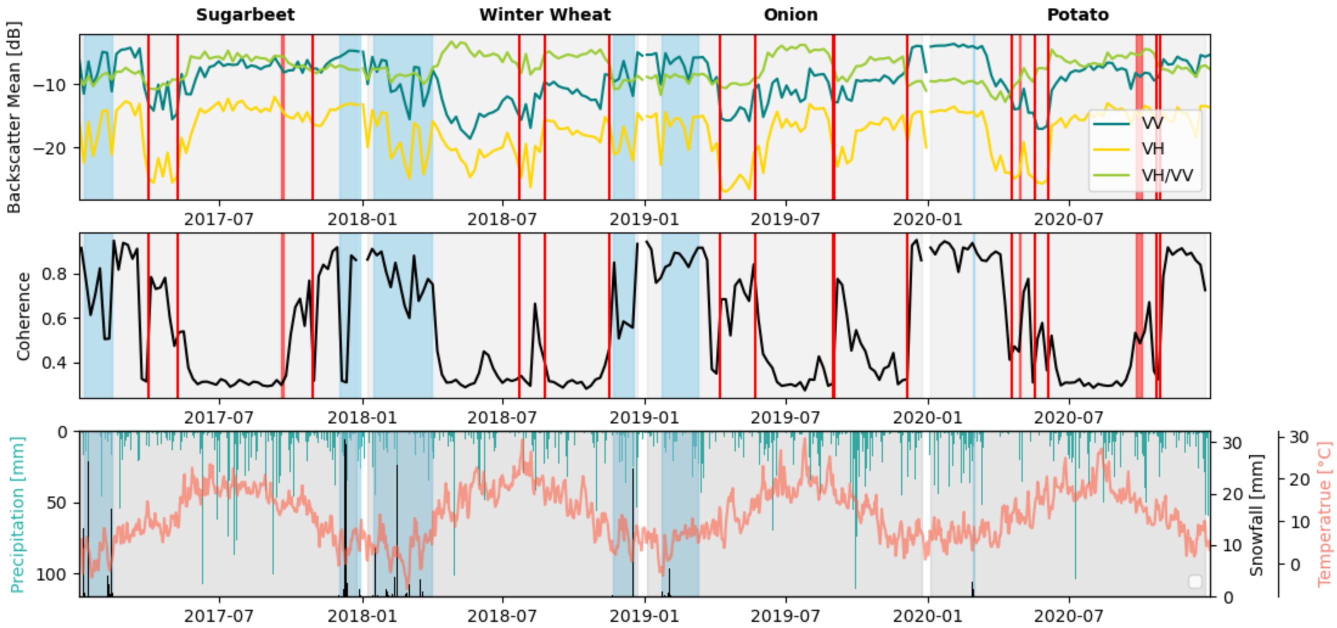

Fig. 1: Time series (backscatter, coherence and weather data) plot showing a four year crop rotation over one selected parcel of the study site. The top time series shows the backscatter intensities of orbit 88 (VV, VH and VH/VV) in dB. The middle time series shows the VV interferometric coherence of orbit 88. In the bottom row, precipitation and snowfall are included as daily accumulations and temperature is shown as daily average. The red vertical lines indicate the date on which farm management activities were labeled by the farmer, and the light blue bars indicate periods on which snow occurred according to the ERA5 data.

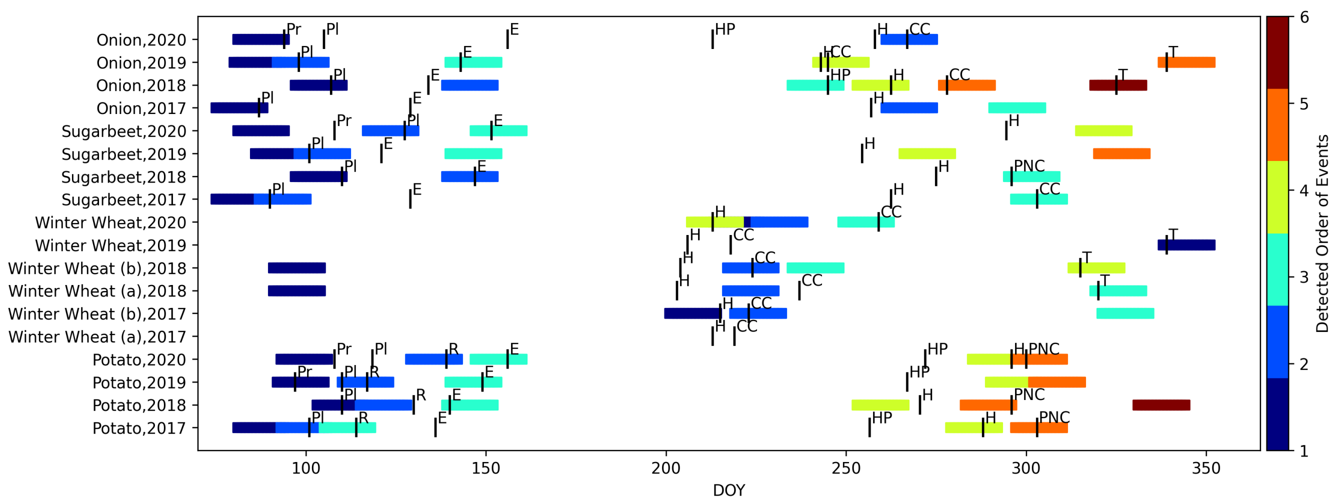

Fig. 2: This Figure shows a time line of all detected and labeled events using the best set of coherence thresholds [<-0.19 and >0.27]. The color-bar shows the amount of events being detected per field. Each recorded event is labeled with an acronym to refer to a certain field activity: Pr is ”Preparation”, Pl is ”Planting”, R is ”Ridging”, E is ”Emergence”, HP is ”Harvest Preparation”, H is ”Harvest”, CC is ”Cover/Catch Crop”, PNC is ”Planting Next Crop” and T is ”Tillage”.

detection rate could be explained that the remaining plant structure after harvest and hence results in minor coherence changes.

Cover/Catch Crops and Next-Crop Planting (CC/PNC 72%), were successfully captured. The same counts for *Ridging (R 75%) and Tillage (T 100%)* events. This high detection rate can be explained as for all mentioned activities the surface structure significantly changes, which therefore causes a strong change in the observed interferometric coherence.

5. CONCLUSION

The established method was based on a set of coherence thresholds <-0.19 and >0.27 and filtering by snow and frost events and achieved a detection rate of 60% for all farming activities (over 70% excluding *Harvest Preparation*). Combining it with prior crop specific knowledge and considering the sequential nature of farming activities we were able to label most of the detected events, e.g. emergence and harvesting DOYs, see Figure 3. This study further shows a strong response of the coherence signal to frozen soil and snow events but (comparatively) less sensitivity for precipitation. Overall, the study highlights that the detection method based on coherence thresholds works very well for activities that cause a sudden coherence change between two images. This can either be from high coherence to low coherence or via versa. Events such as emergence and harvest preparation were challenging to identify because the crop's gradual growth and decay rates resulted in minimal abrupt changes in coherence, but instead a slow, continuous decorrelation. Furthermore, activities which are close to each other can not be separated with the algorithm and will be detected as one event. This could be solved by including additional coherence estimates from other orbits to increase the temporal resolution. Weather influences from snow and frozen soil can impact the interpretation of the coherence signal and need to be filtered carefully as it can cause very similar decorrelations compared to those caused by farmers activities. At last, independent validation data is needed and suggested in following studies to verify this method.

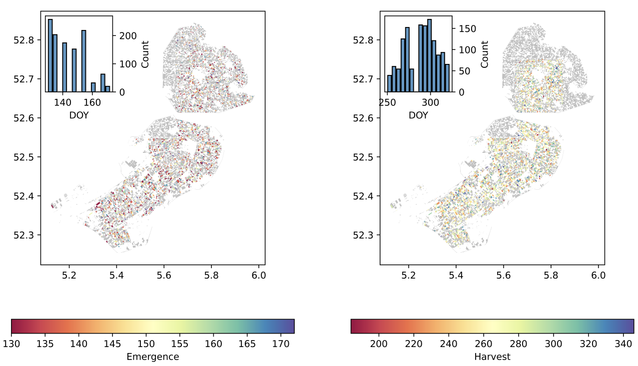

Fig. 3: Overview of estimated DOYs for emergence and harvest considering all four crop types for 2020 over Flevoland.

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