POTENTIAL OF SENTINEL-1 TIME SERIES DATA FOR THE ESTIMATION OF SEASON LENGTH IN WINTER WHEAT PHENOLOGY

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***Abstract*—Time series analysis has high potential for the monitoring of agricultural management intensity and crop yield. The C-band synthetic aperture radar (SAR) data from Sentinel-1 provide a unique source to create area-wide dense time series of indicators that are sensitive to crop parameters. Here, time series of backscattering coefficient ratio from Sentinel-1 were established in individual winter wheat fields over three consecutive years. Phenology metrics were computed in order to indicate the length of the season, where the plant is substantially growing in height and building biomass. The average estimated lengths of season of winter wheat were 112 days in 2017, 77 days in 2018 and 91 days in 2019. The observed lengths of the season in the reference were 114 days in 2017, 73 days in 2018 and 88 days in 2019. The results for the individual winter wheat fields show that the length of the season was estimated with an RMSD (root mean squared deviation) of less than 2 weeks for all three years. The results confirmed that the VH/VV ratio has high potential for monitoring phenological features.**

Keywords—Sentinel-1, Synthetic aperture radar (SAR), time series, winter wheat, phenology

I. INTRODUCTION

Agricultural areas play an important role as areas of food production, whereas there is also the demand that these areas maintain their other ecosystem services such as biodiversity, material cycles, etc. [1]. The length of the growing season and other phenology metrics are important indicators for the monitoring of such services as well as for the impact assessment of climate extremes (e.g. droughts) and a changing environment in general [2,3]. Optical remote sensing and derived vegetation indices have high potential to monitor agricultural areas [3]. However, weather phenomena and cloud cover potentially result in fragmented time series data, whereas a dense and gapless time series might be necessary to monitor and detect the phenology. This is of high relevance in the detection of phenological features and the length of season, because a fragmented time series potentially omits important features. Synthetic aperture radar (SAR) sensors are almost independent of weather and sun, where the Sentinel-1 C-band satellites have high potential for the agricultural monitoring. This is based on the fact that the two Sentinel-1 satellites enable a dense time series of 6 days over Europe [4]. C-band data was found to be sensitive to crop parameters similar to the use of vegetation indices from optical sensors [3]. In addition, it was shown that C-band dual-polarization indices like the ratio of the VH and VV polarization are superior in the detection of phenological features compared to single polarization backscatter time series [5]. Therefore, Sentinel-1 data generally enable the monitoring of the phenology of crops. Depending on the SAR-input time series, different metrics can be used to detect the time of year of phenological stages for agricultural crops [5].

The objective of this study was to assess the length of the growing season (LGS) for winter wheat from annual time series of C-band VH/VV backscatter ratio data of Sentinel-1. Here, the season length was defined as the time difference between shooting and harvest where the crop develops the majority of its height and biomass. Thus, the spatially explicit information of LGS can indicate the impact of management intensity, climate extremes and climate change on the growth, maturity and yield of agricultural crops.

II. DATA

A. Study area

The study was conducted in the eastern part of the federal state of Brandenburg, Germany. The site represents an area of intensive agricultural production with large arable fields in a postglacial lowland landscape. It covers an area of about 3,500 km^2.

B. Sentinel-1 data

Time series for three different years, 2017, 2018 and 2019, of Sentinel-1 C-band SAR data were used for the study. The temporal resolution of the time series data was 6 days using only repeat-pass acquisitions. The Interferometric Wide Swath mode with VH (vertical-horizontal) and VV (vertical-vertical) polarization was used in this study resulting in a resolution of 3 m in range and 22 m in azimuth with a pixel spacing of 2 m in range and 14 m in azimuth.

C. Auxiliary data

Information about the location and delimitation of winter wheat fields in the years 2017, 2018 and 2019 were available from the Land Parcel Identification System (LPIS) of the Integrated Administration and Control System (IACS) of the European Commission. For the federal state of Brandenburg, LPIS data are freely available from the regional authorities of Brandenburg (https://geobasis-bb.de/lgb/de/). For the study, only fields with a size of at least 1 ha were chosen. The management of the fields was generally similar. Overall, a total of 5,762 winter wheat fields were investigated for the three years.

The Climate Data Center of the Deutscher Wetterdienst (DWD) collects phenological data on sample points in a dense national monitoring network [6]. The sample points closest to the respective field were used as a reference for the phenological date. The vegetation period between shooting and harvest was of particular interest in this study based on its relevance for the monitoring of ecosystem services [2,5].

III. Methods

The backscatter coefficient γ^0 was derived from the individual Sentinel-1 acquisitions via thermal noise removal, calibration and finally terrain correction. The data processing was consistent for all individual images. The images were geocoded with a SRTM digital elevation model. The ratio of VH and VV polarized backscatter was calculated as the difference in decibel (dB) scale for each individual acquisition

$$\gamma^0_{Ratio} = \gamma^0_{VH}[dB] - \gamma^0_{VV}[dB]$$

This ratio was considered particularly useful in crop monitoring and the detection of phenological stages [3,5]. The backscatter coefficient ratio was extracted for every acquisition date in each individual winter wheat field. Locally estimated scatterplot smoothing (LOESS) was used to smooth the time series of backscatter ratio data in the temporal domain. The optimal parameters for this local polynomial regression fitting were retrieved by finding the minimal error in a generalized cross-validation, which was confirmed by visual inspection of the fitted curves [5]. The local smoothing ensured that single date phenomena had a minimal effect on the whole time series.

Different seasonal time series metrics were considered useful to detect the dates of certain phenological stages [5]. In order to monitor the LGS, first the start and the end of the season have to be detected. In this study, the shooting and harvest were defined as the respective phenological features for these events. The breakpoints of the backscatter ratio were considered highly potential to detect the date of shooting and harvest [5]. This was based on the fact that changes in the winter wheat field due to growing or harvesting result in a change in the trend of the backscatter ratio time series, which was detectable with breakpoints. The time series was split into different segments for the respective phenological features and breakpoints were derived. (Fig. 1). Finally, the LGS was computed as the time difference between shooting and harvest

$$LGS = t_{harvest} - t_{shooting}$$

The LGS was calculated based on the detected breakpoints in the Sentinel-1 time series data as well as on the observed phenological features provided by the DWD. The differences (in days) between the estimated (Sentinel-1) and observed (DWD) LGS values were calculated for each individual field and the root mean squared deviation (RMSD) of the differences was computed for all winter wheat fields in each year, separately.

IV. Results

The LGS from the breakpoint analysis of the backscatter ratio time series were compared to the LGS of the DWD observations. Overall, the difference was about 13 days or less for all three years (Fig. 2). The smallest difference was observed in the year 2018, where the RMSD of estimated and observed season length was 10.9 days. The RMSD in 2017 was 11.9 days and in 2019 it was 13.1 days (Fig. 2). The differences in the individual phenological features, namely shooting and harvest, resulted in an RMSD of 4.2 days and 11.0 days in 2017, 11.4 days and 9.0 days in 2018 as well as 11.4 days and 9.5 days in 2019, respectively. The average LGS based on the satellite time series in 2017 was 112.2 days, whereas the other years had substantially shorter estimated seasons of 76.8 days and 91.2 days, respectively. This is in accordance with the reference data from DWD that show an LGS of 114 days for 2017 and 73 days and 88 days for 2018 and 2019, respectively.

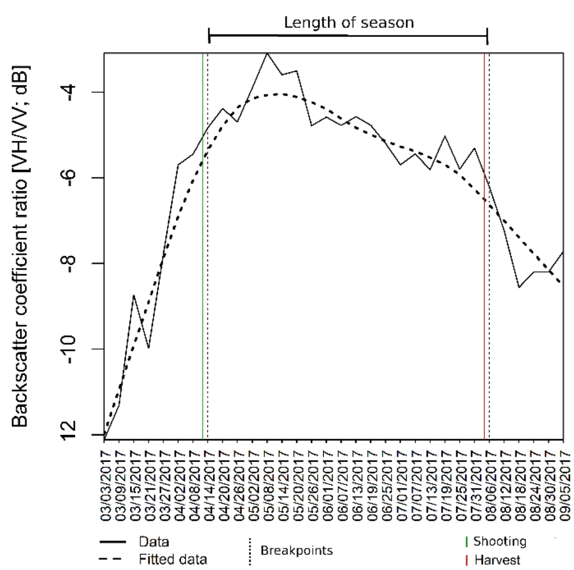

Fig. 1. Backscatter coefficient ratio VH/VV over time for one wheat field in 2017 with smoothed data, detected breakpoints and observed phenological features

The spatial representation of the differences of the LGS did not reveal any spatial pattern (Fig. 3). In general, the majority of the 5,762 wheat fields used in this study indicated a low deviation between estimated and observed LGS, whereas some individual fields resulted in a difference of 15 days or even more.

V. Discussion and Outlook

This study confirmed the potential of time series metrics of backscatter coefficient ratio (VH/VV) data from Sentinel-1 time series to monitor phenological features in winter wheat fields that are related to biomass accumulation during the growing season (Fig. 2). The study suggests that the ratio is sensitive to vegetation properties based on attenuation as well as soil and volume scattering of the two different polarized signals [3,5]. However, it can be assumed that it is less sensitive to acquisition properties variations (e.g. moisture) compared to the individual polarizations, because these variations are to some extent similar in both polarizations and thus are reduced in their difference [5]. The date of shooting as well as the date of harvest was found with high accuracy, especially considering the temporal resolution of 6 days for Sentinel-1. The accurate estimation of individual phenological features can be further used to extract information about the length of specific seasons. In this study, we focused on the season between shooting and harvest, which was detected with similar accuracies compared to the individual dates. It can be assumed that errors in the detection of individual dates propagate to the estimation of the length of the season. The results suggest that this is not necessarily the case since the accuracies of individual dates were almost similar to the length of the season. This indicated that the detection of shooting and harvest can be biased, but the time difference between the two dates can be similar compared to the observation. This can be seen, for instance, in Figure 1, where the LGS was equal compared to the observation, but the individual dates were detected with one day offset for shooting and harvest.

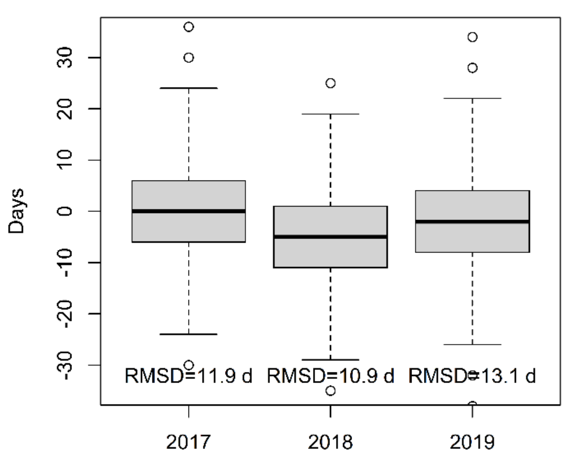

Fig. 2. Distribution of RMSD between estimated and observed LGS for the three years 2017, 2018 and 2019 for all winter wheat fields

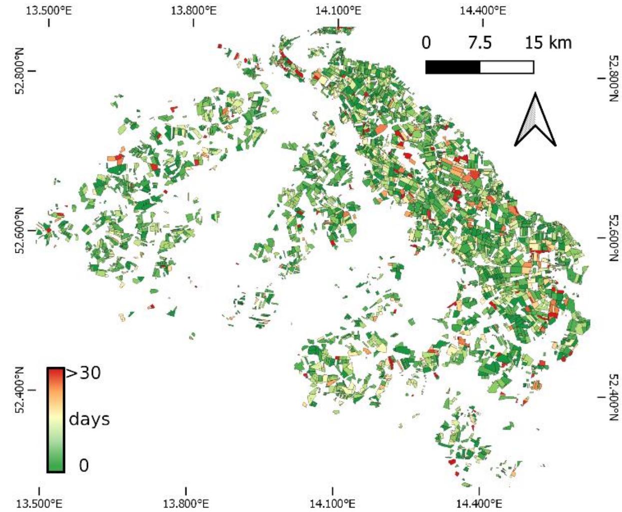

Fig. 3. Spatial distribution of the absolute differences of the LGS between estimated and observed data for all winter wheat fields in the study area of eastern Brandenburg, Germany

The three years represent very different climatic conditions. The results indicated a substantially shorter growing period from shooting to harvest in 2018 and 2019 compared to 2017. The study confirms that Sentinel-1 has high potential to monitor agricultural crops with a high temporal density to detect phenological stages as well as the length of different seasons.

In this study, we focused on the time of shooting and harvest, while also other phenological stages and seasons can be considered important [2]. Since the available observation data only provide rough estimates of the phenological features for larger areas, future work should aim at the validation of the method based on field level reference data. However, the type of crop and management of the fields was generally similar and thus the phenology observations were assumed to be representative for most fields. Further, the method will be adapted to other crop types in the future. The proposed method relies on a simple and reproducible framework. Thus, its applicability to large regions (federal states, countries) will also be investigated. The spatially explicit knowledge about phenological features of crops at field level can be important to develop adaption strategies to short and long-term weather phenomena and changing environmental conditions [5].

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