Agricultural remote sensing information for farmers in Germany

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Abstract.

The European Copernicus program delivers optical and radar satellite imagery at a high temporal frequency and at a ground resolution of 10m worldwide with an open data policy. Since July 2017 the satellite constellation of the Sentinel-1 and -2 satellites is fully operational, allowing e.g. coverage of Germany every 1-2 days by radar and every 2-3 days with optical sensors. This huge data source contains a variety of valuable input information for farmers to monitor the in-field variability and adopt their management strategies. In order to utilize the data in a meaningful way, data needs to be preprocessed and edited, because farmers need a translation from the image data into information and finally decision support based on that information.

The processing chain of the huge amount of data needs an intermediate level, where raw data is converted into information. The Copernicus Program will set up so called "Data and Information Access Services (DIAS)" that allow cloud processing of the raw data into information products. Also cloud computing services like Google Earth Engine or Amazon Web Services offer computing power to process the data.

The "research center for agricultural remote sensing" (FLF) processes the Sentinel Data acquired over Germany and provides several data sets e.g. crop type mapping, actual biomass, leaf area index and yield estimations, which helps farmers even with no precision farming equipment to access data for a start into digital farming. The delivered information products will be tested in the research project AGRO-DE, were consultants, practitioners, researchers and farmers will work with satellite derived information. The information products will be distributed via web services and mobile phone apps readymade for the usage in farm database.

Keywords. *Remote sensing, Sentinel, crop type mapping, yield estimation.*

Introduction

Despite the obvious advantages of precision farming, German agriculture is still characterized by uniform treatment. One of the reasons is the cost-intensive and complicated introduction to precision farming technology, another lack of meaningful input data addressing the infield-variability. The German agricultural structure with an average farm size of 61 ha (BMEL 2018) lead to the adoption of PA mainly by a minority of technology-affine farmers of large enterprises.

Satellite data is a known data source for the identification of in-field variability, or the determination of variable biomass distribution in the field. However the different data availability and poor predictability of data access due to cloud coverage prevented an operational use of satellite data in the past.

With the European *Copernicus* Program, data availability and quality have been increased drastically but at the expense of new technical challenges: *Copernicus* provides mainly raw data which have to be preprocessed in order to be analyzed. The amount of data is about 1 GB per tile (smallest available data set), so even a simple download of the data becomes challenging in the weak data infrastructure of most rural areas.

New concepts of cloud computing changed the paradigm in a way that algorithms can be sent to the data in order to use centralized computing power and to reduce network traffic with vast amounts of raw data.

Readymade remote sensing products might be the pushing force for precision agriculture, due to low investment costs for the user. Even the data products can help to define data and quality standards. With that new data source, site specific management becomes also affordable for smaller and mid-sized businesses.

The European *Copernicus* Program

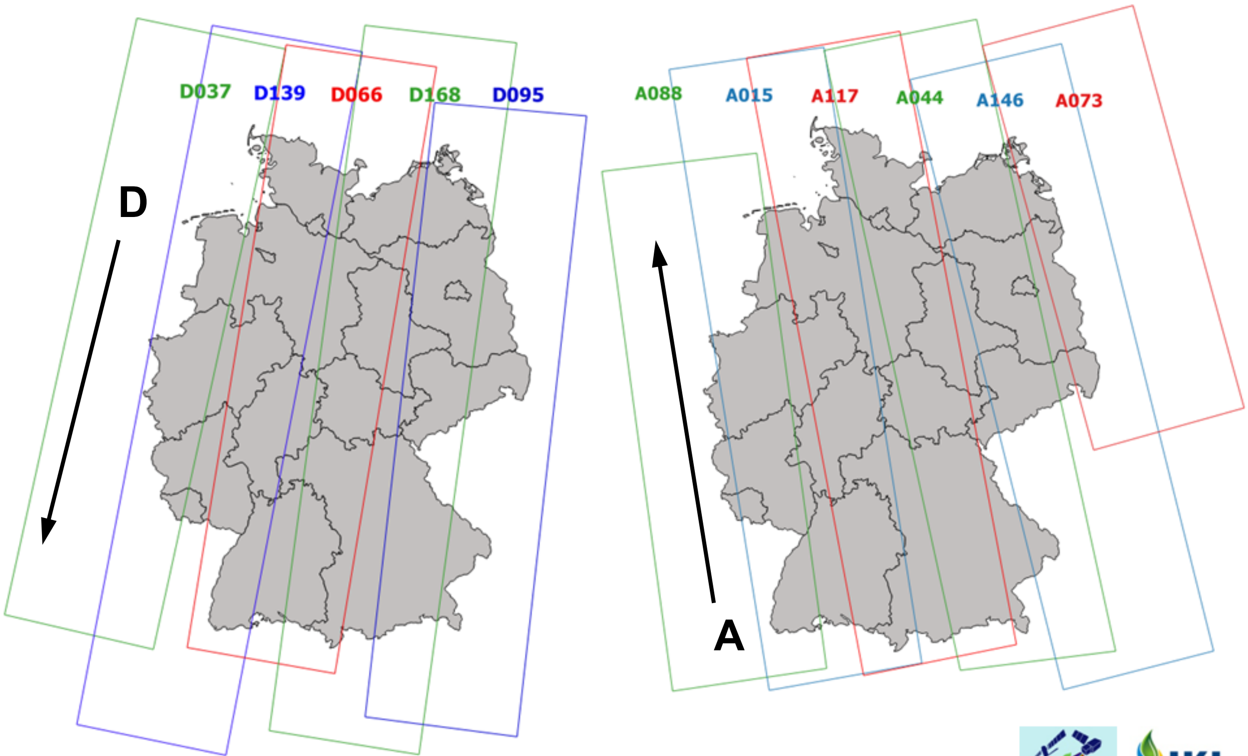
The *Copernicus* program is a long term initiative to improve the European remote sensing capabilities. For precision agriculture the two satellite twins Sentinel-1(A/B) (radar) and Sentinel-2 (A/B) (optical) are the most interesting ones. For technical details see Lilienthal et al. 2016.

The program is already financed for the next twin pairs (C/D) which supposed to be launched around 2024 and technical concepts for the next generation of Sentinels (launched from 2037 onwards) are in planning. This long term perspective as well as the open data policy offers great opportunities for the operational integration of remote sensing data into agricultural practice and for agricultural authorities.

The ground coverage of the Sentinel satellites over Germany is very special due to the location in the higher latitudes. Since the flight tracks overlap with their neighbors, a much higher temporal coverage can be achieved.

The radar satellite Sentinel-1 operates without sunlight; this also allows data acquisition on the dark side of the earth. Figure 1 shows the flight tracks and orbits situation over Germany.

The revisit times of the Sentinel-1 satellites over Germany vary between 1-3 days for every location in Germany. These extremely frequent observations allow an almost real time monitoring of the agriculture in Germany.



D 037	D139	D066	D168	D095	A 088	A015	A117	A044	A146	A073
t_0; t_0+6	t_0+1	t_0+2	t_0+3	t_0+4	t_0+3	t_0+4	t_0+5	t_0; t_0+6	t_0+1	t_0+2

Figure 1. Observation tracks and ground coverage of Sentinel-1A and -B over Germany. Left: Descending orbits at 6 am, right: Ascending orbits at 5 pm.

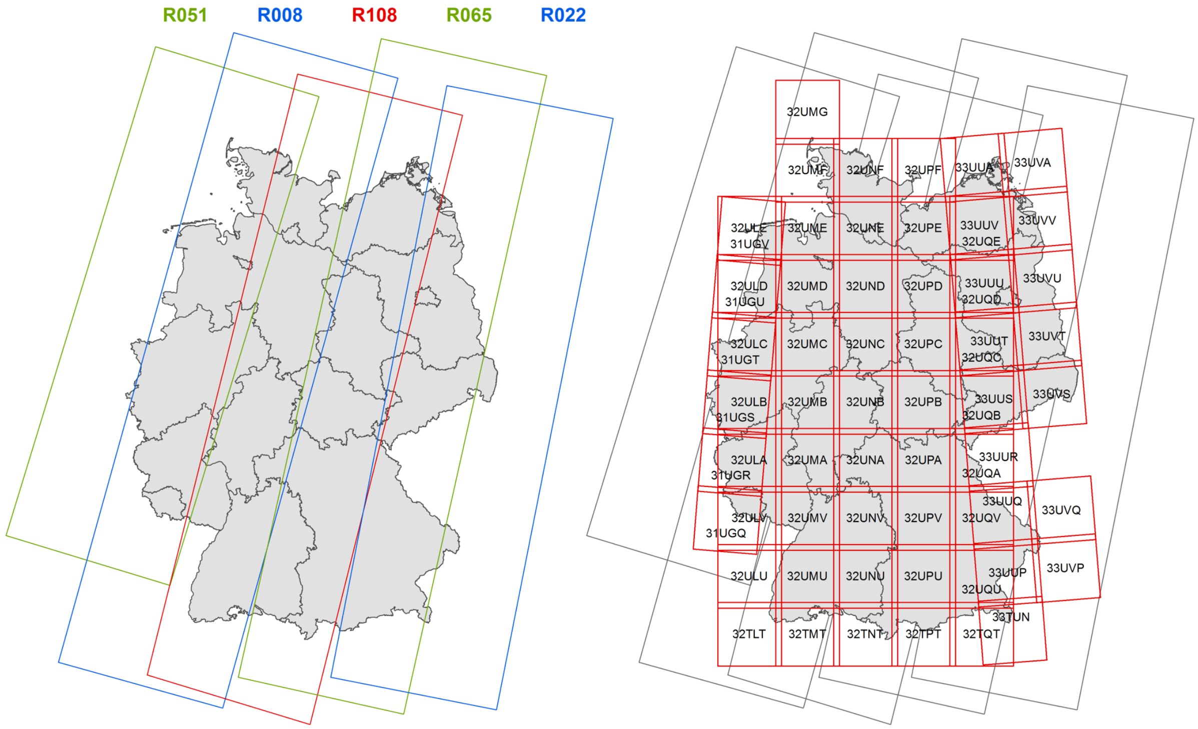
The use of Sentinel-2 data depends on sun illumination and cloud free situations. Anyway the ground coverage and the revisit times over Germany are very high too. Each location in Germany is passed every 2-3 days, which improves the chances for cloud free situation. Figure 2 describes the track positions and revisit times of Sentinel-2.

The raw data need to be corrected for several systematic effects (e.g. terrain and atmospheric conditions) and after corrections they can be used for the generation of data products.

The processing of the data is challenging due to the amount of data, the needed processing time, the produced net traffic as well as limited processing power of the potential users. The European Commission has ambitious plans to tackle these challenges in a big data enabled environment, and has decided to launch the *Copernicus* DIAS – Data and Information Access Services.

A DIAS is a cloud computing environment that keeps all available Sentinel raw data and provides processing power to produce information products from the image data. The users can upload their processing algorithms and processing chains and perform their processing task in the DIAS. An advantage over other commercial providers (e.g. Google Earth Engine, Amazon Web Services) is the application of European data protection law, as all servers are in Europe.

The DIAS are in the start-up phase, information about the longevity and the cost structure of the services are unfortunately not yet known. Due to that reasons, the Julius Kühn-Institut has established the research center for agricultural remote sensing (FLF) to provide data access for authorities and farmers in Germany.



R051	R008	R108	R065	R022
t_0; $t_0 + 5$	$t_0 + 2$, $t_0 + 7$	$t_0 + 4$, $t_0 + 9$	$t_0 + 1$, $t_0 + 6$	$t_0 + 3$, $t_0 + 8$

Figure 2. Observation tracks and ground coverage of Sentinel-2A and -B over Germany.

Left: Observation tracks, right: Tile system for Germay.

Information products and applications

In the ideal case agricultural information products from remote sensing need no interaction with data from farmers, like field boundaries or crop maps. Due to data protection and data ownership issues, field data from farmers should only be used to quality measures and checks and data validation. Since the temporal coverage of the *Copernicus* data, most of the basic information can be retrieved for the satellite data itself. By combining remote sensing data with other data sources (e.g. weather data or elevation information), new dynamic product can be developed.

Crop Type mapping

The basic information and an important prerequisite for many applications is the knowledge of the crops grown on a field. This information can be acquired by time series of Sentinel-1 data and improved and cross checked by the data of Sentinel-2.

The different agricultural management (sowing and harvest times) and the different phenological development of the crops are visible in the time series of the radar data (Fig.3) and help to differentiate between the crops in an automated classification. Although the use of machine learning algorithms to detect the crops grown in Germany is still challenging since the spectrum of the agricultural crops and the different cultivation dates can vary greatly each year depending on the current weather conditions.

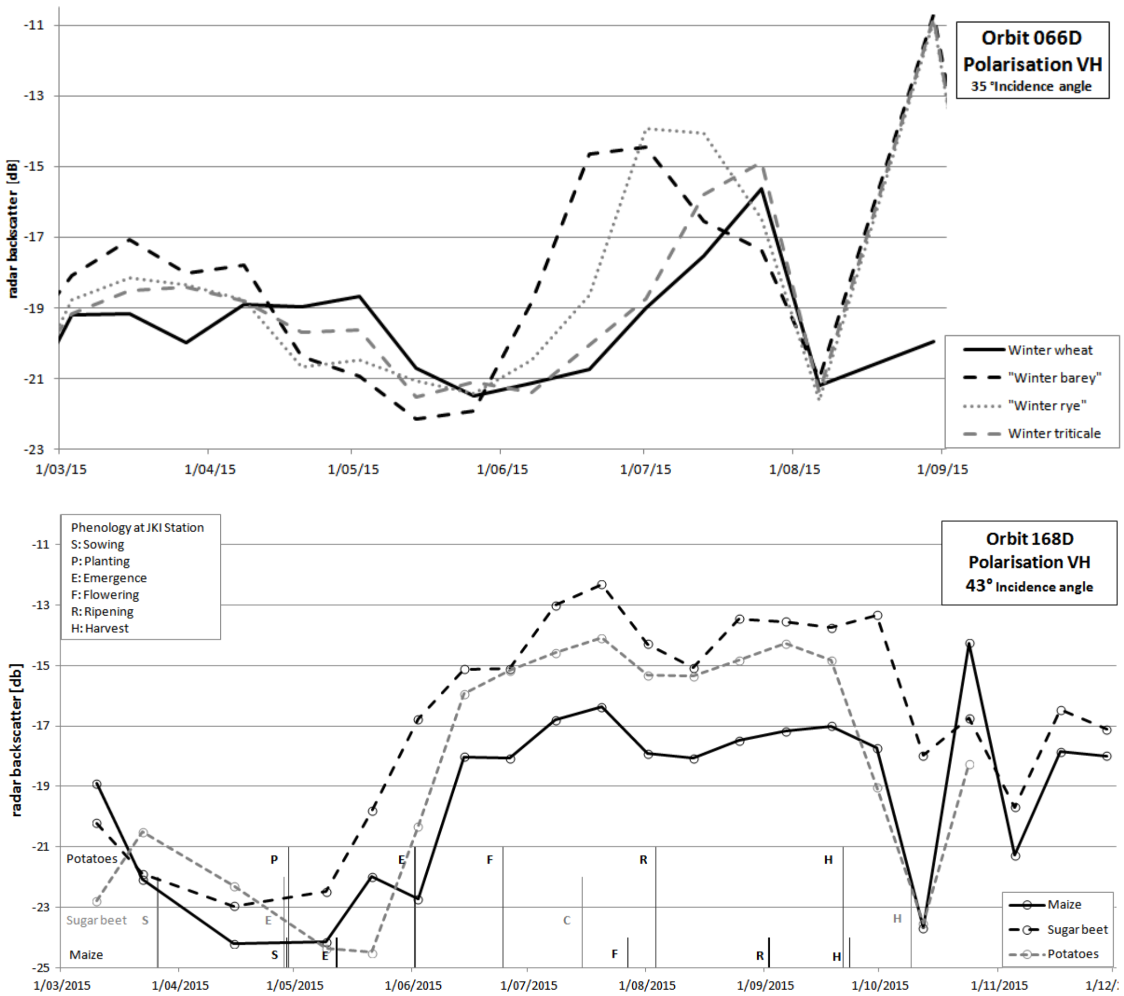


Figure 3. Radar backscatter signatures for different crops and management events.

Based on the different backscatter signatures, and unsupervised clustering of the data can be performed. The different classes will be assigned later to the specific crop types by reference data. The radar data is mostly unaffected by weather event, except strong rainfall.

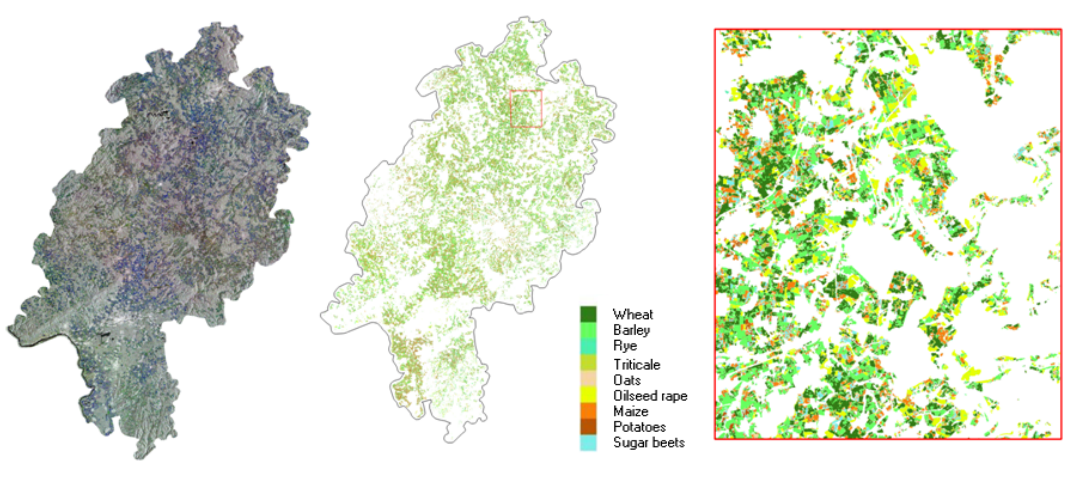


Figure 4. Crop type mapping of the federal state of Hessia, based on Sentinel-1 time series.

In combination with the frequent revisit times, complete coverage of larger regional areas become possible even at short time intervals. Figure 4 shows a crop type map computed for the complete federal state of Hessia. In comparison to optical data this data set was completely acquired over a period of three months (May-July).

Agricultural events

The good temporal resolution of the radar data allows the detections of agricultural management events like sowing or harvest with an accuracy between 1-3 days. Figure 5 shows the estimation of harvest dates with focus on maize. Based on the distinctive decrease of the backscatter signal due to the removal of the biomass from the field, the harvest date can be identified.

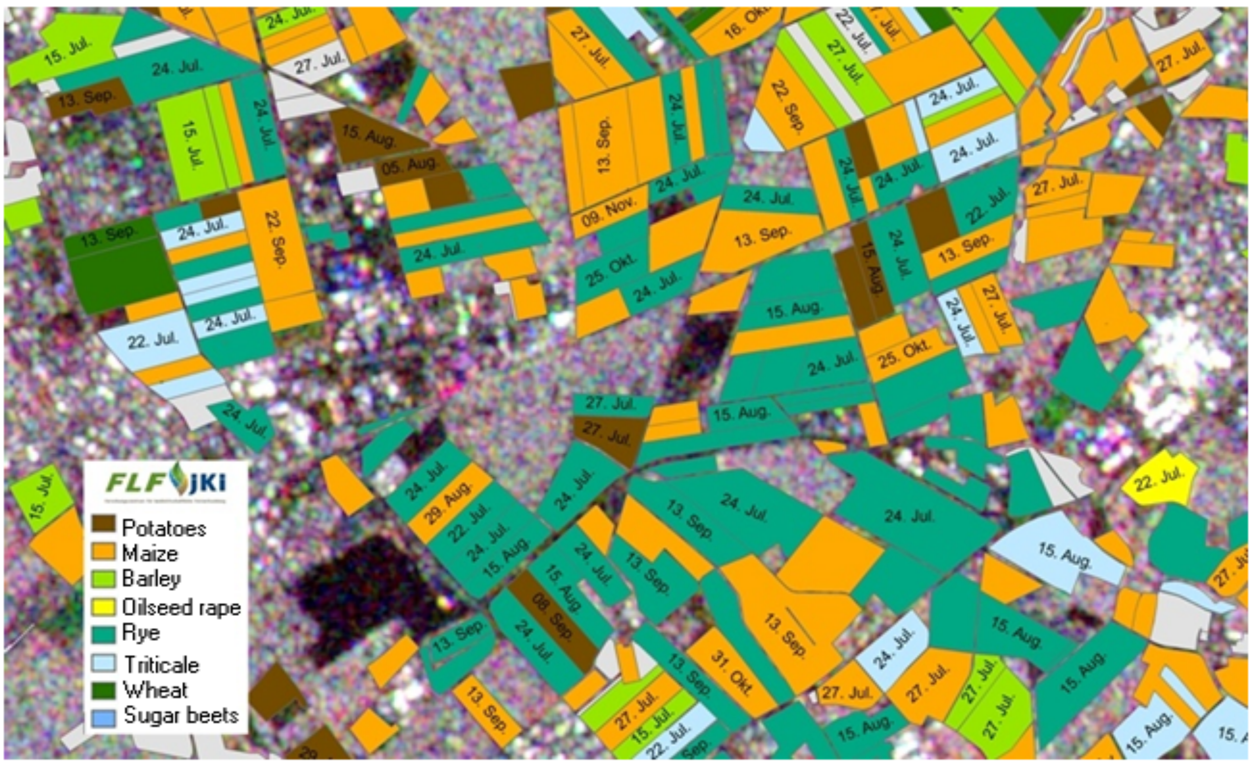


Figure 5. Harvest dates of different crops detected by Sentinel-1 time series.

Another application is the detection of the sowing date, which is important to drive several modeling approaches (e.g. yield estimation or crop phenology).

Biomass and leaf area index estimation

While the radar signal responds to surface roughness and morphology, the optical satellite data provide information about the biophysical and biochemical parameters. Classical approaches are the determination of the leaf area index and the fresh biomass. Both parameters are important input variables to several environmental models, as well as important information for farmers to plan their variable application of fertilizers and pesticides. But timing is a critical point:

In March and April, when most of the fertilization takes place, the elevation of the sun is relatively low producing drop shadow influencing the satellite data.

Figure 6 shows a time series of Sentinel-2 data and the derived leaf area index and fresh biomass maps.

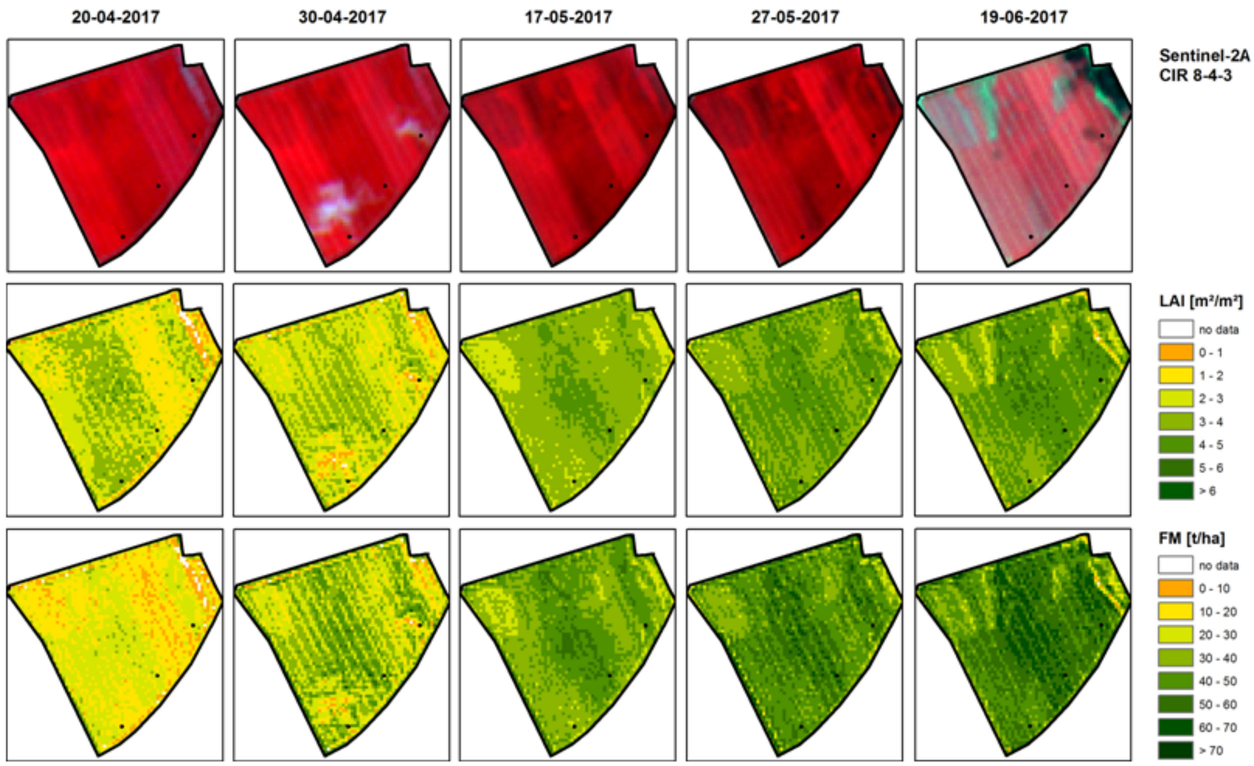


Figure 6. Sentinel-2 time series and estimated leaf area index (LAI) and fresh biomass.

The high spatial resolution (10x10m) allows detecting differently developed zones in a 40 ha wheat field. Also tram lines and their direction can be identified in the Sentinel-2 data.

In-field variability

The detection of the in-field variability is the most important information needed for the development of site-specific application maps. One interesting data set is the Topographic Wetness Index (TWI), which can be computed with a digital elevation model based on the work of Beven et al. (1979) and Moore et al. (1991). The TWI describes the cell that accumulates water from their neighboring cells based on an elevation model. The classification is dimensionless and shows zones which are generally dry or wet. Depending on the current weather situation the TWI will identify more favorable spots in wet years (the dry zones) and in dry years (the wet zones).

The TWI has been computed based on the official German elevation model (DGM10) with a 10x10 m resolution. This corresponds well to the Sentinel-2 data with the same spatial resolution.

Figure 6 presents Sentinal-2 images from spring 2016 to 2018 and the corresponding TWI for a region in Schleswig Holstein in Northern Germany.

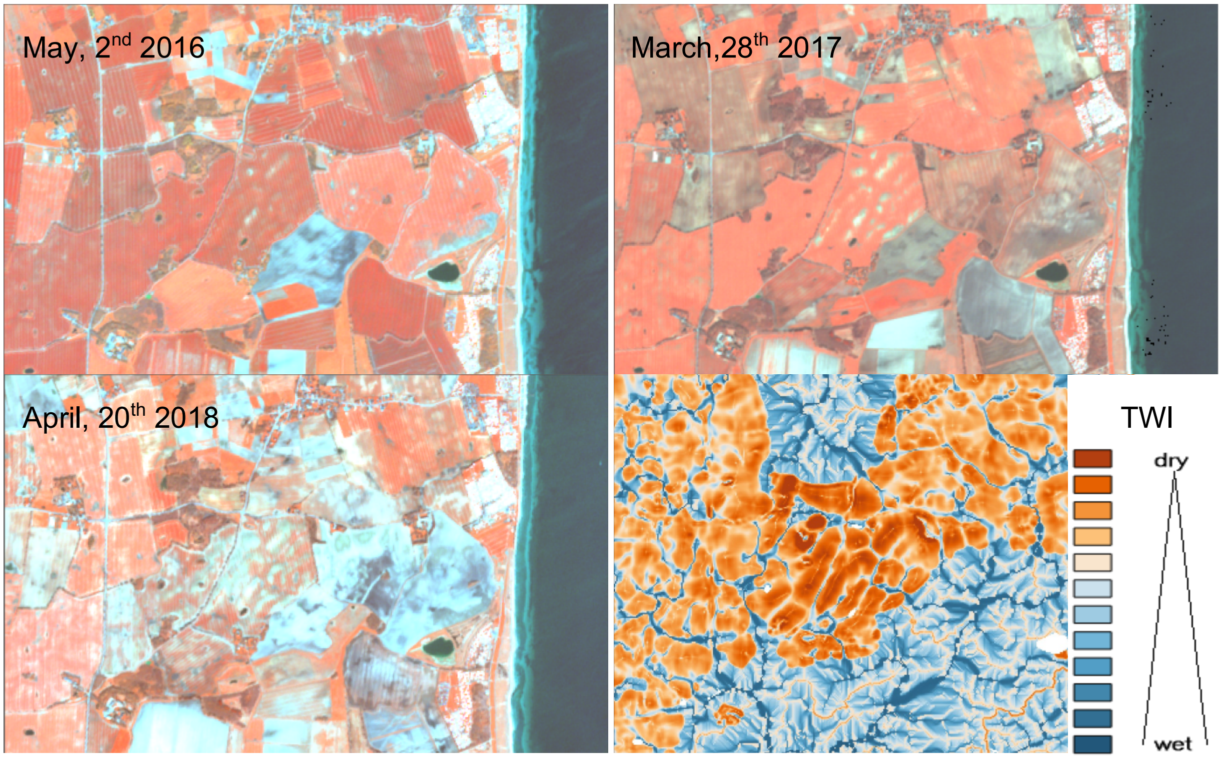


Figure 6. Sentinel-2 time series and computed topographic wetness index (TWI) as input layer for in-field variability.

The zones of the TWI can be identified well in the Sentinel-2 satellite images of different years.

Data distribution

The produced information products from the satellite data need to be distributed in a usable digital form for farmers and local authorities. In general two approaches are suitable:

Web-App

A web-app (or web client) is a map service which works within an internet browser and offers basic functionality like information retrieval, searching and zooming. The big advantages of web apps are the flexibility in terms of usage on several platforms like mobile phones, tablets and desktop computers. The farmer can use the web-app directly in the field and in combination with the GPS in the smartphone the actual information of his position can be retrieved. The FLF provides two web-app services, one in the framework of the AGRO-DE project (www.agro-de.info; https://eoapp-agro.eomap.com/) and the other is the official web-app of the FLF (webapp.flf.julius-kuehn.de). The purpose of the Web-app is the visualization of the data like Web-Map services (WMS) and not to continue working with the data and to integrate it into own farm management systems. To access the data Web Services are needed.

Web Services

In order to develop application maps and to use the full information of the products, the data values need to be accessible. The web services technology used is known from geographic information systems (GIS). The main advantages are the decentralized provision of data and the maintenance/update of different data sets by specialized organizations. The FLF provide different Web services (https://flf.julius-kuehn.de/webdienste/webdienste-des-flf.html) and products. To use these services a GIS is needed to access the data.

Conclusions

The *Copernicus* program offers an interesting source of data for precision agriculture. The raw data is freely available but needs to be processed for final use in agricultural practice. Information products are offered by commercial partners as well as official authorities. By offering data from federal organizations data and quality standards can be defined. Especially since the data needs to be preprocessed (e.g. atmospheric correction for optical data), the algorithms and ancillary data (e.g. digital elevation model) used will affect the resulting image products. The definition of processing standard becomes important, in order to compare the quality of the different remote sensing products from different service providers. Also quality measures have to be defined to estimate the reliability of the information.

With the *Copernicus* Program a long term strategy for global remote sensing has been established. The data and information delivered have to be adopted by agriculture and implemented into the practical workflows. The information integration has to be performed by companies and agricultural consultants since most of the farmer neither have the time nor the skills to use the free raw data.

With the distribution of remote sensing information by the FLF the implementation of precision farming especially for small farmers shall be stimulated. Also the digitalization in agriculture should be promoted in this way.

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