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First experiences with the European remote sensing satellites Sentinel-1A / -2A for agricultural research

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Abstract.

The Copernicus program headed by the European Commission (EC) in partnership with the European Space Agency (ESA) will launch up to twelve satellites, the so called "Sentinels" for earth and environmental observations until 2020. Within this satellite fleet, the Sentinel-1 (microwave) and Sentinal-2 (optical) satellites deliver valuable information on agricultural crops. Due to their high temporal (5 to 6 days repeating time) and spatial (10 to 20 m) resolutions a continuous monitoring of the state of agricultural crops becomes possible. The open data policy offers great opportunities for the operational integration of remote sensing data into agricultural practice.

In April 2014 and 2016 the technical identical Sentinel-1A and -1B satellites have been launched. The radar satellites operate with C-Band (λ~6 cm) and two polarizations (VH, VV) resulting in a spatial resolution over land of nominal 10 m. Combining the orbits of both satellites will result in repeating times of 6 days at equatorial line. In Germany, the revisit time is 4 days even with one satellite only. With its cloud penetrating radar, the Sentinel-1 satellites are very predictable in data availability, which has been the major drawback of the use of remote sensing in agriculture in the past. The high revisit times allow the detection of the phenological stages of different crops, which helps to produce crop type classifications with high accuracy. It has been difficult to distinguish cereals (e.g. barley, rye and wheat) by optical systems so far but this new strategy will render it possible. Also important dates in agricultural management (soil management, harvest dates) can be identified on a field level.

In June 2015, the multispectral Sentinel-2 satellite has been launched. This satellite offers a good spectral resolution with 10 bands and spatial resolutions of 10 to 20 m. This spectral setup helps to retrieve quantitative vegetation parameters like above ground fresh or dry biomass and leaf area index, which serve as input variables to spatial crop growth models. Also a technical identical twin satellite Sentinel-2B is scheduled for launch in 2016. Combining the orbits of both satellites will result in revisit times of 5 days at the equatorial line.

At submission date of the paper, only few cloud free Sentinel-2 images could be acquired for the region of Braunschweig. Also a proper atmospheric correction is not available at the moment, so due to that reasons this paper focused mainly on Sentinel-1A data.

Radar backscatter signatures for the most important crops in Germany will be examined to utilize the high temporal resolution of the data. The new data source offers opportunities to improve crop classification as well as monitoring different phenological stages of the crops.

Keywords. *Remote sensing, Sentinel, vegetation parameters, crop classification, phenology.*

1 Introduction

On April 3rd 2013 the EU regulation no. 377/2014 of the European Parliament and of the European Council came into force, which established the Copernicus Program. Copernicus includes the operation of six thematic services (land and marine environmental monitoring, disaster and crisis management, atmosphere and climate change monitoring, and security) and the Copernicus space component, consisting of a total of 12 remote sensing satellites. For the program, the European Commission will invest approximately € 4.3 billion by 2020 (European Commission, 2014).

The Copernicus program will launch the so called “Sentinels” for earth and environmental observations. Within this satellite fleet, the Sentinel-1 (microwave) and Sentinal-2 (optical) satellites deliver valuable information on agricultural crops. Due to their high temporal (5 to 6 days repeating time) and spatial (10 to 20 m) resolutions a continuous monitoring of the state of agricultural crops becomes possible. The open data policy offers great opportunities for the operational integration of remote sensing data into agricultural practice, like crop classification, which is a prerequisite for several modeling approaches as well as monitoring different phenological stages of the crops.

2 Sentinel satellites

2.1 Sentinel-1A

In April 2014 and April 2016 the technically identical Sentinel-1A and -1B satellite have been launched. The radar satellites operate with C-Band (λ~6 cm) and two polarizations (VH, VV) resulting in a spatial resolution over land of nominal 10 m. Combining the orbits of both satellites will result in repeating times of 6 days at equatorial line. Due to the high latitude of Germany, the flight orbits overlap, so most regions in Germany are already covered about every 4 days, even with one satellite (Fig. 1). With the launch of Sentinel-1B, the flyover frequencies are doubled, so that continuous monitoring becomes possible. Up to now only Sentinel-1A data are available.

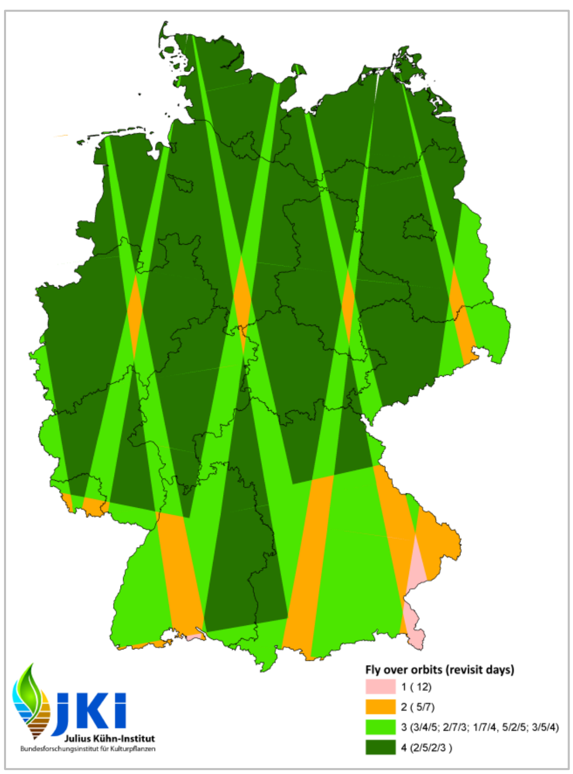

Fig 1. Orbits of the Sentinel-1A satellite over Germany.

The Sentinel-1A passes Germany with eleven flight orbits. Six orbits run from south to north (ascending mode) and fly over at 6:00 pm local time. Five orbits are running from north to south (descending mode) and acquire data at 6:00 am local time.

The active radar sensor is independent from sun light and the emitted microwaves can penetrate clouds, so that the system is independent of the weather situation to a large extent. For land applications two image bands are available, which differ in the polarization plane of the transmitted and receiving electromagnetic waves (in general VV: vertically transmitted and received, VH: vertically transmitted, recorded horizontally). The main technical properties of Sentinel-1 are summarized in Table 1.

Table 1. Key parameters of the Sentinel-1 satellites for land applications (Source: European Space Agency, 2015a modified).

Frequency	Polarizations	Incidence angle range	Look direction	Data quantization	Product Type	Sensor Mode	Swath width	Ground resolution
5.405 GHz (C-Band)	HH+HV, VV+VH, VV, HH	20°- 46°	right	10 bit	Ground range corrected (GRD)	Inter-ferometric Wide Swath (IW)	250 km	10 m

2.2 Sentinel-2A

In June 2015, the multispectral Sentinel-2A satellite has been launched. Sentinel-2 is a wide-swath (290 km), high resolution, multispectral imaging mission. The multispectral instrument offers four spectral bands at 10 meter ground resolution, six bands at 20 meter and three bands at 60 m ground resolution (Tab.2).

Table 2. The key parameters of the SENTINEL-2 for agricultural applications (Source: European Space Agency, 2015b modified).

Band	Center wavelength	Band width	Ground resolution	Remark
1	443 nm	20 nm	60 m	For atmospheric correction
2	490 nm	65 nm	10 m	
3	560 nm	35 nm	10 m	
4	665 nm	30 nm	10 m	
5	705 nm	15 nm	20 m	
6	740 nm	15 nm	20 m	
7	783 nm	20 nm	20 m	
8	842 nm	115 nm	10 m	
8a	865 nm	20 nm	20 m	
9	940 nm	20 nm	60 m	For atmospheric correction
10	1375 nm	30 nm	60 m	For atmospheric correction
11	1610 nm	90 nm	20 m	
12	2190 nm	180 nm	20 m	

Sentinel-2 uses the heritage of the Landsat and Spot programs with an improved spectral and spatial resolution. Especially the narrow bands in the Red Edge (Bands 5 and 6) are an improvement for vegetation monitoring. Germany is covered by six overlapping orbits, resulting in a revisit time of around 5 days with one satellite. For mid 2016 the launch of the twin satellite Sentinel-2B is scheduled, which will improve revisit times in Germany up to two days.

2.3 Sentinel Toolboxes

An important improvement of the Copernicus Program is the availability of free open source analysis software for the satellite data. For each of the Sentinel satellite systems a so called *Sentinel toolbox* is available which contains specific routines to pre-process and analyze the data. The toolboxes can be obtained via the ESA science toolbox exploitation platform (STEP) (ESA, 2016).

3 Material and methods

3.1 Radar data acquisition

Sentinel data is available via *Sentinels Scientific Data Hub* (ESA, 2015c). For Sentinel-1A, data is archived since October 2014. Sentinel-2A data is available since November 2015, but still in pre operational phase. Sentinel-1A data for the area of the federal state of Lower Saxony have been downloaded for orbits 15, 44, 88 and 117 in ascending and for orbits 37, 66, 139 and 168 in descending mode resulting in 186 image acquisitions and a memory volume of 691 GB.

The county of Helmstedt in *Lower Saxony* is covered by four orbits (44, 66, 117 and 168) resulting in 110 observations of the same area during 2015. This county was used as reference to examine the potential of high temporal resolution radar data (Fig. 2).

Since data of Sentinel-1A is sparsely available since October 2014, radar data has been processed from 1st of March 2015 onwards.

3.2 Radar data processing

Raw data of the Sentinel-1A satellite has been processed using the Sentinel-1 toolbox from ESA. The radar data has been calibrated and terrain corrected with the implemented standard routines, data has been converted to sigma nought [σ^0] backscatter coefficients in decibel (dB) and the single image tiles have been joined to a seamless mosaic. Finally the image data was masked to the boundaries of the federal state of *Lower Saxony* and the county of Helmstedt, respectively.

3.3 Reference data

The federal state of Lower Saxony provides a field parcel identification system which contains the field boundaries and the crops of the season 2015. For the county of Helmstedt fields with the most important crops for Germany have been selected to identify the response of the radar backscatter to the specific crop (Fig.2, Table 3).

Table 3. Properties of selected fields from the field parcel identification system of Lower Saxony.

ID	Crop	Field size [ha]	Local incidence angles [°] Ascending orbit A044	A117	Descending Orbit D066	D168
1	Winter wheat	43.6	35	44	35	43
2	Winter barley	41.4	35	43	35	43
3	Winter rye	45.9	34	43	35	43
4	Triticale	12.7	34	42	35	44
5	Oilseed rape	29.8	36	44	33	42
6	Maize	22.3	35	43	35	43
7	Sugar beet	49.3	35	44	35	42
8	Potatoes	25.5	35	43	35	44

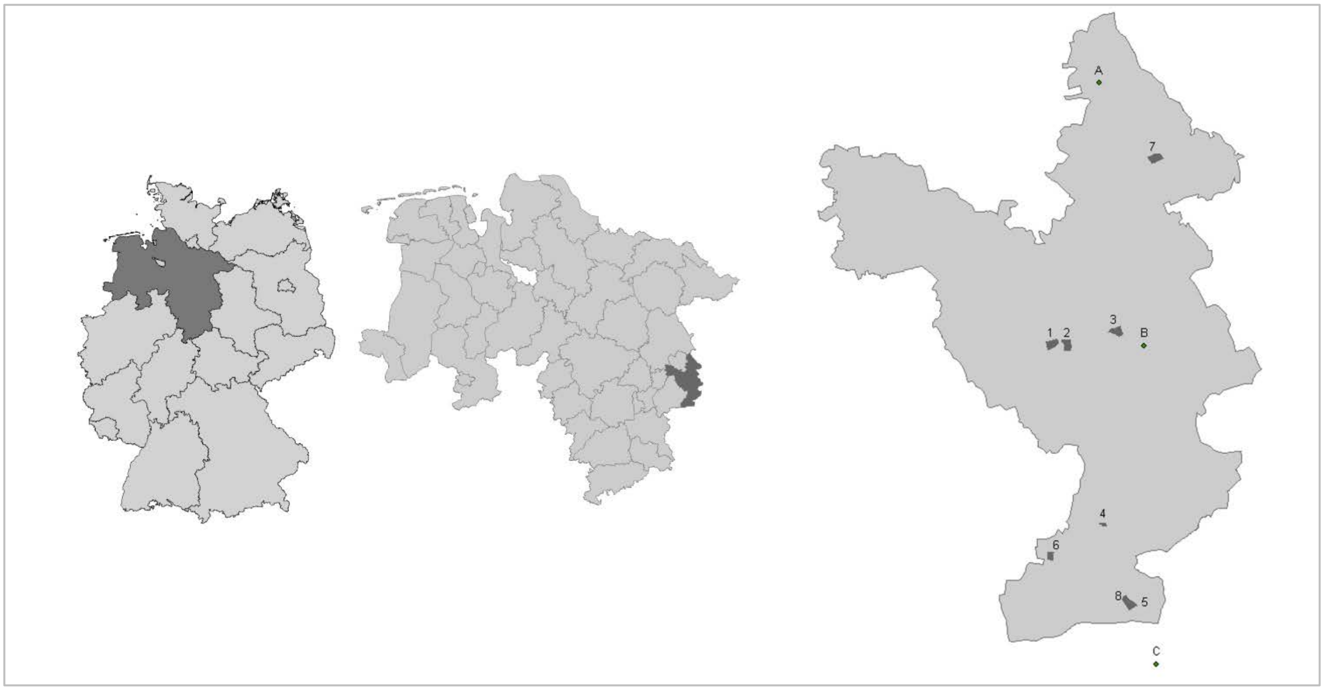

Fig 2. Location of the county of Helmstedt in Lower Saxony(left) and reference fields (numbers 1-8) with corresponding weather stations (A-C) in Helmstedt county. For identification of crops see Tab.3.

Detailed information on crop phenology has been recorded at the JKI experimental station, about 35 km in distance to Helmstedt County. They were used as general reference of the phenological development in the region (Tab.4).

Table 4. Phenological information of the JKI experimental station in Braunschweig 2015. For the dates in grey no images have been analyzed.

Crop 2015	Tillage	Sowing	Emergence	Flowering	Ripeness	Harvest
Winter wheat		20/10/14	13/11/14	08/06/15	15/07/15	03/08/15
Winter barley		01/10/14	16/10/14	12/05/15	15/06/15	27/07/15
Winter rye		29/10/14	21/11/14	20/05/15	06/07/15	03/08/15
Triticale		29/10/14	13/11/14	02/06/15	06/07/15	03/08/15
Oilseed rape		01/09/14	10/10/14	28/04/15	15/06/15	27/07/15
Maize		29/04/15	12/05/15	27/07/15	02/09/15	23/09/15
Sugar beet		26/03/15	28/04/15	15/07/15*	-	09/10/15
Potatoes		29/04/15	01/06/15	24/06/15	03/08/15	21/09/15

* Canopy closure

Finally, rainfall data for three stations in the region has been acquired from the German meteorological survey. General information on the weather stations is given in Table 5.

Table 5. Identification of the weather stations.

ID	Name	Lat	Lon	Height	Precipitation data
A	Danndorf	52.426	10.917	69 m	daily
B	Helmstedt-Emmerstedt	52.247	10.959	110 m	hourly/daily
C	Pabstorf	52.031	10.963	112 m	hourly/daily

4 Results and discussion

Radar is an active energy emitting sensor system. The backscatter of the energy is measured at the sensor again, resulting in negative values, since some energy is always lost in that process. Bare soil results in higher backscatter values compared to green vegetation which leads to a decrease of the signal due to volume scattering. The radar signal is sensitive to the dielectric properties of the measured objects, so the water contents in the plants and soil affect the backscatter signal. Also the wavelength of the radar system determines the object size which can be acquired.

The radar signal is recorded with a side looking aperture, resulting in different absolute backscatter values depending on the local incidence angle. The selected fields showed similar incidence angles for the orbits 44 ascending and 66 descending and 117 ascending and 168 descending respectively. Anyway tramline direction as well as row crops such as maize and potatoes can affect the backscatter response just by structure without any information of crop status.

4.1 Radar backscatter signatures

The radar backscatter data has been extracted as average field value for each crop and every orbit and polarization, resulting in temporal backscatter signatures. An example is given in figure 3, showing the backscatter signatures for cereals in VH polarization.

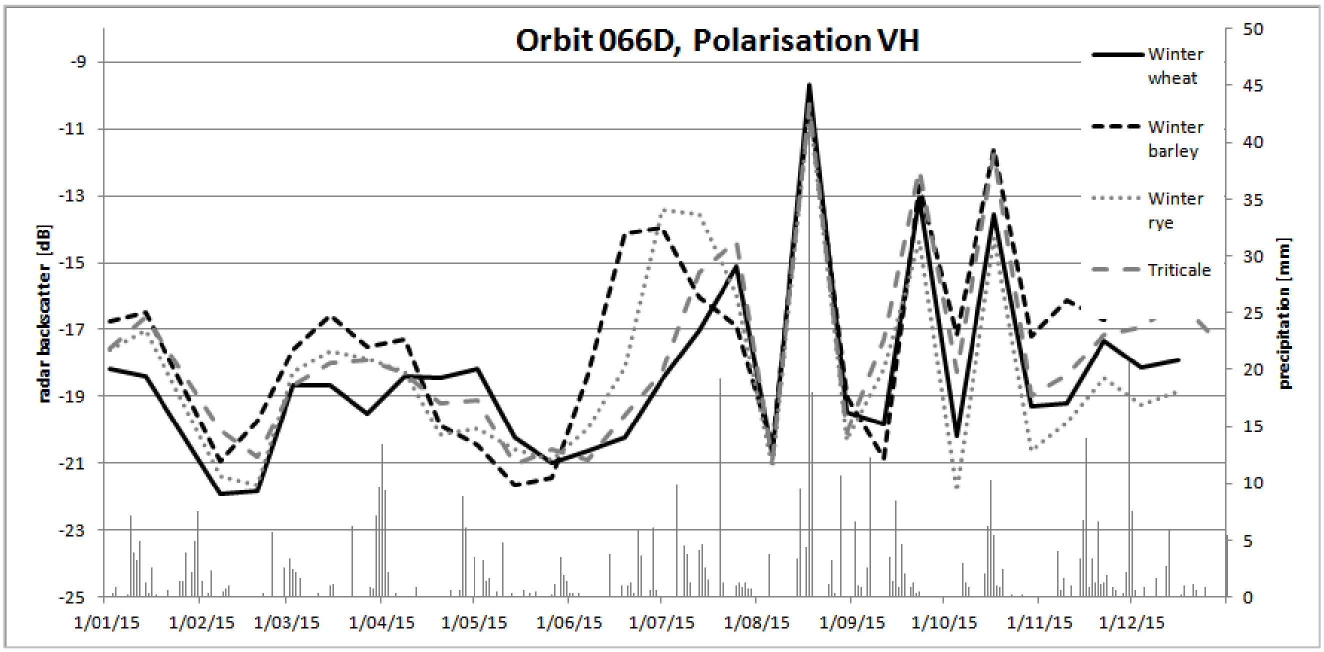

Fig 3. Radar backscatter signatures of Sentinel-1A for different cereals overlaid with daily precipitation data of weather station Helmstedt (B).

Although radar is considered as weather independent measuring process, heavy rainfall can influence the backscatter signal. During the data take on August 18th 2015, 18 mm of rain did fall, resulting in a strong increase of the backscatter signal for all cereals. On the contrary, the strong increase of the backscatter signal on September 23rd and October 17th can be attributed to different soil moisture contents, since the crops were already harvested, and there was no rainfall recorded on those days, but remarkable amounts of rain fell the days before. Therefore, a screening for rain disturbances is indispensable before data analysis in order to interpret the temporal backscatter signatures in a right way.

4.2 Crop specific backscatter profiles

To arrange the multitude of backscatter signatures, crops are sorted by their sowing time in winter or summer. Winter crops are sown in autumn. They outlast the winter and start growing again when mean temperatures rise above 5° C. Summer crops are sown in springtime when soils become warmer.

4.2.1 Winter crops

The main winter crops sown in autumn in Germany are cereals (wheat, barley, rye and triticale) and oil seed rape. The backscatter signatures follow a common shape for cereals (Fig. 4). Until April the backscatter is mainly affected by soil moisture, since vegetation is sparse and soil water content is usually around field capacity. Interpretation at very early stages of the year can be misleading by the occurrence of snow, which influences the dielectric properties of the ground. From April onwards the backscatter signals decrease as vegetation cover increases. After flowering the maximum leaf biomass is reached. From that time on, the backscatter signals increase due to the ripening and the loss of water in the plants. The harvest time can be clearly identified by the strong decrease of the backscatter signal due to the underlying stubble, which changes the backscatter plane. After that a strong increase of the backscatter signal can be noted due to the soil preparation for the next crop. As can be seen in figure 4, differences between polarizations are minor and crop specific.

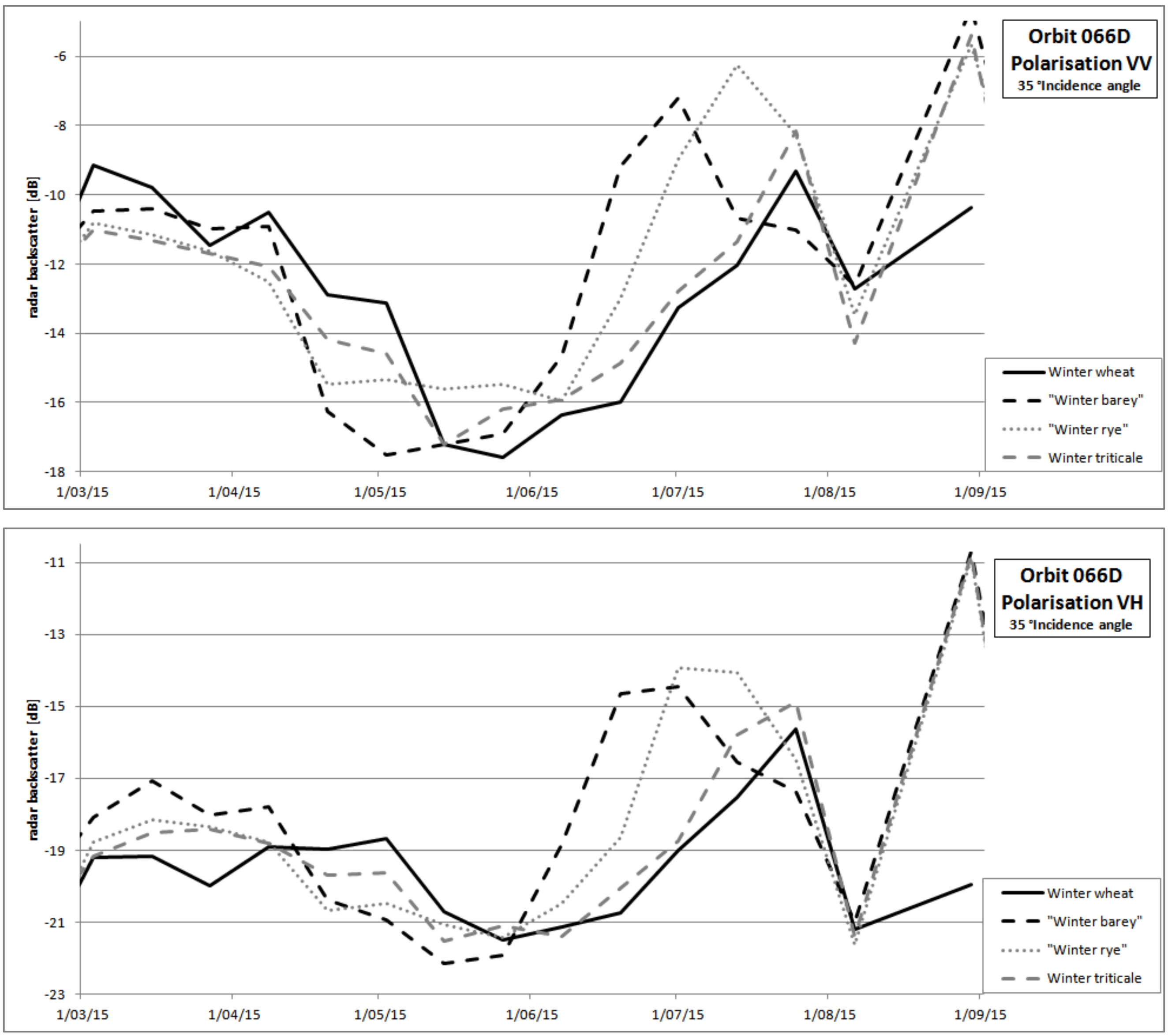

Fig 4. Radar backscatter signatures for cereals, top: co-polarization, bottom: cross polarization.

In terms of crop signature separability, the best time is mid of April to May, as well as June to July.

Co-polarization (VV) shows slightly stronger differences between the crops. The different harvest dates (barley -> rye -> triticale -> wheat) can also be clearly identified in the signatures.

The radar backscatter signatures for oilseed rape in cross-polarization are not very specific. Thus only co-polarizations with different incidence angles are presented in figure 5. Until April the backscatter is mainly affected by changing soil moisture as was discussed for other crops earlier on. During flowering of oilseed rape, the backscatter signal is characterized by a strong decrease. At the end of the flowering period, the backscatter signal increases until fruit development. With the four observing orbits, beginning of flowering could be dated to the time between 27th and 30th of April and end of flowering between 12th and 14th of May. With the beginning of ripening the backscatter signal starts to decrease slightly which is followed by a strong decrease at the time of harvest. Based on the observations, timing of ripening started between 5th and 10th of June and harvest between 16th and 23rd of July.

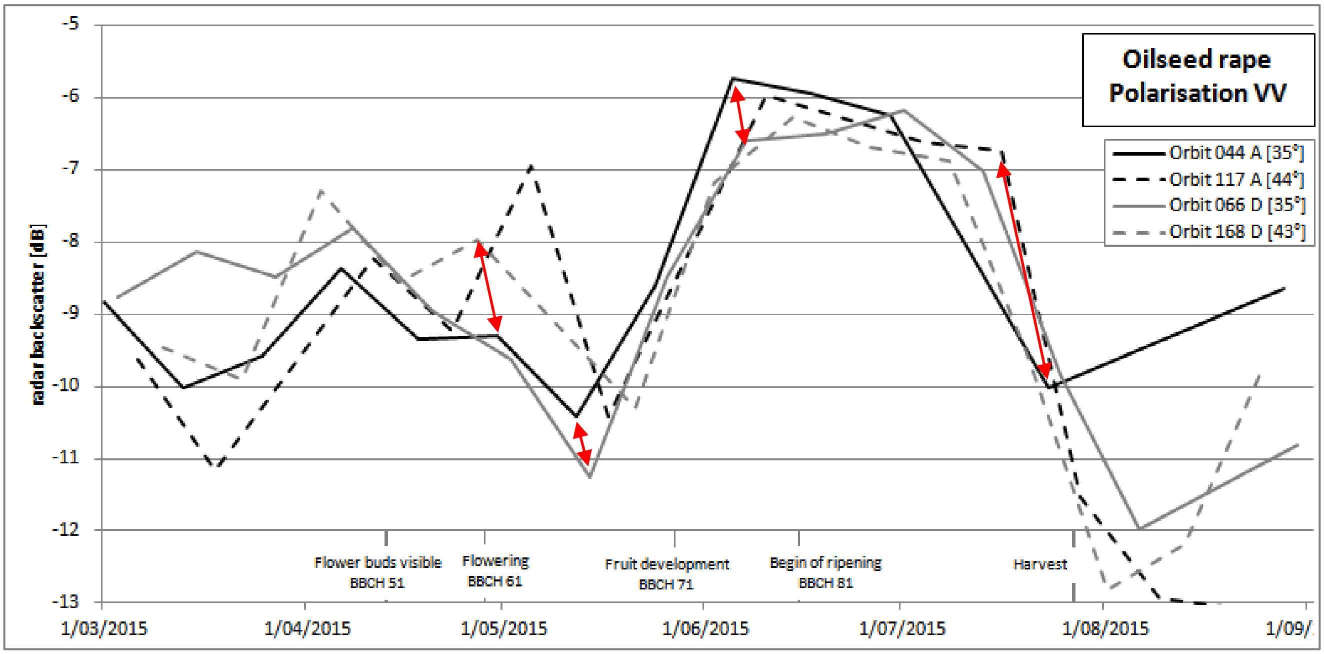

Fig 5. Radar backscatter signatures for oilseed rape at different incidence angles, and phenological dates of oilseed rape at the JKI research station.

4.2 Summer crops

The backscatter signatures of summer crops (e.g. maize, sugar beets and potatoes) differ from cereals. First, the backscatter is low as soil is prepared, then the backscatter signatures increase while vegetation is growing (Fig. 6). This can be explained by the reduced volume scattering of sugar beet and potatoes as they are low in height. The backscatter for maize is mainly affected by the top leaves. Especially potatoes with the row structure at planting result in a very low backscatter signature at planting. The phenological stages emergence and harvest can be clearly detected for all crops from the signatures. Canopy closure in sugar beet can be identified by the maximum backscatter signal in mid-July.

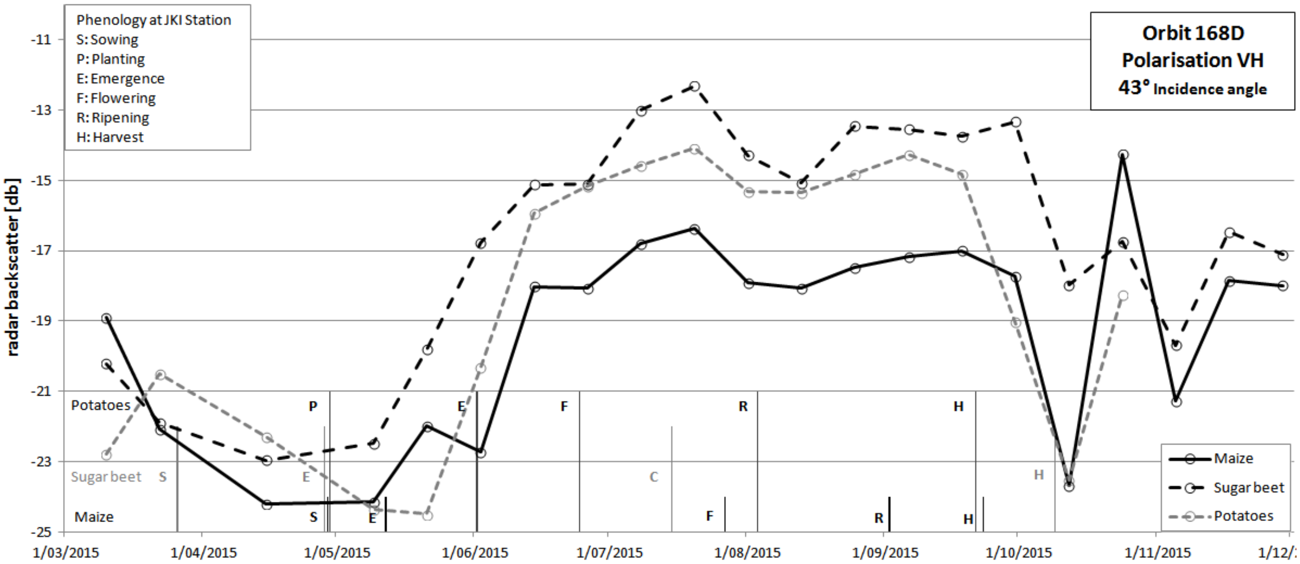

Fig 6. Radar backscatter signatures for maize, sugar beet and potatoes at 43° incidence angle, and phenological dates of the crops at the JKI research station.

5 Conclusion

The Copernicus Program of the European Union offers new opportunities for the high temporal monitoring of crops with remote sensing satellites. Especially the radar satellites Sentinel-1A/B are extremely helpful for crop identification and the detection of several phenological stages (Table 6).

Table 6. Overview of useful polarization combinations for the identification of phenological stages. Questions marks illustrate that no images have been analyzed.

Crop	Sowing	Emergence	Flowering	Ripening	Harvest
Winter-wheat	?	?	-	VH, VV	VH, VV
Winter-barley	?	?	-	VH, VV	VH, VV
Winter-rye	?	?	VH	VV	VH, VV
Winter-triticale	?	?	VH	VH	VH, VV
Oilseed rape	?	?	VV	VH, VV	VV
Maize	VH, VV	VH	VH, VV	-	VH, VV
Sugar beet	-	VH	-	-	VH, VV
Potatoes	-	VH, VV	-	-	VH, VV

A first data analysis showed that summer and winter crops can easily be separated by radar signatures as well as the cereals.
The multitude of factors influencing the backscatter signal (e.g. polarization, incidence angle, phenology), as well as the huge data amount, are very challenging for the processing of the data.
For a correct interpretation of radar images, it will be crucial to examine rainfall data of the region during the time of data acquisition to avoid misinterpretations due to rainfall backscatter.

The synergistic use of radar data and optical data of the Sentinel-2 satellites has a great potential to improve the use of remote sensing in agriculture, since the problem of data availability will most probably be overcome. The next challenge will be to identify and develop suitable products for farmers and decision makers to meet their information needs.

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