PHENOS – PHENOLOGICAL STRUCTURING TO DETERMINE OPTIMAL ACQUISITION DATES FOR SENTINEL-2 DATA FOR FIELD CROP CLASSIFICATION

Henning Gerstmann(1), Markus Möller(1), Detlef Thürkow(1), Cornelia Gläßer(1)

(1) Martin Luther University of Halle-Wittenberg, Institute for Geosciences and Geography, Department Remote Sensing and Cartography, Von-Séckendorff-Platz 4, 06120 Halle (Saale), Germany, Email: henning.gerstmann@geo.uni-halle.de

ABSTRACT
Classification of agricultural areas is often difficult due to highly similar spectral signatures of different crop types. This similarity differs depending on the plant’s developmental stage. Thus, days with higher spectral differences can be detected during a phenological cycle. The detection of these days for specific land cover types is a promising approach to increase the accuracies of land cover classifications. This detection can be achieved by modeling phenological events and combining them with spectral information derived from satellite imagery.

In this contribution we present first results which show the applicability of the phenological structuring approach in the context of the PhenoS joint research project. Six RapidEye-based vegetation indices were tested to assess their applicability for phenological structuring. The results show that different indices indicate different optimal acquisition dates. Since all acquisition dates can be clearly coupled with predicted phenological events, the results indicate an optimal acquisition date selection and potential alternative dates.

1. INTRODUCTION
The European Earth Observation Program COPERNICUS(1) aims at the establishment of remote sensing-based services delivering customized and up-to-date geo-information to support the implementation and monitoring of environmental and security policies. Current information about annual developmental stages of crops can help to improve the quality and efficiency of crop type classification schemes since they support the determination of temporal windows for optimal acquisition dates. In this context, the SENTINEL-2 satellite constellation will be launched to provide data of high geometric, spectral and temporal resolution. Several authors recently included phenological parameters in a classification scheme. However, they all focused on phenological events like Start/End of Season, Amplitude, Rate of Green-up etc (1, 2).

Spectral properties of crops become more insightful when taking into account more detailed information regarding the phenological state of the studied crop species. Phenological events in this context are clearly visible developmental phases like emergence, ripening or flowering (3). Thus, the objectives of this study are to evaluate the potential of using phenology for detection of optimal acquisition dates and to assess whether are those dates differ depending on the used vegetation index.

Some of the cyclic variations are small but plant-specific, so that they can be used to an accurate classification. Knowledge about the relation of spectral features or indices and phenological phases can be used to detect optimal time frames for data selection that provide highest separability of different crop types. This investigation is part of the joint research project "PhenoS - Phenological structuring of high temporal resolution Sentinel-2 data sets to improve land cover classifications"(2), that aims at the development of a web-based tool set for detecting optimal acquisition dates for satellite data for land use classification purposes. It is designed to use automatic coupling of phenological and spectral information instead of using a case-specific parameter assessment.

2. METHODS
2.1. Study sites
Three test sites in Germany characterized by different climatic conditions and cultivation practices were selected. They are located in the lowlands of northern Germany in Western Pomerania, in the Harz mountain range and its surrounding areas and on the foothill of the Alps (Figure 1). The sites represent a gradient of important climate and landscape units in Germany.

2.2. Data
Once that both satellites of the constellation have been launched, SENTINEL-2 is expected to provide satellite imagery in short repetition intervals of approximately 2-3 days (5). Due to the high temporal and spectral

(1) www.copernicus.eu

(2) http://paradigmmaps.geo.uni-halle.de/phenos/
resolutions, the PhenoS project’s focus will be on the usage of SENTINEL-2 data, but also other frequently used multispectral satellite sensors such as RapidEye, MODIS and Landsat-8 are used. AISA-Hawk/Eagle hyperspectral data will be used for simulation of the SENTINEL-2 sensor characteristics and the development of methods and parameters until the Sentinel-2 sensor provides data. Climate data and phenological information provided by the German Weather Service are used for phenological modeling.

Climate data and phenological information provided by the German Weather Service are used for phenological modeling.

For phenological modeling, a statistical model is used and evaluated regarding to its performance in predicting the day of entry of a specific phenological phase. The so-called PHASE model [6] produces Germany-wide spatial phenological data sets by using the Random Forest regression algorithm [7]. PHASE is based on the relation between the timing of observed phenological events [8] and species-specific thresholds of growing degree days with respect to day length [9] and a plant-specific base temperature. By calculation and coupling of these heat sums with the point-related phenological observations, phenological events can be spatially extrapolated by using digital elevation models acting as temperature-related proxy. PHASE has been applied for predicting phenological phases of field crops, especially winter and summer cereals (wheat, rye and barley), maize, rapeseed, potatoes, sugar beet, and agricultural grassland. The model output for the phenological phase of shooting (winter wheat, winter barley and winter rye) in 2010 is displayed in Figure 2.

Parameters derived from spectral characteristics can be coupled with phenological data [10]. For the PhenoS project, well-established vegetation indices (e.g. Normalized Difference Vegetation Index, Enhanced

Figure 1: Location of the study sites

2.3. Phenological structuring

Phenological structuring, which is understood by the authors as coupling of spectral signatures derived from remote sensing data with corresponding phenological phases, is the most important part for the development of a tool set for time frame detection. High temporal resolution of the satellite data is necessary to cover as much different phenological phases as possible. The spectral bands of the SENTINEL-2 sensor are well suited for studies on vegetation, and the high spectral resolution in the red edge and near infrared regions (bands 5 to 9) is unique compared to sensors like RapidEye or Landsat-8.

Figure 2: Predicted day of entry for the phase "Beginning of stem elongation" for winter cereals in 2010 [10] Projection: EPSG code 25832.
Vegetation Index, Green NDVI) are used as such parameters. Satellite images, acquired on points in time with higher index differences, allow a more accurate distinction between crop types with higher accuracies [10]. Relating a specific phenological phase to the point in time where the difference is highest enables an estimation of separability of the crops as function of their phenological state and thus time. A high temporal resolution is necessary for an accurate detection of this point in time. The comparably higher temporal and spectral resolution of SENTINEL-2 is expected to allow significantly better structuring and classification results than the usage of RapidEye or Landsat 8 does. The calculation of the maximum separability can be carried out for any year for which sufficient phenological information, climate data and multiple, comparable satellite images are available. The principle workflow is shown in Figure 3. 

![Figure 3: Principle workflow of the phenological structuring approach](image)

### Table 1: Vegetation indices used for phenological structuring

<table>
<thead>
<tr>
<th>Index</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalized Difference</td>
<td>( \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} )</td>
</tr>
<tr>
<td>Vegetation Index – NDVI [11]</td>
<td>( \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{GREEN}} )</td>
</tr>
<tr>
<td>Green NDVI [12]</td>
<td>( \frac{\text{NIR} + \text{GREEN}}{\text{NIR} + \text{GREEN}} )</td>
</tr>
<tr>
<td>2-band Enhanced Vegetation Index – EVI 2 [13]</td>
<td>( \frac{\text{NIR} - \text{RedEdge}}{\text{NIR} + \text{RED}} )</td>
</tr>
<tr>
<td>Maccioni Index [14]</td>
<td>( 2.5 \cdot \frac{\text{NIR} - \text{RED}}{\text{NIR} + 2.4 \cdot \text{RED} - 1} )</td>
</tr>
<tr>
<td>Simple Red Edge Ratio – SRR [15]</td>
<td>( \frac{\text{NIR}}{\text{RedEdge}} )</td>
</tr>
<tr>
<td>Wide Range Vegetation Index – WDRVI [16]</td>
<td>( 0.15 \cdot \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} )</td>
</tr>
</tbody>
</table>

The first index greyscale image is represented by Band 1 and the latest image by Band 9. In doing so, an vegetation index profile of an object over the phenological cycle can be extracted. For each index time series, the difference of all target crops to each other was calculated for each date of acquisition and the point in time with the highest difference was determined. This DOY of maximum spectral difference is understood as the point in time, were the separability of the respective crop classes is highest. Next, the phenological phase that was observed on the determined day of maximum spectral difference was modelled and coupled to the index profiles. The calculated optimal day of the year was then related to a specific phenological phase.

### 3. RESULTS AND DISCUSSION

For the three target crops maize, winter cereals and rapeseed, one field per type was chosen where the respective crop was grown in 2011. The mean profiles for each crop type and index were extracted. Index values that have been derived from images taken after harvest of the respective crop were excluded. In Figure 4 the profiles of maize, rapeseed and winter cereals produced using the 2-band EVI are exemplarily shown. During the flowering of rapeseed the index values decrease significantly, while winter cereals show...
a continuous increase of index values. Maize is sown in early summer and thus showing increasing vitality when the other crops already show decreasing values.

Figure 4: 2-band Enhanced Vegetation Index (EVI 2) profiles for the target crop. Index values stretched between 0 and 1.

The difference between index values of different crop species varies during the course of a growing season as consequence of non-similar phenological development. As shown in Figure 5 for rapeseed and winter cereals, the detected DOYs of maximal difference differ in dependence to the used index.

By comparing rapeseed and winter cereals, the Simple Red Edge Ratio shows the difference maximum approximately 30 days prior than the other indices do. For maize and winter cereals, the indices can be separated into two groups of different maximal values (Figure 6). Maccioni-Index and WDRVI show the highest difference around DOY 100, while the other indices reach their maxima around DOY 190.

Figure 5: Normalized index differences of rapeseed and winter cereals

The respective phase differs with location and tillage practices. Those phenological phases, which are most likely to be present on the calculated optimal DOY, are listed in Tab. 2.

Table 2: Phenological phase on the calculated optimal days of year. Data Source: [8] transferred to BBCH scale [17]

<table>
<thead>
<tr>
<th>DOY</th>
<th>Maize</th>
<th>Rapeseed</th>
<th>Winter Cereals</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>none</td>
<td>31 dormant</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>190</td>
<td>51</td>
<td>100</td>
<td>85</td>
</tr>
</tbody>
</table>

4. DISCUSSION AND OUTLOOK

The most characteristic phenological event of rapeseed is the yellow flower. Rapeseed fields in the phase of full flowering are easily to separate accurately from other crops, if wider parts of the visible spectral region are included in the classification process. Also the tested vegetation indices show that this phase is optimal for
separation of rapeseed from winter cereals. If other spectral regions are included in the index calculation, the index difference would further increase. Also maize is relatively easy to separate from the other target species without using phenological structuring. This is due to the fact, that maize lasts longest on the fields when all other crops are already harvested. Nevertheless, applied on rapeseed, maize and winter cereals, a clear indication of the applicability of the phenological structuring approach was shown. The discrimination between winter wheat, barley, oats, rye, and different grassland types is the main target of the phenological structuring approach. The cereal species are sowed and harvested almost simultaneously and show a similar phenological development. Thus, separation of those species is much more complicated. Small differences in reflectance that could be detected by Sentinel-2’s higher spectral resolution in the red edge region can be used for phenological structuring and thus increase the accuracies of spectral classification of these crops. To achieve this, new SENTINEL-2-specific indices which will take use of the sensor’s unique spectral resolution in the red edge region will be developed and integrated.

Satellite images are expected to allow the most accurate classification results if they were acquired when the target crops show the optimal phenological phase. However, this assumption is still to be validated in an applied classification process. A higher temporal resolution of about 5 to 10 days would allow more detailed extraction of the optimal time frame and a more precise selection of the data set that the user wants to use for classification. The tested vegetation indices mostly use reflectance in the red and infrared spectral region. Less indices use RapidEye's red edge channel. Contrarily, small differences in vitality and thus reflectance result in the highest reflectance differences in the red edge region of the spectrum.

Once the workflow is fully developed, Germany-wide station-specific phenological information, diurnal climate data and a PHASE-based function for an on-demand prediction of phenological events and optimal days for differentiation of crop types will be the parts of a web-based prediction and information system (WPIS). The WPIS is planned to be implemented following the open source concept and thus to be freely available for the public. In doing so, any potential user can calculate the optimal time frame for image selection or acquisition of the specified satellite sensors for any study site and year, depending on the respective data availability.

5. EXPECTED APPLICATION SCENARIOS

The expected results of the project are of interest for several environmental remote sensing applications. Due to the relevance of the SENTINEL-2 sensor in the scientific community, numerous research projects studying forestry or husbandry could produce more accurate results when phenological structuring and optimal time frames for image acquisition are used. Another possible application is the estimation of vegetation and crop residue cover of agricultural used land. Crop residue and vegetation cover estimations are crucial for modeling soil erosion parameters of the Universal Soil Loss Equation (USLE). Crop residue has characteristic reflectance properties in the short wave infrared spectral region. This region is covered by the Sentinel-2 bands 10 to 12, which is an outstanding feature compared to other sensors like RapidEye.

6. CONCLUSIONS

The design of the new SENTINEL-2 sensor is promising for tasks that combine spectral characteristics of vegetation and crop residues with phenological development of the studied species. For classification and modeling purposes, the phenological structuring approach that takes advantages out of the outstanding spectral and temporal resolution of Sentinel-2 data will enable the detection of optimal time frames for image acquisition of satellite data. A powerful multi-sensor classification and monitoring concept will be developed that includes SENTINEL-2, RapidEye and Landsat-8 data into the phenological structuring process for numerous ecological application scenarios. A web-based prediction and information system allows the detection of the best time frame for image acquisition for user-specific purposes.

ACKNOWLEDGEMENT

The project "PhenoS - Phenological structuring of high temporal resolution Sentinel-2 data sets to improve land cover classifications" (FKZ: 50EE1262) is funded by the German Federal Ministry for Economics and Energy (BMWi) and the German Aerospace Centre (DLR). Project partners are Martin Luther University of Halle-Wittenberg, Julius Maximilians University of Würzburg and the Helmholtz Centre for Environmental Research - UFZ.
REFERENCES


