TOWARDS AN INTRA-ANNUAL VEGETATION ANALYSIS
THE CONCEPT OF A PHENOLOGICAL LIBRARY

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Commissions I, VI, VII: WG I/2, I/4, IV/2, IV/3, VII/2

KEY WORDS: phenologic library, RapidEye, Very High Temporal Resolution (VHTR)

ABSTRACT:

Information about alterations of vegetation compositions and structures within one growth period is required for different applications in ecology, nature conservation, and agriculture. Since plants change their spectral behavior during the growth period, a remote sensing-based classification is complicated, involving exhaustive field-work. Because a variety of plant communities can have a similar spectral signal for a single acquired image, a multitemporal classification is often utilized for class separations. However, this approach multiplies the required field work. But even if a multitemporal classification was successfully applied, the approach will be only limited transferable due to shifting acquisition dates and vegetation compositions.
For monotemporal detecting of different materials, a spectral library is frequently utilized. In order to distinguish a variety of habitats at all stages of a growth period an available spectral library is not sufficient, due to the changing reflectance. Therefore, the concept of a phenologic library is introduced. A phenological library could be used to optimize the image acquisition of earth observation data in terms of detecting the dates of highest separability of classes. With repeated intra-annual spectral measurements of different vegetation types, this method can combine the transferability of spectral library approaches with the higher class differentiation of a multitemporal classification. Additionally, a phenological library is assumed to be transferable to other acquisition dates of other years.

1. INTRODUCTION

The detection of different vegetation classes especially in the context of biological diversity is one of the most frequently addressed topics in remote sensing studies of high spatial and spectral resolution (Ivits, 2008; Im and Jensen, 2008). However, the changes in the seasonality of plants are significant. Due to the limited repetition rate of the most earth observation satellite systems, the information about the temporal development of vegetation was not exploited as thoroughly as for very high resolution spatial and spectral systems. However, recently started satellite systems, such as RapidEye, can increase the number of possible acquired images in mid-Europe to a sufficient number for phenologic analyses.

Phenology is the study of the interrelationship between biotic growth and environment. It refers to seasonal trends in vegetative growth and decline (Campbell, 2006). Annual time-series can indicate seasonal trends in vegetation while comparison of inter-annual data can reveal annual to decadal phenological variability. For terrestrial field mapping, recurring natural phenomena, such as bud burst, flowering, fruit maturity, or leaf colouring, can be observed and combined to a phenological calendar that differentiates phenological seasons (Englert et al., 2008). Unfortunately, only specific events of the plant development are mapped with this method. Observations of the spectral behaviour of vegetation can provide more continuous information about the phenology. Moreover, spectral measurements on the ground can provide a method of verifying the accuracy of satellite-derived trends (O'Connor et al., 2008).

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2. REQUIRED DATA

2.1 Spectral Data Scheme

In order to achieve sufficient phenologic information, which can be linked to satellite images, in-situ measurements with field spectroscopy are required. The derived values of spectral reflectance have to be acquired in cloud-free conditions. Therefore, a weekly sampling of different species during the vegetation period (April to October) should be intended for field measurements, but there will be gaps due to the weather conditions.

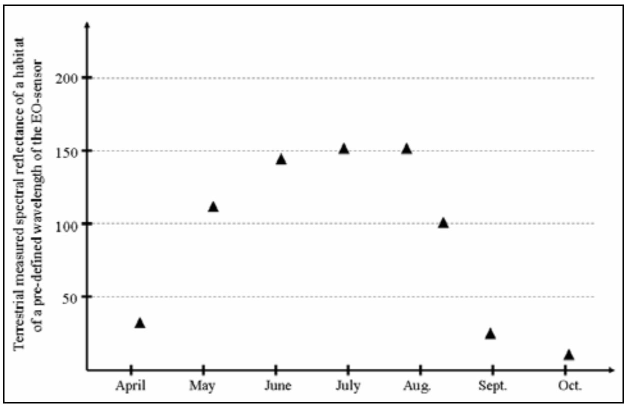

Figure 1. Schematic example of a phenologic profile

However, since the DWD (German Meteorological Service) provides data about the phenological day of the year, measurement of different vegetation periods might be combined with calibrated seasonal dates. Figure 1 shows a realistic schematic example of a phenologic profile of a pre-defined wavelength (e.g. 804 nm) for species or a habitat.

2.2 Satellite Data Scheme

Cloud cover is a major constraint on optical remote sensing, especially on applications that require a time series of images. Studies based on image evaluation and cloud cover products of MODIS and AVHRR estimate the availability of LANDSAT Images in western und mid Europe to approximately 5 to 7 per year (Armitage et al., 2007; Kontoes and Stakenborg, 1990).

For phenological remote sensing studies a repetition rate of ten days to monthly are suggested (Gobron et al., 2005). Nevertheless, especially in phases of rapid vegetation development (e.g. early spring) monthly or twice monthly images would not be of sufficient temporal resolution to detect seasonality change (O'Connor et al., 2008) Instead, a 10-day to 7-day, period would be more appropriate to characterize such accelerated phenological phases.

Recently started sensors with a high temporal resolution, such as RapidEye (repetition rate of 4.8 days at 45° latitude), could provide a nearly sufficient amount of imagery (15 to 20 images per year), while having a high geometrical resolution of 6.5 meters. Together with a spectral band in the near infrared and a red edge channel RapidEye is probably capable of acquiring the imagery required from the phenologic library.

3. CONCEPT OF A PHENOLOGICAL LIBRARY

To establish a phenologic library two vegetation classes were chosen for first tests of in-situ spectral measurements. Firstly, "dry open grasslands on calcareous sands" with goldenrod (*Solidago canadensis* / coverage: 60 %), tall oat grass (*Arrhenatherum elatius* / coverage: 10 %) and small shares of *Rubus idaeus*, *Tanacetum vulgare*, as well as *Galium album* was recorded throughout the vegetation period 2008 by the company Luftbild Umwelt Planung GmbH. Secondly, "common reed" (*Phragmites australis*) was measured in the vegetation period 2008, too. The information was acquired in the nature reserve "Döberitzer Heide" which is situated north-western of the city Berlin. The spectral reflectance was recorded with a field spectrometer (ASD Fieldspec HighResolution) on a proposed weekly basis throughout the growth period, which was limited to fewer dates depending on the weather conditions. The spectral and temporal reflectance information of the reference areas can be fed into a data base.

For the purpose of the classification of satellite scenes (which is only presented as a concept in this article) the phenologic library should be reduced to the possible wave lengths of the selected satellite sensor. For these bands, phenologic profiles will be extracted. These profiles gives a two dimensional reference of a wavelength band (e.g. from 690 to 730 nm) for a growth period. The phenologic profile for a certain vegetation type will not only consist of an optimum graph, because each type has different development stages at the same time, due to growth factors such as aspect and soil type. From the spectral measurements a phenological corridor can be defined (see Figure 2). Hence, a certain spectral upper and lower limit defines the possible occurrence of a vegetation type.

The phenologic profiles (corridors) have to be transferred to the selected sensor. Therefore, transfer functions between the profile and the reflectance value of the satellite image have to be defined and validated. These functions depend largely on satellite specifications as well as the phenologic date of the year, specified by the DWD (German Meteorological Service). The transfer functions allow to assigning a pixel to a spectral value within the phenologic corridor of a specific habitat. Therefore, an area wide classification based on a phenologic library can be performed for the specified habitats at each time of the year within the growth period, even though there will be limited success in dates that were defined as non-optimal separable.

Figure 2 gives a schematically impression of the interpolated phenological optimum and the interpolated phenological corridor for the transferred terrestrial measured spectral reflectance. Additionally, a possible classification approach of the multitemporal satellite images is visualized in Figure 2. If a pixel falls within the phenological corridor for a certain date for all spectral bands it will be assigned to the vegetation class, whereas outside the corridor is no classification derived.

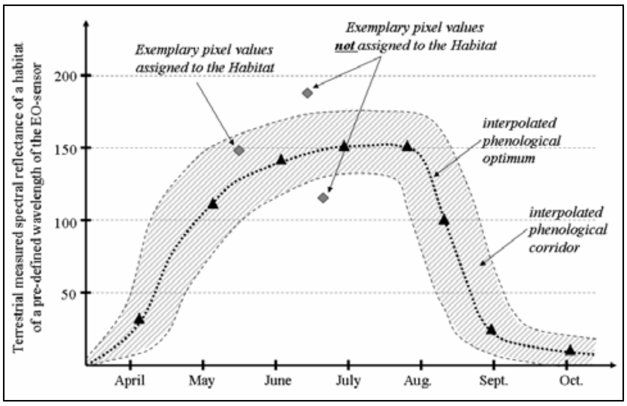

Figure 2. Schematic example of the transfer of phenologic information to a remote sensing image

4. PRELIMINARY RESULTS

The results for the repeated measurement from begin of June to the end of September of "dry open grasslands on calcareous sands" are shown in Figure 3 for four spectral bands.

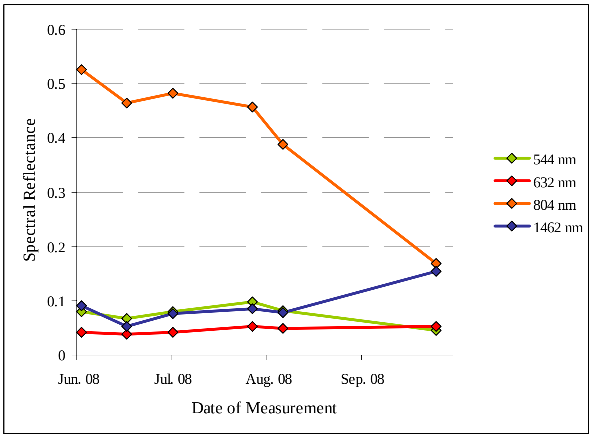

Figure 3. Time series of measurements of a mixed goldenrod (60 %) and tall oat grass (10 %) site

From the selected near infrared reflectance it is visible that the highest spectral reflectance was in the beginning of June. During June and July, the spectral response is relatively stable. However, from the beginning of August, the spectral reflectance at 804 nm is declining as well as at 544 nm. In contrast, spectral reflectance at 1462 nm shows a significant increase at the late summer.

Since the purpose of the concept of phenolocigal libraries is to compare different phenological profiles, the measured spectral reflectances of "dry open grasslands on calcareous sands" were evaluated together with measurements of "common reed". Figure 4 shows the possibility of differentiation of these two vegetation composites in a near infrared wavelength (804 nm). Taking into account, that there will be a phonological corridor (as shown in Figure 2), the differentiation of the classes in the shown spectral range will be presumably possible in June and July.

Moreover different trends in the multitemporal spectral response are visible. While the reflectance for "dry open grasslands" is relatively stable for June and July, it is increasing for "common reed". In further development of classification techniques it might be interesting to utilize the different trends of the graphs, even if the phenological information are both within a potential phenolocigal corridor.

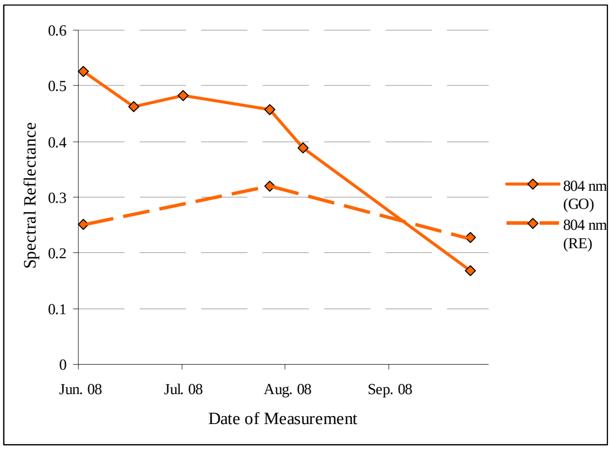

Figure 4. Time series of measurements – comparison between goldenrod (GO) and common reed (RE)

5. CONCLUSIONS

The presented article shows the potentials of the concept of a phenological library. The future access to very high temporal resolution (VHTR) satellite data will enhance classification techniques based on multitemporal knowledge. A phenological library is the temporal translation of a spectral library. The use of such a library will be similar to the use of spectral libraries for hyperspectral image classification. Therefore, an adaptation of recent techniques for hyperspectral classification (e.g. support vector machines) for a multitemporal classification might be useful.

The presented concept is a first draft for better usage of the given temporal information. Only with more standardized temporal (in this case phenological) information, the potential of long inter-annual and intra-annual time-series can be sufficiently utilized.

However, the method will be refined once the satellite time-series of RapidEye is available. There will be almost certainly problems with overlapping vegetation classes of the phenological corridor, which could be solved with a fuzzy approach of declining memberships to a class (Maselli et al., 1995), corresponding to the distance of the interpolated phenological optimum.

Acknowledgements

The authors thank the company Luftbild Umwelt Planung GmbH, which supplied the in-situ spectral field measurements. The development of the field-spec database is part of the research project SARA EnMap. A special thank goes to Annett Frick, Kristin Körth, Gregor Weyer and Anne Clasen for their support.

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