Potentials and limitations of optical and SAR satellite imagery for grassland monitoring

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ABSTRACT

This study served as a starting point to classify converted grassland areas and to determine the ecological value of grasslands. Optical satellite data and SAR data were combined to derive plant parameters and to estimate cutting frequency and cutting dates of grassland sites. Sample points of meadows that had been investigated in the course of the Bavarian grassland monitoring served as ground truth data.
The radiative transfer model SLC (Soil-Leaf-Canopy) was used to derive plant parameters such as leaf area and chlorophyll content of the vegetation from optical remote sensing data for the known sample locations.
Time series of these plant parameters were used to classify meadows that had potentially been converted into other land use classes. The classification shall assist the Bavarian State Office in adapting future monitoring strategies.
Additionally, the analysis of LAI time-series gave an indication of the number of cuts and therefore usage intensity of the investigated samples. The study was completed by observing changes in SAR backscatter values of the investigated sites and comparing the observed patterns to the leaf area time-series of the optical remote sensing data.

1. INTRODUCTION

Grasslands are amongst the ecologically most valuable terrestrial ecosystems in Europe. Due to the constant reduction of grassland areas in developed countries, caused by increased agricultural production, and the continuing loss of species richness on the remaining grassland sites, grasslands have gained increasing interest over the last years. From 2002 to 2008 the Bavarian State Office for Agriculture (LFL) conducted a large field study in which they assessed species richness and species composition of 6108 grassland plots all over Bavaria/Germany [1]. Also the expected hay yield of each plot was estimated. A fraction of the initially investigated sampling points is part of a continuing monitoring programme and revisited for further studies. The initial field study as well as the following monitoring programme are labour and time intensive. This study was conducted to assess possibilities to reduce the effort for further monitoring of grasslands by investigating possibilities to retrieve certain parameters from remote sensing data. The target of this study was to answer two main research questions: 1) Is it possible to see whether a meadow that was investigated in the first part of the study still exists as a meadow or was in the meantime converted into another land use class? 2) Is it possible to detect cutting frequency and dates of meadows by combing optical and SAR remote sensing data?

2. METHODS

2.1. Used data

Within this study we used satellite data of Landsat 7 (ETM+), Landsat 8 (OLI), Sentinel 2A and the RapidEye satellite constellation. For the detection of cutting dates of grasslands synthetic aperture radar (SAR) data of ESA’s Sentinel-1A was used as well.
For the modelling of soil moisture and interception with PROMET weather data of the German Weather Service (DWD) was combined with soil data out of the harmonized world soil database.
The already mentioned grassland data acquired during the Bavarian grassland monitoring served as ground truth data to determine the precise location of grasslands within the study area. For these sample points the species richness had been sampled during an investigation in 2002 to 2008 and the hay yield had been estimated.

2.2. Pre-processing

All optical satellite imagery was pre-processed using the fully automatized Vista’s Image Analysis chains [5]. After downloading the satellite images the data were first converted into Vista’s own data format and then radiometrically calibrated. The atmospheric conditions at the time of image acquisitions were modelled and subsequently being corrected by using the MODTRAN algorithm, resulting in atmospheric corrected images with bottom-of-atmosphere reflectance values [5]. After the calibration and correction of atmospheric effects the data of different missions and differing acquisitions date could be compared to each other and used synergistically
Following the atmospheric correction, a spectral land cover classification was applied during which all pixels of a single scene were classified into one of seven predefined land use classes (open soil, water, clouds, cloud shadow, snow, forest and vegetation). After this

classification procedure clouds and cloud shadows were masked out from the image.

2.3. Derivation of plant parameters

The first step of the grassland study was the derivation of time series of plant parameters for the grassland points that had been investigated during the field survey of the Bavarian State Office for Agriculture (LFL). In this study the leaf area (in m²/m²) and the chlorophyll content of the leaves (in µg/cm²) were derived for 1388 sample points in a study area in Southern Bavaria (Fig.1). For the derivation of the plant parameters the radiative transfer model SLC (Soil-Leaf-Canopy) [2,3] was used. SLC models the reflectance, transmission and absorption processes on the land surface while considering soil, leaf and canopy components [2, 3, 4]. Plant parameters are subsequently being derived through a model inversion process (constrained look-up table approach). In this case the leaf area in m²/m² and the Chlorophyll-a content were derived as final deliverable products. For the comparison with Sentinel-1A SAR-imagery also the plant water content was derived and being taken into account.

2.4. Classification of potentially converted grasslands

For the classification of converted areas, the time series of leaf area that had been derived from satellite imagery for the single data points of the LFL [1] were used. An investigation of the series showed that the leaf area of managed grasslands never drops to absolute zero. This can be explained by the fact that even after cutting a short layer of vegetation remains on the site. Therefore there is not a single moment in time when there is bare soil visible on the grassland patch. The leaf area of cultivated grassland remains always above 0.5.
On the contrary, arable fields show leaf area values below 0.5 during the growing season, namely at the moment when the agricultural crop has been harvested and the field is therefore not covered with any vegetation. Open ground or grassland ploughed up therefore has leaf area values close to zero.
We utilized this effect and analyzed if the leaf area of any of the investigated meadows dropped below a certain threshold - a leaf area of 0.5 - during the time series of investigation. The decrease of the leaf area below 0.5 at least once during the year 2015 resulted in the classification of the meadow as potentially converted. If not only the pixel with the originally sampled data point dropped below the defined level, but also all 25 pixels in the surrounding area (this is to say, an area of 1ha) showed the same low values the data point was classified as very likely being converted.
The classification results were validated for 144 randomly selected data points by checking the available time series (about 2 to 4 data observations, depending on the region) of high resolution aerial imagery available through Google Earth.

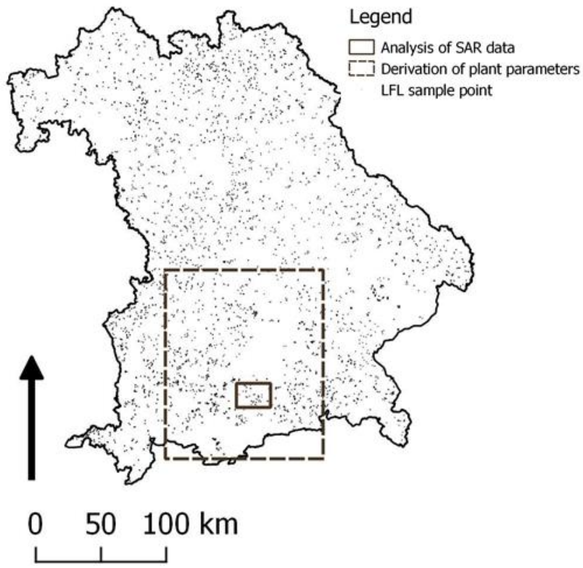

Figure 1: Areas of investigation in Southern Bavaria/Germany, each point represents one sample point of the Bavarian grassland monitoring

2.5. Detection of cutting dates from optical satellite imagery

For the detection of cutting dates the leaf area development of single meadows was investigated for the year 2015. Out of the 1388 sample points in Southern Bavaria for which plant parameters had been derived 52 meadows in the administrative district of Bad Toelz-Wolfratshausen, in the South of Munich, were investigated in more detail (Fig 1). For those areas also the mean leaf area of the entire meadow was investigated. The results were checked for disturbing influences, such as occurrence of cirrus clouds at certain dates of observations. Disturbed observations were excluded from the analysis. The remaining dates of observation were subsequently investigated for characteristic growth patterns of meadows. The leaf area time series were also compared to other agricultural crops, in this case Maize, in order to identify clearly distinguishable differences between growth patterns.

2.6. Comparison of leaf area development to SAR backscatter values

The usability of optical satellite imagery to detect cutting events of grasslands is limited to cloud free and daytime observations. It was therefore tested if SAR data of ESA's Sentinel 1A could be used to complete the time series of optical satellite data. The data were downloaded and clipped to the extent of the study area of the 52 meadows for which the leaf area time series had been analysed in more detail. Before analysing the SAR data, a terrain correction had been applied to simulate flat terrain backscatter values.

For each meadow average values of VV and VH backscatter were extracted for each date of observation. Two observations that had been acquired on a descending orbit were excluded. By limiting the dataset to observations that had been acquired on an ascending orbit no correction for the viewing angle of the sensor had to be applied. The VV and VH backscatter values were then compared to the time series of leaf area. This was first done manually, by plotting the time series in one graph. Since the dates of imagery differed between the optical data and the SAR data (due to varying overpassing times of the different satellites), the times series of leaf area values were additionally interpolated to match the dates of the SAR observations to enable the calculation of correlations.

VV and VH backscatter values were also compared to factors that might potentially influence the signal, in this case soil moisture content and interception. Both variables were modelled on an hourly basis using the hydrological surface process model PROMET [6, 7], driven by meteorological datasets of the DWD. The VV and VH backscatter values were subsequently compared to those factors.

3. RESULTS

3.1. Classification of potentially converted grasslands

Out of the 1388 investigated data points 67 were classified as potentially converted. Additionally, 28 sample points were classified as having a very high probability of conversion (Fig. 3).

Judging from the comparison with Google Earth imagery for 144 randomly selected points, the overall performance of the classification of the data points into meadows and converted areas (to arable fields or built-up area) was 91.7%.

3.2. Detection of cutting dates from optical satellite imagery

An investigation of the derived leaf area time series revealed that grasslands show a significantly different development of leaf area over a single growing season than other agricultural crops. The meadows have several growing cycles throughout the vegetation season whereas for agricultural crops there is only one growing cycle (Fig. 2). The increase and decrease of the leaf area can be explained by mowing/cutting events. The leaf area rises constantly while the meadow is growing and drops abruptly to levels of about 0.5 to 1.0 m²/m² of leaf area when the meadow is being cut. For most

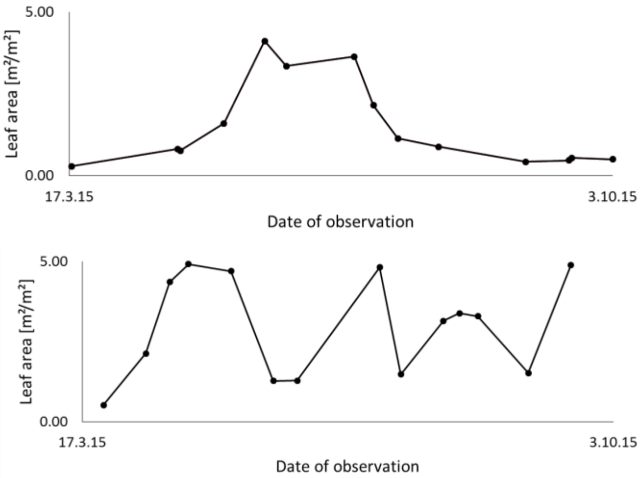

Figure 2: Leaf area development (derived of optical satellite imagery) of maize (upper graph) in comparison to a hay meadow (lower graph). The hay meadow shows several growing cycles throughout the season.

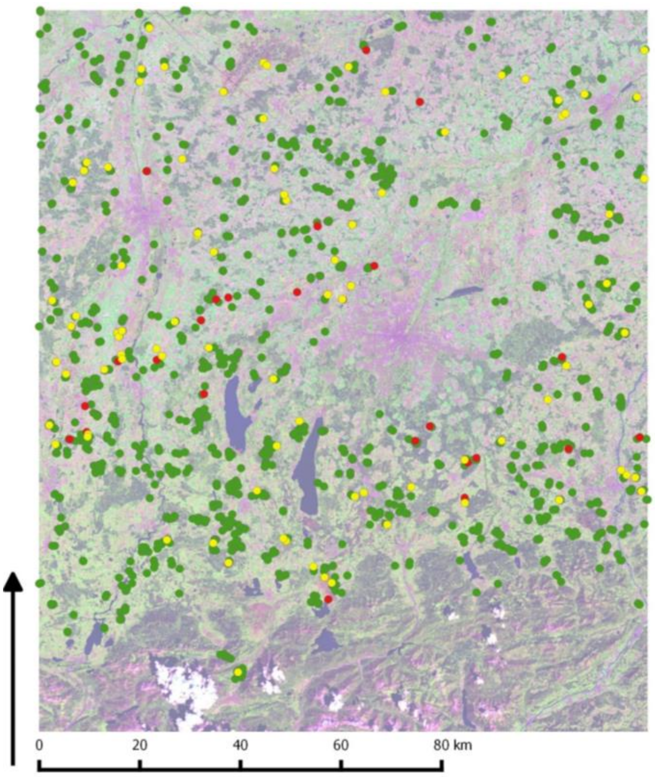

Figure 3: Classification result. Yellow dots indicate meadows that have probably (or with a very high probability = red dots) been converted into another land use class during the past 10 years since the grassland monitoring was conducted. Green points are sample points that have very likely not been converted and are therefore still existing as grasslands

investigated meadows a minimum cutting frequency could be determined out of the available images from optical sensors. However, the analysis of the leaf area time series also showed that the probability of missing single cutting events during the growing season is very high. This is due to long gaps when no cloud free image was acquired (Fig. 3).

3.3. Comparison of leaf area development to SAR backscatter values

No clear direct relationships could be observed between SAR backscatter values (VV and VH) and the leaf area development of the investigated meadows. Correlations between backscatter values and interpolated leaf area values varied around $r^2 = 0.03$. The comparison of SAR backscatter values with soil moisture and interception revealed that VH backscatter values showed a medium correlation with both factors ($r^2 = 0.54$ for interception and $r^2 = 0.55$ for soil moisture). This relationship, overlapping the leaf area dynamic, became also clearly visible during the visual comparison of the extracted time series (Fig. 5).

4. CONCLUSION

4.1. Classification of potentially converted grasslands

Within this project a methodology was developed to classify if a sample point that had been investigated during the Bavarian grassland monitoring in 2002 to 2008 is still existing as grassland in 2015. The results of this classification can be used to adapt future monitoring strategies.

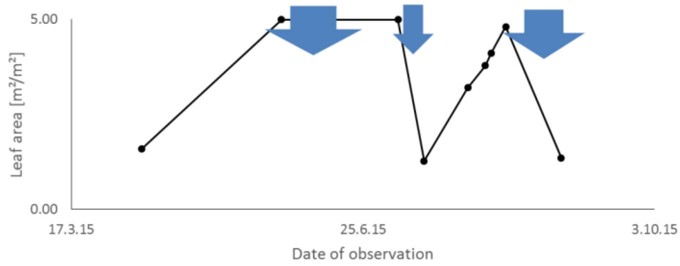

Figure 4: Leaf area development (derived from satellite imagery) for one example meadow. (Potential) cutting dates are indicated with blue arrows.

4.1. Detection of cutting dates from optical satellite imagery and SAR-data

The analysis of leaf area time series derived from optical satellite imagery showed that cutting events of meadows are clearly visible within the time series by the sudden dropping of the leaf area after a cutting event.

So far the analysis of the extracted SAR time series showed that there is an overlapping correlation between the SAR backscatter values, soil moisture and interception.

5. DISCUSSION

5.1. Classification of potentially converted grasslands

During this analysis it was not distinguished if the meadow had been converted into an arable field, forest or into built-up area. Future research could focus on developing analysis criteria to determine into which land use class a meadow was converted.

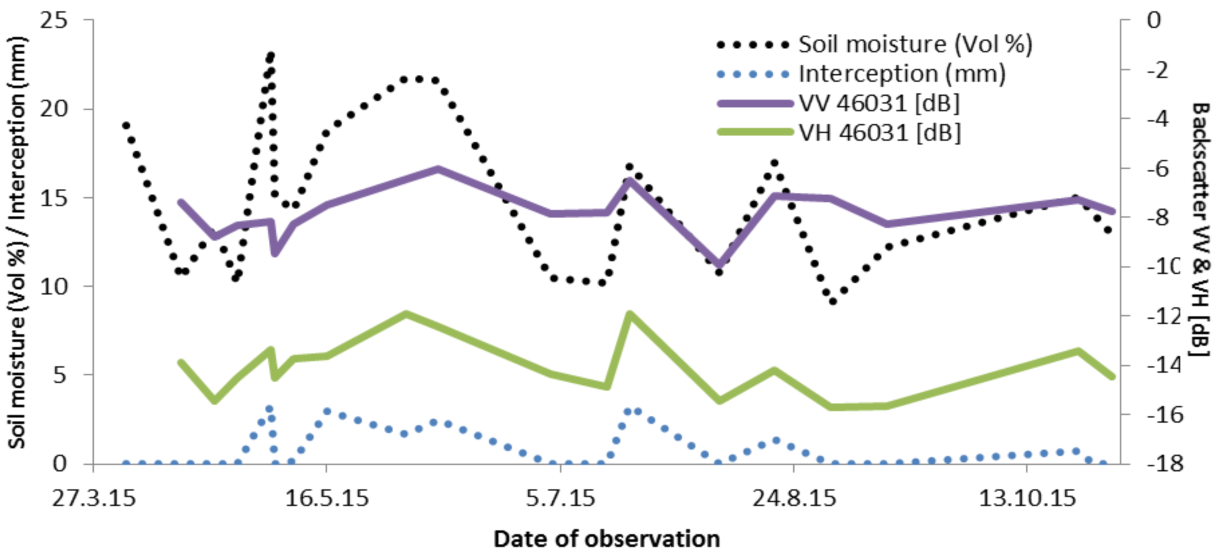

Figure 5: Time series of VV and VH backscatter values, soil moisture and interception for one meadow during 2015

5.2. Detection of cutting dates from optical satellite imagery and SAR-data

The cutting frequency of meadows in the study area can be estimated from optical satellite data, since some cutting events are clearly visible in the time series of leaf area development. Inaccuracies occur due to the lack of data at observations with cloud cover or missing coverage. The partly large gaps between satellite overpass dates make it difficult to determine the precise cutting date of a single meadow, even when all available observations are free of clouds. This hampers the development of a robust algorithm for the detection of grassland cutting dates and frequency.

The combination with Sentinel 1A SAR-data can be a solution to enhance the temporal resolution of available data, due to an increased number of observations. Within this study the need to correct for the influence of soil moisture and interception on the SAR backscatter signal became clear. Further research is therefore needed to develop a reliable methodology to extract cutting dates from the SAR-data time series. As a first step VV and VH backscatter values will be corrected for the effects of soil moisture and interception to reduce the influence of those factors on the SAR backscatter signal.

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