Coupling of phenological information and synthetically generated time-series for crop types as indicator for vegetation coverage information

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Abstract—Soil erosion on agricultural land is a phenomenon with large economical and environmental consequences for both farmers and landscape. The large-scale identification of erosion hotspots as well as the simulation of protection measures require up-to-date information about vegetation coverage which can be provided by the analysis of high resolution remote sensing data.

In this study, we present an approach which couples modeled phenological phases with \(NDVI\) profiles derived from synthetically generated Landsat time-series of high temporal resolution based on the STARFM algorithm. The approach is applied on a phenological spring phase of Winter Wheat in 2011. On the example of a study site in Central Germany, we show how data sets of up-to-date \(FVC\) degrees can be derived.

I. INTRODUCTION

Prolonged soil erosion by water causes soil loss over time, leads to crop yield depression or organic matter loss and contributes to water pollution and silting (1). In Germany, state authorities are responsible for the assessment of the parcel-specific soil erosion risk. In the German Federal State Saxony-Anhalt, a modified adaptation of the empirical \(Universal Soil Loss Equation\) (USLE) approach (2; 3) acts as reference tool for the state-wide soil erosion modeling (4; 5) where \(A\) is the mean annual soil loss in \(\text{tha}^{-1}\text{yr}^{-1}\), \(R\) the mean annual erosivity for a defined period, \(K\) is the soil erodibility indicating the soil’s susceptibility to the erosive forces, \(LS\) is the length-slope factor, \(C\) is the cover management factor and \(P\) the support practice factor. The actual assessment is realized by a threshold-based classification of \(A\) values.

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A = R \times K \times LS \times C \times P \quad (1)
\]

The USLE and its adaptations have been applied in numerous studies for decades. Originally, USLE modeling results characterize a long-termed soil risk of erosion. However, soil erosion is an event-based process which is mainly controlled by the simultaneous occurrence of heavy rain events (\(R\) factor) and low soil coverage (\(C\) factor) during the events (6). Thus, a parcel-specific localization of soil erosion as well as the simulation of water and soil protection measures require USLE factors of higher temporal resolution. The \(R\) factor calculation can be temporally updated, for instance, by the consideration of daily heavy rain events (7). Other authors have estimated the seasonal or monthly rainfall erosivity (e.g. 6; 8; 9). Temporal \(C\) factor modifications are often based on the analysis of multi-spectral remote sensing data providing information about the fractional (green) vegetation coverage (\(FVC\)) using spectral information between of the red and near-infrared visible wavelength range (10). During a vegetation cycle of crop types, their relative coverages differ as consequence to phenological development and phases. The vegetation coverage is relatively low on early phenological phases and increases until maximum vitality of the plants. Shortly after harvest, crop residue coverage is high but decreasing rapidly due to disintegration of the senescent plant components. Extensive phenological information can thus be used as indicator for time frames of high erodibility. They can be derived by the application of phenological models based on observations (11).

In this study, we present an approach which couples modeled plant phenological phases with \(NDVI\) profiles derived from synthetically generated Landsat time-series of high temporal resolution based on the STARFM algorithm (12). The approach is applied on a phenological spring phase of Winter Wheat in 2011. On the example of a study site in Central Germany, we show how data sets of up-to-date \(FVC\) degrees can be derived.

II. DATA AND METHODS

A. Test site

The investigation has been carried out on the example of an area of about 600 km\(^2\) in the German Federal State of Saxony-Anhalt near the city of Halle (Saale). The study site is characterized by intensive agriculture. Dominant crop types are
Figure 1: Saxony-Anhalt in grey and the extent of the study site in red (a), reported parcel-specific LPIS data (b) and the area percentages of the most important crops (c).

Winter Wheat, Winter Barley, Winter Rape, Maize and Sugar Beets (Fig. 1).

1) Sampling of representative digital photographs: Photographs have been taken from specific physical blocks within the test site area during the vegetation period (Fig. 2a). The selection of physical blocks was guided by the existence of complex terrain conditions and the observation of soil erosion events in the past. The samples’ locations have been chosen within classified topographic positions for which a relation to FVC degrees – especially in early phenological phases – is assumed. The photographs have been taken in a vertical and downward manner (10) and cover a defined and referenced surface subset. Similar to (13), the extraction of the photospecific FVC has been realized by a supervised classification using the maximum likelihood method implemented in ENVI software. In Figure 2a, distributions of mapped and classified FVC degrees are shown on the example of Winter Wheat sampled in spring of 2011.

B. STARFM

The Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) is an image fusion approach which has been originally developed for the blending of Landsat images (with high spatial resolution) and Moderate-resolution Imaging Spectroradiometer (MODIS) images (with high temporal resolution) to simulate the daily surface reflectance at Landsat spatial resolution and MODIS temporal frequency (12). In doing so, 49 NDVI data sets have been simulated between April and July 2011.

C. PHASE

The phenological model PHASE enables the fast prediction of the phenological stage of a crop type by relating phenological observations to climate and elevation data using the growing-degree-days approach (14). The accumulated daily temperatures until a phenological observation date beginning on the date of sowing are calculated and spatially interpolated to derive Germany-wide phenological information at 1 km spatial resolution.
III. RESULTS AND DISCUSSION

All phenological phases of Winter Wheat between April and July have been modeled. The mean day of entry of the phases has been determined for each of 1180 individual fields on which Winter Wheat was cultivated. Next, the NDVI values per field were extracted from the STARFM data sets between the starting DOY of a phenological phase to the starting DOY of the successive phase (Fig. 3). All values of one date, that were below the 25%-quantile and above the 75%-quantile, have been removed. The NDVI means increase during phase 15 (shooting), reaches its maximum during phase 18 (heading) and is decreasing during the phases 19 (milk ripening) and 21 (yellow ripening).
ripening) and 21 (yellow ripening) until harvest.

The distributions of $FVC$ observations from 19th April, 3rd May and 23rd May 2011 are plotted in figure 3b. The observations from 19th April and 3rd May 2011 are situated within the phenological phase 15 (shooting). They have been used for a phase-specific regression (here: Random Forest model (15) which has been applied on the example of a simulated data set from 8th May 2011. Figure 4 shows the scatterplots between $FVC$ and corresponding $NDVI$ values derived from samples (red points) and simulation results (black points). Accordingly, $NDVI$ values of $> 0.6$ represent a complete soil coverage by Winter Wheat.

IV. CONCLUSIONS AND OUTLOOK

At particular phenological phases like emergence or shooting, vegetation indices show a high correlation to fractional vegetation cover. We have shown how such relevant time periods can be identified by coupling phenological phases and $NDVI$ values over the vegetation period. Currently, we are extending this approach for the derivation if crop residue coverages (CRC). In addition, an OpenSource WebGIS is under development that will enable to determine phase-specific vegetation coverages for fields of user-supplied land use information.

REFERENCES


