Remote Sensing of Environment 198 (2017) 369–383

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

A new method for crop classification combining time series of radar images and crop phenology information

Damian Bargiel

Technische Universität Darmstadt, Institute of Geodesy, Germany

ARTICLE INFO

Article history:
Received 18 November 2016
Received in revised form 7 June 2017
Accepted 24 June 2017
Available online 3 July 2017

Keywords:
Agriculture
Sentinel-1
Radar
Classification
Phenology

ABSTRACT

Agricultural land cover is characterized by strong variations within relatively short time intervals. These dynamics are challenging for land cover classifications on the one hand, but deliver crucial information that can be used to improve the classifiers performance on the other hand. Since up to date mapping of crops is crucial to assess the impact of agricultural land use on the ecosystems, an accurate and complete classification of crop types is of high importance. In the presented study, a new multitemporal data based classification approach was developed that incorporates knowledge about the phenological changes on crop lands. It identifies phenological sequence patterns (PSP) of the crop types based on a dense stack of Sentinel-1 data and accurate information about the plant's phenology. The performance of the developed methodology has been tested for two different vegetation seasons using over 200 ground truth fields located in northern Germany. The results showed that a dense time series of Sentinel-1 images allowed for high classification accuracies of grasslands, maize, canola, sugar beets and potatoes (F1-score above 0.8) using PSP as well as standard (Random Forest and Maximum Likelihood) classification method. The PSP approach clearly outperformed standard methods for cereal crops, especially for spring barley where the F1-score varied between zero and 0.43 for standard approaches, while PSP achieved values as high as 0.74 and 0.79 for both vegetation seasons. The PSP based approach also outperformed for oat, winter barley and rye. Furthermore, the PSP classification is more resilient to differences in farming management and conditions of growth since it takes information about each crop types' growing stage and its growing period into consideration. The results also indicate, that the PSP approach was more sensitive to subtle changes such as the proportion of weeds within a field.

1. Introduction

1.1. Motivation

The ongoing worldwide population growth is constantly increasing the demand of foods (FAO, 2007). This consequently results in the intensification of agricultural productions. The increased food production threatens those services provided by the ecosystems, also referred to as ecosystem services, that go beyond the production of food (Foley et al., 2005). Such an overstraining of supporting or regulating ecosystem services leads to the loss of e.g. fresh water or fertile soils or to negative changes in climate regulation (Foley et al., 2005; Poh Sze Choo et al., 2005; Tivy, 1993; Matson et al., 1997). Therefore, it is an indispensable premise to keep all services provided by the ecosystems in balance in order to avoid a collapse of the ecosystem services. For this purpose, decision makers, scientists and planners rely on detailed spatial information about the land cover in agricultural areas (Poh Sze Choo et al., 2005; Adamowicz et al., 2005; Feng et al., 2010). Since agricultural land is strongly affected by spatial and temporal dynamics within and between each vegetation season, the mapping of crops represents an especially challenging task. Thanks to regular revisiting intervals and weather independent acquisition capabilities, satellite-based imaging radar is well suited to capture the agricultural land use dynamics for crop mapping. This is shown by a large number of studies using a stack of radar images for multi-temporal classification approaches (McNairn et al., 2002; McNairn et al., 2009b; Bargiel and Herrmann, 2011; Bargiel, 2013; Sonobe et al., 2014; Skriver et al., 2011; Skriver, 2012; Larrañaga and Álvarez Mozos, 2016; Mascolo et al., 2016; Larrañaga and Álvarez Mozos, 2016). Sentinel-1 is a modern C-band imaging radar two satellite constellation, which was launched in 2014 and 2016 for earth observation. It is representing the first sensor designed for the Copernicus Project initiated by the European Union. It provides free data access and unprecedented high temporal resolution, which enables new possibilities to capture the dynamics in agricultural

E-mail address: bargiel@geod.tu-darmstadt.de.

http://dx.doi.org/10.1016/j.rse.2017.06.022
0034-4257/

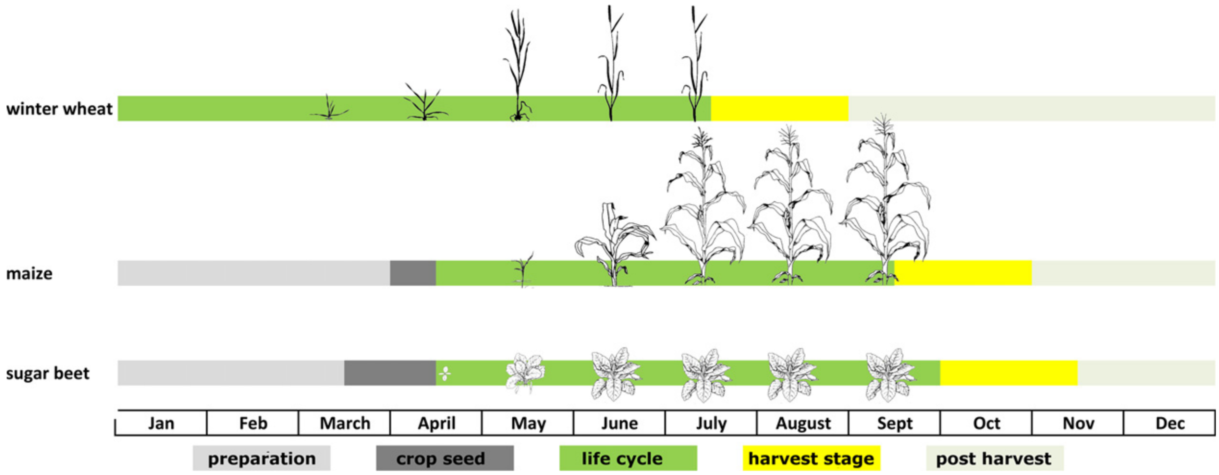

Fig. 1. Sketched dynamics of selected crops in the study area (cf. Section 2.1). Images of plants are taken from Meier and Bleiholder (2006).

areas using multi-temporal classification approaches that include information about the crops' phenology.

1.2. Introduction to the dynamics of agricultural land cover

In contrary to most land cover types, agricultural areas vary strongly within very short time intervals. Most crop types' have a vegetation period of several months. In this time, the plants phenology changes strongly many times between seeding and harvest. Furthermore, the life cycles beginnings and endings differ depending on the crop types (cf. Fig. 1). This is also true for the different stages within the plant's phenological development, for instance germination, leaf development or flowering as illustrated in Fig. 1.

Further dynamics take place during the time intervals before the seeding period (preparation) and after the harvest (post harvest). During this time, the areas are affected by deviating management of the farmers. This is not necessarily unique depending on the types of crops that are planning to be planted or have been harvested. In summary, there are two types of short-term changes: the crop-type specific changes occurring between seeding and harvest (within the life cycle) and the non-crop-type specific differences outside the life cycle depending on the farmers management. Fig. 2 demonstrates the latter one for three fields of sugar beets before seeding in the stage of preparation.

1.3. Objectives and related works

Most existing approaches for multitemporal crop classification based on radar images put a stack of images taken during the whole vegetation season into the classification process. They do not take the knowledge of the dynamics of the crops' phenology (within their life cycle) or the fields' appearance (outer the life cycle) into consideration (Bargiel and Herrmann, 2011; McNairn et al., 2002; Sonobe et al., 2014; Skriver et al., 2011; Skriver, 2012; Larrañaga and Álvarez Mozos, 2016). Although these studies show remarkable results for the classification of certain crop types and prove the high potential for radar-based crop classifications, some of them face challenges to differentiate between certain crop types e.g. single cereals (Bargiel and Herrmann, 2011). Current studies have demonstrated an improvement of crop classification results using polarimetric features of multitemporal SAR-images instead of backscatter intensity values only (Skriver et al., 2011; Skriver, 2012; Larrañaga and Álvarez Mozos, 2016; Mascolo et al., 2016).

The implementation of knowledge about the development and phenology of crops into the classification process introduces further possibilities for improvements of crop classifications. Since the crop's phenology causes temporal dependencies between the single images of the multitemporal stack, more recent studies incorporate these dependencies using statistical models like Markov Random Fields (Leite et al., 2011; Siachalou et al., 2015) or Conditional Random Fields (Kenduiywo et al., 2015, 2016). The statistical modelling of temporal dependencies improves the classification results, serving as evidence for the potential given by a classification approach that is sensitive to temporal variations caused by agricultural dynamics.

The presented study introduces a novel approach to incorporate the full knowledge of the crops' phenology using a sequence based classification approach. As (Julea et al., 2011) proved in an unsupervised classification of multitemporal images, there are certain characteristic sequences, that are detectable in an image stack of agricultural areas. They called these sequences "frequent sequential patterns". The presented study transfers this approach to a supervised classification with the incorporation of phenological knowledge to classify crops based on phenological sequential patterns (PSP). This is a new approach that ensures a full implementation of knowledge about the crops' phenology into the classification approach to improve classification results.

2. Methodology

2.1. Study area and ground truthing

The area of interest for the presented study is situated in northern Germany (Fig. 3). It has an extent of 39 kilometres (km) in east-west expansion and 61 km in north-south expansion. It surrounds the city of Hanover, which is in the centre of the scene. The area is flat and dominated by agricultural land cover. The average annual precipitation is 656 mm and the average annual temperature is 8.9 °C (Deutscher Wetterdienst, 2012).

Ground truthing was conducted during the vegetation periods of the years 2014/2015 and 2015/2016. During the 2014/2015 period, 205 fields and grasslands were visited in eight sites distributed throughout the whole study area (several plots per site). The same areas plus several additional fields were surveyed in the period of 2015/2016, resulting in a total number of 257 areas (Fig. 4). For each field the crop type was recorded and its phenology was described according to the BBCH-scale developed by Meier and Bleiholder (2006) . For meadows the mowing status was recorded by defining whether the parcels have been mown or not. This step included an assessment of the mowing time according to the current growth