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Earth observation method for an operational assessment of crop phenology metric "start of the season"

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Abstract. Vegetation phenology is one of the key indicators for assessing inter annual changes of ecosystems while crop phenology has crucial and practical importance for precise timing of farming practices of today's smart agriculture. The aim of this study is to develop and implement a procedure for filtering and processing daily satellite signals from Moderate Resolution Imaging Spectroradiometer (MODIS) satellites for the operational derivation of vegetation indices and land surface phenology (LSP) metrics. Second, this work investigates and selects precisely adjusted parameters for the calculation of a specific LSP metric – the SOS (start of the season). The SOS obtained from the satellite data was compared with available in situ ground measurements at 80 sites with records from 2000-2012 across the Czech Republic. The coefficients of determination, R^2, for the land surface phenology based on Earth observation and traditional ground phenology indicated differences between the two methods. However, the average R^2 at all sites for agricultural land was 0.31 for winter wheat onset of leaf sheath elongation; the R^2 exceeded 0.5 at 21 sites and was approximately 0.7 at some sites. The developed procedure proved suitable for operational monitoring of actual crop conditions and other influence factors that are important for drought monitoring.

Keywords: land surface phenology, vegetation, start of the season, MODIS, Czech Republic, drought.

1. INTRODUCTION

Phenology is the study of recurring biological life cycle stages and how these are influenced (Lieth, 1974) by seasonal and interannual variations in climate, as well as habitat factors (e.g. soil, site orientation) or agriculture practises and inputs (e.g. application of fertilizers, plant growth regulators, etc.). It is limited to vegetation in general and crops in particular within this study, with events studied in botany and agronomy. Vegetation dynamics play an important role in inter annual vegetation changes in terrestrial ecosystems and are key indicators of climate-vegetation interactions, land use/cover changes and year-to-year productivity (Zeng et al., 2020). Crop phenology has practical importance for precise timing of farming practices. Observation of vegetation conditions and stress are also used for indirect monitoring of drought (Liang et al., 2011; Trnka et al. 2020), even on a large scale (Lin et al., 2014).

The assessment of vegetation growth and condition changes and shifts in phenology are valuable signs. A range of methods for monitoring phases of plant species and their temporal development has emerged to address the relations between climate conditions and vegetation cover (Fraga et al., 2014; Xie et al., 2008). According to Cleland et al. (2007), these methods include: (1) species-level observations; (2) atmospheric monitoring of carbon dioxide concentrations as an indication of the timing of photosynthesis-driven carbon uptake; and (3) remote sensing of ecosystem production. The third approach was employed in this study. It is referred to as *land surface phenology* - LSP (Friedl et al., 2006) that differentiate Earth observation method from in-situ phenology. Remote sensing data record significant improvements regarding availability and temporal and spatial resolution; hence, the importance of using such data is growing. Known limitations are an abundance of noise that arises from various sources (such as atmospheric conditions) and agricultural land crop rotation practices for time series. Both limitations cause the persistent need for filtration of Earth observation data.

The most widely used vegetation index, derived from satellite measurements and closely related to vegetation activity, is known as the normalized difference vegetation index (NDVI) (Tucker, 1979). Zeng et al. (2020) summarise other indices used for LSP, such as physically based leaf area index (LAI). An NDVI time series may be used to estimate phenology metrics, such as the start of vegetation growth, especially on a regional and global scale (Reed at al., 1994; White et al., 2009).

The aim of this study was to develop a robust procedure for the near-real time filtering and processing of daily satellite signals that would otherwise include many missing or invalid values as a result of atmospheric conditions (mostly clouds) and to keep the procedure sufficiently sensitive to vegetation changes within agricultural landscapes. The second aim was to investigate the various settings for the proposed procedure and evaluate its impact. Last task was to identify the start of the season (SOS) with the procedure and compare the results with ground observations.

2. MATERIALS AND METHODS

2.1. Satellite data and ground observations

The NDVI was computed daily at a resolution of 250 x 250 m from red and near-infrared reflectance spectral bands of a Moderate Resolution Imaging Spectroradiometer (MODIS) time series. MODIS instruments are on-board Terra and Aqua satellites. A time series from 2000 to 2012 was used in this study. Although MODIS instruments are still operational long after their planned lifetime, the second dataset (the phenological observations see below) lasts only until 2012, when the ground observations were terminated. For the purpose of our calculations, the original 250 x 250 m resolution data were masked for land cover classes and aggregated to a 5 x 5 km grid; thus, we used only a reasonable fraction (e.g., agricultural land) of the 25 km^2 area that we assigned to a single grid cell. This in turn allowed masking of the annually changing crop composition that originates from altering crops on individual field blocks, while on the farm level, the crop mixture is usually stable. The MODIS product also offers a 16-day composite image that is often used; however, it is not possible to use for operational monitoring due to the time delay of production.

Corresponding phenological observations were taken from the PHENODATA database of the Czech Hydrometeorological Institute (CHMI). These data contain systematic phenological observations from 80 sites in the Czech Republic. The beginnings of phenophases were monitored according to the methodological instruction of the CHMI on selected individual plants. For that reason, we selected agricultural crops that are mostly grown as single-crop monocultures, which correspond to ground observation references. Two early spring phases of different cereals were analysed: the emergence of spring barley and the onset of leaf sheath elongation of winter wheat. Altogether, we identified 21 sites (the calibration set) with consistent observational data with a maximum of 2 missing values for each crop from 2000 to 2012. These sites are spread throughout the agricultural land of the Czech Republic.

2.2. Filtering method development

For the filtering of the remote sensing data, a new software utility called LINcoln (abbreviated as LIN) was developed, programmed and tested during a 2015 research study by the authors at the University of Nebraska–Lincoln. The core algorithm is described in the results (see Sec. 3.1) as its development was one of the main aims of this study. The utility enables the use of 3 parameters – the minimum threshold of the satellite data and the upper and lower coefficients of the standard deviation (see Sec. 3.1). For the comparison and testing of the LIN newly developed filtering method and to derive the SOS, alternate TIMESAT software (Eklundh and Jönsson, 2012) was used. For the TIMESAT settings, see Sec. 2.4.

2.3. LIN calibration phase

The correct setting of the adjustable parameters is crucial for the filtering method to function properly. The parameters have a considerable influence on the results, and it is particularly important to adjust the settings with respect to the region, vegetation type, land cover class and its structure, and spatial and temporal resolution. We also considered aspects of the production process and data availability after each satellite overpass due to the further use of filtered data in the monitoring system. Robust testing of the settings was performed at 21 agricultural testing locations in the Czech Republic (calibration dataset) with different conditions. Selection of the calibration sites was done due to availability of the sufficient phenology ground data for testing; thus, it covers winter wheat and spring barley observations. After visual evaluation, 14 combinations of reasonable settings were chosen. The considered values for the settings were as follows: a minimum threshold for NDVI values of 0.15, 0.2, 0.25, 0.275, 0.3, 0.325, 0.35; an upper coefficient of 0.3, 0.5, 1.0; and a lower coefficient of 1.0, 1.5, 2.0. The differences in the results of the aforementioned filtering settings are shown in Fig. 1.

2.4. TIMESAT software and the SOS

To evaluate the performance of the algorithm and the settings of the calibration phase, the time series was further processed with TIMESAT software (Jönsson and Eklundh, 2002, 2004). This software served two purposes in the study. The first was the additional smoothing of the utility output to assess the level of adaptation to the original data. Second, the software served to compute the start of the season (SOS).

Out of the available filters, the Savitzky-Golay filter (Chen at al., 2004) was applied for its ability to adapt to rapid changes in the NDVI course, which makes it favourable for the monitoring of drought events. As was done with our own algorithm, the time series at the testing sites was processed in TIMESAT with three different settings of the Savitzky-Golay filter. The first setting (in Table 1 referred to as set1) contains outputs of LIN with no significant changes generated by the TIMESAT software and was mainly utilized to calculate the SOS metric. Settings set2 and set3 exert additional smoothing on the time series, balancing the best fit for small changes and a rough NDVI course; noise values were also omitted.

For the calculation of the SOS, two approaches were adopted – absolute and relative threshold values. According to the former, the SOS is defined as the

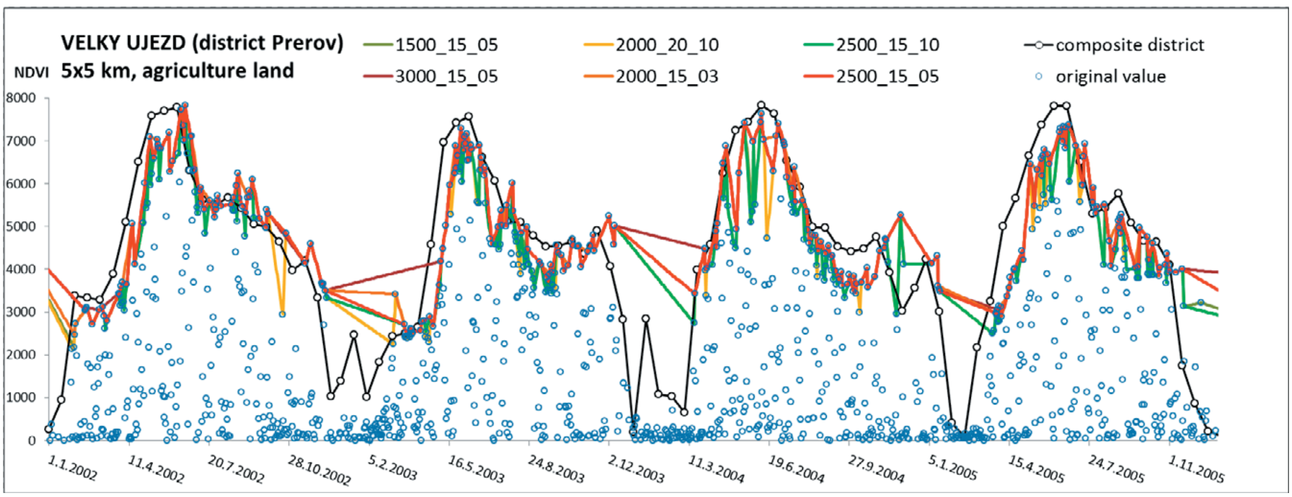

Fig. 1. Example of a MODIS NDVI time series from the Velký Újezd site (a 5 x 5 km area of agricultural land use) for the period from 2002 to 2005. Both the original NDVI satellite data (circles) and the effect of the newly developed filtering LIN method (colour lines) with different settings are shown (in order: minimum NDVI threshold_upper coefficient_lower coefficient). The 16-day composite product (as an average value target region - district Přerov) is depicted as a reference (all NDVI values are multiplied by 10000).

time of year when the threshold value of the NDVI is reached. The relative threshold is expressed as a certain ratio of the seasonal amplitude of the NDVI. The SOS was computed in TIMESAT for 4 different values of the absolute threshold (0.4, 0.45, 0.5 and 0.55) and 4 values of the relative threshold (0.25, 0.35, 0.45 and 0.5).

Different LIN software settings (14 combinations), TIMESAT settings (3 variants) and SOS derivation methods and values (8 cases) were used to compute the SOS at the testing sites. These were linearly correlated with ground observations of two phenological metrics available at the same locations - the emergence of spring barley and the onset of leaf sheath elongation of winter wheat. Matrices of the coefficients of determination (R^2), mean absolute difference and missing values averaged for the 21 testing sites were aggregated to evaluate the performance of the LIN algorithm, its settings and the SOS derivation parameters.

2.5. Correlation of satellite SOS and ground phenological observations

When optimal settings of the LIN filter and SOS derivation were chosen, the SOS for the entire Czech Republic and the whole data span was computed. To evaluate the performance of the LIN algorithm, the coefficients of determination for the linear correlation between the remotely sensed SOS results and the ground observations of phenology metrics were computed for different land cover classes (5x5 km) and for the original resolution (250x250 m) grids at 80 sites with observations. Six land cover classes were used: arable, agricultural, grass and mixed agricultural land; deciduous and conifer forest. This correlation was used to evaluate the performance of the new LSP algorithm and to compare both methods.

3. RESULTS

According to the aims of this study, the results are divided into three subchapters. The first deals with the method of filtering daily NDVI data and deriving the SOS. The procedure for operational processing was designed and implemented in a software utility called LIN. In the second subchapter, the robust testing of the settings for the procedure is evaluated and set. The third goal of this study was to calculate the SOS and evaluate its values compared to those from traditional ground phenology observations at ground sites. This is covered in the last subchapter.

3.1. Software utility - LIN filter

A three-step algorithm (called LIN) for the filtering of daily NDVI data was developed, implemented and tested. The procedure was designed with respect to further use as a simple operational method for MODIS data filtering, generating pixel-based time series and evaluating the SOS. The algorithm steps were constructed after inspection of a vast amount of spatially heterogeneous data values over time. After an erudite and creative algorithm design process, robust testing (this is part of 4.2) of the settings was performed. These are crucial for the performance of the utility for the given purpose and spatial extent.

The iterative steps of the LIN utility for filtering the time series are as follows:

1. Setting of a minimum NDVI value threshold (→ output is RAW1)
   - This setting filters mostly cloudy data and irrelevant values.
   - Values of original data (RAW) below a threshold value (several were tested) are neglected.

2. Adapting to higher values (from RAW1)
   - Assuming that the real vegetation change within 10 days is limited and considering that the highest values are more likely to represent a clear signal (real values)
   - For each day, the 1st, 2nd and 3rd highest values in a +/- 7 day window are selected. (For operational use, a 10-day backward window is applied.)
   - The weighted mean according to the time difference (actual day=100%, day±7=30%) is computed for the three highest values within the time window → RAW2.

3. Removing outliers
   - Calculating delta (the normalized difference between RAW & RAW2)
   - Computing the standard deviation of the calculated delta values in each pixel for the whole period
   - The buffer zone in each pixel is set as a multiplier of the upper and lower coefficients (LowCoef, UpCoef - several were tested) of standard deviation
   - Filtering values if delta is outside the buffer zone (-STDV*LowCoef > delta > STDV*UpCoef)
   - When delta is in the buffer zone, the RAW1 value is accepted → RAW3.

4. Daily linear interpolation of RAW3 → LIN output time series
   - Values for the filtered days are interpolated.

The final version of the software utility uses GeoTIFF files as a raster input of time series. It has the capacity to handle missing data and allows setting of different parameters - the threshold for the minimum NDVI value and the lower (LowCoef) and upper (UpCoef) buffer coefficients. An example of original and filtered NDVI outputs is depicted in Fig. 1 (note that only settings depicted with red line are used in final LIN utility).

3.2. Settings for the LIN filter and land surface phenology

The performance of the algorithm is considerably affected by the parameters that can be set (changed). Its proper tuning depends on local and regional conditions. For the calibration phase, different combinations of input parameters were examined, and the impact on the output was evaluated based on expert knowledge and testing of the credibility of the resulting time series for SOS derivation. Due to availability of consistent ground observations only two cereal crops were used for statistical testing in calibration phase, however same settings for LIN utility are expected within examined territory, weather and natural conditions on vegetated land cover.

To support a decision on the operational settings for LIN filters, the SOSs for crops in testing sites were derived with the use of different variations of settings. The outputs of SOS were correlated with ground observations. The robust correlation matrix for two crops (winter wheat and spring barley) was examined. It contained fourteen different options of the LIN utility in columns: three settings for TIMESAT and eight options for SOS derivation in 24 rows. Only a naturally reasonable time range within the year (the SOS between the 40th and 170th day of the year) was taken into account. Each cell represented an average of R^2 in 21 ground-observation sites for 13 vegetation seasons. The subsets (just the promising rows and columns) of matrices for winter wheat and spring barley are outlined in Table 1.

Investigation of the LIN utility outputs (see example Fig. 2) has shown that filtering is favourable for noisy daily MODIS NDVI data, except for the winter season, when data of the limited vegetation are often unreliable. In general, additional filtering with TIMESAT (set3) yielded slightly higher coefficients of determination for the SOS than when the LIN utility was used (set1). This is at a cost of higher generalization of the NDVI time series. The coefficients of determination for spring barley are generally lower than those for winter wheat. This could be caused by a problematic signal (many missing days due to the minimum threshold value). Additionally, a highly variable sowing date and the onset of suitable growing conditions caused by field accessibility (i.e., soil moisture) lead to inferior results compared to those of wheat. Satisfactory results were achieved for winter wheat, which was sowed during September or October of the previous year before the winter and began to grow according to the actual weather conditions; hence, the results were not influenced by the sowing date.

Table 1. R2 values for the SOS (derived from satellite data) and ground observations; the values are averages of 21 field stations and 13 vegetation seasons. The different settings of the LIN filter are in columns, and the SOS derivation with TIMESAT software are in rows (subset of the whole table).

SOS derivation	Winter wheat							Spring barley						
lower env.	0.5	0.3	0.5	1.0	0.5	1.0	0.5	0.5	0.3	0.5	1.0	0.5	1.0	0.5
upper env.	1.5	1.5	1.5	1.5	1.5	2.0	1.5	1.5	1.5	1.5	1.5	1.5	2.0	1.5
min. thresh.	0.15	0.2	0.25	0.25	0.3	0.3	0.35	0.15	0.2	0.25	0.25	0.3	0.3	0.35
set1, 35%	0.21	0.25	0.32	0.26	0.33	0.29	NA	0.12	0.12	0.12	0.12	0.10	0.15	0.11
set1, 45%	0.25	0.22	0.25	0.22	0.29	0.31	NA	0.11	0.12	0.12	0.14	0.12	0.22	0.19
set1, 0.4	0.25	0.31	0.32	0.26	0.33	0.35	0.17	0.14	0.17	0.20	0.14	0.15	0.19	0.22
set1, 0.45	0.29	0.37	0.38	0.35	0.38	0.38	0.27	0.13	0.14	0.15	0.11	0.16	0.11	0.15
set1, 0.5	0.30	0.32	0.36	0.33	0.35	0.37	0.43	0.12	0.13	0.15	0.14	0.15	0.14	0.16
set3, 50%	0.25	0.22	0.29	0.25	0.32	0.28	0.22	0.12	0.11	0.11	0.19	0.12	0.21	0.13
set3, 0.4	0.26	0.33	0.32	0.31	0.31	0.38	NA	0.18	0.23	0.16	0.18	0.22	0.22	0.28
set3, 0.45	0.30	0.36	0.38	0.30	0.39	0.37	0.27	0.13	0.15	0.14	0.16	0.18	0.15	0.12
set3, 0.55	0.35	0.34	0.37	0.35	0.34	0.37	0.23	0.08	0.11	0.12	0.15	0.11	0.13	0.14

set1=Savitzky-Golay filter (envelope iterations 1, adaptation strength 1, window size 1).
set3=Savitzky-Golay filter (envelope iterations 3, adaptation strength 5, window size 10).

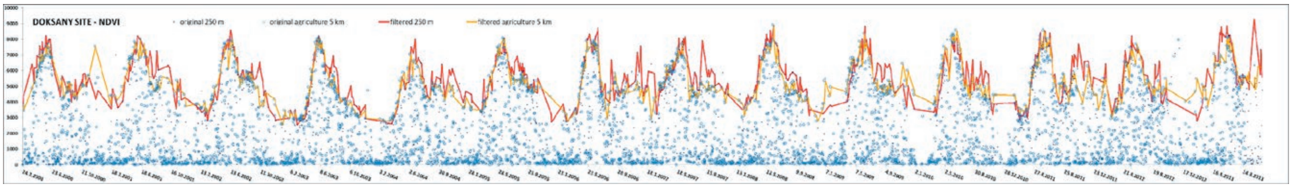

Fig. 2. Example of raw MODIS NDVI data values from the Doksany site in the original (250x250 m) and aggregated (5x5 km, only agriculture land) resolution accompanied by filtered time series (curves).

LIN itself proved to be suitable for data filtering. With respect to the correlation matrices and expert knowledge of site-specific phenology, the optimal minimum NDVI threshold was set to 0.25, the upper coefficient was set to 1.5 and the lower coefficient was set to 0.5 (see red line at Fig. 1 and 3[rd] column at Table 1). For these settings, R^2 is 0.38 on average, with values of approximately 0.7 at some sites (not shown). The start of the vegetation season (SOS) was set as the day in the year when the NDVI reached a threshold value of 0.45.

3.3. Land surface phenology - Start of the season

With the help of the LIN utility, the NDVI time series was filtered for each grid point in the Czech Republic, and the SOS was computed for the years 2000-2012. This is novel information for the Czech Republic. The SOS was compared to ground observations (two metrics were used) that were recorded during this period at field stations. Both datasets were correlated, and several conditions for the SOS were tested to understand similarities and differences between them. This included aggregation of the original data at a resolution of 250x250 for the 5x5 km grid according to the land cover classes.

See the example of the result for the Doksany site in Fig. 3. The SOS for neighbouring agricultural areas is quite consistent and in line with the observations. The coefficient of determination R^2 of the SOS with ground measurements for the corresponding location is 0.58, which shows the ability of land surface phenology to simulate traditional phenology observations in certain cases. Ideal conditions require homogeneous vegetation cover with single plants (monocultures).

The example of the Jaroměř observation site (see Fig. 4) shows differences among different land cover classes at the same 5x5 km aggregated grid. The computed results of the SOS correspond in general to the agricultural land cover class. A lower correlation is also observed for the 250x250 m resolution because there is no generalization effect of mixed signal and different crops at single pixel. Contrary, aggregation to 5x5 km grid proved to be more robust as it represents similar shares of various crops that differ at pixel level.

Tab. 2 shows the average R^2 at all sites in the Czech Republic with a minimum of 4 available pairs of ground- and satellite-based values. There are significant differences among the land cover classes and for the investigated ground observation metrics.

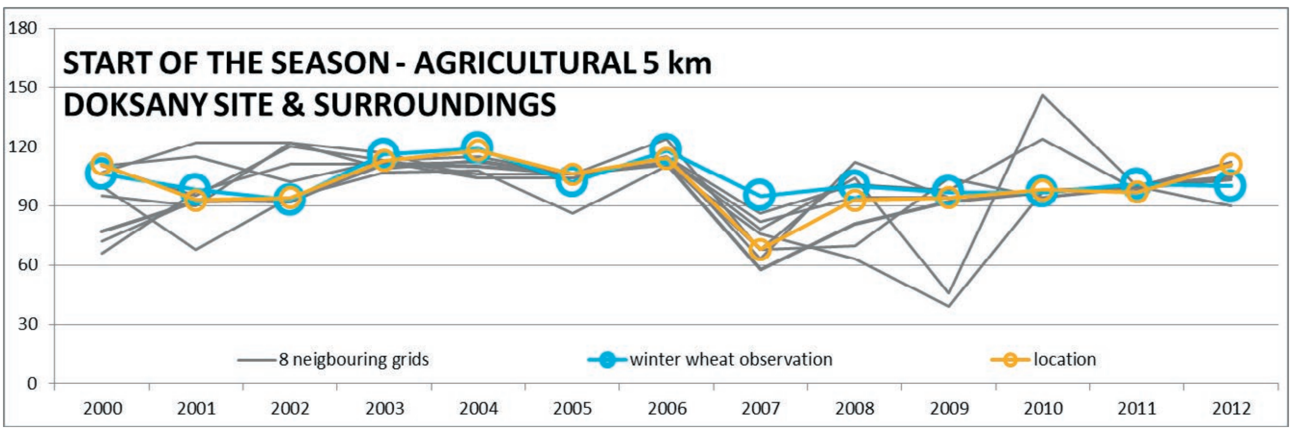

Fig. 3. Day of the year derived as the SOS for 9 neighbouring grid cells (5x5 km) around the ground observation site at Doksany (highlighted orange as "location") compared with ground observations for winter wheat (i.e., the onset of leaf sheath elongation in blue).

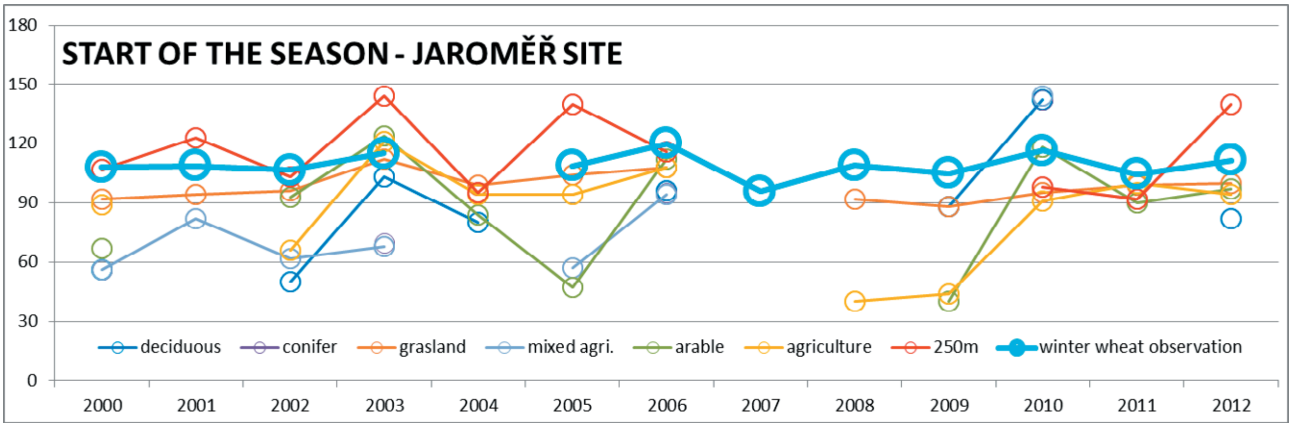

Fig. 4. SOS derived for the different land cover types (aggregated for 5x5 km) together with ground observations at the Jaroměř observation site. The red line shows the results for the SOS at the location using the original satellite data resolution (250x250 m).

Table 2. Correlation of the SOS with two phenological metrics. The table shows the average R2 at all ground stations (row count) with a minimum of 4 observations.

	winter wheat - beg. of leaf sheath elongation							spring barley - emergence						
	250 m	agric	arabl	conif	decid	grass	mixed	250 m	agric	arabl	conif	decid	grass	mixed
No. of ground stations	78	76	76	47	29	55	45	68	65	65	38	27	48	38
Average R^2	0.20	0.31	0.28	0.21	0.29	0.24	0.26	0.17	0.19	0.18	0.33	0.22	0.17	0.16

The correlation of the LSP SOS with the observations of the beginning of elongation of leaf sheath in winter wheat was shown in most tested sites across the Czech Republic (see Fig. 5). Good results are obtained for agricultural (0.31), arable (0.28) and deciduous (0.29) land cover classes; however, there are considerable differences from site to site (see map on Fig. 5). Promising results are obtained for the agricultural land cover class, where 21 out of 76 ground stations have R^2 values higher than 0.5. The R^2 values for winter wheat (0.20) and spring barley (only 0.17) at the original resolution of 250x250 m are, on average, much lower than the aggregated values for the arable and agricultural land cover classes (see Table 2). This might be due to contamination of the satellite signals by different surfaces. Inspection of possible patterns of higher R^2 values based on elevation, districts and primary agricultural production did not result in relevant findings.

The coefficients of determination of spring barley are generally lower than those of winter wheat, which could be caused by the non-crop winter signal (starting from bare land/snow values), the strong influence of the crop sowing date by farmers and a generally lower acreage within the agricultural landscape.

4. DISCUSSION

4.1. Filtering of the MODIS NDVI time series

Visual evaluation of the filtered time series together with the correlation with ground observations showed the suitability of the LIN filter to be used with daily data and produce time series with very good temporal resolution compared to composite MODIS NDVI products. However, the uncertainty of the winter signal needs to be considered in further studies.

Because the testing of the LIN utility showed the redundancy of the TIMESAT filter for additional smoothing, it would be possible to extend the use of our utility for raster data processing and deriving the SOS. To bring the LIN utility into operational use for monitoring vegetation conditions, the window size from the 2nd step of the abovementioned algorithm needs to be adapted to backward use only (as future values are not known in real-time operation). For this 10-day backward window was set, comparable results were derived, proving the hypothesis.

Using the NDVI for vegetation monitoring has known limitations during the vegetation peak when the index reaches saturation (Mutanga and Skidmore, 2004). Investigation of the enhanced vegetation index (EVI) in

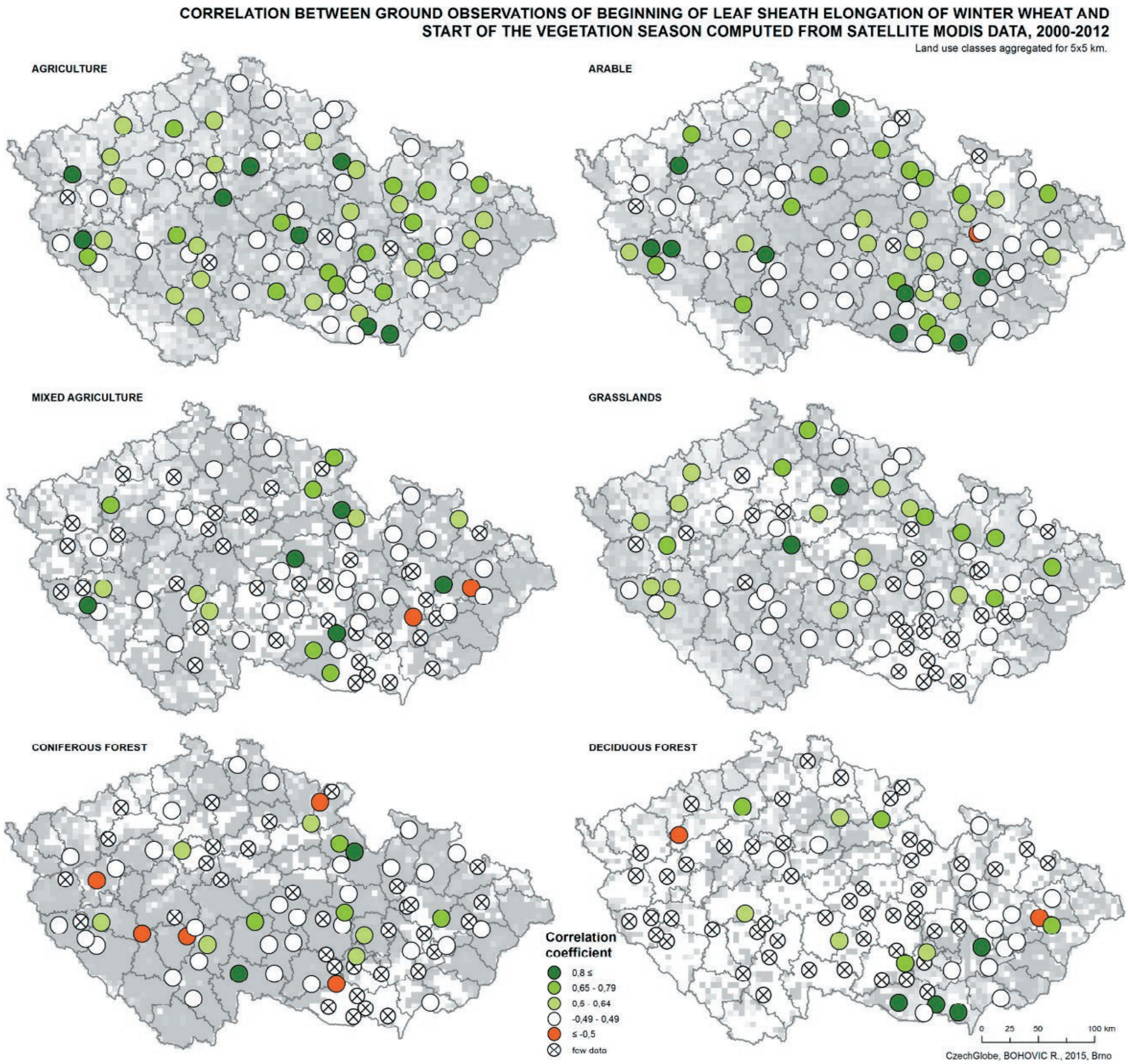

Fig. 5. Map of the correlation between ground observations of the beginning of leaf elongation of winter wheat and the SOS for different land cover classes.

the future is promising, as this is more sensitive to vegetation conditions before it reaches saturation.

The location of short drought events from satellite signals is still awaiting precise tuning.

4.2. Land surface phenology opportunity

The start of the season is the most often computed LSP metric with a wide range of uses. It is an input parameter of many scientific models related to vegetation, climate and climate change predictions. The results (see Sec. 3) of this study show that it cannot serve as an identical substitution for ground phenological measurements (Bohovic et al., 2016). These are species-related and differ significantly within the same ecotope. LSP is by its nature coupled with vegetation cover when the metric signals a certain phase (such as the start of the season) of the whole ecosystem. However, it offers a robust measure that can be obtained for large regions.

It is independent of ground infrastructure and is easily comparable across different regions with no observer-related constraints. LSP can serve as a valuable complement to ground measurements. When designed with the respect to its specifics, LSP can to some extend serve as an alternative to ground observations mainly at ecosystem level. This might be of much interest in the case of the Czech Republic, where a state-wide ground phenology observation network based on field stations was terminated in 2012. At the same time, study shows that species specific ground observations cannot be equally altered from earth observation. Necessity for calibration and evaluation of LSP makes in-situ observation still very valuable.

The average coefficients of determination between in-situ and LSP methods in the original satellite data resolution are quite low for both spring barley (0.17) and winter wheat (0.20). When we aggregate the signal for a larger area (serving as the area average) with respect to the corresponding land cover class (agriculture for crops), an average R^2 value of 0.31 is achieved in 76 stations (see Table 2). This study shows that the overlapping period of satellite data and in situ measurements can be successfully used for calibration of the SOS acquired by both methods.

4.3. Practical potential

The results of this study support two possible uses that can be implemented. The first is the use of the LIN filter and utility for operational filtering of the MODIS NDVI data. This was successfully applied as one of the data inputs for modelling (not part of this paper) in the national drought monitoring portal for agriculture in the Czech Republic called Czech Drought Monitor (Trnka et al., 2020; www.intersucho.cz). Such information is of high value not only for farmers but also for commodity brokers, public administration and state agriculture management. The use of LIN filter in agricultural insurance and compensation after natural disasters could also be considered. However, this requires operational experience for several seasons and is also subject to administrative settings.

The second opportunity for practical exploitation is the use of the LSP to estimate the start of the season as a substitution for ground phenology observations. Such a service could be run at a comparably lower cost than a system that requires a human observer to monitor individual plants in many locations (stations). If such observations were terminated, the LSP can substitute operational use cases where these data are used to support vegetation/agricultural-related decisions. Such transition would require adaptations to acknowledge important differences in the methods (mainly the resolution factor and plant-ecosystem aspect). At the same time, at least limited ground observation is necessary for calibration and validation purposes.

The Terra satellite has already surpassed its planned lifetime and is estimated to remain fully functional until the 2022 (limited science data are expected even further). This will provide a great opportunity for several years of data overlap with Sentinel-2 satellites that have been operational since 2015 (Sentinel-2A) and 2017 (Sentinel-2B).

5. CONCLUSION

The SOS was derived for the entire focus area, and these values were compared with ground phenological observations. Correlations between the LSP metrics and traditional observations have shown that methodological differences exist that prevent the full substitution of ground observations with Earth observation metrics (LSP). However, LSP can be adjusted in specific cases, such as the regionally specific phenology of monocultures. Regardless of the need to correlate LSP with traditional phenology, it can serve as a valuable measure of life phases of vegetation growth.

The main aim of this study, to develop and implement a procedure for filtering daily satellite signals for the operational derivation of a vegetation index and land surface phenology (LSP) metrics, was successfully achieved. A software utility called LIN was developed and was operationally deployed as one of the inputs in a drought monitoring system in the Czech Republic.

Settings considered optimal for the operational monitoring of drought using the LIN utility (a minimum threshold value of 0.25) and the SOS (an absolute NDVI threshold value of 0.45) have been chosen specifically with respect to agricultural land. This is subject to specific use and is also spatially relevant and thus cannot serve as a general conclusion. Other land cover classes would also require different settings, and these need to be investigated further.

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