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TIMESAT Software for Estimating Crop Seasonality Parameter

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02 January 2024 14:36:39

Abstract. Time-series imagery data provides an opportunity to explore the seasonality parameters during the growing seasons of crops. Unfortunately, the quality of time-series data often gets disturbed by outliners and noisy pixels. One of the solutions to this problem is using the TIMESAT program to smooth the time-series data and generate seasonality parameters. Several studies used TIMESAT software to enhance their research data quality. As one of the popular methods in smoothing time-series data and generating seasonality parameters, this paper aims to present the description of the TIMESAT program, provide explanations of the TIMESAT working system, and elaborate the setting of TIMESAT parameters. TIMESAT program consists of several processing logics which provide sequence steps in data processing, making it easy to operate. However, running this program could be challenging in terms of determining the appropriate fitting algorithm and appropriate parameter settings. This paper explores the provided guideline to set TIMESAT parameters and uses one of the previous studies on TIMESAT to explain the process of determining each TIMESAT parameter. To sum up, setting TIMESAT parameters involved trial and error in the range of values provided by the guideline. Once the fitted curve looks appropriate in representing the original time-series data, we can conclude that we have chosen the right parameters.

INTRODUCTION

The ability of earth observation satellites to repetitively capture imagery of a particular location has enabled the emergence of time-series or multi-temporal imagery data, which provides some advantages, such as crop mapping. It is acknowledged that the use of remote sensing data in determining land use of agricultural areas is still very challenging [1]. Different vegetation types frequently demonstrate very similar spectral behavior. As a result, it is difficult to classify crops using one multispectral data alone [1].

However, different physiological growth (phenological) stages of each crop reflect different spectral behaviors [1], which lead to frequent changes in a crop's reflectance at different times [2]. As a result, the use of time-series data can provide an opportunity to capture these differences, and in the end, crops with similar spectral behavior can be classified easily [1]. In addition, time-series data also offer the benefits of providing near real-time information on large areas [3].

Before classifying multi-temporal imagery, an analytical approach is employed to enhance image quality. For example, [1] used the Jeffries-Matusita (JM) separability test to acquire a time-series data set with the best spectral separability, thus preventing the run of a huge number of classification classes. Sun *et al.* [2] used curve shape

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matching in mapping winter wheat and removing time-series noise using Savitzky Golay filter and Fast Fourier Transform (FFT) to smooth the raw data. Xavier *et al.* [4] employed cluster analysis which grouped the sample data. Yang *et al.* [5] used TIMESAT software to smooth enhanced vegetation index (EVI) imagery and acquire the seasonal development by employing the three processing methods available in TIMESAT software.

Several studies used TIMESAT software to enhance their research data quality. As one of the popular methods in smoothing time-series data and generating seasonality parameters, this paper aims to present the description of the TIMESAT program, provide explanations of the TIMESAT working system, and elaborate the setting of TIMESAT parameters.

TIMESAT SOFTWARE

TIMESAT is a software package that can be downloaded for free for non-commercial academic use. The software is used for smoothing time-series imagery data and estimating the growing season by extracting the seasonality parameters [6]. Eleven seasonality parameters are extracted from the time-series data, which include (a) start of the season, (b) end of the season, (c) length of the season, (d) base value, (e) middle season, (f) maximum value, (g) seasonal amplitude, (h) small integral), (h+i) large integral, left derivative, and right derivative [7] (Fig. 1). These seasonality parameters resemble the phenological parameters during the crops' growing period.

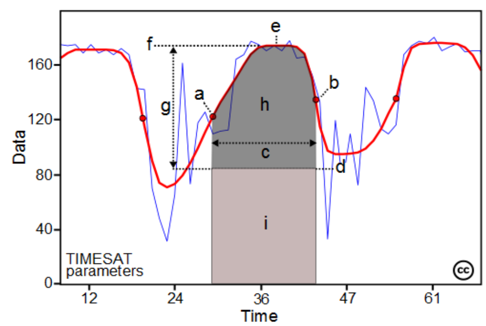

FIGURE 1. Phenological Parameters Generated from The Timesat Software: (a) Beginning of Season, (b) End of Season, (c) Length of Season, (d) Base Value, (e) Time of The Middle of The Season, (f) Maximum Value, (g) Amplitude, (h) Small Integrated Value, (h+i) Large Integrated Value. The Red Line Represents Fitting Data, and The Blue Line Represents The Real Time-series Data [7].

In smoothing the noisy time-series data, TIMESAT iteratively fits mathematical functions and extracts the seasonality parameters from each imagery pixel [9]. The process involves two steps: first, defining the number of seasons and their approximate time, and second, filtering or smoothing the data by using the available mathematical functions, i.e., Savitzky-Golay filter, asymmetric Gaussians function, and double logistic function [10]. It is recommended to use asymmetric Gaussians and double logistic functions in smoothing noisy time-series data [7]. Originally, TIMESAT was used to smooth noisy time-series of AVHRR NDVI data [9], but recently, it has been used in numerous time-series data. Fig. 2 shows the example of smoothing time-series data using the asymmetric Gaussian method in the TIMESAT program.

02 January 2024 14:36:39

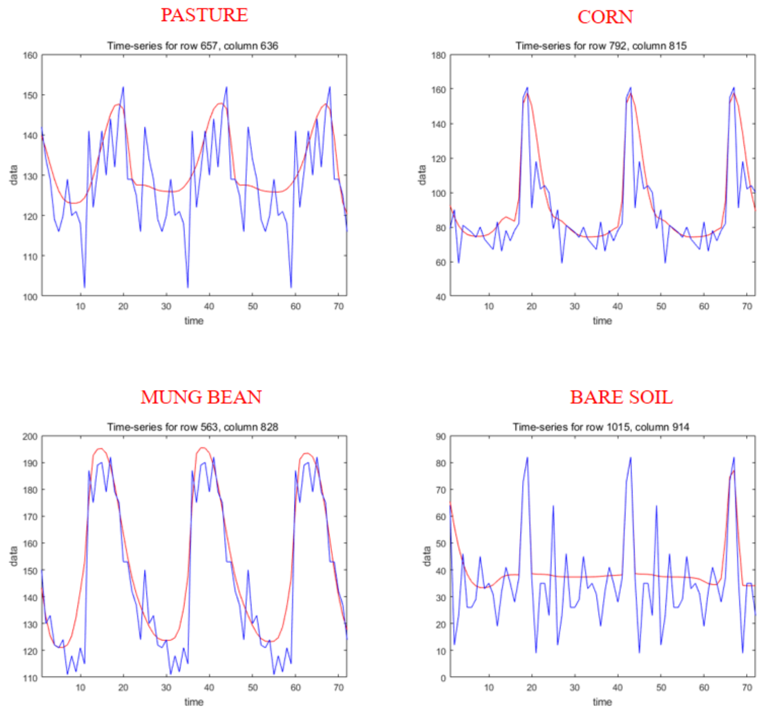

FIGURE 2. The Example of Smoothing time-series Data using the TIMESAT Program.

02 January 2024 14:36:39

TIMESAT has been applied in several studies involving several earth observation satellites. The software has successfully extracted phenological parameters from PROBA-V data in mapping crops in China [11] and Australia [8]. Li *et al.* [12] also used TIMESAT software to filter MODIS EVI data and successfully mapping crop cycles in China using the filtered data. The resulting phenological parameters generated from MODIS EVI data using TIMESAT software also successfully mapped paddy rice in China [5]. Gao *et al.* [13] used TIMESAT software to generate a crop phenology map of LANDSAT-MODIS data fusion and found a strong correlation between the remotely sensed phenological stages with the observed crop physiological growth stages. In addition, Bendini *et al.* [14] concluded that phenological parameters derived from LANDSAT 8 EVI using TIMESAT has the potential for agricultural land use map.

However, [15] suggested the careful use of phenological data retrieved from the TIMESAT program in discriminating rainfed agriculture with grassland in semi-humid tropical regions it may incorrectly classify the classes. In addition, crop calendars of each crop influenced the classification accuracy of crop mapping, although TIMESAT software was employed in filtering the time-series data [16]. It has been discovered that crops with near similar crop calendars had lower classification accuracy than crops with different crop calendars [16].

TIMESAT PROCESSING LOGIC

TIMESAT works by fitting time-series data to the upper envelope of the vegetation index data [7]; thus, it considers negatively biased noise, missing data, and quality data [6]. Two types of input data can be used, namely image data (binary file) and sequential data (ASCII file) [7].

In general TIMESAT consists of five main steps. First, input data preparation and binary data previewing is conducted in *TSM_imageview;* which loads and processes image files and correct the file format settings of images. Second, run small data sets use *TSM_GUI* to check input data quality and explore the suitable fitting algorithm and setting for running the whole data set. Third, the creation of the ASCII settings file in *TSM_settings logic*. This can be done in *general settings* (to process all pixels) or *class-specific settings* (to process a specific land cover class). Fourth, run the whole data set from previous step uses the FORTRAN program of *TSF_process*. Fifth, the generation of output images from the output files of TIMESAT, i.e. binary files of seasonality and fitted data. The output data is generated in the post-processing logic, namely TSM_fileinfo, TSM_printseasons, TSM_viewfits, TSF_fit2time, *TSF_fit2img*, and *TSF_seas2img* [7].

TIMESAT PROGRAM SETTINGS

The processing window in *TSF_process* contains parameters needed in setting TIMESAT program, such as amplitude, seasonal parameter, the start of season method, etc. [7] (Fig 3). For reference, the summary of the setting of TIMESAT parameters from previous studies can be seen in Table 1.

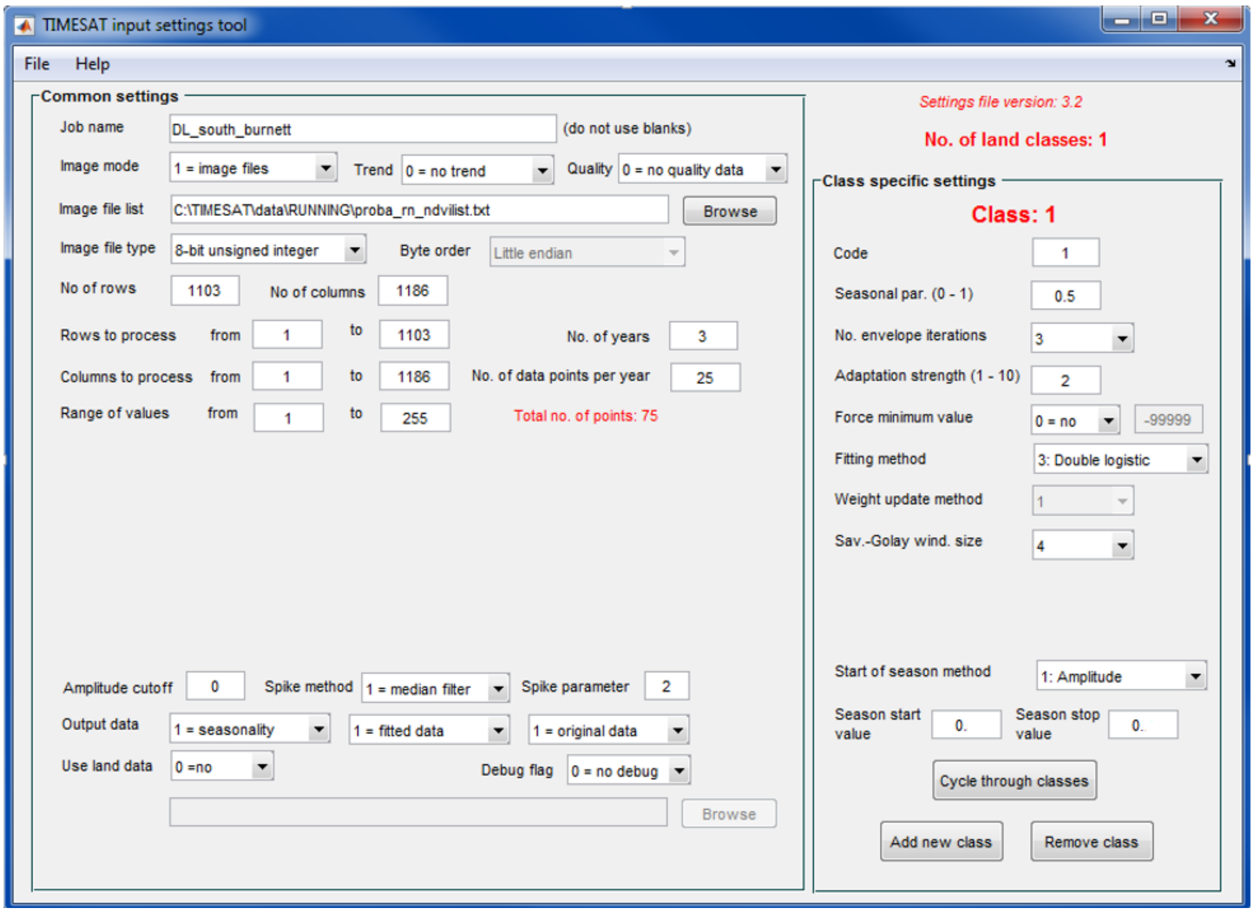

FIGURE 3. Processing window in *TSF process.*

TABLE 1. Summary of TIMESAT parameters settings from previous studies.

Fitting method & TIMESAT parameters	Haerani *et al.* [8]	Yang *et al.* [5]	Denis [16]
Fitting method	AG & DL	SG (3 window)	SG (4 window)
Amplitude value	0	-	0
Spike method	1	1	1
Spike value	2	4	2
Seasonality parameter	0.5	0.5	1
Envelope iterations	3	-	1
Adaptation strength	2	-	2
Start of season method	1	1	1
Season start	0.2	0.3	0.2
Season stop	0.2	0.1	0.2

02 January 2024 14:36:39

Note: AG = Asymmetric Gaussian; DL = Double Logistic; SG = Savitzky-Golay

TIMESAT parameters need to be set carefully by taking an experimental approach [7] in line with TIMESAT guidelines. Choosing amplitude value of 0 will include all pixels of time-series data in running TIMESAT. Spike method could be chosen as 3 (STL weights multiplied with original weights), 2 (STL weights), 1 (median filtering method) or 0 (without spike filtering). Spike value is used to determine the removing level, with a low value means more spike will be removed. The number of seasons are determine by choosing 0 (for dual seasons) or 1 (for single season) in the seasonal parameter. Envelope iterations are used to determine the number of function fits used in approaching the upper envelope of time-series data. Envelope iterations 1 means there is only one functions fits with no adaptation to the envelope, while two or three envelope iterations mean there are two or three iterations toward the upper envelope. Adaptation strength is chosen from 1 to 10, which indicates the strength of the upper envelope adaptation. Method to determine the start/end of the season could be chosen between 1 (start/end occurred when the fitted curve reaches a proportion of seasonal amplitude) and 2 (start/end occurred when fitted curve exceeding a threshold value). Season start and season stop values must be between 0 and 1 [7].

Data range needs to be chosen cautiously as it determines the number of pixels to be processed. A large data range will lead to the processing of unnecessary pixels. In contrast, very narrow data range will lead to very few pixels to be processed (incomplete data sets) [7] Data range in Haerani *et al.* [8] study is 1 – 255. The choice is based on their study data sets' minimum and maximum values. Amplitude value is the cut-off amplitude to be processed. The Time series' amplitude below the amplitude (cut-off) value will not be processed. Choosing zero for the value means that all pixels in the time-series data will be processed [7].

Spike methods have a function to detect and remove outliners. There are three options: median filter, STL replace, and STL original [7]. After trying different options, Haerani *et al.* [8] conclude that median filter is the appropriate spike method for their data sets. The next parameter to set is the seasonality parameter which will guide the number of seasons per year, with a value between 0 and 1. It will enable TIMESAT program to differentiate between noisy data and the second annual season. A seasonality value of 1 will force the program to manipulate data sets into one season, while a value smaller than 1 will manipulate data sets to fit into two seasons [7]. The default setting is 0.5, which is also appropriate in Haerani *et al.* [8] study.

Fine-tuning the fit curve is done by using the combination of parameters of envelope iterations and adaptation strength. Envelope iteration is the number of TIMESAT programs approaching the upper envelope of time-series data, with a choice of 1, 2, and 3 iterations [7]. In their study, Haerani *et al.* [8] found that although envelope iteration was set into 3, the fitting curve was not produced outside the time-series data; as a result, envelope iteration 3 was chosen. Adaptation strength indicates the strength of the upper envelope adaptation. The value options are between 1 and 10, with a normal adaptation value is 2 and 3 [7]. To ensure its fitting curve's fine-tuning, Haerani *et al.* [8] tried all combinations possibility of envelope iterations and adaptation strength. They found that the combination of envelope iteration 1 with any of adaptation strength values produced similar curve fitting. Meanwhile, the combination of envelope iteration 3 with any of the higher values of adaptation strength resulted in bad results. The fitting curve produced a good result when combining envelope iteration 3 with an adaptation strength value of 2. Thus, this combination was chosen.

There are two methods for determining the season's start, i.e., amplitude and absolute value. The former determines season start and season stop based on the proportion of fitted curves measured from the left and right minimum values. The proportion is between 0 and 1. The latter used an absolute y-value to determine season start and season stop, i.e. when the fitted curve reached a defined threshold value between 0 and 1 [7]. Haerani *et al.* [8] used the amplitude method, with a threshold value for season start and season stop was 0.2. This threshold value was chosen after trying all the possibility values and also based on literature, such as [17].

FINAL REMARKS

Time-series imagery data provides an opportunity to explore the seasonality parameters during the growing seasons. Unfortunately, the quality of time-series data often gets disturbed by outliners and noisy pixels. One of the solutions to this problem is using the TIMESAT program to smooth the time-series data and generate seasonality parameters. TIMESAT program consists of several processing logics which provide sequence steps in data processing, making it easy to operate. However, running this program could be challenging in terms of determining the appropriate

02 January 2024 14:36:39

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02 January 2024 14:36:39