Multidisciplinary Research on Geographical Information in Europe and Beyond
Proceedings of the AGILE'2012 International Conference on Geographic Information Science, Avignon, April, 24-27, 2012
ISBN: 978-90-816960-0-5
Editors: Jérôme Gensel, Didier Josselin and Danny Vandenbroucke

Comparison of two remote sensing time series analysis methods for monitoring forest decline

J. Lambert, A. Jacquin, J-P. Denux, V. Chéret
UMR 1201 DYNAFOR - Ecole d'Ingénieurs de Purpan
75, voie du TOEC, BP 57611, F-31076 Toulouse Cedex 03, France
veronique.cheret@purpan.fr

Abstract

In Europe, the 2003 summer heat wave damaged forested areas. The purpose of this study is to compare two methods to analyse time series of NDVI images for monitoring forest decline. The first method is based on phenological indicator linked to spring vegetation activity, and on the analysis of its trend. The second method (BFAST) allows extracting the trend by decomposition of NDVI time series into trend, seasonal and remainder components. The two approaches show similar results for trends estimates. The main advantage of BFAST is its capability to detect breakpoints in the linear trend which highlights the impact of the exceptional climatic conditions in 2003 on forest stands development.

Keywords: time series, NDVI, phenology, forest decline, BFAST

1 Introduction

In France and in most of Europe, exceptional climatic conditions characterized by very high temperatures associated with drought were experienced during most of the summer 2003 and, in some areas, until spring 2004. Consequently, damage on forests was observed [1]. In two provinces located in the South-West of France, a large percentage of wooded areas were impacted. The main affected species of economic interest were spruce, Douglas fir and Vancouver fir. In this context, managers' needs are the evaluation and the cartography of these forest decline phenomena as a decision tool in forestry and planning.

A first estimate and a mapping of the damaged areas were conducted using a time series of MODIS NDVI images [2]. The wide area covered by coarse spatial resolution images enables homogeneous processing of large regions. Time series of remote sensing images are studied for forest health monitoring. Daily data available for several years allow phenological monitoring. This first approach was based on a phenological indicator linked to spring vegetation activity (Spring Greenness phenological metric, SG) [3]. Inter-annual variations of this indicator were studied; unusual decrease of SG value was understood as a vegetation vitality reduction associated with forest decline.

Hereafter, this first phenological based approach is compared to a new method extracting the trend by decomposition of NDVI time series into trend, seasonal and remainder components, with BFAST (Break For Additive Seasonal and Trend) procedure [4] [5]. The first goal is to compare the trends calculated by each method. Then the second goal is to evaluate the ability of BFAST to detect the timing of abrupt phenological changes within the time series and to map them. The effect of the 2003 drought on forest stands development will be highlighted.

2 Material

In the Tarn and Aveyron provinces, in the South-West of France, coniferous forests cover more than 900 km². Detailed forest maps from French National Forest Inventory (IFN) are available at 1:25,000 scale, and can be used to map coniferous forest stands. We processed a time series of MODIS Terra (MOD13Q1) 16-day NDVI image composites, with a spatial resolution of 231 x 231m, from 2000 until 2007. The data errors were preprocessed using a Savitsky-Golay filter.

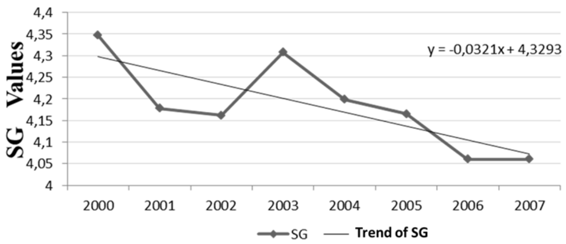
3 Method

3.1 Phenological indicator approach

This first phenological approach consists in monitoring intrannual and interannual variations of NDVI to identify coniferous areas characterized by atypical vegetal activity [2]. NDVI profiles for several years can be averaged to establish a mean phenological profile for each forest stand and to identify the successive phases of vegetation phenology: onset of greenness, maximum of greenness, senescence. To focus on spring vegetation activity, a spring greenness phenological metric (SG) was designed to express annually the level of vegetal activity during the growth period. It corresponds to the sum of NDVI calculated over a fixed period of 5 syntheses from onset of spring greenness (beginning of April) to NDVI maximum (in June) before the dry season [6].

Then, from 2000 to 2007 for each pixel, trend analysis was performed by testing the slope of the linear regression fitted line of the eight SG values [3] (Figure 1).

Figure 1: Trend of SG indicator between 2000 and 2007 extracted from a single pixel of Douglas fir.



The statistical significance of the trend is assessed testing the slope of the trend (ai) against the null slope (a0) using a Student test calculated as in Equation 1:

$$t = (a_i - a_0)/(\frac{\sigma_i}{\sqrt{n-1}}) \quad (1)$$

(ai is the slope of the trend for a given pixel, a0 is the slope of the reference trend (here equal to zero), n is the number of years, σi is the standard deviation)

Using field data, the trend of SG indicator values were grouped in four classes:

- Class 3: Very high decrease in vegetation activity, declining stands, usually cut down
- Class 2: Significant decrease in vegetation activity, most forest stands are declining
- Class 1: Limited decrease in vegetation activity, stands development remains uncertain
- Class 0: Increase or no significant decrease in vegetation activity, probably healthy stands

3.2 BFAST trend approach

The second approach used the BFAST model (Breaks For Additive Seasonal and Trend) that is based on locally weighted regression smoother temporal decomposition method [5]. The original time series is decomposed into three additive components: 1) trend (pluri-annual linear), 2) season (seasonal variations), and 3) remainder (considered as noise) (Figure 2).

Each of these terms may be related to vegetation behavior at different time scales. We chose the harmonic model to fit the seasonality because it is considered to be the most appropriate for natural vegetation [5].

Trends are calculated first using the whole time series and secondly by selecting only the spring syntheses (from April to June) for the seven years. The significance of these trends is assessed as explained in the paragraph above, and the trend values are grouped in the four classes previously defined.

3.3 Comparison of the two methods

To be compared, the slopes of the trends calculated with the two approaches are standardized dividing the values by standard error, and then coefficients of determination and significance levels are used to quantify their statistical relationship.

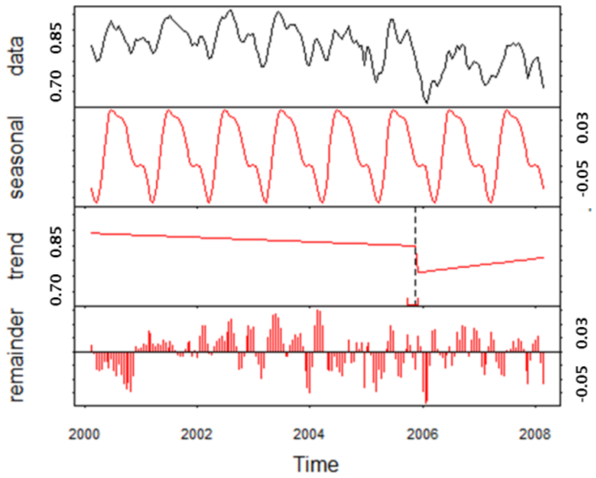
Class values are used to build error matrices in order to analyse their correspondence level.

3.4 Breakpoints detection

BFAST is then used to process a linear trend with breakpoint for each pixel. The factor (h) defining the minimum distance between detectable breaks is set to 0.15, meaning that we find at least one complete phenological cycle between two breakpoints. The breakpoints are characterized by their date, sign and magnitude (Figure 2).

For the pixels showing significant negative trend (classes 1, 2 and 3), the number of breakpoints and their characteristics are analyzed.

Figure 2: BFAST decomposition of NDVI time series over 2000-2007 for a single pixel. The date of the most important breakpoint is indicated (- - -).

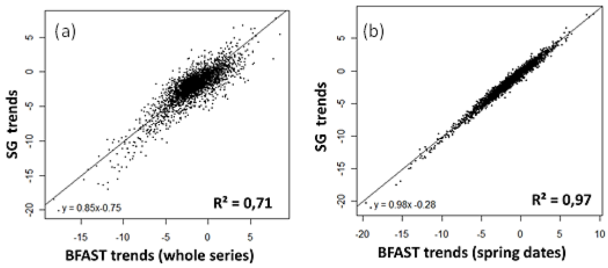


4 Results

4.1 Comparison of the trends processed with the two methods

Figure 3 presents the relationships between the slopes of the trends calculated with the different methods, taking into account all the dates or only the spring season. Coefficients of determination are always highly significant (respectively r^2=0.71 and r^2=0.97 for the whole series and for spring dates only).

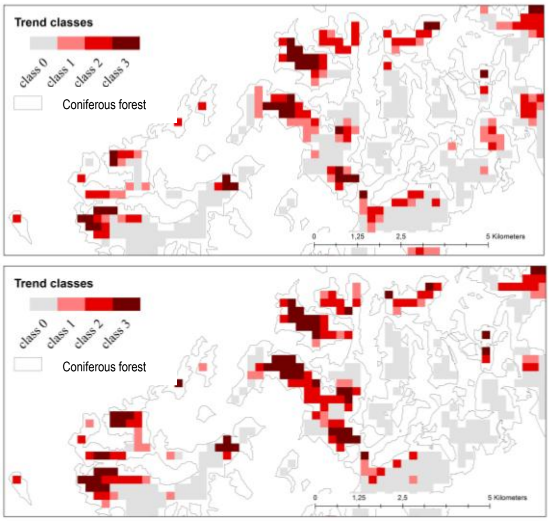
Figure 3: Scatterplots of standardized slope of the trends processed with SG (x-axis) and BFAST (y-axis) for (a) the whole series and for (b) for spring dates only.



The Figure 4 shows an extract of the trend classification map. We observe for both methods, the extend of some forest decline areas, specially class 2 and class 3.

Multidisciplinary Research on Geographical Information in Europe and Beyond
Proceedings of the AGILE'2012 International Conference on Geographic Information Science, Avignon, April, 24-27, 2012
ISBN: 978-90-816960-0-5
Editors: Jérôme Gensel, Didier Josselin and Danny Vandenbroucke

Figure 4: Map of trends (a) from the SG method and (b) from the BFAST method.



The error matrices (Table 1) show strong correspondences between the classes produced with the two methods, particularly for classes 0 and 3. However, when the whole cycle is taken into account compatibility between classes 1 and 2 is weak. This can be due to faulty threshold values or to the high variability of NDVI values during winter and summer periods.

Table 1: Error matrices between classes of (a) SG and BFAST trends for the whole series and (b) SG and BFAST trends for spring dates only.

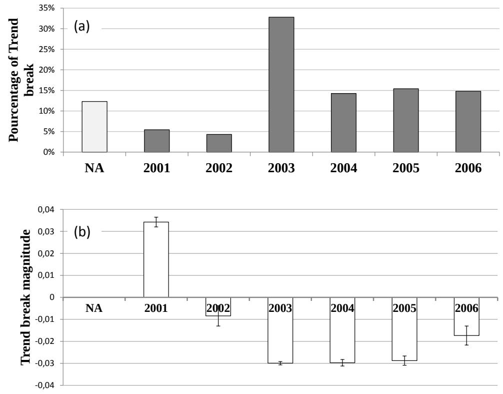
(a)	BFAST trend classes			
SG trend classes	0	1	2	3
0	**93.7%**	5.2%	1.1%	0%
1	72.1%	**21.5%**	6.4%	0%
2	32%	31.8%	**34.6%**	1.6%
3	0.6%	3.2%	36.5%	**59.6%**
(b)	BFAST trend classes (spring dates)			
SG trend classes	0	1	2	3
0	**93.1%**	6.7%	0.2%	0%
1	8.4%	**67.8%**	23.7%	0%
2	0%	7.4%	**86.1%**	6.5%
3	0%	0%	1.9%	**98.1%**

4.2 Breakpoints detection

The results show that 84.2% of the pixels with a significant negative trend have a breakpoint. The dates of these breakpoints are presented in Figure 5(a), where the percentage of breakpoints is shown for each year from 2000 to 2007. It can be observed that most of the breakpoint dates (84.7%) are in the period from 2003 to 2007 and that 2003 is the year with the highest number of breakpoints. Figure 5(b) presents the annual mean of the breakpoints magnitudes. From 2003 to 2006, the breakpoints magnitudes are clearly negative. Inversely, in 2001 the mean magnitude is positive; in 2002 it is close to zero. For these pixels, this shows a strong vegetation activity at the beginning of the seven years period, even when a negative measured trend on the period 2000-2007.

The high percentage of breakpoints detected in 2003 and a very negative magnitude establish the impact of the 2003 drought on the forest stands behavior.

Figure 5: (a) Annual percentage of pixels with detected breakpoint (b) Annual mean of breakpoint magnitude (with standard errors). NA = no detected breakpoint.



5 Discussion

When using NDVI series limited to spring, both approaches present similar results. Differences appear when the whole series is processed with BFAST. This second method is interesting because there is no need to define previously a period of interest to characterize the vegetation activity. Phenological metrics, like the start of growing season or the date of the maximum of vegetation activity, are known to change in time and space. However, it is difficult to know the impact on the measured trend of the variability of vegetation activity (and NDVI values) during summer. As a matter of fact the rate of senescence is highly influenced by annual climatic conditions, particularly when severe drought occurs.

Here, BFAST main interest is the capability to detect breakpoints used to demonstrate the impact of the exceptional climatic conditions in 2003 on forest stands development. Processing of a longer time series (2000-2011) will allow to study regrowth phenomena observed for some stands of the study area, several years after the drought of 2003. In the NDVI series, these situations would be characterized by breakpoints with positive amplitude. Furthermore, there is a study in progress, using field references and NDVI series, to identify clearcut areas in order to avoid confusion with declining stands. This last point is of first importance to apply this method on other areas. In our study area 99% of the clearcutting is due to forest decline and can be include in the class 3 (Figure 4), but this cannot be generalized to other regions.

References

[1] Allen C. D., Macalady A. K., Chenchouni H., Bachelet D., McDowell N., Vennetier M., Kitzberger T., Rigling A.,

Breshears D. D., Hogg E. H., et al. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management,* 259(4): 660-684, 2010.

[2] Chéret V., Denux J. P., Gacherieu C. and Ortisset J. P. Utilisation de séries temporelles d’images satellitales pour cartographier le dépérissement des boisements résineux du Sud Massif Central. *RenDez-Vous techniques*,31:55-62, 2011.

[3] Reed B. C. Trend analysis of time series phenology of North America derived from satellite data. *GIScience & Remote Sensing*, 43(1): 1-15, 2006.

[4] Verbesselt J., Hyndman R., Newnham G. and Culvenor D. Detecting trend and seasonal changes in satellite image time series. *Remote Sensing of Environment*, 114(1): 106-115, 2010.

[5] Verbesselt J., Hyndman R., Zeileis A. and Culvenor D. Phenological change detection while accounting for abrupt and gradual trends in satellite image time series. *Remote Sensing of Environment*, 114: 2970-2980, 2010.

[6] Chéret V. and Denux J. P. Analysis of MODIS NDVI time series to calculate indicators of mediterranean forest fire susceptibility. *GIScience & Remote Sensing*, 48: 171-192, 2011.

Multidisciplinary Research on Geographical Information in Europe and Beyond
Proceedings of the AGILE'2012 International Conference on Geographic Information Science, Avignon, April, 24-27, 2012
ISBN: 978-90-816960-0-5
Editors: Jérôme Gensel, Didier Josselin and Danny Vandenbroucke