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SENSITIVITY OF BREAKS FOR ADDITIVE SEASONAL AND TRENDS (BFAST) METHOD TO DETECT THE VEGETATION CHANGES BASED ON THE CHOICE OF VEGETATION INDICES AND LAND COVER TYPES

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ABSTRACT

Nowadays, Breaks For Additive Seasonal and Trend (BFAST) method based on time series of Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data is increasingly used to monitor the temporal dynamics of vegetation changes. Nevertheless, sensitivity of the BFAST method for detecting the vegetation cover changes based on the choice of vegetation indices and land cover types has not been widely investigated. Breaks For Additive Seasonal and Trend (BFAST) method has applied to MODIS 16-day Enhance Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) composites images (2000-2014) of three land cover types (Urban and Built-Up, Evergreen Broadleaf Forest and Savannah) within Australia. Overall, the number and time of changes detected in the three land cover types differed with both time series data because of the data quality due to the cloud cover. As conclusion, the EVI is more sensitive than NDVI for detecting the seasonal and abrupt changes for the land cover which has the dense vegetation and large canopy background such as evergreen broadleaf forest. Furthermore, NDVI is more reliable to detect the seasonal and abrupt changes that occurred in land cover types which have sparse vegetation such as urban, built-up area and savannah.

Keywords: *Additive Model, BFAST, EVI, NDVI, MODIS*

METHODOLOGY

Three flux towers in Australia representing three land cover types were selected for the study (Table 1). Australia has chosen as the study area because Australia has various land cover types. Due to the size of the continent, there is not one single seasonal calendar for the entire continent. Instead there are six climatic zones and this translates as two main seasonal patterns such as temperate zone and tropical zone. Sixteenth-day NDVI and EVI composites with 250 m resolution (MOD13Q1 collection 5) for these sites were acquired for the period covering 06th of April 2000 to 30th of September 2014 (337 images). One pixel measuring 250 m x 250 m covering the flux tower was selected per land cover type. The binary MODIS Quality Assurance flags were used to choose cloud-free, optimum quality data. However, because the algorithm used to exempt clouds employ bands with coarse resolution. There is no absolute

guarantee that the quality flags totally isolate cloud-corrupted data for the 250 m MODIS pixels. Missing values within the NDVI and EVI series were filled by using linear interpolation

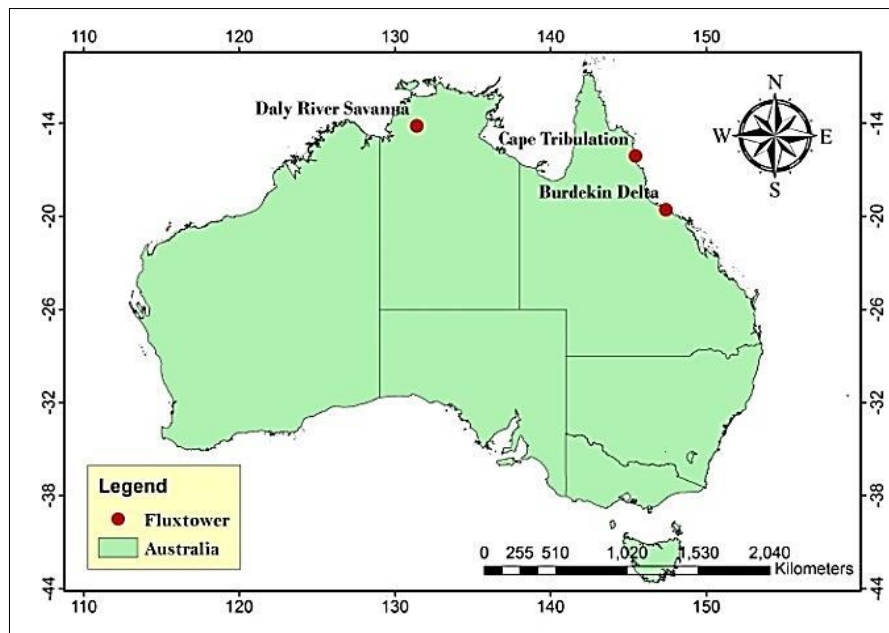


Figure 1. The map location of flux tower in Australia

A change detection algorithm, Break For Additive Trend (BFAST) was used to decompose and detect changes within the NDVI and EVI time series. BFAST decomposes the time series data by iteratively fitting a piecewise linear model to the trend component and a harmonic model to the seasonal component.^{1,12} Anomalies or significant changes in the trend or seasonal components in the data will appear as breakpoints after fitting the model to the data. The principal advantages of BFAST are that it is more generic, independent of data type and change trajectory.

Table 1. Name, location (State), latitude and longitude (lat/long, decimal degrees), land cover types of the flux tower sites in Australia

Flux tower	Lat	Lon	Land cover
Burdekin Delta	-19.57	147.40	Urban and Built-Up
Cape Tribulation	-16.10	145.45	Evergreen Broadleaf Forest
Daly River Savanna	-14.16	131.39	Savanna

The methods are available in the BFAST package for R from CRAN (<http://cran.r-project.org/package=bfast>).^{1,12} The processing data in this research divided into five parts. First, the BFAST method was applied for the EVI and NDVI dataset. Principally, the BFAST method will decompose the time series data to the seasonal, trend and noise component. Second, the phenological and abrupt changes will be analyzed for all components. The breaks

of seasonal component are referring to the number of phenology changes. Furthermore, number of the abrupt changes is displayed by trend components. Fourth, the signal-to-noise ratio ($\Delta c1$) can be used as the control variable for quality control of BFAST result. It will be influenced on the RMSE for detecting the number of phenological changes.¹² This infers that the higher seasonal amplitude (a) of the time series or lower noise level (σ) results means a more accurate detection of the number of phenological changes.¹ The signal-to-noise ratio ($\Delta c1$) can be derived by dividing the seasonal amplitude (a) from seasonal component with the noise level (σ). Finally, evaluation of the sensitivity and reliability between the NDVI and EVI time series data is the most crucial part in this study.

Evaluation of sensitivity and reliability of data were done with an investigation of the quality of data that has been used. This is related to the number of data (NA) that may be lost during the process of masking and cleaning the noise of the data in the BFAST before the interpolation data. The high number of the missing data is equal with the declining quality of interpolation results. The BFAST model was processed by using R programming. Analyze has focused on the amplitude of the seasonal component, the magnitude of the changes in the trend component, the signal-to-noise ratio, and the number of gaps of missing data (dates without data probably due to cloud cover) for every land cover types.

RESULTS AND DISCUSSION

Principally, application of BFAST to the MODIS EVI and NDVI time series for the flux tower pixels generated estimates of the time, number and type of the significant changes. No one site which detected change in seasonal, even in the EVI and NDVI data (Figure 2-4). Nonetheless, urban and built-area in Burdekin Delta site has the highest of seasonal amplitude mostly for NDVI datasets (Table 2). Moreover, the EVI and NDVI seasonal amplitude for the evergreen broadleaf forest in Cape Tribulation is below the minimum limit of 0.1 VI considered adequate for BFAST to capture any phenological change in time series.^{1,12} There are also discrepancies in the number and time of abrupt changes in the trend component from the EVI and NDVI data for every site, except in Burdekin Delta Site (Figure 2).

In Burdekin Delta site, there are no abrupt changes detected for both of EVI and NDVI data in Burdekin Delta site. Moreover, BFAST analysis on the EVI and NDVI data for the Cape Tribulation site indicated one of negative amplitude of abrupt change in trend component which occurred in 6th of March 2011 and 30th of September 2013 respectively (Figure 3). Furthermore, the Daly River Savannah site analysis indicated 7 (seven) of changes for the EVI

data (2001, 2004, 2005, 2006, 2008, 2011 and 2013) and 4 (four) for the NDVI data (2001, 2006, 2011, 2013) which can be seen in trend component (Figure 4).

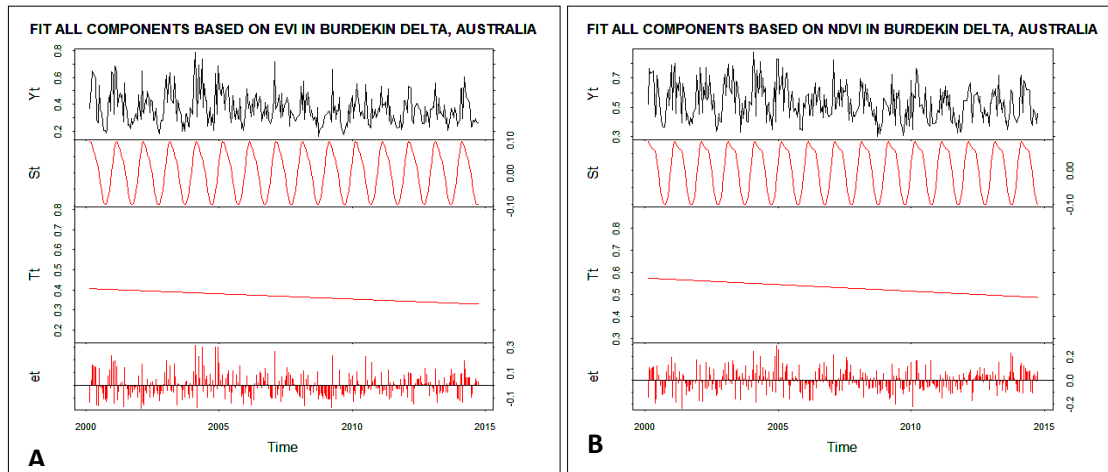


Figure 2. Detected changes (—) in seasonal and trend components (in red) of 16-day EVI (A) and NDVI (B) time series (data) extracted from a single pixel of Urban and Built-area in Burdekin Delta Site, Australia, with no abrupt change in both of the EVI and NDVI data.

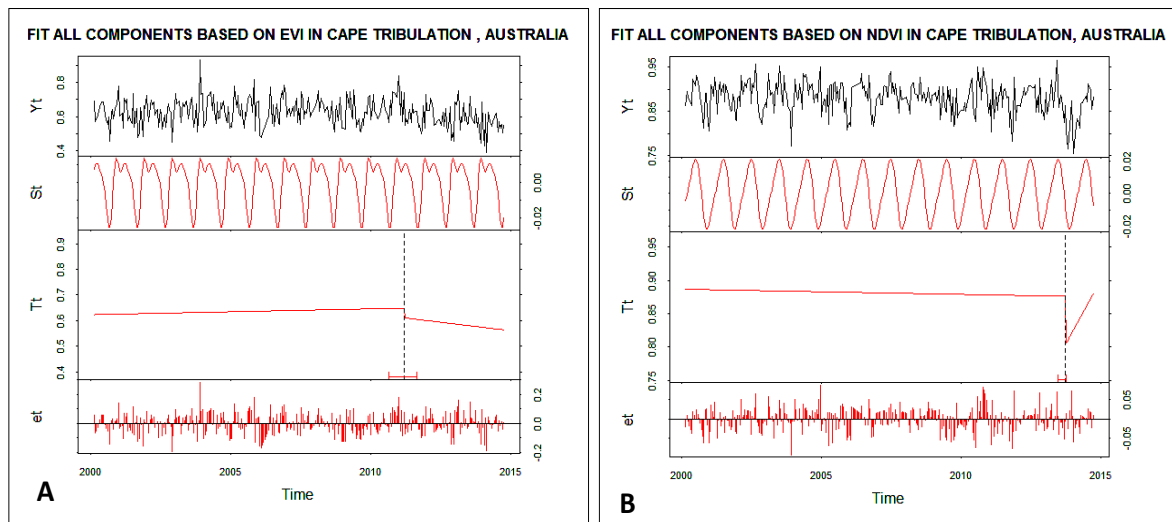


Figure 3. Detected changes (—) in the trend components (in red) of 16-day EVI (A) and NDVI (B) time series (data) extracted from a single pixel of an Evergreen Broadleaf Forest, Cape Tribulation Site, Australia, with one of abrupt change in both of the EVI and NDVI data.

Ideally, results from a BFAST calculation over different of land cover types indicate the different wavelet characteristics of each land cover type (Figure 2-4). In the seasonal component, there are no seasonal changes found in the seasonal component for three kinds of

land cover types. It is known that BFAST is more sensitive to detect the abrupt changes in the trend component than the seasonal component change.¹ Although it was difficult to interpret the differences between each type of land cover without validation the observed data, but the characteristics for every land cover types were captured well by the amplitude of seasonal component.

Overall, the seasonal amplitude of the MODIS NDVI data set was higher than that of the MODIS EVI data set for all land cover types (Table 2). When using NDVI data, the built-up area has the highest seasonal amplitude. This indicates that the NDVI data set captures more seasonal variability in phenology of the vegetation compared to the EVI data sets.^{1,14} Furthermore, urban and built-up area has a notably strong cyclic inter-annual variation with one peak in each year.¹⁴ This is not surprising, as vegetation closer to human settlements are generally disturbed (grazing, farming, fire) the most in Burdekin Delta site, hence high variation in seasonal NDVI. In this case, use of the NDVI time series, particularly by BFAST, is able to describe land cover changes.¹⁴

Mostly, the abrupt changes are triggered by suddenly disturbances such as deforestation, urbanization, floods, and fires.¹ Based on the number of abrupt changes, Burdekin Delta site did not show any abrupt changes in both of datasets (Figure 2). Since Burdekin Delta site consist of urban and built-up area, so that there is no significant abrupt changes which occurred in this location. Although there is vegetation in urban and built-up, but the vegetation grew sparse in some parts and not much disturbed by human. In Cape Tribulation site, a closer look at the signal-to-noise ratio and the missing data indicates that the EVI had higher signal-to-noise ratio and smaller number of missing data than the NDVI time series of this grassland (Table 2). It would therefore appear that the EVI data might truly reflect the condition of the Evergreen Broadleaf Forest than the NDVI data.^{5,15}

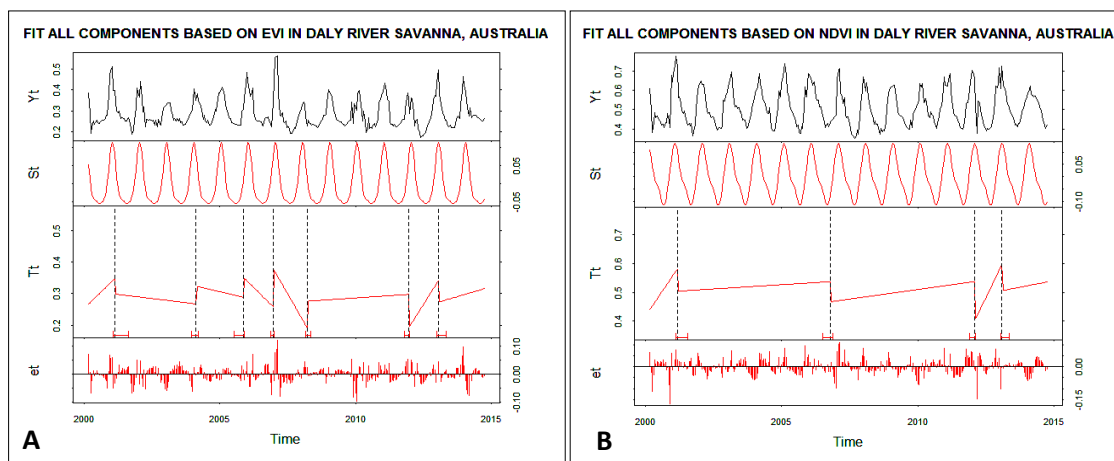


Figure 4. Detected changes (---) in the trend components (in red) of 16-day EVI (A) and NDVI (B) time series (data) extracted from a single pixel of a savannah in Daly River Savannah Site, Australia, with 7 (seven) and 4 (four) abrupt changes in the EVI and NDVI data, respectively.

For Daly River Savanna site, it consists of Savanna which has more sensitive of vegetation changes due to climatic factor and human intervention. In this case, NDVI has a lower missing data than using EVI and equal value of the signal-to-noise ratio with EVI datasets.¹ It can be postulated that NDVI is better to detect the seasonal change and abrupt change in Savanna. Based on the results, it appears that EVI time series was more effective at capturing the changes than the NDVI especially for tropical forest. MOD13Q1 NDVI showed higher seasonal amplitude, but was less accurate at capturing phenology and disturbances compared to the EVI in tropical forest. Finding from this research is relevant to the previous research which has done by Darmawan and Parwati (2012).⁵ They found that EVI is more powerful to apply in tropical forest of Palangkaraya, Indonesia which has similar type of vegetation with Evergreen Broadleaf Forest, Australia. This can be happened because EVI formulated by account the blue wavelength which can reduce the effect of aerosol and canopy background due to the dense vegetation.⁵ The EVI was less affected by variable viewing and illumination geometry in terms of amplitude, but was affected in terms of time shift in periodicities providing erroneous information on phenology.^{1,12}

Table 2. Seasonal amplitude (a), Noise level (σ), Signal-to-noise ratio ($\Delta c1 = a / \sigma$) and number of missing data (DG) of the EVI and NDVI time series data of the land cover types

Parameter	Urban and Built-up Area	Evergreen Broadleaf Forest	Savannah
a	EVI	0.10	0.03
	NDVI	0.20	0.02
σ	EVI	0.30	0.30
	NDVI	0.30	0.10
$\Delta c1$	EVI	0.33	0.10
	NDVI	1.5	0.10
DG	EVI	26	47
			55

Apart from the seasonal amplitude, it cannot be infallibly stated whether the NDVI data was better than the EVI data. Though the seasonal amplitude of NDVI data was higher than the EVI data for all land cover types, the EVI had significant lower number of gaps of missing data especially for Evergreen Broadleaf Forest (Table 2). Generally, the number of missing data for both time series and all land cover types is quite low except for Evergreen Broadleaf Forest (Table 2). The choice of a single pixel (250 m) per land cover type may have been insufficient in capturing information of the land cover because of cloud contamination of the entire pixel. The

effect of cloud cover will be minimized if averages of the vegetation indices are taken over a larger pixel (e.g 3 X 3) for the sites.¹

CONCLUSIONS

A challenge to change detection studies utilizing vegetation indices as a proxy indicator of the condition of land cover lies in the identification of the best vegetation index that suits a particular land cover type. To assess the influence of the choice of vegetation indices on the number and time of detected seasonal (or phenological) and abrupt changes, we applied BFAST, a change detection algorithm, to MODIS 16-day NDVI and EVI composites images (2000-2014) of three locations in Australia. The three land cover types (location) are: urban and built-up area, evergreen broadleaf forest, and savanna. Overall, the number and time of the detected changes in a particular land cover type differed in both NDVI and EVI time series data. Irrespective of the land cover type and the time series, the magnitude of the abrupt changes detected was small. The difference in detected of abrupt changes between the EVI and NDVI time series for every land cover types may be attributed to data quality, as the NDVI data had the higher seasonal amplitude and low missing data than the EVI especially for the land cover which has the sparse vegetation and small canopy (urban and built-up area, savanna). In opposition, EVI is better to capture the seasonal and abrupt changes for land cover which has the dense vegetation and large canopy such an Evergreen Broadleaf Forest.

Commonly, the NDVI had higher seasonal amplitude than the EVI time series for all land cover type, except for the evergreen broadleaf forest. Findings from this research confirm that BFAST is effectively applied by EVI and NDVI which depend on the land cover types. Because of the very limited time available to conduct this study and the dearth of field data to corroborate the findings from our study, we recommend further research that will incorporate field information or ground truth in assessing the influence of choice of vegetation indices in change detection in different land cover types.

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REFERENCES

- Verbesselt, J., R. Hyndman, G. Newnham, and D. Culvenor. 2010. "Detecting trend and seasonal changes in satellite image time series." *Remote Sensing of Environment* no. 114 (1):106 -115.

- Wilson, E.H. and Sader, S.A.,. 2002. "Detection of forest harvest type using multiple dates of Landsat TM imagery" *Remote Sensing of Environment* no. 80 (3):385-396.
- Tucker, Compton J., Jorge E. Pinzon, Molly E. Brown, Daniel A. Slayback, Edwin W. Pak, Robert Mahoney, Eric F. Vermote, and Nazmi El Saleous. 2005. "An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data." *International Journal of Remote Sensing* no. 26 (20):4485-4498. doi: 10.1080/01431160500168686.
- Matsushita, Bunkei, Wei Yang, Jin Chen, Yuyichi Onda, and Guoyu Qiu. 2007. "Sensitivity of the Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) to Topographic Effects: A Case Study in High-density Cypress Forest." *Sensors* no. 7 (11):2636-2651.
- Darmawan, Y., and P. Sofan. 2012. "Comparison of the vegetation indices to detect the tropical rain forest changes using Breaks For Additive Seasonal and Trend (BFAST) Model" *International Journal of Remote Sensing and Earth Science* no. 9 (1):21 – 34.
- Sonnenschein, Ruth, Tobias Kuemmerle, Thomas Udelhoven, Marion Stellmes, and Patrick Hostert. 2011. "Differences in Landsat-based trend analyses in drylands due to the choice of vegetation estimate" *Remote Sensing of Environment* no. 115 (6):1408-1420. doi: <http://dx.doi.org/10.1016/j.rse.2011.01.021>.
- Sjöström, M., J. Ardö, A. Arneth, N. Boulain, B. Cappelaere, L. Eklundh, A. de Grandcourt, W. L. Kutsch, L. Merbold, Y. Nouvellon, R. J. Scholes, P. Schubert, J. Seaquist, and E. M. Veenendaal. 2011. "Exploring the potential of MODIS EVI for modeling gross primary production across African ecosystems" *Remote Sensing of Environment* no. 115 (4):1081-1089. doi: <http://dx.doi.org/10.1016/j.rse.2010.12.013>.
- Dietz, J., D. Holscher, C. Leuscher, A. Malik, and M.A. Amir. 2007. "Forest Structure as influenced by different types of community forestry in a lower montane rainforest of central sulawesi indonesia." *Proceeding of Stability of Tropical Rainforest Margins Linking Ecological, Economic and Social Constraints of Land Use and Conservation*.
- Jiang, Zhangyan, Alfredo R. Huete, Kamel Didan, and Tomoaki Miura. 2008. "Development of a two-band enhanced vegetation index without a blue band." *Remote Sensing of Environment* no. 112 (10):3833-3845. doi: <http://dx.doi.org/10.1016/j.rse.2008.06.006>.
- Glenn, EP., A. Huete, P. Nagler, and S. Nelson. 2008. "Relationship Between Remotely-sensed Vegetation Indices, Canopy Attributes and Plant Physiological Processes: What Vegetation Indices Can and Cannot Tell Us about the Landscape." *Sensors* no. 8:2136-2160.
- J.F., Wallace, and H. Campbell. 1989. "Analysis of remotely sensed data. In *Remote Sensing of Biosphere Functioning*." edited by R.J. Hobbs and H.A. Mononey (New York: Springer Verlag):297-304.
- Verbesselt, J., R. Hyndman, A. Zeileis, and D. Culvenor. 2010. "Phenological change detection while accounting for abrupt and gradual trends in satellite image time series." *Remote Sensing of Environment* no. 114 (12):2970-2980. doi: DOI 10.1016/j.rse.2010.08.003.
- Department of the Environment, Australia Government. 2014. Types of rainfall [Online] 2014 [cited November 10th 2014]. Available from <http://www.environment.gov.au/topics/land/nrs/science-maps-and-data/australias-bioregions-ibra/australias-ecoregions>.
- Tsutsumida, Narumasa, Izuru Saizen, Masayuki Matsuoka, and Reiichiro Ishii. 2013. "Land Cover Change Detection in Ulaanbaatar Using the Breaks for Additive Seasonal and Trend Method." *Land* no. 2 (4):534-549.

Bhandaria, S., S. Phinna, and T. Gilla. 2011. "Assessing viewing and illumination geometry effects on the MODIS vegetation index (MOD13Q1) time series: implications for monitoring phenology and disturbances in forest communities in Queensland, Australia." *International Journal of Remote Sensing* no. 32 (22):513-7538.