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Characterising the land surface phenology of Africa using 500 m MODIS EVI

Tracy Adole[a,*], Jadunandan Dash[a], Peter M. Atkinson[b,a,c]

[a] Global Environmental Change and Earth Observation Research Group, Geography and Environment, University of Southampton, Southampton SO17 1BJ, UK
[b] Faculty of Science and Technology, Lancaster University, Lancaster LA1 4YR, UK
[c] School of Geography, Archaeology and Palaeoecology, Queen's University Belfast, Belfast BT7 1NN, Northern Ireland, UK

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ABSTRACT

Vegetation phenological studies at different spatial and temporal scales offer better understanding of the relationship between the global climate and the global distribution of biogeographical zones. These studies in the last few decades have focussed on characterising and understanding vegetation phenology and its drivers especially using satellite sensor data. Nevertheless, despite being home to 17% of the global forest cover, approximately 12% of the world's tropical mangroves, and a diverse range of vegetation types, Africa is one of the most poorly studied regions in the world. There has been no study characterising land surface phenology (LSP) of the major land cover types in the different geographical sub-regions in Africa, and only coarse spatial resolution datasets have been used for continental studies. Therefore, we aim to provide seasonal phenological pattern of Africa's vegetation and characterise the LSP of major land cover types in different geographical sub-regions in Africa at a medium spatial resolution of 500 m using MODIS EVI time-series data over a long temporal range of 15 years (2001–2015). The Discrete Fourier Transformation (DFT) technique was employed to smooth the time-series data and an inflection point-based method was used to extract phenological parameters such as start of season (SOS) and end of season (EOS). Homogeneous pixels from 12 years (2001–2012) MODIS land cover data (MODIS MCD12Q1) was used to describe, for the first time, the LSP of the major vegetation types in Africa. The results from this research characterise spatially and temporally the highly irregular and multi-annual variability of the vegetation phenology of Africa, and the maps and charts provide an improved representation of the LSP of Africa, which can serve as a pivot to filling other research gaps in the African continent.

1. Introduction

The study of vegetation phenology, which deals with the timing of plant growth stages and their inter-annual variation, can increase our understanding of global climate-vegetation relationships, and in particular can be used to characterise the impact of climate change on terrestrial ecosystem (Broich et al., 2014; Chmielewski & Rötzer, 2001; Cleland, Chuine, Menzel, Mooney, & Schwartz, 2007; Clinton, Yu, Fu, He, & Gong, 2014; Richardson et al., 2013). Consequently, the study of vegetation phenology has received increased attention in recent years, providing detailed characterisation of spatio-temporal changes in terrestrial biogeochemical cycles.

Ground-based observations of vegetation phenology, offer detailed and fine temporal resolution data for different vegetation types (Rodriguez-Galiano, Dash, & Atkinson, 2015b). However, these observations are limited in spatial coverage (Studer, Stöckli, Appenzeller, & Vidale, 2007). On the other hand, satellite-based remote sensing techniques, which measure *land surface phenology* (LSP) (defined "*as the seasonal pattern of variation in vegetated land surfaces observed from remote sensing*" (Friedl et al., 2006)), offer wide spatial coverage, and can monitor the inter-annual variability of vegetation dynamics in areas without ground data (Guan, Wolf, Medvigy, & Caylor, 2013; Julien & Sobrino, 2009; Rodriguez-Galiano, Dash, & Atkinson, 2015a; Zhang, Tan, & Yu, 2014). These techniques also offer the capability of quantifying vegetation response to climate variability (Broich et al., 2014; Guan, Wood, et al., 2014; Ma et al., 2008; Zhu et al., 2012). Other advantages can be seen in studies covering ecosystem processes and diversity, for example, in studies of the phenology of bird communities from space (Cole, Long, Zelazowski, Szulkin, & Sheldon, 2015), and understanding transhumance patterns (Brottem, Turner, Butt, & Singh, 2014; Butt, Turner, Singh, & Brottem, 2011).

In the northern high latitude regions such as Europe and North America, numerous studies have detailed the characteristics of vegetation phenology at both fine and coarse temporal and spatial resolutions, either through ground-based measurements or by remote sensing techniques (Chmielewski & Rötzer, 2001; Ganguly, Friedl, Tan, Zhang,

* Corresponding author. Global Environmental Change and Earth Observation Research Group, Geography and Environment, University of Southampton, UK.
E-mail addresses: T.Adole@soton.ac.uk (T. Adole), J.DASH@soton.ac.uk (J. Dash), pma@lancaster.ac.uk (P.M. Atkinson).

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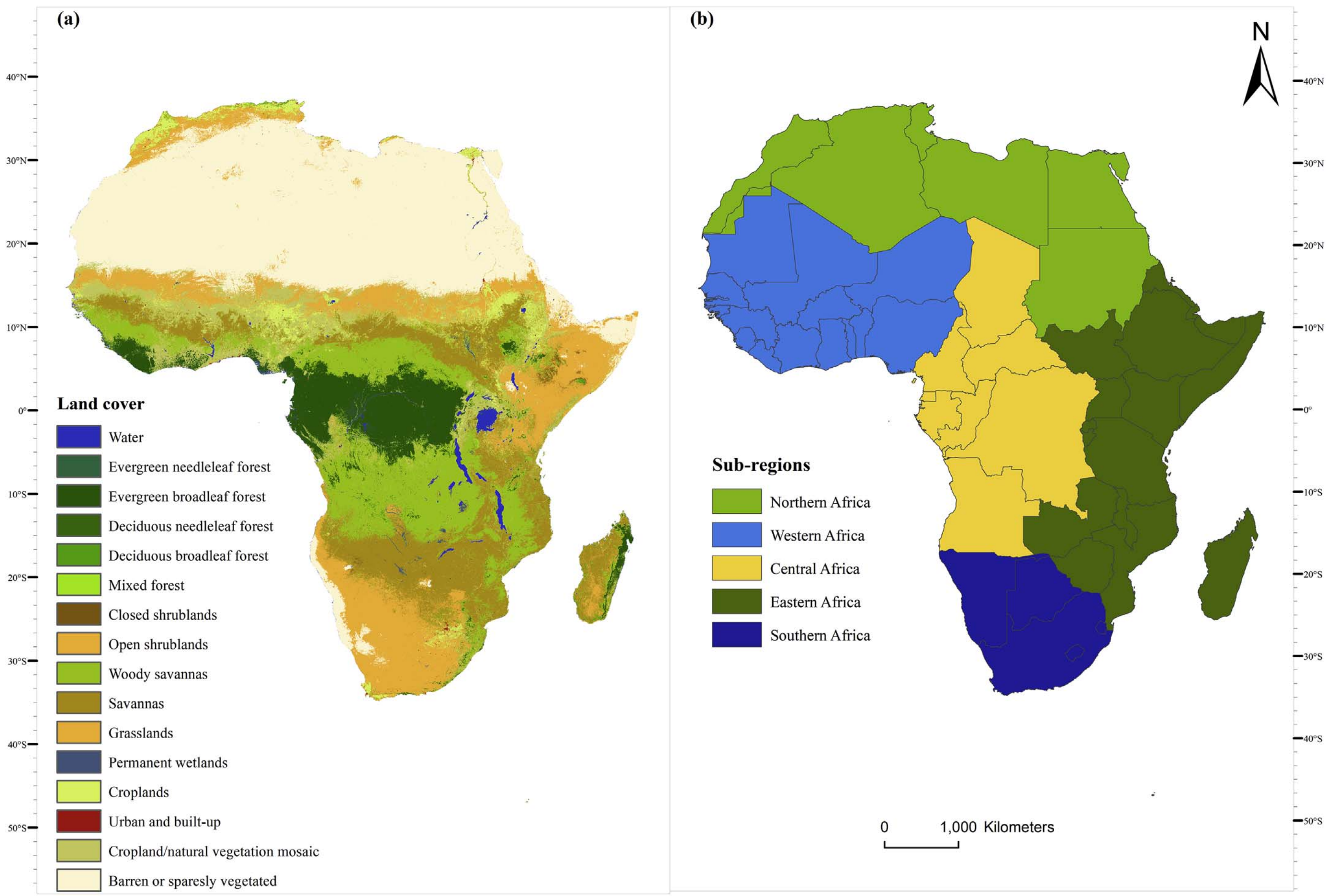

Fig. 1. (a) Land cover map of Africa derived from the 500 m MODIS land cover type product (MCD12Q1) data for 2012, downloaded from NASA's LP DAAC (https://lpdaac.usgs.gov/). (b) Map of Africa, showing the five different geographical sub-regions (Griffiths, 1971; United Nations, 2014).

& Verma, 2010; Jeganathan, Dash, & Atkinson, 2014; Menzel et al., 2006; Rodriguez-Galiano, Dash, & Atkinson, 2015a; Walker, de Beurs, & Wynne, 2014; Wu et al., 2012; Zhang, Friedl, Schaaf, & Strahler, 2004). There are also robust ground-based observation networks in these regions. Examples of such networks are: the US National Phenology Network, the Woodland Trust, UK, International Phenological Gardens (IPG) in Europe and the German phenological network (Boyd, Almond, Dash, Curran, & Hill, 2011; Chmielewski, Müller, & Bruns, 2004; Graham, Riordan, Yuen, Estrin, & Rundel, 2010; Menzel, 2013, pp. 335–350; Wolkovich, Cook, & Davies, 2014; Zhang, Friedl, Tan, Goldberg, & Yu, 2012).

In Africa, there have also been several phenological studies, both ground-based and satellite-based (Adole, Dash, & Atkinson, 2016). However, despite being home to 17% of the world's forest cover (Food and Agriculture Organization of the United Nations, 2010), approximately 12% of the world's tropical mangroves (Donato et al., 2011; Giri et al., 2010), and with a diverse range of vegetation types (Fig. 1), compared to other continents, the number of phenological studies in Africa is very limited (Adole et al., 2016). Similarly, unlike other regions, there are no phenological networks in Africa (Adole et al., 2016).

A recent systematic review by Adole et al. (2016) revealed that of 9566 articles on vegetation phenology globally, only 130 focused on Africa. Moreover, despite the advances in LSP, particularly with the availability of fine spatial resolution data, and knowing that at coarser spatial resolutions phenological information may be misread (Fisher & Mustard, 2007), only 15 studies evaluated LSP at a continental scale using coarse spatial resolution (ranging from 1 to 8 km) data (Adole et al., 2016). Adole et al. (2016, Table 1) found that studies over longer periods used coarse spatial resolution datasets while those with a shorter duration of five years or less commonly used a spatial resolution of 1 km. Additionally, the temporal resolutions of most of these studies were relatively coarse (10–16 day), thereby increasing the potential for errors in vegetation phenology estimation (Zhang, Friedl, & Schaaf, 2009). Although the MODIS Land Cover Dynamics product (MCD12Q2) provides global LSP information at a spatial resolution of 500 m there are large uncertainties, and sometimes unrealistic LSP parameter values, associated with this product (Ganguly et al., 2010; Vintrou et al., 2012) and, thus, may not be reliable for detail characterisation of LSP. Also, this product which was last released in 2012 is not as recent as other MODIS data and does not benefit from the recent reprocessing of MODIS data products. Based on these findings, we have summarized the identified research gaps which are relevant to this below:

(1) There has been no study characterising LSP of the major land cover types in the different geographical sub-regions in Africa.
(2) At a continental scale, only coarse spatial resolution datasets ranging from 1 to 8 km have been used for LSP studies in Africa, and
(3) 10–16 day temporal resolution datasets were used with the exception of only two studies which used daily datasets, albeit at coarse spatial resolutions of 3 and 5 km (see Table 1).

In addition to the above highlighted gaps, Africa is known to have complex vegetation dynamics (Favier et al., 2012) and its vegetation types are very distinct in their responses to climatic factors, resulting in great variability in phenological patterns. Although there are generally two major maximum rainfall seasons in Africa (the June-to-August season in the northern latitudes and the December-to-February season in the southern latitudes) (Griffiths, 1971), the distribution of these