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Monitoring vegetation dynamics with medium resolution MODIS-EVI time series at sub-regional scale in southern Africa

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ABSTRACT

Currently there is a lack of knowledge on spatio-temporal patterns of land surface dynamics at medium spatial scale in southern Africa, even though this information is essential for better understanding of ecosystem response to climatic variability and human-induced land transformations. In this study, we analysed vegetation dynamics across a large area in southern Africa using the 14-years (2000–2013) of medium spatial resolution (250 m) MODIS-EVI time-series data. Specifically, we investigated temporal changes in the time series of key phenometrics including overall greenness, peak and timing of annual greenness over the monitoring period and study region. In order to specifically capture spatial and per pixel vegetation changes over time, we calculated trends in these phenometrics using a robust trend analysis method. The results showed that interannual vegetation dynamics followed precipitation patterns with clearly differentiated seasonality. The earliest peak greenness during 2000–2013 occurred at the end of January in the year 2000 and the latest peak greenness was observed at the mid of March in 2012. Specifically spatial patterns of long-term vegetation trends allowed mapping areas of (i) decrease or increase in overall greenness, (ii) decrease or increase of peak greenness, and (iii) shifts in timing of occurrence of peak greenness over the 14-year monitoring period. The observed vegetation decline in the study area was mainly attributed to human-induced factors. The obtained information is useful to guide selection of field sites for detailed vegetation studies and land rehabilitation interventions and serve as an input for a range of land surface models.

Introduction

Monitoring vegetation dynamics is essential for a better understanding of how the earth system responds to climatic variability and anthropogenic pressures. Phenological characteristics depends on the vegetation (type, composition and condition) environmental parameters (solar radiation, climate, soil, and terrain characteristics) and land use (Hoare and Frost, 2004). Vegetation dynamics as measured from appropriately processed satellite time- series data can thus be used as an integrated indicator of vegetation response to environmental factors such as rainfall and temperature as well as human-induced pressures over large areas (Dash et al., 2010). Climatic variation and land transformations related to exploitative land uses are among the main drivers of ongoing changes in vegetation patterns and land degradation in southern Africa (Harris et al., 2014; Wessels et al., 2008). These changes are likely to accelerate, given the predicted high vulnerability of this region to future climate change coupled with continuous pressure from growing populations (Bryan et al., 2009; Fauchereau et al., 2003; Stringer et al., 2009). However, time-series vegetation and phenometrics datasets at moderate resolutions have not been fully explored to map and characterize vegetation dynamics in southern Africa.

Land surface phenology in dryland ecosystems have not been as intensively studied as more temperate regions (Walker et al., 2014). Often a patchy distribution of semi-arid and arid vegetation is caused by erratic and scattered rainfall events (Landmann and Dubovyk, 2014), while micro-site variations in biophysical characteristics of the landscape further cause differences in vegetation

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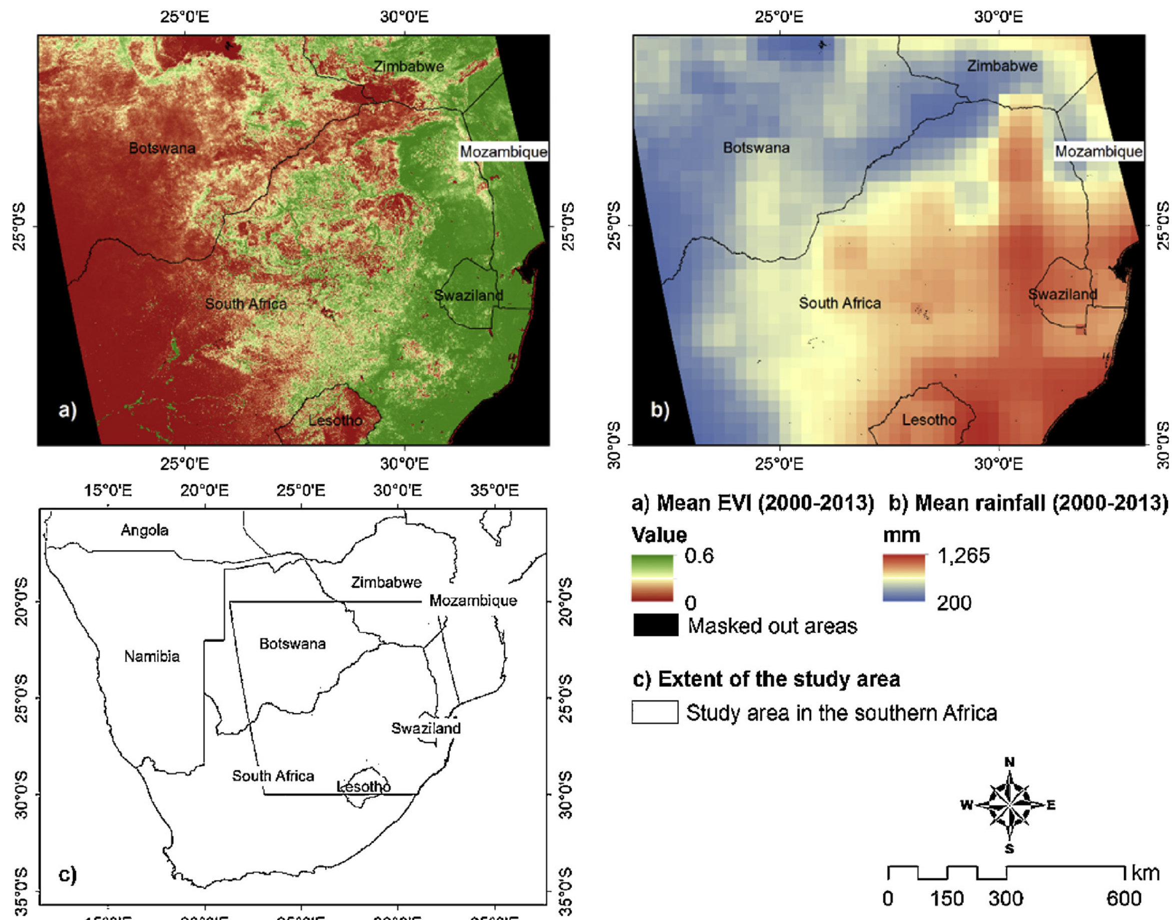

Fig. 1. (a) Mean EVI values averaged over 2000–2013 from the 16-day 250 m MODIS EVI time-series. (b) Mean rainfall for 2000–2013 calculated from monthly time-series rainfall data from the Tropical Rainfall Measuring Mission (TRMM) instrument. (c) Location of the study area in southern Africa.

patterns (Chytrý and Tichý, 1998). The cumulative result is a complex vegetation mosaic at local to regional scales that cannot be easily generalized (Nijland et al., 2013). There is thus a need for high spatial resolution studies on land surface phenology, as coarse datasets are not optimal to capture heterogeneous and small- scale dryland vegetation phenology dynamics (Walker et al., 2014).

Frequent synoptic data observations from earth observation satellites is increasingly used to monitor spatially-explicit vegetation cover patterns (Brown et al., 2013; Reed and Brown, 2005; de Beurs and Henebry, 2005b). Satellite time-series from the Advanced Very High Resolution Radiometer (AVHRR) and vegetation instrument on board of the Satellite Pour l'Observation de la Terre (SPOT) are often used to calculate and analyze wide-area vegetation changes (Neeti et al., 2012; Jeganathan et al., 2014; Pouliot et al., 2008). Both sensors operate at coarse spatial resolutions ranging from 1 km to 8 km (Fensholt and Proud, 2012). The Terra-Moderate Resolution Imaging Spectroradiometer (MODIS) was specifically designed to monitor land surface characteristics (Zurita-Milla et al., 2009). The high temporal resolution of MODIS satellites allows capturing seasonal to decadal vegetation dynamics at a relatively high level of spatial detail (250 m pixel size) (Ganguly et al., 2010). Considering the current call for improved spatial and temporal resolution of satellite time series to monitor land surface phenology (Walker et al., 2014) and given the availability of 250 m time-series data from MODIS spanning from 2000 to current, advances in the mapping of spatial and temporal vegetation patterns are expected.

Most of the previous land surface phenology studies in Africa focused on sub-regions or individual countries (Archibald and Scholes, 2007; Heumann et al., 2007; Olsson et al., 2005), the whole continent (Brown et al., 2010; Vrieling et al., 2013; Zhang et al., 2005) or were a part of global assessments (De Beurs and Henebry, 2005a; de Jong et al., 2011). There are however only a few studies which have explicitly focused on monitoring changes in vegetation phenology in southern Africa. Wessels et al. (2011) mapped patterns of remotely-sensed phenology to re-classify biomes and vegetation gradients in South Africa using 1 km AVHRR–NDVI data for the period 1985–2010. Hoare & Frost (2004) classified vegetation of South Africa using AVHRR-based phenometrics as an input. In a recent study, Harris et al. (2014) analyzed 25-year 8 km GIMMS (Global Inventory Modelling and Mapping Studies) AVHRR–NDVI for the initial determination of vegetation resilience over southern Africa. To our knowledge, there are no current studies focusing on southern Africa that analyzed either spatio-temporal changes in key phenometrics or calculated spatially-explicit trends in these phenometrics. Moreover, no study exists that investigated this topic using medium resolution (250 m) MODIS time-series data.

This paper aimed at analysing vegetation dynamics across a large area in southern Africa using 14- years (2000–2013) of 250 m MODIS-EVI (enhanced vegetation index) time-series data. We hypothesized that: (1) vegetation dynamics in southern Africa varies across environmental and management gradients, (2) spatio-temporal dynamics of these parameters within and between years can be detected by the 250 m MODIS-EVI data, (3) it is possible to interpret spatial patterns of these dynamics with respect to climate and/or human-induced land transformations. First, we derived a key set of phenometrics including overall greenness, peak- and timing of annual greenness and analyzed changes in these parameters over the observation period. In addition, we calculated trends