Detecting inter-annual variability in the phenological characteristics of southern Africa's vegetation using satellite imagery

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Vegetation phenology refers to the timing of seasonal biological events (for example, bud burst, leaf unfolding, vegetation growth and leaf senescence) and biotic and abiotic forces that control these. Daily, coarse-resolution satellite imagery provides consistent measurements of vegetation greenness which captures phenological cycles and vegetation function. Understanding the inter-annual variability in phenology is imperative, as phenological changes will be one of the first signs of the impact of climate change on ecosystem dynamics. This chapter offers new insights into the spatial patterns of the phenometrics and their inter-annual variability that could not be mapped without long-term satellite time-series data. This technique helps to close the gap that existed between plot-level vegetation data and broad-scale climate data during traditional regional vegetation mapping.

Introduction

Vegetation phenology refers to the timing of seasonal biological events (for example, bud burst, leaf unfolding, vegetation growth and leaf senescence) and biotic and abiotic forces that control these [1]. The dynamic phenology of terrestrial ecosystems reflects response of the biosphere to climatic factors (for example, temperature and rainfall) and these climatic drivers are largely responsible for the geographic distribution of different vegetation zones.

Field data on leaf phenology are difficult to obtain. Data collection is labour intensive and the data can only give information at one point on the ground. Daily, coarse-resolution satellite imagery provides consistent measurements of vegetation greenness which captures phenological cycles and vegetation function. South Africa has the rare privilege of having received, archived and processed daily 1 km AVHRR satellite data to calibrated ten-daily, near cloud-free composite images, since 1985.

Each 1 km pixel thus has a time series of data from which vegetation phenology, such as the start, peak and length of the growing season, can be extracted using specific algorithms. These phenological cycles are very different between vegetation types (Figure 3.18). Insightful maps were produced for the entire southern Africa showing patterns in phenological metrics, such as the start of season (Figure 3.19), which otherwise would have been impossible to observe.

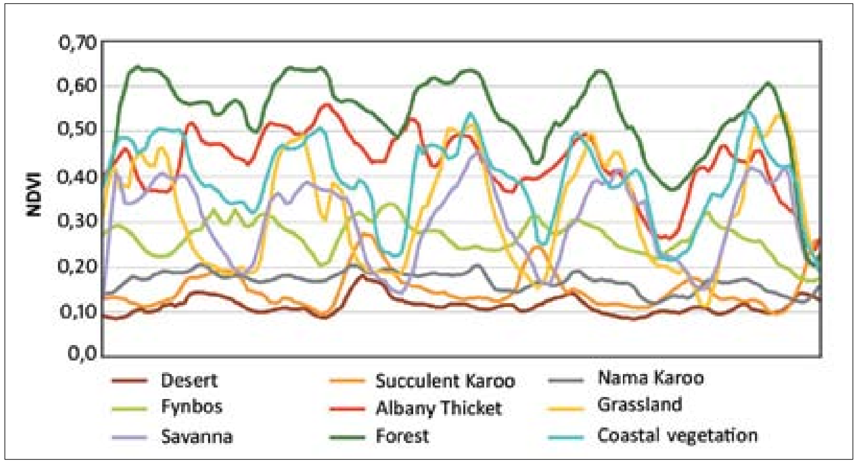

Figure 3.18 Time series of vegetation greenness for a typical pixel in each of the biomes of South Africa.

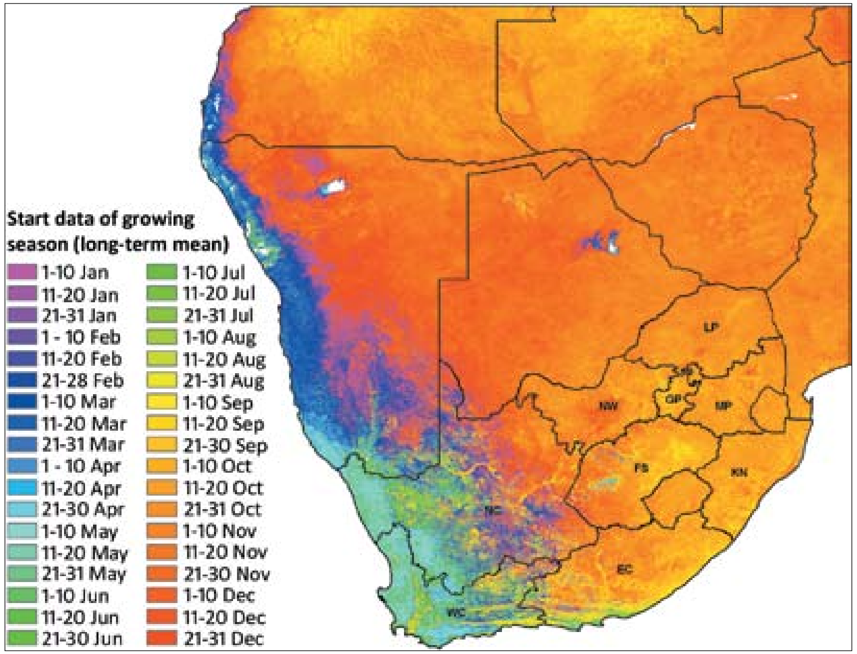

Figure 3.19 Mean start date of the growing season derived from 1 km² AVHRR satellite data, 1985-2000.

It is imperative to understand the inter-annual variability in phenology, as phenological changes will be one of the first signs of the impact of climate change on ecosystem dynamics. Studies based on phenology derived from satellite data have already indicated an earlier start and longer growing season in northern latitudes [2, 3]. Similar trends have not yet been detected in South Africa, however it is important to develop a base line understanding of our phenological patterns as climate change models predict significant changes in the near future [4]. The objective of this research was to describe patterns of satellite-derived vegetation phenology, including their inter-annual variability, across southern Africa.

Extracting vegetation phenology from satellite data

There were various computational problems that needed to be overcome in order to extract useful phonological information. Time series of satellite vegetation index data are notoriously noisy due to cloud and atmospheric contaminations and varying sun and sensor angles. Thus, robust models have to be developed to distinguish the seasonal vegetation signal from the noise and to reconstruct a clean time series for each image pixel (for example, Figure 3.18).

The seasonal cycles of vegetation greenness provide a time series of data for each image pixel from which the start, midposition, end and length of the growing season can be numerically extracted (Figure 3.20) [5]. The total amount of vegetation growth, referred to as net primary production (NPP), can be calculated from the area under the seasonal growth curve (the large integral) (Figure 3.20, point F).

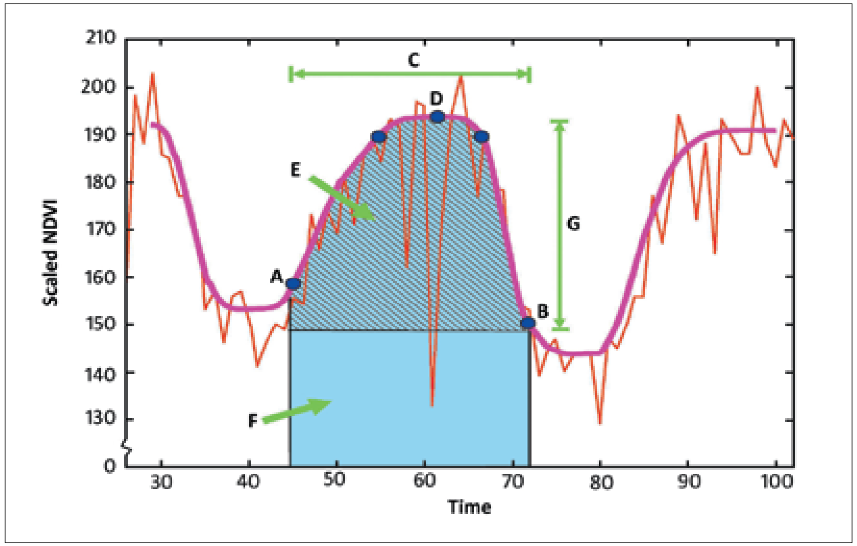

Figure 3.20 Phenology metrics extracted from the seasonal NDVI curve. A – start of season, B – end of season, C – length of season, D – maximum, E – small integral, F – large integral, G – amplitude.

The results show a very clearly defined spatial pattern in the start of growing season which is consistent with known plant phenological patterns and regional rainfall patterns (Figure 3.19). The winter rainfall of the south-western and western coastal strip (start in beginning of May) is clearly distinguished from the summer rainfall regions in the remainder of the subcontinent (start in October to early November). The fynbos, though predominantly in a winter rainfall region, is known to span from winter in the west (start in beginning of May) to summer rainfall regions in the east (start in September) [6]. The areas in the western fynbos with later start dates (October) are mainly wheat fields where the pattern of planting and harvesting gives very uniform phenologies that are distinctly different from the surrounding vegetation (Figure 3.19).

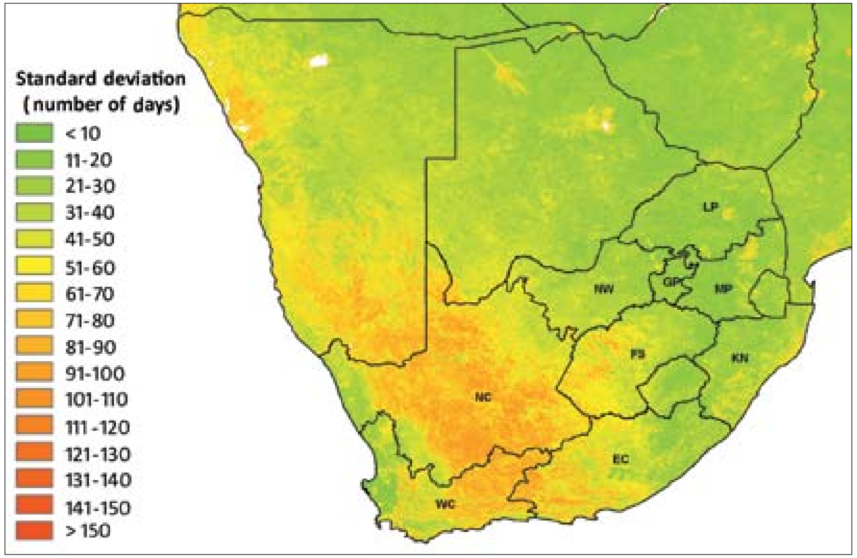

Figure 3.21 Inter-annual variability (standard deviation in days) in the start of growing season derived from 1 km² AVHRR satellite data, 1985-2000.

The standard deviation (in days) of the start of growing season is a measure of the inter-annual variability in this date (Figure 3.21). The greatest variability in the start of growing season dates is associated with arid regions, especially the Nama Karoo with its unpredictable rainfall. The grassland and savanna in the Northern and Mpumalanga provinces show the least variability in the start date, namely 20-30 days. The variability in start date in the cultivated areas of the Free State is very high, while it is very low in cultivated areas of the Western Cape (Figure 3.21), reflecting the difference in the inter-annual variability in first rainfall and planting dates.

The large integral indicating vegetation production shows a clear relationship with rainfall, from the very arid areas in the Northern Cape to the high rainfall of the forests and exotic plantations along the escarpment and the Indian Ocean coastal belt (Figure 3.22). Negative trends in the large integral through time can be used to identify areas experiencing land degradation [7] and/or potentially climate change, whilst taking account of the natural inter-annual variability.

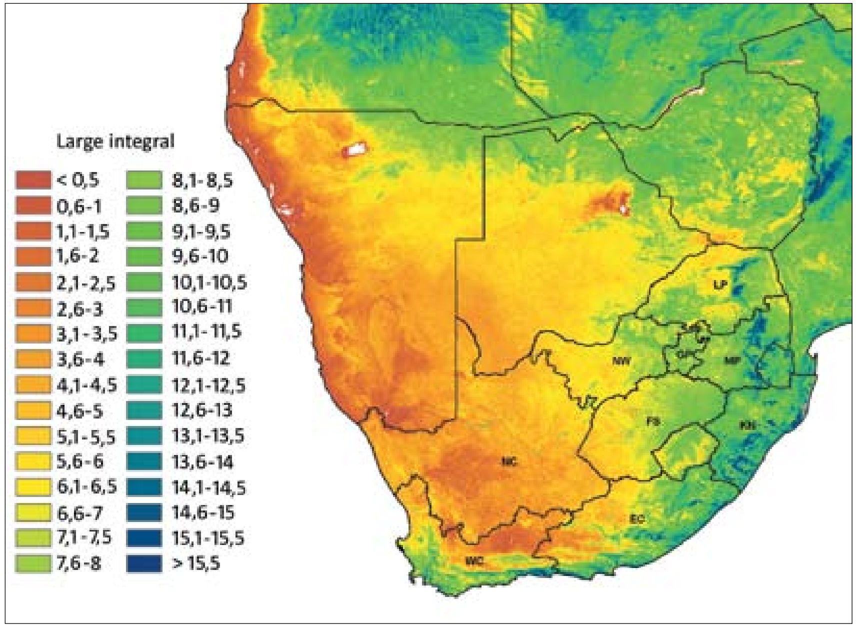

Figure 3.22 The mean large integral of the seasonal growth curve indicating total vegetation growth per season.

Phenology of the biomes of South Africa

The newly-defined biomes of SA include biomes such as Grassland, Savanna, Fynbos, Nama Karoo, Succulent Karoo, and Desert and were mapped based on the grouping of the more detailed vegetation types (based on plant species distribution data), as well as climate data (Figure 3.23) [8]. The phenology of these biomes (for example, Figure 3.18) were analysed to gain insight into their differences in terms of vegetation function and dynamics. It furthermore highlighted the phenological aspects which should be monitored to detect the impact of climate change and potential changes in the distribution of biomes. The satellite-based phenometrics clearly captured functional processes that were not readily predictable from the combination of floristic data and climate variables alone.

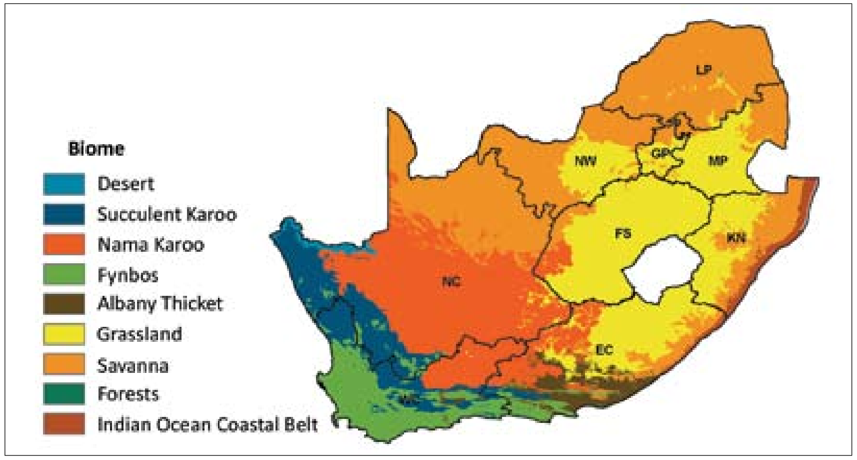

Figure 3.23 Biomes of South Africa. (After [8])

The biome map of South Africa could be reproduced from satellite-based phenology data with an overall accuracy of 75%. This is quite extraordinary considering that the biomes were mapped based on vegetation field data and climate data, while the satellite data recorded vegetation greenness. This technique helps to close the gap that existed between plot-level vegetation data and broad-scale climate data during traditional regional vegetation mapping. It can provide the opportunity to map vegetation functional types over vast areas of southern Africa where little floristic information may be available.

Ongoing research into phenology furthermore include: (a) quantifying the difference between the phenology of transformed land cover types, for example, cultivation and commercial forestry, and the natural vegetation, (b) relating phenological patterns to that of fire, (c) unmixing the phenological signal of grass versus woody components of vegetation, and (d) detecting potential change in phenological patterns through time.

Acknowledgements

The ARC-Institute for Soil, Climate and Water supplied and processed AVHRR and rainfall data. The research was funded by the CSIR Strategic Research Panel.