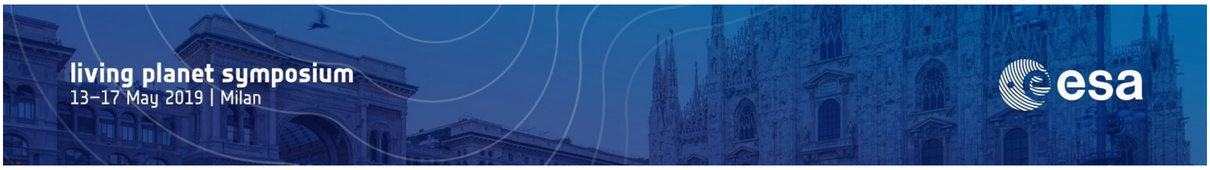

Pervasive Greening of African Savannahs from 1982 - 2016

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Trends in vegetation greenness, measured using the Normalised Difference Vegetation Index (NDVI), are one of the most ubiquitous tools for inferring ecological change at large spatial scales. The NDVI has long been a favoured metric, owing to its simple calculation, correlation with various ecological attributes, and transferability between sensors. In particular, the Advanced Very High Resolution Radiometer (AVHRR) - derived Global Inventory Monitoring and Modelling System (GIMMS) dataset has been used extensively for environmental change purposes.

The regions most studied using GIMMS-NDVI data are the drylands of Africa. These areas are particularly well suited for this form of analysis, due to the limited historical coverage of other Earth-observation archives in the region, with the exception of South Africa. Furthermore, NDVI becomes less sensitive to vegetation in dense canopies (NDVI > 0.7), but is relatively responsive to the low biomass levels found in savannahs and grasslands. Accordingly, a considerable amount of earlier work on the use of NDVI for monitoring environmental change focussed on the Sahel region.

This study investigates the NDVI dynamics of African savannahs using a variety of time-series analysis techniques and NDVI-derived metrics. The overarching aim is to understand how vegetation dynamics have occurred and evolved during the 1982-2016 period and the ecological implications of these changes. Towards this aim, we generate two NDVI time-series from the GIMMS dataset: the annual maximum and aggregate sum values, hereafter NDVImax and NDVIsum, respectively. These series are used as inputs into monotonic linear and breakpoint regression models. The slopes and any associated breakpoints of these models are classified and examined as indicators of large-scale ecological change.

We further processed the GIMMS data to maximum monthly composites and discarded the months for the incomplete 1981 year, resulting in a 34-year (408 months) time-series. When gaps remained after compositing, values were estimated by linear interpolation across months. We calculated the median NDVI using the monthly time-series, and discarded pixels with a value of less than 0.15 or greater than 0.8 from further analysis. This removed areas with very low vegetation cover (e.g the Sahara and Namib deserts) and dense forests (e.g. the Congo and Guinean forests).

The monthly time-series was aggregated into two annual metrics: NDVImax and NDVIsum. This resulted in two 34-year annual time series, to be used as inputs for the trend analyses.

We applied a standard linear regression model on both annual NDVI time-series. Firstly, a standard linear model was implemented with no breaks quantified. Secondly, a model allowing for two structural changes was applied. Breakpoints were determined first by an ordinary-least squares moving sum (MOSUM) test. When breaks were detected, the number was estimated by the Bayesian Information Criterion (BIC), and timings were set based on the residual sum of squares (RSS).

The slopes resulting from the linear models were grouped into three categories: greening, no change, or browning, after removing pixels with insignificant trends. By comparing the trend classifications from the NDVI-max and NDVI-sum models, six combinations were possible. To classify the breakpoint outputs the following procedures were applied. Firstly, all segments with a length less than seven years or resulting from an insignificant break were discounted. Secondly, the remaining components were classified into greening, browning or no change based on the slope value. Finally, as only two breaks were allowed, a maximum of three segments were deemed possible.

According to our results, greening pixels comprised 75% of the NDVIsum slopes, and 80% of the NDVImax, whereas browning was identified in 25% and 20% of pixels, respectively. Removing trends that did not meet a $P < 0.05$ significance threshold eliminated some of these pixels. Pronounced increases in NDVI were observed in the Sahel and southern Africa. Browning was concentrated in east Africa, Angola, Zambia, and Mozambique, with dispersed and isolated patches in the northern Sahel. Results also show that, regardless of NDVI metric, a large majority of African drylands, across all regions, have experienced only greening trends in the 1982-2015 period: a minimum of seven years' increase and no seven-year decrease in the NDVI metrics. Conversely, few areas displayed only browning trends (a minimum of seven years' decrease with no increase). These pixels were geographically clustered in the central Sahel, Angola-Zambia-Mozambique, and Tanzania. Patches of trend reversals (e.g. browning to greening) were present, although not geographically extensive.

In summary, the overarching trends of African savannahs across our study period is of vegetation greening. This has occurred across all regions, even when different precipitation patterns have occurred. This would indicate the role of pan-continental driver(s). There are numerous ongoing trends which are beneficial for plant growth that could contribute to this, such as elevated CO_2 levels, nitrogen deposition, and increased temperatures. Areas of browning predominantly occurred in areas where either population growth had been high, or where phenological change has curtailed the growth season.