

Climate change impacts and vegetation response on the island of Madagascar

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The island of Madagascar has been labelled the world's number one conservation 'hot spot' because of increasing anthropogenic degradation of its natural habitats, which support a high level of species endemism. However, climatic phenomena may also have a significant impact upon the island's flora and fauna. An analysis of 18 years of monthly satellite images from the National Oceanographic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) have demonstrated that there is a dynamic pattern in Madagascar's vegetative cover both annually and seasonally throughout 1982–1999. Over interannual time-scales, we show that this vegetation response, calculated using the normalized difference vegetation index (NDVI), has a strong negative correlation with the El Niño Southern Oscillation (ENSO), which can be attributable to drought events and associated wildfires. Global climate change is predicted to increase the frequency of the ENSO phenomenon, resulting in further decline of Madagascar's natural environment.

Keywords: Madagascar; vegetation change; ENSO (El Niño Southern Oscillation); NDVI (normalized difference vegetation index)

1. Introduction and methods

Madagascar is the world's fourth largest island, with an area of *ca.* 590 000 km², extending 1570 km from 11° 57' S to 25° 32' S and 560 km from 43° 14' E to 50° 27' E off the south-eastern coast of Africa. The island boasts a remarkable array of vegetation habitats, ranging from humid tropical forests, where average annual precipitation exceeds 3500 mm, to arid semi-deserts that receive less than 350 mm of rainfall per year. Considerable debate, however, has surrounded the question of how much pre-settlement forest has been anthropogenically degraded to date. Early discourse about the island's natural history adopted the hypothesis that Madagascar was covered with essentially continuous, dense, climax forest prior to human settlement (Humbert 1927), but recent analysis of charcoal deposits and pollen core

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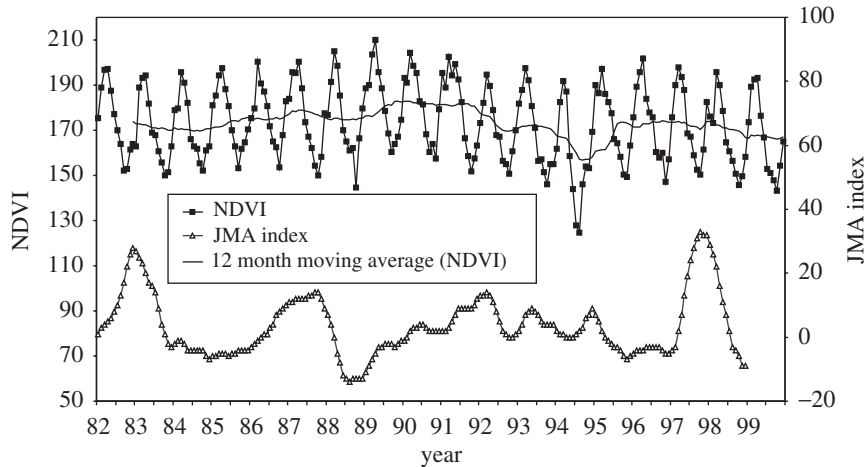


Figure 1. Monthly values for NDVI (primary y -axis) for the years 1982–1999 and the JMA index (secondary y -axis) for the years 1982–1998.

samples collected from lakes and bogs across Madagascar have contradicted this theory (Burney 1987*a, b*).

Cultivation in Madagascar involves slash and burn agriculture (shifting cultivation or *tavy*), in which native forest is cleared and burned, and various crops, mostly dry land rice, are planted for a few years, until the soils are impoverished, and then abandoned. Much of these degraded areas succeed to secondary grassland and other fire-prone open vegetation ecosystems (woodland, bushland, shrubland, etc.). Although it was clearly evident that the landscape had been altered since the arrival of humans around 2000 BP, climate change also contributed significantly to fire events and influenced land-cover dynamics (Burney 1993).

The NDVI, derived from the visible and near-infrared channel radiances (0.58–0.68 μm and 0.73–1.10 μm , respectively) of the NOAA AVHRR provide unique opportunities for mapping, monitoring and evaluating vegetation change. NDVI is a widely used index of green-leaf biomass and numerous studies have related multi-temporal NDVI images to biophysical properties of vegetation including LAI (Tucker 1979), seasonal phenology and for monitoring spatial patterns of vegetation change (Justice *et al.* 1985).

We evaluate monthly and interannual vegetation change on Madagascar from 1982 to 1999 using maximum NDVI value (rescaled from 0–255) composites of daily AVHRR images having a spatial resolution of 8 km to remove cloud contamination and reduce atmospheric, solar and viewing-angle effects (Holben 1986). NDVI is known to be highly sensitive to climatic variables such as rainfall and evapotranspiration (Nicholson *et al.* 1990). However, precipitation data for Madagascar are patchy, both temporally and spatially, and, thus, an analysis of NDVI in direct relation to precipitation was not conducted. Recent work on continental Africa has reported on the response of NDVI to ENSO events (Anyamba *et al.* 2001). As one of the major phenomena of interannual variability, it is known that a dipole structure of sea-surface temperature (SST) anomalies in the Indian Ocean, characteristic of ENSO events, has significant impacts on regional as well as global climate variability (Nicholls 1989). To explore if the variability of NDVI values observed

within this study was related to such a climatic episode, we ran a correlation analysis of NDVI with the Japan Meteorological Agency (JMA) index of ENSO (figure 1). The JMA is an SST-anomaly-based index defined by the JMA and is an indicator for classifying extremes in the ENSO cycle (Meyers *et al.* 1999). The index was based on average monthly SST anomalies between 4° N and 4° S, and from 90° W to 150° W, representing the tropical Pacific Ocean. A five-month running mean was applied to the data to smooth out interseasonal noise. Beginning with the month of October 1980, the JMA index values for every month over a two-year time period were averaged. The two-year average of the JMA index was used in order to represent the biennial mode, which encapsulates the major features of ENSO events, although lower-frequency variation of ENSO does exist (Nicholls 1997). October NDVI values were correlated with the average JMA value derived for the preceding two-year time interval.

2. Results and discussion

A scatter plot of monthly NDVI values and a 12 month moving-average trend line shows strong seasonal variability and a pattern of interannual variability, respectively (figure 1). The seasonal dynamics of the NDVI characterize the vegetation phenology, which closely follows the annual precipitation cycle with the NDVI response exhibiting a lag period of 2–3 months. Throughout the period, the lowest monthly NDVI was for the month of October, which is at the end of the dry season. At interannual time-scales, a correlation of JMA index values with the October NDVI values for the entire island resulted in a Pearson's correlation coefficient of -0.66 ($p < 0.01$). This negative correlation was similar to correlations observed between other ENSO indices and East African NDVI anomalies (Anyamba *et al.* 2001). Precipitation fluctuations associated with ENSO can have grave impacts on human communities and the natural environment. Research has demonstrated a 120% increase in the probability of drought disaster for the year after El Niño onset within southern African countries (Thomson *et al.* 2003). The climate of Madagascar, however, often displays patterns unique from the continent and is highly variable internally due to the island's size, latitudinal expanse and topographic diversity (Jury 2003). Although wetter conditions have been reported to coincide with El Niño in Madagascar (Jury 2003), certain regions of the island have experienced drought conditions either during or after El Niño episodes. For example, the strong El Niño period of 1982–1983 was accompanied by drought in the southern portion of Madagascar in January–August of 1983.† Similarly, the El Niño of 1994–1995 was associated with significantly low rainfall amounts and severe rainfall deficits in 1995, which exceeded 150 mm in the southern two-thirds of Madagascar (WMO 1998). Such dry conditions are favourable for vegetation fires, which often spread uncontrolled and consume thousands of square kilometres of the island's rainforest and secondary bush each year (Kull 2002). In the El Niño year of 1987, Madagascar had the greatest number of recorded wildfires in the world (FAO 2001).

The analysis of the relationship between the JMA index and NDVI presented here only accounts for a small proportion of NDVI variability. The tropical air–sea interactions of the Indian Ocean system are distinct from the Atlantic and Pacific ocean

† See the NDMC (National Drought Mitigation Center) website at <http://www.drought.unl.edu/index.htm>.

systems in that the cooling effect of equatorial upwelling is absent (Jury 2003). These conditions yield a complex system, of which much remains unknown, and indicates that this study represents only a preliminary exploration of the relationship between climatic influences and vegetation within Madagascar. Other relevant climatic phenomena should also be considered within this context. For example, the existence of a dipole structure of SSTs in the Indian Ocean, which is different from ENSO and accounts for *ca.* 12% of Indian Ocean SST variability, has been identified as contributing to abnormally severe climatic patterns in Eastern Africa and surrounding regions (Saji *et al.* 1999). Although a considerable correlation between ENSO and the Indian Ocean Dipole (IOD) has been demonstrated (Nicholls & Drosowsky 2001), debate continues as to whether the IOD operates independently of ENSO (Feng & Myers 2003). Future research on these issues will also be useful for informing our understanding of vegetation and land-cover dynamics in Madagascar.

This research is one of the first attempts at quantitatively identifying the relationship between vegetation response using the NDVI at a national scale and climatic extremes. The reasonable but significant correlation observed here does suggest that El Niño exerts a considerable influence on vegetation greenness on the island. Further research into the trends and predictions of climate phenomena and the influence of climate on vegetation could greatly aid natural-resource management. Fire management in Madagascar may require consideration of not only the direct impact of human use on vegetation, which is often the focus of conservation efforts, but also how the effects of anthropogenic activities may be compounded or enhanced by the influence of climatic extremes.

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