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Determinants of the interannual relationships between remote sensed photosynthetic activity and rainfall in tropical Africa

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Abstract

The response of photosynthetic activity to interannual rainfall variations in Africa South of the Sahara is examined using 20 years (1981–2000) of Normalised Difference Vegetation Index (NDVI) AVHRR data. Linear correlations and regressions were computed between annual NDVI and annual rainfall at a 0.5° latitude/longitude resolution, based on two gridded precipitation datasets (Climate Prediction Center Merged Analysis of Precipitation [CMAP] and Climatic Research Unit [CRU]). The spatial patterns were then examined to detect how they relate to the mean annual rainfall amounts, land-cover types as from the Global Land Cover 2000 data set, soil properties and soil types. Yearly means were computed starting from the beginning of the vegetative year (first month after the minimum of the NDVI mean regime), with a one-month lead for rainfall.

One third of tropical Africa displays significant (95% c.l.) correlations between interannual NDVI variations and those of rainfall. At continental scale, soil types and soil properties are only minor factors in the overall distribution of the correlations. Mean annual rainfall amounts and land-cover types are much more discriminating. The largest correlations, mostly over 0.60, are distinctly found in semi-arid (200–600 mm annual rainfall) open grassland and cropland areas. The presence of one of these two determinants (semi-aridity, and favourable land-cover type, i.e. open grassland and cropland) in the absence of the other does not systematically result in a significant correlation between rainfall and NDVI. By contrast, NDVI variations are independent from those of rainfall in markedly arid environments and in most forest and woodland areas. This results from a low signal-to-noise ratio in the former, and the fact that precipitation is generally not a limiting factor in the latter.

The marginal response of NDVI to a given increase/decrease in rainfall, as described by the slope of the regression, displays a similar pattern to that of the correlation, with maximum slopes in semi-arid regions, except that a weaker response is noted in more densely populated areas, suggesting an incidence of particular land-use and agricultural practises.

One-year lag relationships between annual rainfall and NDVI in the next year were also considered. Ten percent of the grid-points show significant correlations, but the spatial patterns remain difficult to interpret.

Keywords: NDVI; Vegetation; Rainfall; Land cover; Soil properties; Interannual variability; Africa

1. Introduction

In the tropics in general, and in tropical Africa in particular, water availability is regarded by far as the most important determinant to vegetation growth. In the absence of water storage systems, agricultural activities are heavily dependent upon precipitation. The high evaporative demand also makes natural vegetation very sensitive to rainfall variations. In principle, the effects of such variations could be recorded in the photosynthetic activity of the vegetation cover, as deduced from satellite measurements. In tropical Africa, different monitoring programs actually resort to the Normalised Difference Vegetation Index (NDVI) to provide assessments of the rainy season, and to warn for possible food crises in case of much lower than average NDVI values (e.g., USAID Famine Early Warning Systems, FAO-ARTEMIS, MARS crop yield monitoring and forecasting system of the European Commission Joint Research Centre).

Several regional or comparative studies have demonstrated a significant response of NDVI to interannual rainfall variations in African regions such as the Sahel (Herrmann et al., 2005; Malo & Nicholson, 1990; Tucker et al., 1985), East Africa (Davenport & Nicholson, 1993; Justice et al., 1986), the Kalahari area (Farrar et al., 1994; Nicholson & Farrar, 1994; Scanlon

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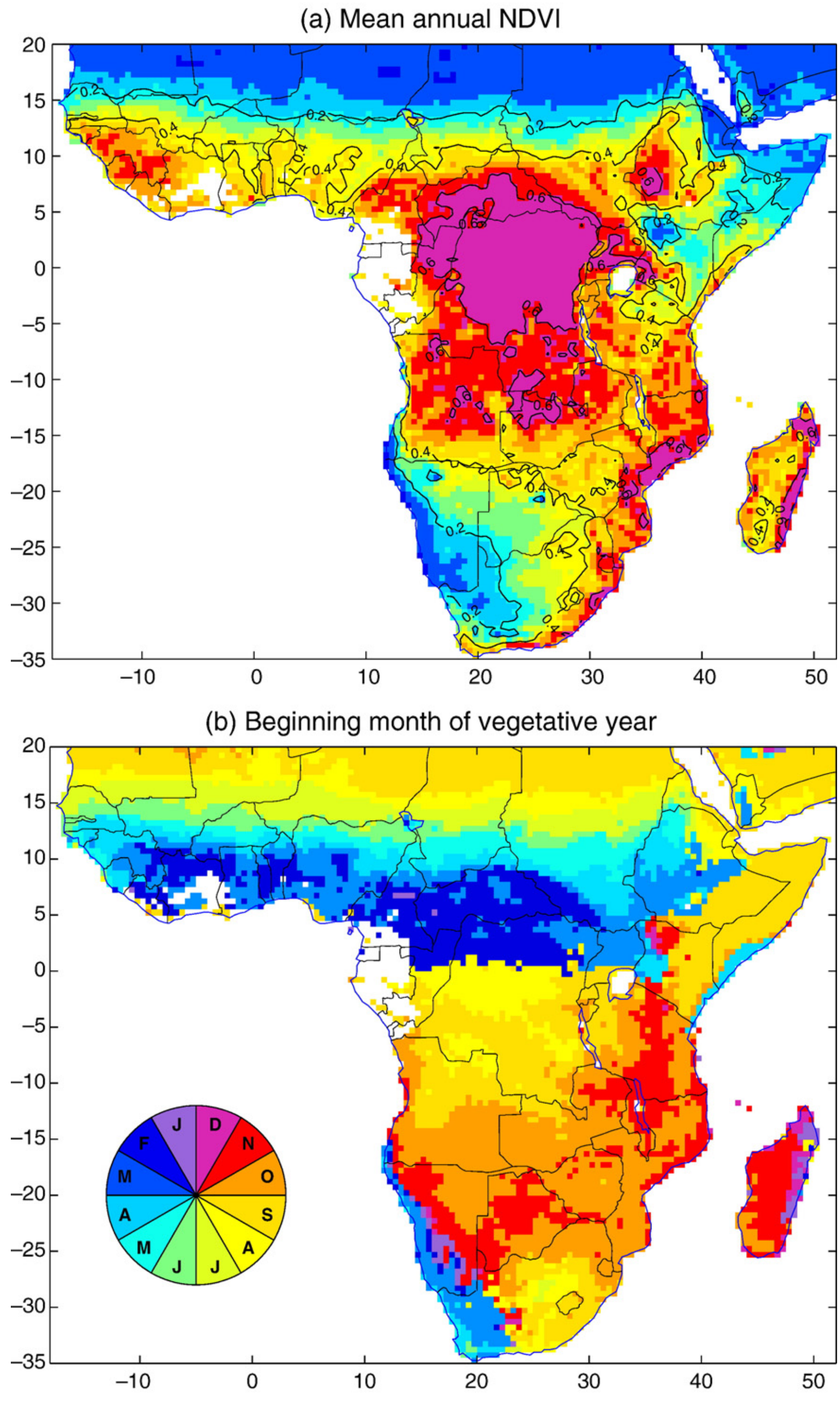

Fig. 1. Mean NDVI patterns over tropical Africa: (a) mean annual values; (b) beginning month of the vegetative season (BVS, see text).

et al., 2002) or southern Africa as a whole (Gondwe & Jury, 1997; Richard & Poccard, 1998). Spatially more limited studies are available for countries like Ethiopia (Hellden & Eklundh, 1988), Sudan (Hielkema et al., 1986), Senegal (Diouf & Lambin, 2001; Li et al., 2004), or parts of South Africa (e.g., Archer, 2004), among others. In some regions, it has been found a high spatial variability in the sensitivity of NDVI to interannual rainfall variations (Richard & Poccard, 1998). Though Lambin and Ehrlich (1997) suggested that year-to-year land-cover changes in tropical Africa as a whole are mostly due to interannual climatic variability, there is a lack of a detailed mapping to show areas where the NDVI response to interannual rainfall variations is strong/weak. The present study aims at filling the gap, by examining the spatial patterns of this response (discontinuities, regional differences) and seeking explanations to them.

An important question is first to assess to what extent the NDVI-rainfall relationship is dependent upon the mean amount of precipitation. Is there any continental threshold of mean annual rainfall after which the dependence would be reduced?