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3.1.7 Precipitation trends and shifts of rainfall regimes in Africa since 1951

CHRISTOPH BECK & JÜRGEN GRIESER

SUMMARY: *Based on a recently available global data set of gridded precipitation observations for the period 1951 to 2000 long-term hydroclimatic variations over Africa are investigated in terms of linear trend estimates, long-term changes of drought indices, and spatiotemporal variations of major rainfall regimes. Significant negative trends in precipitation sums and as well as corresponding significant increases in drought severity appear most striking in sub-Saharan regions and in northern parts of southern Africa. The comparison of the subintervals 1951–1975 and 1976–2000 concerning the percentage of land area designated to major rainfall regimes determined by non-hierarchical cluster analysis shows an expansion of arid and semi-arid climates on the cost of more humid climates especially in sub-Saharan and southern Africa.*

Most parts of the African continent feature tropical or subtropical climate conditions which are characterised by high temperatures throughout the year. Regarding rainfall and water availability on the other hand Africa exhibits a wide range of varying climates in terms of annual precipitation sums and as well intraannual variability thereby spanning tropical areas with annual precipitation sums reaching up to 10,000 mm but also regions in the Sahara with precipitation less than 1 mm/year. However, most of the continent can be characterised as subhumid climates with a prolonged dry season during the year. Thus variations in environmental conditions in most parts of Africa are closely linked to water and rainfall.

The relevance of rainfall variability not only for natural environments but also for agricultural systems and thus economy and human property and life was demonstrated dramatically for example during the drought in 1983 and 1984 that affected most parts of the African continent (BENSON & CLAY 1998).

A high vulnerability of African environmental and socio-economic systems to water and rainfall variability can particularly be stated for arid and semi-arid regions which feature a combination of accentuated climatic variability and human land use leading to land cover changes and degradation for example in Sahelian regions.

Against this background the analysis of the long-term spatiotemporal variations of observed African rainfall gains substantial importance due to several reasons. With regard to the ongoing discussion concerning desertification processes in arid, semi-arid, and dry sub-humid areas it is desirable to derive reliable estimates of long-term precipitation variability. This allows distinguishing between climatic and anthropogenic factors causing the manifold environmental changes linked to desertification (e.g. DESANKER & JUSTICE 2001). Projected regional precipitation changes for Africa simulated by GCMs exhibit distinct uncertainties concerning their magnitude and even direction (e.g. HULME et al. 2001). Thus the analysis of observed long-term precipitation variability is necessary in order to put the range of possible future changes into an historical context.

There are many investigations available dealing with precipitation variations over Africa with a focus on varying time scales and on different regions. A comprehensive overview of objectives and results of these studies is given for example in NICHOLSON (2001). According to this paper the major findings emerging from the various studies are an increase in aridity in almost all African regions especially since the 1980s and particularly a long-term declining rainfall trend in the Sahel.

In this contribution the hydroclimatic variability over Africa in the period 1951 to 2000 is examined in terms of linear trend estimates, long-term changes of drought indices and spatiotemporal variations of major African rainfall regimes. These analyses are based on monthly rainfall data from a newly available global data set of gridded (0.5° lat/lon) precipitation observations for the period 1951 to 2000 (BECK et al. 2005).

Observed precipitation trends since 1951

Linear trend estimates for precipitation over Africa for the period 1951 to 2000 have been determined on a monthly, seasonal and annual basis. As the assumption of Gaussian-distributed data is most often not valid for precipitation time series linear trend estimates based on the least-square method may yield dubious results concerning magnitude or even sign of real long-term precipitation trends (TRÖMEL & SCHÖNWIESE 2005). Thus additionally the non-parametric Mann-Kendall trend test has been applied to the precipitation records. For seasonally and annually aggregated precipitation sums (each expressed as mm/month) absolute linear trend estimates exceeding at least the 90% level of significance according to the Mann-Kendall test are displayed in *Fig. 3.1.7-1*.

As can be seen from this Figure, decreasing trends are the dominating feature of long-term African precipitation variability during the 2nd half of the 20th century. Most widespread and pronounced appear these negative trends in the Sahel and the Soudan regions in summer and – with highest trend values shifted to the south-west – in autumn.

Christoph.Beck@dwd.de

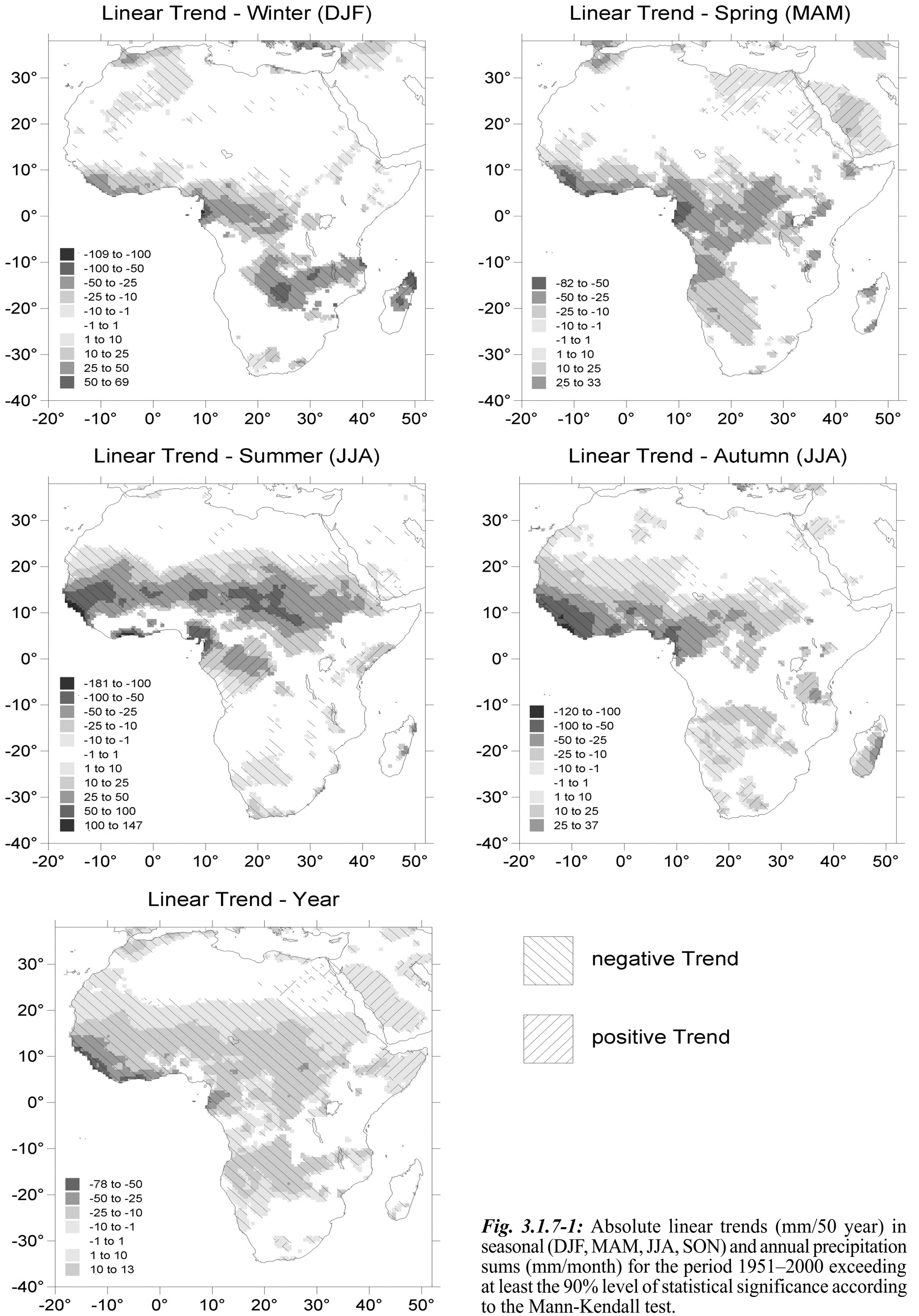

Fig. 3.1.7-1: Absolute linear trends (mm/50 year) in seasonal (DJF, MAM, JJA, SON) and annual precipitation sums (mm/month) for the period 1951–2000 exceeding at least the 90% level of statistical significance according to the Mann-Kendall test.

In winter and spring strongest negative trends occur in parts of Southern Africa, the Congo Basin and the Guinea region. Increasing trends in seasonal precipitation sums on the other hand are detected in much fewer regions and in most cases only during one season. Only for the Horn of Africa and parts of the Arab Peninsula seasonal variations accumulate to significant positive trends in annual precipitation sums. For all other regions exhibiting significant annual trends a long-term precipitation decrease becomes obvious.

Temporal variations in drought severity

Although linked to long-term trends in precipitation sums temporal variability in drought severity is additionally governed by higher frequency (intra- and interannual) precipitation variations. Thus from the several indices available for assessing drought severity (KEYANTASH & DRACUP 2002) the SPI (Standardized Precipitation Index) according to MCKEE et al. (1993) has been calculated for a range of time scales (3, 6, 12 and 24 months) and its temporal variability has been determined. By definition SPI detects meteorological droughts resulting from a shortage of precipitation over the prescribed time scales. However, it yields indirect evidence of agricultural, hydrological and even socio-economic drought impacts if estimated for according time scales. While agricultural droughts are described best by SPIs on time scales of up to 6 months, longer assessment periods (up to 24 months) are better suited for the replication of hydrological droughts. For socio-economic droughts no clear-cut link to the length of the SPI period can be stated as numerous factors control their onset and course.

Fig. 3.1.7-2 shows the spatial distribution of linear trends in 12-month SPI reaching statistical significance at the 90% level and regional time series of 3- and 12-month SPI for two selected regions exhibiting widespread negative or positive trends in SPI respectively. Distinct serial autocorrelation of SPI series has been taken into account using effective sample size estimates for determining the statistical significance of linear trends.

From the map illustrating the spatial distribution of statistical significant trends in 12-month SPI (reflecting hydrological drought impacts) it is apparent that increasing/decreasing tendencies in drought severity most often correspond with respective trends in annual precipitation sums. Concerning shorter assessment periods (3 and 6 months) describing agricultural droughts significant trends appear for the same core regions but less widespread (not shown). However not all regions with statistical significant trends in annual precipitation sums show significant trends in SPI as well (e.g. parts of Southern Africa and the Central Sahel region). Time series of 3- and 12-month SPIs for the Western Sahel region highlight a distinct decrease from 1951 to 1984 – reflecting a long-term positive trend in drought severity culminating in the 1983/84 drought event – and increasing – but for the most parts still negative – SPI values afterwards. For the Horn of Africa on the other hand marked decadal scale variations in drought severity rather than respective clear-cut long-term trends become visible.

Spatiotemporal shifts of rainfall regimes

From the above findings and against the background of ongoing discussions concerning a possible increase in land

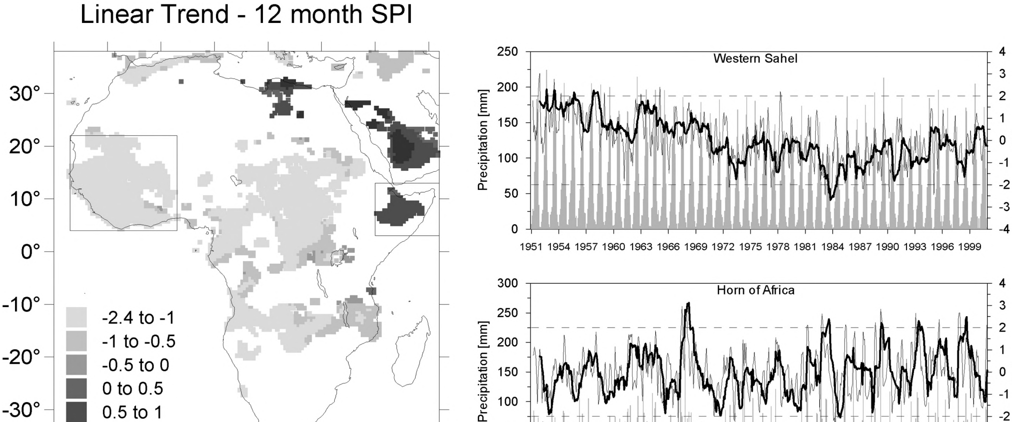

Fig. 3.1.7-2: SPI (Standardized Precipitation Index) variations in 1951–2000. Statistical significant (at the 90% level, adjusted for serial autocorrelation) linear trends for the 12 month assessment period (*left panel*). Regional time series of monthly precipitation sums (*grey bars*) and 3- and 12-month SPI (*thin and thick lines* resp.) for selected African regions indicated by rectangles in the map (right panels), dashed horizontal lines in time series plots indicate extremely wet/dry conditions.

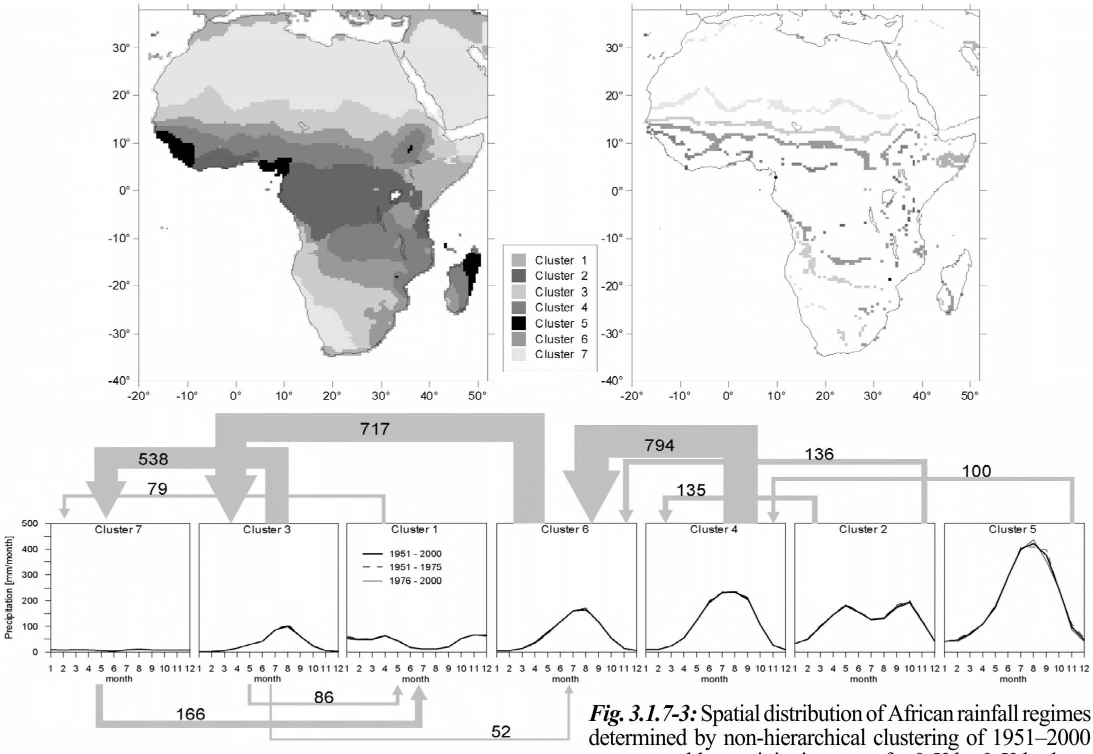

Fig. 3.1.7-3: Spatial distribution of African rainfall regimes determined by non-hierarchical clustering of 1951–2000 mean monthly precipitation sums for 0.5° by 0.5° lat-long gridcells (upper left panel). Spatial distribution of African rainfall regimes for the period 1976–2000 for gridcells which are designated to different rainfall regimes in 1951–1975 and 1976–2000, respectively (upper right panel). Long-term mean annual cycles of rainfall regimes 1 to 7 calculated for the periods 1951–2000, 1951–1975, and 1976–2000. Arrows indicate major redistributions between rainfall regimes from 1951–1975 to 1976–2000. Numbers attached to arrows give the land area (in 1,000 km^2) that changed from one rainfall regime to another (lower panel).

area prone to degradation and desertification the question arises if detected long-term precipitation variations result in spatial shifts of rainfall regimes.

Major African rainfall regimes characterised by their respective mean annual courses in precipitation have been determined by non-hierarchical cluster analysis of long-term averages of monthly precipitation sums for the period 1951–2000. Spatiotemporal variations of the resulting regimes were analysed by assigning individual grid-cells to clusters utilising cluster centres determined for the period 1951–2000 and gridded long-term averages of the sub-periods 1951–1975 and 1976–2000 respectively.

Fig. 3.1.7-3 illustrates that distinct redistributions between rainfall regimes – in terms of land area assigned to clusters – occurred between the 1951–1975 and the 1976–2000 period. Thereby changes from wetter to drier rainfall regimes are clearly dominating. Most striking appear expansions and shifts of Clusters 6, 3 and 7 that can be summarised as a spread of dry climates towards the equator on the cost of more humid rainfall regimes.

Conclusions

Analyses of long-term precipitation variations over Africa during the 2nd half of the 20th century show significant negative trends in precipitation sums and as well corresponding significant increases in drought severity described through the Standardised Precipitation Index (SPI) particularly in regions between 0° and 20°N and in northern parts of southern Africa. The comparison of the two periods 1951–1975 and 1976–2000 concerning the percentage of land area designated to major rainfall regime types determined applying non-hierarchical cluster analysis yields a distinct expansion of arid and semi-arid climates on the cost of more humid climates particularly in sub-Saharan and southern African regions. These detected hydroclimatic changes in conjunction with increasing temperature trends that have been reported for most parts of Africa for the 20th century (Hulme et al. 2001) correspond with observed water related environmental changes including the disruption of growing conditions and resulting crop failures and particularly processes of desertification in arid, semi-arid and dry sub-humid areas of Africa (e.g. Gonzalez 2001). This not only highlights the high vulnerability of African ecosystems to recent hydroclimatic variations but moreover foreshadows the potential impacts of possible future climate change♦