

Defining the onset and cessation of the rainy season for Tanzania

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1 Introduction and methods

1.1 Overview

In various parts in Sub Saharan Africa, the onset of the rainy season is crucial for the crop development in the first development stages after sowing (Omotosho et al. 2000). After sowing, insufficient crop water conditions increase the risk of crop failure. In particular in years with late rainy season onsets, the crop yields response very sensitive (Sivakumar 1990). In Tanzania, the growing season is strongly influenced through the yearly amount and intra-annual distribution of precipitation. Within Tanzania, the yearly amount of precipitation and the rainy season onset and cessation are quite heterogeneous (see Trans-SEC – Weather analysis for Tanzania and FAO 2015). Accordingly, farmers have to adapt their management on the regional rainy season circumstances.

The rainy season onset can be defined by various methods. The method used by Omotosho et al. (2000) based on an analysis of the atmospheric conditions (temperature and upper winds in the inter-tropical discontinuity). Vrieling et al. (2013) calculate the onset and the variability of the rainy season by the Normalized Differenced Vegetation Index (NDVI) from remote sensing time series data. For a region in Kenya around the Lake Victoria, Mugalavai et al. (2008) take the modeled soil water content as onset and cessation definition criteria for an average soil. Another opportunity is the direct use of precipitation records (P). This has the advantage that (i) mostly, precipitation has a higher density of weather stations (in comparison to e.g. solar radiation), (ii) precipitation has a clear intra-annual variation in Sub Saharan Africa (in contradistinction to temperature), and (iii) precipitation is as easy observable climate variable (also observable without measuring instruments) the direct decision basis for agricultural practices of farmers. Thus, assessments of the rainy season onset and cessation based on precipitation records are a powerful and low data demanding opportunity. For the implementation on rainy season onsets, various definitions exist, which based on fulfilled restrictions. These restrictions are mostly very similar, but the criteria of the restrictions differ substantially among the regions.

1.2 Rainy season criteria

To define the rainy season onset, a large range of definitions using different restriction criteria exist in the literature. Odekunle (2006) recommends the number of rainy days rather than the amount of precipitation for the calculation of the rainy season onset and cessation in Nigeria. In Average (across the years), the precipitation amount archives a similar result as the number of rainy days. However, considering inter-annual variability, the number of rainy days leads to more plausible results. To identify the rainy season onset and cessation, Odekunle (2006) use the perceptual, 5 days running average cumulative precipitation curve. From this curve, he takes graphically the first point of a positive curvature as onset and the last point of the negative curvature as cessation. For Australia, Cook and Heerdegen (2001) describe the spatial variation of the rainy season duration and onset based on probability¹ of a 10 day dry spell. For their analysis, they calculate the probability by a 10 days running average. The onset is defined as far as the probability is below 0.5.

A comparatively simple approach is use by Waha et al. (2012) for their global crop yield model LPJmL. Depending on the region, the sowing of annual crops is limited either by temperature or precipitation. In the region Tanzania, the sowing date is limited by the precipitation. The algorithm for a precipitation limited region defines the precipitation around the month with the largest sum of monthly precipitation-to-potential-evapotranspiration ratios of four consecutive months as main rainy season. The first precipitation day ($P_d \geq 1$ mm) within the main rainy season is defined as onset of the rainy season and is equally the sowing date.

For the period from 1978 to 2002, Kniveton et al. (2008) show a trend of later occurring rainy season onsets for Africa. However, their results strongly depend on the onset restrictions. As restriction, they use an definition after Stern et al. (1982), which is frequently use for Africa in agro-climatological applications: "(i) the start of the wet season is not considered until after a particular date, d ; (ii) the potential start date is defined as the first occurrence of at least l mm totaled over k consecutive days; and (iii) the potential start could be a false start if a dry spell of n or more days in the next m days occurs afterwards. The variables d , k , l , m , and n can be defined locally according to user requirements."

Moeletsi and Walker (2012) and Reason et al. (2005) use a similar definition for South Africa. Moeletsi and Walker (2012) use as criteria for the restriction "the last day in which rainfall of 25 mm or above has been

¹However, they do not describe the method behind the word *probability*. As method is a simple cross section analysis across the years, a Bayesian probability, or an estimator by Maximum-Likelihood possible. However, since the method is not further described, I expect they take the simplest.

accumulated over the previous 10 days and at least 20 mm accumulated in the subsequent 20 days.” Reason et al. (2005) take the ”date of the first two pentads with at least 25 mm of rainfall, provided this is followed by four pentads within which at least 20 mm of rainfall occurs.”

For Ethiopia, Segele and Lamb (2005) compare the rainy season onset and cessation with different methods (e.g. upper winds and precipitation restrictions) and different criteria for the precipitation restrictions. As onset criteria, they take, for instance, a precipitation sum of > 20 mm within three days and without a dry spell (< 0.1 mm precipitation) longer than 8 days within the following 30 days. The cessation is defined as date where 20 or more following days occur with precipitation less than 0.1 mm. Therefore, Segele and Lamb (2005) test different definitions of both rainy days ($0.1, 5, 10$ mm d^{-1}) and dry spells (three contiguous dry days (< 0.1 mm d^{-1}), five contiguous days with less than 5 mm rain on any day (< 5 mm d^{-1}), or five contiguous days on which rain do not exceed 10 mm d^{-1}).

1.3 Definition

The most common method of onset definitions for Africa is an algorithm based on fulfilled precipitation restrictions (see Stern et al. 1982). The simplest restriction takes the first day (expressed in days of the year (doy)) with more than 1 mm precipitation (P) as onset of the rainy season (Waha et al. 2012):

$$\text{doy}_{onset} = \text{doy}_d \quad \{ P_d \geq 1 \quad (1)$$

Equation (Eq.) 1 can be expanded by more restrictions (e.g. to prevent that in following 25 days after onset no dry spell occurs²) and specified by changed restriction criteria (e.g. 10 mm d^{-1} instead of 1 mm d^{-1}). Based on the literature and various tested restriction criteria, we use the following approach to calculate the date for onset of the rainy season:

$$\text{doy}_{onset} = \text{doy}_d \quad \left\{ \begin{array}{l} P_d \geq 1 \\ \sum_{d=1}^5 P_d \geq 10 \\ \sum_{d=6}^{30} P_d \geq 1 \\ \text{doy}_{onset-1} < \text{doy}_{cessation-1} \end{array} \right. \quad (3)$$

For the cessation, we calculate the date by the Eq. 4. The last restriction make sure that onset and cessations (Eq. 3 and 4) alternate.

$$\text{doy}_{cessation} = \text{doy}_d \quad \left\{ \begin{array}{l} \sum_{d=1}^{20} P_d < 10 \\ \text{doy}_{onset-1} > \text{doy}_{cessation-1} \end{array} \right. \quad (4)$$

To consider the short and long rains, a further restriction is used. These restriction investigates whether the following 90 days after the end of the rainy season have summed more than 20 mm precipitation. In that case, a second rainy season (with the same onset restrictions) is considered. In particular, whether the onset and cessation dates are averaged by years, the consideration of more than one rainy season is important. Otherwise the onset date will be delayed and the cessation will be calculated premature due to this aggregation.

2 Results and discussion

Fig. 1 shows the observed average distribution of precipitation for different weather stations. On the bottom of each plot are the onset and cessation dates calculated by Eq. 3 and 4. In the case of only one rainy season (see above for the definition), the symbols ($\Delta, +$) are black, for two or more rainy seasons, the symbols are gray. The plots based on the average of the years from 1970-2006, thus black and gray symbols are in the plots. For the regions around Dodoma and Songea, a clear cut between dry and rainy season is observable, while for Bukoba and Mwanza, the rainy season occurs over the whole year with changing intensities.

Fig. 2 shows the variation of the onset dates over the years. To test whether there is a shift of the onset dates within the observed period, a trend analysis is shown for the onset dates. Therefore, we utilize the Mann-Kendall

²Since the crops are able to survive for short periods without sufficient water supply, but longer dry spells (ds) are critical for the crop development, the days without precipitation (dwp)

$$dwp < 10 \quad \left\{ dwp = \sum_{d=1}^D ds_d \quad \left\{ \begin{array}{l} \text{if } P_d \neq 0, \quad ds_d = 1 \\ \text{if } P_d = 0, \quad ds_d = 0 \end{array} \right. \right. \quad (2)$$

can be useful variable. This variable takes into account the plant requirements, while the approach of a precipitation amount within a specific period considers only the amount within one period, but not distribution.

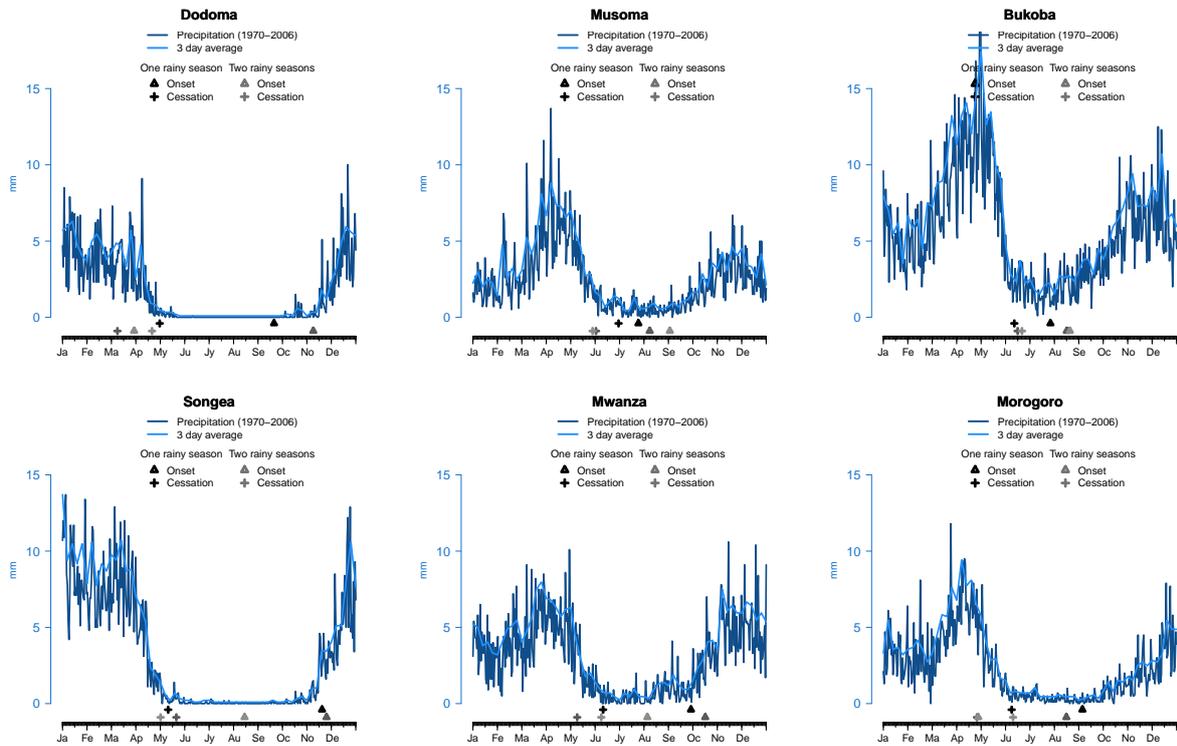


Figure 1: Onset and cessation dates for the rainy season for different weather stations (bottom). The blue line shows the average intra-annual precipitation distribution.

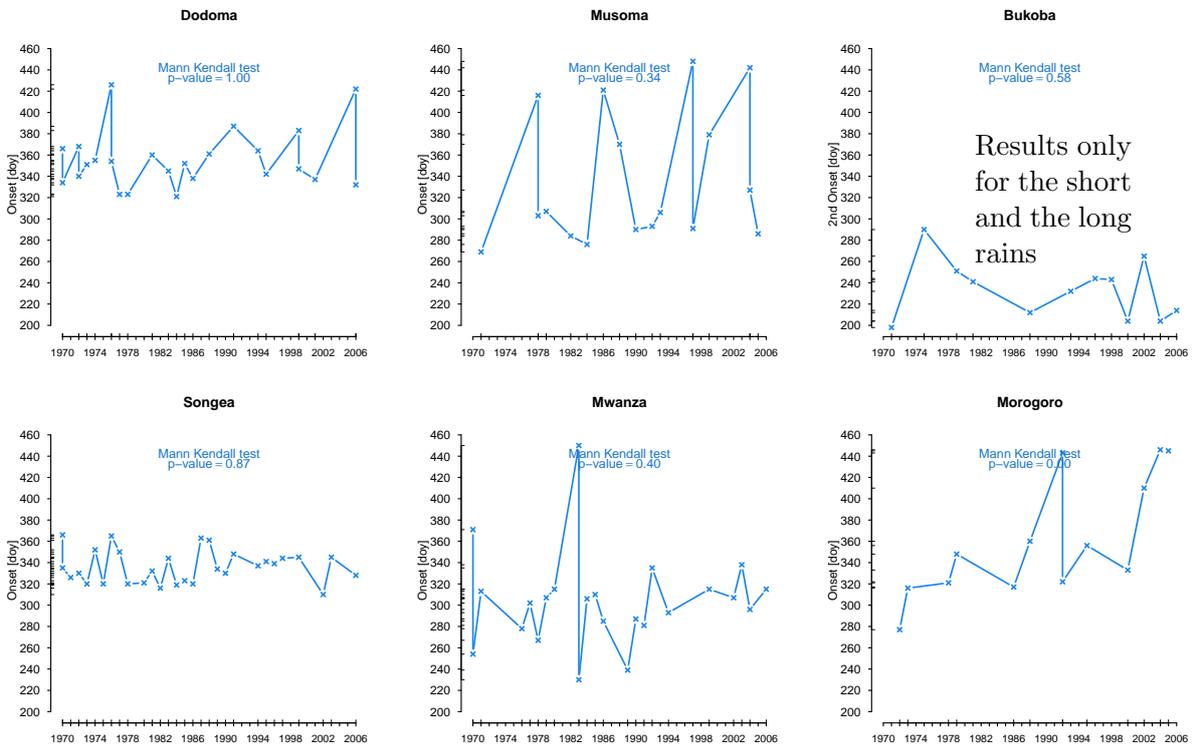


Figure 2: Onset day's (days of the year) variation over the years. The doy 365 is December 31st, the doy 366 is January 1st. The Mann Kendall test shows whether there exists a significant trend over the time. A p -value below 0.05 means there is a significant trend, above 0.05 there is no significant trend in the time series.

test to check whether the time series has a significant trend. If the p -value of this test is $p \leq 0.05$, the time series contains a trend; if $p > 0.05$, no trend is observable. For onsets around December and January (of the following year), the averaging of the day's leads to a technical problem, because June is the average of the December and January. Therefore, we split the year at the 200th day. All days below day 200 are shown as extension of the year (day+365). For all tested 16 weather stations (not all shown in the figure), only Morogoro has a significant trend for the onset for one rainy season per year. In the case of two or more rainy seasons, no weather station has any trend. Since the Morogoro trend only based on 13 observations (in the other years are two rainy seasons) and the Morogoro dataset is compounded by two datasets, the trend might be an error.

Fig. 3 shows the calculated average onset and cessation dates for entire Tanzania. The calculation based on reanalysis weather data (WFDEI 1979-2012). In the maps are clear regional patterns for the onset and cessation dates. These patterns are (more or less) in line with the onset and cessation dates from the remote sensing data observed by Vrieling et al. (2013) and the estimated precipitation data from the FAO (2015).

2.1 Opportunities for improvement

Due to the heterogeneous yearly precipitation amounts within Tanzania, static onset restriction criteria are regional only limitedly able to differentiate between dry and rainy season. In wetter regions with rain events during the “dry season” the rainy season doesn't end (e.g. Fig. 1, Bukoba, Mwanza). In the semi-arid regions in Tanzania (e.g. Fig. 1, Dodoma, Songea) are the restrictions too strong so that in several years the conditions for the onset are not fulfilled. Laux et al. (2008) also argue that constant restrictions lead to unfulfilled restrictions in regions with low precipitation (no onset in one or over more years) and ongoing rainy seasons in wetter regions over more years. Thus, they use a fuzzy logic approach. This approach considers different “dry” and “wet” levels as semi-constant criteria. Boyard-Micheau et al. (2013) use a multivariate analysis for determining the onset and cessation for Kenya and Tanzania. They criticize that the approach with constant restriction criteria rarely is transportable to other crops and other climate environments. To solve this problem, they calculate the onset for all stations, for all years and various combinations of onset restrictions (k , l , m , and n). In a following step, they estimate the impact of the single criteria by a principal component analysis.

2.2 Rainy season, sowing date and farmer behavior

Frequently, farmers sow before the actual rainy season onset (dry seeding) or they start sowing only with the big rains (Graef and Haigis 2001). In both cases, rainy season onset and sowing date are not at the same day. In the case of dry seeding, the crop growing season starts at the rainy season onset (after the sowing date). The duration of the growing season depends on the crop selection; hence the cessation of the rainy season is not equal with the harvest date. This leads to the question, are the onset date calculated by Eq. 3 a good proxy for the sowing date?

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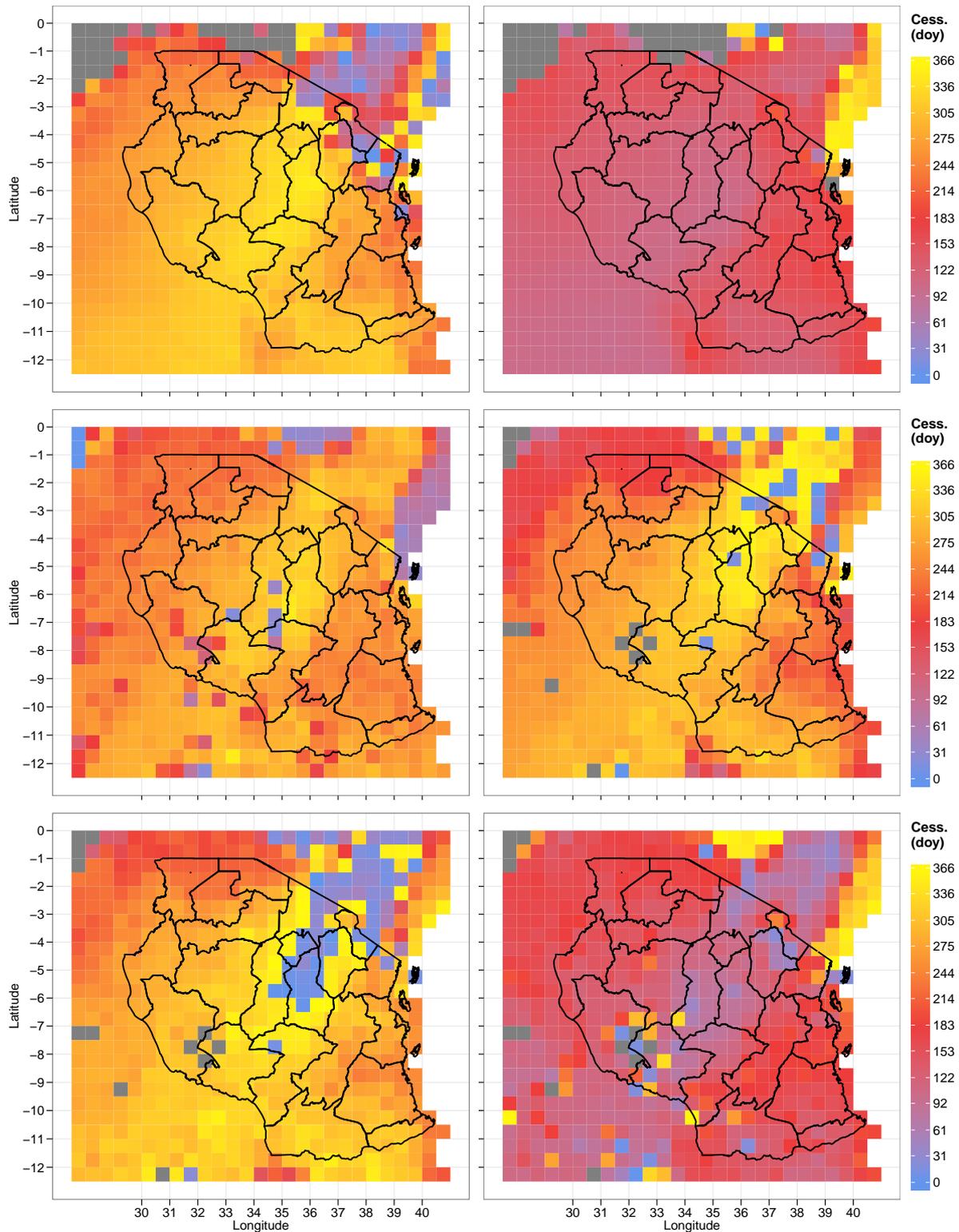


Figure 3: Average onset doy's (days of the year) for entire Tanzania based on WFDEI reanalysis weather data (0.5° grid data). Average onset doy's (left) and average cessation doy's (right) of areas with one rainy season (top), for the first (mid) and the second rainy season (bottom).