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Seasonal parameters of vegetation in the eastern Sahel

1 Introduction

The plant phenology index (PPI) is a relatively new vegetation index that is often used for vegetation monitoring. It is calculated using near-infrared and infrared reflectance and is closely related to leaf area index (LAI) and gross primary production (GPP) (Jin & Eklundh, 2014). It can thus be used to measure plant growth and seasonal parameters like start, end and length of the season. In this project, measurements of PPI will be used to investigate the seasonal parameters of an area in the northeastern African Sahel during a 19-year time span.

The area is located between 10-20 degrees north and 20.3-31.9 degrees east, as seen in the image below (Fig. 1, left image) where the area's corners are marked by the red icons. It's a semi-arid region associated with high climate variability and risk (Buontempo et al, 2012). It borders the Sahara Desert in the north, where rainfall is less than 200 mm/year, and tropical forests in the south that receive up to 800 mm/year. The area experiences a single rainy season, between June and September, with a maximum in August and the absolute majority of the annual rainfall occurs during these months (Buontempo et al, 2012; Biasutti, 2019). It has different types of land cover such as cropland and grassland as well as deciduous forest and shrubland, but also contains large areas of unvegetated desert (European Space Agency Climate Change Initiative, 2020). The climate of the Sahel generally varies from north to south, while it's more homogenous on an east-west basis (Biasutti, 2019). The elevation of the area ranges between around 400 and 1400 meters (Viewfinder Panoramas, 2022).

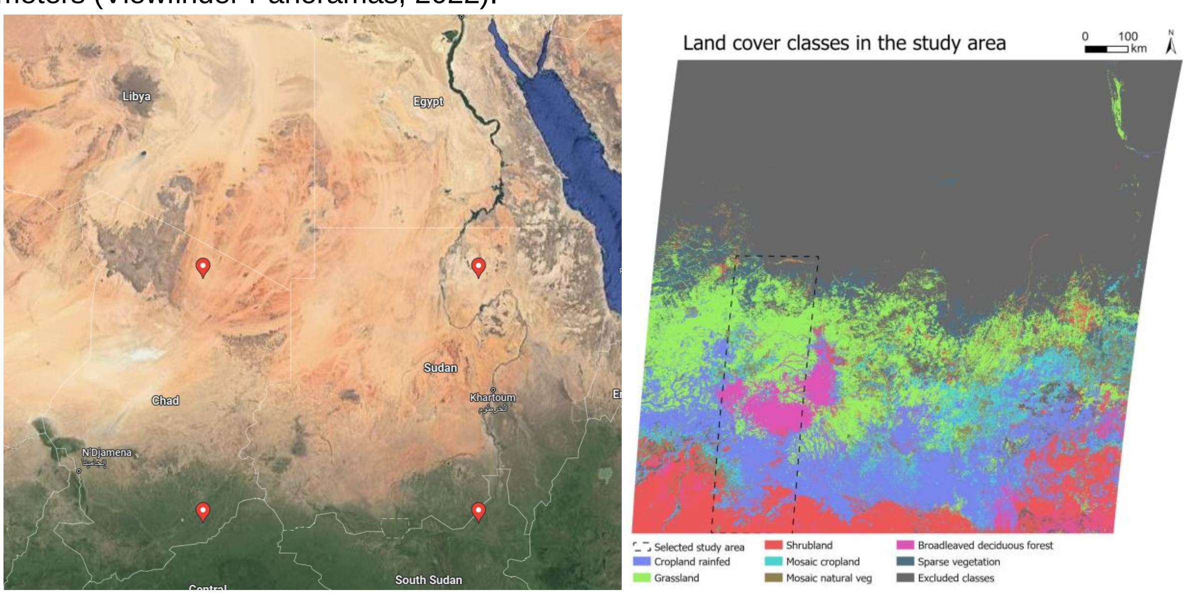

Figure 1: Orthophoto of the study area (entire tile) and surroundings (left) (Google maps, 2022) and land cover classes of the study area, including the boundary of the subset area (right) (ESA-CCI, 2020).

The investigation of the seasonal parameters will be done using PPI data generated from MODIS data and image processing software. This includes the start, end and length of the vegetation season as well the seasonal integrals and spatial distribution. It will also look into precipitation and elevation, and investigate the relationships between these and the seasonal parameters.

Because of the semi-arid climate, we assume that precipitation is the main limiting factor for vegetation productivity and that the timing, duration and amplitude of the vegetation season thus will correlate with the rainy season. We also assume that there will be a slight correlation between elevation and vegetation productivity, due to less precipitation being associated with higher elevation in dry areas.

2 Method and data

The main data of this study was a set of MODIS images covering tile H20V07 in the MODIS sinusoidal grid from the years 2001-2020. The years 2002, 2011 and 2019 were chosen for display in this report due to space and time limitations, although for some parts of the results other years were also examined however not displayed. The temporal resolution was 8 days, resulting in 46 images a year and 920 images in total. The spatial resolution was 500 meters and each image had 2400x2400 cells. However, due to time constraints, a north to south subarea within the tile was chosen to be used for interpretation, since it was clear that the biggest difference in land cover was on a north to south gradient. The subarea was situated between columns 400-800. Since the rows 1400-2400 were dominated by desert, these were excluded from the subarea, resulting in a 401x1401 cell window (dashed rectangle in fig. 1, right image). The reason for this particular subarea being chosen was also due to it being considered one of the areas within the whole study area containing the biggest diversity of land cover classes, which would make it especially interesting for this vegetation study. Land cover data was gathered from the European Space Agency Climate Change Initiative (ESA-CCI), and the seven most dominant land cover types were selected: cropland (rainfed), grassland, shrubland, sparse vegetation, deciduous forest, mosaic dominated by natural vegetation and mosaic dominated by cropland. Other classes were excluded, including most of the desert (dark gray in fig. 1, right image), since these were assumed to not have any vegetation. Excluded pixels were given a value of 0.

Monthly precipitation data was gathered from ERA-5, and the total amount of rainfall was calculated for each year. Elevation data was downloaded from Viewfinder Panoramas. Three years within the twenty-year time series were selected for presentation in this report: 2002, 2011 and 2019. Both precipitation and elevation data were plotted against the seasonal parameters.

The image processing was done using the TIMESAT software package, as well as ArcGIS Pro and TerrSet. Both Savitzky-Golay and Asymmetric Gaussian model fitting methods were used to smooth the vegetation index data based on different land cover classes. The fitting method chosen depended on which one was considered to fit the best for that particular land cover class.

3 Results

3.1 Season start and end

All three years presented in the fig. 2 show an earlier start of season in the south, around the end of May/beginning of June or slightly later (day ~170-180). Further north, the season starts progressively later. In some pixels, the season doesn't start until the beginning of August (day

~220). The images in fig. 2 imply that an earlier start of season (around the end of May/beginning of June) is spreading from the southern area and moving northward through the study area over time. In the northern parts there are instead signs of a slightly later start of season in 2019 (approximately in the beginning of September), than in 2002.

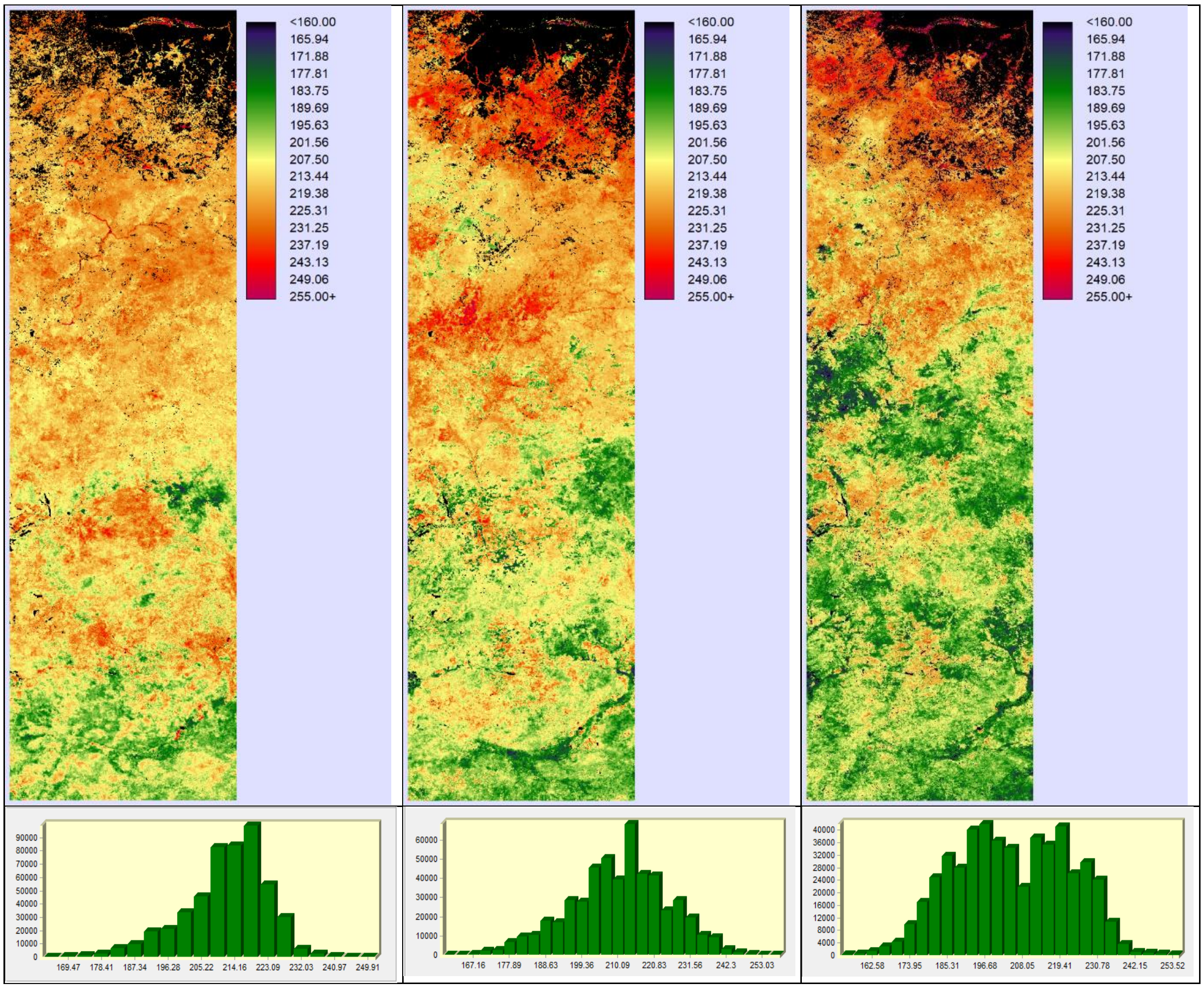

Figure 2: The start of vegetation season for three different years in the Sahel, described as day of year in the legend. Left: 2002, middle: 2011. right: 2019. Histograms showing the distribution of vegetation season start dates.

The end of the season (fig. 3) varies a lot between the areas, but follows a similar pattern to the start of season. It generally ends later in the south than in the north and the southern part seem to have a slightly earlier end of season in 2019 (beginning of October) than in 2002, while some parts in the middle of the study area seem to have a later season end in 2019 (the end of November).

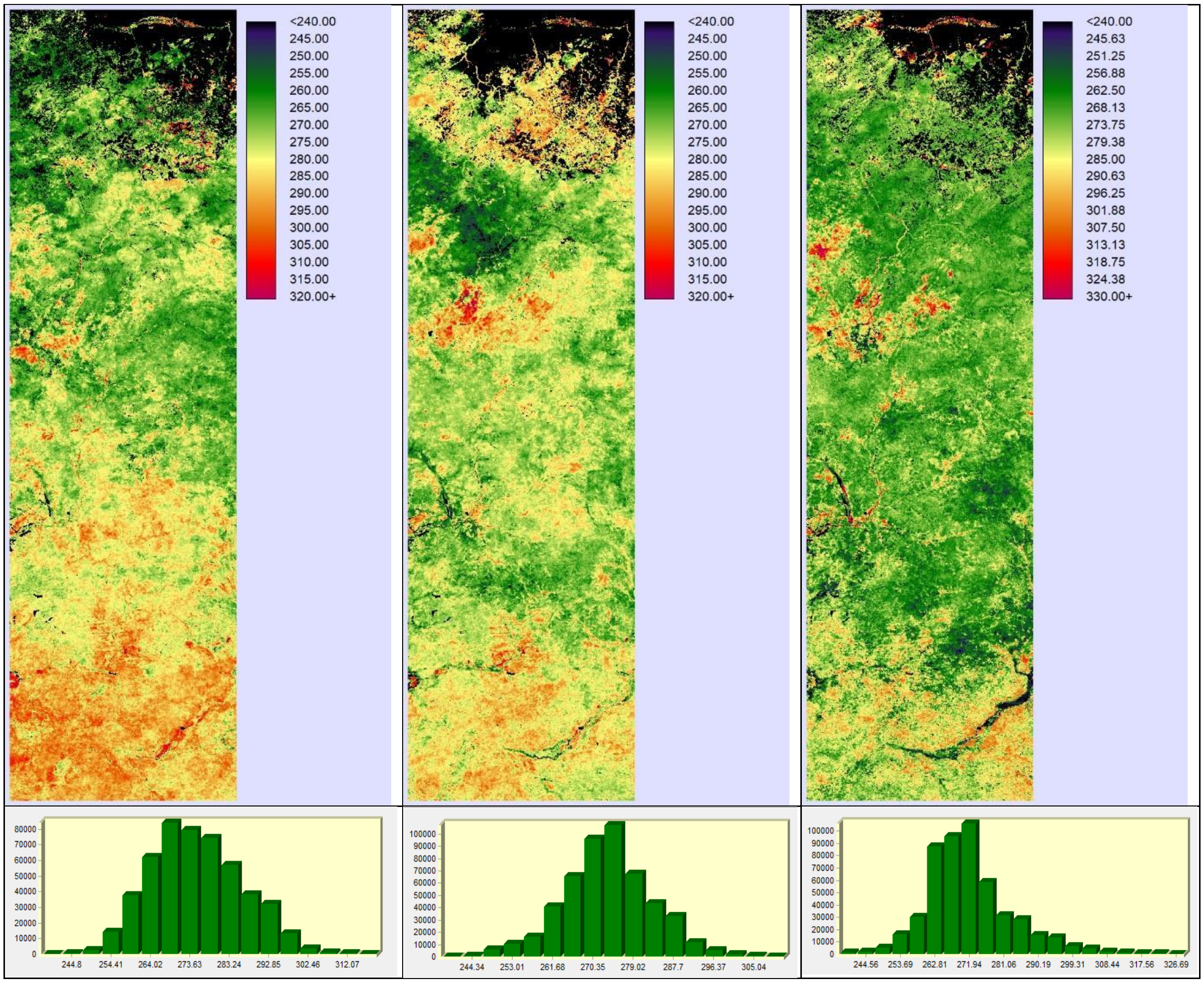

Figure 3: The end of vegetation season for three different years in the Sahel, described as day of year. Left: 2002, middle: 2011, right: 2019. Histograms showing the distribution of vegetation season end dates.

3.2 Season length

The season length in the northern part doesn't seem to change much throughout the years (fig. 4). Roughly, the season length ranges from 40 days in the north to 110 days in the south. In the middle of the area as well as in the lower east corner, there seems to have been an increase in season length.

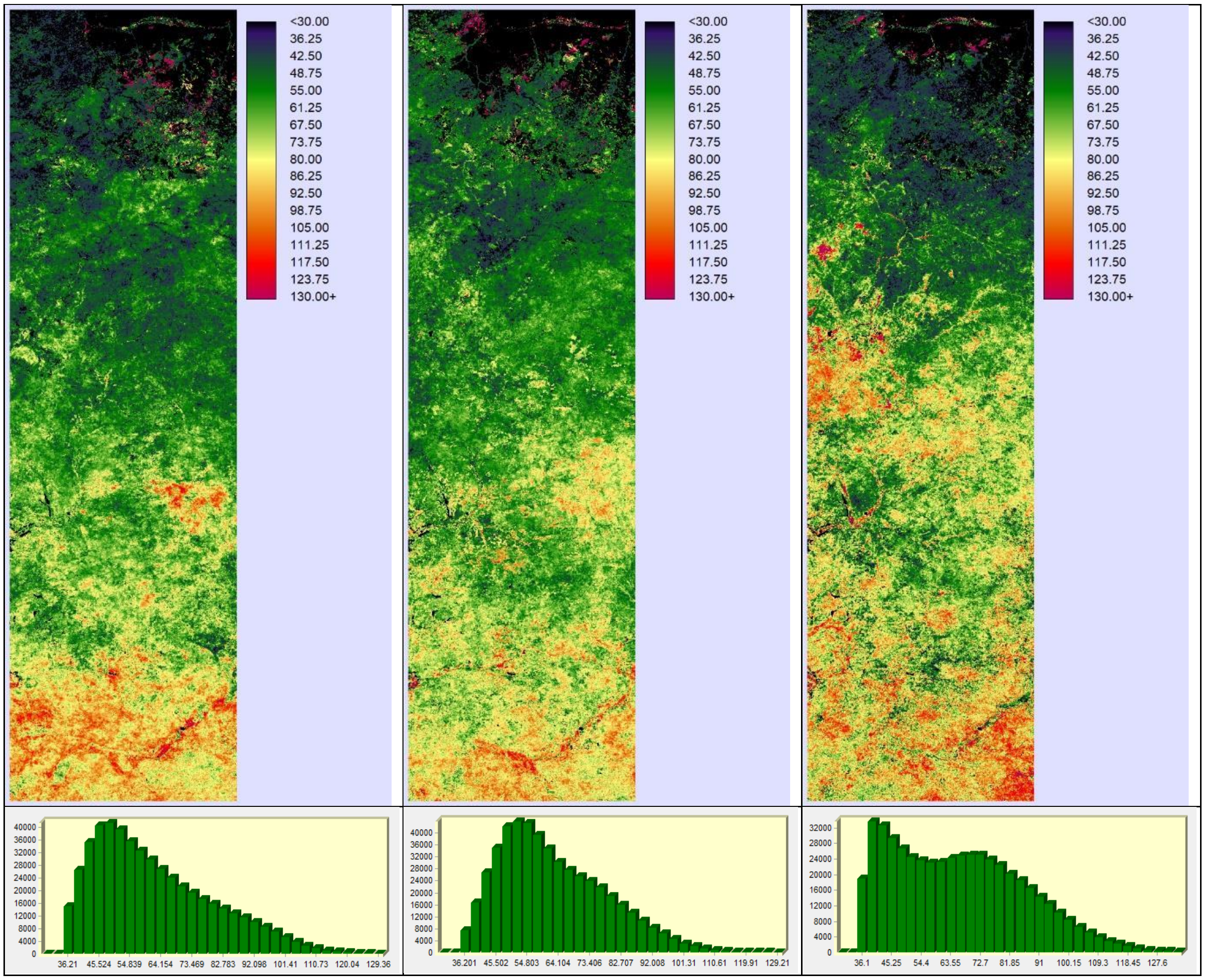

Figure 4: The length of vegetation season for three different years in the Sahel, described as days. Left: 2002, middle: 2011, right: 2019. Histograms showing the distribution of season length.

3.3 Seasonal integrals

Since PPI is closely related to GPP, the small and large integrals can be interpreted as a measurement of the productivity of the ecosystem. The large integral covers year-round vegetation productivity, whereas the small integral only covers the seasonal productivity (Davis et al., 2017). The difference between the two integrals is quite small, implying that the ecosystem is fairly unproductive during the dry season. Both integrals (fig. 5 and fig. 6) show higher values in the south of the area, implying that the ecosystem productivity here is larger than in the north.

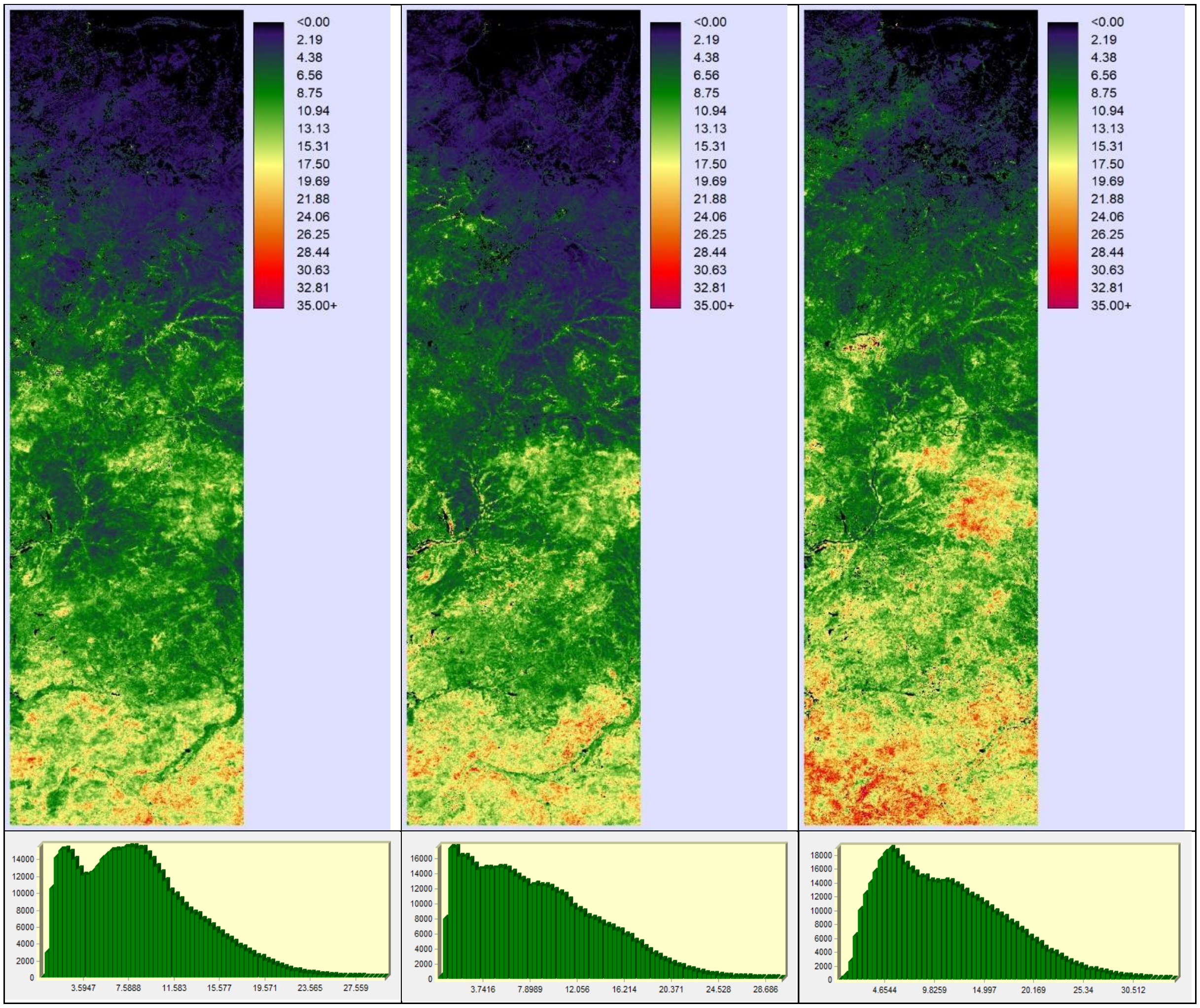

Figure 5. The small integral for three different years in the Sahel, described as total PPI. Left: 2002, middle: 2011, right: 2019. Histograms showing the distribution of seasonal productivity.

Fig. 7 shows the small integral for one pixel belonging to each of the land cover classes. This graph implies that the pixel belonging to deciduous forest had the highest productivity over the years, whereas sparse vegetation and grassland were the least productive. There is a high annual variability across all classes but no clear trend over the time period.

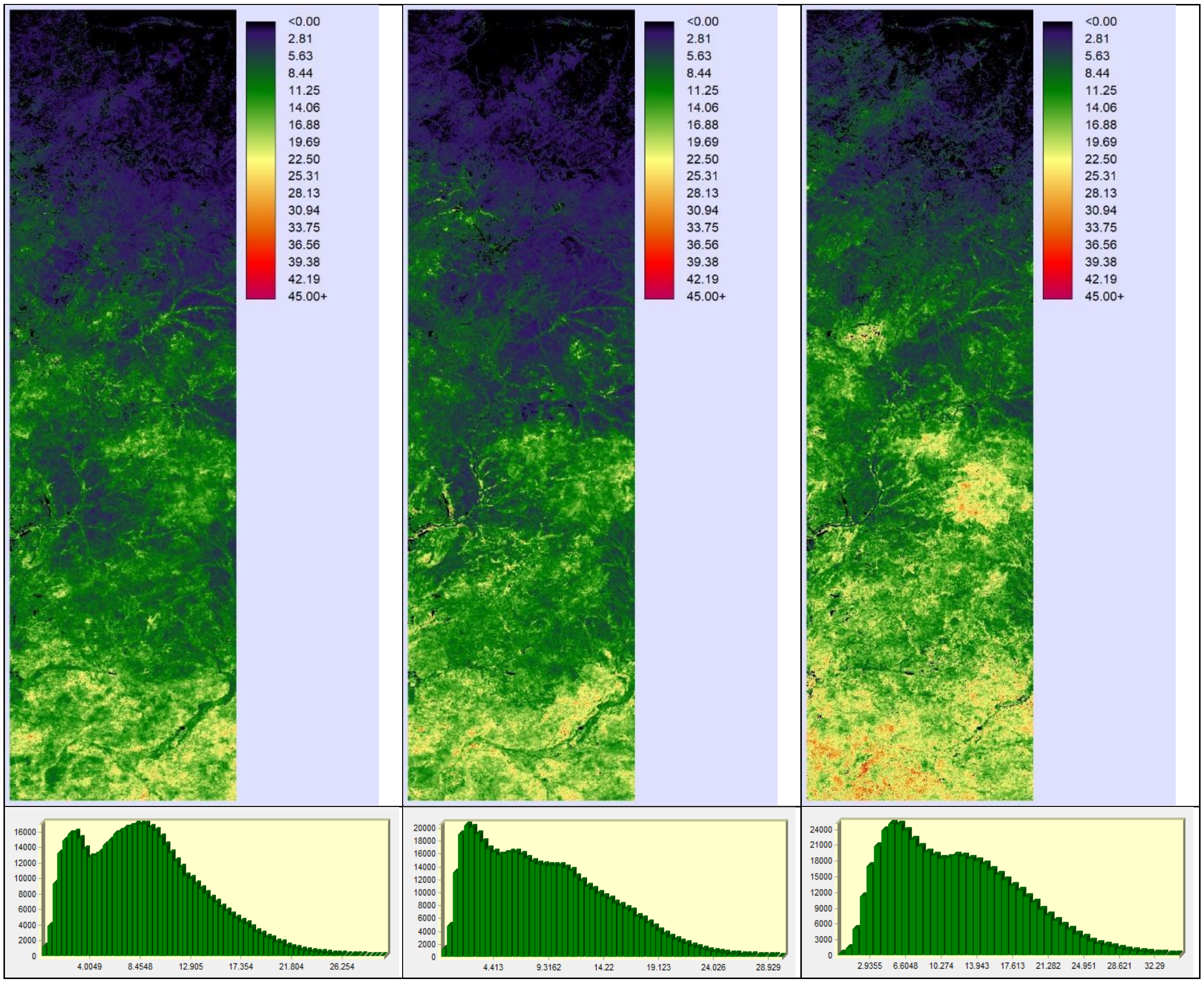

Figure 6. The large integral for three different years in the Sahel, described as total PPI. Left: 2002, middle: 2011, right: 2019. Histograms showing the distribution of vegetation productivity.

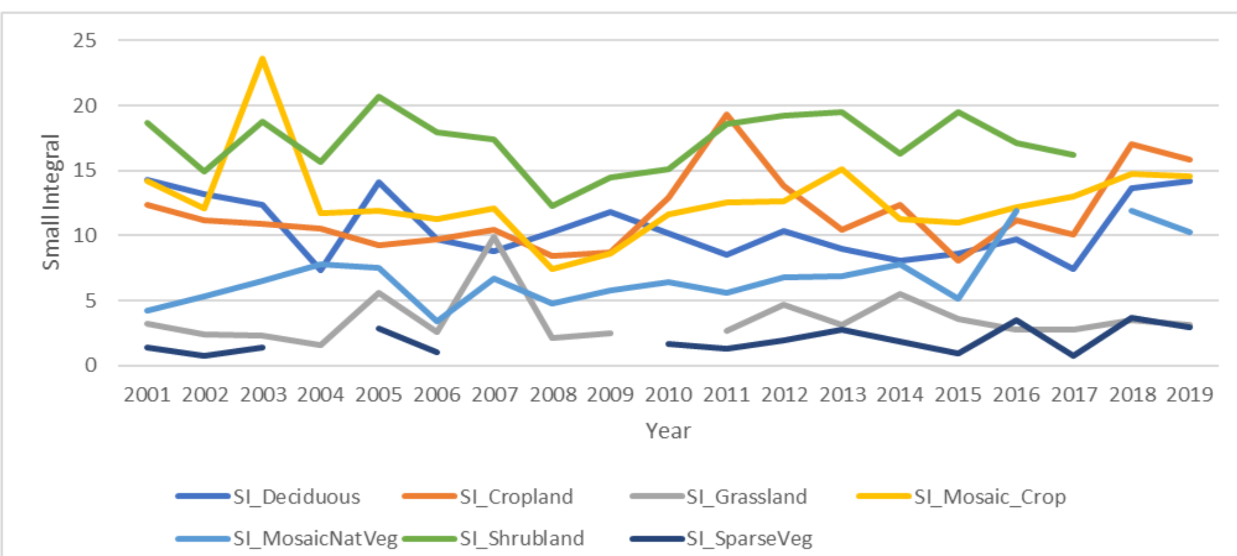

Figure 7. The small integral (SI) of one pixel belonging to each of the land cover classes.

3.4 Precipitation and elevation

When plotting length of season (fig. 8) and the small integral (fig. 9) against the annual precipitation, there was a strong correlation between the two variables, implying that higher precipitation leads to higher vegetation growth and a longer season. The correlation is slightly stronger with the small integral. The R^2 values for the relationship between precipitation and length of season was 0.37, 0.41 and 0.27, respectively for the three years. For the relationship between precipitation and the small integrals, the R^2 values were 0.49, 0.58 and 0.52, respectively.

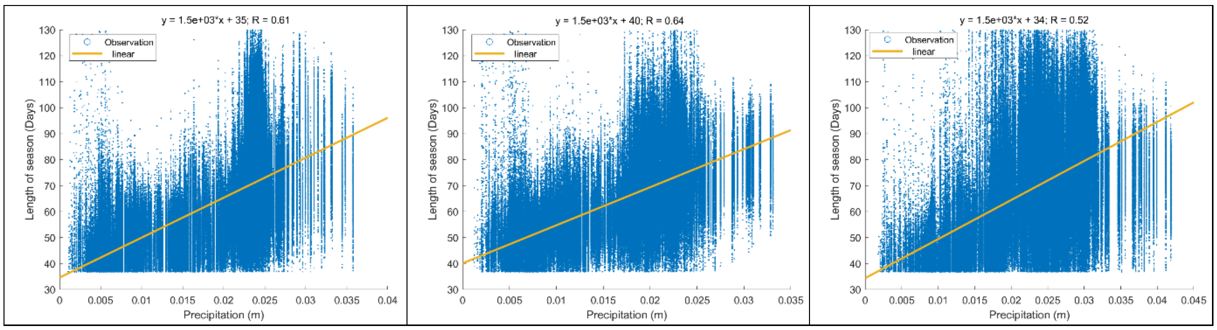

Figure 8: Relations between the spatial distribution of precipitation and length of seasons in three different years in the Sahel. Left: year 2002; R=0.61 and R^2= 0.37. Middle: 2011; R=0.64 R2= 0.41. Right: 2019, R=0.52 and R^2= 0.27.

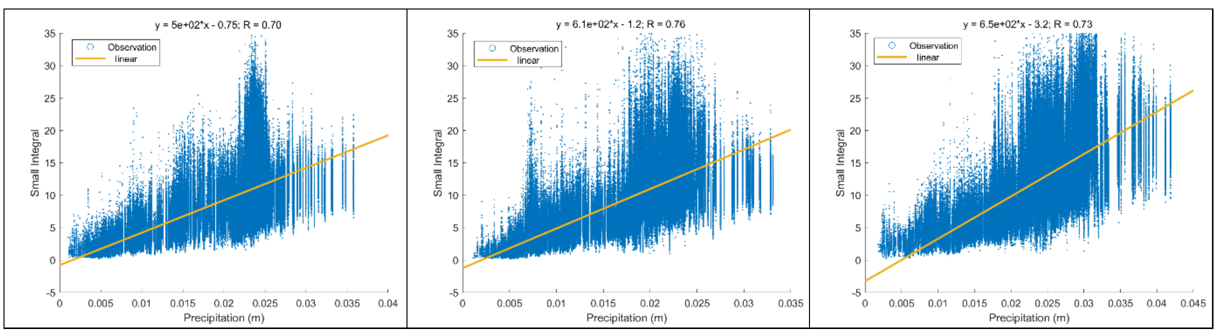

Figure 9: Relations between the spatial distribution of precipitation and small integral in three different years in the Sahel. Left: 2002; R=0.70 and R^2= 0.49. Middle: 2011; R=0.76 and R^2= 0.58. Right: 2019; R=0.73 and R^2= 0.52.

The seasonal parameters have also been plotted against elevation data to find potential patterns (fig. 10).

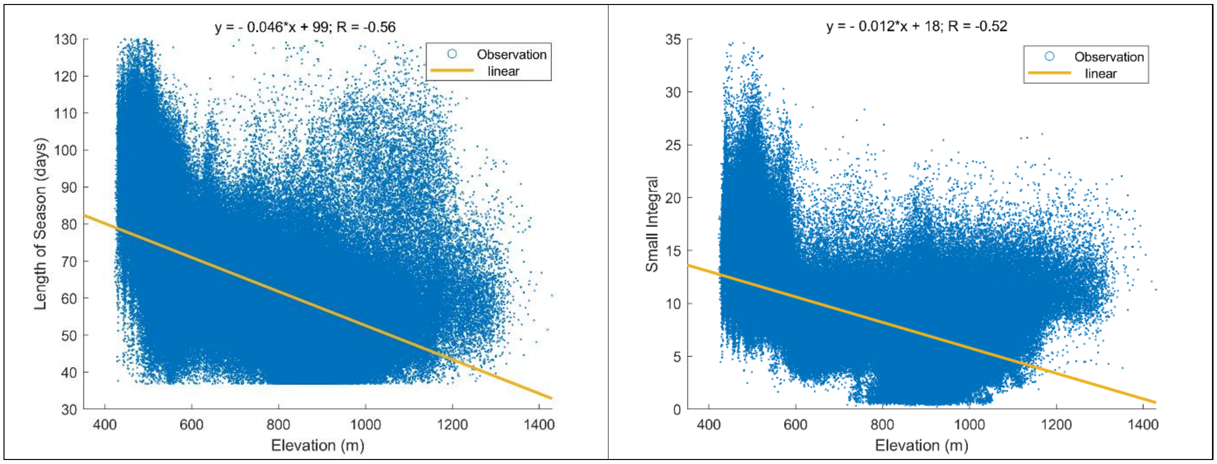

Figure 10. Relations between the spatial distribution of elevation and length of season (left, R = -0.56) and small integral (right, R = -0.52) in one representative year (i.e., 2002) in the Sahel.

As a result of the spatial distribution of rainfall and as seen in the figures above, the main spatial variability of length of season and ecosystem productivity follows a north-south gradient.

4 Discussion

There is a clear spatial pattern in both start, end and length of the vegetation season, going from north to south. The northern part borders the Sahara Desert and experiences very little precipitation whereas the southern part is wetter and borders tropical rainforest. This correlates well with the spatial distribution of rainfall, which also determines which vegetation types are dominating across the Sahel (Biasutti, 2019). This was clearly visible when comparing the land cover map used in this study to the precipitation data. Areas with low precipitation are dominated by shrubland and sparse vegetation while areas that receive higher precipitation are classified as grassland, cropland or deciduous forest.

There is also a strong correlation between the temporal distribution of precipitation and the timing of the seasons, since the start and end of season coincide with the rainy season for all years. Also, a strong correlation between the annual precipitation and season length and vegetation productivity could be noted. The strongest relationship was found between the small integral and precipitation. The higher R^2 value for a small integral than for season length makes sense, because the season start/end is probably mainly determined by the onset and withdrawal timing of the rainy season and not the total amount of rainfall.

We have only analyzed three independent years which is not enough to find any trend over the time period with certainty, even if it by visual inspection seems like the vegetation season is getting progressively earlier and longer. These three images of years 2002, 2011 and 2019 are just snapshots of the time period and the change could just as well be due to annual climate variability.

As for the future vegetation season in the study area, the predictions are complex. As discussed, the climate variability is high in the area, and this makes these future projections difficult

(Bountempo et al., 2012). With increased CO_2 emissions to the atmosphere, the productivity of the vegetation is expected to increase because of the reduced transmission as a response to reduced stomatal aperture (Berg et al., 2020) leading possibly to a longer vegetation season. Especially in the arid lands of the Sahel this is expected due to the severe lack of available water (Berg et al., 2020). A higher CO_2 concentration will at the same time lead to increased temperatures which likely will cause heat stress to a lot of vegetation types in this area and counteract the effect of the reduced stomatal aperture from the increased CO_2 concentrations (Berg et al., 2020). For example, when temperatures exceed 36 °C, many plants' reproductivity shuts down and with the RCP8.5 scenario showing that peak daytime temperatures might exceed 50 °C in some areas of the Sahel in the future, it's clear that this can have severe negative effects on the vegetation productivity and season (Berg et al., 2020). Most climate models do agree on a temperature increase in the area in the future with the mean temperature increasing more than the global average in the Sahel (Buontempo et al., 2012).

While precipitation is thought to be one of the most influential factors in vegetation season, different climate models projections have shown to not agree in the matter according to Buontempo et al. (2012) and there is no clear trend looking at the whole Sahel region. However, when looking at this project's particular area which is situated in the east of the Sahel, models seem to agree that there will be an increase in precipitation (Buontempo et al, 2012; Berg et al., 2020) which could have a positive impact on the vegetation season. Though, it is not only the total annual precipitation that matters, but also its temporal distribution. A longer vegetation season would require a longer rainy season. Extreme weather events like a large amount of rainfall in a short period of time could be more likely to damage the vegetation than benefit it, as it leads to erosion and loss of nutrients in the soil (Sepulveda et al, 2008).

Even though it is difficult to conclude any results of a trend or change over time, based on the results given in this report, if the study was to be conducted using a longer time span it would be easier to make out any trends and changes made to the east Sahels vegetation season. Overall, the time series of phenology data can be used to estimate the impacts of climate change as well as anthropogenic change that will portray our changing planet efficiently. Since vegetation parameters are very sensitive to environmental change i.e., changes in carbon balance and climatic variables, this can be a very effective proxy indicator to study global change.

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