# Identifying and mapping areas that are particularly vulnerable to changes in climate - White Nile and North Kordofan States, Sudan

Progress report, Output 2 of the project Developing Methodology and Capacity for Monitoring Climate Change and its Impacts on Agriculture in Sudan through Earth Observation

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## Contents

# Introduction

Like many other countries in the region, agriculture represents the most important sector of Sudan's economy, contributing to about 35% of the country's GDP or nearly 99% of the country's export earnings if we exclude the oil sector. Approximately 80% of the population is employed in agriculture and related activities. The agricultural sector is very vulnerable to climate change in general and to climate shocks and extreme events in particular, particularly when considering interactions with other stresses such as land degradation and poverty (Zakieldeen 2009). Having timely and spatially explicit information on rainfall events is critical for reducing the vulnerability of agricultural systems in the face of climate change, particularly in marginal agricultural areas. Also, being able to predict extreme events is important for mitigation efforts and for disaster risk management. Sudan established its first weather station as early as 1891 in Sawaken. However, in recent decades, the number of weather stations and rainfall gauges has dropped considerably, resulting in large data gaps. This has resulted in a lack of accurate estimation and prediction of precipitation, and in particular heavy precipitation, which is important for forecasting and managing floods, managing water resources, as well as drought early warning.

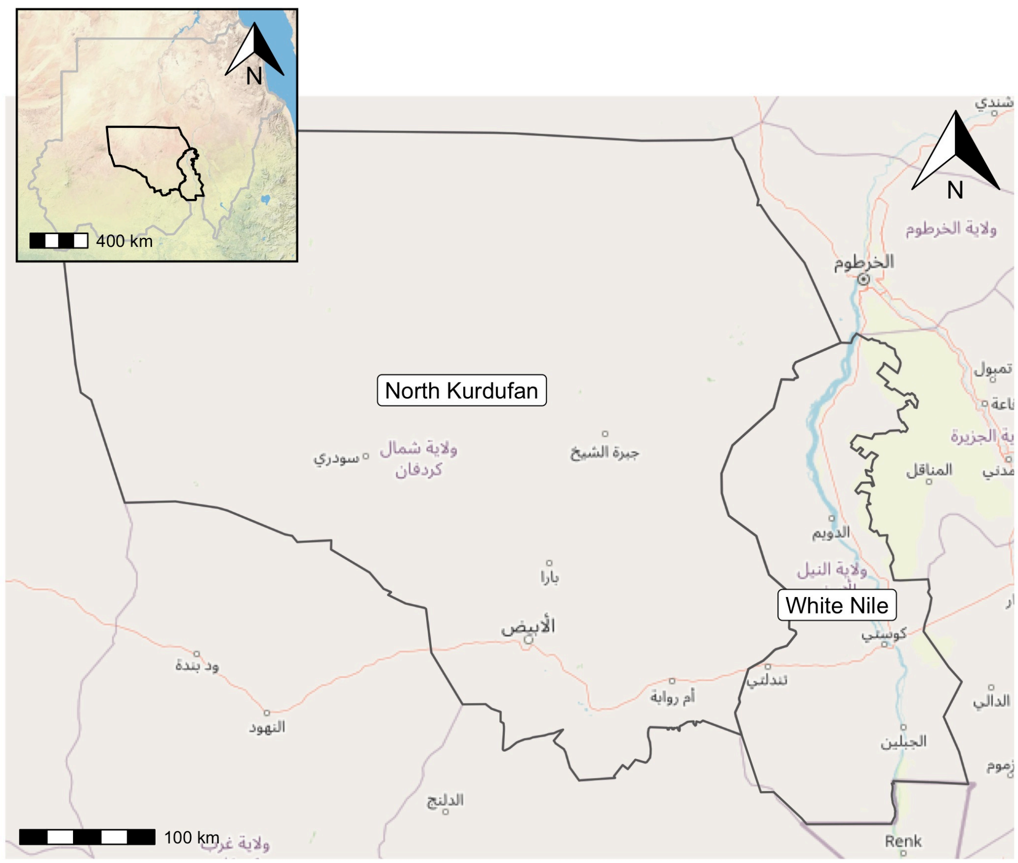


Figure 1: Map showing the locations of North Kurdufan and White Nile states. The inset map shows all of Sudan with the two stated outlined.

Sudan, which is one of the largest countries in Africa, has a climate that is characterized by strong variability, including erratic and highly variable rainfall. There is a strong rainfall gradient from the dry north to the less dry south, as can be seen in the maps for the years 2001 through 2018 in Figure 2. According to some studies rainfall is becoming increasingly unreliable, which is strongly affecting the agricultural sector given that it mostly relies on rainfed farming. While there has been a large expansion of cultivated area in Sudan over the last 5 decades, per unit yields of crops are decreasing due to a decline in soil fertility and increased land degradation (Ayoub 1999), coupled with the already mentioned erratic and unreliable rainfall. These trends are further exacerbated by climate change.

The assessments presented cover North Kordofan and White Nile states. White Nile state has an area of 39,701 $km^2$ and an estimated population of approximately 1,140,694 (2008 census). Since 1994 Rabak has been the capital of the state. Other important cities include Kosti and Ed Dueim. North Kordofan state has an area of 185,302 $km^2$ and an estimated population of 3,340,000 (2011 estimate). El-Obeid is the capital of the state. It is generally arid and has had frequent droughts since the mid-1960s.

This progress report presents outputs from **Output 2: identify and map areas that are particularly vulnerable to changes in climate** of the project. The status of the three activities under this output are as follows:

Activity 2.1: Climate data collection - complete

Activity 2.2: Database design - complete

Activity 2.3: Spatial datasets and associated analysis - complete. Outputs under this activity include analysis of:

- Number of days with rainfall
- Rainfall aggressiveness (or extreme events)
- Mean annual precipitation
- Annual temperature ranges

## Earth-observing satellites for mapping and monitoring of climate variables

This report presents analysis of climate vulnerability within White Nile and North Kordofan states in Sudan (Figure 1). We show data and analysis of rainfall and temperatures based on Earth-observing satellite measurements using the *Integrated Multi-satellitE Retrievals for GPM (IMERG)* data product. We use *Tropical Rainfall Measuring Mission (TRMM)* data to map rainfall distribution and evolution over the period 2001 to 2018, but focus primarily on the period from 2014 through 2019 using *Global Precipitation Monitoring (GPM)* mission data. With IMERG we can track and monitor precipitation event over both space and time.

These products combine observations from microwave and infrared satellite-based sensors, calibrated against a global network of rainfall gauges, and have been shown in studies to provide reliable estimates of rainfall, not least in semi-arid environments (Prakash et al. 2016). The rainfall that form the basis for our assessments has a spatial resolution of 10 km, with a temporal resolution of 30 minutes for the GPM data used. In other words, the IMERG data product provides both historical records of rainfall across large areas, as well as half-hourly precipitation measurements that allow for their application in near-real time assessments and forecasting of extreme rainfall events.

The application of these products in data-sparse environments such as Sudan can significantly improve systems for spatial mapping of rainfall events, durations and intensities, including forecasting of rainfall availability and distribution, prediction of extreme events and subsequent flooding and other hazards, as well as for drought early warning.

For the assessment of annual and monthly land surface temperatures, as well as trends, we used data from the *Moderate Resolution Imaging Spectroradiometer (MODIS)* platform's Land Surface Temperature (LST) and Emissivity product (*MOD21*) at a spatial resolution of 1 km. This product uses the three MODIS thermal infrared bands to dynamically retrieve both LST and emissivity, using a physics-based algorithm.

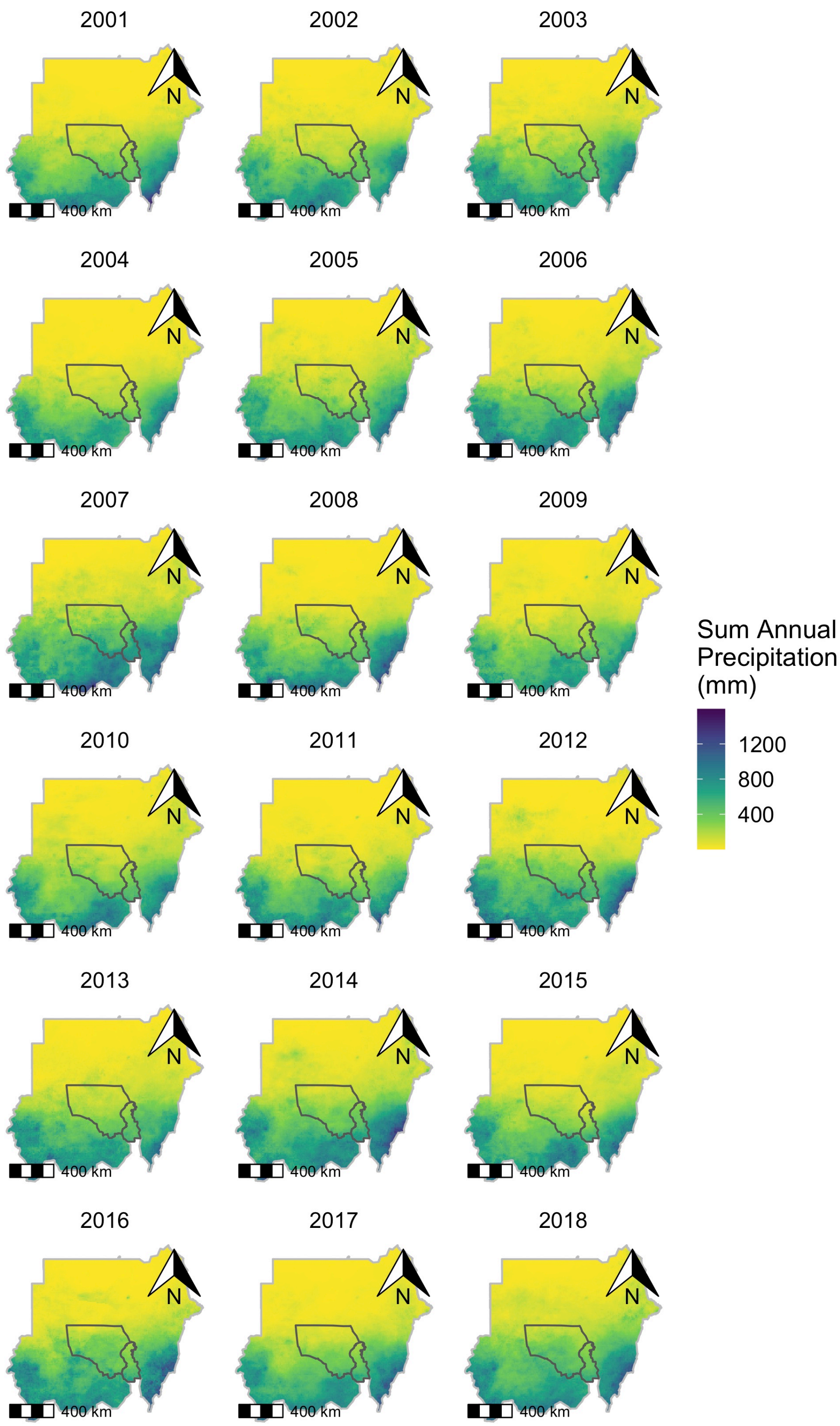


Figure 2: Annual rainfall (mm) for Sudan over the period 2001 to 2018. White Nile and North Kordofan states are outlined.

# Analysis of rainfall variations and trends

## Monthly and annual rainfall

Annual rainfall varies strongly within and between the two states covered by this assessment, as shown in Figure 3, reflecting the north-south gradient for Sudan overall Figure 2, as well as a gradient going from west to east. Data from the TRMM mission between 2001 and 2018 show higher than normal rainfall in 2007 (Figure 3), which was due to a strong El Nino Southern Oscillation (ENSO) event affecting rainfall in the region, with the La Nina stage resulting in much higher rainfall than normal from July to September 2007 (Gamri, Saeed, and Abdalla 2007).

Mean annual rainfall for White Nile state varied between about 370 and 570 mm over the period 2014 to 2019. This is the period covered by data from the GPM mission. North Kordofan is drier than West Nile with mean annual rainfall ranging from 230 to 430 mm. The wettest years over this period were 2014 and 2019 for White Nile (Figure 4 and 2016 and 2018 for North Kordofan (Figure 5), respectively. Both of the states have one rainy season, which starts in May/June and ends in August/September each year. However, there is a lot of variability between years, as shown in Figure 6 for the White Nile and in Figure 7 for North Kordofan. For example, for North Kordofan there was low rainfall in 2015 which had severe impacts on food security in that region.

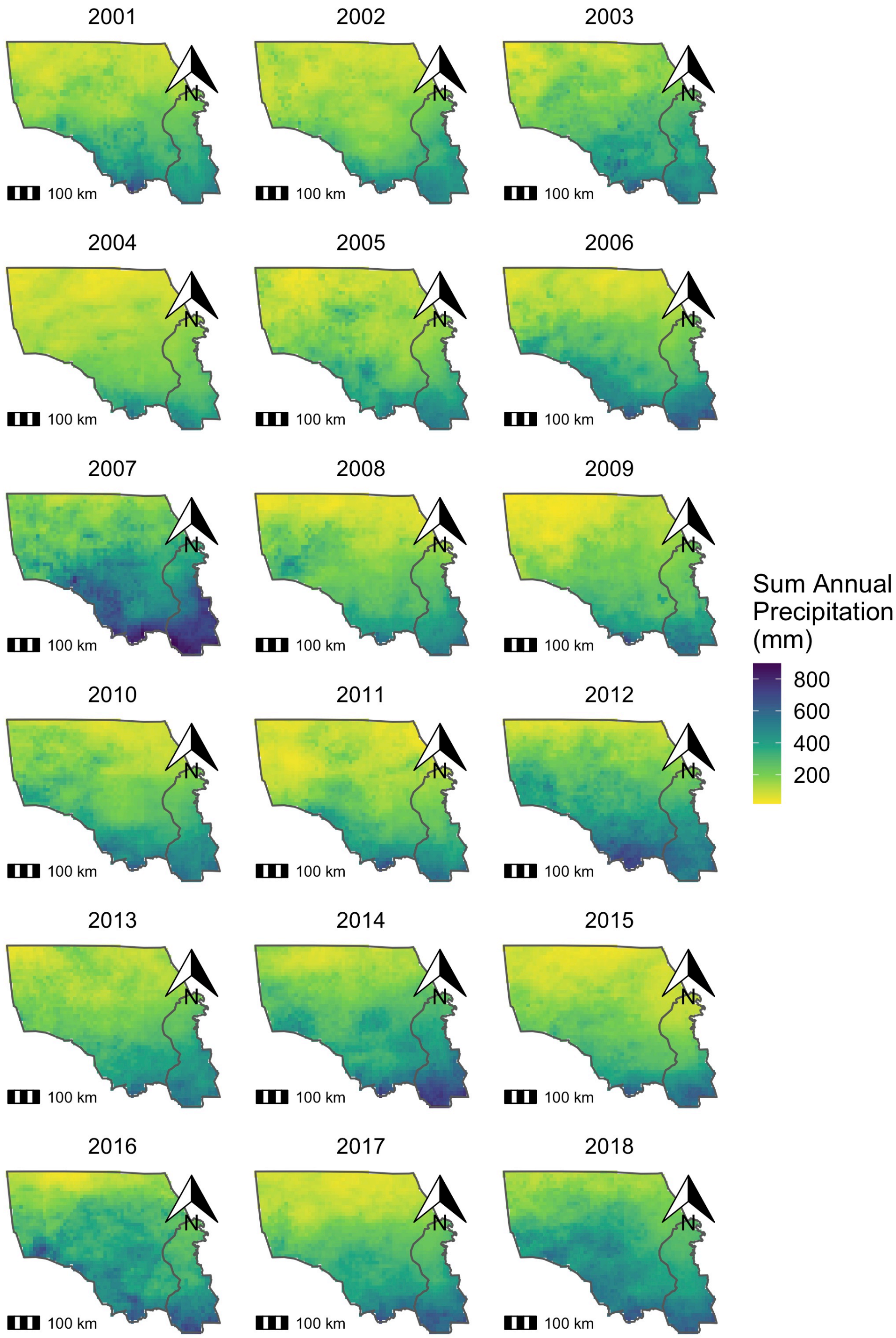


Figure 3: Mean annual rainfall (mm) for White Nile and Kordofan states over the period 2001 to 2018.

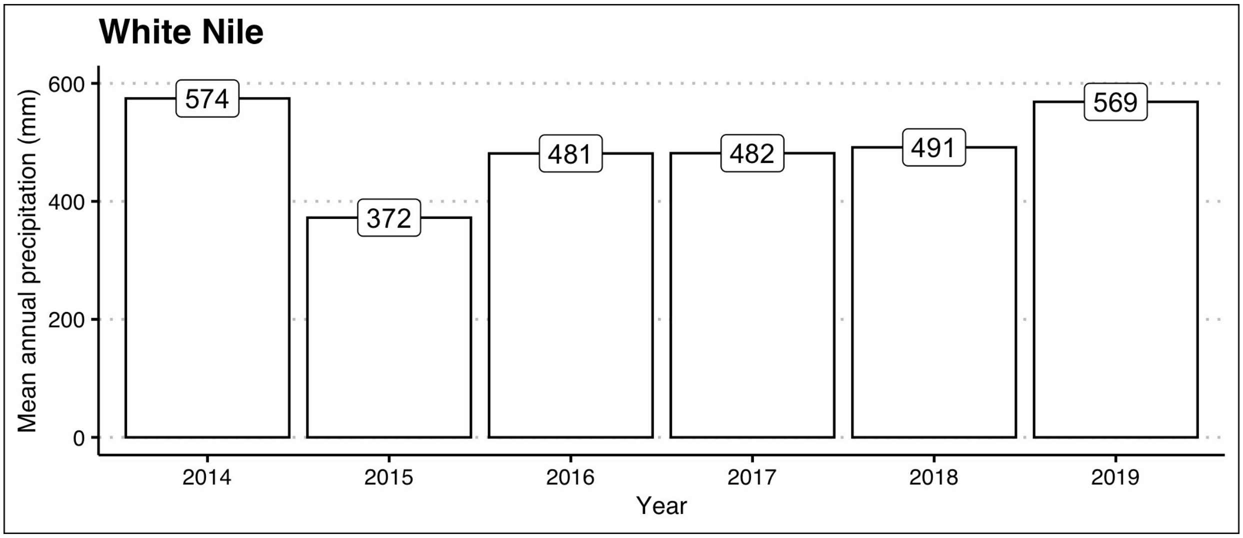


Figure 4: Mean annual rainfall over the period 2014 through 2019 for White Nile state, based on Global Precipitation Monitoring (GPM) data

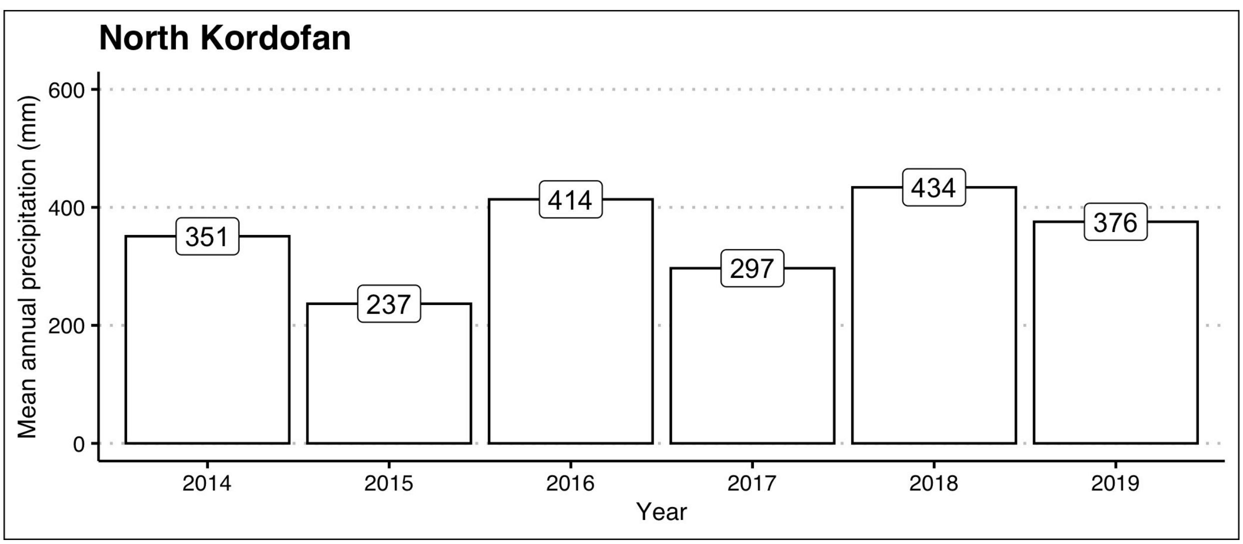


Figure 5: Mean annual rainfall over the period 2014 through 2019 for North Kordofan state, based on Global Precipitation Monitoring (GPM) data

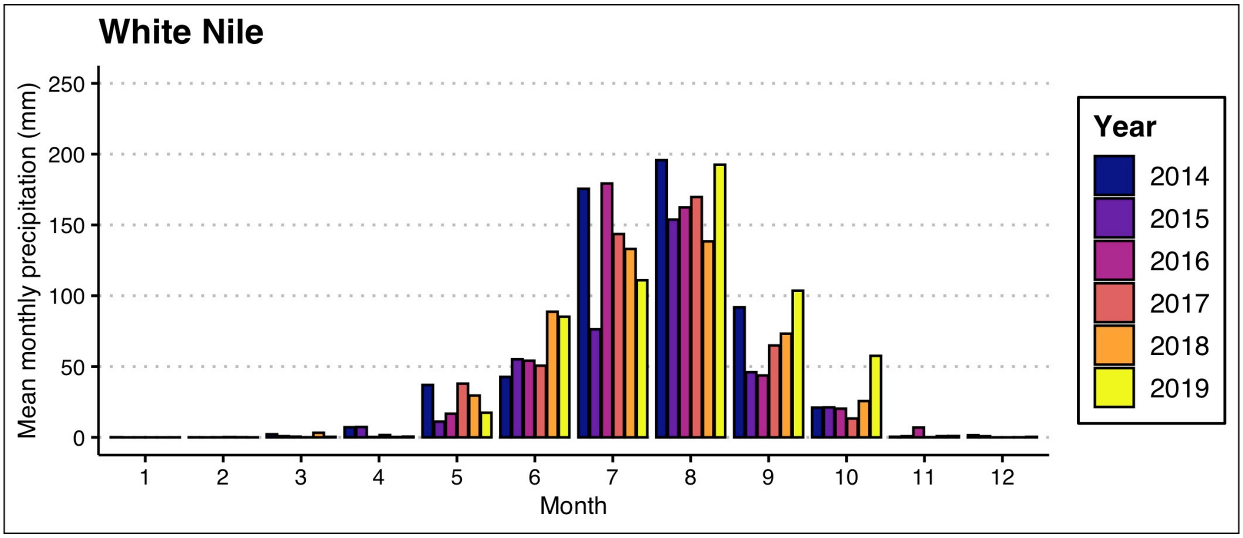


Figure 6: Distribution of annual rainfall by month and year over the period 2014 through 2019 for White Nile state, based on Global Precipitation Monitoring (GPM) data

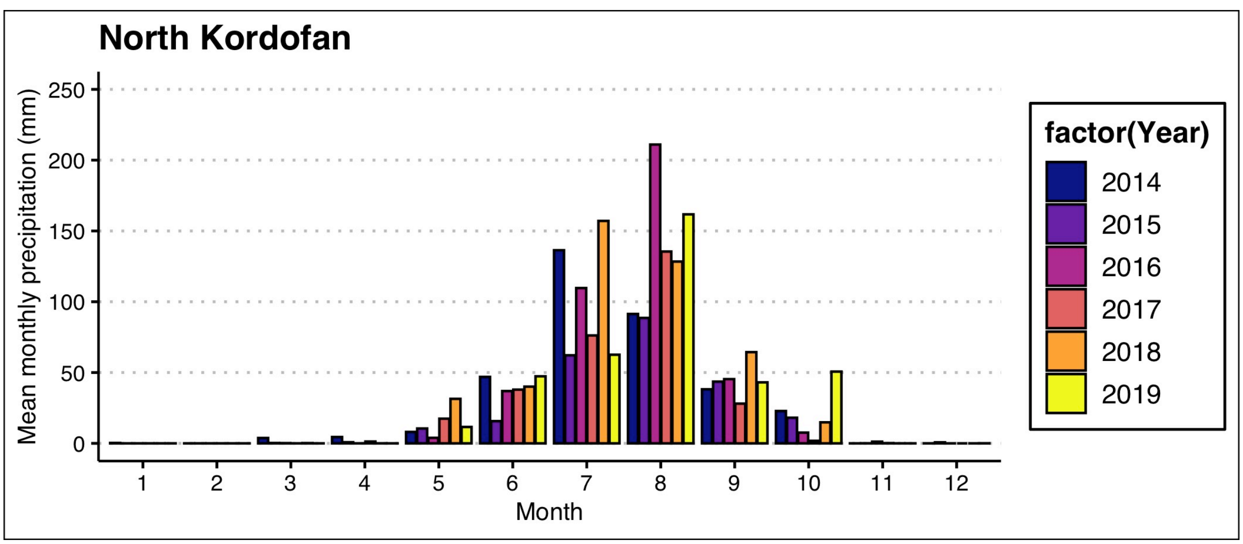


Figure 7: Distribution of annual rainfall by month and year over the period 2014 through 2019 for North Kordofan state, based on Global Precipitation Monitoring (GPM) data

## Number of rainy days

The amount of rainfall needed for a crop to grow will depend on the specific crop as well as factors such as potential evapotranspiration and soil condition, including texture and soil organic carbon content. It is therefore difficult to set a specific threshold for the amount of rainfall needed in a given day. However, based on literature from other dryland systems, we define a rainy day as a *day with 5mm or more cumulative rainfall*. We derived cumulative daily rainfall from half-hourly GPM rainfall data and calculated the number of rainy days for each month and year across each of the two states. If we take the example of Sorghum (*Sorghum bicolour*), which is an indigenous crop to Africa grown across large parts of the drylands in Sudan, it has a water requirement ranging from 400 to 800mm per year and requiring a fairly stable rainfall pattern during the growing season. Increased rainfall variability and particularly variations in or decreases in the number of rainy days will result in high yield variability (Msongaleli et al. 2017). According to some studies, areas with less than 50 rainy days are likely to experience crop failure in hot and arid climates (Rajagopal et al. 2002).

The maps in Figure 8 and Figure 9 show number of rainy days for the two states by year between 2014 and 2019. As we can see from the results in Figure 8, White Nile state has a higher number of rainy days overall, compared to North Kordofan, but with strong variability both between years and within the two states. Large parts of North Kordofan have fewer than 40 rainy days per year, which means that crop production will be strongly constrained and yields very variable in these areas. The northern part of White Nile state also generally has less than 50 days of rainfall in a year. In dry years such as 2015, the northern part of the state had less than 20 days with rainfall.

We can break the above analysis down further and look at number of rainy days by month and year (Figure 10). The most critical part of the year in terms of crop production is the onset of rains, which we can see from the maps in Figure 10, which generally is in June for the southern part of White Nile state and in July for the northern part of the state.

The utility of IMERG satellite-based rainfall data products such as GPM in assessing not only temporal dynamics in rainfall, but spatial patterns can play a key role in assessing climate vulnerability and risk, as demonstrated in the analysis presented here. This also allows for forecasts to be made with reasonable levels of accuracy in areas where weather station and rain gauge networks are sparse or non-existent.

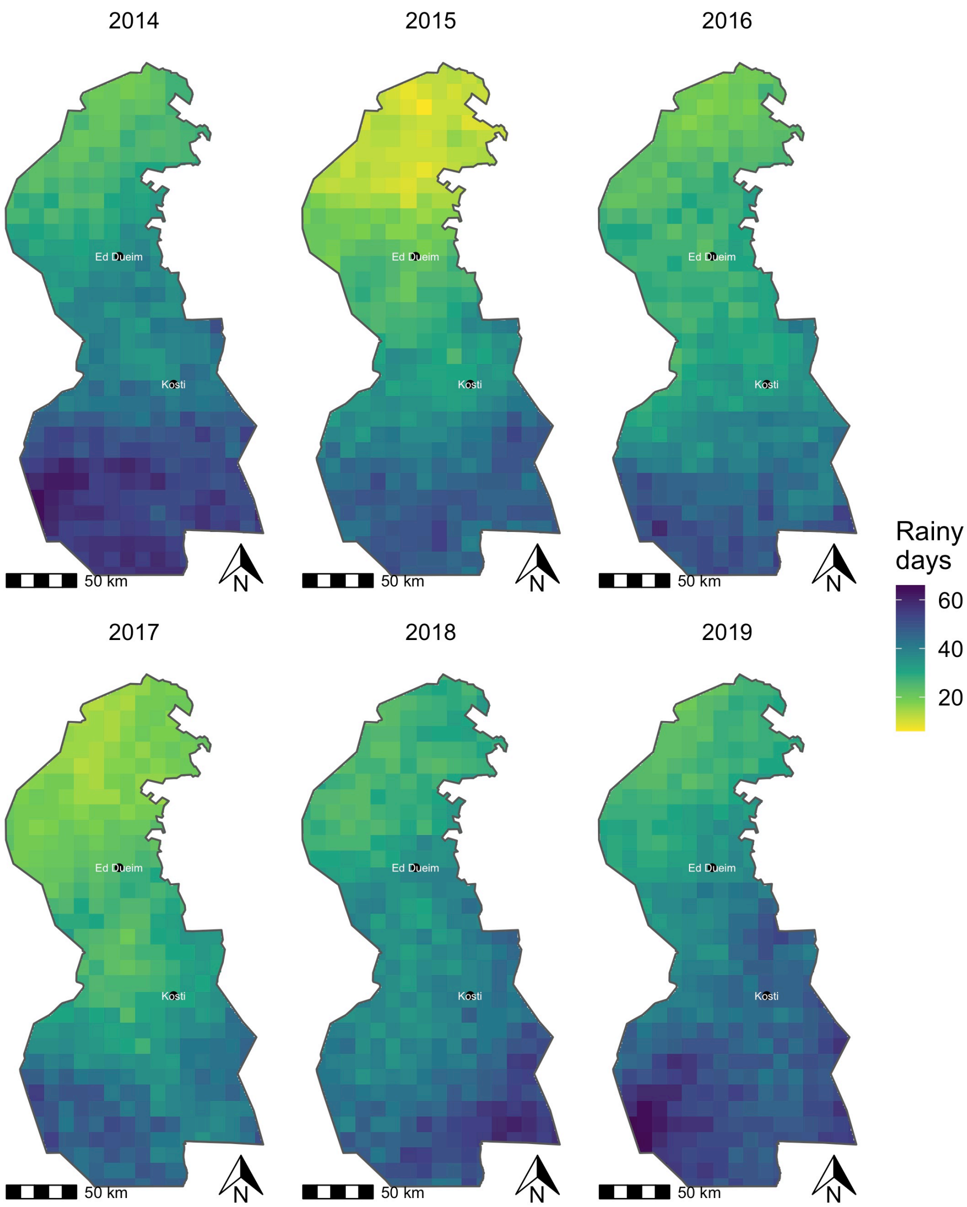


Figure 8: Number of rainy days in White Nile state.

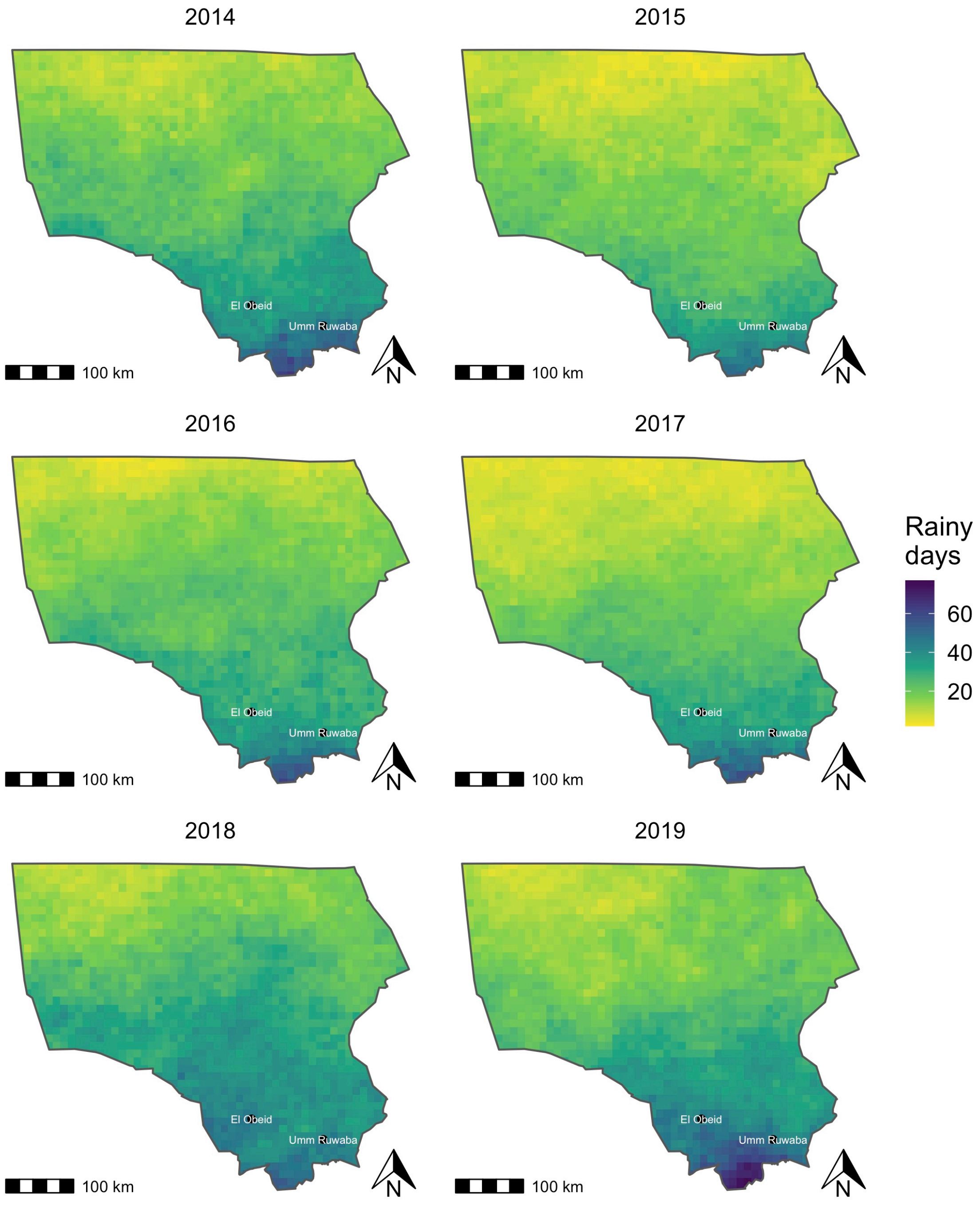


Figure 9: Number of rainy days in North Kordofan state by year.

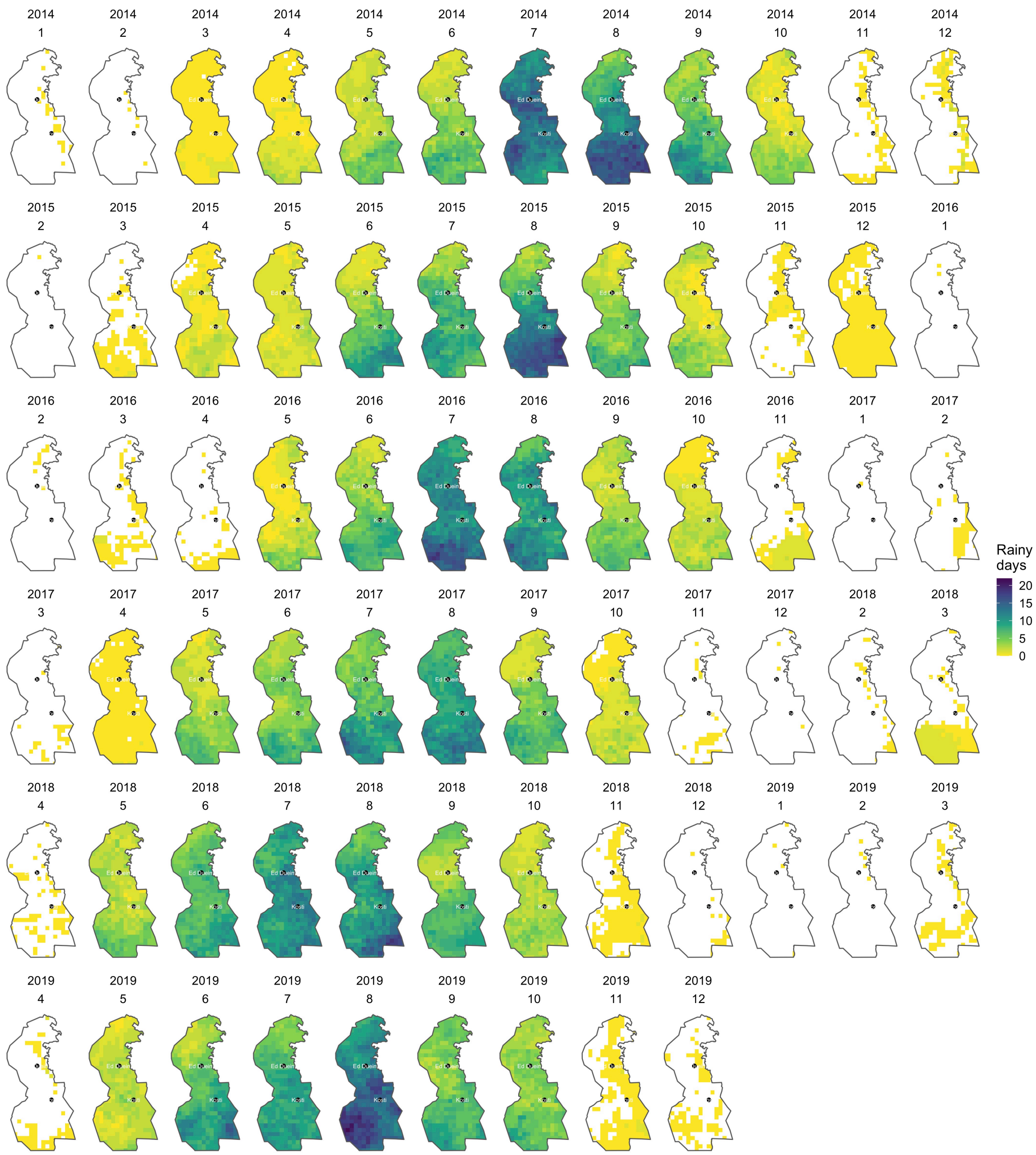


Figure 10: Number of rainy days in White Nile state by month and year. Where months are missing (e.g. January 2015), no rainfall was recorded.

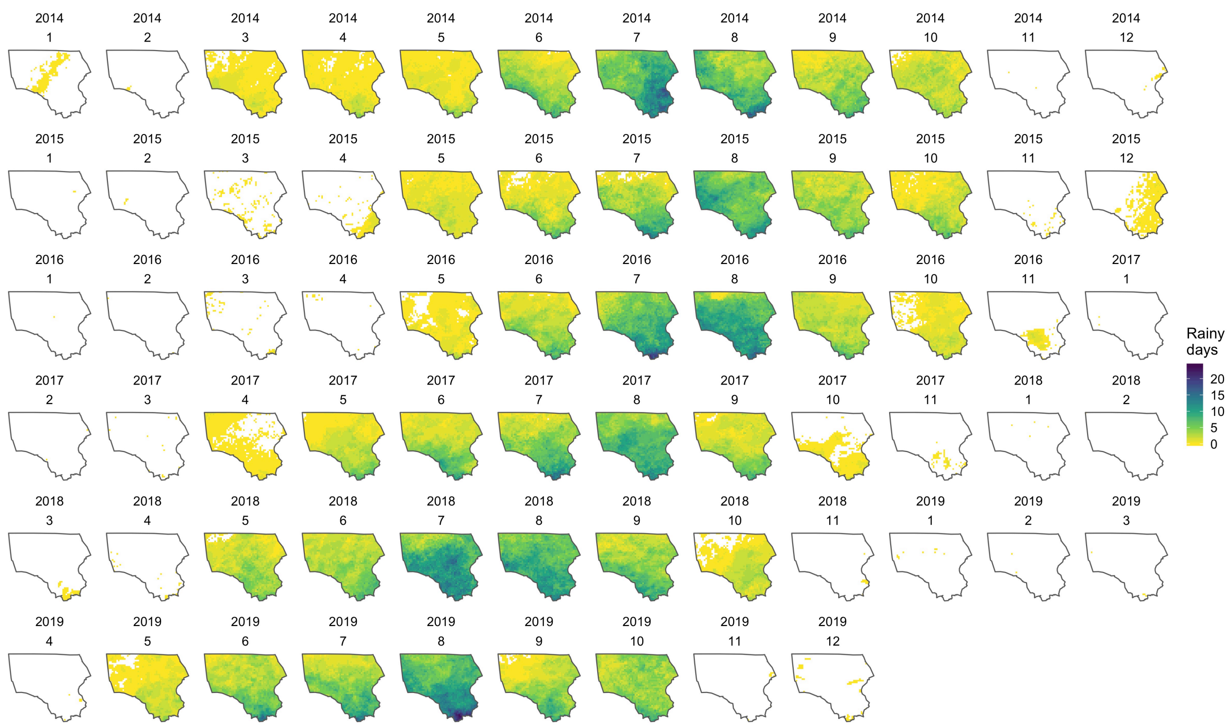


Figure 11: Number of rainy days in North Kordofan state by month and year. Where months are missing (e.g. January 2015), no rainfall was recorded.

## Extreme events

In this section, we focus on the mapping of extreme rainfall events over the period 2014 to 2019 using GPM data. As we have seen above, the number of rainy days, particularly at the start of the rainy season, is a useful metric for assessing climate vulnerability and is often considered more important than overall rainfall for crop production and for reducing yield variability. In the field of climate services, another important aspect is the characterization of rainfall extremes (extreme events), particularly for the identification of rainfall intensities that can trigger excess run-off, soil erosion and land slides as well as floods.

According to Salack et al. (2018), the climate in the Sahel is changing and new patterns of rainfall variability have been observed, in particular since the 1990s, with extreme rainfall events becoming more frequent, combined with longer dry spells. Similar trends have been reported for Sudan. Quantifying such extreme rainfall events has become increasingly challenging in the region in general due to the already mentioned deterioration of weather station and rainfall gauge networks. The use of satellite-derived rainfall measurements or estimates provides a very interesting and important avenue for getting around these limitations by (1) providing data at a high frequency (e.g. every 30 minutes for the GPM data presented here), (2) providing data with a high level of consistency and (3) providing spatially explicit data on rainfall intensities and amounts. We have shown earlier in this report how such data can be used to not only calculate seasonal distributions in rainfall amounts and rainy days, but also how maps can be produced showing how rainfall varies both in time and space.

Extreme rainfall events are often classified as events that exceed a threshold corresponding to the $99^{th}$ percentile of daily rainfall observed in the course of a season [Salack2018a]. Based on studies in the Sahel with comparable climate to Sudan, daily rainfall amounts greater than or equal to 37mm would trigger a warning that there is a some likelihood of flooding or significant runoff. At daily rainfall amounts higher than 65 mm one would expect significant runoff and flooding, while amount higher than 85mm in a day would trigger local disaster management plans (Salack et al. 2018). The actual level of runoff and flooding in any given location will of course depend on factors such as land degradation and soil properties such as texture and soil organic carbon content, which strongly determine infiltration capacity and hence the vulnerability of a given area to flooding.

Based on the above thresholds, we applied a threshold for daily rainfall of 50mm and calculated the number of days in a year with rainfall in excess of this threshold across the two states. Of course other threshold can be applied based on the GPM data used, and the frequency of the data also allows for warnings to be generated. As shown in the maps in Figure 12, the southern part of White Nile state generally has higher frequencies of extreme rainfall events, with particularly frequent events in the south-eastern part of the state in 2019. In North Kordofan we see particularly high frequencies in 2016 and 2018 (Figure 13). The extreme rainfall events and subsequent flooding shown in the map in Wad el Baga, 30 km from El Obeid, in North Kordofan in July 2016 were indeed widely reported in the news.

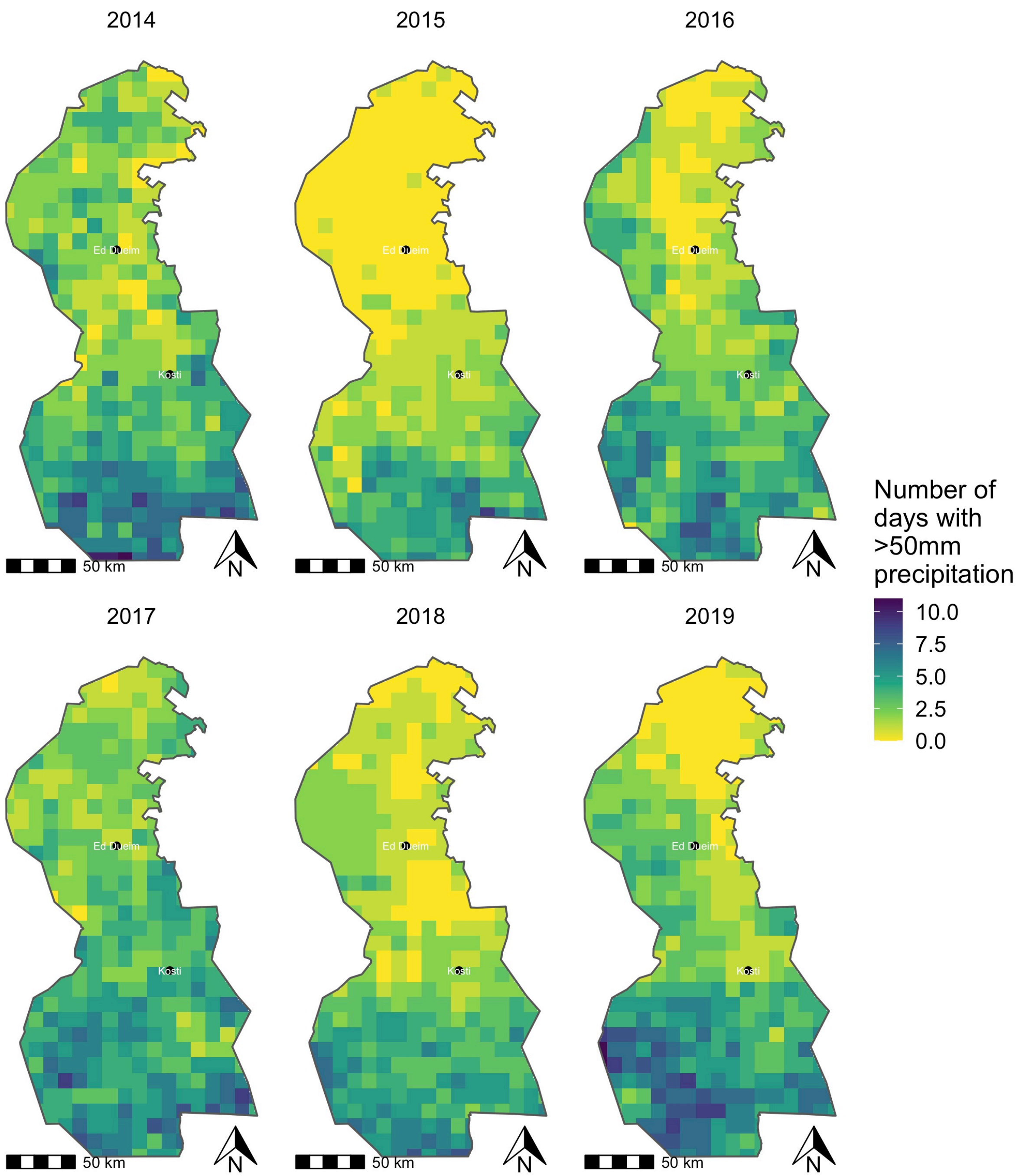


Figure 12: Number of extreme rainfall days in White Nile state by year. The maps show the sum of the number of days per year that have more than 50mm rainfall based on GPM sattelite rainfall data.

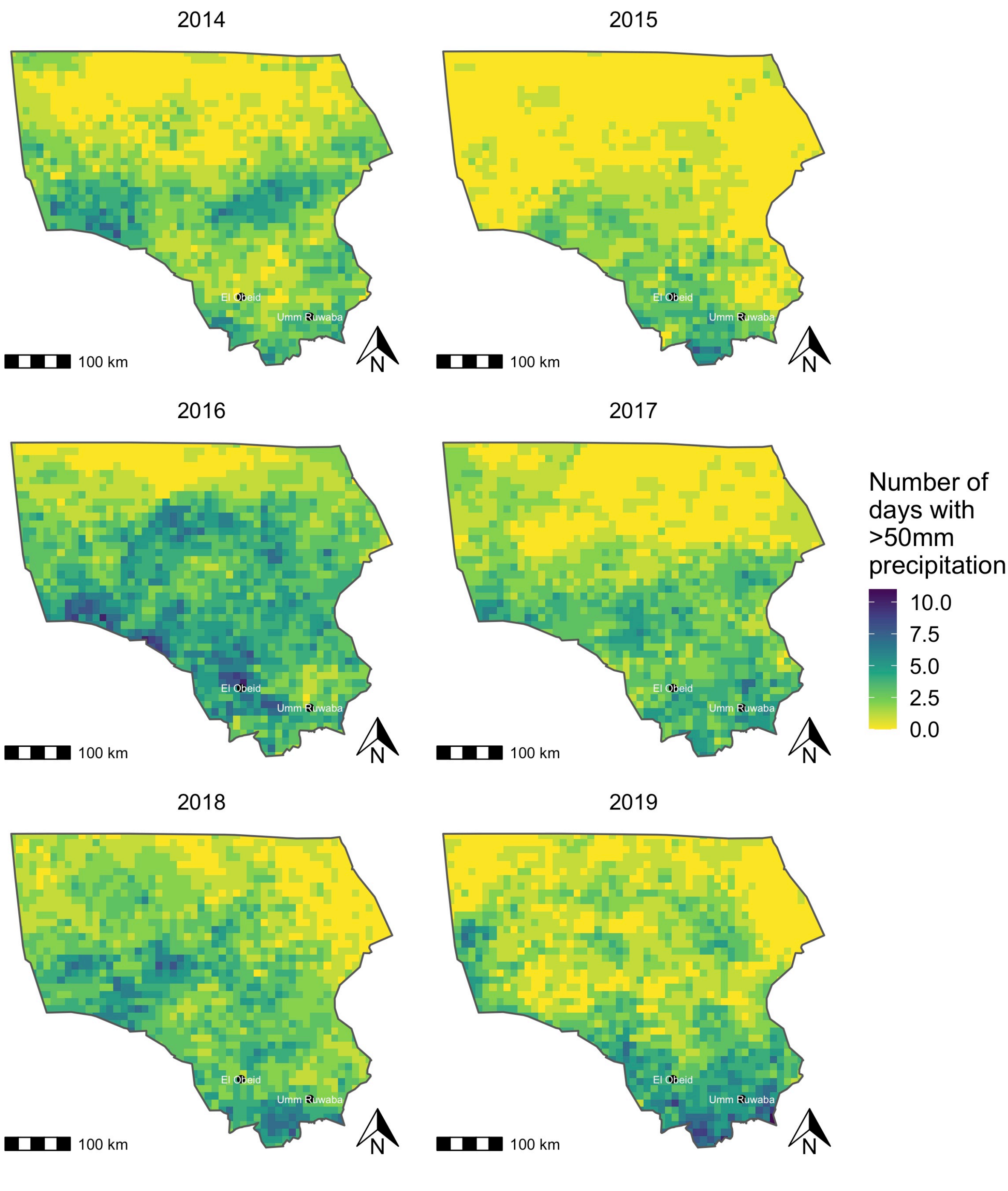


Figure 13: Number of extreme rainfall days in North Kordofan state by year. The maps show the sum of the number of days per year that have more than 50mm rainfall based on GPM sattelite rainfall data.

## Land surface temperatures

Land surface temperatures are high in both states throughout the year, with maximum temperatures approaching 50 °C in March, April and May, before the onset of the rainy season (Figure 14). January, August and December are the coolest months in White Nile state, while January, February and December are coolest in North Kordofan (Figure 14), based on median monthly temperatures between 2001 and 2019. The maps in Figure 15 and Figure 16 show the spatial distribution of mean surface temperatures by month within each state. In the map of White Nile state we can see the cooling effect of the Nile River, which runs from south to north through the state. We also see large spatial as well as seasonal variations in land surface temperatures and a sharp gradient in North Kordofan along the boundary between the dry (~300 mm annual rainfall - FEWS NET climate zone B) in the south and drier semi-desert and desert (~100 mm annual rainfall - FEWS NET climate zone A) climate zones to the north. According to a report produced by World Food Programme (WFP) in 2016 (World Food Programme 2016), land surface temperatures are projected to increase by up-to three °C by 2040.

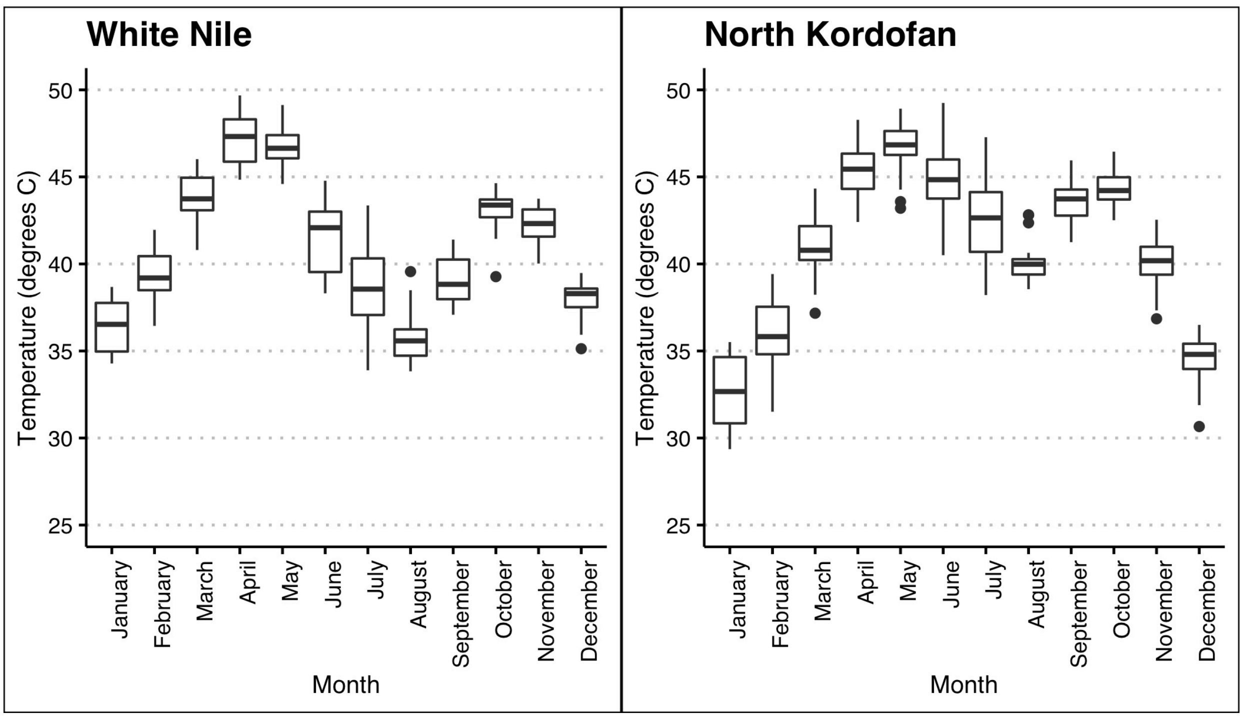


Figure 14: Distribution of mean monthly temperature in each state by month for the period 2001 to 2019.

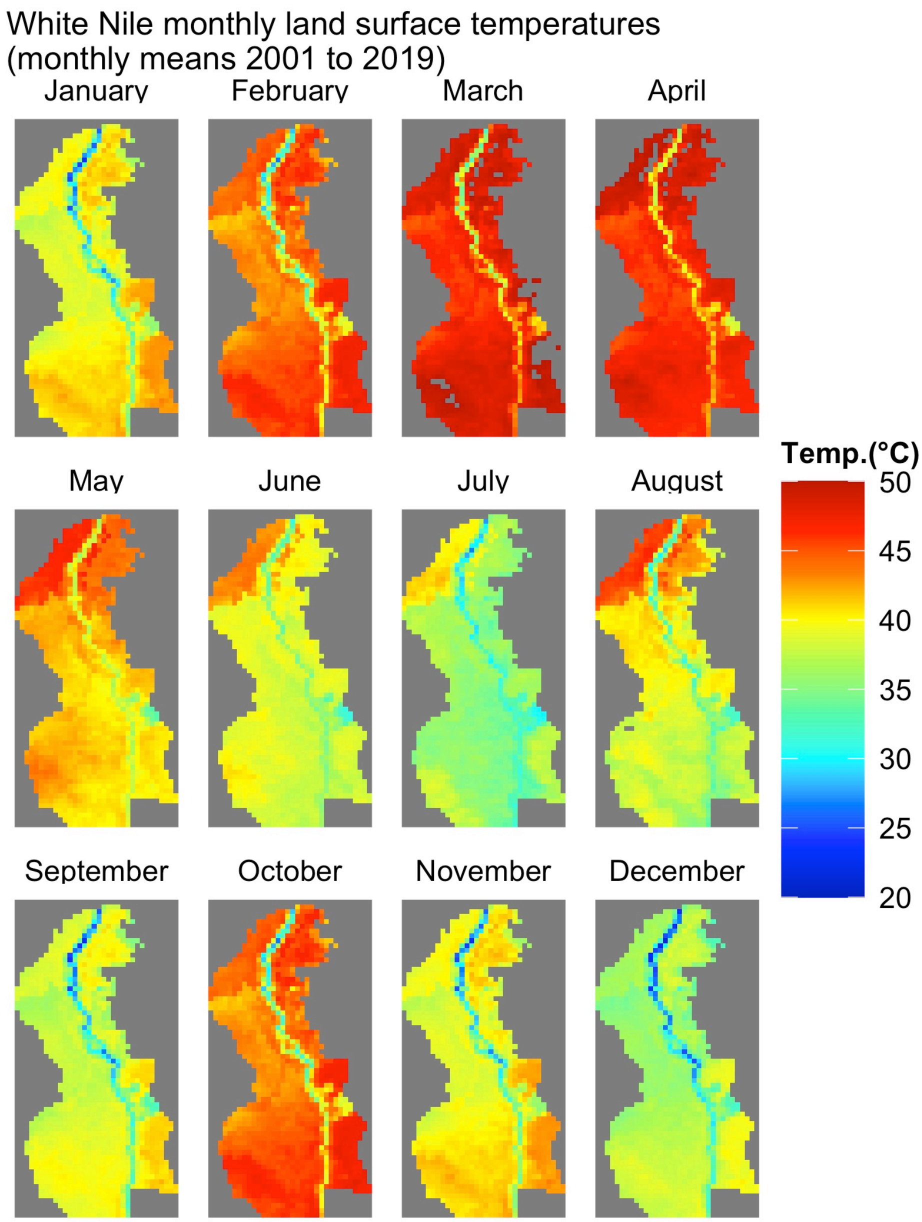


Figure 15: Average (mean) monthly temperatures for White Nile state over the period 2001 to 2019 based on MODIS land surface temperature satellite data.

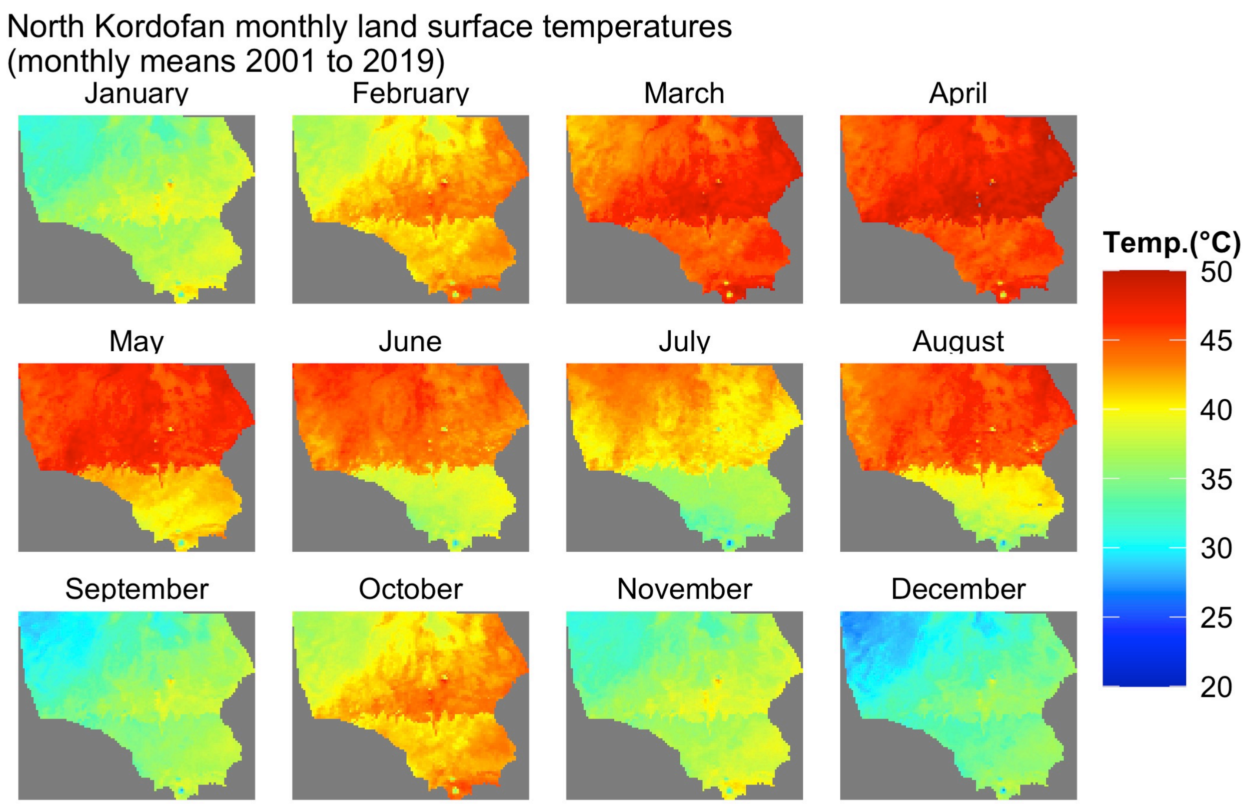


Figure 16: Average (mean) monthly temperatures for North Kordofan state over the period 2001 to 2019 based on MODIS land surface temperature satellite data.

## Conclusions

In the current progress report we presented results of applying satellite-platforms for measurement and mapping of rainfall and land surface temperatures, focusing on White Nile and North Kordofan states in Sudan. These results represent outputs from **Output 2: identify and map areas that are particularly vulnerable to changes in climate** of the project. We have shown the utility of IMERG satellite-based platforms and products for assessing spatial and temporal dynamics in rainfall, as well as extreme events with high rainfall intensities. These products can play a critical role in providing climate data services in areas vulnerable to climate change, particularly considering the steady deterioration of weather station and rainfall gauge networks and hence large gaps in climate data at present. Such assessments are particularly important in marginal parts of the country.

Estimation and prediction of both available rainfall for crop production, seasonal dynamics in total available rainfall as well as number of rainy days, and the frequency and seasonal dynamics of extreme events are critical for the agricultural sector in Sudan. Also, detection of extreme rainfall events can help mitigate disasters and through more acccurate forecasting of such events, disaster response could be improved. We demonstrated the use of GPM rainfall data in detecting such events over the period 2014 to 2019. Given the spatial variability of rainfall in drylands, the data and maps presented here can play a vital role in providing future climate services to the agricultural sector in Sudan. We also presented satellite-based temperature data over the period 2001 to 2019, which can help identify constraints to crop production, as well as trends over time.

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