Remote Sensing of Vegetation

Part II – Sahel examples

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Remote Sensing of Vegetation

African vegetation classification from Principle Component Analysis

Sahel vegetation 1982-2004

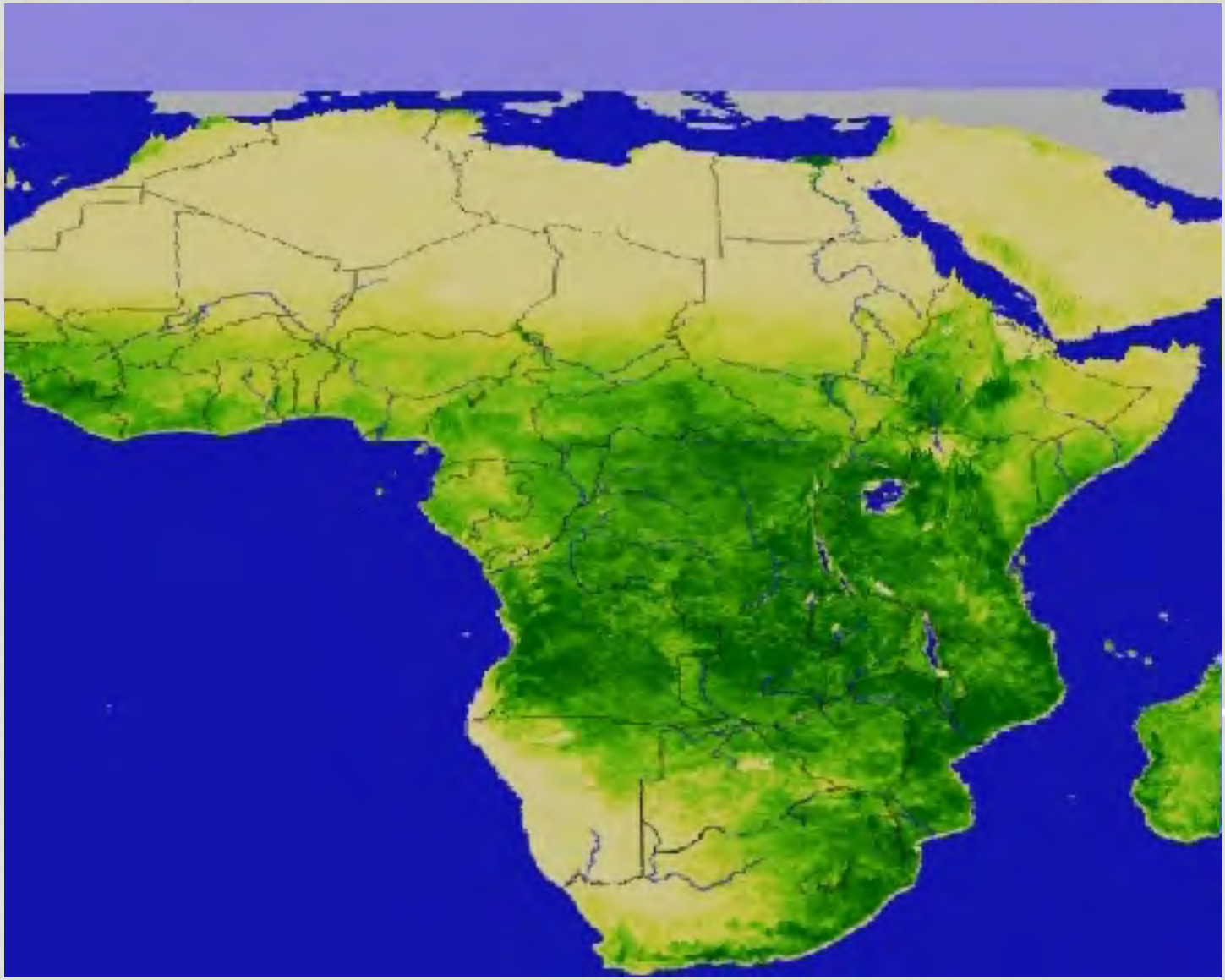
Data sources

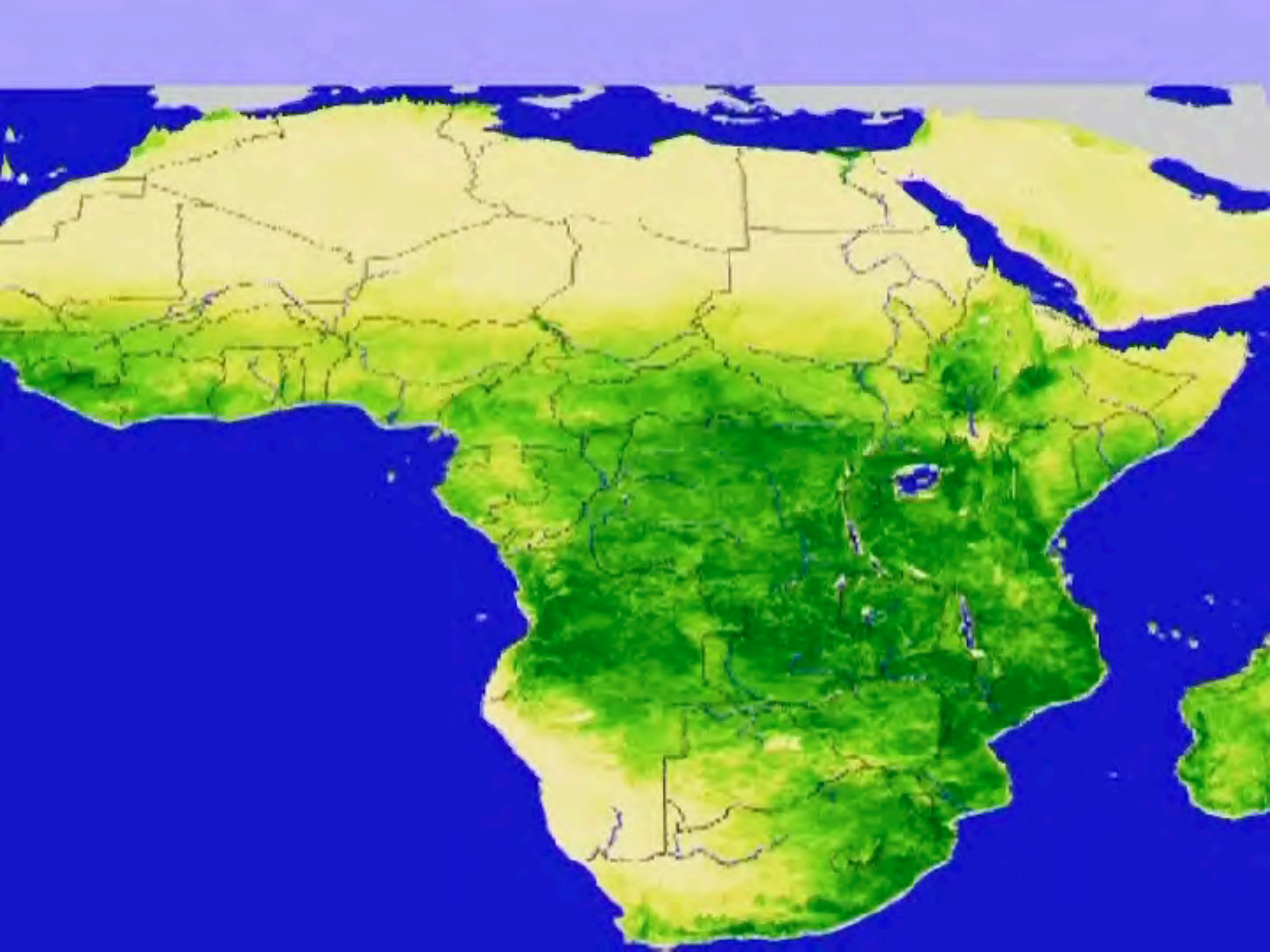
- NOAA AVHRR dekadal data (10day), 1982-2004
- Ground station monthly rainfall, 1931-1996
- Satellite based rainfall estimates, 1996-2004

Sahel vegetation 1982-2004

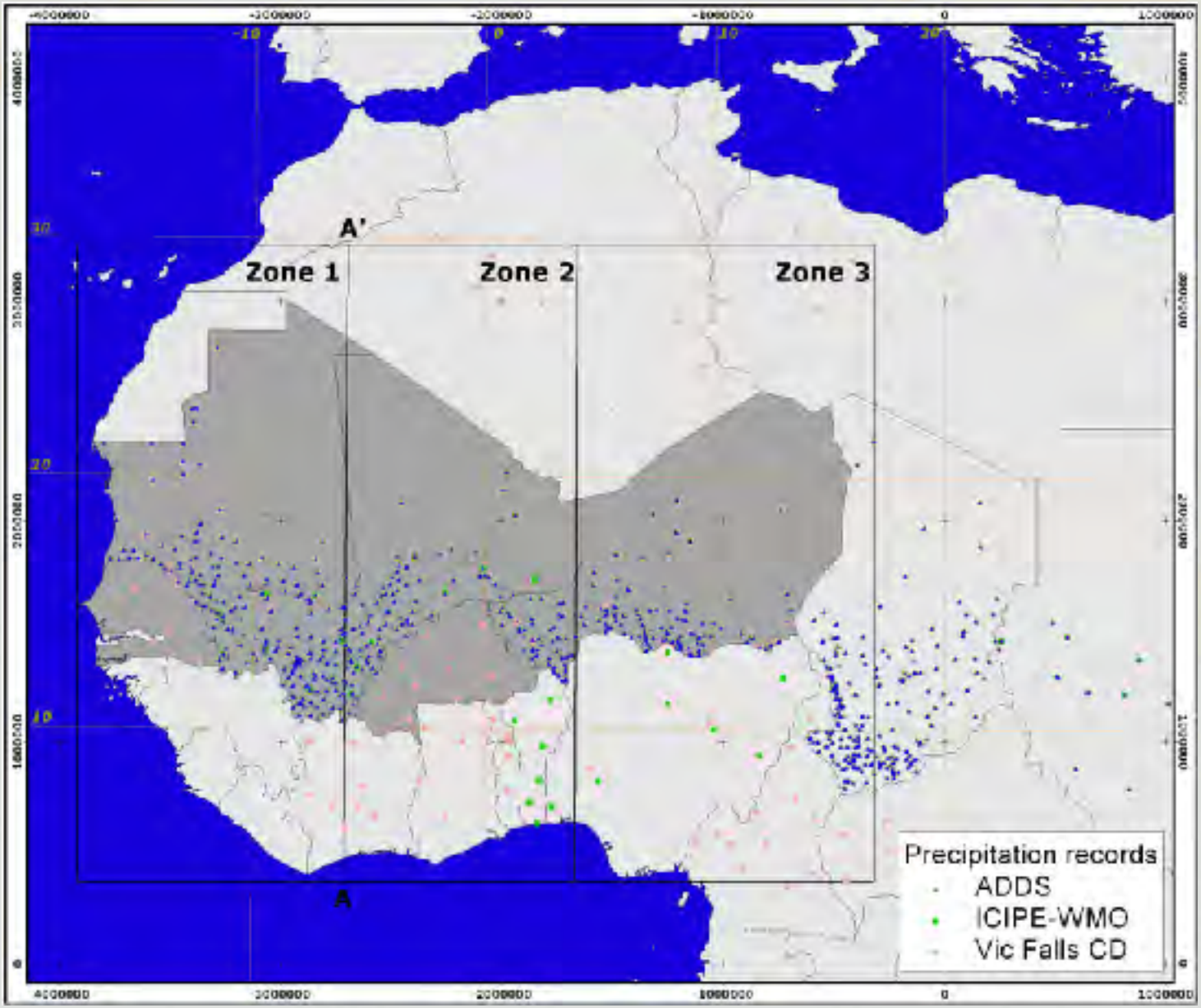
Mauritania
Senegal
Mali
Burkina Faso
Niger

Sahel vegetation annual cycle

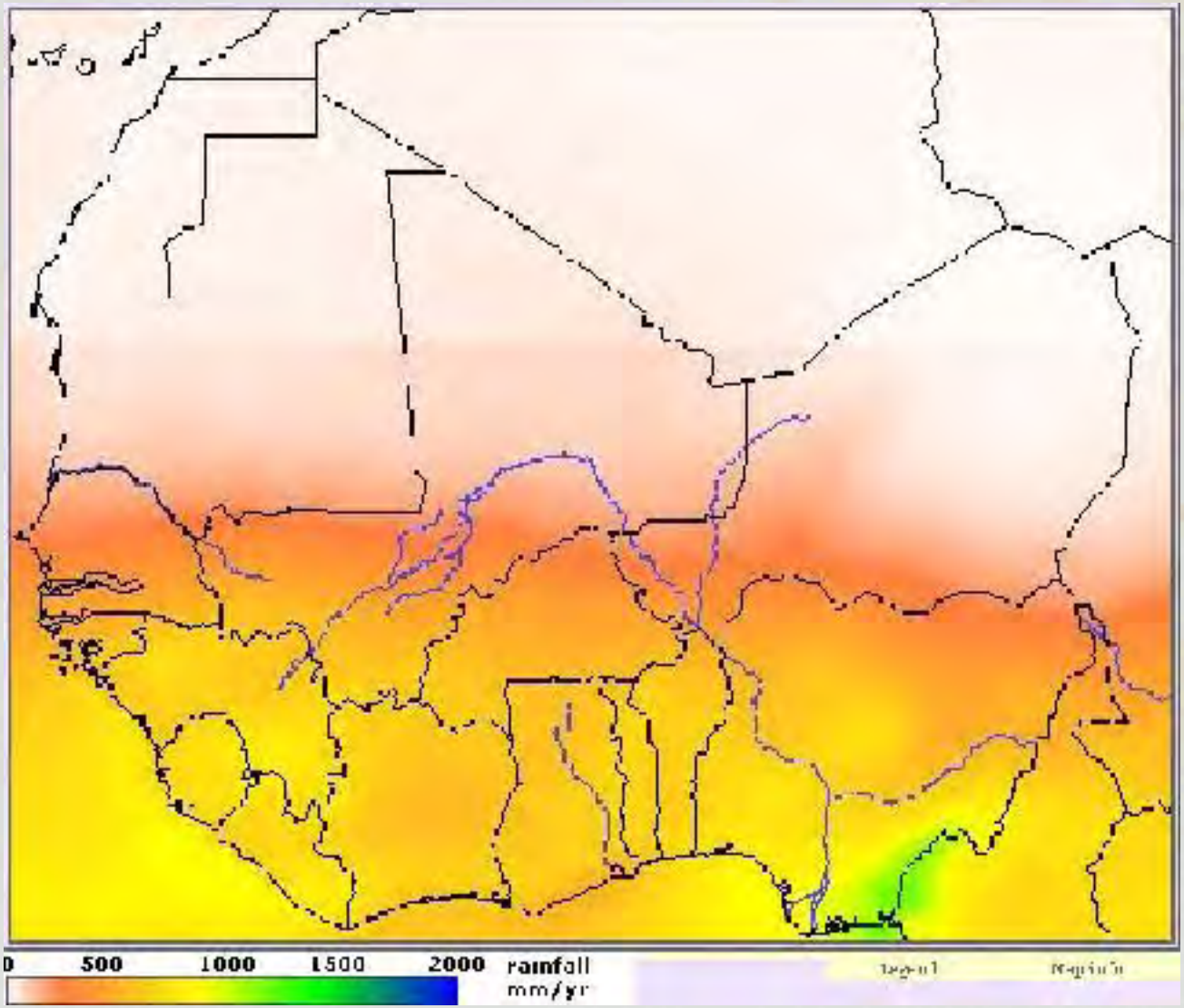




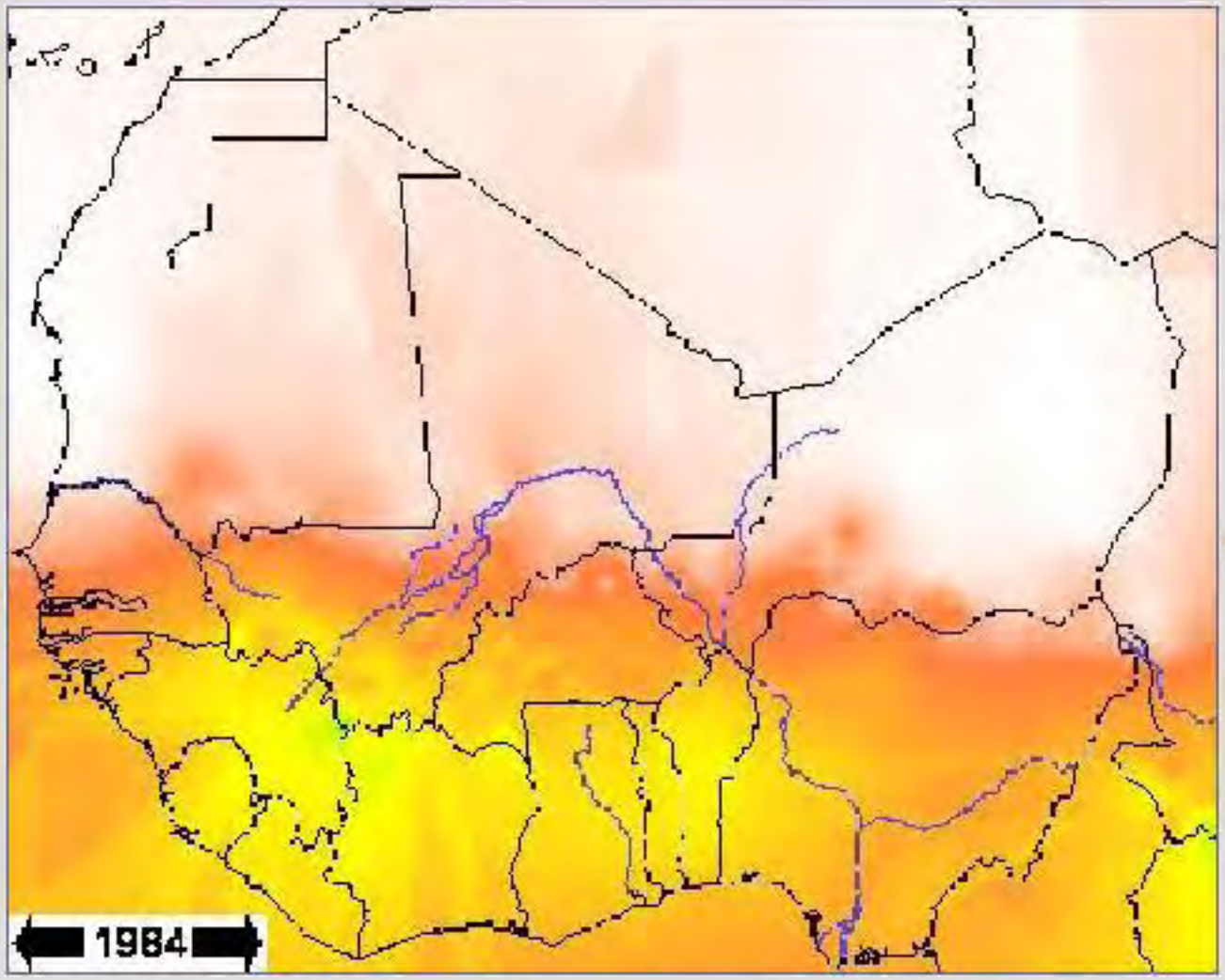
Sahel rainfall stations 1930-1996



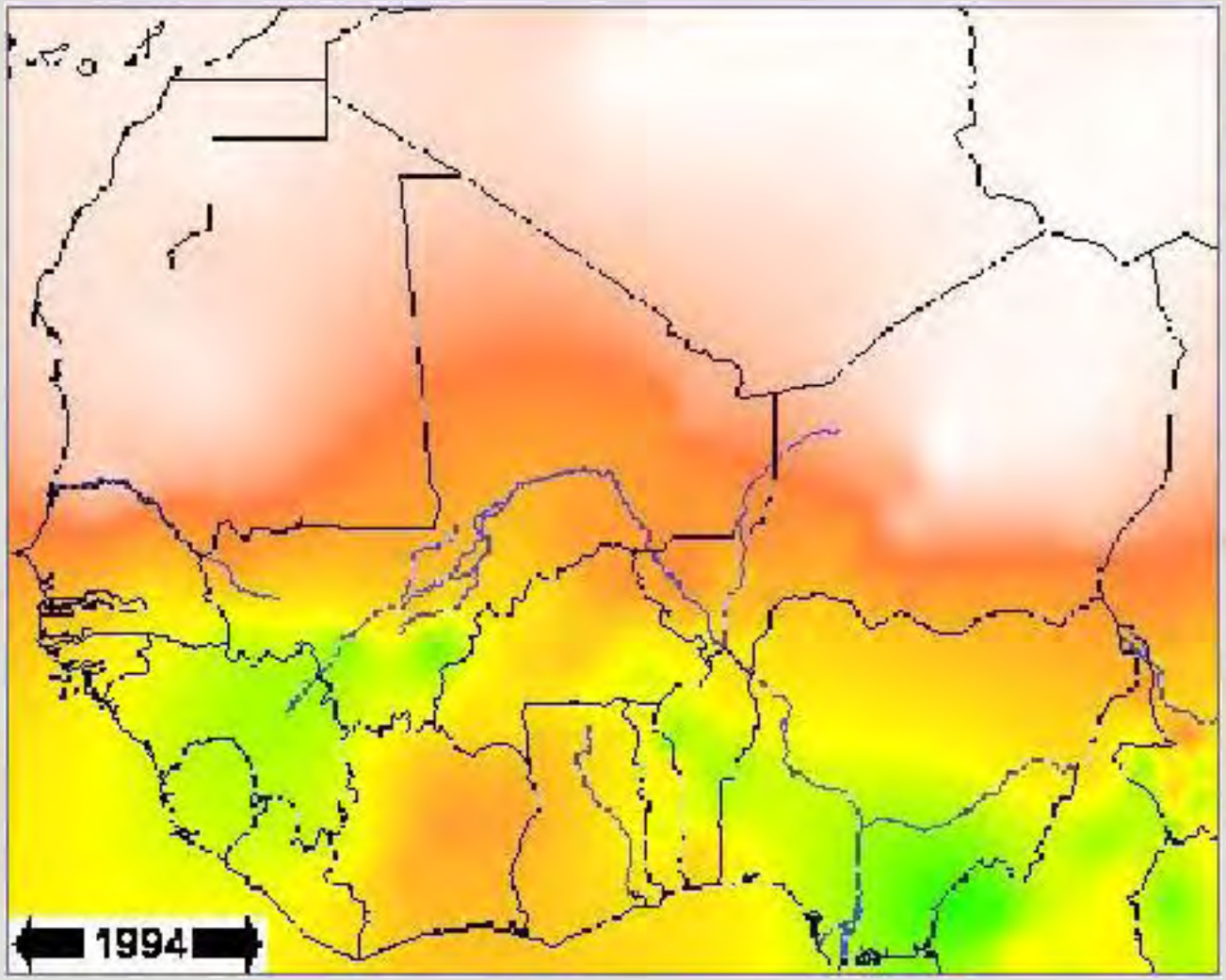
Sahel rainfall average 1982-2004



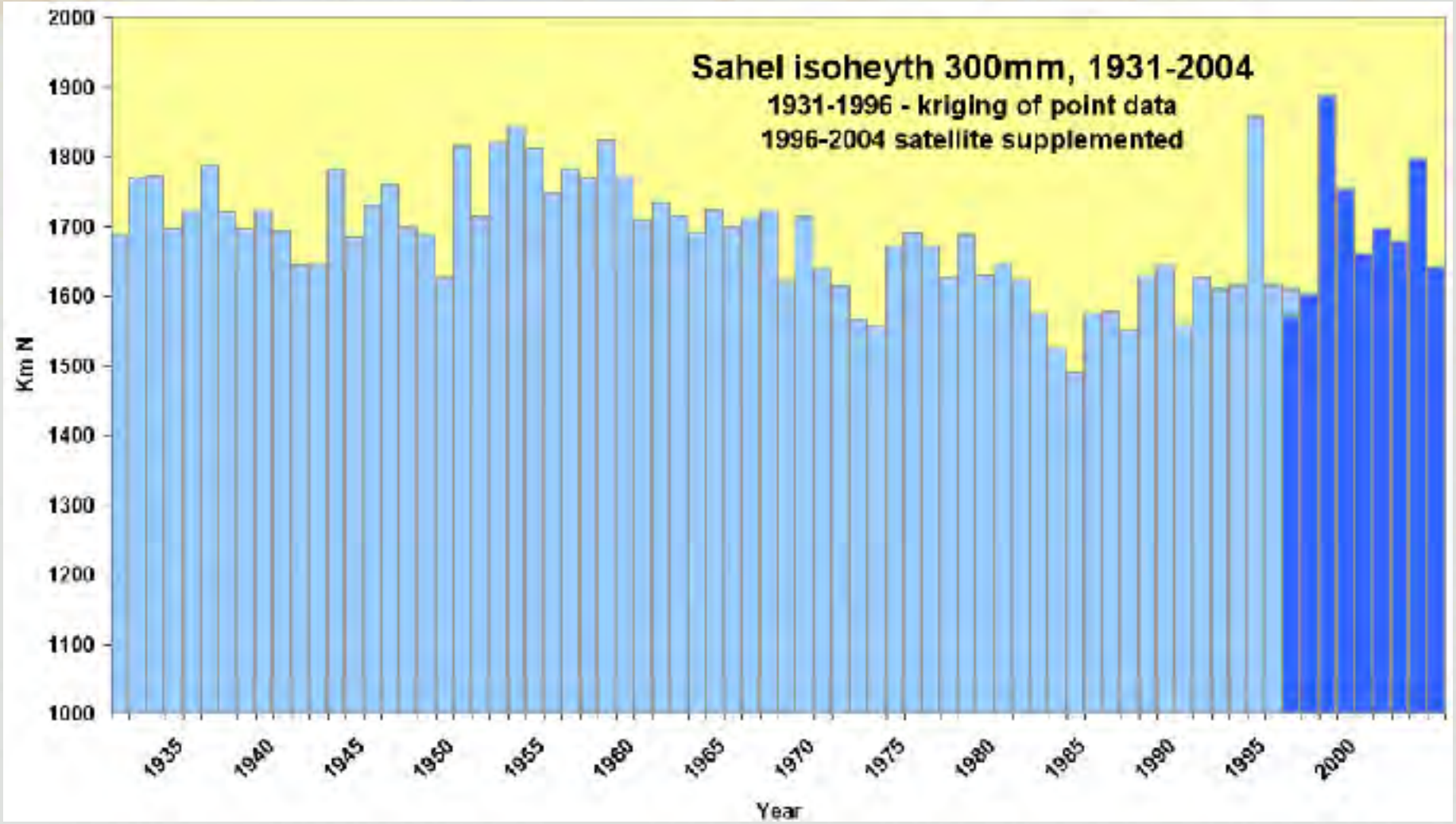
Sahel rainfall average 1984



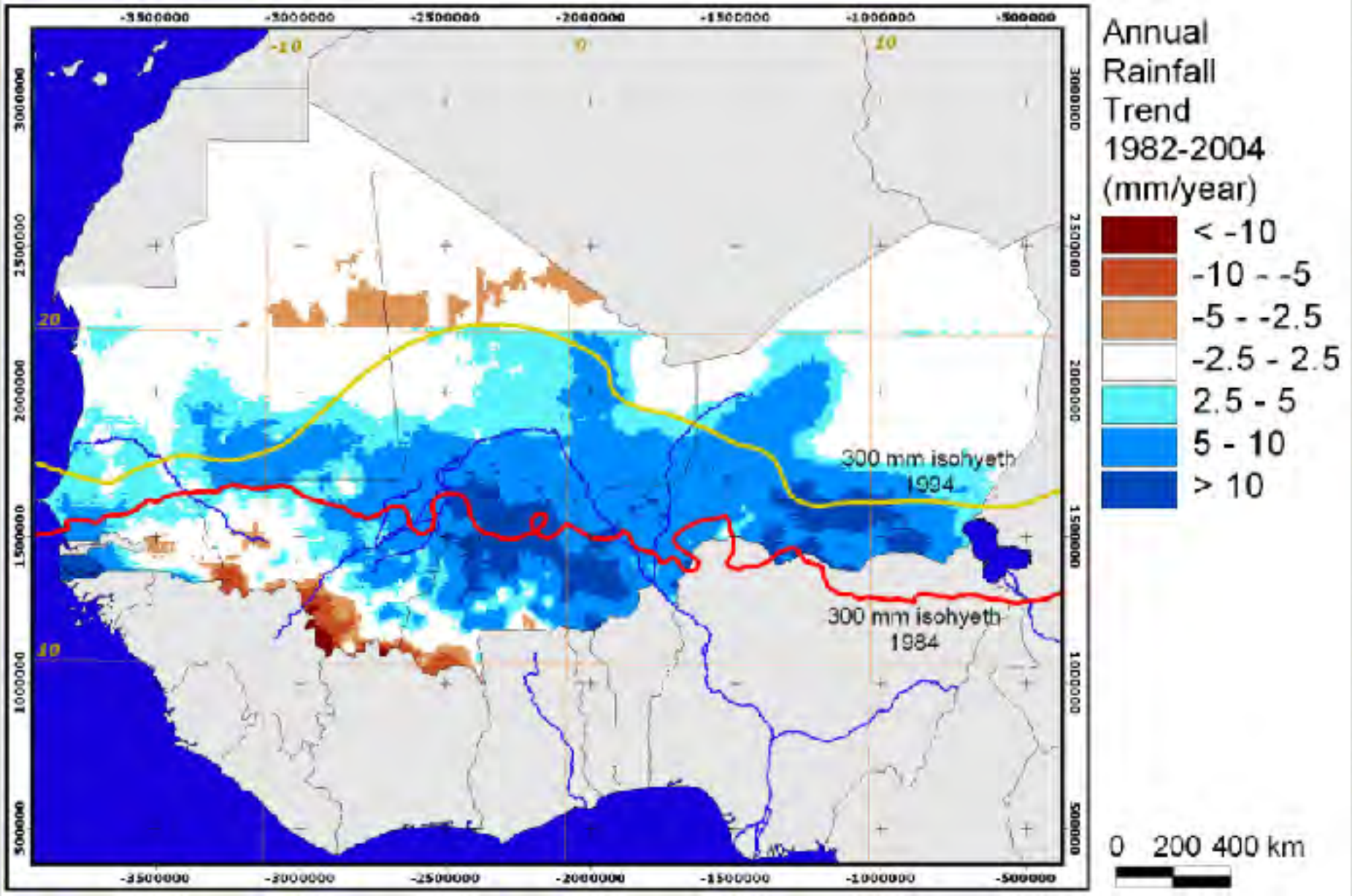
Sahel rainfall average 1994



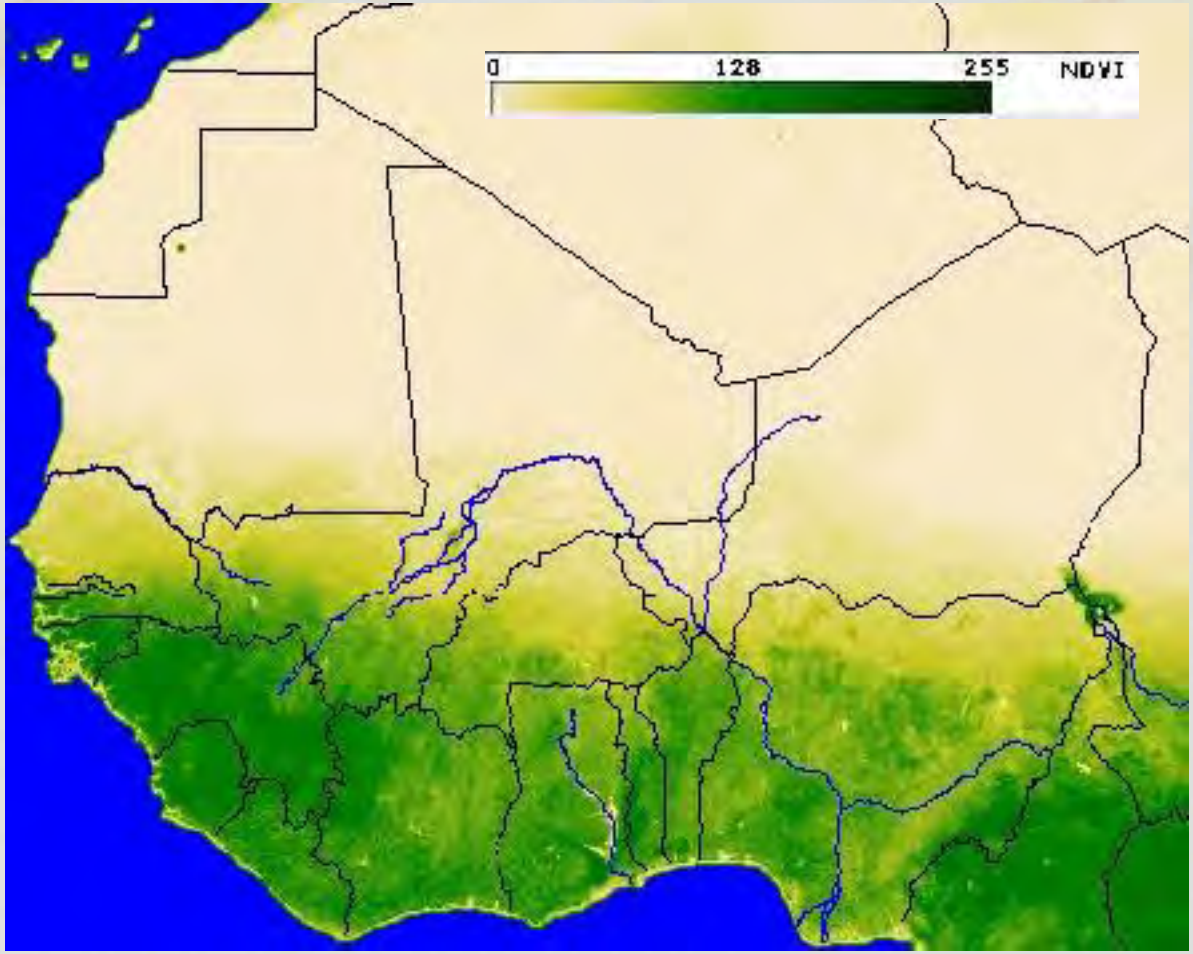
Sahel rainfall 1931-2004



Sahel spatial rainfall trend 1982-2004



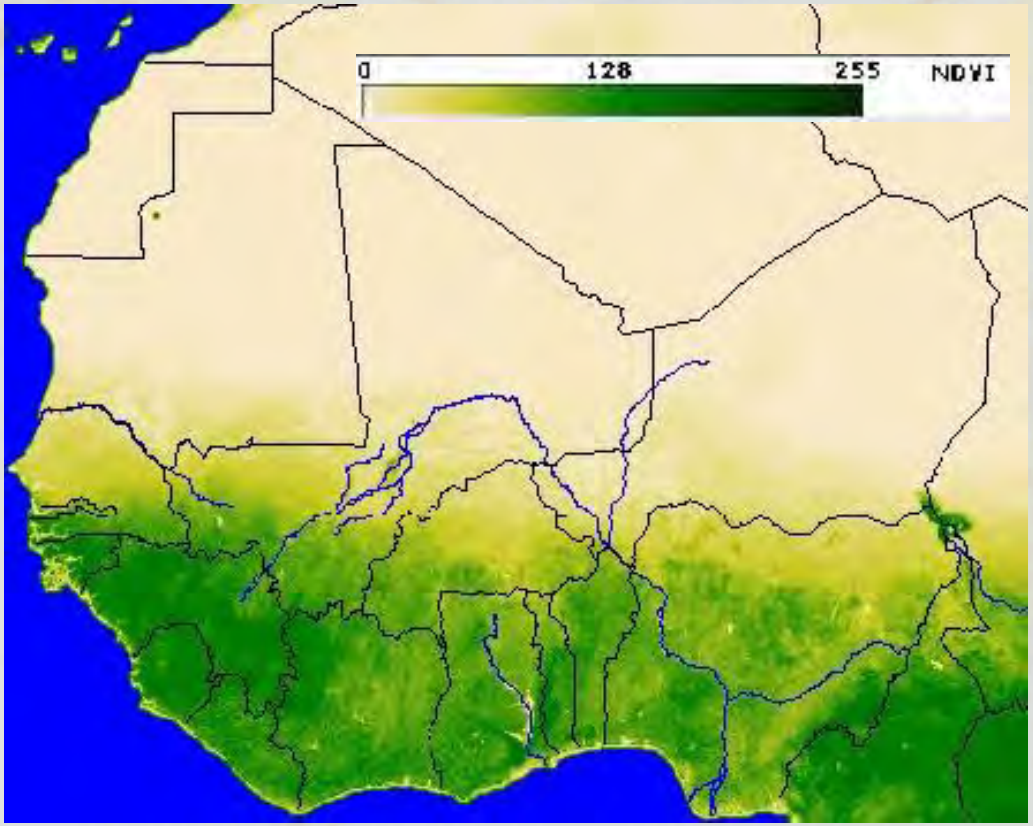
NOAA – AVHRR data



The longest consistent time series of satellite derived NDVI available is from the Advanced Very High Resolution Radiometer (AVHRR) instruments operated by the National Oceanic and Atmospheric Administration (NOAA) in the United States of America.

The data used here is derived from 5 generations of AVHRR sensors, carried onboard NOAA –7, -9, -11, -14 and -16.

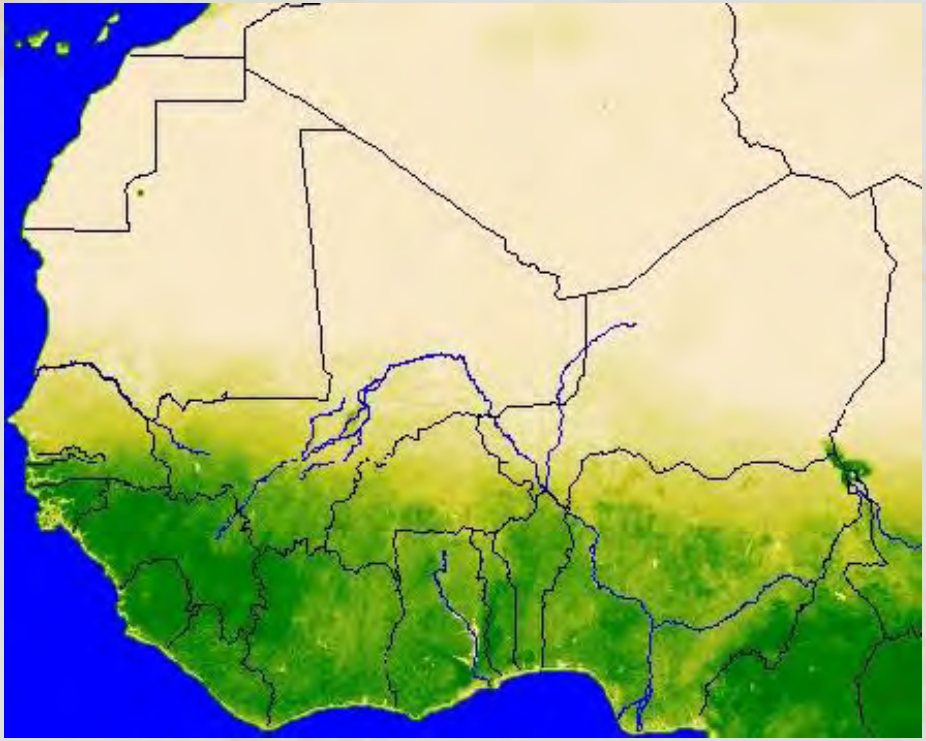
NOAA – AVHRR GIMMS data



The Global Inventory Monitoring and Modeling System (GIMMS) group at NASA/GSFC processed the NDVI data used in this analysis (http://igskmncnwb015.cr.usgs.gov/adds).

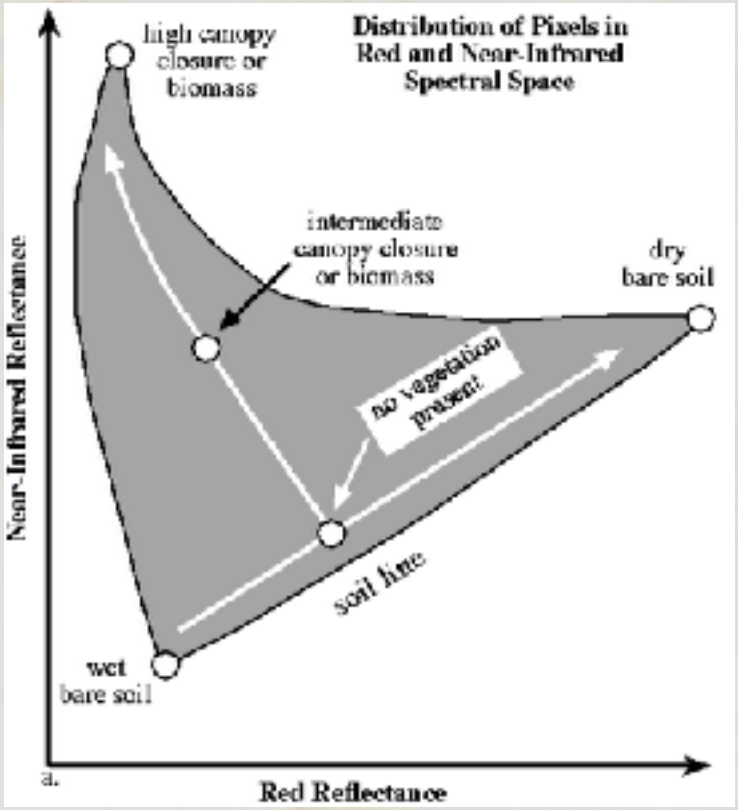
Near-real time data processing for Africa is carried out by GIMMS to support the activities of the United States Agency for International Development (USAID) Famine Early Warning System (FEWS) project.

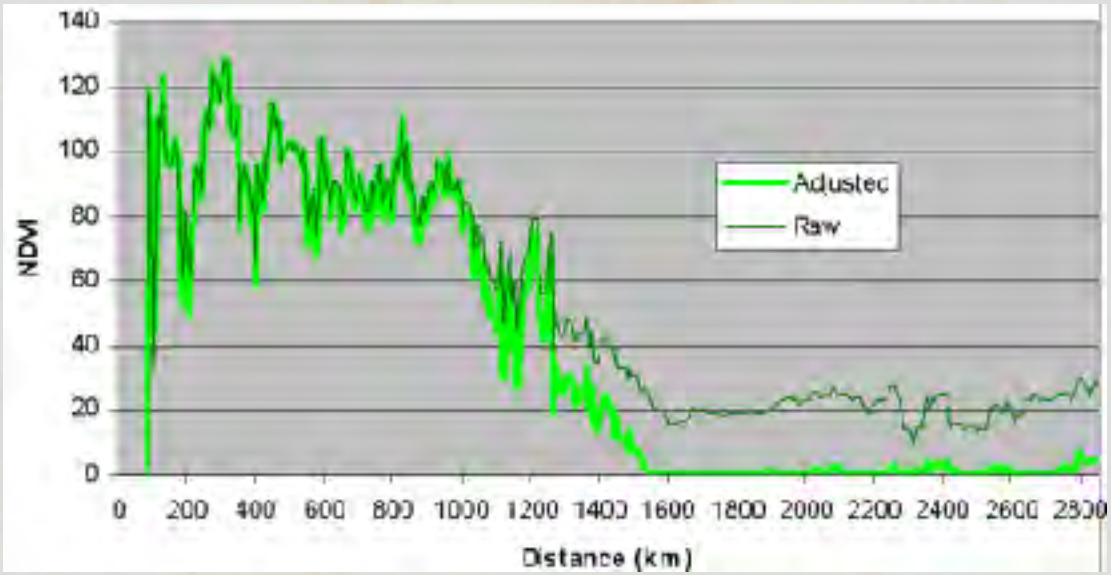
GIMMS NDVI preprocessing



The GIMMS NDVI data is at 8 km spatial resolution.
Preprocessing of the includes corrections for sensor degradation, for satellite orbital drift and for atmospheric volcanic aerosols from eruptions in 1982 and 1991. The data is then agglomerated to 10-day composite using a maximum value compositing procedure to minimize the effects of cloud contamination.

Soil adjustment as a post-process





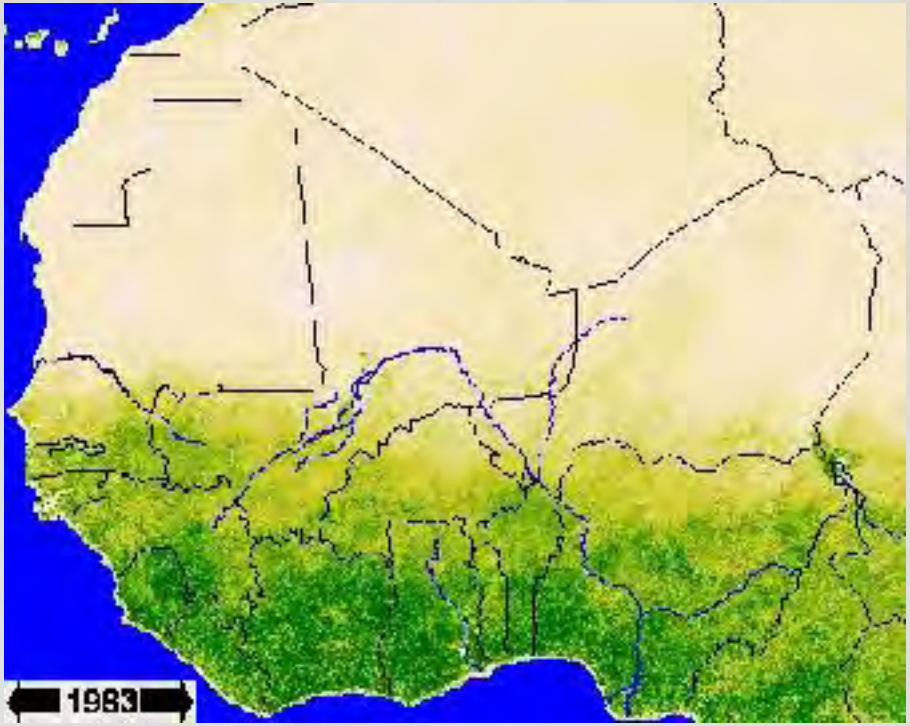
For Sahel we used this formula to adjust NDVI:

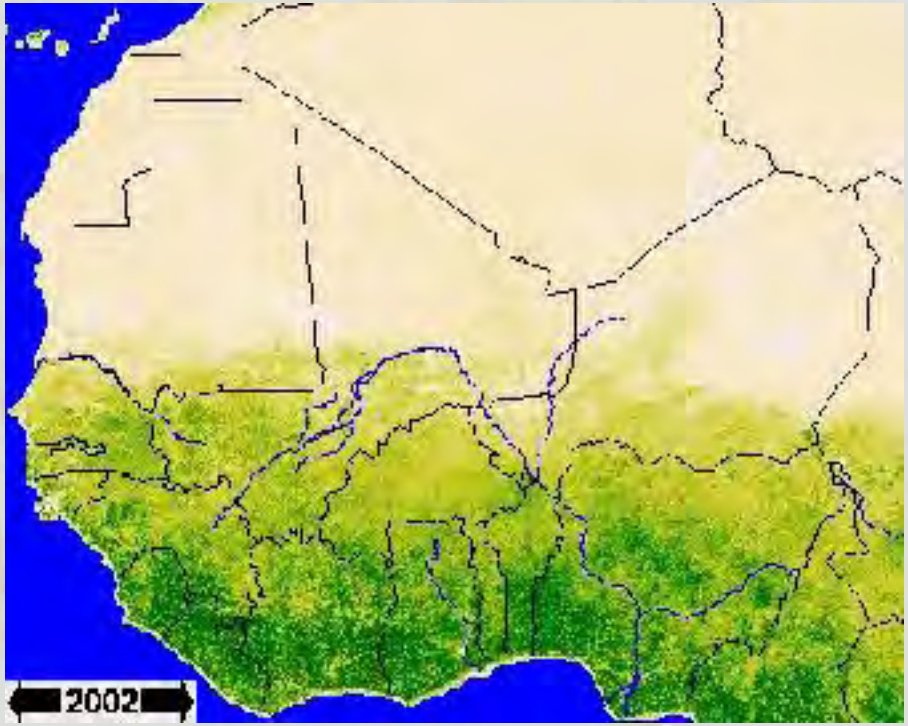
*NDVI = $(NDVI-NDVI_0)/(NDVI_S-NDVI_0)$

Where $NDVI_S$ is the value of NDVI at 100 % vegetation cover (*NDVI = 1.0) and $NDVI_0$ is that value for bare soil (*NDVI = 0)

NDVI overestimates vegetation over bare soil. This is then a problem in dry Regions like the Sahel. The soil effect is best handled by using an alternative to NDVI (e.g. the Soil adjusted Vegetation Index), but that demands the original satellite data.

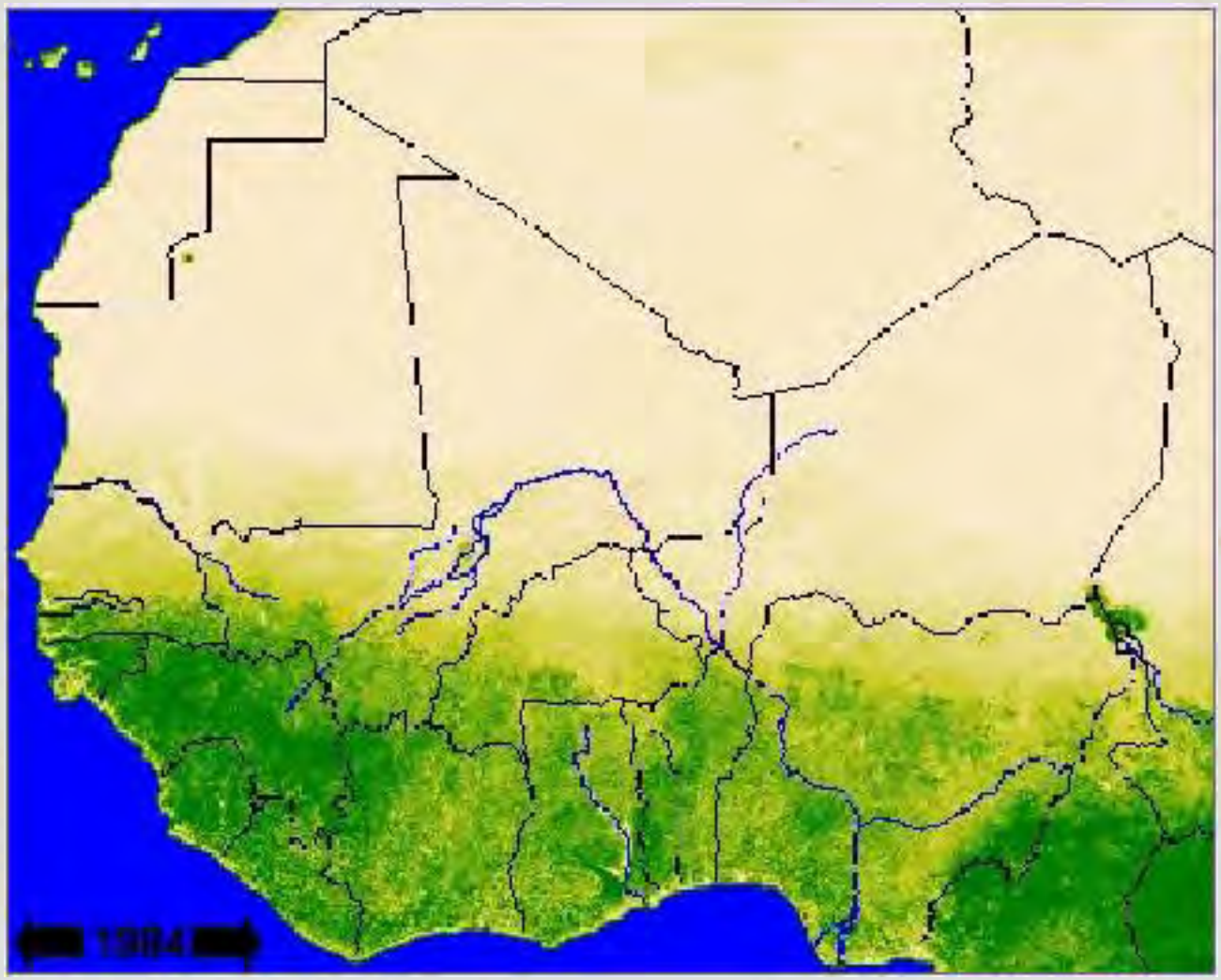
NDVI annual sum or average



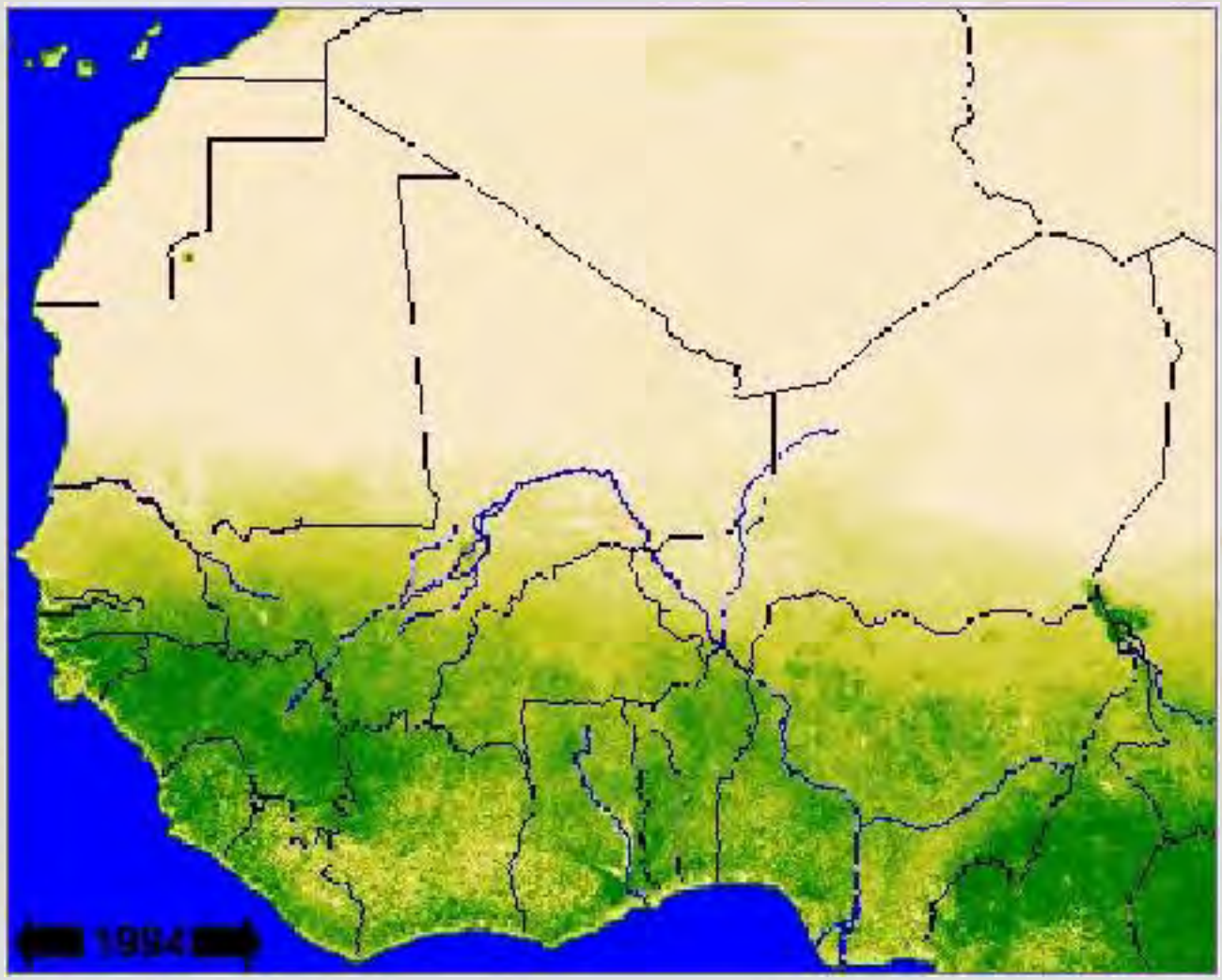


The annual NDVI integral is a measure of the total annual biomass production. It is widely used in both scientific studies and for predictions of biomass (e.g. food) production.

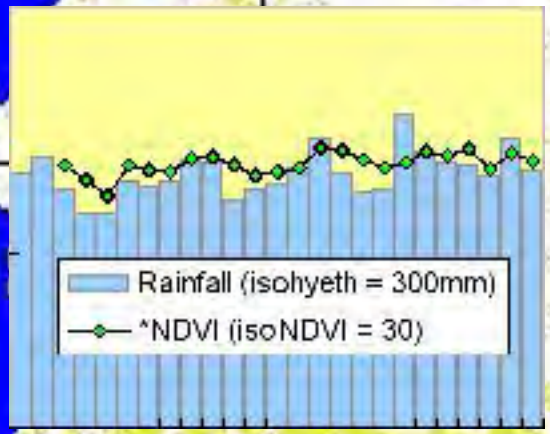
Sahel NDVI average 1984

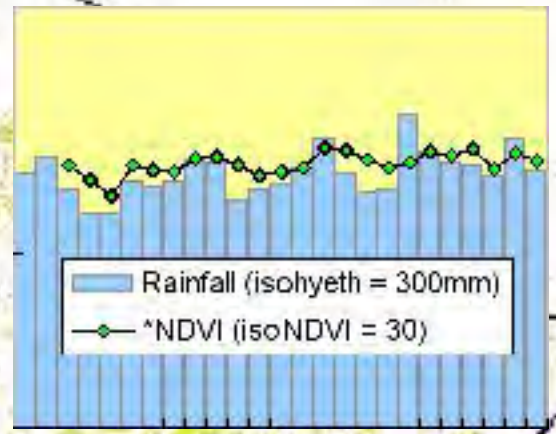


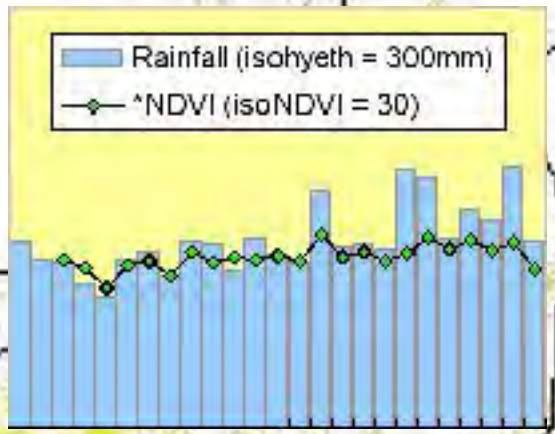
Sahel NDVI average 1994



Trend in annual average NDVI 1982-2004

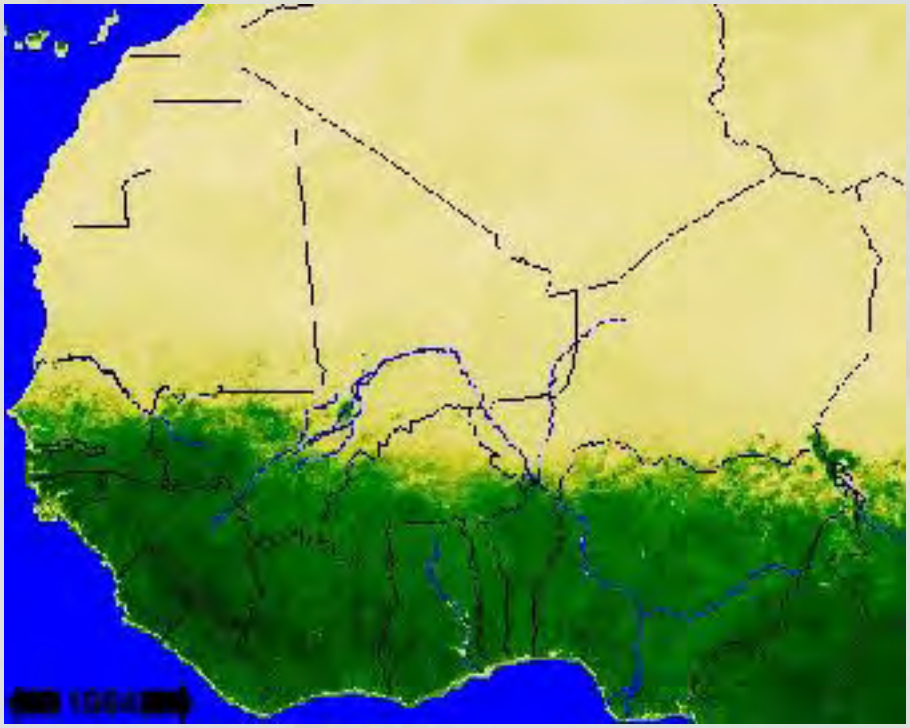


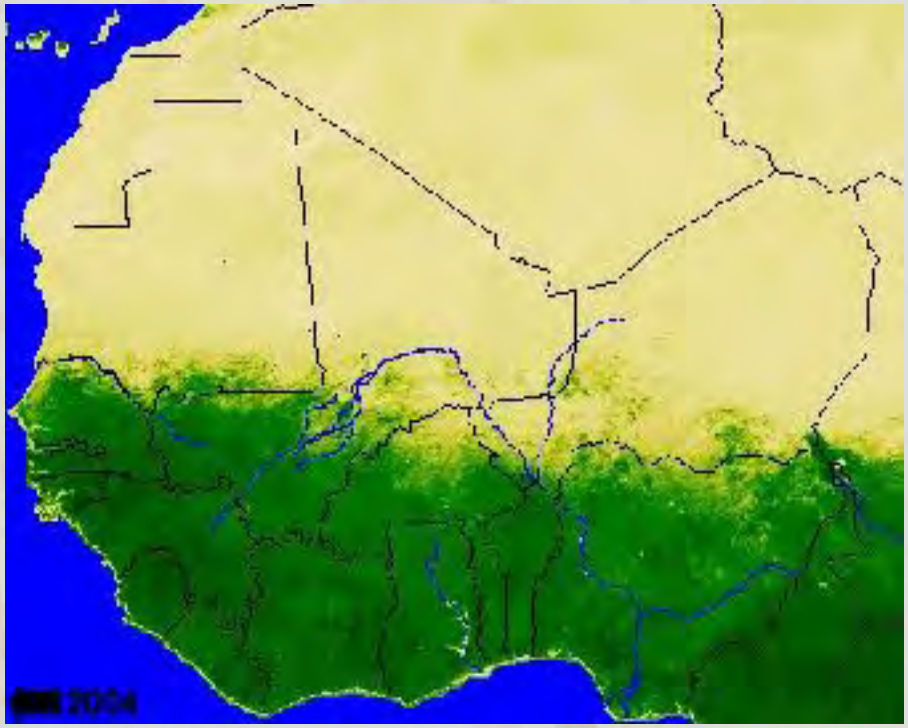




Latitudinal shifts in the average *NDVI for the period 1982-2004 calculated by extracting a position point every 8 km along the isoline for *NDVI = 30. Image backdrop shows per pixel trend.

NDVI annual maximum

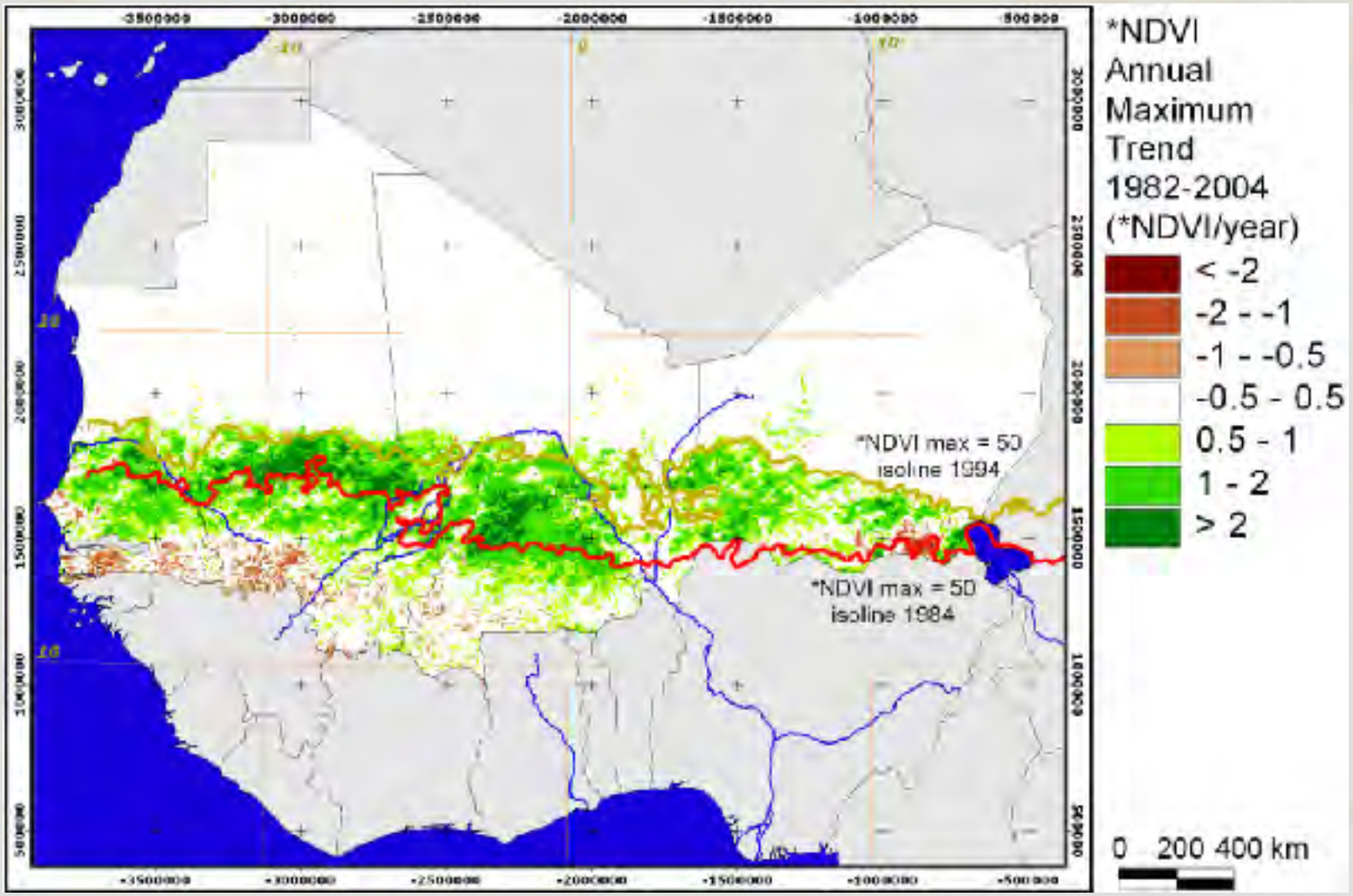




In time series analysis of NDVI images it is common to use either monthly or annual maximum value compositions. This is a way to Make sure that cloud contamination is kept at a minimum.

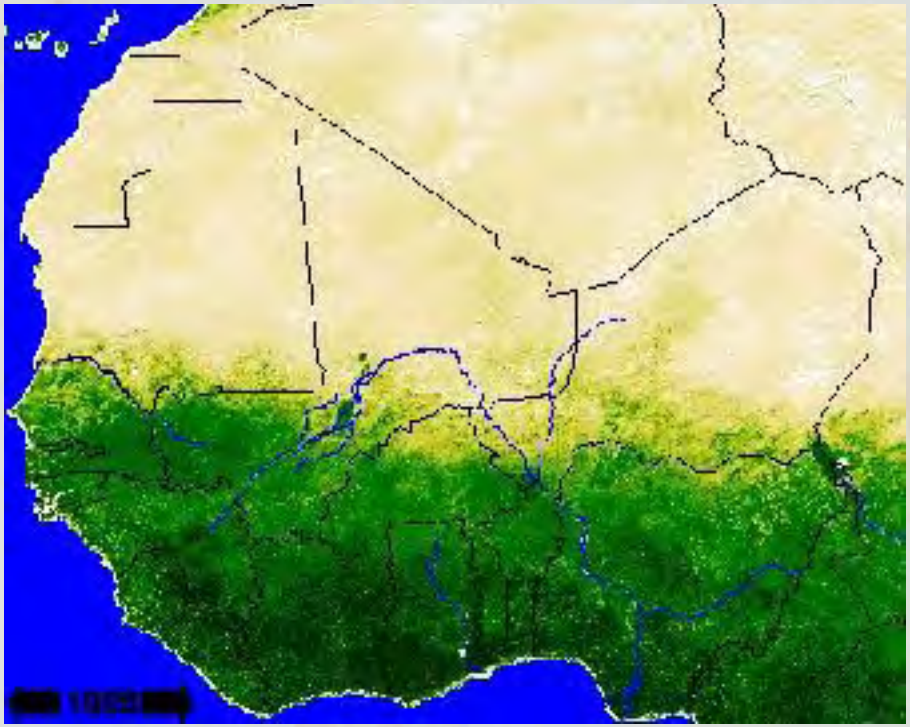
The annual maximum NDVI in rangeland ecosystems is also a measure of the standing crop biomass at the end of the growing season before harvesting.

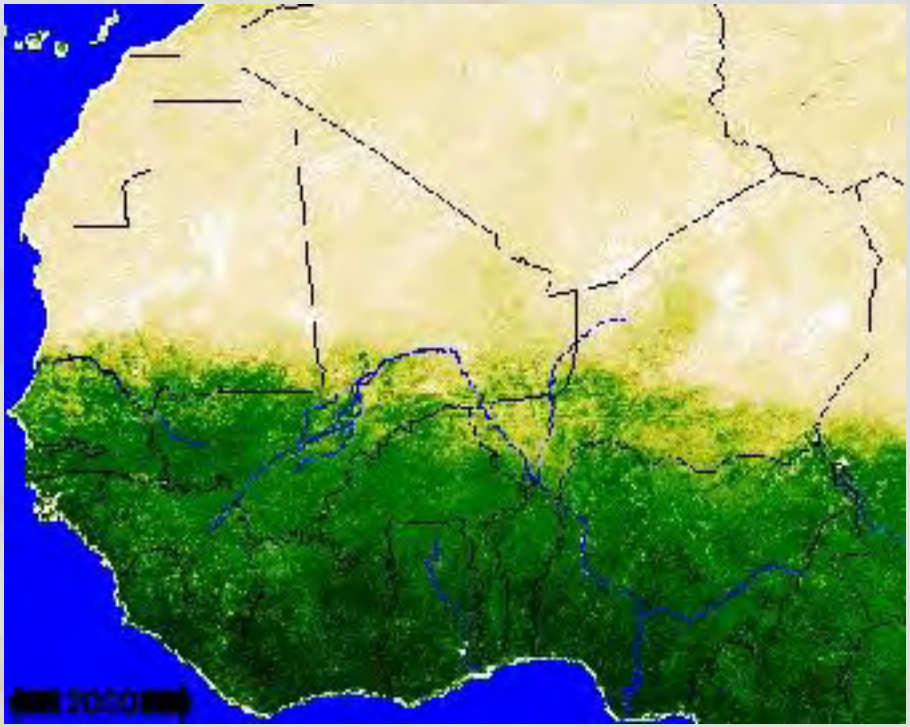
Trend in annual max NDVI 1982-2004



Trend in maximum annual NDVI (*NDVI units/year) for the period 1982-2004.

Annual Net Primary Production



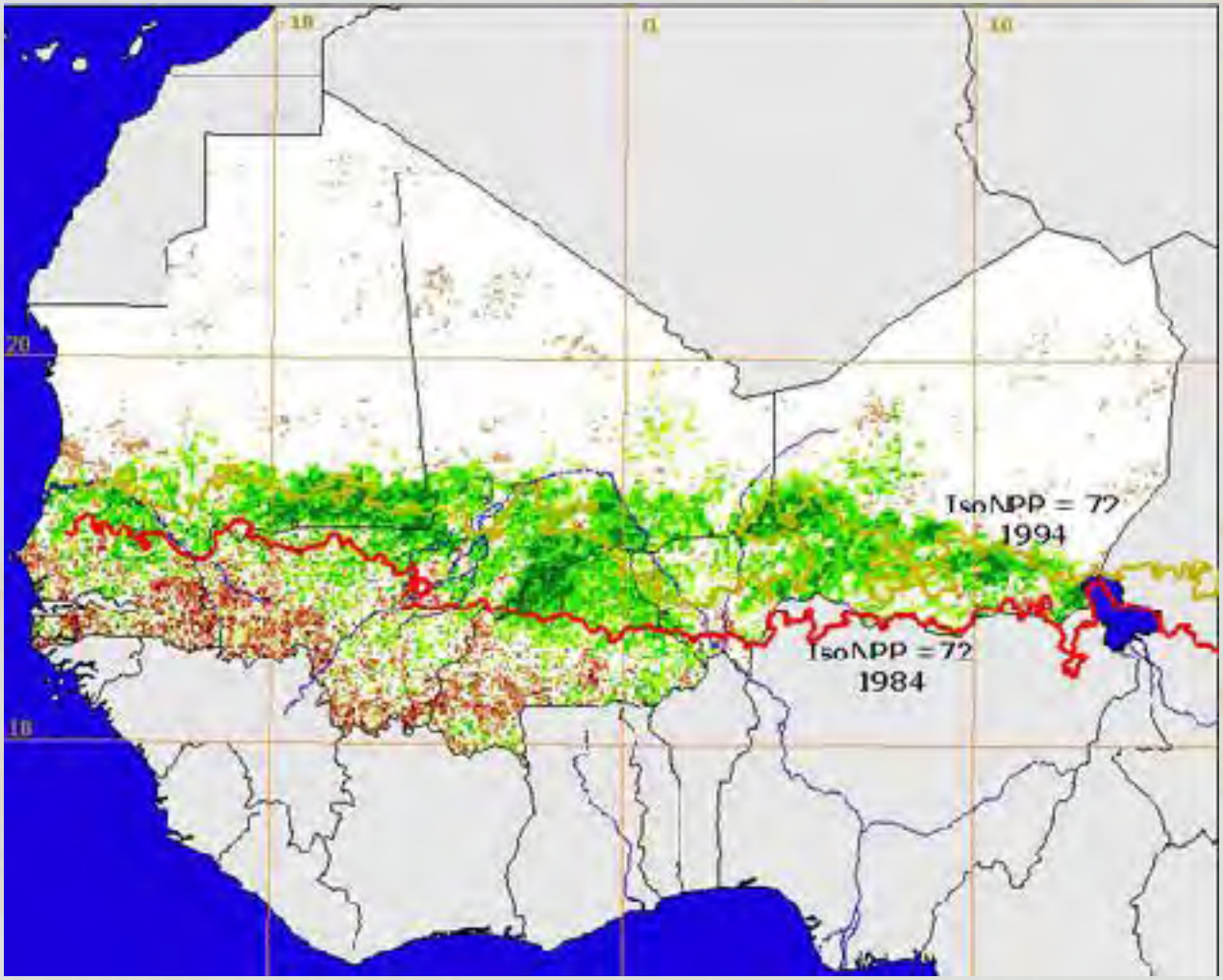


Satellite based estimates of Net Primary production (NPP) in Sahelian grasslands summing the NDVI values over the growing season is widely used. Other studies have indicated that seasonal maximum NDVI may be more highly correlated with biomass production in semi-arid rangelands (Prince et al., 1991):

NPP (Mg ha^{-1} a^{-1}) = 3.139 sum(NDVI-3.852)

N= 239, r=0.684, p<0.001.

Trend in NPP 1982-2004



Trend in Sahelian NPP 1982-2004, calculated the increases in NDVI between each of the individual 36 decades (i.e. difference in *NDVI between current and previous decade) and then summed these increases over the whole year.

Is the Sahel greening up?

The analysis of NDVI time-series data derived from NOAA-AVHRR show a clear greening up trend in the Sahel 1982-2004.

This is a well known trend, but is it dependent on increases in rainfall, or other factors?

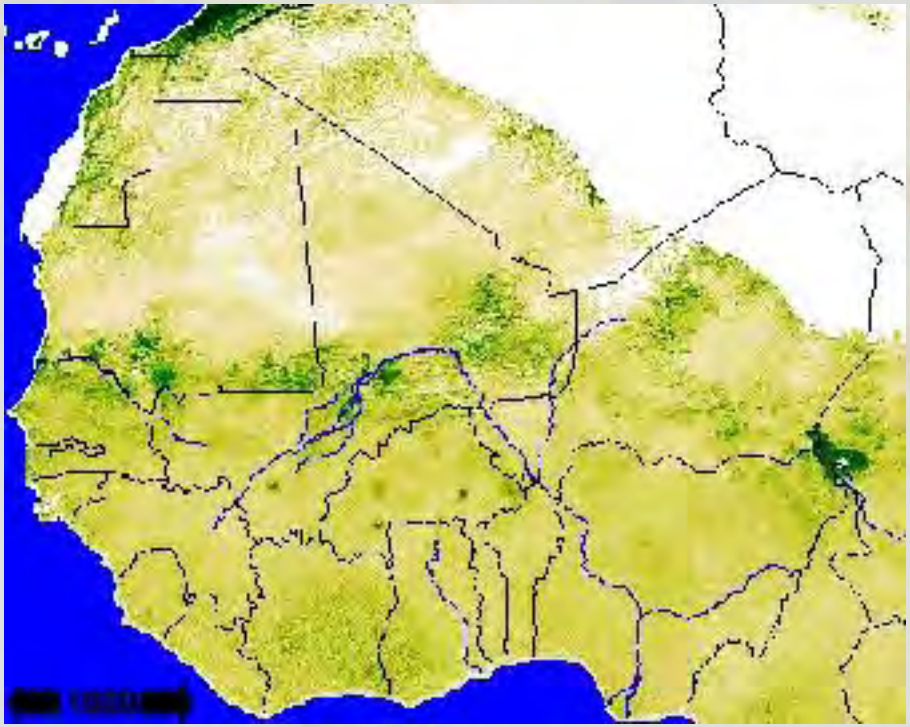
To disentangle rainfall from other factors the concept of Rain Use Efficiency (RUE) was developed.

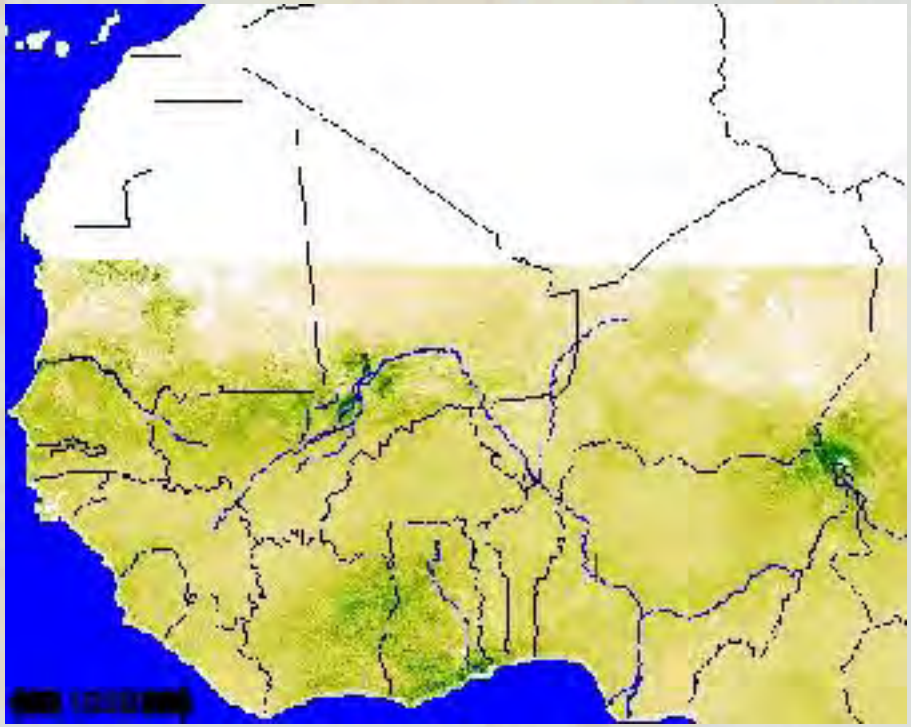
Rain Use Efficiency

Rain Use Efficiency (RUE) combines rainfall and vegetation information, by estimating the vegetation production per rainfall unit. RUE is calculated on an annual time-step and hence bridges seasonal fluctuations. RUE is reported to be lower in degraded arid lands compared to equivalent un-degraded areas and is hence an attractive index for separating the effects of rainfall from human factors on temporal changes of vegetation in rangeland ecosystems.

RUE is defined as Net Primary Production (NPP) divided by rainfall amount over a given period.

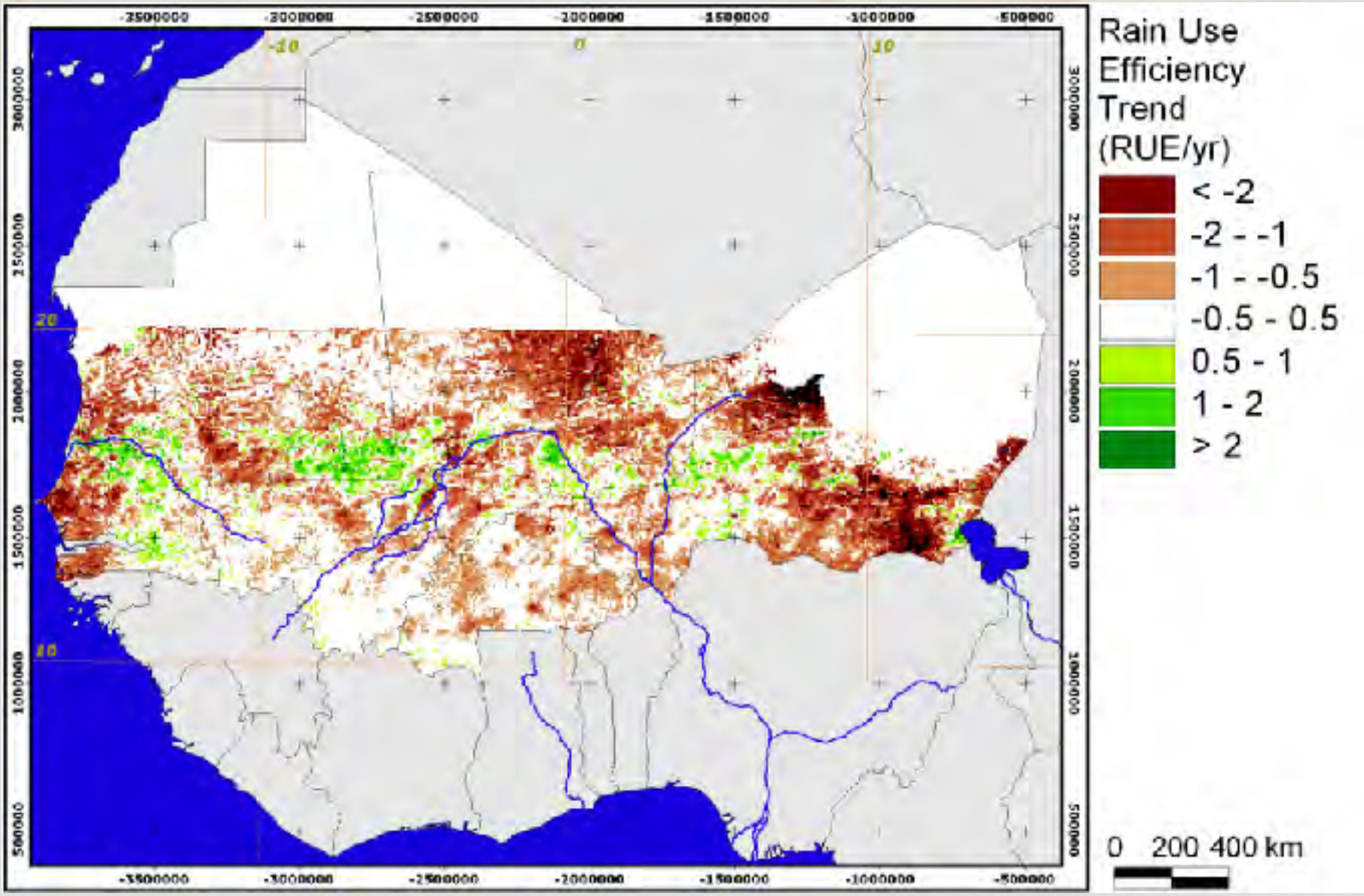
Rain Use Efficiency



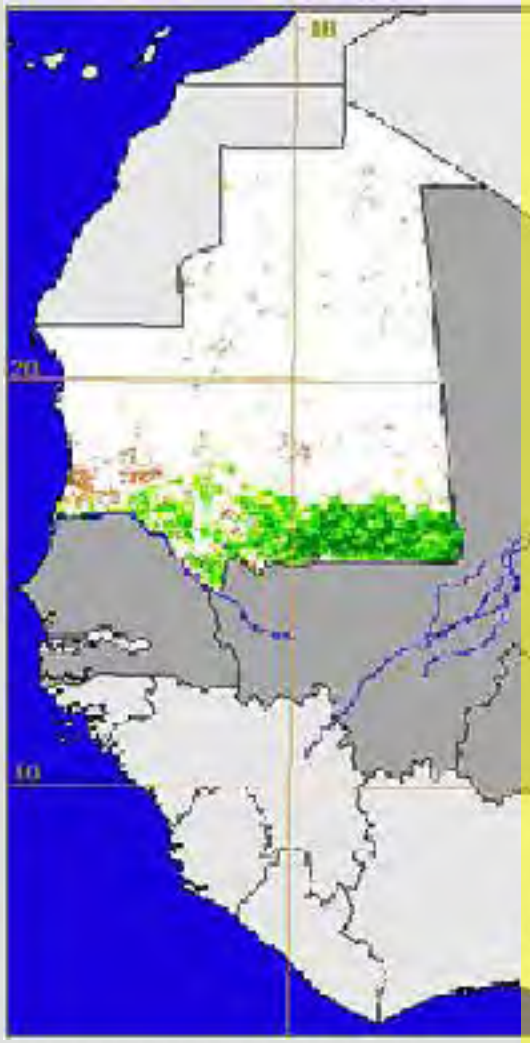


The RUE for the Sahel was calculated from NOAA-AVHRR NDVI in 8 km. Rainfall for the period 1982-1996 was taken from interpolated rainfall station data; data from 1996-2004 was taken from satellite based estimates. For the northern parts of Africa rainfall datais lacking for 1996-2000.

Trend in Rain Use Efficiency 1982-2004

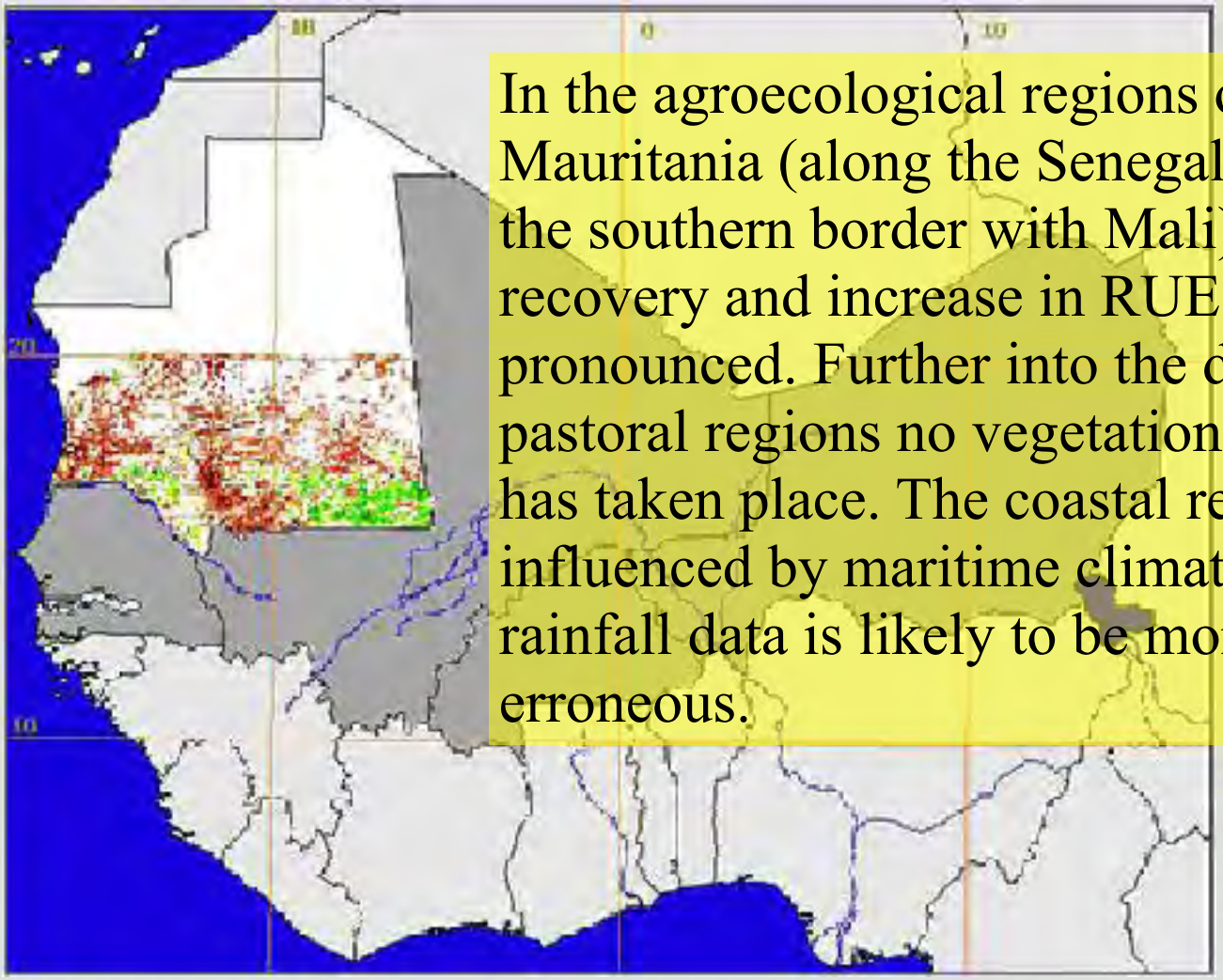


NPP - Mauritania



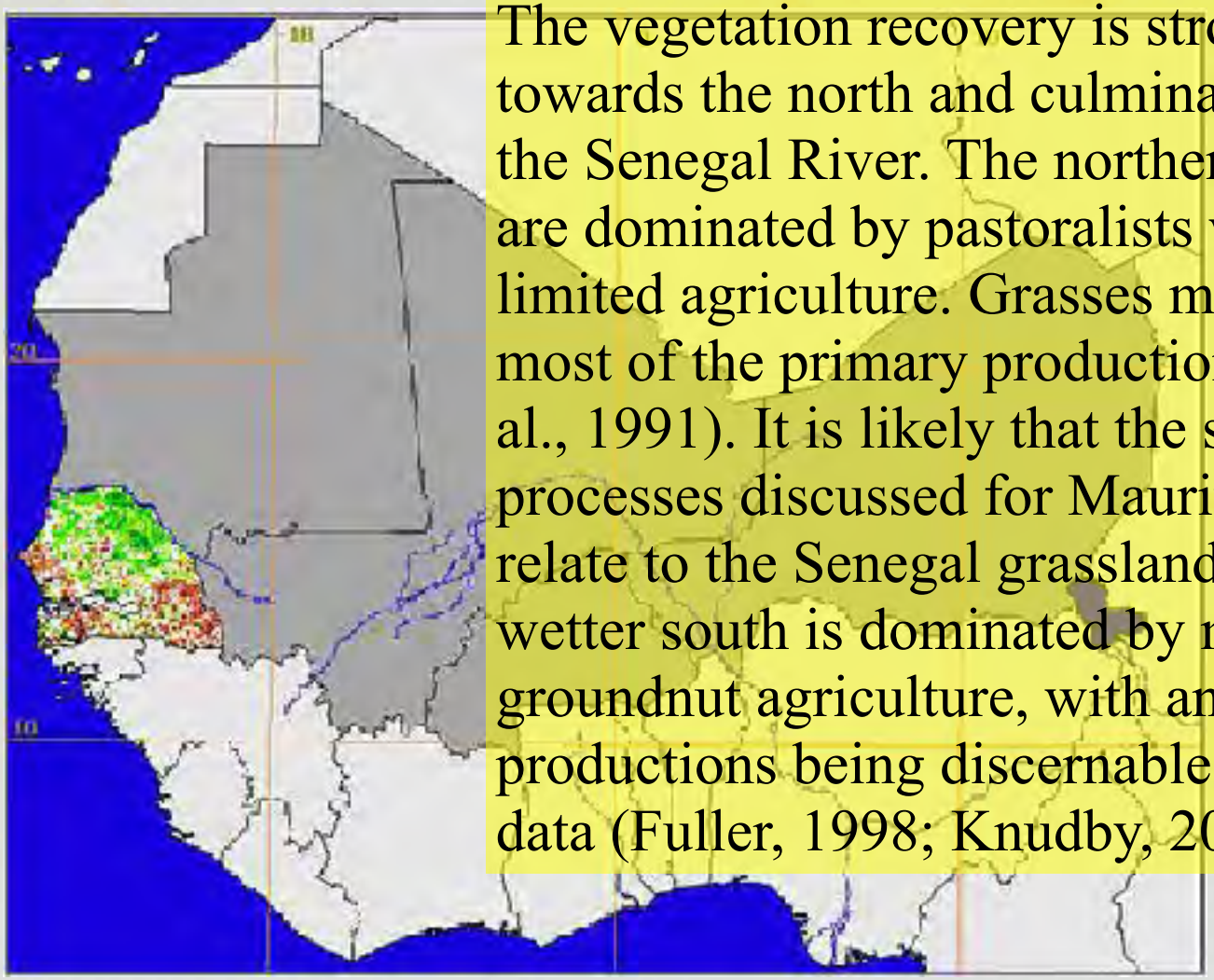
Most of Mauritania has an average rainfall of less than 300 mm. Milich and Weiss (2000) found erratic behavior in vegetation response to rainfall for Mauritanian rangelands and suggested that failure of the seed pool to develop after dry years prevents vegetation to make use of good rains in the following years. They also suggested that animal die-back during the early 1980's drought caused a large increase in vegetation growth in the years following the drought. Small-scale variations in topography and geology probably also influence the hydrology and hence the vegetation.

RUE - Mauritania



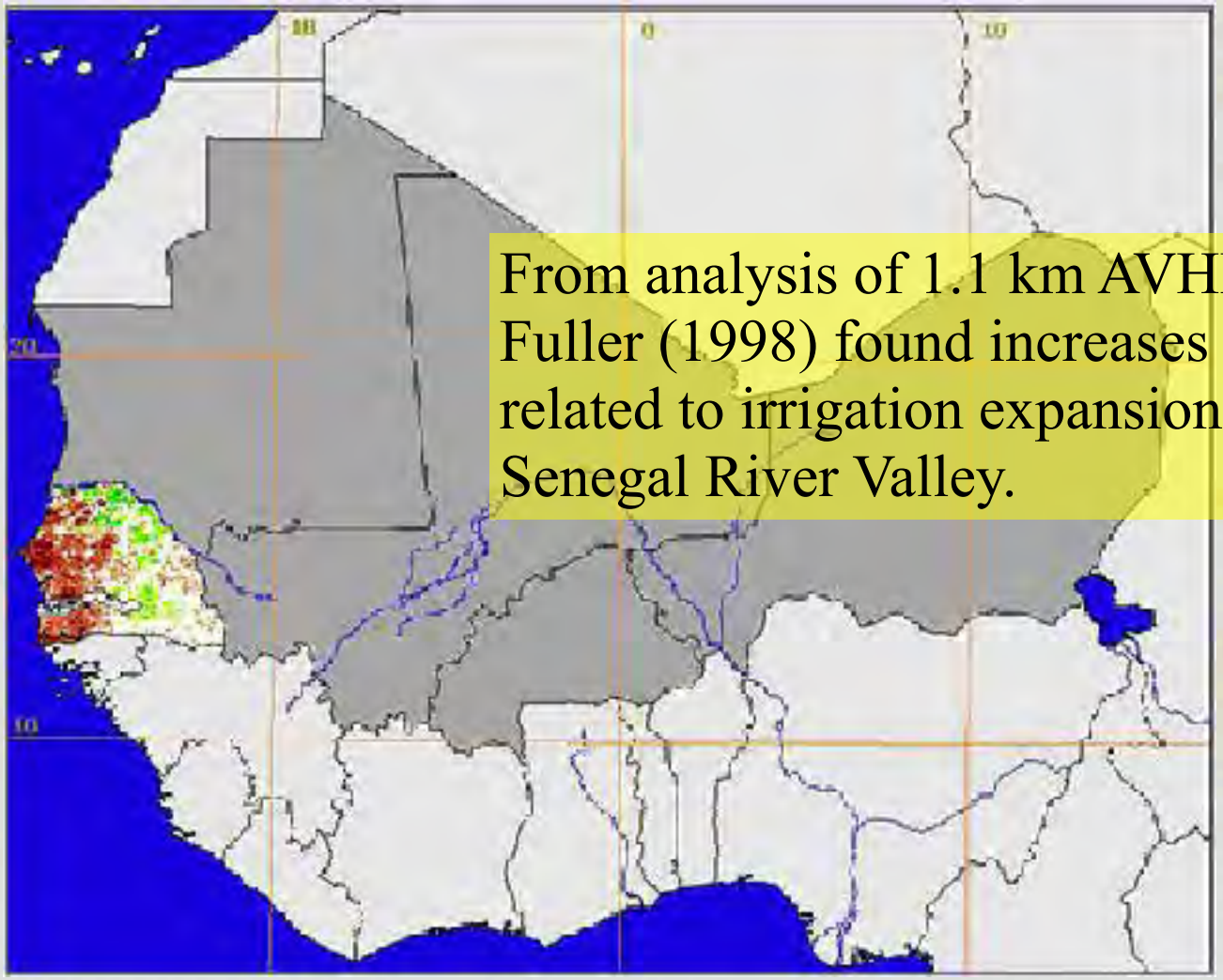
In the agroecological regions of Mauritania (along the Senegal river and the southern border with Mali) vegetation recovery and increase in RUE is pronounced. Further into the drier pastoral regions no vegetation recovery has taken place. The coastal region is influenced by maritime climate, and the rainfall data is likely to be more erroneous.

NPP - Senegal



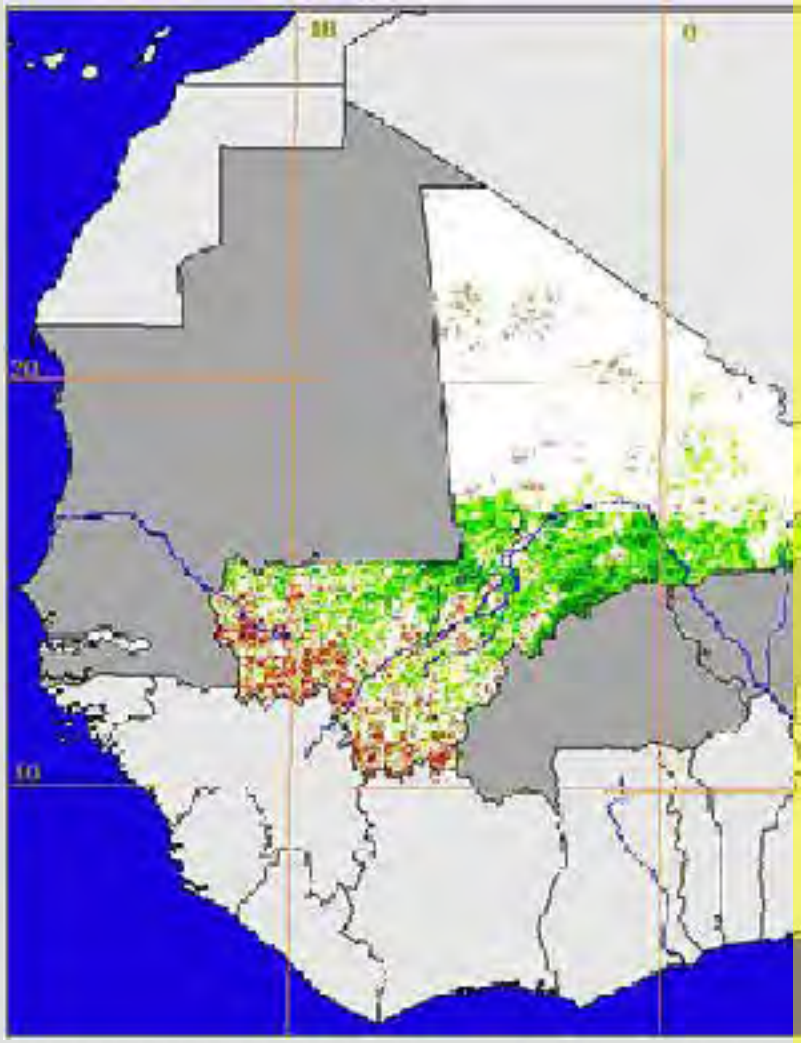
The vegetation recovery is stronger towards the north and culminates around the Senegal River. The northern drylands are dominated by pastoralists with limited agriculture. Grasses make up most of the primary production (Diallo et al., 1991). It is likely that the same processes discussed for Mauritania also relate to the Senegal grasslands. The wetter south is dominated by millet and groundnut agriculture, with annual productions being discernable in AVHHR data (Fuller, 1998; Knudby, 2004).

RUE - Senegal



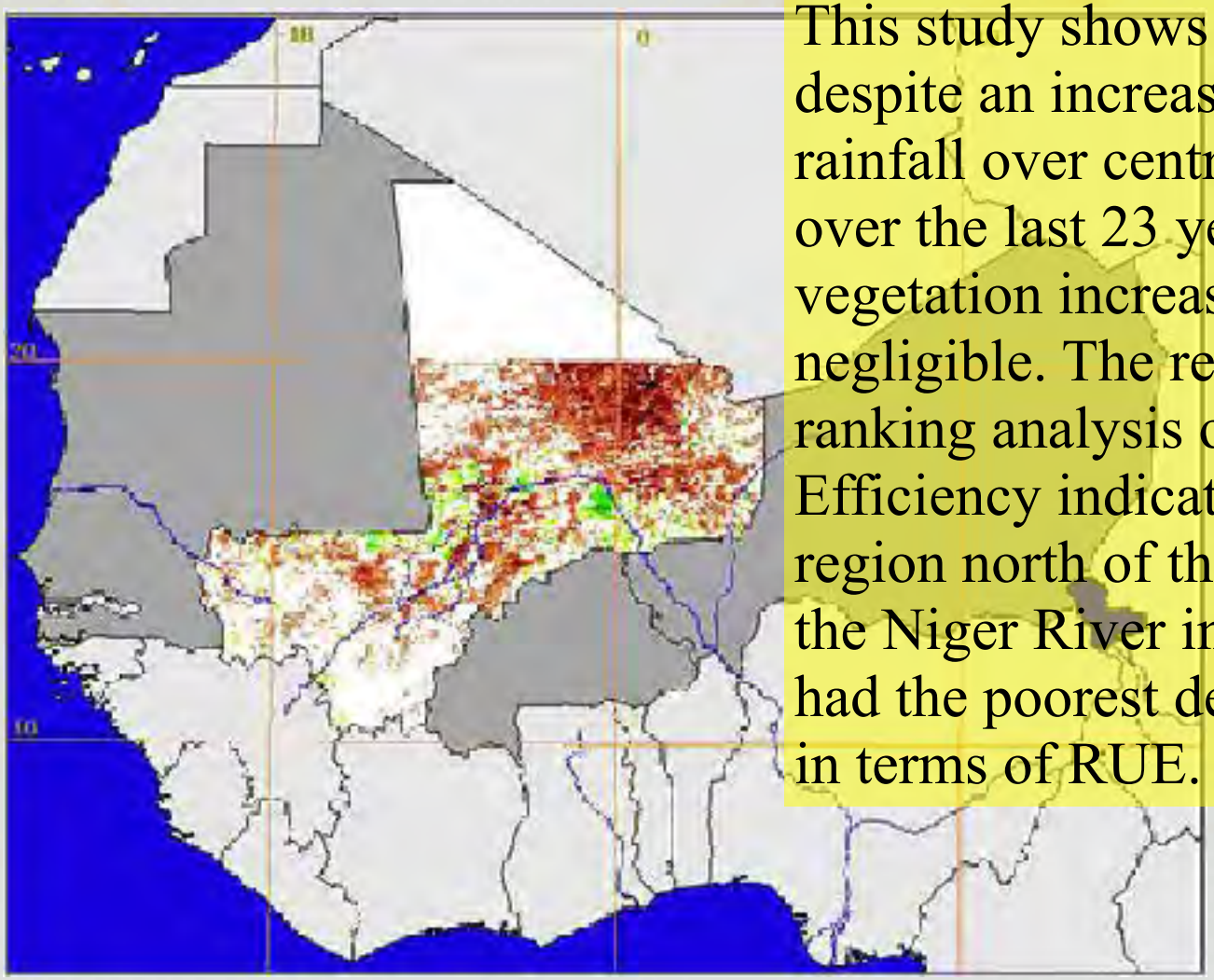
From analysis of 1.1 km AVHRR data Fuller (1998) found increases in NDVI related to irrigation expansion in the Senegal River Valley.

NPP - Mali



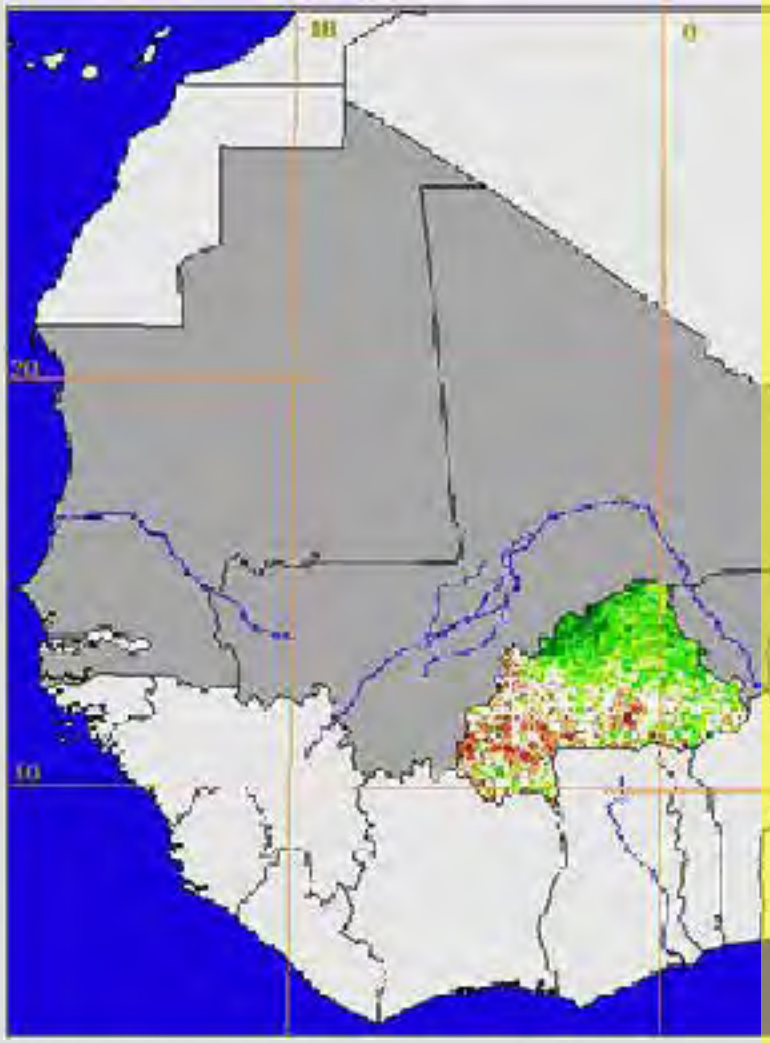
Most of the Sahelian region in Mali (8 - 12 deg N) has experienced a pronounced greening up over the last 2 decades. With areas around the Niger River and Niger inlands Delta being excepted. Herrmann et al (2005) found a stronger greening up than suggested by rainfall alone in the Niger inland Delta, and speculate that this is due to irrigation expansion. In this study no such greening can be seen in the Niger inland Delta.

RUE - Mali



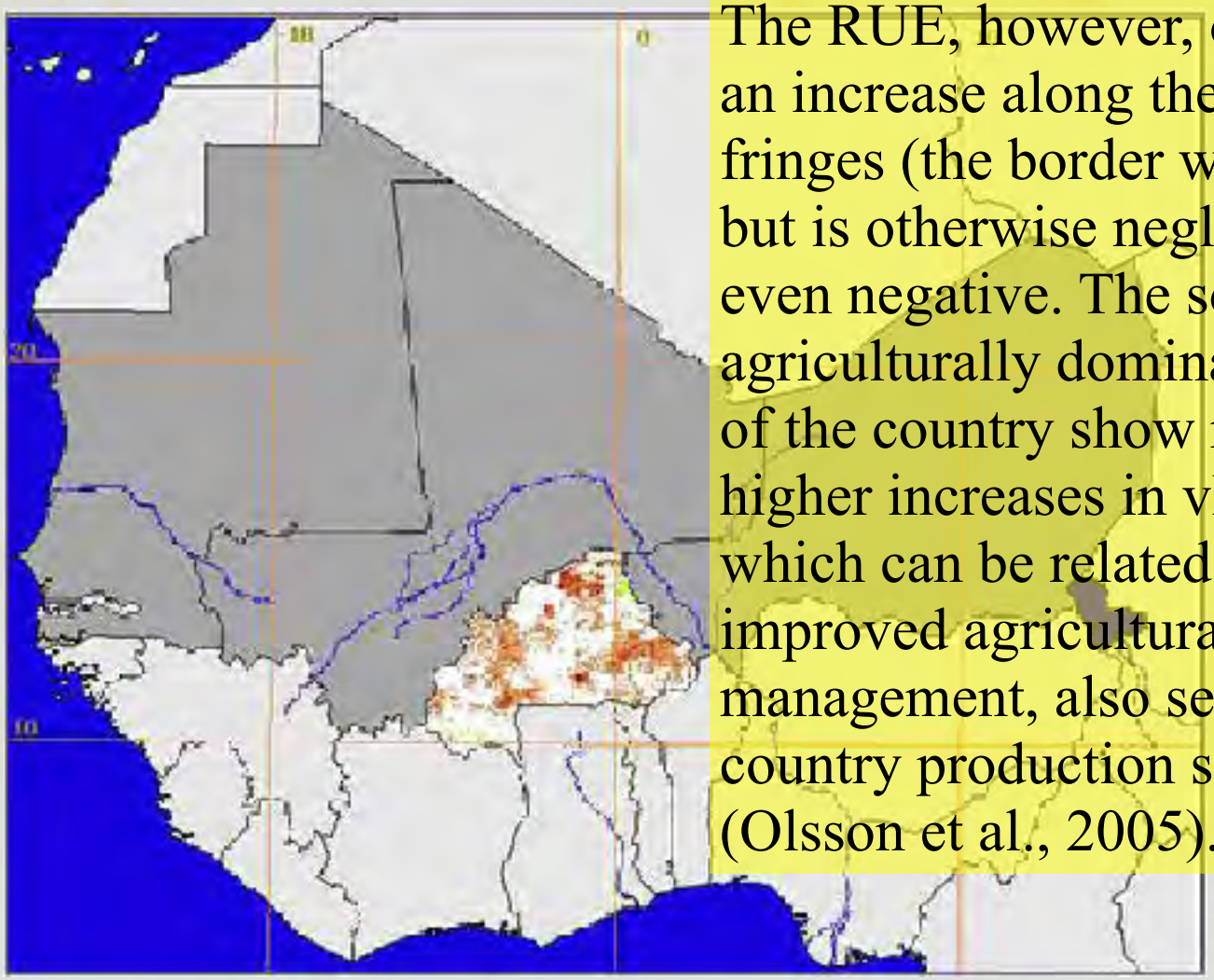
This study shows that despite an increase i n rainfall over central Mali over the last 23 years, the vegetation increase has been negligible. The regional ranking analysis of Rain Use Efficiency indicates that the region north of the bend in the Niger River in Mali has had the poorest development in terms of RUE.

NPP – Burkina Faso



The central plateau of Burkina Faso has been pointed out as one of the areas hit hardest by desertification during the Sahel droughts in the 1970's and 1980's, but Herrmann et al. (2005) identified a stronger than average recovery over the last 20 years over the plateau. In this study the plateau shows the highest rate of increase in rainfall in Sahel over the last 2 decades. This rainfall increase has also fed a very strong vegetation recovery.

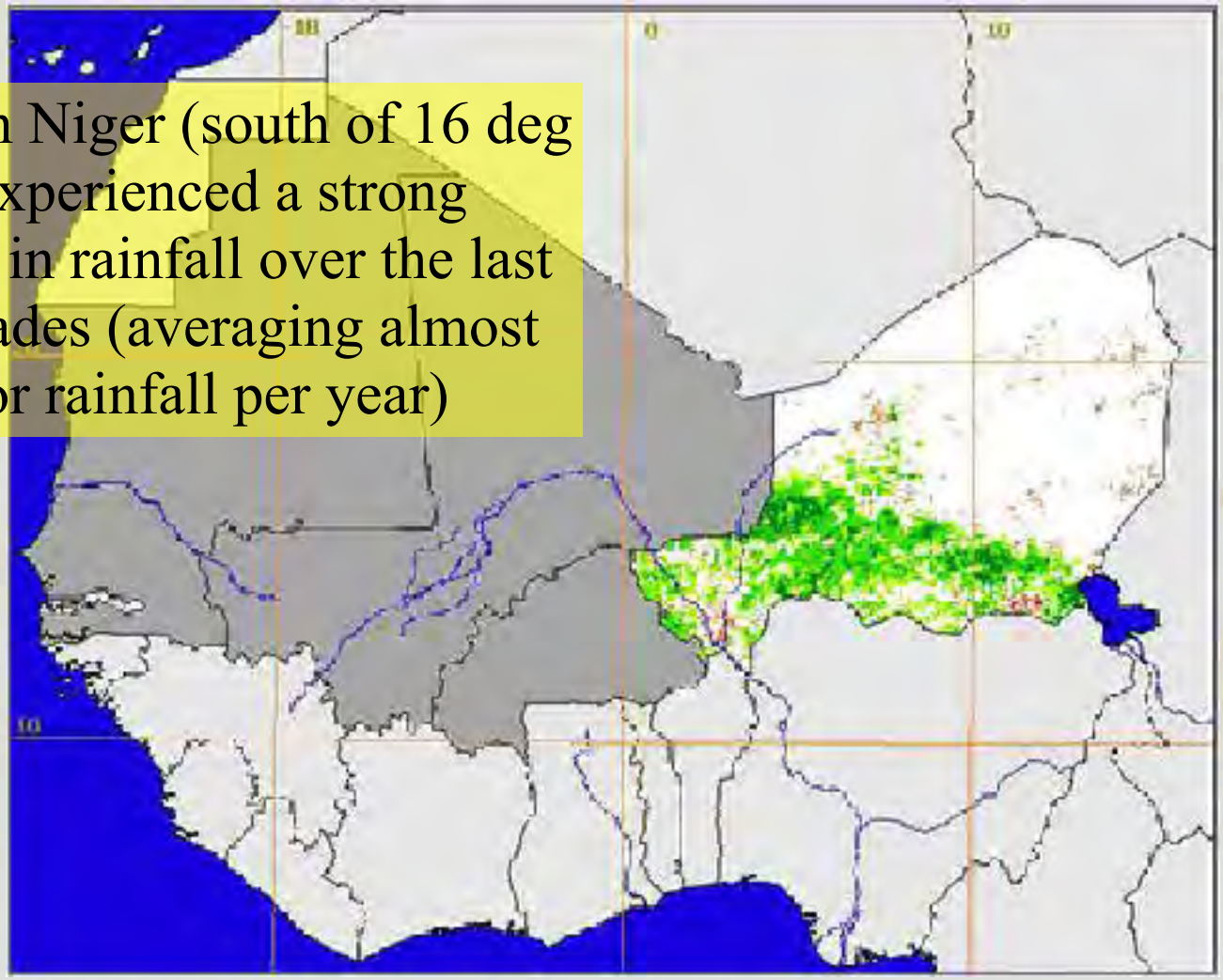
RUE – Burkina Faso



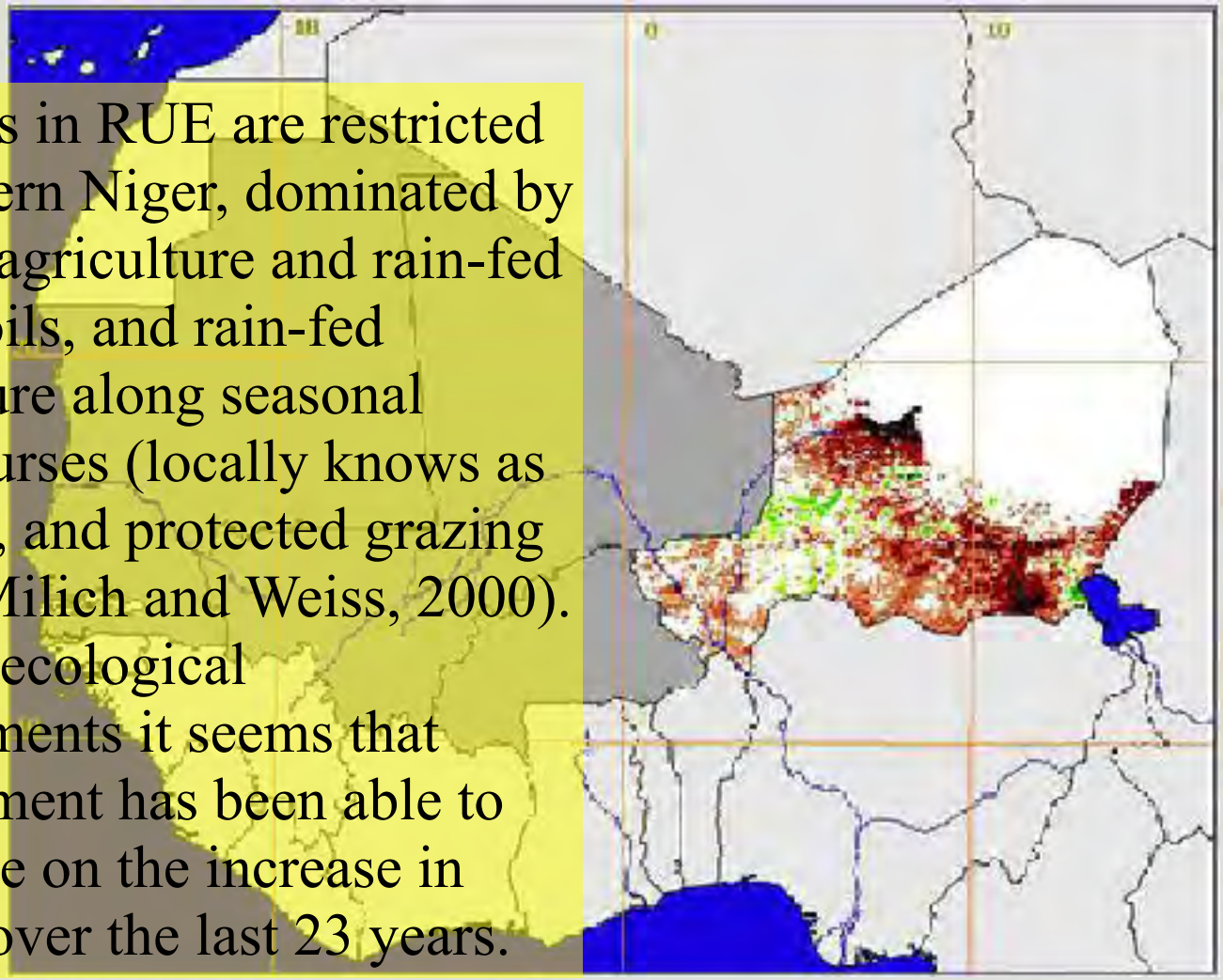
The RUE, however, only shows an increase along the northern fringes (the border with Mali), but is otherwise negligible, or even negative. The southern, agriculturally dominated parts of the country show relative higher increases in vRUE, which can be related to improved agricultural management, also seen in the country production statistics (Olsson et al., 2005).

NPP – Niger

Southern Niger (south of 16 deg N) has experienced a strong increase in rainfall over the last two decades (averaging almost 10 mm or rainfall per year)

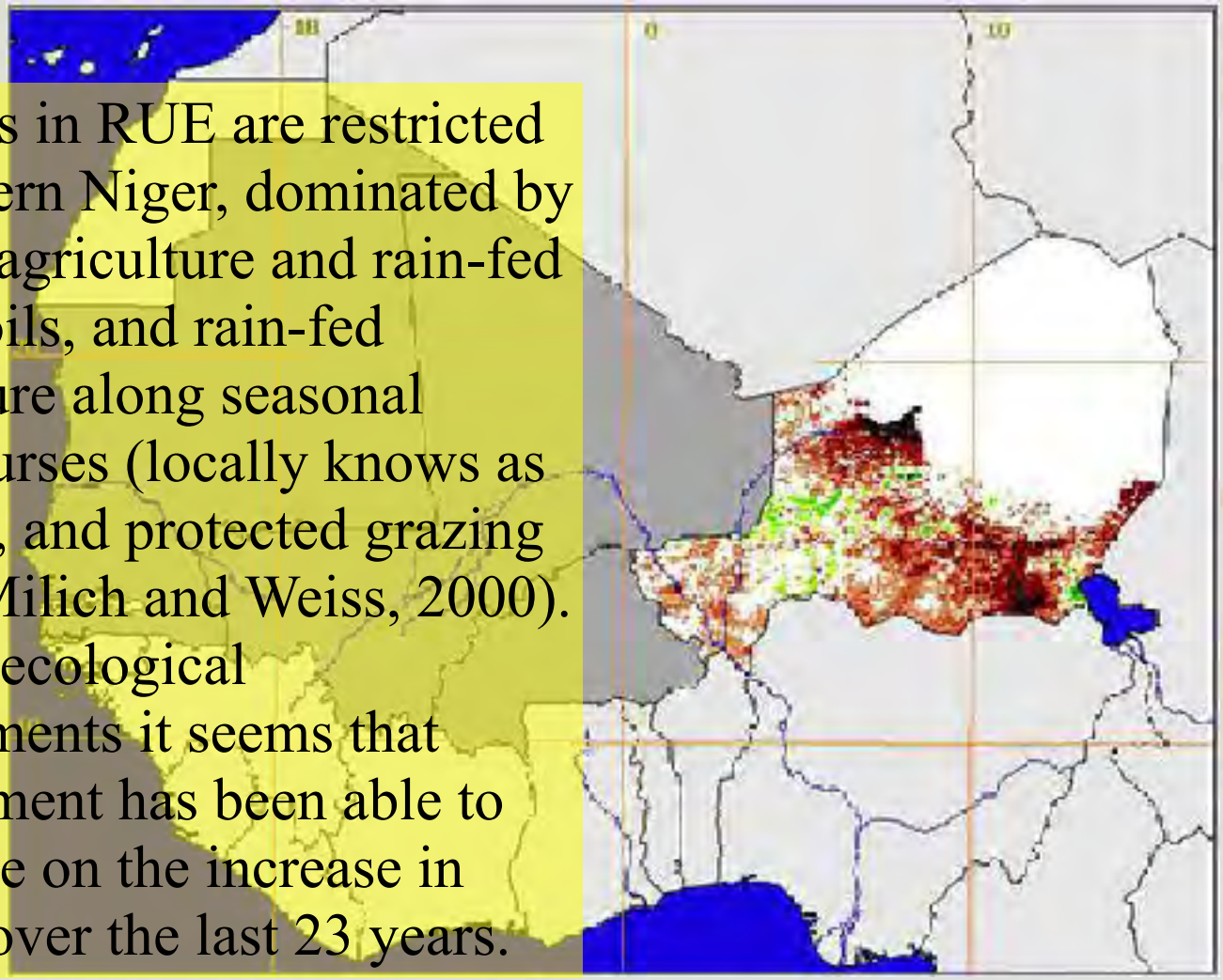


RUE – Niger



Increases in RUE are restricted to southern Niger, dominated by dryland agriculture and rain-fed sandy soils, and rain-fed agriculture along seasonal watercourses (locally knows as fadama), and protected grazing zones (Milich and Weiss, 2000). In these ecological environments it seems that management has been able to capitalize on the increase in rainfall over the last 23 years.

Targeting the worst hit areas



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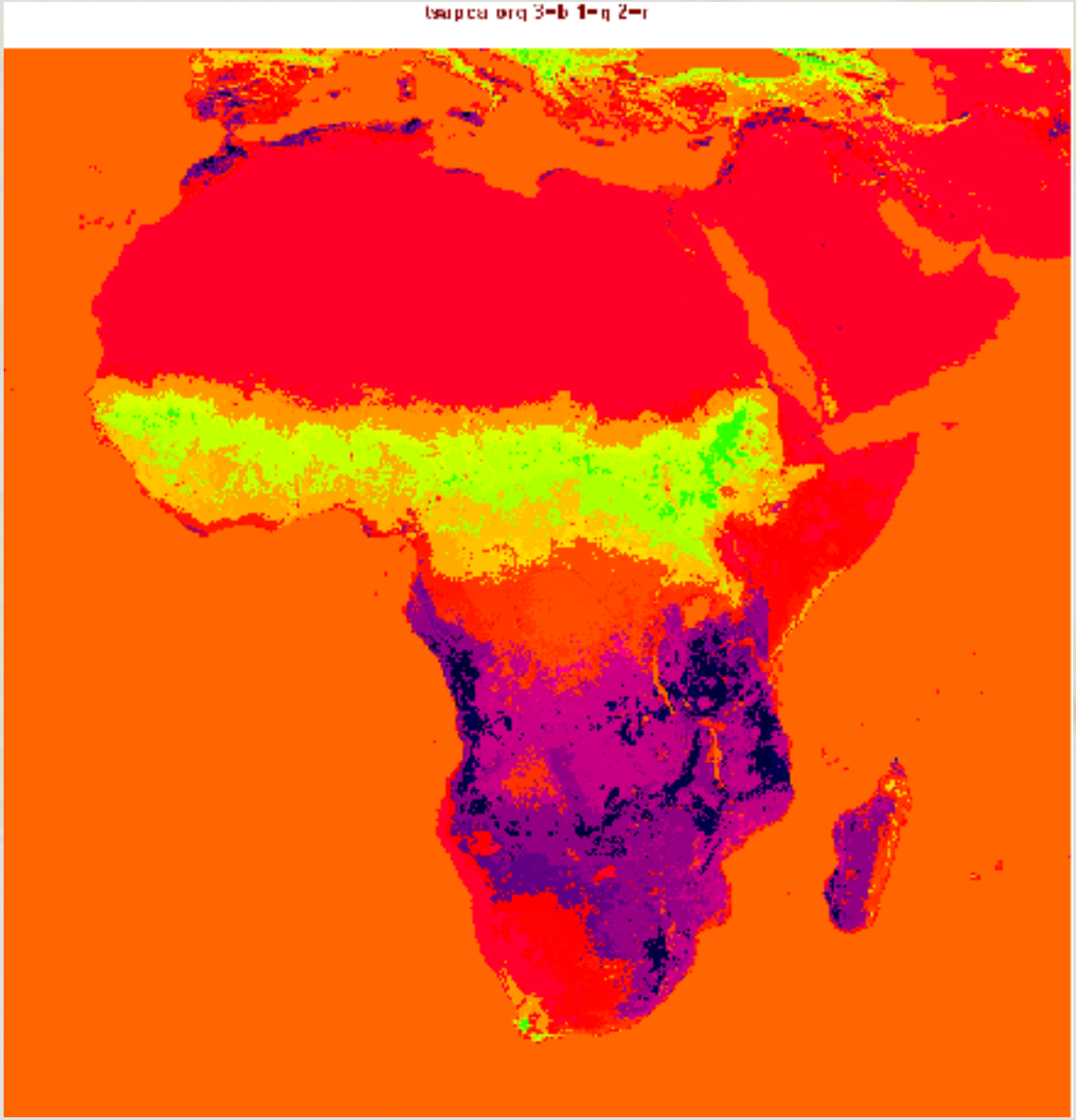
Sahel vegetation phenology

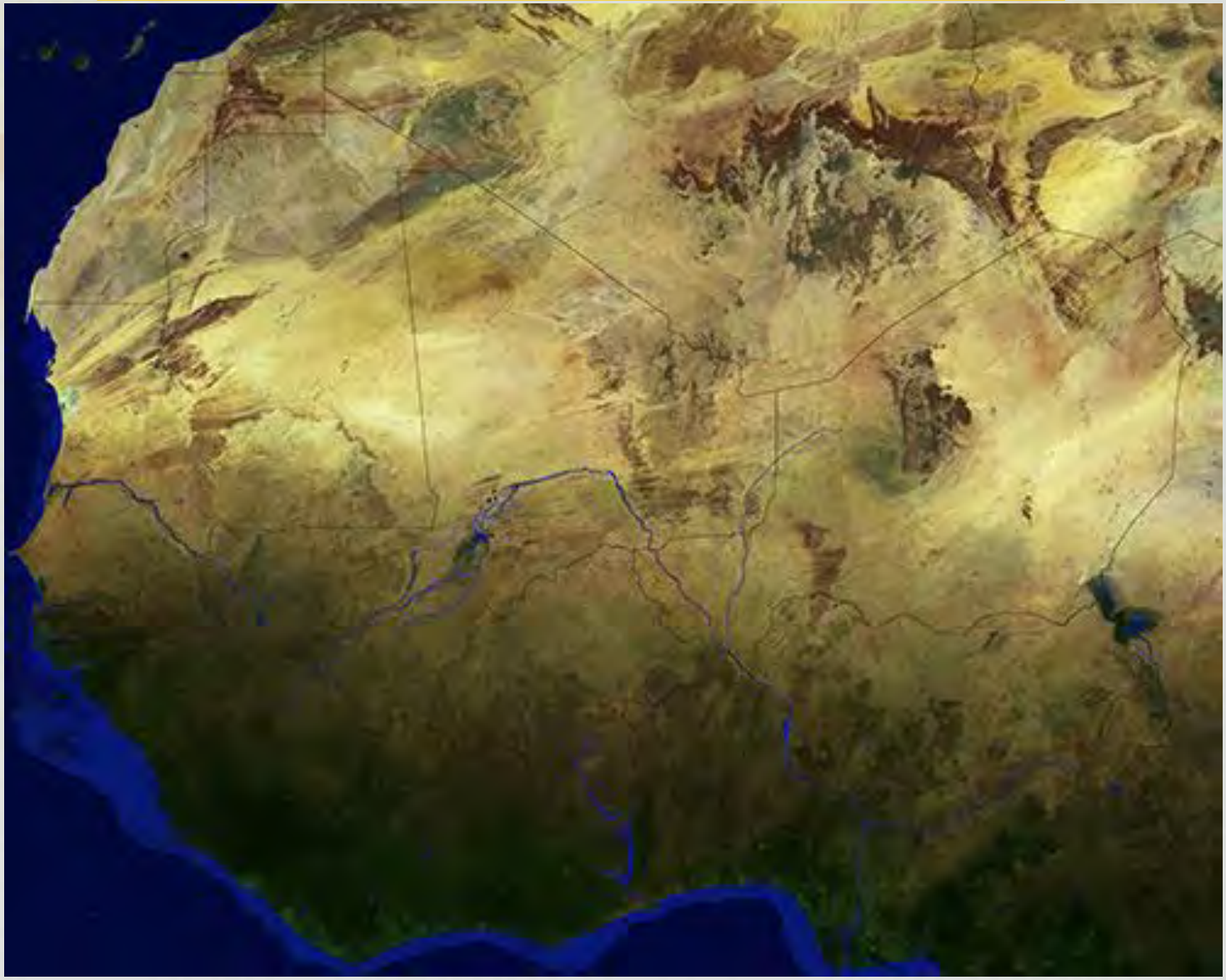


Sahel vegetation - MODIS

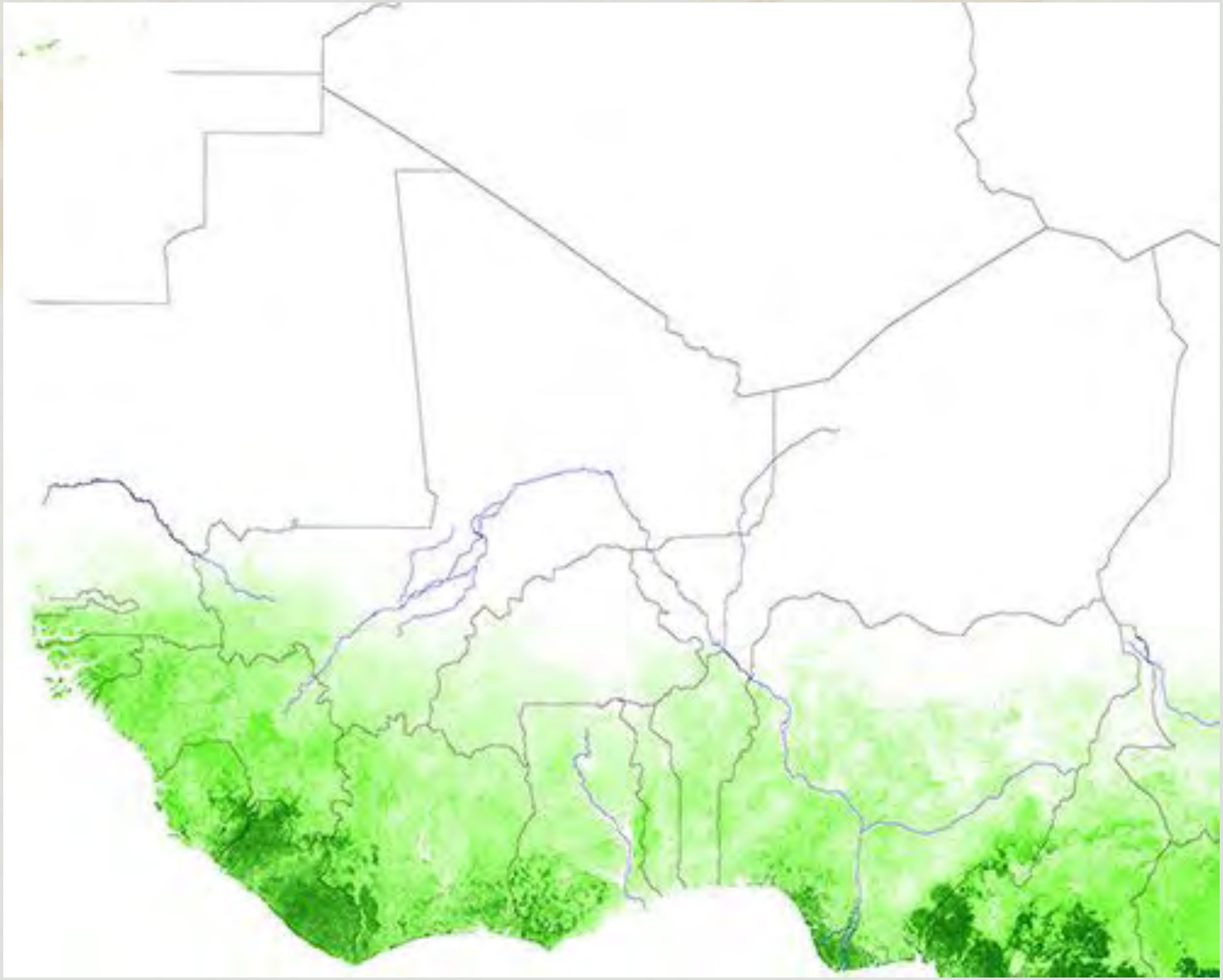
Data sources

- MODIS 32-day composites 2000-2005
- Satellite based rainfall estimates, 2000-2005

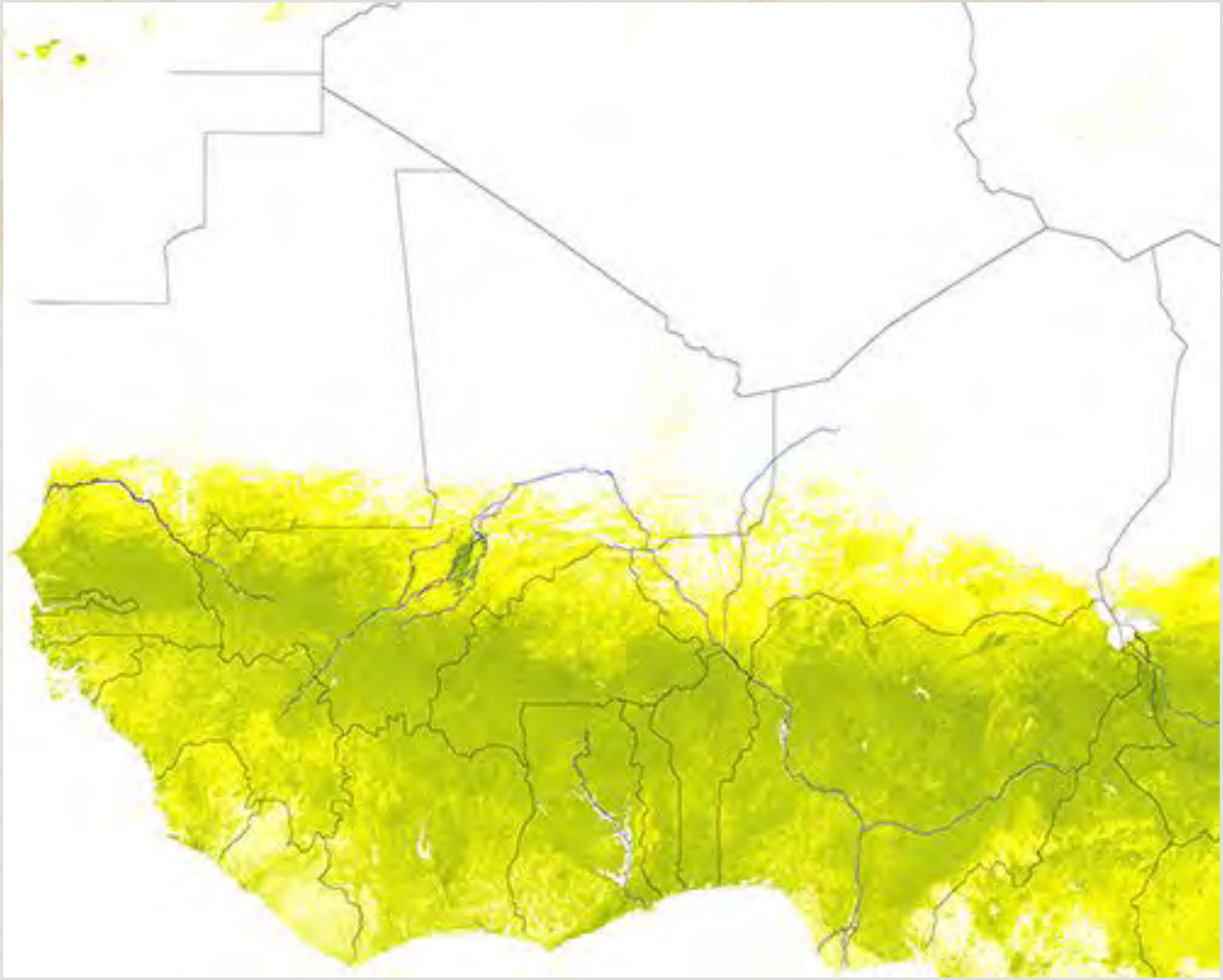
Sahel vegetation - MODIS



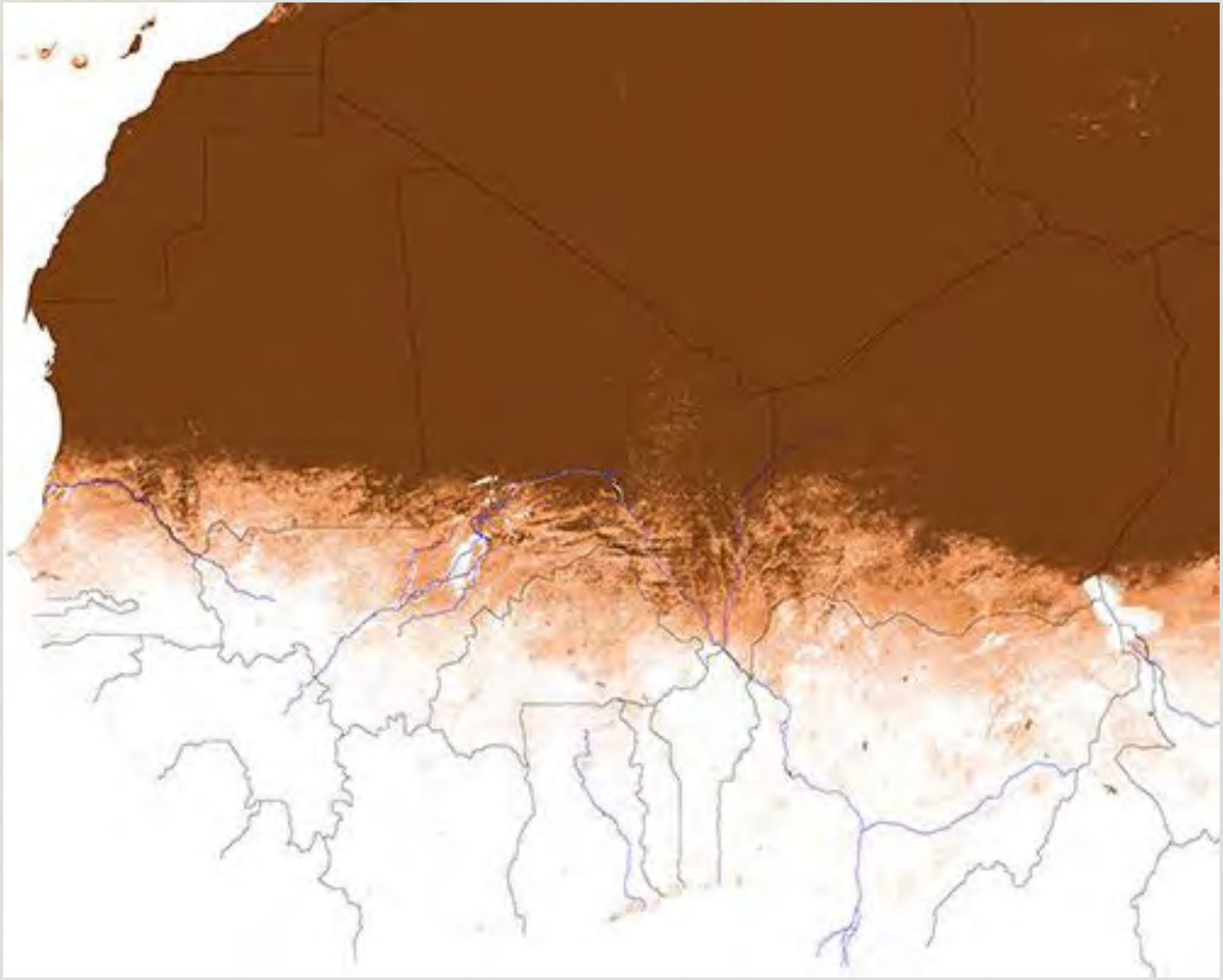
Sahel Treecover - MODIS



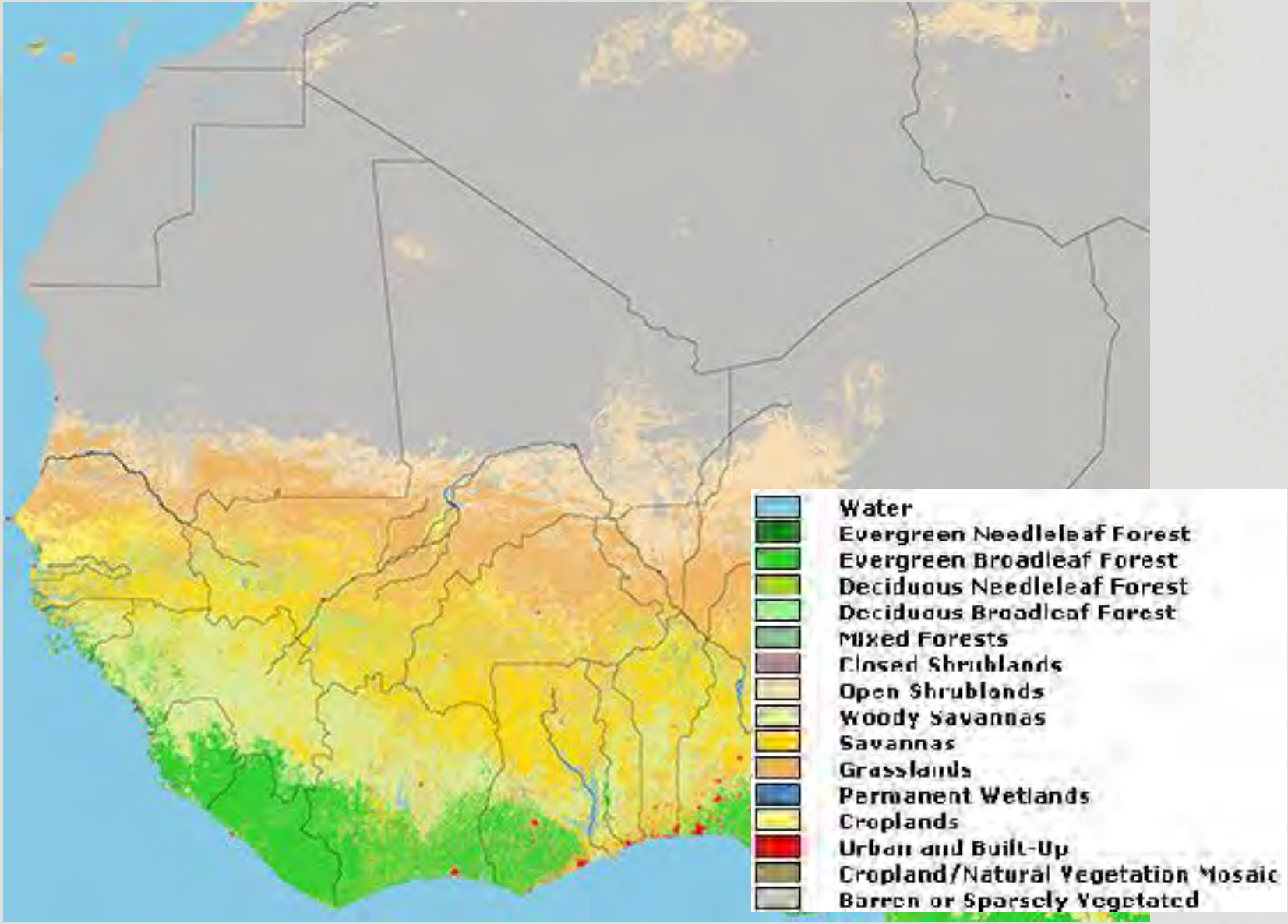
Sahel Herbaceous cover - MODIS



Sahel bare soil - MODIS



Sahel vegetation classes - MODIS



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