Is there desertification or re-greening in Sahel ?

Monitoring vegetation with satellite and field observations

Cécile Dardel (GET)

Collaboration **: Laurent Kergoat, Eric Mougin, Pierre Hiernaux, Manuela Grippa**

Thanks to C.J. Tucker (NASA's Goddard Flight Space Center)
for the new GIMMS « NDVI3g » dataset

cnes

RÉGION MIDI-PYRÉNÉES

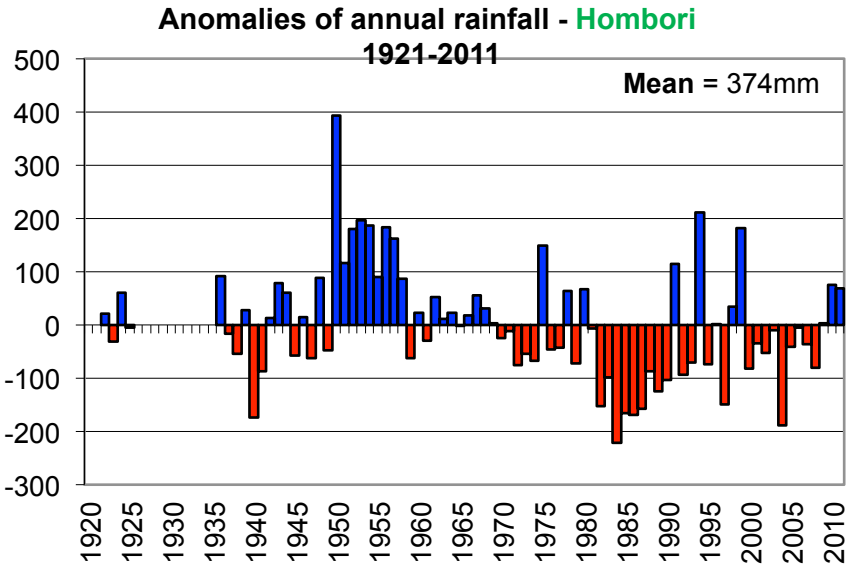
GET GÉOSCIENCES ENVIRONNEMENT TOULOUSE

An historical debate desertification/regreening

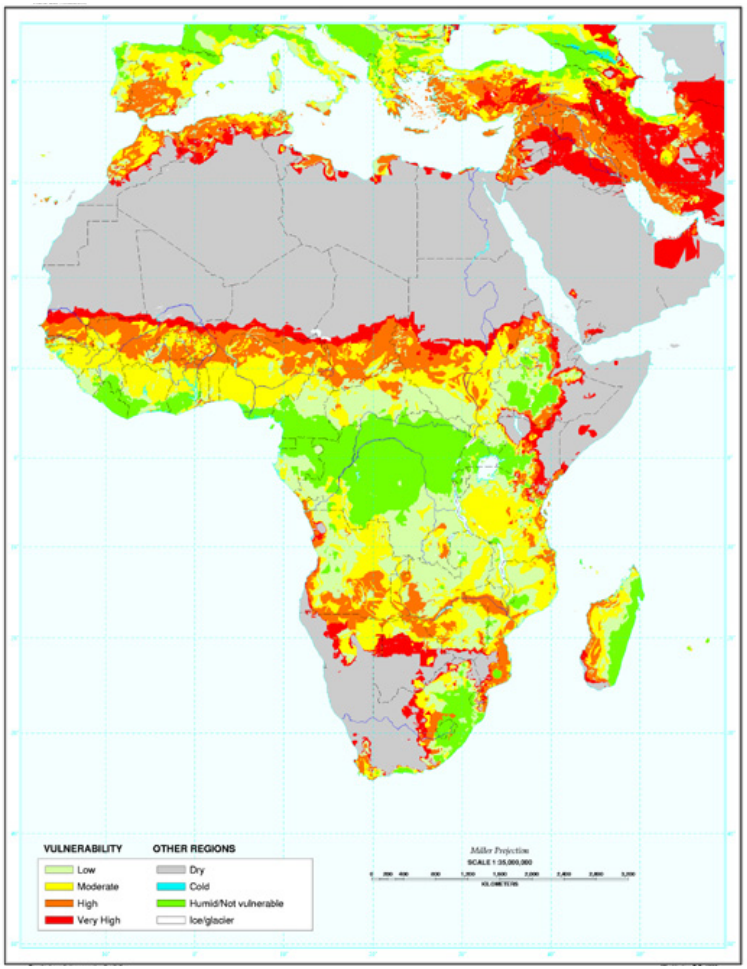
What is desertification ?

Def. United Nations : **"Desertification is the degradation of land in any dryland. It is caused by a variety of factors, such as climate change and human activities"**

Sahel characterized by a very strong interannual variability
=> strong impact on the populations and their resources
=> Many studies about **desertification** in Africa since the early 1900's.



Source : Direction Nationale de la Météorologie (DNM Mali)



Desertification vulnerability of Africa
Source : GLASOD/UNEP (United Nations Environment Program)- 1991

An historical debate desertification/regreening

What is « re-greening » ?

With the appearance of remote sensing data (airbornes first and then satellites), a **global monitoring** of vegetation becomes possible.

Regreening = increase of the vegetation index.

Hypothesis : vegetation index increase **related to vegetation productivity increase.**

Literature : Many papers about the subject (Tucker, Anyamba, Herrmann, Heumann, Fensholt, Olsson, Prince, Seaquist…), showing re-greening trends in Sahel since the 1980's.

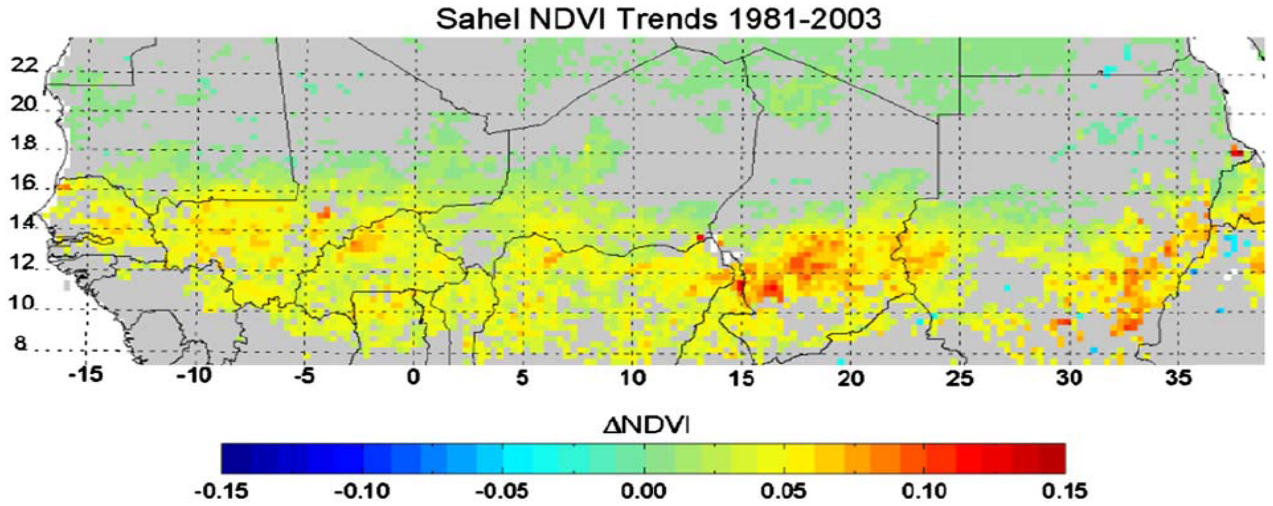


Fig. 6. Summary trend map of changes in Sahel NDVI from 1981–2003. Yellow to red colors indicate areas of significant change at 90% confidence, and gray areas show no significant trend.

Source : Anyamba and Tucker 2005

The objective of this study

Answering the question :

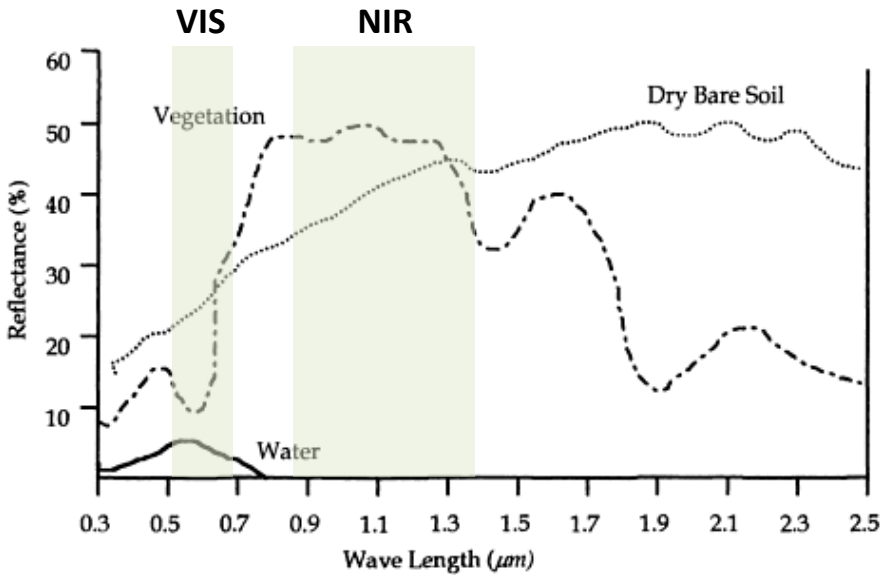
« is there re-greening or desertification of the Sahel ? »

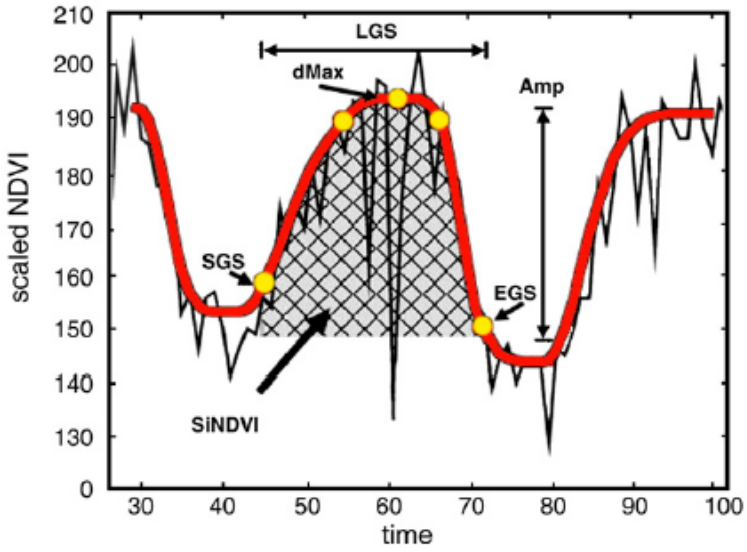
thanks to **two independant datasets** :

remote sensing VS **field observations of vegetation**

NDVI (Normalized Difference Vegetation Index)

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}$$





Source : Heumann et al 2006

NDVI is a **greeness index**

=> linked to photosynthetical activity of green plants (strong absorption in the red band, strong reflectance in the NIR band)

=> NDVI integral during growing season is a good proxy for Net Primary Production (NPP)

NDVI products of the study

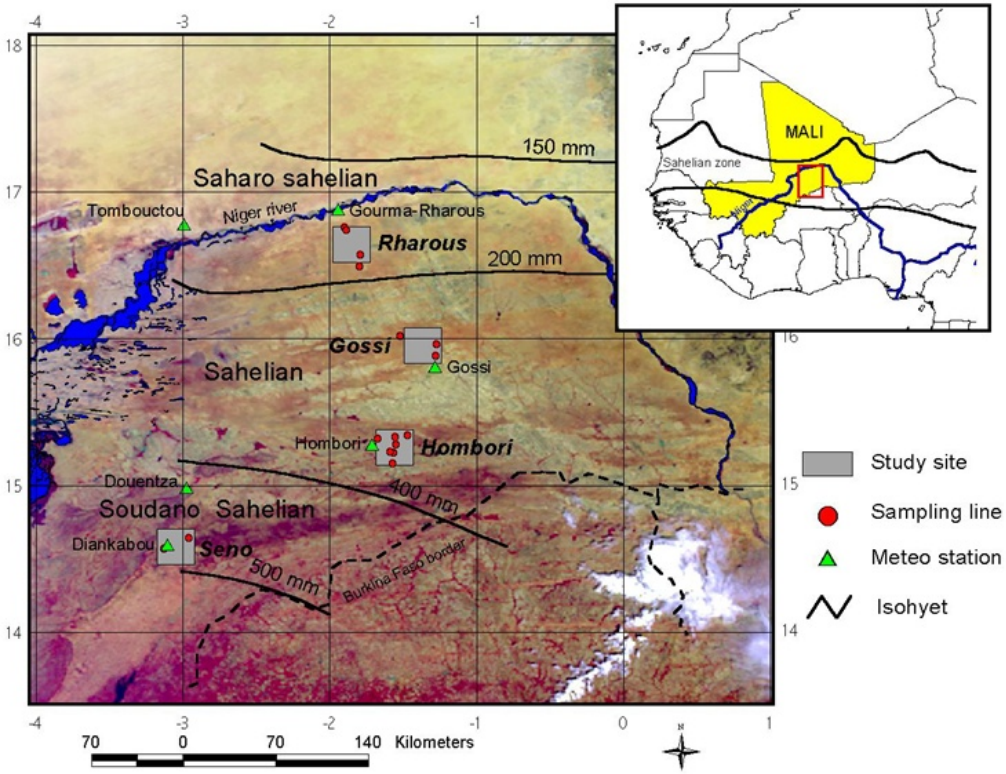
AVHRR NDVI = 4 satellites onboard the **NOAA** series

AVHRR data

- **LTDR** : **1981-1999**, 5km, daily
- **GIMMS2006** : **1981-2006,** 8km, 15day
- **GIMMS NDVI3g** : **1981-2011** - 1/12°, 15day - UNPUBLISHED

- **MODIS** : MOD13Q1, **2000-2012**, 250m, 16day

Vegetation field observations in Gourma (Mali)



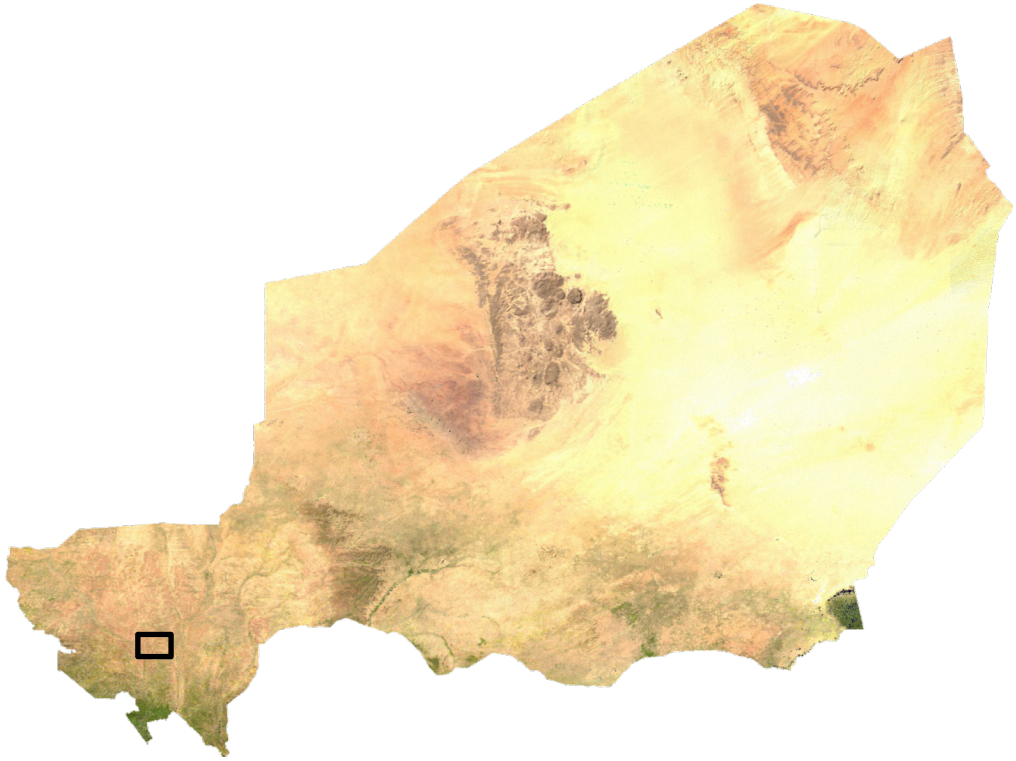
Long field history in Gourma : Boudet (1970's-1980's) – Hiernaux et Diarra (ILRI, 1984-1999) – Mougin et al (AMMA-CATCH experiment, 1999-today)

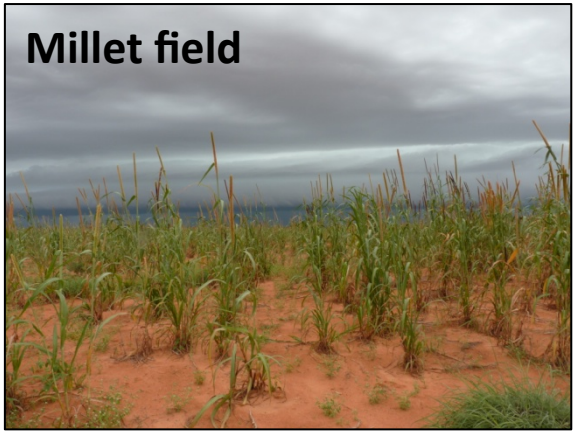
• About **40 sites** (1x1km) located all along the bioclimatic gradient. Sampling method thought to be representative of the landscape heterogeneity.

• Vegetation mostly constituted of **annual herbaceous plants** (woody cover < 5% ; crops superficy < 5%). Field variable : **Herbaceous mass** (DM kg/ha), from **1984 to today.**

=> A 27 year-long field observation dataset of vegetation production.

Vegetation field observations in Fakara (Niger)





A more complex picture : land use = cropped fields, fallows, rangelands
(woody plants cover < 5%)
About 70 sites selected to be representative of the landscape heterogeneity.
Field variable : **Herbaceous mass of millet and weeds**, from **1994 to today.**

=> A 17 year-long field observation dataset of vegetation production.

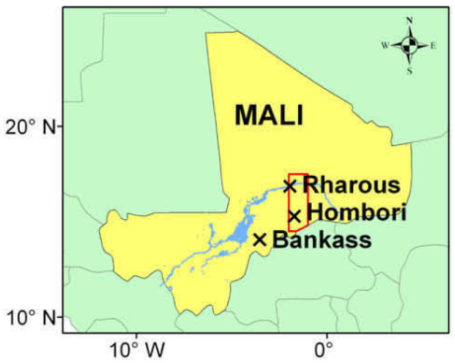
Questions

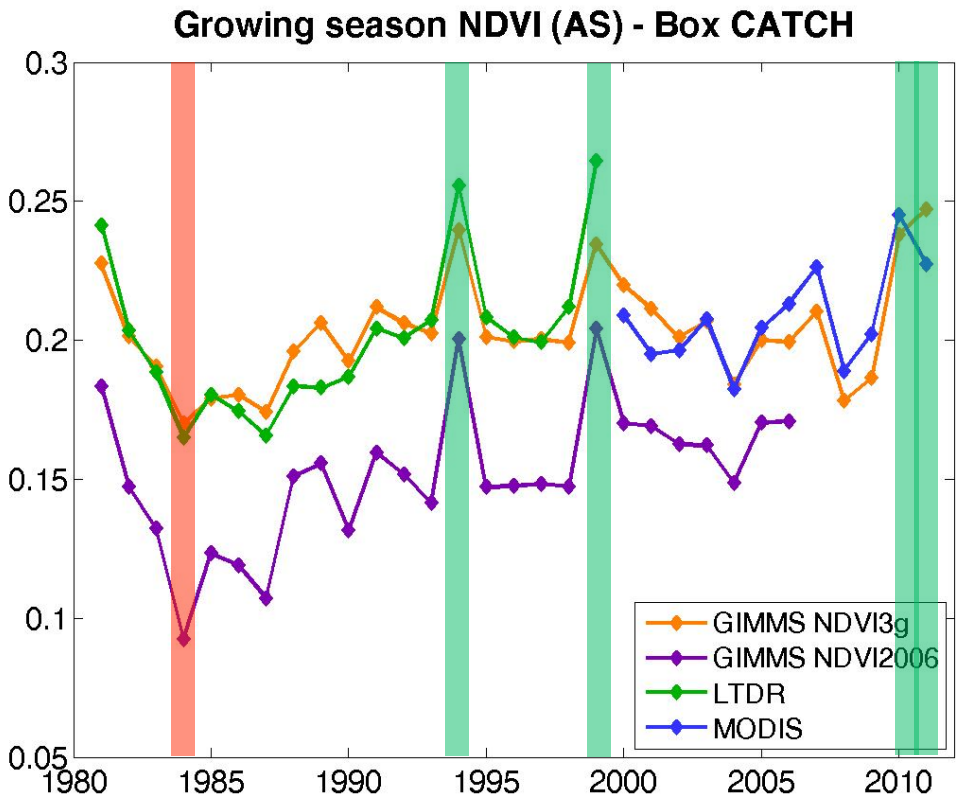
1- Are the NDVI products used in this study in good agreement ?

2- What are the NDVI trends today ? Is there regreening or degradation over the Sahel ?

3- What do field observations say ? Are they in agreement with satellite vegetation monitoring ?

NDVI products of the study



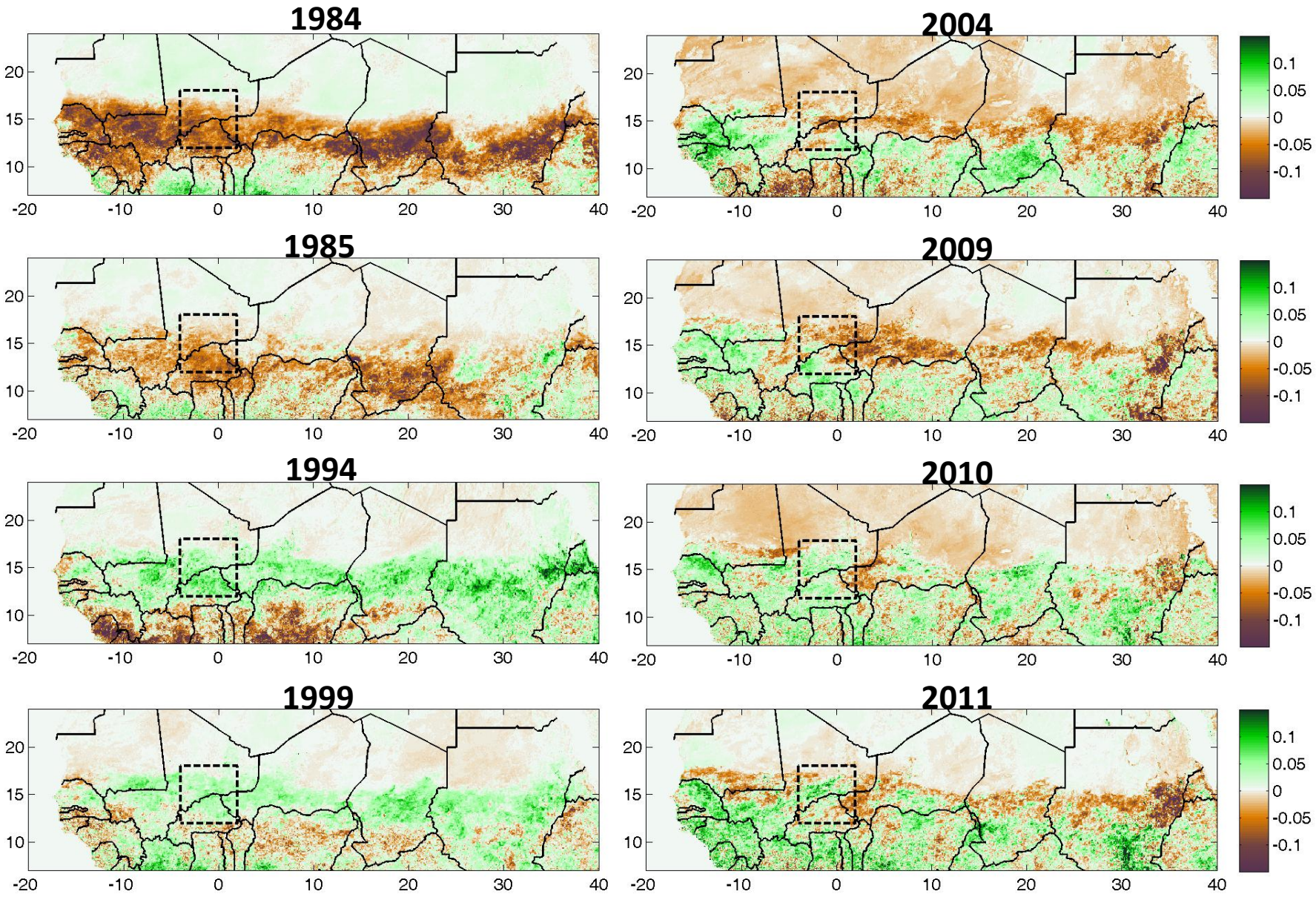


=> Shift in GIMMS NDVI2006 explained by the differences in **atmospheric correction** between datasets

=> **Good overall agreement** between these four datasets (interannual variability and trends)

=> Further analysis with GIMMS NDVI3g (30year-long dataset)

Interannual and spatial variability : GIMMS NDVI3g anomalies (1981-2011)



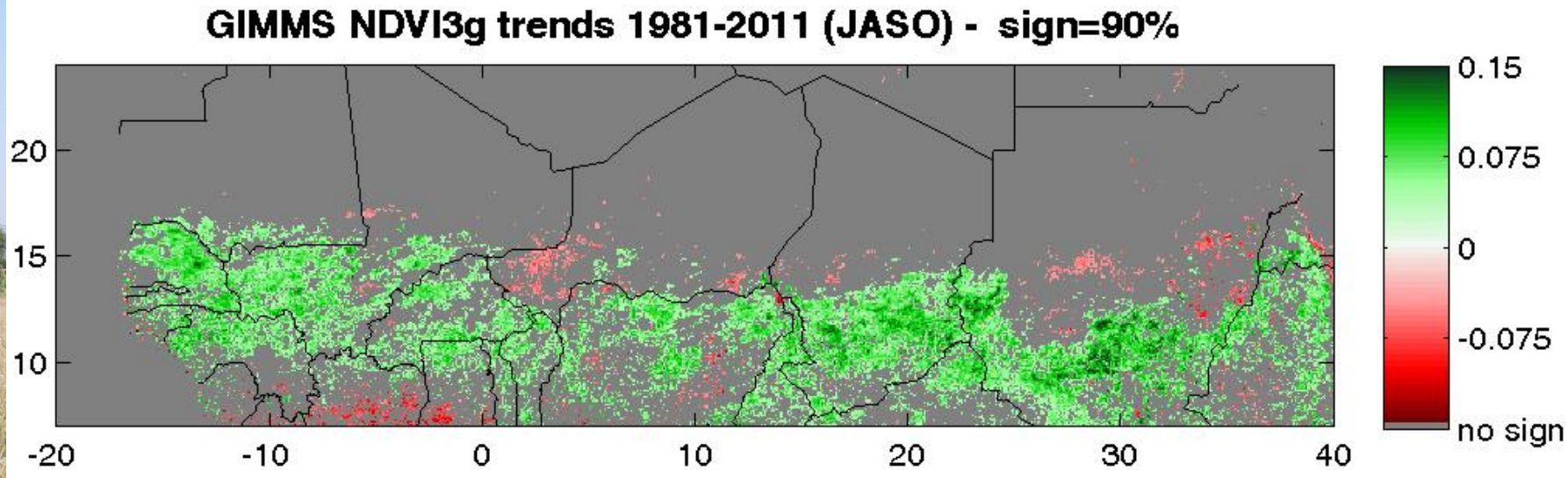
Questions

1- Are the NDVI products used in this study in good agreement ?

2- What are the NDVI trends today ?
Is there regreening or degradation over the Sahel ?

3- What do field observations say ? Are they in agreement with satellite vegetation monitoring ?

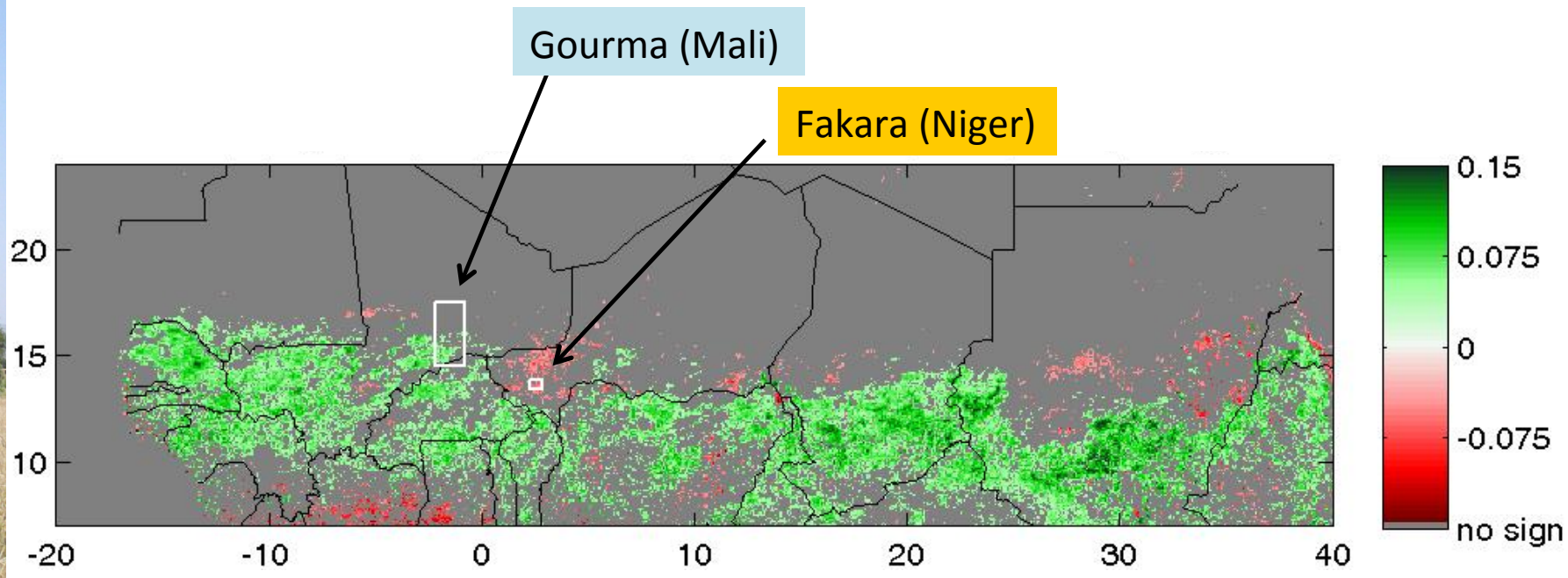
NDVI growing season trends in Sahel



Re-greening trends are observed over most parts of the Sahel, except for western Niger and center Soudan, where negative trends are observed.

These trends are significant over the period 1981-2011.

Sensitivity analysis to time period

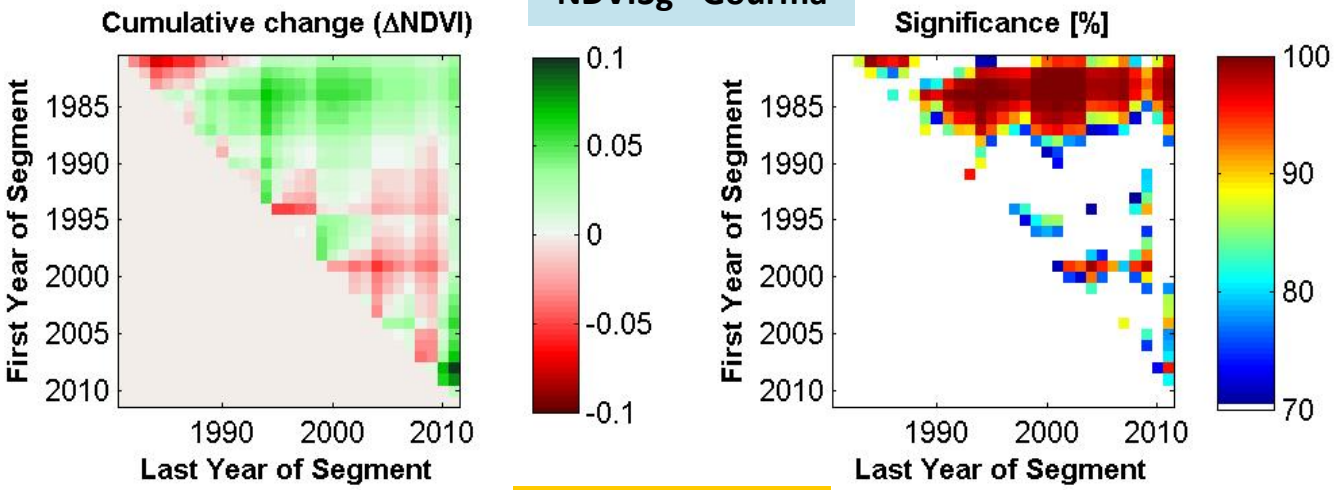


Re-greening trends are observed over most parts of the Sahel, except for western Niger and center Soudan, where negative trends are observed.

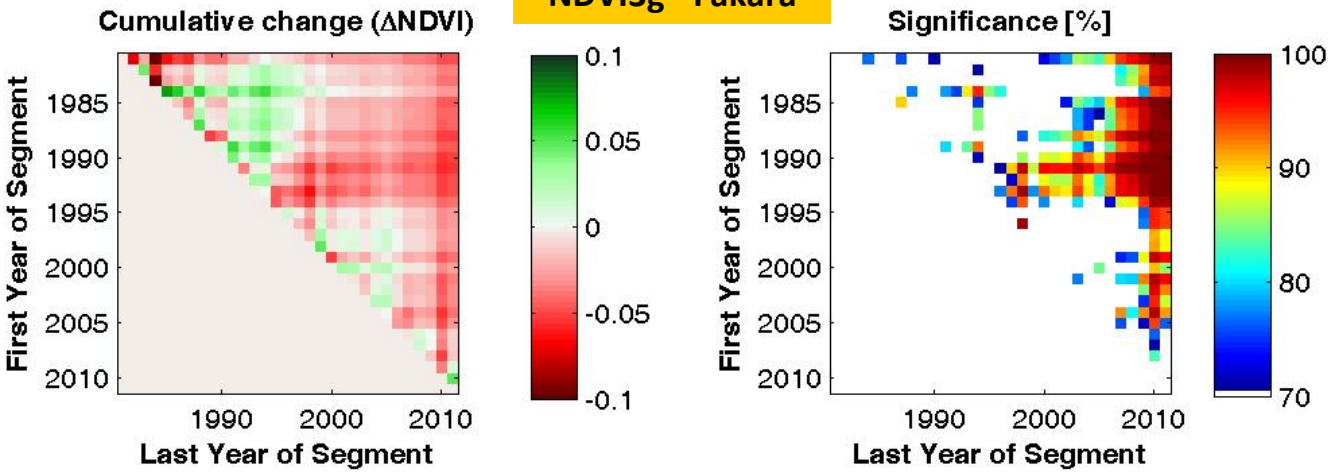
These trends are significant over the period 1981-2011.

Sensitivity analysis to time period

NDVI3g - Gourma



NDVI3g - Fakara



=> Regreening trends in Gourma and degradation trends in Fakara **are robust over time**. **Same recovery behaviour** for Gourma and Fakara right after the drought, but **stories differ after the 1990's.**

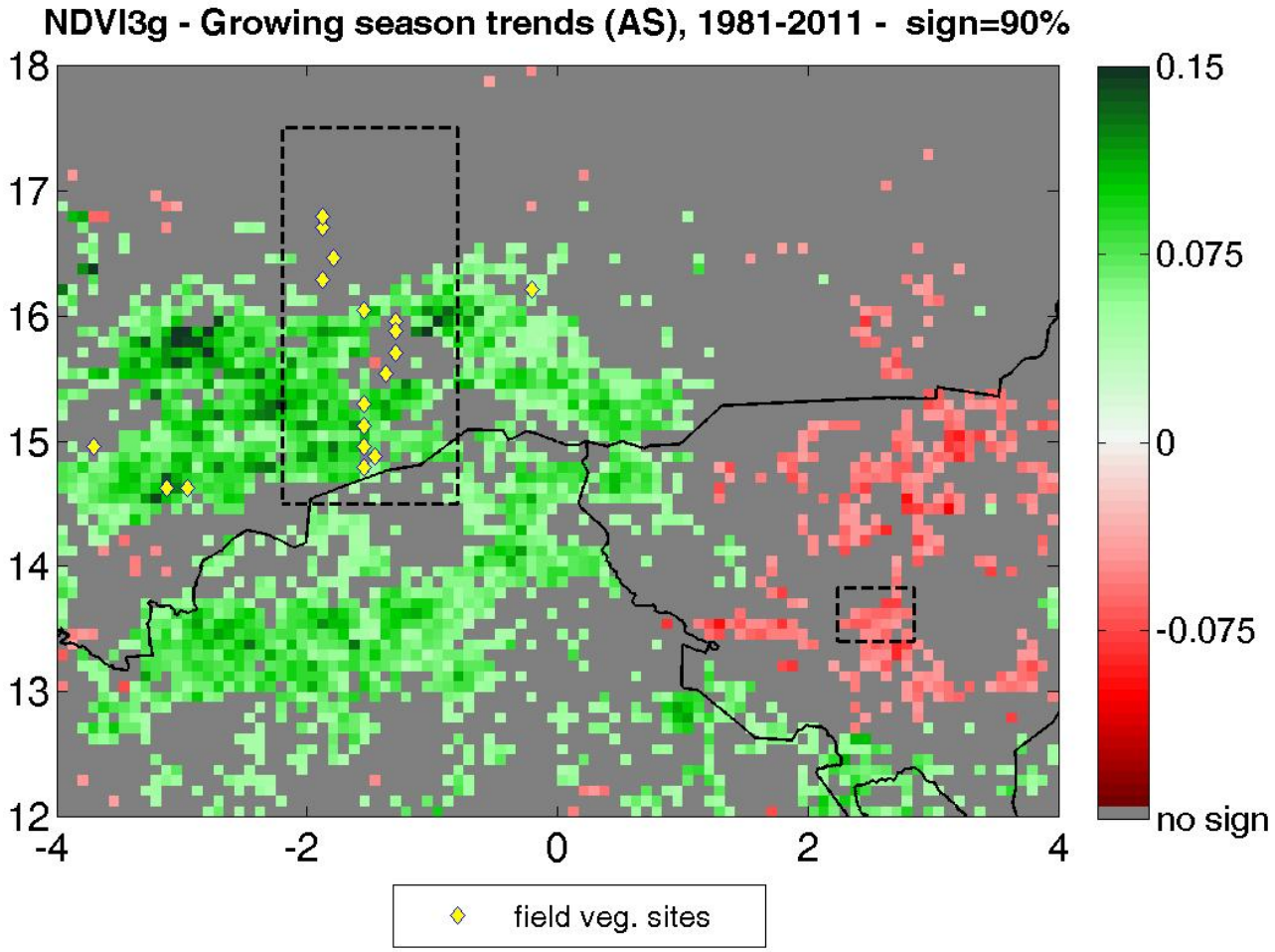
Questions

1- Are the NDVI products used in this study in good agreement ?

2- What are the NDVI trends today ? Is there regreening or degradation trends over the Sahel ?

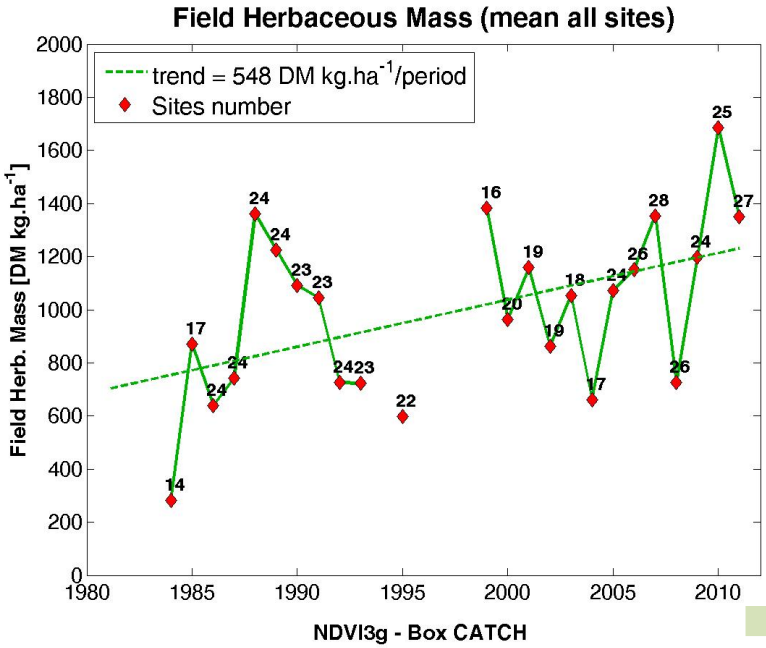
3- What do field observations say ? Are they in agreement with satellite vegetation monitoring ?

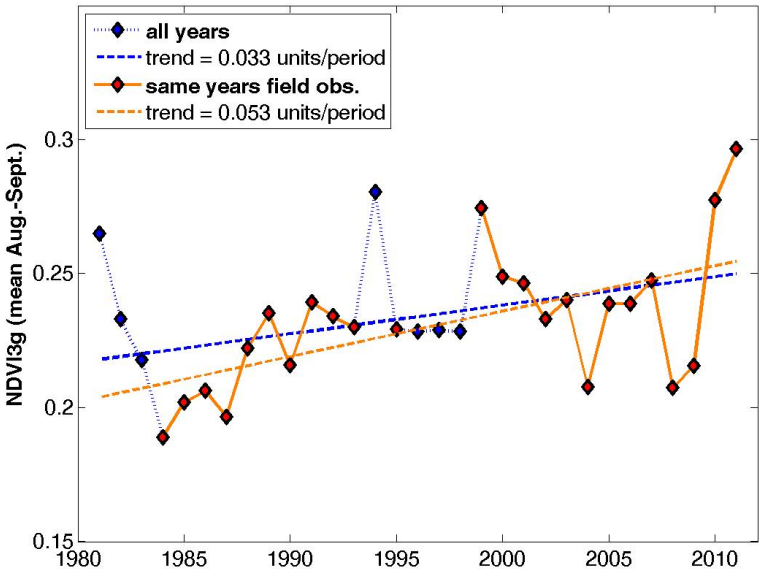
NDVI growing season trends in Gourma and Fakara



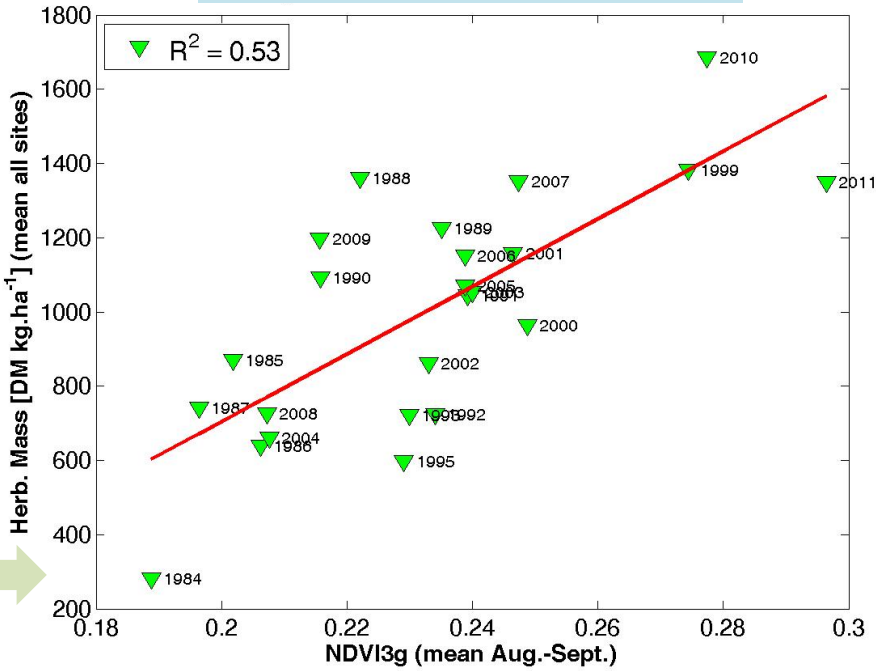
Gourma => re-greening trends
Fakara => degradation trends

Gourma (Mali)





REGRESSION Field/NDVI

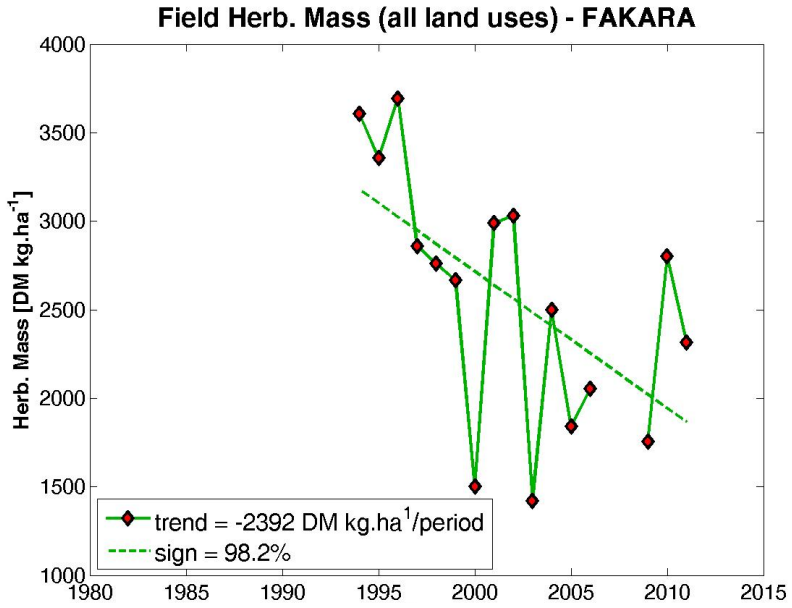


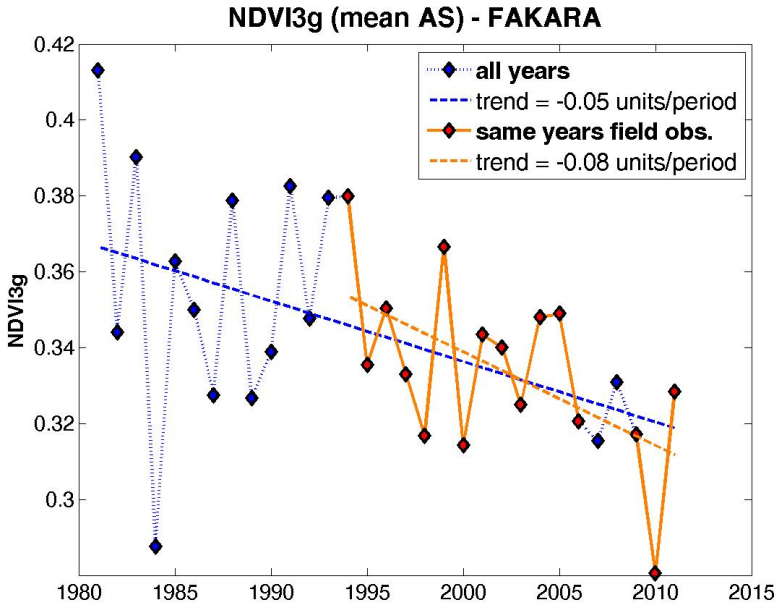
- Good overall agreement between remote sensing and field observations in Gourma.

=> validation of the greening trends observed

- **Demonstrates the sahelian ecosystem resilience to extreme climatic events.**

Fakara (Niger)



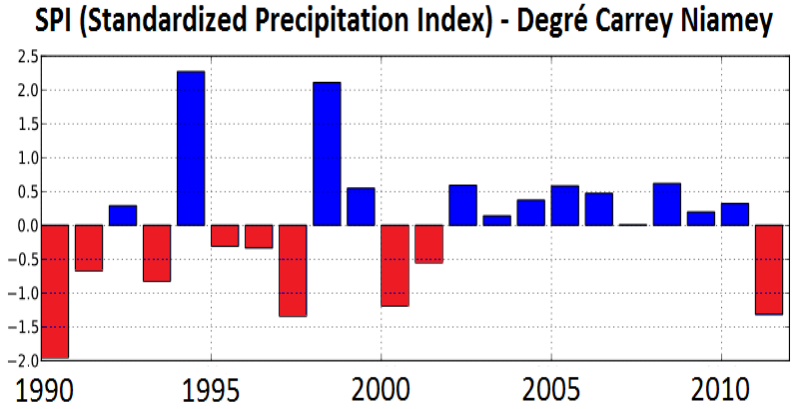


- Good overall agreement between datasets : **both satellite and field observations show a negative trend over Fakara.**

- **Not explained by variations in rainfall**

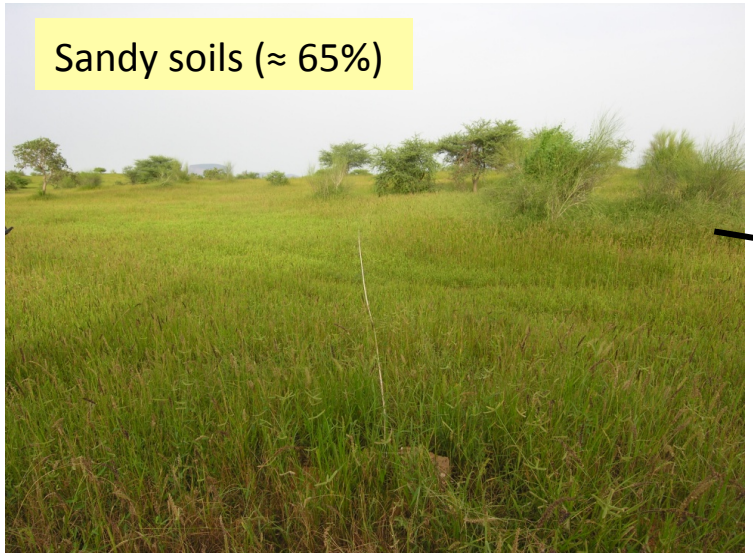
- Observed on **all land uses** (cropped fields, fallow and rangelands)

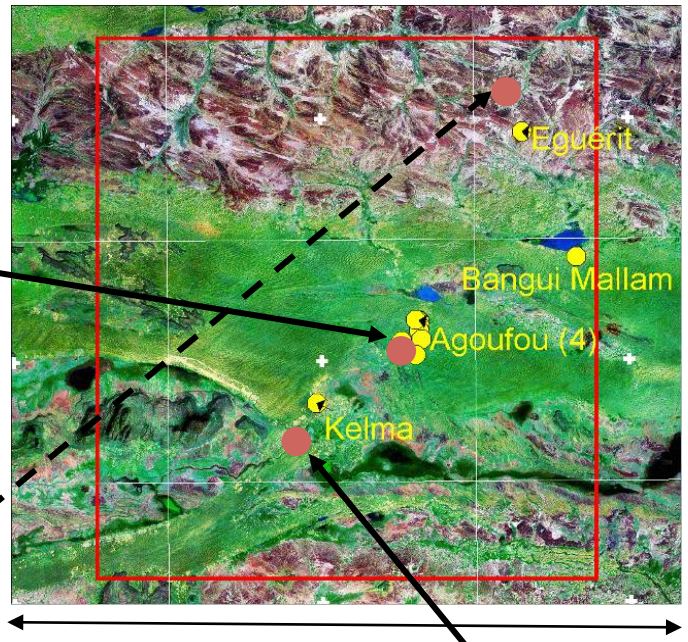
- Multiple causes which might include : **changes in land use** (historical increase in cropped areas, shortening of fallow cycles), decline in **soil fertility**, increased **grazing pressure** during the rainy season.

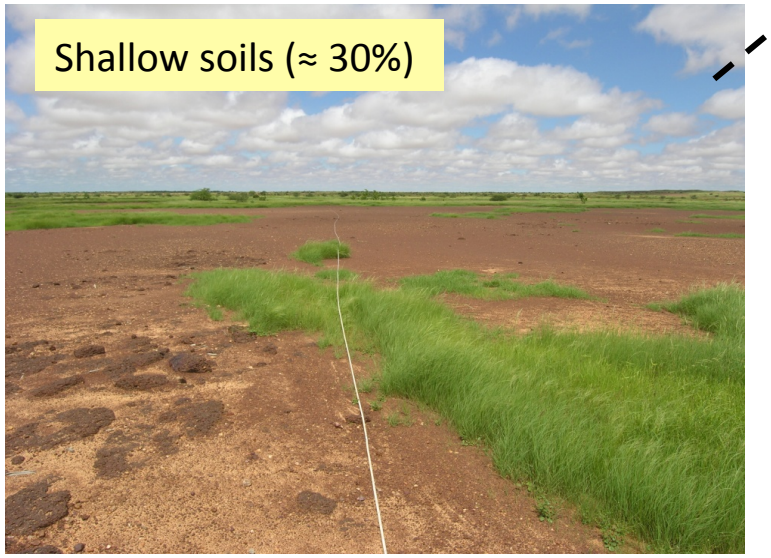


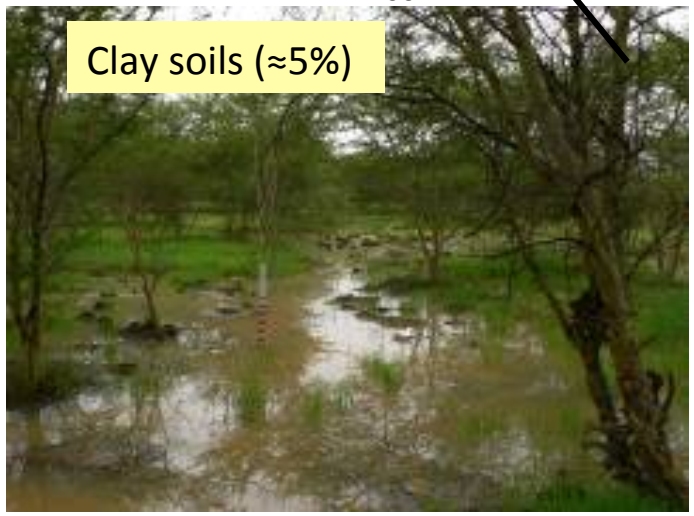
Courtesy G. Quantin

Gourma : a different story

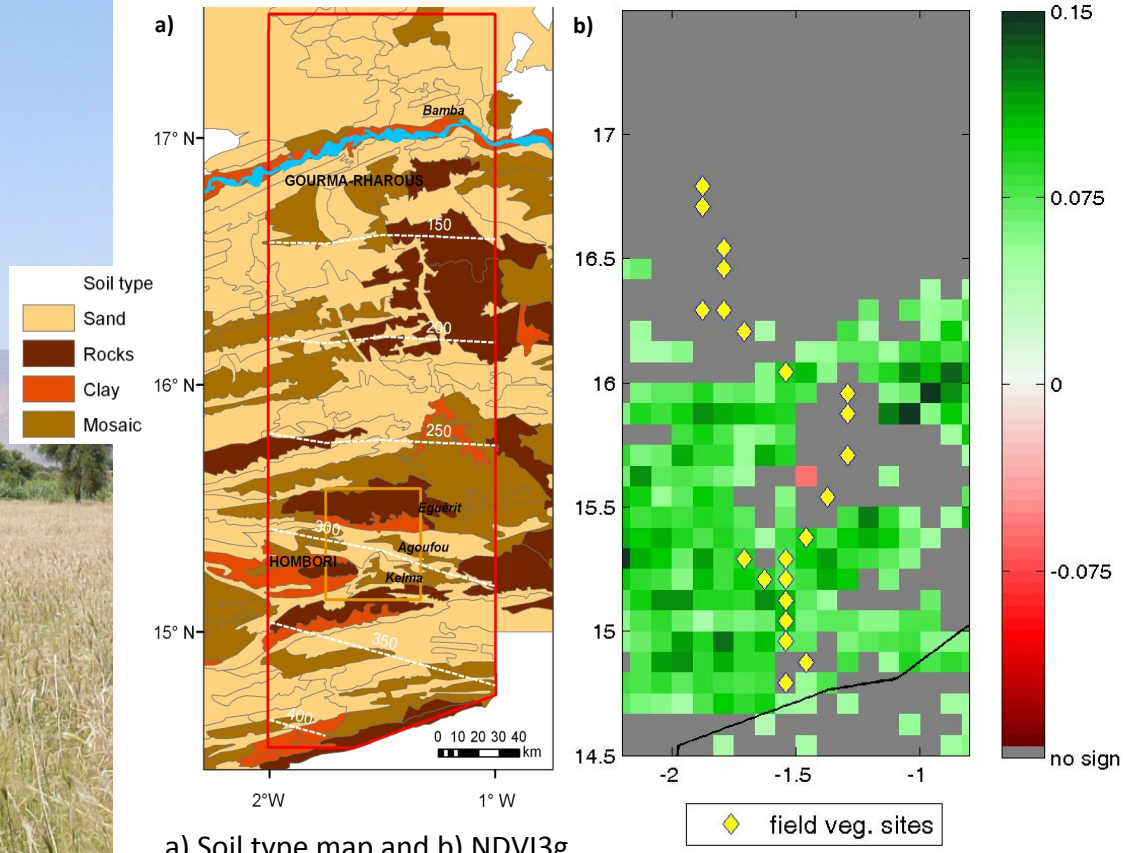




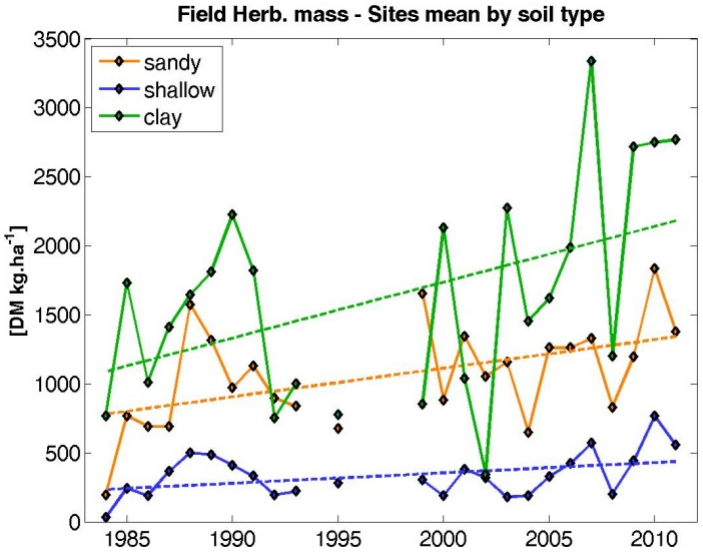




Soil type influence



a) Soil type map and b) NDVI3g trends (Aug.-Sept.)



- **Sandy soils** : significant regreening
- **Shallow soils** : unsignificant trends
- **Clay soils** : satellite resolution too coarse

⇒ **very fast recovery for sandy soils** from the 1983-84 drought (strong rain use efficiency)
⇒ **different dynamics** involved for **shallow** and **clay soils** (depressions) : **erosion** and **run-off** increase on shallow soils, more water in depressions and ponds

Conclusions

1- Yes, satellite NDVI products are in very good agreement.

2- NDVI growing season trends over the Sahel for the 30-y long period 1981-2011 are mostly « re-greening » trends, strongly significant.
Only western Niger and center Soudan show negative significant trends.

3- Field observations are in very good agreement with NDVI trends, both for Gourma (positive trend observed) and Fakara (negative trend observed).

4- In Gourma, recovery after drought for sandy soils was very fast.
Different dynamics are involved for clay and shallow soils (more erosion and runoff on shallow soils, more water and vegetation in clayed soils).

To sum up, re-greening trends are observed on almost all parts of the Sahel, even if locally, degradation trends can also be observed.

Conclusions

1- Yes, satellite NDVI products are in very good agreement.

2- NDVI growing season trends over the Sahel for the 30-y long period 1981-2011 are mostly « re-greening » trends, strongly significant.
Only western Niger and center Soudan show negative significant trends.

3- Field observations are in very good agreement with NDVI trends, both for Gourma (positive trend observed) and Fakara (negative trend observed).

4- In Gourma, recovery after drought for sandy soils was very fast. Different dynamics are involved for clay and shallow soils (more erosion and runoff on shallow soils, more water and vegetation in clayed soils).

To sum up, re-greening trends are observed on almost all parts of the Sahel, even if locally, degradation trends can also be observed.

Conclusions

1- Yes, satellite NDVI products are in very good agreement.

2- NDVI growing season trends over the Sahel for the 30-y long period 1981-2011 are mostly « re-greening » trends, strongly significant.
Only western Niger and center Soudan show negative significant trends.

3- Field observations are in very good agreement with NDVI trends, both for Gourma (positive trend observed) and Fakara (negative trend observed).

4- In Gourma, recovery after drought for sandy soils was very fast.
Different dynamics are involved for clay and shallow soils (more erosion and runoff on shallow soils, more water and vegetation in clayed soils).

To sum up, re-greening trends are observed on almost all parts of the Sahel, even if locally, degradation trends can also be observed.

Conclusions

1- Yes, satellite NDVI products are in very good agreement.

2- NDVI growing season trends over the Sahel for the 30-y long period 1981-2011 are mostly « re-greening » trends, strongly significant.
Only western Niger and center Soudan show negative significant trends.

3- Field observations are in very good agreement with NDVI trends, both for Gourma (positive trend observed) and Fakara (negative trend observed).

4- In Gourma, recovery after drought for sandy soils was very fast. Different dynamics are involved for clay and shallow soils (more erosion and runoff on shallow soils, more water and vegetation in clayed soils).

To sum up, re-greening trends are observed on almost all parts of the Sahel, even if locally, degradation trends can also be observed.

Conclusions

1- Yes, satellite NDVI products are in very good agreement.

2- NDVI growing season trends over the Sahel for the 30-y long period 1981-2011 are mostly « re-greening » trends, strongly significant.
Only western Niger and center Soudan show negative significant trends.

3- Field observations are in very good agreement with NDVI trends, both for Gourma (positive trend observed) and Fakara (negative trend observed).

4- In Gourma, recovery after drought for sandy soils was very fast.
Different dynamics are involved for clay and shallow soils (more erosion and runoff on shallow soils, more water and vegetation in clayed soils).

To sum up, re-greening trends are observed on almost all parts of the Sahel, even if locally, degradation trends can also be observed.


Thank you !

Woody plants dynamics

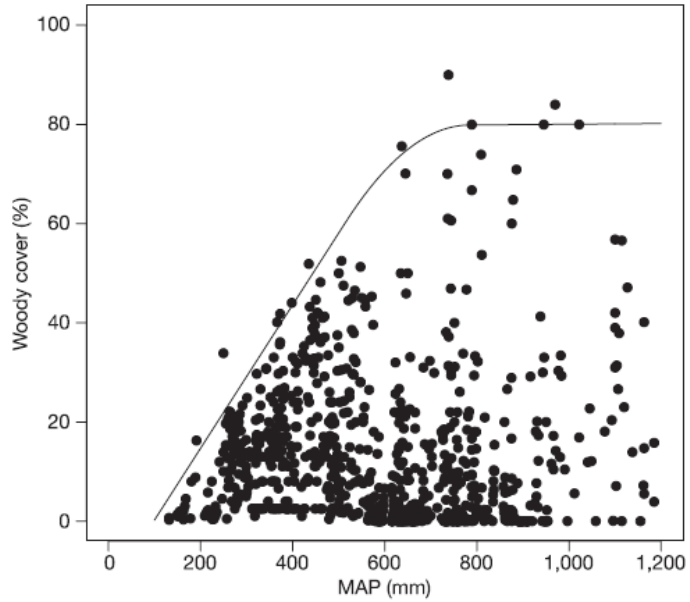
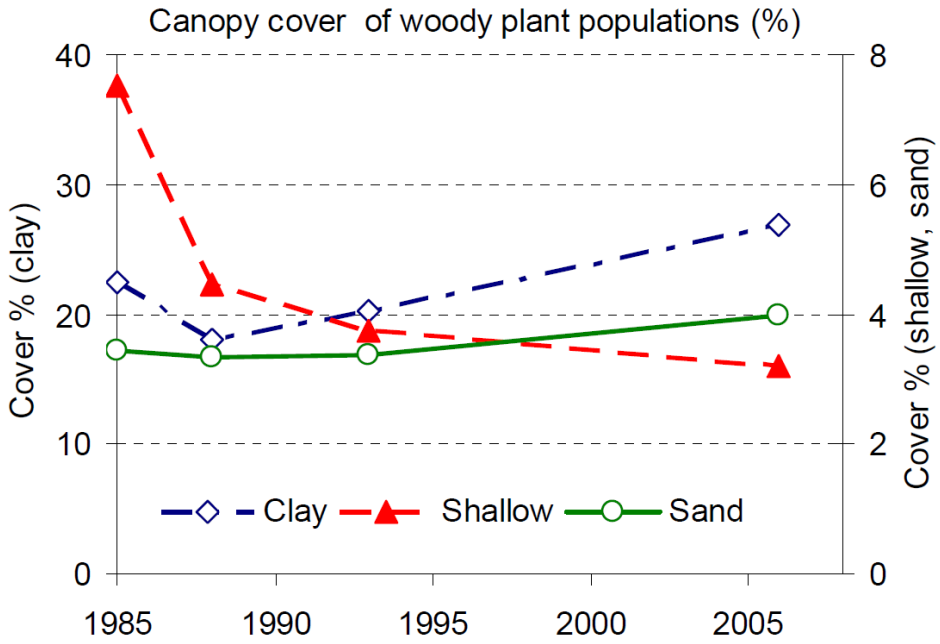


Figure 1 | Change in woody cover of African savannas as a function of MAP. Maximum tree cover is represented by using a 99th quantile piece-wise linear regression. The regression analysis identifies the breakpoint (the rainfall at which maximum tree cover is attained) in the interval 650 ± 134 mm MAP (between 516 and 784 mm; see Methods). Trees are typically absent below 101 mm MAP. The equation for the line quantifying the upper bound on tree cover between 101 and 650 mm MAP is Cover(%) = 0.14(MAP) − 14.2. Data are from 854 sites across Africa.

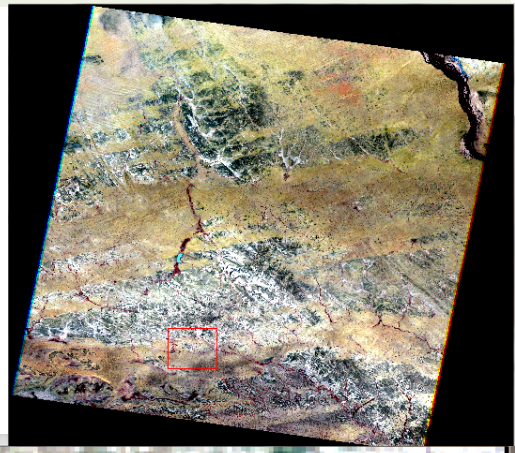
Source : Sankaran et al 2005



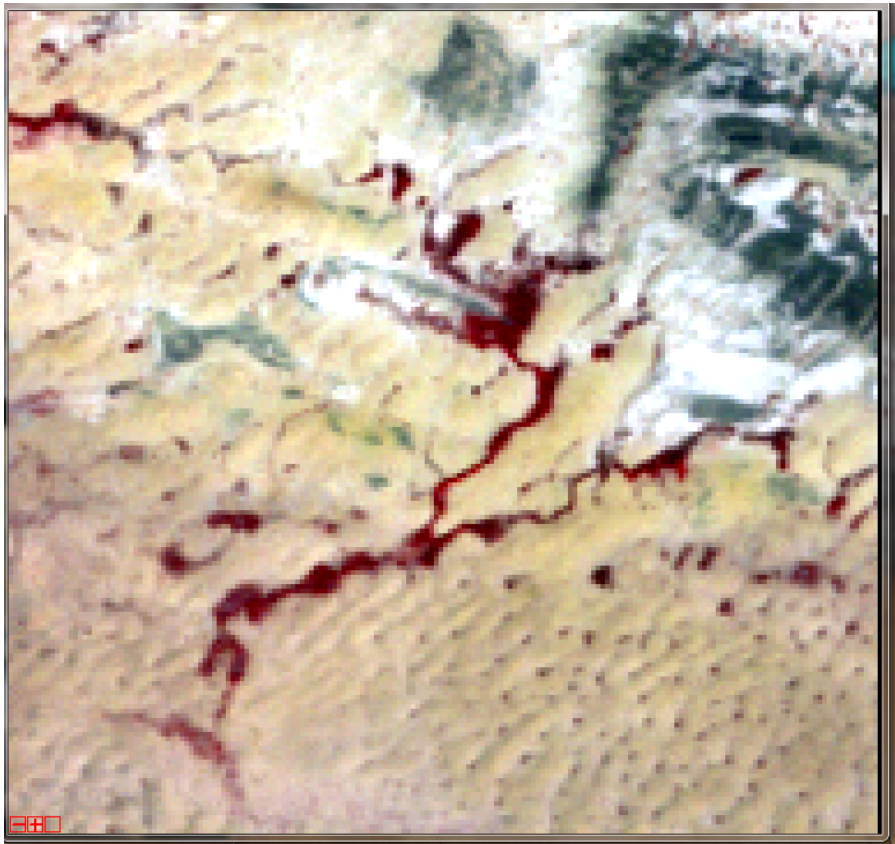
Source : Hiernaux et al 2009

Landscape changes – Gourma

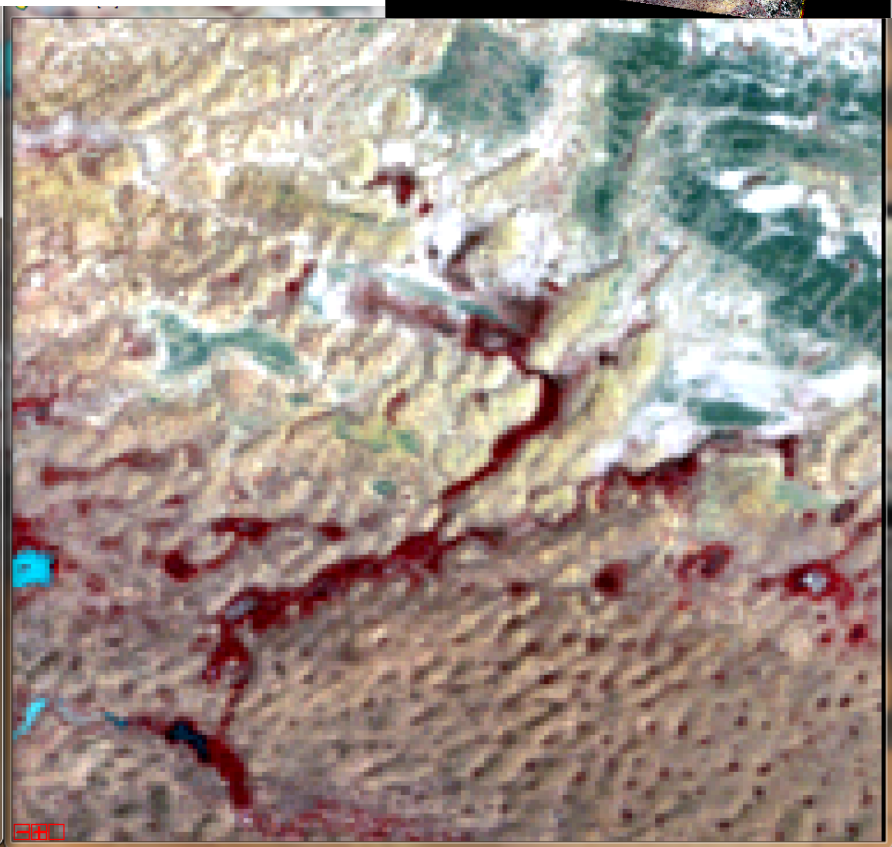
Illustration with LANDSAT imagery , from December 1986 to December 2010.



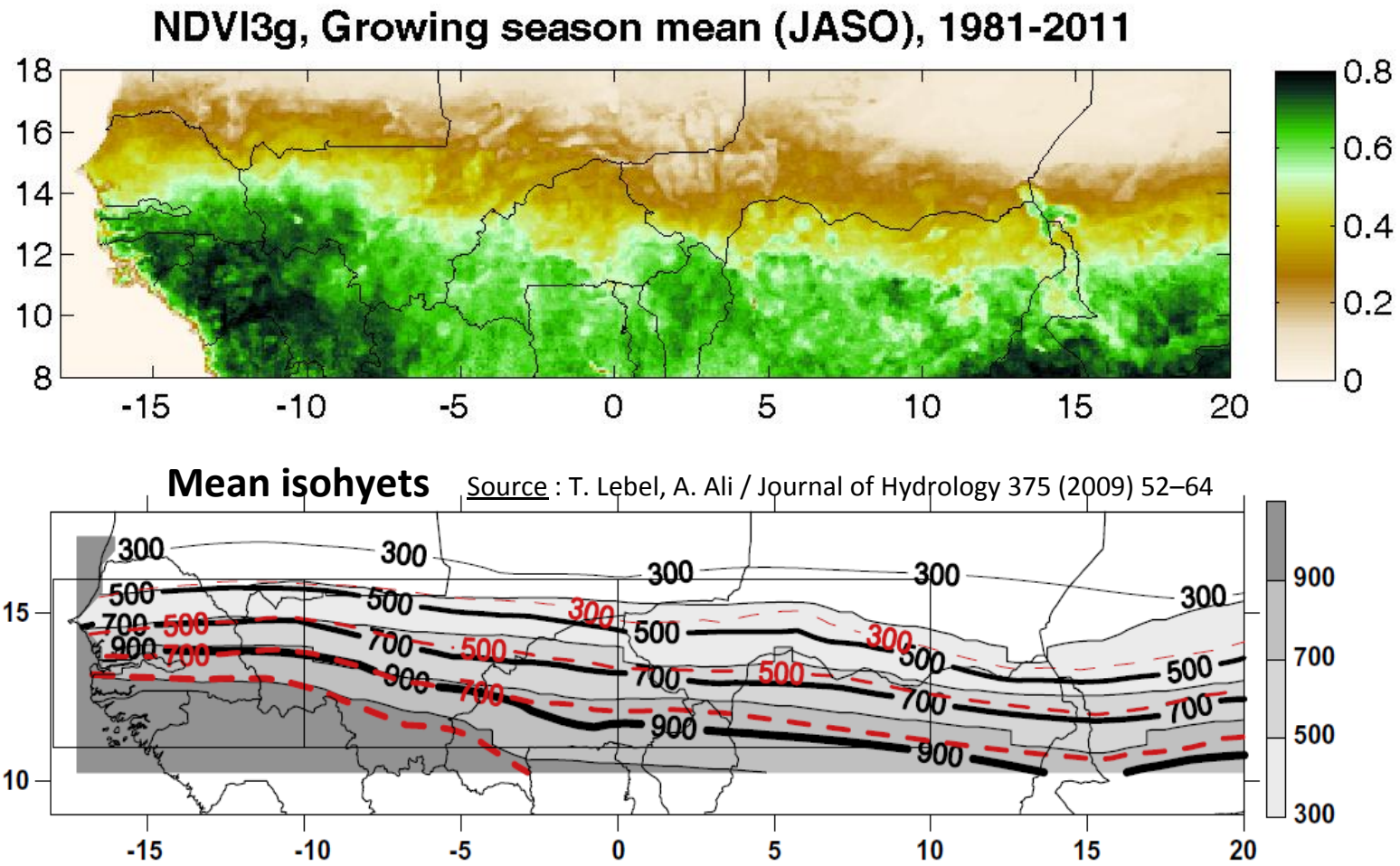
Dec. 1986



Dec. 2010



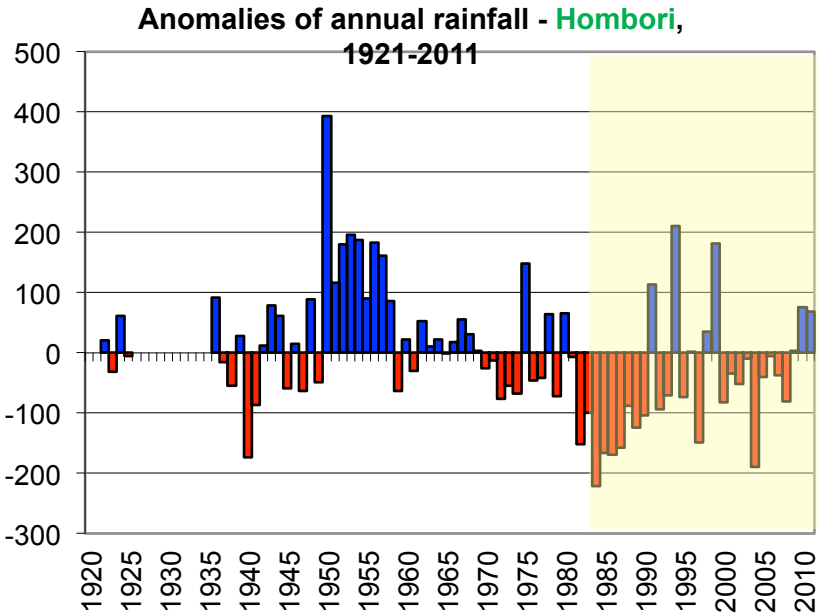
NDVI mean and rainfall isohyetes

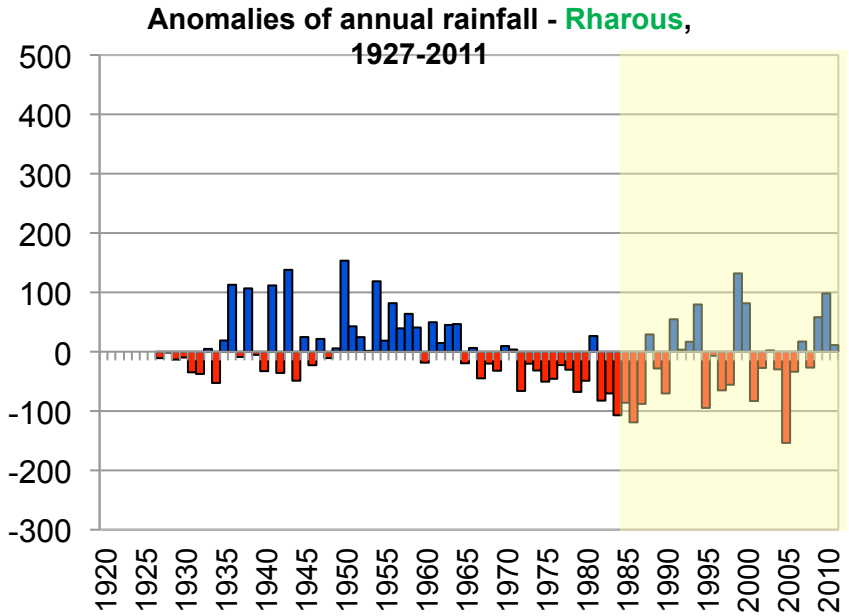


=> Vegetation production correlated to precipitation…

Rainfall

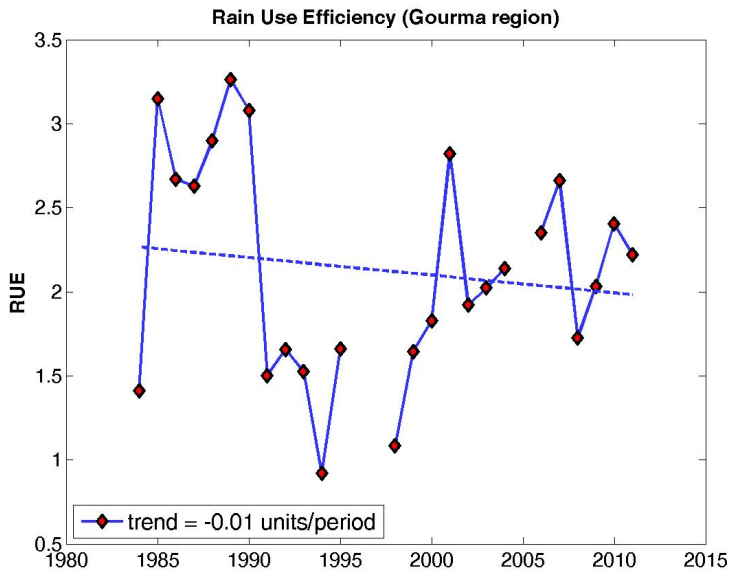
RUE (Rainfall Use Efficiency)





Source : Direction Nationale de la Météorologie (DNM Mali)

$$\text{RUE} = \frac{\text{Herbaceous Mass (mean all veg. sites)}}{\text{Rainfall (mean Hombori + Rharous gauge stations)}}$$

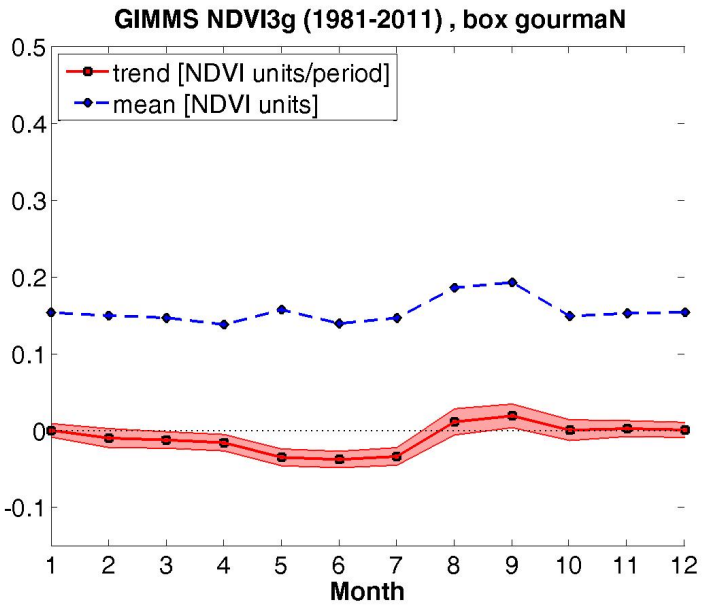


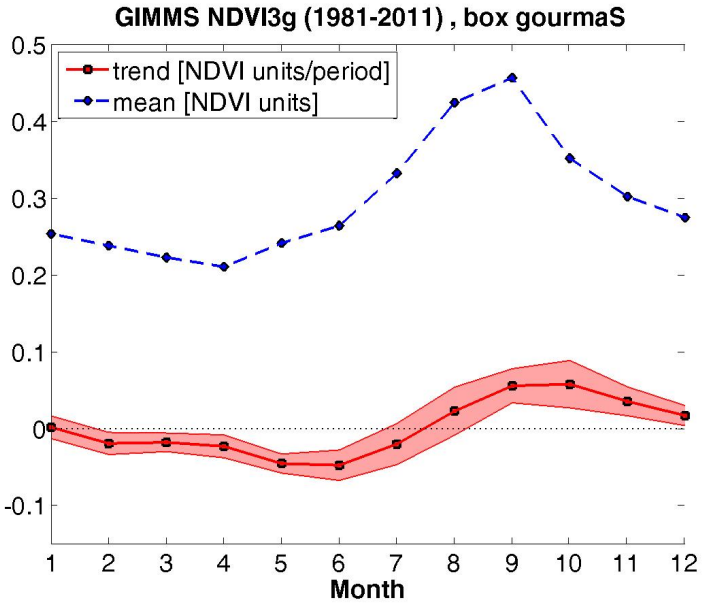
Phenology

Latitudinal differences

Gourma Nord

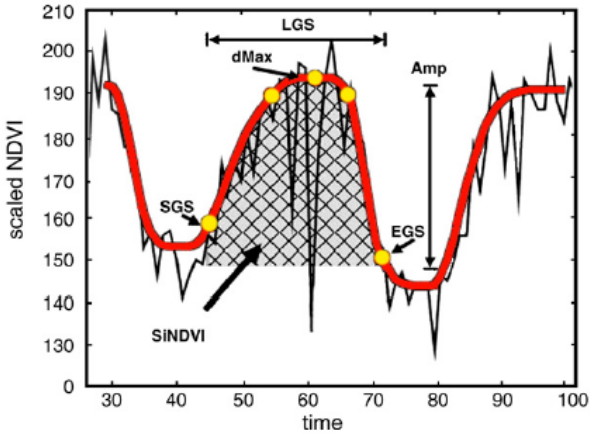
Gourma Sud





Phenology

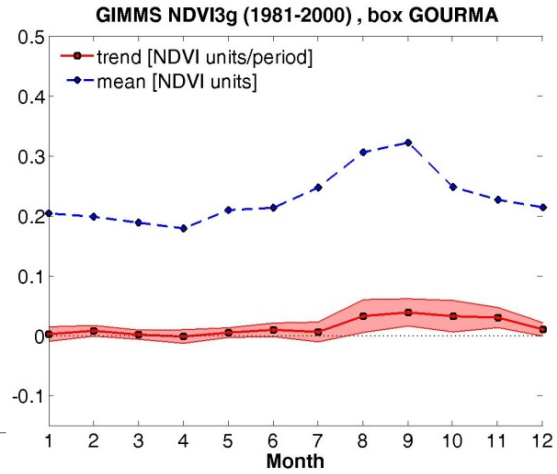
NDVI3g

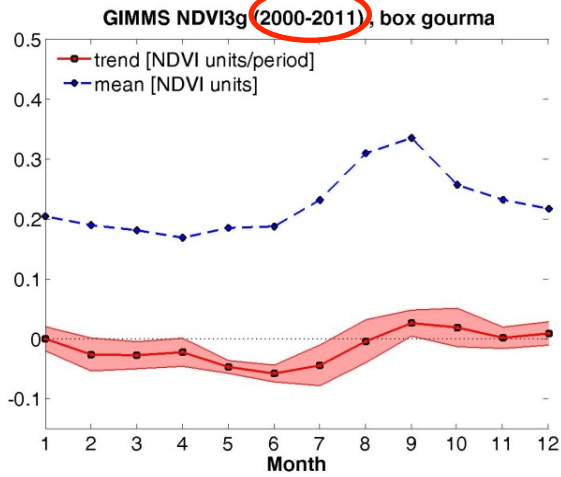


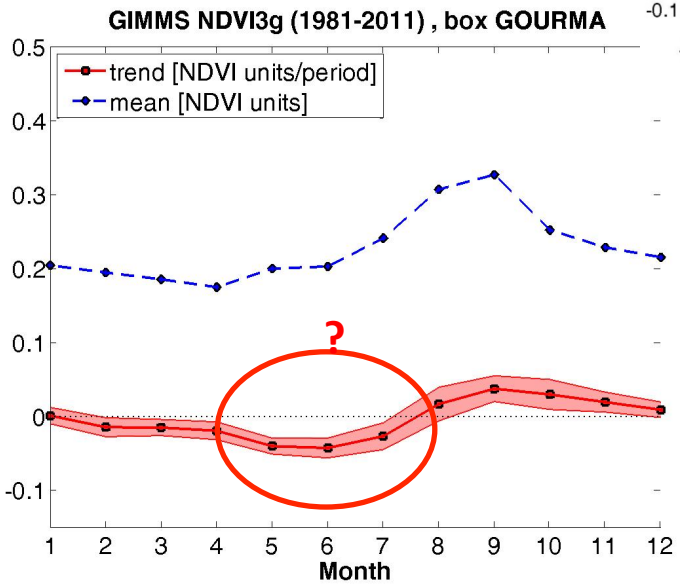
Literature > 2 types of greening :

1- increase of NDVI maximum

2- increase of length of season (later end of season)



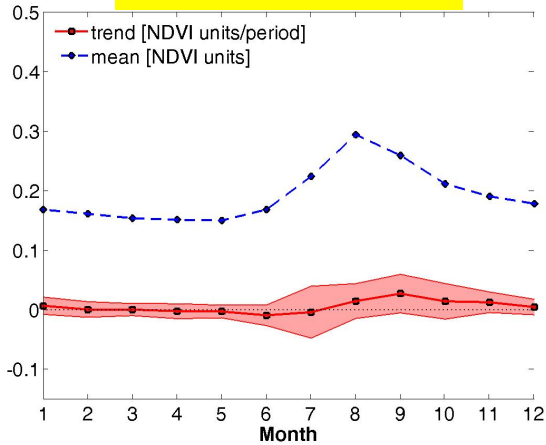




Comparison with **MODIS** on the 2000-2011 period : no such negative significant trends.

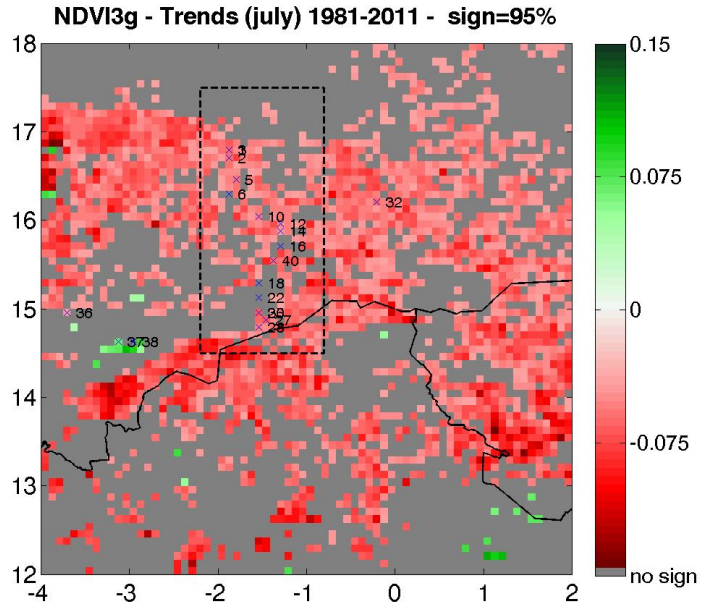
=> Satellite artefact

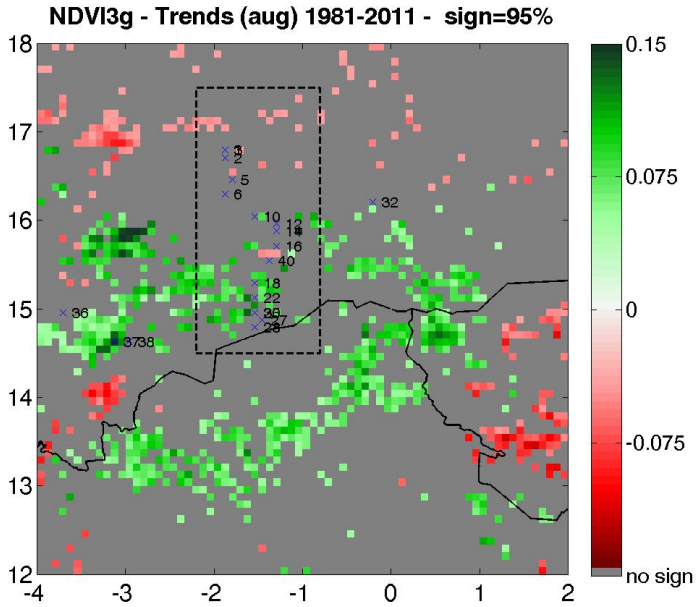
MODIS (2000-2011)

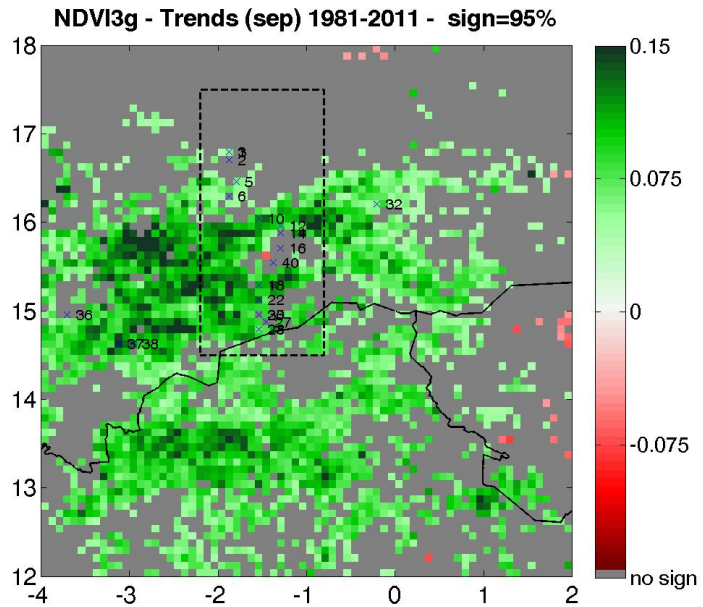


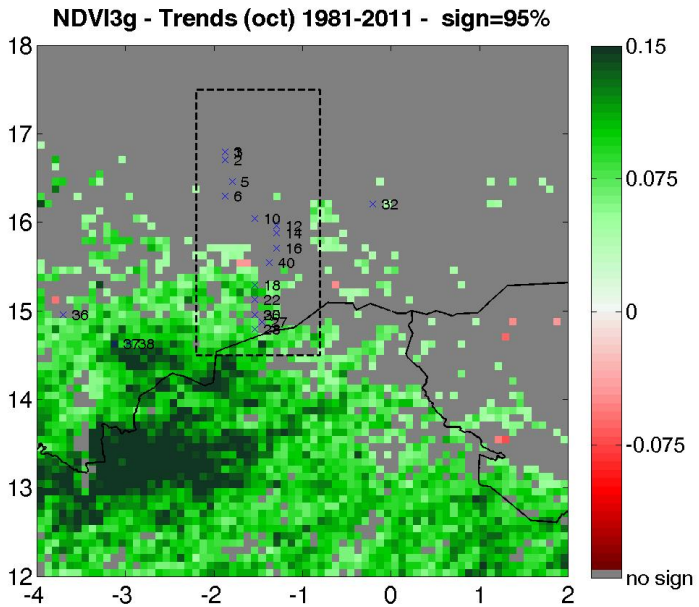
Phenology

Trends maps from July to October



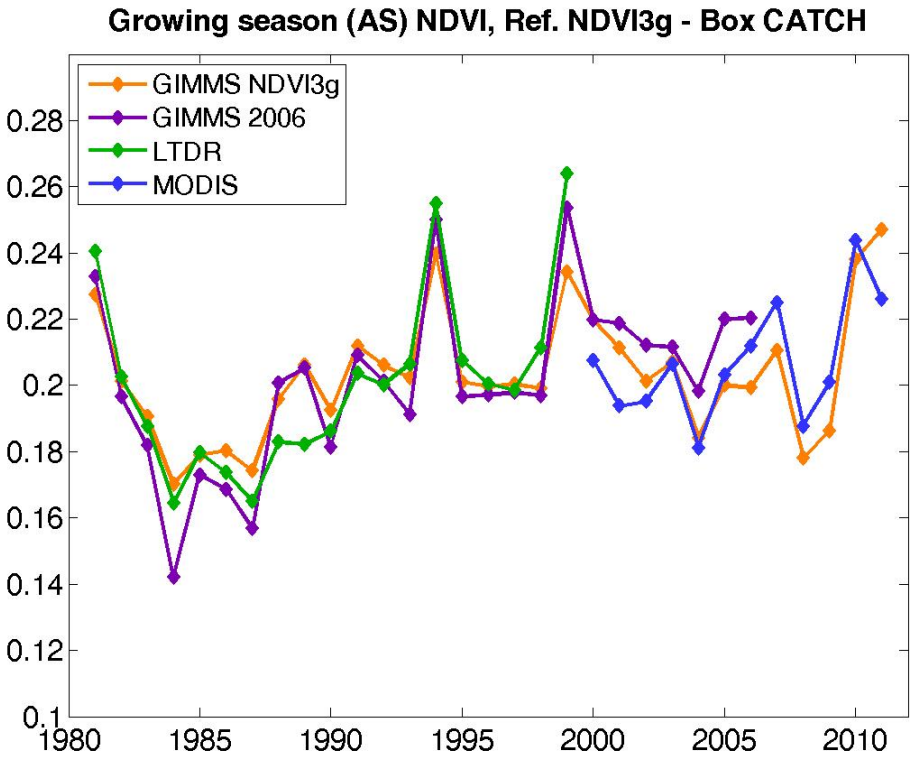






NDVI products intercomparison

Comparison to the « reference » NDVI3g



Comparison to the « reference » GIMMS NDVI3g
(NDVI = NDVI – mean_NDVI3g)
=> Very consistent datasets

Gourma

Observation strategy

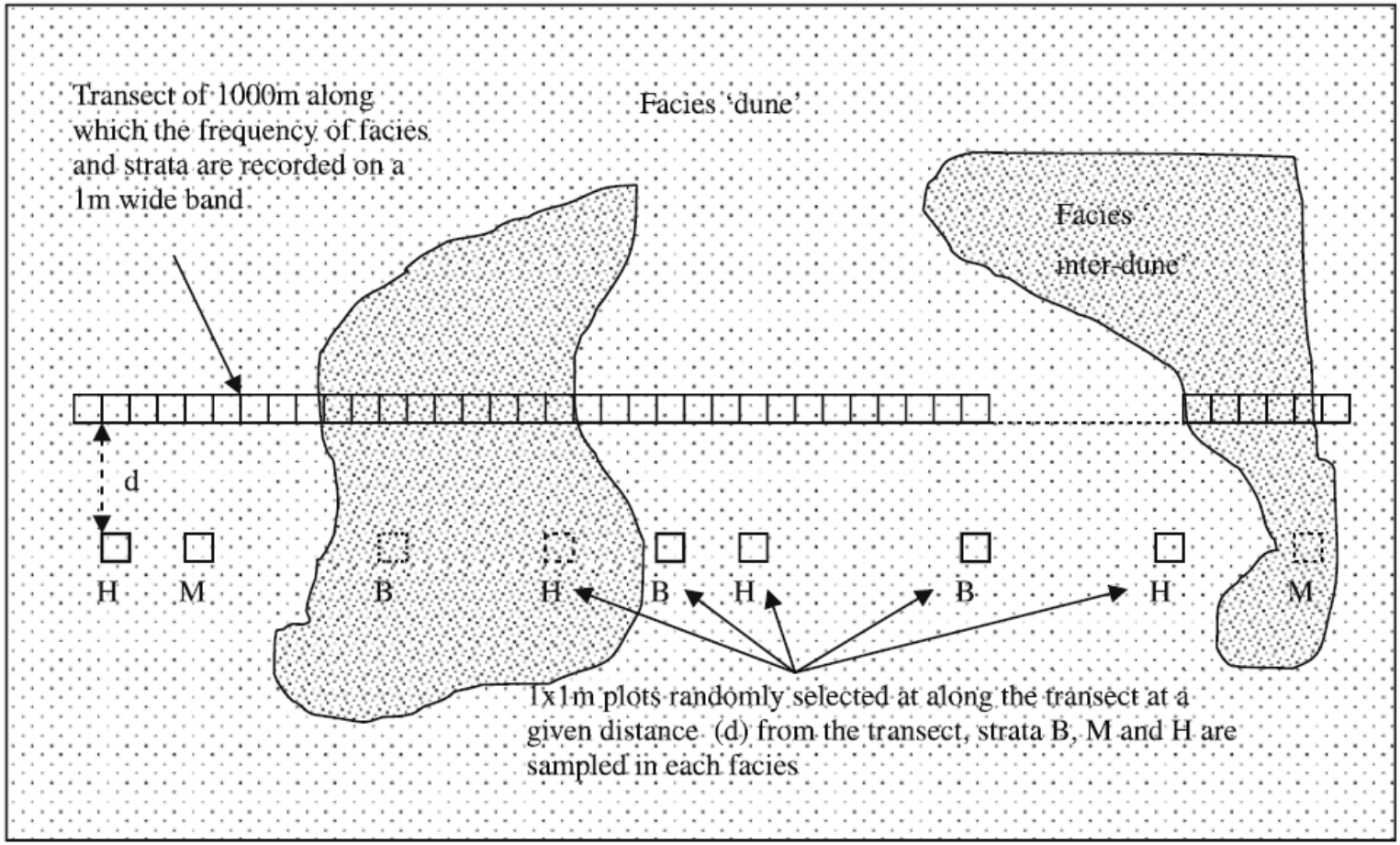


Fig. 2. Each facies includes four strata: O = bare soil, B = low, M = medium, H=High apparent herb density. The strata B, M et H are sampled with a minimum of 3 (B, H) or 6 (M) 1x1 m plots randomly selected along the 1000 m transect.

Fakara

Study area

Source : Hiernaux et al., J. Hydrology 2009

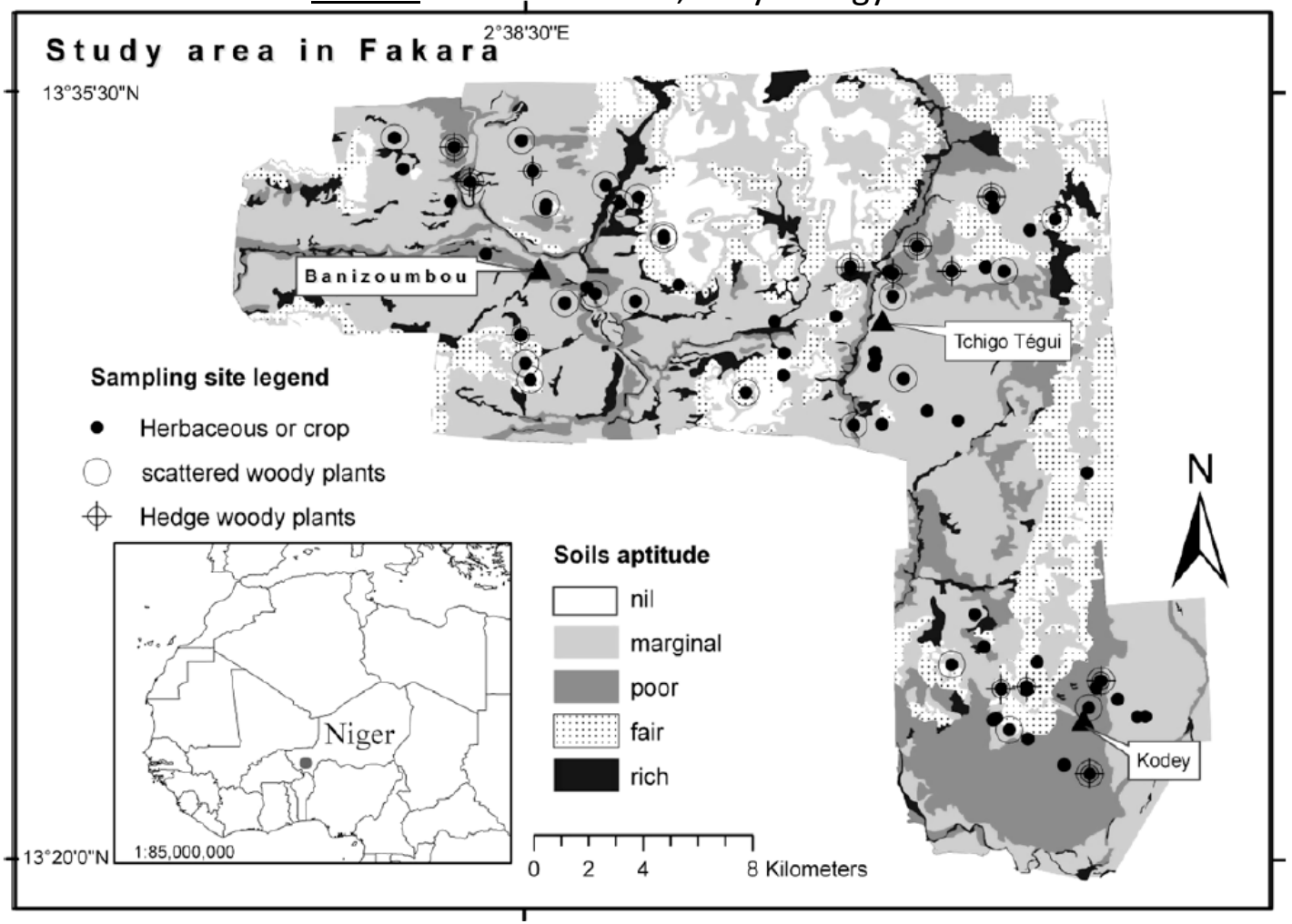


Fig.1. Location of the field study sites within three agro-pastoral territories of the Fakara district in South-western Niger, West Africa: Banizoumbou, Tigo Tégui and Kodey. The five class of soil aptitude to cropping are based on geomorphology, soil texture and soil surface features (Hiernaux and Ayantunde, 2004).

Fakara

Trends by land use, 1994-2011 – Work P. Hiernaux (JoH 2009)