Analysis of time series satellite imagery to monitor vegetated ecosystem dynamics in Sahel

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Developing countries are particularly vulnerable to the ongoing climate changes, and Africa, due to its weak adaptive capacity, is likely to be the most vulnerable (IPCC 2007).

The growing population, with a projection to double in the next twenty years, will exacerbate existing problems and impacts on food production, safe water provision, and natural-resource-based livelihoods.

Climate exerts a significant control on the day-to-day economic development of Africa (particularly for the agricultural and water-resources sectors).

Monitoring of the natural environmental resources and early warning of drought are crucial components of disaster mitigation plans.
SAHEL: dynamic eco-region

Sahel is a transition zone between the arid Sahara in the North and the sub-humid tropical savannas in the South, and is marked by a steep North-South gradient in mean annual rainfall.

The borders of the Sahel are often identified with the boundaries of pastoral and agro-pastoral activities (thus relying on human activities), or with the limits of rainfall isohyets (150-550 mm).

From 1960 to early 80s the area experienced dramatic food crisis, caused by prolonged drought, resulted in tensions and armed conflicts.
Several studies aimed to seek explanations (climatic or human) of the drought phenomena.

- **Charney (1975)** attributed to human mis-management of land resources the year-to-year persistence of drought
- **Lamprey (1988)** stressed an "irreversible and progressive desertification of the Sahel" as effect of long-term droughts
- **Anyamba et al. (2005)** and **Hermann et al. (2005)** showed that from the 80’s a re-greening is visible in satellite images analysis
Context and Objectives

EU and AU Commission jointly promoted different initiatives exploiting Earth Observation Satellite, in order to improve the lives and prospects of people in Africa, and whose livelihoods depend heavily on their environment.

Exploitation of time series of satellite imagery

- **Timely provision of information** on the natural resources conditions, mainly vegetation cover, using environmental indicators derived from satellite data.

- **Highlight critical situations** (hot-spots) where inter-annual vegetation behavior is not explained by climate variability (rainfall pattern and dynamics).

Respect to previous published research we focus on the last 13 years up to 2010 using 1 km resolution satellite data.
From EO Data towards Information

Time series
Vegetation index NDVI 1998 - now
Water Index NDWI 1998 – now
Leaf Area Index LAI 2007 – now
Albedo BBDHR
Land Temperature LST
...

Environmental Indicators
sNDVI Standardized NDVI
VCI Vegetation Condition Index
NGI Normalized Growth Index
VPI Vegetation Productivity Index
fCover fractional vegetation Cover
LST Land surface temperature
TCI Temperature Condition Index
VHI Vegetation Health Index
SWB Surface Water Body

MSG Every 15 min
Spot/VGT Every 10 day
In Senegal and western Mali agro-pastoral season 2009 very favorable.

In Mauritania, exceptional 2009 rain season

Seasonal NGI profile averaged per Administrative Unit
In **Niger** the second part of rainy season was characterized by an early stop of rains (end of August) mainly in the Eastern part of the country.
GeoLand-2 NARMA satellite products:

- **RFE** derived by FEWS NET were used to characterized rainfall variability
  - 8 km spatial 10-day data (1998-2010)

- **NDVI** from SPOT-Vegetation (VGT) were used as proxy of vegetation production
  - 1 km spatial 10-day data (1998-2010)

- **Glob Cover (GC)** was used to analyze behavior in different land cover classes
  - 300m spatial (MERIS data, Year 2005)
Methodology for anomalies analysis

Analysis of anomalies

- **Pre-processing of EO product**
  - $\sum_{\text{NDVI}}$: 10-day NDVI values were cumulated for the period JASO proxy of annual (net and gross) primary productivity (Price, 1991).
  - **Y-Rain**: annual cumulated rainfall which is considered as the most influential parameter on plant production in the study areas.

- **Normalization by Z-score calculation**
  \[
  \text{Anomaly}(i, j) = \frac{DN(i, j) - \bar{X}(i, j)}{\sigma(i, j)}
  \]
  \(DN = \text{annual value of NDVI (or rainfall)}; \)
  \(\bar{X} = \text{mean value for the period 1998-2010}; \)
  \(\sigma = \text{standard deviation for the period 1998-2010}.\)
  \(i, j - \text{indicates pixel coordinates (samples and lines)}\)

- **Temporal trend**
  - **Trend significant**: Mann–Kendall non parametric test used to identify monotonic increase/decrease in the Z-score time series
  - **Trend Magnitude**: slope of the trend was calculated using the Sen’s non-parametric method
Long-term trends of both variables were analyzed together according to the interpretation scheme:

- **Climatic** processes only when significative change in rainfall are detected ($P < 0.1$) with a sensible magnitude ($sl > 0.126 \uparrow \text{ or } sl < -0.126 \downarrow$)

- **Anomaly** condition when NDVI trend present significative slope ($P < 0.1$) and magnitude ($sl > 0.126 \uparrow \text{ or } sl < -0.126 \downarrow$) even in condition of stable rain

- **Unclassified** when $\sum$NDVI trends are not significative ($P < 0.1$) or present very low magnitude

\[ X = \text{Rain trend slope} \quad Y = \text{NDVI trend slope} \]

* not significant trend or low slope trend
• Most of the areas present a **stable situation** at least in the last 13 years.

• **Climatic greening** can be identified north west (Mauritania , Senegal)

• **Climatic degradation** can not be appreciated at regional scale (1% in Nigeria ).

• **Anomalous greening** mainly in the North-west part of Sahel (Mauritania and north Mali), central part of West Sudanian savanna (rain > 800 mm) and forested areas of East Sudanian savanna.

• **Anomalous degradation** located in the cent**ral part of Sahel** (annual rainfall between 200 and 400 mm). **Niger and Chad hot spots** fall in the “Sahel’s fragile high-risk zone” (ECOWAS 2006) suffering from both persistently low and very unpredictable rainfall.

For Niger in these areas livelihood crisis reported (FEW-NET, GIEWS) in the last ten years (2000, 2004, 2005 and 2010) suggesting likely **chronic environmental unfavorable conditions**.
Hot spot at Landsat TM: NIGER

24/09/2000

03/08/2007
Hot spot at Landsat TM: Lake Chad

25/09/2002

17/10/2010
Anomalous greening in Darfur

Anomalous greening occurring after the 2004-2006 Darfur crisis
Conclusions

Despite the documented occurrence of re-greening (1980-2000) the Sahel area continuously (recently) experienced humanitarian crisis.

• Our analysis (1998-2010) shows that precipitations are mainly stable and large portion of the vegetation depends on climatic variability (NDVI driven by changes in rainfall pattern).

• An anomalous greening (increase of NDVI where rains stable) was observed In the Southern part of the study area

• This phenomenon may be explained by improvement in management of cultivated areas by local populations in favorable climatic condition (Closed to open scrubland (GC) presents an expansion of agriculture in the period of analysis)

Hot spots of anomalous degradation are located mostly in agricultural-grazing areas of Niger and Chad (mixture of crop and grassland land cover classes)

✓ Locations where vegetation development is driven by factors other than climate (which interfere in the dynamics of plant development) are more common in pasture areas than in cropland.

✓ Satellite derived maps were found in good agreement with humanitarian crises db (critical areas identified in Niger are all within the crisis boundaries).
Thank you for your attention!

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