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Intraannual Vegetation Dynamic as potential Indicator for Environmental Change in the West African Sahel Zone

R. Leiterer [a,]*, J. Reiche [a], C. Thiel [a], C. Schmullius [a]

[a] Department for Earth Observation, Friedrich-Schiller-University, Jena, Grietgasse 6, 07743, Germany
(reik.leiterer, johannes.reiche, christian.thiel, c.schmullius)@uni-jena.de

Abstract – Studies identified desertification and land degradation as a possible cause for persistent drought in the Sahel. The specific vegetation dynamics in the Sahel are good indicators for this kind of environmental change. Due to the scattered availability of ground truth data in huge parts of the Sahel, EO data might provide the only reliable means for sound analysis and detection of long-term changes. This study focuses on vegetation dynamic monitoring over the Iullemeden Aquifer (SAI) using ENVISAT MERIS data. The biophysical vegetation variables fAPAR and NDVI were analysed in terms of the vegetation changes within one growth period. It turned out that these informations are important indicators to make reliable statements on ecological changes. Considering that in future similar products are available, it's an outstanding tool to monitor the whole Sahel zone with a high temporal resolution to analyse vegetation dynamics in terms of climate change and human impact.

Keywords: Sahel, Vegetation, Dynamic, ENVISAT MERIS.

1. INTRODUCTION

The Sahel is the transition zone between Sahara desert and an area where in the presence of rainfall agriculture is possible. This area is characterized by important interaction between climate variability and socio-economic key factors like agriculture and water resources (Herrmann et al., 2005). The transboundary area of interest SAI (Systéme d'Aquifères d'Iullemeden) is affected by progressive over-extraction, water quality degradation, human induced pollution, associated with soil degradation, and the impacts of variability and climatic change. The specific vegetation dynamic and the dynamic of open surface water bodies in these arid regions are good indicators of environmental change. Long time land cover analysis allows monitoring the negative results from over-extraction of the available water resources as well as the vegetation decrease by human interventions.

This research includes the detection of the land cover at four different dates within one growing season as well as the changes between these points in time. To reach these targets, two different groups of classification types were chosen. The first group consists of land cover and land cover change products. The second group consists of pre-classification change products, focused on seasonal dynamics.

1.1 Test site characteristic

The transboundary area of interest SAI, as we see in Figure 1, covers approximately 525.000 km², including parts of Niger, Nigeria, and Mali. It is located within (1°00'–10°00') E and (10°00'–19°00') N and comprises parts of the northern and southern Sahel (GAF AG, 2006).

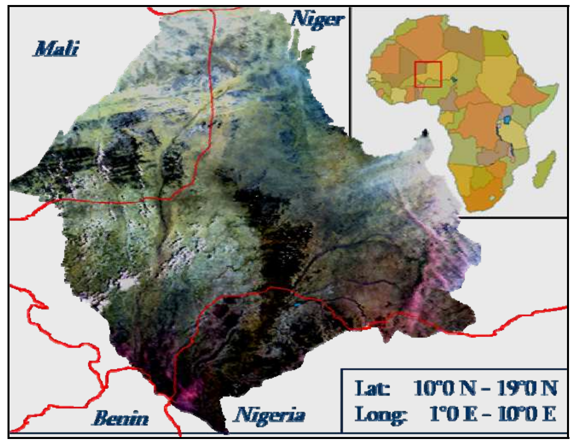

Figure 1. Area of interest SAI (MERIS Oct05 – R[11]-G[7]-B[5])

The climate in the SAI basin is characterised by the annual cycle of rainfall. A short rainy season with high precipitation from June to September is followed by a long drought from October to the middle of May (Love et al., 2004). Water resources from dams or groundwater are used in the drought for irrigation, but individual water bodies may dry out completely and large areas are only cultivated during the rainy season. In the rainy season the number of rainy days and the amount of annual rainfall decrease from the south to the north (CPC, 2008). The floodplains of the main rivers are mostly inundated during this season.

The vegetation adapts to the annual cycle of rainfall with a slight temporal delay. The physiognomy of the vegetation zones changes from contracted vegetation in the Sahara to tree, shrub or grass savannas in the Sahel. During the long drought a huge part of the vegetation withers. These bald trees and bushes show no photosynthetic activity until the next rainfall. The sparse tree density as well as the intensive pasturing results in an increased soil and vegetation erosion in the whole region (Wezel et al., 1999).

2. DATA PROCESSING

The MERIS data was delivered as full resolution (FR) level 1b data. MERIS L1b products provide geocoded Top-Of-the-Atmosphere (TOA) radiances with a pixel spacing of 260 m at nadir. A swath width of 1150 km allows the coverage of the entire earth surface within an interval of 3 days. The instrument

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measures the TOA radiance in 15 bands within the visible and near infrared range from 408 nm to 905 nm. MERIS FR scenes for the following acquisition times have been used: May 2005, Oct 2005, Dec 2005, Mar 2006. As reference and validation data a Landsat-7 mosaic from 2000 and a NigeriaSat-1 scene from 2006 were available. To compare the results with other large scale products the GLC2000 land cover dataset as well as the ESA GlobCover dataset was used for the whole area. A direct field-data sampling was not feasible.

The BEAM Software was used for the data extraction, the orthorectification and the reprojection of the MERIS data. To enable a comparison and to mosaic the different images, it was necessary to convert the TOA radiance values into surface reflectance (SR). In order to correct for atmospheric influences, the Simplified Method for Atmospheric Corrections (SMAC) has been used (Rhaman & Dedieu, 1994). The orthorectification was applied by using the GETASSE30 elevation data as a source for the required geocoded information. Additionally, the MERIS Level 2 biophysical vegetation variables (fAPAR, fCover) were generated by the MERIS TOA-VEG Processor (Baret et al., 2006). The product layers have been co-located with the corresponding orthorectified MERIS image and were combined to create a consistent mosaic across the region.

Vegetation indices provide an excellent basis for the recording of vegetation dynamics and their phenology as well as for the distinction between vegetation and non-vegetation (Eklundh & Olsson, 2003). Due to the inclusion of absorption characteristics of the vegetation, which are related to the seasonal and annual variations in the photosynthetic activity, vegetation indices are very suitable for the detection of seasonal vegetation dynamics. For all MERIS mosaics the indices NDVI, SAVI (Soil Adjusted Vegetation Index) and the MTCI (MERIS Terrestrial Chlorophyll Index) were calculated (Eq. 1, 2).

$$SAVI = \frac{R_{Band\,13} - R_{Band\,7}}{R_{Band\,13} + R_{Band\,7} + L} \cdot (1 + L) \qquad (1)$$

$$MTCI = \frac{R_{Band\,10} - R_{Band\,9}}{R_{Band\,9} - R_{Band\,8}} \qquad (2)$$

The NDVI was calculated from the MERIS bands 13 (865 nm) and 7 (665 nm). Because of the low vegetation density in the SAI region, the value 1 was used as soil-brightness dependent correction factor L for the calculation of the SAVI. Compared to the NDVI, the SAVI highlights the vegetation areas more properly. The MTCI is sensitive to a wide range of chlorophyll contents and provides a good distinction between different photosynthetic activities (Dash & Curran, 2005).

The calculation of the percentage change of the vegetation indices between two acquisition dates is described below. At first, a multitemporal cloud mask for both MERIS mosaics was generated. After cloud masking both NDVI layers were stacked and, using the example of the NDVI, the calculation of the percentage change was applied using Equation 3.

$$Change = \frac{([NDVI_{acq.date\,2} + 1] - [NDVI_{acq.dat\,1} + 1]) \cdot 100}{(NDVI_{acq.dat\,1} + 1)} \qquad (3)$$

Besides the introduced vegetation indices, the biophysical vegetation variables fAPAR and fCover were generated. The TOA-VEG Processor derives fAPAR and fCover directly from the MERIS L1b data. The fAPAR value (Fraction of Absorbed Photosynthetically Active Radiation) refers only to the green parts of the canopy (leaf chlorophyll content > 15µg.cm-2) and varies from 0 (low) to 1 (high). fAPAR is comparable with the already existing MERIS Level 2 fAPAR product MERIS Global Vegetation Index (MGVI). fCover is the fraction of green vegetation covering a unit area of horizontal soil. It only considers green vegetation (leaf chlorophyll content > 15µg.cm-2) and varies from 0 (bare soil) to 1 (full cover) (Baret et al., 2006).

3. VEGETATION CLASSIFICATION

For the land cover classification of the four acquisition dates, different classification approaches have been tested. Supervised (MLC), unsupervised (k-means clustering) and rule based (object oriented) classifications using the MERIS bands as well as several indices (see Ch. 2) have been considered. The qualitative comparison and analysis of the several classifications results pointed out that the rule based (object oriented) approach using Definiens Developer is suited best for the land cover classification. As first the multi-scale segmentation of the input data was accomplished to generate image objects (segments) as basis of the object-oriented classification. The multiresolution segmentation algorithm was applied as segmentation mode and except for the urban mask (weight '0') all input layers were included in the segmentation (weight '1'). In both regions a scale parameter of '2' and a homogeneity criterion of '1' were used as segmentation parameter for the first segmentation level. For the second level a scale parameter of '10' and a homogeneity criterion of '1' was used.

During the progress of the classification hierarchy the basic classes water, green vegetation and other were subdivided into the extended classes water, clouds, urban, low green vegetation, high green vegetation, floodplain vegetation and other. Table A shows the LCCS-standard class description for the extended classes (LCCS 2005).

Table A. LCCS standard description for extended classes

Class	**LCC Formula**
Water	A1-A4 // A1-A5
Urban	A4-A13A16
Floodplain Vegetation	A2A20B4C3 // A1B2XXC3D2E1-E4 // A2A14 // A3B2XXC2D2-C4C10C15C18 A2A20B4C3
High Green Vegetation	A3A20-A2 //A4A20//A5A20//A6A20
Low Green Vegetation	A1A14 // A4A20-A21 // A5A20 // A6A20
Non-Photosynthetic Vegetation	LCC - code assignment not possible
Clouds	LCC - code assignment not possible
Other	Bare areas A6B16-A6B3

For the generation of the cloud mask the high reflection of clouds and haze in the MERIS band 1 and the MERIS cloud ratio (band11/band10) have been used (PREUSKER et al., 2006). Open water bodies are characterised by very low reflection in the near infrared and particularly by very low values in the NDVI. The major limitation of the water body mask results from the low geometrical resolution of the MERIS data (260 m). Hence in the mapped pixel their spectral signature is mixed with the signature of the surrounding land cover (De Chiara et al., 2006). Thus most of the rivers could not be detected.
Green vegetation was classified using an NDVI threshold. High green vegetation and low green vegetation differ by a higher photosynthetic activity of high green vegetation, which is indicated by high values of MTCI and fCover. The MERIS ratio (band14–band13) / (band14+band13) enabled to classify the inundated floodplains, which are intensively cultivated by flood-recession agriculture (Hartenbach & Schuol, 2005). Thus, the detected floodplains in SAI can be classified as vegetation (floodplain vegetation). The radiometric properties of floodplains are a mixture of spectral characteristics of water and vegetation. The above-presented MERIS ratio emphasises inundate floodplains as well as water bodies (water (floodplain)). Floodplain vegetation differs from water bodies by a higher NDVI. During dry season the main part of vegetation in SAI has no photosynthetic activity and appears as bald and dry trees and bushes. Therefore it is to assume that the maximum extend of photosynthetic active vegetation (green vegetation) in the four individual maps represents the expansion of non-photosynthetic vegetation for whole season. By summating the green vegetation masks of all acquisition dates, a mask for the extent of non-photosynthetic vegetation was generated.
As we see in Figure 2, the classification results showed strong varieties in the photosynthetic activity of the vegetation, based on the climate conditions in the region (see Ch. 1.1).

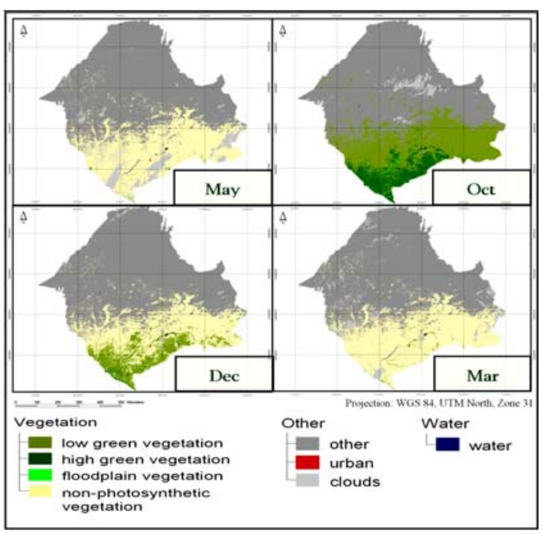

Figure 2. Extended land cover classification

The change between these dates point out the seasonal dynamics and show that it is possible to monitor the extension of vegetation and its phenological dynamic. These informations are important indicators to state ecological changes and local climate fluctuations.

4. VEGETATION DYNAMIC ANALYSIS

The NDVI as well as the biophysical vegetation variables follows the specific vegetation cycles dependent on the yearly rain cycles in the SAI region. To distinguish groups of vegetation by their seasonal (temporal) behaviour the k-means clustering algorithm was used. Beforehand, a common cloud mask for all four MERIS mosaics was generated. After cloud masking, the NDVI, fCover and fAPAR mosaic layers were stacked to one multi-temporal dataset. For the k-means clustering different numbers of initial classes were tested (4, 8, 10, 14). Ten initial classes are best suited to distinguish the multi-temporal layerstacks into groups of vegetation of different temporal behaviour.
To label the different classes, thresholds were defined based on statistical analysis of the clusters and their multitemporal spectral characteristics. For example, due to the strong radiometric effect of bare soil the threshold for photosynthetic activity was defined with an NDVI > 0 or a fAPAR > 0.1. High photosynthetic activity was defined with an NDVI threshold > 0.15 or a fAPAR > 0.35. Figure 3 depicts a subset of the NDVI based vegetation dynamic map.

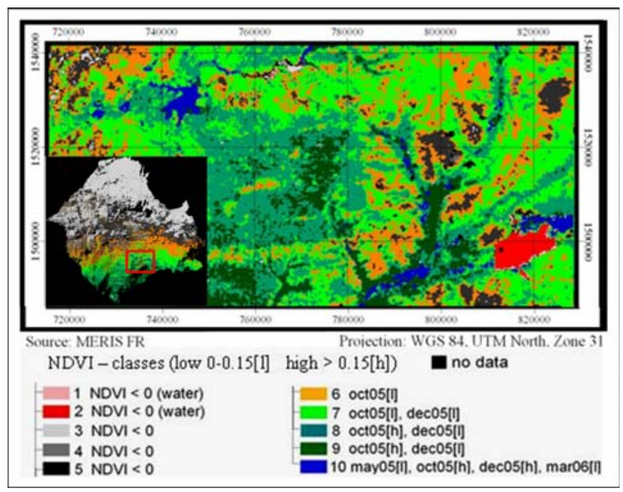

Figure 8. NDVI – Seasonal Change Map

In the case of long time series, these informations are important indicators to make reliable statements about ecological changes or local climate fluctuations. Because of the direct relation between the vegetation and available water resources such vegetation dynamic maps allows statements about water resources and changes in water availability. For instance, it could offer help for the decision making for an improved water management in the Sahel. Alternatively, it allows monitoring the effects of Sahelian drought, overgrazing and the local impact of climate change and help the government take a look at past trends in terms of deforestation, reclaimed land and new settlement areas to determine the long term affect and implement corrective measures.

5. VALIDATION

Based on a *Stratified Random Sampling* approach using *PCI Geomatica*, error matrices were used to assess the classification accuracy and are summarized for all acquisition dates in Table B (100 random points/ class).

Table B. Accuracy assessment for classification

Acquisition Date	May05	Oct05	Dec05	Mar06
Basic LCC				
Overall Accuracy	0,81	0,78	0,82	0,84
Kappa	0,75	0,70	0,76	0,79
Extended LCC				
Overall Accuracy	0,76	0,74	0,71	0,76
Kappa	0,72	0,69	0,66	0,72

For the comparison with the GLC2000 and the GlobCover product two indicators, the correlation coefficient r and the *RMSE* are derived for each class membership (Eq. 4, 5). The *RMSE* reveals the absolute differences between fuzzy class estimates of GLC2000 and the land cover classification maps in opposition to r, which is a measure of relative correspondence.

$$r = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{N}(y_i - \bar{y})^2}} \qquad (3)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(x_i - y_i)^2}{N}} \qquad (4)$$

N = Number of elements
x = Compared LC Map (GLC2000/ GlobCover)
y = LC classification map

The main land cover classes also confirm with GLC2000 and GlobCover. But in comparison to the GLC2000 water and urban area classes, the presented extended land cover classification maps shown very plainly the more accurate and detailed results.

6. CONCLUSIONS

This study demonstrated the performance and suitability of ENVISAT MERIS-FR data for the purpose of monitoring long-term vegetation changes regarding to land cover. It was shown that this kind of large scale land cover monitoring provides an appropriate tool to observe vegetation extension and biophysical based vegetation dynamics in the course of a year.

In the case of long time series, these informations are important indicators to make reliable statements about ecological changes or local climate fluctuations. For instance, it could offer help for the decision making for an improved water management in the Sahel and a basis for the estimation of water resources used for irrigation. For this purpose, the GlobCover project offers a very interesting free available facility. GlobCover provides bimonthly pre-processed MERIS mosaics for 2005, which are a good data-base for large scale coverage with a high temporal resolution. Considering that in the future similar products are available, you have an outstanding tool to monitor the whole Sahel zone and to analyse the vegetation dynamics in terms of climate change and the human impact.

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