Remote Sensing based estimation of potential terrestrial carbon stocks in West Africa

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Abstract – Climate change, initiated by increasing greenhouse gas emissions leads to serious ecological and economic problems especially in developing countries. The potential carbon sinks are analyzed by a combination of different remote sensing based products for three countries (Ghana, Togo, Burkina Faso). In order to derive these information, the following analysis need to be done: Firstly, the net primary productivity was estimated on a regional scale based on MODIS 250 m time series. Secondly, the actual land cover was classified with medium spatial resolution based on multi scale analysis with in situ, Landsat and MODIS data. Thirdly, the potential vegetation was modeled with abiotic factors, whereas land cover of protected areas was used as training data. Based on a combination of these datasets a balance of potential carbon sinks could be estimated over a time period of 100 years. Due to decreasing soil fertility, the potential of emission trading could be an alternative source of income in parts of this region.

Keywords: Carbon, potential land cover, actual land cover, net primary productivity, emission trading.

1. INTRODUCTION

Global warming is nowadays one of the greatest environmental, social and economic challenges. Increasing emissions of the greenhouse gas CO_2 are a major forcing to global warming. The biosphere is one of the most important components and terrestrial carbon stocks are influenced intensely by humankind. About 20 % of anthropogenic CO_2 emissions are due to land cover and land use change (Canadell et al. 2003). This is especially true for regions with high population density on the one hand and potential high photosynthetic activity and biomass on the other hand like in West Africa. In this region the terrestrial carbon pools are the most vulnerable and CO_2 emissions from deforestation and degradation are comparable high (Canadell et al. 2007). But on the other hand the region offers the potential to become an increasing CO_2 sink, because it offers a high potential for afforestation.

2. STUDY SITE

The study site of this work includes three countries in West Africa: Ghana, Burkina Faso and Togo. The region is characterized by a distinct precipitation gradient from the wet and evergreen region in south Ghana to the semiarid to arid conditions in the Sahel in northern Burkina Faso.
High population density and growth rates are found in all three countries. The pressure on landscape is intense and results in high rates of land cover change. Logging activities, fires and agriculture have been forming the landscape to a small scaled heterogeneous landscape composite of fields, woody and herbaceous vegetation.

3. METHDOLOGY

In order to compute the potential of the West African landscape for the function as a carbon sink, information on the productivity of the vegetation as well as information on the actual and potential land cover are needed.

3.1 Modeling the net primary productivity

Based on the theory of Monteith (1972) the net primary productivity (NPP) can be modeled by using the *Absorbed Photosynthetically Active Radiation* (APAR) and a biophysical conversion factor, which is based on the *Light Use Efficiency* (LUE) of plants. Monteith (1977) expressed these relations for crops by the following equation:

$$NPP = APAR \cdot LUE \qquad (1)$$

Sellers (1985), Asrar et al. (1992) and Frouin & Pinker (1995) have shown that the ratio of PAR and APAR, the *Fraction of the absorbed Photosynthetically Active Radiation* (FPAR) correlates strongly with the remotely sensed Normalized Difference Vegetation Index (NDVI). To calculate the NPP using remote sensing data, the equation can be modified in the following way:

$$NPP = PAR \cdot FPAR \cdot LUE \qquad (2)$$

Using MODIS data, input parameters with 250 m resolution were calculated, including fractional vegetation cover, FPAR, temperature and water stress. The NPP for the three countries was calculated using the RBM+ model (Machwitz 2011). Additionally to the total NPP, the NPP for herbaceous and woody vegetation was calculated separately. This is especially important for the calculation of long term carbon sinks because only woody vegetation is able to fix CO_2 over longer periods.
Figure 1 shows the result of modeling the NPP of woody vegetation for the year 2006. The protected areas in the south of Ghana are characterized by higher values of up to 2 kgC/m² in comparison to their surroundings. In the middle and northern parts the NPP is decreasing gradually and reaches values close to zero in the Sahel. Due to the intense use as agricultural and rangeland as well as the decreasing precipitation, the tree density is decreasing. In the surroundings of rivers gallery forests are likely to exist, which is characterized by higher NPP values of woody vegetation with linear features in the central and northern parts.

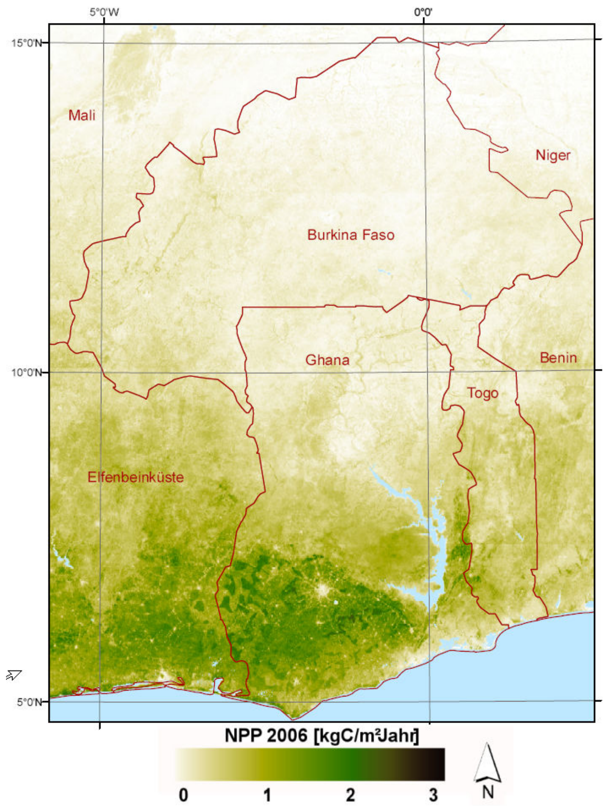

Figure 1. Net primary productivity of woody vegetation for the year 2006 in kg carbon per m².

3.2 Actual land cover

Several global land cover products exist but for the savanna in West Africa the accuracies are low (Giri et al. 2005, Herold et al. 2006). Therefore a new land cover map was calculated using a multi scale (Machwitz et al. 2008). Based on the LCCS field protocol 3000 field samples were collected. Five Landsat and ASTER scenes were classified with the maximum likelihood approach. Additionally, two ASTER classifications were available from other studies (Kübert 2008, Cord et al. 2010). From those classifications training and validation data was extracted to classify 250 m MODIS time series with a random forest of classification trees (Breimann et al. 1984, Breimann 2001).

The result of this classification can be seen in Figure 2. The overall accuracy was 80.2 %. The highest accuracies could be achieved for the classes *closed tree savanna, forest, water* and *sand* with more than 90 % of user's and producer's accuracy. Good to medium accuracies had the classes *grass savanna, agriculture and bare* with values of 80-90 %. The *classes open tree savanna, shrub savanna, urban* and *wetlands* showed medium to low accuracies of 44 to 68 %. The savanna vegetation has very large transition zones and therefore especially the open classes are not represented well by categorical classes. To consider this problem the two classes are combined to one class for the further calculations. The wetlands show a distinct temporal dynamic and are difficult to classify. Because of the very small spatial extend these classification error has no importance for further analyses. The urban areas show similar spectral information to the bare soil class because roads are often not paved. But this mixture does not influence the further calculations which are focused only on the vegetation classes.

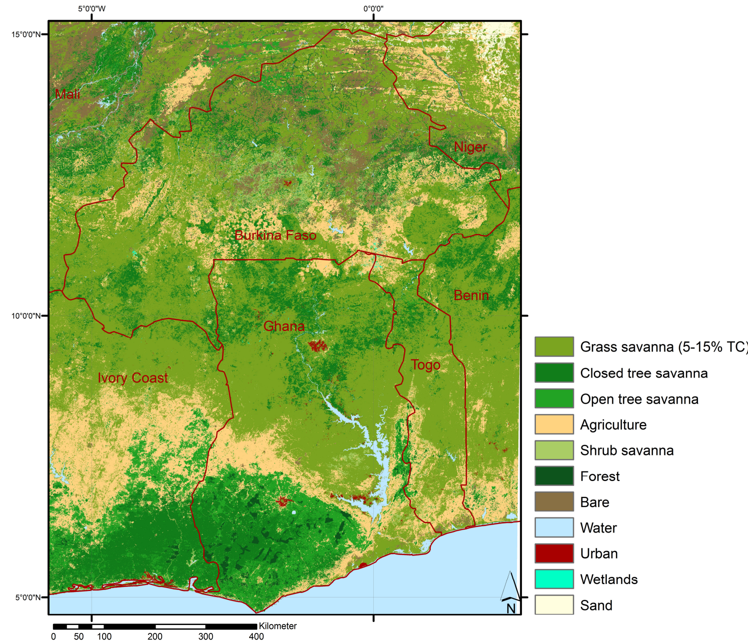

Figure 2. Actual land cover classification based on MODIS 250 m time series (TC: tree cover).

3.3 Potential land cover

The potential land cover is defined as land cover, which would develop if anthropogenic influence stops. The potential land cover was modeled using training data from the actual land cover of the IUCN protected areas. These areas are not free of anthropogenic influence but they are in the closest state to natural condition. The method was the same as for the actual land cover: Random forest classification. The independent variables for the classification were abiotic factors including long term means of precipitation and temperature data (Hijmans et al. 2005), the FAO-HWSD soil map (Batjes et al. 2009) and elevation data (SRTM, Farr et al. 2007). Additionally, based on the elevation model, streamlines were calculated to extract the potential gallery forests.

Figure 3 shows the potential land cover map. The southern parts are covered by evergreen forest limited in south Benin and Togo by the *Dahomey Gap* which is characterized by lower precipitation. The central regions are represented by a mixture of closed to open woodland and the Sahel in the north is covered by grassland with a low tree cover of 5 to 15 %.

For a detailed validation long term studies of vegetation development would be necessary. But the results are plausible and similar to the results of other studies analyzing the potential or natural vegetation (White 1983, Anhuf 1991).

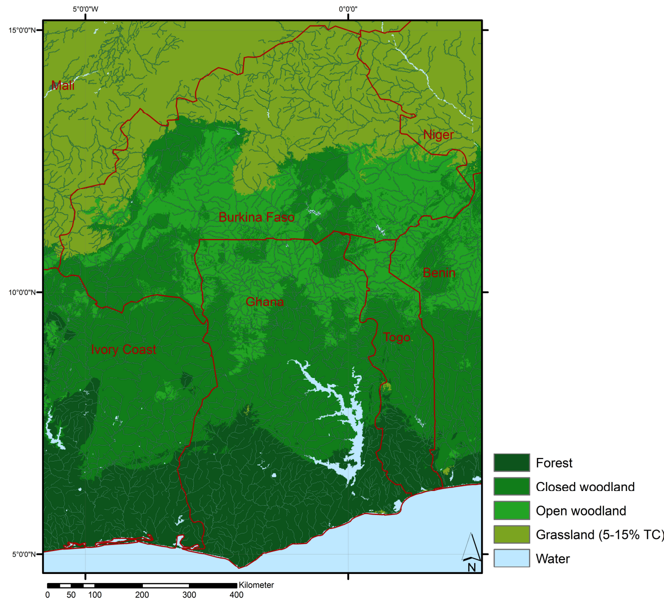

Figure 3. Potential land cover (TC: tree cover).

4. POTENTIAL CARBON STOCKS

A combination of the actual NPP and the actual land cover map allows a calculation of the NPP for every land cover class. If these results are transferred to the potential land cover map, the potential NPP can be extracted.

The woody vegetation can fix parts of the NPP over medium to long terms (decades to centuries, Schulze & Heimann 1998). The fixed part is depending of the age of the tree. Very young trees can only fix little parts of the carbon because they have no or only little woody parts. During the age of 20 to 60 years the trees can save respectively the biggest part of the NPP up to 10 %. If the trees are getting older the fixed part is decreasing again because of the development to a unprofitable proportion of leaves to wood (Larcher 2001).

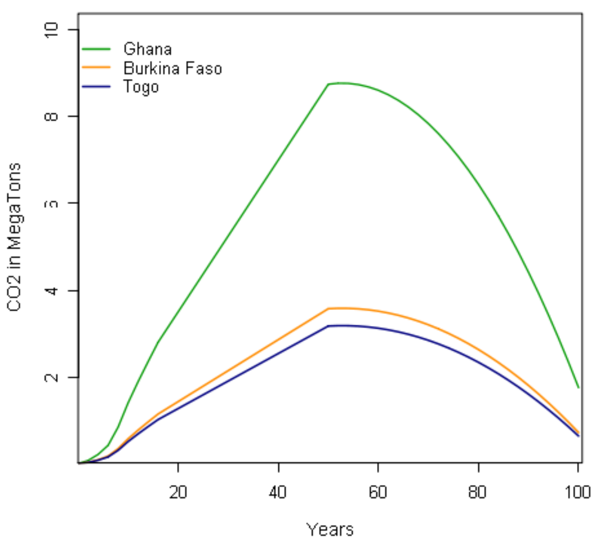

Figure 4. Potential development of the medium and long term carbon stocks.

5. CONCLUSIONS

The potential development of the medium and long term carbon stocks for 100 years on a national basis for the countries Ghana, Burkina Faso and Togo was calculated (Figure 4). The calculation follows the theory that the actual vegetation would evolve into potential vegetation without human interruption. Up to more than 8 megatons of CO_2 per year could be fixed in Ghana and up to more than 3 megatons in Burkina Faso and Togo.

According to the decreasing soil fertility of agricultural land in these regions decreasing world market prices for e.g. cotton, the storage of carbon could become and alternative source of income, if it could be included to the emission trading. Especially, during an age of 40 to 70 years the woody vegetation can fix high amounts of CO_2. The feasibility of the integration of these amounts of CO_2 into the finance market depends on the development of the post-Kyoto programs and on the carbon prices. The price per ton of carbon has to be able to compete with the prices of the agricultural products like cocoa or cotton (Sandker et al. 2010).

The transformation of agricultural used land to protected woodlands or forests could fix big amounts of CO_2 in West Africa. Even for Burkina Faso with dry conditions still large amounts could be stored in woody vegetation. This would allow on the one hand a reduction of greenhouse gases and on the other hand could be an alternative source of income if it would be included in the emission trading.

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