Focali (Forest, Climate, and Livelihood research network) is a Swedish research network focusing on forest / bio-energy, climate change and poverty issues. Several Swedish universities and institutions are represented in the network. Focali develops new and synthesizes existing knowledge, and increases the flow of relevant information between scientists, industry, government and civil society.

Forest, climate & livelihood research network

Focali Brief: 2012:06

Monitoring forest carbon with remote sensing in the Sudano-Sahelian zone

Remote sensing technology is regarded as an indispensible component of a REDD+ Measurement Reporting and Verification (MRV) system. However, deriving relevant information on forest carbon stocks and emissions from remote sensing data is not a straightforward process.

EFFORTS TO reduce carbon emissions from deforestation and forest degradation (REDD+) have mostly been centered on areas with high carbon density, such as rainforests. But including semi-arid and more open forest systems is relevant since these areas cover about 18 percent of the global land surface and the vegetation and the soils therein control significant proportions of terrestrial carbon stocks and fluxes (Lal 2004).

The power of remote sensing

A vital component of a REDD+ mechanism will be access to reliable information on forest cover extent and forest carbon stock densities, including changes over time. In this context remote sensing data, such as satellite and aerial imagery, constitute an essential source of information, especially for developing countries where other types of forest inventory data are often lacking. Four features of remote sensing data make it particularly suitable for forest monitoring purposes:

- it is geographically explicit
- it can be acquired over large spatial scales at relatively low cost
- it can be repeatedly and consistently acquired
- historical data is often available

About this brief

Focali provides knowledge to Swedish ministries, government agencies and other relevant actors for effective forest management to achieve climate-poverty targets. This brief is based on a forthcoming article assessing scientific literature of remote sensing in relation to quantifying vegetation and carbon in the Sudano-Sahelian zone by Martin Karlson.

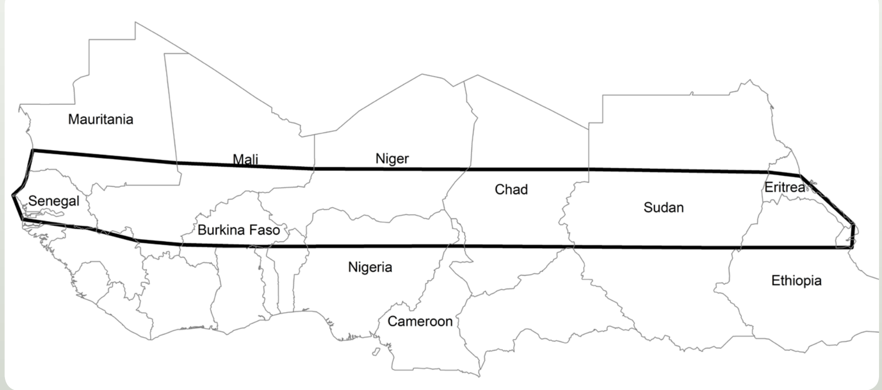


Figure1. The Sudano-Sahelian zone

The Sudano-Sahelian zone

The Sudano-Sahelian zone (see Figure 1 above) receives 200-1000 mm mean annual rainfall. The density of the woody vegetation types are highly related to the annual rainfall levels which increase toward the Equator. The Sahelian biome in the north is characterized by open grass and shrub land landscapes and thorny tree species while the Sudano biome is composed of wooded savannas, agro-forestry parkland systems and dry forests.

Change analysis of the two Ds in REDD+

Deforestation refers to a total conversion of a forested area to, for example, agricultural land use whereas degradation refers to more subtle changes in tree density, crown structure or species composition induced by, for example, selective logging. Remote sensing can be used to assess and monitor these two broad categories of forest cover change. In the most basic setup of change analysis two images from different time periods are compared in order to detect areas and extent of change. An important consideration is that the images must be comparable in terms of vegetation seasonality. For the Sudano-Sahelian zone this is critical because climatic conditions, mainly rainfall, fluctuate within and between years. This variability strongly affects the dynamics of leaf development and thereby influences what can be seen in the remotely sensed image.

Deforestation - a matter of land cover classes

The most widely used method for deforestation analysis involves classifying each image into land cover maps, which are then compared in order to detect changes. Image classification can be done either through manual interpretation, or through the use of computer based classification algorithms. Such algorithms use statistical methods to distinguish between forest types based on differences in how they reflect light or differences in seasonal cycles, for example, the timing and duration of the growing period.

The selection of remote sensing data depends on the scale of the study area and the time period to be covered. Paré et al. (2008) for example, quantified deforestation between 1984 and 2002 in southern Burkina Faso. They manually interpreted Landsat images (30 meter pixel size), and then used aerial photographs to map a number of villages with higher detail. Ruelland et al. (2010) used CORONA (US intelligence photographs from the cold war) imagery, aerial photographs and Landsat imagery to map longer term vegetation changes (1967 to 2007) in a watershed in Mali.

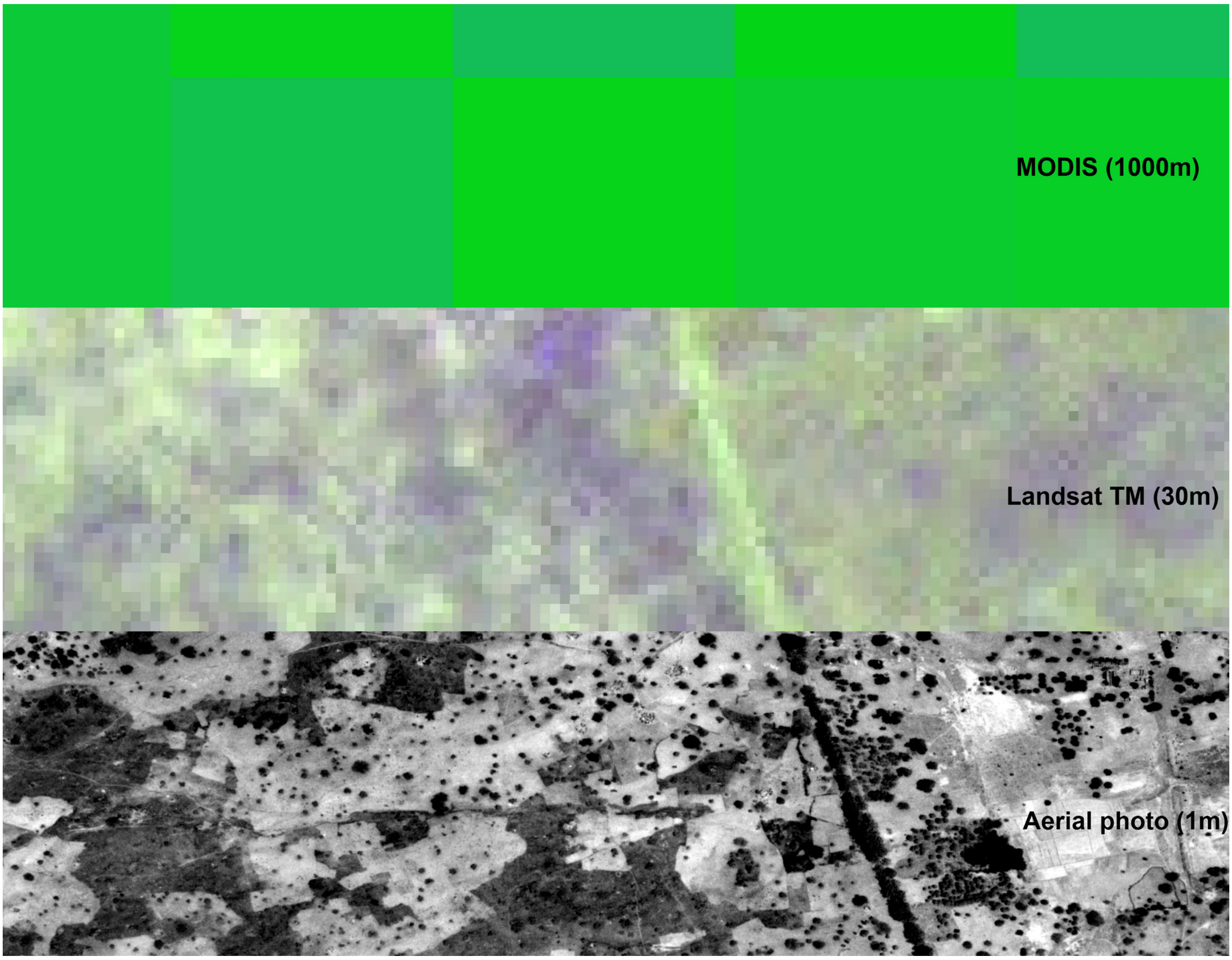
Multi temporal classification requires several images from the same year and this generally limits its application to data from coarse sensors and large areas. For example, Tchuente et al. (2010) developed a vegetation type map for West Africa from the Moderate Resolution Imaging Spectrometer (MODIS) sensor. For Mali, Rian et al. (2009) developed a national vegetation map based on compiled growing season data from the MODIS sensor. The compilation procedure reduces the influence of clouds which is a common and, in terms of optical remote sensing, problematic feature of the growing season. A comparison of images from Landsat, MODIS and aerial photo is presented below, which illustrates differences in spatial resolution between the different remote sensing technologies.

Forest degradation - a matter of seeing the trees

Detecting and quantifying forest degradation, such as modifications in crown coverage or tree density, is far more difficult than detecting and quantifying deforestation. Moderate spatial resolution images (15-80 meter pixel size) do not usually provide detailed enough information about degradation. Thus, images with a higher level of spatial detail, such as aerial photography and Quickbird imagery, in which individual trees can be identified, are required.

Due to the limited spectral information in aerial photography (black and white) and restricted time period covered by Quickbird (started 2001), manual interpretation is generally applied with individual trees detected. Even though sampling strategies can be applied, this obviously restricts large scale application. Despite this, Lykke et al. (1999) analyzed changes in crown coverage between 1974 and 1995 using aerial photography in Burkina Faso. They used both manual interpretation to map smaller plots and supervised classification to map larger areas. Both methods were considered to provide useful results, but only in terms of relative and not absolute changes. In Senegal, Gonzalez (2001) assessed tree density changes between 1954 and 1989 by manually counting trees in aerial photographs using a systematic sampling approach. Schlesinger & Gramenopoulos (1996) used a similar approach to assess tree density changes (1943-1994) in Sudan.

It is important to note that in order to estimate emissions from deforestation and degradation additional carbon stock data needs to be coupled to the remotely sensed



Comparison of images from Landsat, MODIS and aerial photo. The Landsat TM and MODIS data were obtained through the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/get_data). The aerial photo was provided by the Institute of Geography, Burkina Faso.

information. This is exemplified by Woomer et al. (2004) who performed a national inventory of carbon stocks and emissions in Senegal between 1965 and 2000 by coupling field measured carbon stock data to the different land cover classes.

No direct methods to quantify carbon stock

At present, no methods are available to directly estimate carbon or biomass from remotely sensed data. However, indirect methods, which extract quantitative information on the structure of individual trees or tree stands from remote sensing data, can be used. Structural variables, such as tree size, height or density, are often correlated to carbon stock and these relationships form the basis for large scale estimation of forest carbon.

In Mali, Franklin & Strahler (1988) used Landsat TM data to estimate canopy cover, tree density and average tree size. Franklin & Hiernaux (1991) extended the previous method in order to use it for carbon stock estimation. They achieved this by coupling the variables extracted from the Landsat image (average tree/crown size and tree density) to allometric equations (relationships describing size and shape). However, two significant limitations were reported: the relationship between the size of the tree crown and carbon was not robust and independent measurements of carbon stock were not available. Rasmussen et al. (2011) estimated canopy coverage and average crown radius in an area in Senegal using Quickbird data. They established a strong relationship between canopy coverage and basal area which they argue can be used to estimate carbon stock in sparse vegetation types.

An alternative to optical remote sensing data is radar. Radar data has two advantages over optical data; it is unaffected by clouds and it can penetrate through the crowns of trees. This means that the radar signal is more directly affected by the structure of trees, and therefore, by carbon. An important disadvantage is that the spatial resolution of radar data is coarse which makes it difficult to detect small variations in carbon stocks, especially in regions with a sparse vegetation cover.

Conclusions

Currently available remote sensing technology is not adequate to the complicated task of carbon stock quantification in the Sudano-Sahelian zone, despite its sparsely and fairly homogenous vegetation characteristics. It may be feasible to map carbon stock on a small scale but for larger areas improved sensors and/or methods are required.

Remote sensing provides valuable data, however it is important to understand that it does not replace field surveys. The generation of information on forest carbon stocks and emissions requires that remote sensing and field surveys are seen as complementary data sources.

REDD+ in the Sudano-Sahelian zone:

Even though it is not considered a forest carbon 'hot spot' several of the countries in this region are taking part in some of the large REDD+ programmes:

Forest Investment Program (FIP):	Burkina Faso
Forest Carbon Partnership Facility (FCFP):	Ethiopia and Cameroon
UN-REDD:	Nigeria

REDD+ is claimed to be one of the most successfully negotiated mitigation options in the Durban platform, the outcome of COP 17 in 2011 under the UN's Framework Convention on Climate Change (UNFCCC). The platform set the roadmap to get a global climate deal before 2015 and a legal framework in effect from 2020, while the existing agreement, the Kyoto Protocol, ends as of January 2013. The focus on REDD+ has faded somewhat in the last few years. This could be due to the lack of an international agreement in combination with REDD+ development entering a phase of addressing detail and technical fixes (Focali brief 2012:05). However, work is being done on national levels in REDD+ pilot countries as will be exemplified in an upcoming Focali Report on Cambodia.

Landscape view outside Bonogo village in central Burkina Faso. Photo: Lisa Westholm

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The agro-forestry parkland system in Bonogo village, Burkina Faso. Photo: Almina Isberg

Focali consists of representatives from:

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Chalmers University of Technology
Physical Resource Theory

Linköping University
Centre for Climate Science and Policy Research

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Department of Forest Ecology and Management

Stockholm University
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