

Monitoring Agricultural Biomass Using NDVI Time Series

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1 Introduction

In early 2000 the worst floods in nearly half a century ravaged parts of southern Africa, while several countries within the Nile basin were seriously affected by prolonged droughts. During the spring of 2000 regions of East Africa and the Great Lakes faced severe food shortages as a result of low rainfall and drought conditions, civil conflicts and below-average harvest in the preceding 1999/2000 season. Below normal amounts of rainfall were forecasted for parts of East Africa and a greater critical food security situation was expected (FAO, 2001).

The following study was designed to monitor the development of vegetation biomass for different areas in the Nile basin during the 2000 growing season. Time series of Normalized Difference Vegetation Index (NDVI) images were used for the study, as NDVI images have been proven to be a powerful tool to monitor biomass growth during the last dekad (Minamiguchi, 2005). NDVI, which can be directly calculated from satellite data, is related to vegetation canopy characteristics such as biomass and percentage of vegetation cover and is representative of plant photosynthetic efficiency, and fluctuations due to changes in meteorological and environmental parameters. NDVI images allow agricultural managers to analyse vegetation conditions for all season from NDVI/vegetation maps, NDVI curves and figures that anticipate major variations in productivity and potential harvest (Biard and Lepoutre). In addition, low resolution sensors, like NOAA's AVHRR and Spot's Vegetation instrument, provide NDVI images on a dekadal basis and allow an up-to-date assessment of the current growing conditions.

Numerous techniques have been developed to analyse NDVI data and this study, will use NDVI difference images and NDVI time series charts to assess the growing conditions in 2000. While difference images show the spatial distribution of plant growth anomalies, NDVI time series charts help to understand the development of vegetation on a long-term basis.

2 Study areas

Agriculture plays an integrated role in most areas of the Nile basin. Monitoring the annual growing cycle using Earth Observation (EO) data allows the detection of erratic vegetation anomalies between years but also the detection of possible trends in biomass change.

This study will focus on three different regions of the Nile basin to assess 2000 growing season: the Nile Delta in Egypt, the highlands in Ethiopia and the Sudd, a vast wetland in the southern part of Sudan (Figure 1). These areas are intensively cultivated and represent different, characteristic ecosystems along the course of the Nile river itself and its catchments.

3 Vegetation index principles

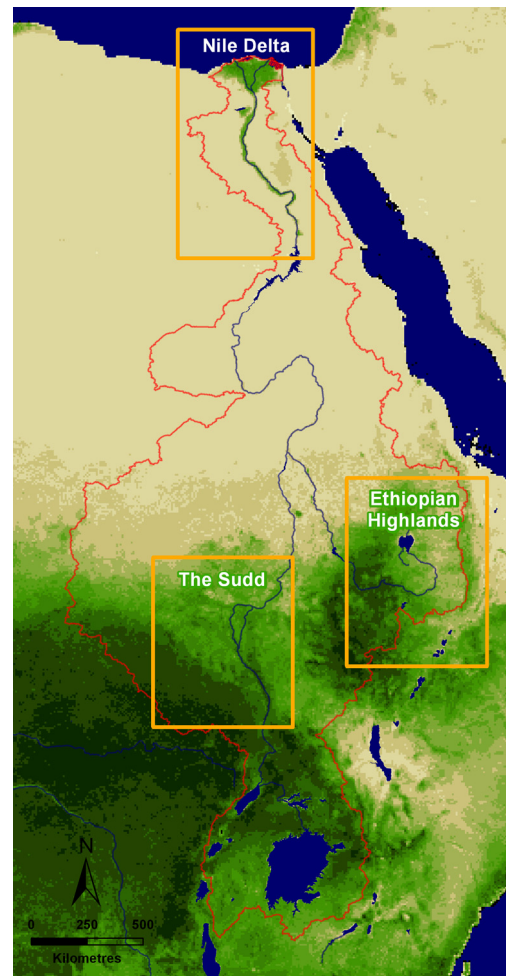
Approximately 20 years ago, Earth scientists began using satellite images to measure and map the density of green vegetation. This information is inherent in satellite images that record the intensity of visible and near-infrared light reflected by land based features. By applying a “Vegetation Index” to the satellite imagery, concentration of green leaf vegetation can be quantified.

3.1 Characteristic plant reflection

Vegetation indices are based on the characteristic reflection of plant leaves in the visible and near-infrared portions of light. Healthy vegetation has low reflection of visible light (from 0.4 to 0.7 μm), since it is strongly absorbed by leaf pigments (chlorophyll) for photosynthesis. At the same time, there is high reflection of near-infrared light (from 0.7 to 1.1 μm). The portion of reflected near-infrared light depends on the cell structure of the leaf. In fading or unhealthy leaves, photosynthesis decreases and cell structure collapses resulting in an increase of reflected visible light and a decrease of reflected near infrared light.

FIGURE 1

Map with the location of the study areas



3.2 Calculating NDVI

NDVI images are obtained by calculating the ratio between the visible (VIS) and near-infrared (NIR) bands of the satellite image. This emphasizes the characteristics and the different statuses of plant vigor and density even further. Mathematically written, the equation is as follows:

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

NDVI values are always in between -1 and $+1$, where higher values represent more vigorous and healthy vegetation. Very low values (0.1 and lower) correspond to barren areas of rock, sand and snow. Moderate values (0.2 to 0.3) indicate shrub and grassland, while temperate and tropical rainforests are represented by high NDVI values (0.6 to 0.8).

4 Method

While NDVI difference images show the spatial distribution of plant growth anomalies, the NDVI time series charts help to understand the development of vegetation on a long-term basis. The basic concepts of both techniques are introduced in the following section.

4.1 NDVI difference images

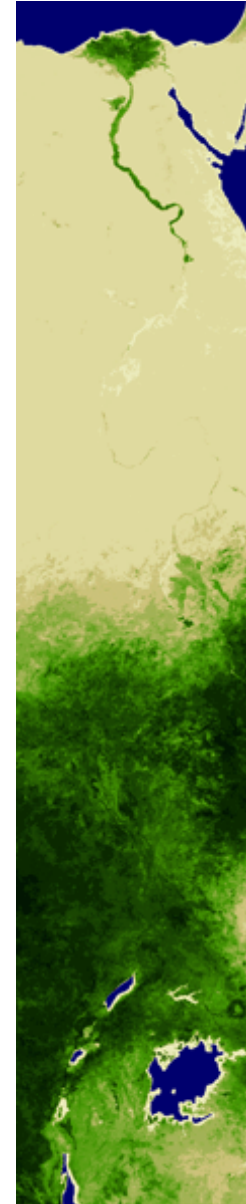
NDVI difference images easily track changes in the amount of biomass for a particular period relative to the historical average or a previous year (Minamiguchi, 2005). Thus the technique highlights areas with comparatively reduced or increased plant growth.

The NDVI difference image ($NDVI_{diff}$) between two time periods is calculated by subtracting the NDVI image of the earlier time period ($NDVI_1$) from the time period of interest ($NDVI_2$):

$$NDVI_{diff} = NDVI_2 - NDVI_1$$

FIGURE 2

NDVI image received from the Spot Vegetation instrument. The NDVI image has been color coded. Bare land is shown in ochre and the intensity of green tones increases as more vigor the vegetation cover is.



Often average images are favored to monitor vegetation anomalies because these images normalize annual variations in plant growth. Thus, average images represent the expected growing cycle. The comparison between the year of interest and the historical average allows for the identification of actual anomalies rather than erratic changes between two single years.

4.2 NDVI time series charts

While NDVI difference images monitor the spatial distribution of vegetation anomalies for a selected time period, NDVI time series charts are an efficient means to monitor vegetation biomass in a defined area (zone) over a longer period of time (Minamiguchi, 2005). This approach extracts zonal NDVI average values from each image from the time series and visualizes these values as a chart. This annual graph can be compared to an average trend calculated from a historical archive. Vegetation anomalies can be detected and evaluated whether they are of erratic kind or whether are aligned in a trend of long-term change.

The zones, for which average NDVI values are calculated, can represent crop areas, administrative units or areas with similar spatial and temporal characteristics (Minamiguchi, 2005; Snijders *et al.*, 2002). Following the last approach, the Food and Agriculture Organization (FAO) recently classified an extensive archive of Global Area Coverage (GAC) NDVI images to create homogenous zones for the whole African continent. The analysis resulted in the generation of approximately 400 zones with homogenous spatial variability and temporal development. In addition, these zones are country based and they are aligned to geographic features (Snijders *et al.*, 2002). In the present study, the calculation of NDVI average values is based on these African zones.

5 Dataset

For this study, monthly NDVI images and monthly average images were selected to monitor the agricultural biomass in the Nile basin. These selected images consisted of Global Area Coverage (GAC) NDVI images acquired by the AVHRR sensor with a spatial resolution of 7.6km, onboard the NOAA satellite.

The Food and Agriculture Organization of the United Nations (FAO) holds an extensive archive of GAC NDVI images. Since 1982, new images are added to the archive every 10 days. Monthly NDVI images, representing the maximum NDVI value per pixel measured during the month, are frequently computed from incoming dekadal images. In addition, dekadal and monthly average images are generated at regular intervals from the archive. Such a database is a valuable source of information for an immediate and up-to-date assessment of vegetation development, and also for the long-term monitoring of possible biomass changes.

6 Results

Based on the GAC archive, NDVI difference images and NDVI time series charts were generated for three different regions in the Nile basin. Difference images were calculated for the ‘seeding’, ‘peak’ and ‘harvest’ season. In addition, NDVI charts were generated to assess vegetation anomalies during the 2000 growing season in context with the long-term development of biomass in the area.

6.1 Nile Delta

The Nile Delta is located in the northern part of Egypt, where the Nile river flows into the Mediterranean Sea. At the apex of the Nile Delta is the city of Cairo, and from here extends northwestwards 160 km to Alexandria and northeastwards 150 km to Port Said. There is a complex pattern of tributaries and channels in the delta but two of them are dominant, the Rosetta Branch in the west and the Damietta Branch in the east. Many of the minor channels have been canalized and additional channels have been built. Waterway engineering works have been carried out to provide both irrigation water for the fertile delta farms and efficient drainage. Much of the delta is an extremely important agricultural area.

FIGURE 3

Nile Delta and location of the observed zone



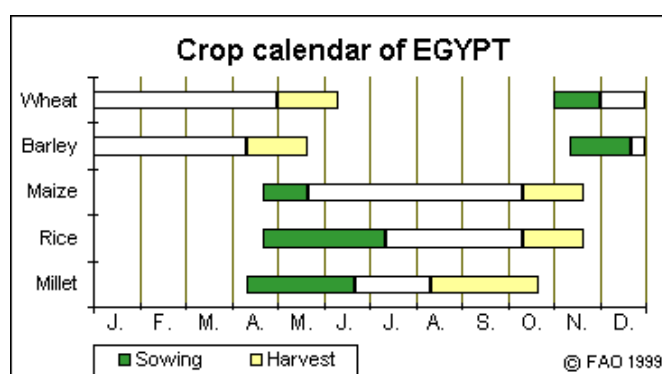
6.1.1 Agricultural activities

Conditions are favorable for the cultivation of rice and rice fields are found within the whole Nile Delta. In addition, farmers cultivate barley, maize, pulse, sorghum and wheat in the delta as well as further south till the Aswan High Dam.

Throughout the Nile Delta agricultural cultivation follow two growing season (Figure 4). One over the summer and another over the winter months. The first cycle starts at the end of April with the sowing of rice and maize, which is then harvested in October/November. Grain like barley and wheat are cultivated during the second growing cycle. Seeding takes place in November/December and harvest starts in April.

FIGURE 4

Crop calendar of Egypt (source: GIEWS Workstation)



6.1.2 NDVI difference images

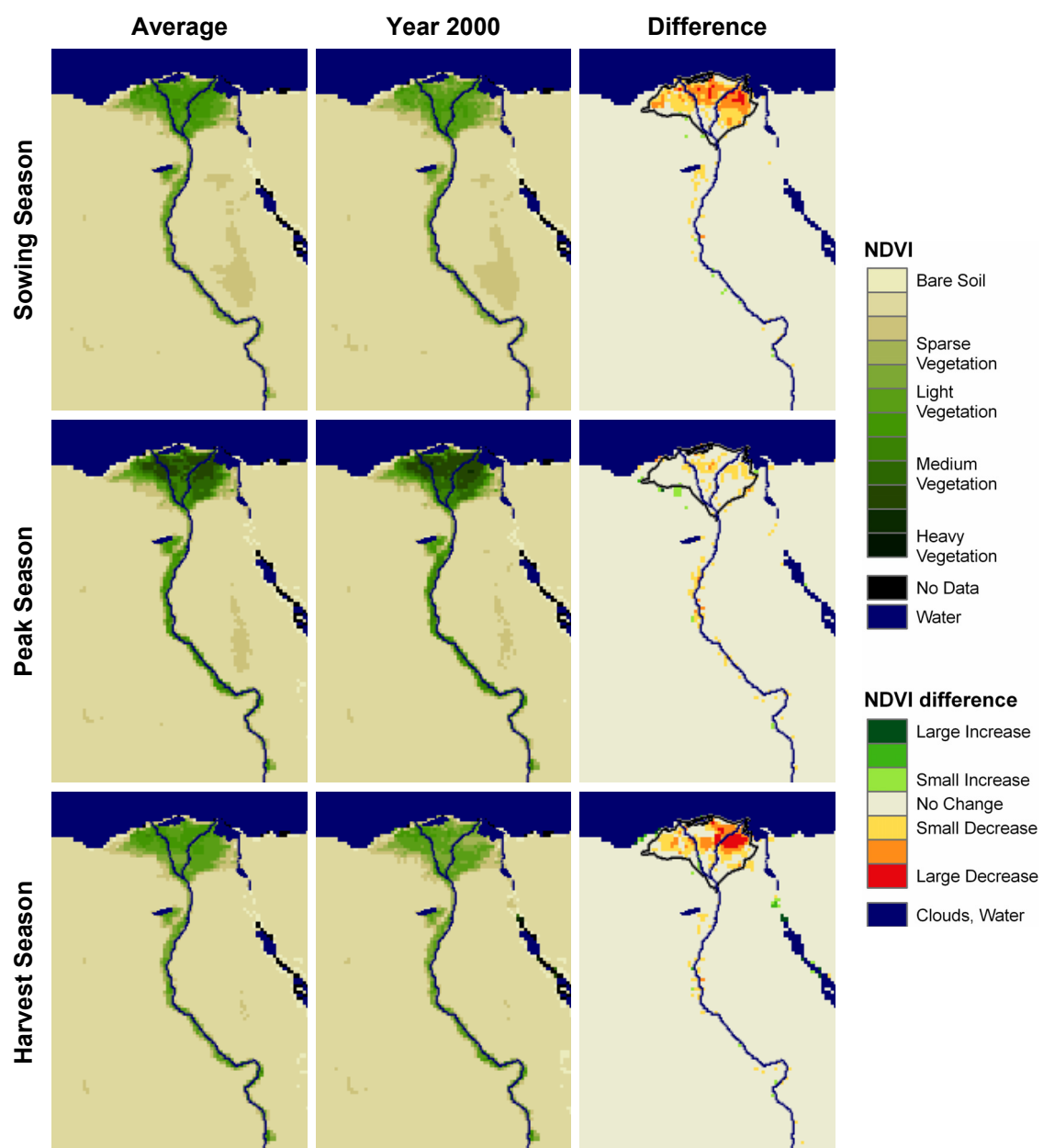
NDVI difference images were calculated for the summer growing season (Figure 5).

During the sowing season in May, visual comparison of the NDVI images shows little difference in vegetation vigor between the year 2000 and the long-term average (Figure 5, sowing season). However the NDVI difference image depicts a slight to severe decrease of vegetation for large parts of the Nile delta. On average the calculated NDVI value was 0.03 below normal, which corresponds to approximately 9% less vegetation vigor for the entire delta. Due to favorable rains, a slight recovery in vegetation growth and vegetation vigor can be seen during the peak season. (Figure 5, peak season). Lack of subsequent rainfall during the harvest season, diminished the growing conditions as can be seen in the NDVI difference image (Figure 5, harvest season). By October 2000 there was circa 10% less vegetation vigor in the whole Nile delta than in a normal year.

Attention should be given to this region in respect to possible yield loss. Field observation and/or validations by local experts are essential to assess the gravity of the situation. This is also necessary because NDVI images do not distinguish between agricultural and natural vegetation.

FIGURE 5

NDVI difference images for the Nile Delta evaluating the growing season in 2000

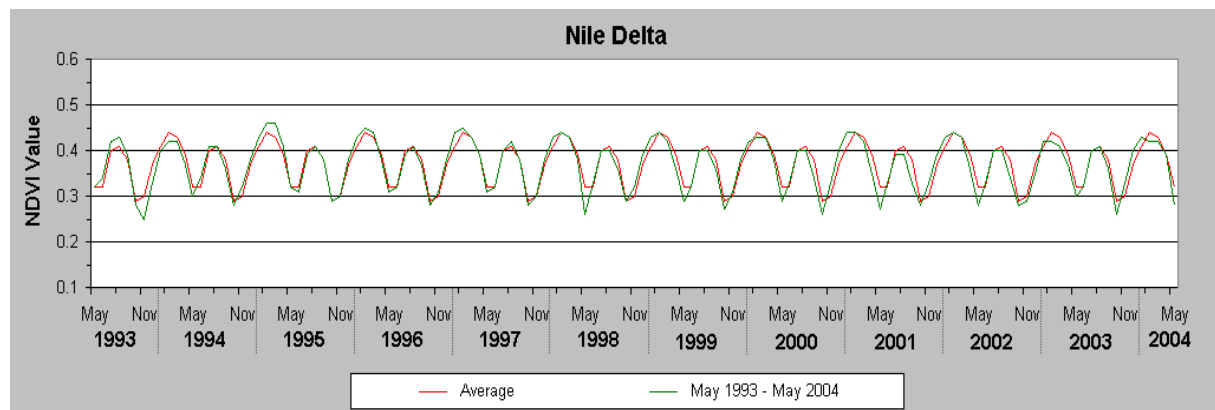


6.2 NDVI time series chart

The NDVI time series chart clearly illustrate the two annual growing seasons in the Nile Delta. It also indicates that the vegetation period is longer and with a denser plant cover during the winter period then in the summer.

FIGURE 6

NDVI time series charts for the Nile Delta (1993-2004)



The NDVI difference images depicted already a reduced amount of vegetation for the beginning of the 2000 summer season. The NDVI chart show the same picture and in the month May the NDVI lays 0.3 values below the average. The graph illustrates that in the following two months vegetation evolves normally in the delta. Still, lack of rainfall results in lower than average NDVI values during the peak season in August and vegetation vigor does not recover till harvest. By October the NDVI value is 0.3 below the expected value, which corresponds to approximately 10% loss of vegetation vigor for the whole Nile Delta compared to a normal year.

In general the vegetation growth cycles of the last 10 years follow a normal vegetation pattern, but the graphs also indicate slight shifts between the two growing seasons. Apparently, vegetation emerges and declines earlier than in previous years. In addition, there is also a tendency of a decreasing amount of biomass during the vegetation breaks in May and October (1993 and 1998-2004).

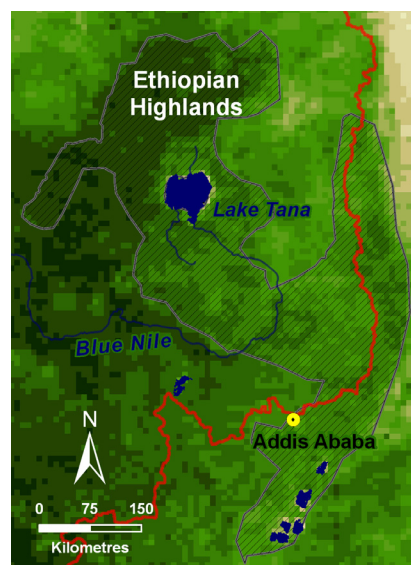
6.3 Ethiopian Highlands

The Ethiopian highlands are located in the northwestern part of Ethiopia. The topography encompasses high and rugged mountains as well as the flat-topped plateaus around Lake Tana.

Rainfall in Ethiopia is highly erratic, and most rain falls with very high intensity, extreme spatial distribution and temporal variability. For this reason there is a very high risk of annual droughts and inter-seasonal dry spells in Ethiopia.

FIGURE 7

Ethiopian Highlands and location of the observed zone



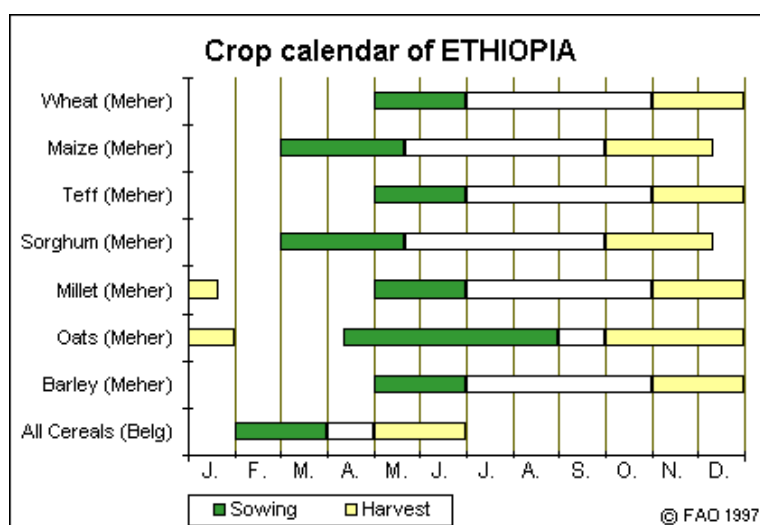
6.3.1 Agricultural activities

The Ethiopian highlands are intensively used for agriculture. The cultivation of crops like barley, wheat, sweet potato, millet and teff is widespread and there are fields of sorghum and maize along the highland border areas.

In western Ethiopia we find a single growing period and one rainy season. It is known as the Meher season (Figure 8). The planting season begins in early February and continues till August, where most crops are sown in May. In September vegetation is fully developed and harvest season lasts from the beginning of October till the end of January.

FIGURE 8

Crop calendar of Ethiopia (source: GIEWS Workstation)

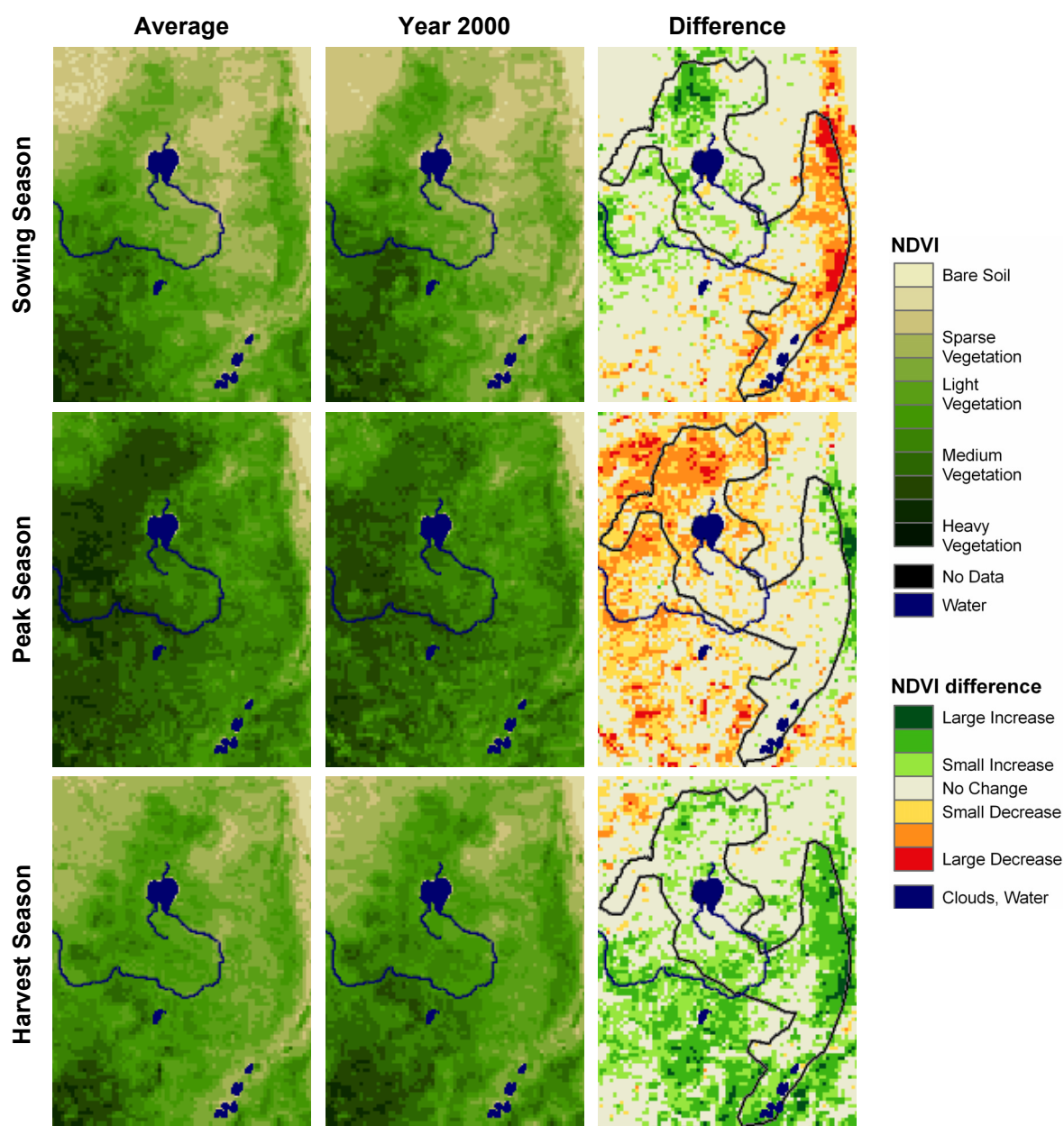


6.3.2 NDVI difference images

The Ethiopian highland growing cycle from May till December is depicted in Figure 9. As illustrated by the crop calendar (Figure 8) sowing of most main crops starts in the month of May. In September vegetation growth reaches its peak and harvest season last from October till January.

FIGURE 9

NDVI difference images for the Ethiopian Highlands evaluating the growing season in 2000



In 2000 the growing season of the Ethiopian highlands starts with a distinct difference between the west and east highlands (Figure 9, sowing season). Higher than normal amount of vegetation biomass can be seen in the western and central regions, while lack of rainfall has led to unfavourable growing conditions in the eastern regions.

The situation of vegetation growth in the plateau region changes drastically in the peak season. Previously well developed vegetation vigor in the western regions suffer from low rainfall, which is visible in the difference image. Contrary to the western part, the situation in the east is much improved with normal vegetation growth.

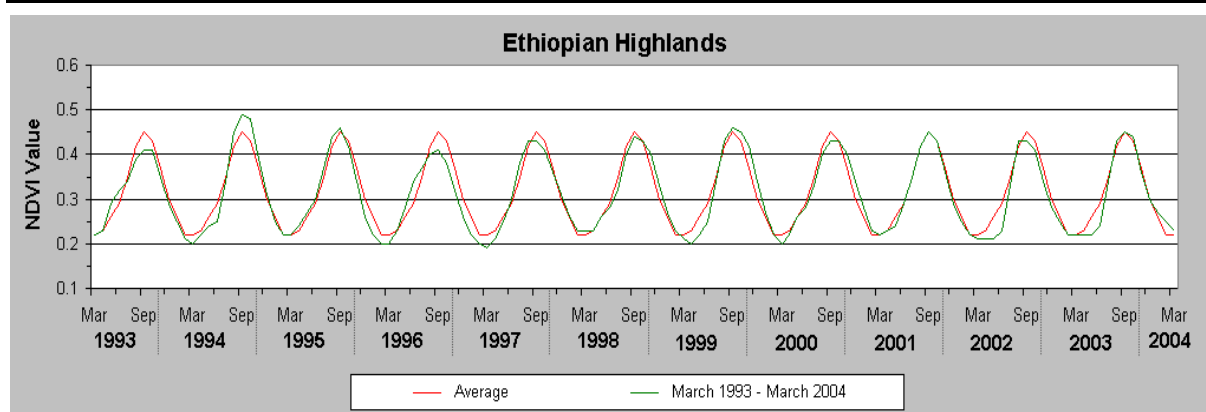
Vegetation growth recovers fully in December and the difference image also indicates a higher-than normal amount of biomass throughout the plateau.

6.4 NDVI time series charts

NDVI time series charts (Figure 10) clearly show the single vegetation cycle throughout the Ethiopian highlands. In a normal growing period, the amount of vegetation biomass is very low (average NDVI 0.23 in February/March) but vegetation emerges slowly but gradually during the subsequent months. Peak season is short (average NDVI 0.45 in September) and vegetation vigor declines steadily afterwards.

FIGURE 10

NDVI time series chart for the Ethiopian Highlands (1993-2004)



There are no extreme vegetation anomalies evident from the NDVI graph for the 2000 growing season (Figure 10). NDVI values are below average during the growth peak in September. However, the graph shows a longer prolonged vegetation period with higher than normal NDVI values during the harvest season from October till December.

The vegetation anomalies of the seeding and peak season, which were visible from the NDVI difference images, are not clearly depicted by the NDVI chart. Because the graph visualizes the regional NDVI average for each time step, different states of vegetation vigor within the region are leveled out during the calculation of the average. It emphasizes that information gained from NDVI difference images and NDVI charts are complementary. While difference images draw a better picture of the spatial distribution of vegetation anomalies for selected time periods, NDVI charts are favourable for the continuous monitoring of vegetation vigor.

The graph shows that the growing cycle in the Ethiopian Highlands is frequently affected by erratic, short-term changes. The year 1994, for example, was an extremely

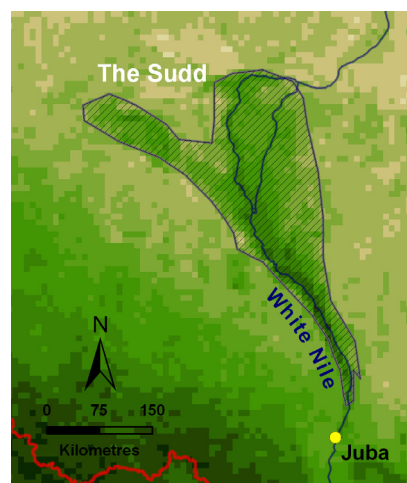
favorable year with circa 12% increased vegetation vigor in the month October. Instead, unfavourable growing conditions resulted in a severe loss of vegetation vigor in the preceded year as well as two years later. In general, the annual graph shows that there is the tendency of a late start of the growing season. This is especially well visible for the years 2002 and 2003.

6.5 The Sudd

The Sudd is a vast swamp in southern Sudan. Its size is variable, but during the wet season it might be over 130,000 km² in area. The swamp is fed by three main waterways; the Bahr el-Jebel, the Bahr el-Ghazal, and the Bahr el-Zaraf, which are all headwaters of the Nile. Thick aquatic vegetation (sudd) disperses the river water into numerous channels. About half of the water is lost through evapotranspiration and absorption before leaving the Sudd.

FIGURE 11

The Sudd and location of the observed zone



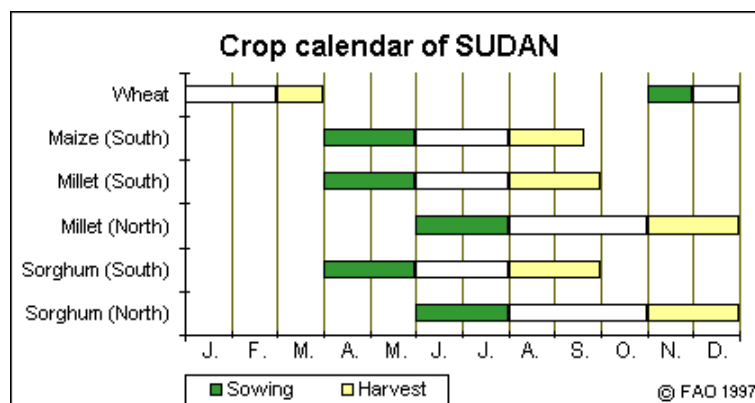
6.5.1 Agricultural activities

Due to the extensively flooded area, the Sudd is favorable for the cultivation of rice. Beside millet and maize it is particularly rice that is grown in the region.

Sudan has mainly one growing season that is slightly shifted between the north and the south of the country (Figure 12). In the Sudd, the crop growing season lasts from April till September. The vegetation cycle begins 2 months later in the North. The major limiting factor in Sudan is not the agricultural potential, but the short duration of the rainy season and the erratic distribution of rainfall during the growing period.

FIGURE 12

Crop calendar of Ethiopia (source: GIEWS Workstation)

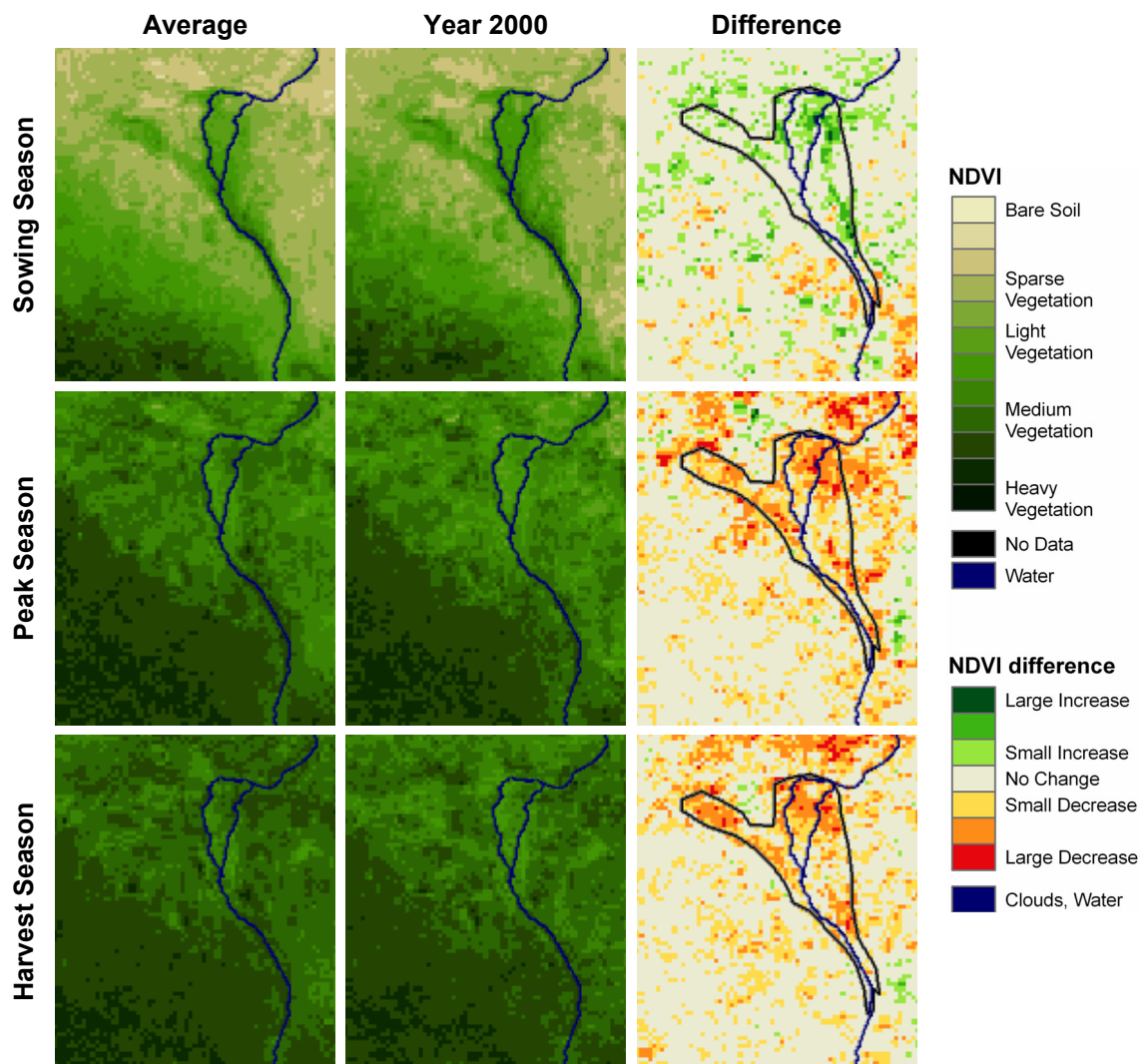


6.5.2 NDVI difference images

Three critical times of the growing season were selected representing the seeding, the peak and the harvest period. For each period the NDVI image, the average image and the difference image between the two were calculated. Areas with higher-than normal vegetation vigor are depicted in green colors, while areas with lower-than normal conditions are shown in red. The difference images show a distinguished growing situation for different parts in the Sub-Sahel region (Figure 13).

FIGURE 13

NDVI difference images for the Sudd evaluating the growing season in 2000



Southern Sudan seeding starts at the beginning of April and vegetation biomass is well developed during this period (Figure 13, sowing season). The amount of healthy vegetation is approximately 9% higher than in a normal year. However, while there are favorable growing conditions in the Sudd the southeastern regions show a low vegetation response.

The growing conditions change drastically at peak season in July. The region suffers from inadequate rainfalls and reduced water supply by the Nile waters. Consequently plant

growth was reduced and there is a decreased amount of biomass (ca. 9%) in comparison to a normal year (Figure 13, peak season).

Negligible improvement is noticeable during the harvest season in September. The entire region suffered from low water supply. The decrease of healthy vegetation amounted to circa 6% at the time of harvest. The orange colors in the difference image might indicate a loss of crop yield for the Sudd in 2000. Final field observations are necessary to assess the extent of affected crops.

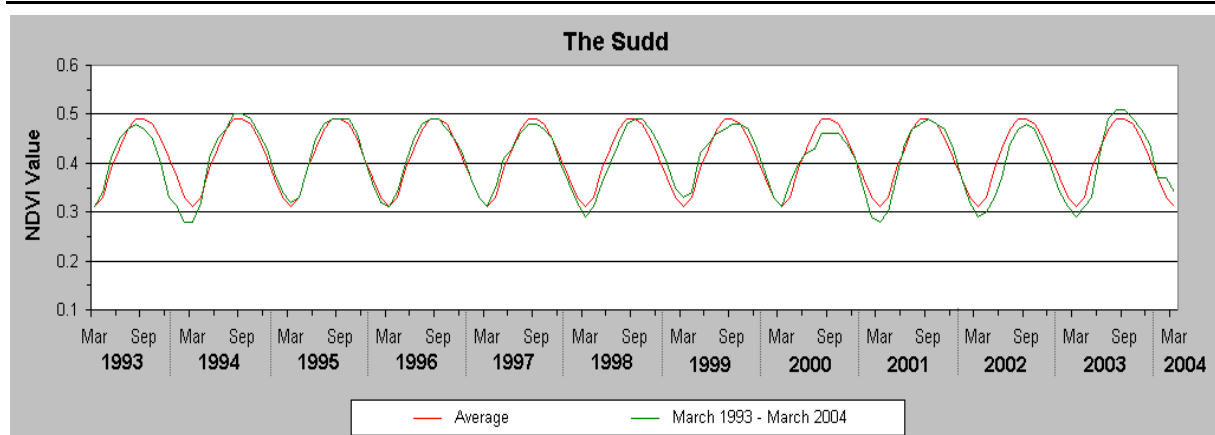
6.6 NDVI time series charts

The NDVI chart of the Sudd shows the development of NDVI values from March 1993 until March 2004. The single, annual growing cycle begins and ends in March, when plant cover is less developed. Vegetation emerges gradually during the following months and is fully developed in August and September.

The Sudd gives an example where the peak of the crop growing cycle (July) does not correspond to the general vegetation peak in August/September. The reason lies in the different growing cycles between crop and natural vegetation. The Sudd is a vast swamp area with a dense cover of aquatic plants. Because the NDVI graph cannot distinguish between different vegetation types, the longer growing cycle of the natural vegetation superimposes the shorter crop growing cycle in the NDVI chart. Therefore, while the natural vegetation is developed fully the crop harvest season has started already (September).

FIGURE 14

NDVI time series chart for the Sudd (1993-2004)



As the difference images have shown the 2000 growing season started with favorable conditions. In April 2000 the NDVI lays 0.03 values above the average, which corresponds to circa 9% more vegetation vigor in the Sudd than in a normal year. The situation stays favorable till mid May, but then a lack of rainfall causes a stagnation of plant growth. The NDVI graph shows well that vegetation evolves hardly in the Sudd during June and July (NDVI values 0.42 and 0.43 respectively). It means that during the crop peak season the

amount of vegetation vigor is circa 9% below the expected value. Vegetation is emerging till the harvest in September, which is shown in an increase of the NDVI graph, but it cannot recover fully, and there is approximately 6% less biomass in the Sudd during the harvest season.

In the long-term perspective the NDVI time series shows a relative stable cycle of growing seasons between the years 1993 and 2004. But the graph illustrates as well the immediate effect of rainfall on the amount and vigor of vegetation. The years 1993, 2000 and 2002 show a lower than normal vegetation index for most parts of the growing season. The lack of rains in these years caused a drop in the amount of healthy biomass. Instead there had been good rainfalls in the growing season 2003/2004 leading to favorable growing conditions in the region.

7 Conclusions

In this study we analysed GAC NDVI time series imagery from the NOAA satellite to monitor the development of biomass in the Nile basin for the year 2000. Therefore, two complementary techniques were applied. With the help of NDVI difference images, calculated between a long-term average NDVI and the year of interest, the spatial distribution of vegetation anomalies could be detected and vulnerable areas highlighted. Attention has to be given to cultivated areas with low vegetation response in respect to possible food shortages after harvest.

Instead, NDVI time series charts provide insight into the long-term development of biomass in a selected region. It is a valuable tool to visualise the current growing cycle in the context to preceding years and to define whether the current vegetation anomaly is of erratic kind or whether a trend of vegetation vigor change can be detected over the years.

For the generation of the NDVI graphs the selection of the zones, for which statistics are calculated, play an important role. When the terrain or the landscape within one zone is very heterogeneous, say with part desert and part forest covered mountain, the extracted average value makes little sense. The high value of the mountains is leveled out by the low values of the desert. Important changes in for example the desert will not be discovered when looking at the statistical trend, because the forest part has such a big impact on the extracted average. This effect often happens when extracting zones based on political boundaries.

It is important to note that NDVI images do not distinguish neither between different vegetation types nor between cultivated and natural vegetation. NDVI images help identify vulnerable areas. In addition, knowledge of the crop calendar and location of growing areas for the different crop types can help analyse the images and trace vegetation that might be affected by a loss of vegetation vigor. However, it is essential to validate findings from the images by field observations or local expert knowledge to assess the gravity of vegetation loss on cultivated land.

Glossary

Cold Cloud Duration (CCD) images are a means to estimate precipitation, and high cold cloud duration over an area indicates the likelihood that significant rainfall has occurred. The CCD data are used to trace the evolution of the rainy season on a 10-day and cumulative basis from the start of the season through harvest. Dekadal and monthly CCD images for Africa are processed at FAO from data of the European METEOSAT instrument.

Global Area Coverage (GAC) NDVI images are produced from data collected by the Advanced Very High Resolution Radiometers (AVHRR) sensor onboard of the NOAA satellite. The GAC NDVI images have a spatial resolution of 7.6 km and are provided to GIEWS every 10 days. FAO's archive of GAC NDVI images dates back to 1982.

Global Information and Early Warning System on Food and Agriculture (GIEWS): In the working environment of the Food and Agriculture Organization (FAO) of the United Nations, satellite images are an integrated part of the Global Information and Early Warning System on Food and Agriculture (GIEWS). Since its inception in 1975, GIEWS has provided policy makers and policy analysts with the most up-to date and accurate information available on all aspects of food supply and demand. The GIEWS warns of any imminent food crises and shortages, droughts and hunger at individual country or sub-regional level. Timely interventions can then be planned by relief agencies and donor organizations, and suffering in the affected countries avoided.

GIEWS makes use of low resolution satellite images to survey the current risk of drought and food insecurity all over the world. This effort is supported by analysing Normalized Difference Vegetation Index (NDVI) images, to assess the vegetation canopy, as well as by analysing Cold Cloud Duration (CCD) images, to assess the likelihood of rainfall. The CCD and NDVI imagery have been proven to be useful for early warning and for drought and crop monitoring over large arid and semi-arid areas. Information extracted from these images is used to corroborate field reports, and to substitute agro-meteorological information normally used to estimate crop yields. The images further provided a cost-effective and efficient solution for monitoring the current seasons. It allows GIEWS's crop assessment mission teams to effectively identify areas suffering from low rainfall and drought, and to timely schedule their field missions accordingly.

Since 1998, FAO has been acquiring the NDVI data derived from the **SPOT VEGETATION (VGT)** instrument every 10 days. The VGT imagery has a spatial resolution of 1 km. It is therefore more suitable for national and regional monitoring of major seasonal variations in vegetation patterns.

Reference

- Biard, F., D. Lepoutre:** On Line Vegetation Condition Monitoring in Europe: Agri-Quest®. A Tool That Helps Users Build Information and Value from Remote Sensing. GEOSYS. S.A. Toulouse, France. (available at <http://www.efita.net/apps/accesbase/bindocload.asp?d=5544&t=0&identjobj=0i5ZNM6f&uid=57305290&sid=57305290&idk=1>).
- FAO (2000a):** Food supply situation and crop prospects in Sub-Saharan Africa. Global Information and early warning system on food and agriculture. Food and Agriculture Organization of the United Nations (FAO), Rome. April 2000, no. 1. (also available at <http://www.fao.org/gIEWS>)
- FAO (2000b):** Food supply situation and crop prospects in Sub-Saharan Africa. Global Information and early warning system on food and agriculture. Food and Agriculture Organization of the United Nations (FAO), Rome. April 2000, no. 2. (also available at <http://www.fao.org/gIEWS>)
- FAO (2000c):** Food supply situation and crop prospects in Sub-Saharan Africa. Global Information and early warning system on food and agriculture. Food and Agriculture Organization of the United Nations (FAO), Rome. April 2000, no. 3. (also available at <http://www.fao.org/gIEWS>).
- FAO:** Gateway to national information on land, water and plant nutrition, Egypt, Nile Delta. (available at http://www.fao.org/ag/agl/swlwpnr/reports/y_nf/egypt/e_ndelta.htm)
- GIEWS Workstation:** <http://www.fao.org/gIEWS/workstation>.
- Minamiguchi, N. (2005):** The Application of Geospatial and Disaster Information for Food Insecurity and Agricultural Drought Monitoring and Assessment by the FAO GIEWS and Asia FIVIMS. Prepared for: Workshop on Reducing Food Insecurity Associated with Natural Disasters in Asia and the Pacific. Bangkok, Thailand, 27-28 January 2005. Food and Agriculture Organization of the United Nations (FAO), FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.
- Snijders, F., R. Giaccio, J. Ticheler & Y. Nicolarea (2002):** Bringing Africa to the Desktop: The ARTEMIS Charting Applet. Sustainable Development Department (SD), Food and Agriculture Organization of the United Nations (FAO), Rome. (available at http://www.fao.org/sd/dim_en2/2001/2002/aca-article/aca_p3.htm).
- Snijders, F., R. Giaccio, J. Ticheler & Y. Nicolarea (2003):** Twenty one years of satellite derived vegetation index and rainfall-related data for Africa. Sustainable Development Department (SD), Food and Agriculture Organization of the United Nations (FAO), Rome. (available at http://www.fao.org/sd/2003/ACA21/t21_yr_p1.htm).