Tracking the Genocide in Darfur: Population Displacement as Recorded by Remote Sensing

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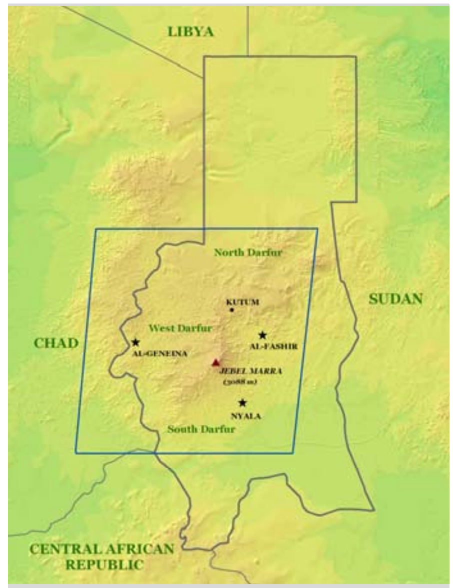
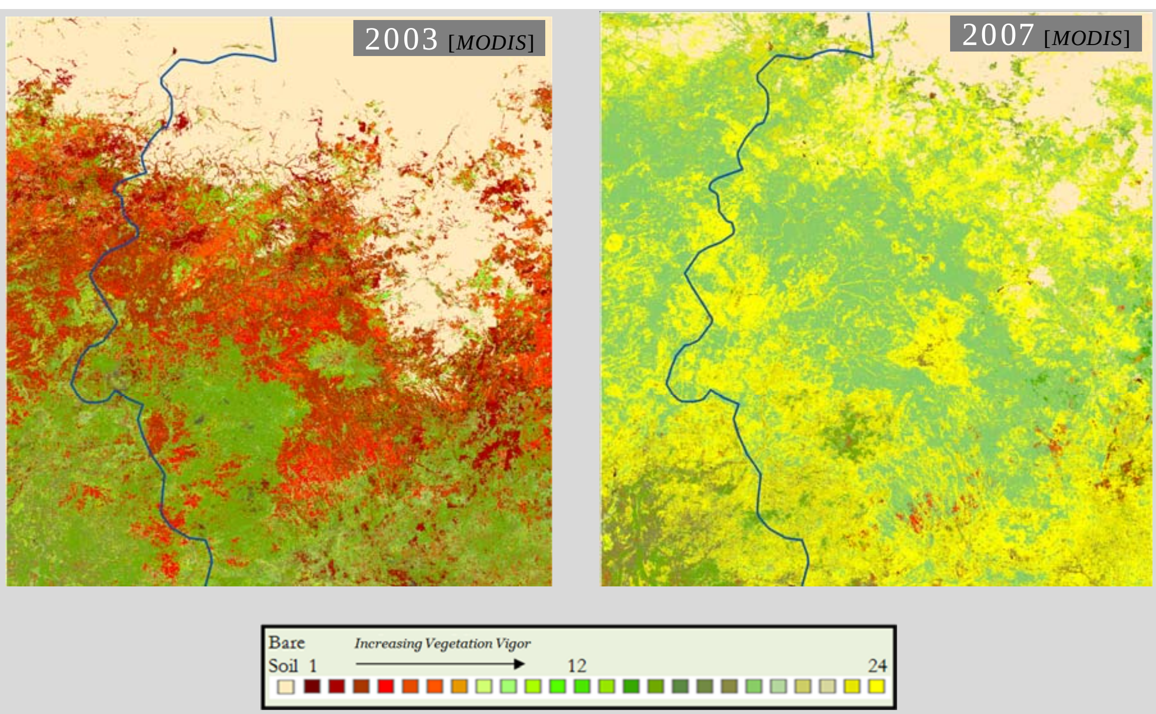
Using two independent satellite imagery products, *MODIS Terra* and *SPOT Vegetation* this paper documents change to land cover, primarily vegetation from 1998 through 2007 in the regions of Darfur most impacted by the genocide since 2003. Its findings show a steadily increasing return of natural vegetation coverage and vigor, likely grasses and shrubs, in formerly agrarian and livestock grazing ranges, since 2004. This environmental recovery is demonstrably not a result of increased rainfall, but of the abrupt change in land use directly related to the systematic violence committed by Sudanese government and militia forces against the peoples of Darfur. In an agriculture-based society, this vegetation rebound resulted from the loss of livestock and the inability to farm, caused by human displacement and the destruction of subsistence resources from 2003 to 2007.



Research area outlined in blue



Vegetation classifications showing increasing health or vigor predominantly of grasses and shrubs by 2007

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PART I

Introduction

In May 2004, the U.N. High Commissioner for Human Rights issued the report *Situation of human rights in the Darfur region of the Sudan*.[1] Among its findings: there have been repeated attacks on civilians by the military forces of the Government of the Sudan and its proxy militia, the *Janjawiid*; the pattern of attacks on civilians includes killing, rape, pillage, looting of livestock, and destruction of property; and there has been massive, often forced, displacement of much of the population of Darfur. In July 2004, a 7,000-member African Union Mission began to deploy there. However, after nearly four years of government sponsored genocidal violence with near impunity, on July 31, 2007, the United Nations-Security Council passed Resolution 1769, which called for the creation of a joint 26,000 UN-African Union (UNAMID) ground force to establish peace in Darfur. The Sudanese government agreed to the deployment and, on December 31, 2007, the first U.N. forces arrived in Darfur, but still face major obstructions to their operations. By early 2008, the U.N. estimated casualties in Darfur at 200,000 dead and 2.5 million displaced since 2003.[2] (Figure 1)

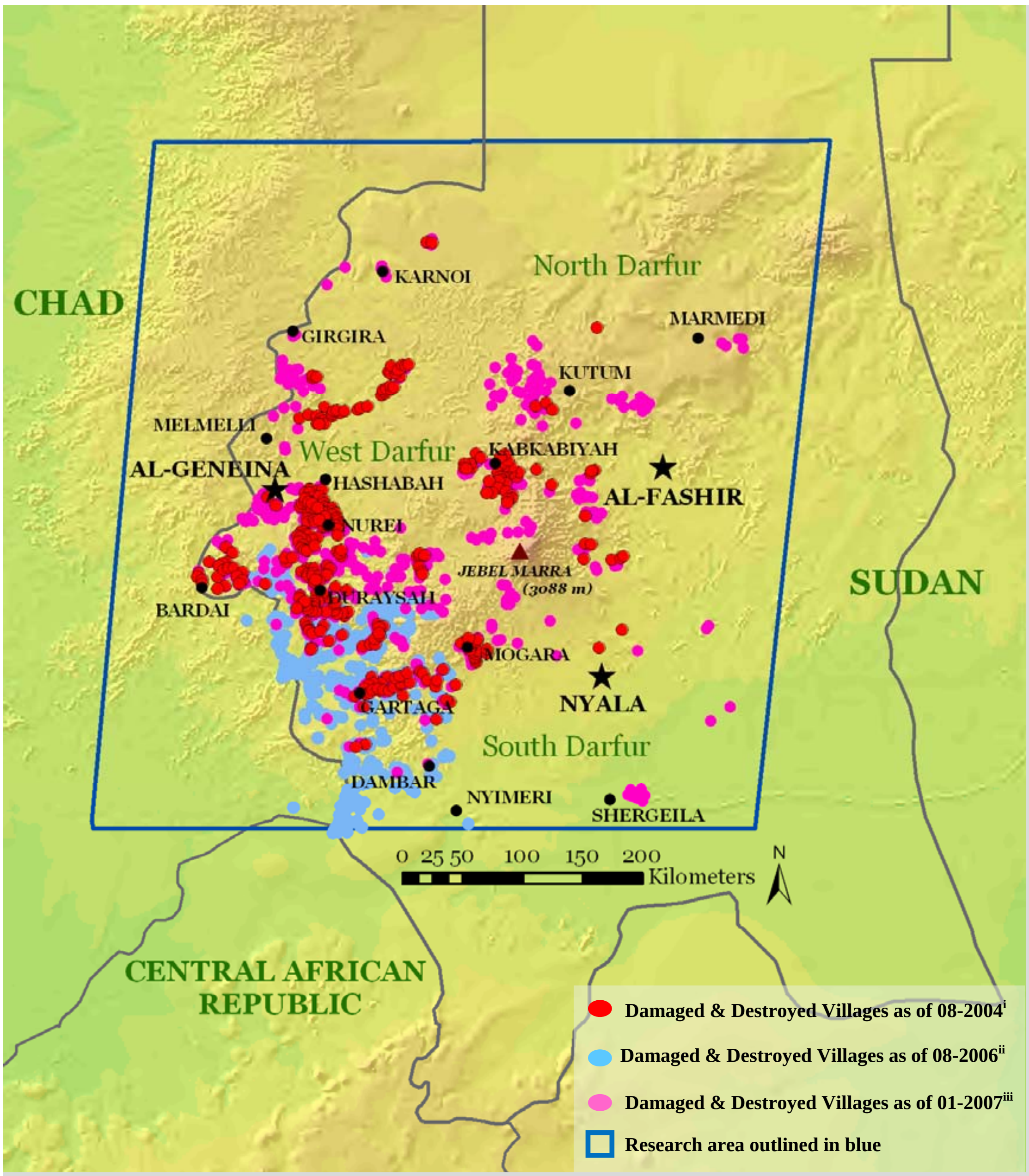
Environmental stress can precipitate and facilitate genocide. It can also testify to the effects. Remote sensing applications can measure the health and vigor of vegetation and availability of water, as well as the speed of environmental recovery, and judge the stress humans and their activities place on the environment. Three factors often stated as precipitating the genocide in Darfur are oil, climate, and competition among ethnic groups for declining available resources, e.g., water and livestock grazing ranges. Because agriculture and livestock grazing are historically dominant economic and subsistence activities in Darfur, abrupt and dramatic disruptions to these normal patterns of land use should necessarily be evident in changes to land cover. Although the declining and fluctuating rainfall can also influence long-term changes and adaptations to land use, systematic violence intended to disrupt these systems can have much faster and more dramatic impacts. These are observable by remote sensing.

Research Method

Approach

The primary research goal was to use remote sensing as a tool to detect trends in land cover change—natural, agricultural, and pastoral—directly related to changes in land use as a result of genocidal activities since 2003 in Darfur. Since 2003, the inability of international organizations to gain consistent on-ground access to the more devastated areas within Darfur and report on the large-scale consequences has resulted in an unclear understanding of changes to the environment. This paper provides a broader understanding, both spatially and temporally, of the devastation of sedentary communal agricultural and semi-nomadic pastoral systems in Darfur.

The research area of approximately 361,000 km^2 covers those regions of North, West, and South Darfur experiencing the highest impact of reported violence since the genocide began in 2003 (Figure 1). Using remote sensing, we measured temporal change in land use from 1999 through 2007 based on vegetation spatial coverage, vegetation vigor, and vegetation phenology; and annual rainfall from 1998 through 2007. We used two satellite imagery products to measure change in land cover, *MODIS Terra* and *SPOT Vegetation*, and one to measure annual rainfall, *TRMM*. The remote sensing application *Normalized Difference Vegetation Index* (NDVI) was the primary means for measuring land cover change and vegetation health. Applying the remote sensing findings, Part II of the research attempts to integrate related ancillary data, using Global Information System (GIS) techniques, with the remote sensing findings. The goal is to establish contextual correlations between land cover changes and their temporal and spatial relation to documented reports and locations of genocidal activities, refugee camps, and oil concessions.



Locations of reported *Damaged & Destroyed Villages* 2004-2006

[i] HIU—Humanitarian Information Unit-U.S. Department of State, 2004; [ii] INTERSOS—Organizzazione Umanitaria Per L'Emergenza, 2006; [iii] U.S. Holocaust Memorial Museum and the American Association for the Advancement of Science, 2007

Research Hypothesis

If human actions cause a primarily agrarian society to experience an abrupt and dramatic disruption to annual crop and pastoral grazing cycles, it should be possible to track these changes using remote sensing through satellite imagery and to distinguish them from any environmental stress due to fluctuations in annual rainfall characteristic of drought conditions.

Based on the climatic, economic, and sociocultural patterns existing in Darfur prior to the 2003 genocide, the following research assumptions were suggested:

1. All other factors equal, changes in natural vegetation (measured in NDVI) will parallel fluctuations in rainfall and will maintain a natural balance based on water availability.
2. Livestock grazing will reduce NDVI vegetation vigor, regardless of water availability.
3. Wet-farming (irrigation) cultivation in a region previously used for grazing or not cultivated will increase the NDVI vigor almost immediately, but this will occur in localized areas near fluvial systems.
4. A reduction in livestock grazing will stimulate a rebound in natural vegetation vigor, but this is usually delayed several years.
5. The displacement of people and the gradual decline of livestock in a region are uniquely related.

Research Materials: Satellite Imagery

Assessing Annual Land Cover and Land Use Change with MODIS Terra 2000-2007

The Moderate-resolution Imaging Spectroradiometer (MODIS) was used to measure temporal change in vegetation vigor and coverage from 2000 through 2007, and create land cover classifications based on 24 phenology classes 2000-2007. The NASA satellite carrying *MODIS Terra* was launched in December 1999. The imagery has a 250 m spatial resolution (.0625 km^2 pixel size) and a spectral range in the visible and near-infrared portions of the electromagnetic spectrum. For this research, MODIS data sets comprised eight total stacks of 23 individual scenes, each stack comprising temporal coverage of one calendar year—one scene acquired per approximately sixteen-day period. The eight stacks represent uninterrupted temporal coverage from 2000 through 2007.

Assessing Annual Land Cover and Land Use Change with SPOT Vegetation 1999-2007

Le Système Pour l'Observation de la Terre (SPOT) was used to test *MODIS Terra* findings 2000-2007 by showing temporal change in vegetation vigor and coverage for 1999-2000. The *SPOT Vegetation Instrument* system on the French CNES, SPOT 4 satellite was launched in March 1998. The imagery has an 1165 m spatial resolution (1.36 km^2 pixel size) and a spectral range in the visible and near-infrared portions of the electromagnetic spectrum. For this research, SPOT data sets comprised nine total stacks of 36 individual scenes, each stack comprising temporal coverage of one calendar year—one scene per approximately ten-day period. The nine stacks represent uninterrupted temporal coverage from 1999 through 2007.

Assessing Annual Climate Change with TRMM 1998-2007

The *Tropical Rainforest Measuring Mission* (TRMM) was used to calculate and graph annual rainfall data for the research area from 1998 through 2007. The NASA satellite carrying the *TRMM Precipitation Radar* was launched in November 1997. The data has a spatial resolution of approximately 16 km^2, and collects microwave measurements; the satellite makes multiple passes daily. For this research, TRMM data sets comprise daily rainfall data with temporal coverage charted from calendar day 101-290 (April through mid-October), the rainy season in Darfur, which triggers general vegetation growth and parallels the agricultural growing season.

Remote Sensing Applications

Normalized Difference Vegetation Index (NDVI)

NDVI is a standard remote sensing application for detecting temporal change in land cover, especially vegetation. NDVI is related to vegetation because healthy vegetation is absorbed in the 500-700 nm red visible range of the electromagnetic spectrum and reflects very well in the 700 to 1300 nm near-infrared NIR range of the spectrum (Figure 2). NDVI is derived from (NIR band - Red band)/(NIR band + Red band).

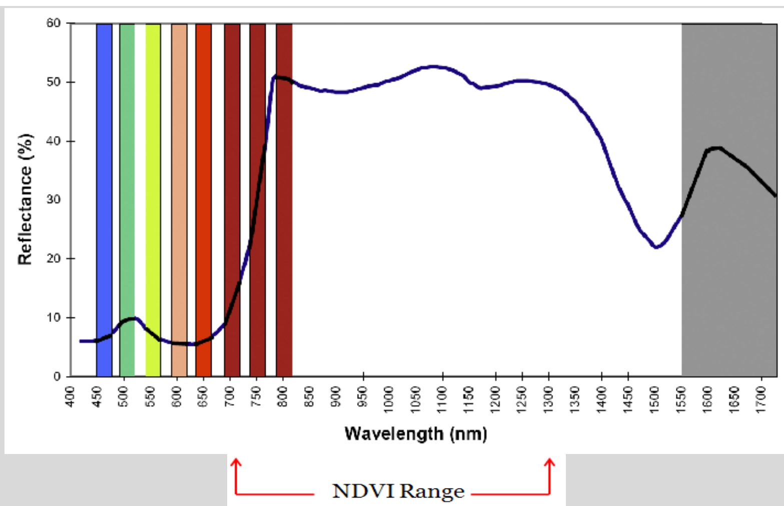


Figure 2. Spectral characteristics of healthy green vegetation superimposed over the electromagnetic spectrum[3]

Applying NDVI to Documenting Temporal and Spatial Change in Vegetation

The algorithm used to record change in NDVI was developed by Roland Geerken and is based on the Fourier classification method.[4,5] Geerken's algorithm is designed to be used with, e.g., NASA-produced *MODIS Terra* imagery, which collect electromagnetic data in the visible and near-infrared ranges and have relatively short periods between repeat passes over the same geographical position. The algorithm measures the amplitude of vegetation reflection, the spatial coverage of vegetation, and vegetation phenology—all components of measuring *biomass*. Phenology is the scientific study of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions. Although phenology does not directly relate to species, it can be used to map vegetation and help to classify vegetation types or species. Phenologies, measured as NDVI data, can provide a baseline from which to monitor changes in vegetation associated with, e.g., fire, drought, climate fluctuations, and climate change.

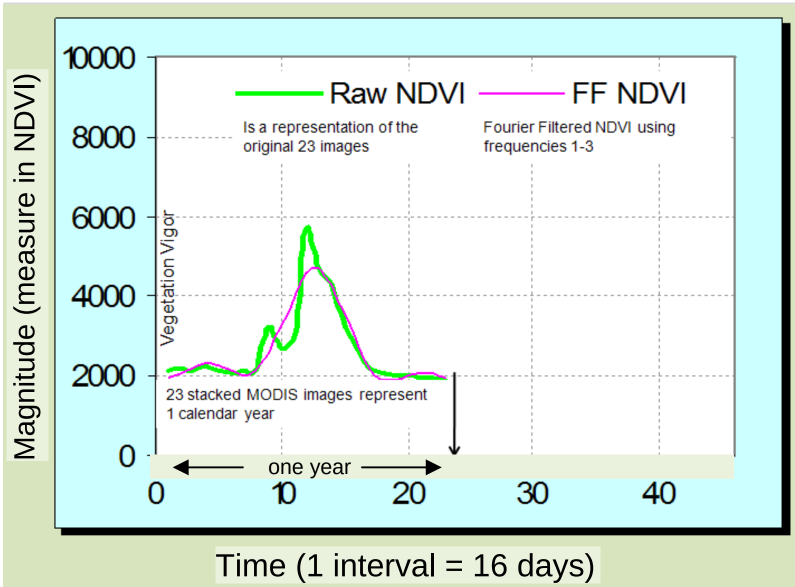


Figure 3. Example of a *Fourier* classified vegetation phenology

Geerken's classification clusters vegetation coverage according to the shapes of their annual growing cycles based on individual measurements of NDVI. The algorithm classifies an annual data set of typically 23 individual satellite scenes with spatial coverage of a single geographic area and stacked in sequential, calendrical order. A major element of the classification is the conversion of NDVI time-series from temporal space to *Fourier* space using a Discrete Fourier Transform (DFT). Like a supervised classification the technique requires the selection of reference cycles, which are used to identify NDVI-cycles of identical shape. These NDVI cycles are then smoothed by reducing the number of frequencies used to define the shape, producing the Fourier frequency, FF NDVI curve (Figure 3). The assumption is that phenology-related variations only occur in the first three to five frequencies. The actual number of frequencies used in the analysis is a function of the number of temporal intervals and data noise, e.g., sensor related, process related, atmosphere related.

Remote Sensing Findings

Climate

Darfur experiences a high variability of annual rainfall. The climate in Darfur ranges from tropical semi-arid in the north to tropical semi-humid in the south.[6] The whole zone falls between the 300 mm and 900 mm isohyets.[7] The temperate climate of the Marrah Mountains has relatively high rainfall and permanent springs; annual average rainfall is 700 mm and many trees remain green year-round.[8] Ten-year rainfall data collected for Al-Fashir indicated wide fluctuations in the annual amount, ranging from as high as 314 mm in 1994 to 155 mm in 1997, and from 377 mm in 1998 to 152 mm in 2003.[9]

The current trend of increasing temperature and decreasing precipitation began in the 1970s.[10] Records kept since 1917 show the temperature in Darfur did not exceed 37 degrees Celsius until the 1960s; in 2002, it reached a record high of 47 degrees Celsius.[11] According to official data, average rainfall in Sudan declined by 6.7 percent from 1960-69 to 1970-79, and by 17.7 percent from 1970-79 to 1980-86.[12] Since the devastating impact of drought and famine in 1984-85, Sudan has experienced droughts in 1989, 1990, 1997, and 2000.[13] Changes in rainfall patterns in the last twenty years have shortened the duration of the rainy season, which formerly lasted from May through September, and currently from June through August.[14]

Deriving Annual Rainfall from TRMM

Annual rainfall was computed for the entire research area and separately for three zones—North, Central, and South—roughly capturing the three climate zones in Darfur (Figure 4), excluding the extreme northern desert zone not part of the research area. For each zone, *total* and *mean* rainfall per calendar year were computed from statistics collected for each of the nineteen 10-day TRMM layers for each year (Figure 5). The annual rainfall for the entire research area was derived by graphing the yearly sampled aggregate mean of rainfall for each climate zone (Figure 6).

Temporally, the data show a steep overall decrease in rainfall from 1999 to 2000, which corresponds to the reported 2000 drought. But after 2000, there was no return to pre-2000 annual rainfall means. Instead rainfall remained relatively constant until 2007, when there was another dramatic decrease in mean rainfall for the entire region. Spatially, the data show the North Zone receives on average the least annual rainfall and Central Zone the highest. In the Central Zone, the Marrah Mountains region is known to have higher rainfall averages than the other two zones. In addition, the Central and South Zones show somewhat parallel and steady trends, whereas the North Zone is more sporadic. Hence, in many respects, the TRMM rainfall data correlates well with both historical and regional rainfall patterns.

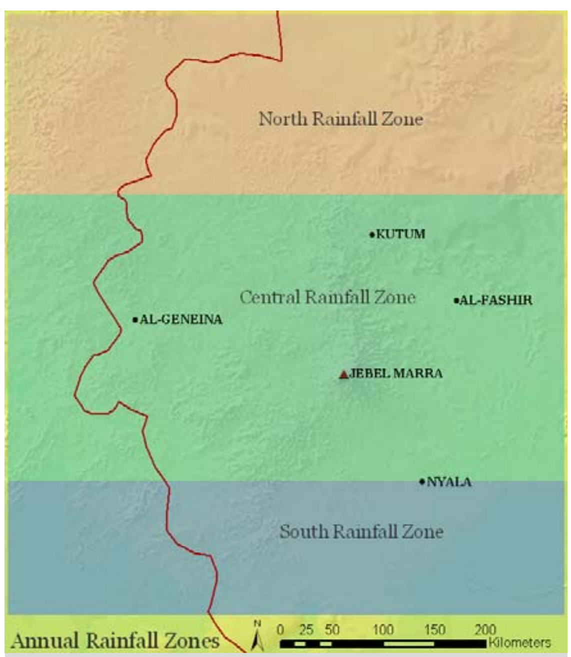


Figure 4. Rainfall Zones

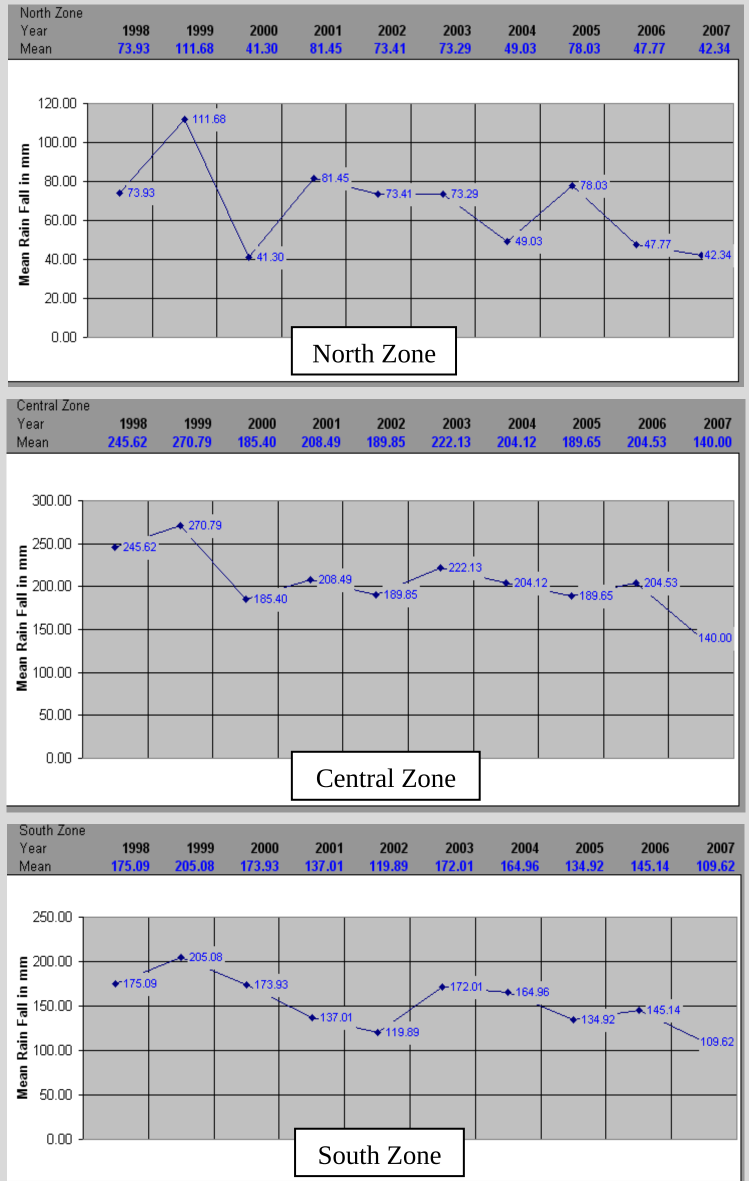


Figure 5. Annual rainfall by zone: North, Central, and South

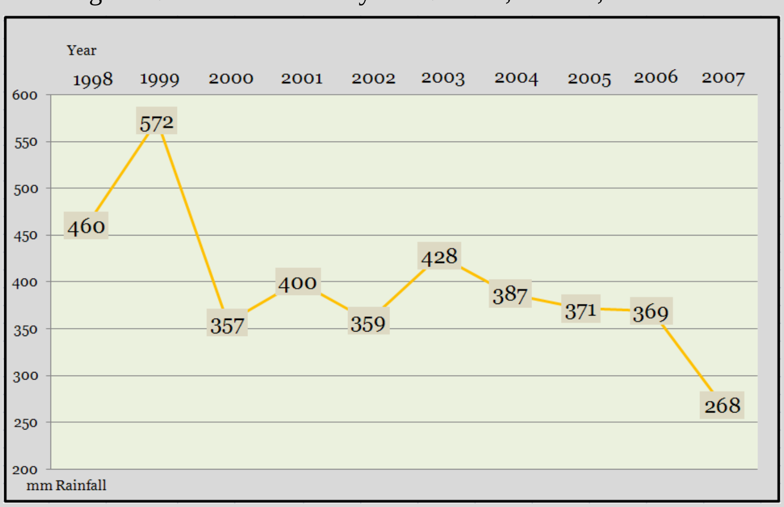


Figure 6. Annual rainfall 1998-2007 for the entire research area

Land Cover and Land Use

Traditionally, three major agricultural systems operated in Darfur: sedentary rain-fed agriculture, sedentary irrigated agriculture, and nomadic pastoralism.[15] Northern Darfur consists primarily of three ecological zones: *goz* (sandy soil areas); *wadi* (areas around watercourses that fill after rainfall); and *tombac* (tobacco-growing area).[16] The northernmost zone is the most ecologically fragile of the three and the most acutely impacted by drought. Southern Darfur consists primarily of three agrarian zones: agro-pastoralist in semi-arid savannah; agro-pastoralist with high production; and agro-pastoralist and cash crop (mainly groundnuts).[17] The central belt of Darfur, including the Jebel Marra massif (approximately 8000 feet high), is the richest and most stable area in terms of soil fertility and water resources.[18]

The Importance of Agriculture in Darfur

In 2003, the majority of the Sudanese population depended on subsistence agriculture, which employed over 80 percent of the workforce and contributed 35 percent of the nation's GDP.[19] The economy of Darfur is also largely agrarian. Its main consumption crops are millet, followed by sorghum. Groundnuts, tobacco, vegetables, and watermelons are the main cash crops.[20] Before 2003, the main household food sources were localized subsistence agricultural production (45–60 percent), livestock (10–30 percent), and market purchases (15–30 percent).[21] Most communities farm according to the following calendar: planting in July-August, weeding in September-October, and harvesting in November-December, sometimes January. Vegetables normally need less time to ripen than cereals.[22] Tombac (chewing tobacco) was a major cash crop.[23] But following the attack of the pro-government forces in May 2004, the areas under tombac cultivation have declined dramatically—most of the tobacco farmers now live as internally displaced people (IDP) in Al-Fashir.[24]

The Livestock Sector

Due to seventy-five years of declining rainfall and crop yields, especially millet, livestock rearing has gained importance in Sudan. Livestock rearing is less dependent on rainfall and is a marketable asset to families during a drought year.[25] But an explosive growth in livestock numbers—from 28.6 million in 1961 to 134.6 million in 2004—resulted in widespread degradation of the rangelands.[26] Because cattle have relatively higher water needs, sheep- and goat-rearing has increased due to their greater adaptivity to the dry environment.[27]

The majority of livestock in Sudan are raised in traditional pastoral systems, on community rangelands.[28] Herders raise an estimated 80 to 90 percent of Sudan's livestock.[29] Six types of animals are reared—camels, sheep, goats, cattle, donkeys, and horses—all with economic importance in Darfur (Table 1).[30] In Darfur, sedentary grazing is almost impossible and moreover ecologically destructive, thus mobile pastoralism dominates.[31] Except for the desert zone north of the 100 mm isohyet, all areas of Darfur are suitable for grazing, provided that drinking-water is available at a reasonable distance.[32]

Between 1991 and 1999, the livestock sector in Sudan grew at an annual rate of nearly 16 percent, the fastest growing non-oil sector of the economy.[33] In 1999, livestock exports accounted for 25 percent of Sudan's foreign exchange earnings.[34] In 2000, the livestock sector accounted for 62 percent of agricultural GDP and 23 percent of the overall GDP.[35] In 2002, the livestock population in Sudan was estimated at 39,479,000 head of cattle, 48,136,000 sheep, 41,485,000 goats and 3,342,000 camels.[36] Sudan livestock exports totaled $137.8 million in 2004.[37]

	Cattle	Sheep	Goats	Camels	Donkeys	Horses
North Darfur	628,530	3,396,505	2,656,808	397,172	700,293	16,907
% of North Darfur animal population	8%	43.57%	34.1%	5.1%	8.9%	0.22%
South Darfur	3,851,663	3,471,773	2,756,688	74,950	535,129	233,986
West Darfur	3,702,195	3,528,225	3,236,112	286,989	805,997	175,828
Total	**8,182,388**	**10,396,503**	**8,649,608**	**759,111**	**2,041,419**	**426,721**
% of national herd	21 %	22 %	22 %	24 %	31%	63 %

Table 1. 2002 Estimates of Livestock Population in Darfur[38]

Year		2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007
Class	Breaks	Area Km²	Area Km²	Area Km²	Area Km²	Area Km²	Area Km²	Area Km²
1	-.25 - -.20	0.06	14.38	0.00	2.50	0.00	17.94	25.38
2	-.20 - -.15	18.75	549.50	1.13	23.44	9.88	74.19	84.69
3	-.15 - -.10	202.81	8,886.25	84.06	812.69	93.44	979.31	290.25
4	-.10 - -.05	5,156.81	61,248.69	3,670.31	25,750.31	3,326.69	24,007.44	2,177.31
5	-.05 - +.05	304,911.50	288,181.69	325,048.63	330,103.25	315,983.25	329,274.63	242,289.44
6	+.05 - +.10	46,444.00	2,052.13	30,160.25	4,218.81	39,060.75	6,045.38	104,337.69
7	+.10 - +.15	3,948.00	74.13	1,955.75	102.38	2,330.56	500.81	10,971.00
8	+.15 - +.20	314.56	6.63	90.38	0.25	177.81	107.56	811.19
9	+.20 - +.25	17.13	0.25	3.13	0.00	23.69	2.94	26.50
10	+.25 - +.30	0.00	0.00	0.00	0.00	7.38	0.00	0.13
Total Area Km²		361,013.63	361,013.63	361,013.63	361,013.63	361,013.63	361,013.63	361,013.63

Table 2. Statistic Results of *MODIS Terra* NDVI *Change in Vegetation Vigor*

Deriving Temporal Changes in Vegetation Vigor from SPOT Vegetation 1999-2007 and MODIS Terra 2000-2007

In order to record any change in biomass, it was important not just to understand change as a function of spatial coverage, i.e., two-dimensionally, but also to add a third dimension— vegetation vigor or health. Simply knowing where and how much vegetation coverage has changed annually does not necessarily convey how healthy the vegetation was for each year. These are in fact two different measurements.

First, NDVI data for each image stack were compared by consecutive year, e.g. MODIS 2000-2001, 2001-2002 . . . 2006-2007, and SPOT 1999-2000, 2000-2001 . . . 2006-2007. The resulting data sets contained per pixel negative or positive values ranging from approximately -2.5 to +3.0 expressing the increase or decrease in vegetation vigor.

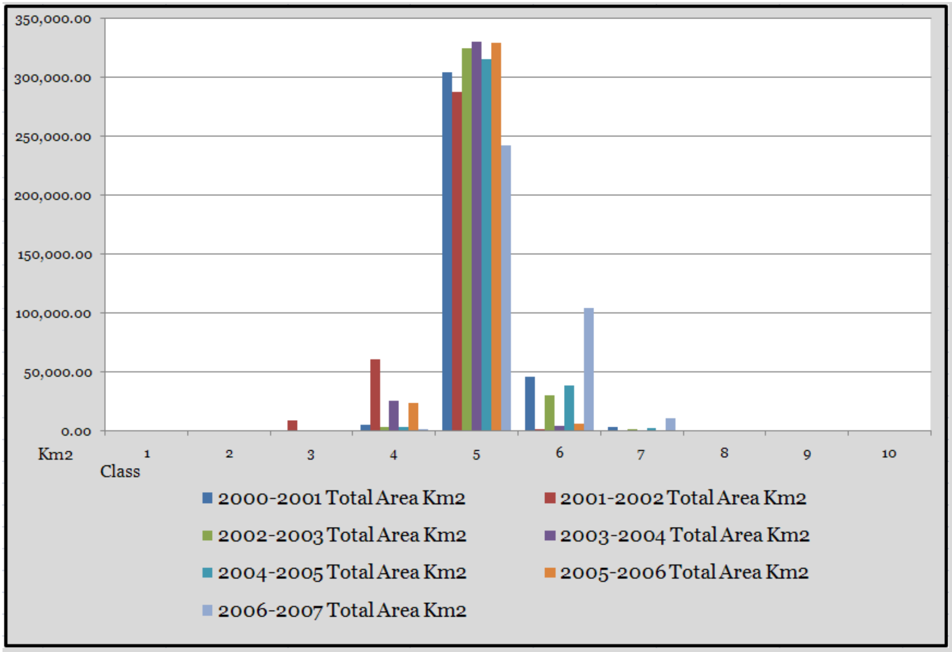


Figure 7. Graphed Results of *MODIS Terra* NDVI *Change in Vegetation Vigor*

Second, the resulting data sets were reclassified into ten classes based on a standardized set of classification breakpoints (Table 2). The number of pixels per class for each data set was multiplied by the image pixel area, e.g., for MODIS, the pixel area is 0625 km^2. These results were then graphed (Figure 7).

Year	2001-2002				
Class	Pixel Count	Pixel Area Km²	Total Area Km²	Factor	Vegetation Vigor Factor
1	230	0.0625	14.38	Null	Null
2	8792	0.0625	549.50	-3.00	-1,648.50
3	142180	0.0625	8,886.25	-2.00	-17,772.50
4	979979	0.0625	61,248.69	-1.00	-61,248.69
5	4610907	0.0625	288,181.69	0.00	0.00
6	32834	0.0625	2,052.13	1.00	2,052.13
7	1186	0.0625	74.13	2.00	148.25
8	106	0.0625	6.63	3.00	19.88
9	4	0.0625	0.25	Null	Null
10	0	0.0625	0.00	Null	Null
				Total	**-78,449.44**

Table 3. *Vegetation Vigor Factor* for 2001-2002

Third, the minimum and maximum classes were eliminated—classes 1, 9, and 10 respectively—for each stack and the *Vegetation Vigor Factor* was derived by first multiplying the total area per pixel class by an arbitrary factor (-3 to +3) and then summing up the total of these products (Table 3). The *Vegetation Vigor Factor* represents the total area change, either positive or negative, as a function of the amplitude of that change. Hence, the per data set *Vegetation Vigor Factor*, used to measure annual vegetation vigor, was weighted by area and is either positive or negative based on the increases and decreases in NDVI.

These data were graphed per stacked image year and, using 2000 as a base year, a mean curve of change in vegetation vigor between consecutive years was derived and compared with change in annual rainfall for the same period (Figure 8). The data show a downward slope in mean vegetation vigor from 2000 to 2003. But after the genocide began in 2003, the trend reverses and the mean begins sloping steadily upward. But for the same period, mean rainfall is steadily decreasing and for 2007, the sharpest decrease in rainfall coincided with the sharpest increase in vegetation vigor. For the most part, however, vegetation vigor reacts positively to increases in rainfall, with the exceptions of 2005 and 2007, when vegetation vigor increased despite negative changes in rainfall.

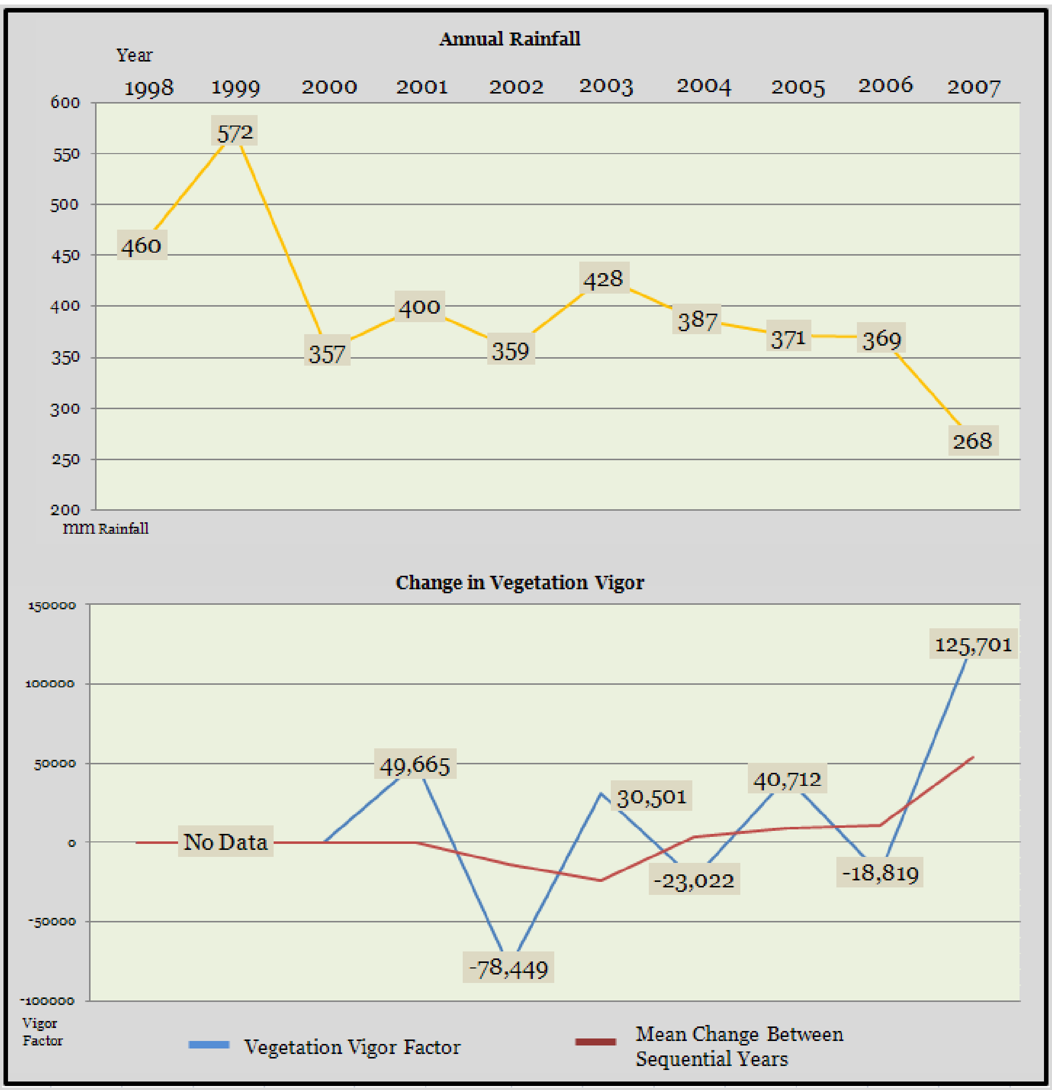


Figure 8. Graphed *Annual Rainfall* and *Change in Vegetation Vigor*

Visualizing Temporal Change in Vegetation Vigor, Sequential Annual Comparison

Using the MODIS and SPOT vegetation vigor data sets, change in vegetation can be visualized in a set of prepared images (Figures 10—15), which show where these changes in vegetation vigor occurred and were most dramatic. Codified by color (Figure 9), a false-color representation of annual change in vigor based on the standardized classification system of eight classes was applied to each data set. The images represent per pixel change in vegetation vigor for consecutive years.[38] The first prepared image shows change in vegetation vigor for 1999-2000, representing the sharp decrease in rainfall in that period (Figure 10).

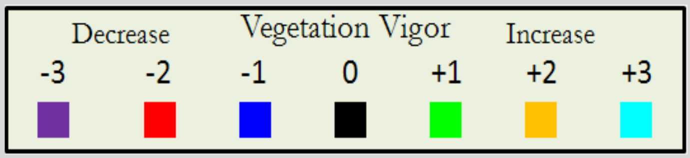


Figure 9. *Change in Vegetation Vigor*

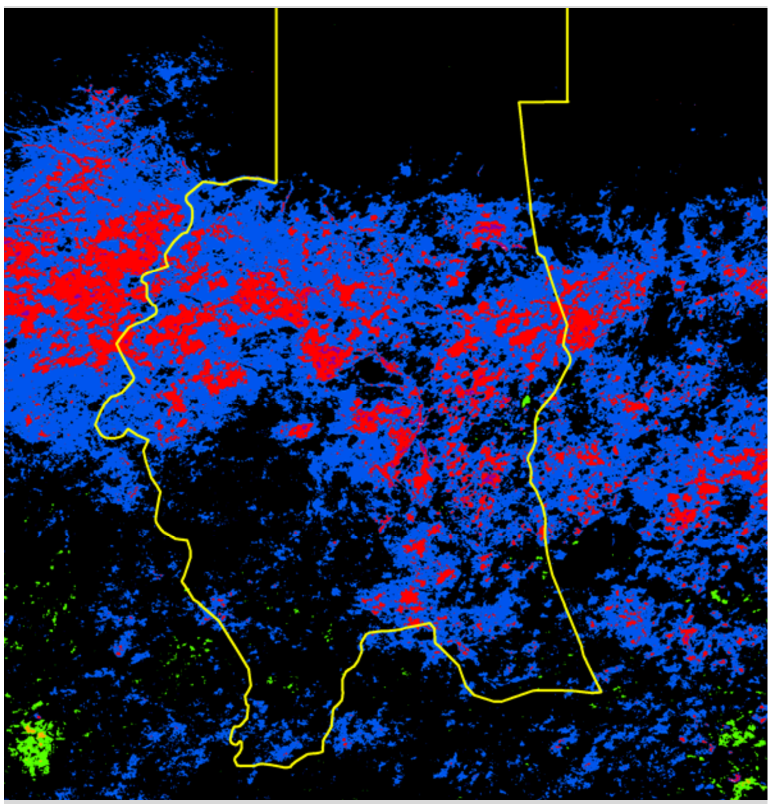


Figure 10. 1999-2000 [*SPOT*] *Change in Vegetation Vigor*

The following two images compare the SPOT and MODIS findings for the same period, 2000-2001 (Figure 11). Although MODIS pixels are 1/16th the size of SPOT pixels, which give MODIS a higher spatial resolution, the results are quite similar. This close similarity in results was observed for every corresponding image set, showing that SPOT corroborated the MODIS findings.

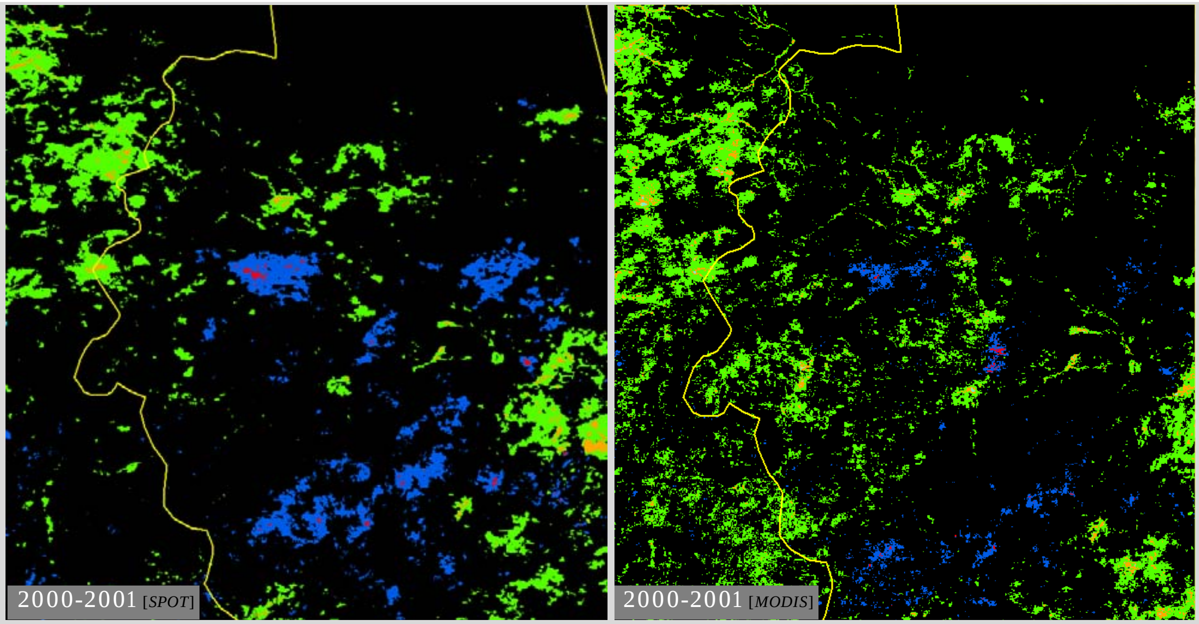


Figure 11. Side-by-side Comparison of *SPOT* and *MODIS* 2000-2001 Findings

The following three prepared images (Figures 12—15) show change in vegetation vigor: in 2003-2004, during the first year of the genocide; in 2004-2005, showing the first divergence of the rainfall and vegetation vigor trends; and in 2006-2007, showing the dramatic divergence between rainfall and vegetation vigor.

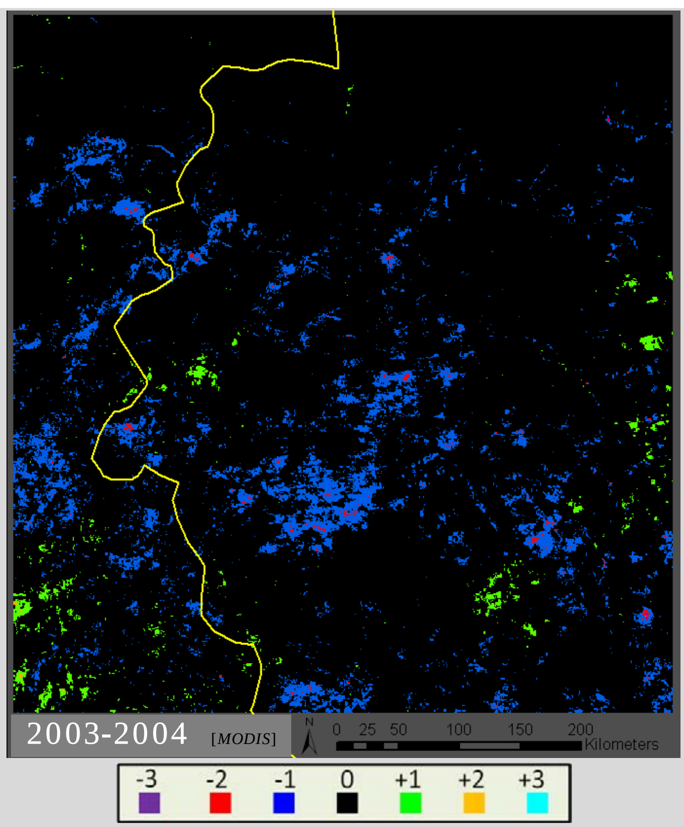


Figure 12. 2003-2004 C*hange in Vegetation Vigor*

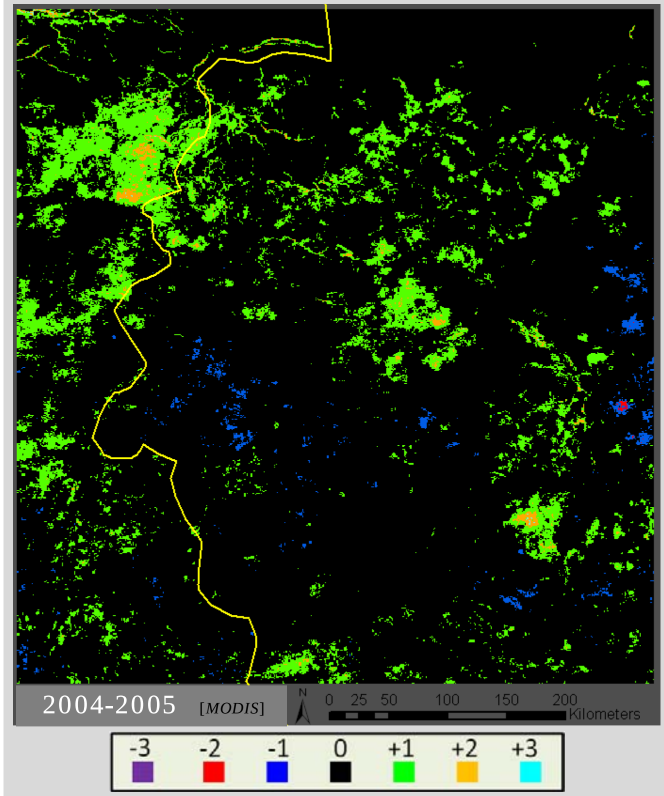


Figure 13. 2004-2005 C*hange in Vegetation Vigor*

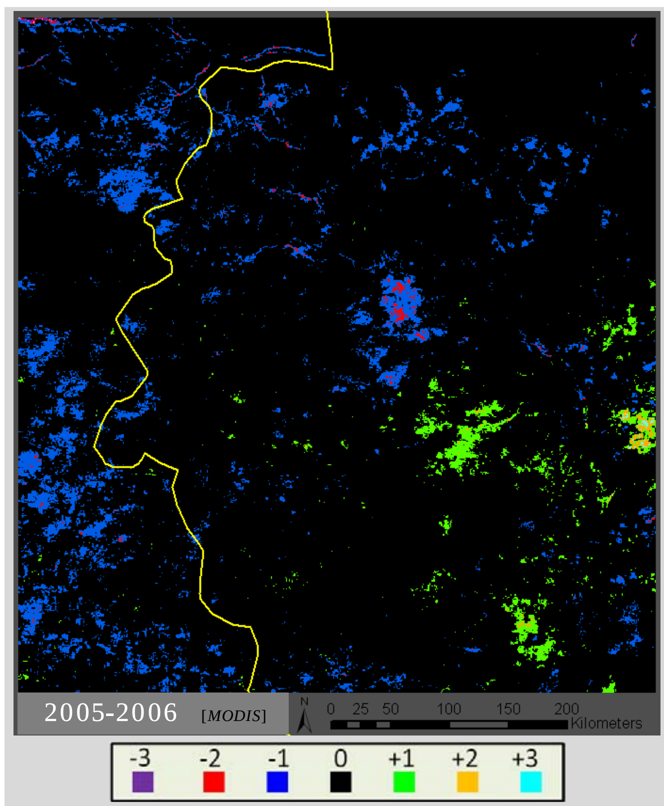


Figure 14. 2005-2006 Change in Vegetation Vigor

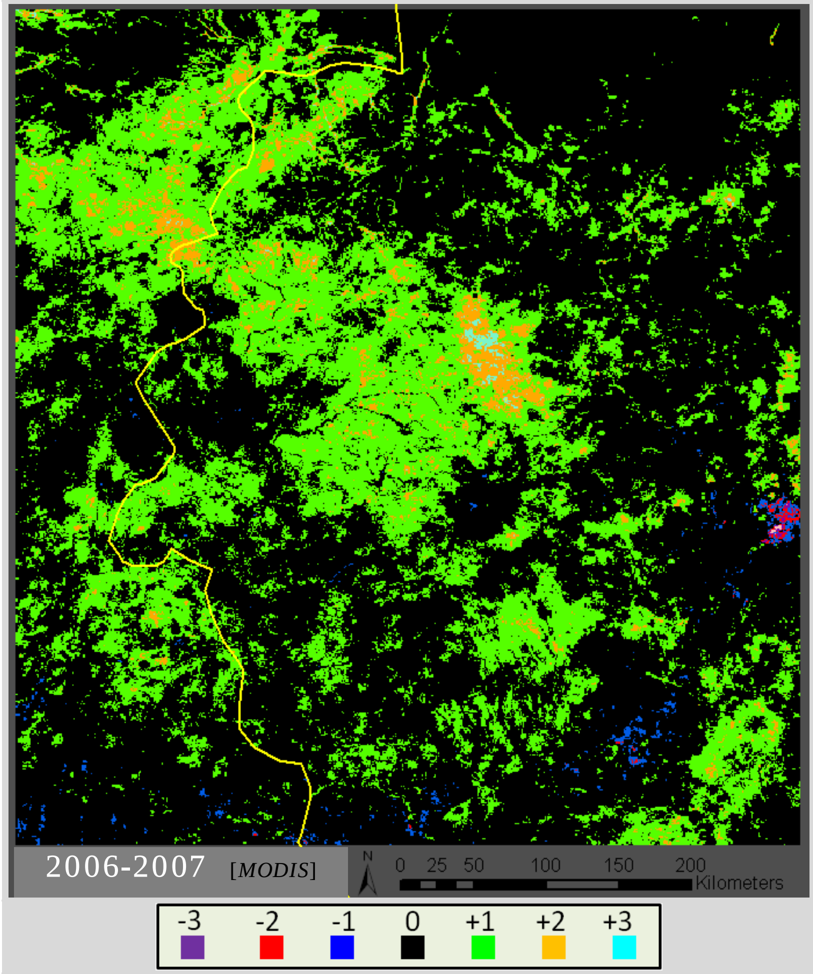


Figure 15. 2006-2007 C*hange in Vegetation Vigor* showing a dramatic increase in vegetation vigor, in spite of a 2007 decrease in rainfall

Research Findings on Temporal Change in Vegetation Vigor

Assumption one of our research hypothesis states that all other factors equal, changes in natural vegetation (measured in NDVI) will parallel fluctuations in rainfall, although slightly delayed, and will maintain a natural balance based on water availability. The findings show that fluctuations in biomass vigor paralleled rainfall in every year except 2005 and 2007. In spite of a sharp decrease in rainfall in 2007, vegetation rebounded dramatically. Some factor other than rainfall stimulated this rebound in vegetation vigor and coverage.

Assumption two states that livestock grazing will reduce NDVI vegetation vigor. A reduction in grazing will stimulate a rebound in natural vegetation but this is usually delayed—some vegetation types will rebound faster than others. In the period from 2003 to 2005, massive government-sponsored livestock looting occurred. The negative mean slope in vegetation vigor had reversed after 2003 and a positive mean slope was gradually increasing, independent of rainfall fluctuations. Hence, reduction in livestock is contemporaneous with an increasing positive slope in vegetation vigor—most dramatic in 2007.

Livestock Looting: a Key Element of the Systematic Violence in Darfur

Since 2003, government-sponsored violence has displaced peoples from large tracts of the more fertile areas of Darfur in what some observers see as a land grab.[39] Local Arab leaders have reportedly reapportioned land that belonged to African communities— Fur, Masalit, and others.[40] Early 2006 assessments indicated that displaced villagers in Darfur had lost between 60 and 90 percent of their animal herds, livestock which frequently have been killed, maimed, or stolen during periods of violence.[41]

In January 2005, the International Commission of Inquiry into Darfur (ICID) issued the *Report of the International Commission of Inquiry on Darfur to the United Nations Secretary-General*.[42] The report described the Sudanese government-sponsored violence in Darfur as “systematic” and what “may amount to crimes against humanity.” In treating the systematic pattern of violence and the looting of livestock, the report stated: “The pillage of villages and the appropriation of livestock, crops, household goods and other personal belongings of the inhabitants by the Government forces or the militias under their control no doubt amounts to a *war crime*.”[43]

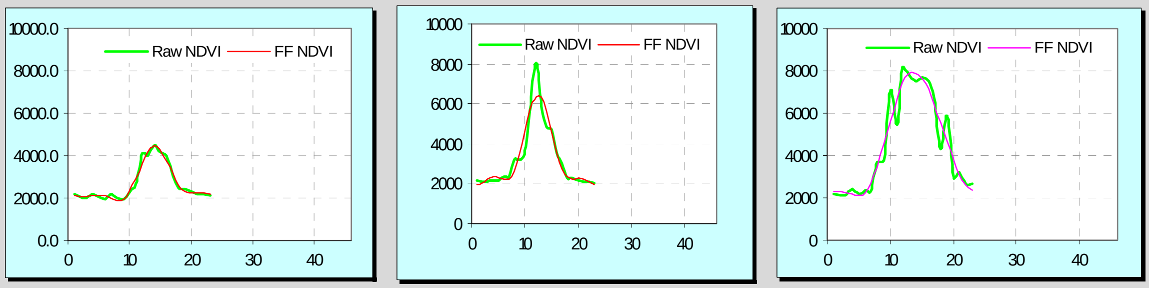
During September 2004, the International Committee of the Red Cross (ICRC) reported that eighteen of twenty villages visited during a three week survey in North, West, and South Darfur claimed that 70-100 percent of their livestock had been looted.[44] In October 2004, Emily Wax of the *Washington Post* reported that stolen animals worth millions of dollars had flooded markets in Nyala, capital of South Darfur province.[45] Some reports claimed livestock had been sent to Chad, the Central African Republic, and the Gulf states.[46] "Janjaweed and Janjaweed leaders are getting rich off of this," said Adam Azzim Mohamed, a professor at the University of Khartoum, who is tracking the profits from the sales.[47]

According to a May 2004 Human Rights Watch report, cattle rustling was organized on an almost industrial scale, in which stolen cows are gathered in *Janjawiid* cattle camps or collection points–the largest in Um Shayala–from where they are driven to the government slaughterhouse in Nyala for export to Libya, Syria, and Jordan.[48] Human Rights Watch describes the looting of livestock in Darfur as “clearly organized and premeditated,” and “[i]n many cases, it appears to have been “organized by the military commander and conducted in a methodical way.”[49] Loot was offered as reward for fighting: a former government soldier stationed in Kutum, North Darfur, explained the looting policy: “The animals are given to Janjaweed nomads who keep them. Then they are sold.”[50] Another eyewitness reported, “Big lorries from Omdurman arrived…They loaded up with sheep from the base and took them away. Three times the lorries came… and transported camels and cows.”[51]

In its February 2006 report, the Coalition for International Justice (CIJ) attempted to estimate the overall percentages of ‘lost’ livestock based on a number of data sources reporting the pre-conflict population; the pre-conflict number of animals, including sheep, goats, donkeys, and camels; the numbers of persons displaced or killed since 2003; and the number of livestock reported lost or stolen since 2003.[52] For example, they calculated with a rough estimate of two sheep per person and a livestock-loss ratio of 90 percent for displaced populations, the high estimate of the number of lost sheep at 4.32 million, a third of the pre-conflict sheep stock. The CIJ report examined 2003-2004 market trends both inside and outside Darfur in order to assess what might have happened to looted sheep. CIJ found that, although some short term trends were noticed in both markets—possibly as a result of an influx of looted animals from Darfur, there were no clear price indices directly confirming a flooded meat market. Data for 2005-07 remains uncollected.

Tracking Temporal Change in Vegetation Phenology & Coverage, Using Fourier Classification

Supervised Classification is a *knowledge-driven* remote sensing application, which allows a user to group similar features appearing on a satellite image. The resulting image groups these features into classes. Using the *MODIS Terra* 2000 *Fourier* data sets, 24 vegetation classes were derived. These classes represent groups of similar phenology types or vegetation species, based on their FF NDVI signatures (Figure 16). From these 24 classes, the MODIS 2001 through 2007 *Fourier* data sets were classified and codified by color (Figure 17) for purpose of visualization.[53] An additional class represents bare soil. The primary purpose was to determine which vegetation species might be contributing to the observed change in vegetation vigor and coverage.



Class 6 Class 10 Class 24

Figure 16. Examples of *Fourier* derived phenology classes representing vegetation species

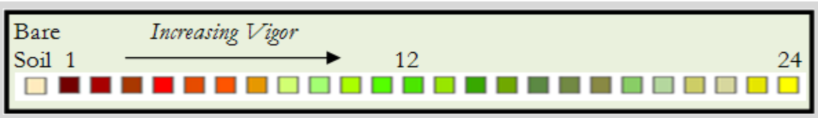


Figure 17. *Phenology Classes* based on increasing vegetation vigor

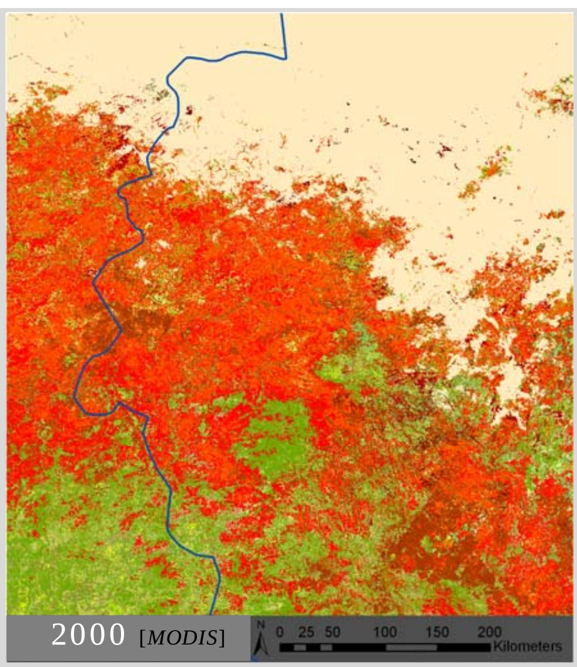


Figure 18. Phenology Classes Representing Vegetation Species

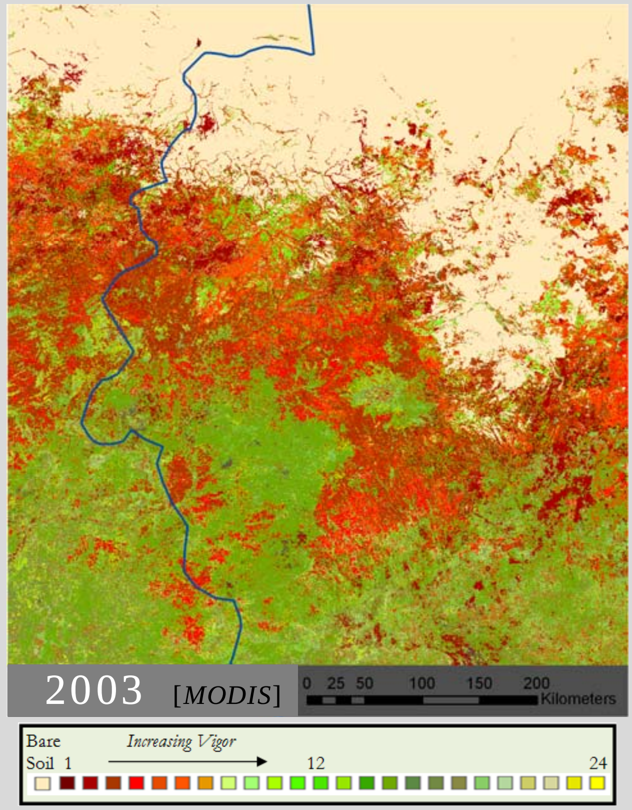


Figure 19. Phenology Classes Representing Vegetation Species

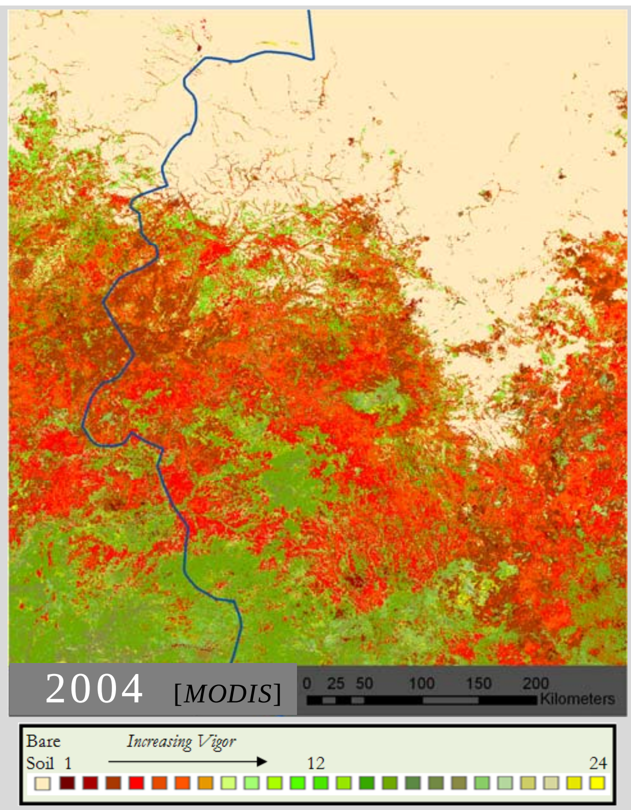


Figure 20. Phenology Classes Representing Vegetation Species

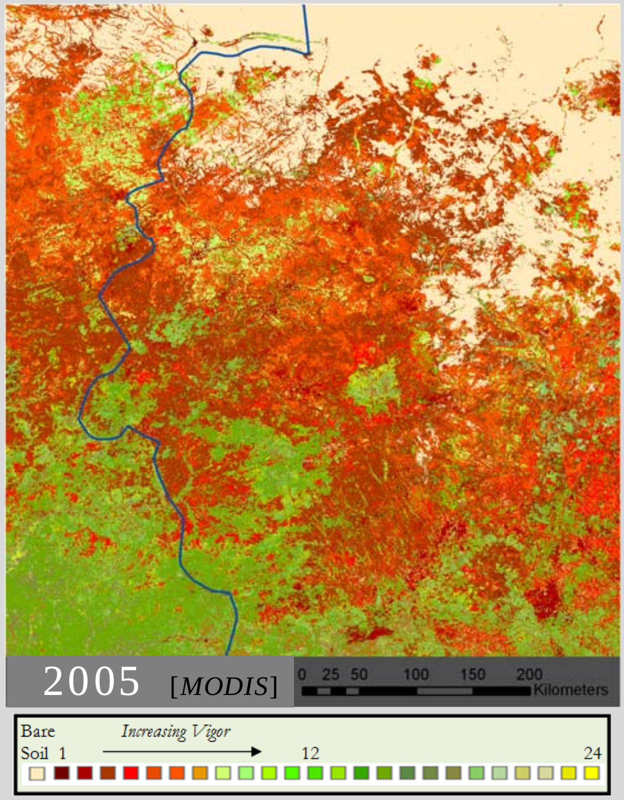


Figure 21. Phenology Classes Representing Vegetation Species

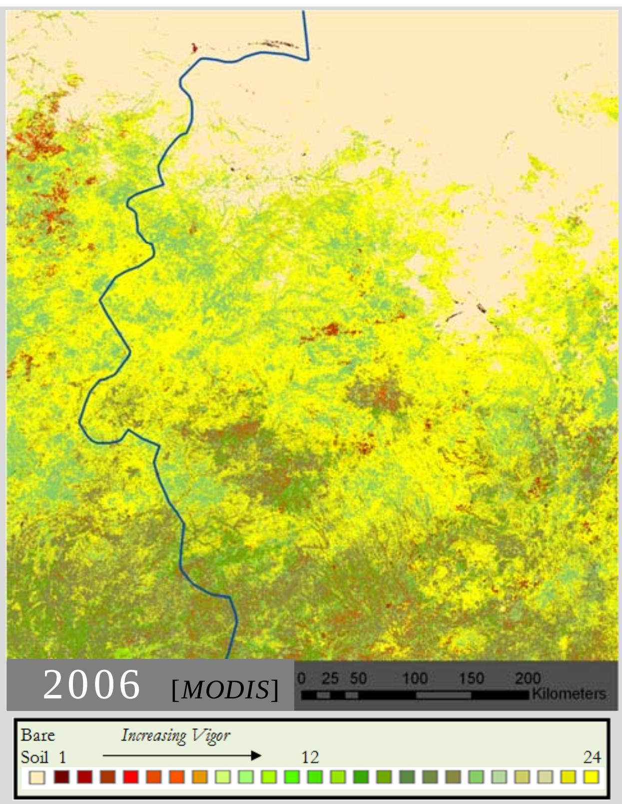


Figure 22. Phenology Classes Representing Vegetation Species

The findings show that from 2000 through 2005, the lower to middle classes dominate the research area (Figures 18—22), e.g., classes six and ten. These are classes of lower amplitude (peaks) and shorter growing cycles, likely representing vegetation species experiencing some kind of environmental stress (see discussion below). By 2006 the phenology classes dominating the research area had changed dramatically (Figure 22), and by 2007, had reversed completely (Figure 23). The emerging classes have higher amplitudes (peaks) and longer growing cycles, e.g., Class 24, representing healthier vegetation. It is yet unclear which particular species or types of species correspond to these phenology classes but they are likely species of wild grasses and shrubs.

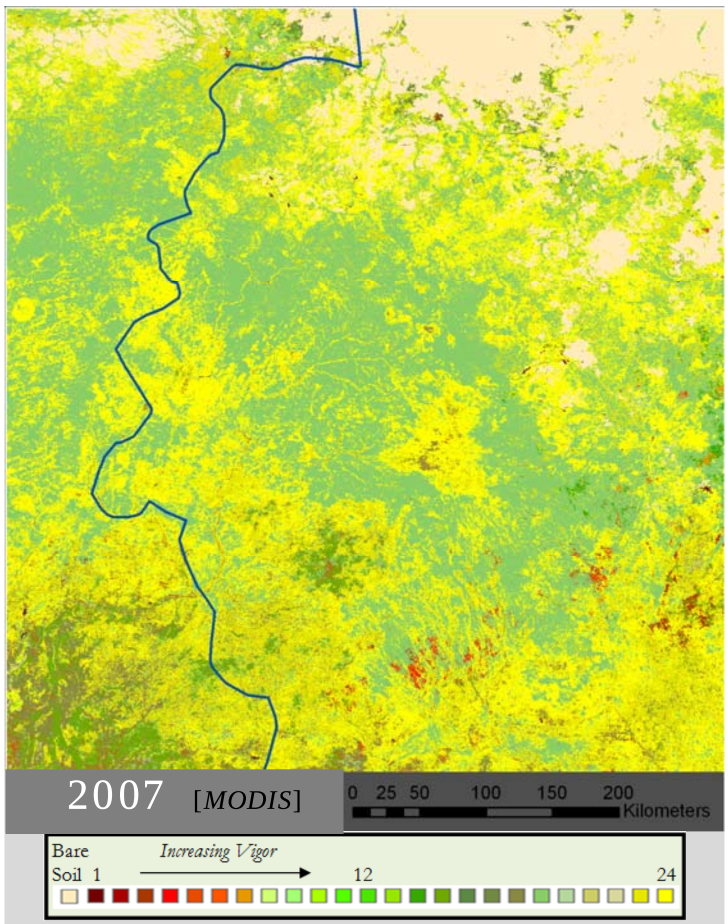
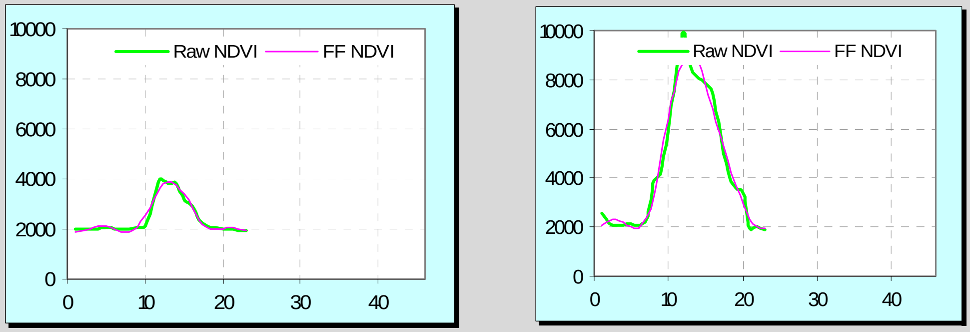


Figure 23. Phenology Classes Representing Vegetation Species

The Effects of Grazing on Vegetation Cycles

A change in vegetation vigor and coverage is likely not a function of an emerging new species but rather signals the increasing vigor of existing species. This is likely the result of newly limited livestock grazing: plant species previously consumed by livestock before reaching full growth were by 2006-07 no longer impacted by grazing. For example, in 2000-03 *Vegetation Class 3* occupied pixels that by 2006-07 were replaced by *Vegetation Class 23* (Figure 24). Because these two classes share somewhat similar growing cycles and only differ considerably in NDVI magnitude, they are probably the same species of grass, which has not been affected by grazing.



Class 3 Class 23

Figure 24. Example of two phenologies which likely represent the same vegetation species

Assumption three of our research hypothesis states that wet-farming (irrigation) cultivation in a region previously used for grazing or not cultivated will increase NDVI vegetation vigor almost immediately but this will occur in localized areas near fluvial systems. Assumption four states that a reduction in livestock grazing will stimulate a rebound in natural vegetation vigor, but that this is usually delayed. This widespread emergence of what appear to be only three to four phenology classes likely represents a rebound of natural vegetation, not crop cultivation. In support of the *change in vegetation vigor* findings, the phenology findings indicate an increase in vegetation vigor influenced by grazing patterns, not by rainfall. As documented by the U.N., ICRC, and others, livestock populations were steadily decreasing by the end of 2003 and mid-2004, and by 2005 and 2007 they had been reduced sharply.

Summary of Findings

The findings illustrate a steady rebound of vegetation coverage and vigor in much of west-central and north-central Darfur since 2003, despite a continuing decrease in annual rainfall. Furthermore, the influences of rainfall and livestock grazing on vegetation vigor are distinguishable. A greatly decreased number of livestock is likely the main factor driving this rebound in biomass. Because of the continual violence from 2003 through 2007, livestock herds might be kept further south in Darfur or elsewhere but there is little evidence that highly concentrated herds of any great number remained in the study area by 2007. The remote sensing findings support the assumption that the displacement of people and the decline of livestock in a region are uniquely related. Hence, tracking temporal and spatial changes to land cover as a function of land use can contribute evidence about the systematic government-sponsored violence and population displacement, which are characteristic of the genocide in Darfur.

PART II

Climate, land, race, and oil have all been identified as possible factors or motives for the genocide in Darfur. An important aspect to genocide studies is showing system, motive, and intent. Part I of this research paper presented remote sensing evidence of a system of violence. This includes the massive displacement of civilians, and the theft and destruction of livestock. The result of this violence is evidenced in the dramatic return of vegetation coverage and vigor in the impacted areas of Darfur. Part II considers motive and intent. Clear spatial and temporal correlations are evident between acts of violence and both short and long-term changes to the land cover. In the high impact zone of West Darfur, which experienced continual violence from 2003 through 2006, the findings show a persistent degradation to the environment in that initial period. But in the sub-Sahara portions of North Darfur, which experienced less concentrated violence and a decrease in grazing, the rebound of vegetation was relatively steady through 2007, in spite of a decrease in rainfall.

Historical, Cultural, and Political Overview

Darfur Overview

Sudan is ruled by the National Islamic Front (NIF), an Islamist regime under General Omar al-Bashir, which has its powerbase in the primarily Arab and Muslim north of the country. In 1994, the Sudanese government divided Darfur into three administrative districts: North Darfur, with its capital, Al-Fashir; South Darfur, with its capital, Nyala; West Darfur, with its capital, Al-Geneina (Figure 25). A 2000 census reported a population of 31.2 million, of which 6 million inhabited Darfur: in North Darfur 1.46 million, West Darfur 1.78 million, and South Darfur 2.76 million.[54] Ethnically, Arabs constitute 39 percent while Africans make up 61 percent; religiously, Muslims make up 70 percent while the rest are Christians and traditional believers.[55]

Figure 25. The Main Tribes of Darfur

The Tribes of Darfur

The Arabic word Dar roughly means homeland and its population is divided into several Dars, not only of the Fur people, who live in central Darfur (Figure 25). There are more than thirty ethnic groups in Darfur, but these can be divided broadly into two main categories: Arab and African.[56] Historically, camel nomads, principally the Zaghawa and Bedeyat, who are non-Arab in origin, and the Arab Mahariya, Irayqat, Mahamid, and Beni Hussein inhabited the north.[57] African sedentary farmers, primarily from three principal African ethnic groups, the Fur, Zaghawa, and Masalit (Masaalit), inhabited central Darfur.[58] Cattle are herded by the Arab nomads of the eastern and southern zones of Darfur, who comprise the Rezeigat, Habbaniya, Beni Halba, Taaisha and Maaliyya.[59] The Rezeigat are prevalent in northern Darfur as well.[60]

Prior to the 2003 violence, no part of Darfur was ethnically homogenous, and there has traditionally been a degree of movement and intermarriage among these groups and social classes, resulting in a blurring of ethnic distinctions.[61] A fragile but necessary balance has existed between the sedentary, primarily agrarian tribes and semi-nomadic pastoralist tribes. For example, Fur peasants provided the millet that forms the staple grain in Darfur, and Baggara supply necessary milk and livestock; making the two populations interdependent.[62] Many tribes, Arab and non-Arab, share ties and traditional homelands across western Darfur and eastern Chad. For example, about half of the Zaghawa land lies in Chad, the other half in Sudan. During the drought disasters of 1972-1973 and 1984-1985, large numbers of Zaghawa migrated southward and settled not only in rural areas, but also in the major towns such as Al-Fashir, Nyala, and Omdurman.[63] In addition, about half the Masalit live in Chad.[64]

The Political Administrative Districts of Darfur

During the past 20 years, Darfur has experienced low-level internal and external conflict. The creation of the three administrative districts in Darfur was perceived by some groups as a strategy on the part of Khartoum to decentralize the traditionally non-Arab Muslim control over much of Darfur.[65] Historical and stable power structures among the tribes and political elites became fragmented and destabilized.[66] The placement of primarily Arab politicians and administrators in governmental offices further disrupted and marginalized the predominantly non-Arab Muslim populations.[67]

2003 Outbreak of Violence

Government Forces and the Janjawiid

The Sudanese government war effort contained three main elements: *Janjawiid*, air force, and Military Intelligence. The *Janjawiid* were outfitted as a full paramilitary force, with communications equipment, arms, some artillery, and military advisors.[68] They were recruited from exclusively Arab nomadic tribes; historically many *Janjawiid* came from the camel-herding *Abbala Rezeigat* of Darfur, known to embrace an Arab racist ideology.[69] The air force was responsible for bombing civilian targets, and Military Intelligence for information gathering, infiltrating targeted villages, and planning attacks and terror campaigns.[70]

Beginning in mid-2003, the *Janjawiid* carried out a government mandated scorched-earth campaign in Darfur, which primarily targeted innocent civilians. The pattern of attacks often started with cattle rustling. Subsequent direct attacks on the target village ensued until most inhabitants were killed or expelled. The villages were often entirely looted, burnt, and abandoned. In May 2004, the U.N. High Commissioner for Human Rights, Bertrand Ramcharan, issued the report *Situation of human rights in the Darfur region of the Sudan*. It stated that the situation in Darfur was characterized by the following features[71]:

> “(a) [r]epeated attacks on civilians by the military forces of the Government of the Sudan and its proxy militia; (b) [t]he use of indiscriminate aerial bombardments and ground attacks on unarmed civilians; (c) [t]he use of disproportionate force by government and Janjaweed forces; (d) [t]hat the Janjaweed have operated with total impunity and in close coordination with the forces of the Government of the Sudan; (e) [t]hat the attacks appear to have been largely ethnically based with the groups targeted being essentially the Zaghawa, Masaalit and Fur tribes, which are reportedly of African origin […]; (f) [t]he pattern of attacks on civilians includes killing, rape, pillage, including of livestock, and destruction of property, including water sources; and (g) [t]hat there has been massive, often forced, displacement of much of the population of Darfur.”

In March 2005, the US State Department estimated that 63,000 to 146,000 “excess” deaths (above normal mortality rates) were attributable to “violence, disease, and malnutrition.”[72]

Mapping the Genocide in Darfur with GIS

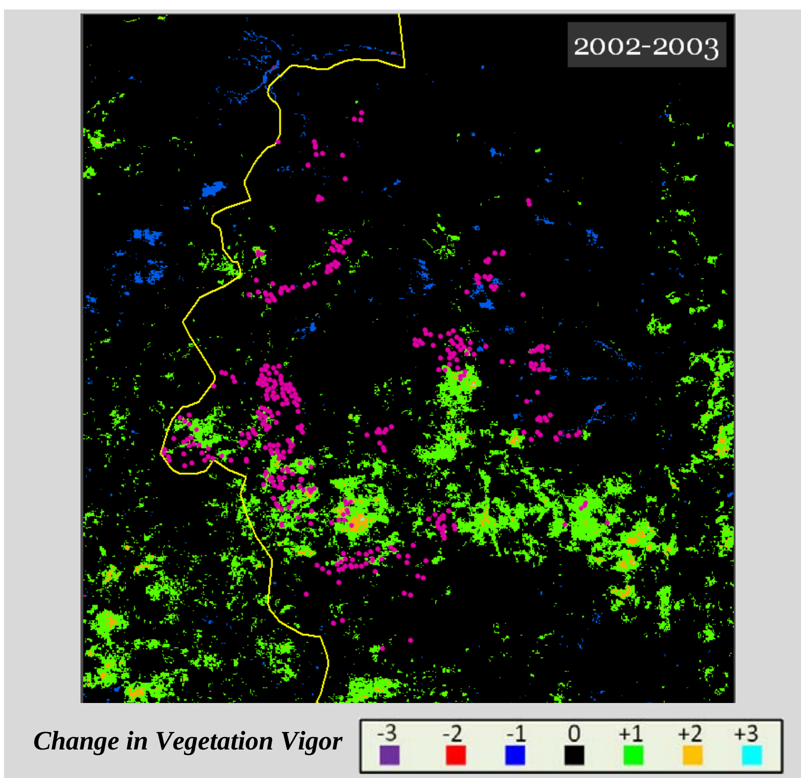


Figure 26. ● *Damaged and Destroyed Villages* reported as of 08-2004 [73]

One advantage of using Global Information Systems (GIS) applications in combination with remote sensing data is the ability to spatially and temporally visualize and analyze multiple types of information. We will now overlay maps of targeted villages onto our earlier prepared images demonstrating the environmental impact.

Mapping the Violence in Darfur 2003-2007

The following seven images map civilian centers and regions adversely effected by violence since 2003 (Figures 26—32). The images show the locations of *Damaged and Destroyed Villages* as reported from August 2004 to January 2007. It is not a comprehensive list but intends to give a summary of general locations and dates of violence to assess how these events might have impacted the changes to the land cover. These locations are plotted on our satellite images showing *Change in Vegetation Vigor* over consecutive years. Because the government-sponsored violence included a scorched earth policy, as well as livestock looting, the following images attempt to track evidence of these acts of violence. We shall see that, especially in West and South Darfur, the displacement of local populations also impacted agricultural production, especially in 2003-04.

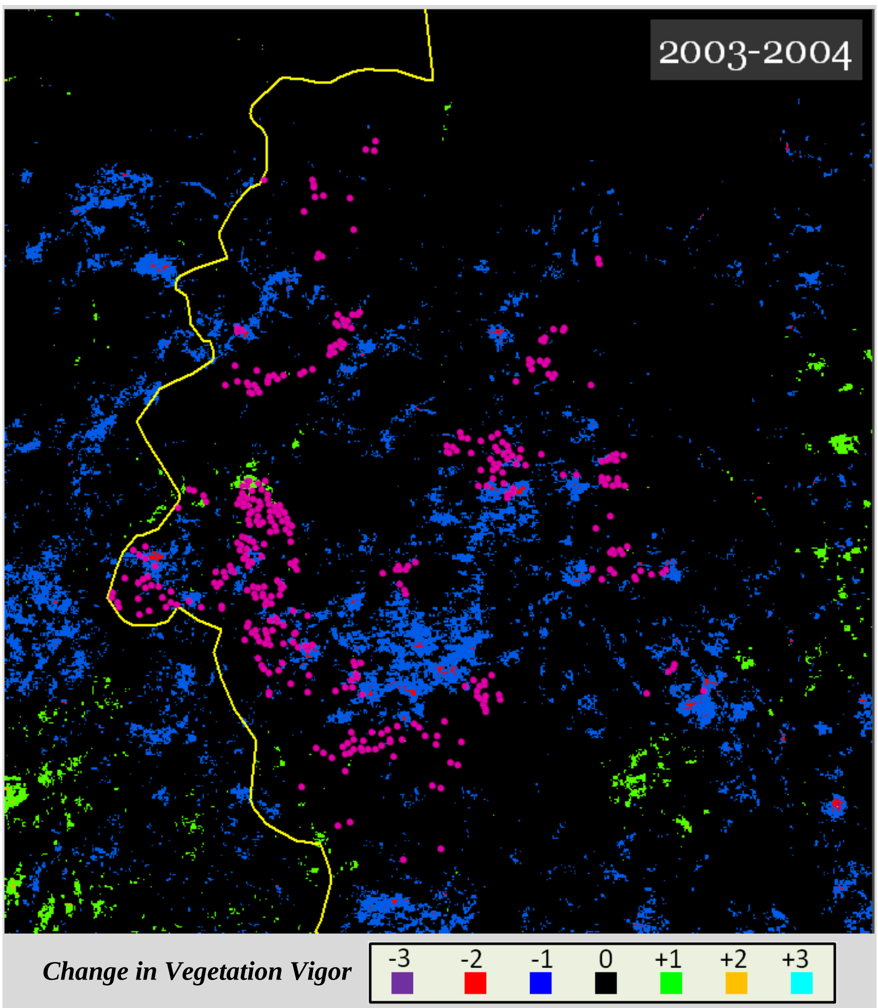


Figure 27. ● *Damaged and Destroyed Villages* reported as of 08-2004 [74]

Because agriculture generally increases vegetation vigor, the clear annual decreases in vigor observed in West and South Darfur from 2003-04 through 2005-06, corroborate both the reduction of agriculture in a predominantly agricultural region and also suggest an increase in livestock grazing (see below). These two well documented events are directly related to the violence and genocide in Darfur. Although a decrease in rainfall from 2003 to 2004 likely contributes to some of the decrease in vegetation vigor, from 2004 through 2006 annual rainfall remains relatively constant, while overall vegetation vigor increases for the same period. However, evidence of this increase in vigor occurs in regions of less concentrated reported acts of violence. Even by 2007, when a dramatic rebound of vegetation vigor is observed, the high-impact zones of violence remain less changed.

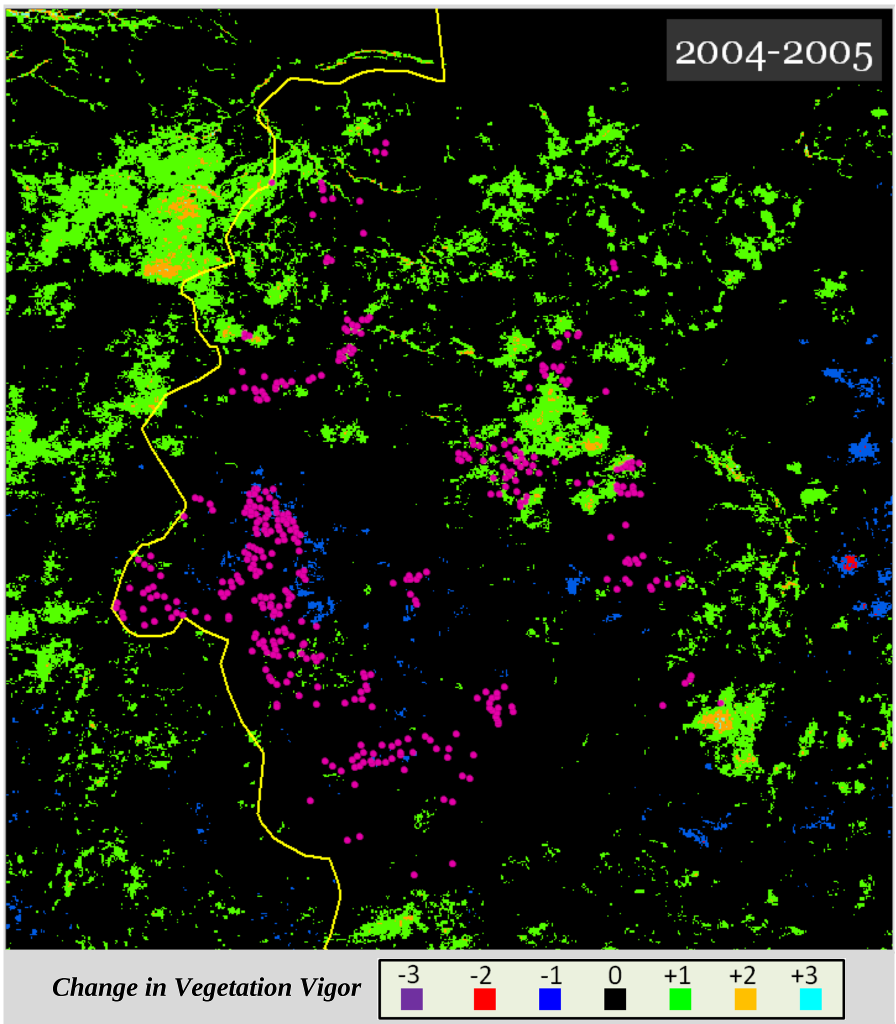
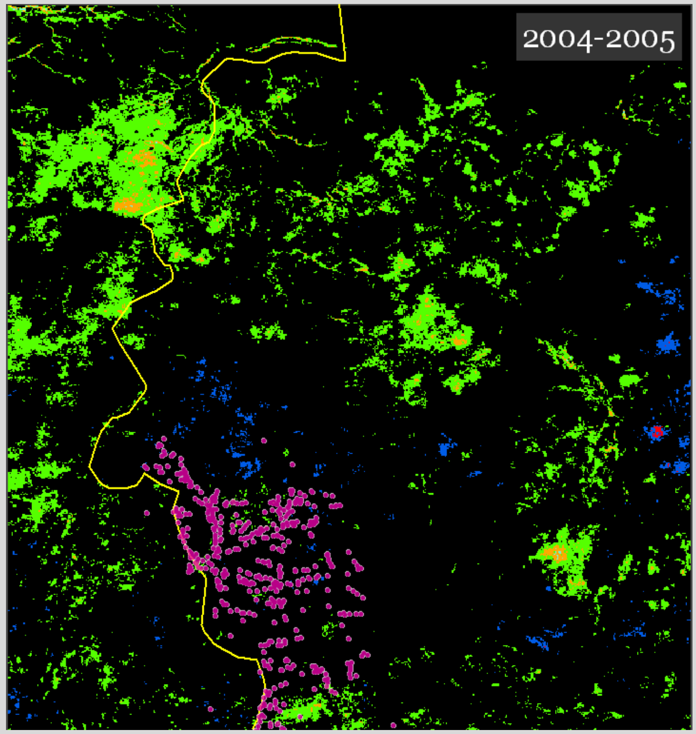


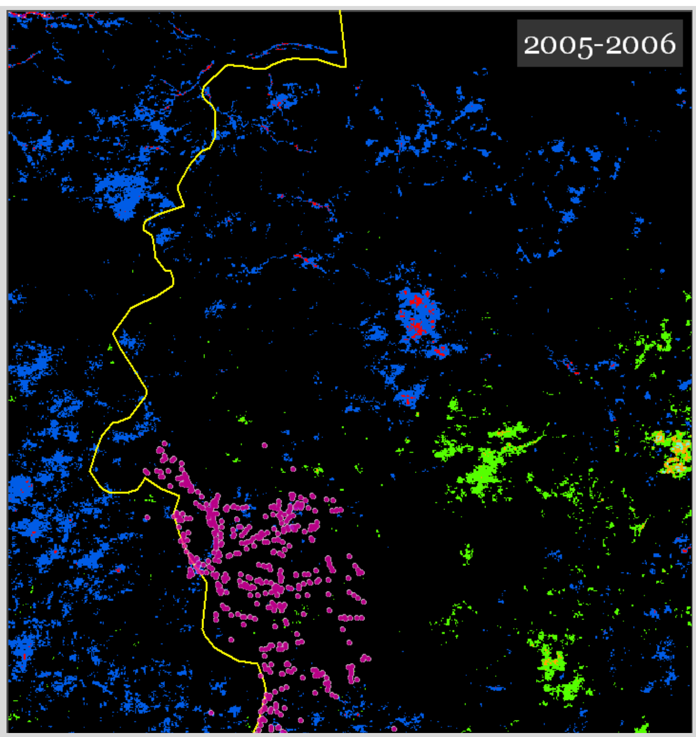
Figure 28. ● *Damaged and Destroyed Villages* reported as of 08-2004 [75]

A third factor, the forced migration of grazing herds into the southern regions of Darfur is discussed in the following section. But clearly there is a spatial correlation between vegetation vigor and high-impact violence. Although climate is a temporal factor, local violence contributes to some of the more spatially significant trends.



Change in Vegetation Vigor -3 -2 -1 0 +1 +2 +3

Figure 29. ● *Damaged and Destroyed Villages* reported as of 08-2006 [76]



Change in Vegetation Vigor -3 -2 -1 0 +1 +2 +3

Figure 30. ● *Damaged and Destroyed Villages* reported as of 08-2006 [77]

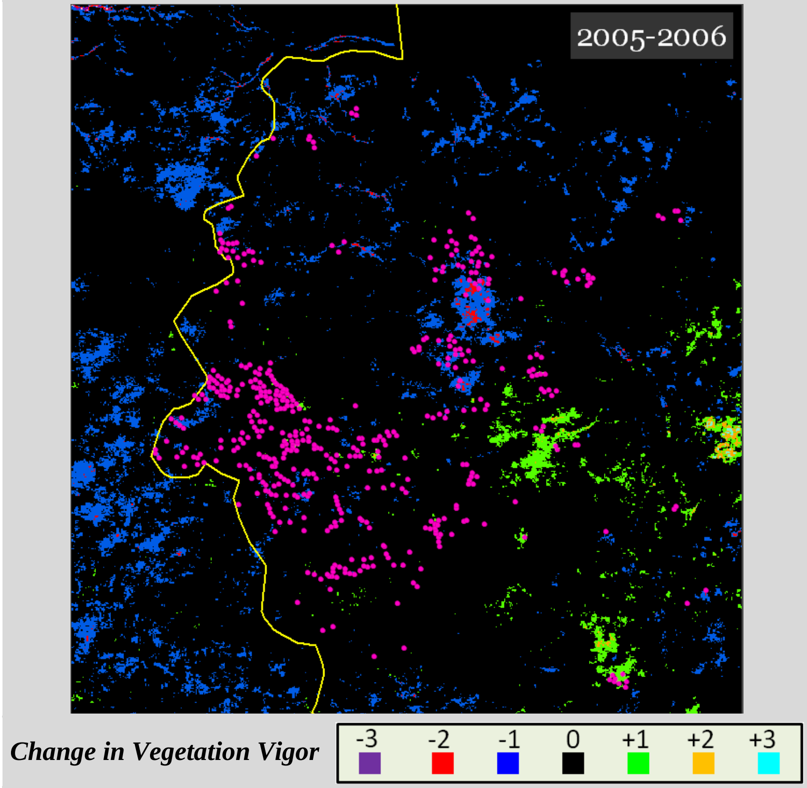


Figure 31. ● *Damaged and Destroyed Villages* reported as of 01-2007 [78]

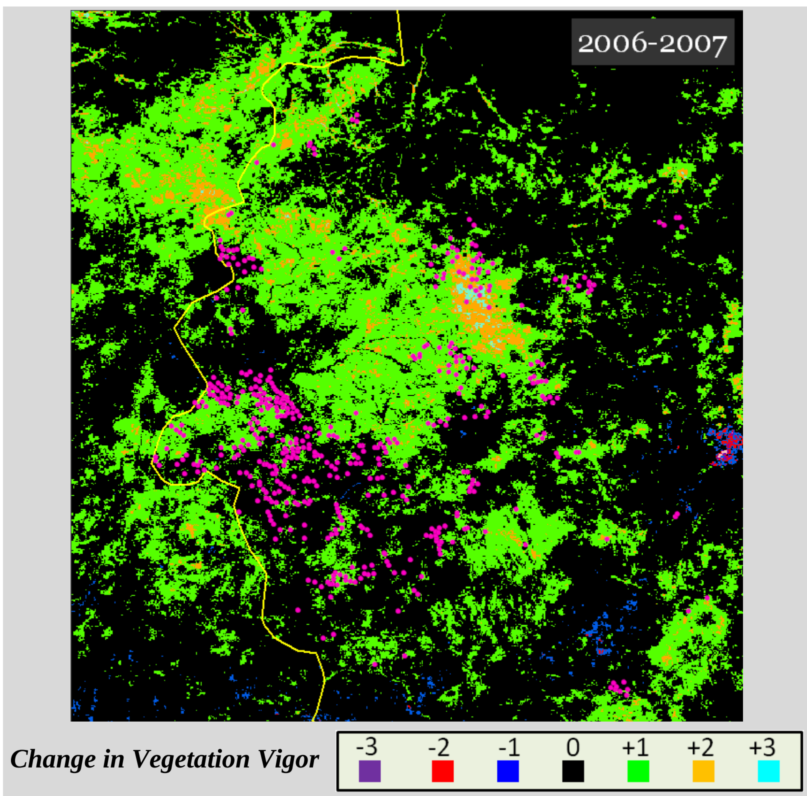


Figure 32. ● *Damaged and Destroyed Villages* reported as of 01-2007 [79]

Mapping Reported Livestock Looting and Environmental Destruction in Darfur 2001-2005

In 2005, the U.N. Food and Agriculture Organisation in collaboration with the North Darfur Veterinary Department issued a report stating that the Darfur crisis had reduced livestock populations, especially sheep, by aerial bombardment in *Dar Zaghawa*, and looting of animals in *Kebkabiya*, *Kutum*, *Tawilla*, and *Korma*[80] (Figure 33). In addition, IDPs from the above areas, who managed to escape in May 2004 with some of their animals, could not sustain them and so sold the animals. By 2005, we see a considerable return of vegetation coverage in the entire affected region. This rebound in vegetation coverage came in spite of a slight decrease in annual rainfall for this region in 2005.

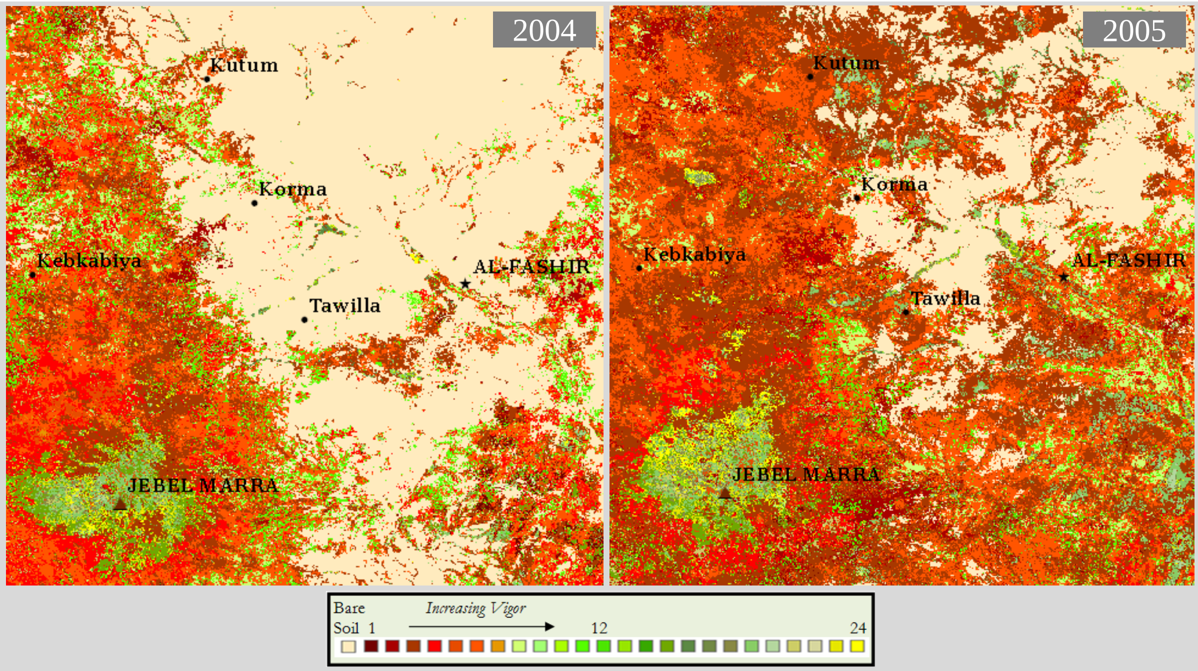


Figure 33. ● Locations of Livestock Looting 2004 [81]

Mapping Changes in Seasonal Livestock Grazing Ranges in Darfur 2003-2005

Traditionally, pastoralists moved north during the rainy season (July to October) and south during the dry season. But since 2003, herds in Darfur have been reported migrating southwards in search of safety, even during the rainy season.[82] The violence has further restricted grazing ranges and, for security reasons, surviving livestock are being contained in concentrated areas, especially in the south, throughout the year.[83]

In a 2005 report, the Southern African Regional Poverty Network (SARPN) described alterations in the traditional seasonal grazing patterns practiced by the different pastoralist tribes.[84] SARPN observed that the conflict had resulted in the concentration of pastoral livestock in the dry season grazing reserves at a time when the livestock should have been in the wet season grazing reserves (Figures 34 and 35). During the wet season, camel herds and sheep used to migrate north up to Giza, Wadi Hawa, and El Altrun, to the southern fringes of the Sahara Desert. Now, camels and sheep belonging to the Abbalas were confined south of the Jebel Mara Mountains.

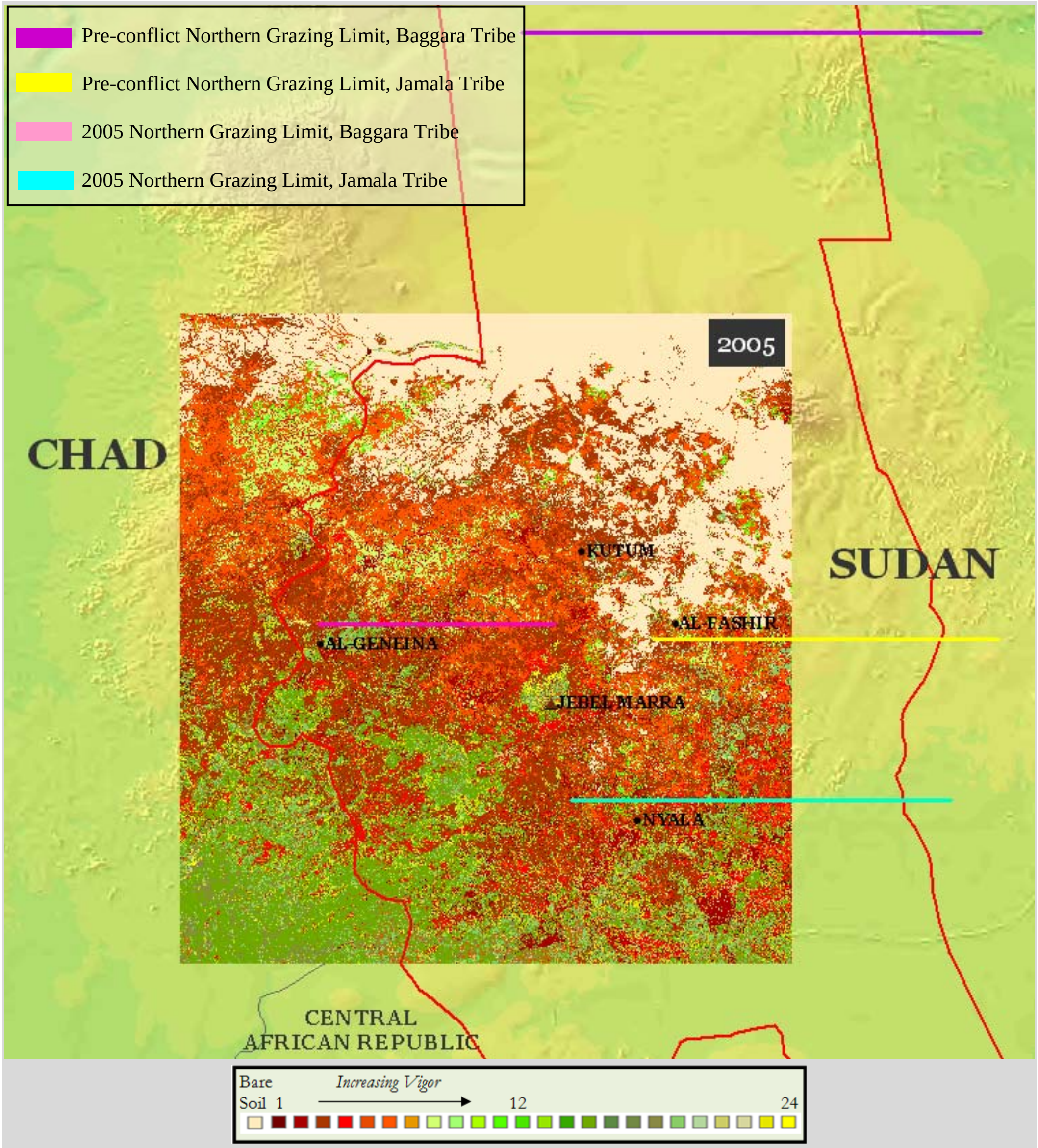


Figure 34. The impact of the genocide on traditional grazing ranges

In addition, the SARPN report observed that cattle belonging to the Baggara were confined around the railway line close to Nyala Town—now the furthest northern point safely reachable—and to Nyala-Kas Zalingi Road in the west. Previously, the Baggaras would travel further north and northeast, close to Al-Fashir Town and Kordofan. SARPN found that, although most of the restricted areas were under the control of the SLA rebels, some other areas had become inaccessible to pastoralists because of banditry, attacks, and counter-attacks among various ethnic groups. SARPN predicted that desperation might persuade pastoralists to move further south than normal—deep into Central African Republic or Bahar Gazal areas—during the middle or end of the dry season. SARPN concluded this could instigate new conflicts with other tribes.

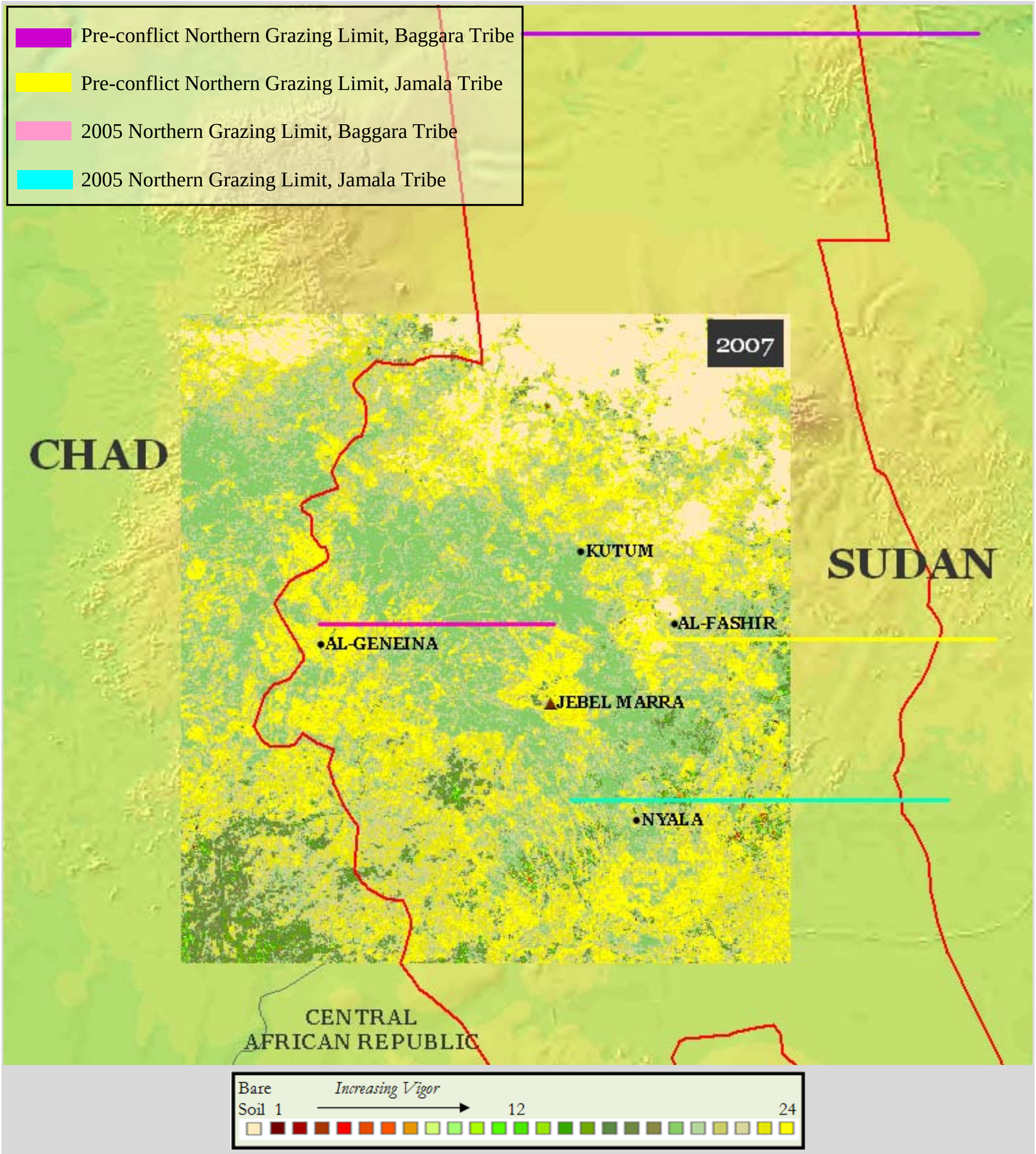


Figure 35. The impact of the genocide on traditional grazing ranges

In its 2005 report, the Food and Agriculture Organisation of the United Nations in collaboration with the North Darfur Veterinary Department also found that livestock movements had been impacted by the crisis.[85] Many Zaghawa pastoralists had relocated to Chad and most other livestock had moved to other locations of security within North Darfur, particularly to areas with tribal affiliations. If livestock grazing remained restricted through 2007, this could have contributed greatly to the rebound in vegetation recorded in remote sensing imagery by 2007.

Mapping Refugee Camps in Darfur and Chad

Two images were prepared showing the locations of refugees reported as of January 2007, plotted on 2005 and 2007 satellite images showing the findings on vegetation phenology or species (Figures 36 and 37). In August 2005, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) issued a report stating that there were just over 1.8 million IDP in Darfur.[86] In November 2005, the office of the High Commissioner for Refugees (UNHCR) reported another 200,000 registered refugees from Darfur located in eastern Chad.[87] Livestock are absolutely fundamental to the people of eastern Chad but the influx of refugees from Darfur with approximately 600,000 of their own animals resulted in conflict over the already sparse resources.[88] In late 2007, villagers in Chad claimed their own animals were dying of starvation in increased numbers because of diminishing grazing ranges, particularly in the dry season.[89] Earlier in 2007, 30 percent of all livestock in one refugee camp, Oure Cassoni (Figure 38), died of starvation.[90]

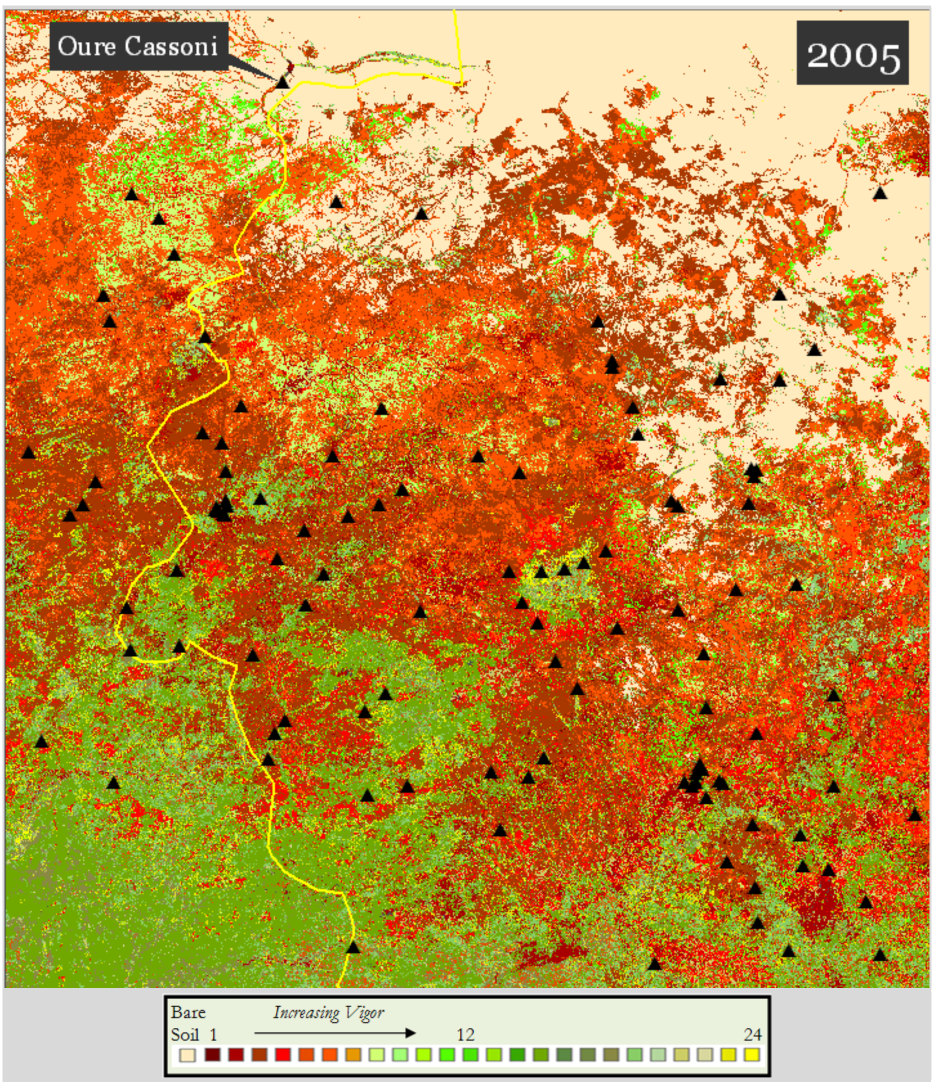


Figure 36. ▲ Refugee Camps reported as of 01-2007 [91]

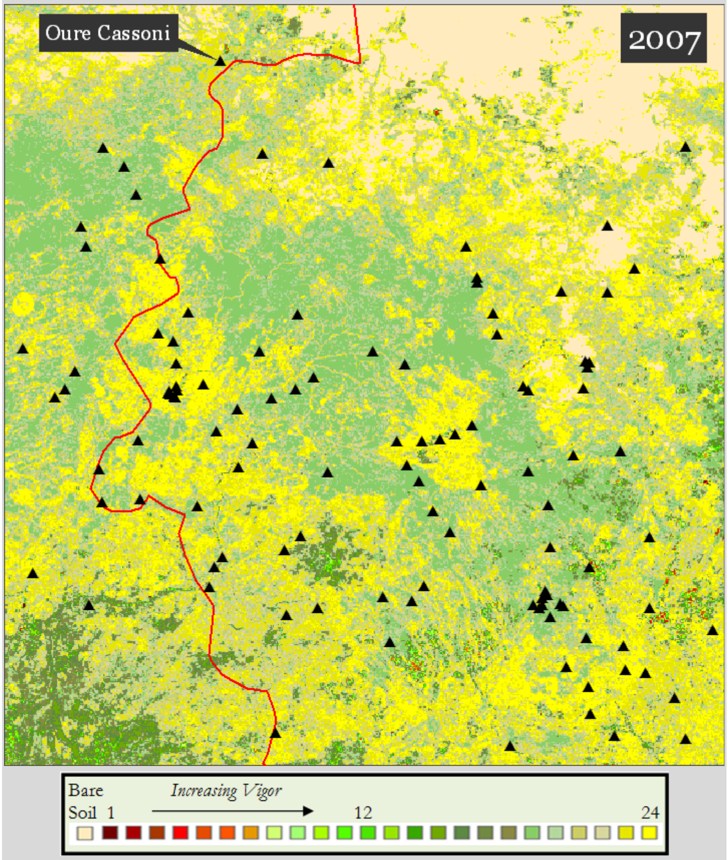


Figure 37. ▲ Refugee Camps reported as of 01-2007 [92]

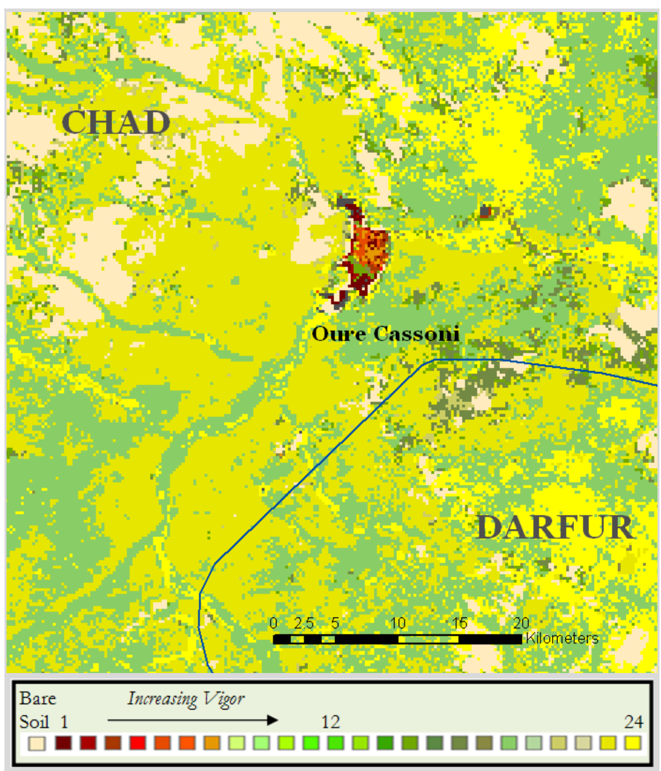


Figure 38. Oure Cassoni refugee camp

Oil in Darfur?

We found two opinions on the role of oil prospects in the genocide and depopulation of Darfur. These different views of the importance of oil are not necessarily mutually exclusive. The first dates from early 2006, the second from two years later:

> Government promotion and development of the petroleum industry in Sudan has involved massive human rights abuses. Patterns of expulsion and displacement preceding oil contracts and exploration are well-documented. As a matter of course, the Government of Sudan (GoS) removes any and all native inhabitants from land where oil exploration is to take place. This has mostly occurred in the South of the country, traditionally inhabited by non-Arab, non-Muslim tribes, where most of Sudan's proven oil reserves are located. Exploration, however, is slated for other tracts in this huge and largely (petroleum-wise) uncharted country and prospecting has recently extended to the eastern section of the country along the Ethiopian border and in the west, in Darfur and elsewhere along the length of the border with Chad.[93]

> Darfur cannot be reduced to a matter of oil and natural resources, though these have played a role. Although the Sudanese have often ascribed foreign interest in Darfur to oil or resource potential, the actual proven reserves have not been extensive. The large oil blocks in Darfur, such as 12B, remain untaken but the potential of undiscovered resource endowments has been a contributing factor. Furthermore, conditions influencing the most recent conflict in Darfur were undoubtedly highlighted by the importance of actual oil money after 1999, contributing to Darfurian rebel grievances and a sense of economic and political marginalization.[94]

Early Exploration

Onshore petroleum activities began in Sudan in 1975 when the government granted the U. S. oil giant Chevron a huge concession in several provinces of south-central Sudan. In 1979, Chevron struck oil near Abu Jabra, and then at al Sharaf, on the border between Darfur and Kordofan. In 1983, when civil war broke out between the Khartoum government and southern rebels of the Sudan People's Liberation Army (SPLA), it began hampering Chevron's oil operations, and by 1990 Chevron had relinquished its holdings completely.[95]

International Oil Investors in Sudan

Currently, Asian countries are the most important investors in Sudan, an increasingly significant source of Sudan's imports, and a dominant feature of Sudan's export profile, largely through oil.[96] China is the foremost external economic actor in Sudan. Other Asian countries investing in Sudan include India, Malaysia, Japan, South Korea, Singapore, Indonesia, and Taiwan.[97] Asian imports constituted 37 per cent of Sudan's total imports in 2005 and 2006, and the percentage of Sudan's exports going to Asia rose to 85 percent in 2005 and 2006, largely accounted for by oil.[98] China is Sudan's top export partner.[99] Since 2000, oil has made up over 98 percent of Sudan's exports to China.[100]

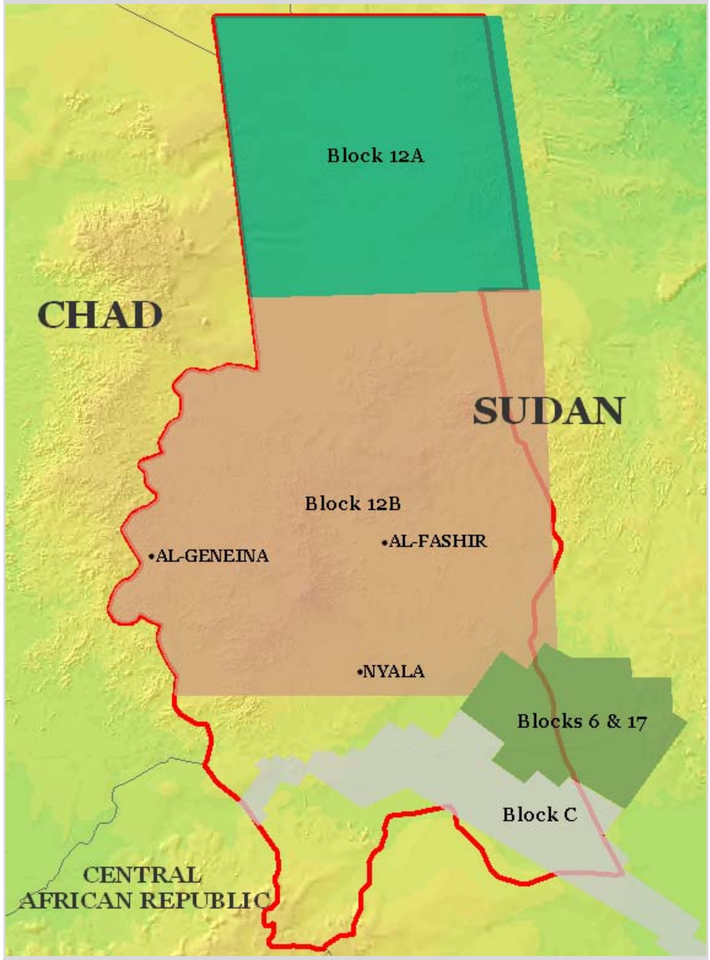


Figure 39. Oil Concessions in Darfur

Mapping Oil Interests in Darfur, Blocks C, 6, 17, 12A, and 12B

In 2006, the United Nations Joint Logistic Centre issued a report on Sudan's fuels.[101] The report included descriptions of oil holdings or blocks, and their present locations and concession owners. Blocks C, 6, 17, 12A, and 12B are partly or wholly within Darfur (Figure 39). Block 12 covers much of North and West Darfur, along the Chad and Libya borders and is split into Blocks 12A (the northernmost part) and 12B (larger and straddling the three administrative districts of Darfur). The northern part of Block C is in South Darfur. It extends into southern Sudan along the southern edges of Blocks 6 and 4.

Block 6 has been producing oil since 2004 and is largely in Southern Darfur, covering 38,468 sq-km. About 20 percent of Sudan's wells have been drilled in this block, of which 95 percent is held by China National Petroleum Company International Sudan (CNPCIS or CNPC) and 5 percent by the state-owned Sudapet (The Sudan National Petroleum Corporation). Its first major production came in late 2004, and in 2006 it was thought to be producing about 40,000 bpd (barrels per day) with an expected increase to 170,000 bpd in coming years.[102] Block C was let in 2003 to the Advanced Petroleum Company (APCO) consortium, comprising Swiss interests, Cliveden (37 percent), the State of Khartoum (10 percent), and Sudanese companies Sudapet (17 percent), Hi-Tech Petroleum (28 percent), and Heglieg Petroleum (8 percent).[103]

A private Indian company, Reliance Energy, as part of a consortium, apparently secured rights to Block 12A in 2006.[104] Concession Block 12B was scheduled to be open for bidding in February 2006 and the Minister of Energy was hopeful that the Indian state-owned ONGC would be able to secure rights.[105] But as of the beginning of 2008, Block 12B apparently remained unclaimed.[106] Much of Block 12B is in the region most impacted by the genocide in Darfur (Figure 40).

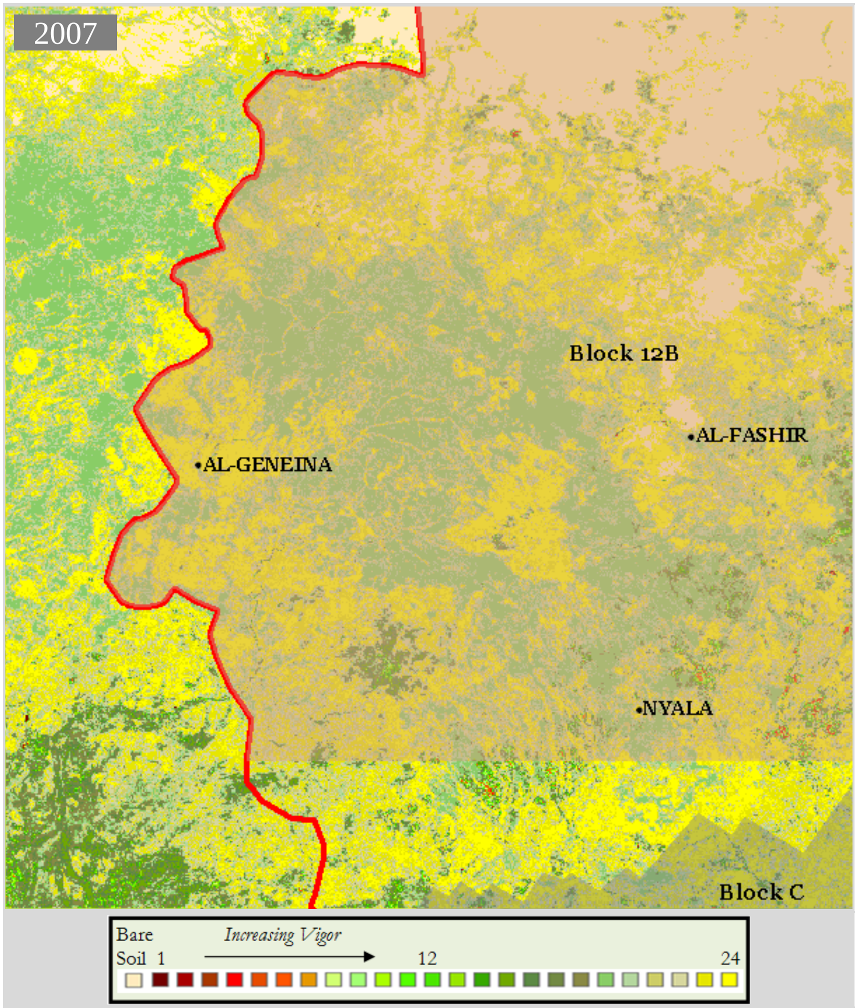


Figure 40. Oil Block 12B

Comparing Khartoum's Strategies—South Sudan and Darfur

Use of the *Janjawiid* as a counterinsurgency paramilitary force was a similar strategy to the use of militias in the Nuba Mountains during the early 1990s and in the contested oilfields of South Sudan starting in 1998. In 1980, eight years after a peace agreement halted the decades long North-South conflict (1955-1972), President Jafar Nimeiri attempted to redraw the Upper Nile southern border to move the Bentiu oil fields into the northern province of Kordofan. In 1983, these efforts caused civil war to break out between the Khartoum government and the southern rebels.

The government armed and deployed militias to combat the rebel threat to oil development. The militias were primarily Arab cattle-herders, Baggara, from western and northern Kordofan and Darfur, known as *murahaleen* (nomadic raiders).[107] In the late 1980s and 1990s, Baggara from south Darfur and south Kordofan served as government militia in Bahr el-Ghazal, and systematically raided cattle stocks of the inhabitants of the oil-rich areas, mostly Nuer and Dinka tribes people.[108] These systematic atrocities committed by the government-sponsored Baggara are hauntingly similar to those later committed by the *Janjawiid*. But we have no evidence of Sudanese government advance plans to target the livestock of African communities in Darfur.[109] Livestock looting may have been a lucrative by-product of the counter-insurgency campaign.[110]

U.N. Resolution 1769

On July 31, 2007, the United Nations Security Council passed Resolution 1769, which was intended to resolve the Darfur conflict.[111] It called for the creation of a joint 26,000 UN-AU (UNAMID) ground force to establish peace in Darfur, replacing the 7,000-member African Union Mission in Sudan. China's vote in favor of this resolution was widely hailed.[112] On December 31, the first U.N. forces deployed in Darfur. As of January 31, 2008, the U.N. reported 9,080 uniformed personnel deployed, including 7,156 troops, 220 military observers, and 1,704 police officers, supported by 66 United Nations Volunteers.[113] According to the news agency *Agence France-Presse* (AFP), as of April 10, 2008, only 1,562 police officers serving in UNAMID have been deployed, far short of the 6,372 police that are supposed to deploy as part of the peacekeeping mission.[114]

China's role in Darfur has been neither marginal, nor direct. Early in the conflict, China reportedly supported Sudan militarily.[115] Furthermore, until Resolution 1769, which China helped broker with Khartoum, Beijing had frustrated direct U.N. involvement in Darfur. Under 1769, however, members of the People's Liberation Army (PLA) will be part of the U.N. deployment to Darfur.[116] The SLA and JEM rebels have reacted violently to China's growing involvement in Darfur, and have issued warnings.

In October 2007, JEM forces attacked the Chinese-owned Greater Nile Petroleum Operating Company (GNPOC) oil fields in southeastern Darfur, which featured hostage-taking and a week-long ultimatum to Beijing to withdraw—described by JEM as "a message to the Chinese companies in particular."[117] In reaction to Chinese participation in the UN–AU Mission in Darfur (UNAMID), the Sudan Liberation Movement's commander for North Darfur, Suleiman Marjan, said "all Darfur is hostile to their presence."[118] Khalil Ibrahim, leader of JEM, reiterated his call on China to "quit Sudan": "I am not saying I will attack them. I will not say I will not attack them. What I am saying is that they are taking our oil for blood."[119]

Conclusion

Part I of this Working Paper shows a direct correlation between the displacement of local populations and the looting of livestock, as evidenced in the rebound of vegetation coverage and vigor in the research area. In Part II, we report evidence that the disruption of seasonal grazing patterns due to the violence likely contributed to this rebound in vegetation by 2007. Prior to the genocide in Darfur, 80 percent of Darfur's economy relied on agricultural activities, primarily livestock. This loss of livestock has had an enormous impact on the peoples of Darfur. The post-2002 violence has disrupted traditional land use patterns and directly damaged land cover. These findings strongly suggest that much of the population of Darfur has been displaced from their normal habitats, and economic and subsistence means.

The overall rebound of vegetation throughout the impacted regions of Darfur, most evident in 2007, is likely the result of two factors: a decrease in overall livestock numbers in Darfur and the difficulty of resettlement under an ongoing threat of violence. Because 2007 also saw the lowest rainfall in more than a decade, traditional land use has been dramatically altered. The livestock wealth has disappeared and, according to recent reports, much of Darfur is facing famine.[120] The rebound of vegetation is a result not of intensified agrarian activities, but of depopulation.

If Khartoum's intent is to clear Darfur of non-Arabs in order to resettle Arab semi-sedentary pastoralists and farmers, this will take time and investment to restock herds and secure territory. Meanwhile, Khartoum has divided, relocated, and is slowly conquering the tribes of Darfur, clearing a path for oil exploitation controlled entirely by Khartoum and its multinational investors.

But more than just monitoring the effects of genocide on the environment in Darfur, our research also shows that it is possible to study the influences of climate and land use on a fragile environment using remote sensing applications. For future research into the prevention of genocide, these types of applications can be useful in understanding and quantifying the factors contributing to environmental strains that can cause violence associated with competition for diminishing resources. If preventive measures can be implemented and enforced based on an understanding of these factors, it might be possible to avoid acts of genocide.

Chronology of Historical Events

1956		Independence marks the end of British-Egyptian condominium rule but Darfur remains politically marginalized within Sudan.
1972		Addis Ababa Agreement, with autonomy for the South, ends a 17-year civil war.
1974		Chevron begins oil exploration.
1981		Chevron discovers oil in commercial quantities, including southern Darfur.
1983		Sudanese President Nimeiri divides the south from one autonomous state into three states, partitioning the oil areas as a part of northern Sudan.
	April	Civil war between northern and southern Sudan reignites.
1984-1985		Drought leads to famine in Darfur.
1987—89		First Arab-Fur war; first organization of *Janjawiid*
1989	June	Omer al Bashir takes power in Khartoum.
1990		Chevron quits and relinquishes all concessions due to the ongoing conflict between northern and southern Sudan
	December	Idriss Deby takes power in Chad.
1994		The Sudanese government divides Darfur into three administrative districts —North Darfur, West Darfur, and South Darfur.
1995	March	Nine *amirs* appointed for the Arabs in Western Darfur
1995—99		Arab—Masalit conflict in Darfur
1997		Clinton issues executive order imposing economic sanctions on Sudan; Khartoum regime adopts "Islamic" constitution.
2000	May	Future organizers and political leaders of JEM publish the *Black Book*, a political and economic anatomy of marginalization in Sudan; the book is widely distributed, especially among Sudanese intellectuals and government officials.
2001		Organization of armed opposition in Darfur.

	August	JEM announces their existence as a political movement.
2002		Conferences held in Nyertete and Kas attempt to mediate the growing conflict in Darfur.
	December	Sudanese Vice-president Ali Osman warns Darfur not to emulate South Sudan and revert to violence.
2003	February	Southern Liberation Army (SLA) announces its existence as a rebel movement.
	March	Justice and Equality Movement (JEM) announces its existence as a rebel movement.
	April	Rebels attack Al-Fashir airport.
	May	Rebels attack Kutum, Mellit, and Tine.
	June	*Janjawiid* counteroffensive begins.
	September	Sudanese government and SLA discuss ceasefire in Abeche, Chad.
2004	January	Sudanese government launches a major offensive in Darfur.
	February	President El Bashir announces victory in Darfur and promises the refugees will be repatriated.
	March	U.N. Coordinator Mukesh Kapila calls Darfur "the world's worst humanitarian crisis' and makes a comparison to Rwanda.
	April	Government-SLA/JEM negotiate in N'Djamena, Chad; the parties agree to a ceasefire and disarmament of *Janjawiid*. But *Janjawiid* violence increase in late April and May.
	May	The U.N. High Commissioner for Human Rights, Bertrand Ramcharan, issues the report *Situation of human rights in the Darfur region of the Sudan* describing the humanitarian consequences of the situation in Darfur as "grave."
	June	U.S. Congress describes Darfur as "genocide."
	July	Joint Communiqué between the Government of Sudan and the United Nations: U.N. passes Resolution 1547 endorsing the conclusions of the Secretary-General with regard to the situation in Sudan, in particular Darfur, and passes Resolution 1556 demanding Sudan disarm militants (*Janjawiid*) in Darfur and facilitate humanitarian assistance.

	August	Sudanese government and the U.N. Special Representative of the Secretary-General, Jan Pronk, sign Darfur Plan of Action; Government and rebels meet in Abuja, Nigeria.
	September	U.S. Secretary of State, Colin Powell, declares crisis in Darfur to be “genocide”; the UN Security Council sets up an Independent Commission of Inquiry into Darfur (ICID).
2005	January	ICID delivers its report and states the Sudanese sponsored violence in Darfur “may amount to crimes against humanity” A Comprehensive Peace Agreement (CPA) is signed between Sudanese government and the (SPLM) in Nairobi, in principle, ending the civil war.
	March	U.N. Security Council passes Resolution 1593, referring the situation in Darfur to the International Criminal Court (ICC). To date no named suspects have been extradited or prosecuted.
	July	Sudanese government, SLA/M, and JEM sign Declaration of Principles in Abuja.
2006	May	Sudanese government and one SLA faction sign Darfur Peace Agreement; the other SLA faction and JEM fail to sign; throughout October 2006 Janjawiid militia launch renewed attacks on villages in eastern Chad.
2007	July	U.N. Resolution 1769 passes, Sudanese government agrees to a joint 26,000 UN-AU (UNAMID) ground force to establish peace in Darfur, replacing the 7,000-member African Union Mission in Sudan.
	December	The first U.N. forces deploy in Darfur.

Glossaries

Glossary of Sociopolitical Terms

Amir	“Prince”: Arab tribal leader under 1995 Khartoum imposed new government system in West Darfur
ICID	International Commission of Inquiry into Darfur, established by UN Security Council in September 2004
IDP	Internally Displaced Persons
Janjawiid	The Janjawiid, whose name means "armed horsemen" in Arabic, is a Sudanese government-supported militia, organized in 2003
JEM	Justice and Equality Movement, announces its existence in March 2003, it is one of two rebel movements in Darfur (see SLA)
SLA/M	Sudan Liberation Army/Movement, announces its existence in February 2003, it is one of two rebel movements in Darfur (see JEM)
SPLA/M	Sudan People’s Liberation Army/Movement

Glossary of Remote Sensing and GIS Terms

Band	A subdivision within an electromagnetic region
ETM+	Enhanced Thematic Mapper Plus
EM	Electromagnetic
EMS	Electromagnetic Spectrum
GIS	Global Information System
Landsat	A series of unmanned NASA earth resource satellites that acquire multispectral images in the visible and IR bands
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
Radiation	Act of giving off electromagnetic energy
RGB	Red, Green, and Blue—the colors used in constructing visible and false color image representations
MIR	Middle Infrared
Spatial Resolution	The ability to distinguish between closely spaced objects on an image; commonly expressed as the most closely spaced line-pairs per unit distance distinguishable
Spectral Reflectance	Reflectance of electromagnetic energy at specified wavelength intervals
Spectral Resolution	Range of electromagnetic wavelengths and intensities recorded by a detector
TM	Thematic Mapper

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