Burned area mapping of southern Africa: case study synthesis and regional application of MODIS data

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Abstract

Systematic monitoring of burned areas is needed by the global change research community as an input to biogeochemical and climate models and is required to understand and model how fire regimes are likely to change as a function of climate, population dynamics, and land use change. This three-year project will conduct synthesis research that integrate results from multiple case studies that address the drivers of Land Cover Land Use Change (LCLUC). The research will utilize the improved remote sensing capabilities provided by MODIS and Landsat ETM+. An applications component is included and meets an important NASA programmatic need to use MODIS data in the applications domain. The applications component follows a guiding Global Observations of Landcover Dynamics (GOLD) / Global Observations of Forest Cover (GOFC) principle that the user community play an active role in defining product requirements and in undertaking product assessment and testing of pre-operational algorithms.

This project is undertaken with collaborators located at case study sites throughout southern Africa. The collaborators will initially evaluate and subsequently utilize satellite data in their decision-making processes for fire management and reporting. Landsat ETM+ data acquired at the case study sites are being used to validate a regional MODIS burned area product. These data will be used to provide an improved understanding of the relationship between fire timing, occurrence, burn size and spatial distribution, land cover change and land use practice. The research will be developed around a number of LCLUC hypotheses that explore the interplay between physical and human variables on fire size and timing. The validated MODIS burned area product will be used to evaluate and establish hypotheses at the regional scale and their robustness will be tested locally using the case study data. The collaborators will identify the pathway to transition these research and product assessment activities into an operational fire monitoring system for southern Africa.

Biomass burning in Southern Africa and information needs

Southern Africa is subjected to some of the most extensive biomass burning in the world. Burning occurs in the dry season from approximately May to November, with perturbations in the timing and amount of burning controlled by anthropogenic and meteorological factors. Fires occur due to both natural and anthropogenic causes, primarily lightening and land management. Fire has local to regional impacts on land use, productivity, carrying capacity, and biodiversity and regional to global impacts on hydrologic, biogeochemical, and atmospheric processes. These impacts are not well understood and are complicated by rapid and substantial social, economic, and environmental changes across the sub-continent. How fire regimes will change as a function of population dynamics and land use change is unclear. Changes in land-use intensity and land-management practices are likely to affect fire regimes directly, through changes in the ways fire is used, and indirectly, by modifying fuel loads and environmental conditions.

There are no adequate data on the occurrence, size distributions or trends in fire numbers or areas burned annually in southern Africa. Local data exist for national parks, forests, and conservation areas, but are not representative of the region as a whole because these lands are largely protected from the influence of people and are subjected to specific fire management policies. Remotely sensed information including the number, spatial location, size and occurrence of fire, in conjunction with ancillary information, are required to understand the basic relationships between fire, population, and land use and to develop a better understanding of the underlying processes. These information are required to allow managers, planners, and policy makers the opportunity to understand fires in their environmental, economic, and social contexts and to formulate their responses accordingly. At regional to global scales this information is required to estimate trace gas and particulate emissions and albedo changes associated with natural and anthropogenic fires, important for understanding loss of biomass and release of carbon and greenhouse gasses to the atmosphere and climate radiative forcing.

MODIS observation of biomass burning

MODIS was launched December 1999 on NASA's first Earth Observing System (EOS-Terra) satellite, and is designed to provide long-term records of the atmospheric, terrestrial, and marine ecosystems. The new spectral bands and spatial resolution of the MODIS instrument provide the means for improved study of fire and burned area at regional to global scales. Global active fire detection is provided using hotspot detection algorithms working on thermal channel data. However, the timing and spatial extent of burning cannot be estimated reliably from these orbital hot spot data, as the satellite may not overpass when burning occurs and because clouds may preclude active fire detection. Burned area mapping algorithms that examine spectral changes, rather than relying on hotspot detection, are generally insensitive to these effects as changes that characterize burned vegetation (deposition of charcoal and ash, removal and alteration of vegetation structure) are temporally persistent. This is the burned area mapping approach developed for application in southern Africa.

MODIS 500m burned area data sets will be made for all of Southern Africa for 2000-2003 using a recently developed algorithm that maps the location and approximate day of burning. The algorithm is an improvement on previous methods due to two main factors, namely the use of a Bi-directional Reflectance Distribution Function (BRDF) model to deal with angular variations observed in multi-temporal satellite data, and the use of a statistical measure to detect change from a previously observed state. The algorithm is adaptive to the number, viewing and illumination geometry of the observations, and to the amount of noise in the data. A BRDF model is inverted against multi-temporal land surface reflectance observations, providing an expectation and uncertainty of subsequent observations through time. The algorithm is applied independently to geolocated pixels over a long time-series of reflectance observations. Large discrepancies between predicted and measured values are attributed to change. A temporal consistency constraint is used to differentiate between temporary changes considered as noise and persistent changes of interest.

Case study sites and collaborators – the Southern Africa Fire Network (SAFNet)

Case study sites have been selected to encompass a range of environmental, land use, and fire management conditions. They are defined by 11 Landsat ETM+ scenes (distributed with approximately increasing plant water availability from west to east). The typical size and spatial distributions of fire vary considerably between the case study sites. The collaborators at each site have existing projects with strong interests for long term fire information to support their research and operational agendas in resource management and environmental assessment. The collaborators are founding members of the Southern Africa Fire Network (SAFNet) which has been stimulated and facilitated directly by this project. The case study sites and collaborators, listed geographically from west to east, are:

- Namibia (Etosha Ecological Institute - *Etosha National Park and surrounding land*)
- Botswana (University of Botswana - *Hainaveld and Gumare*; Harry Oppenheimer Okavango Research Center - *Okavango delta*)
- Zimbabwe (WWF - *Save Valley Conservancy*; Zimbabwe Forestry Commission - *North Western Matebeleland indigenous forests*)
- South Africa (Kruger National Park Scientific Services - *Kruger National Park*)
- Malawi (Forest Research Institute of Malawi - *Chimaliro Forest Reserve*)
- Mozambique (FAO - *Mecuburi Forest Reserve*)

MODIS burned area product validation and assessment

Landsat ETM+ data acquired over the case study sites are being used to validate annual regional MODIS burned area products. The areas that burned between the dates of at least two Landsat acquisitions per site are mapped by the collaborators following a consensus protocol (developed by a traveling meeting held in Zambia and Zimbabwe, 2000). These 30m data are compared with the 500m MODIS burned area product to (i) quantify MODIS product limitations and provide insights into algorithm refinements, (ii) identify what number and spatial configuration of Landsat pixels need to be burned before they are identified in the MODIS product, (iii) quantify regional MODIS burned area estimates and uncertainties, (iv) demonstrate product utility information for different types of user.

The collaborators are beginning to assess and attempt to utilize the MODIS and Landsat ETM+ satellite data in their decision-making processes for fire management and reporting. In the first year, emphasis has been on collaborator assessment of fire information needs, the ability of the MODIS and Landsat products to meet these needs, and the collaborator's institutional capabilities and requirements for handling satellite data. In some cases collaborators have gained familiarity with the products, given feedback on technical issues concerning data distribution, formats and have requested changes. In the second and third years the collaborators will demonstrate the utility of the validated MODIS products within the context of their research and operational fire agendas.

LCLUC Southern Africa fire hypotheses

This project will address and formulate a number of hypotheses by examination of the regional MODIS burned area data, Landsat ETM+ data, and relationships found at the case study sites. The hypotheses are scale dependent, interdependent, and mediated by land use. They explore the interplay between physical and human variables on fire size and timing.

These hypotheses will be negated or confirmed at a regional scale by analyzing the MODIS burned area data in conjunction with regional data on climate, rainfall, vegetation, population density, and land use. The robustness of the hypotheses will be investigated locally using the Landsat ETM+ data in addition to contextual information on rainfall, soils, vegetation, herbivory, land use and local population. Particular attention will be paid to differences between case studies where fire protection/management policies are implemented (the Etosha and Kruger National Park sites) and where they are not (the communal and commercial lands outside the parks and at the other sites). This deductive approach will be complemented by an inductive approach where comparisons between the case study sites will be used to develop new hypotheses. These new hypotheses will be tested by scaling up to a regional scale using the MODIS burned area data.

The relationships that this research will establish will form a basis for future predictive modeling that relate people (e.g., population growth), climate (e.g., interannual variability of rainfall) and fire (e.g., emissions and ecology impacts).

Progress to date

A consensus methodology has been developed for interpretation of Landsat ETM+ data, fieldwork, and burned area mapping required to ensure reliable inter-comparison and scaling up of the case study site data to the regional level. The methodology, originally developed during a week long traveling meeting in Zambia (July 2000), was refined at the Lisbon GOFC-Fire (July 2001) and SAFARI 2000 Siavonga, Zambia (August 2001) meetings.

Daily MODIS land surface reflectance data have been used to produce 2001 and reprocessed 2000 500m burned area data sets for southern Africa. A provisional 2000 500m burned area data set has been provided to pyrogenic emission modelers.

An agreement was brokered with the Landsat ETM+ Project to acquire and store every case study site overpass on the Landsat solid state recorder, downlink these data to EDC DAAC, and report scene availability at a dedicated DAAC ftp site during the 2001 and 2002 burning season. This has enabled timely provision of 28 and 30 Landsat ETM+ scenes to the collaborators in 2000 and 2001 respectively.

Eight laptop computers and hand held GPS have been provided to the collaborators with field work expenses.

This project helped facilitate and organize the Third Meeting of the GOFC/GOLD Southern Africa Fire Network, University of Botswana, Gaborone, Botswana, 29th July - 1st August 2002, develop the SAFNet web site (http://safnet.umd.edu/), and the SAFNet flyer (distributed at the United Nations World Summit on Sustainable Development, August 26 - September 4, 2002).

Publications

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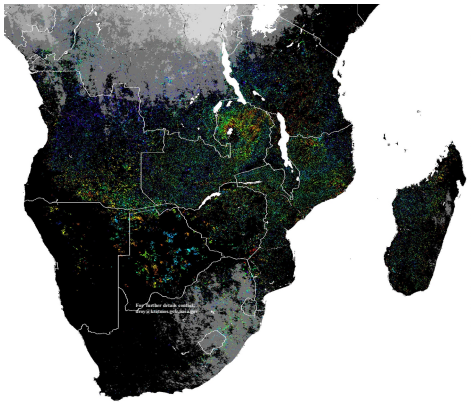
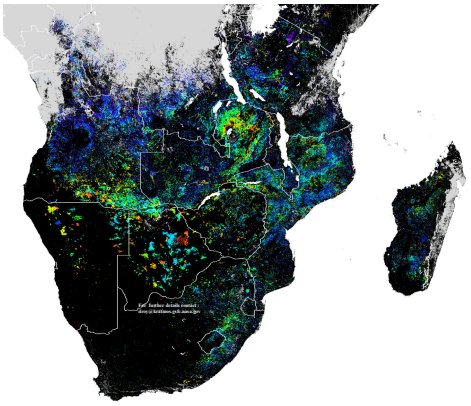
2001 MODIS 1km active fire results (105 days)



MODIS 1km day and night 1km active fire detections. Chronological rainbow color coded to show the day of burning (violet = July 20 to red = November 1 , 2001). Grey shades illustrate the percentage of 1km MODIS day and night active fire detections labeled as cloudy over this period (black = 0-10%, dark grey = 11-20%, grey = 21-30%, light grey = 31-40%).

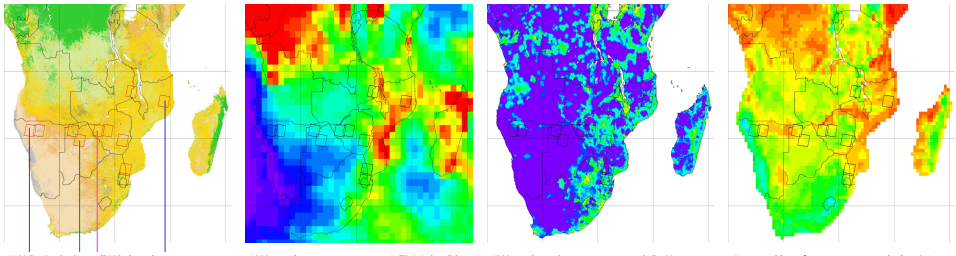
2001 MODIS 500m burned area results (105 days)



MODIS 500m burned area map. Chronological rainbow color coded to show the approximate day of burning (violet = July 20 to red = November 1 , 2001). Grey illustrates where decision could not be made, white illustrates water. The spatio-temporal progression of burning is clearly evident.

Case study sites defined by eleven Landsat ETM+ scenes (~185*185km per scene)

distributed over range of representative burning conditions & where collaborators have existing operational and research fire activities



MODIS 1km landcover (IGBP classes) [EDC DAAC]

1999 annual precipitation estimate, 1° TRMM data (blue < 300mm, yellow > 1000mm, red > 1500mm) [GSFC DAAC]

1990 population density estimate, people/km*km (violet 0-4, .., blue 9-16, .., green 129-256, .., yellow 513-1024, .. Red > 4097) [UNEP GRID]

Mean monthly surface air temperature (violet ~9°C to red ~ 29°C), 0.5° climatology [Leemans & Kramer, 1990]

Example 2001 case study site MODIS 500m burned area validation results

(white squares show ETM+ scene coordinates & vectors show burned areas mapped by collaborators by examination of two ETM+ acquisitions)