The role of Remote Sensing in Wildfire Management

MODIS direct broadcast data for enhanced forecasting and real-time environmental decision making
Natural Disasters

• Natural disasters are continuously increasing in number globally, and there is scientific agreement that:

(i) vulnerability is rising worldwide
(ii) economic damage and the number of affected people will increase
(iii) disasters constitute a severe impediment to economic growth.

• This is especially true for developing countries, which have suffered more than 90% of all fatalities, and have been disproportionately burdened by the economic losses as well, due to, amongst other reasons, their lower GDP, limited reserves, and an underdeveloped insurance industry. While Asia has been confronted with the largest absolute number of annual natural disasters, Africa has seen the most rapid increase in recent years.
Number of natural disaster reported between 1900-2007. (Source: EM-DAT. OFTA/CRED International Disaster Database, Université Catholique de Louvain)
Regional distribution of natural disaster by origin between 1991-2005 (Source: ISDR/EM-DAT. OFTA/CRED International Disaster Database, Université Catholique de Louvain).
Number of reported natural disasters between 1900-2007 per continent. Africa has seen the strongest increase. (Source: EM-DAT. OFTA/CRED International Disaster Database, Université Catholique de Louvain)
Number of affected people per hazard type in Africa, with inset showing the number of fatalities for the Eastern part of the continent (1975-2001).
Background

- Wildfires are one of the major and chronic disasters affecting many countries in Africa.
- Relative to other disasters in the region, wildfires do not necessarily cause many fatalities. However, it causes serious impact on property and human health by smoke pollution.
- Suppression of wildfires demands large amounts of federal resources, costing up to $1.6 billion per year in the USA.
- Historically, as many as 1,500 civilian lives have been lost in a single wildfire incident.
- Indications are that this will get worse with global warming and climate change.
<table>
<thead>
<tr>
<th>Country</th>
<th>Number of fatalities</th>
<th>Number of affected people</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>Benin</td>
<td>2</td>
<td>4,000</td>
</tr>
<tr>
<td>Central African Rep</td>
<td>1</td>
<td>85</td>
</tr>
<tr>
<td>Ghana</td>
<td>4</td>
<td>1,500</td>
</tr>
<tr>
<td>Guinea Bissau</td>
<td>3</td>
<td>1,200</td>
</tr>
<tr>
<td>South Africa</td>
<td>94</td>
<td>1,000</td>
</tr>
<tr>
<td>Sudan</td>
<td>47</td>
<td>0</td>
</tr>
<tr>
<td>Swaziland</td>
<td>2</td>
<td>1,500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>183</strong></td>
<td><strong>9,285</strong></td>
</tr>
</tbody>
</table>

Number of fatalities and affected people per country in Africa due to wildfires (both forest and bushfires) between 1900-2008 (Source: EM-DAT. OFTA/CRED International Disaster Database, Université Catholique de Louvain).
Global fire activity (GBA2000)

Total annual burned area estimated at \( \approx 3.5 \times 10^6 \) km\(^2\)

> 600,000 burn scars detected

Total annual burned area estimated at \( \approx 3.5 \times 10^6 \) km\(^2\)

> 600,000 burn scars

[Tansey et al., Climatic Change 2004]
MODIS BA 2000 - 2008

Slide: Sally Archibald
Slide: Sally Archibald
Fire Management and Information Needs

• Fire Management comprises activities designed to control the frequency, area, intensity or impact of fire.

• These activities ranges from national to local scale and can be undertaken in different institutional, economic and geographic contexts.

• Effective management is reliant on reliable information on which to base appropriate decisions and actions.

• Information will be required at many different stages of fire management - “Fire Management Loop”
Fire Management Loop

- Policies
- Fire Management Objectives
- Information
- Monitoring & Evaluation
- Strategies & Res. Allocations
- Operational Fire Management & Research
Fire Management Objectives

• This results from fire related objectives
• Appropriate objectives require scientific knowledge and up to date monitoring information
• Examples such as vegetation status, fire locations, land use and social economic context
Policies

• At national/governmental level provide legal long term framework to undertake actions.

• Policy creation is however dependent on a good knowledge of the fire issues and their evolution.
Strategies

• Short term framework to prioritise fire management activities
• Development of clear objectives
• Include research and capacity building in fire management
Operational Fire Management

• Concerns the implementation of fire strategy

• Daily activities dependant on up to date information such as fire frequencies, fuel loads and weather conditions in the management area.
Monitoring and evaluation

• Assessment of the effectiveness of different strategies, to document current situations and to learn from the past in order to adapt and improve knowledge management activities
A Fire Management Information System

• An important tool to support integrated fire management.
• Allows the incorporation of various sources of information such as static maps, historical fire locations and vegetation indices
• Could include modelling tools, such as fire spread models
Benefits of Remote Sensing data to Fire Management

• Often less expensive and faster to obtain data than acquiring data from the ground
• It permits the capturing of data across a wider EM spectrum than can be seen by the human eye
• Observations can cover large areas at a times, including remote and inaccessible areas
• It provides frequent updates
• Observations are consistent and objective
Remote Sensing: Introduction

“Remote sensing is the science and art of obtaining information about an object, area or phenomena through the analysis of data acquired by a device that is not in contact with the object, area or phenomena under investigation”

_Lillesand and Kiefer (2000)_
Remote Sensing: Introduction

Key points:
• Spatial resolution
• Swath Width
• Temporal Resolution
• Spectral Resolution
• Cost
• Operational vs. Research satellites
• Data Access
Spatial Resolution: Concept

Half
Quarter
Eighth
Spatial Resolution (Various sensors)

Landsat B2
Landsat B6
Ikonos 4m*
Spot Pan
Spot Xi B3

*1m not available for comparison
Comparison of resolution between SPOT Pan (10m GSD) at top and Russian KVR (2m GSD) at bottom.
Swath Width
Temporal Resolution

The ability to collect imagery of the same area of the Earth's surface at different periods of time is one of the most important elements for applying remote sensing data. Spectral characteristics of features may change over time and these changes can be detected by collecting and comparing multi-temporal imagery.
Spectral Resolution
(Landsat 7)
The diagram illustrates the spectrum of solar radiation and the reflected and emitted radiation bands. It highlights the following key points:

**Reflected Solar Radiation**
- Blue: Atmospheric Scattering, Chlorophyll Absorption at 0.4 μm, Best Clear Water Penetration
- Green: Clear Water Penetration, Contrast Between Clear and Turbid Water, Discrimination of Oil on Water, Reflectance Peak for Vegetation
- Red: Chlorophyll Absorption, Limited Water Penetration

**Emitted Radiation**
- SWIR: Discrimination of Oil on Water, Moisture Status of Soil and Vegetation, Contrast Between Vegetation Types
- MWIR: Smoke Penetration, Daytime Reflectance Mixed with Emission, Nighttime Emission
- LWIR: Thermal Analysis, Some Vegetation Density and Cover Type, Diurnal and Seasonal

**Reflective IR**
- Internal Leaf Tissue Strongly Reflective
  - 0.76 μm - 0.9 μm for Shoreline Mapping
  - 0.76 μm - 0.9 μm for Biomass
  - Some Evergreen and Deciduous Separation
Black Body Radiation Distribution

Sun’s temperature

Wildfire’s temperature

Earth’s surface temperature
Data Cost

• Satellite data costs vary from free, unlimited access to satellite sensors like AVHRR and MODIS to high costs for high resolution data such as QuickBird.

• American low and medium resolution satellites normally free, while European satellites in most cases still have license requirements

• Free Landsat 7 data available from USGS
Operational vs. Research Satellites

• Operational satellite programmes are organised to guarantee the routine availability of data over a specific period of time to ensure consistent products – Example AVHRR (1981 – 2008)

• Research satellites are aimed to demonstrate new technologies and cannot guarantee data availability. Example MODIS (2000 – 2008)
Data Access

• Example: MODIS data
• Internet (http://edcimswww.cr.usgs.gov/pub/imswelcome/)
• Direct Readout reception stations
Remote Sensing products for Fire Management

Prefire activities
- Vegetation/fuels mapping
- Risk assessment
- Fuels treatments
- Fire weather prediction
- Fire preparedness training
- Resource allocation

Continuous activities
- Community awareness
- Planning and budgeting
- Performance measurement

During-fire activities
- Fire detection
- Dispatch
- Fire management/response
- Fire monitoring
- Fire mapping

Postfire activities
- Impact assessment
- Emergency stabilization
- Rehabilitation
- Monitoring

Source: GAO.
Pre-fire activities

- Vegetation/Fuel mapping
- Fire Weather prediction
- Risk assessment
Fire Risk Assessment

- Surface Fuels
- Canopy Fuels
- Historical Fire Occurrence
- Rate of Spread
- Wildland Fire Susceptibility Index
- Fire Effects (Environmental and Suppression)
- Levels of Concern (WPSI and Fire Effects)
During-fire activities

• Active fire detection
• Active fire monitoring
• Fire mapping
Active Fire Product

• Mid-infrared (3 – 4 µm) and thermal bands (10 – 12 µm) onboard satellite sensors permits the detection of active fires on the Earth's surface.

• The essence of fire detection lies in significantly enhanced radiance emitted in the mid-infrared region for typical fire temperatures, as governed by the Planck function.

• The mid-infrared channel is thus highly sensitive to the presence of fires and most useful for fire detection.
Value of active fire data

- Documenting the extent of individual fire fronts and the size of fires
- Document the trends over years
- Document the type of fires according to the vegetation in which they occur
- Identify areas of particular human pressure on natural forest
- Monitoring and evaluating fire strategies (prescribed burning, …)
Main sensors supporting active fire detection

- NOAA-AVHRR
- TERRA/AQUA MODIS
- FY-1/3

<table>
<thead>
<tr>
<th>Channel</th>
<th>Center Wavelength (µm)</th>
<th>Maximum T (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS Ch. 21</td>
<td>3.959</td>
<td>500</td>
</tr>
<tr>
<td>MODIS Ch. 22</td>
<td>3.959</td>
<td>328</td>
</tr>
<tr>
<td>MODIS Ch. 31</td>
<td>11.03</td>
<td>400 (Terra MODIS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>340 (Aqua MODIS)</td>
</tr>
<tr>
<td>AVHRR Ch. 3</td>
<td>~3.75</td>
<td>~325</td>
</tr>
<tr>
<td>AVHRR Ch. 4</td>
<td>~10.8</td>
<td>~325</td>
</tr>
</tbody>
</table>
Goal: Establish a geostationary global fire network

Global Geostationary Active Fire Monitoring Capabilities

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Active Fire Spectral Bands</th>
<th>Resolution IGFOV (km)</th>
<th>SSR (km)</th>
<th>Full Disk Coverage</th>
<th>3.9 μm Saturation Temperature (K)</th>
<th>Minimum Fire Size at Equator (at 750 K) (hectares)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOES-E/-W Imager</td>
<td>1 visible 3.9 and 10.7 μm</td>
<td>1.0</td>
<td>0.57</td>
<td>3 hours</td>
<td>&gt;335 K (G-11)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0 (8.0)</td>
<td>2.3</td>
<td></td>
<td>&gt;335 K (G-12)</td>
<td></td>
</tr>
<tr>
<td>GOES-10 Imager (South America, 2006)</td>
<td>1 visible 3.9 and 10.7 μm</td>
<td>1.0</td>
<td>0.57</td>
<td>3 hours (Full Disk)15-min (SA)</td>
<td>~322 K (G-10)</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0 (8.0)</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MSG SEVIRI</td>
<td>1 HRV 1.6, 3.9 and 10.8 μm</td>
<td>1.6</td>
<td>1.0</td>
<td>15 minutes</td>
<td>~335 K</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>2 visible 4.8</td>
<td>4.8</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FY-2C SVISSR (FY-2D, 2006)</td>
<td>1 visible 3.75 and 10.8 μm</td>
<td>1.25</td>
<td>5.0</td>
<td>30 minutes</td>
<td>~330 K (?)</td>
<td></td>
</tr>
<tr>
<td>MTSAT-1R JAMI (HRIT)</td>
<td>1 visible 3.7 and 10.8 μm</td>
<td>1.0</td>
<td>4.0</td>
<td>1 hour</td>
<td>~320 K</td>
<td>0.15</td>
</tr>
<tr>
<td>INSAT-3D (4th Qtr, 2007)</td>
<td>1 vis. 1.6 μm 3.9 and 10.7 μm</td>
<td>1.0</td>
<td>0.57 ?</td>
<td>30 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0</td>
<td>2.3 ?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GOMS Elektro N2 MSU-G (2010)</td>
<td>3 visible 1.6, 3.75 and 10.7 μm</td>
<td>1.0 km</td>
<td>4.0 km</td>
<td>30 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMS (2008)</td>
<td>1 visible 3.9 and 10.7 μm</td>
<td>1.0 km</td>
<td>4.0 km</td>
<td>30 minutes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Active fire interpretation

- Fire and pixel size can vary due to saturation and fire size
- Fire location accuracy dependant on satellite geometric accuracy
- Only fires actively burning at time of overpass will be detected
- Fires obscured by clouds could be missed
A fire that is considered one incident on the ground (and being fought) may consist of many MODIS fire events. Movement of the fire can be observed by displaying daily fire events in different colours.
Post-fire activities

• Calculation of area affected
• Impact assessment
Burned area principles

The detection of burned area by remote sensing satellites are dependant on:

1. The removal of vegetation
2. Combustion residue deposited on the ground
3. Increased surface temperature between burned surface and surrounding vegetation
Burned area as baseline data

Burned area can provide important information on fire regimes:

• Fire frequency - combining multiple years of burned area maps

• Fire intensity and severity – inferred from date and pattern of burns. Early season less intense while end of season more intense fires normally.
Main sensors supporting burned area mapping

• Landsat and Spot
  – manual image interpretation
  – 10 – 30 m resolution
  – Single scene

• MODIS
  – Existing operational product (MCD45)
  – 500 m resolution
  – Monthly composite
Burned area products

Choose format of burned area product:
Annual maps
Multi-temporal inter annual maps
Fire intensity
Fire severity

Decide on appropriate scale of mapping:
Area to be covered
Level of detail

Select suitable sources of data:
Spot, Landsat, MODIS, AVHRR

Apply appropriate mapping method on data

Assess map accuracy using reference data
Factors influencing burned area products

- Based on lower resolution data (MODIS – 500m and AVHRR – 1km)
- BRDF effects causing differences in surface reflectance
- Clouds and cloud shadows
- Vegetation type and re-growth rates
MODIS burned area product

- MODIS Level 3 Monthly tiled 500m Burned Area Product (MCD45A1)
- The algorithm developed for the MCD45 product uses a bi-directional reflectance (BRDF) model-based change detection approach
- It detects the approximate date of burning by locating the occurrence of rapid changes in daily MODIS reflectance time series
- Because of the BRDF model incorporated in the algorithm, the production of one month of MCD45 requires the availability of 90 days of daily MODIS data
- Time series available for download
Implementing Remote Sensing in a Fire Management Context

• Skilled personnel
  Combination of remote sensing skills and field experience essential
• Access to relevant information
  Staff should have access to publications and literature
• Infrastructure
  Computers hardware and software including GIS tools
• Adequate budgets to maintain information systems
Future Satellites

• NPP
National Polar-Orbiting Operational Environmental Satellite System (*NPOESS*) Preparatory Project (*NPP*) - 2011

• NPOESS
The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is the next generation of low earth orbiting environmental satellites to be launch in 2013

• MTG
Meteosat Third Generation to be launch 2015
Examples of applications of Remote Sensing products in Fire Management in Africa

• Kruger National Park fire disaster (2001)

• Botswana fire management
Kruger Park Fires

23 People died
31 Elephants
2 Rhino’s

4 Sept 2001
Example of Department of Forestry & Range Resources, Botswana

• Daily active fire data in txt from CSIR (MODIS and EUMETSAT) via automated mirror FTP

• Near real time satellite image (250m) ground from MODIS Rapid Response Center for burned area measurements

• Historical MODIS active fire data from University of Maryland

• Decoded GTS based weather data via EUMETSAT data stream to calculate Fire Danger

Anja A. Hoffmann, K. Dintwe, B. Phillimon, Cheewai Lai, Minnie Wong & Diane Davies – 7th SAFNET meeting
MODIS txt
~ 3/day for AOI

EUMETSAT
Every 15min

MySQL data base
AOI Botswana

Up-to date txt file of
MODIS &
EUMETSAT

Archive of
daily txt MODIS &
EUMETSAT file

Generation of
monthly, mtd, ytd
MODIS &
EUMETSAT file

Botswana Mosaic
of 250 m MODIS for
burned area
delineation

Automated mirror FTP
per user defined time
interval

Automated mirror FTP
per user defined time
interval
Daily Use of AFIS data

MODIS FIRE EVENTS 18 -19 (morning) September 2008

The MODIS sensor on board the Aqua & Terra satellite system provides the capability to detect fire activity in near-real time based on temperature measurements. Each MODIS fire location (colored dot) indicates an area on the image which is partly or entirely burning by one or more fires. Different colors indicate consecutive dates as shown in the legend.

A fire that is being fought on the ground may consist of several MODIS fire events. Different colors may show movement of the fire on the ground.

The MODIS sensor is not able to penetrate smoke.

The MODIS data is kindly provided by the South African Council for Scientific & Industrial Research (CSIR). Fire data updates through FTP can be maximum six times per day.
Botswana Fire Events 2001 - 2007 based on Aqua-Terra Modis

<table>
<thead>
<tr>
<th>Year</th>
<th>Aqua</th>
<th>Terra</th>
<th>Total number of Fire Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>0</td>
<td>7302</td>
<td>7302</td>
</tr>
<tr>
<td>2002</td>
<td>2126</td>
<td>12529</td>
<td>14655</td>
</tr>
<tr>
<td>2003</td>
<td>3203</td>
<td>2227</td>
<td>5430</td>
</tr>
<tr>
<td>2004</td>
<td>2076</td>
<td>1705</td>
<td>3781</td>
</tr>
<tr>
<td>2005</td>
<td>4078</td>
<td>3755</td>
<td>7833</td>
</tr>
<tr>
<td>2006</td>
<td>7363</td>
<td>5079</td>
<td>12442</td>
</tr>
<tr>
<td>2007</td>
<td>4630</td>
<td>3440</td>
<td>8070</td>
</tr>
</tbody>
</table>
Historical Analysis of the MODIS data
Burned Area in 2007

The burned area is on-screen delineated from MODIS satellite images (250m, 7,2,1) in ArcGIS by DFRR.
Area Fire Affected per Land Use and Hectares

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest Reserves</td>
<td></td>
</tr>
<tr>
<td>BLDC Ranches</td>
<td></td>
</tr>
<tr>
<td>Commercial Farms</td>
<td></td>
</tr>
<tr>
<td>Freehold Farms</td>
<td></td>
</tr>
<tr>
<td>Game Reserves</td>
<td></td>
</tr>
<tr>
<td>Leasehold Farms</td>
<td></td>
</tr>
<tr>
<td>National Parks</td>
<td></td>
</tr>
<tr>
<td>Wildlife Mgmt Area</td>
<td></td>
</tr>
<tr>
<td>Quarantine camp</td>
<td></td>
</tr>
<tr>
<td>TGLP Ranches</td>
<td></td>
</tr>
<tr>
<td>Pastoral/communal/residential areas</td>
<td></td>
</tr>
</tbody>
</table>

The chart shows the area fire affected per land use and hectares. Each category is represented by a different color, and the y-axis indicates the hectares affected.
Determination of Readiness Levels following Fire Danger based on weather data