REAL TIME MONITORING OF ACTIVE FOREST FIRES FOR BETTER NATURAL RESOURCE MANAGEMENT IN DEVELOPING COUNTRIES

I.D. Downey, P. Ceccato, S.P. Flasse, P. Navarro[1], S.N. Trigg[2], J.B. Williams

Environmental Science Department, Natural Resources Institute, Central Avenue,

Chatham Maritime, Kent, ME4 4TB, UK

Tel: +44-1634-880088, Fax: +44-1634-80066/77

[1] Nicaragua - UK Land Resources Project, Managua, Nicaragua

[2] Indonesia - UK Environment Monitoring Project, Jakarta, Indonesia

ABSTRACT

The Natural Resources Institute (NRI) is an executive agency of Britain's Overseas Development Organisation (ODA). As an integral part of the British governments overseas aid programme, the principal aim of the institutes work is to alleviate poverty and hardship in developing countries by increasing the productivity of their renewable natural resources. Remote sensing offers a powerful means of providing information to address theses problems. NRI has significant experience of operational and experimental vegetation fire detection through UK Overseas Development Administration (ODA) funded projects in Africa, Southeast Asia and Latin America. Regular satellite overviews of daily fire activity during the burning seasons provide a unique measure of the scale, location, timing and (likely) intensity of these events. The use of dynamic systems that are continuously updated, provide timely information on burn events and 'account' for changes in natural resources over time. Research and operational work to provide developing countries with the tools to carry out real time monitoring of active vegetation fires by direct reception of satellite data is ongoing. Already, provincial and national forestry departments are beginning to use NOAA satellites for fire detection, fire risk assessment, and determination of macro changes in vegetation status. These activities are described for different regions of the world.

INTRODUCTION

Fire is a key indicator of both anthropogenic and natural biomass burning. Significant vegetation fires have occurred in North America, Australia, the Mediterranean and Southeast Asia in recent years (ECE/FAO 1995) and the marked rise in the global population over the last 50 years has resulted in a corresponding increase in pressure on vegetation resources. Earth observation (EO) remote sensing and GIS technologies are the most practical and feasible means to quantify and monitor these biomass burning events at the regional or global scale. NRI is conducting ongoing research and operational work to provide developing countries with the tools to carry out at real time monitoring of active forest and other vegetation fires by direct reception of satellite data. Regular satellite overviews of daily fire activity during the burning seasons provide a unique measure of the scale, location, timing and (likely) intensity of these events.

Background

Clearance of vegetation for agriculture, logging access, settlement, hunting, poaching, and even some tree species regeneration all involve fire to some extent. The presence of too many fires over time can cause biodiversity loss and, furthermore, uncontrolled and natural wild fires consume vast areas of vegetation causing significant biomass loss. Also, burning releases large amounts of gases (e.g. CH_4, CO, CO_2, N_2O, NO), volatile compounds and aerosols into the atmosphere which can have effects on climate, weather and alteration of the energy balance at the Earth surface (Justice 1994). Vegetation fires are a global problem, affecting most of the worlds ecosystems and leading to increased soil erosion, a loss of species, habitats and biodiversity. Fire is therefore a key indicator of anthropogenic activity and associated biomass burning. There is often an obvious and immediate short term relevance in monitoring and managing fires but there is also a longer term requirement of trying to understand and

determine the nature and extent of fire activity so that resources and policies can be prioritised and monitored to provide an important contribution to better natural resource management overall.
The most practical and feasible means to quantify and monitor these biomass burning events at the regional or global scale is to utilise Earth observation remote sensing and GIS technologies. NOAA satellite data offer one of the most practical tools for detecting and monitoring biomass burning activity (Robinson 1991). Data from NOAA satellites have been available for over 10 years without interruption. The 12 hour repeat coverage capability is a major advantage of NOAA platforms and the only practical way to attempt to detect short lived fire events operationally and to provide enough observations over time to extract longer term trends of fire activity. The wide area coverage and local reception capabilities also make NOAA data ideal for early warning operations. This fire information can be directly useful. Regular satellite overviews of daily fire activity during the burning seasons provides a unique measure of the scale, location, timing and (likely) intensity of these events. Areas where burning is considered a problem can be identified easily and such information provides important inputs to developing sound natural resources and fire management policies.

Although the technical capability of using satellites to monitor vegetation fires is well known, its uptake has not been widespread often because data collection often tends to be limited to highly centralised facilities. Such centralised facilities may not be ideal for delivering timely fire information to where it is often most needed i.e., to end users in forestry offices at the provincial to village level. NRI experience has shown that PC based NOAA satellite receivers, installed in provincial forestry offices can provide a cost-effective means of monitoring fires at the village to provincial level.

The Environmental Science Department at NRI has developed (in collaboration with Bradford University, Reading University TAMSAT Group and Silsoe College) an approach known as Local Application of Remote Sensing Technology (LARST). One of the principal outputs of this approach has been the development of robust low cost satellite data receivers for the NOAA and Meteosat satellites. Forest fire detection is one of the key applications of the NOAA reception systems world-wide. LARST Systems are based on simple, robust principles that ensure their sustainability and longevity of operation. They are based on PC computers and, through automating as much of the process of data capture as possible, require minimal operator intervention. The receiver system comprises a 60cm x 60cm aperture horn antenna, a receiver unit, 486-PC micro-computer(s) and a printer. Twin polarised low noise amplifiers allow data to be received from the satellite throughout the pass with uniformly high quality, to within 5° of the visible horizon. The hardware is designed to be low-cost, modular and reliable. The horn antenna can be motor driven for convenience, or hand-powered for reliable reception under all circumstances, even when precise positions of the NOAA satellites are not known. The minimum system costs little more than a quality off-road vehicle, but allows national coverage on a daily basis with almost no running costs. Most often the requirement is for reception of a local 'window' of data with rapid processing, but the system can receive and archive data from the full pass, if so required. The software is DOS based.

The receiver systems are usually installed in the host country as part of an aid donor funded technical cooperation project or as a research activity in support of such a project. The systems are most often installed and operated by national or regional institutes to provide rapid, direct access to Earth observation data in-country. For developing countries experiencing increased pressure on their natural resource base, the generation of such rapid, overview information on the state of natural resources allows the development and direct application of timely and improved natural resource monitoring and management.

Over two dozen installations have been established in regions of the world where data acquisition was previously difficult or badly served. Table 1 indicates the present installed base where systems have been used for fire detection. The overall installed base is scheduled to increase during 1995/96. One overall technical objective is to produce sustainable, low cost, satellite fire monitoring systems which can be operated effectively and routinely by local staff, and the information used by concession, conservation and forest management officers. They are seen as a practical means of increasing and improving resource managers awareness of fire events and capabilities for intervention. This information is seen as a crucial part of sustainable management.

Detecting Active Fires in Real-Time

Active fires can be detected by NOAA satellites. Channel 3 of the AVHRR instrument is particularly sensitive to the thermal signal of active fires and surprisingly small fires can be detected despite the nominal 1km resolution of AVHRR data. Preliminary verification of a joint project between the Brazilian Space Agency (INPE) and the Brazilian Institute of Natural Resources (IBAMA) showed that over 90% of the fires identified by AVHRR were matched by field located burn scars or active fires within 500 metres of given AVHRR fire locations (Justice and Dowty 1993).

AVHRR data are continuously transmitted from the NOAA weather satellites so that any suitable receiver can access the direct broadcast data. The data are freely available and may be interpreted in near real-time, using relatively modest and user friendly PC based kits. The data are suitable for large scale surveys and for monitoring widespread environmental phenomena such as changes in vegetation condition and fire hazard and are suitable for monitoring global and regional biomass burning and forest clearance (Ehrlich et al 1994). The AVHRR instrument has been used operationally for fire detection over large land areas (in Africa, USA, Australia and South America), for monitoring forest fires and for estimating forest cover and condition (Levine 1991, Crutzen and Goldammer 1993).

Raw AVHRR data are typically processed through a number of steps before any analysis (e.g. fire detection) takes place. These include radiometric calibration of raw digital counts to radiance (and thus, brightness temperature), some atmospheric correction, land-water boundary definition and cloud screening. Most fire detection algorithms do not require atmospheric correction for successful implementation. However, some approaches have a degree of implicit cloud screening tests as part of the fire detection process.

Table 1 - LARST Installed Base for Fire Detection - May 1995

Installation	Year	Funding	Systems	Applications	Training
Central African Republic-Bangui	1993-94	EU/NRED FRP	NOAA#	Fire and vegetation monitoring	Local
Chile - Punta Arenas	1994	ODA TC	NOAA	Ozone hole detection, fire & maritime	Local/UK
Indonesia- Kalimantan	1993	ODA TC INRED	NOAA	Fire, fire risk and vegetation monitoring for forestry management	Local
Jakarta	1995	ODA-TC BPPT		Fire, vegetation monitoring for watershed management, coastal zone applications	Local/UK
Ivory Coast - Lampto	1993	NRED/FRP	NOAA#	Fire, fire risk and vegetation monitoring for forest/agriculture interface management	Local
Madagascar - Antananarivo	1994	EU NRED/FRP	NOAA# PDUS	Forest fire monitoring	Local
Namibia- Etosha	1992	BHC gift ODA TC	NOAA	Rangeland and park management, vegetation monitoring, animal tracking. fire and fire scar detection	Local/UK
Windhoek	1992 1992 1993 1994	ODA TC ODA TC Met Off. GoN	NOAA PDUS MDD Media	Weather forecasting, vegetation monitoring, offshore fisheries support, rangeland/savannah monitoring (including fire detection, TV/newspaper dissemination.	
Swakopmund	1994	ODA TC	NOAA	Fisheries management, sea surface temperature monitoring	
Nicaragua- Managua	1995	ODA TC	NOAA	Forest fire detection	Local
Poland- Warsaw	1993	GoP	NOAA	Forestry management, vegetation monitoring and fire risk	Local
Zambia- Lusaka	1992	ODA TC Met Off.	NOAA PDUS	Vegetation monitoring for tsetse habitat.	Local
	1994	Met Off.	MDD	Pest habitat monitoring, rainfall estimation, Weather services.	

Channel 3 radiance is composed of both the solar radiation reflected by the Earth's surface and the thermal emission of soils and hot objects, such as fires. Therefore, Channel 3 may be saturated by high reflection on water (Sun glint phenomenon), depending on surface reflectance and temperature, either of these two effects can dominate. Water vapour, methane and nitrous oxide impose noticeable absorption effects on this channel (Justice and Dowty

1993). Some researchers have employed additional threshold tests (in Channels 2 and 4) to overcome the problems of sun glint, bare soils, etc. These appear to work well for fire detection over tropical and temperate forests, but are less successful over African savannas. Also, the presence of aerosols or dry haze over very hot surfaces (e.g. desert areas) can cause false alarm fire signals. (Justice and Dowty 1993, Kennedy et al 1994, Langaas 1994).

It is important to be cautious in fire detection, in order to avoid overestimates of active fires which, consequently, introduce errors into observations of the extent of biomass burning and models of atmospheric physics and chemistry based upon them. Users of fire detection algorithms need only to be aware of these problems. However, fire characterisation, and absolute surface temperature retrieval, require more complex pre-processing and may include atmospheric correction (i.e. knowledge of the air mass constituents). Fire detection from NOAA data is achieved by a number of methods , all of which utilise the dominating effect of hot fires in channel 3 signals at some stage. The simplest algorithm is to retain all pixels which are saturated (or near saturated) in channel 3 beyond a given (single channel) threshold.

- Channel 3 single threshold algorithms

This approach relies on the assumption that only Channel 3 data are required and that a single (empirically derived) threshold value can be used to identify pixels with sub-resolution fires. The detection of fires would be triggered by setting a threshold based on either the digital number (DN) or calculated brightness temperature (T^B 3.75 µm). In most cases, this saturation would indicate unusually hot features and could be assumed to represent a fire. However, in practice, many workers have found that applying appropriate thresholds can be difficult because of diurnal variations, environmental conditions (e.g. hot, bare soils and highly reflective clouds) and variations in the instrument response of AVHRR (Frederiksen 1990, Grégoire et al 1993, Setzer and Malingreau 1993, Setzer and Verstraete 1994). Different thresholds therefore need to be applied at night and during the day within the same ecosystem which makes full automation of these techniques difficult.

- Channel 3 multiple threshold algorithms

These algorithms are rare in the literature, and in practice, but they lie behind some of the developments in the implementation of contextual algorithms described below (Smith and Vaughan 1991).

- Multi-channel threshold algorithms

These algorithms, although largely based on empirical results, have been shown to be regionally robust and simple to implement. They also improve on single channel threshold algorithms due to extra data dimensionality. A wide range of multi channel threshold criteria exist but all of these algorithms utilise combinations of two or more fixed thresholds for Channels 3 and 4 (3.75 µm and 10.8 µm respectively) alone or in combination. The thresholds are usually based on calculated brightness temperatures (T^B) and operate either on a pixel-by-pixel or a contextual (pixel-by-neighbourhood) basis. A series of tests are employed in pixel-by-pixel T^B thresholding, all of which must be passed for a pixel to be classified as a fire pixel. As in the case of simple Channel 3 thresholding, all the published multi-channel thresholds have been developed for specific regions and are based on empirical results. The main disadvantage of pixel-by-pixel approaches is that they are insensitive to variations in normal land surface temperature conditions over time for a given area (Langaas 1994).

- Contextual algorithms

Other techniques can be utilised which rely on spatial analysis or contextual methods. They analyse the spatial variability of thermal signals in a pixel neighbourhood: the brightness temperatures of potential fire pixels are checked against the brightness temperatures of cloud-free (assumed non-burning) neighbouring pixels. This takes into account the spatial-temporal thermal variability of the background which is not easily dealt with in either single channel thresholding or pixel-by-pixel multi-channel thresholding (Langaas 1994).

Most fire detection algorithms do not require atmospheric correction for successful implementation. However, some approaches have a degree of implicit cloud screening tests as part of the fire detection process (Kaufmann 1990, Kennedy et al 1994). NRI experience of fire detection has largely relied on the use of single (Channel 3) or multiple (Channels 2, 3 and 4) thresholding techniques.

In practice, however, NRI have found that applying appropriate thresholds can be difficult in some parts of the world because of diurnal variations, cloud conditions and ecosystem related phenomena. Different thresholds may need to be applied at night and during the day (i.e. different overpass times) within the same ecosystem. They may also need to be altered seasonally and inter-annually. Thus different thresholding algorithms based on absolute thresholds will exclude detectable events or include spurious noise (Robinson 1991) which means that local conditions influence fire detection and that a universal threshold is unrealistic and inappropriate. Other techniques which rely on spatial analysis or contextual methods can be utilised. They analyse the spatial variability of thermal signals in a pixel neighbourhood which is not easily dealt with in either single channel thresholding or pixel-by-pixel multi-channel thresholding (Justice and Dowty 1993, NRI 1995). The adaptation of such contextual algorithms, as developed for global vegetation fire detection (Stuttard et al 1995), is currently being actively researched at NRI in order to phase their implementation into existing project areas as well as new regions as required.

Examples of Implementation

NRI experience of real-time fire detection has been developed over the last five years through a number of different operational and experimental projects in a variety of (largely tropical) regions of the world. These projects have all in areas where fire and biomass burning has a direct impact on natural resources and the environment and thus on the local populations. The projects have been predominantly ODA funded as direct technical support for larger ODA natural resources projects or as research effort to develop generic capabilities suitable for technology transfer when required. The research activities have also benefited from successful and ongoing collaboration with the Joint Research Centre (JRC) of the European Commission.

Côte d'Ivoire - Collaborative work between NRI and the Joint Research Centre (JRC), of the European Commission, has been conducted in the savannah zone of Côte d'Ivoire. This demonstrated that a PC based HRPT receiving system could be used operationally, close to the burn zone, providing images and fire coordinates from NOAA satellites useful for fire management. By linking satellite observations to ground observations in real time some of the key problems of characterising fire events, their impact and management could be addressed. Satellite overpasses were accurately predicted using the system and suitably pre-processed imagery made available within 5 minutes of data capture. The results showed that grassland savannah fires as small as 50 m in length can be detected, that only flaming fires (not smouldering fires) are seen, and that the afternoon overpass corresponds well to the period of peak fire activity in the region (Belward et al 1993).

Central African Republic - Collaborative work has been conducted between NRI, JRC and the Institut Centrafricain de Recherche Agronomique (ICRA) in Bangui, CAR to assess the extent and detectability of fire events. Successful deployment of in-country AVHRR receiving equipment provided data on the progression of burning across CAR during the burn season. This work was supported by calibration from controlled fires set in the field and airborne video coverage during the burn events to gain information on fire size and burn pattern in this ecosystem.

Indonesia - Operational fire monitoring over the Indonesian archipelago faces many challenges. Indonesia comprises around 13,000 islands and covers an area of some 1.9 million km². Much of this land is inaccessible and remote from population centres. Within this framework, fire occurrence (and its consequences) are of growing importance nationally and regionally. The ITTO (International Timber Trade Organisation) has estimated that the 1982-3 fires in Kalimantan cost $US 9 million in timber and non-timber losses. Of the estimated 800 000 ha or more of annual deforestation in Indonesia, up to 300 000 Ha are estimated to be lost through fire. Fire occurrence in Indonesia is also highly variable, both spatially and temporally and the effects of fire are felt at different scales, from the local to international. During 1994, media attention once again focused on the problem of smoke from forest and agricultural fires. The ensuing air pollution caused serious local health hazards and also caused severe restrictions to air and marine traffic. Despite these effects, little systematic information on fires is available today in Indonesia, largely due to the problems of routinely monitoring them.

In 1992, a NOAA receiver was installed by NRI at the ODA's UK-Indonesia Tropical Forest Management Project (UK-ITFMP) (Sub-Project 2) office in Palangkaraya, Kalteng as part of a large ODA technical project looking at tropical forestry management and how to improve its effectiveness. The objective of the research activities is to develop an Operational Fire Monitoring System (OFIS) for Indonesia, also capable of transfer to other continents and environments. The work is supported by the ODA Forestry Research Programme managed by the

Oxford Forestry Institute, UK. Part of the programme includes fire detection and mapping during the burn season and personnel are regularly collecting and archiving data. Thermal thresholding techniques are used to produce maps of probable fire locations within 15 minutes of overpass.

Further work is needed to fully realise the enormous potential. Aspects of this will focus on optimising fire and smoke detection algorithms for Indonesian conditions and encoding the improved techniques into more user-friendly and better automated software applications. Seamless data integration will be developed to combine NOAA information with supplementary data to give assist with data interpretation. The most important aspect will be to improve the dissemination and uptake of the fire information and by forging better links with end-users in order to better understand their information requirements and begin operationally to supply them with the useful fire information that they need.

Related research work with the EC Joint Research Centre to develop a global vegetation fire product (GVFP) has led to the development of new, improved (automatic) contextual techniques for cloud removal and fire detection which will enable more reliable burn regime analysis (Stuttard et al 1995). These developments provide a sound technical platform from which to develop more robust local fire detection capabilities, particularly under the difficult tropical weather conditions encountered in Indonesia. It is anticipated that these techniques will be operational in at least three provincial forestry department receiver systems in Indonesia in the 1995-96 dry season. Successful development and testing of these techniques will encourage uptake in other countries around the world with LARST NOAA satellite receivers which will also benefit from these developments.

A separate ODA project (the Indonesia - UK Environment Monitoring Project - INDEMNITI) was established in May 1995 to undertake demonstration applications in environmental monitoring. This will include consideration of fire detection and monitoring as an input. During 1995, a further project, the EU funded Forest Sector Support Project (FSSP) has been established to provide fire information for forestry sector support at the provincial level in Sumatra. NRI expect to be collaborating actively in developing appropriate fire management information tools and products.

Nicaragua - Nicaragua is one of the poorest countries in Central America. Over ten years of civil strife, economic isolation and declining commodity prices (notably coffee) have resulted in per capita GNP declining at an annual rate of 2.2% throughout the 1980s. Pressure on the environment, including a significant forestry resource extending over 6 million hectares (51% of land area) is considerable. While data on deforestation is weak, forest cover is believed to be disappearing at an annual rate of 2.3% - amongst the highest in the region. The causes of this are many, but the effect of forest fire (the incidence of which may itself be increasing by the process of deforestation) is generally accepted to be a significant, as well as costly (in strict economic terms) factor.

Monitoring of forest (fire) conditions is essential for the sound management of Nicaragua's vital forest resources and the rational allocation of limited resources to meeting fire threats and outbreaks. Information on the occurrence, extent and impact of fires, (and changes to the national forest estate generally) is however, lamentably poor and presents a major handicap to forest management. This is clearly recognised by the National Environment Protection Agency (MARENA: the Ministerio del Ambiente y Recursos Naturales), which has accorded fire monitoring its highest priority, and consequently requested the assistance envisaged in this project.

A collaborative project between ODA and the Ministerio del Ambiente y Recursos Naturales (MARENA) in Nicaragua commenced in May 1995. The principal objective of the project is the provision of information essential for improved forest resource management. This will include fire identification in forested areas and seasonal changes in forest cover, observed from satellite. Complex social economic and institutional issues associated with fire and the use of (real-time) satellite information will be broached during this Phase I project with a view towards sustainable monitoring and optimal utilisation of the information for decision making through developing real time products for managers and decision makers as well as training materials.

This project will, through the development of a Nicaraguan capacity to monitor environmental change by means of low-cost, real-time, satellite data reception and processing techniques, produce timely information on fire risk, fire occurrence and forest state. The project will also assist in ensuring the integration of that information into the resource management and environment protection decision making processes of Nicaragua. Data collection is now operational and an archive is being built up over time. Research activities to start deriving fire risk estimates, daily fire maps and measurements of the encroachment of the "Frontera Agricola" are ongoing.

CONCLUSION

NRI has developed and successfully deployed low-cost, robust receiver stations capable of interpreting the real-time High Resolution Picture Transmission (HRPT) data which are continually transmitted from the orbiting satellites. Field experiments have successfully demonstrated the utility of these systems to provide up to the minute information on forest clearance by fire. The system can be used for large area overview and for local response. The data are received and processed on PC (microcomputers) to provide maps of vegetation fires while they are still burning. The availability of *in situ* AVHRR imagery, in real time, offers important new possibilities for fire management.

Preliminary results suggest that the NOAA fire information, when combined with supplementary information (including high resolution satellite and map data) in a GIS will be have many uses at different scales. At the local scale, it can be used as an early-warning tool in fire suppression, to direct fire fighting teams (where present) to probable fire locations within particular concessions or protection forests. Time series of fire maps combined with supplementary vegetation maps can provide information on fire locations and frequency and locate possible deforestation fronts at the local to national scale. This information, where appropriate, can also be used to help to raise awareness of forest fire activity, or direct extension programmes to promote alternative land use. Smoke plumes can be traced to their source and so help quantify the causes of observed smoke pollution and hence provide pollution control programmes with basic data.

The use of dynamic systems that are continuously updated to provide timely information on burn events and 'account' for changes in natural resources over time provide much needed information on biomass exploitation and protection so leading to integrated and sustainable natural resource management around the world. Already, provincial and national forestry departments (e.g. Indonesia, Nicaragua) are beginning to use NOAA satellites for fire detection, fire risk assessment, and determination of macro changes in vegetation status. Progress to date indicates that local reception of NOAA satellite data is of immense practical value and is a cost effective way of obtaining information on vegetation fires at national or local scale which enables better fire awareness and natural resources management

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