DETECTION AND WARNINGS IN TROPICAL ECOSYSTEMS: FIRES AND DEFORESTATION

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Abstract

Sensors on meteorological and earth observation satellites can provide regular local and global assessments of vegetation fires and deforestation. Suitable images can be made available within minutes of satellite overpass. These provide an up to date description of fuel condition, fire location and forest boundaries. Such information can form the basis of fire risk and deforestation alarms. Furthermore, archives of data can be used to put current forest / fire conditions into an historical perspective. However, work of this nature on continental and global scales, of necessity, requires global data sets; some of the generic issues in collection and management of these data are reviewed.

1. Introduction

The development of space observations for natural hazards assessment places novel constraints upon the technology. Instead of being geared toward the acquisition of data on fairly predictable landscape or ecosystem conditions, such as land cover or crop development, techniques now have to be attuned to rapidly changing surface conditions or to the detection and assessment of elusive and less predictable phenomena such as fires, landslides or volcanic activity This requires observation systems which can work at the global scale, at variable ground resolutions and in direct contact with the agencies and experts in charge of deriving and using the relevant information. Furthermore, such space observation systems must operate at a reliability level more characteristic of military "surveillance" systems than of civilian earth observation missions (*viz.* shortcomings in data distribution and analysis, or problems of obtaining cloud free imagery from optical sensors are unacceptable). Today remote sensing systems specifically tailored to the requirements of natural hazards detection do not exist; the experience gained so far has been acquired, albeit at a slow pace. by addressing the issues with instruments which were never designed for such a purpose. The case of fires in ecosystems and deforestation clearly illustrate this situation.

2. The hazards of fires and deforestation

Tropical deforestation and vegetation fires are two hazards which, although more often man-made than natural, have potentially disastrous consequences for humanity. The physical effects of removing the tropical forest cover are quite profound. Surface run off following rainstorms is dramatically increased, as soil water holding capacity is reduced and as the rain is no longer intercepted by a tree canopy. This in turn can lead to unprecedented levels of soil erosion, such as those experienced in Nepal and the Himalayan foothills (Myers, 1984). The removal of the forest cover also seriously disrupts the local and regional hydrological cycles (Salati, 1987), leading to erratic and unpredictable river flow; floods followed by drought and even threats to urban water supplies.

In the longer term, and from a global perspective deforestation should probably be viewed more as a disaster than a hazard. Recent estimates are that deforestation is eliminating species at a rate on a par with the mass extinctions at the end of the Palaeozoic and Mesozoic eras (Wilson, 1988). The tropical forests contain more than half the Earth's species and have already provided mankind with pharmaceuticals and agricultural crops among many other benefits Though we are eliminating species with little or no regard as to their economic or social value, this is not the only risk Because of species interdependence the loss of one species in an ecosystem can seriously threaten the survival of others. Hence the loss of an individual species is linked to the general impoverishment of the global gene pool.

Deforestation is also clearly implicated in the processes of climate change and global warming. The presence of tree cover significantly modifies the turbulent transfer of heat and water between the surface and the atmosphere (this is referred to as 'surface roughness' in climate models) and a forest covered surface reflects less of the sun's energy back to the atmosphere than cleared ground (often referred to as the albedo effect). In other words removing forest significantly alters the Earth surface - atmosphere energy exchange and hence climate (Nobre *et al.*, 1991). The potential of deforestation as an agent of climate change extends beyond this, as the process has a twofold impact on the global carbon cycle. The forest is one of the key terrestrial sinks for carbon dioxide (CO_2). Deforestation firstly removes the sink and secondly the process is usually achieved through felling and burning. This burning itself releases large quantities of CO_2, further increasing the atmospheric concentrations of this key greenhouse gas (Watson *et al.*. 1992).

The consequences of vegetation fires have received less publicity than those of deforestation, even though fire frequently plays a major role in the deforestation process. The immediate threat of fire to human life and property is axiomatic. There too is the economically detrimental factor of airport closures due to smoke, a common seasonal occurrence in parts of Indonesia and Amazonia. There are the medium term risks to human health from exposure to smoke, and there are also long term, global scale threats associated with climate change. Few terrestrial ecosystems are unaffected by fire. Deforestation fires either linked to commercial logging operations or slash and burn agriculture are thought to be on the increase. Most of the world's savannahs are affected by fire (in Africa alone, recent estimates are that some 75% of the savannah burns annually). 3.8 million ha of temporal and boreal forests are destroyed by fire each year (exceptional events can far exceed this, for example, in May 1987 fire burned 12 million ha of forest in northern China in a mere 21 days). Fire is still commonly used to clear agriculture stubble throughout the temperate regions. And in the last year alone wildfires have caused extensive damage and loss of life in both the United States and Australia.

This far from exhaustive list emphasises to what extent wildfires and fires of anthropogenic origin are a global phenomenon. Including fuel wood and charcoal use, it has recently been estimated that more than 8600 million tons of dry plant material are burned per year, accounting for something in the order of 40% of the world's annual production of CO_2 (Levine, 1991). Add to this the methane emissions from fires, another important greenhouse gas (Crutzen and Andrea, 1990) and nitrogen oxides, which contribute to acid rain (Dignon and Penner, 1991) and we begin to see that fires have a major influence on global atmospheric chemistry, hence climate and hence human well being.

3. Remote Sensing in Fire and Forest Monitoring

Assessment and mitigation of the hazards associated with fires and deforestation start with an inventory of current conditions. Where are the current forest boundaries? What are the immediate threats to the forest ? What fuel is there available for burning? How much of it is there? What is the condition of the fuel? Where and when are the fires lit?

In the past global deforestation assessments have been created by collating local or regional scale data sets (e.g. FAO, 1981). Thus an overview is only achieved by using diverse primary data sources, often on different scales, created using a variety of classification techniques and using different nomenclature for map legends. In 1990 the European Commission in collaboration with the European Space Agency established the TREES project, (TRopical Ecosystem and Environment observations by Satellite). The first phase of this project was devoted to creation of an up to date inventory of all tropical forests using a common data source (satellite remote sensing), a common map legend, common map scale and projection and as far as possible the same classification techniques throughout the world. This phase is now almost complete. A second phase of the project, which has just started, focuses more on monitoring, rather than inventory. Here the goal is detection of active deforestation fronts in a timely manner, so that analysis of possible remedial actions can be concentrated on these regions (Malingreau *et al.*, 1993a).

The work of the TREES project relies heavily on data from the Advanced Very High Resolution Radiometer (AVHRR) on board the United States' NOAA meteorological satellites (Kidwell, 1991) The AVHRR, despite it's name, is characterised by low spatial resolution, in the order of 1 km, but at least in theory, offers daily global coverage. This is important for monitoring work in the tropics as daily data acquisitions increase the chances of obtaining cloud free images. Various types of AVHRR-derived information can be exploited for detecting deforestation features. Indeed, no single discriminator works throughout the tropics, yet all those described below have worked in one region or another, and together provide a pan-tropical picture of current forest/non-forest conditions.

Spectral contrasts between evergreen forest and the more seasonal replacement vegetation are usually greatest towards the end of the dry (or at least drier) season. The photosynthetically active forest canopy contrasts well with the more senescent or even dormant secondary re-growth; the reflectance in both the visible and near-infrared channels of the AVHRR tend to be lower from the forest than the cleared areas (Malingreau *et al.*, 1989) Combining visible and near-infrared measures of reflectance as the Normalised Difference Vegetation Index (NDVI) provides another powerful discriminator between forest and non forest, again particularly towards the end of the dry season . Analysis of time-series of this index can also be used in defining seasonal classes in the forest classification scheme. The evergreen character of some primary forest formations has even been questioned following analysis of AVHRR time-series; multi-year NDVI curves have shown inter-annual variations related to climatic influences, which is surprising for systems essentially located in non-seasonal climatic zones (Malingreau, 1991).

The AVHRR also has channels which record thermal information. Data from these too have proved of great value in separating forest from non forest. The greatest difference in surface temperature between the 'cool' forest to the 'warm' open areas once again occurs during the dry season (Malingreau *et al.*, 1989). The clearest contrast between forest / non-forest is usually seen in the AVHRR's middle-infrared channel. This channel records a mixed temperature - reflectance signal, hence emphasising both the temperature and reflectance increase as one goes from forest to non forest (Malingreau and Tucker, 1990). Circumstantial evidence is also used to identify active deforestation areas and fronts. The presence of fire and smoke are good examples. This was one of the first indicators of the extensive fire which damaged large areas of the East Kalimantan forest during the El Ninõ episode of 1982-83 (Malingreau *et al.*, 1985).

The ability of the AVHRR to detect fires can only be described as fortuitous. This application was never foreseen in the design of what is essentially a meteorological instrument. The middle infrared channel used for fire detection was originally designed for cloud top temperature measurements. Consequently the sensor saturates at very low temperatures, around 47°C (Kennedy *et al.*, 1994), *i e.* the instrument is not capable of discriminating between temperatures greater than this. One practical consequence of this is that very small fires can provide enough energy to 'saturate' the sensor Even though the spatial resolution is 1 km, savannah fires as small as 50 metres long have been detected with this instrument (Belward *et al.*, 1993). On the negative side though, the low temperature for sensor saturation causes problems for fire detection in 'hot' environments such as the northern savannah / sahel margins. In these regions specially adapted fire detection methods have to be used: we are still some way away from a universal fire detection method (Belward *et al.*, 1994, Kennedy *et al.*, 1994). Nevertheless, the AVHRR is now playing an increasing role in fire research programmes, such as the European Commission's FIRE (Fire In global Resource and Environmental monitoring) project, and is beginning to find operational fire detection applications.

For example, the Brazilian National Institute for Space Research (INPE, São Jose dos Campos) have been running an operational fire detection programme for the whole of Brazil since 1987 (Setzer and Pereira 1991). Daily AVHRR data are put through a fire detection routine and within a maximum of 40 minutes of satellite overpass a telex is prepared giving the latitude / longitude of all detected fires for different management / administrative regions. The telexes are sent directly to users, including forest managers, fire services and national park wardens. An excellent example is the Department of Natural Resources and Environment, state of São Paulo. An operations room receives the telex, plots the location of fires, determines the ecological (national parks and reserves) and economic importance (commercial forest plantations) of the fire, and if needed they immediately send out fire fighting crews. The plotting is necessary because the region has many controlled sugar cane fires. These are neither ecologically or economically important to the state and they don't want to send fire crews to them. The São Paulo operation goes by the somewhat emotive name of Operação Mata - Fogo (translated as Operation Fire Killer). The crews rely on fire detection from three sources: satellite (NOAA AVHRR), local observers and aircraft pilots. The importance of AVHRR in the system can be seen from the following statistics. In 1989 Operação Mata - Fogo received reports of 5217 fires. Of these 98.6% came from AVHRR, 1.1% from local observers and 0.3% from airline pilots. However, it should be recognised that the Brazilian operation exists in a single country with its own centralised satellite data receiving station. Such an operation on a global scale is currently impossible. Nevertheless, low cost systems can easily provide the same information on a much more local scale, and are therefore applicable for countries without centralised Space Agencies or receiving stations.

The experience of the FIRE project with a portable AVHRR receiving station developed by the United Kingdom' s Natural Resources Institute bears this out. The LARST system (Williams , this volume) used by the FIRE project in Côte d' Ivoire and the Central African Republic, provided precise latitude longitude co-ordinates for active fires for a region of at least 1,000,000 km^2 within 5 minutes of satellite overpass (Belward *et al*, 1993). This opens up exciting new possibilities, not only for fire detection for the management of national parks or forest reserves, but also for the detection of fires as a secondary feature of other natural disasters, such as cyclones or earthquakes. The LARST system is very robust and truly portable. It is based on PC computer technology so does not require carefully environmentally controlled operating conditions, and can be fully operational within 6 hours of delivery. This fills many of the requirements noted by Dousset *et al.* (1993) who, in a study of the Los Angeles fires started in the riots of April 1992 (following the Rodney King verdict) concluded that "..real-time AVHRR imagery, providing synoptic views of the situation using minimum man power, would be a valuable new tool for assisting fire-fighting efforts in case of major disasters".

The detection of fires using AVHRR data is only part of the story. All the indications are that using these data fuel estimates can be made, that estimates of the magnitude of the active front are possible and that sensing of the emission products from biomass burning is possible (for examples see the papers in Levine (1991) and Crutzen and Goldammer (1993)). Satellite observations of such parameters combined with other data, such as population density, land use practice, meteorological conditions and fire behaviour models could be used for a range of applications; for example, identification of areas with a high fire risk, atmospheric impact following emissions from fires, likely impact of fire on an ecosystem and fire spread rates. This integrated approach was proposed at the Dahlem Workshop on Global Change in the Perspectives of the Past (Malingreau *et al.*, 1993b). The FIRE project is currently testing a prototype Vegetation Fire Information System for local forest protection and national park fire management schemes in Central African Republic and for more regional scale trace gas transport studies between the savannah and the forest.

The latter highlights one important gap in current fire studies. With few exceptions, the existing literature on fire examines individual events, or the process of combustion itself There is little in the way of regional histories of fire activity, and almost nothing on global scale fire distribution and dynamics. Work on these scales represents a formidable challenge, purely from the perspectives of data acquisition and management, if nothing else. Though the AVHRR theoretically offers daily, global cover, the truly global data sets have, until recently, been spatially sampled to give approximately 4 km resolution (the so called Global Area Coverage, or GAC data, Kidwell, 1991). Consistent, global 1 km AVHRR data acquisition only started in April 1992, under the auspices of the International Geosphere Biosphere Programme (Townshend, 1992). Data collection alone involves co-ordination of 29 receiving stations world-wide, plus the central NOAA archives. Processing of these data is so demanding of computer resources that vegetation products from the first six months' data will not be available before October 1994 (J. Eidenshink, EROS Data Center, personal communication).

Pre - 1992, projects with a global perspective, such as TREES, could only collect data on an *ad hoc* basis from the NOAA archives of data recorded on-board the satellite, or from the various receiving stations themselves. This lack of consistent long term data also means that any requirement for a temporal dimension (such as forest seasonality) or the need for an historical perspective (e.g. changes in fire distribution) can only be met using the 4 km GAC data. Such data have already been used by the FIRE project to establish fire dynamics for one year over the entire African continent (Belward *et al.*, 1994) and similar analysis extending back to July 1981 is nearing completion, though again the logistics in terms of data management are enormous. The GAC archive is a daily, global data set, spanning more than 12 years. The raw data alone occupies more than 60,000 computer tapes!

Finally on the subject of data, it is vital to remember that the analysis of low resolution data sets, such as the AVHRR, must be validated using high resolution data provided by the Landsat and SPOT satellites in combination with field visits. The TREES project, for example, has established a systematic procedure to validate and calibrate the AVHRR derived forest classifications using a pan-tropical set of Landsat Thematic Mapper scenes (Malingreau *et al.* ,1993a) This is less true where fire detection is concerned as the SPOT data do not have suitable thermal channels, and the Landsat does not offer high enough frequency of cover. In these situations validation relies on the installation of a LARST-like system in fire affected regions. This *in situ* availability of data in near real time means that fires detected on the imagery can be immediately visited for confirmation of the fire detection methodology used and to measure the physical attributes of the fire such as size of fire front and temperature.

4. Conclusions

It has become evident in the course of the work described above that the monitoring of large scale changes such as those associated with deforestation or the detection of events such as fire require the setting up of observation systems with characteristics hitherto little considered in the civilian sector. The magnitude of the resources needed to ensure a certain level of reliability for global, and permanent, Earth monitoring has been little appreciated to date. The efforts necessary to even partly exploit existing global monitoring instruments such as the AVHRR or the ERS-1 microwave sensor are truly beyond the reach of any "application" agencies. Data sets are large (the AVHRR 1 km global land data for just 10 days represents a volume of more than 30 Gigabytes of raw data), the reference data sets include in some cases 12 years of daily observations, stand-by detection procedures are costly, analysis methods are ecosystem- or region-specific and difficult to generalise. For the lack of necessary resources, most current efforts provide, at best, proofs of concept and are of limited value in operational terms. The authors are of the opinion that significant progress towards hazard assessment and mitigation will be achieved only if a clear mandate is given to develop the technology in this specific direction. This should now be considered in the context of a nascent "environmental security" concept.

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