FOREST FIRES FROM SPACE: CONSIDERING SPATIAL AND TEMPORAL RESOLUTION

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ABSTRACT:

Forest fires are a major environmental concern in Tropical and Mediterranean countries, since it is the main responsible of vegetation degradation. Satellite remote sensing data could play a crucial role in improving current tools of fire prevention and fire effects assessment, since they provide a suitable image of spatial and temporal variation to monitor fire-related factors. Real-time monitoring of vegetation water stress or burned land mapping are examples of products closely connected to fire management planning. This paper explores present applications and future requirements of remote sensing systems for forest fire studies, with special emphasis in the needs of European Mediterranean countries.

1. INTRODUCTION

Wildland fires are becoming a major concern for several Environmental Sciences. Assessment on fire effects at local scale is increasingly considered a critical aspect of ecosystem functioning, since fire plays a crucial role in vegetation composition, biodiversity, soil erosion and the hydrological cycle. At global scale, fire is the most generalised mean to transform tropical forest in agricultural areas, and it has severe impacts on global atmospheric chemistry (Crutzen et al., 1979).

Fire is a natural factor in many climates, such as the Mediterranean, with high levels of vegetation stress during the summer. However, changes in traditional land use patterns have recently modified the incidence of fire in these territories. Rural abandonment in the European Mediterranean basin has implied an unusual accumulation of forest fuels which notably increases fire risk and fire severity. On the other hand, the increasing use of forest as a recreational resource involves a higher incidence of human induced fires, either by carelessness or arson. According to recent fire statistics more than 200,000 fires have affected the Mediterranean countries of Europe between 1990 and 1993. Around 2,000,000 hectares have been burned in these years, although the extension will significantly increase if fires of 1994 were computed, as they burned, only in Spain, more than 400,000 hectares. The damages caused by forest fires are very difficult to estimate, because they have diverse and indirect effects on several environmental processes.

Remote sensing from space is specially suitable for forest fire research. The wide area coverage and repetitively provided by satellite sensors, as well as their information on non visible spectral regions, makes them a very valuable tool for prevention, detection and mapping of wildland fires. During the last decade, the range of applications has significantly increased (Chuvieco and Martín, 1994a), making satellite remote sensing a solid ally in many forest fire strategic plans. Remote Sensing contributions may be classified in four type of applications, related to the temporal scale being underlined: short-term fire danger estimation, long-term fire risk assessment (both are related to pre-fire management), fire detection (during the fire), and fire effects assessment (post-fire). A brief description of the work carried out in these areas follows.

2. SHORT-TERM FIRE RISK MAPPING

Better methods to evaluate the probability of fire out breaks would significantly reduce fire incidence by intensifying aerial or terrestrial vigilance, by forbidding certain risky activities or by adapting the level of alertness of fire suppression resources. Fire danger estimation demands frequent monitoring of vegetation stress. Vegetation moisture is a particularly difficult parameter to estimate as it accounts for little spectral variation with respect to other environmental factors (Cohen, 1991). However, spectral characterisation of vegetation stress is possible if temporal profiles are derived, and the contrast between living and dead components is emphasised.

The most common methodology for the estimation of vegetation water stress has been the analysis of vegetation indices (VI) multitemporal series. VI has proven to be related to critical physiological variables, such as absorbed radiation (APAR), Green biomass or Leaf Area Index (LAI). Therefore, these VI provide a good indication of vegetation healthiness. On the other hand, decrements of VI are related to reduction of plant vigour and greenness which are also linked with vegetation moisture content (Paltridge and Barber, 1988).

An alternative to the use of VI series for vegetation moisture estimation is to follow the thermal dynamism of the vegetation cover. Ratio of actual and potential evapotranspiration (LE/LEp) appears to be a good indicator of canopy water status. This index has been successfully applied to fuel moisture estimation from NOAA-AVHRR data (Vidal et al., 1994). A combination of surface temperature and NDVI has also been successfully applied to fire danger estimation in the South of France (Prosper-Laget et al., 1994).

3. LONG-TERM FIRE RISK MAPPING

Long-term risk refers to permanent factors associated to fire ignition or propagation, such as topography, vegetation structure, human activities or weather patterns. Therefore, the integration capabilities of Geographic Information Systems (GIS) makes them a suitable tool for mapping fire risk. These maps are quite critical for a rational management of forest areas, since fire protection programs will be spatially and temporally oriented to the areas labelled as having high risk.

Several GIS applications have been developed in the last decade to improve management of fire risk, specially to the generation of GIS-based risk maps. Most of these models are locally oriented, so they cover a small area at high resolution (typically from 50 to 100 meter grid size: Burgan and Shasby, 1984; Yool et al., 1985; Chuvieco and Congalton, 1989). However, there are also some experiences with global, low resolution, fire danger maps (Werth et al., 1985; McKinley et al., 1985).

The critical point of these systems is the vegetation layer. Several studies have found a close correlation between the spread and intensity of the fire and fuel characteristics, such as size, plant moisture, compactness and density (Burgan and Rothermel, 1984). Several papers have explored the use of satellite remote sensing to generate these fuel models through digital image processing. Most have worked with Landsat-MSS or TM images (Salazar, 1982), but there are also interesting experiences using low resolution sensors like NOAA-AVHRR (Miller and Johnston, 1985). Finally, radar data can provide complementary information too for fuel mapping, particularly at local scale, since it is very sensitive to temporal and spatial variation of the canopy biomass.

The criteria followed for the combination of these variables may be summarised in the following alternatives: (i) Use of qualitative criteria for assigning danger values to the cross-relationships of the different variables (Yool et al., 1985); (ii) Adaptation of standard danger indices, such as the US National Fire Danger Rating System or some modules of BEHAVE (Woods and Gossette, 1992; Chuvieco and Salas, 1996); (iii) Development of new danger models, based upon the selective weighting of the danger variables (Chuvieco and Congalton, 1989), and (iv) Creation of locally-oriented models, where danger weights for each variable are obtained from multiple regressions computed for that particular area (Chou, 1992).

4. FIRE DETECTION

Fire detection through remote sensing has been based on middle infrared data analysis. Considering that forest fires temperatures commonly range from 500 to 1,000 K (Robinson, 1991), the most suitable band for fire detection is located between 5.8 and 2.9 μm according to Wien's displacement law (middle infrared region of the spectrum), while the thermal infrared region presents the peak of emittance at common Earth temperatures (around 300 K). As a consequence, the middle infrared bands are more sensitive than thermal infrared bands to detect and monitor active fires.

Fire detection from space is obviously very much dependent on temporal resolution. The Earth resources satellites (such as Landsat or SPOT) do not provide enough temporal frequency for fire detection. On the contrary, meteorological satellites have proven to be very useful for these purposes. NOAA-AVHRR images are suitable for fire detection and mapping because of their adequate coverage cycle (12 hours) and good spectral resolution, which also includes middle infrared bands.

The use of AVHRR images for fire detection has been successfully tested in several studies, both at regional and global scale, specially over remote areas where traditional methods are very costly. In Canada, high accuracy for detecting large-scale forest fires was found in a pilot study conducted in Alberta (Flannigan and Vonder Haar, 1986). Accuracy for small fires was limited, 10 to 12 %, although better results were reported if only cloud-free areas were taken into account (up to 87 %). Similar studies have been carried out in Tropical forest (Malingreau, 1990; Langaas, 1992; Kennedy et al., 1994; Setzer and Pereira, 1991). Some experiences are also available over Mediterranean forest (Chuvieco and Martín, 1994b).

In spite of the potential interest in the use of AVHRR channel 3 data for fire detection, these images present several difficulties related to the low thermal sensitivity of this channel, which is saturated at 320 K. As a result, fire spots can be easily confused with agriculture burns or even overheat bare soils, which frequently reach these temperatures during the summer at the afternoon satellite pass (Belward, 1991). Discrimination from agricultural fires could be partially achieved by choosing evening or night images, because this type of burning tends to be done during daylight periods (Malingreau, 1990). Monitoring the temporal dynamism of the target surfaces also provides good classification of fire pixels (Lee and Tang, 1990). In any case, sensors with higher thermal sensitivity are desirable. In the Brazilian Amazonia, airborne experimental fire detection scanners with saturation levels up to 900 K have been successfully tested (Riggan et al., 1993). The future Moderate Resolution Imaging Spectroradiometer (MODIS) will include a middle infrared channel that saturates at 500 K, which will notably increase the potential of satellite fire detection systems.

5. FIRE EFFECTS ASSESSMENT

One of the main problems affecting fire management is the lack of appropriate statistics on burned land. Even the countries more severely affected by this problem do not have proper data on fire incidence, as most of the times fires are not mapped and only general statistics are available. On the other hand, data are not available until several weeks (or even months) after the fire event. As a result, vegetation recovery is not assessed, and a lack of regrowth may constitute a severe soil erosion hazard (Isaacson et al., 1982). Moreover, these field inventories are often very general. Usually, only the scorched perimeter is drawn, but no information about the species affected or severity of damage is provided. Furthermore, studies on vegetation succession after fire are seldom done.

The growing interest in global effects of fire processes demands a quantitative evaluation of the spatial and temporal distribution of fire patterns (Levine, 1991): a wide range of disciplines, such as fire ecology, fire management, atmospheric chemistry and forestry, will benefit from burned land maps at global and local scale.

Most of the fire mapping projects have been based on channel 3 data. However, as it was stated before, this channel presents several difficulties for fire detection and, therefore, for burned land mapping. Another approach for burned land evaluation is based in measuring the consequences of the fire, rather than detecting the fire itself, by multitemporal comparison of vegetation indices acquired from before and after the fire.

Several studies have shown that spectral characteristics of burned land contrast sharply with the response of healthy vegetation. Burned land shows a severe decrease in near infrared reflectance, as a consequence of leaf deterioration, and an increase in red reflectance because of the lack of pigments' absorption (Tanaka et al., 1983). Therefore, the NDVI values of burned vegetation are much lower than those of healthy plants, and multitemporal analysis should clearly portray fire alteration. Some studies have proven this hypothesis, obtaining adequate results from both high and low resolution sensors (Kasischke et al., 1993; Martín et al., 1994; Pereira et al., 1994).

7. FUTURE PROSPECTS

Future availability of better spatial, spectral and temporal resolution sensors will overcome some of the present limitations of satellite data for fire management. MODIS data will increase spatial and spectral detail currently provided by the AVHRR sensor for both short-term fire danger estimation and fire mapping. This sensor, along with the Meteosat Second Generation, will also very valuable for operational fire detection, even in European countries. The growing tendency toward the combined analysis of GIS and Remote Sensing data will benefit fire risk and fire effects assessment as well.

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