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Remote Sensing Applications
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Forest Fire Monitoring

16.1. Introduction

Vegetation fires have been acknowledged as an environmental process of global scale, which affects the chemical composition of the troposphere, and has profound ecological and climatic impacts. However, considerable uncertainty remains, especially concerning intra and inter-annual variability of fire incidence.

Within the total global vegetation, forests constitute a large part of earth's renewable natural resources, which plays a pivotal role in maintaining a near ideal environmental condition for life sustenance, besides serving as an important source of food, fuel wood, fodder, timber etc. Global Forest Resources Assessment 2000 (FRA 2000) concluded that the world's forest cover as of 2000 was about 3.9 billion hectares, or about 0.6 ha per capita. The regional distribution of global forests showed that Europe (including the Russian Federation) has 27 percent of the forests; South America, 23 percent; Africa, 17 percent; North and Central America, 14 percent; Asia, 14 percent; and Oceania, 5 percent.

FRA 2000 also conducted a remote sensing survey of tropical forests to assess forest change. This survey used sampling techniques with satellite imagery. The results indicated that the world's tropical forests were lost at a rate of about 8.6 million ha annually in the 1990s, compared to a rate of around 9.2 million ha per year during the previous decade. During the same period, the annual rate of loss of closed forests decreased from 8.0 million ha in the 1980's to 7.1 million ha in the 1990s. While the reduction in deforestation rates between the two decades was likely not significant in itself, the change estimate for the 1990s coincided well with the country specific findings.

Forest ecosystems are subjected to a variety of environmental threats of which fire is a potentially serious hazard. Fire depending on where, when and why it occurs, can be either an essential factor or otherwise, in the ecological cycle of the forested landscape and the survival of associated plants and animals it is merely a destructive unnatural threat. In tropical deciduous forests, fire is a natural phenomenon due to higher levels of water stress during summer. Traditional land use practices and changes in the weather pattern have affected the incidence of fires. Fire being a good servant and a poor master, has been responsible for causing immense damage to both forest fauna and flora, including the soil inhabitants. Forest fires can have large impacts on both, ecosystems and economy.

The ecological role of fire is to influence several factors such as plant community development, soil nutrient availability and biological diversity. Forest and wild land fire are considered vital natural processes initiating natural exercises of vegetation succession. However, uncontrolled and misuse of fire can cause tremendous adverse impacts on the environment and the human society.

Continued high annual rate of loss of tropical forest cover and outbreak of major wildfires over the past decade, in contrast to increased plantation development, successes in sustainable forest management and increases in protected areas show a complex picture of the past and possible future of the world's forests and mankind's interaction with them.

During the last decade, increased availability of time series of satellite data has contributed to improve our understanding of fire as a global environmental process. Dwyer *et al.* (2000a, b), used one year of the Advanced Very High Resolution Radiometer (AVHRR) fire data to characterise global patterns of fire seasonality and their relationships with climate. More recently, a new generation of satellites sensors brought further advances through enhanced fire monitoring capabilities, resulting in the production of various burned area and fire hotspots datasets at regional or global scales (Arino *et al.*, 2005; Giglio *et al.*, 2003; Giglio *et al.*, 2006; Carmona-Moreno *et al.*, 2005; Ria˜no *et al.*, 2007).

In spite of these studies, considerable uncertainties remain, especially regarding the spatial and temporal variability of global vegetation burning and its relationship with climate dynamics. The Global Climate Observing System (GCOS, 2006) considered fire disturbance an "Essential Climate Variable" and highlighted the need for long data time series to quantify the links between climate and fire (Le Page, 2007).

16.1.1. Causes of fire

Intentional : Forest fires are mostly anthropogenic in nature and caused intentionally. These may occur due to the following reasons (Negi, 1986).

- Forest floor is often burnt by villagers to get a good growth of grass in the following season or for a good growth of mushrooms
- Wild grass or undergrowth is burnt to search for animals
- Firing by miscreants
- Attempt to destroy stumps of illicit fallings

Unintentional :These fires are caused due to man's carelessness i.e., without intention to set fire. Such fires may be due to the following reasons:

- Un-extinguished campfires of trekkers, laborers, camp of roadside charcoal panniers etc.
- Spark of fire from railway engines
- Careless throwing of fire after honey collection
- Un-extinguished bidis, cigarette butts, matchsticks etc., by grazers, travelers, picnickers or even forest laborers
- Burning of agricultural fields adjacent to forested areas. Such fires is left unattended may spread to forest areas
- Careless handling of acid by resin tapers
- During controlled burning by the department, fire may spread to the forest due to negligence of the staff

Natural: Natural causes of fires include:

- Fires caused by lighting
- Fires caused by rolling stones
- Fires may be caused by volcanic eruptions

In our country there was no report forest fire due to natural cause.

Figure 16.1: Ground fire

16.1.2. Classification of forest fire

According to a classification of forest fires by type and causes, three major types of forest fires are prevalent (P S Roy, 2003);

Ground fires: Ground fires occur in the humus and peaty layers beneath the litter of undecomposed portion of forest floor with intense heat but practically no flame. Such fires are relatively rare and have been recorded occasionally at high altitudes in Himalayan fir and spruce forests (Figure 16.1)

Figure 16.2: Surface Fire

Surface fires: Surface fires occurring on or near the ground in the litter, ground cover, scrub and regeneration, are the most common type in all fire-prone forests of the country (Figure 16. 2)

Figure 16.3: Crown Fire

Crown fires: Crown fires, occurring in the crowns of trees, consuming foliage and usually killing the trees, are met most frequently in low level coniferous forests in the Siwaliks and Himalayas (NCA Report, 1976) as shown in figure 16.3.

16.1.3. Global and National Issues, Scenario and Developments

Forest fire is a major cause of degradation of India's forests. While statistical data on fire loss are weak, it is estimated that the proportion of forest areas prone to forest fires annually ranges from 33% in some states to over 90% in others. About 90% of the forest fires in India are started by humans (Roy, 2003). Forest fires cause wide ranging adverse ecological, economic and social impacts. In a nutshell, fires cause: indirect effect on agricultural production; and loss of livelihood for the tribals as approximately 65 million people are classified as tribals who directly depend upon collection of non-timber forest products from the forest areas for their livelihood.

A combination of edaphic, climatic and human activities account for the majority of wild land fires. High terrain steepness along with high summer temperature supplemented with high wind velocity and the availability of high flammable material in the forest floor accounts for the major damage and wide wild spread of the forest fire. The vast majority of wild fires are intentional for timber harvesting, land conversion, slash – and- burn agriculture, and socio-economic conflicts over question of property and landuse rights. In recent years extended droughts (prolonged dry weather), together with rapidly expanding exploitation of tropical forest and the demand for conversion of forest to other land uses, have resulted in significant increase in wild fire size, frequency and related environmental impacts.

Past wild fires have an immense impact in Indonesia, Brazil, Mexico, Canada, USA, France, Turkey, Greece, India and Italy. Large-scale fires and fire hazards were also reported in eastern parts of the Russian Federation and in China northeastern Mongolia autonomous region. There has been a continuous increase of application of fire in landuse system in forest of South East Asian region. This has resulted in severe environmental problems and impacts on society. Wild fires often escape from landuse fire and take unprecedented shape causing problems of transboundary pollution. Author (Roy, 2003) analyzes the forest and wild land fires issues with particular reference to South East Asia and emphasizes on development of national and regional fire management plans considering the complexity and diversity of fire.

Impact of the Forest Fire on the Global Environment: Forest fires controlled or uncontrolled have profound impacts on the physical environment including land cover, land use, biodiversity, climate change and forest ecosystem. They also have enormous implication on human health and on the socio-economic system of affected countries. Economic cost is hard to quantify but an estimate by the economy and environment can be provided. The fire incidence problem for South East Asia put the cost of damages stemming from the Southeast Asian fires (all causes) at more than $4 billion. Health impacts are often serious. As per one estimate 20 million people are in danger of respiratory problems from fire in Southeast Asia. Most pronounced consequence of forest fires causes their potential effects on climate change. Only in the past decade researchers have realized the important contribution of biomass burning to the global budgets of many radiatively and chemically active gases such as carbon dioxide, carbon monoxide, methane, nitric oxide, tropospheric ozone, methyl chloride and elemental carbon particulate. Biomass burning is recognized as a significant global source of emission contributing as much as 40% of gross Carbon dioxide and 30% of tropospheric ozone.

There is a strong need for a comprehensive international set of comparable data on forest fires and other wildland fires, as a tool for policy makers, and for operational planning (for both prevention and suppression), as an essential part of improving understanding of climate change and the factors influencing it, and as a part of an effort to monitor the state of the world's forests.

In recent years the scientific community has shown renewed interest in forest (vegetation) fires, notably because of their significant role in climate change, and new methods of collecting information using remote sensing techniques are being developed. Furthermore, the research community needs global geo-referenced data (although not necessarily at a very fine degree of resolution).

To collect the Fire Statistics in the Countries of the United Nations Economic Commission for Europe (UNECE) has the following commitment.

The Resolution S3 of the Ministerial Conference at Strasbourg committed the signatories (including the EU) to creating a decentralised data base on forest fires. Since then a data base, with fire-by-fire information, has been built up, in those countries/regions of the European Union with a particularly severe forest fire problem. In this system, for each fire, information is collected on first alert and extinction times, location, area, cause, etc., according to a “common core” of parameters. 19 countries of the 27 signatories of Resolution S3 expressed their willingness to adhere to a data base network based on the common core system adopted by EU members, considering it a good, feasible starting point of collecting data on a common base at the pan-European level.

FAO Silva Mediterranea, like the Working Party a subsidiary body of the European Forestry Commission (EFC), covers a region where forest fires are one the most serious dangers to sustainable forest management, and has also stated its interest in moving towards a fire-by-fire information system, based on the EU system.

At the global level, FAO has collected data on forest fires, using the FAO/ECE conceptual framework and definitions, as part of its monitoring of the state of the world’s forests within the context of the Global Forest Resource Assessment.

International Forest Fire News (IFFN), prepared by JG Goldammer, leader of the ECE/FAO. Team of Specialists on Forest Fires, contains both technical and statistical information on forest fires world wide. Goldammer is also developing a Global Vegetation Fire Inventory (GVFI), collecting information by a network of correspondents. GVFI is an activity of the International Global Atmospheric Chemistry (IGAC) project, a core project of the International Geosphere-Biosphere Programme (IGBP).

16.2. Review of Literatures

During last two decade especially in last decade, much work has been carried in the field of forest fire detection, assessment, risk management and other related study considering the global acknowledgment of environmental degradation and direct consequences in climatic change.

16.2.1. Fire Detection

Traditionally, forest fires have been detected using fire lookout towers located at high points in a forested area. A fire lookout tower houses a person whose duty is to look for fires using binocular or other sophisticated equipment such as Osborne fire finder (Fleming and Robertson, 2003). Osborne fire finder is comprised of a topographic map printed on a disk with graduated rim. A pointer aimed at the fire determines the location and the direction of the fire. Once the fire location is determined, the fire lookout alerts fire-fighting crew. Fire lookout towers are still in use around the world with simple binocular or other related sophisticated equipment

Unreliability of human observations in addition to the difficult life conditions for fire lookout personnel have led to the development of automatic video surveillance systems (Fire Watch Web Page ; Breejen *et al.*, 1998; Khrt *et al.*, 2001). Most systems use Charge-Coupled Device (CCD) cameras and Infrared (IR) detectors installed on top of towers. CCD cameras use image sensors, which contain an array of light sensitive capacitors or photodiodes. In case of fire or smoke activity, the system alerts local fire departments, residents, and industries. Current automatic video surveillance systems used in Germany, Canada, and Russia are capable of scanning a circular range of 10 km in less than 8 minutes. (Fire Watch Web Page). The accuracy of these systems is largely affected by weather conditions such as clouds, light reflection, and smoke from industrial activities. Automatic video surveillance systems cannot be applied to large forest fields easily and cost effectively, thus for large forest areas either aeroplanes or Unmanned Aerial Vehicles (UAV) are used to monitor forests. Aeroplanes fly over forests and the pilot alerts the base station in case of fire or smoke activity. UAVs, on the other hand, carry both video and infrared cameras and transmit the collected data to a base station on the ground that could be up to 50 km away. UAVs can stay atop for several hours and are commanded by programming or joystick controls (Aerovision Web Page) .

More advanced forest fire detection systems are based on satellite imagery. Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), Indian Remote Sensing Satellite-Advanced Wide Field Sensor (IRS AWiFS) are being used for active forest fire detection. Current satellite-based forest fire detection systems use data from these instruments for forest fire surveillance. The accuracy and reliability of satellite-based systems are also (unlike ground surveillance) largely impacted by weather conditions. Clouds and rain absorb parts of the frequency spectrum and reduce spectral resolution of satellite imagery, which consequently affects the detection accuracy. Although satellite-based systems can monitor a large area, relatively low resolution of satellite imagery means a fire can be detected only after it has grown large. More importantly, the long scan period—which can be as long as 2 days—indicates that such systems cannot provide timely detection.

There are many existing techniques used for detection of forest fires. One of the most important is described by Boyd M, Harden *et al.*, (1973). Their paper outlines a model, which can be readily adapted for analysis of any forest, and has actually been used to examine various fire detection strategies for the Footner Forest in Northern Alberta. Some research is based on image processing techniques, capturing camera segments and processing and classifying these images for fire detection. Using image processing methods, Roy and UNEP have used a satellite for capturing images from forests and, have detected whether there is a fire possibility or not. Another satellite application in forest fires detection is by Lafarge *et al.*, (2007). They present a fully automated method of forest fire detection from TIR satellite images based on the random field theory where preprocessing is used to model the image as a realization of a Gaussian field. This study shows some interesting properties because the fire areas considered to be in the minority are considered as anomalies of that field. Nakau *et al.*, (2006) developed a fire detection information system from receiving AVHRR satellite to output fire detection map and validated the early detection algorithm using AVHRR satellite imagery.

Another study is computer vision based forest fire detection and monitoring system where fixed cameras are used (Toreyin *et al.*, 2007). Furthermore, there is a great many forest fire detection studies and systems available (Fujiwara *et al.*, 2002, Casanova *et al.*, 2004, Ertena *et al.*, 2002 and Filizzola *et al.*, 2007). Ollero *et al.*, 1998. have studied a scheme using multi-sensorial integrated systems for early detection of forest fires. Several information and data sources in Olleros's study were used, including infrared images, visual images, data from sensors, maps and models, Casanova *et al.*, 2004. present the MSGSEVIRI sensor's ability to detect forest fires and subsequent fire monitoring. There are a number of similar studies on fire detection using sensors.

Justice *et al.*, 2002 and Giglio *et al.*, 2003 developed a multi-year daily active fire product from the Moderate Resolution Imaging Spectroradiometer (MODIS). This product has a good detection rate, due to its 4 daily overpasses. This method is the most popular all over the world but is only available since 15 November 2000. Hence, for global fire mapping is being done since year 2000 only.

The authors (Doolin and Sitar 2005), in their study shown the feasibility of wireless sensor networks for forest fire monitoring. Experimental results are reported from two controlled fires in San Francisco, California. The system is composed of 10 GPS-enabled MICA motes (Crossbow Inc. Web Page) collecting temperature, humidity, and barometric pressure data. The data is communicated to a base station which records it in a database and provides services for different applications. The experiments show that most of the motes in the burned area were capable of reporting the passage of the flame before being burned. In contrast to this system which reports raw weather data, Mohamed H *et al.*, 2007 design processes weather conditions based on the Fire Weather Index System (Canadian Forest Fire Danger Rating System (CFFDRS) Web Page) and reports more useful, summarized, fire indexes. His study addresses the Fire Weather Index (FWI) System, which notes that different components can be used in designing efficient fire detection systems FWI. He has presented the design of a wireless sensor network for early detection of forest fires. Their design is based on the Fire Weather Index (FWI) System, which is backed by decades of forestry research. The FWI System is comprised of six components: three fuel codes and three fire indexes. The three fuel codes represent the moisture content of the organic soil layers of forest floor, whereas the three fire indexes describe the behavior of fire. By analyzing data collected from forestry research, they showed how the FWI System can be used to meet the two goals of a wireless sensor network designed for forest fires: (i) provide early warning of a potential forest fire, and (ii) estimate the scale and intensity of the fire if it materializes. To achieve these goals, they have designed their sensor network based on two main components of the FWI System: the Fine Fuel Moisture Code (FFMC), and the Fire Weather Index (FWI). The FFMC code is used to achieve the first goal and the FWI index is used to achieve the second.

Using animals for disaster detection is not a new idea but it has been limited to a few of disaster types such as earthquake. Yeung, 2007 describes an example of observing animals' behavior for early earthquake alert, but the author gives no guaranty that his study works correctly for every earthquake. Kahn, 2007 suggested an idea that the best and the cheapest biosensors are already distributed globally but generally ignored: They're called animals. Kahn's idea leads the scientists to start new investigations to be made on animals. Lee *et al.*, 2007, in their study, they offered a Bio-adhoc sensors network for early forest fire warning system for mountain areas, and they used animals as wireless adhoc nodes.

However, the proposal presented by Yasar, 2007, is based on the usage of many access points explicitly constructed in the forests instead of an adhoc network structure. Although it may not seem to be feasible to install sufficient number of access points to cover whole forests, some critical points which are highly under the risk of fire, can be selected for the access point locations. Moreover, the usage of the access points would remove the risk of interruption of communication (network failure) that usually occurs in adhoc networks, if animals are used as wireless nodes. Furthermore, Lee *et al.*, in their study focused on the usage of animals' behavior only for detection of fire possibilities. This paper, however, focuses on using both animal behavior classification and thermal detection methods. In this paper (Yasar, 2007), a proposal for a fire detection system combining methods from both animal tracking and current fire detection systems is presented. The system proposed does not claim to detect every possible fire, and can readily be used to augment others.

The main idea presented in this paper is to utilize animals with sensors as Mobile Biological Sensors (MBS). The devices used in this system are animals which are native animals living in forests, sensors (thermo and radiation sensors with GPS features) that measure the temperature and transmit the location of the MBS, access points for wireless communication and a central computer system which classifies of animal actions. The system offers two different methods, firstly: access points continuously receive data about animals' location using GPS at certain time intervals and the gathered data is then classified and checked to see if there is a sudden movement (panic) of the animal groups: this method is called animal behavior classification (ABC). The second method can be defined as thermal detection (TD): the access points get the temperature values from the MBS devices and send the data to a central computer to check for instant changes in the temperatures. The proposed system, additionally, has a classifier which built-in measures to use animal action (panic) to signal a fire alarm in situations where thermal sensors usage is inappropriate. Furthermore, this system may assist in preventing poaching, monitoring animals' death, and understanding animals' group behavior.

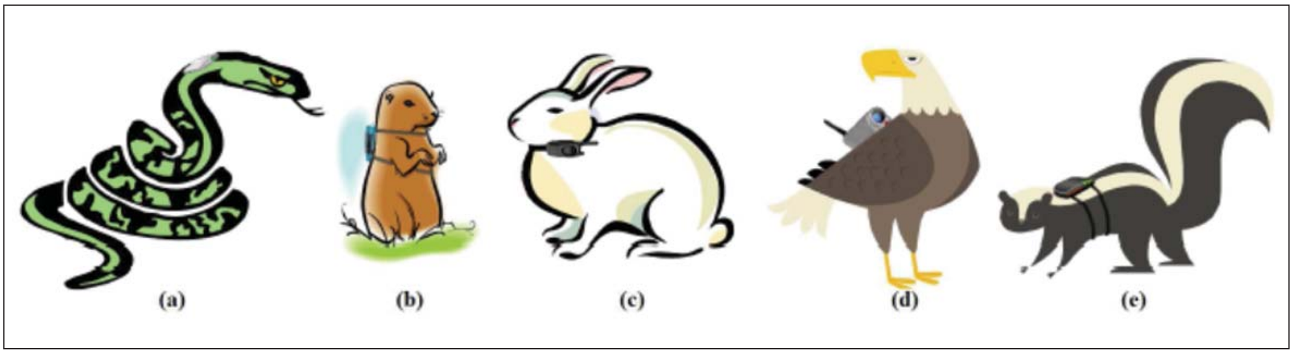

Figure 16. 4: Some animals that can be used as MBS in the system

In this paper he has suggested to choose animals and sensors in accordance with characteristic the forest such as climate zone, natural specifications, and density. Selection of animals which are native to the forest areas, and the choice of sensors depend on which method (TD or ABC) will be applied. The usual pattern of fire spread for a particular forest is another criterion in the selection of animals and sensors. Figure 16. 4 shows examples of animals that can be used as MBS (these animal species can vary in accordance with the territory's specifications), and Figure 16.5 shows sample sensors, which can be attached to animals (Cochran *et al.*, 2007). The most important issue in the selection of sensors is that they must all have GPS features with both methods (TD and ABC).

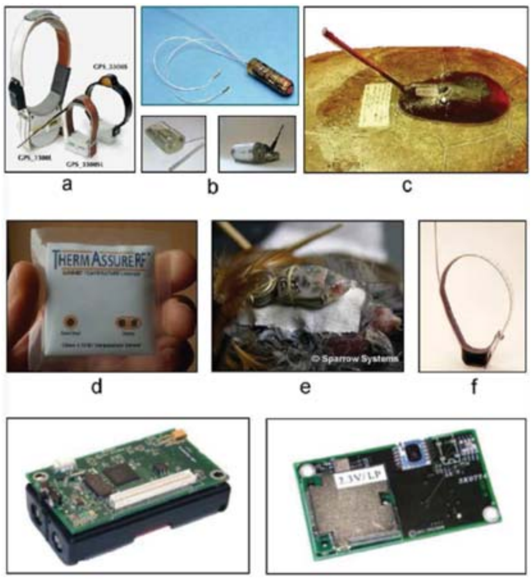

Figure 16.5: Sample sensors which can be attached to animals

More advanced approach of surveillance is automatic surveillance and automatic early forest fire detection. Today there are several different approaches but the most feasible is the system based on video cameras sensible in visible spectra. In almost every country, which encounters high risk of forest fires, at least one such system was developed and proposed. Some of them are on the market under various commercial names. Croatia also has its own system called Integral Forest Fire Monitoring System (in Croatian IPNAS) developed at the Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture

University of Split. The system was experimentally tested during 2005 and 2006 fire seasons on three locations but it is also in everyday use in National Park Paklenica from June 2006.

IPNAS structure is shown in Figure 16.6. The system is based on field units and a central processing unit. The field unit is conceived of pan/tilt/zoom controlled video cameras and a mini meteorological station connected by Wireless LAN to a central processing unit where all analysis, calculation, presentation, image and data archiving is done. The system is Web based because the user interface is displayed in a standard Web browser, and the user can reach any system module through tunnelled SSL (Secure Socket Layer) VPN (Virtual Private Network). Multiple level of authentication stop the potential intruders.

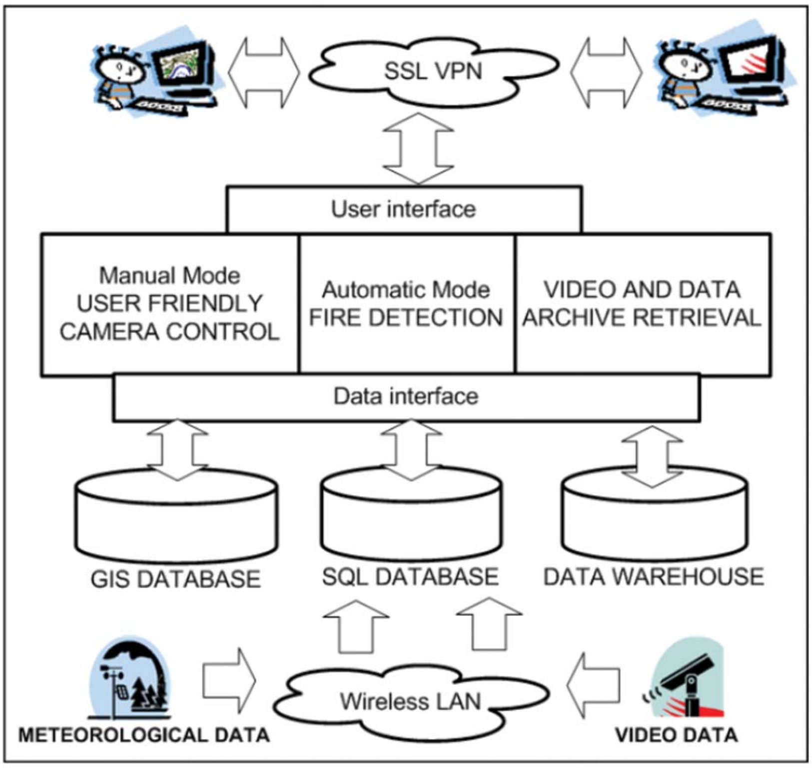

Figure 16.6: Structure of Croatian Integral Forest Fire Monitoring System (IPNAS) (Source :http://www.fesb.hr/~ljiljana/radovi/279548)

IPNAS is based on three types of data

- Real-time video data – Digital video signal is used both in automatic and manual mode. In automatic mode it is a source of images for automatic forest fire detection and in manual mode it is used for distant video presence and distant monitoring using pan/tilt control and powerful zoom
- Real time metrological data –The meteorological data is today used in a postprocessing unit for false alarm reduction, and tomorrow will be useful for local fire risk index calculation in prevention phase and fire spread estimation in fire fighting phase
- GIS (Geographical Information System) database – stores information on pure geographical data (elevations, road locations, water resources, etc.), and all other relevant information related to a geographic position, like fire history, rain-water resource locations, land cover – land use, soil characteristics, local forest corridor map, tourist routes and similar. This data tomorrow will be quite useful for fire management activities and today it is used for user-friendly camera pan/tilt control.

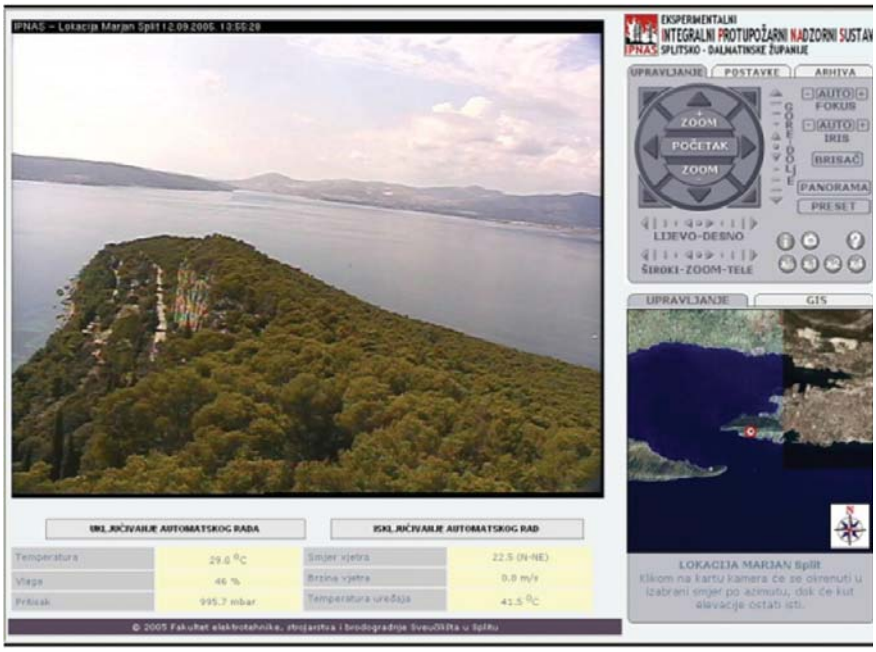

Figure 16.7 (a): IPNAS user interface is a dynamic and interactive Web page with the all real-time data and a user friendly interface for camera control in manual mode(Source :http://www.fesb.hr/~ljiljana/radovi/279548)

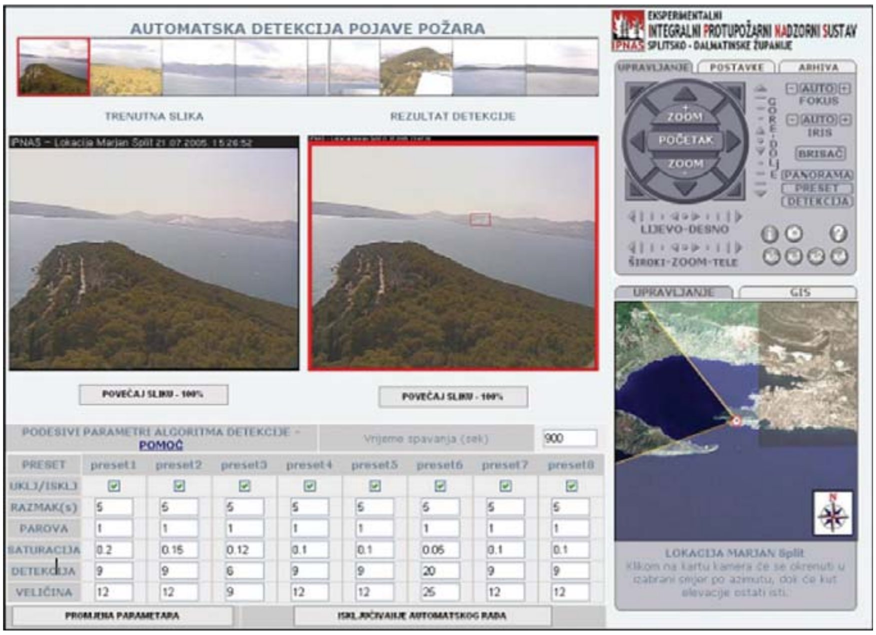

Figure 16.7 (b): IPNAS user screen in automatic mode. Detection algorithms has few parameters which could be adjusted in real time to decrease the false alarm rate(Source :http://www.fesb.hr/~ljiljana/radovi/279548)

The user interface is a dynamic and interactive Web page where real time video and meteorological data is shown together with GIS data and user friendly interface for camera pan/tilt/zoom control in manual mode. Figure 16.7 shows the main user interface page for experimental monitoring unit.

During this experimental period they have acquired a big collection of false alarms that help them to improve the fire detection algorithm and functionality of the whole system. New improved version of Integral Forest Fire Monitoring System was released during 2006.

B. Zhukov *et al.*, have investigated the effect of the resolution on the recognition of fire fronts and on the estimation of their characteristics, as well as on the estimation of the total fire radiative power (FRP) emitted from a fire scene. Data of the spectroradiometers MODIS on the Terra and Aqua satellites, which are obtained on a global scale 4 times a day, are widely used for global and regional monitoring of active fires. A disadvantage of MODIS is a relatively low resolution of 1 km. For this purpose, they compared images of fire scenes in Siberia, Portugal and Australia that were obtained nearly simultaneously by MODIS and by the dedicated small satellite BIRD, which provides a resolution of 370 m in its infrared channels and allows the detection of fires with an area a factor of 7 smaller than MODIS. The results show that BIRD allows the recognition of fire fronts and the estimation of their characteristics, while in the MODIS data fire fronts are usually not clearly distinguished. On the other hand, MODIS proves to be a marginally adequate sensor for the estimation of the total FRP in fire scenes, which is related to the rates of biomass burning and of gas and aerosol emissions. Only in cases of fires with a relatively small front depth, which is typical for bush fires in Australia, MODIS may significantly underestimate the FRP by a factor of 1.8 compared to the BIRD-based FRP estimates.

The results of this study show that the MODIS sensor, with a spatial resolution of 1 km, is marginally adequate for the estimation of the radiative power of forest fires. FRP can be related to the rates of biomass burning and of gas and aerosol emissions. Though MODIS may miss a significant portion of small fires in comparison to BIRD, it underestimated the total FRP of the fire scenes in Siberia only by ~4%. The reason is that in these scenes the major part of FRP (and consequently of the fire pollutant emissions) are produced by large fires that are reliably detectable by MODIS. In cases of fires with a relatively small front depth, which is typical for the bush fires in Australia, MODIS may significantly underestimated the FRP by nearly 50% compared to the BIRD-based FRP estimates. As a conclusion, it is recommended to combine the data of wide swath sensors, such as MODIS and of high-resolution instruments of the BIRD type for effective fire monitoring from space.

Young Gi Byun *et al.*, 2005 proposed a graph-based forest fire detection algorithm which is based on spatial outlier detection methods. Spatial outliers in remotely sensed imageries represent observed quantities showing unusual values compared to their neighbor pixel values. There have been various methods to detect the spatial outliers based on spatial autocorrelations in statistics and data mining. These methods may be applied in detecting forest fire pixels in the MODIS imageries from NASA's AQUA satellite. This is because the forest fire detection can be referred to as finding spatial outliers using spatial variation of brightness temperature. Authors have tested the proposed algorithm to evaluate its applicability. For this the ordinary scatter plot and Moran's scatter plot were used. In order to evaluate the proposed algorithm, the results were compared with the MODIS fire product provided by the NASA MODIS Science Team, which showed the possibility of the proposed algorithm in detecting the fire pixels.

16.2.2. Fire burnt Area Assessment

Devastating fires affected Greece in the summer 2007, with the loss of more than 60 human lives, the destruction of more than 100 villages and hundreds of square kilometers of forest burned. Luigi boschetti *et al.*, have mapped the extent burned and the approximate day of burning in Greece using MODIS burned area product for 22 June to 30 August 2007. Their mapping is independent that of European Forest Fires Information Service (EFFIS). The characteristics of the two datasets, and an evaluation of the areas burned comparing the MODIS and EFFIS data for the same temporal interval are analysed.

The MODIS burned area product (MCD45) mapped 292657 ha as burned from 22 June to 30 August 2007 across the whole of Greece (including the islands), and the EFFIS reported 272163 ha burned for the same period. Of these 242 900 ha were identified as burned by both products, corresponding to approximately 2% of Greece. Differences between the two products occur primarily along the borders of EFFIS mapped polygons, in agricultural regions which are not considered by EFFIS, and for small burned areas that were mapped by EFFIS but not by MCD45.

GeoSpatial Experts' GPS-Photo Link software has been deployed by U.S. Forest Service in the Cleveland National Forest to speed the creation of soil burn severity maps following the devastating California wildfires in October 2007. The software enabled Forest Service personnel to complete the damage assessment more rapidly than would have otherwise been possible, so that plans could quickly be made to protect surviving infrastructure from flooding, landslides and debris flows. The GPS-Photo Link software maps digital photographs to their correct georeferenced locations in geospatial map layers. Requiring only a standard digital camera and handheld GPS device, the software links the photographic images with GPS location data and then accurately integrates them into a geospatial data set along with important attribute data, such as the time, date, and location coordinates of each photo. The software enables users to display their photo locations as icons in digital mapping environment, including GIS and Google Earth map layers.

Roy *et al.*, 2008, have analyzed NASA MODIS Collection 5 burned area product. Total annual and monthly area burned statistics and missing data statistics are reported at global and continental scale and with respect to different land cover classes. Globally the total area burned labeled by the MODIS burned area product is 3.66×106 sq.km for July 2001 to June 2002 while the MODIS active fire product detected for the same period a total of 2.78×106 sq.km, i.e., 24% less than the area labeled by the burned area product. A spatio-temporal correlation analysis of the two MODIS fire products stratified globally for pre-fire leaf area index (LAI) and percent tree cover ranges indicate that for low percent tree cover and LAI, the MODIS burned area product defines a greater proportion of the landscape as burned than the active fire product; and with increasing tree cover (>60%) and LAI (>5) the MODIS active fire product defines a relatively greater proportion. This pattern is generally observed in product comparisons stratified with respect to land cover.

The reasons for the observed product differences are complex, and require further research and independent validation data. The demonstrated complementary nature of the MODIS burned area and active fire products imply that with further research their synergistic use may provide improved burned area estimates. The MODIS burned area product has been recently implemented in the MODIS land production system to systematically map burned areas globally for the 6 year MODIS observation record. Collection 5 is underway, reprocessing the Terra data record starting in 2000 to present.

16.2.3. Fire Risk Assessment

Forest fires can cause substantial damage to natural resources and human lives regardless of whether it is caused by natural forces or human activities. To minimize threat from wildfires, fire managers must be able to plan protection strategies that are appropriate for individual local areas. A prerequisite for the planning is the ability to assess and map forest fire risk zones across both broad areas and local sites. Forest fire risk zones are locations where a fire is likely to start, and from where it can easily spread to other areas.

People studied forest fire risk zones (FFRZ) with a variety of mapping methods. Most of them mapped forest fire risk zones by directly using remote sensing and geographic information systems (GIS) that contain topography, vegetation, land use, population, and settlement information (Chuvieco and Congalton 1989; Chuvieco and Salas 1996). A common practice was that forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers according to their sensitivity to fire or their fire-inducing capability.

XU Dong *et al.*, 2005, have developed a RS & GIS based methodology to map forest fire risk zones (Baihe forestry bureau, Jilin, China) to minimize the frequency of fires, avert damage, etc. Satellite images were interpreted and classified to generate vegetation type layer and land use layers (roads, settlements and farmlands). Topographic layers (slope, aspect and altitude) were derived from DEM. The thematic and topographic information was analyzed by using ARC/INFO GIS software. Forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers (vegetation type, slope, aspect, altitude and distance from roads, farmlands and settlements) according to their sensitivity to fire or their fire-inducing capability. Five categories of forest fire risk ranging from very high to very low were derived automatically. The mapping result of the study area was found to be in strong agreement with actual fire-affected sites.

Patah *et al.*, have developed a model using the integration of remote sensing and GIS to produce Fire Risk Index (FRI) maps which could be modified interactively with changing weather conditions. The model resided on three sub-indices - (i) Topographic danger index (TDI), (ii) Weather Danger Index (WDI) and (iii) Fuel Danger Index (FDI). The TDI was computed based on two parameters – slope, aspect and elevation which were generated from a DEM. The WDI was calculated from the ratio of mean maximum air temperature to mean maximum air relative humidity. In the development of the FDI the research has adopted the integration of digital classification product of the Tasselled Cap Transformed (TCT) datasets and the Forest Canopy Density (FCD) Map which gave a significantly more accurate fuel type map of the study area.

16.2.4. Fire Ecology

Fire ecology is a branch of ecology that concentrates on the origins, cycles, and future stages of fire. It probes the relationship of fire with living organisms and their environment. Following concepts provide the basis for fire ecology.

Fire Dependence: This concept applies to species of plants that rely on the effects of fire to make the environment more hospitable for their regeneration and growth. (2) Fire History: This concept describes how often fires occur in a geographical area. Fire scars, or a layer of charcoal remaining on a living tree as it adds a layer of cells annually, provide a record that can be used to determine when in history a fire occurred. (3) Fire Regime: Fire regime is a generalized way of integrating various fire characteristics, such as the fire intensity, severity, frequency, and vegetative community. (4) Fire Adaptation: This concept applies to species of plants that have evolved with special traits contributing to successful abilities to survive fires at various stages in their life cycles.

One major effect of fire is a change in soil nutrients and soil temperature. Fire may be a chief factor maintaining productivity in colder soils where the lack of nutrients is a major factor limiting plant growth. Fires release nitrogen and other nutrients from woody vegetation back into the soil in the form of mineral-rich ash, which makes them readily available for new plant growth. Plant regeneration begins almost immediately following a fire. At any given location, vegetation develops over time in orderly stages called succession. Each successive stage is determined by climate, soil conditions, available sunlight, and natural disturbances such as wildland fire. Although fire may destroy individual trees and understory plants, the species themselves are well adapted to survive. In many cases, this is accomplished through a high regeneration capacity.

The effects of fire on habitat- an animal’s surroundings or home- are generally more significant than the effects on animals themselves. Forests of different ages support different kinds of wildlife. Different types of birds and mammals seeking food and shelter are attracted to different types of forest types. All of these animals need a variety of resources to provide shelter, food, water, and space. These resources are often found on the borders of two or more plant communities, such as meadow/black spruce or birch/shrubland. These “edges” are created by fires and other disturbances and are beneficial to maintaining a healthy wildlife habitat. Small fires that occur in an area create more “edges” than one large burn. In fact a majority of species generally do best in forests that provide a combination of habitats.

Many wildlife species thrive on the occurrence of fire. The grasses, seedling shrub, and trees that reestablish burned areas provide an ideal environment for many small seed-eating mammals and birds, such as sparrows. Burned trees provide sites for cavity nesting birds like flickers, kestrels, and chickadees, while woodpeckers thrive on the insects that inhabit fire-killed trees.

Although the common conception is that fire is a destroyer of the natural environment, the opposite is actually true, where a carefully planned prescribed burning program can be beneficial and even enhance the health of an ecosystem. Prescribed fires can reduce the amount of combustible fuel buildup that can cause larger more destructive fires. Other benefits of prescribed fire include: insect pest control, removal of undesirable plants competing for nutrients, addition of nutrients from ash, and removal of sunlight inhibiting brushy undergrowth.

However, incorrectly managed prescribed fires can have very adverse effects causing excessive soil heating, loss of nutrients, and removal of woody debris needed to protect seedlings. Wildfires are suppressed in developed and high-fuel areas where intense fire could destroy a plant community or human built structures. Modern fire policy permits the burning of some natural fires and recognizes the use of prescribed fire as a management tool.

16.2.5. Agricultural burning

Agriculture and climate are inextricable related. Dependence of agriculture to climate change has only been established over the last few decades. Agricultural activities including clearing of forests, burning plant matter, cultivating rice, raising livestock and using fertilizers, leads to increased concentration of greenhouse gases in the atmosphere. Present agricultural practices contribute towards 17% of the global warning.

Badrinath *et al.*, have studied the agriculture crop residue burning in Punjab during wheat and rice crop growing periods. Indian Remote Sensing Satellite (IRS-P6) Advanced Wide Field Sensor (AWiFS) data during May and October 2005 have been analysed for estimating the extent of burnt areas and thereby greenhouse gas (GHG) emissions from crop residue burning. Emission factors available in the literature (Jun Wang *et al.*, 2003, Dennisa, *et al.*, 2002 and Reddy *et al.*, 2003) were integrated with satellite remote sensing data for estimating the emissions. Results suggested that emissions from wheat crop residues in Punjab are relatively low compared to those from paddy fields. It is inferred that incorporation of agricultural residues into the soil in rice–wheat systems is highly sustainable and eco-friendly, rather than burning the crop residues.

16.2.6. Biomass burning

Land clearing, an agriculture related activity, has made significant contribution to the greenhouse gas build-ups. When land is cleared, carbon dioxide is released through the burning or decomposition of plant matter and the oxidation of organic matter in the soil. Clearing forestlands for agricultural purpose results in increased carbon emission, because forest ecosystem store 20-100 times more carbon per unit area than cropland. Moreover burning of biomass for agriculture and pasture farming result in significant carbon dioxide emissions.

Biomass burning, in a broad sense, encompasses different burning practices, including open and confined burnings, and different types of vegetation. Emission factors of gaseous or particulate trace compounds are directly dependent both on the fuel type and the combustion process. Emission factors are generally calculated using the carbon mass balance method, applied either to combustion chamber experiments or to field experiments based on ground-level measurements or aircraft sampling in smoke plumes. There have been a number of experimental studies to investigate wildfires in tropical, temperate, or boreal regions. Delmas *et al.*, 1995, presented in their article, an overview of measurement methods and experimental data on emission factors of reactive or radiatively active trace compounds, including trace gases and particles. It focuses on fires in tropical regions, that is, forest and savanna fires, agricultural burns, charcoal production, use of fuelwood, and charcoal combustion.

The MOPITT (Measurement Of Pollution In The Troposphere) aboard the NASA Earth Observing System (EOS) Terra satellite is a thermal and near IR gas correlation radiometer designed specifically to measure CO profiles and total column CH_4. The resolution is 22 km horizontal resolution, though the refresh is 3 days. Pinpointing the sources of airborne chemical species is an important role for MOPITT. Although it cannot distinguish between individual industrial sources in the same city, it can map different points of origin that cover a few hundred square miles. This is accurate enough to differentiate air pollution from a major metropolitan area, for example, from a major fire in a national forest. In addition to being a pollutant, CO gas is a useful tracer for other pollutants, such as ozone at or near ground level. CO can also be used to calculate the level of pollutant-cleansing chemicals in the atmosphere, such as the hydroxyl radical. When CO levels are high, the level of the hydroxyl radical is usually lower and fewer pollutants are removed from the atmosphere. Generally radiative transfer model is being used to determine the amount of CO required to agree with MOPITT observations of elevated CO in conjunction with biomass burning.

MODIS data are also used to predict and monitor emissions from forest fires. This data are used to monitor area recently burned using two methods: a preliminary near-IR spectral test being developed at NASA and the convex hull of the cumulative active fire pixel centers (hot spots) when thick smoke obscures the burn scar. Emission factors from previous studies are used to estimate fire emissions from the MODIS observations. The emission estimates are used by a NOAA model to predict the dispersion of the emissions at three-hour intervals over several days (Wei Min Hao *et al.*).

A new instrument in orbit aboard NASA's ICESat satellite—the Geoscience Laser Altimeter System (GLAS)—reveals another dimension of the California wildfires. By transmitting a green beam of laser light downward at the Earth and then precisely measuring how much of that light is backscattered back up into space, GLAS can determine the vertical structure of clouds, pollution, or smoke plumes in the atmosphere.

Streets *et al.*, 2006 have studied biomass burning and associated atmospheric emission for Asian country. They estimated that 730 Tg of biomass are burned in Asia in a typical year from both anthropogenic and natural causes. Forest burning comprises 45% (330 Tg) of the total; the burning of crop residues in the field comprises 34% (250 Tg), and 20% (150Tg) comes from the burning of grassland and savanna. China contributes 25% of the total, India 18%, Indonesia 13%, and Myanmar 8%. Regionally, forest burning in Southeast Asia dominates. In their study National annual totals are converted to daily and monthly estimates at $1^0 \times 1^0$ grid resolution using distributions based on AVHRR fire counts for 1999-2000. Several adjustment schemes are applied to correct for the deficiencies of AVHRR data, including the use of moving averages, normalization, TOMS Aerosol Index, and masks for dust, clouds, landcover, and other fire sources.

To calculate emissions from biomass burning, the mass of dry matter burned of each type (forest, savanna grassland, or crop residues) is multiplied by an appropriate emission factor from Andreae and Merlet [2001], using the equation

$$E = M * F$$

where, E = total emissions of the source type;

M = mass of dry matter burned; and

F = source-specific emission factor

Biomass burning amounts are converted (using the above equation) to atmospheric emissions, yielding the following estimates: 0.37 T_g of SO_2, 2.8 T_g of NO_x, 1100 T_g of CO_2, 67 T_g of CO, 3.1 T_g of CH_4, 12 T_g of NMVOC, 0.45 T_g of BC, 3.3 T_g of OC, and 0.92 T_g of NH_3. Uncertainties in the emission estimates, measured as 95% confidence intervals, range from a low of ±65% for CO_2 emissions in Japan to a high of ±700% for BC emissions in India.

Annual emissions inventories, although necessary, are notoriously inaccurate, especially when emission factors from developed countries are applied (Guttikunda *et al.*, 2008) to developing countries.

16.2.7. Forest Fire Management System

Reliable up-to date information is critical for effective and efficient prevention and suppression of fires. Hence forest fire information system is a driving force for improved communication with the user department. Presently there are many number of forest fire information systems available globally/country level viz., Canadian wild land fire information system (http://cwfis.cfs.nrcan.gc.ca/en/index_e.php), European forest fire information system (http://ies.jrc.cec.eu.int/94.html), Web fire mapper (http://maps.geog.umd.edu/). Indian Forest Fire Response and Assessment System (INFFRAS).

Fire Information for Resource Management System (FIRMS) is a transitioning from a Research to an Operational System with an Emphasis on Protected Areas. This project integrates Remote Sensing and GIS technologies to provide Global fire information in easy to use formats for decision making, with an emphasis on supplying Protected Area managers. This work builds on Web Fire Mapper, a decision support tool built by researchers in the Department of Geography using NASA research and observations. The project will refine Web Fire Mapper - expanding the prototype into an operational system called the Fire Information for Resource Management System (FIRMS). This operational system will ultimately be housed at the United Nations (FAO and UNEP) to ensure data continuity and aid the UN in meeting its mandate to assist developing countries in protecting biodiversity. FIRMS will consist of a WebGIS with interactive maps, near-real time NASA imagery and email and text message alerts warning of fires in or around Protected Areas. FIRMS is likely to be integrated with INFFRAS soon.

Although fire is an established ecosystem process, and has an important role in conservation areas, frequent and uncontrolled fires can be detrimental. Uncontrolled fires can damage natural resources, diminish the range and diversity of species and erode fragmented forest edges. To be able to manage fires, natural resource managers need timely information both on fires occurring within their area of jurisdiction and within its immediate surroundings. Obtaining fire information in a user-friendly format and in time to use it for operational fire management has not been easy for park managers in remote locations and with limited access to the internet. FIRMS will provide resource managers with a system that delivers fire products with the minimum possible file size and using a delivery system that anyone with Internet connectivity can access.

16.3. Forest Fire Study under Decision Support Centre (DSC), Disaster Management Support Programme (DMSP) at National Remote Sensing Centre (NRSC), India

16.3.1. Indian Forest Fire Response and Management System (INFFRAS)

The Decision Support Center (DSC) at the National Remote Sensing Centre is an integral part of the National Disaster Management Support Program (DMSP) activities of Department of Space. The Indian Forest Fire Response and Assessment System (INFFRAS) have been established under the DSC to facilitate forest fire management. INFFRAS integrates multi sensor satellite data with GIS databases to address forest fire management at following levels

- Pre fire: Preparatory planning for fire control;
- During fire: Near real time active fire detection and monitoring;
- Post fire: Damage and recovery assessment and mitigation planning

Website of INFFRAS is available at NRSC home page as shown in Figure 16.8.

With the advent of series of satellite onboard, it is possible to detect active fires to a minimum of 4 times in a day (viz. MODIS-Terra/Aqua, NOAA-17/ 18, IRS P6) and at least 2 times during nighttime by DMSP-OLS (F15 & F16). In an integrated approach, daytime fire signals using MODIS Terra/Aqua and nighttime fire signals using DMSP-OLS are disseminated to the user (State Forest Department), through INFFRAS. Different spatial & temporal satellite data viz. IRS 1D/P6, MODIS are analysed for fire monitoring and burnt area assessment on the basis of daily fire alert or based on special request from any user and are made available at INFFRAS for the users. In addition to the above, Remote Sensing & GIS based inputs for recovery/ mitigation planning also been provided to the user through INFFRAS. All the activities done under INFFRAS are described in the following sections.

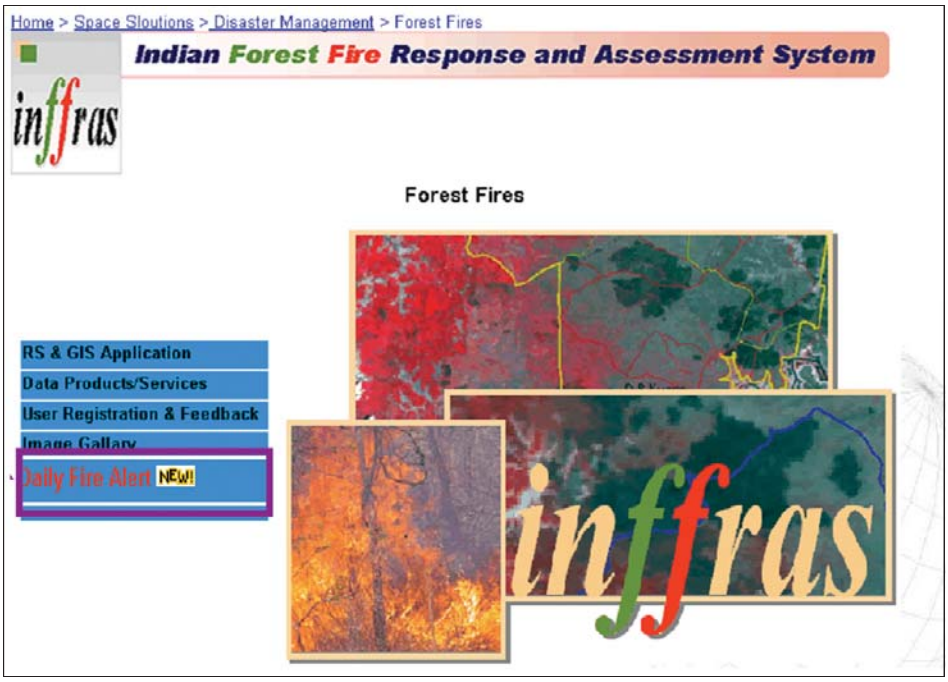

Figure 16.8: INFFRAS web site

16.3.1.1. Active fire detection using Moderate Resolution Imaging Spectroradiometer (MODIS) Terra/ Aqua data

16.3.1.1.1. Introduction

Coarse resolution (1 Km.) satellite data of sensors like MODIS, AATSR and NOAA detect active fires based on the brightness temperature levels recorded in short wave and thermal IR wavelength bands. Detection of active fires as a function of the pixel brightness temperature above that of background depends on fire temperature and size (area under burning) relative to the ground resolution of the sensor, fire and smoldering intensity levels, vegetation type and background land cover and atmospheric interferences.

Active fire locations detected using MODIS satellite data are placed on WEB on daily basis for the entire globe. Based on our initial studies conducted using these databases, it was found that a lot of improvement is required in terms of positional accuracy, detection of small fires and reduction of false alarms. The methods available globally need to be fine tuned while applying them over tropical regions like India by taking into account small extent of fires, different vegetation types and forest boundaries to exclude false alarms. This calls for development of region specific algorithms for detection of fires with improved accuracy.

Experience with the previous few years of high quality data from the (MODIS) through quality control and validation has suggested several improvements to the original MODIS active fire detection algorithm described by Kaufman *et al.*,1998. An improved active fire detection algorithm was developed which offers increased sensitivity to smaller, cooler fires as well as a significant lower false alarm rate. (Kaufman *et al.*, 2003). The improved algorithm can detect fires roughly half the minimum size that could be detected with the original algorithm while having an overall false alarm rate 10-100 times smaller.

The original fire detection algorithm suffered from persistent false detections in deserts and other sparsely vegetated land surfaces. As an example over Pakistan version -3 algorithm yielded nearly 4800 false fire pixels. These pixels were deemed false based on an examination of MODIS 250 m, 500 m, and 1 km imagery and the fact that the large cluster persisted over long periods of time (e.g., weeks). All fire pixels were located in areas of sparsely vegetated soil, and none of the fire pixels have sufficiently high 4 μm brightness temperatures to definitively suggest that true fires might be present. In addition, the top-of-atmosphere visible channel reflectances reveal a complete absence of smoke. This suggests that the majority (if not the entirety) of the fire pixels within a mosaic land cover of vegetative and non-vegetative surface are indeed false alarms. These studies stress a need for fine-tuning the fire detection algorithm on a continuous mode with region specific thresholds especially for sparsely vegetated forest areas in India.

In view of this, present study is proposed with the following objectives:

- To fine tune region specific forest fire detection algorithms using MODIS –Terra/Aqua satellite data
- To provide active fire locations along with forest infrastructure boundaries (if available) on daily basis for entire the country

16.3.1.1.2. Methodology for detection of active fire locations using MODIS Terra/Aqua data

A complete MODIS technical specification is given in Table 16.1 and operational procedure adapted for identification of active fire using MODIS Terra/Aqua satellite data is shown in figure 16.9. Raw MODIS Terra/Aqua satellite data acquired at NRSA ground station has undergone a series of process for the generation of active fire products. The raw satellite data in PDS format has been pass through MS2GT algorithm (down lowed from MODIS fire site) for

Table 16. 1: MODIS Technical Specifications

Orbit	:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular
Scan Rate	:	20.3 rpm, cross track
Swath Dimensions	:	2330 km (cross track) by 10 km (along track at nadir)
Telescope	:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size	:	1.0 x 1.6 x 1.0 m
Weight	:	228.7 kg
Power	:	162.5 W (single orbit average)
Data Rate	:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization	:	12 bits
Spatial Resolution	:	250 m (bands 1-2)
		500 m (bands 3-7)
		1000 m (bands 8-36)
Design Life	:	6 years

Primary Use	Channel	Bandwidth 1	Spectral Radiance 2	Required SNR3
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1	110
Ocean Color/ Phytoplankton Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10	167
	18	931 - 941	3.6	57
	19	915 - 965	15	250
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm
[2] Spectral Radiance values are (W/m^2 - µm-sr)
[3] SNR = Signal-to-noise ratio
[4] NE(delta)T = Noise-equivalent temperature difference
Note: Performance goal is 30-40% better than required

the production of bow tie and geo-corrected satellite data. Geo-corrected satellite data is used as the input to the revised fire algorithm to produce value added fire products.

NRSC followed Version 4 contextual algorithm (Louis Giglio *et al*., 2003), which is based upon the original MODIS fire detection algorithm (Kaufman, Justice *et al.*, for the generation of fire maps. The above algorithm is modified with region specific needs. The algorithm uses brightness temperatures derived from MODIS 4µm and 11µm channels, denoted by T_4 and T_{11} respectively. Thermal channels 21 and 22 ranging from 3.929 µm to 3.989µm of MODIS were considered for the present study. Channel 21 saturates at nearly 500 K and channel 22 saturates at 331 K. Since the low–saturation channel (22) is less noisy and has less quantization error; T4 is derived from channel 22. Brightness temperature T_{11} was derived from channel 31, which saturates approximately at 400K. Brightness temperatures derived from channel 32 is denoted by T_{12} and is used in cloud masking.

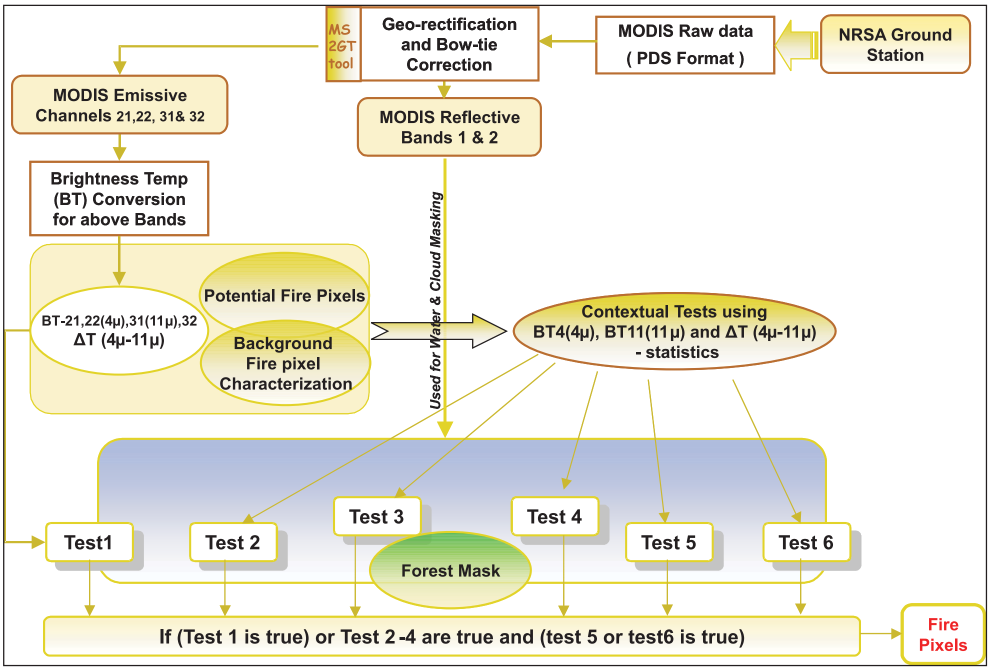

Figure 16.9: Operational procedure of Active fire detection

The 250 m resolution Red and Infrared channels (1 and 2) were aggregated to 1km and were used to reject false alarms and in masking clouds and water bodies. Reflectance of these channels (R,NIR) are denoted by $r_{0.65}$ and $r_{0.86}$ respectively. The details of the adopted algorithm are as follows

16.3.1.1.3. Cloud and water masking

Day time pixels are considered as clouds and obscured if following conditions are satisfied

(ρ 0.65 + ρ0.86 > 0.5) or (T_{12} < 295 K) for small clouds and

(ρ0.65 + ρ0.86 <. 15) or (T_{12} < 298 K) for larger clouds.

16.3.1.1.4. Identification of potential fire pixels

A preliminary classification is used to eliminate obvious non-fire pixels. Remaining pixels are considered in subsequent tests. A daytime pixels are identified as potential fire pixels

if T_4 > 290 K, ΔT > 3K and ρ0.86 < 0.185, where $\Delta T = T_4 - T_{11}$

16.3.1.1.5. Absolute threshold test

The 4 and 11 µm channels in MODIS are designed to be sensitive to temperatures reaching 500 K and 400 K respectively. Therefore except for large wild fires (less possible events in India) these MODIS channels with resolution 1 km at nadir are not expected to saturate. According to Weins displacement law, shorter the wavelength (4 µm), the stronger the sensitivity to the higher temperature region. Moreover 4 µm channel is not affected by water vapor absorption and weakly affected by other gaseous absorption.

Fire pixels are detected based on certain criterion. These are (1) The 4 µm channel brightness temperature to be elevated above a set threshold indicating a fire. (2) The difference between the 4 and 11 µm temperatures must be at least some specific value to avoid hot exposed soils, and the (3) used the 11 µm temperature to eliminate false detections from cool clouds, with small drop size, that are highly reflective in the 4 µm band. Based on the above considerations brightness temperatures for 4 and 11 µm channels were examined. Scatter plot of brightness temperatures of fire pixels represented by 4 and 11 µm channels is shown in Figure 16.10. It has been observed from brightness temperature received by 4 µm channel is always showing greater than 310 K. Hence, for absolute temperature threshold, a brightness temperature of 310 K is identified for picking up fire pixel. Similarly the difference of temperature received by 4 and 11 µm channels are plotted in Figure 16.11 wherein it is clear that delta BT is always higher than 17 K for fire pixels.

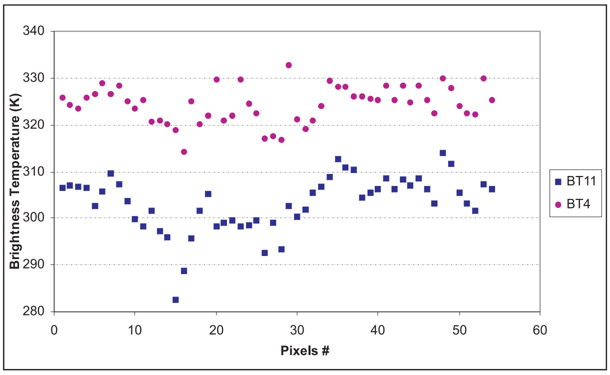

Figure 16.10: Scatter plot of Brightness Temperatures (BT4 &BT11)

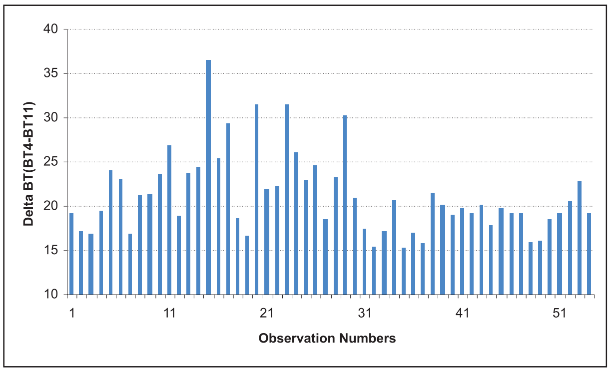

Figure 16.11: Delta BT (BT4-BT11) plotted for different fire pixels

Hence, the absolute threshold criterion considered as

$T_4 > 310$ K and $\Delta T >= 17$ K Test (1)

16.3.1.1.6. Background characterization

Background characterization was performed using the neighboring pixels to estimate the radiometric signal of the potential fire pixel in the absence of fire. Valid neighboring pixels in a window centered on the potential fire pixel are identified and used to estimate background value. Valid pixels are defined as those that (1) contain useful observations, (2) are located on land, (3) are not cloud-contaminated and (4) are not background fire pixels.

Background pixels are in turn defined as those having $T_4 > 323$K and $\Delta T > 20$.

Excluding the background fire pixels, mean and mean absolute deviations of T_4, T_{11} and ΔT for valid neighboring pixels are computed where

$\check{T}4$ and $\delta 4$ are the respective mean and absolute deviation of T_4;

$\check{T}11$ and $\delta 11$ are the respective mean and absolute deviation of T_{11} and

$\Delta\check{T}$ & $\delta_{\Delta T}$ are respective mean and absolute deviation of ΔT.

The 4 µm brightness temperature mean and mean absolute deviations for rejected background fire pixels were also computed as $\check{T}4^{I}$ and $\delta 4^{I}$, respectively.

16.3.1.1.7. Contextual tests

Successful background characterization is followed by a series of contextual tests, which use T_4, T_{11} and ΔT to perform relative fire detection. Relative thresholds are adjusted based on natural variability of the background. They are

$\Delta T > \Delta\check{T} + 3.5\,\delta_{\Delta T}$	Test (2)
$\Delta T > \Delta\check{T} + 6$ K	Test (3)
$T4 > \check{T}4 + 3\delta 4$	Test (4)
$T11 > \check{T}11 + \delta 11 - 4$ K	Test (5)
$\delta 4^{I} > 5$ K	Test (6)

16.3.1.1.8. Creation of forest mask

A forest mask is created to retain fire pixels under forested area and remove fire pixels outside forest (appear as false alarm).

16.3.1.1.9. Tentative fire detection

A daytime pixel is tentatively classified as a fire pixel if {Test(1) is true} or {Tests (2) – (4) are true and {Test (5) or Test (6) is true} and under forest mask. Otherwise it is classified as non-fire.

16.3.1.1.10. Validation / Accuracy Assessment

Since 1.65 μm (IRS P6 – AWiFS/LISS-III) in the electromagnetic spectrum is very sensitive to flame and flaming energy and not very sensitive to smoldering and its energy, FCC with the SWIR, NIR, R combination highlights the active fire pixels (figure 16.12). IRS-P6 satellite pass is at 1030 IST local time and MODIS Terra satellite 1st pass is also around similar time but with slight variation of pass time based on MODIS orbital calendar. Hence, it is expected that fire location as observed by IRS-P6 AWiFS data are also identified by MODIS Terra data based on duration of fire incident and the time lag between two satellite pass. Therefore in synchronization IRS-P6 AWiFS data and MODIS derived fire products are comparable for active fire identification. Thus, MODIS web based algorithm, revised algorithm based and IRS-P6 AWiFS data based fire locations in conjunction with ground data were used in synchronization for the validation of active fire locations.

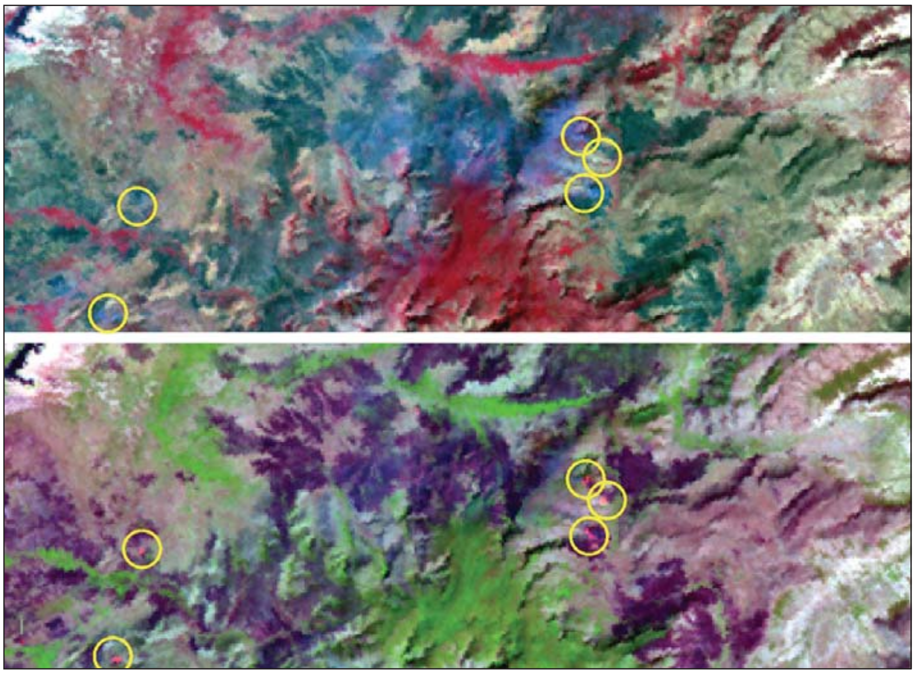

Figure 16.12: Reference active fire location identified using IRS P6 AWiFS data of 24 Feb, .2004 (Top-NIR,R,G and Bottom- SWIR,NIR,R channels were assigned to Red, Green and Blue Channels to enhance fire source location)

16.3.1.2. Active fire detection using Defense Meteorological Satellite Program (DMSP) Operational Line scan System (OLS) data

16.3.1.2.1. Introduction

DMSP OLS is a two band (visible and thermal imaging) system designed for global observation of cloud cover. At night the visible band is intensified with a photo-multiplier tube to permit detection of clouds illuminated by moonlight. The light intensification enables the observation of faint sources of visible-near infrared (VNIR) emissions present at night on the Earth's surface including cities, towns, villages, gas flares, heavily lit fishing boats and fires (Croft 1973, 1978, 1979). By analyzing a time series of DMSP-OLS images, it is possible to define a reference set of "stable" lights, which are present in the same location on a consistent basis. Fires are identified as lights detected on the land surface outside the reference set of stable lights. The Operational Line scan System (OLS) is an oscillating scan radiometer with two spectral bands (visible and TIR) and a swath of ~3000 km. The "visible" bandpass straddles the visible and near-infrared portion of the spectrum (0.5 to 0.9 μm). The thermal band pass covers the 10.5 to 12.5 μm region. Satellite attitude is stabilized using four gyroscopes (three axis stabilization), a star mapper, Earth limb sensor and a solar detector. The OLS visible band signal is intensified at night using a photomultiplier tube (PMT), for the detection of moonlit clouds. The low light sensing capabilities of the OLS at night permit the measurement of radiances down to 10^{-9} watts/cm^2/sr/μm. This is four times lower in magnitude than the OLS daytime visible band or the visible-near infrared bands of other sensors, such as the NOAA AVHRR or the Landsat Thematic Mapper. Fires present at the Earth's surface at the time of the nighttime overpass of the DMSP are readily detected in the visible band data. In contrast, fires rarely show up as hot spots in the OLS thermal band data. The OLS thermal band position (10.5 to 12.5 μm) is not well placed for fire detection.

16.3.1.2.2. Methodology and description of Algorithms

Procedure adapted has been shown in Figure 16.13. The procedures rely on the existence of a stable lights data set derived from a time series of night time OLS observations. The basic procedures used to generate the stable lights have been described by Elvidge *et al.*, (1997). The fire product processing can be grouped into two divisions:

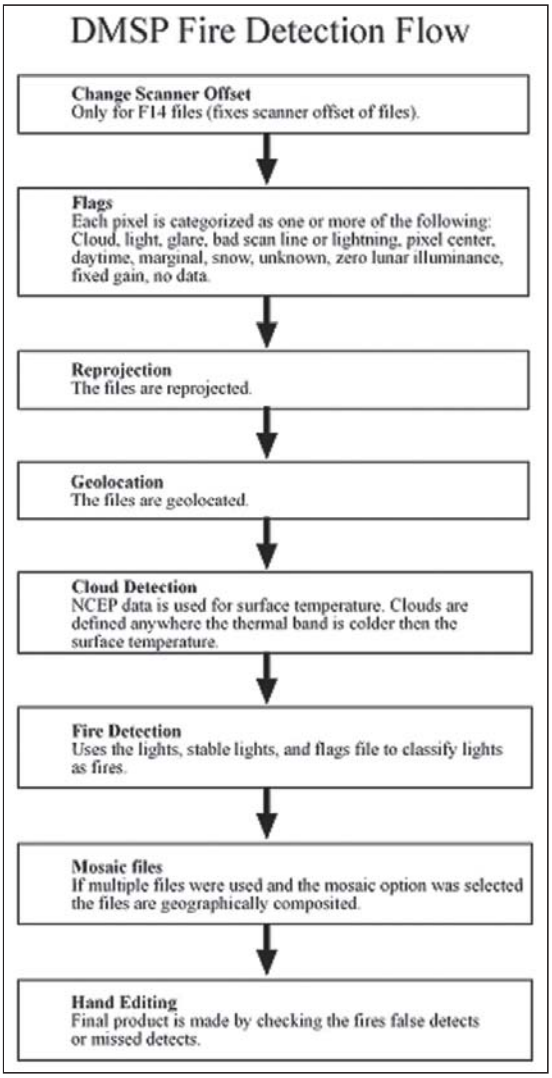

Figure 16.13: DMSP fire detection procedure

processing done on raw OLS data and processing done on geo-referenced OLS data. Certain steps are logically applied while the data are in their raw scan line format. In addition, the raw data has less data volume, which allows the processing to run faster. Processing steps applied to the raw data include: orbit assembly and sub orbiting, cloud identification, light detection, geo-location and girding. Following the light detection there are options for the removal of single pixel light detections and light detections that coincide with clouds on heavily moonlit nights. Pixels identities (e.g., lights, clouds, clouds with lights, missing scan lines) are marked in a flag file which overlays the OLS image data. Steps performed on the geo-referenced data include the removal of lights associated with stable lights, lights over water surfaces, and final editing by an image analyst.

16.3.1.2.3. Factors influencing DMSP fire detection

There are a number of factors or conditions, which will impede the detection of fires with DMSP-OLS data, including: high levels of lunar illumination, cloud cover, and solar glare, moonlit clouds, incomplete stable light set used etc. Thus it is important that the stable lights database be kept up to date and that it is constructed with sufficient numbers of cloud-free observations to ensure that all stable lights are included. Because of the manner in which the stable lights are removed, fires that are adjacent to stable lights can not be readily detected (errors of omission). As final steps in generating a DMSP fire product are performed on 30 arc second grids instead of OLS pixels. Since a single OLS pixel usually occupies nine 30 arc second grid cells, a simple estimate of the number of OLS fire pixels can be made by dividing the total number of 30 arc second cells tagged as fire by nine. Day and Night time operational forest fire products are shown in figure 16.14.

16.3.1.3. Burnt Area Assessment

16.3.1.3.1. Introduction

Currently burnt area reporting in the country is done by individual State Forest Department by integrating the ground reports. The ground-based assessment is very laborious and time taking. As the fires occur simultaneously at several places between January to June many of the cases might also go undetected. The burnt area assessment assumes importance in terms of local and National relevance. The near real time damage assessment can only be achieved through satellite based burnt area

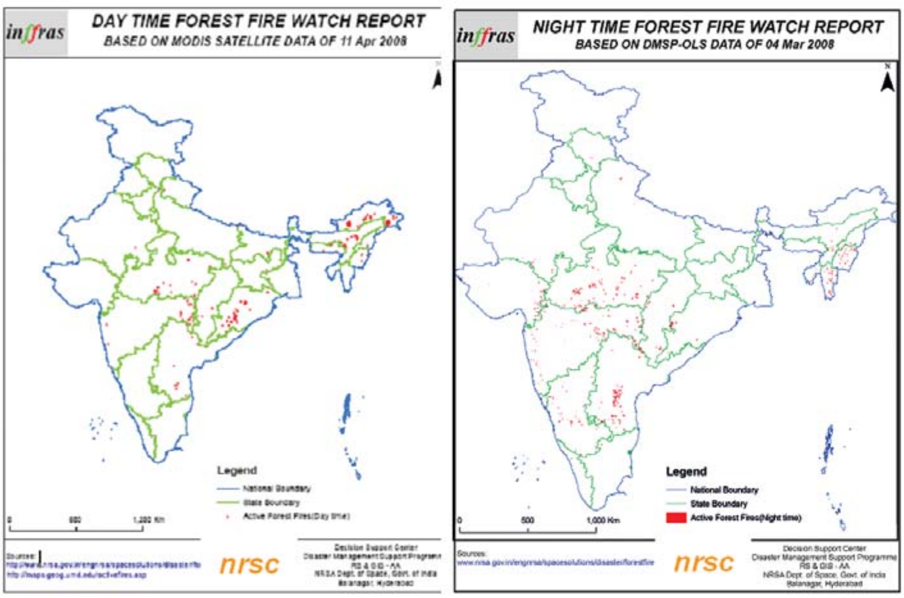

Figure 16.14: MODIS and DMSP-OLS active fire product

assessment and would be critical inputs essentially for protected areas and other ecologically important forested areas. On the other hand National level burnt area assessment has relevance in terms of following issues. This calls for moderate resolution satellite data application to make more precise assessment. In this regard remote sensing & GIS would helps for

- Reliable assessment in terms of area, no of patches and spatial spread
- Base line for temporal monitoring and fire recurrence assessment
- Identification and prioritization of vulnerable areas
- Understanding the impacts on regeneration, succession, biodiversity and wild life
- Assessment in terms of GHGS towards
- Scope for developing web enabled national forest burnt area reporting system
- Fire mitigation planning

The local level burnt area studies were made limited extent to provide inputs for vulnerable assessment and mitigation planning. An operational mechanism, which can provide information on burnt area assessment on real time basis, does not exist in the country. The National Commission on Agriculture (NCA) for the period 1968 to 1973 carried out a study on the incidence of fire. According to NCA, the average number of annual fires was 3,406, affecting an area of 2,576 Sq.Km (0.76 km per fire). In 1986, Ministry of Environment and Forests (MOEF) compiled data on fires for the five-year period 1980 to 1985, and found that 17,852 fires occurred in the country burning an area of 5,724 Sq.Km. This amounts to an average of 3,570 fires affecting 1,145 Sq.Km annually (i.e., 0.32 Sq.Km per fire). Based on the data for 1985 to 1988 compiled by MOEF, Forest Survey of India (FSI) estimated that the stand replacing fires affect about 10,000 Km^2 of forest area annually (FSI, 1988). In the present study, the same percentage of area (estimates by FSI, 1988) has been taken as annual area affected by stand-replacing fires for the reference year 1993.

Table 16.2: Forest range wise area statistics of Rajiv Gandhi National Park using IRS-P6 LISS-III of 14 February 2004

SL #	Forest Range Name	Area (Sq.Km.)	Burnt Area (Sq.Km.)	% Area Burnt
1	Anechowkur	101.21	0.41	0.41
2	Veeranahosahalli	74.44	0.11	0.15
3	Kalhalla	111.96	0.14	0.13
4	Mettikuppe	75.27	9.05	12.02
5	Nagarhole	103.55	0.02	0.02
6	Antarasante	78.83	2.05	2.60
7	D. B. Kuppe	144.78	3.67	2.53
	TOTAL	**690.04**	**15.45**	**2.24**

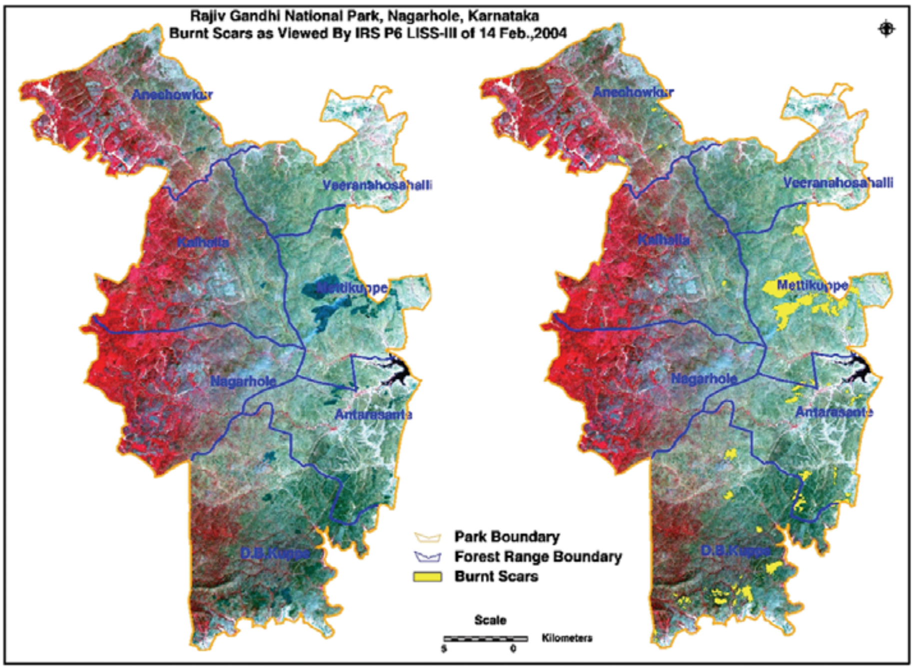

Figure 16.15: Forest Range boundary overlaid on FCC of 14th February 2004

On the other hand the global forest burnt area assessment made by ESA (European Space Agency) using coarse resolution (1.1 km^2) SPOT4-VEGETATION (SPOT-VGT) reported forest burnt area as 9% (47,134 km^2) of the total forest area for the year 2000. The reports are found to be over estimates because of the coarse resolution satellite data used. The global assessments do not reflect the realistic small-scale burning and also associated trace gas emissions due to forest fires. So far reliable spatial accounting of forest burnt area for the entire country is not done.

In view of this, an effort is initiated to undertake burnt area assessment on a regular basis on the following lines.

- Based on trigger from fire watch report
- Response from user departments against the announcement of DSC
- Direct request from user departments
- Internal DSC studies to develop data base

16.3.1.3.2. Burnt area assessment for Rajiv Gandhi National Park

Burnt area assessment for Rajiv Gandhi National Park has been done using IRS P6 LISS-III data of 14 February 2004 as shown in Figure 16.15 and corresponding Forest Range wise burnt area statistics are given in Table 16.2.

16.3.1.3.3. Burnt area assessment in Bhandavgarh National Park, Madhya Pradesh

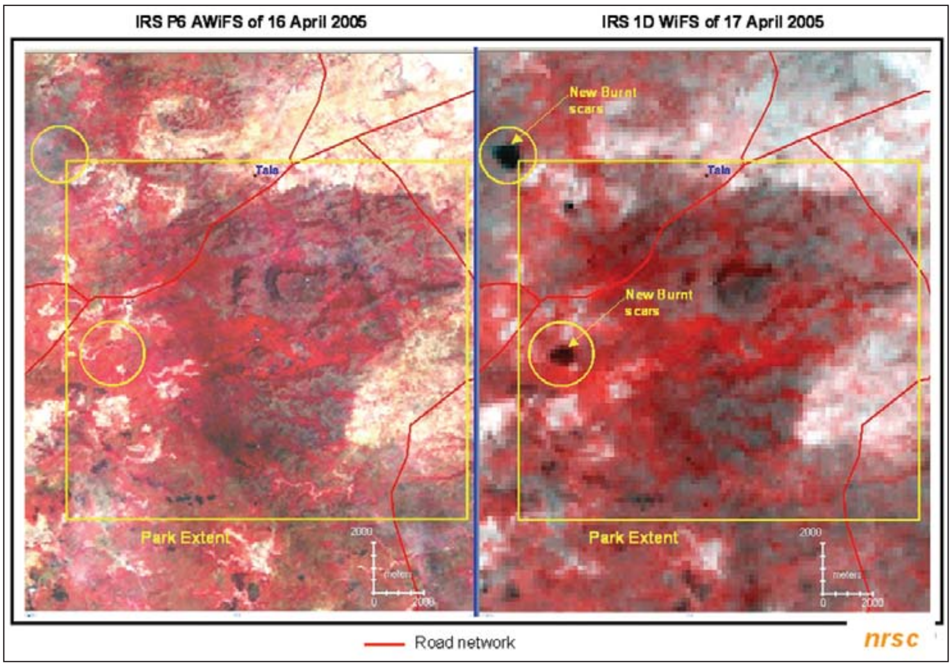

Figure 16.16: Near real time damage assessment in and around Bhandavgarh National Park, Madhya Pradesh

There was a TV news report on 16th April, 2005 at 2030 hrs that forest caught fire in Bhandavgarh National Park, Madhya Pradesh. Report says that fire incidence started in the morning of 16th April, 2005. According to this report, we have browsed all possible satellite data and procured IRS-P6 AWiFS data of 16th April 2005. Study revealed that, no fire burnt scars observed within the Park extent, which indicates that fire started after 1030 hrs morning satellite pass. Hence, next possible satellite pass of 17th April 2005 (IRS 1D WiFS) data was procured and analysed and found burnt scars within the park extent as shown in Figure 16.16. The information was communicated to concerned official on 17th April 2005.Study demonstrated the efficacy of Indian Remote Sensing Satellite in meeting the near real time requirement.

16.3.1.4. Fire progression Monitoring

Fires, whether of human or natural origin, have profound effects on land cover, land use, production, local economies, global trace gas emissions, and health. A fire analysis cycle can be defined that moves from mapping the potential for a fire start if there is ignition, to detecting the start of a fire, through monitoring the progression of a fire, to mapping the extent of the fire scars and the progression of vegetation regeneration. Such information would be useful to managers, policy makers and scientists interested in mitigating and evaluating the effects of fires.

Fire monitoring differs from fire detection in emphasis rather than in fundamental methods. Fire monitoring measures and describes the growth of known fires; three characteristics of interest are the growth of the fire, extent of the smoke plume, and Monitoring the movement and dispersion of fires is a variant of fire detection, where the focus is the analysis of changing fire patterns. As in fire detection, thermal and nighttime visible images are effective for mapping changing fire patterns. Monitoring the extent of the fire burnt scars requires analysis of visible, near infrared and short wave infrared wavelengths.

In India, effective fire control and assessment is tedious due to their randomness of occurrence and their size. Here, numbers of fire occurrence are high but most of them are small in nature. With the advent of series of IRS satellites on board, it is quite possible to monitor the fire progression on a high temporal basis. IRS AWIFS/WIFS temporal images clearly show the spatial and temporal changes in burnt and unburnt areas. This spatial information on progression could be useful in effective planning for ground control operation during the summer month by identifying the areas still prone to fire during the remaining period of current summer season.

Continuous fire burnt area monitoring using high temporal satellite data like IRS P6/1D AWiFS/ WiFS data helps in assessment of progression of fires at frequent intervals to facilitate control operations. As an example during the fire season 2004, Different protected area in India is being monitored and progression of fire was studied using Indian satellite data. Fire burnt areas overlaid with forest infrastructure boundaries were sent to respective State Forest Department to facilitate control planning during current fire season. The information provided has been found to be quite useful to different State Forest Departments for strategic planning. Forest Fires over Indian region mostly occur during the months of February May and the progression of fires depends on the forest types in different parts. The southern dry deciduous forests had more fire episodes during mid February to the end of March. The tropical and temperate forests of North Eastern Region also show fire episodes during the same period and the fires in these regions are associated with shifting cultivation practices. The fires progress from southern to central regions of India during March and April and the central Himalayan region experiences fires during end of May to early June each year. Fire progression in and around Rajiv Gandhi National Park, Nagarhole & Bandipur Tiger Reserve, Karnataka is shown in Figure 16.17.

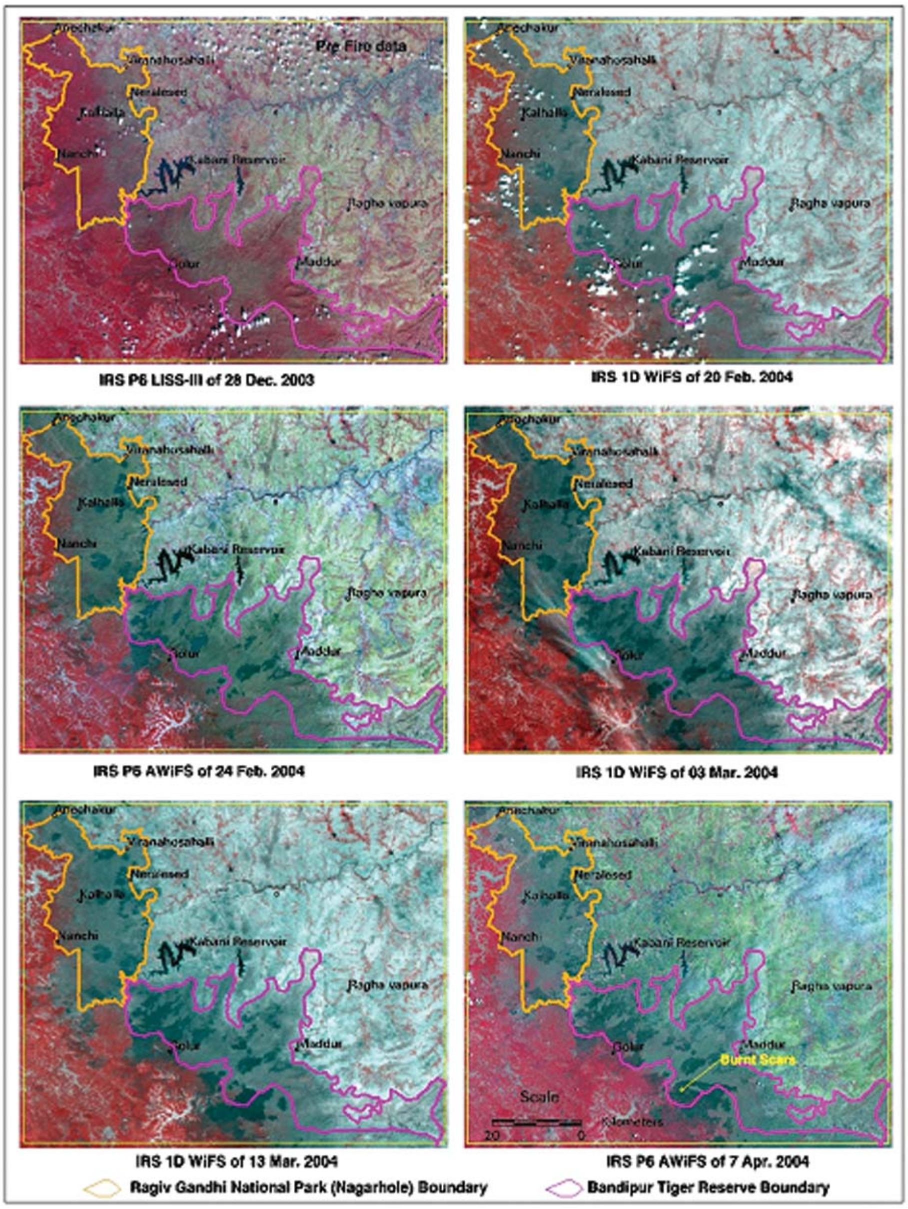

Figure 16.17: Forest Fire monitoring in Rajiv Gandhi National Park and Bandipur Tiger Reserve, Karnataka

16.3.1.5. Fire Risk Assessment- Case Study in India

Badrinath *et al.*, have studied and prepared a Fire danger index map for the Nagarjunasagar Srisailam Tiger Reserve (NSTR) of Andhra Pradesh, India. Two major steps are involved in arriving at the danger indices. The first step is to generate danger variable maps such as fire frequency, topography, surface temperature and relative humidity. The second step involves derivation of intermediate indices using multiple regressions taking fire frequency as dependent variable. The methodology used in the study has been adapted from Roberto Castro *et al.*, 1998. Two major steps are involved in arriving at the danger indices. The first step is to generate danger variable maps such as fire frequency, topography, surface temperature and relative humidity. The second step involves derivation of intermediate indices using multiple regressions taking fire frequency as dependent variable.

Results of the study (figure 16.18) suggests high Fire Danger Index (FDI) values in the proximity of village locations, water bodies and road points. The study area is inhabited by local tribal populations who depend more upon the forest for fuel wood. They cut the grasses and burn the base so as to facilitate the re-growth of the grasses by the on setting of monsoon. Traditional practices such as these account for most of the fire episodes. More over, the study area also being a pilgrim place is more subjected to visitors all round the year. Lighting of cigarettes and cooking practices of these pilgrims have their contribution in forest fires along highways and road points. This suggests that fires in the study area are more of anthropogenic activities than due to natural episodes. Although the proportional weights between variables might be applied to other areas or periods, the specific coefficients are restricted to the area and interval in which fire statistics were collected. The approximations on danger variable calculations such as fuel types, relative humidity are some of the limitations of the study which can be overcome by more ground knowledge and detailed measurements.

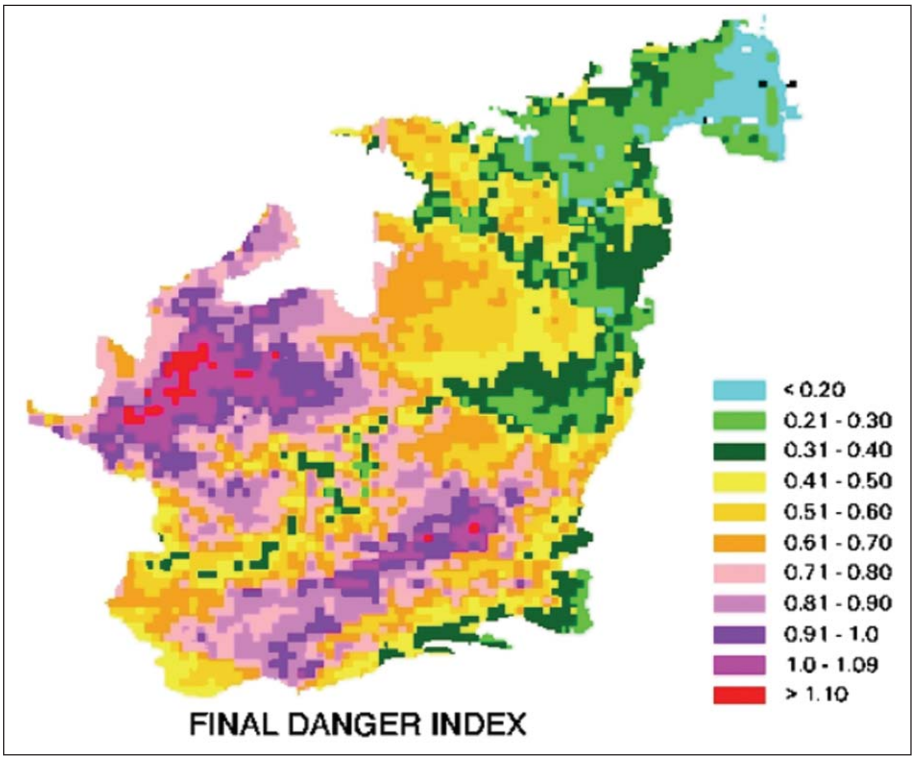

Figure 16.18: Final Fire Danger Index map of Nagarjunasagar Srisailam Tiger Reserve

16.3.1.6. Recovery / Mitigation Planning

As part of recovery / mitigation plan during fire season, a study was conducted to identify the recurrence fire zone map of Rajiv Gandhi National park using satellite data. The study also investigates about, whether the existing watchtowers are adequate for their mitigation planning or not? Towards this, forest fire recurrence and visibility analysis were done and are shown in Figure 16.19 & 20, respectively.

The study has identified the necessity of an additional fire watch tower and its location for monitoring the recurrent fire areas. New locations were suggested based on visibility range identified using canopy heights, terrain heights and forest canopy density.

16.4. Conclusion and Future Aspect

The only effective way to minimize damage caused by forest fires is their early detection and fast reaction, apart from preventive measures. Great efforts are therefore made to achieve early forest fire detection, which is traditionally based on human surveillance. Technically more advanced forest fire surveillance systems is based on video camera monitoring units mounted on monitoring spots and distant monitoring from operation center in conjunction with satellite monitoring. Infrared and laser-based systems are more sensitive and they generate less false alarms, but their price is quite high in comparison to video (CCD) cameras sensitive in visible spectra. For example the price of one typical high quality outdoor pan/tilt CCD camera is 3.000 EUR, and the price of one typical IR thermal imaging camera is 25,000 EUR. Additional feature of CCD video cameras which are today on the market is their dual sensitivity. They are color cameras sensitive in visible spectra during the day, and black and white cameras sensitive in near IR spectra during the night.

The terrestrial systems based on CCD video cameras sensitive in visible and near IR spectra are today the best and the most effective solution for realizing automatic surveillance and automatic forest fire detection systems. In almost every country, which encounters high risk of forest fires, at least one such system are developed or proposed. Some of them are on the market under various commercial names like FireWatch (Germany), FireHawk (South Africa), ForestWatch (Canada), FireVu (England), UraFire (France) etc. In all those systems automatic forest fire detection is based on smoke recognition during the day and flame recognition during the night.

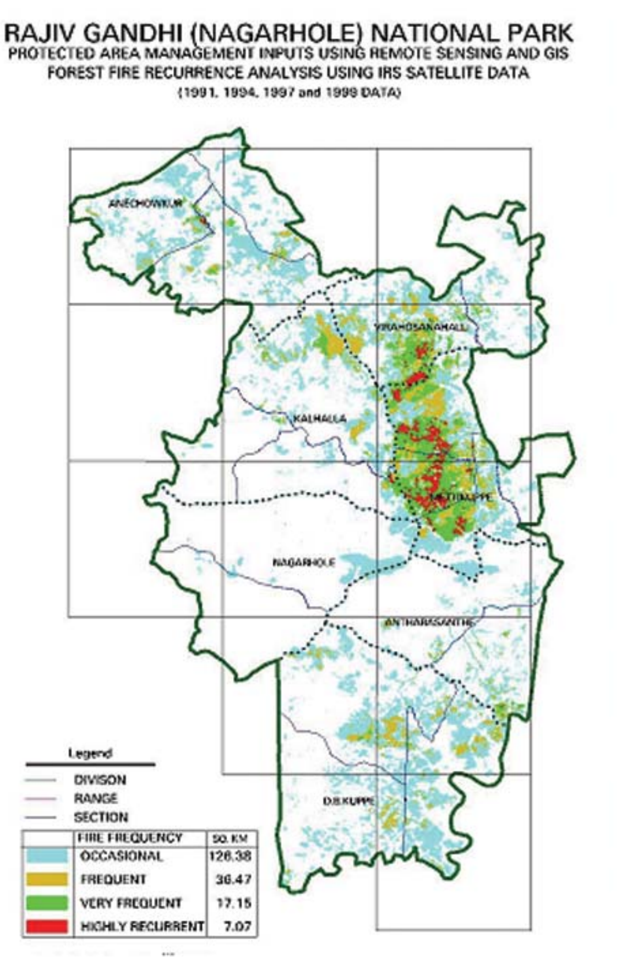

Figure 16.19: Forest fire recurrent analysis

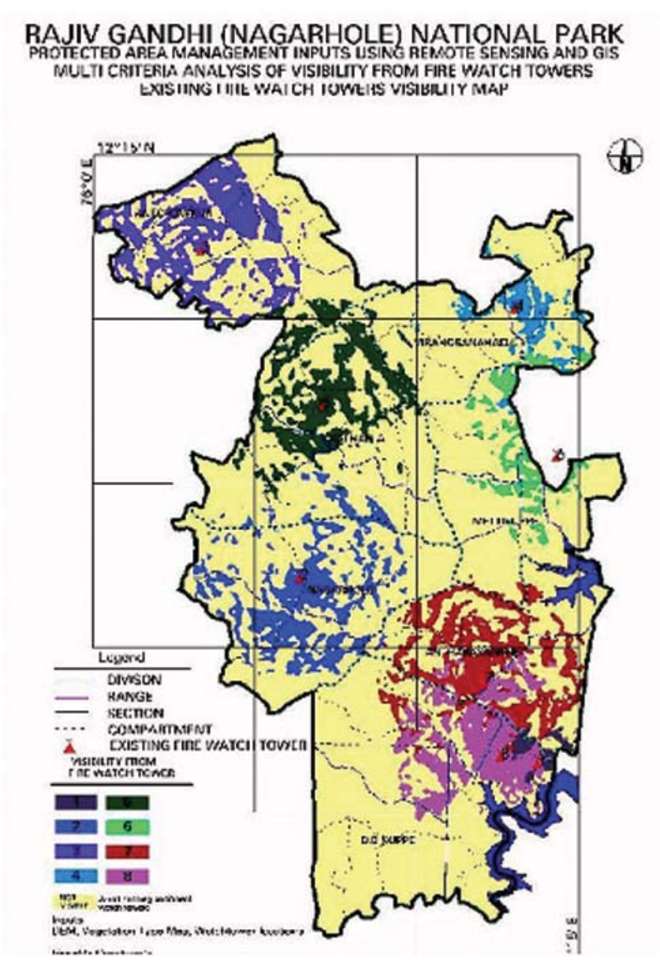

Figure 16.20: Existing watch towers visibility map

With the advent of series of satellites onboard, it is possible to monitor the fires to a minimum of 5 times in a day, facilitating to monitor large episodic fires. In India, with the current capabilities of data processing and data dissemination, it is possible to generate fire signals within one hour of satellite pass. Presently INFFRAS provide one day time (MODIS-Terra/Aqua) and one night time (DMSP-OLS) fire alarm to all the State Forest Department through electronic mail (available in NRSC web site also). In our country, fire watching from ground has also to be strengthened and equipped with sophisticated instrument/system so that mitigation will be done in more effective way.

A new Geostationary Meteorological Satellite INSAT-3D is being designed by ISRO with the capability for fire detection/characterization. Preliminary plans include fire product generation and distribution (GOFC-GOLD Report No 32, October 2007). It will have a six channel advanced imager and a nineteen channel sounder. In addition to satellite imageries in six channels, several new derived products useful in NWP and in day-to-day weather forecasting will be available in the new system. Vertical profiles of atmospheric temperature, moisture and ozone will be available for the first time from an Indian Satellite.

Since, on orbit no of satellites with different sensors are available, it is very important that data pre-processing steps need to be fully characterized. Data fusion of different products types (e.g., burned area and active fire) and between different sensors (polar orbiting and geostationary) needs to be explored.

The quality and consistency of the different geostationary imagers with regard to fire detection and fire characterization needs to be examined. We need to improve communication between data providers and product developers, especially in light of the new instruments becoming operational. Image generation processes should be clearly documented and accessible to product developers, and ideally the applications of active fire detection and characterization should be taken into account when developing new generation sensors (e.g., in terms of dynamic range) and pre-processing procedures (e.g., geolocation and re-gridding).

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