# Fire risk modelling based on satellite remote sensing and GIS

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## ABSTRACT

In a test site in Northern Greece, Halkidik, multitemporal Landsat TM data were used for vegetation mapping to provide basic input data for a regional Fire Management System (FIS). Under the specific circumstances of the test site this approach seems to be the only possiblity to achieve current regional vegetation maps which can serve as a tool for fire management purposes.

Mapping was carried out using a combination of digital and visual classification. For accuracy assessment of the resulting thematic classes a systematic sampling approach was used.

As demonstrated, simple fire risk assessment is possible using the resulting thematic classes only. For more accurate modelling the different vegetation classes were grouped to fuel models, according to Anderson (1982) and were combined with digitized data from a geological map at a scale 1: 50,000. The problems which occur by integrating this data within a FIS for modelling fire risk potentials are discussed.

## 1. INTRODUCTION

The aim of the project described here was the creation of a data base in a test site in Northern Greece which can serve as a measure to support decision makers for appropriate landscape planning, to model fire risk and to evaluate the environmental and socio-economic impacts of uncontrolled burnings in the test site. But the lack of current data about forests and range lands in Greece and other Mediterranean countries is one of the main problems for effective fire prevention policy; e.g. (Goldammer & Jenkins (1990), Kailidis (1992), Naveh (1990), Papastavrou (1991).

Besides many older maps in small scales, no other maps are currently available on larger scales for civil purposes. Available maps, 1: 200,000 scale are insufficient from cartographic standards and are not updated thematically. The existing Topographical Map 1 : 50,000 is not published due to military aspects (LIENAU, 1989, p. 8). Only geological maps at a scale of 1: 50,000 give contour lines (at 40 m distance level) and they represent the most appropriate information about the topography in Greece. But due to military restrictions they provide very little information concerning infrastructure, and nothing about vegetation and landuse. The lack of cadastral data in many forested areas hampers optimized fire prevention policy as well.

Aerial photographs can often substitute lacking maps. Over Northern Greece several photo acquisition campaigns took place since 1945, but due to military restrictions their civil use is restricted. Concerning film type, and scale as well, they often do not fulfil requirements for vegetation mapping.

Under these circumstances it was expected that satellite data only can provide the required rapid and economic means of mapping and monitoring forests to reduce fire damages and potential risks on a regional basis (e.g. Burgan & Shasby (1984), Cosentino *et al.* (1981), Hill (1989), Hough (1992), Karteris & Kritikos (1992), Milne (1986),

Meliadis & Karteris (1992), Oesten *et al.* (1991), Root *et al.* (1986), Shasby *et al.* (1981), Todd *et al.* (1987)). This technology in combination with Geographical Information Systems (GIS) opened new views in regional forest fire management. With the information derived from conjunctive use of satellite remote sensing and GIS software packages, scientists can efficiently manipulate, spatially analyze and display landscape variables which can support the management of forest fires (e.g.: Bradshaw *et al.* (1987), Chuvieco & Congalton (1989), Kientz & Lenco 1992), Karteris *et al.* (1993), Lee & Buckley (1992), Yue (1992))

## 2. STUDY AREA

The Sithonia peninsula of Halkidiki in Northern Greece was selected as study area because of the following reasons:

- proximity of Thessaloniki, allowing easy access to the test site by car,

- several fires occured on Halkidiki during the last years; especially large conflagrations at Mount Athos and at Forest District of Arnea, 1990,

- on Sithonia there exists a great variability of mediterranean vegetation types and degradation (succession) phases,

- availability of maps and aerial photographs covering the whole region,

- many other information available due to previous investigations which were carried out at the Forest Faculty of Thessaloniki and the Forest Research Institute,

- high tourist pressure from both national and international tourism.

The map in **Figure 1** gives the location of the test site Sithonia at Halkidiki, Northern Greece. The colour composite in **Figure 1**, which provides an overview of the test site and its suroundings. It is based on multitemporal Landsat 5 (TM) data from the following two scenes (provided by the Institute of Remote Sensing Applications, Joint Research Centre of the European Commission, Ispra, in the framework of joint research activities on forest mapping in Europe):

<div align="center">

23.06.1989 and 29.06.1991

Path 183 / 32

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The spectral information used for this image are:

- Red: band B5 (middle infra-red 1989),

- Green: band B4 (near infra-red, 1989)

- Blue: band B4 (near infra-red 1991).

The two large conflagrations of 1990 can easily be detected (they occur in violett): One at Holy Mount Athos and one above on the main lands, Forest District of Arnea. Another fire (in the Northern Part of Sithonia) happened in summer 1989 (visible in red-brown). In 1985 the whole southern part of Sithonia was destructed by a large fire. Several minor fires happened at Kassandra (left peninsula).

Sithonia, where the investigations were concentrated on, constitutes the median of the three peninsulas of Halkidiki. It has a length of 43 km and a width of 6 to 18 km. It´s area is about 45,000 ha. Half of it is occupied by **Pinus halepensis** forests, which have an optimum development. The elevation ranges from sea level up to 823 m. The relief is gently sloping but there are places with an inclination of 50-60 %. The soils of Sithonia have been affected by the pressure of the biotic factors of the area. The main rocks found are granites, metamorphic rocks of phyllites and calc-schists and finally deposits of alluvial material and rocks. On the east side of Sithonia, where silicate rocks predominate, the soils are acidic, shallow, with numerous rocks and little fertility. Here, stands of **Pinus halepensis, Pinus pinea** and **Pinus nigra** have been developed. The understory is composed of acid-friendly bushes of **Ericaceae** (tree-heath, strawberry tree) and **Cistaceae**. On non-siliceous soils the maquis is dominating. On the peninsula's west side the soils are developed on soft limestones. There the development of **Pinus halepensis** is quite good in contrast to the **Pinus pinea**. The average temperature is about 16°C and the annual precipitation 690 mm. The population is about 10.000 people. Their general acitivities include farming, livestock feeding, fishing, apiculture, resin tapping and tourism.

## 3. VEGETATION MAPPING

### 3.1 Description of the methodology

During the last 10 years several fires burnt nearly 1/3 of Sithonia peninsula. Still valuable pine forests and dense maquis areas exist but are highly endangered by fires. To estimate the areas of potential fire risk vegetation maps are nessessary which possibly can be correlated to the amount of combustible fuel.

To achieve a fire risk map of Sithonia on 1: 50,000 scale, a vegetation map was produced using multitemporal Landsat TM data from summer 1989 and 1991, respectively. The data were classified applying a combination of visual and
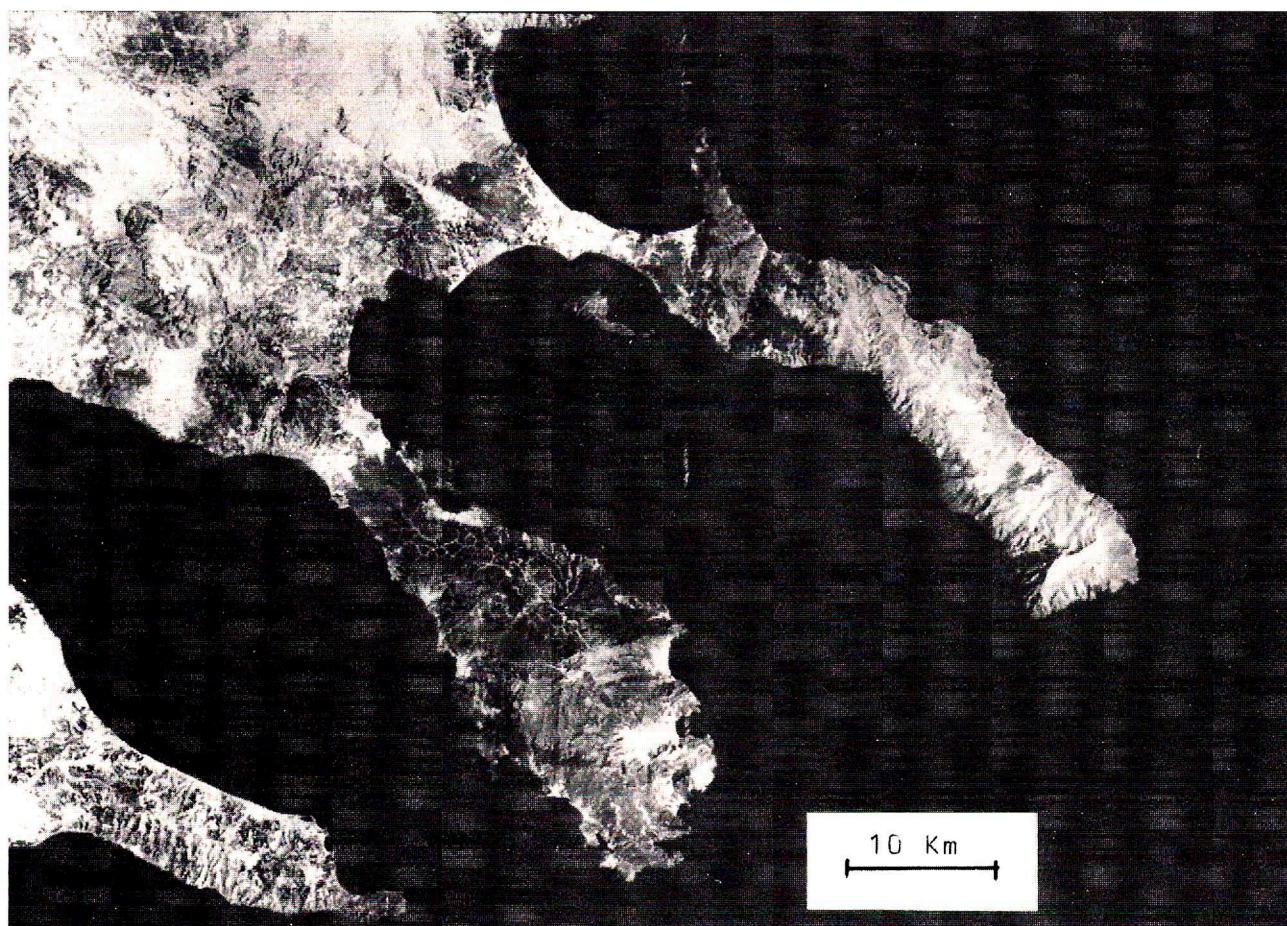
ΕΛΛΑΣ - HELLAS



*Figure 1 - Location of the study area derived from a scanned map 1: 1.5 Mio. and the Chalkidiki-penisula seen from a multitemporal Landsat-TM data set*

digital classification methods. This procedure, developed in Freiburg, reduces the disadvantages of either maximum-likelihood algorithm or visual delination and increases the overall classification accuracy especially under difficult environmental conditions (Schmitt-Fürntratt (1991)).

By visual interpretation a skilled interpretater includes not only the different colors but also uses the textural information surrounding a specific area. However, under operational conditions normally only areas larger than 2 ha can be delinated (Schmitt-Fürntratt (1991). This generalization may have advantages (for map producing) but also disadvantages when high local accuracy is needed (e.g. for modelling). On the other hand computer-aided classifications suffer frequently in accuracy when heterogeneous land use patterns (mixed pixels) occur, which is the usual case under european conditions.

The whole (satellite based) process can be divided into 5 parts:

1. Visual interpretation and delination of vegetation and landuse classes based on an optimized multitemporal Landsat-TM images and afterwards, the digitization of the resulting map.

2. Digital computer-aided classification using supervised Maximum-Likelihood algorithm.

3. Combination of the two maps using a-priori knowledge of the test site.

4. Combination of the results with NDVI of the most recent Satellite data for plausibility control and to update the current vegetation-status in the following years.

5. Combination of different vegetation types to produce fuel models according to Anderson (1982)

By comparison of both classifications (visual delination and maximum-likelihood-classification, respectively) and by comparing the results with ground truth several differences can be observed:

• the computer classifies more accurately the pine forests than the human interpreter especially in the southern part of the peninsula,

• dense maquis can not be separated from decidous trees and decidous forests. Several species which belong to mediterranean climax forests are part of the older maquis. Therefore the signatures are similar during summer (time of aquisition of the data used in this study). The problem can be overcome if additional satellite data from early

spring are available. Then evergreen maquis can be separated easily from the summergreen broadleaves,

• the computer is able to classify the burnt area of 1989 quite accurately. By visual interpretation the differences to other shrubland classes are not that obvious,

• under the heterogeneous circumstances of the peninsula, especially for the different maquis and phrygana types, the computer is much more accurate, because single pixels are classified,

• for the interpreter it is easier to separate the fuel breaks from non-vegetated or sparsely vegetated areas. This is not possible by computer means,

• olive fields are very difficult to be interpreted by both means without additional information. The olive covered areas found and mapped during the field surveys were therefore added to the visually interpreted map and digitized afterwards to reduce the errors.

## 3.2 Combination of visual and digital classification

The final map consists of a combination of both, digitally classified and visually delinated maps based on a-priori knowledge of the real situation. The different classes of the final vegetation map of Sithonia were achieved by giving priorities to computer classification or visual interpretation, respectively, in dependance on their different accuracies compared to the ground truth. **Figure 2** illustrates the resulting vegetation map of Sithonia.



*Figure 2 - Vegetation map of Sithonia, based on multitemporal Landsat-TM data; original map size 1:50,000*

## 3.3 Checking of map accuracy

Accuracy assessment of thematic maps based on remote sensing is a difficult task and needs often much more time than the mapping process itself. Nevertheless, it is nessessary to give at least an indication of accuracy level or errors to be expected. Due to restrictions in time and money, a simple methodology was used in this study to collect some information about the mapping accuracy.

This method was originally developed for checking computer classifications based on high resolution airborne scanner data for forest decline inventories in Central Europe (Kuntz, 1990). In this study it was adjusted to serve for checking satellite based classifications. Therefore sample plots were drawn systematically over the geocoded multitemporal satellite data set at every 150th line and column (= 4.5 km distance between plots on the ground). Size for each plot was 6 x 6 pixel (= 3.24 ha). This size was chosen because:

• it is very difficult under the specific conditions of the test site to exactly locate single pixels

• the number of pixels in a sample plot is large enough to describe statistically a distribution or frequency

This procedure resulted in a total number of 21 sample plots at Sithonia peninsula **(Figure 3)** which were chec-
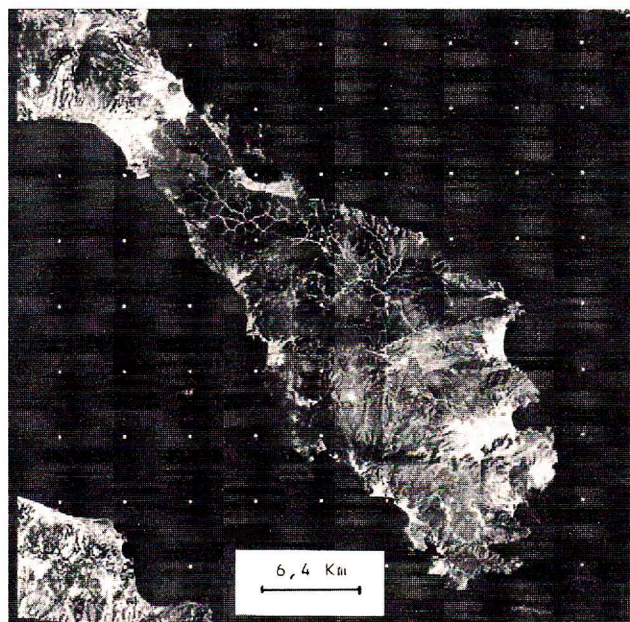


*Figure 3 - Geo-coded color composite of Sithonia based on multitemporal Landsat-TM data with overlaying sample plots for Ground Truth assessment. RGB-Coding: Red: Band B5 (middle infra-red 1989), Green: Band B4 (near infra-red, 1989) and Blue: Band B4 (near infra-red 1991); original map size 1:50,000*

ked in the field. With support of the forest service of Polygiros, which provided a car and personel it was possible to locate the plots on ground sucessfully. Hard copies of the color-composite, 1:50,000 scale with the overlaying sample grid, the thematic classification, geological maps and a listing of the classified pixel of each plot were available for the field campaign. All plots were described in terms of percentage of species, density, coverage, distribution, percentage of barren lands etc. and were photographed as well for documentation. As was expected before, most errors occur in classes "Olives", between different types of "Phrygana" and dried or already harvested "Agricultural Areas". High accuracy was found on the most endangered classes "Pine" and "Maquis".

## 3.4 Fire risk assessment at Sithonia

One basic planning tool in fire management is fire risk assessment of endangered areas. For this purpose the different vegetation classes can simply be aggregated into 4 risk classes for the following reasons:

1. Pine forests have a high fire risk potential combined with both, high economic and environmental values.

2. Dense mediterranean maquis has also high fire risk potential with low economic but high environental values.

3. Low density maquis and phrygana have minor fire risk but even sparse vegetation coverage under mediterranean conditions has certain values for soil protection, wildlife, grazing etc.

4. Agriculture, olive fields without understory, sparsely spread vegetation and bare soils have little or even no fire risk but may be endangered by soil erosion and desertification processes.

As a result of this simple procedure **Figure 4** shows the fire risk map of Sithonia based on the simple combination of vegetation classes.

A second more detailed risk map was produced by combining the vegetation map with the NDVI of Landsat TM data from June 1991. This ratio is frequently used in remote sensing for vegetation assessment from space. Phenology or vitality of plants can be observed by using different vegetation indices e.g. Kattenborn (1987). Several studies demonstrated also the close correlations of different vegetation indices with biomass, water content of leaves, chlorophyll content, leaf area index and growing conditions (e.g. Gardener *et al.* (1985), Jackson *et al.*
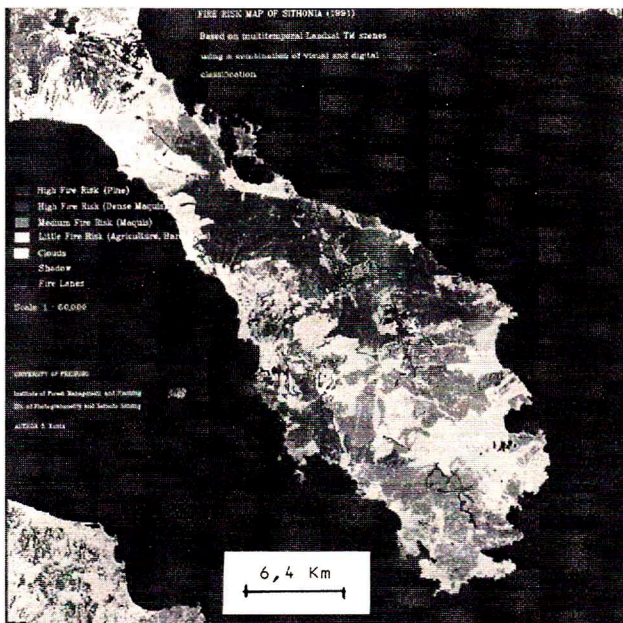
*Figure 4 - Simple Fire Risk Map of Sithonia based on multitemporal Landsat-TM data; original map size 1:50,000*

(1983), Mauser *et al.* (1992), Myers (1983), Tucker (1978)).

In this study NDVI was used for several purposes:

1. to obtain more information about the vegetation density of the test site,

2. because of the higher tolerance of NDVI against illumination conditions as well as atmospherical disturbance of the signal.

   The information about vegetation conditions derived from NDVI are more unbiased than the "raw" data itself. In our case it can be used not only for vegetation density assessment but as well for checking the vegetation map against obvious errors due to mixed pixel occurrence in heterogenous areas as well.

3. as a cheap and easy measure for monitoring large areas in the future.

   To facilitate the monitoring on a more frequent basis (anually or even two or three times every year during the hot season) it is not necessary (and even not possible) to run through the whole process of vegetation mapping described above. Once there is a vegetation map generated it might be sufficient to use NDVI to monitor the current vegetation status even over larger regions frequently for several years. However, this will only be possible under the assumption, that landuse in general does not change too rapidly.

Using only information gathered by NDVI, accurate risk mapping is not possible. NDVI is sensitive especially to green vegetation, areas covered by dry vegetation (which are of course very conductive for fires) may be difficult to map. It is also not possible to separate dense pine forests from maquis or to separate different open maquis types using only this information. But combining vegetation density from NDVI with the different vegetation types from the vegetation map increases the information on the two major endangered classes Pine and Dense Maquis, respectively (**Figure 5**).
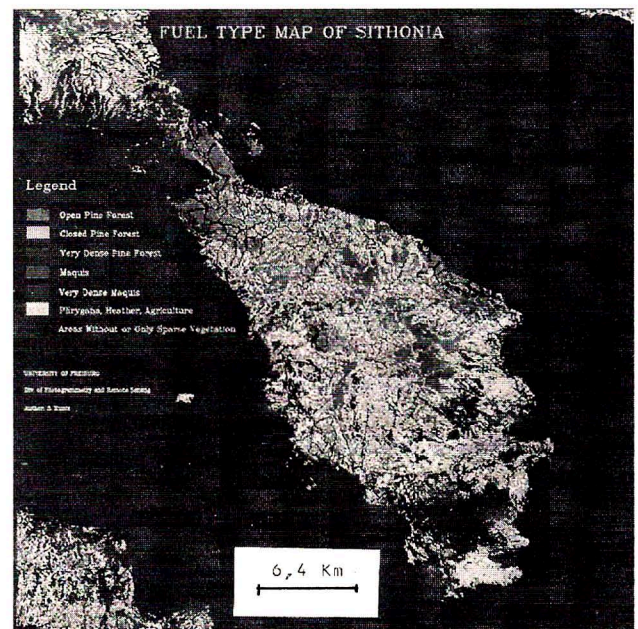


*Figure 5 - Fire risk map of Sithonia using the vegetation map in combination with the NDVI from 1991; original map size 1:50,000*

## 3.5 Fire behavior modelling

It is obvious that the "fire risk" map of Sithonia described above is quite simple. Several aspects of fire risk modelling are still lacking but should be included in optimized models. However, the existence of reliable information about vegetation conditions is a prerequisite for any modelling approach. For more sophisticated fire behaviour modelling fuel models are necessary, which are representative to certain vegetation conditions. However, no local fuel models were available for this study. Therefore the different vegetation classes of Sithonia peninsula were grouped into 6 fuel models according to Anderson (1982).

The second essential information is a digital terrain model (DTM). In our case a DTM is useful:

– to include slope information for fire risk modelling. The steeper the slopes the higher is the risk that a fire will reach dangerous dimensions, the more difficult is fire attacking, the more severe become post fire effects like soil erosion and the more expensive become reforestation or protection activities.

– to add information on different aspects and therefore on different evapo-transpiration conditions for fuel humidity assessment.

– to use the slope information for modelling of potential soil erosion (in combination with soil data).

– to use the DTM for correction of different illumination conditions and atmospheric effects of satellite data.

Here a DTM was derived from digitized contour lines of a geological map of Sithonia, scale 1: 50,000. From the digitized contour lines height, elevation and slope were computed using SEM software of ARC-INFO (property of ESRI Inc). A third input source was the thematic information of the geological map itself.

The dataset achieved so far can now be used for modelling purposes. However, how the different parameters should be combined in an optimized and reliable way is still a matter of research. With only the three layers mentioned above it is now possible to combine:

6 fuel models + 8 expositions
+ 2 different altitudes levels + 5 different slopes
+ 10 geological types.

This simple combination of layers results in 4800 possibilities of different risk combinations for every cell in the database In addition the parameters are of different importance and no dynamic aspects like wind effects, which are essential for appropriate modelling, are included. As an example to overcome the problem a simple model was proposed by Chuvieco and Congalton (1989). Using a data base, they computed a "hazard index", where the different layers of the GIS were weighted according to their impacts on increasing the fire hazard. The model works well, however the authors mentioned that the weighting factors are arbitrarily chosen, based on their experience.

A more accurate approach should make more use of the physical properties of different fuel models described by Rothermel (1972). They avoid subjective weighting and offer the possibility to include dynamic factors like wind speed, too. Integrating these sophisticated models within a GIS, and providing fire behaviour information for each cell grid will be included in our future research activities.

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