Article

Combined use of weather forecasting and satellite remote sensing information for fire risk, fire and fire impact monitoring

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Abstract

The restoration of fire-affected forest areas needs to be combined with their future protection from renewed catastrophic fires, such as those that occurred in Greece during the 2007 summer season. The present work demonstrates that the use of various sources of satellite data in conjunction with weather forecast information is capable of providing valuable information for the characterization of fire danger with the purpose of protecting the Greek national forest areas. This study shows that favourable meteorological conditions have contributed to the fire outbreak during the days of the unusually damaging fires in Peloponnese as well as Euboia (modern Greek: Evia) at the end of August 2007. During those days, Greece was located between an extended high pressure system in Central Europe and a low pressure system in the Middle East. Their combination resulted in strong north-northeasterly winds in the Aegean Sea. As a consequence, strong winds were also observed in the regions of Evia and Peloponnese, especially in mountainous areas. The analysis of satellite images showing smoke emitted from the fires corroborates the results from the weather forecasts. A further analysis using the Fraction of Absorbed Photosyntetically Active Radiation (FAPAR) as an indicator of active vegetation shows the extent of the destruction caused by the fire. The position of the burned areas coincides with that of the active fires detected in the earlier satellite image. Using the annual maximum FAPAR as an indicator of regional vegetation density, it was found that only regions with relatively high FAPAR were burned.

Keywords forest fires; fire risk; ecosystems; Mediterranean.

1 Introduction

The most destructive fires of the past decades in Greece occurred in August 2007, resulting to the burning of vast areas mostly with forests but also with other land uses. Early studies based on satellite data showed that more than 12% of the Greek forest area was damaged (Boschetti et al., 2008). The restoration of those areas in fact requires their future protection from new fires as well as adequate means of observation and warning. Weather forecasts in particular may constitute an appropriate early warning tool used by fire brigade, civil protection agency and other relevant authorities. However, it is not enough to have information only about the meteorological conditions in order to predict a high fire risk and take appropriate action timely. It is also vital to have information related to the vegetation types present in the area, as well as the dryness of the air and land surface. Furthermore, after a fire has occurred it is also necessary to acquire information concerning the total area burnt. Such data can only be made available over large regions from space remote sensing observations.

This work aims to examine the combined use of a numerical weather prediction model (NWP) with satellite data to study the meteorological conditions prevailing in Greece and particularly in the regions of Peloponnese and Evia, during August 2007. For this purpose, meteorological forecasts of the atmospheric analysis and prediction model SKIRON (Kallos, 1997; Nickovic et al., 1998, 2001; Papadopoulos et al., 2002, Kallos and Pytharoulis, 2005) are used in conjunction with data from the satellite sensor Advanced Very High Resolution Radiometer (AVHRR) of the U.S. Agency for Oceanic and Atmospheric Administration (NOAA) and the sensor Medium Resolution Imaging Spectrometer (MERIS) of the European Space Agency (ESA).

2 Data and Methods

2.1 The weather prediction model SKIRON

The NWP model SKIRON has been developed by the Atmospheric Modelling and Weather Forecasting Group (AM&WFG) of the University of Athens (http://forecast.uoa.gr) and is based on the Eta/NCEP model. SKIRON is currently used for operational and research purposes in a large number of meteorological institutes including the University of Athens, the Aristotle University of Thessaloniki (AUTH), the Hellenic National Meteorological Service, the Hellenic Centre for Marine Research, the State University of New York at Albany in the United States and elsewhere.

SKIRON is a non-hydrostatic full-physics numerical model suitable for simulations in areas with diverse physiographic characteristics. The variables are represented horizontally on the staggered Arakawa E-grid and vertically using the step-mountain Eta coordinate (Mesinger, 1984). The model includes appropriate physical parameterizations for the representation of radiation (GFDL scheme), sub-grid scale convection (Betts-Miller-Janjic scheme), large-scale clouds and precipitation (Ferrier scheme), boundary layer (Mellor and Yamada, 1982) and land surface/soil processes at six layers to a depth of 2.55 m (Oregon State University scheme; Ek and Mahrt, 1991). A viscous sub-layer scheme is used over ground and water surfaces in order to improve the calculation of the surface fluxes (Janjic, 1994; Zilitinkevich, 1995). The topography, land-sea distribution and vegetation data are available from U.S. Geological Survey (USGS) at a resolution of 30x30 arc sec. The UNEP/FAO (2x2 arc min) dataset is used for soil textural class after its conversion from soil type to soil textural ZOBLER classes (Papadopoulos et al., 1997).

The model is used operationally in the Department of Meteorology and Climatology (DMC) of the Aristotelian University of Thessaloniki since May 2007, providing 3-day forecasts in two areas of integration (which are not nested). The one domain covers most of Europe, Middle East and part of northern Africa with a spatial resolution of 0.2°x0.2° (~ 20 km x 20 km – Fig. 1a), while the other one covers most of the Balkan peninsula (and mainly Greece) with a spatial resolution of 0.05°x0.05° (~ 5 km x 5 km – Fig. 1b). 38 Eta levels are used in the vertical direction extending up to 25 hPa (~ 20 km) with higher resolution in the boundary layer.

The SKIRON model that is integrated at the premises of DMC-AUTH produces weather forecasts on a daily basis using initial and boundary conditions with spatial resolution of 0.5°x0.5° at 26 isobaric levels from the 1200 UTC cycle of the global NCEP/GFS model. Therefore, only one forecast cycle (1200 UTC) of SKIRON is available each day. The sea surface temperatures (SSTs) which are updated daily are also provided by NCEP at a resolution of 0.5°x0.5°. Statistical analysis of the abovementioned forecasts produced from June 2007 to April 2009 at 21 surface meteorological stations covering Greece showed that SKIRON model exhibits a remarkable maintenance of its skill throughout the forecast period (Pytharoulis, 2009). The operational SKIRON forecasts produced at DMC-AUTH are freely available on the Internet, in the form of charts and time-series, through the website of the department (http://meteo.geo.auth.gr), while those of AM&WFG become also available through its website (http://forecast.uoa.gr).

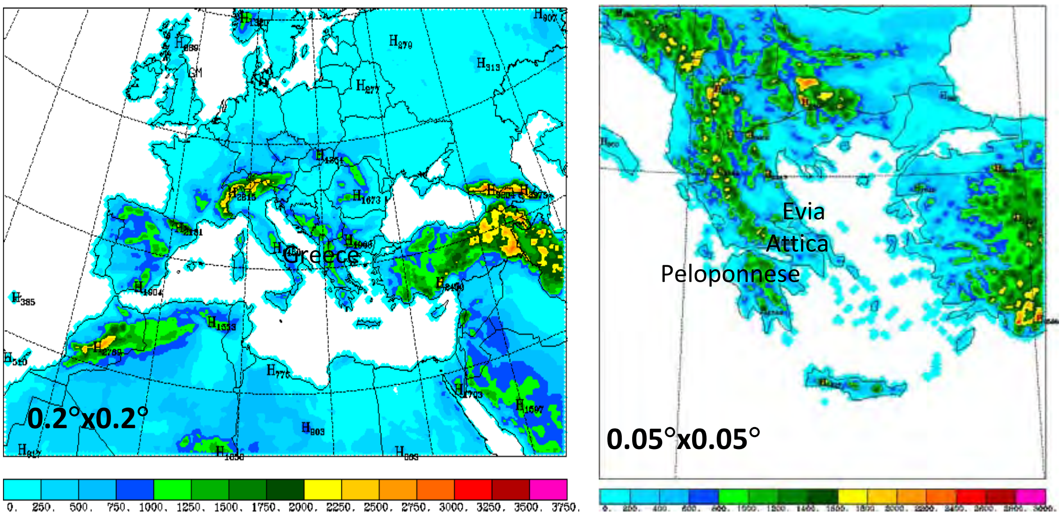


Fig. 1 Topograph (m) of the two domains of the NWP model SKIRON. The horizontal resolution of each domain appears at the lower-left corner of each panel.

2.2 Satellite observations from AVHRR and MERIS

The AVHRR sensor is placed onboard the NOAA series of sun-synchronous and nearly polar-orbiting satellite platforms. It records information in several spectral bands between the visible and the thermal infrared part of the electromagnetic spectrum, at a spatial resolution of approximately 1 km. Major advantages of AVHRR include the fact that data are free and the almost continuous global coverage since June 1981. The orbits of satellites are scheduled to allow coverage of Earth twice a day per orbiting platform. The number of daily AVHRR observations over a given area depends on the number of available platforms. Currently, there are five satellite platforms on which AVHRR sensors are mounted (most recently the NOAA-19, which entered orbit on 12 February 2009) and operate at relatively low altitude orbits.

The MERIS satellite instrument is mounted onboard the ENVISAT platform, launched by the European Space Agency (ESA). MERIS data are with a spatial resolution of 1.2 km, covering the entire Earth's surface in 3 days, recording information in 15 spectral channels from the visible and near-infrared radiation of the electromagnetic spectrum.

MERIS data used in this study included the Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) product, which is computed from the spectral information recorded in the blue, red and near-infrared regions of the electromagnetic spectrum, using the methodology proposed by Gobron et al. (1999). It should be noted that FAPAR is indicates the presence of vegetation and the absorption of photosynthetic active radiation by green (healthy) leaves compared to the ground, trunks and dried plant materials. As indicated by a study based on the comparison of a vegetation model using FAPAR (Knorr et al., 2007), the FAPAR is reduced in case of soil moisture reduction and for this reason this product is also suitable as an indicator of drought.

2.3 Data processing and analysis

In the present study, the daily SKIRON forecasts with 12 to 35 hours forecast range during the period 21 to 31 August 2007 were analyzed on an hourly basis. The first 12 forecast hours were not utilized in order to avoid model spin-up. In the analysis of the fire produced smoke track, the spectral channels 1 - 4 of the AVHRR were used. For this purpose, the available AVHRR LAC (Local Area Coverage) images were downloaded from NOAA (http://www.nsof.class.noaa.gov/saa/products/) covering the area of interest. Basic pre-processing (geometric correction, conversion of the digital pixel values to reflection on the highest level of the atmosphere) was applied on those images using the commercially available image processing software ENVI (version 4.5). FAPAR data in turn, were processed according to the method of Gobron et al. (1999) based on images of the sensor MERIS (spatial resolution of 1 km). The present analysis is based on composite images for a period of 10 days, details can be found in Gobron et al. (2007).

3 Results

Analysis of meteorolgical data reveals that the winter preceding the summer of 2007 had been extremely dry in Greece. Between November 2006 and January 2007 the precipitation amounts were much lower than normal climatology (Fig. 2; source: GPCP 2008). Fig. 3 shows the 24-hour forecasts of the wind conditions at a height of 10 m for the entire southern mainland of Greece, valid each afternoon at 1200 UTC from 22 until 27 August. The wind analysis exhibits the occurrence of strong winds in Evia, Attica and eastern Peloponnese from 23 August (> 10 m/s), as well as in western Peloponnese from 24 August, remaining relatively stable during a 24 hours time period. The same conditions prevailed until 25 August and in the mountainous regions the wind speed reached 12-15 m/s. However, on 26 August the wind speed did not exceed 5 m/s near the fires. This situation continued during the following days. At the same time, the strong winds in the Aegean Sea remained east of the region of interest.

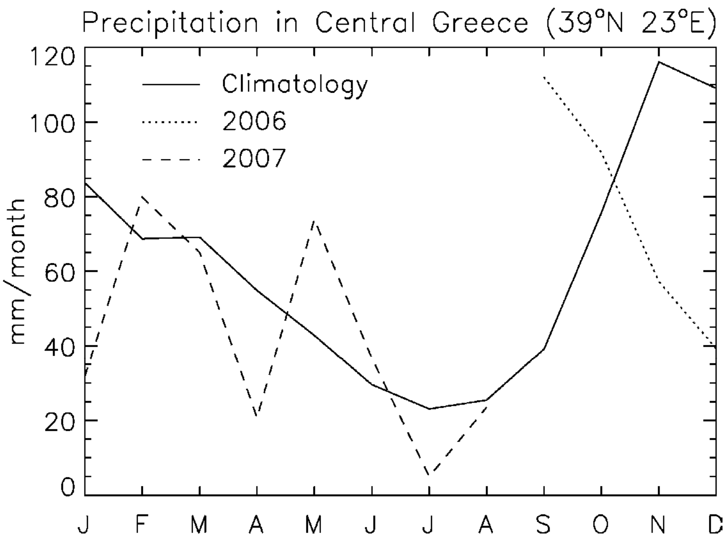


Fig. 2 Monthly precipitation (mm/month) in central Greece (39°N, 23°E) averaged during 1979-2008 (climatology; solid line) and during the year before the forest fires that occurred at the end of August 2007, that is Sep-Dec 2006 (dotted line) and Jan-Aug 2007 (dashed line).

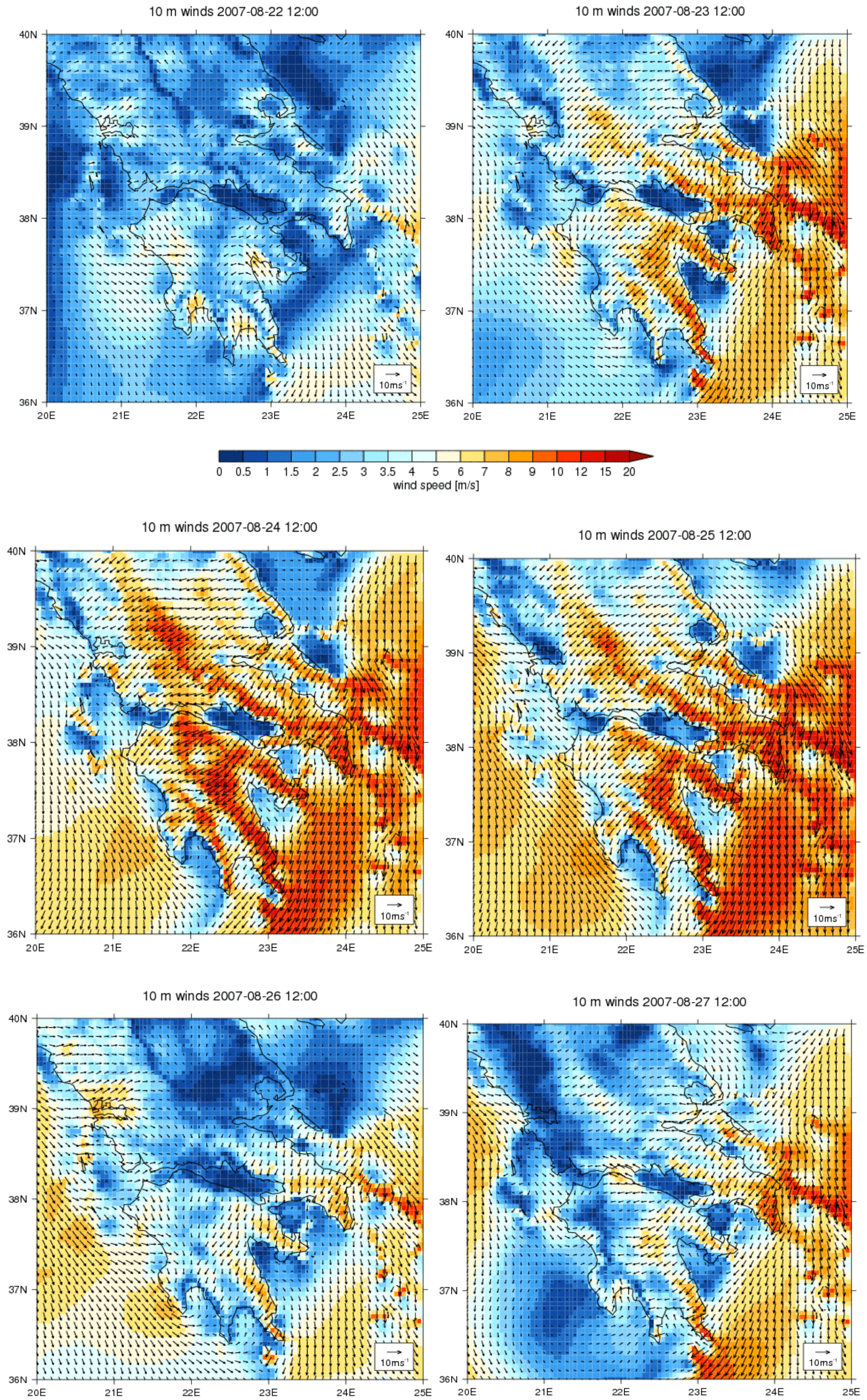


Fig. 3 24-hour SKIRON forecasts of wind speed (m/s) and direction valid from 22 to 27 August 2007, at 12:00 UTC (that is before and during the fires in Peleponnese and Evia).

It can be seen that strong winds had to extend westward and turn to north-northeast, before the fire outbreak was triggered. The generally arid nature of air masses coming from Eastern Europe also contributed to the development of a status of high fire risk. As shown in Fig. 5a, five major and several smaller fires were active on August 25. Fig. 4 shows the meteorological conditions prevailing at 850 hPa in the region on 25 August 2007, 1200 UTC stimulating an extraordinary danger of fire. A centre of low geopotential height appeared in the eastern Mediterranean, while an extensive area of anticyclonic circulation prevailed in central Europe. At the same time, Greece was located between very warm air masses in Middle East and a zone of colder air masses in north-western Europe. These synoptic conditions resulted to the development of a north-easterly flow in central and southern Greece at the level of 850 hPa (about 1500 m). However near the ground, northerly and north-easterly winds prevailed in the central Aegean sea and Peloponnese, respectively (Fig. 3).
Satellite images of processed satellite data from AVHRR radiometer are also presented. They confirm the prevalent wind direction through the smoke emanating from ten separate fires on only one day in August (Fig. 5a). The location of active fires depicted in the satellite data is also consistent with the strong winds predicted by the SKIRON model (Fig. 3). Eventually, Fig. 5b shows the maximum FAPAR during 2007 taken from the 10-day MERIS composite data. While FAPAR varies throughout the year depending on temperature and drought (Knorr et al., 2007), its maximum value is a suitable index of the prevailing form of vegetation in the area. The analysis thus shows an area of more vigorous vegetation in western Peloponnese, in the location of the most devastating fires, in contrast to the mountainous regions of eastern Peloponnese that show lower FAPAR. Despite the strong winds, no fires were detected in this region.

Apart from the identification of high fire risk areas, FAPAR fields are also suitable for detecting burnt areas (Fig. 6). As a result of the reduction of green biomass due to the fire that passed over the area, FAPAR value decreased over large areas, particularly so, in central and western Peloponnese and Evia. The location of these areas is consistent with the geographical location of the fires, that are depicted in Fig. 4 and can be identified by the smoke.

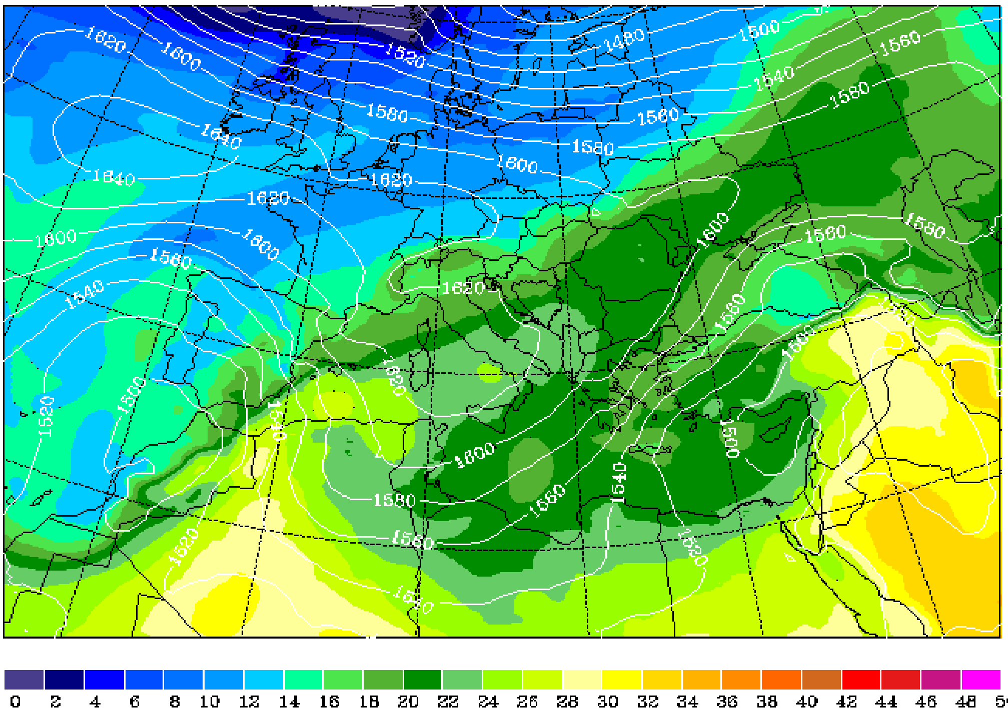
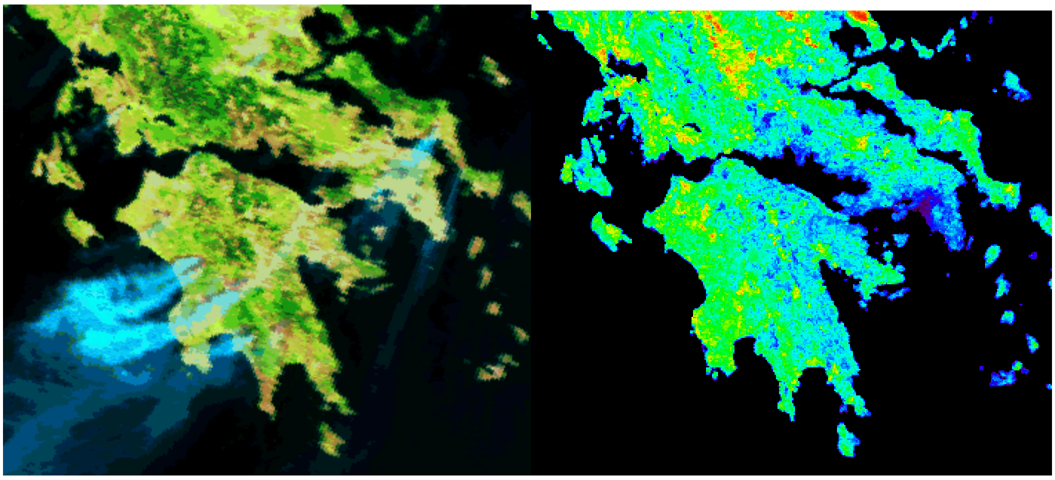
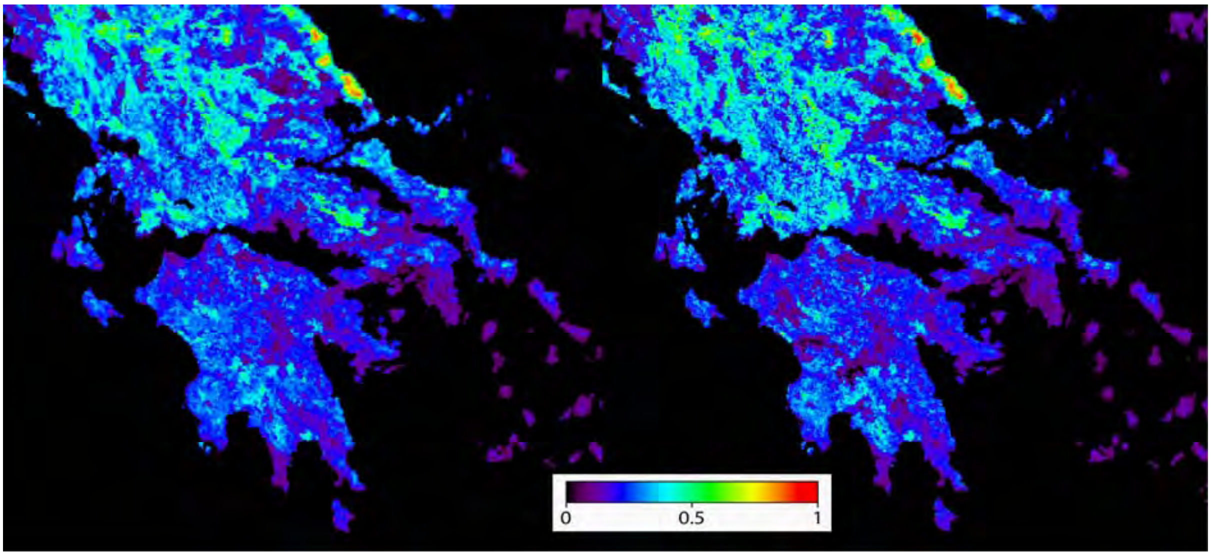


Fig. 4 24-hour SKIRON forecast of temperature (°C; colour shading) and geopotential height at 850 hPa (gpm; contours) valid at 1200 UTC on 25 August 2007.



a b

Fig 5. a: Satellite image from AVHRR sensor of 25 August 2007, 9:48h as false colour image using red=red channel, green=near-infrared channel and blue=middle infrared channel. Smoke appears light blue due to high middle-infrared reflectance. b: Maximum FAPAR of 2007. For colour scale, see Fig. 6.



a b

Fig. 6 FAPAR before (a: period 21-30 August 2007) and after (b: 1-10 September 2007) the fires. Note that the regions of reduced FAPAR agree with those of the active fires in Fig. 5a indicated by smoke plumes.

4 Discussion

The purpose of the present study was to show how readily available data can be combined to deliver a comprehensive picture of fire risk, for occurrence and post-fire assessment for a particular study area in the Mediterranean. All the data streams shown could be easily integrated into a fire warning system. These are: standard meteorological station data, hourly short-term weather forecasts, daily AVHRR imagery, and 10-daily FAPAR composites. We suggest use of the data in the following order:

1) FAPAR data should be used to denote areas of high enough vegetation cover indicative of fire fuel load.

2) Station data can be used to monitor drought conditions. Especially dry winters in combination with high fuel load lead to high fire danger.

3) Usually, both conditions are not enough to actually trigger fires. In this analysis, wind plays a crucial role. Hourly weather forecasting data can be used to forecast such wind conditions in areas of high fire danger.

4) Under those conditions of probably fire, active fires can be detected using freely available AVHRR imagery. Wind direction can also be derived from these images and compared to the weather forecasts.

5) Further weather forecasting data and AVHRR data can be used to monitor continuing fire-prone weather and existence of fires.

6) After the fires have died down, FAPAR composite data can be used to assess change in vegetation post-fire. This information is useful for directing reforestation efforts as well as serve as a risk assessment for landslides and floods because of the reduced water-holding capacity of denuded lands.

As a summary, this study suggests that the combination of appropriate risk indicators with regional weather forecasts is an important early warning tool for the protection of forests and other natural ecosystems that are either still unaffected by a catastrophic fire or are undergoing regeneration following a past fire event. The local meteorological conditions and the state and density of vegetation are important factors that can be estimated and used to predict a forest fire. This work demonstrates the usefulness of the satellite derived FAPAR, as well as of the data from the AVHRR sensor, for monitoring the general state of vegetation, active fires, wind direction and consequently the direction of the fire front by observing the smoke. After the fire suppression the above data can be further employed to monitor the burnt areas.

In particular, it should be noted that data from the AVHRR radiometer are available at no cost and at high temporal resolution permitting the monitoring of weather conditions conducive to a fire outbreak as well as the physical regeneration of areas afflicted by fire.

Finally, it is important to mention that according to this analysis, based only on meteorological data, the conditions appeared to be similar in both eastern and western Peloponnese. However, only areas of the western part of Peloponnese burned (Gitas et al., 2008). The analysis of satellite data, revealed at the same time that the eastern regions had significantly lower FAPAR values due to more sparse vegetation, and that no fires developed there. Such result confirms the conclusions of a study conducted in northern Australia. The latter demonstrated through the detailed analysis of burnt areas with climate and crop conditions (Spessa et al., 2005) that fires prevail in regions of intermediate rainfall rate and vegetation density. The drier parts are burnt relatively rarely, as in the example of eastern Peloponnese, This phenomenon is explained by the relative lack of dry material that prevents the development of a small fire in an extensive fire incident. In addition, the analysis of synoptic conditions is important and their combination with local meteorology is critical for fire risk prevention. After all, synoptic weather conditions can be predicted earlier and more accurately than local phenomena such as rainfall and soil drought. For this reason, the combination of synoptic and local phenomena through operational numerical weather prediction models is particularly important for predicting weather conditions favourable to the triggering of large fires.

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